Goings on between the stars

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Empty space is both more crowded and more interesting than you might have thought; so concurred the participants at a recent meeting*. Among the many topics on which new results were presented, three that stood out were: first, fine-scale structure in the interstellar gas; second, the distribution of gas in space and among temperature-density phases; and third, rates and circumstances of star formation.

Suppose you walked the length of an American city block (1 per cent of the scale height of the Earth's atmosphere) and found that the density of air had changed by a factor two or more. Or you went up a few miles in a balloon, and the prevailing wind speed and direction changed a dozen times (while your colleague in a balloon 100 m away also saw a dozen wind components, but not always the same ones). You would be surprised. Yet the interstellar medium (ISM), with a vertical scale height of about 100 parsecs (pc) and an average density of about one atom per cubic centimetre, is highly inhomogeneous on scales of 1 pc or less.

Analogous to the balloon-ascent case, the absorption of starlight along a single line of sight through the ISM can easily require eight or more components with different gas velocities and densities to fit the observed line profiles (Laura Danly, Space Telescope Science Institute). And two sight lines separated by only a few minutes of arc, in the direction of supernova 1987A and nearby stars in the Large Magellanic Cloud, show rather different components (G. Vladilo, Osservatorio Astronomico di Trieste). Guido Münch (Max-Planck Institute for Astronomy, Munich) noted, first, that the phenomenon is a common one, showing up for the sight lines to visual binary stars and, second, that the higher the spectroscopic resolution used, the more components revealed.

Molecular gas acts like the mythical air on the short walk. Y. Murata (Univ. Tokyo) showed the distribution of NH, and CS molecules in part of the Orion Nebula which are clumpy on scales of 0.05 pc and 1 km s⁻¹. John Bally (AT&T Bell Laboratories) has found similar structure, with the morphology of filaments and bubbles, in the CS distribution in other nearby clouds as well.

On larger scales, we can ask at least two questions about the distribution of the ISM. First, how does its average density change with position in the Galaxy? And second, how is it divided among phases of different temperature and density around the average? Quite remarkably, a large number of speakers agreed that the basic morphology is a thin disk (scale height about 100 pc and density near the sun about 1 atom cm⁻³) in which most of the gas mass is neutral, and a lower-density thick disk (scale height 1–2 kpc) in which most of the gas is ionized (Carl Heiles, Univ. California, Berkeley; Klaas S. de Boer, Univ. Bonn; Michal Rozycka, Warsaw Univ. Observ.; Franz Kahn, Univ. Manchester; Donald Cox, Univ. Wisconsin). The interface is wiggly, according to Cox.

For instance, de Boer noted that only 15 per cent of the neutral hydrogen (H I), but most of the highly ionized gas (Si iv, C iv, and so on) is more than 1 kpc from the Galactic plane, and there are probably few high-velocity clouds of H I outside 1.5 kpc. From an optical and ultraviolet vantage point, Danly and C. Elise Albert (US Naval Academy) showed that a significant number of absorption line components arise between 0.3 and 1.0 kpc out of the plane, but fewer between 1 and 2 kpc.

Agreement dissolved over the issue of whether there is a third, nearly spherical, halo component. Neither radio nor X-ray data for our Galaxy seem to require such a component (S. L. Snowden, MPI for Extraterrestrial Physics, Munich), though they arguably do for some other spiral galaxies.

The theoretical point is that it is quite difficult for even very powerful expanding bubbles of hot, ionized gas, driven by many supernovae and stellar winds, to break out of the thick, ionized disk. The issue was addressed by José Franco (Univ. Nacional Autónoma de Mexico), John Dyson (Univ. Manchester), Heinrich Völk (MPI Kernphysik, Heidelberg),

Heiles, Rozycka, Kahn and Cox. The voting was two yeses, three noes and two maybes. The significance of additional driving of the gas by cosmic rays inside the bubbles was emphasized by Kahn, Völk and H. Bloemen (Leiden Observ.), who noted that the association of some high-velocity clouds with Cox B γ-ray sources is evidence for it. I. Felix Mirabel (Univ. Puerto Rico) suggested that about 10 per cent of the highest-velocity neutral hydrogen is falling into the Galaxy with positive total energy. Such gas presumably occupies a roughly spherical volume, but it never had the problem of getting out of the disk.

Within the disk, most of the mass is clearly in dense clouds of cold molecular and neutral gas. These occupy rather little of the total volume. The disputed issue is how to divide the remaining (small) mass and (large) volume among warmer diffuse Radio map of an area measuring 1,200 x 1,200 parsec (pc) in the northeastern spiral arm of the Andromeda galaxy. It shows the distribution of neutral hydrogen moving at a heliocentric velocity of -115 km s⁻¹, the density increasing with the intensity of shading. The circular feature at the centre of the figure is thought to enclose a spherical cavity 330 pc in diameter (15 mm on the page) blown out by a stellar association over 20 x 10⁶ years old. Induced star formation in the spherical shell is revealed by bright Hα emission and the numerous O-, B- and Wolf-Rayet stars there. The energy required to create the shell is thought to be about 6 x 10³⁹ erg. (Map courtesy of E. Brinks, R. Braun and S. W. Unger.)

