



Chandra: Revolution through Resolution

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The Chandra X-ray Observatory



Launched 5 years ago 23 July 1999

revolutionized X-ray astronomy,
and all of astronomy.

What is X-ray Astronomy?

What is Chandra?

Why has Chandra done its job so well?

And what exactly has Chandra done?

What is X-ray Astronomy?

When we look up at the night sky
we see it filled with stars

But,

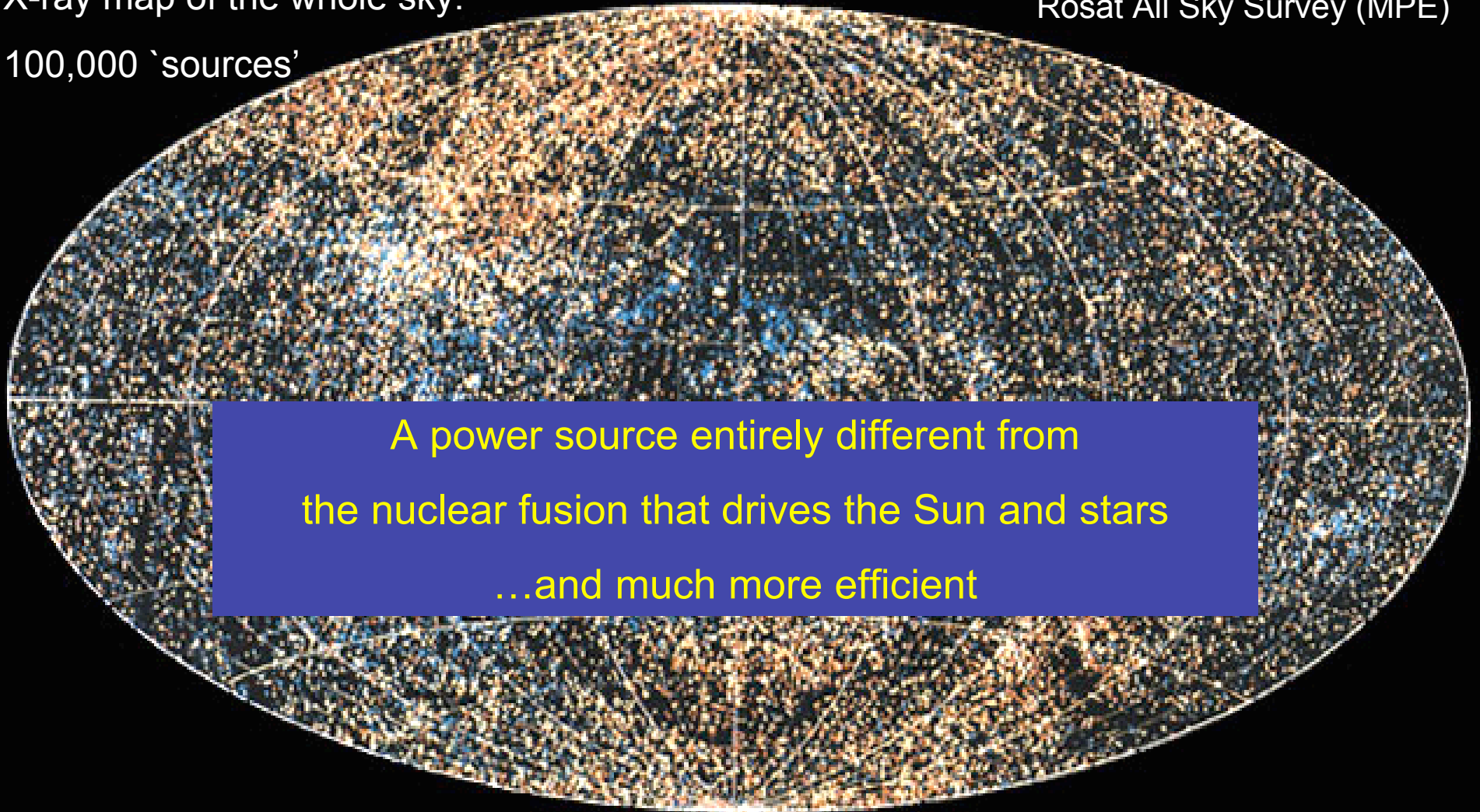
Outside the narrow range of colors
our eyes are sensitive to,
something quite different dominates
the night sky...

Powerful sources of X-rays

X-ray map of the whole sky:

Rosat All Sky Survey (MPE)

100,000 'sources'



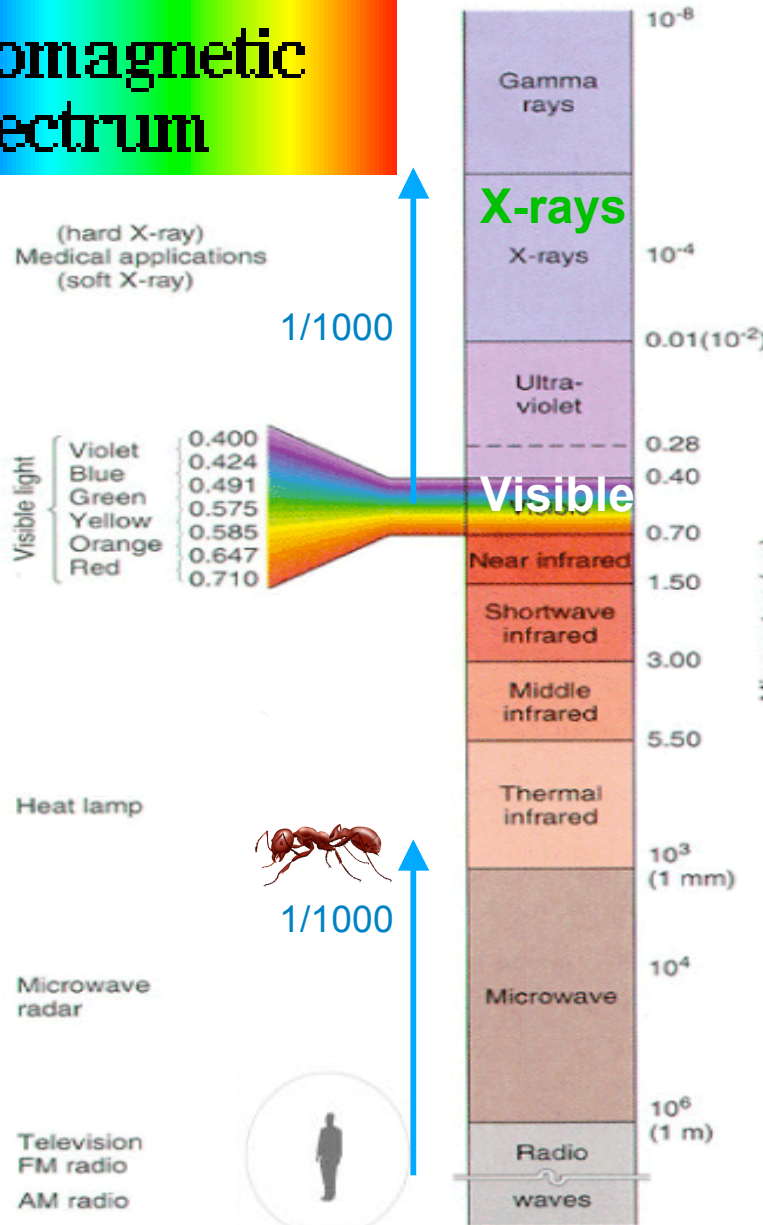
A power source entirely different from
the nuclear fusion that drives the Sun and stars
...and much more efficient

