X-RAY ASTRONOMY IN 1974

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I. INTRODUCTION

Although cosmic X-ray sources were first discovered in 1962 and have been studied since then using instruments on rockets, balloons, and small satellites, the full scope of X-ray astronomy became apparent only after the extended observations provided by the satellite **Uhuru** (Tananbaum, 1973; Kellogg, 1973). X-ray observations now play a role in modern astrophysics comparable to that of radio, optical, and infrared astronomy. In addition to increasing the number of detected sources fourfold, because of the increased sensitivity, the long term observations have discovered time variations on scales inaccessible to rockets and balloons. This has resulted in the discovery of a new class of celestial objects, the pulsating X-ray sources in stellar binary systems.

Here we review results from **Uhuru** and from other experiments on which recent advances in high-energy astrophysics are based.

II. OBSERVATIONAL STATUS

X-ray astronomy conveniently divides itself into energy ranges where instrumental technique, state of development, and physical processes all differ. In the 1 - 10 keV range (1.2 - 12 Å) where the early discoveries were made, and where the **Uhuru** operates, observations are made with collimated proportional counters. At lower energies, 0.2 - 2.0 keV, proportional counters with very thin windows of organic materials have measured absorption effects and structure due to the interstellar medium (Friedman et al., 1973; Hayakawa, 1973) and soft X-rays from relatively cool supernovae remnants (Pounds, 1973). One dimensional reflecting telescopes have been used as "concentrators" in conjunction with thin window proportional counters to determine the soft X-ray structure of these remnants (Gorenstein et al., 1971; Borken et al., 1972). Although a focusing device on the Copernicus satellite has also provided new information on these as well as other objects (Fabian et al., 1973; Fabian et al., 1974a), a grazing incidence X-ray telescope, which can form images directly as in conventional astronomy, has not yet been flown with enough area to permit definitive observations of cosmic sources. Such a device on Skylab has, however, obtained high resolution pictures (∼5″) of solar active phenomena at wavelengths as short as 4 Å (Vaiana et al., 1973). Scintillation counters are usually employed above 20 keV, where observations may also be made from high altitude balloons (Peterson et al., 1972). Here, however, the steep spectra, combined with the difficulty of implementing large area, low background detectors, has restricted spectral measurements to perhaps only 40 of the strongest sources and then usually only to energies less than 100 keV (Peterson, 1973).

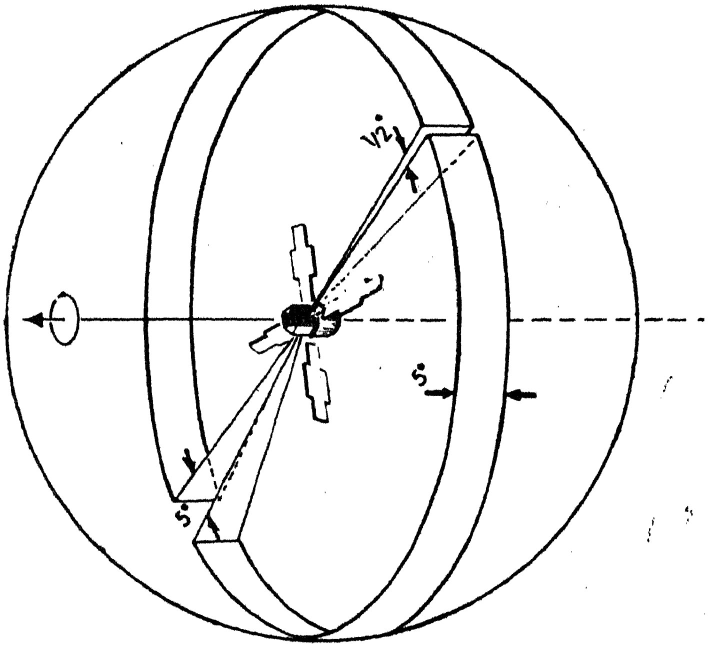

Figure 1 : The concept of an X-ray astronomy observation as exemplified by **Uhuru**. *Proportional counters collimated to a field of view a few degrees wide scan across a source as the vehicle rotates.*

The concept of an X-ray measurement with a collimated counter on **Uhuru**, or any other scanning vehicle, is shown in Figure 1. As the spacecraft scans, a source passes through the nearly triangular response function, resulting in an increase in the counting rate. Background is obtained before and after the scan. **Uhuru** was launched 12 Dec. 1970, had a sensitive area of 840 cm^2, and could detect as little as 2×10^{-3} counts/cm^2 sec, or about 1/500 the flux from a strong source, such as the Crab Nebula. This corresponds to an energy input in the range 10^{-8} to 10^{-11} ergs/cm^2-sec, or for sources at a few kiloparsecs, to X-ray luminosities, L_X of 10^{35} to 10^{38} ergs/sec. An extragalactic source at 10 Mpc must radiate $L_X \geq 10^{41}$ ergs/sec in 1 - 10 keV X-rays to have been detected.

The X-ray sky map in galactic coordinates as obtained by **Uhuru** is shown in Figure 2 (Giacconi et al., 1974). Also shown are the 1878 "lines of position" from which source locations are obtained, and regions of the sky which have been surveyed to a sensitivity of 10 c/sec or better. The sources are located to positional areas typically a few tenths of a square degree in size, depending considerably on source strength, the number of observations, etc. Only about 40 X-ray sources have been identified with known radio or optical objects. Although about 100 of the 161 sources are concentrated in the galactic plane, their locations do not coincide in detail with known galactic features such as OB associations, H II regions, novae, non-thermal radio sources, etc. The 64 sources at $b_{II} \geq 20^\circ$ are generally of a weaker nature. Although

