Astronomy in the Age of Space: Overview

Aneta Siemiginowska

Chandra X-ray Center

For Astrostatistic Working Group

OUTLINE

- What is astronomy?
  - different type of astronomical sources
- Astronomers Tools
  - how do we get basic information about the astrophysical source?
  - radio, IR, optical, X-ray and gamma-ray
- High Energy Sky
- Chandra X-ray Observatory
  - examples of typical X-ray data,
  - an example of a data analysis process
  - statistical challenges
  - what do we learn from the data?

What is Astronomy?

- Astronomy => "Law of the stars"

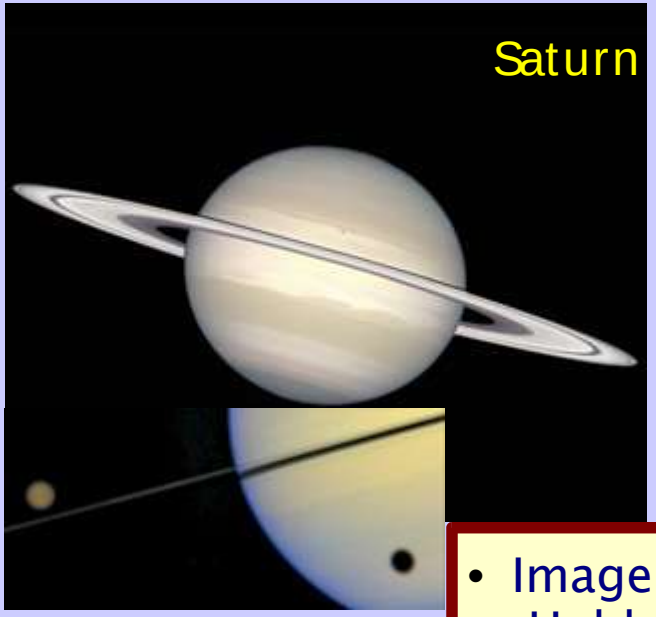
"Scientific studies of the Universe beyond the Earth involving observation, calculation and interpretation of the positions, dimensions, distribution, composition and evolution of celestial bodies and phemonena."

Webster's New College Dictionary

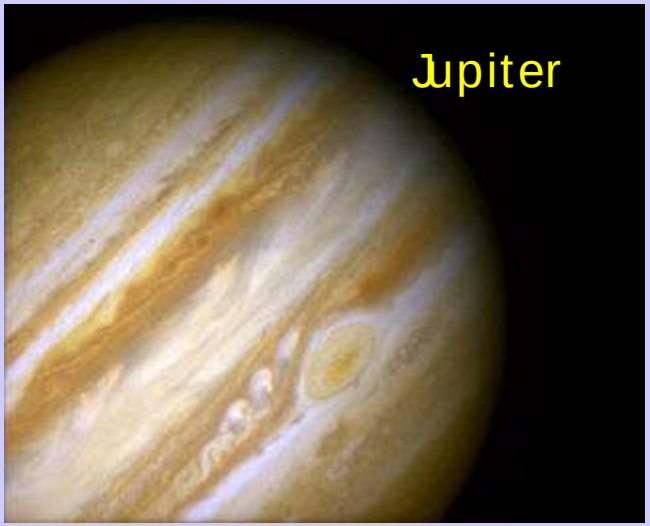
What type of celestial bodies and phenomena do we study and how?

- Solar System:
  - Sun and sollar wind, planets, moons, asteroids, comets
- Our Galaxy – Milky Way:
  - center, stars, binary systems, nebulae, supernovae
- Extragalactic Objects:
  - galaxies, active galaxies and quasars, clusters of galaxies, large scale structures
- the Universe:
  - intergalactic medium, background radiation

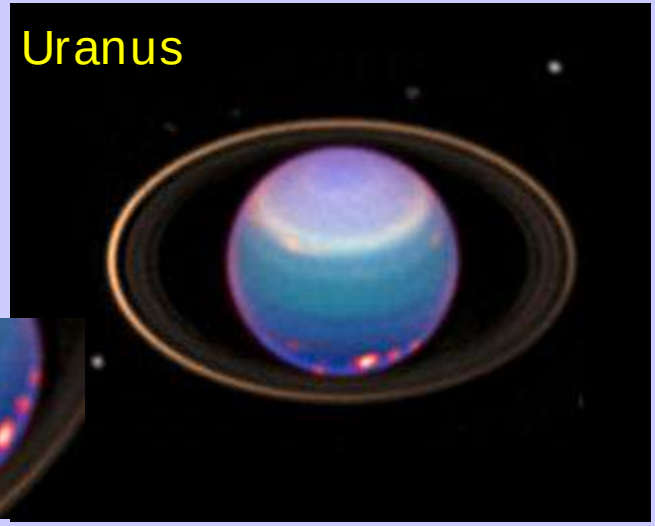
Solar System



Learn about our neighborhood!



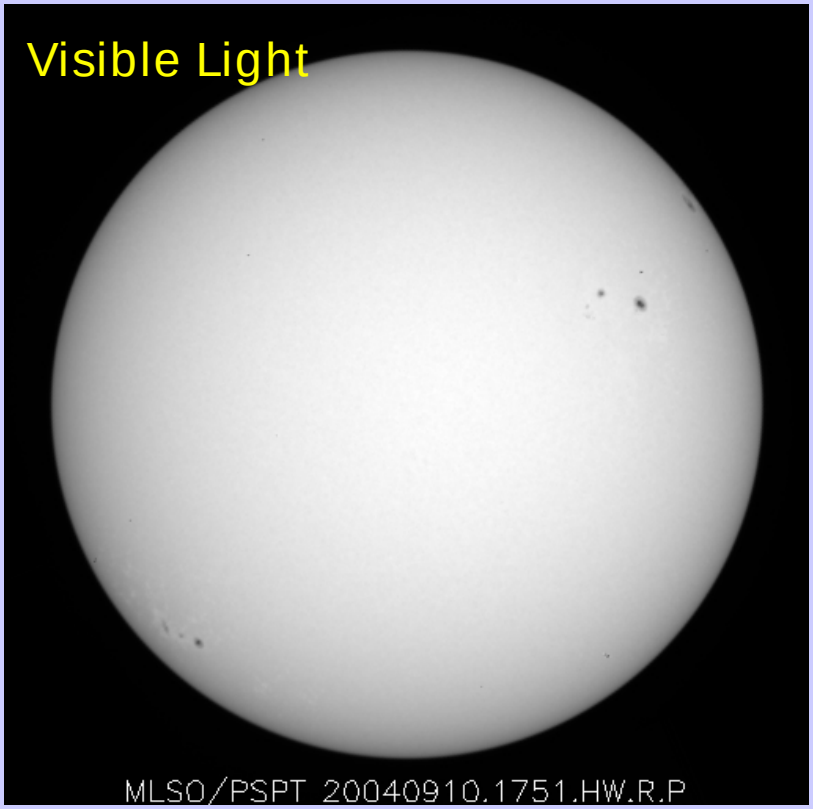
- Images of Planets from the Hubble Space Telescope
- Characteristics of planets, colors, composition,structure, environment, dynamics

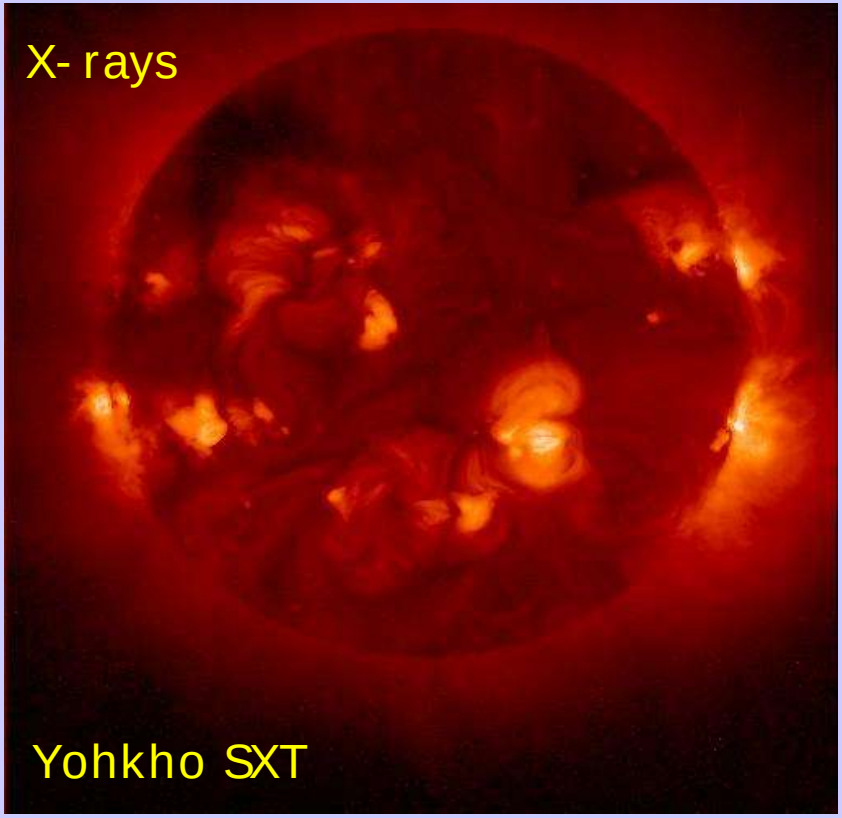


The SUN – the nearest star!

Very active object when observed in different wavelenghts!

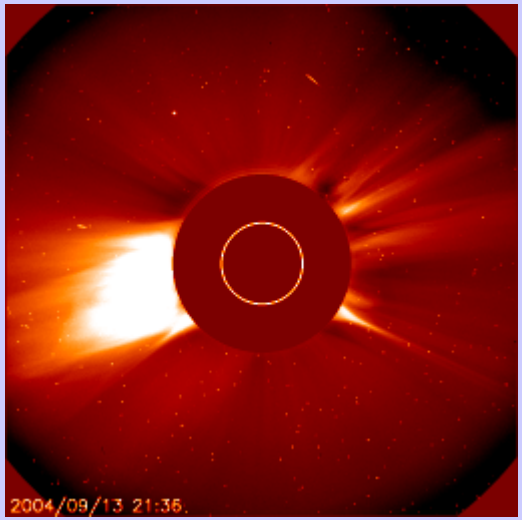
Mauna Loa Observatory – optical photometry



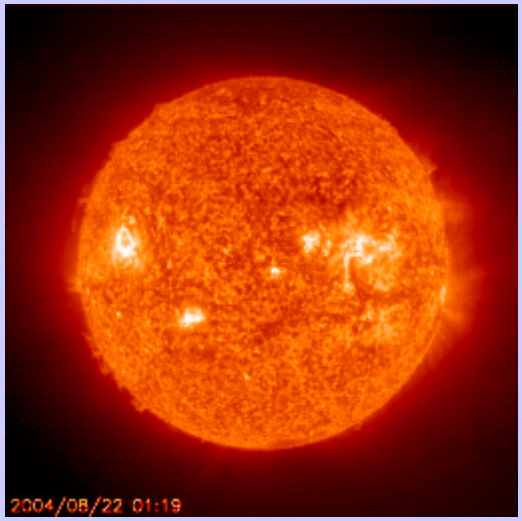


SUN is very active!

Coronal Mass Ejections



Rotating Sun
shows active regions



Images from SOHO (Solar & Heliospheric Observatory)

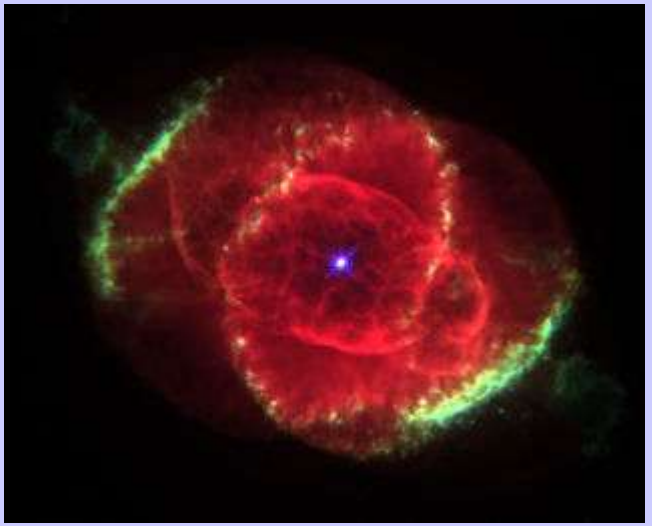
The Galaxy – Milky Way

Spiral Galaxy – similar to Milky Way

Stars and Star Clusters

M80- the densest star cluster in Milky Way

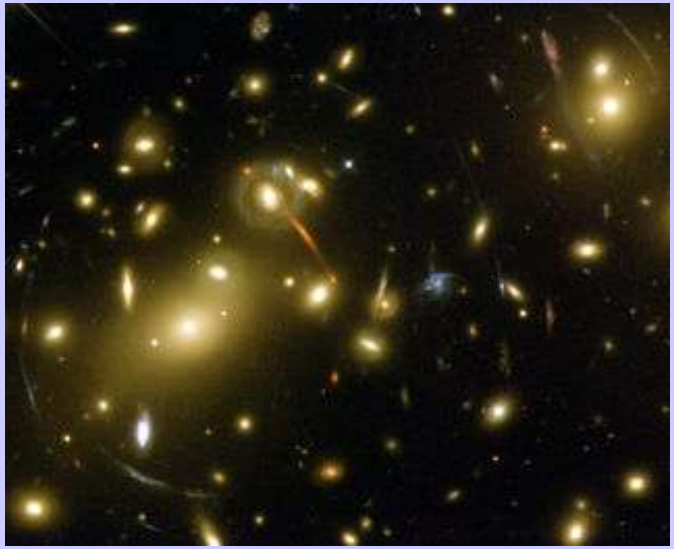
Nebulae



Cat's Eye Nebula

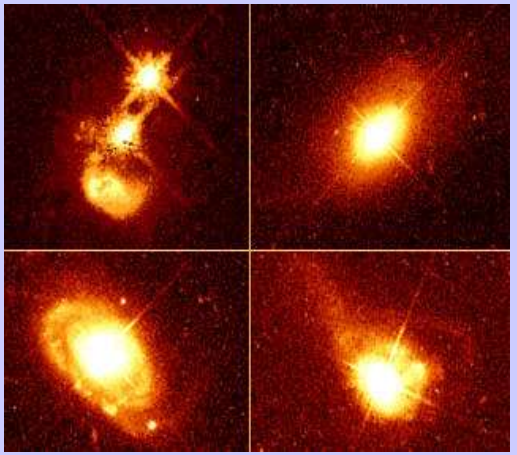
Extragalactic Objects

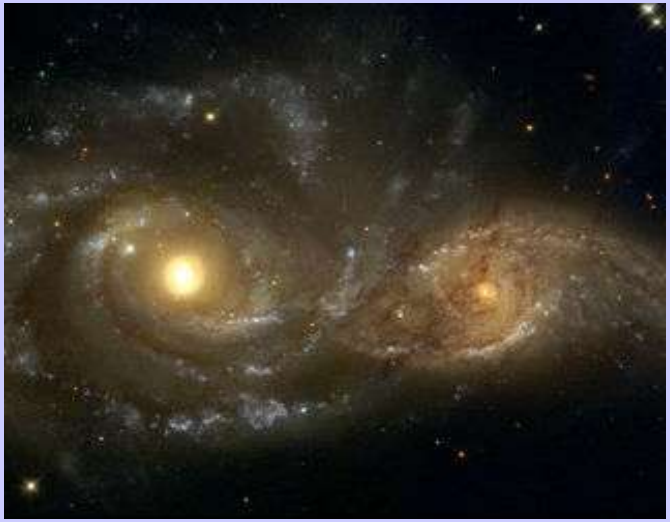
Optical Images from
Hubble Space Telescope



