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

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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

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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

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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

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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

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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.

SH71A-06 1015h

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

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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/

SH71A-07 1030h

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

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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.

This work was supported by NASA under contract NAS7-1407.

SH71A-08 1045h INVITED

Advances in Charged Particle Scattering Theory

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We review advances in charged particle scattering theory made in the last decade and attempt to apply these advances to solar and galactic cosmic ray propagation, pickup ion scattering, and interplanetary shock acceleration. In the process of doing this, we will draw on recent discoveries and trends in the interpretation of interplanetary magnetic fluctuations. These advances include, but are not limited to, magnetodynamic scattering theories, the geometry of interplanetary fluctuations, fully-consistent scattering through 90 degrees, electrodynamic scattering theory, and the role of transients.

This work was supported by CIT subcontract PC251439 under NASA grant NAG5-6912 for support of the ACE magnetic field experiment and by NASA grant NAG5-10911.

SH71A-09 1105h

Predicting Transport Coefficients of Heliospheric Particles from Solar Wind Observations

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We present a model for the parallel transport of energetic particles which addresses the effects of propagation and thermal damping of waves, and time dependent decorrelation of magnetic fluctuations.The model is able to explain the observations of particle mean free paths ranging from keV electrons to GeV protons. In particular, it is found that the dynamical effects, leading to a strongly non-resonant pitch angle scattering through 90° at low rigidities, can be described by a single parameter which is estimated from the observed density, temperature and magnetic field strength in the solar wind. The predictive power of the model is then basically limited by the current lack of knowledge of the exact decomposition of the fluctuations. Possibilities to, conversely, use the energetic particles to probe properties of the fluctuations are discussed. Supported by NASA grant NAG5-11603.

SH71A-10 1120h INVITED

Turbulence, magnetic field complexity, and perpendicular transport of energetic particles in the heliosphere

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In a dynamically active magnetoplasma such as the solar wind or lower corona, it is difficult to avoid generation of structure in the direction transverse to a large scale mean magnetic field. Magnetic fluctuations of this type having "high k-perp," and described in various formalisms as "structures," or "quasi-2D turbulence" or "reduced MHD," can be generated by resonant incompressive couplings as well as phase mixing-type couplings. These couplings are all present in the full description of MHD turbulence, and in each case the couplings that produce these fluctuations involve amplification of fine scale gradients that are transverse to the large scale magnetic field. Here we review the nature of the anisotropies that are expected in MHD turbulence, and describe the nature of the transverse complexity that is produced in the magnetic field. This gives rise to random walk or diffusion of magnetic field lines that differs greatly from what is expected in the quasi-linear or "slab" limits. In particular, strongly 2D field lines can admit islands of slowly transporting field lines separated by regions of rapid transport. Finally, implications are discussed for collisionless charged particle transport across the magnetic field. When transverse complexity is absent or weak, parallel diffusion suppresses perpendicular transport to a subdiffusive level. Recent work also shows that perpendicular diffusion is restored when transverse complexity is strong, but at a level lower than what is expected in the Field Line Random Walk limit in which particle simply stream along field lines. This research supported in part by NSF grant ATM-0105254, and by NASA SECTP theory program grant NAG5-8134.

SH71A-11 1140h

Energetic Charged Particle Transport in Two-dimensional MHD Solar Wind Turbulence

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In recent years, accumulative evidence from nearly incompressible MHD theory, simulations, and solar wind observations pointed to the possibility of the strong presence of two-dimensional (2D) MHD turbulence in the solar wind. However, not much has been done to investigate theoretically the consequences of 2D turbulence for energetic particle transport. Within the framework of quasi-linear kinetic theory we will discuss the theoretical implications of 2D MHD turbulence for large-scale energetic charged particle transport in the heliosphere during quiet solar wind conditions. We will deal with two cases: (i) Anisotropic particle distributions where we will focus on pickup ion pitch angle scattering and stochastic acceleration in the quiet slow low-latitude solar wind, and (ii) near-isotropic particle distributions where we will discuss cosmic-ray transport in terms of spatial diffusion parallel and perpendicular to the large-scale magnetic field. The discussion will include topics such as the importance of turbulent motional electric field fluctuations for particle transport in the solar wind, and how a new kind of cosmic-ray transport equation arises when 2D turbulence is important for parallel diffusion.

