The History of X-Ray Astronomy in Germany

Joachim Trümper

X-Ray Astronomy: Towards the next 50 Years

Milano 1-5 October 2012

Prehistory at Kiel University – From Cosmic Rays to X-Rays

1955 From East to West Germany
1956 From Theory and Mathematics to experimental nuclear physics
1959 PhD University Kiel on an early-type spark chamber
1960 Using that to measure the muon momentum spectrum on the Zugspitze
1960-65 Construction of the Kiel Air Shower Experiment at 10^{15}-10^{17} eV
1962 -- I noticed the discovery of cosmic X-rays, but was busy with my work
1967-68 I was fascinated by the discovery of pulsars
-- Could they be the cosmic ray accelerators?
1969-70 Sabbatical at MPE in the gamma ray group of Kaus Pinkau
-- Working on pulsar models: The high energy electrons accelerated by the Gunn-Ostriker mechanism produce optical and X-ray pulses by curvature radiation
-- First plans for an X-Ray astronomy program in Germany
1970 Proposal for a German X-Ray satellite to search for X-Ray pulsars
1971 Director of the Astronomical Institute of the University of Tübingen (IAAT)
1975-01 Director at MPE, collaboration between MPE and IAAT

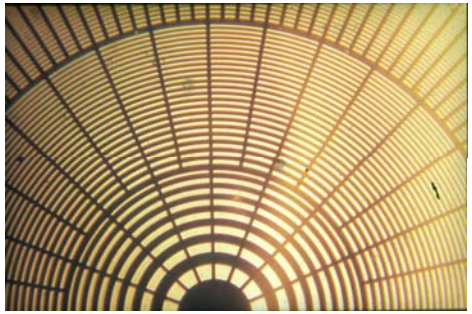
Prehistory at Tübingen University – Solar X-rays

1956 Gerhard Elwert, the last PhD student of Sommerfeld (1938) calculates the X-ray spectrum of the solar corona and predicts the limb brightening

History I: Solar X-ray Astronomy

(at IAAT and MPE)

1966 A Fresnel Zone Plate (FZP) from Tübingen flown by Friedman on a NRL rocket

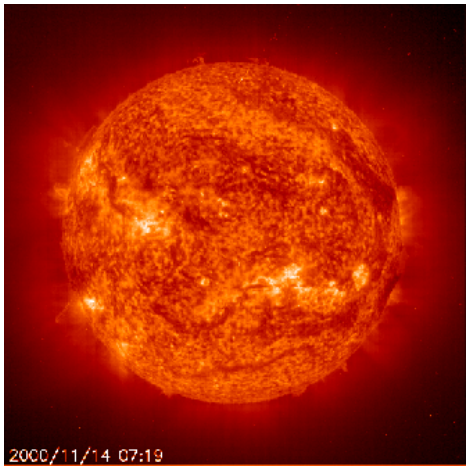


1971 Rocket experiment R170 with FZPs, Sardinia

1971 J.T. joins IAAT
1975 J.T. joins MPE

1975 and 1979 Rockets with batteries of FZPs & crystal spectrometer in Woomera
Problem: Film as the Detector!

1980s Development of a Wolter- type II telescope by MPE/Carl Zeiss (Aschenbach) for SOHO-CDS



1995 Launch of SOHO with the Coronal Diagnostic Spectrometer

II. Hard X-ray balloon program IAAT - MPE

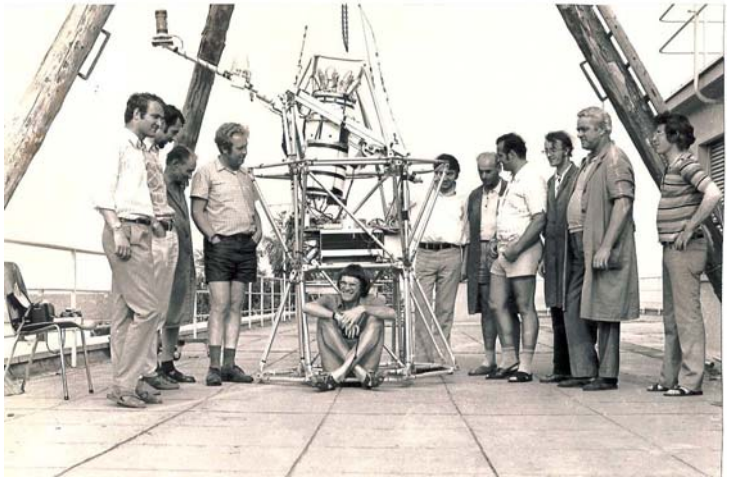
(Our „bread and butter program“, Rüdiger Staubert et al.)

1971 Proposed by J.T. to the German Science Foundation - scientific objectives :

-- observation of UHURU sources at 20-200 keV

-- spectra and time variability (1 μsec)

-- measurement of the secular decrease of the Crab pulsar luminosity



The first balloon gondola on the roof of IAAT in Tübingen (1973)

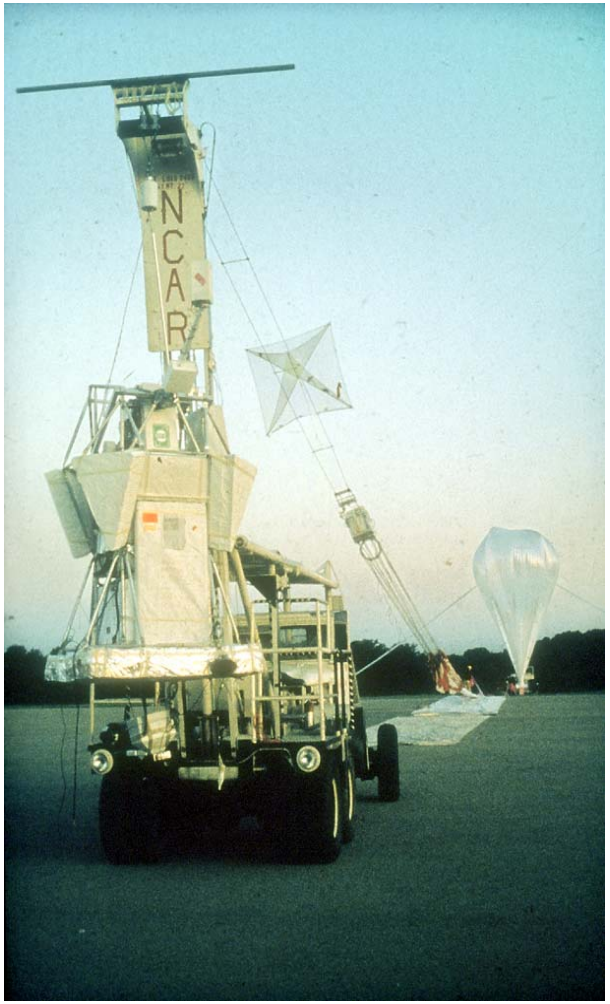
-- 19 balloon launches , 14 successful, in Texas, Alice Springs 1973-1987

-- total observing time: 222 hours

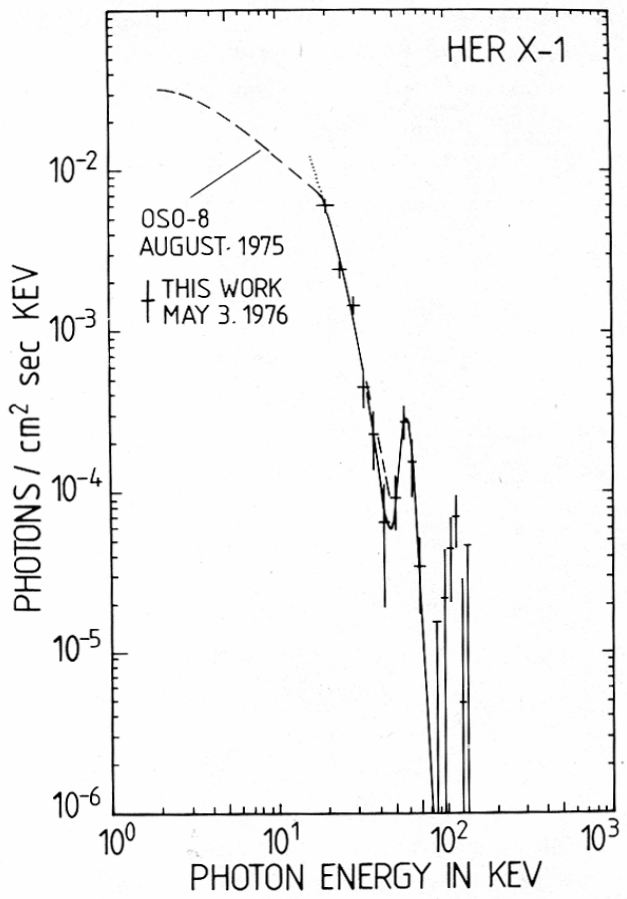
-- 40 observed X-ray sources: Crab, BH binaries (Cyg X-1 et al.), many binary pulsars (Her X-1 et al.), 3C273 et al

Discovery of Cyclotron Lines

(Trümper et al. 1977, 1978)



HEXE I



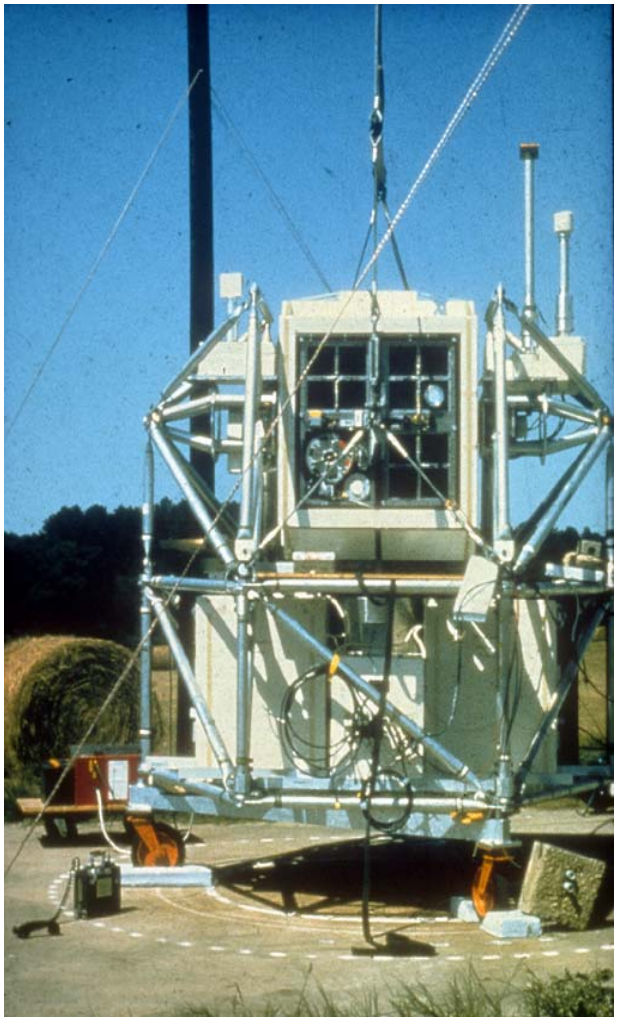
Cyclotron line at 40 keV

B = 4×10^{12}G:

The first spectroscopic measurement of a neutron star magnetic field

Today ~ 20 cyclotron line sources

Balloon - HEXE II

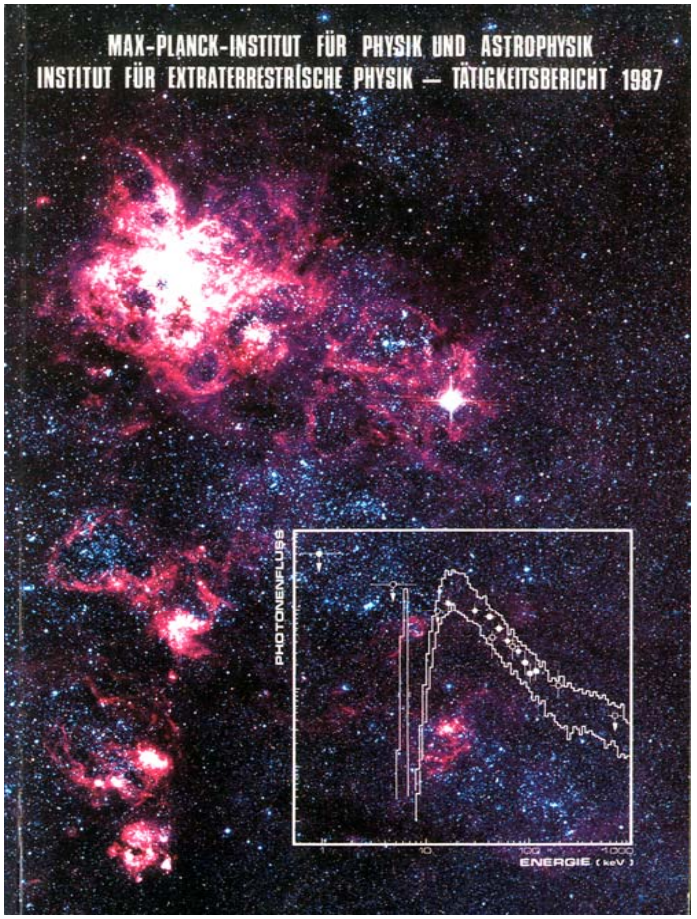


2300 cm^2 Phoswich

100 cm^2 Ge-Detector

1980 -1987

Supernova 1987 A:



HEXE on the Soviet-Russian Mir-Station (1987- 2001)

Explosion 23. February 1987
First Detection in July 1987:
0.07 solar masses of Ni 56
(Sunyaev, Truemper et al., Nature 1987)

III. Development of X-ray Telescopes

1972 We decided to develop X-ray telescopes.

Basic philosophy
-- Mirror systems built by Carl Zeiss
-- Focal plane instruments and X-ray tests in the institute

1) Flat samples from Zeiss; tests in a 6 m X-ray beam facility.
An iterative procedure led to a microroughness of 0.25 nm!
(the Einstein mirrors had ~ 2 nm)