Cluster of Galaxies

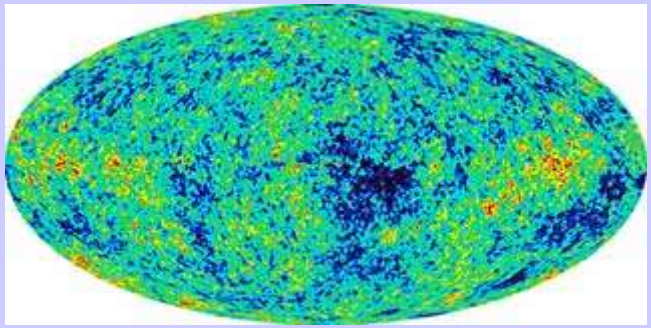
Active Galaxies and Quasars



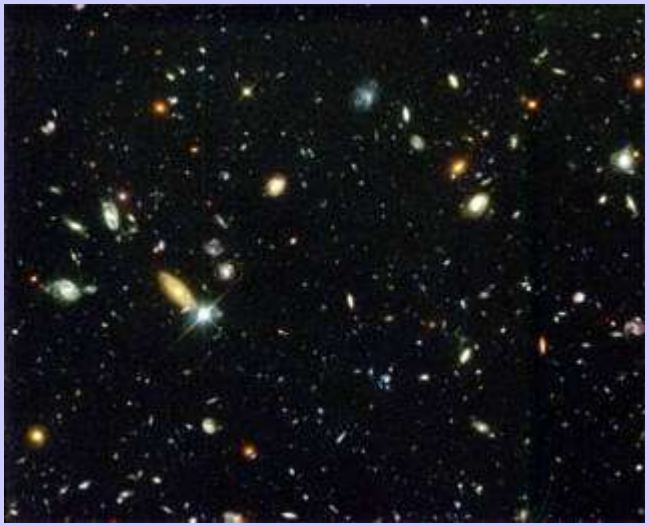


Interacting galaxies

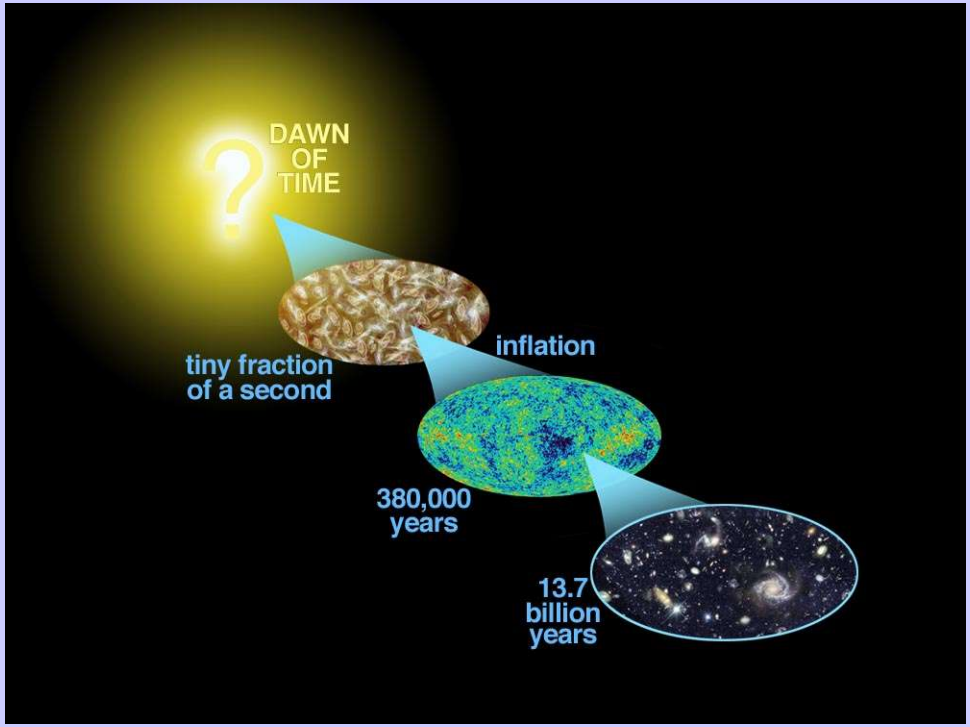
Universe



WMAP image of temperature fluctuations in the Cosmic Microwave Background radiation.



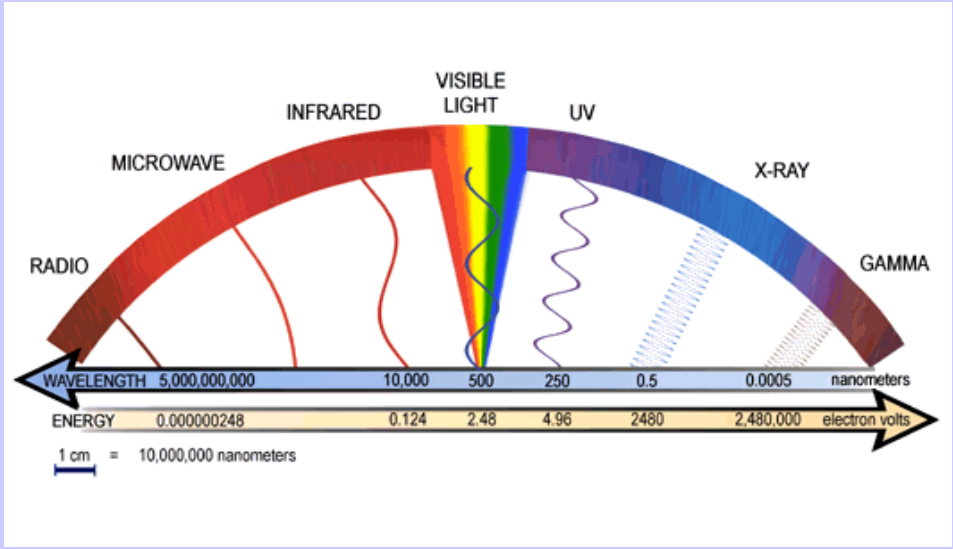
Galaxies in Hubble Deep Field - Optical Image

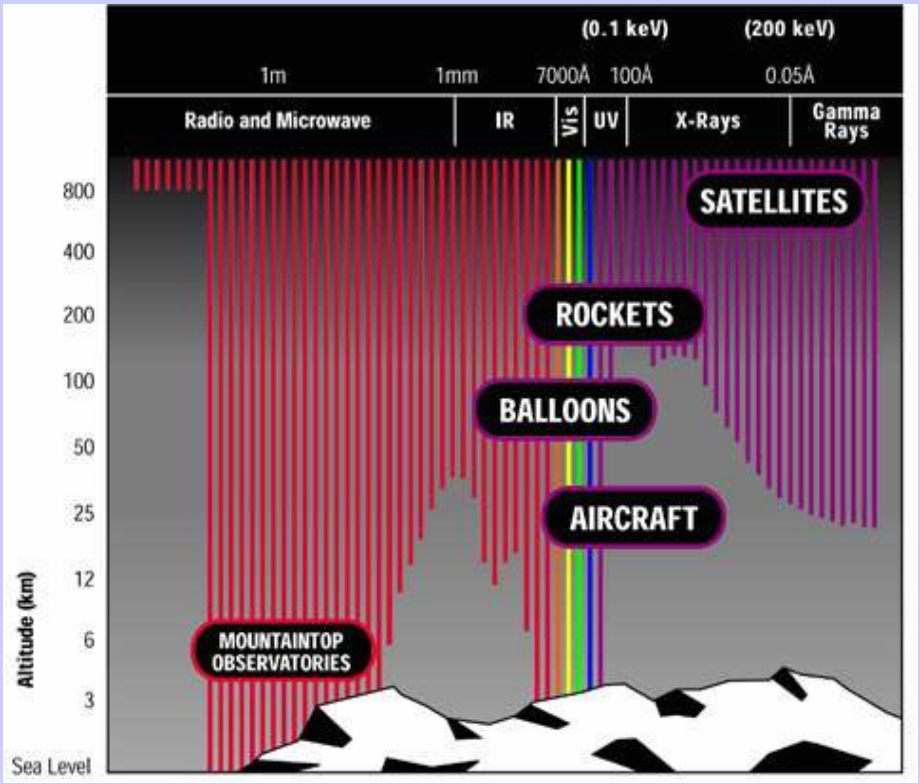


Rainbow of Light!

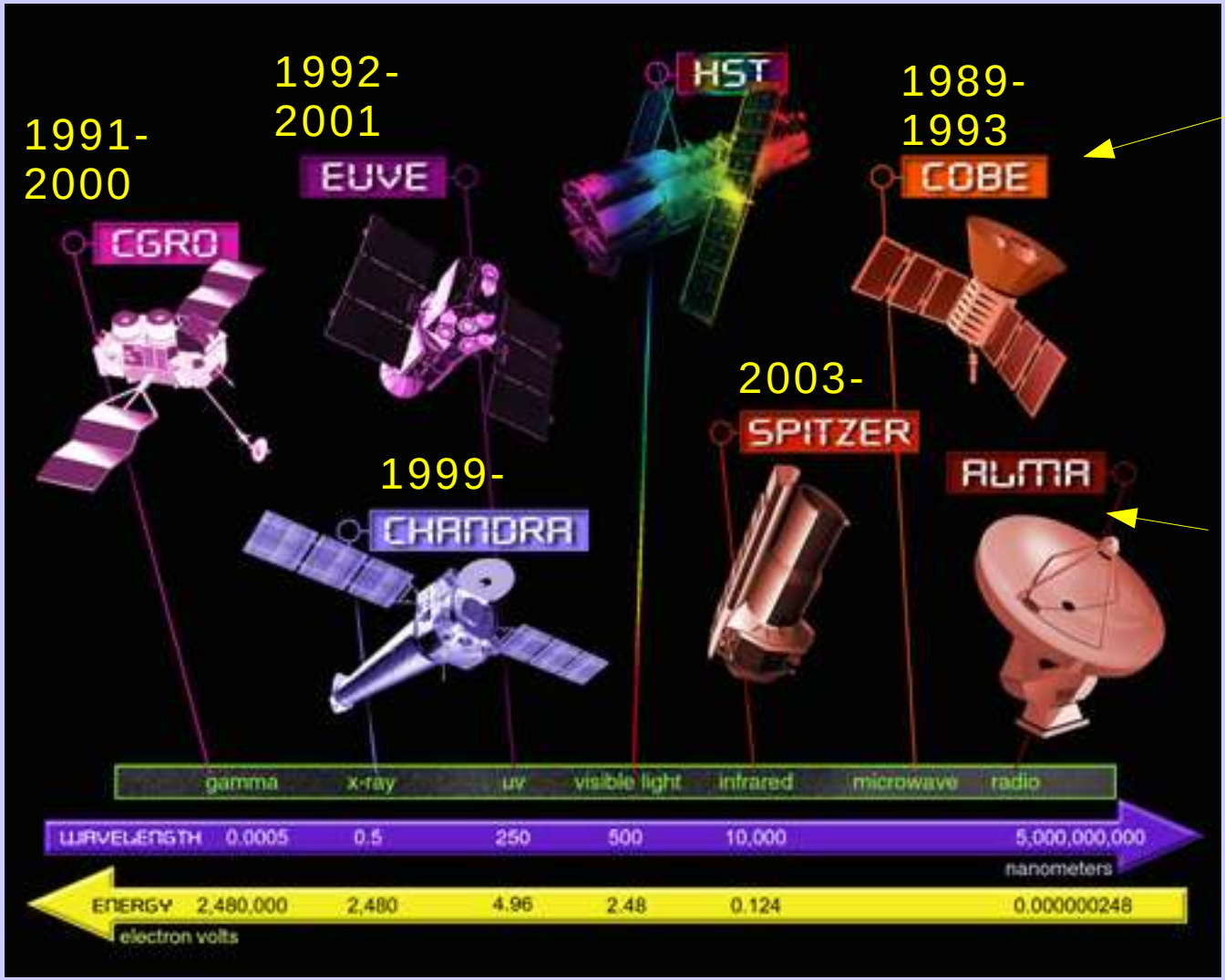
We can see the rainbow in Visible Light, but electromagnetic waves have much broader range.

The Earth atmosphere blocks a lot of radiation. We need satellites to observe objects in high energy.



