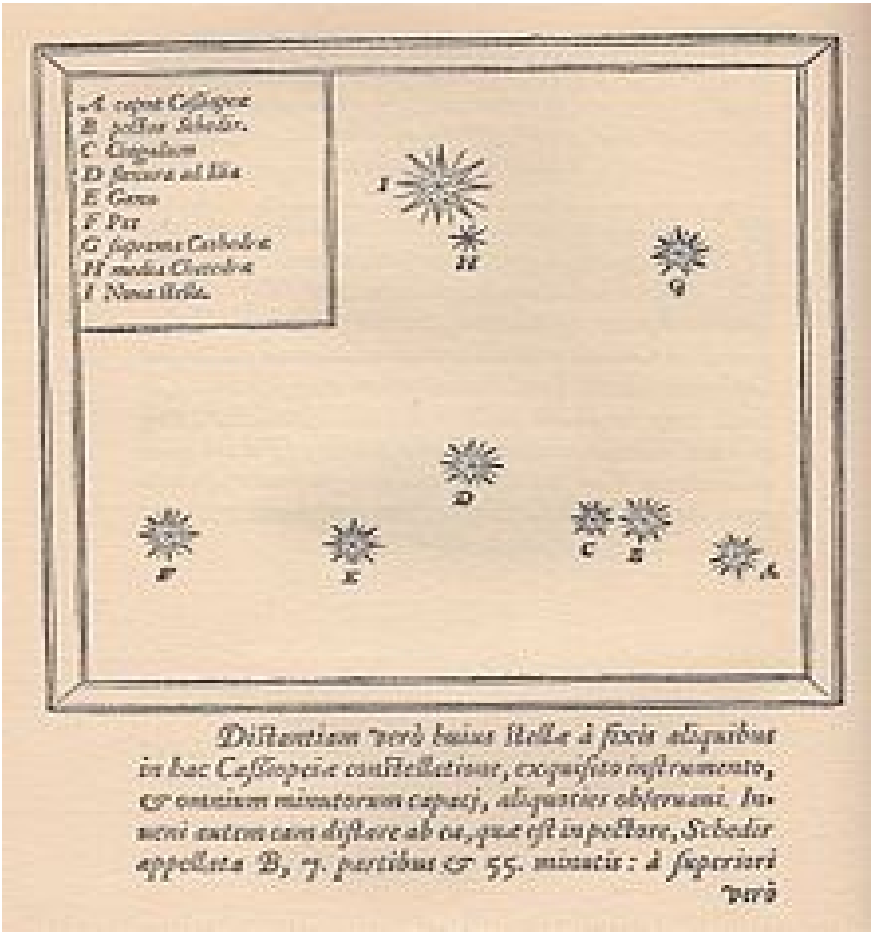
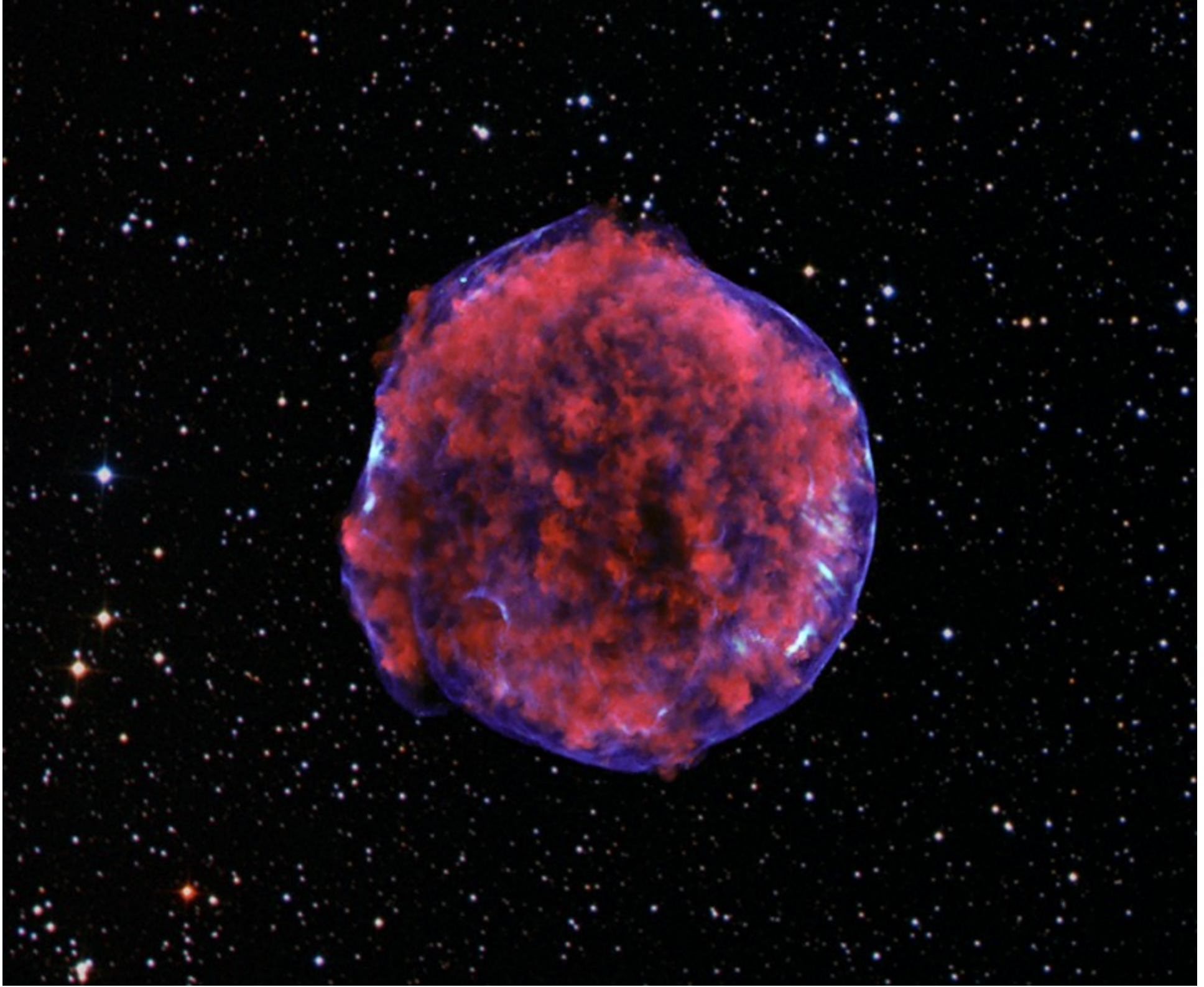
The Chandra X-ray Observatory
Jonathan McDowell

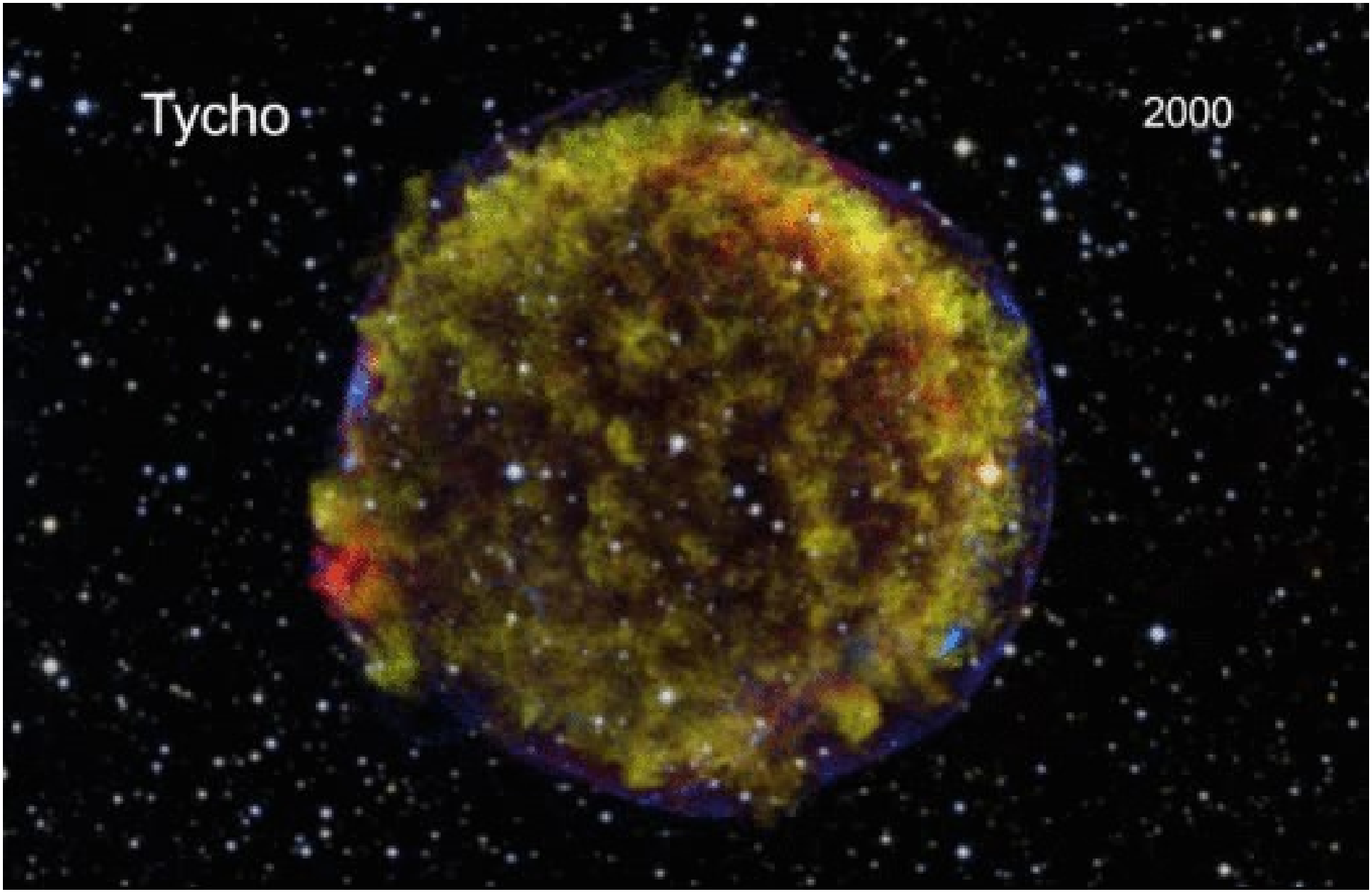
Smithsonian Astrophysical Observatory

In 1572, Danish astronomer Tycho Brahe recorded a 'new star' in the constellation Cassiopeia

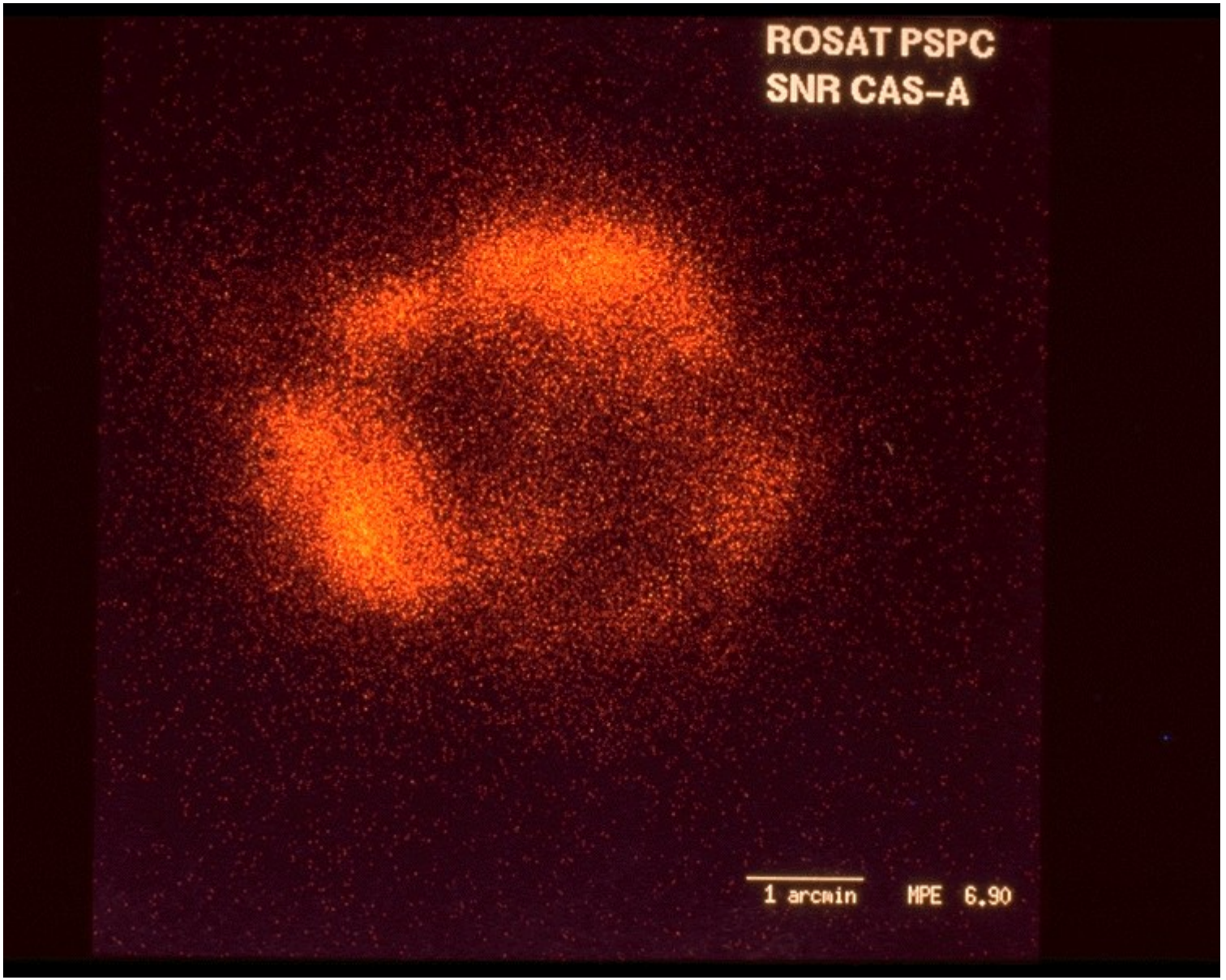
It was visible to the naked eye until 1574, slowly fading from view..

