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The history of X-ray astronomy in Germany

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Abstract. As in other countries in Germany cosmic X-ray astronomy was started by physicists who came from cosmic ray physics and from solar X-ray astronomy. In this paper, I sketch the development of the field in Germany from the beginnings in the 1960's to the era of ROSAT, Chandra and XMM-Newton.

1. Introduction

In 1955 I escaped as a physics student from the GDR and moved to Hamburg, where I joined a nuclear physics group at the University which moved to Kiel University in 1959. There I received the PhD with a thesis on an early version of a triggered spark chamber. As a postdoc I started the Kiel air shower experiment in 1960 with the goal to study the cosmic ray spectrum and chemical composition in the "knee region" (10^{15}-10^{17} eV). At the time of the discovery of Sco X-1 and the X-ray background by Giacconi and his group I was very busy with building up the ambitious experiment. In 1967/68 we had collected a lot of data on the electronic and hadronic core structure of air showers, when Hewish and Bell discovered the pulsars. I was fascinated. Could they be the long searched sources of cosmic rays at very high energies? I started working on pulsar emission mechanisms and used the Gunn-Ostriker model to calculate the curvature radiation emitted by electrons/positrons accelerated in the wave zone of the pulsar. I found that the spectrum could extend up to the X-ray range. During a sabbatical in 1969/70 I visited the gamma ray group of Klaus Pinkau at MPE and started to make plans for an X-ray astronomy program in Germany. In 1970 I became member of the mission definition group of the Highly Eccentric orbit Lunar Occultation Satellite (HELOS, later on EXOSAT) where I met Ken Pounds, Len Culhane, Johan Bleeker and others.

1971 was an eventful year for me: - I wrote a proposal for a small German X-ray satellite ("A6") to perform a sensitive search for young X-ray pulsars. It was rejected four years later for budgetary reasons. - I gave a talk on "X-ray astronomy" in the Fest-Colloquium celebrating the 60^{th} birthday of Hans Wolter, who had invented the X-ray optics in 1951/52 at Kiel University. The subject of my talk was the status of X-ray astronomy and the prospects of using Wolter telescopes for studying celestial X-ray objects like the Crab nebula. – Also in 1971 I accepted the offer to become the Director of the Astronomical Institute of the University of Tübingen (AIT), which was crucial for realizing my plans in X-ray astronomy. The driving force behind the call had been Gerhard Elwert, a Professor of Theoretical Astrophysics in Tübingen, who got his PhD in 1938 from Arnold Sommerfeld with a the-

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sis on bremsstrahlung processes. After World War II he started working on the solar coronal EUV and X-ray emission. He received international recognition since his findings were relevant for the interpretation of the early X-ray observations of the sun. Elwert collaborated with a small group at the AIT (Bräuninger et al. 1971) which worked on rocket experiments with Fresnel zone plates to image the sun in different X-ray emission lines. Their first rocket flight took place in 1971 (Bräuninger et al. 1971), just at the time when I joined the AIT. Through the seventies we continued to use this technique on rockets, but gave up at the end because of the difficulties with the detector calibration (X-ray film) and the competition by the more powerful Wolter telescopes.

In the following I will concentrate on cosmic X-ray astronomy which we started at AIT in 1971 with a hard X-ray balloon program and in 1972 with first steps for the development of Wolter telescopes. In 1975 I accepted the Director's position at the Max-Planck-Institute for Extraterrestrial Physics (MPE), because it provided a much more powerful basis for carrying out satellite missions.

