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My early days in X-ray astronomy

Y. Tanaka[1,2]

[1] Max-Planck-Institut für Extraterrestrische Physik, D-85748 Garching, Germany
[2] Institute of Space and Astronautical Science, Sagamihara, Kanagawa 229, Japan
e-mail: `ytanaka@mpe.mpg.de`

Abstract. I was a cosmic-ray physicist 50 years ago. While working at the Cosmic-Ray Working Group, Leiden, in 1964 we started the observation of the cosmic X-ray background. Since then, I worked in X-ray astronomy at Nagoya University and later at the Institute of Space and Astronautical Science (ISAS), first with balloons and rockets and later with satellites. Here I will discuss the space science policy of Japan, and the central role of ISAS. I was engaged in four X-ray astronomy missions till my retirement from ISAS in 1994. With brief descriptions of ISAS X-ray astronomy missions, I intend to show how quick the development of X-ray astronomy and the detector techniques has been, and how rich is the physics of X-ray astronomy.

Key words. X-rays: astronomy – X-rays: history– X-rays: missions

1. Introduction

X-ray astronomy started 50 years ago. In June 1962, Giacconi, Gursky, Paolini and Rossi discovered an unexpected bright X-ray source (Giacconi et al. 1962) outside the solar system. This marked the start of the decade in which great discoveries, occurring one after the other, revolutionised astronomy: QSO, 3K microwave background, radio pulsars, a black hole in Cyg X-1.

In 1962, I moved from the Institute for Nuclear Study (INS) to Satio Hayakawa's group in Nagoya University. At INS, I had been doing air shower experiments, but in Nagoya I started balloon observations of cosmic-ray electrons and gamma-rays.

In 1963, Minoru Oda, head of the INS air shower group, left for MIT to join the X-ray astronomy group of Rossi. In the same year, I received quite unexpectedly an invitation from Prof. Oort to come to the Netherlands to lead the new "Cosmic-Ray Working Group" and to prepare the cosmic-ray electron measurement. The group was amazingly young. Except for the formal boss, Henk van de Hulst, I was the single senior staff, 32 years old, and the other members were all graduate students of 20+ years. They were all enthusiastic. Johan Bleeker was one of them.

We performed balloon observations of cosmic-ray electrons, and later successfully conducted a satellite observation on NASA's OGO-5 in 1968 (Bleeker et al. 1970). This was my first experience on satellite experiment.

I often traveled to U.S. during preparation of this satellite experiment. On these occasions, I visited Oda at MIT. He invented the modulation collimator around that time. His explanation on the rapid development of X-ray astronomy excited me very much.

Send offprint requests to: Y. Tanaka

2. Cosmic x-ray background measurement

The rocket experiment by Giacconi and collaborators discovered not only the bright source Sco X-1 but also the isotropic cosmic X-ray background (CXRB). Many people tried to measure the CXRB. We noted that many of them were not careful enough about the cosmic-ray induced background. I thought I could do a better job, and our group started to carry out balloon observations of the CXRB since 1964.

We designed an X-ray counter (Bleeker et al. 1968). A beryllium-window NaI(Tl) scintillator was mounted in a cup-shaped shield surrounded by a plastic scintillator. In addition, a rotating shutter periodically opened and closed the front field of view, allowing us to measure the difference of counts. We called it the shutter method. Furthermore, we flew two identical detectors from Leiden and Nagoya jointly with Nagoya group. It was possible to test contamination by cosmic-ray induced background. Magnetic latitudes and hence cosmic ray fluxes are significantly different at these two places. The results did not reveal the latitude effect.

Fig. 2. The balloon-borne detector (Makino 1975).

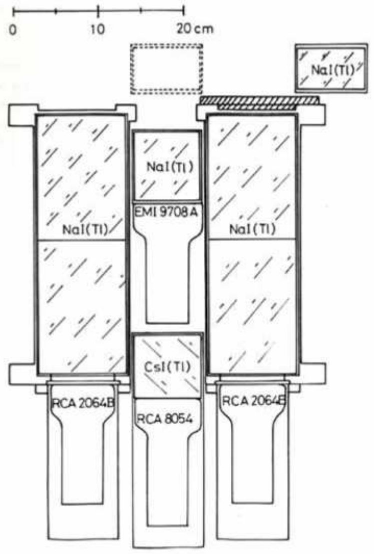

Fig. 1. The schematic diagram of a large hard X-ray detector (Makino 1975). Note that the shutter (top) is also a NaI(Tl) crystal.

