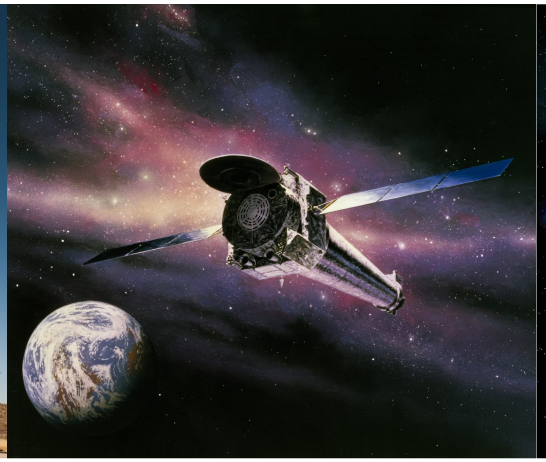
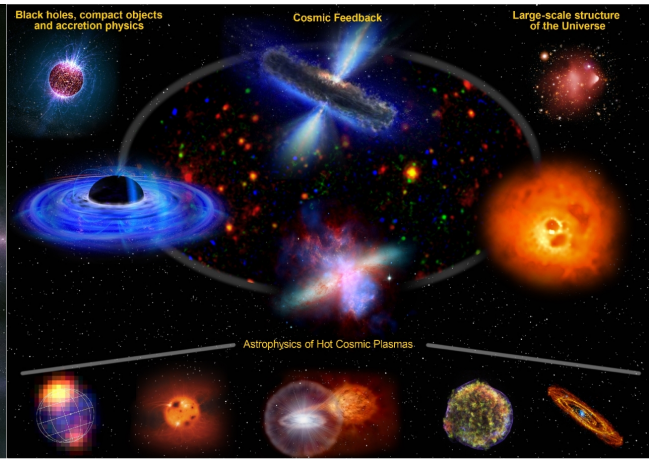
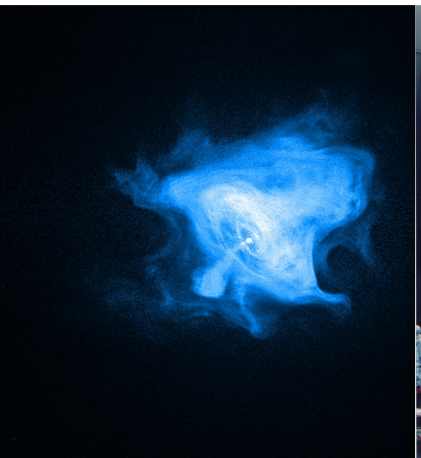
50 Years of X-ray Astronomy

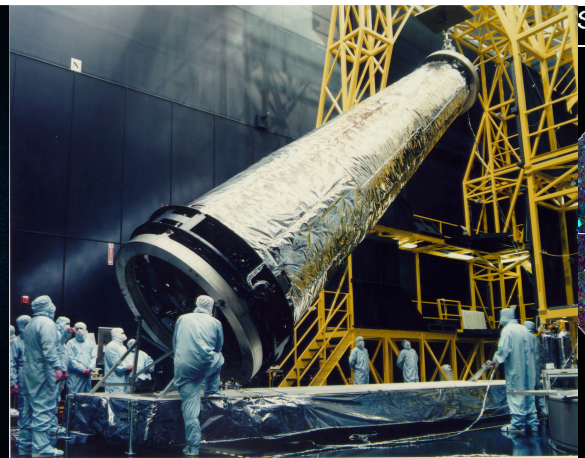


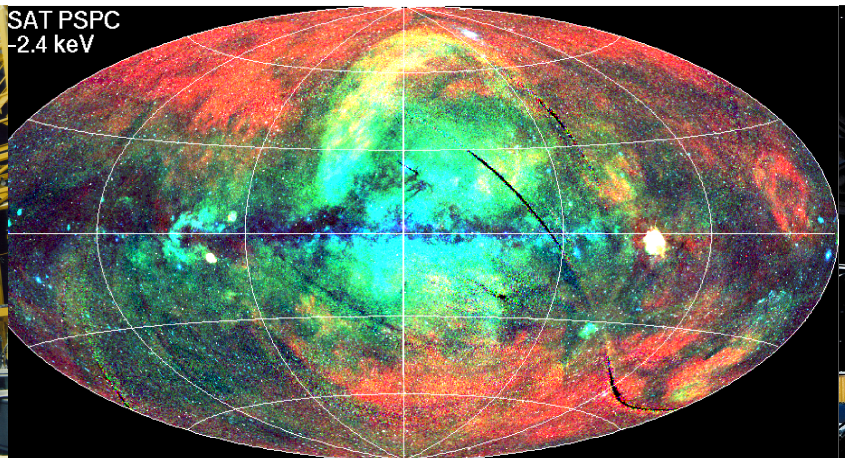


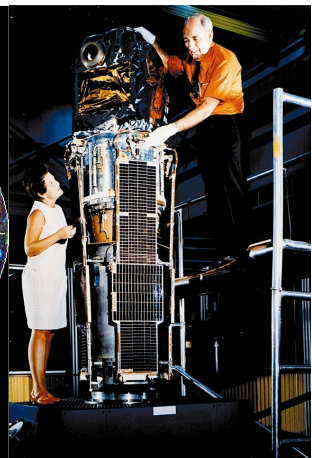
Stephen Walker
University of Cambridge

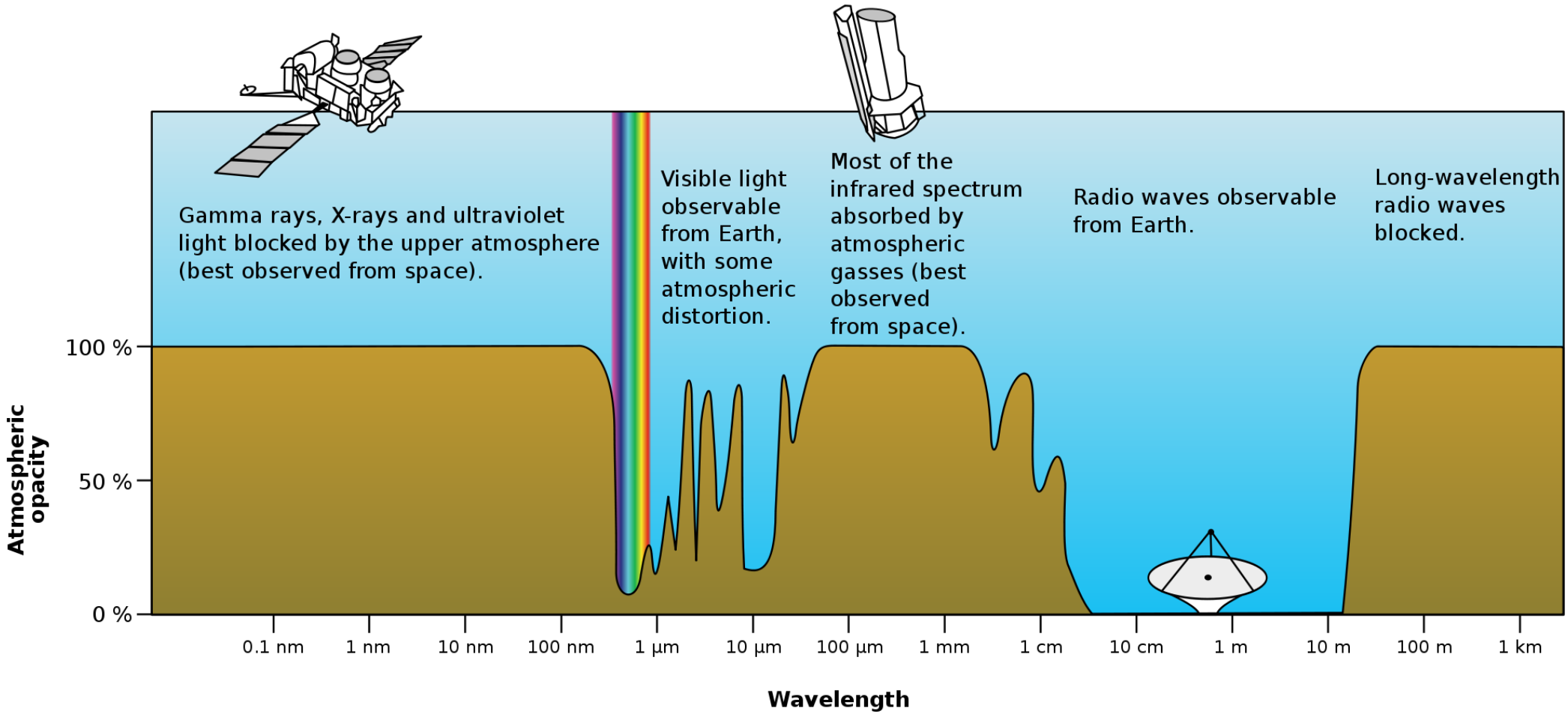
Cambridge X-Ray Astronomy

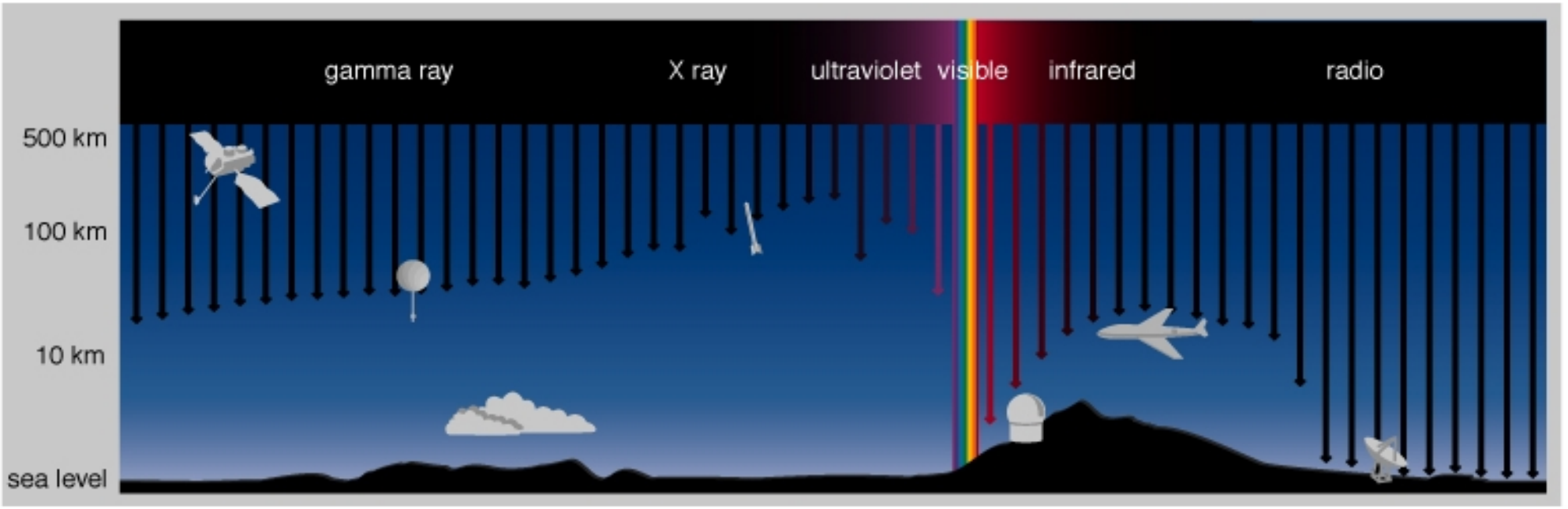


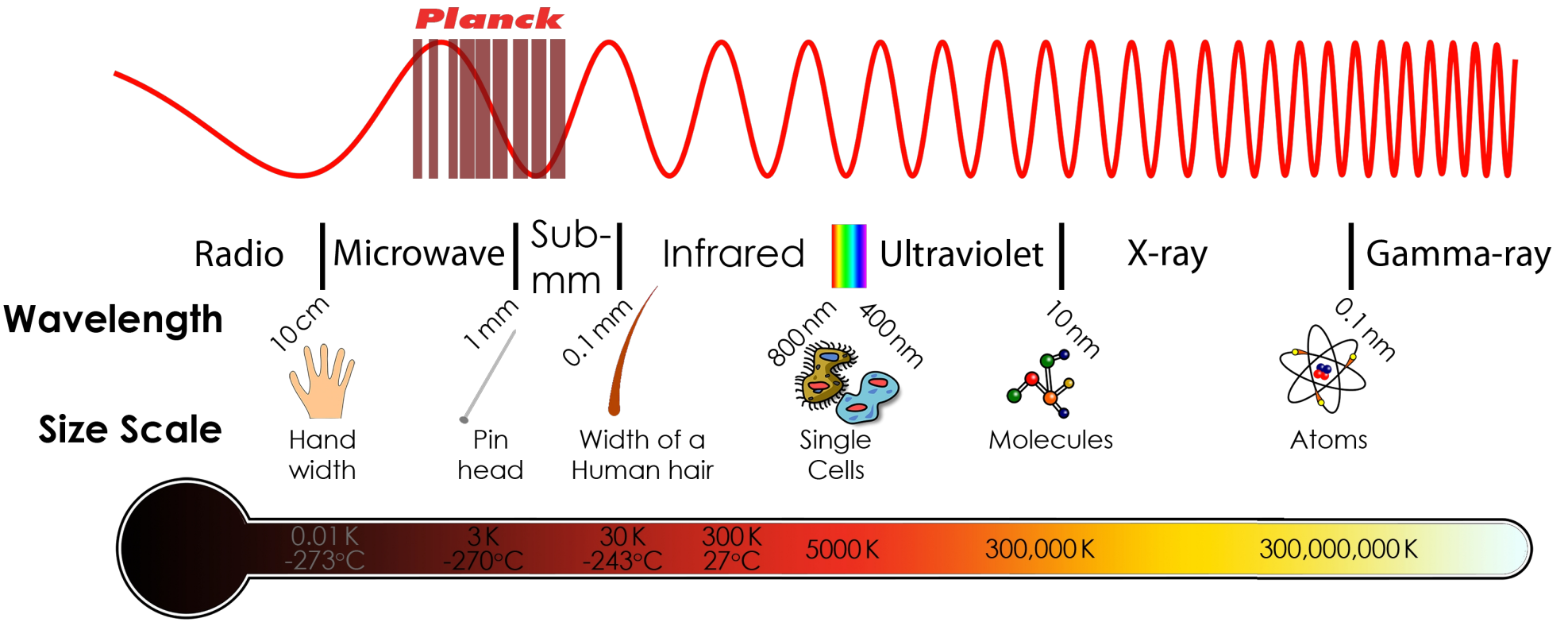




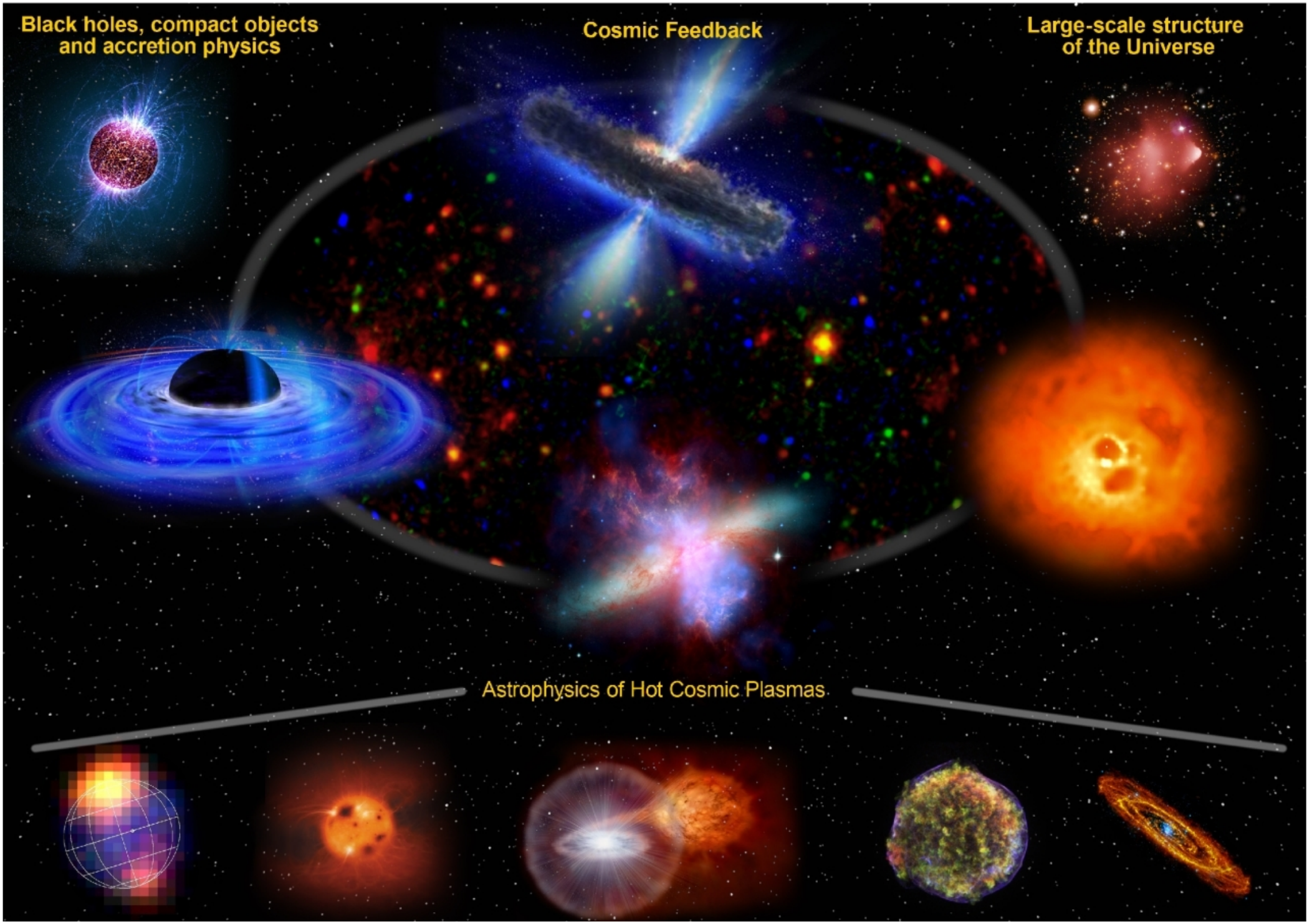


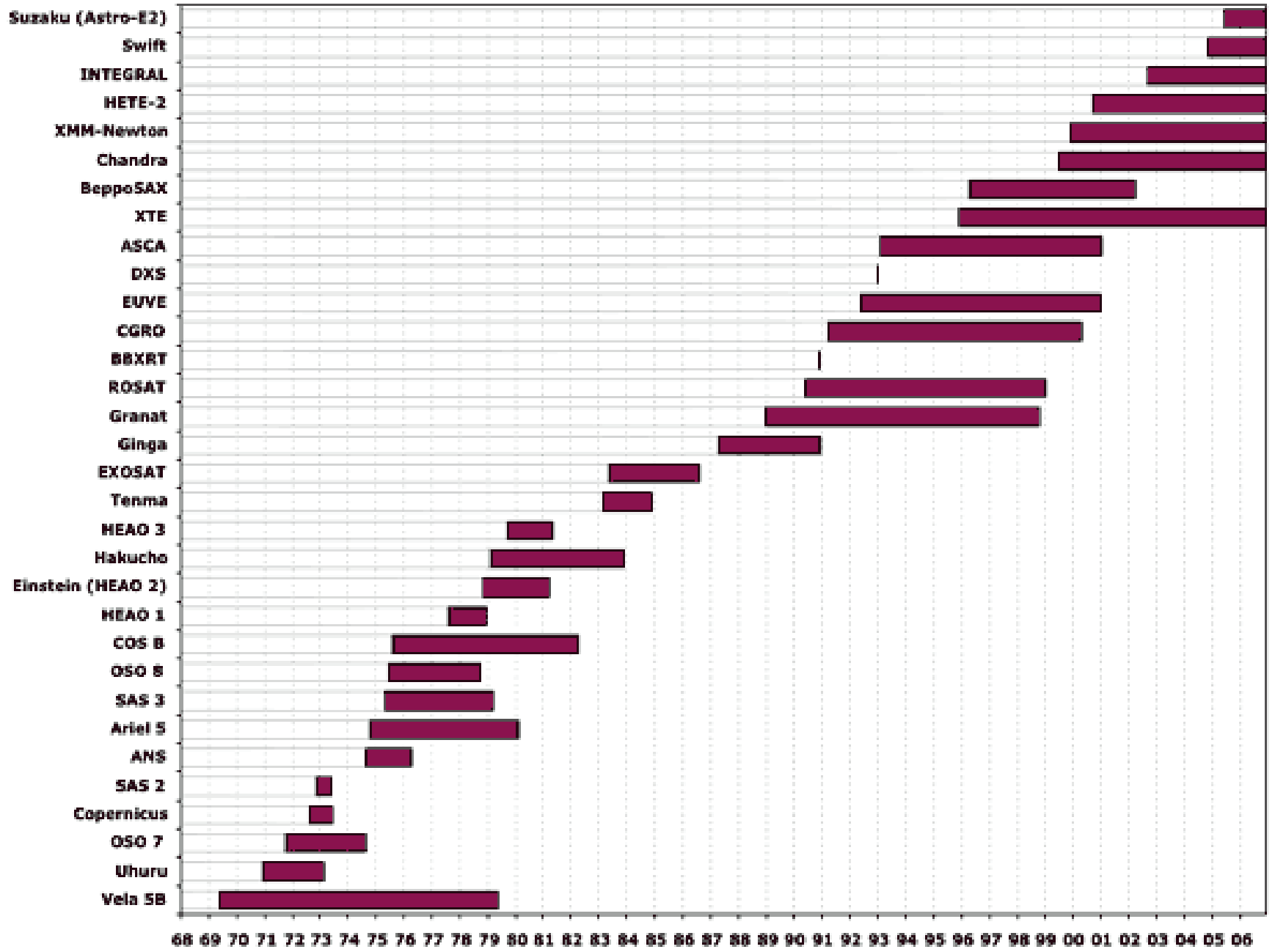

Gamma rays, X-rays and ultraviolet light blocked by the upper atmosphere (best observed from space).
Visible light observable from Earth, with some atmospheric distortion.
Most of the infrared spectrum absorbed by atmospheric gasses (best observed from space).
Radio waves observable from Earth.
Long-wavelength radio waves blocked.
100 %
50 %
0 %
Atmospheric opacity
0.1 nm
1 nm
10 nm
100 nm
1 µm
10 µm
100 µm
1 mm
1 cm
10 cm
1 m
10 m
100 m
1 km
Wavelength




Planck
Radio
Microwave
Sub-mm
Infrared
Ultraviolet
X-ray
Gamma-ray
Wavelength
10 cm
1 mm
0.1 mm
800 nm
400 nm
10 nm
0.1 nm
Size Scale
Hand width
Pin head
Width of a Human hair
Single Cells
Molecules
Atoms
0.01 K -273°C
3 K -270°C
30 K -243°C
300 K 27°C
5000 K
300,000 K
300,000,000 K

What gets so hot?


Black holes, compact objects and accretion physics
Cosmic Feedback
Large-scale structure of the Universe
Astrophysics of Hot Cosmic Plasmas


Suzaku (Astro-E2)
Swift
INTEGRAL
HETE-2
XMM-Newton
Chandra
BeppoSAX
XTE
ASCA
DXS
EUVE
CGRO
BBXRT
ROSAT
Granat
Ginga
EXOSAT
Tenma
HEAO 3
Hakucho
Einstein (HEAO 2)
HEAO 1
COS B
OSO 8
SAS 3
Ariel 5
ANS
SAS 2
Copernicus
OSO 7
Uhuru
Vela 5B
68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06

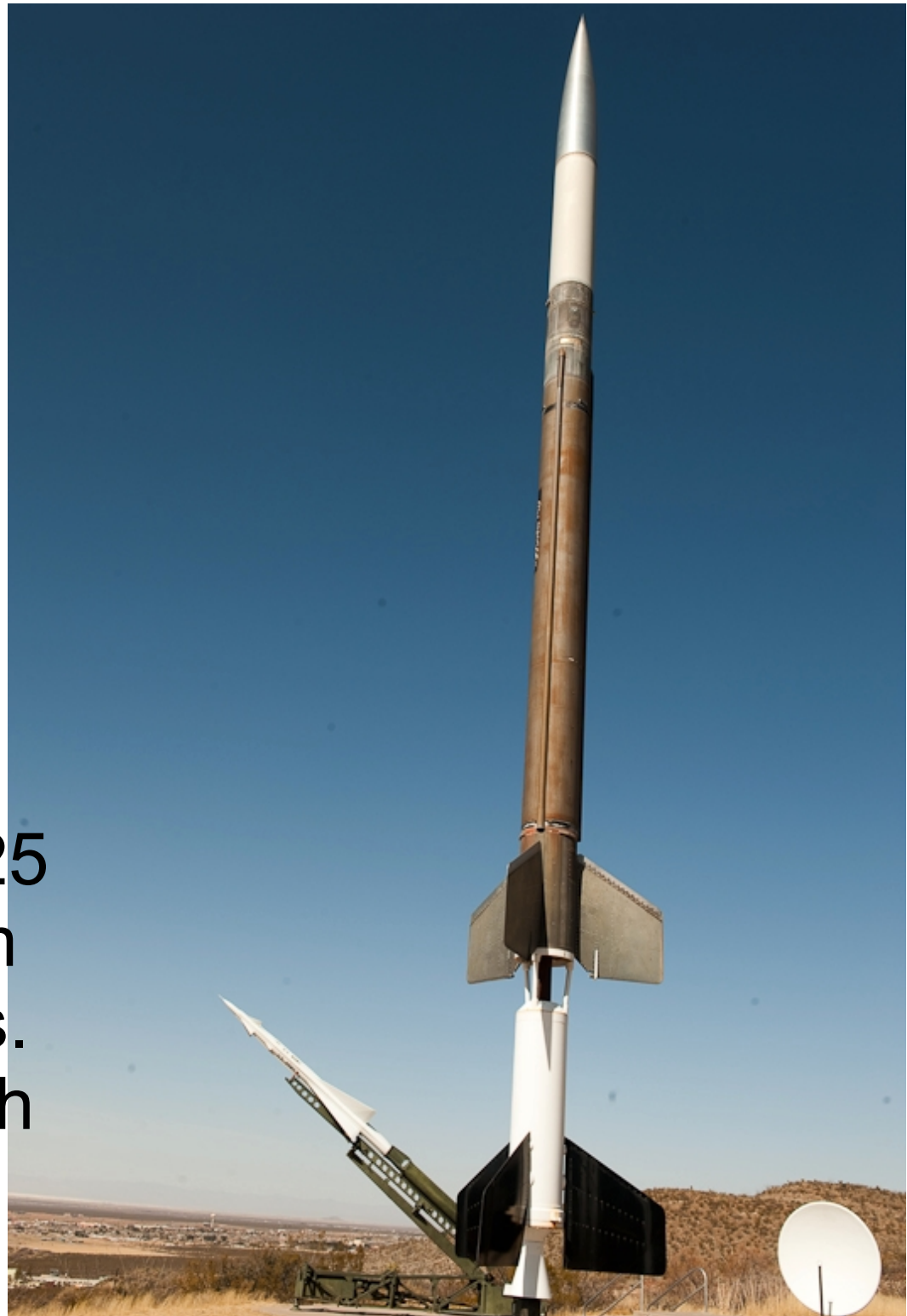
1948: X-rays from the Sun

- X-rays were detected from the Solar corona by Herb Friedman and collaborators at the US Naval Research Lab (in Washington DC).