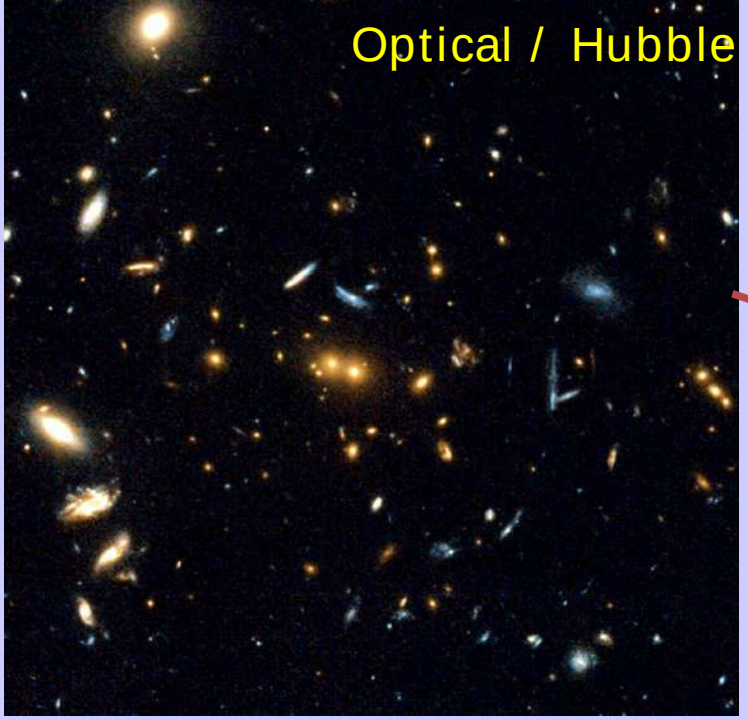


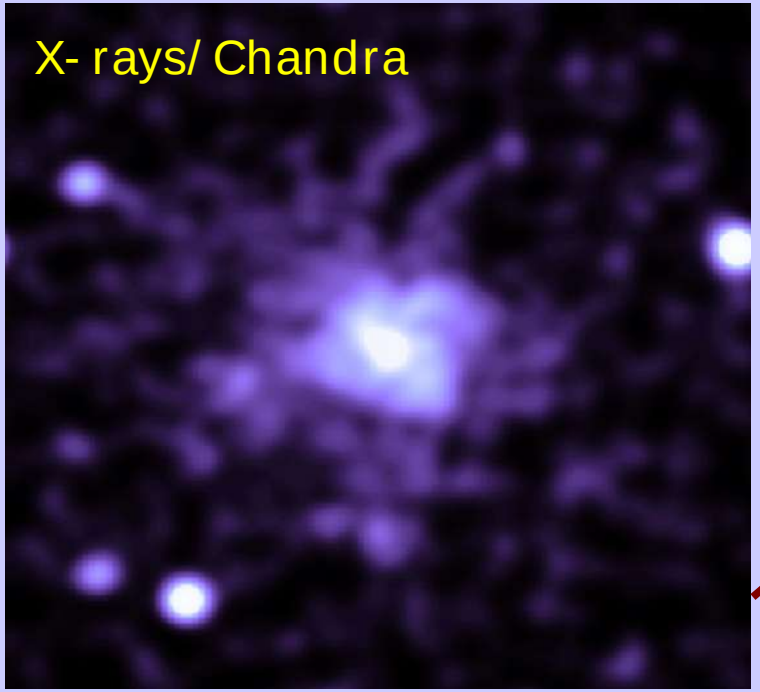
GREAT OBSERVATORIES ON ORBIT



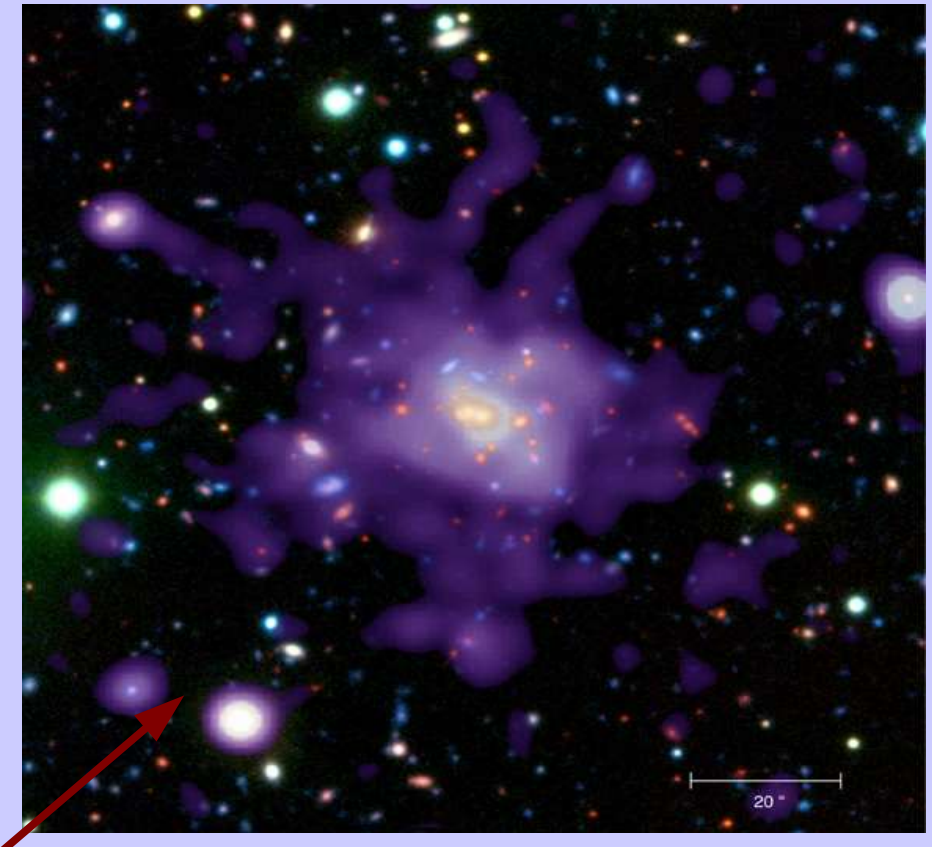
WMAP/ 2001 -

Atacama, Chile





Information from Optical and X-rays

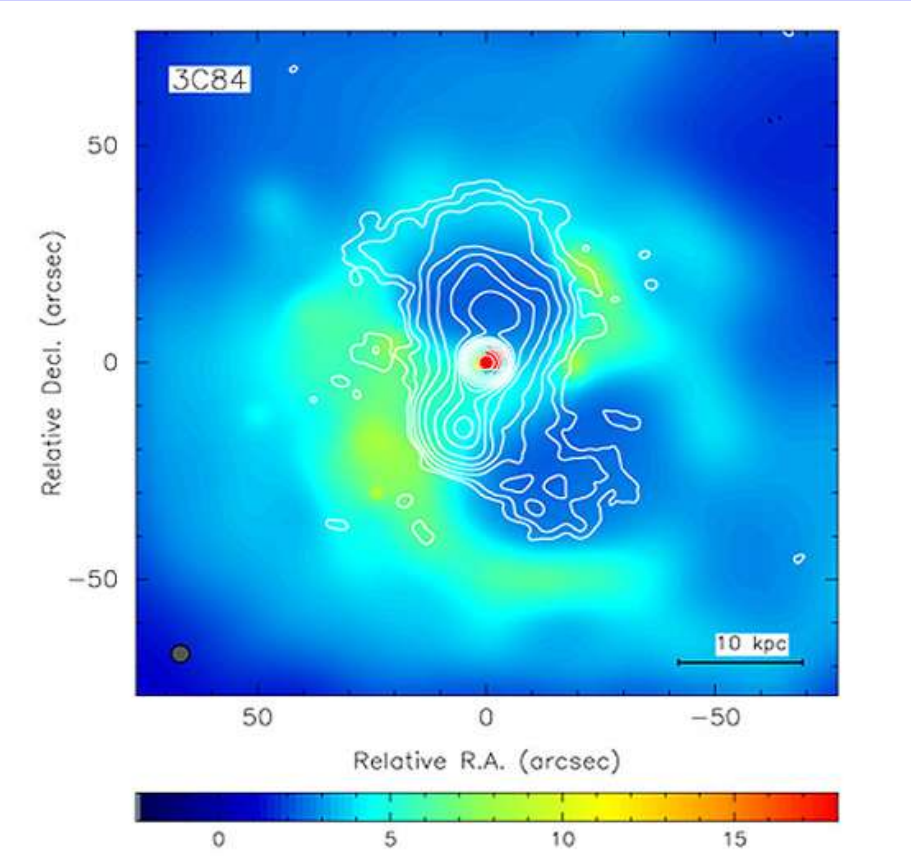


Optical/X-ray Overlayed

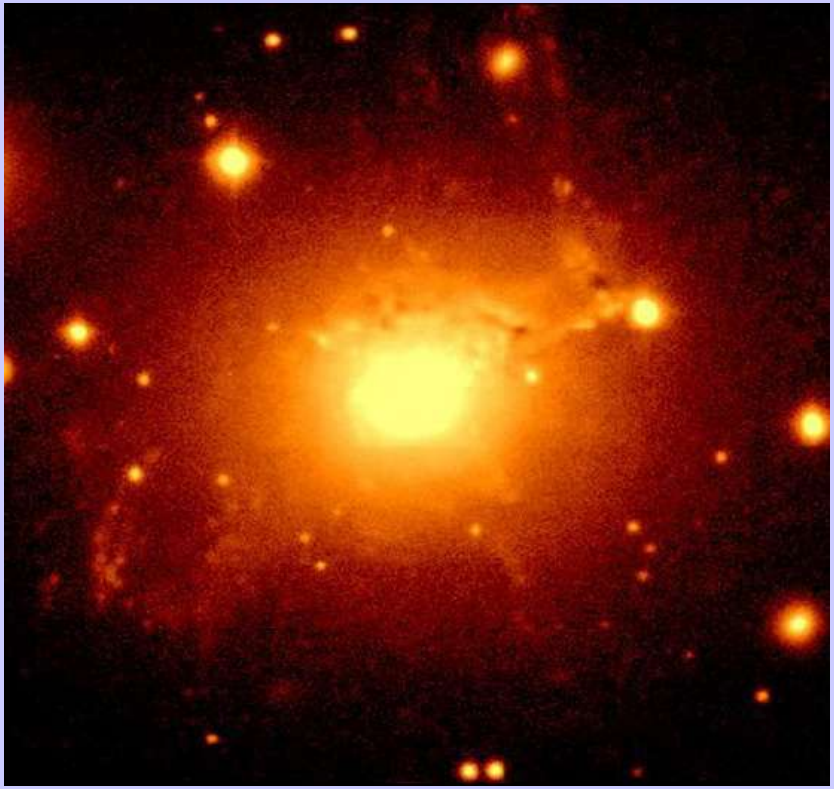
Credit: NASA/CXC/ESO-VLT/HST
Rosati et al 2004

Perseus A

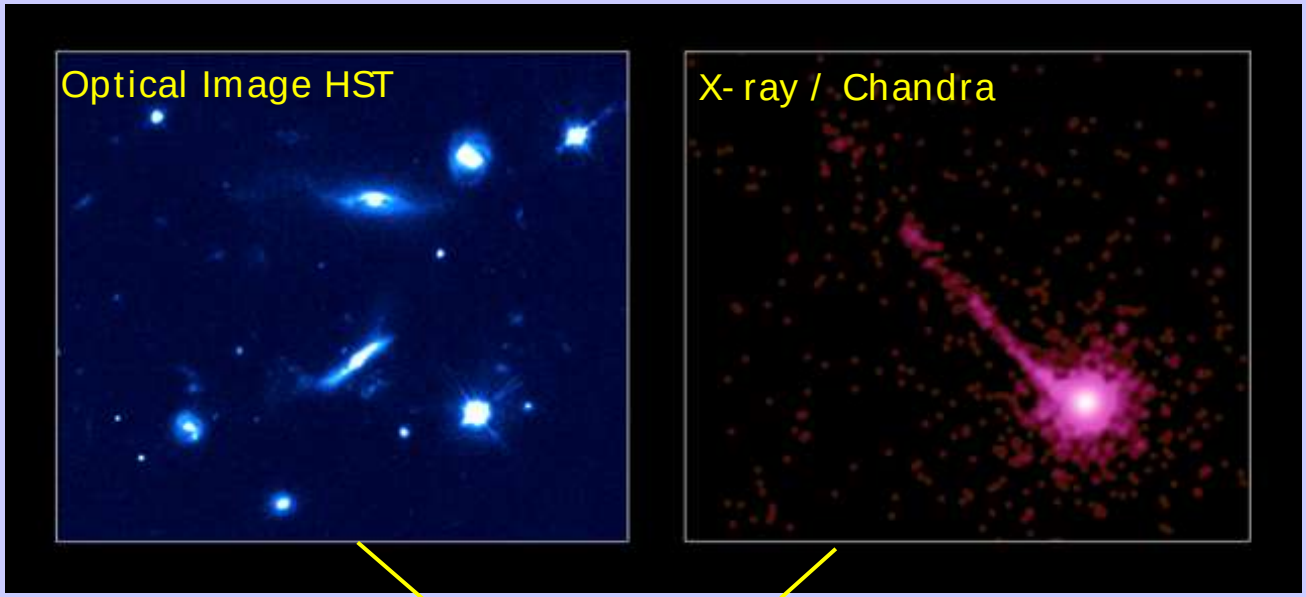
X-ray/Radio



Optical

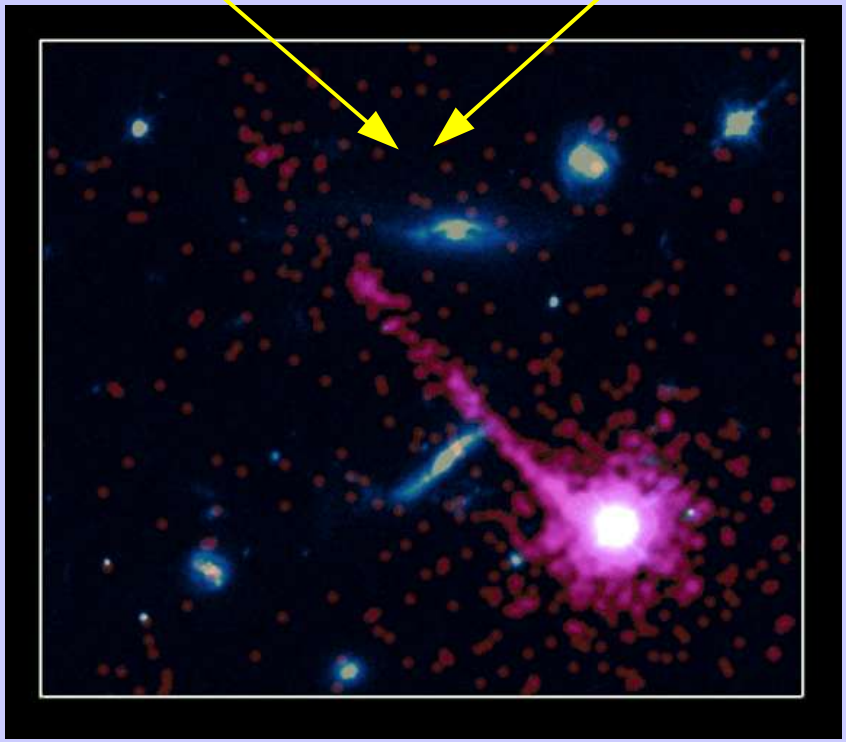


Fabian et al (2000)



