The Third Solar Wind Conference:

A Summary

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Abstract:

The Third Solar Wind Conference was convened from March 25 to 29, 1974 at the Asilomar Conference Grounds, Pacific Grove, California. The conference consisted of nine sessions dealing with solar abundances; the history and evolution of the solar wind; the structure and dynamics of the solar wind; the structure and dynamics of the solar corona; macroscopic and microscopic properties of the solar wind; cosmic rays as a probe of the solar wind; spatial gradients; stellar winds; and interactions with objects in the solar wind. This paper summarizes the invited and contributed talks presented at the conference.

The third Solar Wind Conference was held at the Asilomar Conference Grounds, Pacific Grove, California, from March 25 to 29, 1974. It was organized jointly under the auspices of the University of California and the University of Arizona by C.P. Sonett, P.J. Coleman, Jr. and C.T. Russell. The purpose of the conference was to review the knowledge of the solar wind gained since the last solar wind conference* and pursue in depth some of those solar wind related topics which were not adequately treated in 1971. The conference was attended by over 120 scientists from a broad array of backgrounds including Astronomy, Astrophysics, Lunar Physics, Geophysics and Plasma Physics. Over 25% of the participants were from countries other than the United States.

The conference consisted of nine sessions covering solar abundances; the history and evolution of the solar wind; the solar corona; macroscopic and microscopic properties of the solar wind; cosmic rays as a probe of the solar wind; spatial gradients; stellar winds and solar wind interactions. The sessions consisted primarily of invited talks followed by discussion, with shorter contributed talks scheduled at the end of each session. One session, that on cosmic rays as a probe of the solar wind, included a panel discussion on the cosmic ray gradient or lack thereof.

*The proceedings of this conference have been published as Solar Wind NASA SP-308, edited by C.P. Sonett, P.J. Coleman, Jr. and J.M. Wilcox, 1972.

The proceedings of the conference are presently being edited for publication in mid-1974 as a report of the Institute of Geophysics and Planetary Physics of the University of California, Los Angeles. The proceedings will contain most of the invited talks and contributed talks for which authors have prepared manuscripts. Some of the longer reviews have been submitted for publication in the Reviews of Geophysics and Planetary Physics and will not appear as such in the present volume of the Proceedings.

In this paper I shall briefly summarize the contents of each session. To prepare this summary I have used the manuscripts submitted to the proceedings supplemented by my personal notes taken at the conference. No attempt has been made to completely abstract the contents of the papers presented. Those desiring more detailed information are referred to the original authors for preprints of their papers and to the proceedings of the conference which are now being prepared.

1. Solar Abundances

W.A. Fowler opened the conference with a discussion of solar abundances from the viewpoint of an astrophysicist. He described the steps in element building since the big bang: Hydrogen burning, Helium burning, Carbon-Oxygen burning and neutron capture. While the neutrinos released in Hydrogen burning are not detectable with present techniques, the neutrinos released in Helium burning are. The latest data from Cl^{37} capture experiments show that the present day neutrino flux is less than 20% of that expected. There have been several solutions proposed for this neutrino "defficiency". Among those are that the heavy elements are concentrated at the solar surface, that the gravitational constant is increasing, or that a transient mixing event has just occurred, and the neutrino flux is still recovering. If this is so, then the solar luminosity is probably presently diminished below its long term average value. He concluded by stating that carbon-oxygen burning is presently the big mystery.

J. Hirshberg followed with a review of coronal and solar wind abundances, concentrating on helium for which most of the observations are made in the solar wind and iron for which most of the observations come from the corona. In the lower solar atmosphere mixing keeps the composition uniform, while high in the atmosphere there are gradients. Iron can be observed in the photosphere, the chromosphere and the corona. The few spectra obtained in the solar wind when the temperature was low enough to resolve the iron lines reveal a composition about the same as in the corona. At present it is impossible to determine the solar abundance of helium, and it is customary to use the cosmic abundance of 9% as an approximation to the solar value. In the solar wind there are large fluctuations in the helium abundance which varies from 1% to 25% by number. Fluctuations have been observed on the time scale of minutes up to and including solar cycle variations. The average abundance of helium in the solar wind is roughly 4% by number.