SH72A MCC: Hall D Sunday 1330h

Particle Populations Upstream of the Earth's Bow Shock: Observations, Theory, and Simulations III Posters *(joint with SM)*

Presiding: **H Kucharek,** University of New Hampshire

SH72A-0545 1330h POSTER

Cluster Observations of ULF waves in the Terrestrial Foreshock

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The terrestrial foreshock exhibits a wide variety of wave activity, in particular Ultra Low Frequency (ULF) waves observed at frequencies well below the ion cyclotron frequency. Of particular interest is the way in which these waves are generated and subsequently interact with the ion populations in the foreshock, since the interaction of reflected ion beams with the inflowing solar wind is mediated by wave-particle processes. We present observations of ULF foreshock waves based on data from the multi-spacecraft Cluster mission, the first space mission to characterise the spatial variation of plasma properties in 3 dimensions simultaneously. Observations of wave power, frequency and polarisation are presented, in combination with an analysis of propagation directions and velocities in the plasma rest frame using multi-spacecraft techniques. Details of the associated plasma properties are also discussed.

SH72A-0546 1330h POSTER

The Possible Source of the Short Quasi-Harmonical Structures in the Earth's Foreshock

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Presence of accelerated ("reflected") particles propagating upstream from the shock front and wave modes generated in wide range of frequencies and amplitudes is the major characteristic feature of the foreshock. High time resolution plasma and magnetic field measurements made onboard INTERBALL-1 satellite during Earth's foreshock crossings allowed us to obtain information about interrelation between these accelerated particles and the waves in a very small time scale (few tens of seconds). Namely, the quasi-harmonical structures with a period of a few seconds and duration up to half of minute observed in the foreshock simultaneously in the magnetic field and solar wind ion flux data were compared with the features of accelerated particles. Dozens of such events were studied. In order to determine possible trigger or cause of these quasi-harmonical structures 3D distribution functions of accelerated ions in the foreshock were reconstructed on 10 sec. intervals. Almost all cases clearly demonstrate a presence of narrow additional beam of particles just before the occurrence of quasi-harmonical structure. This beam commonly propagates at some significant angle to the background magnetic field direction. Basic parameters of these beams were also calculated in each case and then statistically processed to determine their average values for several types of quasi-harmonical foreshock structures.

SH72A-0547 1330h POSTER

Chaotic transverse modes wave activity far upstream of the ion foreshock during intervals of an interplanetary magnetic field near parallel to the solar wind velocity.

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Several events have been identified of an ion foreshock extending up to 250 RE upstream of the Earth. These events occur mostly during periods of slowly drifting radial interplanetary magnetic field (IMF) when the 1-min average values of the strengths of the IMF and the solar wind (SW) speeds are mostly steady (Berdichevsky et al., 1999). Here we present an overview of our current investigation on the nature of the observed transverse modes of oscillation and a preliminary interpretation of their association to the observed diffuse ion population. These observations use high resolution Wind WAVES, MFI, 3DP, and SWE data.

Berdichevsky, D., G. Thejappa, R. Fitzenreiter, R. Lepping, T. Yamamoto, S. Kokubun, R. McEntire, D. Williams, and R.P. Lin, Widely spaced wave-particle observations during GEOTAIL and WIND magnetic conjunctions in the Earth's ion foreshock, J. Geophys. Res., 104, 463-482, 1999

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SH72A-0548 1330h POSTER

An Analytic Gasdynamic Approach to the Modeling of Earth's Bow Shock

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