VLTI Summer School

I

- Warn them about the optical/IR bias

(i) Phenomenology → just 2 images
(ii) Energy output

$SN \rightarrow 10^{51}$ erg

→ $1W = 10^7$ erg/s ←
→ $1\ yr = \pi \cdot 10^7\ s$ ←

- Accretion: $E = mc^2$

$\Rightarrow L = \dot{E} = \dot{m}c^2 \cdot \eta$

↑ conversion

$$\Longrightarrow \boxed{\dot{M}\left[\frac{M_\odot}{yr}\right] = 6 \cdot L_{45} \cdot \eta_{0.1}^{-1}}$$

- mass: Eddington: $F_{Grav} \geq F_{rp}$

$$F_G = \frac{GMm}{r^2}, \quad F_{rp} = \frac{\sigma}{c} f = \frac{\sigma L}{4\pi c r^2}$$

$$\Rightarrow \frac{GMm}{r^2} \geq \frac{\sigma L}{4\pi c r^2}$$

assume $\sigma = \sigma_T = 6.6 \cdot 10^{-29}\ m^2$

$m = m_p = 1 \cdot 10^{-27}$ kg

$$M \geq \frac{\sigma_T L}{4\pi G c m_p}$$

or $$\boxed{M \geq 8 \cdot 10^6 M_\odot \cdot \left(\frac{L}{10^{45}\ erg/s}\right)}$$

• gravitational radius = $v_K = c$

$$\frac{GMm}{r} = \frac{mc^2}{r} \Rightarrow R_G = \frac{GM}{c^2}$$

(NB: SSR = $2R_G$)

($\rightarrow$ related energy $E = -\int_{R_G}^{\infty} = \ldots = mc^2$

• emission: assume $R \simeq 1000 R_G$

$$L = \sigma_{SB} \cdot 2\pi R^2 \cdot T^4$$

$$\Rightarrow T \approx L^{1/4} \cdot \text{const.} \cdot R_G^{-1/2} \simeq L^{1/4} \cdot M^{-1/2} \cdot \left[\frac{c}{(R/R_G)^2 \cdot 2\pi \sigma_{SB}}\right]^{1/4}$$

$$\Rightarrow T(1000 R_G) \simeq 3 \cdot 10^4 K$$ i.e. peak @ 100nm $\rightarrow$ optical

$\rightarrow$ note that this is extremely simplified!

$\rightarrow$ SED

(III) AGN unification

- variety of emission characteristics
- variability
- spectra

(iv) Dusty torus

- dust local thermal equilibrium

in: $L_{in}^{\nu} = Q_{\nu abs} \cdot \pi a^2 \cdot \frac{L_{\nu}^{AGN}}{4\pi d^2} \approx \frac{L_{\nu}^{AGN}}{4} \cdot \frac{a^2}{d^2}$

($Q_{\nu abs} \cdot \pi a^2$ ↓ ≈ 1)

out: $L_{em}^{\nu} = 4\pi a^2 \cdot Q_{abs\,\nu} \cdot \pi B_{\nu}(T)$

$\int L_{in}^{\nu} d\nu \approx \frac{L_{AGN}}{4} \frac{a^2}{d^2}$

$\int L_{em} d\nu = 4\pi^2 a^2 \int Q_{abs\,\nu} B_{\nu}(T)\, d\nu = 4\pi a^2 Q_{abs,P}\, \sigma_{SB} T^4$

note that $\int B_{\nu}(T)\, d\nu = \sigma T^4$

$\frac{\int Q_{abs}^{\nu} B_{\nu}(T)\, d\nu}{\int B_{\nu}(T)\, d\nu} = Q_{abs,P}$

(Planck mean abs. efficiency)

- inner radius.

start with SB:

$L = \sigma_{SB} \cdot A \cdot T^4 = \sigma_{SB} \cdot 2\pi r^2 \cdot T^4 \times \varepsilon_s$

(↑ $\times \varepsilon_s$)

$\Rightarrow r = L^{1/2} \cdot T^{-2} \cdot \left(\frac{1}{\varepsilon_s \cdot \sigma_{SB} \cdot \pi} \right)^{1/2}$

$$r_{in} = \ldots \approx 0.2\,pc \cdot L_{45}^{1/2} \cdot T_{1500K}^{-2} \cdot \varepsilon_s^{-1/2}$$

• mass

→ half of AGN is covered

⇒ $A_t \simeq 2\pi R_t^2$

⇒ $m_t = m_H A_t \cdot N_H \simeq 2\pi R_t^2 \cdot m_H \cdot N_H$

$\simeq 5 \cdot 10^4 M_\odot \cdot R_t^2(pc) \cdot N_{H,24}$

→ but: R_{th} scales with L

⇒ $M_t \simeq 10^5 M_\odot$

• supply: 10^{45} erg/s needs $6 M_\odot/yr$

⇒ $t_{supply} \simeq 10^4$ years

(V) Cosmological context ~8 min

- M_{BH} relations
- train wrecks
- lum. function
- Video

I

(I) Models?

