AGN & QSOs

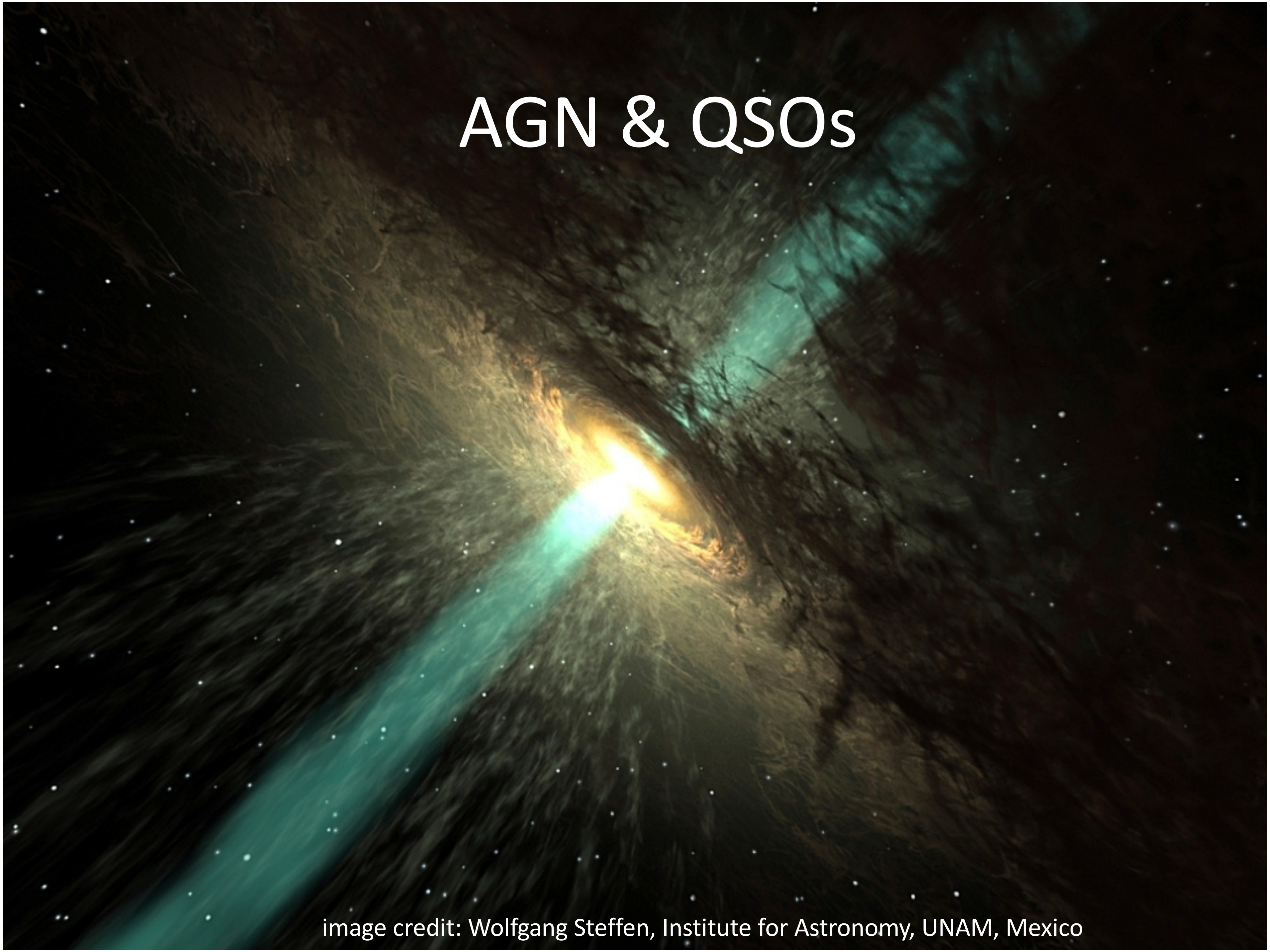
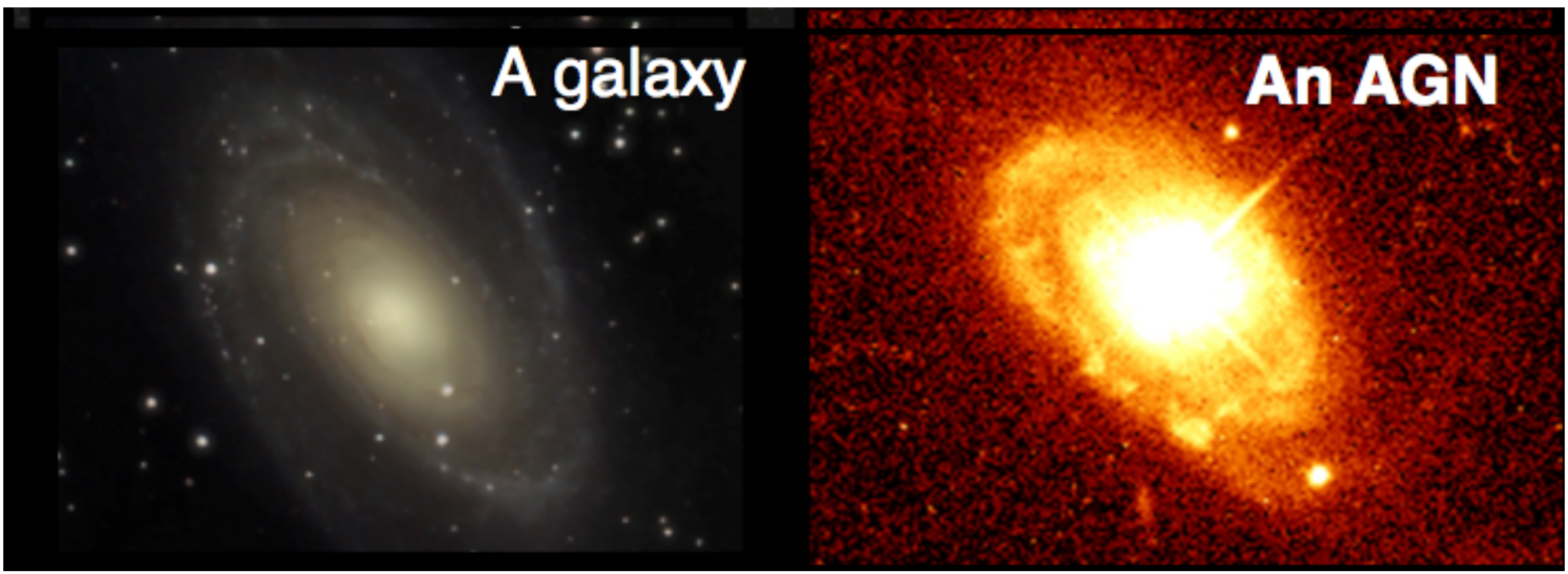


image credit: Wolfgang Steffen, Institute for Astronomy, UNAM, Mexico

AGN

- AGN: A galaxy nucleus that shows evidence for accretion onto a supermassive black hole through non-stellar radiation across the electromagnetic spectrum



Why do we care about AGN?

- Black Hole Mass can be determined from AGN properties
- Black Hole Growth Correlates with Galaxy Properties
- (U)LIRGS & QSOs – extreme central engines : merger hypothesis & UV/IR background
- QSOs as probes of the IGM (absorption lines) and of Large Scale Structure & early universe

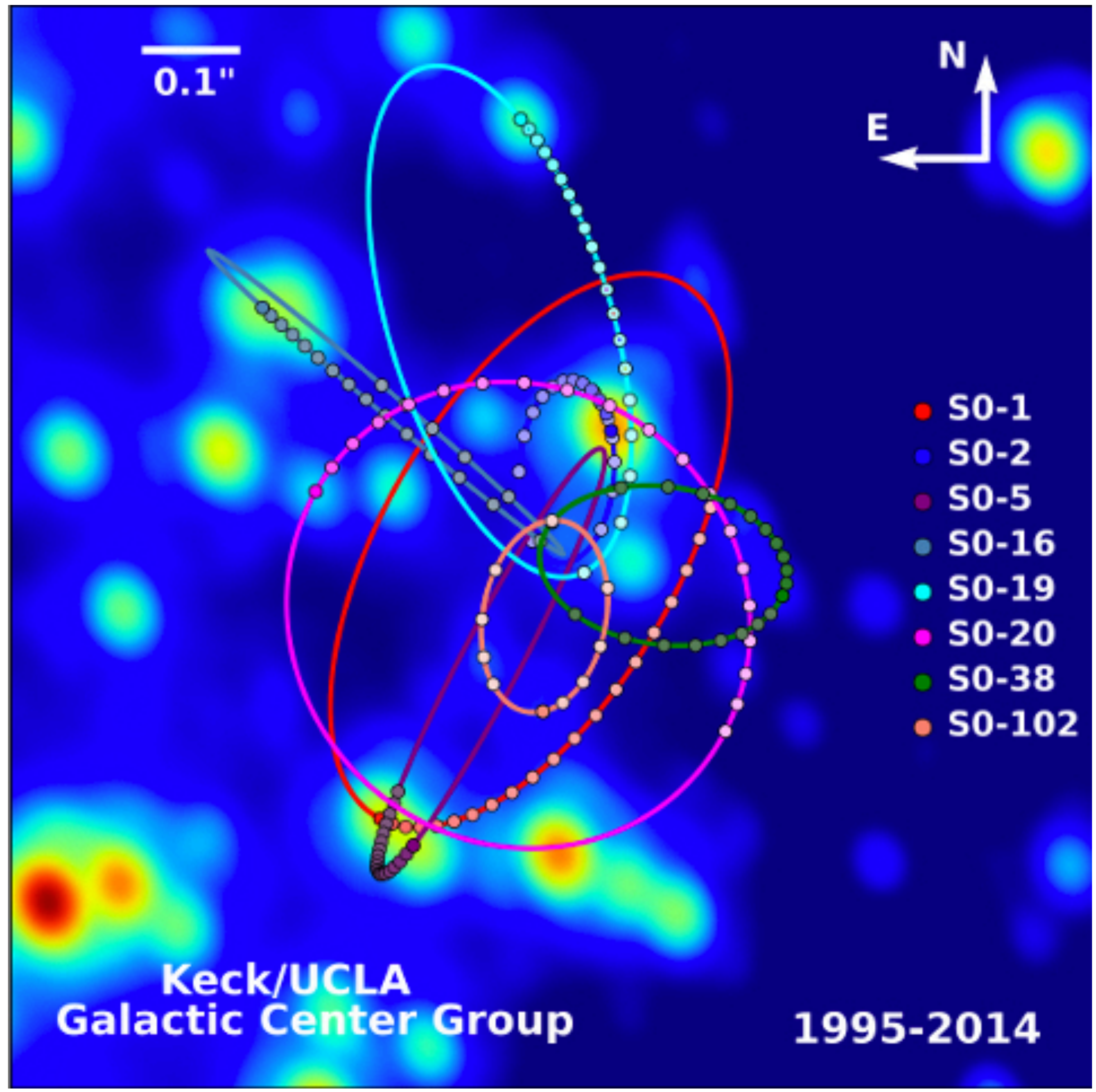
The SMBH in our Galaxy

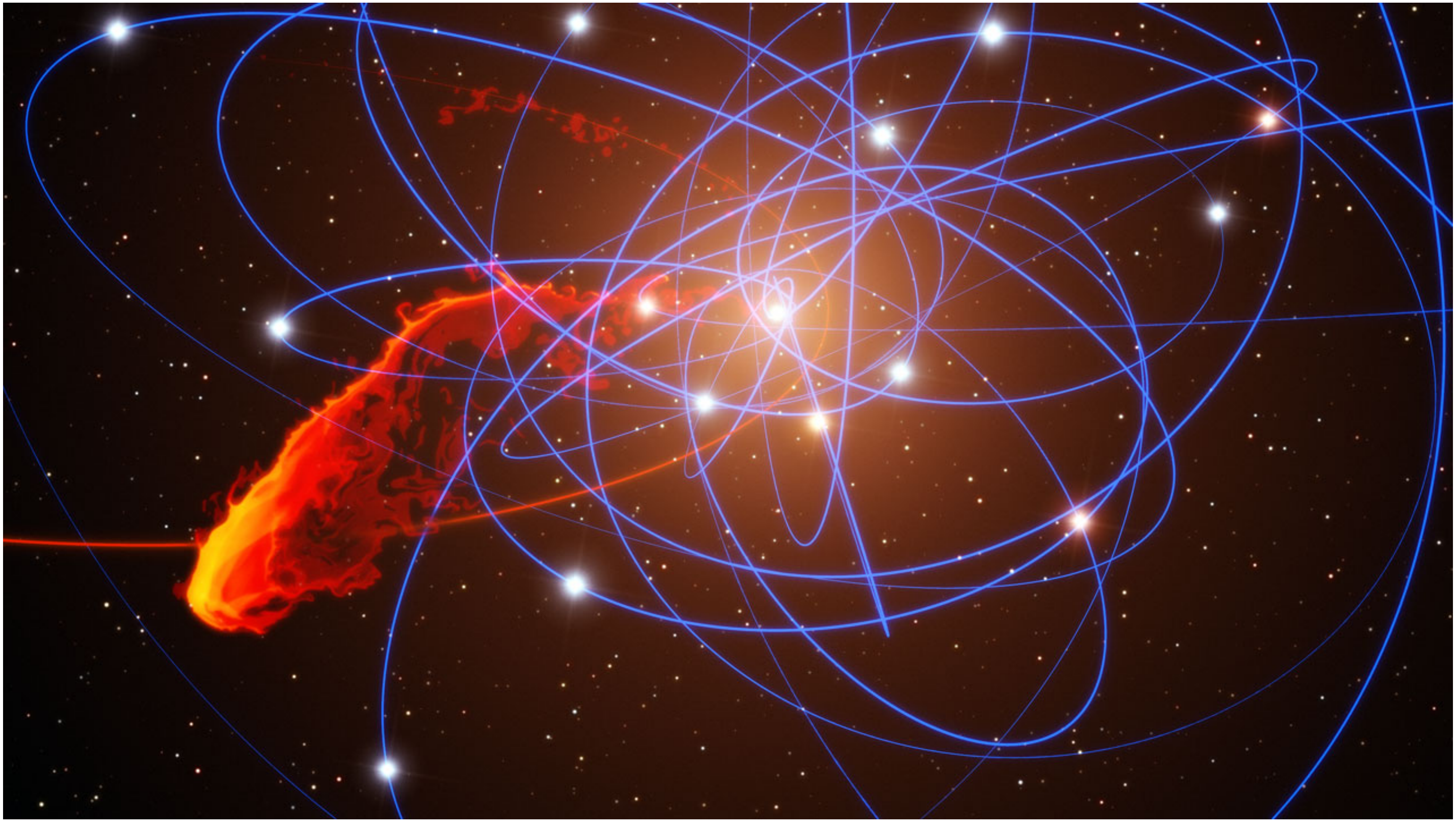
$M_{BH} = 3 \times 10^6$ Msun
$L_{edd} = 10^{44}$ erg/s
L actual = 10^{-10} L_{edd}

Lowest accretion rate known..
Most galaxies have big black holes, but low accretion rates.

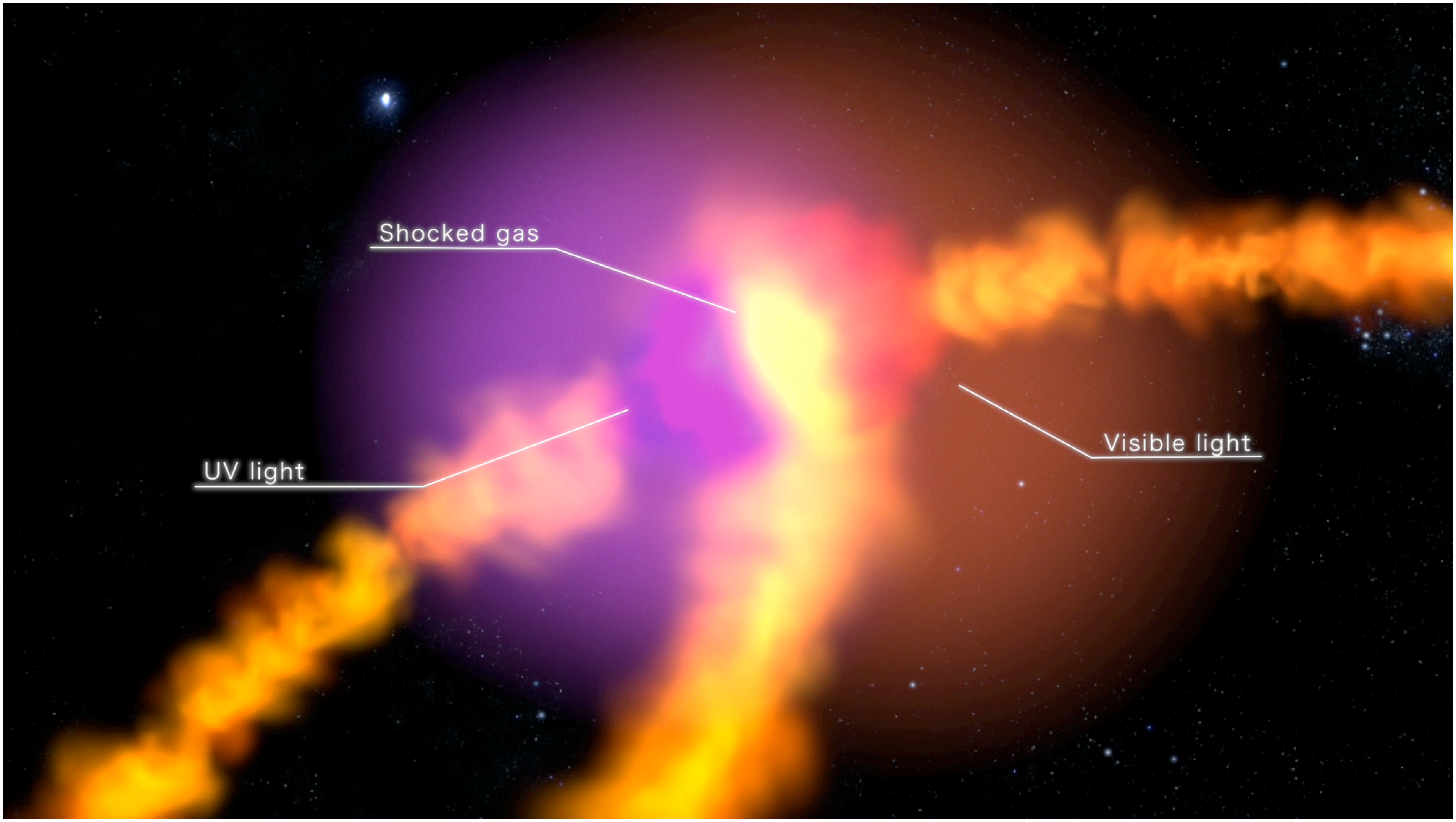
Full phase coverage has been measured for two stars: S0-2 with an orbital period of 15.56 years, and S0-102 with 11.5 years.

