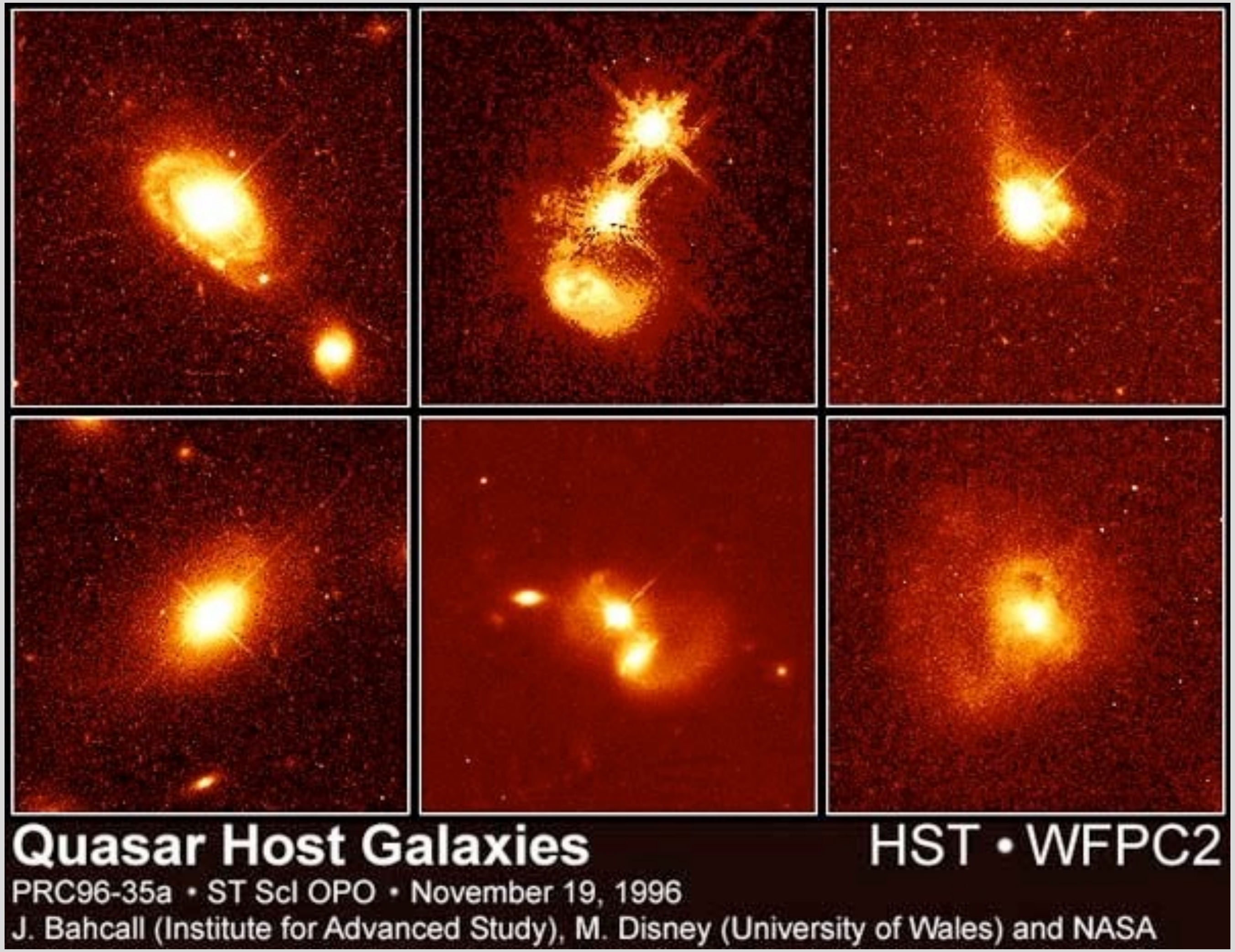
Triggering of Active Galactic Nuclei in Galaxy Clusters

Lots of evidence that galaxy interactions trigger nuclear activity in galaxies.



Triggering of Active Galactic Nuclei in Galaxy Clusters

Lots of evidence that galaxy interactions trigger nuclear activity in galaxies.

So would we expect lots of AGN in clusters?

Pros: Lots of galaxies, lots of collisions.

Cons:

- Galaxies are predominantly E/S0 galaxies, so they are preferentially gas poor.
- Galaxy encounter velocities are fast, so they may not trigger as strong a response, and they may not lead to many mergers.

Data Mining project

Studying AGN in clusters (writeup: thesis proposal style)

Project overview

Step 1: Find galaxy clusters

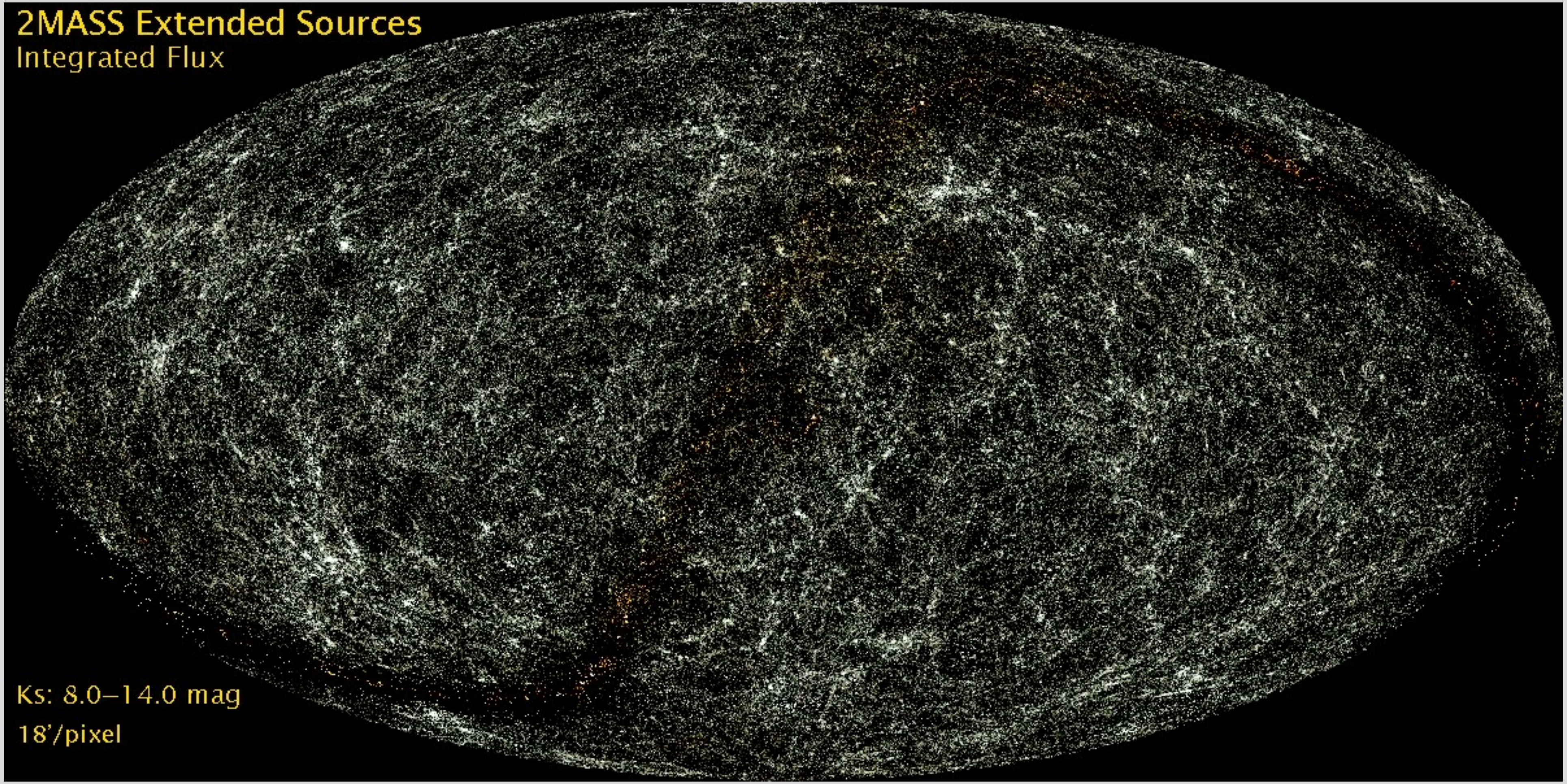
Step 2: Decide which galaxies are members of the cluster