Later, Fumiyoshi Makino of the Nagoya group constructed a much larger detector that could measure CXRB up to ~ 1 MeV (see Fig. 1, 2 from Makino 1975). This was flown in India in cooperation with Tata Institute of Fundamental Reseearch.

These Leiden-Nagoya results are included in the observed CXRB data shown in Fig. 3, which are in good agreement with the later, much more precise results, such as those of HEAO-1 A2.

Combined with the rocket results below 20 keV, the presence of a distinct knee around 20 keV was evident as early as 1968. This caused a long debate concerning the origin of CXRB. The observed spectrum happened to fit to a thermal spectrum of $kT \sim 40$ keV (Marshall et al. 1980). However, if this hot plasma fills the universe, it requires an unrealistic amount of energy. On the other hand, quite a few AGN were resolved, which favoured a discrete source origin. Yet they showed much steeper spectrum than that of CXRB below 20 keV.

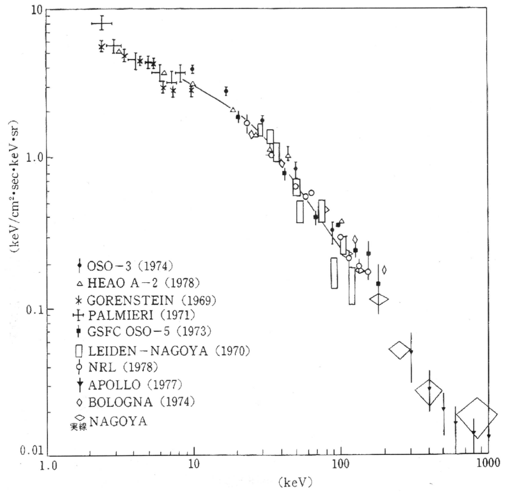

Fig. 3. The early results of the CXRB spectrum

This was called the "spectral paradox". Later, the problem was solved in terms of the presence of a number of heavily absorbed AGN (e.g. Setti & Woltjer 1989).

However, the flux of CXRB has not yet been accurately determined. Even 50 years after its discovery, the absolute flux is uncertain as much as 30 %. This is a great shame. We are proposing a measurement using the moon as an occultation disk.

3. Foundation of ISAS

The Institute of Space and Aeronautical Science (ISAS) was founded in the University of Tokyo in 1964. This institute became the center for the development of rocket and space technology, and served for the space science of all the universities in Japan.

Minoru Oda came back from MIT to ISAS in 1966, and founded a new X-ray astronomy group. I came back to Hayakawa's group of Nagoya University in 1967, and led the X-ray astronomy group there. The total number of scientists in these two X-ray astronomy groups was no more than 10. This "two-group" period lasted about ten years. It should be mentioned that, prior to my return, Hayakawa and Matsuoka (a graduate student then) had conducted a rocket observation of CXRB in 1965 (Hayakawa et al. 1965), the first rocket experiment of X-ray astronomy in Japan.

At the Nagoya group, I wanted to do something new. New discovery of soft X-rays below the carbon K-edge by the NRL group (Henry et al. 1968) using thin Mylar window counters drew my interest. We looked for plastic films better than Mylar, and found polypropylene (PP) film. A PP film can be stretched 5 times in one direction. So, by stretching a 25 micron thick film criss-cross, a 1 micron thick film can be obtained. The PP film transmits soft X-rays much more than Mylar film, since PP is composed of only hydrogen and carbon (Tanaka & Bleeker 1977).

We started rocket observation with counters equipped with this thin PP film since 1969. It was extended to joint experiments with the Leiden group, named LEINAX (Leiden Nagoya X-ray) experiment. The results of these soft X-ray experiments are summarised in a review paper (Tanaka & Bleeker 1977).