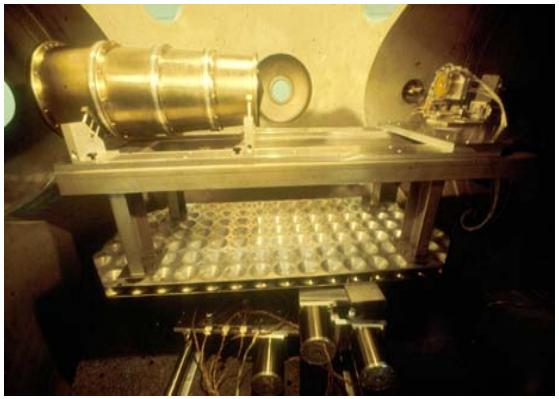
2) An array of 12 paraboloidal mirror telescopes flown on an Aries rocket (Vela SNR) in 1977

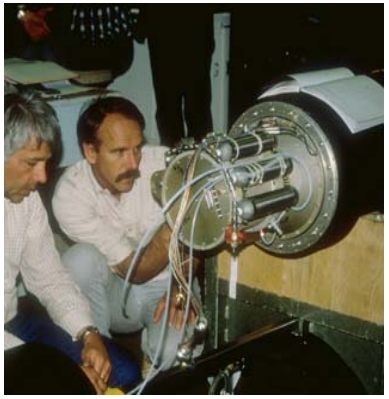
3) Three Wolter telescopes with 32 cm diameter flown on rockets:
1978 (Puppis-A)
1981 (Cas-A)
1987 (SN 1987A)

4) 84 cm - Telescope on ROSAT

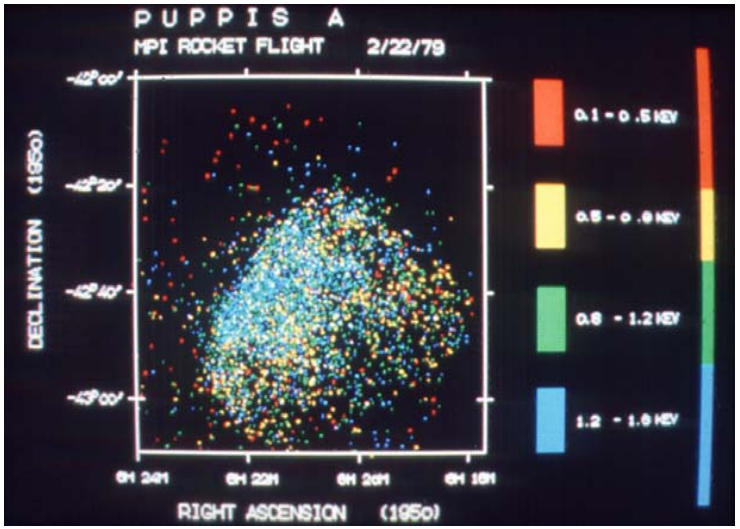
First launch of an European X-ray telescope (Astro 4-2)

Woomera Australia Februar 1979





E. Pfeffermann with the PSPC



Worldwide first X-ray colour image of a cosmic object - the supernova remant Puppis A

ROSAT Prehistory

1970 ESRO Mission definition group of HELOS (Ken Pounds, Johan Bleeker, J.T. et al.)
The main goal was to make lunar occultation of X-ray source (positions, diameter…)

We thought that telescopes were a better choice and started industry studies:

GIXRAT (Gracing Incidence X-Ray Telescope) : UK, NL, G
EXO ⟶ ASRO (Astronomical Roentgen Observatory) UK, NL, G
IXE ⟶ IXEE (International X-ray [& EUV] Explorer) US, UK, NL, G

All these attempts (1971-1977) failed for financial reasons.

That led me to consider a national approach with a simple concept:
A large X-ray Telescope plus two Position Sensitive Proportional counters (PSPC)

(No „christmas tree“ - an „telescopic analogue to UHURU“)

Brief ROSAT Project History

1974/5 AO on „Big national Projects“ by the Ministry of Research & Technology (BMFT)
J. T. proposes a satellite carrying a large X-Ray telescope which is selected along with PETRA (DESY) and a Millimeter Radio Telescope
Industry studies, development of the X-ray mirrors and the PSPCs

1977 DFVLR cost estimate: 1 Billion DM! (based on the estimated mass of 1 ton and the rule of thumb for costs of satellite experiments)

Our response: It will be much cheaper – „ROBISAT“ (Cheap Röntgen Satellite)

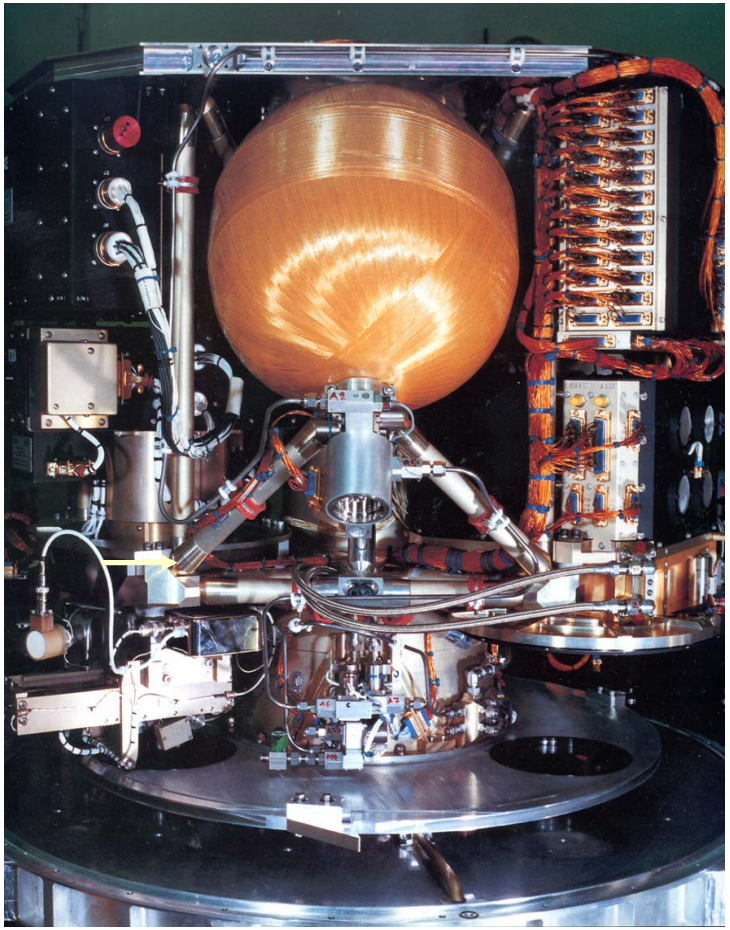
1980 BMFT: Big projects must show a “substantial international contribution”

1982/83 MOUs with NASA and SERC:
NASA: Shuttle launch, HRI and back-up ground stations (support from Riccardo Giacconi, Steve Holt, Harvey Tananbaum, Gil Ousley et al.)
SERC: XUV Telescope (Ken Pounds et al.)

1986 Challenger explosion: Shuttle launch delayed from 1987 to 1994/5
Shuttle launch ⟶ rocket launch

1990 June 1, - Launch from Cape Caneveral

Focal Plane Assembly



PSPC

5-sided anticoincidence:
low particle background

exact wiring (σ ~ 1 μm):
good angular and spectral resolution

1 HRI
(CFA)
M. Zombeck
et al.

2 PSPCs
(MPE)
E. Pfeffermann
et al.

Mirror assembly at Carl Zeiss

H. Bräuninger & B. Aschenbach

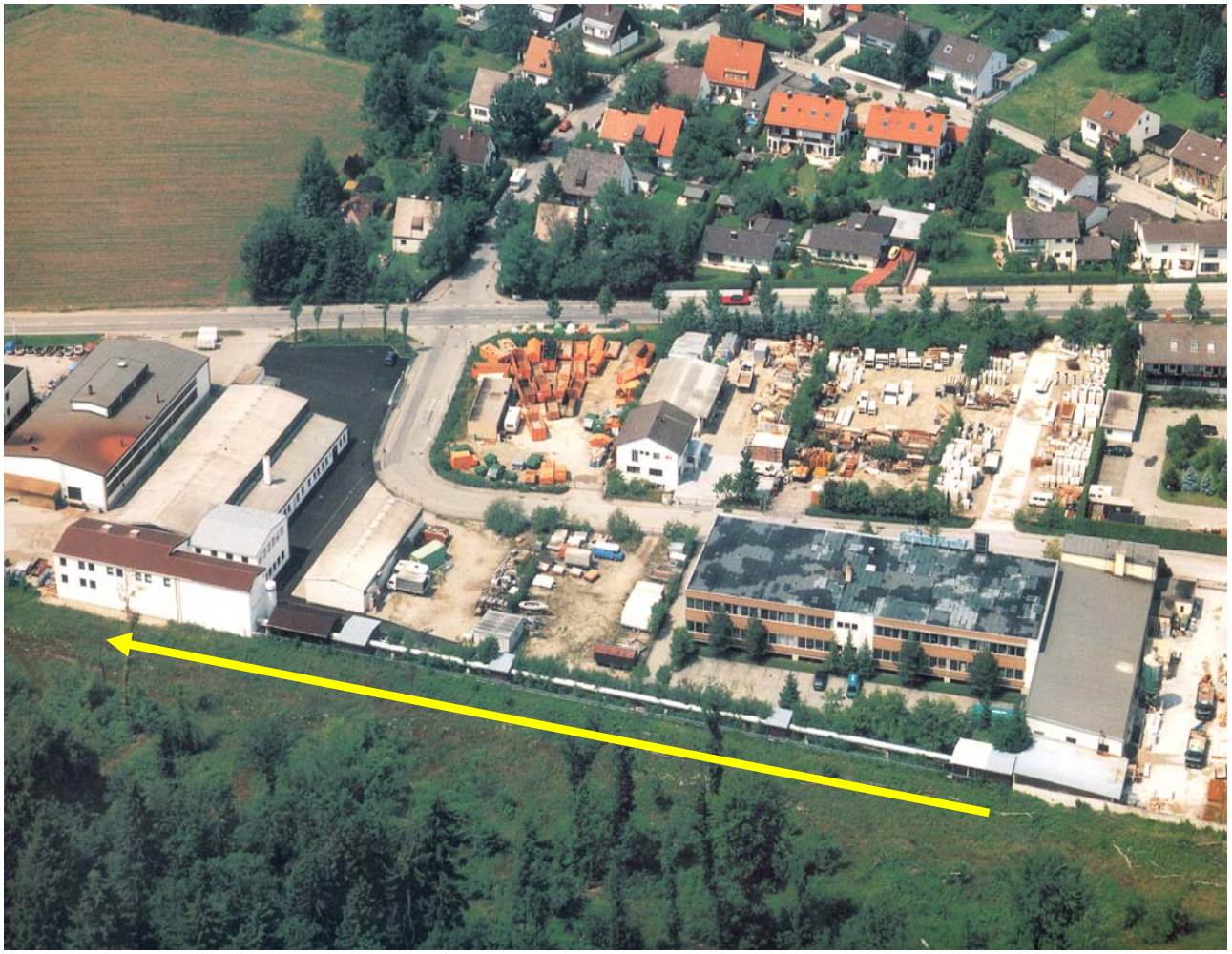
Novel features:

Zerodur

Microroughness 0.25 nm:
Very low mirror scattering

Magnetic electron deflector:
Low particle background

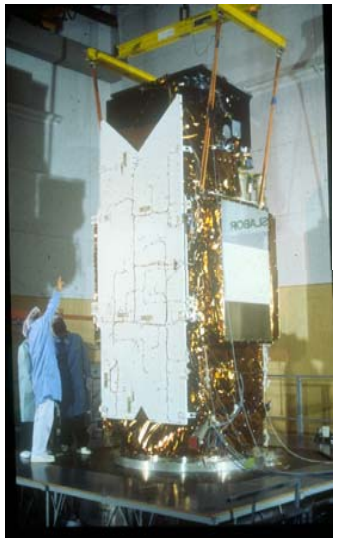
Panter – Test facility of MPE in Munich



H. Bräuninger et al. 1980 – 2012

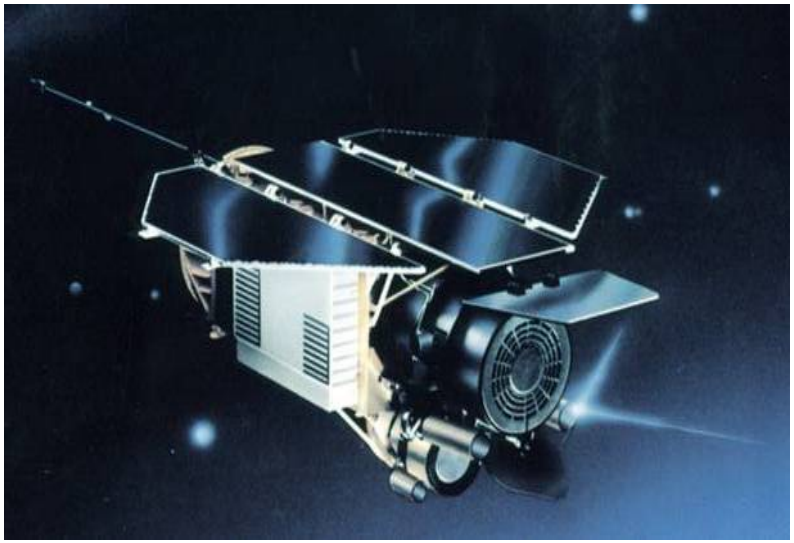
Built for ROSAT, but used also for EXOSAT, Chandra, XMM- Newton, SOHO-CDS, BeppoSAX, Swift, Constellation-X…