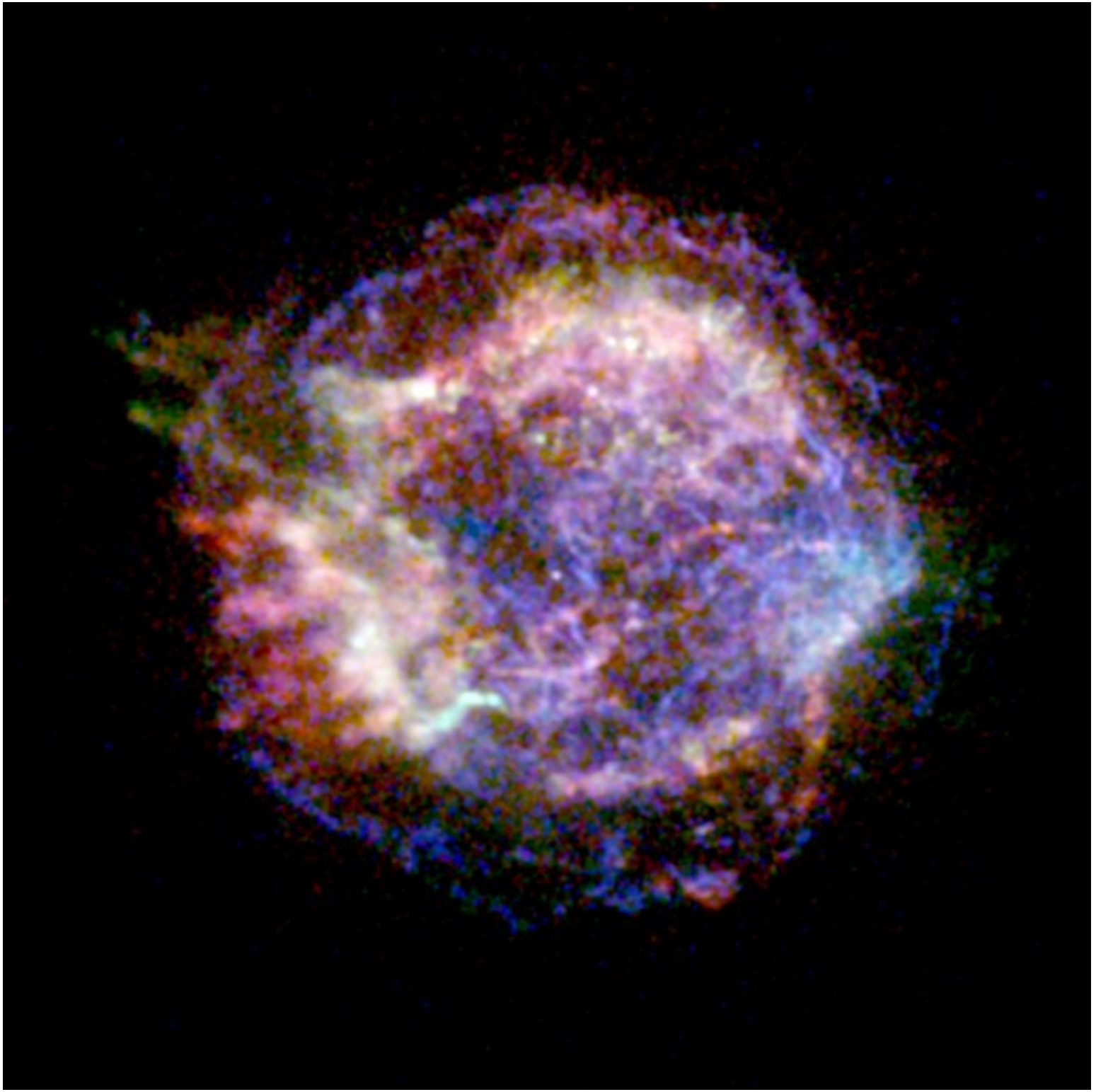





Tycho
2000

Milky Way galaxy: Supernova remmant (X-ray)



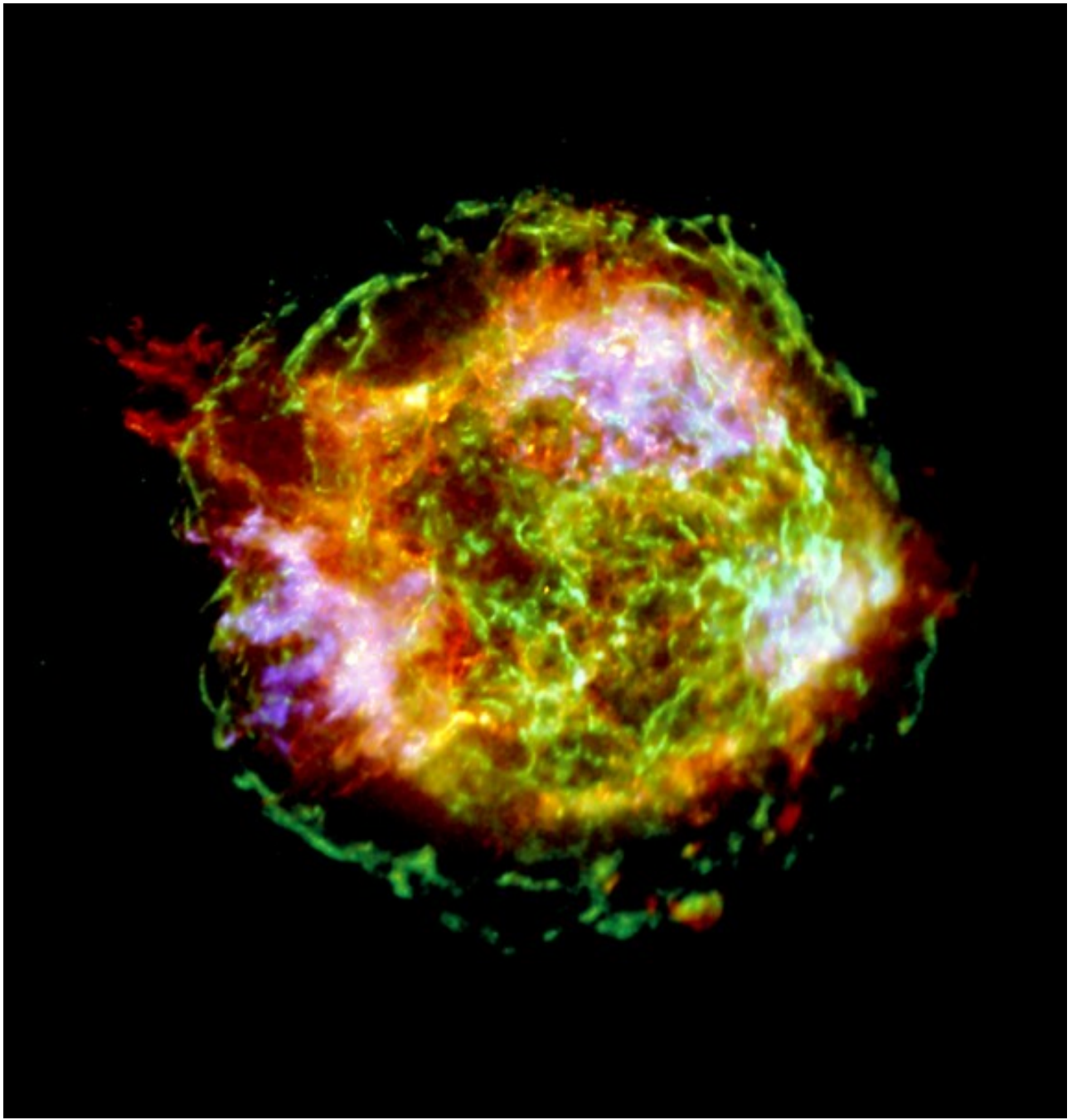


1 hour
with
Chandra

Milky Way galaxy: Supernova remmant (X-ray)

- 1 megasecond (11 days)
- Blue: Iron
- Red: Silicon
- Green: outer shock wave

Cas A with Chandra (Una Hwang)



11000 light years away

16 light years across

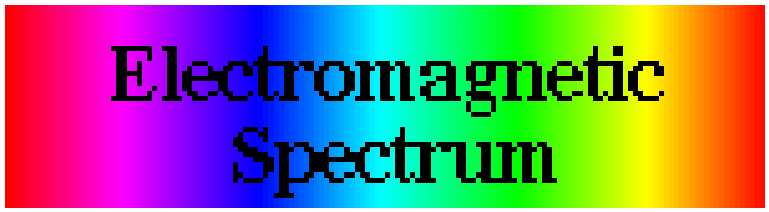
The Chandra X-ray Observatory

Launched 17 years ago 23 July 1999

A revolution in X-ray astronomy

and astronomy in general

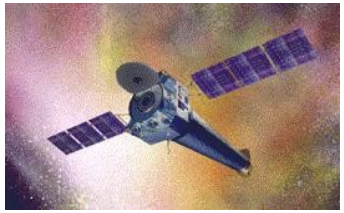
We are now in the era of multiwaveband astronomy



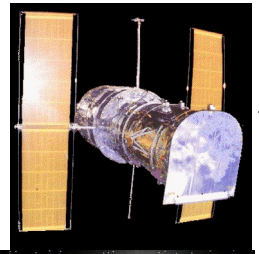
10_5 range of wavelength in astronomy

Whipple 10 meter

Fermi gamma-ray Observatory



Chandra



Hubble

MMT

Spitzer

Sub-millimeter array

VLA

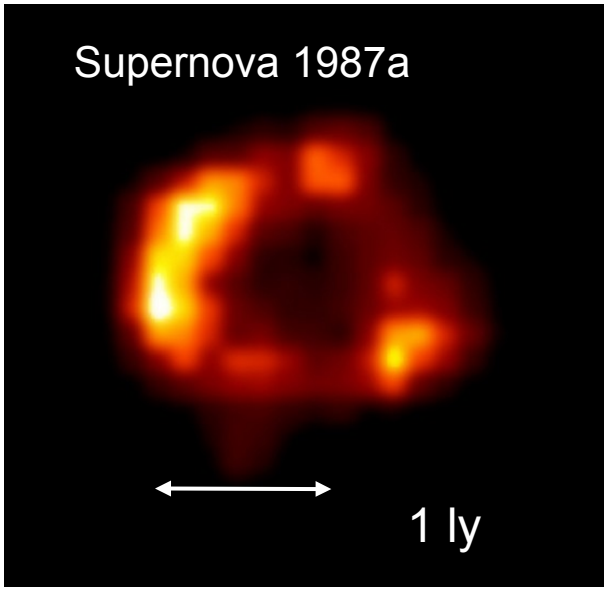
Sources of X-rays

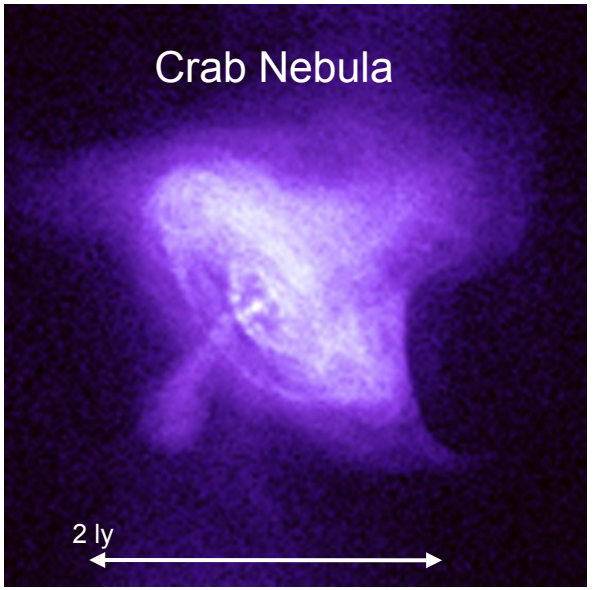
- Shock waves in plasma (ionized gas)
- "Synchrotron" caused by energetic particles in magnetic fields (like a natural particle accelerator)
- Energy release from gravity ("accretion" power)

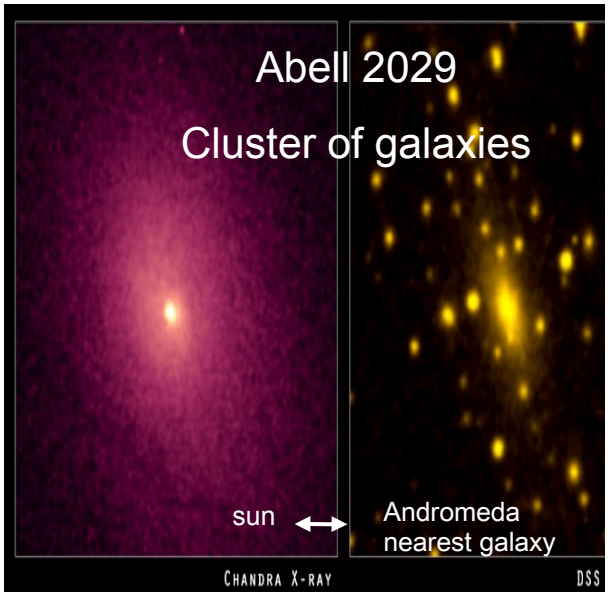
Explosions: Supernovae and their remnants

Particles moving near the **speed of light in magnetic fields**

Matter falling into **deep gravitational wells**







In the optical, we see mostly energy from nuclear fusion

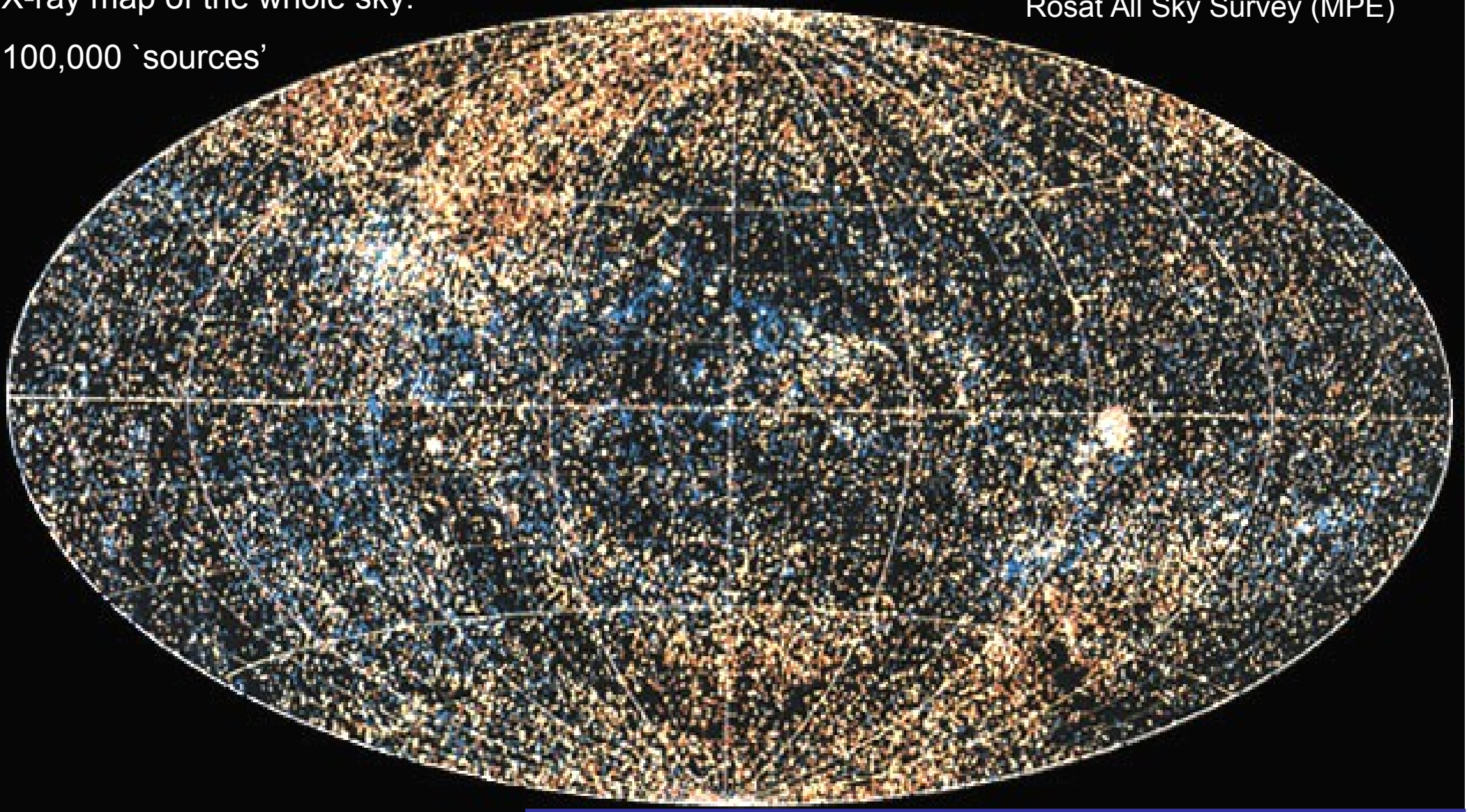
In X-rays, we see mostly accreting sources: energy from gravity!

