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X-RAY DETECTORS IN ASTRONOMY

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Contents

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G. W. Fraser
Frontmatter
More information

Preface

The first cosmic X-ray source was discovered in June, 1962, during the flight of an Aerobee sounding rocket from the White Sands missile range in New Mexico (Giacconi *et al.*, 1962). As the rocket spun about its axis, three small gas-filled detectors scanned across a powerful source of low-energy X-rays in the constellation of Scorpius, in the southern sky. Even though the position of the source (later designated Sco X-1) could only be determined to within an area of some hundred square degrees, cosmic X-ray astronomy had begun.

As usually recounted, the story of Sco X-1 and the birth of X-ray astronomy bears a not inconsiderable resemblance to the story of X-rays themselves. The element of serendipity seems all-important in both discoveries. Wilhelm Roentgen, in 1896, had been intent on measuring the aether waves emitted by a low-pressure gas discharge tube when, by chance, he discovered his new and penetrating radiation. In 1962, the expressed aim of the American Science and Engineering (AS&E)–MIT research group led by Riccardo Giacconi was to detect the X-ray emission, not of distant stars, but from the moon.

Detailed consideration undermines this neat parallel. There is in fact a clear evolutionary line linking X-ray astronomy and the pioneering solar studies carried out in the USA by the Naval Research Laboratory (NRL) group under Herbert Friedman. Friedman's solar X-ray observations had begun with the flight of a captured German V2 rocket in September, 1949. As early as 1956, the NRL group had detected a hint of the cosmic X-ray background radiation whose formal 'discovery' accompanied that of Sco X-1, and by 1957 were flying detectors specifically to search for cosmic X-ray sources (Friedman, 1972). Nor was an awareness of the X-ray sky confined to the USA. Boyd (1979) has recalled a 1959 minute of the British National Committee on Space Research which read: 'Current theories suggest that there may be objects in the sky with strong X-ray emission, although inconspicuous visually. A search for these objects is a matter of great interest and importance.'

Recent first-hand testimony (Tucker and Giacconi, 1985) makes it plain that cosmic X-ray astronomy was born, not really by accident, but out of the determination of the AS&E researchers to beat down the sensitivities of the then available X-ray detectors until the first faint stellar signals, extrapolated from the known X-ray luminosity of the sun, emerged from the instrumental noise. The search for lunar X-ray fluorescence was a sideshow, a means of securing funds for astrophysical X-ray detector development in moon-obsessed, post-Sputnik America. Fortune favoured the AS&E group only in making the intrinsic X-ray luminosity of Sco X-1 so enormously, and unexpectedly, greater than that of the sun.

X-ray astronomy has taken many giant strides since 1962. X-ray sources up to seven orders of magnitude fainter than Sco X-1 have now been located with positional uncertainties of only a few arcseconds. In adolescence and maturity, as at birth, progress in the subject has been intimately linked to advances in photon-counting electronic X-ray detectors. It seems timely to describe the first 25 years of astronomical X-ray instrumentation and to summarise areas of current detector research, giving particular emphasis to imaging devices and to non-dispersive devices of high spectral resolution. Perhaps because it is a true space astronomy (getting above the earth's absorbing atmosphere is not just highly desirable but absolutely essential), X-ray astronomy illustrates supremely well the maxim: 'Astronomy advances only as fast as its instrumentation allows'.

In 25 years X-ray astronomy has become part of the mainstream of astrophysics. Modern astronomers bring data from different regions of the electromagnetic spectrum to bear on the study of particular objects, so that the interpretation of X-ray data is no longer confined to specialists with an assured first-hand knowledge of the photon-collecting hardware. An up-to-date, comprehensive account of detection techniques would therefore appear to be of interest, not only to the X-ray hardware specialist, in the context of a review, but to the wider astronomical community.

X-ray astronomy is, moreover, linked by its instrumentation to fields as diverse as particle physics, medicine, X-ray diffraction studies, X-ray microscopy and fusion plasma diagnostics. A number of recent conferences, recognising these links, have tried to bring together X-ray astronomers and workers in these other fields. A very important aim of this monograph is to stress the broad applicability of new detector technologies developed for astronomical X-ray research.

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G. W. Fraser
Frontmatter
More information

In providing an oblique history of the subject through the development of its hardware, this monograph may lastly prove to be of interest to the general, astronomically minded reader with a background in physics. Appendix A lists a number of reviews which would allow the reader to trace the same history through the astrophysics of the X-ray sources.

The timescales of satellite projects in X-ray astronomy are now very long. Ten years passed between approval of the EXOSAT Observatory by the European Space Agency (ESA) and launch of the spacecraft in May, 1983. The gestation periods of future missions, such as the US Advanced X-ray Astrophysics Facility (AXAF) and the European X-ray spectroscopy 'cornerstone' mission (XMM) promise to be even longer. Where does the 'frontier' lie in such a subject? Of course it must be with the data analysts, poring over the latest images and spectra from the satellites now in orbit. On the other hand, these people are using instruments whose designs were frozen long ago, instruments which may be a decade out of date. The frontier of X-ray astronomy also lies in those labs around the world where, amid cries of frustration and blown preamplifiers, the next generation of X-ray detector is being developed. It is to sufferers at this frontier that this monograph is dedicated.

Leicester, January, 1988

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Units and constants

Most of this monograph is concerned with X-ray energies in the range $0.1 < E < 50$ keV, with regular excursions outside the range as the detector technology demands. One kiloelectronvolt (1 keV) equals 1.6×10^{-16} joules. We shall, however, use X-ray energy E and X-ray wavelength λ interchangeably. If λ is expressed in ångströms (1 Å $= 10^{-10}$ m) and E is in keV then:

$$E = 12.4/\lambda$$

The following fundamental physical constants appear in the text:

permittivity of free space $\varepsilon = 8.85 \times 10^{-12}$ farads/metre (F/m)
Boltzmann's constant $k = 1.38 \times 10^{-23}$ joules/kelvin (J/K)
electron charge $e = 1.60 \times 10^{-19}$ coulombs (C)
electron charge-to-mass ratio $e/m = 1.76 \times 10^{11}$ coulombs/kilogram (C/kg).