X-RAY ASTRONOMY SATELLITE GINGA

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Abstract. The X-ray astronomy satellite *Ginga* carries three scientific instruments, the Large Area proportional Counters (LAC), All Sky X-ray Monitor (ASM) and Gamma-ray Burst Detector (GBD). The LAC is the main instrument with an effective area of 4000 cm^2 giving it the highest sensitivity to hard X-rays so far achieved. *Ginga* observed about 250 targets up to the end of 1989.

1. Introduction

Ginga is the third Japanese X-ray astronomy satellite following *Hakucho* (Kondo *et al.* 1981) and *Tenma* (Tanaka *et al.* 1984). The fabrication, launching and operation of *Ginga* were carried out entirely by the Institute of Space and Astronautical Science (ISAS). General properties of *Ginga* have been described in the literature (Makino *et al.* 1987) and are summarized in Table 1. *Ginga* was launched on February 5, 1987 from Kagoshima Space Center of ISAS by the M-3S-II launch vehicle. The initial orbital parameters were a perigee height of 505.5 km, an apogee height of 673.5 km, an inclination of 31.1° and a period of 96.5 min. The altitude of *Ginga* has decreased rapidly since early 1989, because of high solar activity. The perigee and apogee height were 575.1 km and 471.0 km respectively in April 1990.

The total mass of the satellite is 420 kg of which 105 kg is for scientific instruments, and the rectangular main body measures 1 m × 1 m × 1.5 m with four deployable solar panels 1.7 m long and 0.75 m wide. A maximum power of 500 W can be generated from the solar panels and normal power consumption is about 150 W.

The scientific instruments are the Large Area proportional Counters (LAC), All Sky X-ray Monitor (ASM) and Gamma-ray Burst Detector (GBD). The LAC and GBD are prepared in collaboration with University of Leicester and Rutherford/Appelton Laboratory in the U.K. and Los Alamos National Laboratory in the U.S.A. respectively.

All the instruments have functioned normally to date, April 1990. The total number of targets observed to the end of 1989 is about 250, 51% are Galactic sources and 49% extra-Galactic sources.

2. Scientific instruments

2.1. Large Area proportional Counters (LAC)

The LAC is the primary instrument of *Ginga* and consists of eight identical counters (Turner et al., 1989). The total effective area is 4000 cm^2. Each counter is a multicell proportional counter which comprises 13 cell counters of four layers. The cell

Y. Kondo (ed.), Observatories in Earth Orbit and Beyond, 41–48.

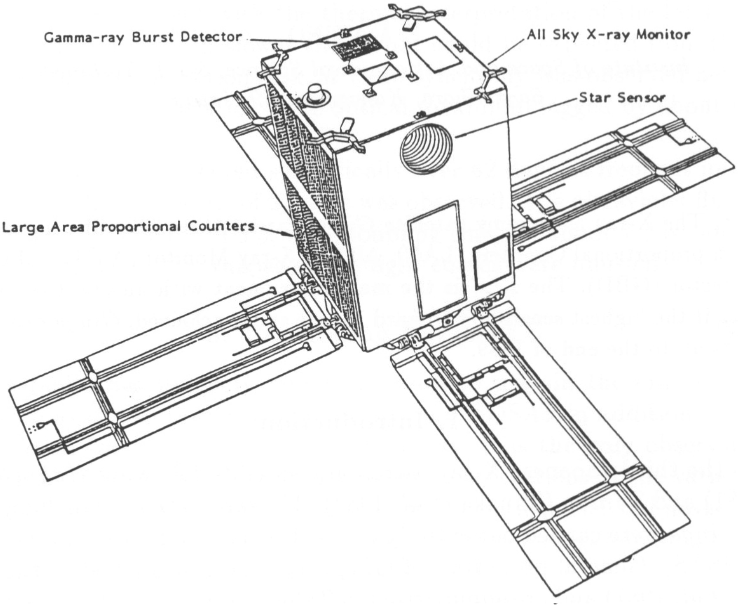

Fig. 1. The outside view of *Ginga*.

