Active Galactic Nuclei
= AGN

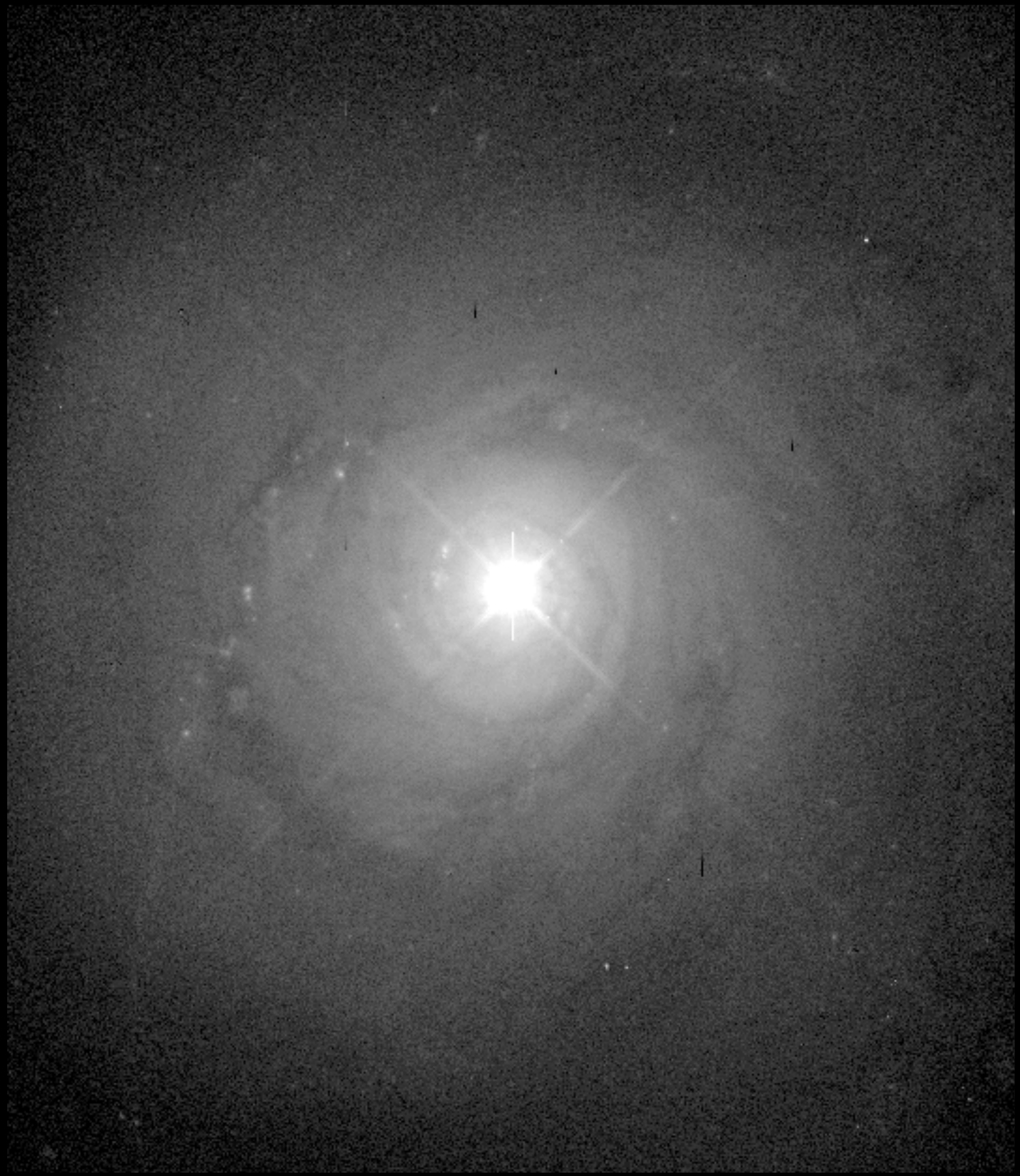
ASTRO 330, 10/29/2010

The first AGN

- 1918: M87 - Curtis observed a "curious straight ray"

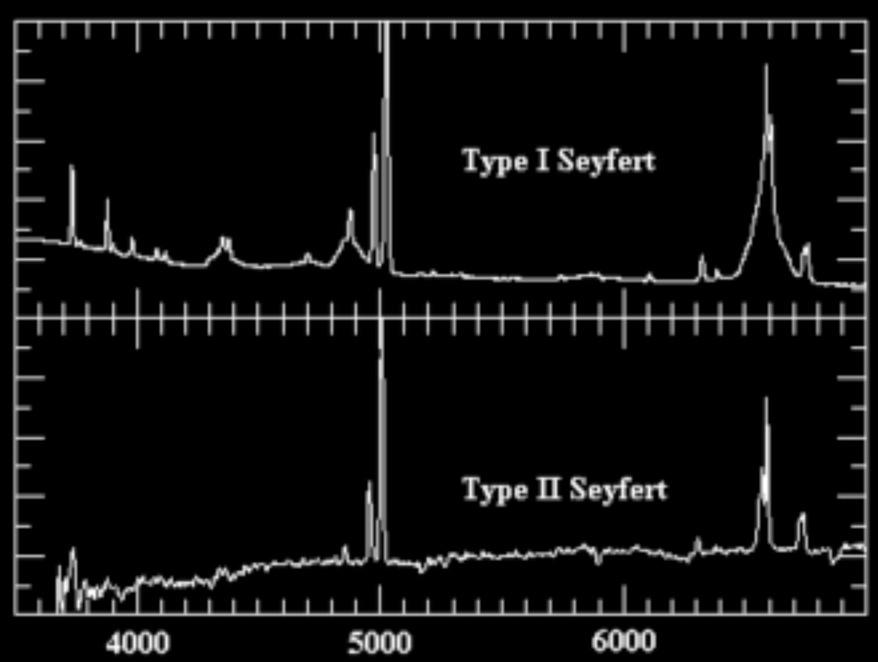
Seyferts

- 1940's: Seyfert galaxies
  - ⋆ Extremely bright nucleus



Seyferts

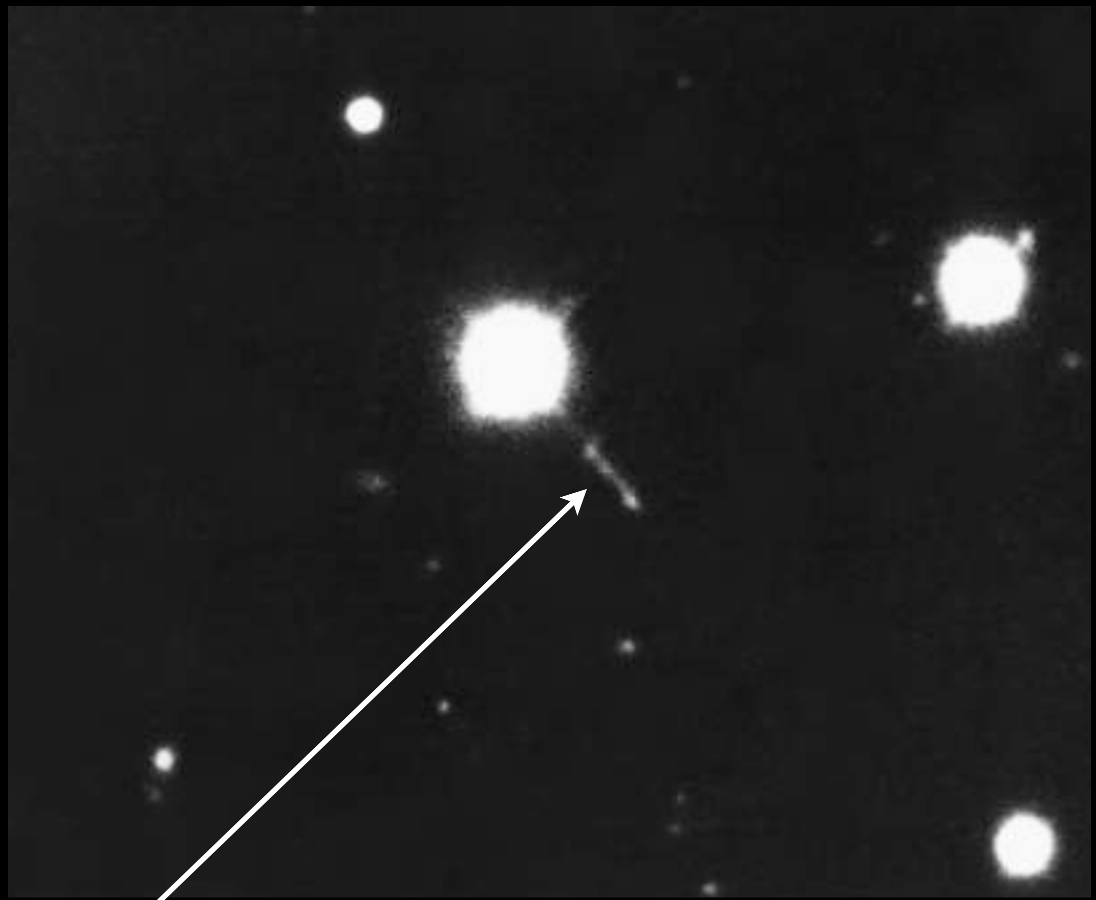
- 1940's: Seyfert galaxies
  - ⋆ Extremely bright nucleus ("Active Galactic Nucleus")
  - ⋆ Strong interstellar emission lines from nucleus
    - ✳ Sometimes very broad (500-3000 km/s) ➛ Type 1
    - ✳ Sometimes narrow ➛ Type 2



Observed wavelength [Å]

