# Exploring the Exotic Universe

Albert Kong 江國興

# What is "Exotic" ?

- From Oxford English Dictionary
  - Introduced from abroad; having the *attraction* of the strange or foreign

# *X-ray*
# Exploring the ~~Exotic~~ Universe

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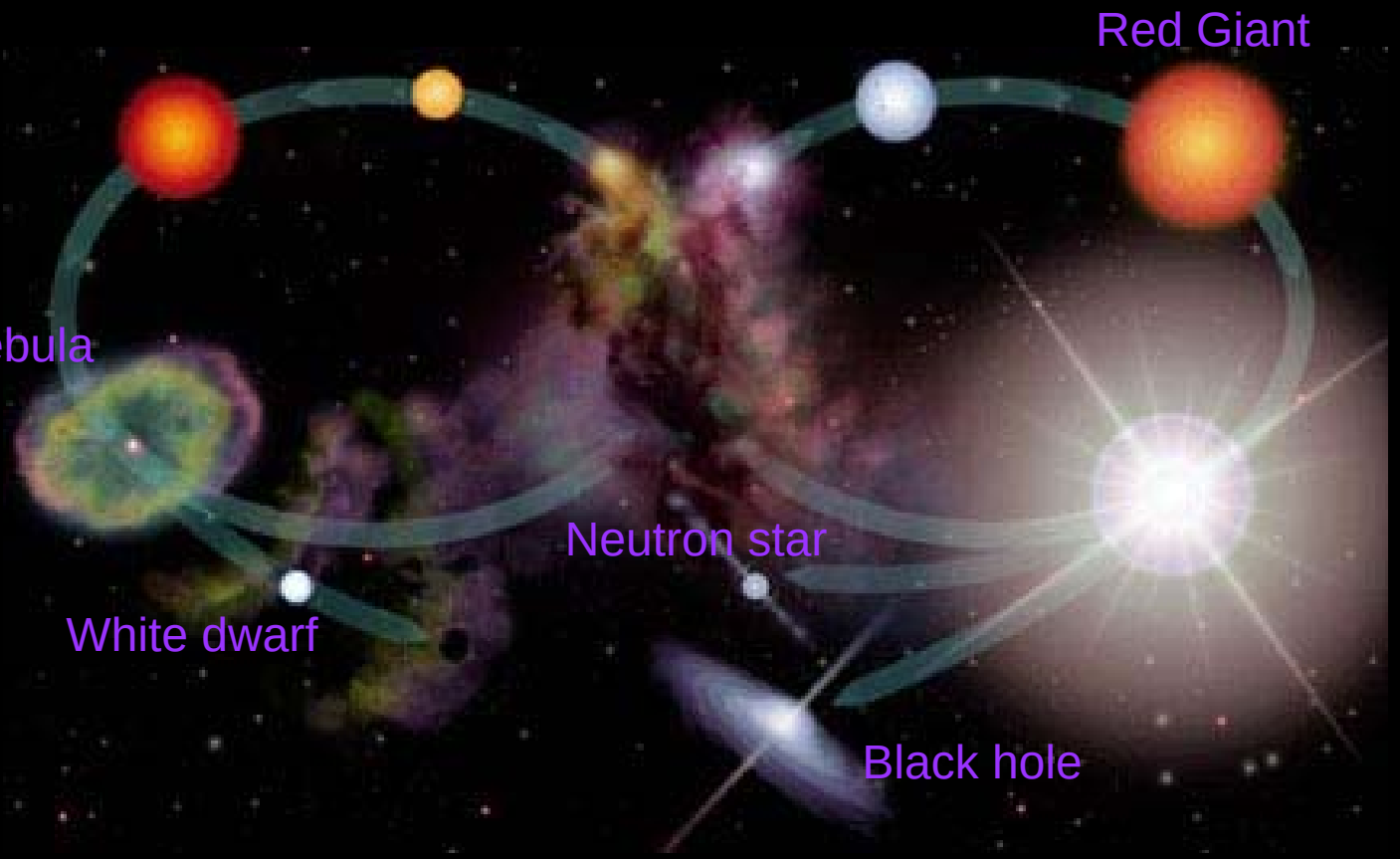
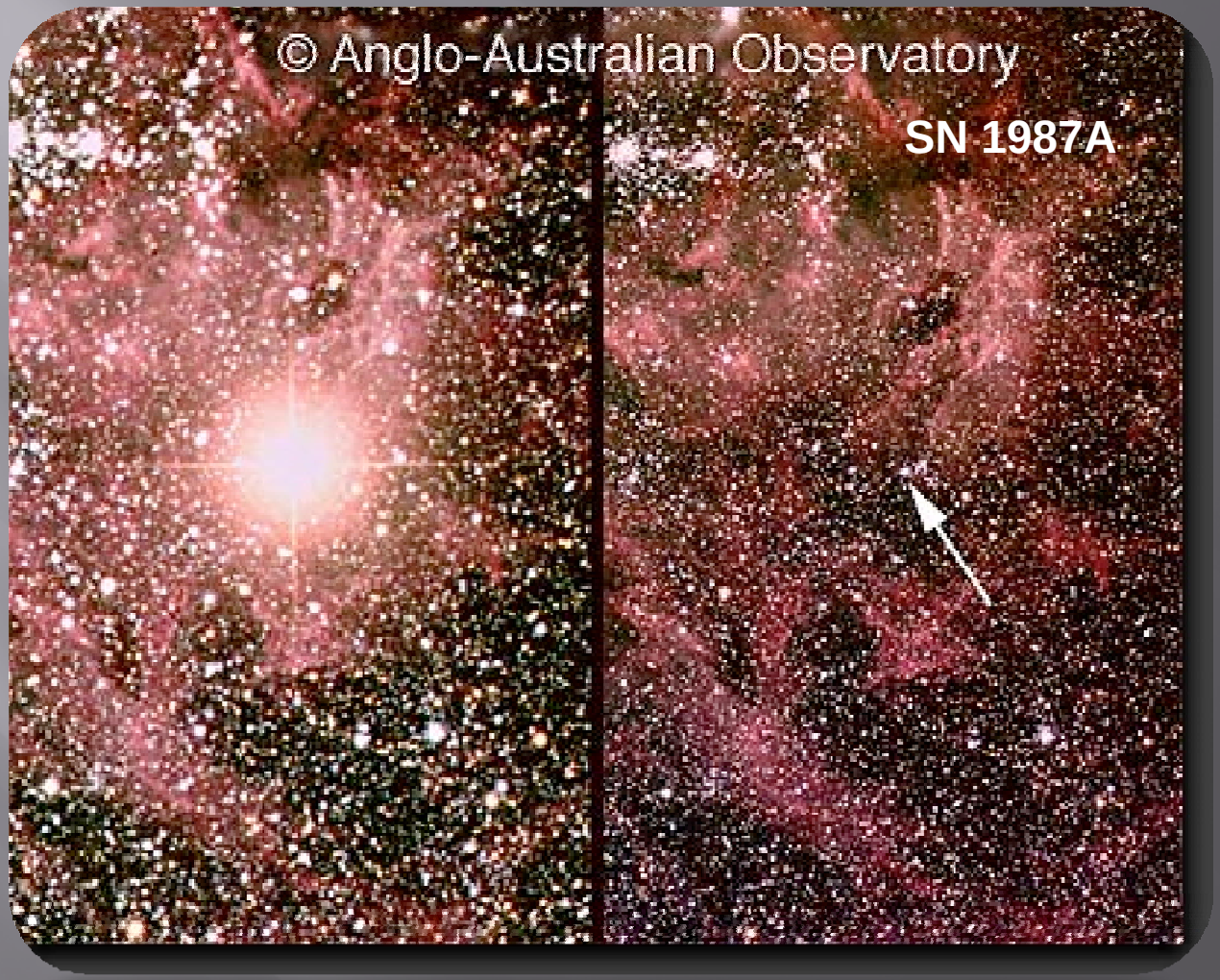
# The Life Cycle




Sun-like Stars

Massive Stars

# Supernova !



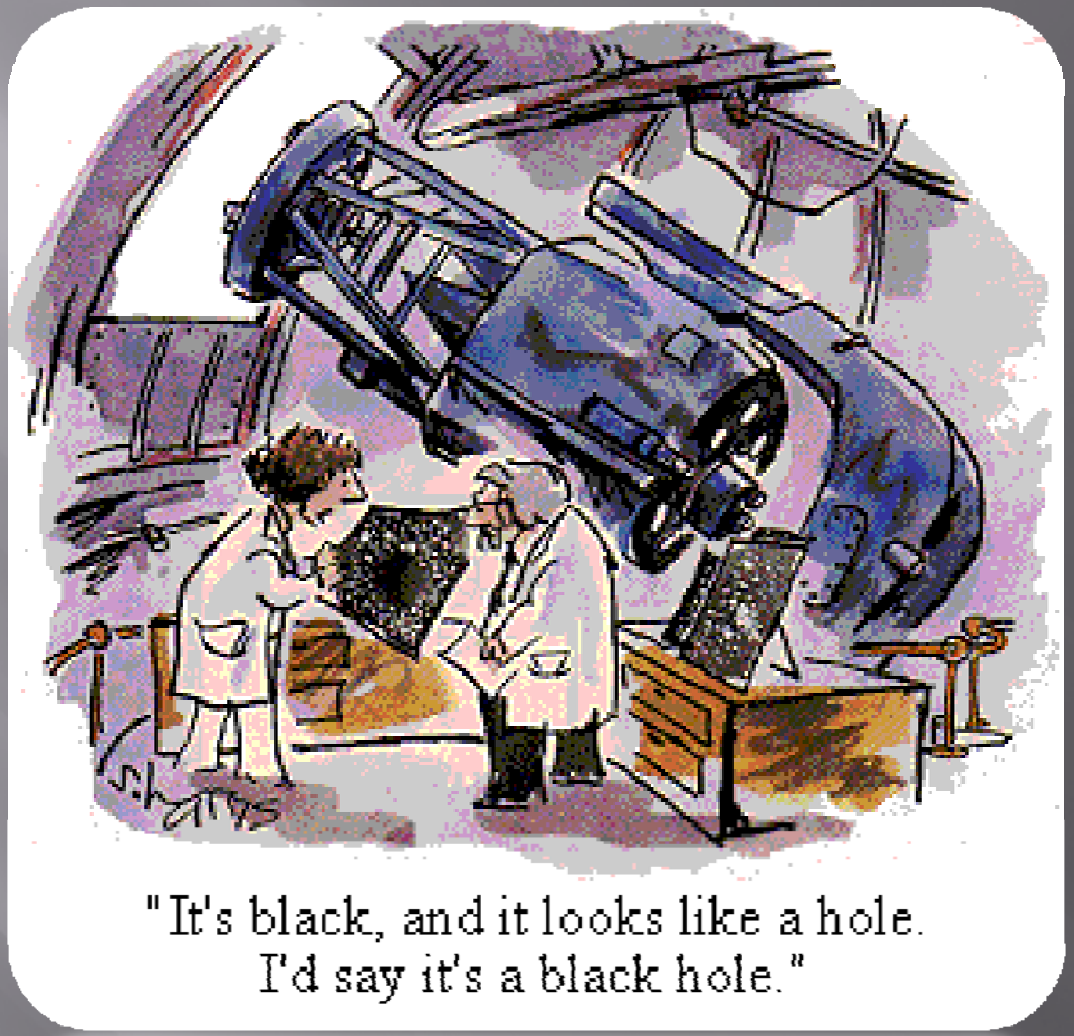
# What's next?

