A BRIEF HISTORY OF X-RAY ASTRONOMY IN GERMANY

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It is a great honor and pleasure for me to receive the Marcel Grossmann Award, though I am a bit embarrassed by the fact that this puts me in a line with so many towering scientists – among them Riccardo Giaccconi who founded X-ray astronomy with a spectacular discovery 44 years ago. Since those early days this new field has exploded and become an essential part of astrophysics and cosmology. We had the luck and the privilege to contribute a little to the development of the field, and this has been rewarding in many respects. I would like to thank Remo Ruffini and his committee for this exceptional distinction.

Remo has asked me to say a few words on the history of X-ray astronomy in Germany. Actually, like many of the first generation X-ray astronomers, I came from nuclear physics and cosmic rays. At the time when Riccardo Giacconi and his team made their great first discoveries, I was a young postdoc in a nuclear physics institute at the University of Kiel. The sixties were golden times for young people and I was only 28, when I could start my own quite large cosmic ray experiment with a handful students. Our goal was to measure the chemical composition of cosmic rays at 10^{14} -10^{17} eV (in the so-called cosmic ray knee region) and to find hints on the origin of cosmic rays. Later I was fascinated by the discovery of pulsars. At the same time I followed with increasing interest the early work on the bright X-ray sources powered by accretion of matter onto neutron stars or black holes particles. All this convinced me that the secrets of cosmic rays could be better deciphered by looking at high energy photons which unlike cosmic rays would not be affected by magnetic fields but travel on straight lines or geodetics.

Therefore in the late sixties we began to make plans for a German program in X-ray astronomy, which became reality when I was appointed Director of the Astronomical Institute at the University of Tuebingen in 1971. Our first step was to start a hard X-ray balloon experiment aiming at observations of X-ray sources just found by Giacconi's Uhuru satellite. With this experiment we soon became competitive on an international scale. Only three years later, in 1974, I received a call from the Max-Planck Society and moved to the MPI for Extraterrestrial Physics in Garching where we continued our balloon flights in collaboration with Tuebingen. One highlight of these investigations was the discovery of cyclotron lines in the spectrum of the accreting neutron star Hercules X-1 in 1976 which provided the first direct measurement of a neutron star magnetic field: 4×10^{12} Gauss (1). This discovery stimulated a lot of theoretical work on the radiative transfer in strongly magnetized plasmas at MPE and elsewhere. Another interesting result was the discovery of a break in the spectrum of the black hole candidate Cyg X-1 which was interpreted in terms of Comptonization of soft photons in a hot plasma cloud, a model which was also useful for explaining the hard X-ray spectra of AGN's (2).

In the eighties EXOSAT provided a first great opportunity for X-ray observations and in spring of 1987 a space version of our balloon experiment HEXE was launched to the

MIR space station. The timing was very lucky because it was a few weeks after the explosion of Supernova 1987A. Half a year later we discovered its hard X-ray emission with the MIR-HEXE resulting from Ni-Co gamma quanta which were comptonized in the expanding supernova shell (3). The thermal emission from the supernova shock wave was discovered only much later (in 1991) with ROSAT.

ROSAT was our by far largest project. Already in 1972 we began to develop imaging telescopes and flew them on rockets to obtain X-ray images of Puppis A and Cas A. X-ray telescopes use an optical configuration invented by Hans Wolter in 1951 at Kiel. When I came as a student to Kiel he had already left to become a physics professor at the University of Marburg. I met him first only in 1971, when I had the honor to give the talk at the Fest-Colloquium celebrating his 65th birthday. The punch line of my talk was the enormous scientific potential which Wolter optics would provide for cosmic X-ray astronomy. This was confirmed eight years later in a very impressive way by the Einstein observatory flown by the Giacconi group.