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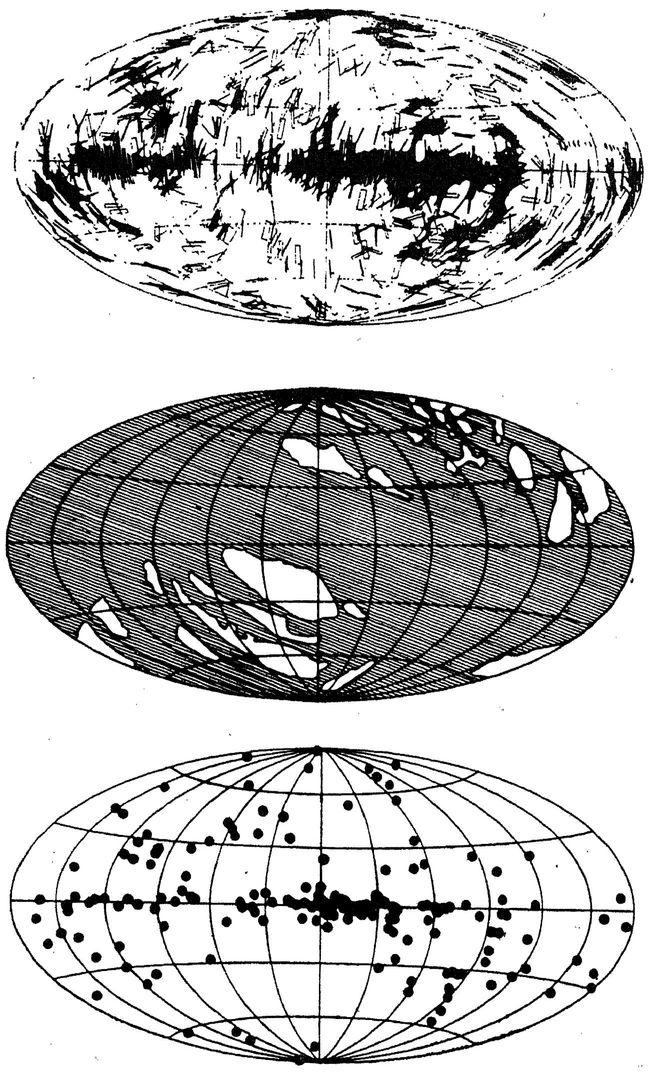

Figure 2 · The X-ray sky map in galactic coordinates obtained by **Uhuru** *from approximately 125 days of operation. The upper panel shows the 1878 " lines of position " from which the 161 source locations in the bottom panel were obtained. The central panel (shaded) shows areas of the sky covered to a sensitivity better than 10 c/sec, or about 10^{-2} that of the Crab Nebula.*

some are associated with known extragalactic objects, and a few are galactic, the majority are simply unidentified (Schwartz and Gursky, 1973).

The photon spectrum, which is a signature of the emission process, can be obtained from pulse height analysis of the proportional or scintillation counter events to an ultimate resolution of 5 - 10 per cent. Emission from an optically thin hot gas at 10^7 to 10^{8}°K produces an exponential spectrum, while synchrotron emission and Compton scattering from power law electron distributions also produce power-law photon spectra. Although black-body emission in X-ray may also occur from an optically thick region, a thermal object with $kT > 20$ keV is extremely compact, even if at galactic distances.

Discrete K- or L-shell X-rays, expected from 10^7°K thermal plasmas with normal cosmic abundances, have been searched for extensively. The most conclusive detection seems to be from the Cygnus loop (Stevens et al., 1973). Gamma-rays, expected in the 20 keV to 1 MeV range due to nuclear process following catastrophic events, have also been searched for and not found (Peterson and Jacobson, 1970).

III. THE BINARY X-RAY SOURCES

Although the suggestion was made soon after the discovery and identification of several galactic X-ray sources that these were binary stellar systems with large mass transfer (Prendergast and Burbidge, 1968), such associations were not conclusive until the **Uhuru** observations. Observationally, the sources known to be binary systems fall into two classes, pulsating and eclipsing, and those that simply eclipse or have other periodic variations. The observational status of binary X-ray sources has recently been reviewed by Gursky and Schreier (1974).

A) The pulsating, eclipsing sources

Figure 3 shows counting rates observed for Cen X-3 on a number of time scales (Gursky, 1972; Schreier et al., 1972). The rates during a single 90 sec scan are modulated not only by the aperture response of the detector but are pulsed at a $4^s.8$ rate, due to the source. The average rate over many such scans (center panel) shows a characteristic on/off feature, which repeats with a $2^d.067$ period. Analysis shows the $4^s.8$ + period is frequency modulated in phase with the same $2^d.067$ period.

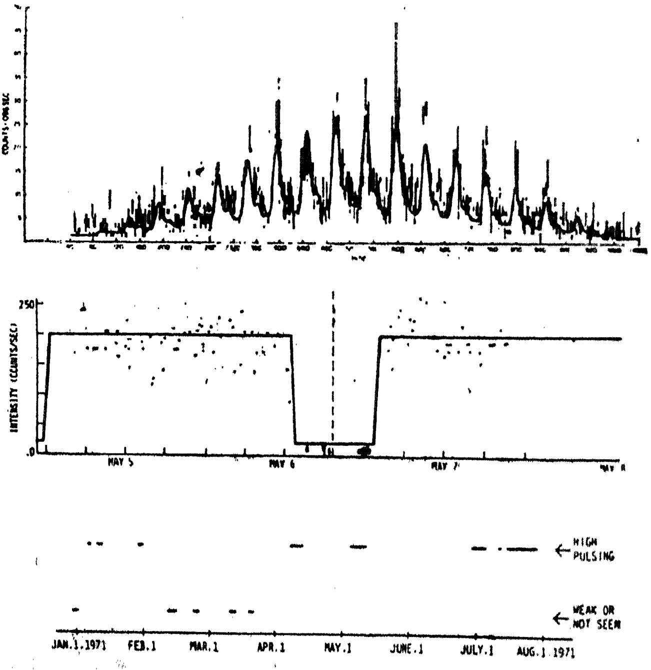

Figure 3 : Time variations observed on 3 different scales from the binary source Cen X-3. The upper curve shows the $4^s.8$ + pulses during a single Uhuru scan ; middle panel the $2^d.067$ variation associated with the binary eclipse, and the lower panel the long-term quasi-random " on " and " off " states.

