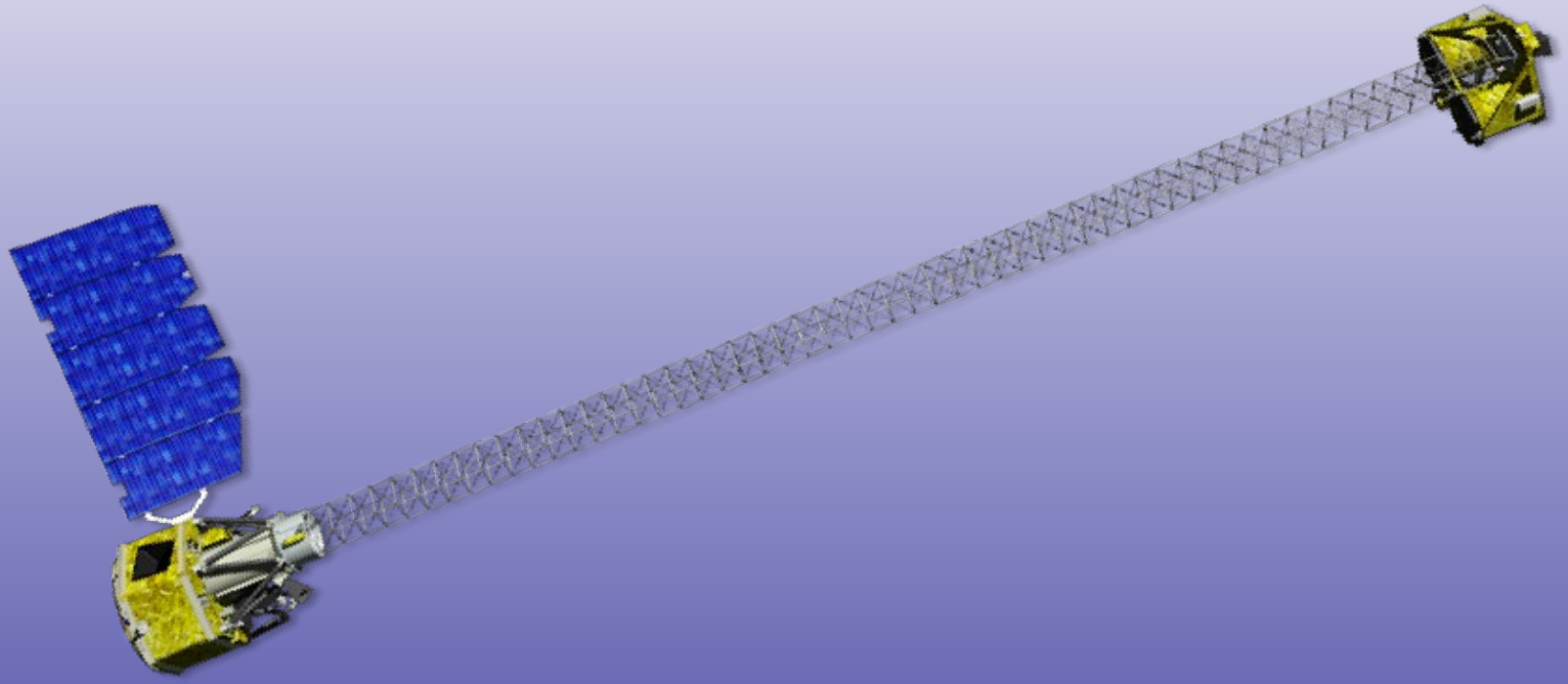
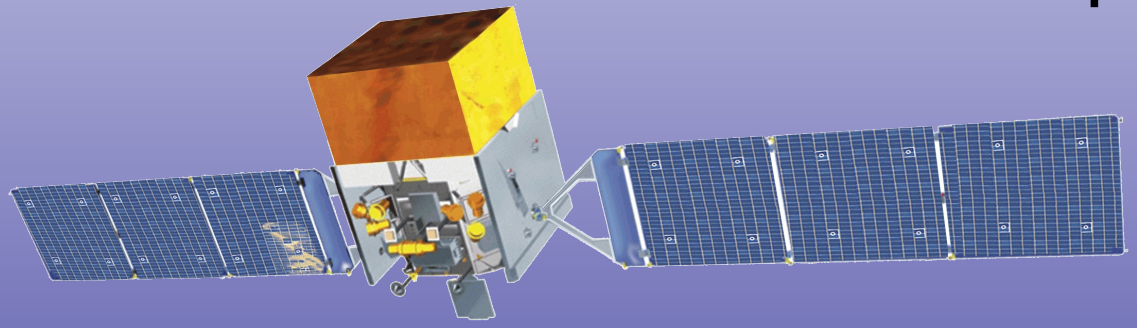
NuSTAR's Extreme Universe



Prof. Lynn Cominsky
NASA Education and Public Outreach
Sonoma State University

The NASA Education and Public Outreach Program at SSU

We are a group of scientists and educators working on high-energy astrophysics space science missions and other projects.



Fermi

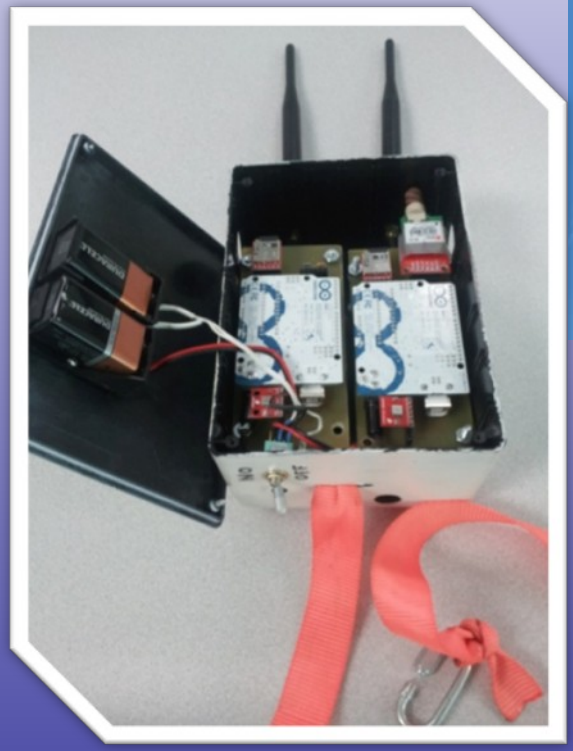
On-line course for college students

XMM-Newton

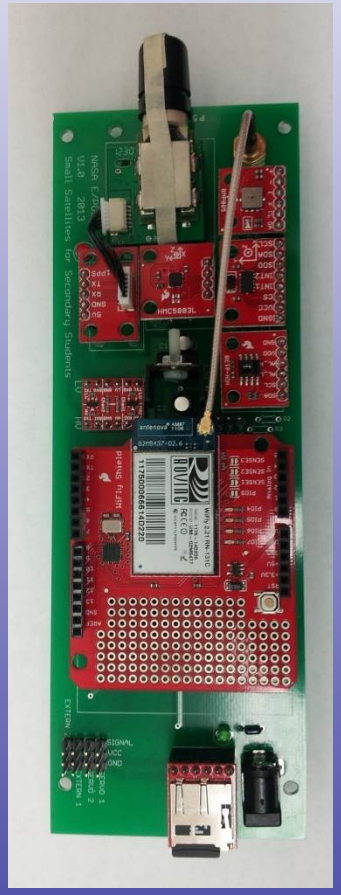
Swift

Small Satellites Project

Balloon payload by Kevin Zack



Balloon payload launched on tether



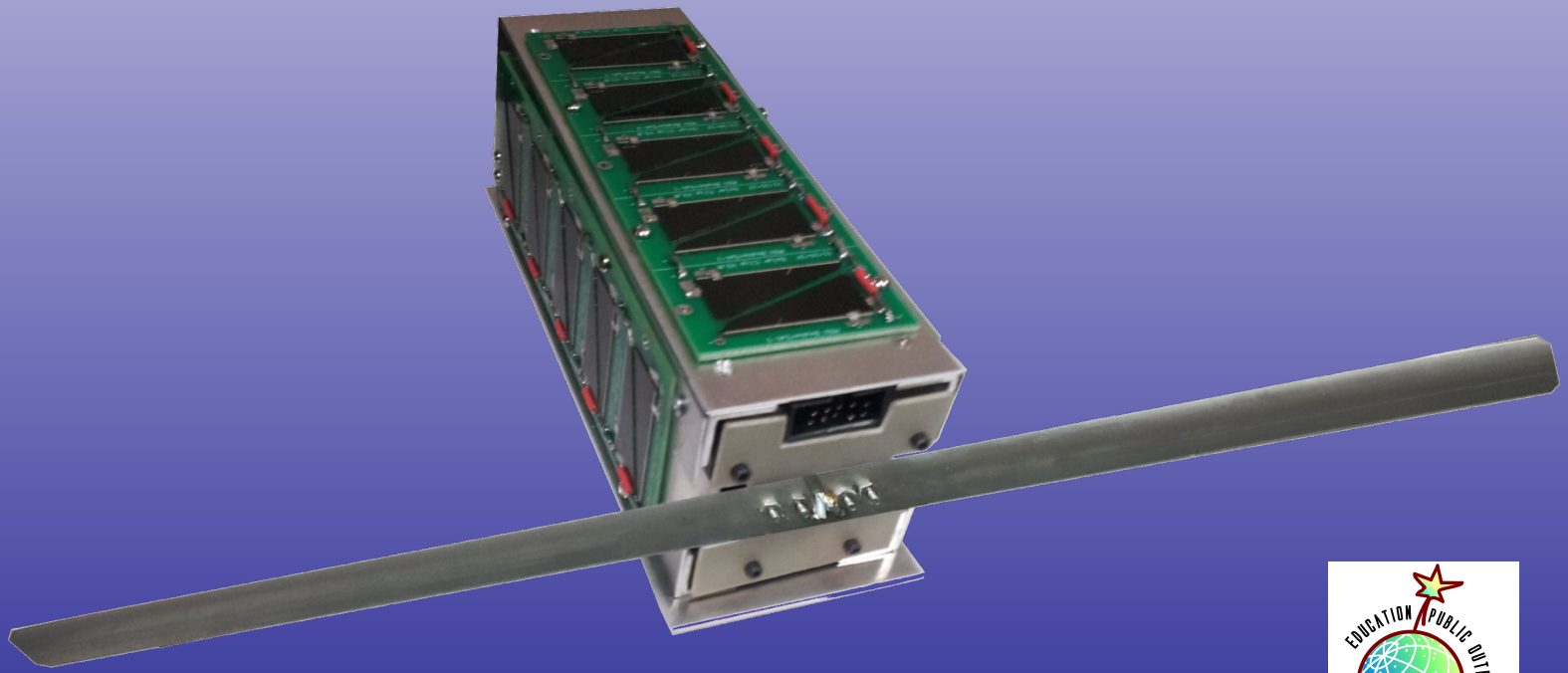
Payload designed by Kevin Zack

Zack's L2 rocket at Black Rock

http://epo.sonoma.edu/s4
Teachers needed!