2. Hard x-ray observations with detectors on balloons and the Mir Station

My first official action at AIT was to submit a proposal to the German Science Foundation (DFG) for a balloon program in hard X-rays. The main objectives were to study the spectra and time variability of the newly discovered Uhuru sources at 20-200 keV. A secondary specific goal was to measure the secular decrease of the X-ray luminosity of the Crab nebula due to the spin-down of the pulsar. The balloon experiment was built up by Rüdiger Staubert and Eckhard Kendziorra, who had both followed me from Kiel. It continued as a joined MPE-AIT activity after I had moved to MPE in 1975, with Claus Reppin as the leading scientist on the MPE side. The HEXE (High Energy X-Ray Experiment) was very productive: On 14 successful balloon flights from 1973 through 1987 about 40 X-ray sources were observed with a total observation time of 222 hours. The collecting area of the experiment was increased from 120 cm^2 (1973, Fig. 1 left) to 800 cm^2 (1977), and to 2400 cm^2 (1980). An early highlight was the discovery of the cyclotron line in Her X-1 which represented the first spectroscopic measurement of the magnetic field of a neutron star: 4 x 10^{12} G. (Fig. 1 right, Trümper et al. 1978). This opened a new field, which was further developed by satellite experiments (HEAO-1, Ginga, Mir-HEXE, ASCA, BeppoSAX, Suzaku etc.). Another highlight was a campaign in 1977 with three observations of Her X-1 at different phases of the 35 day cycle - in the on-state, the off-state and the short on-state. Later on, observations with EXOSAT of the pulse profile changes of Her X-1 through the 35 day cycle led us to propose that the neutron star is freely precessing (Trümper et al. 1986).

In March 1987 a space hardened version of the 800 cm^2 detector built by MPE/AIT and MBB was launched to the Mir Station as part of the Kvant module. We were lucky, since the Supernova 1987A had exploded just a few weeks before, and this source became our first target. The models of McCray et al. (1987) and Grebenev & Sunyaev (1987) had predicted that the gamma rays from the decay of Ni^{56}-Co^{56}-Fe^{56}would be Comptonized in the expanding shell, resulting in a hard X-ray spectrum. This hard emission was discovered by the Mir-HEXE on August 10, 1987, a few months earlier than predicted, indicating a mixing of the radioactive material in the expanding shell (Sunyaev et al. 1987).

3. The development of Wolter telescopes – towards the ROSAT mission

In 1972 we began the development of Wolter telescopes with Carl Zeiss as a partner. We did it in a systematic way, starting at AIT with flat samples, and continuing at MPE with paraboloidal concentrators and finally with Wolter telescopes. In the seventies we participated together with the Leicester and Leiden groups in a series of proposals (GIXRAT, EXO, ASRO), aiming at a powerful trilateral

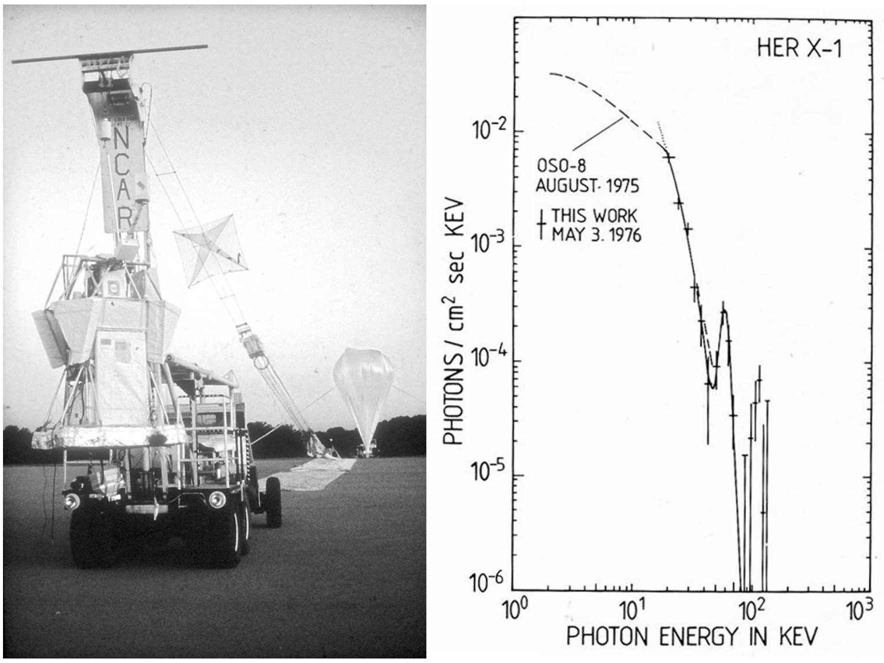

Fig. 1. left: HEXE before launch in Palestine/Texas; right: X-ray Spectrum of Her X-1