- When the remaining mass is < ~5 solar

  => Neutron star
- When the remaining mass is > ~5 solar

  => Black hole

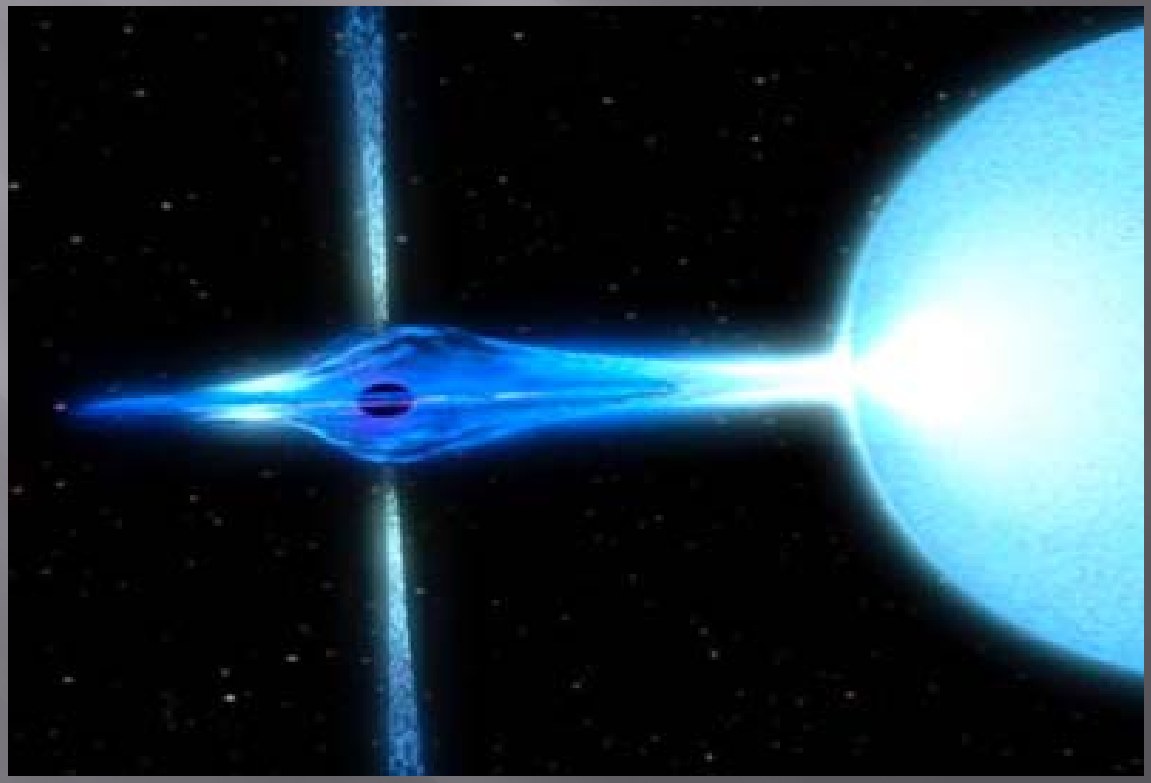
However, they are very faint as an isolated object. How can we observe them?



"It's black, and it looks like a hole.
I'd say it's a black hole."

# A whole new life: X-ray binaries

In close binary systems, material flows from normal star to neutron star or black hole. X-rays emitted from disk of gas around neutron star/black hole.

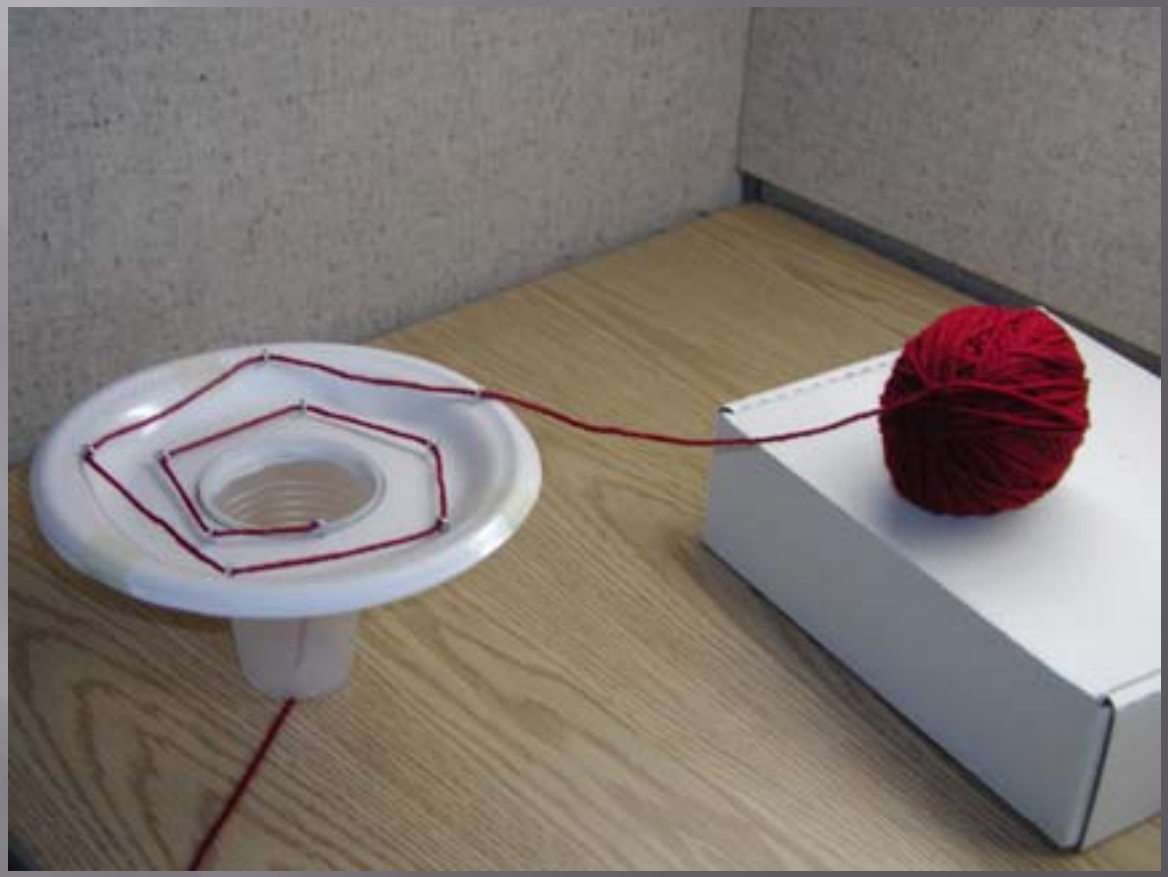


# Power of Accretion

- Material in Disk gains energy as it falls into black hole.
  - Gravitational energy is converted to kinetic energy.
    - Kinetic Energy is converted to heat and x-rays.

- Up to 42% of the mass of infalling material is converted into energy.
  - That's $10^{38}$ erg/s ! (100,000x more than sun)