X-ray Astronomy tries to find out what could cause such extraordinary power

X-ray Astronomy studies the short wavelength light from the Universe

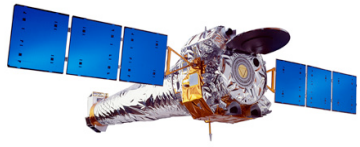
Electromagnetic Spectrum

**10^{15} range of wavelength in astronomy
 million billion between shortest & longest**

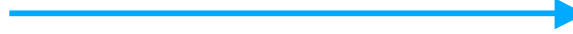


Source: Christopherson (2000) Geosystems

Whipple 10 meter
 Compton gamma-ray Observatory
 Chandra
 Hubble
 MMT
 Sub-millimeter array
 VLA

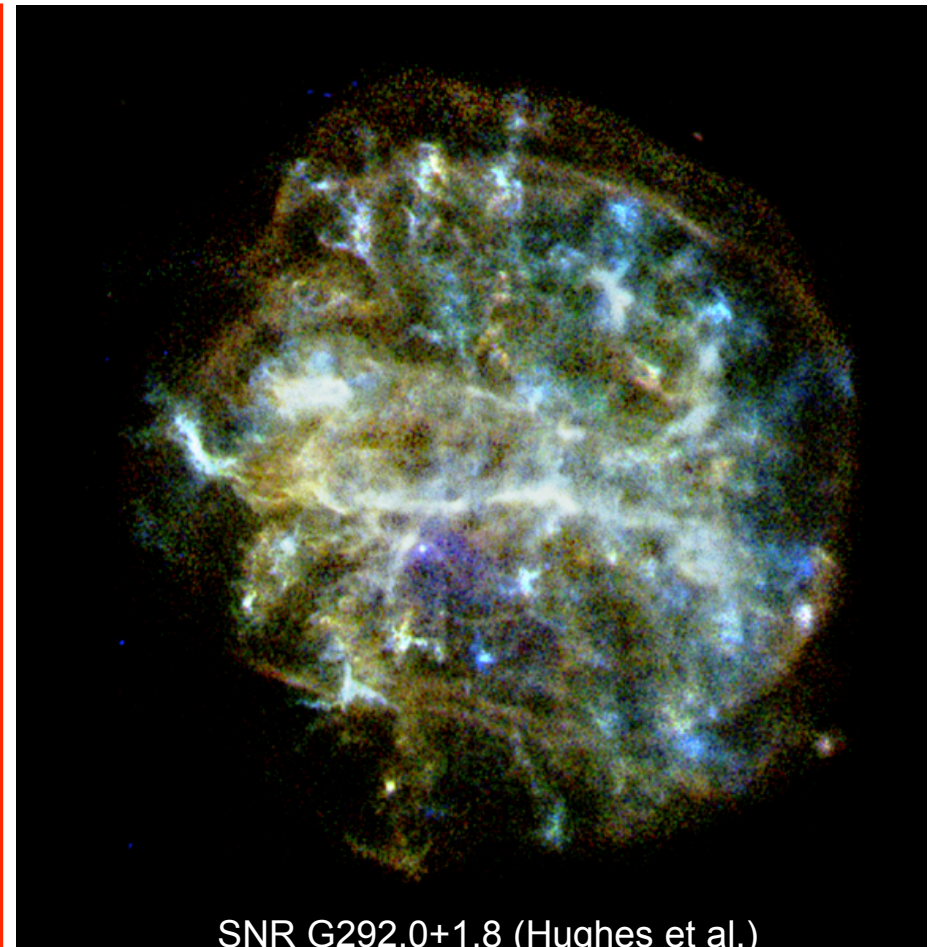


Compare Visible light and X-rays: “1000 times”

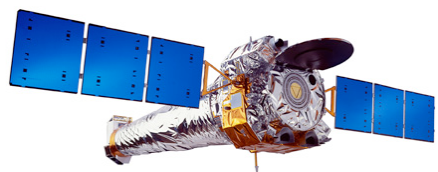


X-rays have:

- ❖ **Wavelengths: 1/1000 visible light**
 - ❖ 0.1-6 nm (1-60Å) vs. 500 nm (5000Å)
- ❖ **Energies: 1000 x visible light**
 - ❖ “keV” instead of “eV” (electron volts)
 - ❖ About 0.02 Joules/photon
- ❖ **Temperatures: 1000 times hotter**
 - ❖ 10 million degrees vs. 10 thousand degrees for stars
 - ❖ $E=kT$
(k = Boltzman’s constant, $1.398e-9$ J/K)



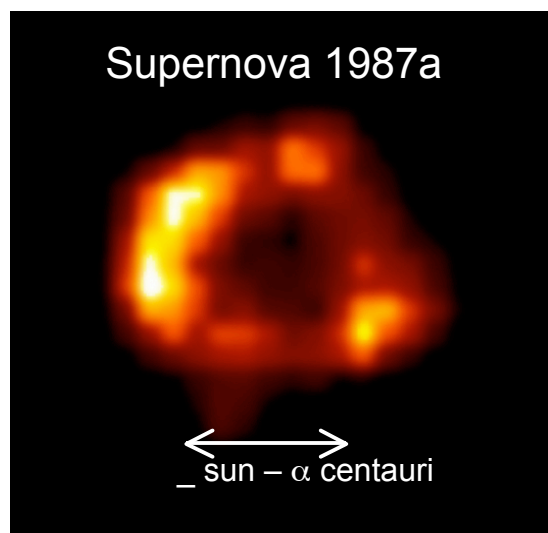
SNR G292.0+1.8 (Hughes et al.)