D. Hovestadt reviewed the nuclear compostion of solar cosmic rays. The only cosmic ray particles whose origin can be uniquely ascribed to the sun are those emitted by flares and active regions. The proton to alpha ratio varies drastically from flare to flare at low energies but less so at high energies. At high energies the p/α ratio is high, i.e., 60-100, whereas values from 11 (expected solar abundance) to 22 (solar wind ratio) might be expected. Above 10 Mev/nucleion, Si and Mg are over-abundant by about 400% while Li, Be, B and F are rare. Below 10 Mev/nucleon, heavy elements are enhanced relative to lighter elements, to a degree increasing with increasing nuclear charge and decreasing energy. Measurements of the ionic charge are difficult and sparse. What evidence is available suggests that at low energies the solar cosmic rays with high Z are highly ionized but not fully, whereas at high energies they may be fully stripped.

Hovestadt noted that nuclear reactions seem to play a less important role in solar flare particles than in galactic cosmic rays. However, the γ-ray line of deuterium has been seen in an intense solar flare, and deuterium, tritium and He^3 have been observed in solar flare particle events. Since tritium has a half-life of 12.3 years and no deuterium has been found in the solar wind, it appears these were created in the flare event.

2. History and Evolution of the Solar Wind

The second session was opened by C.P. Sonett who reviewed the evidence for a primordial solar wind. Electrical heating provided by a strong T Tauri solar wind flow appears to be the only plausible heat source for the parent body progenitors of meteorites. Sonett showed that there are difficulties with fossil nuclide heating and that accretional heating would only be significant for bodies with planetary radii greater than 1000 km. Two electric modes are available for this process, the transverse magnetic in which currents flow from the solar wind through the surface of the planet and transverse electric in which currents are induced within the planet by a time varying interplanetary magnetic field. Such a model could account for the melting of the lunar surface material.

P.B. Price followed with a discussion of the paleontology of cosmic rays as revealed by lunar and meteoritic data. Samples from lunar surface show contancy of the energetic proton and alpha particle output of the sun for the last 10^6 years and iron tracks in meteorites reveal constancy over a period of 10^7 years. Core samples store a historical record over about 10^9 years, and show no changes greater than a factor of 2 in ratio of iron to trans-iron tracks. Finally, the low energy iron abundance relative to helium was greater than that at high energies in the past as it is at present.

P. Eberhardt reviewed the information gained about the recent and past solar wind from the analysis of lunar samples. These analyses show that the D/H ratio in the solar wind is smaller than 3×10^{-6}. The isotopic composition of C, Ar (except A^{40}) and Kr in the solar wind are found to agree with terrestrial compositions within approximately $\pm 3\%$, while terrestrial Ne is enriched in the heavier isotopes. Terrestrial and solar wind Xe have very different isotopic compositions. Using the lunar samples to delve into the past, provides some evidence for a secular decrease in the He^4/He^3 ratio. The average solar wind flux in the past was probably higher than at present, but, while the average solar wind energy has varied, no long time trend in the average energy is apparent.

Next S. Epstein discussed his recent measurements of the hydrogen/deuterium ratio deposited in lunar samples by the solar wind. To date no solar wind deuterium has been detected. M. Maurette followed with a discussion of the thermal history of the solar wind deduced from lunar soil samples. In a preliminary study of 8 different strata from the Apollo 15 core tube, no regular increase or decrease in energy of the solar wind was observed to a depth of 3 meters suggesting no secular variation in the solar wind energy over $\sim 10^9$ years.

In the final presentation of this session measurements of heavy solar wind particles during the Apollo 17 mission with the Lunar Surface Cosmic Ray Experiment were reported by

E. Zinner. Heavy ions of solar wind energy produce shallow pits in etched mica. While neither the average width nor size distribution exhibit a strong mass dependence, there is a marked dependence of the depth of the pits; pits produced by Fe ions are deeper than those produced by O ions. The derived Fe-group flux from this experiment was $(3.9\pm1.0)\times10^{4}$ $cm^{-2}sec^{-1}$ compared to a hydrogen flux measured on Imp 7 at this time of 8.9×10^{8} cm^{-2}-sec^{-1}, giving an Fe/H ratio of 4×10^{-5}. At present only a crude estimate of $\sim2.7\times10^{-3}$ can be made for the CNO/H ratio.

