Outstanding Science with a Great Observatory

The *Chandra* X-ray Observatory

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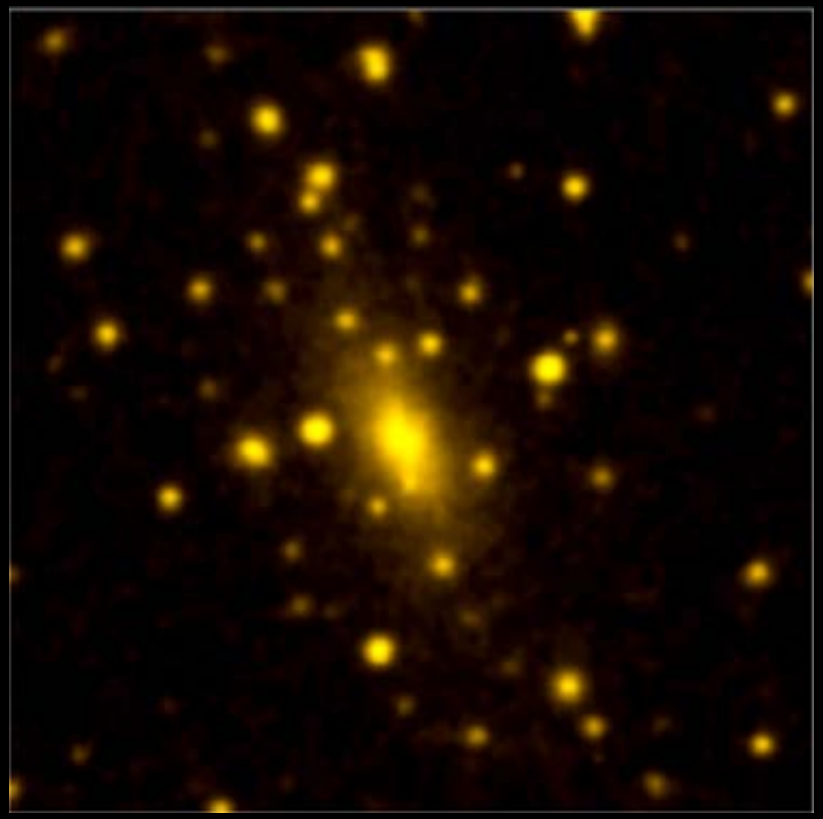
Outline

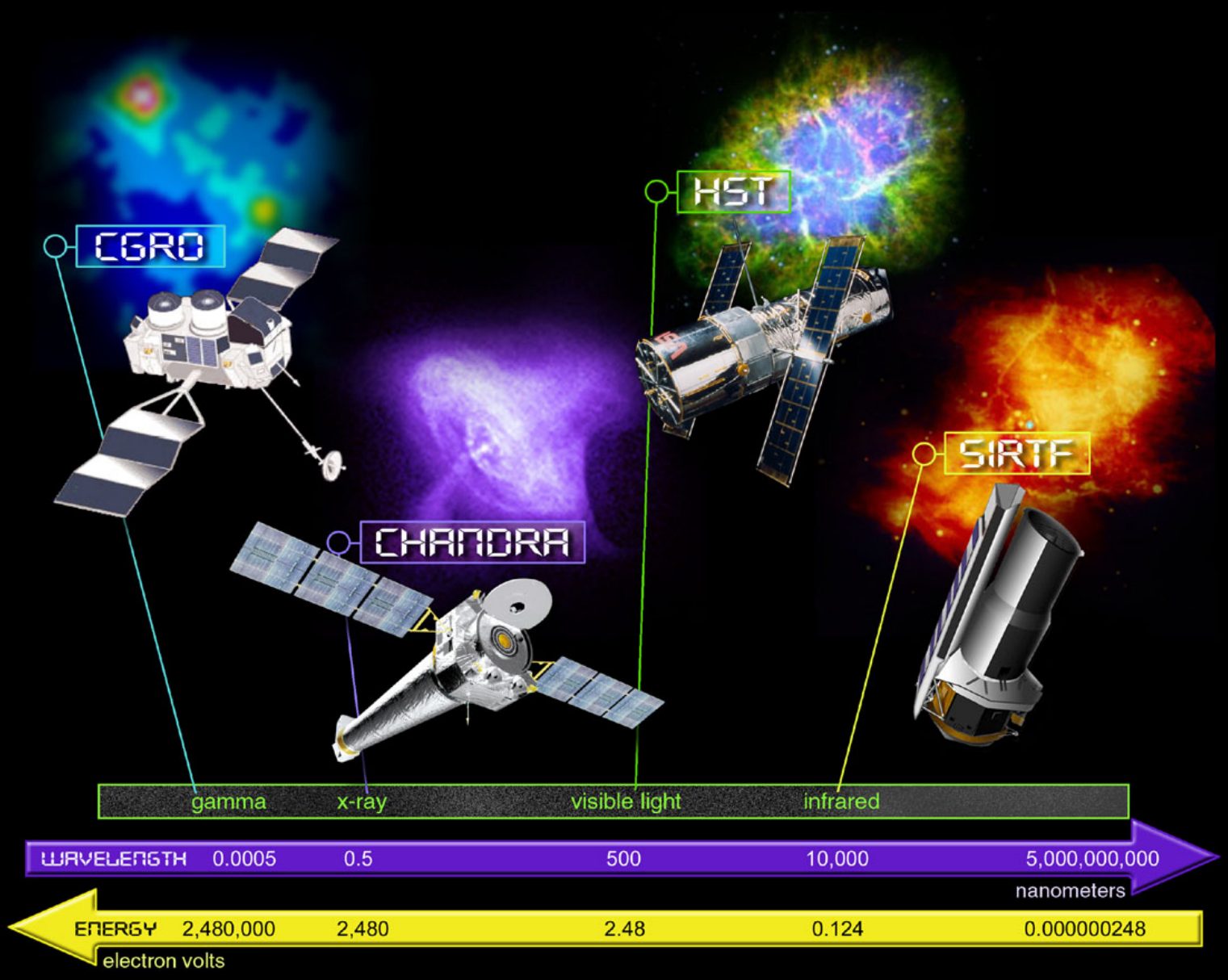
- Why X-ray Astronomy is so important
- NASA's Great Observatory Program
- A (very) brief history of X-ray astronomy
- The building of the Observatory
- Launch, deployment, first light!
- Some of the wonderful science

The importance of X-ray Astronomy



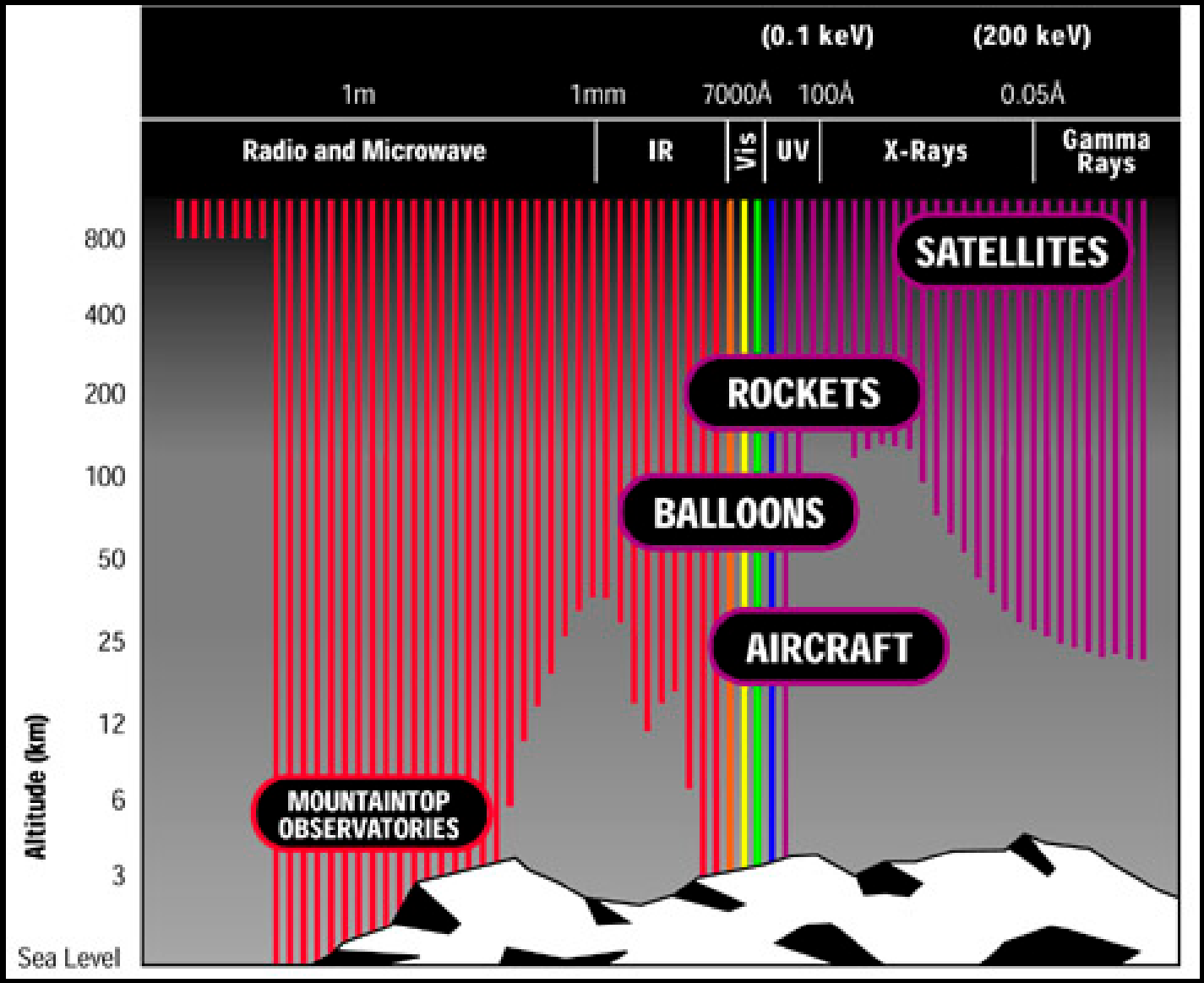
- Most of the matter that we “see” in the universe is via its X-ray emission
- The bulk of this matter is the hot, X-ray-emitting gas in the great galaxy clusters

NASA's Great Observatories

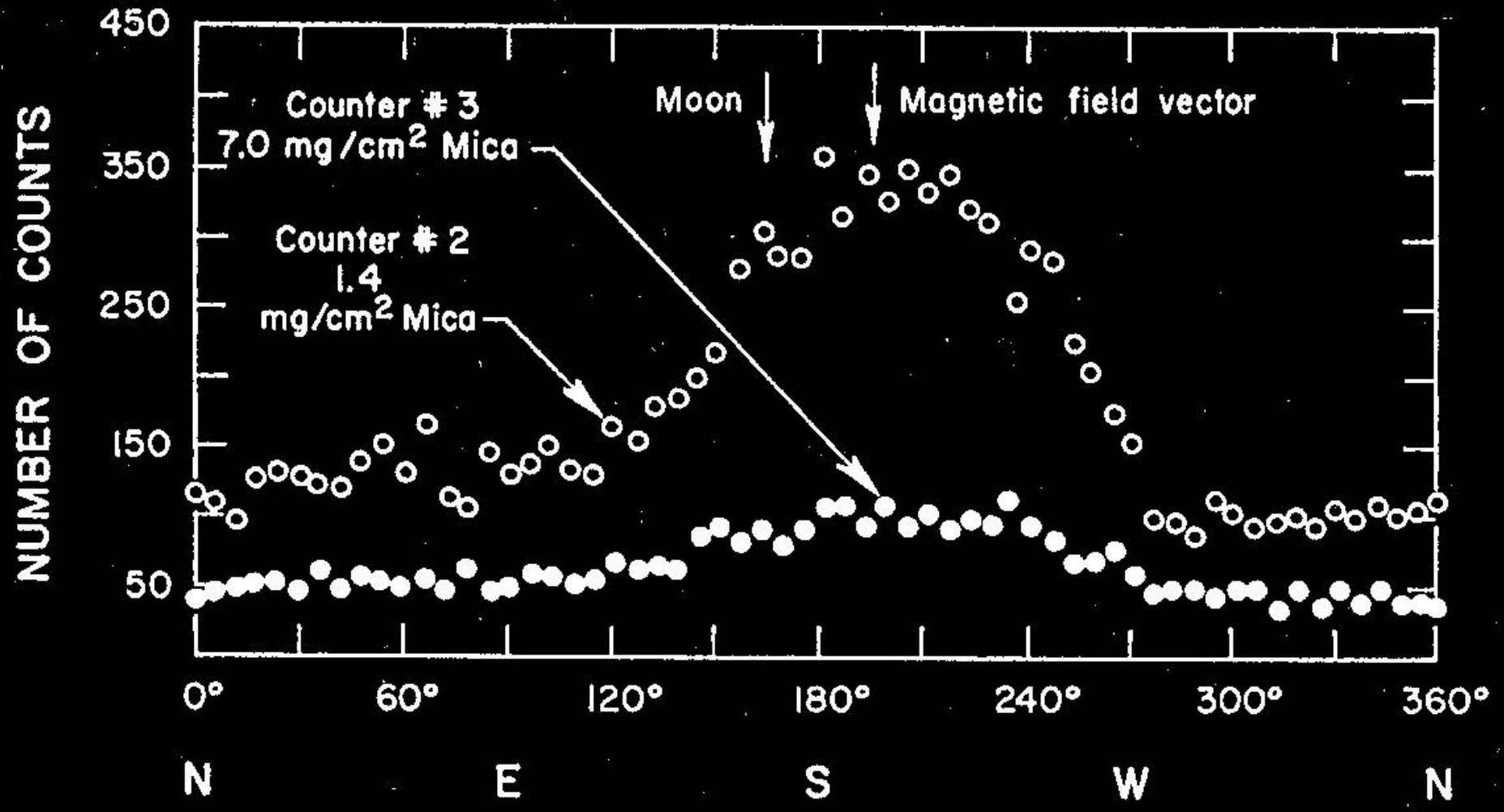


The Atmosphere is a Nuisance

Altitude (km)

