AGU Chapman Conference on

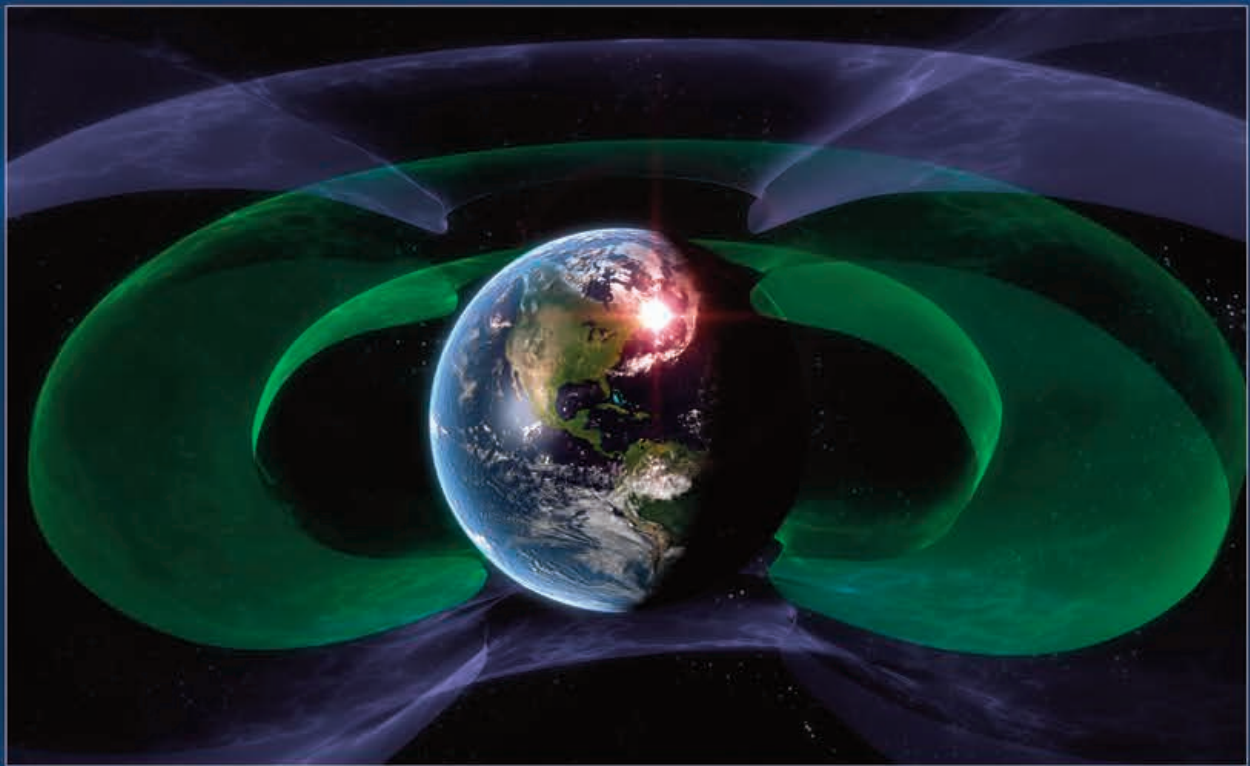# Dynamics of the Earth's Radiation Belts and Inner Magnetosphere

Conference Program

AGU Chapman Conference on Dynamics of the Earth's Radiation Belts and Inner Magnetosphere

Newfoundland and Labrador, Canada
17 – 22 July 2011

Conveners

Danny Summers, Memorial University of Newfoundland, St. John's (Canada)
Ian Mann, University of Alberta, Edmonton (Canada)
Daniel Baker, University of Colorado, Boulder (USA)

Program Committee

David Boteler, Natural Resources Canada, Ottawa, Ontario (Canada)
Sebastien Bourdarie, CERT/ONERA, Toulouse (France)
Joseph Fennell, Aerospace Corporation, Los Angeles, California (USA)
Brian Fraser, University of Newcastle, Callaghan, New South Wales (Australia)
Masaki Fujimoto, ISAS/JAXA, Kanagawa (Japan)
Richard Horne, British Antarctic Survey, Cambridge (UK)
Mona Kessel, NASA Headquarters, Washington, D.C. (USA)
Craig Kletzing, University of Iowa, Iowa City (USA)
Janet Kozyra, University of Michigan, Ann Arbor (USA)
Lou Lanzerotti, New Jersey Institute of Technology, Newark (USA)
Robyn Millan, Dartmouth College, Hanover, New Hampshire (USA)
Yoshiharu Omura, RISH, Kyoto University (Japan)
Terry Onsager, NOAA, Boulder, Colorado (USA)
Geoffrey Reeves, LANL, Los Alamos, New Mexico (USA)
Kazuo Shiokawa, STEL, Nagoya University (Japan)
Harlan Spence, Boston University, Massachusetts (USA)
David Thomson, Queen's University, Kingston, Ontario (Canada)
Richard Thorne, Univeristy of California, Los Angeles (USA)
Andrew Yau, University of Calgary, Alberta (Canada)

Financial Support
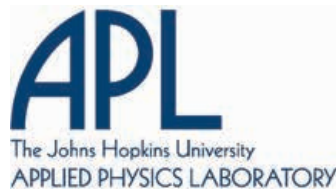
Cover photo: Andy Kale (andykale@gmail.com)

AGU Chapman Conference on Dynamics of the Earth's Radiation Belts and Inner Magnetosphere

Meeting At A Glance

Sunday, 17 July 2011

1800h – 1930h	Welcome Reception

Monday, 18 July 2011

0845h – 0900h	Welcome
0900h – 1030h	Introductory Lectures
1030h – 1100h	Coffee Break
1100h – 1230h	Current State of Knowledge of Radiation Belts I
1230h – 1400h	Lunch On Your Own
1400h – 1530h	Current State of Knowledge of Radiation Belts II
1530h – 1600h	Tea Break
1600h – 1700h	Current State of Knowledge of Radiation Belts III
1700h – 1800h	Discussion I
1830h – 2100h	Conference Reception at The Rooms

Tuesday, 19 July 2011

0830h – 1030h	Inner Magnetosphere Missions I
1030h – 1100h	Coffee Break
1100h – 1230h	Inner Magnetosphere Missions II
1245h – 1415h	Reception by Lt. Governor at Government House (for registered Delegates and guests only)
1245h – 1430h	Lunch on Your Own
1430h – 1530h	Modeling, Simulation & Theory I
1530h – 1700h	Tea & Poster Session I
1700h – 1800h	Modeling Simulation & Theory II
1830h – 1930h	Visit to the Cabot Tower and Marconi Museum

Wednesday, 20 July 2011

0830h – 1030h	Energy Coupling I
1030h – 1100h	Coffee Break
1100h – 1230h	Modeling, Simulation & Theory III
1230h – 1400h	Lunch On Your Own
1400h – 1900h	Optional Tours

Thursday, 21 July 2011

0830h – 1030h	Radiation Belts & Space Weather I
1030h – 1100h	Coffee Break
1100h – 1230h	Radiation Belts & Space Weather II
1230h – 1400h	Lunch On Your Own
1400h – 1530h	Energy Coupling II
1530h – 1700h	Tea & Poster Session II
1700h – 1800h	Discussion II
1900h – 2200h	Conference Banquet – The Spirit of Newfoundland

Friday, 22 July 2011

0900h – 1030h	Radiation Belts in a Planetary and Cosmic Context I
1030h – 1100h	Coffee Break
1100h – 1200h	Radiation Belts in a Planetary and Cosmic Context II
1200h – 1300h	Wrap-up Session

SCIENTIFIC PROGRAM

SUNDAY, 17 JULY

1800h – 1930h   **Welcome Reception**

MONDAY, 18 JULY

0845h – 0900h   **Welcome**

Introductory Lectures
Presiding: Danny Summers
Salon A

0900h – 0945h   **Stamatios M. Krimigis** | Discovering Earth's Van Allen Belts and the Quest for Radiation Belts at all the other Planets *(INVITED)*

0945h – 1030h   **Michael Schulz** | Foundations of Radiation-Belt Physics *(INVITED)*

1030h – 1100h   **AM Coffee Break (Monday)**

Current State of Knowledge of Radiation Belts I
Presiding: Ian R. Mann
Salon A

1100h – 1130h   **Geoffrey D. Reeves** | Radiation Belt Observations: What Do We Know; What Do We Think We Know; and What Do We Know We Don't Know? *(INVITED)*

1130h – 1200h   **Daniel N. Baker** | Studying changes of energetic particle properties in the Earth's radiation belts using the SAMPEX and POLAR missions *(INVITED)*

1200h – 1230h   **Mary K. Hudson** | Radiation Belt Electron Response to CME- and CIR-driven Geomagnetic Storms *(INVITED)*

1230h – 1400h   **Lunch On Your Own (Monday)**

Current State of Knowledge of Radiation Belts II
Presiding: Ian R. Mann
Salon A

1400h – 1430h **Frederick W. Menk** | Ground-Based Remote Sensing of Plasma Density in the Inner Magnetosphere and the Radiation Belts *(INVITED)*

1430h – 1500h **Nigel P. Meredith** | Plasma Wave Observations from CRRES *(INVITED)*

1500h – 1530h **Brian J. Fraser** | Electromagnetic Ion Cyclotron Waves, Plasma Drainage Plumes and Geomagnetic Storms *(INVITED)*

1530h – 1600h **Tea Break**

Current State of Knowledge of Radiation Belts III
Presiding: Craig Kletzing
Salon A

1600h – 1615h **John R. Wygant** | Electric Fields and Energetic Particle Measurements in the Inner Magnetosphere: CRRES and Polar Results *(INVITED)*

1615h – 1630h **Cynthia A. Cattell** | Large Amplitude Whistler Waves and Electron Energization in the Earth's Radiation Belts *(INVITED)*

1630h – 1645h **Wen Li** | Wave Normal Angle Analysis of Chorus Waves and Its Implication on Chorus Generation Mechanism *(INVITED)*

1645h – 1700h **Reiner H. Friedel** | The energetic electron and proton radiations belts during solar cycle 23 as viewed from the GPS constellation *(INVITED)*

1700h – 1800h **Discussion I**

1830h – 2230h **Conference Reception at The Rooms**

6:30 p.m. - Buses will depart

6:45 p.m.-9:00 p.m. - Reception

TUESDAY, 19 JULY

Inner Magnetosphere Missions I
Presiding: Barry H. Mauk
Salon A

0830h – 0850h **Ramona Kessel** | RBSP Mission Overview *(INVITED)*

0850h – 0910h **David G. Sibeck** | RBSP Collaborative Science Opportunities with Ongoing Missions: THEMIS

0910h – 0930h	**Ian Mann** | Radiation Belt Science Using Ground-Satellite Conjunctions *(INVITED)*
0930h – 0950h	**Robyn M. Millan** | The Balloon Array for RBSP Relativistic Electron Losses (BARREL) Experiment *(INVITED)*
0950h – 1010h	**Harlan E. Spence** | FIREBIRD: Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics *(INVITED)*
1010h – 1030h	**Jay Albert** | Exploring the MEO Regime: The Demonstration and Science Experiment (DSX) Satellite *(INVITED)*

1030h – 1100h	**AM Coffee Break (Tuesday)**

Inner Magnetosphere Missions II
Presiding: Nicola Fox
Salon A

1100h – 1115h	**Yoshizumi Miyoshi** | Japanese Geospace Exploration Project: ERG *(INVITED)*
1115h – 1130h	**David R. Shklyar** | RESONANCE Project for Studies of Wave-Particle Interactions in the Inner Magnetosphere *(INVITED)*
1130h – 1145h	**Craig Kletzing** | Electric and Magnetic Field Measurements on the RBSP Mission *(INVITED)*
1145h – 1200h	**Sebastien A. Bourdarie** | Radiation Belt Data Assimilation With Kalman Filter Using the Salammbô Code *(INVITED)*
1200h – 1215h	**Brian T. Kress** | Radial transport and energization in the Earth's radiation belts driven by solar wind dynamic pressure fluctuations *(INVITED)*
1215h – 1230h	**Steven Morley** | Observational Evidence for Drivers and Mechanisms of Electron Radiation Belt Dropouts *(INVITED)*

1245h – 1415h	**Reception by Lt. Governor at Government House**

Modeling, Simulation & Theory I
Presiding: Brian J. Fraser
Salon A

1430h – 1500h	**Richard M. Thorne** | Outstanding Problems in Radiation Belt Physics *(INVITED)*
1500h – 1530h	**Yoshiharu Omura** | Formation process of relativistic electron flux through interaction with chorus emissions in the Earth's inner magnetosphere *(INVITED)*

1530h – 1700h **Tea & Poster Session I**
Salon B

P-1 **Andrew W. Yau** | Opportunities for Collaborative Plasmaspheric Studies Using e-POP and RBSP

P-2 **Kanako Seki** | Study of the inner magnetospheric response to pressure pulses in the solar wind based on the GEMSIS-RC model

P-3 **Yoshizumi Miyoshi** | Large flux enhancement of outer belt electrons associated with high speed coronal hole stream

P-4 **Barry H. Mauk** | What role does global convection play in the population of the ring current regions?

P-5 **Natalia Y. Ganushkina** | Locations of Boundaries of Outer and Inner Radiation Belts as Observed by Cluster and Double Star

P-6 **Craig J. Rodger** | Ground-based estimates of outer radiation belt energetic electron precipitation fluxes into the atmosphere

P-7 **Shrikanth G. Kanekal** | Relativistic electron losses in the outer radiation belts

P-8 **Drew L. Turner** | Investigating the mechanism responsible for non-adiabatic losses of outer radiation belt electrons during geomagnetic storms

P-9 **Aleksandr Y. Ukhorskiy** | The Role of Drift Orbit Bifurcations in Energization and Loss of Electrons in the Outer Radiation Belt

P-10 **James L. Roeder** | Radial Profiles of Radiation Belt Electron Fluxes: Complimentary Views in Adiabatic and Measured Coordinates

P-11 **Angélica Sicard-Piet** | Radiation belts electron precipitation lifetime calculated using WAPI code and DE1, POLAR and CLUSTER-1 data

P-12 **Jean-Francois Ripoll** | High energy electron diffusion by resonant interactions with whistler waves in the inner radiation belt

P-13 **shinji saito** | Study of electron microburst associated with whistler chorus in the outer radiation belt: GEMSIS-RB Wave simulations

P-14 **Jaejin Lee** | Electron Microburst Energy Dispersion calculated by Test Particle Simulation

P-15 **Alexander W. Degeling** | Modelling ULF Wave Driven Outer Radiation Belt Electron Dynamics: Convective or Diffusivive Transport?

P-16 **Marc Lessard** | Propagation Characteristics of EMIC Waves in the High Latitude Ionospheric Waveguide

P-17 **Vladimir Krasnoselskikh** | Empirical model describing whistler waves statistical characteristics in the Earth radiation belts

P-18	**Misha A. Balikhin**	Analysis of waves in the inner magnetosphere using Cluster multipoint measurements

P-18   **Misha A. Balikhin** | Analysis of waves in the inner magnetosphere using Cluster multipoint measurements

P-19   **David Schriver** | Generation of Whistler Waves and Associated Non-Linear Processes in the Inner Magnetosphere

P-20   **Peter H. Yoon** | Whistler Waves With Arbitrarily Large Amplitude

P-21   **S P. Gary** | Whistler anisotropy instability: Linear theory, particle-in-cell simulations, and fast test-electron computations

P-22   **Maria Usanova** | THEMIS observations of EMIC Pc1 waves in the inner magnetosphere: a Statistical study

P-23   **Kaijun Liu** | Excitation of Magnetosonic Waves in the Terrestrial Magnetosphere: Particle-in-cell Simulations

P-24   **Nicholas L. Bunch** | Characterization of High Latitude and Dayside Outer Zone Chorus Observed by the Polar Plasma Wave Instrument

P-25   **Michael G. Henderson** | A Comparison of L* Calculations Using Different Algorithms and Field Models

P-26   **Illia Silin** | Warm Plasma Effects on EMIC Wave Interactions with Relativistic Electrons in the Magnetosphere

P-27   **Galina I. Korotova** | Themis Observations of Compressional Pulsations in the Dawn Magnetosphere

P-28   **Joseph F. Lemaire** | What happened when the geomagnetic field (GF) reversed

Modeling Simulation & Theory II
Presiding: Robyn M. Millan
Salon A

1700h – 1715h   **Yuri Shprits** | Dynamics of the Radiation Belts During Storms and Superstorms *(INVITED)*

1715h – 1730h   **Jay M. Albert** | Analytical Estimates of Coherent Wave-Particle Interactions *(INVITED)*

1730h – 1745h   **Binbin Ni** | A multi-satellite analysis of radiation belt electron phase space density distribution and the possible relationship with solar wind condition *(INVITED)*

1745h – 1800h   **Scot R. Elkington** | Radial transport as a function of azimuthal ULF wave distributions *(INVITED)*

1830h – 1930h   **Cabot Tower and Marconi Museum**

Visit to Cabot Tower and the Marconi Museum

Bus will depart promptly at 6:30 p.m. for Signal Hill

WEDNESDAY, 20 JULY

Energy Coupling I
Presiding: Andrew W. Yau
Salon A

0830h – 0850h   **Michael W. Liemohn** | Analyzing the role of keV-energy particles in modulating rapid trapping of radiation belt injections from the tail *(INVITED)*

0850h – 0910h   **Vania K. Jordanova** | The Role of the Ring Current in Radiation Belt Dynamics *(INVITED)*

0910h – 0930h   **Stein Haaland** | Ionospheric Outflow as a Source of Plasma for the Magnetosphere

0930h – 0950h   **Naritoshi Kitamura** | Observations of very-low-energy ion outflows dominated by O^+ ions in the region of enhanced electron density in the polar cap magnetosphere during geomagnetic storms *(INVITED)*

0950h – 1010h   **Maha Ashour-Abdalla** | Electron Transport within Earthward Propagating Dipolarization Fronts as a Seed Population for Storm Time Energetic Electrons

1010h – 1030h   **Gwang-Son Choe** | Evolution of the Magnetosphere Loaded with a Transiently Enhanced Ring Current

1030h – 1100h   **AM Coffee Break (Wednesday)**

Modeling, Simulation & Theory III
Presiding: Yoshiharu Omura
Salon A

1100h – 1115h   **Yuto Katoh** | Electron hybrid simulation of nonlinear wave growth of whistler-mode chorus emissions *(INVITED)*

1115h – 1130h   **Danny Summers** | Comparison of Linear and Nonlinear Growth Rates for Magnetospheric Whistler-mode Waves

1130h – 1145h   **James P. McCollough** | The Role of Shabansky Orbits in Compression-related EMIC Wave Growth

1145h – 1200h   **Chia-Lin Huang** | Magnetopause Shadowing Signature During Relativistic Electron Flux Dropout Events

1200h – 1215h   **Kunihiro Keika** | Ion injection and plasmaspause location during the storm recovery phase: Comparison between different solar wind drivers

1215h – 1230h   **Vladimir Krasnoselskikh** | Reconstruction of Chorus Type Whistler Wave Statistics in the Radiation Belts and in the Inner Magnetosphere Using Ray Tracing *(INVITED)*

1230h – 1400h	**Lunch On Your Own (Wednesday)**
1400h – 1900h	**Optional Tour - Lighthouse Picnic at the Colony of Avalon (Ferryland Archaeological Dig)**
1400h – 1900h	**Optional Tour - The Birds and Whales of Witless Bay (Whale Watching Tour)**

THURSDAY, 21 JULY

Radiation Belts & Space Weather I
Presiding: Daniel N. Baker
Salon A

0830h – 0900h	**Louis J. Lanzerotti**	Space weather effects on technologies *(INVITED)*
0900h – 0915h	**Takahiro Obara**	Energetic Electron Dynamics in the Inner Magnetosphere Inferred from JAXA Satellite Observations *(INVITED)*
0915h – 0930h	**Joseph F. Fennell**	Storm Responses of Radiation Belts During Solar Cycle 23: HEO observations *(INVITED)*
0930h – 0945h	**Jeongwoo Lee**	Time Profiles of VLF signals Detected at High Latitude Groundbased Stations
0945h – 1000h	**Larisa Trichtchenko**	Study of the radiation environment on Molniya orbit *(INVITED)*
1000h – 1015h	**Daniel T. Welling**	Ring Current Modeling with Space Weather Applications Using RAM-SCB *(INVITED)*
1015h – 1030h	**Ryuho Kataoka**	Modeling and forecasting geomagnetically induced currents in Hokkaido, Japan *(INVITED)*

1030h – 1100h	**AM Coffee Break (Thursday)**

Radiation Belts & Space Weather II
Presiding: Louis J. Lanzerotti
Salon A

1100h – 1115h	**Craig J. Rodger**	Radiation belt electron precipitation due to geomagnetic storms: significance to middle atmosphere ozone chemistry
1115h – 1130h	**Giovanni Lapenta**	Space Weather Forecasting activities in Europe, within Soteria and Swiff
1130h – 1145h	**Shawn L. Young**	Working to Improve Spacecraft Charging Specification and Forecast Capabilities

1145h – 1200h	**Misha A. Balikhin** | Forecasting Relativistic Electron Flux Using Dynamic Multiple Regression Models
1200h – 1215h	**Aaron W. Breneman** | Large Amplitude Transmitter- and Lightning-Associated Whistler Waves in the Earth's Inner Plasmasphere at L < 2
1215h – 1230h	**Darren M. Wright** | Characteristics of high-latitude ion outflows derived from ground-based radar and spacecraft measurements
1230h – 1400h	**Lunch On Your Own (Thursday)**

Energy Coupling II
Presiding: Richard M. Thorne
Salon A

1400h – 1415h	**Zuyin Pu** | Secular variation of the inner zone proton environment over the past one hundred years
1415h – 1430h	**Finn Soraas** | Low altitude observations of energetic protons and neutral atoms (ENA) during geomagnetic storms
1430h – 1445h	**David J. Thomson** | Background Magnetospheric Variability as inferred from long time—series of GOES data *(INVITED)*
1445h – 1500h	**Jonathan Rae** | Empirical Estimates of Radiation Belt Radial Diffusion Characteristics from ground-based and in-situ measurements
1500h – 1515h	**Weichao Tu** | Adiabatic Effects on Radiation Belt Electrons at Low Altitude
1515h – 1530h	**Louis Ozeke** | Radial Diffusion of Outer Radiation Belt Electrons - The Influence of Electric and Magnetic ULF waves

1530h – 1700h	**Tea & Poster Session II** Salon B
P-31	**Quintin Schiller** | Reanalysis of Radiation Belt Electron Data using a Kalman Filter
P-32	**Kyle R. Murphy** | Characterising the night-side current systems and magnetic field perturbations associated with substorms
P-33	**Alexander B. Crew** | A Statistical Analysis of Microburst Event Fluxes
P-34	**Ahmed R. Kirmani** | Relationship between Interplanetary Magnetic Field and AE Index
P-35	**Lidia Nikitina** | STATISTICAL ANALYSIS OF THE RADIATION ENVIRONMENT ON MOLNIYA ORBIT
P-36	**Tavis J. Saito** | A Statistical Analysis of the Relationship between ULF Waves and Particle Modulation in the outer Radiation Belts

P-55	**Xin Tao**	Test particle calculations of interactions between electrons and large amplitude chorus subpackets
P-56	**Craig J. Rodger**	Remote Sensing Space Weather Events Through Ionospheric Radio: The AARDDVARK Network
P-57	**Dmitri Kondrashov**	Operator-splitting Kalman Filter as efficient data assimilation method for radiation belts
P-58	**James A. Hutchinson**	A Novel New Radar Technique to Study Geomagnetic Storms: Superposed Latitude-Velocity-Time Plots
P-59	**Ksenia Orlova**	Bounce-averaged pitch angle, mixed, and momentum diffusion coefficients in a realistic magnetic field model
P-60	**Viacheslav Pilipenko**	Variations of the relativistic electron fluxes at L=3.0-6.6 as observed by CORONAS-F satellite
P-61	**Richard L. Mace**	Ring current tail enhanced EMIC instability in the vicinity of L = 4
P-62	**Lunjin Chen**	Modeling of Plasmaspheric Hiss Spectrum

1700h – 1800h **Discussion II**

1900h – 2200h **Conference Dinner - The Spirit of Newfoundland**

FRIDAY, 22 JULY

Radiation Belts in a Planetary and Cosmic Context I
Presiding: Sebastien A. Bourdarie
Salon A

0900h – 0930h **Barry H. Mauk** | Radiation belts of the Solar System and Universe *(INVITED)*

0930h – 1000h **George B. Hospodarsky** | Plasma wave observations at Earth, Jupiter and Saturn *(INVITED)*

1000h – 1030h **Angélica Sicard-Piet** | Comparative Earth, Jupiter and Saturn's radiation belts *(INVITED)*

1030h – 1100h	**Coffee Break (Friday AM)**

Radiation Belts in a Planetary and Cosmic Contex II
Presiding: Sebastien A. Bourdarie
Salon A

1100h – 1130h	**Mitsuo Oka** | Electron Acceleration by Multi-Island Coalescence *(INVITED)*
1130h – 1145h	**Rongxin Tang** | Energetic electron fluxes at Saturn from Cassini observations *(INVITED)*
1145h – 1200h	**David Schriver** | Does Mercury Have a Radiation Belt?
1200h – 1300h	**Wrap-up Session**

ABSTRACTS
listed by name of presenter

Agapitov, Oleksiy

Remote sensing of plasma fluctuations by means of multi-point cross-correlation analysis of VLF waves waveforms

Agapitov, Oleksiy[2, 1]; Krasnoselskikh, Vladimir[2]; Khotyaintsev, Yuri[3]; Rolland, Guy[4]

1. National Taras Shevchenko University of Kyiv, Kyiv, Ukraine
2. LPCEE, Orleans, France
3. IRF, Uppsala, Sweden
4. CNES, Toulouse, France

Random inhomogeneities of plasma density are known to effect the propagation of whistler mode waves resulting in fluctuations of the refractive index of the waves. Irregularities of the refractive index along the ray path lead to the loss of the phase coherence of the wave packet. Such irregularities are often present around the plasmapause and in the radiation belts; they occur at scales ranging from a few meters up to several hundred kilometers and can be highly anisotropic. The statistical characteristics of these irregularities can be probed by means of inter-satellite correlations of their phases and amplitudes. From such cross-correlation analysis we reconstruct the statistical properties of the density fluctuations along the wave propagation path. This allows us to distinguish the wave source properties from the effects of the wave propagation through the media. The proposed technique is applied to the discrete ELF/VLF chorus emissions observed onboard Cluster and Themis. Chorus type whistler waves are the most intense electromagnetic plasma waves that are observed in the radiation belts. They are assumed to be generated in source regions in the vicinity of the magnetic equator and in minimum B pockets in the dayside outer zone of the magnetosphere. The parallel and perpendicular to the background magnetic field correlation scales of the plasma density fluctuations are determined by analyzing the wave phase difference dependence upon the duration of the signal recording time. The results obtained can be summarized as follows: 1. The characteristic spatial scales of plasma density irregularities transverse to the local magnetic field are found to be in a range from 60 to 110 km in the inner magnetosphere and about 300–350 km for L-shell about 8–9, which is of the order of the local ion gyroradius. We find that the chorus wave phase coherence scale near the generation region is defined by the density fluctuation scale but not by size of the source. The correlation scale along the magnetic field is found to be 5–10 times greater than transverse. 2. The location of the wave sources is found to be in a good agreement with its determination from the multi-point Poynting flux measurements. The distance from the spacecraft to the wave source (from 300 to 1000 km) is found to be sufficiently smaller than the characteristic thickness of the source region, which is known from previous studies to be of the order of 3000–5000 km. From this we come to the conclusion that the estimated parallel scale of the fluctuations corresponds to the characteristic scale of the inhomogeneity of the source.

