X-ray Astronomy and the Chandra X-ray Observatory

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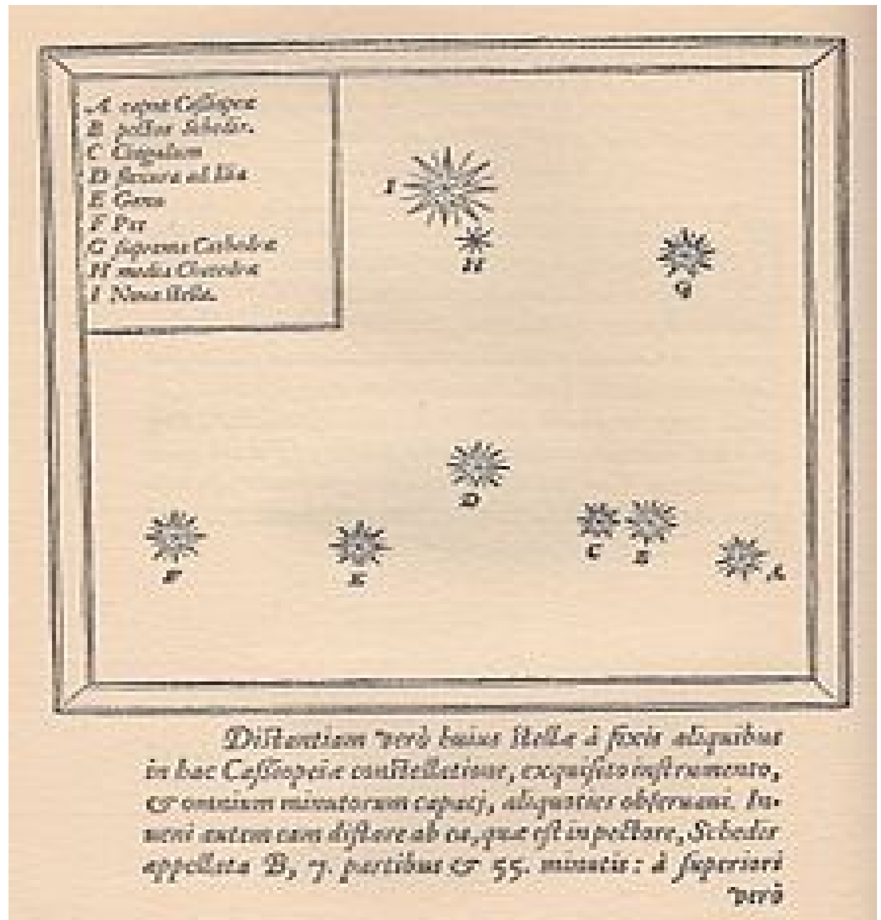
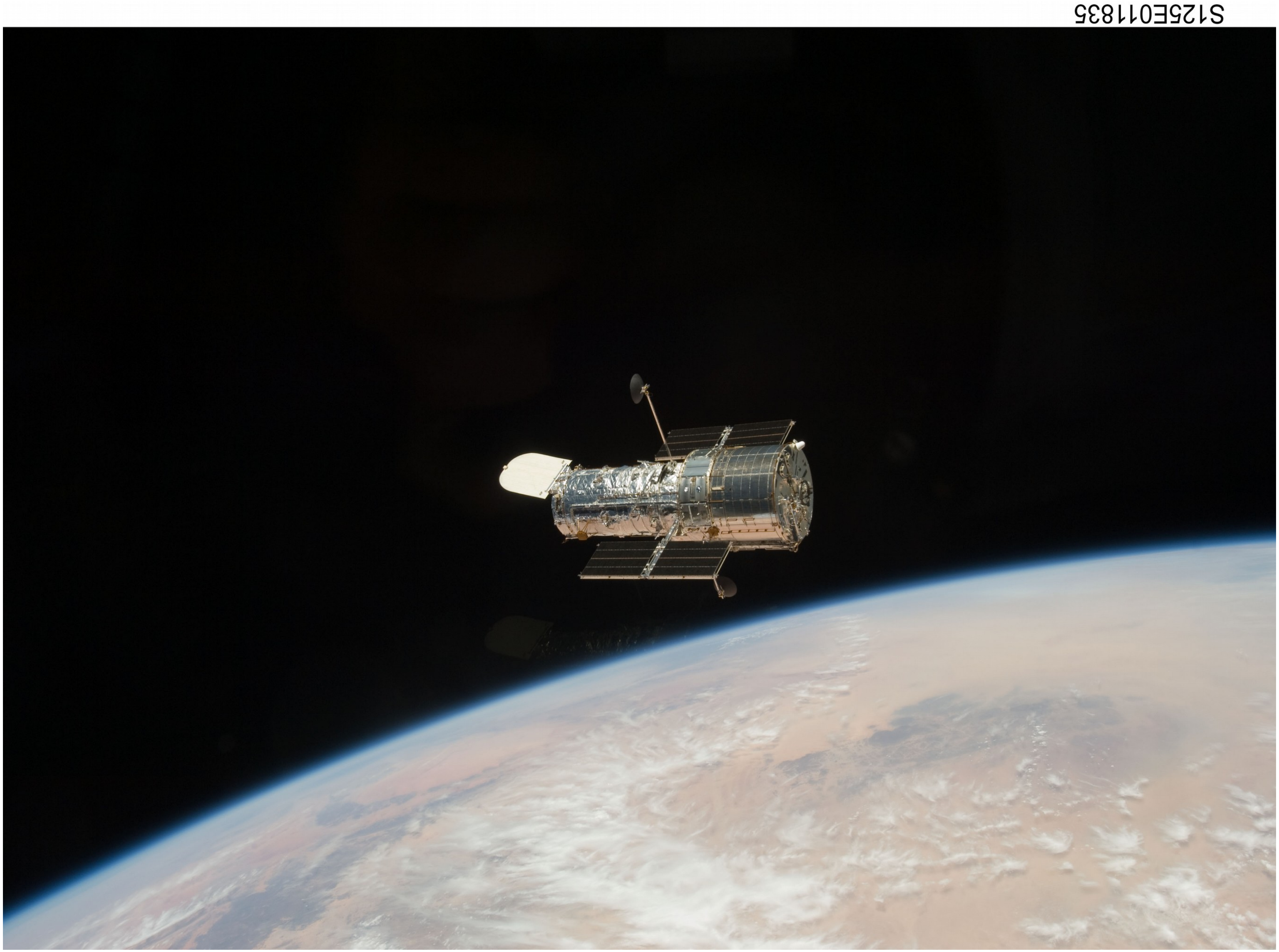
Part 1: The invisible universe

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..





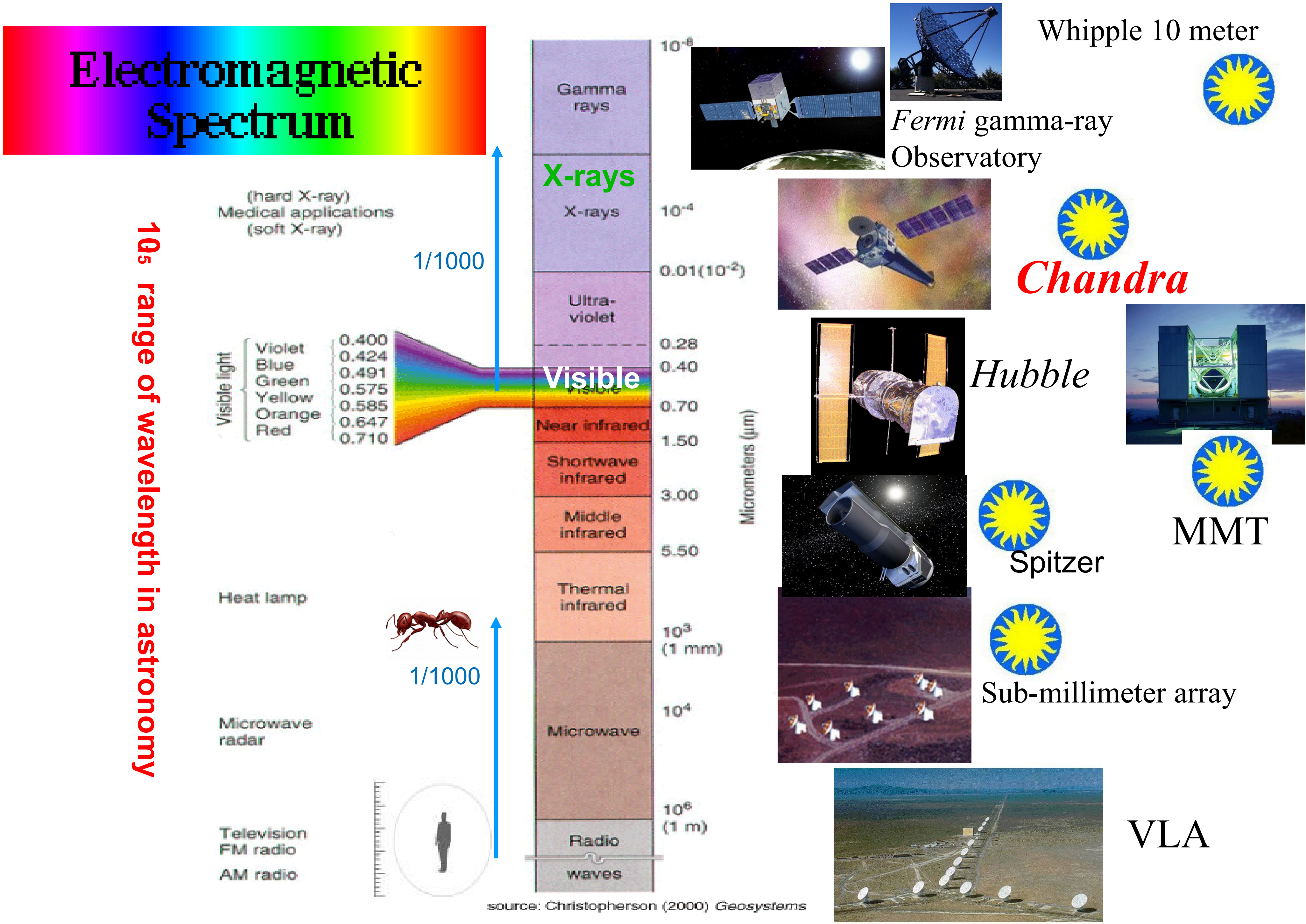
Astronauts' last view of Hubble in May 2009 after the final refurbishment mission

The Chandra X-ray Observatory

Launched 18 years ago 23 July 1999

A revolution in X-ray astronomy
and astronomy in general

We are now in the era of multiwaveband astronomy



Visible-light photons are like raindrops
- each one is 'small' (has a small amount of energy)
- there are lots of them, but don't do any damage

X-ray photons are like hailstones
- each one is 'big' – lots of energy
- there are many fewer of them
- but each one packs a wallop

If you up the INTENSITY (number of photons) in a beam of light you increase the total energy you get but not the energy per 'packet'
If you want to get a tan (or worse) you have to increase the energy per photon, not just the number of photons.
We have a word for the energy of a photon: “COLOR”
(well, “COLOUR” but I'll defer to the local sensibility)

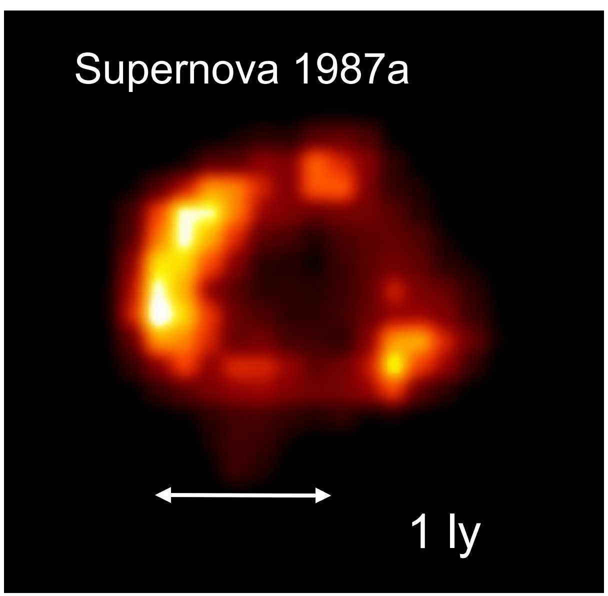
Sources of X-rays

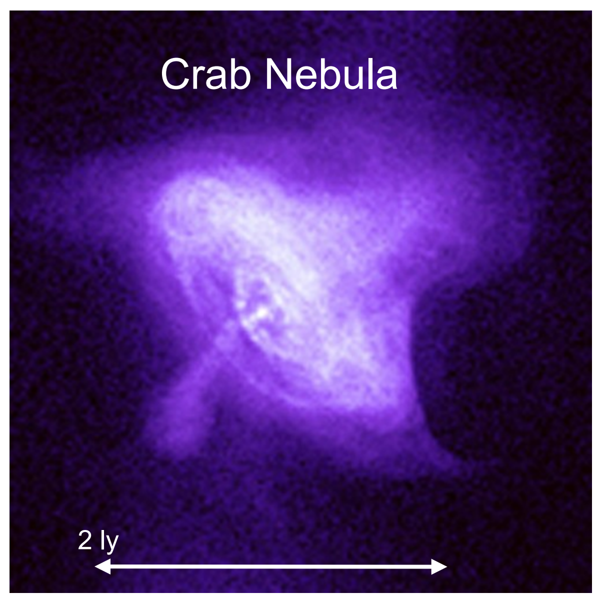
- Shock waves in plasma (ionized gas)
- "Synchrotron" caused by energetic particles in magnetic fields (like a natural particle accelerator)
- Energy release from gravity ("accretion" power)