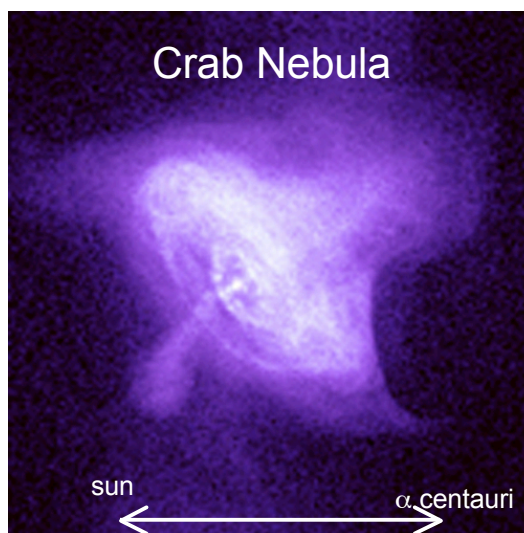
What gets so hot?

- Surely not much can get so hot as a million degrees?
- Oh yes it can...

Explosions: Supernovae and their remnants



Particles moving near the speed of light in magnetic fields



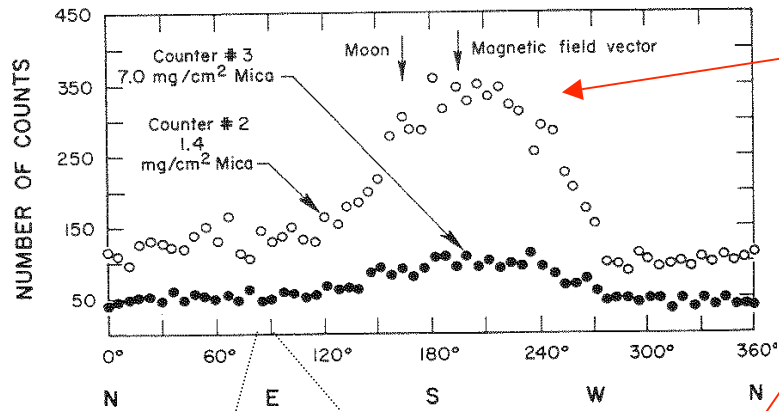
Matter falling into deep gravitational wells



Sounds obscure but ...