Quasars

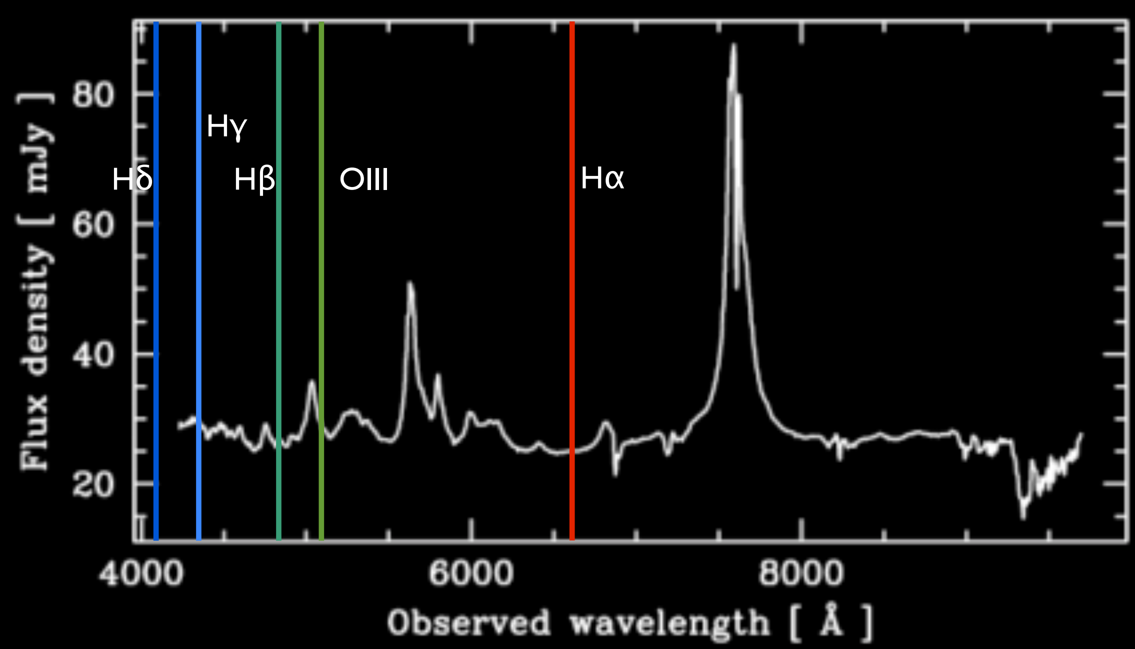
- 1950's: Radio telescopes discover bright objects
- Schmidt, 1962: optical counterpart to radio source 3C273
  - ⋆ Point-like (quasi-stellar)



Hey, look: Another "curious ray"!

Quasars

- 1950's: Radio telescopes discover bright objects
- Schmidt, 1962: optical counterpart to radio source 3C273
  - ⋆ Point-like (quasi-stellar)
  - ⋆ Bright, extremely broad emission lines



red-shift: z=0.158

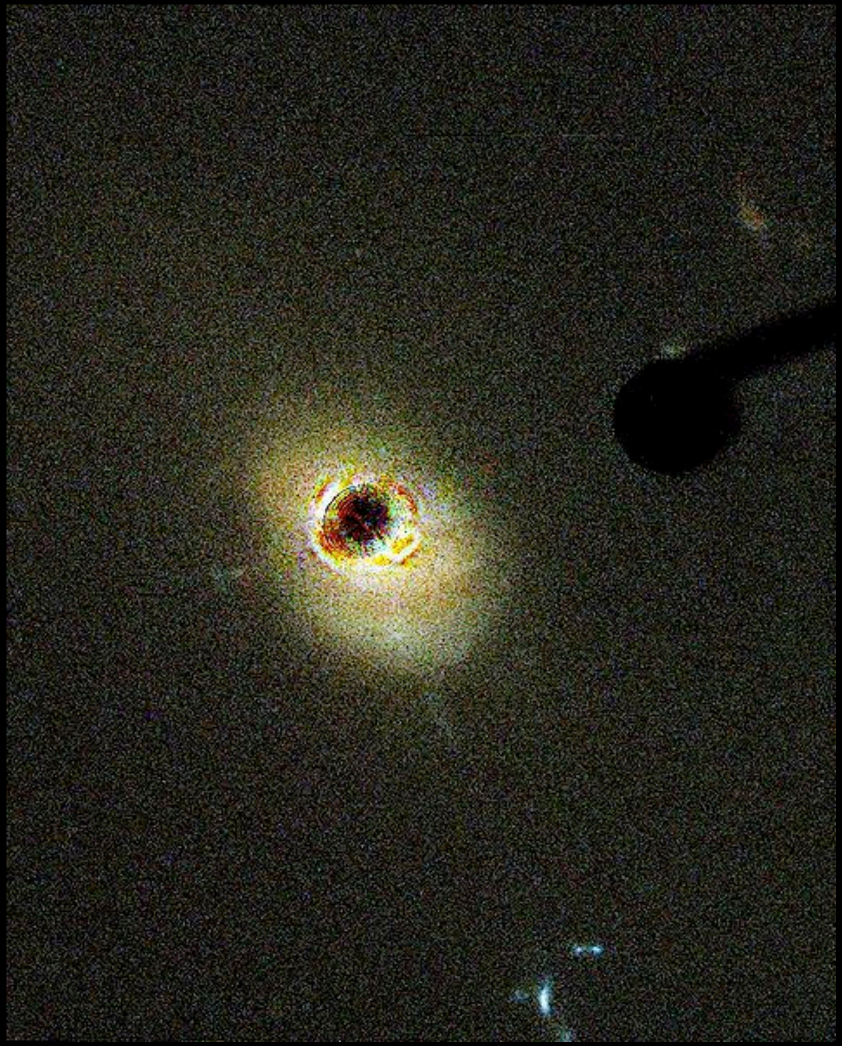
Quasars

- 1950's: Radio telescopes discover bright objects
- Schmidt, 1962: optical counterpart to radio source 3C273
  - ⋆ Point-like (quasi-stellar)
  - ⋆ Bright, extremely broad emission lines
  - ⋆ Red-shift: 0.158
  - ⋆ "Quasi-stellar radio source" = Quasar
- At luminosity distance of 750 Mpc:
  - ⋆ $L_{3C273} \sim 4 \times 10^{46}$ ergs s^{-1}

compare: $L^{*} = 8 \times 10^{43}$ ergs s^{-1}

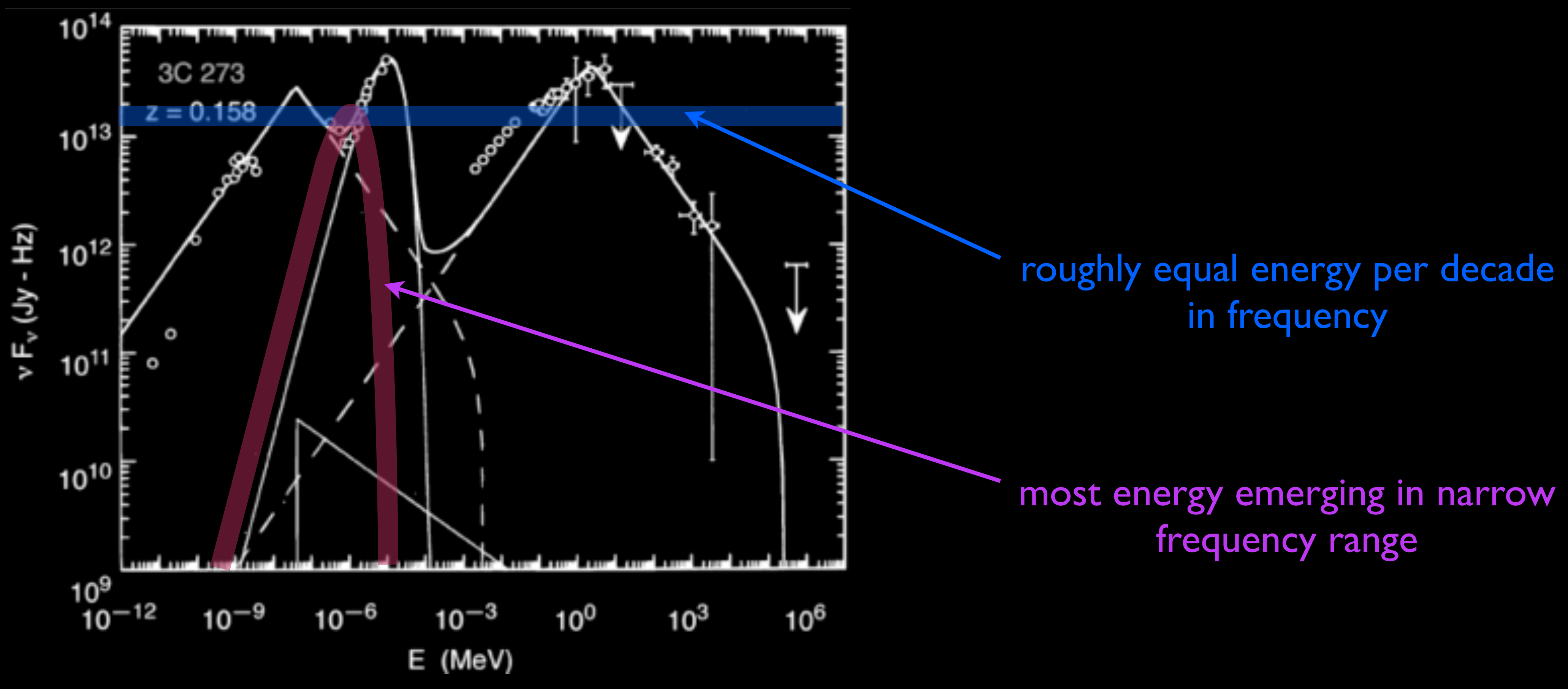
Quasars

- 1950's: Radio telescopes discover bright objects
- Schmidt, 1962: optical counterpart to radio source 3C273
  - ⋆ Point-like (quasi-stellar)
  - ⋆ HST: There is a *galaxy* underneath quasar PSF!
  - ⋆ Quasars *actually* at *centers* of massive galaxies