3. Structure and Dynamics of the Corona

R.G. Stone opened the session on the structure and dynamics of the solar corona with a review of solar radio bursts. Present evidence favors the generation of type III bursts at the second harmonic of the plasma frequency by streams of energetic electrons emitted along open field lines, while type I bursts, which occur during storms of continuum radiation at meter wavelengths, appear to be generated on closed field lines. Type II bursts, characterized by their slow drift from high to lower frequencies, are generated by plasma radiation produced by shock waves in the corona, and are usually associated with the explosive flash phase of large flares. Synchrotron radiation generated by high energy electrons trapped in the magnetic field can account for many of the observed properties of properties of moving type IV bursts. He concluded his talk with a computer generated movie of burst locations deduced from Imp-6 radio observations.

J. Gosling followed with a presentation of the results from the white light coronograph carried on board the Skylab mission. The most exciting discovery of this experiment was the existence of coronal transient events which take the form of loops expanding outward with velocities of from 200 to greater than 1000 km-sec^{-1}, while retaining connection to the sun for at least several days. Effects in stable streamers are seen ahead of these ejections indicating the presence of pressure waves. While most of these events are not associated with radio bursts, five were associated with type II bursts and four with type IV. Two were flare associated. There was no detectable unusual coronal activity prior to the events.

E. Roelof reviewed coronal structure as revealed in solar X-ray, EUV photographs, coronal green line data, extrapolated magnetic structure and solar cosmic ray data. Sources of recurrent geomagnetic disturbances (M-regions) appear to be associated with open magnetic structures. These open structures apparently are the source of high velocity solar wind streams. The expansion of the solar wind from these regions leads to cooling and reduced density and thus the formation of the hole.

Dr. A.S. Kreiger discussed X-ray observations of coronal holes and their relation to high velocity solar wind streams. The X-ray observations were obtained with the American Science and Engineering X-ray Telescope Experiment, which was part of the Apollo Telescope Mount (ATM) array of solar instruments carried by Skylab. Since the lower layers of the solar atmosphere are much cooler and do not emit X-rays, this experiment permits the corona to be observed in projection against the solar disk. X-ray photographs reveal the corona to contain small bright emitting features called X-ray Bright Points, large scale active regions, and large dark features called "Coronal Holes". Since solar X-ray observations from rockets have suggested the association of coronal holes and fast solar wind streams, coronal X-ray photographs for 4 solar rotations were compared with the solar wind observations at 1 AU made with the MIT plasma experiment on Imp-H. The results of this comparison was that most, but not all, high speed solar wind streams are associated with coronal holes and most but not all coronal holes are accompanied by high speed streams. Thus, while the coronal holes appear to be a key element in the generation of fast solar wind streams, the exact nature of this role is still to be elucidated.

R. Noyes followed with a discussion of the extreme ultraviolet solar observations made on the Skylab mission. These data suggest that the mechanical energy into the holes is the same inside and outside the holes. The hole is strictly a coronal phenomenon.

The spectral characteristics of flares were discussed by A. Title who showed a movie of the temporal development of a series of Hα spectra across a solar flare. Work is presently in progress, reducing the data from several dozen flares, in order to specify the parameters of the typical event, or class of events.

Finally, S.T. Wu discussed possible generation mechanisms for coronal transients. He showed that both thermal pulses and mass pulses low in the corona (30,000 km above the photosphere) would lead to outward mass flow with the observed velocities if the amplitude of the pulse were sufficiently large ($\Delta T/T_0$ and ρ/ρ_0 $\sim$1.5 to 5).

4. Macroscopic Properties of the Solar Wind

The session on macroscopic properties of the solar wind was introduced by A.J. Hundhausen who discussed the structure and dynamics of the solar wind. The principal characteristic of the structure of the solar wind is the fast-slow stream structure. The unsolved problem with this structure is the nature of the boundary conditions where fast streams begin in the corona. Coronal transients cannot be responsible for recurrent structure, but coronal holes may have some bearing.