gravity power is the most common source of X-rays in the sky

40 Years of X-ray Astronomy: 1 billion times more sensitive

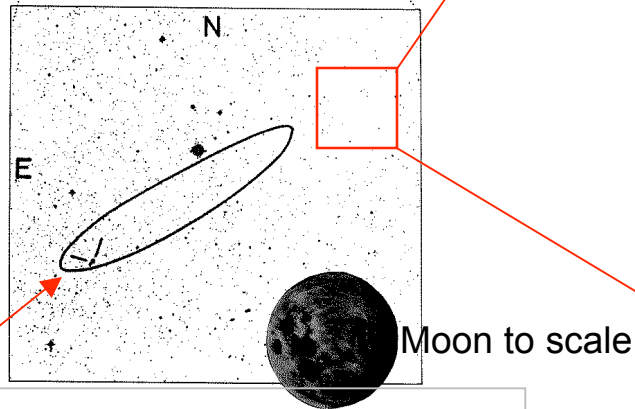


Sco X-1: the brightest source of X-rays in the sky

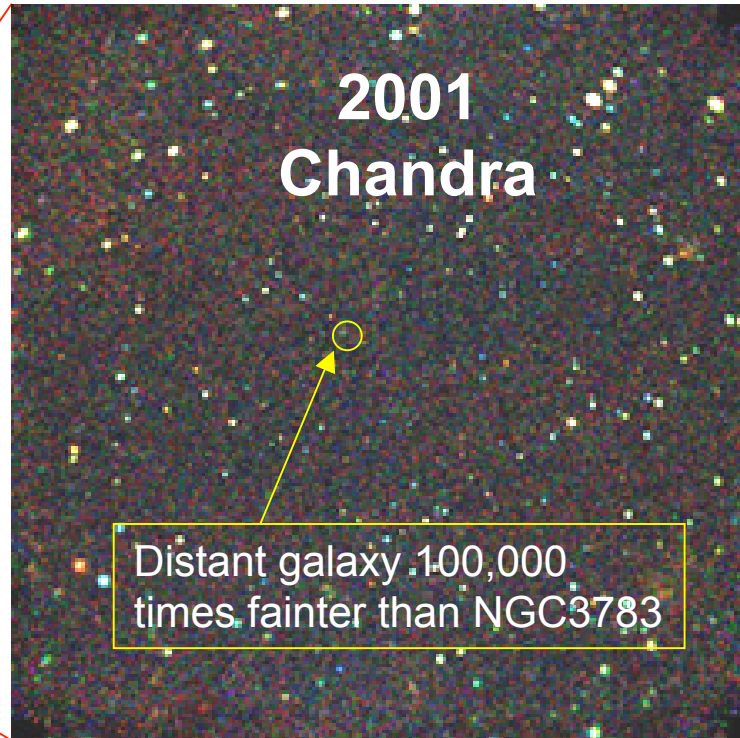
1962
Good for 1 (one) Nobel Prize

1978

good enough
for my thesis



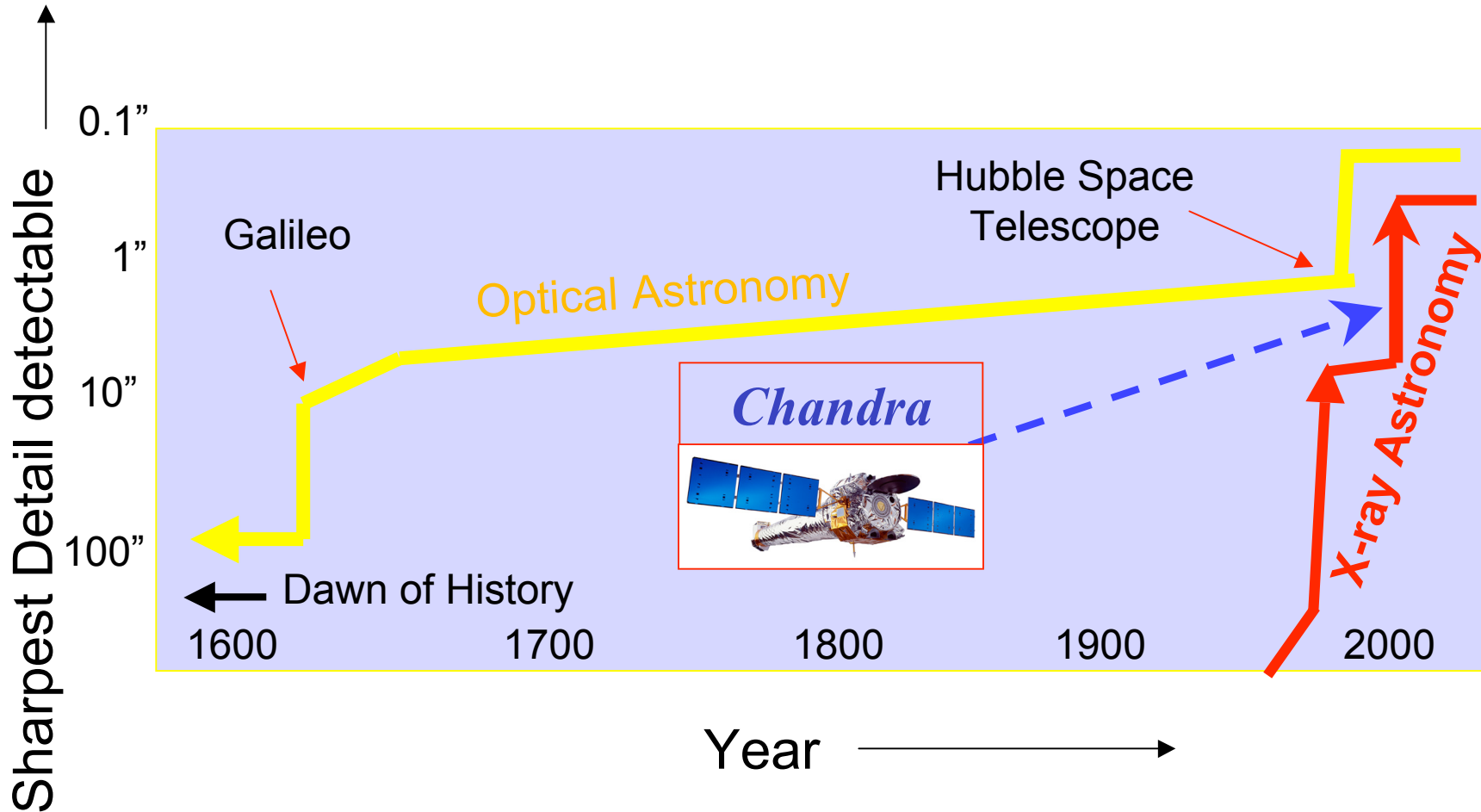
NGC3783: a quasar appearing
10,000 times fainter than Sco X-1



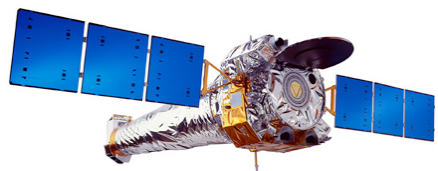
Distant galaxy 100,000
times fainter than NGC3783

Resolution is the key

Chandra takes X-ray Astronomy from its 'Galileo' era to its 'Hubble' era in a single leap



X-ray astronomy took just 40 years to match 400 years of optical astronomy



What is Chandra?

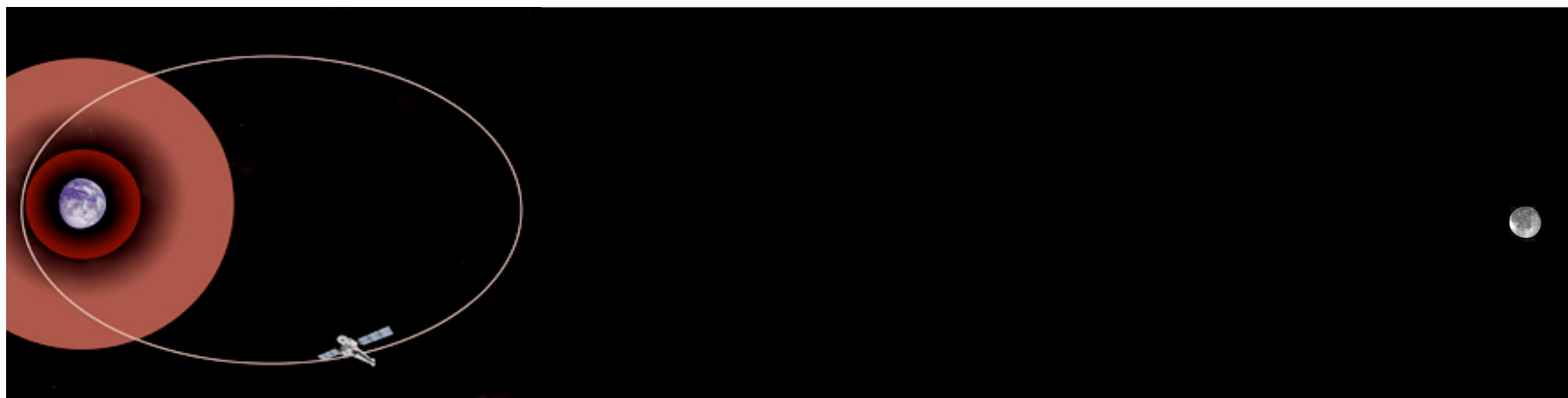
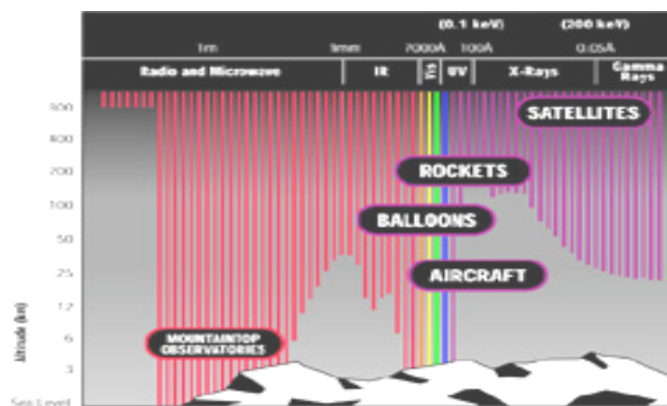
Chandra is the greatest X-ray Observatory ever built

