The Chandra X-ray Observatory and the X-ray Universe

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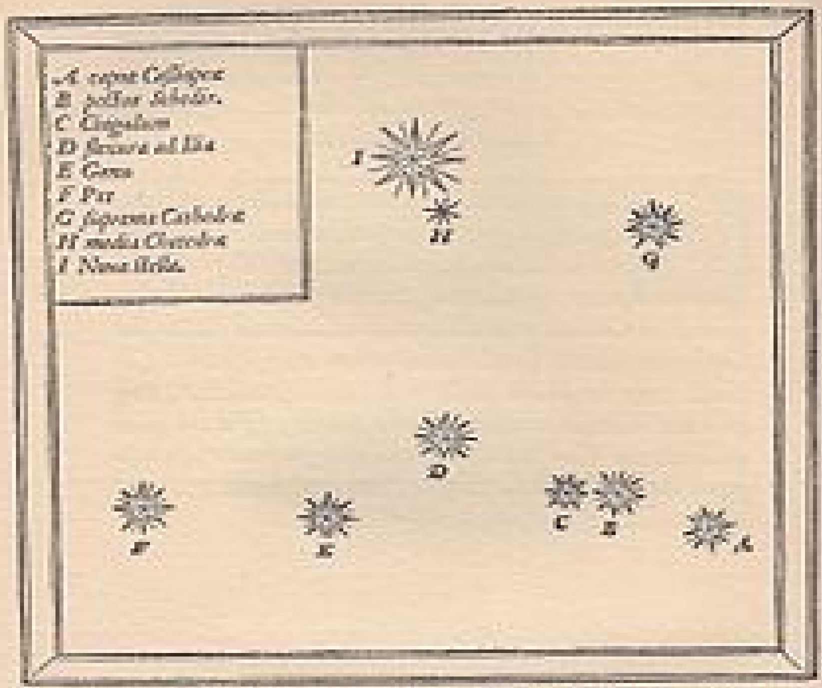
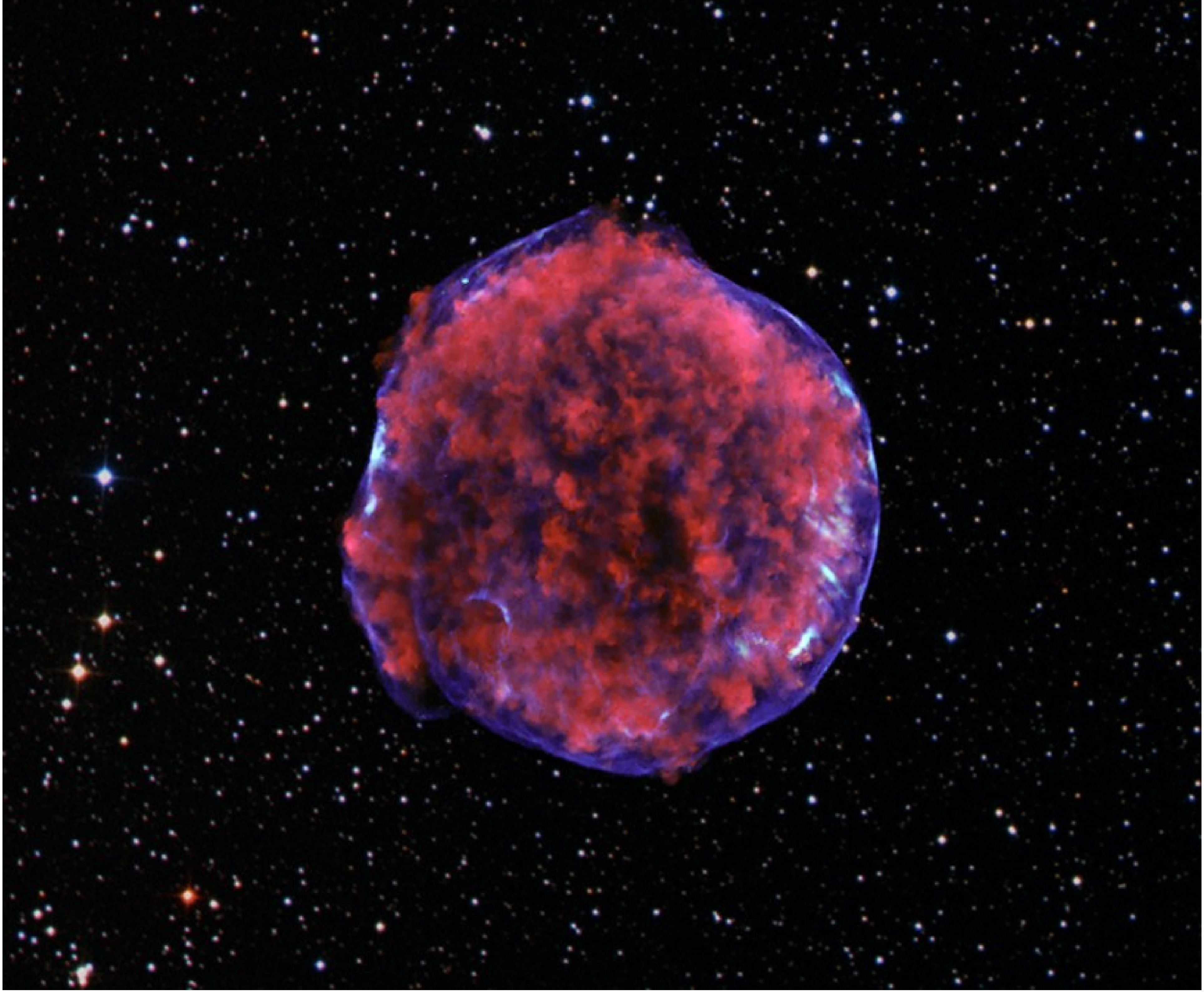
- Harvard & Smithsonian -

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..



Distantiam verò huius stellæ à fixis aliquibus in hac Cassiopeiæ constellatione, exquisito instrumento, & omnium minutorum capaci, aliquoties obseruaui. Inueni autem eam distare ab ea, quæ est in pectore, Schedir appellata B, 7. partibus & 55. minutis: à superiori verò



Digression: What's an X-ray?

A lot of people are familiar with, but confused by, medical X-rays

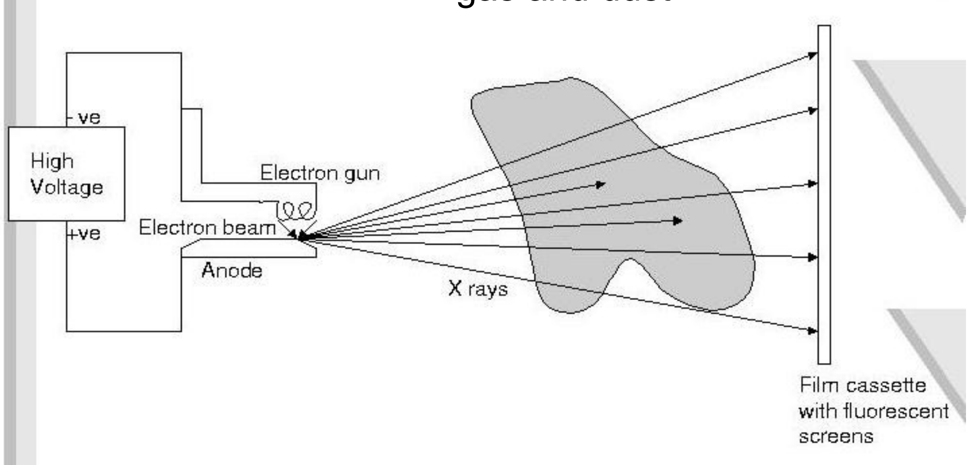
The photo at left is a picture of an X-ray light bulb, photobombed by someone's hand

The X-rays are the light bit. The dark areas are where there aren't any X-rays because the hand has blocked them.

X-ray bulb
= star,galaxy

Hand
= interstellar
gas and dust

X-ray
camera



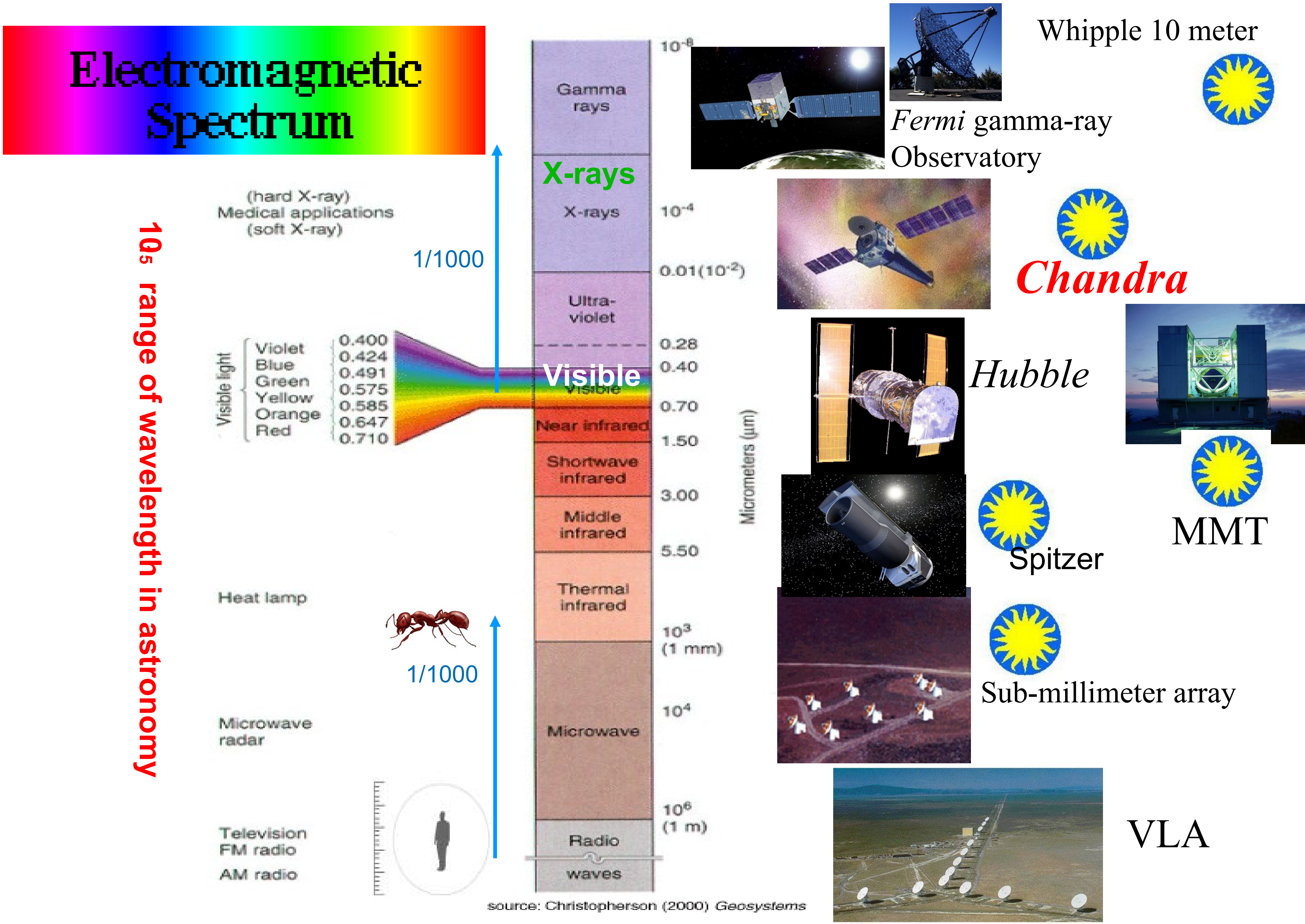
In X-ray astronomy we are usually taking a picture of the “light bulb” (the star making the X-rays) and not interested in the “hand” (stuff blocking the X-rays between the star and us)

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: "COLOUR"
Colour is how our brains encode the photon energy our eyes detect

We are now in the era of multiwaveband astronomy



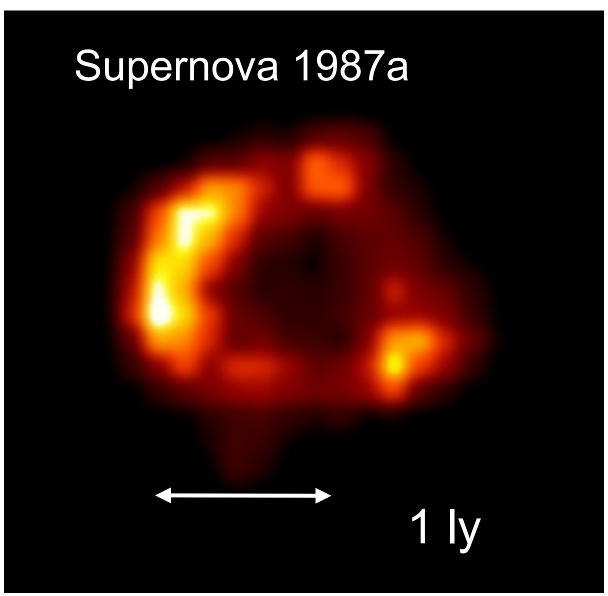
Sources of X-rays

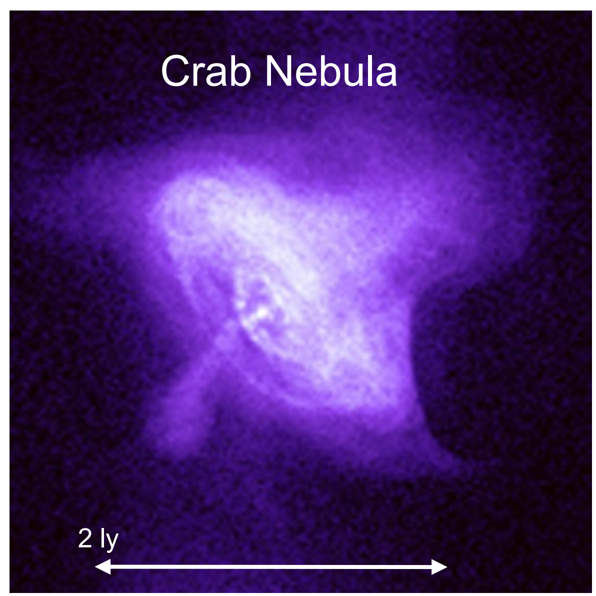
- Shock waves in plasma (ionized gas)
- "Synchrotron" caused by energetic particles in magnetic fields (like a natural particle accelerator)
- Energy release from gravity ("accretion" power)