T-LogoQube – SSU's first satellite

- About 5 cm x 5 cm x 15 cm and 1 pound
- Polar orbit at 634 km

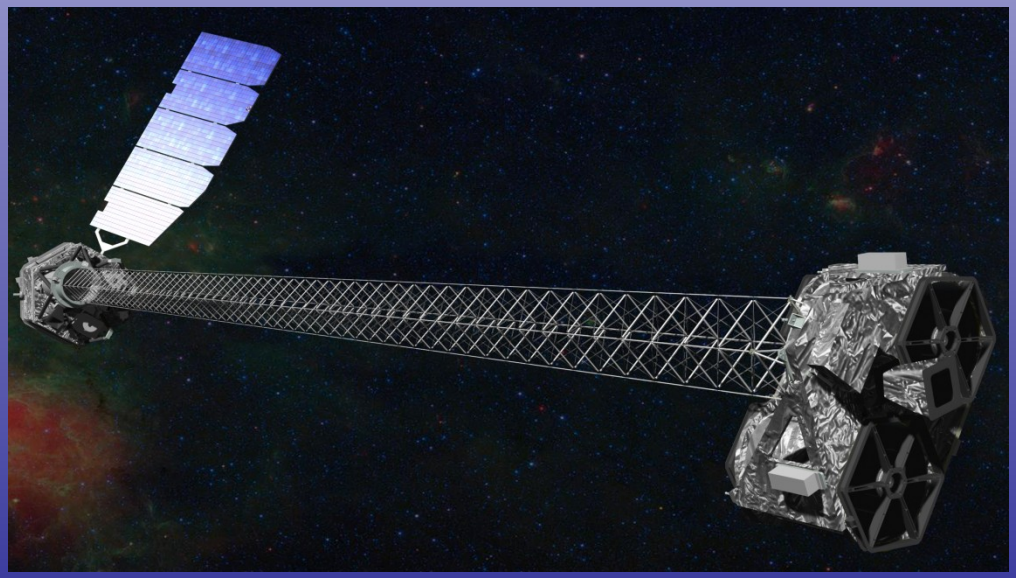


E/PO Group Satellite Missions

- *XMM-Newton* – launched 12/10/1999
  - Focusing soft x-ray telescope
- *Swift* – launched 11/20/2004
  - Gamma-ray burst explorer
- *Fermi* (aka *GLAST)* – launched 6/11/2008
  - High energy gamma-ray sky survey +GRBs
- *NuSTAR* – launched 6/13/2012
  - Focusing hard x-ray telescope

NuSTAR

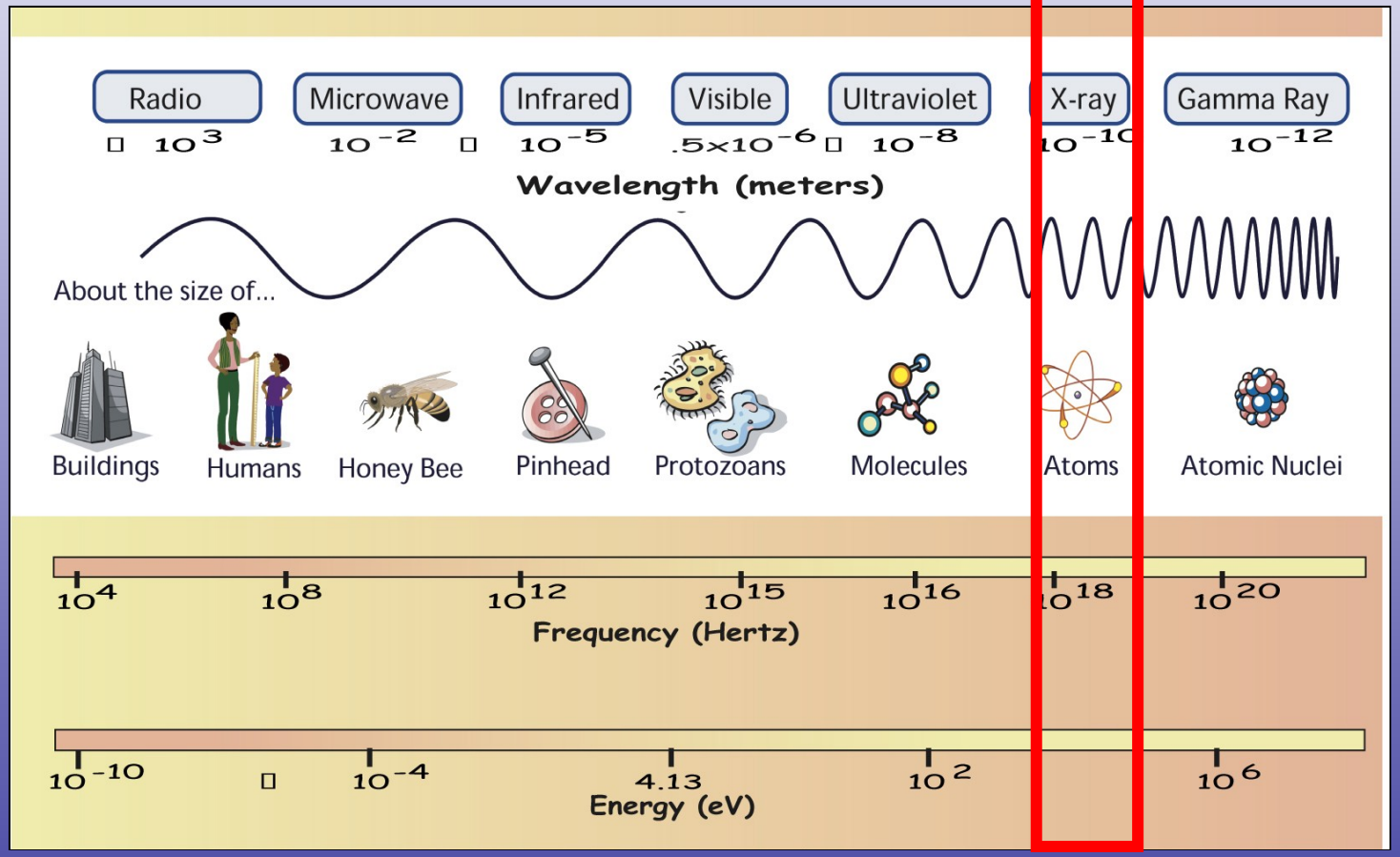
- **Nu**clear **S**pectroscopic **T**elescope **AR**ray
- NASA's newest "Eyes on the Skies"
- Focuses X-rays creating images at higher energies than ever before



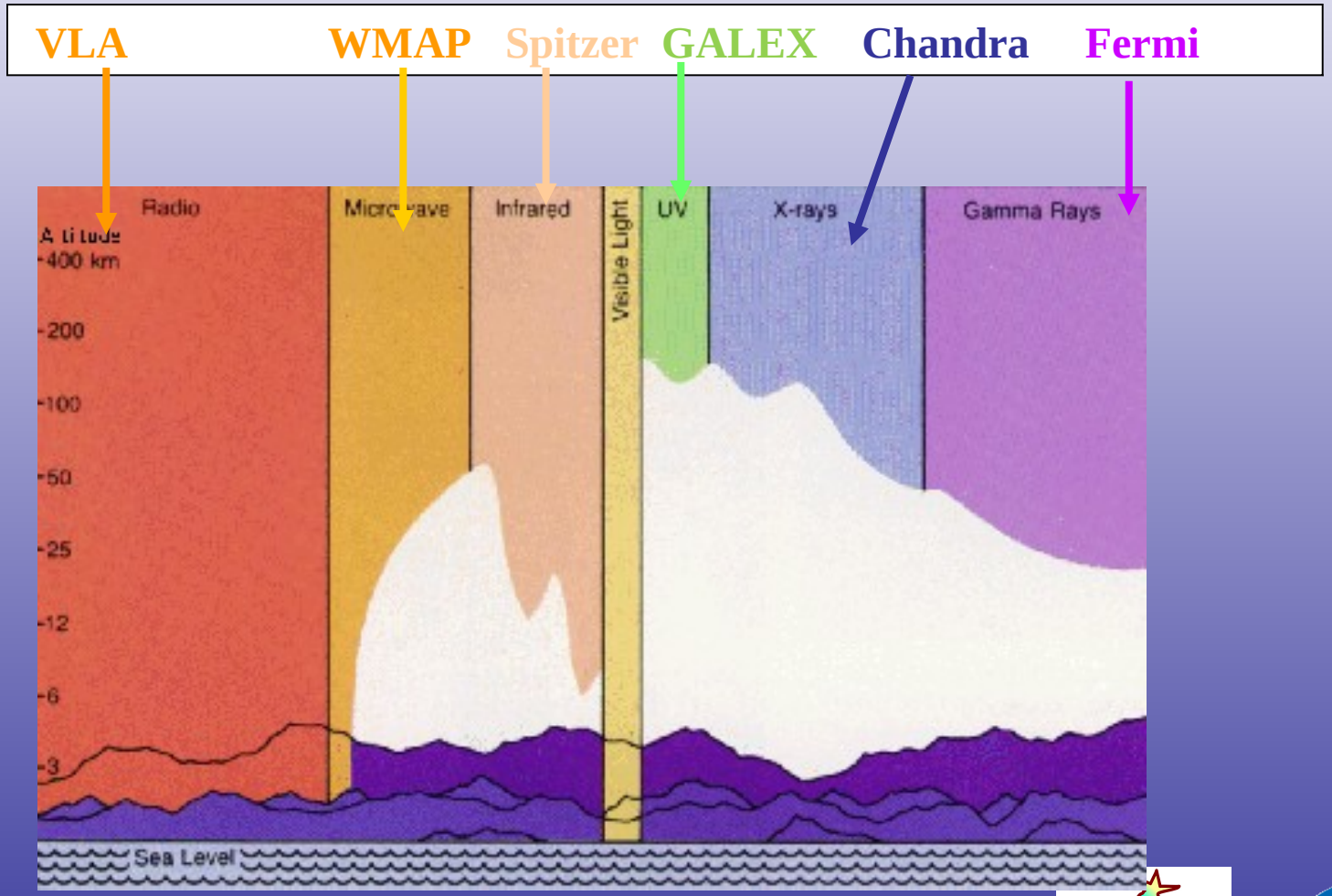
http://www.nustar.caltech.edu

NuSTAR observes "hard" X-rays

10-79 keV



What you can see from Earth



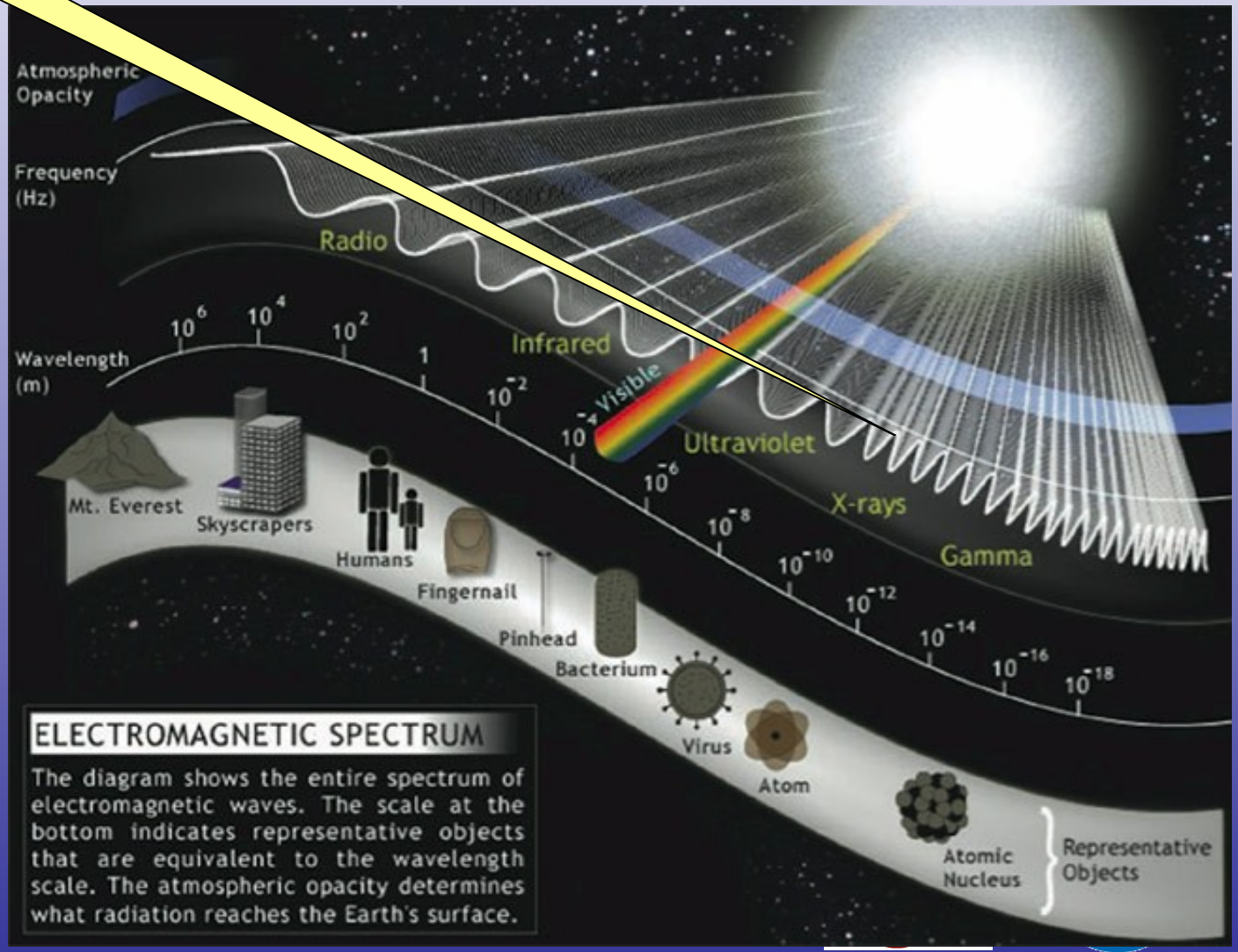
Exploring the Space Environment with X Rays

The second most energetic band of the EM spectrum

Wavelengths about the size of atoms

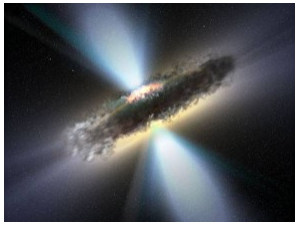
Photon Energies range from around 1000 to 100,000 times that of visible light

Emitted by objects at temperatures of millions of degrees. Including supernova remnants and disks of gas orbiting black holes

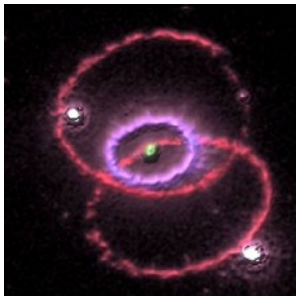


EDUCATION PUBLIC OUTREACH SSU

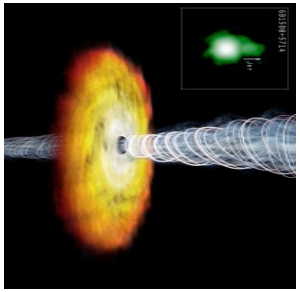
Why Hard X-rays?