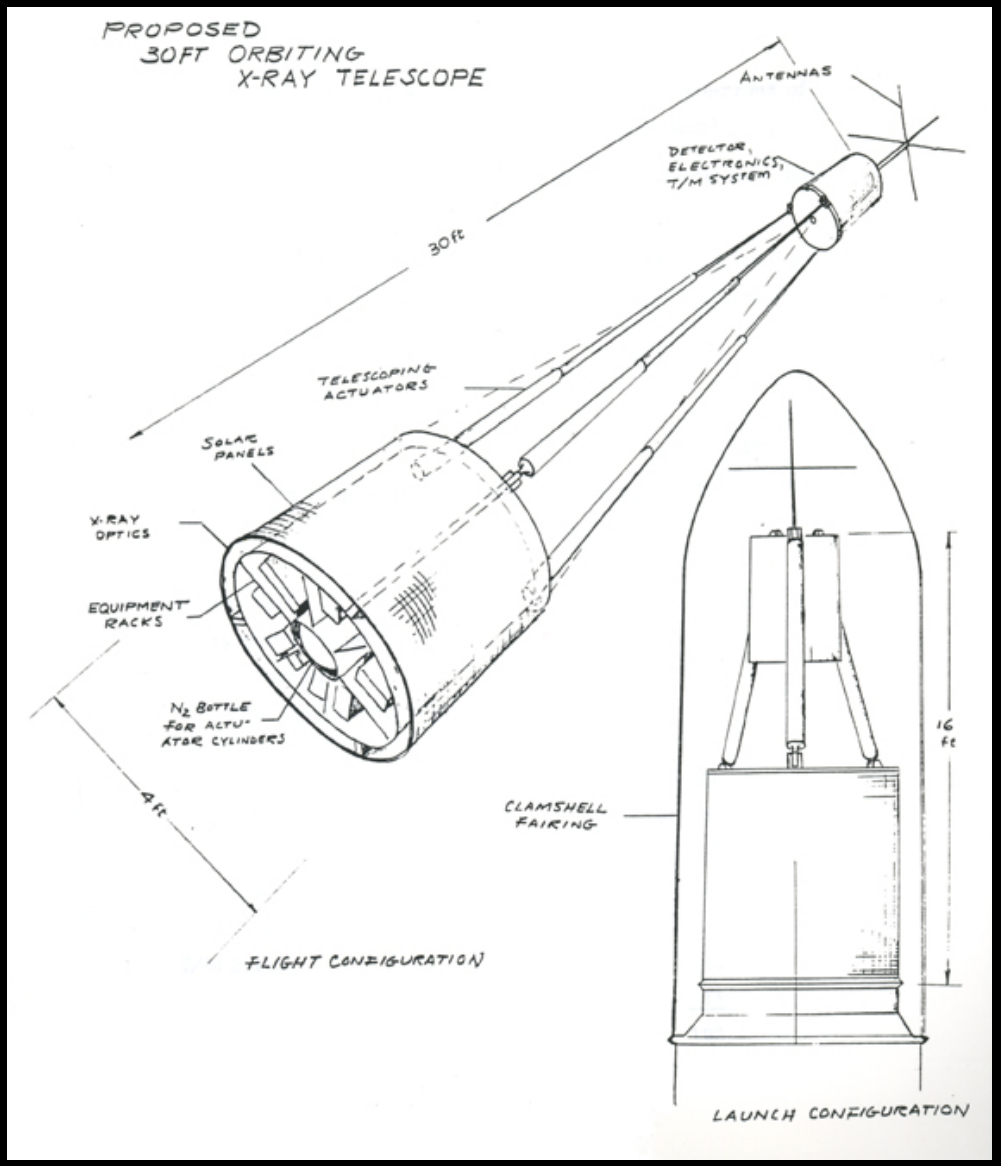


The First Extra-Solar X-ray Source (1962)

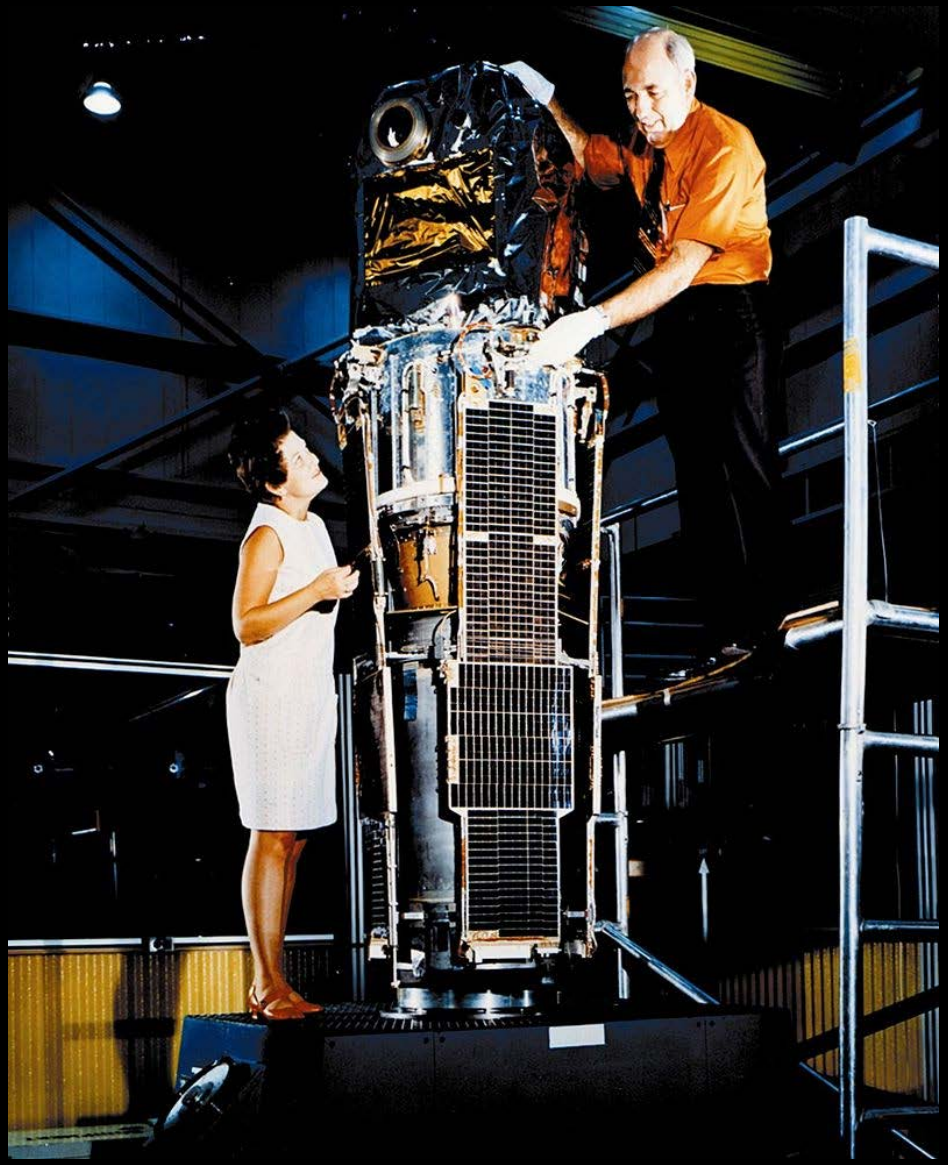


The Vision (1963)

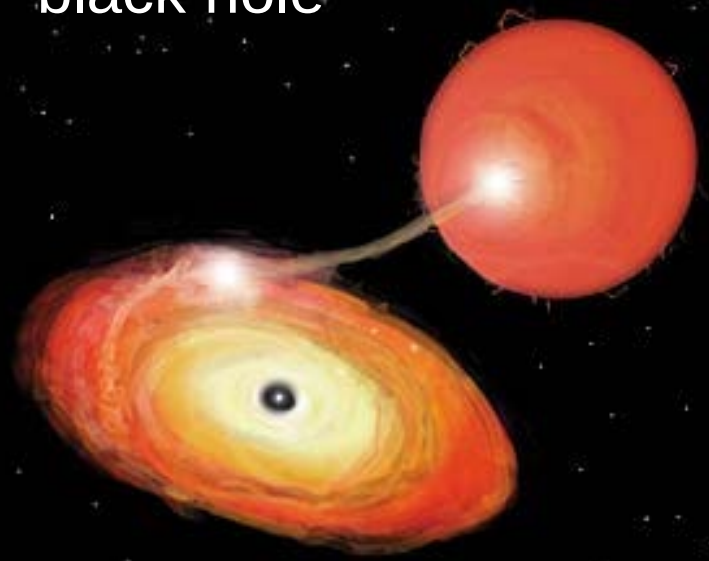
Riccardo Giacconi



UHURU satellite (Dec 1970 – Mar 1973



- Simple detector
- Comprehensive catalog of the brightest X-ray sources
- Discovery of the pulsing “accretion-powered” X-ray binaries
  - Neutron stars and the first black hole



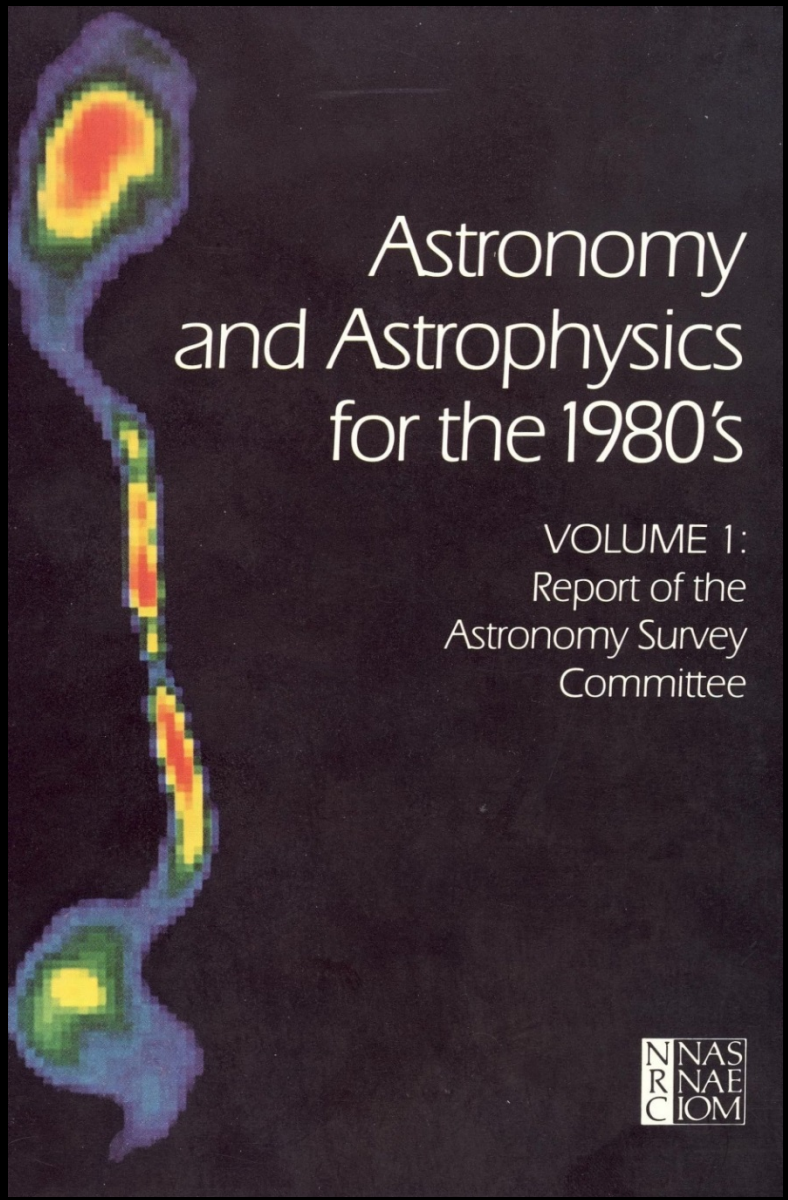
The *Einstein* Observatory (Nov 1978 – Apr 1981)