These effects are understood under the concept that the pulsating X-rays are produced by a compact object revolving about a larger one, which occults the smaller one during a portion of the orbit. The change in pulse arrival time, interpreted in terms of a Roemer shift, gives the projected orbit size as 1.19×10^{12} cm. The fast pulsation requires a source region of radius less than 10^9 cm. Cen X-3 also shows quasi-random "off" periods, which last for weeks or months as shown in the lower panel of Figure 3. Because of its location in highly obscured region, Cen X-3 has only recently been tentatively identified with a reddened early OB star (Krzeminsky, 1974; Vidal et al., 1974). This identification becomes more likely in view of the recent improved position obtained from Copernicus (Parkinson et al., 1974).

The second and most extensively studied pulsating binary system is Her X-1 which has a $1^s.24+$ period, a $1^d.7$ eclipse cycle, and a 35 day on-off periodicity, and is now identified with the variable stellar object HZ Her Although HZ Her has the general appearance of a late A or early F star, its intensity is modulated $\Delta m_V \simeq 1$ at the $1^d.7+$ period (Bahcall et al., 1974). The mass function for a binary system is :

$$\frac{M^3 \sin^3 i}{(m+M)^2} = \frac{V^3{}_{\rm obs}\, T_{\rm obs}}{2\pi G},$$

where m and M are the masses of the unseen and observed star, respectively, i is the orbit plane inclination and the observed period and projected radial velocity are T and V. Assuming the larger star M is indeed an F0, at $\sim 2\, M_\odot$, the smaller object is in the range $0.7 \lesssim M \lesssim 1.2\, M_\odot$.

X-ray emission of compact objects in binary systems is usually explained in terms of accretion (Zel'dovich and Novikov, 1971; Ostriker and Davidson, 1973), in which gas flowing out of the visible star accumulates in an orbiting disc around the compact object. If the latter is a rotating neutron star with an intense magnetic field oblique to the rotation axis, matter from the disc may fall, or "accrete," onto the magnetic polar surfaces, become gravitationally heated, and emit X-rays. The pulsations are due to modulation at the rotation rate by the geometry of the emission region. Simple consideration shows that an accretion rate of $10^{-9}\, M_\odot$/yr onto a 10 km radius, 1.0 $M_\odot$ neutron star will easily result in a kinetic temperature of 10^{8}°K, and an emission of 10^{37} erg/sec from a polar region less than 1 km across !

The most difficult feature of the Her X-1 system to explain is a slow modulation of the X-ray emission at $\sim 34^d.88$ period, typically about 11 days "on" and 24 days "off" (Gursky, 1972). Possibilities include 35^d expansion of the visible star envelope, precession of the neutron star rotation axis, instability or precession of the accretion disc, or perhaps even a third body. No important changing optical feature appears associated with the 35d period, although small effects on the 1.7d variation may exist (Grandi et al., 1974).

The composite X-ray spectrum, averaged over the $1^s.24+$ period, obtained from many balloon, satellite and rocket observations is shown in Figure 4 (Iyengar et al., 1974a). Because of the complex variability, agreement among measurements is not expected. The spectra generally are rather flat at lower energies, and become a power law which has been measured to nearly 100 keV. Alternatively, the average spectra can be fitted by an exponential function corresponding to a temperature of 3×10^{8}°K. Based on a recent measurement (Iyengar et al., 1974a), the pulsed component diminishes considerably at higher energies. Little is known about X-ray spectral variations during the $1^s.24+$ pulsations, or during the $1^d.7$ eclipse period.

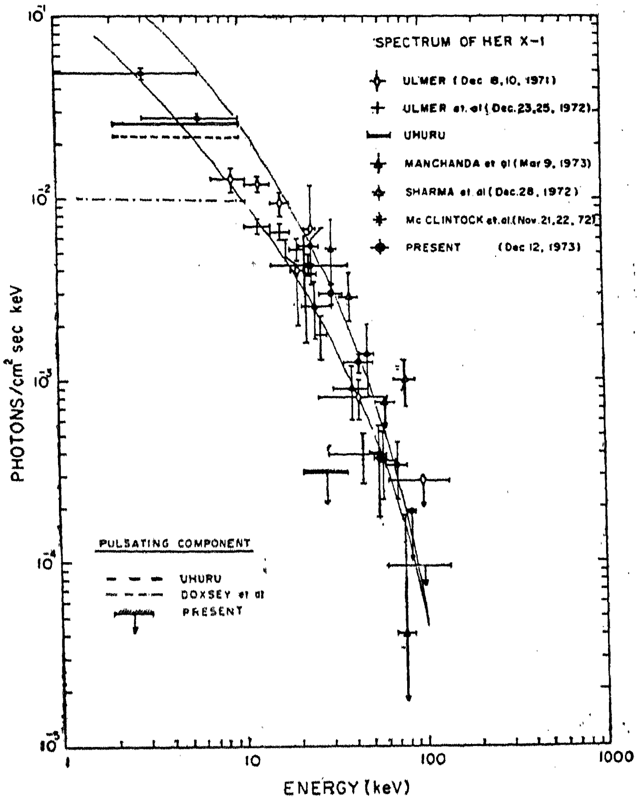

Figure 4: The spectrum of Her X-1 as observed by many workers. All these data are averaged over the $1^s.24+$ pulsation period, but are at different times during the $1^d.7$ " on " eclipse, and the ... 35 day " on/off " cycle. The pulsating componenrt apparently has an energy dependence, being essentially absent at ~ 30 keV.

(B) The irregular, eclipsing sources.