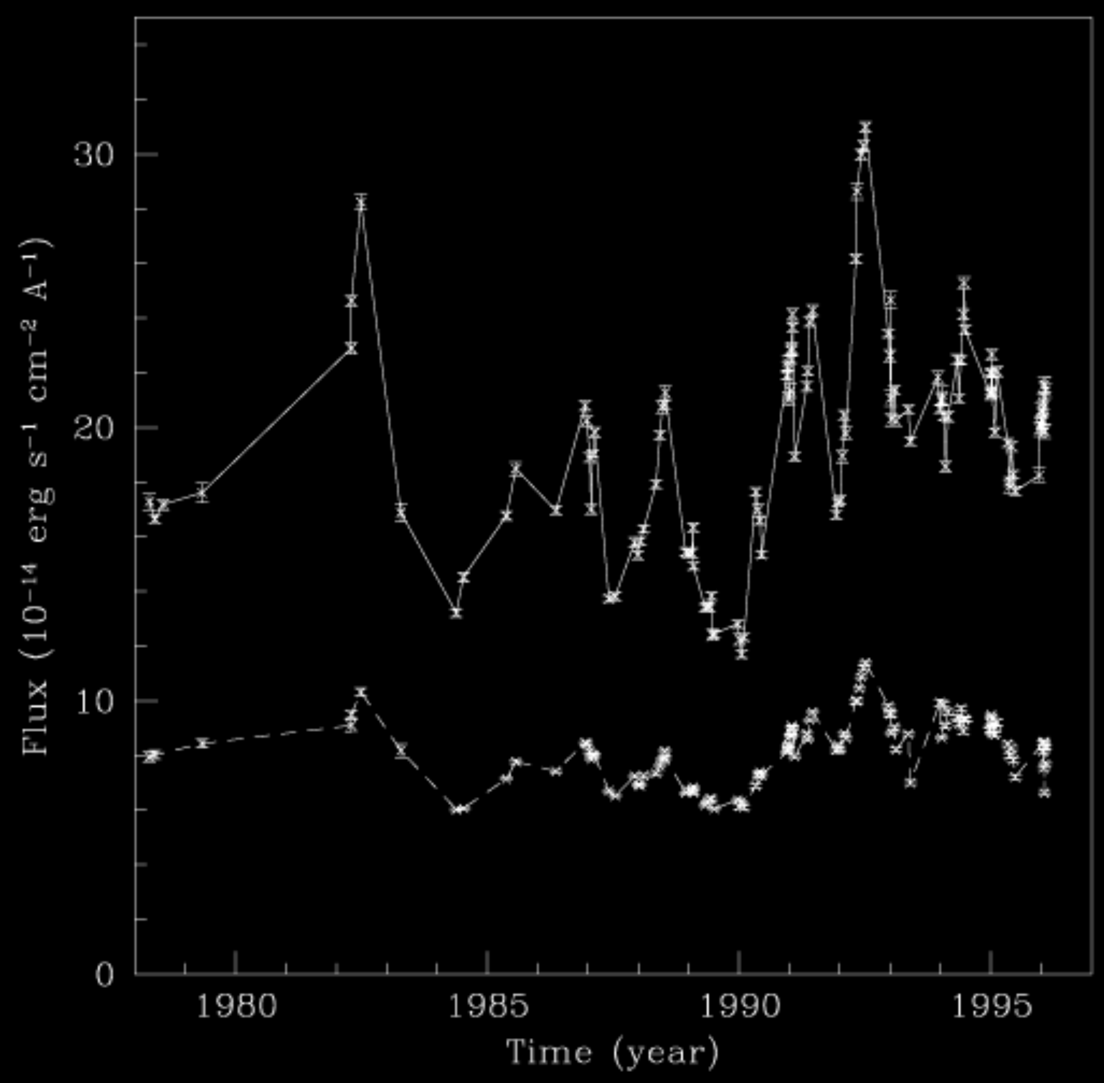
AGN Spectra

- 1970's: X-rays from basically all Seyferts and QSOs
  - ⋆ Point-like
  - ⋆ Extremely bright at all wavelengths - flat, *non-thermal* spectrum



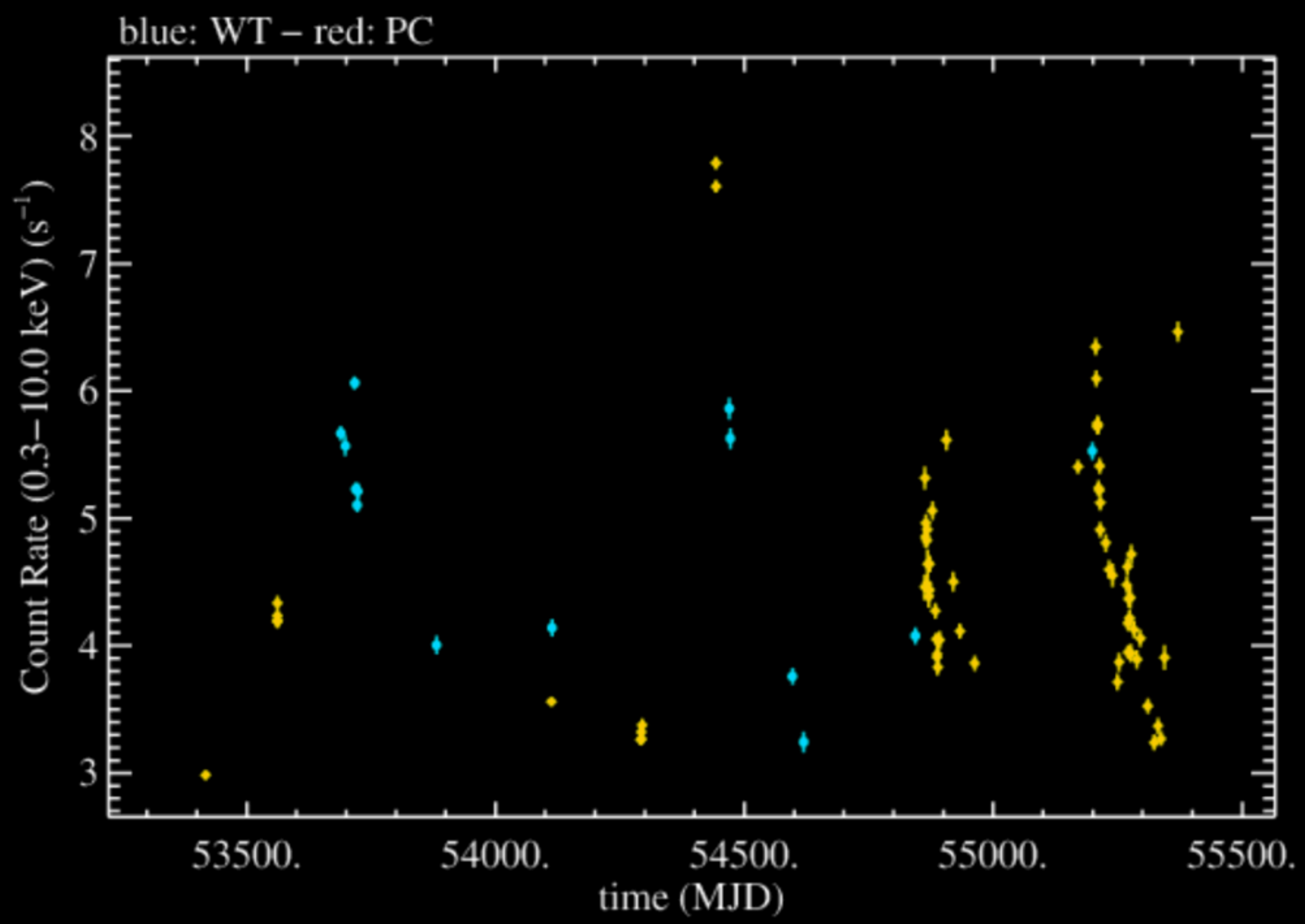
AGN Variability

- AGN are variable!
  - ⋆ Optical: 50% on time scales of < 1 yr



AGN Variability

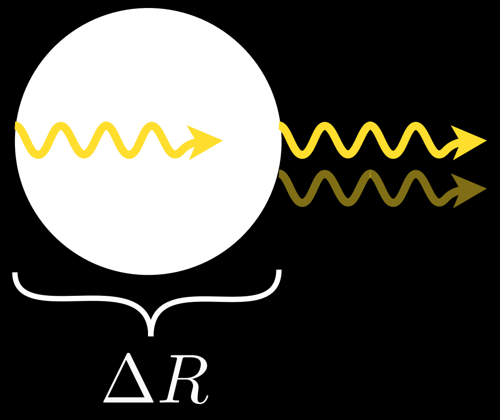
- AGN are variable!
  - ⋆ X-ray: >100% on time scales of < 1 day!



What is an AGN?

What is an AGN?

- What could the size scale ΔR of an AGN be?
  - ⋆ Variability on time scale $\Delta\tau$
- Causality:
  - ⋆ Object *must* change brightness in less than $\Delta\tau$
  - ⋆ But: light travel delay front to back:



$$\Delta t \approx \Delta R/c \; < \; \Delta\tau$$

$$\Rightarrow \quad \Delta R < c\,\Delta\tau$$

What is an AGN?

