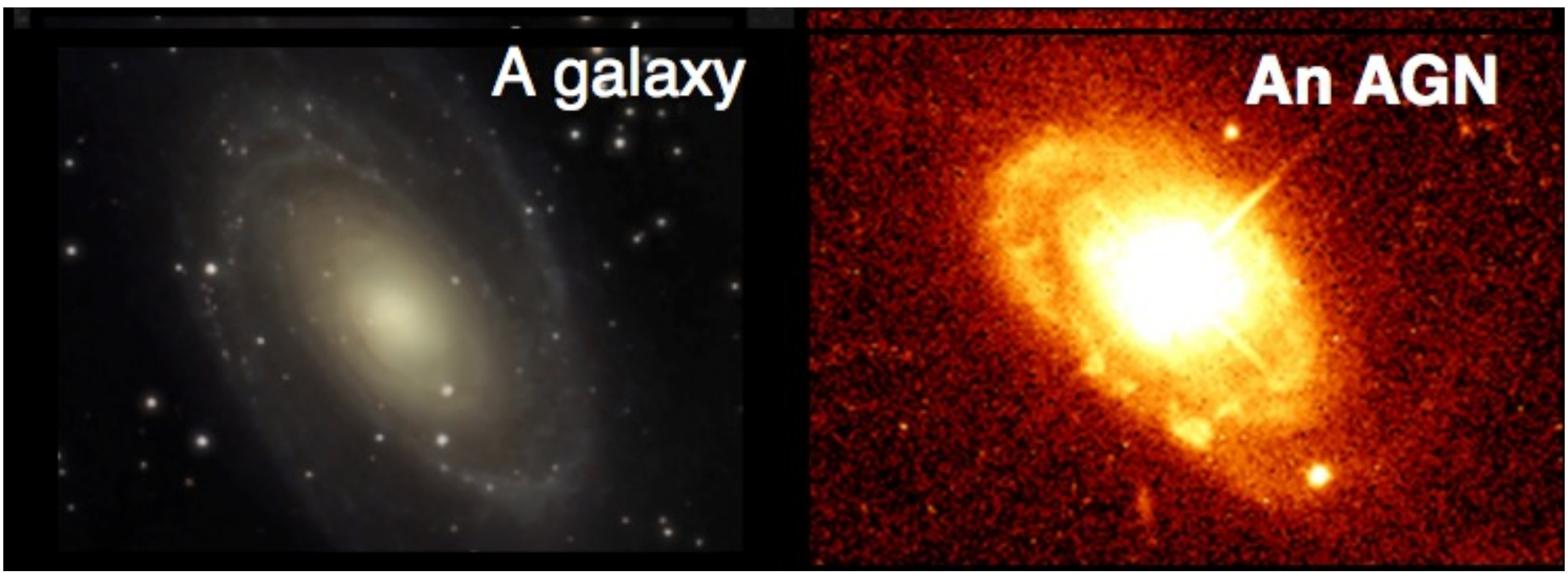
AGN & QSOs

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 & Bright AGN (QSOs) – extreme central engines : merger hypothesis & UV/IR background
- Bright AGN (QSOs) as probes of the IGM (absorption lines) and of Large Scale Structure & early universe

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

Radiative Mode:

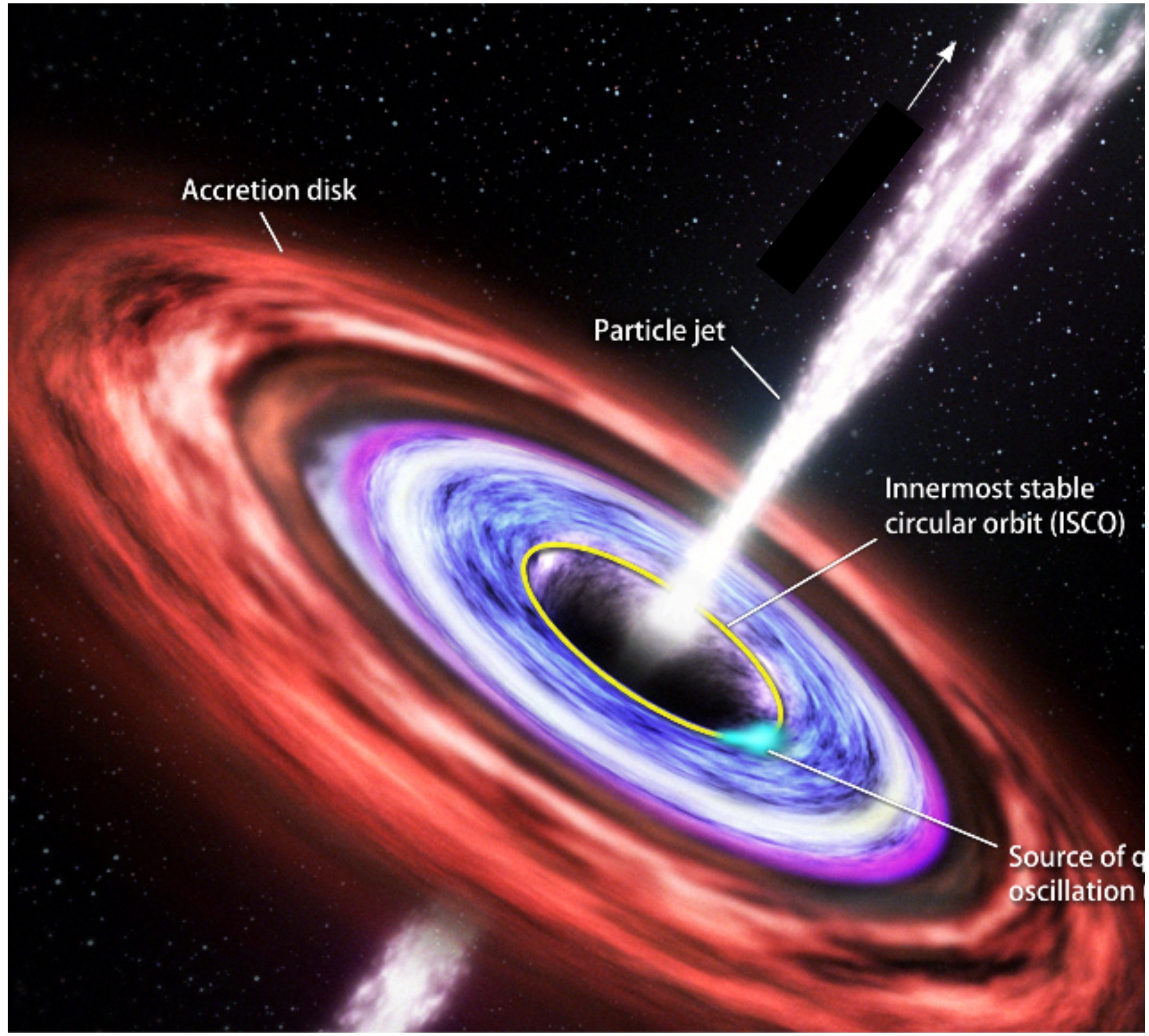
Gas falls in: PE -> KE

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 (M31),
η = 0.1 (efficiency of the mass-radiation transfer)

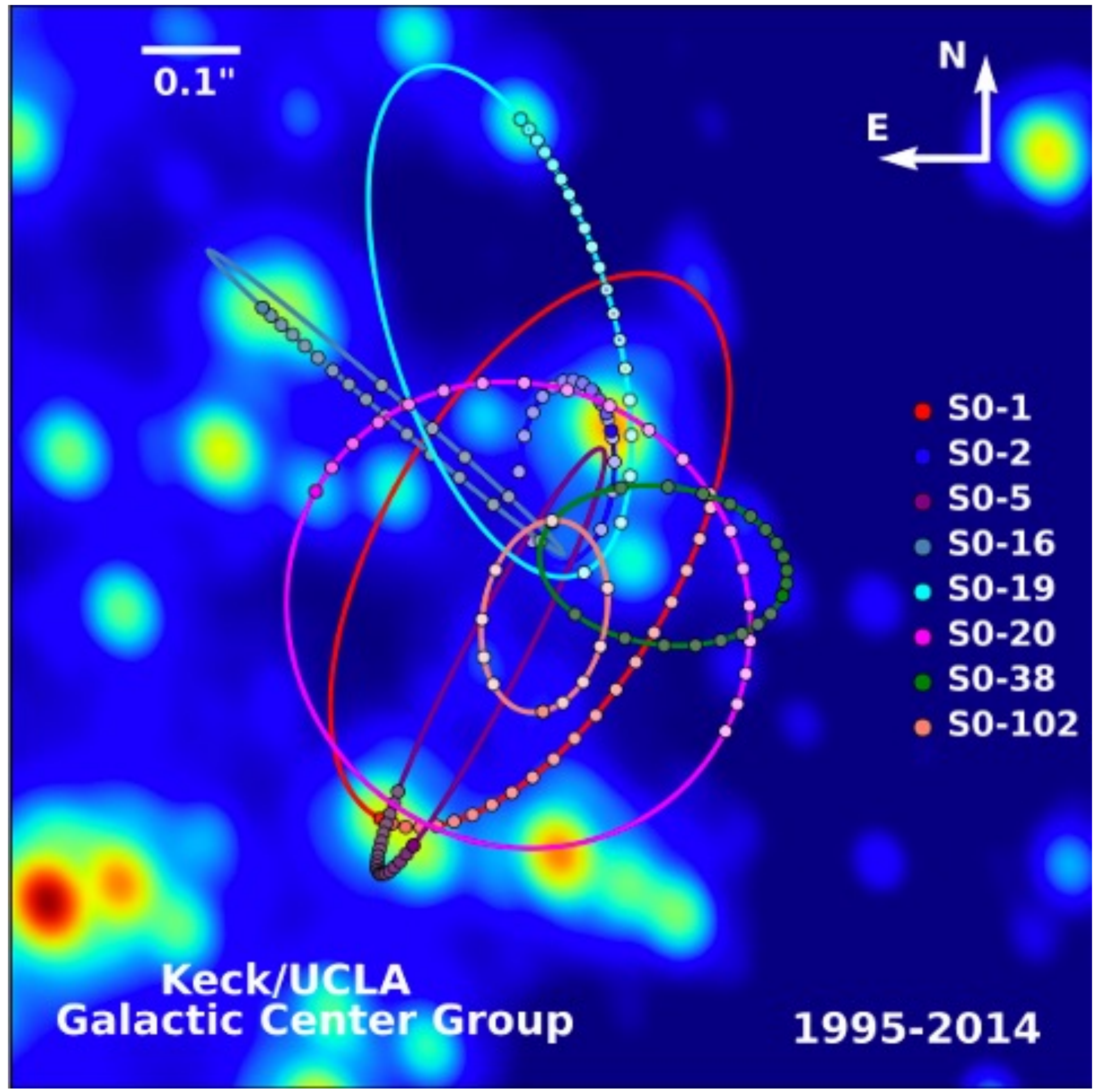
The SMBH in our Galaxy

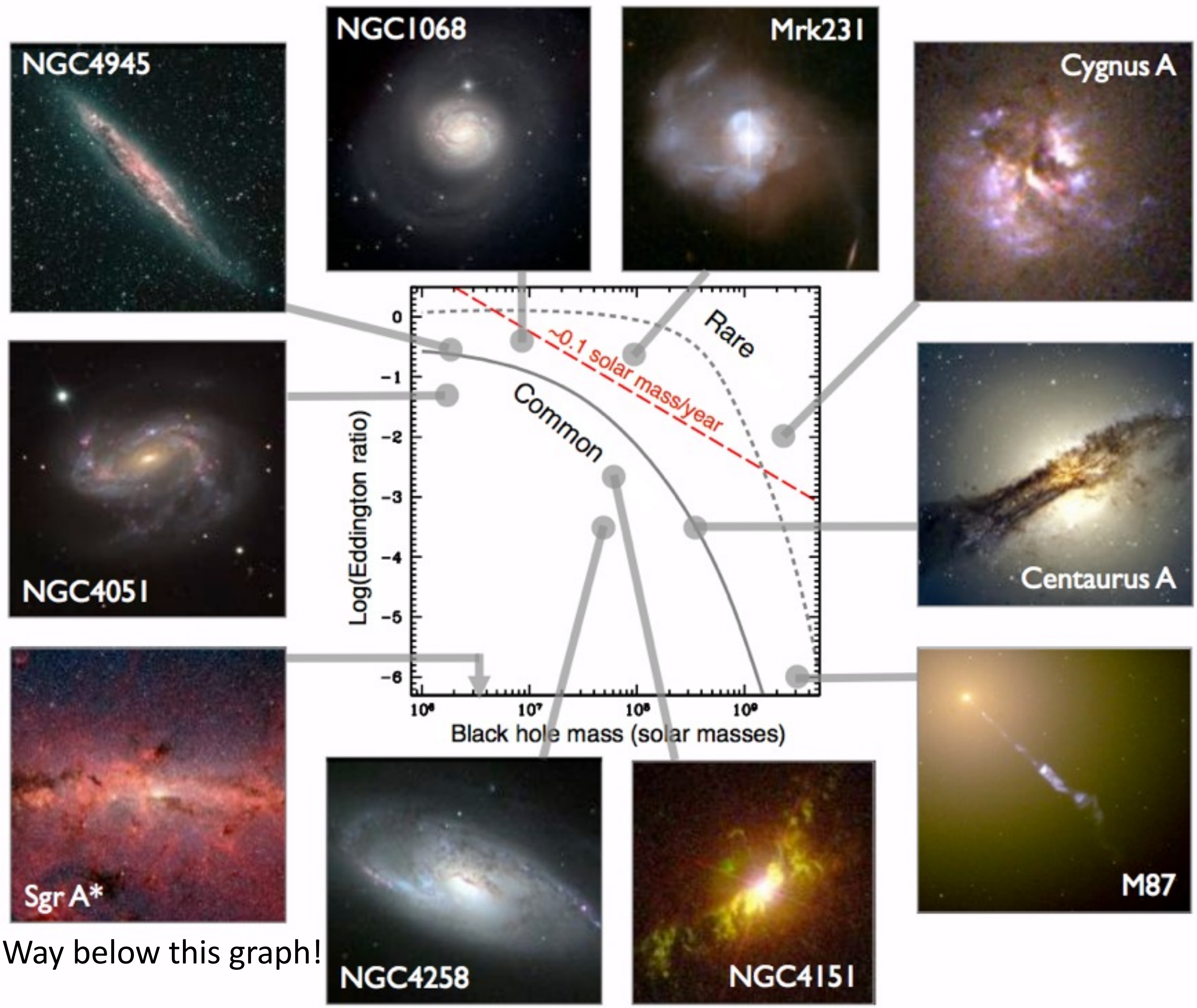
$M_{BH} = 3 \times 10^6$ Msun
$L_{edd} \sim 10^{44}$ erg/s
L actual = 10^{-10} L_{edd}

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.