Step 3: Search for AGN in the clusters

Step 4: Study cluster galaxies that host AGN

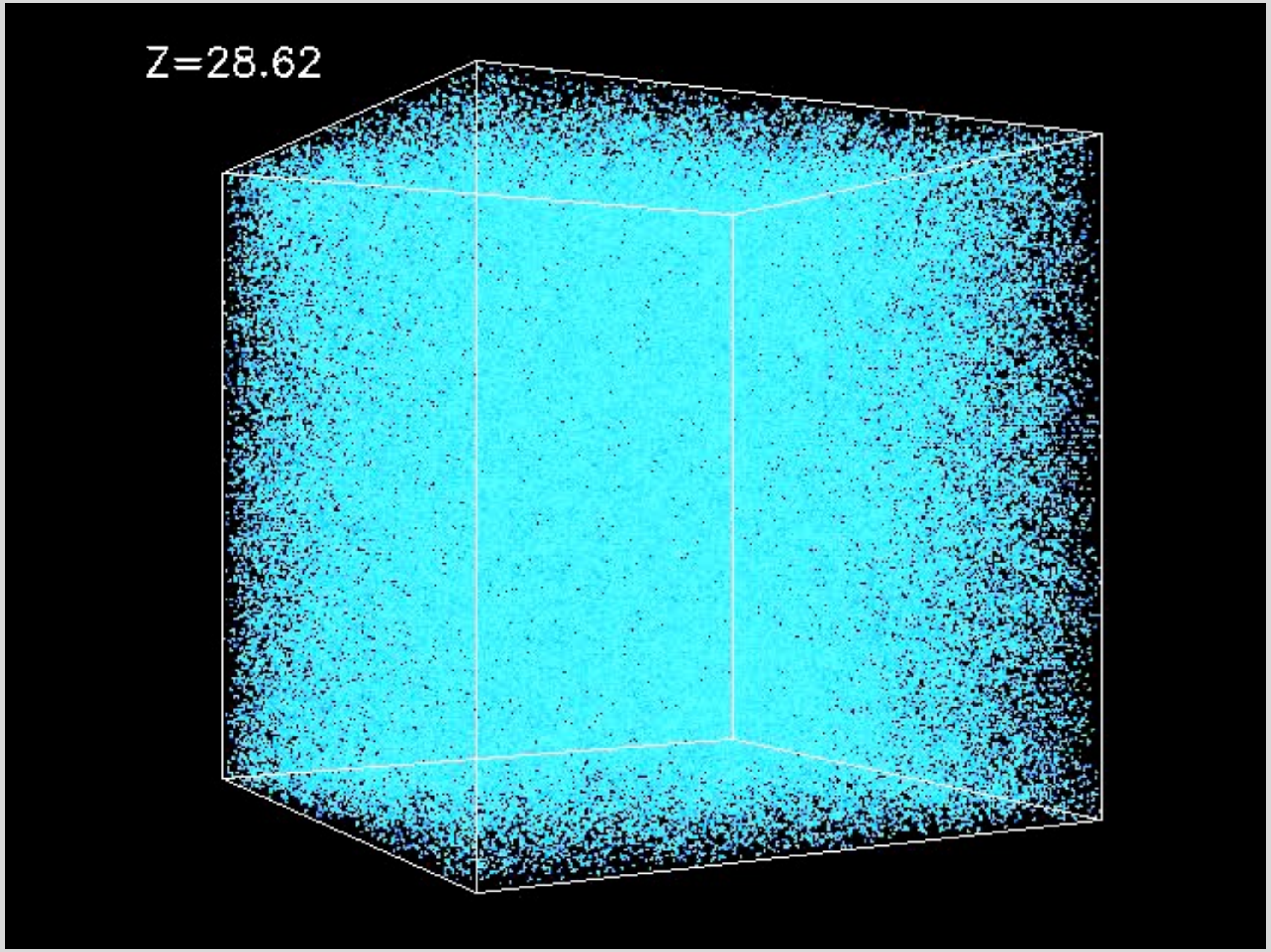
Step 1: Identifying Galaxy Clusters

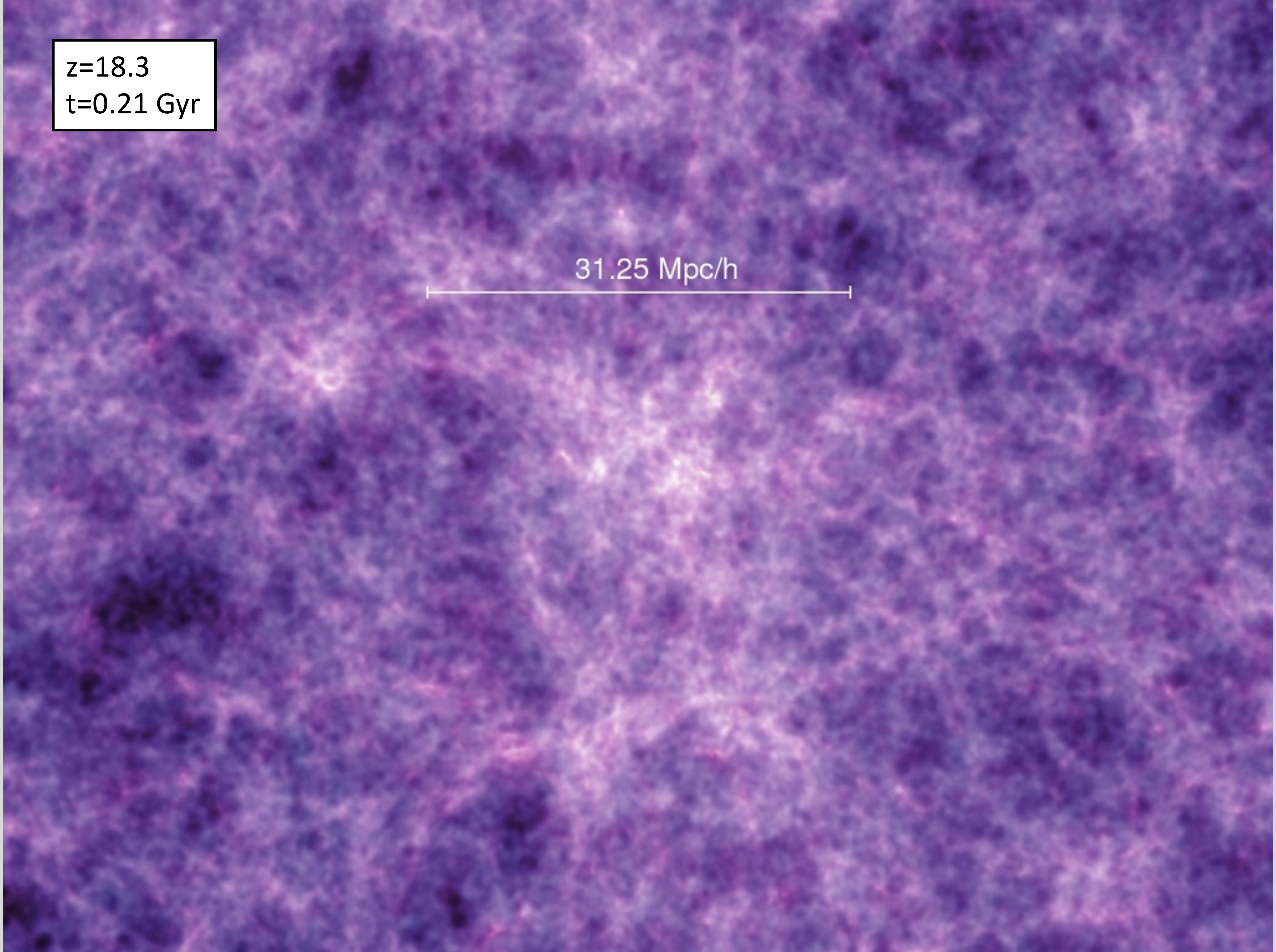
Distribution of galaxies on the sky – look for clusters?



Step 1: Identifying Galaxy Clusters

Think about the physics of cluster formation

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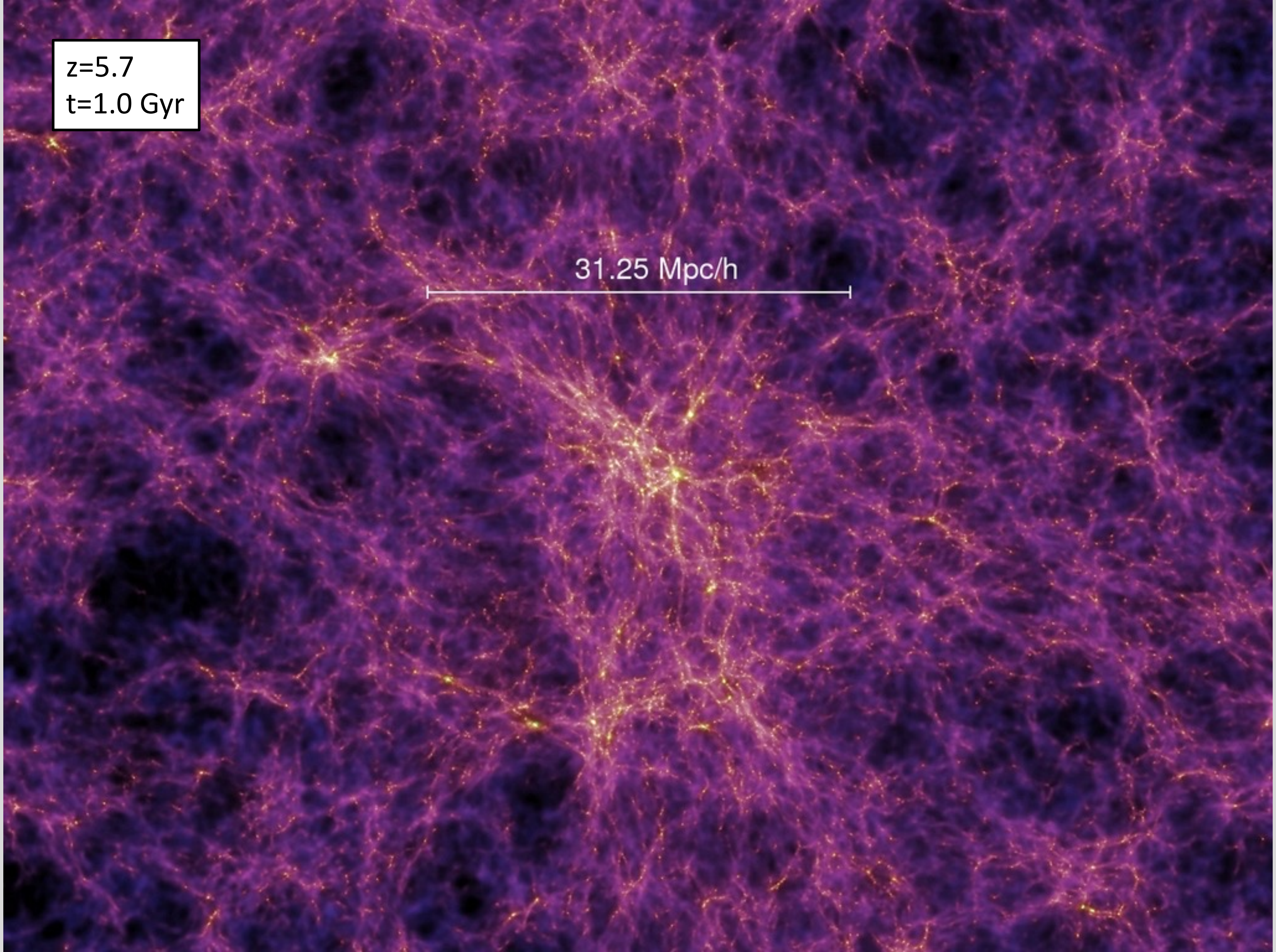
31.25 Mpc/h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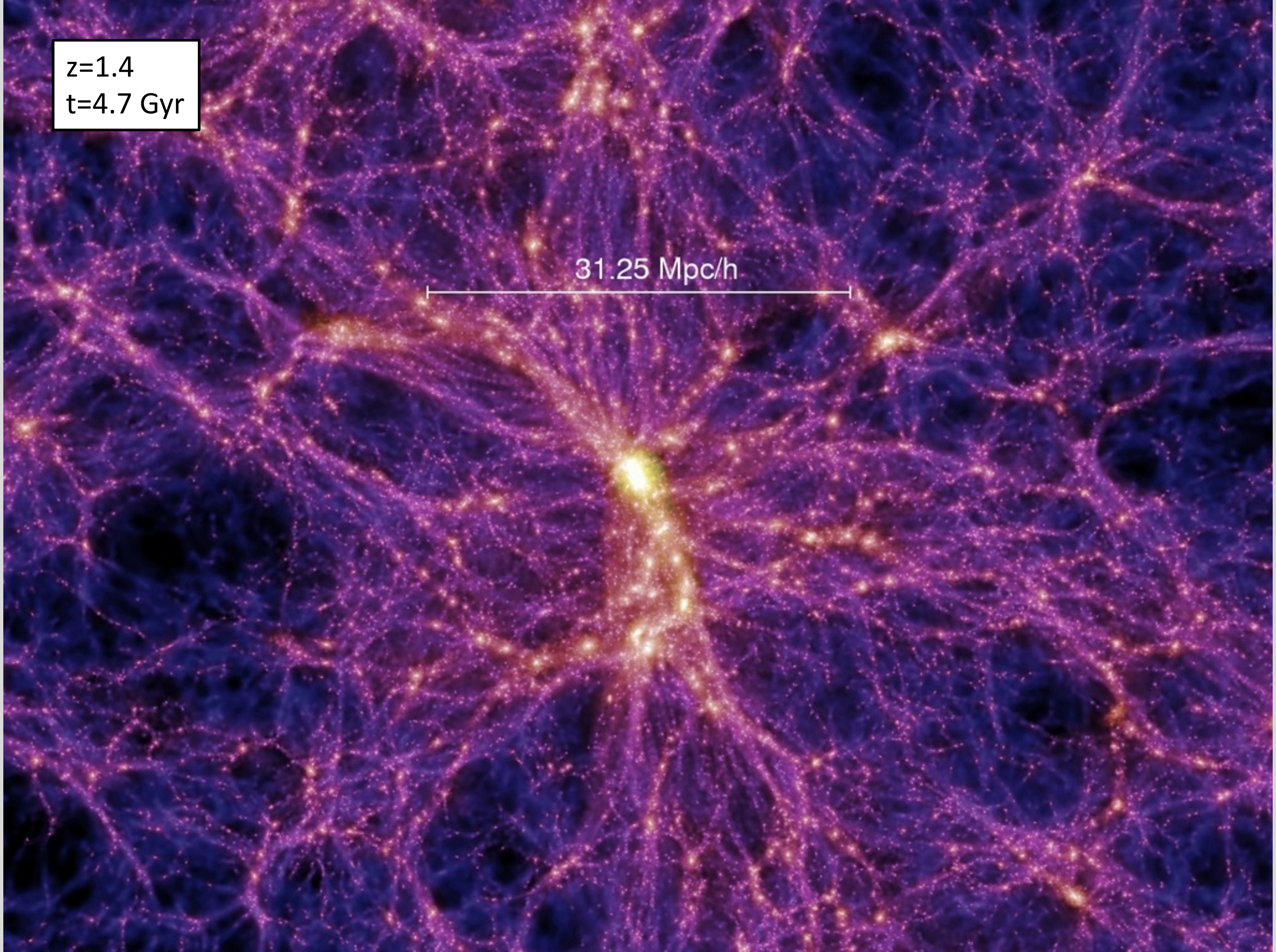
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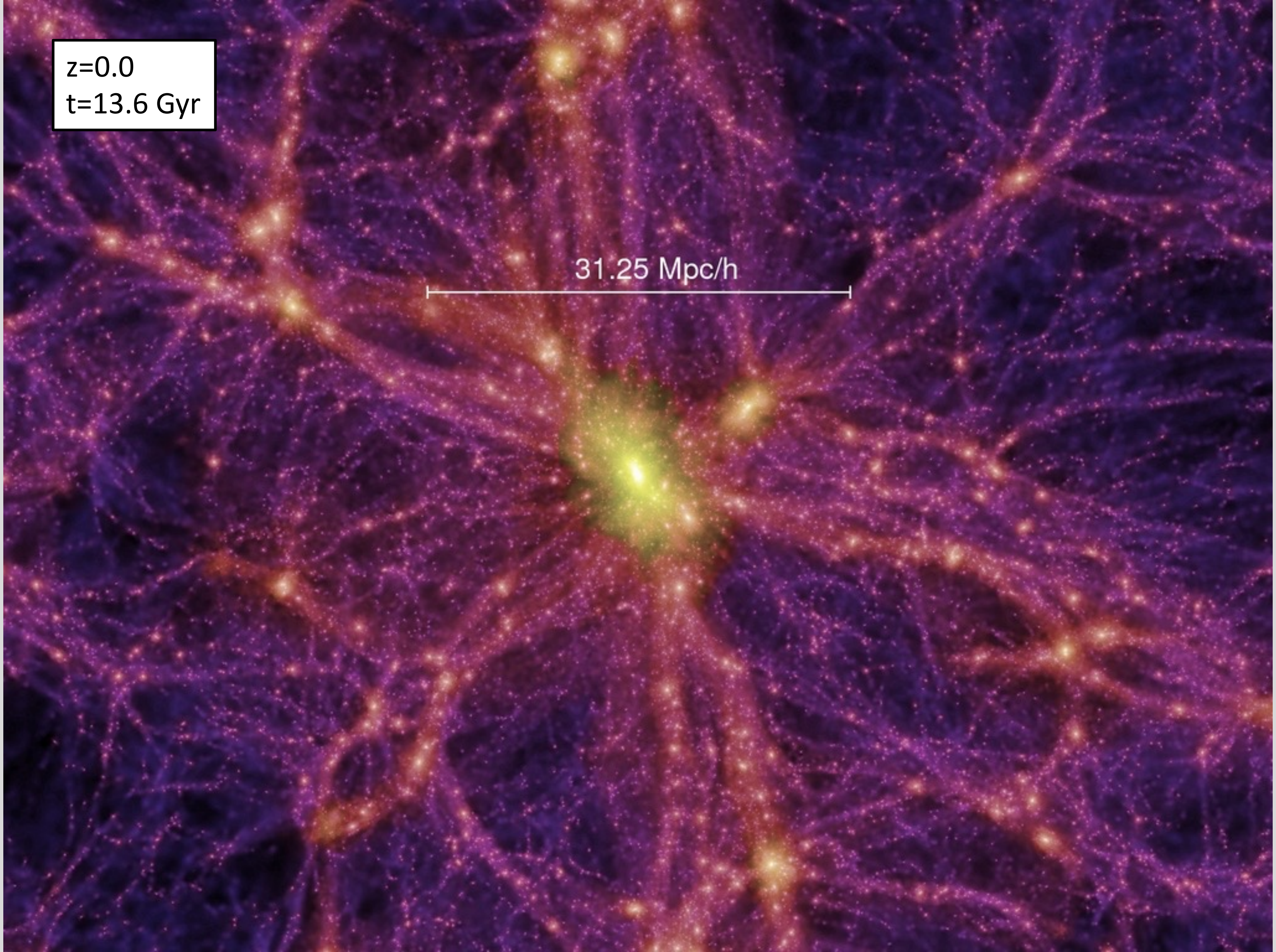