- First X-ray telescope for non-solar observations
- A forerunner of *Chandra*
  - X-ray telescope
  - Multlple detectors

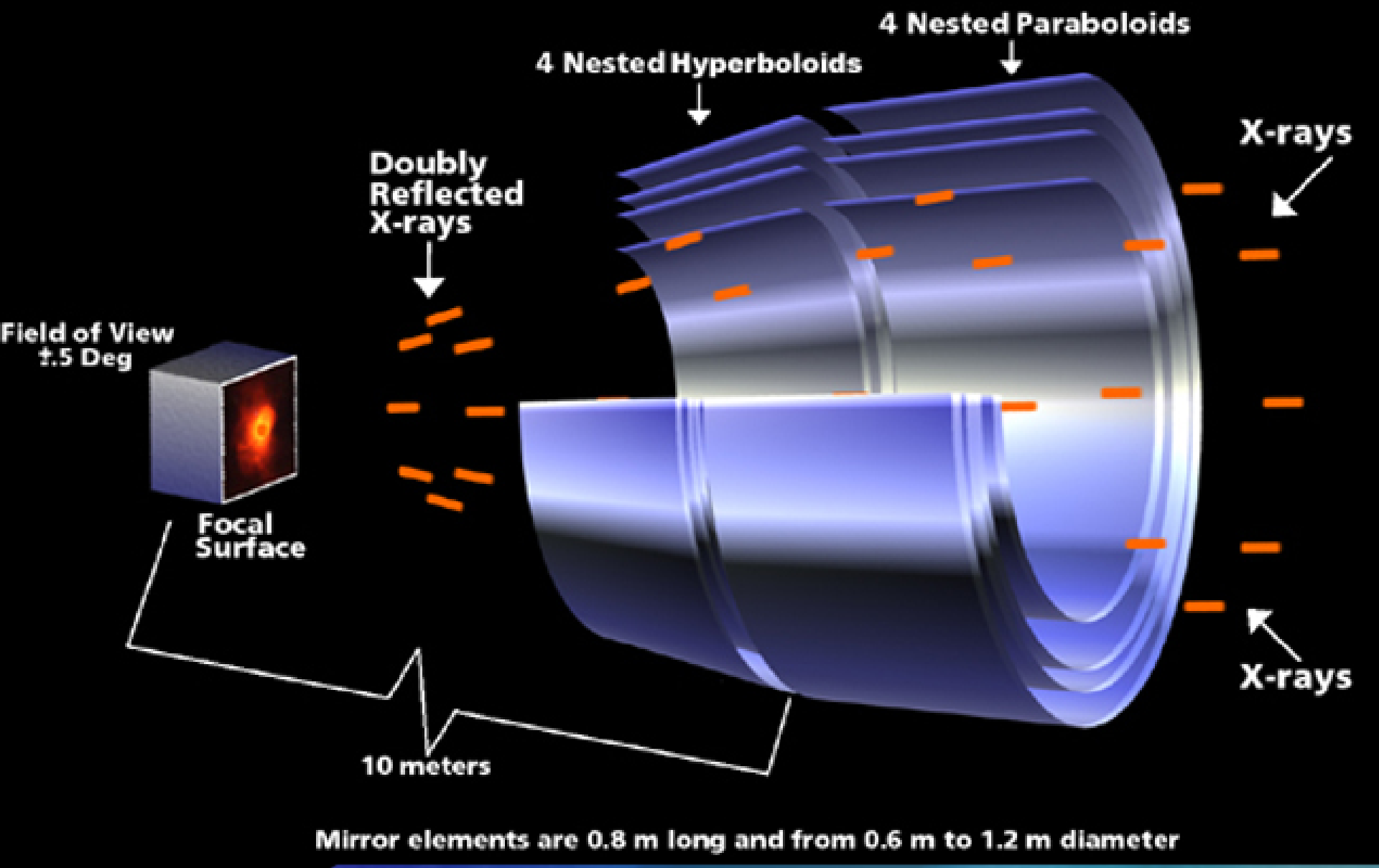
- Showed that *every* known class of astronomical object, or a subset, was a source of X-rays

National Academy of Sciences

Major New Programs
#1: An Advanced X-Ray Astrophysics Facility (AXAF)



Optics

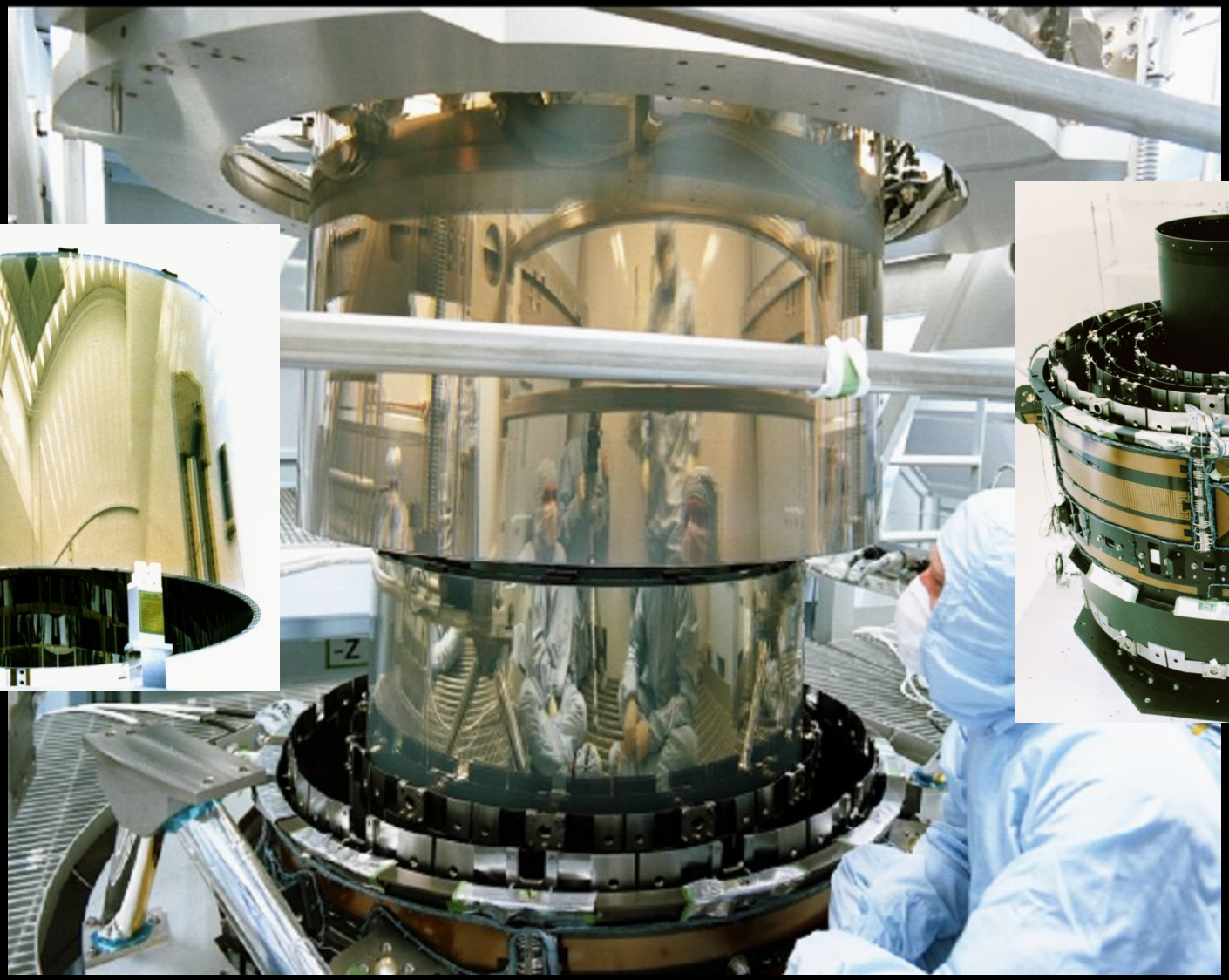


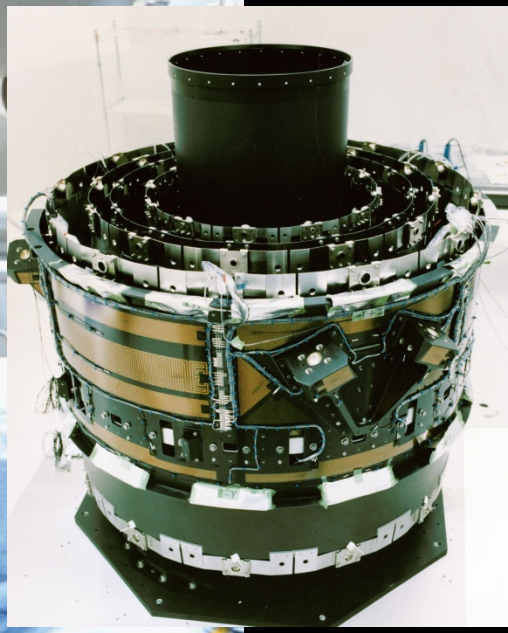
Mirror elements are 0.8 m long and from 0.6 m to 1.2 m diameter

Optics: Purchase of mirror blanks (1987)

