in individual ^{3}He-rich events. We find large enhancements of a number of neutron-rich isotopes. For example, $^{22}Ne/^{20}Ne$ and $^{26}Mg/^{24}Mg$ are each >0.5, significantly in excess of the solar wind values of 0.07 and 0.14, respectively. We report the ACE spectra and composition observations and compare with the elemental composition in "average" ^{3}He-rich events as well as in several recently-reported events with unusual enrichment patterns (Mason et al. 2002). We discuss these new observations in the context of models of particle acceleration in ^{3}He-rich events.

Supported by NASA at Caltech (grant NAG5-6912), JPL, GSFC, and Maryland (grant 251429).

SH61A-0440 0830h POSTER

A Comparison of SEP Ionic Charge States in Local Shock and Impulsive Events

Mark A. Popecki[1] (mark.popecki@unh.edu); E. Moebius[1]; A. B. Galvin[1]; L. M. Kistler[1]; H. Kucharek[1]; B. Klecker[2]

[1]Space Science Center and Department of Physics, University of New Hampshire, Durham, NH 03824, United States

[2]Max-Planck-Institut fur extraterrestrische Physik, Giessenbachstr., Garching D-85740, Germany

The SEPICA instrument on the Advanced Composition Explorer (ACE) spacecraft has measured ionic charge states of solar energetic particles (SEPs) from late 1997 through 2000. Charge state measurements provide insights about the acceleration and propagation history of SEPs. In impulsive events, SEP charge states provide information about the flare environment, where source heating and collisions are important. In interplanetary shock events, SEP charge states are diagnostics of the rigidity-dependent acceleration process and particle seed populations. For example, 3He enrichment has been observed in some events with a local shock passage (Desai et al., 2001). An enhancement in high charge state Fe has also been observed in these events (Popecki et al., 2001). This suggests that the seed population for the interplanetary shock contained ions previously accelerated in flares.

SEP charge states from impulsive events will be compared to those from events with a local shock passage (ESP events). In addition, the ESP events wil be separated into those with and without 3He enrichment. Results will be presented in the context of mission-integrated ionic charge state distributions for each species.

SH61A-0441 0830h POSTER

On the Heliospheric He+ Pickup Ion Acceleration by CME Driven Shocks

Elena Moise[1,2] (734-647-3665; emoise@physics.arizona.edu)

Thomas H. Zurbuchen[2] (734-647-6835; thomasz@umich.edu)

Ke Chiang Hsieh[1] (hsieh@physics.arizona.edu)

George Gloeckler[2,3] (gg10@umail.umd.edu)

Lennard Fisk[2] (734-647-3660; lafisk@umich.edu)

[1]University of Arizona, Department of Physics, 1118 East 4th Street, Tucson, AZ 85721, United States

[2]University of Michigan, Space Science Research Laboratory, 2455 Hayward Street, Ann Arbor, MI 48109, United States

[3]University of Maryland, Department of Physics, College Park, MD 20742, United States

We present the results from the study of local acceleration in the vicinity of CME-driven shocks using ACE/SWICS He+ pickup ion data at 1 AU. The pickup ions are injected for acceleration and develop a power-law spectrum at energies above 30 keV. These power-law tails are compared with theoretical predictions of shock-accelerated particles. We find that, generally, the acceleration process is less efficient than anticipated from the shock acceleration theory. We attribute this to the efficiency of these physical processes that lead to injection into shock acceleration. We discuss the scenario that the source of injection may not be associated directly with the shocks, but with statistical acceleration processes due to the compressed shock turbulence.

SH61A-0442 0830h POSTER

Coronal Mass Ejections (CMEs) Induced Shock Formation and Properties

Shi Tsan Wu[1] (256-824-6413; wus@cspar.uah.edu)

Bruce Tsurutani[2] (818-354-7559)

Tianxi Zhang[1] (256-824-6297; zhangt@cspar.uah.edu)

[1]The University of Alabama in Huntsville, Center for Space Plasma Aeronomic Research, Huntvile, AL 35899, United States

[2]Jet Propulsion Laboratory, California Institute of Technology, Mail Code 169-509, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

It has been recognized that solar energetic particles (SEPs) are accelerated at interplanetary shocks from the point of their formation in the lower corona to 1 A.U. and beyond. In this study, we will investigate the formation and propagation of induced shocks from the inner corona to 1 A.U. using a CME three-dimensional, axisymmetric (i.e. 2.5-D) magnetohydrodynamic (MHD) code. A well-studied CME event (1997 January Sun-Earth Connection Event) is used as a baseline to match the solar wind conditions measured at 1 AU (WIND data) to model CME driven shocks. The properties of the shock as a function of distance and latitude from the Sun up to 1 A.U. will be presented. Also, the geoeffective parameters are computed using disturbed solar wind properties.

