Professor Belinda Wilkes

A Clear View of the X-ray Universe with NASA's Chandra X-ray Observatory"

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Belinda Wilkes, University of Bristol
Former Director, Chandra X-ray Center

Personal Christian Story

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NASA’s Chandra X-ray Observatory

1999→

Image credit:
CXC/SAO/NASA

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Smithsonian

NASA

NASA's Great Observatories

across the Electromagnetic Spectrum

No longer operating

2008: Fermi Gamma Ray Telescope

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Launch: 23 July 1999

Shuttle: “Columbia”, Cape Canaveral, Florida

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Deploying *Chandra*

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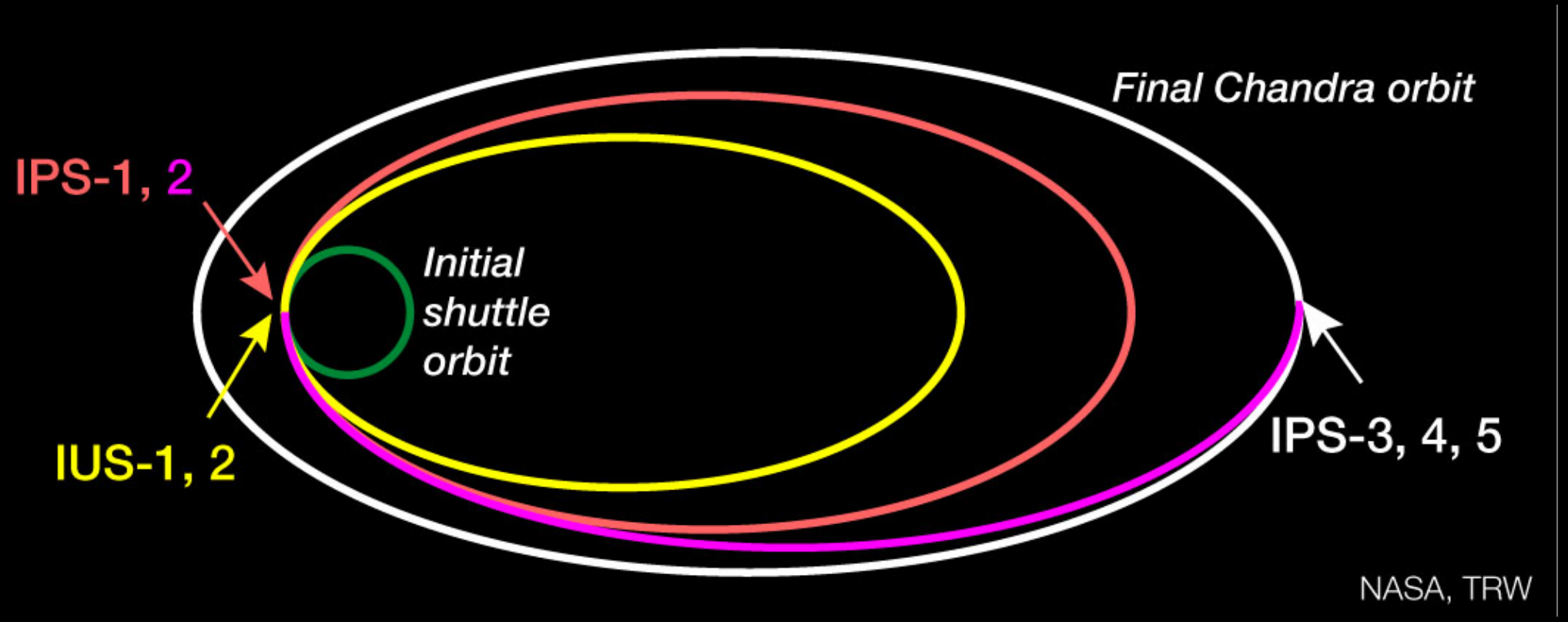
Chandra's Orbit: 63.5 hours



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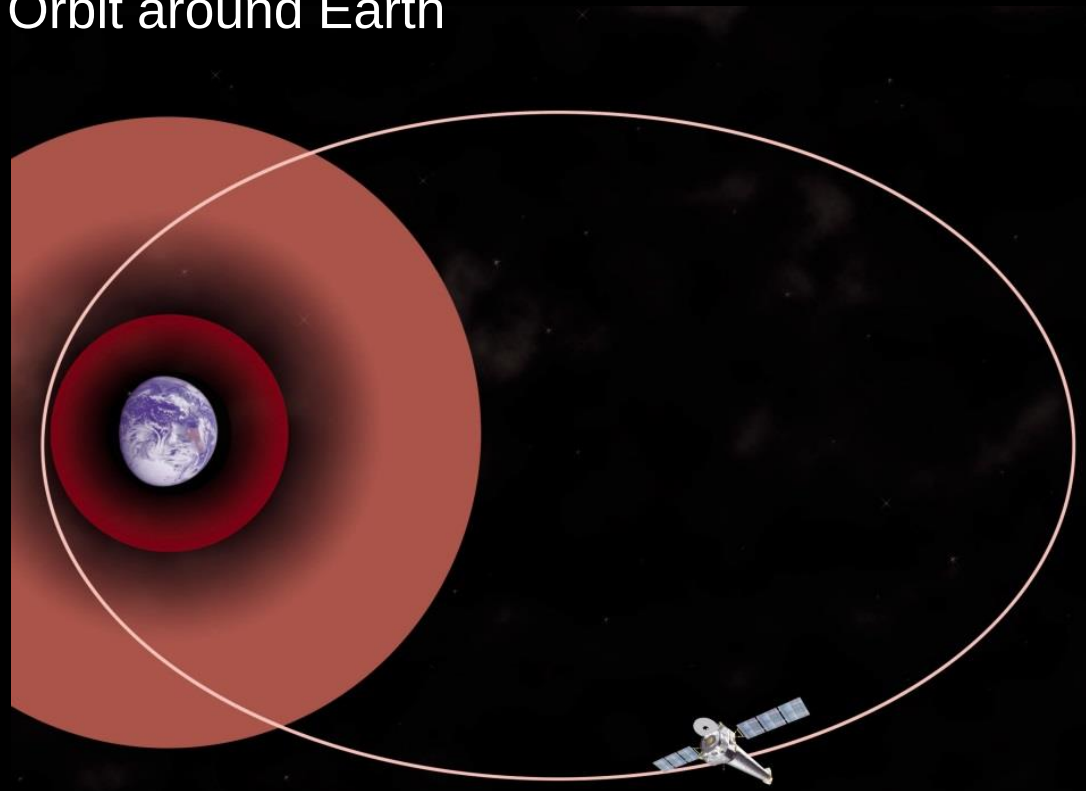
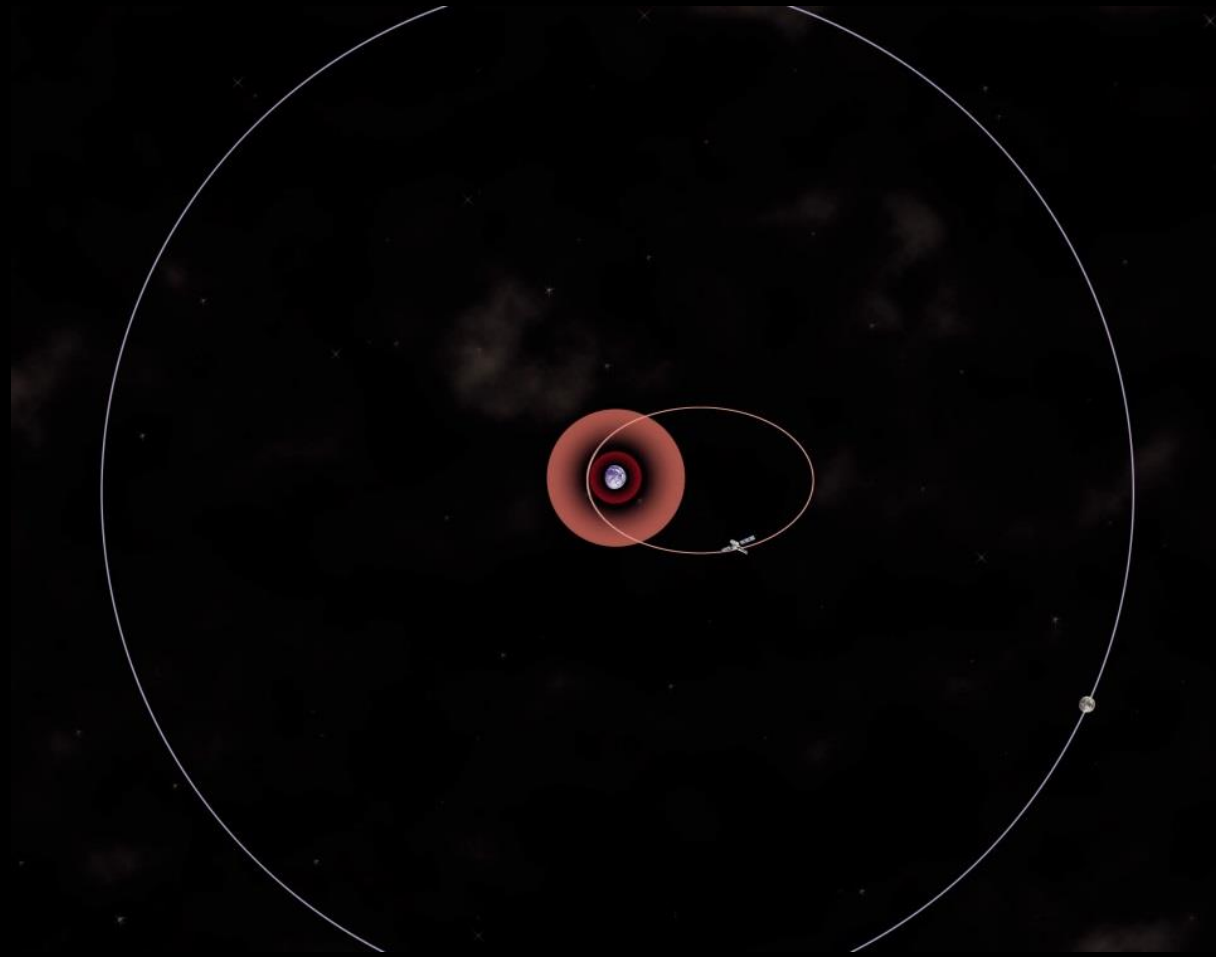
Chandra’s Orbit in Space

Earth/Moon/Chandra

Orbit around Earth





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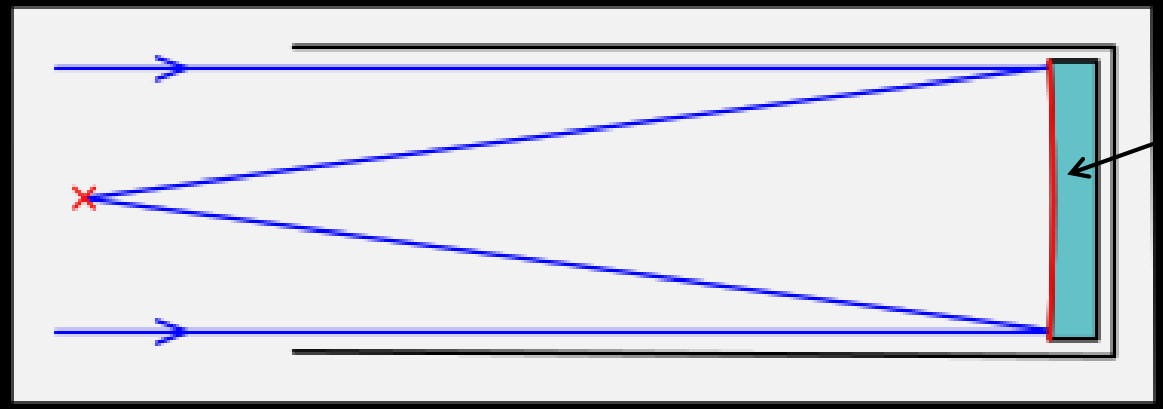
Focussing light to make an Image



Visible light mirror

Normal Reflection

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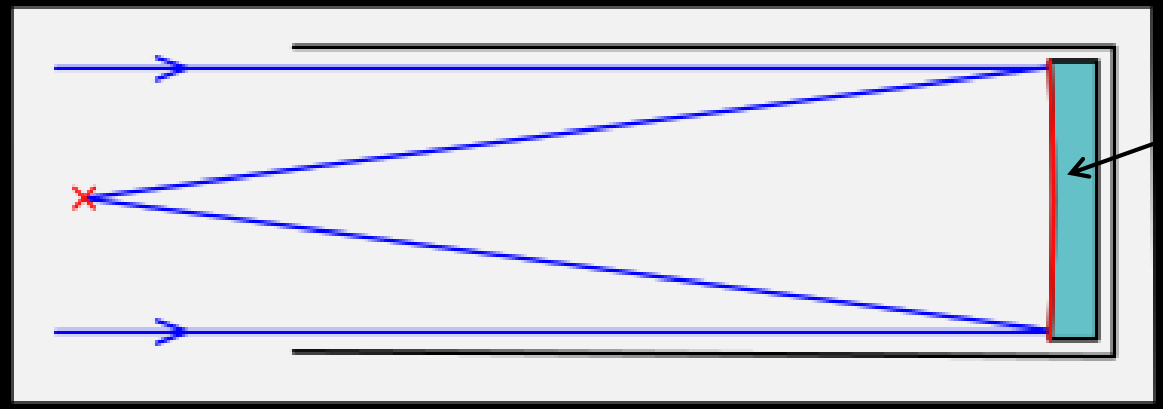

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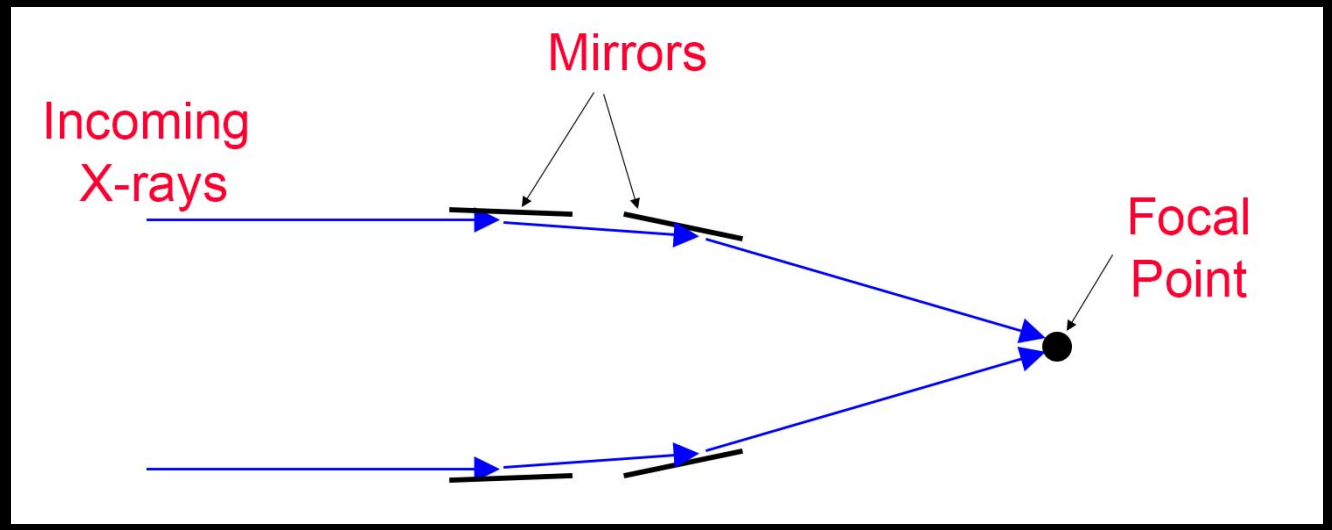