Albert, Jay

Exploring the MEO Regime: The Demonstration and Science Experiment (DSX) Satellite **(INVITED)**

Ginet, Gregory P.[1]; Starks, Michael[2]; Scherbarth, Mark[2]; Albert, Jay[2]

1. MIT Lincoln Laboratory, Lexington, MA, USA
2. Space Vehicles Directorate, Air Force Research Laboratory, Albuquerque, NM, USA

The Air Force Research Laboratory is developing the DSX satellite for a nominal Oct 2012 launch into a 6000 km x 12000 km, 60 deg inclination orbit. DSX comprises three science experiments designed to: (1) validate models of Very Low Frequency (VLF) wave injection, propagation and wave-particle interactions in the radiation belts; (2) measure the distribution of energetic particles and plasmas in the medium-Earth orbit (MEO) regime; and (3) investigate radiation effects on advanced spacecraft technologies. Unique opportunities exist to perform joint experiments with NASA's Radiation Belt Storm Probes and other satellites to include, for example, simultaneous multi-point particle flux measurements at varying magnetic latitudes and the direct measurement of the VLF propagation efficiency between pairs of in-situ magnetospheric points. Such data will be valuable in quantifying the global propagation properties of VLF wave populations and their ultimate contribution to radiation belt dynamics. An overview of the payloads, the mission concept of operations and the science questions motivating the mission will be discussed.

Albert, Jay M.

Analytical Estimates of Coherent Wave-Particle Interactions **(INVITED)**

Albert, Jay M.[1]

1. AFRL/RVBXR, Air Force Research Lab, Hanscom AFB, MA, USA

For charged test particles experiencing coherent interactions with individual, cyclotron-resonant waves, quasilinear theory is not the appropriate framework. The behavior of such particles falls into three classes, delineated by the "inhomogeneity parameter" which essentially describes the competition between wave strength, which perturbs the resonant particle, and the detuning of the resonance by space or time dependence. It has long been known that for small waves/strong spatial variation, the particle motion is diffusive, at a rate given by a simple

analysis. It has recently been shown that this rate, suitably averaged over an ensemble of waves, reproduces broadband quasilinear diffusion, somewhat justifying its use. For stronger waves, particles experience phase bunching, with or without trapping, which prolongs the resonance. Analytical results are also available for these processes, in several levels of detail. Unlike the diffusive situation, they lead to pitch angle and energy changes with nonzero mean. They can thus be formulated as advection coefficients in a velocity space transport equation, and treated in a similar framework to diffusion. Since different particles will respond differently to the same waves, this allows a convenient approach to global, large scale modeling. A major hurdle is the sensitivity to the modeled wave parameters, since they determine qualitatively different types of behavior. The effects of phase bunching, with or without trapping, accumulate much more rapidly than diffusion, but tend to have opposing effects; it is not yet clear to what extent they compete. Another complication is the frequent coexistence of coherent and incoherent waves, e.g. chorus combined with a hiss band, which has not yet been addressed analytically.

Ashour-Abdalla, Maha

Electron Transport within Earthward Propagating Dipolarization Fronts as a Seed Population for Storm Time Energetic Electrons

Ashour-Abdalla, Maha[1, 2]; Schriver, David[1]; El-Alaoui, Mostafa[1]; Walker, Raymond J.[1, 3]

1. IGPP, UCLA, Los Angeles, CA, USA
2. Department of Physics and Astronomy, UCLA, Los Angeles, CA, USA
3. Department of Earth and Space Science, UCLA, Los Angeles, CA, USA

In recent years there has been renewed interest in Earthward propagating dipolarization fronts which are found in the near-Earth magnetotail during magnetospheric substorms. Dipolarization fronts are characterized by rapid increases in the Bz component of the magnetic field. Observations from Cluster and THEMIS show that the dipolarization fronts can be accompanied by large increases in the energy fluxes of 100s of keV electrons. We have investigated the transport and acceleration of electrons at dipolarization fronts by using a combination of global magnetohydrodynamic (MHD) simulations and particle trajectory calculations during geomagnetic events. In these calculations we launch a large\ number of electrons into the time dependent electric and magnetic fields from the MHD calculations. We then collect the particles at the location of the spacecraft and compare our theoretical results with the observations. We find that electrons undergo acceleration in a two step process at different locations. The first is near the reconnection site in the mid-tail (~ 15-20 RE) where particles acheive energies ~ 1 – 10 keV. The second acceleration occurs at the inward propagating dipolarization front where it is found that electrons can gain energies of 100 keV or more by betatron acceleration at about 10 RE. We will extend these findings by continuing to follow the electrons into the inner magnetosphere at distances < 10 RE and detetermine whether these electrons accelerated at the dipolarization fronts act as a seed population for the highly relativistic energy electrons found in the radiation belt region during magnetic storms and substorms.

Baker, Daniel N.

Studying changes of energetic particle properties in the Earth's radiation belts using the SAMPEX and POLAR missions **(INVITED)**

Baker, Daniel N.[1]

1. Lab Atmospheric & Space Physics, Univ Colorado at Boulder, Boulder, CO, USA

The near-Earth region responds powerfully to changes of the Sun and subsequently the solar wind. The Earth's radiation belts and inner magnetosphere show pronounced differences in their characteristics as the Sun's magnetic and solar wind plasma properties change. Solar coronal holes produce regular, recurrent solar wind streams in geospace, often enhancing highly relativistic electrons and causing recurrent magnetic storms. These phenomena are characteristics of the approach to solar minimum. On the other hand, major geomagnetic disturbances associated with aperiodic coronal mass ejections occur most frequently around solar maximum. Such disturbances also often produce radiation belt enhancements. We describe the observational and modeling results that describe differences throughout the inner part of geospace during the course of the 11-year solar cycle. We place particular emphasis on long-term, homogeneous data sets from the SAMPEX and POLAR missions, which in many ways have revolutionized our views of the dynamic radiation belt environment.

Balikhin, Misha A.

Analysis of waves in the inner magnetosphere using Cluster multipoint measurements

Balikhin, Misha A.[1]; Sibeck, David G.[2]; Walker, Simon N.[1]

1. ACSE, Univ Sheffield, Sheffield, United Kingdom
2. NASA/GSFC, Greenbelt, MD, USA

Identification of the dispersion relation for waves is the most reliable method to study the composition of plasma turbulence in key regions of the magnetosphere. Other approaches can lead to erroneous conclusions as was recently demonstrated using an example of mirror waves associated with substorm activity. Closely spaced measurements are required to identify the wave dispersion from data. Cluster multipoint measurements are used to present a survey of various plasma waves observed within the magnetosphere.

Balikhin, Misha A.

Forecasting Relativistic Electron Flux Using Dynamic Multiple Regression Models

Balikhin, Misha A.[1]; Wei, Huliang L.[1]; Billings, Stephen A.[1]; Boynton, Richard J.[1]

1. Univ Sheffield, Sheffield, United Kingdom

The forecast of high energy electron fluxes in the radiation belts is important because the exposure of modern spacecraft to high energy particles can result in significant damage to onboard systems. A comprehensive physical model of processes related to electron energisation that can be used for such a forecast has not yet been developed. In the present paper a systems identification approach is exploited to deduce a dynamic multiple regression model that can be used to predict the daily maximum of high energy electron fluxes at geosynchronous orbit from data. It is shown that the model developed provides reliable predictions.

Blum, Lauren W.

A comparison of magnetic field measurements and a plasma-based proxy to infer EMIC wave distributions at geosynchronous orbit

Blum, Lauren W.[1]; MacDonald, Elizabeth[2]; Li, Xinlin[1]

1. University of Colorado, Boulder, CO, USA
2. Los Alamos National Laboratory, Los Alamos, NM, USA

Wave particle interactions are fundamental to the dynamics of the outer radiation belt. Both whistler and electromagnetic ion cyclotron (EMIC) waves can resonate with high energy electrons, causing pitch angle diffusion as well as energy diffusion. These waves often act locally - thus accurately measuring their spatial and temporal distributions is critical to understanding the various local acceleration and loss mechanisms active in the outer radiation belt. Using LANL Magnetospheric Plasma Analyzer (MPA) data from geosynchronous orbit, we develop a proxy for enhanced EMIC wave growth, and we calculate a wave power for the inferred waves. We then compare this proxy to in situ wave measurements taken by the GOES satellites, also at geosynchronous orbit, to examine both the wave occurrence rates as well as magnitudes. We see signatures of EMIC waves in both GOES data and the MPA proxy for similar local times as well as storm phases - primarily in the afternoon sector and during the main phase of storms. The broad spatial coverage of the LANL satellites makes them ideal for providing EMIC wave information over a range of local and storm times. This study enables broader understanding of the powerful applications of using plasma data to infer wave distributions in space, as well as understanding of the source populations and growth mechanisms for EMIC waves.

Bourdarie, Sebastien A.

Radiation Belt Data Assimilation With Kalman Filter Using the Salammbô Code *(INVITED)*

Bourdarie, Sebastien A.[1]; Maget, Vincent[1]; Lazaro, Didier[1]; Friedel, Reiner[2]; Cayton, Tom[2]

1. DESP, ONERA, Toulouse, France
2. ISR-1, LANL, Los Alamos, NM, USA

Particle observations at geostationary orbit show that only 53% of geomagnetic storms result in a net increase in the electron flux while 19% result is a net decrease and the flux remains almost the same for the remaining 18% of storms (Reeves et al., 2003). These observations clearly demonstrate that the relative importance of all competing physical processes involved in the radiation belt dynamics changes from storm to storm and the net result on particle distribution might then be very different. Even if the key physical processes that govern the dynamics of radiation belts are identified today, their temporal evolution (dynamics) is not well-understood. These are the main limitations of the current pure physical modelling of radiation belt dynamics. The most common practice is to deduce empirical formula from statistical studies in which physical processes are driven by one or more proxies like Kp, Dst and/or solar wind parameters. This introduces errors, which become even more important for high magnetic activity where statistics are usually poor. On the other hand, past observational studies, which use data from single or limited multiple points in space, are limited due to sparse coverage of measurements. To guide radiation belt model to converge toward the time dependent "best estimate" of the radiation belt state, a particle data assimilation tool based on the Salammbô physical model and an ensemble Kalman filter has been developed. The current approach consists in a filtered data assimilation scheme termed The Kalman Filter. The Kalman filter is a sequential method that performs a maximum likelihood estimation between weighted current observations and weighted predicted state of the radiation belt at one time. An assimilative sequence can be decomposed into two steps: the forecast and update steps. During the forecast step, the Kalman filter propagates in time the initial state according to Salammbô model assuming that the initial state as well as the model is not perfect. The benefit is represented by the propagation forward in time of a matrix containing variances and covariances of errors at each grid points. Monte Carlo techniques are applied in order to sample and thus approximate the error-covariance matrix. The basic idea is to construct an ensemble of m initial states such that the ensemble mean is the initial state of the Kalman filter and whose dispersion is an approximation of the initial error-covariance matrix. Consequently, the computational cost is reduced to the propagation and the update of an ensemble matrix A containing m members of N phase space density grid points. The time evolution of the covariance approximation is obtained through the parallel propagation of the individual ensemble members using the Salammbô 3D radiation belt model. Thus, ensemble members are time-

spread into the state space which approximates the time-diffusion of the uncertainties contained in the error-covariance matrix for the Kalman Filter. Only during the update step, the sample covariance of the ensemble A is calculated in order to adjust the model forecast using the new set of observations. Global 3D results obtained during the October 1990 storm will be shown and data assimilation with an ensemble Kalman filter will be discussed.

Breneman, Aaron W.

Large Amplitude Transmitter- and Lightning-Associated Whistler Waves in the Earth's Inner Plasmasphere at L < 2

Breneman, Aaron W.[1]; Cattell, Cynthia[1]; Wygant, John[1]; Kersten, Kris[1]; Wilson III, Lynn[2]; Kellogg, Paul[1]; Goetz, Keith[1]; Schreiner, Sam[1]

1. School of Physics and Astronomy, University of Minnesota, Minneapolis, MN, USA
2. Goddard Space Flight Center, Greenbelt, MD, USA

We report observations of very large amplitude whistler mode waves in the Earth's nightside inner radiation belt enabled by the STEREO Time Domain Sampler. Amplitudes range from 30-110 mV/m (zero-peak), two to three orders of magnitude larger than previously observed in this region. Measurements from the peak electric field detector (TDSMax) indicate that these large amplitude waves are prevalent throughout the plasmasphere. A detailed examination of high time resolution electric field waveforms is undertaken on a subset of these whistlers at L<2, associated with pump waves from lightning flashes and the Naval transmitter NPM in Hawaii, that become unstable after propagation through the ionosphere and grow to large amplitudes. Many of the waveforms undergo periodic polarization reversals near the lower hybrid and NPM Naval transmitter frequencies. The reversals may be related to finite plasma temperature and gradients in density induced by ion cyclotron heating of the plasma at 200 Hz, the modulation frequency of the continuous mode NPM Naval transmitter signal. Test particle simulations using the amplitudes and durations of the waves observed herein suggest that they can interact strongly with high energy (>100 keV) electrons on a timescale of <1 second and thus may be an important previously unaccounted for source of energization or pitch angle scattering in the inner radiation belt.

Bunch, Nicholas L.

Characterization of High Latitude and Dayside Outer Zone Chorus Observed by the Polar Plasma Wave Instrument

Bunch, Nicholas L.[1]; Spasojevic, Maria[1]; Shprits, Yuri Y.[2, 3]

1. STAR Lab, Dept. of Electrical Engineering, Stanford University, Stanford, CA, USA
2. IGPP, UCLA, Los Angeles, CA, USA
3. Dept. of Atmospheric Sciences, UCLA, Los Angeles, CA, USA

Whistler mode chorus emissions at high magnetic latitudes are thought to be of prime importance to the acceleration and loss of relativistic radiation belt electrons. It has long been suggested that in addition to equatorially generated chorus, emissions observed at high latitudes in the dayside outer zone (DOZ) magnetosphere could be generated off the equator in minimum B pockets. Moreover, DOZ chorus waves generated in these minimum B pockets that propagate to lower latitudes where B increases would locally represent enhanced low-frequency chorus, which is most effective for interacting with relativistic electrons. Thus, adequate understanding of chorus wave properties in the off equatorial region, particularly on the dayside, is crucial to accurate modeling of relativistic energies in the radiation belts. Mostly due to a long standing emphasis on observation and molding of chorus in the equatorial region, adequate characterization of chorus significantly off the equator is lacking. In this study we employ a database of chorus observations from the Plasma Wave Instrument (PWI) Sweep Frequency Receiver (SFR) onboard the Polar spacecraft, which are used to further the statistical characterization of high latitude and DOZ chorus properties. This presentation will focus on high latitude and DOZ chorus observation rate and wave power distribution and their dependence on space and geomagnetic conditions (e.g. AE and solar wind speed), as well as spectral distribution with respect to normalized frequency (e.g. equatorial or minimum gyrofrequency). These characteristics are crucial in coming to an adequate understanding of the radiation belt wave environment and determining essential inputs for radiation belt models.

Cattell, Cynthia A.

Large Amplitude Whistler Waves and Electron Energization in the Earth's Radiation Belts *(INVITED)*

Cattell, Cynthia A.[1]; Breneman, Aaron[1]; Kersten, Kris[1]; Kellogg, Paul[1]; Goetz, Keith[1]; Wygant, John[1]; Wilson III, Lynn[2, 1]; Looper, Mark Looper[3]; Blake, J Bernard[3]; Roth, Ilan[4]

1. School of Physics and Astronomy, Univ Minnesota, Minneapolis, MN, USA
2. Goddard Spaceflight Center, Greenbelt, MD, USA
3. Aerospace Corporation, El Segundo, CA, USA
4. Space Science Laboratory, University of California, Berkeley, CA, USA

One of the critical problems for understanding the dynamics of Earth's radiation belts is determining the physical processes that energize and scatter relativistic electrons. Recent measurements from satellites with waveform capture instruments have provided strong evidence that large amplitude (100s mV/m) whistler-mode waves are ubiquitous during magnetically active periods. The large amplitude whistlers are usually non-dispersive and obliquely propagating, with a large longitudinal electric field and significant parallel electric field. Simulations show that the waves can result in energization by many MeV and/or scattering by large angles during a single wave packet encounter due to coherent, nonlinear processes including trapping. We will review observations from the Wind and STEREO Waves instruments on properties of the large amplitude whistler waves. We will also review comparisons of STEREO and Wind wave observations with SAMPEX observations of electron microbursts. The experimental observations combined with simulations suggest that quasilinear theoretical models of electron energization and scattering via small-amplitude waves, with timescales of hours to days, may be inadequate for understanding radiation belt dynamics.

Chen, Lunjin

Modeling of Plasmaspheric Hiss Spectrum

Chen, Lunjin[1]; Bortnik, Jacob[1]; Thorne, Richard[1]; Li, Wen[1]; Horne, Richard[2]

1. Atmospheric & Oceanic Sciences, UCLA, Los Angeles, CA, USA
2. British Antarctic Survey, Cambridge, United Kingdom

A 2D ray tracing of chorus waves launched outside the plasmasphere with varying wave frequencies and wave normal angles is used to track the evolution of chorus emission. It is found that a portion of chorus rays are able to enter the plasmasphere and trap inside, forming a hiss spectrum with frequency range consistent with the hiss observation. Our modeling also reveals the wave normal angle distribution and spatial distribution of plasmaspheric hiss. We also investigate how the hiss spectrum respond to the change in the chorus spectrum and the change in the background plasma environment.

Choe, Gwang-Son

Evolution of the Magnetosphere Loaded with a Transiently Enhanced Ring Current

Choe, Gwang-Son[1]; Park, Geunseok[2]

1. School of Space Research, Kyung Hee University, Yongin, Republic of Korea
2. National Meteorological Satellite Center, Korea Meteorological Administration, Jincheon, Republic of Korea

The dynamical evolution of the Earth's magnetosphere loaded with a transiently enhanced ring current is investigated by numerical magnetohydrodynamic simulation. Two cases with different values of the initial ring current are considered. In one case, the initial ring current is strong enough to create a magnetic island in the magnetosphere. The magnetic island readily reconnects with the earth-connected ambient field and is destroyed as the system approaches a steady equilibrium. In the other case, the initial ring current is not so strong, and the initial magnetic field configuration bears no magnetic island, but a wake of bent field lines, which is smoothed out through the relaxing evolution of the magnetosphere. The relaxation time of the magnetosphere is found to be about five to six minutes, over which the ring current is reduced to about a quarter of its initial value. Before reaching a steady state, the magnetosphere is found to undergo an overshooting expansion and a subsequent contraction. Fast and slow magnetosonic waves are identified to play an important role in the relaxation toward equilibrium.

Crew, Alexander B.

A Statistical Analysis of Microburst Event Fluxes

Crew, Alexander B.[1]; Spence, Harlan[1]

1. University of New Hampshire, Durham, NH, USA

Electron microbursts are believed to be a significant form of radiation belt losses. We present a study of the statistical distribution of flux levels involved in microburst events observed by SAMPEX. Characterizing the different loss levels present in both an absolute and a relative scale has implications for both instrument design and microburst detection, as well as for assessing the total electron loss on a global scale. Previous work, such as that of [O'Brien et al., 2004] has attempted to characterize the overall losses during storms and relate it to the overall relativistic electron population in the belts. We probe into the fluxes present in the individual bursts to provide a picture of what the microburst spectrum looks like. Furthermore, we demonstrate how these results can be applied to mission planning in the context of the FIREBIRD cubesat.

Degeling, Alexander W.

Modelling ULF Wave Driven Outer Radiation Belt Electron Dynamics: Convective or Diffusivive Transport?

Degeling, Alexander W.[1]; Rankin, Robert[1]; Elkington, Scot R.[2]

1. Physics, University of Alberta, Edmonton, AB, Canada
2. LASP, University of Colorado, Boulder, CO, USA

We examine the process of radiation belt electron energization driven by ultra low frequency (ULF) waves during geomagnetic storms. It is understood that energization in this case arises through the adiabatic transport of electrons into regions of higher magnetic field strength, via drift-resonant interactions with the ULF waves. Generally this has been considered a diffusive process, driven by a typically broad spectrum of ULF wave activity. However it is often the case that ULF waves during CME and CIR driven storms have a strong monochromatic component. Moreover, the fast timescales of electron enhancements, as well as the appearance of phase space density peaks and drift echoes phase-synchronized with ULF waves may indicate that electron transport in these cases is convective rather than diffusive. To address this question, we use a numerical model for ideal MHD waves within a magnetosphere including day/night asymmetry and parabolic magnetopause to drive the adiabatic transport of equatorially mirroring electrons. ULF waves with a specified frequency spectrum are launched from the magnetopause and the resulting electron transport analyzed for diffusive or convective characteristics. First results indicate that narrowband ULF waves can lead to significant convective transport for multiple wave periods, before becoming diffusive on a timescale that depends on the spectral bandwidth of the driver.

Elkington, Scot R.

Radial transport as a function of azimuthal ULF wave distributions *(INVITED)*

Elkington, Scot R.[1]; Chan, Anthony A.[2]; Tao, Xin[3]

1. Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder, Boulder, CO, USA
2. Department of Physics and Astronomy, Rice University, Houston, TX, USA
3. Atmospheric and Oceanic Sciences, UCLA, Los Angeles, CA, USA

Magnetospheric ULF waves at Pc5 (mHz) frequencies can be an efficient driver of radial transport among the relativistic electrons comprising the outer zone radiation belts. Large-scale, low wave number ULF waves driven by the solar wind may occur over a broad range of local times. However, azimuthal variations in the power spectral density of such waves can have a significant impact on the rates of radial diffusion in the outer zone, depending on the broadband spectral characteristics of the waves driving the transport. In this work we examine transport rates for relativistic electrons being driven by wave profiles

characteristic of those associated with pressure variations in the solar wind, and by waves associated with shear interactions at the flanks. We discuss the relationship between particle transport rates and the azimuthal extent of ULF waves as a function of wave autocorrelation times, and make an initial examination of the relationship between spectral properties in the solar wind and magnetospheric environments.

Fennell, Joseph F.

Storm Responses of Radiation Belts During Solar Cycle 23: HEO observations *(INVITED)*

Fennell, Joseph F.[1]; Blake, J. B.[1]; Kanekal, S.[2]; Roeder, J. L.[3]

1. Space Science Applications Laboratory, The Aerospace Corp, Los Angeles, CA, USA
2. Goddard Space Flight Center, Greenbelt, MD, USA
3. Space Sciences Department, The Aerospace Corp., Los Angeles, CA, USA

We present the radiation belt responses throughout solar cycle 23 using HEO satellite observations. We track the "global coherence" of the radiation belt responses in terms of storm time enhancements and storm and non-storm losses of energetic electrons by comparing the history of flux levels at low and high B values on the same L's for a wide range of L over several years. We show the relationship between microburst precipitation observed at low altitude near the loss cone by SAMPEX and the simultaneous flux responses at high altitudes observed by the HEO satellites near the maximum of the solar cycle. We show the range of observed loss rates for L < 4 and the statistics on the observed energetic flux changes relative to Dst for the storms of cycle 23. We put these observations into the context of what they mean in terms of Space Weather with emphasis on the impact to space systems and what we can expect during the RBSP mission.

Fraser, Brian J.

Electromagnetic Ion Cyclotron Waves, Plasma Drainage Plumes and Geomagnetic Storms *(INVITED)*

Fraser, Brian J.[1]

1. Centre for Space Physics, University of Newcastle, Callaghan, NSW, Australia

It is known that electromagnetic ion cyclotron (EMIC) waves make an important contribution to localized ring current loss during geomagnetic storms, and also radiation belt electron loss. More recently it has been shown that EMIC waves observed by the GOES and POLAR satellites are associated with extended plasma drainage plumes seen in the plasmasphere and magnetosphere by the IMAGE-EUV instrument, and supported by LANL geostationary satellite thermal energy plasma data. In this study we will investigate the properties of EMIC waves seen by the fluxgate magnetometers onboard the CRRES elliptically orbiting satellite and the GOES geostationary satellites during pre-storm quiet times, and the main and recovery phases of

geomagnetic storms. Also considered is the relationship between EMIC waves and associated plasma drainage plumes observed in IMAGE-EUV imaging data, CRRES plasma wave experiment electron density data and LANL satellite thermal energy plasma data. Individual case studies and statistics over selected storms and plume associated events will be presented. The results will provide new results on conditions in the magnetosphere under which EMIC wave generation occurs.

Friedel, Reiner H.

The energetic electron and proton radiations belts during solar cycle 23 as viewed from the GPS constellation *(INVITED)*

Friedel, Reiner H.[1]; Cayton, Thomas[1]

1. ISR-1, LANL, Los Alamos, NM, USA

Los Alamos has been flying energetic particle detectors on the GPS constellation spacecrafts since 1983. During solar cycle 23 (May 1996 - December 2008) density of measurements increased from 3 instruments to 11 instruments, providing and unprecedented spatial and temporal resolution of the radiation belts in the region from L=4 outwards, especially during the declining phase of solar cycle 23 and the long, extended minimum. We present here GPS data for trapped energetic electrons (100 keV - 10 MeV), trapped energetic protons (~1MeV), untrapped solar energetic protons up to 60 MeV and background cosmic rays for the past solar cycle and throughout the extended minimum. Trapped 1 MeV protons show an anti-cyclical behavior reaching their maximum during solar minimum, with the fluence delivered by these particles far outstripping the predictions of AP8. Trapped electron fluences from 0.1 MeV to around 4 MeV where roughly bounded by AE8 max and AE8 min during first part of the solar cycle, but outstripped the AE8 predictions in the declining phase from 2003 onward, especially at the higher energies. During the prolonged solar minimum from 2008 onwards until the April 2010 storm fluences were essentially flat.

Ganushkina, Natalia Y.

Locations of Boundaries of Outer and Inner Radiation Belts as Observed by Cluster and Double Star

Ganushkina, Natalia Y.[2, 1]; Dandouras, Iannis[3]; Shprits, Yuri[4]; Cao, Jinbin[5]

1. Finnish Meteorological Inst, Helsinki, Finland
2. University of Michigan, Ann Arbor, MI, USA
3. Centre d'Etudes Spatiale des Rayonnements, Toulouse, France
4. UCLA, Los Angeles, CA, USA
5. Beijing University of Aeronautics and Astronautics, Beijing, China

Cluster CIS ion spectrograms measured during the period of the recent solar minimum between April 2007 and June 2009, when Cluster was deep in the radiation belts with its perigee as close as L = 2, are analyzed. The analysis is complemented by Double Star TC-1 satellite data from HIA ion spectrograms on perigee passes during the period of May 15, 2007 to September 28, 2007. We demonstrate how the background counts produced by energetic partciles of the radiation belts in Cluster CIS and Double Star HIA instruments can be interpreted to obtain the locations of the boundaries of the outer and inner belts. The obtained L-MLT distribution of boundaries reflects the general structure of the radiation belts. Closer examination of the time-dependent L locations of the boundaries reveals several dips to lower L-shells (from L = 6 to L = 4) in the outer boundary location. The importance of the solar wind pressure increases for the Earthward shift of the outer boundary of the outer belt is discussed. The location and thickness of the slot region are studied using the determined inner boundaries of the outer belt and the outer boundaries of the inner belt. It was found that during intervals of low activity in the solar wind parameters, the slot region widens, which is consistent with weaker inward radial diffusion, and also with weaker local acceleration that can occur only at higher L-shells outside the plasmasphere. We conclude that boundaries of radiation belts determined from back ground measurements on the instruments with energy ranges that do not cover the radiation belts' energies provide valuable additional information that is useful for radiation belts' model development and validation.

Gary, S P.

Whistler anisotropy instability: Linear theory, particle-in-cell simulations, and fast test-electron computations

Gary, S P.[1]; Liu, Kaijun[1]; Winske, Dan[1]

1. Los Alamos National Laboratory, Los Alamos, NM, USA

Linear kinetic dispersion theory has been carried out for whistler fluctuations driven unstable by the electron temperature anisotropy $T_{\perp e}/T_{\parallel e} >$ 1. If the ratio of the electron plasma frequency to the electron cyclotron frequency is greater than unity and $\beta_{\parallel e} >$ 0.02, the maximum growth rate of the whistler anisotropy instability is at propagation parallel to the background magnetic field ${\bf B}_o$ and the fluctuating fields are substantially electromagnetic. At smaller values of $\beta_{\parallel e}$, the maximum growth rate shifts to propagation oblique to ${\bf B}_o$, and the fluctuating electric fields become primarily electrostatic. Particle-in-cell simulations of this instability confirm this theoretical prediction and demonstrate the differences between these two cases with respect to the fully nonlinear properties of the fluctuating field spectra and thermal electron velocity distributions. Finally, test particle computations for fast electron trajectories using enhanced fluctuating fields from the simulations will be described.