SH62A MCC: 124 Saturday 1330h

Particle Acceleration at Heliospheric Shocks: Observations, Theory, and Modeling II

Presiding: **T Zurbuchen,** University of Michigan**; G Li,** University of California, Riverside

SH62A-01 1330h INVITED

Identifying the Real Seed Population for Shock Accelerated Energetic Particles: Recent Observational Progress

G M Mason[1] (301-405-6203; glenn.mason@umail.umd.edu)

J E Mazur[2] (joseph.e.mazur@aero.org)

M I Desai[1] (desai@uleis.umd.edu)

J R Dwyer[3] (dwyer@galileo.pss.fit.edu)

[1]Dept of Physics, University of Maryland, College Park, MD 20742, United States

[2]Aerospace Corp., 2350 E. El Segundo Blvd., El Segundo, CA 90245, United States

[3]Dept. Physics Space Sci., Florida Inst. of Technology, Melbourne, FL 32901, United States

Gradual solar energetic particle events, traveling interplanetary shocks, and corotating interaction regions are examples of shock acceleration of particles in the heliosphere. Although shock acceleration of particles has long been the subject of theoretical investigation, nevertheless key energetic particle properties such as intensity and spectral index are only roughly correlated with predictions of the theories. This may be due to limitations of the theories, but it may also be due to a lack of understanding of properties of the seed population. Recent measurements have shown that trace elements in the thermal plasma (e.g. singly ionized He, and 3He) often show dramatic enhancements in the energetic particle population. Although the observational picture is far from complete, it appears that the injection threshold in these events is about 1.5-2 times the solar wind speed. In this range, multiple particle sources are present, including solar wind suprathermals, pick up ions, and remnant material from prior shocks and impulsive events. Thus, the enhancements are not due to properties of the shock acceleration, but rather are primarily due to the properties of the seed population. This points to new opportunities for theoretical and experimental investigations to quantitatively model shock accelerated particle populations using realistic seed populations.

SH62A-02 1350h

Solar Energetic Particles and Interacting CMEs: Cause or Coincidence?

R. A Mewaldt[1] (626-395-6612; RMewaldt@srl.caltech.edu); C M. S. Cohen[1]; R. A. Leske[1]; G. M. Mason[2]; R. C. Ogliore[1]; E. C. Stone[1]; T. T. von Rosenvinge[3]; M. E. Wiedenbeck[4]

[1]Caltech, 220-47 Downs Lab., Pasadena, CA 91125, United States

[2]University of Maryland, Dept. of Physics, College Park, MD 20742, United States

[3]Goddard Space Flight Center, Code 661.0, Greenbelt, MD 20771, United States

[4]Jet Propulsion Laboratory, MS 169-327, Pasadena, CA 91109, United States

A recent study by Gopalswamy et al. has determined that more than 80 percent of the largest solar energetic particle (SEP) events during solar cycle 23 were associated with interacting coronal mass ejections (CMEs), suggesting that such interactions somehow facilitate SEP acceleration processes. Using data for 44 large SEP events from the Solar Isotope Spectrometer on ACE, we examine this hypothesis by searching for compositional and spectral signatures of possible CME interactions and by measuring the time-of-acceleration of high-energy protons and heavier ions near the Sun. For heavy ions we illustrate an approach that makes use of the measured mass and kinetic energy to compute particle velocity to an accuracy of 0.1 percent. By comparing the inferred particle acceleration times near the Sun with CME trajectories measured by SOHO, and assuming that it is a shock driven by the fastest CME that accelerates the particles, we find that in many events the acceleration of high energy protons and heavy ions begins within a few solar radii of the Sun. By comparing the time and location where acceleration begins in a sample of magnetically well-connected events with the time and location of possible CME interactions in the same event, we find that in most cases particle acceleration begins well before the primary CME has had an opportunity to interact with preceding CMEs. We conclude that CME interactions are not a necessary condition or cause of particle acceleration in most large SEP events.