→ Simple PL model

$$F_\nu(r) = \varepsilon_s \left(\frac{r}{r_{in}}\right)^{\alpha} \cdot \pi B_\nu(T(r))$$

and $T(r) = T_{in} \cdot \left(\frac{r}{r_{in}}\right)^{\beta}$

(II) Interferometers
(III) clumpy
(IV) What kind of tori
(V) Surveys
(VI) Surprises
(VII) One more thing

· vertical support and clumpiness:

* prerequisite: scale height $h \sim \frac{\sigma}{v_K}$

geom. thick $\Rightarrow \sigma \simeq v_K \simeq 100\ km/s$

$$v_K = \left(\frac{GM}{r}\right)^{1/2}$$

* hydrostatic equilibrium:

$$pV = \rho\sigma^2 V = m\sigma^2 = kT$$

$k = 10^{-23} \frac{kg\,m^2}{Ks^2}$, $\sigma \simeq 10^5\ m/s$, $m = m_p = 10^{-27}\ kg$

$\Rightarrow T \simeq 10^6\ K$ ↯ $T_{sub} \simeq 10^3\ K$

- solution: * spherical supply
  * clumps → equivalent to dyn. pressure in stellar clusters

Active Galactic Nuclei

I. An Introduction

Sebastian F. Hoenig

Lecturer & Marie Curie Fellow

University of Southampton

Outline and learning goals

- **I. Phenomenology**
  What are AGN?
  How are they identified?
- **II. Energy output**
  Where is the energy coming from?
  In which wavebands does the energy get radiated out?
- **III. The AGN zoo and unification**
  How can we make sense of the different AGN types?
- **IV. The dusty torus**
  Why is it interesting?
  Where is the radiation coming from?
  What is its structure?
- **V. AGN in the cosmological context**
  Why should the universe (and funding agencies) care about black holes?

I. Phenomenology

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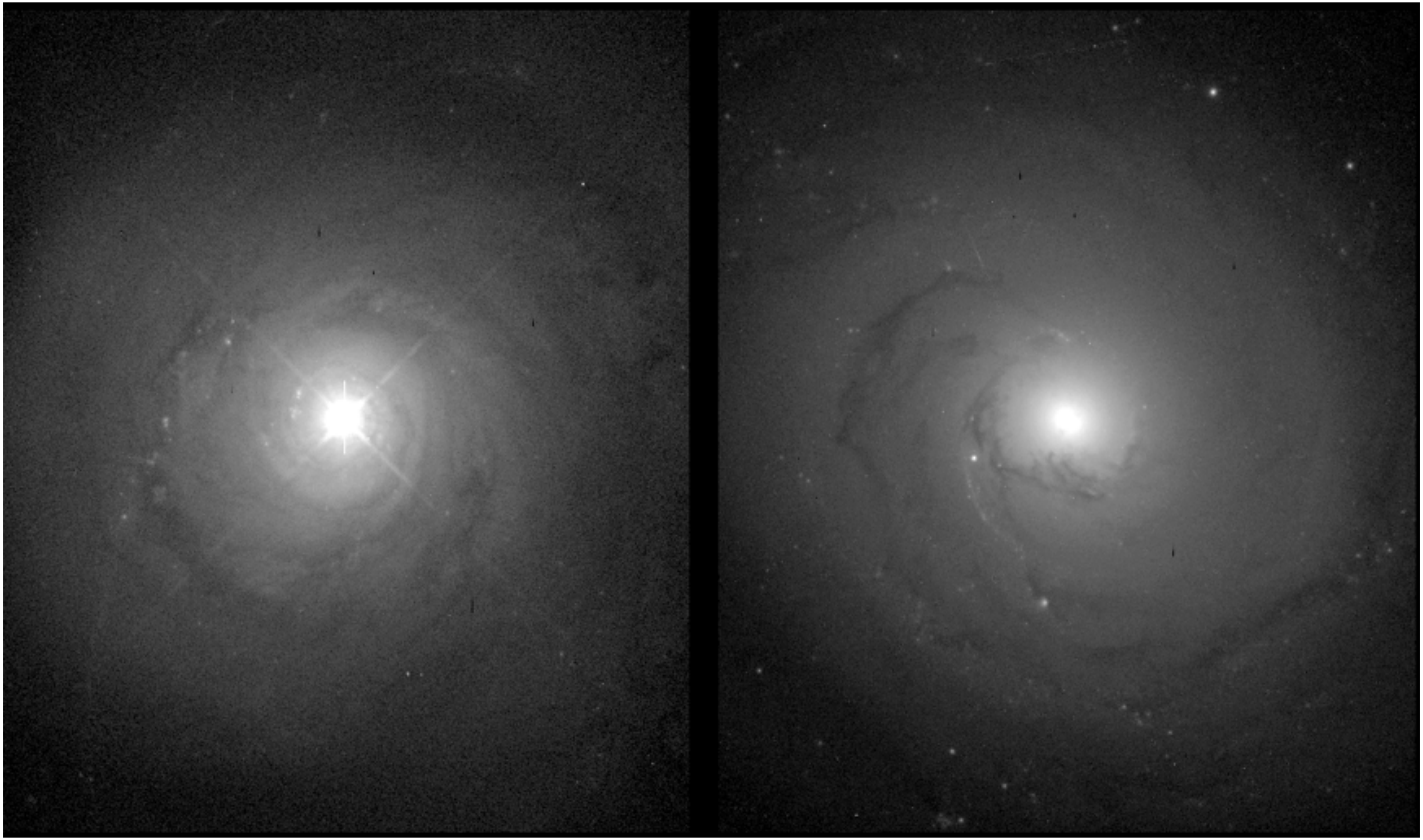
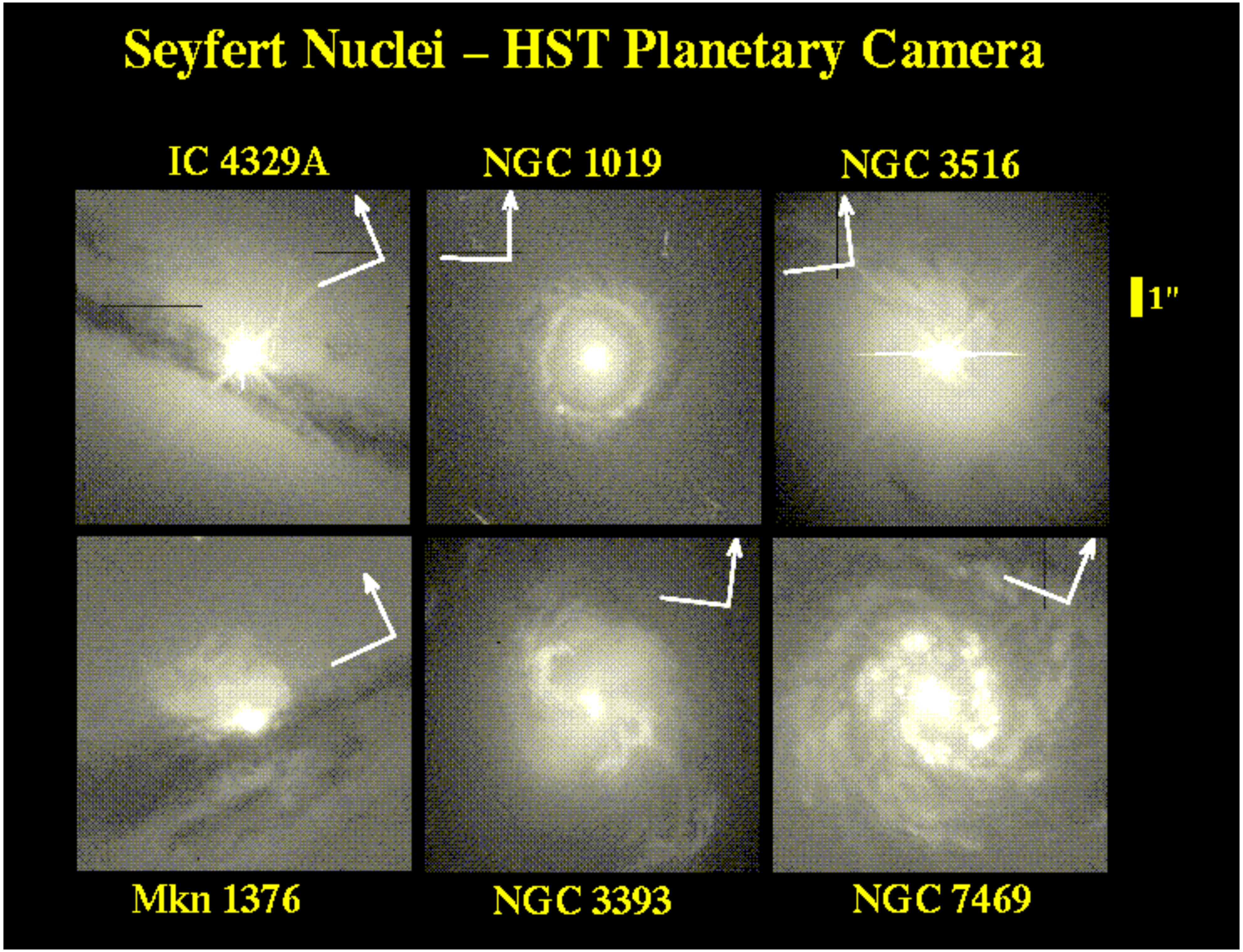