Hard X-rays are the peak in emission from active black holes in the centers of galaxies; shining with a luminosity that rivals that of starlight

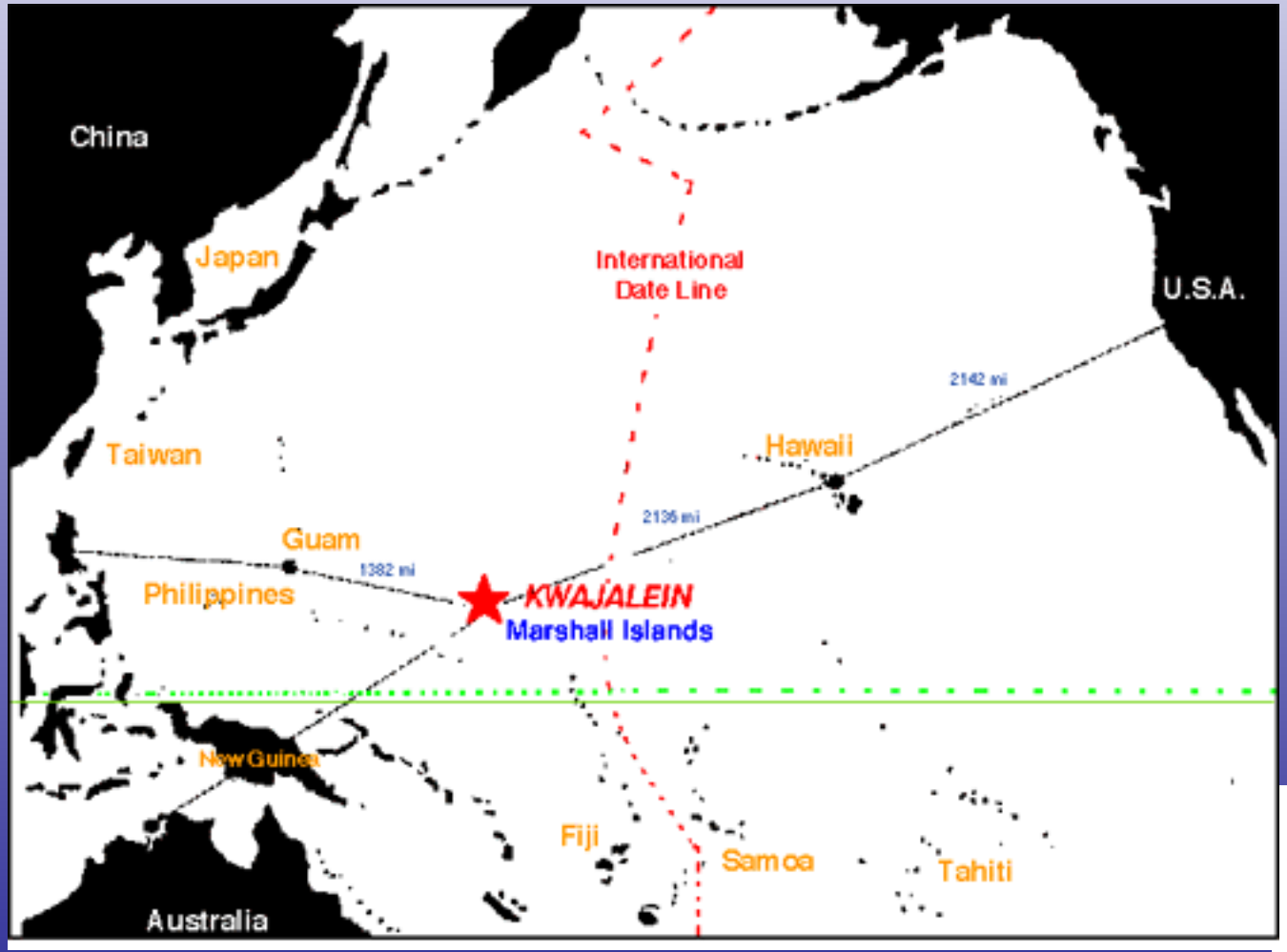


Hard X-rays escape from the deepest layers of exploding stars, revealing newborn chemical elements

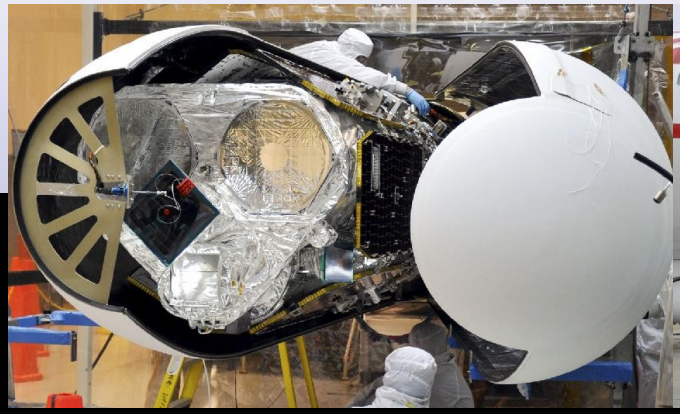


Hard X-rays are copiously emitted by the most extreme particle accelerators found anywhere in the universe