Powerful sources of X-rays

X-ray map of the whole sky:

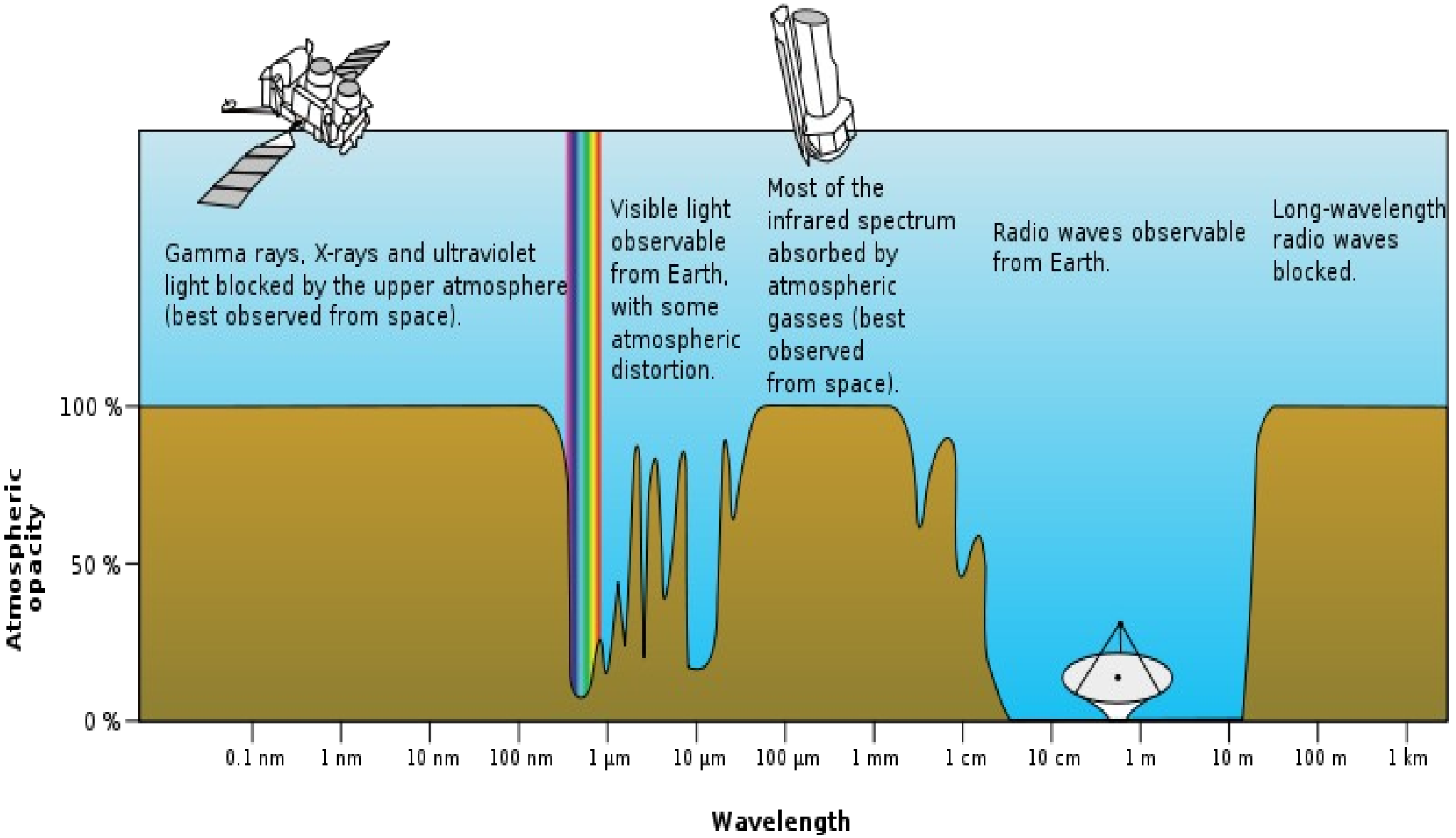
100,000 `sources'

Rosat All Sky Survey (MPE)



A power source entirely different from the nuclear fusion that drives the Sun and stars

…and much more efficient


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

What is Chandra?

The greatest X-ray telescope ever built!

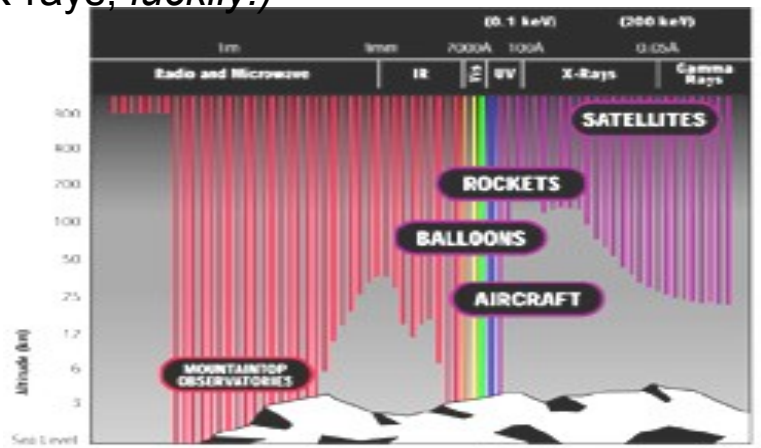
Orbits the Earth to be above the atmosphere (which absorbs X-rays, *luckily!)*

Goes 1/3 of the way to the Moon

every 64 hours (2 ½ days)

Chandra takes superbly sharp images:

with good spectral resolution (colors) too!



X-ray Telescopes are different

Chandra's mirrors are almost cylinders

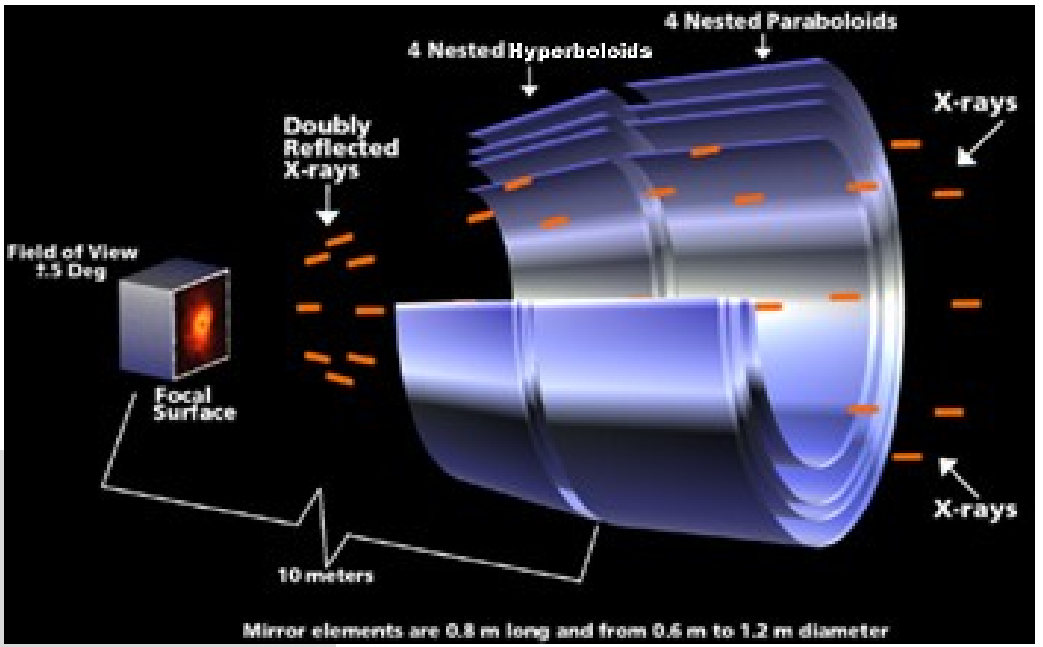
X-rays don't reflect off a normal mirror – they get absorbed.

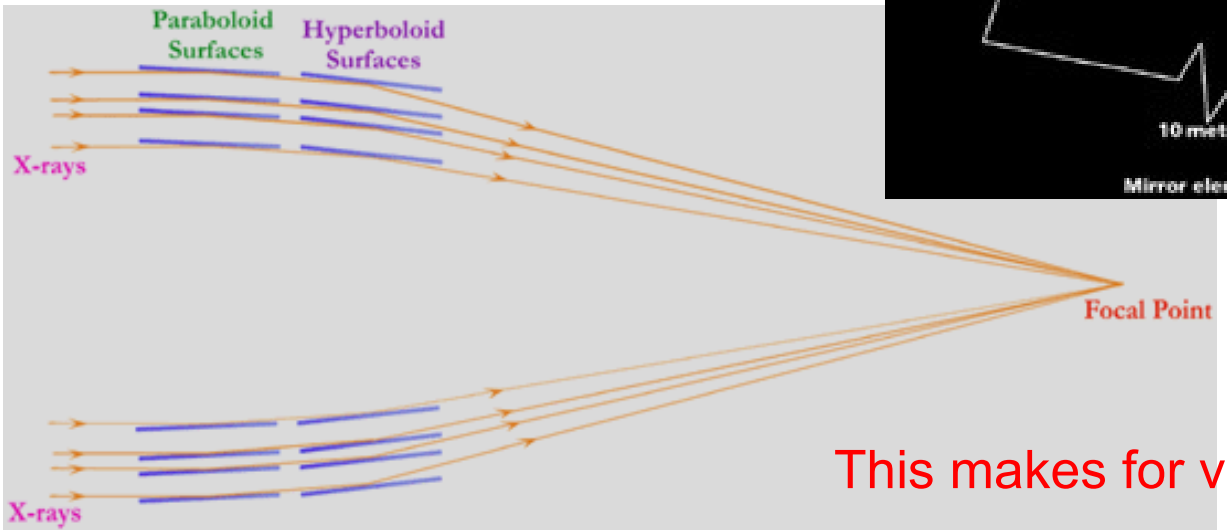
Only by striking a mirror at a glancing angle, about 1°,

do X-rays reflect.