One of the main results was that the observed spectral shapes of the diffuse soft X-ray background were the same in all directions, which was fitted to a thermal spectrum of $kT \sim 150$ eV (Fig 4). This was interpreted as evidence that the sun is located within a hot bubble (Tanaka & Bleeker 1977). If so, the polar diagram of the soft X-ray intensity, shown

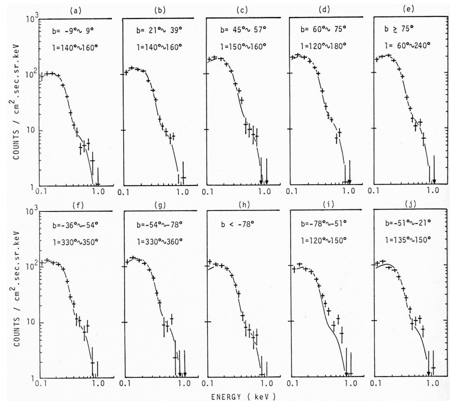

Fig. 4. The observed spectra of the soft X-ray background in various directions.

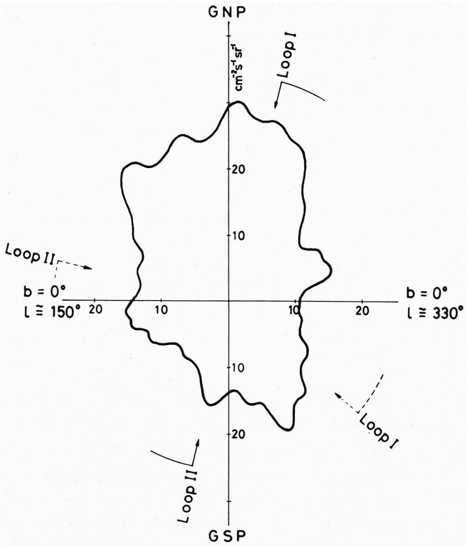

Fig. 5. The polar diagram of the soft X-ray intensity.

in Fig. 5, may schematically represent a cross section of the bubble.

This interpretation is currently suspected. An alternative is that the observed emission is due to the lines emitted by charge exchange reaction of the solar wind in the geo-corona. This is to be resolved with high-resolution spectroscopy.

4. Satellite Era

In 1970, the first X-ray astronomy satellite UHURU was launched, which vividly demonstrated the power of a satellite. In the same year, ISAS succeeded to launch a tiny satellite. This was encouraging for us. We eagerly wanted to have our own satellite.

I moved to ISAS in late 1974 and formed a new X-ray astronomy group with Matsuoka, Koyama, and Inoue.

The first chance for launching an X-ray astronomy satellite (CORSA) came in 1976, but the rocket failed to place it into the orbit. This was a great shock and disappointment for all of us. Nevertheless, we obtained a second chance in 1979 by the heroic effort of Minoru Oda.

Within these years, X-ray astronomy advanced a great deal. UHURU discovered many Galactic and extragalactic X-ray sources. The idea of mass-accreting gravitationally collapsed objects such as a neutron star (NS) or a black hole (BH) in binaries was widely accepted. Furthermore, the grazing-incidence telescope mission EINSTEIN was soon to be launched. What to do with our small mission was a difficult problem.

We chose to install modulation collimators which rotate with the spacecraft spin. This enabled us to pin-point the source location. This satellite named ”Hakucho” was launched successfully, and obtained useful results for the X-ray burst physics, subtle changes of pulsar periods, etc. We definitely entered into the satellite era.

5. ”Small but frequent”

In 1975, the Ministry of Education adopted the basic space science policy: to support one small mission every year, and one medium/large mission every (roughly) 5 years by international cooperation. This allowed us to have a mission every 4 ∼ 5 years in each of major fields Even if what we could do with each small mission was limited, this allowed us a long-range planning and to conduct up-to-date science. Also, the launch capability of the ISAS rockets doubled in every 5 ∼ 7 yrs.

ISAS itself also grew bigger, and it became no longer possible to expand within the University of Tokyo. After a long effort, the new ISAS (Institute of Space and Astronautical Science) was founded in 1981 as an independent, inter-university institute. This was a historical step for the space science of Japan.