X-ray light mirrors

Grazing Incidence
Reflection

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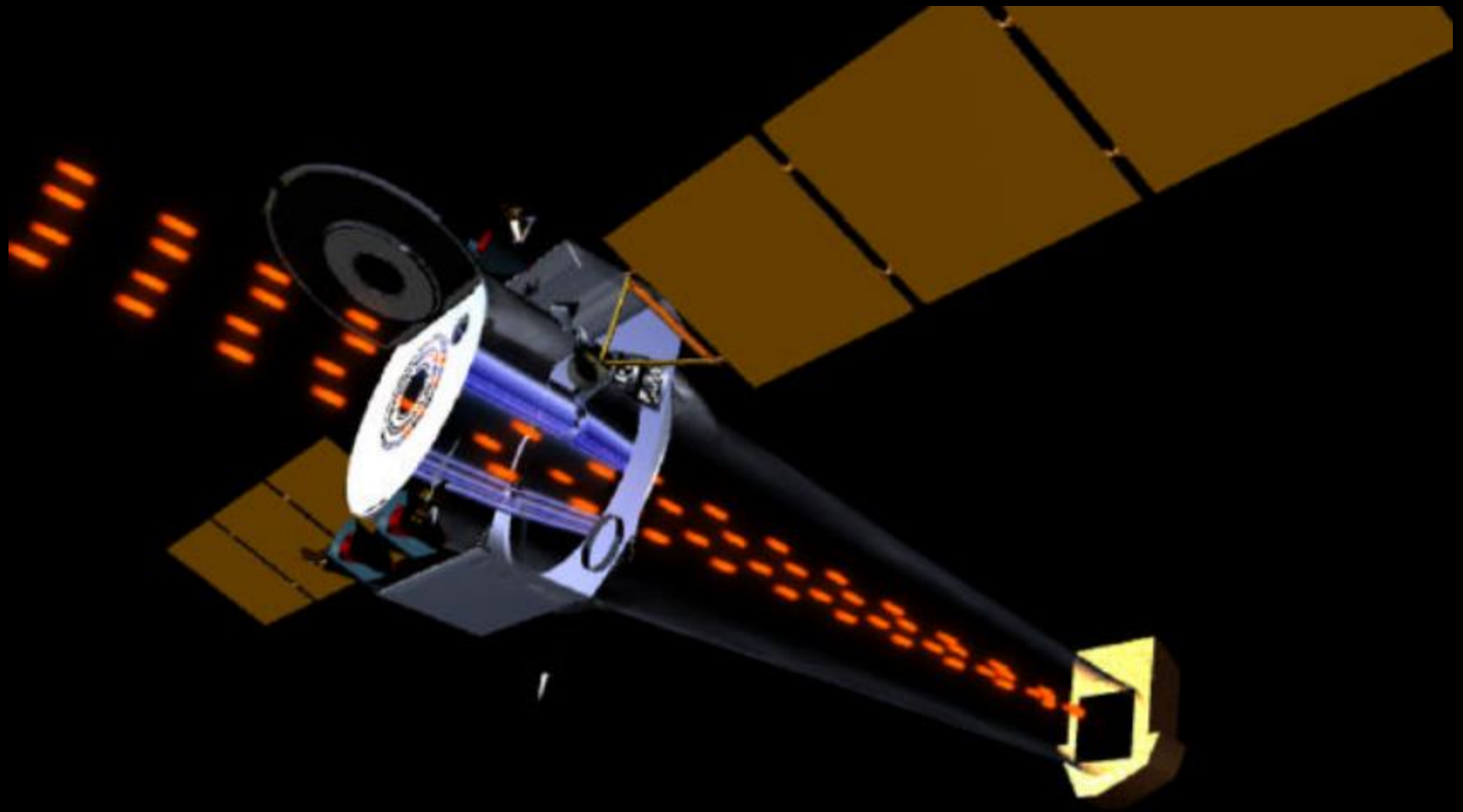

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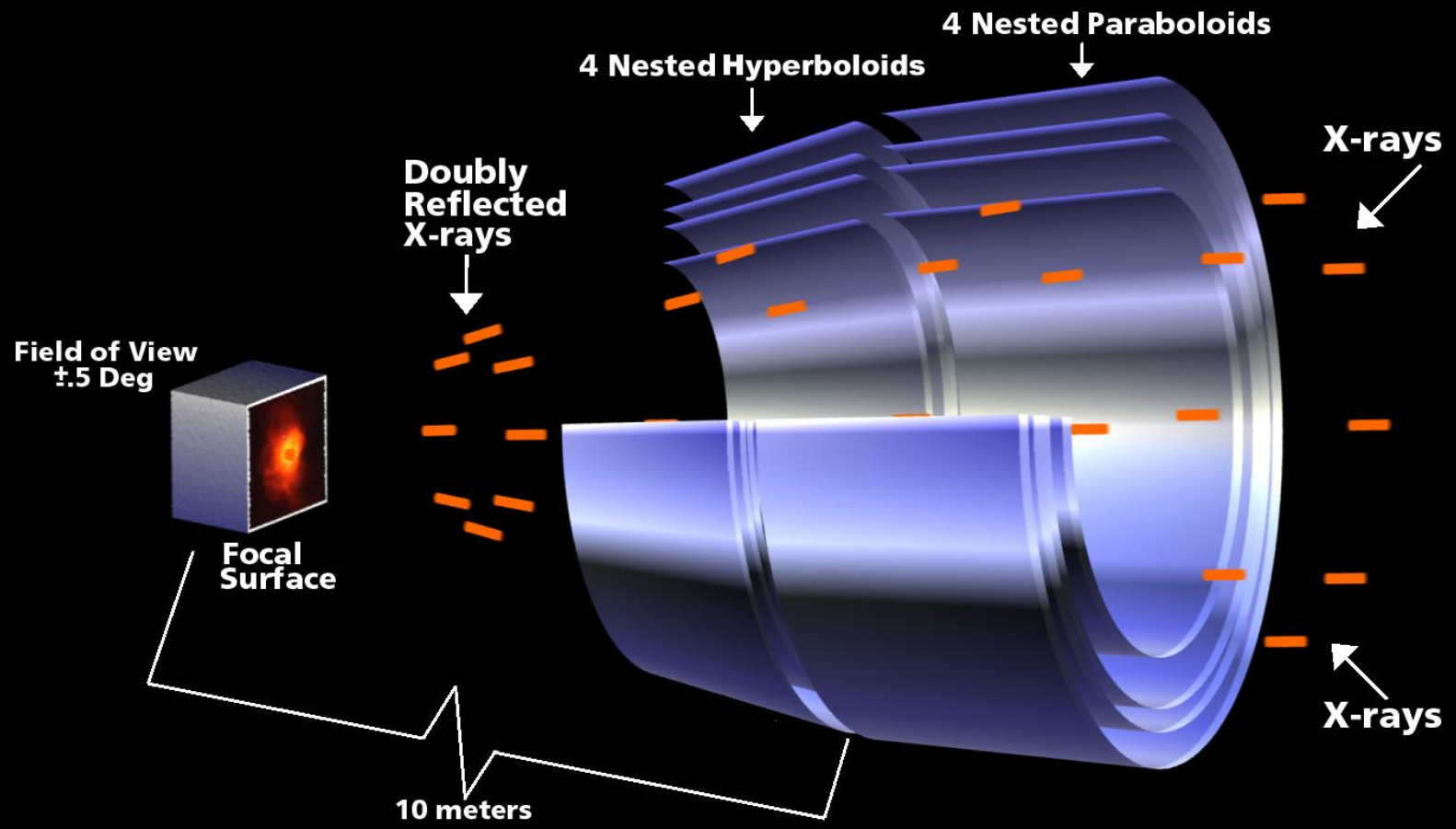
Chandra Light Path
Grazing Incidence Mirrors



Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter

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Orion Nebula: star forming region

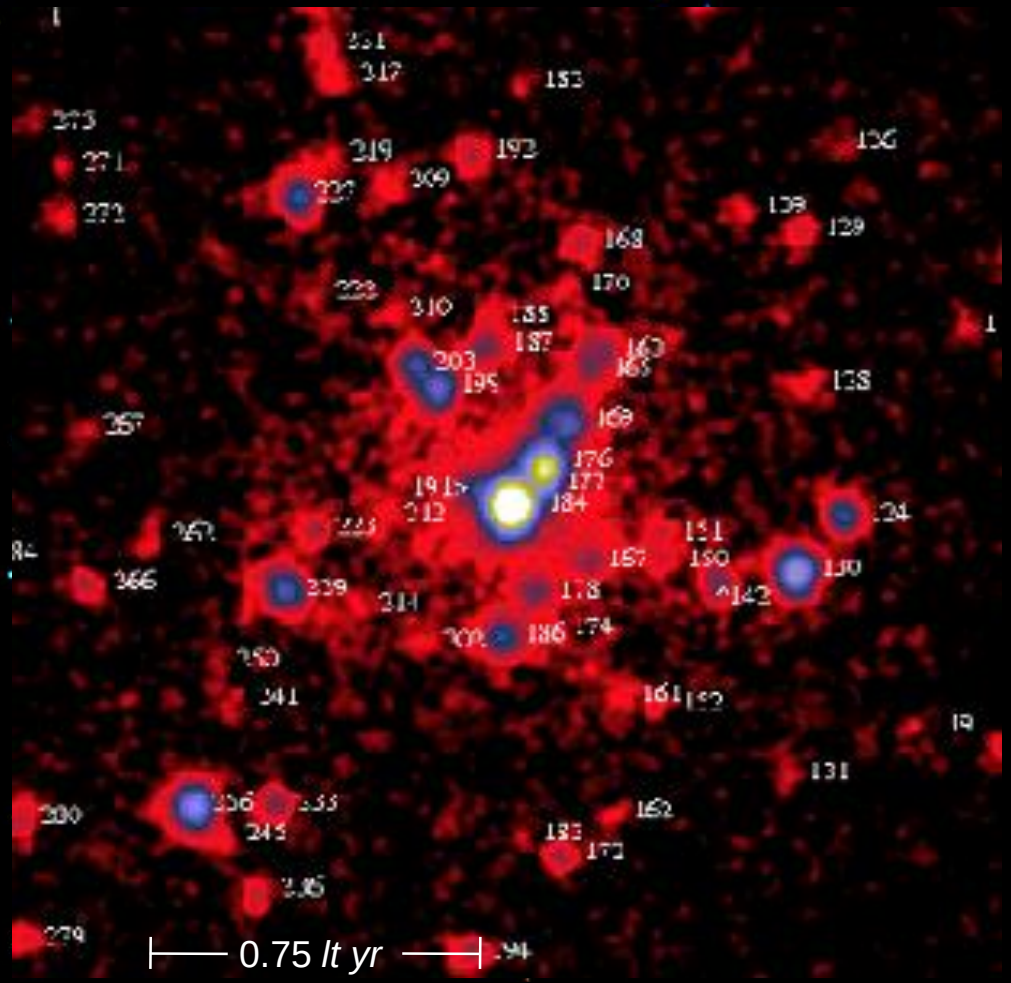
Exquisite, 0.5” Spatial Resolution

ROSAT:
~250 sources

Chandra, deep:
~1400 sources

Young stars are unstable and violent places

Chandra is an excellent “Young star finder”



ROSAT

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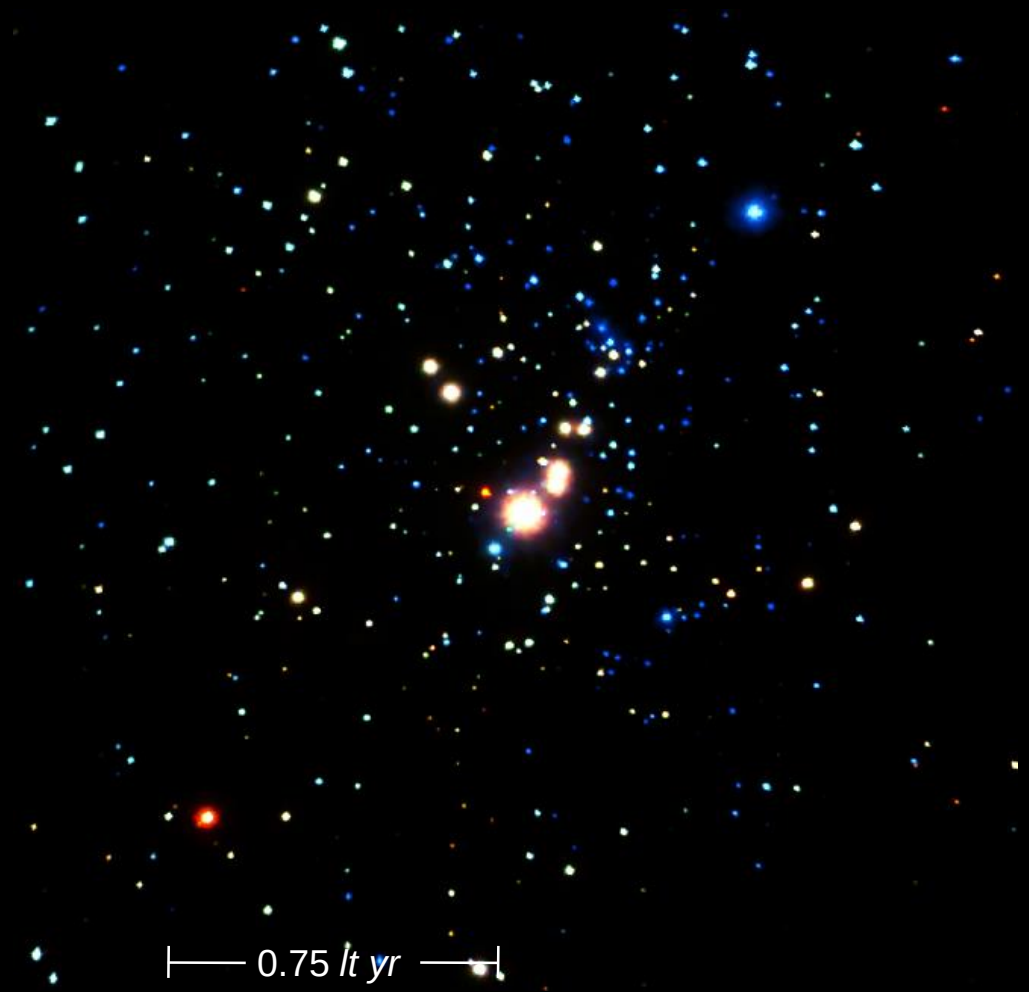

Chandra

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Chandra
& HST Optical

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X-rays come from the hottest and most violent places in the Universe!