1962: The birth of X-ray Astronomy

1962: Sco X-1

- Bruno Rossi, Riccardo Giacconi, and collaborators
- Successfully launched a detector to look for X-ray emission from the moon using Aerobee rocket
- A maximum altitude of 225 km and was above 80 km for a total of 350 seconds. Traveled almost due north for a distance of 120 km.



PHYSICAL REVIEW
LETTERS

VOLUME 9 DECEMBER 1, 1962 NUMBER 11

EVIDENCE FOR X RAYS FROM SOURCES OUTSIDE THE SOLAR SYSTEM*

Riccardo Giacconi, Herbert Gursky, and Frank R. Paolini
American Science and Engineering, Inc., Cambridge, Massachusetts

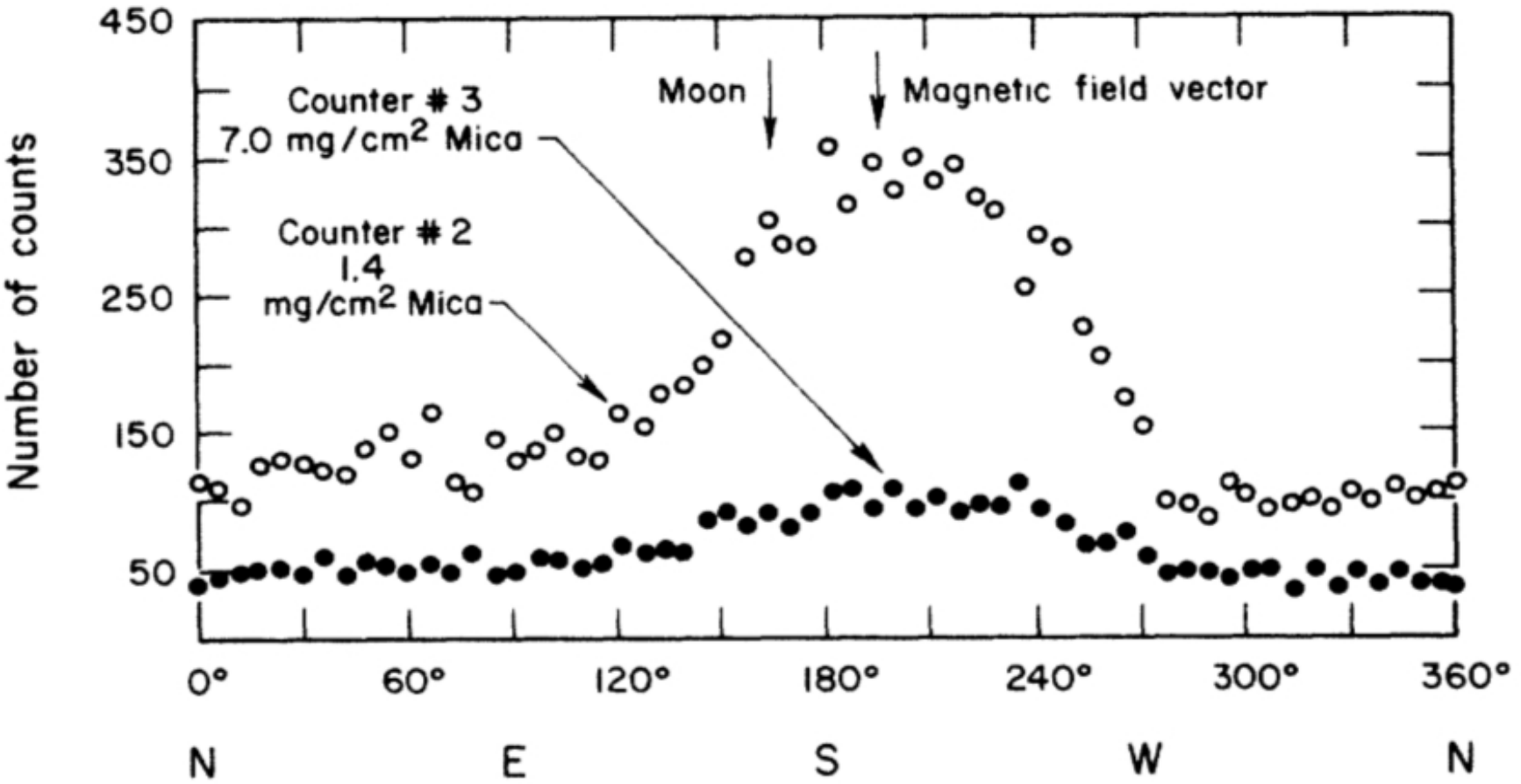
and

Bruno B. Rossi
Massachusetts Institute of Technology, Cambridge, Massachusetts
(Received October 12, 1962)

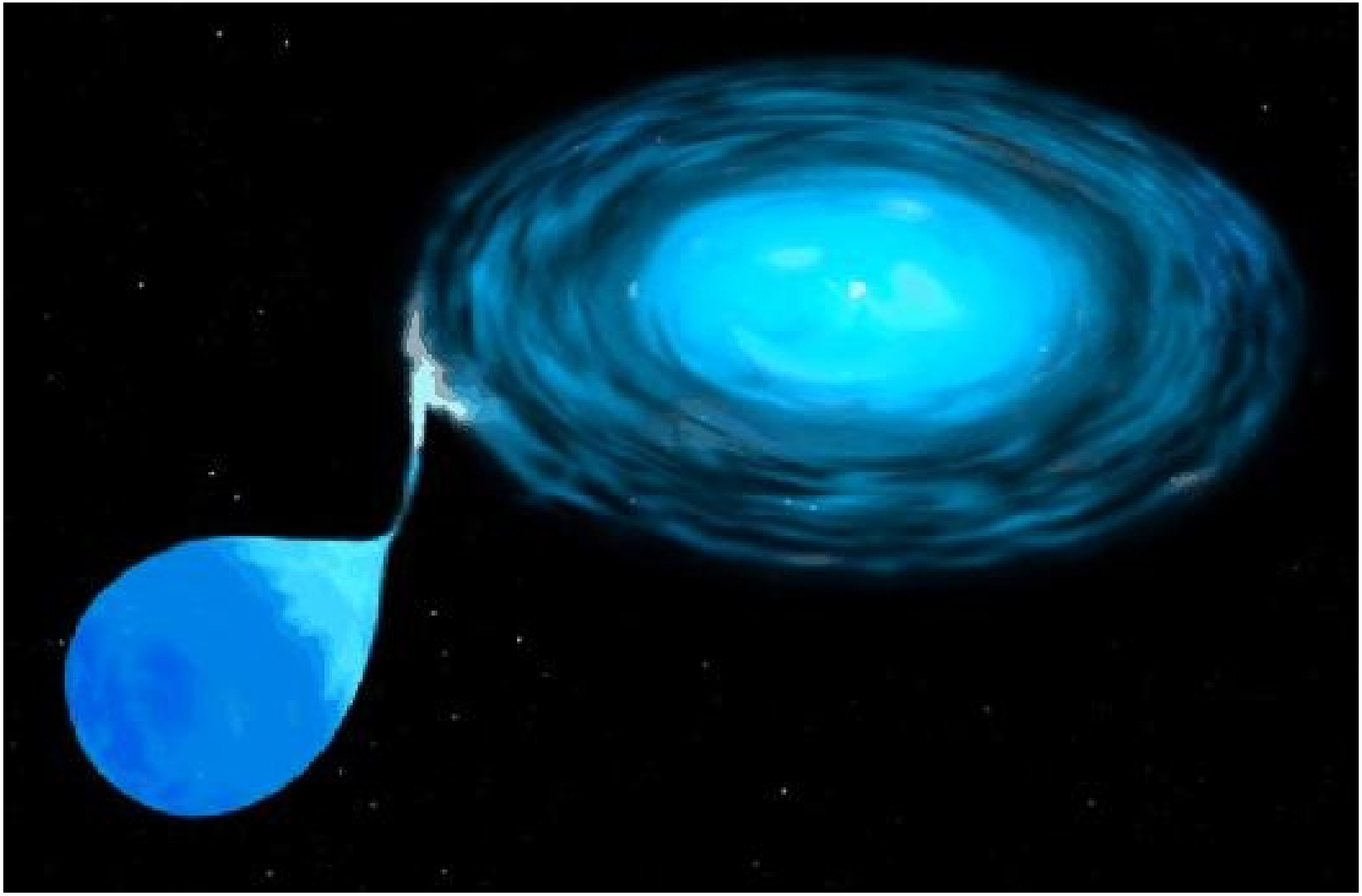
Data from an Aerobee rocket carrying a payload consisting of three large area Geiger counters have revealed a considerable flux of radiation in the night sky that has been identified as consisting of soft x rays.

The entrance aperture of each Geiger counter consisted of seven individual mica windows com-

ter was placed in a well formed by an anticoincidence scintillation counter designed to reduce the cosmic-ray background. The experiment was intended to study fluorescence x rays produced on the lunar surface by x rays from the sun and to explore the night sky for other possible sources. On the basis of the known flux of solar x rays


Number of counts
450
350
250
150
50
Counter # 3
7.0 mg/cm² Mica
Counter # 2
1.4
mg/cm² Mica
Moon
Magnetic field vector
0°
60°
120°
180°
240°
300°
360°
N
E
S
W
N

LMXB – donor star 0.42M_solar

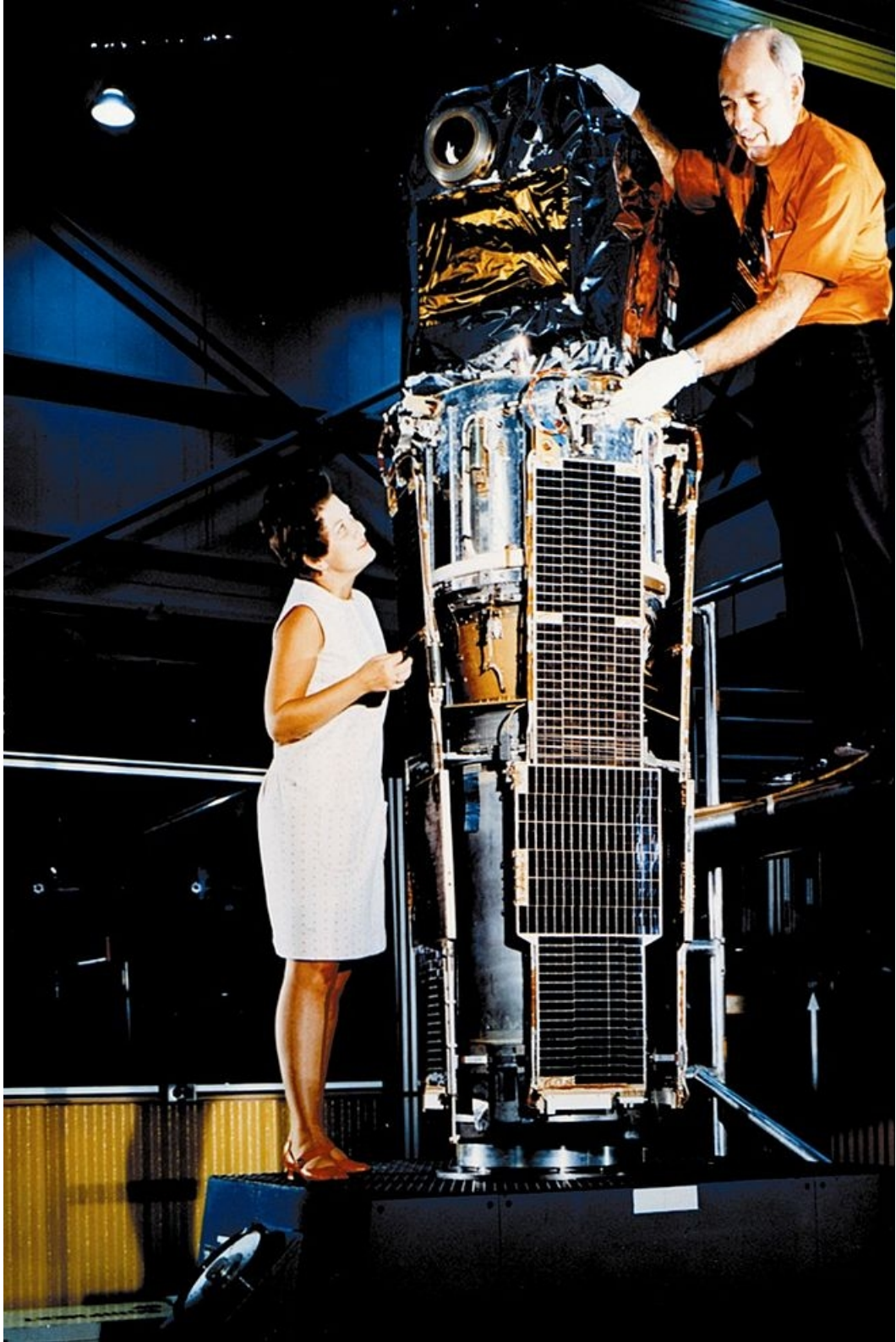


- Also discovered the X-ray background

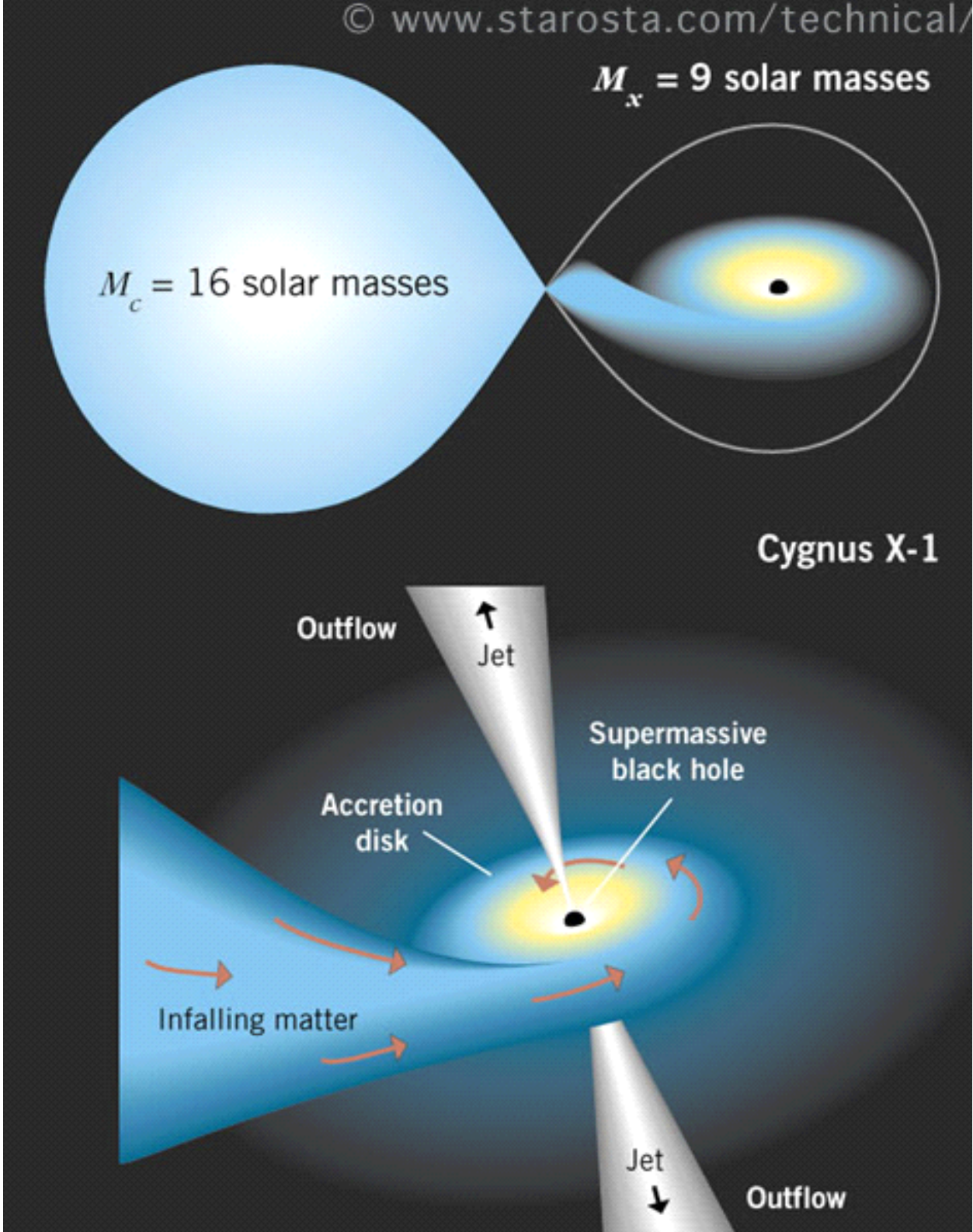
Riccardo Giacconi receives 2002 Physics Nobel Prize from King of Sweden

Uhuru 1970

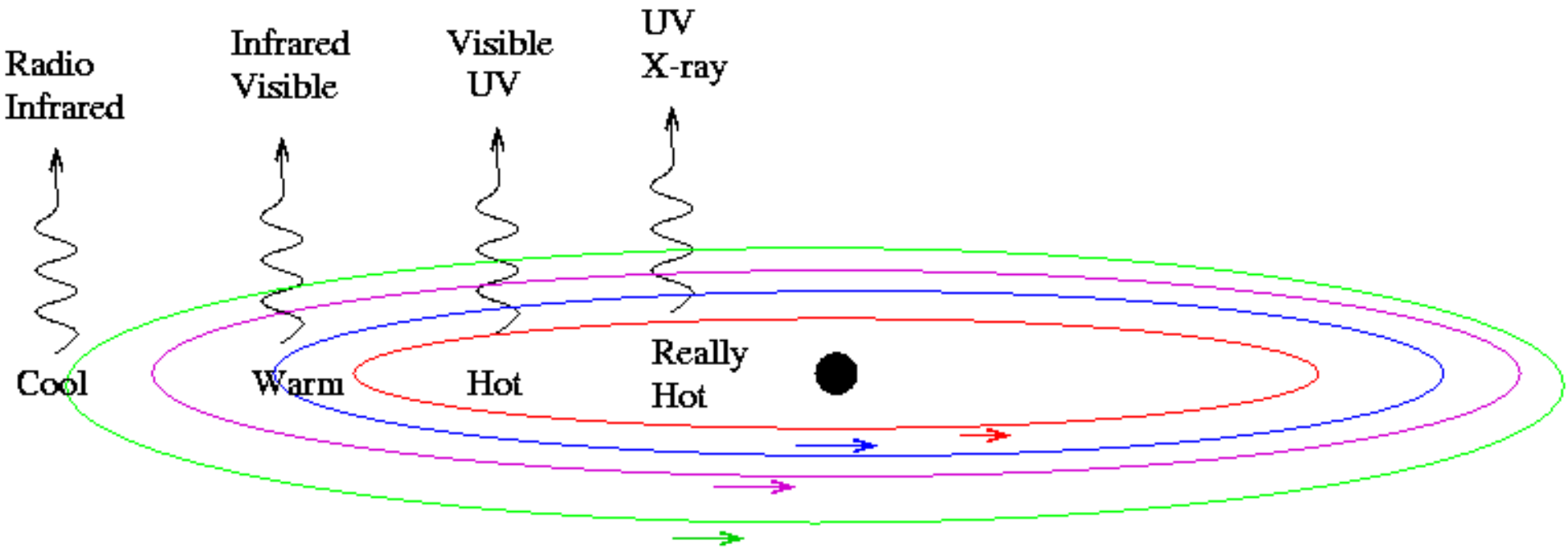
- First comprehensive survey of the entire sky for X-ray sources
- Discovery and detailed study of the pulsing accretion-powered binary X-Ray sources such as Cen X-3, Vela X-1, and Her X-1, the identification of Cygnus X-1, the first strong candidate for an astrophysical black hole

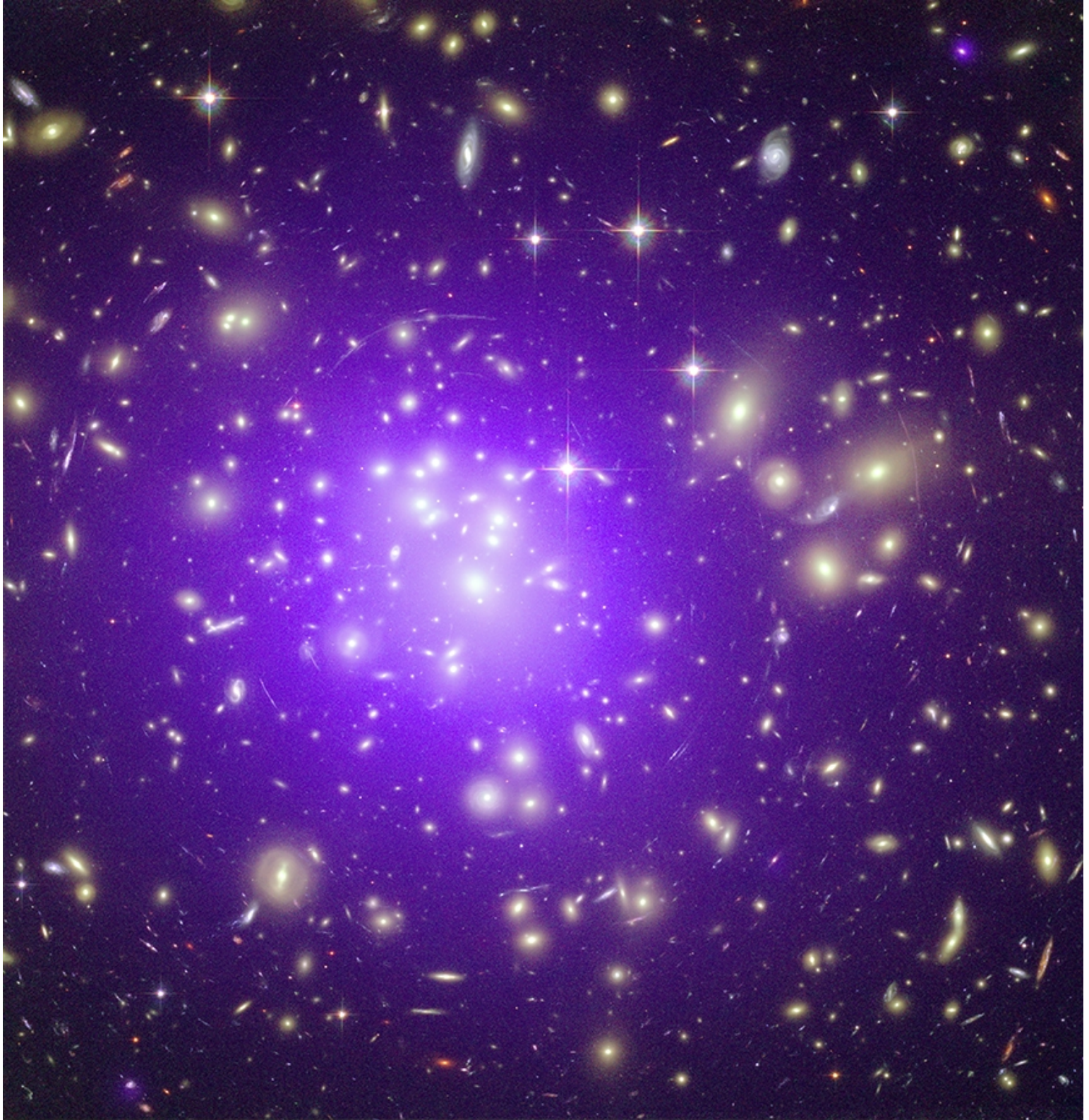


Cygnus X-1

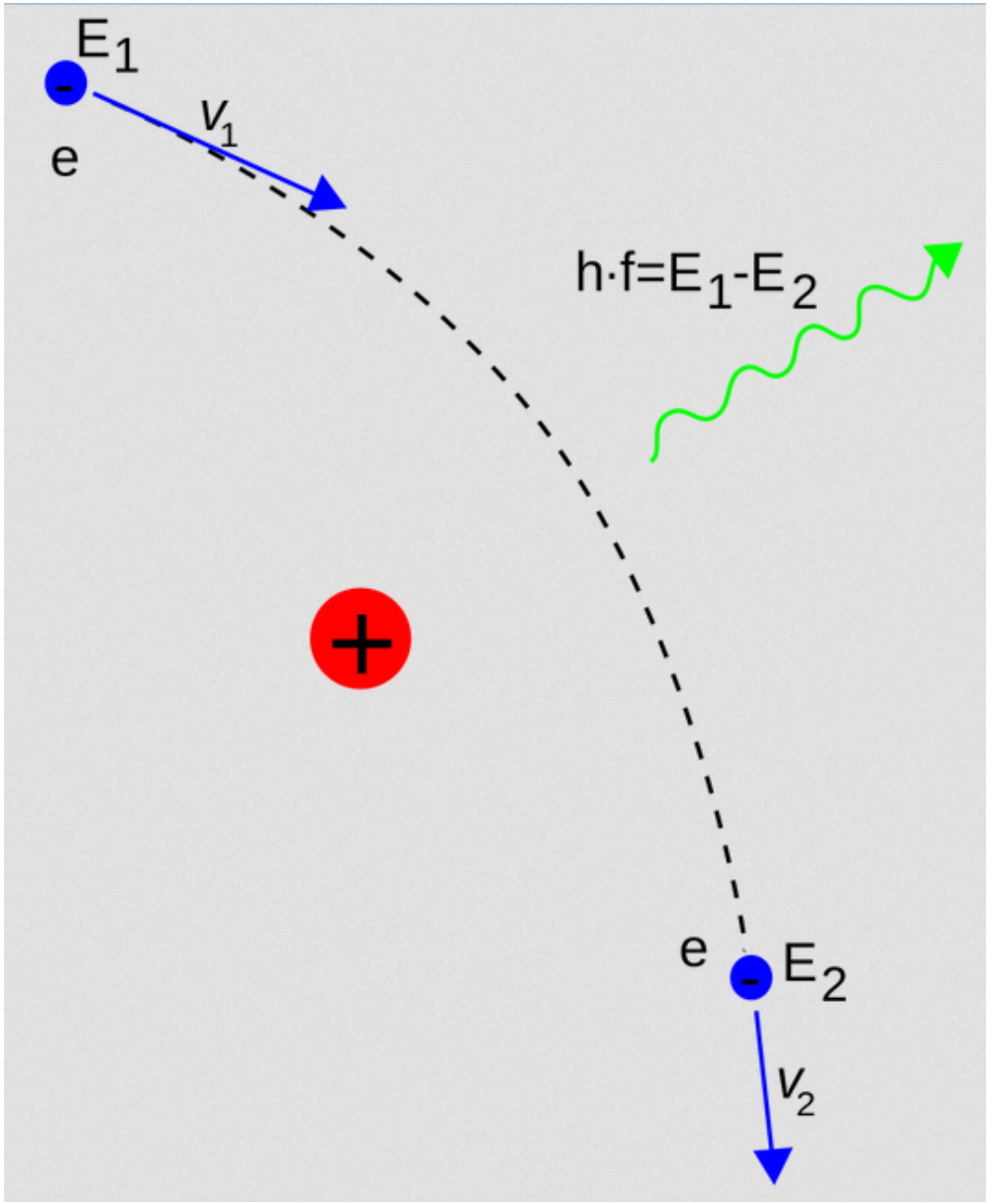

© www.starosta.com/technical/
M_x = 9 solar masses
M_c = 16 solar masses
Cygnus X-1
Outflow
Jet
Supermassive black hole
Accretion disk
Infalling matter
Jet
Outflow