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 ($2\frac{2}{3}$ days)

Chandra takes superbly sharp images:
'high resolution imaging'





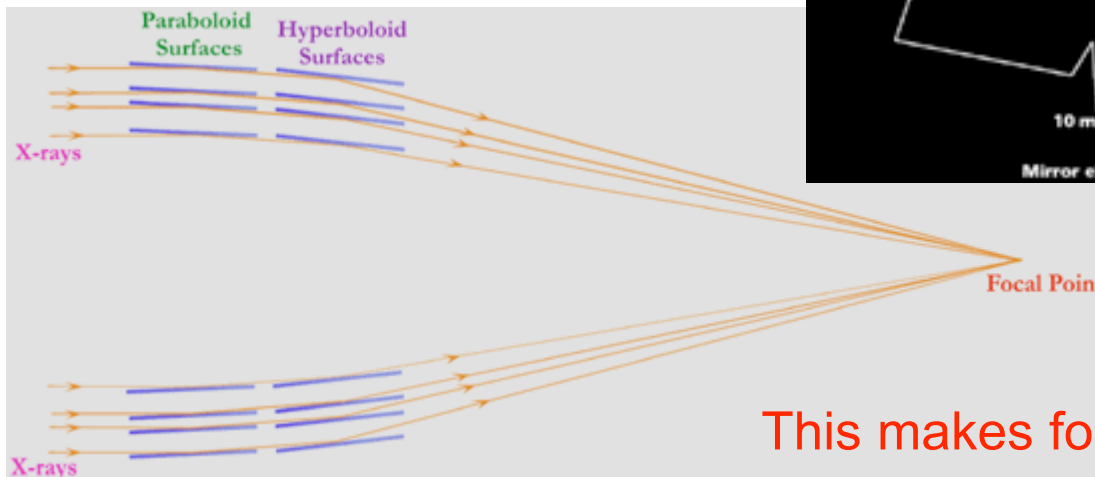
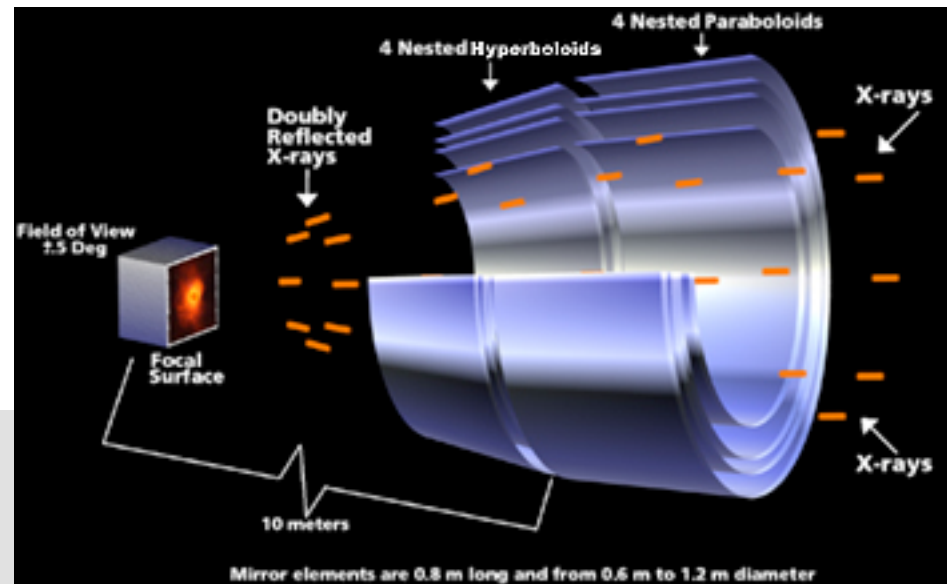
X-ray Telescopes are different

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.