PKS1127-145

Quasar at
z=1.18



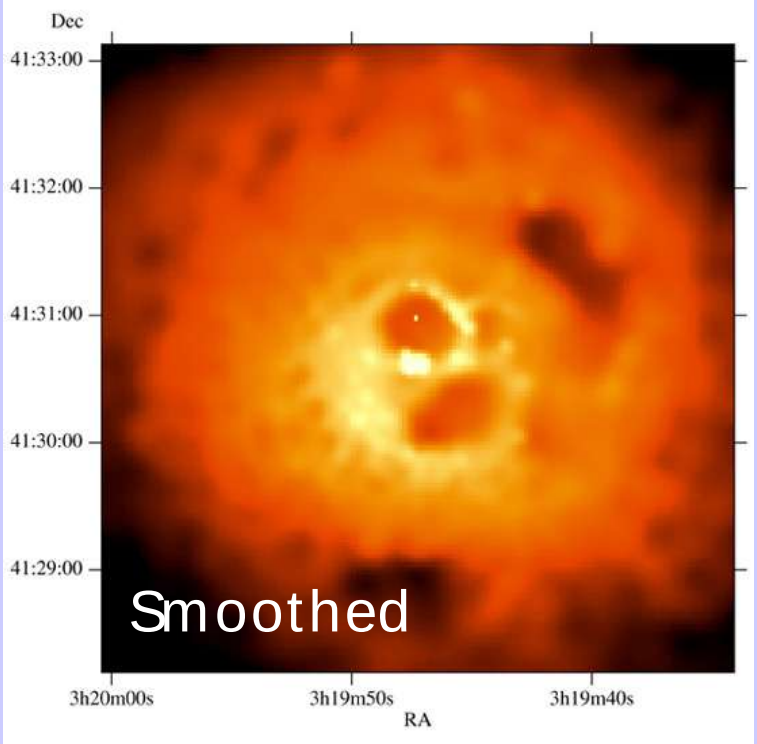
CHANDRA X-RAY Image
Revealed a Large Scale Jet

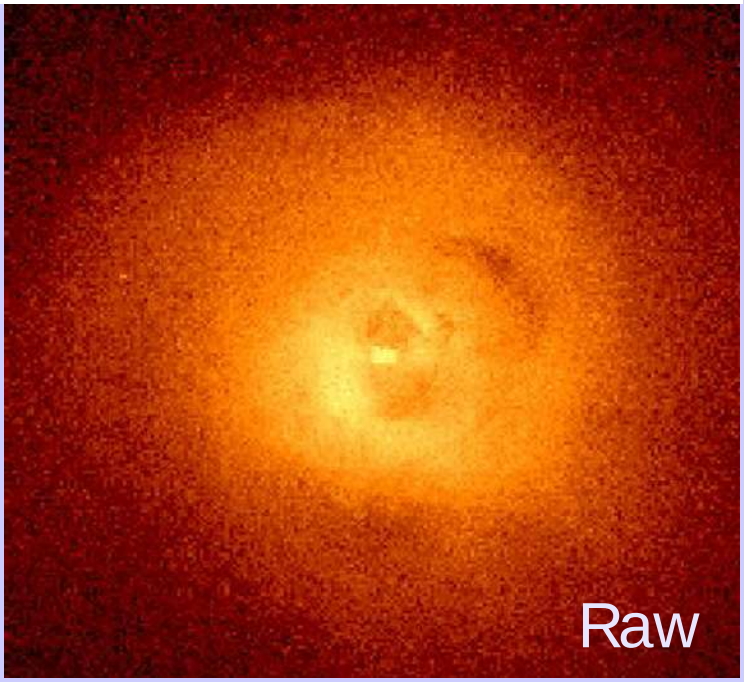
X-ray Images

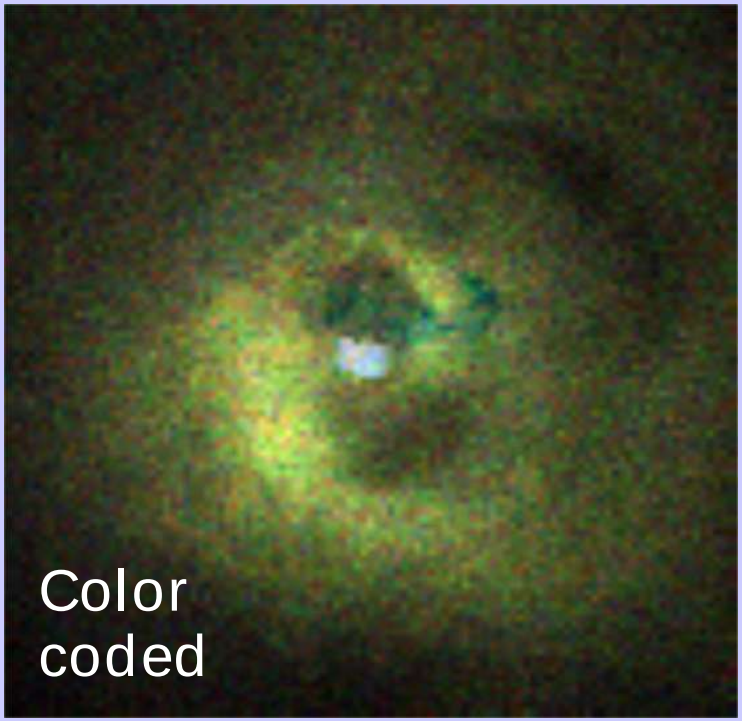
- Intensity Maps
  - color represents variations in the intensity
- Raw vs. Smoothed images
  - true counts per pixel
  - average counts/pixel
- True/False color images
  - color represents energy
- Temperature maps
  - Color represents temperature
- Images from different bands:

    X-rays/radio/optical

Perseus A
CHANDRA ACIS-S

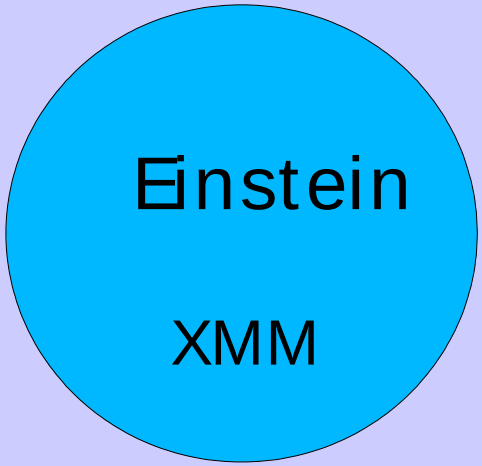






Fabian et al (2000)

Angular Resolution => Sharp Image

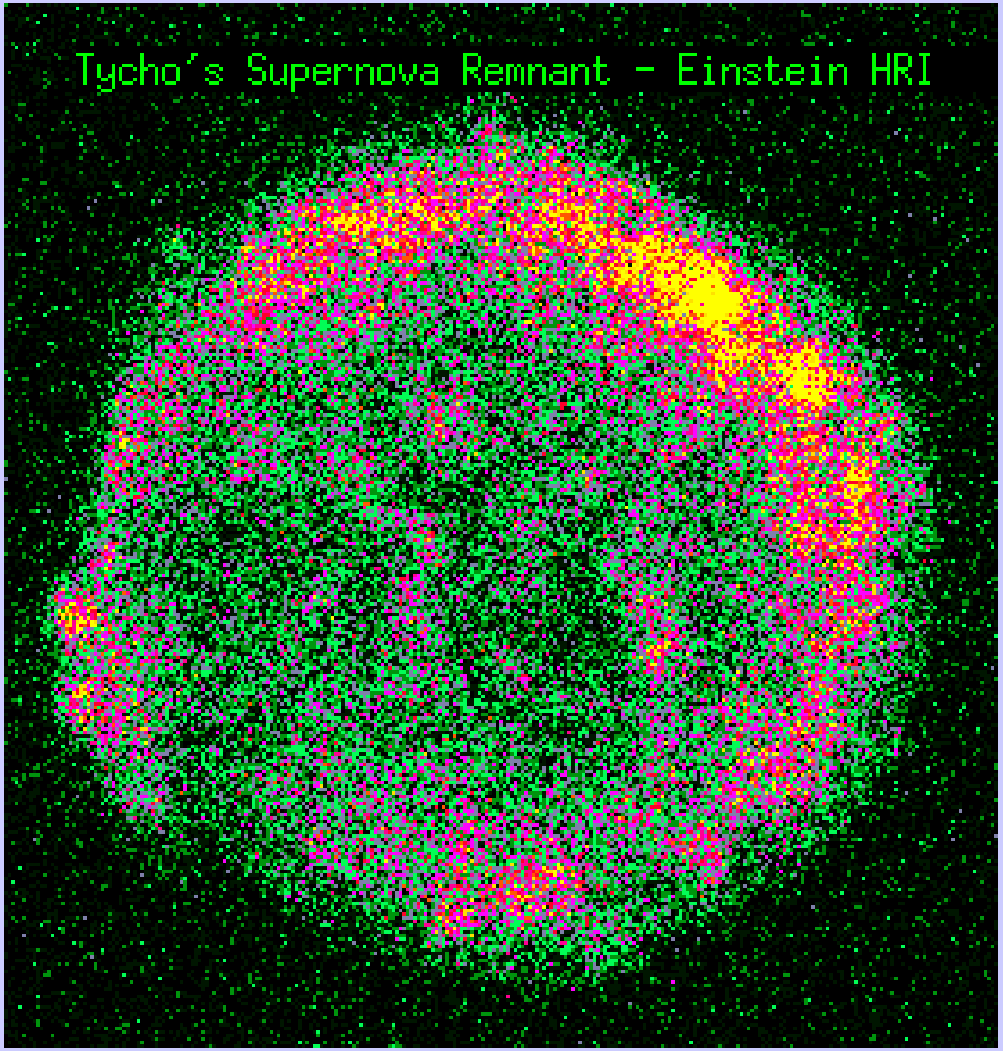


Chandra

FWHM ~ 0.5 arcsec

FWHM ~ 6 arcsec

First X-ray Imaging Telescope The Einstein Observatory (HEAO-2)