- Stars:
  - being born, interacting, merging, dying
- Black Holes:
  - accreting material: “active”
- Galaxies:
  - Very hot gas
- Planets:
  - Jupiter’s aurorae
  - Interaction between magnetosphere and plasma

→ Most types of celestial sources

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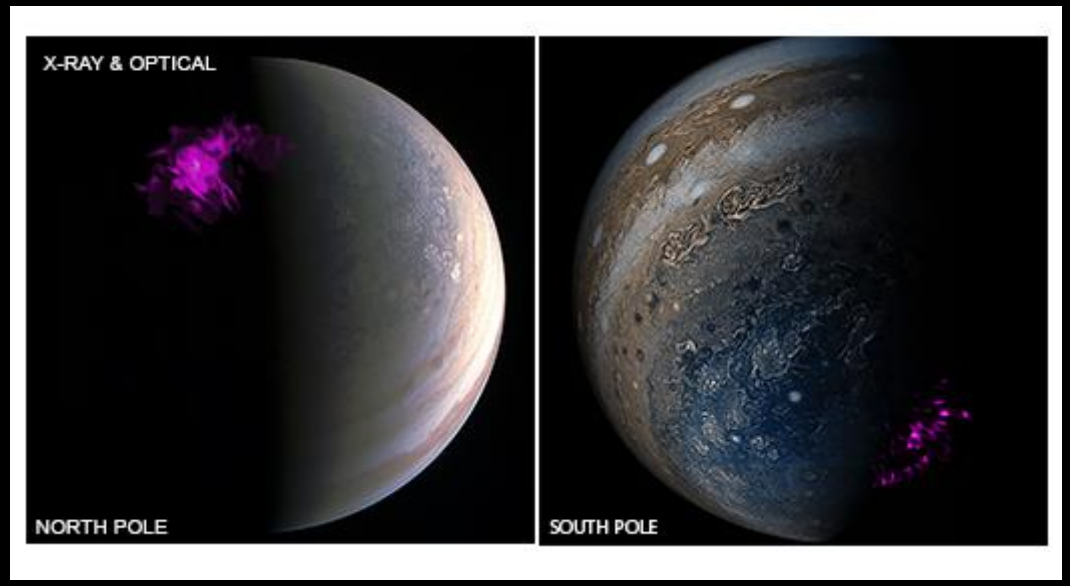

→ Most types of celestial sources

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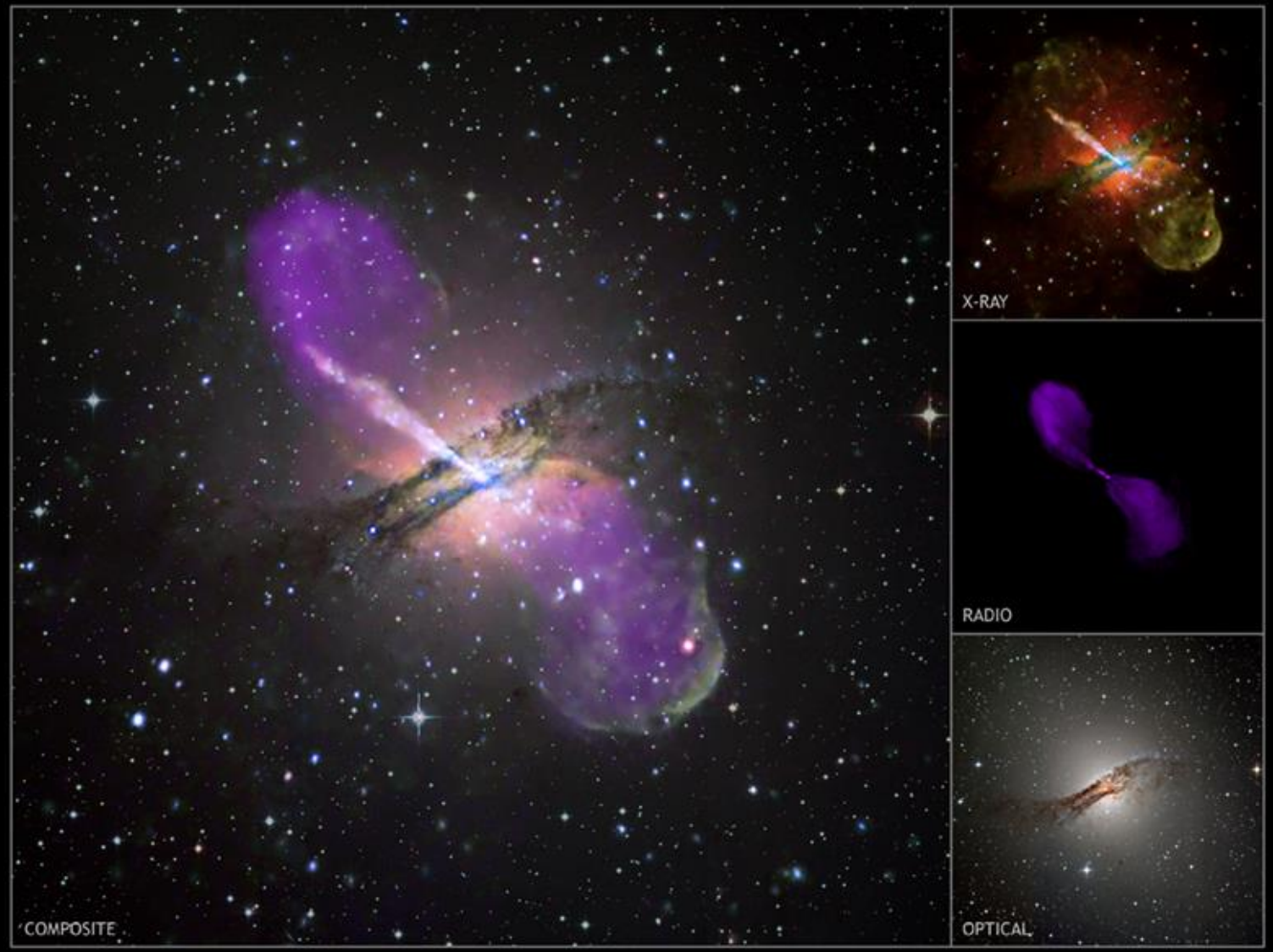
Why do we need so many Telescopes?

Sources look different
in different wavebands



Centaurus A
Radio-loud active galaxy
Nuclear super-massive black hole

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Supernova Remnants

When a massive star runs out of fuel for fusion, it explodes!

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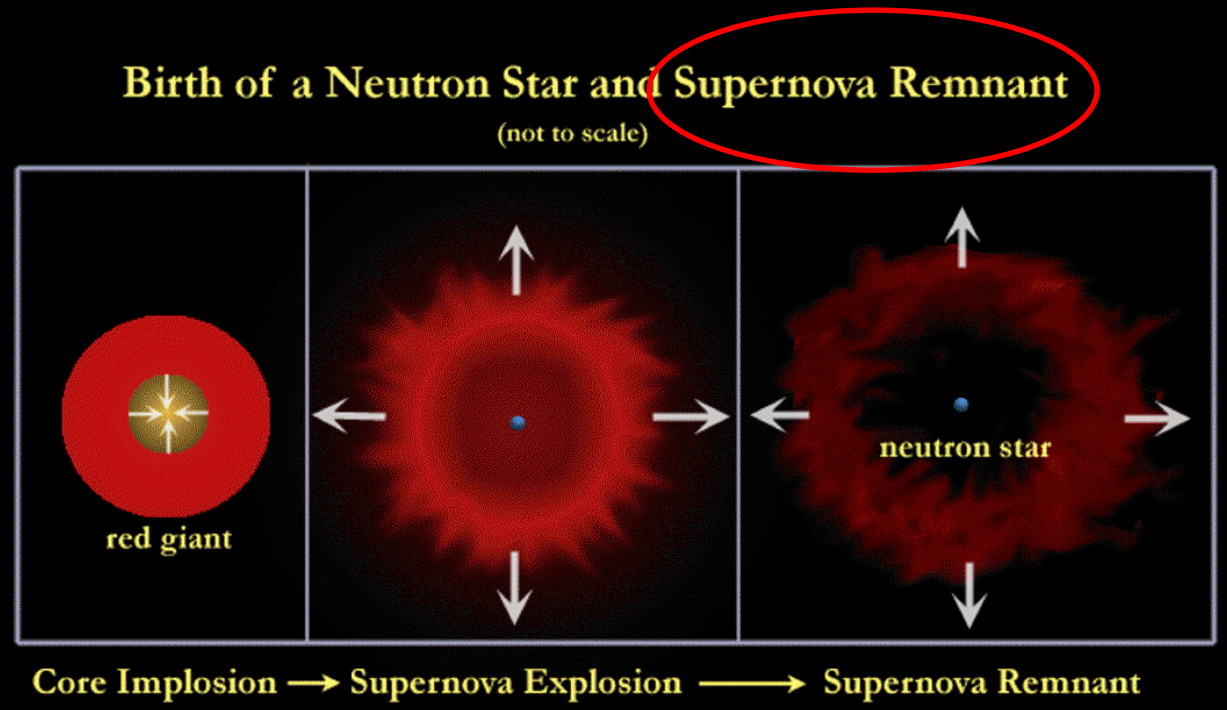
Death of a Massive Star

- When all fuel runs out, the core collapses → Neutron Star
- Outer regions of star explode outwards → Supernova (SN)
- SN shine more brightly than a galaxy for a few hours/days
- SN are the primary way “heavy elements” (>H,He) are distributed
- We are made of Star Dust!

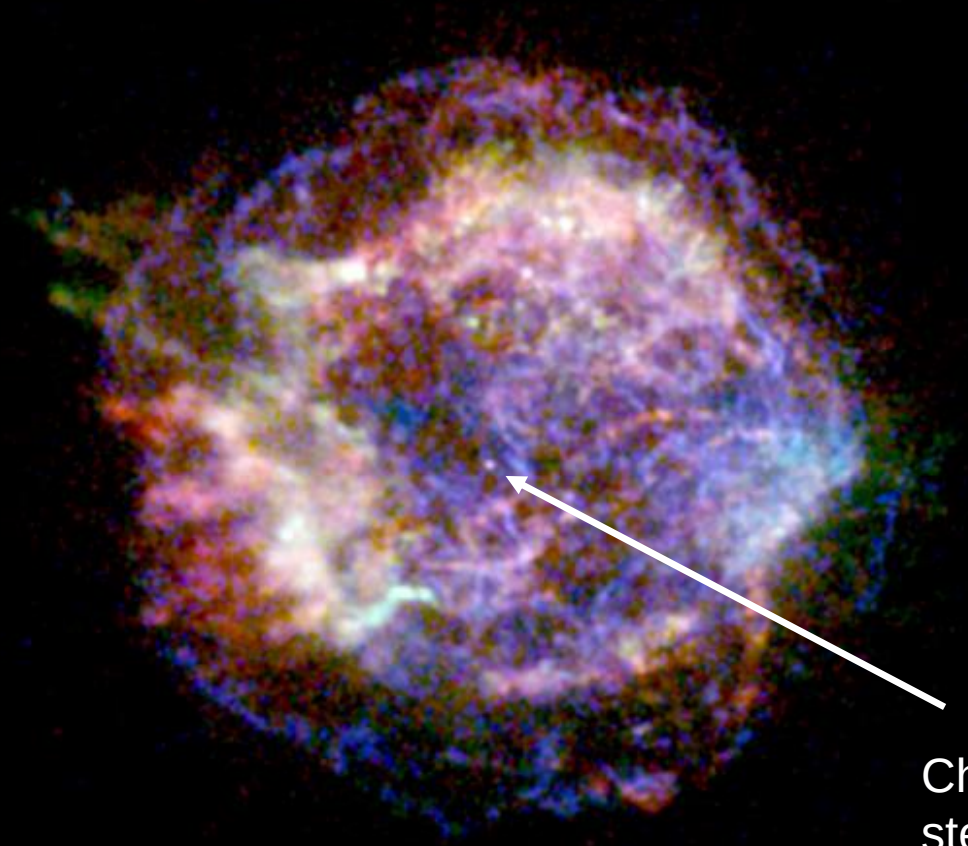


Official First Light (Aug 1999)

Supernova Remnant: Cassiopeia A

Age: 340 years

Size: 29 lyrs



1 Msec Deep
Image (12 days)

Chandra-discovered
stellar remnant

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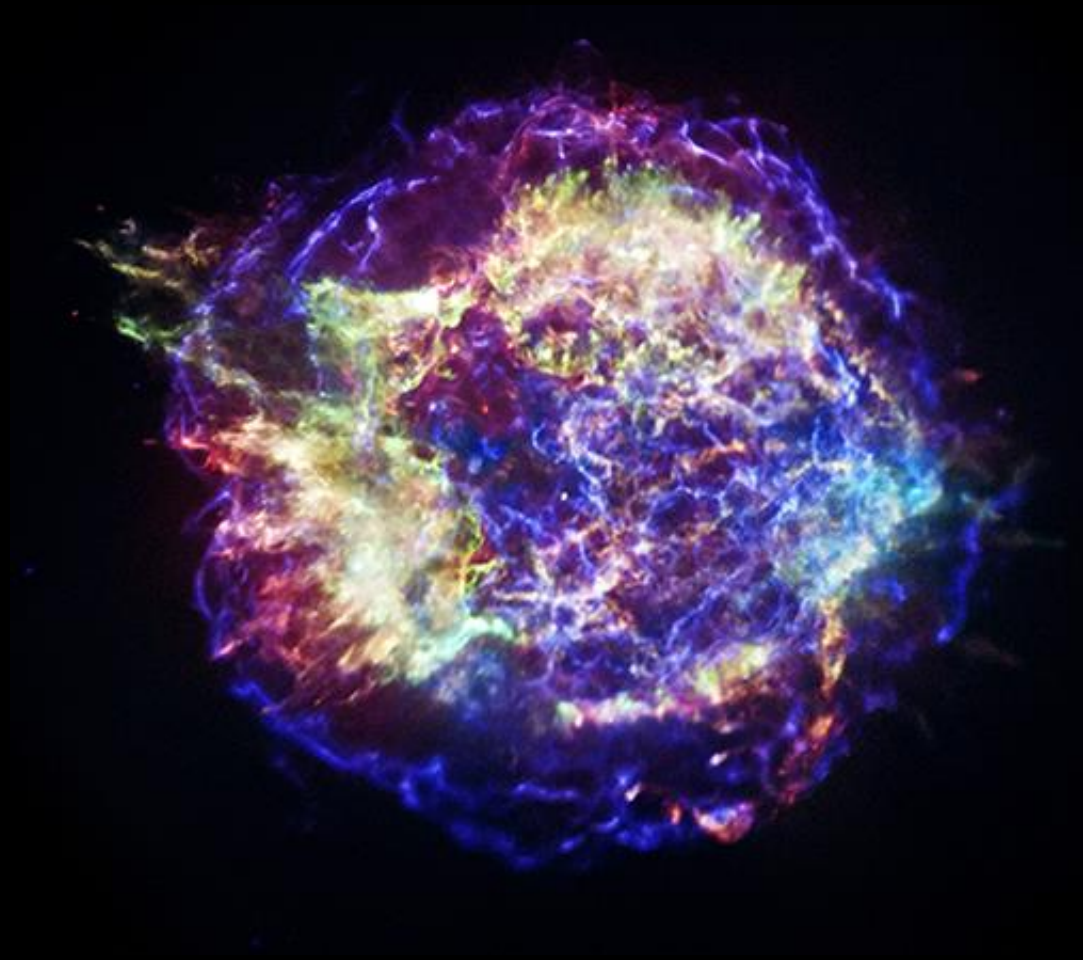