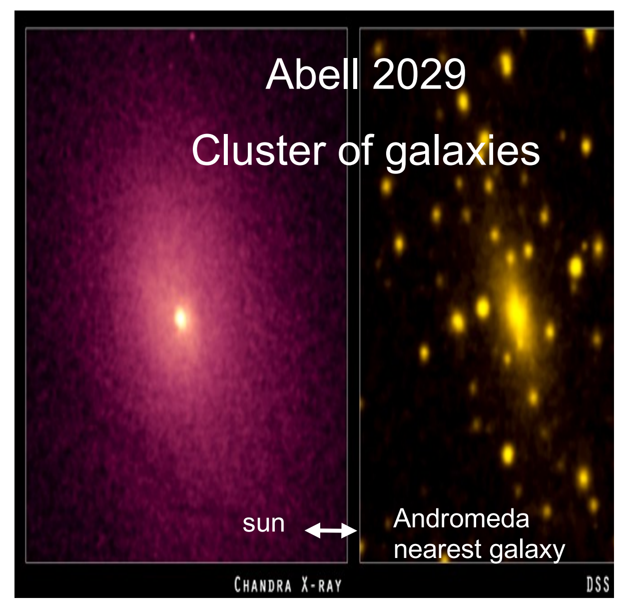
Explosions: Supernovae and their remnants

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

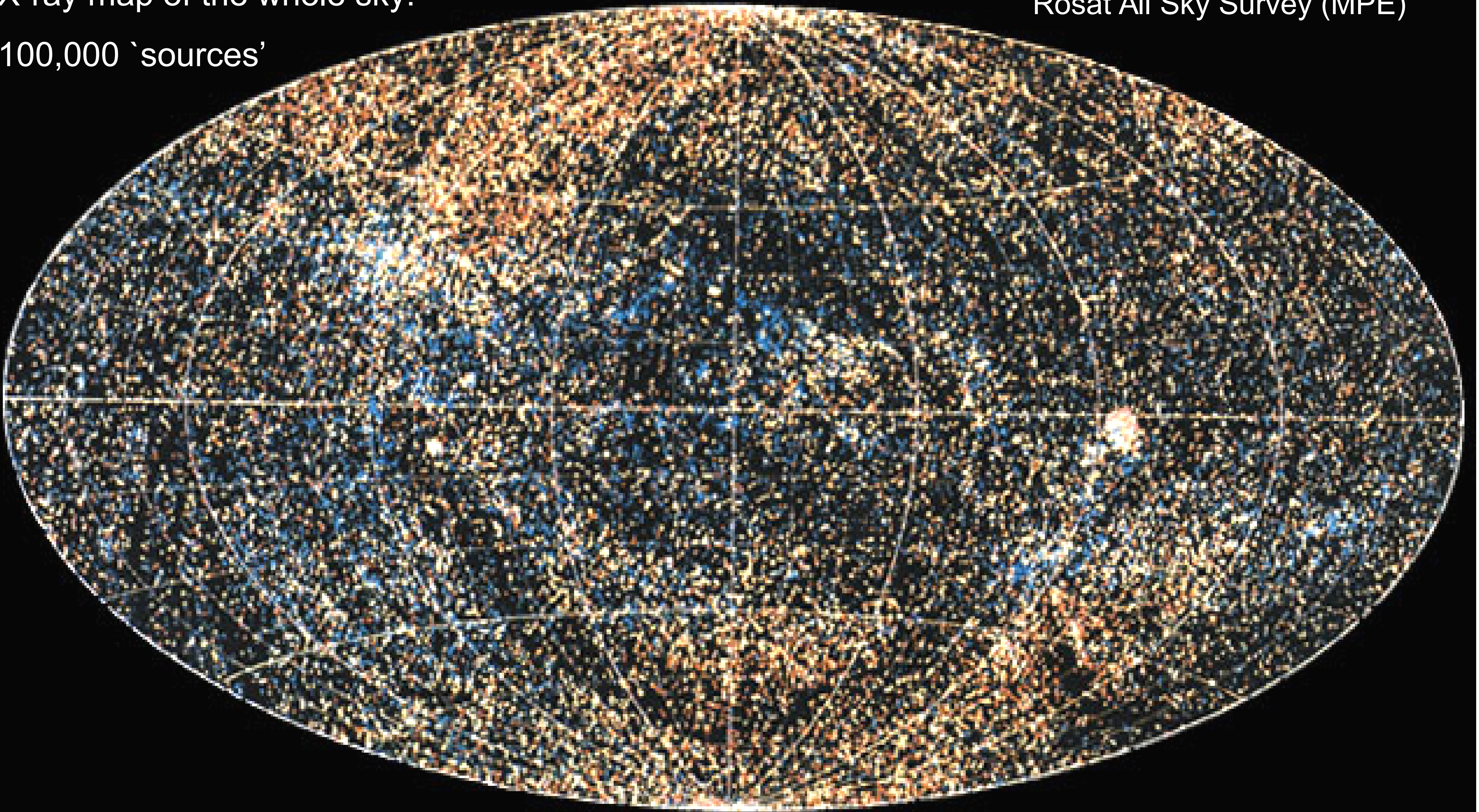
In X-rays, we see mostly accreting sources: energy from gravity!

Powerful sources of X-rays

X-ray map of the whole sky:

100,000 `sources'

Rosat All Sky Survey (MPE)

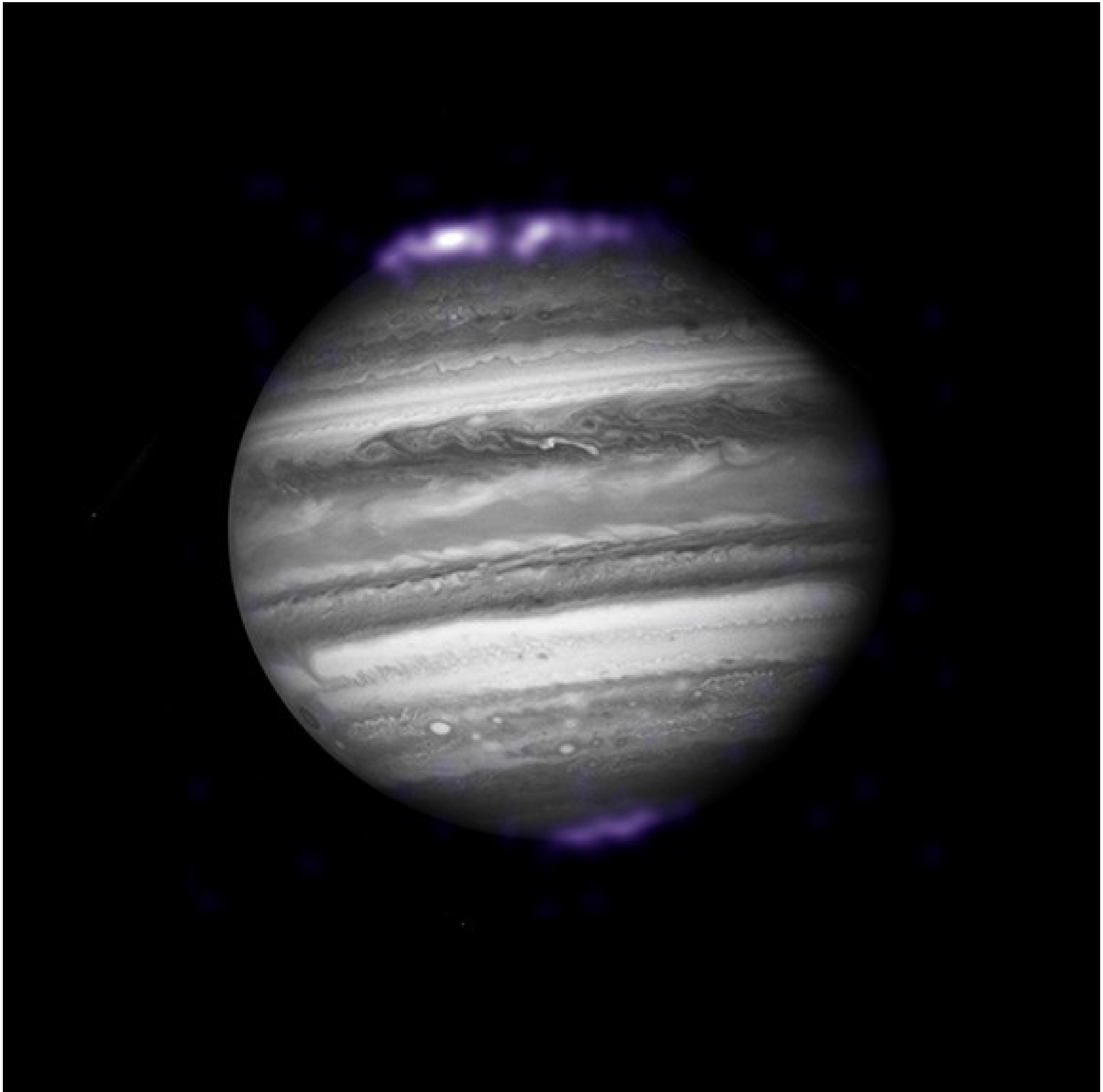


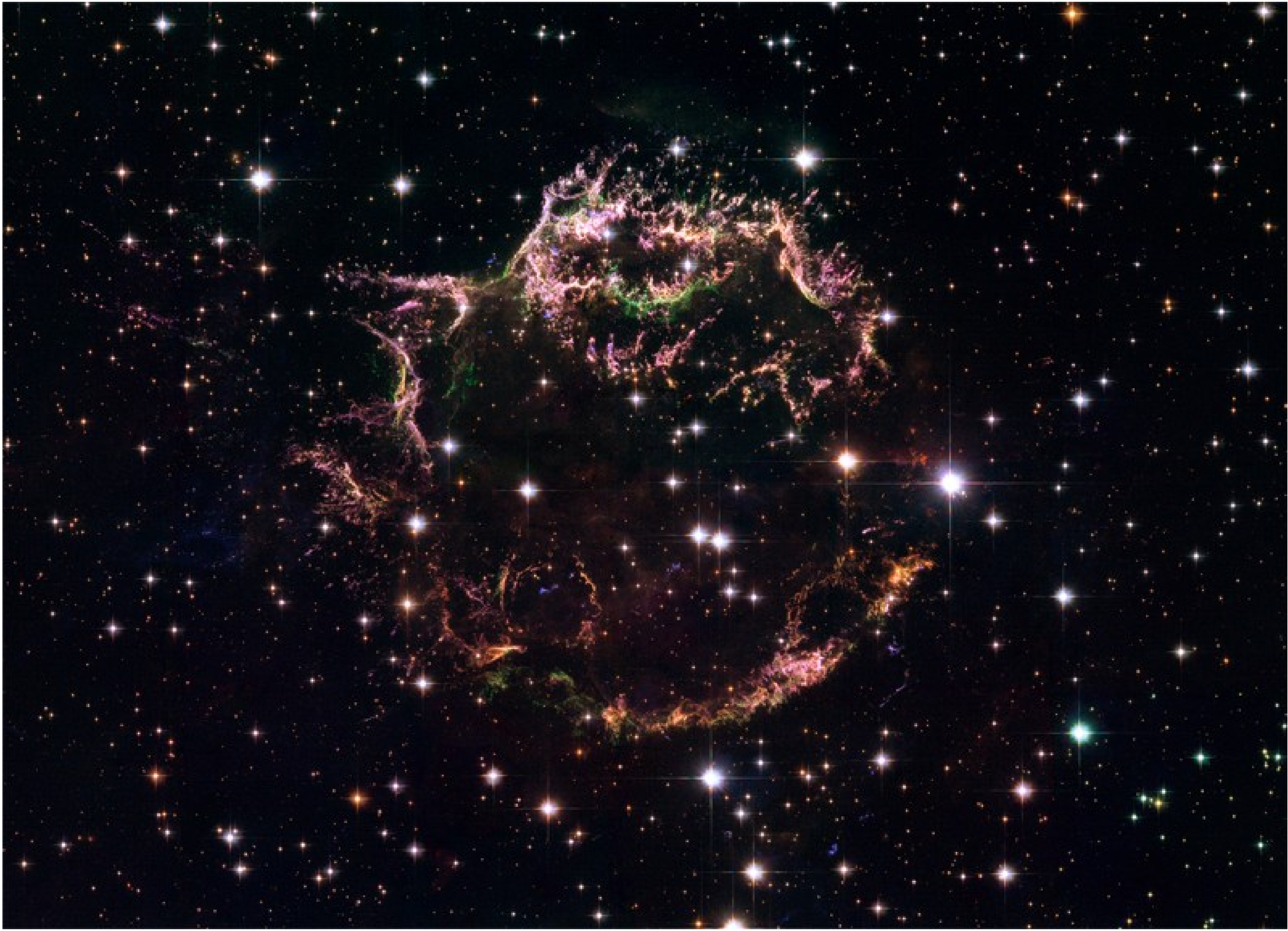
A power source entirely different from the nuclear fusion that drives the Sun and stars