SH62A-03 1405h INVITED

Challenges for Modeling Acceleration and Transport in Solar Energetic Particle Events

Allan J Tylka (202-767-2200; tylka@gamma.nrl.navy.mil)

US Naval Research Laboratory, Code 7652 High Energy Solar Radiation Section, Washington, DC 20375, United States

Shocks, driven by fast coronal mass ejections (CMEs), are believed to be the primary accelerator of energetic particles in large, so-called gradual solar particle events. Thus far in Cycle 23, instruments on ACE, Wind, SOHO, and IMP8 have provided detailed observations of the energy spectra, composition, and temporal evolution of nearly 50 large events in which the differential proton intensity at ~20 MeV exceeded galactic cosmic ray levels by a factor of more than 10^4. These events exhibit a large range of variability in all of their characteristics. Some of this variability is reasonably well understood in terms of familiar notions about shock acceleration, source-plasma composition, and particle transport. For other aspects we appear to have a qualitative understanding that is not yet bolstered by detailed quantitative modeling. However, many observed characteristics, such as spectral variability among elemental species, clearly challenge our present understanding. We will review these new challenges and speculate about the physics issues that must be addressed in future modeling efforts.

SH62A-04 1425h INVITED

Particle Acceleration by Interplanetary Shocks

Gary P Zank[1] (909-787 4508; zank@ucrac1.ucr.edu)

Gang LI[1] (ganli@citrus.ucr.edu)

W. Ken Rice[2]

[1]Institute of Geophysics and Planetary Physics, University of California, Riverside, CA 92521, United States

[2]Shool of Physics and Astronomy, University of St Andrews, St Andrews, Fife KY16 9SS, United Kingdom

Interplanetary shocks can accelerate both solar wind ions and flare-released high-energy particles to high energies. The acceleration process is generally thought to be diffusive shock acceleration although almost entirely based on a highly simplified steady-state description. The importance of the evolving shock and the time constraints for accelerating particles diffusively at a shock, coupled to the inhomogeneous magnetic field and the expanding solar wind have not been widely recognized. We have developed recently a fully time-dependent model to describe particle acceleration at an expanding interplanetary shock wave, including the self-consistent calculation of the spatial diffusion coefficient in the vicinity of the shock, particle escape and transport into the upstream wind. We review results for strong and weak interplanetary shocks, showing intensity profiles, escaping particle spectra at 1 AU, spectra at and behind the shock, particle distributions,

and estimate the maximum possible energies that can be accelerated at an interplanetary shock. Preliminary results for 2D time-dependent interplanetary shocks are presented too.

SH62A-05 1445h

Modeling Shock Acceleration in Evolving Magnetic Field Configurations

Jozsef Kota (1-520-621-4396; kota@lpl.arizona.edu)

University of Arizona, LPL, University of Arizona Lunar and Planetary Laboratory, Tucson, AZ 85721-0092, United States

Solar energetic particles (SEPs) in large gradual SEP events are thought to be accelerated at shocks driven by coronal mass ejections (CMEs). A profound feature of CME driven shocks is that the field configuration (both the shock strength and geometry) may undergo remarkable variation as the CME evolves.

We developed a numerical code solving the Fokker-Planck equation including convection, focusing, adiabatic cooling and acceleration, and pitch-angle scattering of charged energetic particles moving along magnetic field lines. First, the Fokker-Planck equation is cast in a new form that is more suitable for incorporating time-dependent magnetic fields. We report on preliminary results of our numerical simulations. Acceleration at single and multiple shocks (including interacting shocks) will be discussed.

SH62A-06 1500h INVITED

Particle acceleration processes in CME and CIR driven shocks

Thomas H Zurbuchen[1] ((734) 647-6835; thomasz@umich.edu)

L. A. Fisk[1] (lafisk@umich.edu)

[1]University of Michigan, Space Research Building, Ann Arbor, MI 48109-2143, United States

Shocks driven by Coronal Mass Ejections (CMEs) and Co-rotating Interaction Regions (CIRs) accelerate particles throughout the inner heliosphere. However, many of the physical processes that lead to particle injection in these shock acceleration processes are not currently understood. We are presenting results from ACE and Ulysses that suggest that there are important physical effects that appear to energize particle distributions that appear to be relatively independent from shocks. These processes are likely statistical in nature and have important consequences for the efficiency of particle acceleration in shocks. We will review these observations and offer theoretical explanations for these models.