z=0.0
t=13.6 Gyr
31.25 Mpc/h

Step 1: Identifying Galaxy Clusters

Think about the physics of cluster formation

Galaxy clusters are full of stars, gas (hot and cold), and dark matter. In hydrostatic equilibrium, the thermal energy of the hot gas and the gravitational potential energy of the cluster must balance:

$$\frac{GM}{R} \approx kT_{gas}$$

So for a massive cluster like the Coma Cluster,

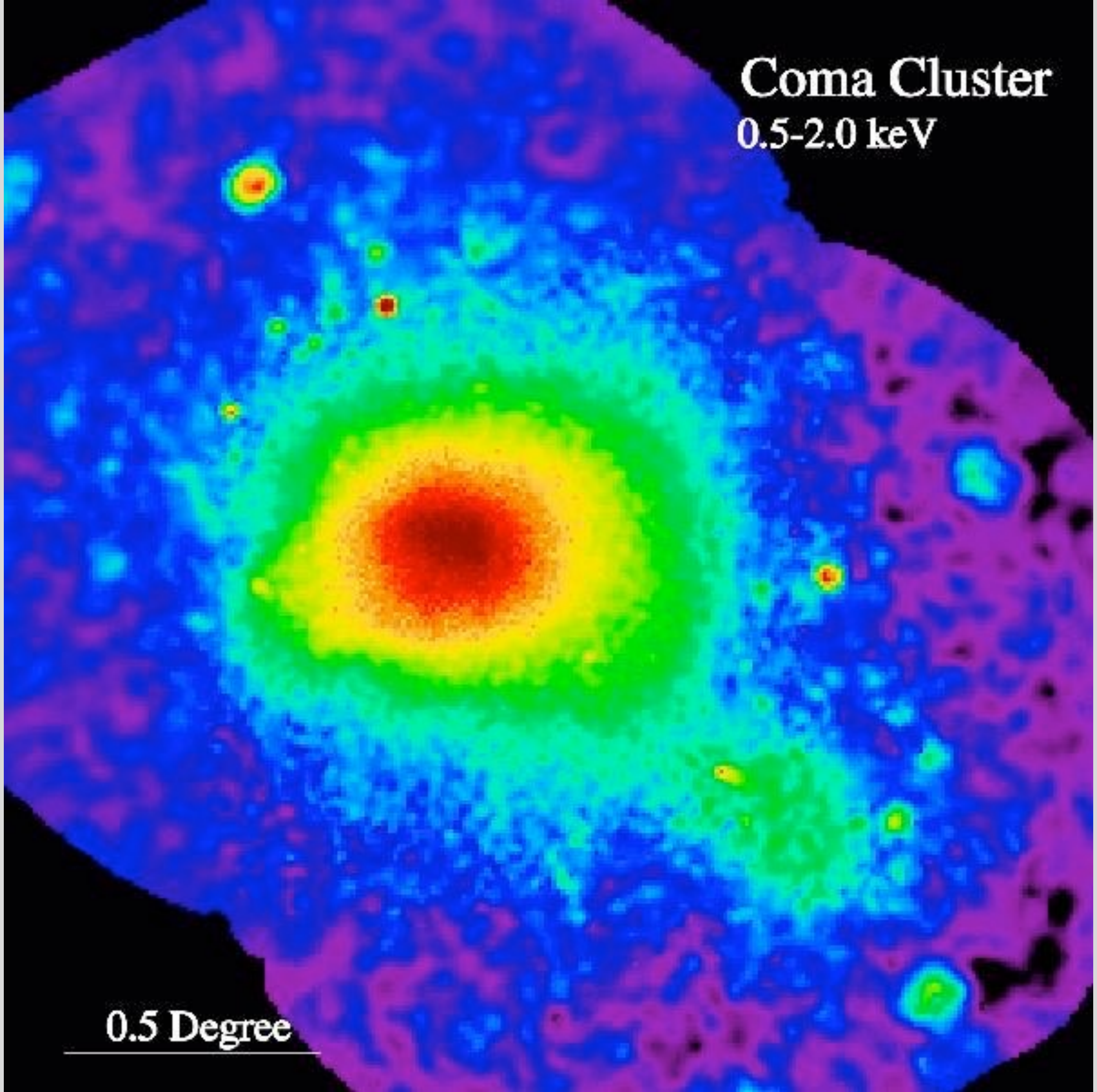
- $M \approx \ 10^{15}\ M_{\odot}$
- $R \approx$ few Mpc
- $T_{gas} \approx \text{few} \times 10^{6}\ \text{K}$

At this temperature the gas is ionized, and emits energy via Bremsstrahlung or ("free-free") radiation.

$kT \approx h\nu$ → soft X-ray emission (keV energies)

Coma Cluster Optical

Coma Cluster X-ray



Step 2: Which galaxies are actually in the cluster?

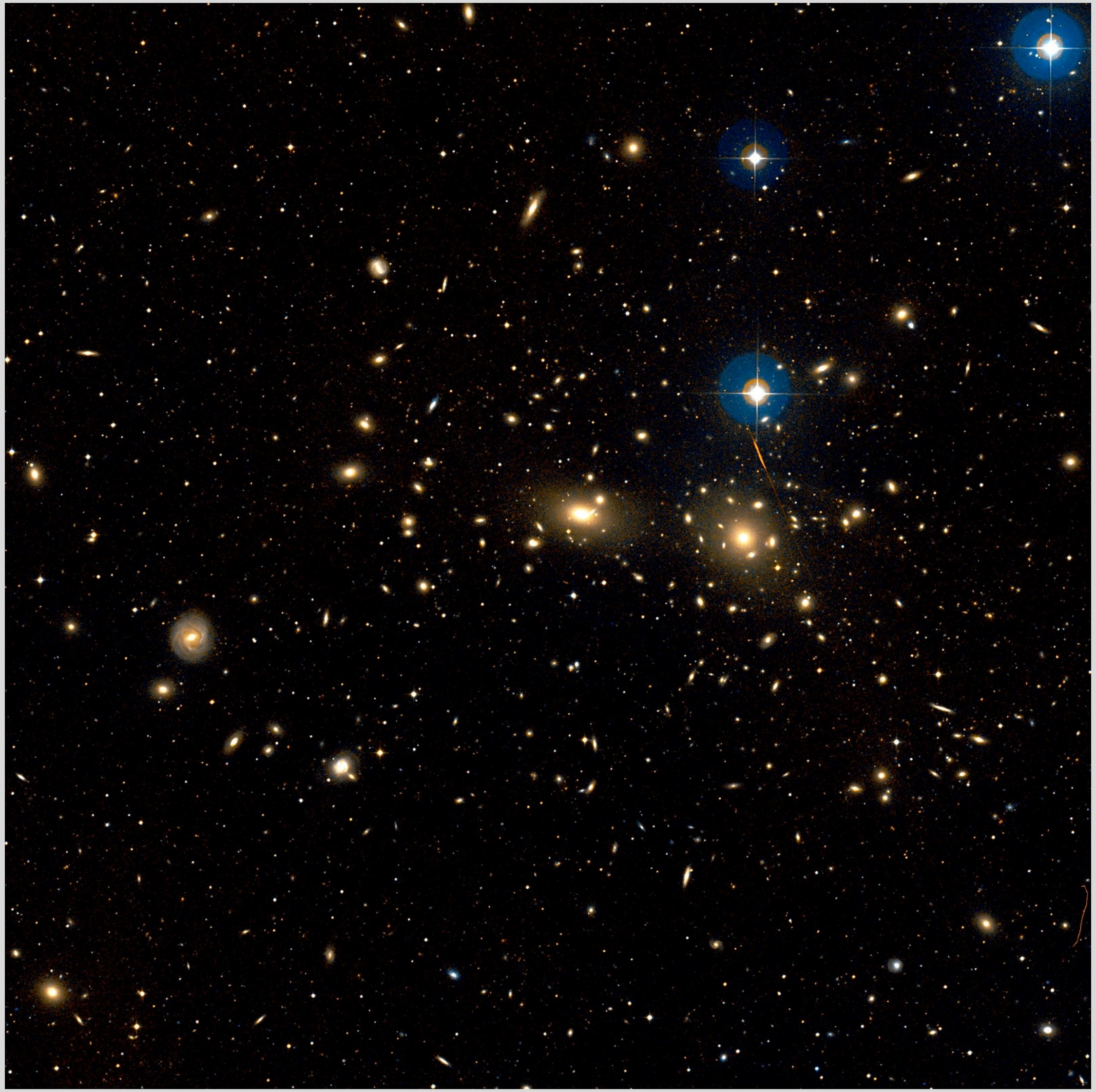
Spectroscopy?