Launch Location



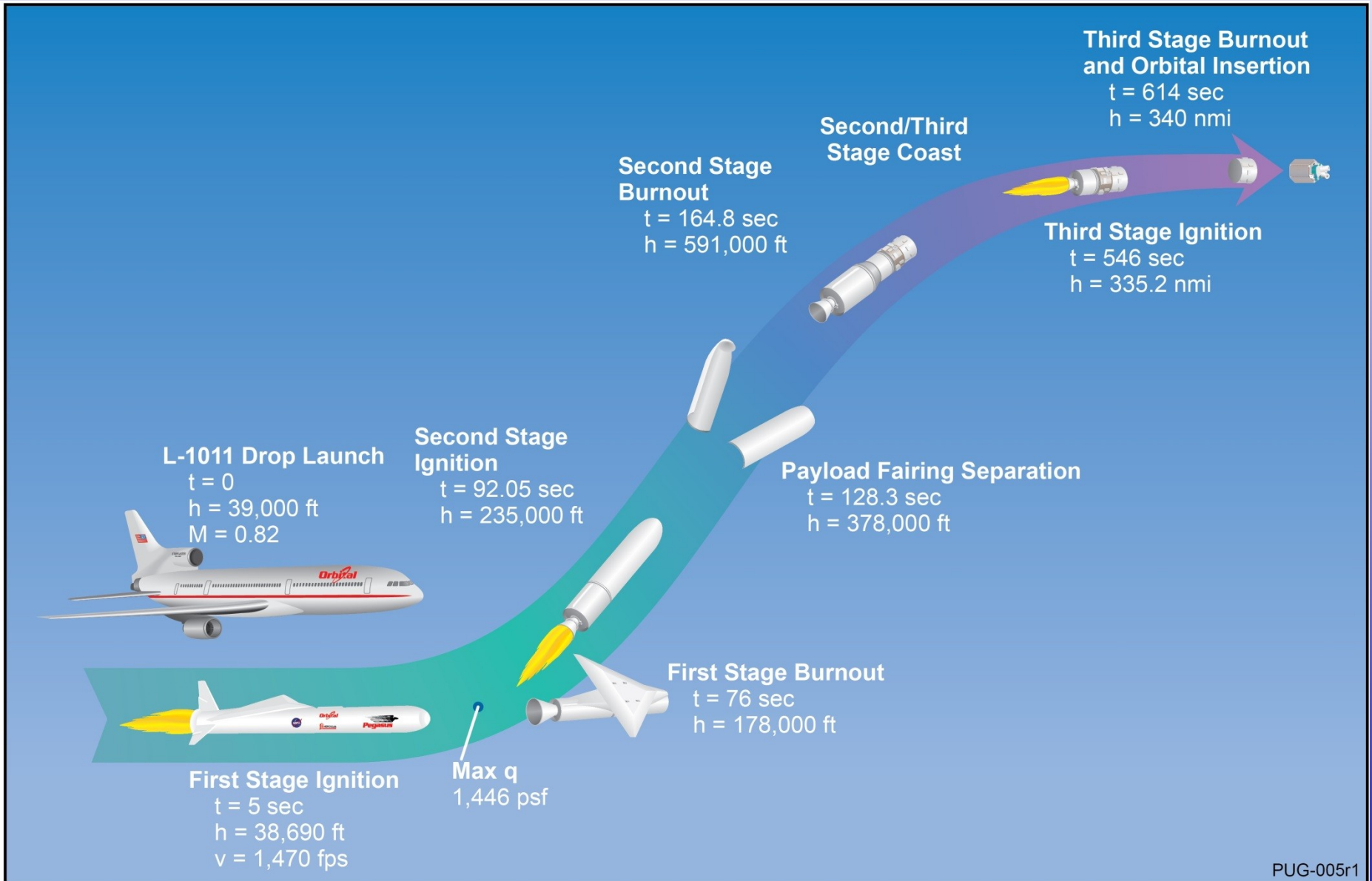
NuSTAR arrives



Launch June 13, 2012

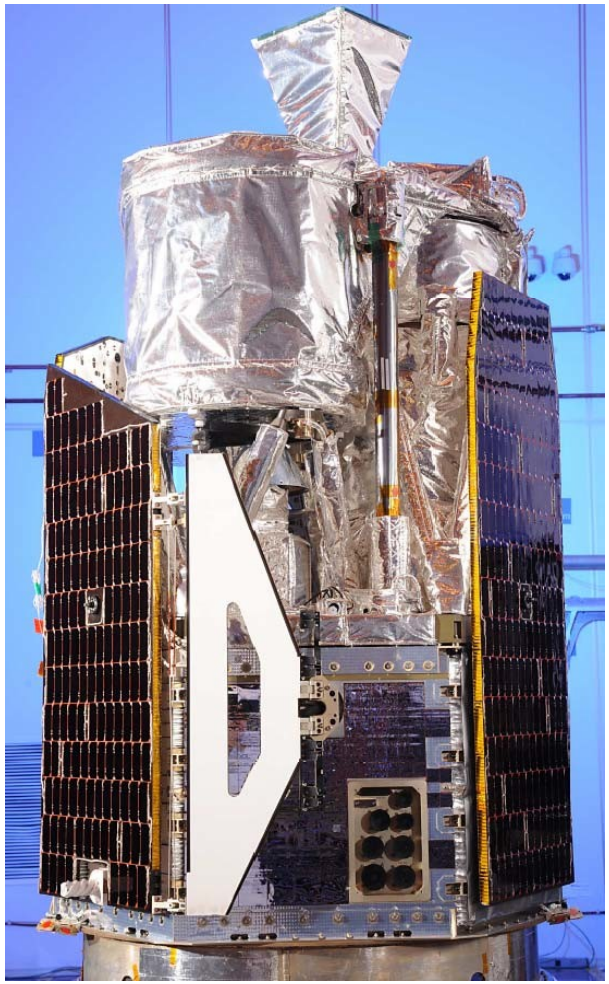
Reagan Test Site, Kwajalein Atoll

Launch flight profile

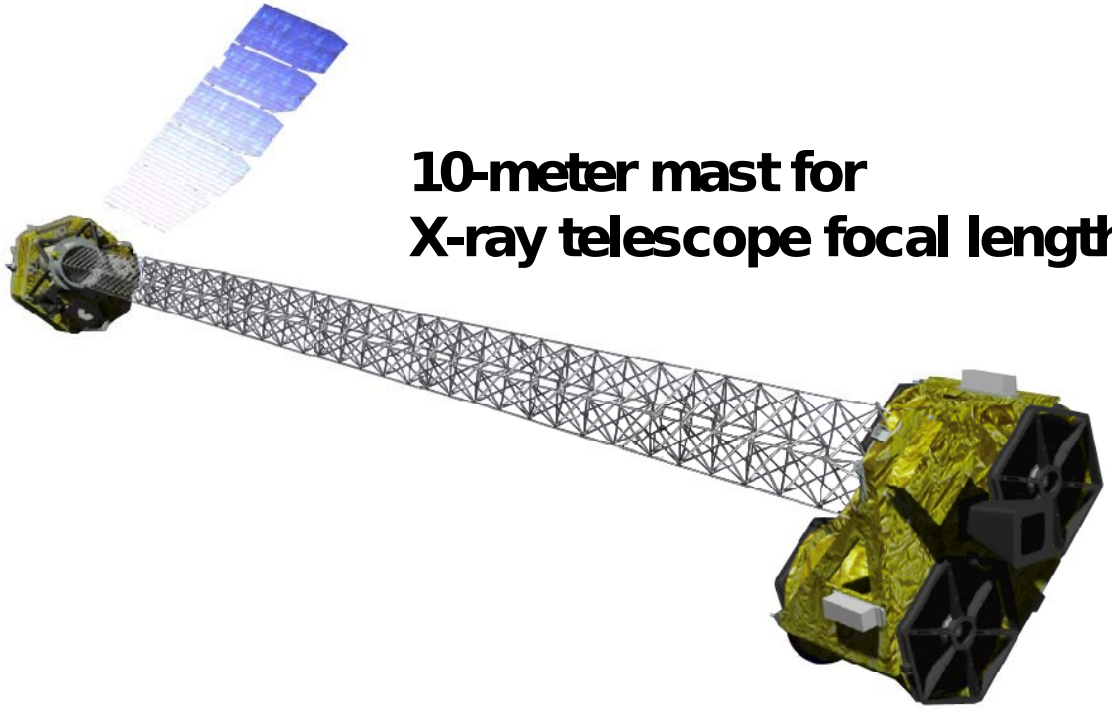



MISSION OPERATIONS CENTER
UNIVERSITY OF CALIFORNIA, BERKELEY

Before and after launch



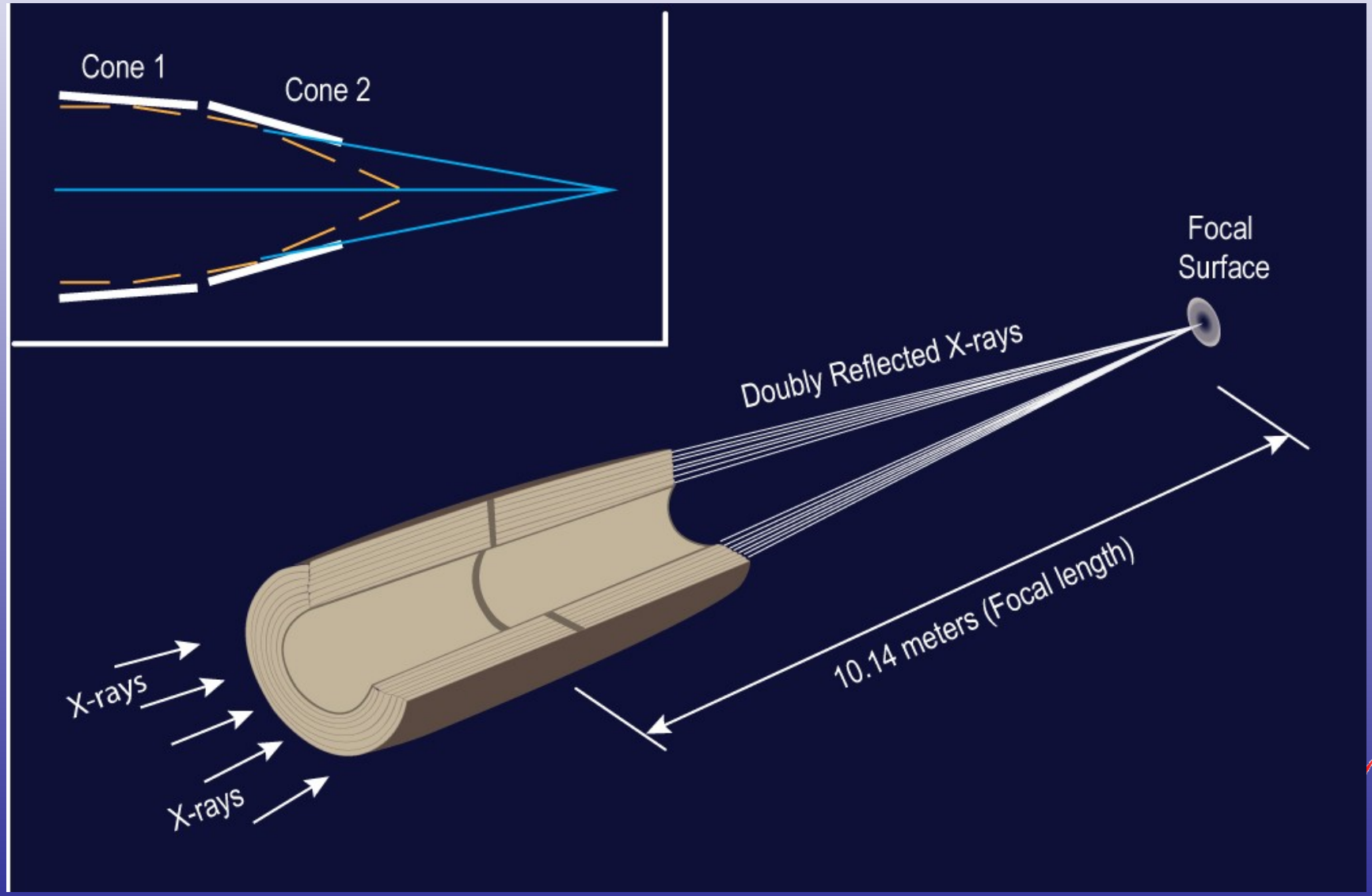
Stowed observatory



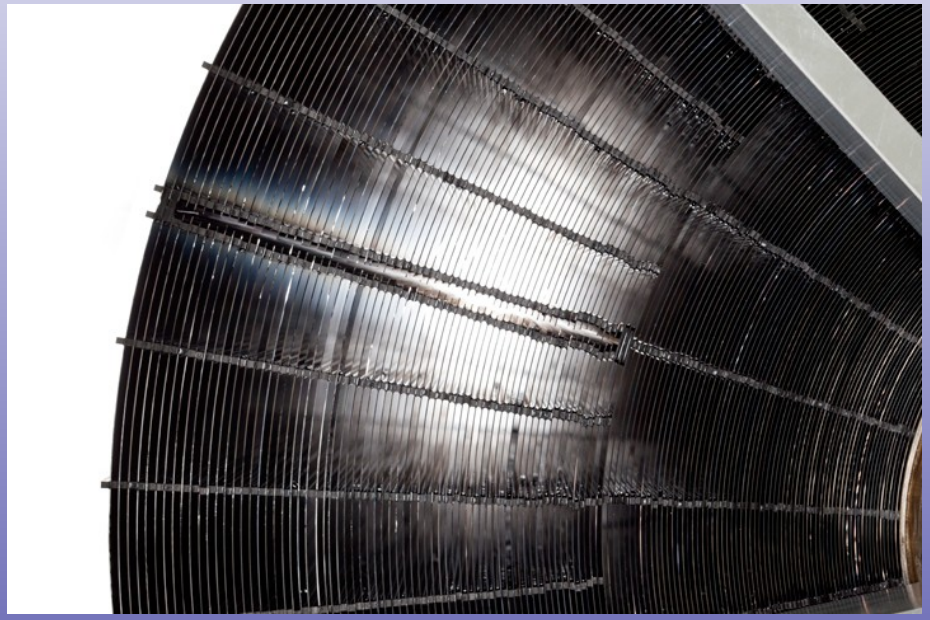
Deployed observatory

NuSTAR's "24 min of terror"

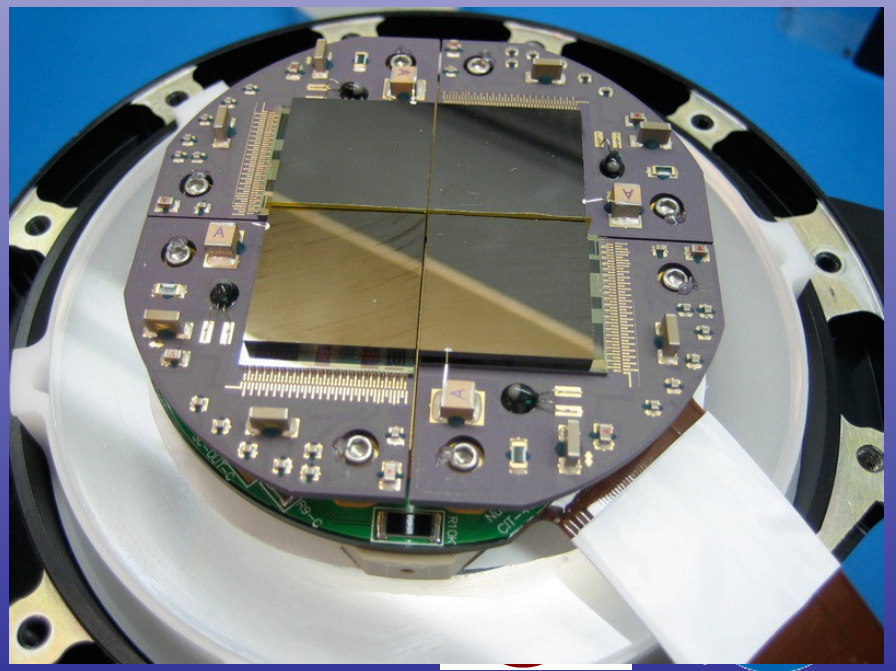
How to focus X-rays



NuSTAR's mirrors and detectors

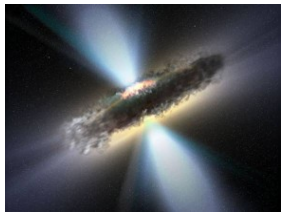


133 nested mirrors made of multilayers that reflect higher-energy X-rays



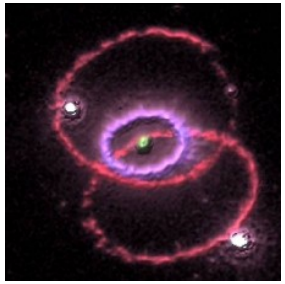
A 2 x 2 array of Cd-Zn-Te detectors and electronics

NuSTAR Science Objectives



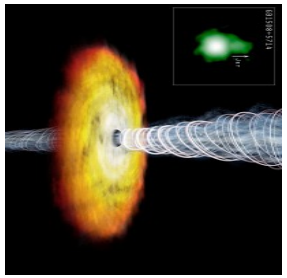
Goal #1: How are black holes distributed through the cosmos, and how do they affect the formation of galaxies like our own?

- *15 months surveying regions of the sky*



Goal #2: How do stars explode and forge the elements that compose the Earth?

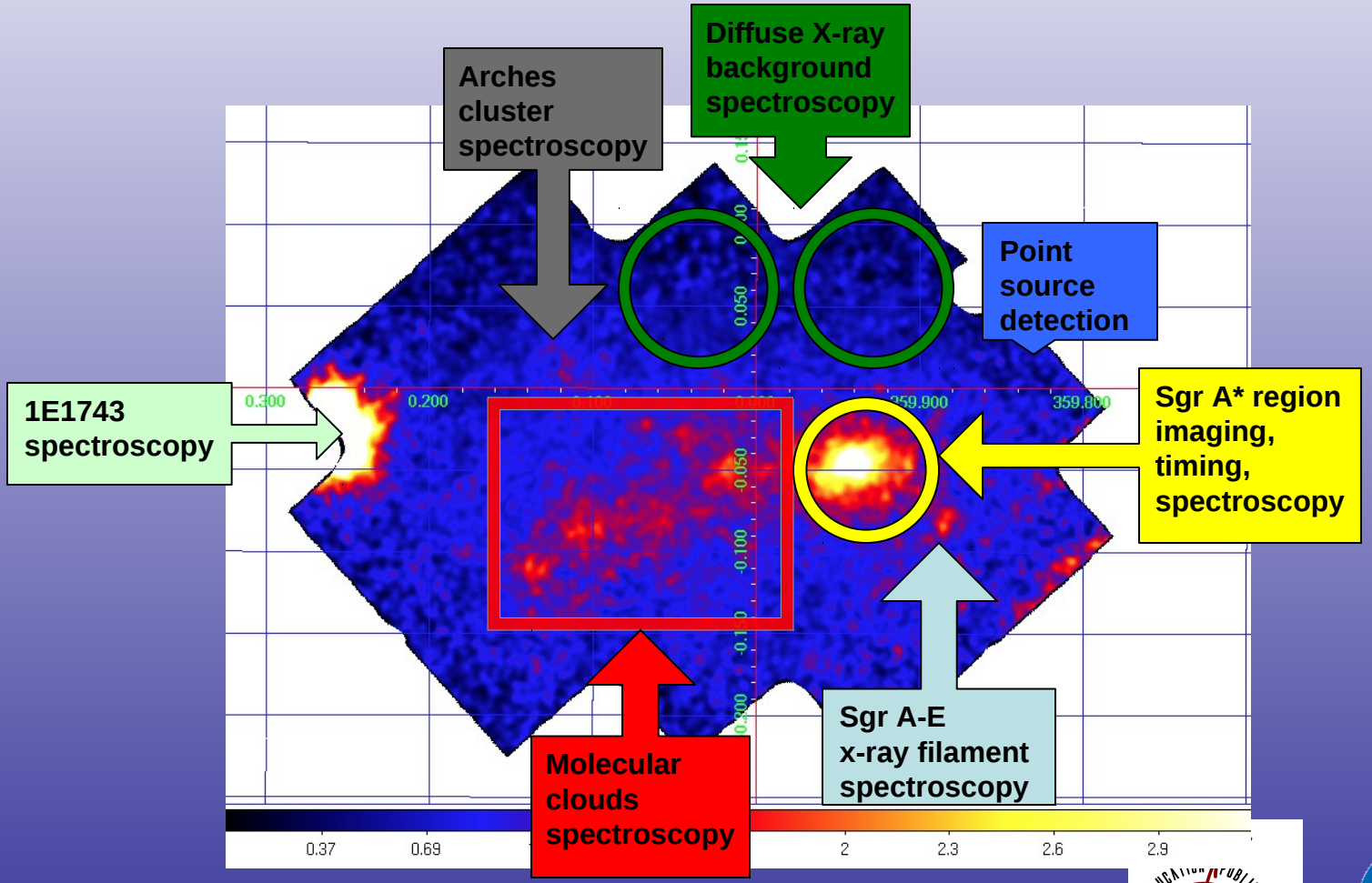
- *6 months mapping young supernova remnants*