…and much more efficient

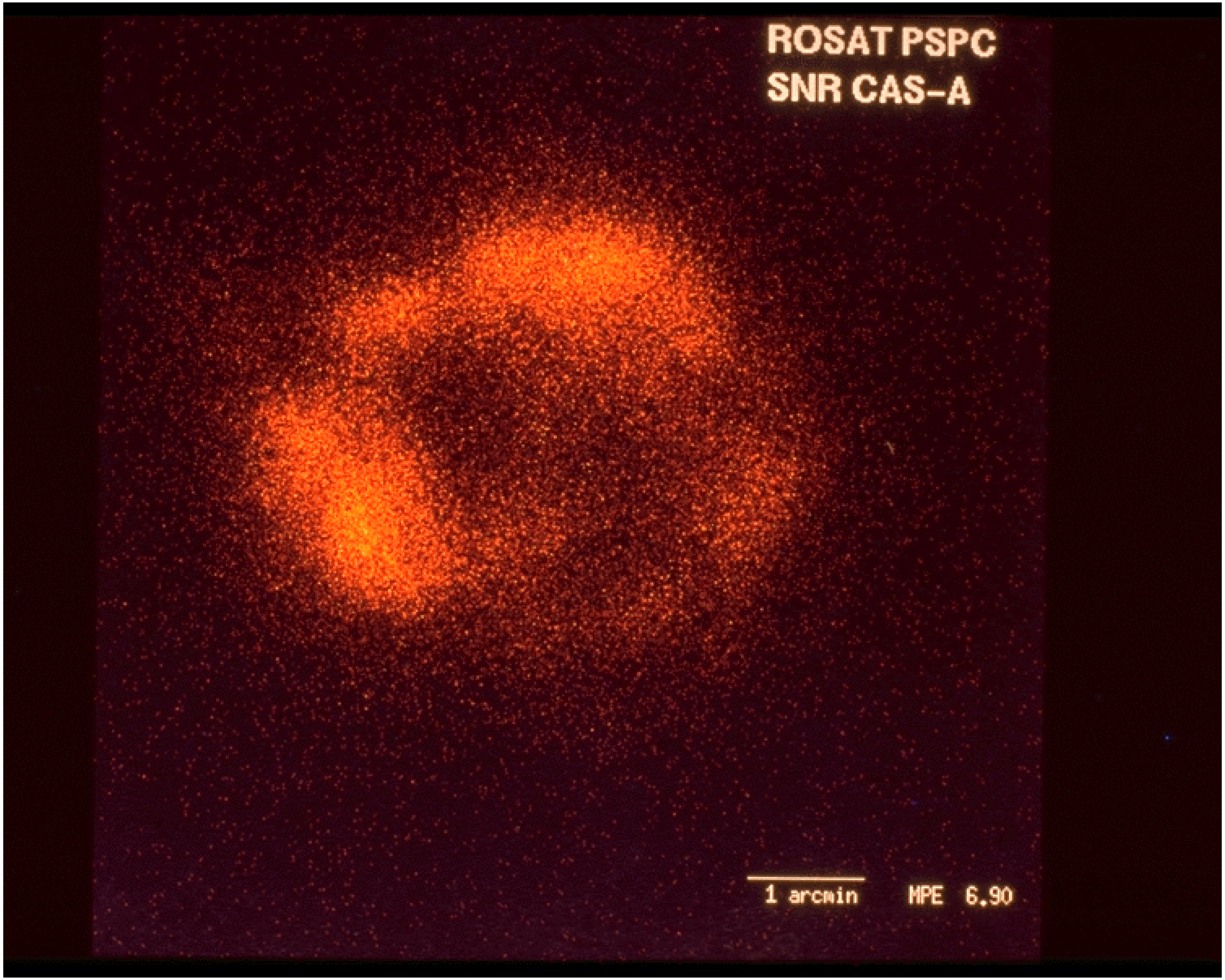
Part 2: An orientation tour of the multicolor Universe

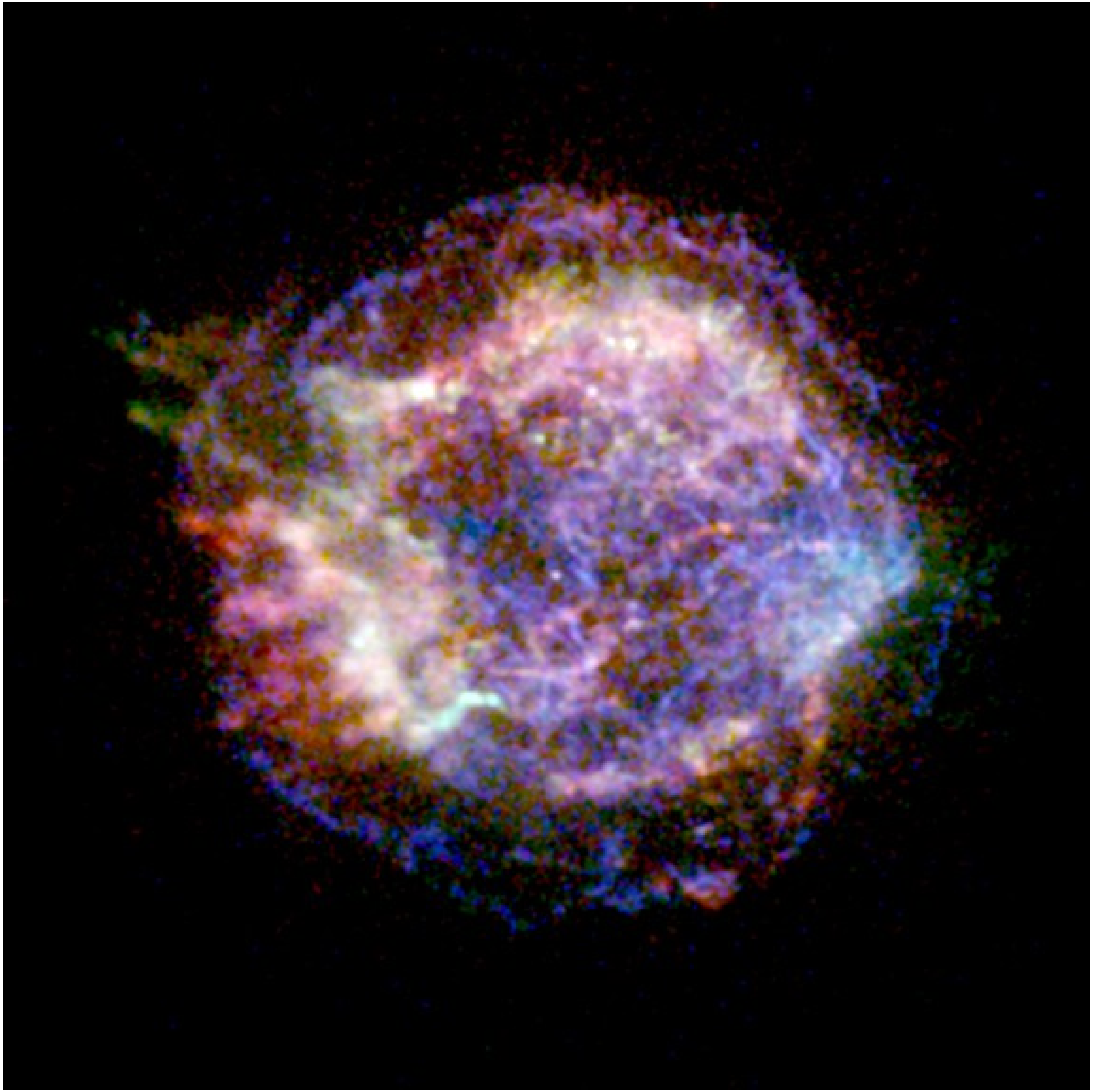
From the Earth to distant galaxies





Milky Way galaxy: Supernova remmant (X-ray)



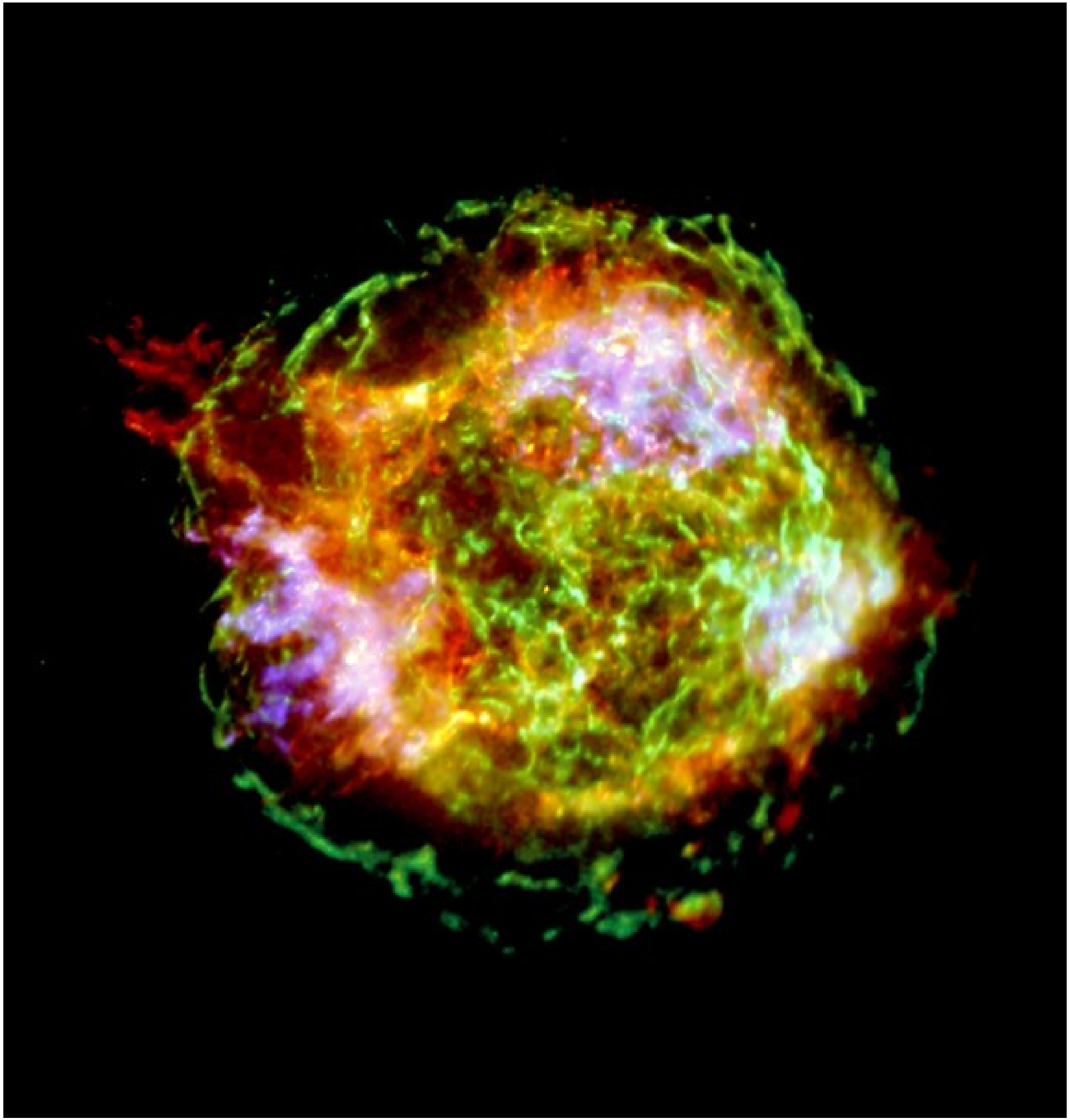


1 hour
with
Chandra

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)