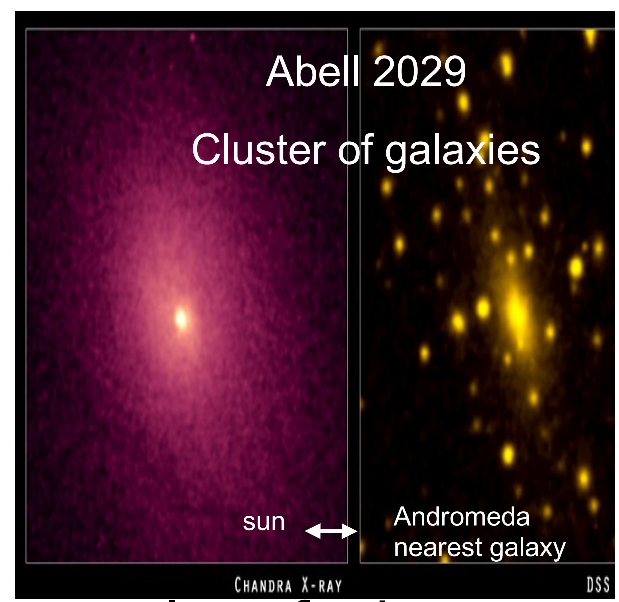
Explosions: Supernovae and their remnants

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

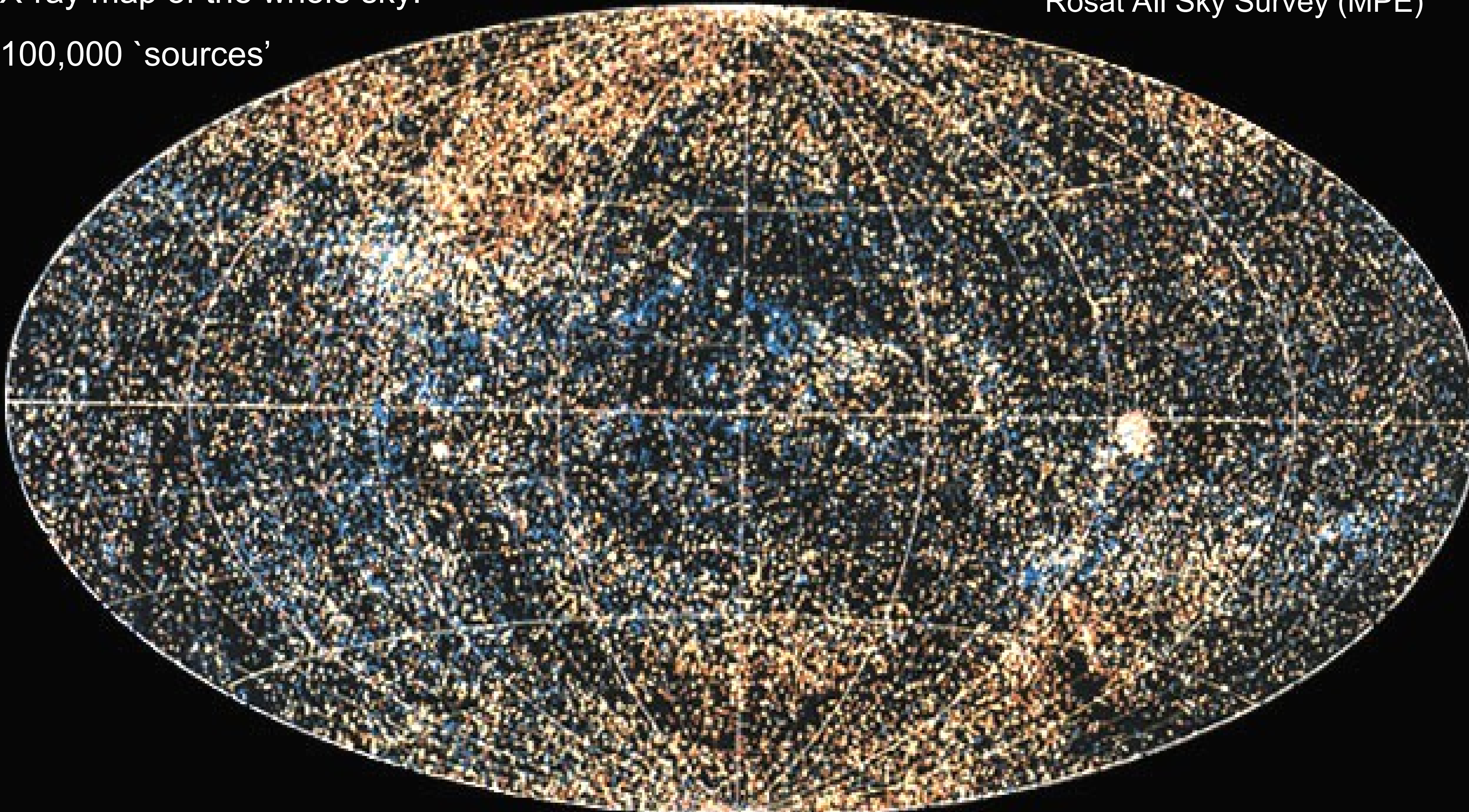
In X-rays, we see mostly accreting sources: energy from gravity!

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

The Chandra X-ray Observatory

Launched 25 years ago 23 July 1999

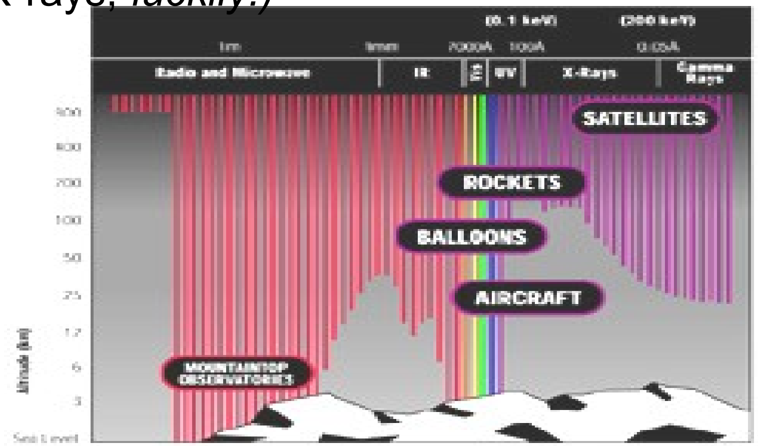
A revolution in X-ray astronomy

and astronomy in general

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

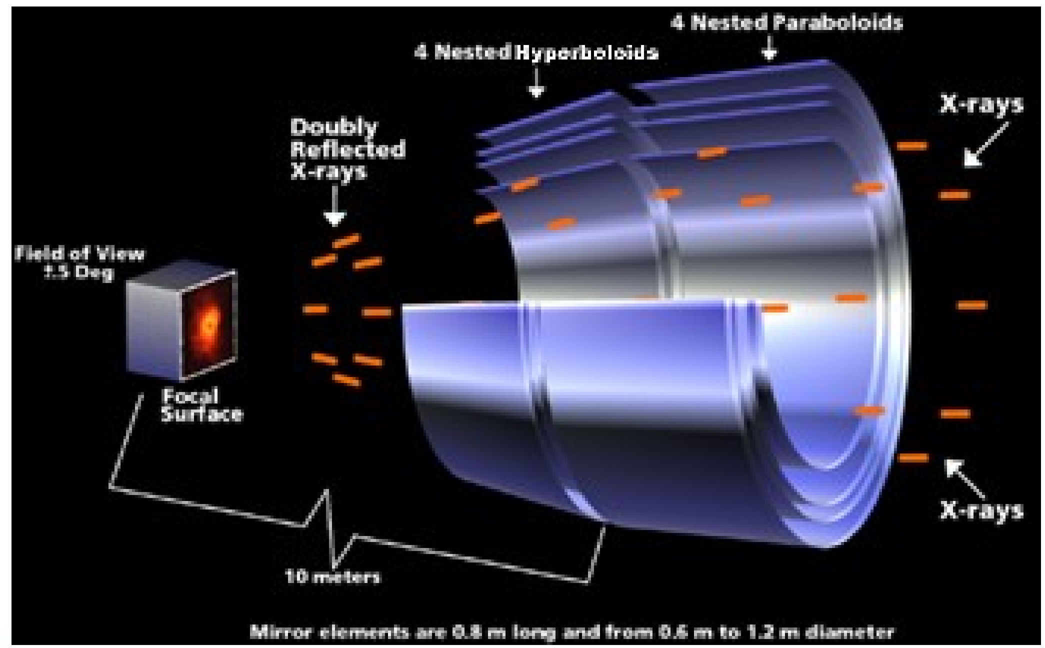
X-rays don’t reflect off a normal mirror – they get absorbed.

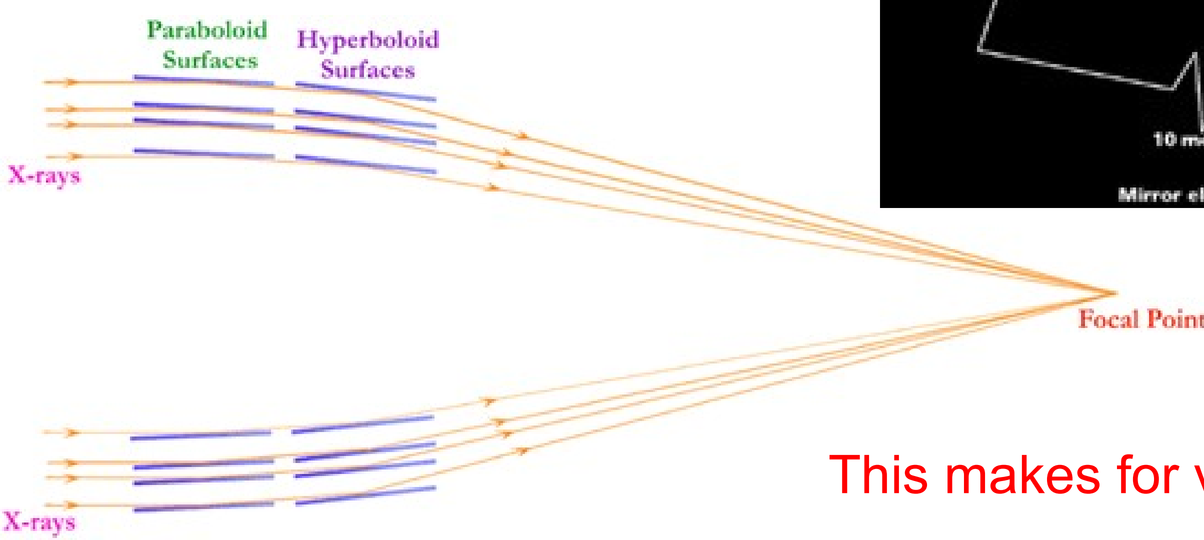
Only by striking a mirror at a glancing angle, about 1°,

do X-rays reflect.

Then they act like visible light

and can be focused

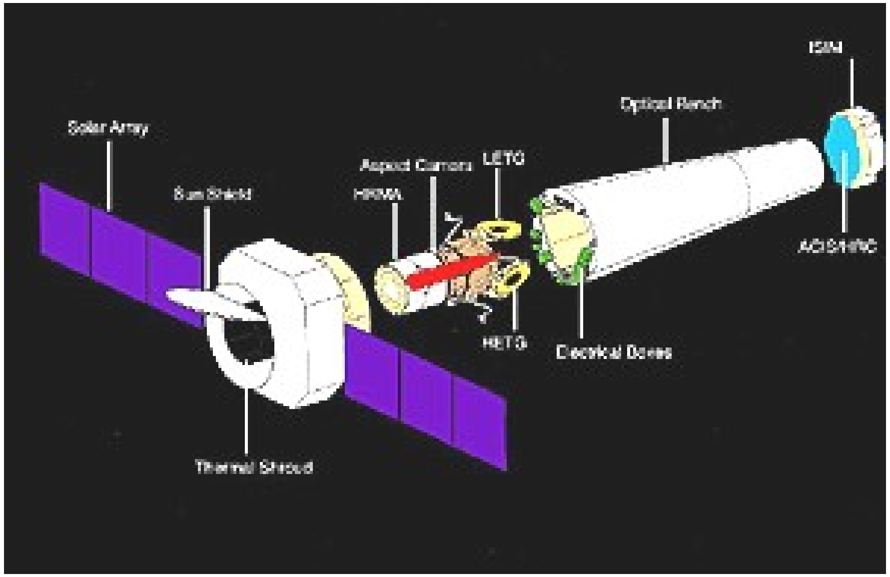




This makes for very long telescopes

The Chandra spacecraft

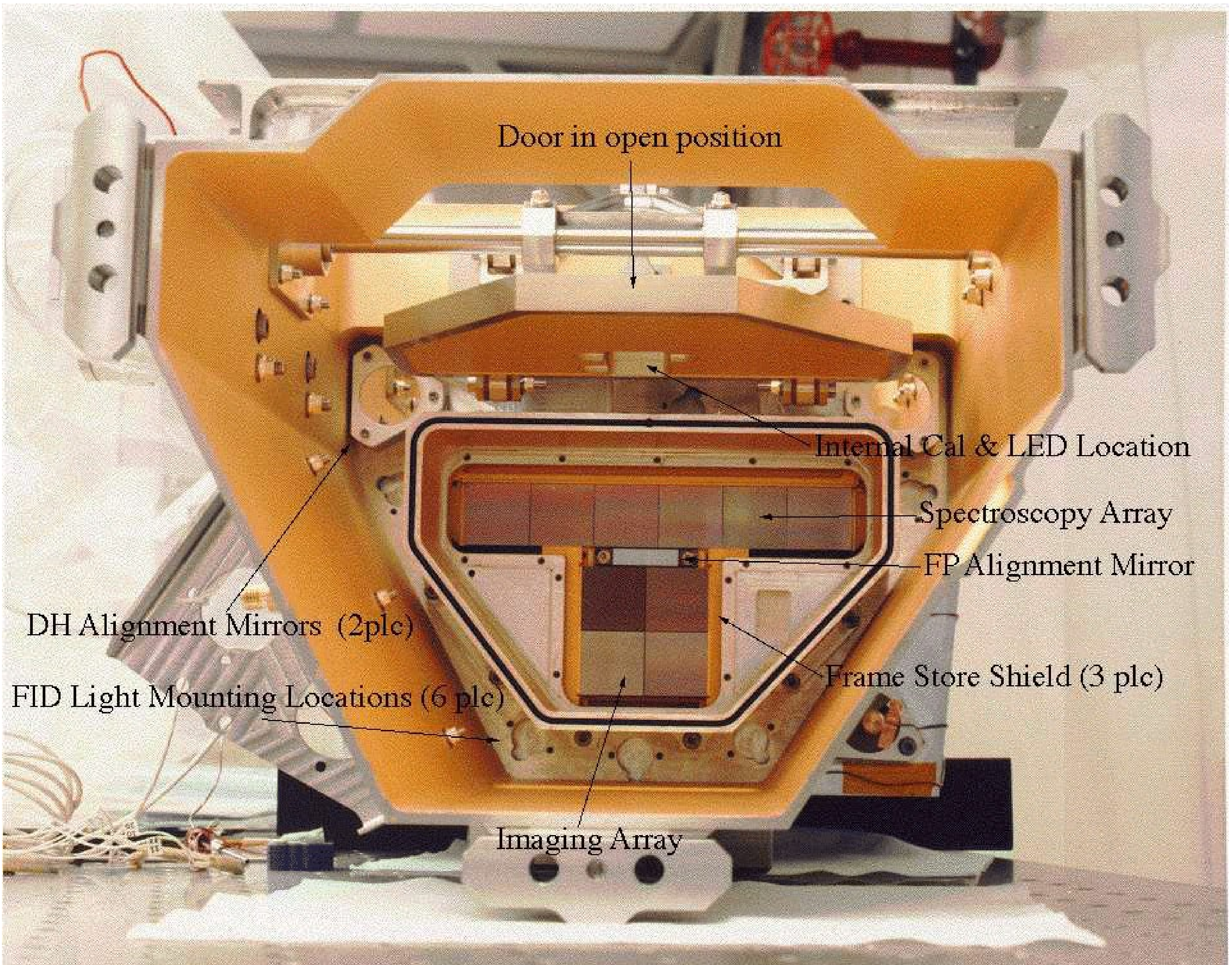
10 meters (32 ½ ft) from mirror to detector, 1.2 meters (4ft) across mirror