ROSAT 1990 -2011



at Dornier 1989/90

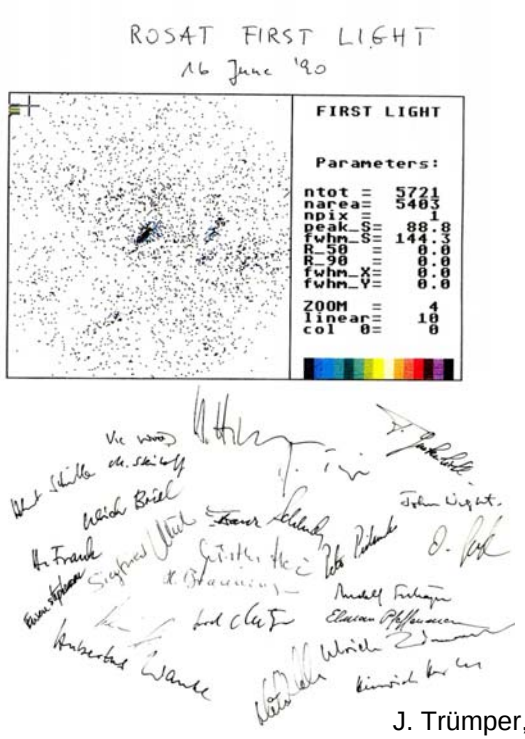
Cape Caneveral
1 June 1990



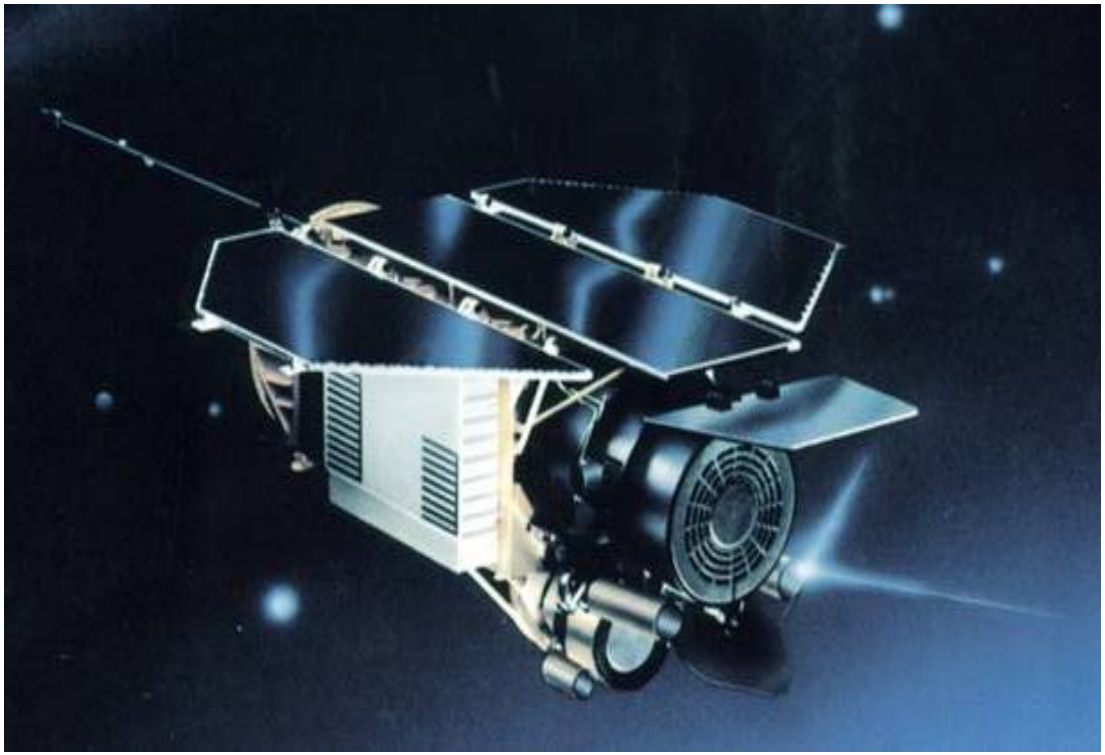
just
after
launch

two weeks
later at GSOC
16 June
before midnight

Supernova
1987A



The mission timeline in a nutshell

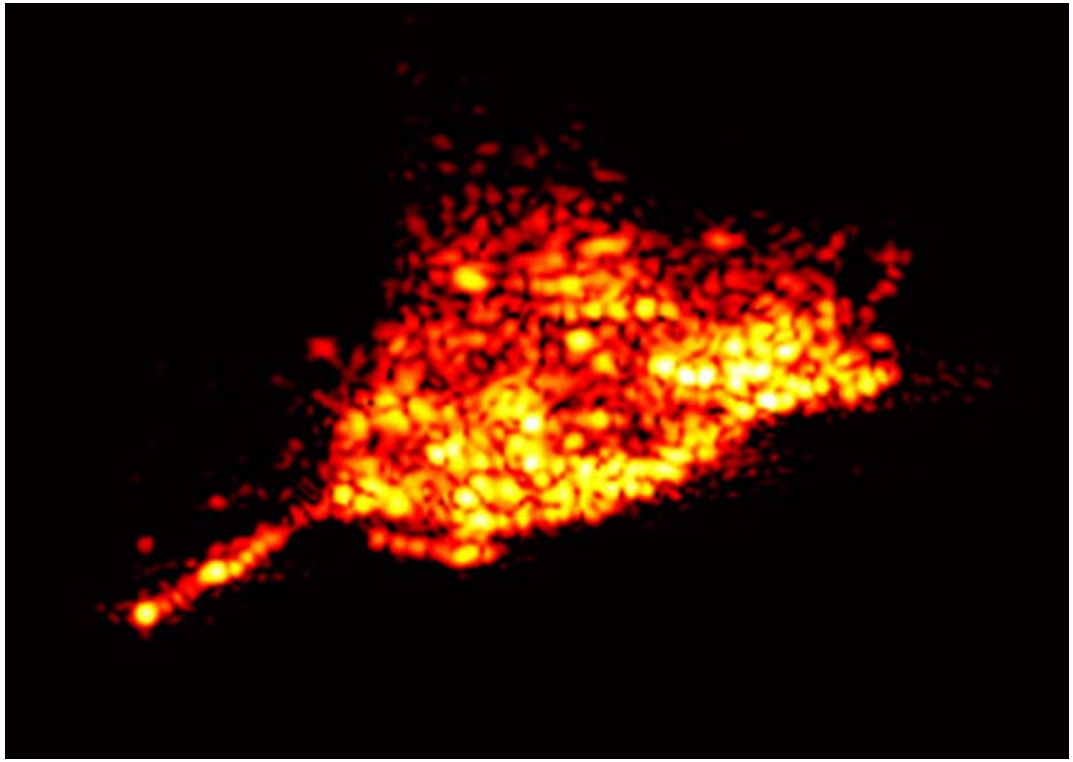


- PSPC First light at GSOC June 16, 1990

- All Sky Survey ~ 6 months
- Pointed Observations ~ 8 years (planned were 1.5 years)

- Final Observation December 17, 1998
- Final GSOC contact with ROSAT on February 12, 1999

The End of ROSAT



antenna **solar generator**

My last image of ROSAT of 20 October 2011
Imaging Radar Fraunhofer-Institute, Wachtberg near Bonn

Re-entry
23 October 2011, 3:50 MEZ
Gulf of Bengal

Progress with ROSAT

First All Sky Survey with an Imaging X-ray Telescope

- factor > 100 increase in sensitivity compared with previous surveys
- Unlimited field of view
- large flux limited samples
- discovery of rare classes of objects

First All Sky Survey in the XUV

Eight years of pointed observations:

ROSAT PSPC versus Einstein IPC:

- grasp ~ 5
- spectral resolution ~ 4
- angular resolution ~ 3
- non-X-ray background per arcmin^2 ~ 0.06
  per angular resolution element ~ 0.01

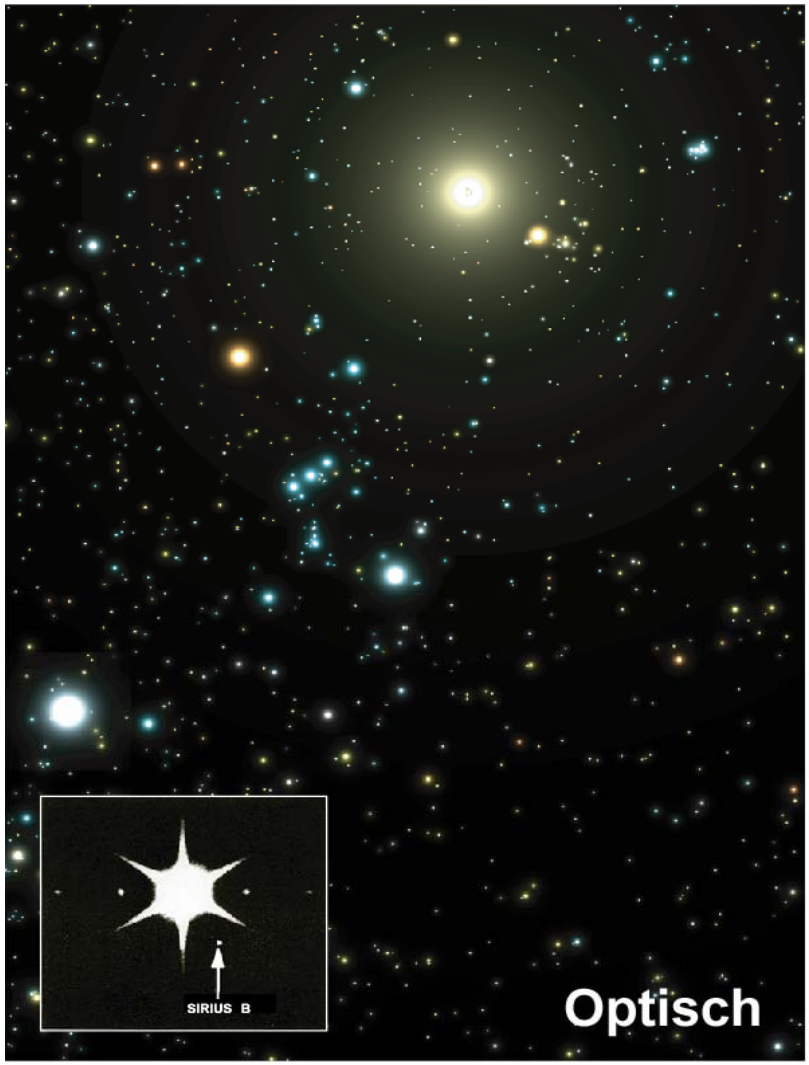
(~ 1 non-X-ray background count per arcmin^2 in three days!)

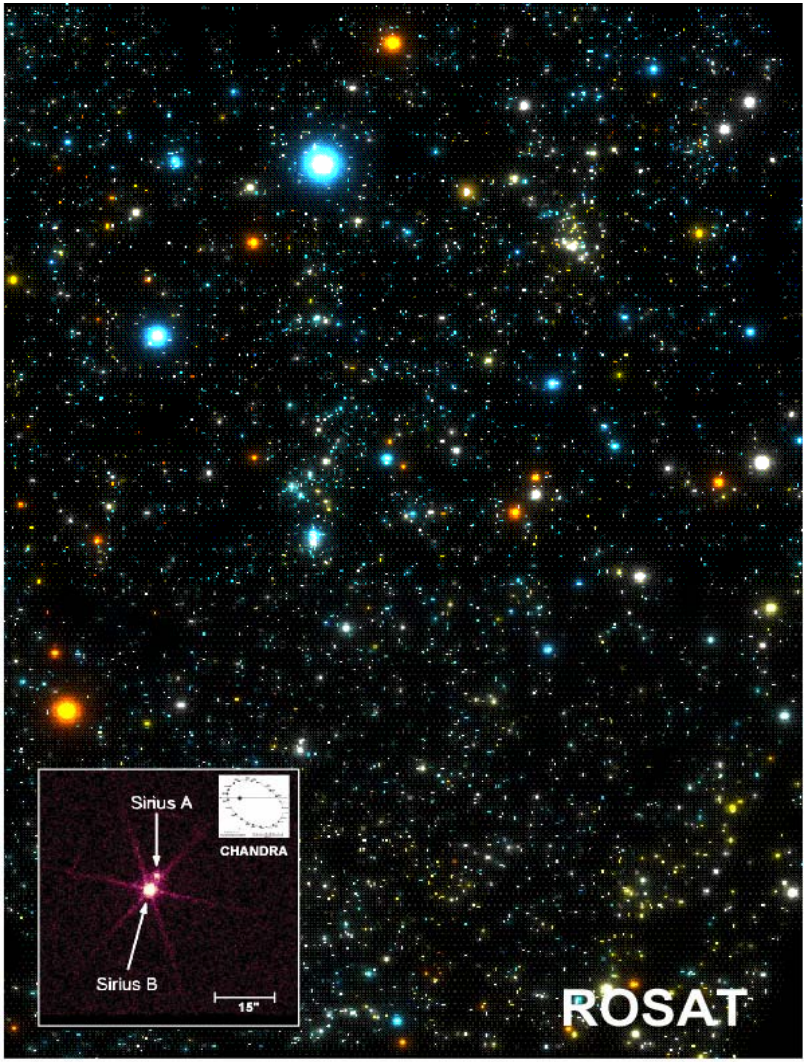
ROSAT was the first mission to image the "X-ray background"!

