SOME NEW RESULTS IN X-RAY ASTRONOMY PRESENTED AT THE ANNUAL MEETING OF THE HIGH ENERGY ASTROPHYSICS DIVISION OF AAS

The annual meeting of the High Energy Astrophysics Division (HEAD) of the American Astronomical Society on "X-ray Astronomy" was held between January 28-30, 1980 at the Harvard/Smithsonian Center for Astrophycics, Cambridge, USA. This meeting was followed by a "Workshop on Cool Stars" on January 31, 1980. The main theme of the HEAD meeting was to review and discuss recent results obtained with the Einstein Observatory. Theoretical interpretation of these results and other related observations of X-ray sources were also discussed at this meeting. The first two days of the meeting were devoted to a series of reviews on the observational results on the various categories of galactic and extragalactic objects and their theoretical interpretations. The third day was completely devoted to contributed papers from scientists of the four consortium institutions, involved in the design and development of the Einstein Observatory, as well as from the various Guest Investigators on the Einstein.

1. EINSTEIN OBSERVATORY

The Einstein Observatory consists of a focusing X-ray telescope sensitive in 0.1—4 keV energy band and has several kinds of instruments at the focal plane for low and high resolution imaging and spectroscopy of X-ray emitting objects. Four of the main instruments most extensively used for observations are: (I) Imaging Proportional Counter (IPC) used for obtaining X-ray images of objects to an angular resolution of about 1 arc minute; (II) High Resolution Imager (HRI) which provides high angular resolution images of X-ray sources to a limiting resolution of about 2 arc seconds; (III) Solid State Spectrometer (SSS) which consists of a lithium drifted silicon detector having an energy independent resolution of about 160 eV FWHM in 0.5-4.5 keV energy band and is used for spectroscopy of X-ray sources; (IV) Focal plane crystal spectrometer which is used for high resolution spectroscopy.

2. Observations of Stellar Sources

Before the launch of Einstein, only a few categories of late spectral type stellar objects had been discovered as X-ray emitters, mainly with the HEAO-1 observatory. This included RS Canum Venaticorum (RS CVn) group of binaries like Capella, UX Ari etc., cataclysmic variables like SS Cygni, U. Gem etc., and a few flare stars like UV Ceti, YZ CMi etc. The Einstein Observatory has now discovered that stars of all spectral types are X-ray emitters and that early type stars are bright X-ray sources. This has been an unexpected and important result from the Einstein. Observations of non-degenerate stellar X-ray sources and interpretation of X-ray emission as coronal emission from coronae around these stars were discussed in detail in review talk as well as in a number of contributed papers. Observations of the stars of various spectral type carried out so far suggest a correlation between the X-ray luminosity (L_X) and the spectral type of stars. In general, early-type stars are brighter X-ray sources than the late-type stars. For OB stars, observed values of L_X lie in 10^{32}—10^{33} ergs / secs range and decreases as one goes to later spectral types being $\sim 10^{30}$ ergs/sec for A9 stars and $\sim 10^{27}$-ergs/sec for M stars. Within stars of a given spectral type, the value of L_X however varies by about two orders of magnitude. Analysis of the Smithsonian Astrophysical Observatory (SAO) group suggests that within a spectral group, rapidly rotating stars appear to be brighter X-ray sources, indicating that rotation plays a very significant role in the evolution of X-ray sources.

(a) Early Type Stars :

Observations of several O and B supergiants like ϵ Ori (B0Ia) and κ Ori (B0.5Ia) which were detected at flux levels of 5 x 10^{-12} and 2 x 10^{-12} ergs/cm^2-sec respectively, indicate that the energy spectra of these stars are consistent with the corona + warm wind model of Cassinelli and Olson. A survey of OB associations and clusters carried out by the SAO group led to the discovery of X-ray emission from 26 of the O stars in these associations. The brightest X-ray source amongst all these stars is HD 93129 in Cluster Trumpler 14. Average value of L_X for these stars is $\sim 10^{33}$ ergs/sec and average ratio of X-ray luminosity to optical luminesity (L_X/L_O) for these stars is found to be $\sim 10^{-4}$. The SAO group interprets its observations in terms of emission from coronae around these stars. Observations of several binary systems, both components of which are stars of spectral type O/B, like γ Gem, HD 47129, HD 159176, indicate a possible correlation between L_X and the orbital period of the binary, L_X being higher for short period binaries.

