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FUTURE X-RAY AND GAMMA RAY OBSERVATIONS OF SUPERNOVA 1987A

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Abstract

A brief outline of the prospects for carrying out x-ray and gamma ray observations of SN 1987A in the near future is presented in this paper.

1.0 Introduction

At present there are three satellites carrying x-ray and gamma ray instruments suitable for observations of SN 1987A. They are the Japanese 'Ginga' x-ray astronomy satellite, the Russian 'MIR' space station with its 'KVANT' x-ray observatory and the American "Solar Maximum Mission" with its hard x-ray/ gamma ray spectrometer. A number of exciting results have already been reported from observations using these instruments. These include the earlier than expected detection of x-ray emission from the SN, the observation of a rather hard x-ray spectrum, possible time variability of the medium energy x-rays and the discovery of 847 KeV gamma ray line expected from the decay of $^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$. The above instruments will almost certainly monitor the supernova in the near future also.

A number of x-ray and gamma ray astronomy satellites are planned to be launched during the decade 1990 - 2000 AD. Prominent among them include the German 'ROSAT' x-ray imaging telescope, the American 'Advanced X-ray Astrophysics Facility ' (AXAF), the European 'X-ray Multiple Mirror' (XMM) mission and the American 'X-ray timing explorer' (XTE). The Italian satellite for x-ray astronomy (SAX) and the Indian x-ray astronomy satellite experiment (IXAS) are also planned for launch during that decade. The American 'Gamma Ray Observatory' (GRO), waiting for launch onboard the shuttle during the early 1990's will form the major facility for gamma ray observations of the supernova in the next decade. We shall present in this paper some of the salient features of the above missions.

2.0 X-ray astronomy missions

2.1 Existing Missions

2.1.1 The Ginga X-ray astronomy satellite

As mentioned earlier, the Japanese Ginga satellite has already discovered an unusual hard x-ray emission from SN 1987A (Dotani et al., 1987). The satellite was launched in February 1987, fortunately just in time before the signals from the explosion reached the earth. The observatory's main instrument consists of a large area (4000 cm^2) proportional counter operating in the energy range of 2-30 KeV and fitted with slat collimators of FOV $2^o X 4^o$ FWHM. Since the supernova is only about 0.6^o away from the strong soft x-ray source LMC X-1, it was necessary to offset the collimator and carry out a scan manoeuvre, to separate the flux from the supernova alone. Even so, the flux measurements below 10 KeV are likely to be contaminated by the contributions from LMC X-1 and the weak source SNR 0540-69.3. This might probably explain partly the large temporal variations of the flux from the SN during June - October 1987. Fortunately SN87A has a hard spectrum above 10KeV and hence the Ginga observations will continue to make important contributions towards flux measurements in the energy range 10 - 3o KeV in the coming years. This is also important as a check and calibration of the hard x-ray observations from the Kvant x-ray observatory.

The Ginga measurements showed a flux from the SN of $\sim 5X10^{-11}$ erg cm^{-2} s^{-1} in the energy range 10-30KeV. This gives a luminosity of $\sim 1.5X10^{37}$ erg s^{-1} for a distance of 50 kpc. At present, the observed hard x-ray fluxes could be explained in terms of Comptonisation of the 847 KeV gamma ray line resulting from radioactive decay of ^{56}Co $\rightarrow$ ^{56}Fe. As and when the central pulsar, likely to exist at the site of the explosion, shows up above the continuum, the Ginga observatory may be one of the few lucky instruments that may discover it.

2.1.2 The Kvant x-ray observatory

The Russian space station MIR carries the Kvant x-ray observatory which consists of several instruments from European and Russian astronomical institutes. Hard x-ray emission from SN87A during Aug-Sept 1987 has already been detected by two of the telescopes (Sunyaev et al., 1987). The measurements indicate a hard spectrum from 20 KeV to 300 KeV with a photon power law index of ~1.4. A luminosity over the same energy range of $\sim2X10^{38}$ erg s^{-1} (assuming a distance of 55 kpc) has been reported.