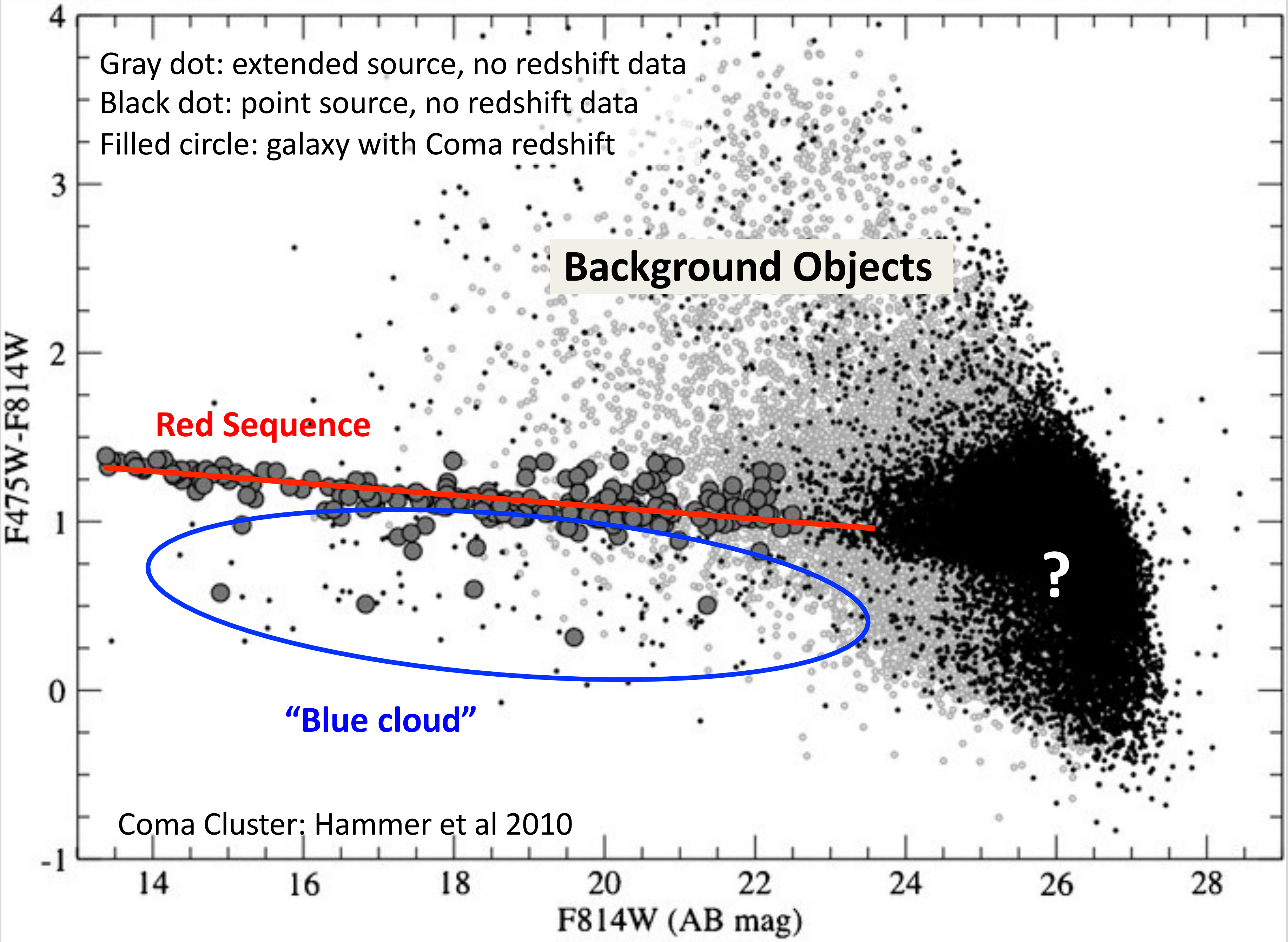
Accurate redshifts, but takes a lot of telescope time.

Particularly hard for faint galaxies or galaxies without emission lines (red galaxies).

Photometry?

Look at the galaxy color-magnitude diagram.




Gray dot: extended source, no redshift data
Black dot: point source, no redshift data
Filled circle: galaxy with Coma redshift
Background Objects
Red Sequence
?
"Blue cloud"
Coma Cluster: Hammer et al 2010
F475W-F814W
F814W (AB mag)
4
3
2
1
0
-1
14
16
18
20
22
24
26
28

Step 3: Which galaxies host active nuclei?

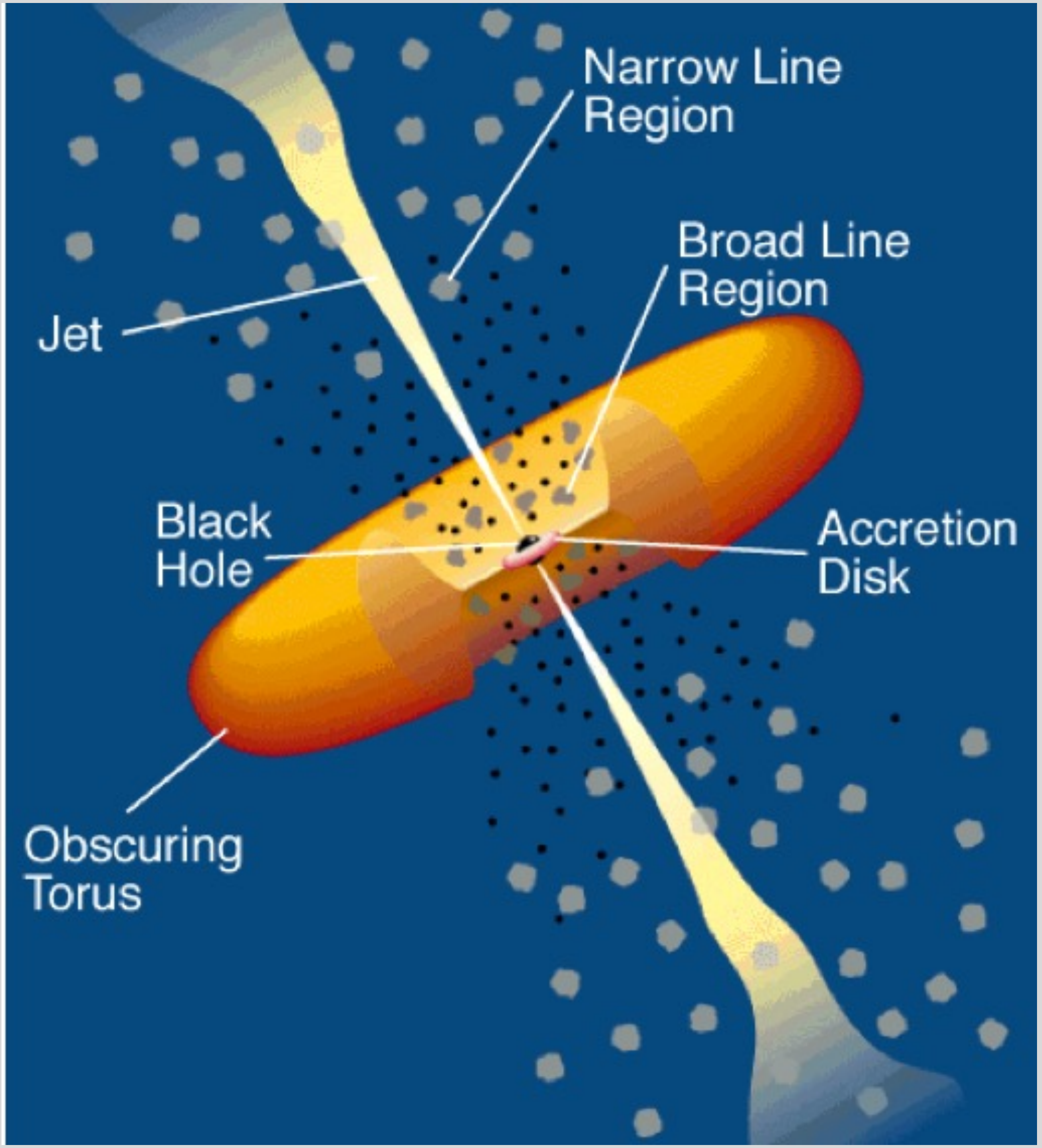
Accretion disk: hot, luminous gas accreting onto the black hole.

Jets: charged particles moving at relativistic speeds out of the nucleus

Broad-line region: Gas clouds near the accretion disk, turbulent motions at high speed.

Dusty torus: a ring of denser gas and dust surrounding the nucleus.

Narrow-line clouds: Gas clouds further out, moving more slowly.



Step 3: Which galaxies host active nuclei?

Optical or Infrared spectroscopy of the inner parts of the galaxies

- High ionization emission lines
- Very blue continuum (from accretion disk, not stars)
- High velocity line widths – fast motions (1000s of km/s)

Spectra: Normal Galaxies

Spectra show integrated starlight (continuum plus stellar absorption lines).

Also see narrow emission lines from ionized gas in star-forming regions.