Haaland, Stein

Ionospheric Outflow as a Source of Plasma for the Magnetosphere

Haaland, Stein[1, 4]; Svenes, Knut[2]; Lybekk, Bjorn[3]; Pedersen, Arne[3]; Johnsen, Christine[4]; Eriksson, Anders[5]; Engwall, Erik[5]

1. Max-Planck Institute, Bern, Switzerland
2. Norwegian Defense Research Establishment, Kjeller, Norway
3. Department of Physics, University of Oslo, Oslo, Norway
4. Department of Physics and Technology, University of Bergen, Bergen, Norway
5. Swedish Institute of Space Physics, Uppsala, Sweden

Ion outflow from the polar ionosphere is an important source of plasma for the Earth's magnetosphere. Low energy ions travel along the magnetic field lines and enter the magnetospheric lobes where they are convected towards the tail plasma sheet. Recent results from the Cluster mission indicate that the field aligned outflow velocity is sometimes much higher than the convection towards the central plasma sheet. A substantial amount of plasma therefore escapes downtail without ever reaching the central plasma sheet. In this work, measurements of ionospheric outflow, field aligned acceleration and lobe convection are combined to quantify the amount of plasma recirculated to the magnetosphere for various geomagnetic activity levels. The results show that the outflow rate can vary up to a factor 3 as a result of enhanced solar irradiance and subsequent ionospheric ionization, but is less sensitive to geomagnetic activity level. The convection, and thus the supply to the plasma sheet and inner magnetosphere, on the other hand, is largely controlled by the interplanetary magnetic field (IMF). For northward IMF, esentially all of the outflowing ions are lost downtail due to stagnant convection. Correspondingly, a southward IMF results in enhanced convection and the outflowing ions are almost completely recirculated to the plasma sheet.

Haaland, Stein

Determination of Polar Cap Size and Shape Using Energetic Particles

Haaland, Stein[1, 2]; Søraas, Finn[2]; Kronberg, Elena[1]; Daly, Patrick[1]; Oksavik, Kjellmar[3]

1. Max-Planck Institute, Lindau, Germany
2. Department of Physics and Technology, University of Bergen, Bergen, Norway
3. Department of Arctic Geophysics, The University Centre in Svalbard, Longyearbyen, Norway

The size and shape of the terrestrial polar cap provides valuable information about the state of the magnetosphere. The polar cap area is also important for the total loss of plasma from the polar ionosphere into the solar wind via ion outflow along open field lines. In this study we have used energetic particles from the Cluster and NOAA satellites to infer the boundary between open and closed field lines. The more than 60'000 identified boundary crossings allow for sorting according to geomagnetic disturbance level,

interplanetary magnetic field and solar wind dynamic pressure. From these subsets, we can then identify the processes governing the size and shape of the polar cap.

Henderson, Michael G.

A Comparison of L* Calculations Using Different Algorithms and Field Models

Henderson, Michael G.[1]; Morley, Steve K.[1]; Koller, Josef[1]

1. Los Alamos National Laboratory, Los Alamos, NM, USA

In radiation belt physics, the third adiabatic invariant (the drift invariant), Φ is often converted into an L-shell-like parameter called L* by using the analytic formula for L as a function of Φ for a reference centered dipole field. The prescription for performing the calculations numerically was given many years ago by Roederer and as computers have become faster and more capable, a number of codes have been developed to compute L* from a variety of magnetospheric magnetic field models. These include SpenVis, Onera/IRBEM-LIB, LanlGeoMag, and a neural network approach (LANL*). Here, we compare the results obtained with these different approaches using different field models.

Hospodarsky, George B.

Plasma wave observations at Earth, Jupiter and Saturn *(INVITED)*

Hospodarsky, George B.[1]

1. Physics and Astronomy, University of Iowa, Iowa City, IA, USA

A variety of plasma waves, including whistler mode emissions such as chorus and hiss, have been detected in the magnetospheres of Earth, Jupiter, Saturn, Uranus, the Jovian moon Ganymede, and possibly at Neptune. At the Earth, these whistler mode waves have been shown to be very important in energizing and scattering particles associated with the Van Allen Radiation Belts. More recently, analysis of plasma wave measurements from the Galileo spacecraft have shown that these waves are also important in energizing particles in the Jovian magnetosphere. The Cassini mission to Saturn has also detected a variety of plasma waves in the Saturnian magnetosphere, and the importance of these waves with regard to energizing particles in the Saturnian system is an active area of research. The characteristics of the plasma waves detected at each planet and their possible importance in energizing and scattering particles will be discussed.

Huang, Chia-Lin

Magnetopause Shadowing Signature During Relativistic Electron Flux Dropout Events

Huang, Chia-Lin[1]; Spence, Harlan[1]; Singer, Howard[2]

1. Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH, USA
2. Space Weather Prediction Center, NOAA, Boulder, CO, USA

The radiation belt electron flux level is maintained through a competition between multiple source and loss processes occurring within the magnetosphere and driven by the solar wind. While most of the attention has focused on understanding electron flux enhancement, data from the geosynchronous regions uncovered many unexplained rapid flux decreases. One possible loss mechanism could cause such flux dropout is drift loss of electrons to the magnetopause boundary. Using magnetospheric configurations predicted by a recent version of the Tsyganenko model (TS05), we found that ˜80% of geosynchronous flux dropouts are on open drift paths, a signature of magnetopause shadowing (MPS). These MPS events have steeper flux decrease and slower flux recovery, stronger and sharper solar wind pressure pulse, and smaller southward IMF Bz compared to events without MPS signature. The local time distribution of MPS flux dropouts is concentrated at night side where the magnetic contour is closest to the magnetopause location. This work demonstrates the importance of accurate magnetic field modeling when determining the loss mechanism of radiation belt electrons which was not available in previous studies. Thus, we will utilize the newly developed TS07D model to compare the timing and "openness" of the open drift paths versus flux decrease levels, and to follow the trajectories of electrons through changing field configurations.
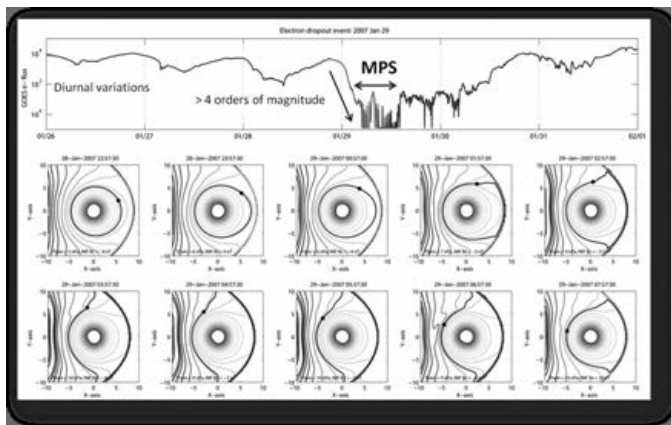
Electron dropout events measured by GOES-11. Top panel shows electron flux with energy greater than 2 MeV. Lower panels are contour maps of magnetic equator during flux dropout with GOES location marks as black dot.

Hudson, Mary K.

Radiation Belt Electron Response to CME- and CIR-driven Geomagnetic Storms *(INVITED)*

Hudson, Mary K.[1,3]; Brito, Thiago[1]; Elkington, Scot[2]; Kress, Brian[1]; Li, Zhao[1]; McGregor, Sarah[1]; Wiltberger, Michael[3]

1. Physics and Astronomy Dept., Dartmouth College, Hanover, NH, USA
2. LASP, University of Colorado, Boulder, CO, USA
3. HAO, NCAR, Boulder, CO, USA

CME-shock driven geomagnetic storms are characterized by prompt change in outer zone electron fluxes including radial loss as well as loss to the atmosphere, at times faster than convective build up of the ring current which produces radial losses when combined with inward motion of the magnetopause. Particularly strong CME shocks also produce radial transport of multi-MeV electrons on a drift time scale which can produce a 'new belt', less common than drift time scale loss. Several storms around the last solar maximum have been examined using the LFM-MHD code to compute internal magnetospheric E and B fields from upstream solar wind parameters, combined with 2D and 3D guiding center test particle codes to examine: 1) radial transport and 2) enhanced precipitation loss to the atmosphere. Inward radial transport increases flux at a given energy and L value, while outward radial transport to the inward moving magnetopause produces loss, along with enhanced loss to the atmosphere. On the longer time scale of a storm, including build up of the ring current, additional radial loss results from fully adiabatic and diffusive transport. Enhanced ULF wave activity can produce both coherent and diffusive transport and energy exchange with electrons in drift resonance with azimuthally propagating ULF waves. Coherent interaction with ULF waves can occur at a rate which exceeds nominal radial diffusion estimates but is slower than prompt injection on a drift time scale. Precipitation losses for the January 20, 2005 storm occur on the time scale of magnetosonic impulse propagation through the magnetosphere, following arrival of a CME-shock, much faster than the time scale for build up of the ring current and enhanced EMIC wave precipitation losses. The balance between enhanced and decreased phase space density when losses are included will be examined, along with CIR-driven storm comparisons from the Whole Heliosphere Interval in 2008, during the declining phase of solar activity approaching the recent solar minimum. The latter can produce sustained electron flux increases exceeding those of CME-driven storms.

Hutchinson, James A.

A Novel New Radar Technique to Study Geomagnetic Storms: Superposed Latitude-Velocity-Time Plots

Hutchinson, James A.[1]; Wright, Darren M.[1]; Milan, Steve E.[1]; Grocott, Adrian[1]; Boakes, Peter D.[1]

1. Dept. of Physics & Astronomy, University of Leicester, Leicester, United Kingdom

Geomagnetic storms cause large global disturbances in the Earth's magnetosphere, during which large amounts of energy are deposited in the magnetotail and inner magnetosphere, producing an enhanced ring current and energising plasma to relativistic levels by little-known excitation mechanisms. As we approach more active times in solar cycle 24, predicting the effects of space weather will be crucial in protecting both space and terrestrial based applications such as GPS and national power grids. By exploiting data from the Advanced Composition Explorer (ACE) spacecraft in conjunction with space- and ground-based measurements of geospace over the last solar cycle, a superposed epoch analysis of 143 geomagnetic storms identified from the global SYM-H index has been completed. Using a superposition method based on average periods of storm phases rather than a simple t0 alignment, it was found that there is a dual trend seen in the main phase duration with storm size, given by maximum negative excursion of SYM-H, contrary to previous studies results. We also discuss a comparison of CME and CIR driven storms in terms of storm size, phase duration and evolution, and the associated solar wind-magnetosphere coupling. Current work uses radar backscatter observed by the Super Dual Auroral Radar Network (SuperDARN) and auroral imagery from the IMAGE spacecraft mission to better constrain the storm time coupling between the solar wind and magnetosphere and to develop storm phase trends previously identified. We present initial findings of a new radar technique using line of sight, latitude-velocity-time plots analogous to standard RTI plots but using ionospheric convection maps to allow better superposition by removing temporal/spatial problems of moving radars. These, along with cross-cap potential data derived from map potential data, are compared to superposed auroral keograms and the geomagnetic and SW data from our previous study. Initial findings show that the cross cap potential increases during storm main phase and confirm the oval radius - ring current relationship identified by Milan et al., 2009.

Jordanova, Vania K.

The Role of the Ring Current in Radiation Belt Dynamics *(INVITED)*

Jordanova, Vania K.[1]

1. Space Science and Applications, Los Alamos National Laboratory, Los Alamos, NM, USA

The dynamical coupling of the ring current and the radiation belts is studied during geomagnetic storms. We use our four-dimensional (4-D) ring current-atmosphere interactions model (RAM), which includes time-dependent transport, all major loss processes, and is coupled with a dynamic 2-D plasmasphere model. RAM solves the kinetic equation for H+, O+, and He+ ions and electrons and is two-way coupled with a 3-D equilibrium code that calculates self-consistently the magnetic field (SCB) in force balance with the anisotropic ring current distributions. The boundary conditions are specified by a plasma sheet source population at geosynchronous orbit that varies both in space and time. We study the effects of non-dipolar magnetic field configuration on ring current dynamics and the formation of ion ring distributions due to energy dependent drifts and losses. We find that as strong depressions in the self-consistent magnetic field develop on the nightside during the main phase of a storm, the particles' gradient-curvature drift velocity increases, the particle fluxes are reduced and the ring current is confined close to Earth. As a result of drift-shell splitting, the pitch angle anisotropy decreases at large L shells on the nightside and increases on the dayside. Strong electromagnetic ion cyclotron (EMIC), chorus, and magnetosonic waves are excited near minimum Dst and during the recovery phase of the storm at various locations in the equatorial magnetosphere. The effects of these plasma waves on energetic particle dynamics are investigated.

Jorgensen, Anders M.

Data Assimilation of Plasma Density Measurements Into the Dynamic Global Core Plasma Model

Jorgensen, Anders M.[1]; Ridley, A. J.[2]; Dodger, A. M.[2]; Chi, P. J.[3]; Lichtenberger, J.[4]; Moldwin, M. B.[2]; Ober, D.[5]; Boudouridis, A.[6]

1. Electrical Engineering Department, New Mexico Tech, Socorro, NM, USA
2. University of Michigan, Ann Arbor, MI, USA
3. University of California Los Angeles, Los Angeles, CA, USA
4. Eotvos Lorand University, Budapest, Hungary
5. Air Force Research Laboratory, Albuquerque, NM, USA
6. Space Science Institute, Boulder, CO, USA

We will present the results of data assimilation of density measurements into the Dynamic Global Core Plasma Model (DGCPM) using a particle filter approach. Being able to produce accurate maps of plasmaspheric density is important because plasma density gradients are sites of waves which contribute to acceleration or loss of radiation belt particles. The plasmasphere is largely described in terms of plasma flow out of and into the ionosphere, as well as a convection electric field, with the electric field being primarily responsible for the dynamics. The plasmasphere appears to respond in an integral way, meaning that the present drivers for the most part do not manifest themselves in present observations (except of course for a direct measurements of the drivers). Instead, present observations provide constraints on drivers in the past. In this talk we will

begin by discussing data assimilation and plasmasphere dynamics. We will then show an example of an assimilation of density measurements from Field Line Resonance, VLF whistler observations, and in-situ observations. We will compare the data assimilation with open loop plasmasphere runs using existing electric field models and maps, including the output of the AMIE procedure.

Kanekal, Shrikanth G.

Relativistic electron losses in the outer radiation belts

Kanekal, Shrikanth G.[1]; Fennell, J. F.[2]; Baker, D. N.[3]; Klecker, B.[4]

1. Code 672, NASA Goddard Space Flight Center, Greenbelt, MD, USA
2. he Aerospace Corporation, Los Angeles, CA, USA
3. LASP / University of Colorado, Boulder, CO, USA
4. Max Planck Institut fur Extraterrestriches Physick, Garching, Germany

Relativistic electrons in the magnetosphere are lost by escaping the magnetosphere and via their interaction with plasma waves such as whister chorus, plasmaspheric hiss and EMIC waves. We study relativistic electron losses in the outer radiation belts by characterizing decay times scales at low and high altitudes and their relationship to microbursts. We use data collected by SAMPEX, a low Earth orbiting spacecraft in a highly inclined polar orbit and the HEO spacecraft in a high altitude Molniya orbit. The sensors onboard these spacecraft measure electrons of energies > 0.6 MeV, > 1 MeV, > 3 MeV, 2-6 MeV, 3-16 MeV. High time resolution data enable identifying and characterizing electron microbursts observed at low altitudes.

Kataoka, Ryuho

Modeling and forecasting geomagnetically induced currents in Hokkaido, Japan *(INVITED)*

Kataoka, Ryuho[1]; Pulkkinen, Antti[2]; Watari, Shinichi[3]; Ichiki, Masahiro[4]

1. Tokyo Institute of Technology, Meguro, Japan
2. CUA and NASA/GSFC, Greenbelt, MD, USA
3. National Institute of Information and Communications Technology, Koganei, Japan
4. Tohoku University, Sendai, Japan

In this paper a model for computing geomagnetically induced currents (GIC) from local geomagnetic field observations carried out in Hokkaido, Japan is constructed. The model is composed of system parameters mapping the horizontal geoelectric field to GIC and of 1D conductivity model. A rigorous model validation is used to show that the model reproduces the observed GIC with a very good accuracy. Statistical occurrence of GIC is computed using the constructed model and geomagnetic field recordings covering years 1986.2008. The modeled GIC is used to generate a list of 10 largest GIC events in Hokkaido, Japan. It is found that the 10 largest events between 1986 and 2008 were associated with various phases of coronal mass ejection

driven major geomagnetic storms. It is also shown that although smaller GIC are fairly common, the largest possible GIC are likely limited to the amplitudes of the order of 10 A. The constructed 1D ground conductivity model is interpreted in the context of the local geological setting and it is shown that the subduction zone dynamics likely play an important role in the observed GIC and geomagnetic field characteristics. Crustal conductor associated with the subduction zone is the cause for unusual direct relation between GIC and the local geomagnetic field rather than its time derivative and GIC.

Katoh, Yuto

Electron hybrid simulation of nonlinear wave growth of whistler-mode chorus emissions *(INVITED)*

Katoh, Yuto[1]; Omura, Yoshiharu[2]

1. Dept Geophys, Grad Sch Sci, Tohoku Univ, Sendai, Japan
2. RISH, Kyoto Univ, Uji, Japan

Whistler-mode chorus emissions are narrow band electromagnetic emissions often observed on the dawn side of the Earth's magnetosphere. Results of in situ observations reveal that chorus emissions are generated in the equatorial region of the magnetosphere. For the generation process of chorus emissions, previous theoretical studies suggested the importance of nonlinear resonant interactions between coherent whistler-mode waves and energetic electrons in the region close to the magnetic equator. Recently we have proposed the nonlinear wave growth theory for the generation mechanism of chorus emissions, based on the theoretical consideration and the analyses of the simulation result. We have conducted numerical experiments of the nonlinear wave particle interactions in an inhomogeneous magnetic field by using an originally developed electron hybrid code. The electron hybrid code is based on the model treating background cold electrons as a fluid and hot electrons as relativistic particles by the particle-in-cell method. We follow evolution of electromagnetic waves propagating along a reference magnetic field line by solving Maxwell's equations and relativistic equations of motion of energetic electrons bouncing in the dipole magnetic field. The nonlinear growth theory suggests that the frequency sweep-rate of a chorus element is related to the wave amplitude of coherent chorus elements in the region close to the magnetic equator. We have confirmed this prediction by performing simulations with different initial number densities of energetic electrons. We have also found that the theoretical amplitude threshold for the nonlinear wave growth is consistent with the simulation results.

Keika, Kunihiro

Ion injection and plasmapause location during the storm recovery phase: Comparison between different solar wind drivers

Keika, Kunihiro[1]; Brandt, Pontus C.[2]; Mitchell, Donald G.[2]; Miyoshi, Yoshizumi[3]

1. NJIT, Newark, NJ, USA
2. JHU/APL, Laurel, MD, USA
3. STEL, Nagoya Univ., Nagoya, Japan

Geomagnetic storms, which are represented by the Dst index, show different time profiles between solar wind drivers such as Coronal Mass Ejections (CME) and Corotating Interaction Regions (CIR). A super-posed epoch analysis of Dst [Miyoshi and Kataoka, 2005, GRL] shows a distinct difference in the late recovery phase; Dst for CIR-driven storms is smaller than that for CME-driven storms. In addition, the flux of radiation belt electrons is higher for CIR-driven storms than for CME-driven storms. The intensification of the outer radiation belt during the storm recovery phase is primarily controlled by local acceleration through whistler-mode chorus waves and the injection of the source population from the plasma sheet. It is believed that the local acceleration occurs in low-density regions, that is, outside of the plasmasphere. The injection mostly occurs during substorms, accompanied by ion injection. In this study we examine, for the storm recovery phase, (i) the strength of ion injection and the total number of injection events and (ii) the location of the plasmapause and its temporal variations. We then compare these two characteristics between CIR- and CME-driven storms. To identify (i), we use ENA data obtained with the High Energy Neutral Atom (HENA) imager onboard the Imager for Magnetopause-to-Aurora Global Exploration (IMAGE) satellite. We examine ENA energy spectra to identify in which energy range the ion flux in the inner magnetosphere increases significantly. We identify (ii) from data obtained with the extreme ultraviolet (EUV) imager onboard IMAGE.

Kessel, Ramona

RBSP Mission Overview *(INVITED)*

Kessel, Ramona[1]

1. NASA Headquarters, Washington, DC, USA

The Radiation Belt Storm Probes Mission, part of NASA's Living With a Star program, will provide unprecedented insight into the physical dynamics of the radiation belts and give scientists the data they need to make predictions of changes in this critical region of space. Beginning in 2012, two spacecraft will orbit the Earth, sampling the harsh radiation belt environment where major space weather activity occurs and many spacecraft operate. The two spacecraft will measure the particles, magnetic and electric fields, and waves that fill geospace. The Johns Hopkins Applied Physics Laboratory is designing and will operate the twin Radiation Belt Storm Probes for NASA. RBSP is currently in the Integration and Testing phase. This presentation will give an overview of the Mission and an update on current status.


Radiation Belt Storm Probes Mission
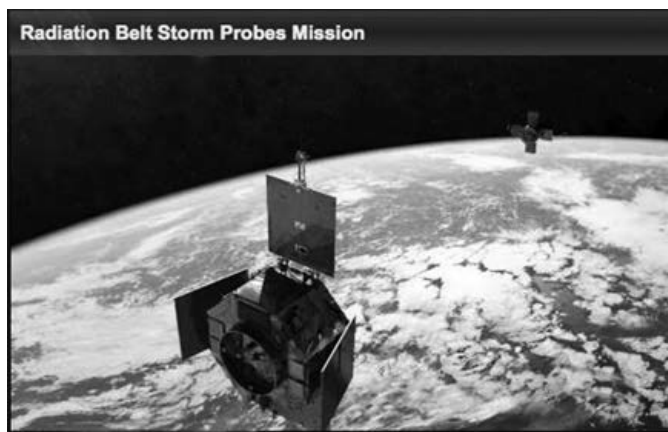
Kirmani, Ahmed R.

Relationship between Interplanetary Magnetic Field and AE Index

Kirmani, Ahmed R.[1,2]; Awasthi, Arun K.[2]; Jain, Rajmal[2]

1. Department of Physics, AMU, Aligarh, India
2. Astronomy and Astrophysics Division, PRL, Ahmedabad, India

Solar wind carries the magnetic field of the Sun along with it, known as the interplanetary magnetic field (IMF). Solar wind and IMF affect the earth's magnetic field resulting in the formation of magnetosphere and change its configuration. The high magnitude of the solar wind and appropriate direction of IMF generate storms and substorms in the earth's magnetosphere as a consequence of magnetic reconnections of the open field lines. The storms are measured in terms of disturbed storm time (DST) index. The reconnection also causes particle acceleration, which gyrate along the field lines and travel to poles of the earth, where they produce aurora. The aurora measured as AE (auroral electrojet) index is another signature of geomagnetic storms. It has been recently proposed that climate change on the earth is related to IMF. However, in order to prove it we require homogeneous IMF data for a longer period. Currently regular measurement of IMF at L1 orbit is available since 1997 from the magnetometer on-board the ACE mission. The other IMF data are varying over orbits. Thus in order to probe the IMF data for the past 100 years period over a fixed location L1 point, we first establish relationship between IMF and AE indices for the period of 1997 to 2010. The AE indices, however, are available for the last more than 100 years. The daily IMF data from 14 August, 1997 as a function of AE indices is studied. We made 5nT bins to reduce noise levels. We found the best fit of these two data sets by a polynomial of the order of 5. This enabled us to predict the IMF to first approximation and to observe the 11 year solar activity.
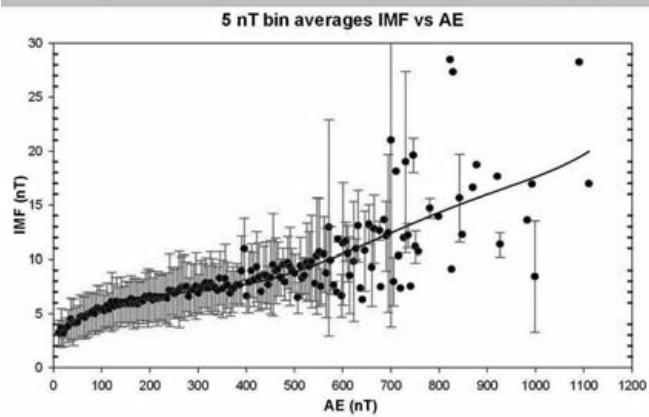
$$IMF=2.2579+0.0511*AE-0.0002*AE^2+4.721E-7*AE^3-4.158E-10*AE^4+1.32E-13*AE^5$$

The IMF-AE relationship
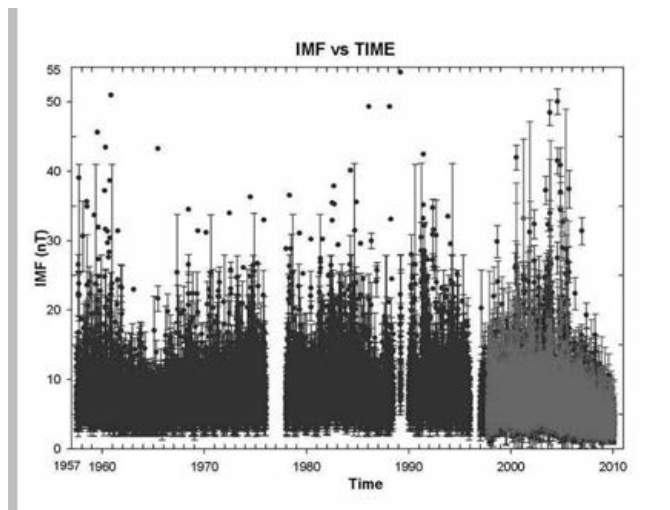
The IMF predictions

Kitamura, Naritoshi

Observations of very-low-energy ion outflows dominated by O[+] ions in the region of enhanced electron density in the polar cap magnetosphere during geomagnetic storms *(INVITED)*

Kitamura, Naritoshi[1]; Nishimura, Yukitoshi[2]; Ono, Takayuki[1]; Ebihara, Yusuke[3]; Terada, Naoki[1]; Shinbori, Atsuki[3]; Kumamoto, Atsushi[4]; Abe, Takumi[5]; Yamada, Manabu[5]; Watanabe, Shigeto[6]; Matsuoka, Ayako[5]; Yau, Andrew W.[7]

1. Department of Geophysics, Tohoku University, Sendai, Japan
2. Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Japan
3. Research Institute for Sustainable Humanosphere, Kyoto University, Uji, Japan
4. Planetary Plasma and Atmospheric Research Center, Tohoku University, Sendai, Japan
5. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Japan
6. Earth and Planetary Science Division, Hokkaido University, Sapporo, Japan
7. Department of Physics and Astronomy, University of Calgary, Calgary, AB, Canada

Velocity distributions of upflowing ions in the polar ionosphere are crucial to understand their destinations. Natural plasma wave observations by the plasma wave and sounder (PWS) experiments and thermal ion observations by the suprathermal ion mass spectrometer (SMS) onboard the Akebono satellite at ˜9000 km altitude in the polar magnetosphere during the geomagnetic storms showed that ions in the region of enhanced electron density in the polar cap were dominated by very-low-energy O[+] ions (˜85%) with upward velocities of 4–10 km/s, corresponding to streaming energies of 1.3–8.4 eV. The fluxes of very-low-energy upflowing O[+] ions exceeded $1*10^9$ /cm²/s (mapped to 1000 km altitude) across wide regions. These signatures are consistent with high-density plasma supplied by the cleft ion fountain mechanism. Trajectory calculations of O[+] ions based on the Akebono observations as the initial condition showed the transport paths and accelerations of the O[+] ions, and indicated that the velocities of the very-low-energy upflowing O[+] ions through the dayside polar cap are enough to reach the magnetosphere under strong convection. The calculations suggest the importance of the very-low-energy upflowing O[+] ions with large fluxes in the total O[+] ion supply toward the magnetosphere, especially the near-Earth tail region and inner magnetosphere. The initially very-low-energy O[+] ions can contribute significantly to the ring current formation during geomagnetic storms, since some of the O[+] ions were transported into the ring current region with typical energies of ring current ions (several tens of keV) in the trajectory calculations.

