The Unified Model for AGN

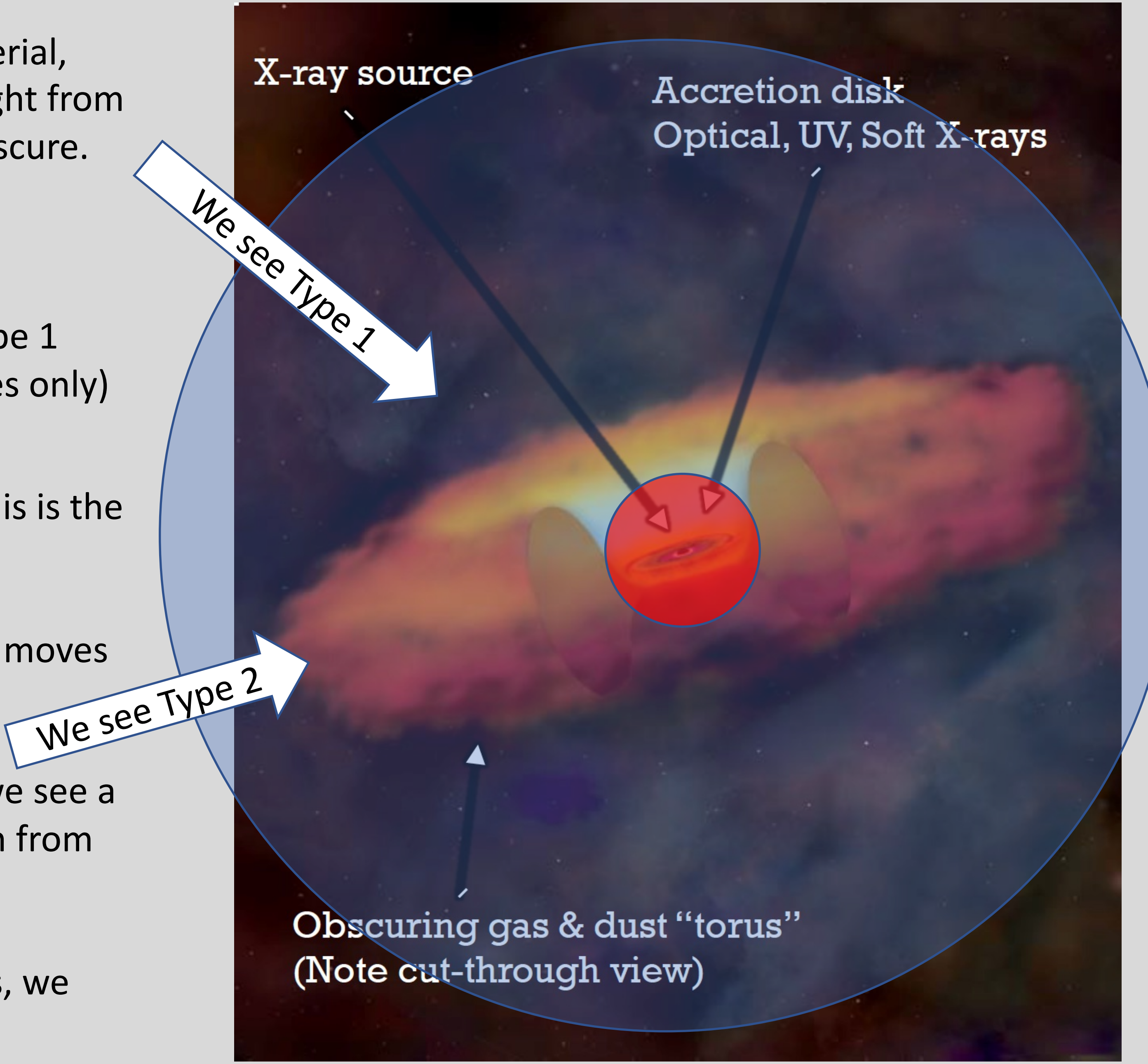
Accretion disk is embedded inside a dusty torus of material, which blocks optical light. In the optical, can only see light from the accretion disk at angles where the torus doesn't obscure.

X-rays are not blocked by dust, so all AGN show X-rays.

Type 1 / Type 2 dichotomy: The difference between Type 1 (broad + narrow emission lines) and Type 2 (narrow lines only) AGN is due to *viewing angle*.

- Gas moves very fast inside torus ($V^2 \propto GM/R$), so this is the **broad-line region.**
- In the larger scale environment outside the torus gas moves more slowly, so this is the **narrow-line region**.
- If we view from angles that can see into the center, we see a Type 1 AGN: broad+narrow lines plus blue continuum from hot accretion disk at center.
- If our view of the center is blocked by the dusty torus, we see a Type 2 AGN: narrow lines only.

0.1-100 light year scales:



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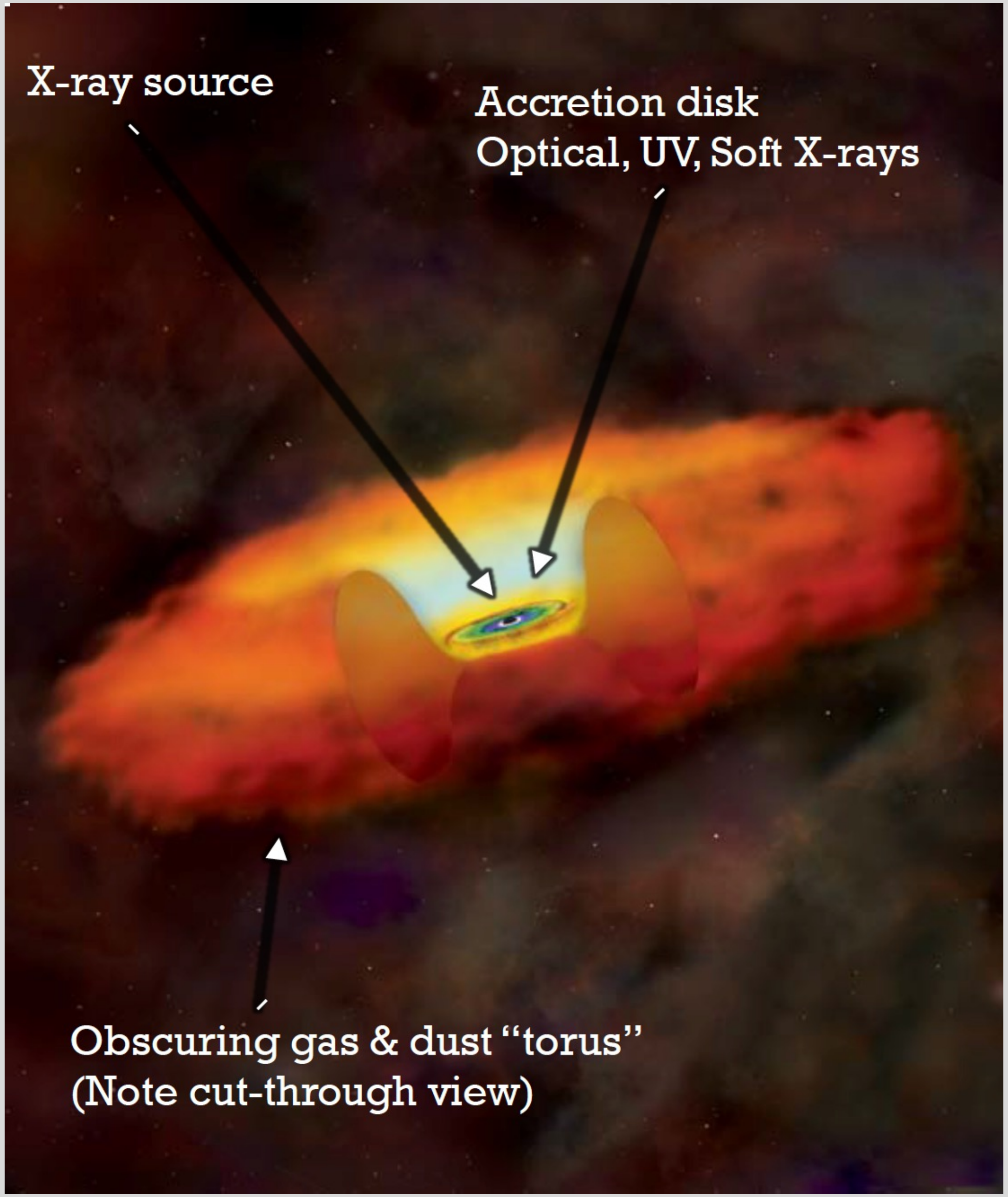
Low / hi luminosity: Differences in luminosity are differences in physical effects:

- **Accretion rate differences:** more gas falling on to the accretion disk ⇒ higher luminosity
- **Black hole mass differences:** more massive black holes can heat the disk to higher temperatures and have more massive disks ⇒ higher luminosities

0.1-100 light year scales:



The Unified Model for AGN

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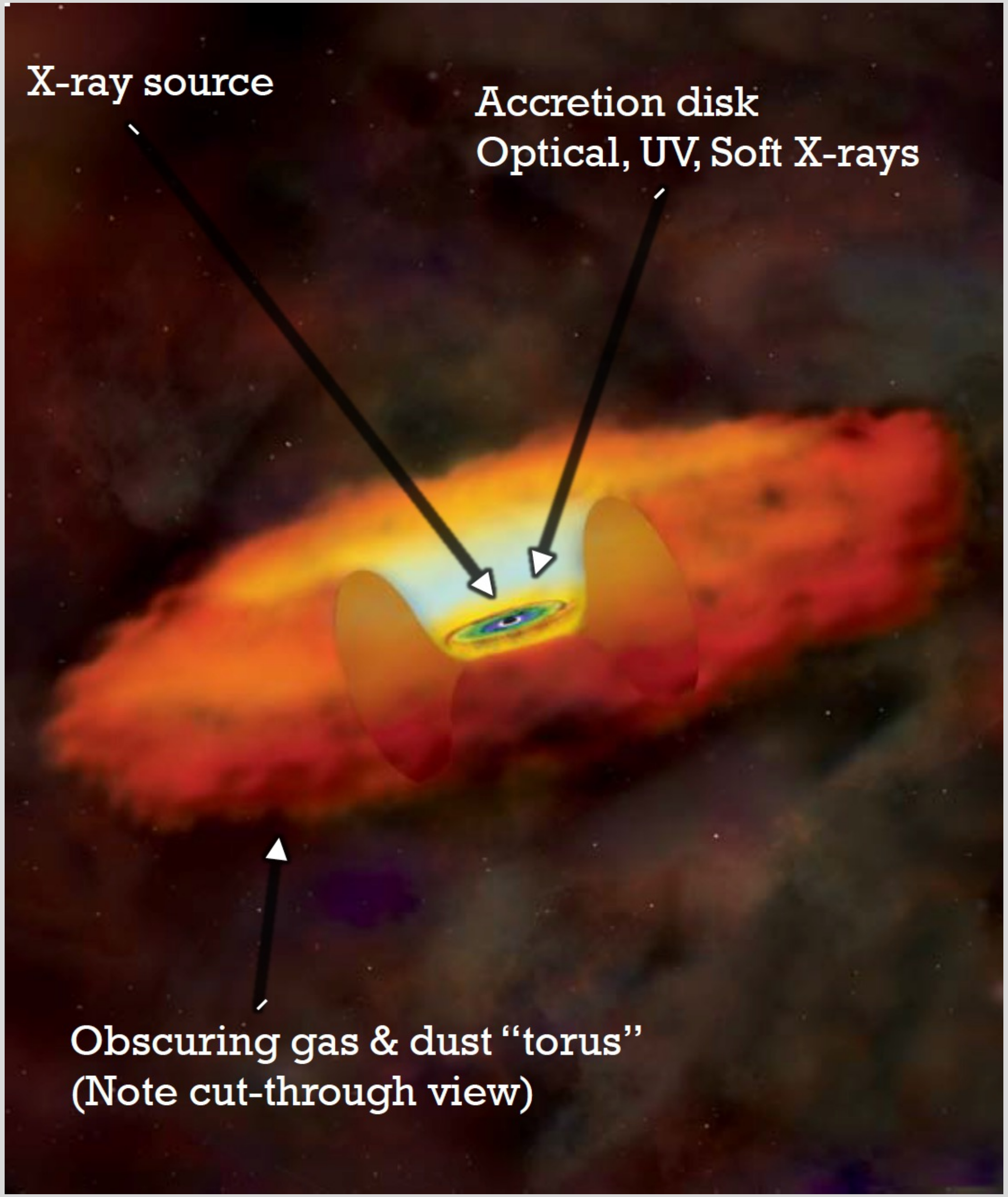
Radio loud vs radio quiet

Radio loud AGN tend to be in ellipticals, while radio quiet AGN tend to be in spirals. But its not a hard rule.