The Kvant observatory has four x-ray telescopes. The Pulsar X-1 x-ray spectrometer (Space Research Institute, Moscow consists of 4 hard x-ray detectors operating in the energy range of 50KeV - 1000KeV.Each detector is made up of a phoswich of 20cm X 3cm NaI(Tl) coupled to a 20cm X 3cm CsI(Tl).Graded shield passive collimators of lead and copper restrict their FOV to $3^{o}X3^{o}$ FWHM.

The high energy x-ray experiment HEXE (Max Planck Institute, Munich and Astronomy Institute, Tubingen) consists of four phoswich detectors with total effective area of $800cm^{2}$. They operate in the energy range 20-250KeV. Each detector employs a $143X143X3.2\ mm^{3}$ NaI(Tl) coupled to a $143X143X50.8mm^{3}$ CsI(Tl) scintillation crystals viewed by PMTs. Two honey-comb collimators restrict the FOV to 1.6^{o} FWHM. Each collimator can be tilted individually by $2.3^{\smile}$ at 2 arc min intervals.

The coded mask imaging spectrometer, TTM (Space Research Institute, Utrecht and University of Birmingham) employs a pseudo random coded mask camera in which a position sensitive multiwire proportional counter operating in the energy range 2-32 KeV serves as the two dimensional imaging sensor. It has an FOV of $7.8^{o}X7.8^{o}$ FWHM and a fine angular resolution of 1.8 arc min. Although the TTM did image the region of the supernova during August -September 1987, it could only place an upper limit on its emission in the medium energy x-ray range. This upper limit is however not consistent with the higher fluxes reported by the Ginga team. As the energy source from radio active decay of ^{56}Ni fades away with the expansion of the SN envelope, the likely pulsar within the nebula will be detected if its luminosity is of the order of $10^{37}-10^{38}$ erg s^{-1}.

The Kvant also carries a gas scintillation proportional spectrometer, Sirene-2 (Estec,Noordjvik) that operates in the energy range 2-100 KeV. It has a FOV of $2^{o}X2^{o}$ FWHM and an effective area of 314cm^{2}. Surprisingly no data from this instrument is available in the report of the discovery of hard x-ray emission from SN 1987A using the Kvant observatory.

2.2 Planned/Proposed Missions

2.2.1 ROSAT x-ray imaging telescope

Awaiting a shuttle launch early in 1990's, the West German ROSAT mission carries an x-ray imaging telescope that is more sensitive than that of the Einstein observatory (Trumper, 1982). The fourfold nested Wolter type I x-ray mirror system has an outer aperture of 83cm and a focal length of 240cm. The unobscured collecting area is 1141 cm^{2}.The energy response extends from 0.1 to 2 Kev. The focal plane instruments consist of two position sensitive proportional counters (PSPC) and a high resolution imager (HRI). The telescope with the

PSPC provides a circular FOV of 2^{o} and on-axis angular resolution at 1 KeV of 30arc sec (FWHM). With HRI it offers a 36 arc min FOV and 7arc sec on-axis angular resolution.

ROSAT will also carry a British wide field XUV camera operating in 0.041 to 0.21 KeV energy range. The latter has a 5^{o} FOV and an on-axis angular resolution of 1 arc min.

ROSAT mission envisages an all-sky survey during its first 6 months in orbit. After completion of this survey, the instruments will be used for detailed observations of selected objects, which will definitely include SN 1987A, with respect to spatial structure, spectra and time variability. For pointed mode observations, the sensitivity of the ROSAT telescope in the HRI mode is a factor of 2 higher than that of Einstein observatory. In the PSPC mode it is higher by a factor of 2 to 5 depending on the exposure duration.