Andrea Ghez's team; UCLA





Animation of the G2 Cloud being cannibalized by SgA*


Shocked gas
UV light
Visible light

Most of the BH's energy is radiated by the accretion disk

Radiative Mode:

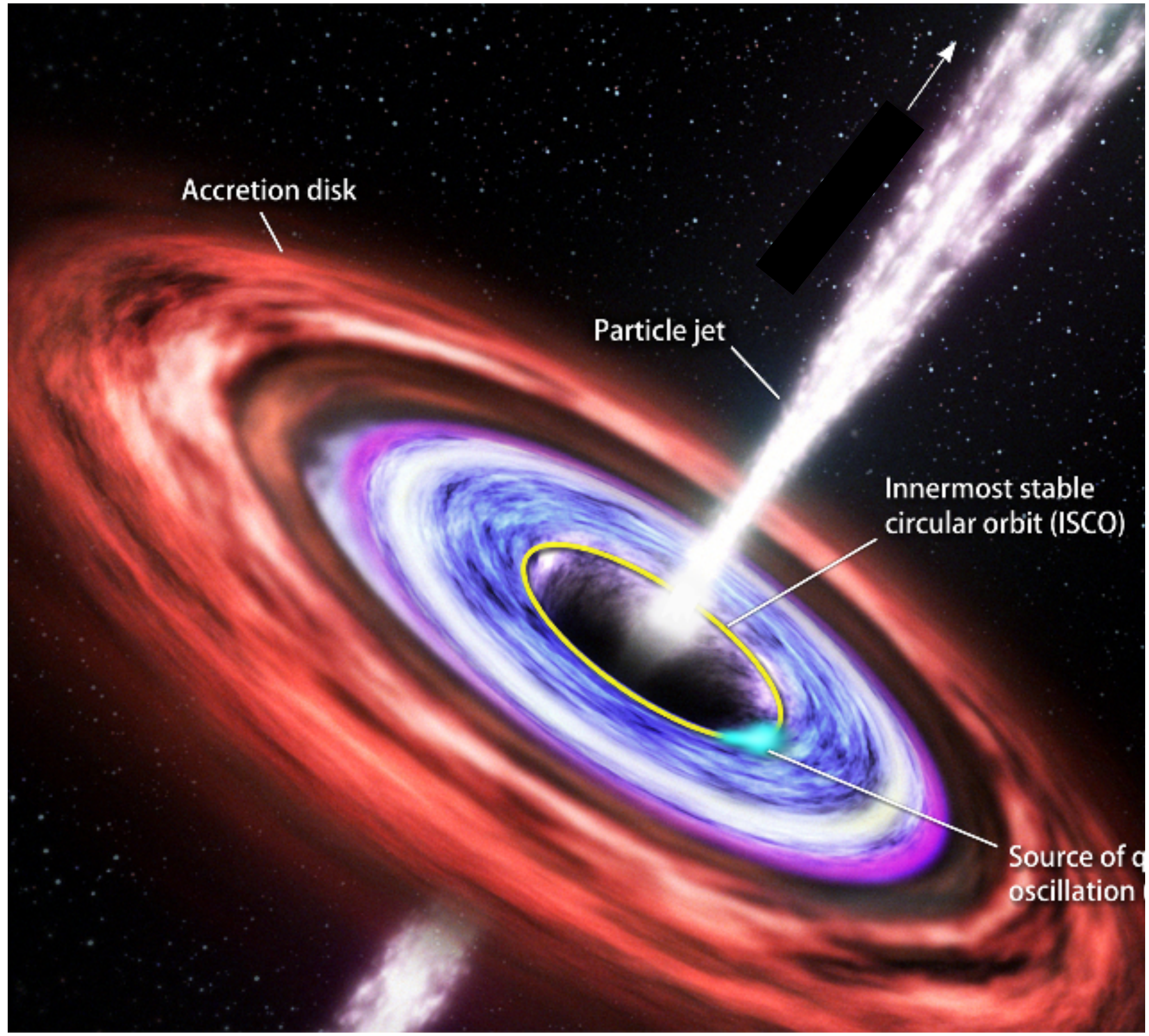
Gas falls in: PE -> KE

Gas rotates with Keplerian velocities: $v \propto r^{-1/2}$

Friction between gas rings heats gas

Gas radiates and energy loss causes it to fall in

Net effect: gravitational energy converted to radiation



Accretion Rate Powers the AGN luminosity

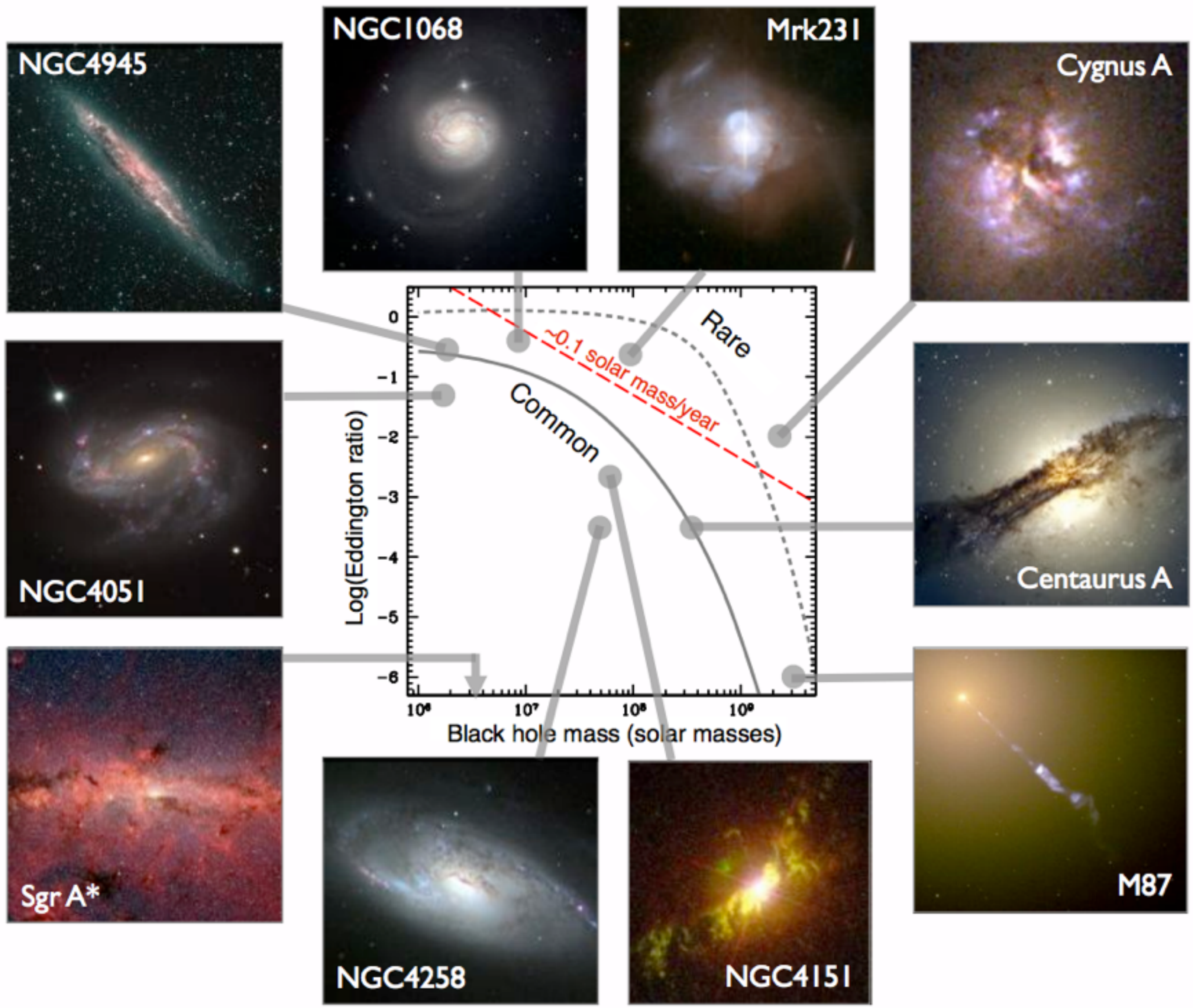
- Eddington Luminosity: Max Luminosity such that there is a balance between radiation and gravitational force

$$L_{\mathrm{Edd}} = \frac{4\pi G M m_{\mathrm{p}} c}{\sigma_{\mathrm{T}}}$$
$$\cong 1.26 \times 10^{31} \left(\frac{M}{M_\odot}\right) \mathrm{W} = 3.2 \times 10^{4} \left(\frac{M}{M_\odot}\right) L_\odot$$

- Accretion Rate $L = dE/dt = \eta \dot{M} c^2$

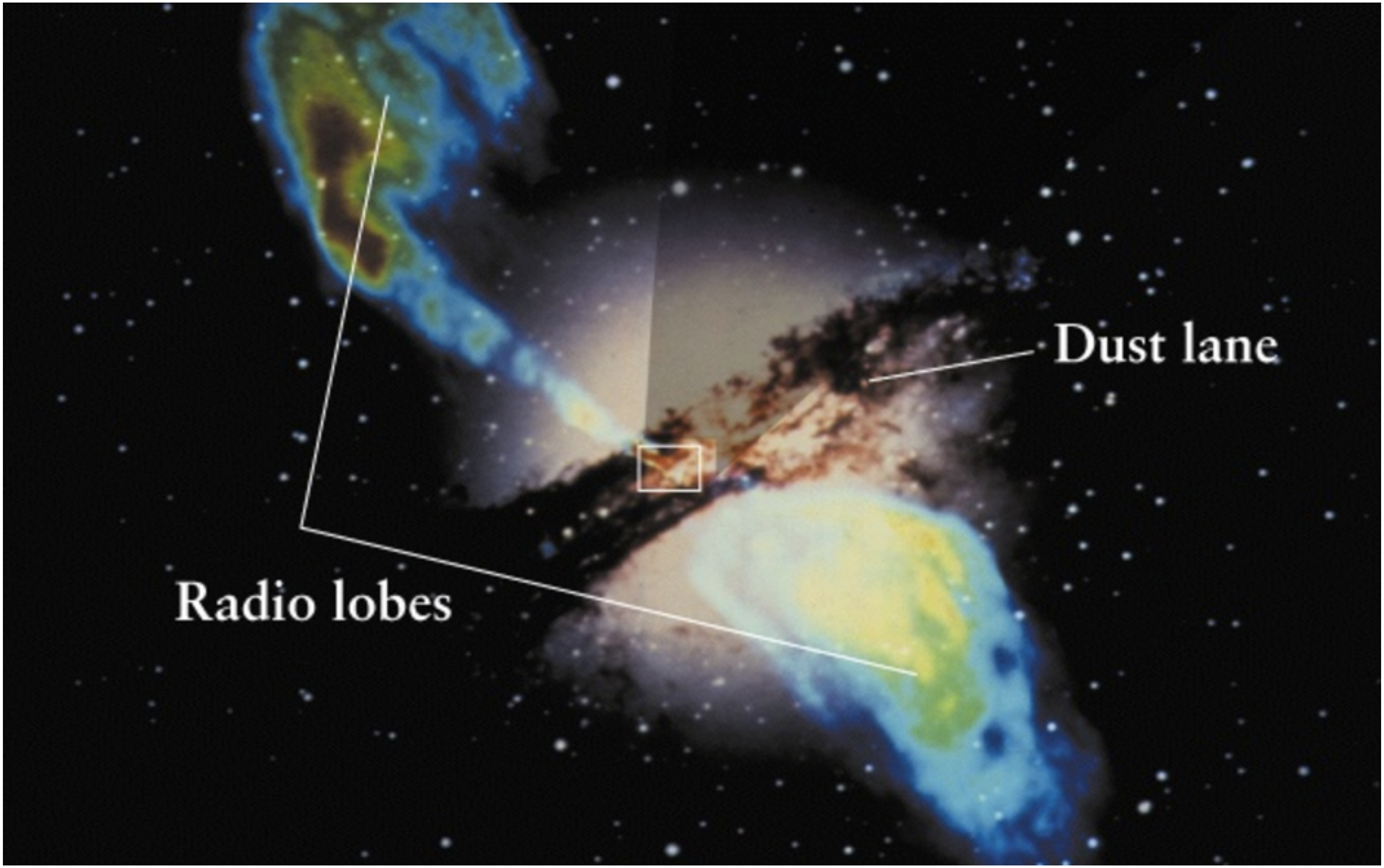
$$\eta \dot{M} c^2 = L_{edd} = 3.82e46 \mathrm{erg/s} \qquad \dot{M} \sim 3 M_\odot / yr$$

If M_{BH} = 3 x 10^8 Msun, and η = 0.1



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

Centaurus A: Radio Galaxy



Jets are ~ 10 kpc in length

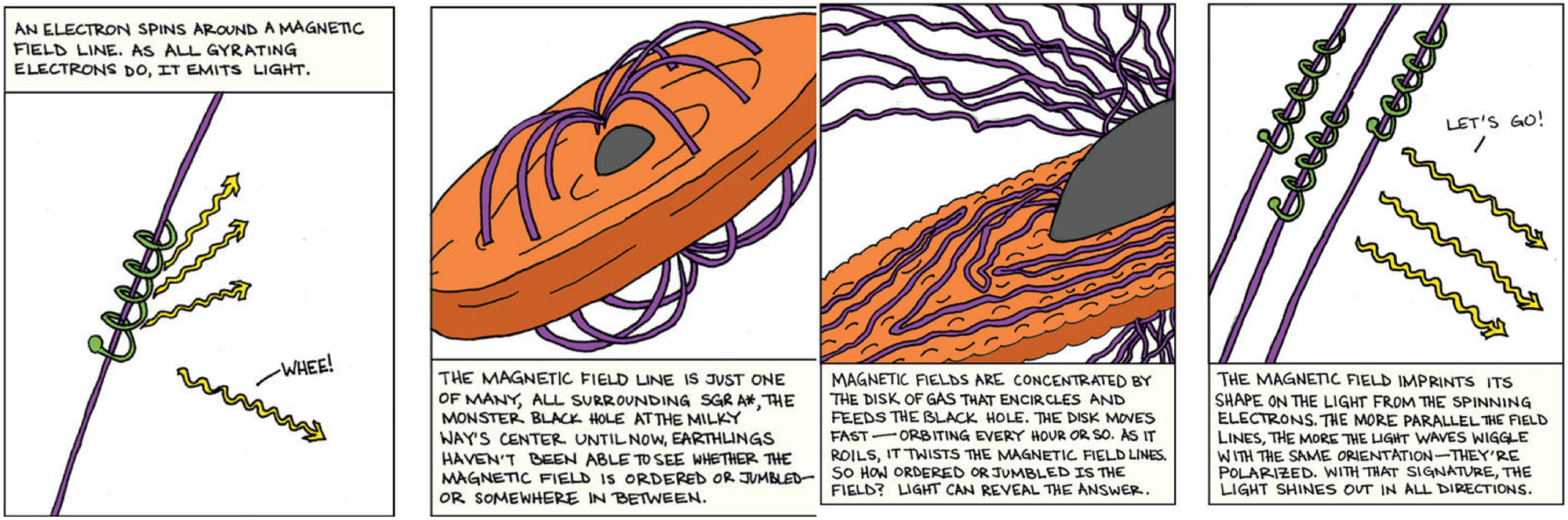
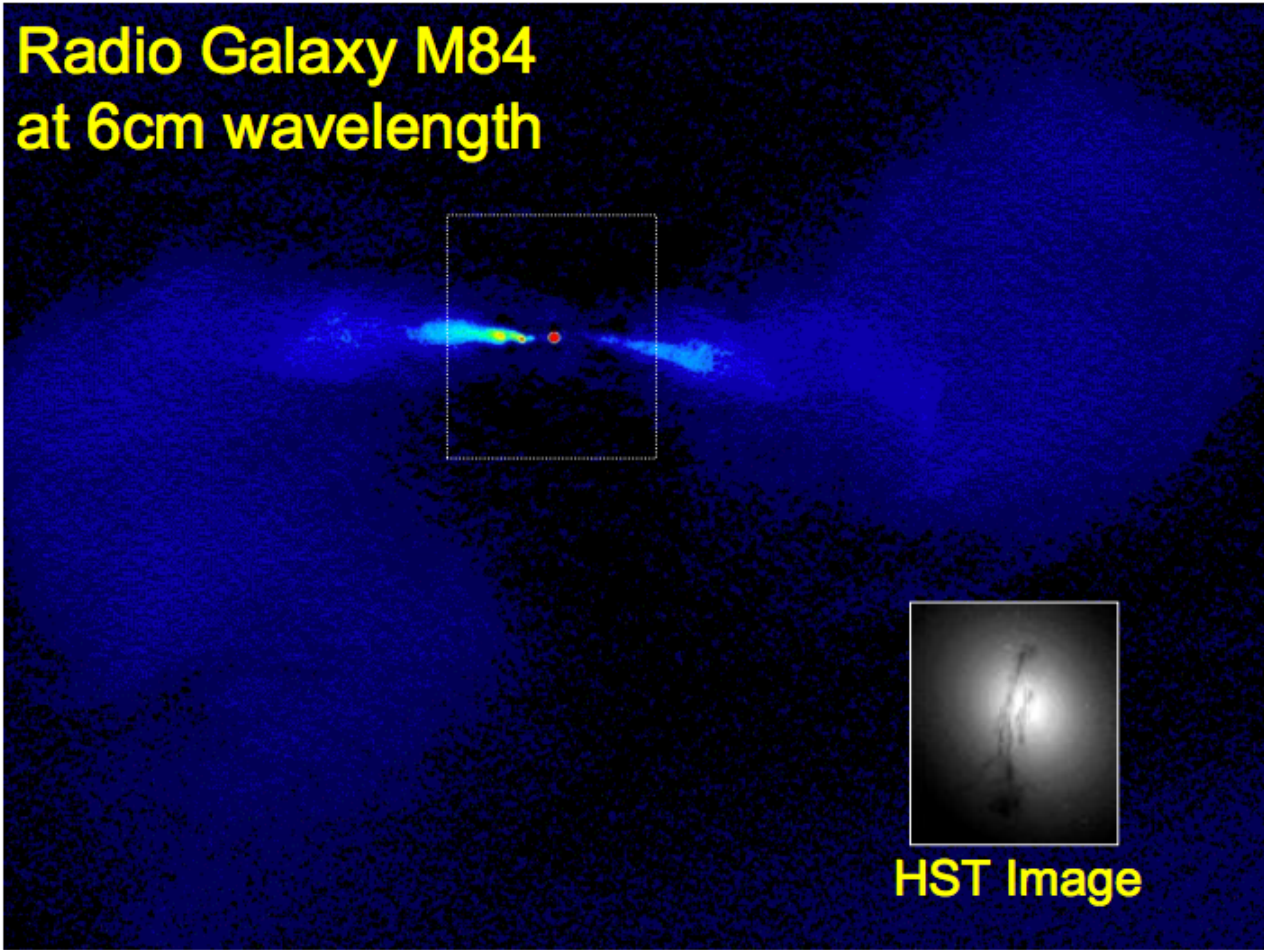
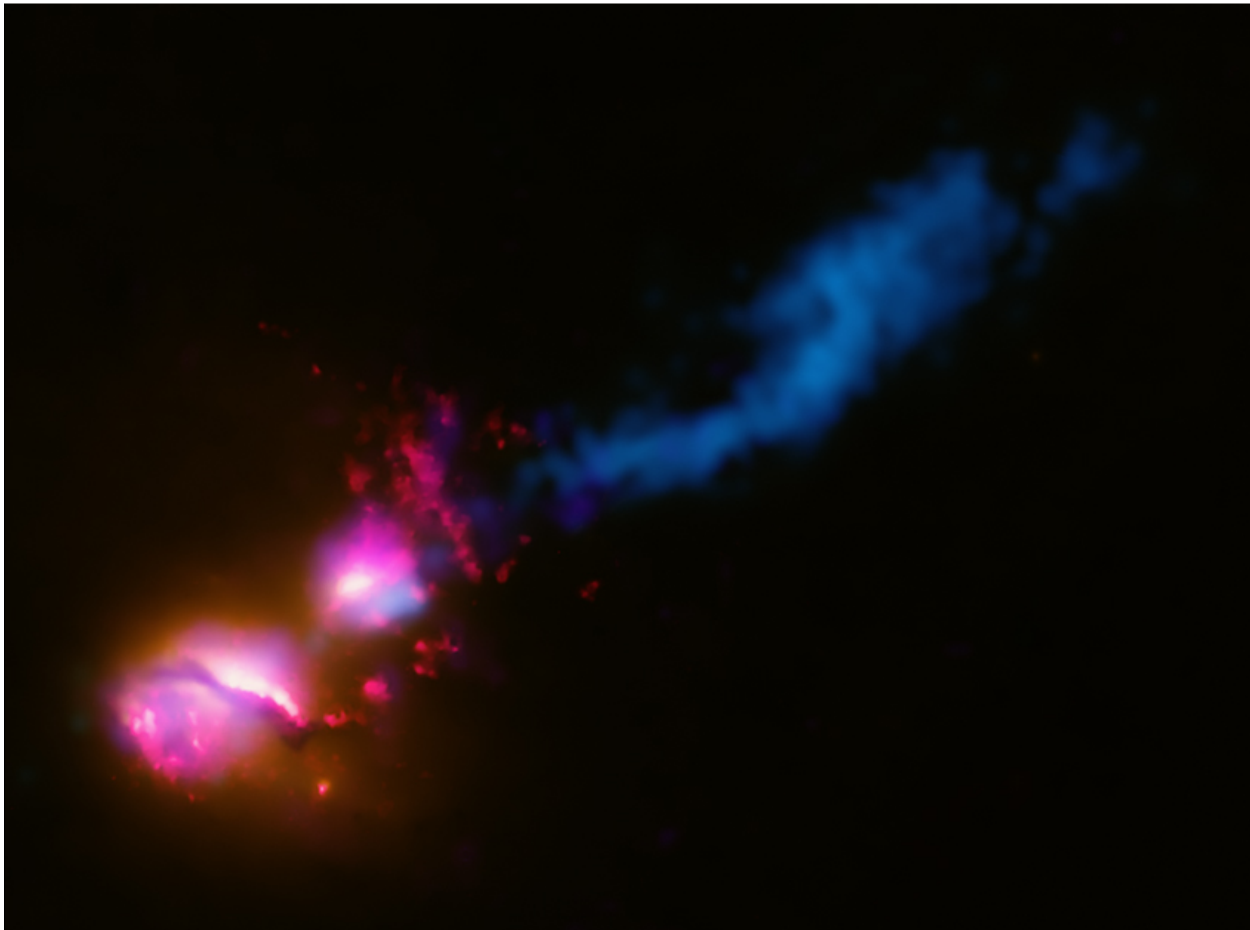