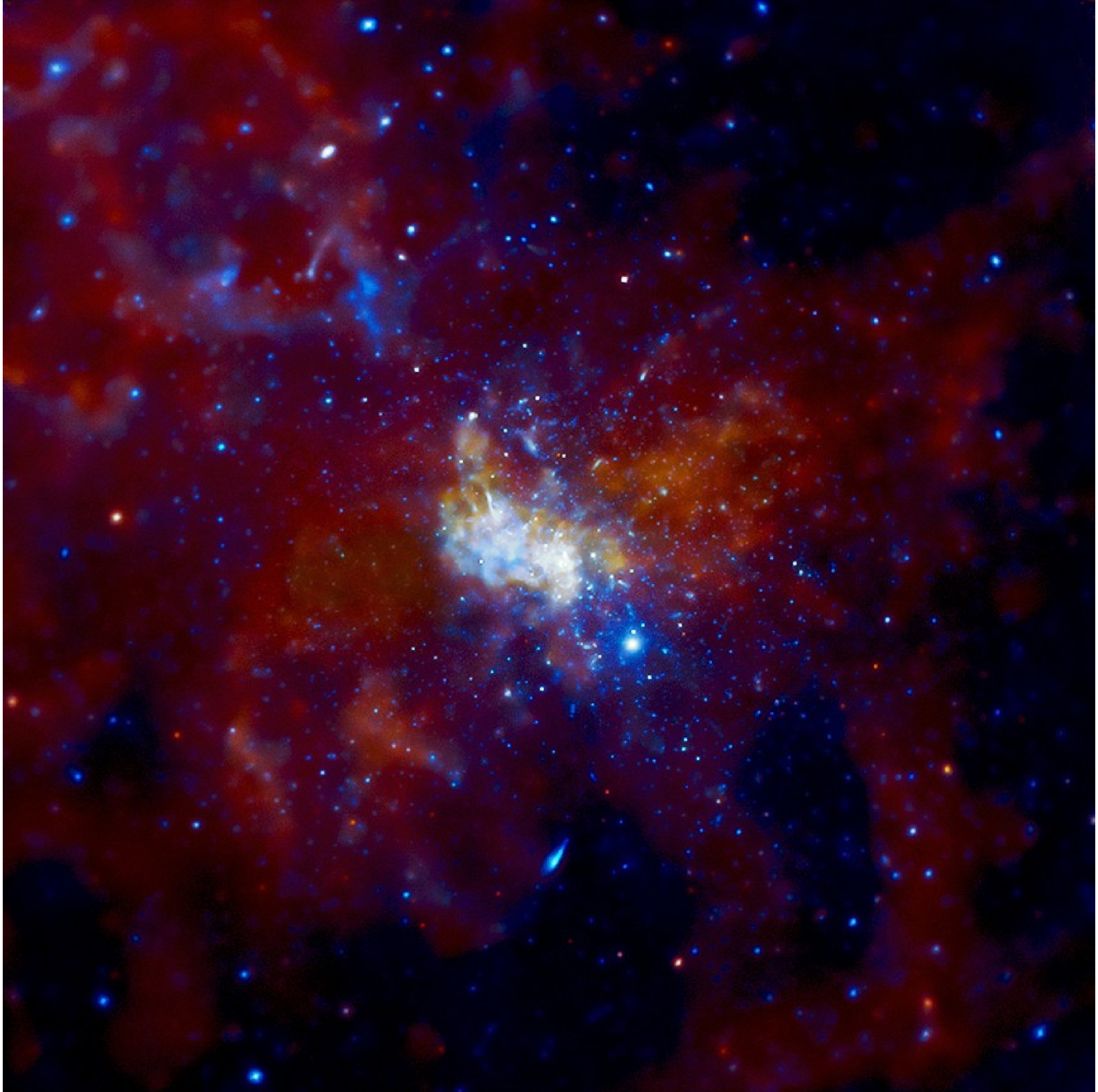


11000 light years away

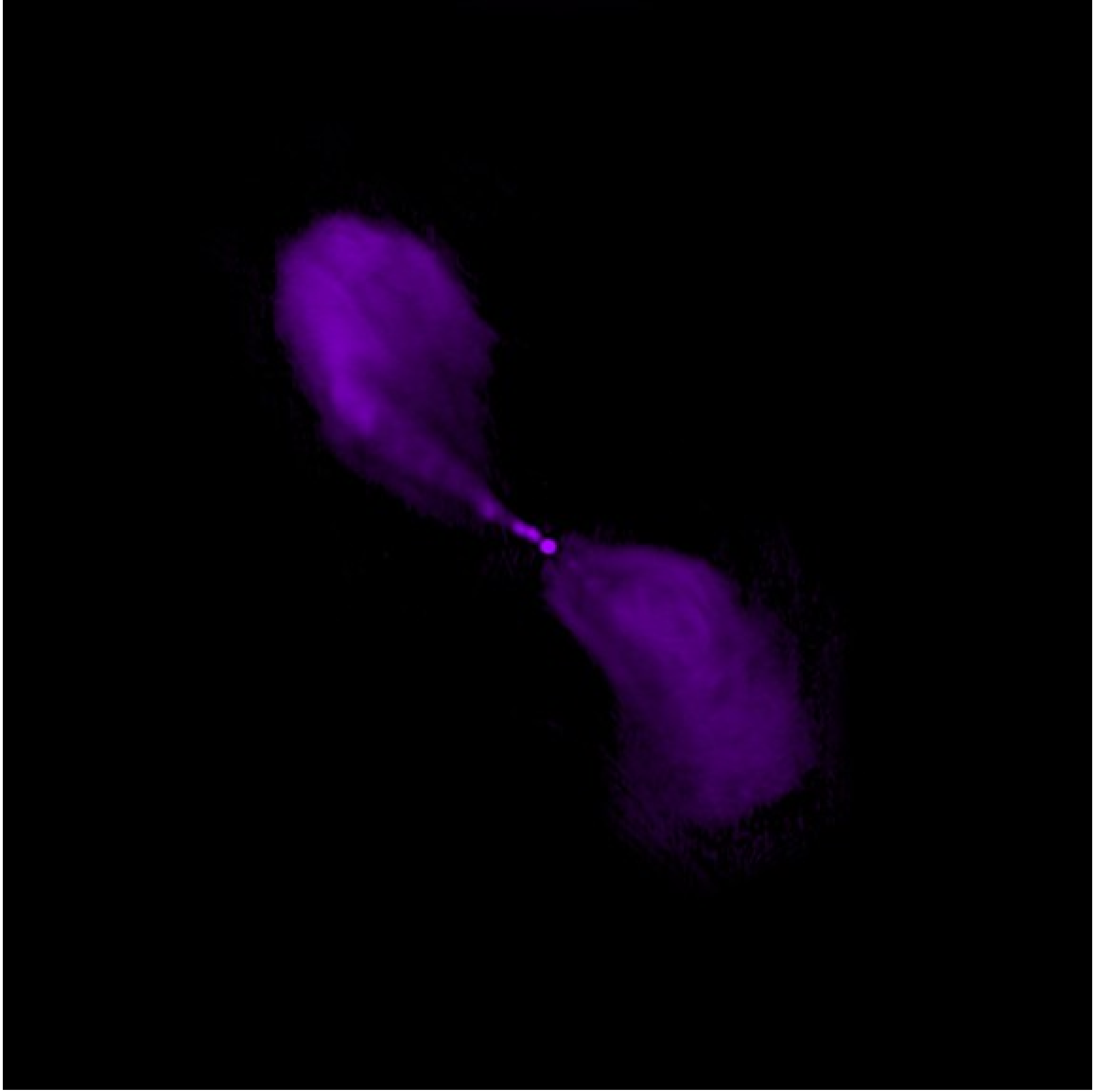
16 light years across

The Milky Way Galaxy: Galactic Center

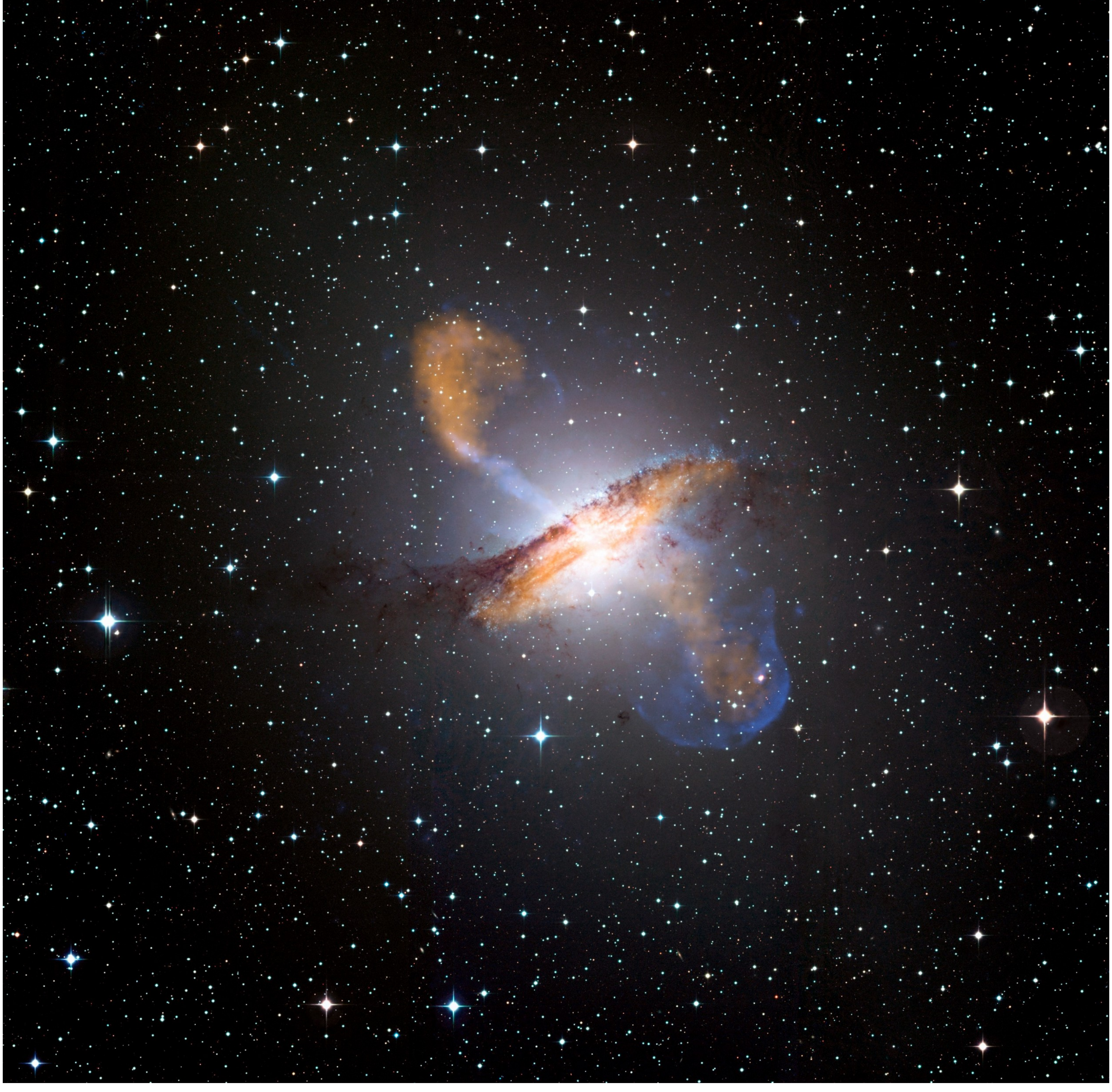
Milky Way in Sagittarius: 30000 Years Away
Seen as it was when modern humans had just evolved