Five other sources exhibit an X-ray periodicity between $4^h.8$ (Cyg X-3) and $8^d.95$ (Vela X-1). While most of these show considerable variability during non-eclipsed phases, none have shown periodic pulsations like Cen X-3 or Her X-1. Cyg X-3, which has been associated with a remarkable series of radio outbursts (Hjellming, 1973), has now been positively identified with a variable infrared object (Becklin et al, 1973). The X-ray variations are nearly sinusoidal, as are the in-phase IR periodicities. It has been suggested that Cyg X-3 may be a binary system, where the compact object is a white dwarf (Davidson and Ostriker, 1974). The $4^d.7$ SMC X-1 is in the Small Magellanic Cloud, and therefore has an intrinsic X-ray luminosity $L_X \sim 3 \times 10^{38}$ ergs/sec, considerably above the typical galactic binary of $\sim 5 \times 10^{37}$ ergs/sec. All of the binary sources now have tentative optical associations (Gursky and Schreier, 1974).

Another well studied object is Cyg X-1, the "black hole" X-ray source whose extreme and complex variability on all time scales has been seen from many previous rocket, balloon and satellite observations (Overbeck and Tananbaum, 1968; Oda et al., 1972; Rothschild et al., 1974). The source is now positively identified with the $5^{d}.6$ spectroscopic binary system HD 226868. Since $5^{d}.6$ X-ray periodicities are not seen, the assumption is that the X-ray emission occurs from an unseen, uneclipsed compact companion accreting matter onto its surface. From the mass function, assuming the visible object is a $\geq$ 20 $M_{\odot}$ Bo1b supergiant, the companion has a mass $\geq$ 3 $M_{\odot}$ which, if collapsed, has a radius inside the Schwarzschild limit, and therefore has the properties of a black hole. The intense, highly variable X-ray emission, requiring extreme compactness, and the unseen nature of the companion, are all consistent with the "black hole" hypotheses. Other sources, such as Vela X-1 and 3U1700-37 may be in the same category. The requirement for a black hole has recently been questioned by Fabian et al (1974b), who have suggested a tertiary object which reduces the mass requirement to an "ordinary" neutron star.

IV. OTHER GALACTIC SOURCES

(A) Supernovae remnants

These form a distinct class. In addition to the Crab Nebula, a unique source discussed later, X-rays have now been observed from Cas A, SN1572, Tycho's SN, the Cygnus Loop, Pup A, and Vela X (Pounds, 1973; Fabian et al., 1973; Gursky, 1972), and possibly others. These latter objects all have steep spectra characteristic of a hot gas at a few million degrees, although several exhibit more complex, multicomponent spectra (Stevens and Garmire, 1973; Coleman et al, 1973). The Cygnus loop is not even seen in 2-6 keV counters because of its softness. "Maps" of the emission region have, however, been obtained at 0.2-0.5 keV, and compared with optical and radio structure (Stevens and Garmire, 1973; Rappaport et al., 1974). Since the distances are usually well known, luminosities may be determined, and it is found the supernovae remnants fall in a class 10^{35}-10^{36} ergs/sec, which is less than the typical galactic emitter of 10^{37}-10^{38} ergs/sec. The X-ray emission is thought to result from an expanding gaseous shell which may go through an extreme heating phase during its evolution. The relation of this gas to the energetic electron populations producing non-thermal radio emission usually observed in these remnants is unclear (Shklovsky, 1972).

(B) Crab Nebula and NP0532

This was the first X-ray source identified with an optical counterpart and is one of the strongest in the sky. The mass of data now available on this object, and its interpretation have been recently reviewed by Apparao (1973). Early observations indicated that the emission was distributed over a diameter of about 100″ approximately centered on the optical synchrotron-emitting region, and that the spectrum over the 1-500 keV range had a power law shape with a photon number index -2.1 (Peterson and Jacobson, 1970). In 1969, it was found about 15 per cent of the X-ray emission was also pulsed at the 33 ms rate of the radio pulsar NP0532, and in phase with the optical pulse. Figure 5 shows the hard X-ray spectrum of both the nebula, and NP0532, as determined by a recent UCSD balloon investigation (Laros et al., 1973a). The pulse shape, obtained by folding the entire 5000 sec. of balloon data, modulo the 33+ms period is shown in the inset. The pulsed spectrum has been observed to extend to nearly 10^{11} eV and there is some evidence for a non-pulsed component in the 1-10 MeV region whose intensity is above the extrapolation of the power law in Figure 5 (Baker et al., 1973; Gruber, 1974).

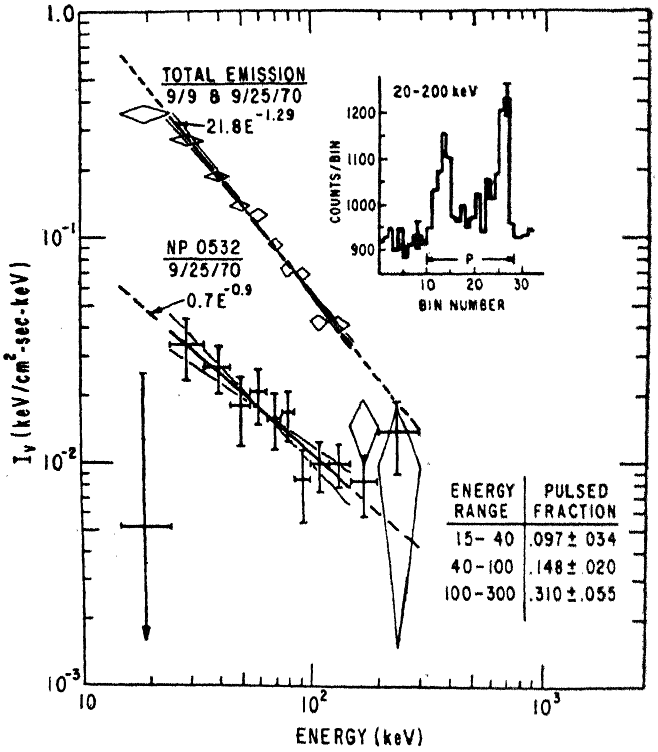

Figure 5 : A balloon observation of the hard X-ray, spectrum of the Crab Nebula, and NP0532. The power law spectrum over the 1-200 keV range is believed due to synchrotron radiation from energetic electrons in the ~10^{-4} *gauss nebular field The mechanism of the pulsed component, and its relation to the nebular emission is unclear at present.*

It is now generally accepted that NP0532 is a rotating neutron star and the nebula is being powered by kinetic energy converted from its slow down. The details of the particle acceleration in the neutron star magnetosphere and the transfer of energy to the nebula are not understood, however. If the emission of the extended region is indeed due to synchrotron radiation of electrons injected from NP0532, then their lifetime in the ~4×10^{-4} Gauss nebular field is insufficient for them to have propagated to the observed distances, and an additional acceleration process must be operative. Crucial to this question is the size of the region at higher energies, which may be determined by balloon observations during upcoming lunar occultations, or by using a wire grid "modulating collimator" in front of proportional or scintillation counters (Bradt et al., 1968).