SH62A-07 1540h INVITED

Compression Acceleration of Energetic Charged Particles

Jack R. Jokipii (520-621-4256; jokipii@lpl.arizona.edu)

Dept of Planetary Sciences, University of Arizona, Tucson, AZ 85721, United States

Collisionless shocks are probably the accelerator of most of the energetic charged particles observed in space. In fact, diffusive acceleration by shocks is so efficient and fast, and shocks are so ubiquitous, that one is tempted to suggest that energetic charged particles are all accelerated by collisionless shocks. However, it is quite clear that there are situations where a shock cannot be the accelerator of observed energetic particles. One example consists of the energetic particles observed in association with co-rotating interaction regions near one AU, where the co-rotating shocks have yet to form. The lack of a rollover in the energy spectrum strongly implies that the acceleration of the particles occurs locally, near 1 AU, where the co-rotating shocks have not yet formed. Hence some mechanism other than shock acceleration is responsible for the acceleration of these particles.

A variety of non-shock charged-particle acceleration mechanisms have been proposed over the years, including the venerable 2nd-order Fermi mechanism, reconnection and magnetic pumping. Each has disadvantages. A "new" mechanism will be introduced here, which is a hybrid of 2nd-order Fermi acceleration and diffusive shock acceleration. Because the mechanism involves using particle transport in compressions of the ambient fluid, we have called it "diffusive compression acceleration". Applied to co-rotating non-shock compressions observed in the solar wind at one AU, the mechanism provides a natural and compelling interpretation of observed particles. Numerical simulations have been carried out which show very good agreement with observations.

Further application of this idea to turbulent flow compressions in a collisionless plasma, and the relation of the mechanism to diffusive shock acceleration, magnetic pumping and 2nd-order Fermi acceleration will be discussed.

SH62A-08 1600h

Rise Times of Solar Energetic Particle Events and Speeds of CMEs

Stephen Kahler[1] (stephen.kahler@hanscom.af.mil)

Don Reames[2] (reames@milkyway.gsfc.nasa.gov)

[1]Air Force Research Laboratory, Space Vehicles Directorate, 29 Randolph Rd, Hanscom AFB, MA 01731, United States

[2]NASA, Goddard Space Flight Center, Greenbelt, MD 20771, United States

Gradual solar energetic particle (SEP) events are assumed to be produced in coronal and interplanetary shocks driven by fast coronal mass ejections (CMEs). These fast CMEs are decelerated as they move through the slower ambient solar wind. However, the Alfven speed is decreasing with increasing distance. Faster CMEs may therefore continue to drive strong shocks for longer characteristic times than do the slower CMEs, such that shock production and injection of SEPs of a given energy will also continue longer with the faster CMEs. We test this proposition observationally by comparing the times to maxima of 20 MeV SEP events with the observed speeds of associated CMEs. The SEP/CME events are sorted by solar longitude to factor out the longitudinal dependence of the SEP rise times. A preliminary analysis comparing 20 MeV protons from the GSFC EPACT detector on the Wind satellite with CMEs observed by the LASCO coronagraph on the SOHO spacecraft showed a correlation between SEP rise times and CME speeds. We expand the database to include the 1996-2001 period for a more definitive test of the correlation. The implications of the results will be discussed.

