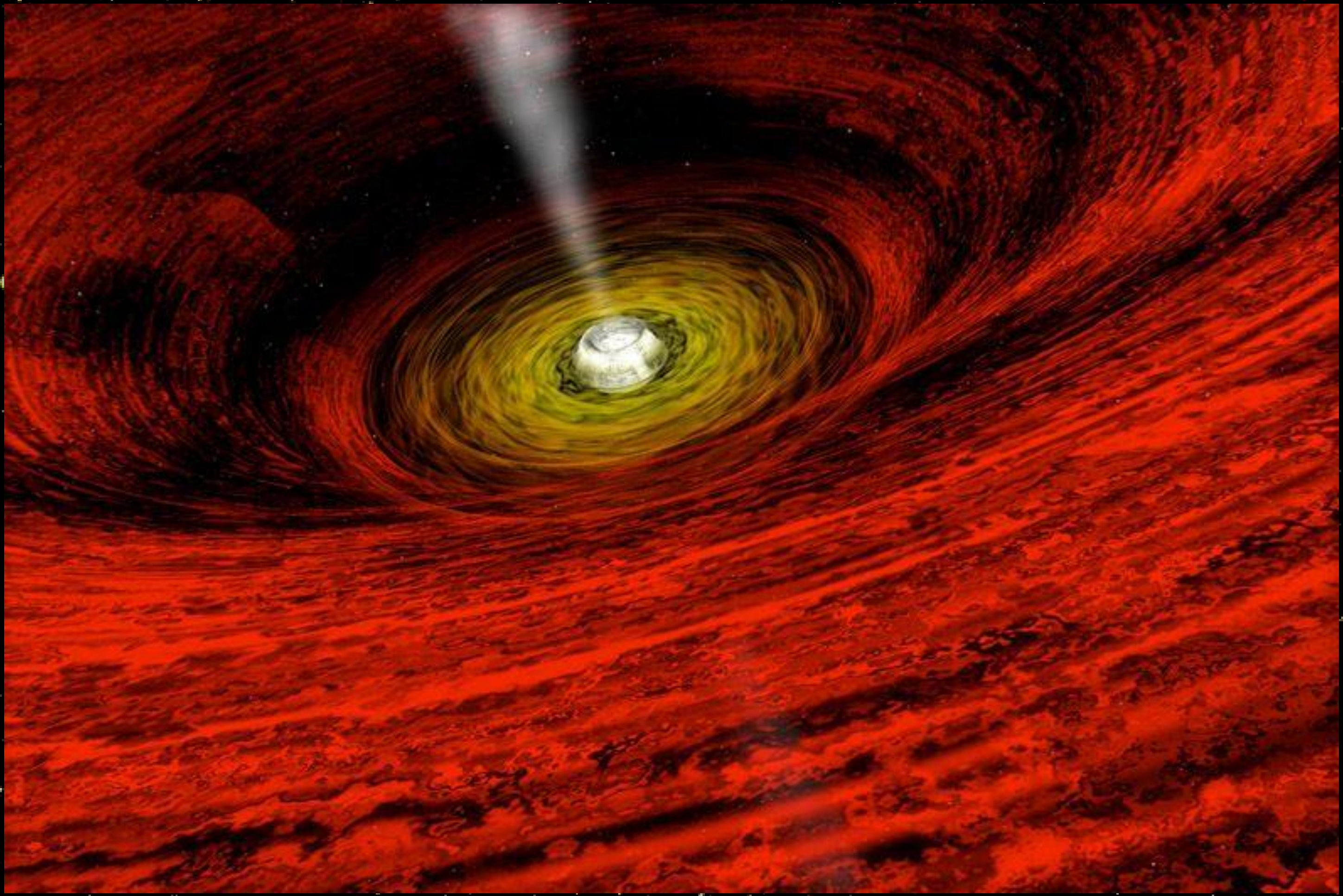
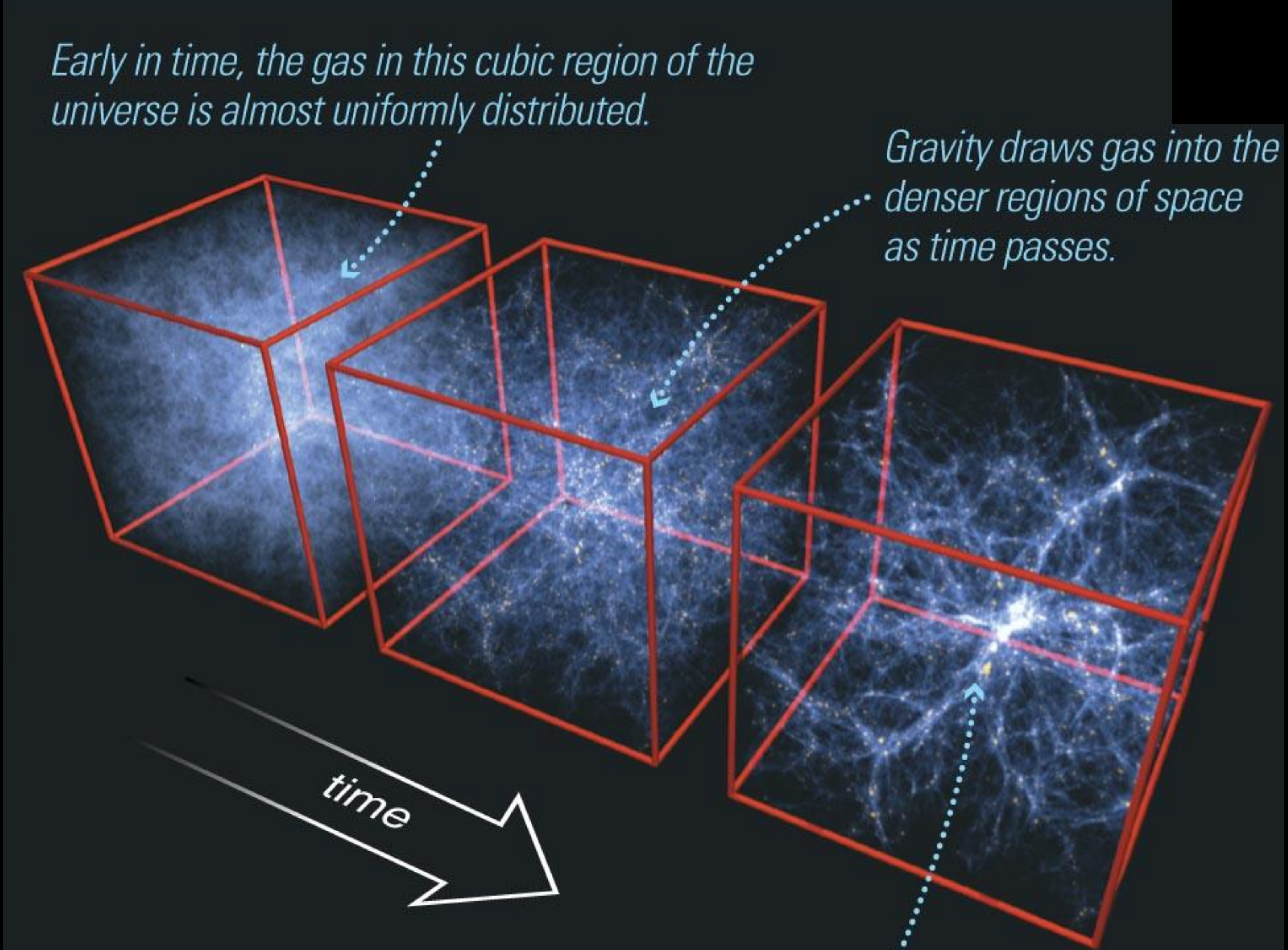
Feeding the Beast