ROSAT HRI versus Einstein HRI:

- angular resolution ~ 2 (due to the mirrors)

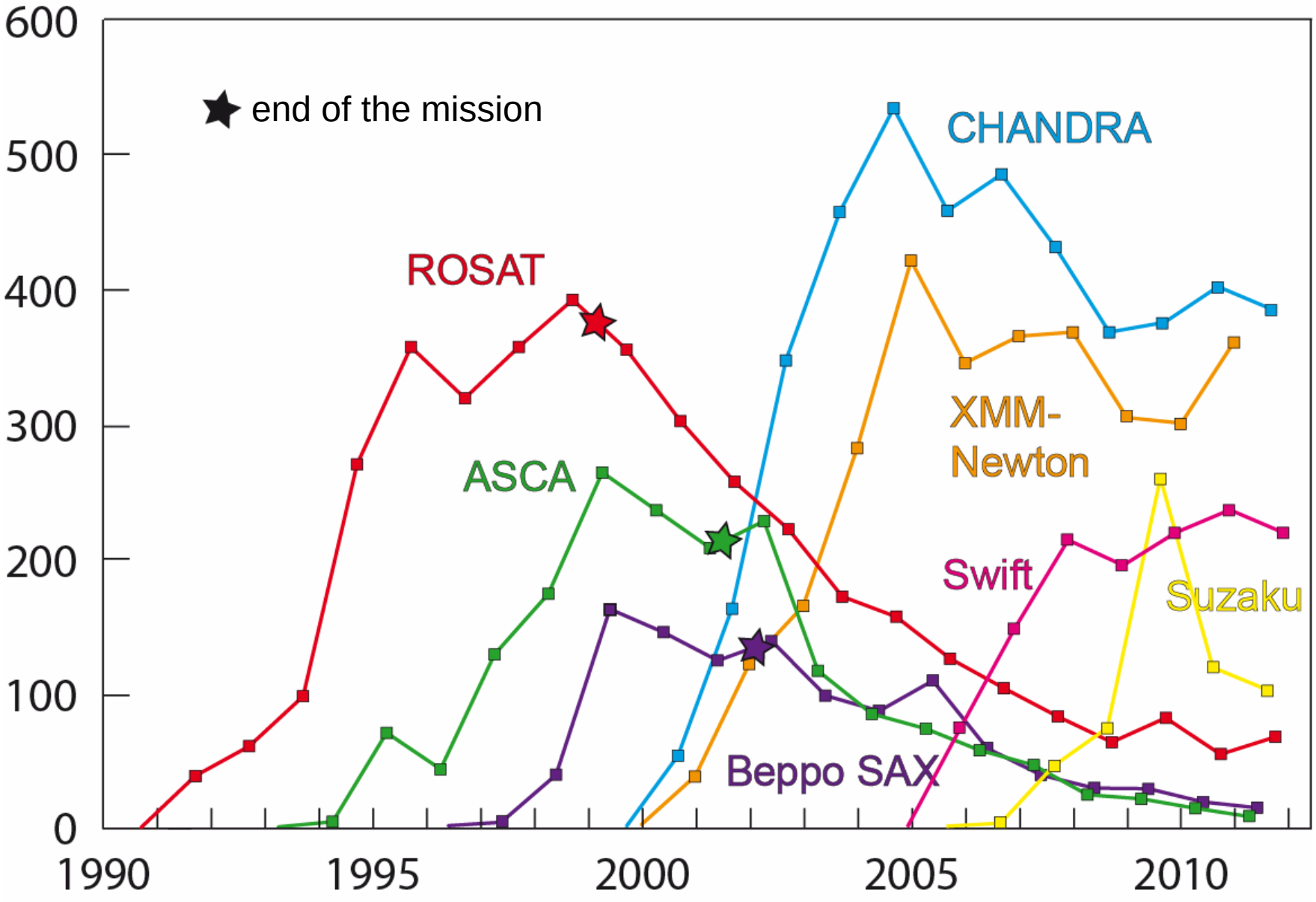
The Sky in optical light and in X-rays





Der Sternenhimmel über München im Winter 75° × 50°

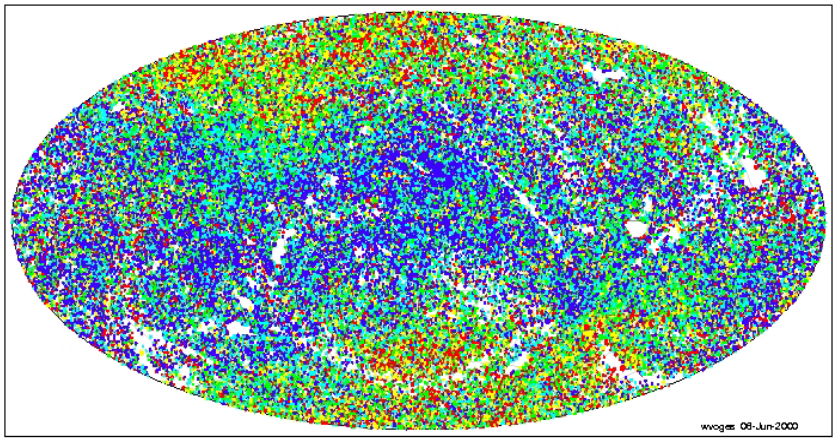
Number of Publications in refereed Journals (ADS)



J. Trümper, Milano 2012

A Gallery of Discoveries and Highlights

The ROSAT Surveys

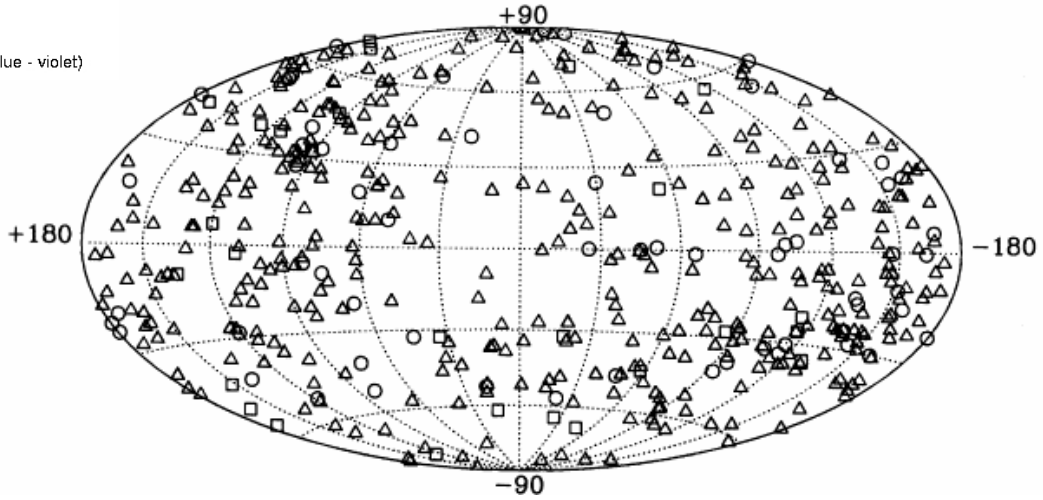


Energy range: 0.1 - 2.4 keV
Number of RASS-II sources: 105924
Hardness ratio: -1.0 | -0.6 | -0.2 | 0.2 | 0.6 | 1.0 (soft -> hard : red - yellow - green - blue - violet)

X-ray Sky
- **100.000 sources**

Voges et al. MPE catalogue

XUV Sky
Pounds et al. MNRAS 1993
Pye et al. MNRAS 1995

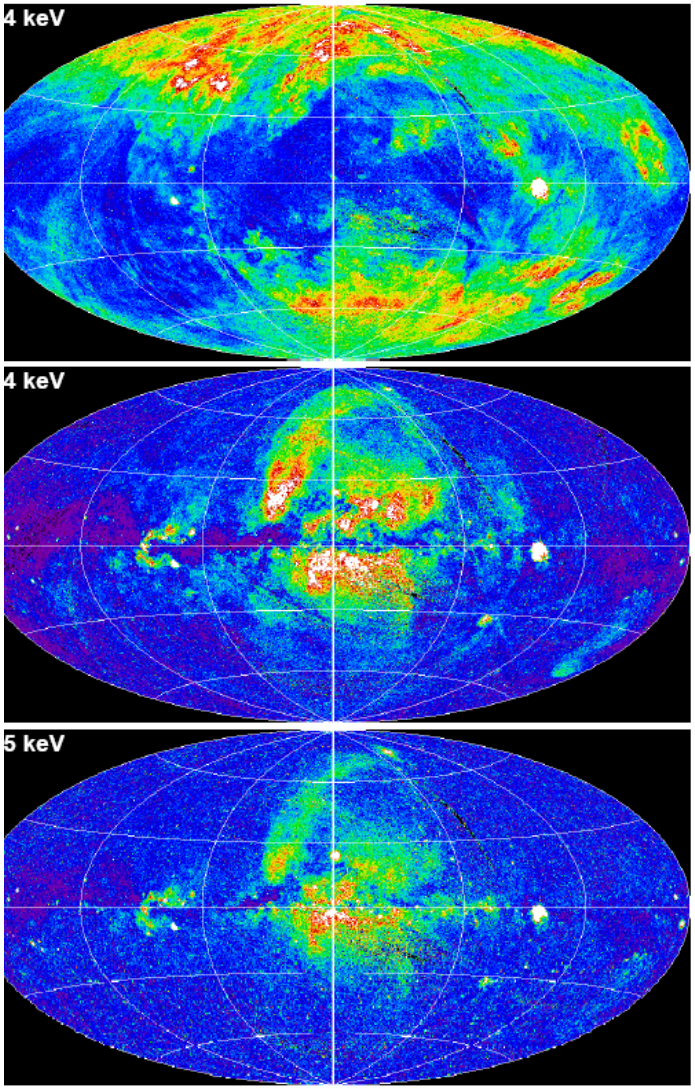


Discovery: PSPC & WFC surveys detect only 175 White Dwarfs, while 5500 were predicted!

- **Mixing of heavy elements into the photospheres (Fleming et al. 1996)**

RASS – Diffuse Emision

The final product
> 99.9 % complete

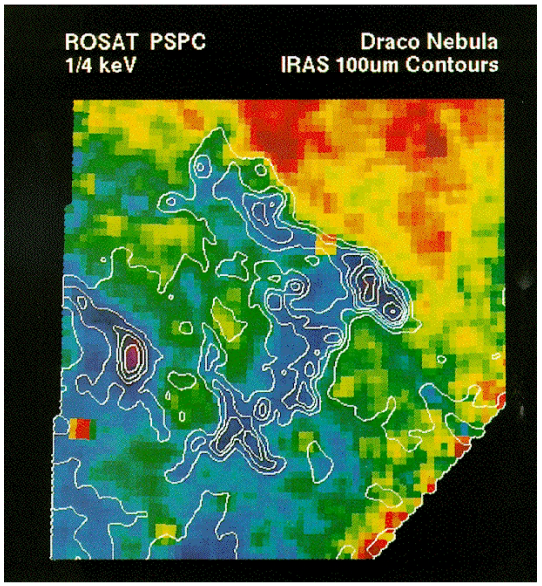


0.1-0.4 keV

0.4-1.4 keV

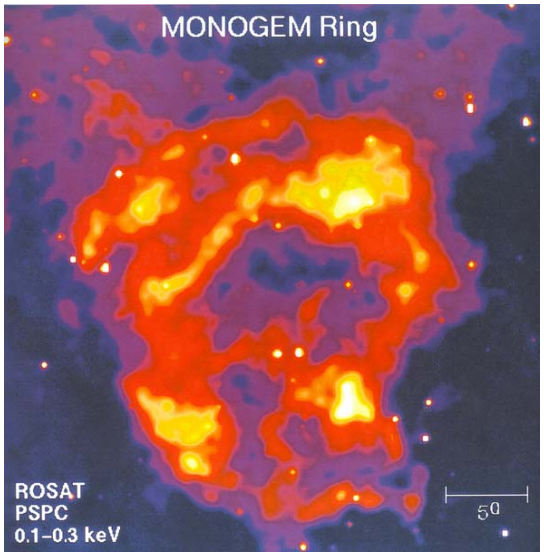
1.4-2.5 keV

First Discovery of X-Ray Shadows

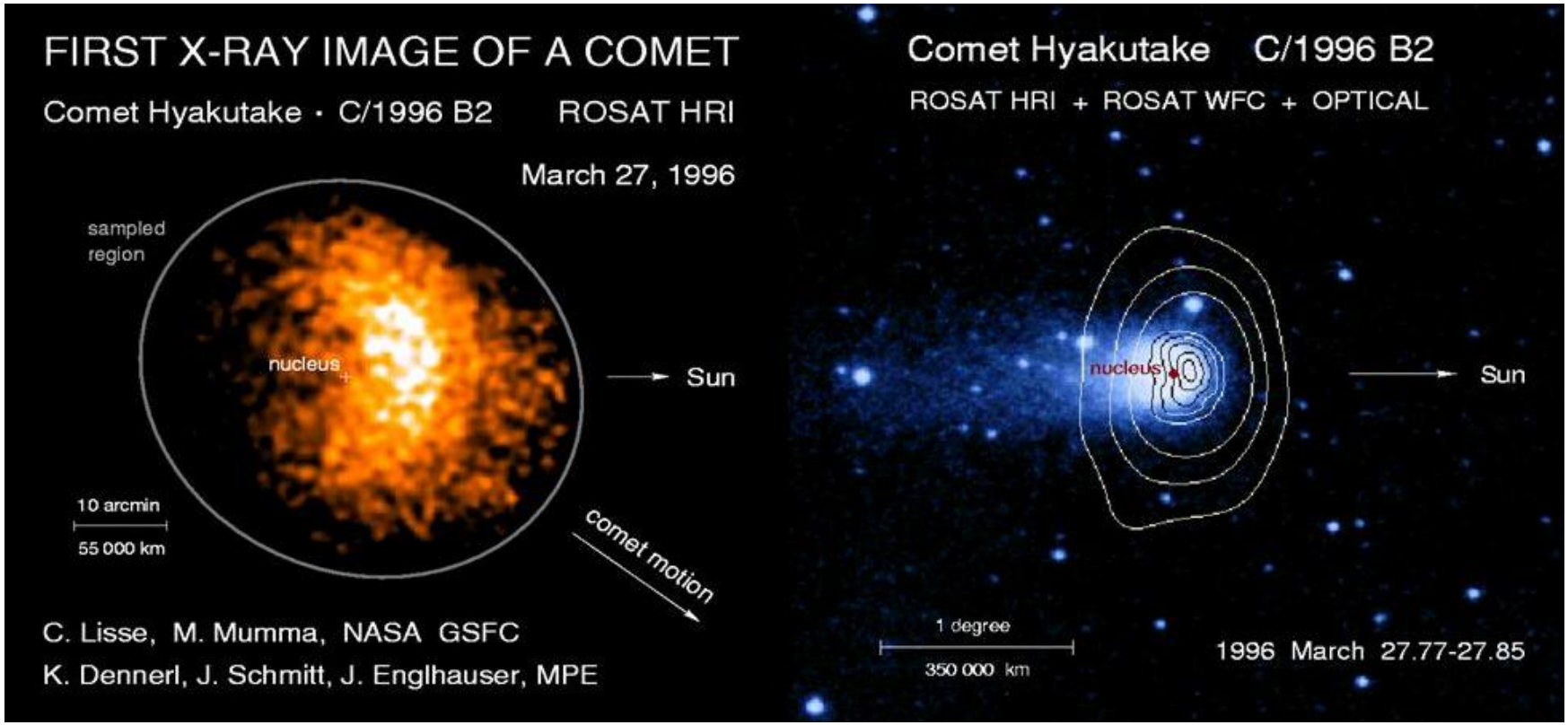


Snowden et al. 1991

The unlimited Field of View



Surprise: X-ray emission from dirty snowballs!