SH62A-09 1615h

ACE observations of energetic particles associated with transient interplanetary shocks

D. Lario[1] (david.lario@jhuapl.edu); G. C. Ho[1] (george.ho@jhuapl.edu); R. B. Decker[1] (Rob.Decker@jhuapl.edu); E. C. Roelof[1] (edmond.roelof@jhuapl.edu); C. W. Smith[2] (chuck@bxclu.bartol.udel.edu); M. I. Desai[3] (desai@uleis.umd.edu)

[1]The Johns Hopkins University. Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723, United States

[2]Bartol Research Institute, University of Delaware, Newark, DE 19711, United States

[3]University of Maryland, Department of Physics, College Park, MD 20742, United States

We present preliminary results from a survey of the effects of interplanetary shocks on energetic >47 keV ions and >38 keV electrons as observed by the field (MAG), plasma (SWEPAM) and energetic particle (EPAM) experiments on the ACE spacecraft. From September 1997 to December 2001 ACE observed over 270 shocks, from which we have selected a total of 168 forward transient interplanetary shocks. Particle events associated with these shocks range from large particle intensity enhancements lasting several hours to small shock spikes lasting only a few minutes, as well as events where no intensity increases are observable. Our survey of the proton and electron intensity-time profiles reveals the following: (1) intensity increases associated with a shock passage are more frequently observed in the low-energy ion fluxes; (2) electron shock events, which occur less frequently than ion shock events, are mainly spikes or step-like post-shock increases; and (3) peak intensities are usually observed within $\sim$2 minutes of the shock passage with a clear trend towards occurrence in the downstream region of the shock. Selected events from our survey will be analyzed in detail, paying special attention to the evolution of the energy particle spectra, the three-dimensional anisotropy distributions of ions, and the magnetic turbulence around the shock. The characteristics of these events will be compared with predictions of current theories of shock acceleration.

SH62A-10 1630h

Energy Dependence of Abundance Variation in Gradual SEP Events - Implications on Acceleration

Chee K Ng[1,2] (1-301-286-1504; cheeng@milkyway.gsfc.nasa.gov)

Donald V Reames[1] (1-301-286-6454; reames@milkyway.gsfc.nasa.gov)

[1]NASA Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, United States

[2]Department of Astronomy, University of Maryland, College Park, MD 20742, United States

We use a numerical model of the coupled evolution of solar energetic partilces (SEPs) and Alfvén waves to study SEP abundance variation in gradual events. In this model, shock-accelerated protons traveling upstream from a CME-driven shock amplify interplanetary Alfvén waves en route, producing wave spectra that vary in wavenumber, space, and time. The evolving Alfvén waves with non-Kolmogorov spectra scatter accelerated minor ions at varying wavenumbers, leading to complex variation of the SEP abundances in energy and time. We will present results from our simulations, emphasizing on the energy and time dependence of Fe/O and He/H from 320 keV/amu to 20.5 MeV/amu, in the range of SEP observations on Wind and ACE. Possible effects of coupling between acceleration and transport will be considered.

SH62A-11 1645h

Two Classes of Solar Energetic Particle Events: Time for a New Paradigm?

Tycho T. von Rosenvinge[1] (301-286-6721; tycho@milkyway.gsfc.nasa.gov); Christina M.S. Cohen[2] (cohen@srl.caltech.edu); Alan C. Cummings[2] (ace@srl.caltech.edu); Richard A. Leske[2] (ral@srl.caltech.edu); Richard A. Mewaldt[2] (rmewaldt@srl.caltech.edu); Edward C. Stone[2] (ecs@srl.caltech.edu); Mark E. Wiedenbeck[3] (mew@heag1.jpl.nasa.gov)

[1]NASA/Goddard Space Flight Center, Code 661, Greenbelt, MD 20771, United States

[2]California Institute of Technology, M/C 220-47, Pasadena, CA 91125, United States

[3]Jet Propulsion Laboratory, MS 169-327, Pasadena, CA 91109, United States

The current paradigm for solar energetic particle (SEP) events is that there are two classes of events, impulsive and gradual. The former have heavy element abundances enhanced relative to coronal abundances and are associated with small, well-connected solar flares. The latter are associated with shocks driven by Coronal Mass Ejections. The elemental abundances in gradual events might be expected to match coronal abundances; however the observed abundances show significant temporal variations during events as well as from event to event. These variations have been explained by rigidity dependent propagation, the build-up of waves in the vicinity of the shock, and the presence of particles from prior impulsive events. Since the beginnings of this paradigm there have been questions as to whether the two classes of events are truly distinct or are merely on opposite ends of a continuum of possibilities. Alternatively, it has been suggested that some events are hybrids of the two types. It has recently been argued by Reames that the two classes are truly distinct and that hybrids do not occur. We will present observations of SEP events made by the Solar Isotope Spectrometer on-board the ACE spacecraft which we find difficult to explain in terms of the current paradigm.