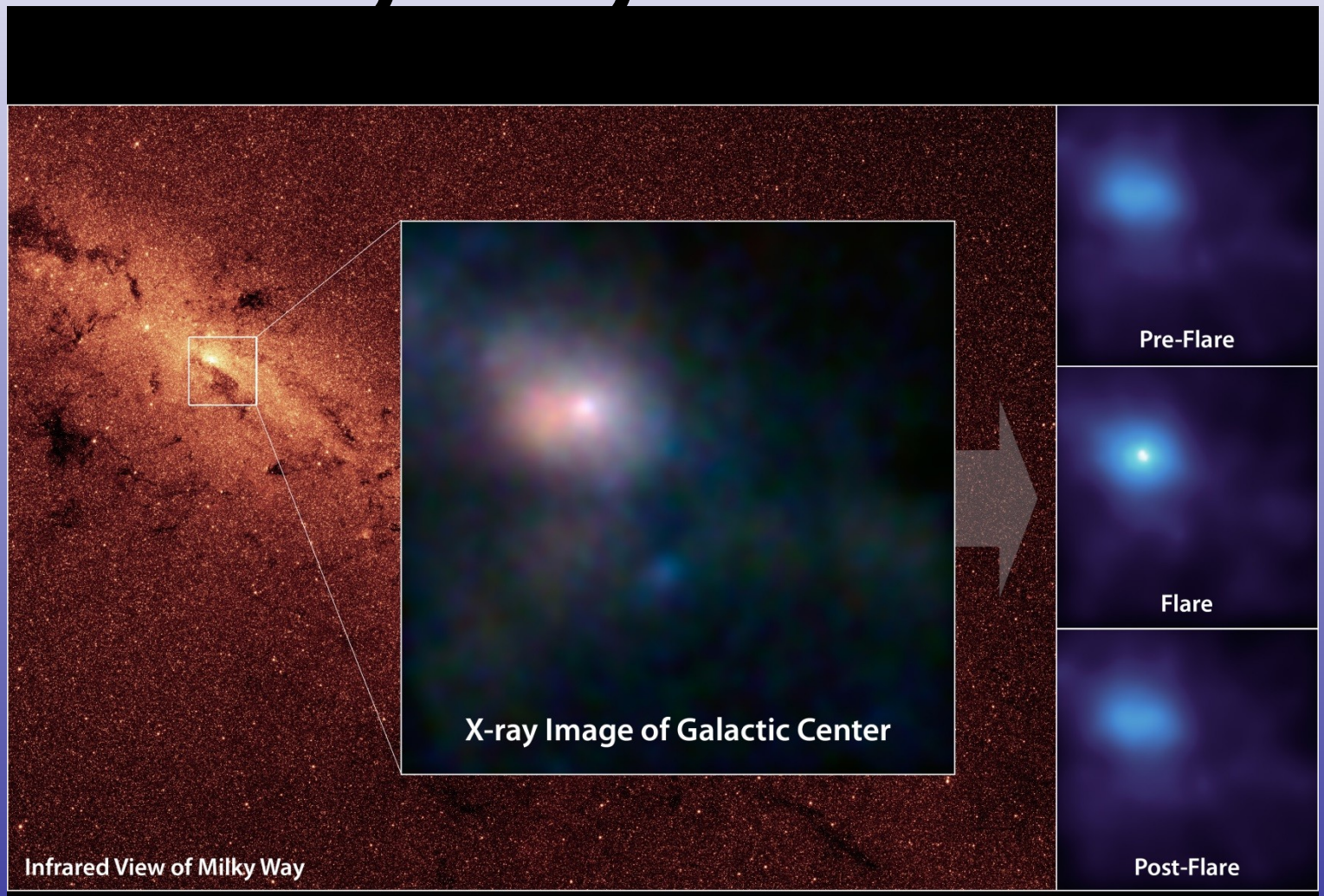
Goal #3: What powers the most extreme active galactic nuclei?

- *3 months monitoring extreme black holes.*

Mini-survey of Galactic Center

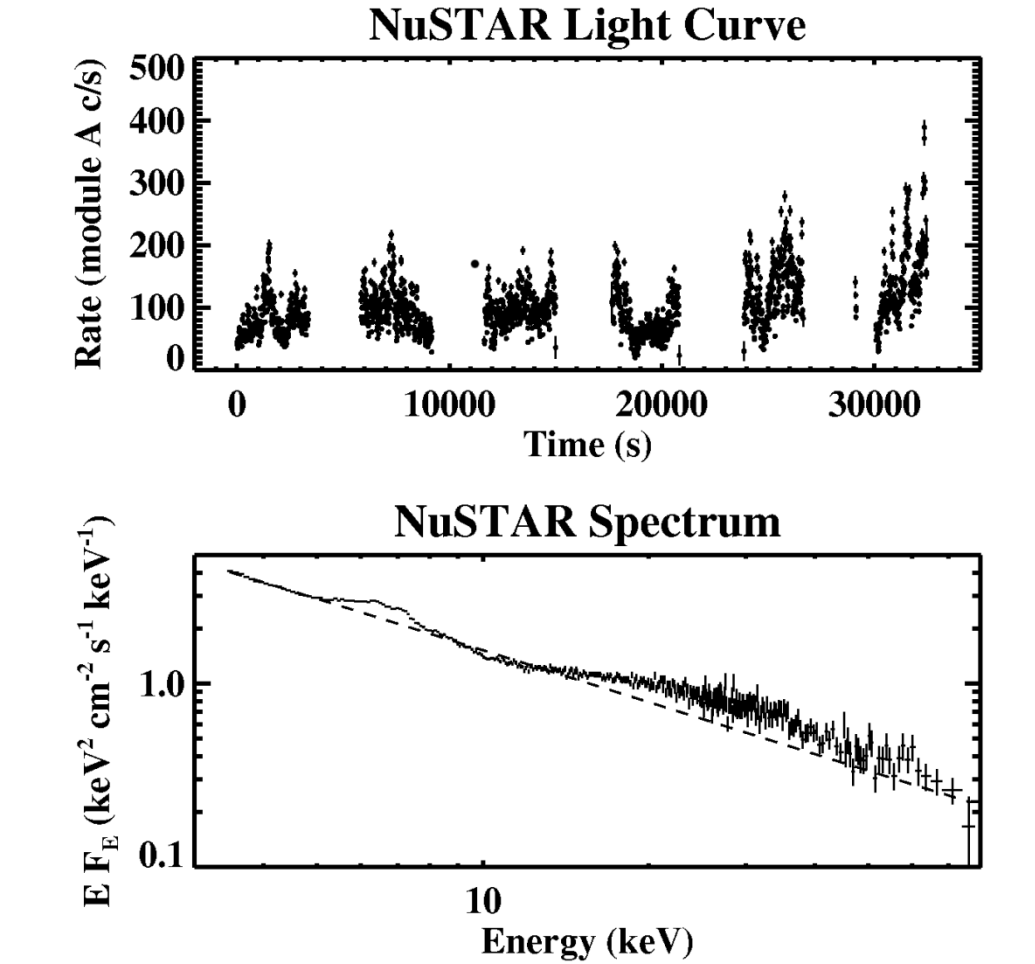


NuSTAR sees Flare from Milky Way's Black Hole



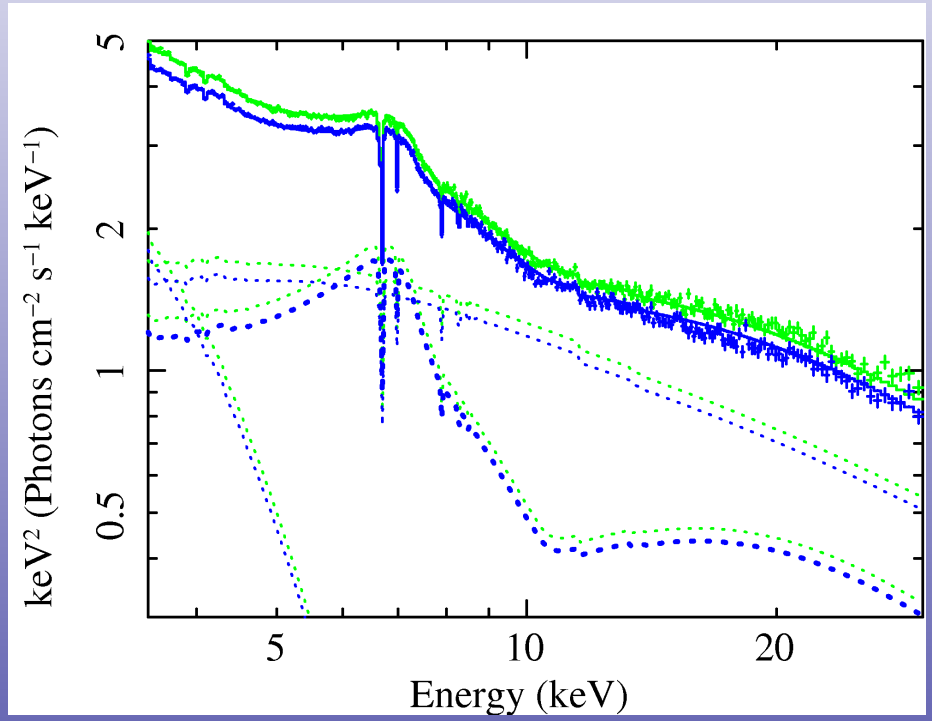
NuSTAR and Black Hole Spin

NuSTAR timing of Cyg X-1

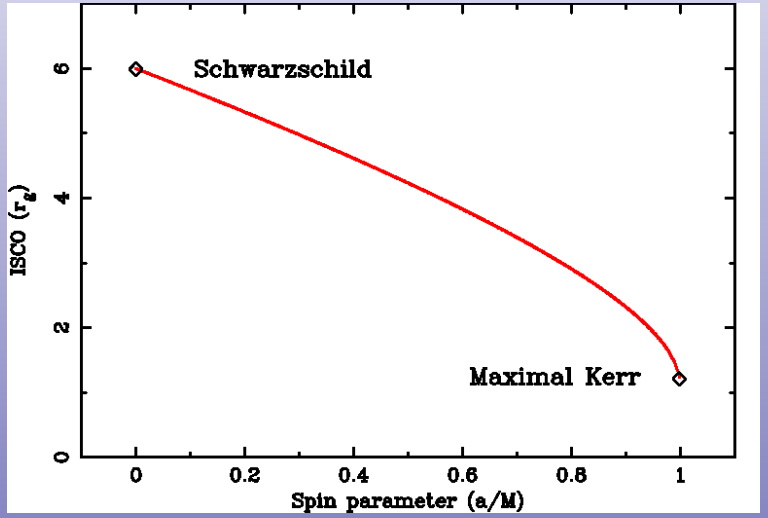


- Cyg X-1 is a stellar mass black hole in a binary system that is accreting matter from a supergiant companion star
- *NuSTAR* saw it in the soft state