Then they act like visible light

and can be focused

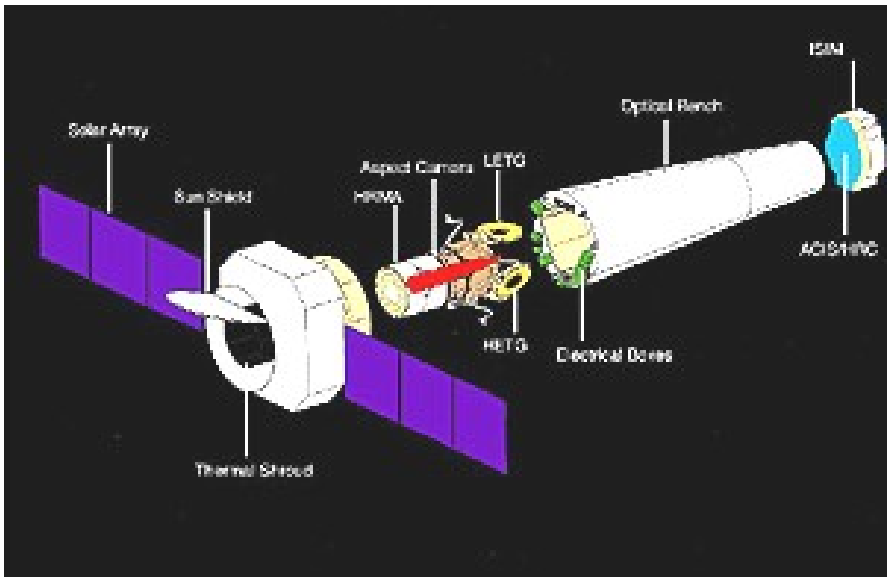




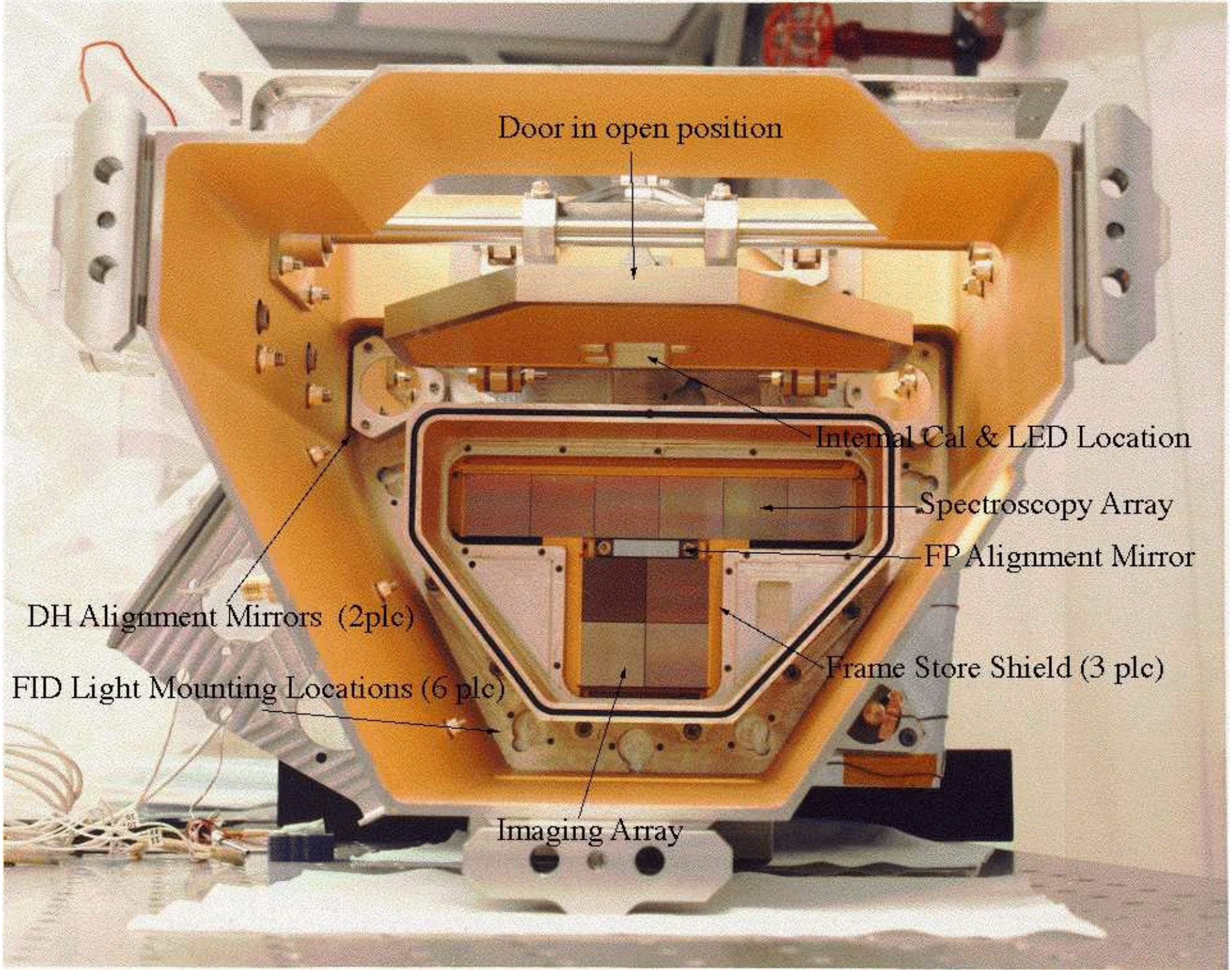
This makes for very long telescopes

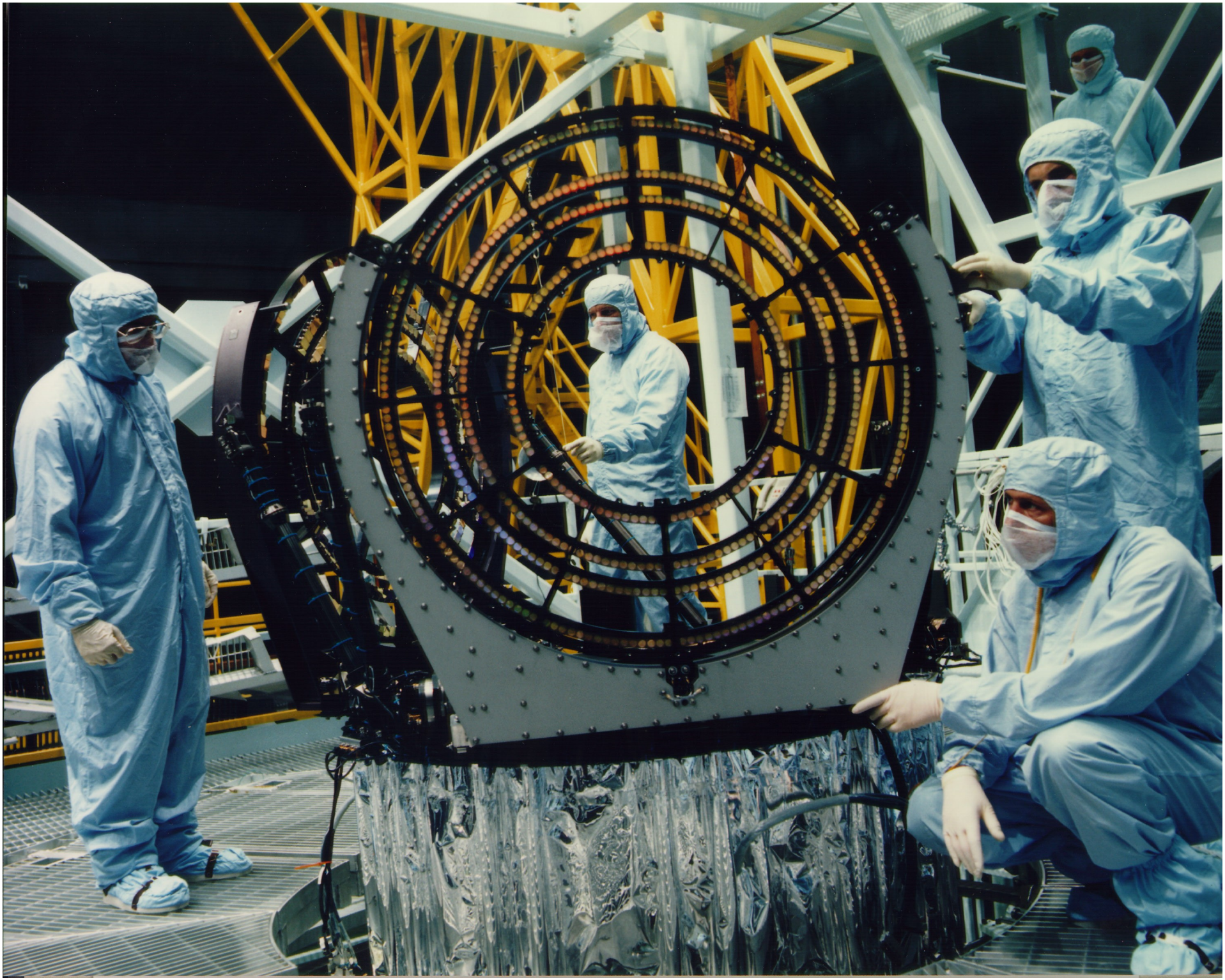
The Chandra spacecraft

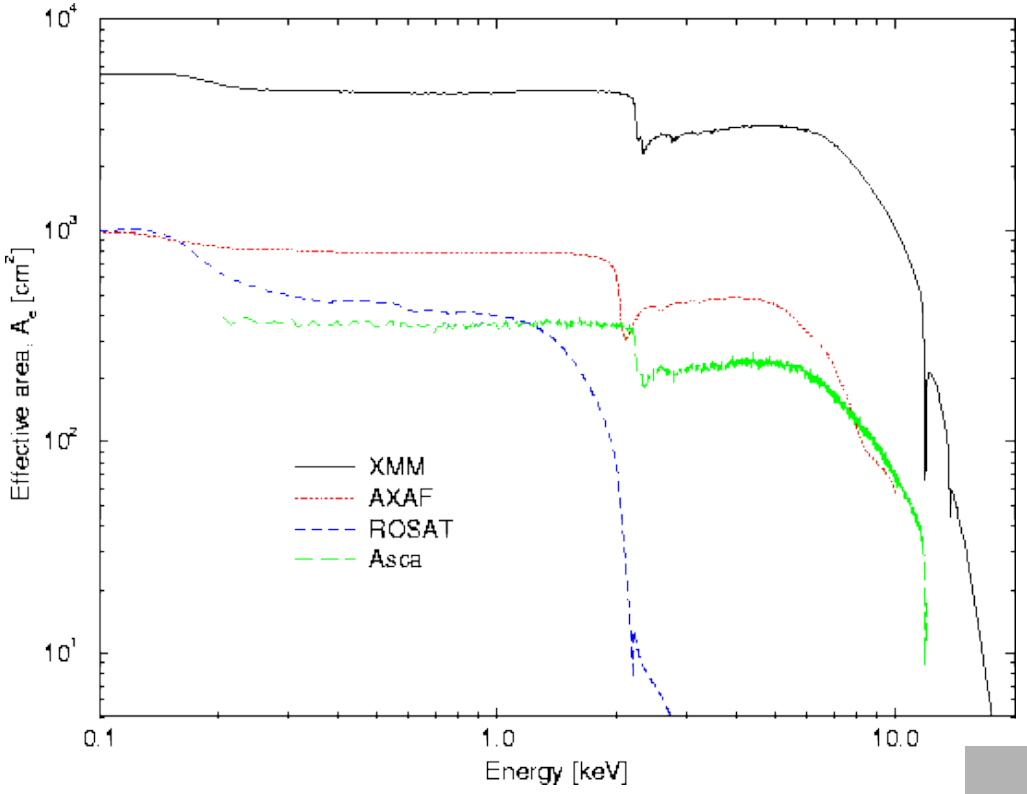
10 meters (32 ½ ft) from mirror to detector, 1.2 meters (4ft) across mirror

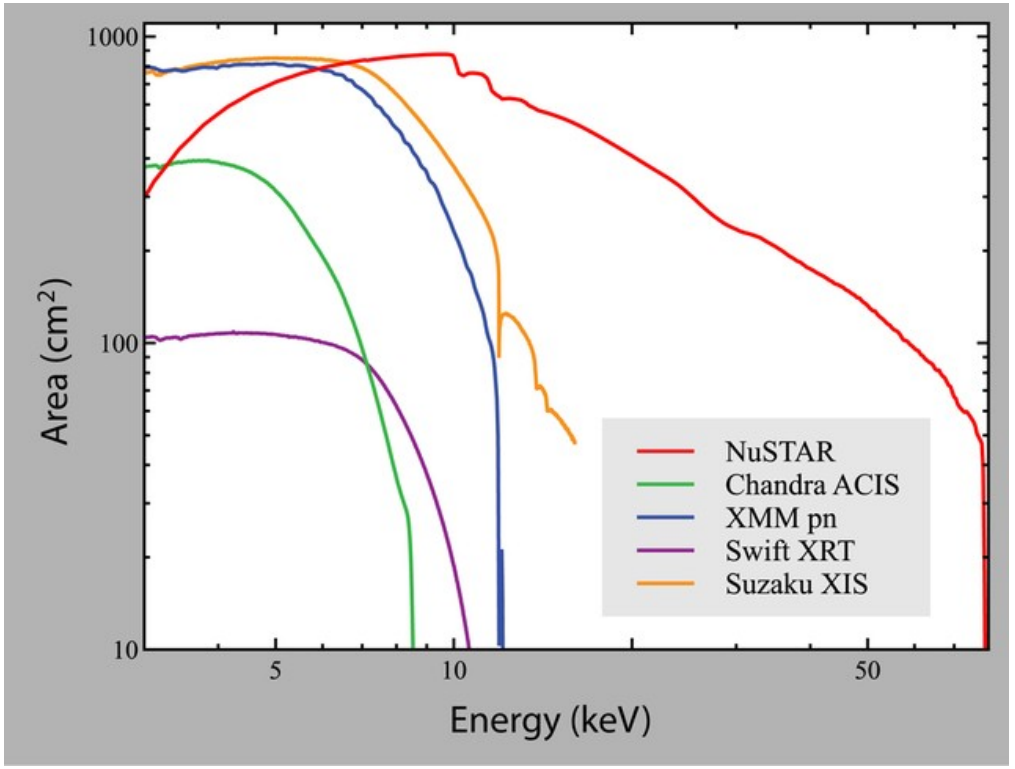


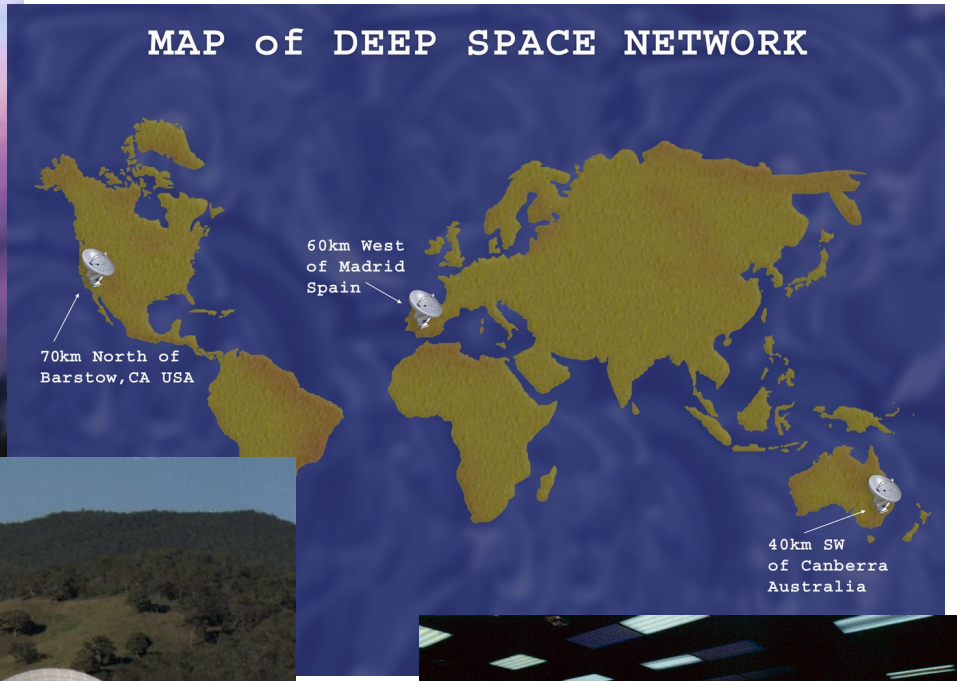
…but focuses X-rays onto a spot only 25 microns across


Door in open position
Internal Cal & LED Location
Spectroscopy Array
FP Alignment Mirror
DH Alignment Mirrors (2plc)
Frame Store Shield (3 plc)
FID Light Mounting Locations (6 plc)
Imaging Array




Effective area, A_e [cm^2]
Energy [keV]
XMM
AXAF
ROSAT
Asca


Area (cm^2)
Energy (keV)
NuSTAR
Chandra ACIS
XMM pn
Swift XRT
Suzaku XIS



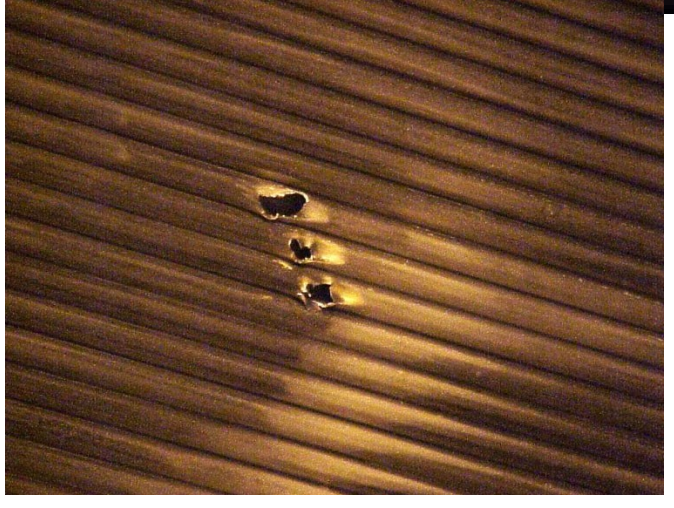
DSN control
at Jet Propulsion Lab
Pasadena, CA

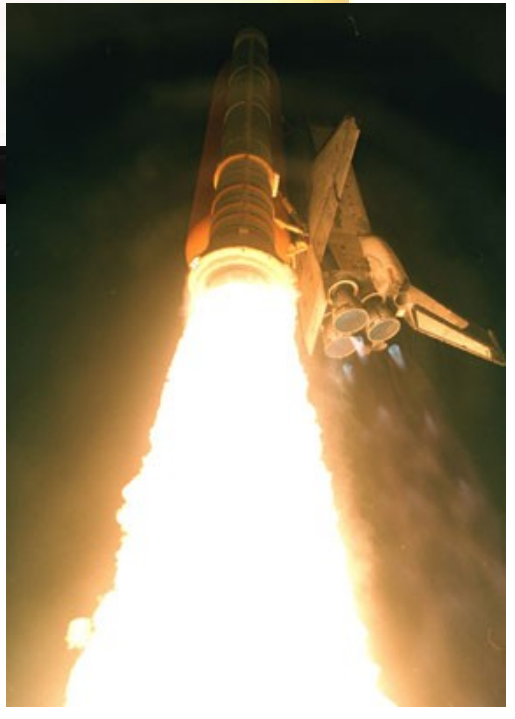
Chandra science center
Smithsonian Observatory, at
Harvard (Cambridge, MA)