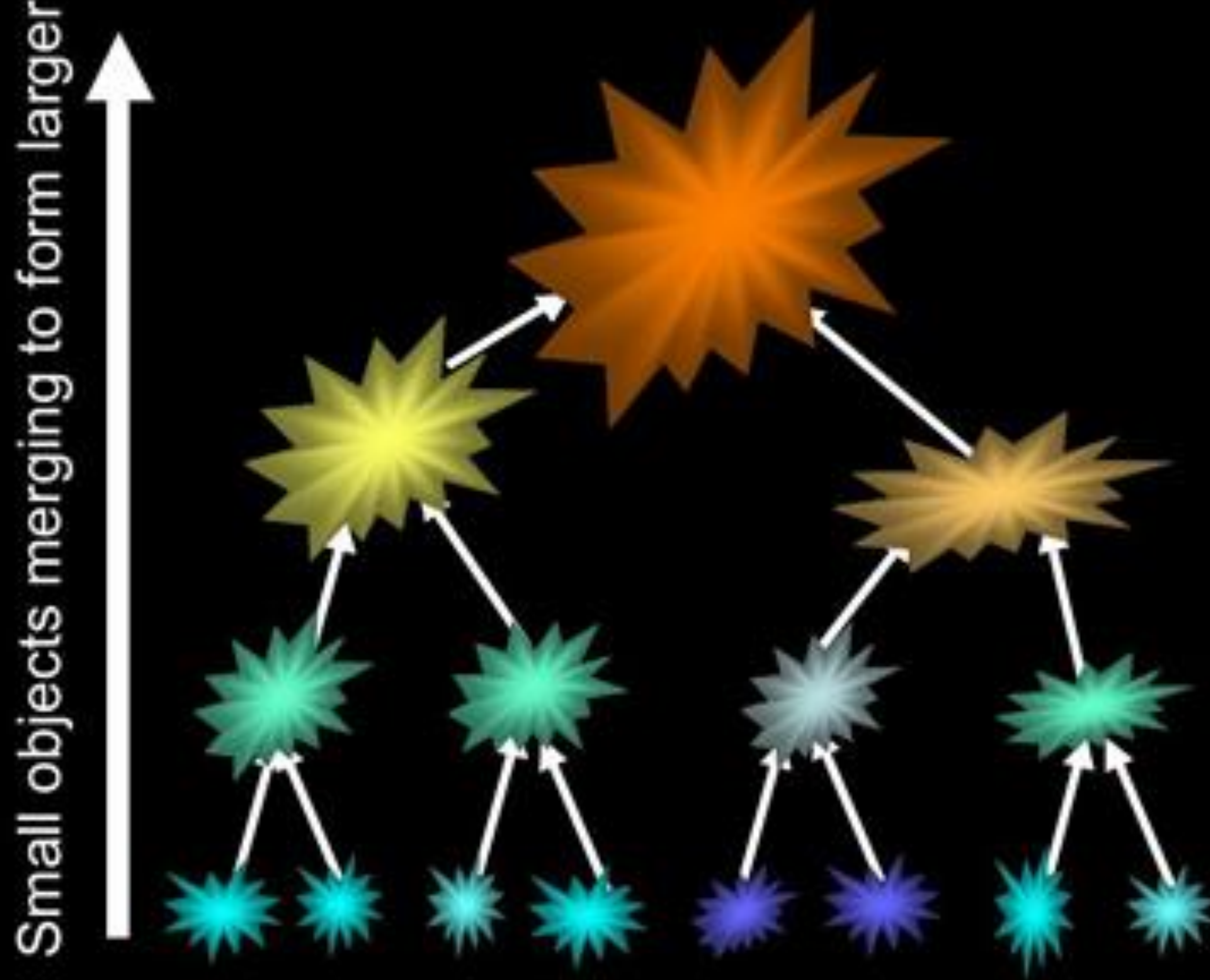


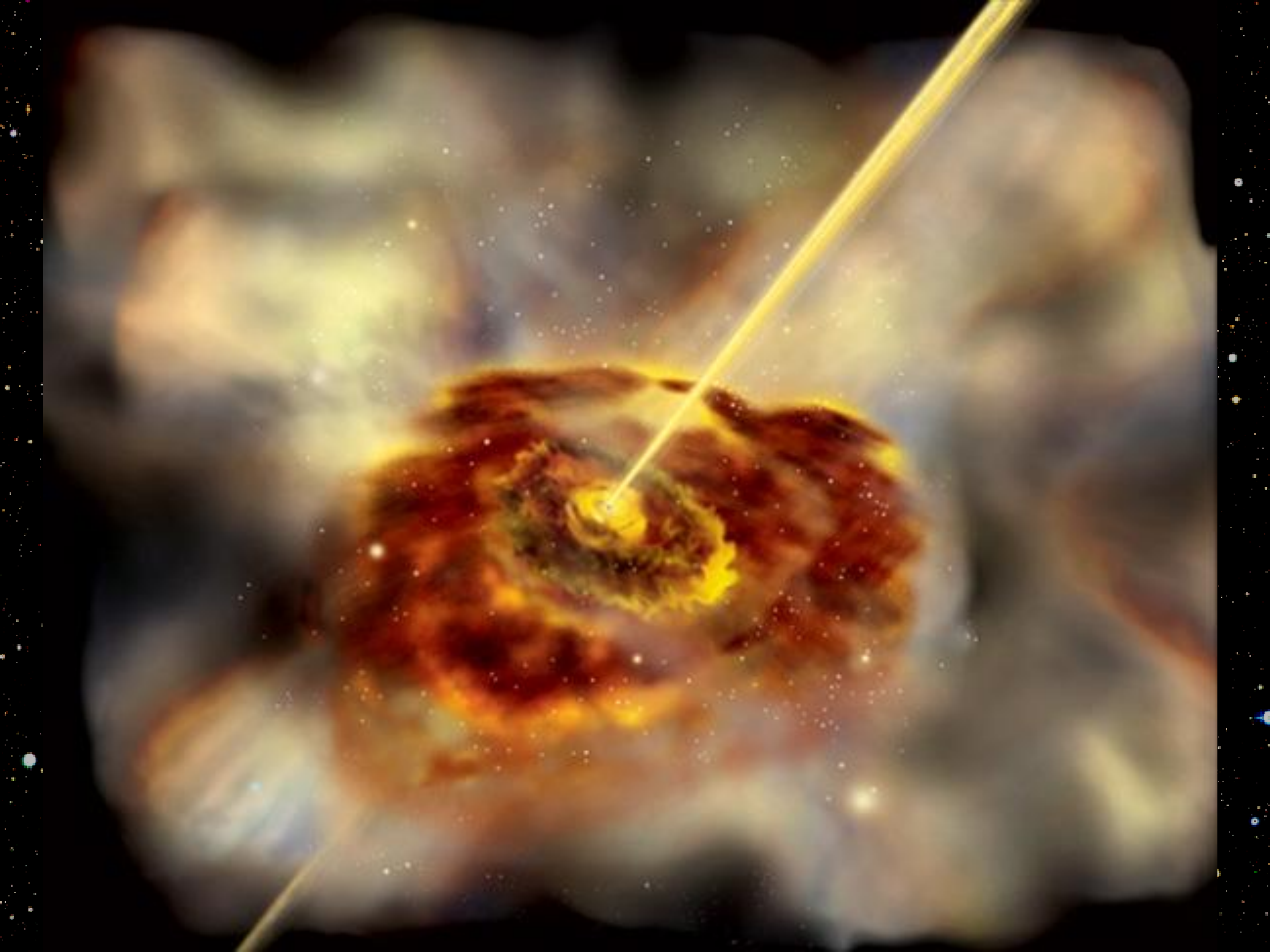
Chris Impey (University of Arizona)



Note: the box is growing due to cosmic expansion but this is "factored out."

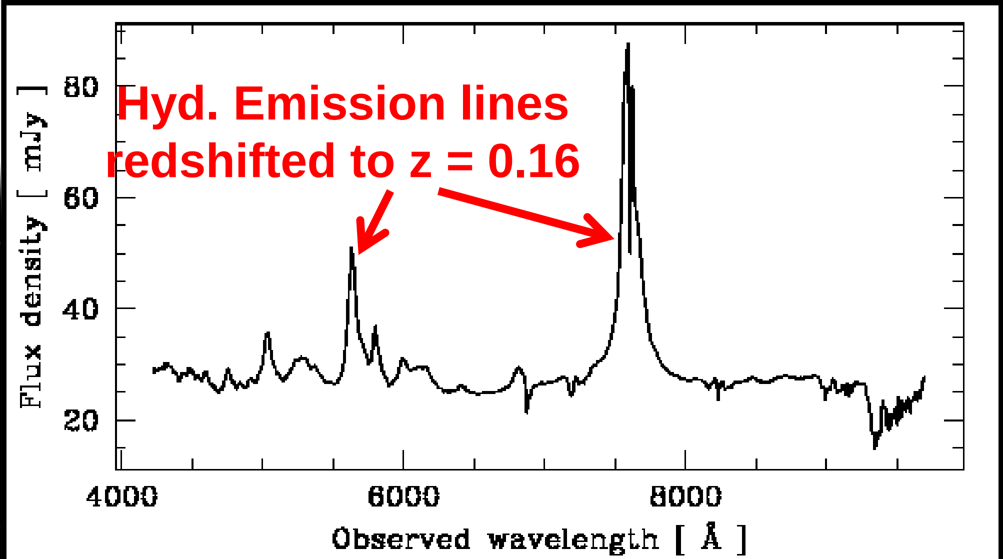
Heirarchical Structure

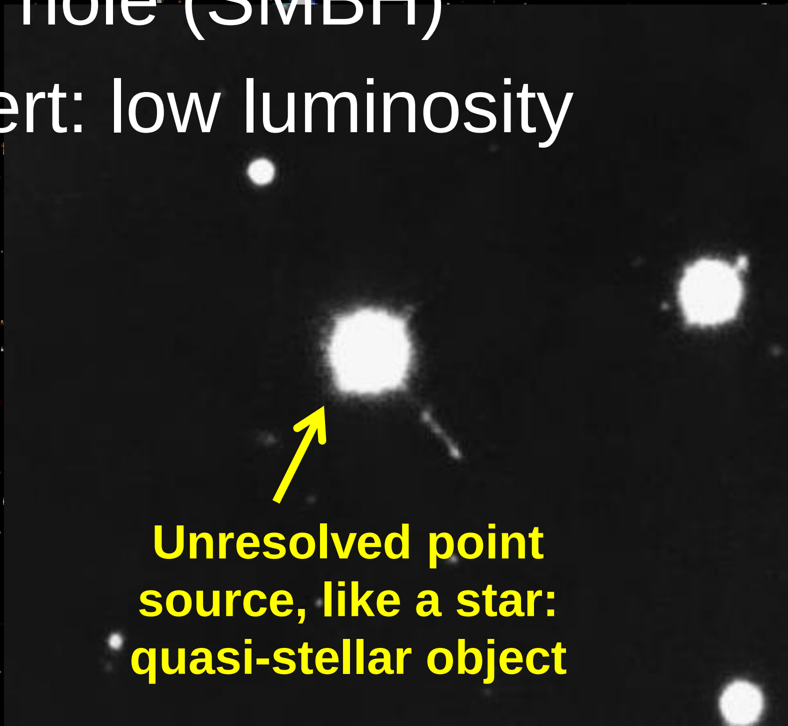




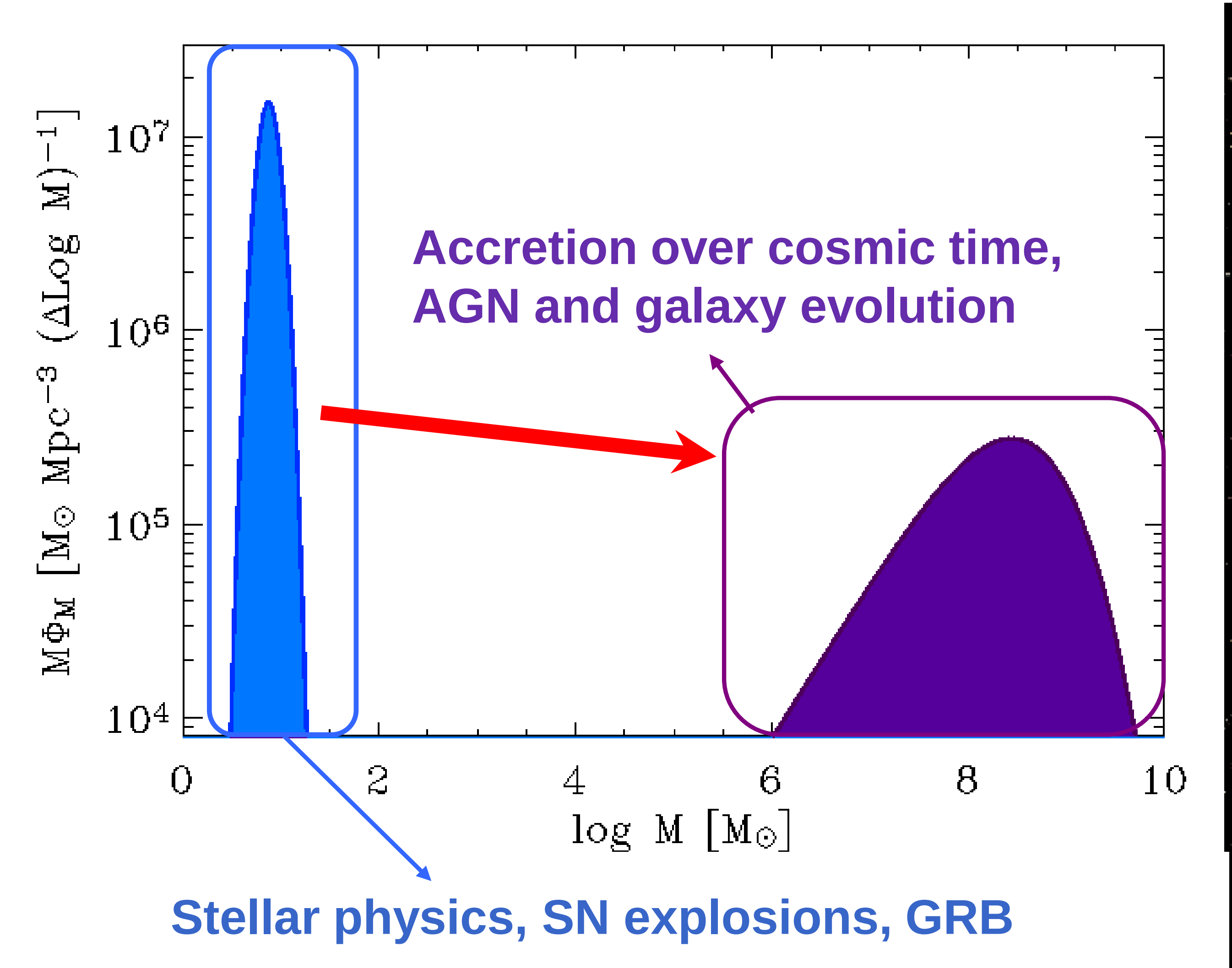
Active Galactic Nuclei (AGN)

- Nuclear activity in galaxies known since 1940's
- Luminous AGN (QSO's) discovered in 1960's
- Luminosity requires a gravity engine: accretion onto a super-massive black hole (SMBH)
- QSO: high luminosity, Seyfert: low luminosity