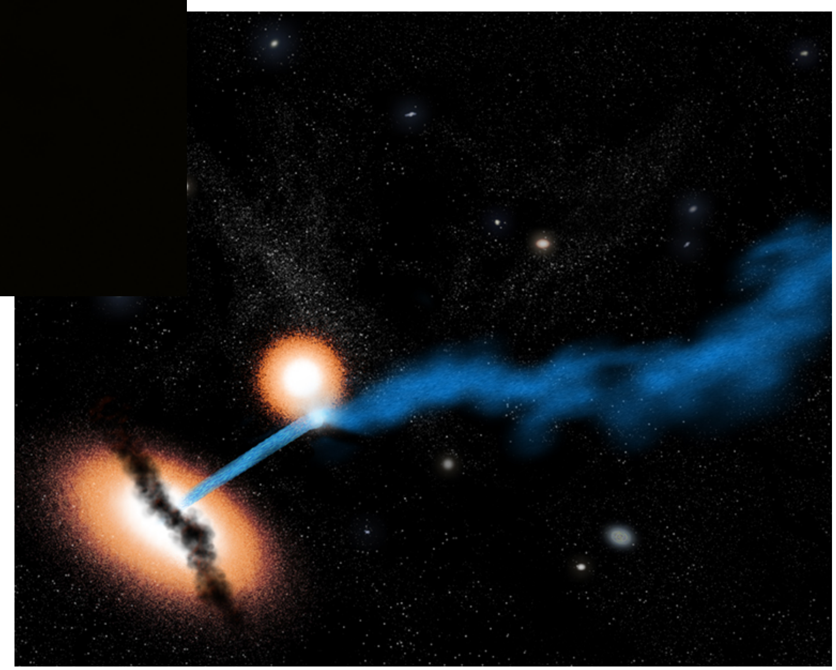
Image Credit: Katie Peek

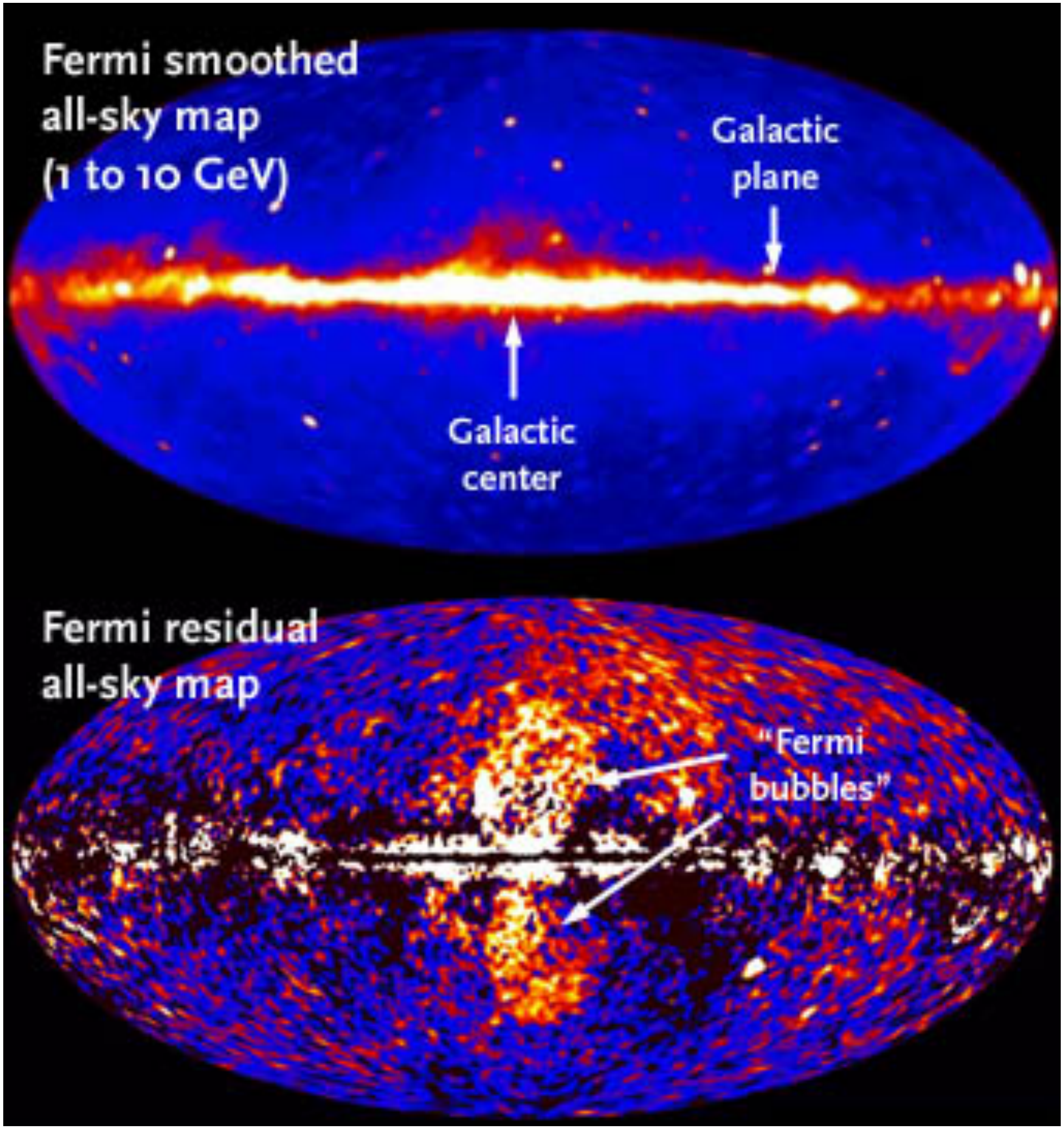

Radio Galaxy M84
at 6cm wavelength
HST Image

Death Star Galaxy!

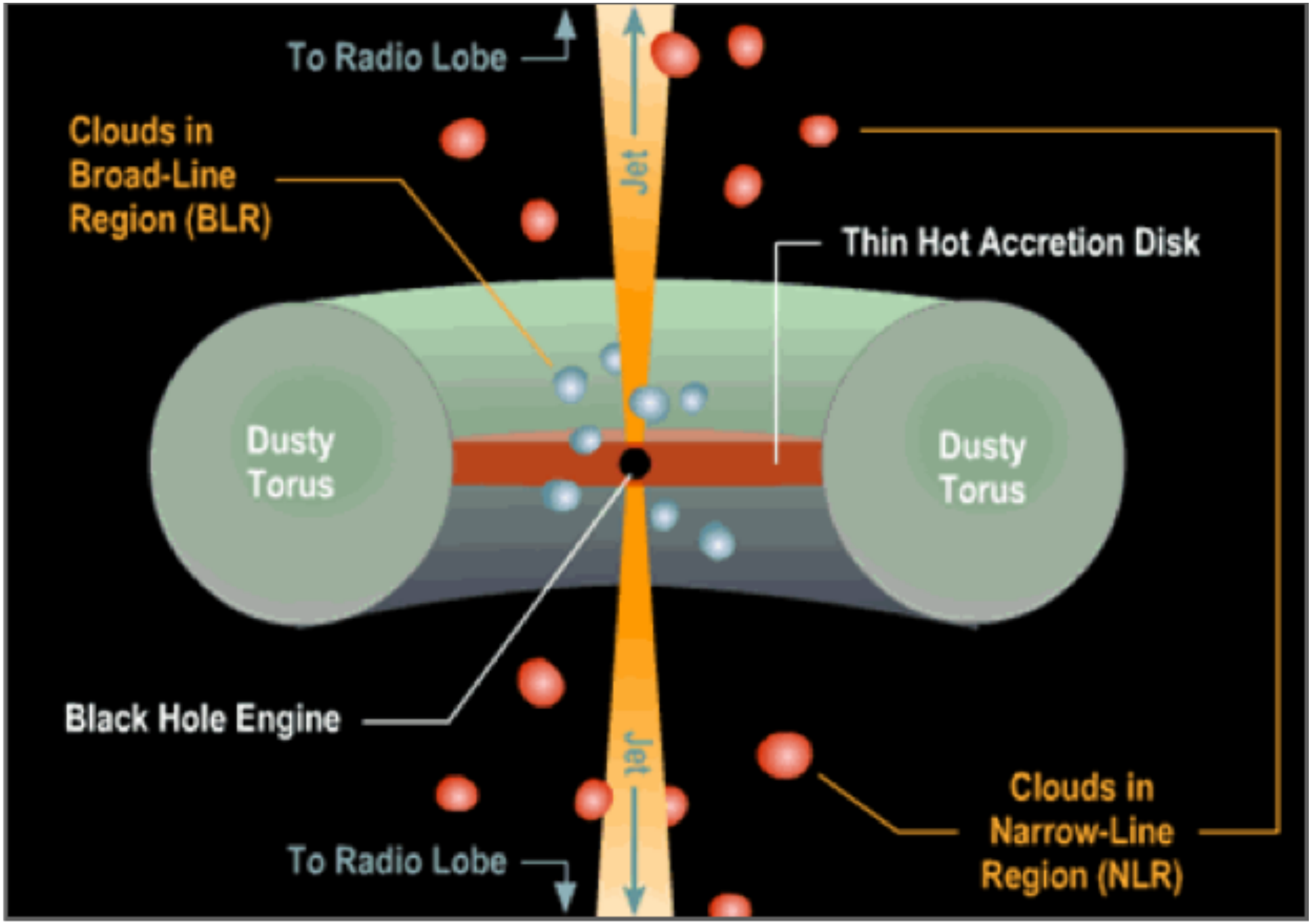


This is a composite image showing a jet from the black hole at the center of the main galaxy (lower left) striking the edge of a companion galaxy (upper right). X-rays from Chandra (colored purple), visible and UV from Hubble (red & orange), and radio from the Very Large Array and MERLIN (blue)




Fermi smoothed
all-sky map
(1 to 10 GeV)
Galactic
plane
Galactic
center
Fermi residual
all-sky map
"Fermi
bubbles"

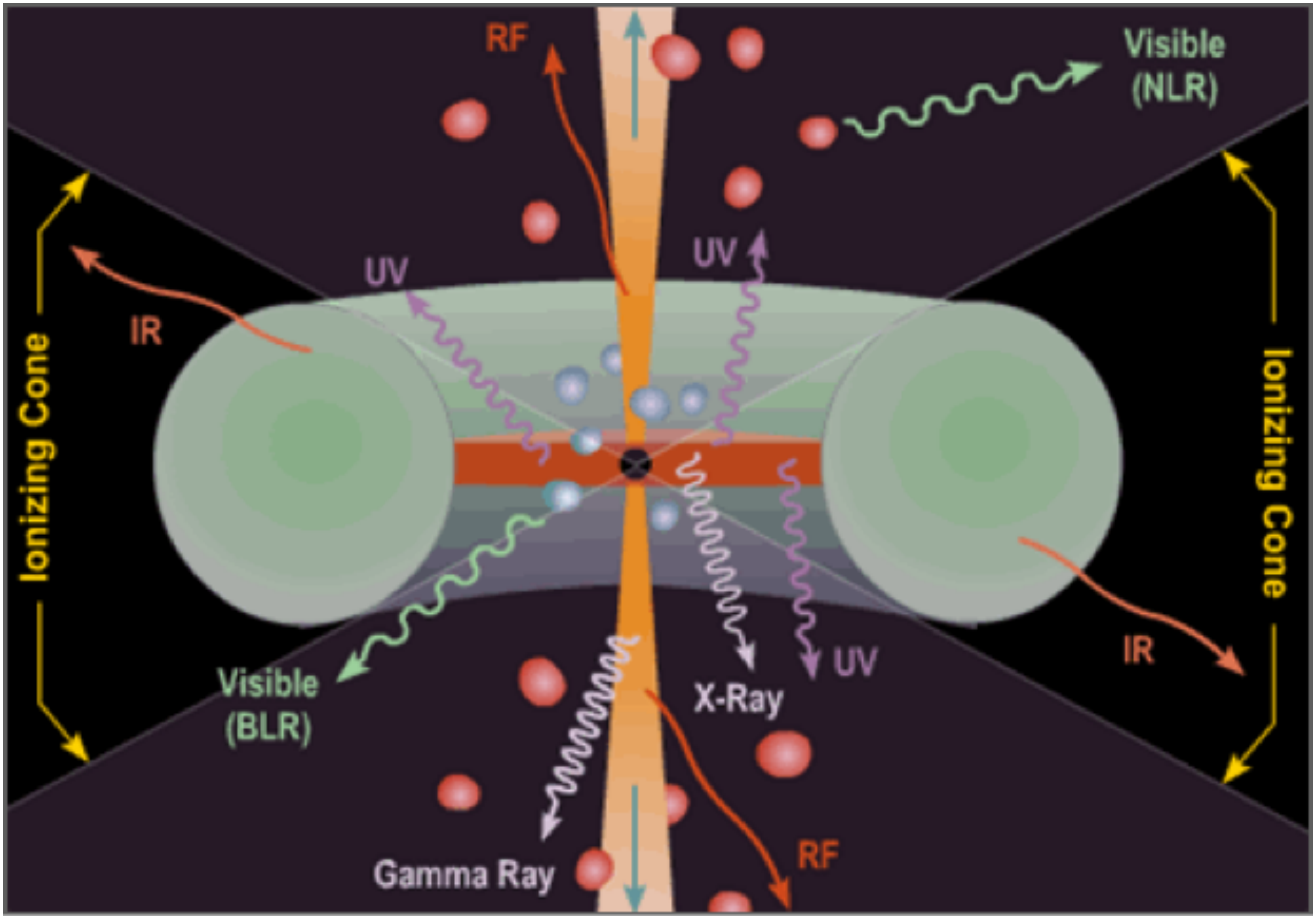
Unified Model



Brooks/Cole Thomson Learning

Brooks/Cole Thomson Learning

Unified Model

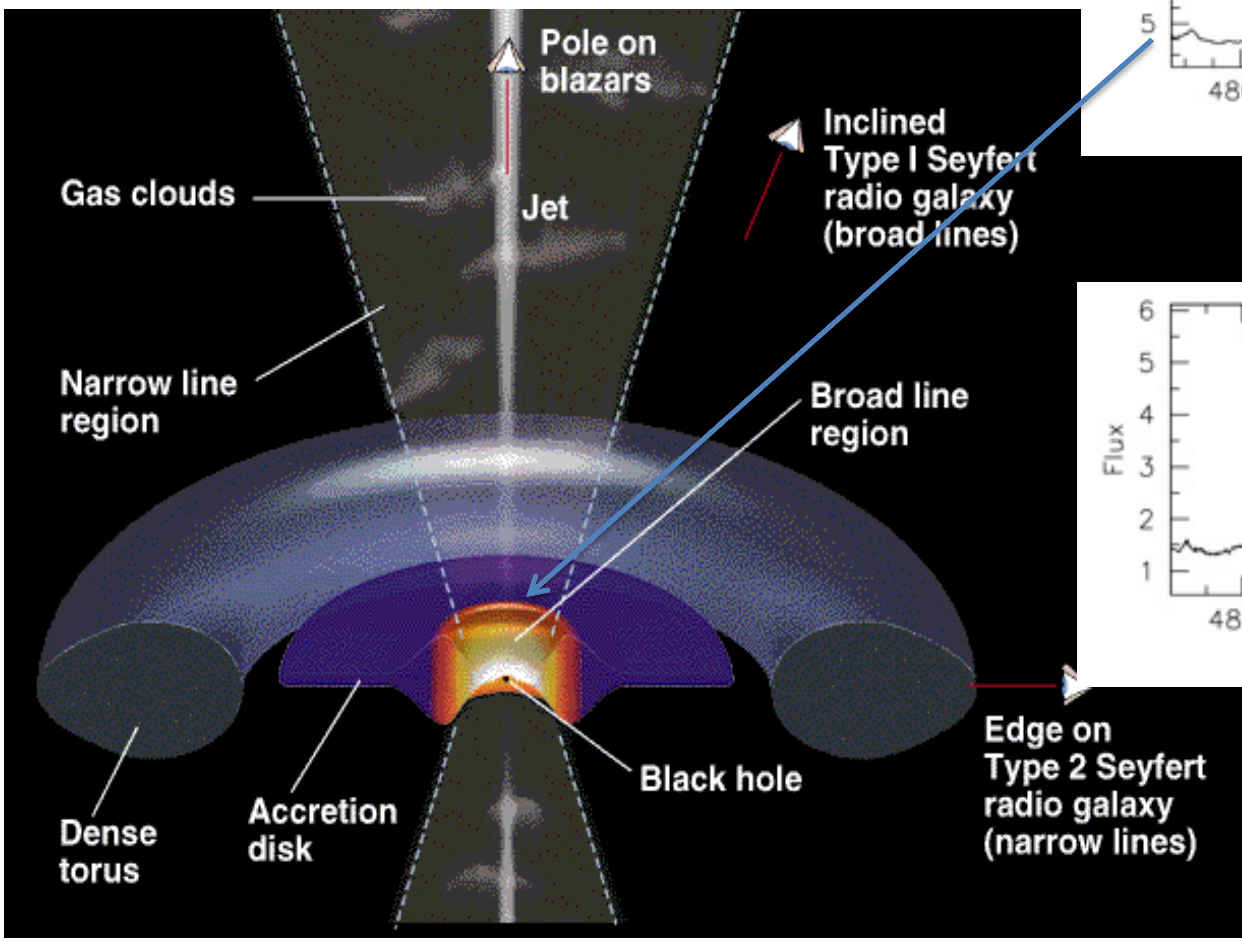


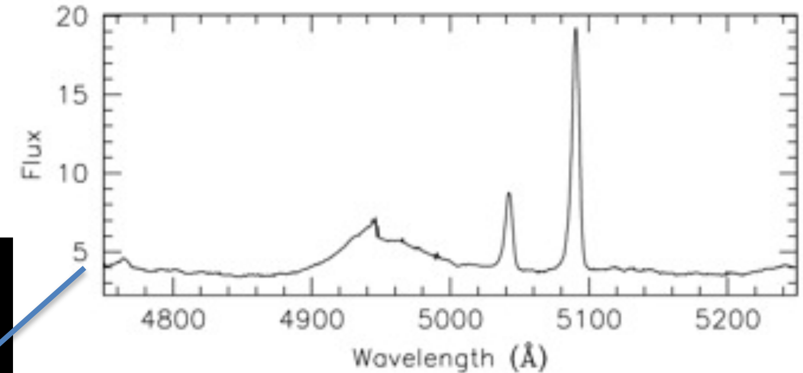
Brooks/Cole Thomson Learning

Taxonomy

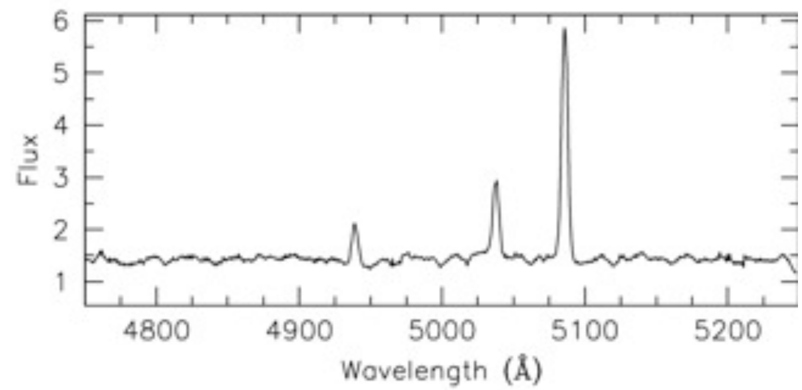
- UV/O/IR luminosity:
  - QSOs (Lnuc > Lgal): Quasi Stellar Object
  - Strong AGN (Lnuc < Lgal) [Seyferts]
  - Weak AGN (Lnuc << Lgas) [Low Luminosity AGN]
- Radio Luminosity (jet power)
  - Radio Quiet (LR < 1e-4 Loptical)
  - Radio Loud (LR > 0.1 Loptical) → Quasar
- Viewing Angle
  - Broad + Narrow Lines (can see BLR) (type 1)
  - Narrow lines only (can’t see BLR) (type 2)