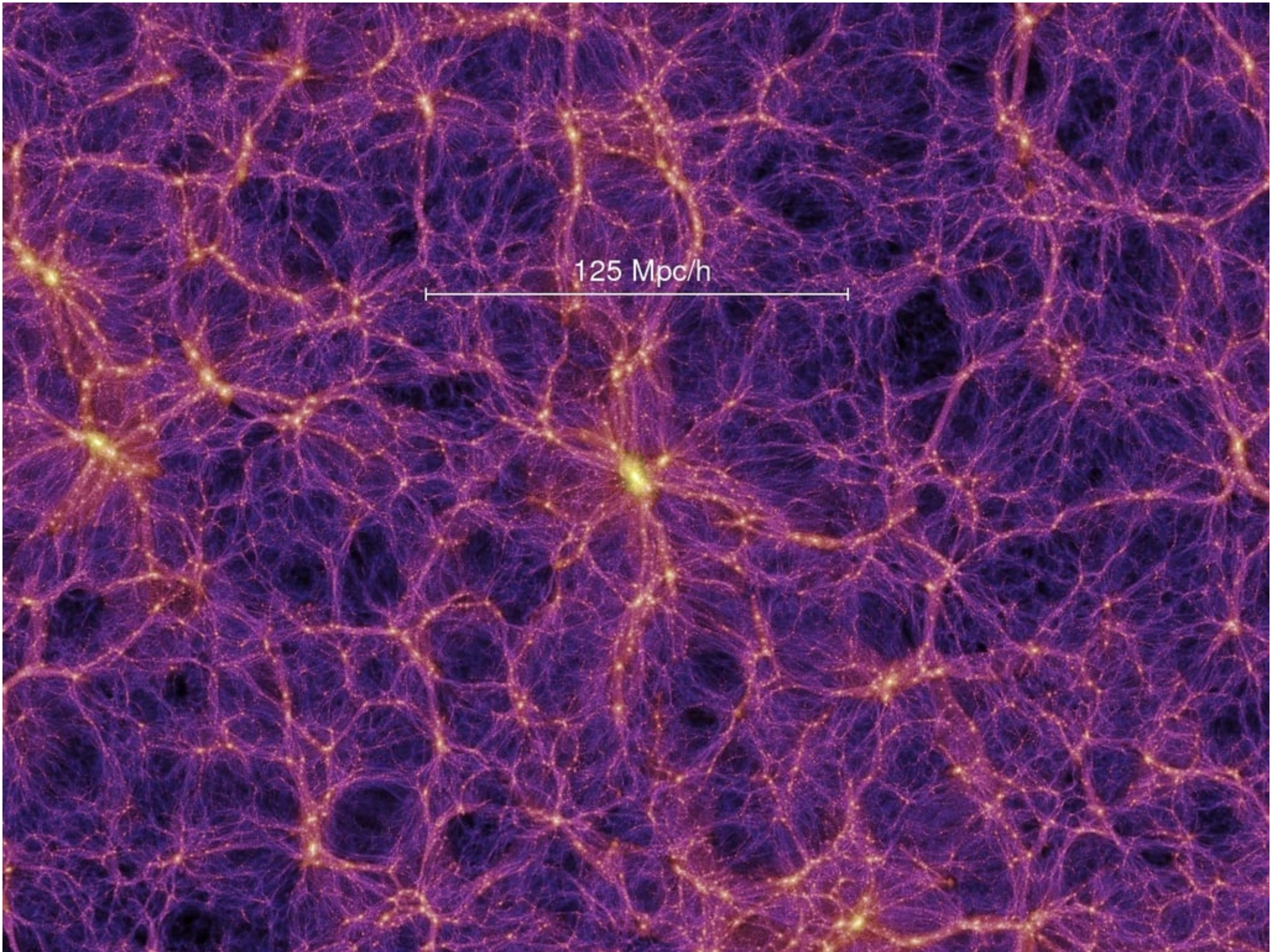
Accretion disk

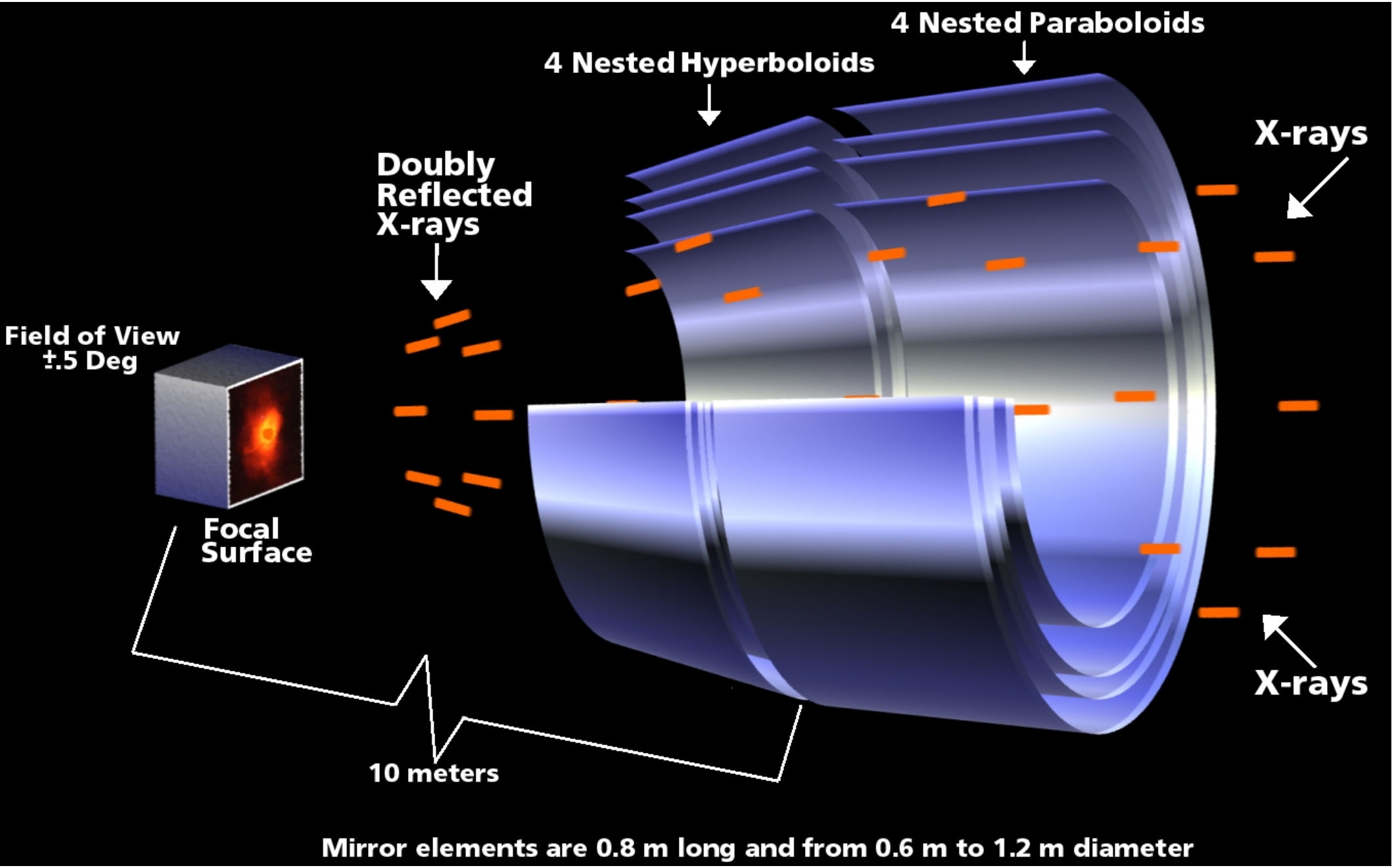




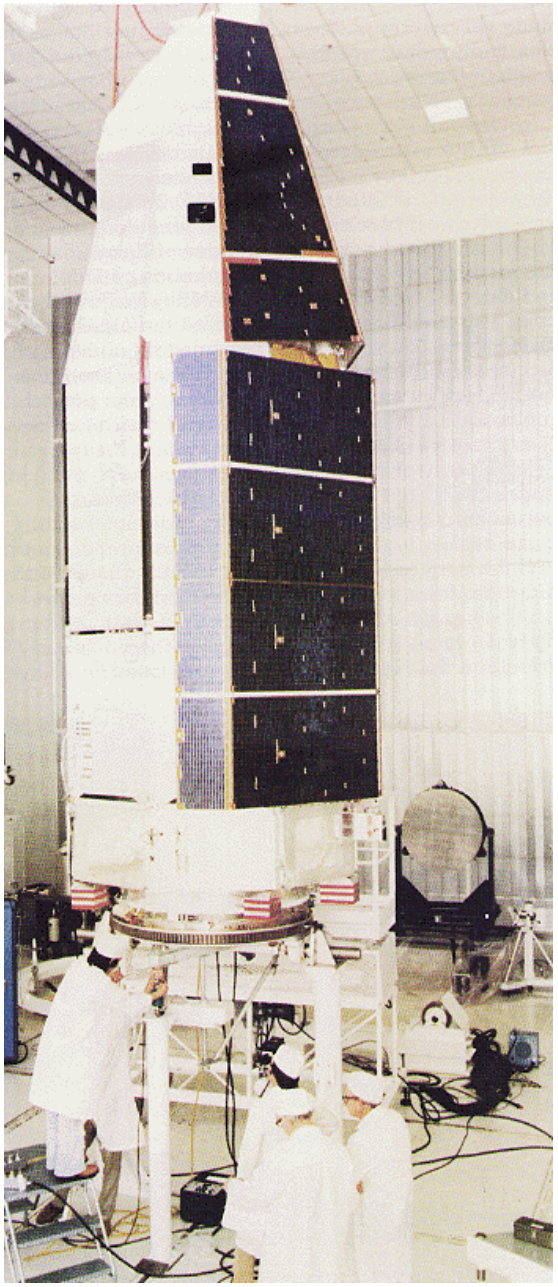
Bremsstrahlung

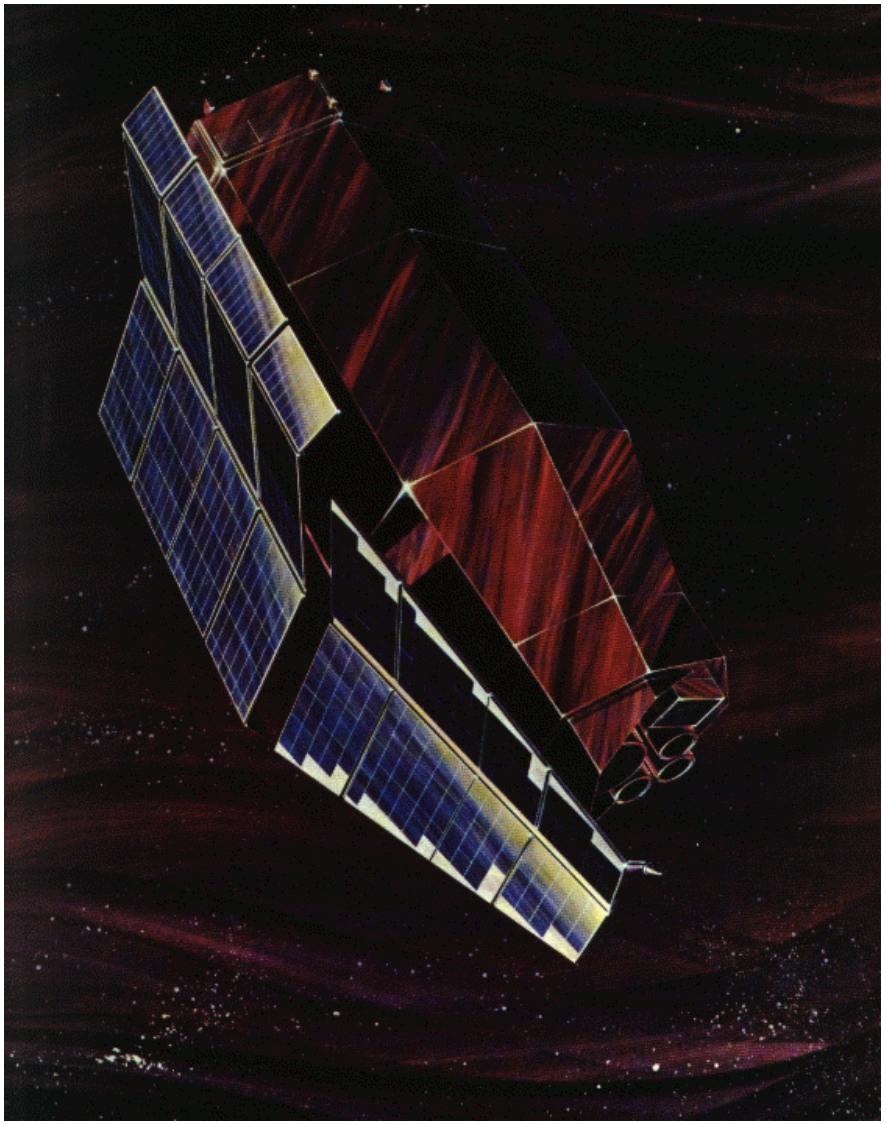


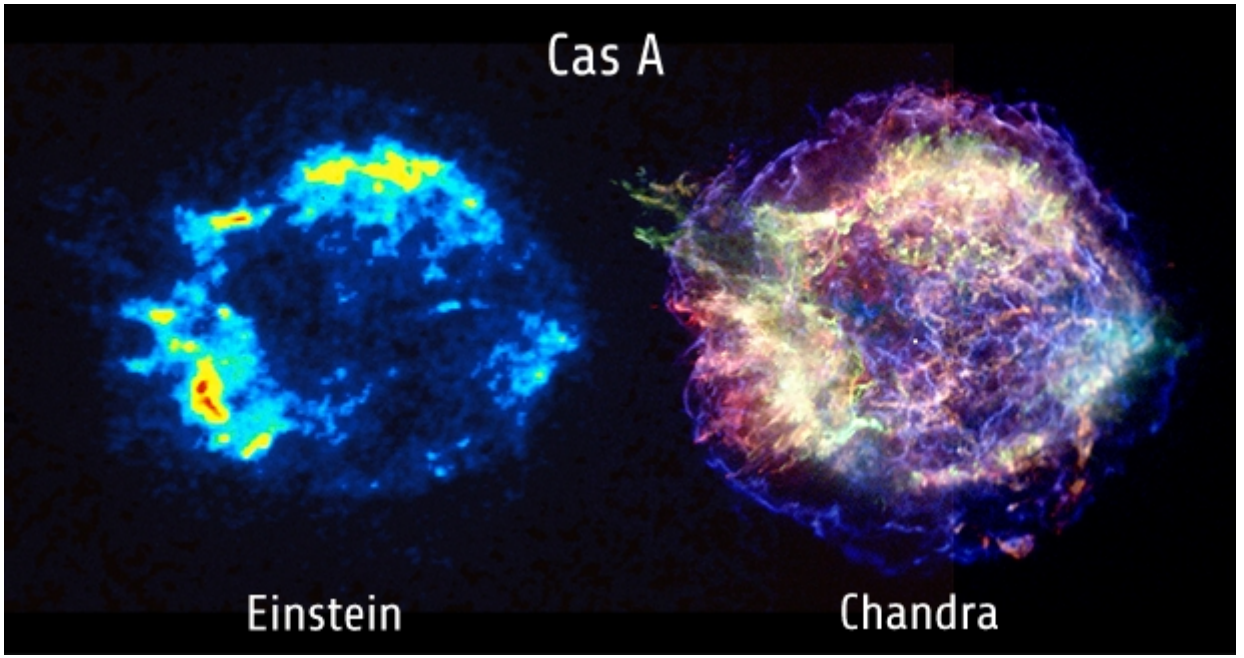

125 Mpc/h

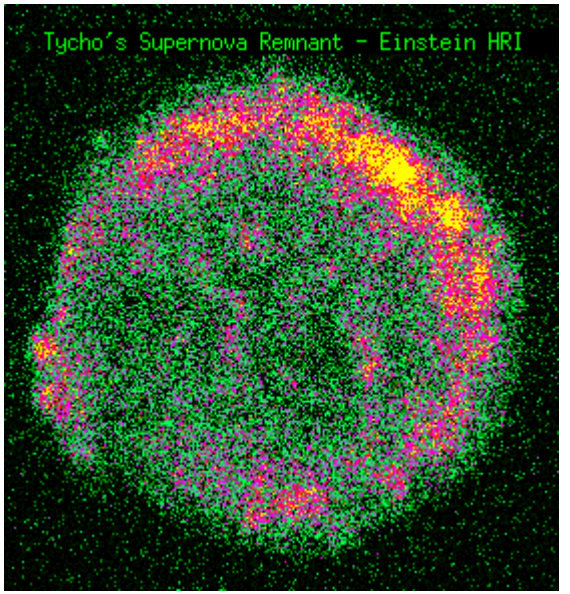

4 Nested Paraboloids
4 Nested Hyperboloids
X-rays
Doubly
Reflected
X-rays
Field of View
±.5 Deg
Focal
Surface
X-rays
10 meters
Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter

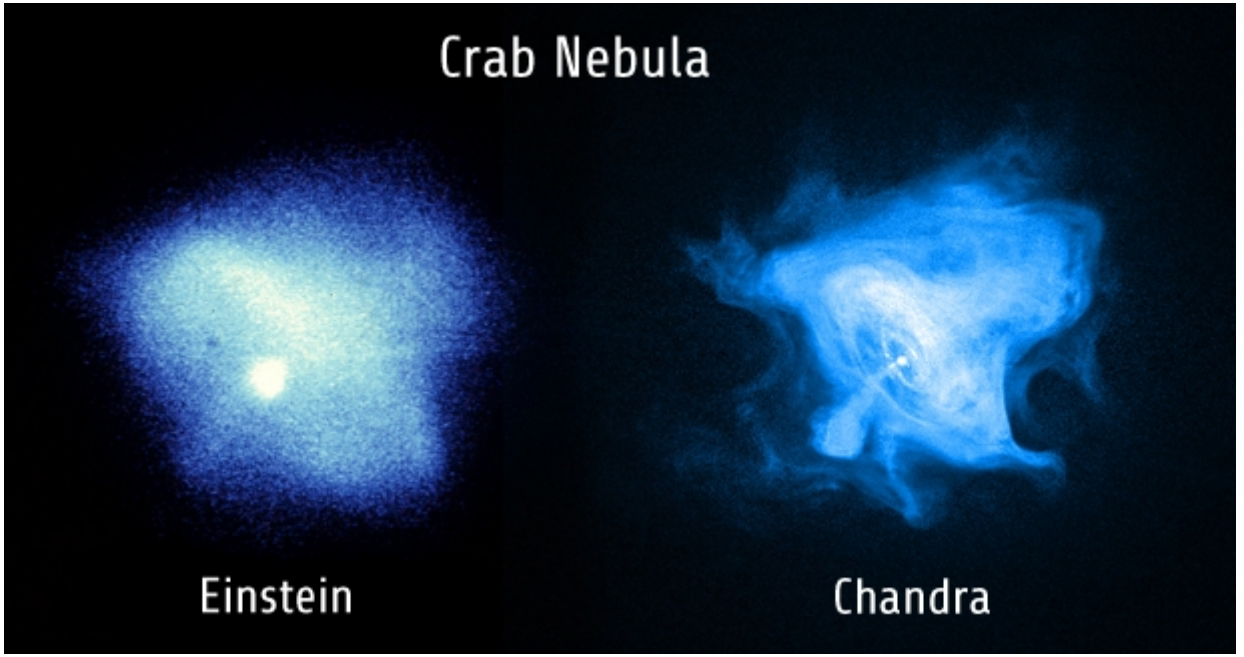
Einstein – 1978 (NASA)

