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ELIHU BOLDT

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Rocket borne observations of solar x-rays have been in progress for about twenty years.[1] The transition to galactic x-ray astronomy did not occur until 1962 when R. Giacconi et al.,[2] while searching for lunar x-rays, detected a strong source in the Scorpius constellation, designated Sco X-1. For wavelengths shorter than about 4 angstroms (Å), the observed flux from Sco X-1 exceeds that of the quiet sun.[3] For an object at a distance of about 800 light years,[4] the power output of this galactic x-ray source ($\sim 5 \times 10^{36}$ ergs/second) is 10^{14} times greater than the x-ray power output of the quiet sun, over the band 1 - 10 Å. Since 1962, rocket and balloon borne experiments have detected at least 30 additional discrete galactic sources,[5] with x-ray luminosities comparable to Sco X-1. The status of galactic x-ray astronomy reported upon here was achieved before the first successful x-ray telescope was placed in orbit by the satellite OSO-III during March 1967 by L. Peterson (University of California, San Diego).

Unlike optical and radio astronomy, x-ray astronomy is necessarily based upon observations made from vantage points well above the bulk of the earth's atmosphere. A ten million cubic foot balloon lifts a 300 lb. payload to an altitude of about 135,000 feet (2.5 millibars pressure); at this altitude the x-ray transmission of the residual atmosphere exceeds 50% only for wavelengths shorter than 0.4 Å (i.e. photon energy greater than 30 keV). At rocket altitudes ($\gtrsim$300,000 feet), the observed flux from galactic x-ray sources is limited only by the intervening interstellar gas.[6] Thus, the region near the galactic center, at a distance of 3×10^4 light years, is not observable at x-ray wavelengths greater than approximately 8 Å. A relatively nearby object, such as Sco X-1, may be examined to x-ray wavelengths as long as about 30 Å (photon energy $\approx$ 400 e.v.).

The photon energy domain of x-ray astronomy appears to be essentially 1 - 100 keV. Towards the lower energy end, thin-window gas counters (e.g. proportional, Geiger) have proven to be suitable[7] because the probability for a photo-electric interaction is high (e.g. exceeds 50% at energies less than 10 keV, for 10 milligrams/cm^2 of argon) and the resultant electron energy required to produce an ion-electron pair is only 27 e.v. At the upper energy end, alkali halide scintillation crystals have provided[8-12] the required high detection efficiency with an energy resolution of 30-60% (full width at half-maximum).

The spectrum of Sco X-1 has recently been measured[11,12] over the interval 0.9-50 keV and is consistent with the emission from a transparent thermal plasma at a temperature of 5×10^7 °K, up to an energy of 40 keV. A possible non-thermal spectral structure [12] between 40 and 50 keV awaits further confirmation. The x-ray spectrum from the quiet sun[3] is also consistent with the emission from a transparent thermal plasma, but at 4.5×10^6 °K, an order of magnitude lower than the temperature for Sco X-1.

A wire grid modulating system invented by M. Oda[13] made it possible to determine that the x-ray size of Sco X-1 is less than 20 arc seconds[14] and to locate the position with sufficient precision to allow for an optical search and subsequent identification[4] in 1966. The optical power emission of the object so located is comparable to the sun. However, the optical spectrum exhibits an unusual ultra-violet excess and significant time variations of intensity on time scales of minutes and hours. Photographic plates of the Harvard observatory dating back to 1896 indicate that the long-term optical power level has remained essentially constant. This optical power level is about 10^3 times less than the x-ray power emitted by this source at wavelengths shorter than 10 Å. No radio emission has been detected.

The descriptions of Sco X-1 are not as yet definitive; some indicate an old nova[4] or a binary system, one component of which is an old neutron star.[15] Another source similar to Sco X-1 in brightness and gross spectrum was discovered by K. McCracken et al.[16] during a rocket borne survey experiment launched from Australia in April 1967. This source in the Crux constellation of the southern sky, designated Crux XR-1, is expected to yield important comparison data for this class of stellar object.