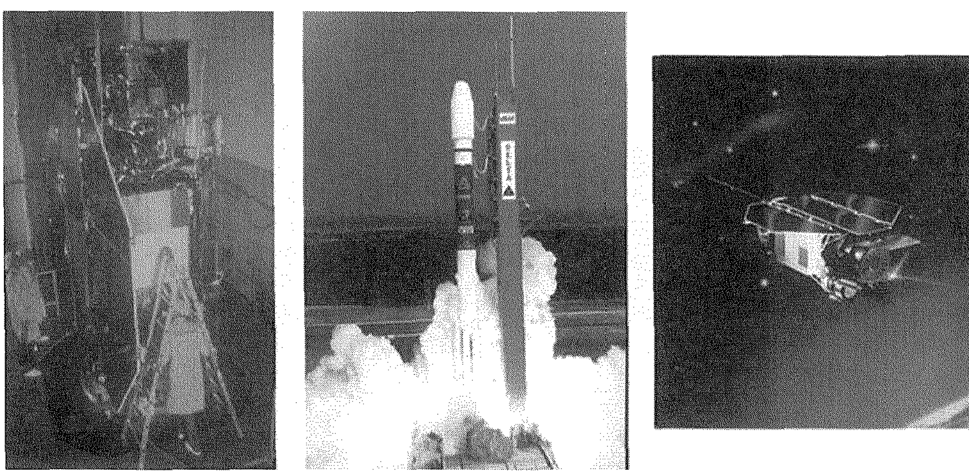

Fig. 1: ROSAT before launch and in orbit

ROSAT was launched in 1990 (fig.1) and kept us busy for 8.5 years (4). It performed the first all sky survey with an imaging X-ray telescope, digging more than two orders of magnitude deeper than Uhuru. The ROSAT survey gave for the first time a detailed picture of the diffuse X-ray emission of the entire sky on the arc minute level (fig.2), (5) which led to the discovery of the long-sought X-ray shadows cast by absorbing cool clouds and yielded accurate maps of the giant galactic loops like the North Polar Spur, the Monogem ring, the Cygnus super bubble and old extended supernova remnants such as the Cygnus loop and the Vela SNR.

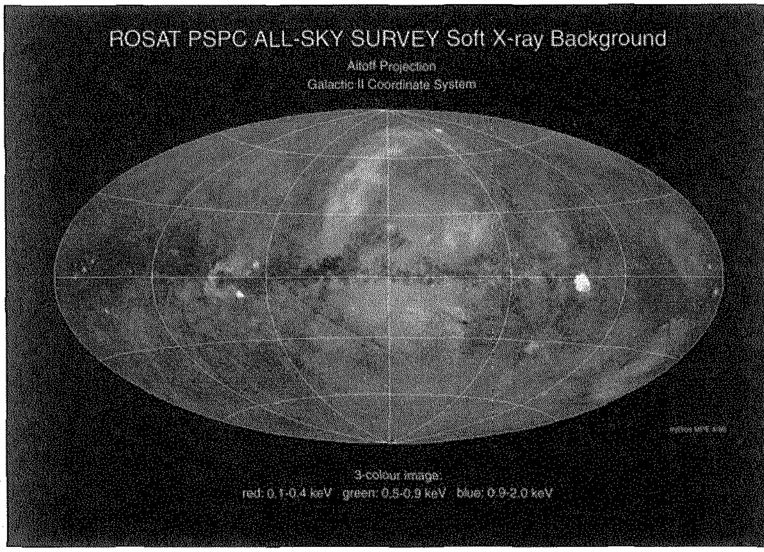

Fig. 2: The ROSAT all-sky survey provided a comprehensive picture of the diffuse X-ray galactic emission and absorption

In the Vela SNR explosion fragments were discovered outside the shock wave boundary (6). The number of point source found in the all sky survey exceeded 100,000. Fig. 3 exhibits the 20,000 brightest of them (7). The program of ROSAT pointed observations which was open to guest observers lasted about eight years and led to many discoveries as well. Let me briefly mention a few in which I was personally involved:

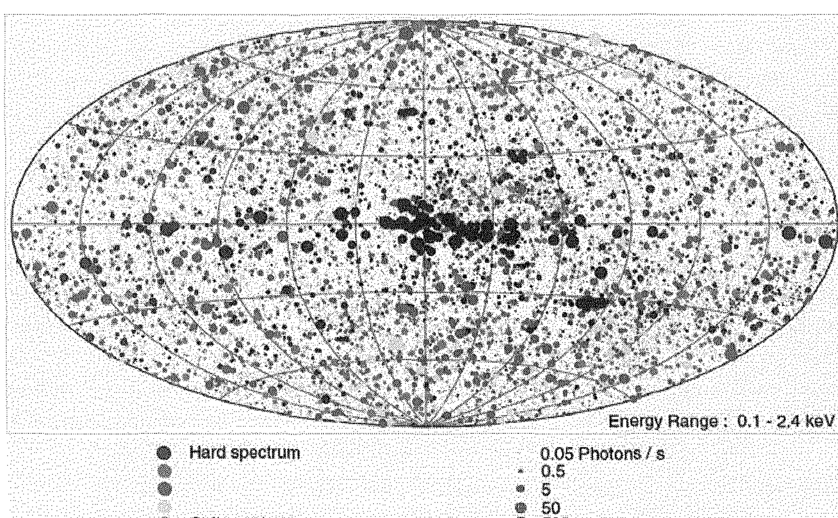

Fig. 3: Distribution of the ~ 20,000 Bright ROSAT Sources

- The ROSAT deep survey (fig. 4) was the first project to resolve a large fraction of the extragalactic X-ray background (75-80%) into the emission of quasars and other active galactic nuclei (e.g. 8), thus answering the question raised by the historical rocket flight of Giacconi et al. (which had aimed at the detection of X-rays from the moon). Actually ROSAT provided the first X-ray image of the moon (fig. 4), and also showed that the moon casts a shadow onto the X-ray background (9).