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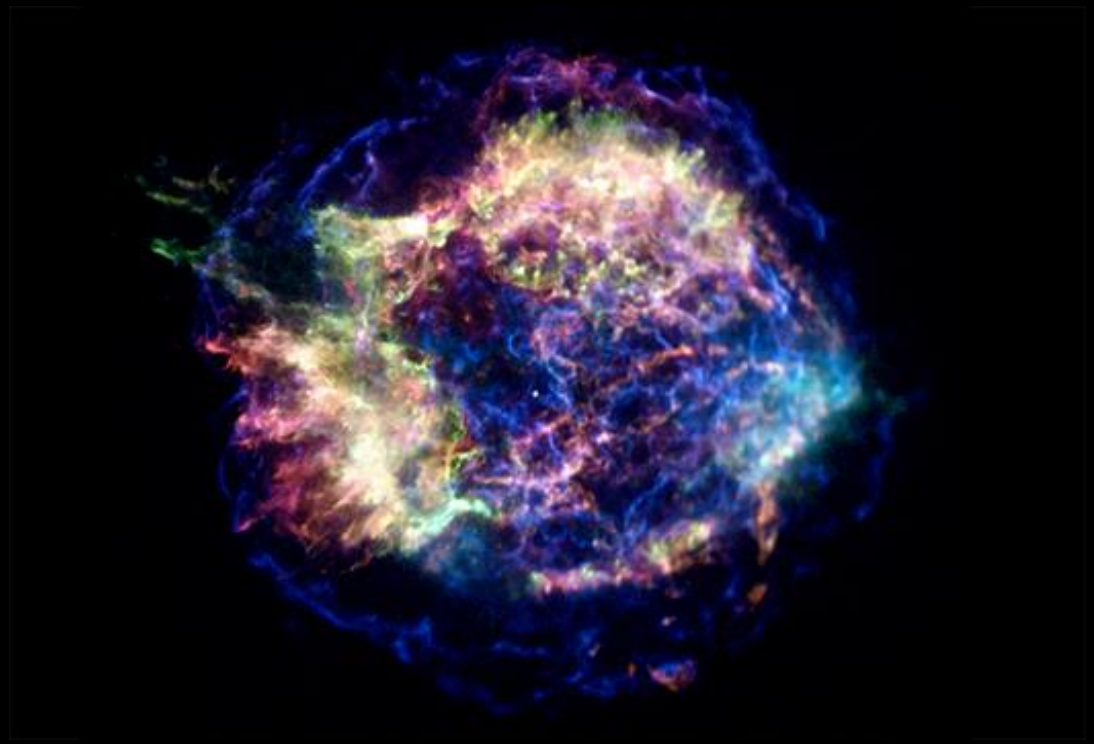
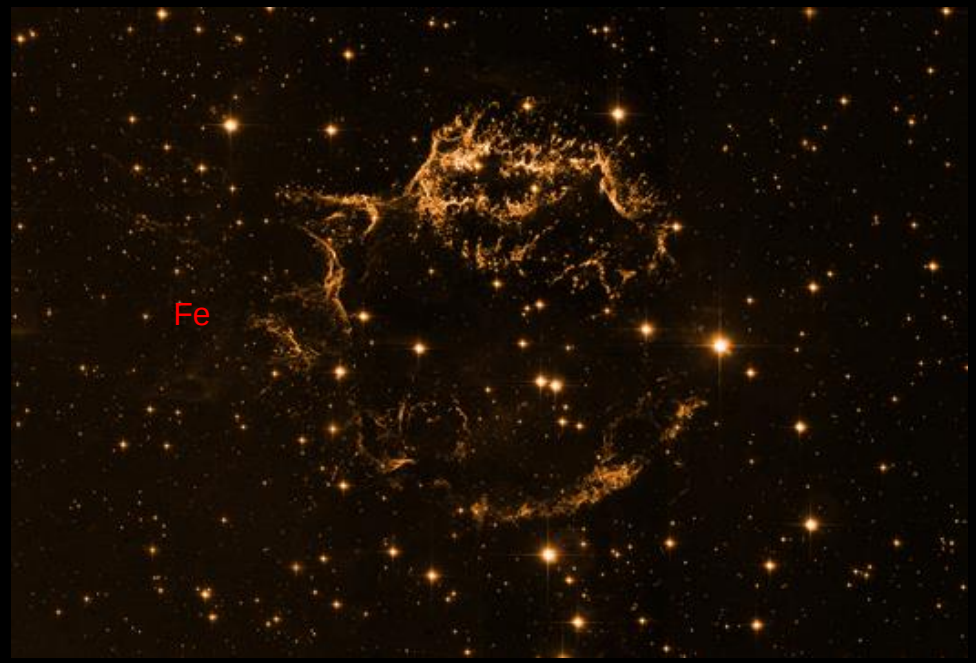
Cassiopeia (Cas) A

Supernova Remnant

X-rays
hot gas + non-thermal emission



Optical: stars + cool gas/dust



- Neutron Star: find and study
- Explosion – inside out
- SNR expansion

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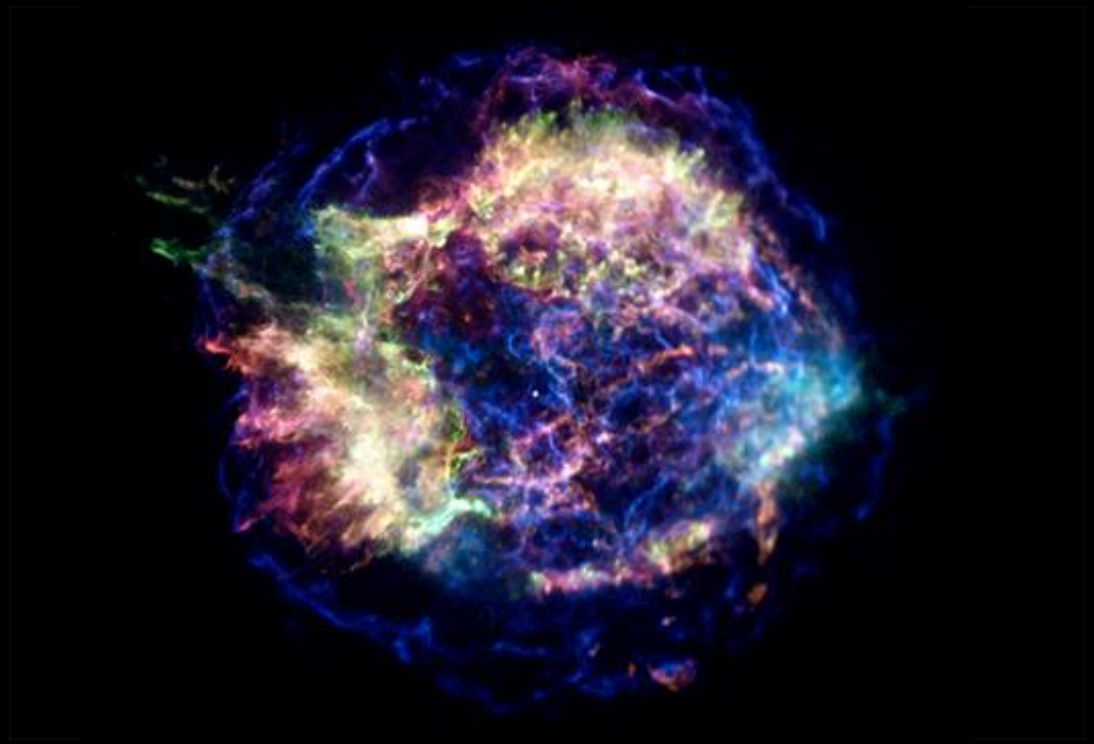

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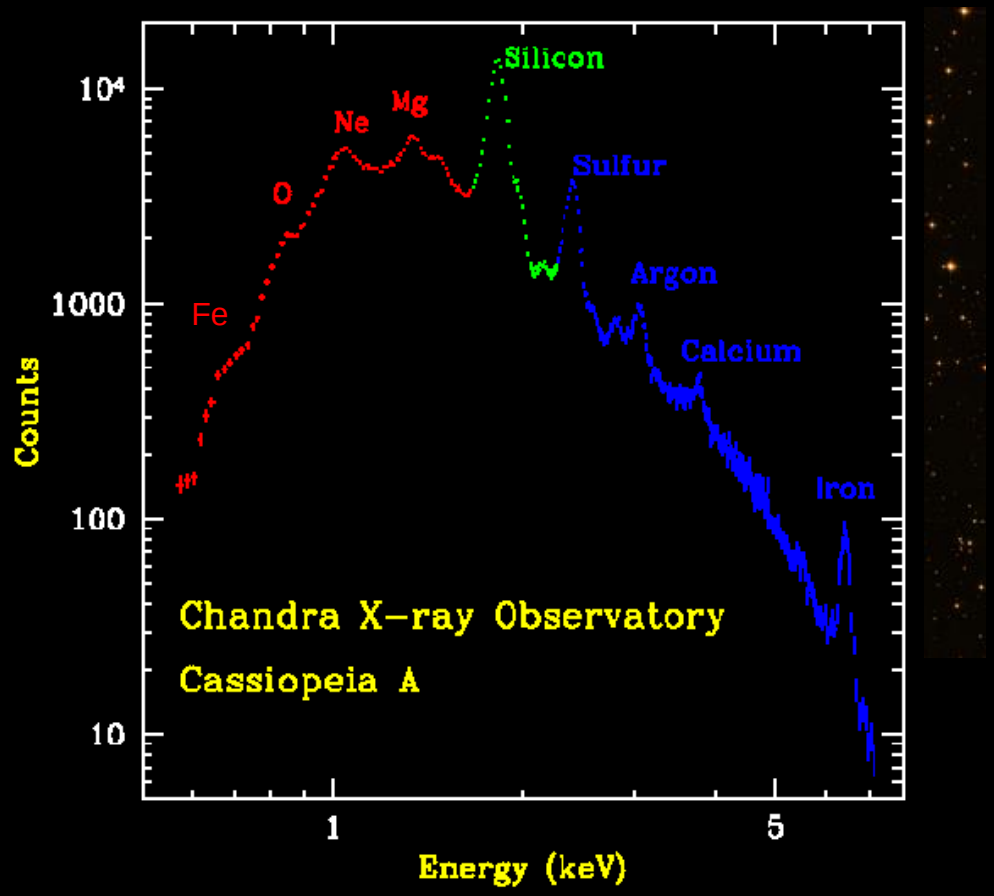

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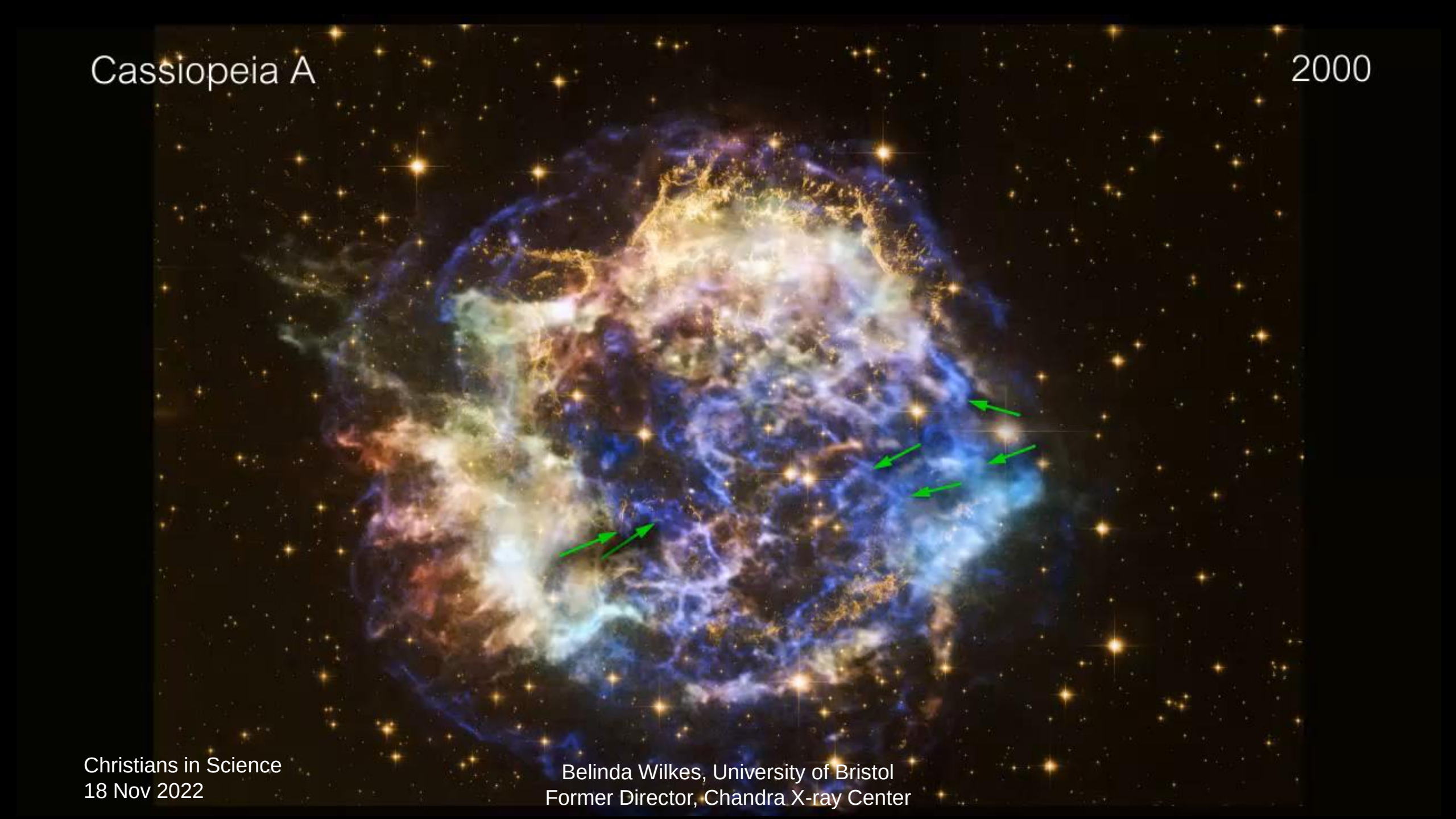

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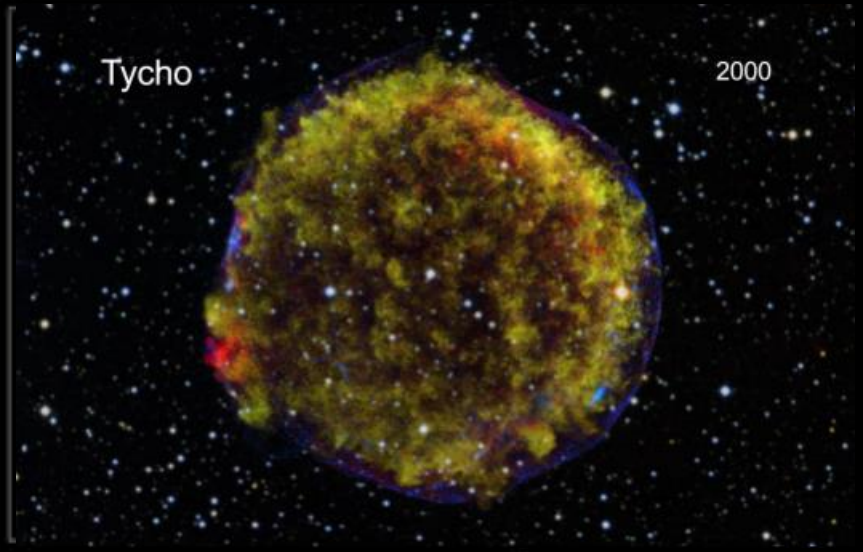
SNR: Many shapes + sizes

Crab Nebula



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Quasars

Radio emission from Quasar: *Cygnus A*

Super-Massive Black Holes (~1M-10B solar mass)
in the nuclei of galaxies

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First Targeted Source
Quasar: PKS 0637-75

- Point Source to focus: Quasar
  (z~0.66, 9 Glyrs away)