G.L. Siscoe reviewed discontinuities in the solar wind. Recent work indicates roughly equal numbers of rotational and tangential discontinuities. All possible types of shocks have been observed: reverse and forward, fast and slow. However, a reverse rotational discontinuity has not been observed. Remaining problems include investigating the origin of discontinuities; their three dimensional structure; the plasma physics of the interior of discontinuities, and their heliographic latitude dependence. J.W. Chao presented results suggesting that shocks may dissipate and reform in the solar wind. J. Belcher discussed the nature and location of rotational waves in the solar wind.

R.P. Lin reviewed recent observations of suprathermal particles in the interplanetary medium (1 kev $\leq$ E $\leq$ 1 Mev). The observed particle fluxes may be classified according to their behavior into roughly 4 types: flare events; interplanetary shock spikes; active region associated fluxes; and "quiet" fluxes. The total energy density of these suprathermal particles, particularly protons, may at times dominate the solar wind plasma and magnetic field but in no case to date was the total energy density above 40 kev more than 10% of the bulk motional energy of the quiet solar wind. Lin suggested that the interplanetary shock itself may be generated by suprathermal particles accelerated at the sun. Finally, he discussed the association between suprathermal particles and Type III emissions. Velocity dispersion causes a peaked distribution needed to generate coherent Cerenkov radiation. In situ observations of waves and particles at 1AU favors the generation of the waves at the second harmonic of the plasma frequency.

Next W.C. Feldman reviewed interpenetrating solar wind streams. When a satellite is in a region of interpenetration, double ion velocity peaks are observed. Such features are seen at boundaries between fast and slow streams, where the velocity is decreasing and density increasing. This process is important for it may be the source of heating postulated to be needed near 1AU.

R.S. Steinolfson presented a numerical simulation of interplanetary shock ensembles. Two separate numerical codes were used in the study: one solving the ordinary fluid dynamic equations and one solving the magnetohydrodynamic equations. These codes were used to model a shock pair observed by the HEOS 1 satellite. It is possible to reproduce the data if the magnetic field and azimuthal velocity is included and the fact that the shocks do not travel radially is accounted for. The models indicate the shocks were formed at about 0.84 AU in accord with previous estimates.

V. Formisano discussed HEOS 1 and OGO-5 observations of neutral sheets in the solar wind. The neutral sheets studied had thicknesses of the order of 5000 km which is close to the predicted collision free tearing length. From a comparison of the signatures of the neutral sheet crossings at the two closely spaced satellites, the neutral sheets are either rapidly evolving or have very tortuous spatial structures.

G. Moreno discussed the long term variations in the solar wind. In this study, he first intercalibrated IMP 1, Vela 2, 3, 4, Explorers 33, 34, 35 and HEOS 1 using overlapping data. The resulting coherent set of data revealed a 40% reduction of the proton density between solar minimum and solar maximum, while the velocity is relatively constant. The heliographic latitude dependence of the solar wind density found by Hundhausen and coworkers disappears at solar maximum, producing the observed decrease at solar maximum. A. Barnes followed this talk with a discussion of the properties and role of coronal turbulence. Next, the effect of magnetic force on solar wind expansion was covered by Tyan Yeh, who examined a family of critical solutions for an isothermal magnetized solar wind with azimuthal motion. This study indicates that the magnetic force enhances solar wind expansion. Finally, Marcia Neugebauer reported on a study of the difference between the alpha-particle and proton flow velocities using OGO-5 data in late 1968. Alpha-particle velocities are on the average a few km/sec greater than proton velocities, but this velocity difference disappears when the variance of the flux is high.

5. Cosmic Rays as a Probe of the Solar Wind

The session on deducing solar wind properties from cosmic ray propagation began with a review of H. Volk of the theory of cosmic ray propagation. He described the main ideas of propagation theory, including the phenomenological diffusion picture, the random walk of field lines and the mechanisms involved in transient phenomena such as Forbush decreases. Next he discussed the macroscopic theory of pitch angle scattering and parallel diffusion and compared a theory, based on the spatial dependence of Alfven waves with Pioneer 10 measurements.

