Commission 34
Interstellar Matter (Matiere Interstellaire)

President: John S.Mathis (USA)
Vice-President: Harm Habing (Neth)
Scientific Organizing Committee: K. S. de Boer (Ger), M. Dopita (Australia), A. Fabian (UK), David Flower (UK), R. Genzel (Ger), N. Kaifu (Japan), J. Lequeux (France), B. Shustov (USSR), C. Lada (USA), L. Rodríguez (Mex), D. York (USA). Chairs of Working Groups: Y. Terzian (Planetary Nebulae); Helene R. Dickel (Nomenclature); A. Dalgarno (Astrochemistry).

During the XXI General Assembly, the Commission was the prime sponsor of Joint Discussion I ("An Overview of the Interstellar Medium"), Joint Commission Meeting V (Late Evolution of Low-Mass Stars), and was a co-sponsor of JCM III (Atomic and Molecular Data for Space Astronomy). It also held a joint commission meeting with Comm. 35 (Stellar Structure), and held several commission meetings on specialized topics regarding the interstellar medium (ISM). Sessions at the GA included only invited reviews, but poster papers describing new results were also presented. This summary provides an overview of the review talks and of the business meeting of the commission by the president; any errors are probably his and not the speakers'.

The program began with the Joint Discussion I (with Comm 28, 40, 44, and 48) of "An Overview of the Interstellar Medium", to be published in *Highlights of Astronomy*.

D. Lambert opened with a review of the chemical and physical properties of clouds. Two general approaches to understanding the conditions within clouds have been taken: (a) Correlations among observable characteristics (molecular column densities, line widths, etc.) from many lines of sight in several clouds, and (b) detailed modelling of individual clouds. Many observations (fine-structure lines of [C I], [C II], and [O I]; CO and H_2 arising from various levels; many molecular lines, etc.) must be fitted to produce a self-consistent model with gas-phase chemistry (excepting the formation of H_2 on grain surfaces). However, there are also many adjustable parameters: the temperatures and densities within the clouds, many cross sections, the properties of grains, and the rate of ionization and heating by cosmic rays. Generally the agreement between models and observations is quite good, but CH^+ and NH are observed stronger than predicted by 2 - 3 orders of magnitude. Shocks may play vital roles in many cases.

H. Lizst discussed the intercloud medium, and the organization (spatial characteristics) of various components. He referred to the conventional dense regions as "clowds" to emphasize that there is a continuous variation of physical conditions, but the convenience of referring to typical dense regions by a name is irresistible. The "interclowd" medium has at least three components itself: the neutral H, that may be cool ($\approx$ 100 K) or warm ($\approx$ 8000 K), the diffuse, warm, ionized component ($\approx$ 8000 K), and hot ($\approx 10^6$ K). The general properties of the components were mentioned. Detailed studies show that there must be a *gradual* change in the neutral gas from low-T, high-density conditions near the centers of clouds to low-T, high n material in the outer regions.

J.-L. Puget reviewed interstellar dust. Only one parameter, commonly taken to be R [$\equiv$ A(V)/E(B-V)], characterizes the wavelength variation of the extinction cross section among various lines of sight over the range 1 μm - 0.1 μm. The depletion of refractory elements onto dust grains also varies among sight lines. Another very important aspect of interstellar dust is the emission in the NIR bands that dominate the *IRAS* 12 μm and 25 μm filters for the ISM and contribute heavily to the 60 μm window. A very promising explanation: a continuum of grain sizes extending from large molecules (2.5 Å - 12 Å) through "Very Small Grains" (size ≈ 12 Å - 50 Å) to the conventional grains, ranging up to about 250 Å.

R. Wielebinski reviewed the information that low-frequency radio observations taken at the 100-meter telescope at Effelsberg can provide regarding the magnetic field in spirals, with some comments about our own galaxy. The direction of the field can be partially inferred from the polarization and its frequency dependence, as well as the Faraday rotation of supernova remnants. The field geometry seems complex and varies among objects.