TABLE I
General characteristics of *Ginga*

Launch	February 5, 1987
Launch Vihicle	M-3SII-3
Initial Orbit	Perigee : 505.5 km, Apogee : 673.5 km Inclination : 31.1°, Period : 96.5 min
Mass	Total : 420 kg, Experiments : 105 kg
Experiments	Large Area Proportional Counters (LAC) All Sky X-ray Monitor (ASM) Gamm-ray Burst Detector (GBD)
Stabilization	Biased momentum three-axis control
Attitude Sensors	Two CCD Star Trackers, Sun Sensor, Four Gyroscopes and Geomagnetic Aspectmeters
Telemetry Bit Rate	High:16384 bps, Medium:2048 bps, Low:512 bps
Data Recorder	41.9 Mbit Bubble Memory Recording Time:42m40s(H), 5h41m(M), 22h44m(L)

counters sided by counter wall are connected together and used for anti-coincidence to lessen background, as well as the signals from the end plates. Because most of the background counts are produced by Compton scattering of hard X-rays and gamma-rays in the counter body. The anodes of the central two layers are connected together and those of the cell counters sided by entrance window are connected alternately. The signals from these three anode groups are analyzed by onboard data processor and are transmitted. Mutual anti-coincidence among these three anode groups is also employed for background reduction.

The entrance window is beryllium foil of 62μm thick which is supported by honeycomb type collimators made with stainless steel plates. The counters are filled with a gas mixture of argon (75%), xenon (20%) and carbon dixide (5%) at 2 atm at 293 K. The sensitive energy range is from 1.5 keV to 35 keV. The collimator field of view is elliptical of 1 degrees by two degrees (FWHM). The counting rate of X-rays from Crab Nebula is about 10000 cps, while the background rate is 70 cps of which 18 cps is due to cosmic diffuse X-ray background (CDXB). The detection limit of the LAC is confusion limit which is defined as sky to sky fluctuation of CDXB due to intensity source number relation. The 3σ limit is 2.1 cps, roughly equal to 0.2 mCrab (Hayashida *et al.* 1989). The sensitivity is the highest so far achieved in this energy region.

The time resolution depends on the number of energy channels for pulse height analysis and the telemetry bit rate. The highest is 1 ms in the case of 2 energy channels and 16 kbps, and the lowest is 16 s in the case of 48 energy channel and 500 bps. However, a temperature dependence of the clock frequency appeared after launch, but can be compensated for using temperature data for high resolution timing analysis (Deeter and Inoue, 1990). No degradation of the LAC has been observed to the end of April 1990.

2.2. All Sky X-ray Monitor (ASM)

The ASM consists of two identical proportional counters, each containing three independent counters with veto cell counters at the back (Tsumeni *et al.* 1989). These six counters are attached to a collimator of 1° by 45° (FWHM) of various slant angles. The monitoring of a wide sky region is conducted by slow rotation of the satellite around the z-axis. The position of the source can be determined by the time deferences of the peak position of the source for each counter. The normal frequency of scanning is once per day. The sky region which can be monitored is constrained to the equatorial region of satellite coordinate system determined by the LAC target.

The effective area of each counter is 70 cm^2. The counters are filled with xenon (96.7%) and carbon dioxide (3.3%) at 1 atm. The thickness of beryllium windows are 50μm. The detectors are sensitive to X-rays from 1 kev to 30 keV. The detection threshold is about 50 mCrab but becomes higher with increasing elevation angle from X-y plane of the satellite.

2.3. GAMMA-RAY BURST DETECTOR (GBD)

Two detectors, a NaI(Tl) scintillation counter and a Xe-filled proportional counter have been used for gamma-ray burst observation (Murakami et al. 1989). The NaI(Tl) is 8.8 cm in diameter and 1 cm in thickness, and measures hard X-rays from 13 keV to 400 keV. The proportional counter has an effective area of 63 cm^2, covering energy region from 2 keV to 30 keV. The X-ray observation of gamma-ray bursts has been conducted for the first time.