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

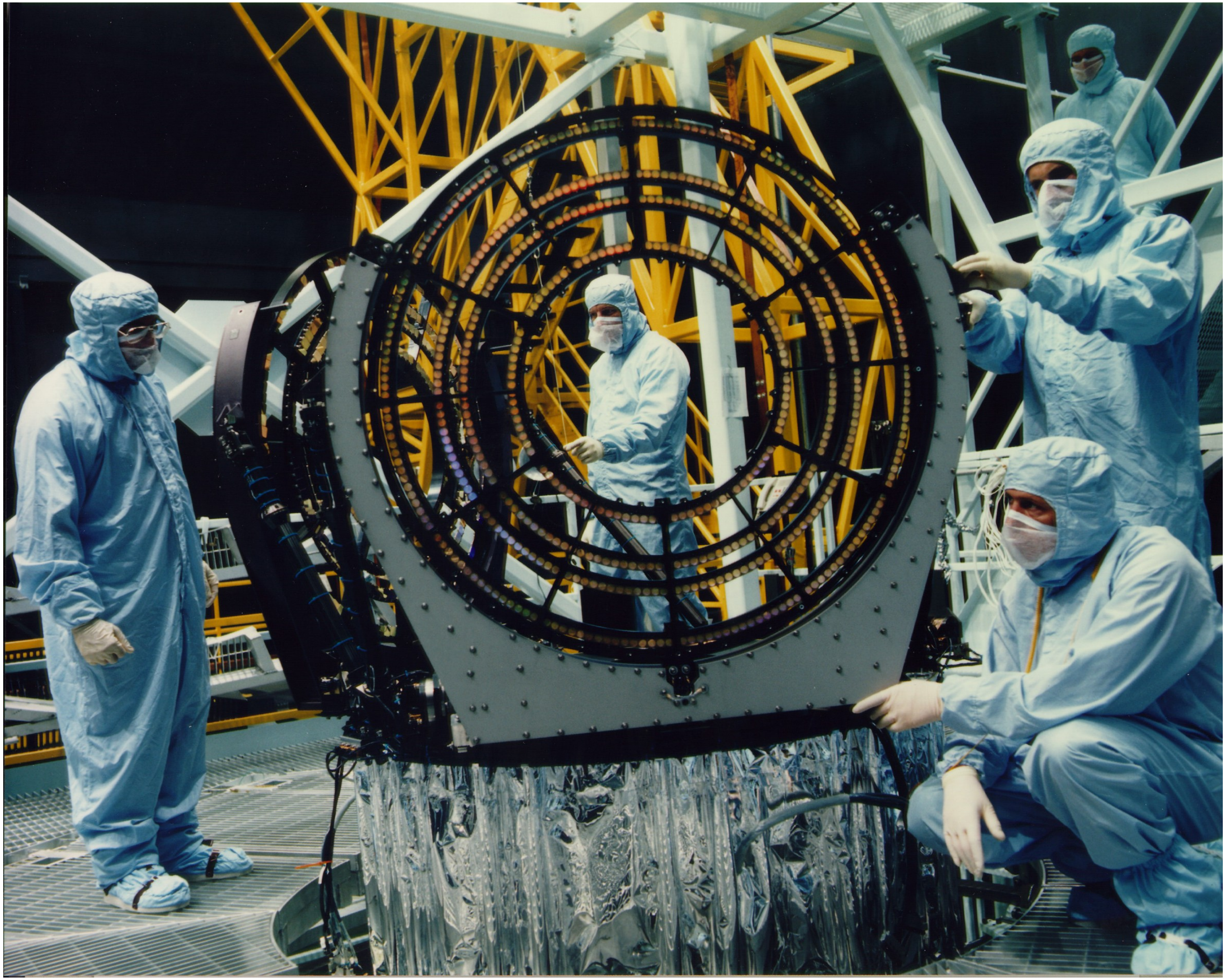
Main camera is ACIS - Advanced CCD Imaging Spectrometer

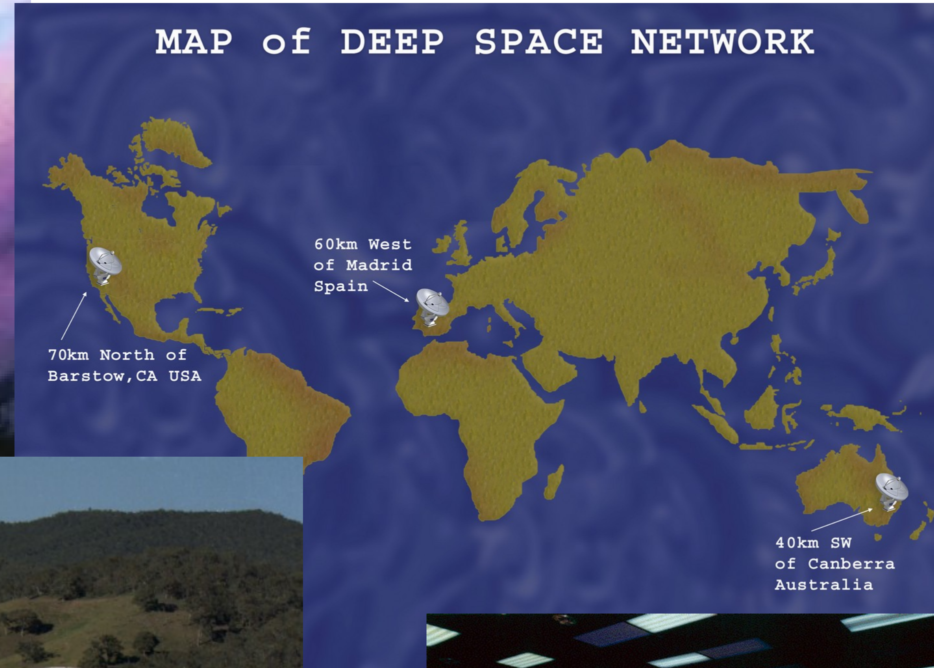
10 megapixel X-ray CCD camera with 0.5" spatial resolution (24 micron pixels)
Each 1 megapixel chip has 7 arcmin field



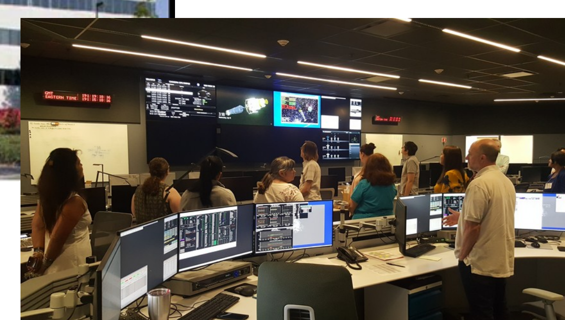
Chandra also carries transmission gratings which can disperse the X-ray light to make spectra

They are swung into the optical path when needed





DSN control
at Jet Propulsion Lab
Pasadena, CA



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

Chandra mission control
Burlington, MA


07 45 58

Meanwhile:

December 1999

Kourou

XMM-Newton: the European X-ray observatory

Chandra versus XMM:

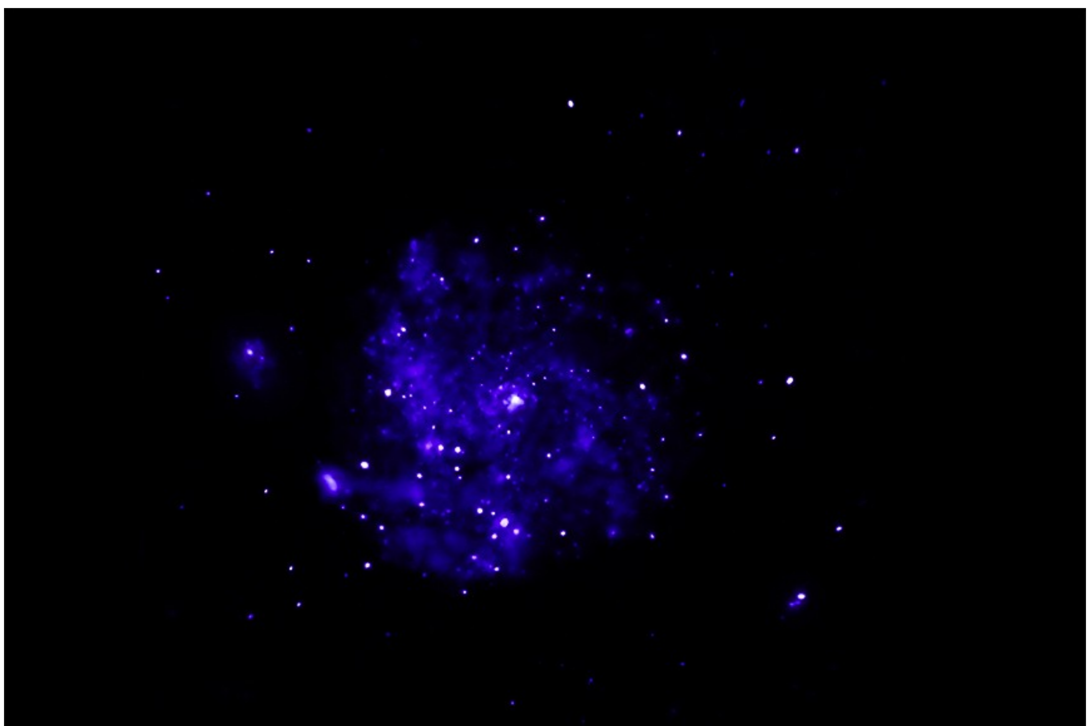
Chandra: sharper images, fainter sources

XMM: more sensitive for bright sources, bigger field of view

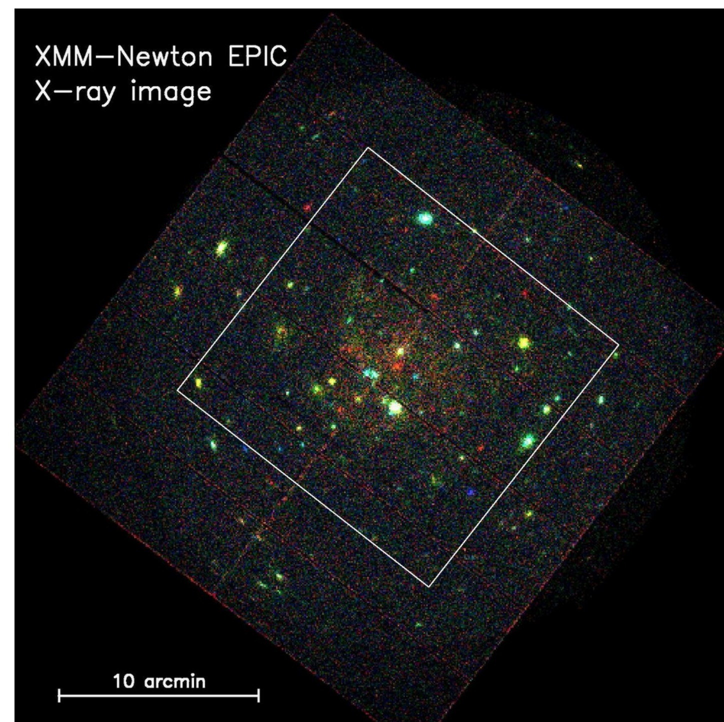
The two spacecraft are nicely complementary!