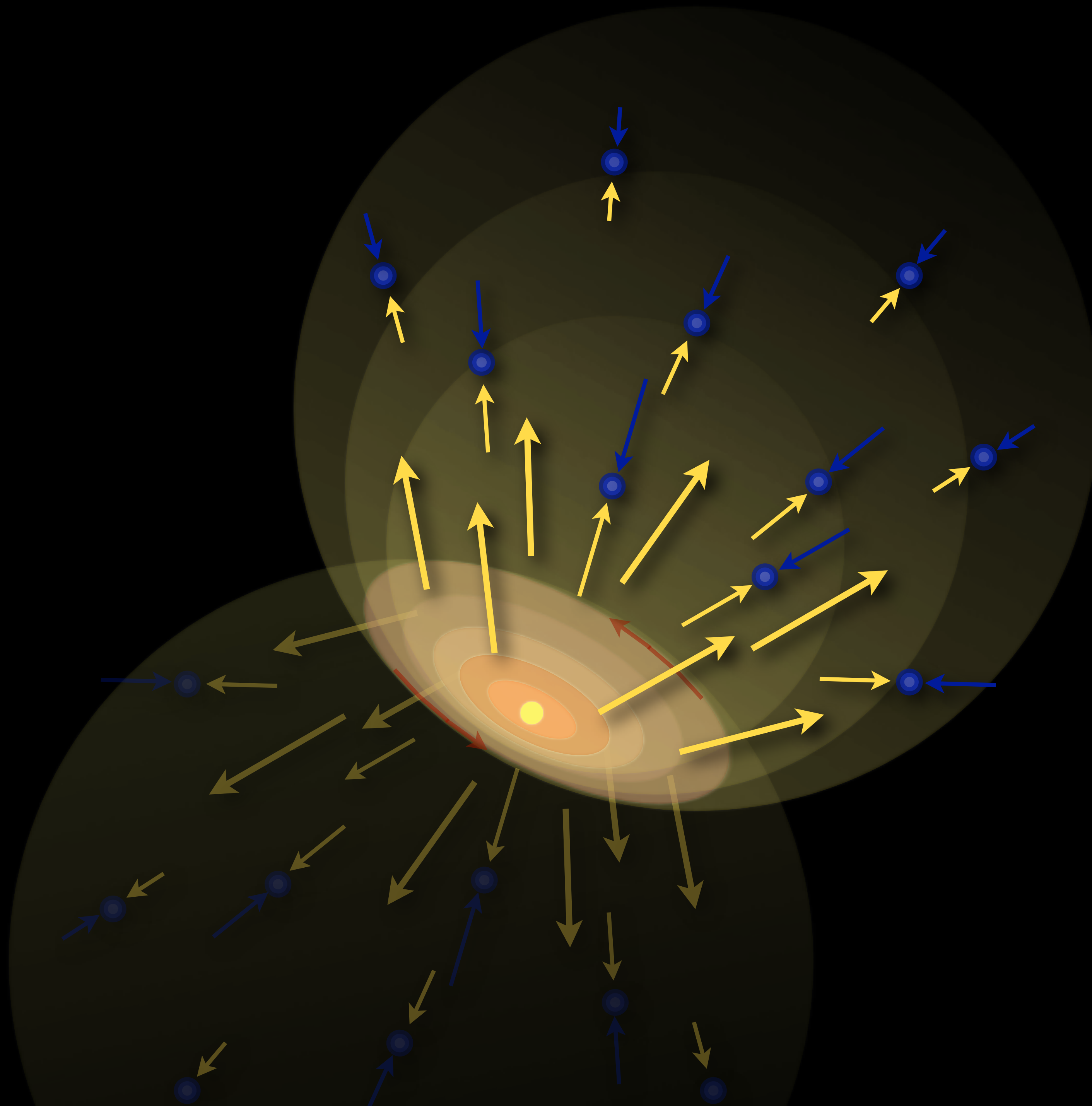
- What could the size scale ΔR of an AGN be?
  - ⋆ Causality: $\Delta R < c\Delta\tau$
- E.g.: 3C273
  - ⋆ X-ray variability ~ hours

  ⇒ Nucleus concentrated to less than $\Delta R < 6\ \mathrm{AU}$

  ⇒ 10 trillion solar luminosities coming from within 6 AU

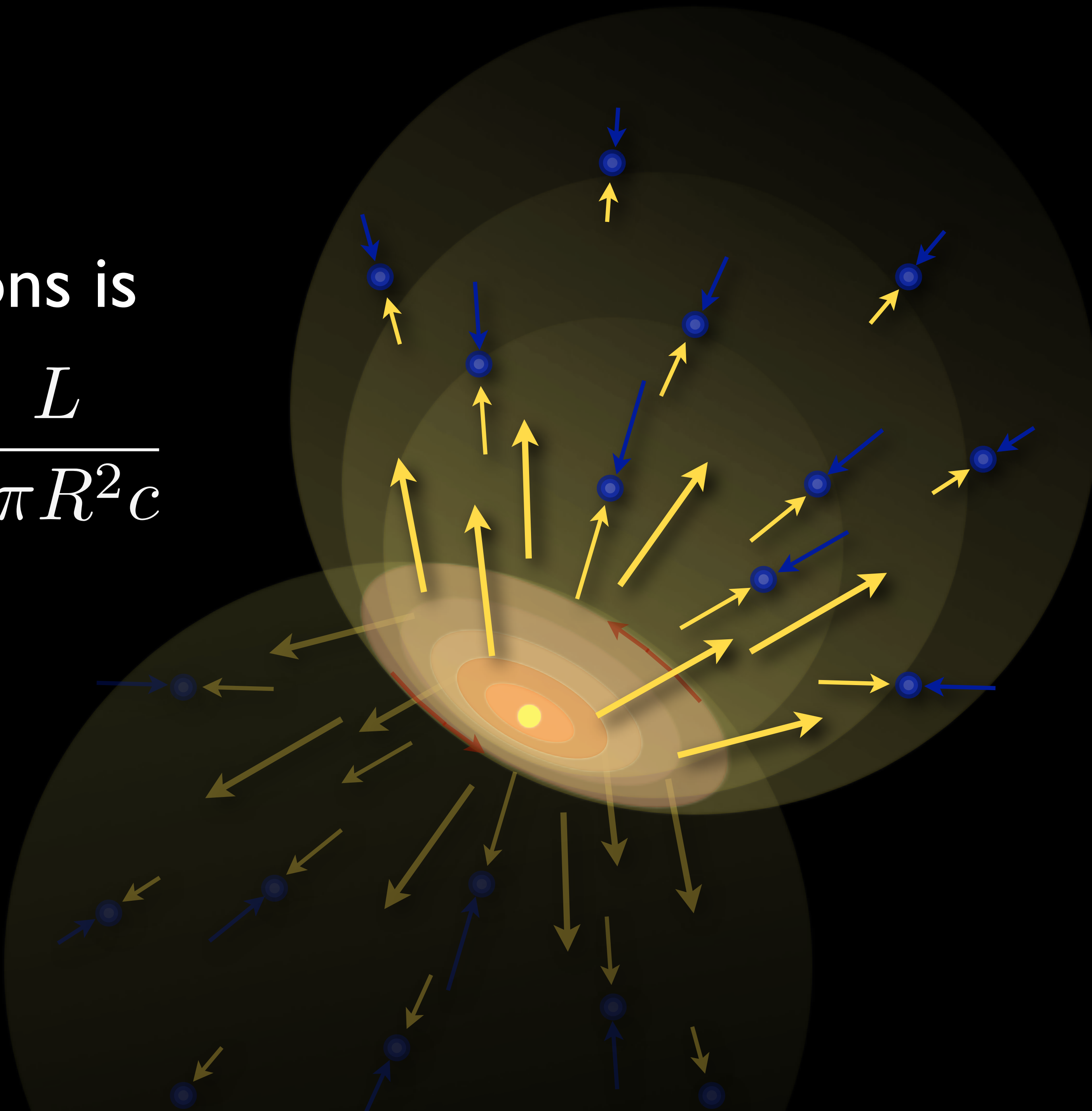
The Eddington Limit

- Any radiation source has outward radiation pressure:



The Eddington Limit

- Any radiation source has outward radiation pressure:
  - ★ $$p_{\rm rad} = \frac{L}{4\pi R^2 c}$$
- Outward force on electrons is
  - ★ $$F_{\rm rad} = \sigma_{\rm T} p_{\rm rad} = \sigma_{\rm T} \frac{L}{4\pi R^2 c}$$



The Eddington Limit

- Any radiation source has outward radiation pressure:
  - ⋆ $$p_{\rm rad} = \frac{L}{4\pi R^2 c}$$
- Outward force on electrons is
  - ⋆ $$F_{\rm rad} = \sigma_{\rm T} p_{\rm rad} = \sigma_{\rm T} \frac{L}{4\pi R^2 c}$$
- Need an inward force to keep object from flying apart
- Suppose object has mass M:
  - ⋆ $$F_{\rm in} = \frac{GMm}{R^2}$$

The Eddington Limit

- We have ~ 1 proton per electron, so

$$F_{\rm in} = \frac{GMm_{\rm p}}{R^2} \qquad\qquad F_{\rm out} = \frac{\sigma_{\rm T} L}{4\pi R^2 c}$$

- When $F_{\rm out}$ > $F_{\rm in}$ object no longer bound

⇒ Upper limit on Luminosity of an object of mass M:

  ⋆ $L < L_{\rm Edd} \equiv \frac{4\pi c G M m_{\rm p}}{\sigma_{\rm T}} = 1.3 \times 10^{38}\,{\rm ergs\,s^{-1}}\,\frac{M}{M_\odot}$

  ⋆ This is the "Eddington limit"

And the answer is...