This review was followed by two brief comments, by T. Kaiser on computer simulation of cosmic ray diffusion with emphasis on diffusion near 90° pitch angles, and by M. Goldstein on cosmic ray diffusion theory.

Then followed the panel on the cosmic ray gradient, which began with a discussion of the Pioneer 10 data by the three investigator groups. J.A. Simpson discussed the measurements of the University of Chicago Pioneer 10 cosmic ray experiment. To maximize the amount of useful data, the measurements have been reanalyzed by solar rotation and compared with Imp 5 and 7 measurements at 1AU. They find for E>67 MeV protons the gradient was 4-5% AU^{-1} from 1-4.5 AU. He also noted that the August 1972 event may have had drastic effects on the heliocentric modulation. Results for the differential gradient measurements are similar to those for the integral gradient. For 0.54-1.85 MeV protons from 1-3.8 AU the gradient is 8 $\pm$ 6% AU^{-1}; for 29.5-67 MeV protons from 1-4.8 AU the gradient is 3 $\pm$ 3% AU^{-1}. Similar results hold for helium in the same range of energy per nucleon. For 6-30 MeV electrons from 1-3.6 AU only an upper limit of <50% AU^{-1} could be determined.

F.B. McDonald discussed the measurements of the GSFC cosmic ray experiment. These were entirely consistent with those of the Chicago group. The gradient in >56 MeV protons was $\sim$2%/AU for heliocentric distances less than 2 AU and $\sim$6% from 2 to 4 AU but <6% >4 AU. The gradient is dynamic and changing with both time and solar conditions. At 1 MeV solar protons dominate all the way to Jupiter. MeV electrons were observed streaming back from Jupiter.

Michelle F. Thomsen represented the Iowa cosmic ray experiment which consists of seven Geiger-Mueller tubes with various amounts of shielding and collimation. After correcting the data for temperature changes and the decay products of the radio-isotope power supply, the gradient for galactic cosmic rays with E>80 MeV over the range 1.0 to 4.1 AU was found to be <0.23% AU^{-1} to within an uncertainty of less than 1% AU^{-1}.

Next L. Fisk suggested a possible source of the low energy cosmic rays, in which interstellar neutral particles charge exchange or are photo-ionized in the solar wind and then by some unspecified mechanism are accelerated to cosmic ray energies. E. Barouch then discussed an alternative to the present picture of cosmic ray diffusion. Instead of many scattering centers causing small angle deflections, he showed that a model with a few large angle deflectors would explain many of the otherwise unexplained features of cosmic ray propagation, in particular, Forbush decreases and the low radial gradient observed by Pioneer 10. Finally, J.R. Jokipii discussed the effect of the pressure of the cosmic ray gas on the heliopause. He noted that this pressure would increase the magnetosonic velocity for perpendicular propagation at large radial distances so the solar wind could become subsonic without a shock.

6. Stellar Winds

P.H. Roberts opened this session with a review of the evidence for stellar winds and of the theory of steady, spherically-symmetric coronal expansion. The existence of winds in a wide class of stars can be inferred from a number of threads which together weave a strong chain. First, stars of spectral type F5 and later have active chromospheres, implying that they have hot coronas and potent winds. Second, stars of these types have Calcium H and K line anomalies. Third, there is a relationship between strength of H and K lines and angular velocity, and fourth on the sun, the intensity of Calcium lines is correlated to surface field strength. The last three threads suggest that the angular velocity, and surface field of stars decreases with time. Stellar wind theory predicts the former inference because when a star is appreciably magnetic, it can shed angular momentum, at least for stars later than F5, and the latter inference is not inconsistent with present thoughts on dynamo theory. In the second half of his talk Roberts reviewed both one and two fluid spherically symmetric stellar wind theory. While many solutions have been explored, this still remains a very active area of research with much work left to be done.

G.L. Siscoe presented a qualitative treatment of stellar winds in binary systems, in the simplest case where the stars and winds are identical. He described the flow field, the geometry of the critical surface and the role of shocks between the two stars. Stellar magnetic fields would merge, at the boundary between the two stellar winds, when these fields were oppositely directed, thus, providing an acceleration mechanism for cosmic rays. These fields could also account for the otherwise unexplained close separation of some binaries and for the dependence of eccentricity on the separation distance.