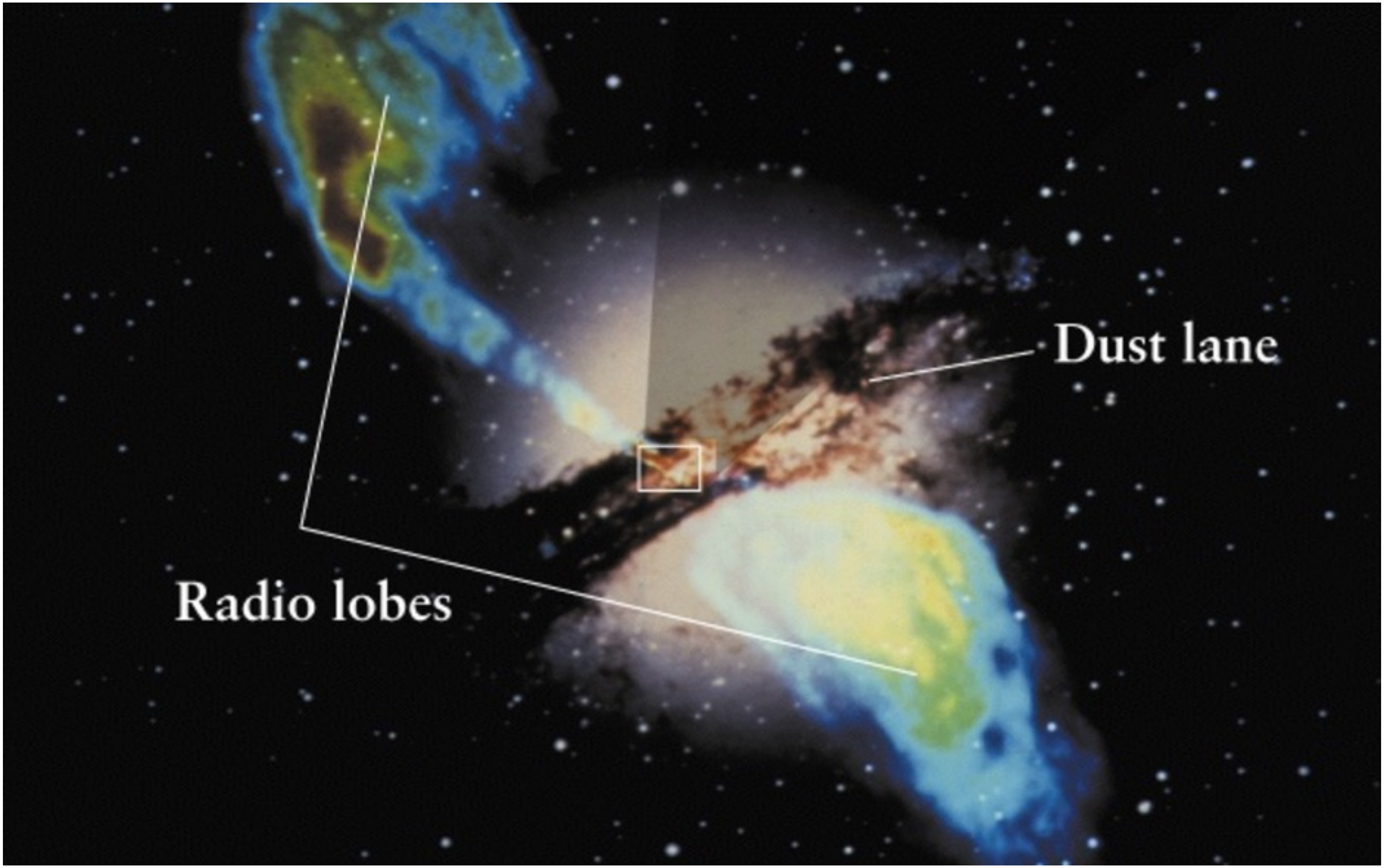
Andrea Ghez's team; UCLA





MW: Way below this graph!

Centaurus A: Radio Galaxy



Jets are ~ 10 kpc in length

Blandford-Znajek Process: This theory explains the extraction of energy from magnetic fields around an accretion disk, which are dragged and twisted by the spin of the black hole. Relativistic material is then feasibly launched by the tightening of the field lines.

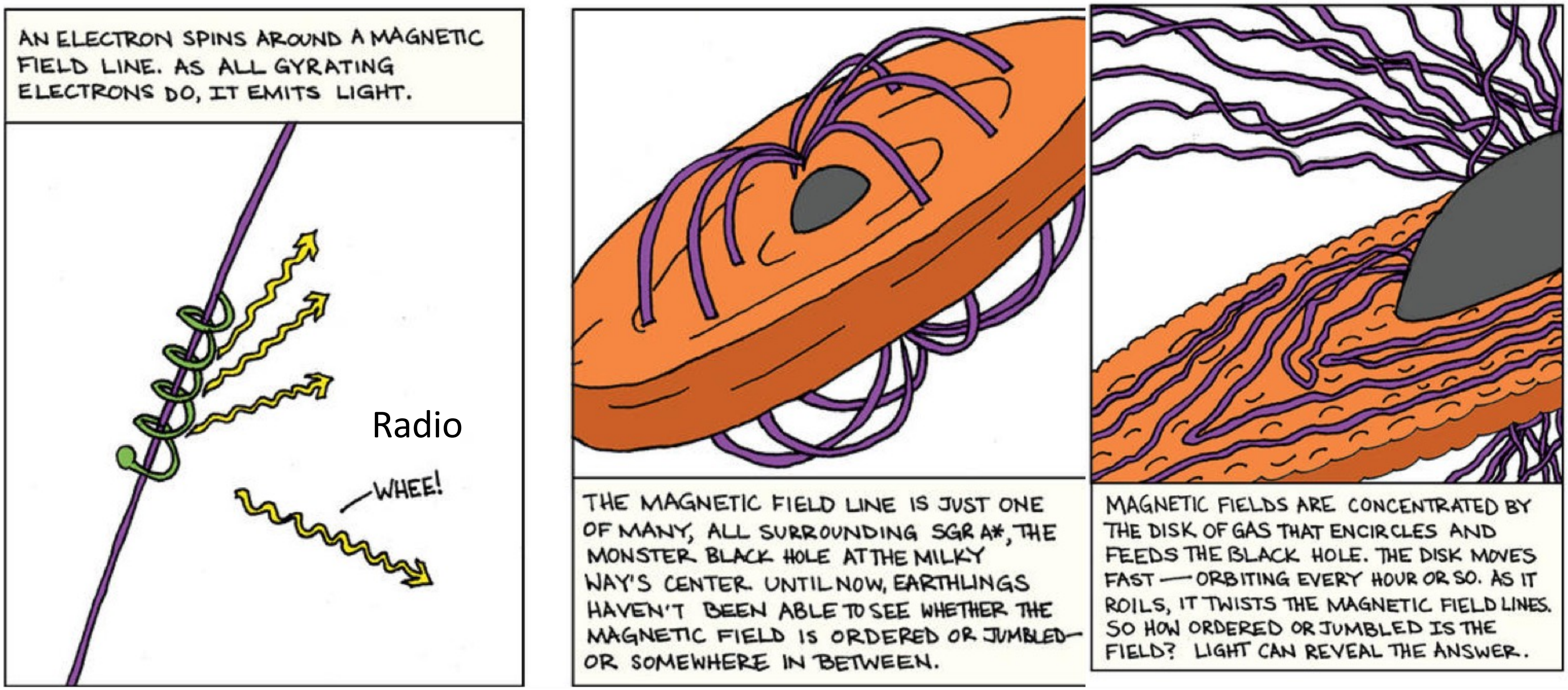
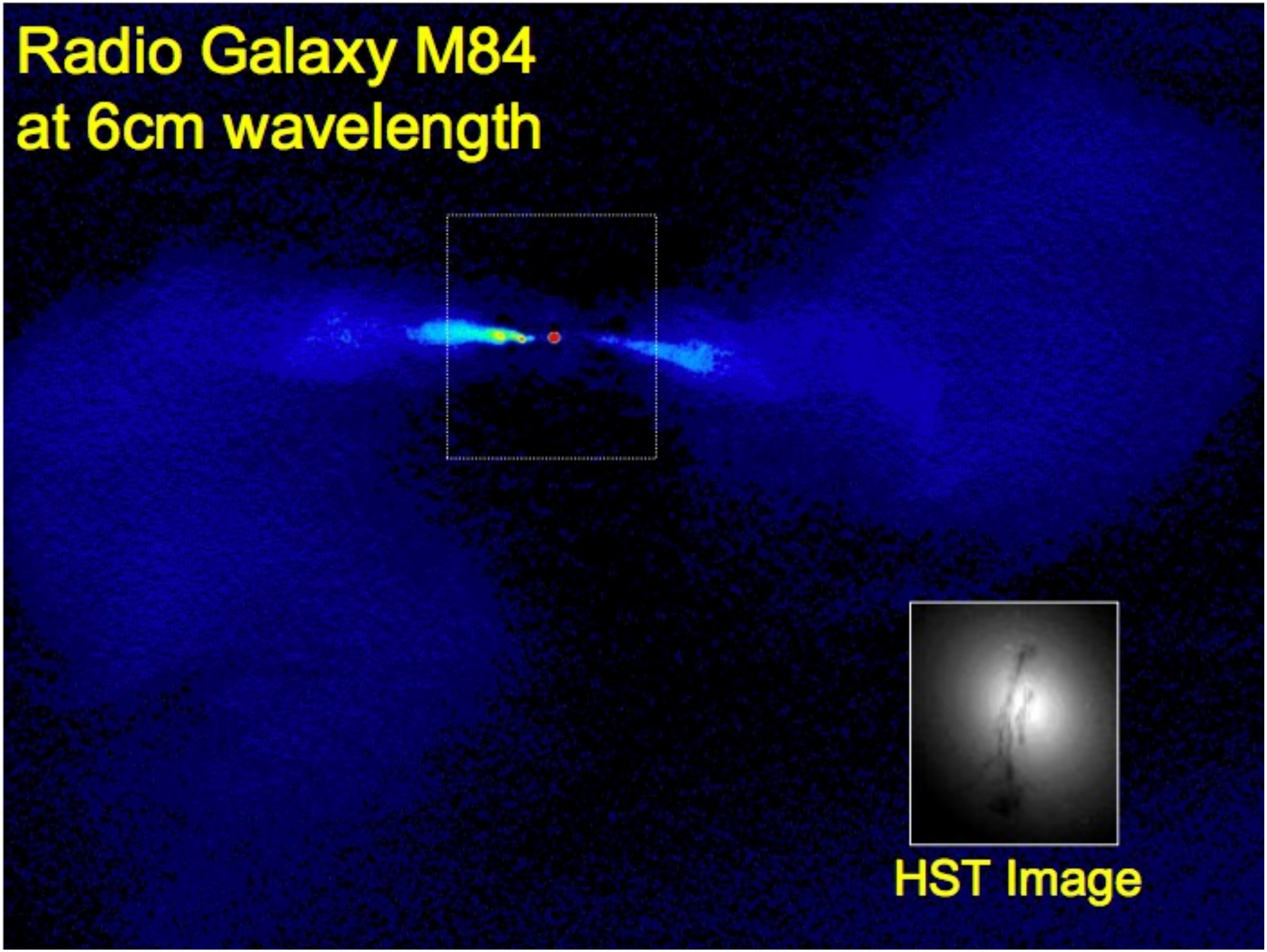
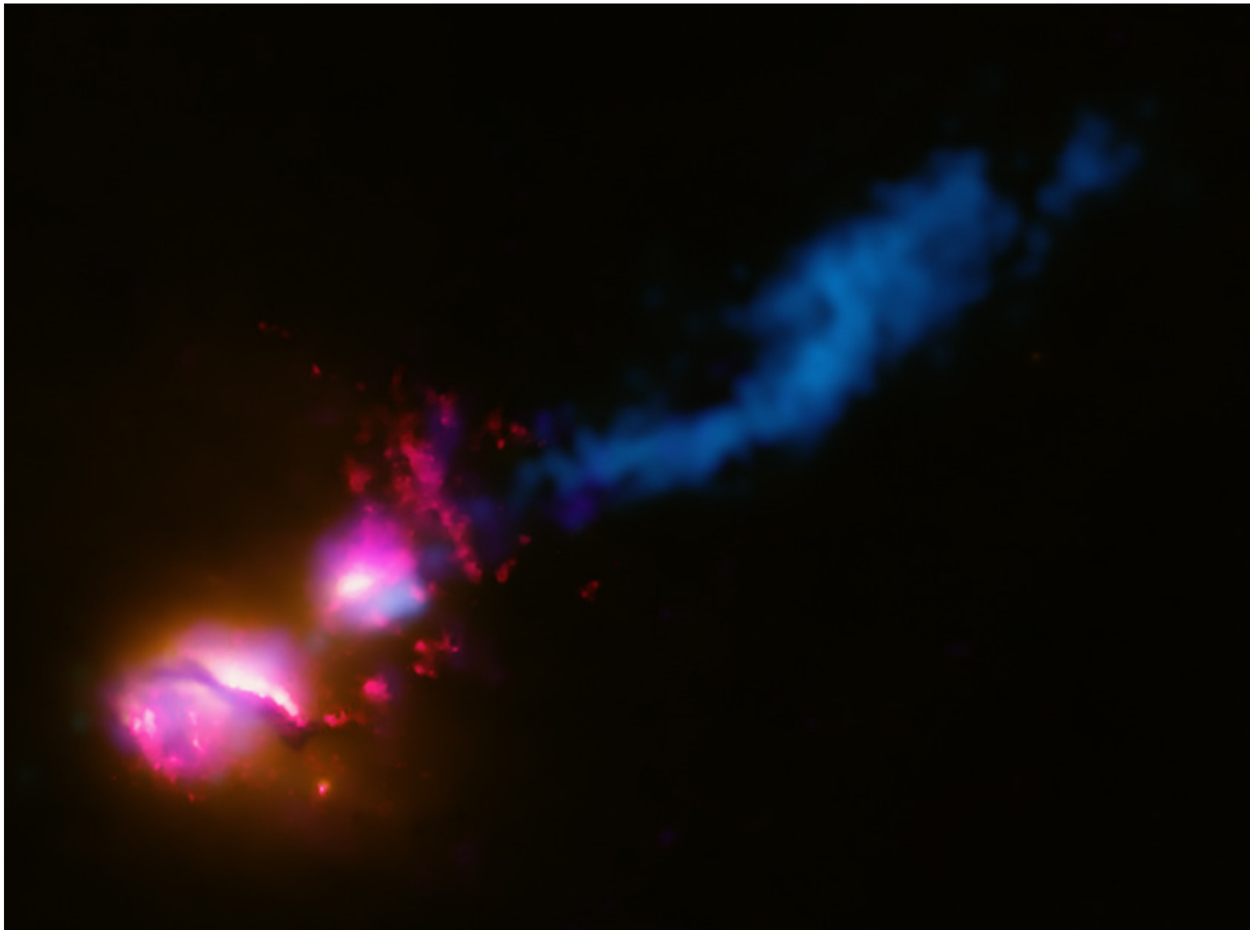


Image Credit: Katie Peek

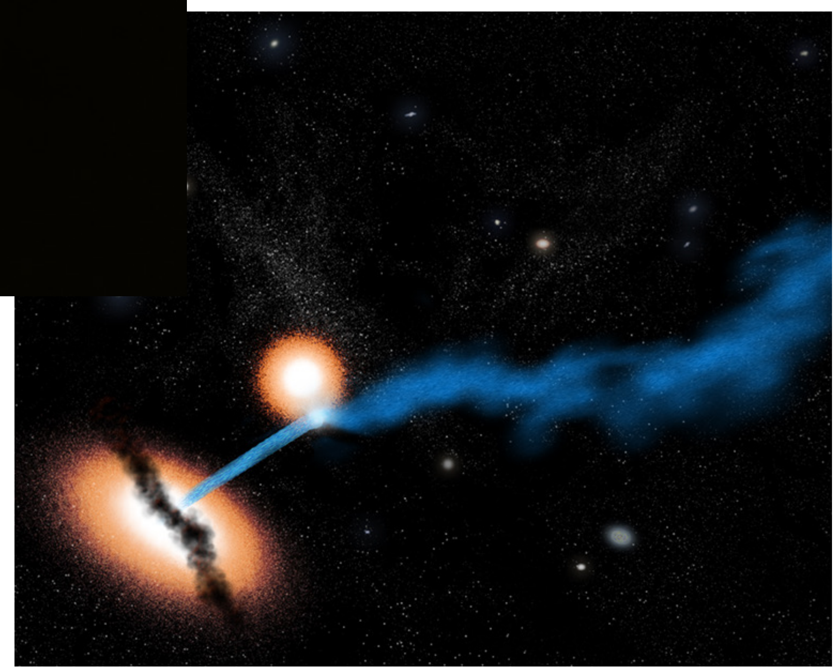

Radio Galaxy M84
at 6cm wavelength
HST Image

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)