2.2.2 Indian x-ray astronomy satellite

The Indian SROSS-4 satellite to be launched in early 1990's will carry an x-ray astronomy payload. The instrumentation will consist of two proportional counters (PPC) with an effective area of 400 cm^{2} for pointed-mode observations and one monitor proportional counter (MPC) with an effective area of 60 cm^{2} for scan mode observations. The counters will operate in the energy range 2-20 KeV and 2-10 KeV respectively. The PPCs will have an FOV of $3^{o}X3^{o}$ FWHM and the FOV of the MPC will be $1^{o}X60^{o}$ FWHM.

Broad band counting rates and pulse height spectra will be measured simultaneously. The best time resolution available is 1ms. The processing electronics employs an 80086 microprocessor. A total of 6.6 megabits of memory is available for data storage. In order to search for a central pulsar at the site of SNR 1987A, the above memory is sufficient to store 16s of data at 1ms integrations.

The five sigma sensitivity of the PPC's for a 5 minute exposure is estimated to be 10 Uhuru flux units (1 UFU = 1 Uhuru count s^{-1} = $2.4X10^{-11}$ erg cm^{-2} s^{-1} in 2-10 KeV).

Hence, a two hour exposure will be needed to detect SN1987A at 5σ level of confidence if the luminosity of the source during early 1990's is atleast as high as that detected in September 1987 (i.e., if the central pulsar is very active by that time!)

2.2.3 Advanced x-ray Astrophysics Facility (AXAF)

NASA's Advanced X-ray Astrophysics Facility scheduled for space shuttle launch in the middle of 1990's and designed for an operational life of atleast 15 years, will be one of the most powerful instruments ever flown into space by mankind (Weisskopf, 1985) . The x-ray telescope will consist of 6 nested Wolter type I mirror assemblies, with an outer aperture of 120cm, inner aperture of 60cm and focal length of 10m. The geometrical area is 1700 cm^2 and the on-axis angular resolution 0.5 arc sec. The energy response extends from 0.1 KeV to nearly 10 KeV, which therefore includes the complex of spectral lines due to highly ionised iron. The focal plane instruments consist of

- An array of x-ray CCD's with sub arcsec angular resolution and 150 eV energy resolution
- X-ray calorimeter with better than 10 eV energy resolution and high quantum efficiency over the entire AXAF band width.
- A microchannel plate imager with 32' X 32' FOV and 0.5 arc sec angular resolution
- A Bragg crystal spectrometer employing a variety of crystals with resolving power ranging from 50 to 2000 at selected energies within the AXAF bandwidth.
- High energy transmission gratings with resolving power ranging from 1000 to 100 in the energy range 0.5 - 9 KeV and
- Low energy transmission gratings wherein resolving power varies from 2000 to 100 in the energy range 0.1 to 2 KeV.

The volume of space accessible to AXAF for sampling will increase by a factor of 1000 over that sampled by the Einstein observatory. Even the coronae of O and B stars in the Magellanic clouds will be detectable. The likely baby pulsar within the remnant of SN 1987A will most likely be detected by its thermal x-ray emission even if its x-ray beam is not directed towards the earth!

2.2.4 The x-ray timing explorer

NASA's x-ray timing explorer (XTE) proposed for launch by the middle of 1990's, is designed for high sensitivity temporal studies and broadband spectroscopy of compact x-ray sources in the energy range 2-60 KeV (McClintock and Levine, 1983). The instrumentation will consist of an array of Xenon-methane proportional counters (PCA) with an effective area of 1 m^2, operating in the energy range 2-60 KeV and fitted with tubular collimators of FOV 1^o FWHM. The smallest integration time will be 10 μs. Pulse height analysis with 128 channels will be possible. At the rate of 20 bits to characterise the timing spectral and other information for detected event SN 1987A at its present luminosity is expected to produce about 4 kilobits of data every sec. The instrument can detect a source at $5X10^{-4}$ Crab intensity in about 20 sec with 30% accuracy.

The XTE will also have onboard a NaI/CsI phoswich detector, with effective area of 2000 cm^2, and FOV of 1^o FWHM co-aligned with PCA and operating in the energy range 20-200 KeV. A set of all sky cameras will monitor the entire sky once every orbit for the detection of x-ray transients.