Credit: HEASARC

Nov. 1978-April 1981

High Resolution Imager

Energy: **0.15-3 keV**

Effective Area **5-20 cm^2**

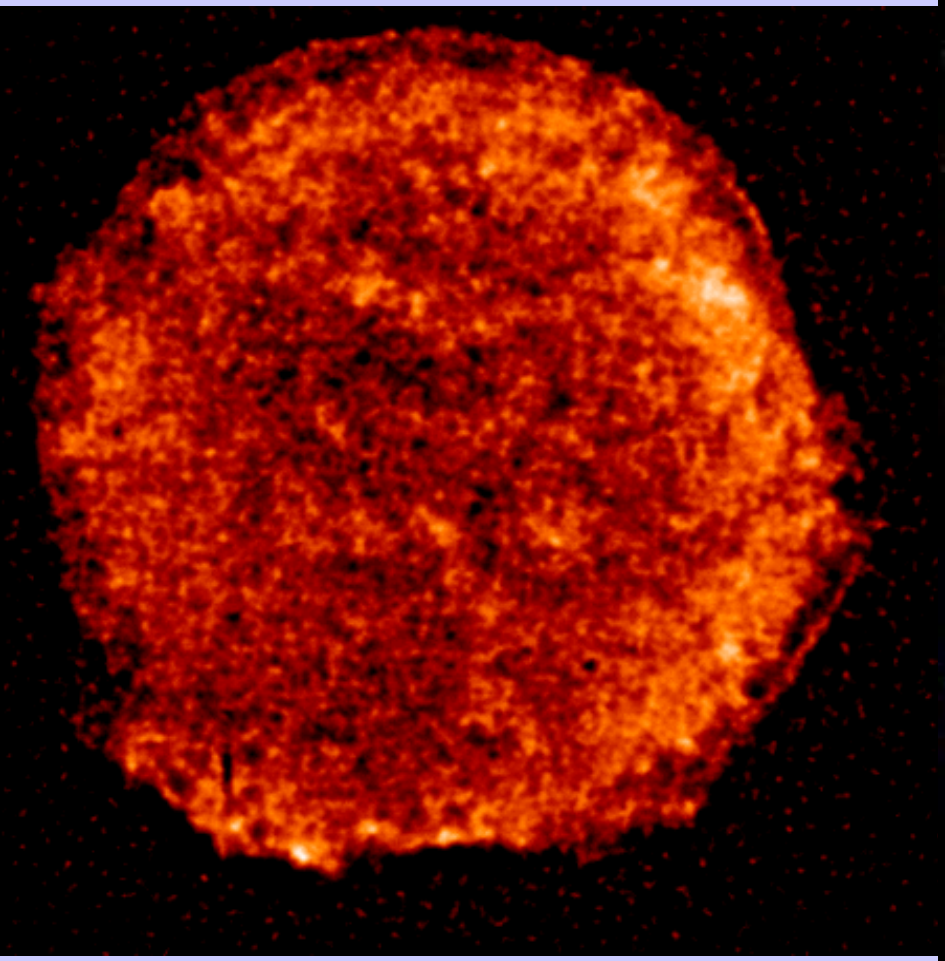
FOV ~25 arcmin

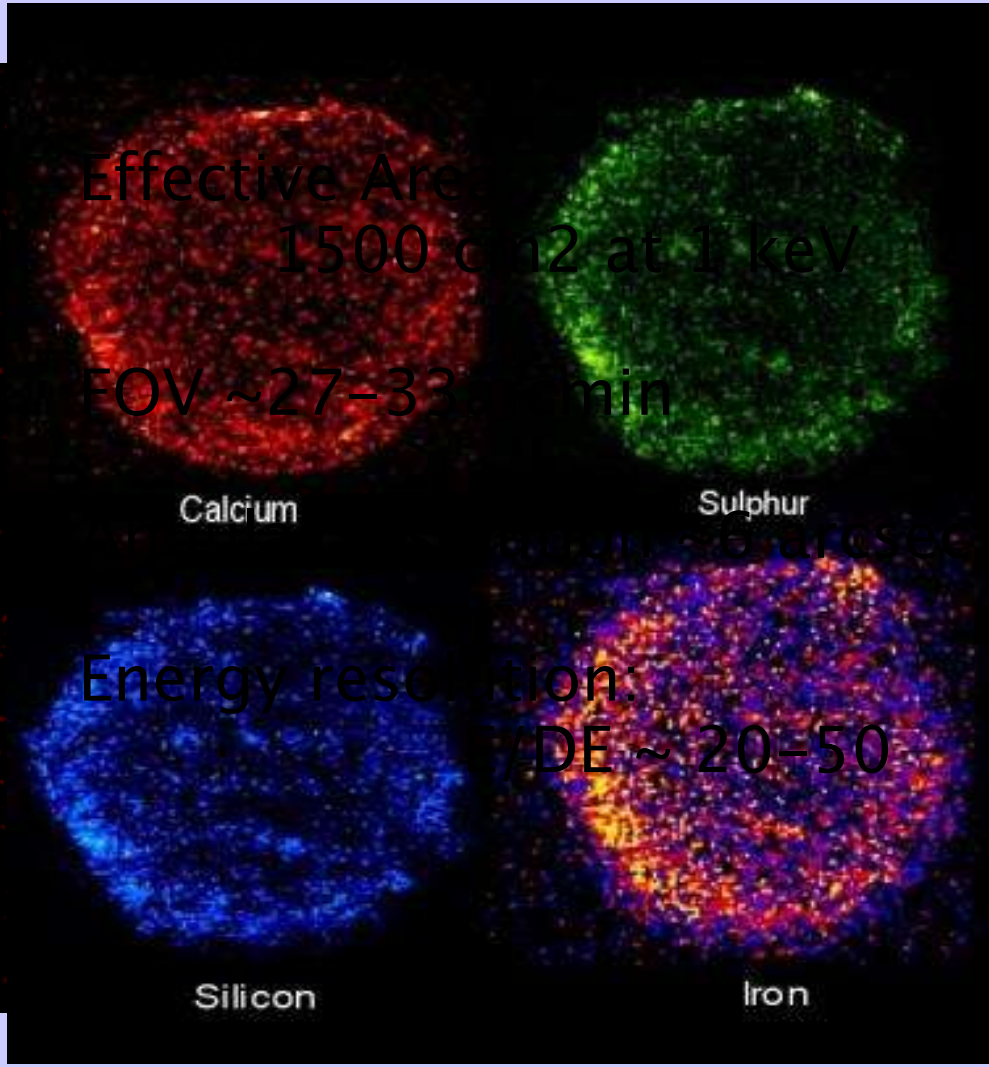
Angular resolution ~6 arcsec!

Tycho Supernova Remnant (1572)

XMM Newton

Launched in Dec.1999





Effective Arc
1500 c m2 at 1 keV

FOV ~27–3? min

Energy reso tion:
/DE ~ 20–50

Tycho Supernova Remnant

Aschenbach et al (2000

CHANDRA X-ray Observatory

- Launched in July 1999
- Energy Range: 0.1-10 keV
- Effective Area:
- ACIS-I ~ **500 cm2**
- HRC-I ~ **225 cm2**
- FOV: ACIS-I **16'x16'**
  HRC-I: **30'x30'**
- Energy Resolution:
  E/DE ~ **20-50** @1keV
- **Angular Resolution**
  < 1 arcsec

Color-coded image

Credit: CXC

The Chandra X-ray Observatory

Launched 5 years ago on July 23,1999

Has revolutionized X-ray astronomy

What are X-rays?

Example 1: Quasars Wind

Example 2: Clusters of Galaxies

What is X-ray Astronomy?

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

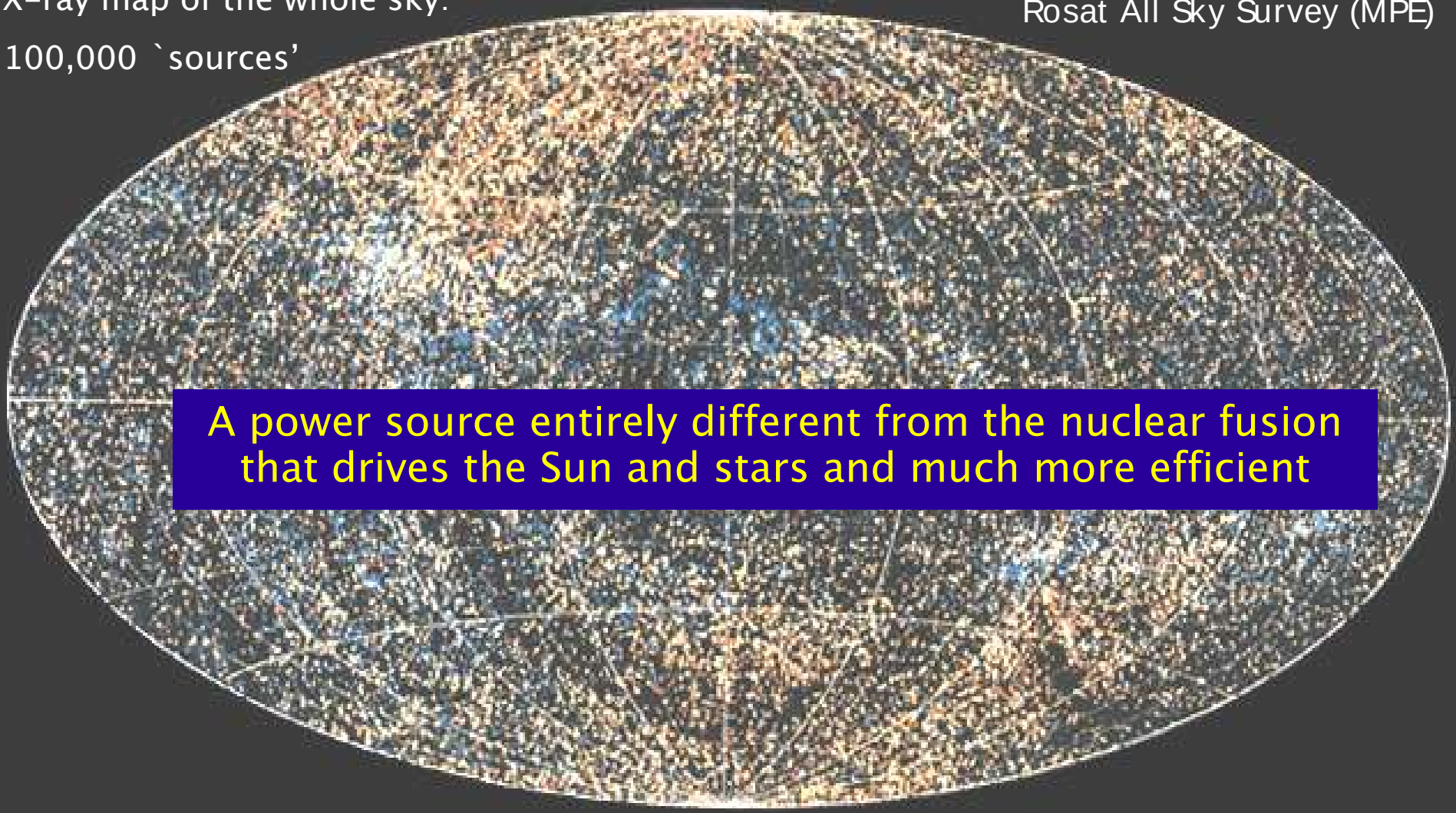
But,

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:

100,000 `sources'

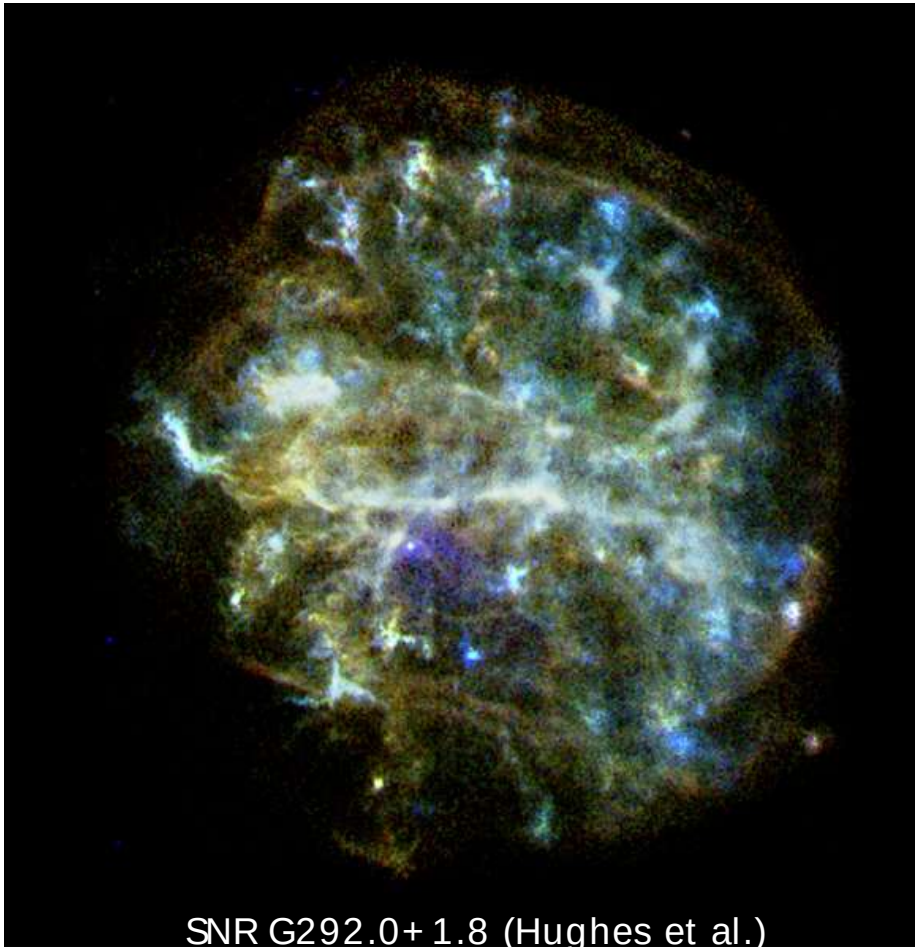


A power source entirely different from the nuclear fusion that drives the Sun and stars and much more efficient

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

Compare Visible light and X-rays: "1000 times"

- X-rays have:
- Wavelengths: 1/1000 visible light
  - 0.1-6 nm (1-60A) vs. 500 nm (5000A)
- 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)



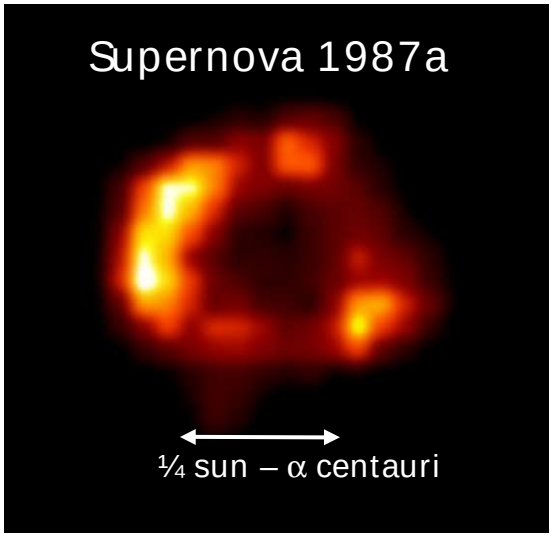
SNR G292.0+1.8 (Hughes et al.)

Credit: Elvis 2004

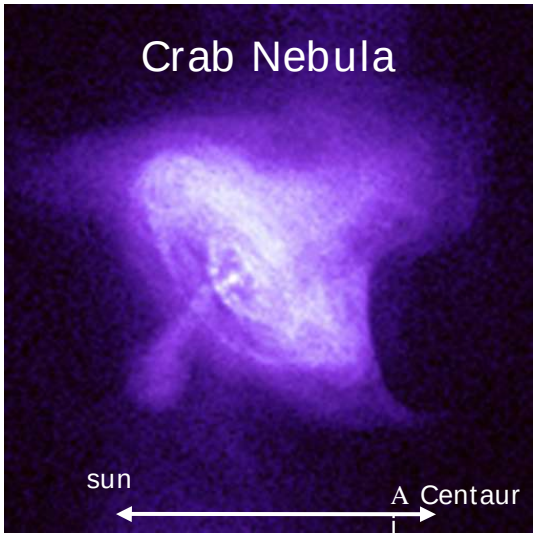
What gets so hot?