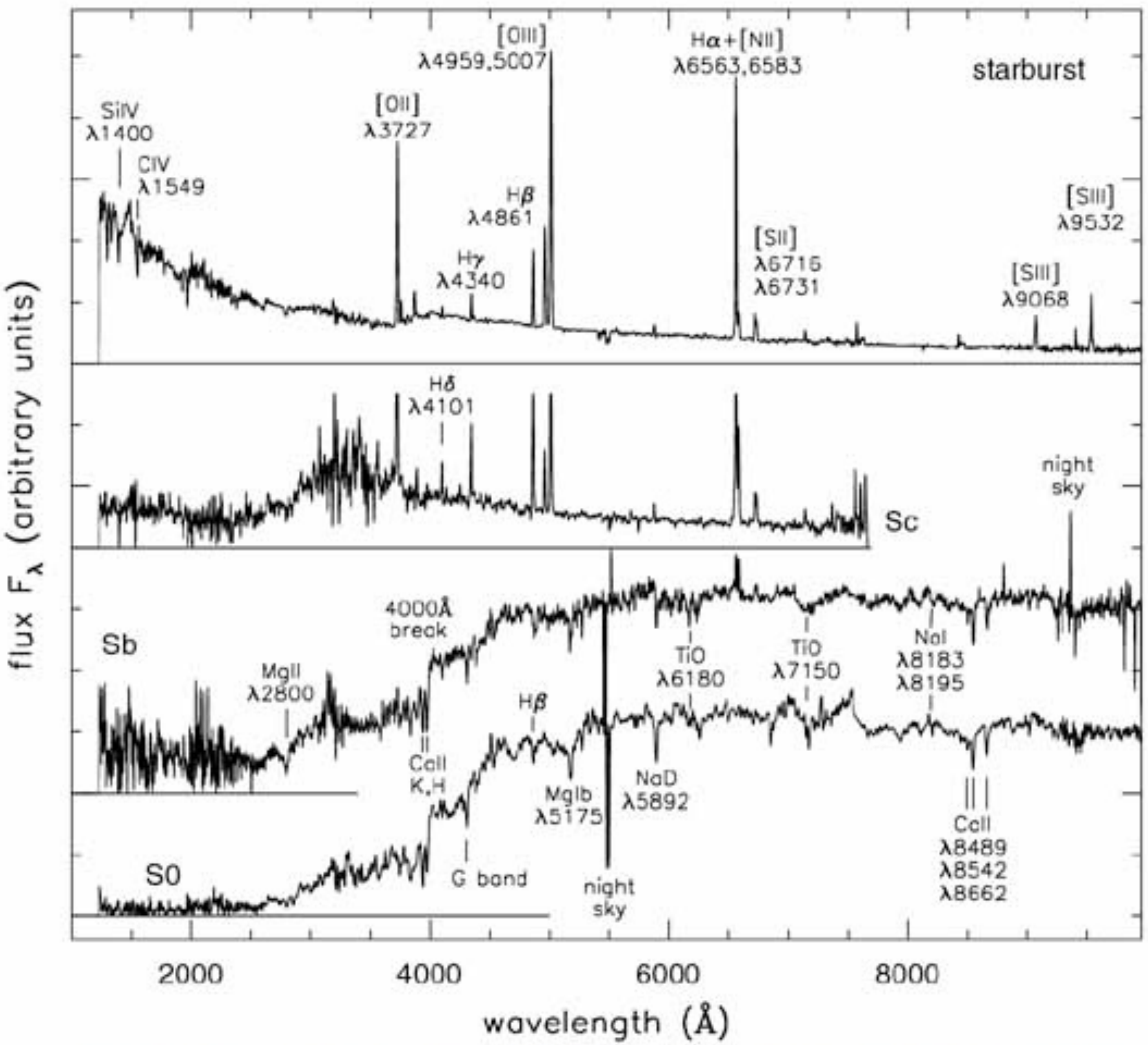


Fig 5.24 (A. Kinney) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Spectra: AGN

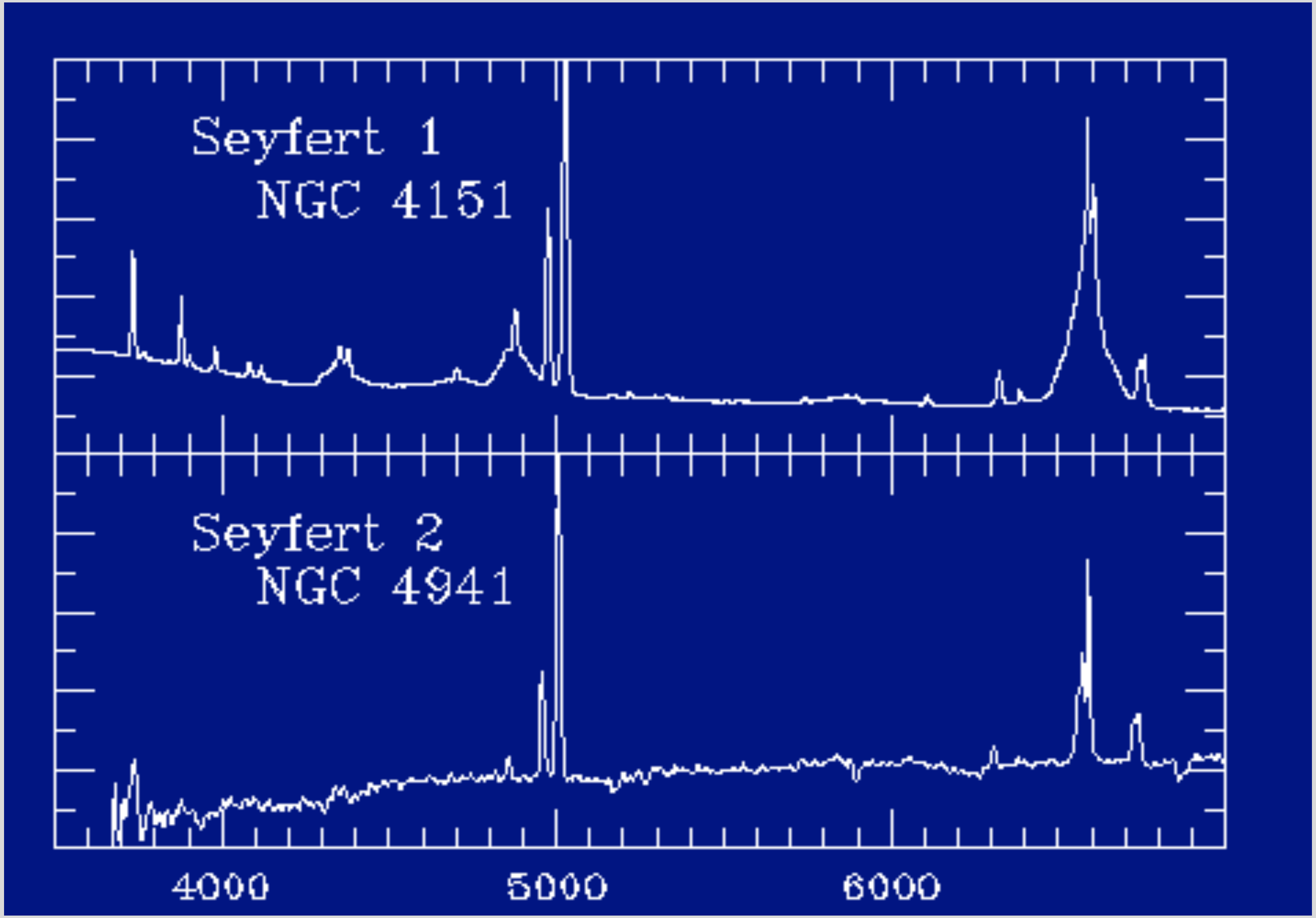
Example: Seyfert galaxies

Type 1: narrow+broad emission lines from ionized gas, also very blue continuum.

Seeing the accretion disk plus broad line region.

Type 2: Narrow emission lines, no blue continuum.

View to the accretion disk is blocked by the surrounding dusy torus.



courtesy Bill Keel, U Alabama

Quasar Spectrum

Very blue continuum, very broad emission lines, very highly ionized atoms: energetic AGN!

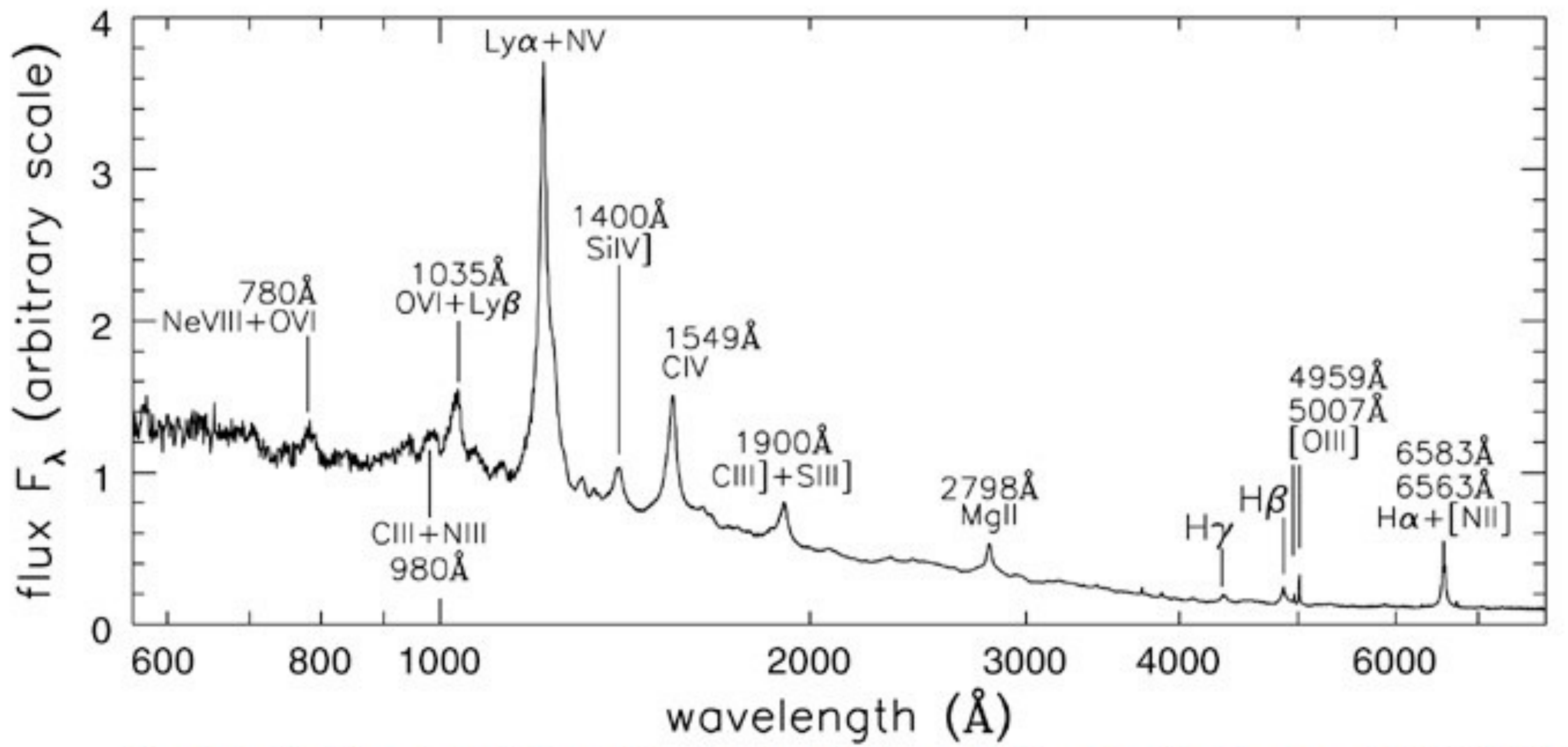
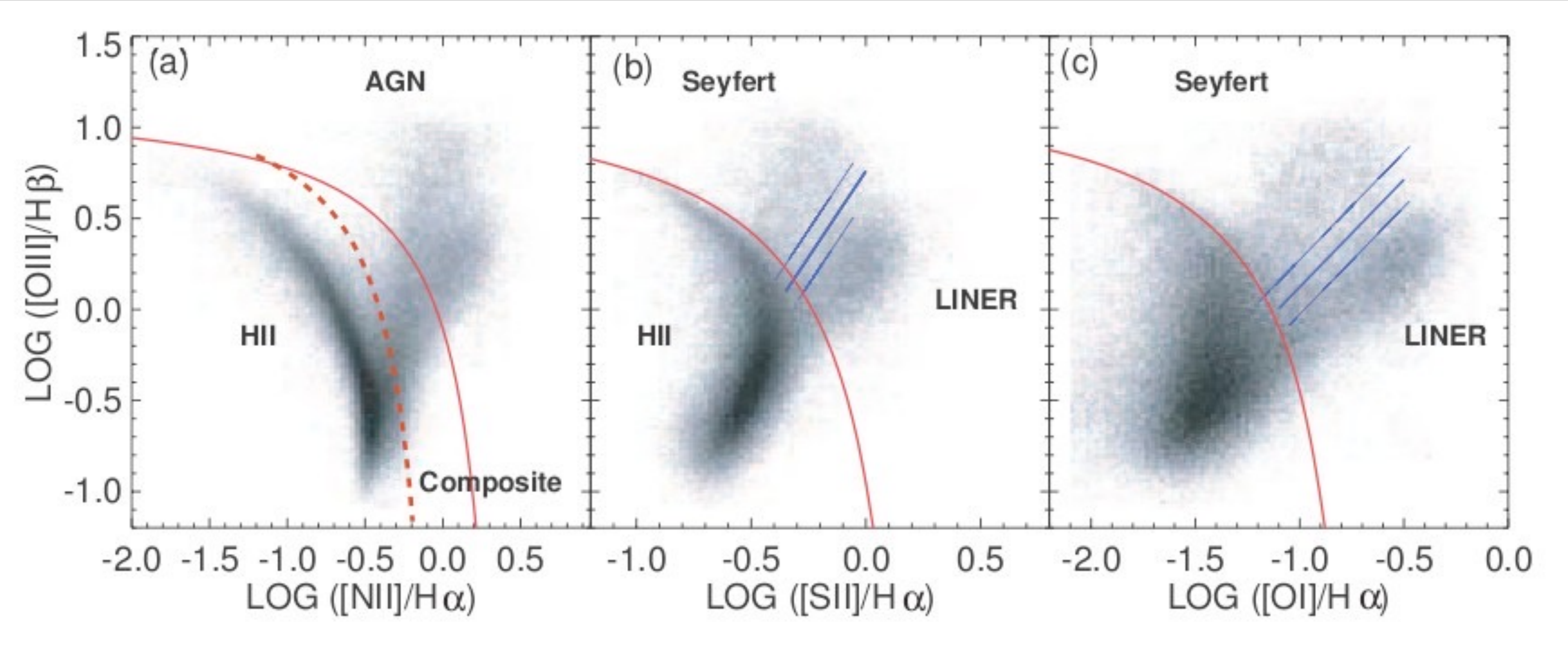