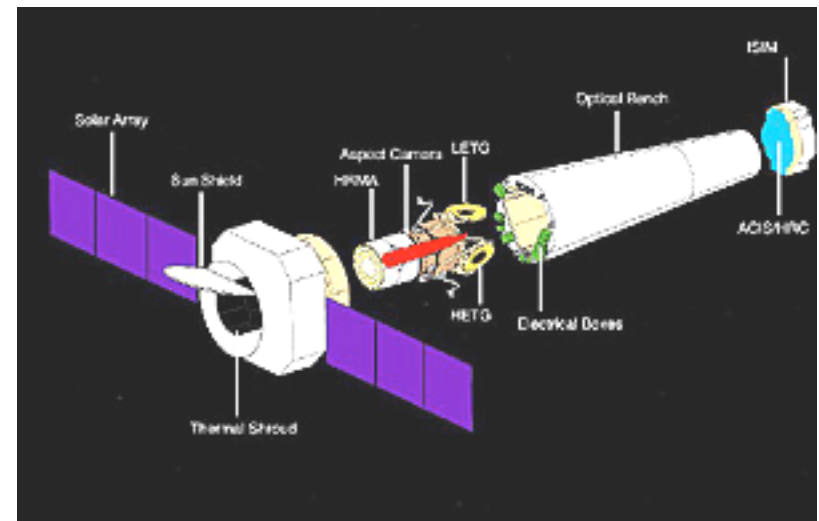
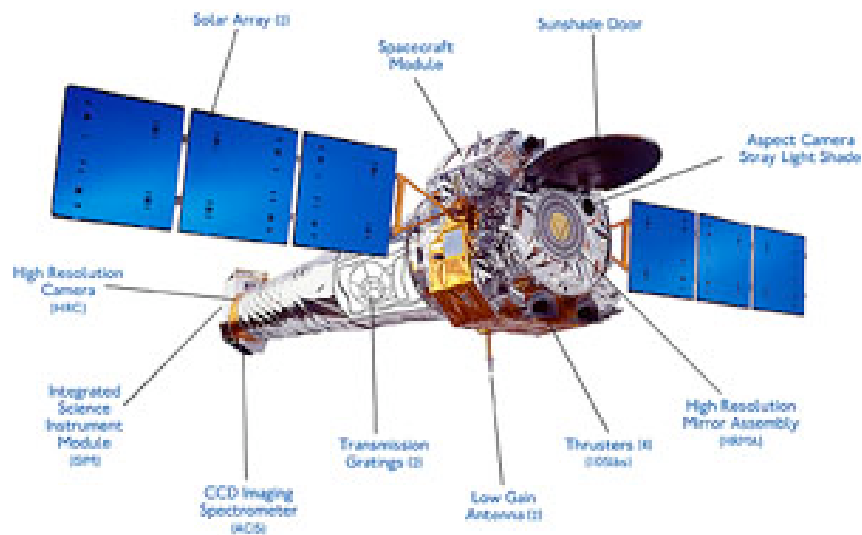
Then they act like visible light and can be focused



This makes for looooooong telescopes

Chandra is as big as a moving truck

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



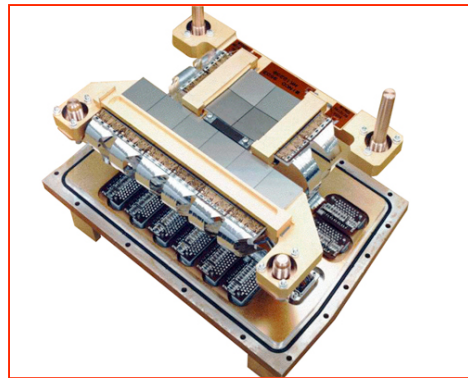
...but focuses X-rays onto a spot only 0.025mm (1/1000 inch) across

That's why Chandra is powerful

Chandra detects individual photons

Uses Wave-Particle Duality of Light

CCD detectors count each X-ray individually

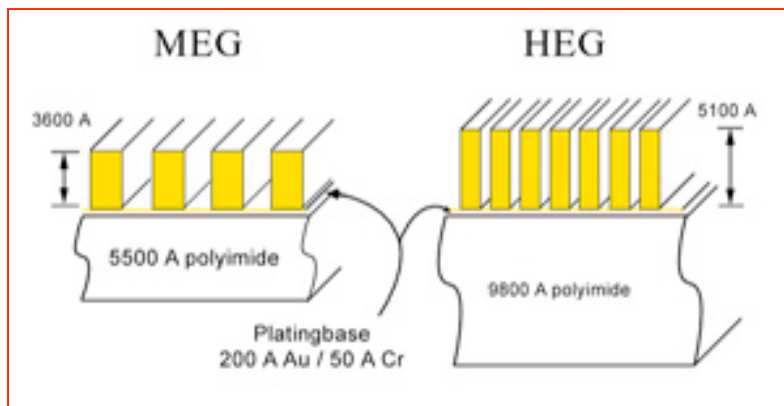


each X-ray knocks free enough electrons to detect as a pulse of electricity

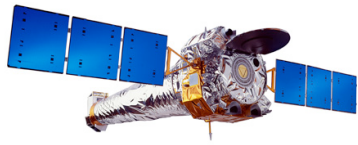
→ **Light as particles**

...but can disperse the incoming X-ray light: **Light as Waves**

Delicate gold gratings diffract the light



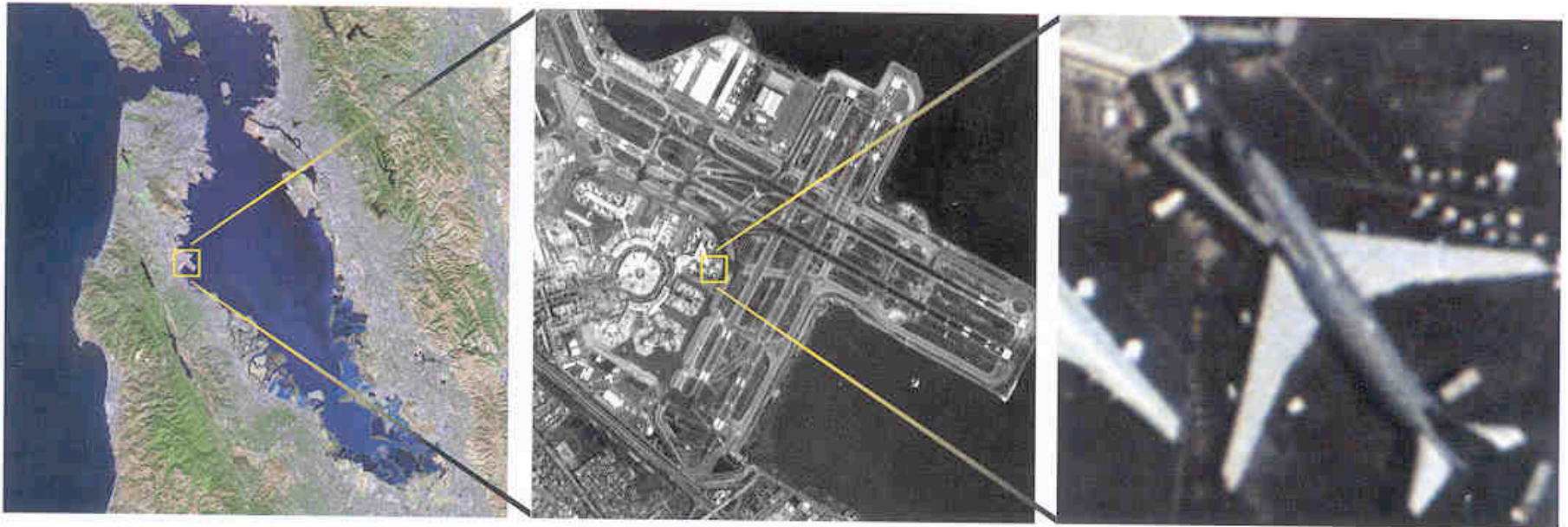
Chandra provides a great example of how *Quantum wave/particle duality* works in a real machine



Chandra's sharp focus revolutionizes our understanding

Earth observing satellite equivalents of ...