Viewing perspective





BLR ~ 0.02 – 0.1 pc
V ~ few 10^3 km/s

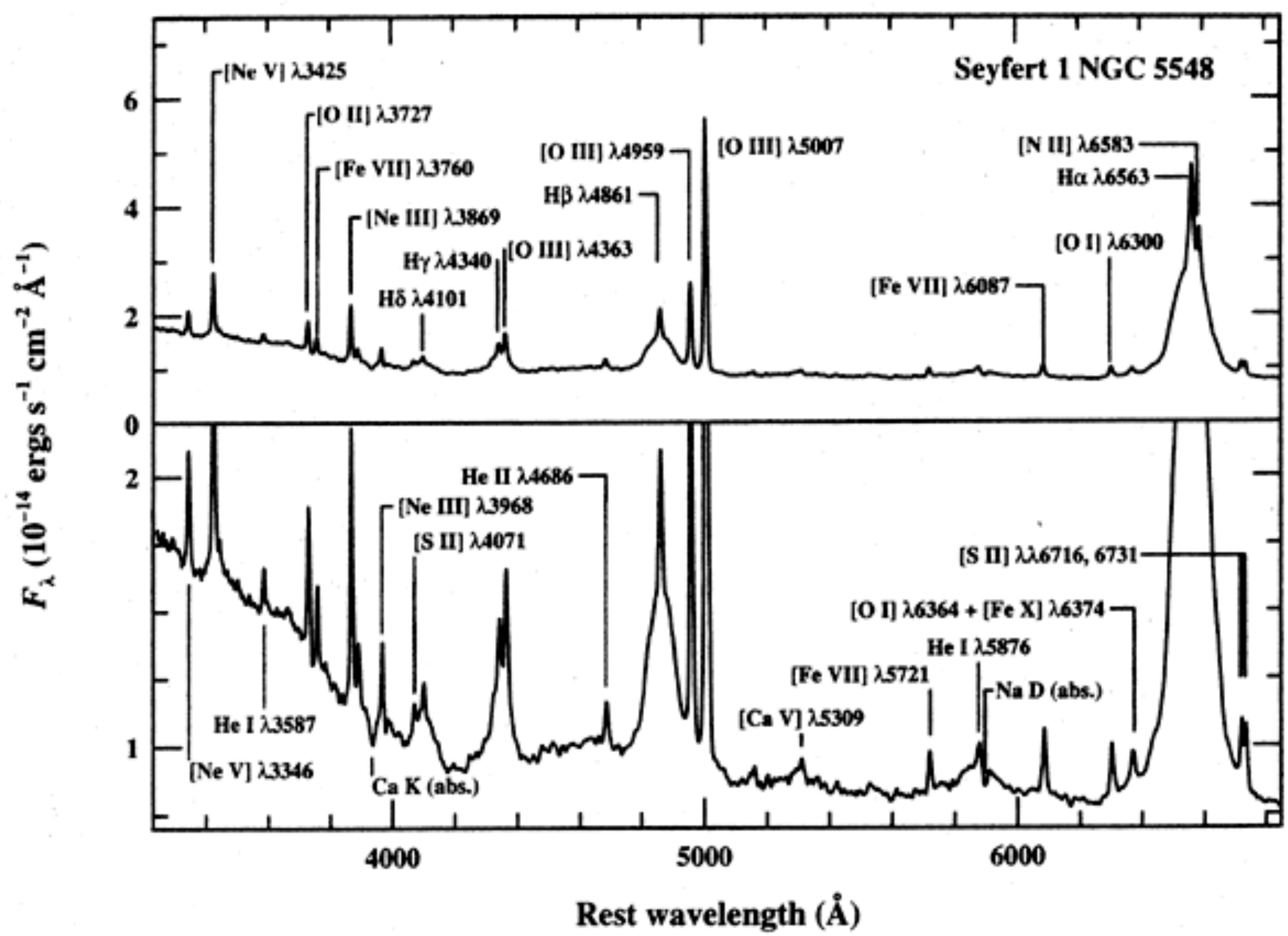


NLR 10 pc – 1 kpc
V ~ few x 100 km/s

Wadsmorth Publishing

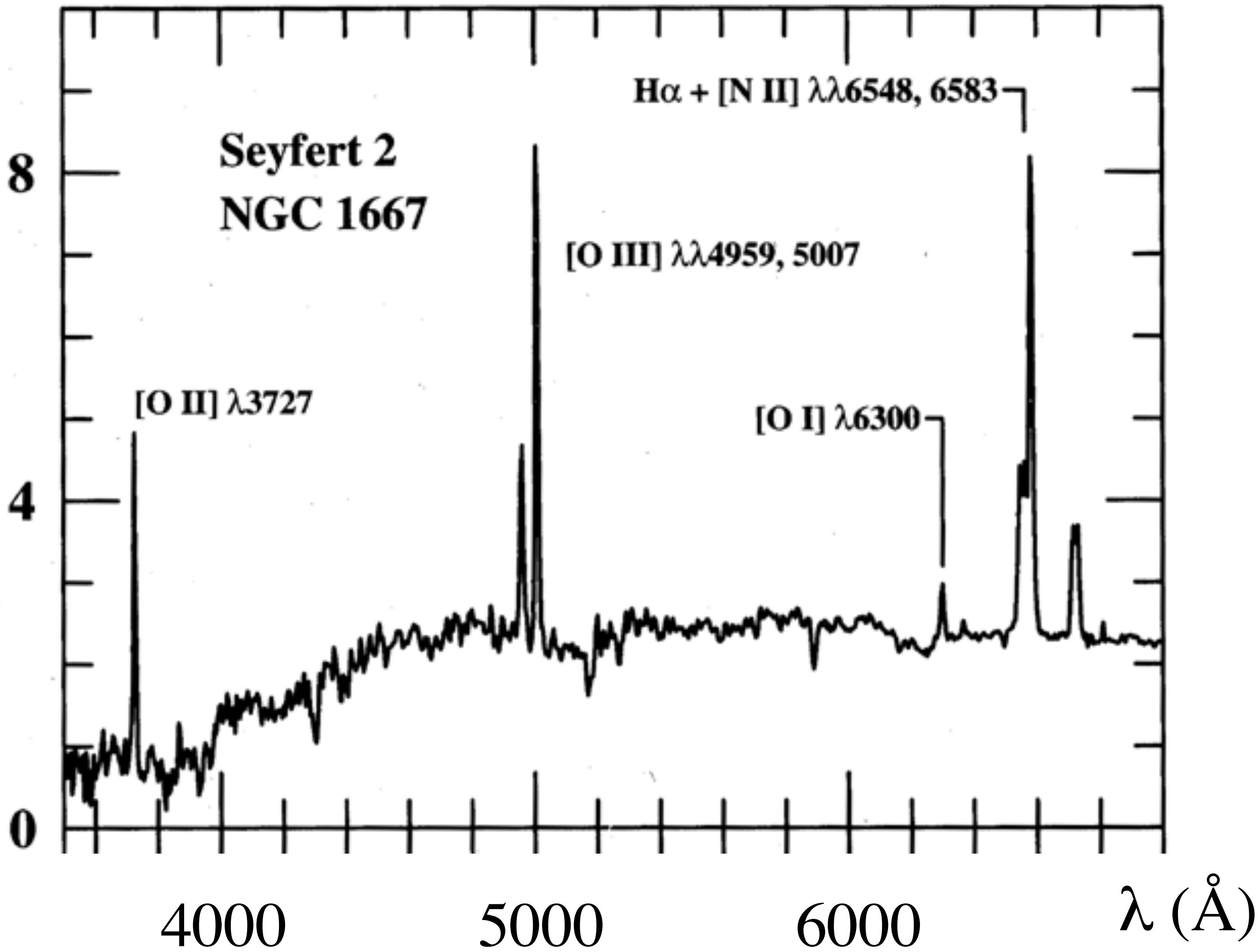
Spectra: Broad Lines (Type I)

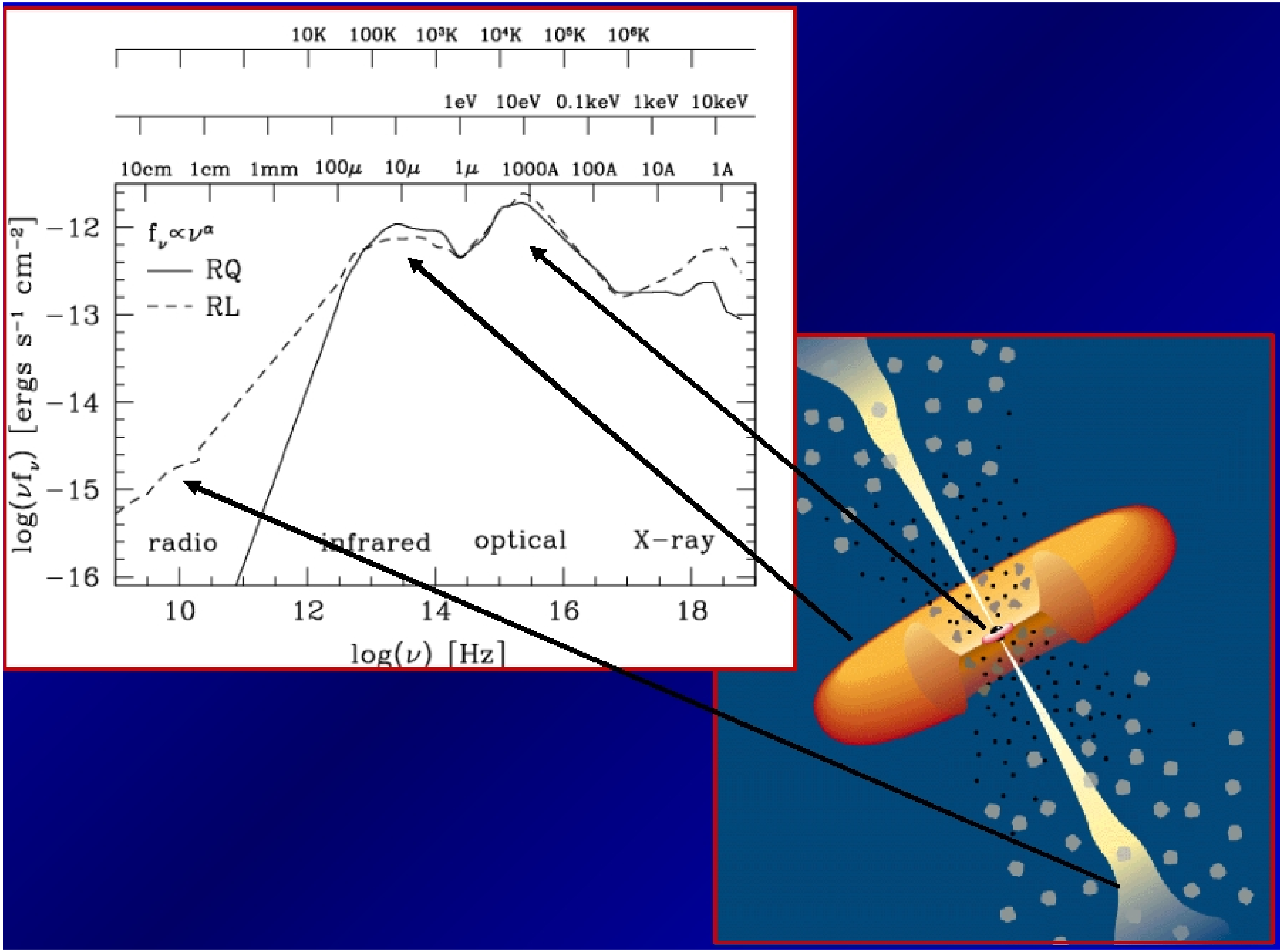
- **Narrow emission lines**, with a width of several hundred km/s
- **Broad emission lines**, with widths up to 10^4 km/s



They also have brighter and bluer nuclei

Spectra: No Broad Lines (Type II)



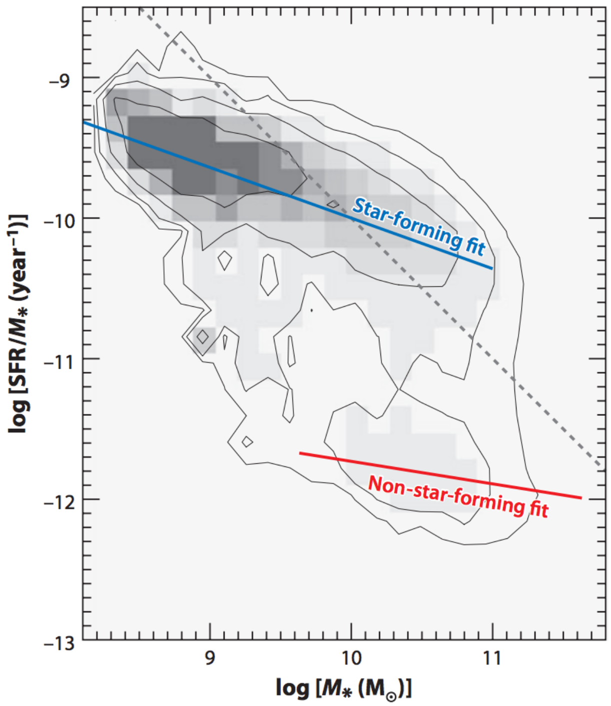


10K 100K 10^3K 10^4K 10^5K 10^6K
1eV 10eV 0.1keV 1keV 10keV
10cm 1cm 1mm 100μ 10μ 1μ 1000A 100A 10A 1A
$f_\nu \propto \nu^\alpha$
RQ
RL
radio
infrared
optical
X-ray
$\log(\nu f_\nu)$ [ergs s^{-1} cm^{-2}]
$\log(\nu)$ [Hz]

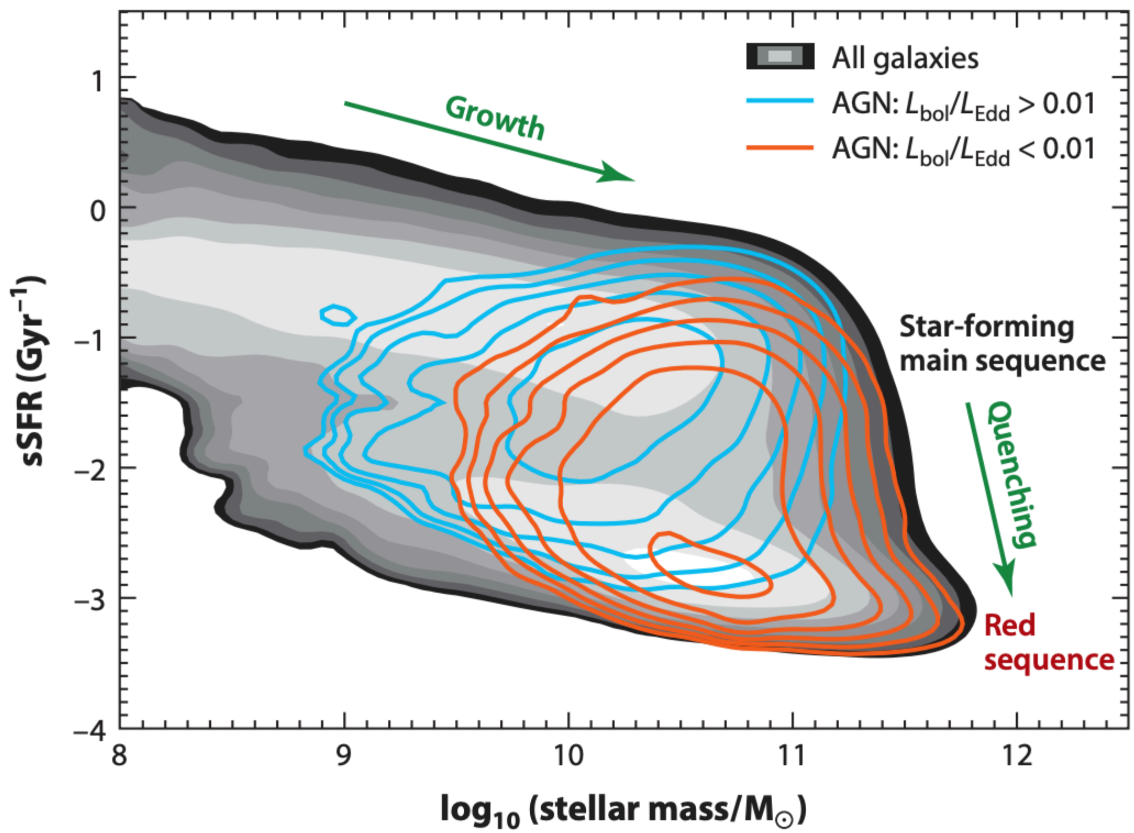
	$L/L_{Edd} \lesssim 0.01$	$L/L_{Edd} \gtrsim 0.01$	
	Jet mode little radiation, primary energetic output is bulk kinetic energy transported in jets Ho (2008).	**Radiative mode** Efficient conversion of potential energy of the gas accreted by the SMBH **Type 2**	**Type 1**
Radio-loud	**Low-excitation radio source** • Very massive early-type galaxy • Very massive black hole • Old stellar population; little star formation • Moderate radio luminosity • FR1 or FR2 radio morphology • Weak (or absent) narrow, low-ionization emission lines	**High-excitation radio source** • Massive early-type galaxy • Massive black hole • Old stellar population with some ongoing star formation • High radio luminosity • Mostly FR2 morphology • Strong high-ionization narrow lines	**Radio-loud QSO** Host-galaxy properties like high-excitation radio source, but with addition of: • Direct AGN light • Broad permitted emission lines • Sometimes, beamed radio emission
Radio-quiet	**AGN LINER** low-ionization nuclear emission-line regions • Massive early-type galaxy • Massive black hole • Old stellar population; little star formation • Weak, small-scale radio jets • Moderate strength, low-ionization narrow emission lines	**Type 2 QSO / Seyfert 2** • Moderately massive early-type disk galaxy with pseudobulge • Moderate-mass black hole • Significant central star formation • Weak or no radio jets • Strong high-ionization narrow lines • QSOs more luminous than Seyferts	**Radio-quiet QSO/Seyfert 1** Host-galaxy properties like Type 2 QSO and Seyfert 2, respectively, but with addition of: • Direct AGN light • Broad permitted emission lines • Bias toward face-on orientation
	Light dominated by host galaxy		**Direct AGN light**