When I moved to ISAS, I wanted to start something new. I thought that X-ray spectroscopy would develop. There were many interesting subjects, such as the study of physics of mass accretion, SNR, cluster of galaxies, etc. We started to develop gas scintillation proportional counters (GSPC) that had twice better energy resolution than ordinary proportional counters (PC). Around that time, a new graduate student Ohashi joined our group.

GSPC requires strong electric field, hence much higher voltage than PC. After a long struggle against surface discharge, we succeeded to produce GSPC of 10 cm diameter.

Our second X-ray astronomy satellite Astro-B (post-launch name ”Tenma”) launched in 1983 carried ten such GSPC units, making a total of 800 cm^2 (Tanaka et al. 1984) as shown in Fig. 6. The good energy resolution and wide energy range covering, with a large effective area produced many interesting results.

The fine spectroscopy allowed us plasma diagnostics of the supernova remnants and cluster of galaxies. The iron emission line was detected from many binariy sources as well as AGNs. For the first time, the iron Kα line (6.7 keV) was discovered along the Galactic plane (Koyama et al. 1986).

Most of the bright X-ray sources were thought to be low-mass binaries including a neutron star by that time. Mitsuda et al. (1984) found from observations with the Tenma GSPC that their spectra were composed of two components, i.e. one blackbody component and another softer thermal component (Fig. 7). They were identified as the emission from the neutron star surface and from the accretion disk, respectively. They further showed that the disk spectrum is expressed using only two parameters: the radius of the innermost stable circular orbit (ISCO) and the innermost disk temperature. This model has been employed widely as “multicolor disk model” or “disk blackbody model” for analysing the X-ray binary spectra.

We also intensively studied X-ray burst spectra. There was a puzzling finding. We found an intense absorption line-like feature around 4 keV in the burst spectra from a few low-mass binaries, the most pronounced features from X1636-53 and X1608-52, the brightest burst sources (see Fig. 8). We certainly suspected the instrumental effect first. But, the GSPC units on board were thoroughly tested over the entire range before the flight, and we could not reproduce the feature with a spare unit in the lab. Similar features were not observed by the later missions. This remains still unsettled.

Unfortuna tely, the battery system of Tenma satellite failed in less than 2 years.

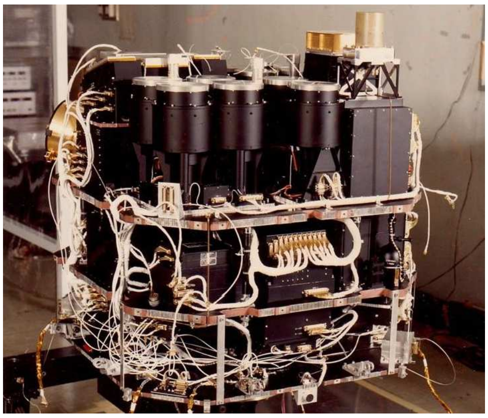

Fig. 6. The GSPCs on board Tenma.

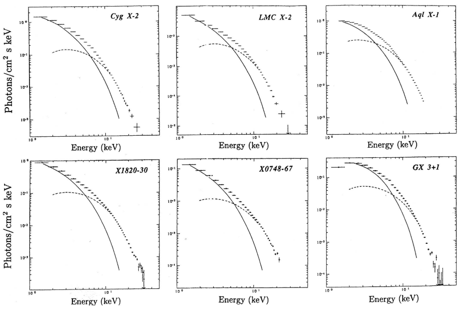

Fig. 7. The GSPC spectra of low-mass binaries with NS, decomposed into a blackbody component (dotted line) and a multicolour disk component (solid line).

6. International collaboration

6.1. Ginga

Astro-C was our first experience of a large-scale international cooperation. It began in 1980, even before the launch of Tenma. The basic plan of Astro-C had been fixed earlier to be a large-area proportional counter array (LAC: with a total area ~0.4 m^2). The UK proposal was that the Leicester group, headed by Ken Pounds, would prepare the proportional counters (a GSPC of this area was too difficult to build).