Below is a cartoon version of the left

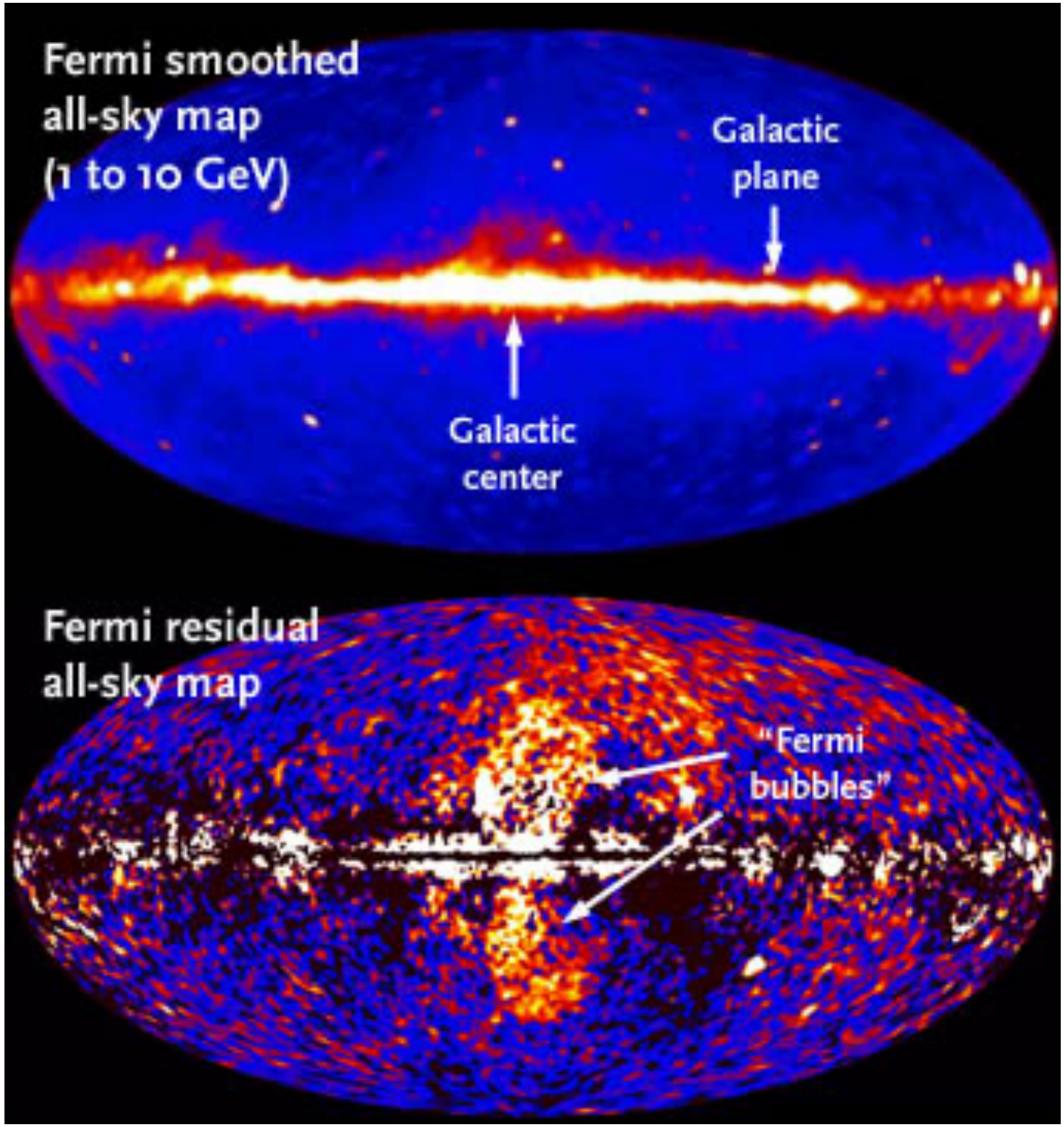


Evidence for jets from the MW's SMBH

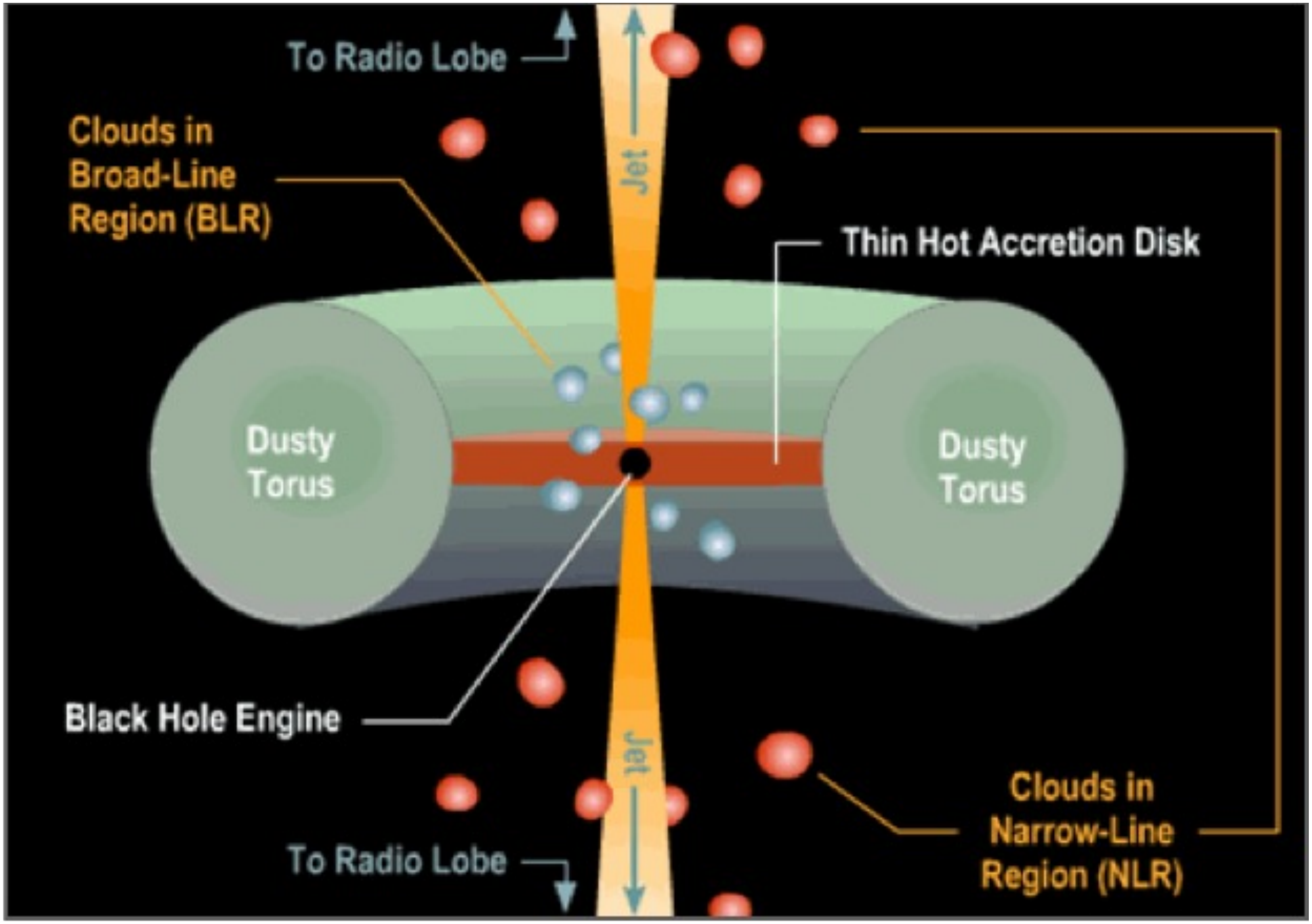
Bubble is also seen in x-rays (E-Rosita)

Models Find:
Black Hole Jet turned on 2.6 Myr ago, lasting 1 Myr

(Yang+2022, Nature Astronomy, 6)



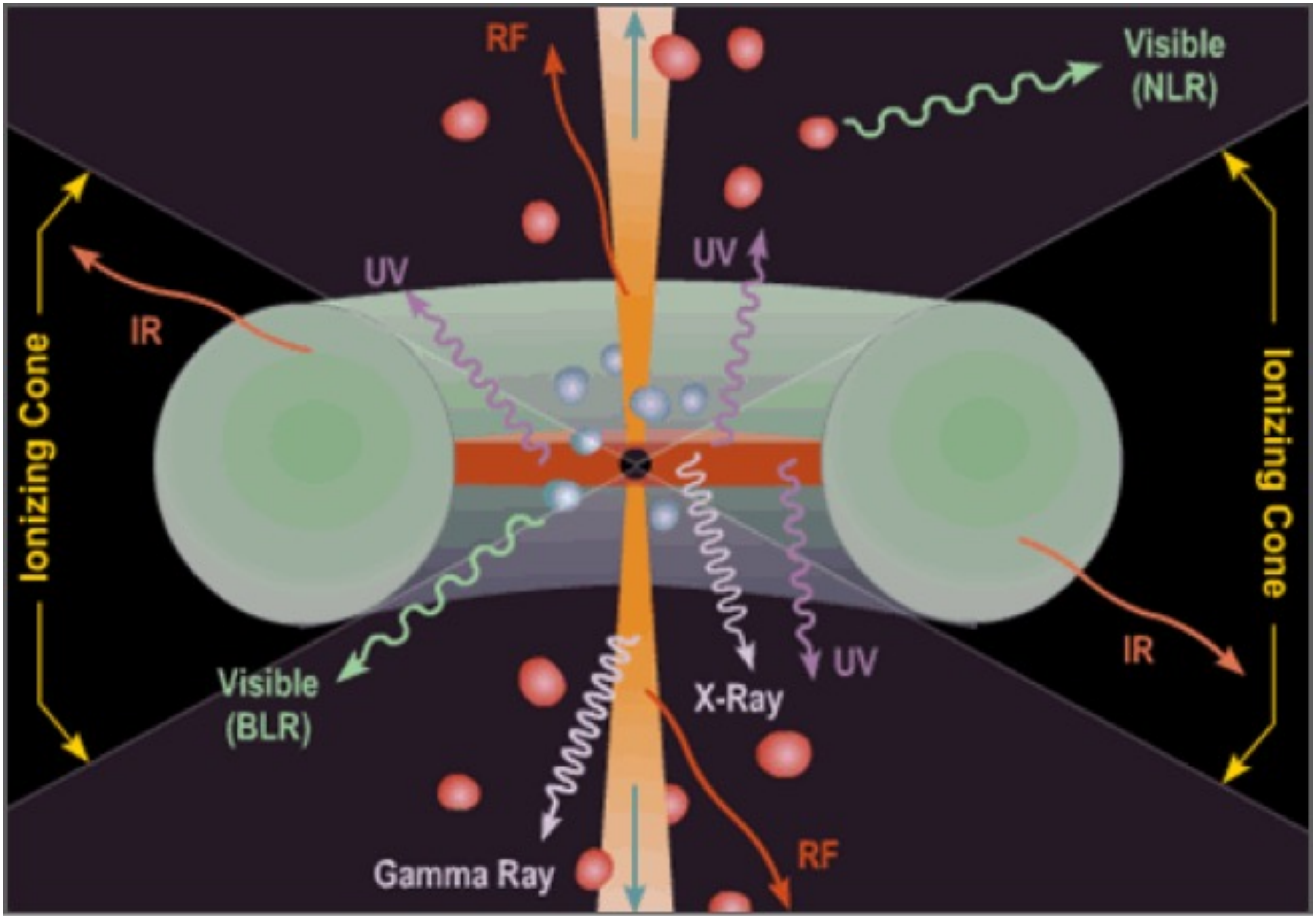
Unified Model for AGN



Brooks/Cole Thomson Learning

Brooks/Cole Thomson Learning

Unified Model for AGN



Brooks/Cole Thomson Learning

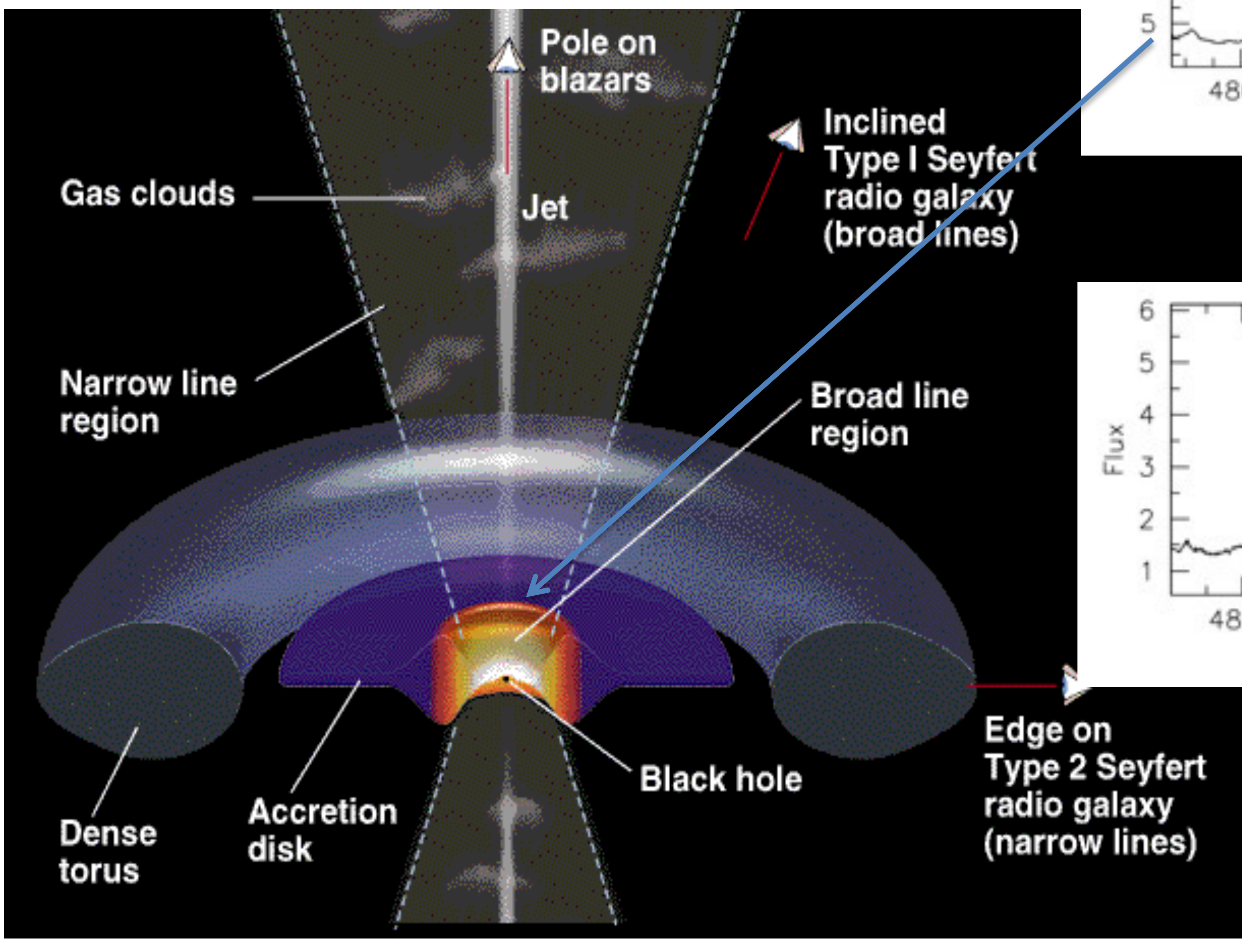
Taxonomy

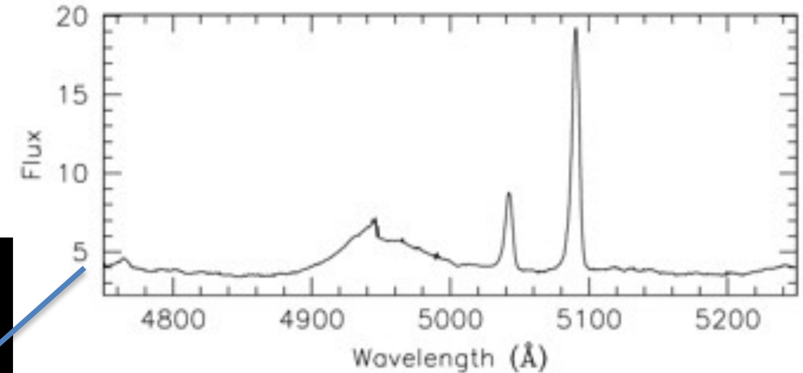
- UV/O/IR luminosity:
  - QSOs (Lnuc > Lgal): **Quasi Stellar Object**
  - Strong AGN (Lnuc <~ Lgal) [**Seyferts**]
  - Weak AGN (Lnuc << Lgas) [**Low Luminosity AGN, LINERS**]

- Radio Luminosity (jet power)
  - **Radio Quiet** (LR < 1e-4 Loptical)
  - Radio Loud (LR > 0.1 Loptical) → Quasar