Sources often indicate absorpotion in the 0.2-2.0

keV range, which may be of either interstellar or local origin. Although the origin may be uncertain in compact sources, the observed absorption from the Crab Nebula is clearly of intersellar character. Since the X-ray absorption is independent of the state of the un-ionized matter, i.e. atomic, molecular or granular, X-ray measurements indicate the total hydrogen column density. Although there is some disagreement among measurements, the absorption from the direction of the Crab indicates a column density of 3.5×10^{21} H/cm^2, or about twice that of the 21 cm radio observations (Iyengar et al. 1974b; Margon, 1974).

(C) Transient X–ray sources

Since 1967, about 5 strong sources have been observed to abruptly appear and then decay into the background level after a few weeks or months (Gursky and Schreier, 1974). These sources show a spectrum which softens with time and decays in intensity similar to that of galactic novae, hence the term " X-ray novae " (Evans et al., 1970; Ulmer et al., 1973). None of these have been seen during the rising phase, and none are positively identified with known nova, or with any optical or radio object. The recently discovered transient gamma-ray sources are apparently of a different nature, having very hard spectrum, and time scales of only tens of seconds (Strong et al., 1974).

(D) Others :

This includes the majority of the galactic sources. Some, such as SCO X-1 and Cyg X-2, have been observed extensively since the early days of X-ray astronomy and have optical counterparts (Gursky and Shreier, 1974 ; Peterson, 1973). SCO X-1 may be explained in terms of a 50×10^6.K gas of 10^{16} atoms/cm^3 having a radius of 10^8 cm. Such a configuration becomes optically thick in the near infrared, consistent with observations. Others, such as Cir X-1, have extreme variability on all time scales (Jones et al., 1974; Baity et al., 1974). This source has in fact been dubbed a " super black hole ".

The energization of these sources is a major problem. Therefore it has been suggested that *all* galactic X-ray emitters, with the exception of the Crab and other supernovae remnants, are of compact binary nature, in which the binary characteristics have been suppressed because of the configuration, or because of absorption by thick envelopes (Tananbaum, 1973). It is clear, however, that X-ray sources are a rare galactic phenomenon, with perhaps only a few hundred in our galaxy, all emitting in the 10^{37}-10^{38} ergs/sec range, and with the exception of the supernovae remnants, no large population in the 10^{35}-10^{36} ergs/sec class (Gursky, 1972; Gursky and Schreier, 1974).

V. EXTRAGALACTIC SOURCES

Much less is known about extragalactic X-ray emitters, because of their inherently weaker flux, and steeper spectra. These are not only important in terms of galactic structure and evolution, but may contribute importantly to cosmological effects. Although most of the approximately 60 sources with galactic latitude $> | 20^\circ |$ are presently unidentified, emission has been detected from certain clusters of galaxies, such as Perseus and Virgo, strong radio objects such as Cen A and possiblg M87, a Seyfert galaxy, and a QSO, 3C273 (Kellogy, 1973).

(A) Extended objects

X-ray emission has been observed over extended regions, $\sim$0.7°, from the galactic clusters Perseus, Virgo and Coma by **Uhuru** (Gursky et al., 1972) and Copernicus (Griffiths, 1974). The **Uhuru** flux is typically < 50 c/sec, implying $L_X \sim 3 \times 10^{44}$ ergs/sec for Perseus and Coma. It has been suggested that the emission is due to a hot intercluster gas, $\sim 10^{8}$°K, sufficient to provide the " missing mass " required by the virial theorem for dynamic stability. The X-ray emitting mass required, however, depends critically on the " clumpiness " and other parameters, and the whole problem is controversial at present. Alternatively, the X-rays may originate from scattering on the 3°K radiation by an intercluster population of cosmic-ray electrons leaking from the galaxies.

Since these strong sources are associated with " rich " clusters, the luminosity may be related to the richness class. About twelve additional **Uhuru** sources in the 2-7 c/sec range have been tentatively associated with Abell clusters of varying richness (Kellogg et al., 1973). At these low fluxes, however, it is impossible to determine the extent of the source, or the spectrum.

(B) Compact objects

These include the closest QSO, 3C273, the Seyfert galaxy NGC4151, and the radio sources Cen A and Cyg A, all of which are detected at $\sim$5 c/sec (Giacconi et al., 1974). 3C273 has a luminosity $\sim 4 \times 10^{45}$ ergs/sec, about 1/20 of the infrared power, while other sources do not exhibit such large X-ray power, being in the range 10^{41}-10^{42} ergs/sec. The mechanism is also unclear ; however in the strong radio sources, Compton scattering seems likely, and in fact Cen A (NGC5128) is observed to have a power law spectrum measured to $\sim$100 keV, whose number index is in the range 1.5 to 2.0 (Peterson, 1973). Based on the **Uhuru** data, most of the emission from Virgo is from a diffuse source although the possibility of a component extending to $\sim$50 keV from M87 cannot be excluded (Catura et al., 1974 ; Laros et al., 1973b). Several point sources, in addition to SMC X-1, have also been indentified from the Magellanic clouds (Rapley and Tuohy, 1974).