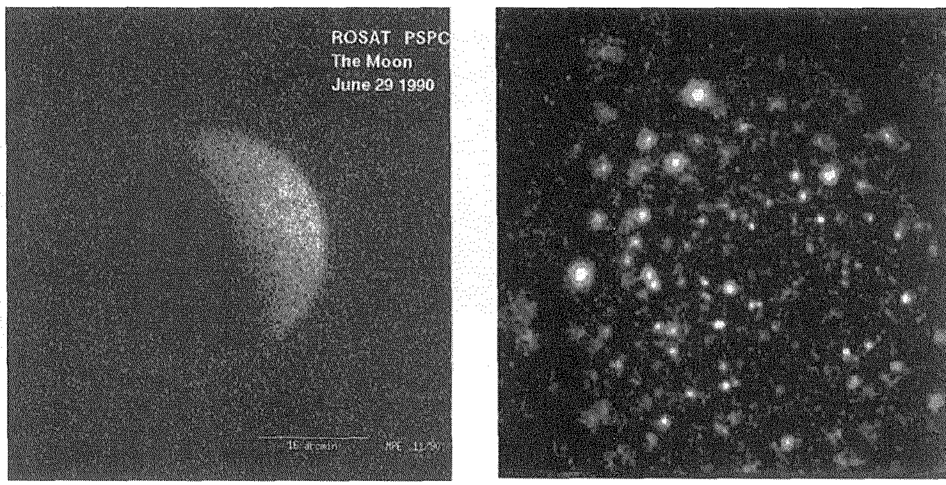

Fig. 4: X-ray image of the moon (left) and the ROSAT Deep Survey (right) resolving most of the cosmic X-ray background into point sources, mainly quasars and other AGN.

- The survey of the Large Magellanic Cloud showed a number of sources which had luminosities close to the Eddington limit, but temperatures of only a few hundred thousand degrees, two orders of magnitude lower than those of the well-known X-ray binaries (10). These "super-soft sources" turned out to represent in part a class of cataclysmic variables, which had already been predicted by theory and in which the accreted matter undergoes steady nuclear burning on the surface of the white dwarf.

- A great surprise was the discovery of X-rays from the coma of comet Hyakutake in 1996 (11) followed by the detection of several other comets in the all sky survey data and by target of opportunity observations. The answer to the immediate question why a cloud made of water and dust would emit X-rays was given soon: The ions of the hot solar wind undergo charge exchange reactions with water molecules of the coma, leaving the neutralized ions in excited states which emit EUV- and soft X-rays at de-excitation. The X-ray emission lines expected in this scenario have been discovered with the Chandra LETG.

- During the last 40 years I have come back again and again to neutron stars. I have already mentioned the discovery of cyclotron lines. With EXOSAT we provided evidence for neutron star precession in Hercules X-1 (12). With ROSAT we discovered the first millisecond pulsar in X-rays (13) and showed that normal and millisecond pulsars obey a linear relationship between the non-thermal X-ray flux and rotational energy loss (14). Among the point sources of the ROSAT all sky survey seven objects have been found showing purely thermal spectra in X-rays and faint optical spectra lying close to the Rayleigh-Jeans extension of the X-ray flux. These "Magnificent Seven" represent single cooling neutron stars, which are slowly rotating. They are fascinating since we are observing directly the hot photospheres of these tiny stars. Spin-down data and proton cyclotron lines indicate strong surface magnetic fields $\geq 10^{13}$ G. One of these objects (RX J1856-3754) shows a perfect blackbody measured with the Chandra LETG (15). Using the measured HST parallax a blackbody radius of ~17 km can be derived for this neutron star, indicating that the equation of state of nuclear matter at high densities is stiff (16, 17).

Soon after the death of ROSAT in 1999 the two new powerful observatories Chandra and XMM-Newton were launched, which provide a substantial gain in scientific capabilities. MPE has contributed to the instrumentation of both satellites and is participating actively in their observation programs. Both missions have already had a great scientific impact and have broadened and deepened our astrophysical knowledge enormously. The last two decades have been called the Golden Age of X-ray astronomy. They have been a wonderful time for many of us. I would like to thank all the people who were involved in our scientific projects, at MPE and in collaborating scientific institutes as well as in industry and government organizations. And finally I thank again you, Remo, for this prestigious award.

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