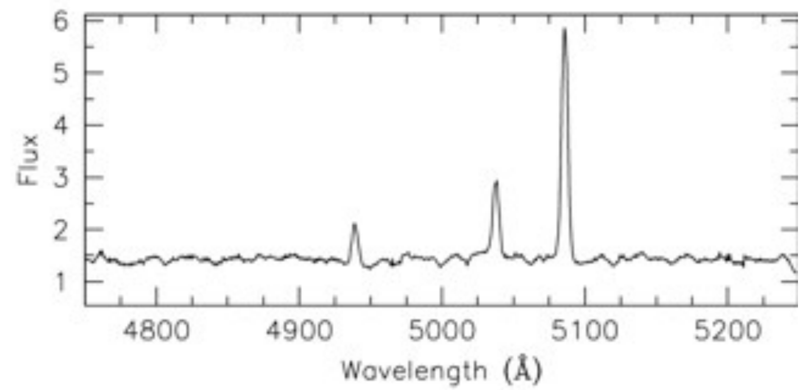
- Viewing Angle
  - Broad + Narrow Lines (can see BLR) (**type 1**)
  - Narrow lines only (can't see BLR) (**type 2**)
  - If seeing down the jet (**Blazar)**

Viewing perspective





BLR ~ 0.02 – 0.1 pc
V ~ few 10^3 km/s

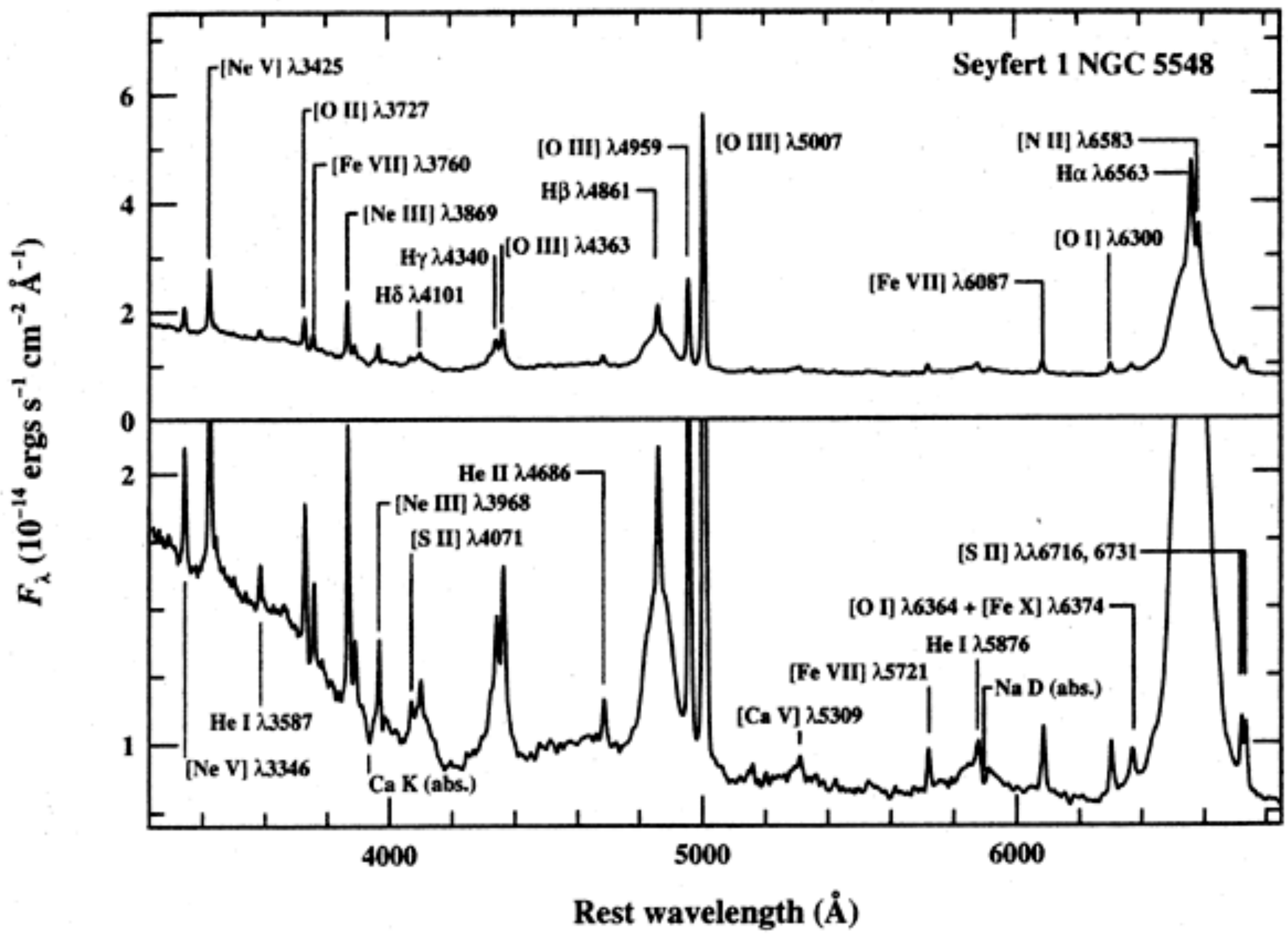


NLR 10 pc – 1 kpc
V ~ few x 100 km/s

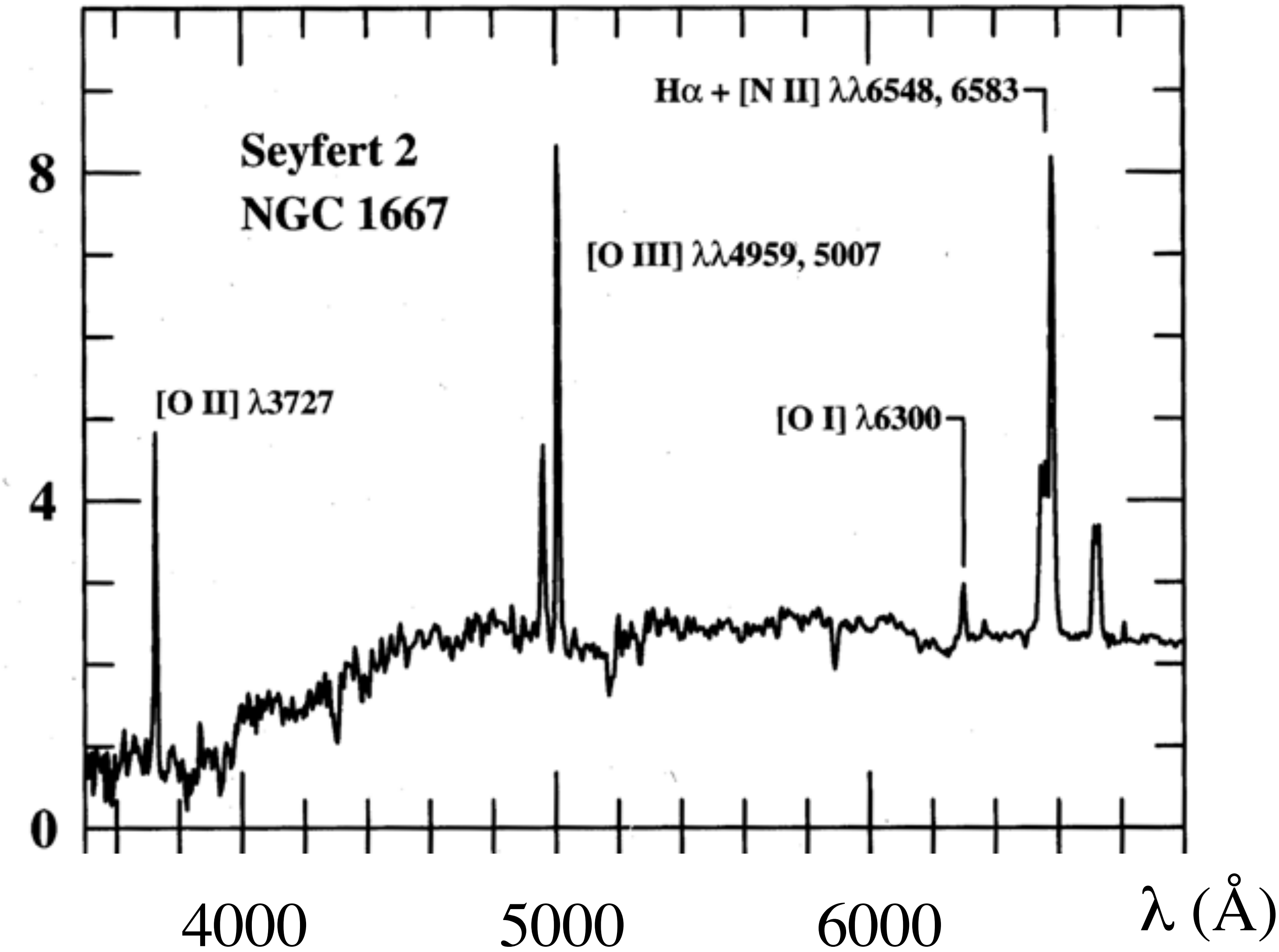
Wadsmorth Publishing

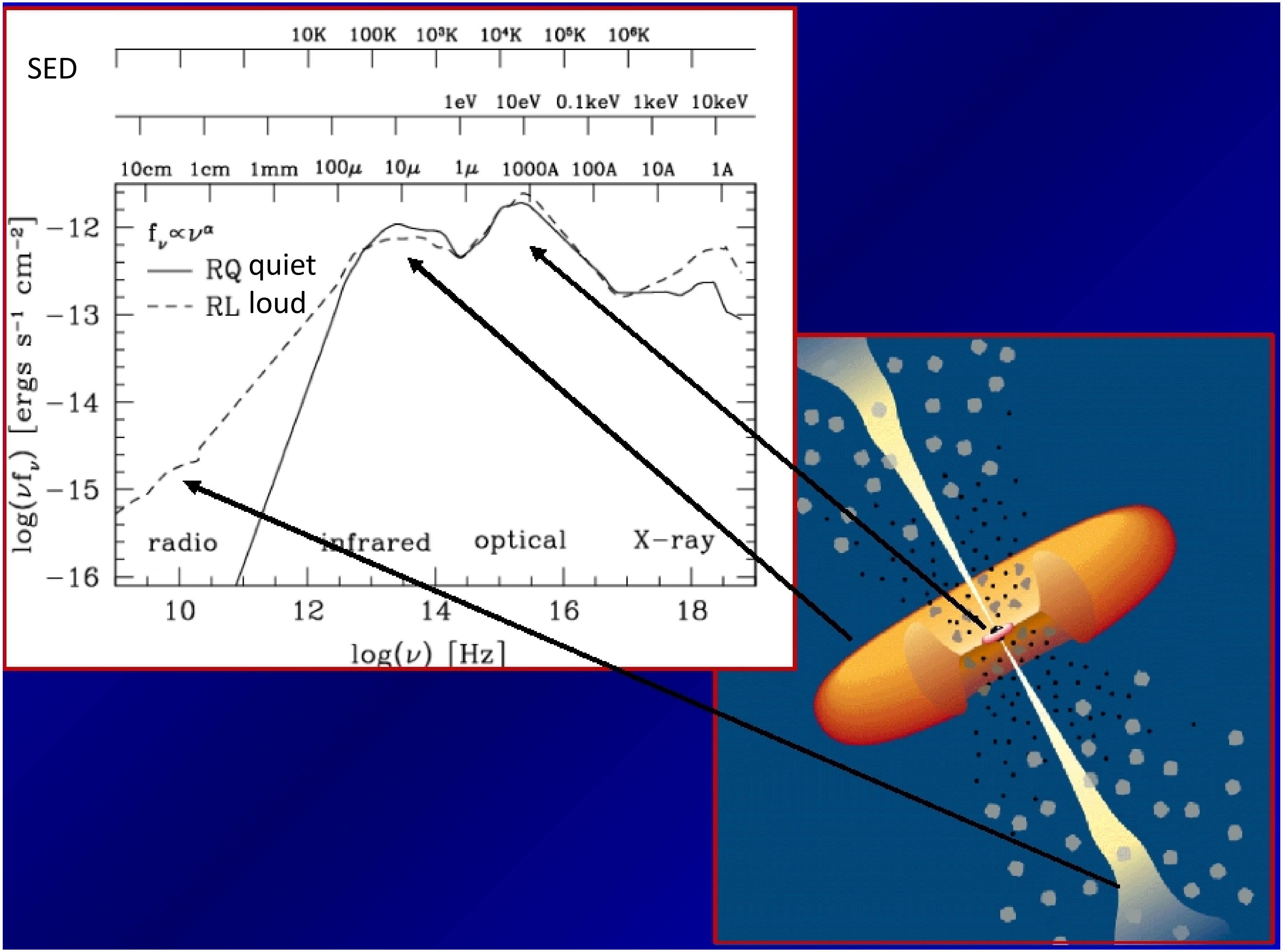
Spectra: Broad Lines (Type I)

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

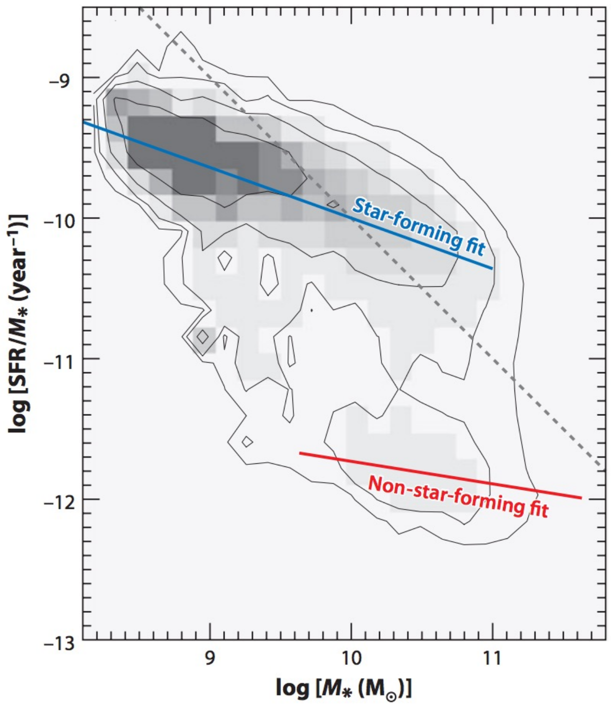


Spectra: No Broad Lines (Type II)

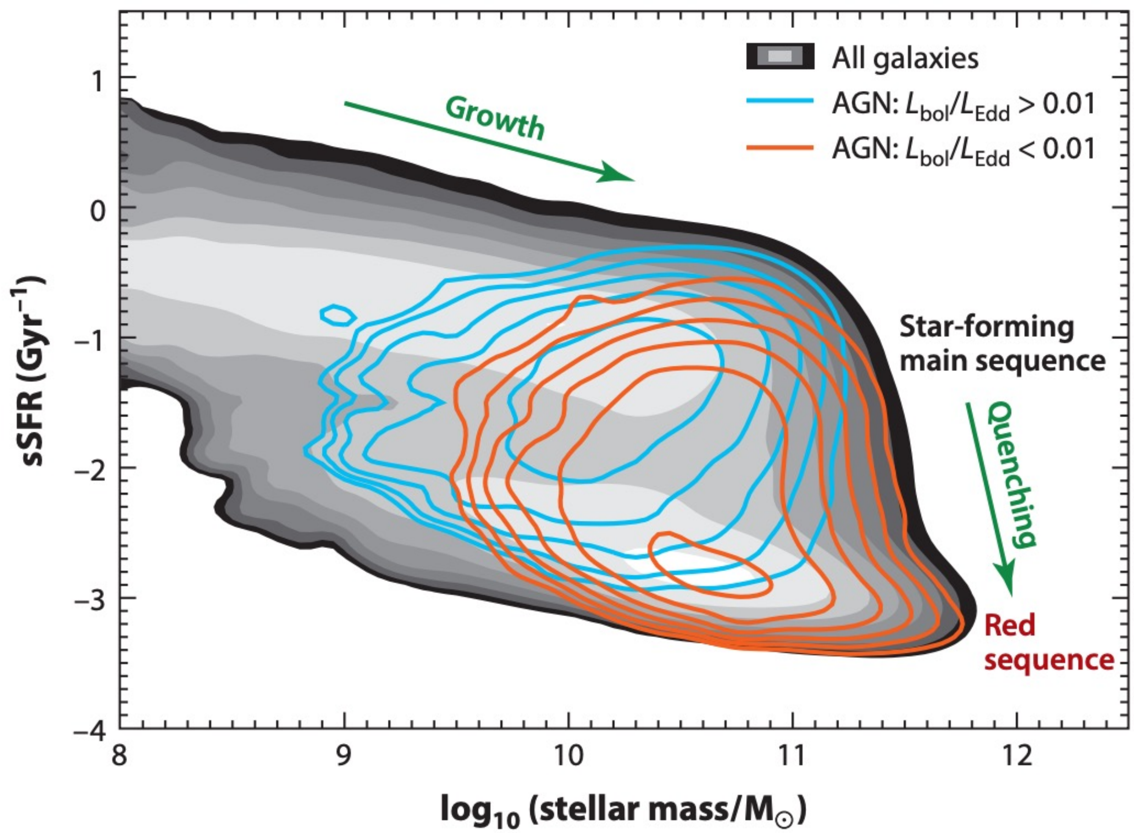



SED
10K 100K 10³K 10⁴K 10⁵K 10⁶K
1eV 10eV 0.1keV 1keV 10keV
10cm 1cm 1mm 100μ 10μ 1μ 1000A 100A 10A 1A
$f_\nu \propto \nu^\alpha$
RQ quiet
RL loud
radio
infrared
optical
X-ray
log(νf_ν) [ergs s⁻¹ cm⁻²]
log(ν) [Hz]