The remnant of a supernova observed optically in 1054 A.D., the Crab nebula (Tau A), is the only strong x-ray source (Tau XR-1) so far identified[17] to also exhibit significant emission in both the optical and radio regions. In 1964 G. Clark[8] succeeded in observing hard x-rays (20 - 60 keV) from Tau XR-1 during an 80 minute exposure conducted with a balloon borne scintillation detector. Subsequent measurements[9,11] from rocket and balloon borne detectors have defined the spectrum over the interval 1-100 keV. For a source at a distance of 33×10^2 light years, these measurements indicate that the power output in x-rays is about 10^{37} ergs/sec. This is to be compared with 10^{36} ergs/sec in the optical and 10^{34} ergs/sec in the radio range.[18] The emission in the radio and optical bands is known[18] to exhibit the polarization characteristic of synchrotron radiation. The x-ray spectrum is also consistent[9,11] with arising from the synchrotron emission of energetic ($\sim 10^{13}$ e.v.) electrons that are spectrally distributed according to a power law ($\alpha E^{-3.2 \pm 0.4}$) within a magnetic field $\gtrsim 10^{-4}$ gauss. A definitive conclusion about the synchrotron process must await polarization measurements for the x-rays; a polarization as high as 15% is anticipated.[19]

The size of Tau XR-1 was first measured by S. Bowyer et al.[20] on July 7, 1964 via observations of the x-ray flux variation during the course of a lunar occultation. This indicated an extended source (~1 light year), comparable to the visible object. It ruled out speculations about a neutron source for Tau XR-1, since such a source would be small ($\approx 10^4$ meters). Recent experiments by M. Oda et al.[21] have confirmed that the optical and x-ray emission of the Crab nebula have a common center, to within 15 arc seconds, and that the optical and x-ray emitting regions are of comparable distribution, but unlike certain aspects of the radio emission.

Another supernova remnant that has been identified as an x-ray source (Cas XR-1) is Cassiopeia A[22], the brightest radio source in the sky, estimated to have exploded in (1702 ± 14) A.D. Once again, the x-ray power emission is estimated at 5×10^{36} ergs/sec in the band 1-10 Å. In this instance, the radio emission is comparable though less, at 3×10^{35} ergs/sec.

A recent survey by H. Friedman et al.[5] indicates that a weak x-ray source (Cep XR-1) may be associated with the remnant of the Tycho Braha supernova observed in 1572 A.D. The x-ray power emitted within 1-10 Å may be estimated as 5×10^{34} ergs/sec, compared with the emitted radio power[18] of 6×10^{31} ergs/sec.

A vast majority of the galactic sources so far identified[5] have not exhibited optical or radio counterparts. These sources appear to group into two broad clusters, close to the galactic plane. Eight of the sources are in the Cygnus-Cassiopeia region, spaced within an average of ± 7 degrees from the galactic plane, and could be associated with the Orion-Cygnus spiral arm of which the sun is a member. H. Friedman et al.[5] estimate that the average x-ray luminosity within this group is less than half that of Tau XR-1. Several observations[10, 11, 23, 24, 25] indicate that at least one source in the Cygnus region emits hard x-rays, with a spectrum comparable to Tau XR-1 or even harder.

Most of the remaining sources are clustered towards the galactic center at an average of ± 3.5 degrees from the galactic plane and are thereby estimated[5] to be at an average distance of 8×10^3 light years, assuming they are distributed above and below the galactic plane as the general stellar distribution. The sources of this second group are consistent with being part of the Saggitarius spiral arm of the galaxy, with an average luminosity about twice[5] that of Tau XR-1. Recent observations[26, 27] of the central region of the galaxy indicate that the average source spectrum here is harder than Sco X-1, particularly within the vicinity of Sgr X-1.[27]

If the estimated[5] x-ray luminosity of our galaxy ($\sim 10^{40}$ ergs/sec, for 1-10 Å) is typical of all spiral galaxies in the universe, then the diffuse isotropic background flux should be $\approx 10^{-8}$ ergs/(cm^2 sec. sterad.). However, the measured[6, 22, 28-30] diffuse background flux is an order of magnitude greater than this, and balloon borne observations[28-30] indicate that the background spectrum may be harder than that for typical discrete sources within the galaxy. Electromagnetic processes within our own galaxy may make significant contributions to the diffuse background; V. K. Balasubrahmanyan et al.[31] have considered the x-ray emission arising from the process of electron ejection from interstellar hydrogen atoms via the impact of charged cosmic rays. The resolution of this question of origin for the diffuse background requires refined measurements of the spectral and angular structure of the non-stellar x-ray flux.

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