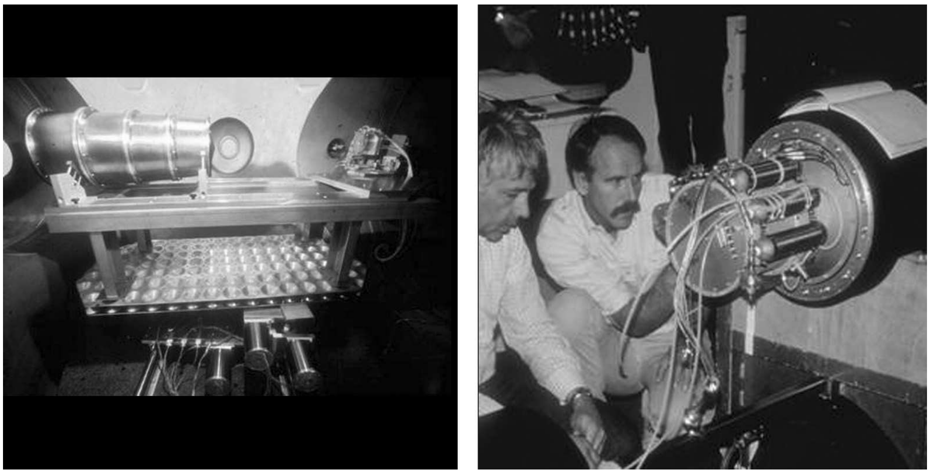

Fig. 2. left: The 32-cm-Telescope in the PANTER; right: final touches to the PSPC before the rocket launch

X-ray telescope mission. They all collapsed for budgetary reasons. Later attempts in collaboration with American groups (IXE, IXEE) were unsuccessful as well. This disappointing experience led me to consider a national telescope project. In response to a call for "big projects" by the German Ministry of Science (BMFT) in 1975, we proposed a simple, but powerful satellite with an 80-cm Wolter telescope and position sensitive proportional counters. No Christmas tree! It was accepted and industry studies approved the concept. But a problem arose when BMFT asked DFVLR (now called DLR) to provide a cost estimate. It resulted in a price tag of 1 billion DM – an astronomical number, probably based on the rule of thumb for satellite costs "1 kg in orbit = 1 million DM". We countered that a large fraction of the mass would be in the mirror system which would be much cheaper. In order to stress the point we called the project "ROBISAT", where BI stood for billig (cheap). In the meantime our X-ray telescope development had progressed. In 1979 we flew a rocket with a 32 cm- mirror (Fig. 2) and an early version of the PSPC built by Elmar Pfeffermann (Fig. 2). It produced the first colour picture of a supernova remnant - Puppis A (Pfeffermann et al. 1981). Two other of these telescopes were used successfully to observe Cas A and in fall 1987 to search for soft X-ray from SN1987A (Aschenbach et al. 1987).

In order to support the development of the 80 cm-telescope we needed a long beam test facility. This was built up by Heinrich Bräuninger et al. in 1980/81 and named PANTER. It provided an invaluable service - from the tests of the first single mirrors shells through the final calibration of the ROSAT payload. It also played a crucial role for many other projects (EXOSAT, BeppoSAX, SOHO-CDS, XMM-Newton, Chandra-LETG, Swift, eROSITA etc.). At this point I also should stress the role of Bernd Aschenbach, who got involved in designing the ROSAT optics in 1977 (Aschenbach 1988) and worked closely together with Heinrich Bräuninger and Carl Zeiss Company for many years on our telescope programs.