7. Spatial Gradients

E.J. Smith began the session on spatial gradients with a summary of the Pioneer 10 magnetic field observations. The magnetic field appears to decrease as expected from the Parker model and continues to lie along an Archimedean spiral. The fluctuations fall off roughly as the inverse fourth power of the heliocentric distance. In addition, he discussed a two satellite study of the motion of discontinuities in the solar wind which indicated the presence of a latitudinal gradient of 11 km-sec^{-1} per degree of heliographic latitude.

J. Wolfe complemented Smith's review by reporting on the solar wind observations from Pioneer 10. The stream-stream structure so obvious at 1 AU, is erased to a large extent by 5 AU. As expected, there is no detectable radial velocity gradient between 1 and 5 AU, and the mass flux varies inversely as the square of the heliocentric distance R. The proton temperature decreases roughly as $R^{-4/3}$, but has large deviations from this.

R.L. Rosenberg surveyed the dependence of the solar wind parameters on heliographic latitude. While the annual range of heliographic latitude of the earth is small ($\pm 7\ 1/4^{o}$), spacecraft in the ecliptic have detected significant variations in the dominant polarity of the interplanetary magnetic field (∿2% deg^{-1}), the polar component of the interplanetary field (∿0.1 -deg^{-1}), the abundance of helium, the solar wind density and bulk velocity (∿10 $km\text{-}sec^{-1}\text{-}deg^{-1}$). The existence of such large latitudinal gradients in the solar wind argues strongly for an out-of-the-ecliptic mission.

S. Suess reviewed the various attempts to model the three dimensional study of the solar wind. This problem can be broken into basically two parts, the corona in which the magnetic field controls the flow and the solar wind in which the magnetic field is fairly passive. One of the predictions of these models is meridional flow, and latitudinal variations in the mass and magnetic flux. This latter effect should result in a 25% mass or radial magnetic flux depletion at 5 AU over that at 1 AU extrapolated using the r^{-2} scaling law. This effect should also alter the expected Lyman α backscatter from interstellar neutral hydrogen, moving the maximum backscatter direction from the solar apex, the direction of motion of the sun relative to nearby stars, towards the solar equator. This is observed. These models and their supporting observations show clearly the limitations of deriving all our knowledge of the solar wind from a limited band of latitudes near the solar equator.

C.R. Winge reported on his extension of the Weber-Davis solar wind model to include the effects of latitude. This model assumes steady state, a polytropic law, infinite electrical conductivity, parallel field and flow in the corotating system, and rotational symmetry. Variations of the boundary conditions with latitude have been included in the model and these do increase the latitudinal gradients at 1 AU. However, even a pole to pole variation of coronal temperature of 50% will only produce a latitudinal gradient of 5 km/sec/deg, half that observed.

Jacques Blamont discussed the variation of the solar wind flux with heliographic latitude as deduced from its interaction with interplanetary hydrogen. The two sources of interplanetary hydrogen considered were comets and interstellar hydrogen, and the hydrogen was observed by its Lyman α emission. By modelling the observed isophotes of the Lyman α emission around comet Bennett, it was possible to deduce that Bennett produced about 7×10^{28} atoms-ster^{-1}-sec^{-1} at a velocity of about 8 km/sec. During the week of comet Bennett observations of the solar proton flux changed from 2×10^8 protons -cm^{-2}-sec^{-1} at a heliographic latitude of about 30^o to 6×10^8 protons -cm^{-2}-sec^{-1} at about 50^o latitude. Similarly it is possible to match the interplanetary glow measurements with flux increases of a factor of 2 above 45^o. Since the increase of velocity with latitude observed by scintillation measurements and comet tails is not this large Blamont concluded that at least part of this flux increase must be due to an increase in number density.