2.2.5 X-ray multi-mirror mission

ESA's X-ray multi-mirror mission (XMM) is a high throughput x-ray spectroscopy observatory, proposed for launch towards the latter half of 1990's (Bely-Dubau et al., 1987). The emphasis is to achieve large collecting areas over the energy range 0.2 -10 KeV, with some sacrifice in the achievable angular resolution. The design envisages a collecting area of 10000 cm^2 at 2 KeV, reducing to 5000 cm^2 at 10 KeV and an angular resolution better than 30 arc sec at 7 KeV. An array of four or seven (under study) co-aligned telescopes, each with 58 nested thin shell Wolter type I mirrors and a focal length of 8m is being considered. Focal plane instrumentation will consist of low resolution spectrometers (E/ΔE upto 60) that use CCDs, GSPCs PSPCs Si (Li) solid state detectors and/or x-ray bolometers as x-ray sensors, and high resolution grating and Bragg crystal spectrometers.

2.2.6 The SAX mission

The Italian satellite for x-ray astronomy (SAX), to be launched by space shuttle in early 1990's, is designed for x-ray observations in the energy range 0.1 to 200 KeV (Spada, 1983).

It carries instrumentation consisting of:

- X-ray concentrators - spectrometers for imaging a 30 arc min FOV with moderate angular resolution ($\sim$1 arc min) with effective area of 175 cm^2 at 7 KeV and broadband spectroscopy ($\lambda/\Delta\lambda \sim 10$) in the energy range 0.1 to 10 KeV using position sensitive GSPCs.

- continuum and cyclotron line spectroscopy ($\frac{\lambda}{\Delta\lambda} \sim$ 5 to 20) in the energy range 3 - 200 KeV using high pressure GSPCs (3 -120 KeV) and phoswich detector systems: GSPC will have an effective area of 350 cm^2 at 7 KeV and FOV of 1^o FWHM. The phoswich (15-200 KeV) will have 680 cm^2 effective area and 1.5^o FOV (FWHM) and

- coded mask wide field cameras (2-30 KeV) for detection of X-ray transients/x-ray bursters.

It is estimated that the GSPC can detect SN 87A at 5σ level during an integration lasting about 2000 sec.

3.0 Gamma ray astronomy missions

3.1 The Solar maximum mission

As mentioned in the introduction, the Solar Max satellite's Gamma Ray Spectrometer has already been used to measure the 847 KeV gamma ray line emission from the supernova at a level of $(1.0 \pm 0.25) \times 10^{-3}$ photons $cm^{-2}\ s^{-1}$ during August 1 to October 31, 1987. The Gamma ray spectrometer consists of 7 NaI(Tl) detectors, each being 7.6 cm diameter by 7.6 cm thick, surrounded by 2.5cm thick CsI(Na) shield on the sides and 7.6 cm thick CsI(Na) at the back. The detectors are trained onto the sun and the SN87A virtually shines on to the detectors from the sides. No angular resolution is therefore applicable and hence the emission from the source is estimated by subtracting the background rates when the source is occulted by the earth. The instrument operates in the energy range 0.3 to 9 MeV. Pulse height analysis in this entire range with 476 channels is available every 16.4 s. In the restricted energy range of 3.5 - 6.5 MeV and 0.3 -0.35 MeV, time resolutions of 2 s and 64 ms respectively are also available. SMM observations of SN 87A will definitely continue, but the instrument is not suitable for the detection of a fast pulsar within the remnant. Since the energy resolution of the detectors at 660 KeV is about 7% only, detailed study of the profiles of the 847 KeV linewill also be difficult.