- 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**

Hubble Space Telescope

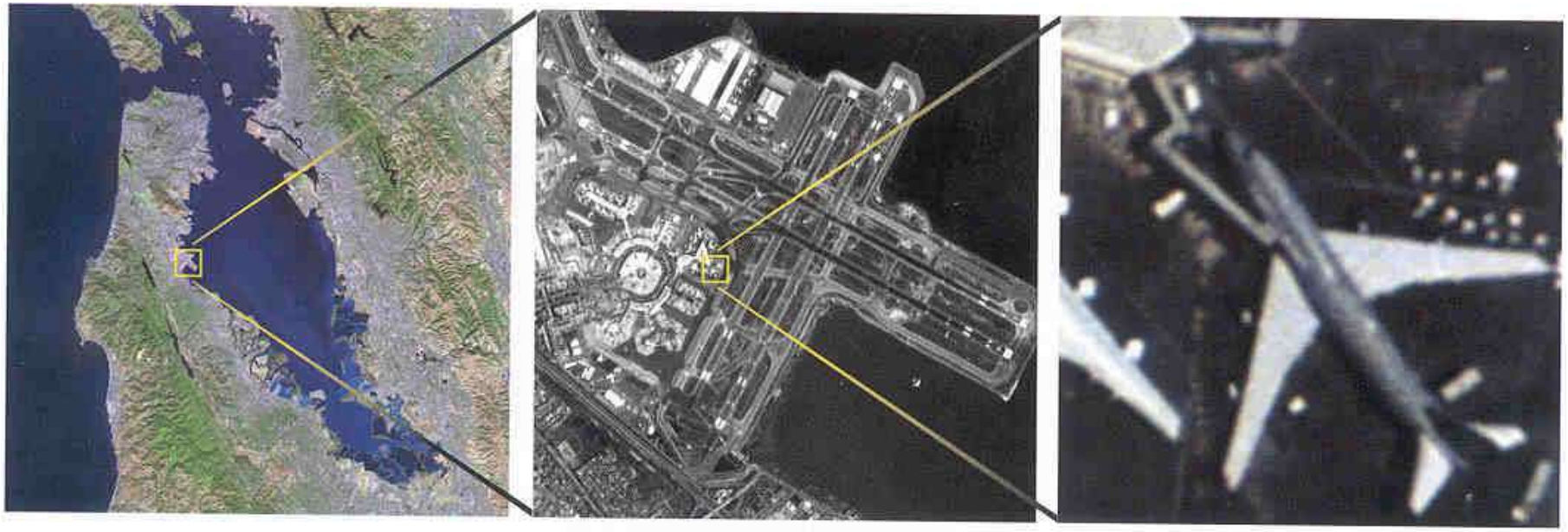
Optical Image

Chandra X-ray Image

Plenty of galaxies!

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

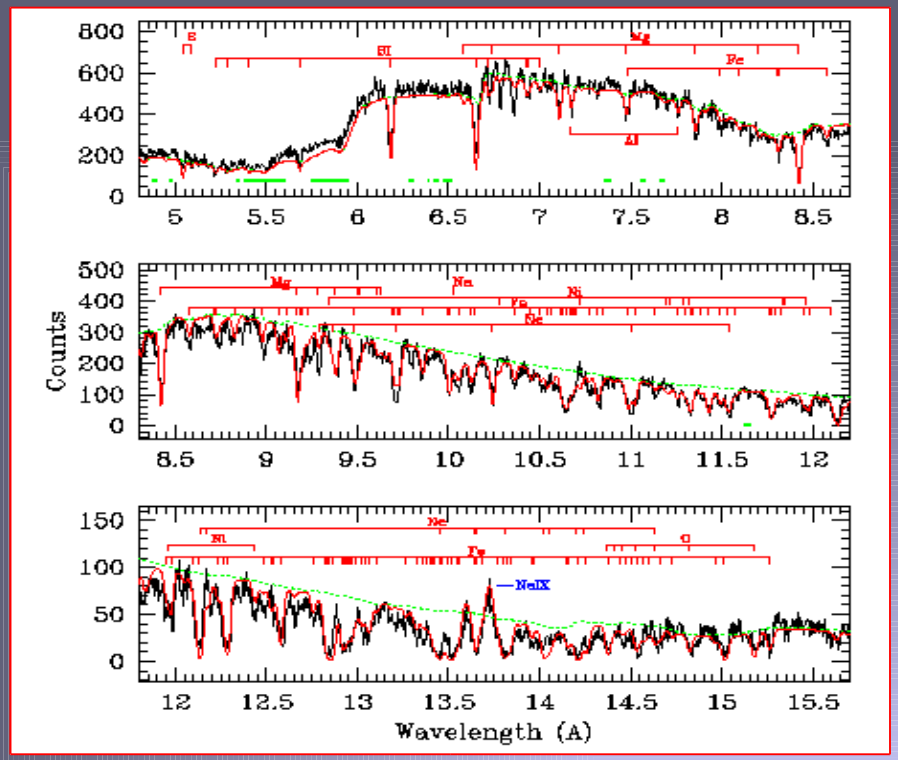
I get it!

Credit: Elvis 2003

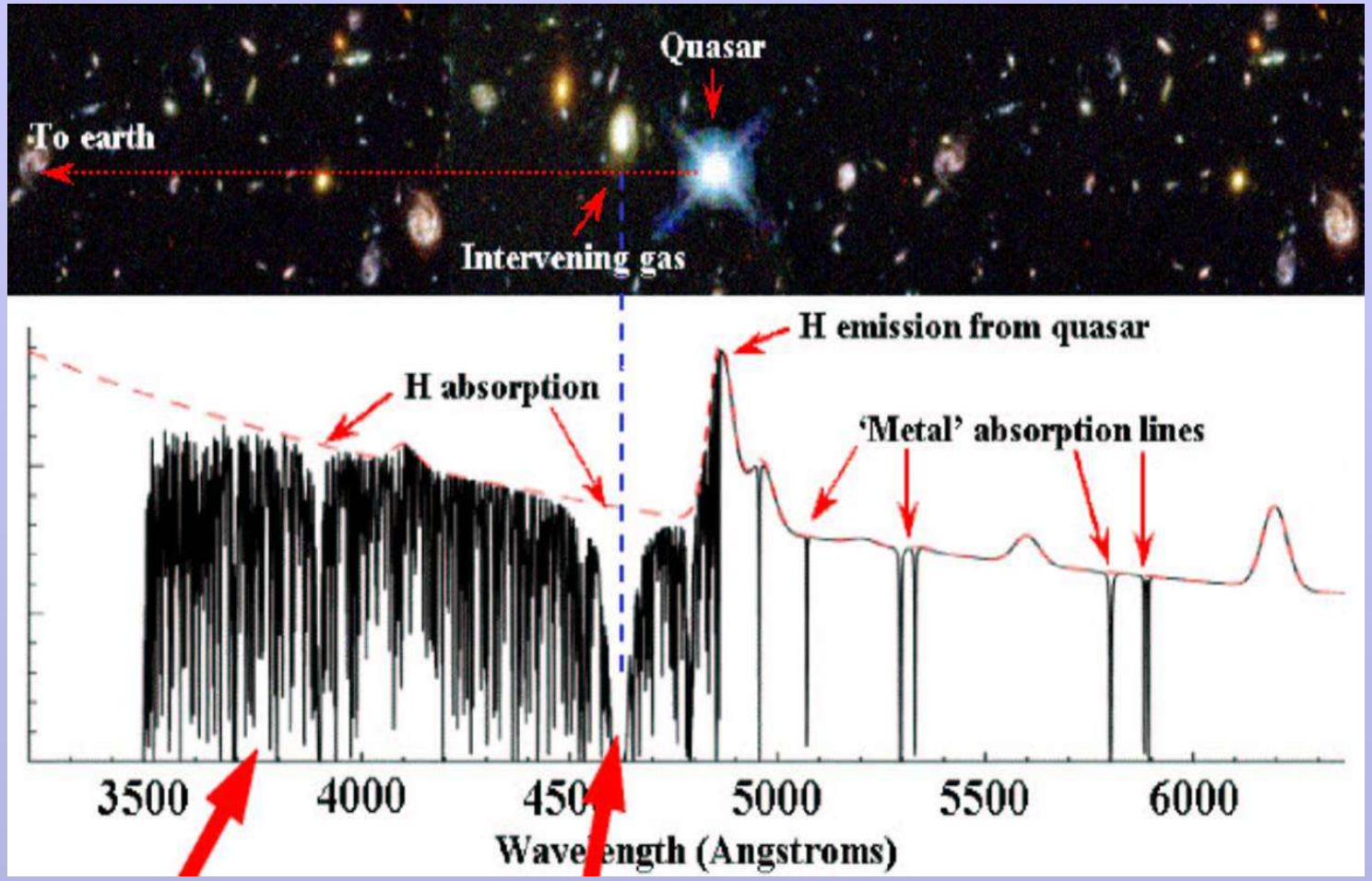
X-ray Studies with Chandra

High Resolution X-ray Spectra

High Resolution Imaging



Absorption Lines in Quasars Spectra



Lines!

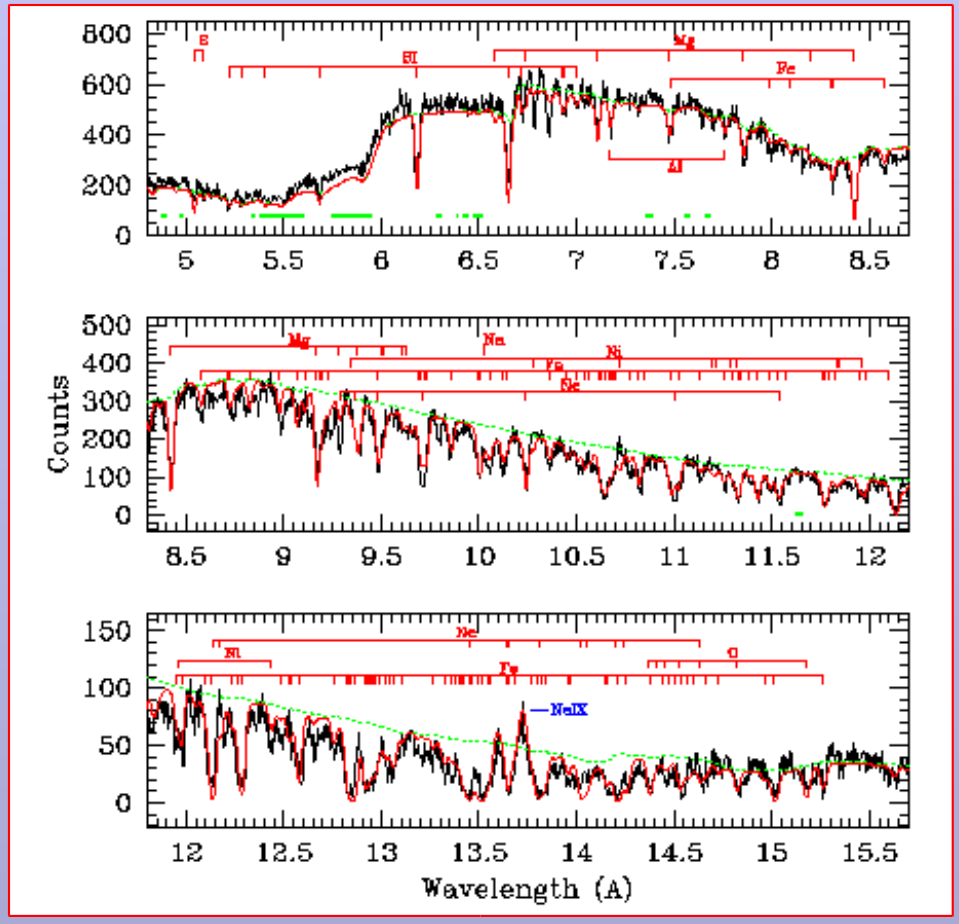
Lines!

Pettini 2003

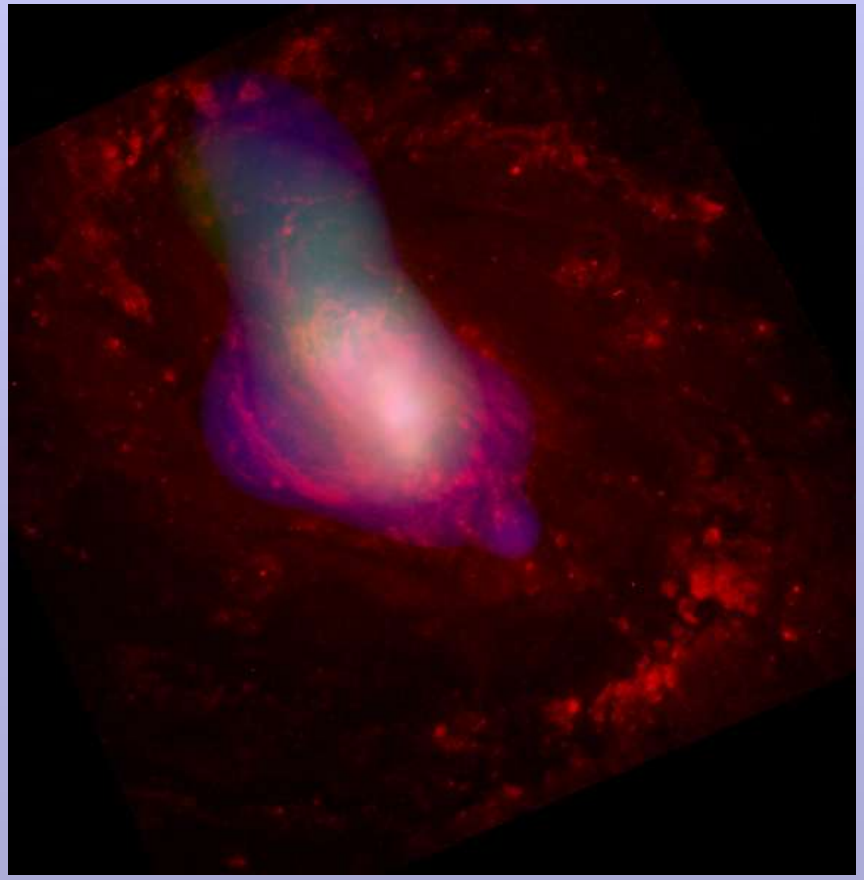
What do we learn?