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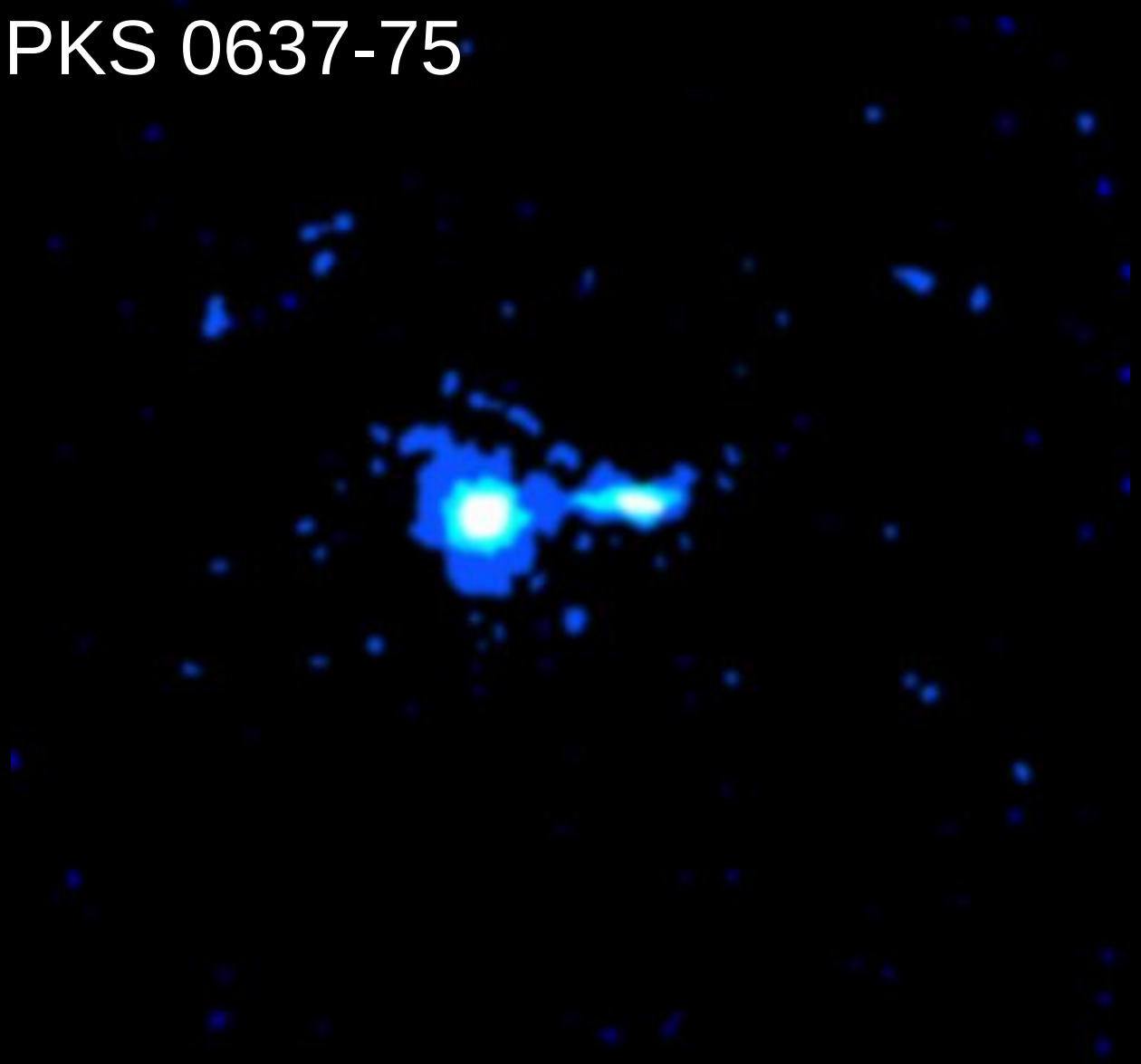

- Point Source to focus: Quasar
  (z~0.66, 9 Glyrs away)

- X-ray Jet visible: 9” long, (~250,000 lyrs)
- No X-rays beyond the jet bend
- Synchrotron emission from high energy electrons streaming along the magnetic field lines

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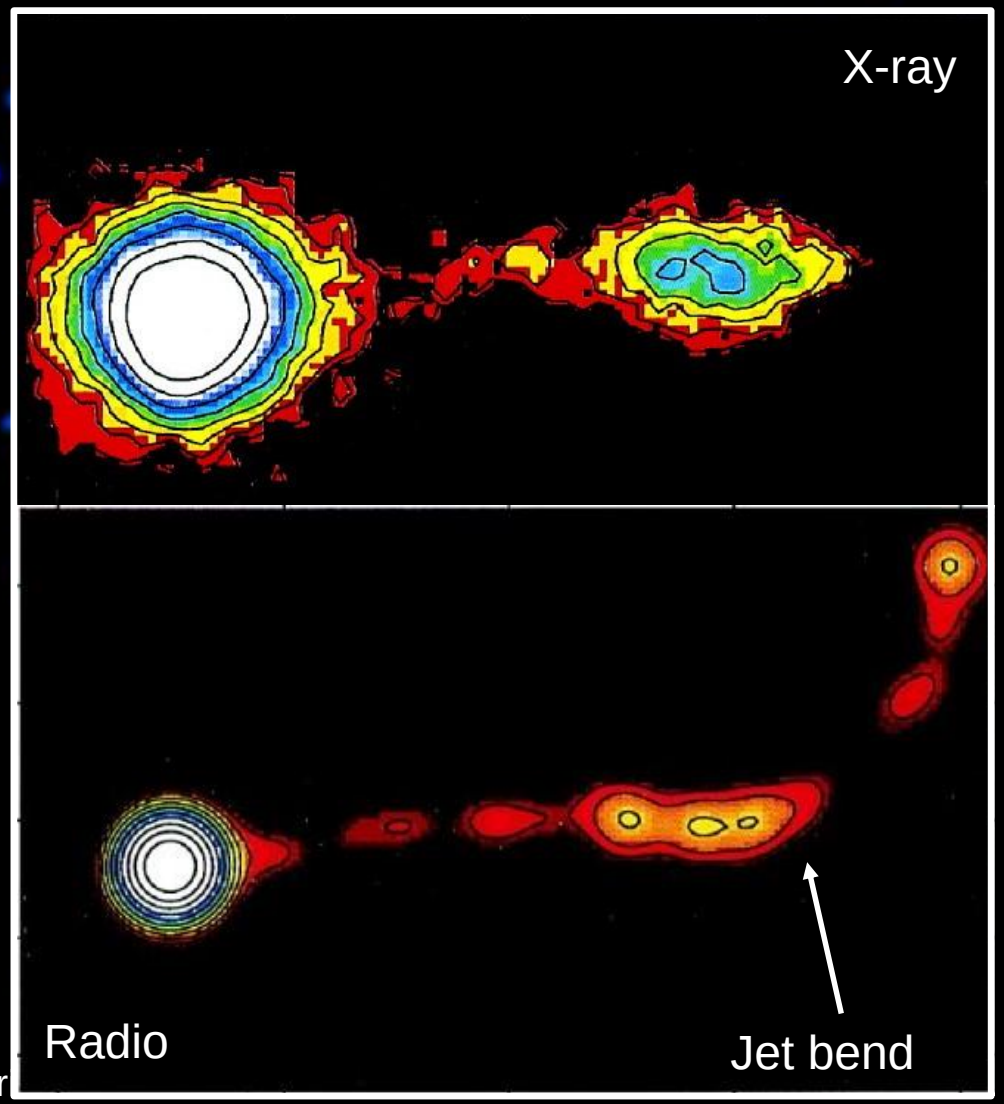

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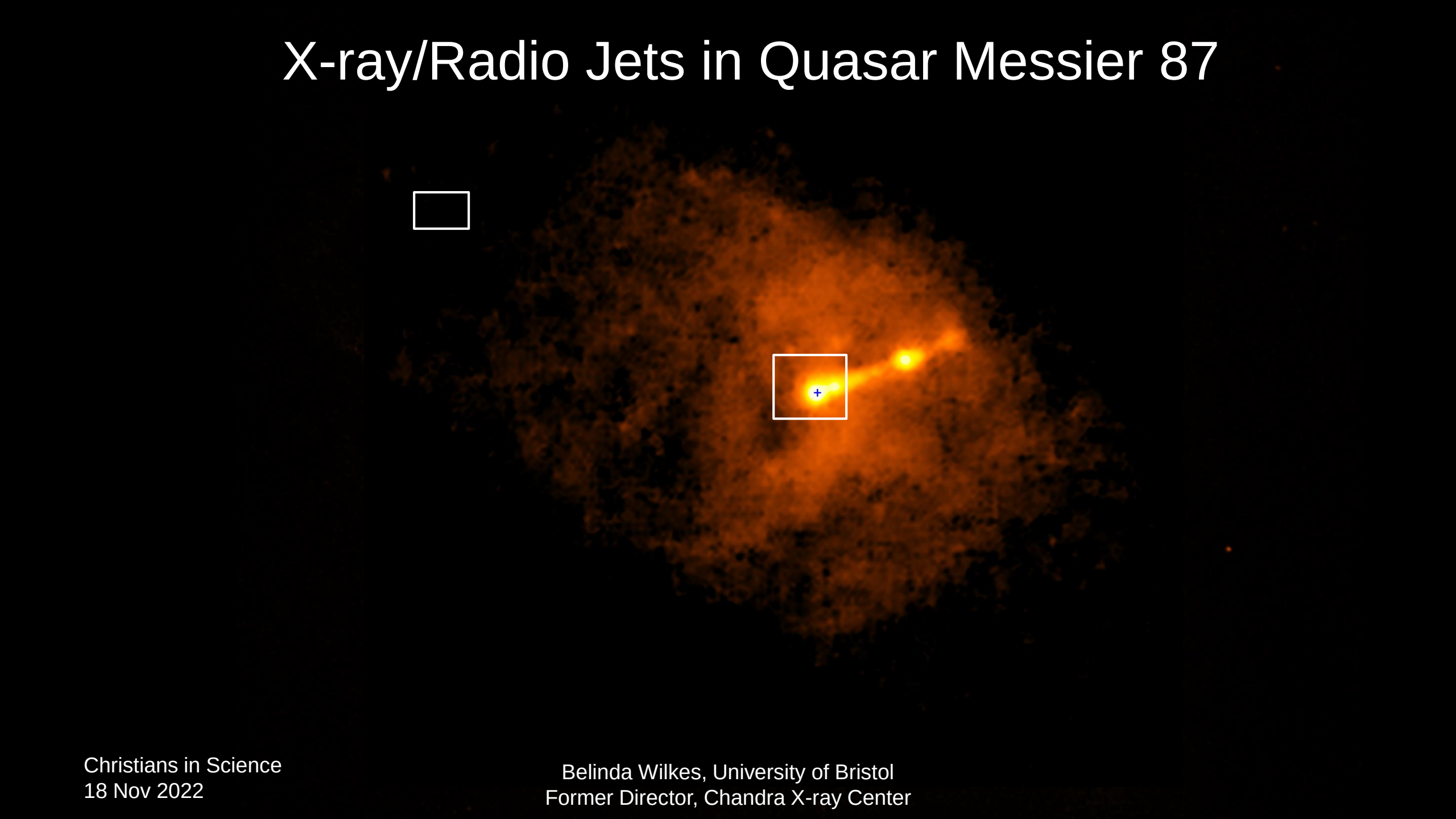
X-ray/Radio Jets in Quasar Messier 87



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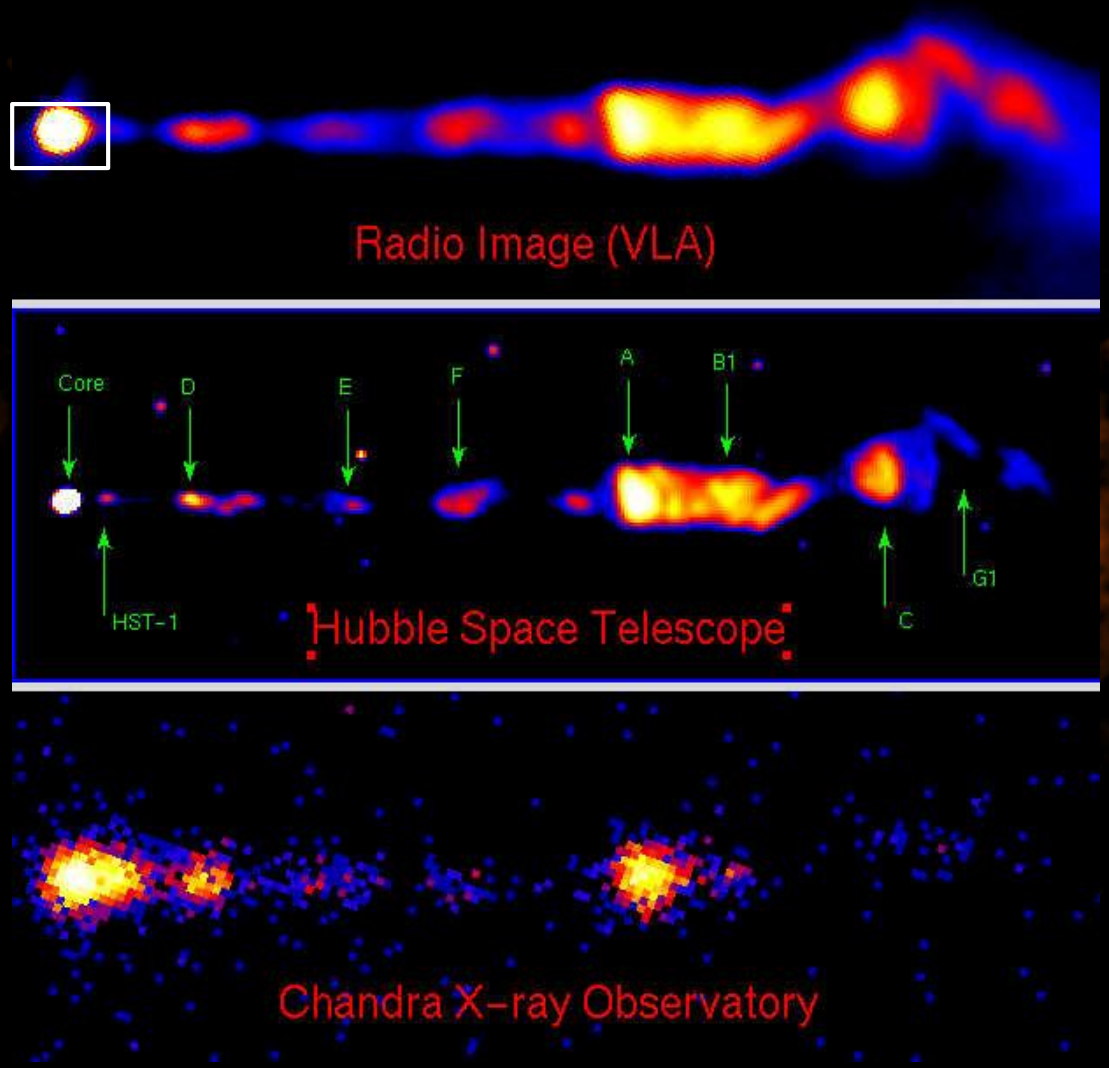