Fig 9.1 (Telfer et al.) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

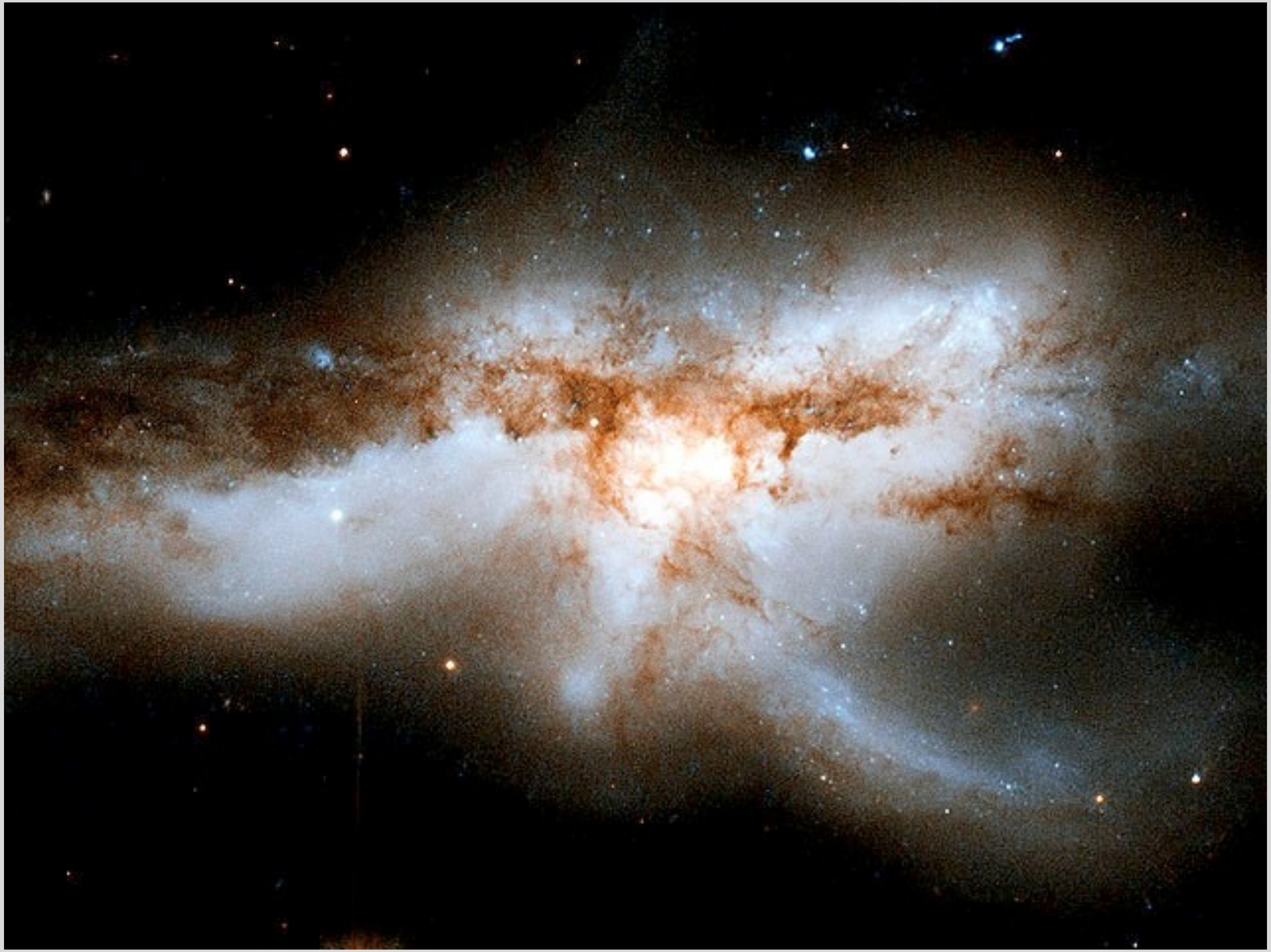
Emission Line Diagnostics



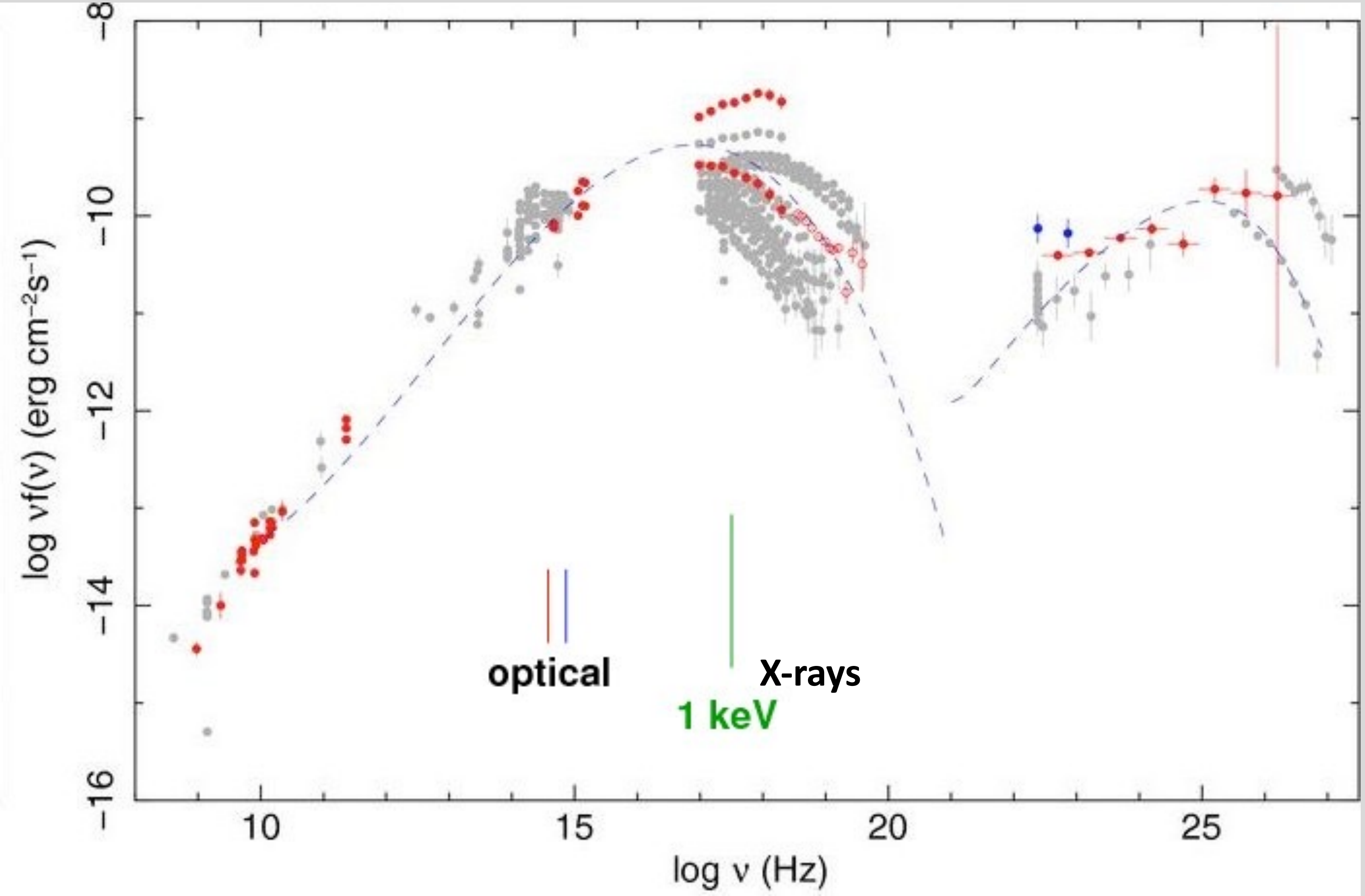
Some emission lines come from normal star formation (gas ionized by hot stars), others come from active nuclei (gas ionized by accretion disk). Line ratios can be used to tell the difference.

(from Groves and Kewley 2008 via Mike [Richmond's Top 10 Signs You've Found an AGN]page.)