A new hurdle arose in 1980: The BMFT required a "substantial" international participation for all projects of the big project class. In private discussions with me Riccardo Giacconi had already expressed interest in an US participation. But NASA had to be convinced as well. At the Uhuru Memorial Symposium at GSFC in December 1980 I gave a talk with a quite realistic description of our ROSAT plans (Trümper 1981). In the coffee break after my talk Steve Holt - who at that time was responsible for high energy astrophysics at NASA HQ – came to me and expressed great interest. Subsequent official negotiations led to the US contribution with a free shuttle launch and a focal plane instrument, the HRI, to be provided by CFA/SAO. In parallel an offer was made to the ESA member states for participation, which resulted in the contribution of the Wide Field Camera (WFC) by Ken Pound's group. The implementation of the small WFC did not pose severe technical problems, but the HRI required a higher mirror resolution compared with the PSPC. Fortunately, it was not a great problem for Carl Zeiss to match the requirements. At the end the ROSAT mirror system (Fig. 3) had an angular resolution of 4 arc sec half energy width, and an unprecedentedly small surface micro-roughness of < 0.3 nm. In 1982 the project was finally approved and went into phase C/D with Dornier Systems as the main contractor and Messerschmitt-Bölkow-Blohm responsible for the attitude measurement and control system as well as for the power system. The focal plane assembly of the X-ray telescope (Fig. 3) was designed and built by MPE, with the HRI as an add-on instrument.

On 28 January 1986 the tragic Challenger explosion destroyed our dream of a launch in 1987. The new shuttle manifest showed the launch in 1994. With the help of our American friends we fought for a rocket launch, which was finally approved in 1988. The main advantage of the rocket launch was that we could choose an optimum height (580 km) and inclination (52 degrees) of the orbit which allowed the German Ground Control Centre (DLR-GSOC) in Oberpfaffenhofen near Munich to control the satellite. The necessary changes of the ROSAT spacecraft gave us time for very extensive calibrations at the PANTER, as well as for tuning the data analysis system at MPE and the satellite control at GSOC.

4. Progress with ROSAT

The launch of ROSAT on June 1, 1990 with a Delta from Cape Canaveral went perfectly, as well as opening of the telescope door and the first lights of all instruments, PSPC, HRI and WFC. After a few weeks of calibration and verification the first all sky survey with an imaging X-ray telescope began, which provided a

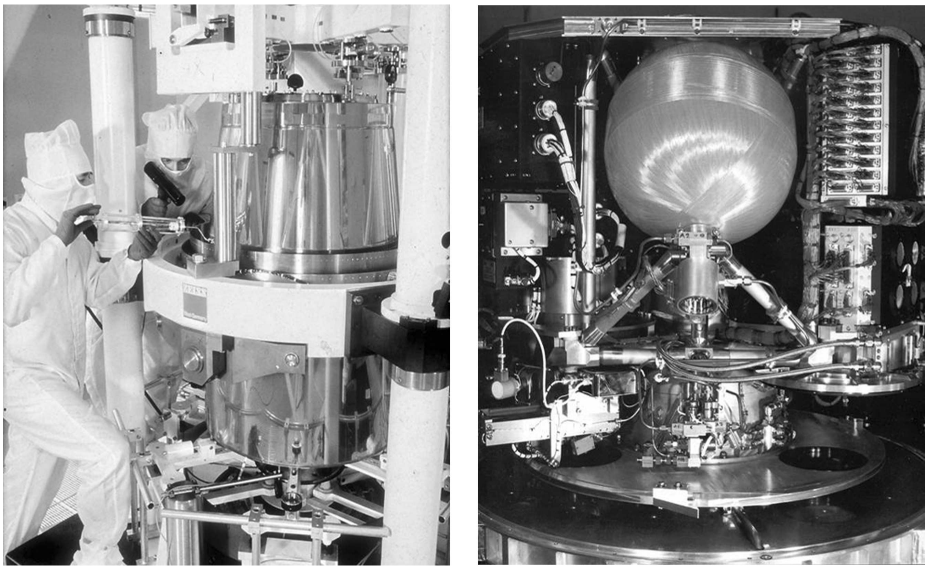

Fig. 3. left: Mounting the ROSAT mirrors by Carl Zeiss; right: ROSAT focal plane assembly with HRI (left) and PSPC (right)