The gamma-ray bursts are unpredictable transient events shorter than 1 min. Two memory systems are employed to record bursts. The one is a fast memory triggered by the rise of the burst and is frozen until read out by command from the ground station. The sampling time is 31 ms for pulse counts and 0.5 s for pulse height distributions. The data in the time interval 16 s before and 48 s after the onset of the burst are recorded. The "time-to-spill" mode of data acquisition was used to cover wide dynamic range. The onset time are measured with accuracy of 244 μs. Only one burst can be stored in the fast memory. The other memory is a continuously sampling slow memory which sampling rate is either 125 ms, 1 s or 4 s depending on bit rate. The GBD includes small semiconductor detector to monitor radiation belt (RBM) and generate RBM flag to turn off high voltage supplies for LAC, ASM and GBD.

3. Notable results obtained with *Ginga*

3.1. CYCLOTRON FEATURES OF PULSAR SPECTRA

The merit of the LAC is high sensitivity in the energy region higher than 10 keV. Spectral structures in the hard X-ray region were detected from five X-ray pulsars, Her X-1 (Mihara *et al.* 1990), 4U 1538-52 (Clark *et al.* 1990), V 0332+53 (Makishima *et al.* 1990), 1E 2259+58 (Koyama *et al.* 1989a) and 4U 0115+634). The most pronounced spectrum was obtained from V0332+53 on October 1, 1989, as shown in Fig. 2. The spectrum can be expressed by power law with resonant absorption at 28.5 keV.

Possible interpretation of this structure is cyclotron absorption by electrons in highly magnetized plasma. The magnetic field can be estimated as 2.5×10^{12} G. Further analysis, such as pulse phase dependence of absorption energy and depth will reveal X-ray transport in pulsar plasma.

3.2. X-RAY SCATTERING BY INTERSTELLAR DUST GRAINS

The moon occulted accidentally transient X-ray source (GS 1741-28) appeared near the Galactic center. The observation was conducted on October 26, 1987 (Mitsuda *et al.* 1990). The light curves in three energy bands are shown in Fig. 4. The gradually decreasing and increasing component around the point source, which corresponds to sharp fall and rise is clearly seen at ingress and egress respectively. The light curves show that this extended component decreases with increasing X-ray energy. One can conclude that the extended component is due to scattering by cosmic dust grains from the energy dependence of relative intensity and angular

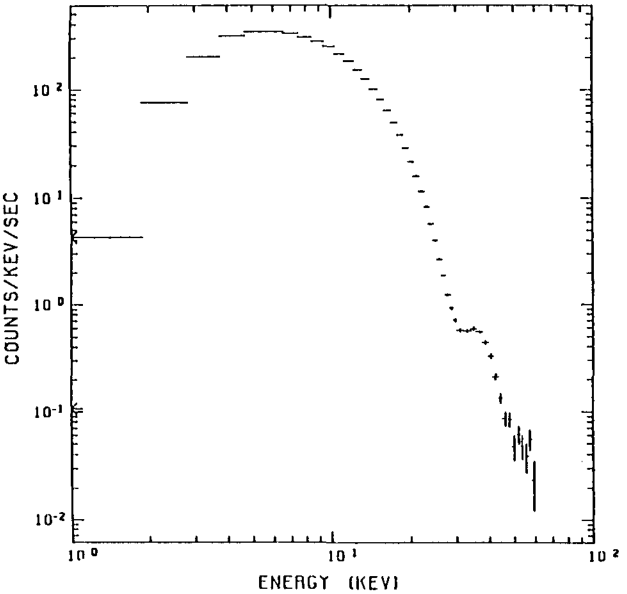

Fig. 2. The spectrum of X-ray transient pulsar V 0332+53. An absorption feature at 28 keV is clearly seen (Makishima *et al.* 1990).