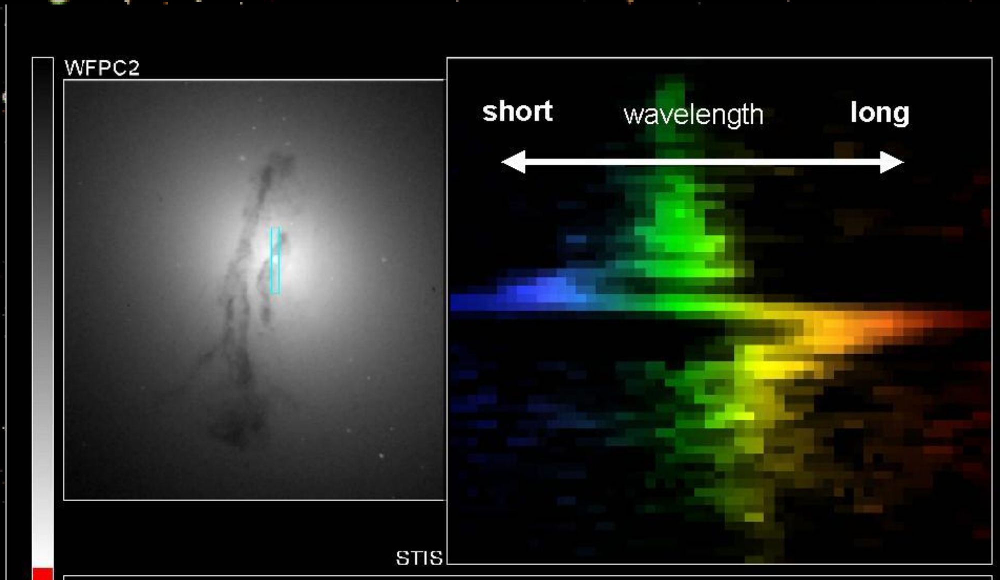


Black Holes Big and Small



Black Holes in Galaxies

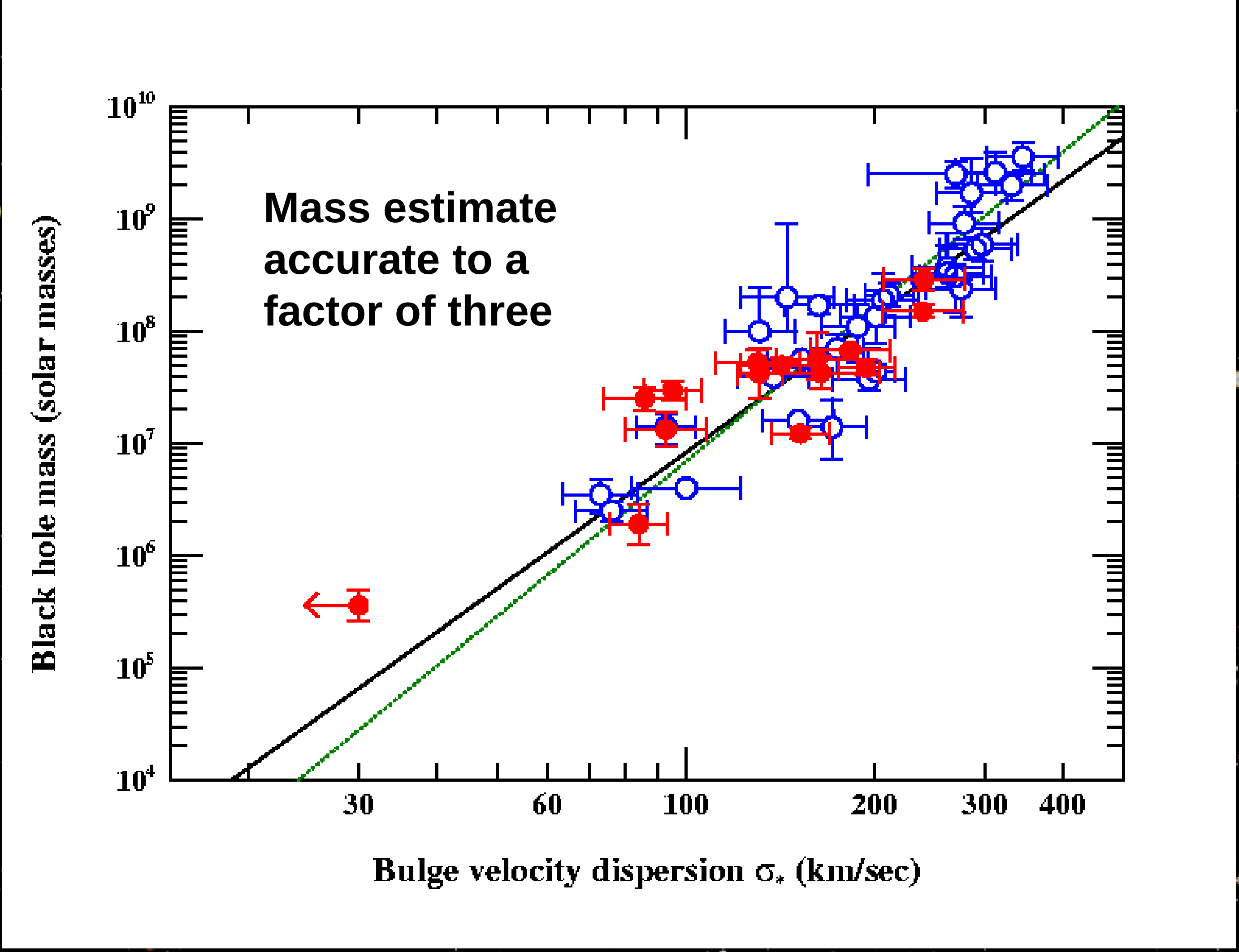
- All nearby galaxies have massive black holes at their centers. The Milky Way is a good example.
- These black holes are mostly dormant.
- All galaxies may pass through a quasar-like stage. The BH is revealed by high central gas velocities.

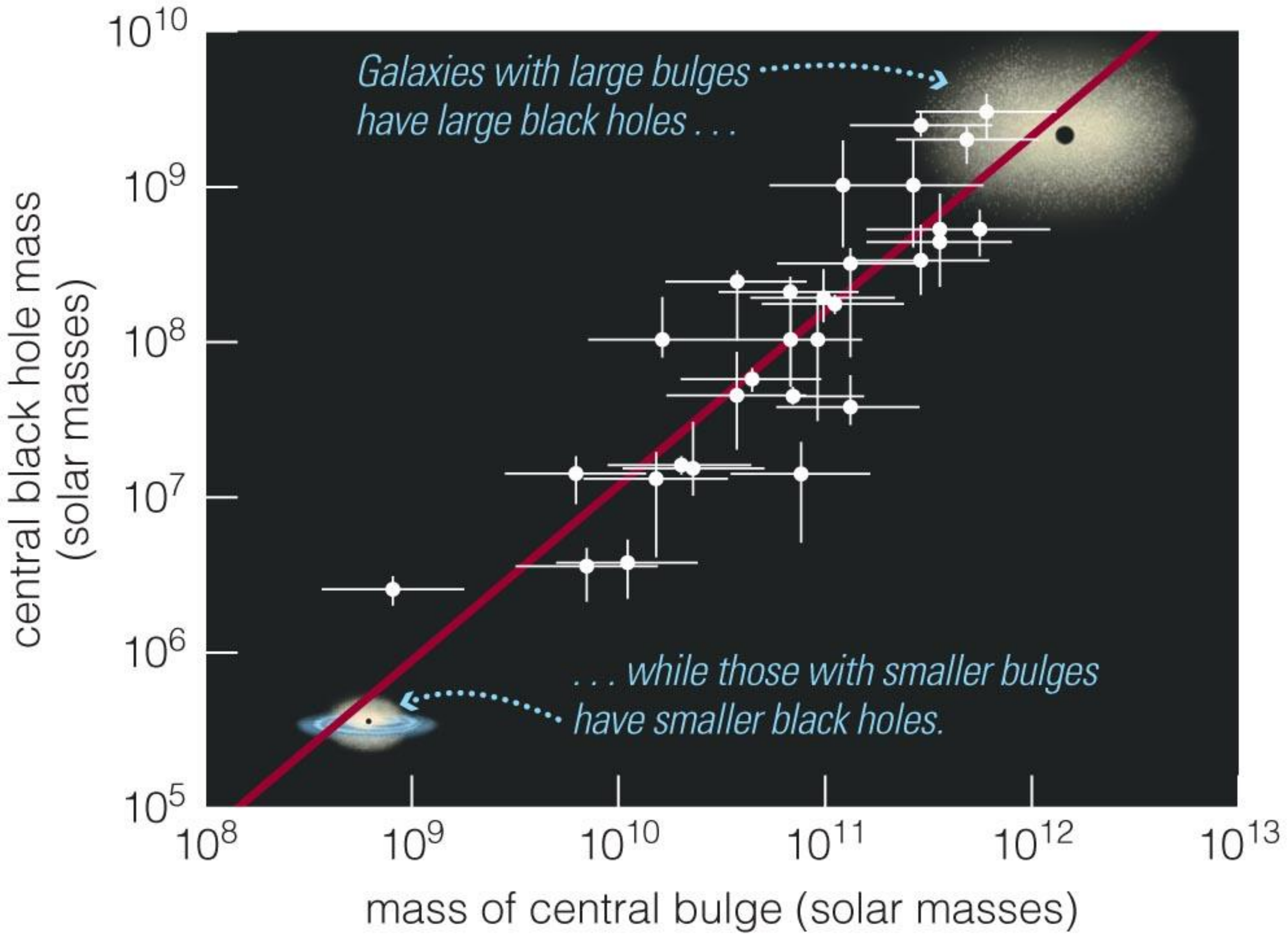


Supermassive Black Holes

- SMBH Ubiquitous
- Cycles of activity
  - Active like AGN
  - Passive like Sag A* in our Milky Way
- May be obscured by gas/dust
  - From host galaxy
  - Or local to AGN
- Key role in galaxy evolution

Black Hole Masses

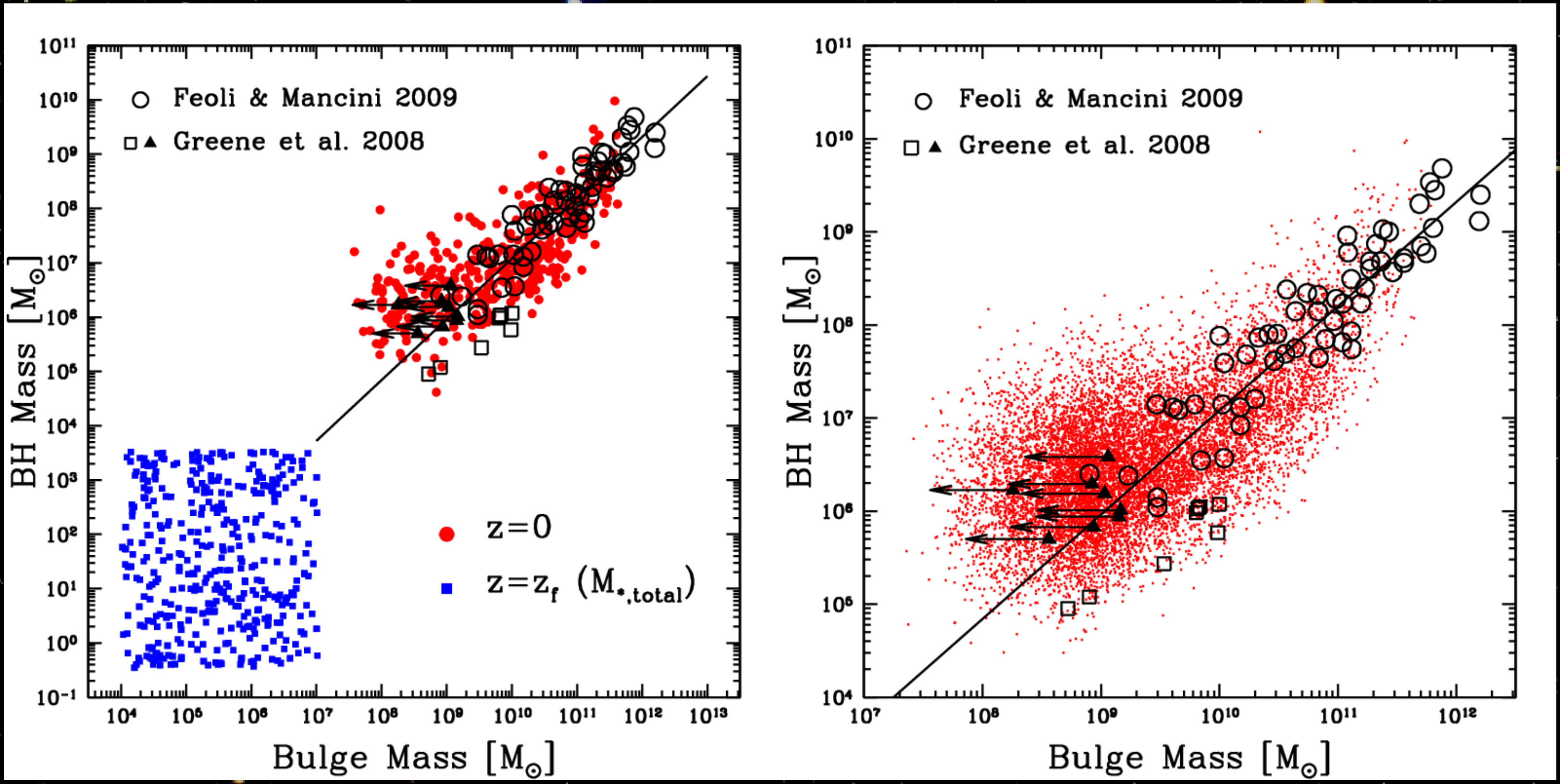




Galaxies with large bulges have large black holes . . .
. . . while those with smaller bulges have smaller black holes.
central black hole mass (solar masses)
mass of central bulge (solar masses)
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}
10^{13}