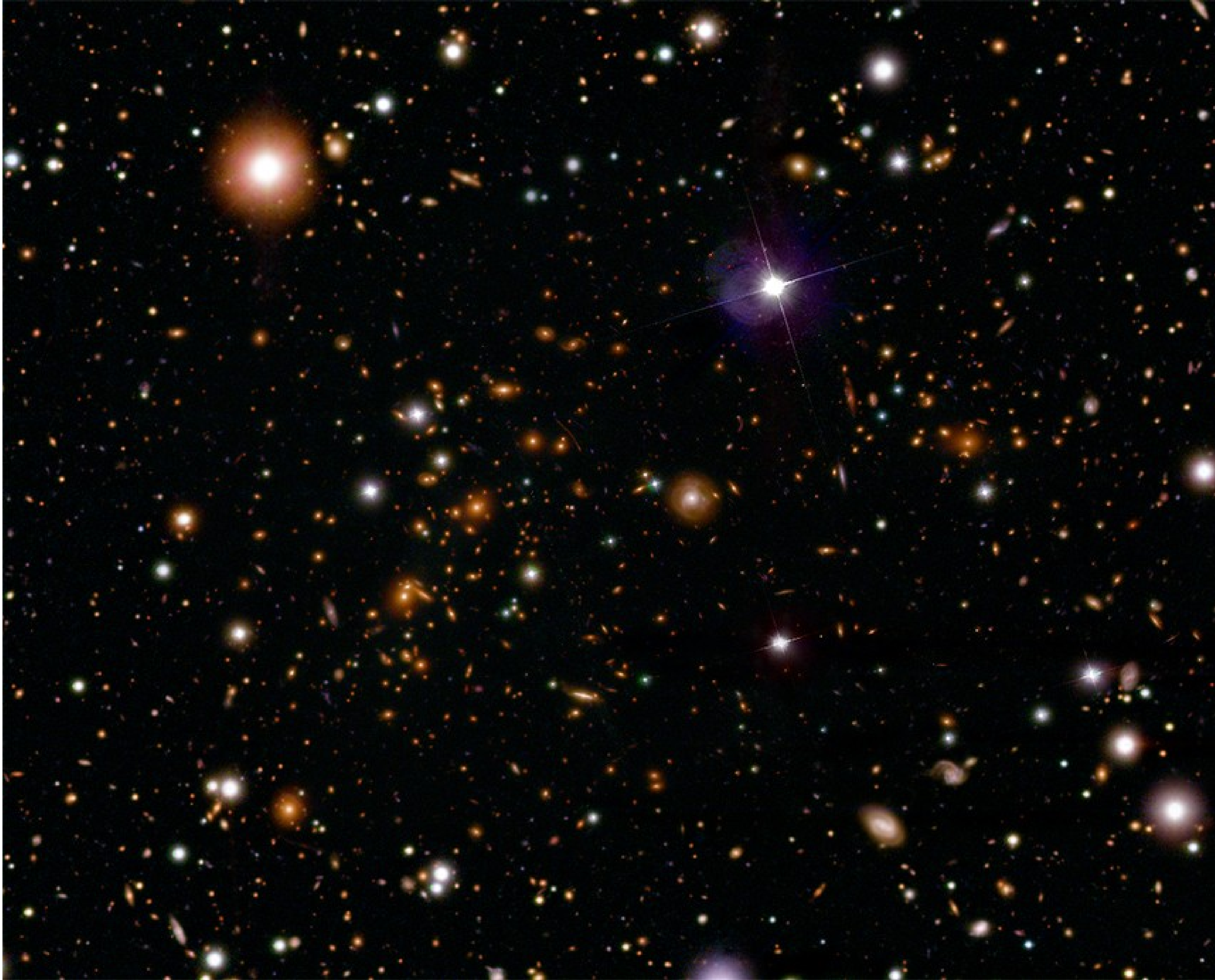


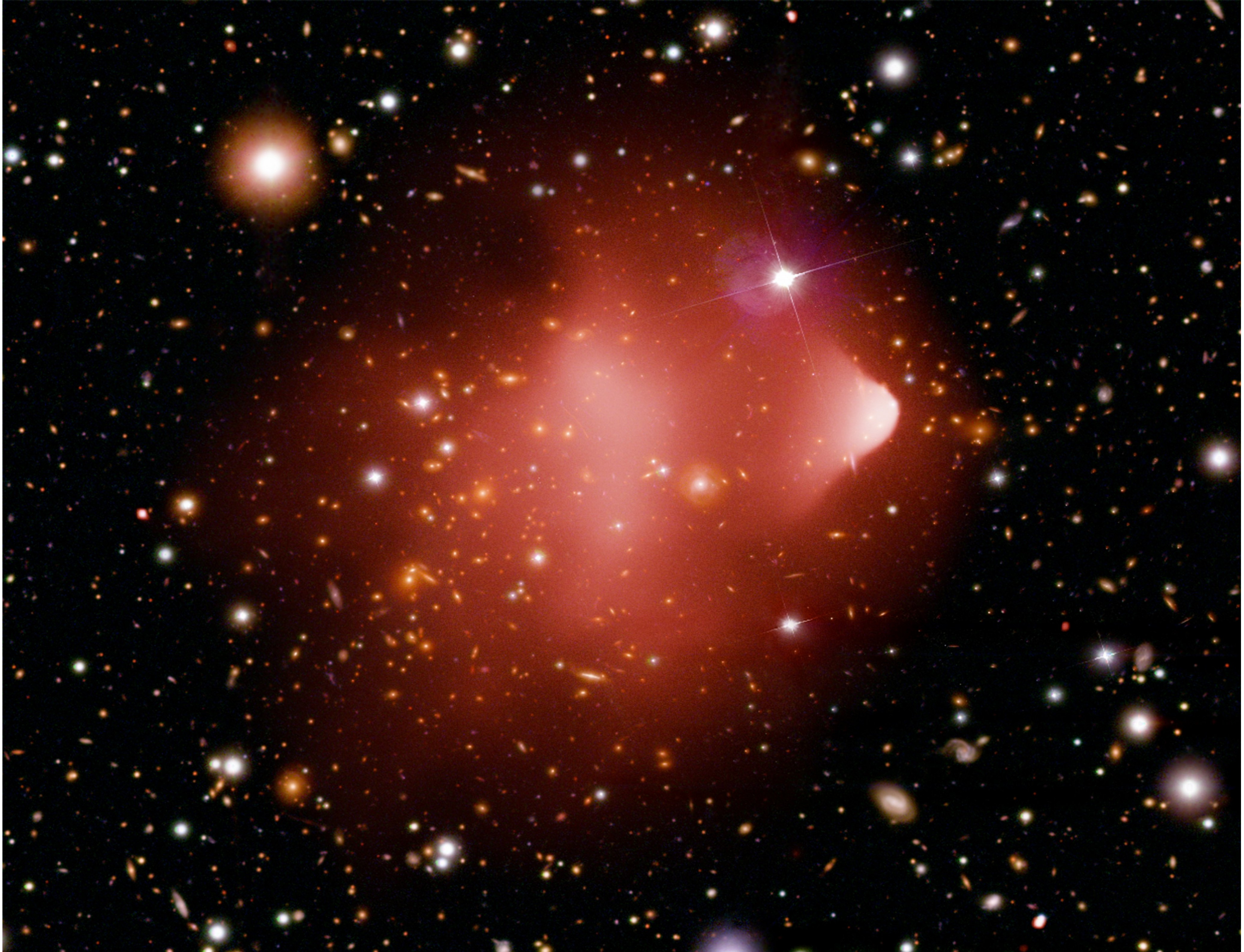
Galaxy Centaurus A (NGC 5128) - 12 million light years away



Extragalactic Universe: Active Galaxy (X-ray)







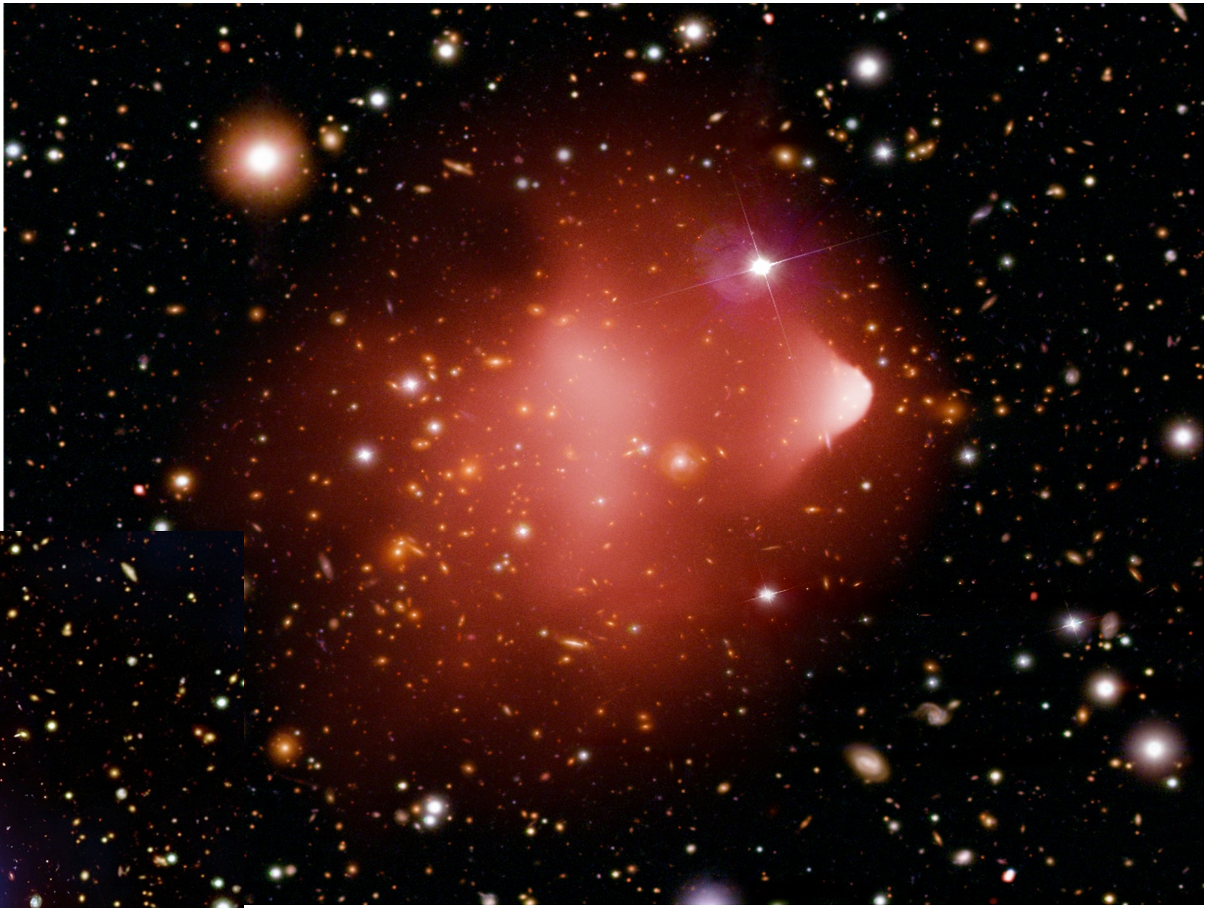
Extragalactic universe:
Cluster of galaxies (X-ray, visible and dark-matter model)