The majority of the high latitude sources are simply unidentified and may in fact be a new class of extragalactic objects (Kellogg, 1973), although a population of local galactic sources with $L_X \sim 10^{34}$ ergs/sec cannot be excluded (Holt et al., 1974). Figure 6 shows the integral number intensity plot (ln N-ln S) for high latitude sources, both total and unidentified. The high latitude sources show the -1.5 law, and if extragalactic, L_X must be about 5×10^{43} ergs/sec. Normal galaxies, such as our own, and M31, which has been weakly detected, are in the range 0.2-1.0×10^{40} ergs/

sec, consistent with the non-detection from other, nearby galaxies.

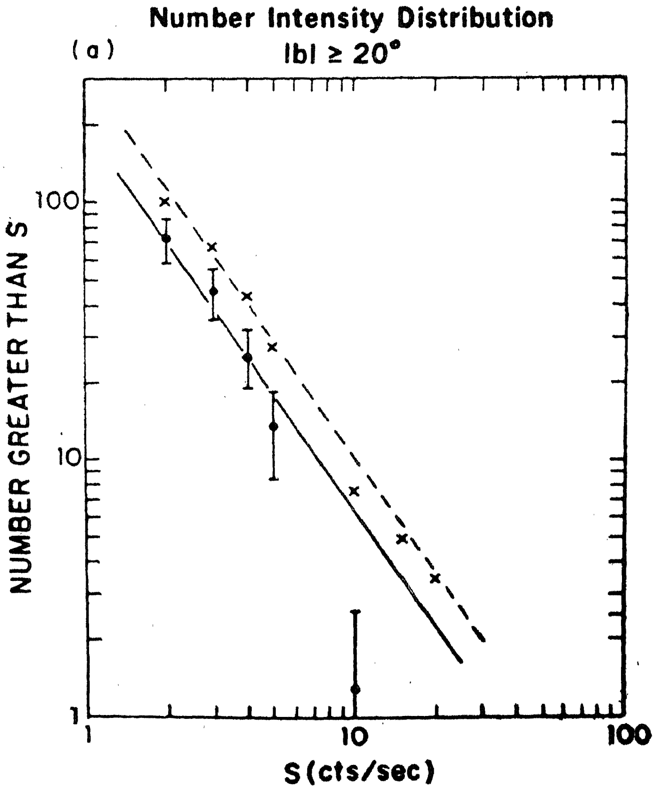

Figure 6 : The ln N-ln S plot for the high latitude sources indicates a -3/2 slope (dashed and solid lines) expected from an isotropic distribution. The crosses are for all sources $b_{II} > 20°$*, and the bars are for these unidentified with known objects.*

(C) The diffuse component

Related to the problem of the extragalactic sources is the diffuse component of cosmic X-rays, whose 2-7 keV intensity is $\sim 10^{-8}$ ergs/cm²-sec-sr, and which has been measured to be isotropic and uniform to a few per cent, on both large and small scales (Schwartz, 1970 ; Schwartz and Gursky, 1973). Although the spectrum has now been extended to over 100 Me V, and can be grossly described in terms of $dN/dE \sim E^{-2.2}$ (Pal, 1973): the details indicate complex, multicomponent origin (Trombka et al., 1973; Schwartz and Gursky, 1973; Silk, 1973).

Three possibilities for the origin have been reviewed by Felten (1973). Compton scattering of intergalactic electrons on the 3°K radiation produces a spectrum which is naturally a power law, with changes in slope due to diffusion and lifetime of the electrons. An $\sim 7 \times 10^{7°}$ K intergalactic medium of sufficient density to close the universe ($\sim 10^{-29}$ gm/cm^3) produces more than the observed X-ray intensity depending somewhat on the big-bang or steady state model. A reduction in the Hubble constant to <40 km/s per Mpc, among other effects, could remove this problem. One would still however, have to invoke an added component to explain the radiation at energies > 50keV X rays.

It may also be that the diffuse flux is due to the superposition of many discrete sources. The lack of " lumpiness " in the back round however, implies a very large number of sources, $\geq 10^7$. The volume emissivity of the *known* discrete extragalactic objects: rich clusters, quasars, Seyfert galaxies, strong radio sources and normal galaxies, when extrapolated over all their classes with the measured X-ray luminosity, fails to account for the observed diffuse intensity by a factor of 5 (Schwartz and Gursky, 1973). The unidentified sources can account for about one half the background in the 2-7 keV range. Explaining the diffuse component in terms of discrete sources therefore requires another, new class of undiscovered objects, or greater emissivity of known objects in earlier cosmological epochs. Furthermore, the presently observed sources nearly all have steep spectra, kT$\sim$5keV, therefore the new class must have flat spectra, or a third origin must again be invoked for the > 50 keV X-rays.

VI. SOFT X-RAYS

This review would be incomplete without discussion of recent rocket work on cosmic X-rays in the 0.2-1.0 keV range. Here the galaxy is no longer transparent to X-rays, so fluxes measured represent a competition between photons from the diffuse component, or possibly other extragalactic sources, and absorption and production within the galaxy (Hayakawa, 1973). The X-ray sky (Friedman et al., 1973) looks markedly different in the 44-60A range ($\sim$0.35 keV) (Bunner et al., 1972) than that obtained by the **Uhuru** in Figure 2. In fact, the most intense emission is observed from the galactic poles where the hydrogen column density is a minimum.

Explaining the measured dependence on galactic latitude in terms of an origin characterized by a simple scale height above the galactic plane seems not to explain the observations at all wavelengths. Adding an isotropic extragalactic flux permits constructing a model which reconciles the data (Friedman et al., 1973). The extragalactic flux, however, should appear absorbed by nearby galaxies. This effect is not observed for the Small Magellanic Clouds (McCammon et al., 1971) and M31 (Margon et al., 1974) so the entire question of the origin of the soft X-ray background is unclear (cf. Silk, 1973). It is certain, however, that an extragalactic flux in excess of that predicted by extrapolation of the diffuse component as a power law to lower energies is not required.