3.2 The Gamma Ray Observatory

Awaiting a shuttle launch during the middle of 1990, NASA's Gamma Ray Observatory (GRO) is expected to make the next major step in gamma ray astronomy by providing comprehensive observations of celestial gamma ray sources covering the range 0.05 MeV to 30,000 MeV at a sensitivity nearly 10 times better than any other previous mission. GRO will consist of the following four instruments:

i) Energetic Gamma Ray Telescope (EGRET) is a wide FOV, high energy gamma ray telescope, based on a wire spark chamber system, a multielement time-of-flight coincidence system and a total absorption scintillation counter, covering an energy range 20 to 30,000 MeV. Source location accuracy will range from 0.5^{o} to 0.1^{o}, depending on source intensity. EGRET has a maximum effective area of 2000 cm^{2} and has an estimated source sensitivity of $\sim.5X10^{-8}$ photons cm^{-2} s^{-1} (continuum source) above 100 MeV.

ii) Imaging Compton telescope (COMPTEL) is a wide FOV, double Compton telescope covering 1 to 30 MeV. Best angular resolution is 7.5 arc min, It has an effective area of $50cm^{2}$ and a point source sensitivity of $3X10^{-5}$ to $3X10^{-6}$ photons cm^{-2} s^{-1} for lines and $5X10^{-5}$ photons cm^{-2} s^{-1} for the continuum.

iii) Oriented Scintillation Spectrometer Experiment (OSSE) consists of four identical shielded and collimated phoswich scintillators, witha $3.8^{o}X10^{o}$ FOV (FWHM) and covering 0.1 to 10 MeV. Effective area is

2 5

2310 cm and the estimated sensitivity is $2X10^{-5}$ photons cm^{-2} s^{-1} (line) and $3X10^{-5}$ photons cm^{-2} s^{-1} (continuum).This experiment is therefore likely to determine the intensity and profile of the ^{56}Co lines from SN 87A even after two years from now, when the radioactivity from the debris decreases due to the expansion of the shell.

iv) Burst and Transient Source Experiment (BATSE) is designed to monitor continuously a large portion of the sky for the detection and characterisation of celestial gamma ray bursts. For burst detection and localisation, it consists of 8 NaI scintillators, each 50.8 cm diameter by 1.25 cm thickness viewed by three 12.5cm diameter PMTs. They operate in the energy range 0.04 to 0.6 MeV. The maximum effective geometric factor is 15000 cm^2 sr. For burst spectroscopy, BATSE has an energy range of 0.05 to 20 MeV, resolution of 3 KeV per channel and an effective area of 127 cm^2 on each of 4 NaI detectors.

The GRO team will thus be anxiously counting the months before 1990 for their first look at SN 87A and the baby pulsar inside its remnant!!

4.0 Observations from other platforms

A number of groups are planning to conduct observations of SN 87A using rocket-borne payloads. Typical observing times from a rocket range from 5 to 10 minutes. Indian sounding rockets are all spin-stabilised ones and hence the obseration times will be further reduced by the ratio given by the opening angle of the telescope divided by 360°. Because of this reason, and since the bright source LMC X-1 is only 0.6° away from SN 87A, using Indian rockets for SN 87A observations is not likely to be rewarding. American teams are planning to fly three x-ray imaging telescopes with CCD, GSPC and Si(Li) detectors as focal plane instruments. A high throughput broad band x-ray telescope using confocal, conical x-ray mirrors and covering 0.3 to 12 KeV is planned to be flown on the second shuttle high energy astrophysics laboratory (SHEAL-2) in 1992 (Riegler,1988) A number of gamma ray instruments for the detection of gamma ray lines and the continuum will also be flown from Australia by teams from USA during 1988-89. These include high resolution solid state germanium detectors, large area scintillation spectrometers and a double Compton high energy gamma ray telescope. Balloon flights from Indian bases will not be attractive because of the extremely low elevation of the source as seen from India.

5. Conclusion

We have presented in this paper the salient parameters of a number of major satellite missions that will carry out significant x-ray and gamma ray observations of Supernova 1987A in the decade 1990-2000 AD. Most of these major observatories of the future depend on a space shuttle launch and hence the long wait till 1990's!

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