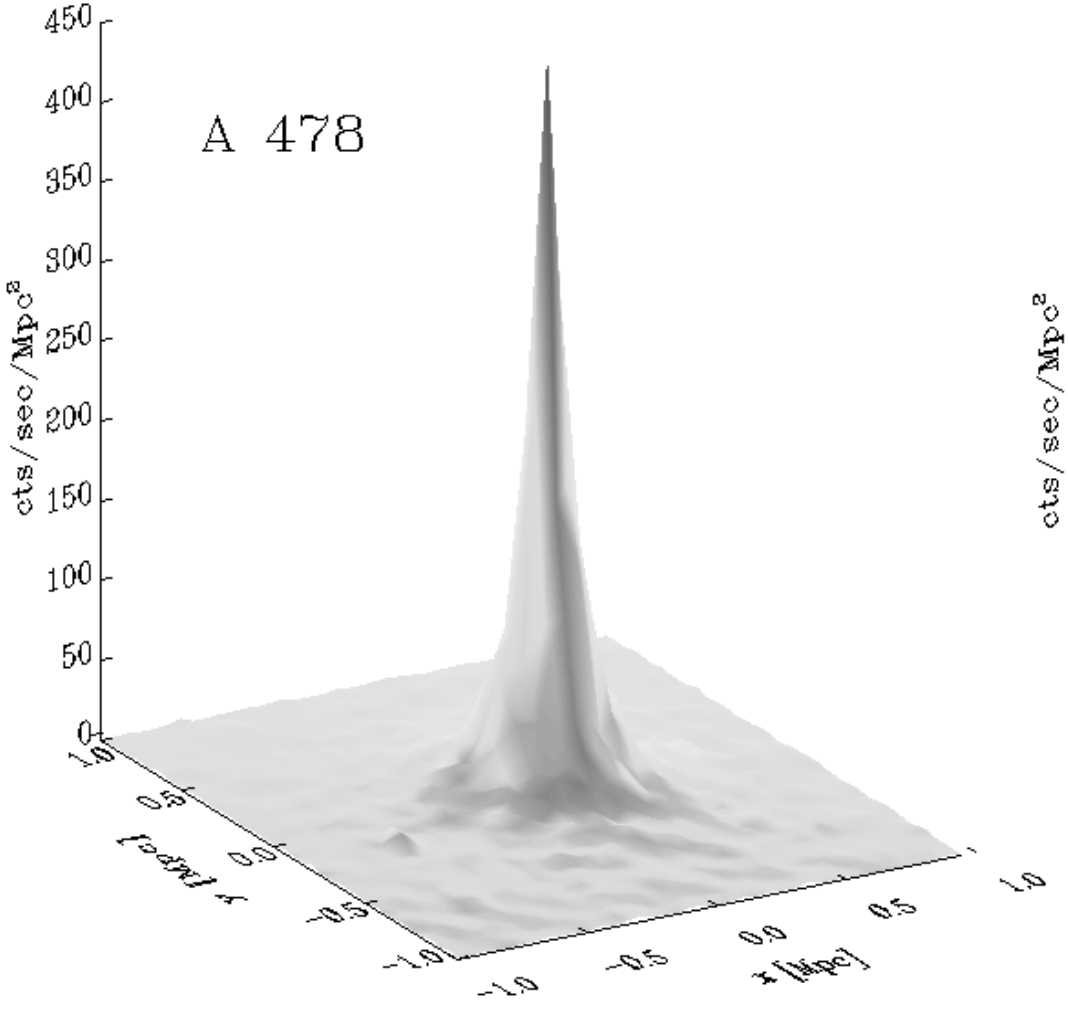


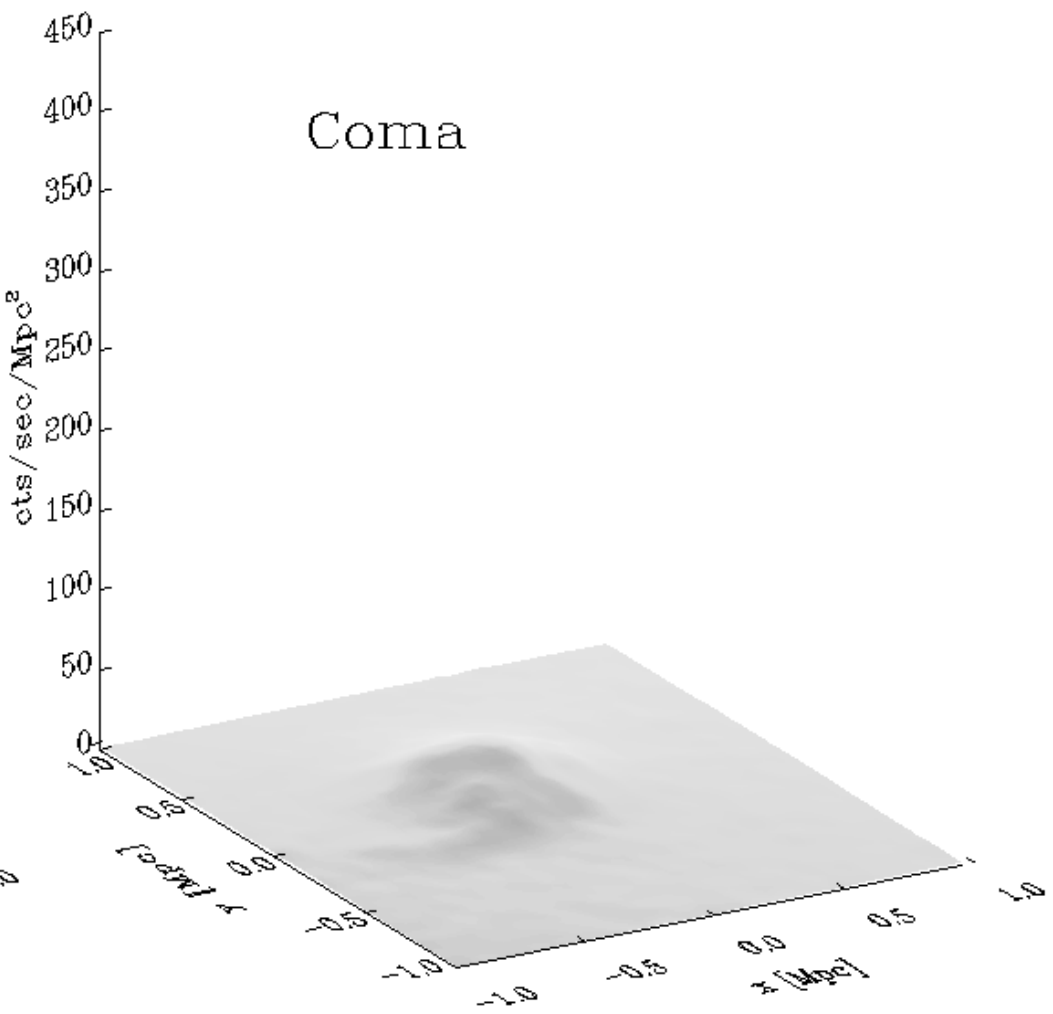



Cas A
Einstein
Chandra

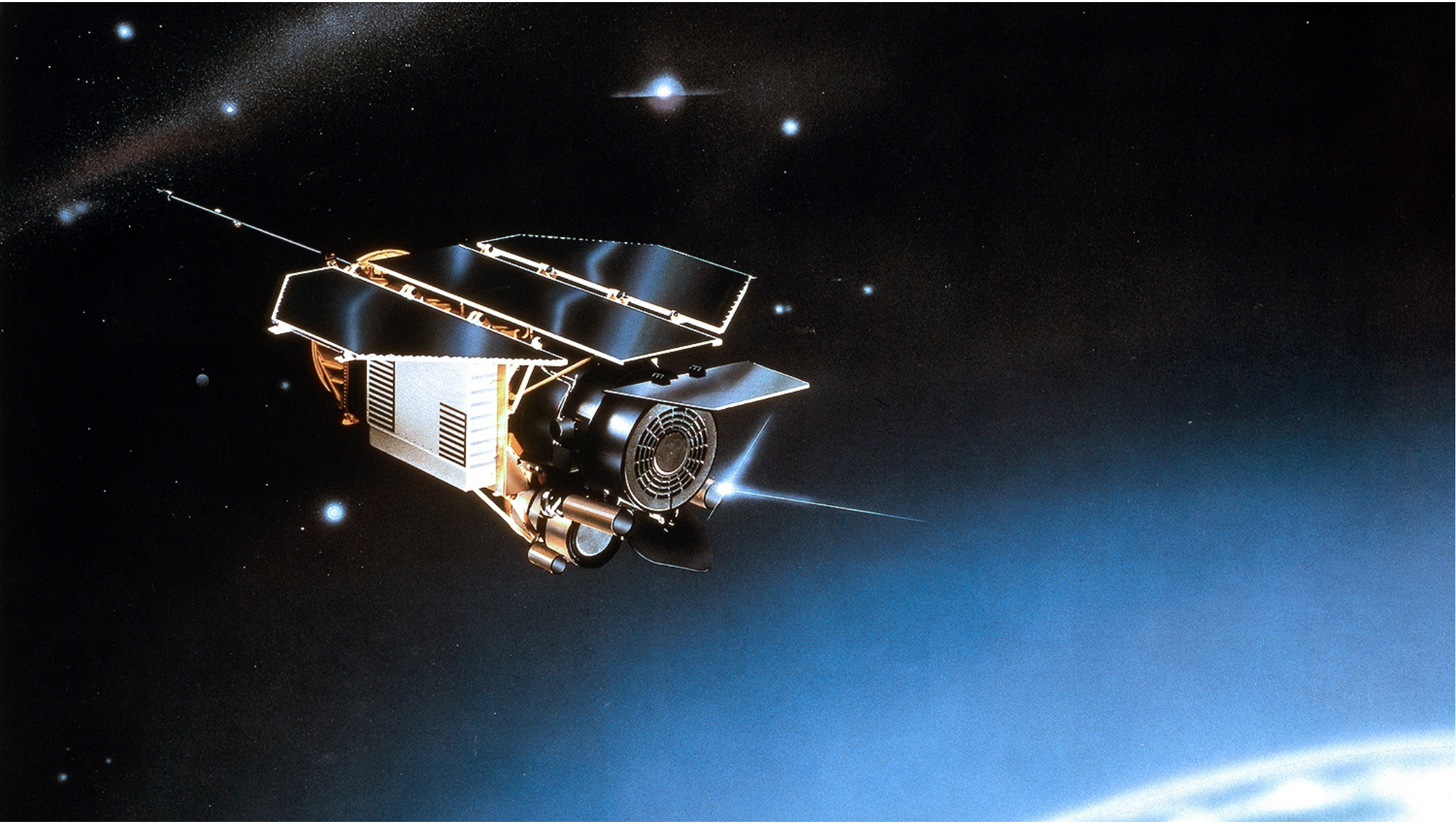

Tycho's Supernova Remnant - Einstein HRI


Crab Nebula
Einstein
Chandra

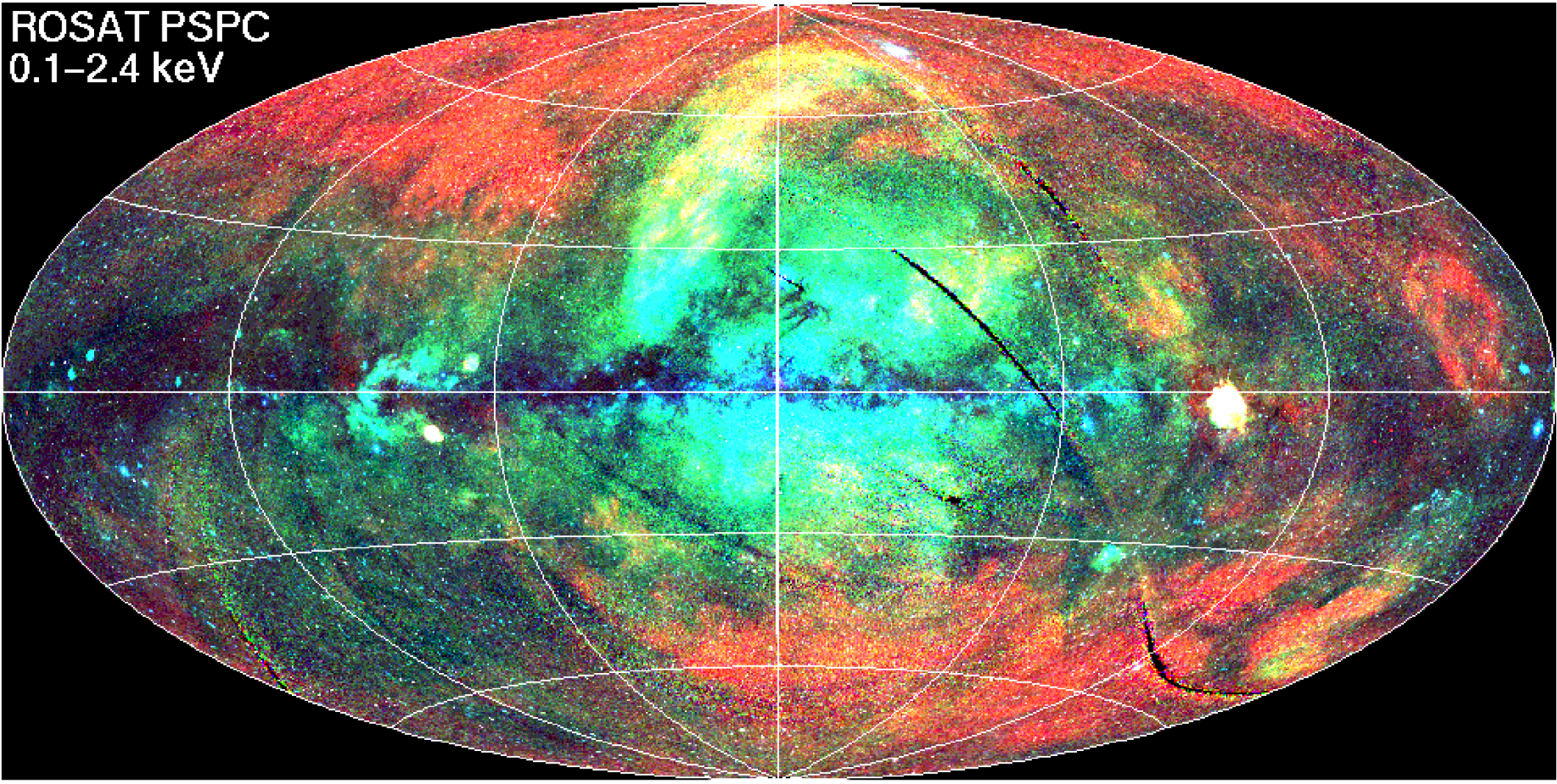

A 478
cts/sec/Mpc^2
450
400
350
300
250
200
150
100
50
0
y [Mpc]
x [Mpc]
1.0
0.5
0.0
-0.5
-1.0

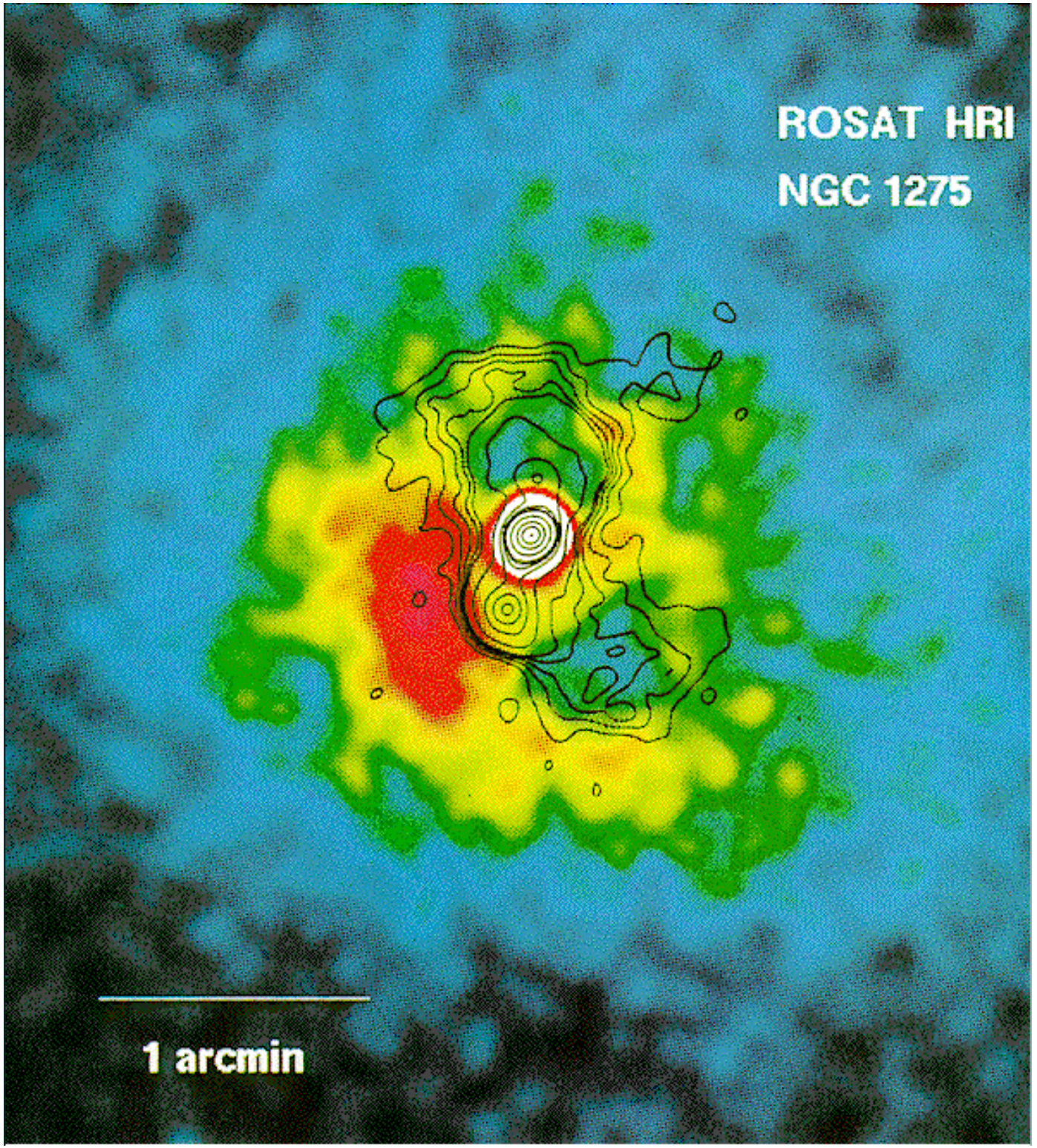

Coma
cts/sec/Mpc^2
450
400
350
300
250
200
150
100
50
0
y [Mpc]
x [Mpc]
1.0
0.5
0.0
-0.5
-1.0

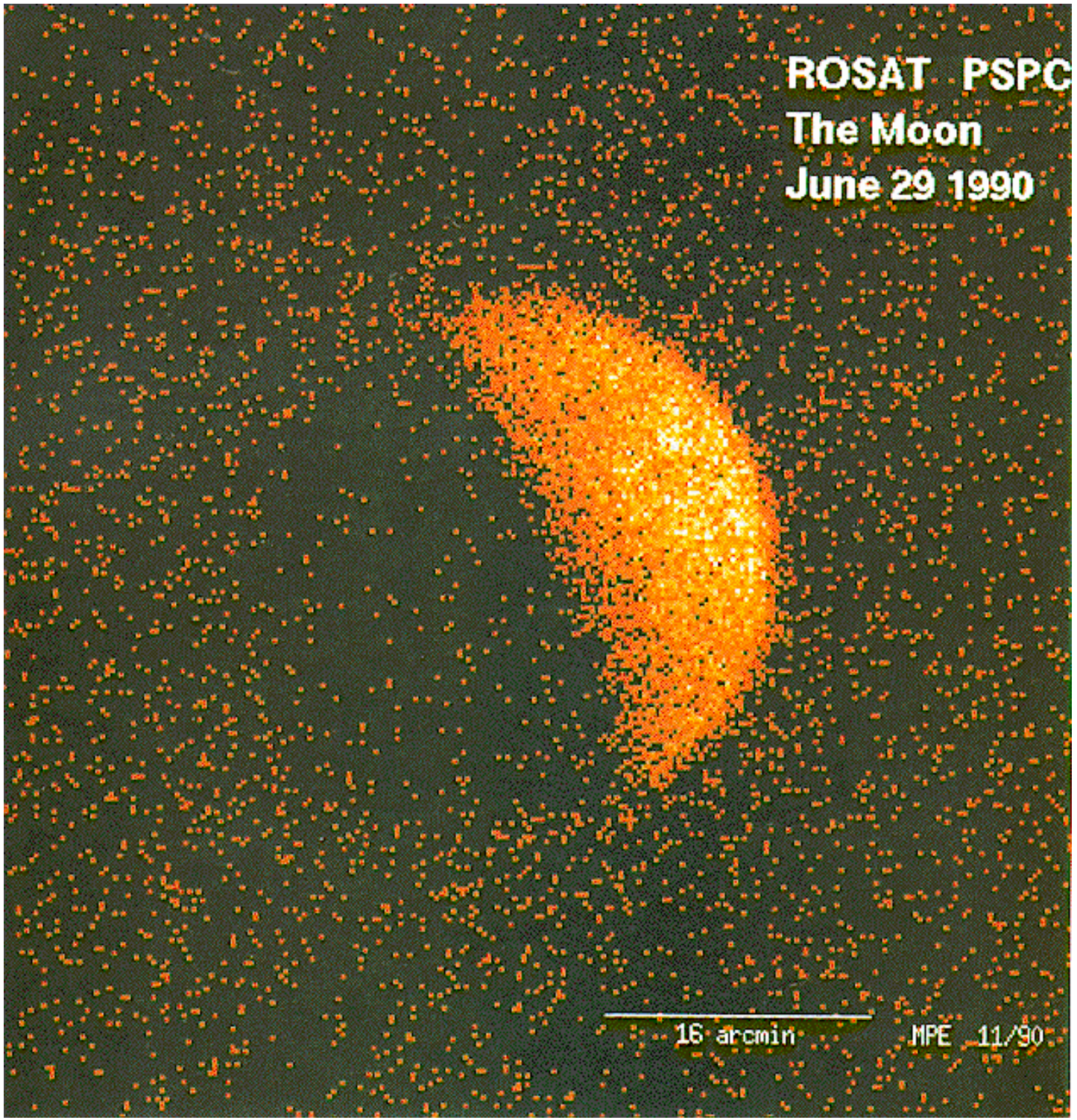
ROSAT 1990 (German, UK, US)