Kletzing, Craig

Electric and Magnetic Field Measurements on the RBSP Mission *(INVITED)*

Kletzing, Craig[1]; Wygant, John[2]; Bonnell, John[3]; Kurth, William[1]; MacDowall, Robert[5]; Torbert, Roy B.[4]

1. Physics & Astronomy, University of Iowa, Iowa City, IA, USA
2. School of Physics and Astronomy, University of Minnesota, Minneapolis, MN, USA
3. Space Sciences Laboratory, University of California, Berkeley, Berkeley, CA, USA
4. Space Science Center, University of New Hampshire, Durham, NH, USA
5. Goddard Space Flight Center, Greenbelt, MD, USA

The physics of the creation, loss, and transport of radiation belt particles is intimately connected to the electric and magnetic fields which mediate these processes. A large range of field and particle interactions are involved in this physics from ions and ring current magnetic fields to microscopic kinetic interactions such as whistler-mode chorus waves with energetic electrons. To measure these kinds of radiation belt interactions, NASA will launch the two-satellite Radiation Belt Storm Probes (RBSP) mission in 2012. As part of the mission, the Electric and Magnetic Field Instrument Suite and Integrated Science (EMFISIS) investigation and the Electric Field and Waves (EFW) investigation provide a comprehensive set of instruments covering both electric and magnetic fields over the key frequency ranges from DC up to 400 kHz. Examples of key field science such as the interactions of radiation belt particles with various wave modes such as VLF hiss, magnetosonic equatorial noise, electromagnetic ion cyclotron waves, and chorus are presented as well as convection electric fields and Alfven waves.

Kondrashov, Dmitri

Operator-splitting Kalman Filter as efficient data assimilation method for radiation belts

Kondrashov, Dmitri[1]; Shprits, Yuri[1]; Ghil, Michael[1, 2]

1. Department of Atmospheric and Oceanic Sciences and Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA, USA
2. Geosciences Department and Laboratoire de Meteorologie Dynamique (CNRS and IPSL), Ecole Normale Superieure, Paris, France

The Van Allen radiation belts are composed of charged particles confined by the Earth's magnetic field. Energetic electron activity in Earth's radiation belts can present dangerous hazard to satellites in space. In this study, we rely on operator splitting to make Kalman filter computationally efficient for assimilating electron phase space density (PSD) into the radiation belts model. We compare the conventional Kalman filter, on the one hand, and its modification developed in this study, on the other, by assimilating synthetic data, as well as actual satellite observations into multi-dimensional Fokker-Plank equation for PSD. The

operator-splitting Kalman filter is considerably faster compared to the standard Kalman filter implementation, while yielding similar analysis errors.

Korotova, Galina I.

Themis Observations of Compressional Pulsations in the Dawn Magnetosphere

Korotova, Galina I.[1, 2]; Sibeck, David G.[3]

1. IZMIRAN, Moscow, Russian Federation
2. IPST/UMD, College Park, MD, USA
3. GSFC/NASA, Greenbelt, MD, USA

We present results from a study of compressional pulsations observed by the THEMIS spacecraft in the dawn magnetosphere from 2007 to 2009. We survey the events to determine their characteristics as a function of L shell, latitude and local time. We use finite gyroradius techniques to determine their motion and inspect pitch angle distributions to determine their effects on resonant/non-resonant particles. In particular, we investigate the conditions favoring the generation of double frequency compressional pulsations, distingushing between interpretations in terms of substorm injections, drift mirror mode waves, and drift-bounce resonances.

Krasnoselskikh, Vladimir

Empirical model describing whistler waves statistical characteristics in the Earth radiation belts

Krasnoselskikh, Vladimir[1]; Agapitov, Oleksiy[1, 2]; Rolland, Guy[3]

1. LPCEE, LPC2E CNRS - Univ Orleans, Orleans Cedex 2, France
2. Departement of Physics, Taras Shevchenko Kiev National University, Kiev, Ukraine
3. CNES, Toulouse, France

We performed a statistical study and constructed the probability distribution of wave amplitudes and wave normal vectors making use of the wave measurements on board Cluster satellites during nine years 2001–2009. This statistical database covers the regions of the magnetosphere frequently visited by Cluster satellites, L-shells from 2 to 7, at different local times and on different magnetic latitudes for quiet, moderate and active magnetosphere activity. The analysis is performed in the frequency range from 8.8 Hz up to 3.56 kHz making use of the STAFF-SA instrument measurements. The results can be summarized as follows: The most intensive chorus waves are observed in the range from 23 to 13 hours MLT and at L-shells from 2 to 3 and from 4 to 6 which is consistent with previous studies. Statistical characteristics of distributions are different for low and moderate magnetospheric activity conditions (Kp < 5) and high magnetospheric activity conditions (Kp > 5). There are two well distinguishable regions where statistical properties of wave amplitudes and normal vector distributions exhibit different statistical characteristics under low and moderate activity conditions: 1) L = 2–4 (up

to plasmapause) where lightning generated and magnetospheric chorus generated whistlers are supposed to dominate; 2) the region where the chorus type whistlers dominate, L = 4–6.5. The magnetic latitudinal dependence of the wave normal vectors distribution obtained for the first time clearly shows the increase of the maximum of the distribution from about 20° at equator up to 80° at about 30° magnetic latitude. The probability distribution of wave activity parameters are usually non-symmetric and have significant non-Gaussian tails, thus one can suggest that they cannot be well-described by long-term time averages. The results obtained can have important consequences for the description of the diffusion process of wave-particle interaction. The conventional averaging procedures cannot be performed without taking into account relatively rapid departure of wave normal vectors from quasi-parallel propagation conditions, thus they should take into account more realistic wave energy and k-vector distributions. We present the analytical mapping of the probability distribution function of the wave-vector directions which allows to restore the VLF wave distribution in the inner magnetosphere by analytical approximation with small number of parameters: particularly the mean values of the angle between wave normal and the background magnetic field and the amplitude distributions for each magnetic latitude and magnetic local time.

Krasnoselskikh, Vladimir

Reconstruction of Chorus Type Whistler Wave Statistics in the Radiation Belts and in the Inner Magnetosphere Using Ray Tracing *(INVITED)*

Krasnoselskikh, Vladimir[1]; Zaliznyak, Yuriy[2]; Agapitov, Oleksiy[3, 1]; Breuillard, Hugo[1]; Rolland, Guy[4]; Mendzhul, Dmytro[3]

1. LPCEE, LPC2E CNRS - Univ Orleans, Orleans Cedex 2, France
2. Institut for Nuclear Research, Kiev, Ukraine
3. Departement of Physics, Kiev University, Kiev, Ukraine
4. CNES, Toulouse, France

Quasi-monochromatic whistler wave packets are formed in the vicinity of the magnetic equator and are frequently observed aboard Cluster spacecraft. It was shown recently making use of 10 years of Cluster observations (2001-2010) that the distribution of wave vectors strongly deviates from the quasiparallel propagation on magnetic latitudes as low as 20-25° (Agapitov et al., 2011). The objective of our study is a reconstruction of realistic characteristics of chorus emissions in the radiation belts and in the inner magnetosphere. The data sets of wave measurements onboard DE, Polar, Cluster do not allow to have complete coverage of different regions of magnetosphere. To study radiation belts dynamics one needs to know the wave amplitude, frequency and k-vector distributions in all the regions of the magnetosphere. To achieve this aim the data from the electric and magnetic field measurements onboard Cluster satellites are used to determine the major characteristics of the chorus signal around the equator

region, namely, its amplitude, averaged wave vector, frequency and wave vector distribution, Poynting flux and polarization. Then the propagation of such a wave packet is modeled in the framework of ray tracing technique using the original code which employs K. Rönnmark's WHAMP code to obtain hot plasma dispersion function along the wave packet trajectory. The observed ("real") rays at the equator are first fitted to the "initial distribution" of observed waveforms using Cluster observations (initial conditions) and then these rays are propagated numerically through the inner magnetosphere in the frame of the WKB approximation. The density distributions of particles in the magnetosphere aiming to describe the plasmashere and inner and outer magnetosphere are taken from the Gallagher et al. GCPM package that is provided by the authors and distributed as free software. Ray tracing allows one to reconstruct the properties of waves such as electric and magnetic fields, the width and the central wavenumber of the packet in k-space along the ray propagation path. The simulations take into account realistic effects of the spreading of the signal due to propagation in the inhomogeneous and anisotropic magnetized plasma, the dependence of signal propagation characteristics upon initial conditions, deviation from the initial L-shell. Our calculations make it possible to follow the wave packets and calculate their properties in the desired regions, e.g. the regions where an efficient wave-particle interaction is expected to occur. We compare the results obtained with the statistical distributions observed onboard Cluster satellites. We discuss possible averaging procedures to be used for evaluation of the quasilinear diffusion coefficients taking into account statistical characteristics of the waves.

Kress, Brian T.

Radial transport and energization in the Earth's radiation belts driven by solar wind dynamic pressure fluctuations *(INVITED)*

Kress, Brian T.[1]; Hudson, Mary K.[1]; Ukhorskiy, Aleksandr Y.[2]

1. Dartmouth College, Hanover, NH, USA
2. Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA

Radial transport in the Earth's radiation belts is frequently modeled using a diffusion equation, however in some cases solar wind dynamic pressure fluctuations can cause significant changes in the PSD radial profile that are not diffusive, e.g., shock acceleration. Three types of radial transport that have been identified are: (1) radial diffusion [Falthammer, 1965], (2) significant changes in the PSD radial profile due to a single or few ULF drift-resonant interactions [Ukhorskiy et al., 2006; Degeling et al., 2008], and (3) shock associated injections of radiation belt electrons occurring in less than a single drift period [Li et al., 1993]. A progress report will be given on work to fully characterize these different forms of radial transport, corresponding solar wind driving conditions, and their effect on radiation belt dynamics. The work is being carried out by computing test-particle trajectories in electric and magnetic

fields from a simple analytic ULF field model and from global MHD simulations of the magnetosphere. Degeling, A. W., L. G. Ozeke, R. Rankin, I. R. Mann, and K. Kabin, (2008), Drift resonant generation of peaked relativistic electron distributions by Pc 5 ULF waves, J. of Geophys. Res., 113, A2, A02208. Falthammer, C. G. (1965), Effect of time dependent electric fields on geomagnetically trapped radiation, J. Geophys. Res., 70, 2503. Li, X., I. Roth, M. Temerin, J. R. Wygant, M. K. Hudson, and J. B. Blake, (1993), Simulations of the prompt energization and transport of radiation belt particles during the March 24, 1991 SSC, Geophys. Res. Lett., 20, 2423. Ukhorskiy, A. Y., B. J. Anderson, K. Takahashi, and N. A. Tsyganenko (2006), Impact of ULF oscillations in solar wind dynamic pressure on the outer radiation belt electrons, Geophys. Res. Lett., 33, 6, L06111.

Krimigis, Stamatios M.

Discovering Earth's Van Allen Belts and the Quest for Radiation Belts at all the other Planets *(INVITED)*

Krimigis, Stamatios M.[1, 2]

1. Applied Physics Laboratory, Johns Hopkins Univ, Laurel, MD, USA
2. Office of Space Research and Applications, Academy of Athens, Athens, Greece

The idea for establishing a program for an International Geophysical Year (IGY) germinated at a dinner organized by James and Abigail Van Allen at their home in Silver Spring, Maryland, on April 5, 1950. Van Allen was still leading the High Altitude Research Group at the Applied Physics Laboratory (APL) of The Johns Hopkins University, where they had instrumented several V-2 rockets in the preceding few years to study cosmic radiation with altitude, among other things. Van Allen moved to Iowa City later that year and established the group that not only made key discoveries before and during the IGY, but built the sensors that led to the discovery of Earth's radiation belts (later named the Van Allen Belts) in 1959. Van Allen, his associates and graduate students were working at a frenetic pace to establish the physical characteristics of the belts when I arrived as a first-year graduate student on the campus in the fall of 1961. After doing a quick MS on solar protons incident on Earth's polar caps using APL's solid state detectors (SSD) on Injun 1, I was assigned to investigate the question of elemental composition of the belts (Injun 4), and to design an SSD system to search for protons trapped in Mars' expected radiation belts (Mariners 3,4), both launched in November 1964. A near-copy of the Mariner 4 detector was launched on Mariner 5 to Venus in 1967, while another SSD was flown on Injun 5 in 1968 to search for nuclei with Z>2 in the belts. Soon thereafter Pioneer 10, 11 were proposed to investigate Jupiter's expected magnetosphere, while planning commenced in 1969 for a mission to all the outer planets that eventually became Voyager 1,2. Finally in 1974 Mariner 10 flew by Mercury and discovered to everyone's surprise that it possessed a magnetic field, and since March 18 MESSENGER is orbiting that planet. Voyager 1 in the meantime is at the solar system's edge at 116 AU and has discovered a belt of energetic particles surrounding the heliosphere. Earth's Van Allen Belts have provided the "ground truth" that has helped us understand the physics of plasmas and energetic particles trapped within planetary magnetic fields. It is indeed remarkable that similar processes, each with a local twist, operate everywhere in the solar system where measurements have been possible.

Kronberg, Elena

Survey of Oxygen to Proton ratio in the inner magnetosphere

Kronberg, Elena[1]; Haaland, Stein[1, 2]; Daly, Patrick[1]; Fraenz, Markus[1]; Kistler, Lynn[3]; Dandouras, Iannis[4]

1. Max-Planck Institute for Solar System Research, Katlenburg-Lindau, Germany
2. Department of Physics and Technology, University of Bergen, Bergen, Norway
3. University of New Hampshire, Durham, NH, USA
4. Institut de Recherche en Astrophysique et Planetologie, Toulouse, France

We investigate the oxygen to proton ratio in the Earth's inner magnetosphere at radial distances from 6 to 12 RE. The results are based on 7 years of ion flux measurements in the energy range ˜10 keV (intermediate) to ˜1 MeV(energetic) from the RAPID and CIS instruments on board the Cluster satellites. Overall, we find enhanced fluxes of energetic oxygen in the dusk region, close to the magnetopause. Storm activity, reflected by a more negative Dst index, is correlated with increased abundance of both energetic and intermediate oxygen. During strong magnetospheric storms the flux of energetic oxygen can be as high as, or higher than the flux of energetic protons. Short time disturbances associated with substorm and bursty bulk flow activity and reflected by the AE index show a positive correlation with the oxygen to proton ratio. This ratio also varies with solar activity. Higher irradiance and thus enhanced ionization is reflected by higher oxygen to proton ratio for intermediate energies, and the opposite for high energy ions.

Lanzerotti, Louis J.

Space weather effects on technologies *(INVITED)*

Lanzerotti, Louis J.[1]

1. Ctr Solar-Terrestrial Research, Newark, NJ, USA

Beginning with the era of development of electrical telegraph systems in the early 19th century, the space environment around Earth has influenced the design and operations of ever-increasing and sophisticated technical systems, both in space and on the ground. Important first events in communications occurred in Newfoundland, including the landing of the first telegraph cable in Hearts Content (1866), the first reception of trans-Atlantic wireless signals at Signal Hill in St.John's (1901), and the first trans-Atlantic telecommunications cable in Clarenville (1956). All of the systems represented by these 'firsts' suffered from

effects of space weather. This talk will briefly review some of the historical effects of space weather on technologies from the telegraph to the present, and will note several events that impacted communications and electrical power systems in Canada

Lapenta, Giovanni

Space Weather Forecasting activities in Europe, within Soteria and Swiff

Lapenta, Giovanni[1]

1. Wiskunde, KU Leuven, Leuven, Belgium

The European Commission, the executive governing body of the European Union, has recently invested in a number of new research consortia for the study of space weather. We report here the activities of Soteria (soteria-space.eu) and Swiff (swiff.eu). Soteria gathers observations of all phases of space weather from the photosphere to the Earth impact, organises them in a homogeneous form via a virtual observatory (SODA) linked with the new european VO HELIO. Swiff, instead, works towards a first-principle physics-based forecasting software that can form a basis of the future space weather forecasting activities in Europe. Both projects are coordinated by the Giovanni Lapenta at the Katholieke Universiteit in Leuven, near Brussel in Belgium. We report here the plans and achievements so far for these projects. We give an overview of all activities, focusing especially on the inner magnetosphere and radiation belts. The main innovation of our effort is a new the approach to the coupling of kinetic and fluid models within a new tool based on the implicit moment method.

Lazaro, Didier

IPODE : Ionising Particle Onera DatabasE for Earth's Radiation Belts Analysis

Lazaro, Didier[1]; Bourdarie, Sébastien[1]; Sicard-Piet, Angélica[1]

1. DESP, ONERA, Toulouse, France

Satellite engineers, operators, and radiation belt researchers share a common desire to understand and predict the structure and variability of Earth's radiation belts. In the radiation belts community, there is a need for improved scientific understanding of the radiation belts, more accurate dynamic and climatological models, space weather restitution and prediction and a mechanism for more efficient transfer of scientific understanding to the space community. To allow for such advancements to take place, IPSAT (Ionising Particle in Space Analysis Tool) has been developed at ONERA under CNES funding in the frame of the CRATERRE project. This web based virtual radiation belt observatory tool offers access to near-real-time measurements, historical data, analysis and visualization software. This tool relies mainly on a current data base now known as IPODE (Ionising Particle Onera Database). This database is composed of nearly a hundred spacecraft/instrument couples for in-situ Earth's particle measurements (electron, proton and alpha particles fluxes). A wide range of orbits are covered: geosynchronous (GEO), global positioning systems (GPS), elliptical (HEO) and low altitude (LEO). Measurements have been and are still gathered through open source data or collaborations between ONERA and international institutions such as Los Alamos National Laboratory (LANL), Aerospace Corporation, JAXA (CNES-JAXA agreement), Moscow State University (MSU) and CONAE (CNES-CONAE agreement). The principal strength of this data base is its global spatial and long time coverage. This data base, automatically managed by a set of cron jobs, is updated according to the availability of new raw data, in ISTP/CDF standard file format. These new data are automatically filtered to ensure good quality of measurements and therefore allows to perform radiation belts dynamics survey in near real time and in various regions of the Earth's space. This data base has already resulted in the development of models such as IGE 2006, MEO V2, MEO at and nearby Galileo Orbit, OZONE the outer zone electron belt specification model, and is used for radiation belt data assimilation and Salammbô code validation.

Lee, Jaejin

Electron Microburst Energy Dispersion calculated by Test Particle Simulation

Lee, Jaejin[1]; Cho, Kyungsuk[1]; Kim, Yeunhan[1]; Park, Youngdeuk[1]

1. KASI, Daejeon, Republic of Korea

Electron microbursts, energetic electron precipitation having duration less than 1 sec, have been thought to be generated by chorus wave and electron interactions. While the coincidence of chorus and microburst occurrence supports the wave-particle interaction theory, more crucial evidences have not been observed to explain the origin of microbursts. We think one of the observational evidences could be energy dispersion of microbursts. During chorus waves propagate along magnetic field, the resonance condition should be satisfied at different magnetic latitude for different energy electrons because chorus waves are coherent waves having narrow frequency band and electron microbursts have wide energy range, at least several hundreds KeV. If we observed electron microbursts at low altitude, the arrival time of different energy electrons should make unique energy dispersion structures. In order to observe the energy dispersion, we need a detector having fast time resolution and wide energy range. Our study is focused on defining the time resolution and energy range required to measure microburst energy dispersion. We performed test particles simulation interacting with simple coherent waves like chorus waves. By the wave-particle interaction, energetic electrons (test particles) changed pitch angles and some electrons were detected with energy dispersion at 600 km. We assumed a detector measuring microbursts at the altitude of 600 km. These results provide useful information in designing electron detectors for the future mission.

Lee, Jeongwoo

Time Profiles of VLF signals Detected at High Latitude Groundbased Stations

Lee, Jeongwoo[1]; Min, Kyungguk[1]; Lew, Alex[2]; Keika, Kunihiro[1]

1. Ctr Solar-Terrestrial Research, Physics Dept., NJIT, Newark, NJ, USA
2. High Technology High School, Lincroft, NJ, USA

We have searched for the ground VLF signals that correlate with substorm electron flux enhancements measured in space. Events were selected from two sets of substorm list of the THEMIS and IMAGE/FUV observations for the period of 2007-2009 and 2000-2002, respectively. The electron fluxes measured with the THEMIS and LANL during these periods were compared with the corresponding VLF signals at three channels: 0.5-1 kHz, 1-2 kHz, and 2-4 kHz obtained as part of the Polar Experiment Network for Geospace Upper-atmosphere Investigations (PENGUIn) project. We found four classes of activities: (1) near simultaneous increases of VLF signals with electron fluxes implying substorm electron injection already in anisotropic pitch angle distributions, (2) gradual increase of the VLF signals with frequency as expected from the electron drift and gyroresonant interactions with whistler waves, (3) long delayed VLF signals indicative of electron echoes rather than direct substorm injections, and (4) impulsive VLF enhancements in the day side magnetosphere whose physical causes are not so obvious. These results along with a proper theoretical modeling may help use of the time profiles of the groundbased VLF signals as a diagnostic tool for several major physical processes occurring in the radiation belt.

Lemaire, Joseph F.

What happened when the geomagnetic field (GF) reversed

Lemaire, Joseph F.[3, 2]; Singer, S. Fred[1]

1. Science & Environmental Policy Project, Arlington, VA, USA
2. Belgian Institute Space Aeronomy, Brussels, Belgium
3. Center Space Radiations, Louvain-La-Neuve, Belgium

During a geomagnetic field (GF) reversal, the Inner (proton) Radiation Belt (RB), created by cosmic-ray albedo neutrons (CRAN) would of course be emptied into the atmosphere. Following GF reversal, the high-energy proton belt would gradually rebuild, with the energy spectrum flattening during the course of many millennia. [For details, see ref. 1] Considering that the entry of Solar Energetic Particles (SEP) and the seed population of relativistic electrons in the outer radiations belts with energies above some threshold are controlled by the intensity of Bz, the northward component of the interplanetary magnetic field (IMF) - as shown by the extended Störmer theory (EST) [ref. 2] - we speculate that at earlier epochs when the geomagnetic dipole was reversed, the entry of these energetic particles in the geomagnetic field was facilitated when the IMF was directed northward. During epochs when the Earth's dipole did reverse, we argue that the penetration of SEP and low-energy Galactic Cosmic-Ray particles down to their geomagnetic cut-off was facilitated and less strongly controlled by the orientation of the IMF. Further, during a GF reversal, magnetospheric ring currents (RC) and main-phase magnetic storms [ref. 3] would be absent. We speculate also on the effect that reversals of the Earth's dipole might have on the formation of other related geophysical phenomena. [1] Singer SF and JF Lemaire, Geomagnetically trapped radiation: half a century of research, in "Fifty years of Space Research," Eds: O. Zakutnyaya and D. Odintsova, IKI (Space Research Institute of Russian Academy of Sciences), pp. 115-127, 2009. [2] Lemaire, JF, The effect of a southward interplanetary magnetic field on Störmer's allowed regions, Advances in Space Research, 31, no. 5, 1131-1153, 2003. [3] Singer, SF, A new Model of Magnetic Storms and Aurorae, Trans. Am. Geophys. Union, 38, 175-, 1957; Role of Ring Current in Magnetic Storms, Trans. Am. Geophys. Union, 39, 532-, 1958

Lessard, Marc

Propagation Characteristics of EMIC Waves in the High Latitude Ionospheric Waveguide

Lessard, Marc[1]; Kim, Hyomin[2]; Engebretson, Mark[3]; Young, Matthew[1]

1. Space Science Center, University of New Hampshire, Durham, NH, USA
2. Center for Space Science and Engineering Research, Virginia Tech, Blacksburg, VA, USA
3. Department of Physics, Augsburg College, Minneapolis, MN, USA

EMIC wave data were acquired using a ground array of search-coil magnetometers predominantly in the pre-noon to post-noon sector of Antarctica. With extensive coverage from geomagnetic latitudes of 62 to 87 degrees ILAT (a distance within the ionosphere of 2920 km) and good alignment along the magnetic meridian, search-coil magnetometers operating aboard Automated Geophysical Observatories (AGOs) and manned ground stations show clear ducting of these waves with unexpectedly low attenuation in the waveguide. Halley Station, located at the lowest latitude, typically observes the highest wave power and well-defined band-limited signatures with the same wave event, showing less wave power, found at the other four stations at higher latitudes. This is a clear indication of the ducting effect (within a region centered around the electron density maximum near the F2 ionization peak). Since the events were observed over a very wide range in latitude, the observation of propagation within the ionosphere provides fundamental information regarding ducting efficiencies. This study presents the observations of over 100 EMIC events showing spectral power attenuation in the waveguide. In addition, changes of the polarization properties such as ellipticity and polarization ellipse major axis direction during the propagation are also discussed. Finally, ionosphere effects (i.e., conductivity) are presented.

Li, Wen

Wave Normal Angle Analysis of Chorus Waves and Its Implication on Chorus Generation Mechanism *(INVITED)*

Li, Wen[1]; Thorne, Richard M.[1]; Bortnik, Jacob[1]; Shprits, Yuri[1]; Nishimura, Yukitoshi[1, 2]; Angelopoulos, Vassilis[3]; Chaston, Christopher[4]; Le Contel, Olivier[5]; Bonnell, John[4]

1. Atmospheric and Oceanic Sciences, UCLA, Los Angeles, CA, USA
2. Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Japan
3. IGPP/ESS, UCLA, Los Angeles, CA, USA
4. Space Sciences Laboratory, University of California, Los Angeles, Los Angeles, CA, USA
5. Laboratoire de Physique des Plasmas, St Maur-des-Fossés Cedex, France

Chorus waves, which have received intense attention recently due to their significant role in radiation belt electron dynamics, typically occur in two frequency bands (lower-band and upper-band chorus) and frequently consist of rising and falling tones. The global distributions of wave amplitudes and wave normal angles of chorus waves are investigated in the present study using THEMIS wave burst data for the lower-band and upper-band separately. Statistical results show that large amplitude chorus (> 500 pT) predominantly occurs from premidnight to dawn with wave normal angles typically less than 20°, whereas modest or weak chorus extends further into the afternoon sector. Compared to the lower-band chorus, upper-band chorus is likely to be more confined to the equator and occurs at smaller L-shells (L < 7). The wave normal angle of upper-band chorus is generally larger than that of lower-band chorus, but the occurrence rate still peaks at wave normal angles of 10°-20° near the equator. Furthermore, lower-band chorus waves are analyzed for rising and falling tones respectively. Our results show that rising tones are more likely to be quasi-field-aligned with higher ellipticity, whereas falling tones are very oblique with lower ellipticity. These new findings suggest that two separate mechanisms may be responsible for the generation and non-linear evolution of rising and falling tone chorus.

Liemohn, Michael W.

Analyzing the role of keV-energy particles in modulating rapid trapping of radiation belt injections from the tail *(INVITED)*

Liemohn, Michael W.[1]; Ilie, Raluca[2]; Fok, Mei-Ching[3]; De Zeeuw, Darren[1]; Ganushkina, Natalia Y.[1, 4]; Zheng, Qiuhua[3]; Glocer, Alex[3]

1. University of Michigan, Ann Arbor, MI, USA
2. Los Alamos National Laboratory, Los Alamos, NM, USA
3. NASA Goddard Space Flight Center, Greenbelt, MD, USA
4. Finnish Meteorological Institute, Helsinki, Finland

The Radiation Belt Environment (RBE) model is now fully coupled within the Space Weather Modeling Framework (SWMF), allowing for detailed simulation studies of the coupling between relativistic electron motion in the inner magnetosphere and the dynamics and nonlinear feedback processes taking place across the rest of the magnetosphere. In particular, it allows for an assessment of the influence of the time-varying electric and magnetic field distortions of near-Earth space on relativistic electron drift paths. These E and B perturbations are caused as plasma sheet particles are convected into the inner magnetosphere, creating localized pressure peaks and current systems. One of the advantageous features of the RBE is that it solves for the local time distribution of the relativistic electrons, therefore allowing investigations of the trapping of injections from the magnetotail. Usually, such injections drift to the east and hit the dawnside magnetopause. In several of our storm-time simulations, however, intense injections have avoided this loss process and survived their initial transit around Earth. These injections eventually distribute themselves in local time (due to energy-dependent drift) and become a new torus of relativistic electrons within the outer belt. This study presents a systematic comparison of the different simulations that have and have not yielded these rapid injections, in particular focusing on the role of the keV-energy plasma population in modulating the effectiveness of this injection.