Optics: Ground and Polished

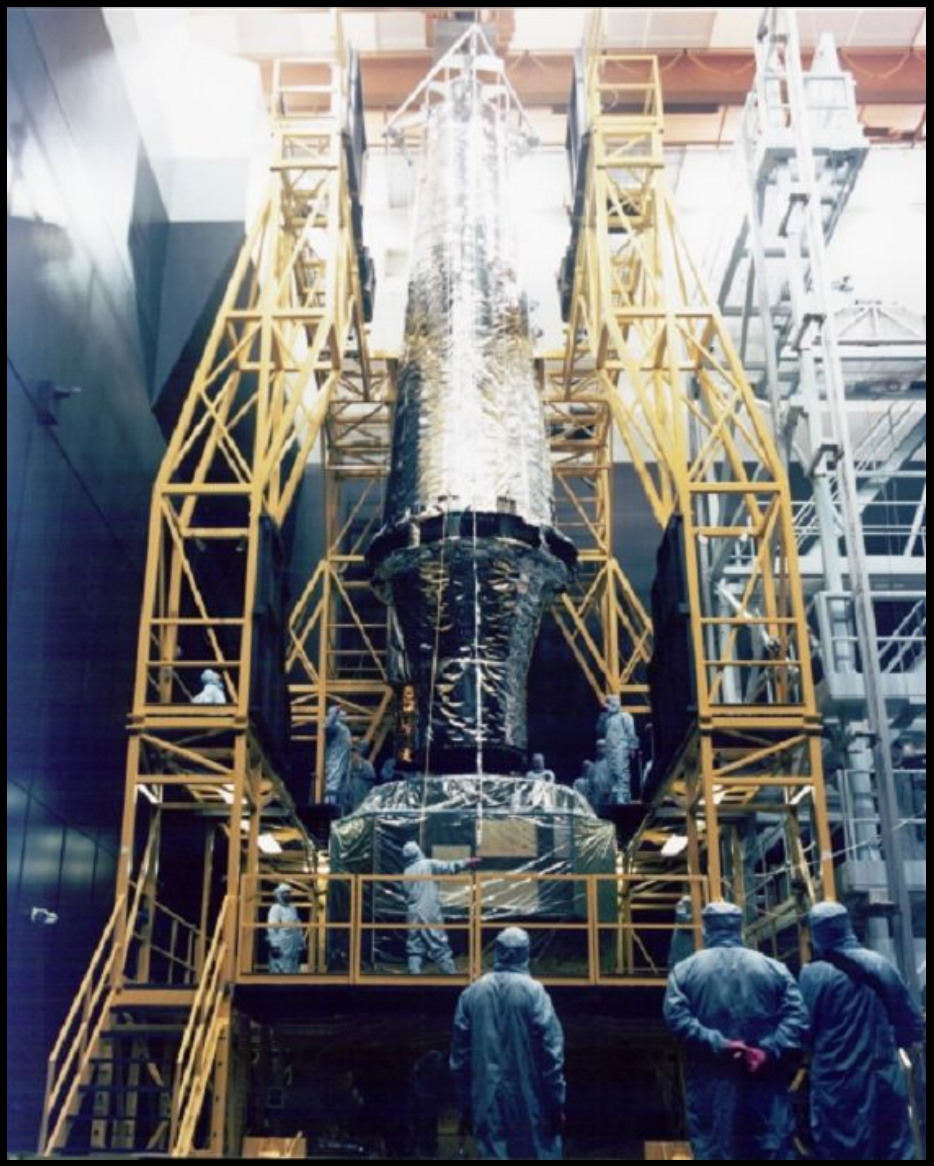
Optics: Coated, Assembled & Aligned



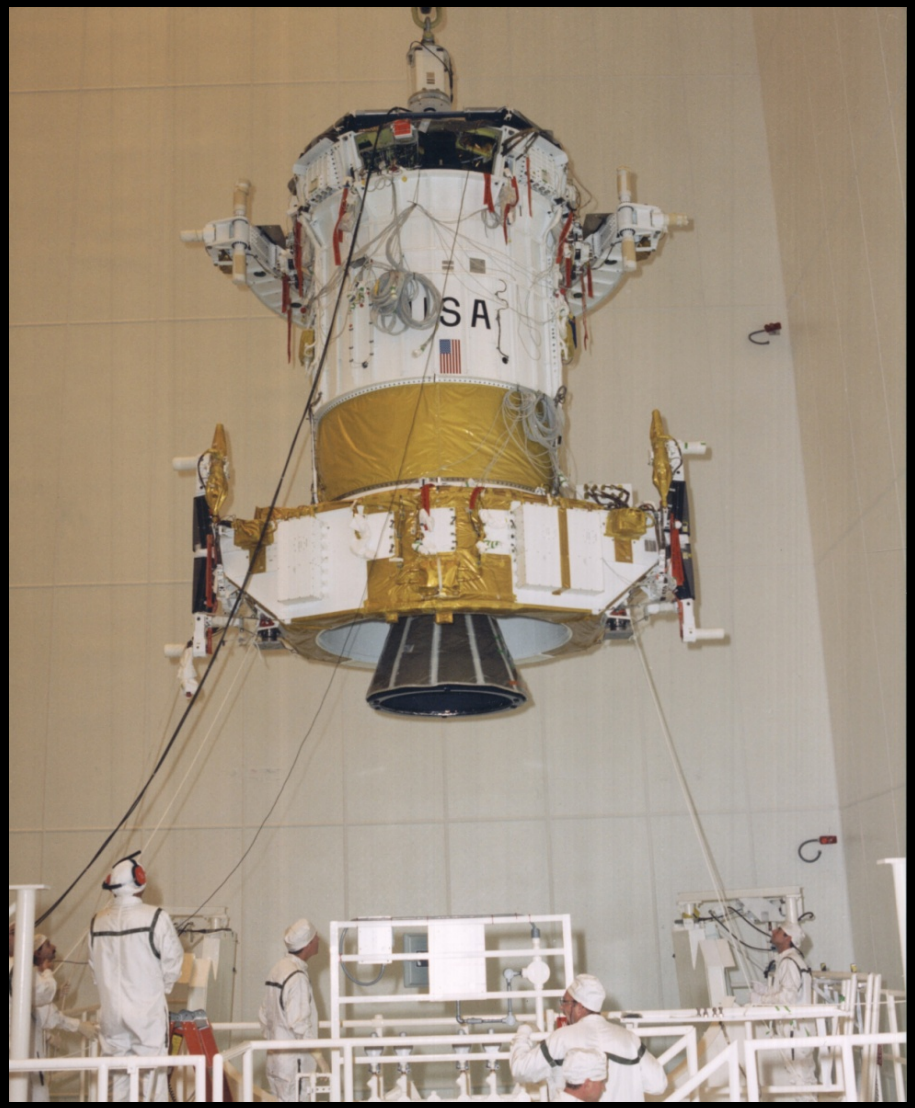


The X-ray Calibration Facility at MSFC

Telescope Meets Spacecraft (1998)



Include the Upper Stage



The longest and heaviest payload ever launched by the Shuttle

Mrs Chandra at the Launch

The Launch – July 23 1999

Beyond the Sky

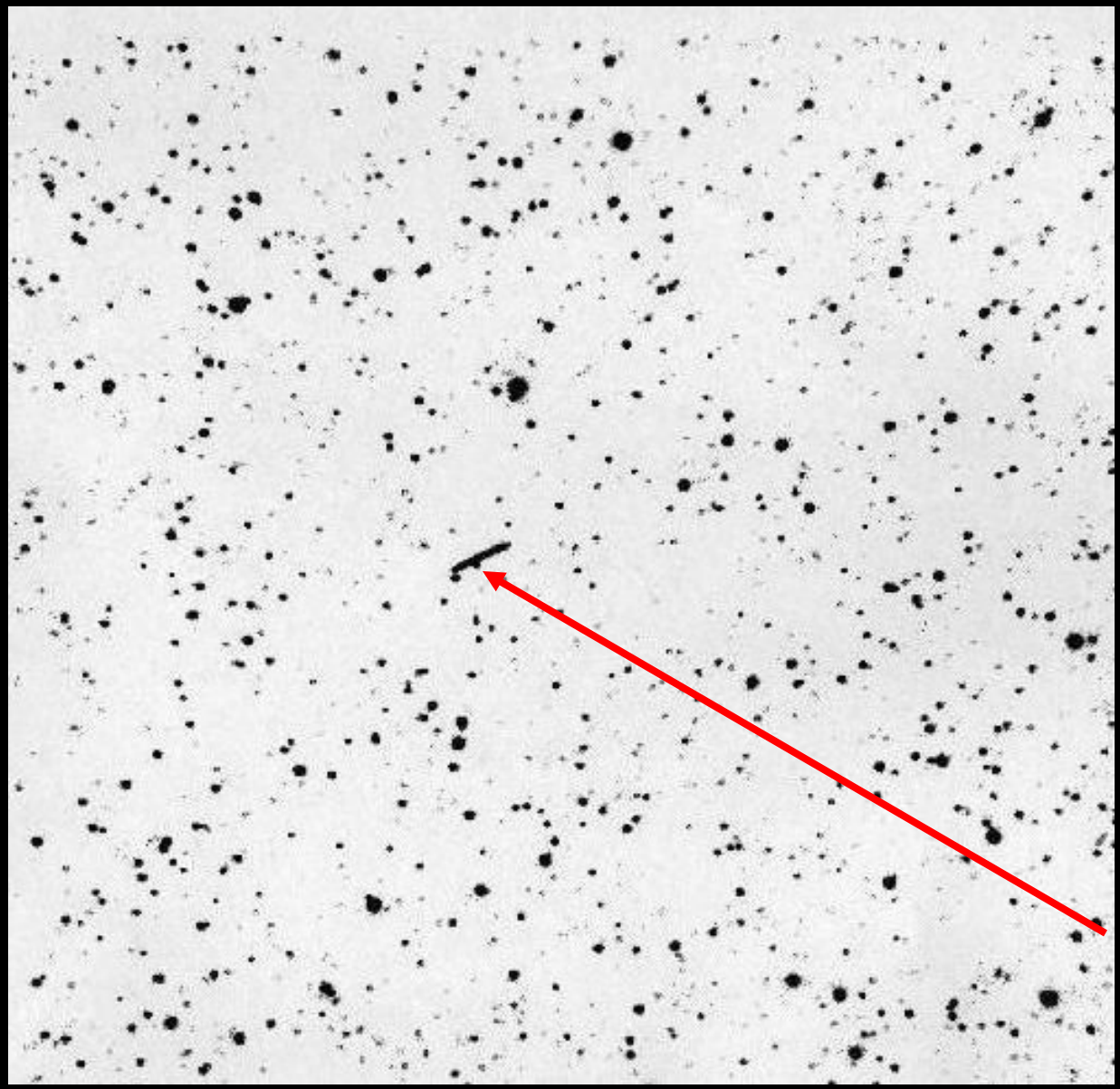
Words and Music by Judy Collins

And we will fly beyond the sky
Beyond the stars beyond the heavens
Beyond the dawn we'll carry on
Until our dreams have all come true
To those who fly - we sing to you

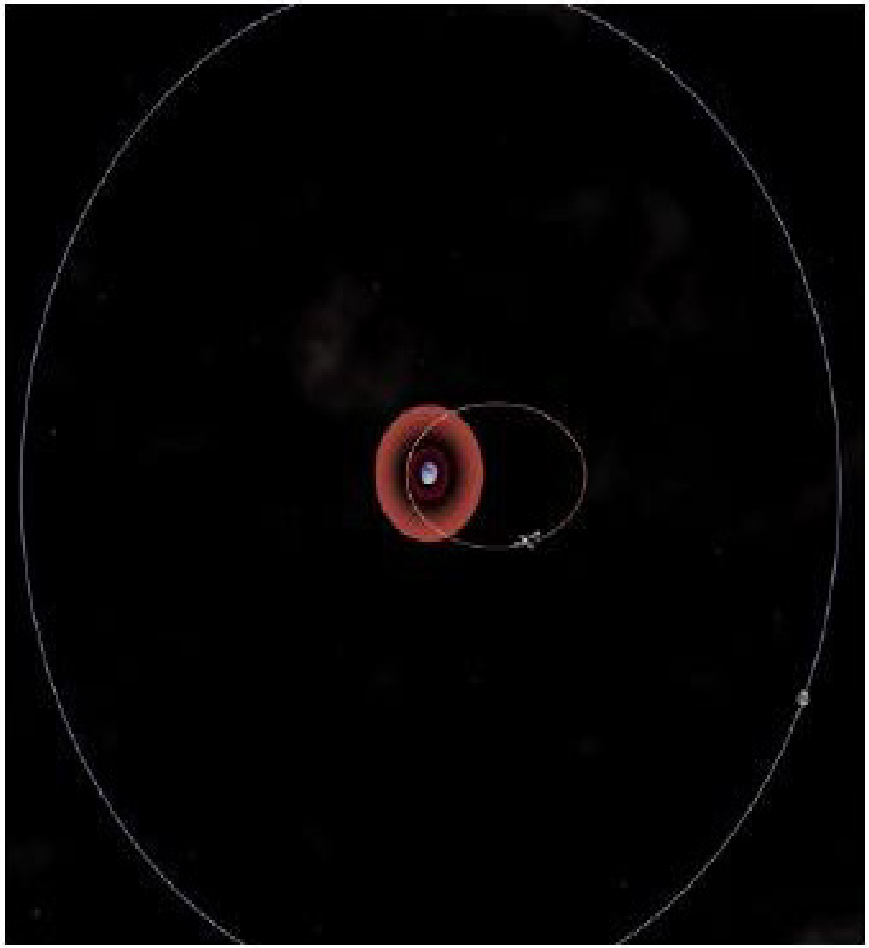
In Columbia’s Cargo Bay

Deployed!