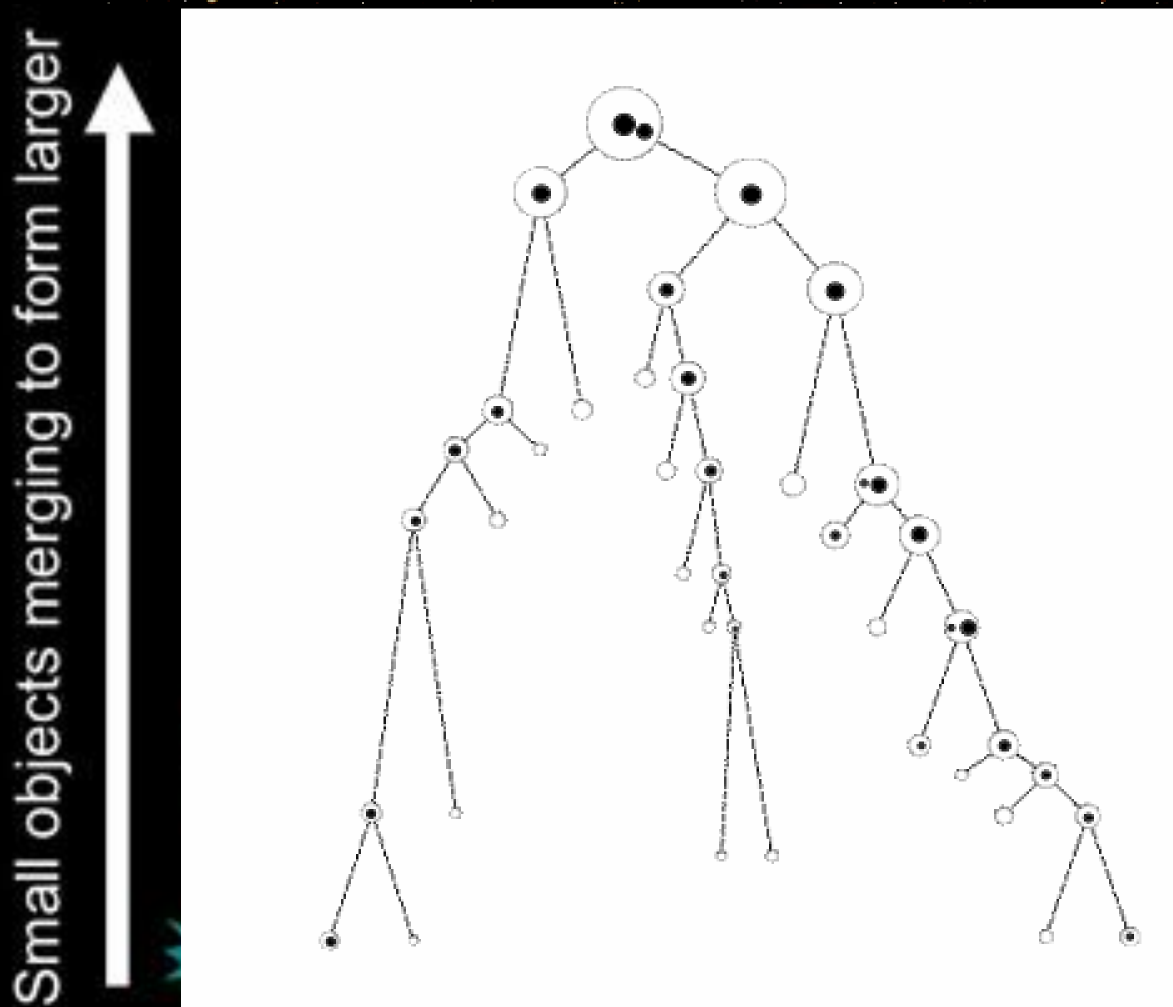
SMBH and the Host Galaxy

- Tight relation between M_{BH} and M_{bulge} or L_{bulge}
- Every galaxy has a SMBH, and they co-evolve

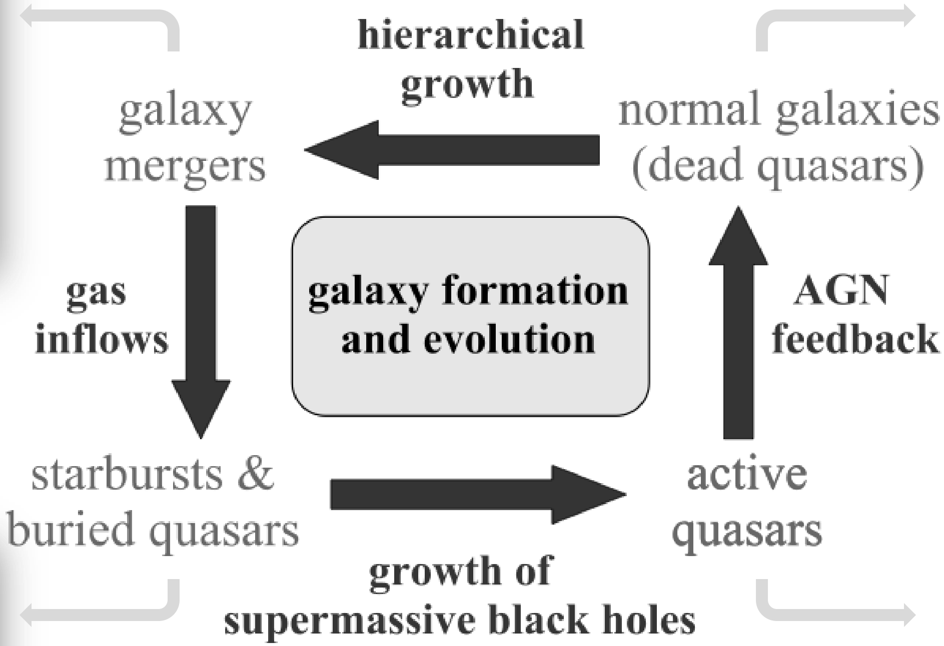


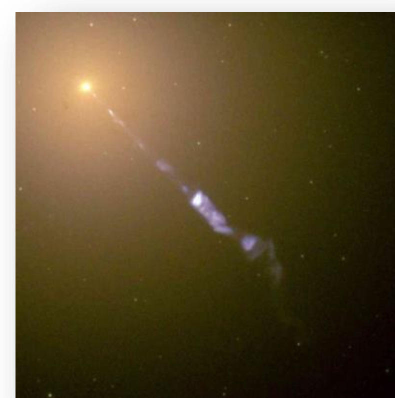
Mergers and Acquisitions

- Galaxies and SMBH grow together by mergers.
- How do their growth rates change over cosmic time?
- Which came first, galaxies or SMBH?



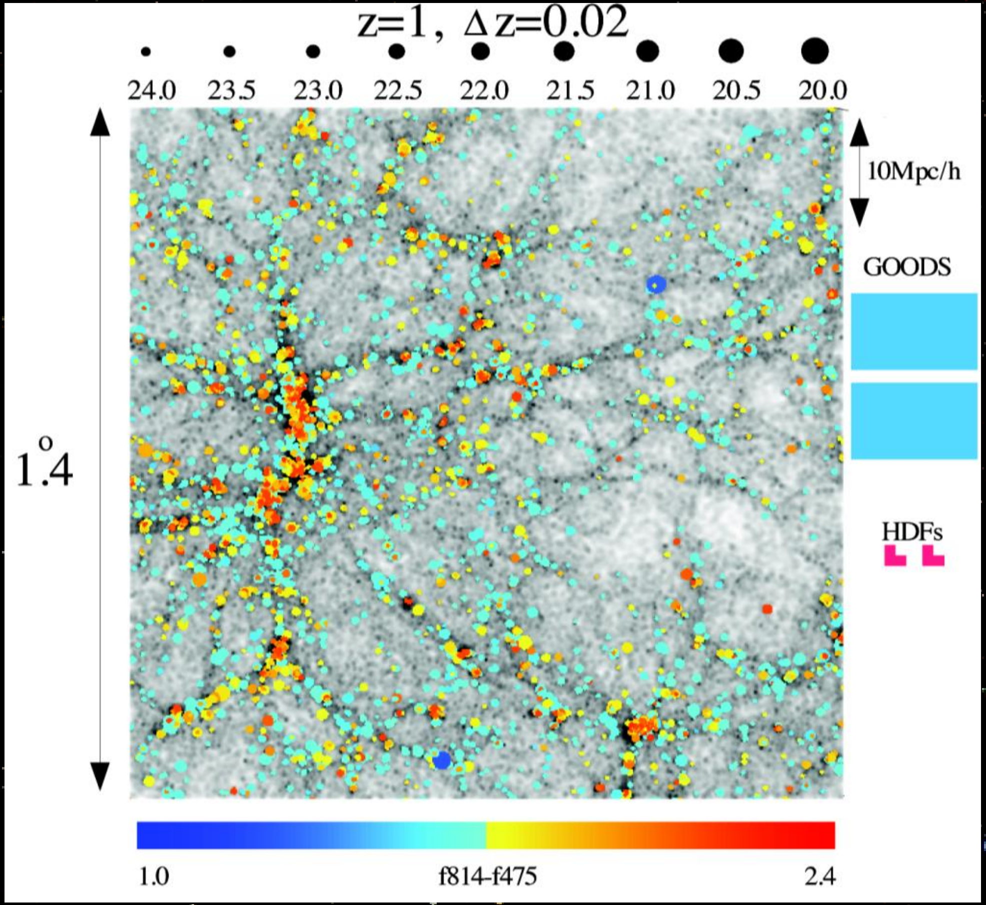
Hierarchical Evolution of Galaxies



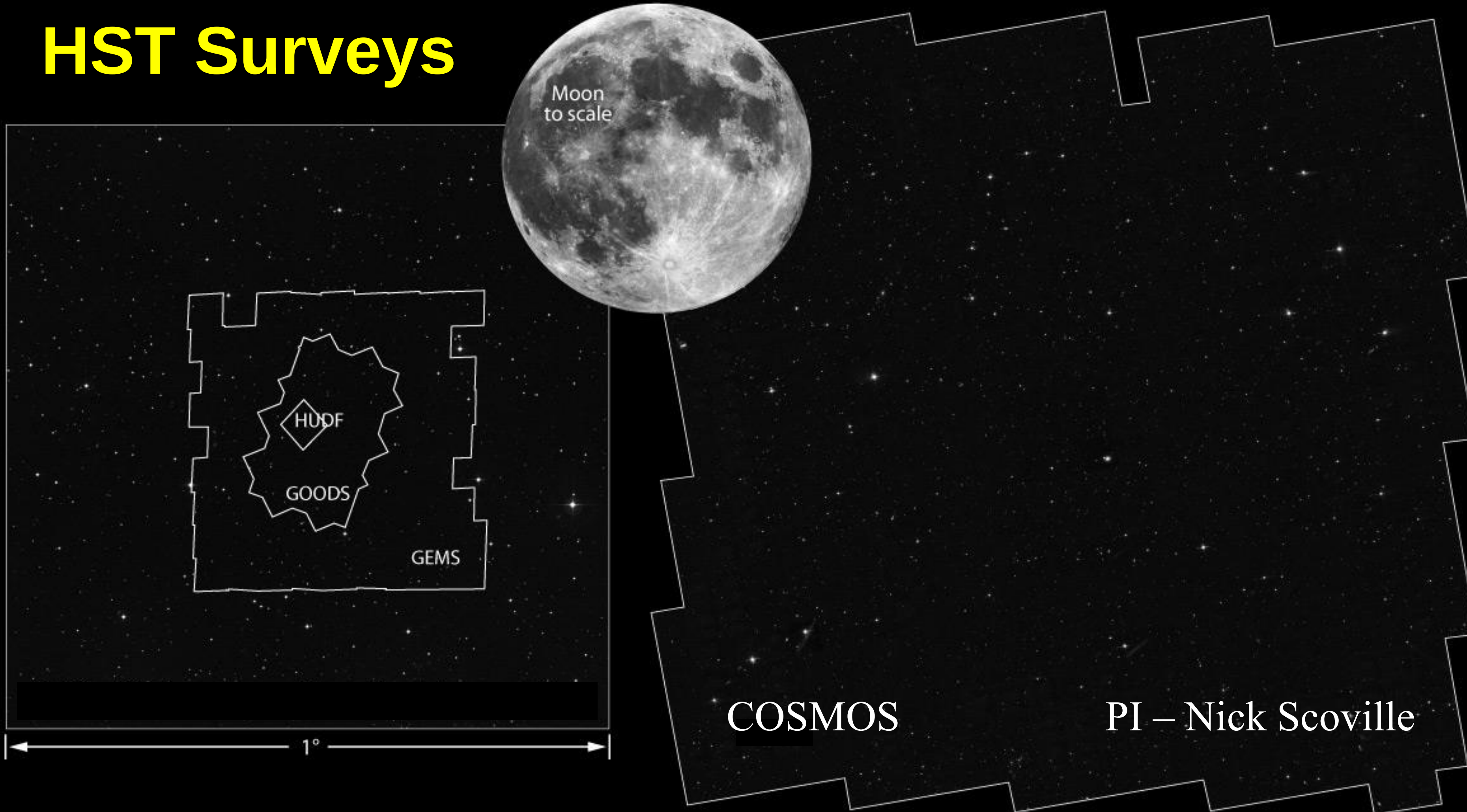


COSMOS Science Goals

- Tracing the coupled evolution of large scale structure, of star formation, and active galaxies.
- Similar volume to Sloan Digital Sky Survey, but at high redshift, with large sample sizes.