This work was supported by NASA at Caltech (under grant NAG5-6912), JPL, and GSFC.

SH62A-12 1700h

A Multi-Instrument Survey of the Ionization States of Heavy Ions in Large Solar Particle Events: 1992-2002

Joseph E Mazur[1] (310-336-2389; joseph.mazur@aero.org); Mark Popecki[2]; Berndt Klecker[3]; Alexander Bogdanov[4]; Glenn M Mason[5]; Eberhard Mobius[2]; Lynn M Kistler[2]

[1]The Aerospace Corporation, 2350 E. El Segundo Blvd., El Segundo, CA 90245, United States

[2]University of New Hampshire, Morse Hall 39 College Raod, Durham, NH 03824, United States

[3]Max Planck Institute for Extraterrestrial Physics, Garching, Munchen D-85741, Germany

[4]Institute for Geophysics and Meteorolgy, Technical University of Braunschweig Mendelssohnstrasse 3, Braunschweig 38106, Germany

[5]University of Maryland, Department of Physics, College Park, MD 20742, United States

The ionization states of energetic particles carry information about the particle seed populations, the acceleration processes, and the particle transport through the interplanetary medium. For example, the charge states enable us to examine the influence of rigidity on

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particle arrival times and energy spectra and to determine if the inferred temperature of the source plasma is consistent among many elements. In this survey we consider the charge states of He-Fe in some of the most intense events associated with coronal mass ejections from 1992 to the present. Our measurements are based on electrostatic deflection and geomagnetic cutoff techniques, allowing us to compare the charge states from different instruments and techniques in the same events. We focus on the measurements from the Low-energy Ion Composition Analyzer (LICA) on board the low-Earth orbiting SAMPEX satellite, the Solar Energetic Particle Ion Charge Analyzer (SEPICA) on ACE, and the Suprathermal Time-of-Flight (STOF) instrument on SOHO, extending the energy range for iron charge states from 20 keV/n up to 2 MeV/n.

SH71A MCC: 124 Sunday 0830h

Energetic Charged Particle Transport in the Heliosphere I

Presiding: **M A Forman,** State University of New York, Stony Brook**;** **M Zhang,** Florida Institute of Technology

SH71A-01 0830h INVITED

Galactic Cosmic-ray Transport in the Global Heliosphere

Vladimir Florinski[1] (1-909-787-3943; vflorins@citrus.ucr.edu)

Gary P. Zank[1] (1-909-787-4508; zank@ucrac1.ucr.edu)

Nikolai V. Pogorelov[2] (7-095-434-3374; pgrlv@ipmnet.ru)

[1]Institute of Geophysics and Planetary Physics, University of California, Riverside, 900 University Avenue, Riverside, CA 92521, United States

[2]Institute for Problems in Mechanics, Russian Academy of Sciences, 101-1 Vernadskii Avenue, Moscow 119521, Russian Federation

Galactic cosmic ray propagation in the heliosphere has traditionally been the domain of modulation studies for the past three decades. To date, virtually all such models have lacked a self consistent treatment of the three principal particle species – plasma with magnetic field, interstellar neutral atoms and galactic cosmic rays. To overcome this drawback we have developed a global self-consistent model of the heliosphere which we use to study the entry of the galactic cosmic rays into the heliosphere directly from the local interstellar medium population. An important improvement over the previous global heliospheric models is that a kinetic description for the cosmic rays is used instead of the usual fluid approach, which allows us to study the evolution of the particle spectra with distance. Our model is axisymmetric with respect to the interstellar flow, but includes a complete three-dimensional heliospheric magnetic field. Cosmic-ray diffusion coefficients are computed from the quasi-linear theory assuming a constant (but different) power spectrum of the fluctuations in both the solar wind and the interstellar medium. Our results show that low energy particles are strongly attenuated by the magnetic wall in the inner heliosheath and do not reach the termination shock. The model predicts small cosmic rays gradients implying little modification to the heliospheric boundaries. Particle spectra in the inner heliosphere are found to be in agreement with the observations. We also find the inner heliospheric galactic cosmic-ray population is not sensitive to the upstream-downstream asymmetry of the termination shock.