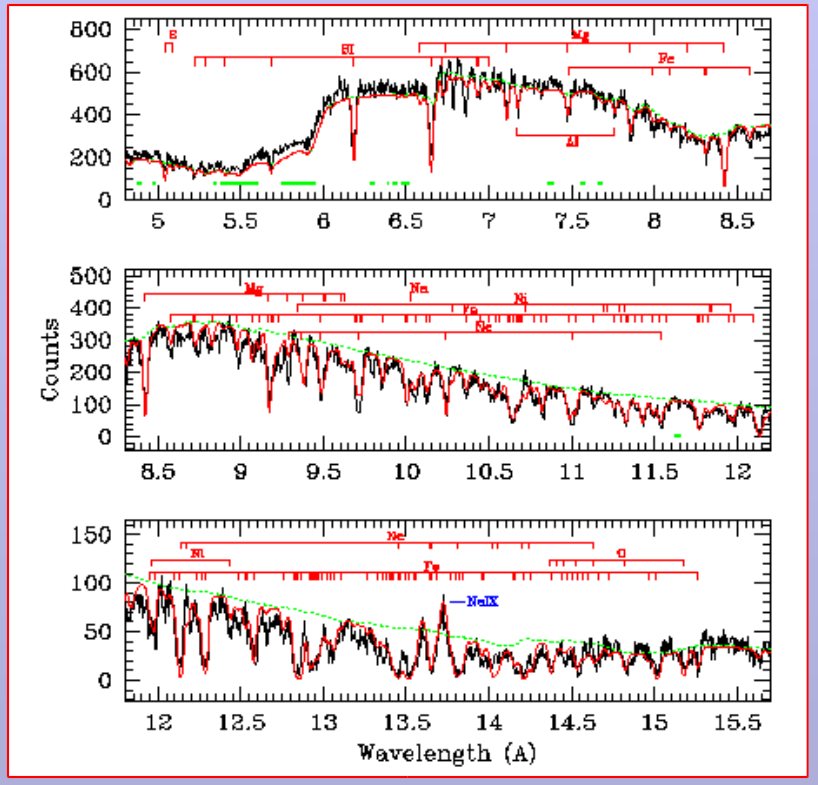
- The **width** of the lines
  => **Velocity**
- Line **location**
  => **Composition**
- **Energy** of the line
  => **Temperature**
- Line **variability**
  => **Distance**

from the Quasar



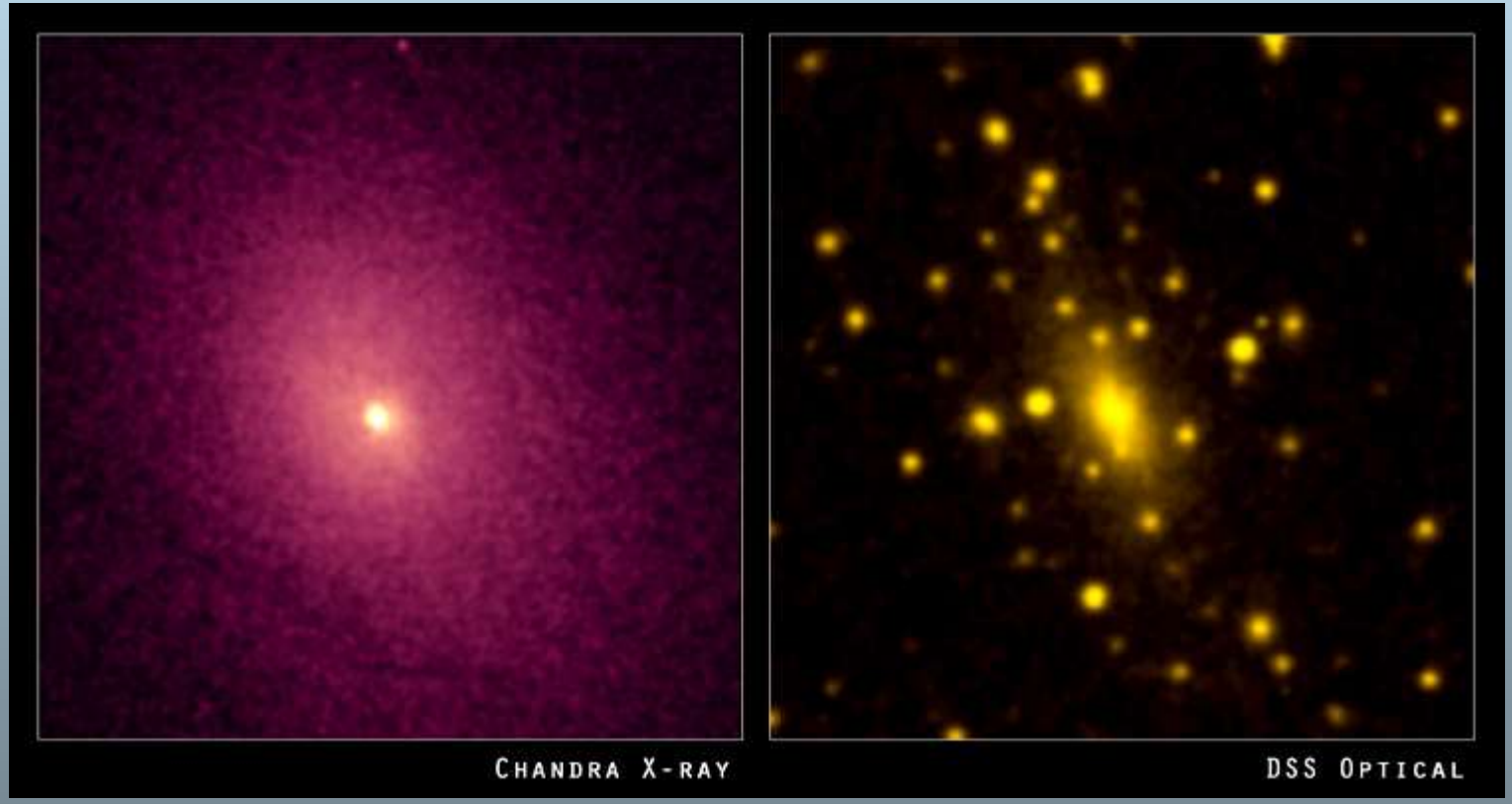
Quasars Wind





Hot outflowing wind, large distance from the center!

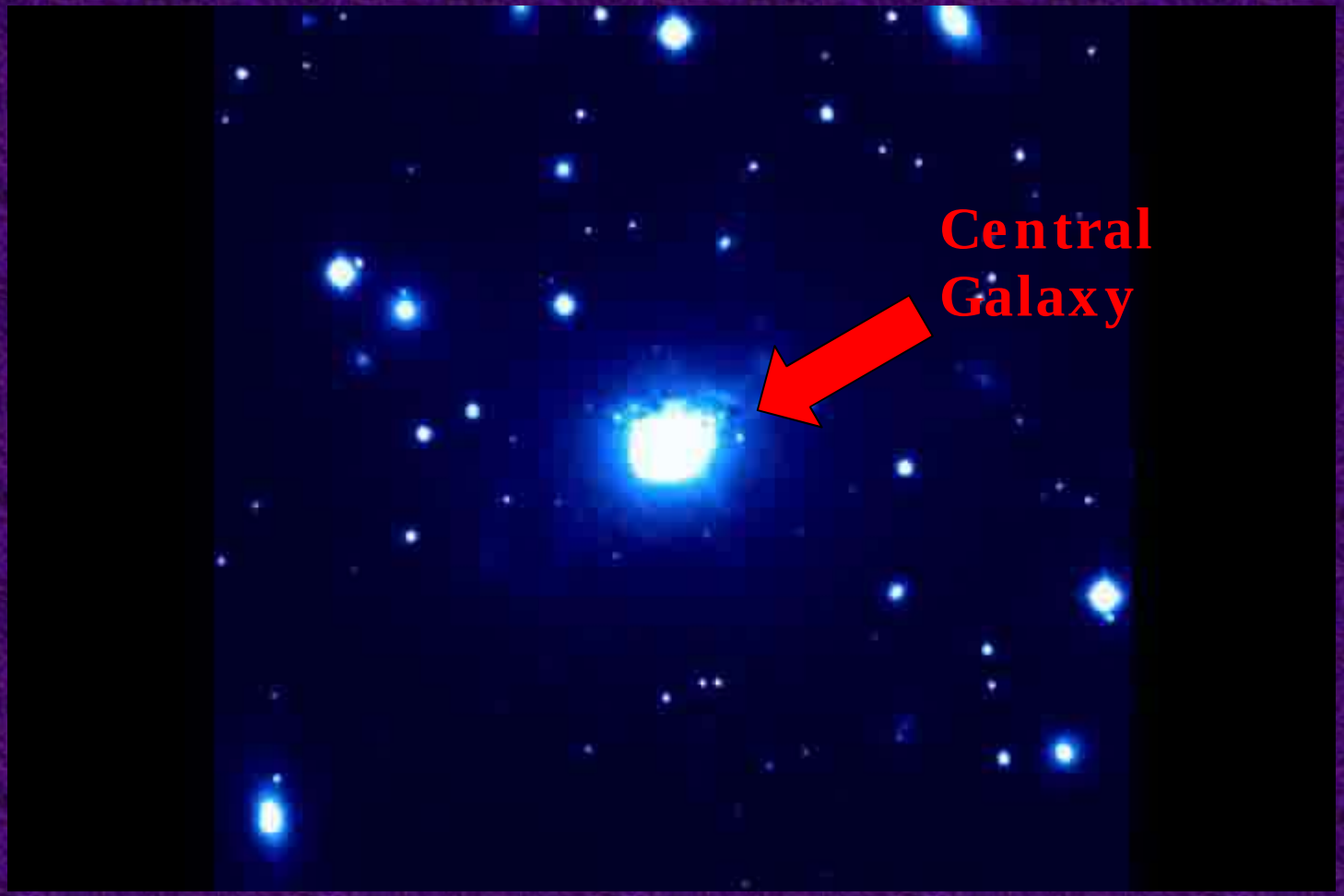
Example 2: Cluster of Galaxies



X-rays

Optical

Optical => X-ray Image of Perseus Cluster of Galaxies

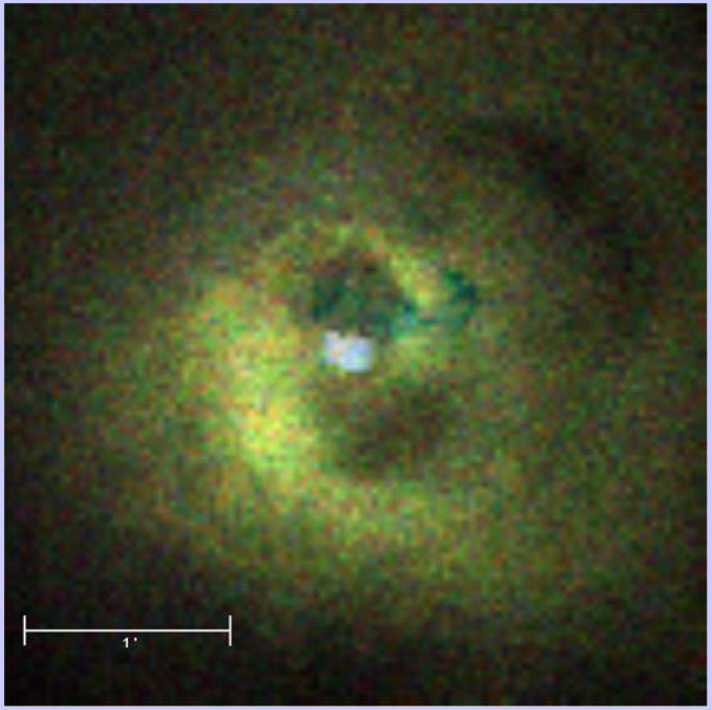


NASA/ CXC Fabian et al 2003

Questions:

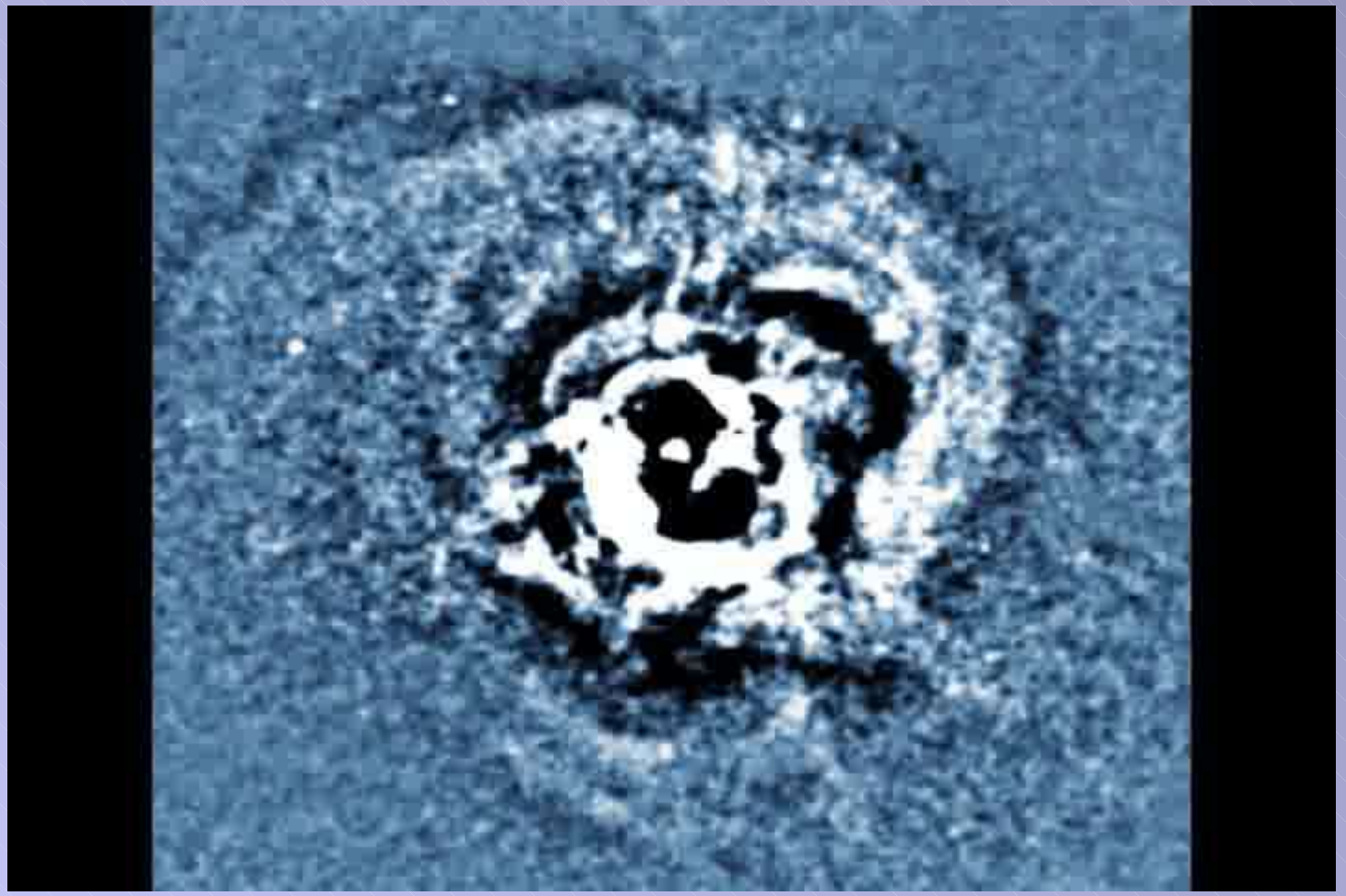
- What is the temperature of the emitting gas?
- What prevents the cooling process?
- Is there a cold gas? Where?
- What process heats this gas?
- What process creates the cavities?
- Can we determine the age of the structures?