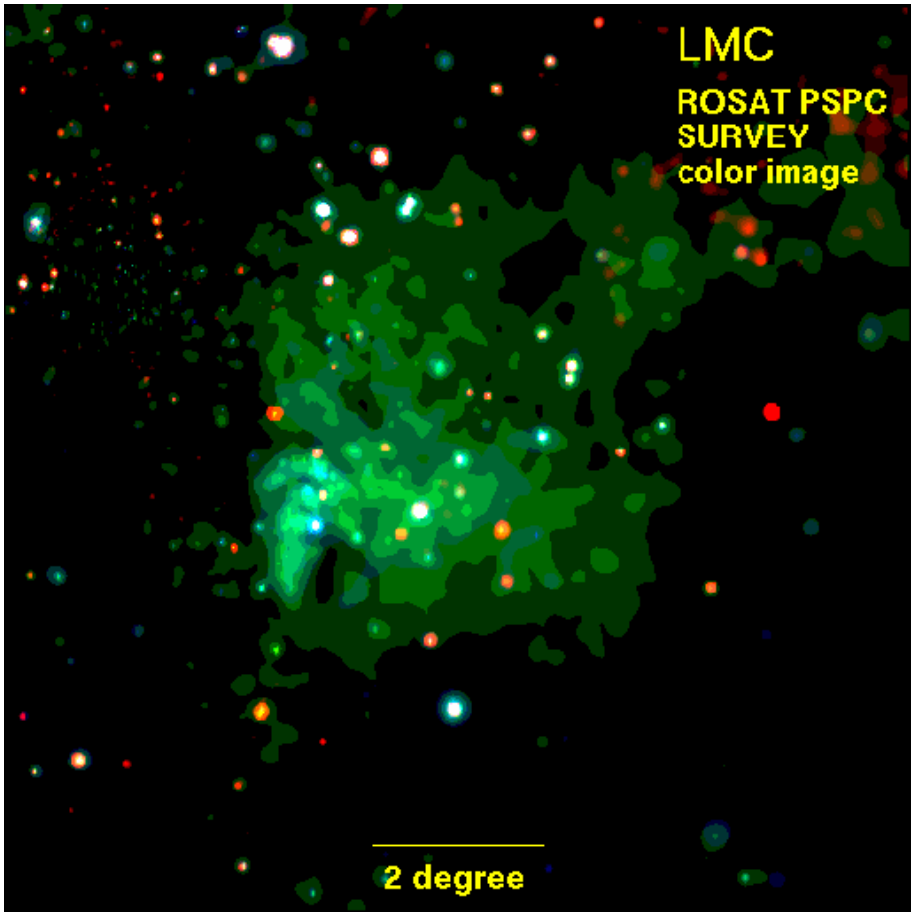


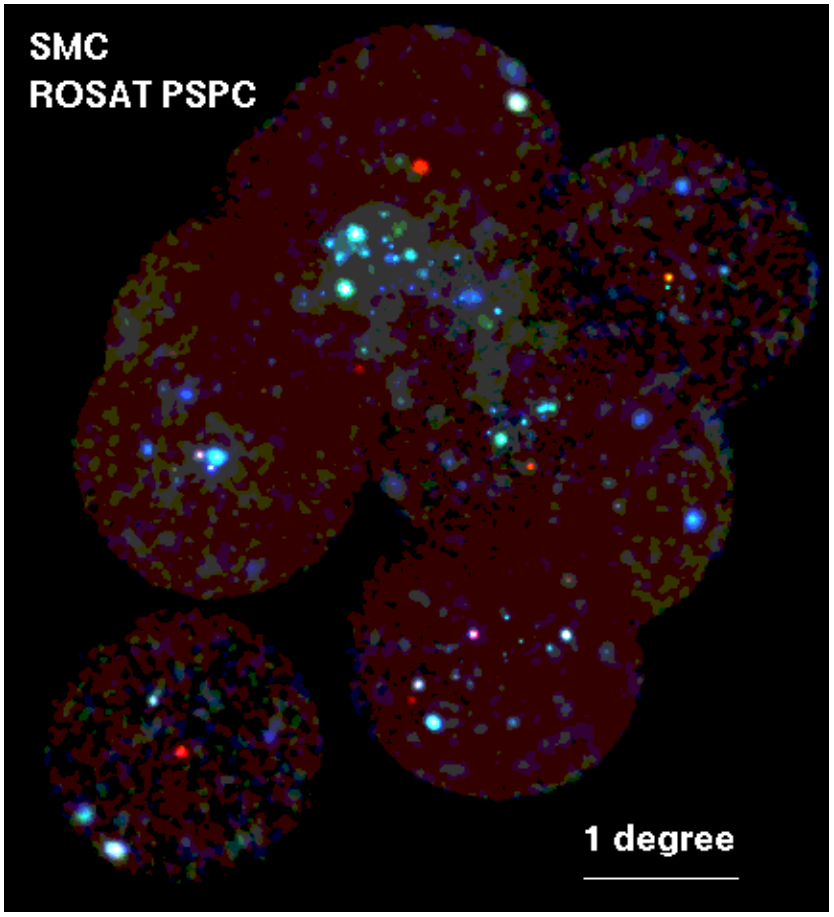
charge exchange between solar wind ions and water molecules in the cometary coma

up to now 23 comets have been X-ray detected,
11 by ROSAT
and 12 by EUVE, Chandra & XMM-Newton et al. (Dennerl 2010)

Discovery of the new class of supersoft sources in the LMC

Trümper et al. 1990

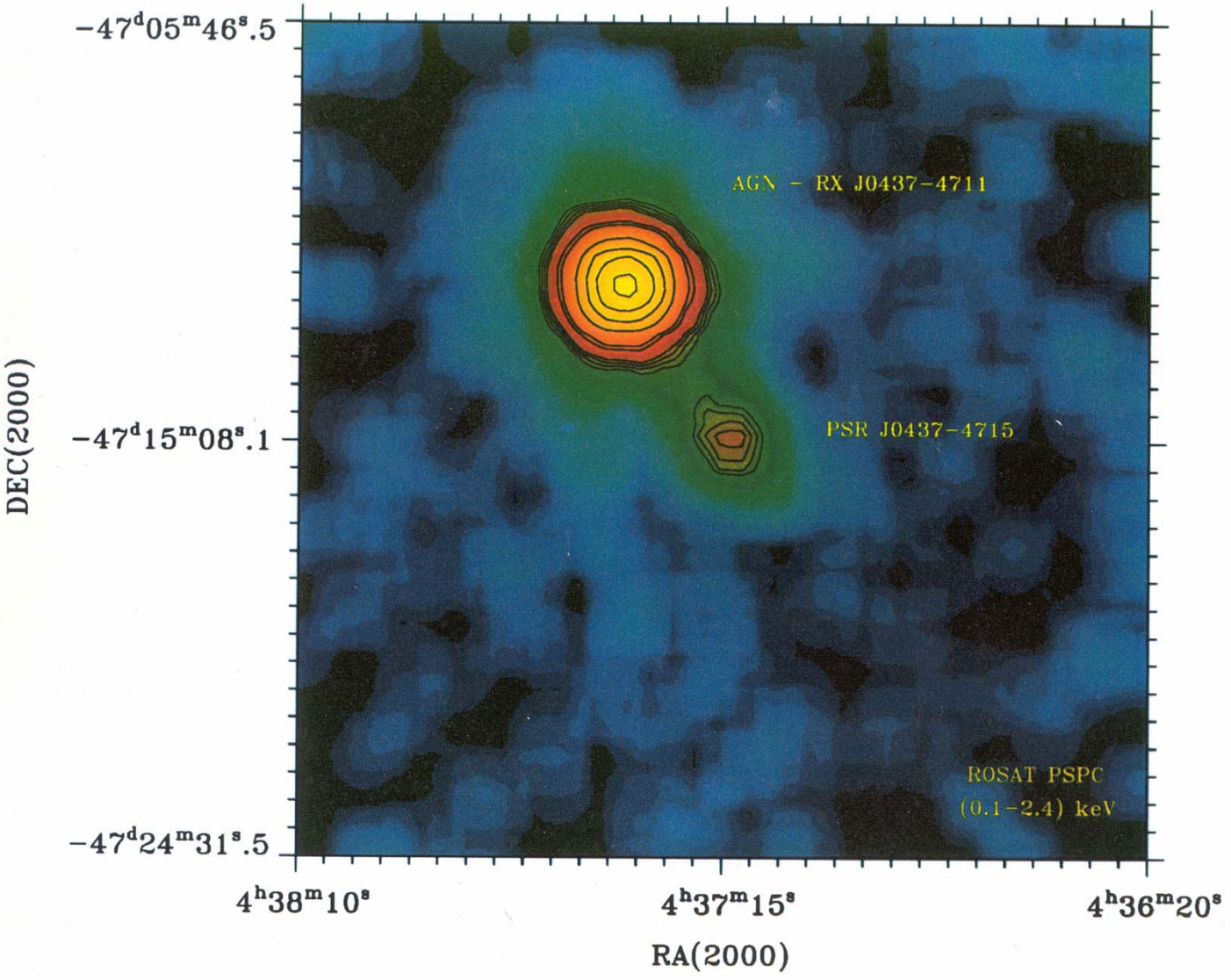




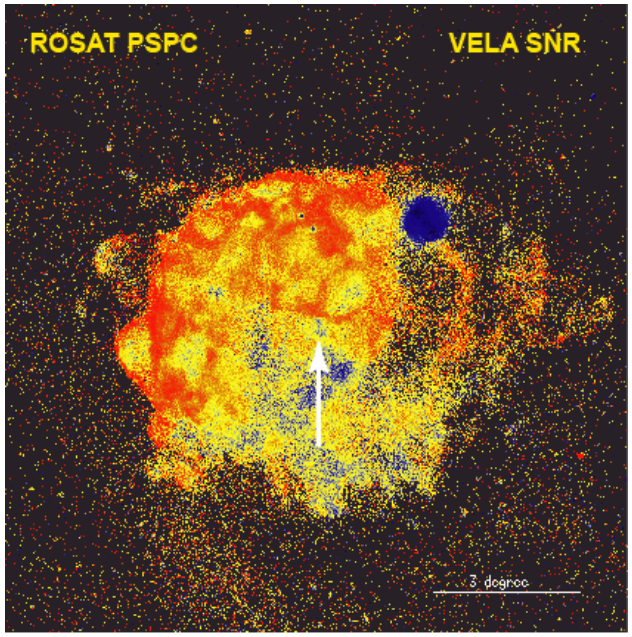
CV's, nuclear burning of accreted matter on the White Dwarf surface

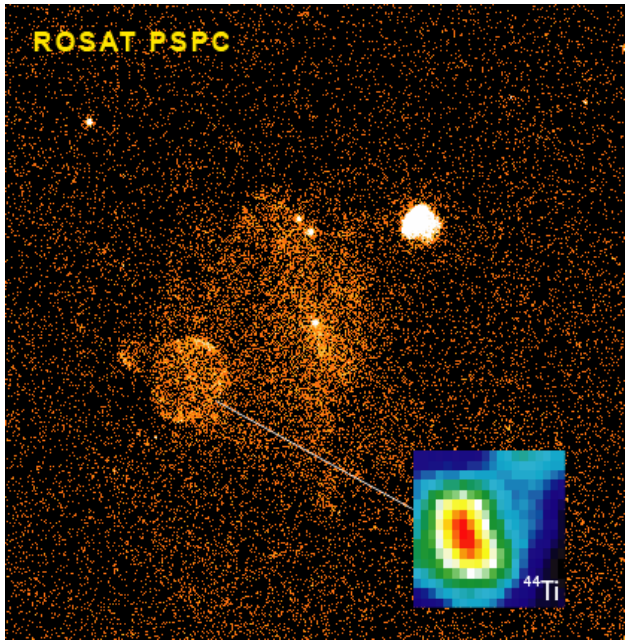
Discovery of the first Millisecond Pulsar in X-rays