	Eff.Area	Angular res
Chandra	440 cm2	0.5”
XMM	4650 cm2	15”

Galaxy M101 (Chandra)



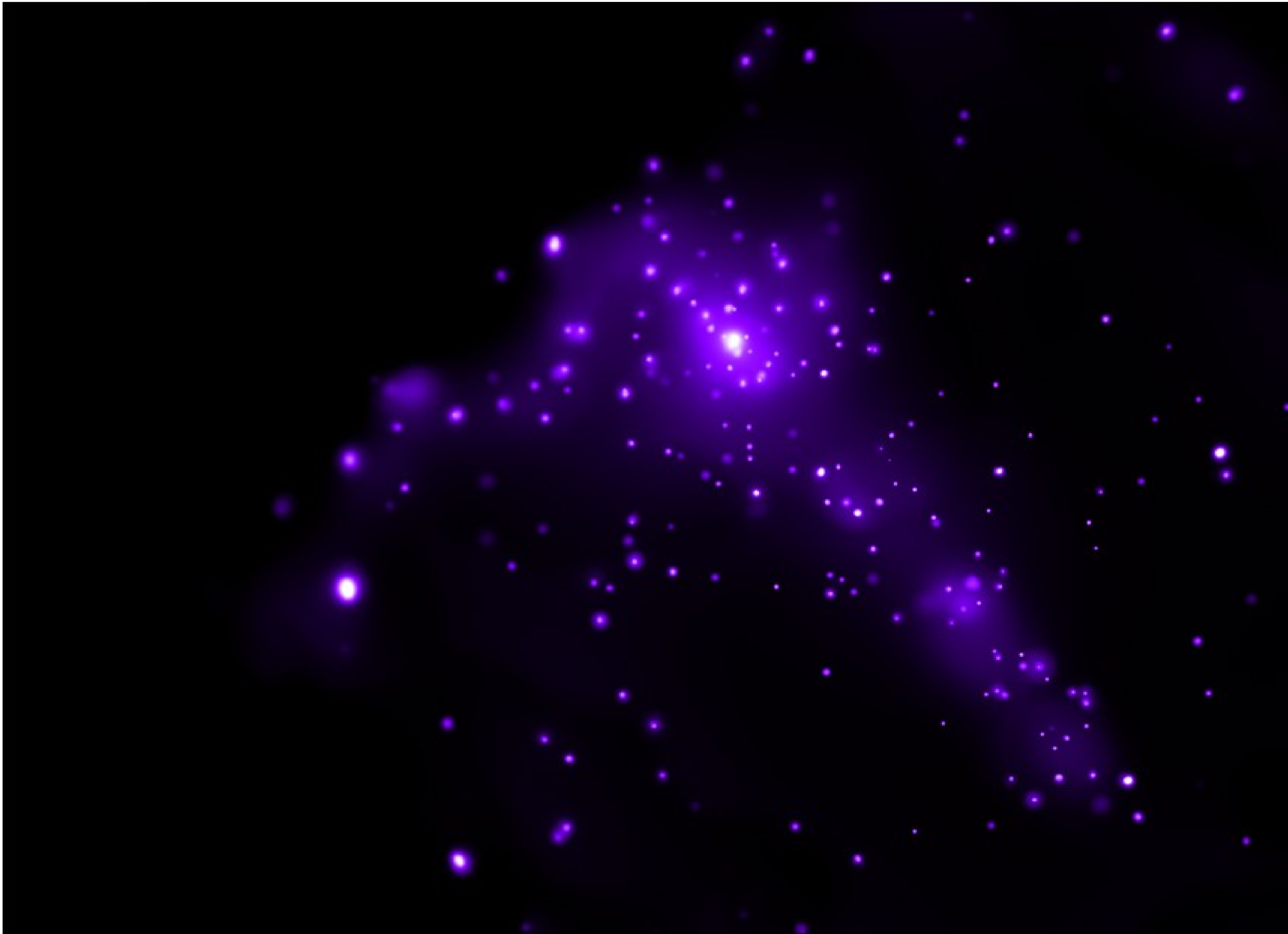
Galaxy M101 (XMM)



Milky Way galaxy: star cluster (infrared)

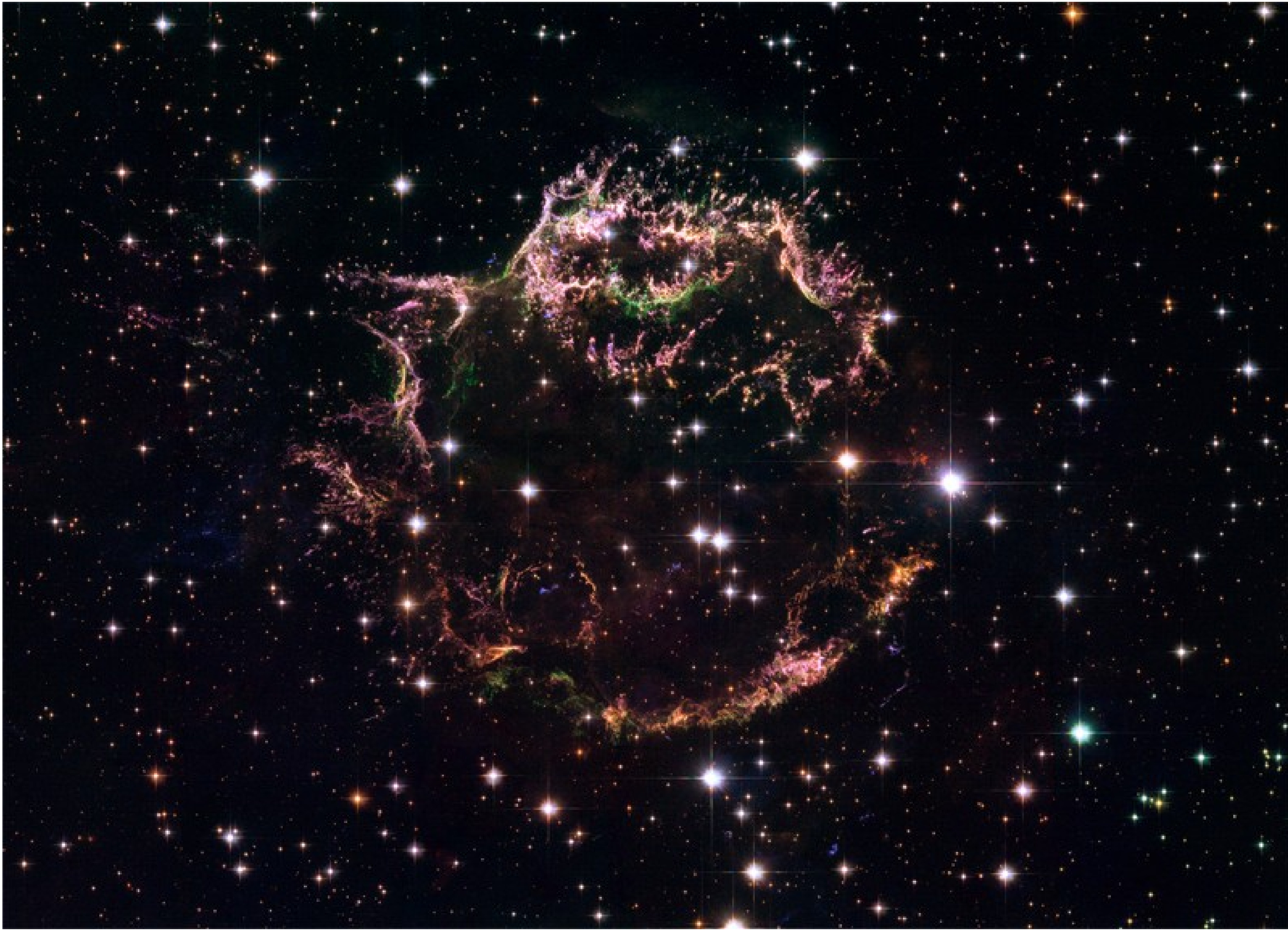
NGC 281 star cluster – infrared
10000 light years away

Milky Way galaxy: star cluster (X-ray)

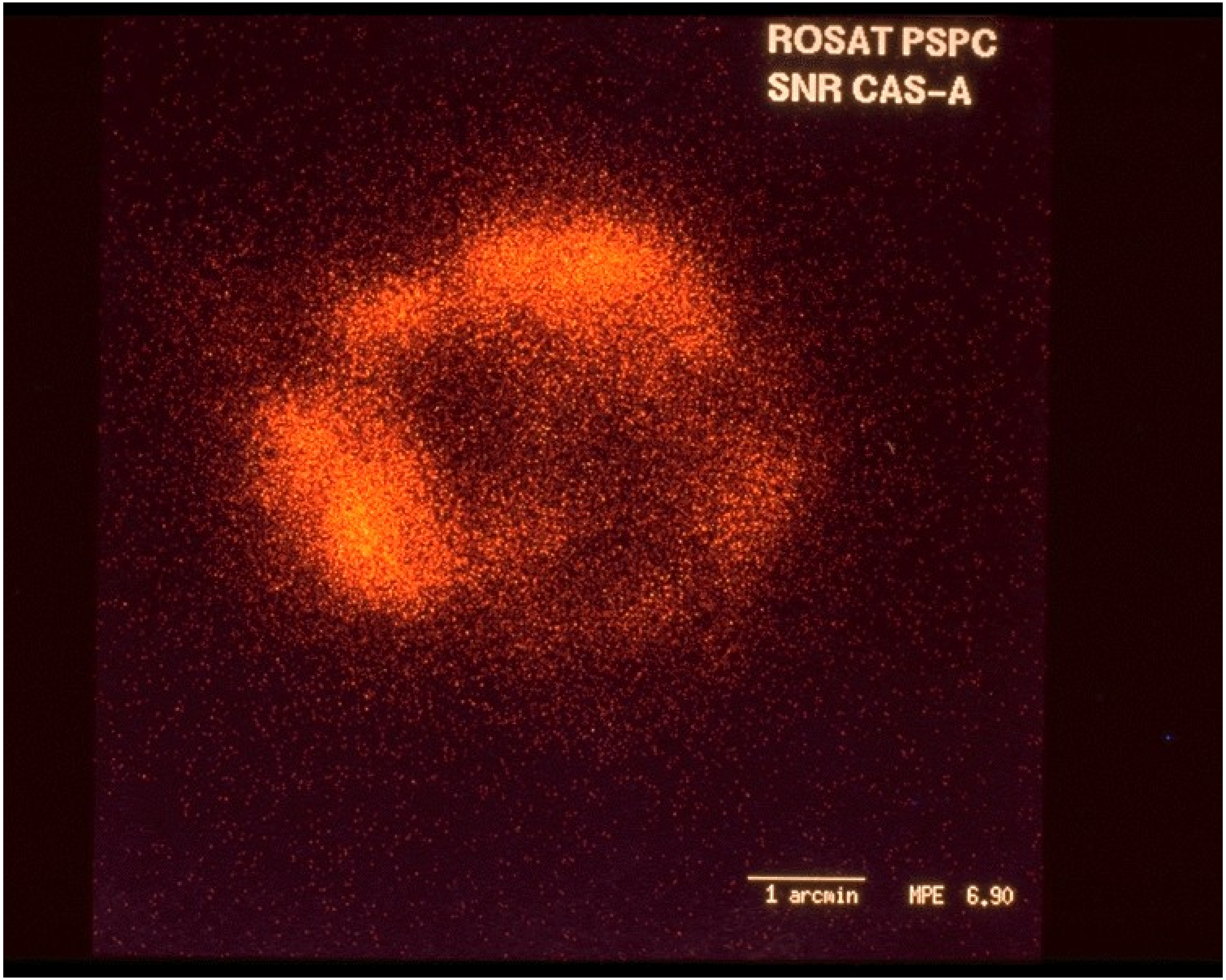


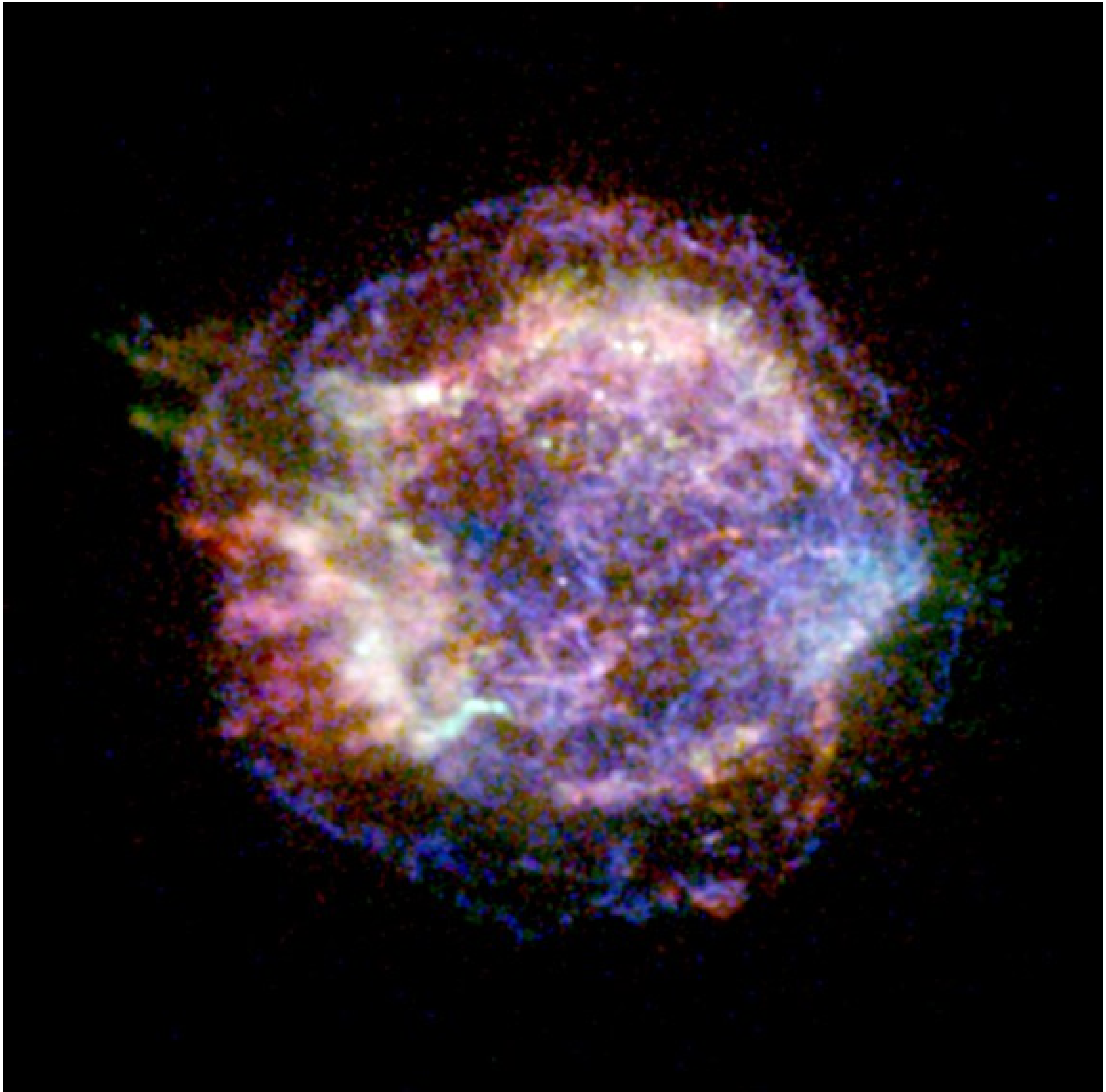
Milky Way galaxy: star cluster (infrared +X-ray)

NGC 281 (Scott Wolk, SAO) 9500 years away



Milky Way galaxy: Supernova remmant (X-ray)