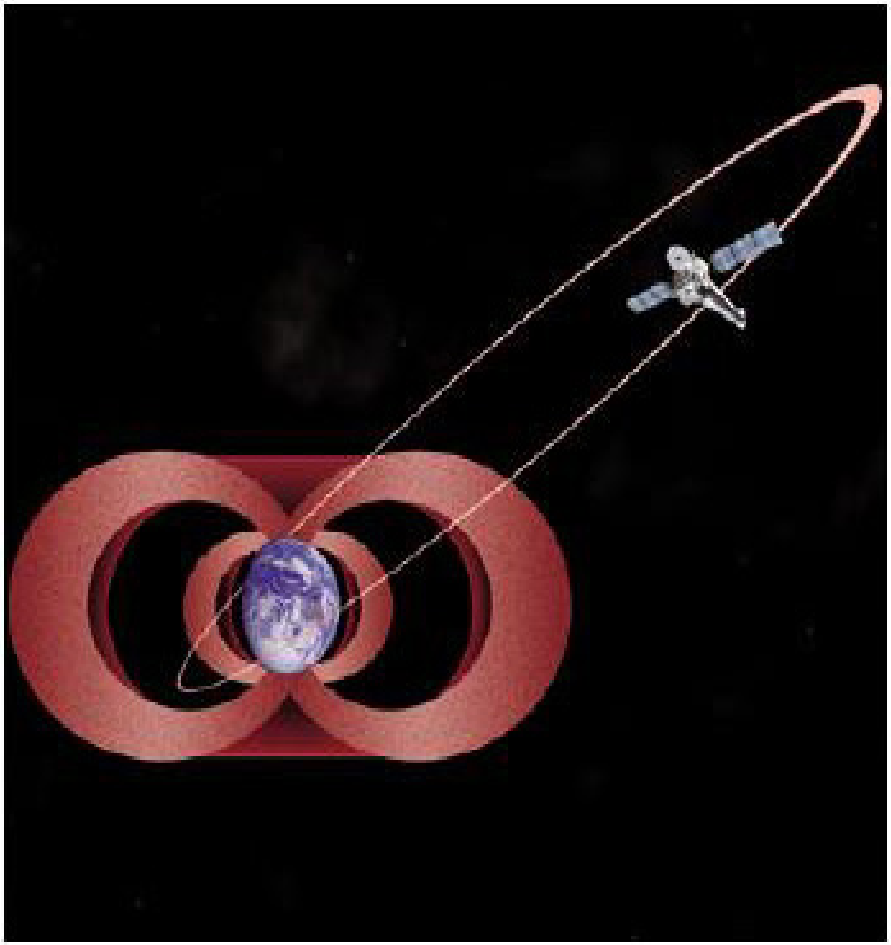
In Low-Earth Orbit



The final orbit

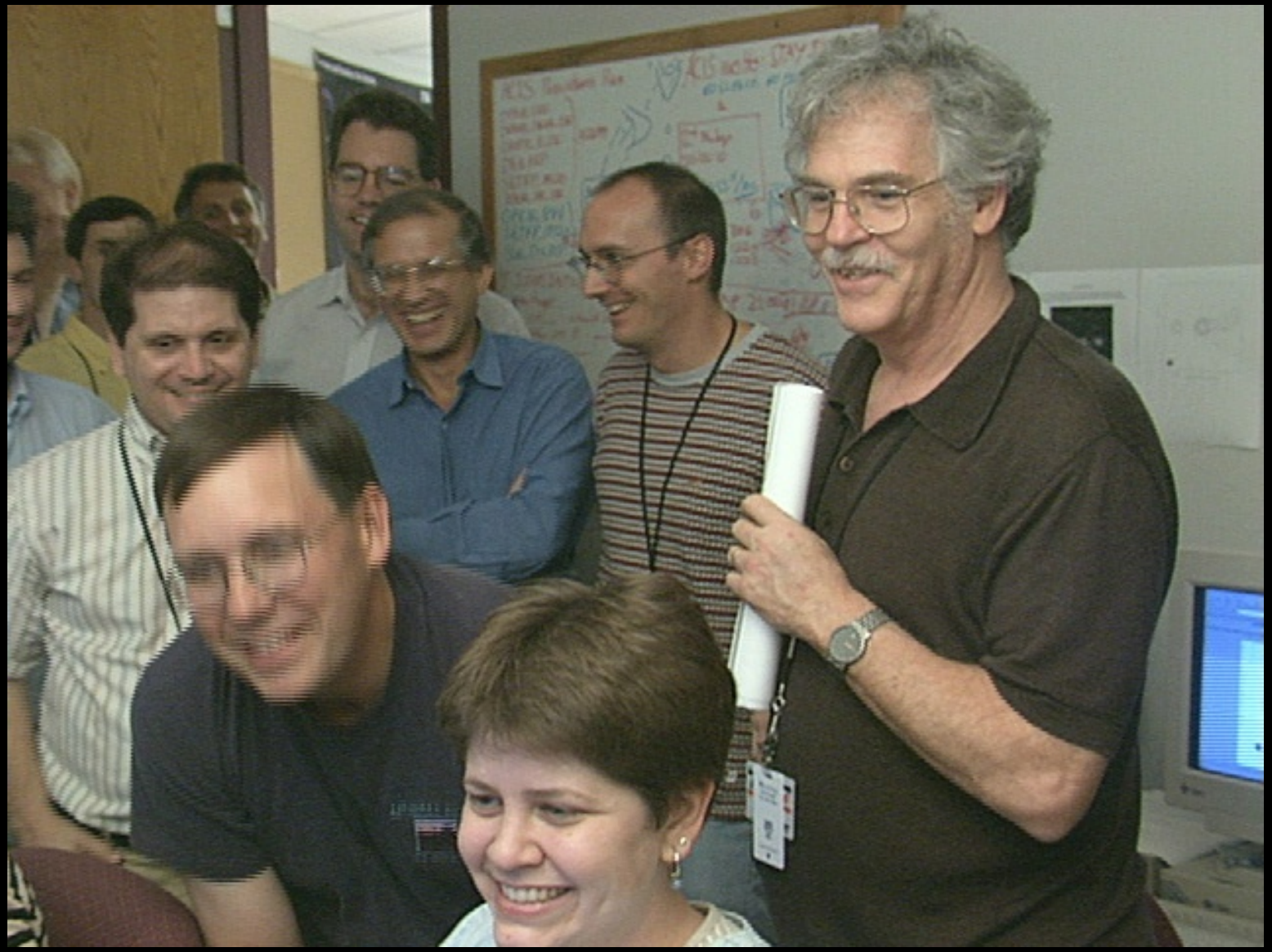


From above, with radiation belts & Moon

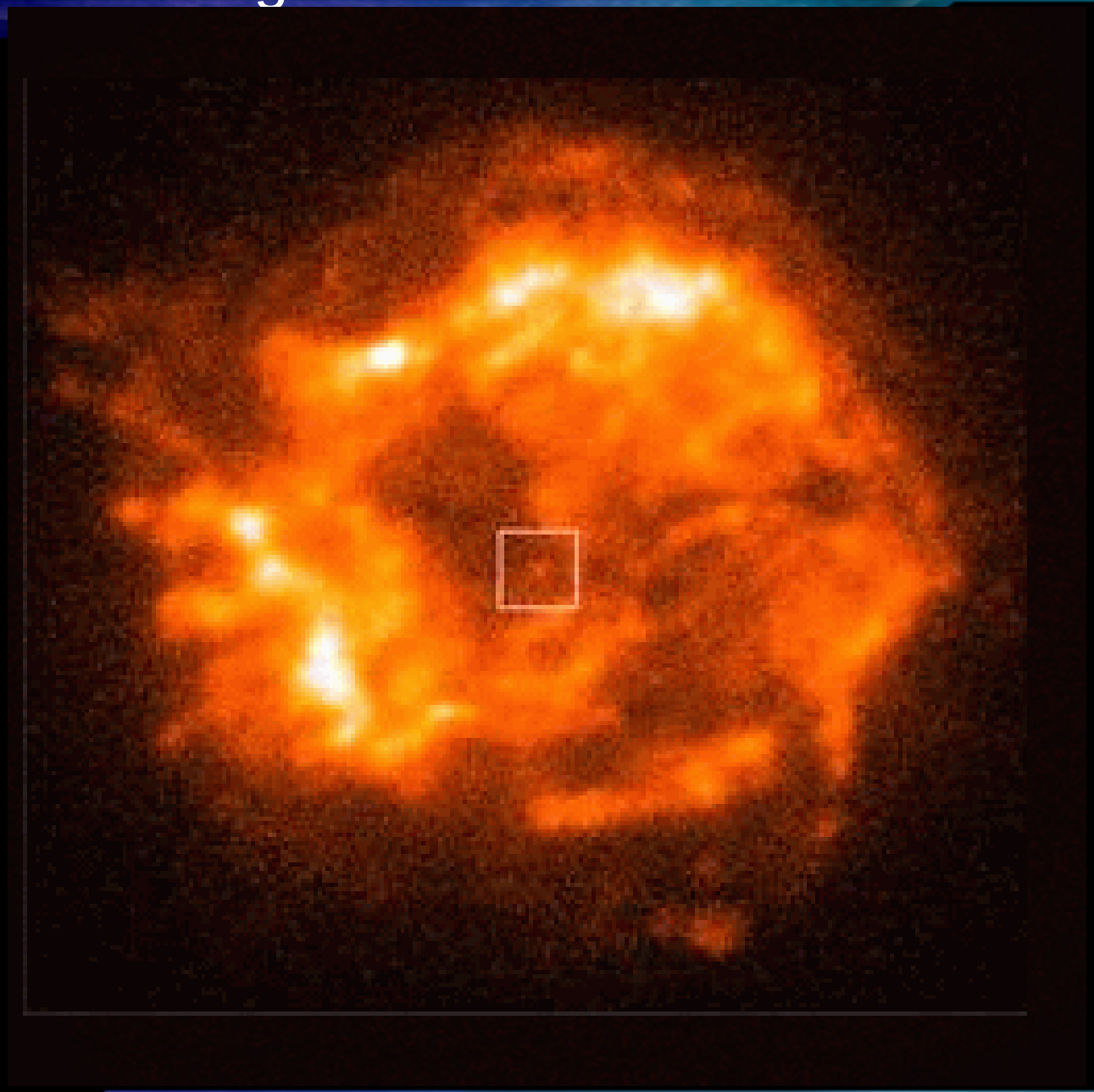


Side view, showing radiation belts

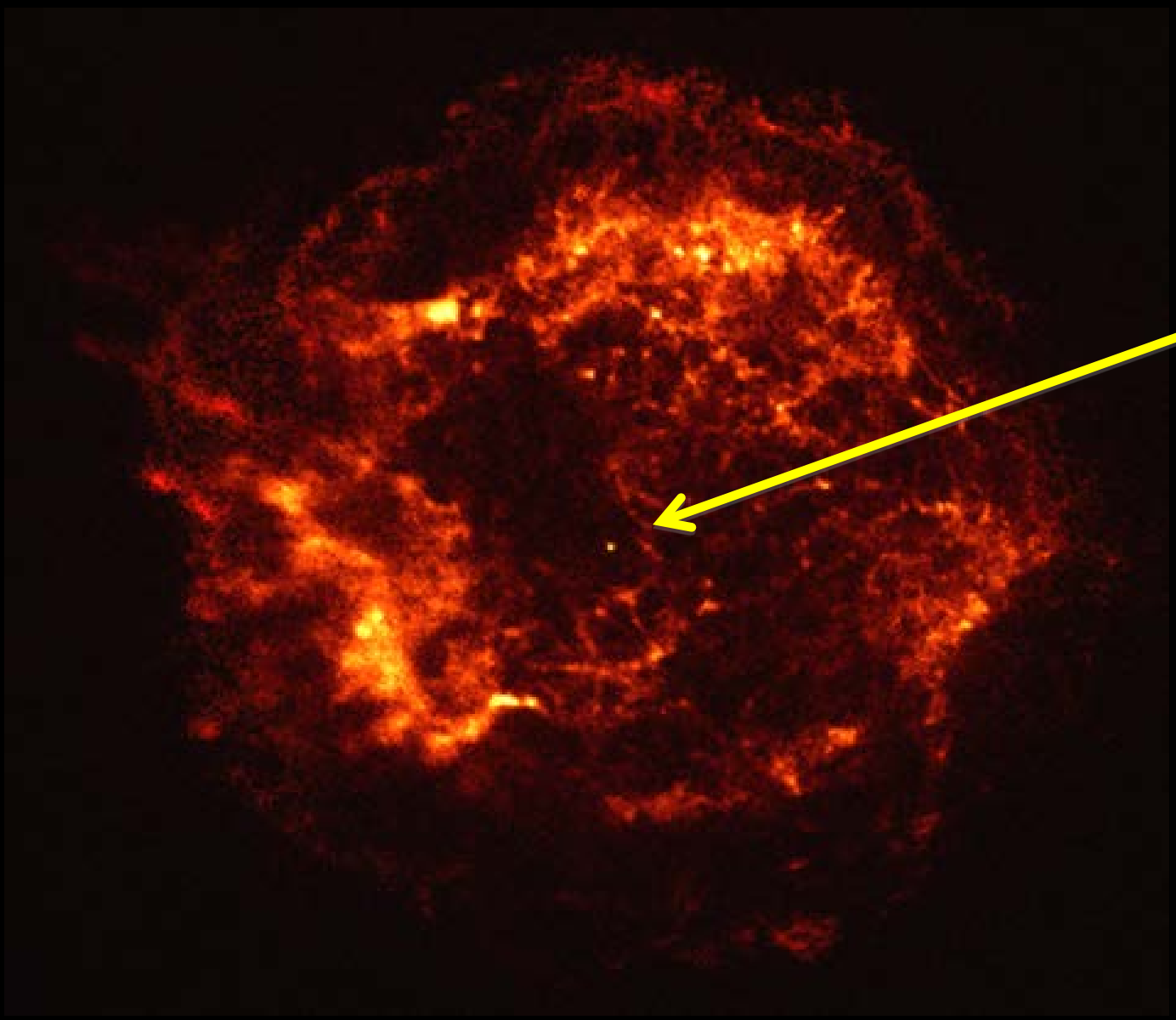
First light!