HST/NASA/ESA — Bill Keel

I. Phenomenology



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II. Energy output

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- How much energy is this over a year?
- How does this compare to a SN?

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$$\frac{\dot{M}}{\mathrm{M_\odot/yr}} \approx 6 \times \frac{L}{10^{45}\mathrm{erg/s}} \cdot \frac{0.1}{\eta}$$

- Efficiencies:
  - nuclear fission - 10^{-4}
  - nuclear fusion - 10^{-3}
  - **accretion - 0.1**

→ accretion onto massive compact object

II. Energy output

- **How massive?**
- consider balance of **radiation pressure and gravity** on ionised gas

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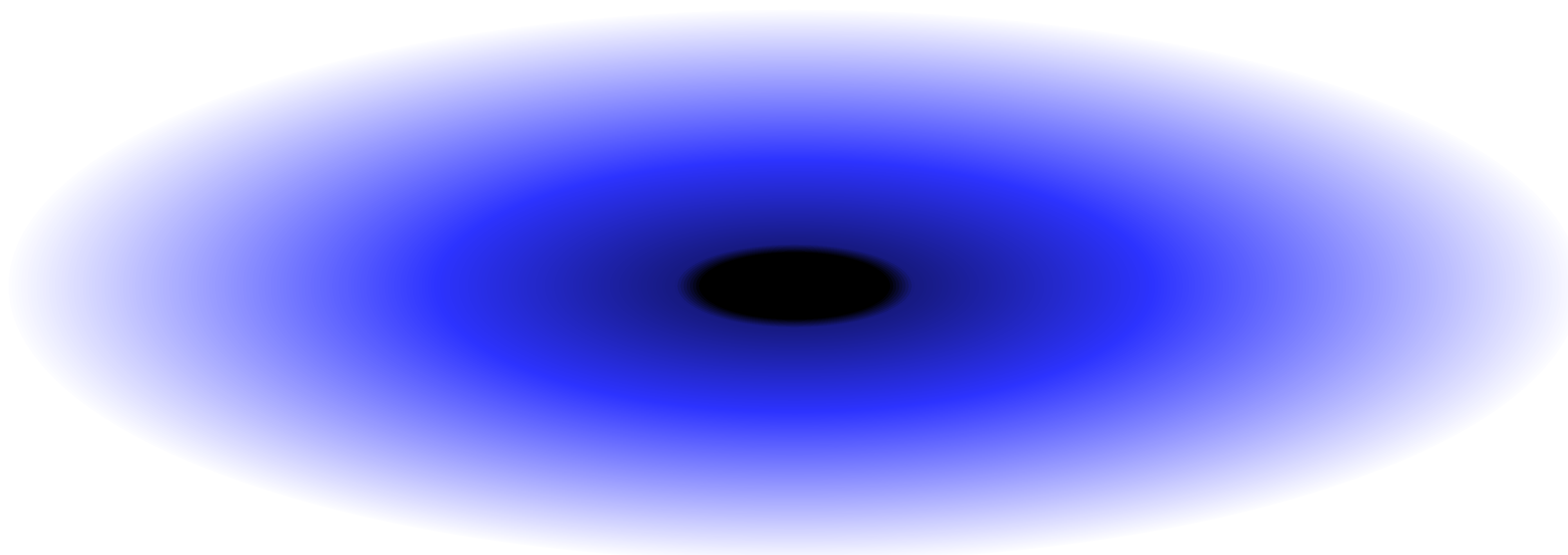
$$M \geq 8 \times 10^6 \, \mathrm{M}_\odot \cdot \frac{L}{10^{45} \, \mathrm{erg/s}}$$

- **What spectrum?**

$$T \approx 10^4 \, \mathrm{K}$$

→ optical + UV emission from accretion onto a supermassive black hole

II. Energy output



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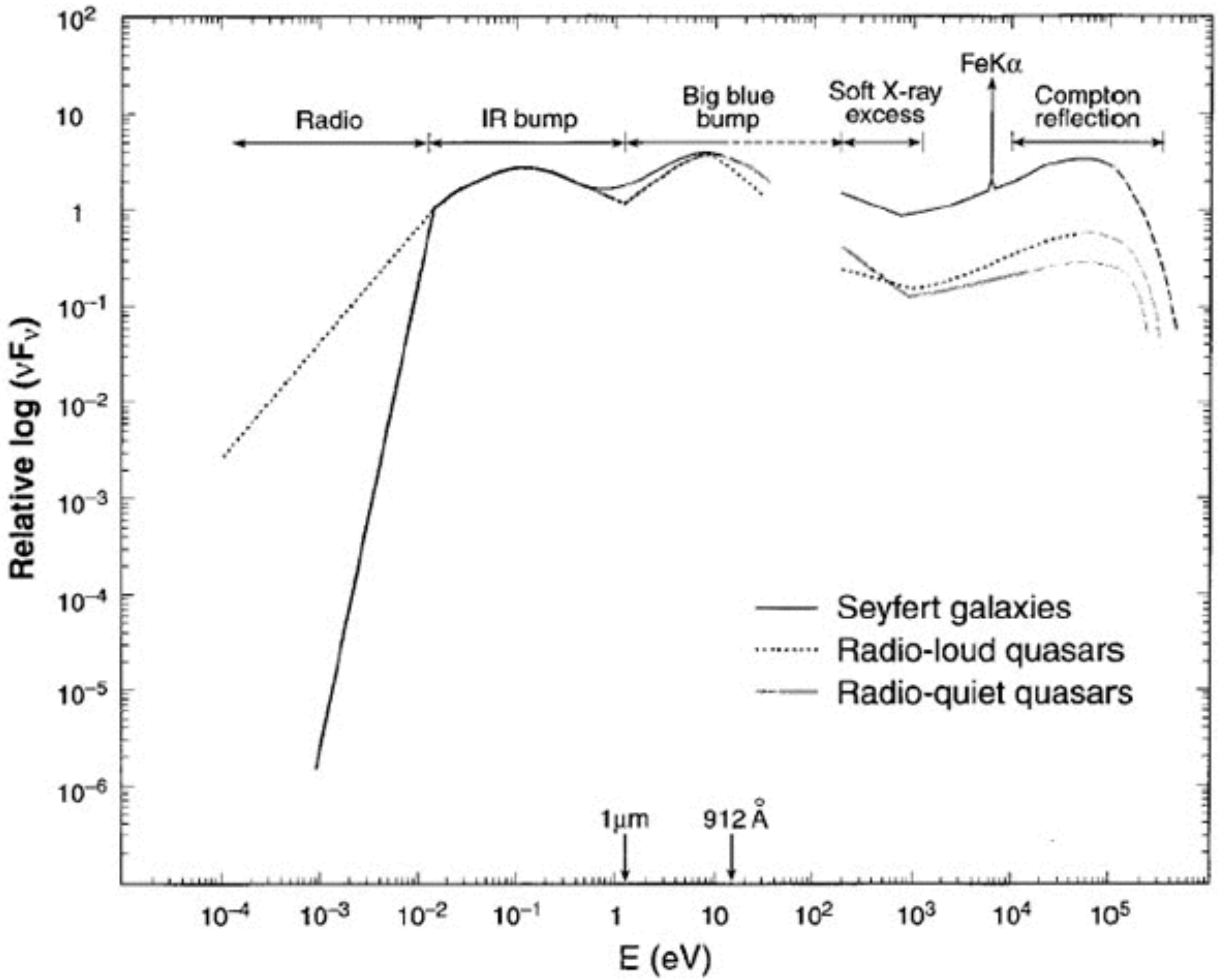