The high-energy component of the ISM was discussed by C. Cesarsky. The smooth power-law spectrum for cosmic-ray (CR) proton energies in the 10 - 10^6 GeV range, $n \propto E^{-2.73 \pm 0.09}$, suggests a Fermi-type acceleration mechanism. The isotropy indicates confinement and diffusion within the Galaxy for the lower-energies, and the large abundances of the very light elements (Li, Be, and B) produced through spallation provide estimates of the amount of material through which the CRs have passed. The higher-energy CRs escape from the Galaxy, and the injection spectrum is about $E^{-2.1}$. Shocks from supernovae should provide approximately that type of injection spectrum, at least up to energies of ≈ 10^{14} eV. However, it is difficult to see how the maximum energies of CRs (>10^{20} eV) can be produced by supernova shocks; perhaps they arise from shocks produced by collections of supernovae. The amount of secondary CRs (produced from the original CRs by collisions with the interstellar gas) is inconsistent with the low supernova rate in the ISM. The decrease of the ratio of primary/secondary CRs with energy shows that there is more than simple Fermi acceleration involved. The ratio of positrons to electrons, and its energy dependence, is also a mystery.

The center of the Galaxy was reviewed by F. Yusef-Zadeh, starting with the overall structure for the inner 500 pc and narrowing to the inner cluster presumably at the center. The stellar velocity dispersion decreases with distance from the center, and the center of the stellar cluster may contain a compact object of about few x 10^6 $M_\odot$. If there is no black hole, one needs $n(\text{stars}) \propto r^{-2.8}$ for the kinematics, inconsistent with the light if (M/L) = constant for the stars. A black hole at the center will show an Einstein ring from the background at about 30 milliarcsec.

T. van der Hulst discussed the morphology of the ISM in various galaxies; M51, M31 have CO and H I coincident, and H I in both cold and warm clouds. M33 has holes in H I from a few x 10 pc in size up to kpc with the ages of a few x 10^6 yr. Many other types of galaxies were mentioned, especially NGC 891 (an edge-on spiral, in which the ISM at large z can be studied) and M 101, a grand design Sc with empty regions along its arms. The pressure required to produce the holes requires hundreds of supernovae, but this might be plausible. There might be gas infalling into the holes.

The theory of the ISM was summarized by J. M. Shull. What supports the ISM at large z from the Galactic plane: is pressure supplied by thermal motions, kinetic energy of clouds, magnetic pressure, or CRs? Possibly all of the above! Gas pressure alone is not enough to support the total weight of all of the known gas. A magnetic field of ≈ 5 μG would help greatly, and possibly heating by MHD waves increases the gas pressure at large z. Another mystery is the source of ionization of the Hα observed by Reynolds (see below). Possibly the H^+ is produced in a layer of turbulent mixing between hot and cold regions in the ISM, a process that should produce about the right spectrum. Shull also discussed galaxy mergers as suggested by N-body calculations, and the recent observations of the "Lyman-α forest" lines in the spectrum of 3C273 by the High Resolution Spectrograph of the Hubble Space Telescope.

The commission also held a joint meeting with Commission 35 (Stellar Structure). P. Myers reviewed molecular cloud cores and star formation, explaining the variation in physical conditions in clouds from isolated diffuse clouds through giant molecular clouds, with special attention to their cores. He reviewed the determination of cloud conditions (T, mean density <n>, and optical depth) via the NH_3 hyperfine lines. Some clouds contain embedded OB stars while others with very similar line widths, shapes (elongated, with about 2:1 aspect ratios), and sizes do not. Most clouds seem prolate (cigar-shaped). The observed relation between velocity dispersion and column density is that predicted by virial equilibrium, with nonthermal motions unimportant for the smallest clouds but dominant for giant clouds. Rotation is not significant in providing support for the clouds. Outflows and magnetic heating are sufficient for some clouds, since magnetic heating should be comparable to CR heating for fields of $10^{-4} - 10^{-3}$ G observed in clouds.

F. Adams reviewed theories of star formation. The standard scenario is that the material with the lowest angular momentum falls into the center of the cloud and produces a central protostar. Quickly a disk forms surrounded by the spheroidal collapsing gas/dust cloud in which rotation is not dominant. The collapse is far from homologous. The source of energy is the shock heating of the disk by infalling material as well as from the compression of the central star. A polar outflow develops along with the equatorial infall through the cloud and disk. The last stage before a single star is a naked star plus disk. Outflows are observed from molecular microwave lines in clouds; disks are seen in T Tauri stars. Both the pure inflow and the outflow-plus-inflow stages have about the same luminosity but a spectrum much broader than any single Planck function. The disks can be "passive", producing no energy of their own but simply reradiating stellar energy, or "active", emitting their own energy from viscous dissipation. Active disks are massive ($0.1 - 1\ M_\odot$) and luminous ($\approx L_*$), with sizes of $\approx$ 100 AU. The actual disk physics is still obscure, but nonaxisymmetric modes ($m = 1$) are unstable and the most global. The mass contained within the instability is sufficient to displace the star from the center of gravity of the system, perturbing the disk and increasing the instability. However, the formation of binary system and prediction of the mass spectrum of the forming stars from first principles are still very obscure.