- 3C273 hasn't exploded in the past 50 years, so:
  - ⋆ $L = 4 \times 10^{46}\,\mathrm{ergs\,s^{-1}} < L_{\mathrm{Edd}}$
  - ⋆ $M > 3 \times 10^{8}\,M_{\odot}$
  - ⋆ $R_{\mathrm{3C273}} < 6\,\mathrm{AU}$

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  - ⋆ $R_{3C273} < 6\,\mathrm{AU}$
- Recall the Schwarzschild radius of a black hole:
  - ⋆ $R_{\mathrm{S}} = \dfrac{2GM}{c^2} = 3 \times 10^{5}\,\mathrm{cm}\dfrac{M}{M_{\odot}} = 6\,\mathrm{AU}\dfrac{M}{3 \times 10^{8}\,M_{\odot}}$

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$\Rightarrow$ 3C273 *must* be a black hole!

How do AGN shine?

How do AGN shine?

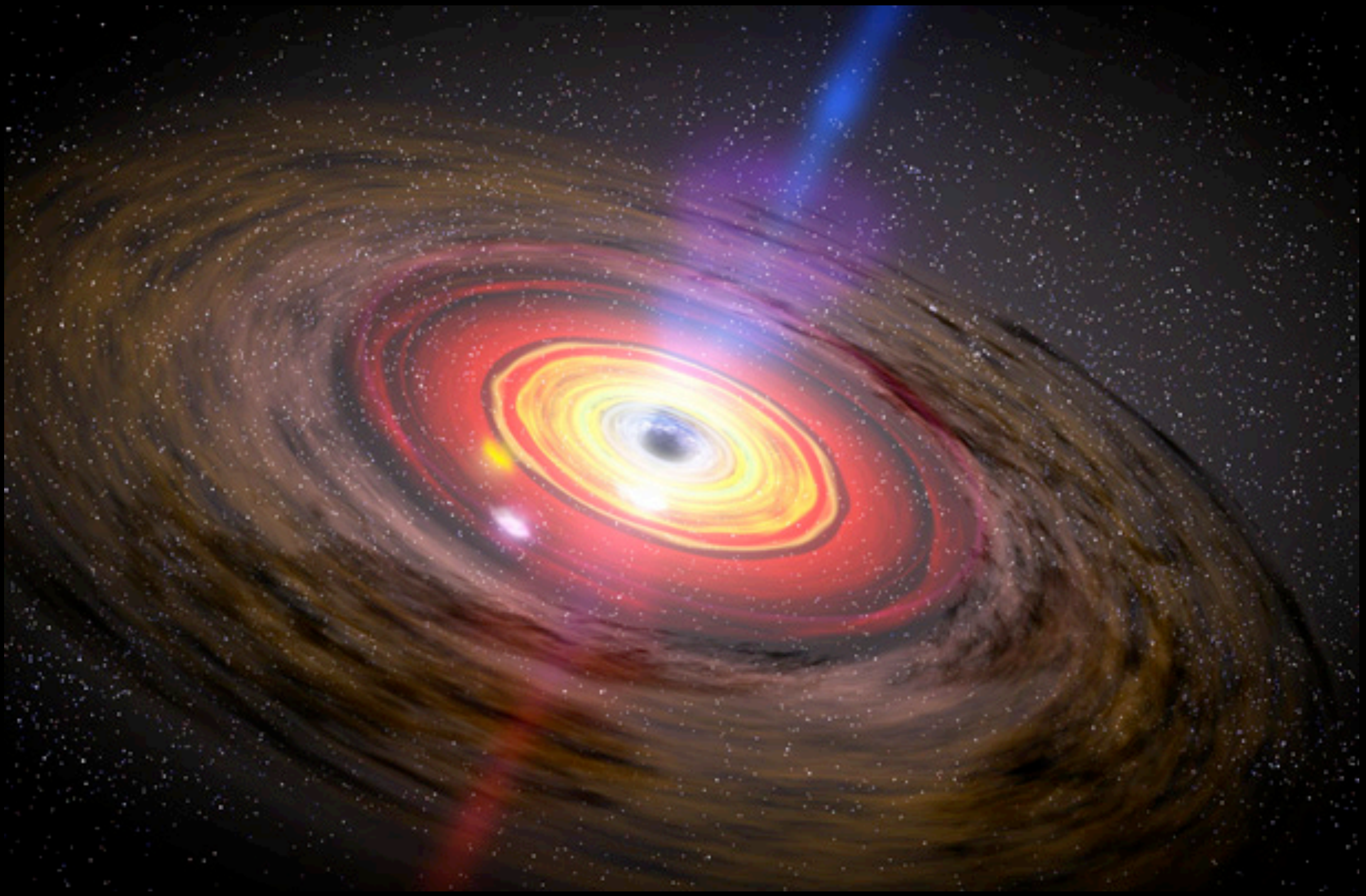
- AGNs shine by ***accretion***:
  - ⋆ Throw mass into a black hole...
  - ⋆ ...get up to 10% of rest mass energy back out
  - ⋆ 100 x more efficient than nuclear fusion
  - ⋆ Black hole powered car would get ~ 10^{10} miles per gallon!

How do AGN shine?

- How does accretion work?
  - ⋆ Angular mom. conservation forces matter onto Kepler orbits
  - ⋆ Inner orbits move faster ➛ friction!
  - ⋆ Angular momentum transported outward
  - ⋆ Grav. pot. energy liberated ➛ radiation!

How do AGN shine?

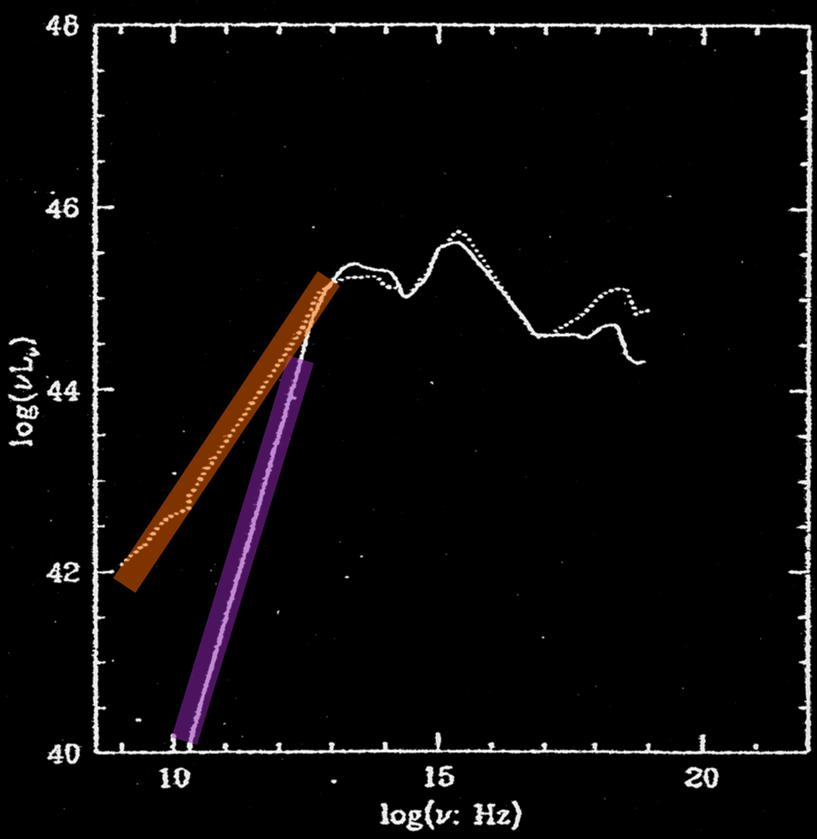
- Artist's impression:



Radio galaxies & jets

Radio galaxies & jets

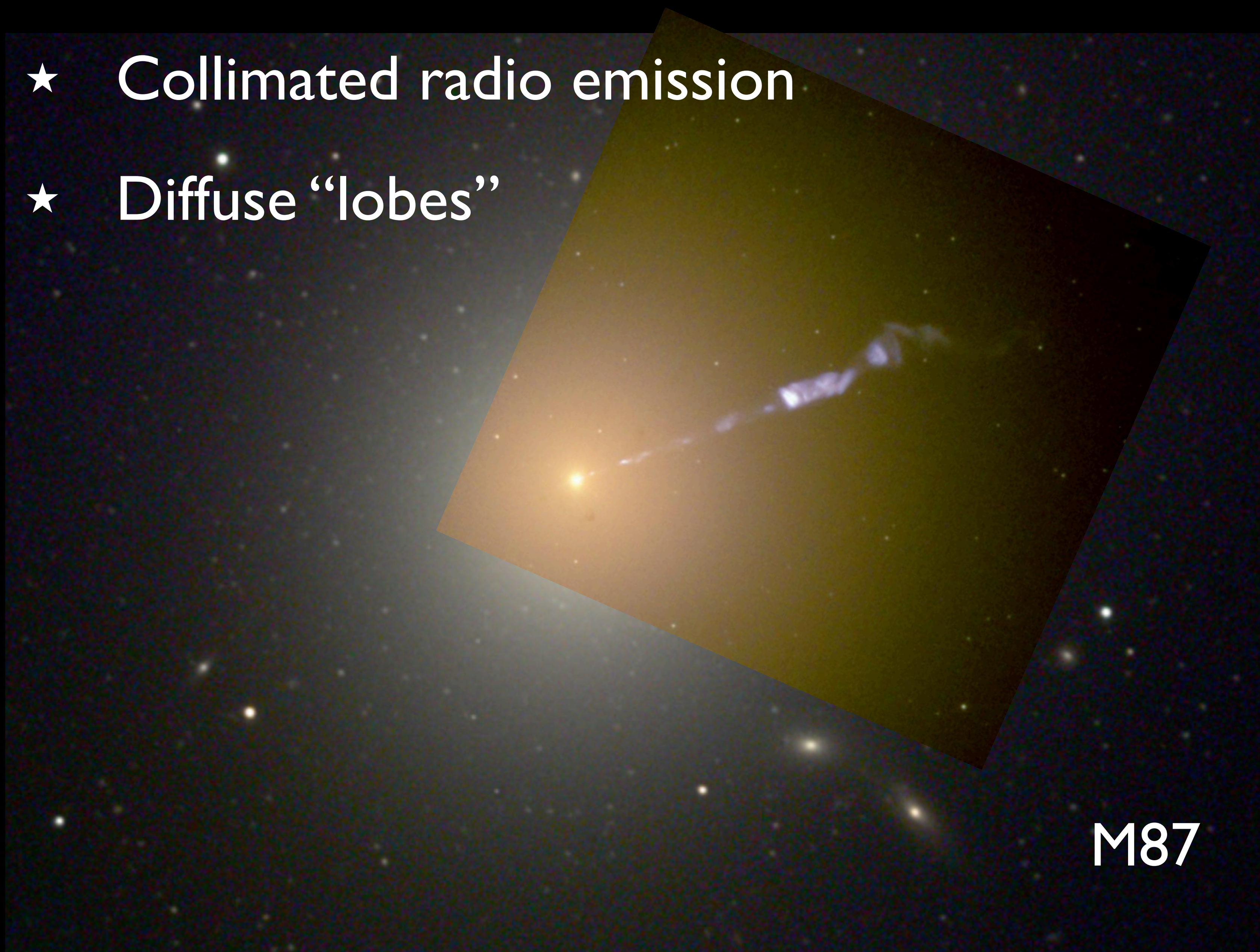
- Some AGN have much brighter radio emission than the average AGN
  - ⋆ "Radio loud" AGN
  - ⋆ About 10% of bright AGN are radio loud, 90% radio quiet



composite AGN spectra (Elvis et al. '94)

Radio galaxies & jets

- Radio emission:
  - ⋆ Often resolved - not point-like
  - ⋆ Collimated radio emission
  - ⋆ Diffuse “lobes”



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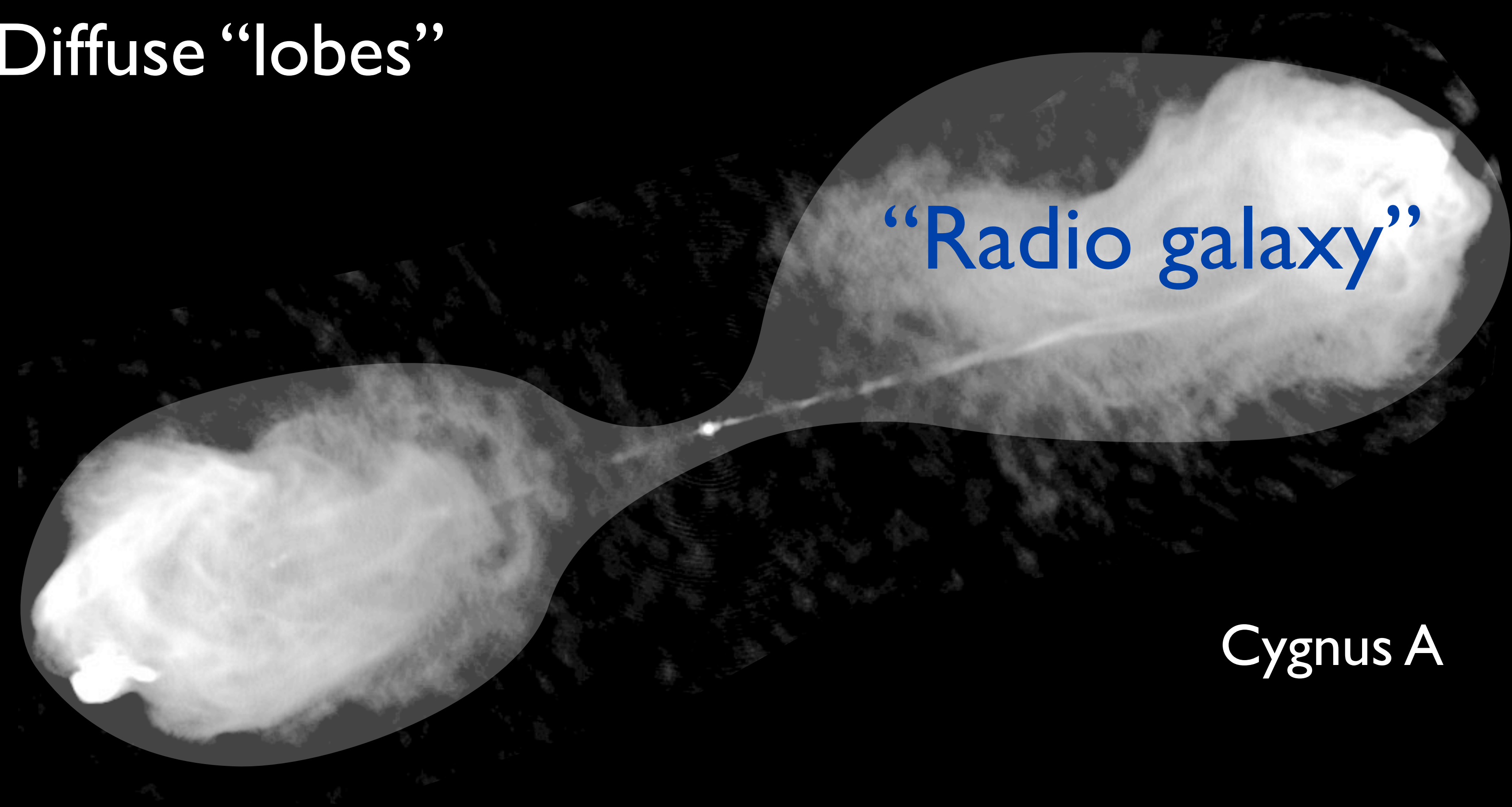
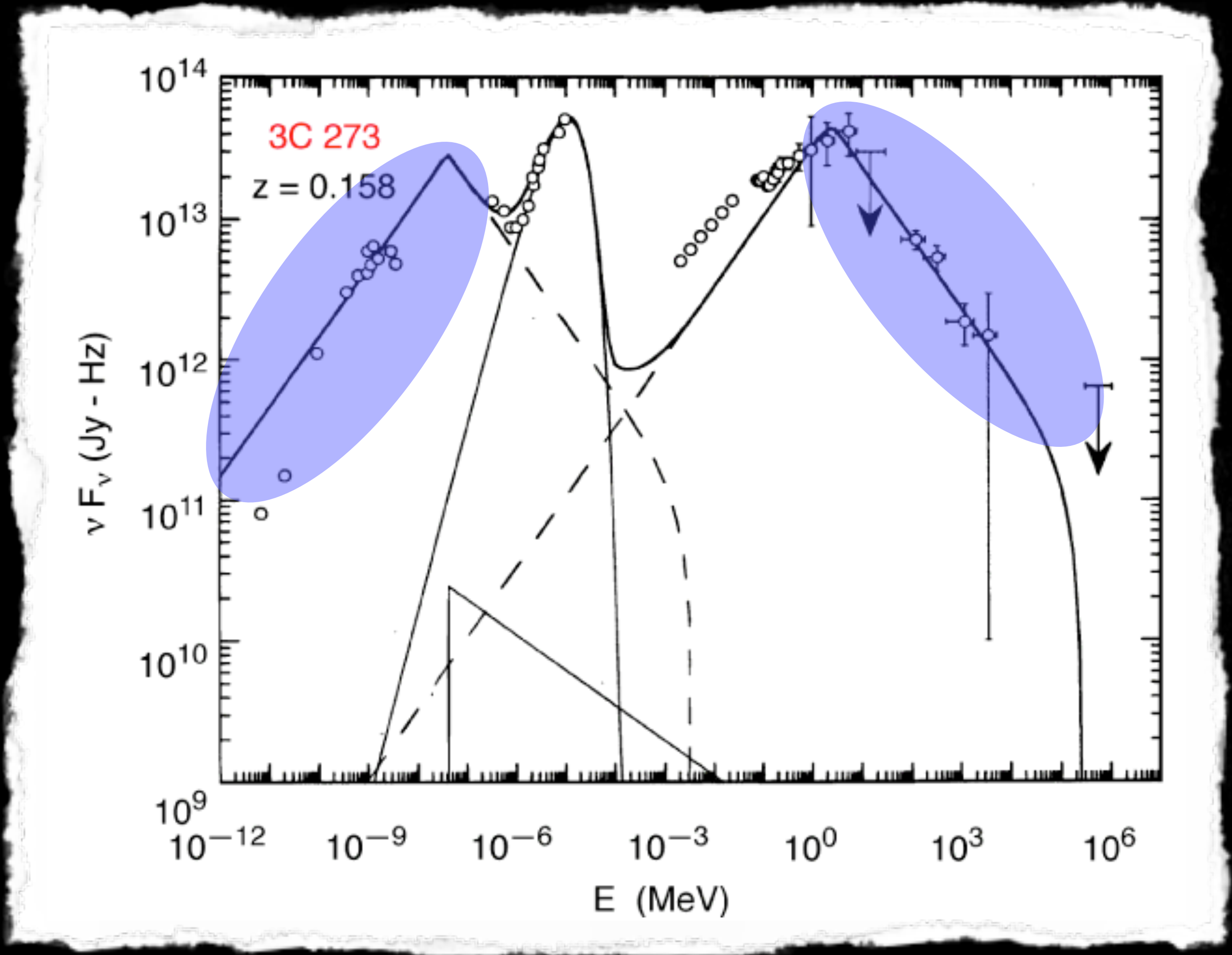