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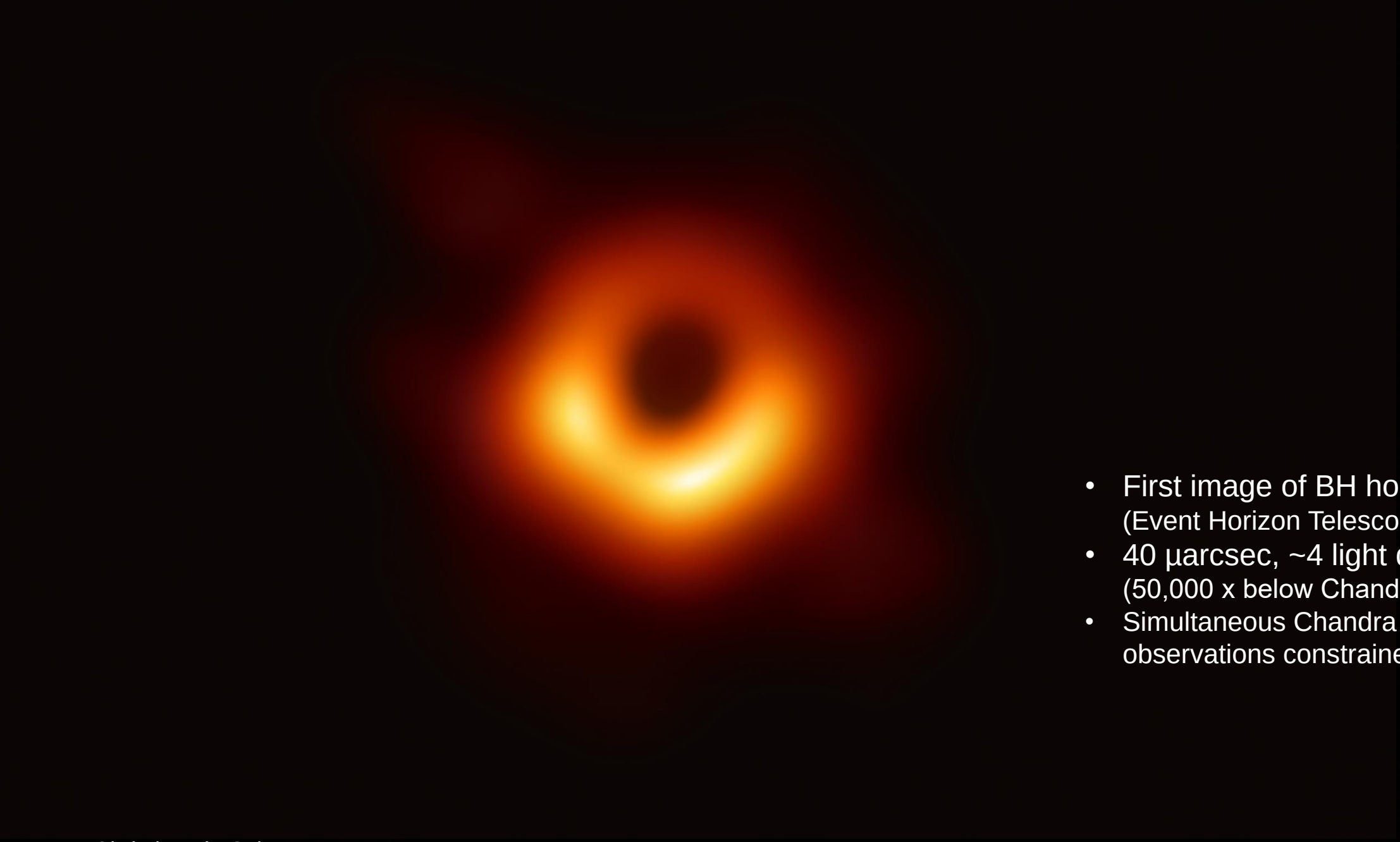

- First image of BH horizon
  (Event Horizon Telescope)
- 40 μarcsec, ~4 light days
  (50,000 x below Chandra's resolution)
- Simultaneous Chandra X-ray observations constrained this final model

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Binary Super-Massive Black Holes (SMBH)

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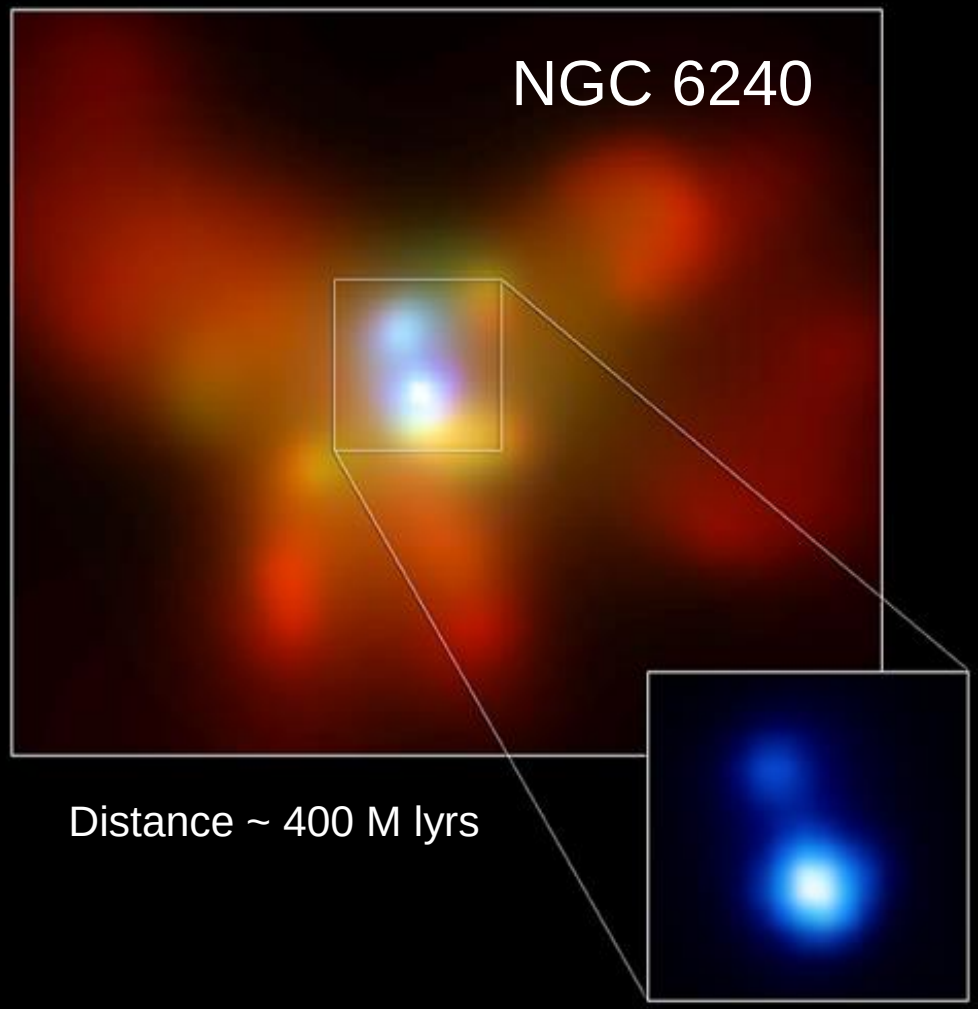
First Binary SMBH seen by *Chandra*



- Two galaxies merging
- Binary BHs (3000 light years apart) will merge in about 100 Myrs

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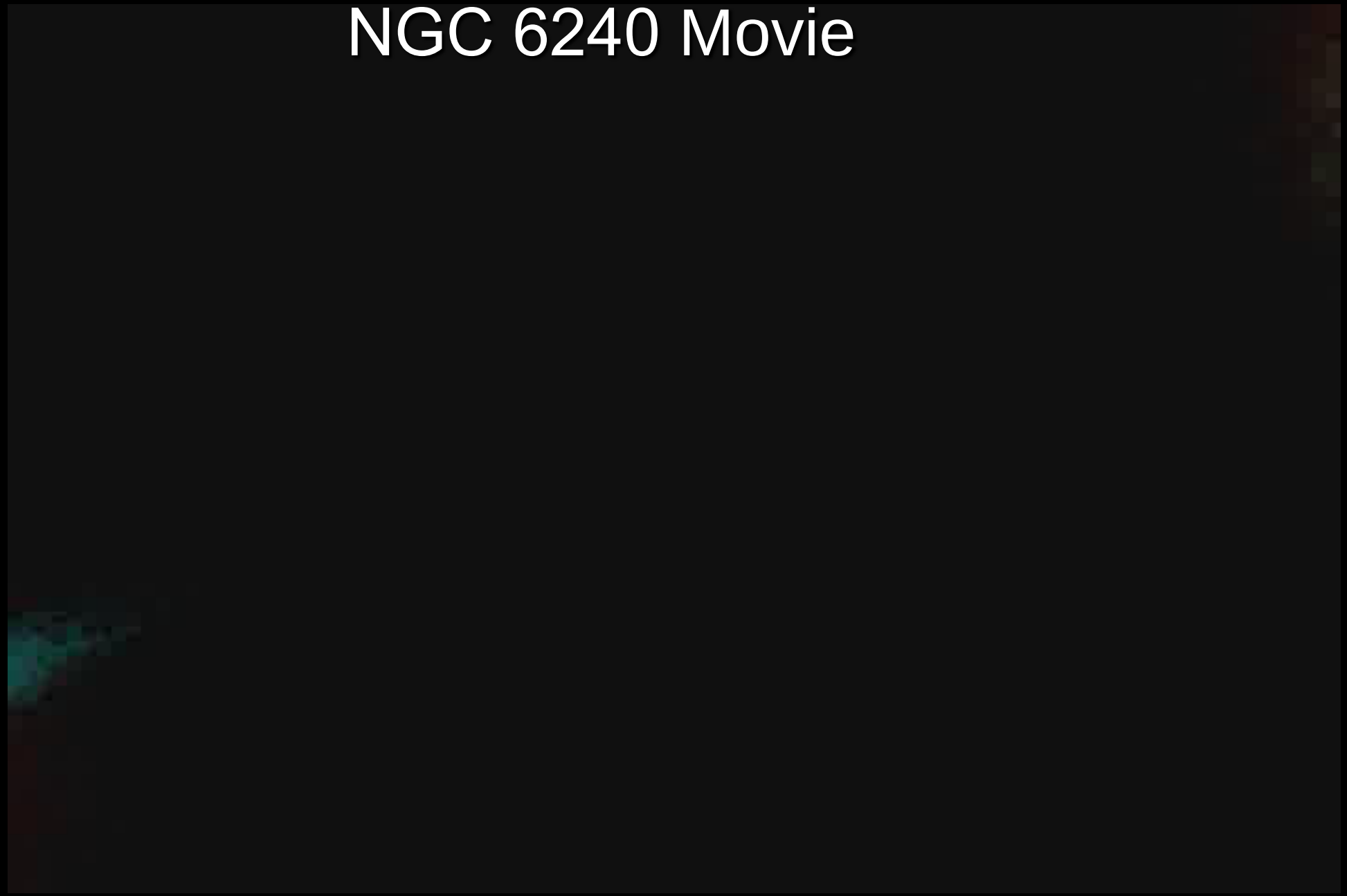
NGC 6240 Movie



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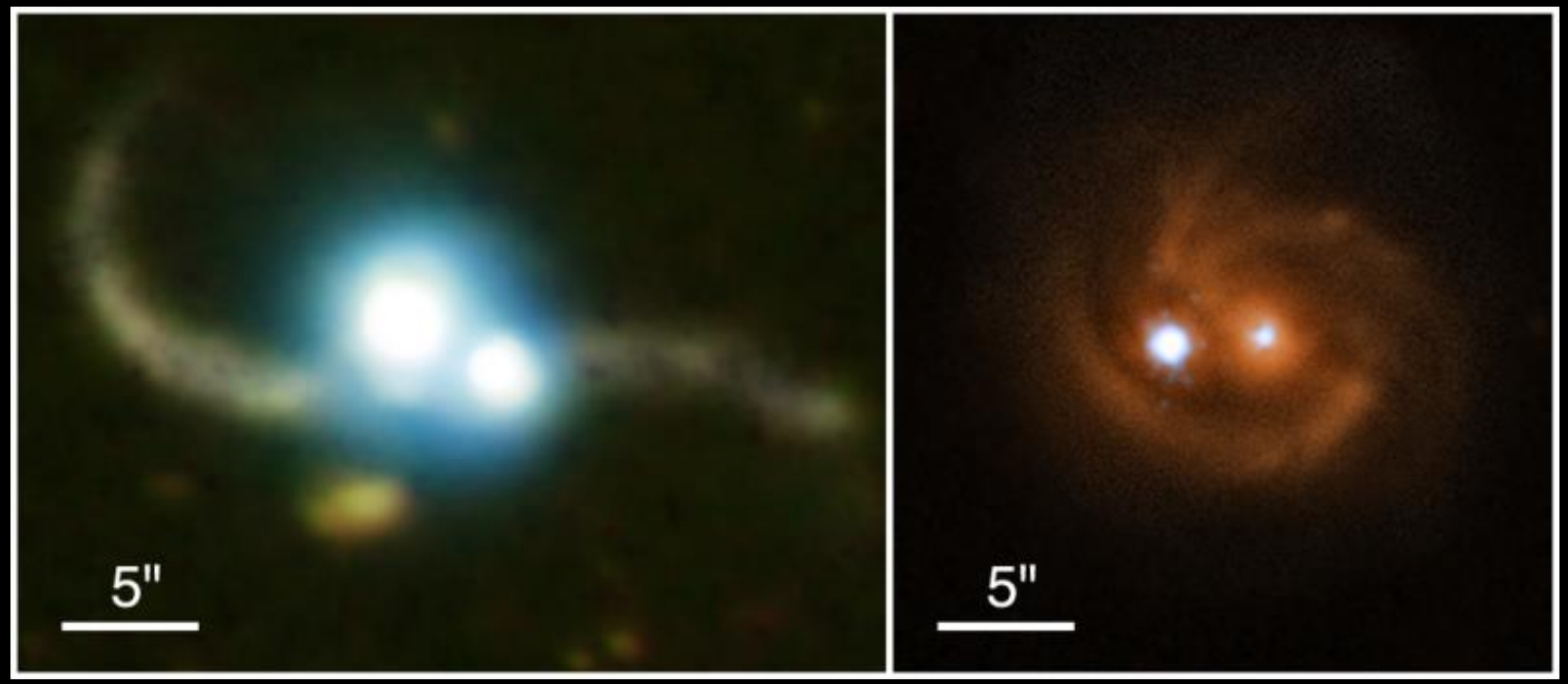
Binary Super-massive Black Holes