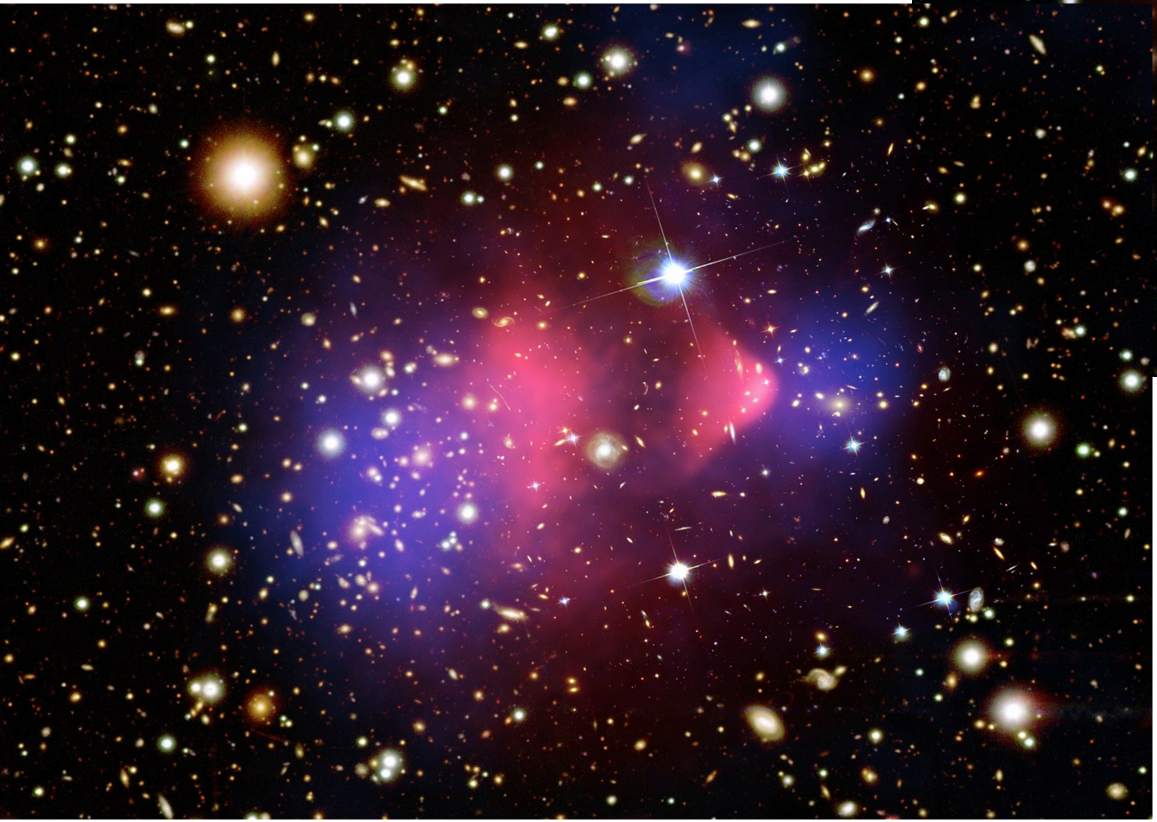
The Bullet Cluster, 1E0657-56

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

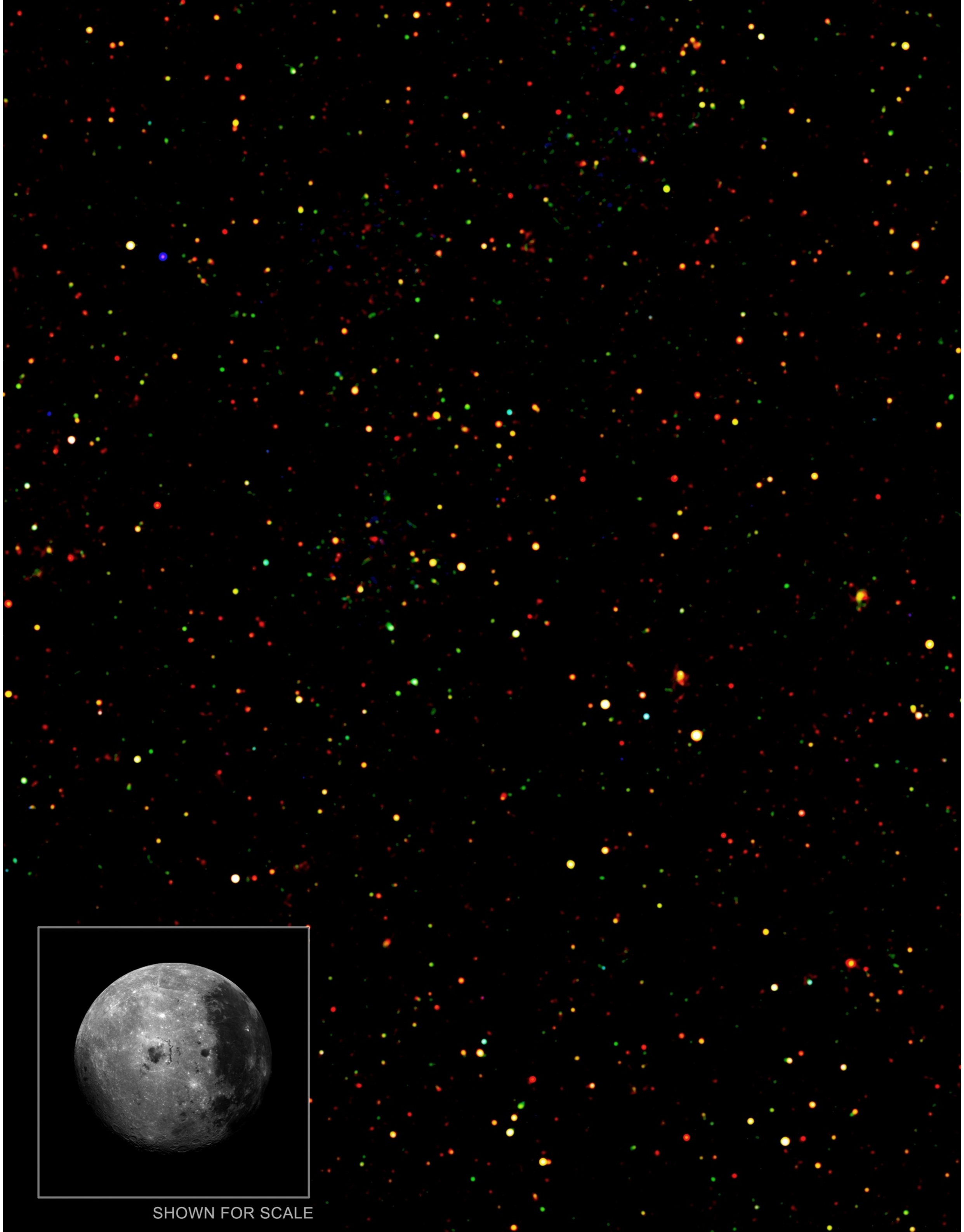




Distance: 3.3 billion light years

Size: 3 million l.y.

Data: Maxim Markevitch et al.



Extragalactic universe:
Quasars (X-ray)

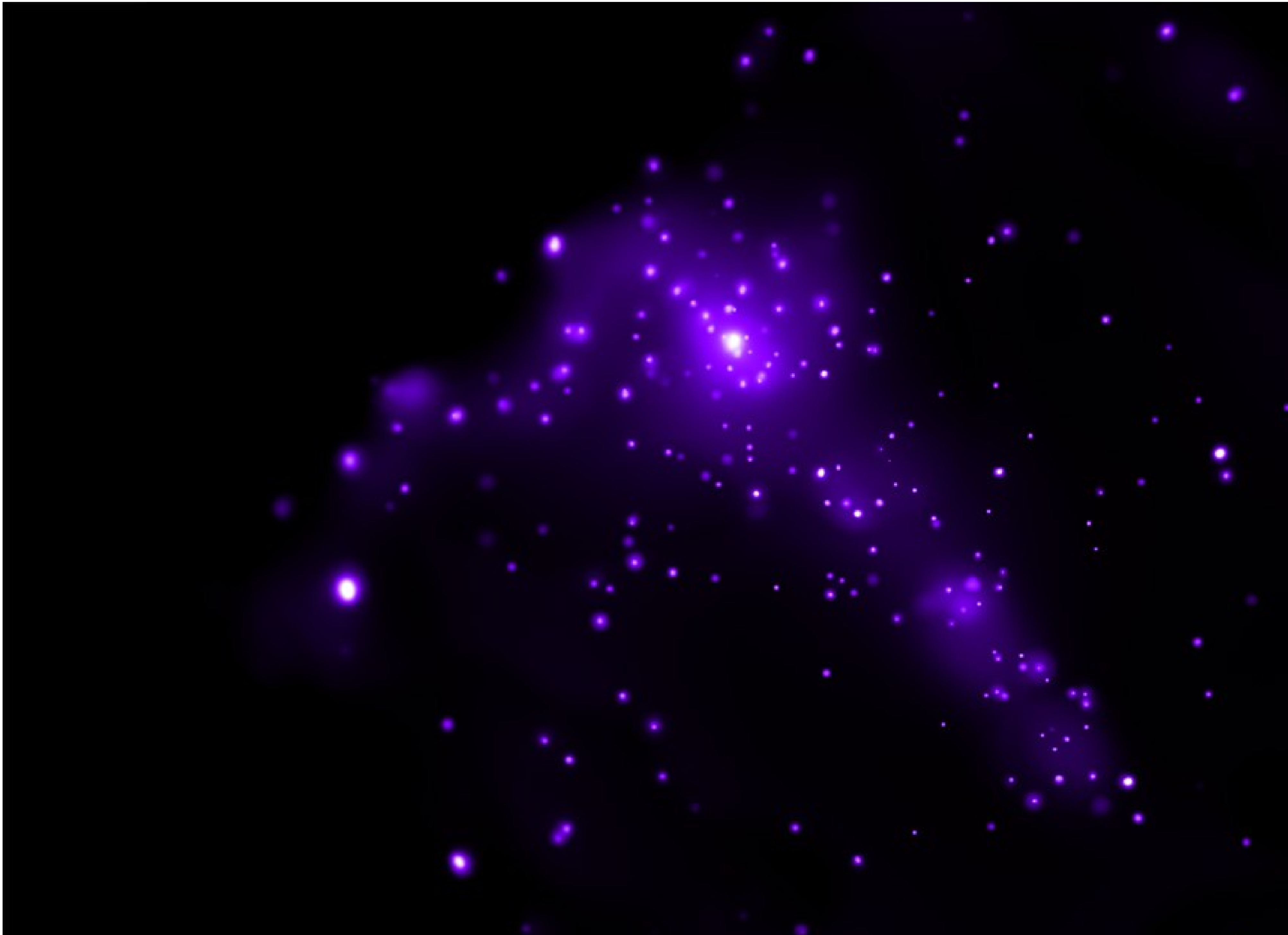
The Bootes survey

1000 supermassive black holes

Milky Way galaxy: star cluster (infrared)

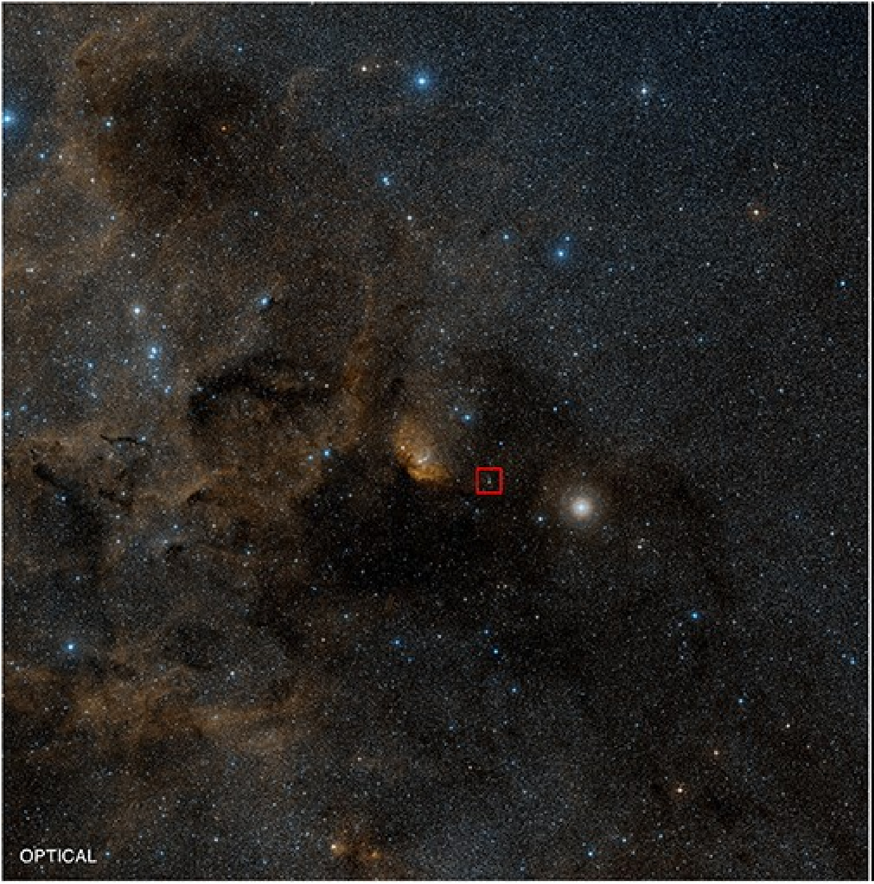
NGC 281 star cluster – infrared
10000 light years away