Heckman & Best 2014 ARAA

AGN & SF Main Sequence



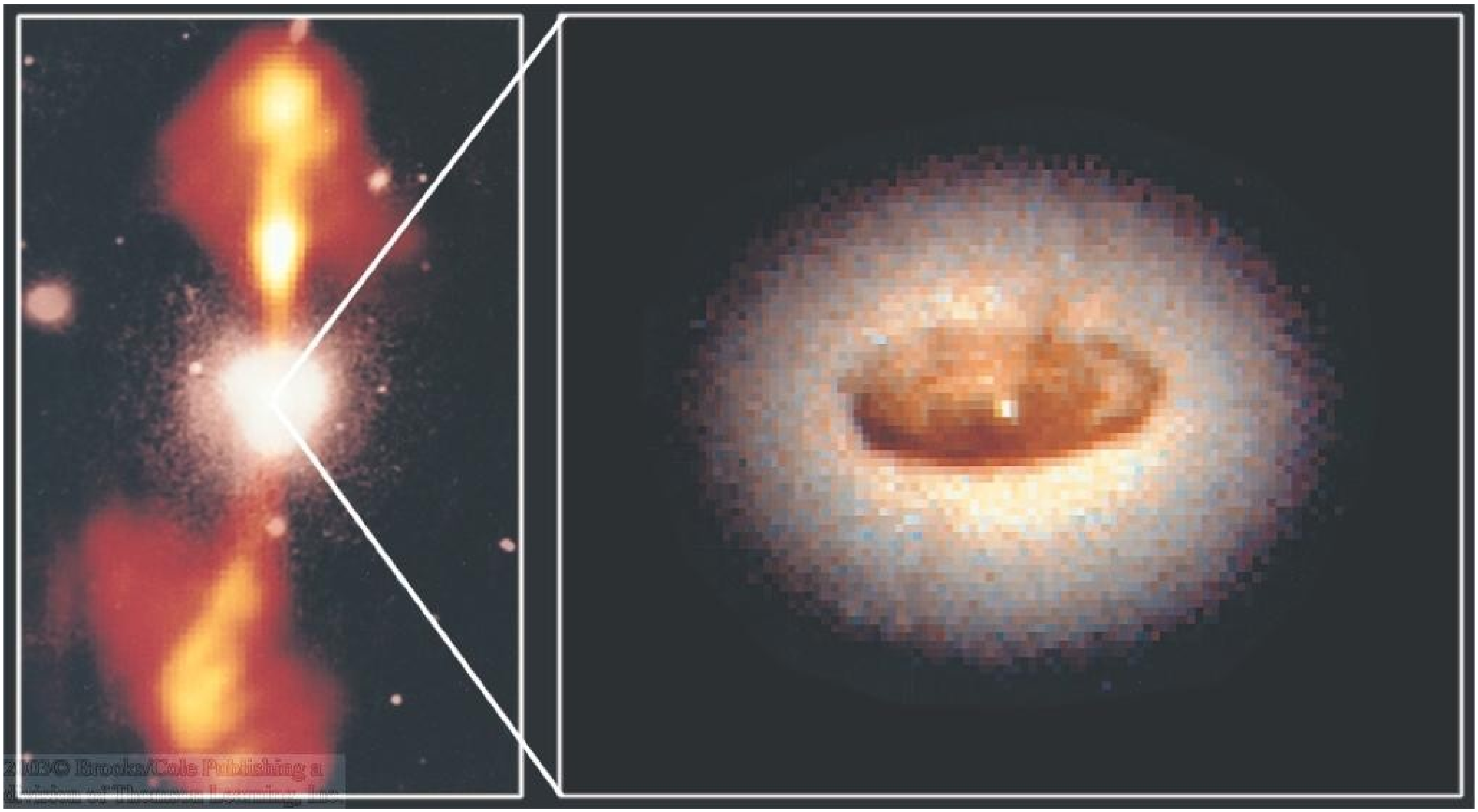
Recall: SF Main Sequence
Kennicutt & Evans 2012



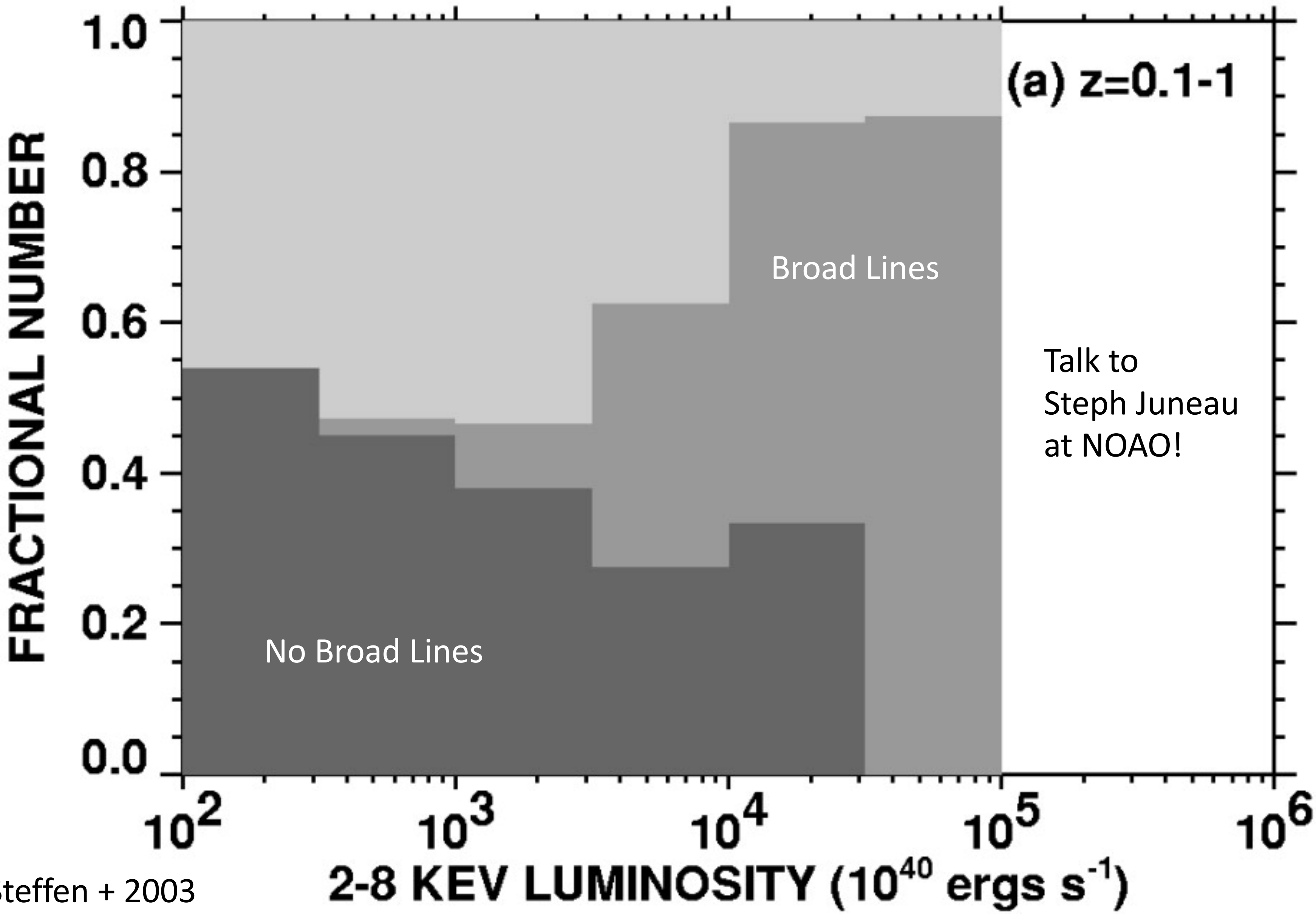
Heckman & Best 2014 ARAA

Evidence for the Unified Model

The Dust Torus in NGC 4261



Issues with the Unified Model?



Steffen + 2003

AGN obscuration scenarios

Torus obscuration

Host obscuration
(extreme conditions: e.g., gas-rich mergers)

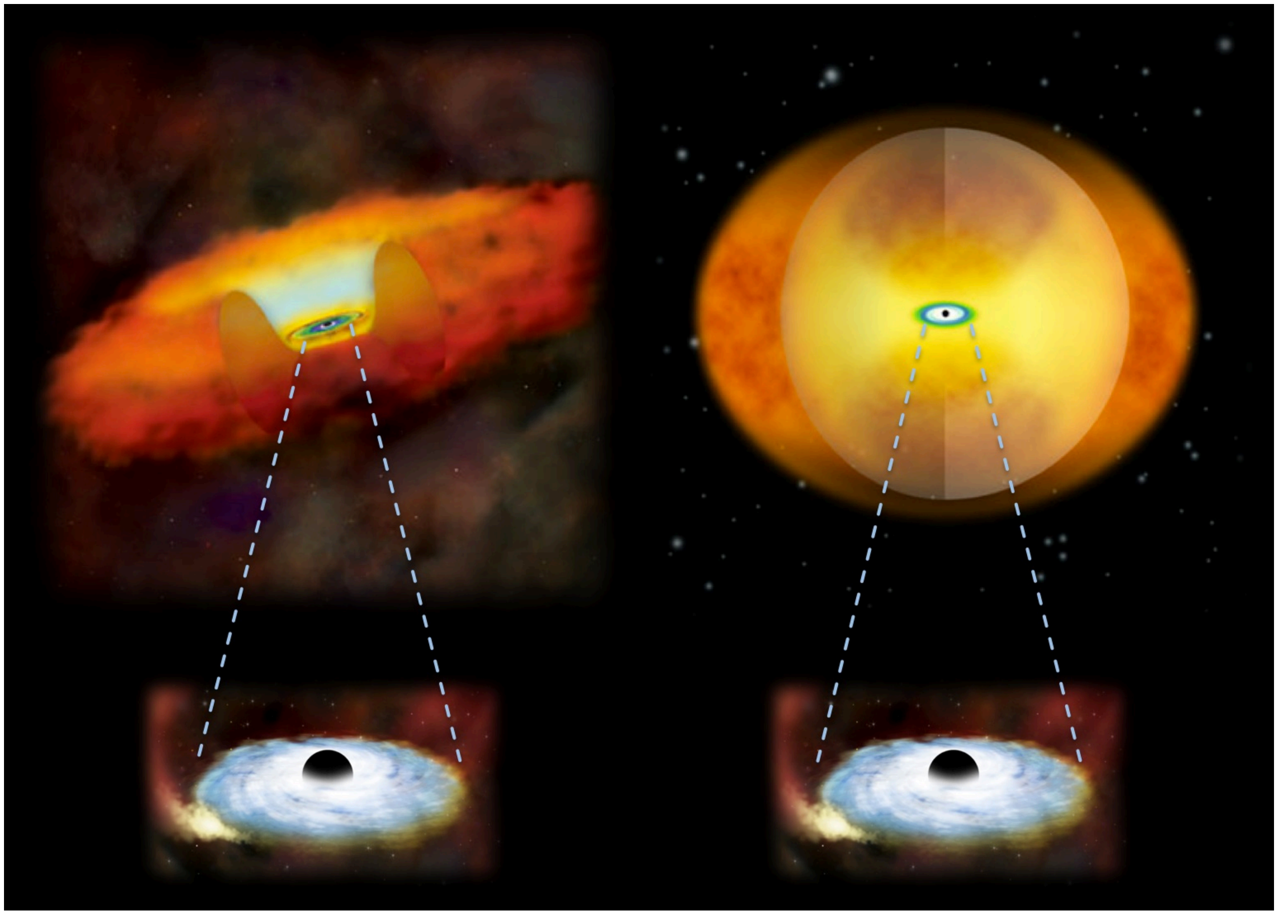


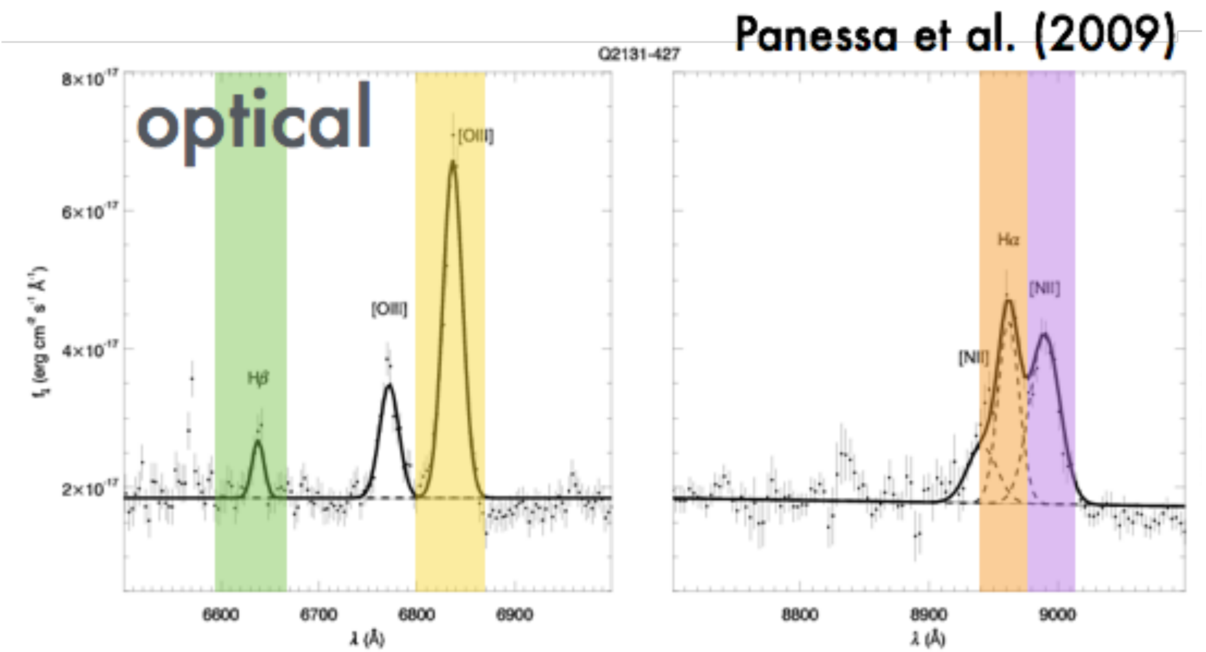
Image credits: NASA (lower & upper left). NAOJ, Naomi Ishikawa (upper right)

Courtesy Steph Juneau

Obscuration of central engine depends on evolutionary phase of host galaxy

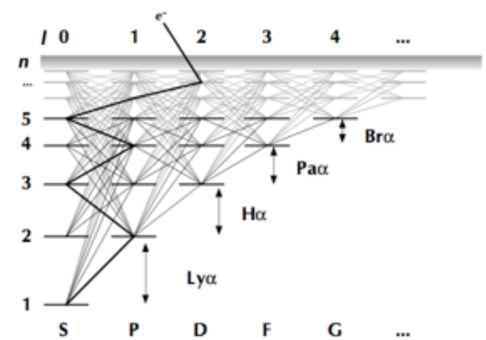
"Buried" AGN, missing X-ray AND optical signatures

Selection of AGN: Optical Emission Lines



- diffuse gas gets ionized/excited by stellar light
- use strong (easily observable) lines to come up with diagnostic tools.
- H-α line a commonly used tracer for star formation.

Optical spectroscopic selection targets emission line ratios that trace the hard radiation field of an AGN.



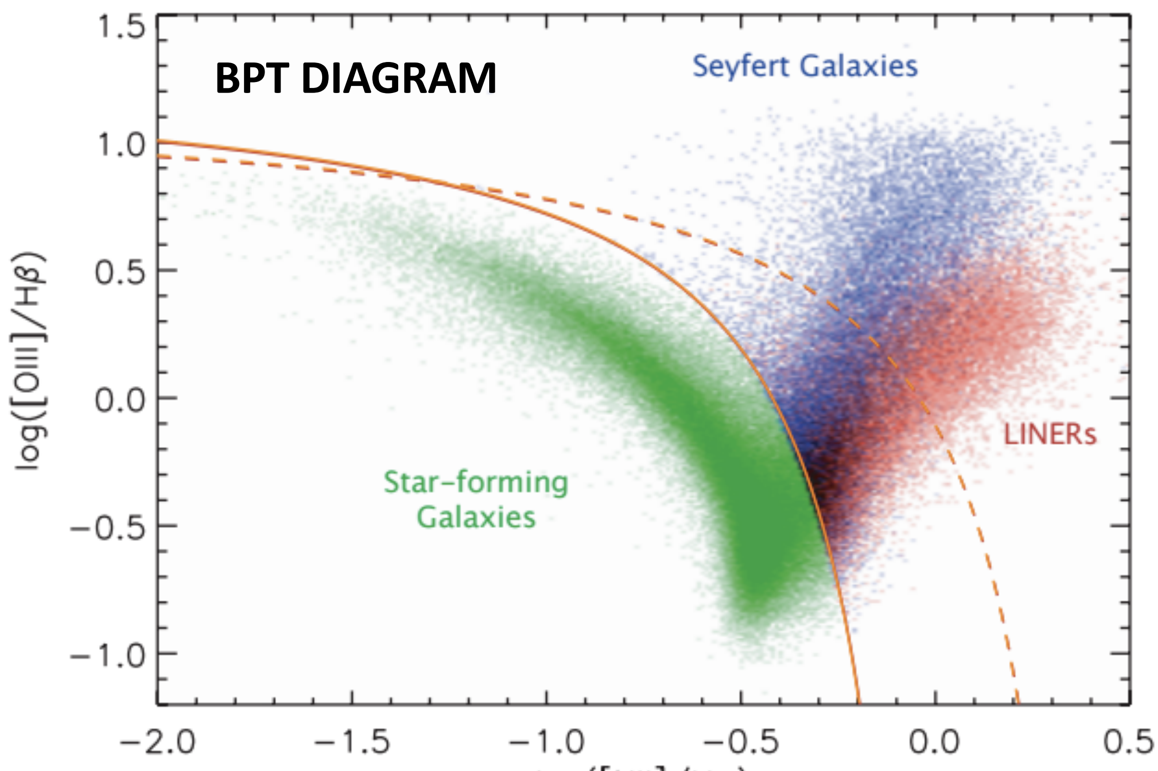
Courtesy Hainline

Selection of AGN: Optical Emission Lines

- Original Baldwin, Philips & Terlevich (1981) Diagnostic Diagram

- ionized radiation produced by hot stars/BB <-> AGN power law.

> 100.000 galaxies from SDSS

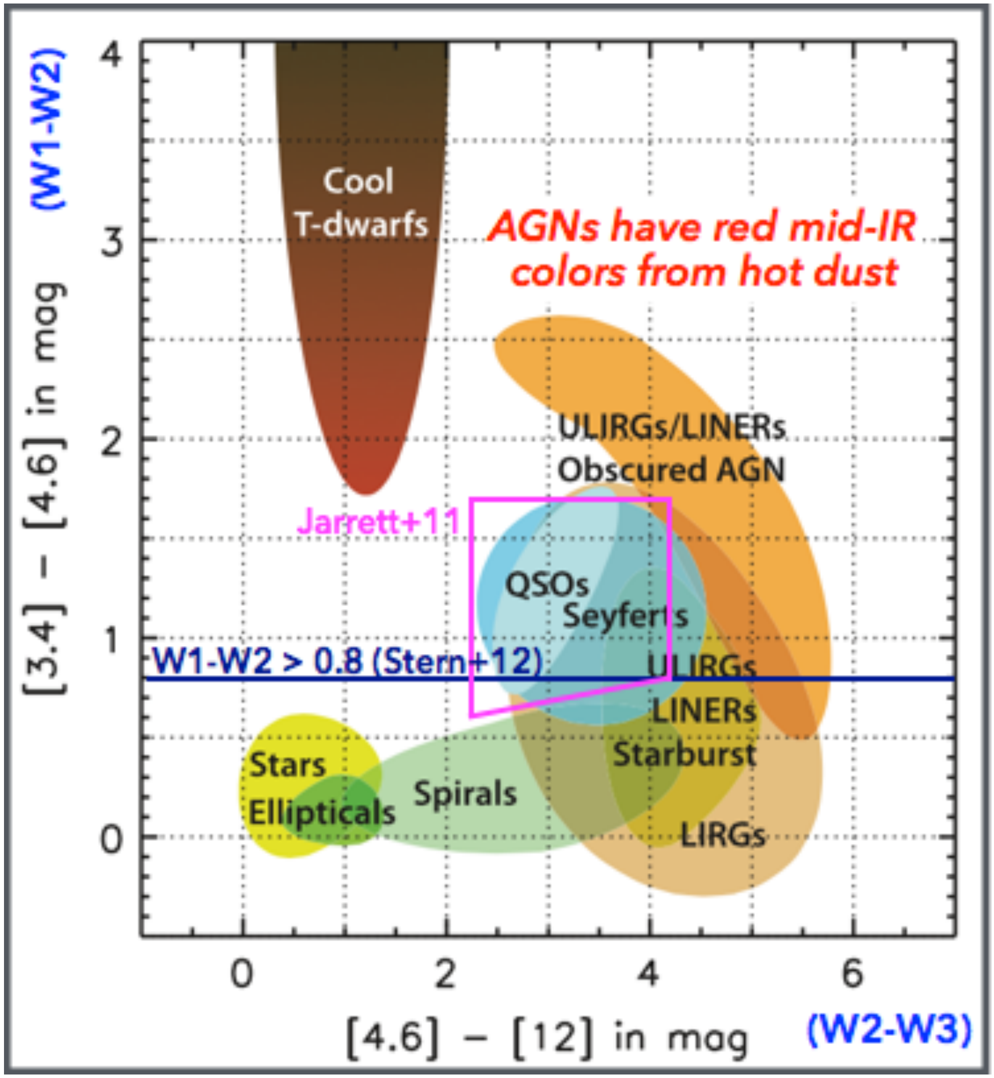


Groves et al 2006

starburst/AGN separator

Courtesy Rix

Selection of AGN: Mid-IR (luminous AGN)