What about dusty galaxies

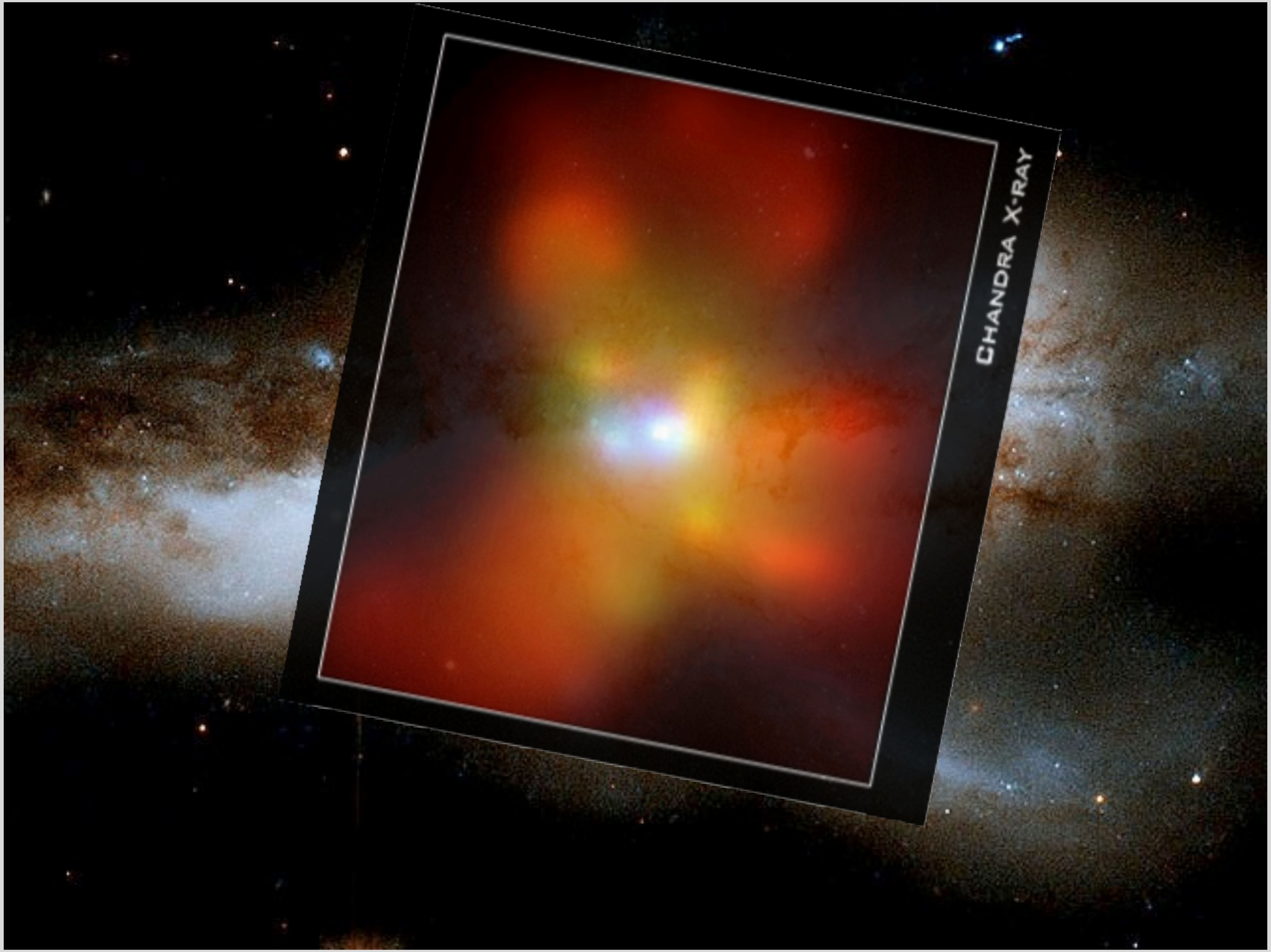


Multi-wavelength AGN spectrum



AGN emit lots of hard X-rays, which easily can be seen through dust.

(from Abdo 2010 via Mike [Richmond's Top 10 Signs You've Found an AGN]page.)


CHANDRA X-RAY

Step 3: Which galaxies host active nuclei?

Optical or Infrared spectroscopy of the inner parts of the galaxies

- High ionization emission lines
- Very blue continuum (from accretion disk, not stars)
- High velocity line widths – fast motions (1000s of km/s)

Hard X-ray emission

- More robust: can detect AGN in very dusty/obscured galaxies
- Can easily detect AGN even at higher redshifts.

Project overview

Step 1: Find galaxy clusters

Look for soft X-ray sources in all sky surveys (ROSAT)

Step 2: Decide which galaxies are members of the cluster

Use optical imaging and spectroscopy to build a cluster CMD (SDSS)

Step 3: Search for AGN in the clusters

Look for hard X-ray sources in pointed observations (Chandra)

Step 4: Study cluster galaxies that host AGN

Use imaging (morphology/colors) and spectroscopy to study galaxies hosting AGN (SDSS)

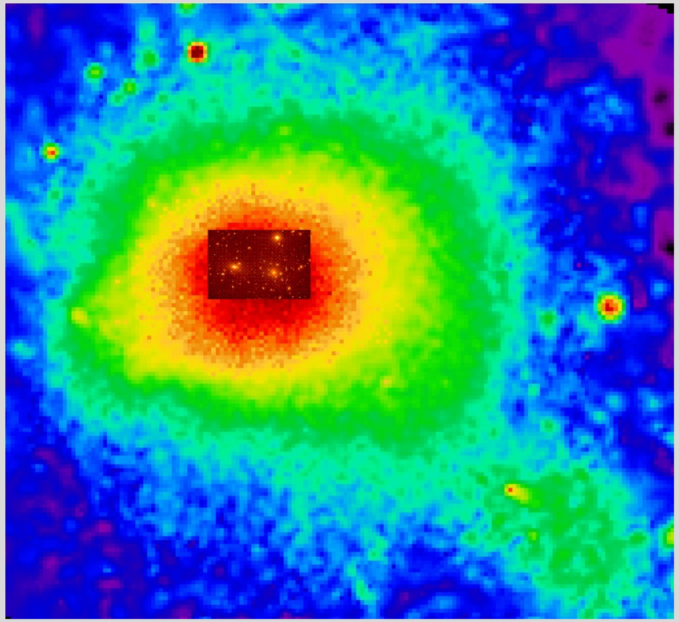
X-ray Astronomy

Our project uses X-ray data for two things:

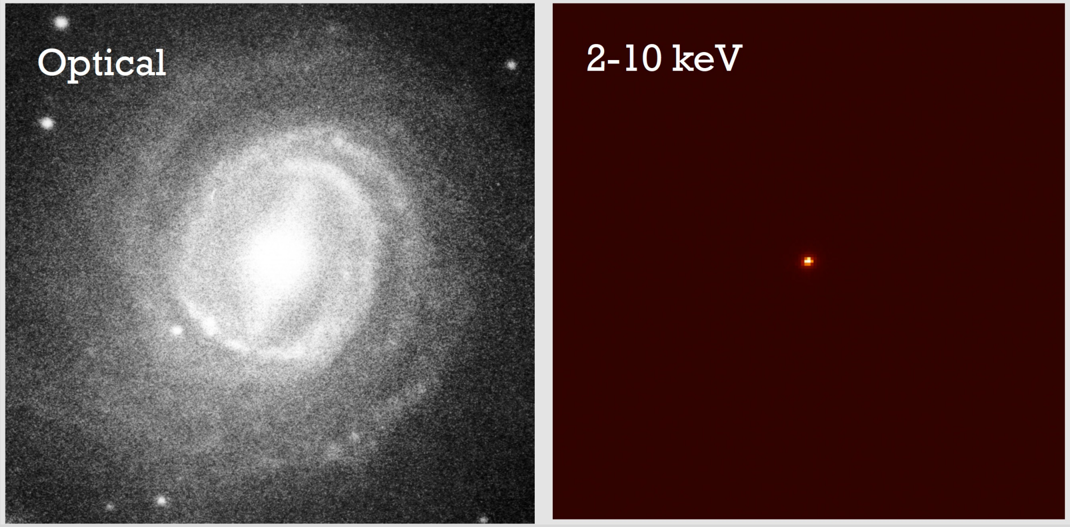
1. **Finding galaxy clusters** by the hot X-ray emitting gas that fills the cluster. Low energy "soft" X-rays, with energies of about 1-2 keV. Spatially extended on the scale of the galaxy cluster.

2. **Finding AGN** by the X-rays emitted from the hottest part of the accretion disk around the black hole. Both "soft" and "hard" X-rays, with energies above 2 keV. Since the actual AGN is so small it is unresolved spatially: X-ray point sources.

Coma cluster in soft X-rays



AGN in hard X-rays

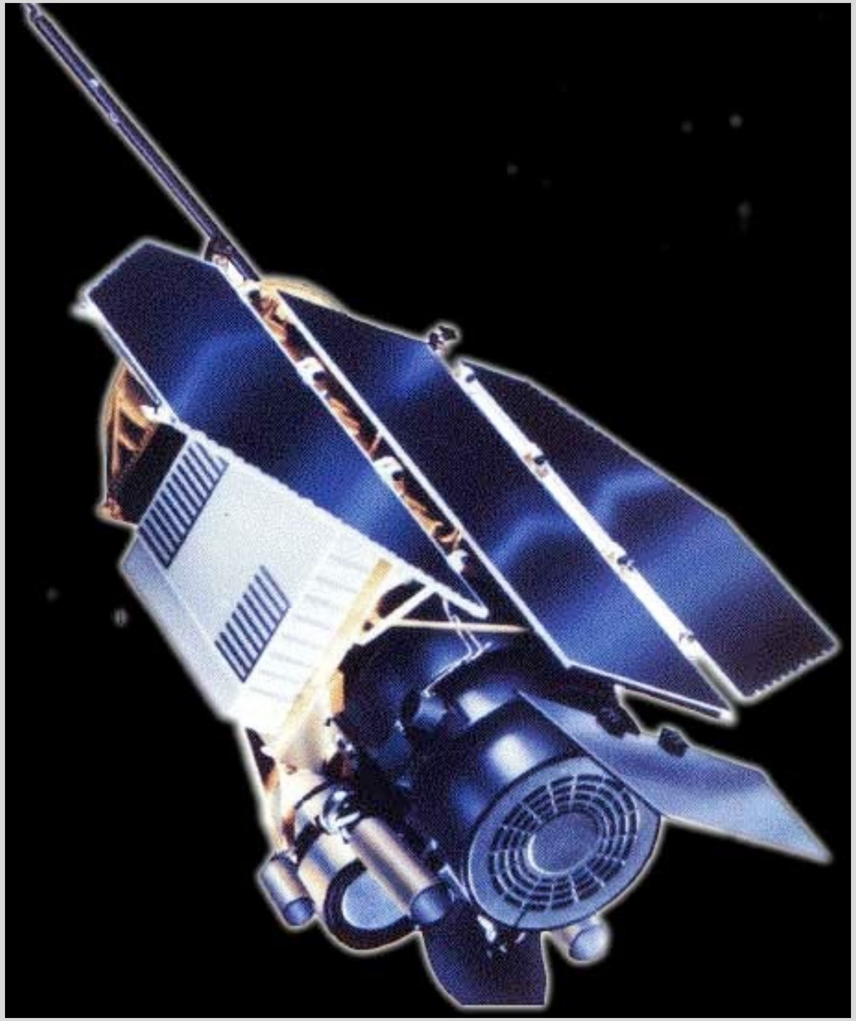


X-ray "**hardness**" $= \ (H - S)/(H + S)$

where

- S = soft X-ray flux from 0.5 − 2 keV
- H = hard X-ray flux from 2 − 10 keV

essentially a measure of "X-ray color"