Cox, astoundingly, proposed that some of his own earlier conclusions had been wrong. He had previously suggested that the supernova remnants would sweep everything else out of the way, tearing up the diffuse material into hot gas bubbles with dense thin shells around them. As gas with an embedded magnetic field is rather incompressible, he now believes that the interface layers are thick and of lower density contrast and that much of the material remains in smooth, diffuse phases. Elias Brinks (Royal Greenwich Observatory) showed H I maps of shell structures in the Andromeda galaxy (M31; see figure) supporting the latter model, whereas D. Breitschwerdt (MPI Kernphysik, Heidelberg) favoured the former one.

The stability and balance of the several phases ought, in principle, to be subject to
Origins of full-scale agriculture

The harvesting of crops using replicas of ancient sickle-blades from the Near East, and comparison of the resulting wear on the replicas with that on the original blades, suggest that early soil tillage and plant cultivation began as long ago as the eleventh millennium BC. Romana Unger-Hamilton, now reports1 her investigations of the lustred flint sickle-blades found commonly at some sites in the Near East.

Wild cereal on Mount Carmel. She used almost 300 experimental flint blades of various kinds to harvest different species of the wild and cultivated plants common to the epipalaeolithic and neolithic sites of the Levant — wild progenitors of cereals (emmer, einkorn, barley), bread wheat and macaroni wheat, and plants growing among wild cereals, such as grasses, wild oats and vetches.

Unger-Hamilton finds that it takes about 10,000 strokes to develop a strong lustre on the blades, suggesting that the ancient blades were used for some time, perhaps as multi-purpose tools. The distribution of the polish on the blade depends on the species harvested, presumably because of the stem structure of the plant. The number of striations on the blade is also dependent on the type of ground in which the plant grows. The striations are caused by loose soil trapped at the base of the stems rather than by the plant itself. When the plants are cut close to the ground, the soil comes between blade and stem, so the side of the blade turned towards the ground becomes more striated. This last observation supports the findings of Korobkova4, who first attributed microscopic striations on flint blades used to harvest crops to contact with soil loosened by tillage.

Unger-Hamilton’s striations are particularly numerous on blades used to harvest macaroni wheat at Jericho, where weeds tend to trap the dust, compared with only one or two striations on blades used to harvest plants from a grassy cover, even after thousands of strokes at the base of the plants. These data can be compared with those on ancient flint blades from the southern Levant, dated to the natufian period (10,000–8,000 BC), and from Jericho in the early neolithic (8,000–6,000 BC). Only about a quarter of the natufian blades were heavily striated, compared with about half from the beginning of the early neolithic and three-quarters towards the end. Unger-Hamilton concludes that most of these blades were used to harvest cereal plants close to the ground, including the stem, during the early natufian, but that the degree of loose earth increased with time, indicating a change in harvesting from filled soil. Although other factors may have been involved, Unger-Hamilton interprets her data to show that full-scale agriculture in the southern Levant began in the second phase of the early neolithic, about 7,000 BC, and that cultivation of cereals began in the early natufian, in the eleventh millennium BC.

These proceed to become garden-variety, low-mass stars. But many of the cores are surrounded by disks of varying mass and it is accretion from these that produces rarer, high-mass stars, in a power-law distribution \( N \propto M^{-2.5} \) (typically). While the disks are present, the protostars have stronger gravitational (tidal) interactions than they will at later stages, and Larson suggested that this is likely to be important for understanding formation of binary stars, ejection of runaway stars from clusters, and other dynamical processes.

The dichotomy between high- and low-mass star formation shows up in several ways. Massive pre-main-sequence stars are more strongly clustered than low mass ones, according to separate infrared and radio mapping studies by C. Eiroa (Observatorio Astronomico-Ign., Madrid) and Eric Keto (Lawrence Livermore National Laboratory). The disks remain in evidence for about 10^7 yr around low-mass stars (Anneila Sargent, California Institute of Technology) but only 10^5 yr around high mass ones (Keto). At the stage probed by Sargent’s 1-mm continuum emission studies, the disks quite often have masses \((0.001–0.1 M_\odot)\) and velocity structures (keplerian) much like the disk that is thought to have produced our own Solar System, suggesting that such planetary systems ought to be common.

Starting almost immediately after their formation, stars begin returning gas and energy to the ISM in winds, bipolar outflows and so forth, followed eventually by supernovae, planetary nebulae and supernova ejecta. But this is another comparatively long story and will have to be told elsewhere. 

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