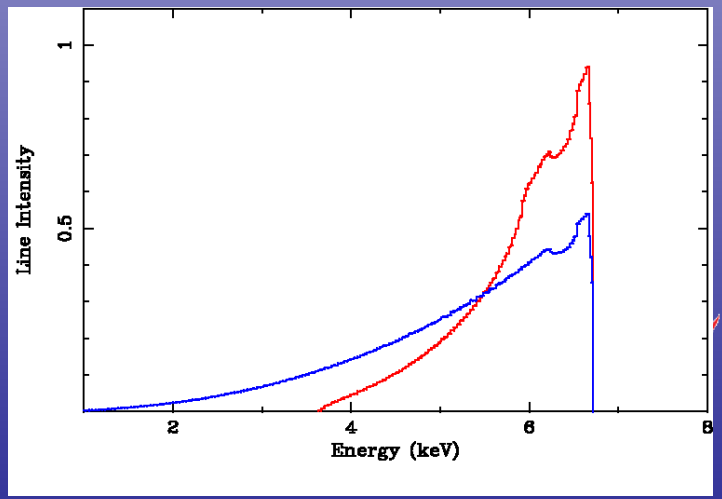
Cyg X-1 Energy Spectrum



Miller et al. 2007

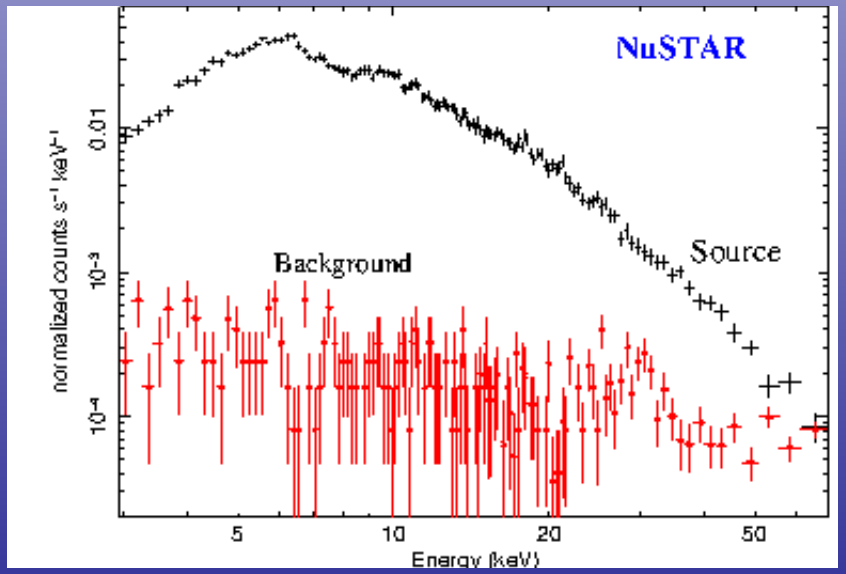


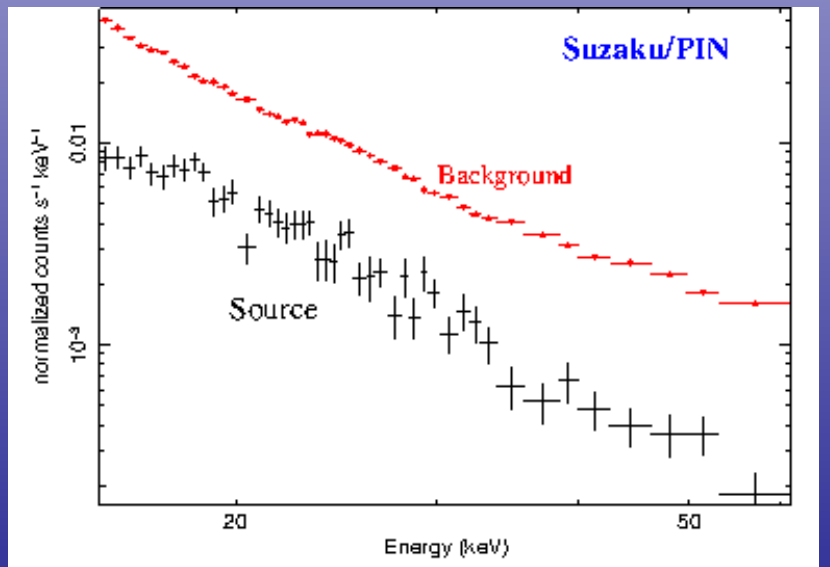
- General Relativity predicts line shapes for spinning black holes



NuSTAR measures NGC 1365

- *NuSTAR*'s measurements ruled out clouds of gas as the source of the broad line emission and revealed the BH spin rate is >84% of maximum





NuSTAR images two BHs in distant galaxy

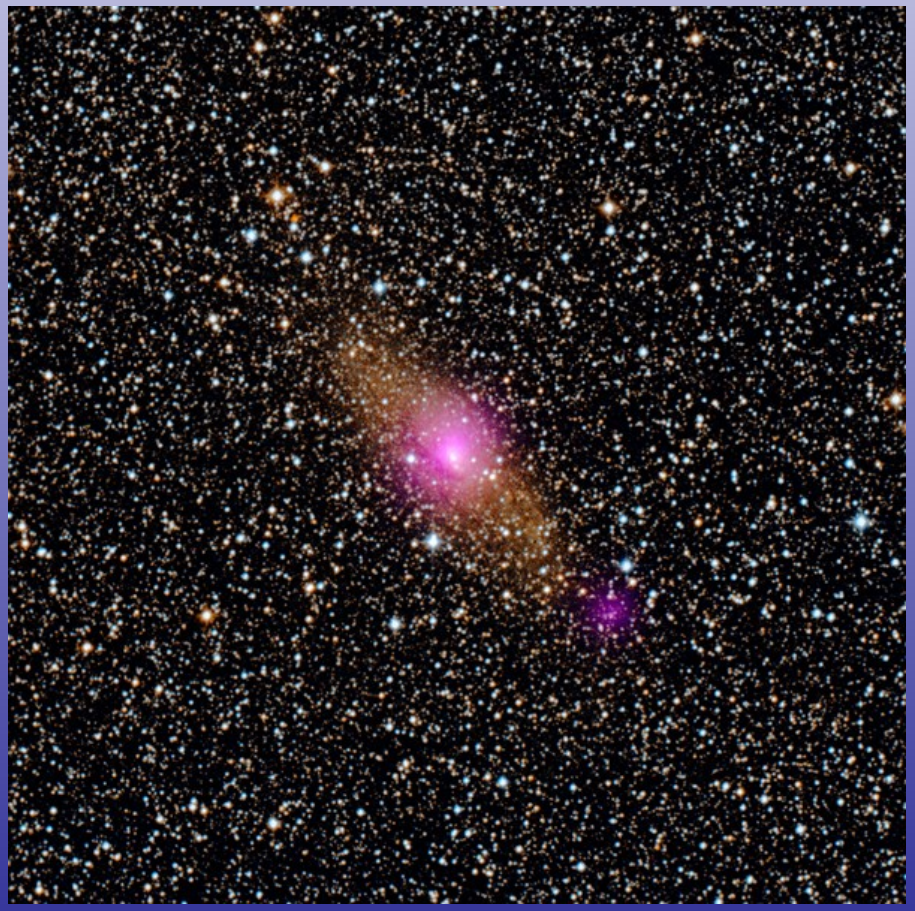
Since BHs are not in center, they are probably “intermediate mass” BHs

IC 342/Caldwell 5

More Medium-sized BH

NGC 1313 (70 and 30 solar)