AGN & SF Main Sequence



Recall: SF Main Sequence
Kennicutt & Evans 2012



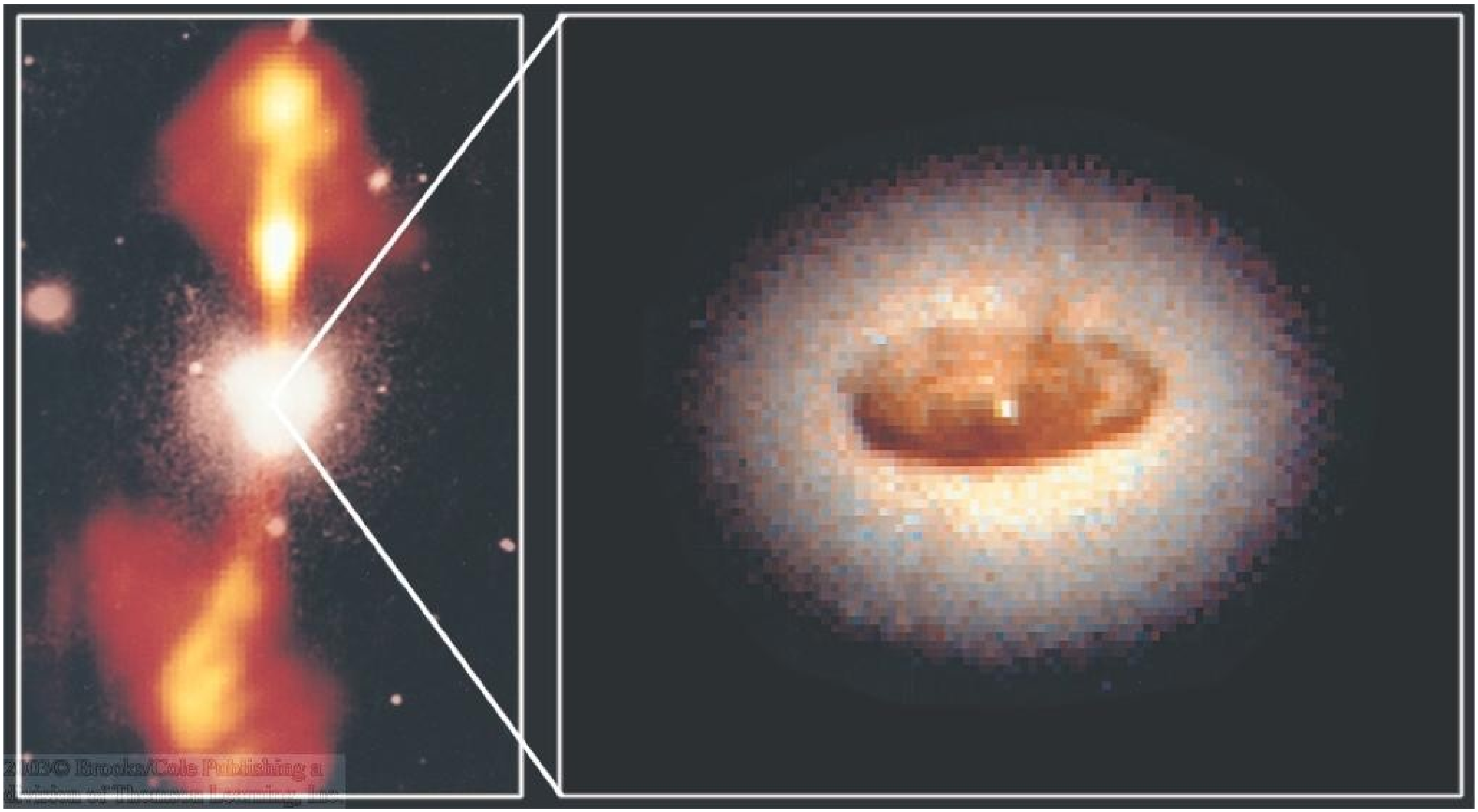
Heckman & Best 2014 ARAA

Low luminosity AGN are more likely to be on Red Sequence

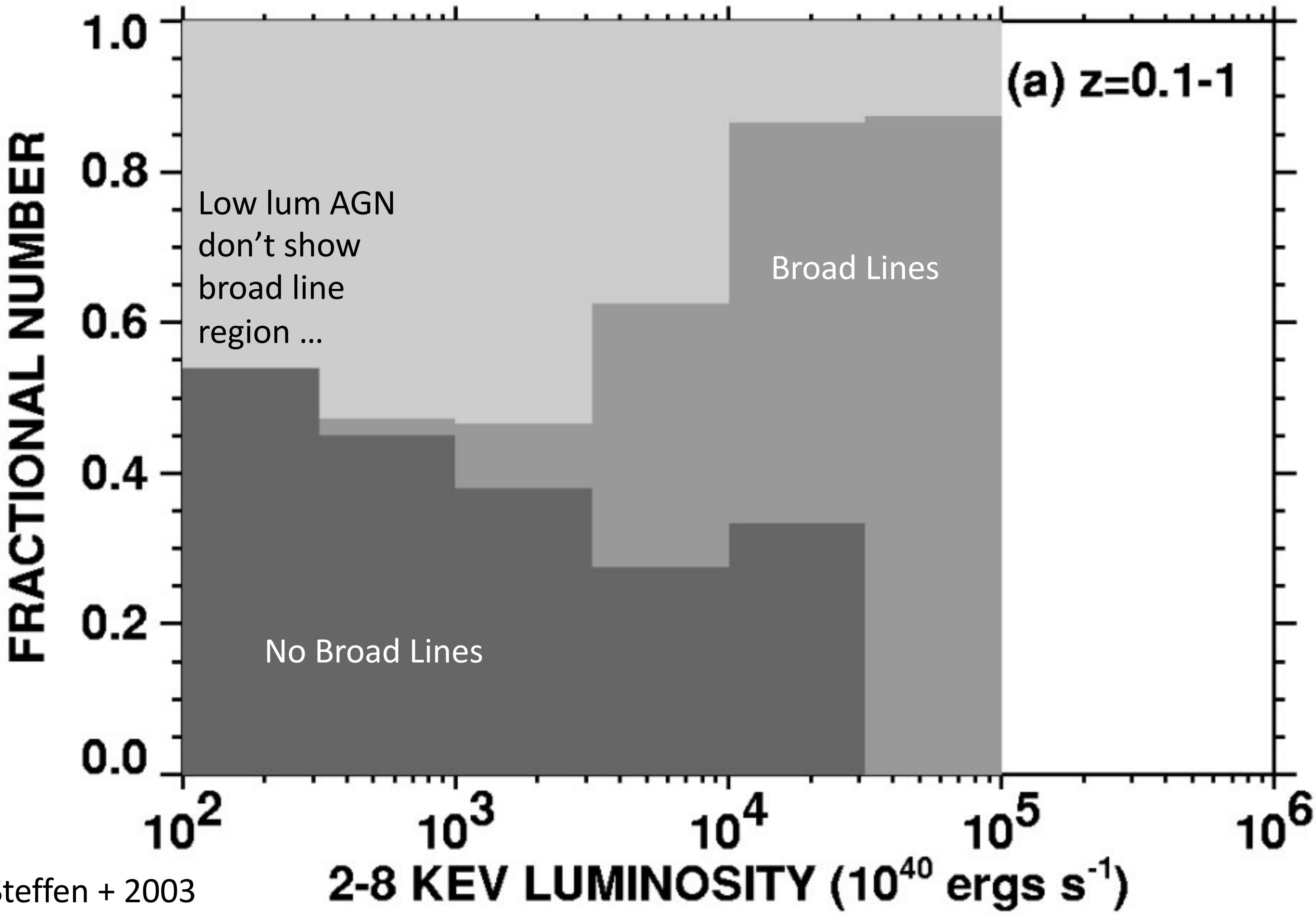
(Note the units on Y axis of the two plots – Yr v Gyr)

Evidence for the Unified Model

The Dust Torus in NGC 4261

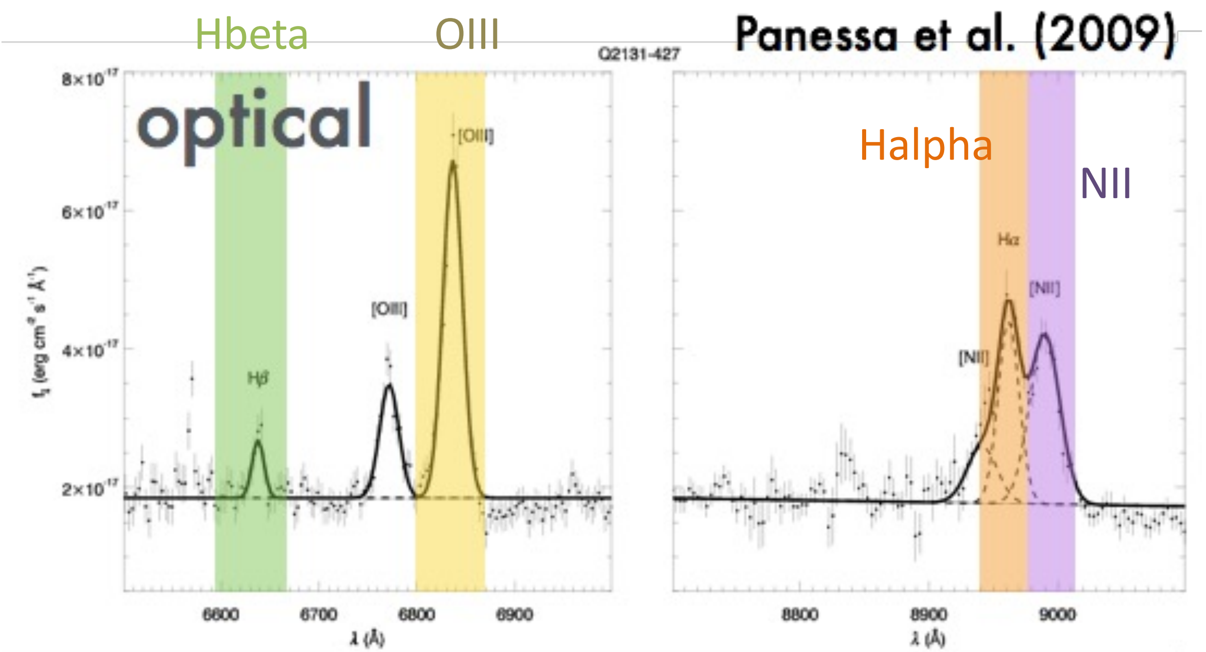


Issues with the Unified Model?



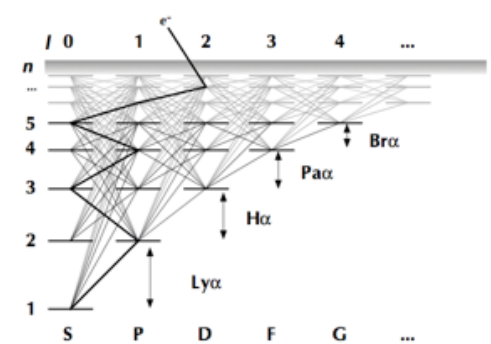
Steffen + 2003

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.



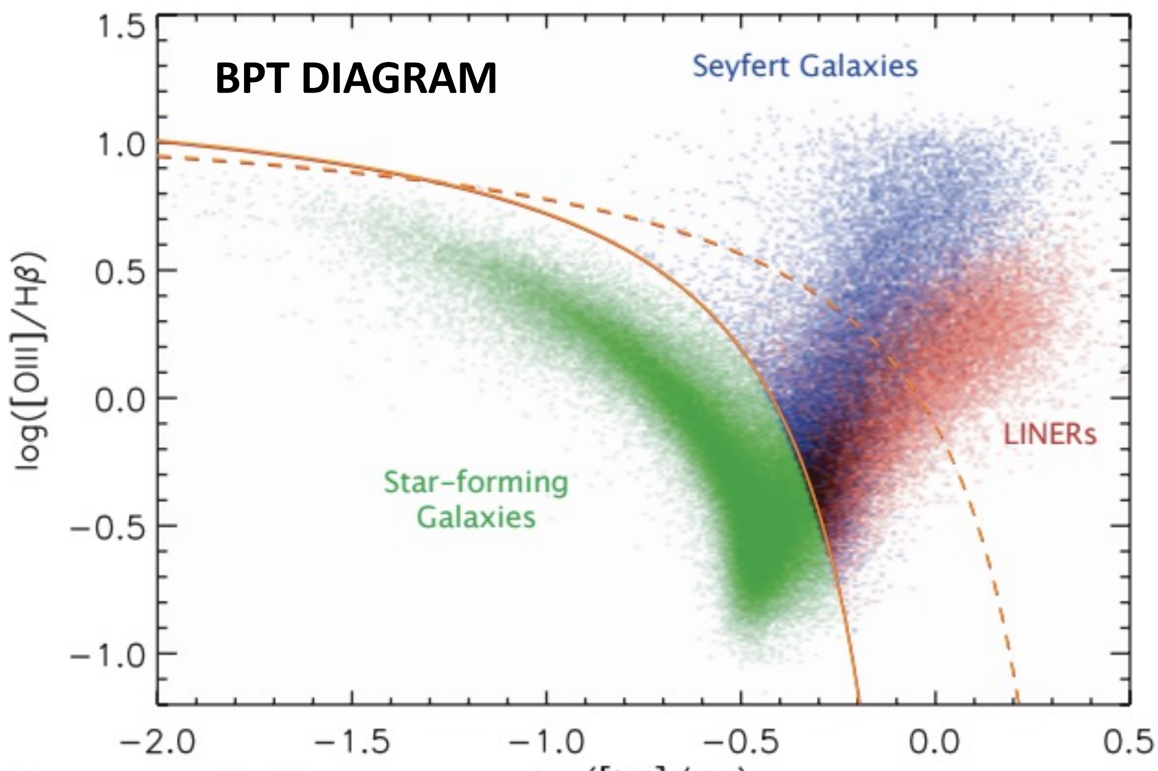
Courtesy Kevin Hainline

Selection of AGN: Optical Emission Lines

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

Looking at the ratio of tracers of emission from hot stars vs. AGN hard radiation