Liu, Kaijun

Excitation of Magnetosonic Waves in the Terrestrial Magnetosphere: Particle-in-cell Simulations

Liu, Kaijun[1]; Gary, S. P.[1]; Winske, Dan[1]

1. Los Alamos National Laboratory, Los Alamos, NM, USA

Two-dimensional electromagnetic particle-in-cell simulations are performed to study the temporal development of an ion Bernstein instability driven by a proton velocity distribution with positive slope in the perpendicular velocity distribution $f_p(v_\perp)$, where $\perp$ denotes directions perpendicular to the background magnetic field $\mathbf{B}_0$. A subtracted Maxwellian distribution is first used to construct the positive slope in $f_p(v_\perp)$ and linear kinetic dispersion analysis is performed. The results of a simulation using such an initial proton distribution agree well with the linear kinetic analysis. The simulation results demonstrate that the ion Bernstein instability grows at propagation angles nearly perpendicular to $\mathbf{B}_0$, and at frequencies close to the harmonics of the proton cyclotron frequency. The distribution in the simulation is further generalized to contain a proton shell with a finite thermal spread and a relatively cold ion background. The simulation results show that the presence of the cold background protons and the increase of the shell velocity shift the excited waves close to the cold plasma dispersion relation for magnetosonic waves, i.e., $\omega_r=kv_A$, where ω_r is the wave frequency, k is the wave number, and v_A is the Alfv\'{e}n velocity. The general features of the simulated field fluctuations resemble observations of fast magnetosonic waves near the geomagnetic equator in the terrestrial

magnetosphere. A test particle computation of energetic electrons interacting with the simulated electromagnetic fluctuations suggests that this growing mode may play an important role in the acceleration of radiation-belt relativistic electrons.

Lu, Jianyong

Global Magnetospheric Simulation and Space Weather Forecasting

Lu, Jianyong[1]; Kabin, Konstantin[2]; Rae, Jonathan[3]

1. National Center for Space Weather, China Meteorological Administration, Beijing, China
2. Royal Military College of Canada, Kingston, ON, Canada
3. University of Alberta, Edmonton, AB, Canada

We use a physics-based global MHD model to investigate the magnetospheric and ionospheric responses to the solar wind, especially the open-closed boundary, the location and shape of Earth's bow shock and magnetopause. First we compare results with and without Rice Convection model in the calculation. Then we look at a relatively unusual interval on 5th June 1998, where open/closed field line boundary can be determined in the ionosphere using a combination of instruments during a period encompassing northward to southward interplanetary field turning. We find that when the inner magnetospheric module is incorporated, the modelling both qualitatively and quantitatively reproduces many elements of the studied interval prior to an observed substorm onset. Finally We use this global model to investigate the location and shape of Earth's bow shock and magnetopause. The new bow shock model and magnetopause model are derived for the 3-D shape: the bow shock model as functions of magnetopause curvature radius and solar wind conditions, and the magnetopause model as functions of interplanetary magnetic field and solar wind conditions. Both models are compared with empirical models and are able to run quickly, which make them suitable for the purpose of space weather.

Mace, Richard L.

Ring current tail enhanced EMIC instability in the vicinity of L = 4

Mace, Richard L.[1]; Sydora, Richard[2]; Silin, Illia[2]

1. School of Physics, University of Kwazulu-Natal, Durban, South Africa
2. University of Alberta, Edmonton, AB, Canada

The near Earth plasma sheet is an important plasma source for the storm-enhanced ring current. Plasma sheet ion populations are known to be non-thermal, possessing velocity distributions with power law tails that can be well-modelled by the kappa distribution under a variety of geomagnetic conditions. If the power law tails are not erased during inward convection then the ring current plasma should exhibit this kinetic feature, also. This paper addresses the impact that non-thermal power law tails on ring current ion velocity distributions have on the growth rate and instability criteria of the electromagnetic ion cyclotron (EMIC) wave in a multi-ion plasma. EMIC waves are important because they are believed to undergo a strong gyro-resonant interaction with relativistic electrons and hence play a role in their precipitation loss from the magnetosphere. With few exceptions, the presence of hard power law tails on the velocity distributions of the ring current ion species is observed to significantly enhance EMIC instability growth rates relative to a bi-Maxwellian ring current model. For a ring current composed of only hot protons, all EMIC wave branches are unstable, with the helium branch exhibiting the fastest growth rate for the chosen parameters. The addition of equal number densities of helium and oxygen ions to the ring current plasma has a dramatic stabilizing effect on the proton and helium branches. In this case it is frequently only the oxygen branch of the EMIC wave dispersion relation which is unstable. The complex plasma composition produced by the overlap of ring current and plasmaspheric regions gives rise to various competing processes. In particular, the detailed balance between cyclotron damping produced by one species and growth produced by another elevates the importance of the velocity distribution spectral index so that it can serve as a "switch" to turn on instability of certain branches. This is a new effect that underscores the importance of kinetic effects associated with ring current ions, in particular the existence of power law tails.

Mann, Ian

Radiation Belt Science Using Ground-Satellite Conjunctions *(INVITED)*

Mann, Ian[1]; Rae, Iain J.[1]; Usanova, Maria[1]; Ozeke, Louis G.[1]; Murphy, Kyle[1]; Milling, David K.[1]

1. University of Alberta, Edmonton, AB, Canada

Radiation belt science increasingly relies on understanding the integral effects of transport, acceleration and loss processes acting simultaneously on radiation belt particle distributions. Typical radiation belt electrons sample wave disturbances from all local times in around 5 minutes, such that the overall response of the belts is necessarily a superposed response to processes which can be acting simultaneously, but having different impacts, in different local time sectors. In this talk I review the importance of measurements from ground-based arrays, with meso- and global-scale coverage, for interpreting local single (or small number of point) measurements from satellites. I will pay particular attention to the value of ground-based magnetometer array data for interpreting radiation belt wave-particle interactions which will be seen by the upcoming NASA Radiation Belt Storm Probes (RBSP) mission, as well as the proposed CSA ORBITALS and JAXA ERG missions. In particular, ground-based magnetometer data can provide unique information on ULF wave power distributions, wavelengths, wave directions of propagation, estimates of the background mass density for Alfven speed and plasmapause identification, as well as a global/meso-scale measures of the extent and local time variation of waves affecting radiation belt evolution. Examples showing

the diagnosis and value of these parameters for interpreting point data from upcoming radiation belt science missions will be presented.

Mauk, Barry H.

What role does global convection play in the population of the ring current regions?

Mauk, Barry H.[1]; Ukhorskiy, A. Y.[1]

1. Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA

A standard scenario incorporated into both past and some modern simulations of inner magnetosphere and ring current behaviors is that, during geomagnetic storms, more distant plasma sheet populations are transported into the middle and inner magnetosphere in conjunction with the strong enhancement of large-scale global "convective" electric fields. The transported populations are energized as a consequence of the invariance of the adiabatic invariants of gyration and bounce. Here we review several lines of evidence, including both electric field and plasma measurements that suggest that this scenario is highly misleading. Rather we will support the scenario here whereby localized and transient processes appear to overwhelmingly dominate the transport (e. g. Hori et al., 2005), and global convection serves to redistribute the injected particles. Pressure distributions associated with the transient injections serve to modify and enhance the global convective fields, generating large scale patterns that show no increases in the regions needed to transport particles from the plasma sheet, and are hard to explain on the basis of the standard shielded convection configuration (e. g. Roland and Wygant, 1998). We argue that models that do not capture fast injection physics do not capture the fundamental physics that populates the ring current regions.

Mauk, Barry H.

Radiation belts of the Solar System and Universe *(INVITED)*

Mauk, Barry H.[1]

1. Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA

Here I review the similarities and differences between the radiation belts of all of the strongly magnetized planets of the solar system with the motivation of identifying unifying physical processes of control. I address the question of how one can reasonably compare radiation populations within different systems. Does the fact that Jupiter is 10 time bigger than Earth and also with a surface magnetic field strength that is 10 time greater, mean that Jupiter should have a radiation that is 10 time more intense; 100 time more intense? Recent works from several sources on electron radiation belts have updated the theories for the so-called Kennel-Petschek and have identified it as a possible "absolute standard" for comparing the intensities within different systems, at least for electron energies of order several MeV and less. Other hypothesized control factors for electrons that do not match this standard include the absence or presence of vigorous particle injections, which can control the influence of wave acceleration processes, and the presence of absorbing materials. One outcome of these studies is the validation at relativistic energies of a "universal" electron spectral shape (Intensity ~ 1/E), which begs the question: to what extent do studies of radiation belts in the solar system inform us about radiation belts throughout the universe? While "lip service" is often paid to this possibility, I initiate here a discussion about whether derived quantitative information about solar system radiation belts is truly useful for studies of extrasolar systems, for example the hyper-energetic electron populations of the Crab Nebula. Since synchrotron radiation is the principal tool for diagnosing such systems, I use Jupiter's unique synchrotron emissions as a stepping stone for these discussions. We show that important mysteries remain to be resolved even for this relatively well-diagnosed system.

McCollough, James P.

The Role of Shabansky Orbits in Compression-related EMIC Wave Growth

McCollough, James P.[1]; Elkington, Scot R.[2]; Baker, Daniel N.[2]

1. Space Vehicles Directorate, AFRL, Albuquerque, NM, USA
2. Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA

Electromagnetic ion-cyclotron (EMIC) waves arise from temperature anisotropies in trapped warm plasma populations. In particular, EMIC waves at high L values near local noon are often found to be related to magnetospheric compression events. There are several possible mechanisms that can generate these temperature anisotropies: energizing processes, including adiabatic compression and shock-induced and radial transport; and non-energizing processes, such as drift shell splitting and the effects of off-equatorial minima on particle populations. In this work we investigate the role of off-equatorial minima in the generation of temperature anisotropies both at the magnetic equator and at higher latitudes. There are two kinds of behavior particles undergo in response: particles with high equatorial pitch angles (EPAs) are forced to execute so-called Shabanksy orbits and mirror at high latitudes without passing through the equator, and those with lower EPAs will pass through the equator with higher EPAs than before; as a result, perpendicular energies increase at the cost of parallel energies. By using a 3D particle tracing code in a tunable analytic compressed-dipole field, we parameterize the effects of Shabansky orbits on the anisotropy of the warm plasma. These results as well as evidence from simulations of a real event in which EMIC waves were observed (the compression event of 29 June 2007) are presented.

Menk, Frederick W.

Ground-Based Remote Sensing of Plasma Density in the Inner Magnetosphere and the Radiation Belts *(INVITED)*

Menk, Frederick W.[1]; Waters, Colin[1]; Sciffer, Murray[1]; Clilverd, Mark[2]; Mann, Ian[3]

1. University of Newcastle, Callaghan, NSW, Australia
2. British Antarctic Survey, Cambridge, United Kingdom
3. University of Alberta, Edmonton, AB, Canada

The Earth's radiation belts and inner magnetosphere are the home of interesting and dynamic particle populations which are at the heart of space weather processes. These include, for example, density structures such as plasma plumes and biteouts which often occur near the plasmapause. While these regions can be probed in situ using spacecraft, remote sensing using ground-based techniques provides both spatial and temporal information. In this presentation we discuss remote sensing using ground magnetometer and radar data and VLF measurements, combined with spacecraft data, to provide information on the mass density distribution and the plasma composition. We focus in particular on the signatures of complex radial mass density gradients in the vicinity of the plasmapause revealed using experimental data and modelling, and on situations where wave-particle interactions may occur. In either case the spatial resolution depends on the influence of the ionosphere on ULF wave transition to the ground and the radial spatial structure of the resonance in the magnetosphere.

Meredith, Nigel P.

Plasma Wave Observations from CRRES *(INVITED)*

Meredith, Nigel P.[1]

1. British Antarctic Survey, Cambridge, United Kingdom

Plasma waves play a fundamental role in the dynamics of the Earth's radiation belts and inner magnetosphere. Gyroresonant interactions between particles and plasma waves break the first two adiabatic invariants leading to pitch angle scattering and energy diffusion. They play important roles in the acceleration and loss of radiation belt electrons, in the decay of the ring current, as a source of the diffuse aurora, and in heating thermal electrons and ions. In this talk I will review the plasma wave observations from the Combined Release and Radiation Effects Satellite (CRRES) and how they have helped to improve our understanding of the dynamics of the Earth's radiation belts and inner magnetosphere. Directions and requirements for future study will also be discussed.

Millan, Robyn M.

The Balloon Array for RBSP Relativistic Electron Losses (BARREL) Experiment *(INVITED)*

Millan, Robyn M.[1]; Sample, John G.[2]; McCarthy, Michael P.[4]; Smith, David M.[3]; Woodger, Leslie A.[1]; Comess, Max[3]; Liang, Andrew[3]; Yando, Karl B.[1]; Anderson, Brett[1]; Hudson, Mary K.[1]; Lin, Robert P.[2]; Collier, Andrew B.[5]; Clilverd, Mark A.[6]; Panasyuk, Mikhail I.[7]

1. Department of Physics and Astronomy, Dartmouth College, Hanover, NH, USA
2. Space Sciences Laboratory, U. C. Berkeley, Berkeley, CA, USA
3. Department of Physics, U. C. Santa Cruz, Santa Cruz, CA, USA
4. Department of Earth and Space Sciences, University of Washington, Seattle, WA, USA
5. Hermanus Magnetic Observatory, Durban, South Africa
6. British Antarctic Survey, Cambridge, United Kingdom
7. Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russian Federation

BARREL is a multiple-balloon investigation that will study electron losses from Earth's Radiation Belts. Atmospheric loss of relativistic electrons plays an important role in radiation belt dynamics; precipitation into the atmosphere can deplete the radiation belts during the main phase of some geomagnetic storms and is also observed during relatively low geomagnetic activity levels. BARREL will consist of Antarctic balloon campaigns conducted in Austral summers of 2012 and 2013. During each campaign, a total of 20 small (~20 kg) balloon payloads will be launched to an altitude of 30-35 km to maintain an array of payloads extending across up to 8 hours of magnetic local time. Each balloon will carry a NaI scintillator to measure the bremsstrahlung X-rays produced by precipitating relativistic electrons as they collide with neutrals in Earth's atmosphere, and a DC magnetometer to explore the nature of observed Ultra Low Frequency temporal modulations of precipitation. We present an overview of the BARREL investigation which will provide the first balloon measurements of relativistic electron precipitation while in situ measurements of both plasma waves and energetic particle distributions are available. The combination of BARREL with the in situ measurements from RBSP, THEMIS, and other missions provides a unique opportunity to study the wave-particle interactions believed to be responsible for the precipitation.

http://www.dartmouth.edu/~barrel

Min, Kyungguk

Global distribution of EMIC waves inferred from THEMIS observations

Min, Kyungguk[1]; Lee, Jeongwoo[1]; Li, Wen[2]; Keika, Kunihiro[1]

1. Center for Solar Terrestrial Research/Department of Physics, New Jersey Institute of Technology, Newark, NJ, USA
2. Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, CA, USA

We have investigated spatial distribution of electromagnetic ion cyclotron (EMIC) wave events occurred from 2007 to 2009 as detected by the five probes of the Time History of Events and Macroscale Interactions during Substorms (THEMIS) mission. In this period strong geomagnetic storms are rare and most of them have DST > -30 nT. We selected the events that occurred at 4 < L < 10 with wave power > 10^{-2} nT^2/Hz and duration > 20 minutes, and found 352 H^+ band events and 177 He^+ band events in total. In our preliminary result, the H^+ band events are widely distributed around noon between 5 and 18 MLT with a slightly higher occurrence probability in dawn-noon sector and they are confined within a narrow range of L value in the outer magnetosphere (9 < L < 10). To compare the EMIC wave occurrence probability with the average electron density inferred from the spacecraft potential, the region of the most common H^+ band events is not necessarily the high density region. The He^+ band events are, on the other hand, more confined in the noon-dusk sector along the high density and high density gradient region. It is thus likely that the important factors for H^+ EMIC wave generation are solar wind and high L-shell location rather than high cold plasma density. For He^+ EMIC waves, the density is an important factor perhaps provided by the extended plasmaspheric plumes and/or the plasmapause. We will extend this study to the global distribution of the energetic ion anisotropy and associated solar wind condition for a more quantitative conclusion.

Miyoshi, Yoshizumi

Japanese Geospace Exploration Project: ERG (INVITED)

Miyoshi, Yoshizumi[1]; Ono, Takayuki[2]; Takashima, Takeshi[3]; Seki, Kanako[1]; Hirahara, Masafumi[1]; Asamura, Kazushi[3]; Obara, Takahiro[3]; Kasaba, Yasumasa[2]; Kumamoto, Atsushi[2]; Matsuoka, Ayako[3]; Kojima, Hirotsugu[4]; Fujimoto, Masaki[3]; Shiokawa, Kazuo[1]; Nagatsuma, Tsutomu[5]

1. STEL, Nagoya Univ., Nagoya, Japan
2. Tohoku University, Sendai, Japan
3. JAXA, Sagamihara, Japan
4. RISH, Kyoto University, Uji, Japan
5. NICT, Koganei, Japan

We present the current status of the geospace exploration project: ERG (Energization and Radiation in Geospace). In order to investigate the acceleration mechanism of relativistic electrons of the outer radiation belt as well as the space storm dynamics, the ERG project has been proposed in Japan. The ERG project consists of the satellite program (SPRINT-B/ERG satellite), the ground-based network observations, and the integrated studies group. The SPRINT-B/ERG satellite will be launched in the early declining phase of solar cycle 24 (FY 2014-2015). The planned apogee altitude is about 4 Re and the perigee is about 300 km. The SPRING-B/ERG satellite is currently designed to have a comprehensive set of plasma/particle sensors that can measure electrons from 10 eV to more than 10 MeV and ions from 10 eV/q to about 200 keV/q with a mass discrimination. The satellite also measures field and waves from DC to more than 1 MHz (electric field) and to 20 kHz (magnetic field) in order to observe several plasma waves in the inner magnetosphere that are essential for the particle acceleration, transportation, and loss. Several ground-based observation networks such as magnetometers, SuperDARN HF radars, optical imagers, VLF receivers, and riometers join the ERG project. These remote-sensing observations provide spatial distribution of fields and particles, which is essential for the comprehensive understanding of the geospace. The ERG project team also has the integrated studies group that is developing integrated-data analysis system including several simulation codes of particle acceleration and loss in the inner magnetosphere to understand various satellite and ground observations obtained during the ERG project.

Miyoshi, Yoshizumi

Large flux enhancement of outer belt electrons associated with high speed coronal hole stream

Miyoshi, Yoshizumi[1]; Kataoka, Ryuho[2]; Kasahara, Yoshiya[3]

1. STEL, Nagoya Univ., Nagoya, Japan
2. Tokyo Institute of Technology, Tokyo, Japan
3. Kanazawa University, Kanazawa, Japan

We investigate the solar wind-radiation belt coupling process, focusing on large flux enhancement of outer belt electrons associated with high speed coronal hole streams. The flux enhancement events tend to occur during the high speed streams with predominantly southward interplanetary magnetic field (IMF). The IMF dependence can be understood as follows: A non-adiabatic acceleration by wave-particle interactions is especially effective when a continuous source of hot electrons is maintained to produce chorus waves in the inner magnetosphere for several day periods. The continuous hot electron injections are activated during a prolonged period of intense convection and/or substorms, which are driven by the southward IMF in the high speed streams. In this presentation, we show clear differences of the hot electrons, whistler mode chorus waves, and convection/substorms between in the high speed events with predominantly southward and northward IMF to propose a model of solar wind radiation belt coupling in which wave-particle interactions driven by continuous hot electron injections play an important role for the large flux enhancement.

Miyoshi, Yoshizumi

Rapid flux losses of the outer belt electrons due to the magnetopause shadowing effect: THEMIS observations

Matsumura, Chiemi[1]; Miyoshi, Yoshizumi[1]; Seki, Kanako[1]; Saito, Shinji[1]; Angelopoulos, Vassilis[2]; Koller, Josef[3]

1. Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Japan
2. IGPP, UCLA, Los Angeles, CA, USA
3. Los Alamos National Laboratory, Los Alamos, NM, USA

Relativistic electrons of the outer radiation belt show dynamical variations associated with solar wind disturbances. One of the potential loss mechanisms is the magnetopause shadowing effect (MPS), in which the electron drift orbits of the outer belt intersect the magnetopause, allowing electron escapes outside the magnetosphere. Therefore MPS has been proposed as possible loss process, but there have been only few observational studies to identify this process. This study focuses on rapid electron loss of the outer radiation belt, by using GOES and THEMIS observations. We detect rapid electron loss at geosynchronous orbit, and separate these loss events using the movements of the outer edge of the outer radiation belt. Using the value of 20% of the peak flux as a proxy of the outer edge of the outer belt, we examine a relationship between the outer edge and the solar wind parameters as well as the magnetopause standoff distance. As a result, we find that the outer edge of outer belt has a good correlation with the solar wind dynamic pressure, the IMF Bz, and the magnetopause standoff distance. Comparing with the GEMSIS-RB simulation, which includes only the MPS loss process, we suggest that the observed rapid losses are explained by the MPS.

Morley, Steven

Observational Evidence for Drivers and Mechanisms of Electron Radiation Belt Dropouts *(INVITED)*

Morley, Steven[1]; Friedel, Reiner[1]; Reeves, Geoff[1]; Koller, Josef[1]; Henderson, Michael[1]; Spanswick, Emma[2]; Fraser, Brian[3]

1. Space Science and Applications, Los Alamos National Laboratory, Los Alamos, NM, USA
2. University of Calgary, Calgary, AB, Canada
3. University of Newcastle, Newcastle, NSW, Australia

Predicting losses or enhancements of relativistic electron fluxes during stormtime has proven difficult, with only ~50% of Dst storms showing a net increase in fluxes and about 20% showing a net decrease. Under high-speed stream driving the predictability of net flux increases is enhanced by the Russell-McPherron effect but substantial variability is still observed. Dropouts are also known to occur in a substantial fraction of storm main phases, though the contribution of adiabatic transport is difficult to quantify routinely. Much of the research effort in understanding non-adiabatic losses in the electron radiation belt still concentrates on geomagnetic storms, as defined by the ring current disturbance level, yet we also know that dropouts are neither a consistent feature of storms, or confined to occuring only during stormtime. We present an overview of the work leading to our current understanding of electron radiation belt dropouts, much of which has been based on measurements from geosynchronous orbit only. Recent observations using the GPS constellation have shown that dropouts extending to L*~4 are a consistent response to high-speed streams, irrespective of whether the stream drives a geomagnetic storm. Individual and statistical studies show that these dropouts can occur on timescales of less than 3 hrs and recovery to pre-event count levels can take in excess of two weeks. Using GPS particle data from up to 10 satellites, and supporting measurements and modeling, we discuss how these different statistical and individual studies inform our understanding of the processes driving losses in the outer electron radiation belt.

Murphy, Kyle R.

Characterising the night-side current systems and magnetic field perturbations associated with substorms

Murphy, Kyle R.[1]; Mann, Ian R.[1]; Rae, I. J.[1]; Anderson, Brian J.[3]; Milling, David K.[1]; Singer, Howard J.[2]

1. Physics, University of Alberta, Edmonton, AB, Canada
2. NOAA Space Weather Prediction Center, Boulder, CO, USA
3. The Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA

On the ground, the substorm current wedge (SCW) is typically viewed as an equivalent current system composed of net downward field aligned current in the east, a westward electrojet and net upward field aligned current in the west. In the night side magnetosphere, this current system is generally believed to be formed via the diversion of the cross-tail current, though equivalent signatures may also be driven via perturbation of the directly driven convective current system and resultant enhancement of the westward electrojet. Utilising in-situ observations from the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) and the Geosynchronous Operational Environmental Satellites (GOES), as well as ground-based magnetometer observations (from CARSIMA, THEMIS, CANMOS and GIMA magnetometer arrays) we present a detailed spatial and temporal analysis of magnetic perturbations observed in both the magnetosphere and ionosphere during isolated substorms in order to fully characterise the development of the substorm current system. A complete characterisation of how the SCW forms is key to understanding the physical process in the near-Earth magnetosphere during substorm onset and ultimately how both substorms and magnetic storms couple to inner magnetosphere, particle injections and the ring current as well as to the ionosphere.

Nedie, Abiyu Z.

Phase Coherence on Open Field Lines Associated with FLRs

Nedie, Abiyu Z.[1]; Fenrich, Frances[1]; Rankin, Robert[1]

1. Physics, University of Alberta, Edmonton, AB, Canada

A wide variety of waves occur in the magnetospheric regions of Earth excited by sources internal to the magnetosphere and external sources in the solar wind. Amongst them are the ULF waves whose direction of propagation is an important indicator of where the source mechanism might be located. For years, ULF field line resonances were known to cause oscillations in the F-region plasma flows, which are detected in SuperDARN's measured line-of-sight Doppler velocities. In this talk, discernible FLR signatures at 0.8-mHz, extended azimuthally along the latitude contour and its associated source in the solar wind using simultaneous measurements from multiple HF radars will be presented. We characterize ULF observations with coordinated simultaneous HF radars, optical instrumentation, ground-based magnetometers and satellite-borne instrumentation. During the time interval of interest, Geotail was on an outbound pass from the dawn side magnetosheath into the upstream solar wind region. In this talk, we present a completely new feature of phase coherence on open field lines at exactly the same resonant frequency. Equally important and new in this study is; our suggestion on how SuperDARN could be used as a potential tool of providing a direct diagnostics on how MHD waves in the solar wind could enter into magnetosphere right at the boundary providing improved understanding of large-scale processes on a time scale of a minute. This potential capability of SuperDARN could enable researchers for the first time to test various theories on how energy is transported into the boundary of the magnetosphere in a global scale view through continuous monitoring of the high latitude ionospheric convection. Results in this study support the hypothesis that the coherent phase on open field lines and the discrete frequency FLR at 0.8-mHz were being driven by an external wave source in the solar wind at the same discrete frequency.

www.physics.ualberta.ca

Ni, Binbin

A multi-satellite analysis of radiation belt electron phase space density distribution and the possible relationship with solar wind condition *(INVITED)*

Ni, Binbin[1]; Shprits, Yuri Y.[2]

1. Atmospheric and Oceanic Sciences, UCLA, Los Angeles, CA, USA
2. IGPP, UCLA, Los Angeles, CA, USA

Radial profiles of electron phase space density (PSD) are a key ingredient to accurately determine the radiation belt electron sources and losses and to physically explore the long-term responses of the radiation belts to solar activity. With the availability of a multi-satellite dataset that includes the measurements from LANL, GEO, GPS, Akebono and Polar satellites for the entire year of 2002, we perform a comprehensive study of electron PSD distribution, its radial gradients, and the temporal variations with respect to solar wind conditions. On basis of the data assimilation technique (Kalman filter approach) that allows for blending of sparse satellite data with a simple radial diffusion model, we further reconstruct the electron PSD radial profile in the radiation belts with high resolution in both time and space for various sets of the three adiabatic invariants. The reanalysis results of electron PSD can provide us useful and important information (1) to investigate the locations and magnitudes of peaks in radial profiles of electron PSD and the rate and radial extent of the dropouts during storms, (2) to achieve the electron PSD variability in both the source region and the radiation belts, (3) to estimate the radial diffusion timescales under different geomagnetic activity levels, and (4) to identify the preferential solar wind conditions for the formation of electron PSD peaks and dropouts, all of which have great potentials to considerably improve our understanding of the roles of resonant wave-particle interactions, (inward and outward) radial diffusion, magnetopause shadowing in the radiation belt electron acceleration and loss processes during a variety of solar activities and geomagnetic activities.