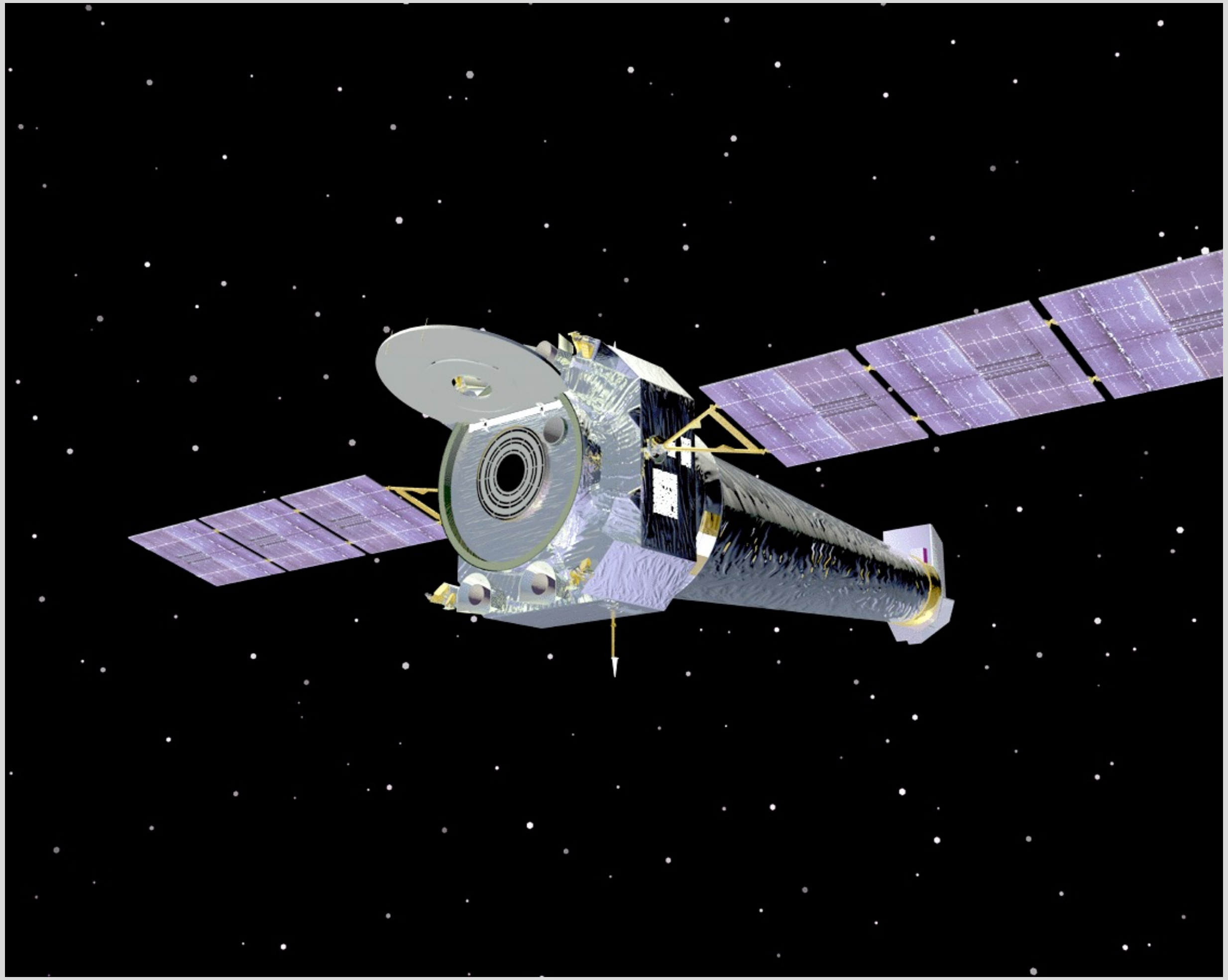


ROSAT – Roentgen Satellite

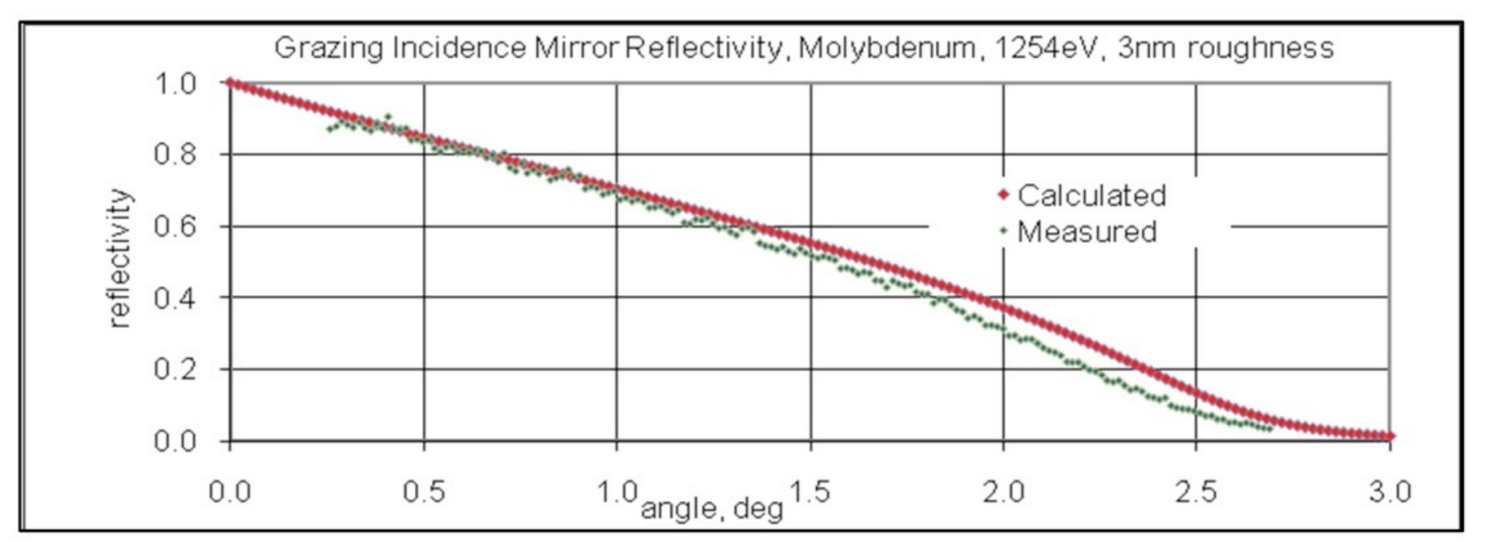
Joint facility: US, Germany, UK
Operated 1990 – 1999
All-sky survey + pointed observations

Chandra X-ray Observatory

US Mission
Operating 1999 – present
Pointed observations

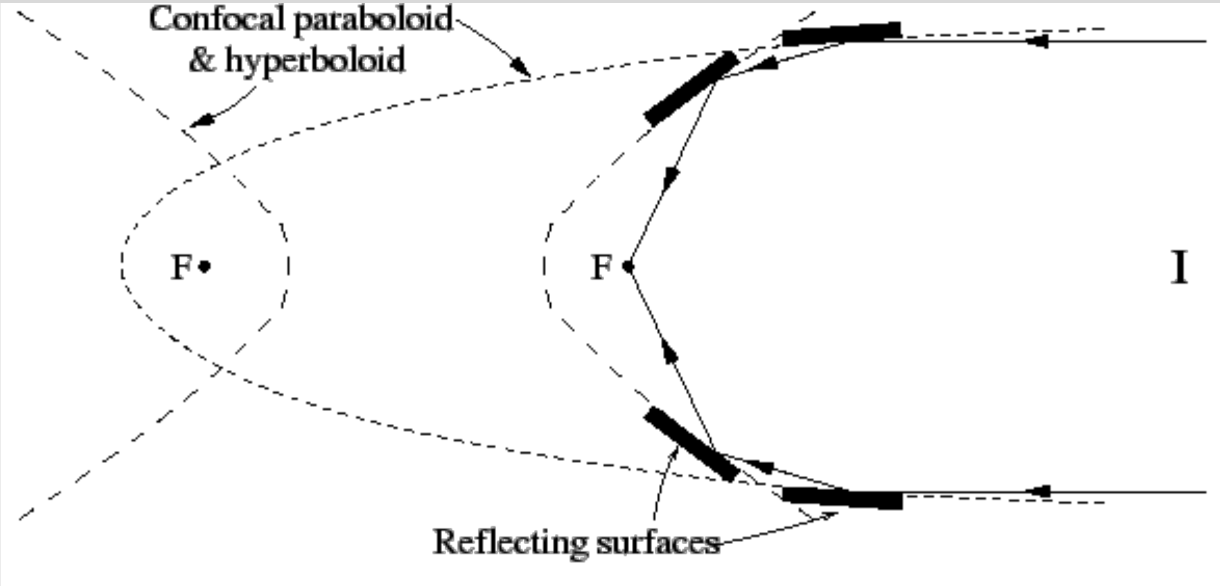


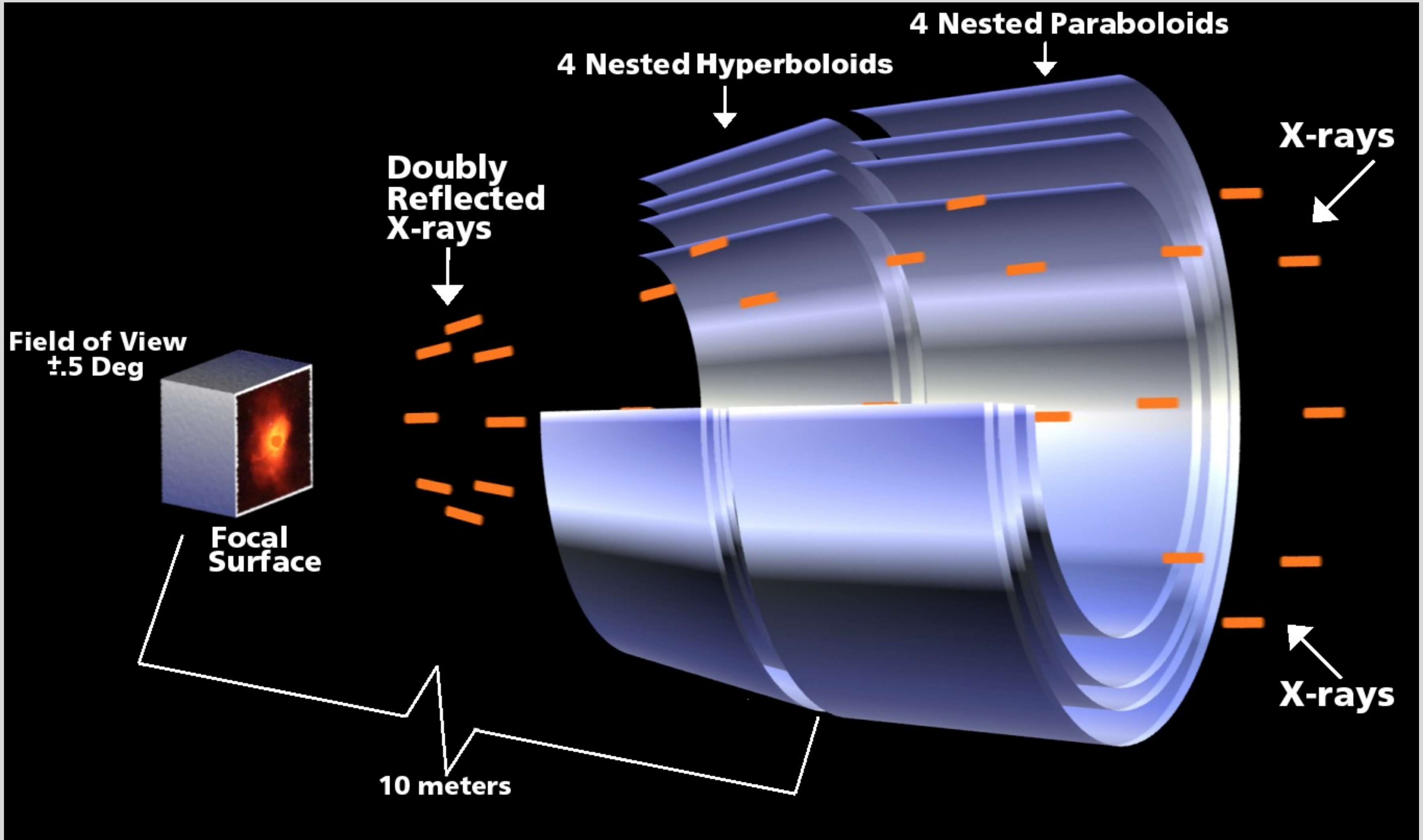
How do you focus X-rays?



Wolter X-ray telescope

- What is the collecting area (the size) of the telescope?
- How can we improve the collecting area?





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