- **Smothering**(?): spirals have lots of dense gas which can block the jet from getting out ⇒ No radio jet, no radio lobes
- **Black hole spin**(?): Fast spin rates lead to highly twisted magnetic fields which launch the radio jet. Mergers form ellipticals(?), the black holes merge and "spin up", launch radio jet and lobes.
- Something else?

Still very unclear what the main effect is!

0.1-100 light year scales:



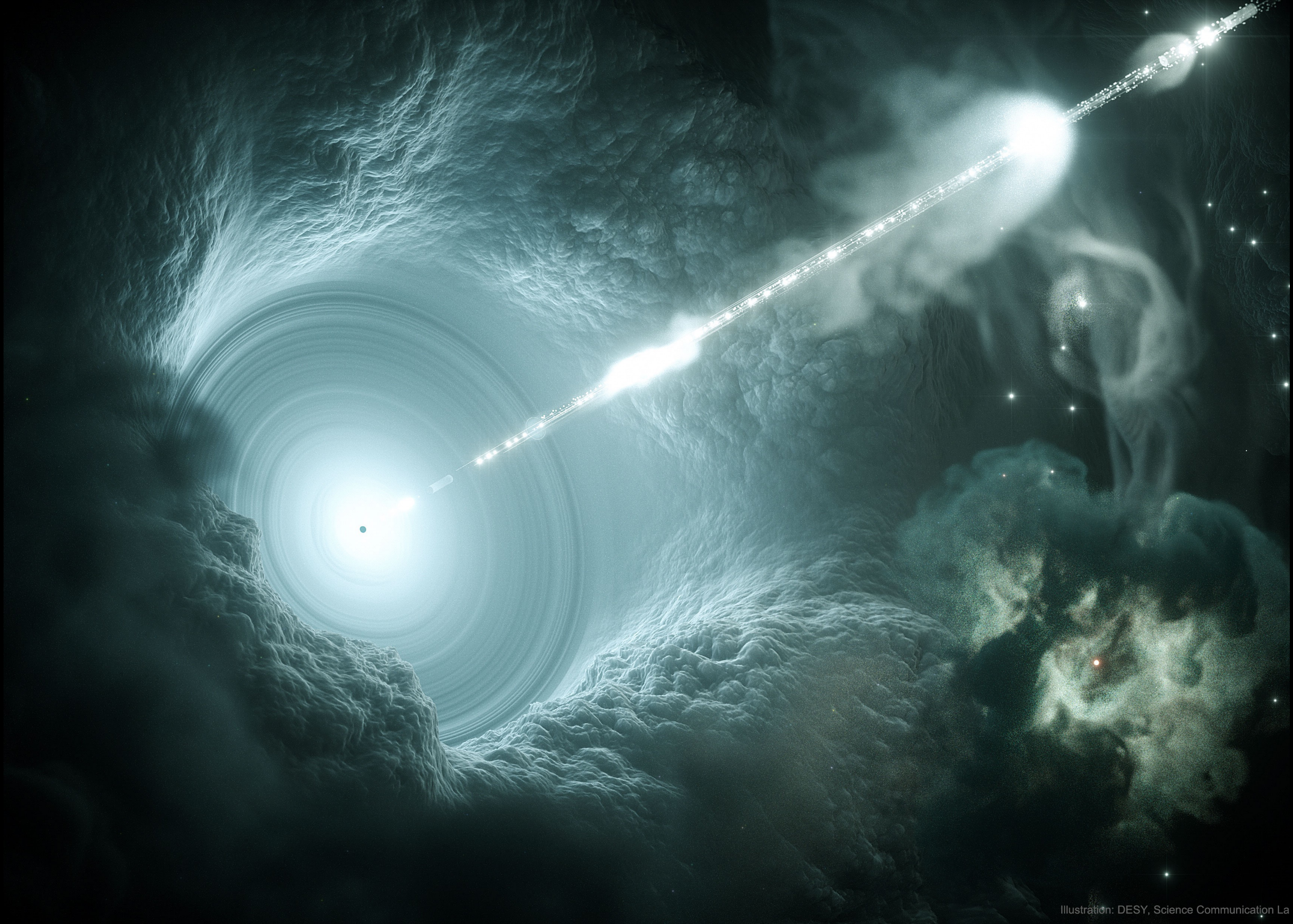


Illustration: DESY, Science Communication La

AGN “Demographics”: Linking AGN to galaxies and environments

Want to make **large** and **statistically complete** samples of AGN and their host galaxies.

Big questions:

- How do we find them?
- How common are they?
- What types of galaxies host them?
- What kind of environments are they found in?
- How do they change with redshift?

Why is this important?

- Triggering of AGN
- Coupled evolution of galaxies and black holes
- Impact of the AGN on the galaxy

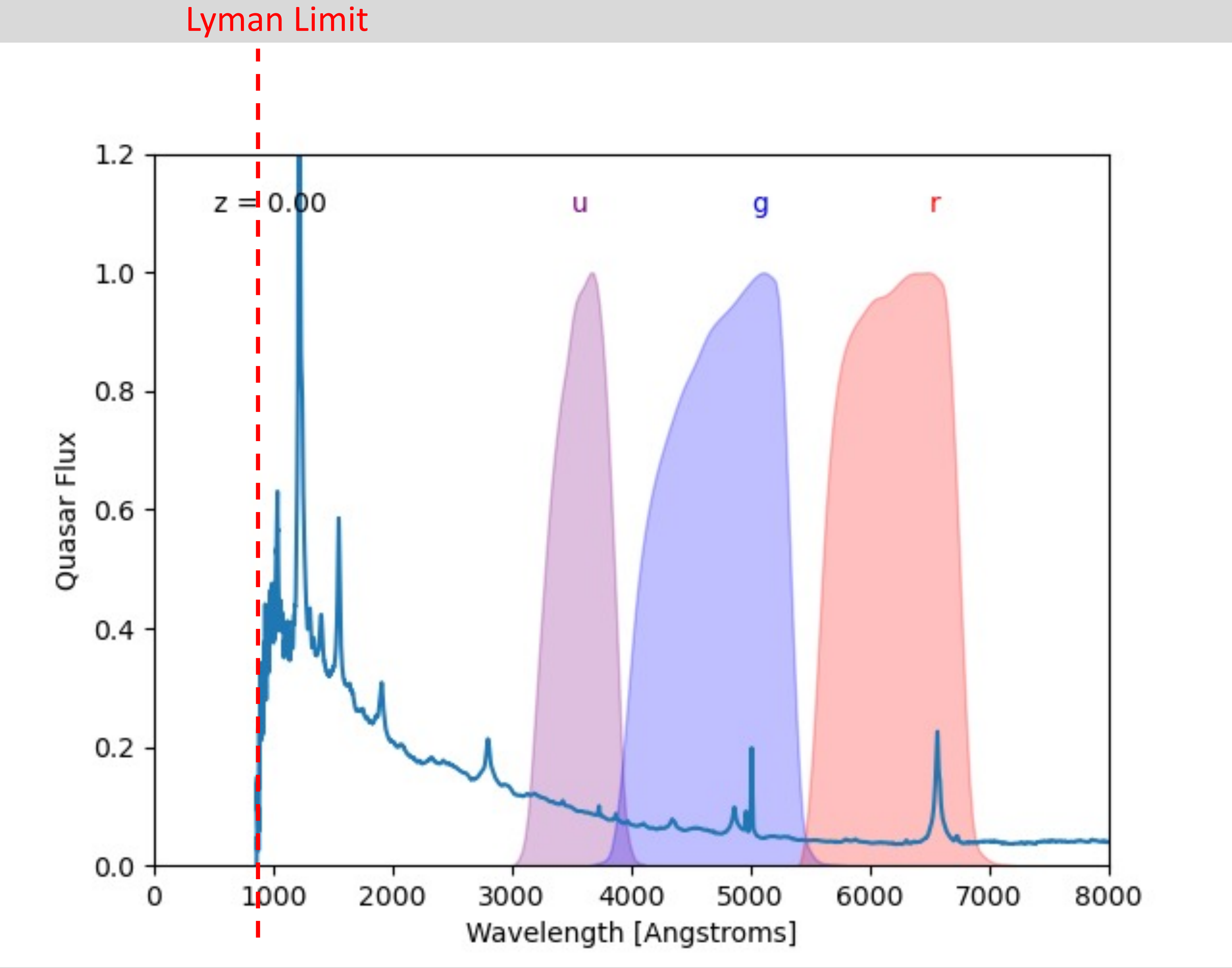
Finding AGN I: Optical/UV searches

Look an AGN spectrum:

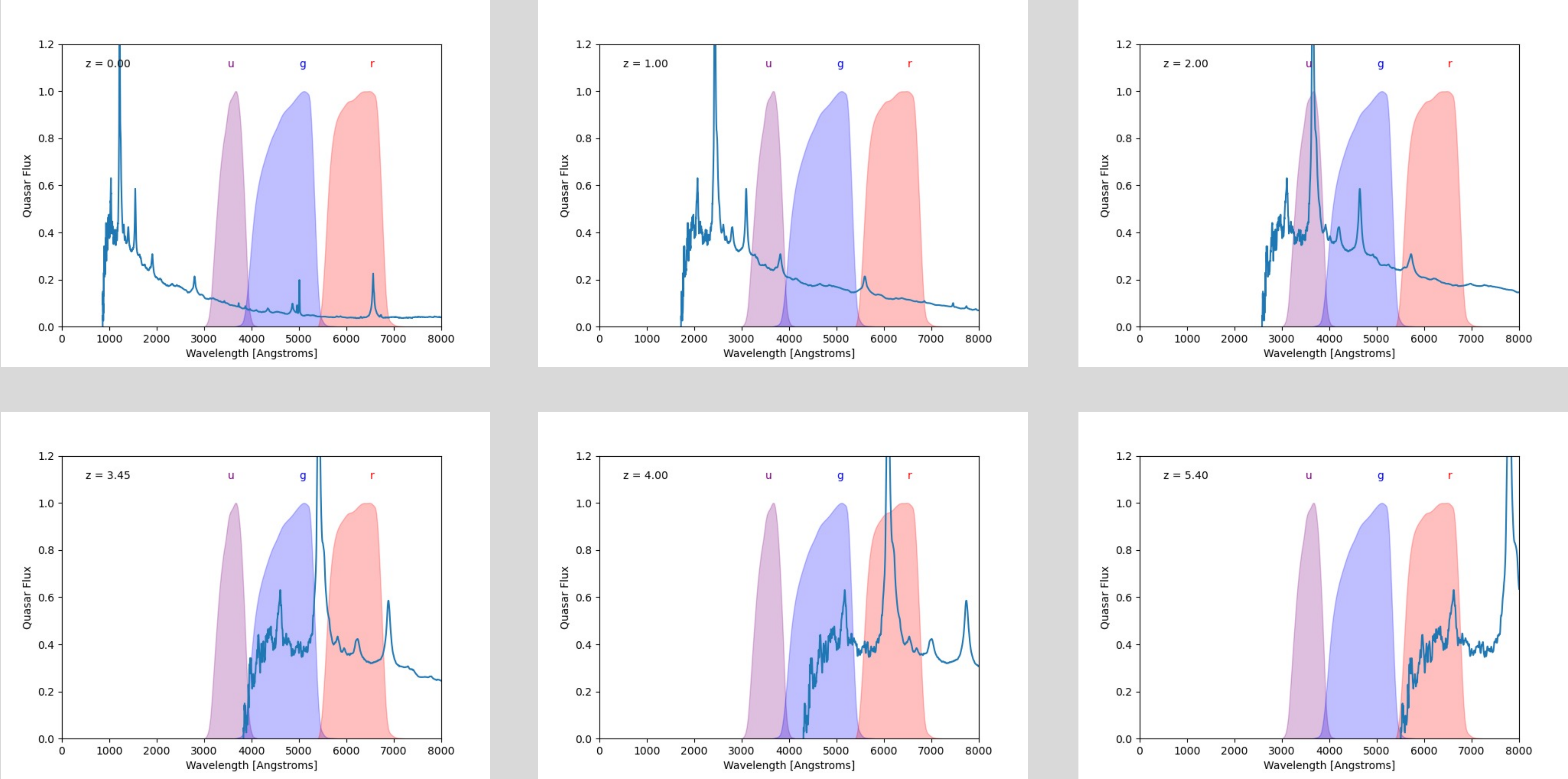
The intrinsic spectrum is **very blue** (much bluer than individual stars) with lots of **emission lines**.

At wavelengths shorter than 912 Angstroms, the photons are energetic enough to ionize hydrogen. Any hydrogen gas along the line of sight will absorb those photons, so there is a sharp cutoff (the “Lyman limit”) in the spectrum below 912 Angstroms.

For quasars at higher redshift, the observed spectrum is redshifted, and this cutoff falls in different optical filters.



Finding AGN I: Optical/UV searches



Finding AGN I: Optical/UV searches

Point source color selection:

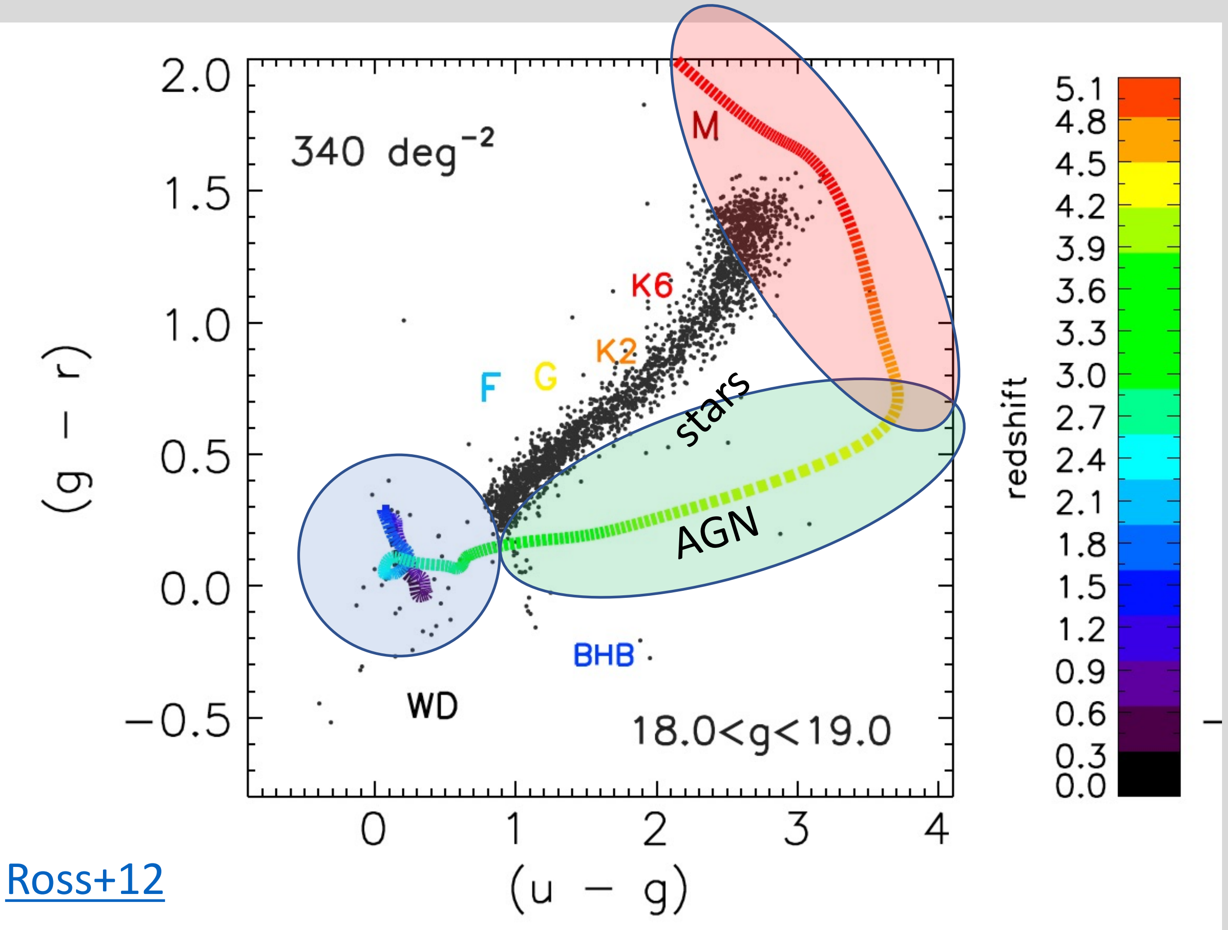
Measure colors in blue and red portion of the spectrum

$(u - g)$: color measured in blue part of spectrum
$(g - r)$: color measured in red part of spectrum

Low redshift: AGN are blue in both colors

Intermediate redshift: Because of the Lyman limit, AGN "drop out" of bluest filter (u), become red in $(u - g)$, stay blue in $(g - r)$.

High redshift: AGN "drop out" of both u and g, so they become red in $(g - r)$ as well.



Ross+12

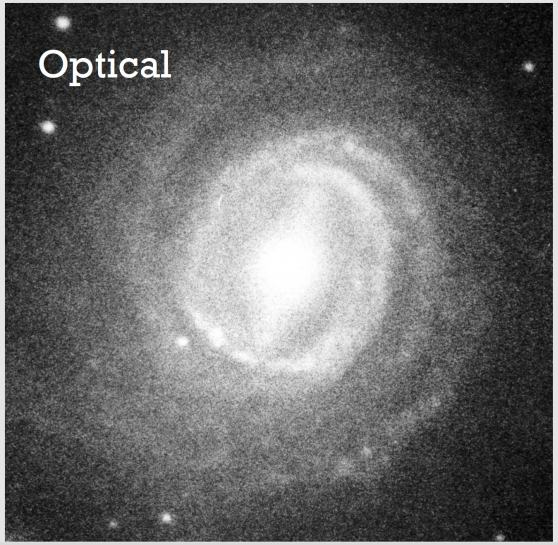
So quasars are largely distinct in color space from stars. Look for point sources with the right colors, build a quasar sample.

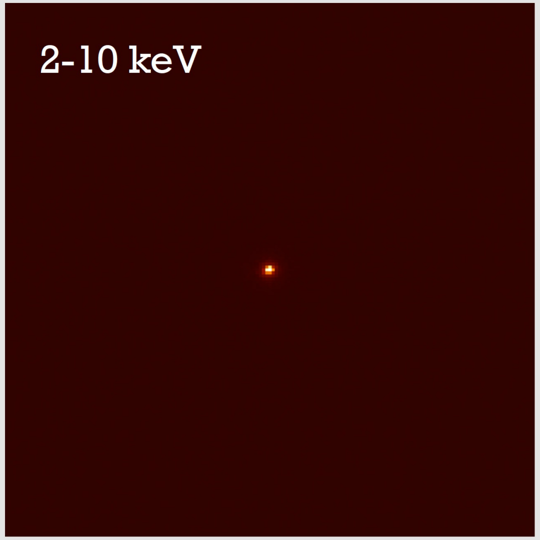
Finding AGN II: X-ray Surveys

Virtually all AGN produce X-rays

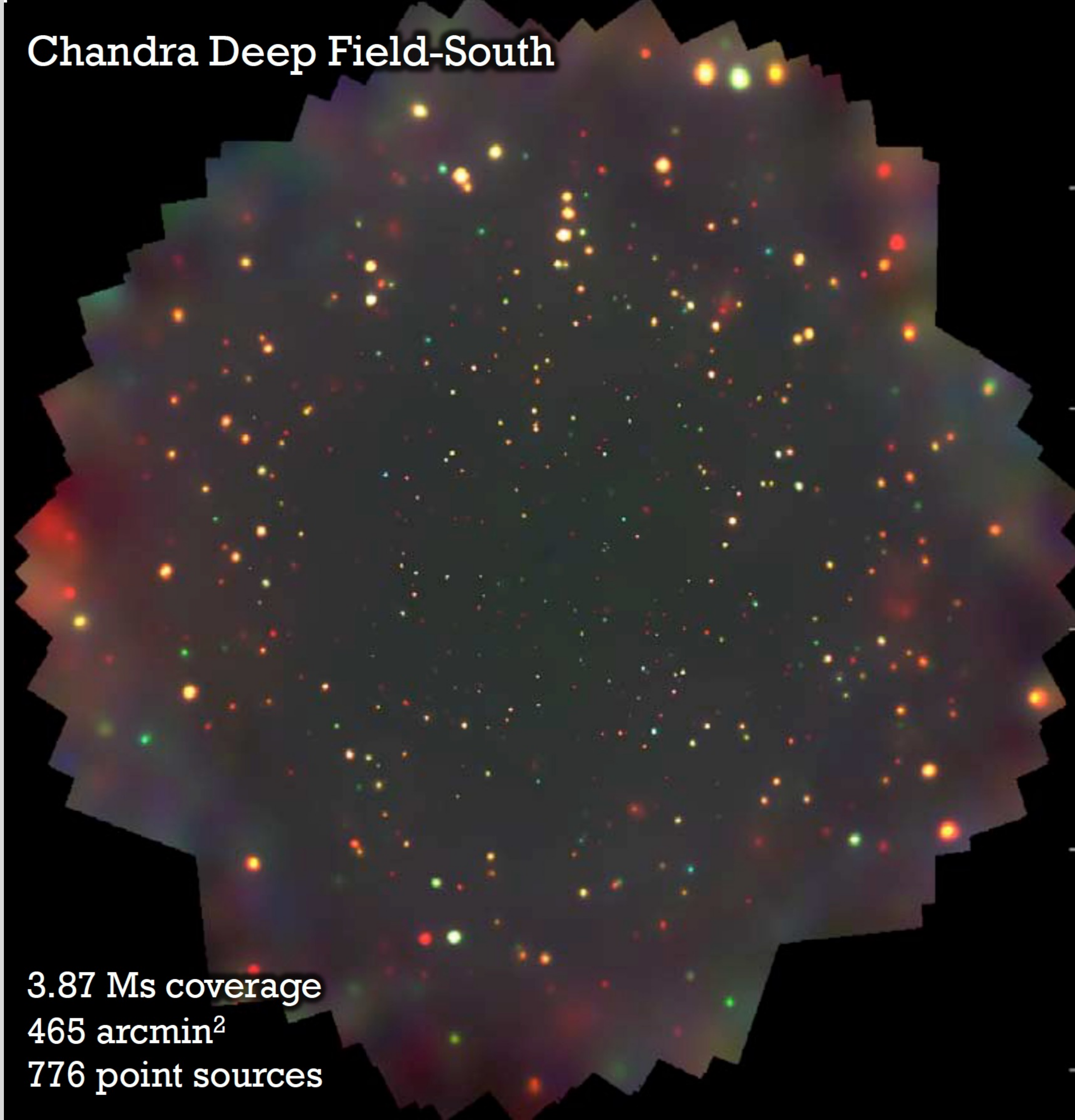
X-rays are not blocked by dust, so they reveal obscured AGN that optical searches would miss.