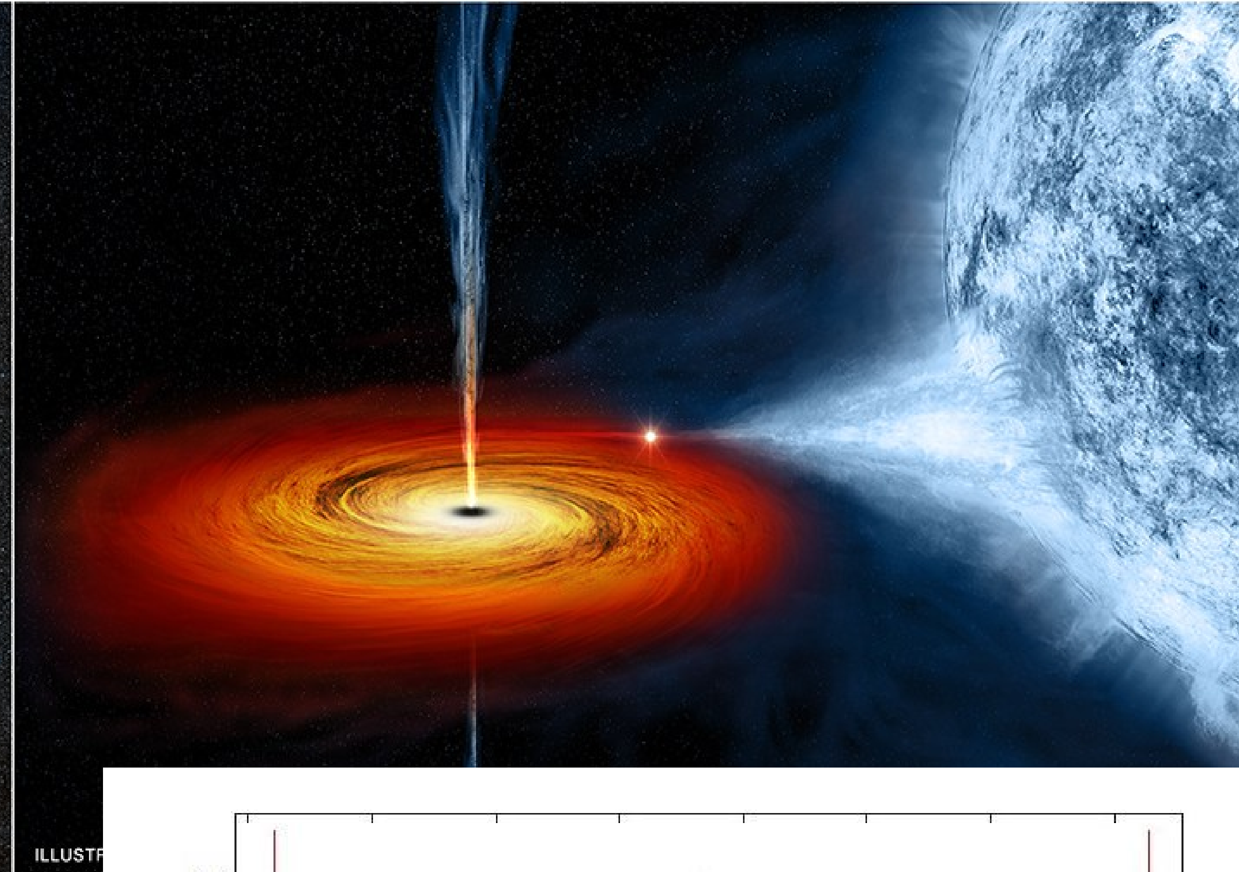
Milky Way galaxy: star cluster (X-ray)

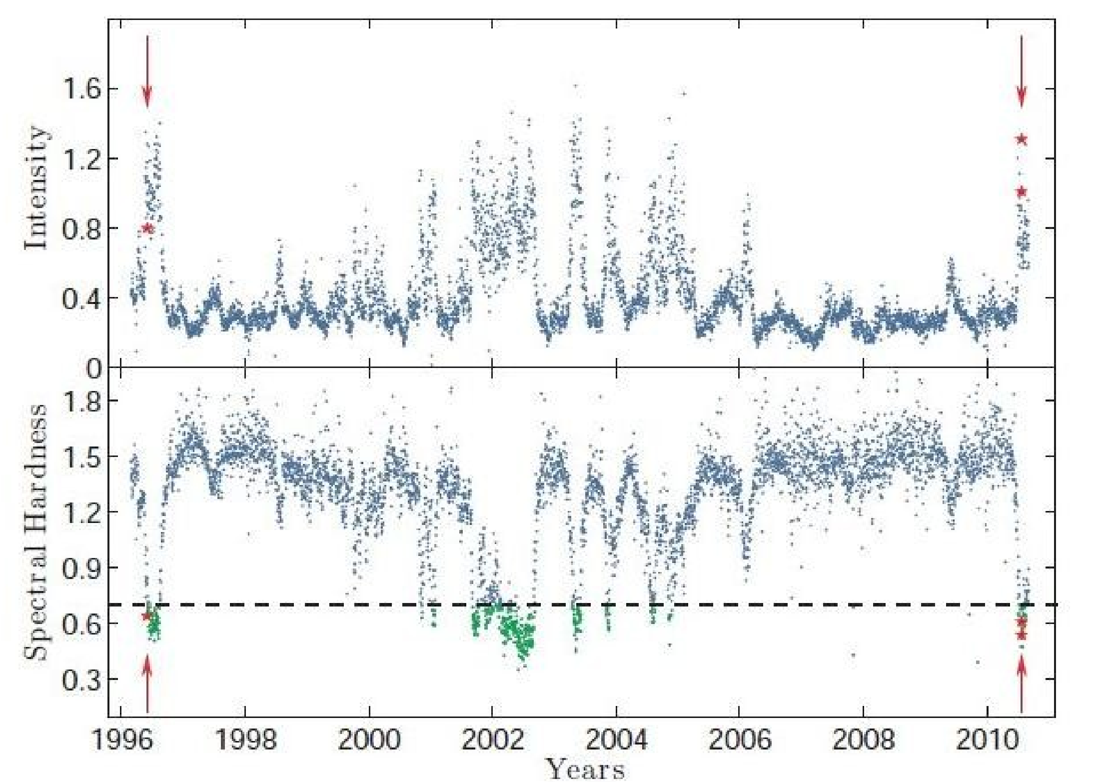


Milky Way galaxy: star cluster (infrared +X-ray)

NGC 281 (Scott Wolk, SAO)







Cygnus X-1
A massive blue star slowly being eaten by its companion black hole
When the stream from the blue star hits the material swirling around the hole X-rays are produced

The Rossi XTE satellite monitored the brightness of Cyg X-1 over 14 years

What is Chandra?

The greatest X-ray telescope ever built!

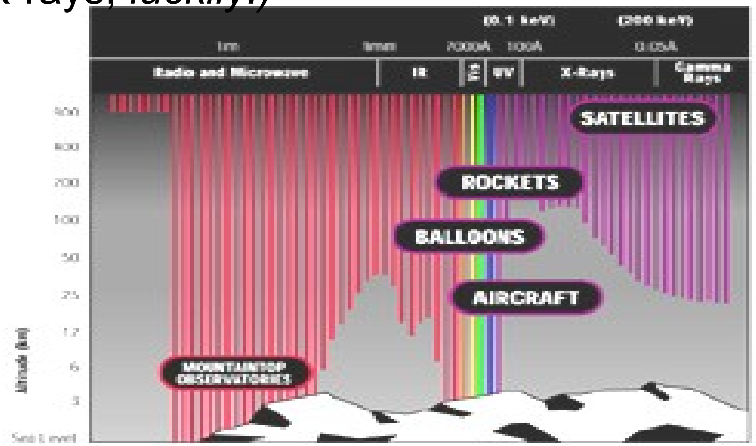
Orbits the Earth to be above the atmosphere (which absorbs X-rays, *luckily!)*

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

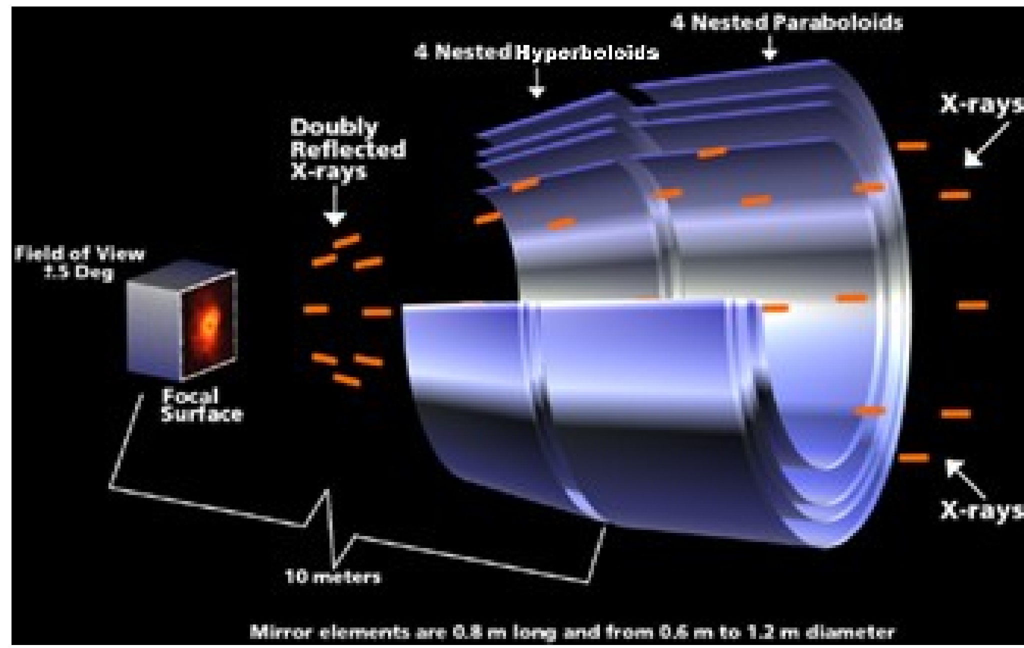
X-rays don't reflect off a normal mirror – they get absorbed.

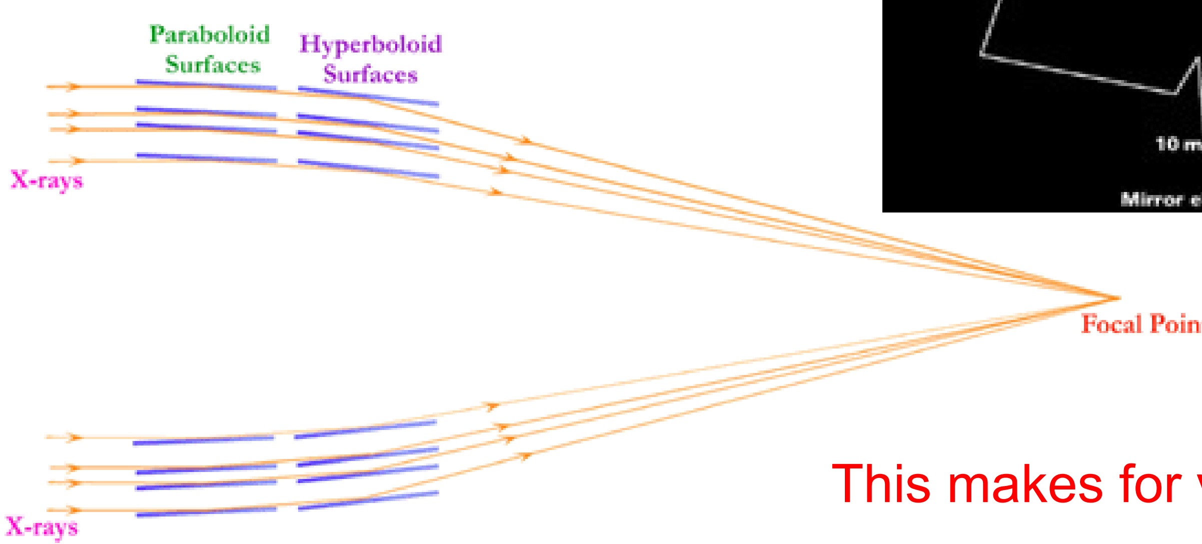
Only by striking a mirror at a glancing angle, about 1°,

do X-rays reflect.