Perseus Cluster



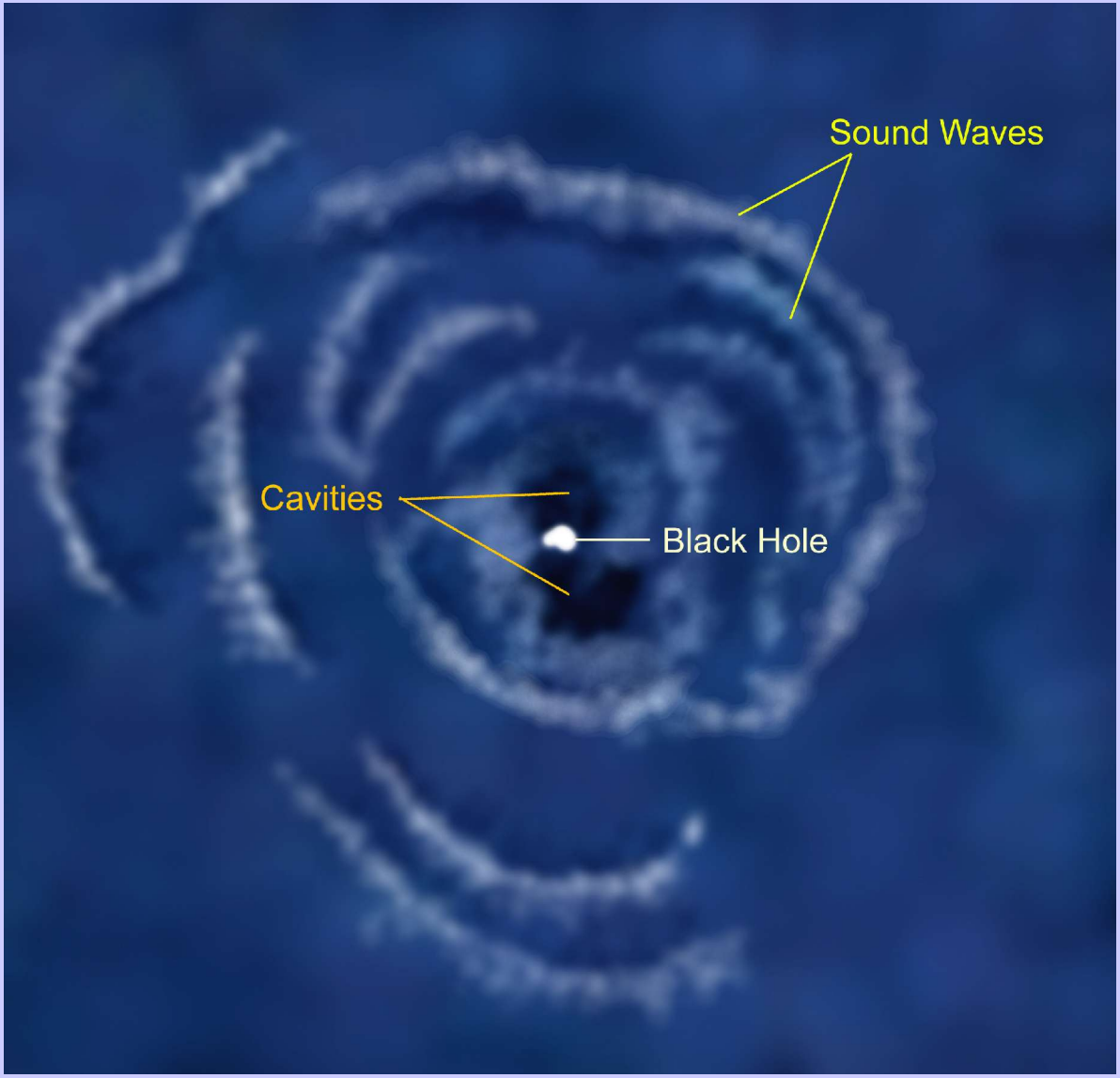
Fabian et al 2003

Image Processing

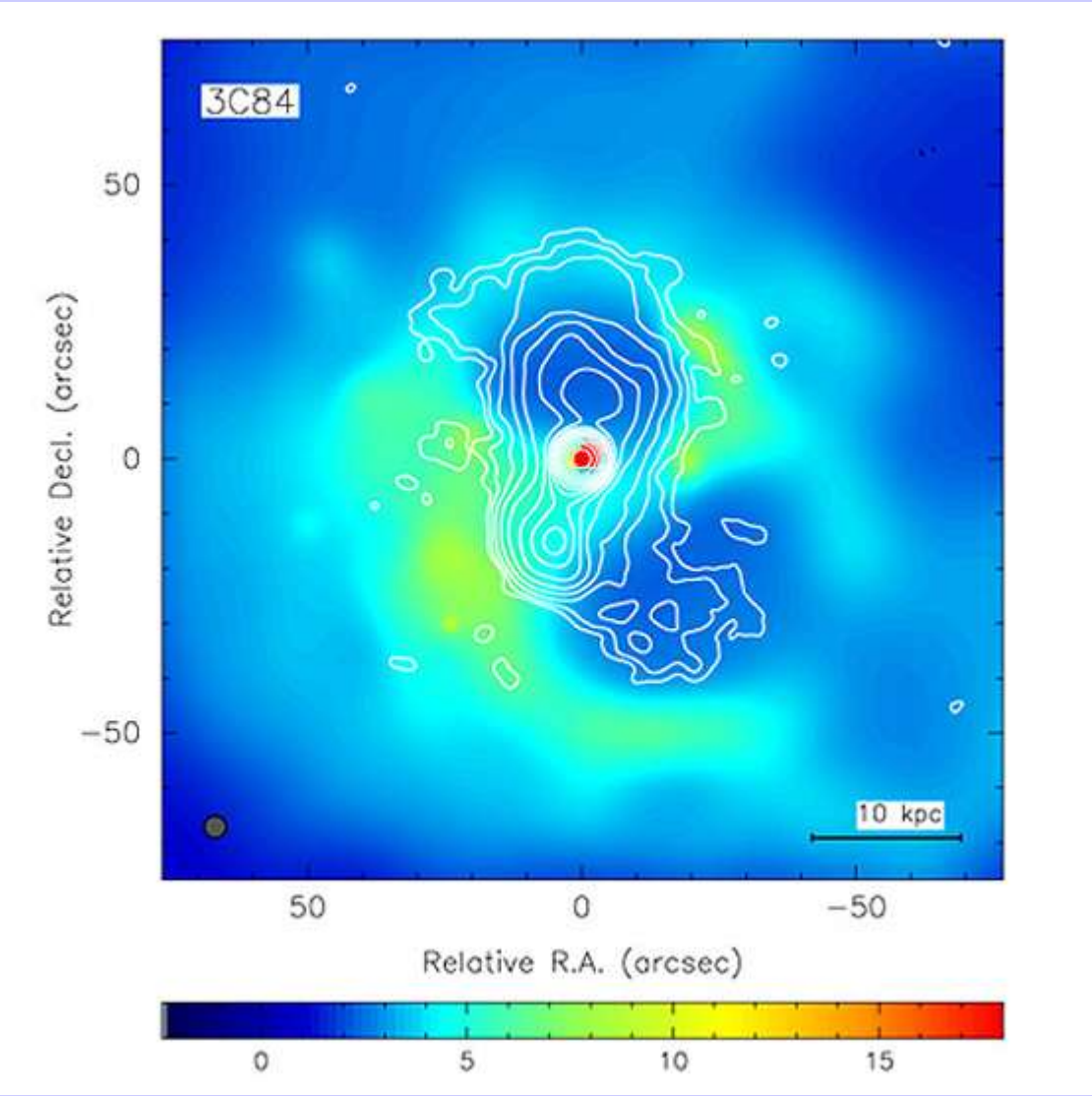


NASA/ CXC/ Fabian et al 2003

Illustration of Ripples in Perseus

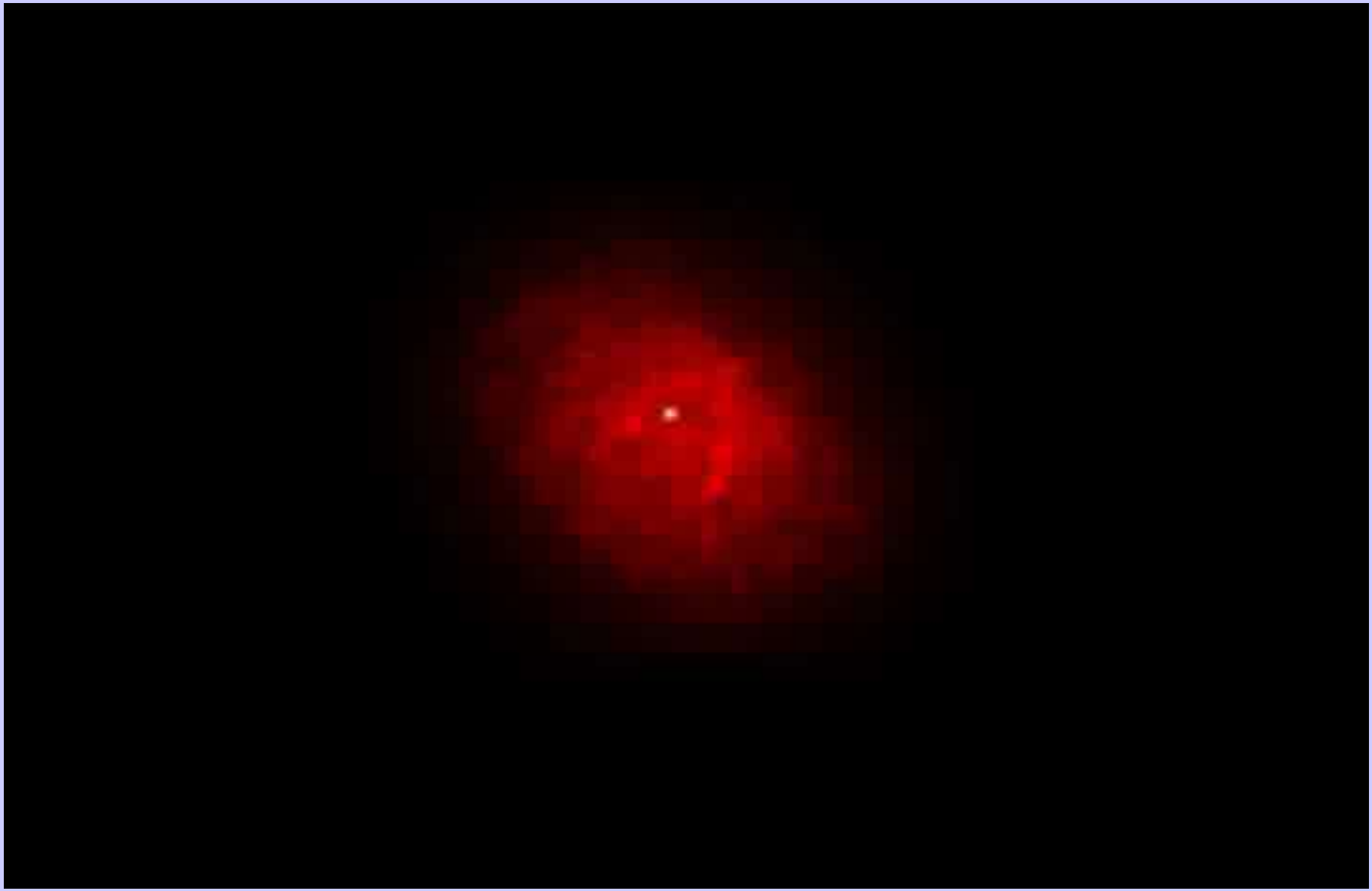


Perseus cluster



Contours – Radio wavelength

Animation of the Perseus cluster



Scientific Analysis

- How significant are the features in the image?
- How real is the image?
- What is the distance between the ripples?
- Is this the best model?
- How to discriminate between different models?

What are the goals of Data Analysis in Astronomy?

- Create a nice picture :-)
- Understand the **nature** of the source:
  - Understand **the shape and size** of the emitting regions
  - Understand **temperature distribution, velocity density distribution, composition and metallicity** etc.
  - Differentiate between **emission processes**.
  - Understand **energy and power involved** in the observed emission
- **Evolution** of the source and how it relates to other sources.