Nikitina, Lidia

STATISTICAL ANALYSIS OF THE RADIATION ENVIRONMENT ON MOLNIYA ORBIT

Nikitina, Lidia[1]; Trichtchenko, Larisa[2]

1. School of Mathematics and Statistics, Carleton University, Ottawa, ON, Canada
2. Geomagnetic Laboratory, Natural Resources of Canada, Ottawa, ON, Canada

Highly Elliptical (Molniya) Orbits have been very popular for quite a while to provide communication services for Northern areas. The satellite environment on Molniya orbit is highly variable due to its passage through the trapped radiation and through the area of "open" magnetic field lines affected by transient events. Recently, Canadian Space Agency has expressed interest in this type of orbit as one of the candidates for the planned Polar Communication and Weather (PCW) space mission. To establish an understanding of the climatology of the space environment on this orbit, a statistical analysis of the available data has been done. In this paper we present the results of the analysis based on the on-line data (http://virbo.org/HEO) collected on board of HEO1 and HEO3 Molniya-orbiting missions operated by Aerospace Corporation in cooperation with the American Air Force. The statistical results include time-dependent distribution and spatial distribution of the one-minute radiation dose along the orbit as well as average position of the radiation belt and its dynamics depending on the phase of the solar cycle. To indicate the place on the orbit we used two coordinates: time period passed after the perigee moment and the radial distance from the Earth's centre. The radiation dose was averaged for every minute,

and the distribution histograms were obtained using data from all orbits in the specific year corresponding to the different positions on the solar cycle curve (maximum, minimum, ascending, descending). Based on these distribution functions, the climatological model has been derived. For every minute point on the orbit the mean, minimal and maximal values of the parameter (dose or particle fluxes), standard deviation and confident interval were defined together with levels corresponding to 50%, 95% and 99.5% cumulative characteristics in the specific year. To validate the stability of the point on the orbit relative to the geomagnetic coordinates the distribution histograms were obtained also in L, B coordinates. The climatological model in these coordinates is not orbit-dependent (but rather B-model dependent) and can be compared with other models (AE-8, AP-8) and other satellite data.

O'Donnell, Scott W.

Variation of the Radial Diffusion Coefficient with L-Shell for Equatorially Mirroring Electrons in Response to ULF Waves in the Outer Radiation Belt

O'Donnell, Scott W.[1]; Degeling, Alexander W.[1]; Elkington, Scot R.[2]; Rankin, Robert[1]

1. Physics, University of Alberta, Edmonton, AB, Canada
2. Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA

Variations in outer radiation belt electron flux following geomagnetic storms and high solar wind intervals are known to be correlated with ultra low frequency (ULF) wave activity, suggesting a causal relationship (e.g. Rostoker et al., 1998; Elkington et al., 2003). We seek to examine the effect of ULF waves on the dynamics of the outer radiation belt electrons by providing a test particle code for the electrons with electromagnetic field inputs from the ULF wave model of Rankin et al. (2006). The wave model provides shear Alfvén wave eigenfunctions with polarization and eigenfrequencies calculated using the cold plasma ideal magnetohydrodynamic (MHD) equations for low frequency waves. The test particle code, which calculates equatorially mirroring guiding center electron trajectories, will be used to calculate the radial diffusion coefficient, D_LL, under the action of these waves. The variation of D_LL with L-shell and ULF wave parameters will be discussed.

Obara, Takahiro

Energetic Electron Dynamics in the Inner Magnetosphere Inferred from JAXA Satellite Observations *(INVITED)*

Obara, Takahiro[1]

1. ARD, JAXA, Tsukuba, Japan

In order to investigate space environment and its temporal variation, JAXA has been installing radiation particle detectors on LEO satellites (GOSAT, ALOS, Jason-2), GEO satellites (ETS-V, DRTS), GTO satellites (ETS-VI, MSD-1) and Quasi zenith orbiting satellite (QZS-1). With these radiation particle data, some distinguished sciences of energetic electrons have been obtained. Intensity of highly energetic (MeV) electrons in the outer radiation belt increases drastically during the magnetic storms in a very wide region from $L \sim 3$ to $L \sim 8$. Increase of MeV electrons in the outer radiation belt ($L \sim 3$ to $L \sim 8$) seems to be controlled by solar wind velocity as well as magnetic activities. Seasonal variation of the increase in the intensity of MeV electrons was found with peaks of spring and autumn. This is understood as Russell-McPherron effect. With these relations, we have constructed an advanced (dynamic) outer radiation belt model, and compared it with observations. Strong injection or transportation of intermediate energy (40-100keV) electrons from the plasmasheet into the heart of outer radiation zone ($L \sim 4$) was identified during the major and big storms. These intermediate energy electrons should be seeds of highly energetic (MeV) electrons in the outer radiation belt. Thus means that seed electrons should be accelarated internally in the outer radiation zone via wave particle interaction. It was found that MeV electrons penetrated into the inner radiation belt across the slot region during the big magnetic storm. We also found that low energy (40keV) electrons have been transported to very near Earth region; i.e. a few thousand km above sea level. We will make comparison with simulation results to interpret observations.

Oka, Mitsuo

Electron Acceleration by Multi-Island Coalescence *(INVITED)*

Oka, Mitsuo[1]; Phan, Tai[1]; Krucker, Sam[1]; Fujimoto, Masaki[2]; Shinohara, Iku[2]

1. Space Sciences Laboratory, UC Berkeley, Berkeley, CA, USA
2. Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Sagamihara, Japan

Energetic electrons of up to tens of MeV are created during explosive phenomena in the solar corona and in the Earth's magnetotail. While many theoretical models consider magnetic reconnection as a possible way of generating energetic electrons, the precise roles of magnetic reconnection during acceleration and heating of electrons still remain unclear. Here, we show from two-dimensional particle-in-cell simulations that coalescence of magnetic islands that naturally form as a consequence of tearing mode instability and associated magnetic reconnection leads to efficient energization of electrons. The key process is the secondary magnetic reconnection at the merging points, or the "anti-reconnection," which is, in a sense, driven by the converging outflows from the initial magnetic reconnection regions. We also performed a simulation of a conventional, single X-line reconnection and show that a system with multiple reconnection sites or 'X-lines' along a thin current sheet indeed leads to a larger number of energetic particles (both ions and electrons) when compared to a single (or isolated) X-line case. In this talk, we discuss possible applications to the energetic electrons observed in the Earth's magnetotail.

Omura, Yoshiharu

Formation process of relativistic electron flux through interaction with chorus emissions in the Earth's inner magnetosphere *(INVITED)*

Omura, Yoshiharu[1]; Yoshikawa, Masato[1]; Summers, Danny[2,3]; Hikishima, Mitsuru[1]

1. Research Institute for Sustainable Humanosphere, Kyoto University, Kyoto, Japan
2. Department of Mathematics and Statistics, Memorial University of Newfoundland, St. John's, NF, Canada
3. School of Space Research, Kyung Hee, Yongin, Republic of Korea

We perform test particle simulations of energetic electrons interacting with whistler-mode chorus emissions in the inner magnetosphere. We assume a pair of chorus elements propagating northward and southward along the magnetic field from the equator. The variation of the wave amplitude and frequency of the chorus emissions is determined by nonlinear wave growth theory. By tracing the trajectories of many particles along a magnetic field line,we obtain a numerical Green's function as a function of energy and pitch angle. We vary the energy and pitch angle over the respective ranges 0.01 - 6 MeV and 5 - 90 degree to obtain a set of Green's functions. We demonstrate very efficient nonlinear acceleration processes called relativistic turning acceleration (RTA) and ultra-relativistic acceleration (URA). We assume an initial distribution function of energetic seed electrons, and perform a convolution integral with the Green's functions numerically. We hence determine the variation of the distribution function in phase space following the nonlinear particle interaction with a pair of chorus elements. By repeating the convolution integral many times, we follow the time evolution of the distribution function interacting with a repeated sequence of chorus elements. Rapid formation of the relativistic electron flux due to chorus emissions in the radiation belts is achieved via the nonlinear acceleration processes called RTA and URA. Resonant particles in the lower energy range (less than 100 keV) are scattered to lower pitch angles resulting in precipitation to the Earth's atmosphere.

Orlova, Ksenia

Bounce-averaged pitch angle, mixed, and momentum diffusion coefficients in a realistic magnetic field model

Orlova, Ksenia[2,1]; Shprits, Yuri[1]; Ni, Binbin[1]

1. UCLA, Los Angeles, CA, USA
2. SINP MSU, Moscow, Russian Federation

Radiation belt diffusion codes require as an input precomputed bounce-averaged pitch angle, mixed, and momentum diffusion coefficients which are usually bounce-averaged in the dipole magnetic field model. We present the results of computations of bounce-averaged quasi-linear pitch-angle $< D\alpha\alpha >$, mixed $< D\alpha p >$, and momentum $< Dpp >$ scattering rates in a realistic magnetic field model. We

consider resonant interaction of electrons (from 10 keV to 10 MeV) with oblique and field-aligned whistler mode chorus waves. We also show the bounce-averaged diffusion coefficients computed in the dipole field model and discuss the differences. Our study shows that while there are still a number of unknown parameters that determine scattering rates, inclusion of bounce-averaging in the realistic field is crucially important for radiation belt modeling. For many applications to planetary magnetospheres and elsewhere in the Universe, it is desirable to average physical quantities such as particle and plasma transport coefficients over a charged particle's bounce motion between magnetic mirror points along field lines. We perform such bounce-averaging in a way that avoids singularities in the integrands of expressions that arise in calculations of this sort. Our method applies in principle to an almost arbitrary magnetic field model. We illustrate the advantage of using our method for removing the integrand's singularity through a change of variables (rather than by truncating the integral over latitude at points progressively nearer to the mirror point) by computing the $< Dpp >$. We show that the inaccuracies of the truncation approach can introduce errors up to an order in magnitude. Moreover, we develop improved analytical approximations for particle bounce periods in a dipolar magnetic field by minimizing mean square errors with respect to expansion coefficients in algebraic representations of the bounce period.

Osmane, Adnane

On the potentiality of particle acceleration due to nonlinear wave-particle interaction outside resonances

Osmane, Adnane[1]; Hamza, Abdelhaq M.[1]; Meziane, Karim[1]

1. Physics, University of New Brunswick, Fredericton, NB, Canada

Recent observations of radiation belt electrons have shown growing confirmations that the wave-particle interaction must act as a primary mechanism to explain the acceleration of electrons to MeV energies inside geosynchronous orbits. Whereas many wave-particle interaction models have been investigated, they have often relied on cyclotron resonances, hence sometimes neglecting the study of non-resonant particles. Consequently, focus on gyroresonant particles has lead to the omission of obliquely propagating waves since their physical impact on resonant particles is minimal and their mathematical treatment is more complicated. This report aims at demonstrating that when the assumptions of gyroresonances and parallel propagation are lifted, particle acceleration to relativistic energies is achievable. We first demonstrate that when oblique propagation is considered, non-resonant particles can be subject to secular acceleration when interacting with a monochromatic wave. This result is established using a dynamical system approach. That is, we have derived a model for the interaction of a particle with an obliquely propagating wave under relativistic regimes. It can then be shown that the dynamical system possesses a class of fixed

points under which a particle can be locked in phase-space and experience a constant electric field primarily along the background magnetic field direction. The acceleration process is a purely relativistic effect and can not be accounted for parallel propagation. The regime in parameter space (i.e. wave amplitude, wave frequency, propagation angle) under which such process is likely to occur is quantified by applying a basic stability analysis of the dynamical system. In order to reduce limitations imposed by the interaction with a single wave and in a desire to reach to modeling capacities, we pursue the study by building a Zaslavsky map co-jointly with the dynamical system to mimic the interaction of a particle with a wave-packet and a monochromatic wave. It will be argued that despite limitations intrinsic to the dynamical system method, our test-particle approach might underlie a wider branch of fast processes that could be at work for particle acceleration. Most importantly, implications of our results on the wave-particle interaction for resonant as well as non-resonant radiation belt electrons will be discussed.

Ozeke, Louis

Radial Diffusion of Outer Radiation Belt Electrons - The Influence of Electric and Magnetic ULF waves

Ozeke, Louis[1]; Mann, Ian R.[1]; Murphy, Kyle[1]; Rae, Ian J.[1]

1. university of alberta, Edmonton, AB, Canada

MeV energy electrons are thought to be transported inwards from the plasma sheet into the radiation belts under the action of radial diffusion. Waves in the ultra-low frequency (ULF) band have frequencies which can be drift resonant with these electrons in the outer zone suggesting the potential for strong interactions, and enhanced radial diffusion. In the usual situation, where the plasma sheet acts as a source of phase space density, the radial diffusion transports particles inward - these particles also conserving their first invariant and being energised as they move inwards towards higher magnetic fields. The diffusion coefficients depend on the power spectral density (PSD), of the waves electric and magnetic fields in space in the equatorial plane. Due to the small number of satellite missions which have passed through the equatorial plane of the outer radiation belts with ULF wave electric and magnetic field instruments these PSD measurements have only been taken over short time periods or narrow L-shell ranges. Here ULF wave electric field diffusion coefficients will be presented which are determined from over 10 years of ground-based magnetometer measurements from L<4 to L>7. These electric field diffusion coefficients are determined using the mapping technique outlined in Ozeke et al, JGR, 2009 to estimate the electric field PSD in space in the equatorial plane from the magnetic field PSD measured by the ground-based magnetometers. In-situ measurements of the magnetic field PSD in space are also used to determined the magnetic diffusion coefficients. These diffusion coefficients are compared to those previously obtained from CRRES measurements and from the analytic expressions in Brautigam and Albert 2000. In addition,

radial diffusion simulations of electrons driven by these diffusion coefficients will presented illustrating that both the electric and magnetic field diffusion coefficients may play an important role in the dynamics and energization of the Earth's outer radiation belt region.

Pilipenko, Viacheslav

Variations of the relativistic electron fluxes at L=3.0-6.6 as observed by CORONAS-F satellite

Pilipenko, Viacheslav[1]; Irina, Mjagkova[2]; Nataly, Romanova[3]

1. Space Research Institute, Moscow, Russian Federation
2. Skobeltsyn Institute of Nuclear Physics, Moscow University, Moscow, Russian Federation
3. Institute of the Physics of the Earth, Moscow, Russian Federation

We consider the events in 2002 with the relativistic electron flux increases at different L-shells for various space weather conditions. We use the 1.5-3 MeV electron detector data from the low-orbiting CORONAS-F satellite and 1.1.-1.5 MeV electron data from the geosynchronous LANL monitor. We have compared a relativistic electron response to the high-speed solar wind streams (HSS) from coronal holes and to the coronal mass ejections (CME). The electron behavior has turned out to be essentially different at L = 3 – 4 and at L>4; an increase of electron fluxes at low L-shells is not synchronous with the increase at higher L. During CME-related storms the electron fluxes increase simultaneously at all L up to L=4, whereas during the HSS-related storms the flux increases proceed from higher L to lower L. We have estimated statistically the electron response to the magnetospheric ULF activity as characterized by ULF-index. For HSS events the ULF activity contribution in the electron energization at L>4 is higher than for CME events. The ULF driven electron energization at L = 4 - 5.5 for HSS events is slower than for CME events. At L = 5.5 – 6.6 the growth rate is about the same, ~2 days, for both types of events. We suppose that for HSS events the ULF driven radial diffusion and energization dominate at L > 4. For CME events the local acceleration mechanisms become more significant.

Pu, Zuyin

Secular variation of the inner zone proton environment over the past one hundred years

Pu, Zuyin[1]; Xie, Lun[1]; Shen, Yishan[1]; Cao, Xin[1]; Fu, Suiyan[1]; Zong, Qiugang[1]

1. Peking Univ, Beijing, China

During the past century, the Earth's eccentric dipole moment has been noticeably decreasing and the non-dipole field has drifted westward. Consequently, the structure of the inner radiation belt must have varied substantially in connection with the secular evolution of the geomagnetic field. A better understanding of long-term variations of the inner radiation environment is of interest to spacecraft design and operation. It has been known for many years that the secular geomagnetic variation will induce an inward drift of trapped particles to lower altitudes (Schultz and Paulikas,

1972; Farley and Kivelson, 1972). We have proposed the drift shell tracing (DST) method for estimation of long-term variations of trapped particle fluxes in the inner zone region, with the NASA standard radiation models as the reference state (Pu et al., 2005). This paper presents the evolution of low-altitude radiation environment during the past century (1900-2010) based on the DST calculations, with usage of the 11th generation of the International Geomagnetic Reference Field Model (Finlay et al., 2010). The results show that over the past ˜100 years, the drift shells of inner zone particles have descended a significant distance toward the Earth, the proton fluxes at altitudes ˜1000 km in the South Atlantic Anomaly (SAA) region have significantly increased and the proton SAA region has apparently expanded and moved westward.

Rae, Jonathan

Empirical Estimates of Radiation Belt Radial Diffusion Characteristics from ground-based and in-situ measurements

Rae, Jonathan[1]; Mann, Ian[1]; Ozeke, Louis[1]; Murphy, Kyle[1]; Chan, Anthony[2]; Elkington, Scot[3]; Milling, David[1]

1. University of Alberta, Edmonton, AB, Canada
2. Rice University, Houston, TX, USA
3. University of Colorado, Boulder, CO, USA

Ultra Low Frequency (ULF) wave power in the Pc4 and Pc5 period bands are thought to play an important role in the radial transport and energisation of electrons in the Earth's outer radiation belt. Typically ULF wave power and diffusion coefficients are expressed as a function of Kp, however ULF wave activityare better correlated with solar wind speed. We present a statistical analysis of the ground-based and in-situ electric field power spectral densities as a function of solar wind speed, MLT and L-shell for input into radiation belt diffusion models. The ground-based magnetic ULF wave observations are mapped into electric fields in the equatorial magnetosphere using the Ozeke et al. [2009] model. We compare these derived power spectras to those derived from previously published CRRES estimates and from the THEMIS satellites. We find an excellent agreement between the ground-based estimates and in-situ observations. Interestingly, the ground-based power spectra show evidence of mHz spectral power peaks consistent with those observed on CRRES. This suggests that field line resonances may play an energetically significant role in radial diffusion. We further calculate the magnetic diffusion coefficients using data from THEMIS and GOES, and compare these with previous estimates. Overall such analysis provides a physical basis for calculating diffusive transport using observed ULF wave fields.

Reeves, Geoffrey D.

Radiation Belt Observations: What Do We Know; What Do We Think We Know; and What Do We Know We Don't Know? *(INVITED)*

Reeves, Geoffrey D.[1]

1. Space Sciences Group, Los Alamos National Laboratory, Los Alamos, NM, USA

Next year will see the launch of NASA's Radiation Belt Storm Probes (RBSP) mission which was designed to answer some of the most pressing questions in our field. Meetings like this Chapman Conference are striking evidence of the new level of scientific interest in radiation belt dynamics and the fast pace at which we are making new discoveries. We know a lot more about the radiation belts than we did when the RBSP mission was designed but we also have a more sophisticated understanding of the complexity and depth of the most fundamental questions of what physical processes control radiation belt acceleration, transport, loss, and coupling to other parts of geospace. The 1990's saw a true revolution in our understanding of radiation belt dynamics. Satellites such as CRRES, LANL-GEO, GOES, SAMPEX, POLAR, GPS, HEO, and others gave us our first systems-level look at radiation belt structure and dynamics. We discovered changes in the radiation belts that took place on time scales of minutes could be produced by interplanetary shocks. We found that the rates of acceleration at different L-shells was incompatible with the "recirculation" model. We came to understand the delicate balance between acceleration and losses that are responsible for the wide diversity of radiation belt responses during storms. We realized the importance of storm-time adiabatic restructuring and moved from studies of flux at fixed energies and pitch angle to studies of phase space density at fixed magnetic invariants. At the same time theories of radiation belt dynamics were being developed at a pace that even outstripped the observational discoveries. Much of our efforts to understand the radiation belts has focused on the relative importance of locally-resonant wave particle interactions vs. global (drift) resonances and diffusion, linear vs. non-linear effects, precipitation vs. magnetopause losses, internal processes vs. solar wind driving, etc. The complexity of radiation belt dynamics, however, makes definitive tests of theory difficult. Despite a growing body of observational evidence these questions remain at the heart of radiation belt science and a quantitative understanding of radiation belt processes remains elusive. As we prepare for a transformational period of new missions and new observations it is valuable to honestly assess what we know, what we think we know, and what we know we don't know about radiation belt physics.

Ripoll, Jean-Francois

High energy electron diffusion by resonant interactions with whistler waves in the inner radiation belt

Ripoll, Jean-Francois[1]; Mourenas, Didier[1]

1. CEA, Arpajon, France

Trapped radiation dynamics in the radiation belt has been studied at CEA for satellite protection purpose since Reveillé et al. (JGR 106, 2001) and based on pioneering models of Roberts (Rev. Geophys. 7, 1969) and Lyons (JGR 77, 1972). The different modeling choices we made for simplifying the quasilinear diffusion coefficients are always motivated by the reduction of the computational cost of operational codes. One model we recently selected for this reason is the Mean Value Approximation (MVA) formulated by J. Albert in 2007, in which the wave integral is replaced by a mean value taken on the resonant wave angle domain. We will show how the model expression can be simplified when the resonance with Hiss waves dominates, i.e. at low L numbers and applying the low frequency limit, as done in Lyons 1972. Numerical results will be presented and compared to recent literature results (Summers 2005, Meredith 2007, Albert 2008) to analyze the model accuracy.

Rodger, Craig J.

Ground-based estimates of outer radiation belt energetic electron precipitation fluxes into the atmosphere

Rodger, Craig J.[1]; Clilverd, Mark A.[2]; Gamble, Rory J.[1]; Ulich, Thomas[3]; Raita, Tero[3]; Seppälä, Annika[2]; Green, Janet[4]; Thomson, Neil[1]; Sauvaud, Jean-André[5]; Parot, Michel[6]

1. Department of Physics, University of Otago, Dunedin, New Zealand
2. British Antarctic Survey (NERC), Cambridge, United Kingdom
3. Sodankylä Geophysical Observatory, University of Oulu, Sodankylä, Finland
4. Space Weather Prediction Center, NOAA, Boulder, CO, USA
5. Centre d'Etude Spatiale des Rayonnements, Toulouse, France
6. Laboratoire de Physique et Chimie de l'Environnement, Orleans, France

Currently there is intense debate as to the ultimate effects of solar activity on tropospheric and stratospheric variability, particularly through direct and indirect effects of chemical changes induced by energetic particle precipitation. However, there are key unresolved questions concerning the understanding of the effects of energetic particle precipitation on the lower atmosphere, one of which is magnitude and temporal variability of precipitating radiation belt energetic electrons. Definitive answers are very difficult to provide from satellite measurements alone because of the complexity in measuring electron fluxes unambiguously in the whole bounce-loss cone without contamination from fluxes in the drift-loss cone or trapped fluxes. In this work we have used AARDDVARK data from a radiowave receiver in Sodankylä, Finland to monitor transmissions from the very low frequency communications transmitter, NAA, (24.0 kHz, 44°N, 67°W, L=2.9) in USA since 2004. The transmissions are influenced by outer radiation belt (L=3-7) energetic electron precipitation. In this study we have been able to show that the observed transmission amplitude variations can be used to routinely determine the flux of energetic electrons entering the atmosphere along the total path affecting attitudes between ~50 and 90 km. Our analysis of the NAA observations shows that electron precipitation fluxes can vary by three orders of magnitude during geomagnetic storms. Comparison of the ground-based estimates of precipitation flux with satellite observations from DEMETER and POES indicates a broad agreement during geomagnetic storms, but some differences in the quiet-time levels, with the satellites observing higher fluxes than those observed from the ground. Typically when averaging over L=3-7 we find that the >100 keV POES 'trapped' fluxes peak at about 10^6 el.cm^{-2}s^{-1}str^{-1} during geomagnetic storms, with the DEMETER >100 keV drift loss cone showing peak fluxes of 10^5 el.cm^{-2}s^{-1}str^{-1}, and both the POES >100 keV 'loss' fluxes and the NAA ground-based >100 keV precipitation fluxes showing peaks of ~10^4 el.cm^{-2}s^{-1}str^{-1}. During a geomagnetic storm in July 2005, there were systematic MLT variations in the fluxes observed: electron precipitation flux in the midnight sector (22–06 MLT) exceeded the fluxes from the morning side (0330–1130 MLT) and also from the afternoon sector (1130–1930 MLT)The analysis of NAA amplitude variability has the potential of providing a detailed, near real-time, picture of energetic electron precipitation fluxes from the outer radiation belts.

Rodger, Craig J.

Radiation belt electron precipitation due to geomagnetic storms: significance to middle atmosphere ozone chemistry

Rodger, Craig J.[1]; Clilverd, Mark A.[2]; Seppälä, Annika[2, 3]; Thomson, Neil R.[1]; Gamble, Rory J.[1]; Parot, Michel[4]; Sauvaud, Jean-André[5]; Ulich, Thomas[6]; Berthelier, Jean-Jacques[7]

1. Department of Physics, University of Otago, Dunedin, New Zealand
2. British Antarctic Survey (NERC), Cambridge, United Kingdom
3. Earth Observation, Finnish Meteorological Institute, Helsinki, Finland
4. Laboratoire de l'Environnement et de l'Espace, Orleans, France
5. Centre d'Etude Spatiale des Rayonnements, Toulouse, France
6. Sodankylä Geophysical Observatory, University of Oulu, Sodankylä, Finland
7. Laboratoire Atmosphères, Milieux, Observations Spatiales/IPSL, CNRS-UVSQ-UPMC, Paris, France

Geomagnetic storms triggered by coronal mass ejections and high-speed solar-wind streams can lead to enhanced losses of energetic electrons from the radiation belts into the atmosphere, both during the storm itself and also through the post-storm relaxation of enhanced radiation belt fluxes. Currently there is intense debate as to the ultimate effects of solar activity on tropospheric and stratospheric variability, particularly through direct and indirect effects of chemical changes induced by energetic particle precipitation. It is challenging to accurately measure radiation belt precipitation, both to describe radiation belt dynamics and as inputs to the atmosphere/ionosphere. In this study we have analyzed the impact of electron precipitation on atmospheric chemistry (30-90 km altitudes) as a result of a single geomagnetic storm. The study conditions were chosen such that there was no influence of solar proton precipitation, and thus we were able to determine the storm-induced outer radiation belt electron precipitation fluxes. We use ground-based subionospheric radio wave observations to infer the electron precipitation fluxes at L=3.2 during a geomagnetic disturbance which occurred in September 2005, and describe how the precipitation varies across a ˜2 week period. By contrasting with satellite observed plasmaspheric hiss levels, we show that the precipitation is most-likely driven by hiss We go to investigate the significance of this electron precipitation to the neutral atmosphere. Through application of the Sodankylä Ion and Neutral Chemistry model, we examine the significance of this particular period of electron precipitation to neutral atmospheric chemistry. Building on an earlier study, we refine the quantification of the electron precipitation flux into the atmosphere by using a time-varying energy spectrum determined from the DEMETER satellite. We show that the large increases in odd nitrogen (NOx) and odd hydrogen (HOx) caused by the electron precipitation do not lead to significant in-situ ozone depletion in September in the Northern Hemisphere. However, had the same precipitation been deposited into the polar winter atmosphere, it would have led to >20% in-situ decreases in O_3 at 65-80 km altitudes through catalytic HOx-cycles, with possible additional stratospheric O_3 depletion from descending NOx beyond the model simulation period. This is a similar level to that observed due to the impact of

Rodger, Craig J.

Remote Sensing Space Weather Events Through Ionospheric Radio: The AARDDVARK Network

Rodger, Craig J.[1]; Clilverd, Mark A.[2]

1. Department of Physics, University of Otago, Dunedin, New Zealand
2. British Antarctic Survey (NERC), Cambridge, United Kingdom

The joint NZ-UK Antarctic-Arctic Radiation-belt (Dynamic) Deposition - VLF Atmospheric Research Konsortia (AARDDVARK) is a new extension of a well-establish experimental technique, allowing long-range probing of ionisation changes at comparatively low altitudes. One of the few experimental techniques that can probe these altitudes uses very low-frequency (VLF) electromagnetic radiation, trapped between the lower ionosphere (˜85 km) and the Earth; these signals can be received thousands of kilometres from the source. The nature of the received radio waves is determined by propagation inside the Earth-ionosphere waveguide, with variability largely coming from changes in the electron density profiles at and below the lower ionosphere. Most other instruments which can probe the same altitudes are limited to essentially overhead measurements. We have recently developed the AARDDVARK global-scale network of sensors that monitor fixed-frequency communications transmitters, and hence provide continuous long-range observations between the transmitter and receiver locations. Our receivers log small changes in the phase and amplitude of powerful VLF communications transmitters (˜13-30 kHz). By monitoring distant VLF stations we undertake long-range remote sensing of changes to the waveguide, and particularly the ionosphere. This Science area impacts our knowledge of space weather processes, global atmospheric change, communications, and navigation. AARDDVARK measurements are well suited for comparison with spacecraft measurements, to provide continuous measurements of radiation belt precipitation while satellites observe dynamic changes, particularly near the geomagnetic equator. Future additions to the network will increase the science potential and provide global coverage of space weather event signatures. In 2010 a new AARDDVARK station was deployed near Edmonton, Canada, and two new "deep field" sites are planned in the Antarctic to support the planned fleet of radiation belt science platforms (RBSP, DSX, RESONANCE, ERG, ORBITALS, etc). This presentation will provide updates on AARDDVARK science. In particular we will focus on precipitation observations

during the radiation belt dropouts occurring during high speed solar wind streams. More information can be found at the homepage of the AARDDVARK network: http://www.physics.otago.ac.nz/space/AARDDVARK_homepage.htm

ANTARCTIC-ARCTIC RADIATION-BELT (DYNAMIC) DEPOSITION - VLF ATMOSPHERIC RESEARCH KONSORTIA
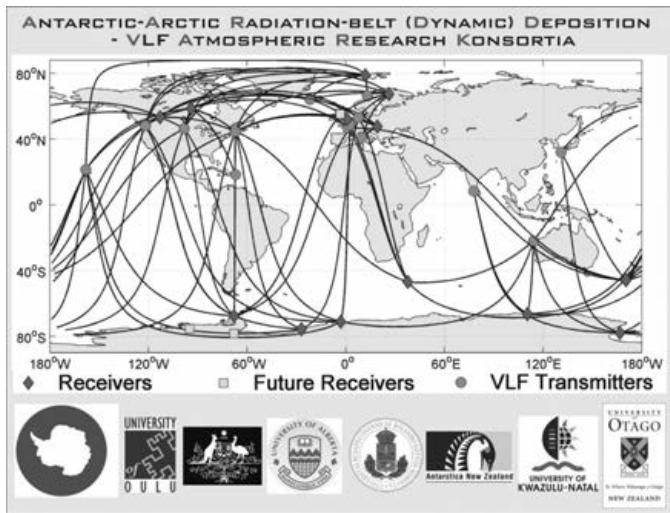
Roeder, James L.