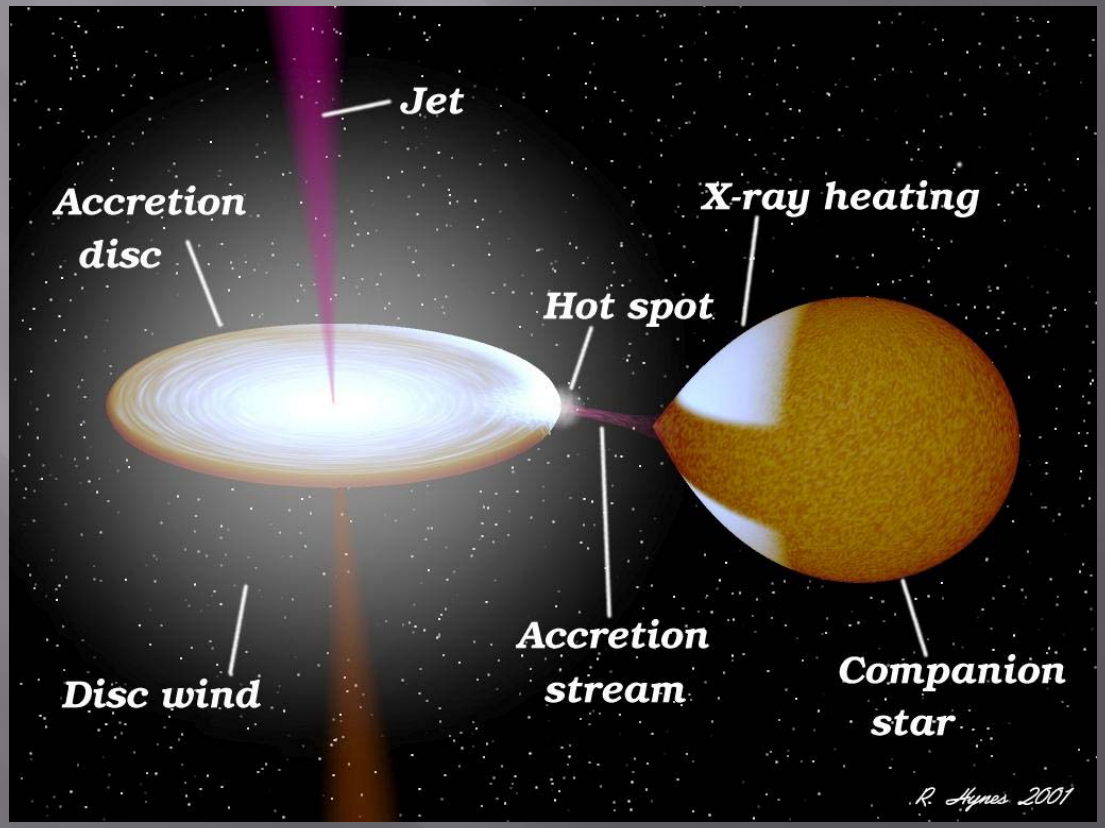
# Getting to Know your X-ray Binary



- The Groovy X-ray Binary Model

# X-ray Binaries

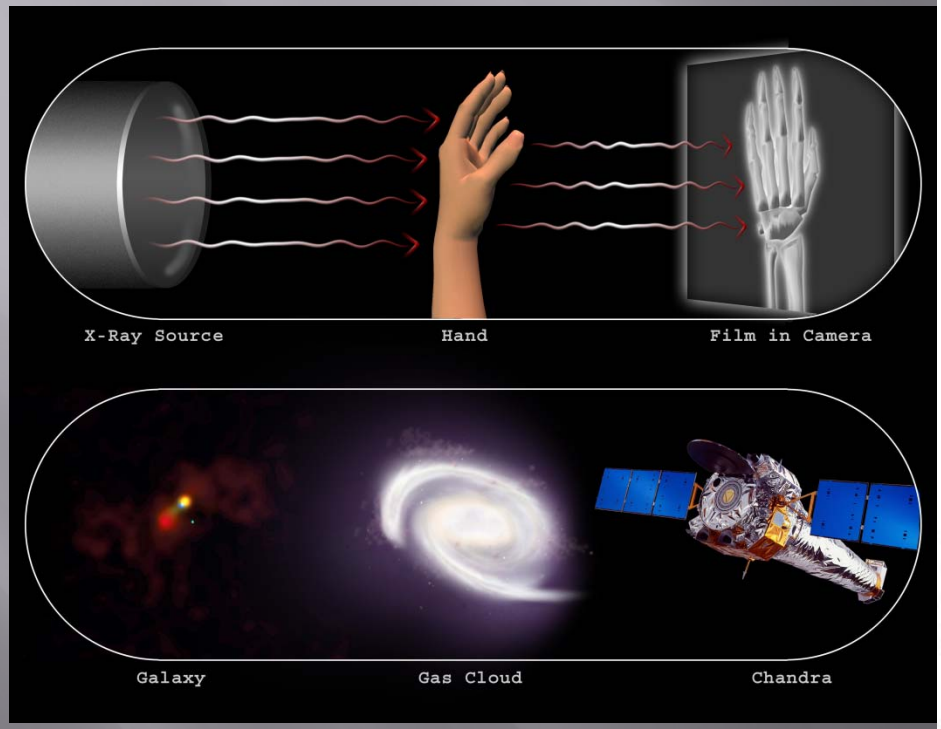
- Low-mass X-ray binaries (LMXBs)
  - low-mass (< 1 $M_{sun}$) donors
- High-mass X-ray binaries (HMXBs)
  - high-mass (~10 $M_{sun}$) supergiant donors

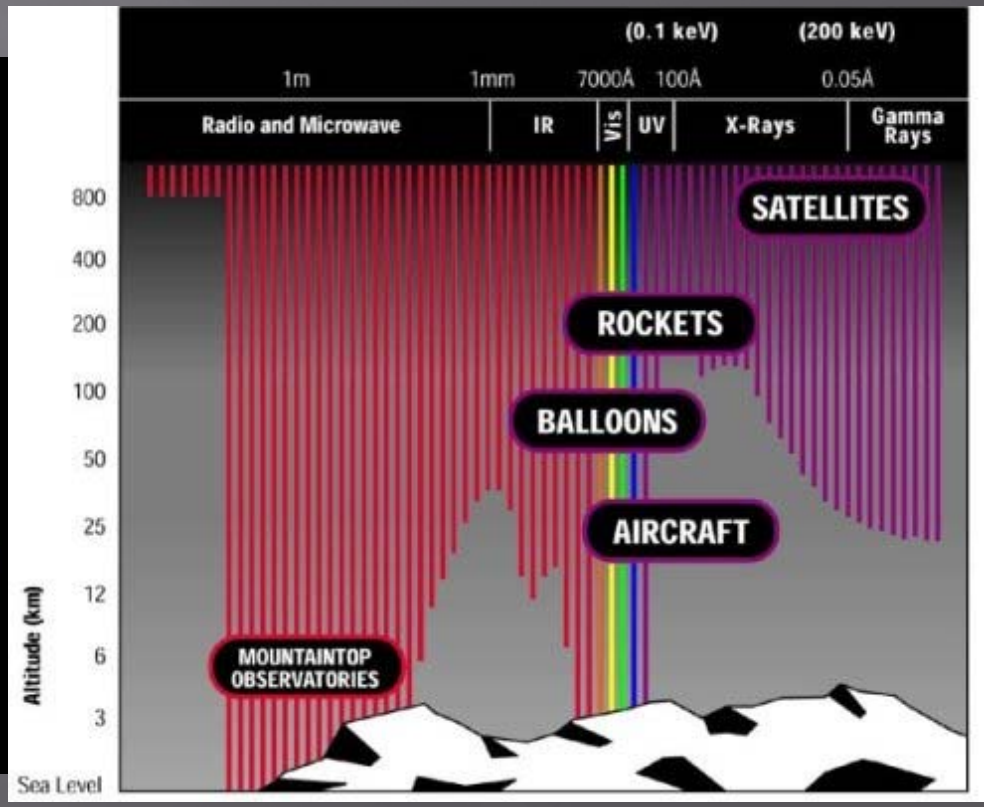


# If we can't see black holes, how do we know they're there?

- X-ray observations
- 1st BH binary; Cyg X-1 (discovered in 1960s)
- A luminous persistent X-ray source
- Optical identification (Webster & Murdin 1972)
- A high-mass X-ray binary
- 9th magnitude supergiant star HD226868
- The 2nd BH binary is also a HMXB (LMC X-3)
- The 3rd BH binary, A0620-00, is a LMXB with totally different behaviors (McClintock & Remillard 1986)

# How can we observe X-rays from astronomical objects?

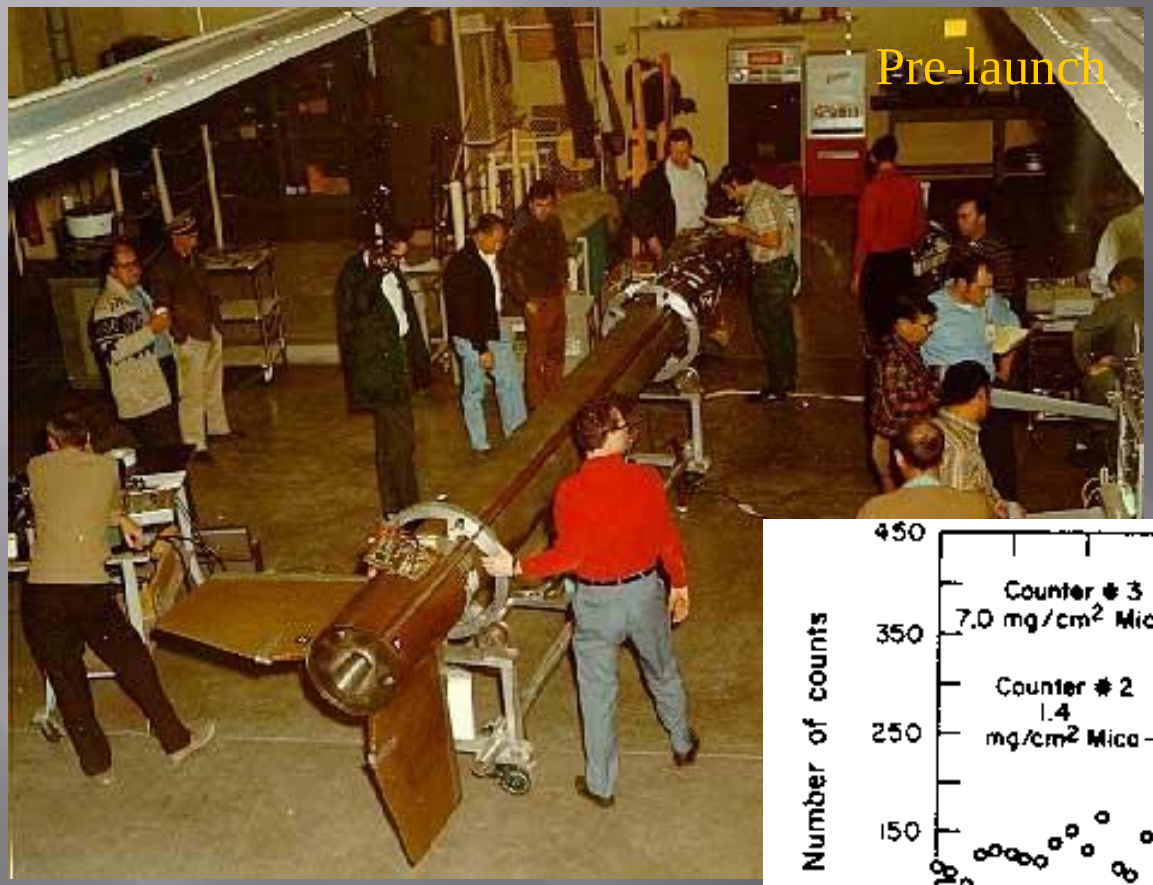


# Early days of X-ray astronomy: the discovery of Sco X-1

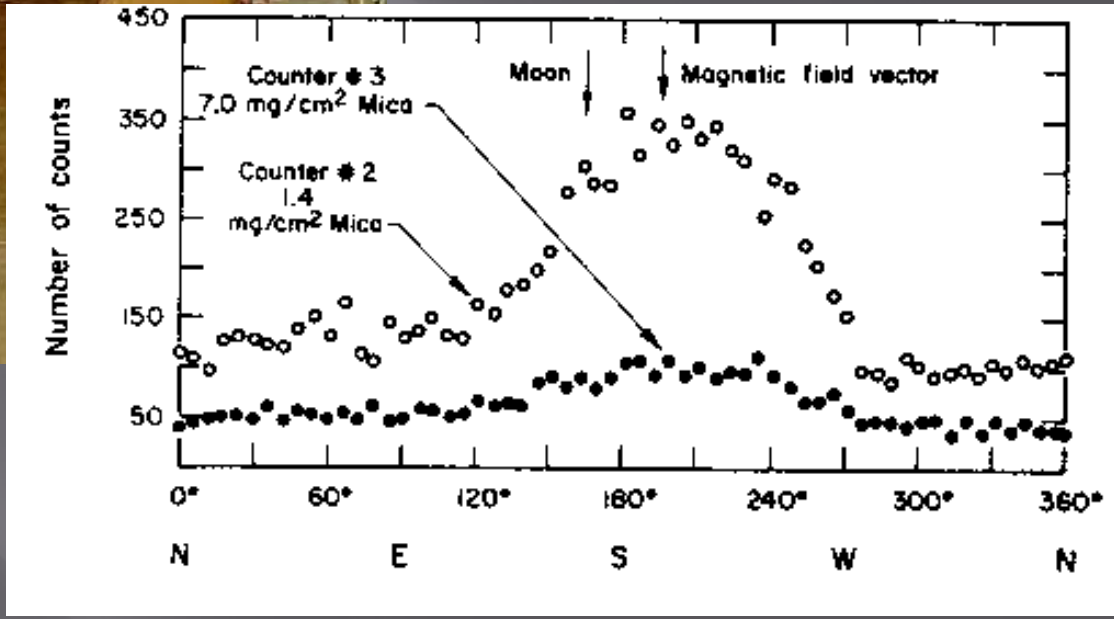
- 1901: the 1st Nobel in physics is for Wilhelm Rontgen due to his discovery of X-rays in 1895.
- 1962 Jun 19: the 1st X-ray detector is put into the space by a rocket. The project is led by Riccardo Giacconi (2002 Nobel laureate) and Bruno Rossi.
- Search for X-rays from the moon.
- Discover a bright X-ray source: Sco X-1.
- 1963: Discovery of X-ray emission from Crab nebula….

