Plasma diagnostics in an astrophysical setting

from David J. Helfand

PLASMA DIAGNOSTICS using high-resolution X-ray spectroscopy is a field of expanding importance in both fusion reactor research and high-energy astrophysics. In the laboratory, the goal is to measure temperatures and densities of the confined plasma and to chart the spatial and temporal distribution of impurities, which, through radiation losses, limit the all-important density/confinement time product in Tokomak machines. The aims of the astrophysicist are remarkably similar: to determine the temperature and density distribution in the emitting region and to derive the elemental abundances of the hot gas. The primary difference between the two fields is the factor of $\sim 10^{20}$ in the distance of the observer from the source.

The Einstein Observatory X-ray telescope was launched nearly 3 yr ago, carrying instruments designed to probe celestial sources emitting radiation in the 0.1–5 KeV band (corresponding to temperatures of 10^6–10^8K). Although many of the most spectacular early results were obtained with the observatory's two imaging detectors (see J.L. Culhane *Nature* **284**; 509, 1980 and D.J. Helfand *Nature* **285**, 133, 1980), nearly 20 per cent of the satellite's lifetime was devoted to spectroscopy. The increasing number of significant new results beginning to emerge from these observations serve to emphasize the coming of age of X-ray astronomy as a result of the Einstein mission.

Supernovae are the dominant generators of hot gas in the Galaxy. The expanding shock from the explosion heats the ambient medium to temperatures of 10^7–10^8K, ionizing the diffuse gas, evaporating cold interstellar clouds and enriching the material with heavy elements generated during the lifetime of the exploding star and/or in the explosion itself. For $\sim$ 10 yr the expansion is adiabatic, with the kinetic energy of the shock being steadily converted to the thermal energy of the hot gas. Then radiation losses become significant and the temperature of the supernova remnant (SNR) begins to decline, until ultimately, the ions recombine, the shock dissipates and the remnant becomes indistinguishable from the interstellar medium.

This general model of SNR evolution has been discussed for over a decade, but many important aspects, such as the dynamics of the shock wave in a non-uniform medium and the amount of heavy element enrichment, are just beginning to be explored both theoretically and observationally. Early data from the moderate-resolution instrument on Einstein, the solid-state spectrometer built by the Goddard Space Flight Center, showed strong lines of silicon, sulphur, argon and magnesium in the spectra of several young SNR (Becker *et al. Astrophys J.* **243**, L73; **235**, L5; **237**, L77; 1980), implying that the X rays arose in a multi-temperature medium containing substantial overabundances of the silicon group elements. The instrumental resolution of $\sim$ 150 eV was, however, insufficient to resolve the individual transitions which can be used as sensitive probes of plasma conditions within the sources.

David J. Helfand is Assistant Professor of Astronomy at Columbia University, New York.

The *Astrophysical Journal Letters* (15 May) reports the first results on the X-ray emission from SNR obtained with the other major spectrometer on Einstein, the focal plane crystal spectrometer (FPCS) built by MIT. The instrument consists of a curved crystal placed at the focus of the X-ray telescope; X rays meeting the Bragg condition are reflected from the crystal onto an off-axis, position-sensitive proportional counter. The crystal can be rocked back and forth during observation to scan a small band of energies (typically $\sim$ 50 eV) around a preselected spectral feature. The instrument covers the energy range 0.2–3 keV with a resolving power $\Delta E/E$ of 50–500. Due to the small effective area of the device ($\sim$ 1 cm^2), long integrations (up to half a day) are required to scan each potential line.

The data presented are for the relatively old SNR Puppis A; nearly continuous coverage over the range 500–1,100 eV (representing 4 days of observing time) has been achieved and a total of eight isolated lines and three line blends detected. The dominant features are the resonance lines of helium-like oxygen and neon ions, although other ionic species of these elements and lines of iron and nitrogen are also detected. All the features have been previously observed from the hot coronal plasma above active regions on the Sun.

Several factors determine the observed line intensities, including the temperature distribution of the plasma, its ionization

100 years ago

THE FOG

A remarkable phenomenon occurred in New England on September 6, almost exactly similar to one that occurred in the same region on May 19, 1780. The *Springfield Daily Republican* describes it as follows: In this city the day began with a slow gathering of fog from all the watercourses in the early hours, the thin clouds that covered the sky at midnight seemed to crowd together and descend upon the earth, and by sunrise the atmosphere was dense with vapour, which limited vision to very short distances, and made those distances illusory; and as the sun rose invisibly behind, the vapours became a thick, brassy canopy, through which a strange yellow light pervaded the air and produced the most peculiar effects on the surface of the earth. This colour and darkness lasted until about three o'clock in the afternoon, once in a while lightening, and then again deepening, so that during a large part of the time nothing could be done conveniently indoors without artificial light. The unusual complexion of the air wearied and pained the eyes. The grass assumed a singular bluish brightness, as if every blade were tipped with light. Yellow blossoms turned pale and gray; a row of sunflowers looked ghatly; orange nasturtiums lightened; pink roses flamed; lilac-hued phlox grew pink; and blue flowers were transformed into red. Luxuriant morning-glories that have been blossoming in deep blue during the season now were dressed in splendid magenta; rich blue clematis donned an euqally rich maroon; fringed gentians were crimson in the fields. There was a singular luminousness on every fence and roof-ridge, and the trees seemed to be ready to fly into fire. The light was mysteriously devoid of refraction. One sitting with his back to a window could not read the newspaper if his shadow fell upon it — he was obliged to turn the paper aside to the light. Gas was lighted all over the city, and it burned with a sparkling pallor, like the electric light. The electric lights themselves burned blue, and were perfectly useless, giving a more unearthly look to everything around. the darkness was not at all like that of night, nor were animals affected by it to any remarkable extent. The birds kept still, it is true, the pigeons roosting on ridge-poles instead of flying about, but generally the chickens were abroad. A singular uncertainty of distance prevailed, and commonly the distances seemed shorter than in reality. When in the afternoon the sun began to be visible through the strange mists, it was like a pink ball amidst yellow cushions — just the colour of one of those mysterious balls of rouge which we see at the drug-stores, and which no woman ever buys. It was not till between five and six o'clock that the sun had sufficiently dissipated the mists to resume its usual clear gold, and the earth returned to its everyday aspect; the grass resigning its unnatural brilliancy and the purple daisies no longer fainting into pink. The temperature throughout the day was very closed and oppressive, and the physical effect was one of heaviness and depression. What was observed here was the experience of all New England, so far as heard from, of Albany and New York city, and also in Central and Northern New York. In reference to this phenomenon the New York *Nation* suggests that it may be worth the while of weather-observers to note the approximate coincidence between the interval separating the two dark days in New England (May 19, 1780, and September 6, 1881) and nine times the sun-spot cycle of eleven years.

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