Cygnus A

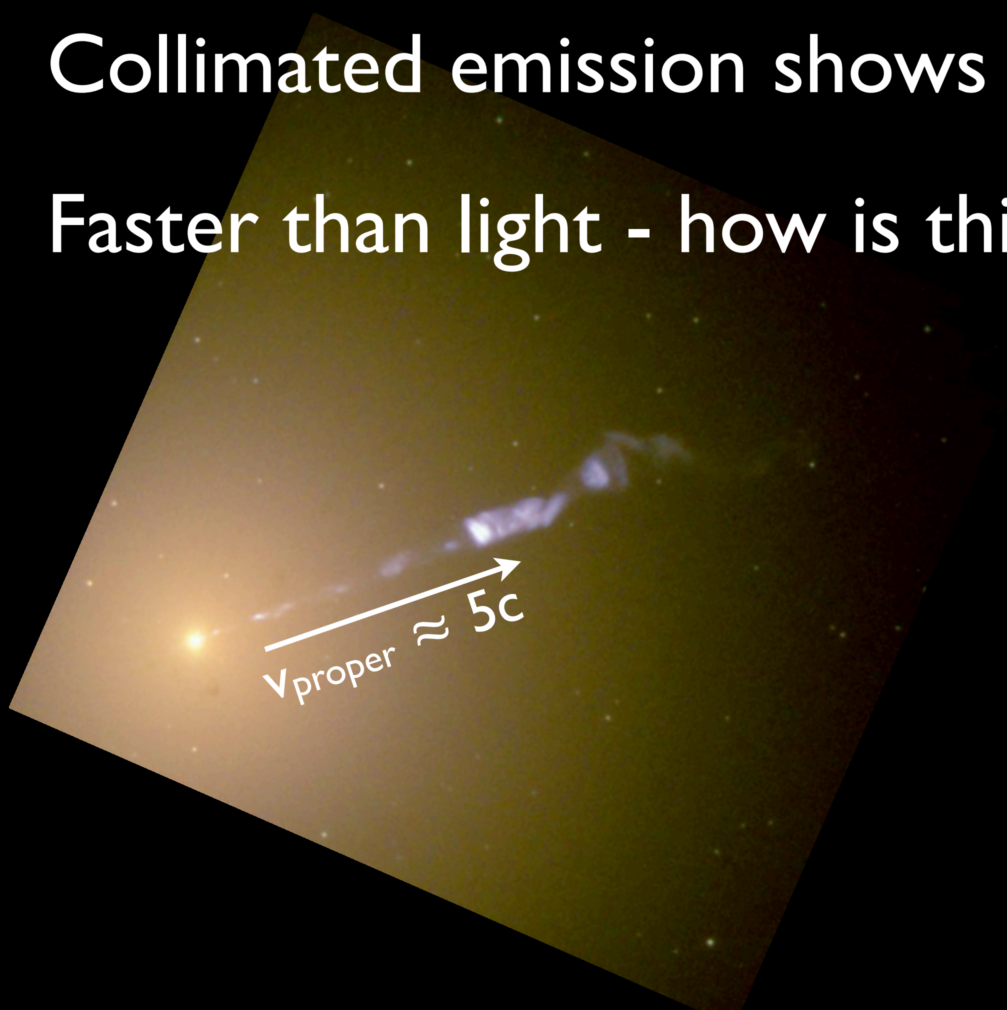
Radio galaxies & jets

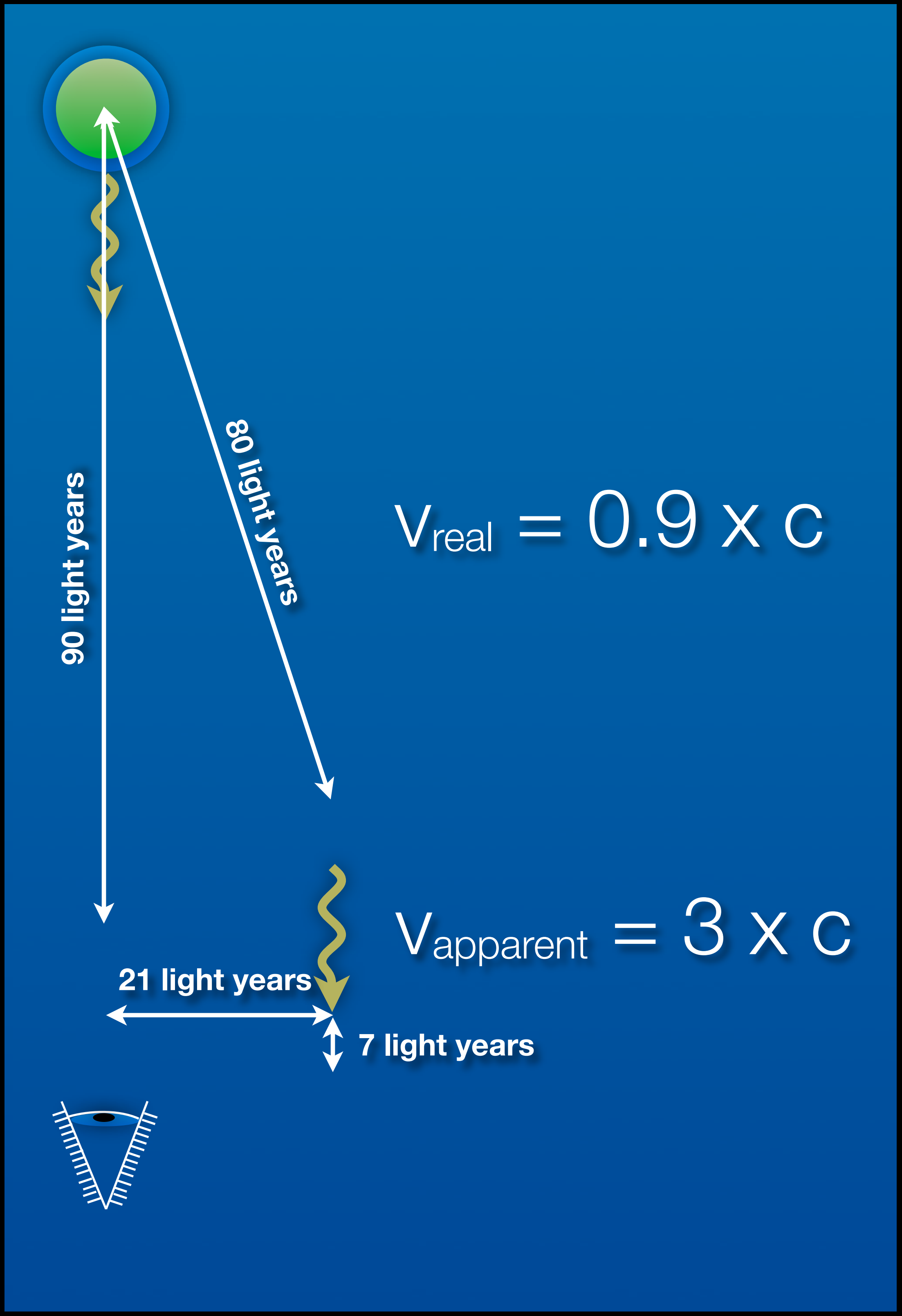
- Radio emission:
  - ⋆ Highly polarized
  - ⋆ Non-thermal powerlaw spectra
  - ⇒ Synchrotron radiation
    - ✳ relativistic electrons
    - ✳ spiraling around B-field
  - ⋆ Responsible for
    - ✳ radio emission
    - ✳ gamma-ray emission