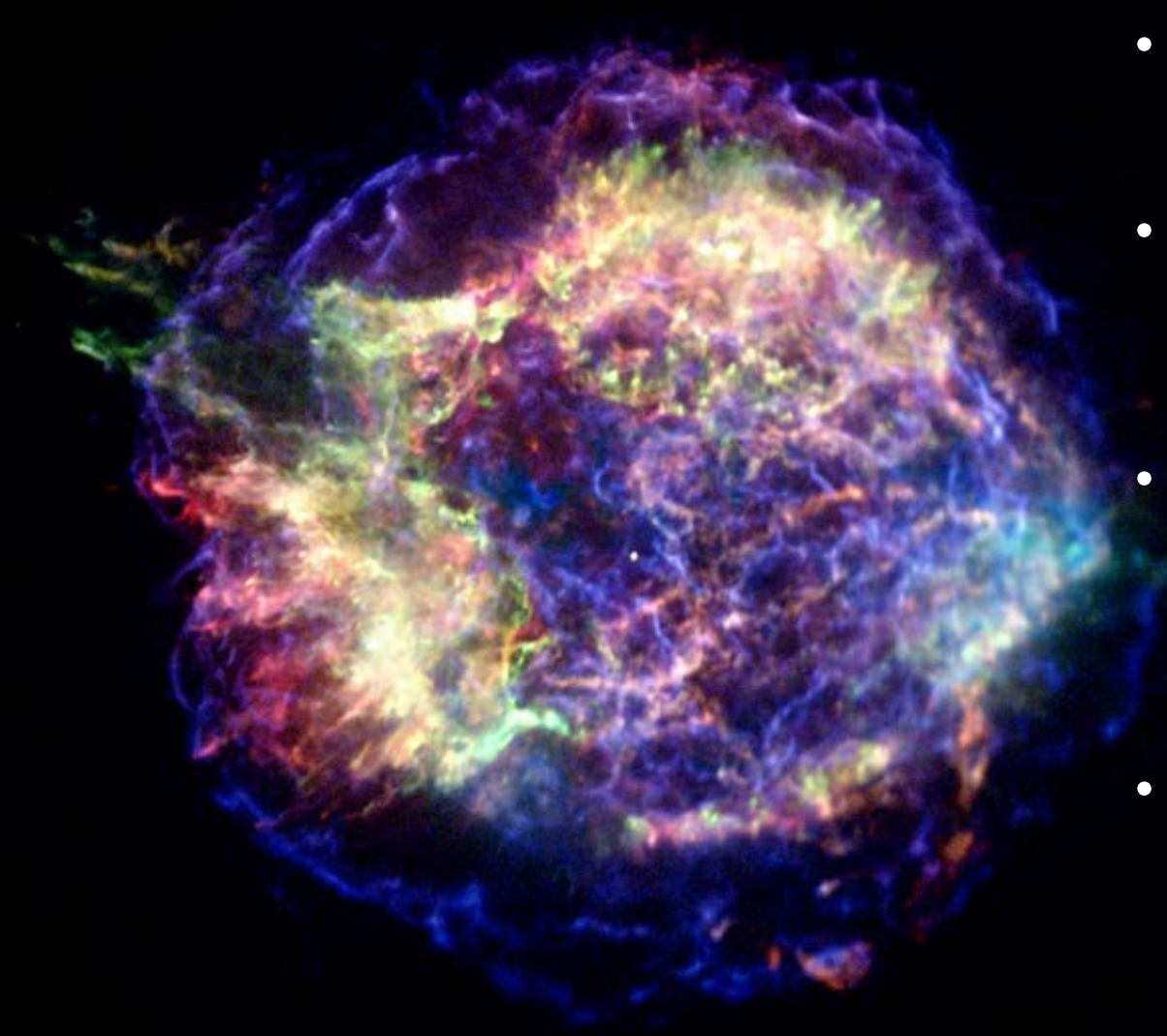
The Official First Light: Cas A



First Light

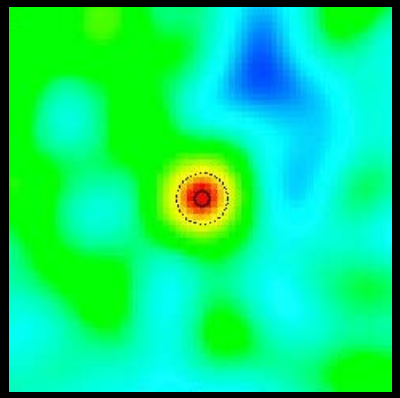


Add in the Spectroscopy: Cas A

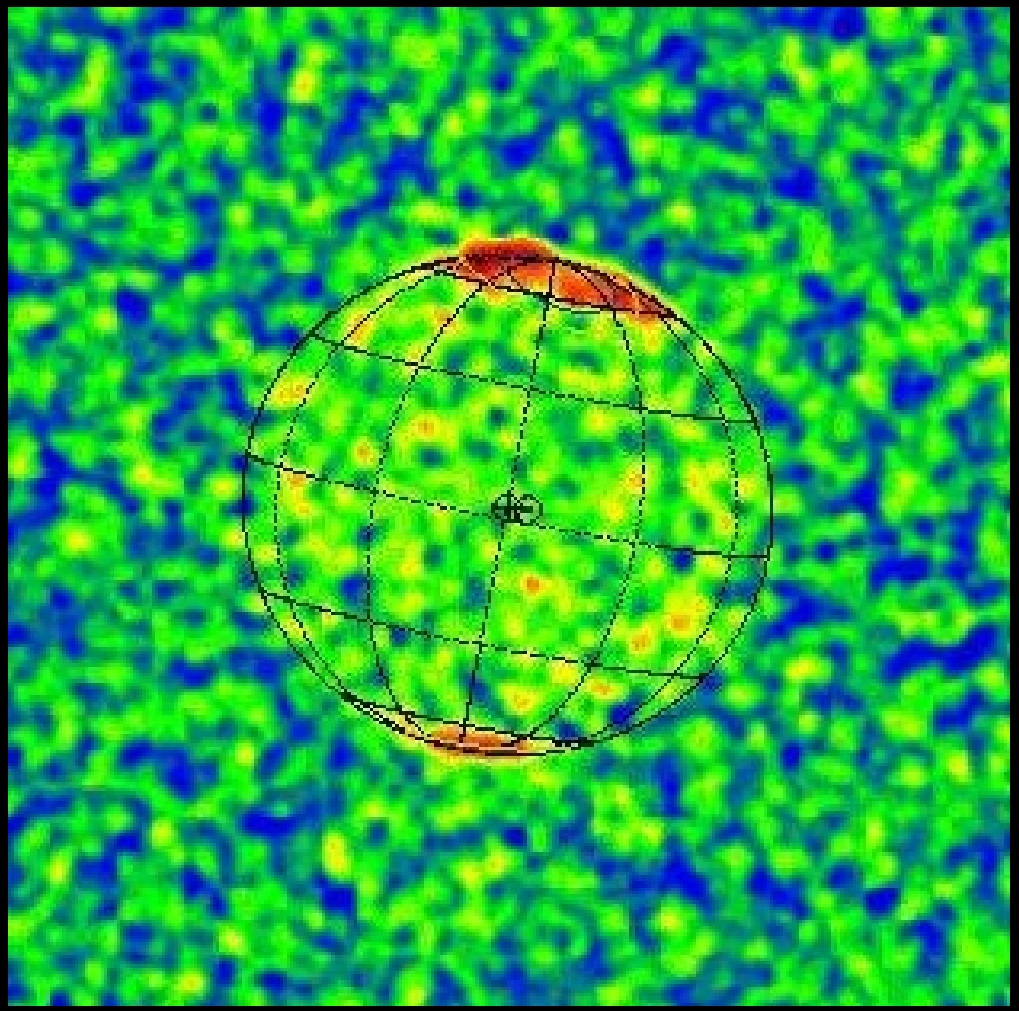


- Temperature increases from red to blue
- Bright outer ring ~ten light years in diameter marks location of blast wave
- Expansion slowing more than expected: ~30% of energy accelerating cosmic rays
- Reddish fingers are almost pure iron: produced in core & ejected with higher velocity?