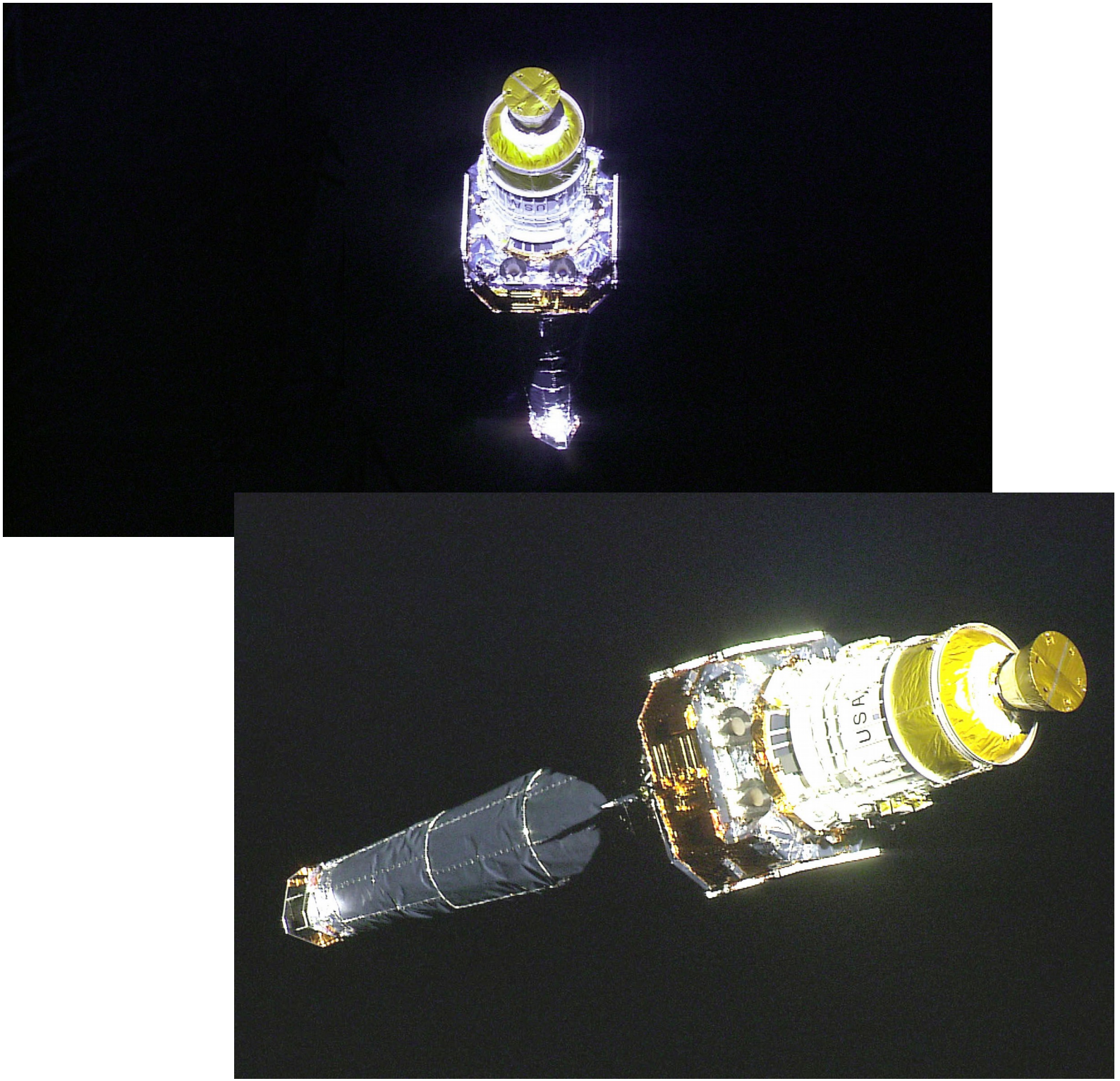
Chandra mission control
Near MIT in Cambridge, MA