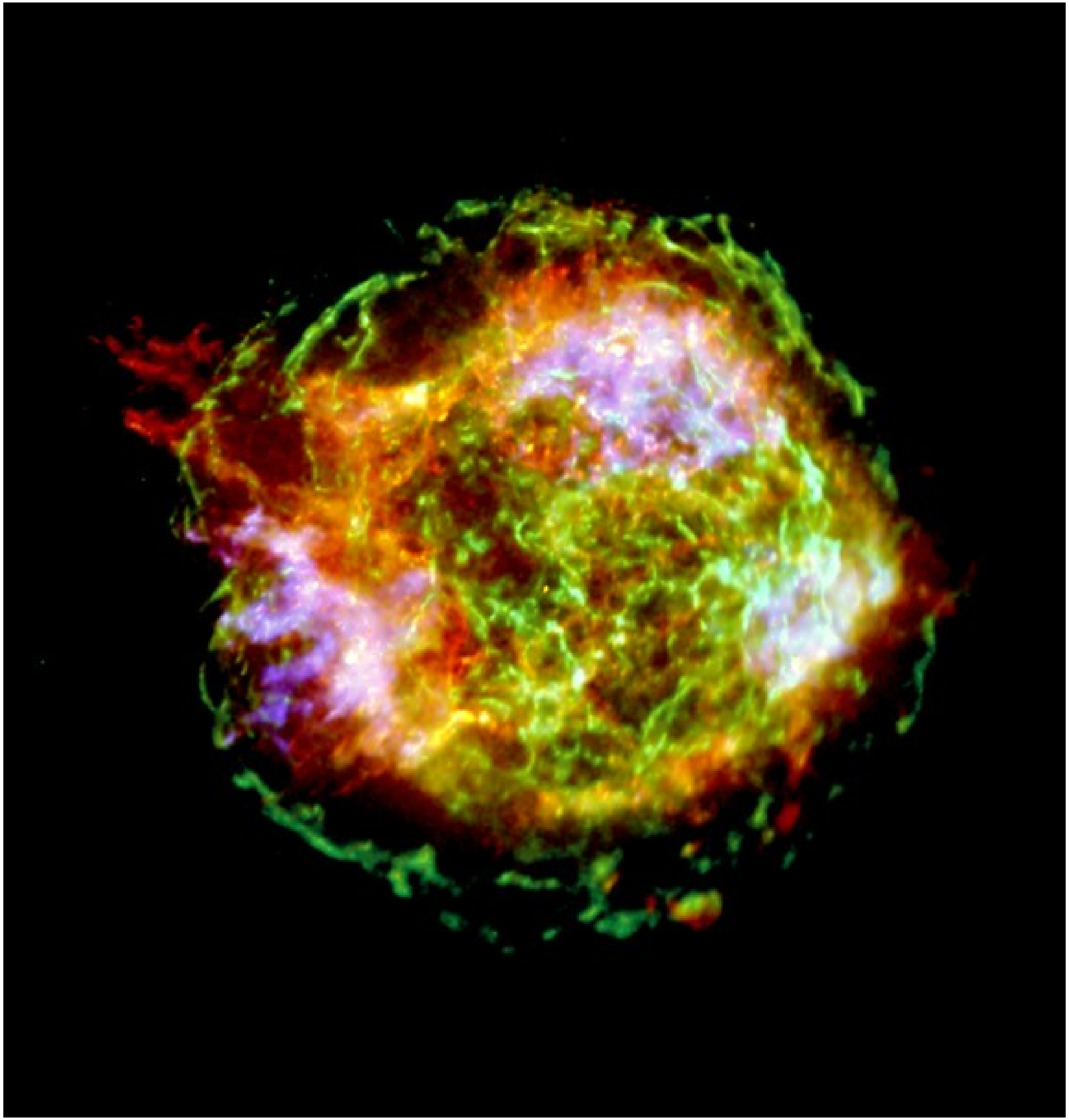


1 hour
with
Chandra

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)