SPACE IMAGING



Best X-ray image of whole sky (ROSAT)

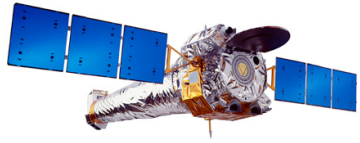
Any sign of life?

Best X-ray images before Chandra (ROSAT)

What's this odd thing?

Chandra images

I get it!



Like looking up the answers at the back of the book

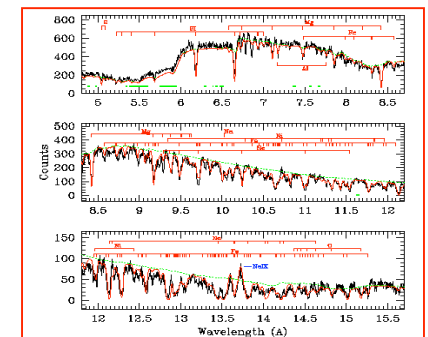
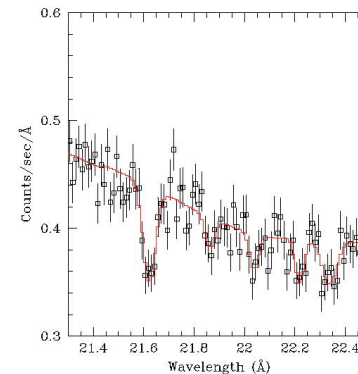
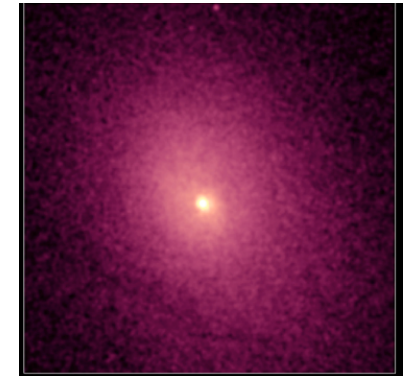
Chandra has solved 20 year old mysteries in just one shot:

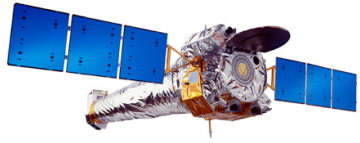
Yes – *the background X-ray light is made up of contributions from millions of quasars*

No – gas is not pouring down onto the galaxy at the center of a cluster of galaxies. Something stops it, but what?

Yes -- *Our Milky Way sits in a bath of hot gas stretching to the Andromeda galaxy and beyond*

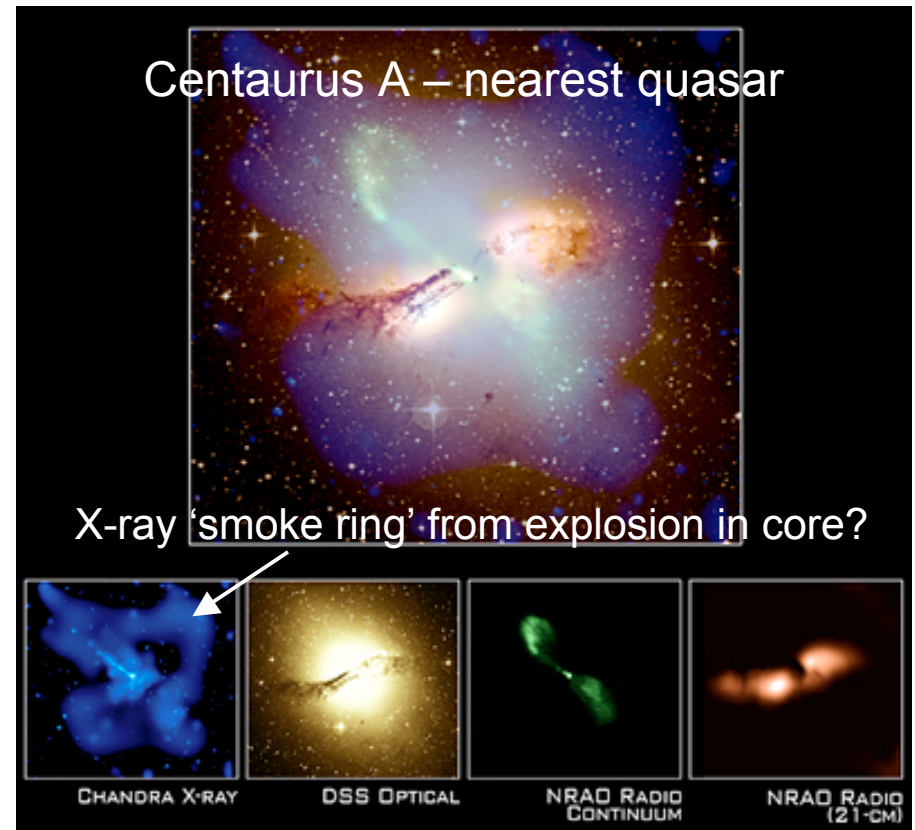
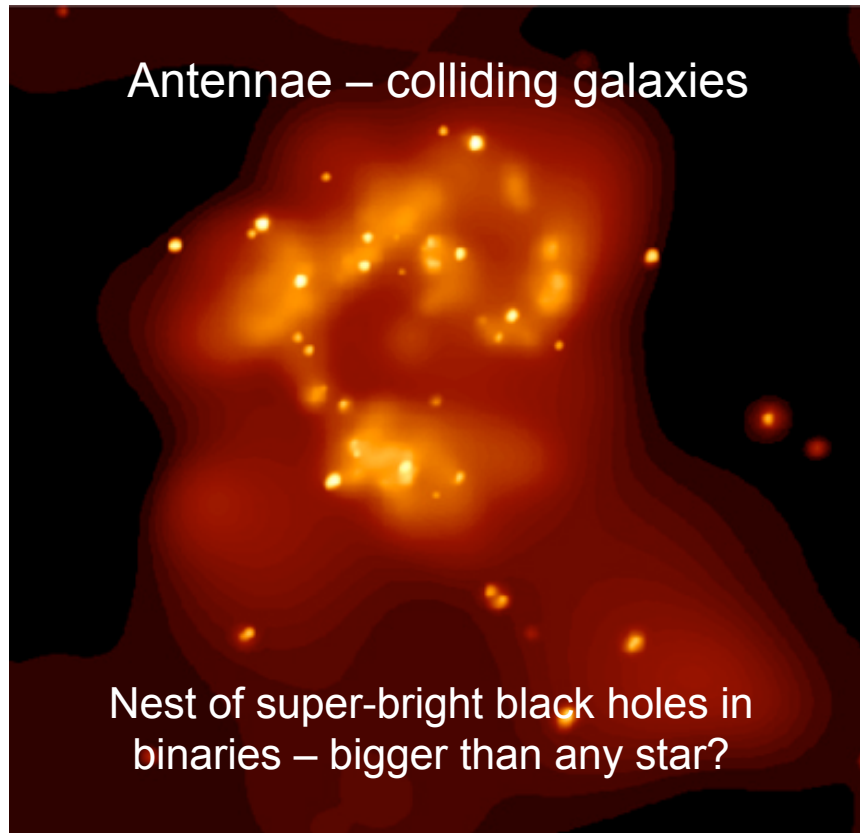
Yes – quasars have hot winds blowing from their cores, at 2 million miles per hour