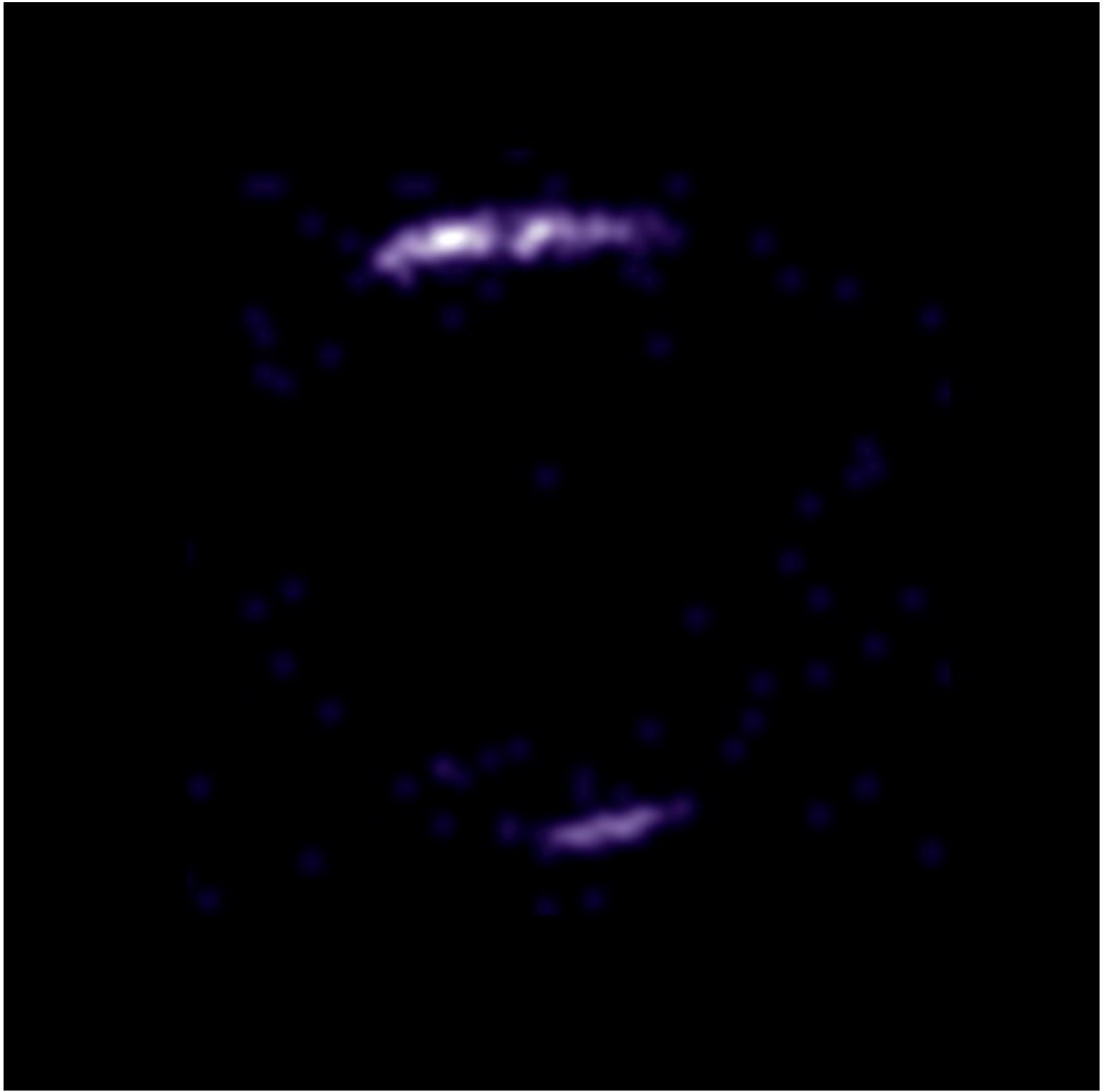

-07:45:58

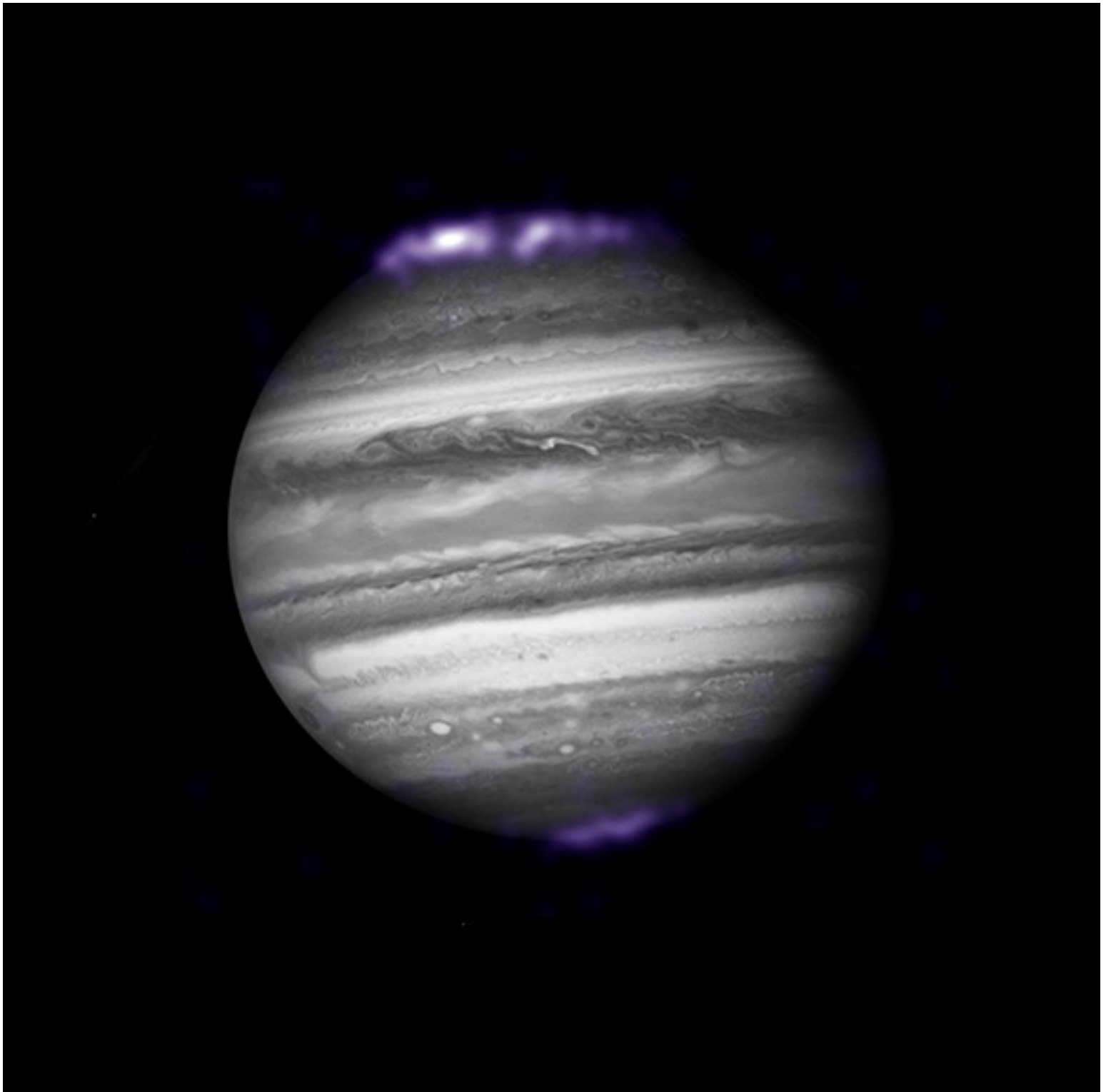

STS-93 Camera ET-207
Hot Wall Leak





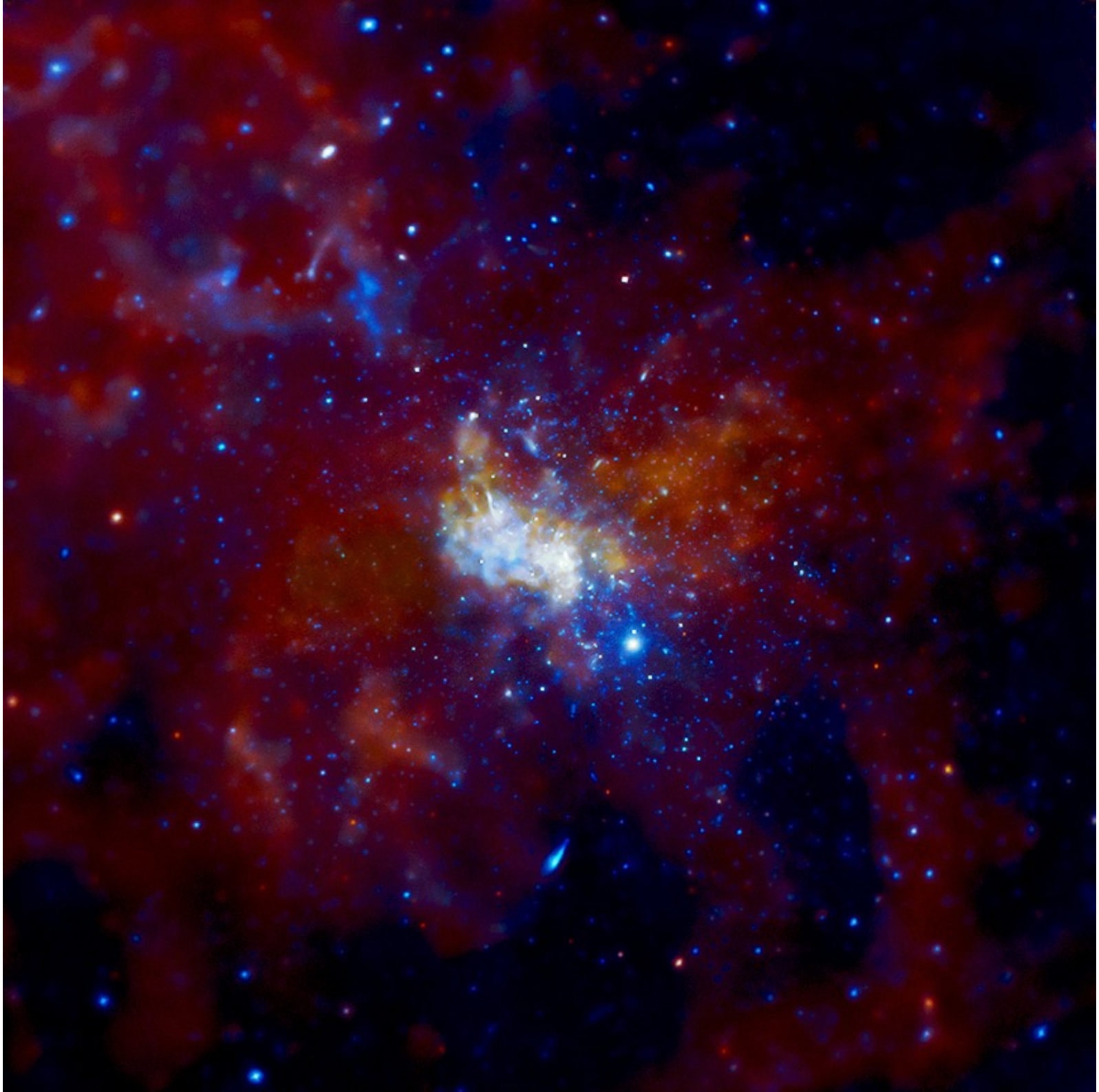


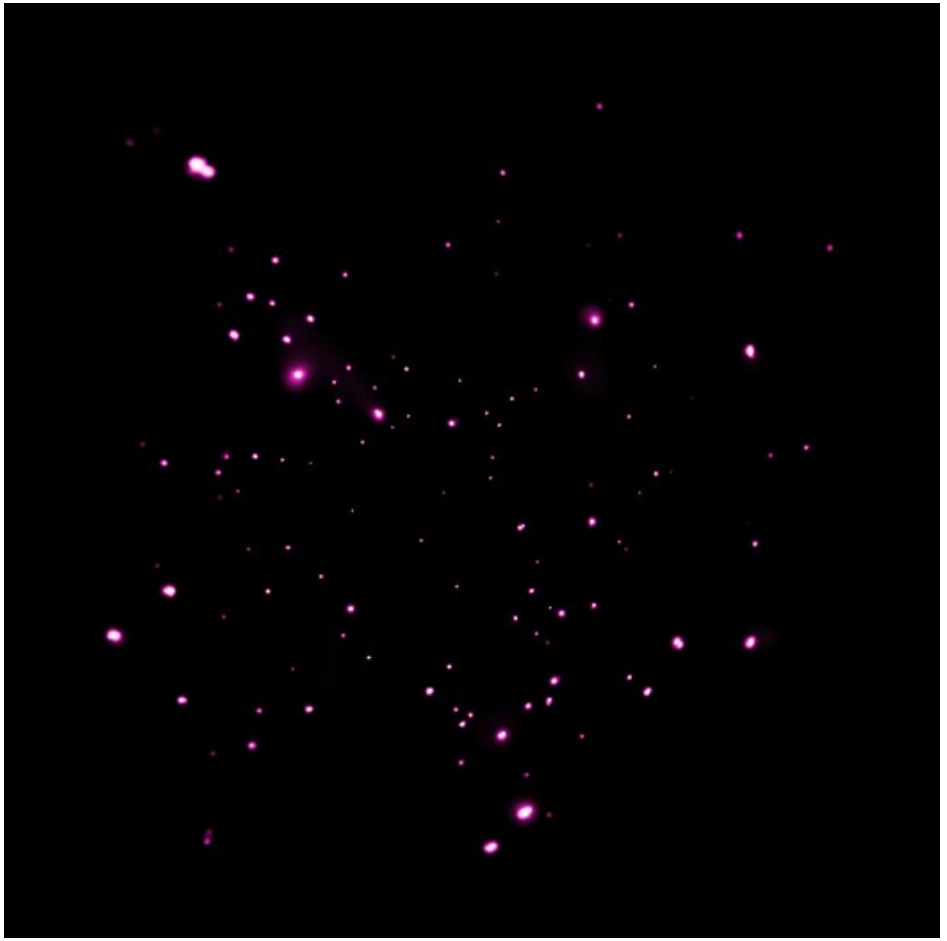




The Milky Way Galaxy: Galactic Center

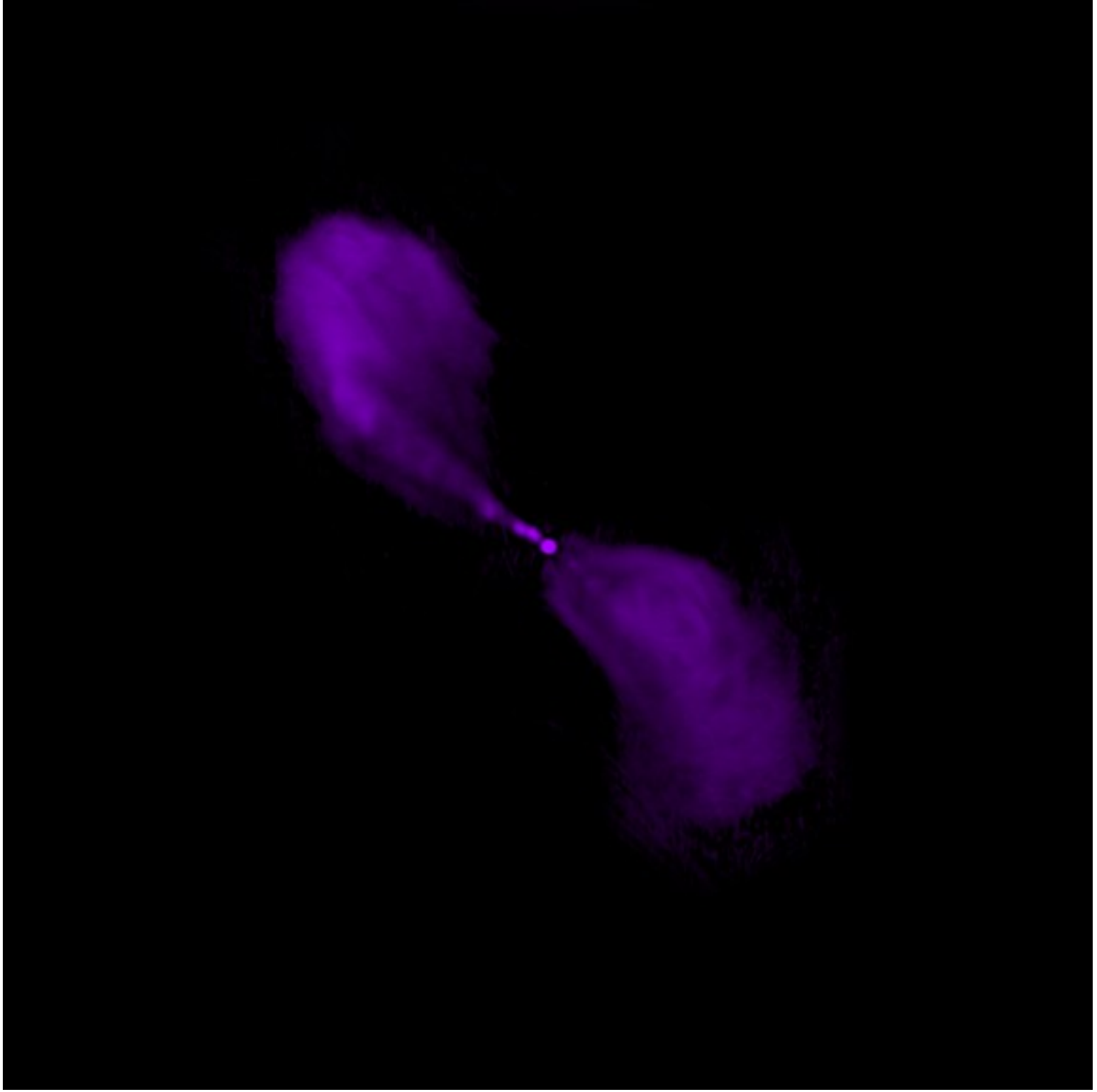
Milky Way in Sagittarius: 30000 Years Away
Seen as it was when modern humans had just evolved



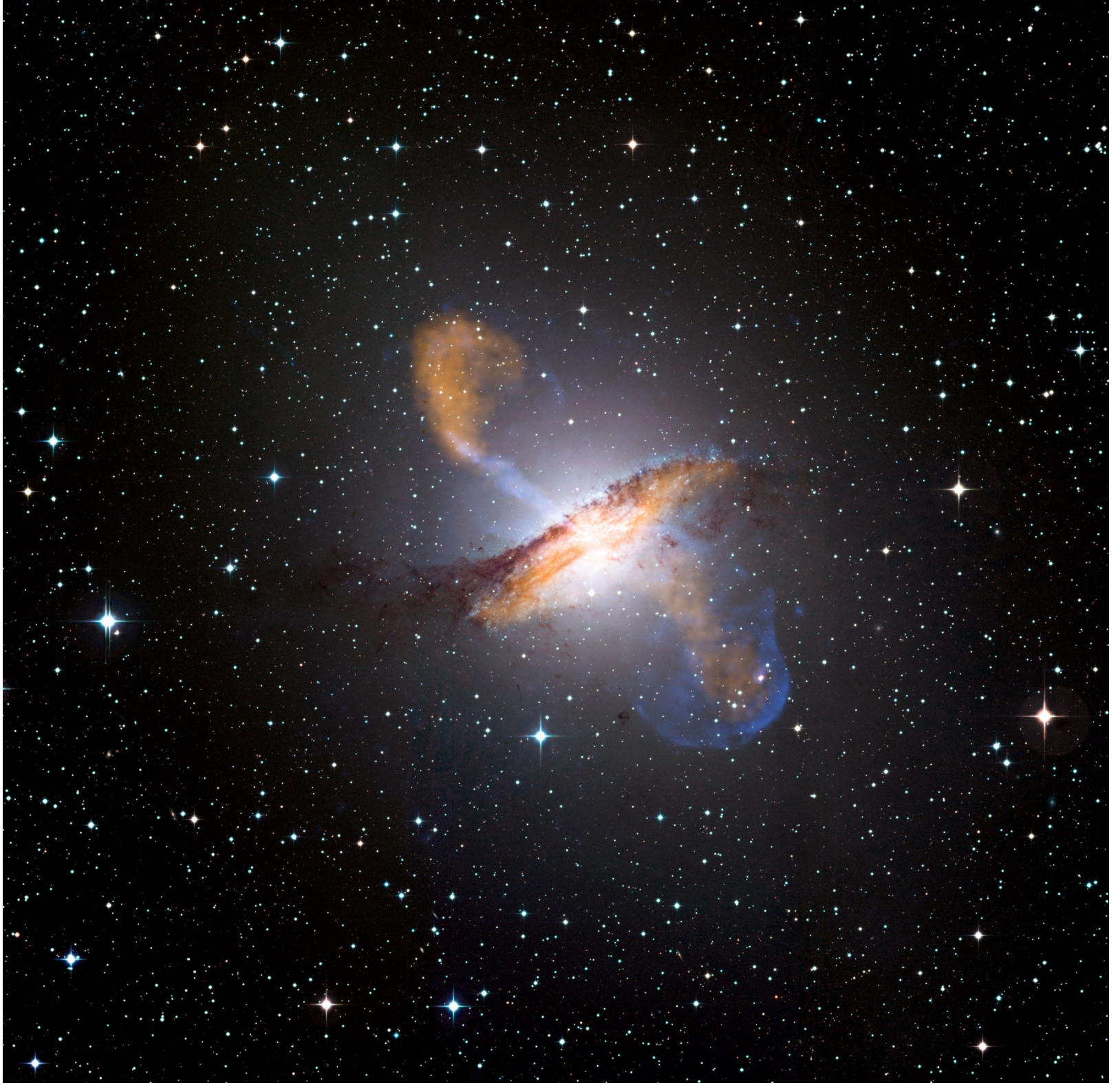


NGC 1333
(Winston et al 2010)

Galaxy Centaurus A (NGC 5128) - 12 million light years away



Extragalactic Universe: Active Galaxy (X-ray)



Radio data
on an even
bigger scale

Feain et al
Australia Tel.