(b) Late Type Stars :

A magnitude limited survey of stars brighter than $m_V \leq 8.5$ carried out by the SAO group resulted in 33 detections (at $\geq 3\ \sigma$ level) out of 276 stars surveyed in an area covering 180 square degrees of sky. This survey revealed F stars as the most copious X-ray emitters, with 31% of the surveyed F stars detected as X-ray sources. Average value of L_X for F stars was found to be 10^{29} ergs / sec and the ratio L_X / L_O to be about 10^{-4}. Another survey of very late type dwarf stars (late dK to dM) showed that every such star which was looked at, was a soft X-ray source. The principal conclusion of this survey was that very late type dwarf stars constitute a class of soft X-ray emitters, with their average L_X in the range of $10^{27} - 10^{28}$ ergs /sec the lower value of L_X being the same as observed for the quiet Sun. A small fraction of these dwarf stars were however found to be exteremely bright with $L_X \sim 10^{30}$ ergs / sec.

Observations of the nearby binary α Centauri (G2 V + K IV) with HRI showed both stars as X-ray emitters, with the optically faint K IV star being brighter X-ray source by factor of 2 compared to its companion. Detection of a bright X-ray flare from Proxima Centauri was also reported. Another nearby multiple star system, Wolf 630, which has 4 stars, was observed with HRI and two of the stars of spectral types dM 3.5e and dM4e were detected as flaring X-ray sources, with peak flux of $\sim 1.5 \times 10^{-11}$ erg/cm²-sec.

(c) RS CVn Binaries :

In the Cool Star Workshop, Einstein Observations of RS CVn group of binary stars, which had been earlier discovered as a new class of soft X-ray source with the HEAO-1 observatory, were reported. All of the 37 RS CVn binaries, belonging to both the regular and long period groups, which were looked at, were detected as X-ray emitters with L_X in the range of 10^{30}—6×10^{31} ergs/sec. No dependence of L_X on the phase of photometric wave, as reported earlier for one of the RS CVn system UX Ari, was however detected. Discovery of X-ray flares from a new RS CVn like binary identifietd wih HD 8357, was also reported from HEAO-1. One of the most interesting results presented at this meeting concerned the X-ray spectra of several RS CVn binaries obtained with the SSS. These binaries included Capella, RS CVn, UX Ari, HR 1099, AR Lac, λ And, σ CrB. The spectra of some of these RS CVn binaries clearly reveal the presence of X-ray emission lines of magnesium, silicon, sulphur and iron (L-transition lines). The K-X ray lines of silicon at about 1.8 keV stand out quite strongly in the spectrum of Capella and are also seen unambiguously in the spectrum of σ CrB. The observed X-ray spectrum of σ CrB, based on about 9000 sec of pointed mode observation with SSS, is shown in Fig. 1, with the positions of the X-ray lines indicated by arrows. Detection of X-ray emission lines has made it possible for the first time to measure elemental abundances in these X-ray emitting stars based on X-ray data alone, and make comparison with similar measurements made in the optical band. A detailed study of the spectra of several RS CVn binaries now shows that there is no evidence for under aboundance of iron and other heavy elements in the RS CVn systems as has been indicated for some RS CVn objects from optical observations. The presence of X-ray emission lines also beautifully confirms the thermal origin of X-rays and show that the X-ray emission most probably comes from hot coronae around the X-ray emitting stars in these binaries. The requirement of two temperature component spectral fits to the observed X-ray spectra is however inconsistent with isothermal coronae. The X-ray data are best explained in terms of an inhomogeneous corona in which the X-ray emitting plasma is confined to magnetically contained loops, as explained by Rosner, Tucker and Vaiana for the Sun.