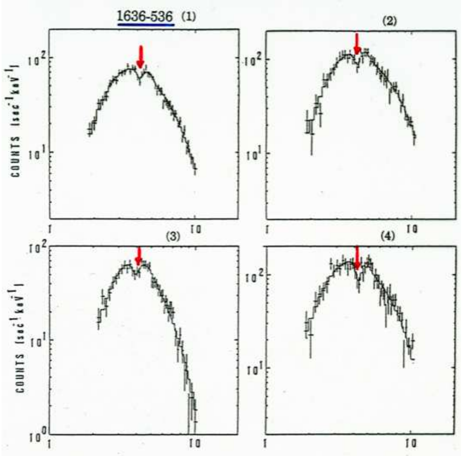

Fig. 8. Examples of the absorption line features observed in the burst spectra. These are the cases from X1636-53.

All the Japanese members (no more than 20 at that time) got together and discussed this proposal. Opinions were divided. At the critical moment, Oda gave me the casting vote. I was definitely positive for collaboration with the belief that Japanese science must be more internationalized. The MOU was signed in early 1982, an epoch-making start.

The Leicester-made proportional counters were of excellent quality. Late Martin Turner and Takaya Ohashi (then at Leicester) made crucial contribution. Yet, it was not all smooth. There were difficulties. Still, the end result was very successful. Astro-C (Fig. 9) was launched in February 1987, and renamed ”Ginga” (Makino 1987). The large area and the wide energy coverage of LAC was the strength of Ginga.

An unforgettable episode: less than 20 days after launch, we got a call in the middle of the night telling us that SN1987A went off. We patiently watched the region over months. From August we noticed an unusually hard source which became brighter day by day. I rushed to an IAU Colloquium held in Tokyo at that time and reported the appearance of the SN (Tanaka 1988). This news surprised the audience, since they had expected a much later appearance. This gave evidence for large-scale mixing inside the ejecta.

Ken Pounds and his collaborators studied spectra of Seyfert 1 AGN, and discovered the Compton hump and the presence of warm absorber. These gave evidence for a Compton-thick disk. This was the first detailed wide-band study of AGN spectra (Pounds et al. 1990).

A small all-sky monitor was on board. It detected many transient sources that were subsequently observed with LAC. Among them, Ginga discovered four transients which turned out to include stellar-mass black holes. Three of them showed multicolor disk spectra (Fig. 10) lacking blackbody components: no signature of solid surface providing strong evidence for a BH. Indeed, the values of the parameters of the ISCO model remained con-

Fig. 9. Astro-C satellite (postlaunch name Ginga)

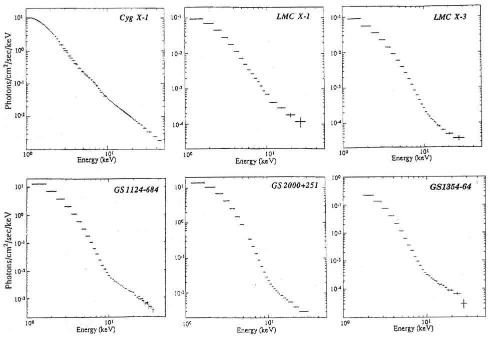

Fig. 10. The *Ginga* spectra of low-mass binaries including a black hole. The lower three objects were discovered by the All Sky Monitor.

stants against the brightness variation (Tanaka & Lewin 1995), and were consistents with a few times the Schwarzschild radii (based on the optically determined mass), all consistent with the BH hypothesis. ISCO vs. BH mass has a potential of determining the spin of the BH (Remillard et al. 2006).

Success of the international collaboration of Ginga had strong impact. In fact, all the astronomical missions of ISAS following Ginga were conducted with international cooperations.

6.2. "ASCA"

We begun planning Astro-D even before launching Ginga. We had long wanted a grazing-incidence X-ray telescope, but we had no technology nor the payload capacity.

There was one possibility. That was the multi-nested conical foil mirror that Peter Serlemitsos at NASA GSFC had been developing for a long time. While the image resolution is modest, it provides a large effective area, wide energy range and among others super-light weight. Luckily, Hideyo Kunieda was working with Serlemitsos at GSFC and strongly supported this cooperation.

A difficulty was that the telescope had a focal length of 3.5 m, which was too long to be accommodated within the nose fairing. For the solution, we adopted an extensible optical bench: folding it during the launch and extend it in orbit. This was probably the first attempt of an extensible optical bench in space.