No contamination from galaxy light (stars dont emit much X-ray light).





Xue+ 11



Finding AGN III: Radio Surveys

Radio-loud AGN show up in radio surveys.

The first known AGN were detected this way ("3C" objects in the 1950s)

Stars do not emit strongly at radio wavelengths, so there is little contamination from stars.

But only 10% of AGN are radio loud.

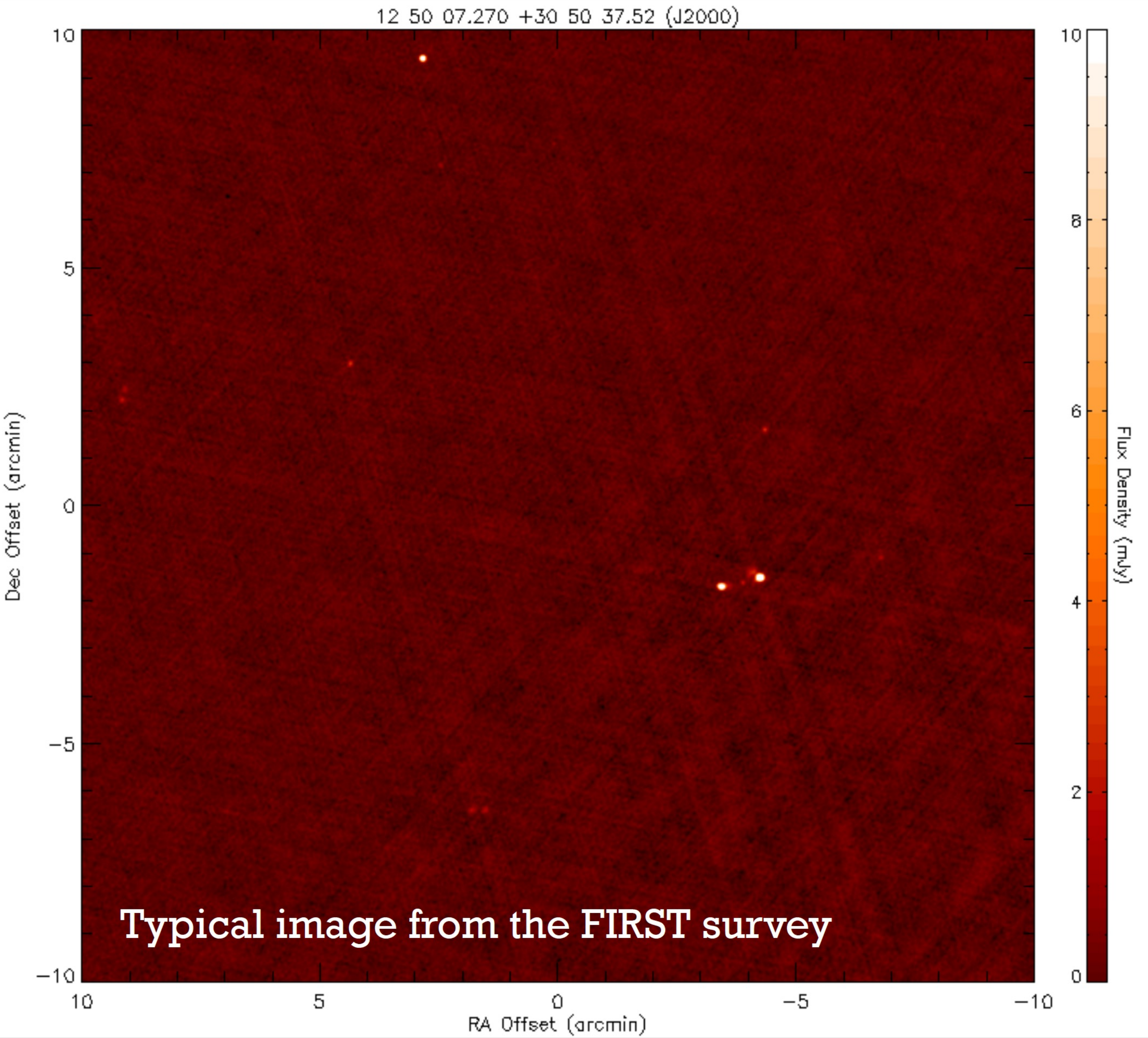
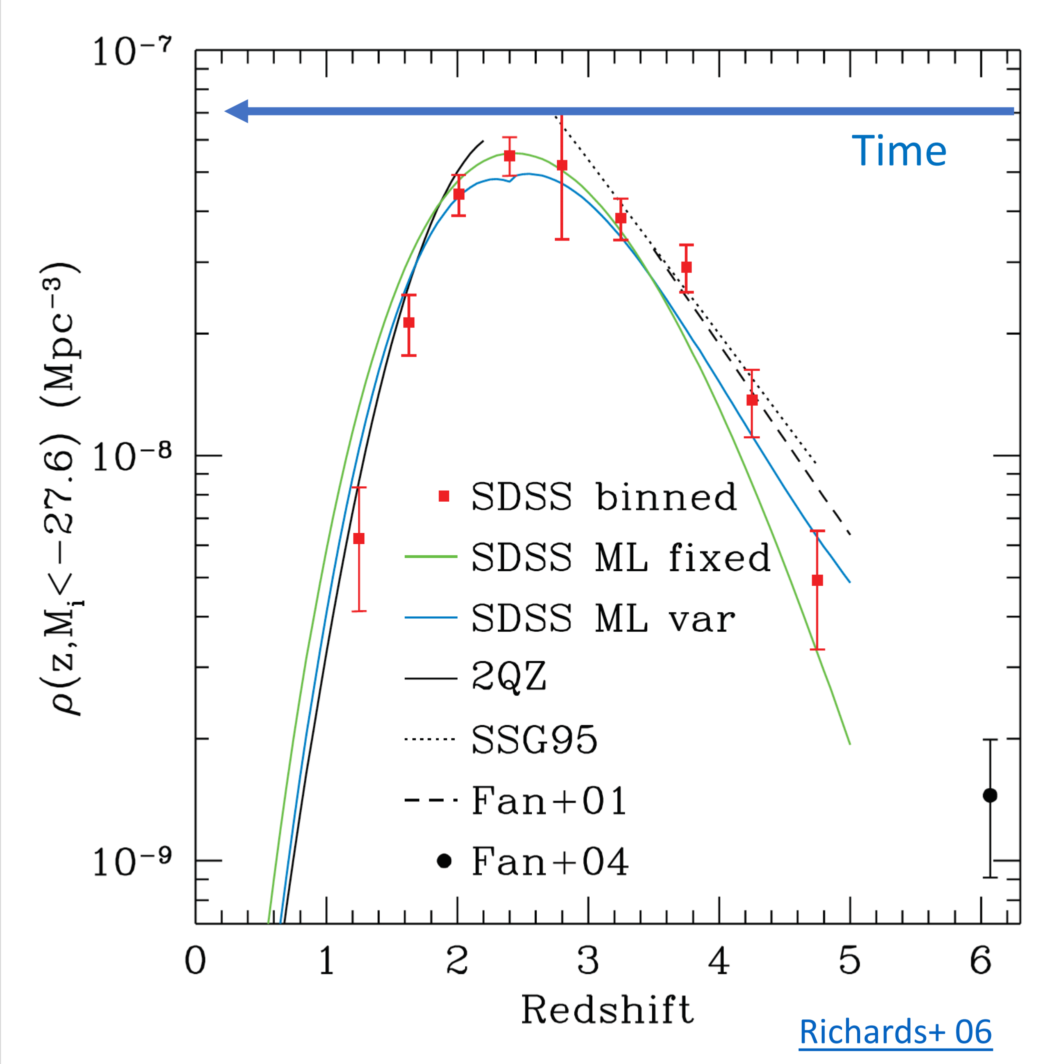


Image from VLA FIRST survey, measuring radio continuum sources at $\nu = 1435$ MHz

Evolution with redshift: Bright quasars

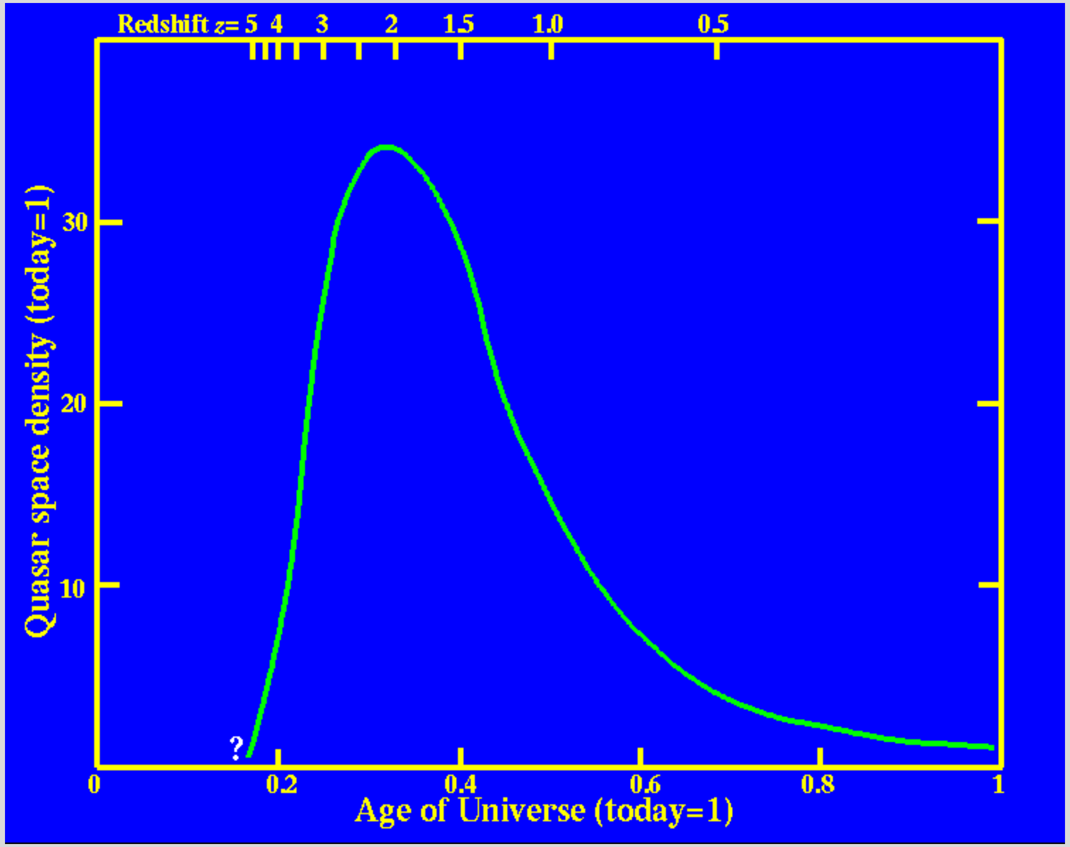
The epoch of the ***most luminous*** quasars was quite early in the universe's history.