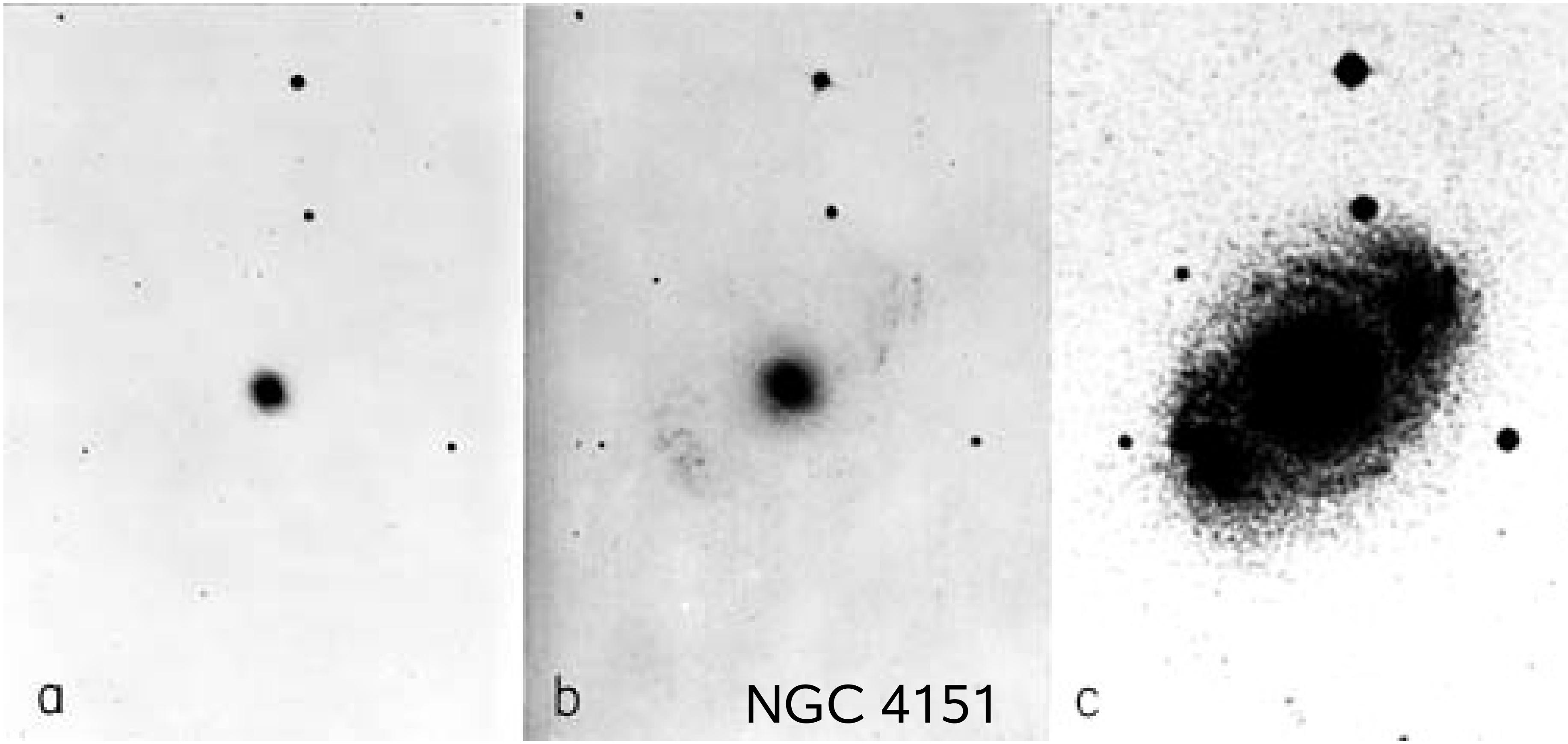
AGNs have red mid-IR
colors from hot dust

Wise Color-Color Diagram
Wright+2010

Courtesy: Amy Reines

Quasars & QSOs

- Most are found between $z = 2\text{-}4$
  - Now more than 60 at $z > 5.7$. Most distant $z \sim 7$
- Typical QSO $L > 100\text{-}10^5 \times L_{MW}$
- ULIRGs & LIRGs may be highly obscured counterparts
- Triggered by gas flowing on SMBH at a high rate
  - Currently the rate of gas consumption by massive black holes must be much less



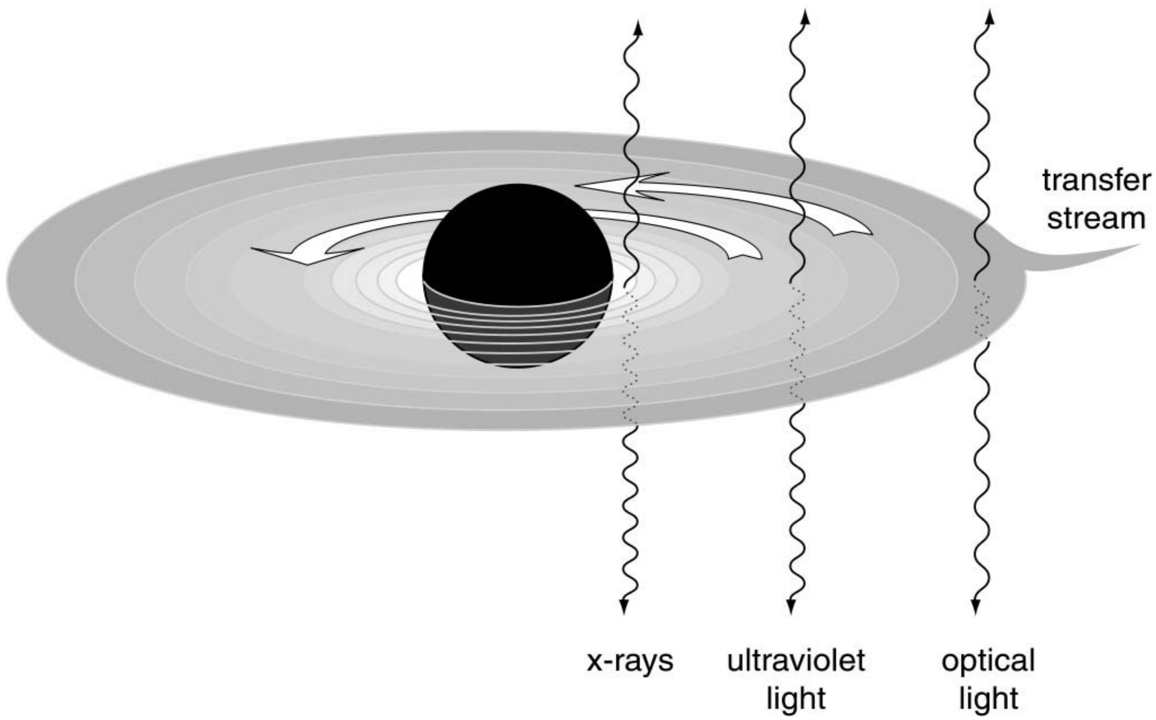
short exposure

long exposure

10000 times brighter than our galactic nucleus!

Energy Release From Central Engines

Some of it will emerge as a mix of ***thermal emission*** from various parts of the accretion disk; some emerges as a ***non-thermal synchrotron emission*** from particles accelerated by the magnetic fields embedded in the accretion disk or the BH itself

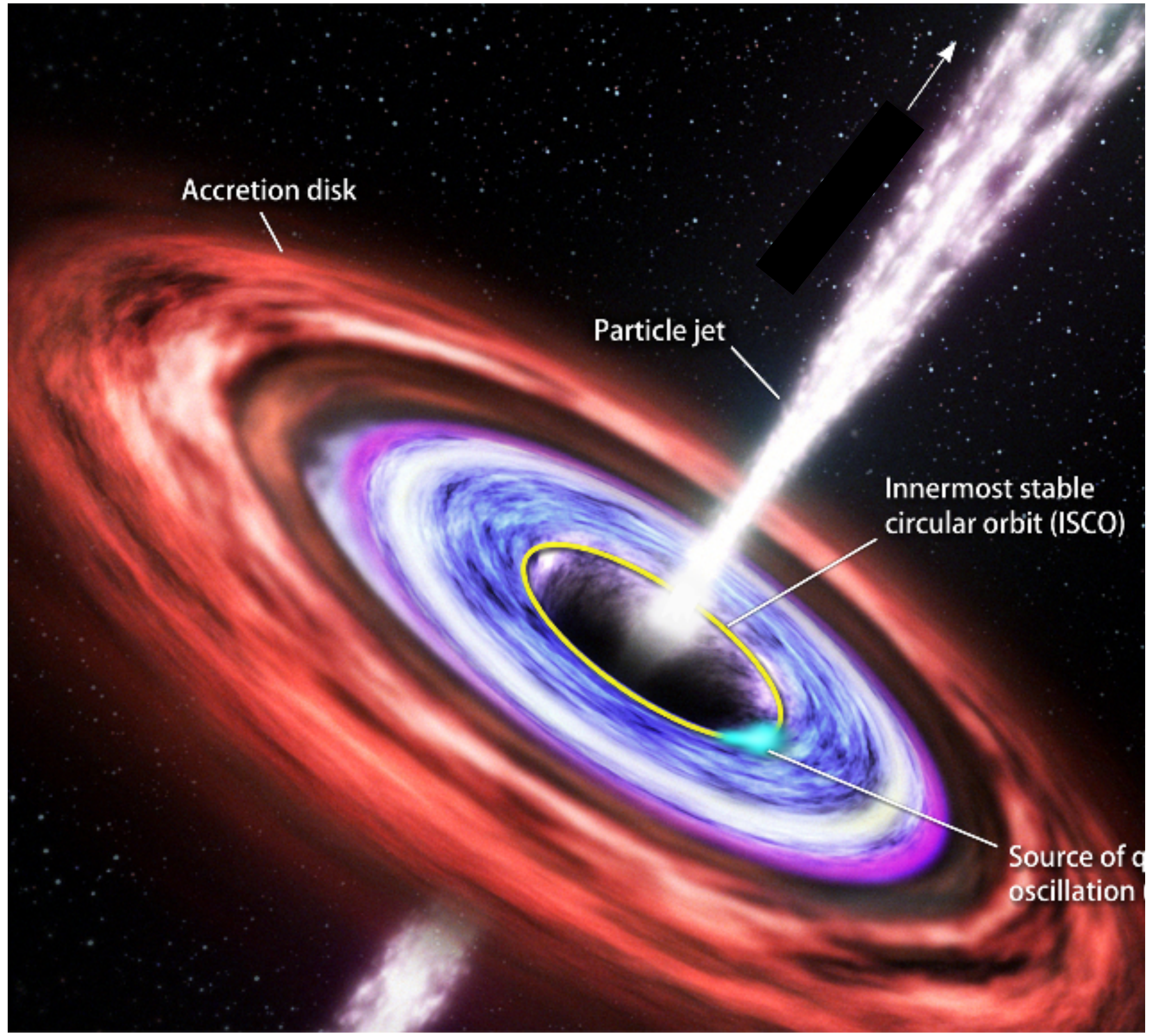


R ~ 10-3 pc
V ~ 0.3c

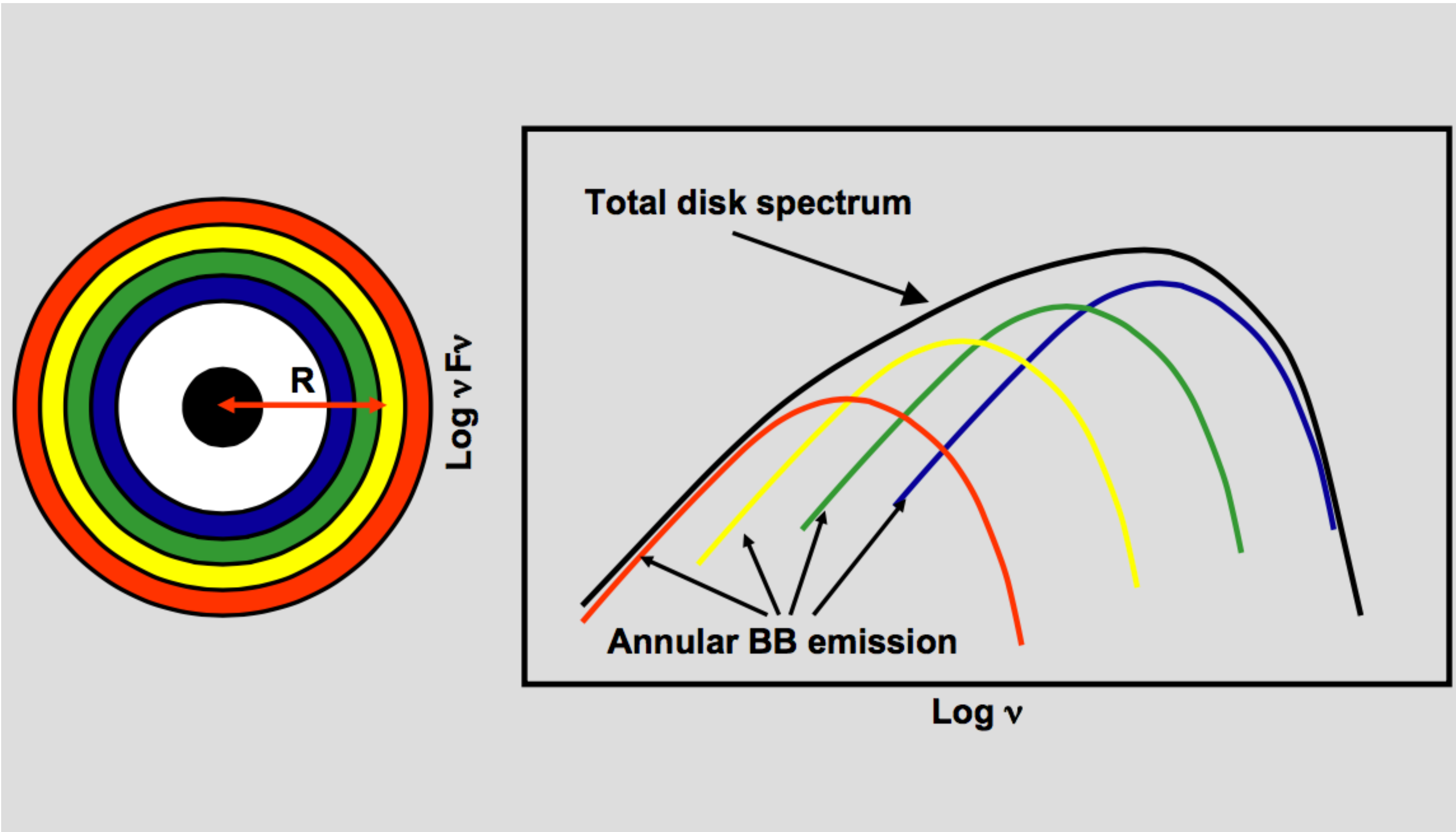
Most of the BH's energy is radiated by the accretion disk

Inner part of the accretion disk is the hottest and orbits the fastest (V_{circ} can get up to 0.3c-0.5c), T~10^7 K (emits in x-rays), varies with time quickly.

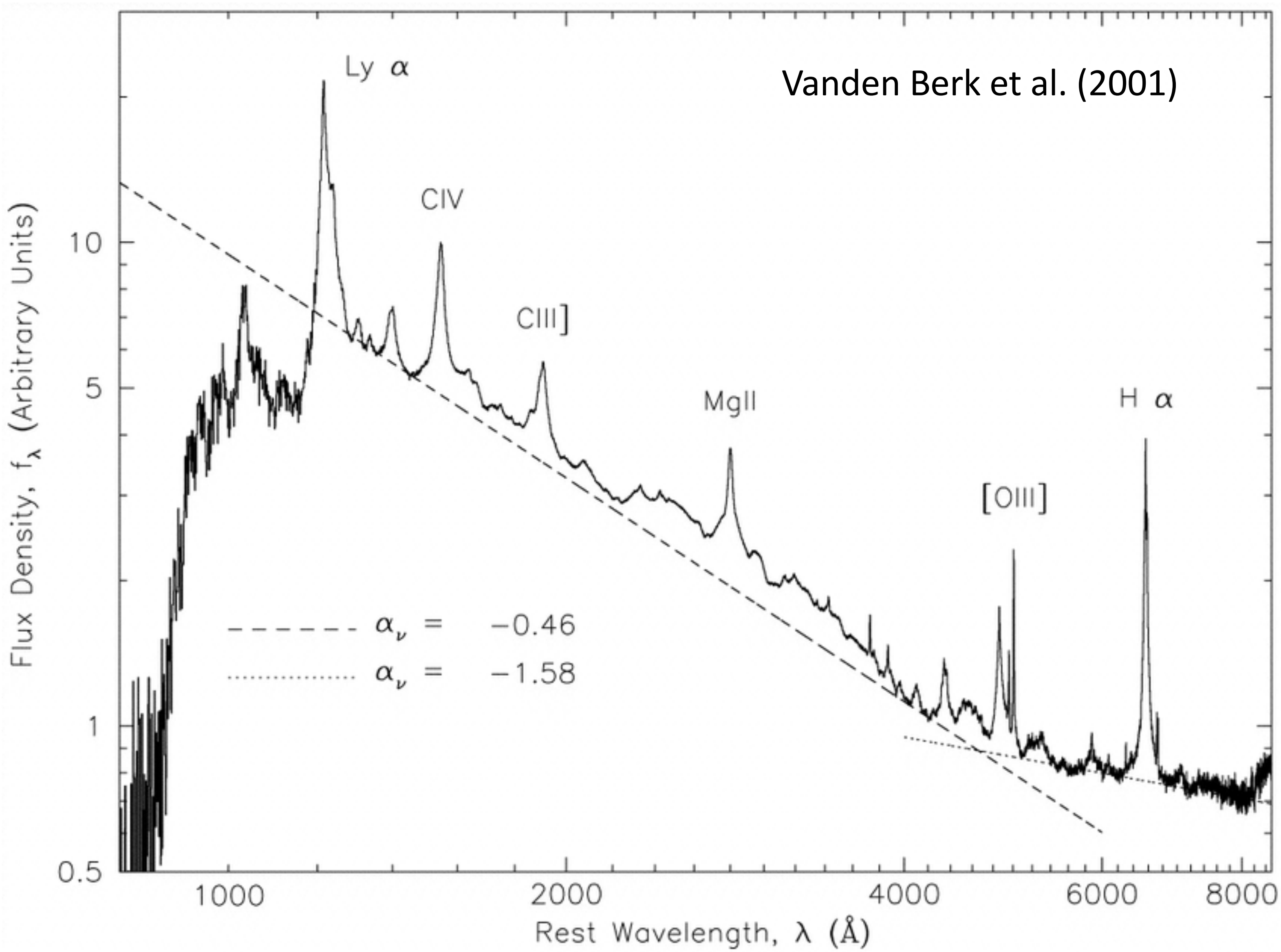
Outer accretion disk orbits less quickly, has cooler gas that emits optical light primarily and does not vary as much on short timescales.