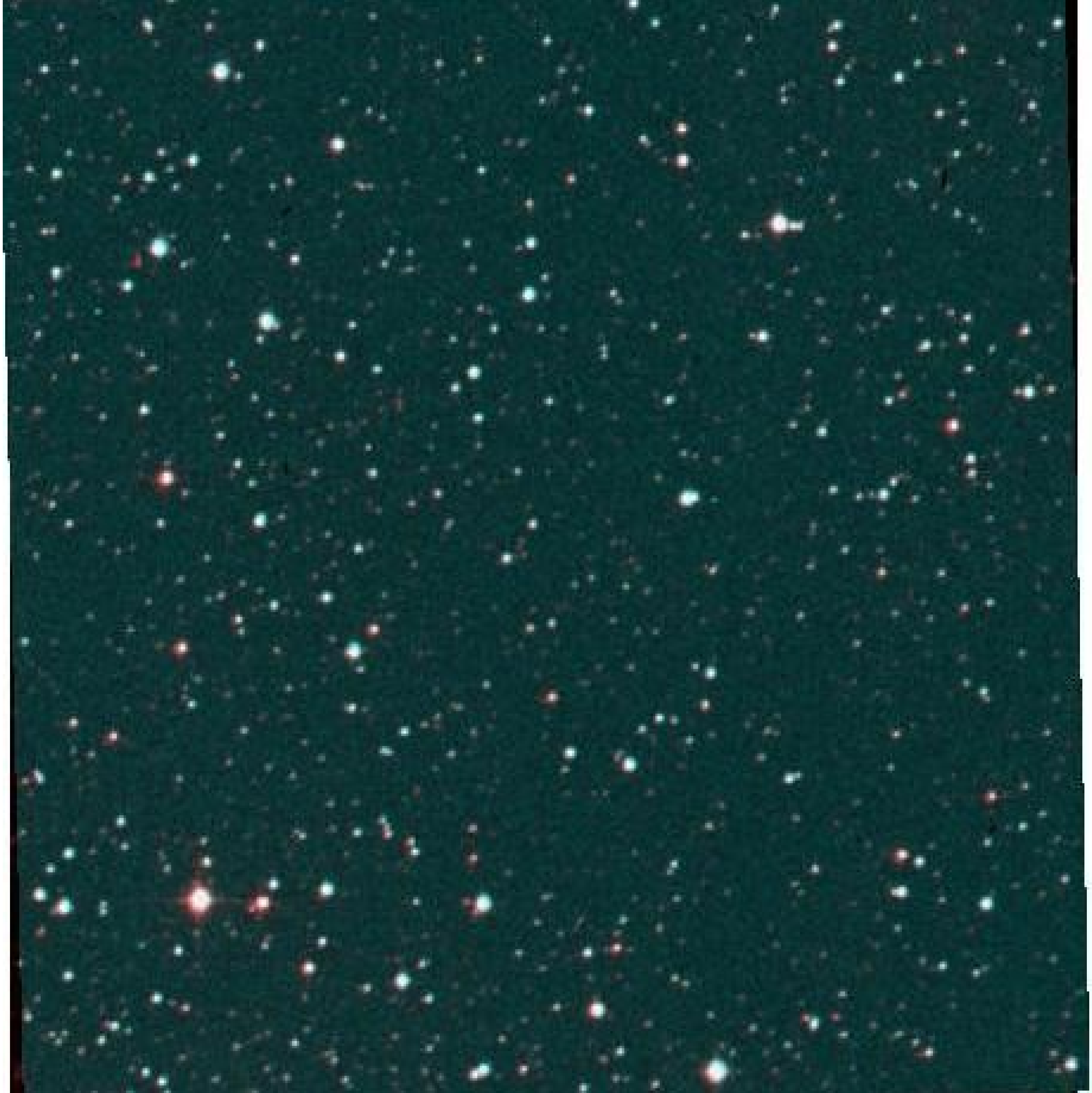


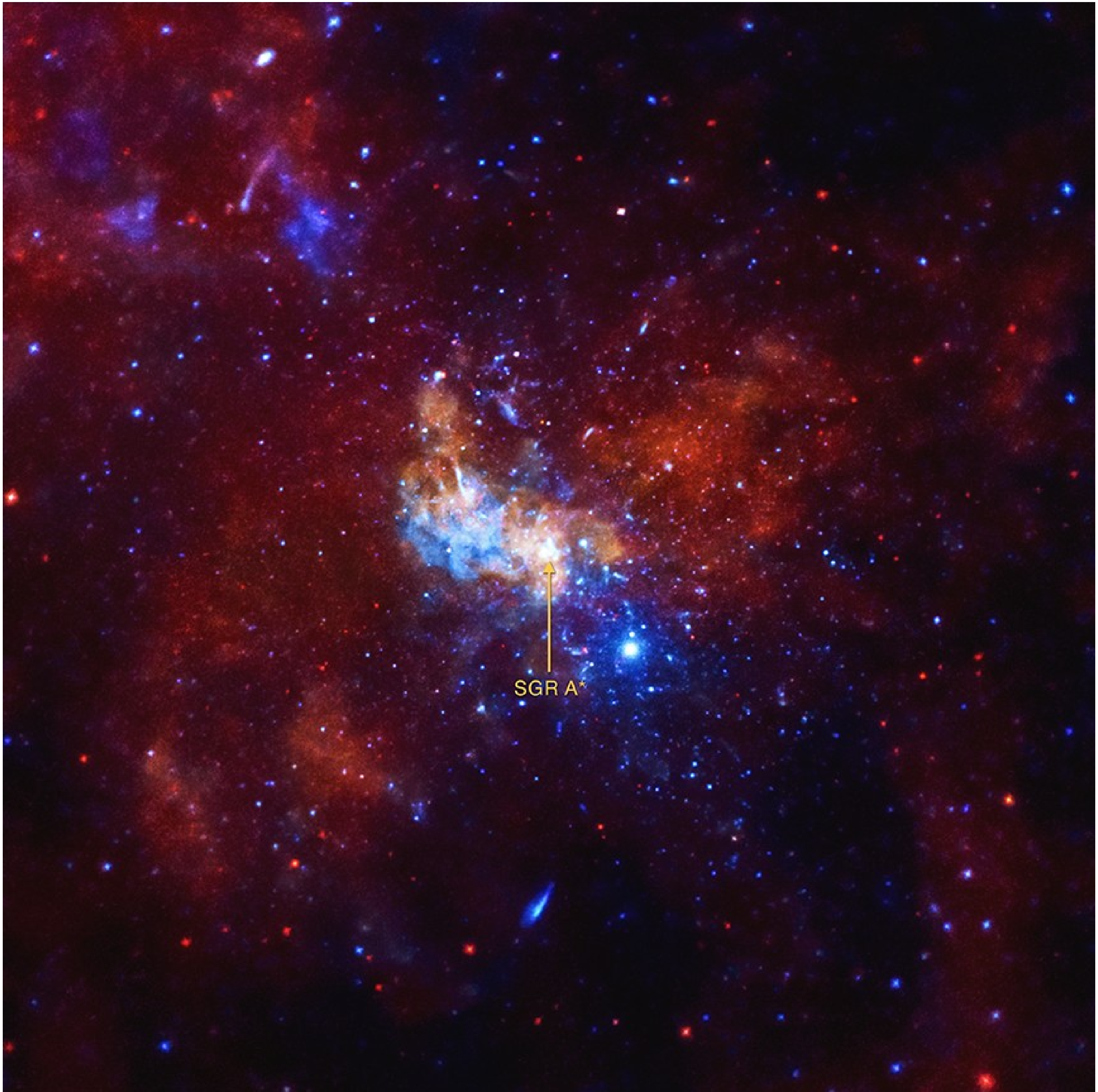
11000 light years away

16 light years across

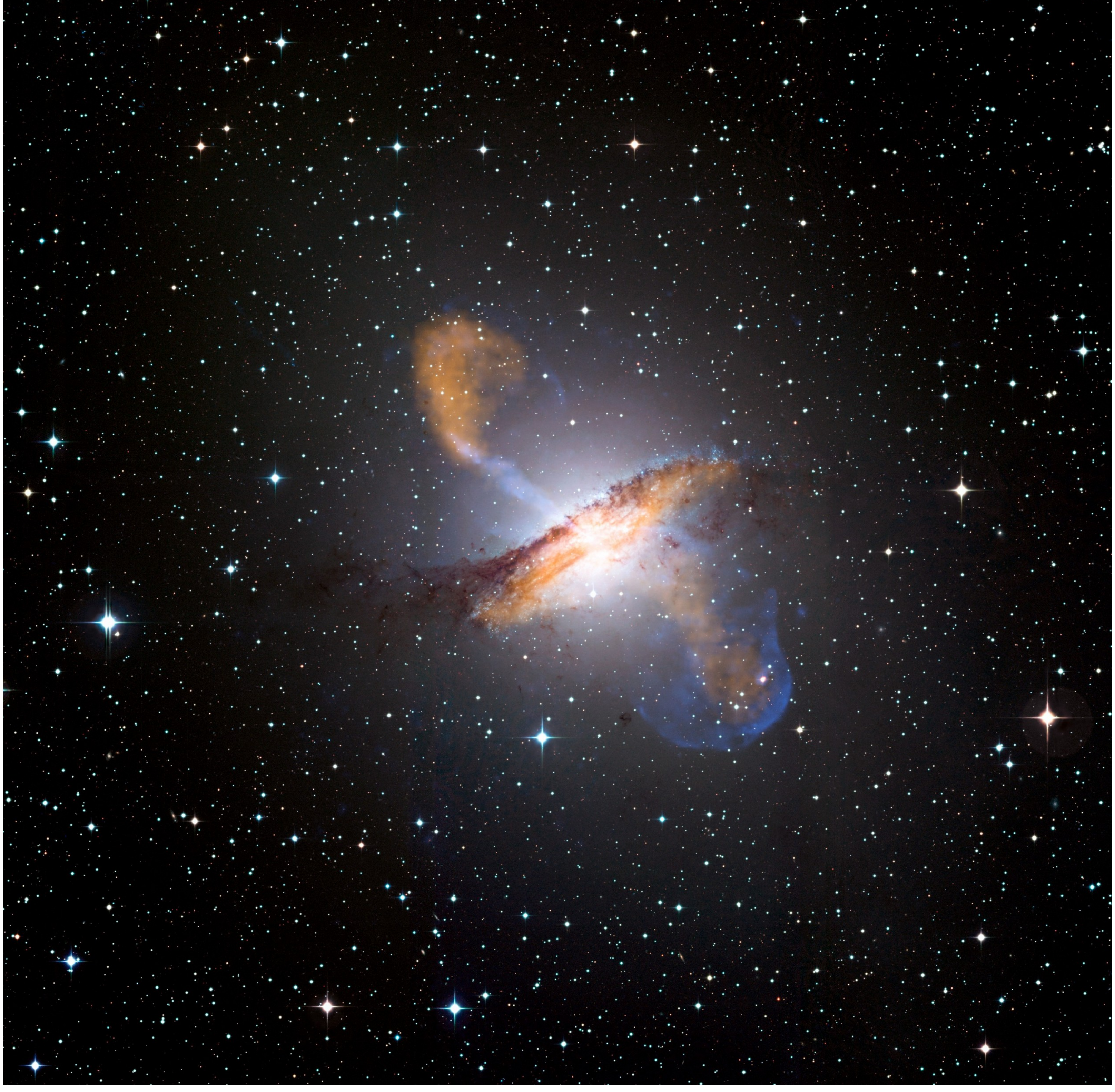
The Milky Way Galaxy: Galactic Center

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




SGR A*

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



Galaxy NGC 4993 -   130 million years away

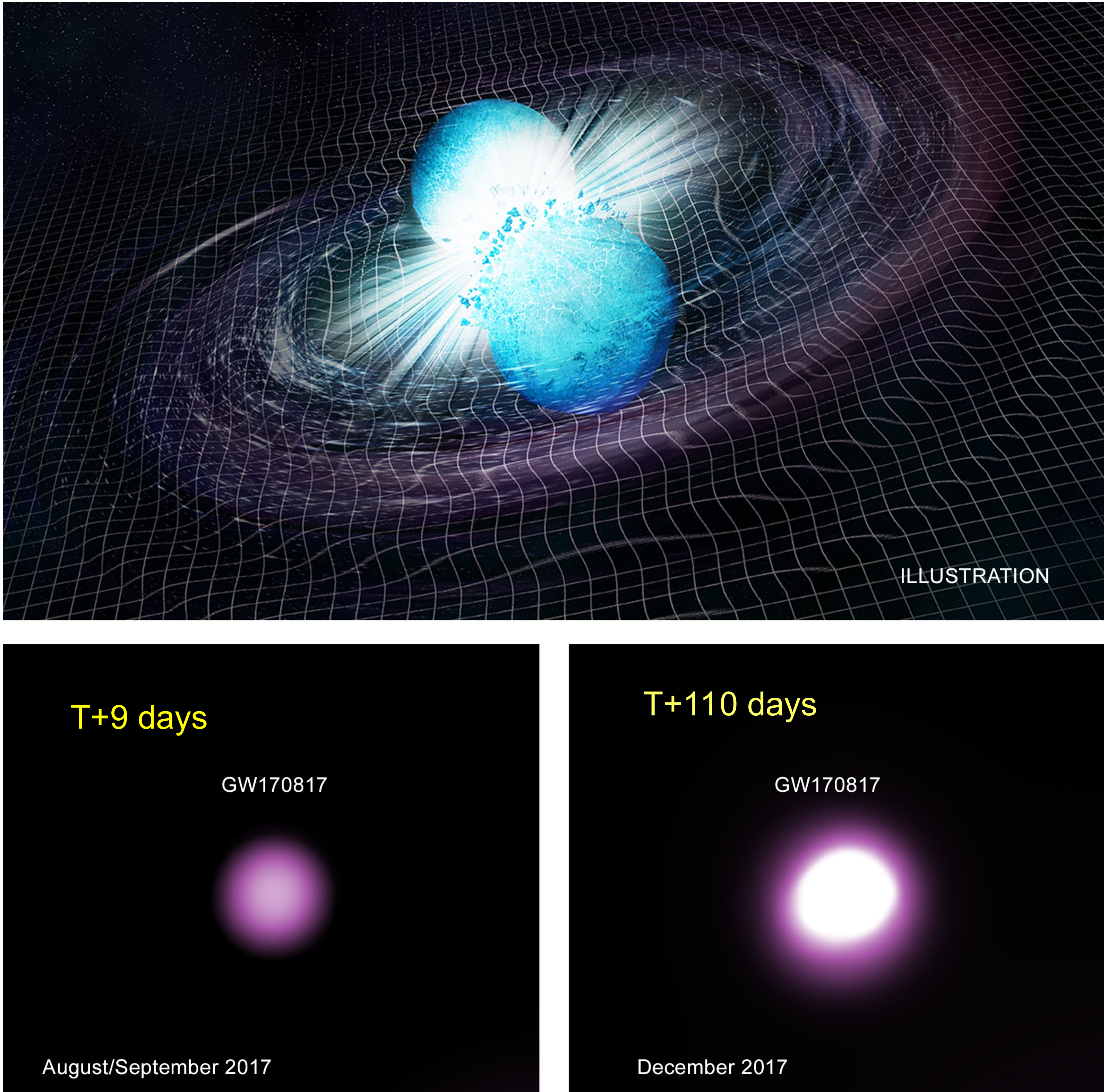
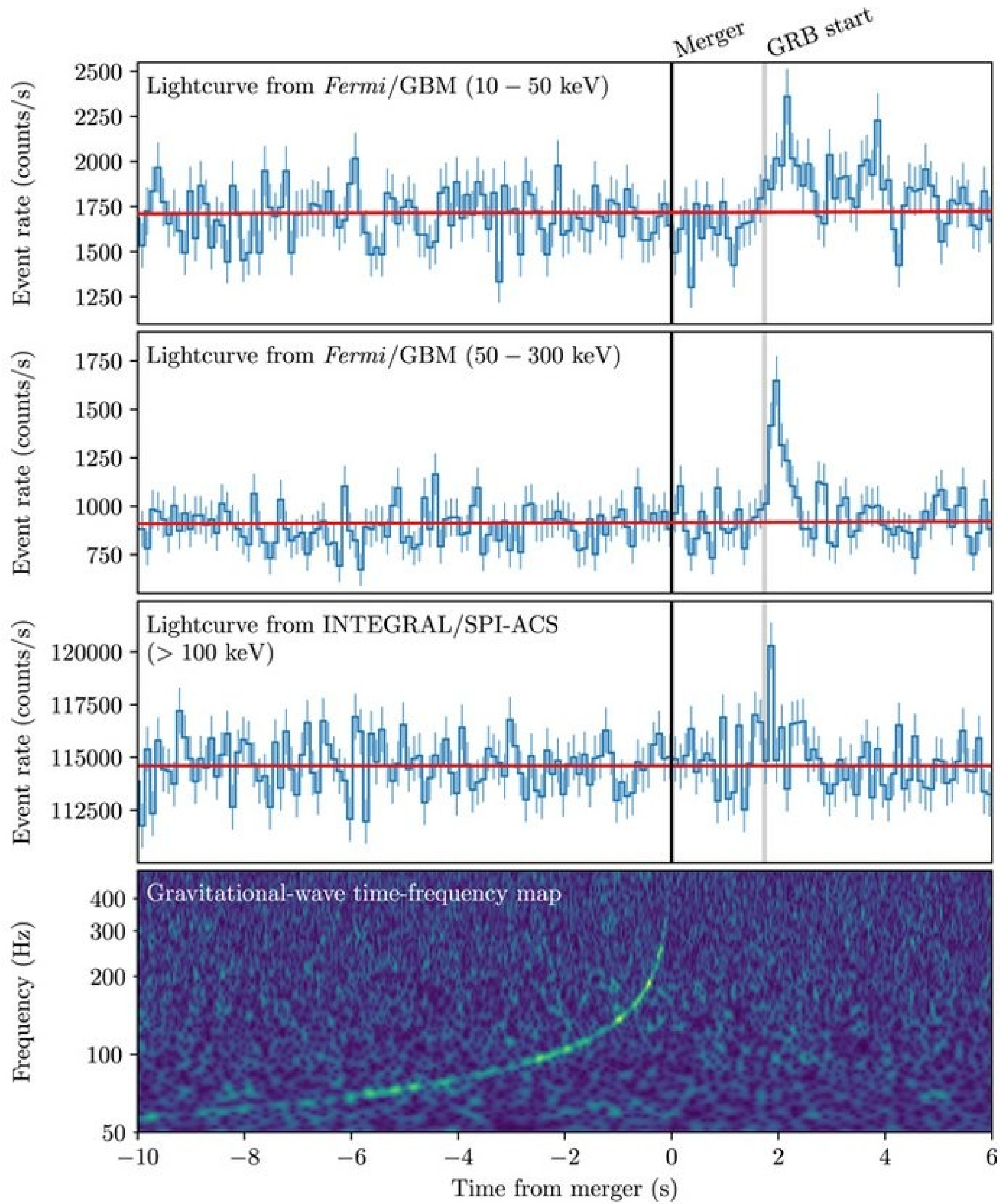
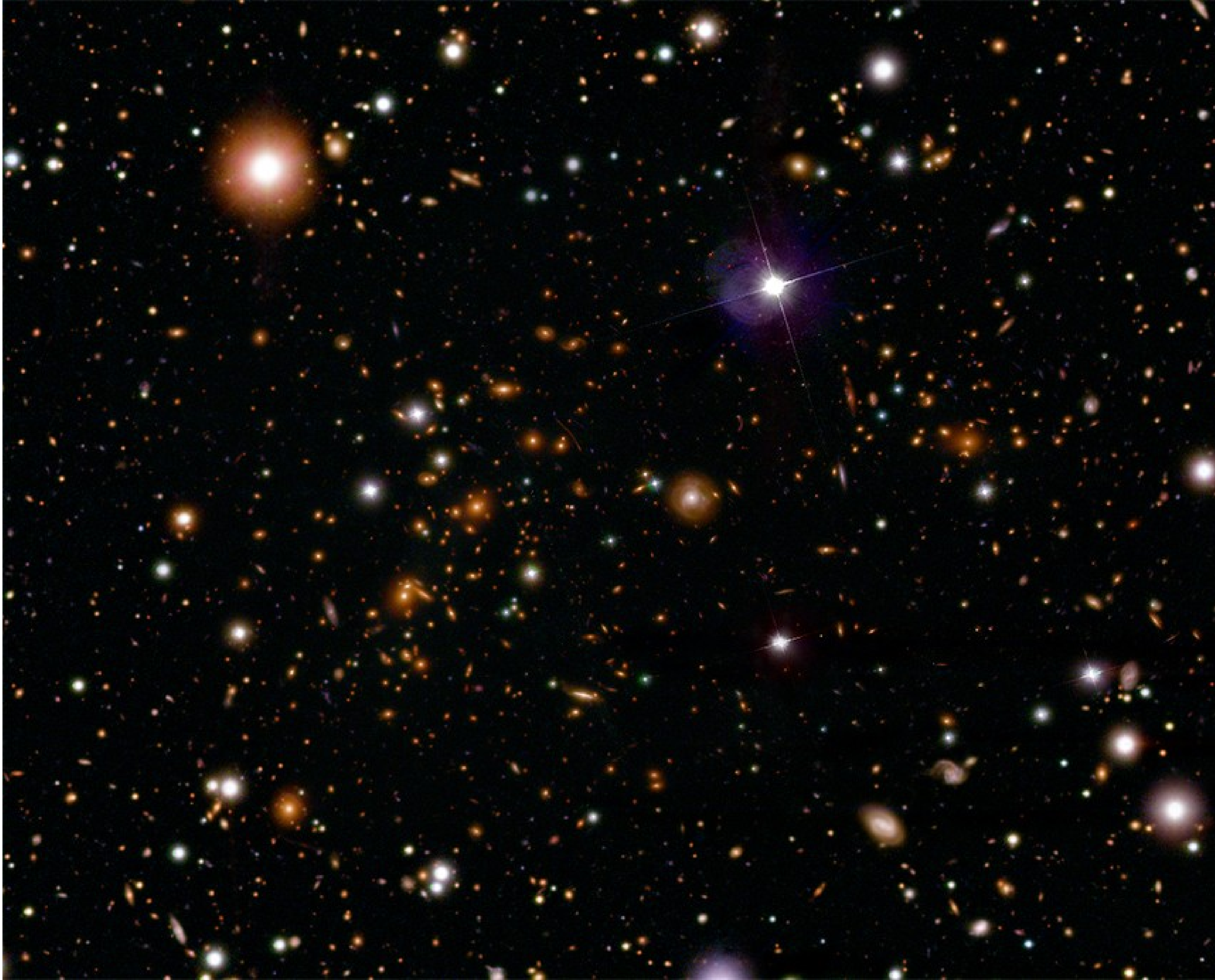
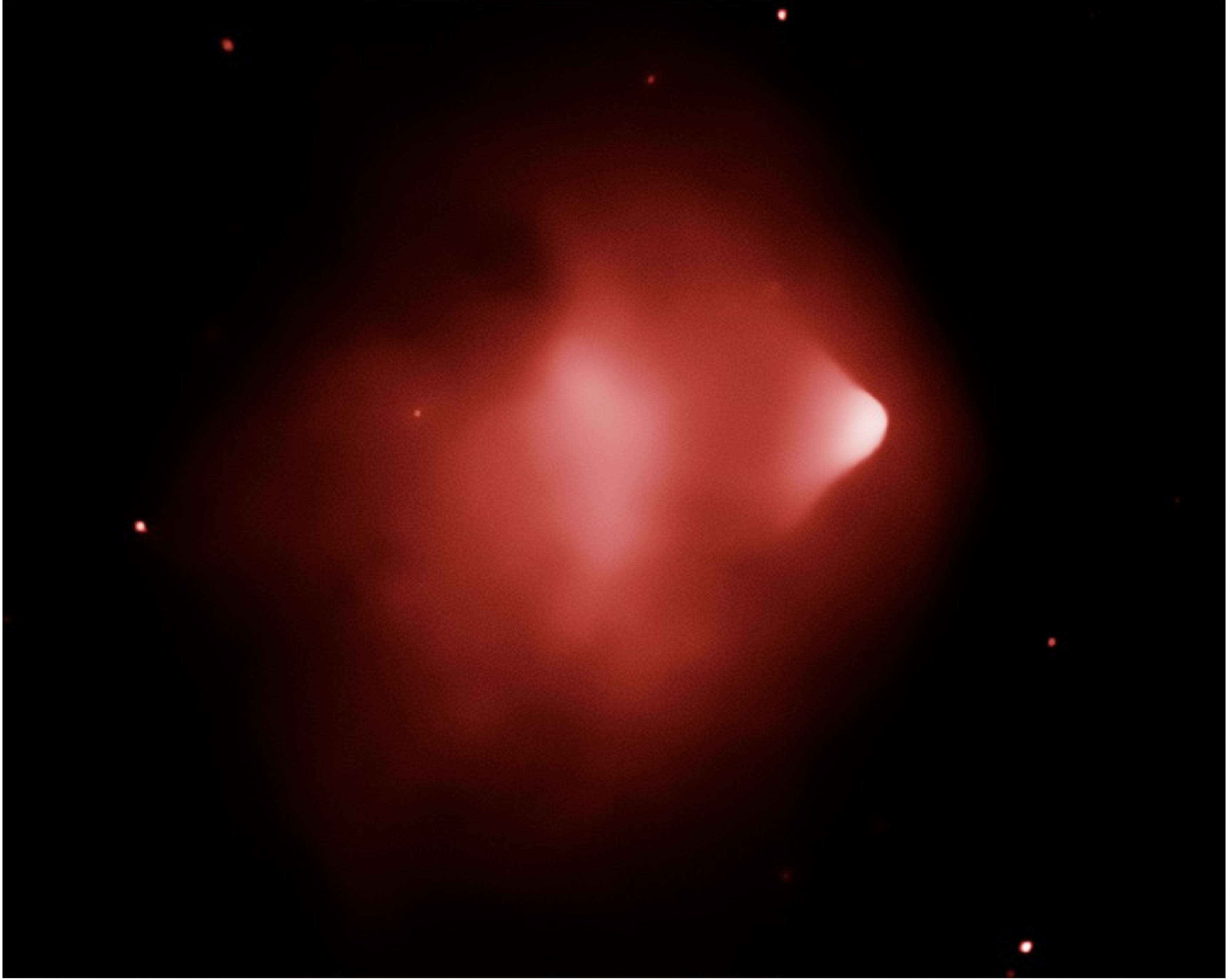