HST Surveys



575 orbits covering two sq. deg. (10% of HST for 2 years)

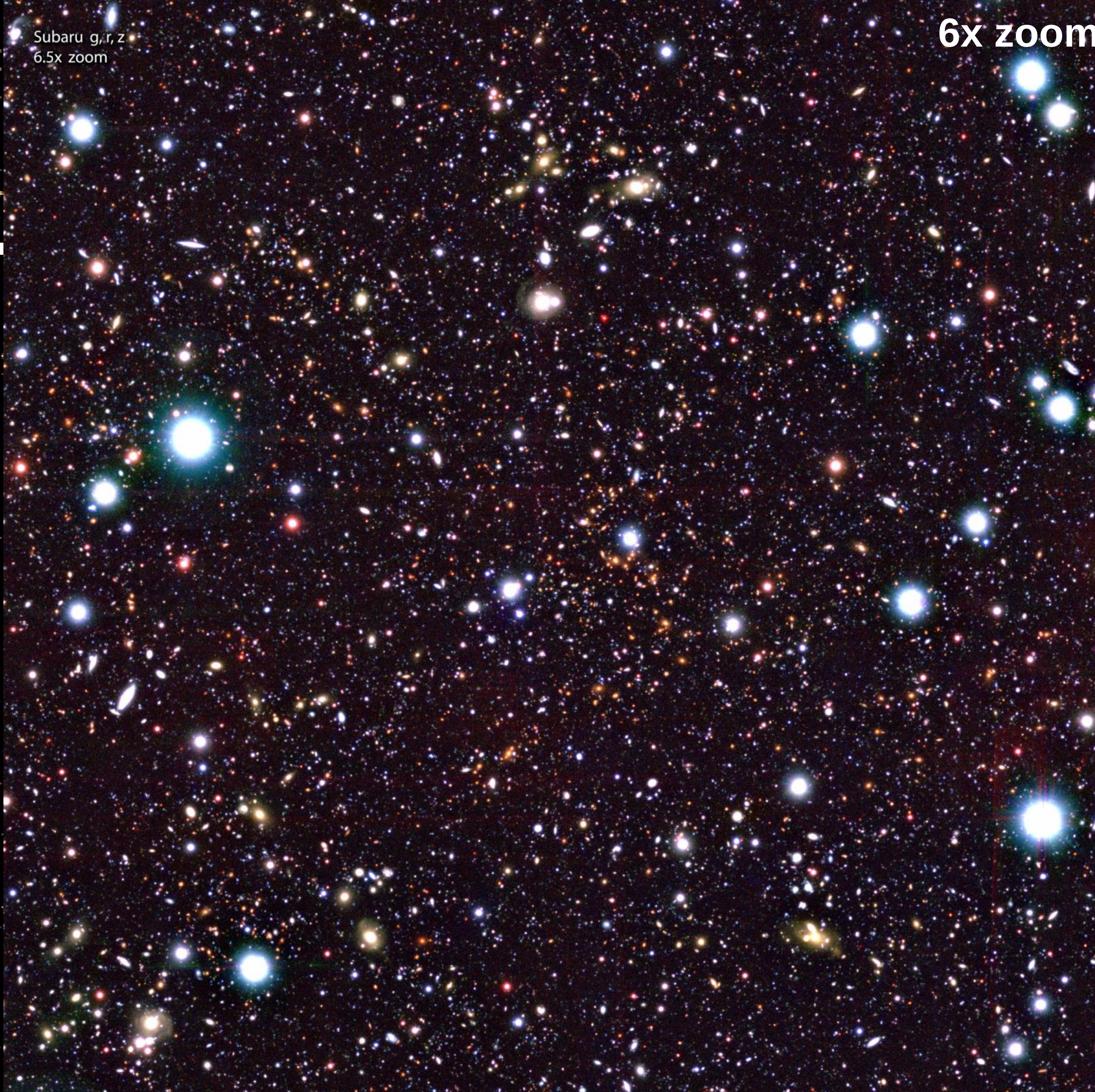
COSMOS is 9x any previous HST image: ~100 gigapixels

Two million galaxies at z ~ 0.2 to 5 (like SDSS, but high z)

Optical

Subaru
8m, PI :
Taniguchi
45 nights

Very deep images in 34 opt & IR bands give colors and redshift of galaxy, and morphology

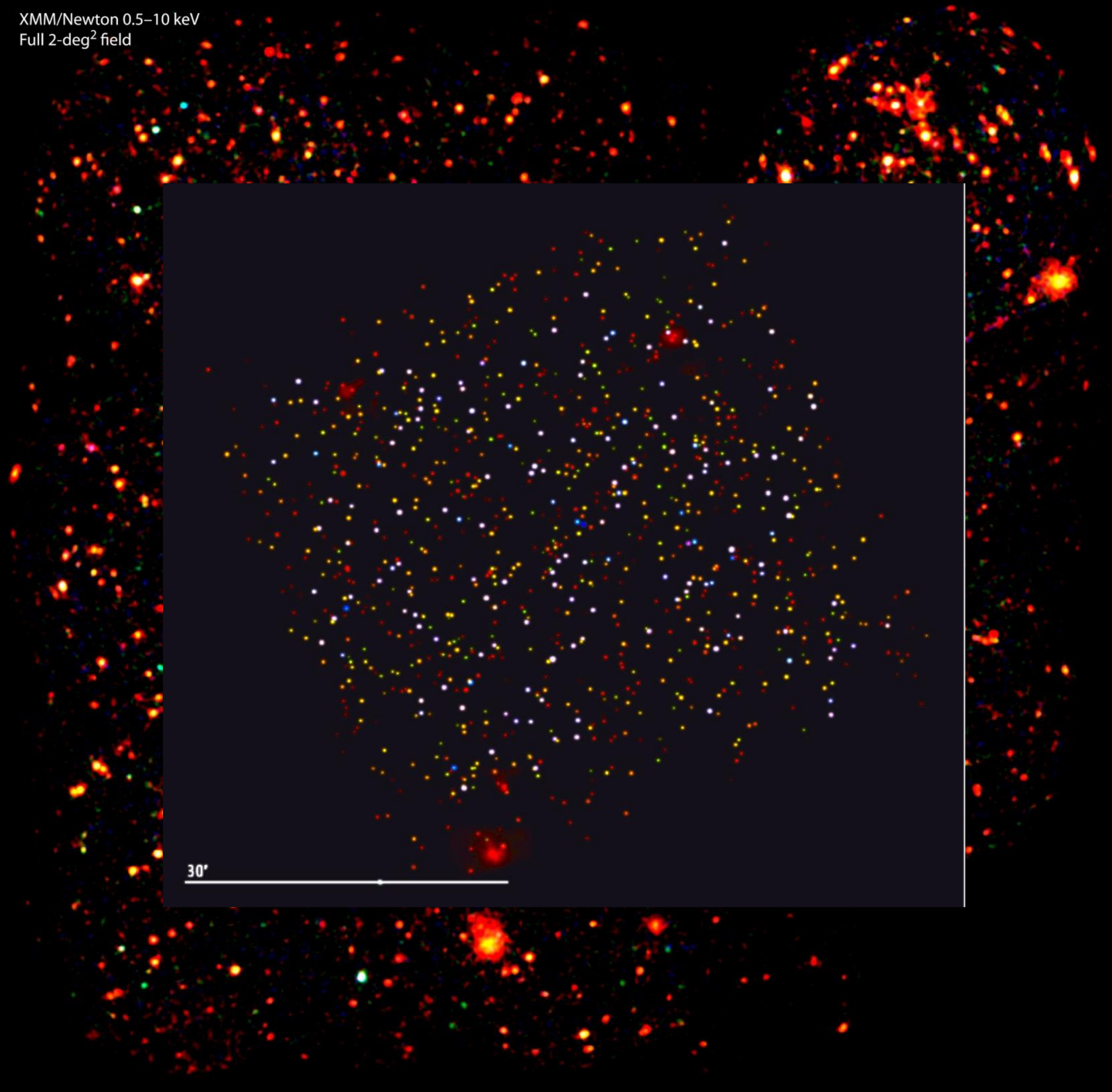


X-ray

XMM, PI : Hasinger 2.1 Msec

CXO, PI : Elvis 1.8 Msec

Sensitive to hot cluster gas, & most efficient way to find AGN, ~2000 deg^{-2}.



Infrared

Spitzer IRAC, PI : Sanders, +600 hrs w/ MIPS

Cool dust, SF rate in galaxies, obscured AGN pops.

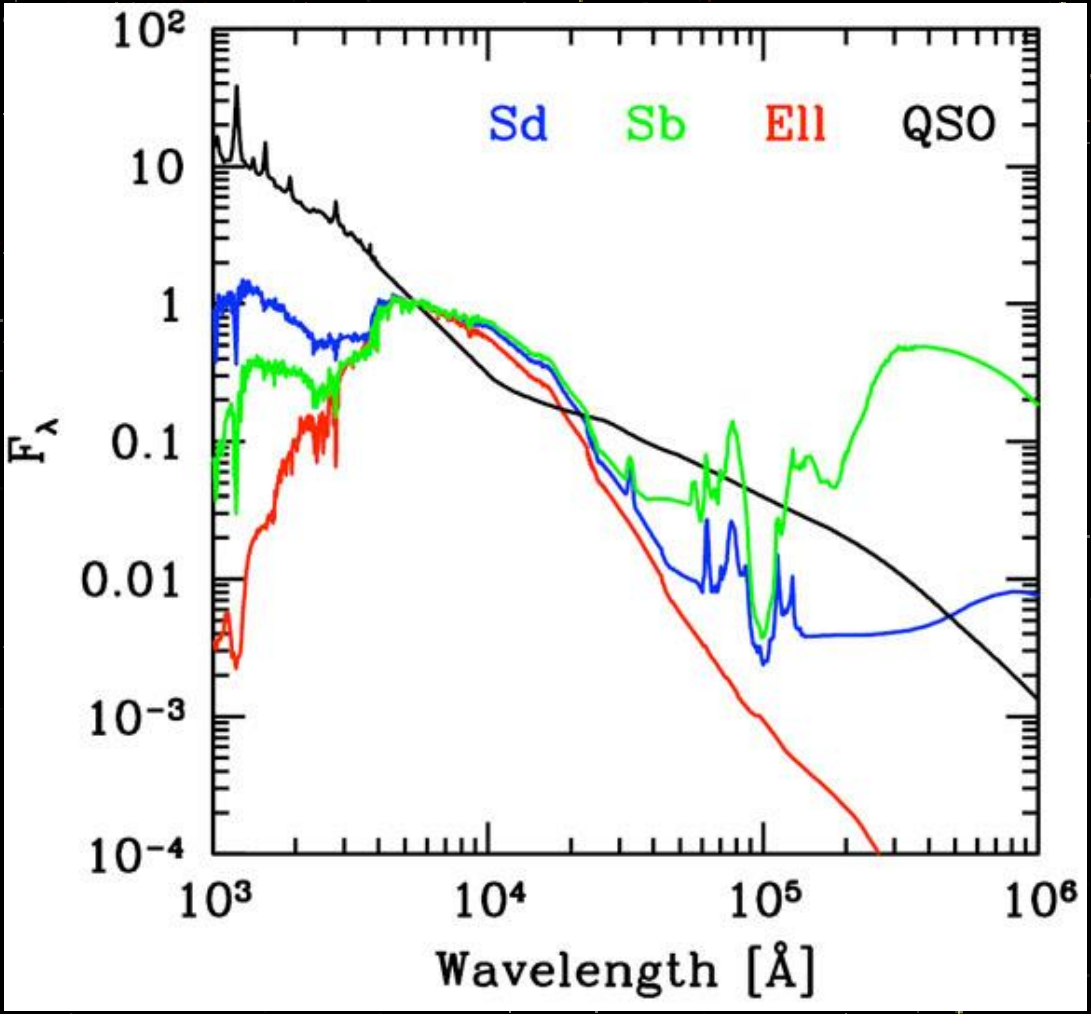
Radio

VLA, PI : Schinnerer
300 hrs, to 7-10 μJy

Proxy for, SF rate in galaxies, radio-loud AGN pops.