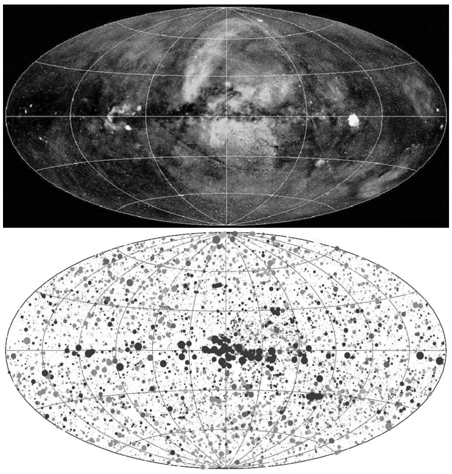

Fig. 4. top: The ROSAT Sky in galactic coordinates in 4 colors; bottom: Distribution of the ∼ 20 000 brightest sources

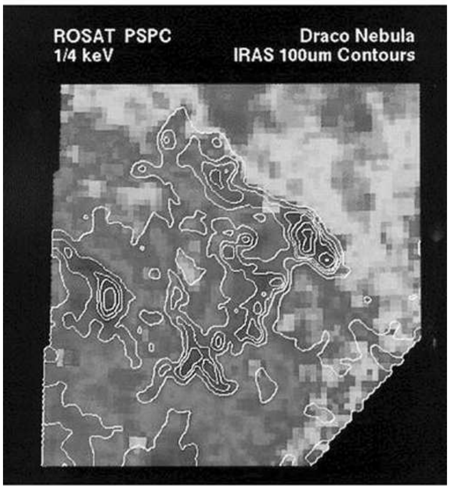

Fig. 5. Shadow cast by the Draco cloud onto the X-ray background

quantum jump in sensitivity (∼ factor 100) and enabled imaging of objects with an unlimited field of view (Fig. 4).

ROSAT was the first and until now only satellite which could image the X-ray background directly, since the particle background in the PSPC was very low (∼1 count per arcmin^2 in 3 days!), due to a five-sided anti-coincidence system and a novel magnetic deflector eliminating low energy electrons. The all sky survey allowed to collect large flux limited samples of various types of objects like

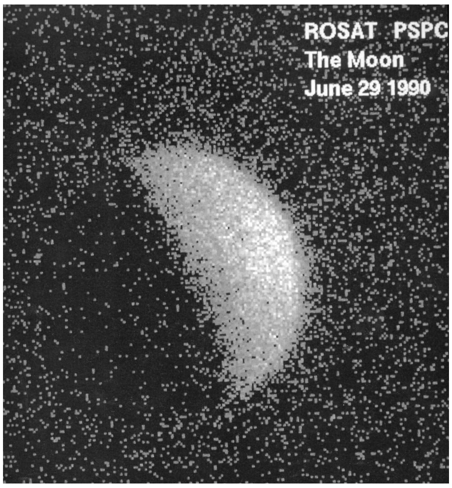

Fig. 6. The first X-ray picture of the Moon, which is occulting the X-ray background

stars, AGN, clusters of galaxies as well as the discovery of rare classes of objects such as neutron stars showing purely thermal emission ("Magnificent Seven") or the class of "Super-Soft Sources" (Trümper et al. 1991), which turned out to be white dwarfs in CVs showing nuclear burning of accreted material at their surface (van den Heuvel et al. 1992). The all sky survey resulted in ~ 105 000 X-ray sources. Fig. 4 shows the map of the ROSAT Bright Survey (RBS, Voges et al. 1999), comprising the ~ 20 000 brightest sources. The survey also allowed for the first time to measure the soft galactic X-ray emission with arc min resolution and to discover the X-ray shadows cast by cool interstellar cloud onto the galactic X-ray background (Snowden 1991, c.f. Fig. 5). The number of sources detected in the XUV survey was 479 (Pye et al. 1995), comprising mainly of cool stars and white dwarfs.

The 8 years of pointed observations were extremely successful as well. Highlights were the first X-ray picture of the moon showing the occultation of the cosmic X-ray background (Fig. 6, Schmitt et al. 1991), the observations of X-ray halos by Predehl & Schmitt (1995), the discovery of the first brown dwarf (Neuhäuser & Comeron 1998) and of the millisecond pulsar in X-rays (Becker & Trümper 1993), the idendification of the enigmatic source Geminga as an X-ray pulsar (Halpern & Holt 1992), the discovery of shrapnels in the Vela SNR (Fig. 7, Aschenbach et al. 1995) and Vela Junior (Fig. 7, Aschenbach 1998).