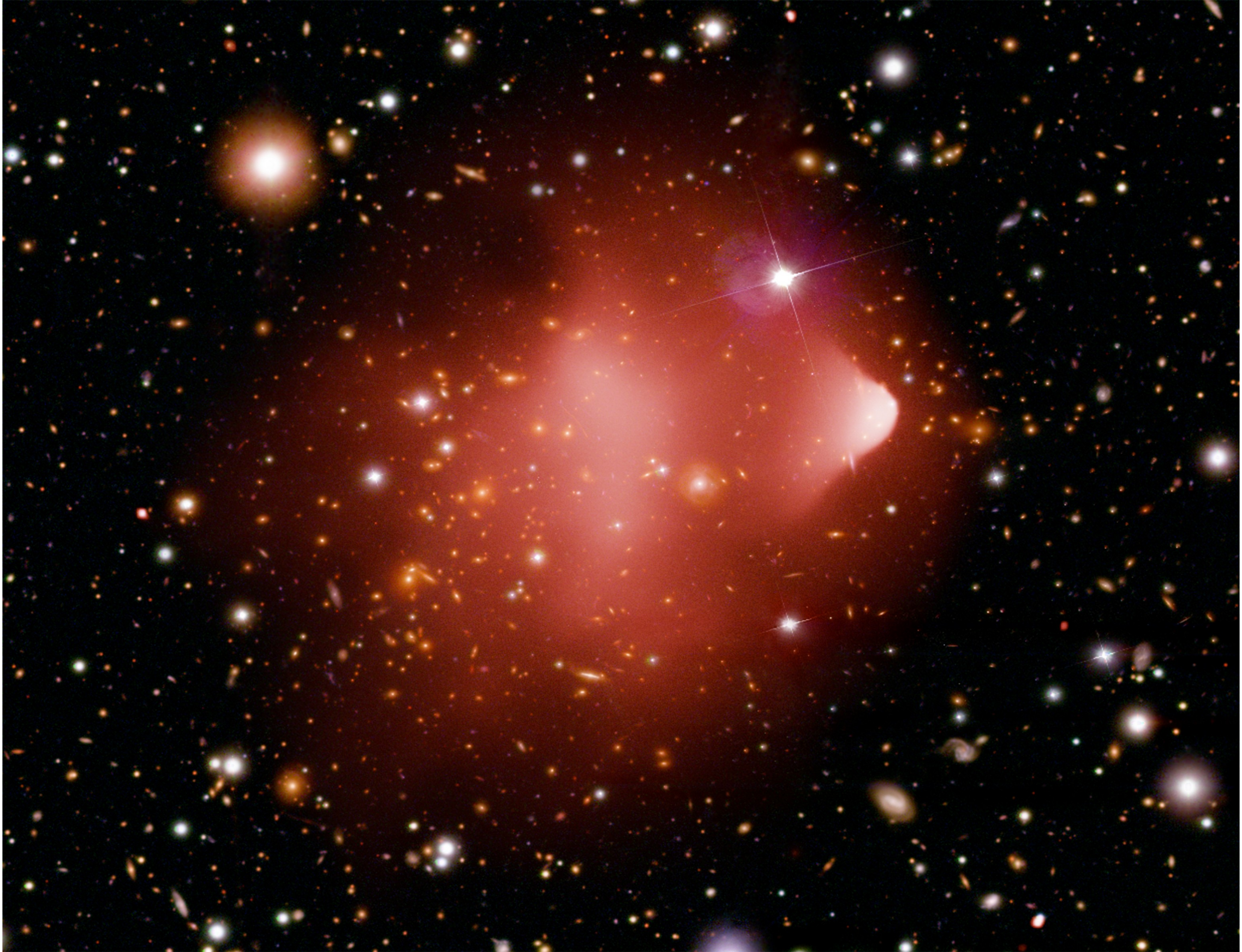
ILLUSTRATION
T+9 days
GW170817
August/September 2017
T+110 days
GW170817
December 2017



Merger
GRB start
Lightcurve from *Fermi*/GBM (10 – 50 keV)
Lightcurve from *Fermi*/GBM (50 – 300 keV)
Lightcurve from INTEGRAL/SPI-ACS (> 100 keV)
Gravitational-wave time-frequency map
Event rate (counts/s)
Frequency (Hz)
Time from merger (s)







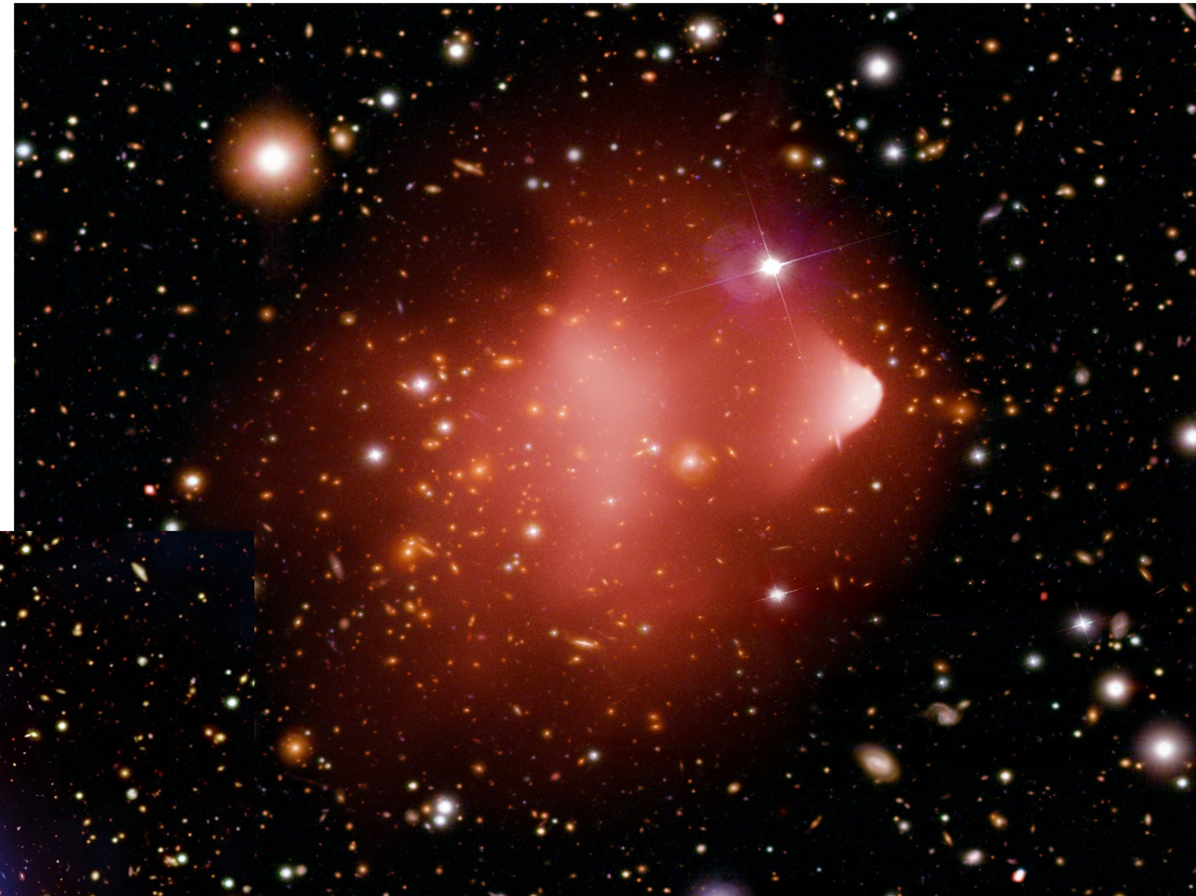
Extragalactic universe:
Cluster of galaxies (X-ray, visible and dark-matter model)

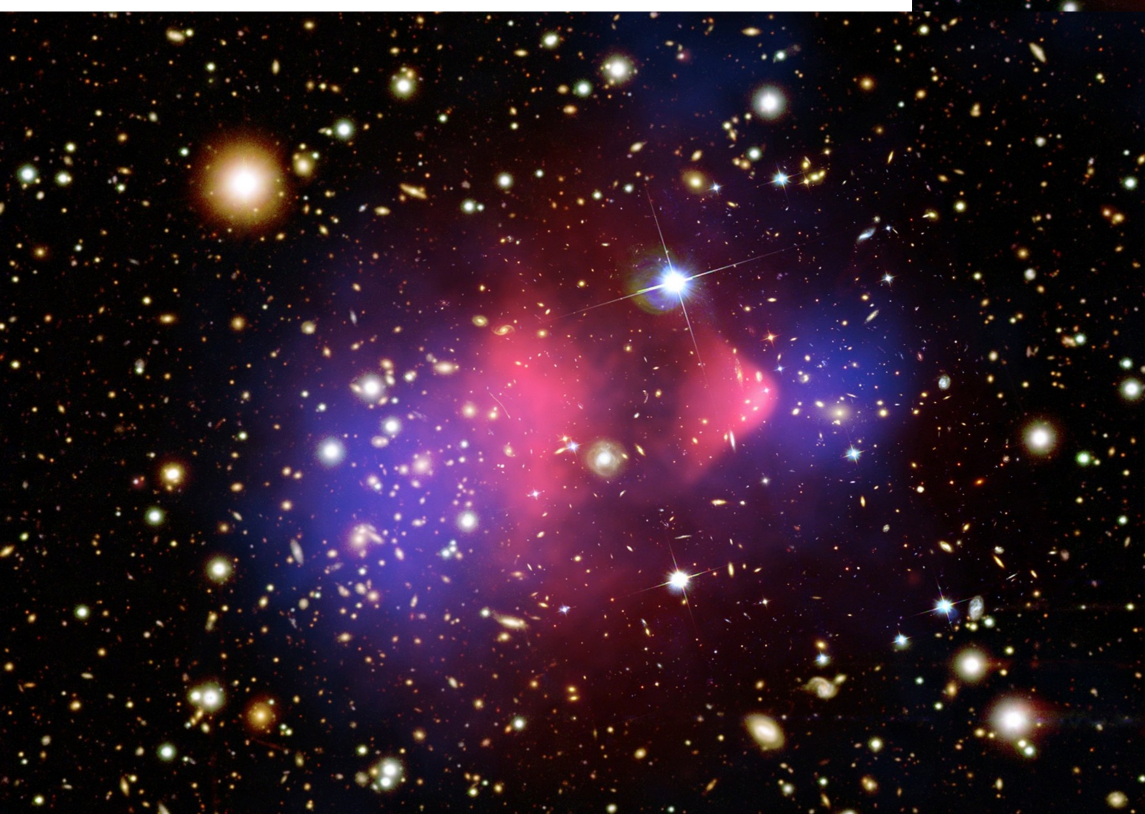
The Bullet Cluster, 1E0657-56

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



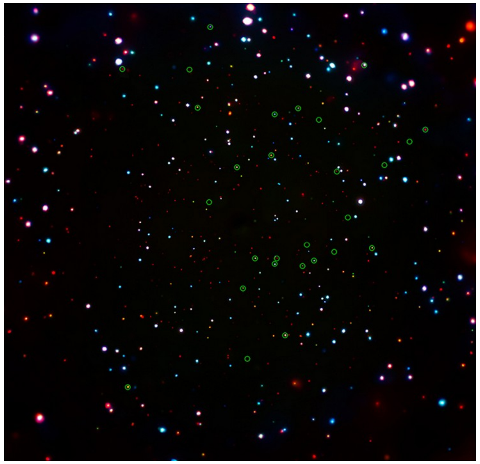


Distance: 3.3 billion light years

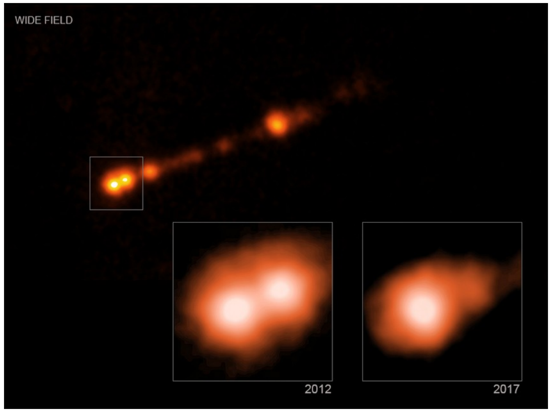
Size: 3 million l.y.

Data: Maxim Markevitch et al.