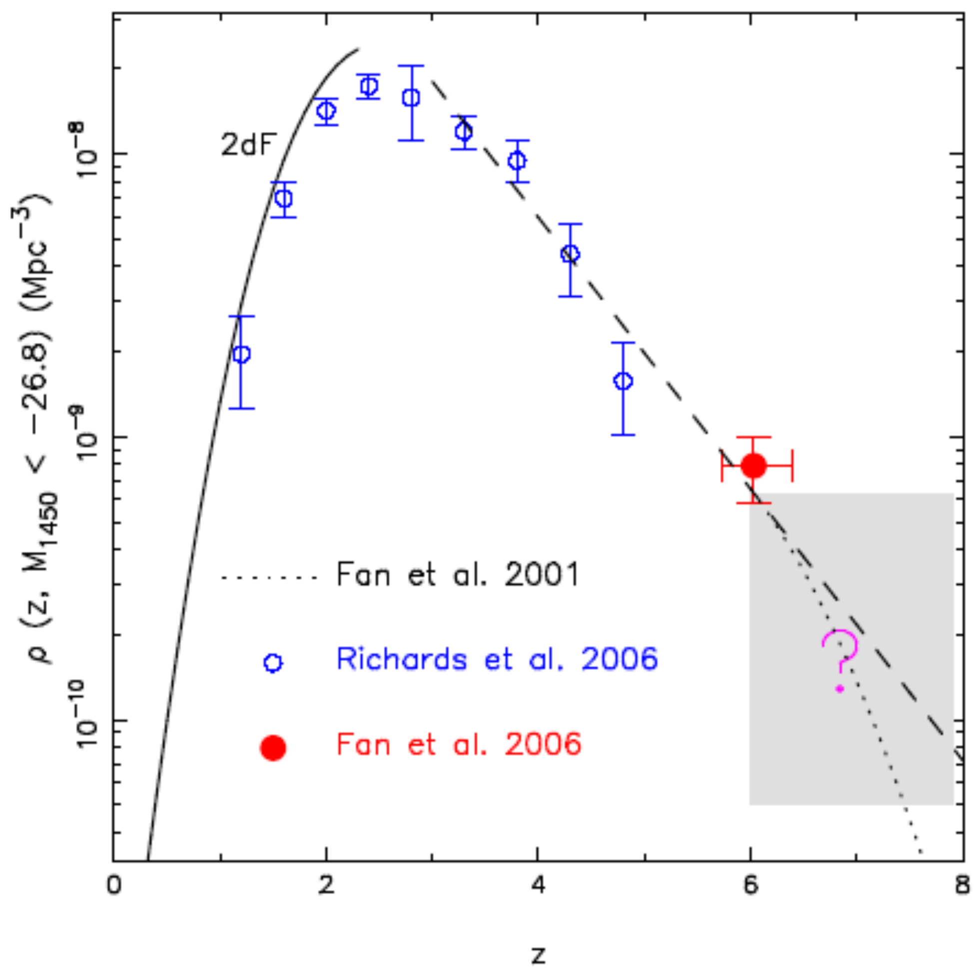
UV/Optical: Accretion Disk



Composite QSO Spectrum (optical)

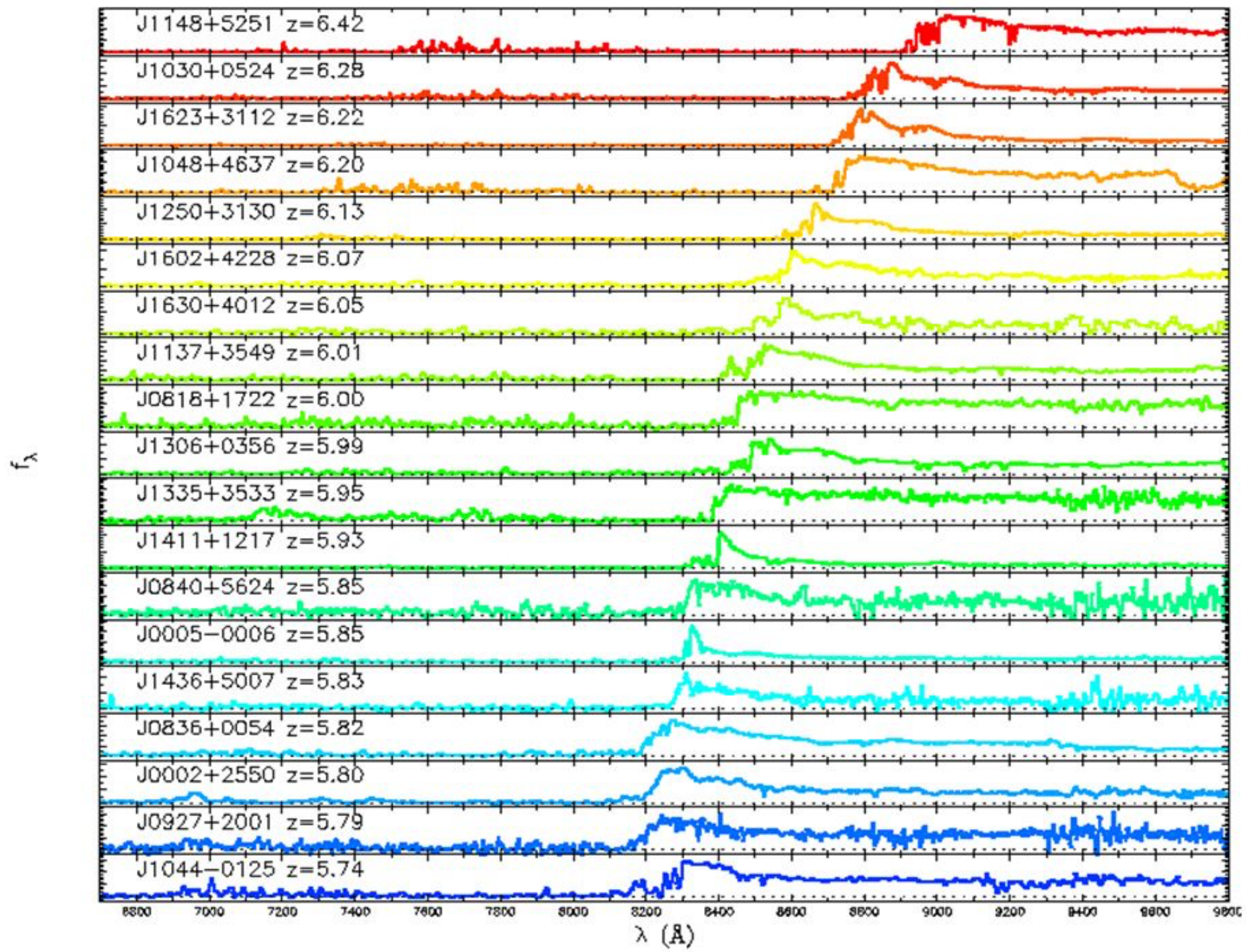


QSO luminosity fxn and space density

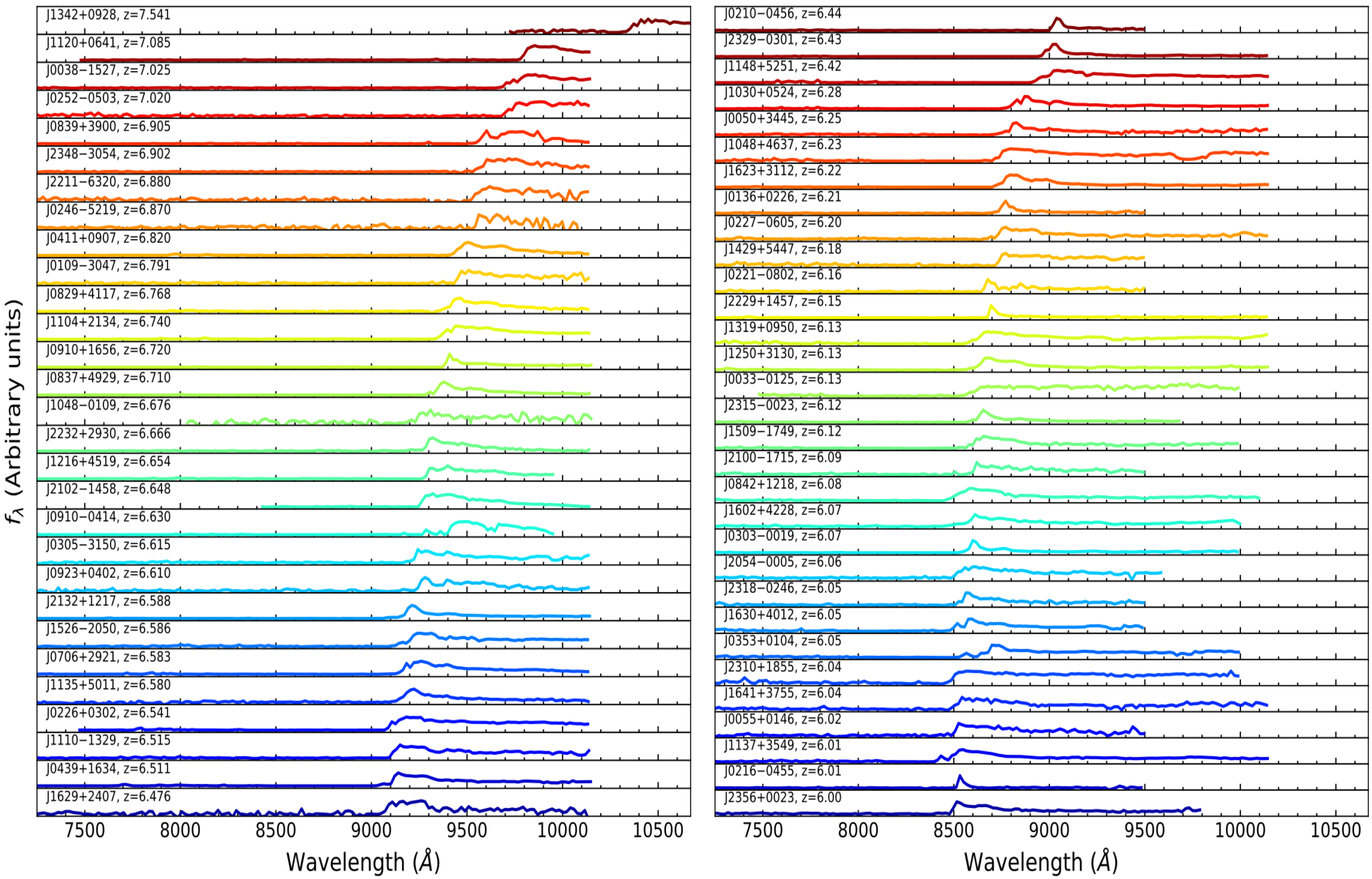


Fan + 2006

z~6 quasars: 2006

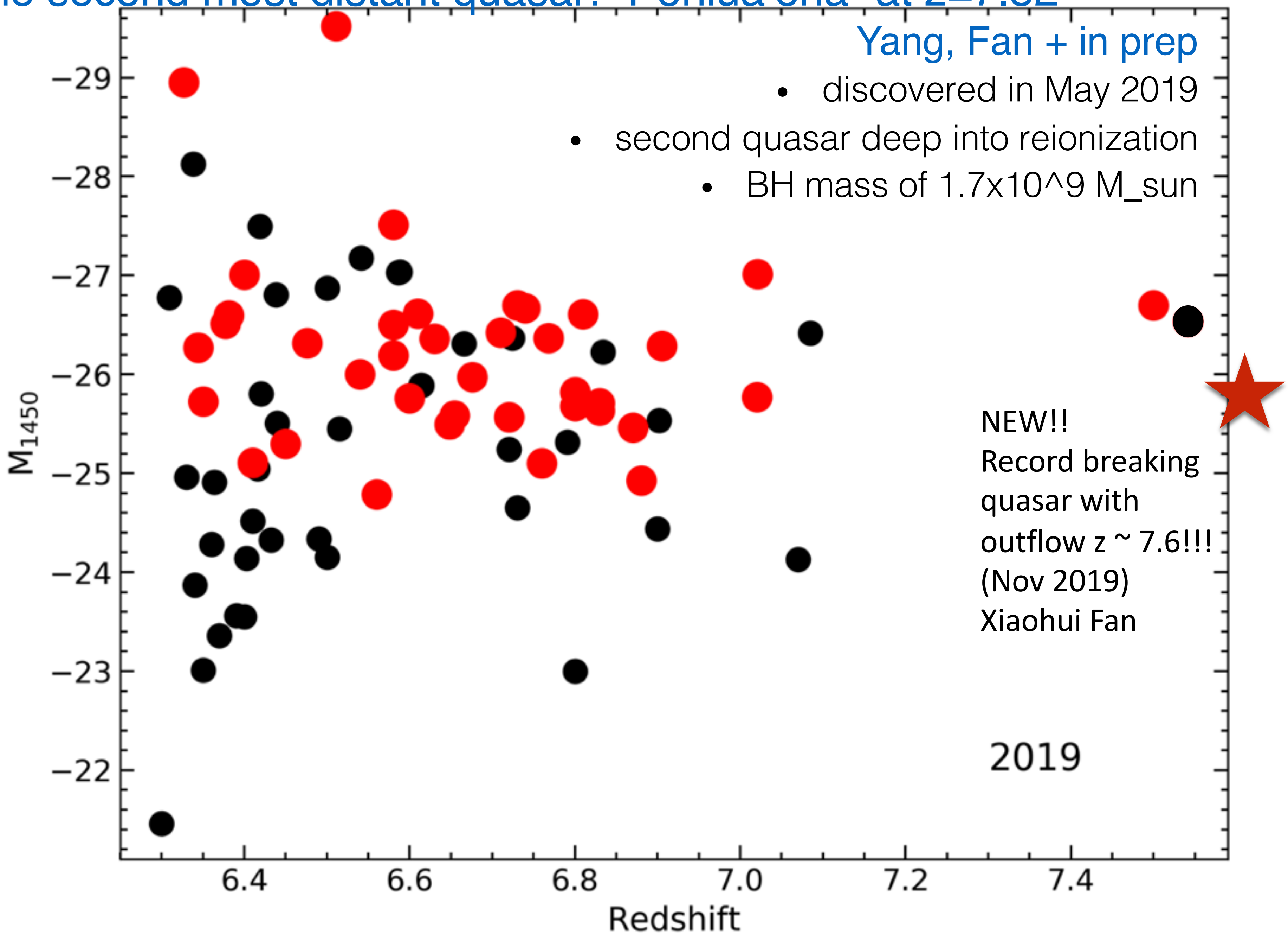


Now...



>500 at z>5; ~150 at z>6; >=9 at z>7

the second most distant quasar: “Pōniuaʻena” at z=7.52



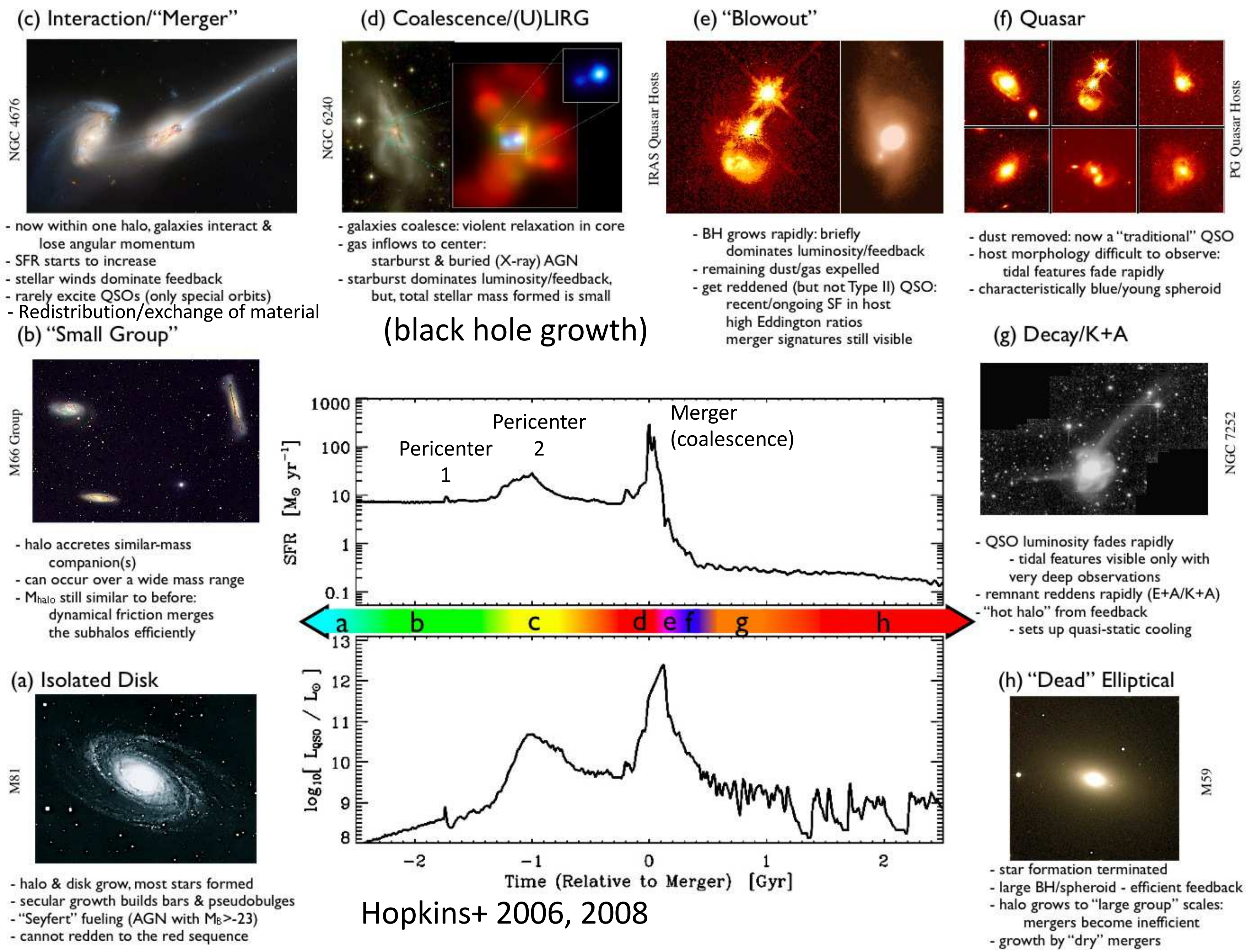
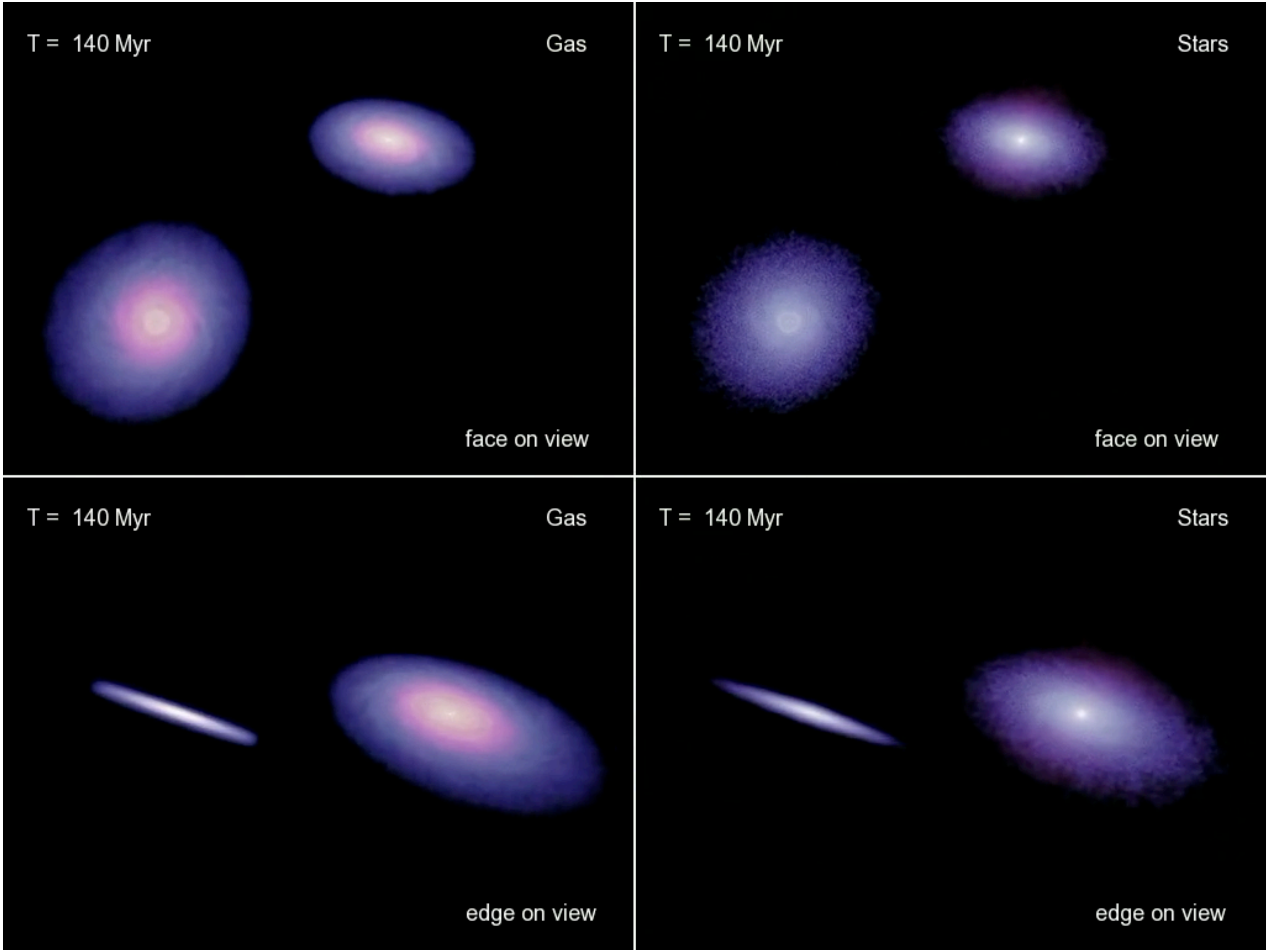
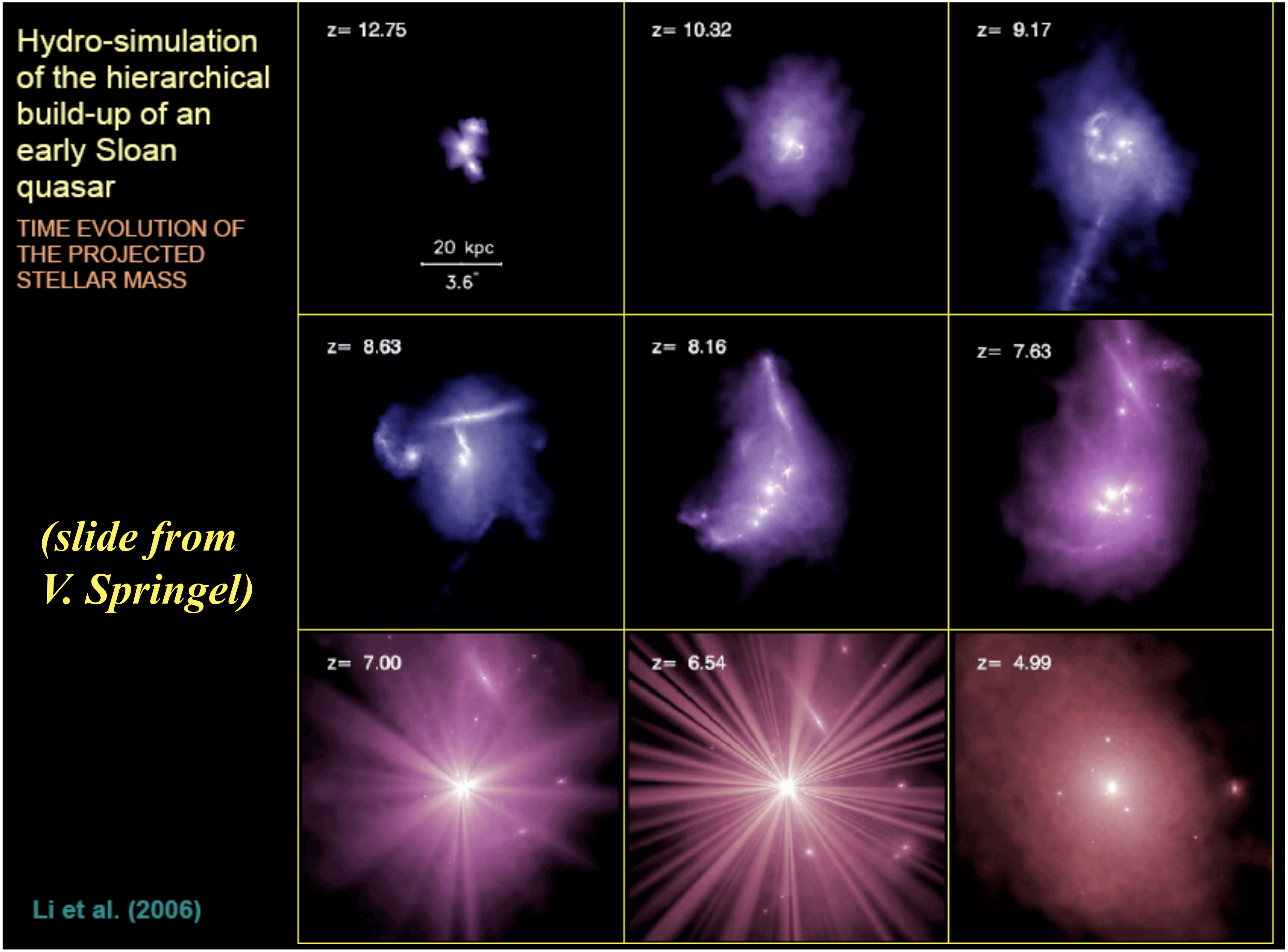
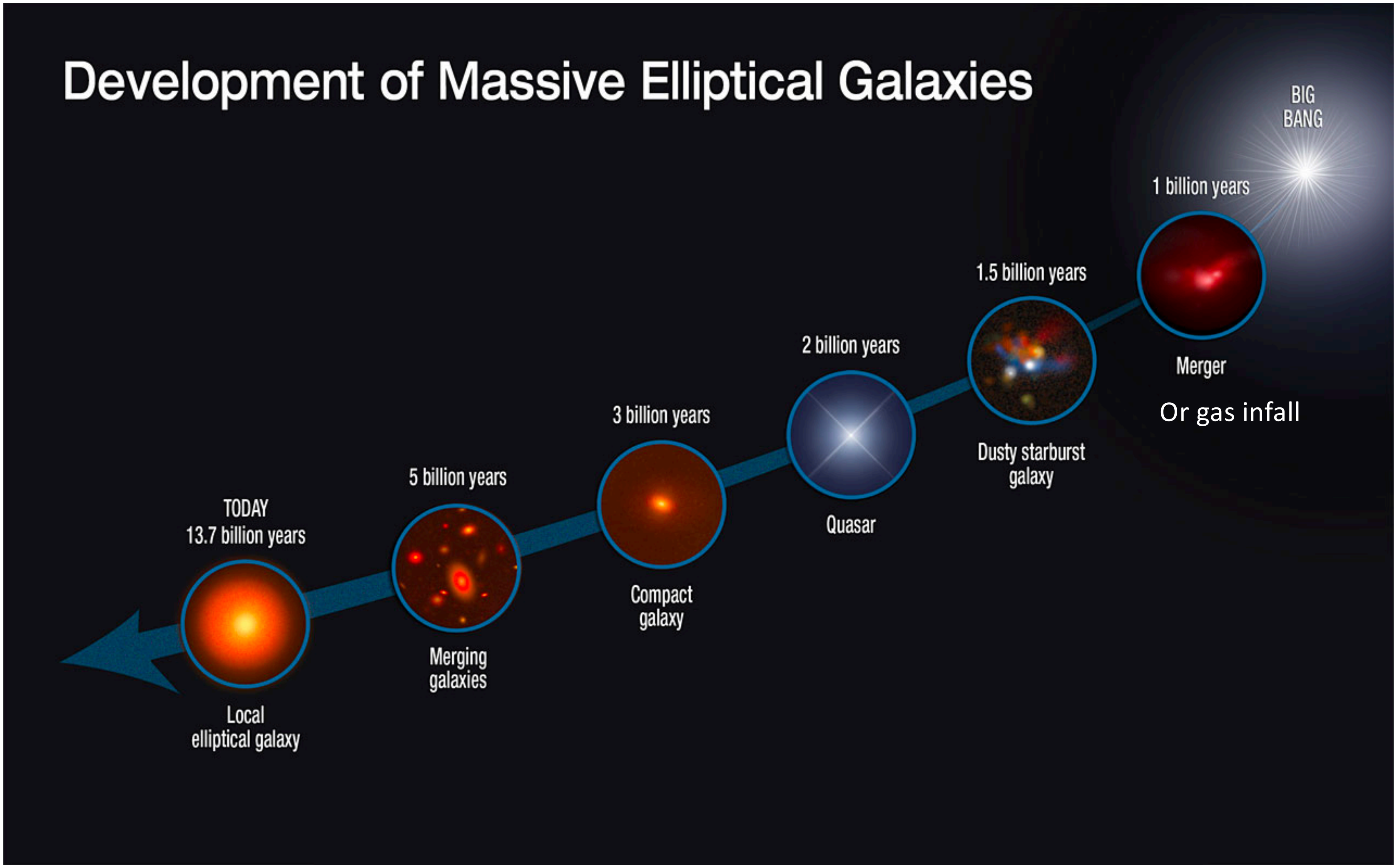