A great surprise was the discovery of the first comet Hyakutake (Fig. 8, Lisse et al. 1996) and other comets (Dennerl et al. 1997), which demonstrated the importance of charge transfer reactions in astrophysics (e.g. Dennerl 2010). Of the many discoveries in the fields of clusters of galaxies I would like to mention the first discovery of bubbles blown by an AGN (NGC 1275) into the surrounding plasma of the Perseus cluster (Fig. 9, Böhringer et al. 1993) and the determination of $\Omega_m$and σ_8 from the REFLEX cluster survey (Schücker et al. 2003). In the realm of AGN I would like to quote the work on the highly variable narrow-line Seyfert-1 galaxy IRAS 13224-3809 (Boller et al. 1995) which turned out to be very useful for studying the environments of the innermost region around an accreting supermassive black hole. The ROSAT deep survey resolved 70-80 % of the soft X-ray background into sources, mostly AGN (Fig. 10, Hasinger et al. 1998). A fairly complete account of the ROSAT harvest is given in the book "The Universe in X-Rays" edited by Trümper & Hasinger (2007). Among all X-ray missions ROSAT is placed second behind Chandra in terms of number of refereed publications (> 4 000) and citations (> 135 000).

Finally I note that ROSAT was the first satellite using magnetic navigation. After the second gyro dropped out in 1993 the magnetometers (used for unloading the attitude control momentum wheels) were used to navigate in the earth's magnetic field. MBB had a patent on the method, but they did not believe that it was accurate enough to point the satellite. A small MPE team under Günther Hasinger verified by analysing the attitude and magnetometer data of the first few years that the accuracy was sufficient. After MBB had reconfigured the attitude system it worked for the rest of the mission. Actually by this major change the operational lifetime of ROSAT was more than doubled.

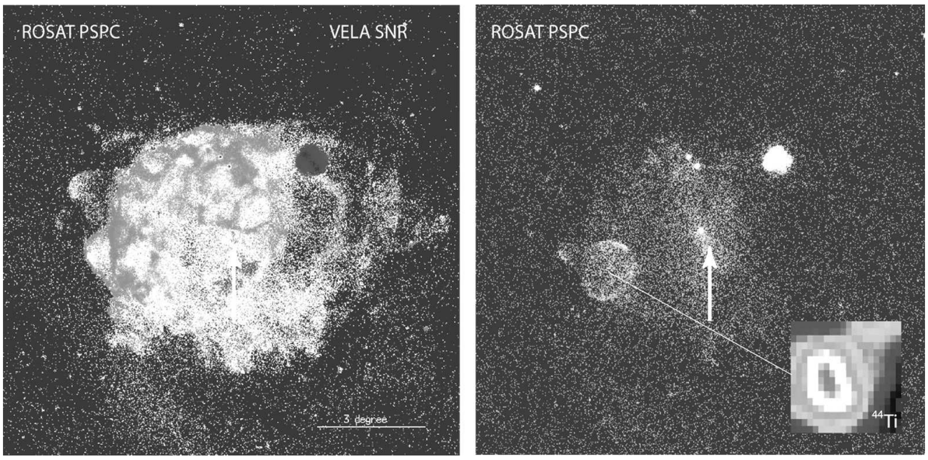

Fig. 7. left: Discovery of shrapnels in the Vela SNR right: Discovery of the Vela-Junior SNR

5. Chandra and XMM-Newton

Already in 1980 we dreamed about a "ROSAT II", which was a copy of ROSAT with a coma-corrected low energy transmission grating behind the mirror system. The scientific goal was to perform a spectroscopic follow-up survey of the brighter ROSAT sources. This plan could not be realized due to the shuttle-related delays and budget problems, but the gratings developed by MPE/Heidenhain were used for the AXAF-LETG (Brinkman et al. 2000).