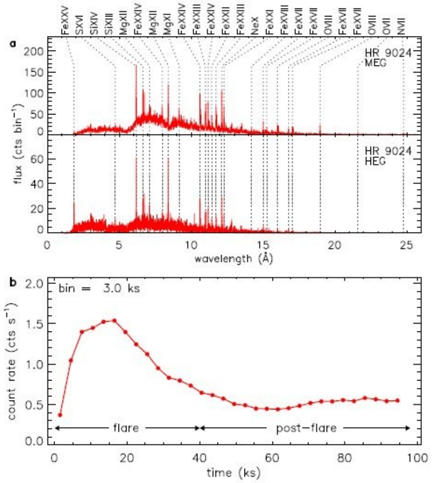
Some recent Chandra discoveries:



Identification of dust-shrouded quasars (CDF-S)
(F. Vito et al, Chile)



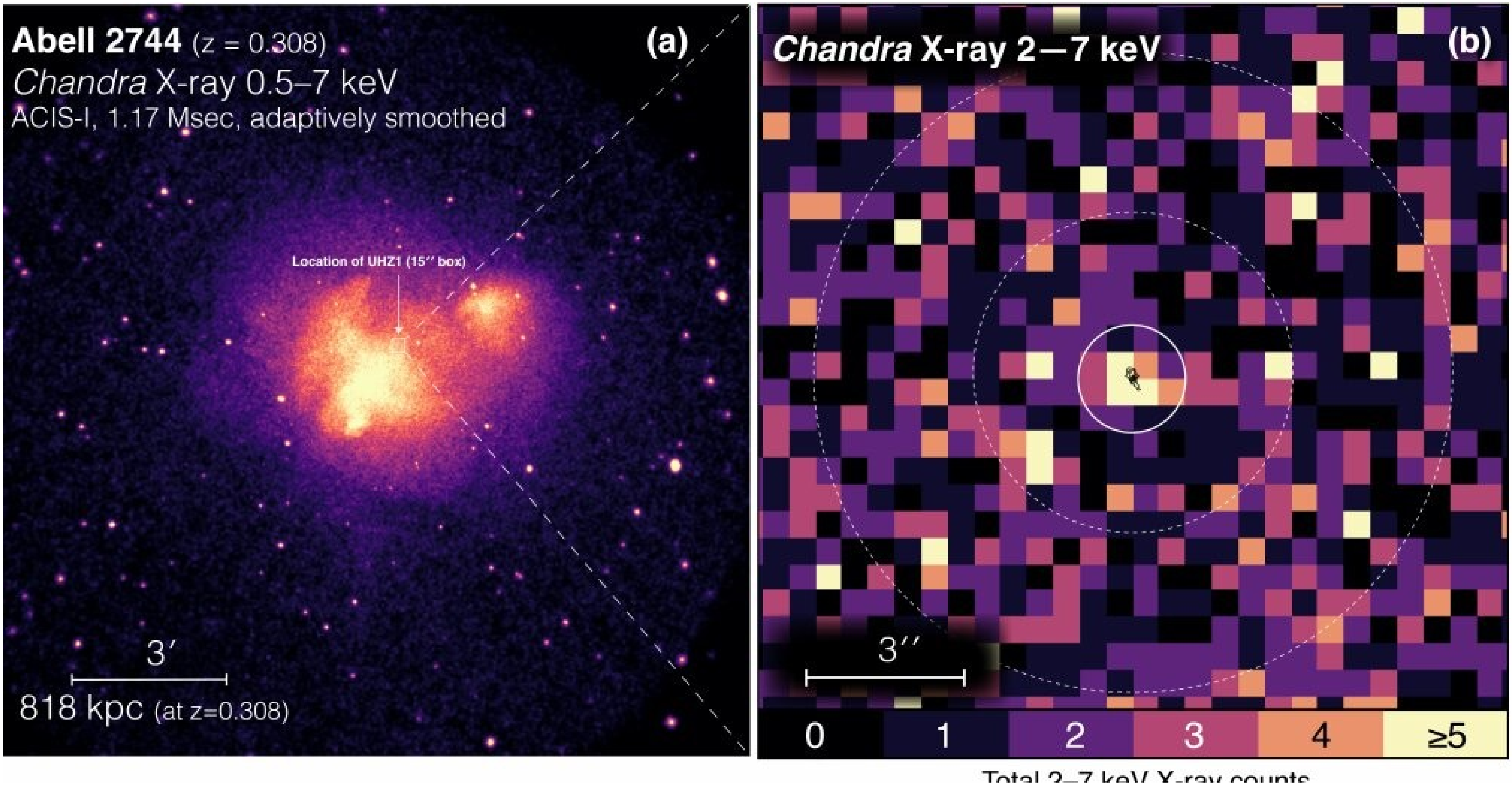
Measurement of M87 jet speed of 99% the speed of light (Snios et al, USA)



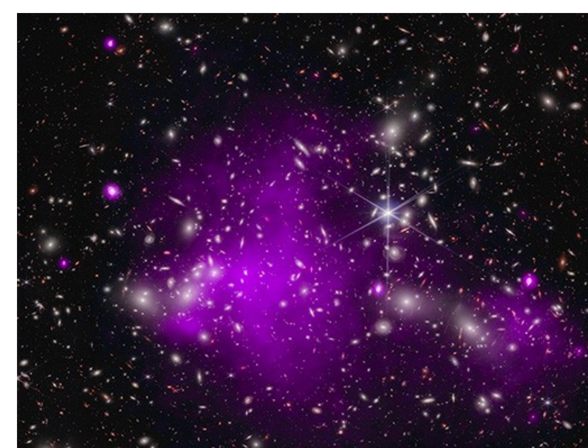
First CME (stellar eruption) seen in a star other than the Sun:
grating observations of HR9024 (C. Argiroffi et al, Italy)

Observations of 2 galaxy clusters about to collide 1E2215.7-0404/1E2216.0-0401
(Liyu Gu et al, Japan/Netherlands)

- ANY SCIENTIST WORLDWIDE CAN SEND IN A PROPOSAL TO USE CHANDRA
- LOTS OF FREELY AVAILABLE DATA IN THE CHANDRA ARCHIVE cxc.harvard.edu

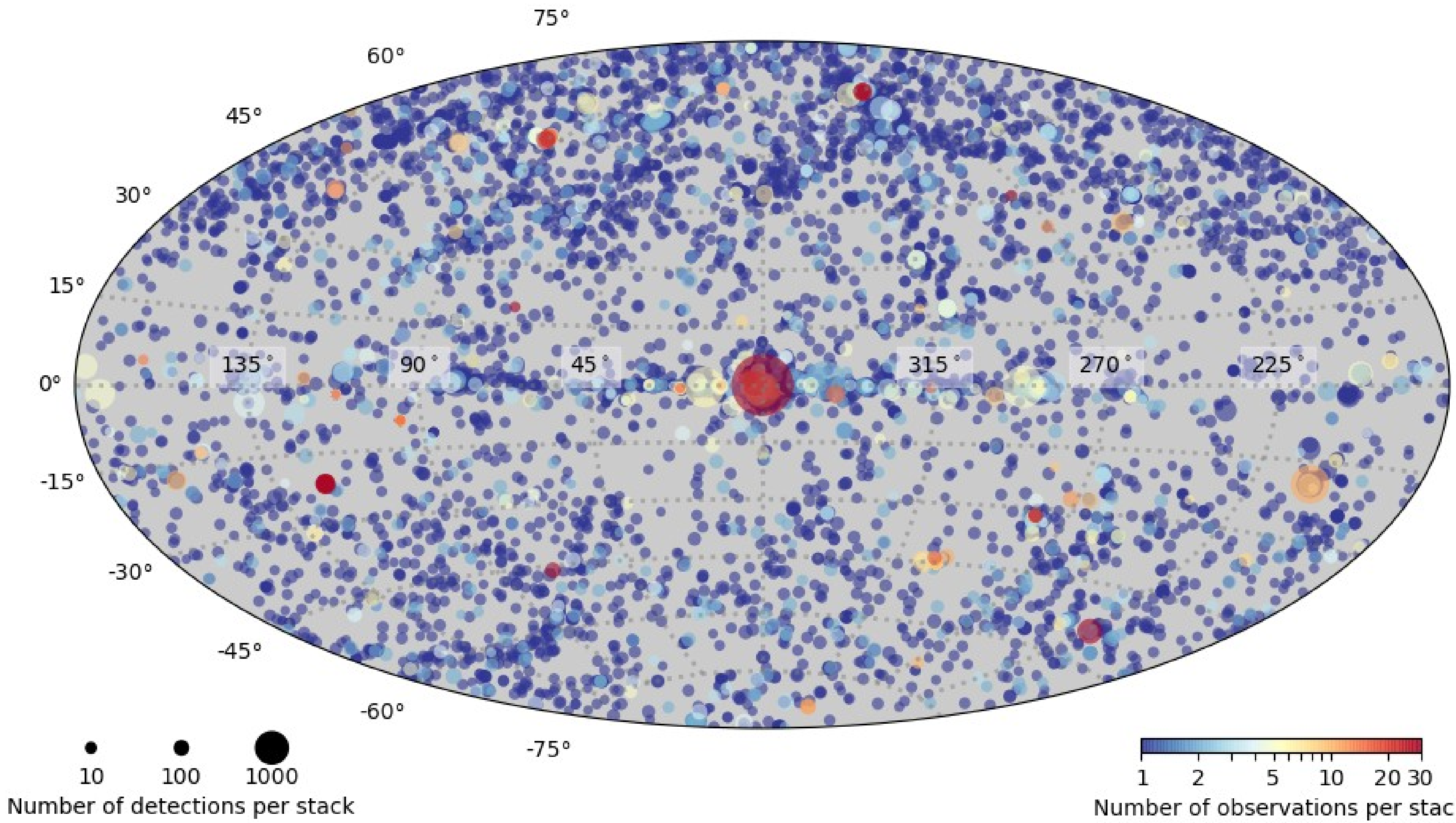


Chandra sees a quasar at redshift 10.3 (32 billion light years away, 0.46 billion years after the Big Bang) with a 10-100 megasun black hole
It's hiding behind a much closer cluster only 4 billion ly away (z=0.31)
Left: JW Right: JW+Chandra



CHANDRA SOURCE CATALOG

Released 2019: 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)



Chandra and XMM were meant for 5 year missions
Now both almost 25 years old

Chandra has lost some sensitivity in its main camera at ‘redder’ X-ray colors
But still sees clearly in the ‘bluer’ colors

Chandra’s thermal insulation isn’t working well, have to plan observations carefully so the spacecraft doesn’t get too hot or too cold

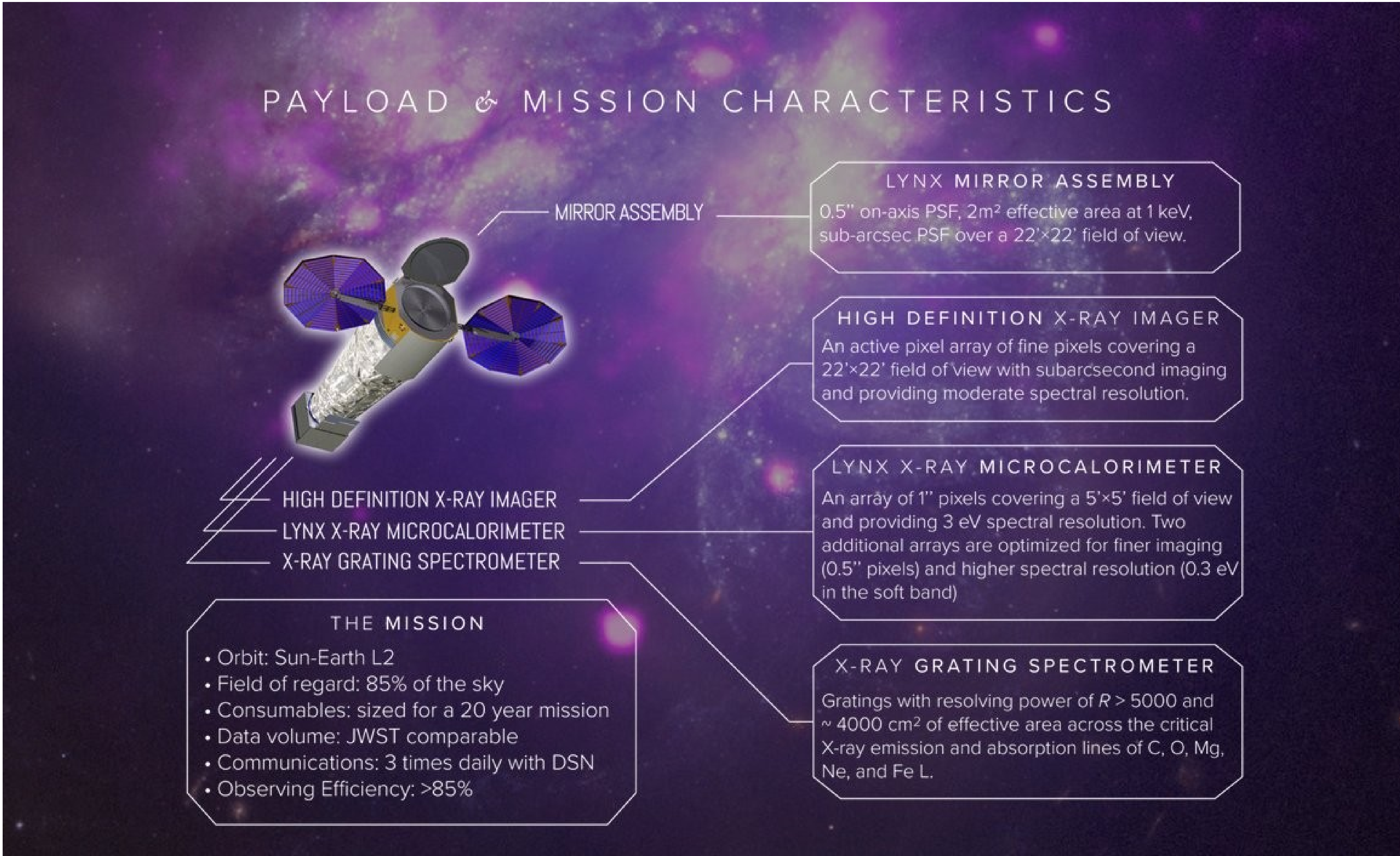
XMM has lost several CCD imaging chips

But:
Both missions plan to keep operating for years to come!

Europe has funded a successor to XMM called ATHENA

The US has no funded followon to Chandra: the LYNX project (a super-Chandra) was one design considered recently but not yet funded

LYNX: 100 times more sensitive, 16x field of view, 10x spectral res.



PUBLIC WEB SITE

chandra.harvard.edu

CHANDRA X-RAY CENTER
WEB SITE FOR SCIENTISTS: ARCHIVE, PROPOSALS, DATA ANALYSIS

cxc.harvard.edu

- FREE DATA, OPEN SOURCE SOFTWARE, DOCUMENTATION

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

- 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.