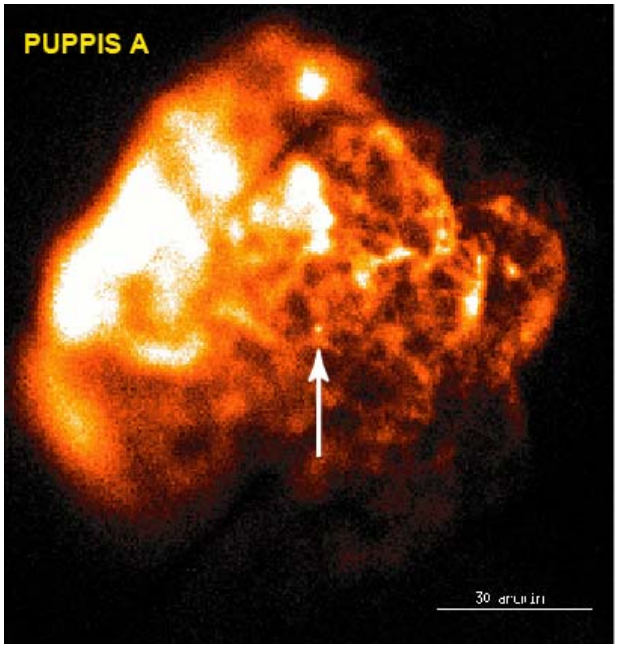
Becker & Trümper, Nature 1993



ROSAT discoveries in the Vela-Puppis-A complex







Mach cones in the hot ISM caused by explosion fragments

Aschenbach et al. Nature 1995

„Vela Junior“ In the hard PSPC band young and closeby

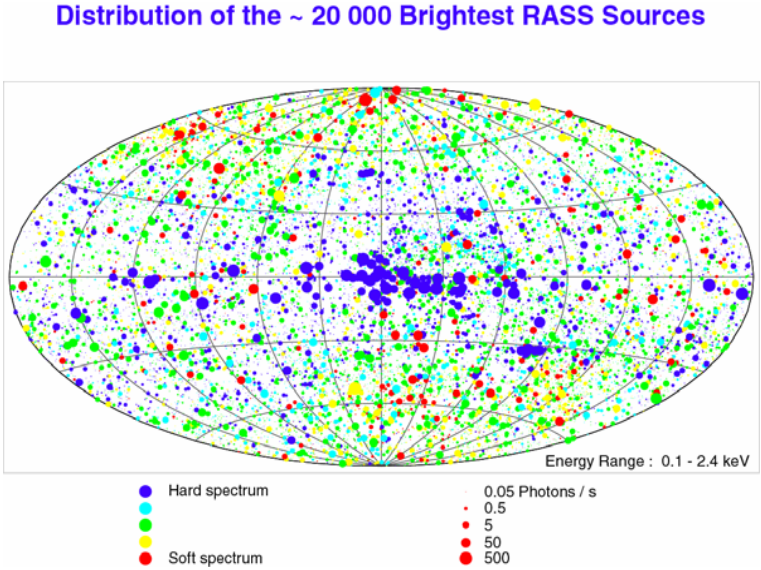
Aschenbach Nature 1998

Thermal Emission from the neutron star in Puppis A

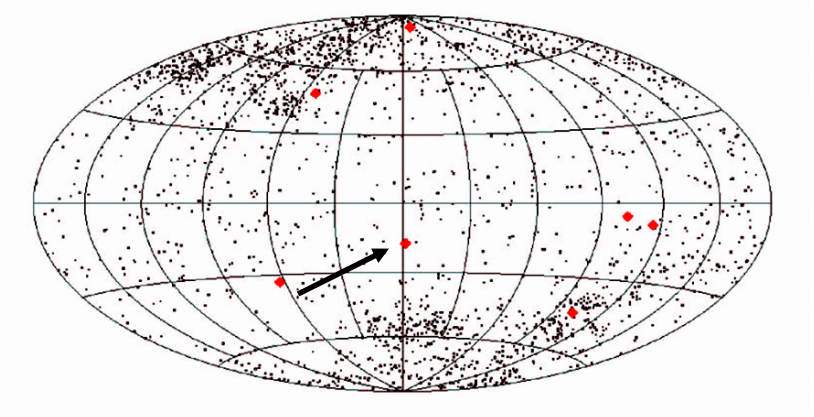
Petre et al. A&A 1996

Discovery: 7 neutron stars showing purely thermal emission

ROSAT Bright Survey (~ 20 000 Sources)

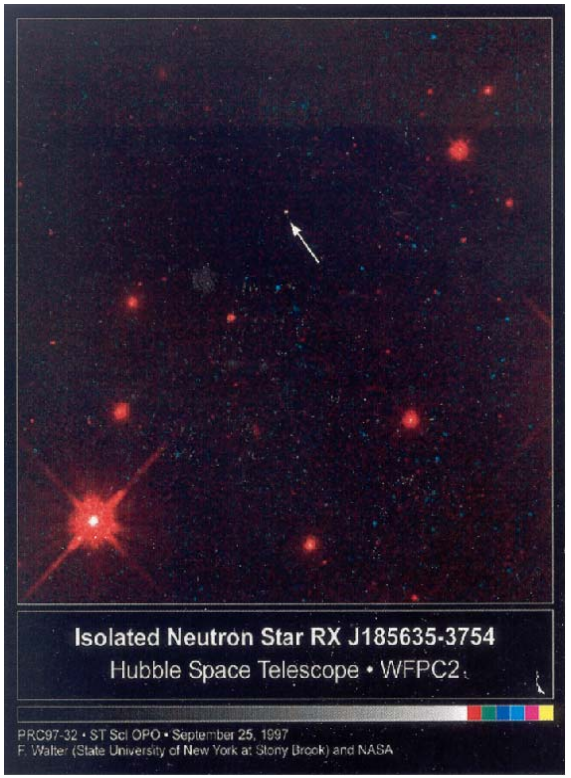


Soft X–ray spectrum + faint in optical



Walter et al., Nature 1996 : RX J1856-3754

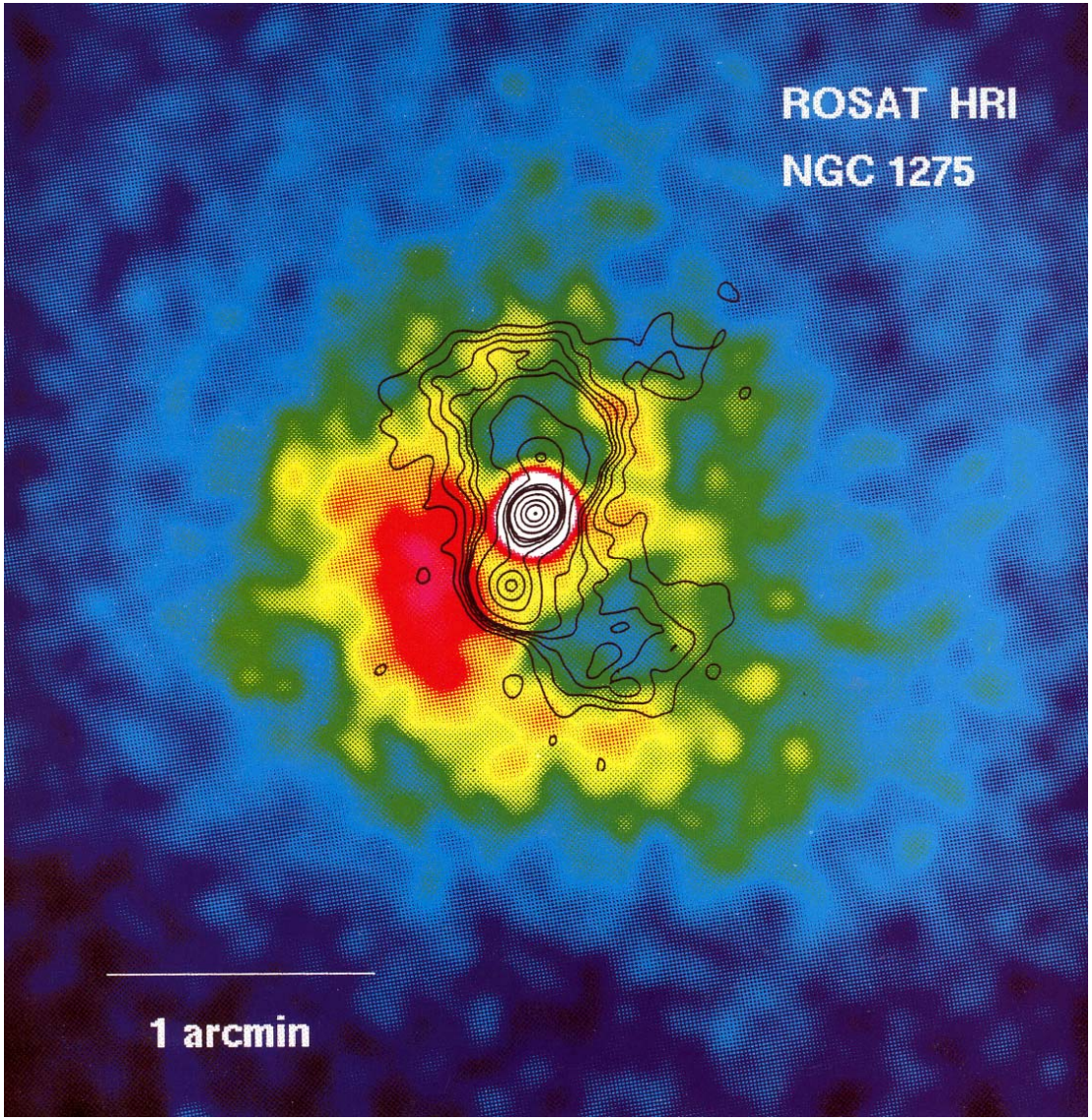
RX J1856-3754 :
perfect blackbody in X-rays
and in the optical range
d = 120 +/- 8 kpc (HST)
(Walter et al. 2010)
Large NS radius! (13- 14 km)



HST: m = 25,7

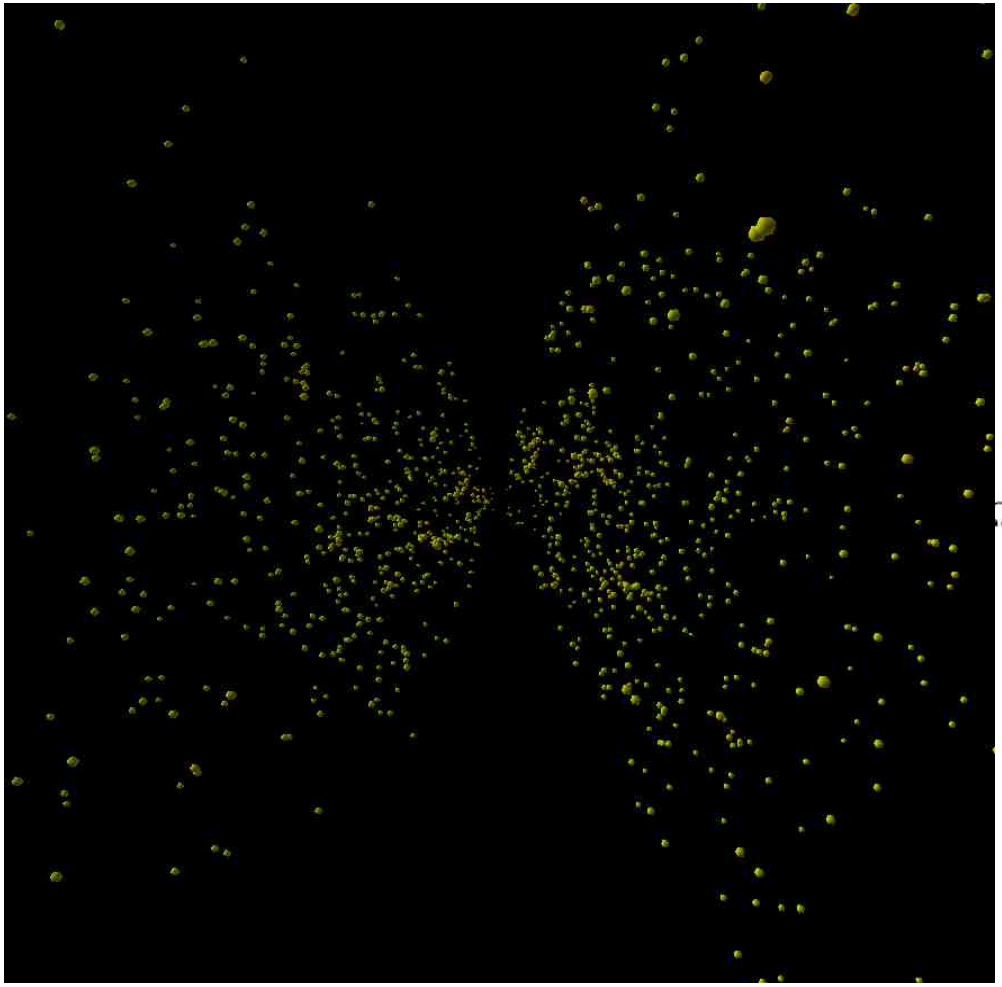
First discovery of bubbles blown by the AGN jets into the hot cluster medium