Then they act like visible light

and can be focused

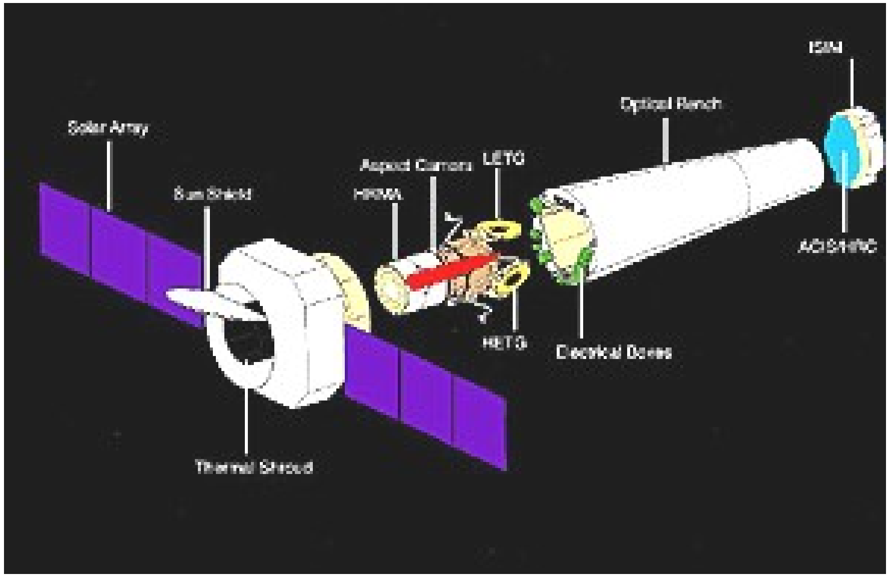




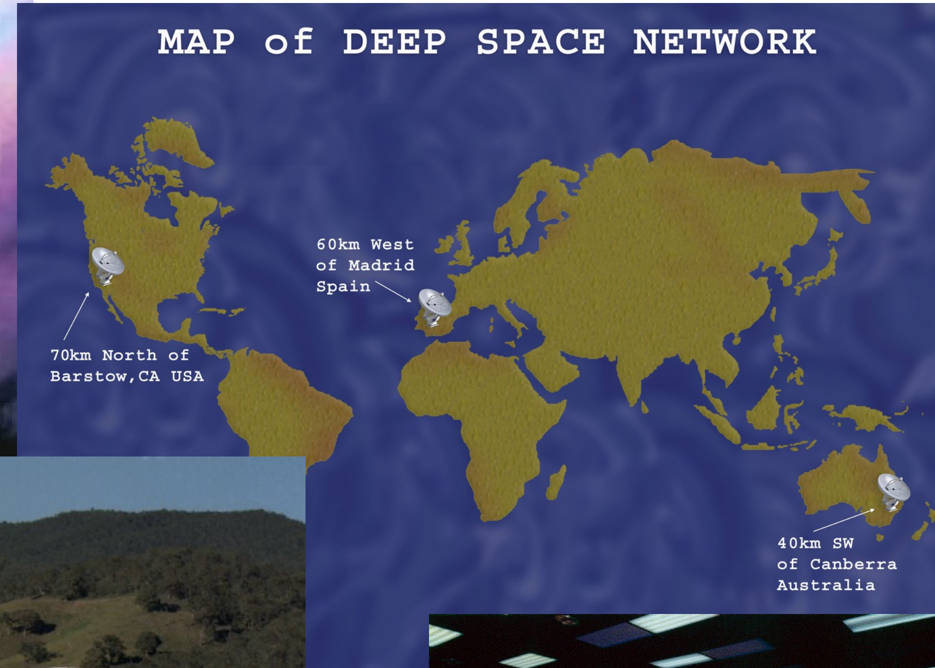
This makes for very long telescopes

The Chandra spacecraft

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

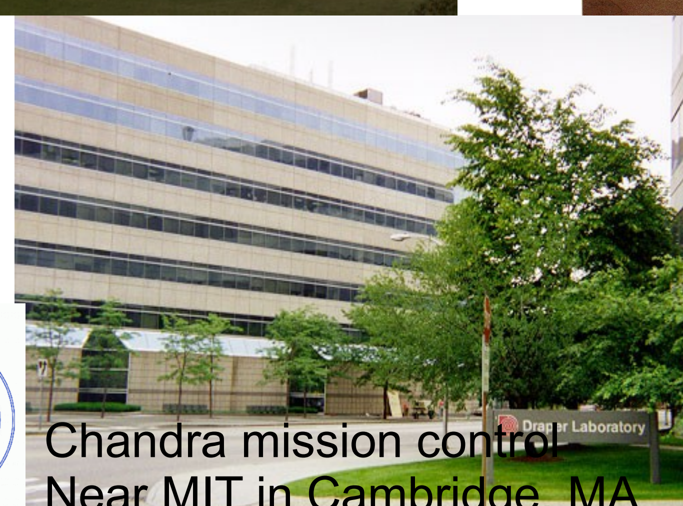


…but focuses X-rays onto a spot only 25 microns across



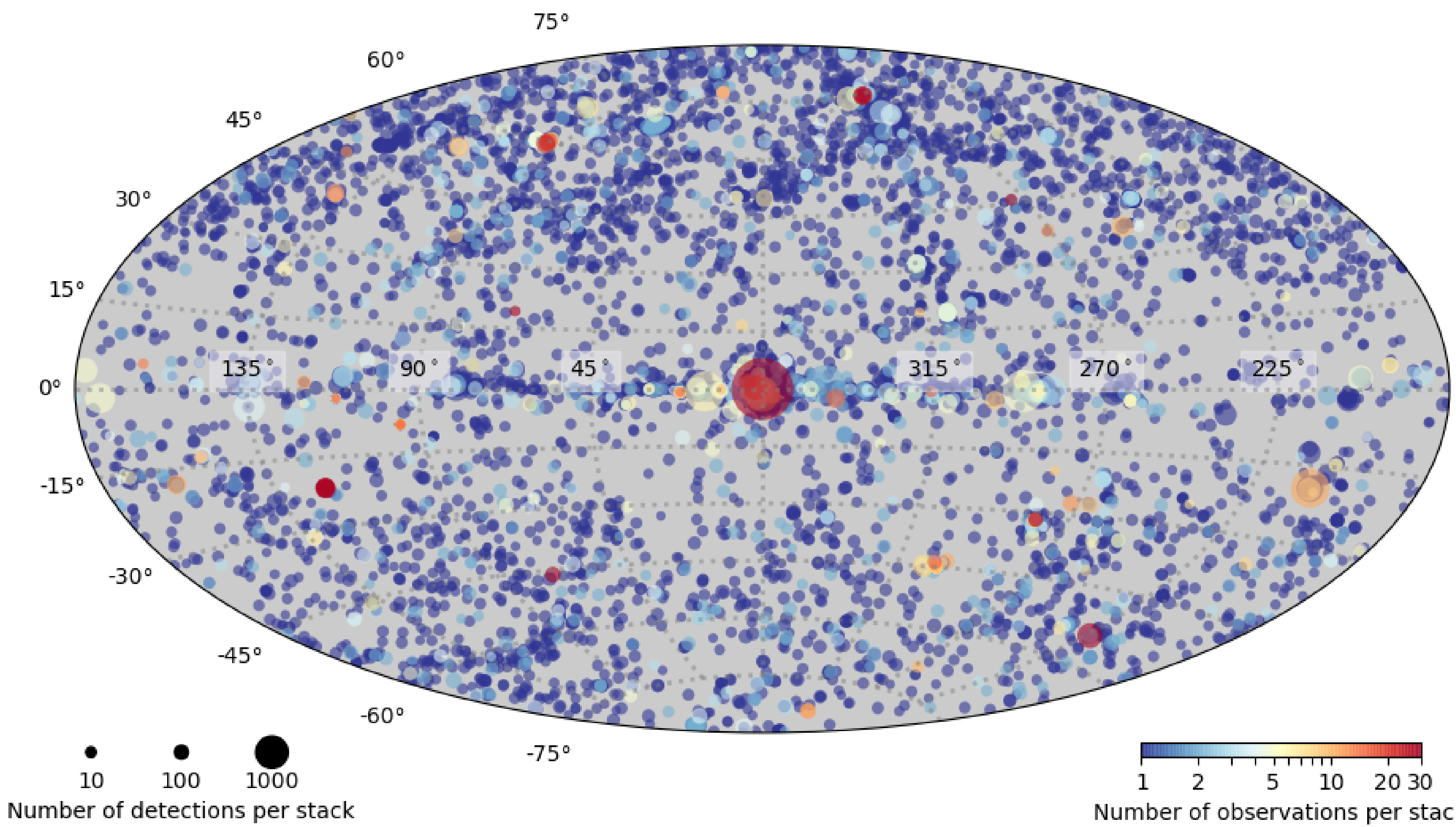
DSN control
at Jet Propulsion Lab
Pasadena, CA

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

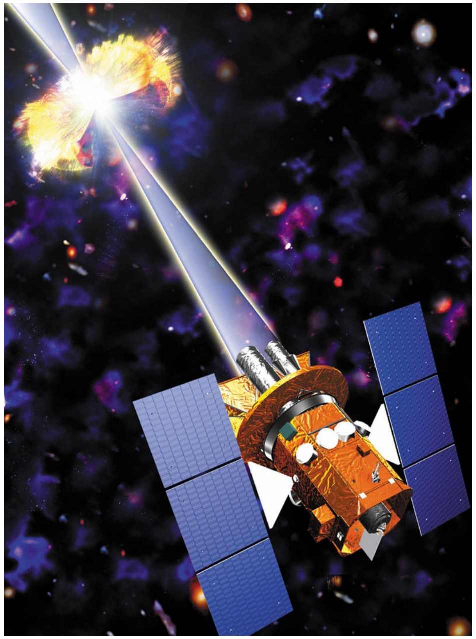


Chandra mission control
Near MIT in Cambridge, MA

Releasing spring 2018: CSC2
Catalog of 315875 X-ray sources seen by Chandra
Majority are accreting supermassive black holes
Also many X-ray sources near the Milky Way's central black hole (red splodge at center)



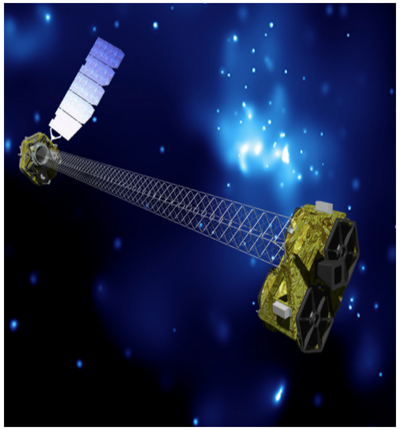
X-ray satellites

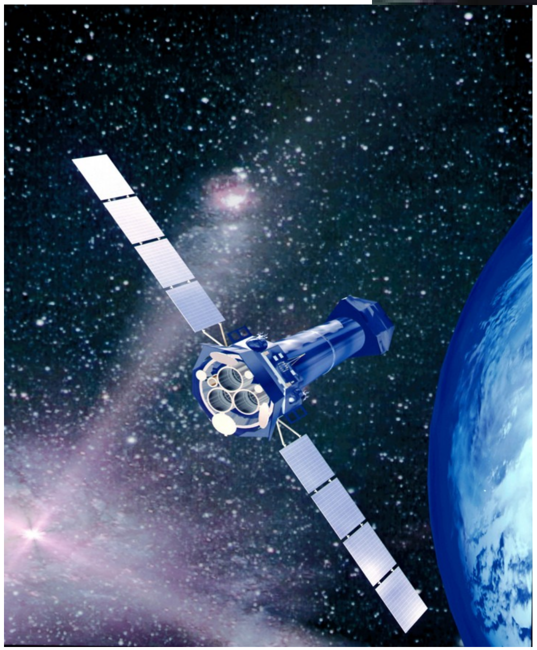


SWIFT – Low Earth Orbit

Chandra

NuStar – Low Earth Orbit





XMM – High Earth Orbit

Coming in the 2020s:
XARM (JAXA)
Athena (ESA)
2030s?
Lynx (NASA study)

The Universe in the 21st Century:

Here and now:

- Most stars have planets (Kepler mission)
  Earth-sized planets very common
  Habitable planets? Coming soon...

- Relative amounts of Earth chemical elements understood from nuclear reaction rates in stars ('we are stardust')
  Now studying freshly made elements in supernova fireballs

- Our galaxy grew partly by gobbling up dwarf galaxies
  See partly digested streams of stars

Back in the day:

- We know the Universe is 13.7 billion years old
  (big update was due this morning!)
- We now see galaxies at only 0.5 billion years after the Bang
- The young universe was crowded and violent, lots of colliding galaxies and quasars
- The universe is not just full of stars shining by nuclear fusion
  Much of the energy is coming from gravity reactors – gas falling into giant black holes – and natural particle accelerators – jets from spinning black holes.