SDSS J1254+0846
70 klys separation
Chandra + Magellan

MRK 739
10 klys separation
Chandra + SDSS



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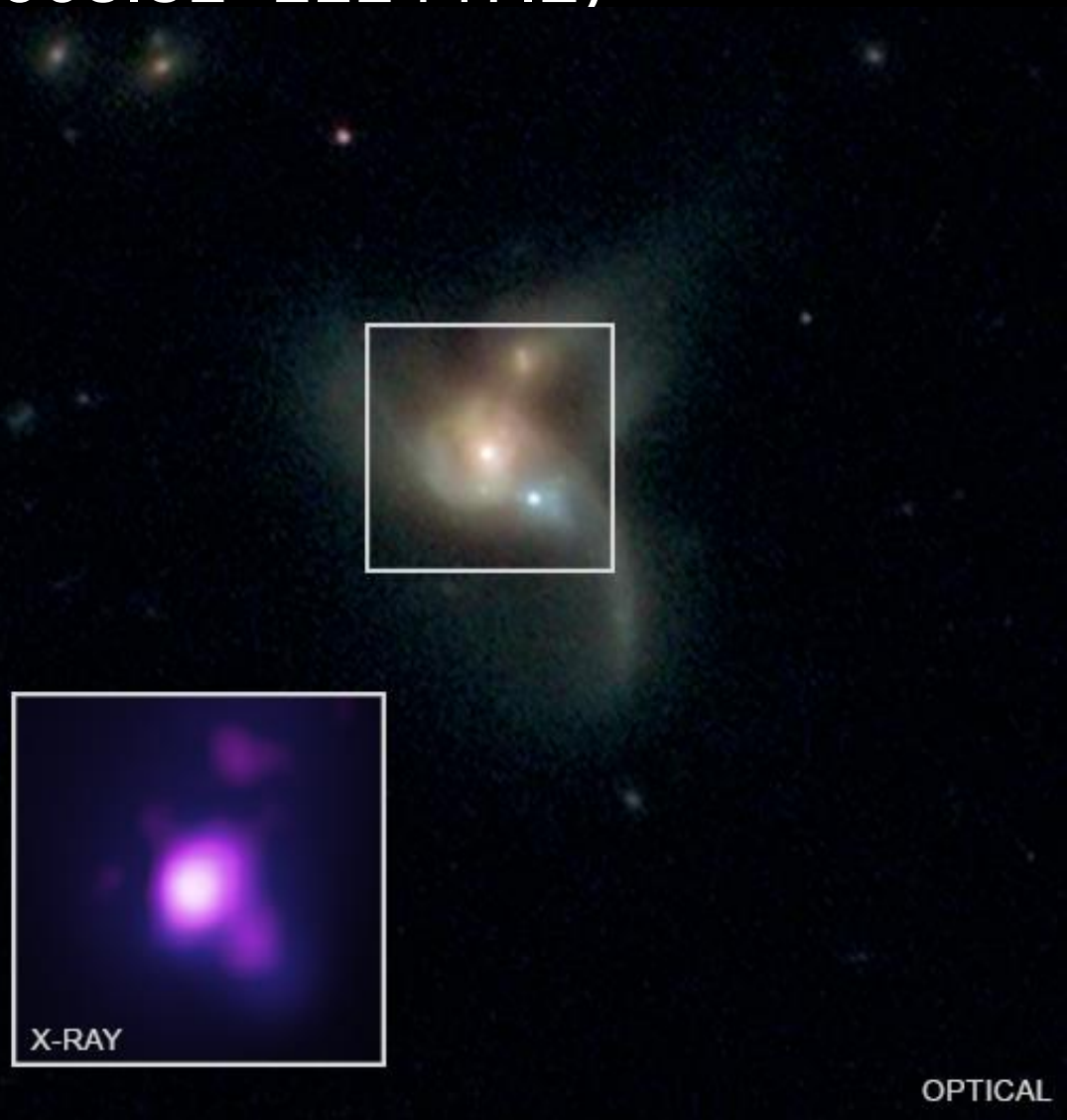
Rare Triple SMBHs in Merging Galaxy system (SDSS J084905.51+111447.2)

- Distance, 1 Blyrs,
- BH separations <30,000 lyrs
- Chandra X-ray data confirms 3 AGN



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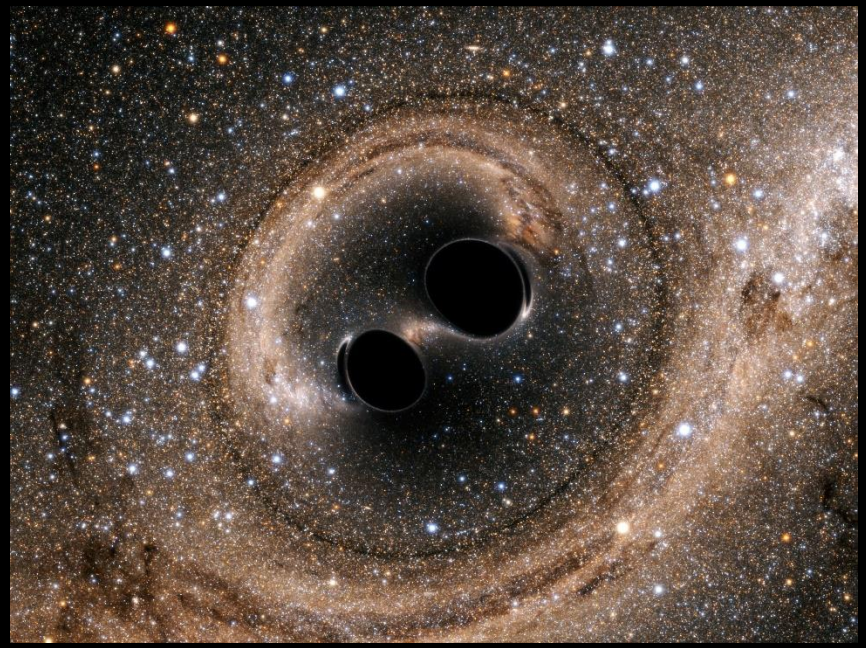
The birth of Gravitational Wave Astronomy

Laser Interferometer Gravitational-Wave Observatory (LIGO)
Livingston, LA & Hanford, WA
+ VIRGO in Italy

Merging Black Hole Simulation



No electromagnetic (EM) emission (light) expected

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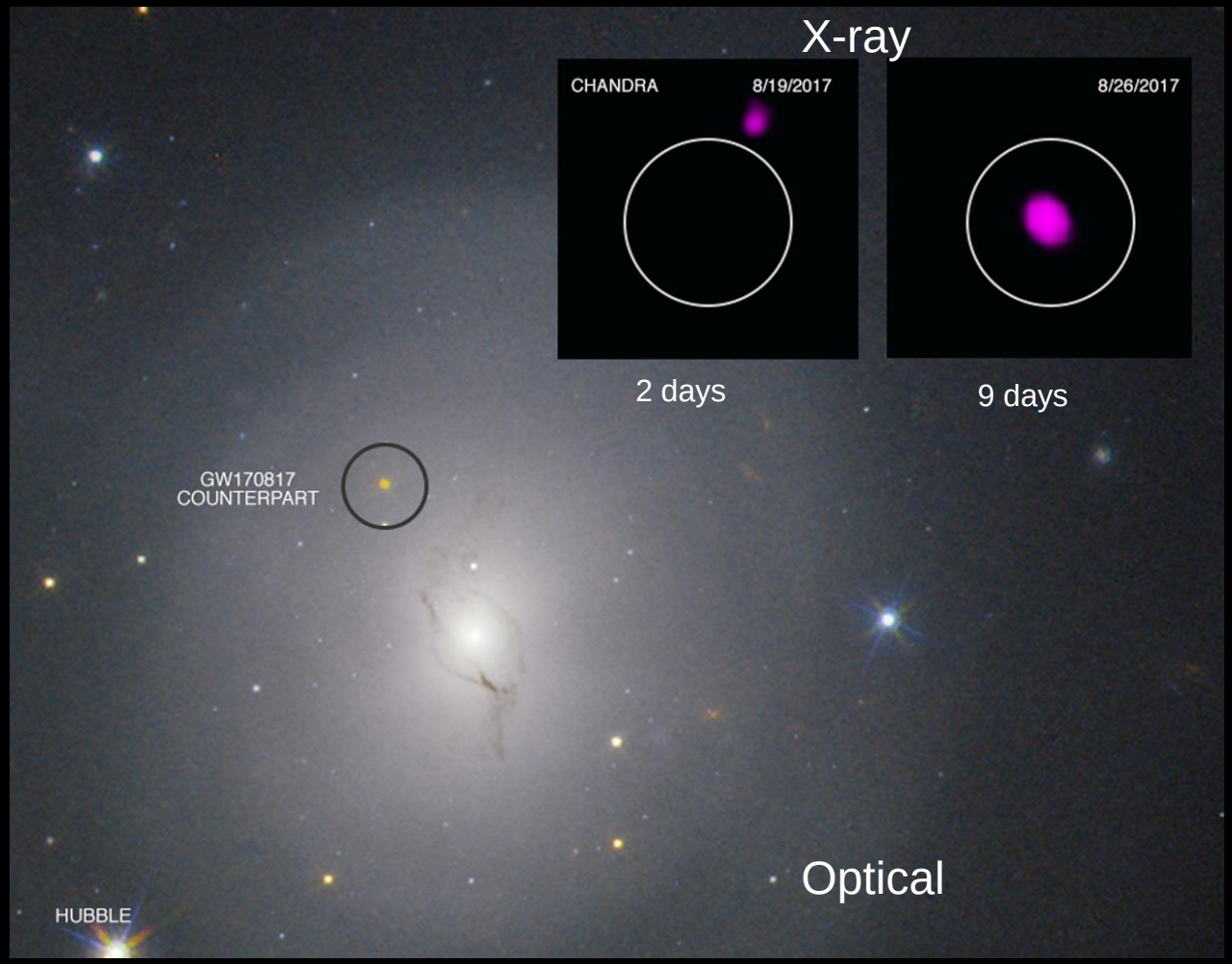
Merging Neutron Stars
LIGO/Virgo: GW170817

First EM detection of GW source!!

- Detected via gravitational wave signal
- Not detected by Virgo -> constrained sky position
- *Fermi & Integral*: Faint, short gamma-ray burst ~2s later
- Optical counterpart found, tracked, faded and reddened over ~2 weeks: kilonova
- Optical spectra showed signatures of r-process elements (>Fe)
- → X-ray & gamma-ray jet viewed off-axis
- Source went behind the sun – no X-ray observations until December
- X-ray & Radio emission continued to brighten, and then faded



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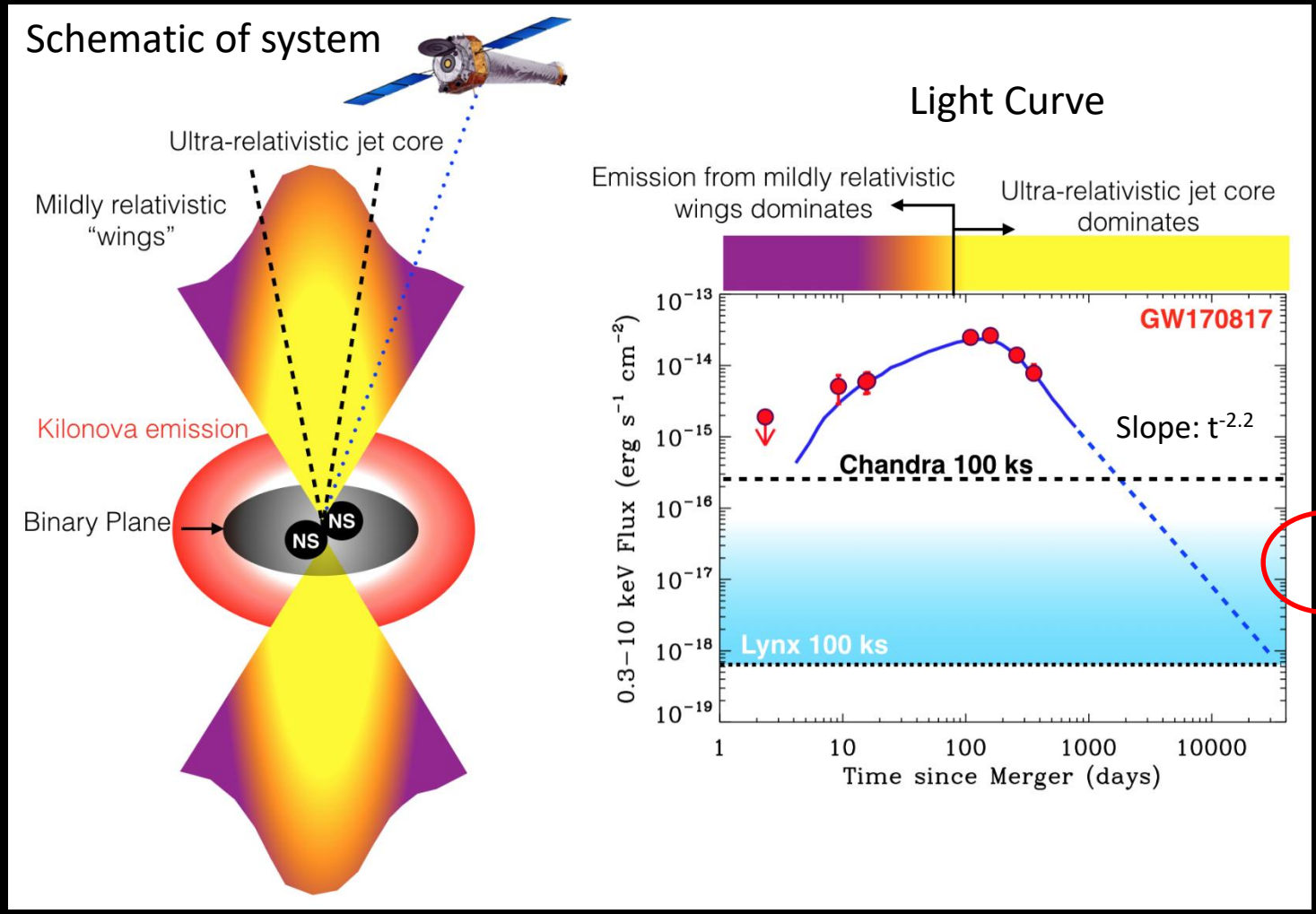
GW170817: off-axis jet

- *Chandra* X-rays key to constraining models
- Rise as jet expands
- Peak corresponds to view down widening jet core

- *Chandra* monitoring (only) continues
- New X-ray component, δt ~ 3.4 yrs
- 1) synchrotron from ejecta
- 2) accretion on to remnant



Credit: Hajela, Margutti, Fong, Haggard et al.