D. Intriligator discussed the spectral shape of fluctuations in solar wind parameters. Well below the proton gyrofrequencies the spectra have approximately power law slopes. However, M. Neugebauer countered with direct observations at frequencies overlapping those of the scintillation measurements, which revealed a small but statistically significant power enhancement at a frequency corresponding to the convection of a proton gyroradius past the observer, as expected from the interpretation of the scintillation measurements by Hewish. L. Svalgaard reported a pattern of converging and diverging fields at sector boundaries, so that it appears that, in one polarity, the field direction lies inside the Parker spiral, and in the other, it lies outside. Finally, R.H. Cohen suggested that the resonant mode decay, leading to selective degradation of portions of the spectrum of Alfven waves may be responsible for Smith's observation that 24-hour variances of the interplanetary magnetic field decrease with heliocentric distance faster than 1-hour variances.

8. Microscopic Properties

J.V. Hollweg opened the session on microscopic properties with a survey of waves and instabilities in the solar wind. He began with a brief review of the properties of hydromagnetic waves and their roles in heating and accelerating the solar wind, in creating thermal anisotropies, in heating and accelerating alpha-particles, in the behavior of interstellar neutral particles ionized in the solar wind, and finally in the "fluid-like behavior" of the solar wind. He concluded his talk with a summary of the observational evidence for the presence and action of non-hydromagnetic waves.

W.C. Feldman reviewed heat conduction in the solar wind. The heat flux caused by coronal electrons is the dominant energy source which drives the solar wind. Theoretical treatments lead to the expectation of the development of instabilities which limit the plasma thermal conductivity. In support of this, the electron dimensionless third moment is observed to be independent of temperature and the heat flux appears to be nearly the same both before and after an abrupt connection to the earth's bow shock. Furthermore, solar wind electron velocity distributions at 1 AU appear to be marginally stable to the growth of electromagnetic ion cyclotron and/or magnetosonic waves.

The simulation of colliding solar wind streams using multifluid computer codes was reported by K. Papadopoulos. The model used consists of a set of multifluid equations to be integrated numerically, and self-consistently include the effects of wave-particle interactions through anomalous transport coefficients. To describe the velocity distribution function the dominant thermalization mechanism is identified from the multifluid calculation, simulated in a particle code, and the ion velocity distribution after thermalization is calculated. Distribution functions similar to that found by Feldman in interpentrating streams are obtained in these codes.

B.J. Rickett reviewed interplanetary scintillation measurements, beginning with an explanation of the technique. These measurements reveal the solar wind to be expanding radially within $\pm$ 1/2^{o}, with an average speed that varies with solar latitude from 400 km-sec^{-1} at the equator to 550 km-sec^{-1} at $\pm 70^{o}$ with little velocity dependence on distance. The number density spectrum is represented by a power law dependence on wave number. However, sometimes there is evidence of micro-turbulence.

R.H. Cohen discussed the nonlinear evolution of hydromagnetic waves in the solar wind. In nonlinear hydromagnetic theory, an arbitrary fluctuation propagating along the mean field direction steepens into shocks and evolves subsequently into a purely Alfvenic fluctuation of lower mean energy density. For typical solar wind conditions, the time scale for this process is of the order of the time for waves to travel 1 AU. Thus, the energy dissipated in this process may account for an appreciable fraction of the observed ion thermal energy density at 1 AU.

Next, M.L. Goldstein presented a treatment of the propagation of nonplanar, large amplitude Alfven waves in an infinite homogeneous plasma with no background flow. The results of his analysis are: that the group velocity is directed along the field at the usual Alfven velocity, that the field magnitude remains constant; and that the plasma velocity and field perturbations are proportional. However, the direction of propagation of these waves, which are nonplanar, cannot in general be determined from the direction of minimum variance.

M. Dobrowolnly discussed a model for the generation of Alfven waves in the solar wind by a Kelvin-Helmholtz instability due to spatial variations in the solar wind velocity. This analysis shows the solar wind should be unstable at the leading edge of high velocity streams. Then, H.B. Garrett presented an analysis the correlation of the variance of the interplanetary magnetic field with various solar wind parameters. This study showed that field fluctuations were greatest in the rising portion of high velocity streams.

Finally, N. Lotova, unable to attend personally, submitted a manuscript discussing a new method of analyzing interplanetary scintillations, based on the shape of the temporal cross-correlation function.

9. Solar Wind Interactions

The last session began with a review of the interaction of the solar wind with comets by L. Biermann. The two principal aspects of the interaction are momentum transfer which causes the observed accelerations in the gas or plasma tail, and the ionization of the cometary molecules by charge exchange. After discussing the theoretical and observational aspect of cometary interactions Biermann concluded with a summary of the early history of solar wind investigations.