Selecting Active Galaxies

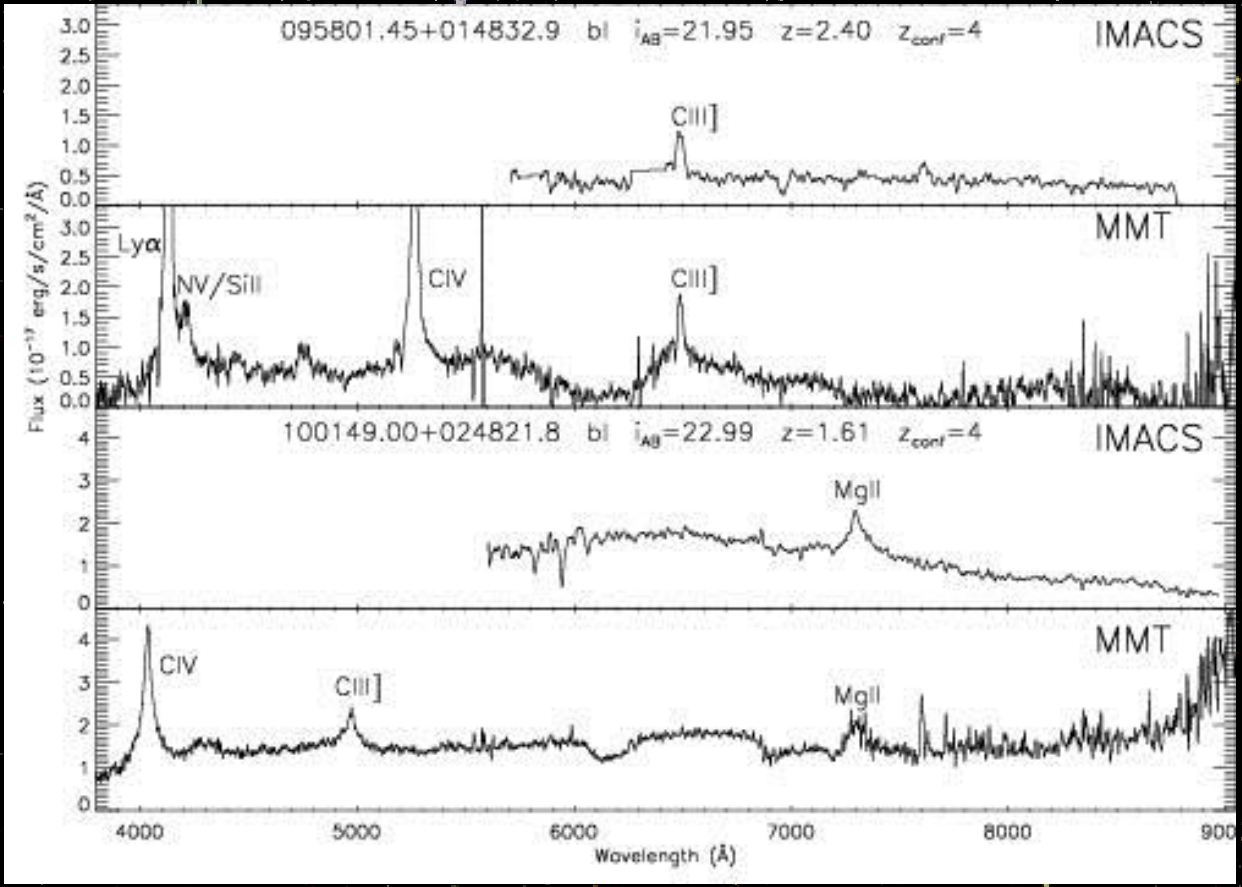
- AGN do not have stellar distributions of energy.
- Big excess of ultraviolet and X-rays means they stand out by energy dist.



The Spectroscopy

Magellan/IMACS, 29 nights over 4 years

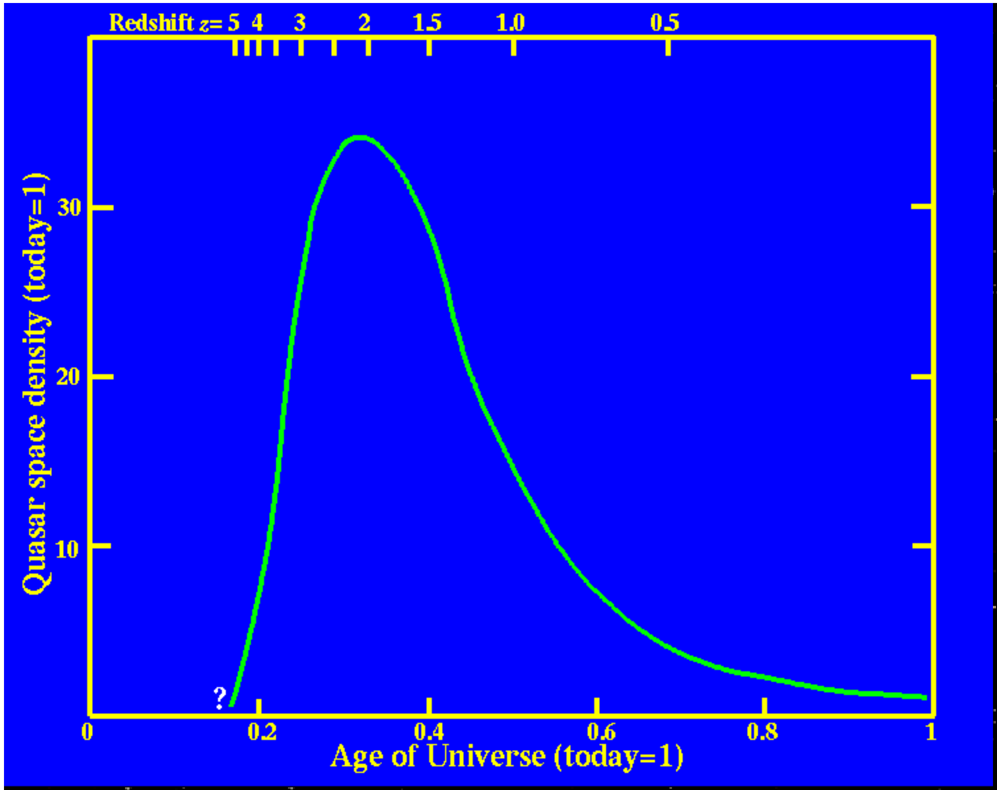
- Supplementary MMT spectra for additional blue spectral coverage
- 1600 spectra, including ~540 X-ray selected AGN confirmed



Magellan and IMACS

- Large 25’×20’ field
- 200 - 450 slits / field
- 5600-9200 Å, 10 Å res.
- 29 nights, 2005-2008
- Nod & shuffle technique

The Age of Quasars

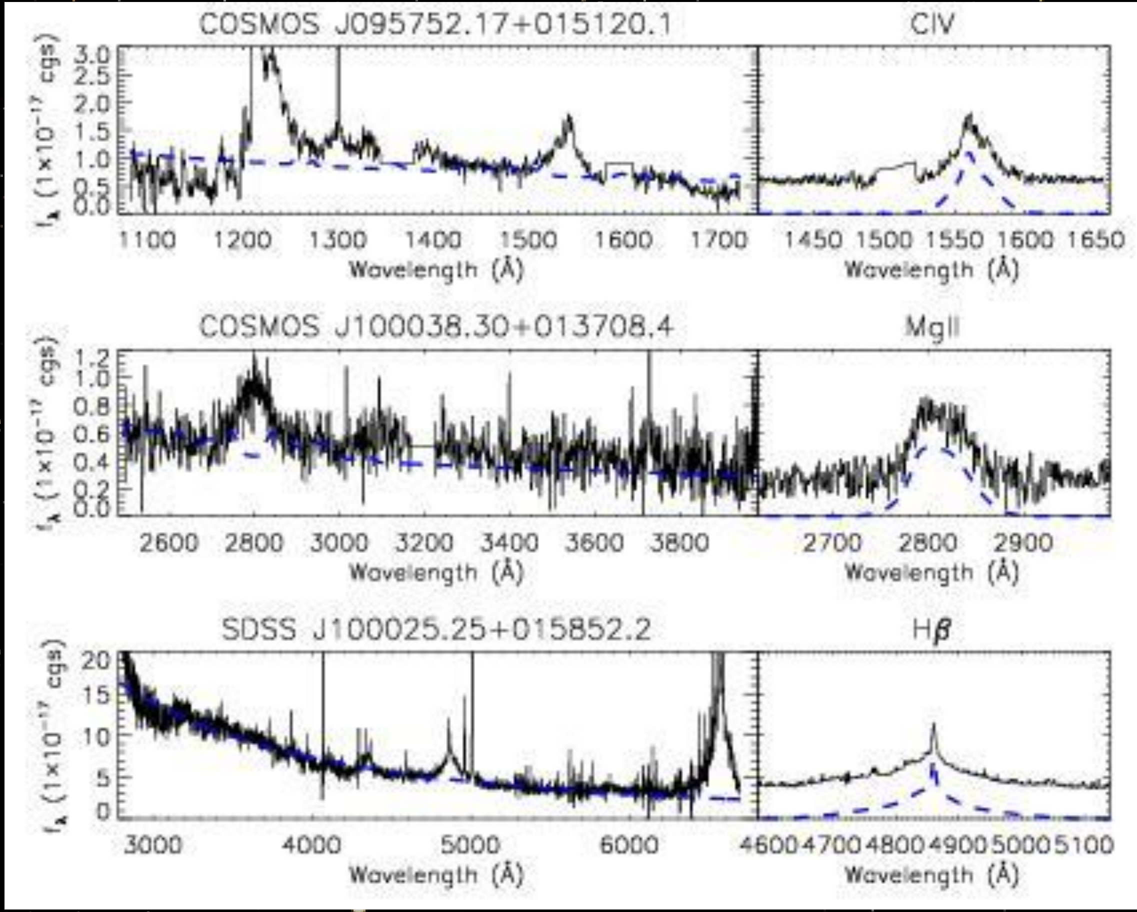


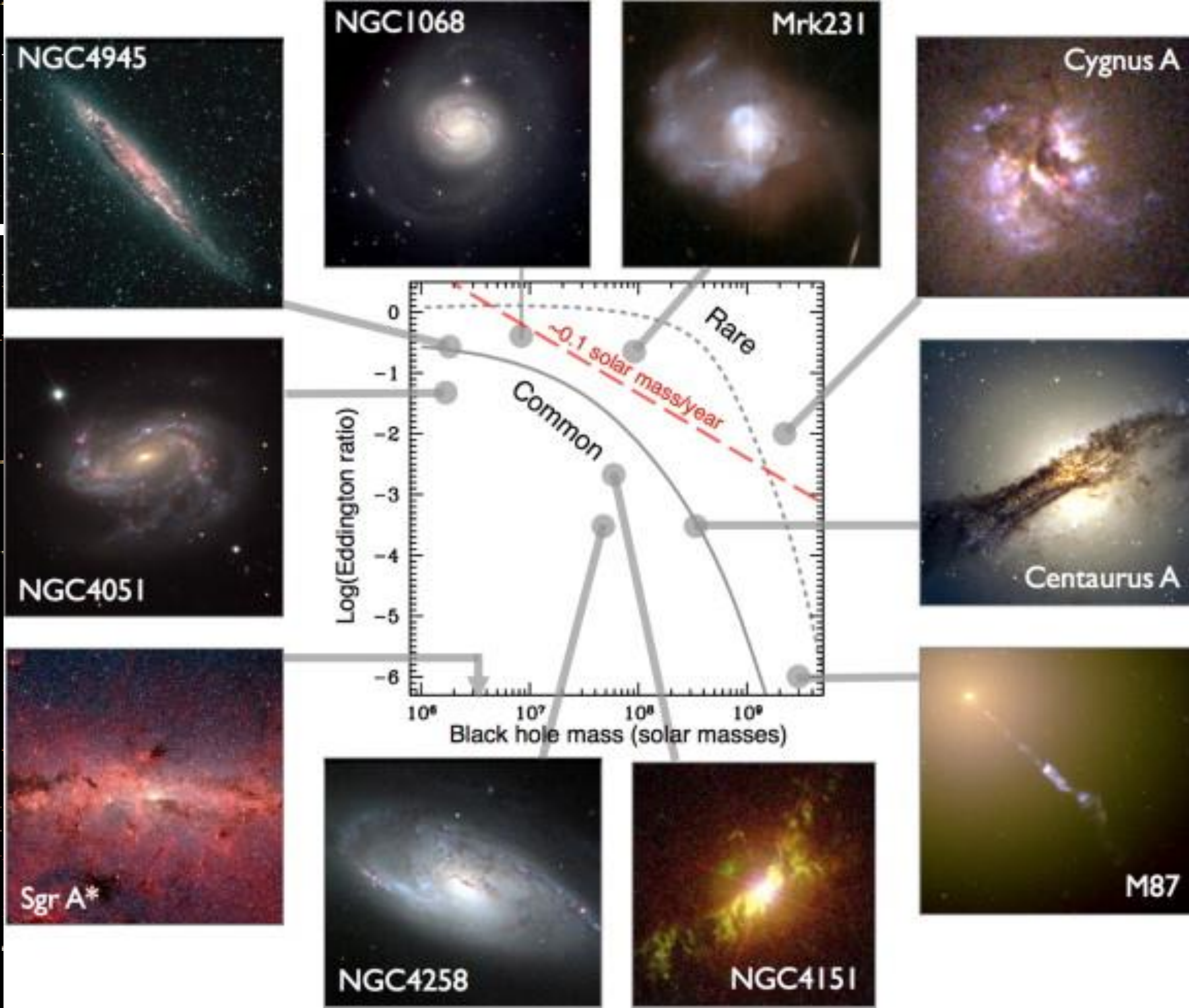
Quasars switched on early as black holes grew and there was copious gas as fuel. As gas is consumed and there are fewer galaxy interactions, this activity declines.