Space density of luminous quasars as a function of redshift



Richards+ 06

Expressed linearly in density and time



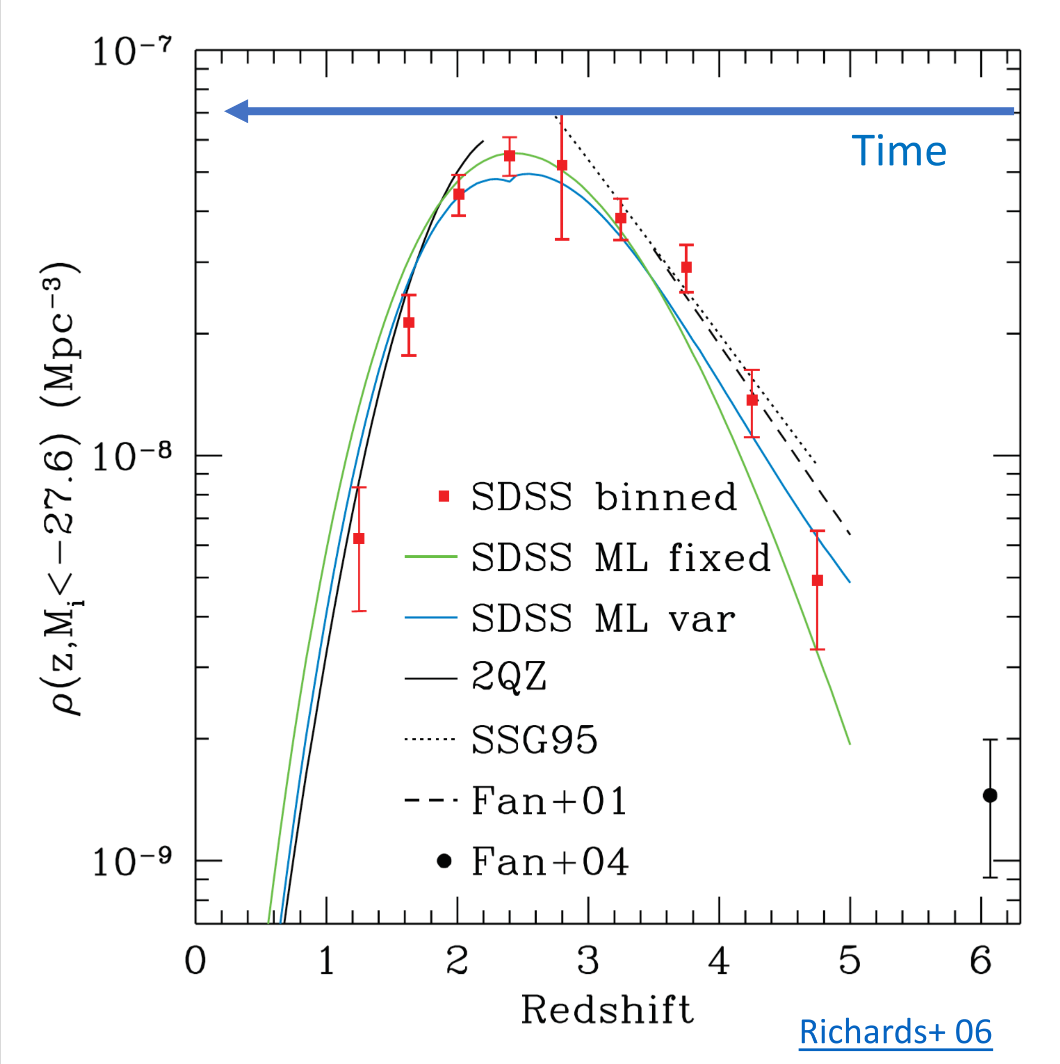
courtesy Bill Keel

Time

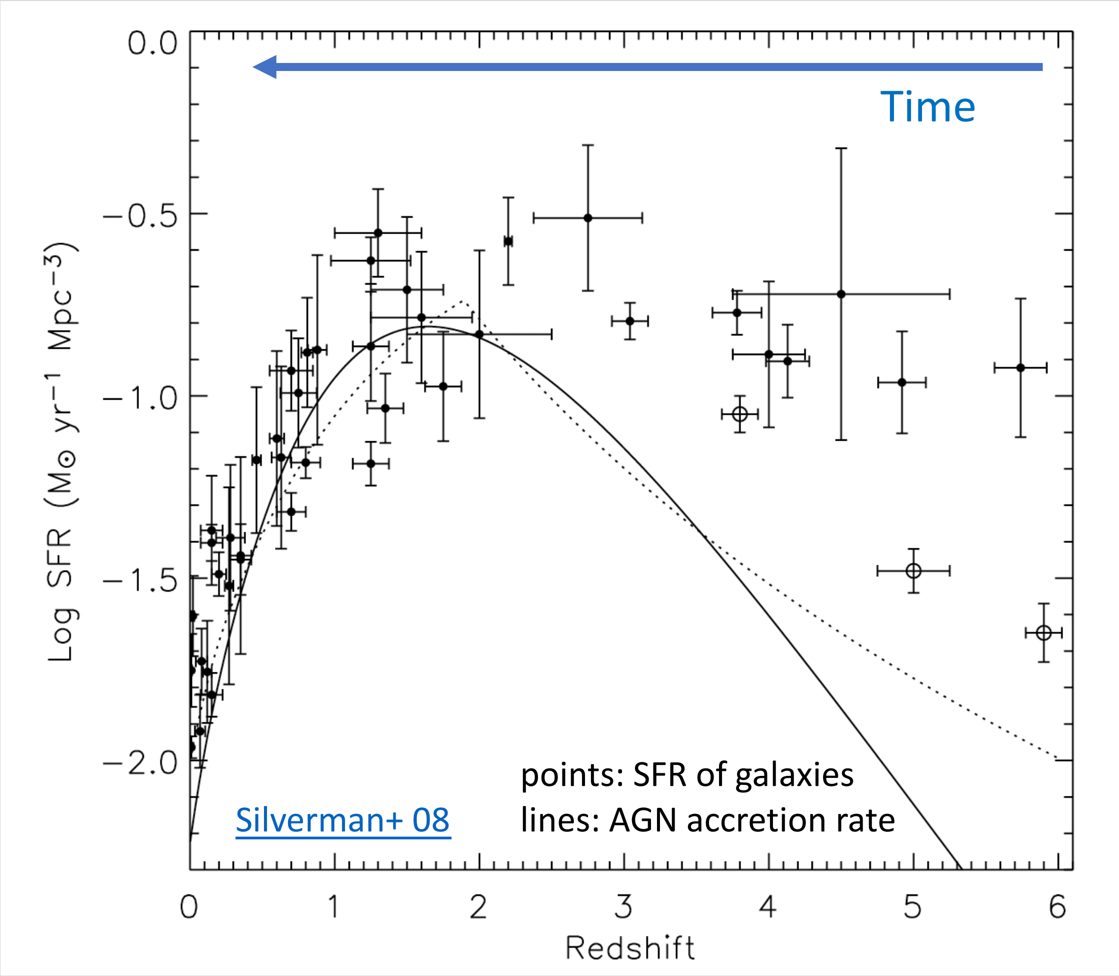
Evolution with redshift: Bright quasars

The epoch of the ***most luminous*** quasars was quite early in the universe's history.

Space density of luminous quasars as a function of redshift



Rate at which universe forms stars shows a similar behavior. ⇒ *AGN activity linked to galaxy growth!*



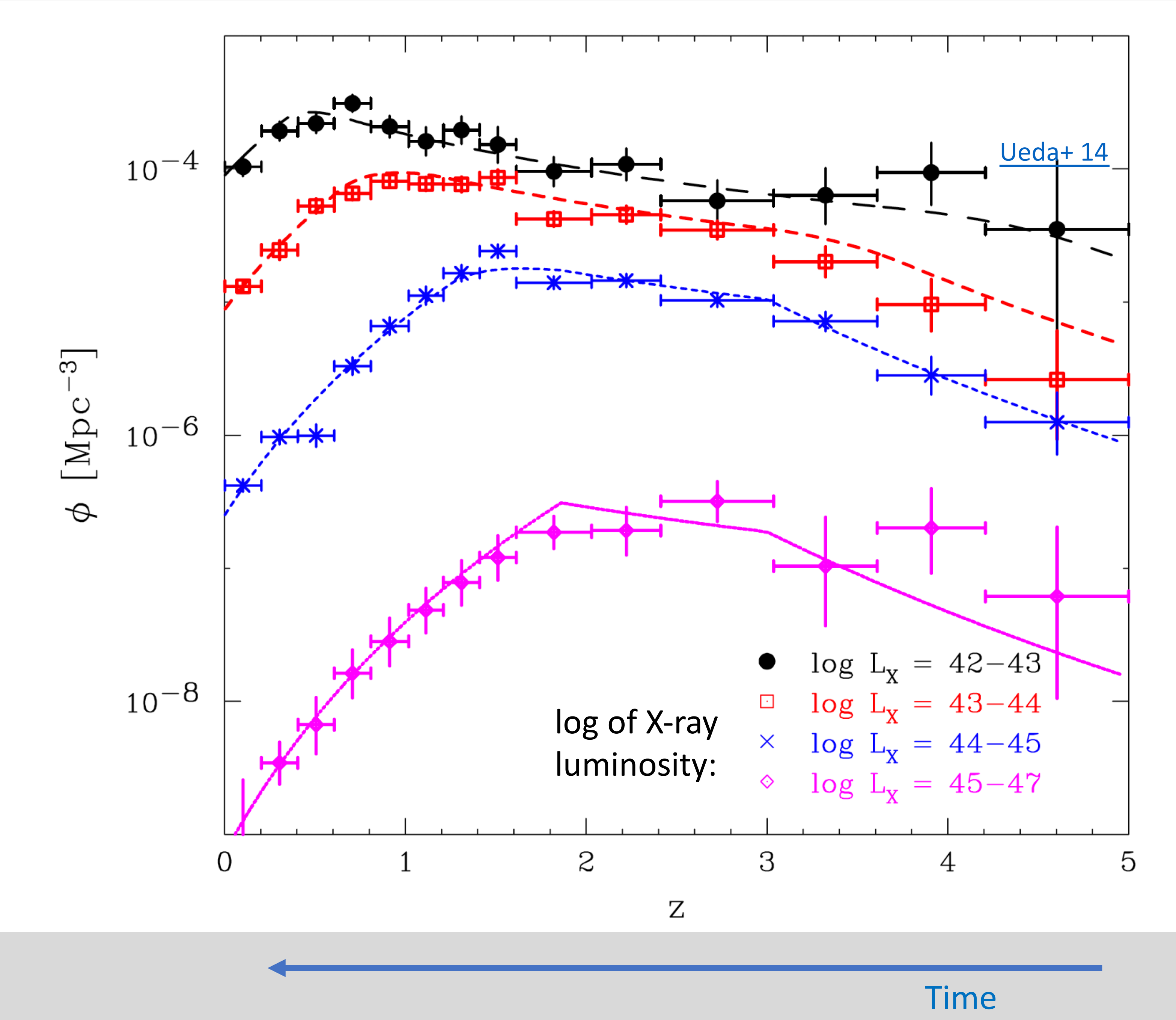
Evolution with redshift: AGN in general

Space density of AGN of different luminosities, as a function of redshift ⇒

Most luminous
Less luminous
Even less luminous
Least luminous

Lower luminosity AGN:

- more common than luminous AGN
- epoch of peak abundance occurs later in time ("downsizing")



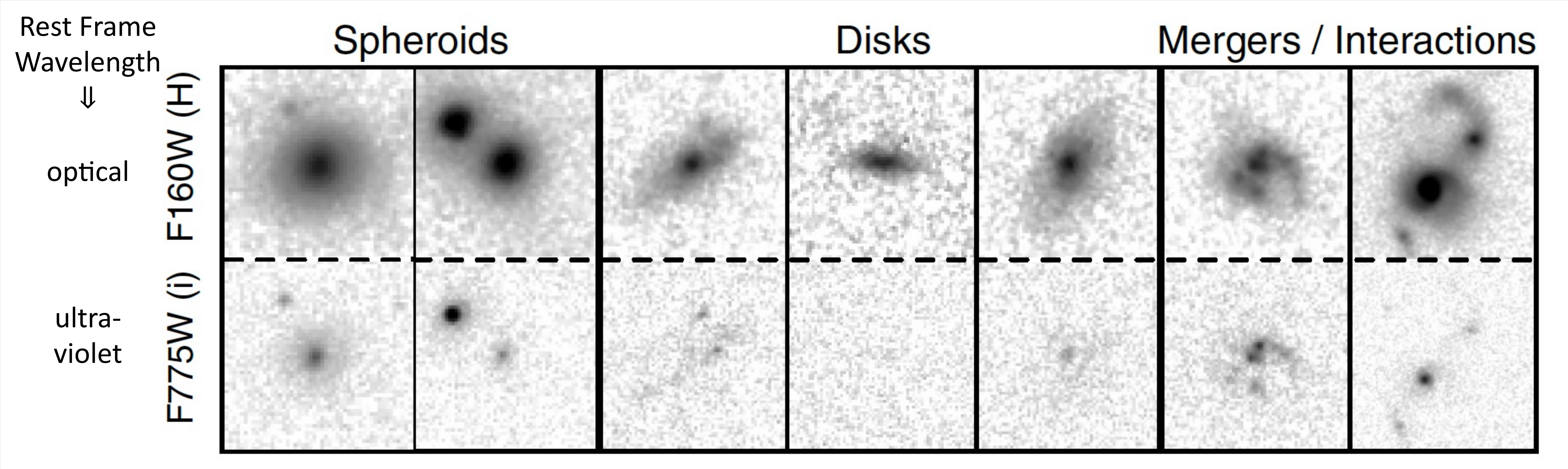
Co-evolution of Galaxies and Central Black Holes

- Black hole accretion rate tracks (roughly) galaxy star formation rate.
- Black hole mass scales with galaxy spheroid mass (but not disk mass).
- Interactions/Mergers seem effective at building spheroids, while slow, gradual accretion better at building disks.
- Interactions more common at higher redshift.
- Interactions good at driving gas inwards to the nucleus.

Therefore: reasonable to think interactions at high redshift would drive AGN activity, right?

X-ray selected AGN morphology at z=1.5−2.5

Kocevski+ 12



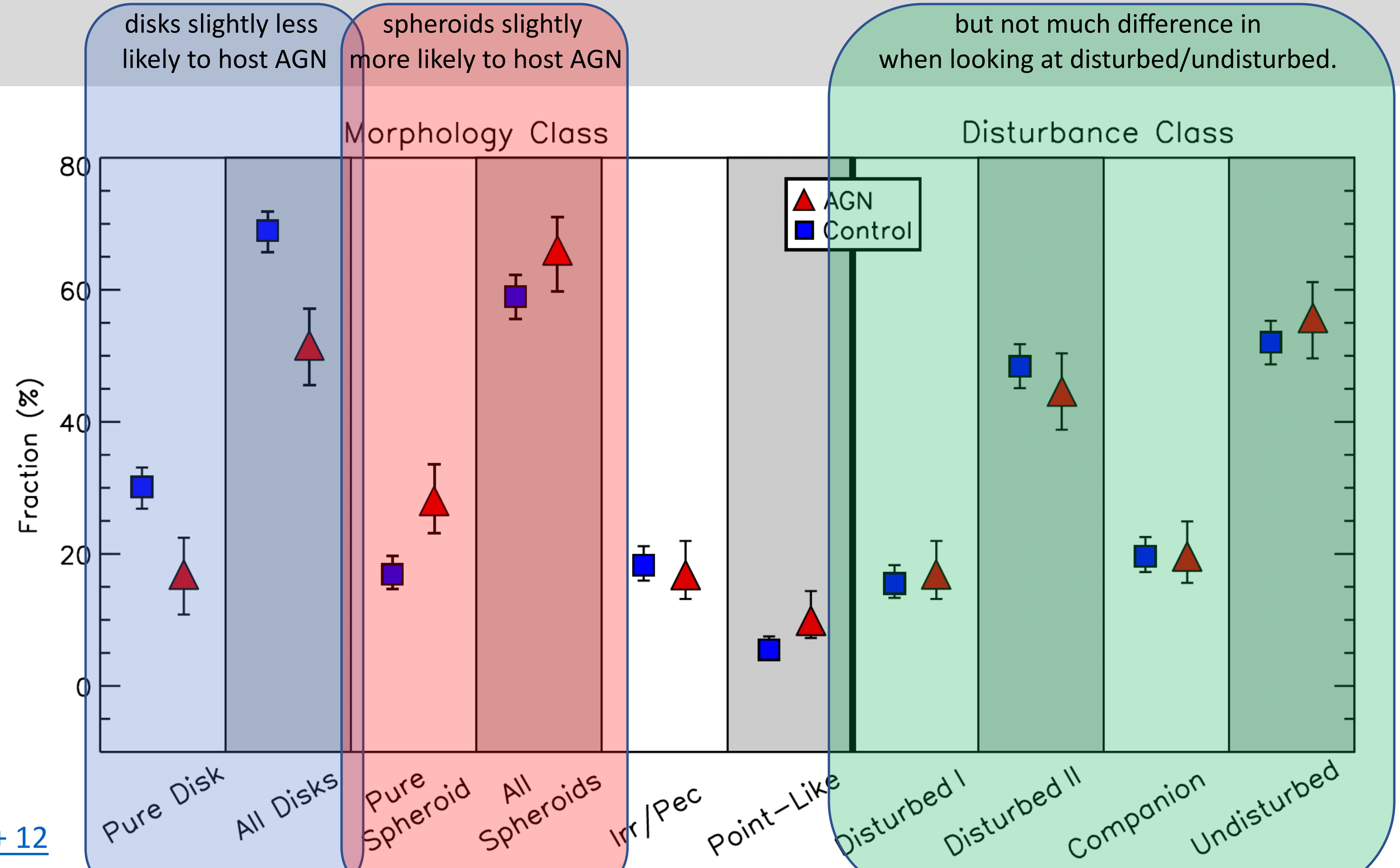
But no strong evidence that mergers drive AGN activity!

Comparing morphology of two galaxy samples:

- **AGN** sample (▲)
- **Control** sample (■) (non-AGN)

Then look at the fraction of each sample that consists of galaxies of different types.

So it's not obvious that interactions are the main driver of AGN activity. And many other studies show comparable results. 🤔



Kocevski+ 12

Figure 4. Fraction of AGN hosts (red triangles) and control galaxies (blue squares) at $1.5 < z < 2.5$ assigned to various morphological and disturbance classes. The *Pure Disk* class includes only disks without a central bulge. The *Pure Disk* class is a subsample of the *All Disks* class, which includes disks with and without a central bulge. Similarly, the *Pure Spheroid* class includes only spheroids with no discernible disk component. The *All Spheroids* class includes both *Pure Spheroids* and disk galaxies with a central bulge. The *Disturbed I* class is limited to heavily disturbed galaxies in a clear merger or interaction. The *Disturbed II* class includes galaxies in the *Disturbed I* class, as well as those showing even minor asymmetries in their morphologies. See the text for details.

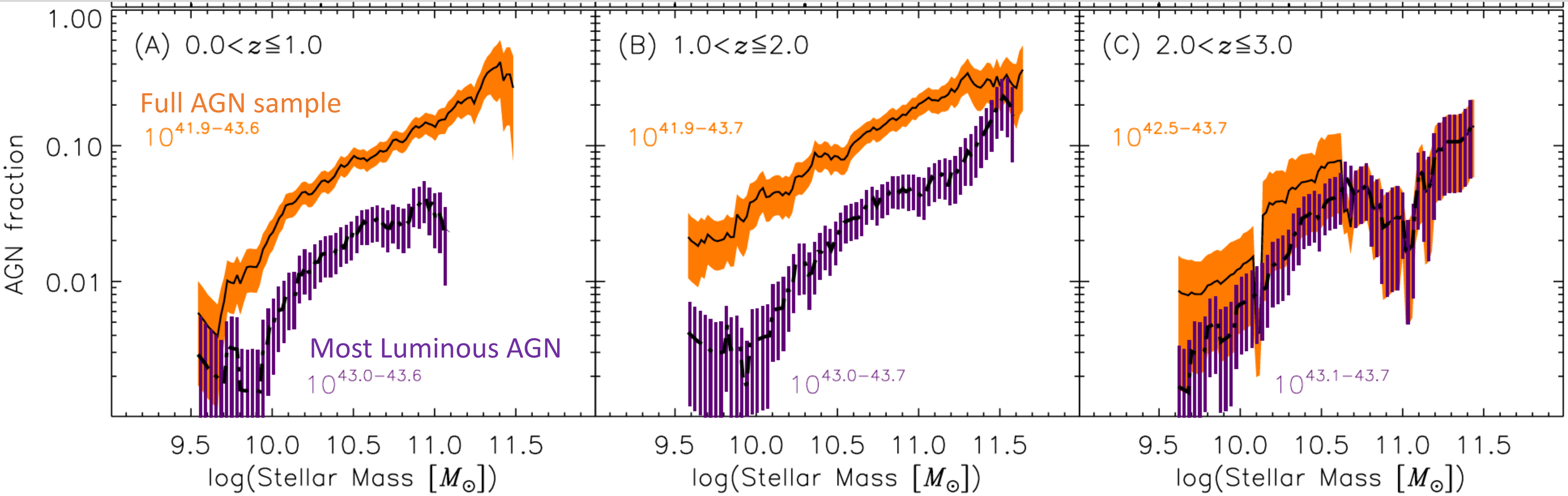
AGN galaxy demographics

- 40–50% early types (E/S0-ish)
- 20–30% late types (disks)
- rest are irregular/peculiar/unresolved

Upshot: Exact connection between AGN, host galaxy, and triggering mechanism is not entirely clear. It's more than just interactions.....

AGN also more common in massive galaxies

Xue+ 10



AGN: Cluster vs Field Enviroment

The fraction of galaxies hosting AGN is lower in clusters than in the field.