> 100.000 galaxies from SDSS

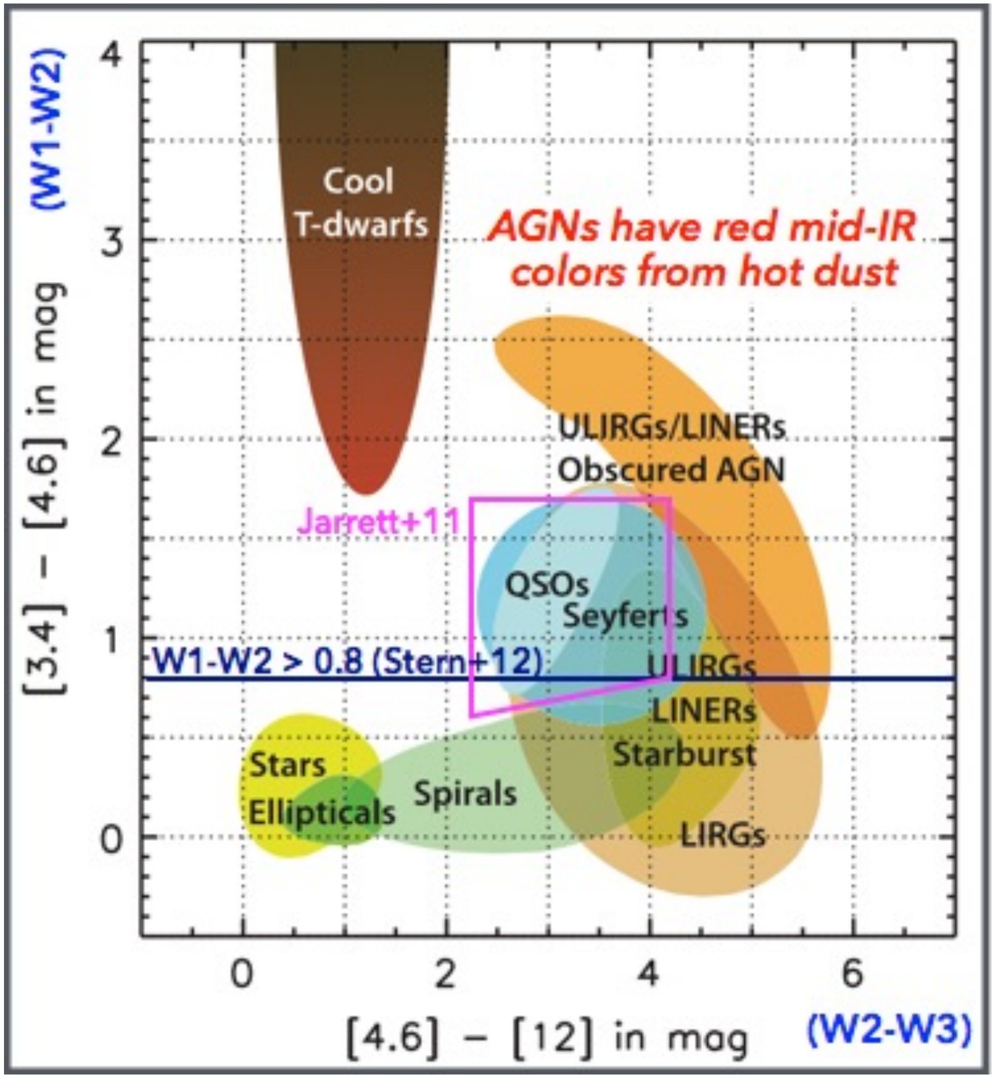


Groves et al 2006

starburst/AGN separator

Courtesy Hans-Walter Rix

Selection of AGN: Mid-IR (luminous AGN)

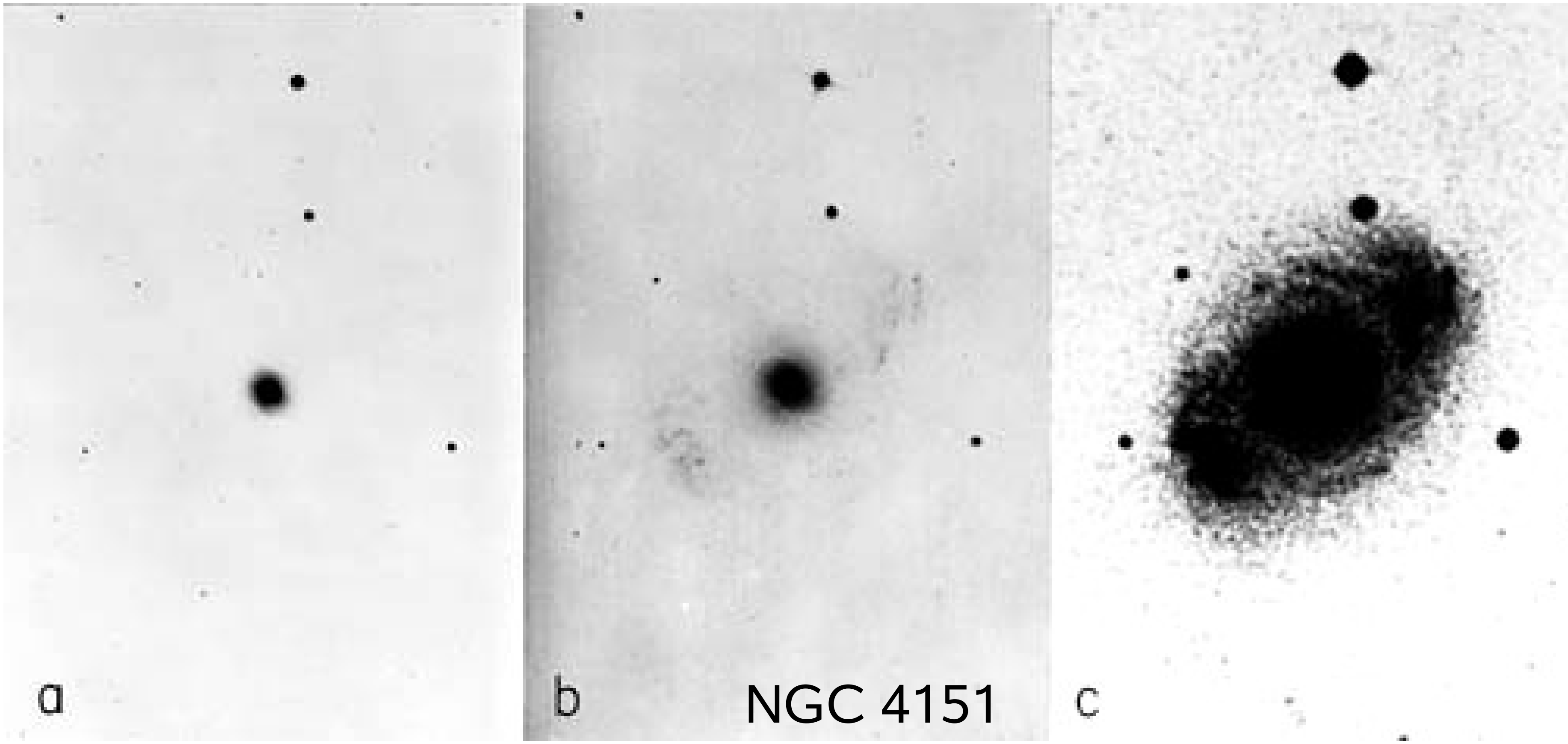


Wise Color-Color Diagram
Wright+2010

Courtesy: Amy Reines

Quasars & QSOs

- Typical QSO L > 100-10^5 x L_{MW}
- Triggered by gas flowing on SMBH at a high rate
  - Currently the rate of gas consumption by massive black holes must be much less



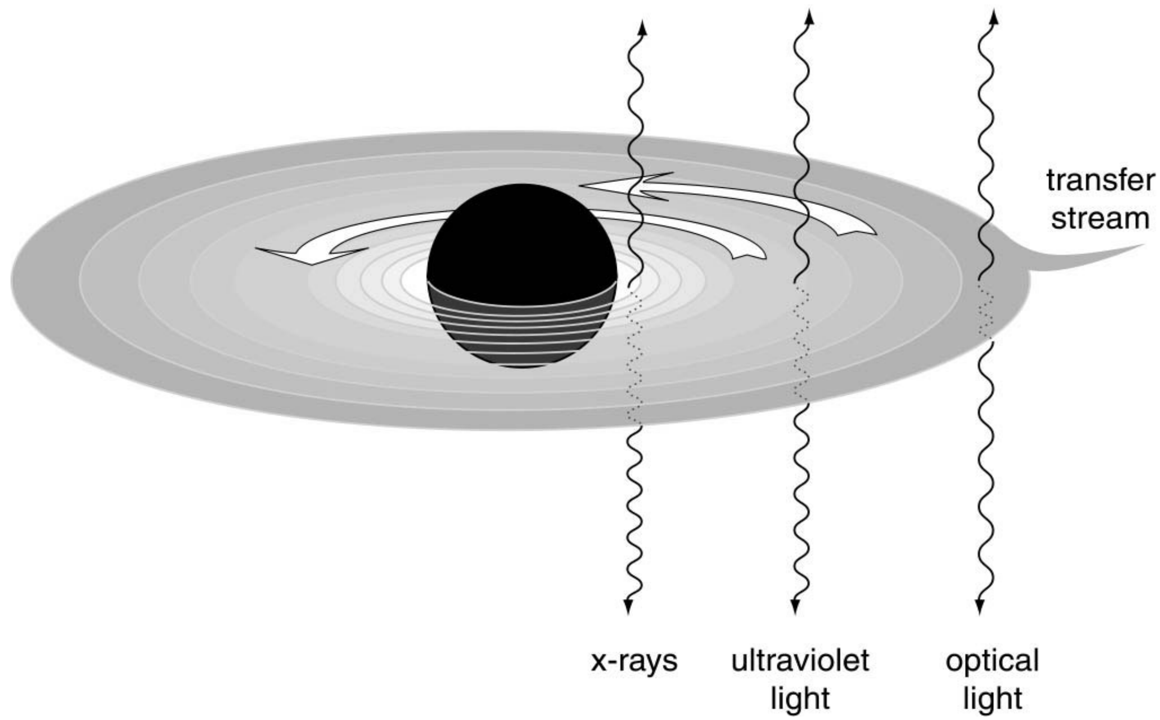
short exposure

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

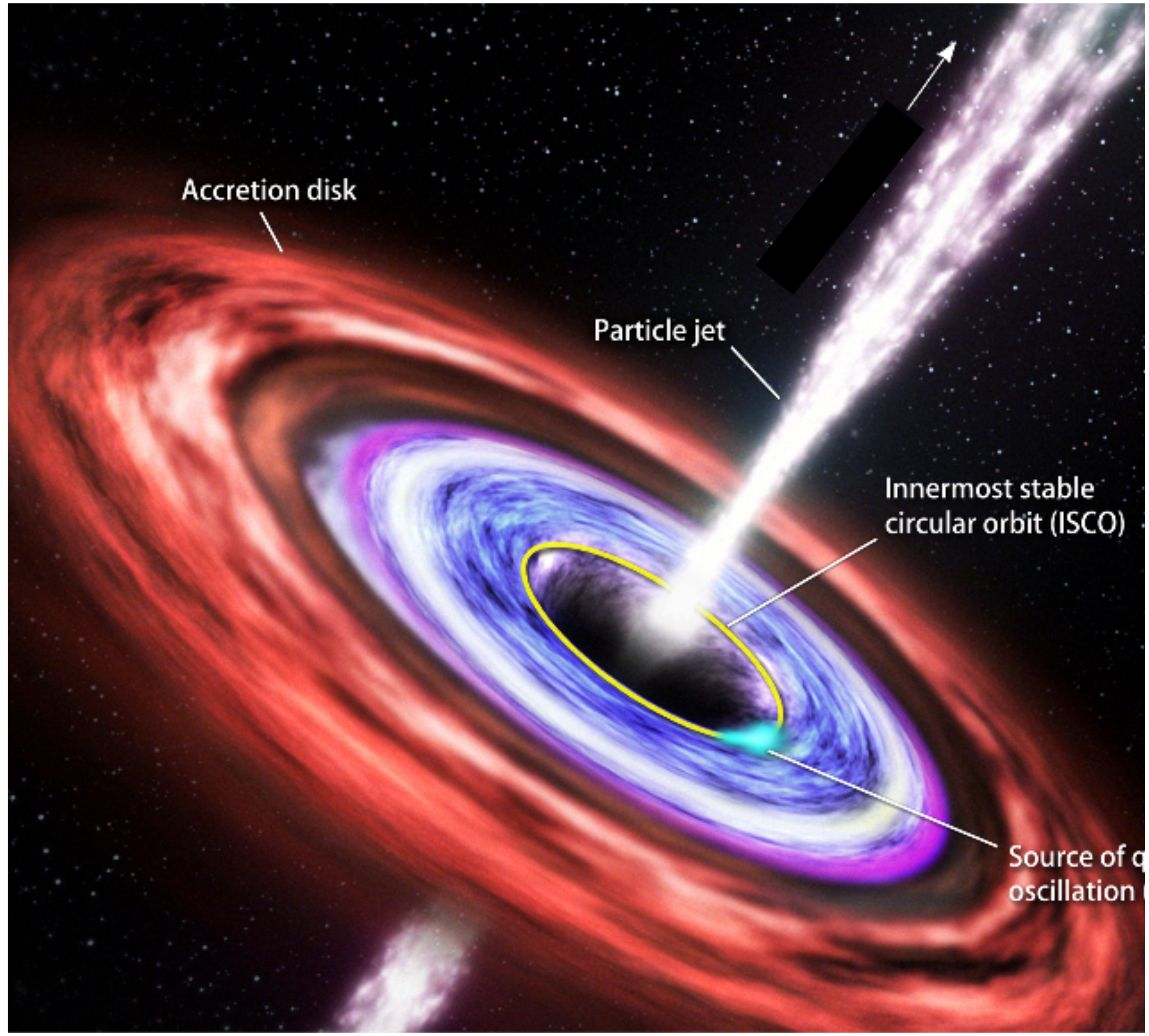


R ~ 3-10 pc
V ~ 0.3c

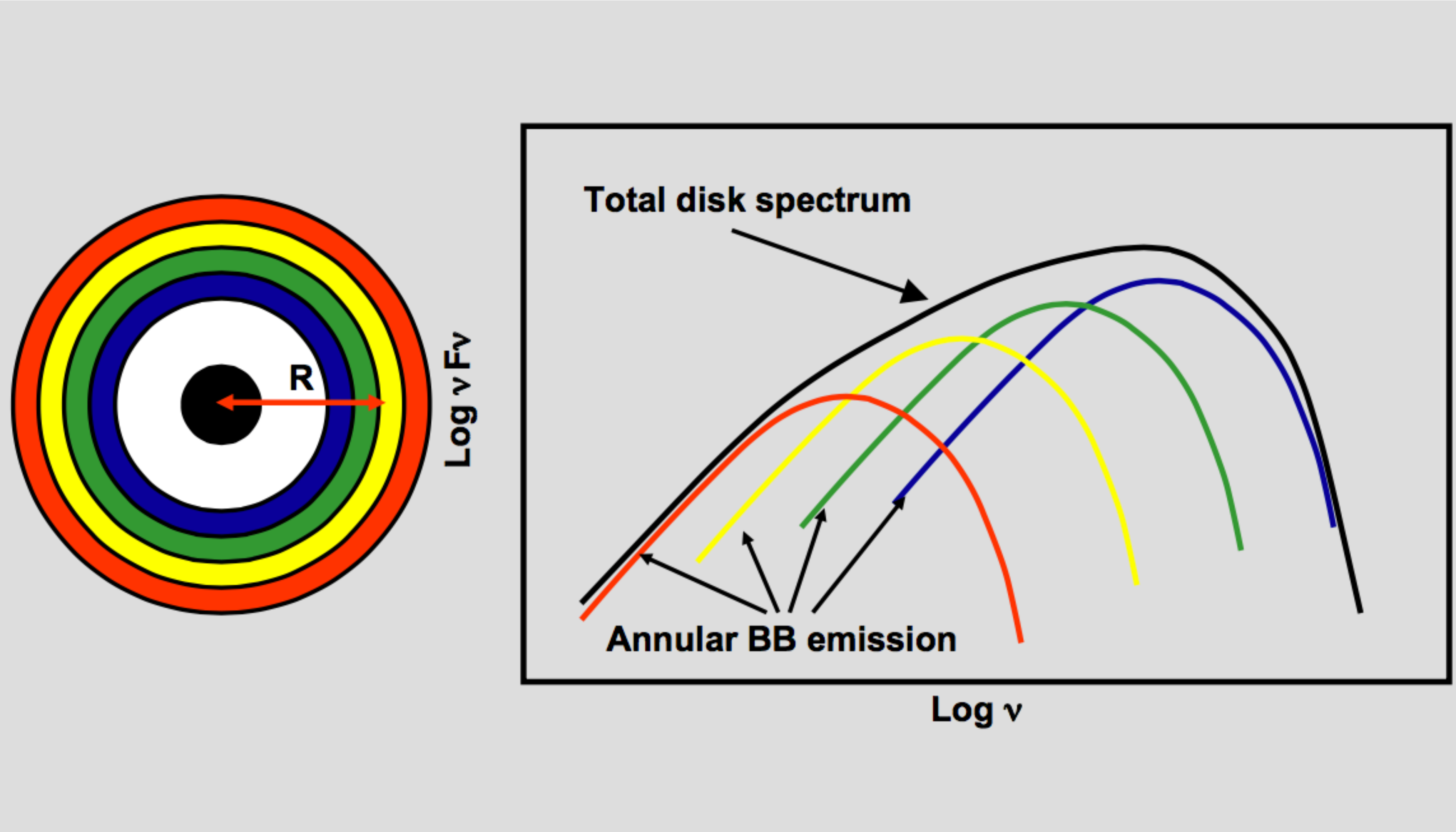
Most of the BH's energy is radiated by the accretion disk

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.