Quasars peaked in number and brightness about 7-8 billion years ago and have faded or died since.

Black Hole Masses

- Broad Line AGN: $M_{BH} \sim L^{0.5} \times v_{fwhm}^{2}$
- Width of the emission line gives the gas speed which leads to the inferred mass.
- Estimate is crude, factor of three error.



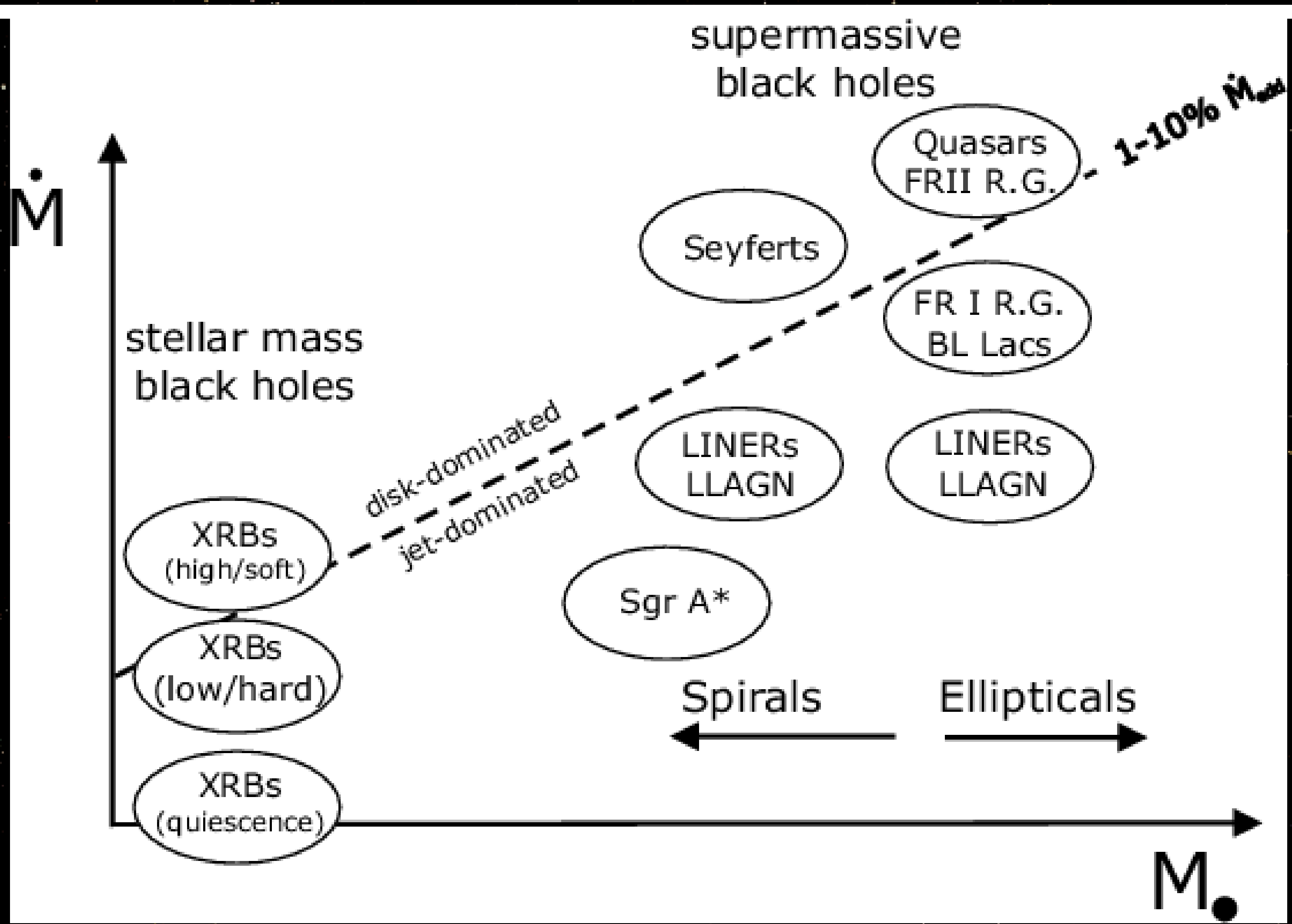


NGC4945
NGC1068
Mrk231
Cygnus A
NGC4051
Centaurus A
Sgr A*
M87
NGC4258
NGC4151
Rare
Common
~0.1 solar mass/year
Log(Eddington ratio)
0
−1
−2
−3
−4
−5
−6
10^6
10^7
10^8
10^9
Black hole mass (solar masses)

AGN Fueling

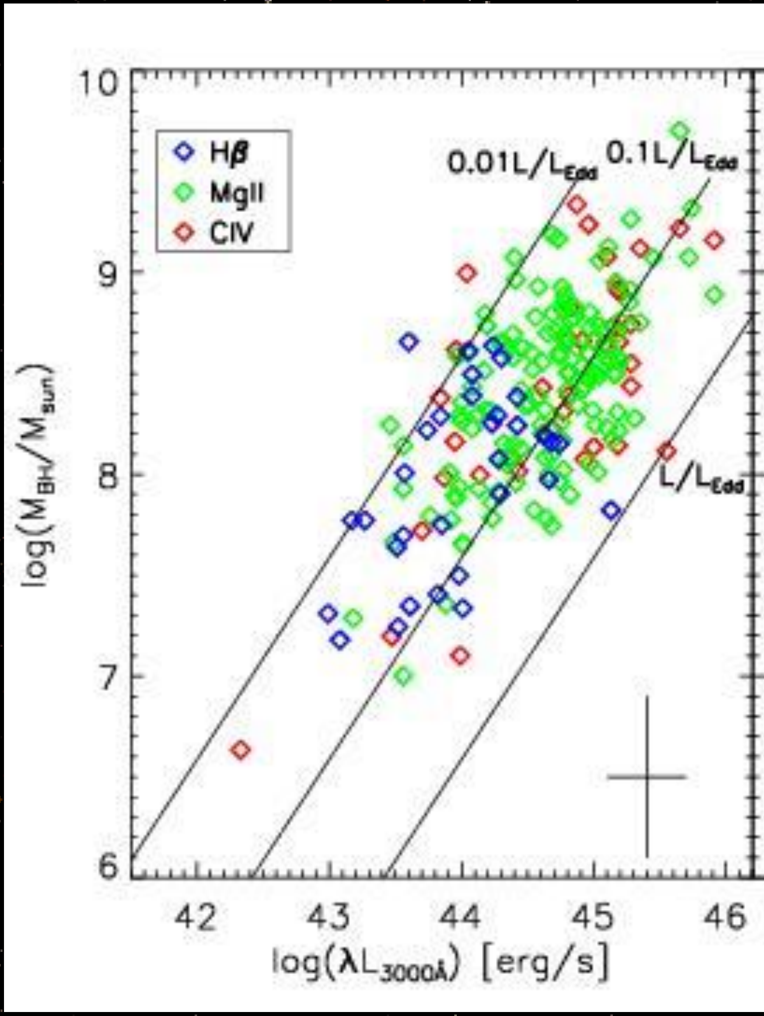
- The maximum efficiency of energy release from a black hole, in theory and observation, is about 10% of the mass accretion rate.
- The Sun – releases its energy at 0.1% at efficiency over 10^{10} years, converting 10^{-13} of its mass into radiant energy per year.
- A quasar – coverts a solar mass into pure energy at 10% efficiency each year, so it has the brightness of a trillion suns.

Mass and Accretion Rate

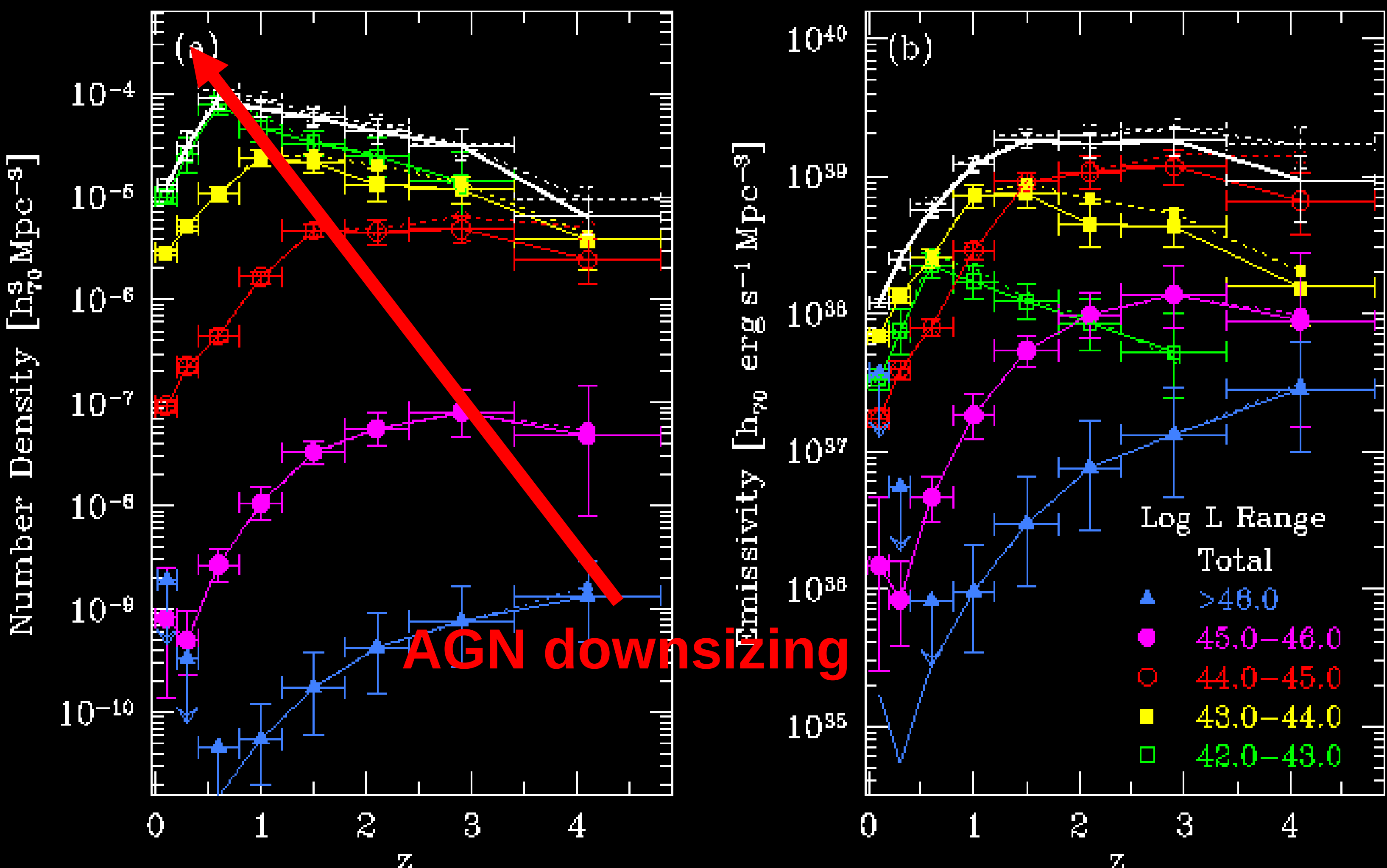


The Limit of Accretion

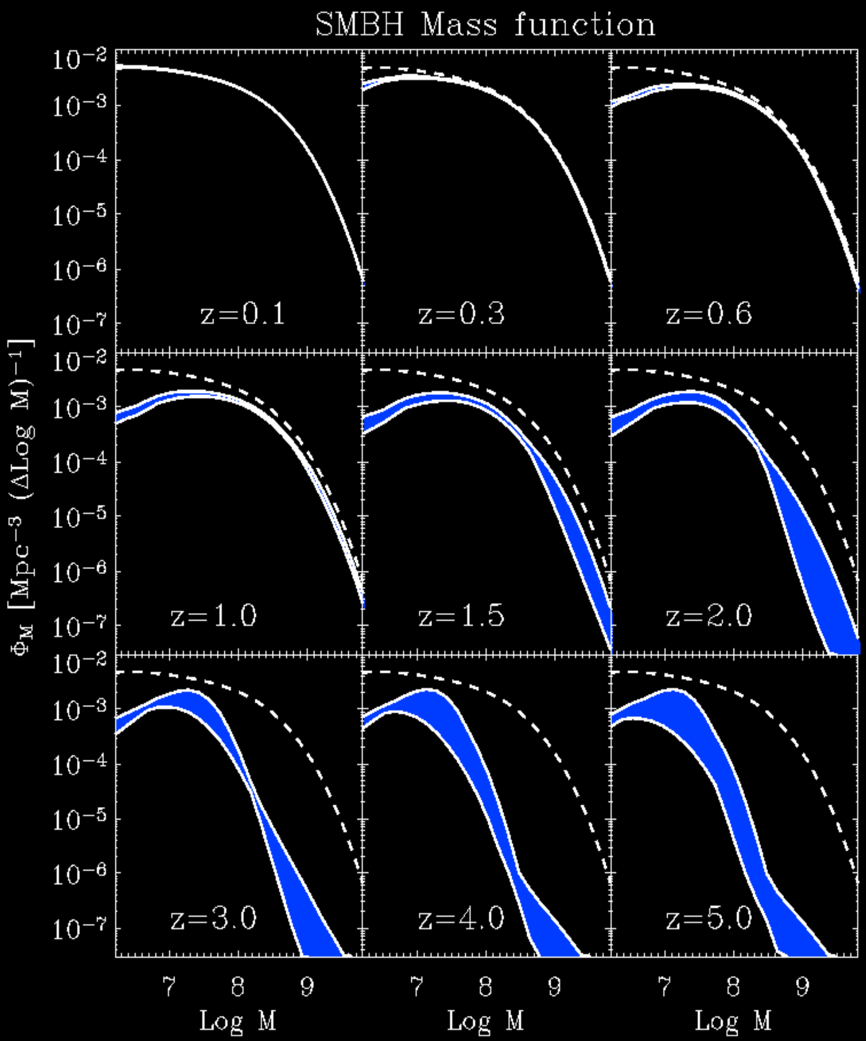
- COSMOS is deep and sensitive to low mass and low accretion rate SMBH, analogous to the Milky Way black hole.
- A lower bound on mass accretion rate is seen, at 0.1% efficient conversion of mass-energy, like that of stellar fusion.