SH71A-02 0850h

Second Order Correction to the Gradient/Curvature Drift Term of Cosmic Ray Transport in Heliospheric Magnetic Fields

Bryan M Ball[1] ((321) 674-7293; bball@cr1.pss.fit.edu)

Ming Zhang[1] ((321) 674-8891; mzhang@fit.edu)

[1]Florida Institute of Technology, 150 West University Boulevard, Melbourne, FL 32901-6975, United States

In heliospheric cosmic ray transport problems the equations contain particle gradient and curvature drift effects. When calculating the drifts, however, the velocities derived can often be greater than the speed of light despite the use of a relativistic expression. This problem is due to the breakdown of the guiding center approximation in the polar regions of the heliosphere. When the scale sizes of both magnetic field changes and particle gyroradii lengths are comparable, the usual first order guiding center approach is no longer valid. We derive here a correction term to the drifts in these regions using a second order expansion in the particle gyroradii. Several new terms emerge from our initial calculation, but when we average over pitch angle we reduce the final solution to a simple form that is straightforward to evaluate in any energetic particle transport or cosmic ray modulation problem. The effects that this can have on the modulation problem are explored here. We also illustrate these drifts using some simple particle orbit traces in the Parker magnetic field.

SH71A-03 0905h

Diffusive Compression Acceleration and Turbulent Diffusion of Cosmic Rays

Garry M Webb[1] (520-621-4480; gwebb@lpl.arizona.edu)

Chung M Ko[2] (03-425-1175; cmko@phy.ncu.edu.tw)

Gary P Zank[3] (909-787-4508; zank@ucrac1.ucr.edu)

Randy Jokipii[1] (520-621-4256)

[1]Lunar and Planetary Laboratory, University of Arizona, 1629 E University Blvd,, Tucson, AZ 85721, United States

[2]Department of Physics, Institute of Astronomy and Center for Complex Systems, National Central University,, Chung-Li, Taiwan, Chung-Li 320, Taiwan

[3]IGPP, University of California Riverside, University Ave., Riverside, CA 92506, United States

Multiple scales perturbation methods are used to study the transport and acceleration of energetic charged particles in a quasi-periodic, fluid velocity structures in one, two or three space dimensions, for cases where the spatial period of the velocity structure is much less than the diffusion-convection scale length of the background flow. The large scale transport equation obtained by averaging over the short scale velocity variations shows that the particles are accelerated stochastically due to the two-point correlations between the fluid velocity divergence at different points in the flow. The spatial diffusion tensor of low energy particles, with sufficiently small microscopic diffusion tensor elements, are effectively transported by turbulent diffusion, whereas higher energy particles, with a large effective diffusion coefficient are unaffected by turbulent diffusion. The formalism is generalized to describe particle transport in turbulent background flows. The form of the spatial turbulent diffusion tensor for both incompressible and compressible turbulence is discussed.

SH71A-04 0920h

The Effect of a Fisk-type Heliospheric Magnetic Field on Cosmic Ray Modulation

Renier A. Burger[1] (fskrab@puknet.puk.ac.za)

Mariette Hitge[1] (mhitge@intekom.co.za)

[1]Potchefstroom University, Space Research Unit, School of Physics,, Potchefstroom, NW 2520, South Africa

A heliospheric magnetic field (HMF) with a meridional component, such as the model of Fisk, leads to a more complicated form of the transport equation (TPE) for cosmic rays than is the case for the Parker model of the HMF. The number of terms with mixed derivatives increases and as a result the three-dimensional numerical codes used to solve the TPE becomes unstable more easily. In this paper we present a hybrid Fisk/Parker HMF, which is a pure Fisk HMF at mid-latitudes, but changes to a Parker HMF in the solar equatorial plane and above the solar poles. Although this field will under-estimate the full effects of the Fisk field to some degree, it's use should give some insight into the effect of an HMF with a periodic meridional component on cosmic-ray modulation. To study this hybrid field, we solve the three-dimensional steady-state TPE in a system corotating with the Sun, using spherical coordinates in an ADI numerical scheme which covers the entire heliopshere. The solar wind speed is assumed to be independent of latitude. For the parallel diffusion coefficient we use a standard QLT expression. The perpendicular diffusion coefficients have the same spatial dependence as the parallel diffusion coefficient, but have a flatter rigidity dependence. We use the standard weak-scattering form for the drift coefficient and a wavy current sheet with a small tilt angle. We present results for galactic cosmic-ray protons and electrons, covering an energy range from 10 GeV down to a few MeV. We find that the 27-day intensity variations are more pronounced when the latitudinal gradient is large. The latitudinal gradient itself is reduced with respect to the gradient for a pure Parker HMF. This reduction does not change the rigidity at which the maximum latitudinal gradient occurs for either protons or electrons.