# Early days of X-ray astronomy: the discovery of Sco X-1

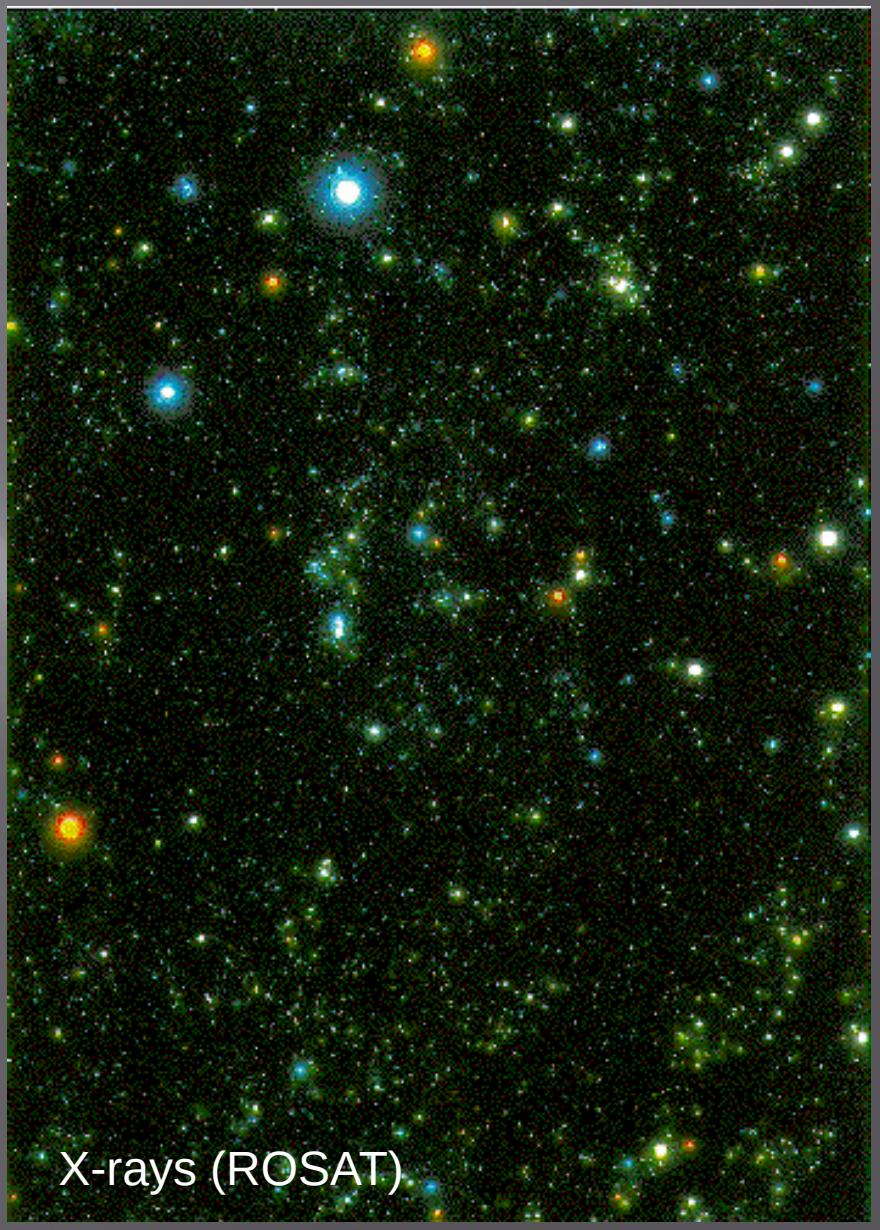


Pre-launch

Discovery of Sco X-1




Visible light

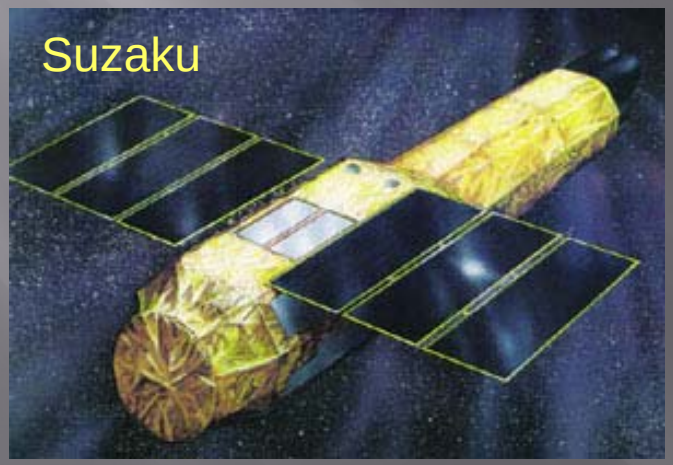

X-rays (ROSAT)

# X-ray Observations

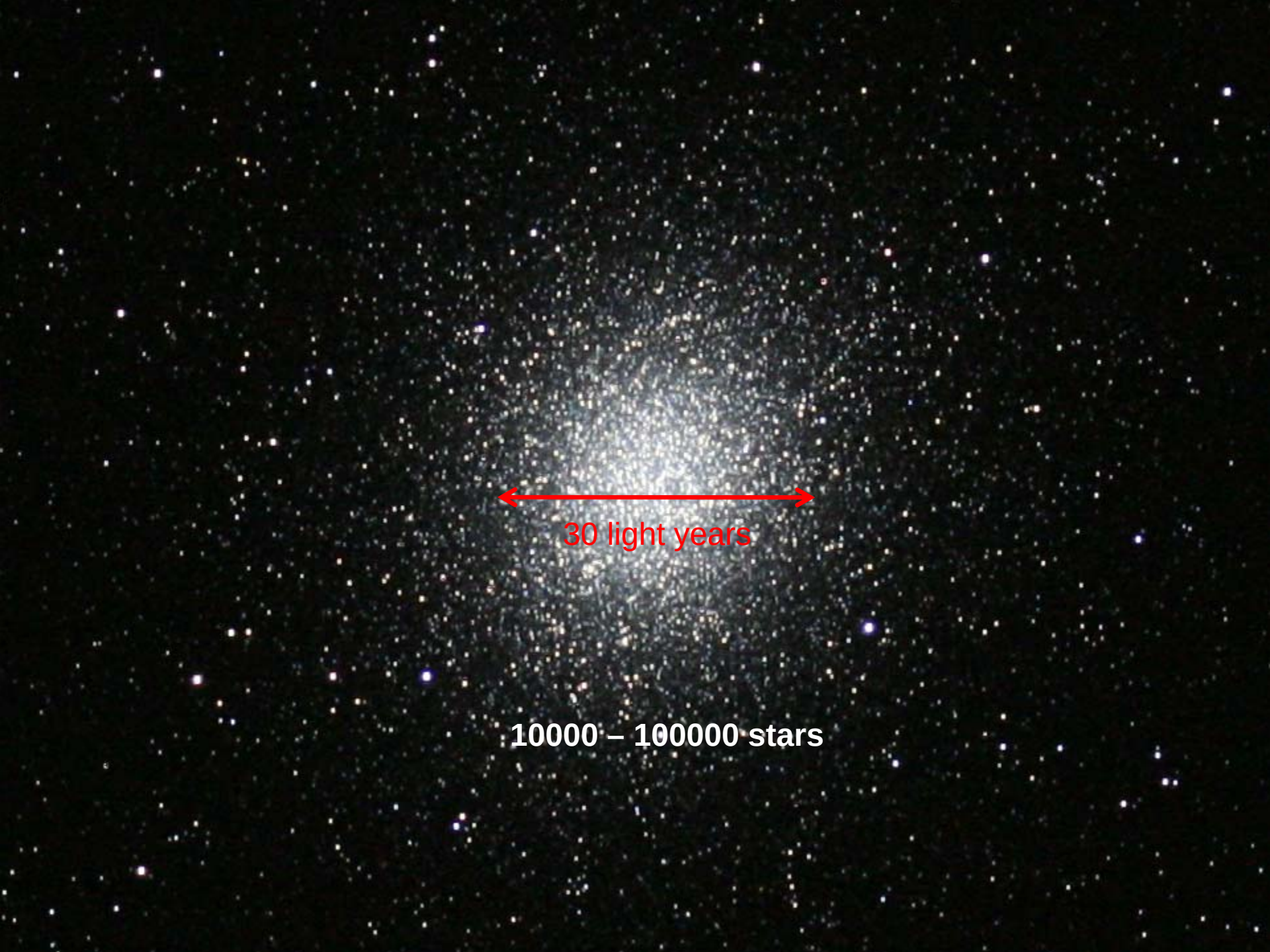
## X-rays reveal high temperatures and highly energetic phenomena.

- Current X-ray satellites include the Chandra X-ray Observatory, XMM-Newton, Rossi X-ray Timing Explorer, Suzaku, INTEGRAL, and Swift.


Chandra X-ray Observatory


Suzaku


XMM-Newton


30 light years
10000 – 100000 stars

# Globular Cluster X-ray Sources

- The first X-ray detections were made in 1970s with the Uhuru and OSO-7 Observatories (e.g. Giacconi et al. 1972).
- About 10% of luminous X-ray sources in our Galaxy are found in GCs.
- The probability of finding a luminous X-ray source in a GC is orders of magnitude higher than in the rest of our Galaxy.
- Many interesting close dynamic interactions (e.g. exchanges in encounters with binaries, direct collisions, destruction of binaries, and tidal capture) between stars occur in GCs because of the high stellar density.
- GCs are very efficient factories to produce exotic binary objects like low-mass X-ray binaries, cataclysmic variables (CVs), and millisecond pulsars.

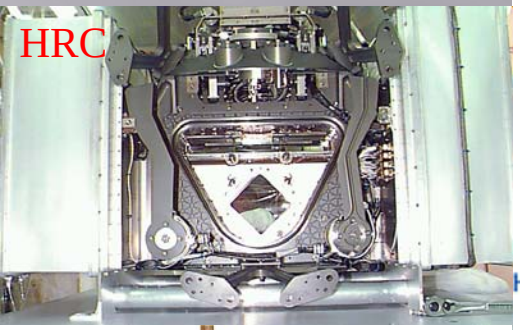
# Formation of GC X-ray Sources

- Tidal capture from close encounters due to the high stellar densities (Clark 1975; Fabian et al. 1975)
- Number of X-ray sources $\propto$ core density?