The effects of star formation on the surrounding ISM was discussed by L. Rodríguez. The 150 km s^{-1} outflows produce cavities in the clouds and also shells of H_2 (as seen in ^{18}CO); these flows make the whole cloud core more turbulent by 1 km s^{-1}, which is supersonic. The timescale of dissipation of the turbulence, (cloud size)/(line width), is 10^7 yr, shorter than the timescale of consumption of the gas in the cloud cores (10^8 yr). Maybe the clouds have long dissipation times because the magnetic field controls the motions.

There are about 10 times more ultracompact H II regions (detected from their almost unique set of IRAS colors, confirmed by VLA observations of the free-free radiation) than expected if the freshly ionized gas expands freely from the central star and star formation rate is steady. Probably the gas is confined by the ram pressure of the star's motion through the surrounding cloud, as in a cometary nebula.

Infrared observations of star formation in other galaxies were reviewed by C. Telesco. At 2 μm one observes the old stars directly; at 10 μm, the reradiated radiation from warm dust. Interacting galaxies produce a high 60/100 μm color temperature and a large blue luminosity relative to FIR. It is clear that interaction triggers star formation, as is also shown in barred spirals. Perhaps even M 82, the classical interacting galaxy (with M 81), has a bar, since it is bilobal in 10 μm radiation. There are knots of $\approx$ 1 kpc size (= 1 arcsec) with $L = 10^8\ L_\odot$. The mass associated with a given luminosity depends strongly upon the low-mass cutoff in the IMF; if this cutoff is 0.1 $M_\odot$ in the center of M 82, *all* of the mass would have to be in very young stars (a very doubtful assumption). The low-mass end of the IMF is presumably greatly reduced there.

P. Cox reviewed FIR and sub-mm radiation as diagnostics of star formation in galaxies. One needs to know dust properties and the geometrical association of stars and dust to make accurate predictions. Most of the FIR production (70%) arises from atomic gas (the "cirrus" discovered by *IRAS*), ionized gas most of the rest, and molecular clouds only 7%. About 70% of the FIR arises from OB stars. But the Rosette Nebula region emits most of its FIR in the molecular clouds, not near the OB stars in the cluster; about 30% of the luminosity of the OB stars is reradiated as FIR. In general, the FIR production of the OB stars is spread through the ISM by their contribution to the general interstellar radiation field, not absorbed locally in their natal molecular clouds. Within the 4 kpc ring in the Galaxy, recently formed stars (types OBA) contribute about 70% of the dust heating, while the old disk stars the remainder. The overall conclusion is that the FIR luminosity of galaxies indicates mainly the star formation rate within the last Gyr or so, except for starburst galaxies where the rate is very nonsteady.

The fundamentals of using molecules as diagnostics of the physical conditions in molecular clouds were reviewed by A. Hjalmarson. The temperature must be derived from an optically thick molecular line (e.g., CO), while clumping within the clouds, on a scale different for each molecule, is a major problem in comparing species. The transfer of line radiation in various situations of level populations was discussed. Turbulence occurs on all scales, from winds from bipolar nebulae, MHD waves, and cascading turbulence from galactic rotation.

Shocks are an important ingredient of the ISM, leading to heating, compression, excitation and dissociation of molecules. D. Neufeld gave an overview of their classification and physical effects on the gas chemistry. When the relative speed of the shocked and unshocked material exceeds the speed of sound there is a jump in the physical conditions, producing a J-shock. However in the presence of a magnetic field the ISM behaves as two fluids: one is the charged particles (ions, electrons, small grains), frozen to the field, and the other the bulk of the neutral gas. If the difference in the upstream and downstream speeds is supersonic but less than the Alfven speed in the charged fluid alone (recall that the Alfven speed contains the fluid density), and the cooling time is less than the time of relaxation of the ions and neutrals, there is not a jump in the physical parameters (T, n, etc). Rather, there is a continuous change in n and T, and the shock is called a C (= "continuous") shock. The chemistry of the two types is markedly different. Behind slow J shocks in molecular clouds ("slow" means H_2 is not dissociated, $v < 50$ km s^{-1}) the temperature rises enough so that some endothermic reactions (esp. forming CH^+) occur and H_2 is excited to high levels. Most of the predictions look good. The Orion KL region is a good laboratory for shock diagnostics, with observations of the infrared transition in H_2 seen with broad line wings to ± 100 km s^{-1}. Temperature-sensitive ratios are surprisingly constant. A possible solution is a bow-shock model that has a scale-invariant geometry. Water masers might also be produced in fast shocks.