In the mid 1980's ESA's mission XMM took shape. Bernd Aschenbach became the telescope scientist, responsible for the design and the tests of the mirror systems. To this end the PANTER facility had to be modified to accommodate the XMM mirrors with their long focal lengths. Our second major contribution was the pnCCD (Strüder et al. 2001). It was developed and built by a team around Lothar Strüder in the MPI semiconductor laboratory, which was founded in 1992 mainly for this purpose. During 13 years of operation in orbit the pnCCD has been the most frequently used instrument on XMM-Newton

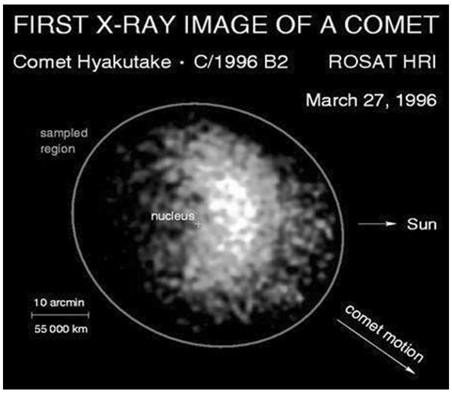

Fig. 8. Discovery of the first comet in X-rays

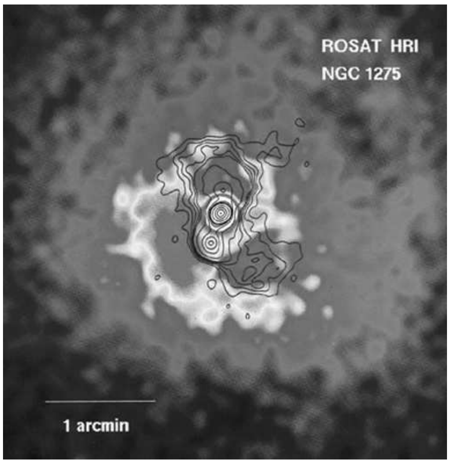

Fig. 9. Discovery of bubbles blown by the jets of NGC 1275 into the plasma of the Perseus cluster

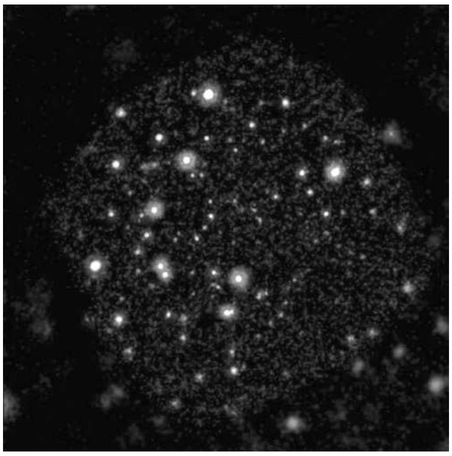

Fig. 10. The ROSAT deep survey resolves 70-80 % of the cosmic X-ray background.

6. eROSITA and the Future

In the 1990's Günther Hasinger and I proposed a small national project ABRIXAS (A Broad Band Imaging X-Ray All Sky Survey). Our goal was to scan the sky at larger sensitivity and wider energy range (0.3-10 keV) than ROSAT. It carried 7 X-ray multi-shell telescopes, with a single pnCCD of the XMM-Newton type recording the seven focal images. Immediately after the successful rocket launch in 1999 from Kapustin Yar the satellite's battery system failed and the mission was lost. After my retirement in 2001 Günther Hasinger started the project ROSITA, an improved version of ABRIXAS which evolved into eROSITA, which is expected to be launched in 2014 (see the P. Predehl contribution at this conference). Its primary goal is to study the effects of Dark Energy by surveying ~100 000 clusters of galaxies. Moreover, with a sensitivity of ~ 25 times ROSAT, its wider energy band and better energy resolution it will pave the way for the further development of X-ray astronomy. Unfortunately, the future of the field is in the dark after the early 2020's. A promising candidate for this era is ATHENA which will be discussed by Paul Nandra. In the long run, say over the next 50 years, there are many possibilities for further progress, e.g. by the development of diffraction limited X-ray telescopes which potentially can provide milli-arcsec resolution (see the P. Gorenstein contribution at this conference).

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