SH71A-05 0935h INVITED

The Transport of Anomalous Cosmic Rays

Edward C Stone[1] (626-395-8321; ecs@srl.caltech.edu)

Alan C Cummings[1] (626-395-6708; ace@srl.caltech.edu)

[1]California Institute of Technology, 220-47 Downs Laboratory, Pasadena, CA 91125, United States

The gradients of anomalous cosmic rays provide a measure of the rigidity dependence of the diffusive radial mean free path. During period of negative solar magnetic polarity and minimum solar activity, the gradients are small when the current sheet is flat and increase with increasing current sheet tilt. For positive polarity, the gradients during solar minimum are small and independent of tilt for tilts up to about 50 degrees, suggesting that drifts map mid-latitude gradients to lower latitudes. Mean free paths at 1.5 GV during solar minimum beyond 50 AU are larger than 1 AU and increase linearly with radius as expected at higher latitudes in the absence of stream driven turbulence. During solar maximum, the gradients are much larger, corresponding to a factor of ten reduction in mean free path. This large decrease may be associated with the inhibition of drifts and the presence of increased stream driven turbulence at higher latitudes. This work was supported by NASA under contract NAS7-1407.

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Evidence That Particle Drift Does not Contribute Significantly to Low-Rigidity ACR Transport During A > 0 Recovery

Matthew E Hill[1] (301-405-6209; mehill@umd.edu)

Douglas C Hamilton[1] (douglas.c.hamilton@umail.umd.edu)

Stamatios M Krimigis[2] (tom.krimigis@jhuapl.edu)

[1]University of Maryland, Department of Physics, College Park, MD 20742-4111, United States

[2]Johns Hopkins University, Applied Physics Laboratory, Laurel, MD 20723

We report on 0.6 to 40 MeV/nucleon outer heliospheric anomalous cosmic ray (ACR) ions having a broad range of rigidities from 130 MV to 4.3 GV during the A $>$ 0 recovery phase from 1991 to 1999. Intensity measurements (made primarily with the Voyager 1 and 2 Low Energy Charged Particle instruments) of ACR H, He, and O with rigidities below approximately 2 GV provide evidence that diffusion, convection, and adiabatic cooling are significant transport effects but that curvature and gradient drifts are not. Above 2 GV we find that drifts do play a significant role in ACR transport. This understanding is based in part on our unexpected determination of negative latitudinal intensity gradients for low-rigidity ACRs and our numerical solution to the cosmic ray transport equation. We present the observational and modeling evidence for this interpretation and make estimates regarding transport parameters. This study of ACRs has a direct bearing on our understanding of the relative importance of various mechanisms in the transport of energetic charged particles in the heliosphere.

URL: http://space.umd.edu/VOYAGER/

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Flow Directions and Mean Free Pathlengths of Energetic Particle Populations in the Outer Heliosphere

A. C. Cummings[1] (626-395-6708; ace@srl.caltech.edu)

E. C. Stone[1] (626-395-8321; ecs@srl.caltech.edu)

[1]California Institute of Technology, Mail Code 220-47, Pasadena, CA 91125, United States

First-order anisotropies of particle intensities can be deduced from measurements from the four low-energy telescopes on the Voyager Cosmic Ray experiment. Anisotropy observations will be reported for H with 3.3-7.8 MeV, He with 4.0-7.8 MeV/nuc, and O with 5.4-17.1 MeV/nuc for various intervals from 1993 through the present. This period includes the recent solar minimum when anomalous cosmic rays dominate the He and O observations and solar maximum when other particle populations dominate the H and He observations. The ACR O anisotropy observations can be combined with observed radial gradients to deduce the mean free pathlengths of the particles, and the streaming directions can suggest the location of the source of H and He during solar maximum.

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