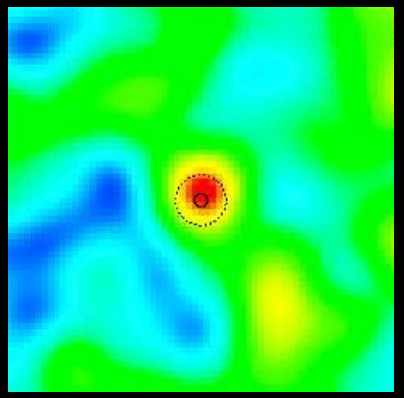
Planets and their Moons



Io



Jupiter



Europa

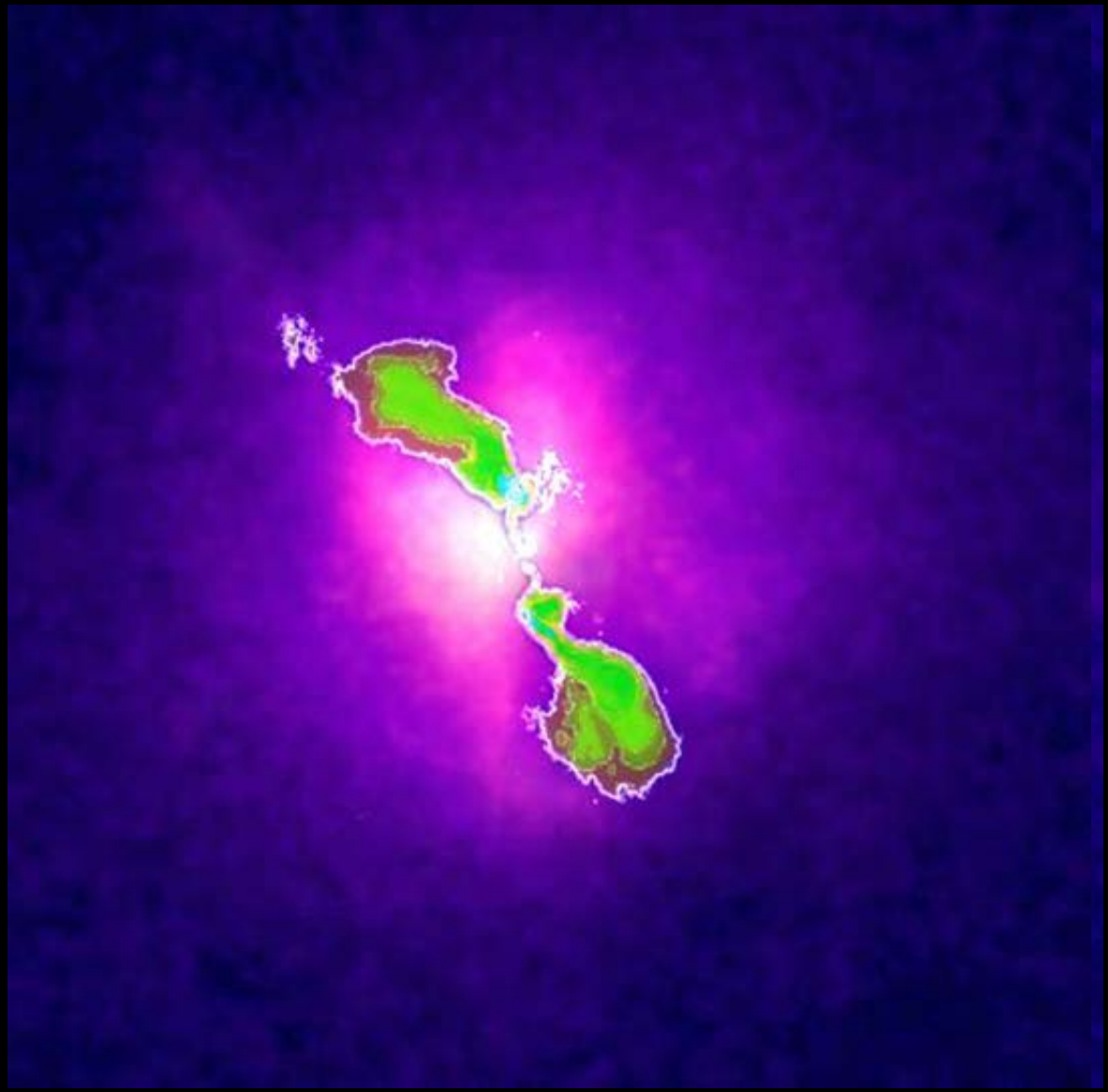
The Crab Nebula and its Pulsar Revealed

- First view of the inner ring
- Pulsar is always on

Chandra-VLA image of Hydra A Galaxy Cluster

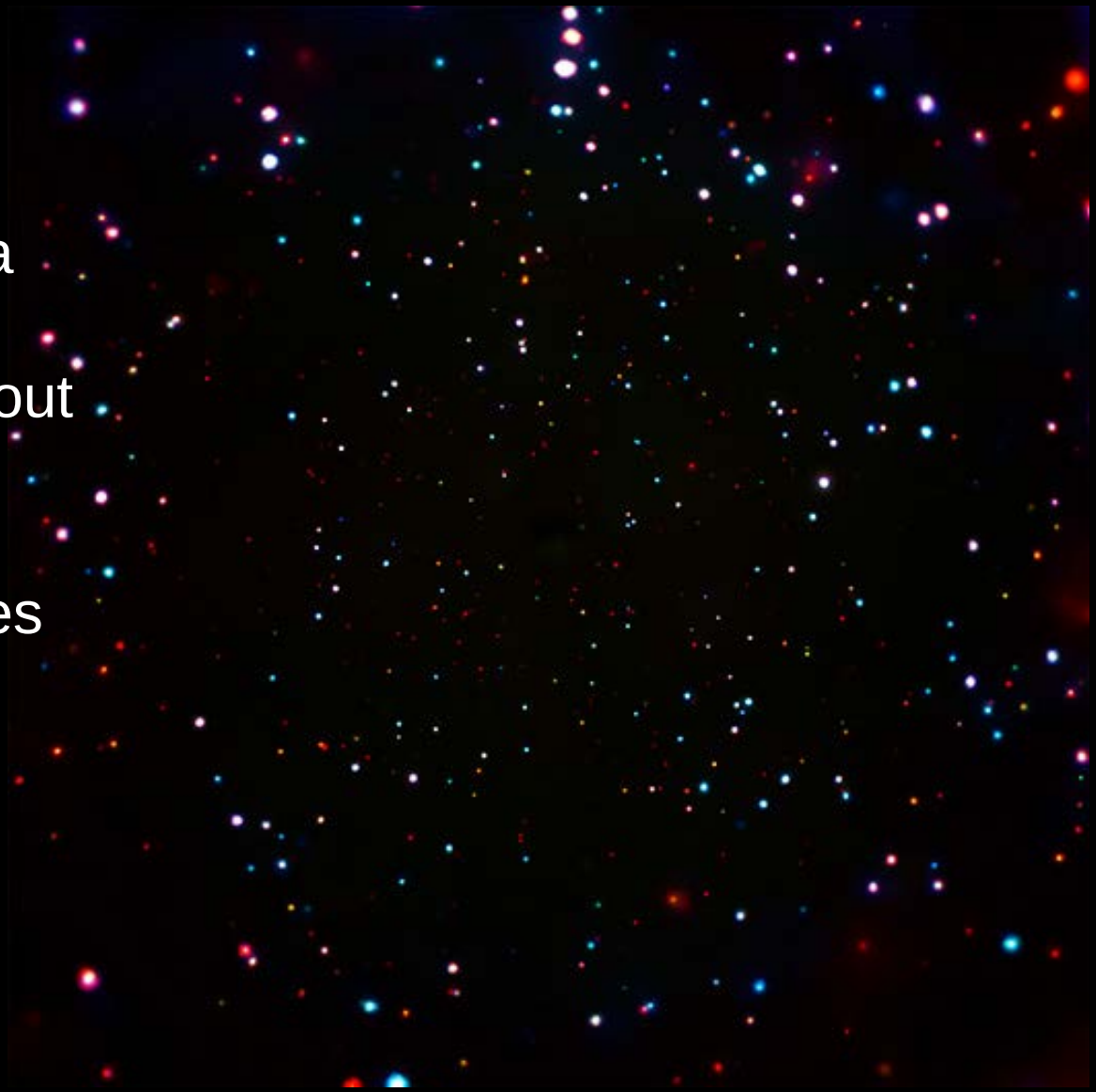
Cosmic feedback

Green – Radio
Blue-white – X-ray



Kirkpatrick et al. ApJL, 2009, **707**, L69-L72

The Deepest X-ray Look Ever



7 million seconds of data

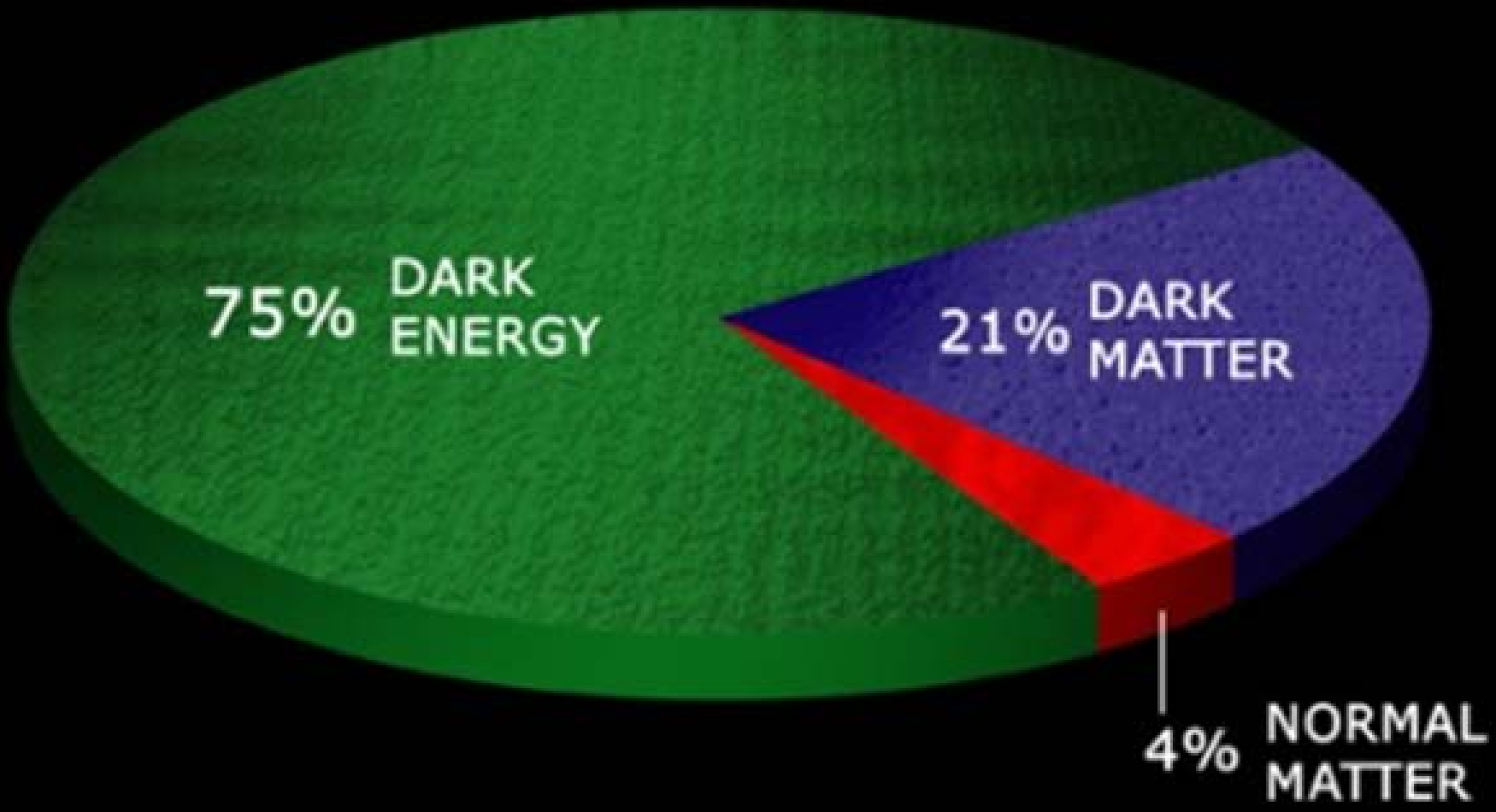
Total area covered is about the size of the moon