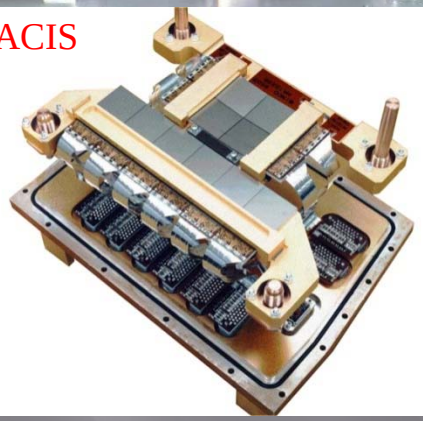
We need sub-arcsecond X-ray resolution to prove the above theoretical prediction

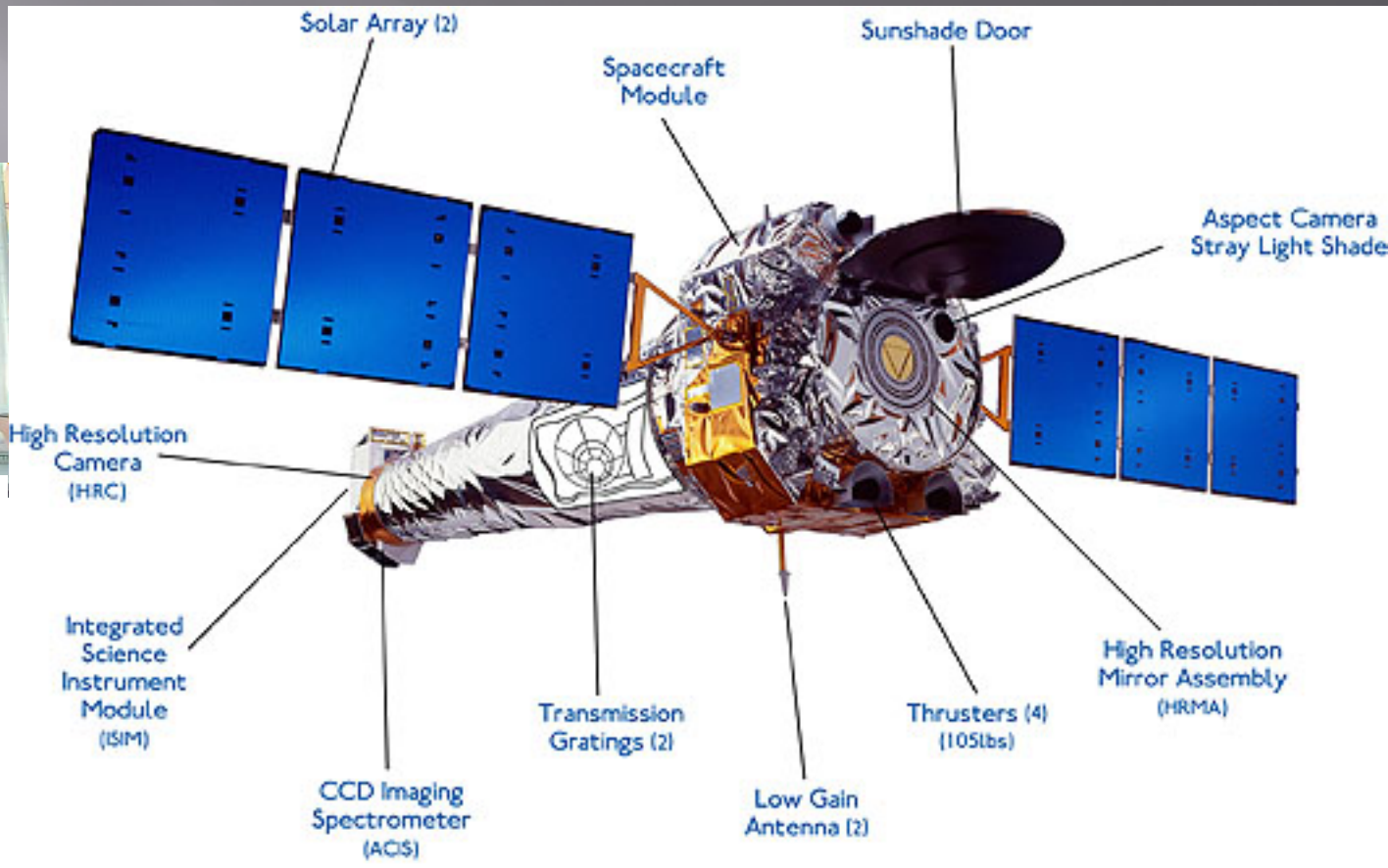
# Chandra X-ray Observatory

HRC



ACIS

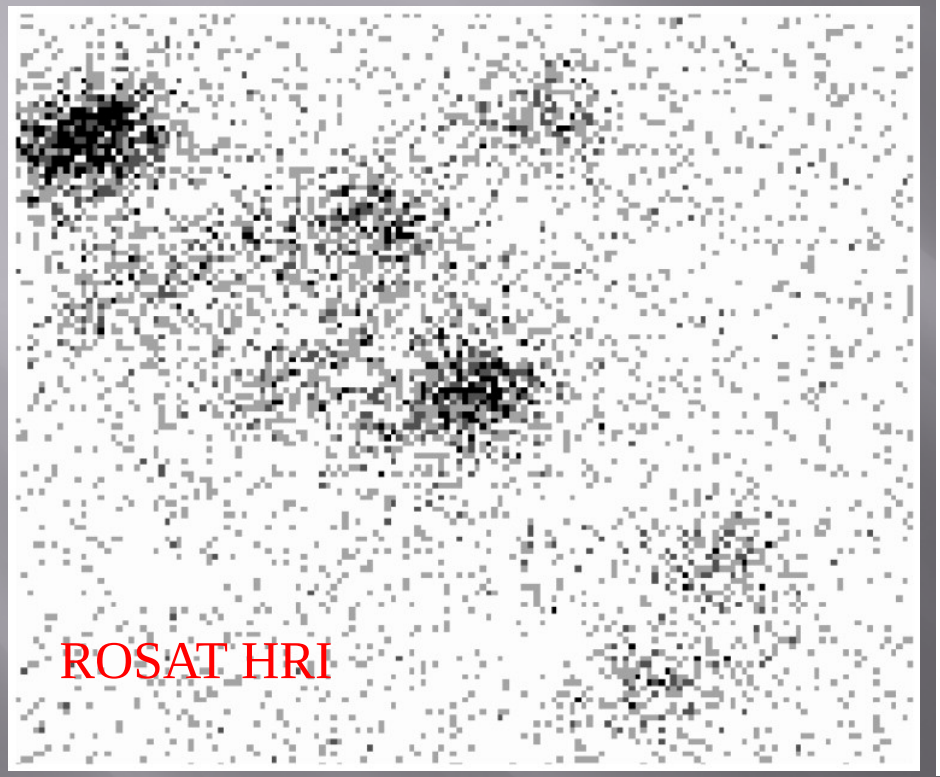


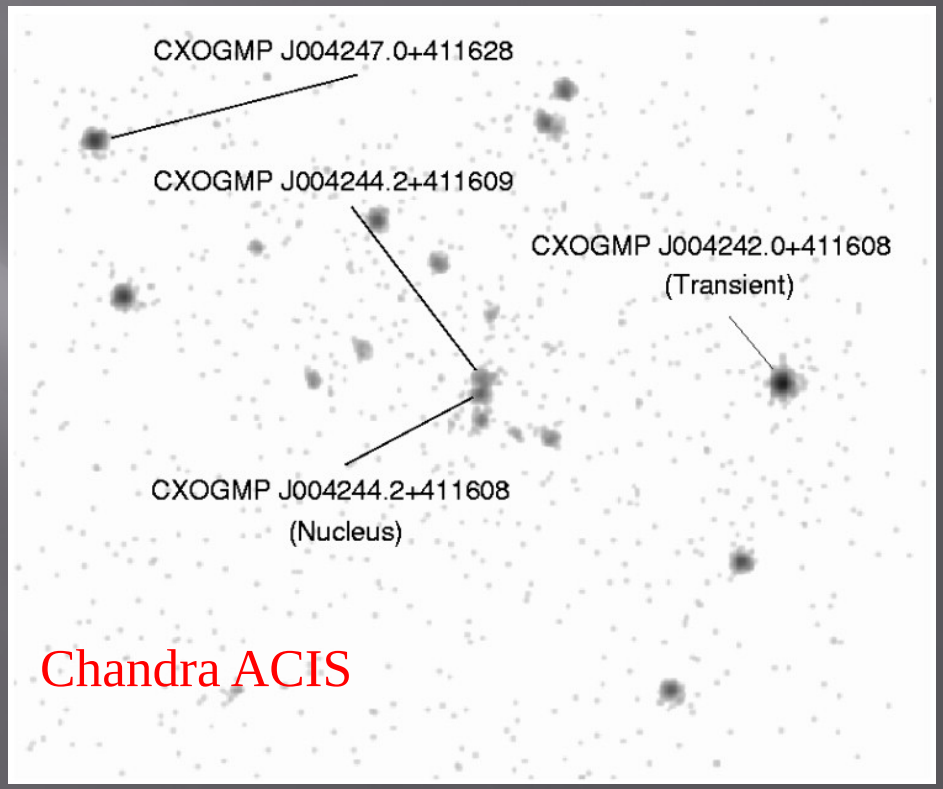



Launched on 1999 July 23 by Columbia

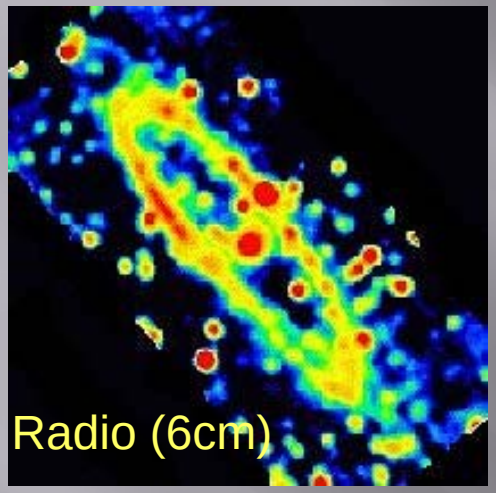
0.5” spatial resolution sensitive from 0.1-10 keV