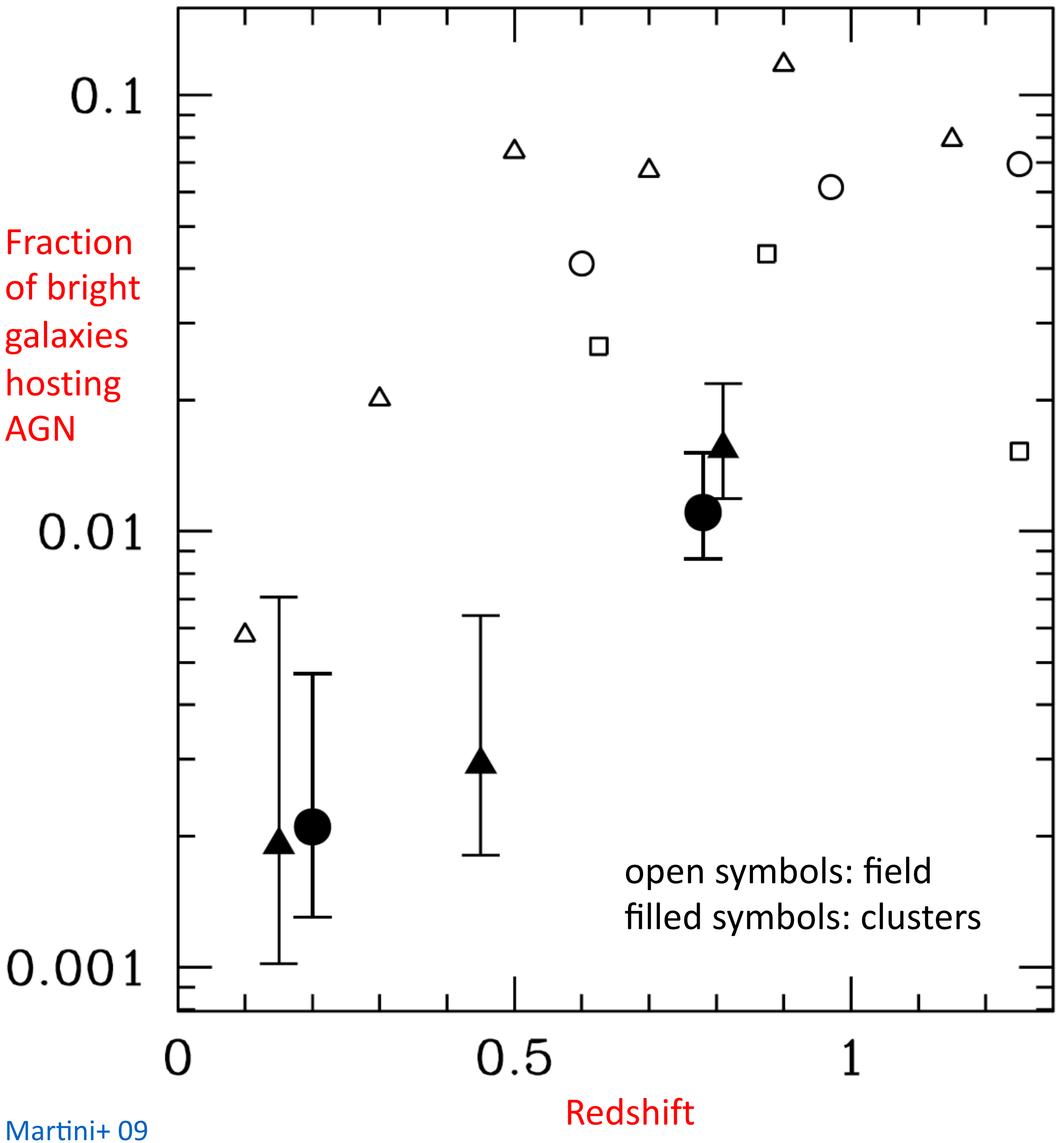
Why?

- ram pressure stripping removes gas from galaxies?
- high galaxy collision velocities suppresses merging?

Fraction of galaxies hosting AGN rises in both field and cluster samples at higher redshift.

Recent studies suggest situation may reverse at very high redshift – dense environments may be *more* likely to host AGN.

ASTR 306 project preview: searching for AGN in galaxy clusters….



Martini+ 09

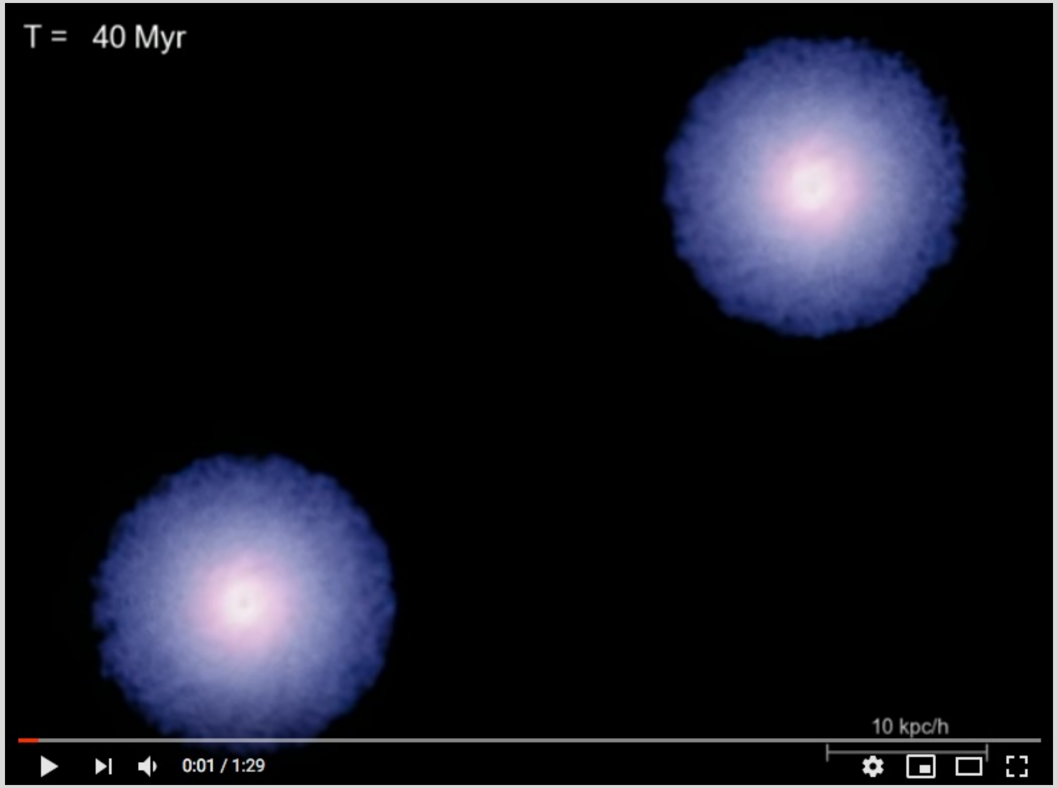
AGN Impact on Host Galaxy: Winds and Outflows

AGN release enough energy to affect surroundings ("**Feedback**"):

- **Mechanical energy** (winds, particles): drive shocks, outflows of gas from the galaxy
- **High energy radiation**: ionize surrounding environment (out to quite large scales)

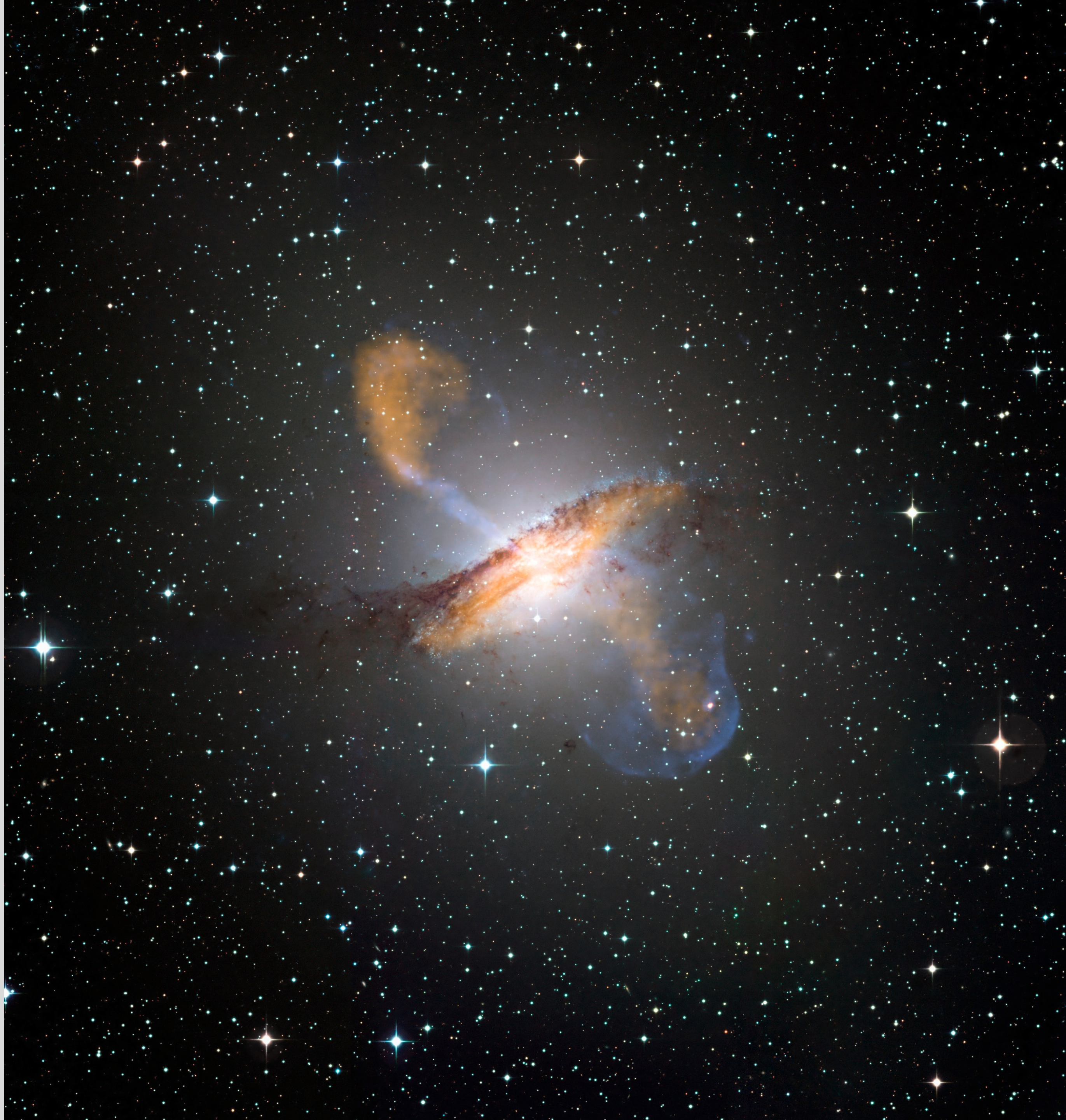
Artist's Conception

Theorists' Simulation (di Matteo+ 08)