Böhringer et al., MNRAS 1993

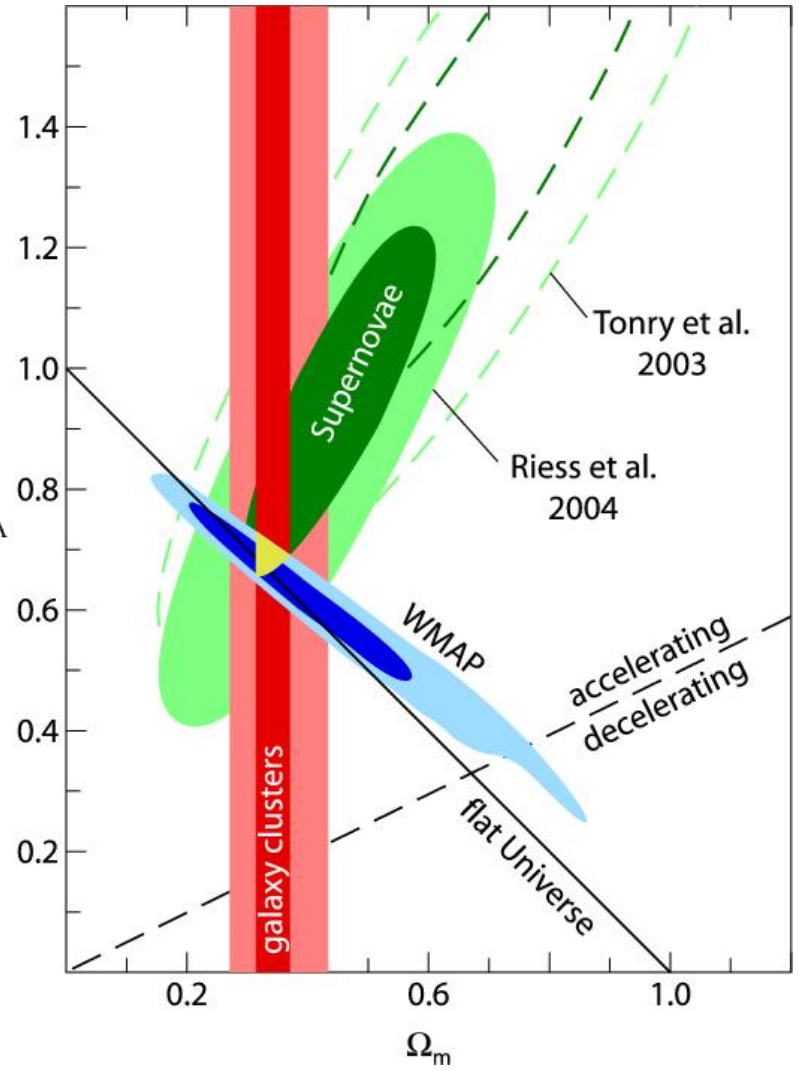


REFLEX Survey - Constraints on Dark Matter

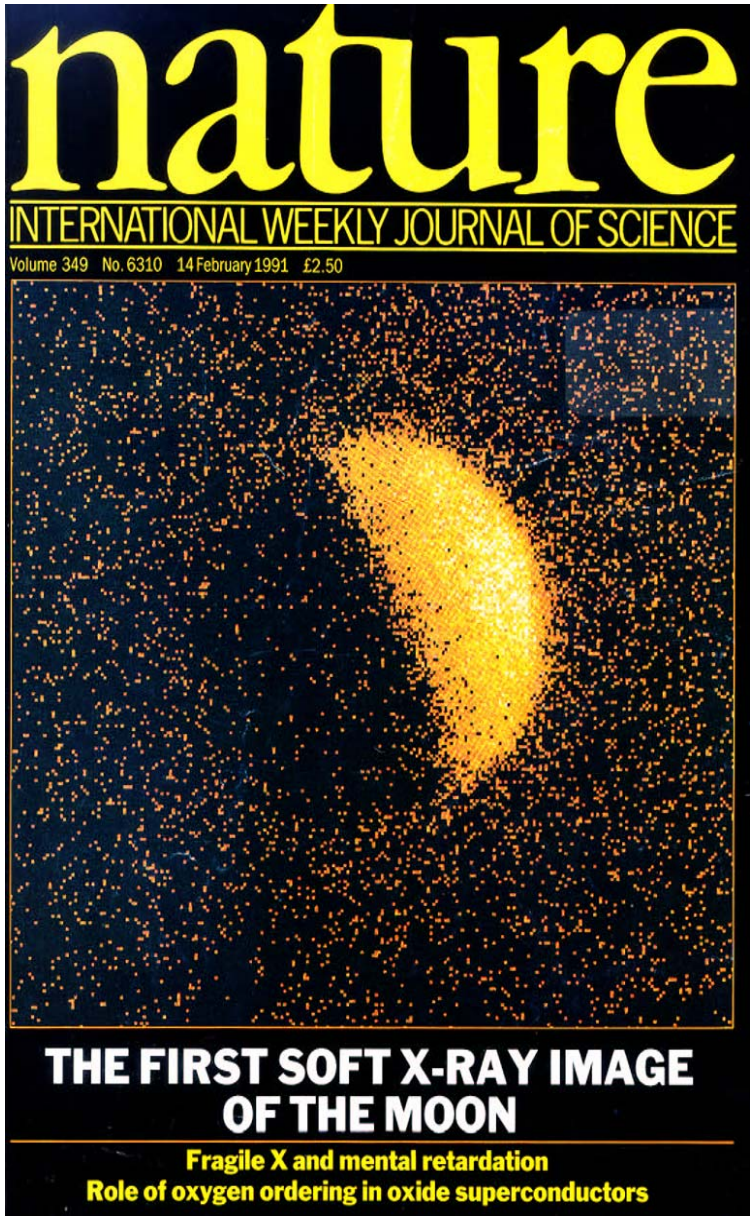
Böhringer et al. A & A 2004



Schücker et al. A & A 2003



ROSAT 1990 – Back to the Moon



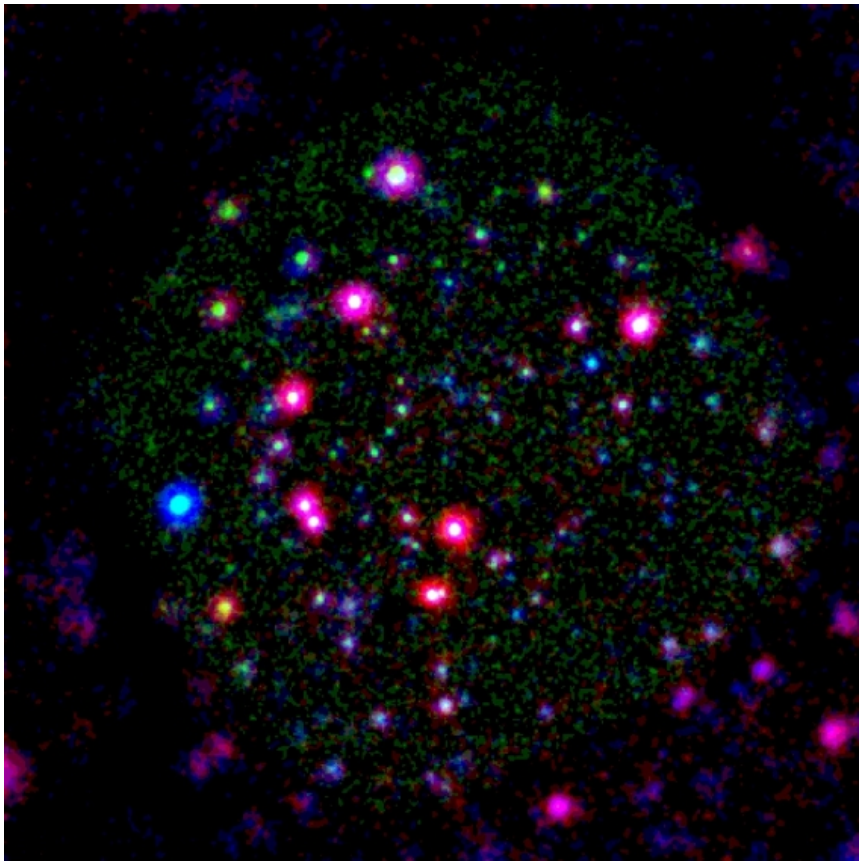
Schmitt et al. 1990

The moon occults the X-ray background!

ROSAT Deep Surveys: Resolving the X-ray background

G. Hasinger, R. Giacconi, M. Schmidt, J. Truemper et al. A&A 1998

1.4 Ms PSPC + HRI image



~ 80% of the sky background resolved into sources, mostly AGN; (Einstein observatory: ~ 20%)

(as predicted by Setti & Woltjer 1979)

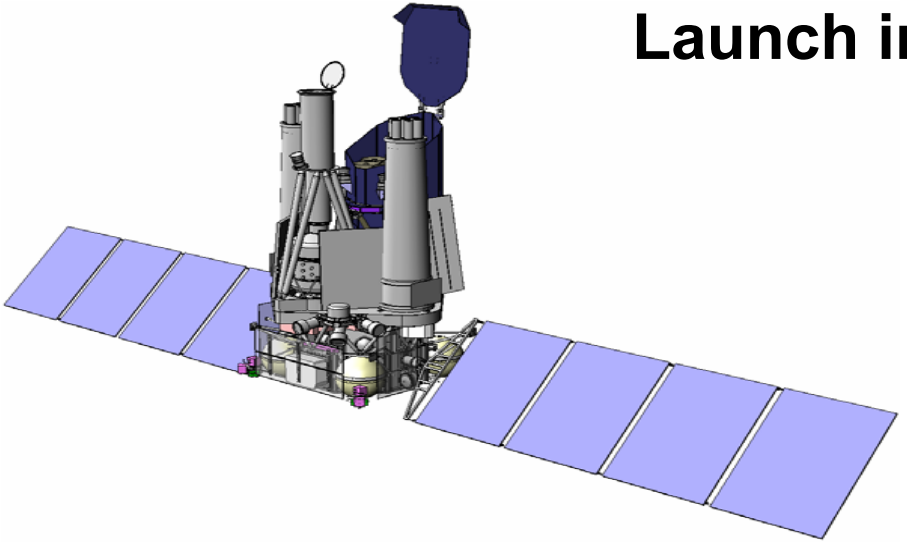
AGN evolution……

Towards the next 50 years at MPE

eROSITA

Peter Predehl talk

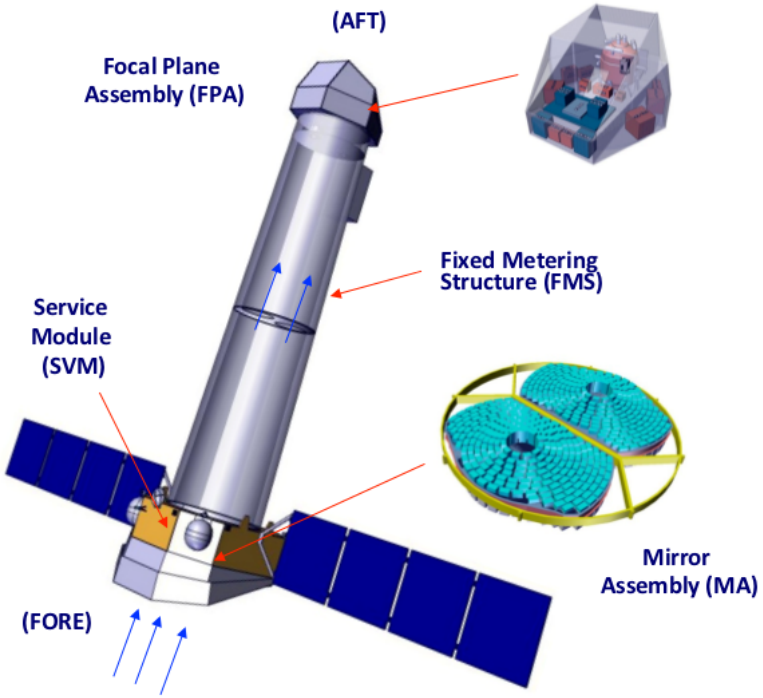
Launch in 2014



ATHENA

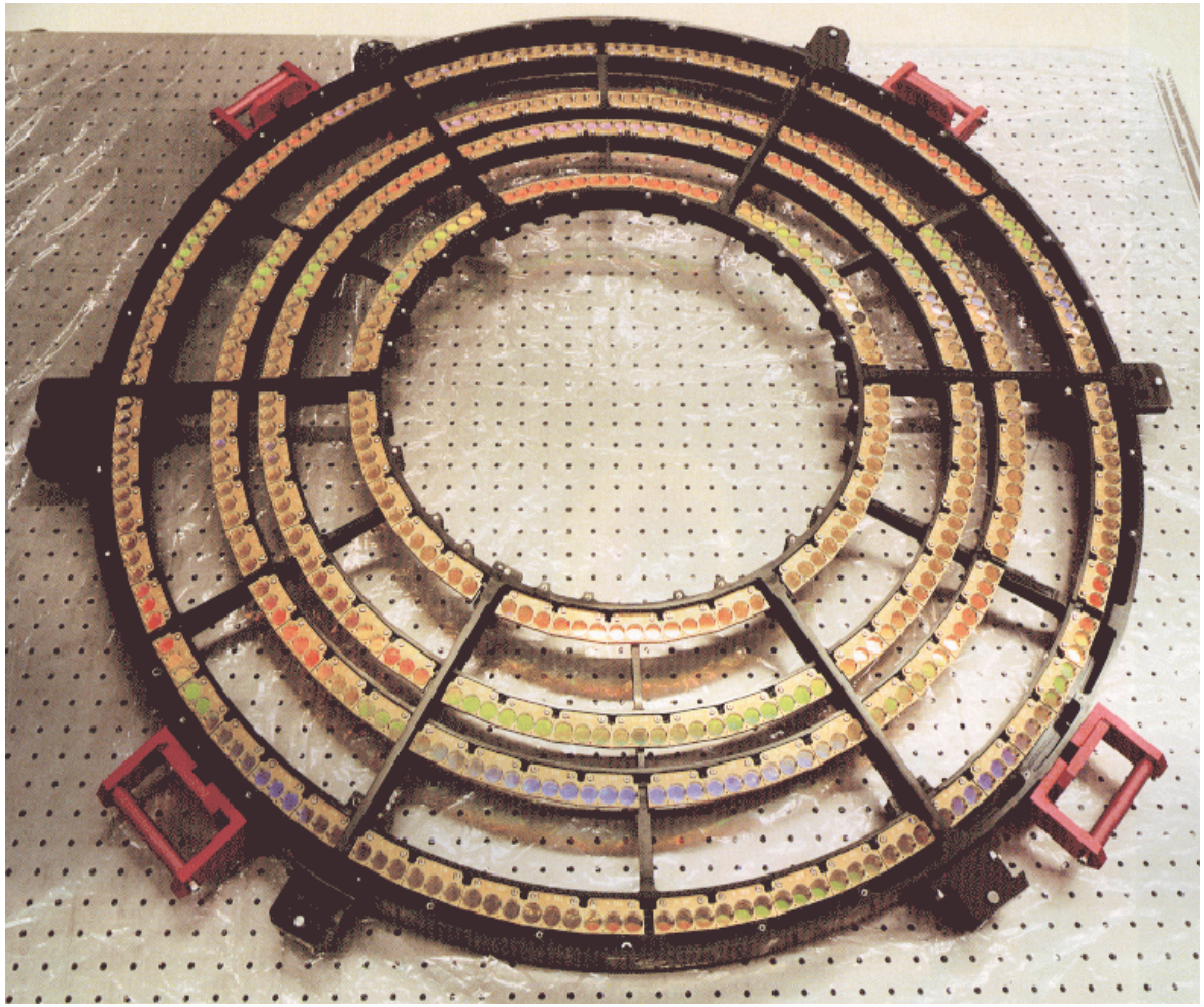
Paul Nandra talk

Launch > 2020



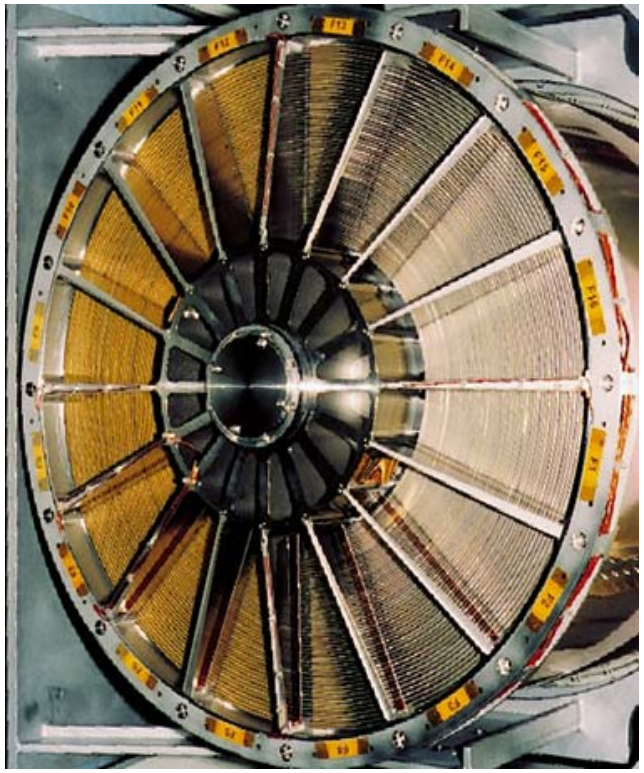
Legacy of the project ROSAT II („Spectrosat“): Chandra – Low energy transmission grating