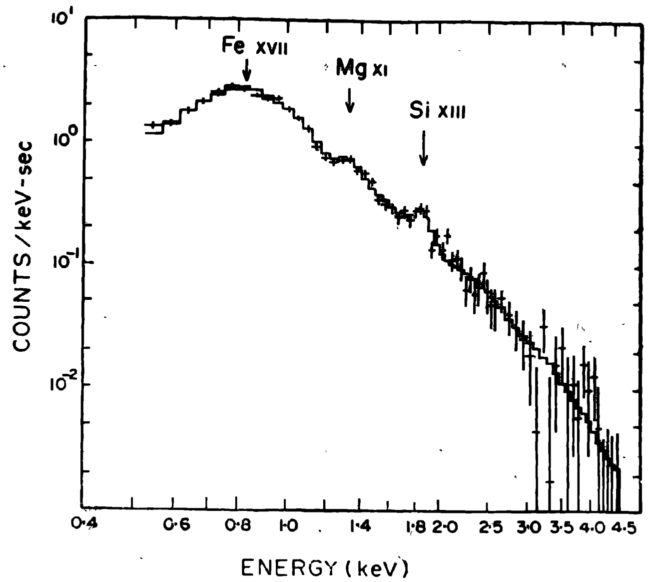

Fig. 1 : The X-ray spectrum of σ Cr B observed with the solid state spectrometer (SSS) on the Einstein Observatory.

(d) Cataclysmic Variables :

Several cataclysmic variables like SS Cygni, U Gem etc. had been discovered as flaring X-ray sources with HEAO-1. Observations of 12 more cataclysmic variables were carried out with the Einstein Observatory and nine of these stars were detected as X-ray emitters. All the sources were found to have hard spectra ($kT \geq 5$ keV) and their flux values ranged from 1×10^{-11} erg/cm²-sec to 2×10^{-13} erg/cm²-sec in 0.15—4.5 keV range. The well known magnetic rotator DQ Her was however not detected, 2 σ upper limit on its flux being 1×10^{-13} erg / cm² - sec.

(e) Theoretical Interpretation :

Theoretical interpretation of X-ray emission from non-degenerate stars was given by J. Linsky. It was emphasised that conventional theory of formation of corona due to heating by acoustic energy flux is inconsistent with the recent Einstein observation of coronal emission from stars of all spectral types. In particular, it is difficult to explain formation of coronae around O and B stars, a large number of which have been detected by the Einstein. It was proposed that coronal heating is due to conversion of magnetic field energy via hydrodynamic waves and coronal current. It was also suggested that rotation plays a very critical role in the formation of stellar coronae.

3. SUPERNOVAE REMNANTS (SNRs)

Another category of galactic objects on which the Einstein has produced truly remarkable results are supernovae remnants (SNRs). Results on SNRs and their interpretations were discussed in two review talks as well as in a large number of contributed papers. Of the 120 or so known SNRs in the galaxy, 9 had been discovered as X-ray sources till 1975. X-ray emission from 7 more SNRs was discovered with the HEAO A-2 experiment. For a few SNRs like Cygnus Loop, Vela X, Puppis A and Cas A, X-ray surface brightness distribution maps, with relatively coarse resolution, were available before the launch of Einstein. There was no available information concerning the X-ray structure of the remaining SNRs. Similarly, the X-ray spectra of the SNRs were of insufficient resolution to unambiguously show the presence of X-ray lines in the spectra. The imaging instruments on the Einstein have now produced very beautiful X-ray images of a large number of these SNRs, which reveal shell structure, limb brightening effect, presence of knots etc. in many of these SNRs. As a result, it is now possible to compare these high resolution X-ray maps with similar maps in the optical and radio regions.