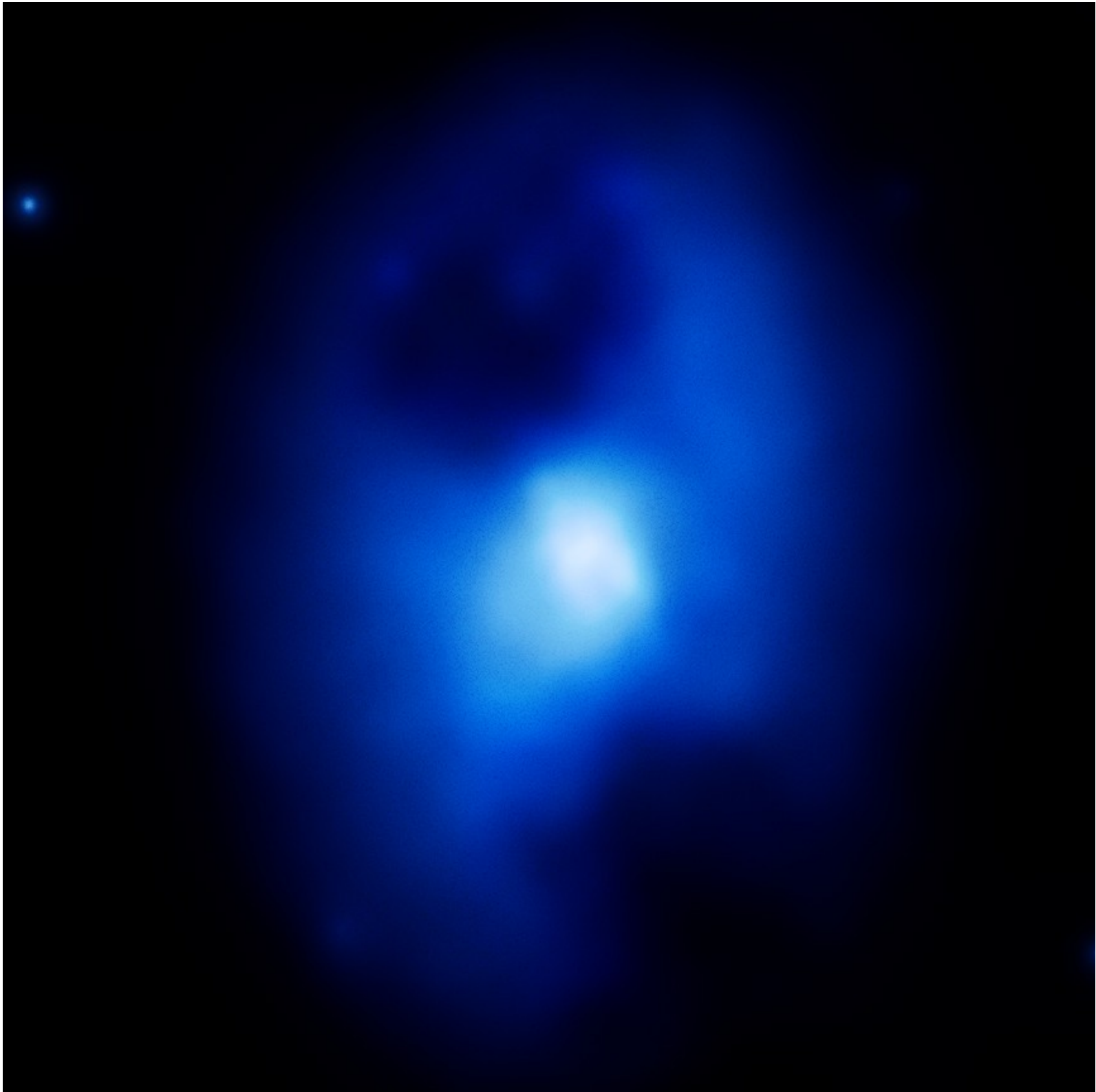
1.5 million light years
end to end

We also see a big cloud of gamma rays

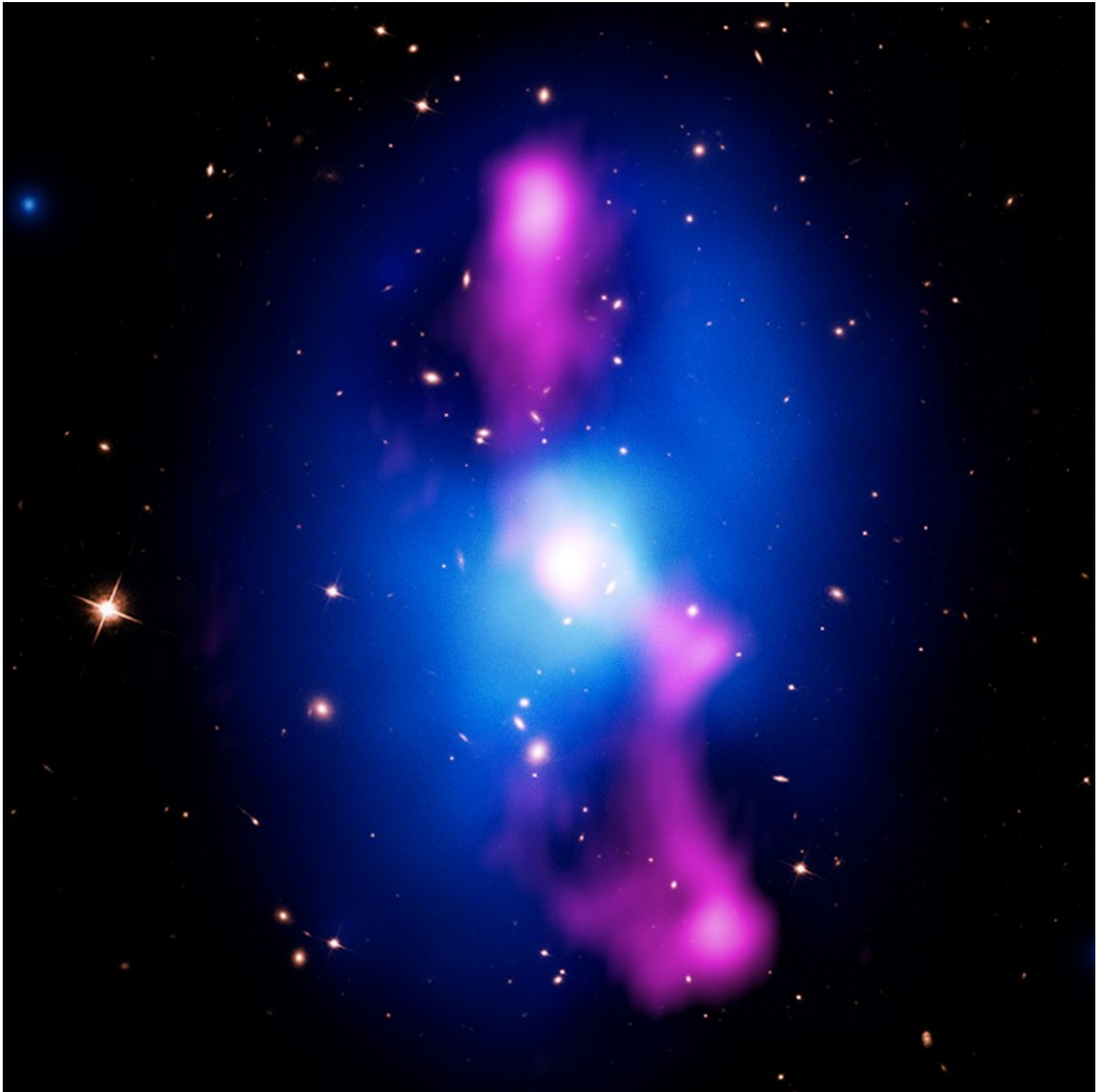
(Fermi data, Teddy Cheung)

Pictor A (Hardcastle et al 2016)

MS0735.6+7421
z=0.22
Vantyghem et al
2014



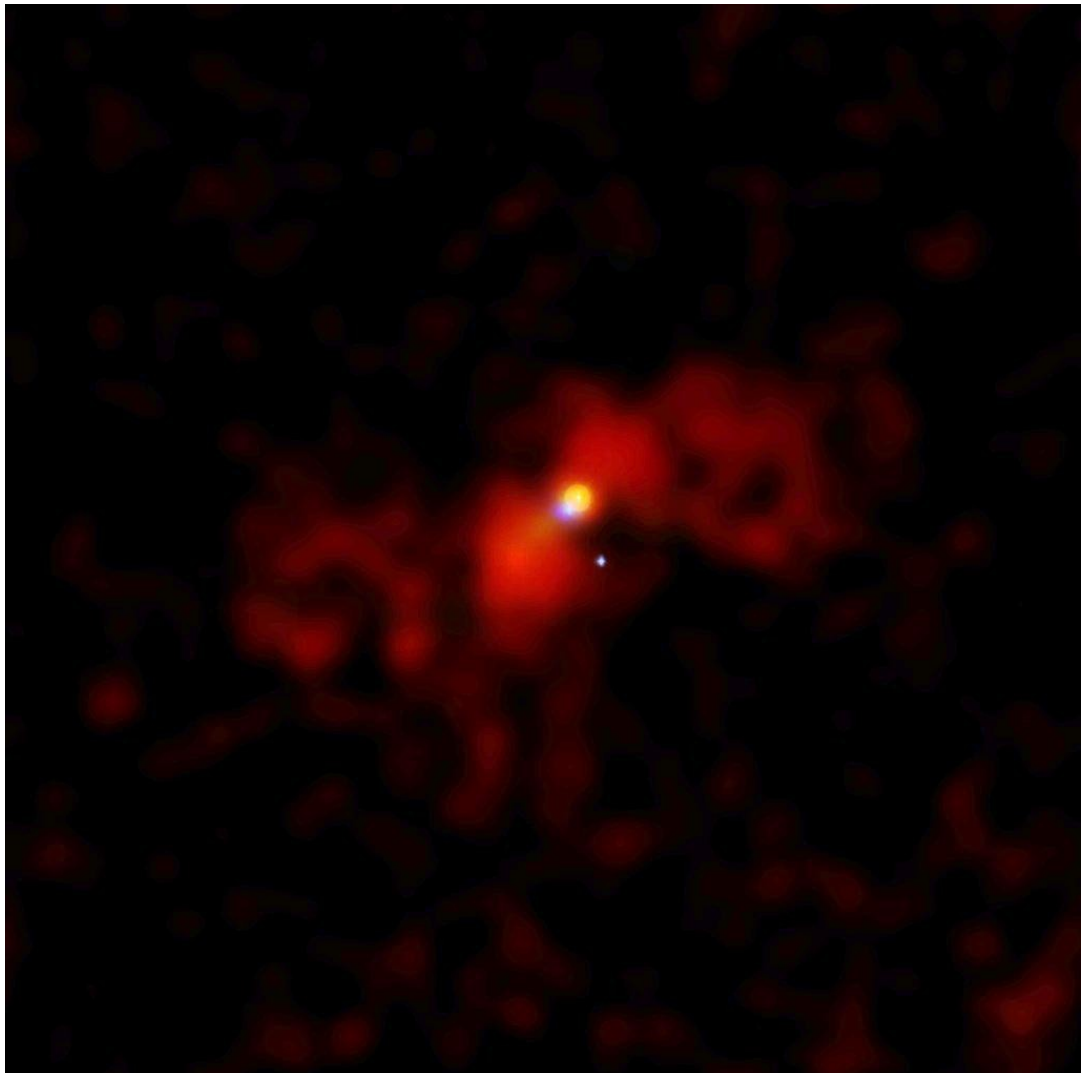
MS0735.6+7421
z=0.22
Vantyghem et al
2014

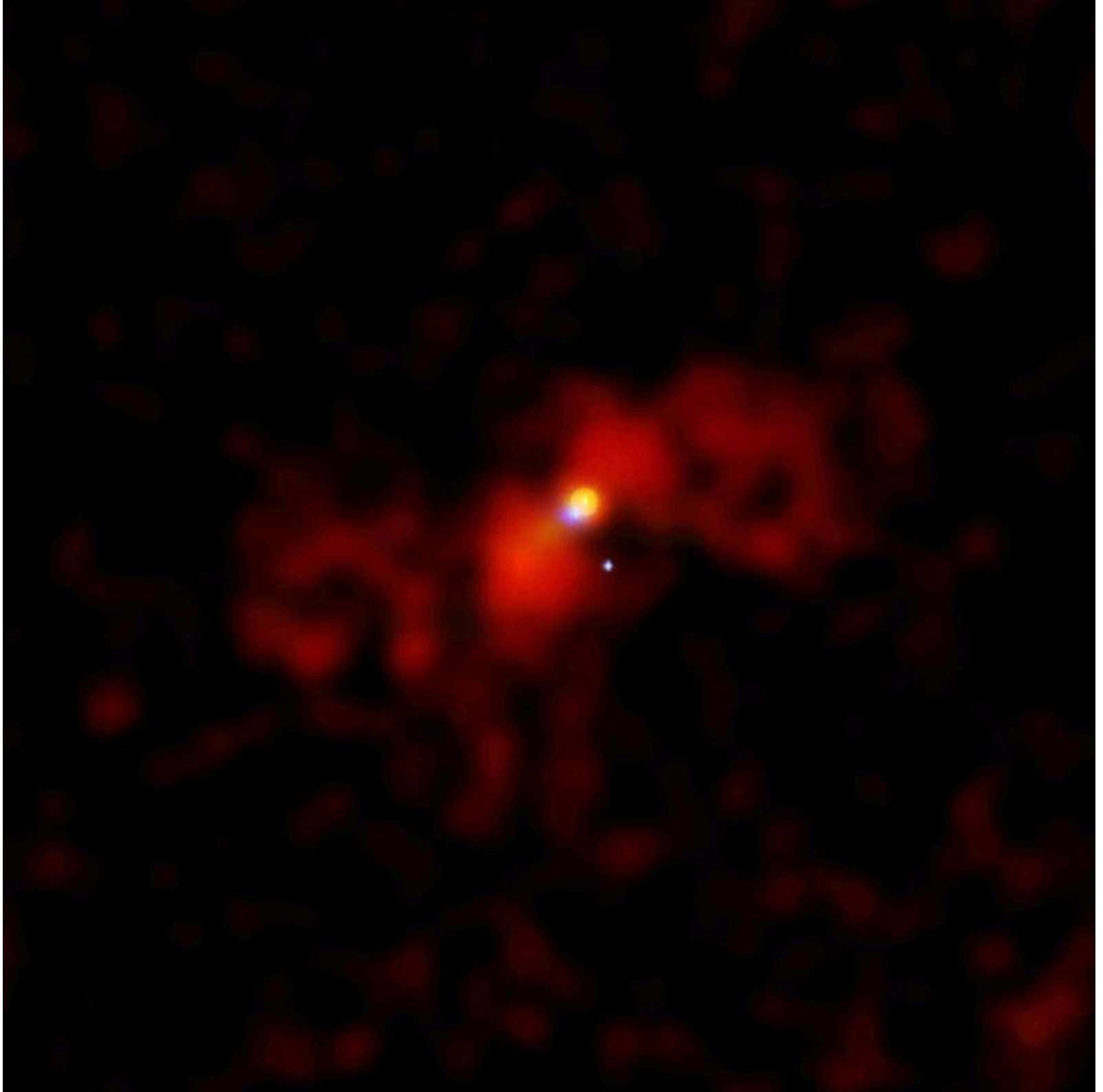


Extragalactic universe:
Merging galaxy (visible light)

Merging galaxy Arp 220

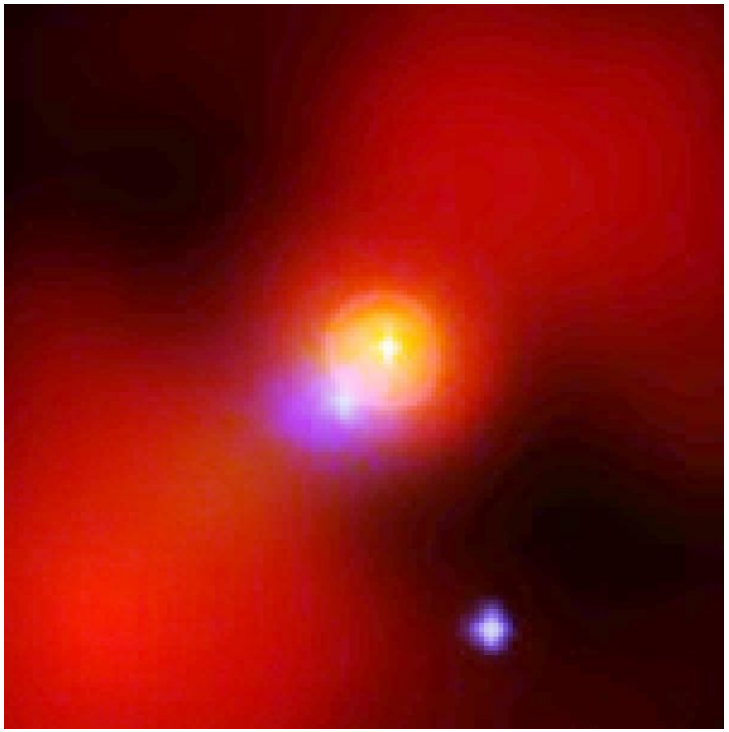
- z=0.018 (250 million light years)
- Energy output: 1 trillion suns
- Most energy output in the infrared
- 20-year controversy: star formation or quasar?
- Answer: both, but mostly star formation
- Work with Dave Clements (Clements et al 2002, ApJ 581,974; McDowell et al 2003, ApJ 591,154)





Arp 220 nucleus

- Deep in the galaxy, Chandra reveals:
- - a large region of newly forming stars (yellow)
- - a source of 'hard' X-ray radiation partly obscured by dust and gas, and coinciding with a pair of bright points seen with radio telescopes – at least one (and maybe 2) supermassive black holes at the very center of the galaxy
- Firther from the middle, a bright X-ray binary star, probably with a black hole – brighter than any x-ray star in our galaxy



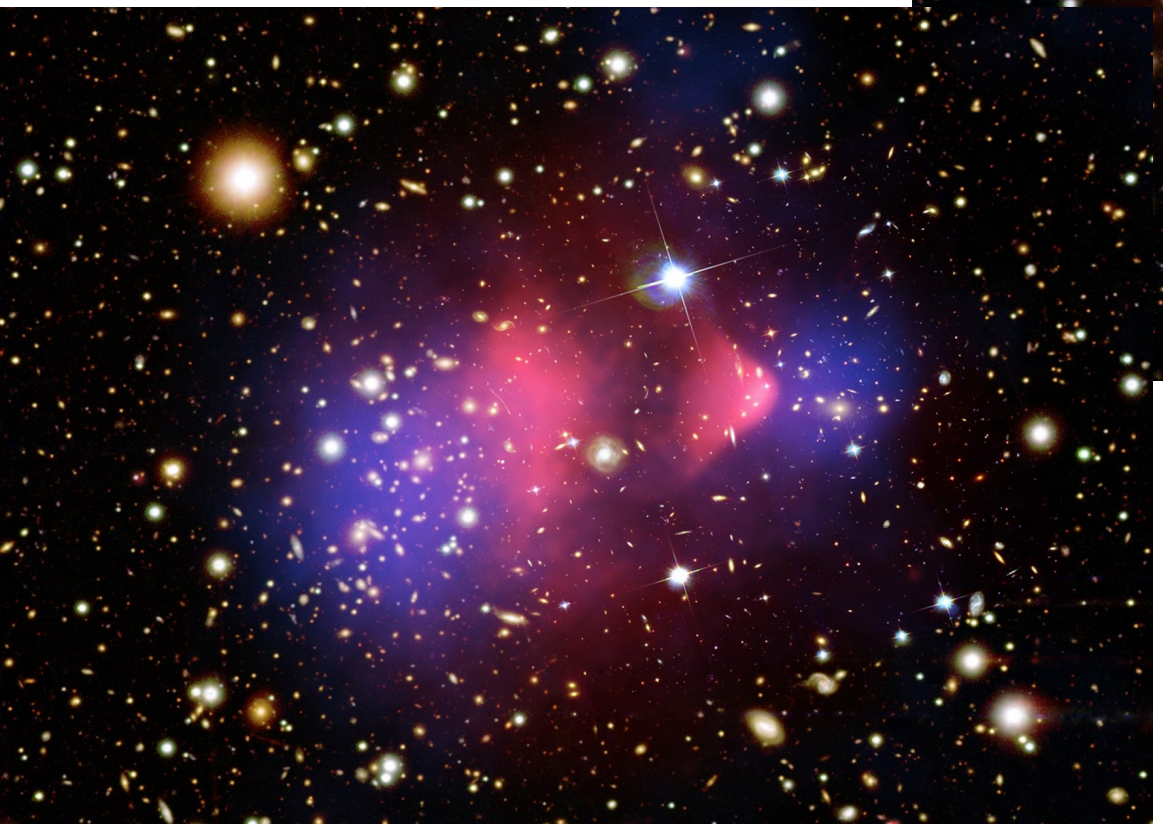
Extragalactic universe:
Cluster of galaxies (X-ray, visible and dark-matter model)