Colors represent energies
- Red –lowest
- Blue highest

~ 5000 black holes

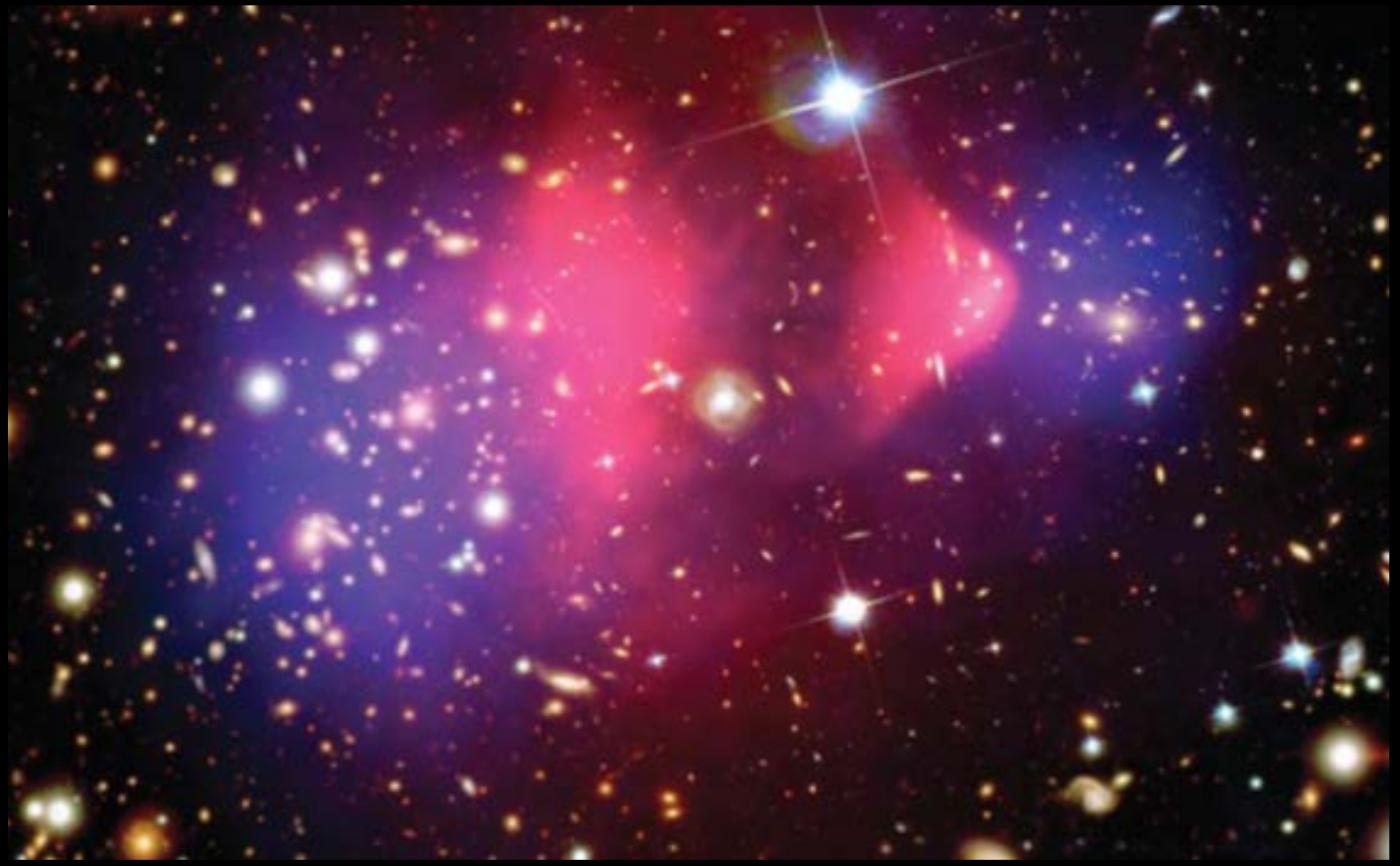
Luo et al. 2017, ApJS..228....2L

Dark Energy and Dark Matter



Colliding clusters of galaxies and dark matter

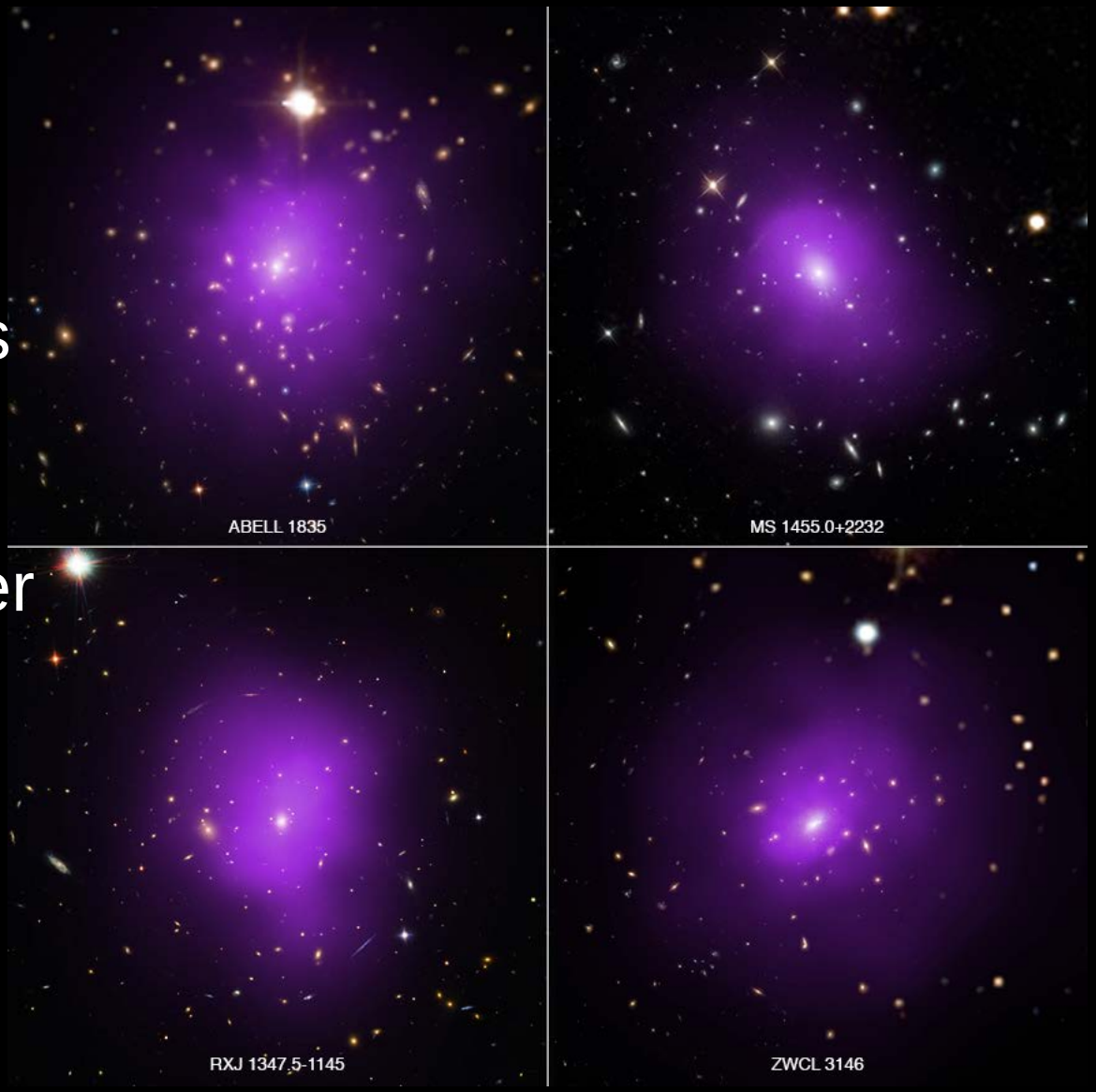
Blue – most of the mass
Pink – normal X-ray emitting matter



Clowe et al. 2006, ApJL, 648, L109

Probing Dark Energy with Chandra

- This study examined nnnn
- Growth of clusters versus redshift
- Compliments other studies
- Confirms the “cosmological constant”

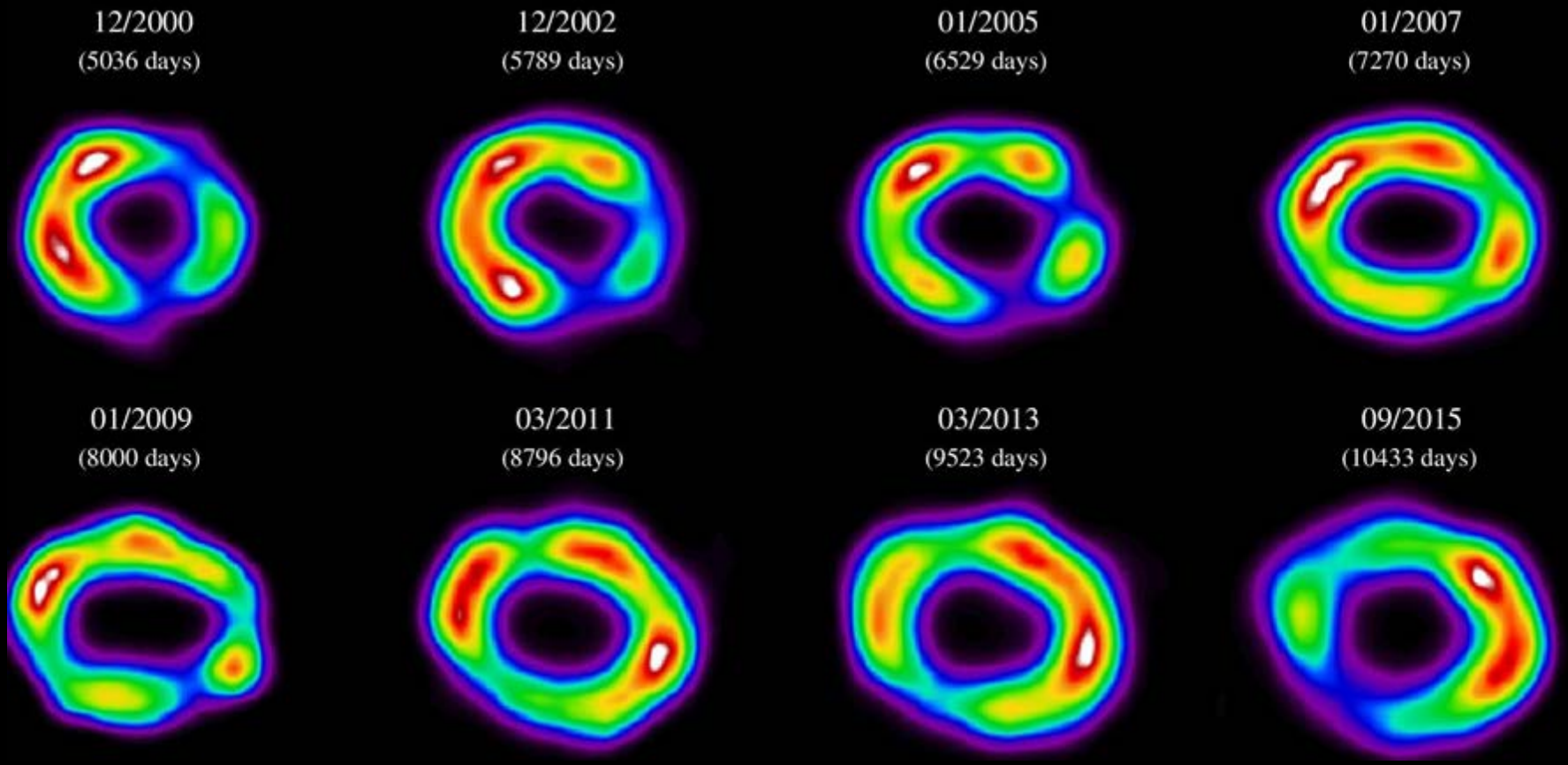


Morandi & Sun 2016, *MNRAS*, 457, p3266

Chandra is Long-Lived and Well-Calibrated

Stable and calibrated performance provide another dimension to Chandra's uniqueness and usefulness to the community

Long-term monitoring of SN 1987A (3.6" x 3.6")



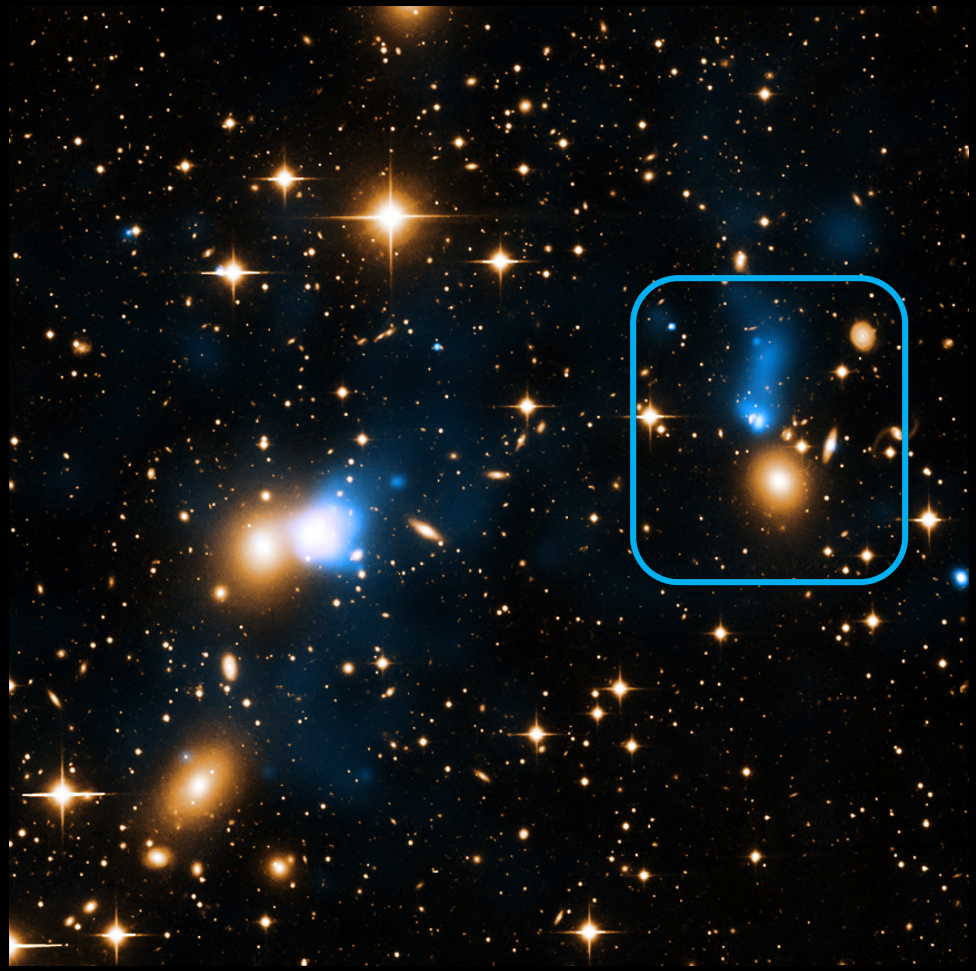
Colors represent intensity

Courtesy Dave Burrows

Chandra is Essential

Chandra is well-matched to capabilities of major observatories at all wavelengths, making it critically important for providing a more complete view of many phenomena

- Galaxy cluster Zwicky 8338
  - Z = 0.050
  - Blue X-ray
  - Yellow-white Optical
- Gas fully stripped from the companion galaxy
  - Longest tail seen
  - Bow shock?
- Gas cooler than the ICM



:Shellenberger & Reiprich 2015 A&A **583**, id.L2

Chandra is Unique

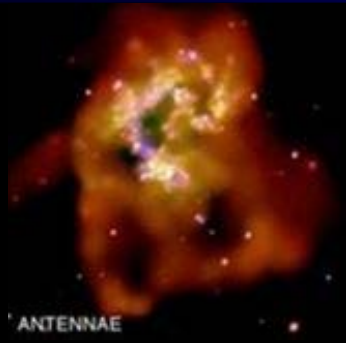
No other X-ray observatory, now or in the foreseeable future, approaches Chandra's angular resolution and sensitivity for X-ray source detection and mapping

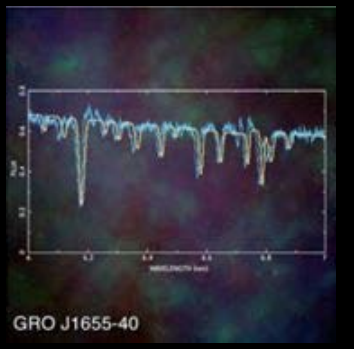
- B3 0727+409
  - z = 2.5
- Serendipitous but not unexpected discovery of an X-ray jet
  - 100 kpc in length
- Not seen in the radio
  - New population?

Simionescu et al, 2015, ApJ, 816, 15

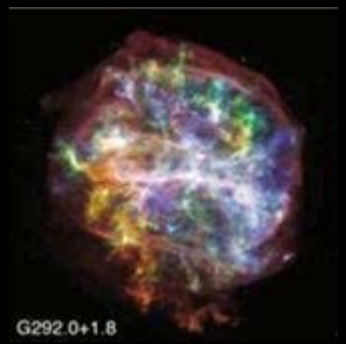
The 2002 Nobel Prize Riccardo Giacconi

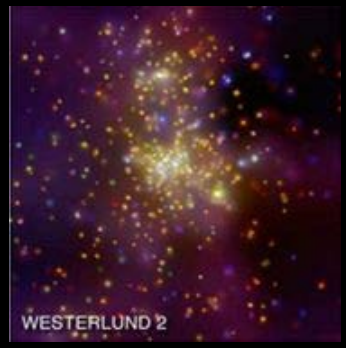
Where to Learn More





http:chandra.harvard.edu





The opportunity for exploration and discovery with Chandra remains as high today as it was at launch