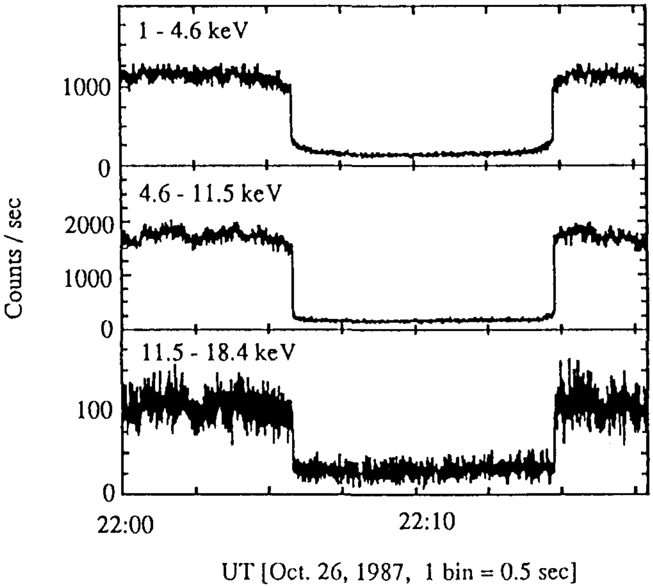

Fig. 3. Light curves of transient X-ray source GS 1741-28 in a occasion of lunar occultation. The slowly varying component is clearly visible at ingress and egress (Mitsuda *et al.* 1990).

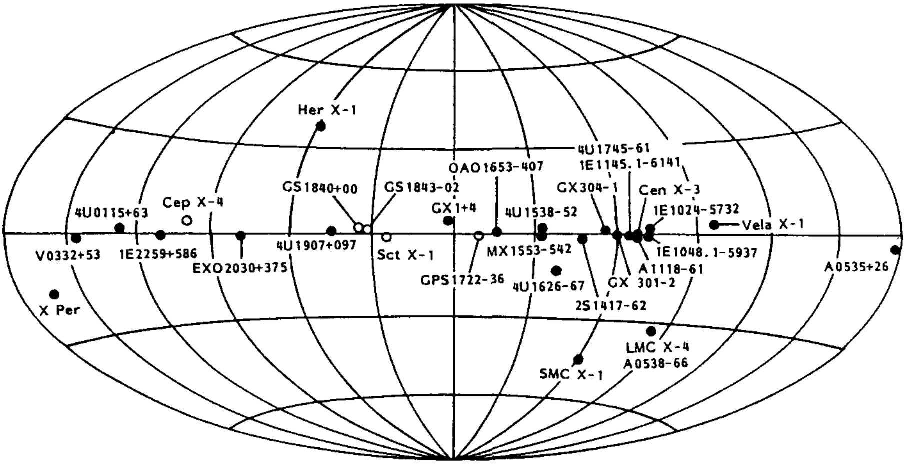

Fig. 4. Distribution of X-ray pulsars in Galactic coordinate. New pulsars discovered with *Ginga* are indicated by open circles.

diameter. The size and chemical composition responsible for X-ray scattering were estimated as about 0.1 μm in diameter and iron compound.

3.3. DISCOVERY OF NEW TRANSIENT X-RAY PULSARS

Five X-ray pulsars, Cep X-4, GS 1843+00, GPS 1722-362, GS 1843-02 and Sct X-1 have been discovered with *Ginga* (Koyama and Takeuchi, 1989). The scanning observation of Galactic plane discovered several transient X-ray sources. Most of new sources are faint and have the hard X-ray spectra characteristic of X-ray pulsars. The low energy part of the spectra is heavily absorbed by interstellar matter, and hydrogen column densities are higher than 10^{23} H-atoms cm^{-2}. These new transients which are candidate pulsars and new pulsars are concentrated in Scutum region, possibly located in 5 kpc Galactic ring. The total number of X-ray pulsars known before *Ginga* is 26 and they are located within a few kpc from solar system. *Ginga* observations suggest existence of many faint pulsars associated with inner Galactic arms.