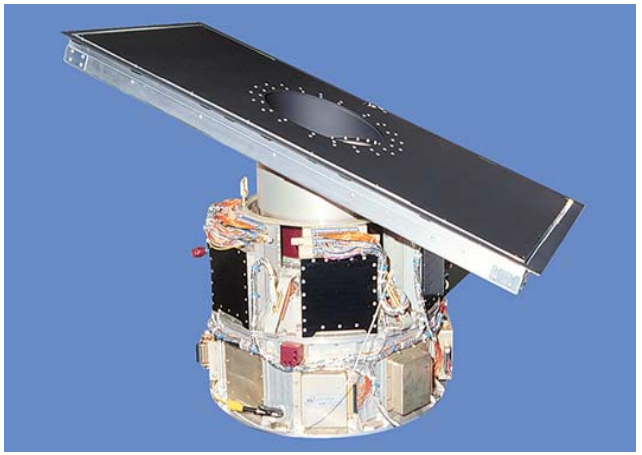
Collaboration SRON - MPE

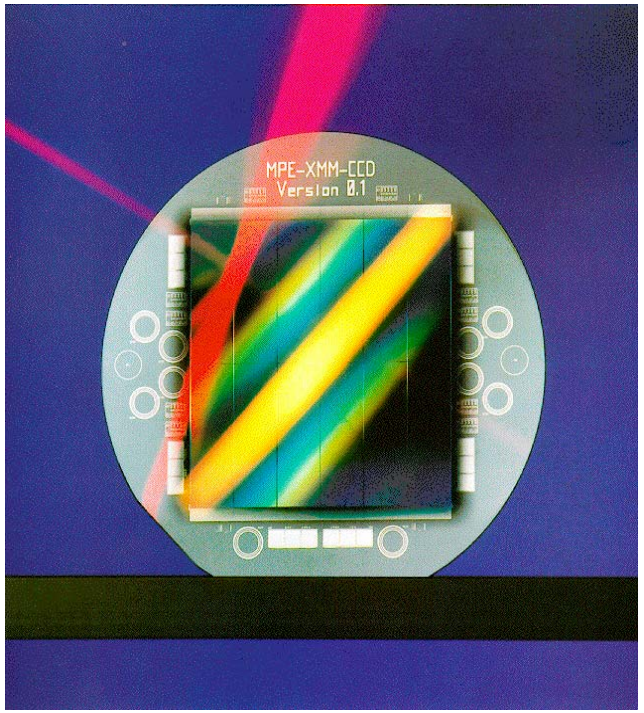


MPE contribution: Free-standing gold gratings with 1 µm pitch
P. Predehl et al.

New technologies on XMM-Newton



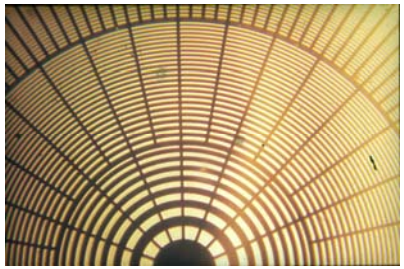




One out of three mirror systems made by Zeiss/Media Lario
B. Aschenbach (Mirror Scientist)

The novel pnCCD camera on XMM-Newton
L. Strueder et al.

Diffraction limited X-ray astronomy within the next 50 years ?



Fresnel zone plate for solar observations
smallest pitch 1µm
diameter : ~ 1 mm
focal length ~ 1 m

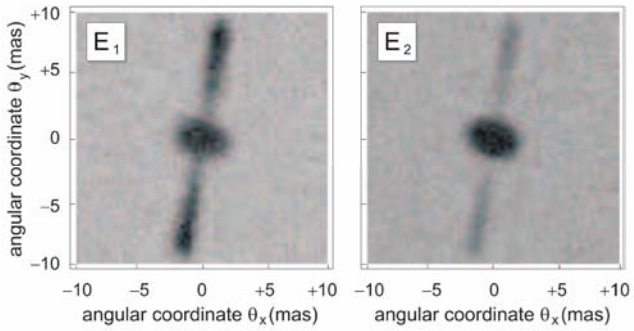
We dreamed about applications to cosmic sources since the 1970‘s.

Braig and Predehl have studied scaled up versions from 2004-2012, e.g.

Fresnel lens diameter 2.8 m,
optimised for hard X-rays (6 keV, 15.7 keV)
focal length 290 km

simulated images of the region around the black hole in NGC 4594:

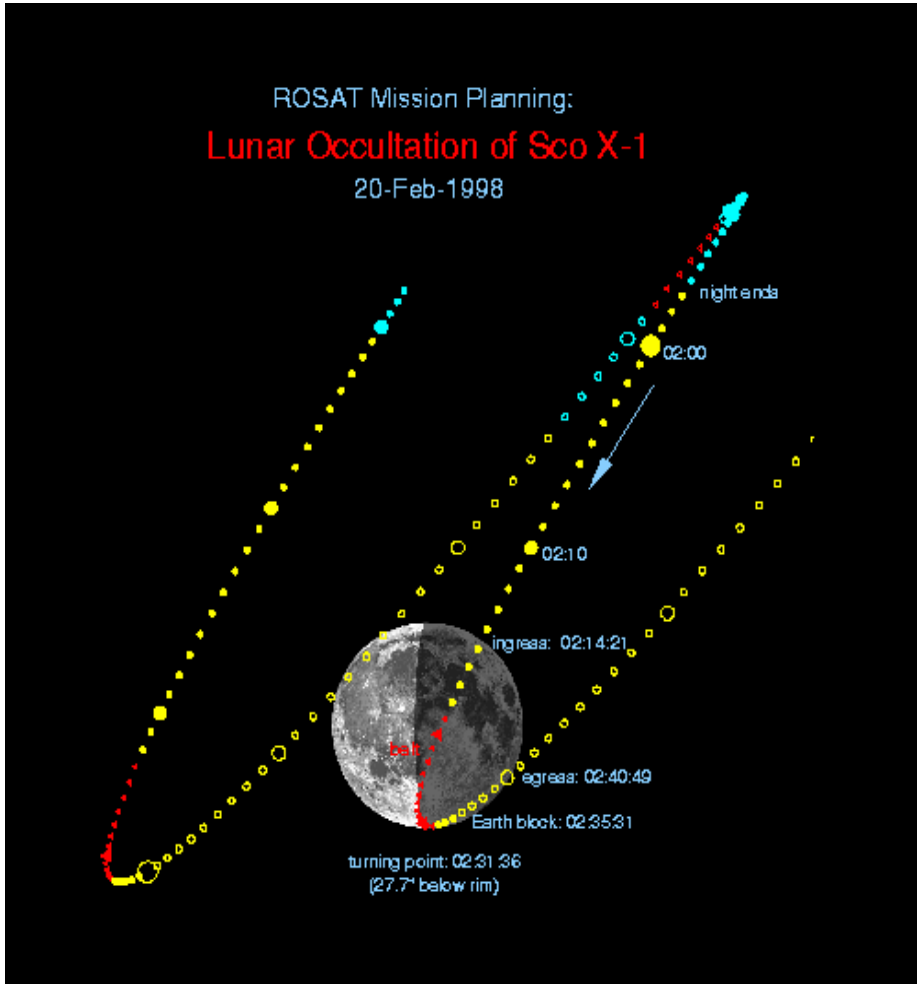
6 keV **15.7 keV**



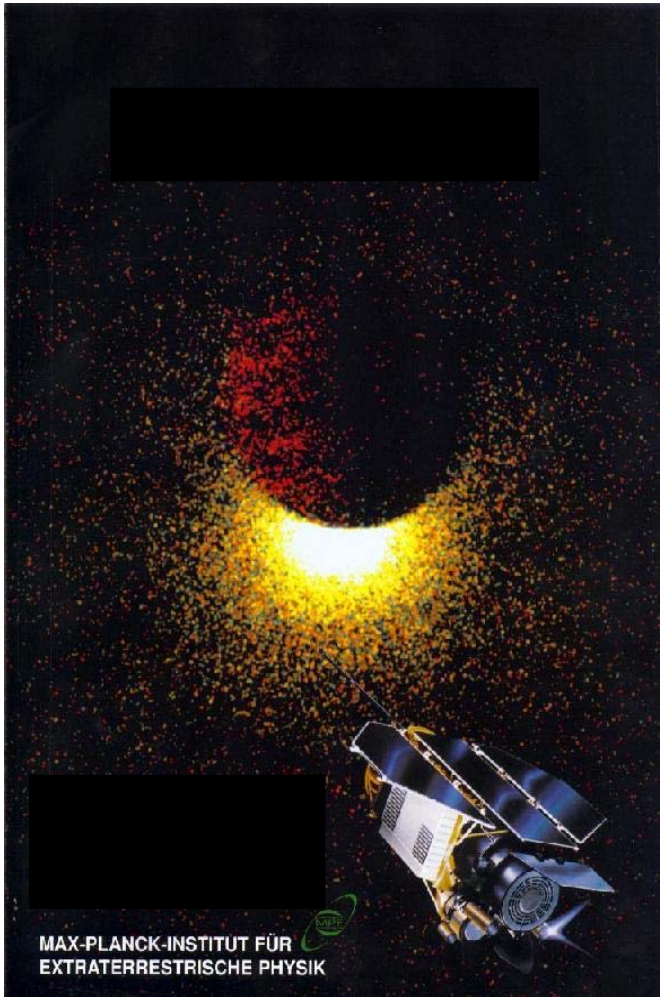
~ 1 milliarcsec
10^6 sec

see also:
Paul Gorenstein talk
Gerry Skinner 2001 - 2012

A rare spectaculum: The Moon meets Scorpius X-1: The occultation on 20 February 1998



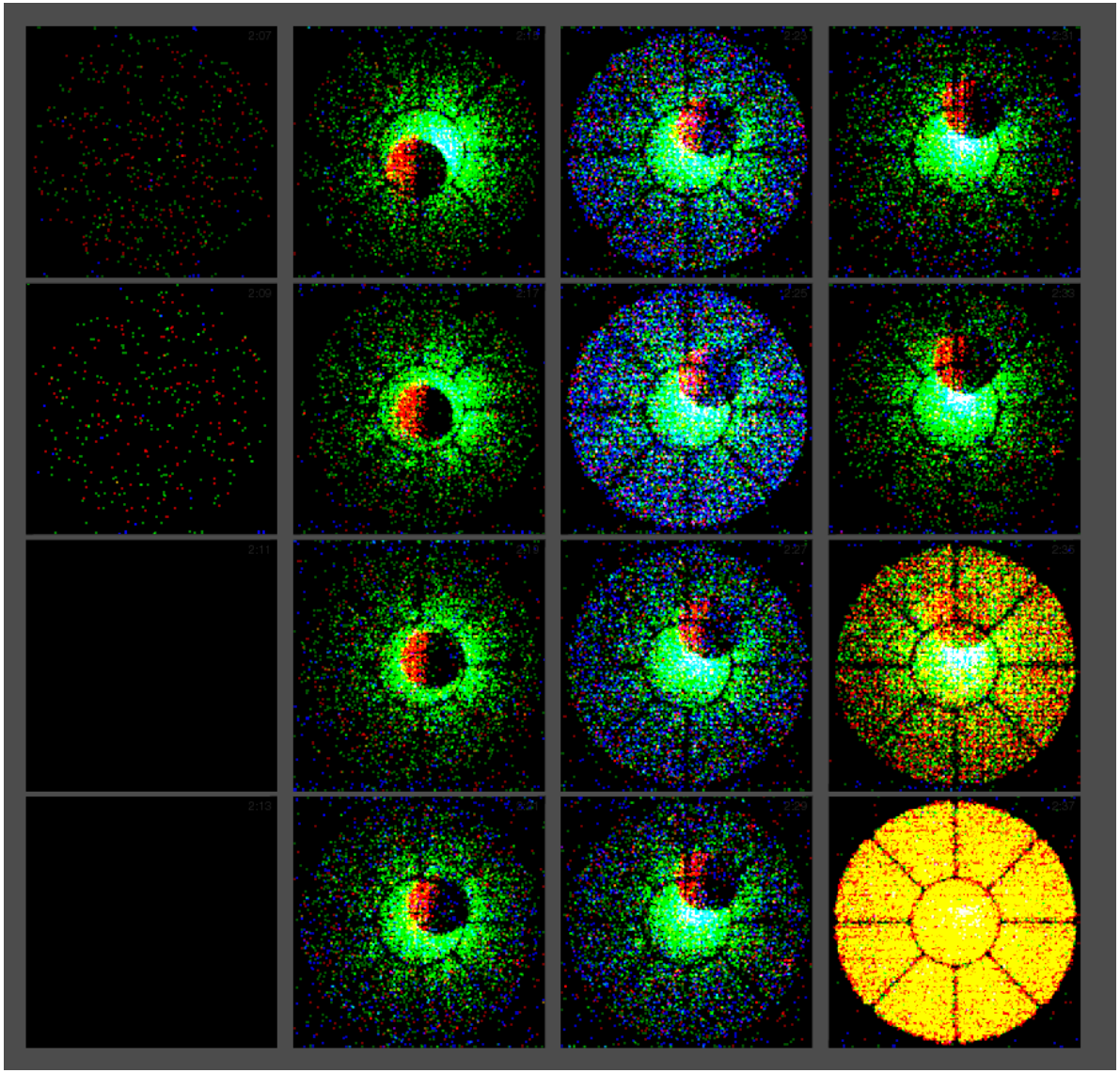
Path of Sco X-1 in the rest frame of the Moon



The dust scattering halo

The lunar occultation of Sco X-1 on April 28, 1998

Predehl & Englhauser, unpublished



THANK YOU!

the next occasion will be in fall 2016!