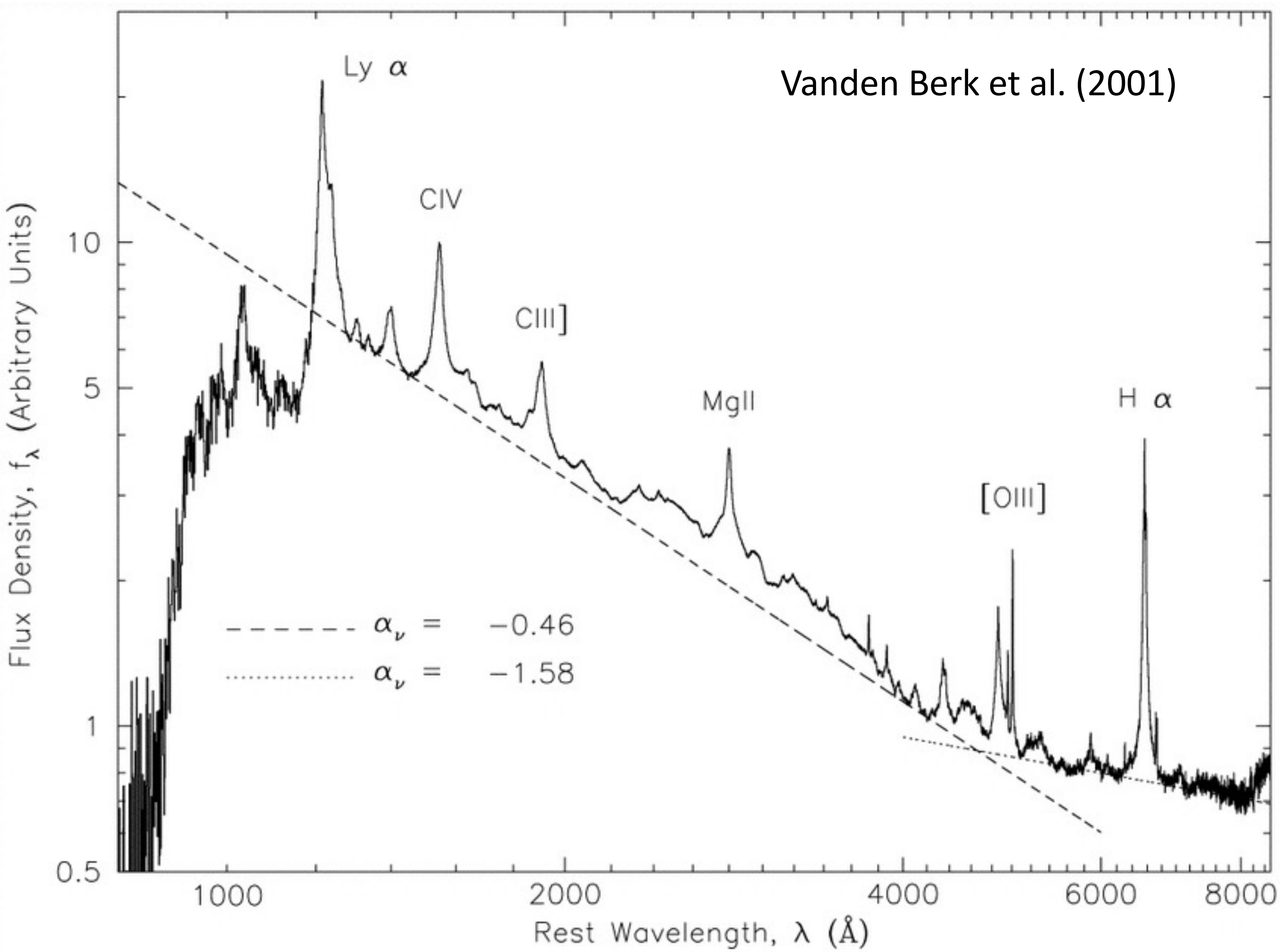
Outer accretion disk orbits less quickly, has cooler gas that emits optical light primarily and does not vary as much on short timescales.



UV/Optical: Accretion Disk

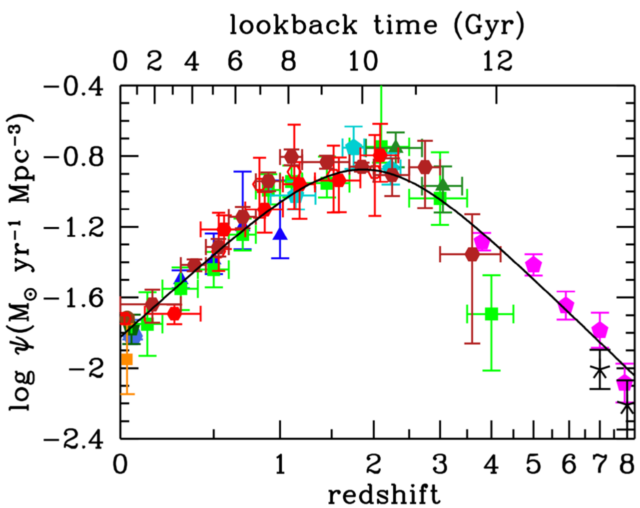


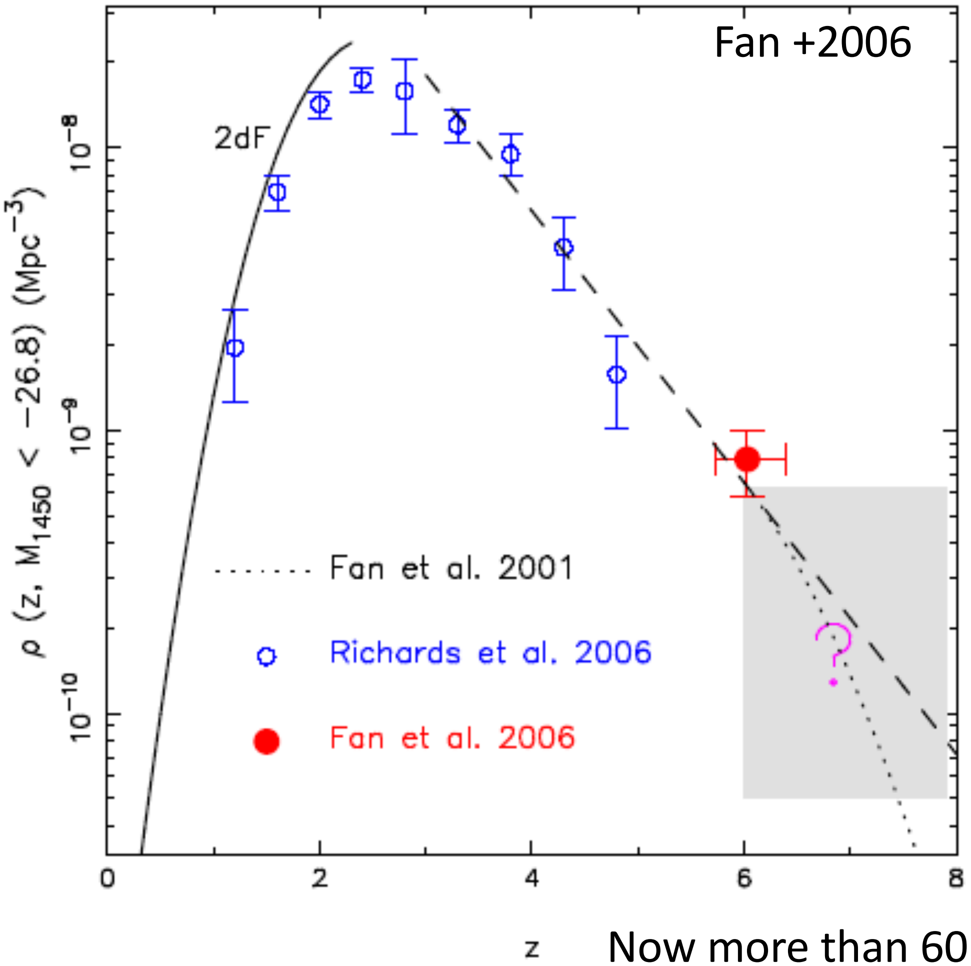
Composite QSO Spectrum (optical)



Quasars & QSOs

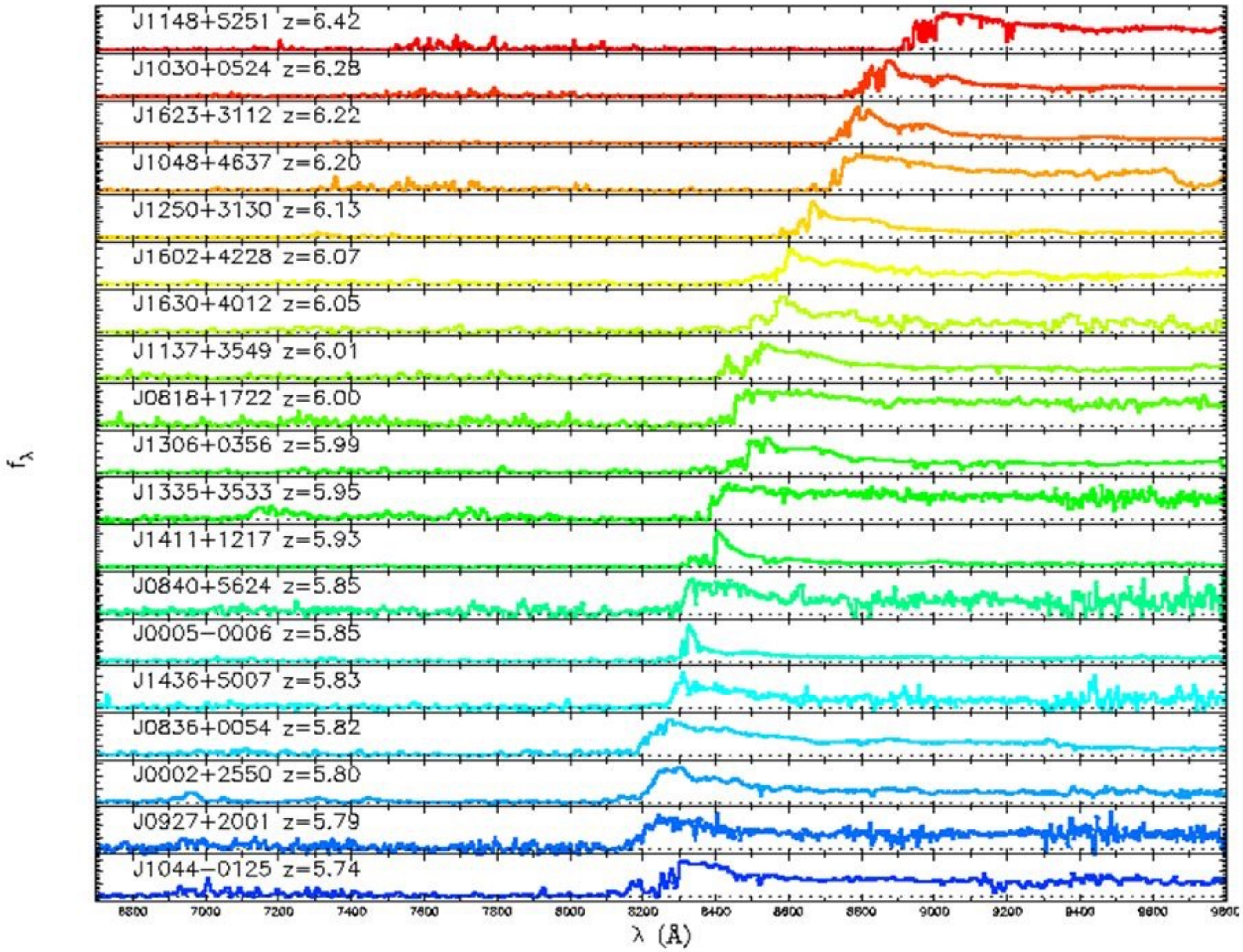
- Most are found between z = 2-4
- Coincides with "Cosmic noon"





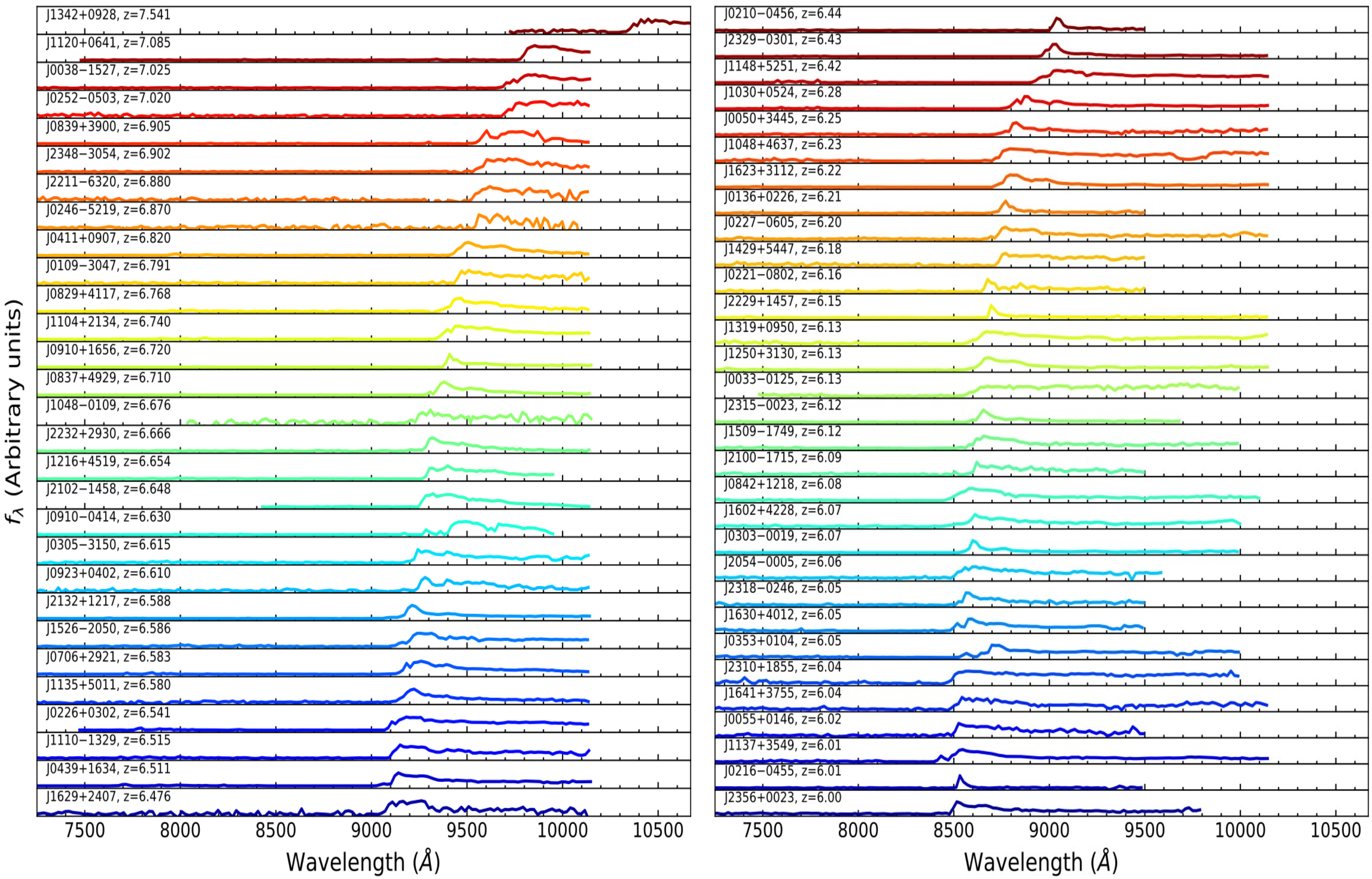
Now more than 60 at z > 5.7
Most distant z ~ 7.6

z~6 quasars: 2006



Courtesy X. Fan

Now...