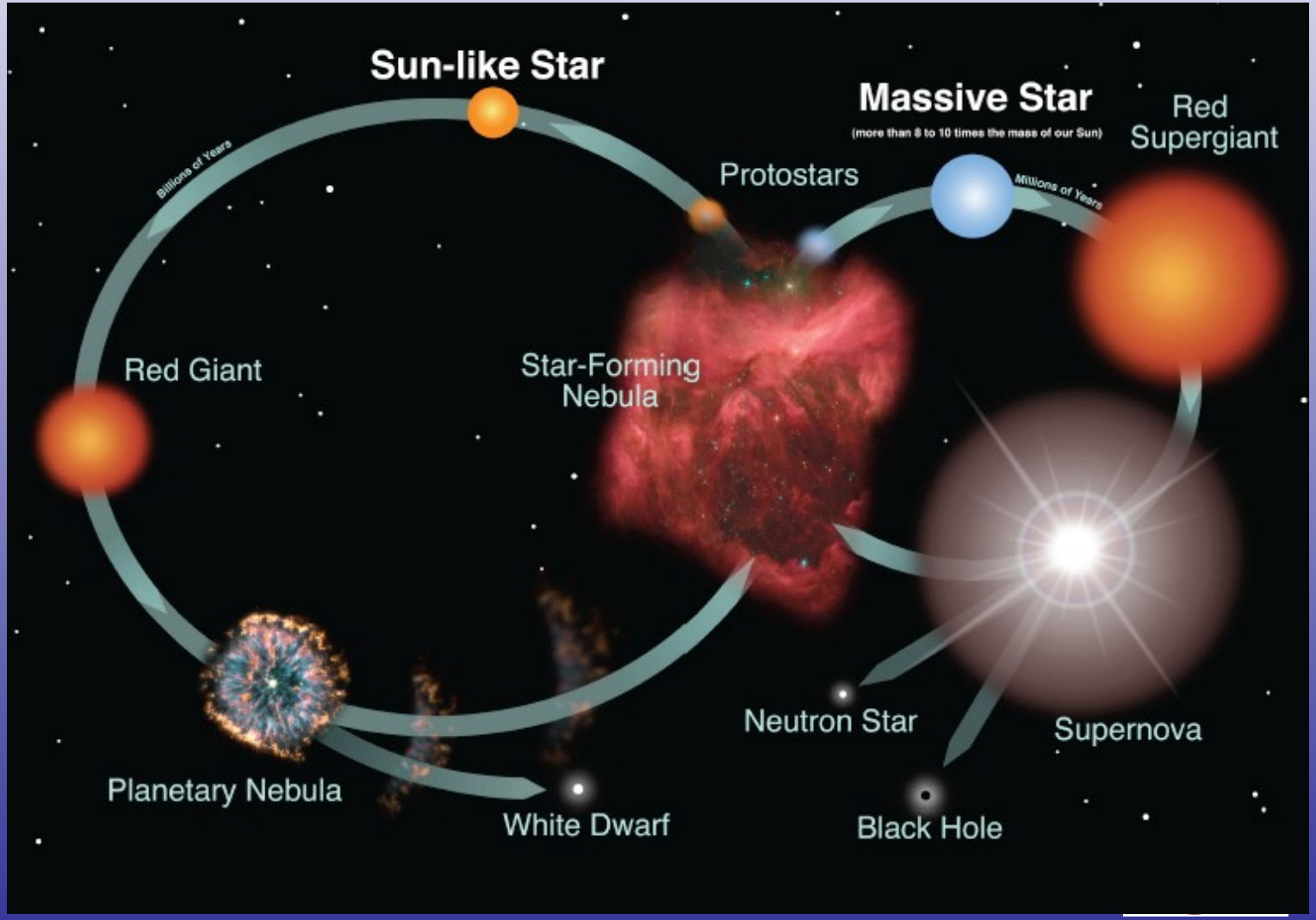
Circinus galaxy – SMBH + IMBH



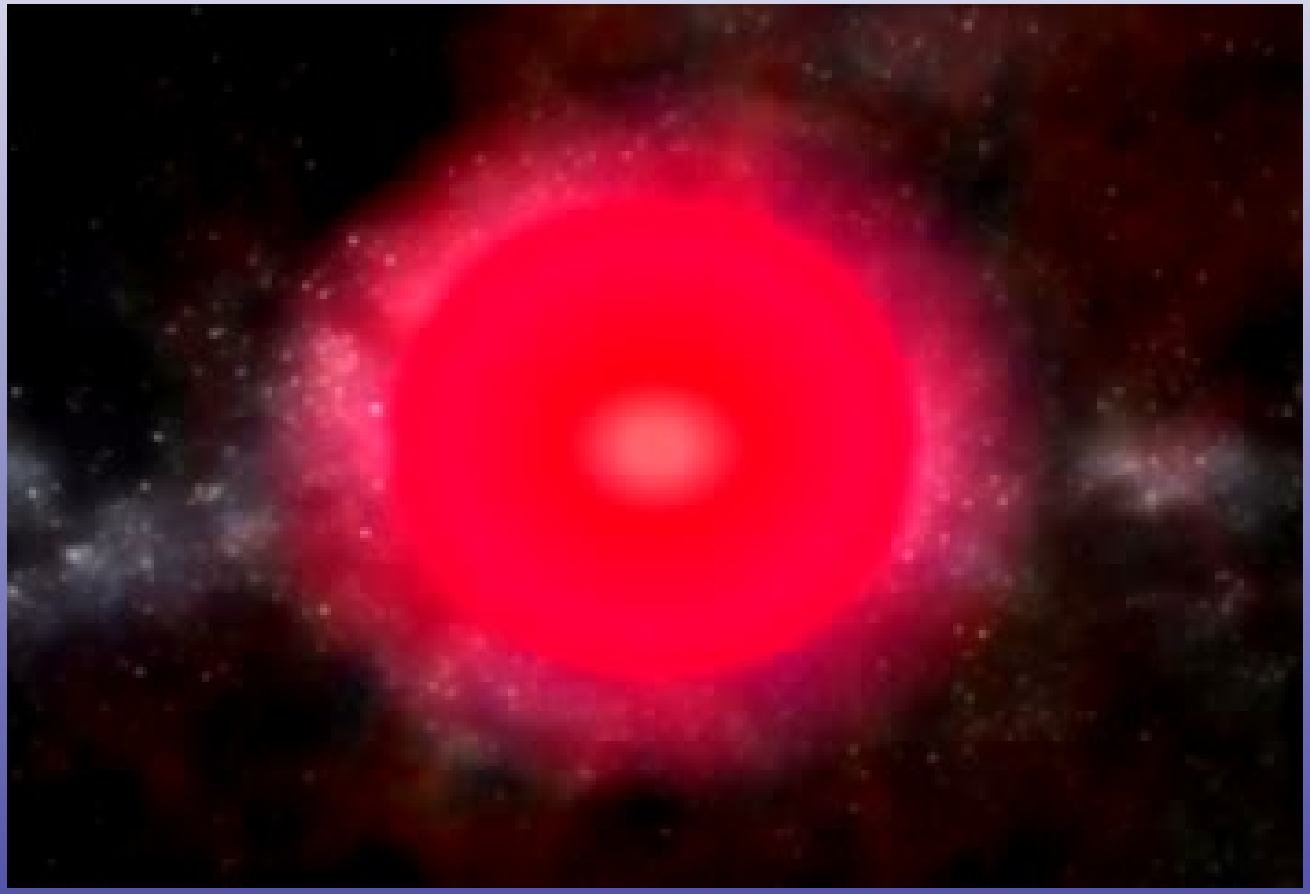
Find the Supernova

Credit: R. Jay GeBany

Life Cycle of Stars



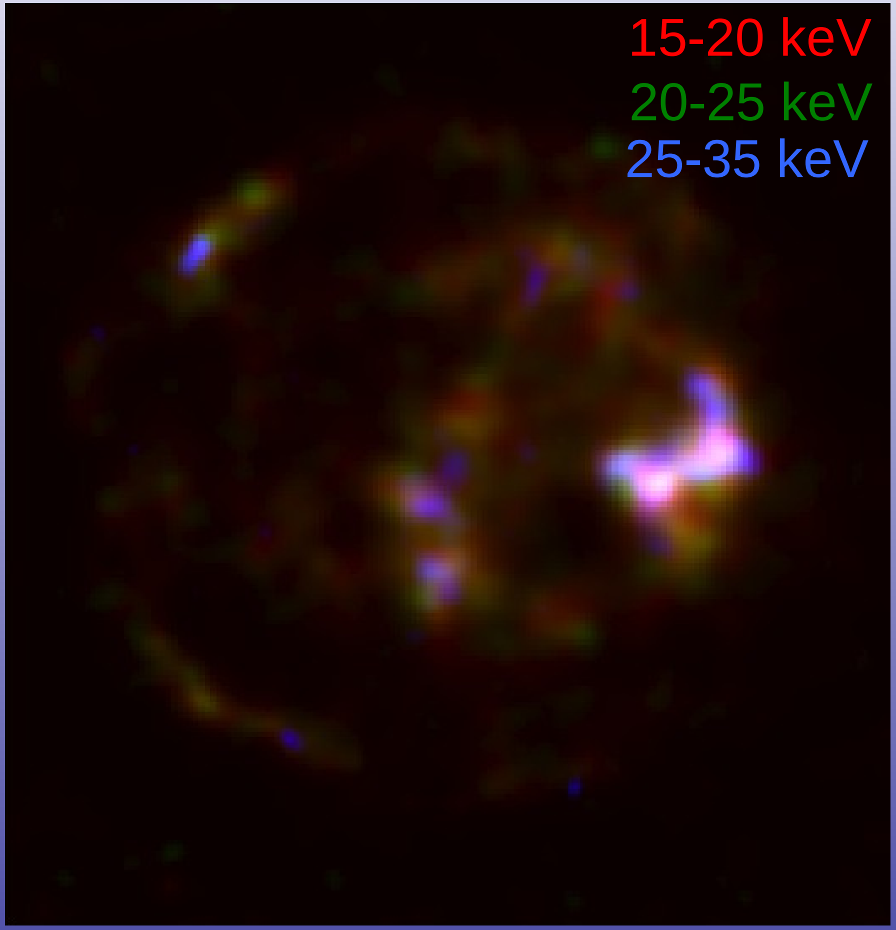
Supernova!



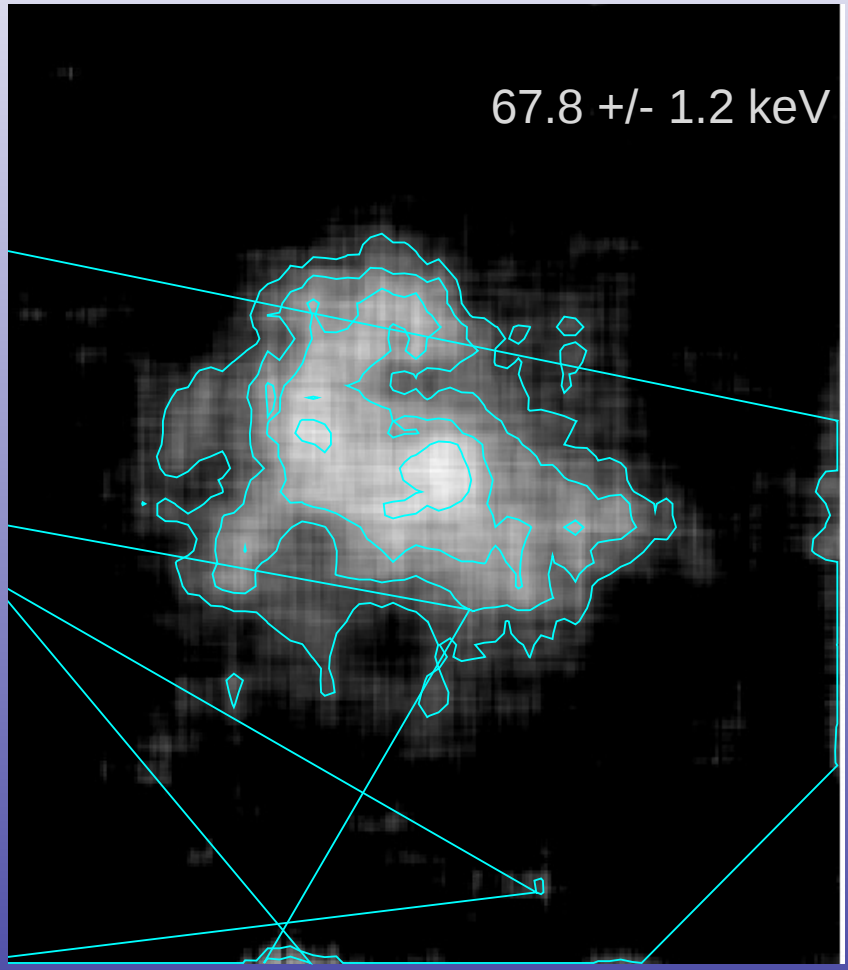
NuSTAR Cas A image

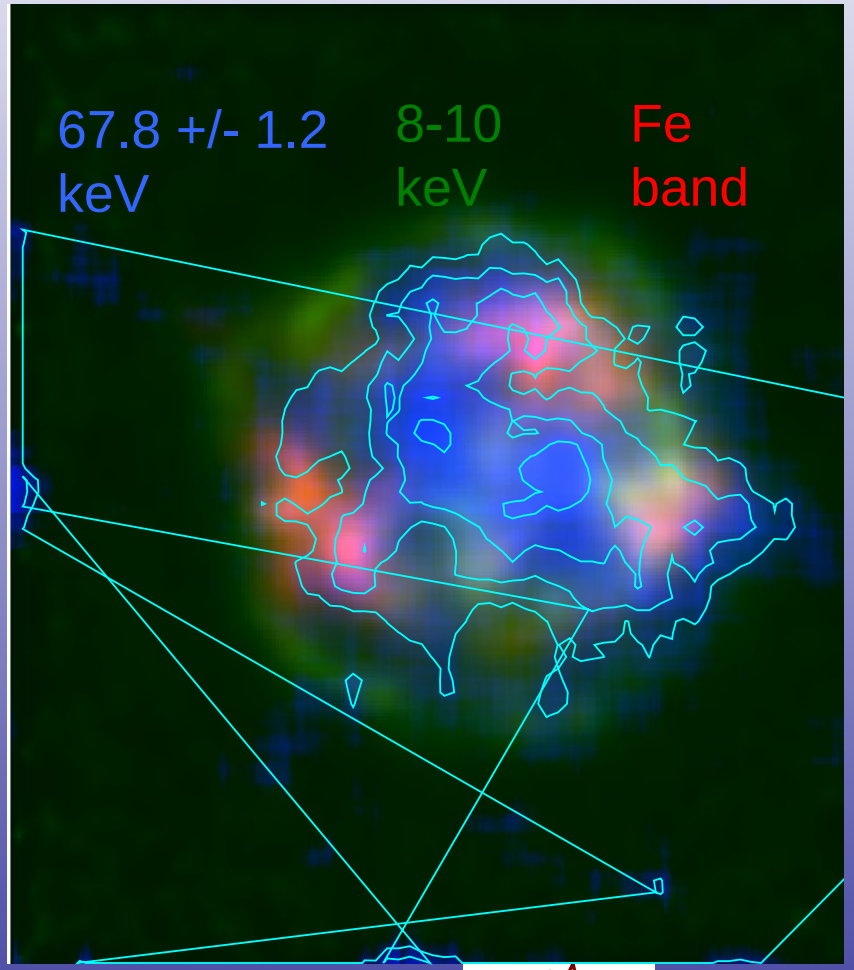
Blue shows the highest energy X-rays, not imaged before *NuSTAR*
Green and red show the lower energy X-rays, also seen with Chandra

Detailed look at Cas A Continuum



^{44}Ti Imaging Cas A





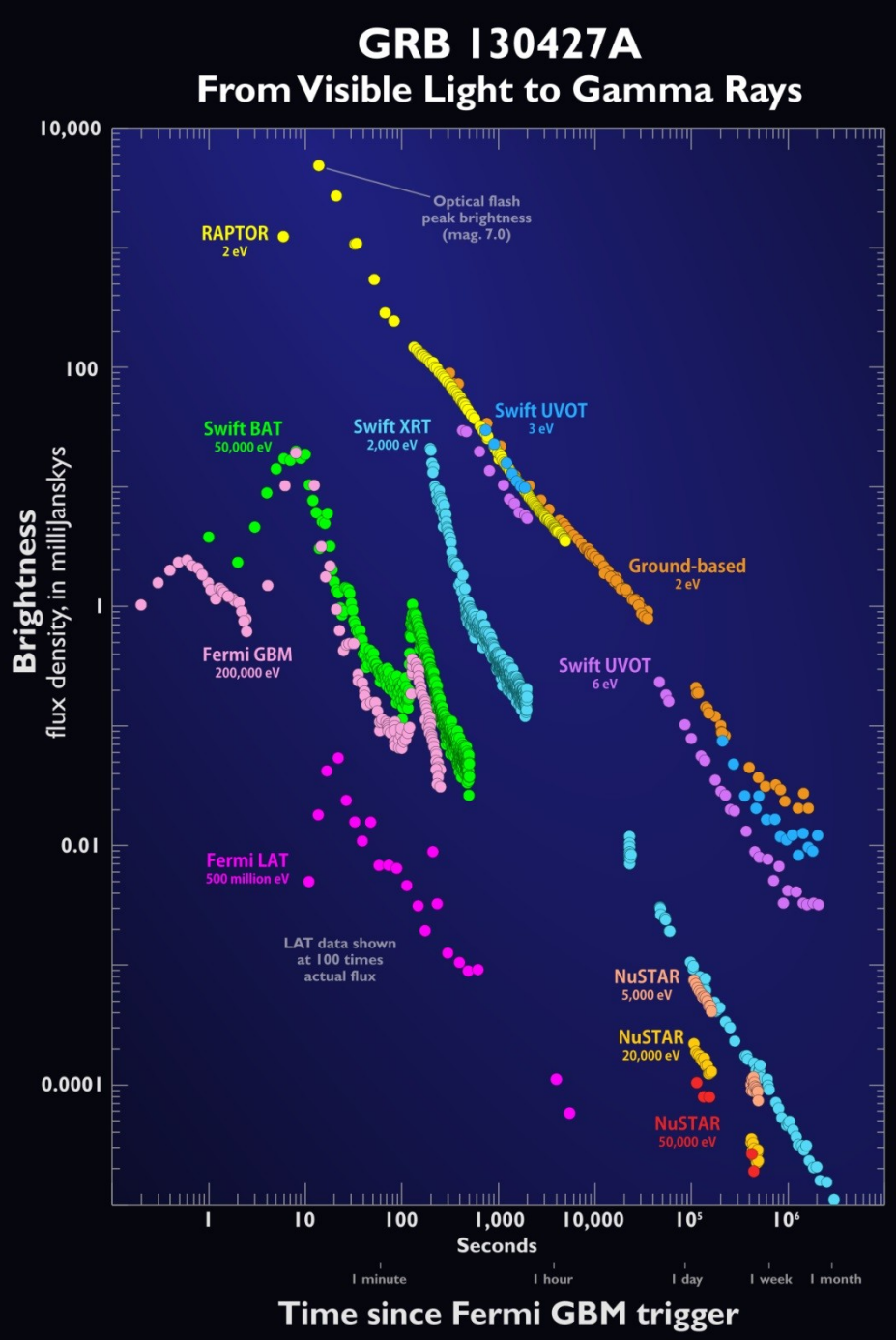
Solar Supernova?