Since H_2 produces no observable lines unless it is relatively hot, while CO is readily observable, one of the most important numbers in astronomy is $X \equiv N(H_2)/[\int T(CO)\, dv]$, expressed in units of (10^{20} molecules K^{-1} km^{-1} s). T. Dame explained that this number can be found indirectly through correlating dust extinction with both $N(H_2)$ and $\int T(^{13}CO)$ dv in molecular clouds, and using the $T(^{13}CO)/T(^{12}CO)$ found in clouds. A second approach is to use the absorption at 2.4 μm of clouds seen against the background galactic bulge, and obtaining the mass of each cloud through the virial theorem. Both methods relate extinction to H_2 mass by the value in the *diffuse* ISM, and its variation with metallicity throughout the Galaxy. Clouds seem to be in virial equilibrium, and determinations of X in the outer galaxy (same metallicity as local) agree with those from the inner regions. Another independent method of finding X is through γ-rays produced by interaction of CRs with nuclei in the ISM. One can find X by considering molecular clouds and subtracting the estimated atomic H contribution, with no assumptions regarding the extinction/H_2 ratio. However, one must estimate the galactic density of CRs and their penetration into clouds.

A. Wolfendale gave a short presentation from the perspective of a γ-ray astronomer. He basically agreed with Dame's interpretation of the uncertainties in the methods. The "final" value of X preferred by Dame was between 3 and 1.8, with 2.2 preferred. Wolfendale assessed it to be 1 - 1.5. Older values in the literature are up to 3.6. There are exceptional regions: in the Galactic center, $X \approx 0.2$, and in the outer Galaxy, $X \approx 4 - 9$.

The session on diffuse emission started with an excellent talk by R. Reynolds on the ionized diffuse emission. Reynolds's basic observation is of very faint Hα seen in every direction, with a required ionizing luminosity equivalent to 100% of all supernovae, or 14% of O stars. The local n_e is 0.1 cm^{-3}; T from the lines strengths is $\approx$ 8000 K; the volume filling factor is about 0.2. The distribution of n_e with z contains 2 components; one with a scale height of 170 pc, the other very smooth and exponential with a scale height of 900 pc. The mass is in the extended component. Most of the ISM is ionized above 700 pc. The spectrum is strong [S II], weak [O III], [O I], and [N II]. Clouds are resolved in velocity; sometimes they are correlated with H I, sometimes anticorrelated. The source of ionization could well be O stars, but the problem is the penetration of the ionizing radiation from the plane to high above the plane. Perhaps the ISM is in strings or other highly clumped structures.

The ISM far from the Galactic plane, except for the H^+ layer, was discussed by C. Blades. The observational data are the absorption line components of various ions as seen against the spectra of background stars. The material is in very patchy clouds (i.e., discrete absorption components). The recent HST spectrum of 3C273 is most interesting, with absorption clouds at -650, -325, and -50 pc if the Galactic rotation law is assumed. Low stages of ionization (C II, Mg II, etc.) are ubiquitous, and high stages (C IV, Si IV, N V, etc) appear at 1 - 3 kpc. C IV is very patchy out to 1 kpc. Ti II, found with H I, is very smooth up to 1 kpc. There are strong depletions in the abundances of most elements, and the higher velocity clouds have lower depletions than do the lower. The High Resolution Spectrograph on HST, with its vastly better resolution and signal/noise ratio, will make a vastly better analysis of the clouds possible.

The crucial role of supernova remnants (SNR) in the ISM was reviewed by Joel Bregman. Massive stars stir, ionize, and heat the ISM by their radiation and winds, but most of the kinetic energy is deposited by supernovae. The phases of SNR are well understood: a free expansion at first, followed by a blast wave solution of expansion, then a radiative shock, and finally a pressure-driven snowplow phase, during which the interior of the SNR cools.