(a) Kepler's SNR :

X-ray image of Kepler's SNR obtained with HRI is a fine example of a near perfect shell-like structure. Limb brightening effect is also clearly revealed in the image. It is found that X-ray and radio morphologies are remarkably similar in this SNR. There is however no evidence for a reverse shock. The sruface brightness along the shell varies by a factor of 3. The shell thickness is estimated to be 0.7 pc and the radius of the SNR is found to be 4 pc. There is no evidence for a compact object at the center of the X-ray shell and the limit on the temperature of any such object is $\leq 2.5 \times 10^6$K.

(b) Puppis A SNR :

The HRI image of Puppis A however indicates a highly complex X-ray morphology for this SNR. The X-ray and radio shells coincide and show good correlation in brightness. However the interior of the SNR reveals many diffuse emission features, bright knots, and filaments, many of which have no corresponding counterparts in the optical or radio maps. Along the edge of the remnant one sees remarkably sharp fall-off in X-ray intensity conincident with the shock front as identified by radio observations. The highest X-ray surface brightness region includes the nebulosity from which Fe XIV (5303A°) coronal line has been detected. The shell thickness for Pup A is found to be 0.65 pc. Extensive observations of Puppis A with FPCS have led to detection of X-ray lines of O VIII and O VII. A detailed analysis of the intensities of these lines indicates that hot plasma in Puppis A is near thermal equilibrium and has a temperature of $\backsim$ (2-5) x 10^6 K. Besides oxygen, lines, the FPCS has also detected lines from Ne IX, Ne X, Mg XI and Fe XVII ions. The neon lines are found to be unexpectedly strong and suggest that Ne/O abundance ratio in Puppis A is about twice that in the Sun.

(c) Cas A SNR :

The FPCS has also made extensive observations of Cas A. Earlier measurements of the X-ray spectrum of Cas A with the SSS had revealed strong emission lines of silicon, sulphur and argon consistent with transitions of helium-like ions. Better resolution observations with FPCS now identify the sulphur and silicon emission features as due to Lyman Alpha line from S XVI and the trio of $n = 2 \longrightarrow n = 1$ lines from both S XV and Si XIII. Comparison of the relative strengths of the lines indicates that in Cas A ionization of silicon and sulphur are in a stage where helium-like and hydorgen-like ions are abundant but lithium-like ions are rare.

(d) RCW 103 SNR :

The Einstein has made a remarkable discovery in the SNR RCW 103 which was first discovered as a soft X-ray source with the HEAO A-2 experiment. This SNR is relatively young (age $\leq 10^3$ years) and its distance is estimated to be $\backsim$ 3.3 kpc. It has also been optically identified. Observations of RCW 103 with HRI by the Califorina Institute of Technology group show a nice shell structure. Bright X-ray regions coincide with bright optical filaments. At the centre of the shell is located a point-like X-ray source from which 40 excess counts were detected. An optical search shows a 20th magnitude stellar object close to the position of the X-ray source. If association of the point source with the SNR is real, then the X-ray source is most probably the stellar remnant of the supernova explosion i.e. a neutron star. This will make RCW 103 the third SNR, Crab Nebula and Vela X being the other two, in which a stellar remnant has been detected. Assuming the X-ray source to be a neutron star, its temperature and luminosity are derived to be (2.3 — 2.5) x 10^6K and 2.5 x 10^{34} ergs/sec respectively.

(e) SN 1006 :

Generally SNRs with shell structure have thermal spectra, as indicated by the presence of X-ray emission lines. Results from Einstein show that this is not true for the SN1006. The IPC observations of this object show a limb brightened shell of about 30′ diameter. Enhanced X-ray emission is seen in two quadrents (NE and SW) and the bright region appears like the cresent moon. In the 1/4 keV band, however, the shell appears filled. Large spectral variations are also detected over the object. It is however surprising that the X-ray spectrum of SN 1006 measured with the SSS shows no evidence for X-ray emission lines and indicate only a continuum spectrum similar to that of the Crab Nebula. The X-ray spectrum is well described by a power law model with photon number index of -2.15. The power law fit suggests that the X-ray emission from SN 1006 is due to synchrotron process. This raises the possibility of the presence of a pulsar in SN1006.