In addition to the general dependence on galactic latitude, the soft X-ray flux shows special features which may be associated with the North Polar Spur, and the Vela supernova remnant (Bunner et al., 1972). As already discussed, soft X-rays have been studied from the Cygnus Loop and Puppis remnant, and possibly others. The galactic soft X-ray flux requires a superposition of sources, which may be stellar, or nebulous. Additional supernovae remnants, radio spurs, accretion onto main sequence stars, and heating in active, convective stars, such as T-Tauri type, have all been suggested (cf. Hayakawa, 1973). In the near future, spacecraft carrying experiments specifically designed for soft X-ray studies will be launched, and the long term observations will doubtless again provide new discoveries.

VII. ACKNOWLEDGEMENTS

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References

Apparao, K. M. V., 1973, *Ap. and Sp. Sci.* **25**, 3.

Baity, W. A., M. P. Ulmer, L. E. Peterson, 1974. UCSD preprint (to be published).

Baker, R. E., R R. Lovett, K. J. Orford and D. Ramsden, 1973. *Nature Phy. Sci.* **245**, 18.

Bahcall, J. N., P. C. Joss and Y. Avni, 1974. *Ap. J.* **191**, 211.

Becklin, E. E., G. Neugebauer, F. J. Hawkins, K. O. Mason, P. W. Sanford, K. Matthews and C. G. Wynn-Williams, 1973, *Nature* **245**, 302.

Borken, R., R. Doxsey and S. Rappaport, 1972. *Ap. J. (Letters)* **178**, L115.

Bradt, H., G. Garmire, M. Oda, G. Spada, B. V. Sreekantan, P. Gorenstein and H. Gursky, 1968 *Sp. Sci. Rev.* **8**, 471.

Bunner, A. N., P. L. Coleman, W. L. Kraushaar and D. McCammon, 1972. *Ap. J. (Letters)* **172**, L67.

Catura, R. C., L. W. Acton, H. M. Johnson and W. T. Zaumen, 1974. *Ap. J.* **190**, 521.

Coleman, P. L., A. N. Bunner, W. L. Kraushaar, D. McCammon, F. O. Williamson, E. Kellogg and D. Koch, 1973. *Ap. J. (Letters)* **185**, L121.

Davidson, A. and J. P. Ostriker, 1974. *Ap. J.* **189**, 331.

Evans, W. D., R. D. Belian and J. P. Conner, 1970. *Ap. J. (Letters)* **159**, L57.

Fabian, A. C., J. C. Zarnecki and J. L. Culhane, 1973. *Nature Phy. Sci.* **242**, 18.

Fabian, A. C., J. C. Zarnecki, J. L. Culhane, F. J. Hawkins A. Peacock, K. A. Pounds and J. H. Parkinson, 1974a. *Ap. J. (Letters)* **189**, L59.

Fabian, A. C., J. E. Pringle, and J. A. J. Whelan, 1974b. *Nature* **247**, 351.

Felten, J. E., 1973. *IAU Sym.* No **55**, eds. Bradt and Giacconi (Dordrecht/Boston: D. Reidel Publishing Company), 258.

Friedman, H., G. Fritz, S. D. Shulman and R. C. Henry, 1973. *IAU Sym.* No 55, *op. cit.*, 215.

Giacconi, R., S. Murray, H. Gursky, E. Kellogg, E. Schreier, T. Matilsky, D. Koch and H. Tananbaum 1974. *Ap. J. Suppl.* No 237, 37.

Gorenstein, P., B. Harris, H. Gursky, R. Giacconi, R. Norvick and P. Vanden Bout, 1971. *Science* **172** 369.

Grandi, S. A., P. M. N. O. Hintzen, E. B. Jensen, A. E. Rydgren, J. S. Scott, P. H. Stickney, J. A. J. Whelan and S. P. Worden, 1974. *Ap. J.* **190**, 365.

Griffiths, R. E., A. Peacock, P. J. N. Davison, F. Rosenberg, and N. C. Smart, 1974. *Nature* **250**, 471.

Gruber, D. G., 1974. Ph. D. Thesis, UCSD, to be published.

Gursky, H., 1972. *ASE Preprint* 3066. Presented at Les Houches Summer School (to be published).

Gursky, H., A. Solinger, E. M. Kellogg, S. Murray, H. Tananbaum, R. Giacconi and A. Cavaliere, 1972. *Ap. J. (Letters)* **173**, L99.

Gursky, H. and E. Schreier, 1974. SAO Preprint, to be presented at *IAU Sym.* No 67, Moscow.

Hayakawa, S., 1973. *IAU Sym.* No 55, *op. cit.*, 235.

Hjellming, R. M. 1973. *Science* **182**, 1089.

Holt, S. S., E. A. Boldt, P. J. Serlemitsos, S. S, Murray, R. Giacconi, E.M. Kellogg and T. A. Matilsky. 1974. *Ap. J. (Letters)* **188**, L97.

Iyengar, V. S., R. K. Manchanda, N. Durgaprasan. G. S. Gokhale, P. K. Kunte and B. V. Sreekantad, 1974a. TIFR preprint, submitted to *Nature.*

Iyenger, V. S., S. Naranan, and B. V. Sreekantan, 1974b. TIFR preprint, submitted to *Ast. and Space Sci.*

Jones, C., R. Giacconi, W. Forman and H. Tananbaum, 1974. *Ap. J. (Letters)* **191**, L71.

Kellogg, E. M., 1973. *IAU Sym.* No 55, *op. cit.*, 171.

Kellogg, E. M., S. Murray, R. Giacconi, H. Tananbaum and H. Gursky, 1973, *Ap. J. (Letters)* **185**, L13.

Krzeminski, W., 1974. *IAU Circ.* 2612.

Laros, J. G., J. C. Matteson and R. M. Pelling, 1973a. *Nature Phys. Sci.* **246**, 109.

Laros, J. G., J. L. Matteson, R. M. Pelling, 1973b. *Ap. J.* **179**, 375.

Margon, B., 1974. *Nature* **249**, 24.

Margon, B., S. Bowyer, R. Cruddace, C. Heiles, M, Lampton and T. Troland, 1974. *Ap. J. (Letters)* **191**, L117.