# Spatial Resolution of Chandra (An example of M31)



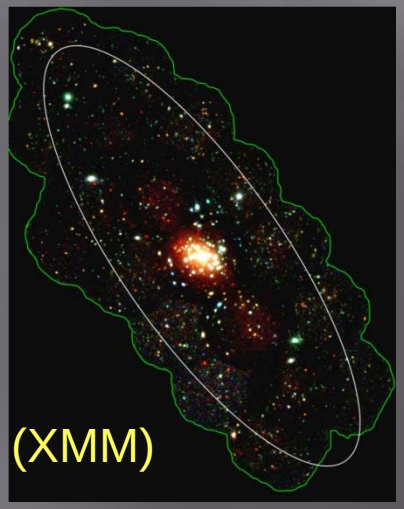



# Multiwavelength observations of M31

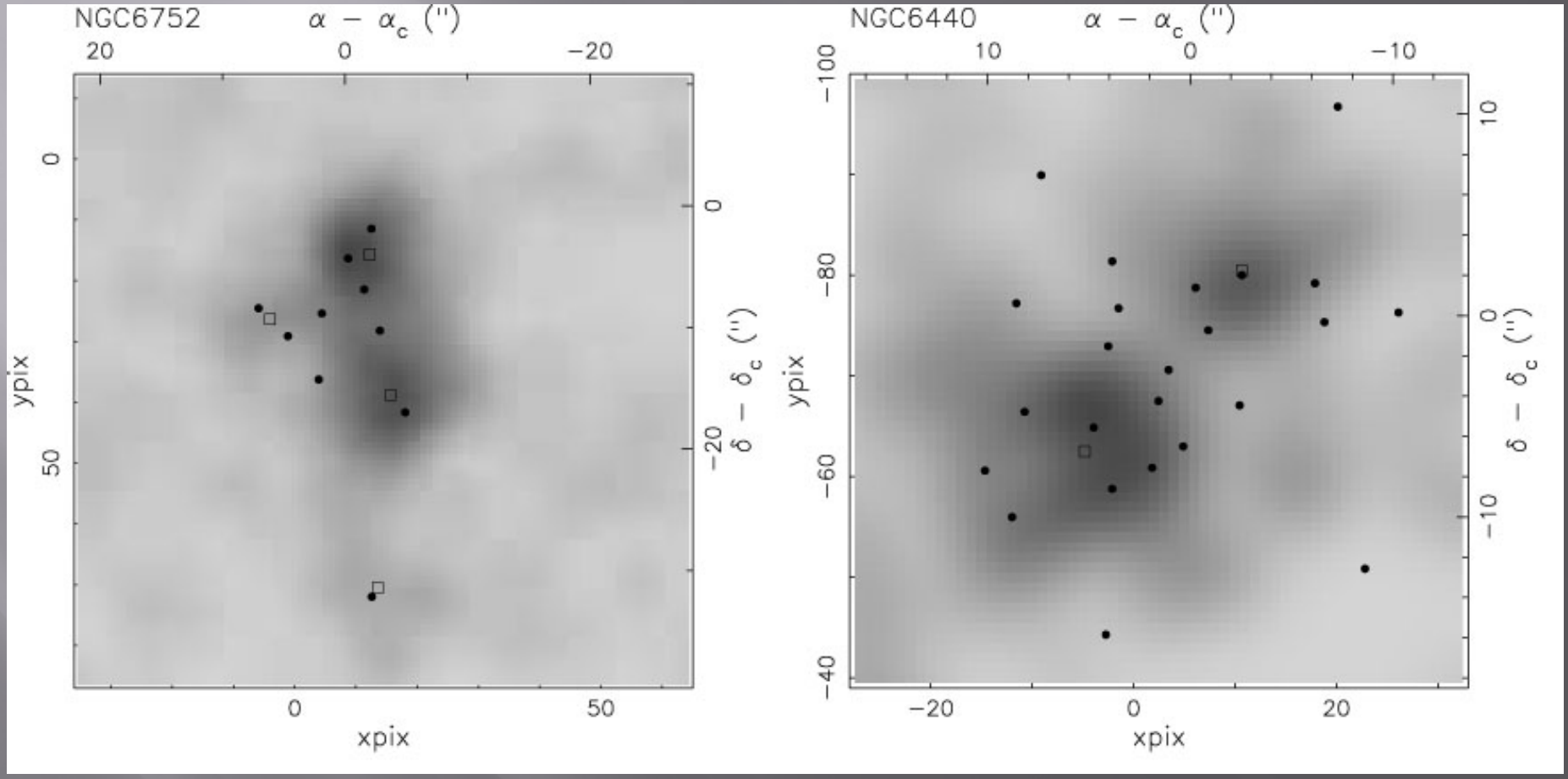




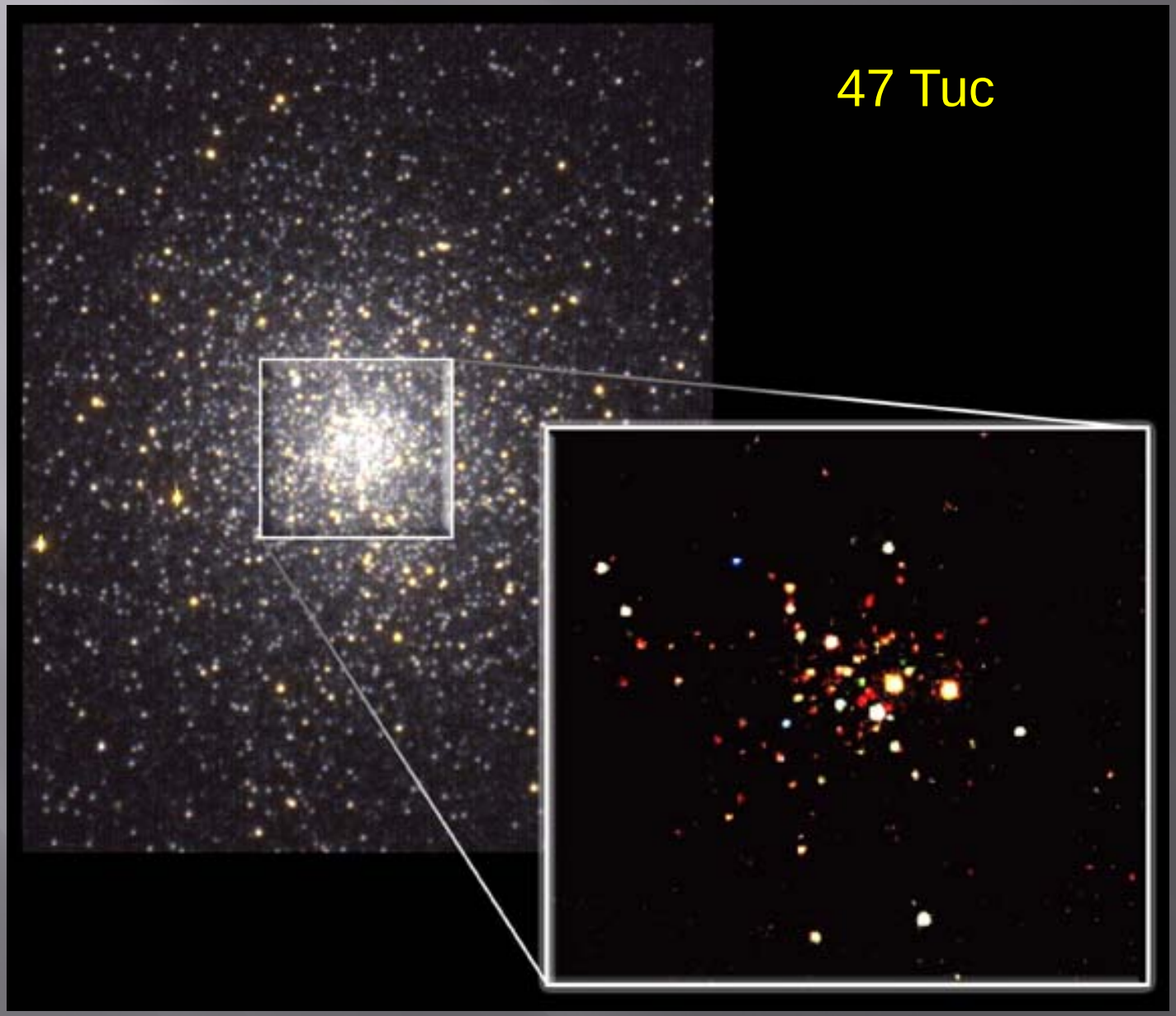




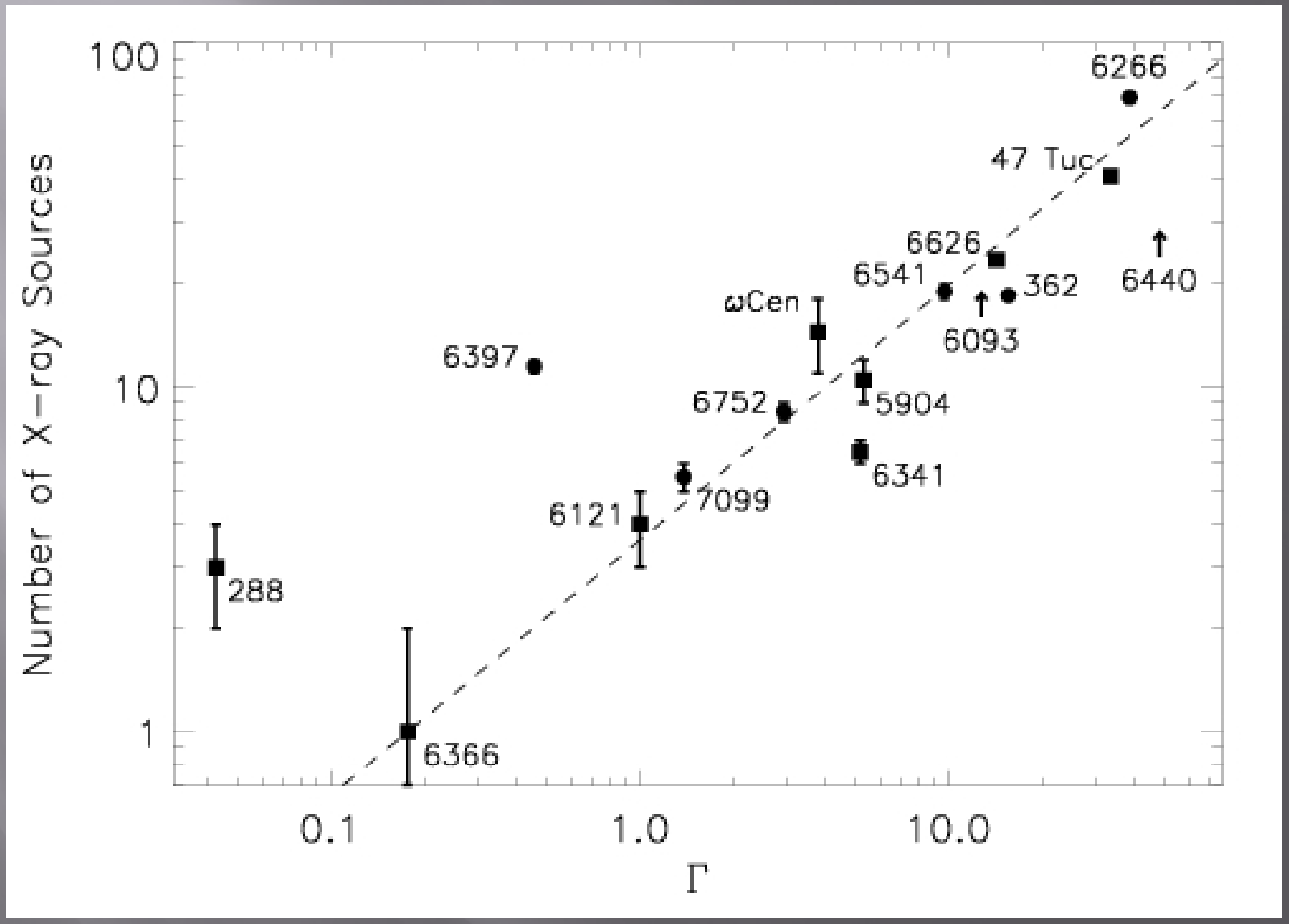
# Spatial Resolution of Chandra (Examples of GCs)