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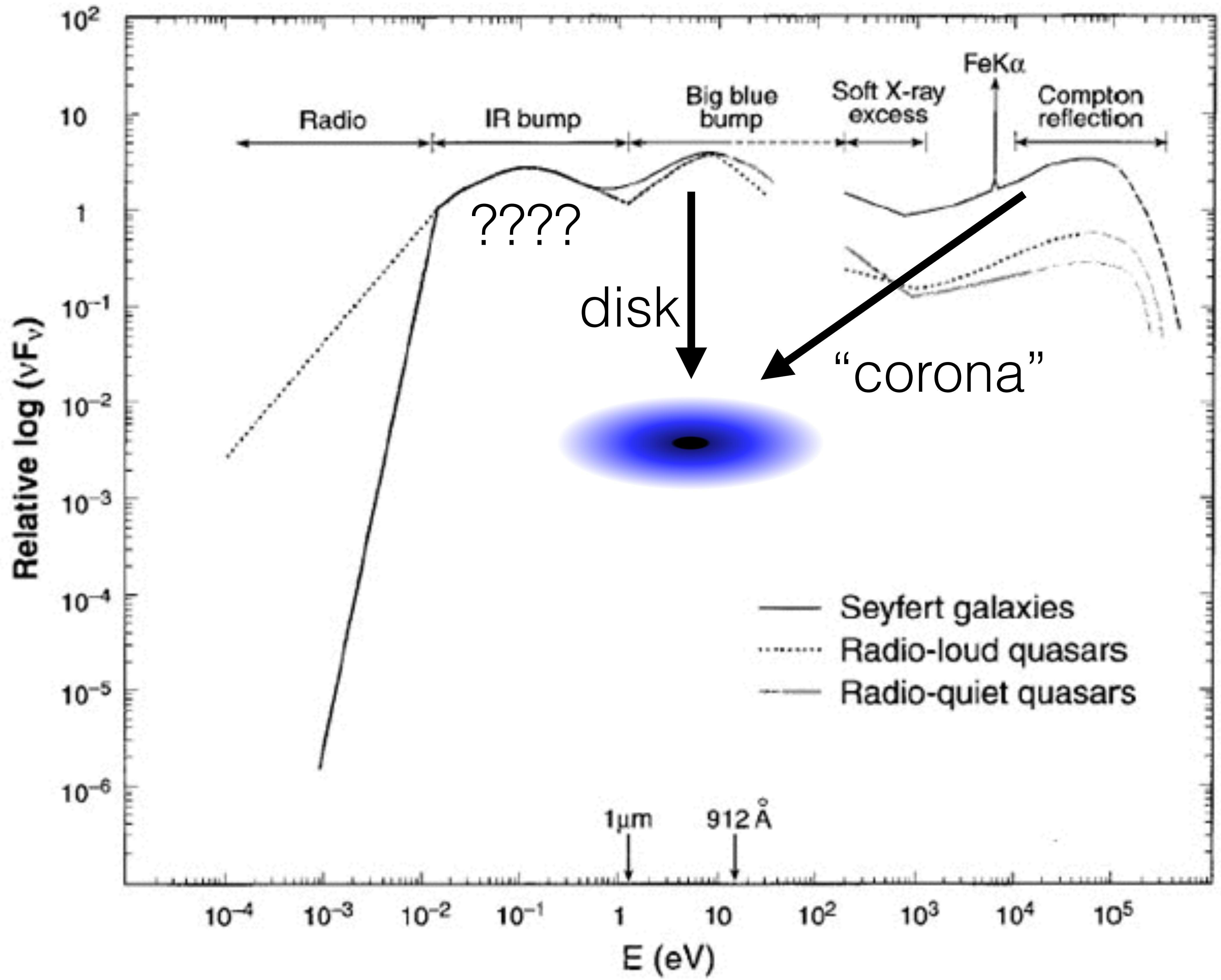