ROSAT All Sky Survey



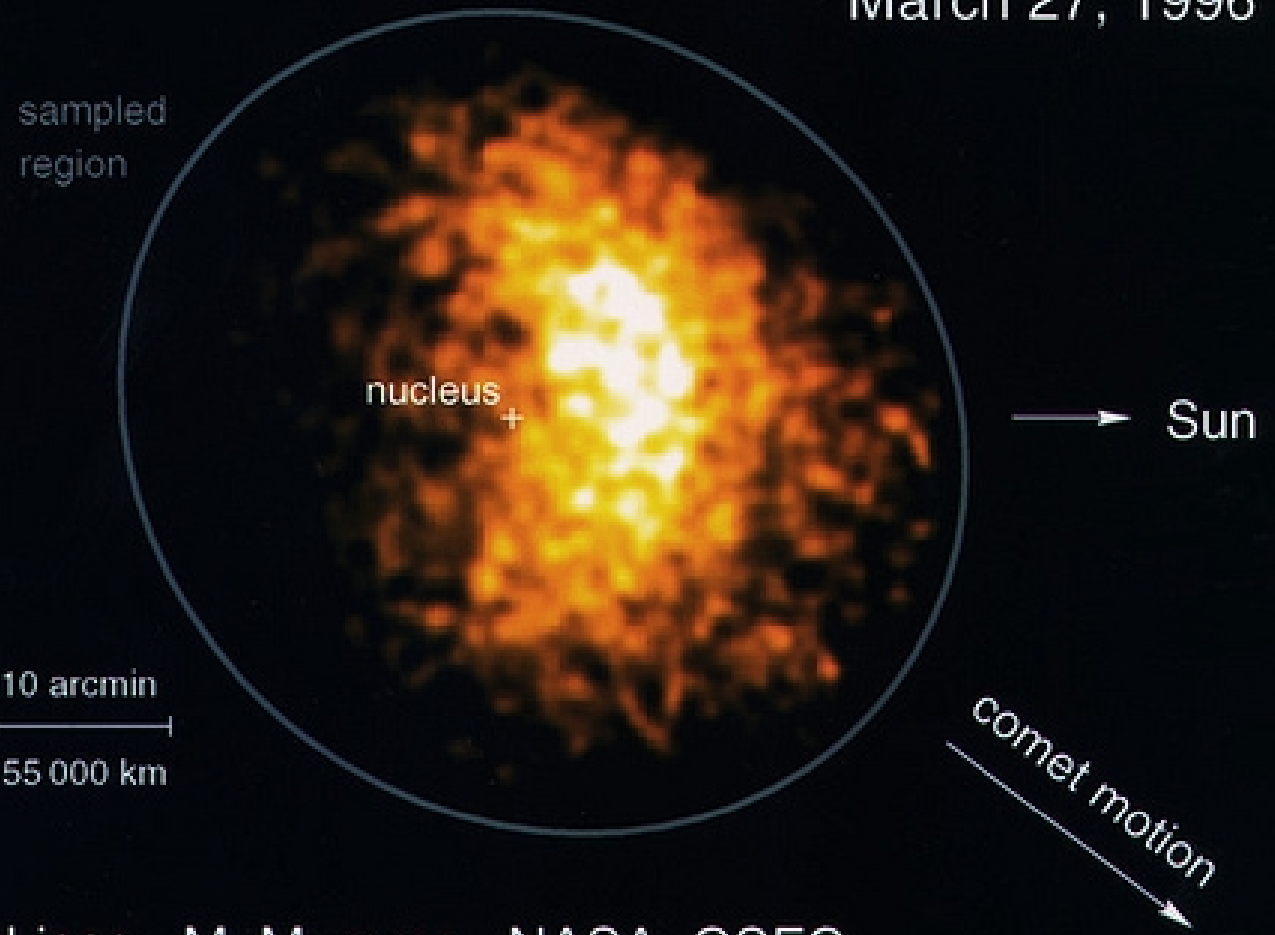

ROSAT HRI
NGC 1275
1 arcmin


ROSAT PSPC
The Moon
June 29 1990
16 arcmin
MPE 11/90

FIRST X-RAY IMAGE OF A COMET

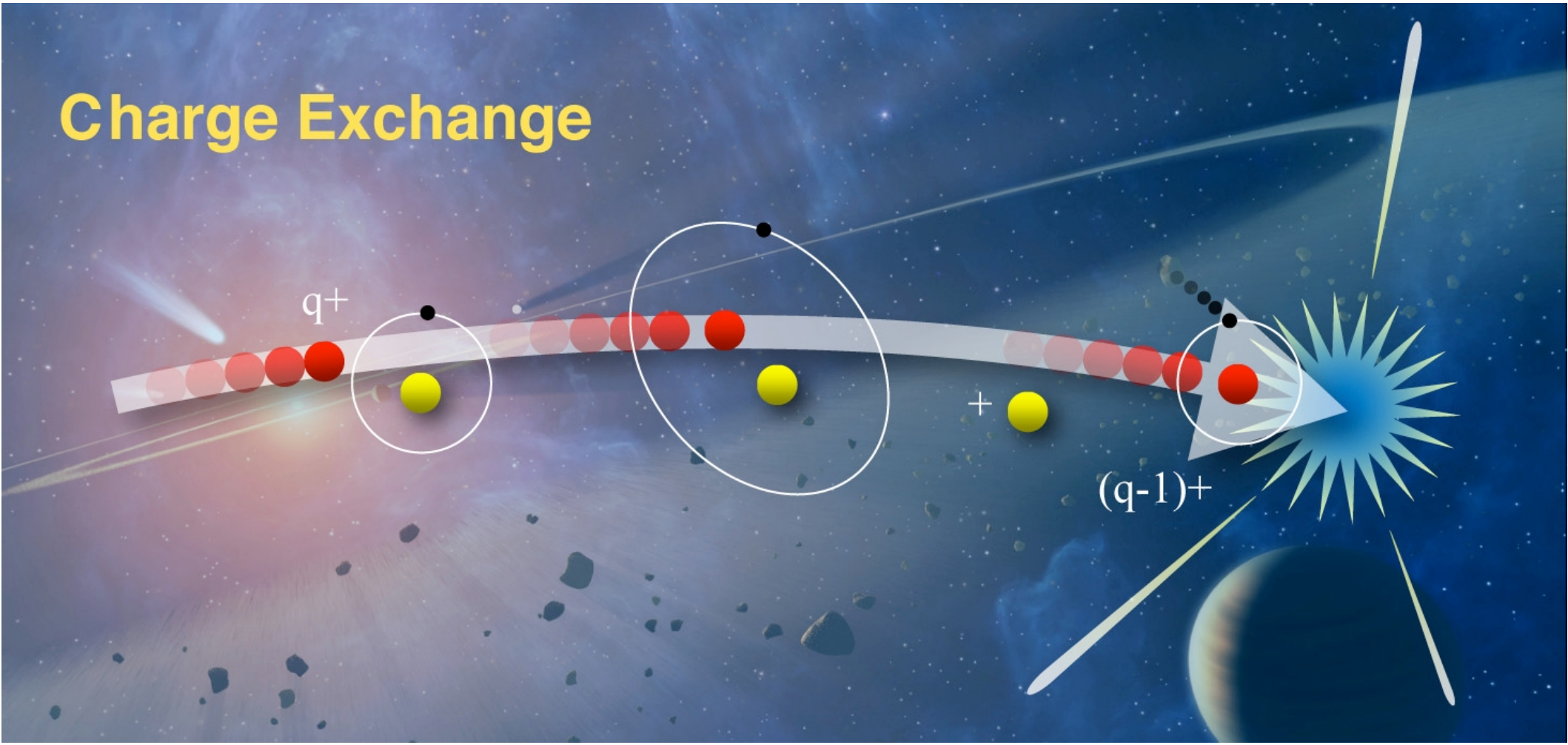
Comet Hyakutake · C/1996 B2 ROSAT HRI

March 27, 1996

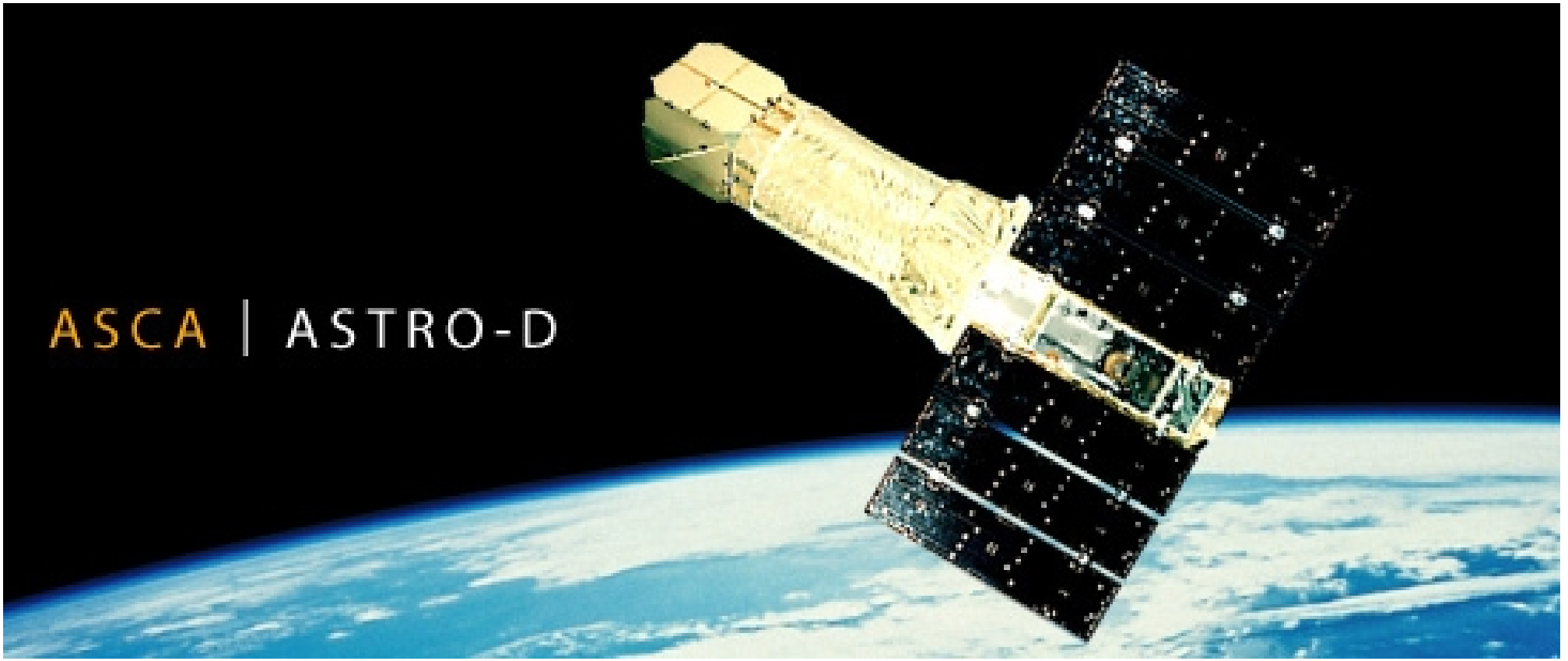


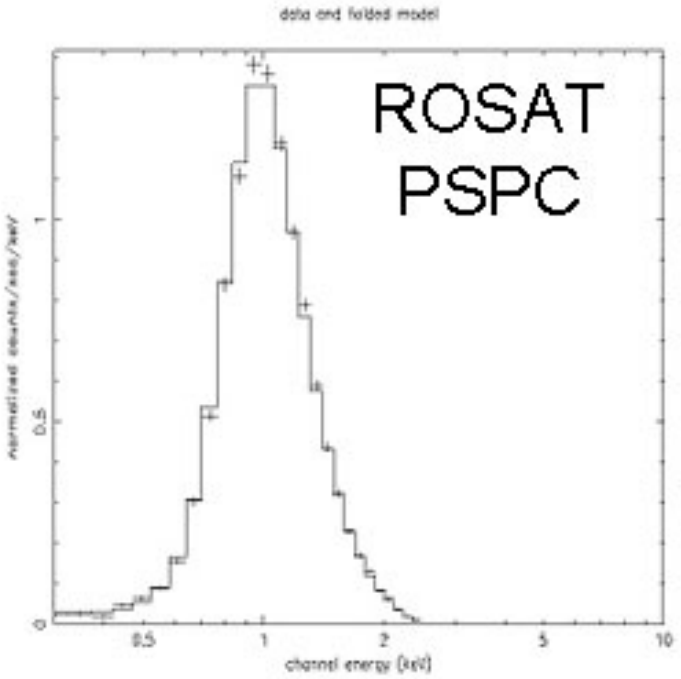
C. Lisse, M. Mumma, NASA GSFC

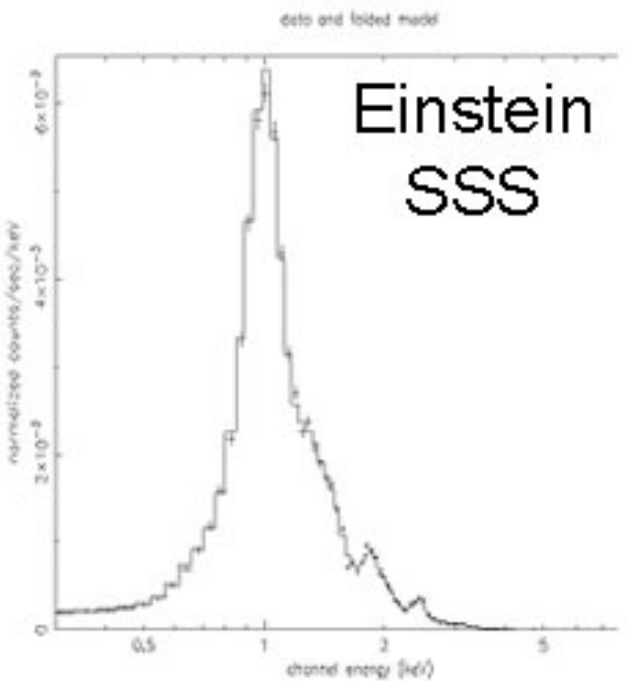
K. Dennerl, J. Schmitt, J. Englhauser, MPE

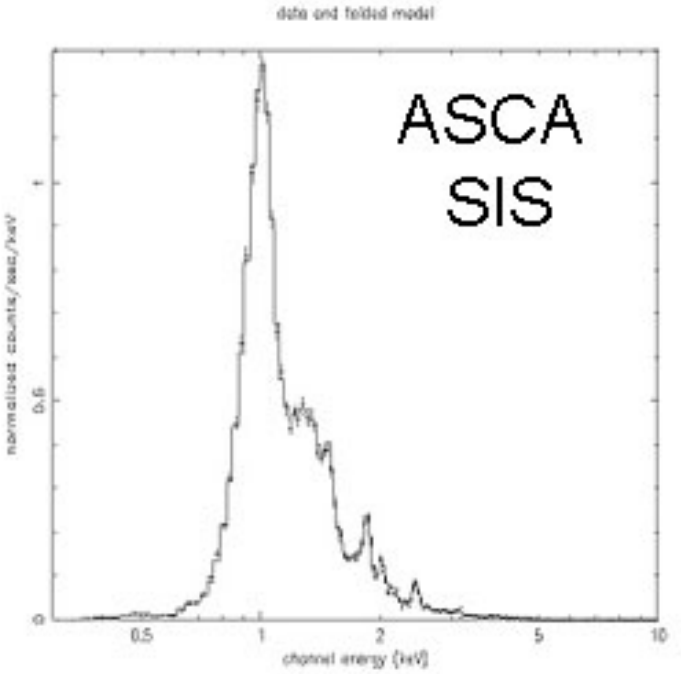

Charge Exchange
q+
+
(q-1)+

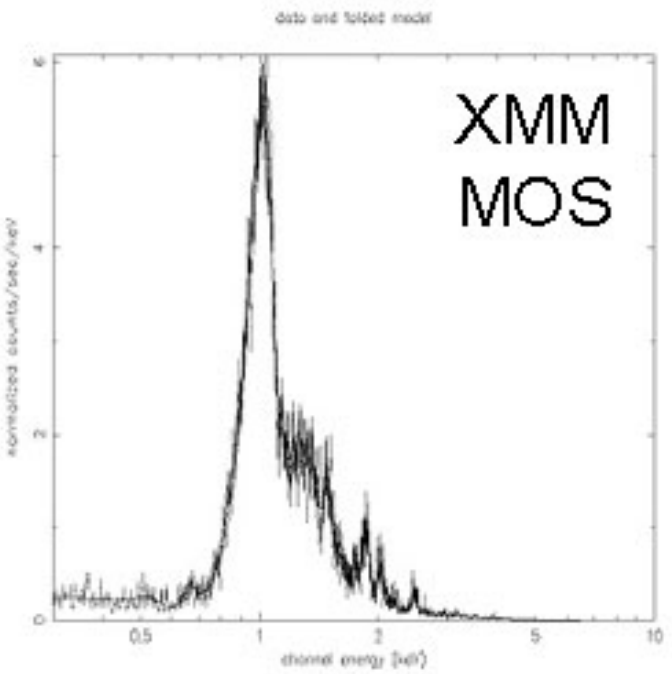
ASCA – 1993 (Japan)



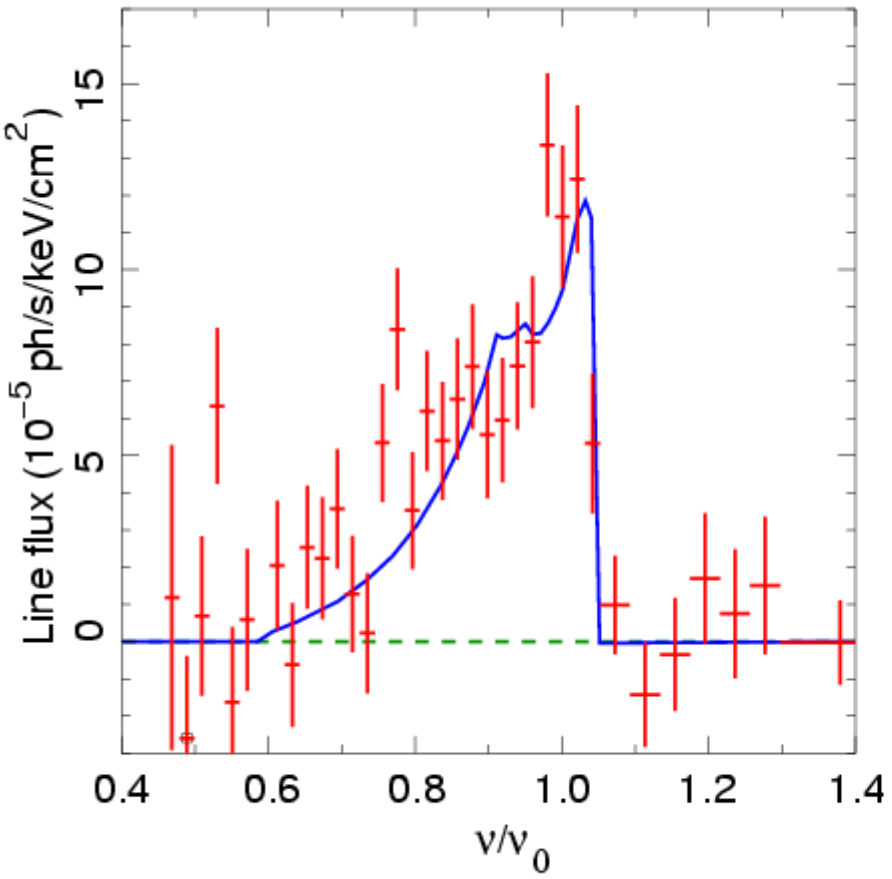

data and folded model
ROSAT
PSPC
normalized counts/sec/keV
channel energy (keV)

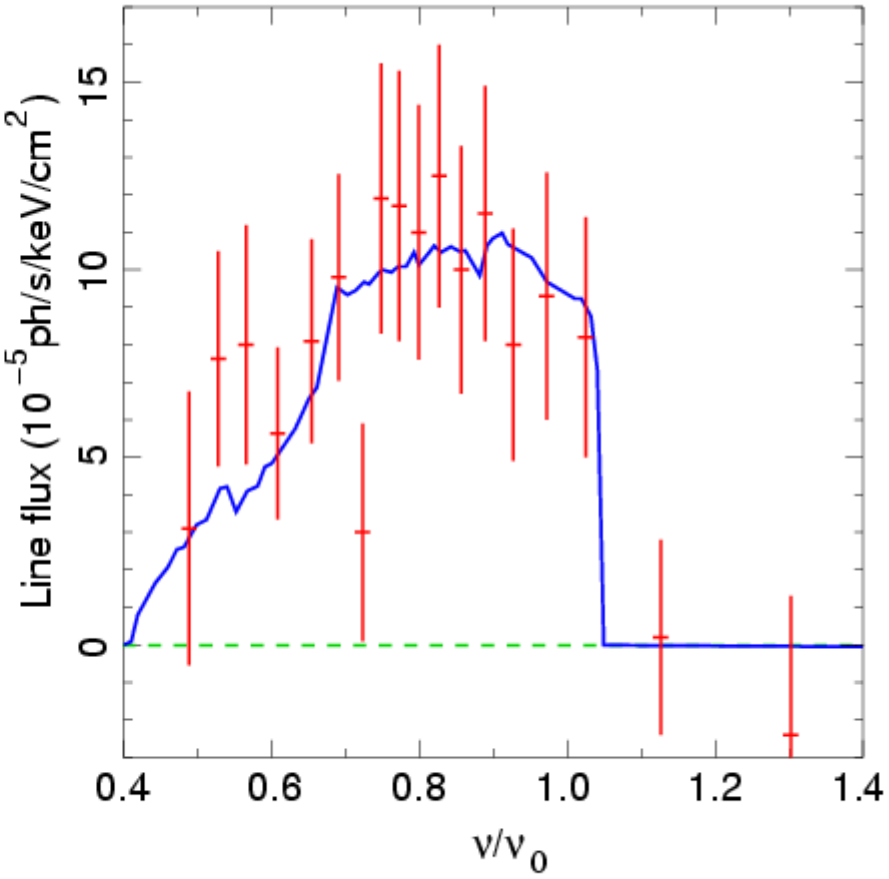

data and folded model
Einstein
SSS
channel energy (keV)


data and folded model
ASCA
SIS
normalized counts/sec/keV
channel energy (keV)

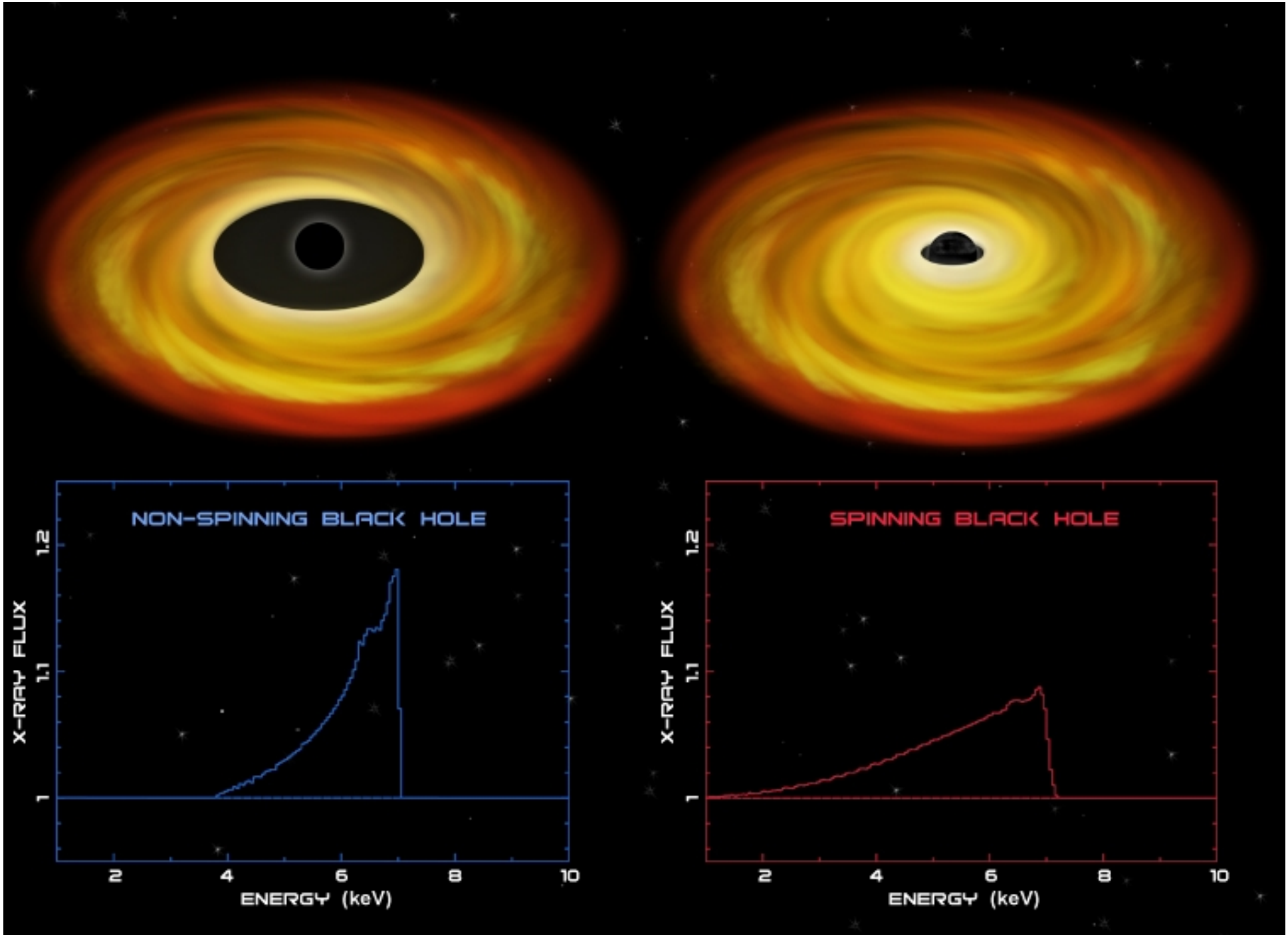

data and folded model
XMM
MOS
channel energy (keV)

ASCA – Broad iron line

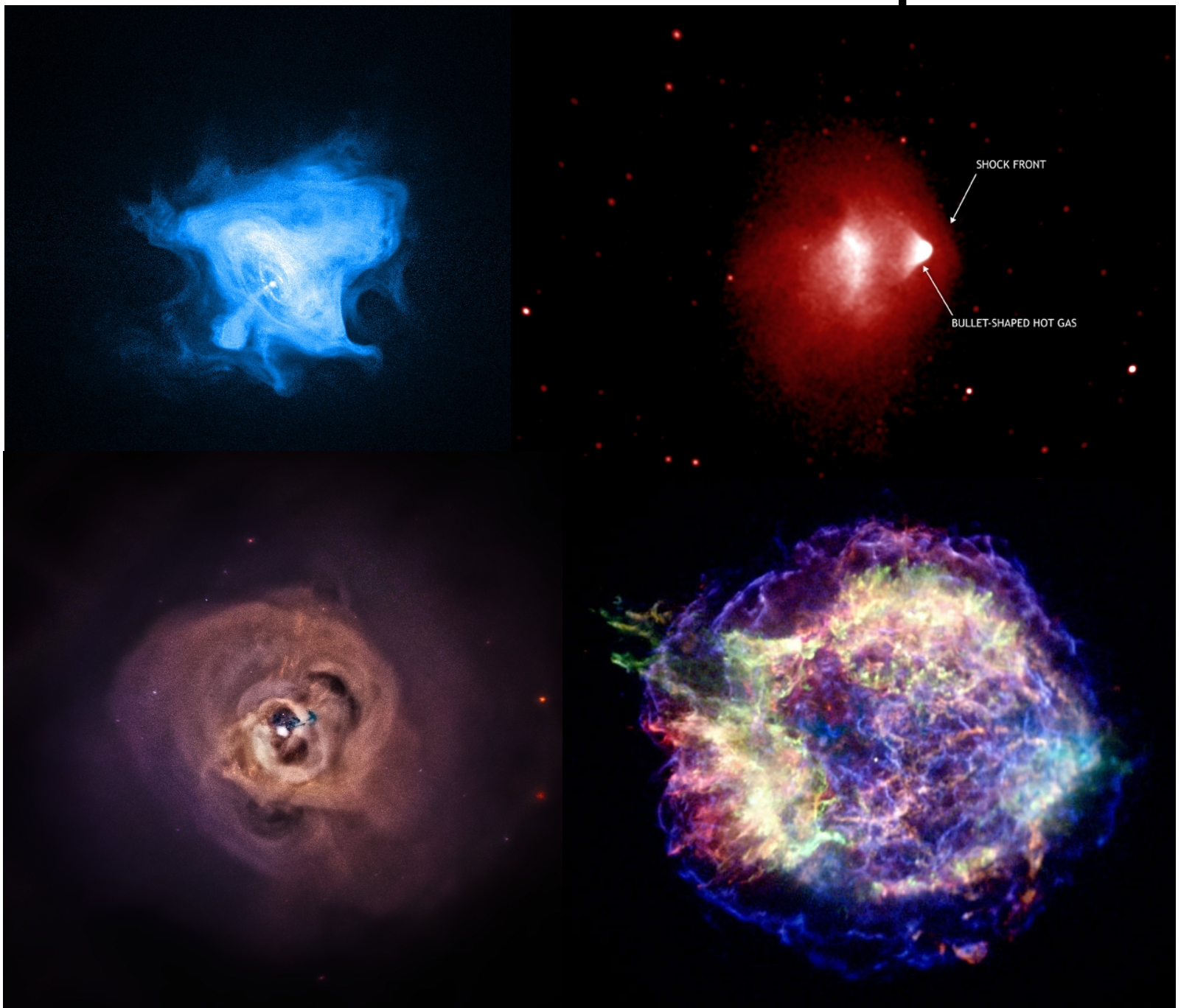




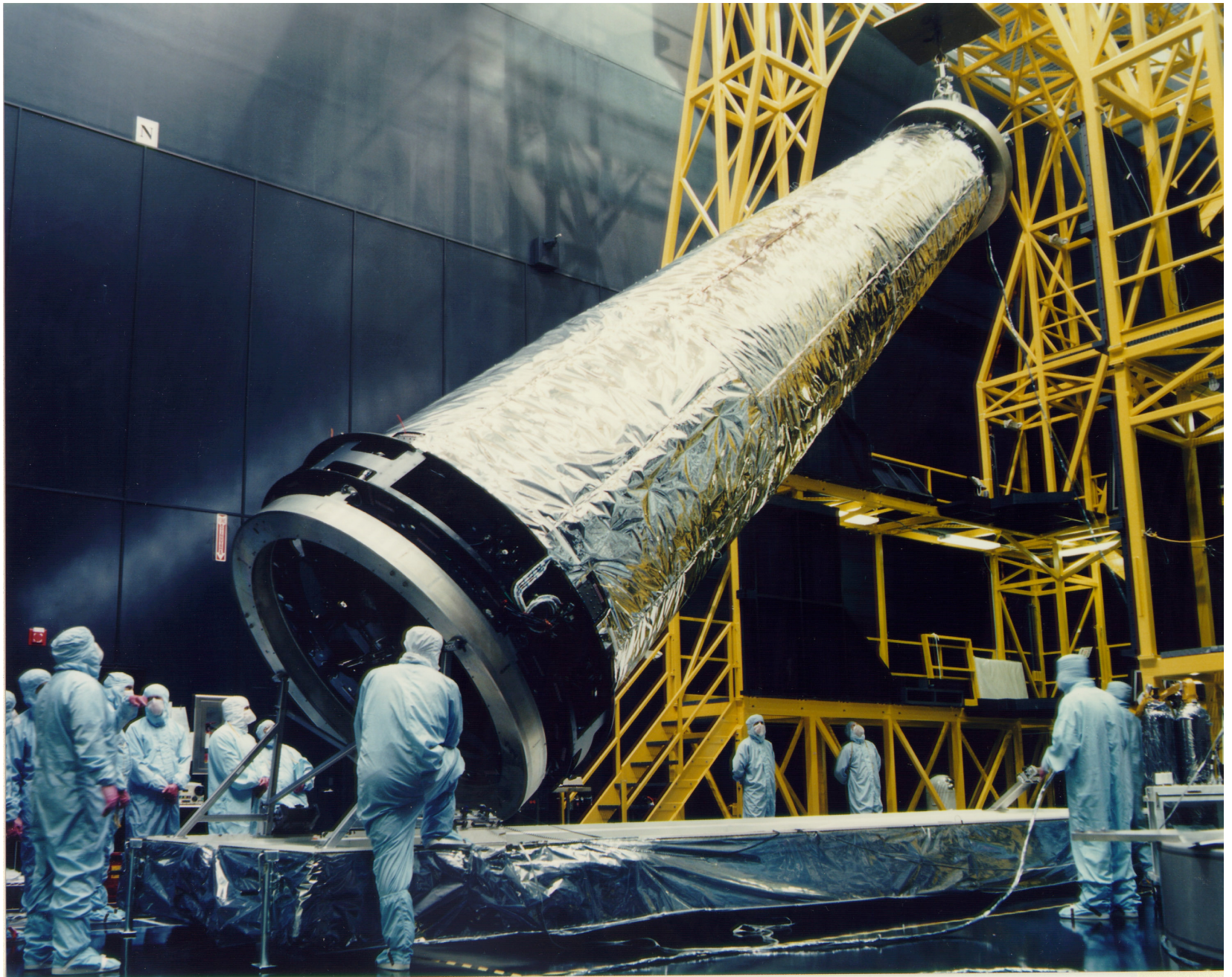
MCG−6-30-15 ($z = 0.008$): first AGN with relativistic disk line


NON-SPINNING BLACK HOLE
X-RAY FLUX
1
1.1
1.2
2
4
6
8
10
ENERGY (keV)
SPINNING BLACK HOLE
X-RAY FLUX
1
1.1
1.2
2
4
6
8
10
ENERGY (keV)