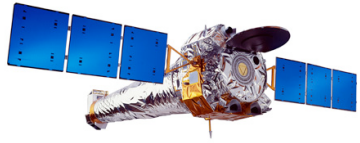




...but also being given a whole new SAT test, without taking the class

2 examples: What *are* we looking at?





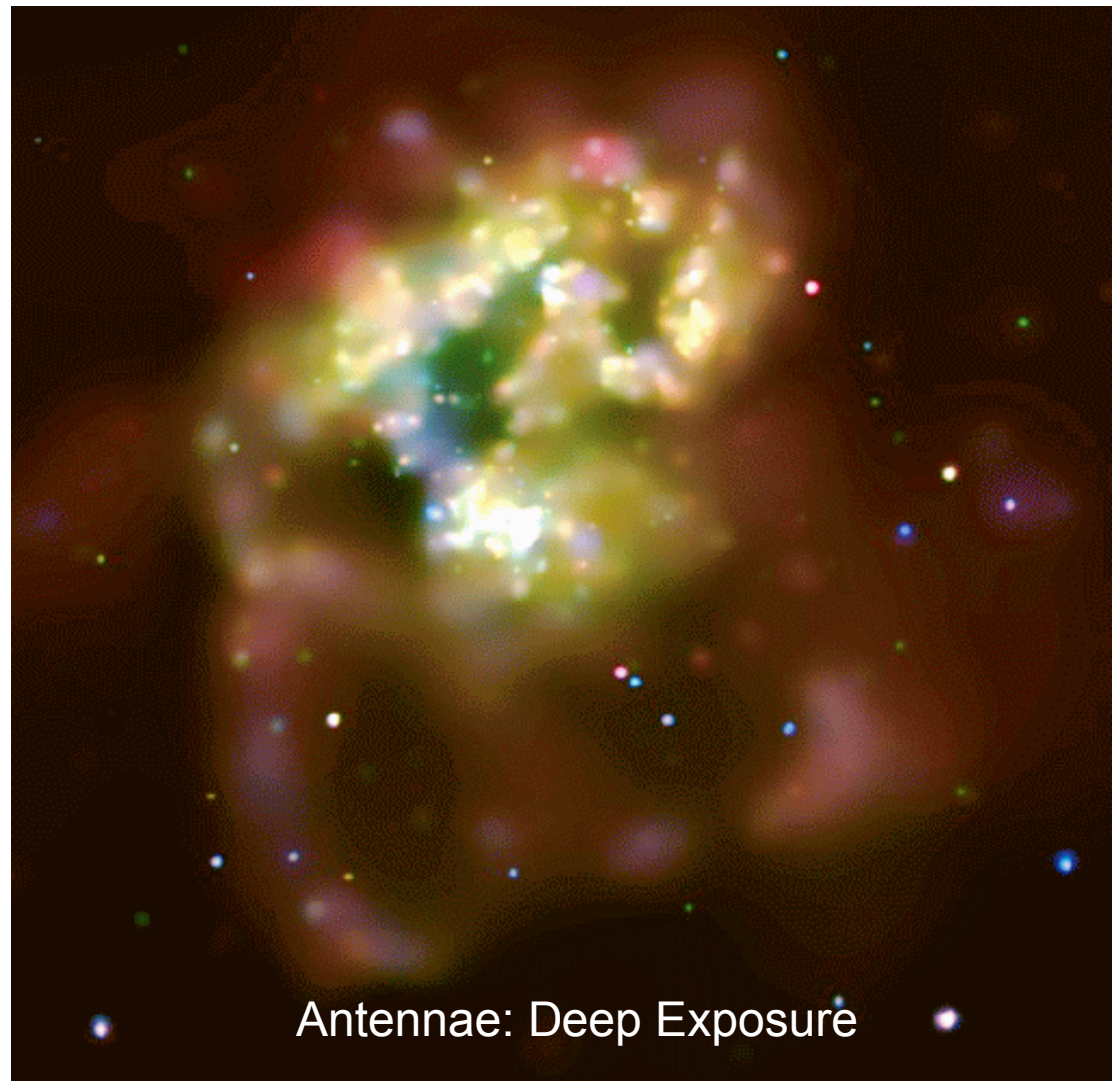
Chandra's Revolution through Resolution continues...

Chandra set to run for
5 more years

& may last much longer

Deeper looks show

- more and more detail,
- more and more surprises



Antennae: Deep Exposure