- Learn about stellar lifecycles and determine the fate of the Sun
- http://mystery.sonoma.edu

More super than a supernova?

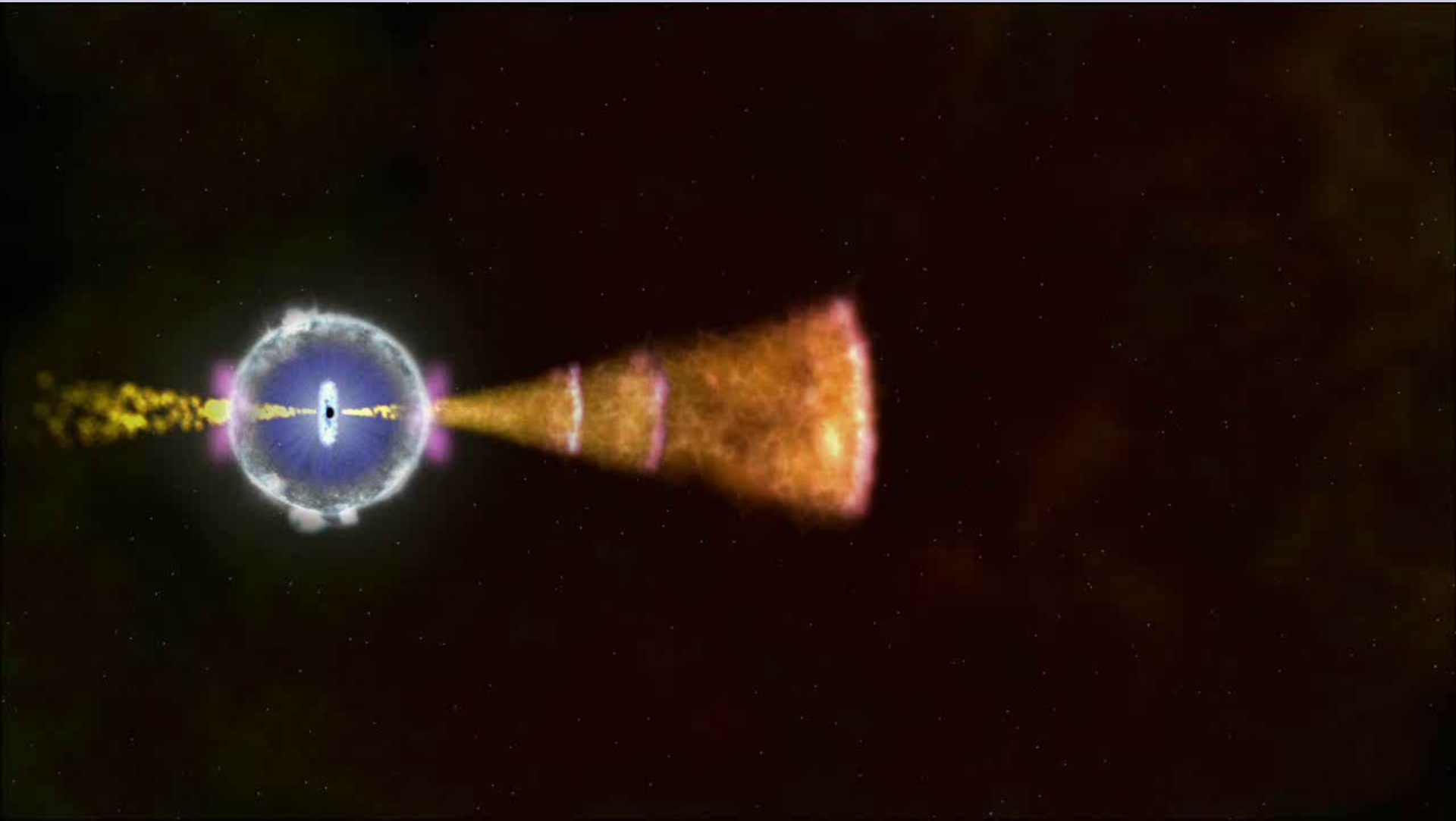
- A gamma-ray burst!
- The core collapse of a 20-30 M_0 star all the way down to a black hole
- NuSTAR and other missions saw a record breaking burst on April 27, 2013
- It was longer and brighter than almost any burst seen to date
- Emitted more energy in a few seconds than our Sun in its entire lifetime

GRB 130427A


GRB 130427A
From Visible Light to Gamma Rays
Brightness
flux density, in millijanskys
10,000
100
1
0.01
0.0001
Optical flash
peak brightness
(mag. 7.0)
RAPTOR
2 eV
Swift BAT
50,000 eV
Swift XRT
2,000 eV
Swift UVOT
3 eV
Ground-based
2 eV
Fermi GBM
200,000 eV
Swift UVOT
6 eV
Fermi LAT
500 million eV
LAT data shown
at 100 times
actual flux
NuSTAR
5,000 eV
NuSTAR
20,000 eV
NuSTAR
50,000 eV
1
10
100
1,000
10,000
10⁵
10⁶
Seconds
1 minute
1 hour
1 day
1 week
1 month
Time since Fermi GBM trigger

GRB Animation

How the jets emit X and γ-rays

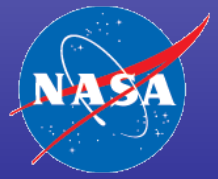


Conclusions

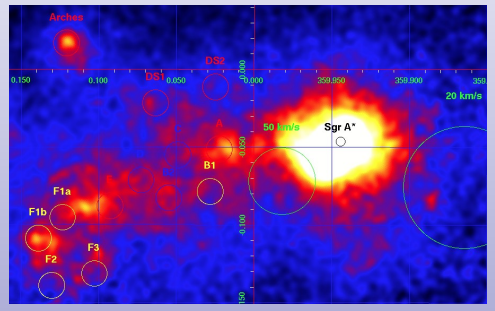
- NuSTAR is bringing the high energy universe into focus
- We are getting sharper views and looking through the dust and gas into the centers of galaxies
- Stay tuned for more – we are just getting started!

Resources

- **http://epo.sonoma.edu** – our group's main page
- http://www.nustar.caltech.edu for latest discoveries from NuSTAR
- http://mystery.sonoma.edu – to play the Space Mystery games



Science Highlights



Galactic Surveys

120.13 Krivonos et al. Arches cluster

126.49 Zhang et al.

Extragalactic Surveys

109.09 Civano et al.

300.04 Ballantyne et al.

lc_nustar_since120701.png 800×600 pixels 4/8/13 9:21 PM

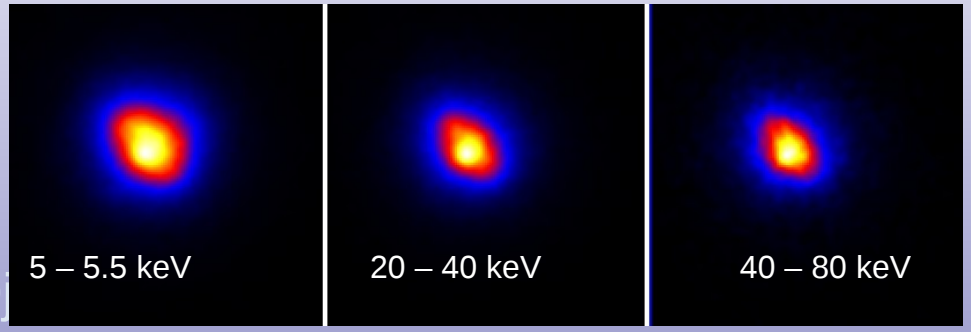
Blazars – Mkn 421

108.17 Balokovic et al.

Science Highlights

Accreting pulsars
402.01 Fuerst – Her X-1
129.01 Bellm - - J1008-57

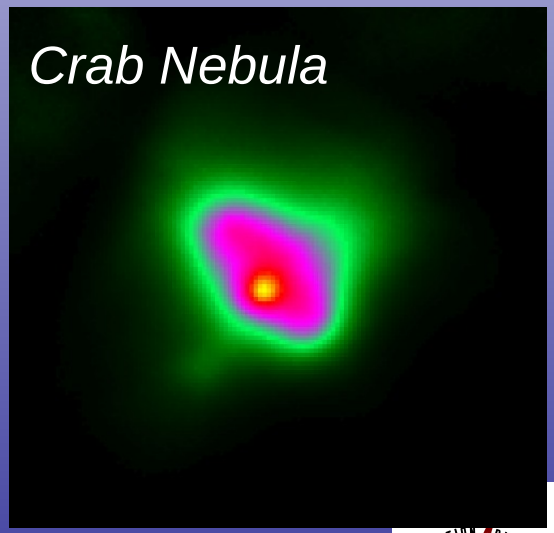
Supernovae
402.04 Zoglauer = SN2010j



Clusters
401.02 Wik – Bullet

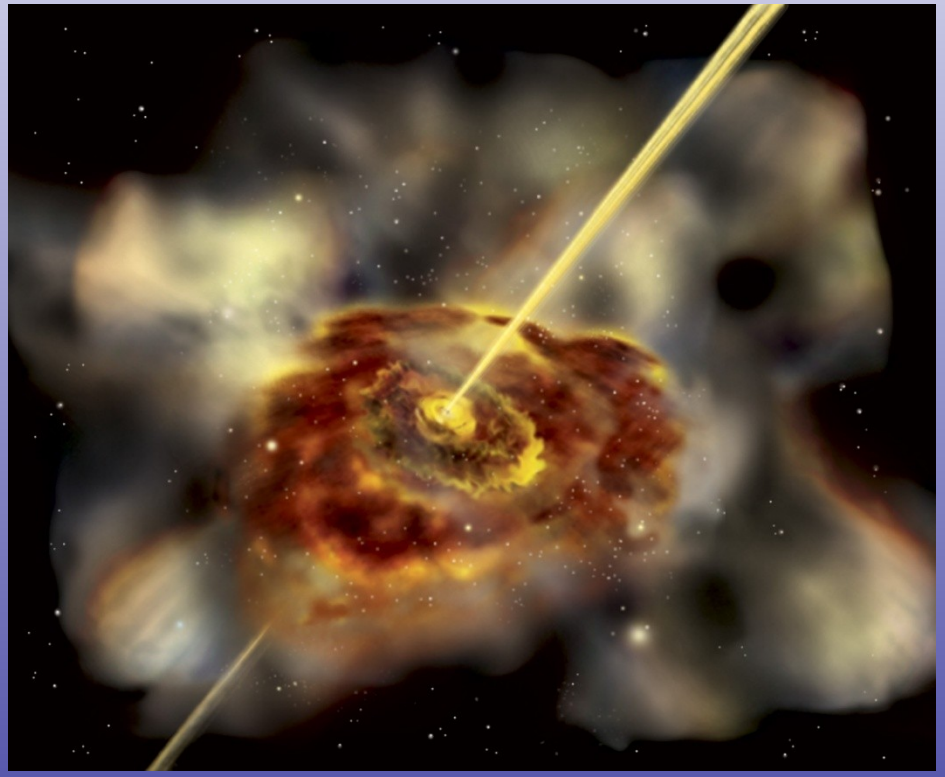
Starburst Galaxies
120.15 Ptak

Pulsar Wind Nebulae
400.05 Madsen



Studying Active Galaxies

- Active Galaxies emits both X-rays and gamma rays
- Galaxies that point their jets at us are called “blazars”
- How do the black holes send out jets?



Art by Aurore Simonnet

Active Galaxies

- Show movie here

Anatomy of an active galaxy