Next, J.C. Brandt and S.P. Maran gave a progress report on the study of Comet Kohoutek concentrating on possible comet-solar wind interactions. Extensive in situ solar wind measurements were made during the comets passage by a variety of spacecraft, and with the Pioneer 8 dual frequency radio occultation experiment. Lyman α measurements were made from Skylab, an NRL Aerobee rocket, and from Mariner 10, and of course, extensive ground-based visual photography was carried out.

M. Wallis, though unable to attend, submitted a review covering the interaction with Venus. Three models have been proposed: a pseudo-magnetosphere model, in which induced magnetic fields balance the solar wind pressure; a fluid model, in which the ionosphere holds off the solar wind; and an ionizing flow model, in which solar wind energy and ion flux are absorbed in the atmosphere. Wallis concludes that the present evidence favors the last of the three models. Next, recent Mariner 10 observations of Venus were reported by Y.C. Whang and A.J. Lazarus. The data definitely show the existence of a bow shock around Venus. Whang suggested there was evidence in the data for either a weak planetary field or an induced magnetosphere.

P. Cloutier reviewed the interaction with Mars. He concluded that the Mars 2, 3 magnetometer measurements reveal a magnetic field so weak that it may not dominate the interaction. Thus, the solar wind interaction with Mars may be very similar to that with Venus.

The interaction with the moon was covered by G. Schubert. This interaction is weak; no bow shock is seen. The principal effect of the moon is to absorb the incident solar plasma, creating a plasma void on the antisolar side. When certain selenographic regions appear at the terminator, compressional disturbances are observed above the lunar limbs, apparently due to the deflection of the solar wind by local lunar magnetic fields.

The structure of the terrestrial bow shock was reviewed by E.W. Greenstadt, who showed that bow shock structure could now be correlated with Mach number, M, the ratio of plasma to magnetic pressure, β, and the angle between the upstream magnetic field direction and the shock normal θ_{nB}. Shocks are classified as quasi-perpendicular if θ_{nB} is roughly between 45^{o} and 90^{o}. In these shocks electromagnetic noise increases with β independent of M, while plasma wave noise and turbulence in the shock transition layer increase with M, independent of β. For quasi-parallel shocks where $\theta_{nB}<45^{o}$ the shock layer broadens, pulsates, and shows limited levels of plasma wave noise and marked precursor activity. The parallel shock $\theta_{nB}\approx 0^{o}$ produces a hybrid average ion spectrum characteristic of neither the solar wind nor magnetosheath.

J.K. Chao followed this talk with a discussion of the effect of heat flux on the variation of specific heat across a detached bow shock.

F.C. Michel bridged the gap between the earth and Jupiter with a comparison of the terrestrial and Jovian magnetospheres. Perhaps the most important difference of all is caused by the rapid rotation of Jupiter which creates a corotational electric field in the magnetosphere that should dominate other known sources of electric fields. Thus, the Jovian magnetosphere should be more disc-shaped than spherical.

J.A. Simpson began the reports on the Pioneer 10 Jovian observations with a discussion of upstream electron bursts seen at least a month before encounter, and tentatively identified as electrons escaping from the Jovian magnetosphere and/or bow shock. J. Mihalov discussed the measurements of the Jovian bow shock as seen with the Ames solar wind instrument. The extrapolated nose position of the shock ranged from 60 to 130 R_J. Proton temperatures were observed to rise 2 orders of magnitude across some of the shock crossings.

E.J. Smith discussed the magnetic field data. Both the magnetopause and shock appeared to be more variable in location than their terrestrial counterparts. The shocks appeared to be laminar, or quasi-laminar, rather than turbulent, and some upstream waves were observed similar to those upstream from the earth. The outer magnetosphere appeared to be stretched out by centrifugal force, with a region near the equator quite similar to the earth's plasma sheet.

Finally, M. Dryer commented on the comparison of the Jovian bow shock with theory, showing the excellent agreement between the observations of Wolfe and Smith and the predictions of the hypersonic analog.

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