Four foil mirrors were mounted on it. The focal plane detectors were two imaging gas scintillation proportional counters (GIS) and two X-ray CCDs (SIS). GIS was made by the group of Makishima and Ohashi, and the CCDs were provided by George Ricker and his group at MIT. NASA strongly supported these cooperations. The team was quite international. A group of senior members from U.S. and UK also participated.

Astro-D was launched in 1993 and renamed "ASCA" (Fig. 11 Tanaka et al. 1994). It would not be an overstatement that ASCA and ROSAT, having complementary capabilities, supported X-ray astronomy in the decade of 1990's. This was the period when the U.S. had a hiatus of space missions due to the Challenger accident.

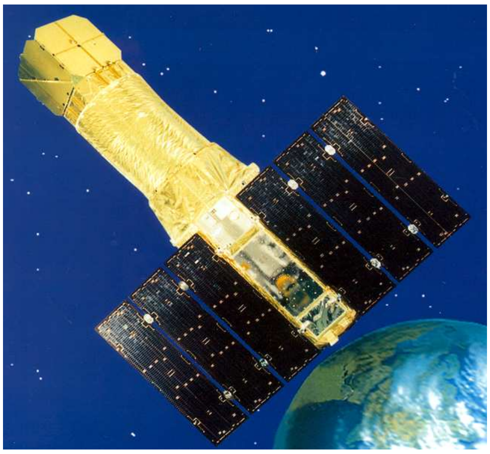

Fig. 11. ASCA satellite

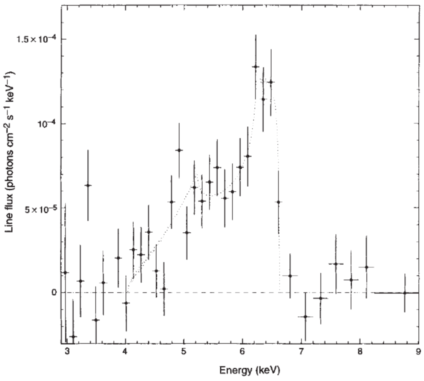

Fig. 12. First broad iron line detected with ASCA (Tanaka et al. 1995).

ASCA was a general purpose observatory. Therefore, results on wide range of topics were obtained. Here, we pick up only a few. SN1993J greeted ASCA, reminding us of SN1987A right after the Ginga launch.

The red-ward broadened iron line was first detected from MCG-6-30-15, as shown in Fig. 12 (Tanaka et al. 1995). Andy Fabian, one of the predictors of the effect (Fabian et al. 1989) strongly proposed to observe this Sy1 for whatever inspiration he had, and succeeded. This effect was interpreted to show the general relativistic effects near a BH. However, it is fair to mention that some people argue against this interpretation (e.g. Inoue et al. 2011).

ASCA discovered strong iron fluorescent line from the molecular clouds surrounding the Galactic Center. This can be interpreted as the result of irradiation by X-rays from the activities of the GC a few 100 years ago (Koyama et al. 1996).

7. Epilogue

I was engaged in four X-ray astronomy missions at ISAS. This was a hard, yet challenging experience. I retired from ISAS in 1994, a year after ASCA was launched. The last year was very fruitful and enjoyable in the fully international atmosphere.

I have been inside X-ray astronomy from soon after its birth until today, during which period the advance of X-ray astronomy was truly astounding. Not only observing the advance but I was lucky enough to be one of the players of this drama. To meet such a good luck in one's life must be rare.

When I started X-ray astronomy, there was only one group in Japan, Hayakawa's, with about five people. At the time of Ginga, still no more than twenty. But now, the total number of Japanese X-ray astronomy researchers (including graduate students) may be around 100. X-ray astronomy is such attractive, and the most rapidly grown field.

However, we are not very optimistic for the future. The chance of big missions has become remote. Yet, X-ray astronomy still maintains crucial importance in astronomy. So, we can not miss it. To overcome the difficulty, we must join our force world-wide. Beside the effort for a big X-ray observatory, it may be useful to recall the lessons we obtained in the past. "Small but frequent" may still be viable.

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