The modern era: 1999-present

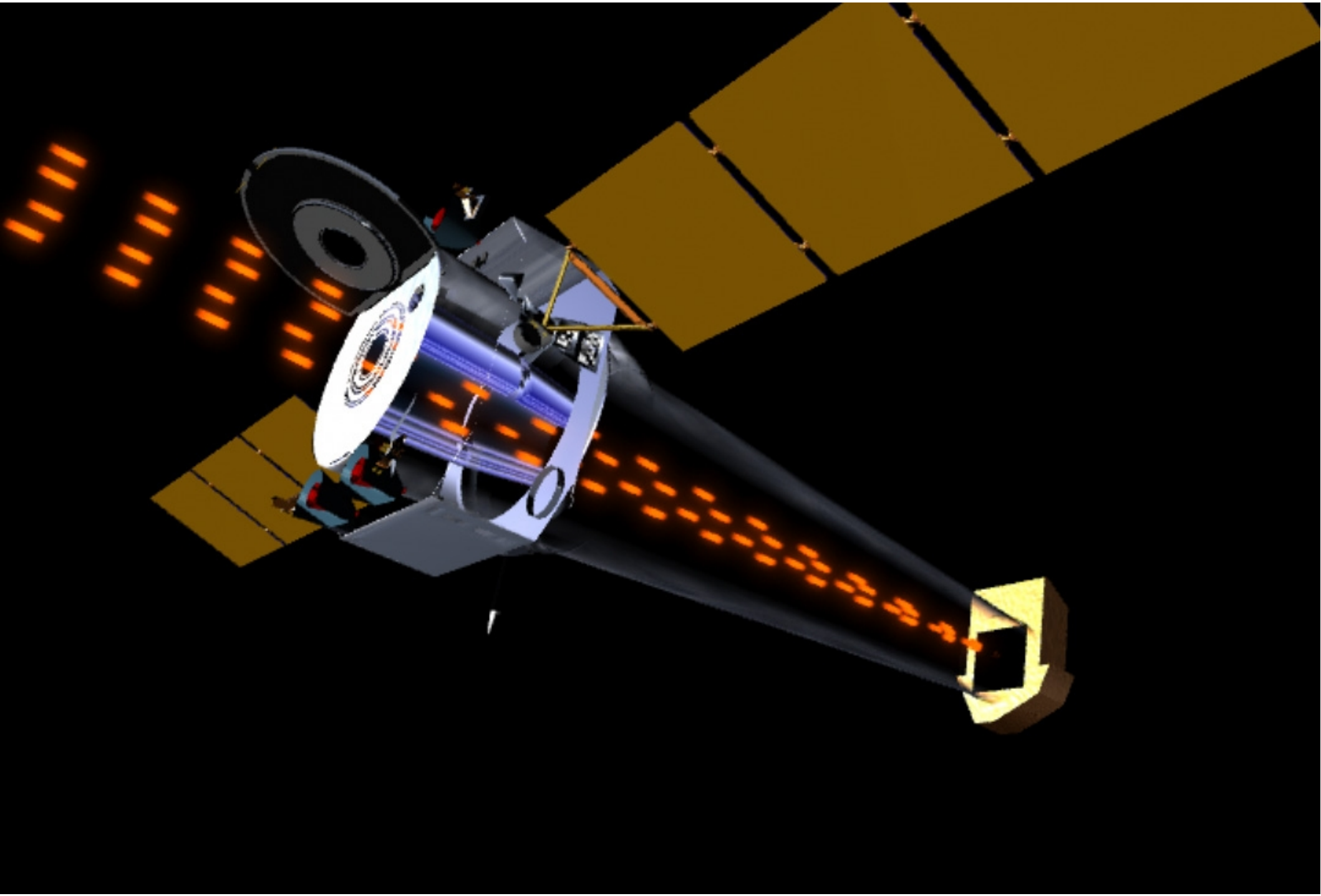


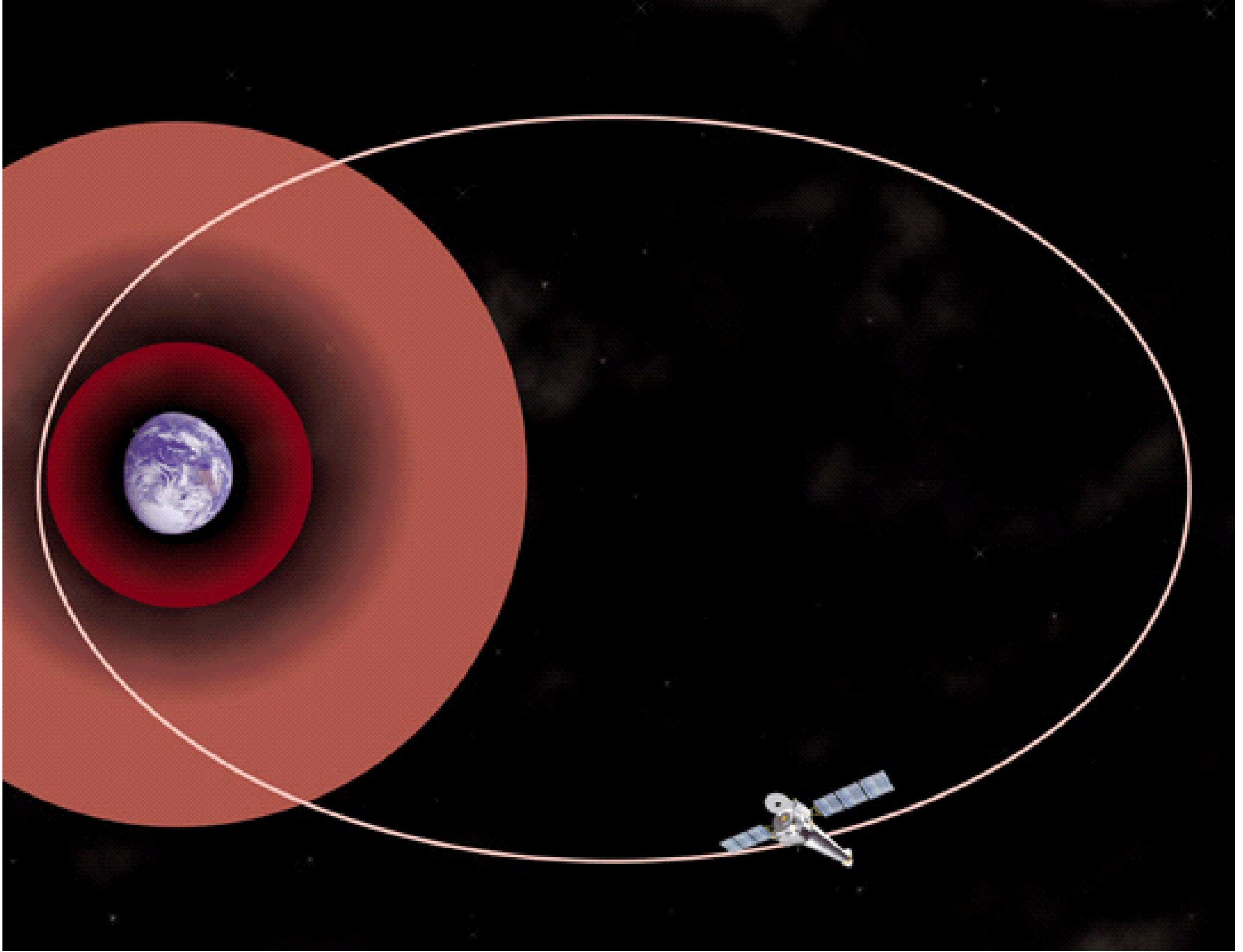
Chandra 1999-present (NASA)



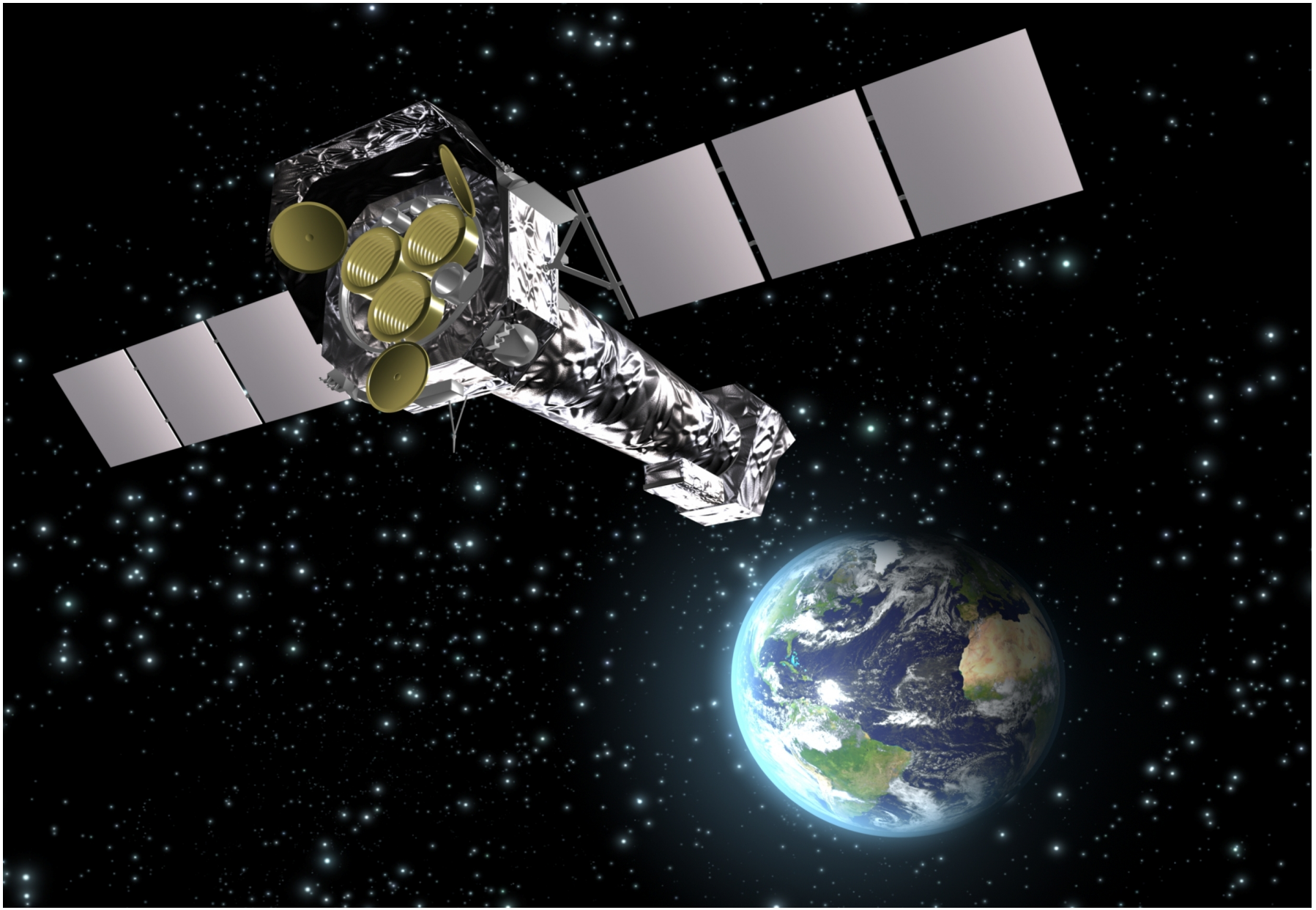

USA

- The smoothest and cleanest mirrors ever made.
- Imagine making the surface of the Earth so smooth that the highest mountain was less than two meters (78 inches) tall!
- 1 tonne of glass for 400 sq cm of area.

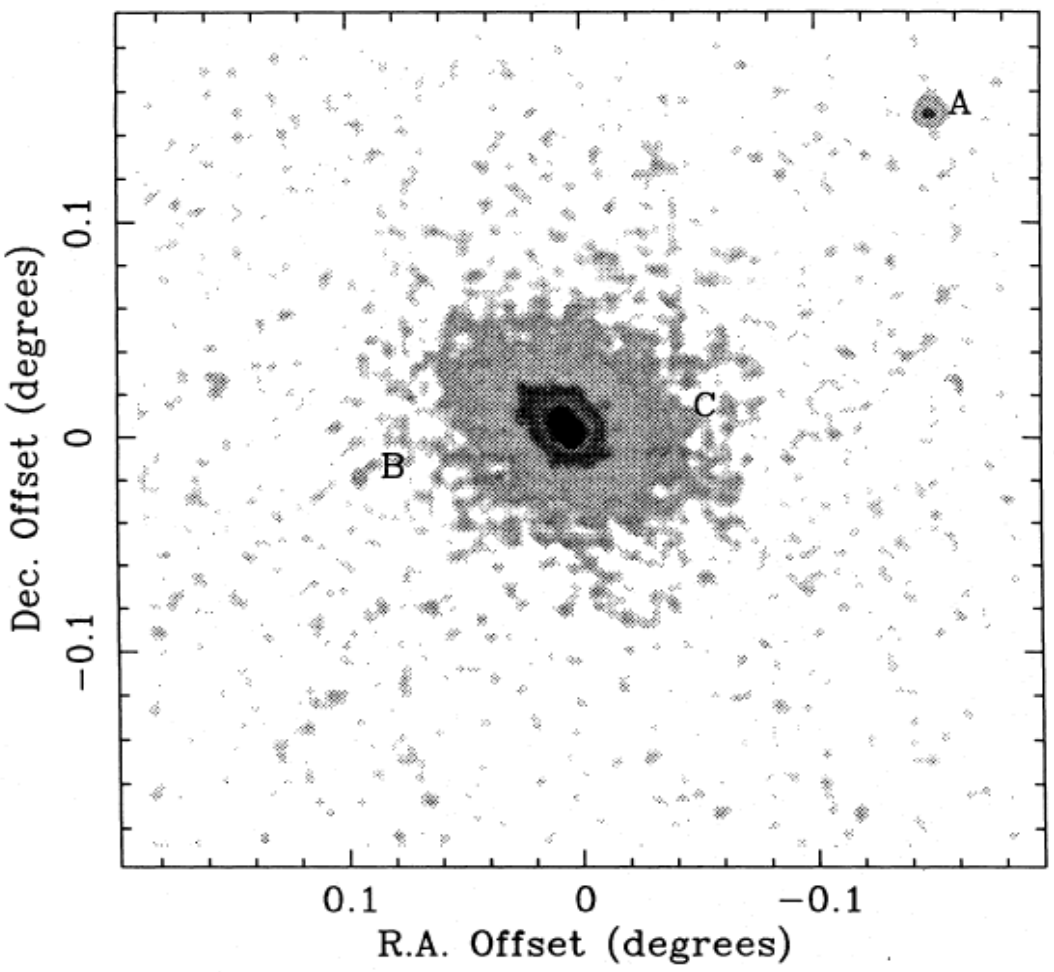


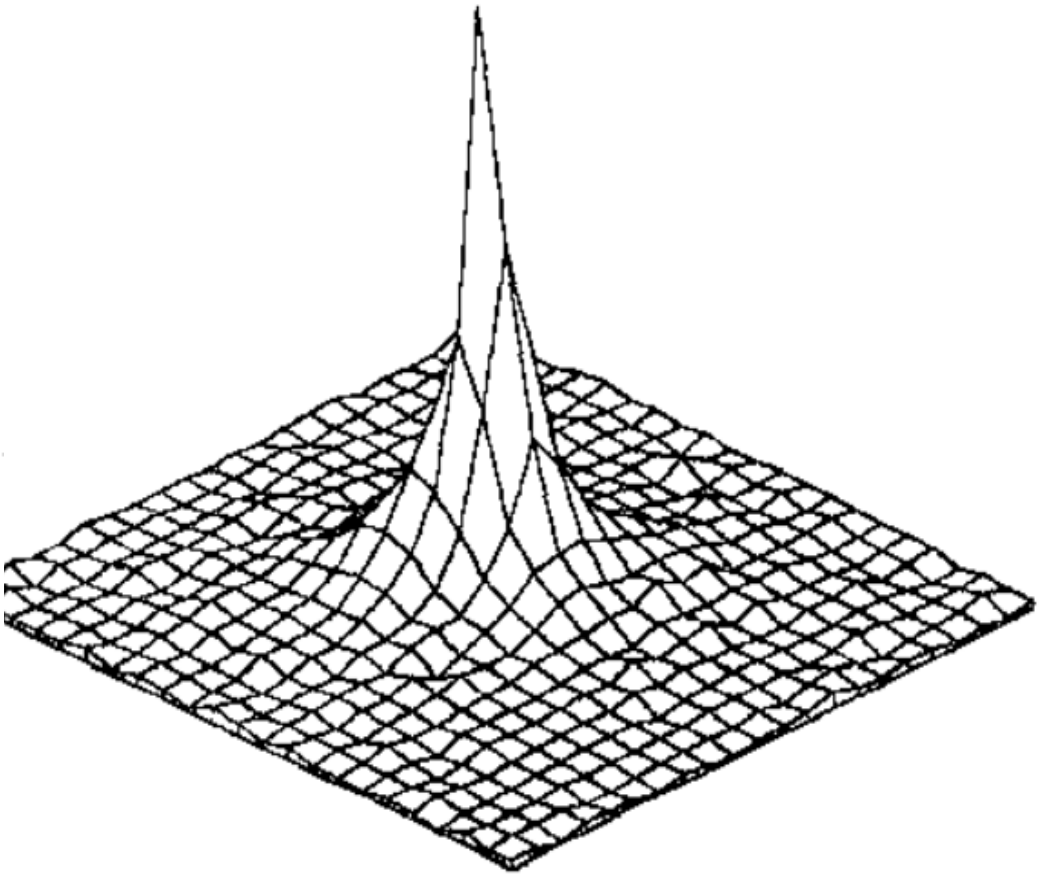


XMM-Newton 1999-present (ESA)

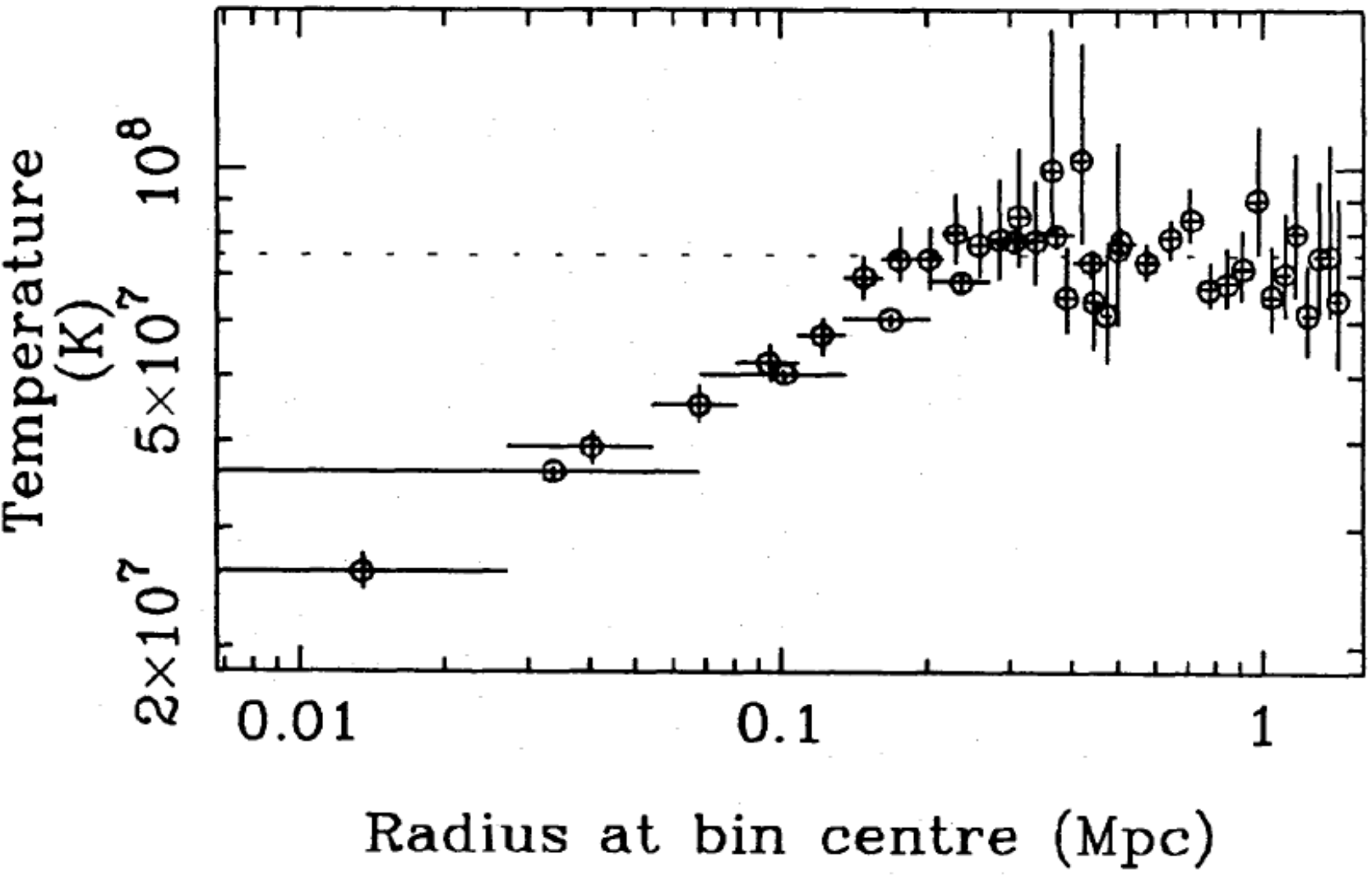


A very brief history of cooling flows

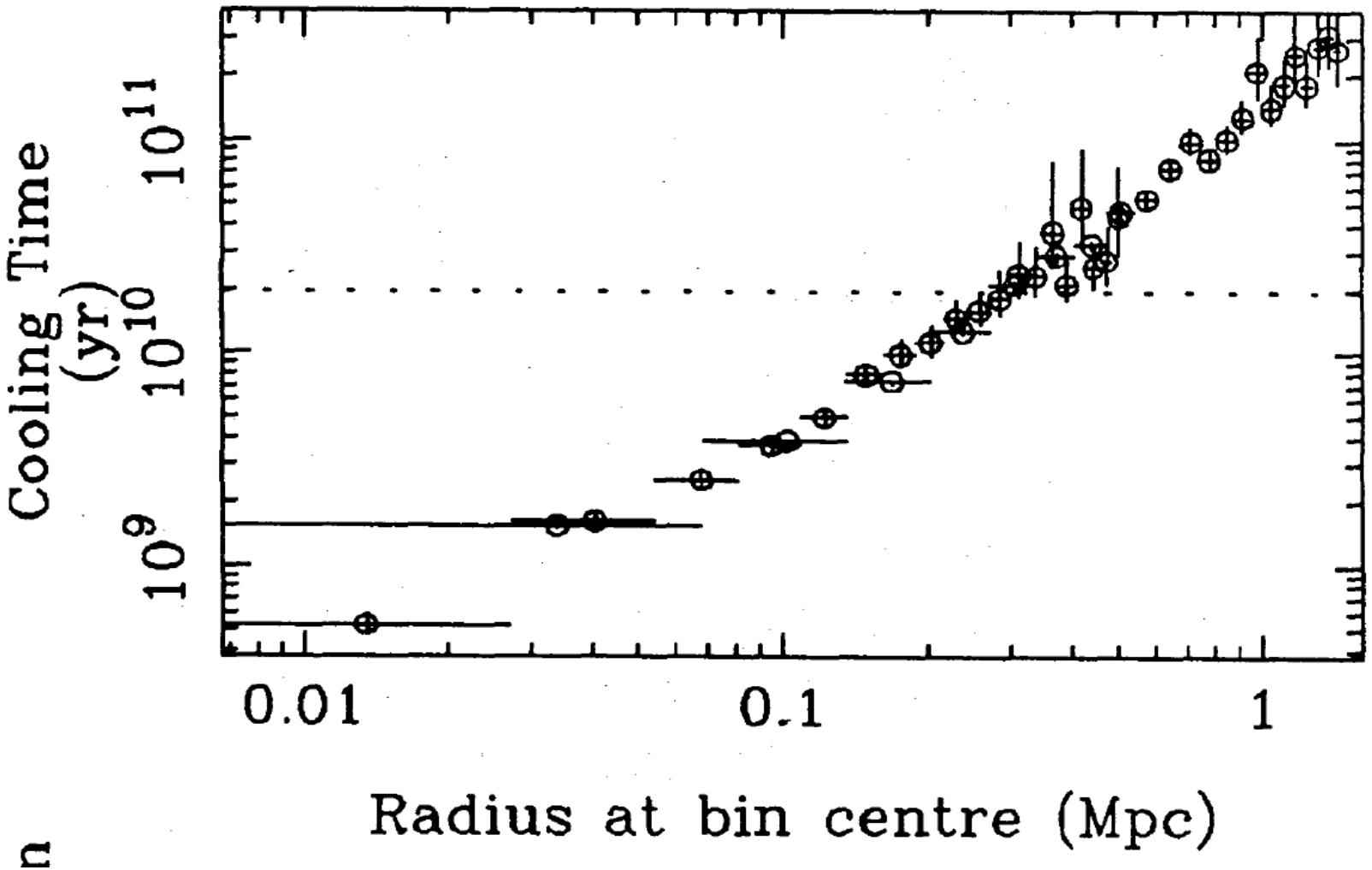




Fabian 1994, White et al. 1994



Abell 478, White et al. 1994



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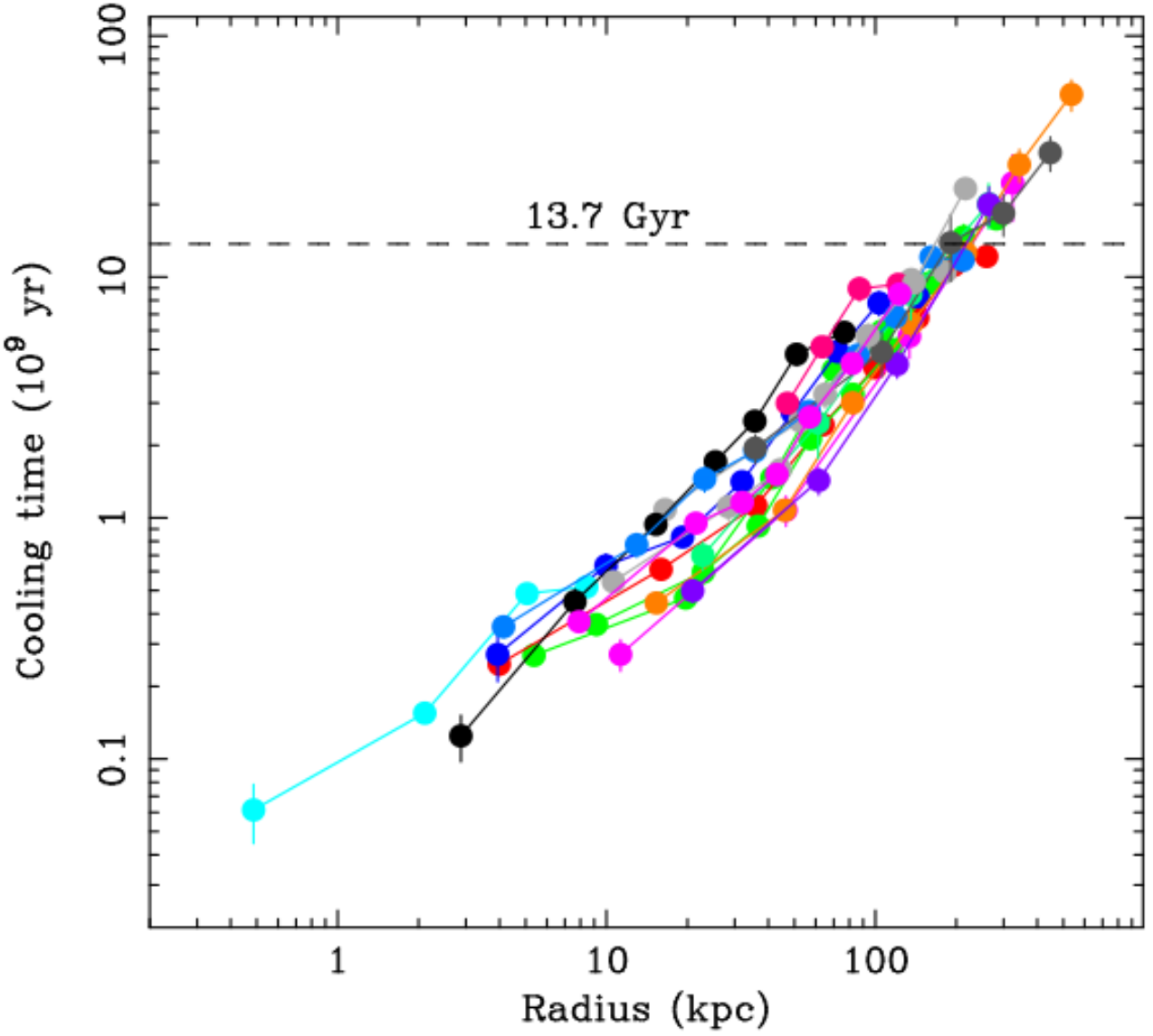
Abell 478, White et al. 1994



Voigt & Fabian (2004)

We would expect:

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- Gas temperature drops rapidly to <10,000K
- Condenses on central galaxy
- Inwards flow of up to 1000 solar mass /yr

- Rates of observed star formation too low

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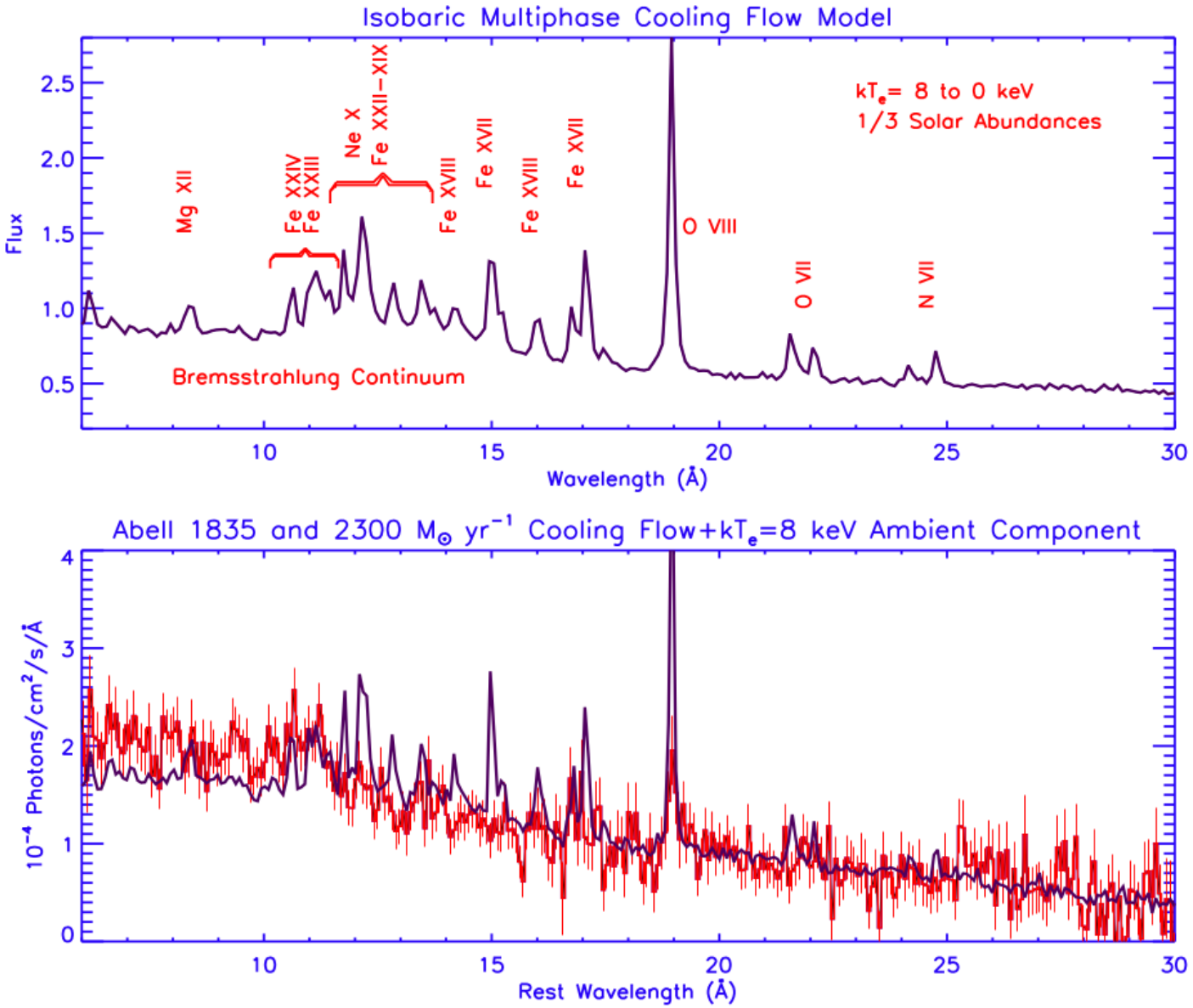
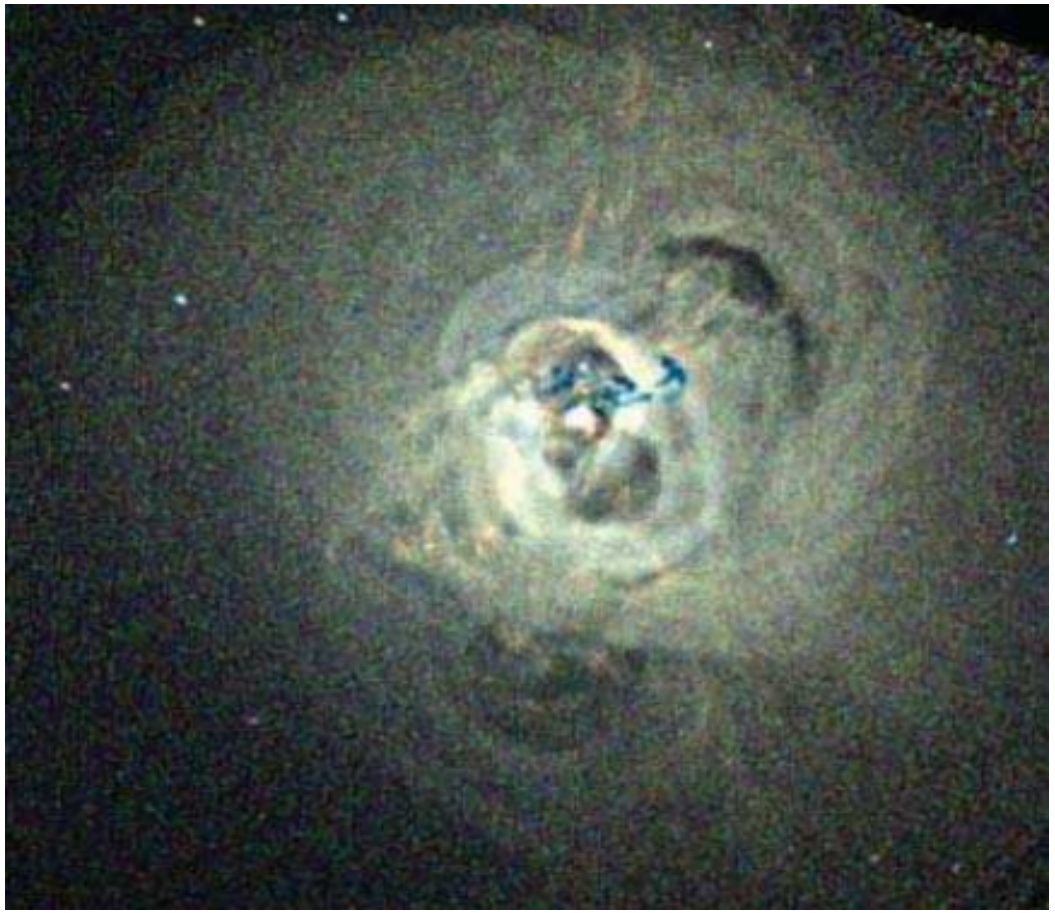
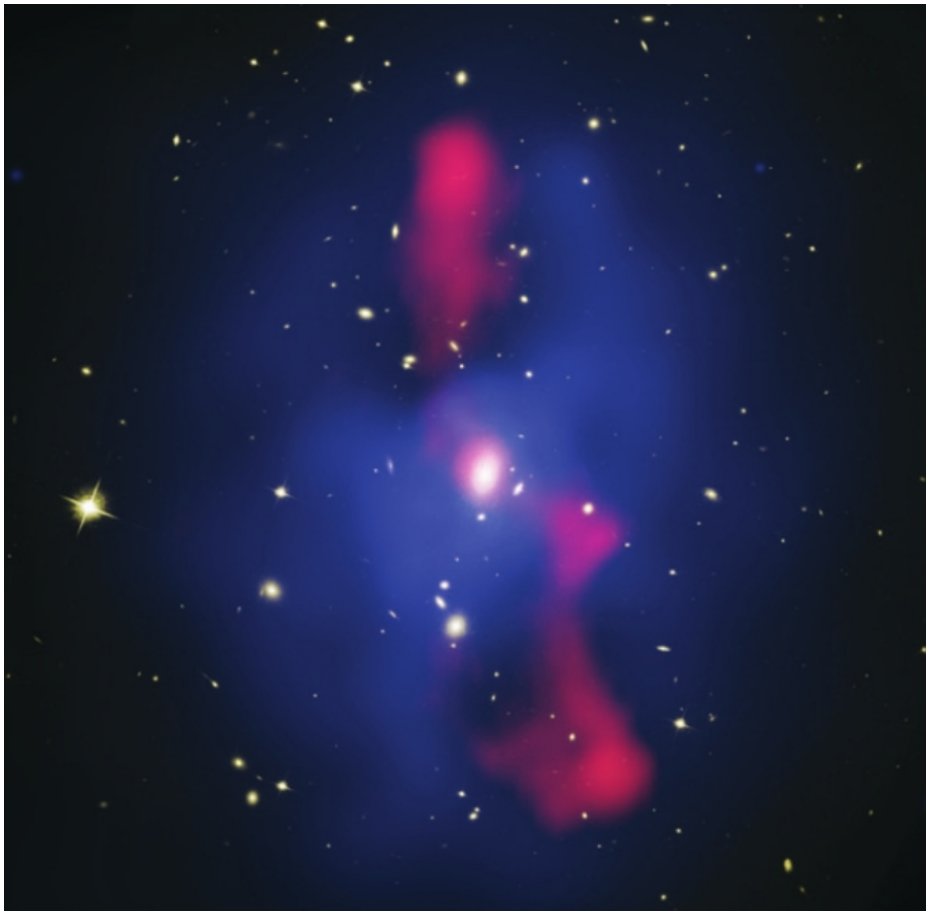
- Problems fitting soft X-ray emission



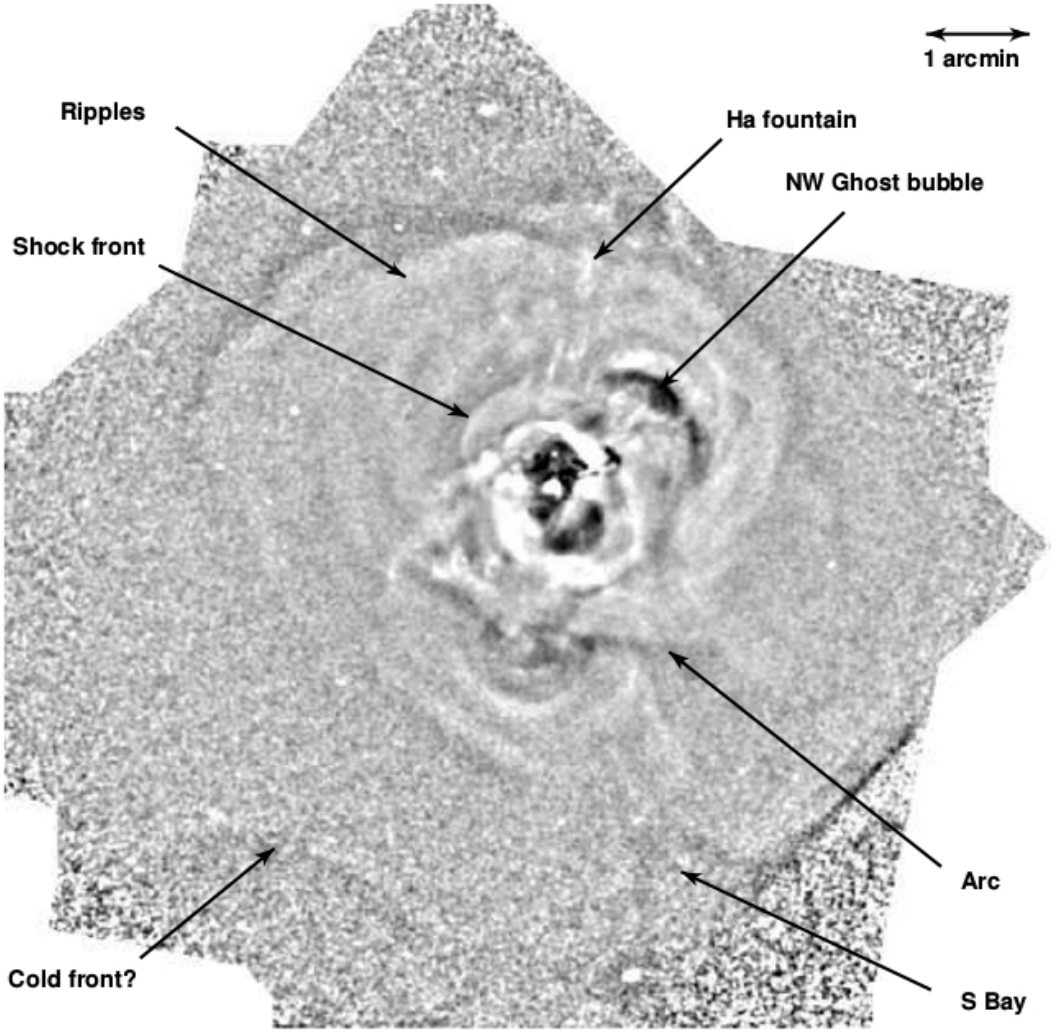
A1835, Peterson et a (2001)

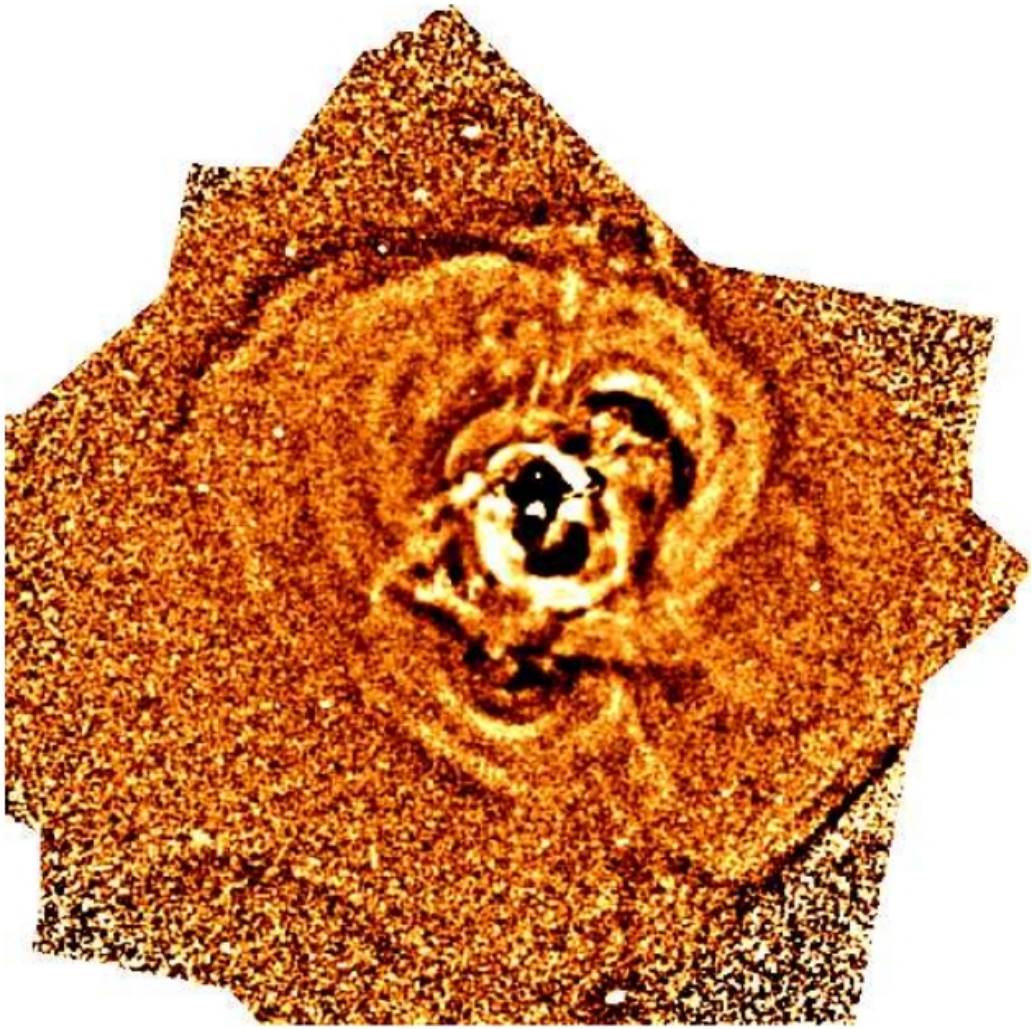


Perseus cluster

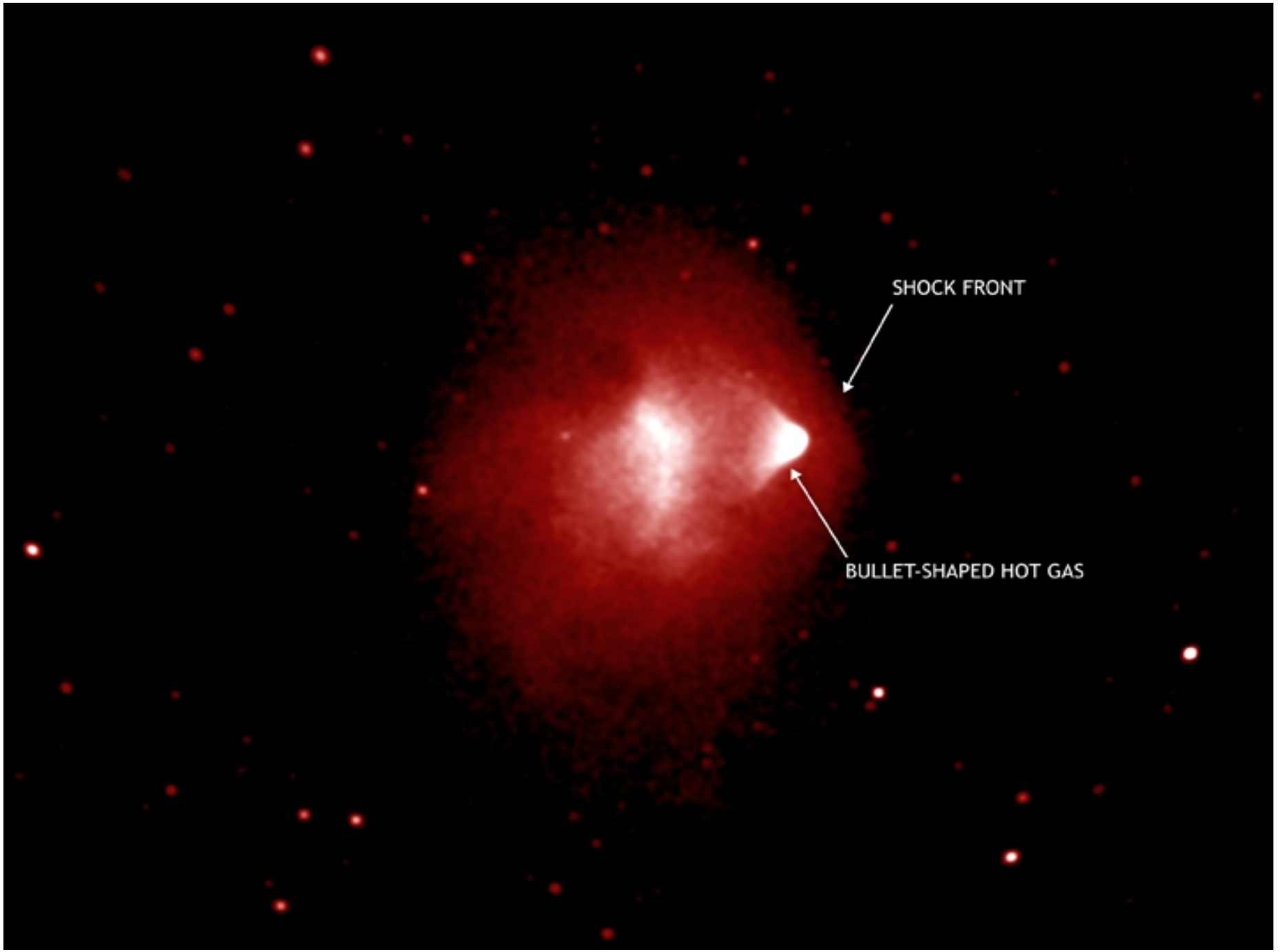


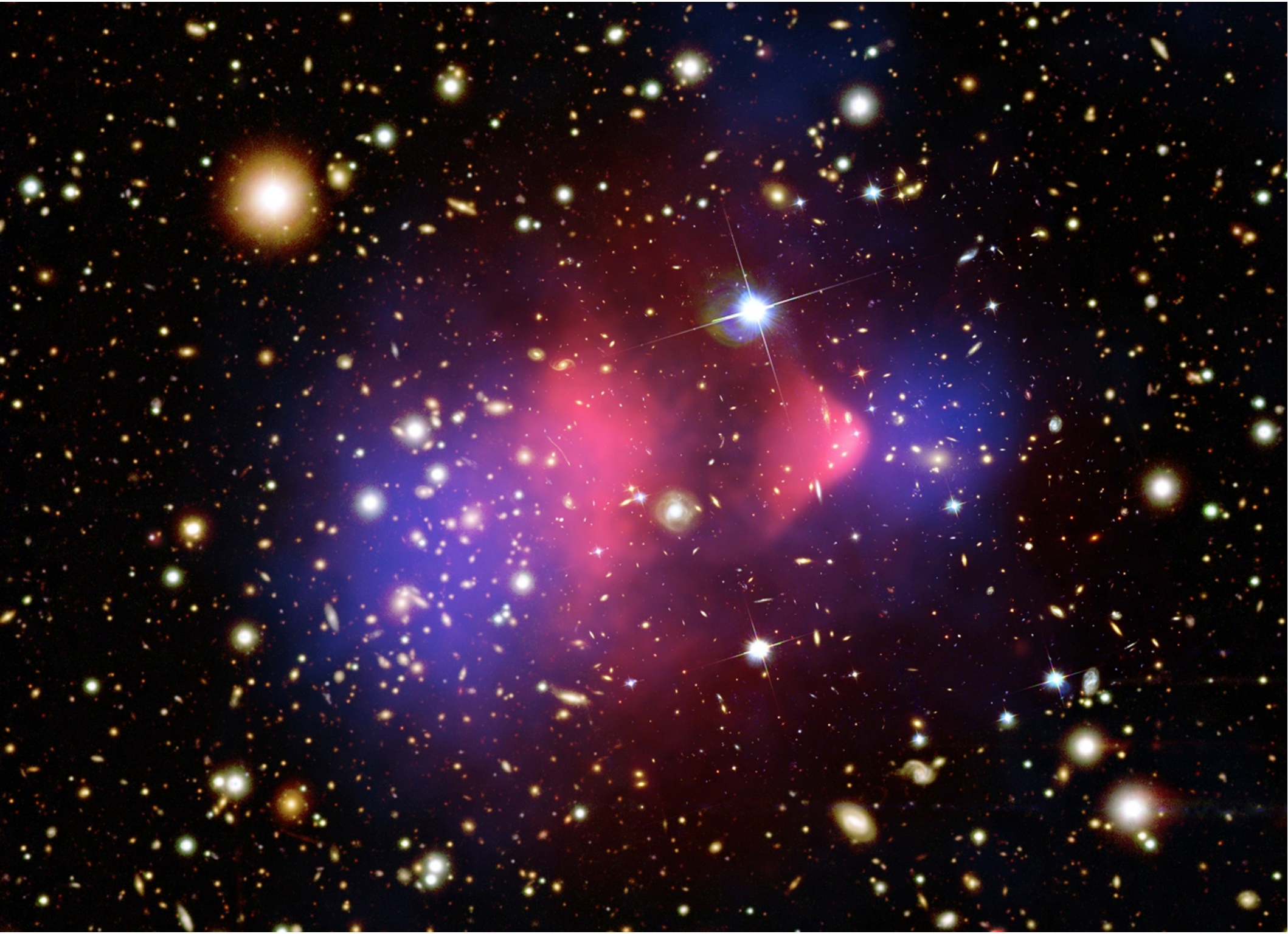
MS0735.6+7421





Fabian et al. (2006)


SHOCK FRONT
BULLET-SHAPED HOT GAS



The Future of X-ray Astronomy

The Future of X-ray Astronomy

- Need bigger effective area
- Need way of making a huge number of very fine, very smooth concentric mirrors
- Needs to be lightweight
- We can't just make a 'bigger version' of Chandra.