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

Courtesy X. Fan

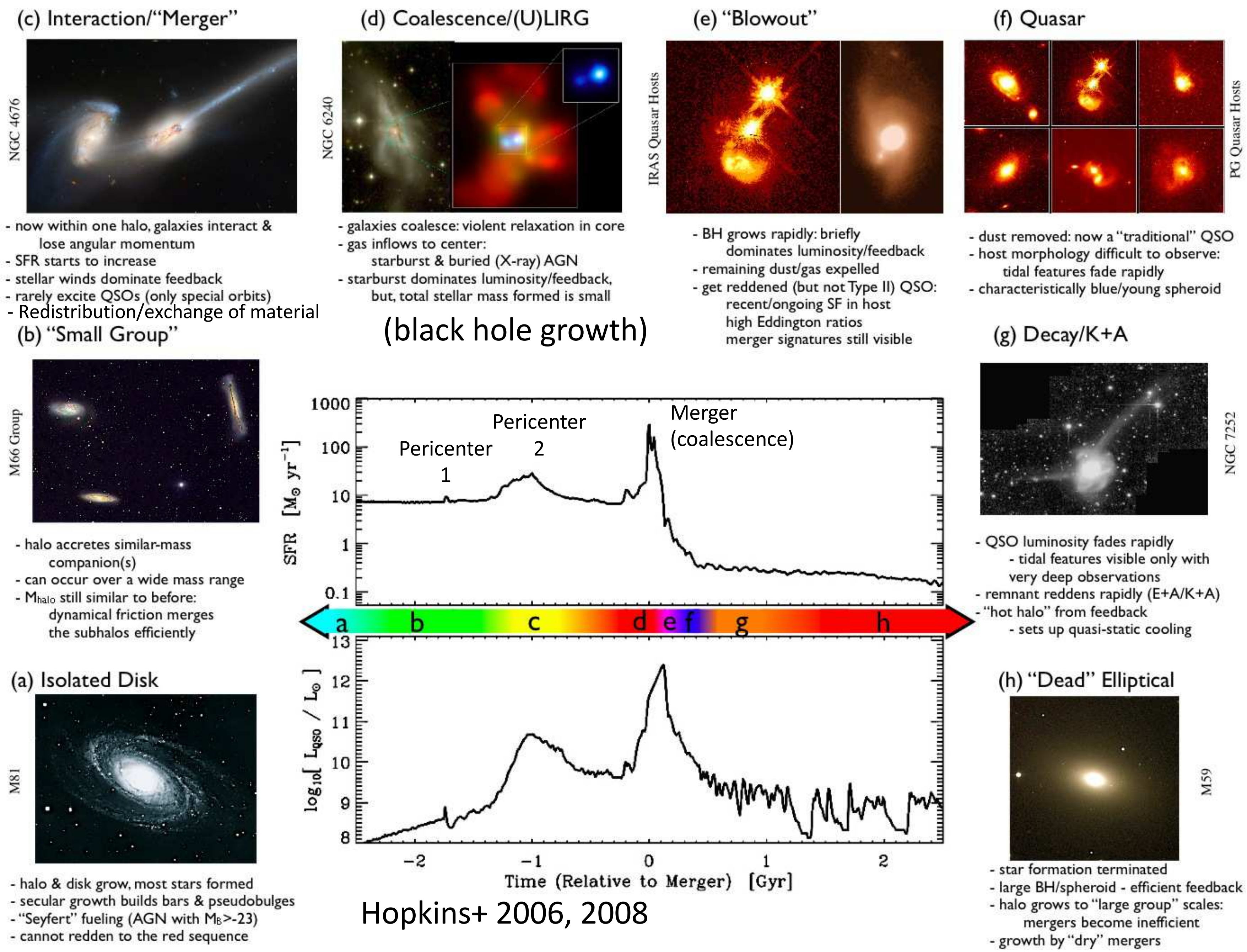
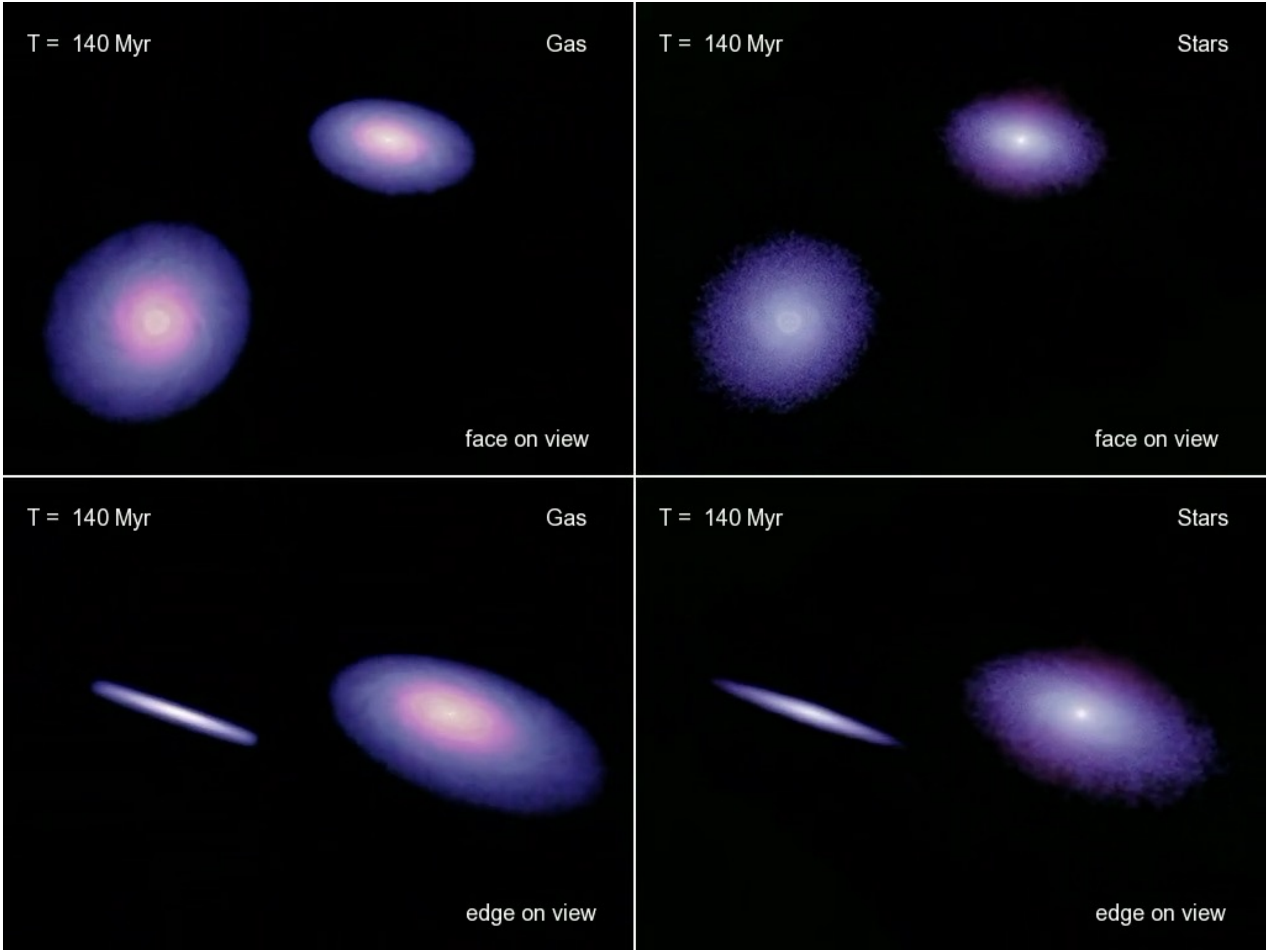
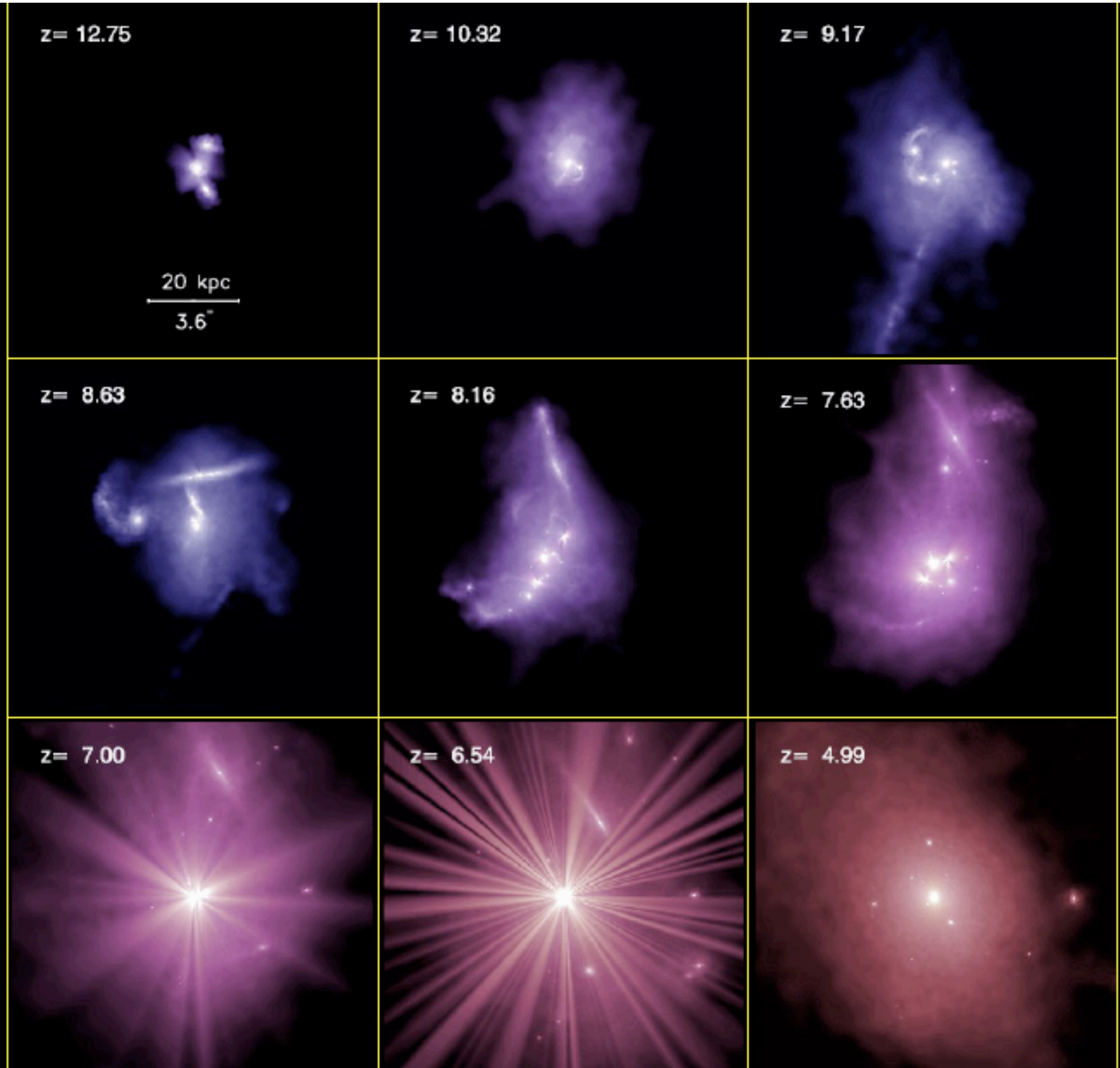


FIG. 1.— An schematic outline of the phases of growth in a "typical" galaxy undergoing a gas-rich major merger. *Image Credit:* (a) NOAO/AURA/NSF; (b) REU program/NOAO/AURA/NSF; (c) NASA/STScI/ACS Science Team; (d) Optical (left): NASA/STScI/R. P. van der Marel & J. Gerssen; X-ray (right): NASA/CXC/MPE/S. 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

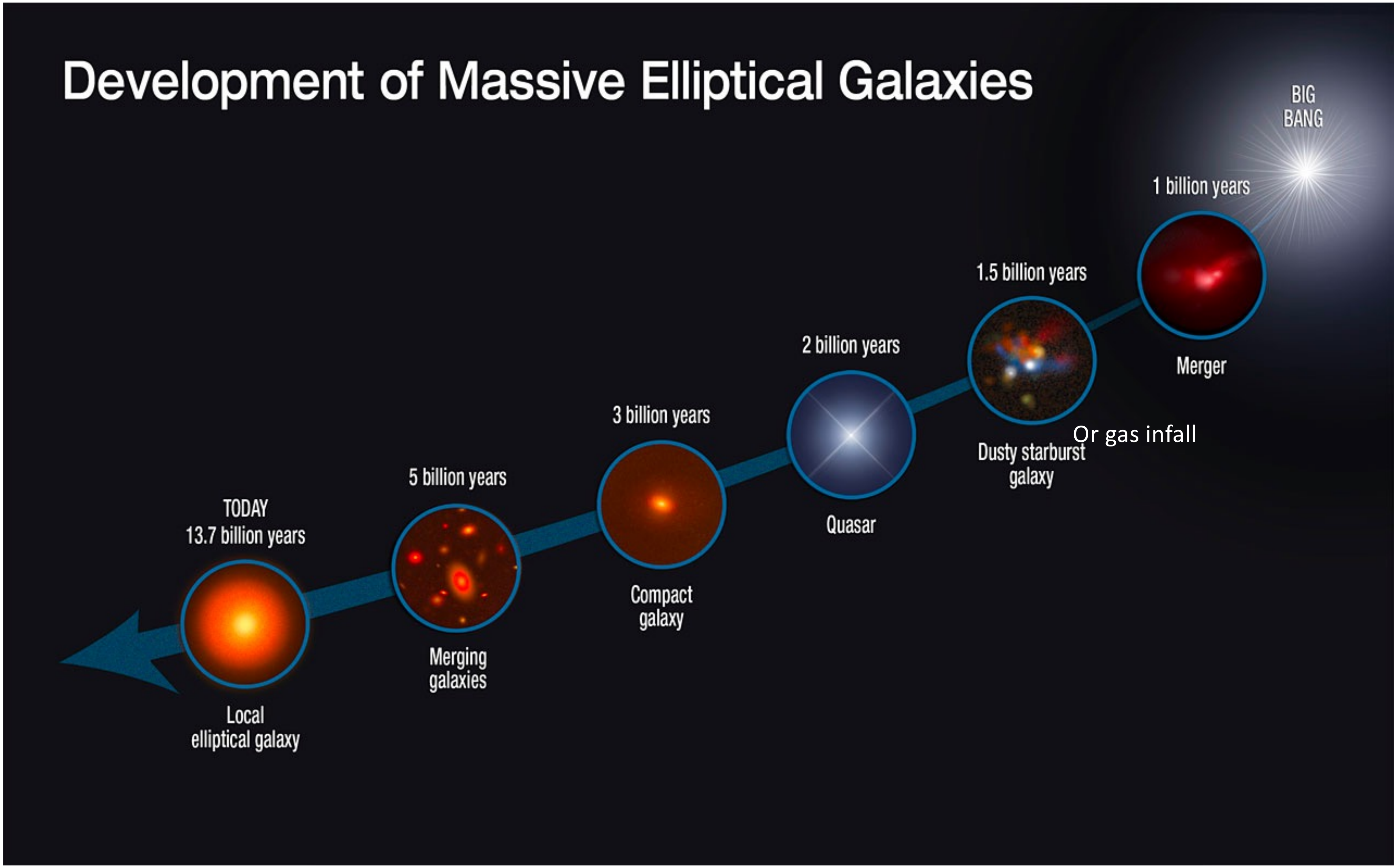
Hydro-simulation of the hierarchical build-up of an early Sloan quasar

TIME EVOLUTION OF THE PROJECTED STELLAR MASS



(slide from V. Springel)

Li et al. (2006)


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