3.4. INTENSE IRON LINE EMISSION FROM GALACTIC CENTER

The scanning observation along Galactic plane revealed diffuse emission of iron line peaked at Galactic center (Koyama *et al.* 1989b). The line energy of 6.7 keV suggests the emission is from high temperature plasma. The distribution of iron line shows sharp peak at Galactic center with angular diameter of 1.8° corresponding to 300 pc at the Galactic center. The peak flux is 1.5×10^{-7} erg s^{-1} sr^{-1} cm^{-2} and integrated luminosity of iron line is 2.3×10^{36} erg s^{-1}. The distribution of iron line extends to Galactic ridge. A possible origin of high temperature plasma

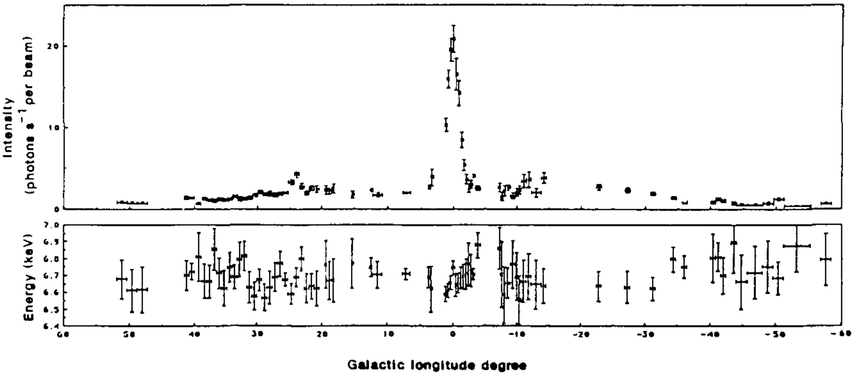

Fig. 5. Galactic longitude distribution of iron K-line. Lower panel shows line energy (Koyama *et al.* 1989b).

is supernova remnants. The distribution in such a narrow region suggests that the succesive explosion occurred at the epoch not earlier than 105 years.

3.5. SPECTRAL FEATURES AND VARIABILITY OF SEYFERT GALAXIES

Important discoveries were made on X-ray emission from Seyfert galaxies by *Ginga*. The iron line emission and K-absorption edge were observed from all Seyfert galaxies observed with *Ginga* (Pounds, 1989, Matsuoka *et al.*, 1990, Kunieda *et al.*, 1990). The line energy is 6.4 keV that is fluorescent X-rays from cold matter. The equivalent widths of iron line were about 100 eV or more. While the absorbing matter density determined from spectra below 2 keV is less than 10^{22} H-atom cm^{-2}. Therefore, the reprocessing matter is not distribute along the line of sight but it should sustend wide solid angle to central source. A possible configuration is an accretion disc (George *et al.* 1989). The variability of iron line emission from the low luminosity Seyfert 1 galaxy, NGC 6814 was observed by Kunieda *et al.* (1990). They obtained a positive correlative variation between the iron line and the continuum, and time lag between them was shorter than 250 s. This is comparable to observed variability time scale. This suggests that a geometrically thin cold accretion disc extends to the vicinity of central source. On the other hand, the continuum emission from NGC 4051 and MCG-6-30-15 varied in correlated way with spectral indices (Matsuoka *et al.* 1990). The spectra became steeper with increasing flux. This may be a further evidence for the existence of a scattered continuum which variability time scale is longer than the main component. *Ginga* observed Seyfert 2 galaxies, NGC 1068 (Koyama *et al.* 1989c), Mkn 348 (Warwick *et al.* 1989) and Mkn 3 (Awaki *et al.* 1990). Intense iron line emission at 6.4 keV was observed from NGC 1068 and Mkn 3. The equivalent widths were as high as 1 keV. The absorbing matter densities were in the order of 10^{23} H-atom cm^{-2} for Mkn 348 and Mkn 3. These facts support an idea that the Seyfert 2 galaxies are obscured Seyfert 1 galaxies. This may have an impact on the origin of the cosmic diffuse

X-ray background.

4. Concluding remark

Ginga has achieved highest sensitivity in the energy range from 1.5 keV to 40 keV and has revealed new aspects of X-ray astronomy.

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