although the recent demonstration that a substantial piece of chloroplast DNA is present in the mtDNA of maize[8] shows that DNA can get into mitochondria. Real experimental analysis of these evolutionarily important processes will have to await the development of techniques for the genetic transformation of organelle genomes. □

Thomas D. Fox is at the Section of Genetics and Development, Cornell University, Ithaca, New York 14853.

X-ray astronomy

Hot astrophysical plasmas

from Richard McCray

BEGINNING with the launch of the UHURU satellite in 1969, more than 10 X-ray detectors have been flown on satellites to create a revolution that has affected virtually all areas of astronomy. High-temperature (> 10^6 K) plasmas have been observed in most types of stars, interstellar and intergalactic gas, compact binary sources, active galactic nuclei and distant quasars. The outstanding scientific questions of X-ray astronomy were reviewed at a recent conference* held in Nice, with the aim of developing a strategy for future European space missions.

At present, X-ray astronomy is experiencing a hiatus with only one relatively modest instrument, the Japanese *Hakuchō* satellite, in orbit. The situation will improve in summer 1983 with the launches of the EXOSAT mission by the European Space Agency (ESA) and of the ASTRO-B mission by Japan. Beyond this, the only X-ray satellites under construction are the Japanese ASTRO-C (launch expected in 1986) and the German ROSAT (launch expected in 1987).

Studies of laboratory plasmas complement those of astronomers, as was evident in the review (R. Mewe, Space Research Laboratory, Utrecht) of X-ray emission by optically thin plasmas, including interstellar matter, supernova remnants, solar flares and Tokamak plasmas. In each case the X-ray spectra are rich in emission lines, the interpretation of which may yield the temperature, element abundances and density of the gas. The main thrust of current theoretical research is to understand how the X-ray emission spectrum is affected by the departures from the static ionization balance likely to occur in these environments.

The X-ray spectra of supernova remnants (H. Itoh, Institute of Astronomy, Cambridge) show, suprisingly, that the abundance of Si and S are enhanced much more than that of iron (which was expected to be the main product of nucleosynthesis). Furthermore, supernova shells do not seem to decelerate according to the Sedov blast wave model that has long been a mainstay for their interpretation. Perhaps the interstellar medium around the supernova has been removed by the pre-supernova star or previous supernovae.

X-ray emission from intergalactic gas in clusters of galaxies (A. Cavaliere, Institute of Physics, Rome; R. Mushotzky, NASA-Goddard Space Flight Center) contains emission lines of Fe, Si and S which imply that the abundances of heavy elements are comparable with those in the solar neighbourhood, indicating that the gas is not primordial but comes from the galaxies themselves. Furthermore, a few rich clusters show evidence for cooling flows towards the dominant central galaxies at a rate of a few hundred solar masses per year. The major challenges now are the processes that remove gas from the galaxies and control the flow of the intergalactic gas, and the consequences for galactic evolution.

X rays have been observed from almost every type of star (except red giants), often with luminosities far exceeding that of the solar corona. In the case of hot supergiant stars (C. De Loore, University of Brussels), the X-ray emission seems to indicate hydrodynamic instabilities in the powerful winds of these stars. In the case of low mass-stars (J. Heise, Space Research Laboratory, Utrecht), the X-ray emission suggests magnetic activity similar to that on the solar surface, but often on a much greater scale. Intense and rapidly varying coronal activity seems to be a characteristic of young stars and may provide important clues to star formation.

Compact galactic X-ray sources, including accreting white dwarfs, neutron stars and black holes in binary systems, are characterized by rapid X-ray variability and complex spectra. Galactic compact binary sources (S. Ilovaisky, Observatoire de Besançon; J. van Paradijs, Astronomical Institute, University of Amsterdam) fall into two distinct groups. Population I sources have early-type massive companion stars and hard X-ray spectra; most are X-ray pulsars and almost certainly are magnetized neutron stars. The enigmatic population II sources (including X-ray bursters) have low-mass companions, soft X-ray spectra and do not pulse; most are probably neutron stars with weak magnetic fields.

Quasars and active galactic nuclei (A.C. Fabian, Institute of Astronomy, Cambridge) have hard X-ray spectra extending in some cases to > 100 keV. The rapid variation in their enormous X-ray luminosity approaches and even appears to exceed fundamental theoretical limits. As with the 'superluminal' motions of radio lobes, however, the problem may be resolved if the X-ray-emitting regions have relativistic bulk motions. The presence (in Seyferts and quasars) or absence (in BL Lac objects) of broad emission line regions may be related to the spectral index of the central X-ray source, as a consequence of the equation of state of gas illuminated by X rays. X-ray spectra of some active galactic nuclei (L. Culhane, Mullard Laboratory) indicate photoabsorption by gas clouds near the nucleus.

The scientific discussions all pointed to a need for X-ray telescopes with substantially increased collecting area and capability for spectroscopy. To understand supernova remnants and clusters of galaxies we need the capability to obtain two-dimensional images of the sources with moderate ($\lambda/\Delta\lambda \sim 100$) resolving power. To understand stellar coronae we need higher ($\sim$ 1,000) spectral resolution. Observations of time variability of the spectra of compact binary sources are needed to unravel the complex problems of spectral formation, radiative transfer and gas dynamics. Higher sensitivity will provide a greater sample of active galactic nuclei and better statistics on the time variability of their spectra, both in soft (< 2 keV) X rays where absorption by gas clouds is evident and in hard ($\sim$100 KeV) X rays where most luminosity appears.

Future plans for X-ray astronomy are still unsettled. The technology for constructing X-ray mirrors, spectrometers, and detectors has advanced to a stage where it is feasible to build X-ray telescopes with vastly improved sensitivity and spectroscopic capability. No nation has made, however, a commitment to build them. The US AXAF telescope will not be launched until the early 1990s. The 1987 ROSAT mission will conduct a sensitive all-sky survey of more than 10^5 sources, but lacks spectroscopic capability.

There is no shortage of exciting plans. British astronomers have proposed a mission with a resolving power of $\sim$ 50–500 from 100 eV to 10 keV, while an Italian proposal is for a telescope with relatively low spectral resolution but extended (2–200 keV) spectral range. The ESA CORONA mission could map the diffuse soft X-ray background with moderate ($\sim$100) spectral resolution. The versatile X-80 mission proposed for ESA could address virtually all the scientific problems discussed at the meeting. For the mid 1990s, European astronomers have proposed a spectroscopic mission, MMX, of truly awesome size and power. In 1983, ESA and Japan will take over the leadership in X-ray astronomy from NASA. By building powerful spectroscopic missions such as those proposed at the conference, European astronomers could maintain this leadership for a long time. □

Richard McCray is Professor of Astrophysics at the Joint Institute for Laboratory Astrophysics of the University of Colorado and the National Bureau of Standards, Boulder, CO 80309.

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