(f) Other SNRs :

Two SNRs which have a Crab-like amorphous structure in the radio band were also observed by the Einstein. These objects are 3C58 and MSH11-54. The HRI images of both these objects appear disc-like with no evidence for shell structure. The X-ray spectrum of MSH11-54 obtained with the SSS, however, shows intense X-ray lines, indicative of thermal origin for the X-rays. However, no line emission is detected in the spectrum of 3C58, which is a pure continuum spectrum described by a power law, indicating a non-thermal emission mechanism in this source. Another SNR W44, which has a clear shell structure in the radio, shows no such structure in its IPC image and its X-ray structure looks amorphous like that of the Carb Nebula. From this summary, it is clear that X-ray morphologies of the various SNRs show wide variations and that these are not always similar to their radio morphologies.

4. LARGE MAGELLANIC CLOUD (LMC)

The Columbia Astrophysics Laboratory (CAL) has carried out an extensive survey of LMC, the nearest extragalactic object, with IPC on the Einstein. LMC is an irregular galaxy located at a distance of 52 kpc. Before the Einstein survey, six X-ray sources had been discovered in previous observations of LMC. The CAL survey has so far resulted in the discovery of 75 X-ray sources, at significance level of $\geq 5\,\sigma$, in the LMC. Of these sources, 21 can be identified with the known radio / optical SNRs in the LMC. Most of the remaining sources are yet to be identified. The X-ray emitting SNRs in LMC differ in two respects from those in our galaxy. Firstly, SNRs in LMC are intrinsically brighter than those observed in our galaxy. Thus while 10 SNRs in LMC have L_X in $10^{36} - 10^{38}$ ergs / sec, there are only 5 SNRs, in our galaxy with $L_X \geq 10^{36}$ ergs / sec. Secondly energy spectra of SNRs in LMC are markedly softer than those observed for the galactic SNRs. Of the remaining unidentified point sources, 10 have $L_X \geq 10^{36}$ ergs / sec. The LMC X-ray survey indicates that the X-ray luminosity per unit mass of LMC is three times that of our Galaxy.

5. SURVEY OF M31 (Andromeda Nebula):

The nearest normal spiral galaxy M31 has been carefully surveyed by the SAO group with the IPC on the Einstein. Preliminary results of this survey had been published earlier. This survey has so far led to the detection of 88 point sources with $L_X \geq 10^{37}$ ergs/sec. in M31. Of these sources, 17 have been identified with the globular clusters, and their average L_X value is $\sim 5 \times 10^{37}$ ergs/sec. One of the X-ray sources in M31 has been found to be pulsating with a period of 8.35 sec. The statistical significance for pulsation is at about 5-1/2 σ level.

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ANNOUNCEMENT

The Sixth Scientific and General Body Meetings of the Astronomical Society of India will be held at the Physical Research Laboratory, Navrangpura, Ahmedabad 380 009 between November 25-29, 1980; Prof. B. Pratap is the Chairman of the Local Organizing Committee. Abstract of papers to be presented at the scientific meeting should reach Dr. K. R. Sivaraman, Convenor, Programme Committee, Indian Institute of Astrophysics, Sarjapur Road, Bangalore 560 034 before August 31, 1980. A special session on the Total Solar Eclipse of February 16, 1980 will be held.

Application for travel grants accompanied by full text of the paper should also reach Dr. Sivaraman by August 31, 1980.

Have you Renewed your Membership of the Astronomical Society of India ? or your Subscription to the Bulletin of the Astronomical Society of India? If not, Please Send The Money to Dr. M. B. K. Sarma, Treasurer, A.S.I., Department of Astronomy, Osmania University, Hyderabad 500 007, India.