McCammon, D., A. N. Bunner, P. L. Coleman and W. L. Kraushaar, 1971. *Ap. J. (Letters)* **168**, L33.

Oda, M., M. Wada, M. Matsuoka, S. Miyamota, N. Muranaka and Y. Ogawara, 1972. *Ap. J. (Letters)* **172**, L13.

Ostriker, J. P. and K. Davidson, 1973. *IAU Sym.* No 55, *op. cit.*, 143.

Overbeck, J. and H. Tananbaum, 1968. *Phys. Rev. Letters* **20**, 24.

Pal, Y., 1973. *IAU Sym.* No 55, *op. cit.*, 279.

Parkinson, J. H., K. O. Mason and P. W. Sanford, 1974. *Nature* **249**, 746.

Peterson, L. E. and A. S. Jacobson, 1970. *Pub. of Ast. Soc. of the Pacific* **82**, 412.

Peterson, L. E., R. M. Pelling and J. L. Matteson, 1972. *Sp. Sci. Rev.* **13**, 320.

Peterson, L. E., 1973. *IAU Sym.* No 55, *op. cit.* 51.

Pounds, K. A., 1973. *IAU Sym.* No 55, *op. cit.*, 105.

Prendergast, K. H. and G. R. Burbidge, 1968. *Ap. J. (Letters)* **151**, L83.

Rapley, C. G. and I. R. Tuohy, 1974. *Ap. J. (Letters)* **191**, L113.

Rappaport, S., R. Doxsey, A. Solinger and R. Borken, 1974. Preprint, submitted to *Ap. J.*

Rothschild, R. E., E. A. Boldt, S. S. Holt and P. J. Serlemitsos, 1974. *Ap. J.* (*Letters*) **189**, L13.

Schreier, E., R. Levinson, H. Gursky, E. Kellogg, H. Tananbaum and R. Giacconi, 1972. *Ap. J.* (*Letters*) **172**, L79.

Schwartz, D.A., 1970. *Ap. J.* **162**, 439.

Schwartz D. A. and H. Gursky, 1973, *GSFC Sym. on Gamma-Ray Astrophysics*, *NASA SP*-339, 15.

Shklovsky, I. S., 1972. *Nature* **238**, 144.

Silk, J., 1973. *Ann. Rev. Astr. and Ap.* **11**, 269.

Stevens, J. C. and G. P. Garmire, 1973. *Ap. J.* (*Letters*) **180**, L19.

Stevens, J. C., G. R. Riegler and G. P. Garmire, 1973, *Ap. J.* **183**, 61.

Strong, I. B., R. W. Klebesadel, R. A. Olson, 1974. *Ap. J.* (*Letters*) **188**, L1.

Tananbaum, H. D., 1973. *IAU Sym.* No. 55, *op. cit.*, 9.

Trombka, J. I., A. E. Metzger, J. R. Arnold, J. L. Matteson, R. C. Reedy and L. E. Peterson, 1973. *Ap. J.* **181**, 737.

Ulmer, M. P., W. A. Baity, W. A. Wheaton and L. E. Peterson, 1973. *Ap. J.* (*letters*) **184**, L117.

Vaiana, G. S., J. M. Davis, R. Giacconi, A. S. Krieger, J. K. Silk, A. F. Timothy and M. Zombeck, 1973. *Ap. J.* (*Letters*) **185**, L47.

Vidal, N. V., D. T. Wickramasinghe, B. A. Peterson and M. S. Bessell, 1974. *Ap. J.* (*Letters*) **191**, L23.

Zel'dovich, Ya. B. and I. D. Novikov, 1971. *Relativistic Astrophysics* (Chicago : University of Chicago Press), Chapter 13.

EIGHTH ESLAB SYMPOSIUM ON HII REGIONS AND THE GALACTIC CENTRE

A symposium on HII regions and the galactic centre was organised by the Space Science Department of the European Space Research Organisation. It was held at ESRO Establishment in Frascati, Italy, from June 4 to June 7.

About forty papers were presented at the symposium. The papers presented included observations at infrared, millimetre and radio wavelengths. A large number of papers on the observations in the infrared region reflected the growing interest in this field. There was an emphasis on the correlation of observations made at different wavelengths, and on the role of dust, and molecules associated with HII regions.

The infrared emission from HII regions and the role of dust in this emission was discussed in detail. The observations in 1-25μ region indicate that most of the emission is from dust grains which are well mixed with the ionised gas. Resonantly trapped Lyman α photons can account for the heating of dust. The absorption feature around 10μ, usually associated with silicates, shows similar structure for many different sources, and its optical depth is correlated with the depth of H_2CO absorption obtained from radio observations. The observations at longer wavelengths ($\geqslant 40\mu$) show source sizes comparable to radio contiuum sizes, and the two luminosities are also correlated. The cool dust and molecular clouds,(which give the absorption feature around 10μ,) could be responsible for longer wavelength emission.

The association between the infrared emission and molecular sources was also a topic covered in detail. The observations at 1-20 μ infrared wavelengths have shown sources associated with molecular masers within HII regions. These sources do not have a radio continuum and are possible candidates for protostars. Association of CO emission was reported with far infrared ($\sim 100\mu$) sources, and with sources having excess emission at short infrared wavelengths.

A paper reported the observation of preferential association of OH masers with compact sources and lack of association with broad sources in HII regions. This indicates that the star in the process of arriving at the main sequence gives rise to a maser, but as the star heats up the maser disappears.

Several models of infrared emission and absorption from dust towards the galactic centre were discussed. A picture consisting of a hot core, of a few parsec, and a cooler halo emerges if the dust is assumed to have a resonance behavior at 10μ. This resonance picture is consistent with the observed absorption feature around 10μ. The calculations based on the 10μ absorption feature indicate an average hydrogen density of about 5 atoms. cm^{-3} in the galactic centre direction, assuming normal silicon abundance and the source of absorption feature as silicates. A lower value of hydrogen density would require a high silicon abundance. The observations on association Cyg OB2 were also suggestive of a very high dust to gas ratio.

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