# Chandra Observations of GCs



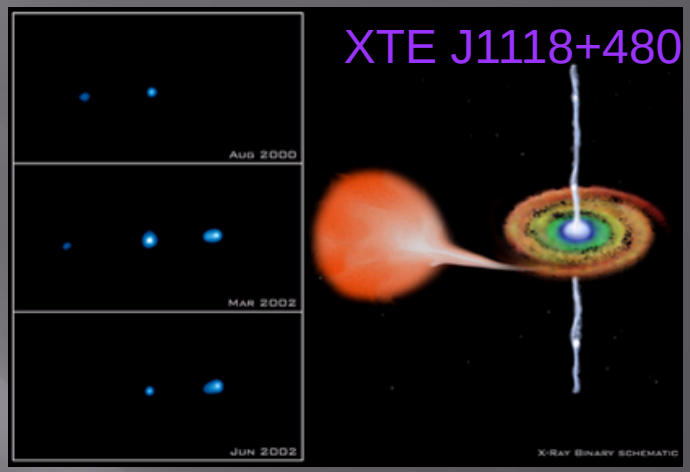
# Observational Evidence for Dynamical Formation of X-ray Sources in GCs

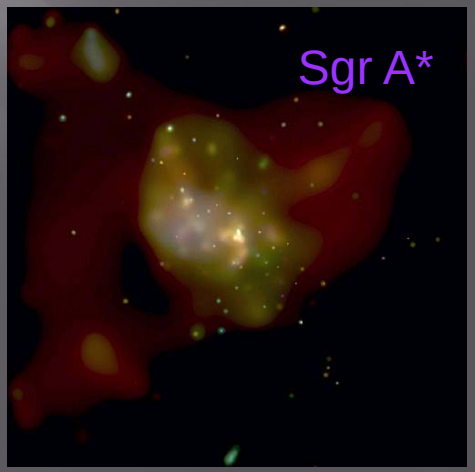


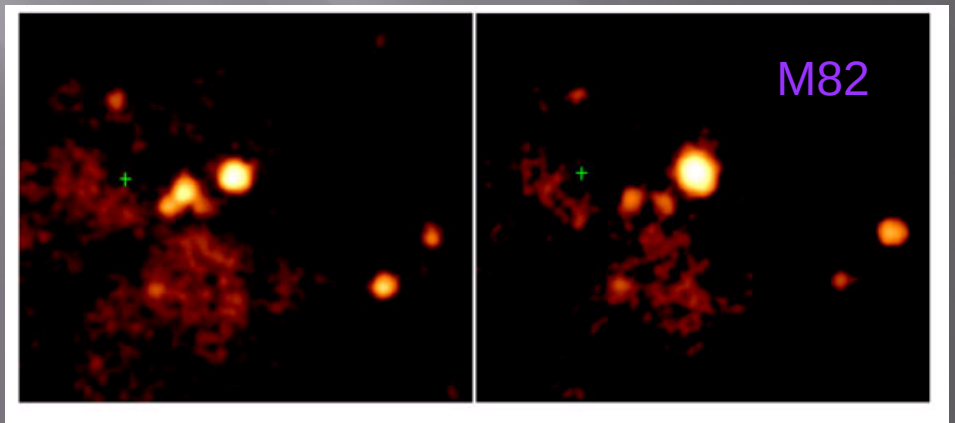

Updated after Pooley et al. 2003

# Classification of Black Holes

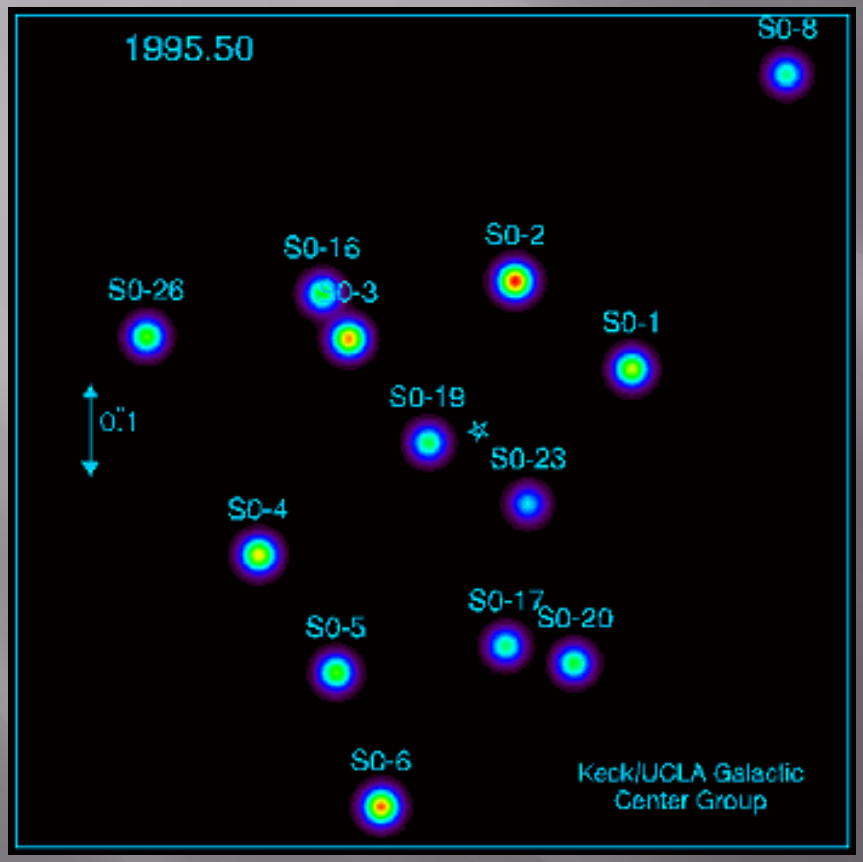
- Stellar-mass (~ 10 Solar)
- Supermassive ($10^6$-$10^9$ Solar) – Center of galaxies
- Intermediate-mass (~100-10000 Solar)

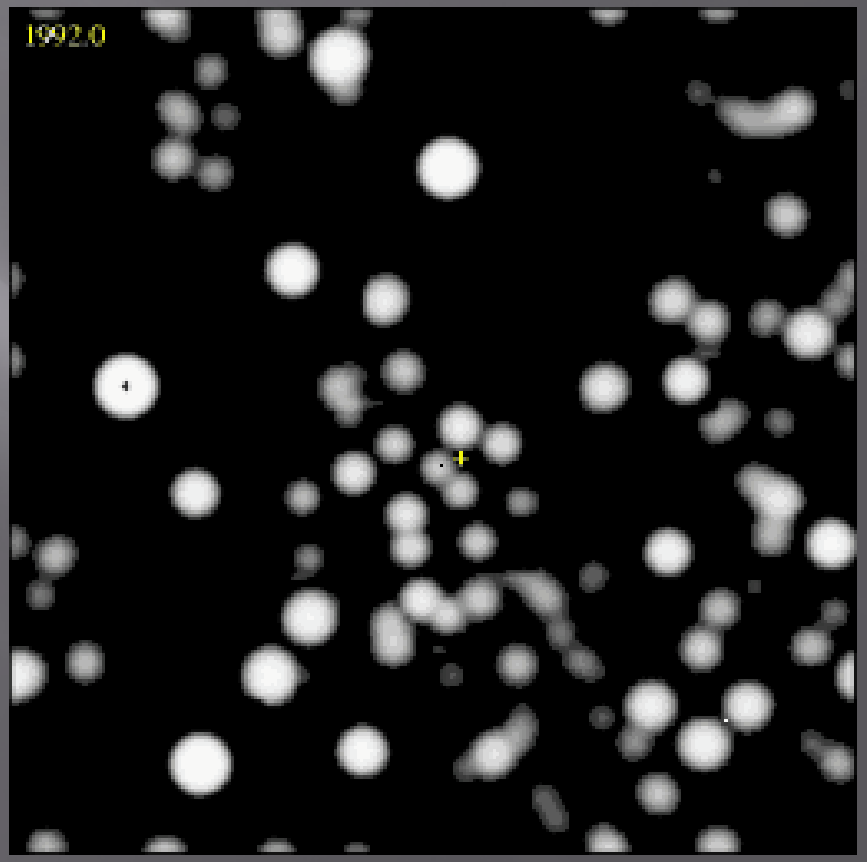


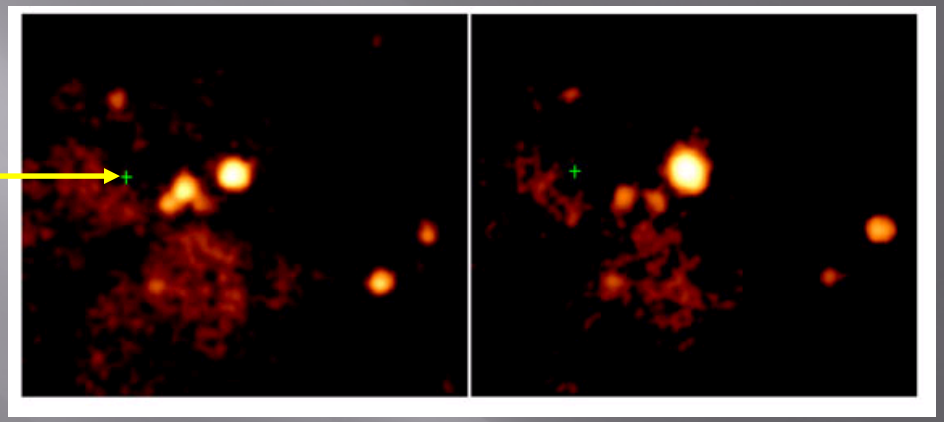



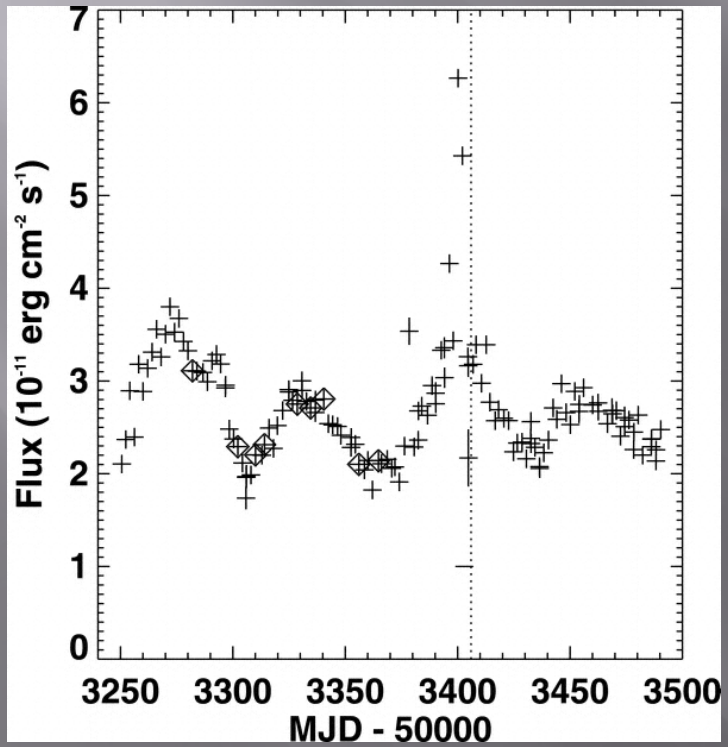
# Supermassive Black Hole at the Galactic Center