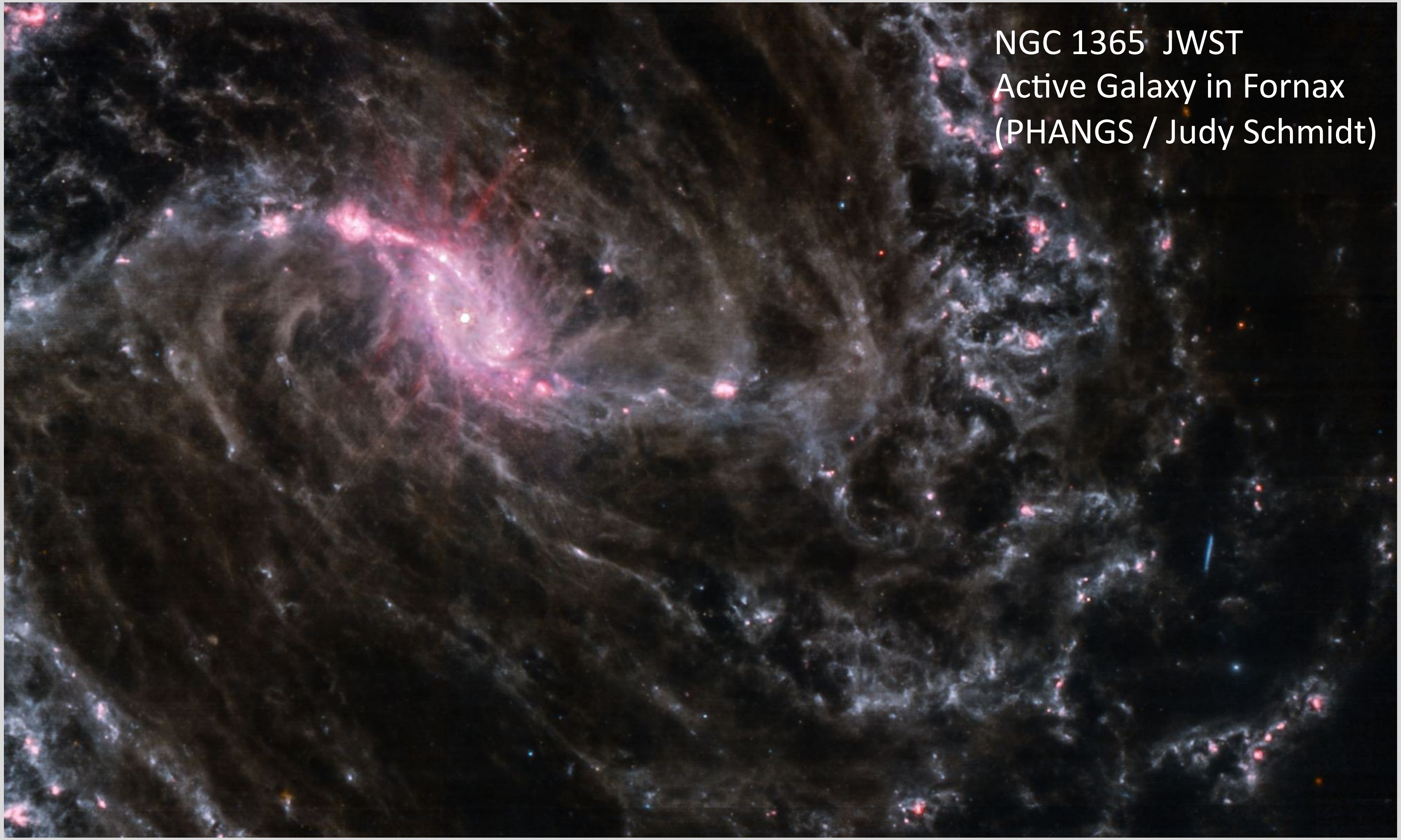
Winds and Outflows: Observational Evidence

- Jets around AGN



Winds and Outflows: Observational Evidence

- Jets around AGN
- Filaments of ionized gas



Winds and Outflows: Observational Evidence

- Jets around AGN
- Filaments of ionized gas
- X-ray shocks/bubbles around AGN in galaxy clusters

Simionescu+19

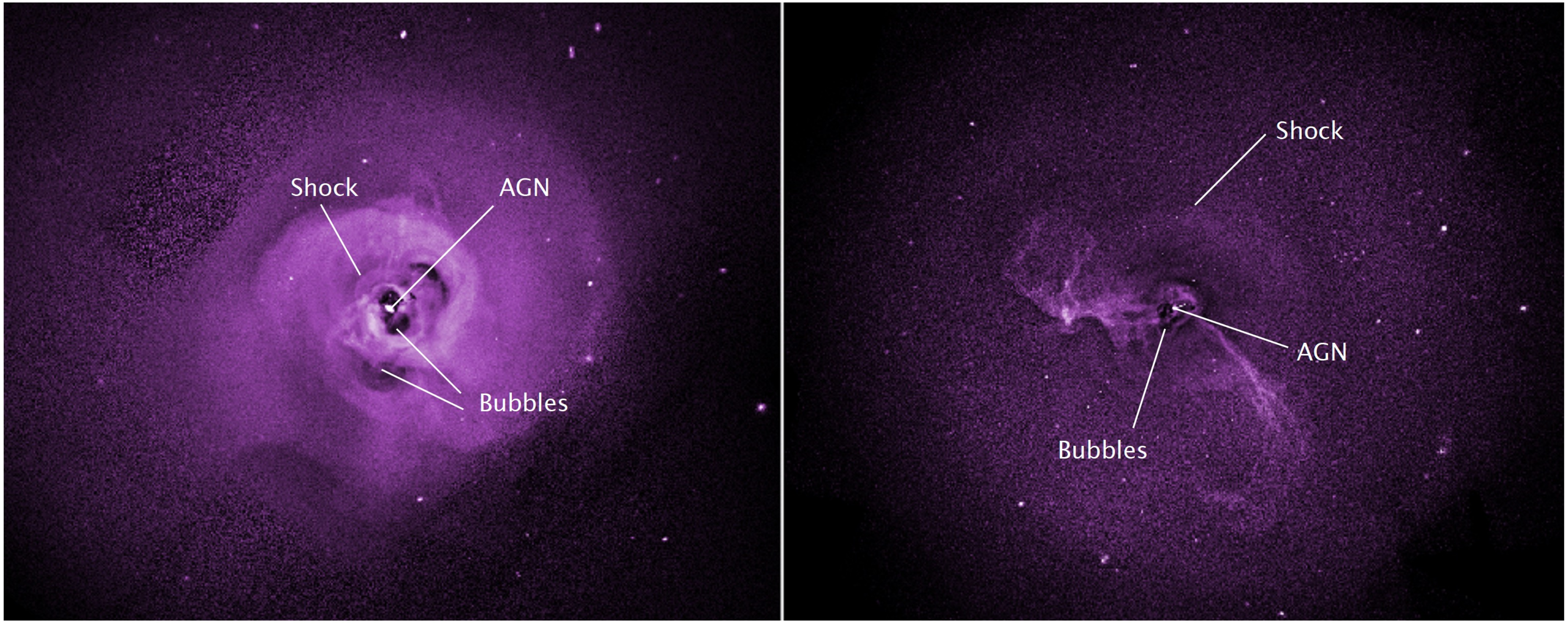
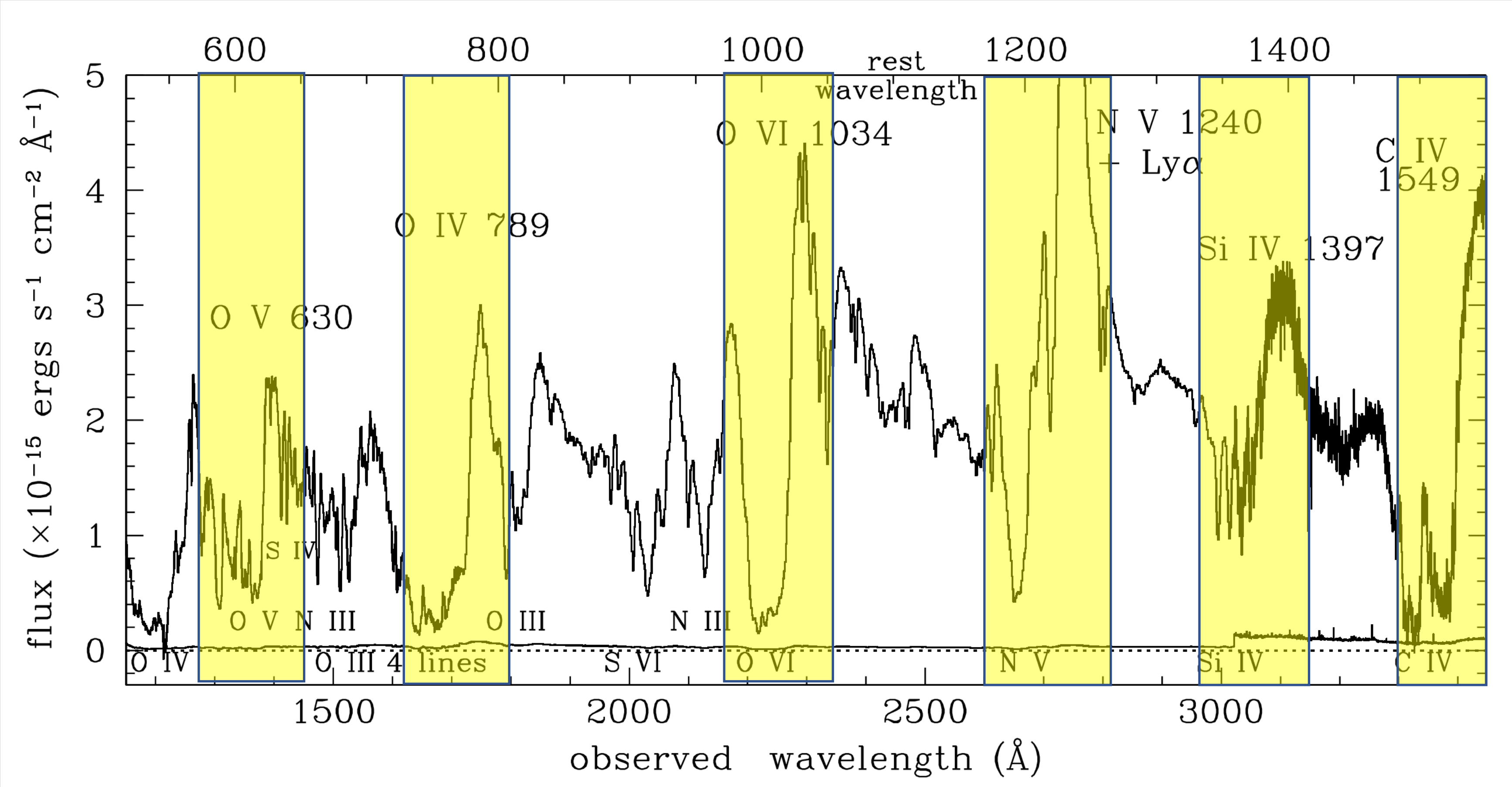


Fig. 7 *Chandra* residual images of the cool cores in the Perseus (left) and Virgo (right) galaxy clusters. Adapted from NASA/CXC/Stanford/Zhuravleva et al.

Winds and Outflows: Observational Evidence

- Jets around AGN
- Filaments of ionized gas
- X-ray shocks/bubbles around AGN in galaxy clusters
- Fast (1000 km/s) absorption features in quasar spectra ("**P Cygni profiles**")

PG 0946+301: [Arav+01]



Winds and Outflows: Observational Evidence

- Jets around AGN
- Filaments of ionized gas
- X-ray shocks/bubbles around AGN in galaxy clusters
- Fast (1000 km/s) gas absorption features in AGN spectra

Lots of evidence for energetic outflows, but what's less clear is how much mass is involved. $E = \frac{1}{2}MV^2$. Is it a lot of mass being blown out, or is it a small amount being driven out quickly?

Possible Impacts on Host Galaxy and Surroundings

- Gas heated, ejected, forms hot X-ray halo around galaxy.
- Strong outflows terminate accretion onto the black hole, shut down AGN ("AGN quenching")
- Strong outflows blow out enough gas on galaxy scale to shut down star formation ("galaxy quenching")
- Shocks or photoionization heats/ionizes surrounding environment, strips/heats gas in nearby satellite galaxies, shuts down their star formation ("proximity effect")
- Central AGN in galaxy cluster can heat gas in the cluster core