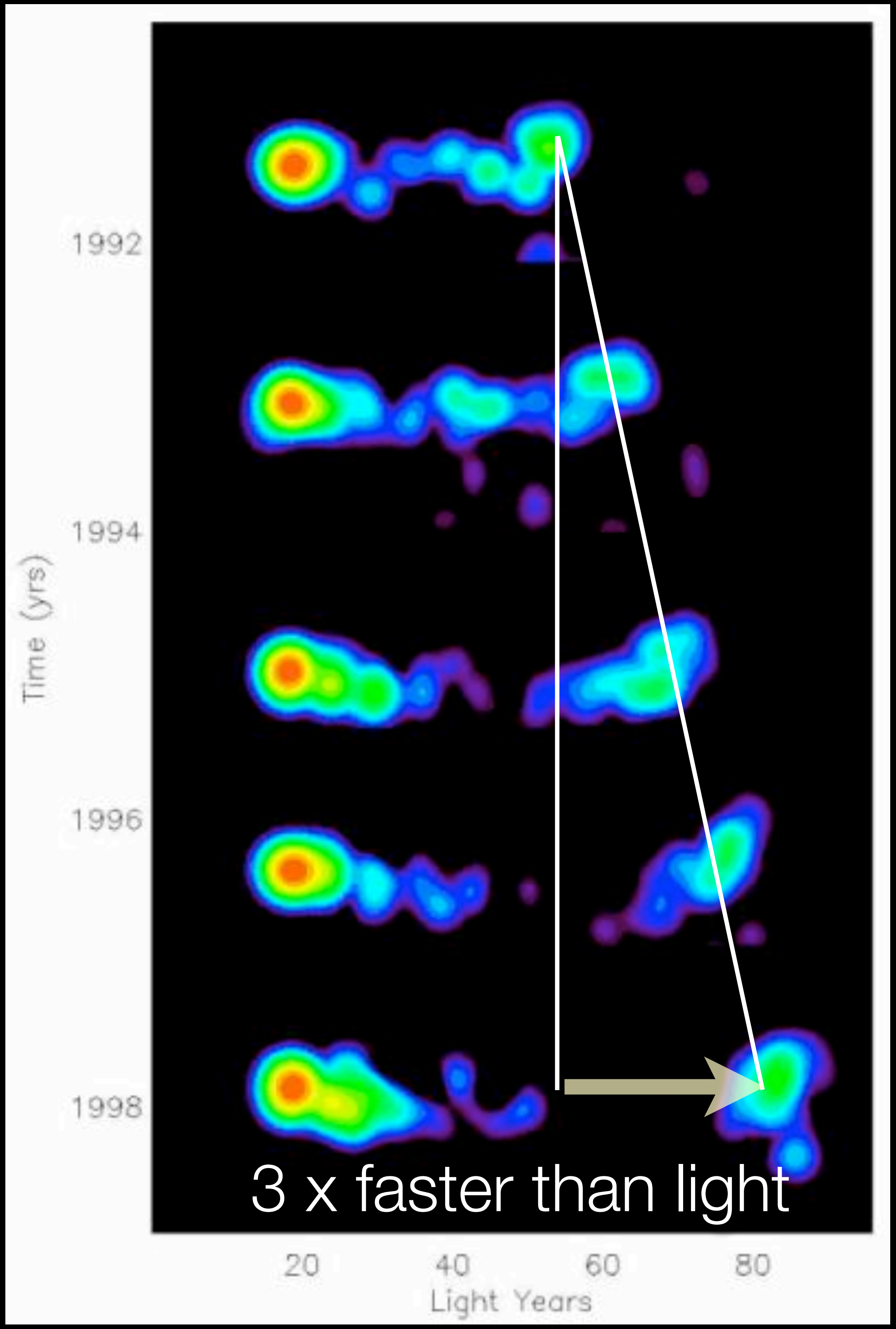
Radio galaxies & jets

- Opening angle of collimated emission < 10°
  - ⋆ "Jets" of plasma
- HST + VLBA:
  - ⋆ Collimated emission shows *proper motion*
  - ⋆ Faster than light - how is this possible?



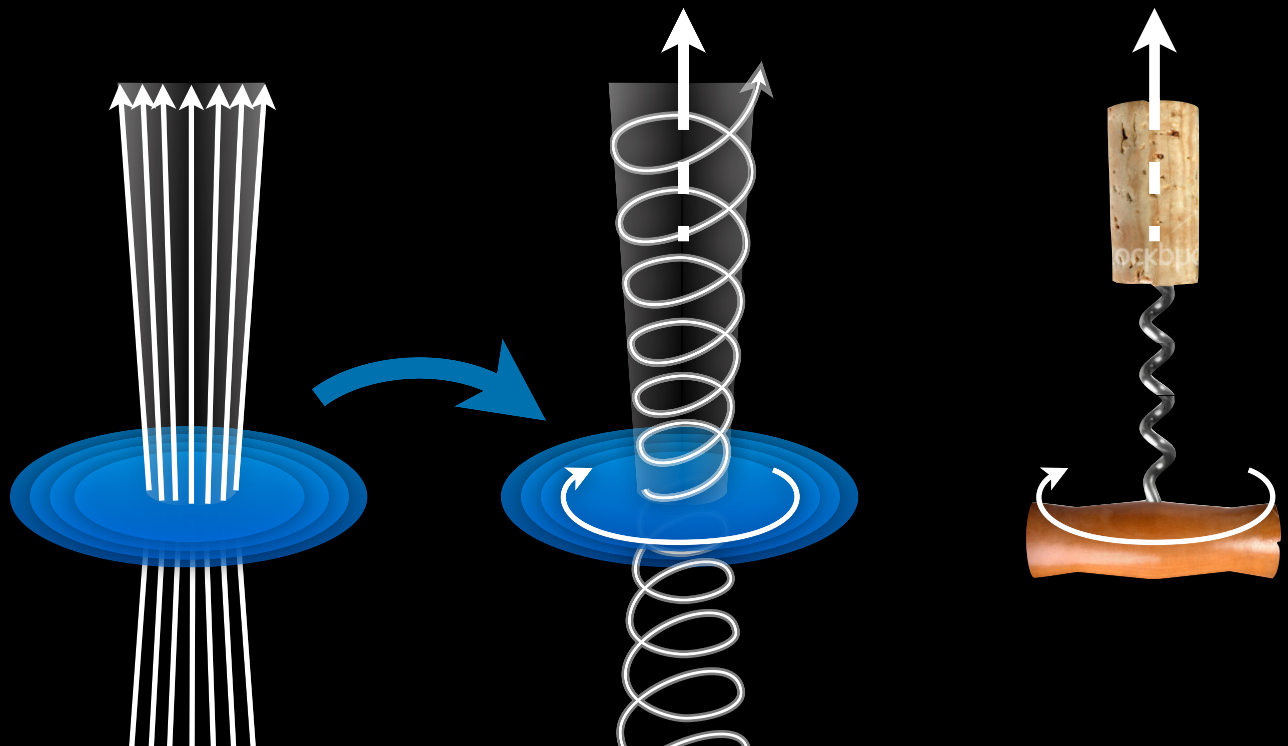


3C 279: Wehrle et al. / NRAO



Relativistic jets

- If black holes are supposed to swallow everything, how come they shoot out streams of relativistic gas?
  - ★ Accretion?
  - ★ Black hole spin?
- In either case, it works by winding up magnetic field lines:



AGN unification

AGN unification

- Observationally, there's a zoo of AGN:

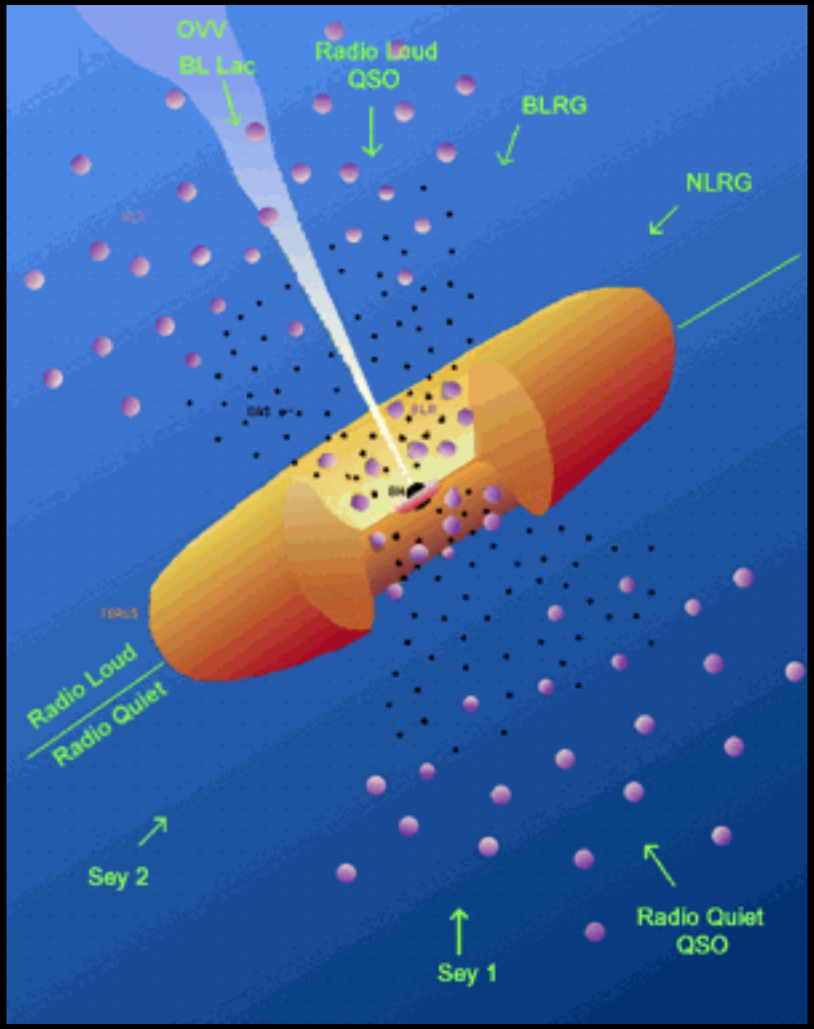
Class	Broad lines	Radio	Variable	Point-like	Polarized
Radio loud QSO	Yes	Yes	Yes	Yes	Some
Radio quite QSO	Yes	No	Weak	Yes	Weak
Broad line radio galaxy	Yes	Yes	Weak	Yes	Weak
Narrow line radio galaxy	No	Yes	No	No	No
OVV quasar	Yes	Yes	Yes	Yes	Yes
BL Lac Objects	No	Yes	Yes	Yes	Yes
Seyfert type 1	Yes	Weak	Some	Yes	Weak
Seyfert type 2	No	Weak	No	No	Some
LINERs	No	Some	No	No	No

Operational definition

- AGN are:
  - super-massive black holes...
  - ...that grow and shine through accretion

Operational definition

- Hypothesis: Differences in AGN types can be explained by
  - ★ accretion rate:
    - ✳ higher = brighter
  - ★ viewing angle:
    - ✳ edge-on: Type 2
    - ✳ face-on: Type 1
  - ★ jet:
    - ✳ present: radio loud
    - ✳ absent: radio quiet



- Note: This picture is undergoing severe revisions