The Bullet Cluster, 1E0657-56

Two clusters in collision: studying this object let us measure the dark matter

Right: what we see directly in X-rays (red) and optical

Below: blue shows the matter distribution we infer

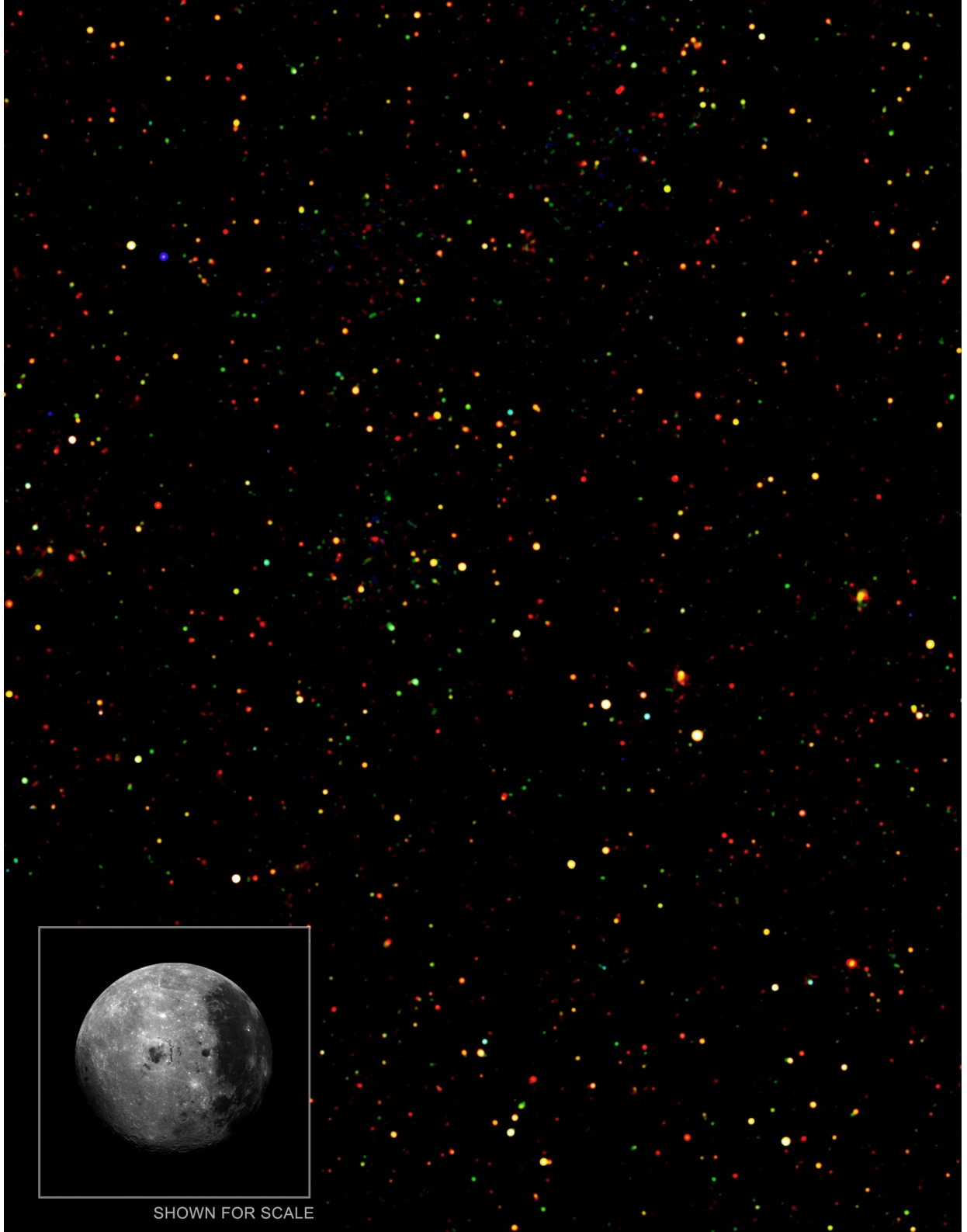


Distance: 3.3 billion light years

Size: 3 million l.y.

Data: Maxim Markevitch et al.

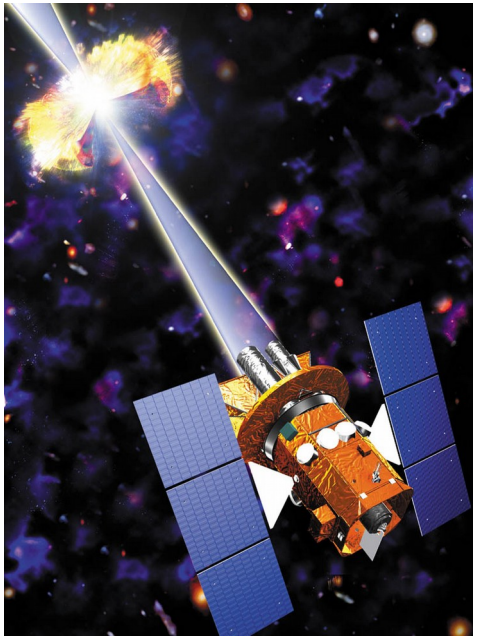
Extragalactic universe:
Quasars (X-ray)



The Bootes survey

1000 supermassive black holes

X-ray satellites

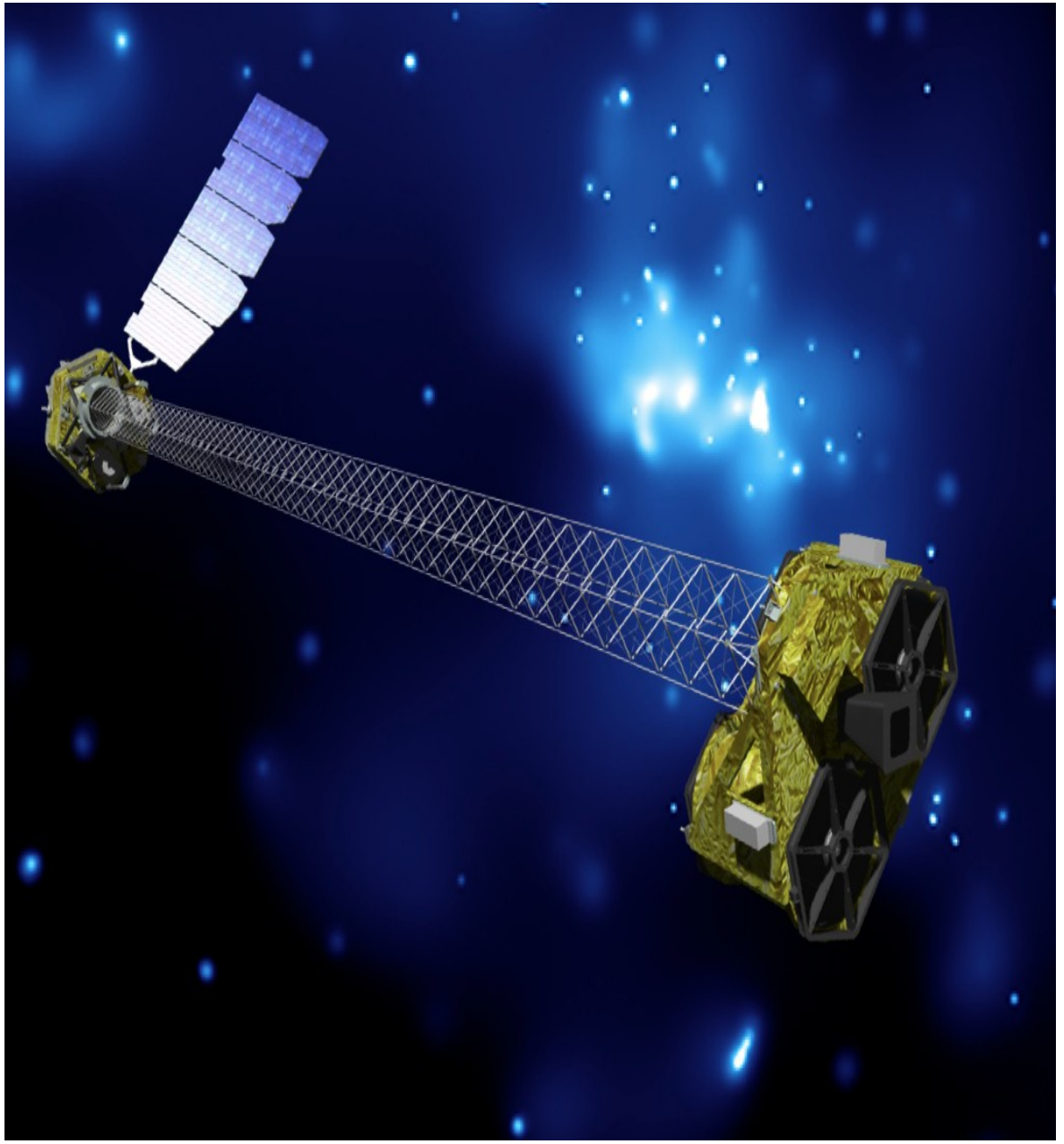


SWIFT – Low Earth Orbit

Suzaku – Low Earth Orbit

XMM – High Earth Orbit

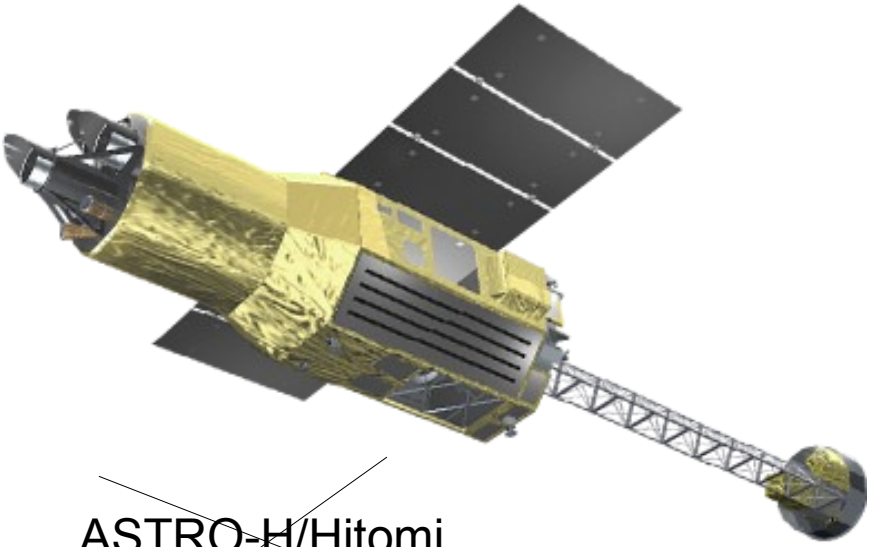
Chandra



NuSTAR

Launched June 2012

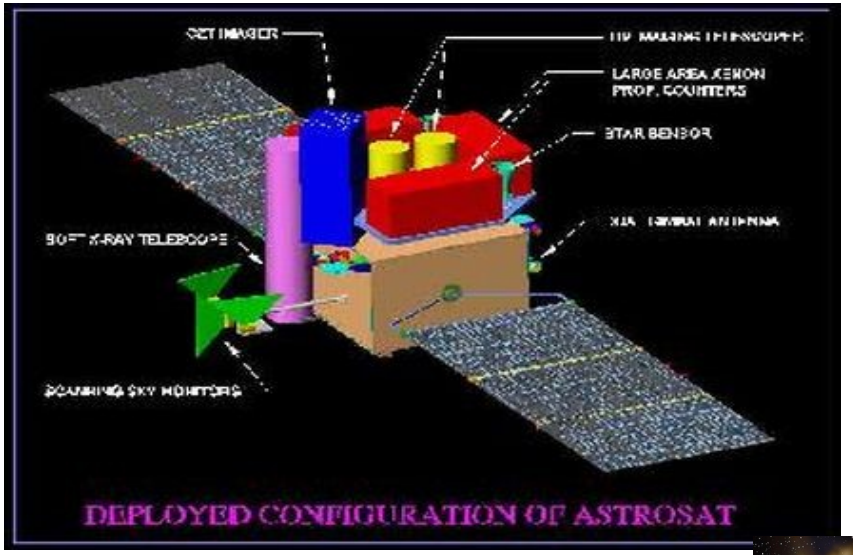
Just made first definitive measurement of a black hole spin rate – evidence for general relativity effects



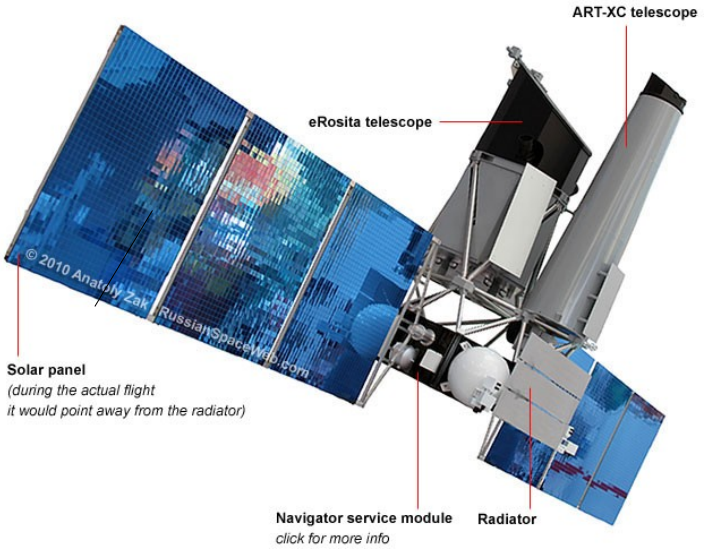
ASTRO-H/Hitomi

RIP

Athena (ESA 2028)



Astrosat (India) 2015



Spektr-RG/ eROSITA 2017??

SVOM (France/China) 2021?