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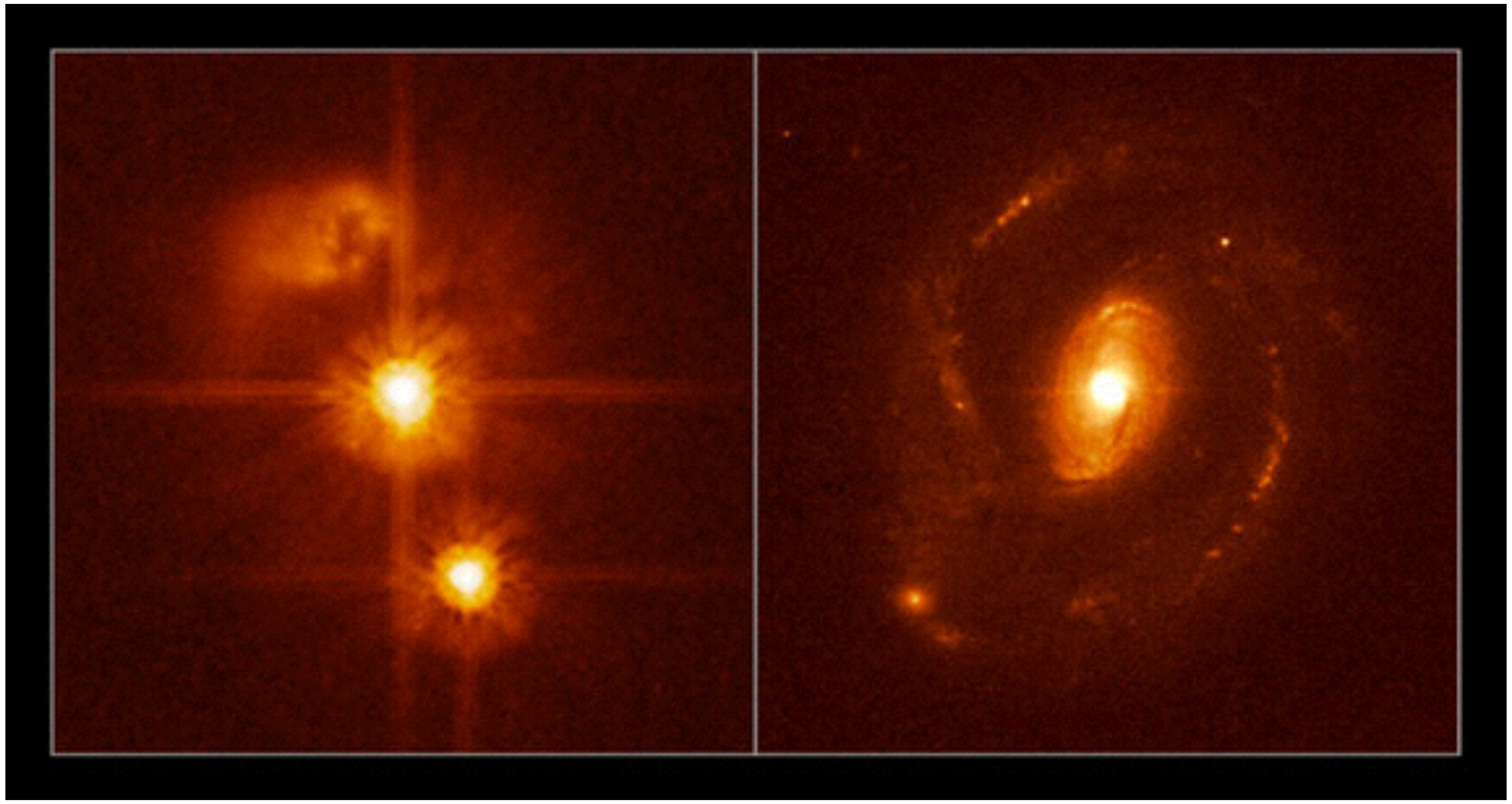

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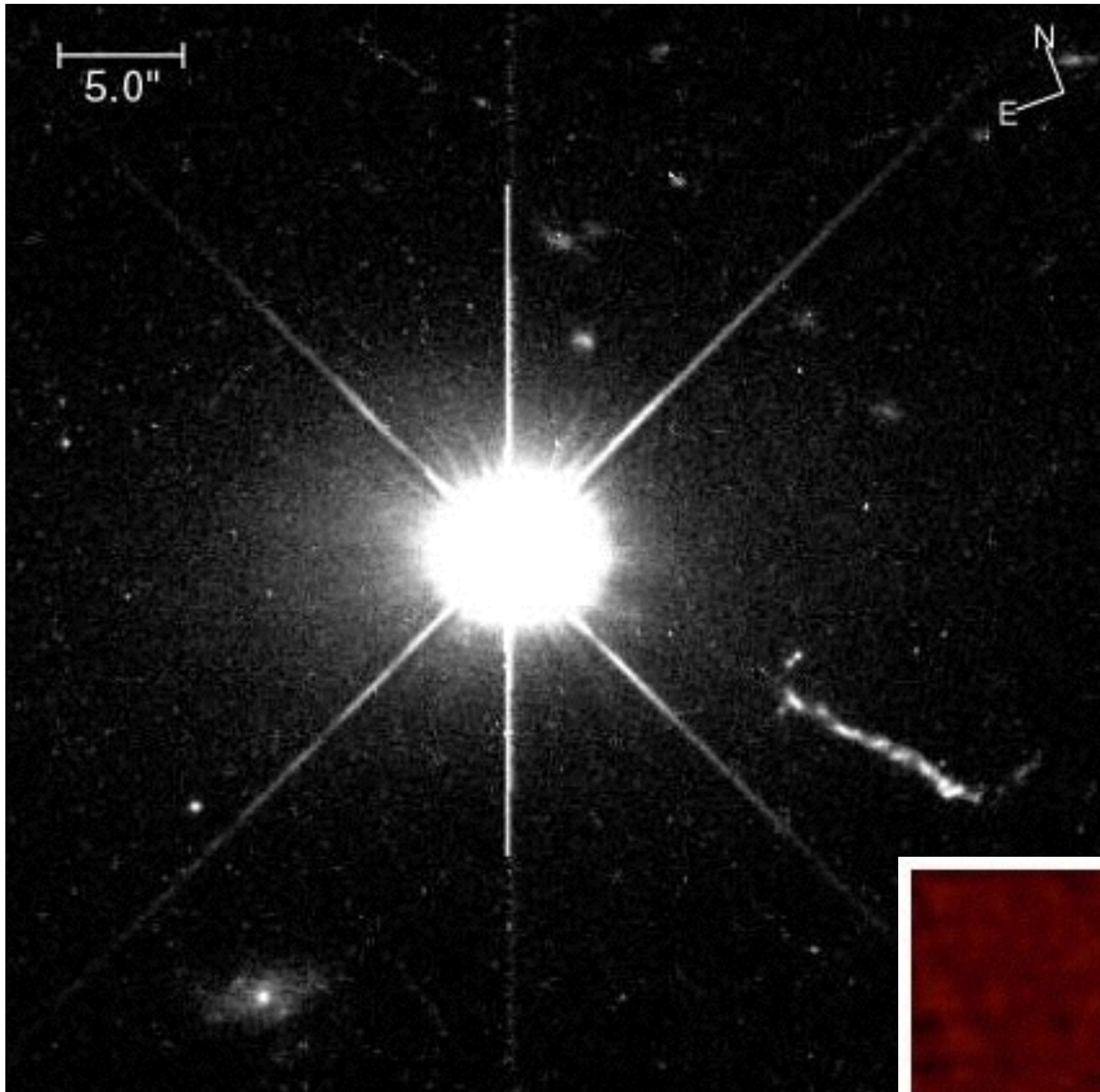