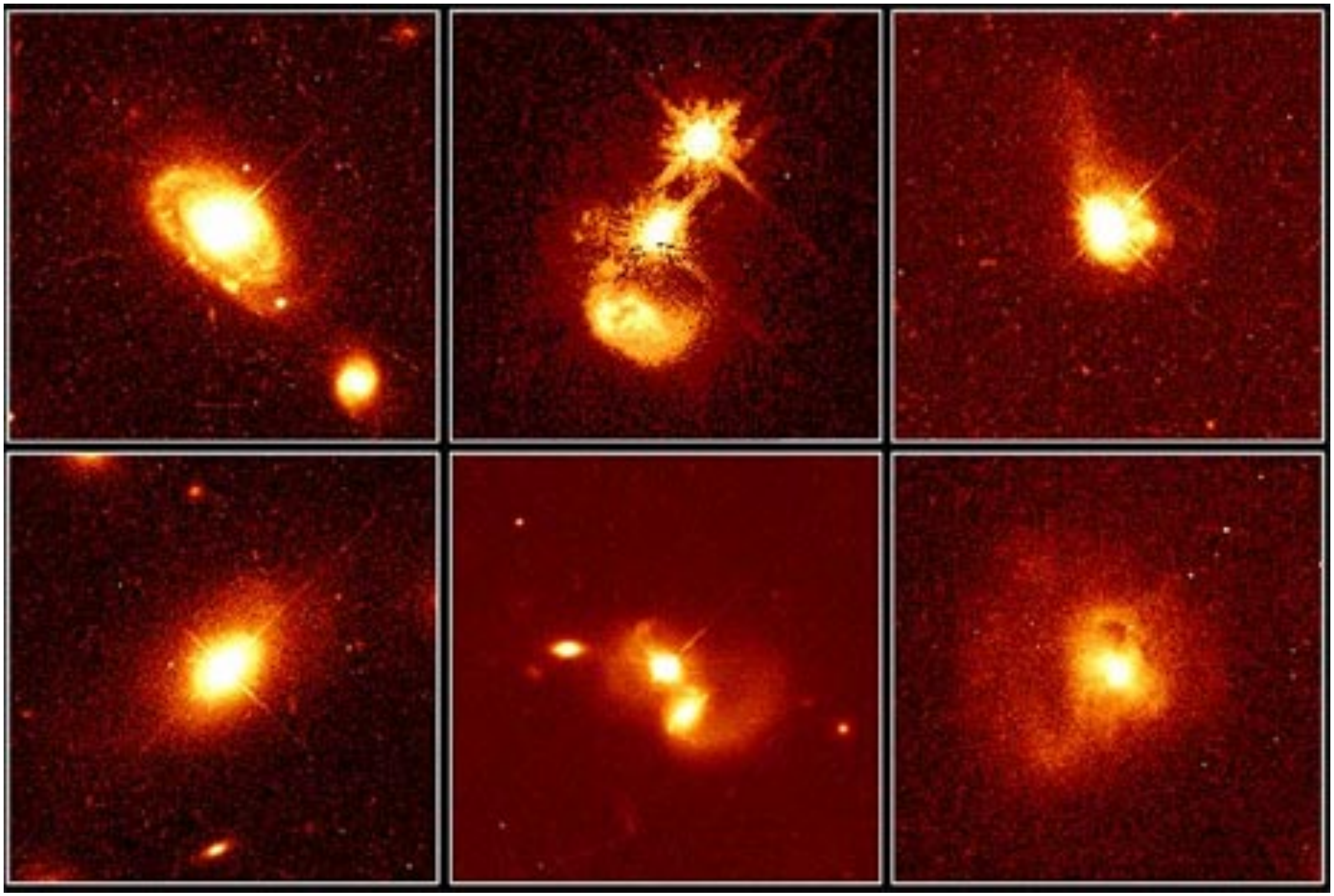
FIG. 1.— An schematic outline of the phases of growth in a "typical" galaxy undergoing a gas-rich major merger. *Image Credit:* (a) NOAO/AURA/NSF; (b) REU program/NOAO/AURA/NSF; (c) NASA/STScI/ACS Science Team; (d) Optical (left): NASA/STScI/R. P. van der Marel & J. Gerssen; X-ray (right): NASA/CXC/MPE/S. Komossa et al.; (e) Left: J. Bahcall/M. Disney/NASA; Right: Gemini Observatory/NSF/University of Hawaii Institute for Astronomy; (f) J. Bahcall/M. Disney/NASA; (g) F. Schweizer (CIW/DTM); (h) NOAO/AURA/NSF.


T = 140 Myr
Gas
face on view
T = 140 Myr
Stars
face on view
T = 140 Myr
Gas
edge on view
T = 140 Myr
Stars
edge on view

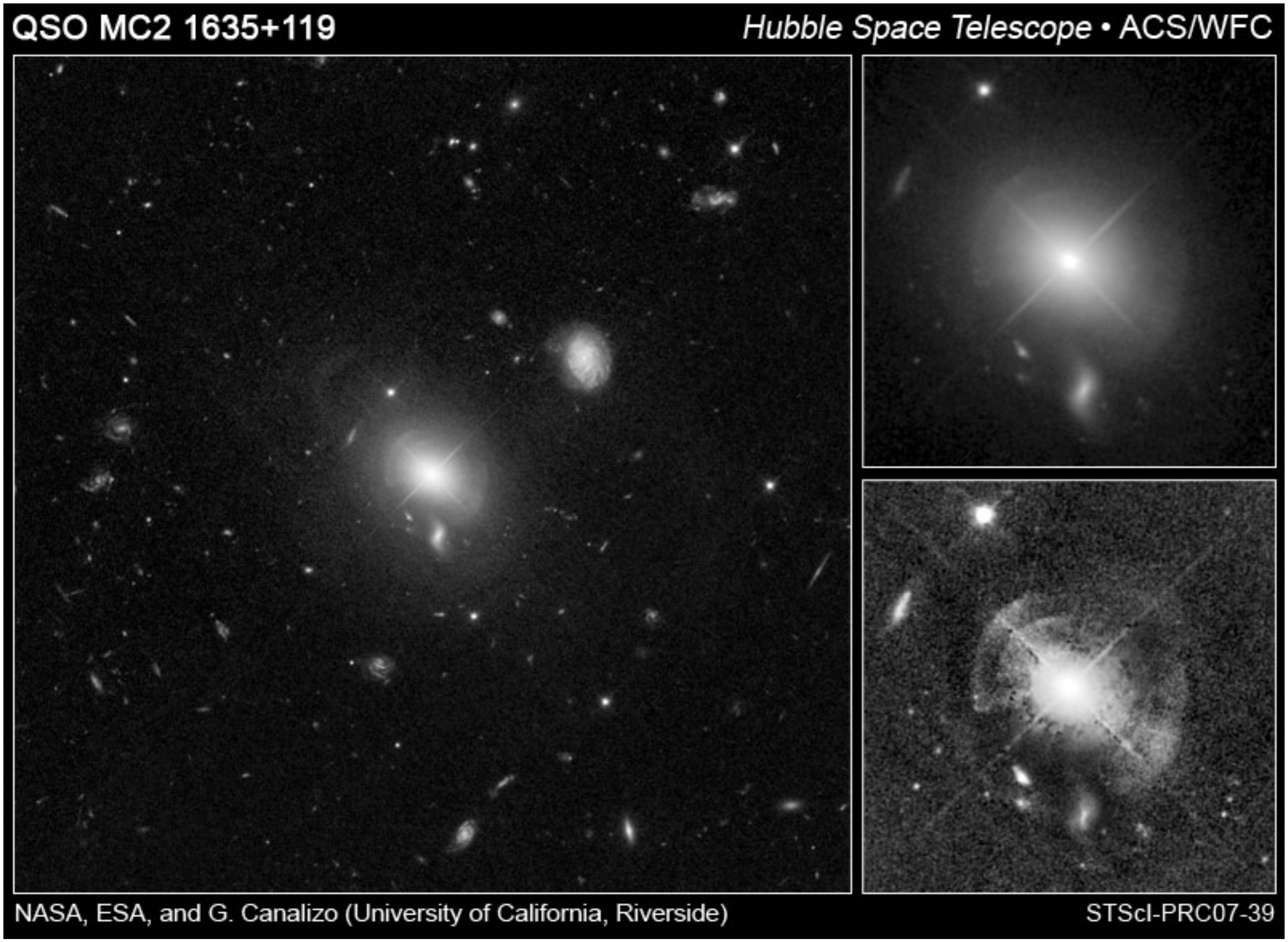

Hydro-simulation of the hierarchical build-up of an early Sloan quasar
TIME EVOLUTION OF THE PROJECTED STELLAR MASS
(slide from V. Springel)
Li et al. (2006)
z= 12.75
20 kpc
3.6"
z= 10.32
z= 9.17
z= 8.63
z= 8.16
z= 7.63
z= 7.00
z= 6.54
z= 4.99


Development of Massive Elliptical Galaxies
BIG
BANG
1 billion years
Merger
Or gas infall
1.5 billion years
Dusty starburst
galaxy
2 billion years
Quasar
3 billion years
Compact
galaxy
5 billion years
Merging
galaxies
TODAY
13.7 billion years
Local
elliptical galaxy

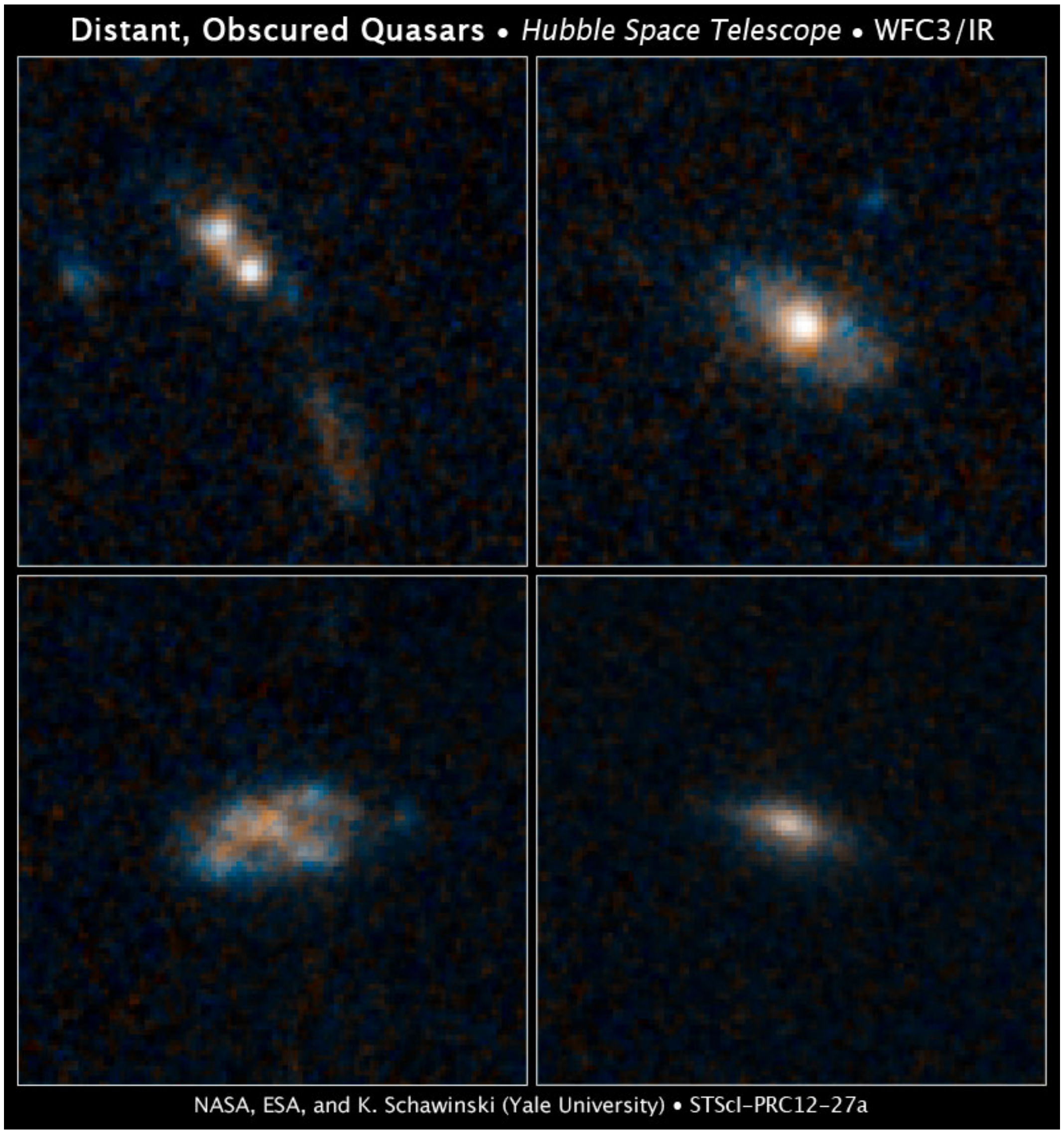
QSO Hosts?
HST showed that QSO hosts are galaxies



QSO with shells



Lack of Evidence for Mergers?



QSOs found in CANDELS about normal looking galaxies (except for top left)

26 out of 30 showed no obvious signs of mergers

Disk instabilities instead?