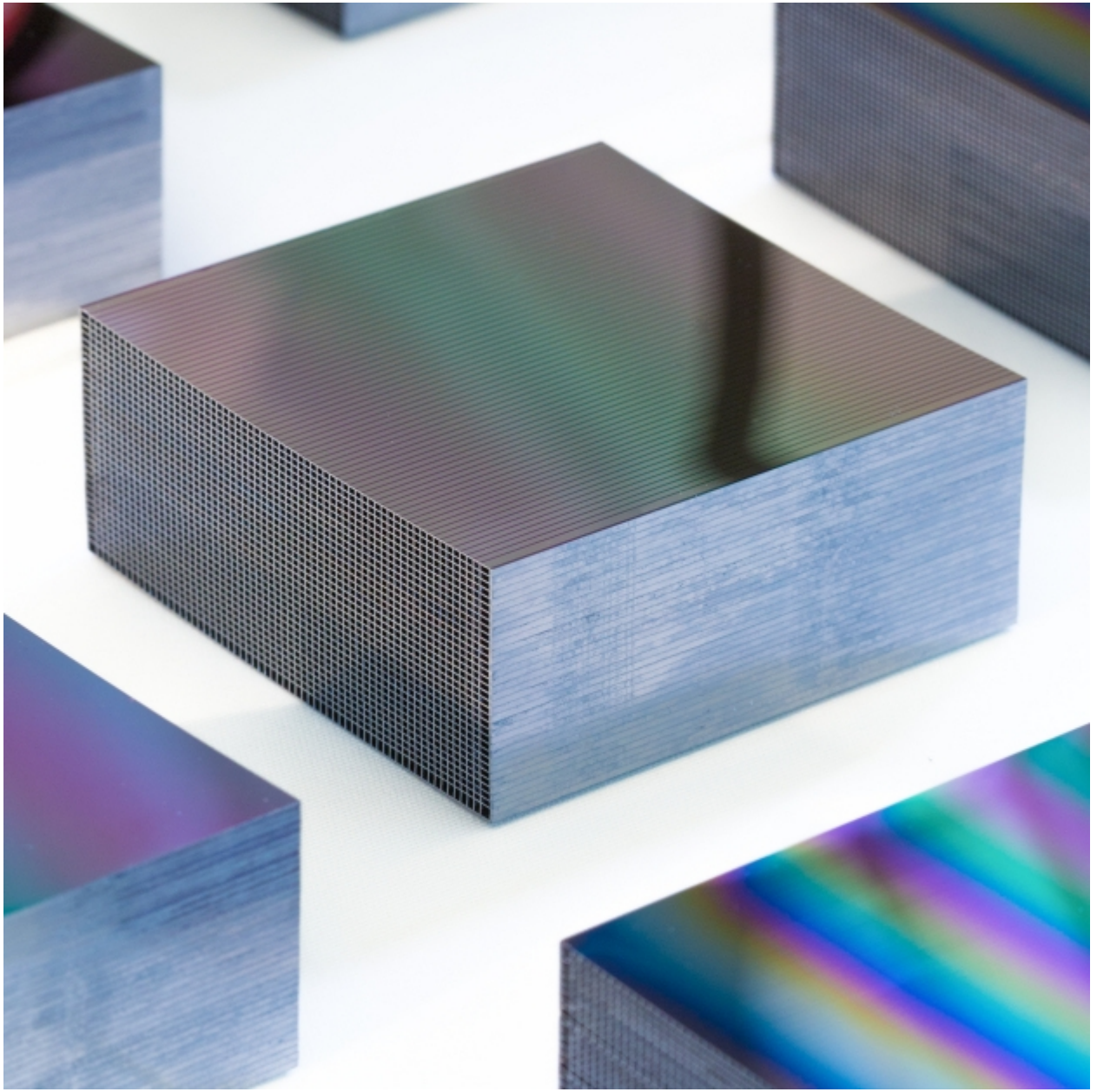
27 June 2014 Last updated at 11:31

Athena: Europe plans huge X-ray space telescope

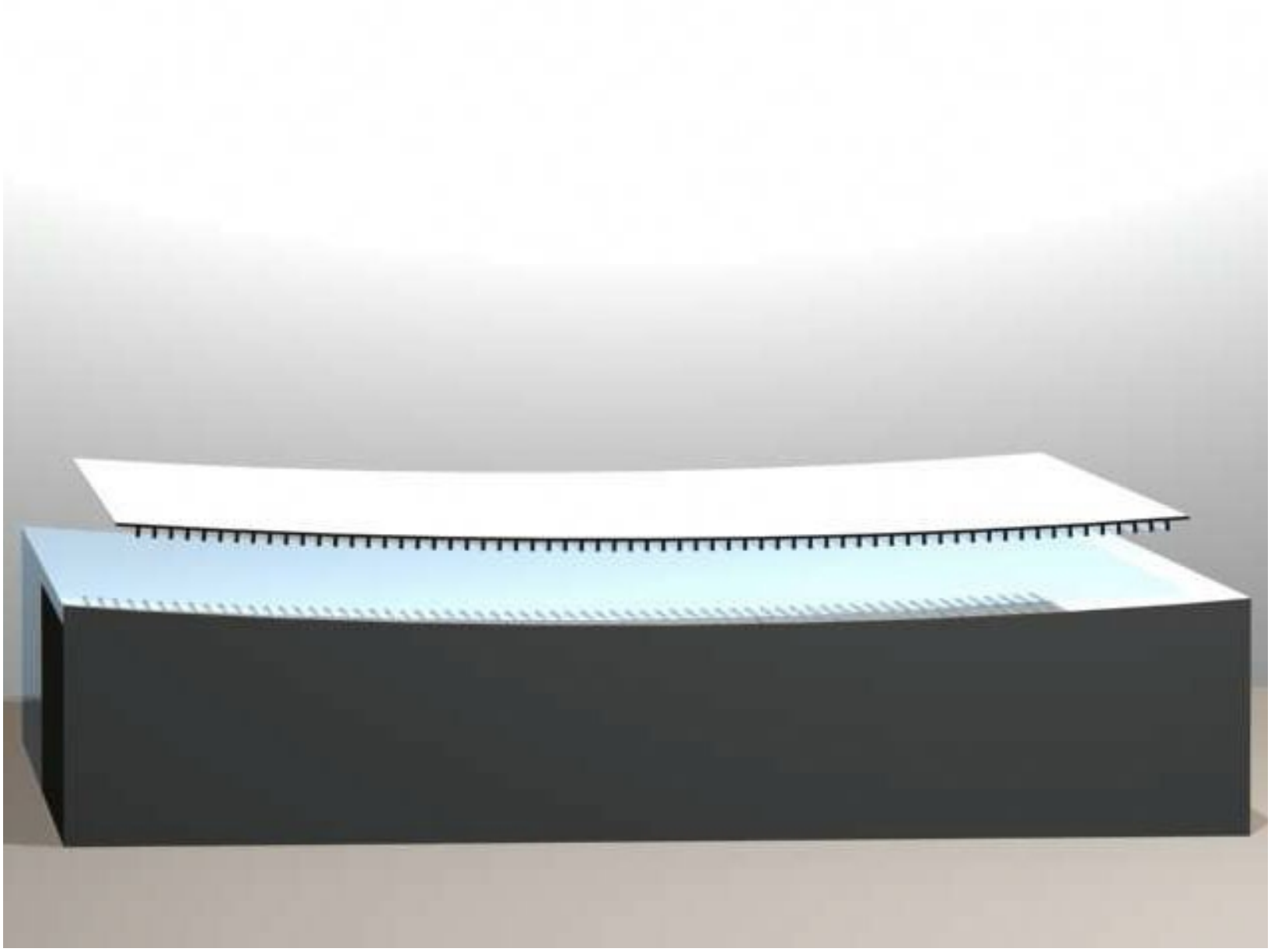
By Jonathan Amos
Science correspondent, BBC News

The Athena concept has been under study for several years already

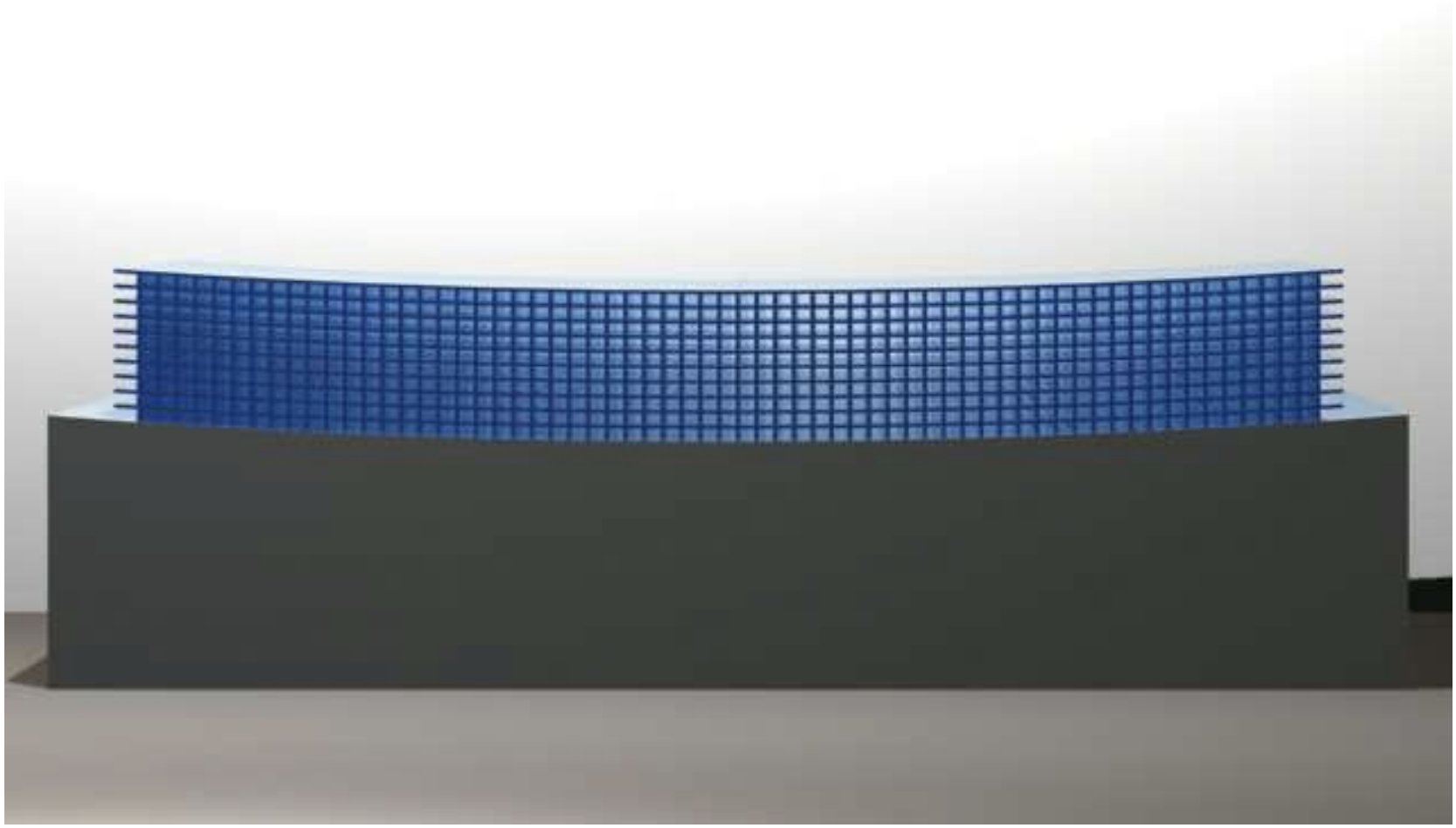
ATHENA – silicon pore optics



ATHENA – silicon pore optics



ATHENA – silicon pore optics



The road to a next generation X-ray observatory

ESA

XEUS concept 1996

NASA

Constellation-X concept 1995-6

ESA + JAXA

XEUS CV proposal 2007

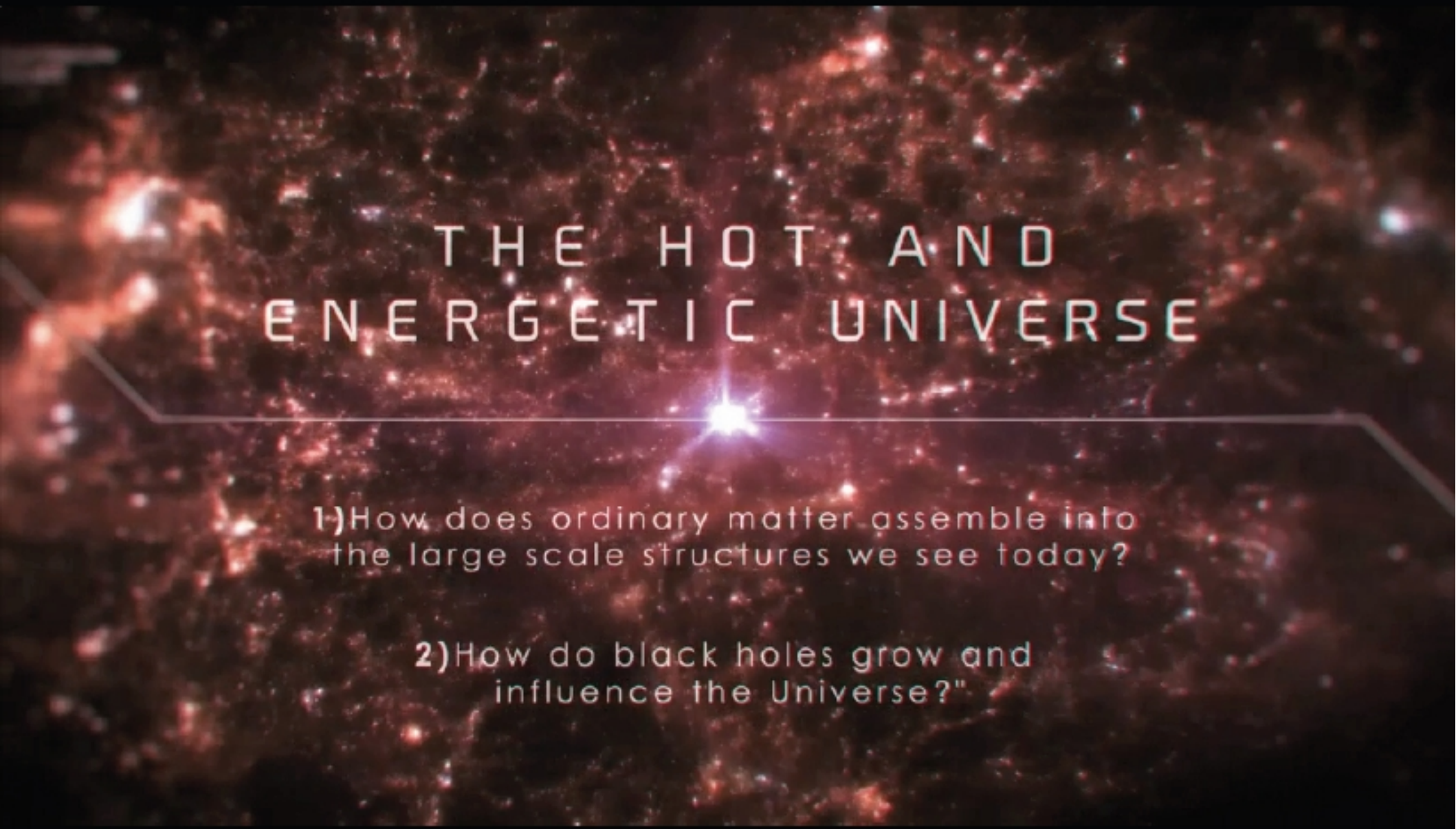
ESA + JAXA + NASA

IXO concept 2008

ESA
(+ JAXA, NASA ?)

ATHENA concept 2011

ATHENA+ 2013

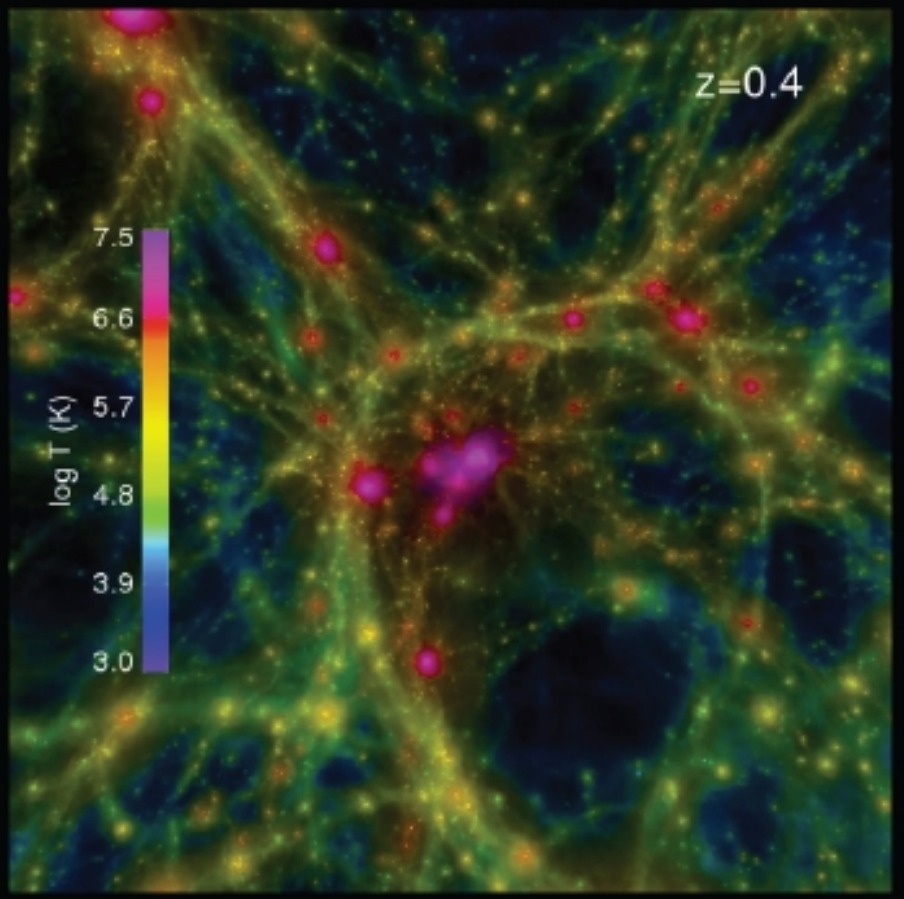


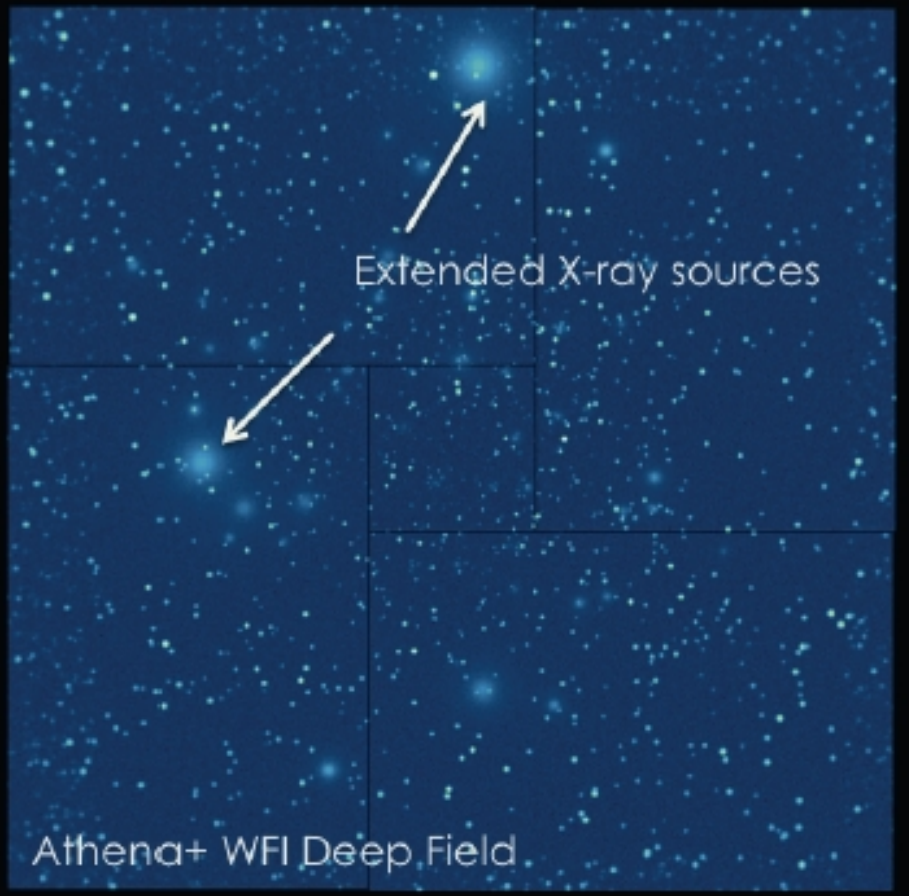
The Science Theme motivating the Athena+ mission

ATHENA+

Key questions for observational astrophysics in 2028

1. How does ordinary matter assemble into the large scale structures we see today?





NASA - SMART-X

- Slumped glass mirror technology.
- Lots of concentric very thin mirrors.

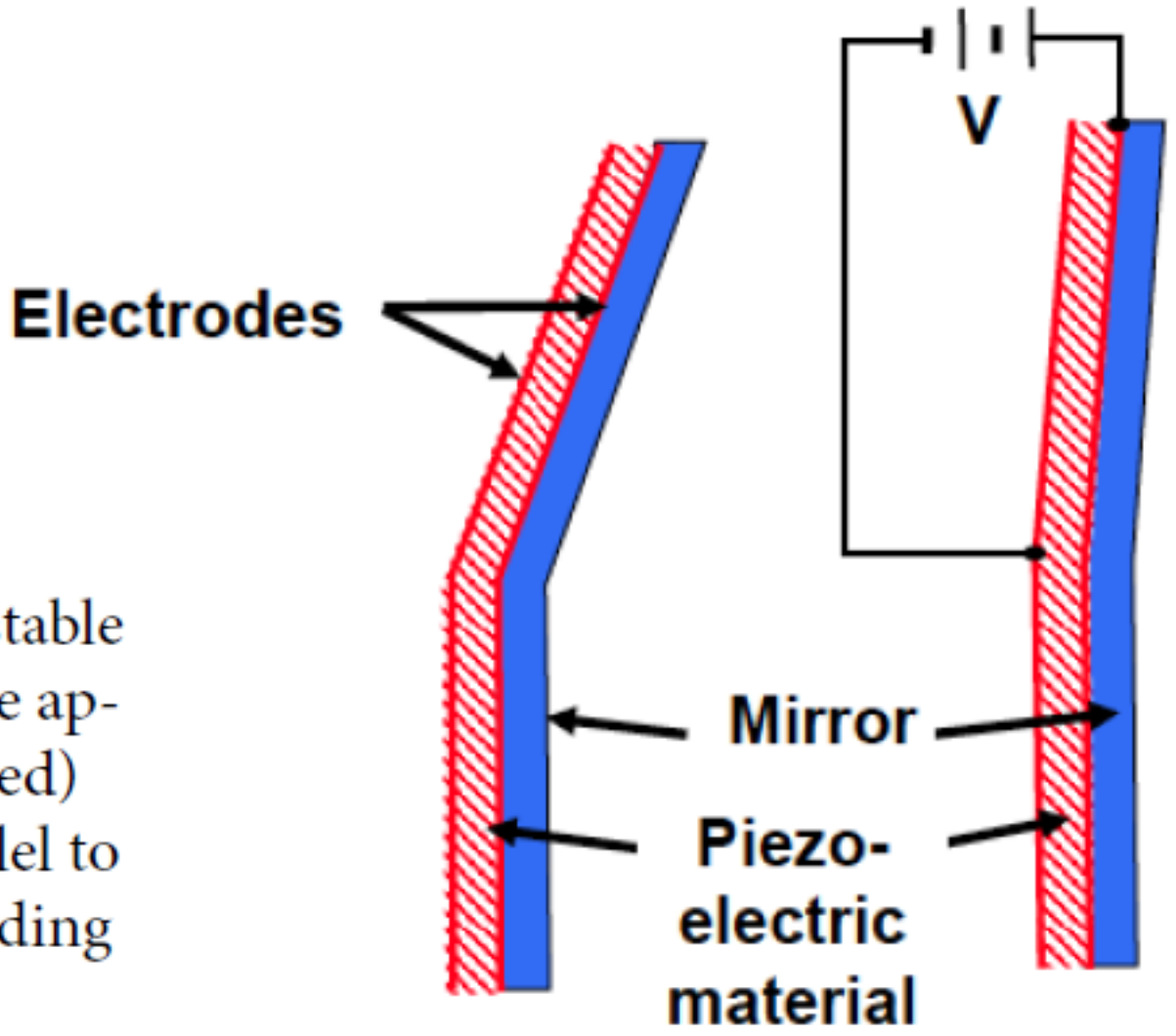
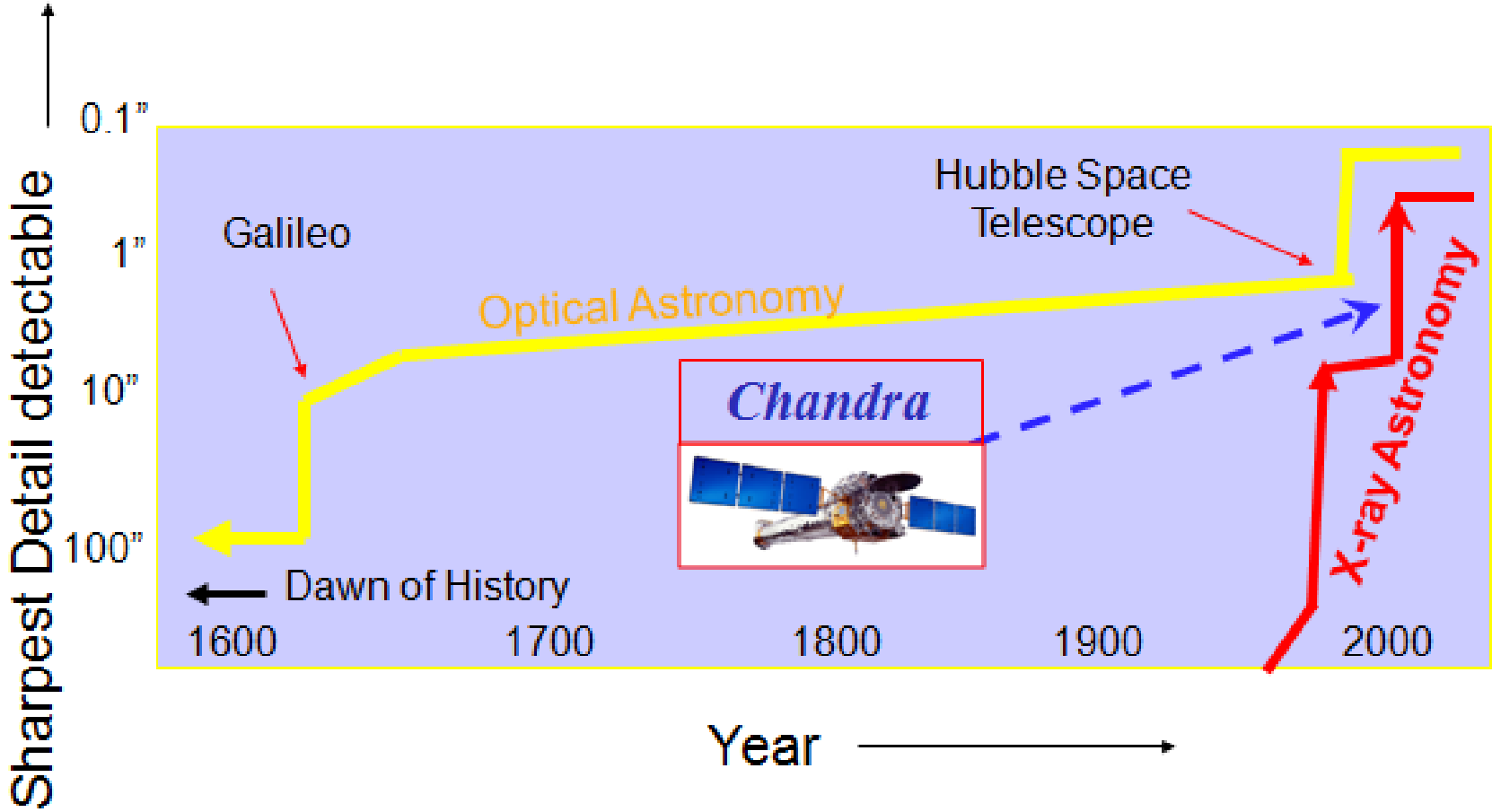


Fig. 2— Bimorph adjustable mirror concept. Voltage applied across the PZT (red) produces a strain parallel to the mirror surface, yielding a localized deflection.

Chandra takes X-ray Astronomy from its 'Galileo' era to its 'Hubble' era in a single leap



X-ray astronomy took just 40 years to match 400 years of optical astronomy

Thank you