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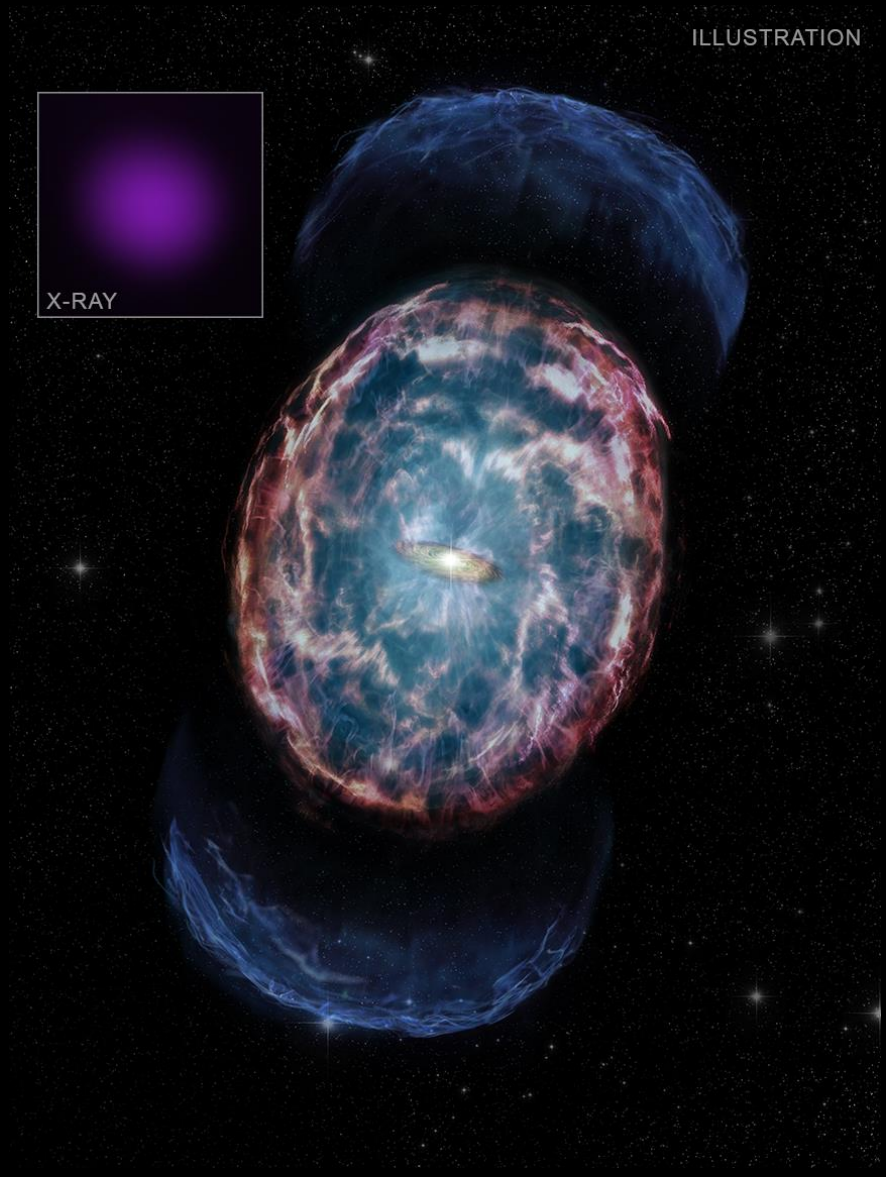
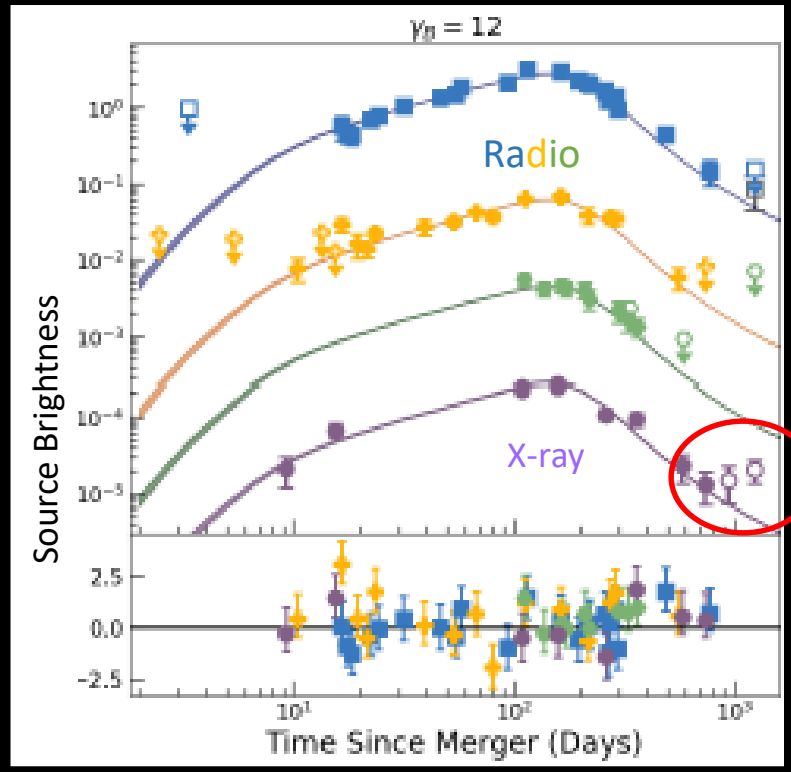


Light Curve



Credit: Hajela, Margutti, Fong, Haggard et al.

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Clusters of Galaxies

Largest Gravitationally Bound Systems in the Universe
50-1000 galaxies

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Perseus Cluster

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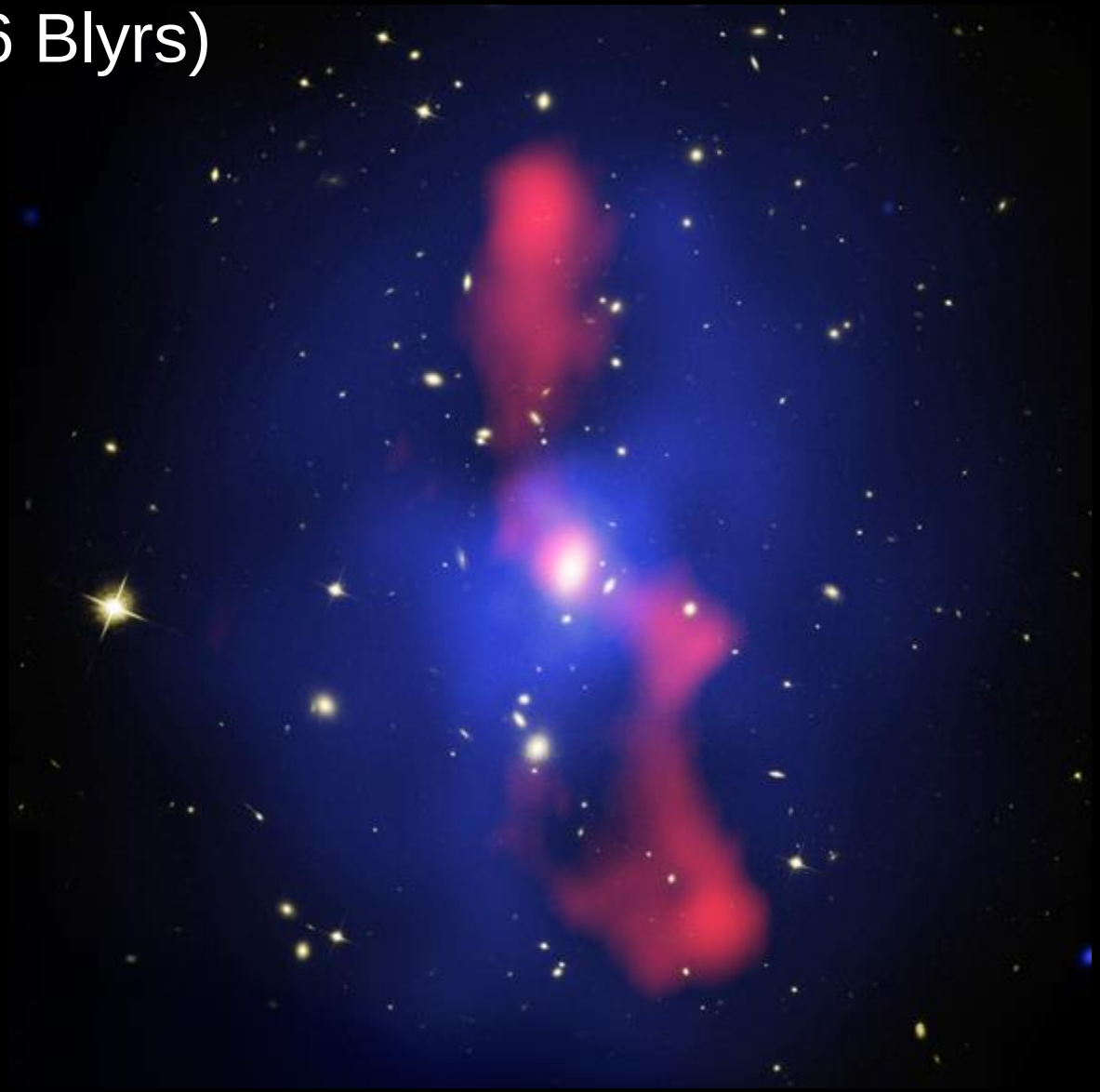
Credit: Paul Nandra, ESA

Cluster: MS 0735.6+7421
(2.6 Blyrs)

- Galaxies and stars (white)
- Hot X-ray-emitting gas dominates normal matter
  - Site of star formation
  - Accretes onto central active nucleus
- Radio jets push hot gas aside, creating X-ray cavities
- Radio jets deposit energy in intercluster medium over ~10^8 yrs
- “Feedback” loop moderating stellar and SMBH growth
- Largest continuous radio jet: >1 million lt yrs



Christians in Science
18 Nov 2022

Belinda Wilkes, University of Bristol
Former Director, Chandra X-ray Center

1999: on the shuttle

Pilot: Jeff Ashby

Mission Specialist
Steve Hawley

Flag/banner now hangs in the Operations Control Center

Chandra Mission Specialist
Cady Colman

Commander
Eileen Collins

ESA Astronaut
Michel Tognini

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2014: 15 Years of Chandra Science

4 of 5 shuttle astronauts visited: Eileen Collins (Commander), Cady Coleman (Mission Specialist), Steve Hawley, Michel Tognini

(Pilot: Jeff Ashby unable to attend)

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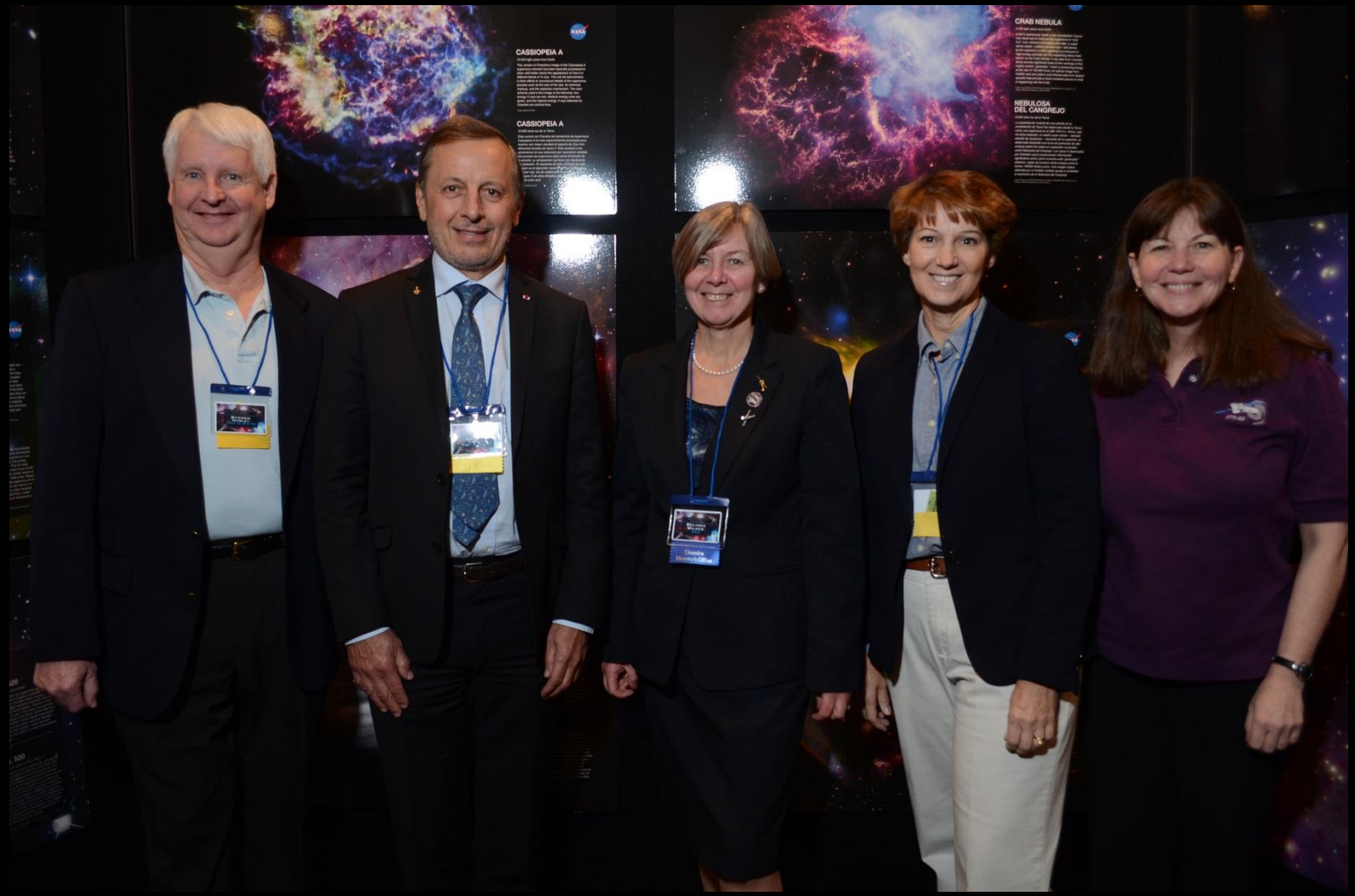

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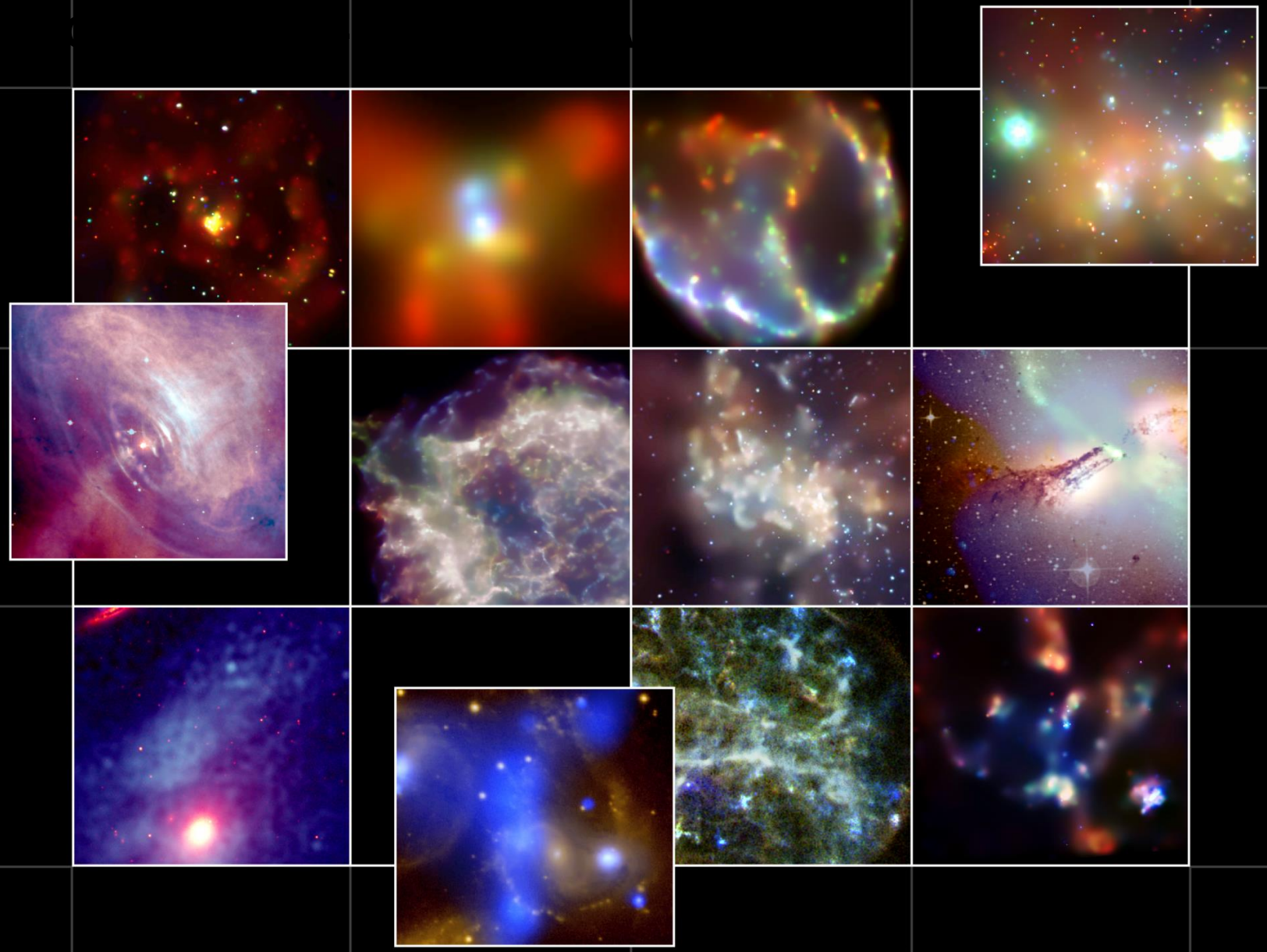

Twitter:
@BelindaWilkes

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Chandra Website:
chandra.si.edu