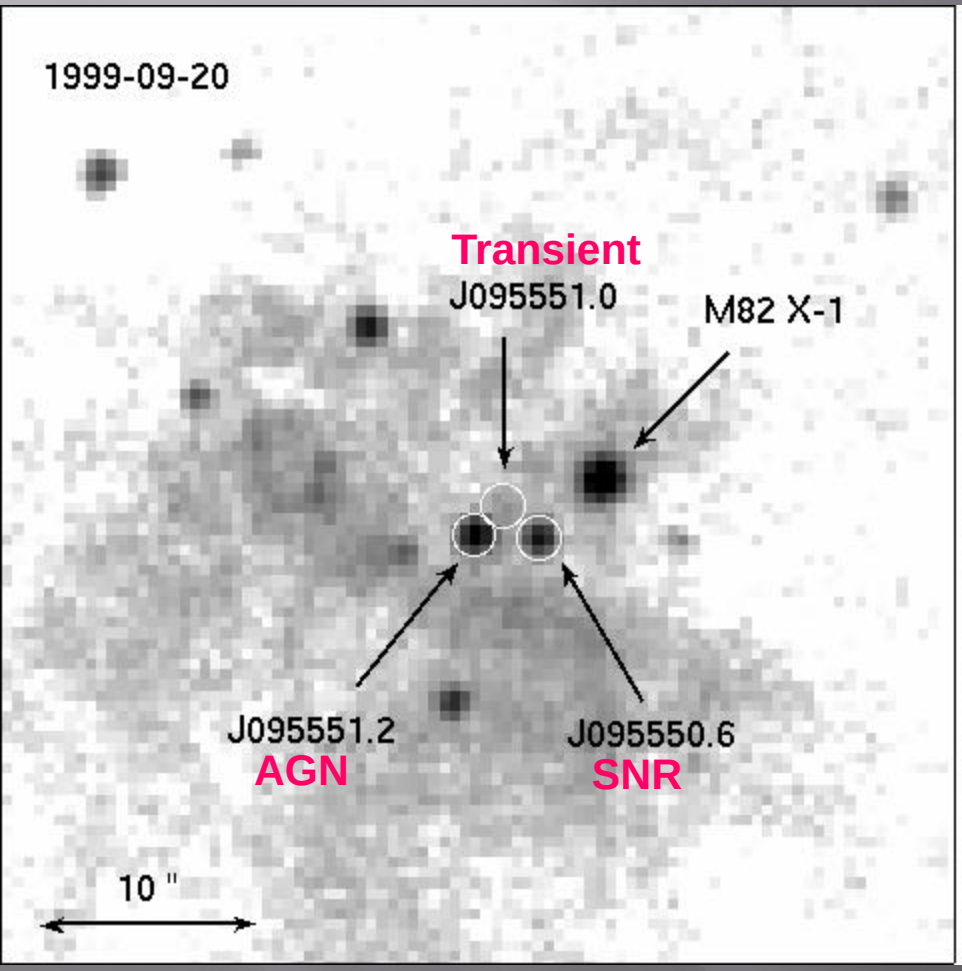
# The best IMBH candidate: M82 X-1

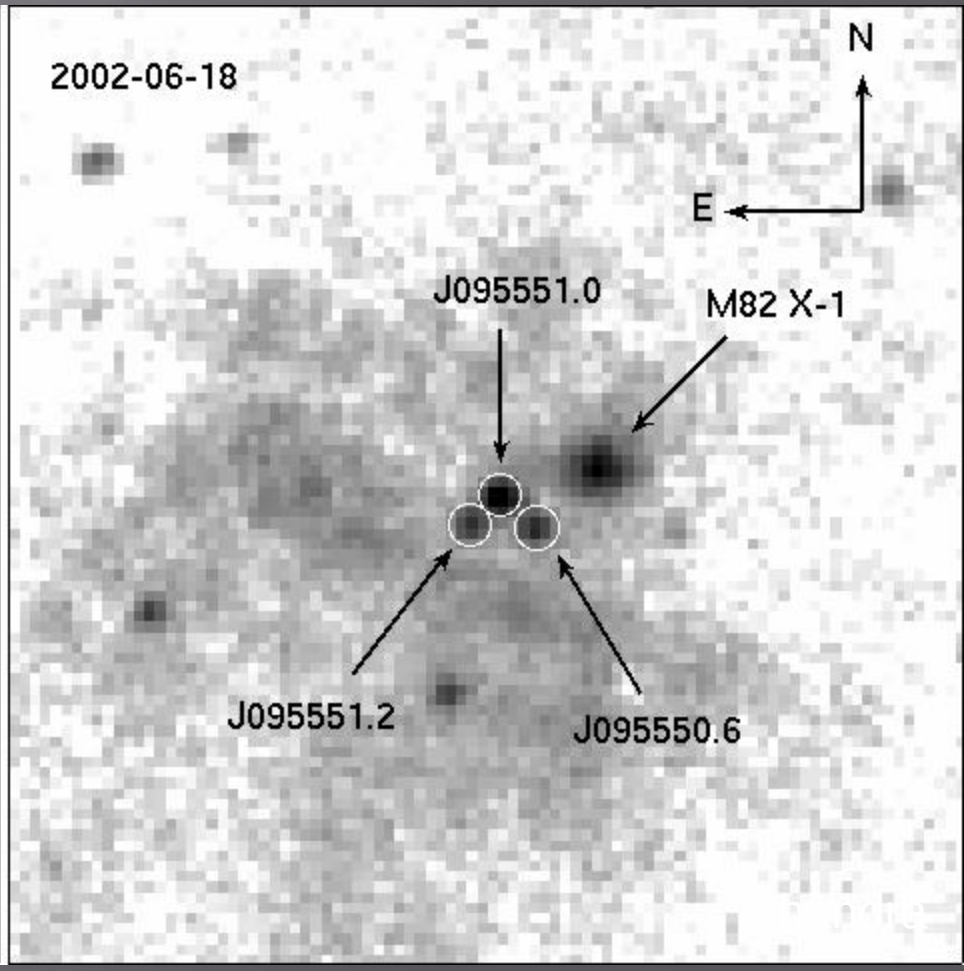


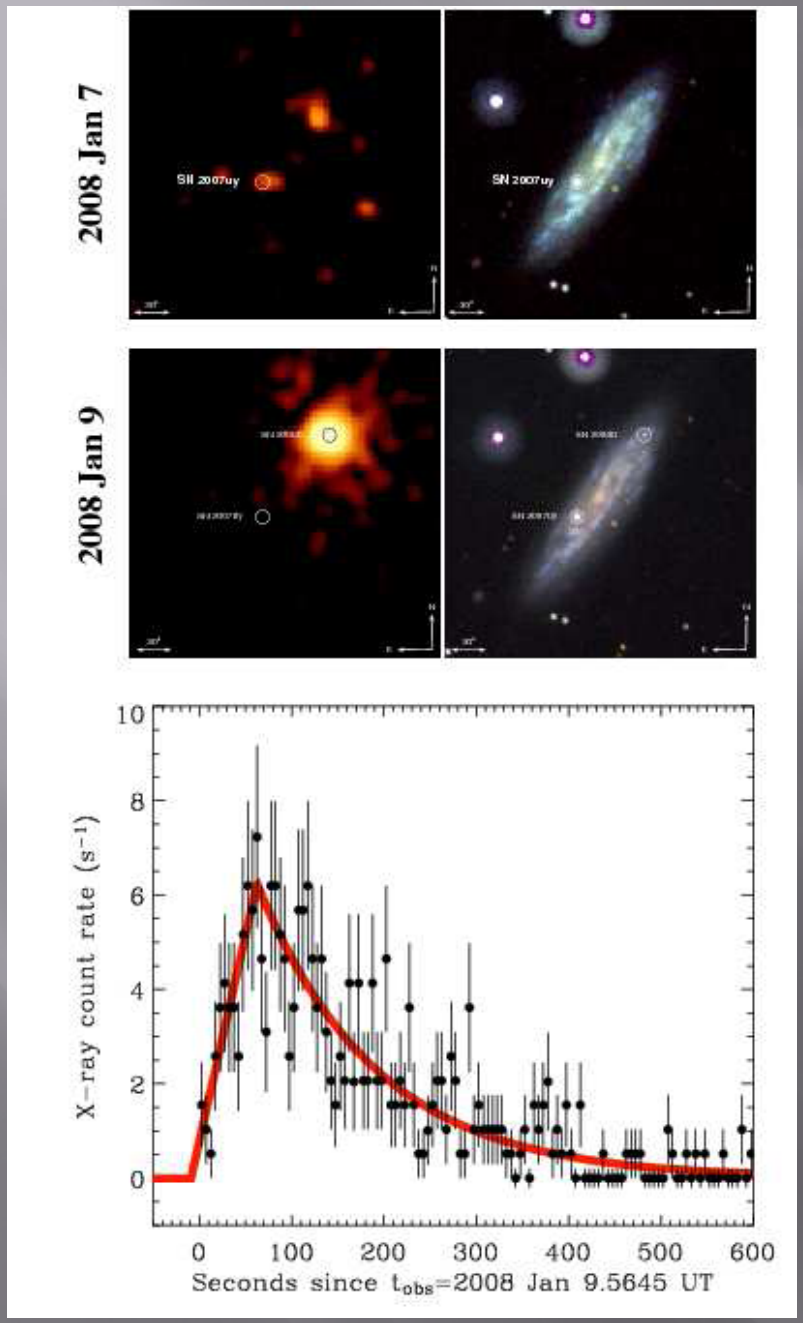

- Very luminous: ~$10^{41}$ erg/s
- Not at the galactic center
- 62-d periodicity; orbital period?
- 50-100 mHz QPO
- near a young cluster
- > 500 solar mass ?

# An Ultraluminous X-rayTransient in M82




Kong et al. 2007




# The birth of a supernova

- A very luminous X-ray outburst was found in the galaxy NGC2770 (d=27 Mpc) on 2008 Jan 9 (Berger et al. ATel#1353; Kong et al. ATel#1355) with Swift.
- The X-ray luminosity reaches $10^{43}$ erg/s but no gamma-ray emission.
- The X-ray outburst is the shock break-out from the compact object.
- We are watching a supernova at the time of explosion for the first time.

Soderberg et al. 2008, Nature, 2008 May 22 (astro-ph/0802.1712)