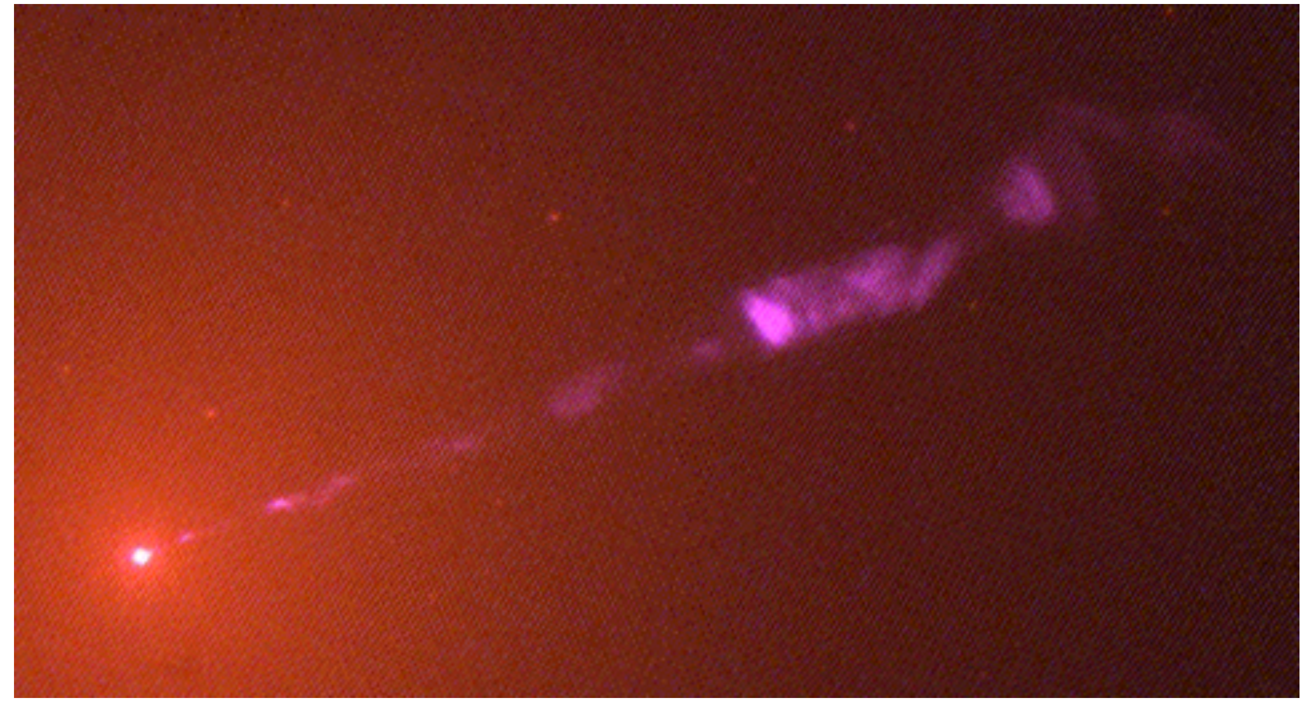

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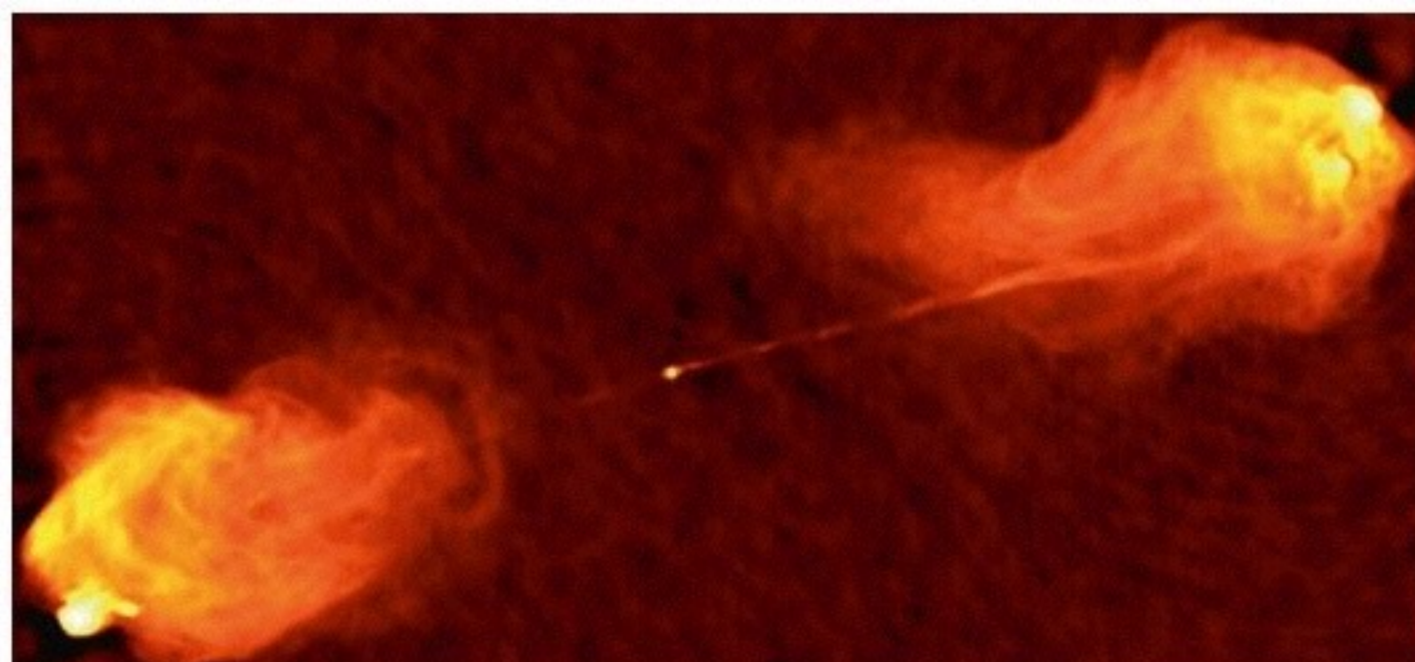

Carilli & Barthel