Radial Profiles of Radiation Belt Electron Fluxes: Complimentary Views in Adiabatic and Measured Coordinates

Roeder, James L.[1]; Fennell, Joseph F.[1]

1. Space Sciences Applications Laboratory, Aerospace Corporation, Los Angeles, CA, USA

Analyses of radiation belt electron flux measurements have typically followed one of two general schemes. The more rigorous approach is to compare radial profiles of the electron phase space density (PSD) at constant values of M and K, the first and second adiabatic invariants of the electron motion, respectively. If the magnetic field variations occur more slowly than the electron bounce and gyro-motions but faster than the drift period, then diffusion shifts electrons in the radial coordinate L*. This process results in changes to the third adiabatic (drift) invariant of the electrons, while the first two invariants are conserved. The analysis enables the simple diagnosis of flux changes as the results of radial diffusion. Positive gradients in the PSD signal inward diffusion and negative gradients suggest outward diffusion. Locally growing or decaying peaks may indicate a local acceleration or loss process, in which one or both of the first two invariants are violated through the effects of waves or magnetic topology. The second analysis scheme is simply to plot the radial profiles of the flux as a function of the measured parameters of energy and pitch angle. The energy and pitch angle diffusion caused by ELF and VLF plasma waves are controlled by, and result in features in the electron energy spectra and pitch angle distributions. So the analysis in these quantities is more relevant to those processes, but has little relation to radial diffusion. To help better understand the physics, we analyze SCATHA SC3 electron observations concurrently using both approaches. If a growing peak is detected in the PSD at a

particular value of the three invariants, then one can easily investigate the changes in the electron energy-pitch angle distribution that resulted in that PSD peak. For example, in the recovery phase of the storm of May 6, 1986 a peak was observed in the PSD at L* ~5.5, and M=1890 MeV/G and K=0.2-0.6 R_e $G^{1/2}$, but not at lower K. At this L*, the invariants correspond to approximately 2.6 MeV and 25-45 degrees pitch angle. The increasing peak is consistent with pitch angle diffusion flattening the distributions at this energy during this interval. The goal is to gather statistics about how the peaks in PSD relate to changes in the electron energy and angular distributions and compare those to models of wave induced acceleration and loss.

Saito, Shinji

Study of electron microburst associated with whistler chorus in the outer radiation belt: GEMSIS-RB Wave simulations

Saito, Shinji[1]; Miyoshi, Yoshizumi[1]; Seki, Kanako[1]

1. Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, Japan

Wave-particle interaction between radiation belt electrons and whistler chorus is studied to understand electron microburst by using GEMSIS-RB Wave (RBw) simulations, which is based on test-particle simulation code. The GEMSIS-RBw code demonstrates scattering by cyclotron resonance between test-electrons and whistler chorus propagating parallel to the background magnetic field during a few days, considering the wave-particle interactions during a few msec. This simulation code can apply typical whistler chorus parameters based on spacecraft observations, such as emission region, wave frequency, frequency drift rate, and wave amplitude. Comparing with the spacecraft observations, this study focuses on the electron microburst associated with whistler chorus to understand a physics of energetic electron precipitation into the earth's atmosphere.

Saito, Tavis J.

A Statistical Analysis of the Relationship between ULF Waves and Particle Modulation in the outer Radiation Belts

Saito, Tavis J.[1]; Mann, Ian[1]; Angelopoulos, Vassilis[2]

1. Physics, university of alberta, Edmonton, AB, Canada
2. Earth and Space Sciences, University of California, Los Angeles, CA, USA

ULF wave-particle interactions are one of the leading theories for energization and transport of energetic particles in the magnetosphere. Polodial and toroidal mode ULF waves have been shown to accelerate electrons in the radiation belts, and in theoretical models, coherently in the time domain. I will discuss the results of a statistical analysis examining ULF waves observed on the ground and their correlation with particle modulation in the radiation belts. I performed the analysis when a THEMIS spacecraft geomagnetic footprint was within ±5 degrees of the Gillam

CARISMA ground magnetometer station and remains in that region for longer than 1 hour. I examined oscillations in both H and D components of the magnetic field on the ground and compared these oscillations with the particle modulations observed in-situ with the solid state telescope (SST) from the THEMIS spacecraft. Finally I will discuss the relevance of the observed relationships and their significance for the dynamics of energetic particle populations in the outer radiation belt.

Sauer, Konrad

Whistler wave emission: Transition from unstable waves to oscillitons

Sauer, Konrad[1]; Sydora, Richard D.[1]

1. Department of Physics, Institute of Geophysics, University of Alberta, Edmonton, AB, Canada

Joint studies of whistler waves, using dispersion analysis, nonlinear fluid approach and PIC simulations have shown that two generation mechanisms exist which are responsible for two wave types with different propagation characteristics. The first one (called type A) is directly related to wave instabilities owing to electron temperature anisotropy and/or electron beams in the wave number regime ($kc/\omega\_e > 1$). Frequency of this upper band and propagation angle are approximately related by the resonance cone condition, $\omega \tilde{} \Omega\_e . \cos\theta$. Another type of whistler waves (called type B) stands in relation to the so-called Gendrin modes whose nonlinear identity occurs as whistler oscillitons. Their frequency versus propagation angle dependence is given by $\omega \tilde{} 0.5\Omega\_e . \cos\theta$. The associated wave number, however, is fixed at $kc/\omega\_e = 1$ which means the waves are weakly damped. PIC simulations of beam and temperature anisotropy excited waves have revealed that a spectral shift of type A waves up to smaller wave numbers, obviously by nonlinear wave-wave interaction, takes place. This leads to the excitation of type B waves in form of whistler oscillitons in the (lower) frequency band below $\Omega\_e/2$. Spectral measurements aboard satellites and Stenzel's laboratory experiment (1977) are discussed in the view of the new model of whistler wave generation.

Schiller, Quintin

Reanalysis of Radiation Belt Electron Data using a Kalman Filter

Schiller, Quintin[1]; Li, Xinlin[1]; Koller, Josef[2]

1. LASP, University of Colorado, Boulder, CO, USA
2. Los Alamos National Lab, Los Alamos, NM, USA

The highly energetic electrons in Earth's radiation belts form an extremely hazardous environment to both manned and unmanned space missions, and mitigating the related risks requires a full understanding of the dynamics of the system. However, determining the relative contribution of local acceleration, loss, and radial diffusion terms is a complicated task. A sequential algorithm, such as a Kalman filter, is capable of estimating electron phase space density and parameters for the source, loss, and radial transport

terms. We report the results of applying an Extended Kalman Filter to energetic electron data using a Fokker-Planck equation. The dataset provides sparse observations of electron PSD from L = 4 to L = 10 for first and second adiabatic invariants M = 2083 MeV/G and K = 0.1 G1/2 RE (corresponding to about 1.1 MeV at GEO). This data assimilation technique fills in gaps in the dataset in both space and time, allowing for the estimation of phase space density for the full radial range (L=3 to L=10). We also present the results of simultaneous estimation of parameters for source, loss, and transport terms, and a sensitivity analysis on the model solutions. Finally, we discuss the applications of data assimilation to a radiation belt forecast model to provide a quantitative uncertainty analysis of the forecast results. The improved forecast will mitigate spacecraft risks associated with energetic electrons in the inner magnetosphere.

Schriver, David

Generation of Whistler Waves and Associated Non-Linear Processes in the Inner Magnetosphere

Schriver, David[1]; Ashour-Abdalla, Maha[1, 2]; Travnicek, Pavel M.[3, 4]; Decyk, Viktor[2]; Pickett, Jolene S.[5]; Santolik, Ondrej[6]; Winningham, James D.[7]; Goldstein, Melvyn L.[8]

1. IGPP, UCLA, Los Angeles, CA, USA
2. Department of Physics and Astronomy, UCLA, Los Angeles, CA, USA
3. Space Science Laboratory, UCB, Berkeley, CA, USA
4. Astronomical Institute, ACSR, Prague, Czech Republic
5. Department of Physics and Astronomy, University of Iowa, Iowa City, IA, USA
6. Deparment of Math and Physics, Charles University, Prague, Czech Republic
7. Southwest Research Institute, San Antonio, TX, USA
8. Laboratory for Geospace Science, NASA Goddard Space Flight Center, Greenbelt, MD, USA

Whistler wave chorus emissions are commonly observed in the Earth's inner magnetosphere radiation belt and these waves can result in the acceleration and loss of electrons in the region. Here the generation and properties of whistler waves are examined using fully self-consistent numerical simulations guided by satellite data. Events are examined when whistler waves are observed in coincidence with a strong temperature anisotropy and then a linear theory and two-dimensional particle in cell simulation study is carried out to understand the physics of wave generation, saturation and energy redistribution. Theoretical results show that for an event taken from Cluster satellite data the anisotropic electron distribution can linearly excite obliquely propagating whistler waves in the upper band, i.e., greater than one-half the electron gyrofrequency, while non-linear wave-wave coupling excites waves in the lower band, i.e., less than one-half the electron gyrofrequency. The instability saturates by a combination of a decrease in the anisotropy of the mid-energy electrons, as well as by heating of the cold electron population. Implications of the analysis for this event and for other events concerning whistler waves and

their effects on electrons in the radiation belt region will be discussed.

Schriver, David

Does Mercury Have a Radiation Belt?

Schriver, David[1]; Travnicek, Pavel M.[2, 3]; Anderson, Brian J.[4]; Ashour-Abdalla, Maha[1, 5]; Baker, Daniel N.[6]; Benna, Mehdi[7]; Boardsen, Scott A.[8]; Gold, Robert E.[4]; Hellinger, Petr[9]; Ho, George C.[4]; Korth, Haje[4]; Krimigis, Stamatios M.[4, 10]; Richard, Robert L.[1]; Sarantos, Menelaos[8]; Slavin, James A.[8]; Starr, Richard D.[11]

1. IGPP, UCLA, Los Angeles, CA, USA
2. Space Science Laboratory, UCB, Berkeley, CA, USA
3. Astronomical Institute, ACSR, Prague, Czech Republic
4. Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA
5. Department of Physics and Astronomy, UCLA, Los Angeles, CA, USA
6. Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA
7. Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD, USA
8. Heliophysics Science Division, NASA Goddard Space Flight Center, Greenbelt, MD, USA
9. Department of Space Physics, Institute of Atmospheric Physics, Prague, Czech Republic
10. Academy of Athens, Office Space Research Technology, Athens, Greece
11. Physics Department, Catholic University of America, Washington, DC, USA

It is well established now that Mercury has an intrinsic magnetic field and as such has a magnetosphere. The strength of Mercury's magnetic dipole is relatively weak, compared to that of Earth, and the magnetopause-nose standoff distance between the solar wind ram pressure and the intrinsic magnetic field pressure is located between about 1.3 and 1.7 Mercury radii ($\approx$ 2440 km), depending on solar wind conditions. Since the discovery of Mercury's mini-magnetosphere by the Mariner 10 flybys in the 1970s, features of which have been confirmed by the 2008-2009 MESSENGER flybys, one question that has been debated is whether Mercury has a trapped plasma population around the planet akin to Earth's radiation belt. In this talk we will consider this question using global simulation modeling and MESSENGER data. Results from global simulations of Mercury's magnetosphere and particle trajectory tracing strongly indicate that a quasi-trapped ion and electron ring is formed around the planet within the magnetosphere, at least for relatively quiet solar conditions, and data from the first two MESSENGER flybys in 2008 and 2009 tend to support this contention. Simulation results will be presented, and with the successful orbital insertion of MESSENGER around Mercury on March 18, 2011, new orbital data will also be examined to explore the existence and properties of a trapped-particle radiation belt around Mercury.

Schulz, Michael

Foundations of Radiation-Belt Physics *(INVITED)*

Schulz, Michael[1]

1. Lockheed Martin Retiree, Redwood City, CA, USA

This talk offers a historical overview of radiation belts and their underlying dynamical principles. Topics covered include the anticipation and discovery of Earth's radiation belts, early misconceptions and their resolution, adiabatic invariants of charged-particle motion and their relationship to action-angle variables in classical mechanics, magnetic drift shells, source populations for radiation-belt particles, loss processes (e.g., atmospheric drag, atmospheric scattering, synchrotron emission, and wave-particle interactions), weak and strong pitch-angle diffusion, consequent limits on stably trapped particle fluxes and their energy spectra, mechanisms for diffusive radial transport and consequent particle energization in the magnetosphere, canonical and practical coordinates for transport theory, in situ particle energization, and recent developments in the understanding of planetary radiation belts.

Seki, Kanako

Study of the inner magnetospheric response to pressure pulses in the solar wind based on the GEMSIS-RC model

Seki, Kanako[1]; Amano, Takanobu[2]; Miyoshi, Yoshizumi[1]; Matsumoto, Yosuke[1]; Umeda, Takayuki[1]; Saito, Shinji[1]; Miyashita, Yukinaga[1]; Ebihara, Yusuke[3]

1. Solar-Terrestrial Environment Laboratory, Nagoya University, Aichi, Japan
2. Graduate School of Science, Nagoya University, Nagoya, Japan
3. Research Institute for Sustainable Humanosphere, Kyoto University, Uji, Japan

Electron acceleration mechanisms to cause drastic variation of the Earth's outer radiation belt is one of key issues of the geospace researches. While the radial diffusion of the electrons driven by ULF waves has been considered as one of the candidate mechanisms, efficiency of the mechanism under realistic ULF characteristics and distribution is far from understood. GEMSIS is the observation-based modeling project for understanding energy and mass transportation from the Sun to the Earth in the geospace environment. Aiming at understanding the coupling between fields and particles in the inner magnetosphere, we have developed a new physics-based model of the ring current (RC). The GEMSIS-RC model is a self-consistent and kinetic numerical simulation code solving the five-dimensional collisionless drift-kinetic equation for the ring-current ions in the inner-magnetosphere coupled with Maxwell equations. It is demonstrated that the present model can successfully describe the propagation of magnetohydrodynamic waves. Our approach is unique in the sense that it includes MHD wave modes as well as deformation of magnetic field configuration due to the ring current self-consistently. In

order to investigate responses of the inner magnetosphere to pressure pulses in the solar wind, time variation of magnetic and electric fields as well as the ring current ion distributions is simulated based on the GEMSIS-RC model with simple boundary conditions to mimic an abrupt compression of the inner magnetosphere. We investigate effects of the pressure pulses on excitation of ULF waves, generation of FAC, and change in the pitch angle distribution of ring current ions.

Seough, Jungjoon

Empirical modeling of quasilinear evolution of electromagnetic ion cyclotron instability for finite beta plasmas

Seough, Jungjoon[1]; Yoon, Peter H.[1,2]; Kim, Khan-Hyuk[1]; Lee, Dong-Hun[1]; Lee, Ensang[1]

1. School of Space Research, Kyung Hee University, Yongin, Republic of Korea
2. IPST, University of Maryland, College Park, MD, USA

Electromagnetic ion-cyclotron (EMIC) waves are believed to be important for the loss of relativistic electrons in the radiation belt. On the basis of such a notion, scientists applied quasilinear diffusion theory to compute various diffusion time scales and so forth in order to assess the impact of EMIC waves in the electron loss process. In all these efforts, however, cold plasma dispersion relation is employed although it is well known that the plasma beta in the inner magnetosphere during storm times can reach values as high as the unity. The reason is because the numerical warm plasma dispersion relation makes the computation intractable. In the present paper we put forth an empirical model for the warm plasma dispersion relation, and compare the analytical model with exact solutions. The approximate but sufficiently accurate results are practical enough so that it might be possible to reformulate the classic radiation belt electron diffusion theory by means of the analytical warm plasma dispersion relation. Such a task is beyond the scope of the present paper, but in the present paper, we carry out quasi-linear analysis of the anisotropy-driven EMIC instability over a wide range of the anisotropy factor and plasma beta. Upon comparison with exact numerical solutions it is shown that the empirical model is an excellent substitute for a wide range of parameters.

Shklyar, David R.

RESONANCE Project for Studies of Wave-Particle Interactions in the Inner Magnetosphere *(INVITED)*

Demekhov, Andrei G.[1]; Mogilevsky, Mikhail M.[2]; Petrukovich, Anatoly A.[2]; Shklyar, David R.[2]; Zelenyi, Lev M.[2]

1. Institute of Applied Physics, Nizhny Novgorod, Russian Federation
2. Space Research Institute, Moscow, Russian Federation

We discuss the problems of origin of electromagnetic emissions and their influence on energetic-particle dynamics in the inner magnetosphere as related to the tasks of the Resonance project. Since the project has been proposed, many interesting results have been obtained in studies of wave-particle interactions. In particular, theory and simulations of chorus emissions have been developed, and spacecraft data have been fruitfully used to reveal chorus properties. The role of chorus emissions in the acceleration of energetic electrons to relativistic energies was demonstrated observationally and investigated theoretically. Chorus has been proposed as an alternative source of plasmaspheric hiss. Precipitation of energetic ions from the ring current due to the resonant interactions with ion cyclotron waves was studied experimentally and theoretically, and some new properties of electromagnetic ion-cyclotron emissions (e.g., a finite size of their source region, ±11° near the magnetic equator), have been obtained from observations. We outline the state of the art in the above mentioned studies and consider how the planned orbits and instruments onboard the spacecraft constellation will help in pursuing the unsolved problems of wave-particle interactions in the inner magnetosphere.

Shoji, Masafumi

Simulation of Electromagnetic Ion Cyclotron Triggered Emissions in the Earth's Inner Magnetosphere

Shoji, Masafumi[1]; Omura, Yoshiharu[1]

1. RISH, Uji, Japan

In a recent observation by the Cluster spacecraft, electromagnetic ion cyclotron (EMIC) triggered emissions were discovered in the inner magnetosphere. We perform hybrid simulations to reproduce the EMIC triggered emissions. We develop a self-consistent one-dimensional (1D) hybrid code with a cylindrical geometry of the background magnetic field. We assume a parabolic magnetic field to model the dipole magnetic field in the equatorial region of the inner magnetosphere. Triggering EMIC waves are driven by a left-handed polarized external current assumed at the magnetic equator in the simulation model. Cold proton, helium, and oxygen ions, which form branches of the dispersion relation of the EMIC waves, are uniformly distributed in the simulation space. Energetic protons with a loss cone distribution function are also assumed as resonant particles. We reproduce rising tone emissions in the simulation space, finding a good agreement with the nonlinear wave growth theory. In the energetic proton velocity distribution we find formation of a proton hole, which is assumed in the nonlinear wave growth theory. A substantial amount of the energetic protons are scattered into the loss cone, while some of the resonant protons are accelerated to higher pitch angles, forming a pancake velocity distribution.

Shprits, Yuri

Dynamics of the Radiation Belts During Storms and Superstorms *(INVITED)*

Shprits, Yuri[1, 2]

1. IGPP, UCLA, Los Angeles, CA, USA
2. DAOS, UCLA, Los Angeles, CA, USA

Five decades after the beginning of the space age and the discovery of trapped radiation, understanding the Van Allen radiation belts still presents a major challenge. The dynamical evolution of the radiation belt fluxes results from the competition of various acceleration and loss mechanisms including resonant interactions between particles and plasma waves. Similar acceleration and loss processes occur at other planets of the solar system and may occur at other corners of the Universe. Recent observations combined with predictive and data assimilative modeling showed that energetic electrons can be accelerated locally to relativistic energies by taking energy from plasma waves. After solar superstorms, local acceleration may become very efficient at distances of less than three Earth Radii; this situation would significantly increase the near-Earth radiation hazard and may be devastating for near-Earth orbiting satellites.

Sibeck, David G.

RBSP Collaborative Science Opportunities with Ongoing Missions: THEMIS

Sibeck, David G.[1]; Kanekal, Shrikanth[1]; Grebowsky, Joseph M.[1]; Ukhorskiy, Alexandr[2]; Fox, Nicola[2]; Mauk, Barry[2]

1. Space Weather Laboratory, NASA/GSFC, Greenbelt, MD, USA
2. JHU/APL, Laurel, MD, USA

The three remaining spacecraft that comprise the THEMIS mission operate in equatorial orbits with apogees of 11.7 RE and periods of 1 day that precess 330 degrees about the Earth once each year. The spacecraft carry identical payloads capable of measuring particles with energies from 30 eV to 6 MeV, AC and DC electric fields. In this presentation we explore opportunities for join work with the RBSP mission, in particular by measuring source region plasmas and outer magnetospheric drivers, tracking injections, and determining the extent of magnetospheric wave fields.

Sicard-Piet, Angélica

Radiation belts electron precipitation lifetime calculated using WAPI code and DE1, POLAR and CLUSTER-1 data

Sicard-Piet, Angélica[1]; Boscher, Daniel[1]

1. DESP, ONERA, Toulouse, France

The wave-particle interaction in the Earth radiation belts is a topic of great interest for the scientific community. Indeed, the acceleration and losses caused by the interaction between energetic particles and waves present in the environment appear to contribute significantly to the large flux variations observed in the radiation belts during magnetic storms and other disturbances. Consequently, it is important to better understand this physical process in order to develop better models to specify and predict the radiation belts. To do this, two areas of study are required: first, it is essential to have a good model of wave-particle interaction using quasi-linear theory and secondly to better define the characteristics of waves from the surrounding environment (intensity, frequency, direction of propagation). For this purpose, the SPace Environment Department (DESP) of ONERA has developed, first, a new code, WAPI (Wave Particle Interaction), based on quasi-linear theory, to calculate pitch angle, energy and mixed diffusion coefficients for resonant wave-particle interaction, whatever the frequency (from Hiss to VLF) and the direction of propagation. On the other hand,, DESP has developed a wave data base based on data from DE1/PWI, POLAR/PWI and CLUSTER_1/STAFF-SA, with the expertise of the LPCEE in France. From this wave data base, the intensity of the waves is defined over frequency, for several L (McIlwain parameter) and Kp (3h magnetic index) values and was used in WAPI code. Using this wave data base and WAPI code, added to the physical model of radiation belts, Salammbô, precipitation life times for radiation belts electrons were calculated and compared with data (SAC-C and DEMETER data, Benck et al., 2010).

Sicard-Piet, Angélica

Comparative Earth, Jupiter and Saturn's radiation belts *(INVITED)*

Sicard-Piet, Angélica[1]; Bourdarie, Sebastien[1]; Lorenzato, Lise[1]; Boscher, Daniel[1]

1. DESP, ONERA, Toulouse, France

Since the 1990s ONERA/DESP has developed a physical model of the Earth radiation belts, called Salammbo 3D. During the early 2000s, this model has been adapted to Jupiter environment, and then to the case of Saturn since 2009. Salammbô models include the main physical processes that govern the particles of the radiation belts and are based on solving the Fokker Planck equation. These models have been successfully compared to measurements and, for the Jovian case, to radioastronomy images. From lessons learned from these modelling activities we plan here to review the main characteristics of radiation belts in the vicinity of magnetised body illustrated with Earth, Jupiter and Saturn environment. We will show how the same fundamental physical processes (radial diffusion, interactions with exosphere and ionosphere-plasmasphere) lead to similarities between the three sets of belts. Nevertheless we will emphasize the specificity of each planet. In the Earth case, the lower magnetic field intensity leads to strong dynamics while in the Jupiter and Saturn cases, there is a strong influence of dust particles and moons.

Silin, Illia

Warm Plasma Effects on EMIC Wave Interactions with Relativistic Electrons in the Magnetosphere

Silin, Illia[1]; Mann, Ian R.[1]; Sydora, Richard D.[1]; Summers, Danny[2, 3]; Mace, Richard L.[4]

1. Department of Physics, University of Alberta, Edmonton, AB, Canada
2. Department of Mathematics and Statistics, Memorial University of Newfoundland, St. John's, NF, Canada
3. School of Space Research, Kyung Hee University, Yongin, Republic of Korea
4. School of Physics, University of KwaZulu-Natal, Durban, South Africa

The full kinetic linear dispersion relation in a warm plasma with He^+ and O^+ ions is used to estimate the minimum resonant electron energies required for resonant scattering of relativistic electrons by electromagnetic ion-cyclotron (EMIC) waves. We find two significant differences from the cold-plasma approximation: 1) waves can be excited inside the stop-bands and at ion gyrofrequencies for relatively small wave numbers $k < \Omega_p/v_A$; 2) short wavelengths with $k > \Omega_p/v_A$ experience strong cyclotron damping. We show that, in general, minimum resonant energy of electrons E_{min} depends only on the wave number k, magnetic field strength B and plasma mass density ρ, and depends on the wave frequency ω only implicitly, via the dispersion relation. Formulae for E_{min} as function of ω based on cold-plasma approximation predict the lowest energy loss where $\omega \to \Omega_{He+}$, since in this approximation $k \to \infty$ at these frequencies. We show this inference is incorrect, and that kinetic effects mean that the ion gyrofrequencies are no longer necessarily preferential for low energy loss. The lowest values of E_{min} are obtained where the dispersion supports the largest wave numbers k, and in the regions of the largest mass densities ρ and the lowest magnetic fields B. For realistic magnetospheric conditions $E_{min} \sim 2$ MeV and can only drop to $E_{min} \sim 500$ keV inside dense plasmaspheric plumes, with plasma density of the order of $\rho \sim 500$ cm^{-3}, or during plasmaspheric expansions to high L-shells ($L \sim 7$).

Soraas, Finn

Low altitude observations of energetic protons and neutral atoms (ENA) during geomagnetic storms

Soraas, Finn[1]; Marita, Sørbø[2, 1]

1. Dept.Physics and Technology, University of Bergen, Bergen, Norway
2. Bergen Oilfield Services, Bergen, Norway

Aurora is the result of the interaction between precipitating energetic electrons and protons with the upper atmosphere. The aurora generally occurs as ovals of light around the geomagnetic poles. There are, however, auroras that are detached from the oval and occurs equator ward of it. Energetic Neutral Atoms (ENAs) in the Earth's magnetosphere are produced via charge exchange mechanism between singly charged ions and neutral atoms in the exosphere. The produced neutrals leave the interaction region with essentially the same energy and velocity as the originally impinging ions, and are unaffected by ambient electric and magnetic fields. ENA emission is markedly brightest at the lowest altitudes, in the auroral zone, because the density of the ambient neutrals strongly increases with decreasing height. The ENAs produced in the proton aurora are spread in all directions and also over the polar cap region where they are lost into space. ENAs are also observed around geomagnetic equator at low L-values. Their source are ring current protons existing at larger L-values. Through charge exchange with the geocorona the ring current protons become ENAs and are spread in all directions and can be detected at low altitudes around the geomagnetic equator. Satellite observations of ENAs, with an instrument not dedicated to ENA observations, are possible in the polar cap where the magnetic field lines are open and normally not populated with energetic particles. In the equatorial regions a satellite in a low altitude orbit is below the intense trapped radiation and can thus observe the ENA flux from the ring current. Low altitude observations of proton precipitation and ENAs will be presented and related to the source and loss mechanisms of the storm time ring current.