Luminosity Evolution



Black Hole Evolution



SMBHs rapidly reach present abundance at low mass, 1-10 million solar masses.

The rarest and most massive SMBH grow slowly. Growth is over after 5-6 billion years.

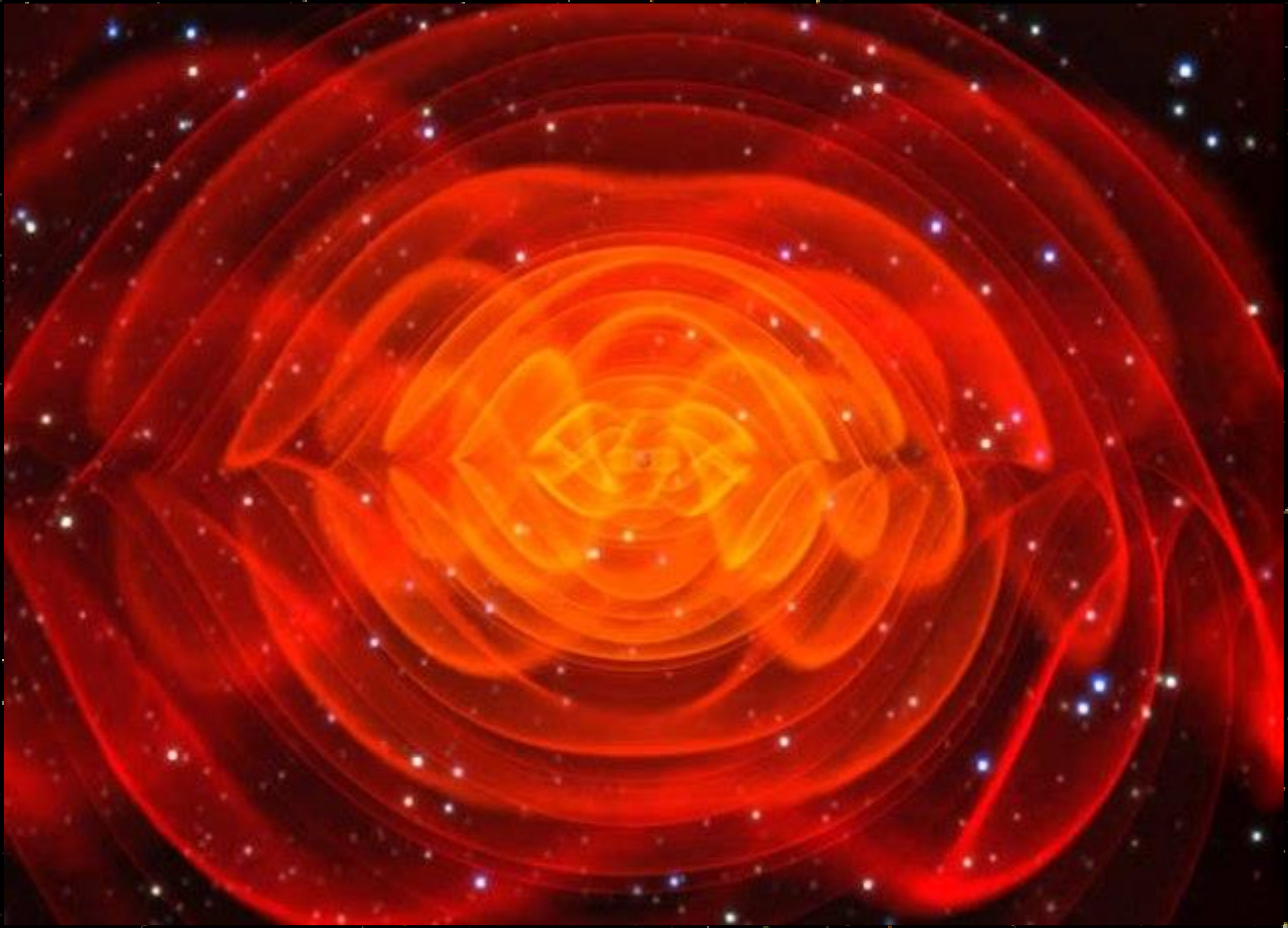
Conclusions

- COSMOS is sensitive to fainter, smaller AGN
- Analogs of the Milky Way black hole are found
- There's a lower bound to accretion efficiency
- Nuclear activity is triggered within a galaxy
- Most SMBH grow quickly then are starved

To come…

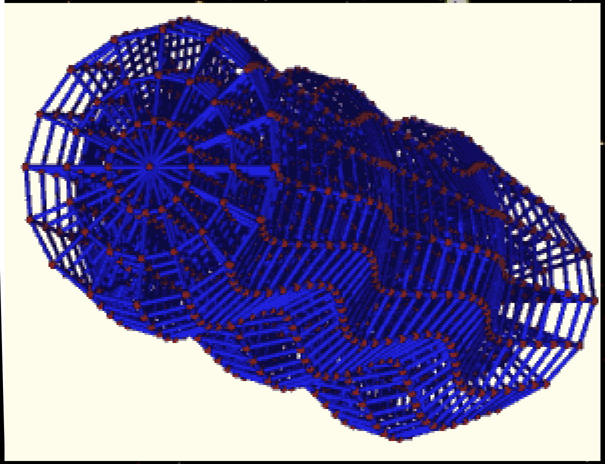
- New and improved black hole masses
- Variability to watch black holes eat stars
- Telescope array to see event horizon shadow
- Detecting gravity waves from SMBH mergers

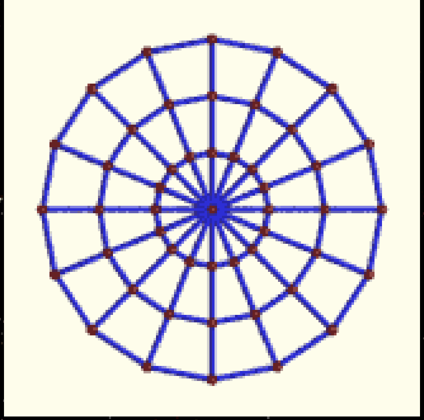
Gravity Waves

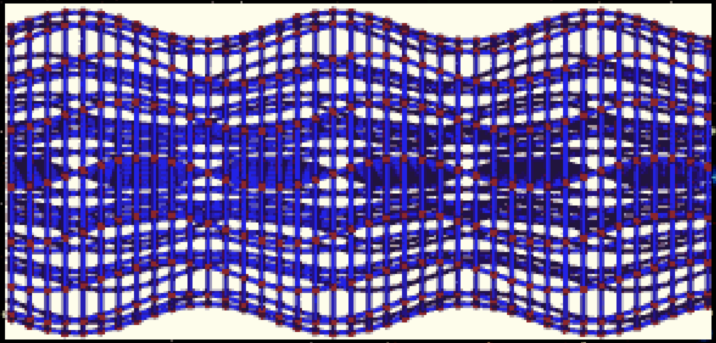


Ripples in Space-Time

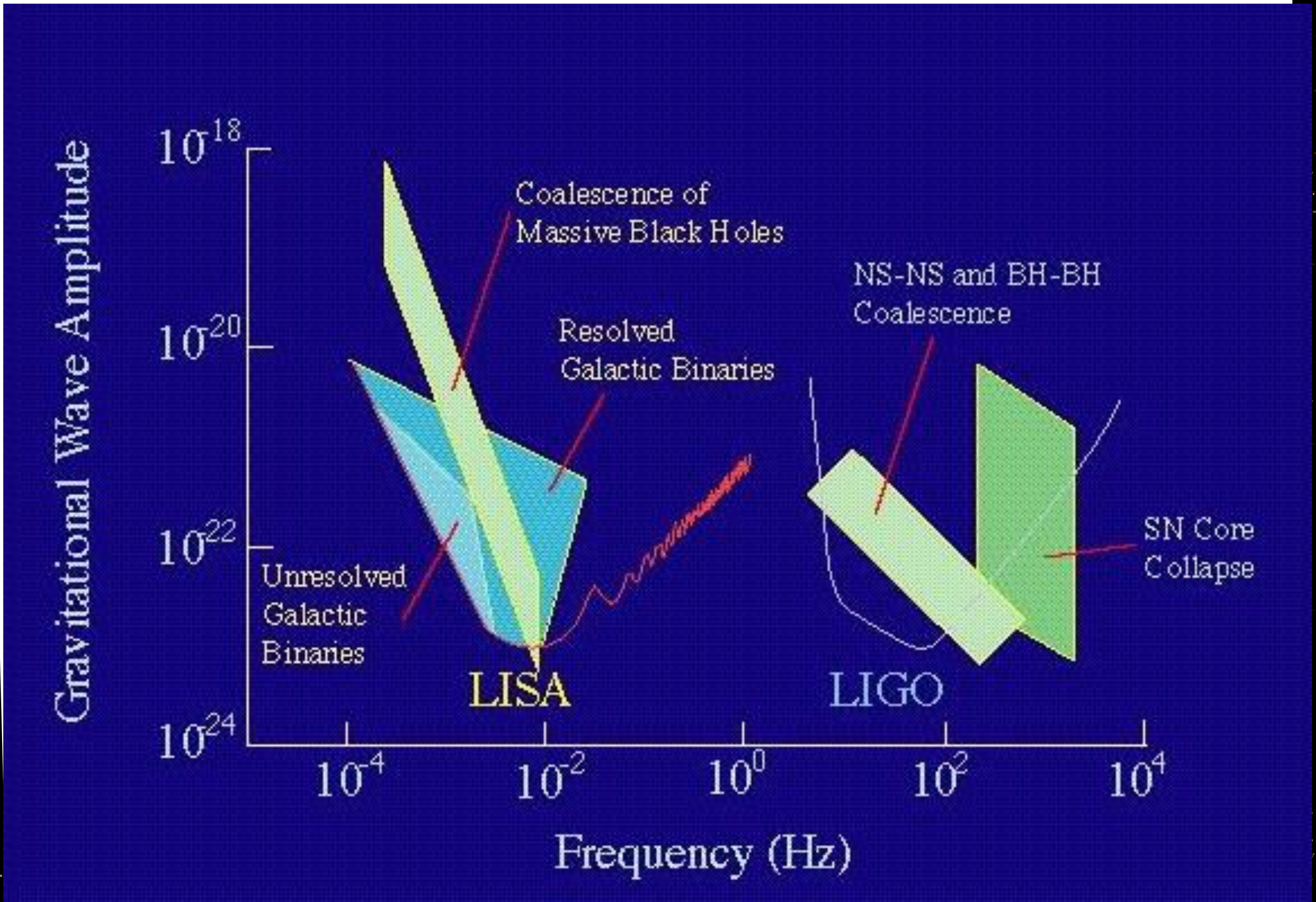
In General Relativity when a mass distribution changes, it creates ripples in space-time that propagate in 3D at the speed of light. The blue lines connect red markers of (invisible) space.







LIGO and LISA




THE END