About a half of SNe ought to occur in OB associations of massive stars of similar ages, with the other half in isolated stars. In the OB association, if a second and other later SNe (perhaps up to 30) occur in the remnant during the snowplow phase, a superbubble with a shell of accelerating H I is formed. The acceleration produces Rayleigh-Taylor instabilities that form clumps. "Chimneys" occur when the thickness of the superbubble is comparable to the scale height of the gas. The magnetic field has a considerable effect upon the evolution if its strength is 5 - 7 μG, but not if $|B| \leq 3\ \mu$G. Conduction is inhibited if the strong field is tangled but can take place along the field if it is aligned. The O VI absorption lines observed by the *Copernicus* satellite might arise from old SNRs cooling by radiation rather than by conduction. If the field is strong, the energy is confined to the disk of the Galaxy, but an aligned field can allow bubbles.

An important question: is the H I in clouds or sheets? An answer is provided by the number of Ly-α components relative to the 21-cm intensity along a line of sight. Almost any sheet would be thick enough to introduce a Ly-α component, while the 21-cm arises from the volume emissivity. Models fitted to the observational data suggest that clouds are too clumpy (or mottled) in appearance, or that there should be more dispersion in the strengths of the Ly-α absorptions. Also the *IRAS* cirrus suggests a sheetlike structure. The ISM seems to be dominated by a continuous medium pushed around by SNRs. Numerical simulations suggest a similar picture.

A major activity of the Commission was the Joint Commission Meeting V, "Late Evolution of Low-Mass Stars", chaired by Y. Terzian. The talks reviewed observations of red giants and Mira variables, theoretical evolution of AGB stars, the planetary nebula phase (of primary concern to Commission 34), and white dwarfs. M. Peimbert discussed the types and abundances of planetaries, while S. Kwok covered planetary nebula evolution and the formation of multiple shells. The talks were in general excellent and will be recorded in *Highlights of Astronomy*, so they will not be summarized here for reasons of economy of space.

The final session of the Commission was to have taken place on 31 July. Unfortunately a fire prevented any meetings from taking place in the San Martín Cultural Center. The commission agreed to relinquish its room in the Plaza center, and the final reviews, by A. G. G. M. Tielens ("IR emission bands from the ISM") and F. Boulanger ("IR Continuum Emission from the ISM") could not be heard. Although disappointed at this turn of events, we realized that many people were interested in the early results from the Hubble Space Telescope.

During the business meeting, the deaths of 3 members of the commission during the preceding triennium were noted with deep regret: Drs. A. H. Barrett, M. V. Penston, and B. L. Webster. They have all made their marks on the understanding of interstellar matter and upon the world around them as well.

The Working Group on Astronomical Nomenclature, chaired by Helene R. Dickel, was disbanded at her request. The members of this WG have worked for over ten years and have, in collaboration with WGs from other commissions, adopted a set of guidelines for the naming and designation of astronomical objects. These guidelines have been published in *Publ. Astr. Soc. Pacific*, **102**, 1231, 1990 and also in A&A, Supplementary issue, May 1991, pp. A11 - A13 and partially in the July 1991 issue of A. J., p iv. Other major astronomical journals have been asked to publish the guidelines in due time. The Commission strongly commended its members who have worked on this project over the years. In addition to Dr. Dickel, they are: T. Chester, K. S. de Boer, J. Dickey, M. Felli, L. Higgs, L. Kohoutek, M. Kutner, M.-C. Lortet, R. Manchester, J. M. Meade, J. Moran, N. Panagia, and R. Schwartz.

The commission elected the following officers to serve during the 1991-1994 triennium: President, H. Habing (Neth); Vice-President, D. Flower (UK); new members of Scientific Organizing Committee: F. Bruhweiler (USA), E. Falgarone (France), T. Lozinskaya (USSR), P. Martin (Canada), P. Myers (USA), S. Pottasch (Neth), and M. Rosa (Ger). The president thanked the departing members (Drs. de Boer, Lada, Lequeux, Shustov, and York), as well as the continuing members, for their advice and assistance. Dr. Habing thanked the departing president for his efforts on the commission's behalf during the past period.

The commission discussed whether or not the Reports on Astronomy, the triennial review of the field with extensive bibliographic references, was worth the considerable effort that goes into its production. A few of the attendees had used the Reports of the past (fewer than a similar poll of commission presidents and vice-presidents suggested later in the Assembly). The general consensus was that a reduced version of the Report is appropriate for Commission 34.

The Commission will sponsor an IAU Symposium on "Planetary Nebulae" in Innsbruck, Austria, 13 - 17 July 1992.