Spence, Harlan E.

FIREBIRD: Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics *(INVITED)*

Spence, Harlan E.[1]; Crew, Alex[1]; Smith, Sonya[1]; Larsen, Brian[2]; Klumpar, David[3]; Mosleh, Ehson[3]; Springer, Larry[3]; Blake, J. B.[4]

1. Institute for the Study of Earth, Oceans, and Space, University of New Hampshire, Durham, NH, USA
2. Los Alamos National Laboratory, Los Alamos, NM, USA
3. Montana State University, Bozeman, MT, USA
4. The Aerospace Corporation, Los Angeles, CA, USA

The FIREBIRD mission (Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics) is a targeted, goal-directed, space weather NSF Cubesat mission to resolve the spatial scale size and energy dependence of electron microbursts associated with the Van Allen radiation belts. Relativistic electron microbursts appear as short durations of intense electron precipitation measured by particle detectors on low altitude spacecraft, seen when their orbits cross magnetic field lines which thread the outer radiation belt. Previous spacecraft missions (e.g., SAMPEX) have quantified important aspects of microburst properties (e.g., occurrence probabilities), however, some crucial properties (i.e., spatial scale) remain elusive owing to the space-time ambiguity inherent to single spacecraft missions. While microbursts are thought to be a significant loss mechanism for relativistic electrons, they remain poorly understood, thus rendering space weather models of Earth's radiation belts incomplete. FIREBIRD's unique two-point, focused observations at low altitudes, that fully exploit the capabilities of the Cubesat platform, will answer three fundamental scientific questions with space weather implications: What is the spatial scale size of an

individual microburst?; What is the energy dependence of an individual microburst?; and How much total electron loss from the radiation belts do microbursts produce globally?

Summers, Danny

Comparison of Linear and Nonlinear Growth Rates for Magnetospheric Whistler-mode Waves

Summers, Danny[1, 2]; Tang, Rongxin[1]; Omura, Yoshiharu[3]

1. Memorial Univ Newfoundland, St John's, NF, Canada
2. School of Space Research, Kyung Hee University, Yongin, Republic of Korea
3. RISH, Kyoto University, Kyoto, Japan

The generation process of magnetospheric whistler-mode waves in the vicinity of the magnetic equator comprises a linear growth phase followed by a nonlinear growth phase. During linear wave growth,which is driven by an assumed energetic electron temperature anisotropy,the wave frequency is constant. After the linear growth phase,the wave amplitude and frequency evolve nonlinearly. We solve the pair of coupled nonlinear differential equations ("chorus equations") for the wave amplitude and frequency as functions of time. We hence determine the nonlinear wave growth rate as a function of time or frequency.We compare the maximum values of the linear and nonlinear wave growth rates for a variety of input parameter values. We also consider how the results depend on the assumed form of the electron distribution function.

Tang, Rongxin

Energetic electron fluxes at Saturn from Cassini observations *(INVITED)*

Tang, Rongxin[1, 2]; Summers, Danny[1, 3]

1. Department of Mathematics and Statistics, Memorial University of Newfoundland, St John's, NF, Canada
2. Academy of Space Technology, Nanchang University, Nanchang, China
3. School of Space Research, Kyung Hee University, Yongin, Republic of Korea

Energetic electron fluxes (15 keV-10 MeV) observed by the MIMI/LEMMS instrument on the Cassini mission during 2004 to 2008 are analyzed. We consider 101 orbits, and in particular selected portions of the orbits that lie within 0.5 Rs of the magnetic equatorial plane, where Rs is Saturn's radius. We determine the average electron differential flux spectrum and integral flux at specified L-shells in the range $4.5 < L < 11$. In addition, comparisons are made between the observed fluxes and the corresponding self-limiting values derived from Kennel-Petschek theory.

Tao, Xin

Test particle calculations of interactions between electrons and large amplitude chorus subpackets

Tao, Xin[1]; Bortnik, Jacob[1]; Thorne, Richard M.[1]; Albert, Jay M.[2]

1. Atmospheric and Oceanic Sciences, UCLA, Los Angeles, CA, USA
2. Space Vehicles Directorate, Air Force Research Laboratory, Hanscom Air Force Base, MA, USA

Interactions between large amplitude chorus subpackets and electrons in a dipole field are investigated using a test particle code. Previous work on interactions between large amplitude chorus waves and electrons uses a monochromatic wave to model a single chorus wave element, leading to nonlinear processes like phase trapping and bunching when the wave amplitude is large enough. However, detailed analysis of chorus wave structure presented by previous observational work showed the presence of the chorus subpackets, which could be best modeled by superposition of a few narrowband waves. In this work, we adopt a simple two-wave model in order to better represent the chorus wave subpackets. By varying the frequency spacing between two waves, we model the subpacket structure with different beat frequencies. The effect of subpacket beat frequency on the nonlinear processes is then presented. We demonstrate that when resonance overlap condition is satisfied, the resulting change of pitch angles and energies could be different from what has been predicted by previous nonlinear theories using a monochromatic wave. Our results indicate that the subpacket structure of chorus waves should be considered when modeling interactions between electrons and large amplitude chorus waves.

Thaller, Scott A.

Investigation of the relationship between storm time evolution in high altitude wave Poynting flux, low altitude electron precipitation, and energetic particles in the inner magnetosphere

Thaller, Scott A.[1]; Wygant, John R.[1]; Dombeck, John P.[1]; Nishimura, Toshi[2]; Hamre, Alyssa[1]; Cattell, Cindy[1]; Dai, Lei[1]; Mozer, Forrest[3]; Russell, C. T.[4]

1. School of Physics and Astronomy, University of Minnesota, Minneapolis, MN, USA
2. Department of Atmospheric and Oceanic Sciences, University of California at Los Angeles, Los Angeles, CA, USA
3. Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA, USA
4. Institute of Geophysics and Planetary Physics, University of California at Los Angeles, Los Angeles, CA, USA

Previous works have shown that intense Alfvenic Poynting flux at 4-7 Re, capable of powering magnetically conjugate auroral emissions, exists on the plasma sheet boundary layer [Wygant et al., 2000, 2002] and within the

plasma sheet [Keiling et al., 2002,2005]. In this study, we use electric field, magnetic field, and particle data from the Polar spacecraft along with electron data from the FAST and DMSP spacecraft, to investigate the evolution of high altitude, night side, wave Poynting flux as an energy source for the acceleration of low latitude precipitating electrons over the course of major geomagnetic storms. Of particular interest is the relation of the storm time dynamics of the near tail and inner magnetosphere to the increase in the wave Poynting flux intensity by multiple orders of magnitude on low latitude field lines. Implications for energy flow and transport in the inner magnetosphere will be discussed. These results will be presented in the context of energetic particles observations and the high latitude limit of the region characterized by energetic particles.

Thomson, David J.

Background Magnetospheric Variability as inferred from long time—series of GOES data *(INVITED)*

Thomson, David J.[1]

1. Mathematics and Statistics, Queen's University, Kingston, ON, Canada

In this paper I examine the background state of the equatorial magnetosphere as revealed through multi—year time—series of magnetic fields, electrons, protons, and solar X-rays from the {GOES} satellites. Flares, substorms, and similar transient events are rejected as outliers. The main finding is that, in common with data from interplanetary space, fluctuations in magnetospheric data are dominated by the normal modes of the Sun. Specifically, the power spectrum contains many narrow line components superimposed on a smooth background. These results are easily reproduced; the main requirements for doing so are to: remove strong known periodic terms and interpolate across outliers; use a multitaper spectrum estimate; and, most important, use at least five years of data in a single block so there is enough frequency resolution to separate modes. Most of the low—frequency, < 1500 uHz p-modes identified by the GOLF and BISON helioseismology teams are easily detected as lines in the spectra. However, the l=0 radial modes of the Sun appear to be split by ˜ +-530 nHz; one does not expect l=0 modes to be split and the observed splitting is larger than the ˜+-430nHz seen in optical measurements of higher l p-modes in the same frequency range. This splitting may be related to the ˜ 10 day periodicity observed in Ulysses electrons and also in the Penticton 10.7 cm solar flux, Kp, and Ap indices. Again in common with data from ACE and Ulysses, there are slight differences observed between frequencies estimated from magnetic field data and those from high—energy protons, possibly a relativistic effect. At still lower frequencies, < 400 uHz many solar gravity modes are prominent with frequencies that agree with estimates made using data from the simpler environments at ACE and Ulysses. The line profiles appear to have a limiting width of ˜ 25nHz, possibly from frequency shifts associated with changes in solar irradiance. Finally, in addition to splitting by intrinsic solar processes, many of these modes are strongly split by Earth's rotation and orbit and possibly by magnetospheric processes. Not all lines are obviously split and the vector magnetic field data suggest that splitting (and amplitude) may be related to the mode's polarization. This appears to evolve over time spans of a few years. These observations imply that a large fraction of the background fluctuations observed in the magnetosphere are systematic and driven by the Sun and not by local turbulence or similar effects. How can this be? First, the solar convection zone is turbulent, and this excites the Sun's normal modes. Second, both modes and turbulence drive surface processes on the Sun and their characteristic spectral signatures propagate outwards from the Sun causing the observed dynamics in interplanetary space. The solar wind then couples into the magnetosphere where daily and orbital geometric modulations generates the observed splittings. Thus the low—frequency f^-5/3 background of power spectra of interplanetary and magnetospheric data is a fossil signature of the solar convection zone turbulence, that is observed along with the modes.

Thorne, Richard M.

Outstanding Problems in Radiation Belt Physics *(INVITED)*

Thorne, Richard M.[1]

1. Atmospheric and Oceanic Sciences, UCLA, Los Angeles, CA, USA

Despite the recent progress in radiation belt physics, there are many areas where our understanding is incomplete, due either to limited observations or to deficiencies in our theory and modeling capabilities. Hopefully, the major observational uncertainties will be resolved during the upcoming RBSP mission, and the theory and modeling community are beginning to address the key issues related to quantifying the dominant acceleration, loss and transport mechanisms, and how all important processes can be best incorporated into global radiation belt and ring current models. This invited review will address some of the major unresolved issues, including quantification of the dominant electron acceleration process, the mechanism for sudden electron drop-outs, and the role of non-linear wave-particle interactions on either acceleration or loss.

Trichtchenko, Larisa

Study of the radiation environment on Molniya orbit *(INVITED)*

Trichtchenko, Larisa[1]; Nikitina, Lidia[2]

1. NRCan, Ottawa, ON, Canada
2. Carleton University, Ottawa, ON, Canada
3. Moscow State University, Moscow, Russian Federation

The satellite environment on Molniya orbit is unique and highly variable due to its passage through the horns of the radiation belts and dwelling in the area of "open" magnetic field lines directly affected by transient events. Despite the fact that these orbits have been and continue to

be used to provide communication services for Northern areas, its dynamic radiation environment is not well covered by data and models. In recent years several space programs identified Molniya orbit as highly suitable for planned operational and scientific space missions, such as Canadian Polar Communication and Weather mission (PCW), Kua-Fu B (China), Arctica (Russia). In anticipation of the planned Canadian mission and to provide radiation hazard assessment for mission design considerations, a review of the radiation environment based on available literature and on analysis of available data was undertaken and some of the results will be discussed in presentation. The literature review part includes results from early 70s Russian Molniya satellite particle measurements and the numerical part of the study was based on data from two relatively recent missions HEO1 and HEO3 flown at Molniya orbit by the Aerospace Corporation in cooperation with the American Air Force. These data are generously provided on-line at http://virbo.org/HEO . We present the statistics-based climatological model and dynamical deviations from this model due to different types of space weather variability.

Tu, Weichao

Adiabatic Effects on Radiation Belt Electrons at Low Altitude

Tu, Weichao[1]; Li, Xinlin[1]

1. LASP, University of Colorado, Boulder, CO, USA

The storm-time adiabatic effects of radiation belt electrons mirroring at low altitude are not analogous to those of equatorially mirroring electrons. During the main phase of a geomagnetic storm the adiabatic effects on low-altitude electrons include the expansion of the drift shell, the rise of the mirror point in altitude that is unique for electrons mirroring off-equator, and the shift in the energy spectrum. Calculations of the adiabatic flux change at low altitudes using a modified dipole model demonstrated that the storm-time adiabatic flux change is both altitude and storm dependent. The rise of the electron mirror points can lead to a null flux region at the low altitudes. A satellite in the null flux region sees zero flux during the storm time just due to adiabatic effects, which can persist when the non-adiabatic pitch angle diffusion is very slow. A low-altitude satellite above the null flux region can see a fractional flux drop due to the adiabatic effects, e.g., a factor of 2.4-2.8 decrease in the March 2008 geomagnetic storm with minimum Dst of -72 nT for relativistic electrons mirroring at 700 km and L*=4.5, which is less compared to the adiabatic flux drop of equatorially mirroring electrons ($\tilde{}$ a factor of 42). We propose that the resulting adiabatic change in the electron pitch angle distribution can cause increased electron precipitation without changing the pitch angle diffusion rate. This work is the first quantitative analysis combining both observation and modeling for the adiabatic effect on the variation of outer radiation belt electrons at low altitude.

Turner, Drew L.

Investigating the mechanism responsible for non-adiabatic losses of outer radiation belt electrons during geomagnetic storms

Turner, Drew L.[1]; Shprits, Yuri[1]; Hartinger, Michael[1]; Angelopoulos, Vassilis[1]

1. Institute of Geophysics and Planetary Physics, University of California, Los Angeles, Los Angeles, CA, USA

Relativistic electron fluxes in Earth's outer radiation belt can vary by orders of magnitude on a wide range of timescales. The system is particularly dynamic during geomagnetic storms, and many outstanding questions remain concerning the underlying source, loss, and transport mechanisms responsible for storm-time variability. Relativistic electrons throughout the belt experience a dramatic flux decrease during the main phase of most storms. These flux "dropouts" were originally thought to be simply a result of fully adiabatic transport, but a variety of studies over the past 15 years have concluded that non-adiabatic loss is ultimately taking a major role during dropouts. However, due to the lack of coordinated storm time measurements from spacecraft near the magnetic equator that fully traverse the radiation belt and those at low altitude capable of quantifying the loss of electrons to the atmosphere, the relative importance of different radiation belt electron loss mechanisms during these dropouts has yet to be fully understood. Using data from THEMIS in eccentric, near-equatorial orbits, GOES at geosynchronous orbit, and the constellation of NOAA-POES in low-Earth, high-inclination orbits, we study the sudden electron losses observed during the main phases of several storms. This array of spacecraft allows for observations of both the trapped population near the equator and at low-Earth orbit as well as the population precipitating into the atmosphere. These measurements provide a nearly global picture of the radiation belt throughout each storm. We use these observations to determine whether non-adiabatic losses during each storm's main phase are primarily to the magnetopause, by way of magnetopause shadowing and outward radial diffusion, or to the atmosphere via various scattering mechanisms. Here, we will present these results for several storms with different characteristics (e.g. CME vs. CIR driven, those with strong substorm activity vs. those without, and those resulting in an overall enhancement vs. those resulting in a system-wide loss).

Ukhorskiy, Aleksandr Y.

The Role of Drift Orbit Bifurcations in Energization and Loss of Electrons in the Outer Radiation Belt

Ukhorskiy, Aleksandr Y.[1]; Sitnov, Mikhail[1]; Millan, Robyn[2]; Kress, Brian[2]

1. Johns Hopkins Univ, Laurel, MD, USA
2. Dartmouth College, Hanover, NH, USA

During storms radiation levels in Earth's outer electron belt vary by orders of magnitude. Multiple acceleration and

loss processes operate across the belt and compete in defining its global variability. One such process is the drift orbit bifurcation effect. We investigate implications of drift orbit bifurcations to global variability of the outer electron belt. We use three-dimensional test-particle simulations of electron guiding center motion in a realistic magnetic field model. We show that bifurcations affect a broad range of the belt penetrating inside geosynchronous orbit. This has an important practical implication for the analysis of experimental particle data: the electron phase space density cannot be expressed in terms of three adiabatic invariants. Long-term transport of electrons due to drift orbit bifurcations cannot be reduced to the evolution of the first two moments of the distribution function in the spirit of the Fokker-Plank equation. Drift orbit bifurcations can produce electron losses through magnetopause escape and atmospheric precipitation. Most electrons, however, stay quasi-trapped in the bifurcation regions. The pitch-angle and radial transport due to drift orbit bifurcations lead to their meandering back and forth across the region producing mixing and recirculation of particle populations. This amplifies electron energization by radial diffusion. The combined action of radial diffusion and drift orbit bifurcations can double electron energization at each recirculation cycle. Our results suggest that drift orbit bifurcations can play an important role in the build up of electron fluxes in storm recovery phase.

Usanova, Maria

THEMIS observations of EMIC Pc1 waves in the inner magnetosphere: a Statistical study

Usanova, Maria[1]; Mann, Ian R.[1]; Shao, Leo[1]; Angelopoulos, Vassilis[2]; Bortnik, Jacob[2]

1. University of Alberta, Edmonton, AB, Canada
2. UCLA, Los Angeles, CA, USA

Electromagnetic ion cyclotron (EMIC) waves are transverse plasma waves generated by anisotropic proton distributions with Tperp>Tpara. EMIC waves are believed to play an important role in the dynamics of the ring current and radiation belts, therefore, it is important to know their localization in the magnetosphere. Using observations from multiple satellites traversing the same region of space in a "string-of-pearls" configuration, it is possible to resolve spatial-temporal ambiguity and define regions of enhanced EMIC wave activity. Utilizing magnetic field data from three THEMIS probes, Usanova et al., 2008 observed radially confined EMIC waves in the inner dayside magnetosphere, just inside the plasmapause. We applied an automatic Pc 1 detection algorithm (see Bortnik et al., 2007) to THEMIS FGM data to identify EMIC Pc1 waves. We will present a statistical study of EMIC wave radial extent in the inner magnetosphere, typical location with respect to the plasmapause, and wave power. These observations can be further used for calculation of pitch-angle diffusion rates of energetic particles scattered by EMIC waves.

Weaver, Carol

Persistent Excitation over Several Days of EMIC Waves in Association with a High Speed Stream

Weaver, Carol[1]; Lessard, Marc[1]; Farrugia, Charlie[1]; Engebretson, Mark[2]; Pilipenko, Viacheslav[2]

1. Physics, University of New Hampshire, Durham, NH, USA
2. Physics, Augsburg College, Minneapolis, MN, USA

Electromagnetic ion cyclotron (EMIC) wave data are presented to show an event that persisted about five days (14 - 18 April 2010). The event is associated with a Stream Interaction Region ahead of a high speed stream from a coronal hole. In situ measurements from the WIND satellite showed a typical stream interface between the slow and fast winds, though with an extended period of enhanced dynamic pressure over the course of a few days. Following the high speed stream compression of the magnetosphere, EMIC waves are detected around the globe over the next several days, for several hours surrounding local magnetic noon at more than 20 ground based induction coil magnetometer stations. The structure of the waves remains approximately constant over the days with the power increasing and decreasing perhaps in response to pressure fluctuations in the solar wind (and, presumably, a resulting temperature anisotropy in the magnetosphere). The polarization angle of EMIC waves can help infer a region of injection from the magnetosphere into the ionosphere which in turn may be used to map to a source.

Welling, Daniel T.

Ring Current Modeling with Space Weather Applications Using RAM-SCB *(INVITED)*

Welling, Daniel T.[1]; Jordanova, Vania[1]; Zaharia, Sorin[1]; Reeves, Geoff[1]

1. Los Alamos National Laboratory, Los Alamos, NM, USA

Central to the problem of space weather effects on human technological systems is the ring current. It plays a key role in the evolution of the radiation belts because, as the main pressure carrying population, it controls the shape of the inner magnetosphere by affecting the magnetic field and is capable of generating waves important to the relativistic population, such as electromagnetic ion-cyclotron waves. More directly, the ring current includes the plasma population responsible for spacecraft surface charging. Understanding, monitoring, and predicting the ring current electron and ion environment is key to mitigating spacecraft operational anomalies and losses related to surface charging. LANL's Ring current-Atmosphere interactions Model with Self-Consistent Magnetic field (RAM-SCB) is uniquely positioned as an established ring current research model and a developing operational tool, DREAM-RC. It combines a kinetic model of the ring current with a 3D force-balanced model of the magnetospheric magnetic field to create a magnetically self-consistent inner magnetosphere model. This combination yields spacecraft-specific energy, species, and pitch-angle resolved particle flux output inside the

code's domain. This work reviews these capabilities and presents data-model comparisons for medium Earth and polar orbiting satellites for several geomagnetic storms. Surface charging is calculated based on an empirical formula derived from LANL geosynchronous measurements.

Wright, Darren M.

Characteristics of high-latitude ion outflows derived from ground-based radar and spacecraft measurements

Wright, Darren M.[1]; Davies, Jackie[2]; Glocer, Alex[3]; Imber, Suzie M.[3]; Strangeway, Robert[4]

1. Department of Physics and Astronomy, University of Leicester, Leicester, United Kingdom
2. Rutherford Appleton Lab, Didcot, United Kingdom
3. NASA Goddard Space Flight Center, Greenbelt, MD, USA
4. Institute of Geophysics and Planetary Physics, UCLA, Los Angeles, CA, USA

The escape of heavy ions from the upper atmosphere is an important process through which planetary atmospheres are lost, and plays a crucial role in determining the mass and energy density of the overlying magnetosphere. This additional mass affects the transport of magnetospheric energy from the ring current by MHD waves. Detailed observations of such outflow events are required in order to establish the physical processes - such as energy input from precipitating electrons, the convection electric field and wave-particle interactions - that can accelerate the heavy ions so they can overcome the effects of gravity. An important question to be addressed is whether the main cause of the initial ion upwelling is ion frictional heating or ambipolar electric fields set up by electron precipitation into the ionosphere, and whether this population is subsequently accelerated by some form of wave-particle interaction. A number of conjunctions between the EISCAT incoherent scatter radars, located in Scandinavia, and the FAST satellite (over the whole lifetime of the spacecraft) have been examined in order to characterise the conditions required for ionospheric upwellings detected by the radars to become ion outflows identified by FAST. The radars offer a unique diagnostic of ionospheric composition and vertical motion, and their observations are essential in order to resolve the question of what is the dominant mechanism leading to upwellings and whether these events are directly related to the outflows observed. In addition, these observations have recently been used to validate and constrain the Polar Wind Outflow Model (PWOM). This model of ionospheric outflow, together with the multi-fluid MHD version of the BATSRUS magnetosphere model, is used to investigate causes and consequences of outflow during particular events. Preliminary results of this effort are provided.

http://www.ion.le.ac.uk/

Wygant, John R.

Electric Fields and Energetic Particle Measurements in the Inner Magnetosphere: CRRES and Polar Results *(INVITED)*

Wygant, John R.[1]

1. School of Physics and Astronomy, University of Minnesota, Minneapolis, MN, USA

This talk presents results from the CRRES and Polar spacecraft of measurements of electric fields in association with particle acceleration in the inner magnetosphere with a special emphasis on especially strong geomagnetic storms and substorms. Some of these acceleration mechanisms include substorm injections event which can accelerate electrons to near relativistic energies; enhancements in the the large scale convection electric field which can inject and energize ring current plasma; impacts by interplanetary shocks which can accelerate electrons to >13 MeV over short time periods, and radial diffusion. Outstanding questions and the capabilities of the RBSP mission in addressing them will be discussed.

Yau, Andrew W.

Opportunities for Collaborative Plasmaspheric Studies Using e-POP and RBSP

Yau, Andrew W.[1]; James, H. G.[2]

1. Physics and Astronomy, University of Calgary, Calgary, AB, Canada
2. Communications Research Centre Canada, Ottawa, ON, Canada

Although the Enhanced Polar Outflow Probe (e-POP) on the Canadian CASSIOPE small satellite is primarily targeted at ionospheric ion outflow and other space plasma processes in the topside polar ionosphere, its instrument complement is also suited for the study of ionosphere-plasmasphere coupling processes in the mid-and low-latitude topside ionosphere, and the current delay of the e-POP launch to late 2011/early 2012 provides an excellent and previously unanticipated opportunity for collaborative studies of plasmaspheric dynamics in conjunction with the Radiation Belts Storm Probes (RBSP), which are scheduled for launch in 2012. The e-POP instrument payload consists of a suite of 8 plasma and field instruments, including an imaging ion mass spectrometer, a suprathermal electron imager and a fluxgate magnetometer, for measurements of ion composition and velocity, electron energy and pitch angle distribution in the eV to 100 eV range, and perturbation magnetic field due to field-aligned currents, respectively. In conjunction with data from RBSP, observation data from these instruments will provide a unique opportunity with which to investigate various questions on plasmaspheric dynamics, such as heavy ions in outer plasmaspheric refilling and their effects on field-line resonance.

Yoon, Peter H.

Whistler Waves With Arbitrarily Large Amplitude

Yoon, Peter H.[1]; Lee, Dong Hun[2]

1. IPST, University of Maryland, College Park, MD, USA
2. Kyung Hee University, Yongin, Republic of Korea

In a recent STEREO observation during the satellite's passage through the Earth's dawn-side radiation belt, very high amplitude, nearly monochromatic whistler waves were detected [Cattell et al., GRL, 35, L01105, 2008]. Such an observation indicates an alternative mechanism for the energization of relativistic electrons in the Earth's radiation belt other than the standard diffusion process may be important. In the present paper, it is shown that an exact analytical solution to the whistler wave exists when the wave propagation is parallel to the ambient magnetic field. The analytical solution shows that the sinusoidal form of whistler wave can have arbitrarily large amplitude. On the basis of the exact closed form solution for parallel propagation, the obliquely propagating whistler wave and its associated characteristics are investigated by numerical means.

Yoon, Peter H.

Quasilinear Diffusion Coefficients Using Warm Plasma Dispersion Relations

Yoon, Peter H.[1]; Summers, Danny[2]

1. IPST, University of Maryland, College Park, MD, USA
2. Memorial University, St Johns, NF, Canada

Modeling the sources and losses of Earth's radiation belt electrons is an important research topic in view of NASA's upcoming Radiation Belt Storm Probes (RBSP) mission. One of the most important theoretical tools for such modeling is that based on quasi-linear theory, which has been in use since the 1960s. However, one of the key assumptions in such efforts is that the waves are described by cold plasma theory. The radiation belts are characterized by finite plasma betas. It is well known that the plasma dispersion relation for finite betas can deviate substantially from the cold-plasma solution. Nevertheless, cold plasma theory has been invariably used in radiation belt transport coefficient calculations because the hot/warm-plasma (or finite-beta) dispersion relation makes the calculation intractable. In this presentation, we recalculate the quasi-linear diffusion coefficients by using hot/warm plasma theory that has been recently developed. Instead of using a transcendental plasma dispersion relation, the recent work modeled the numerical solution by analytical functions. Such an empirical model makes the hot/warm plasma diffusion coefficient calculation tractable, which hitherto had been impossible. We compare the outcome with that based upon cold plasma theory in order to assess the impact of warm plasma effects.

Young, Shawn L.

Working to Improve Spacecraft Charging Specification and Forecast Capabilities

Young, Shawn L.[1]; Perry, Kara L.[1]; Nelson, Steven G.[1]; Hilmer, Robert V.[1]; Fok, Mei-Ching H.[2]; McCollough, James P.[1]

1. Battlespace Division, Air Force Research Laboratory, Kirtland Afb, NM, USA
2. Geospace Physics Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, USA

While there are multiple environmental hazards to spacecraft in the inner magnetosphere the current focus of the Air Force Research Laboratory's Space Weather Forecasting Laboratory (SWFL) is on improving operational specification and forecast capabilities for spacecraft charging. This task involves both working with model developers to bring more advanced environmental models (keV and MeV electrons) into operations and also working closely with the users to identify new and better uses of existing capabilities. In order to bring more advanced models into operations we must first validate the present operational models to use as a baseline for measuring progress. This provides us with a better understanding of the current state of the art, helps to identify needed improvements and provides a quantitative estimate of forecast and specification improvement to help decision makers decide when to bring in a new capability. With our improved understanding of operational needs and current capabilities we can also more effectively help users identify near term improvements and other uses for their current capabilities. We will discuss our work to improve both deep dielectric and surface charging capabilities and where appropriate we will summarize validation results.