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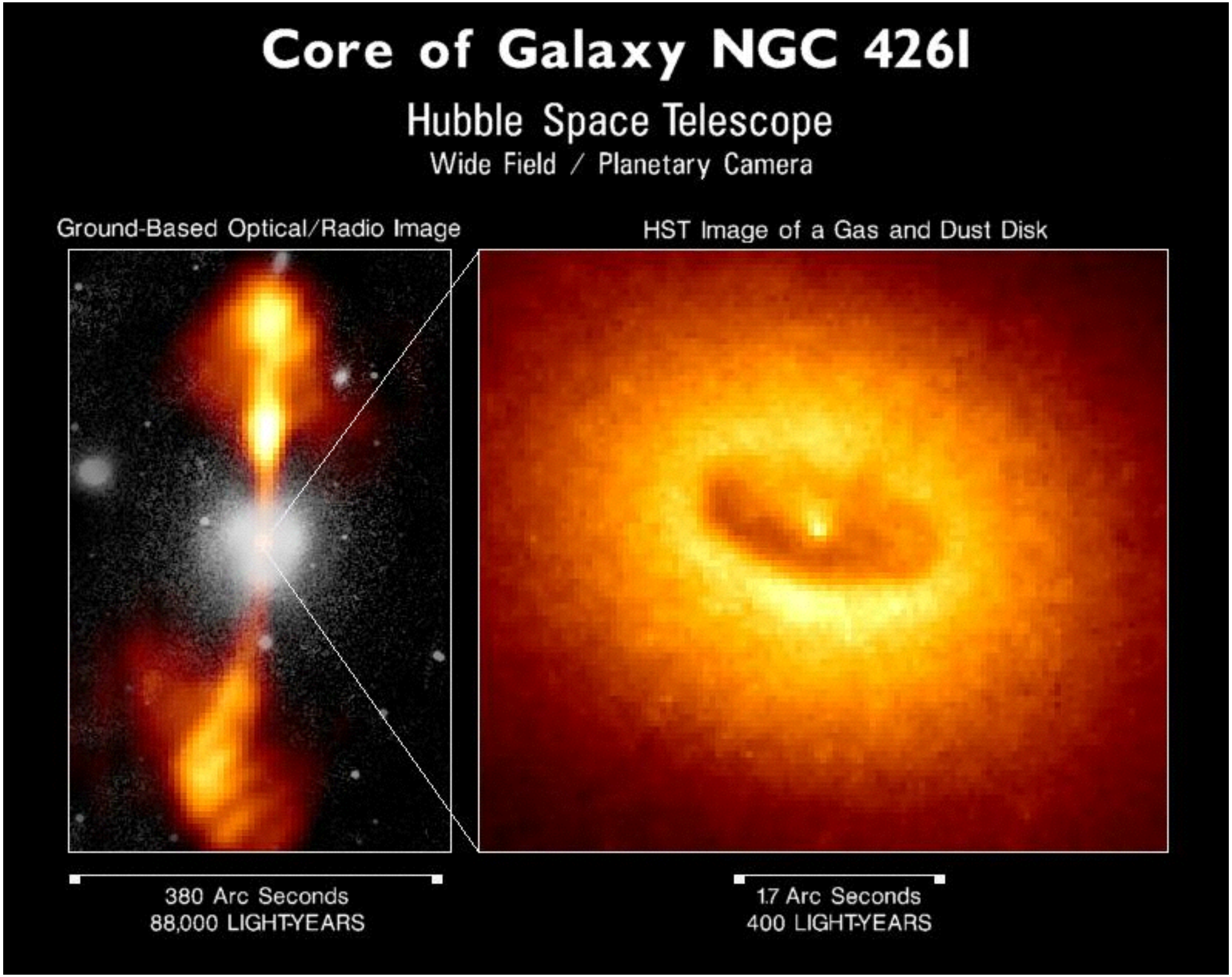

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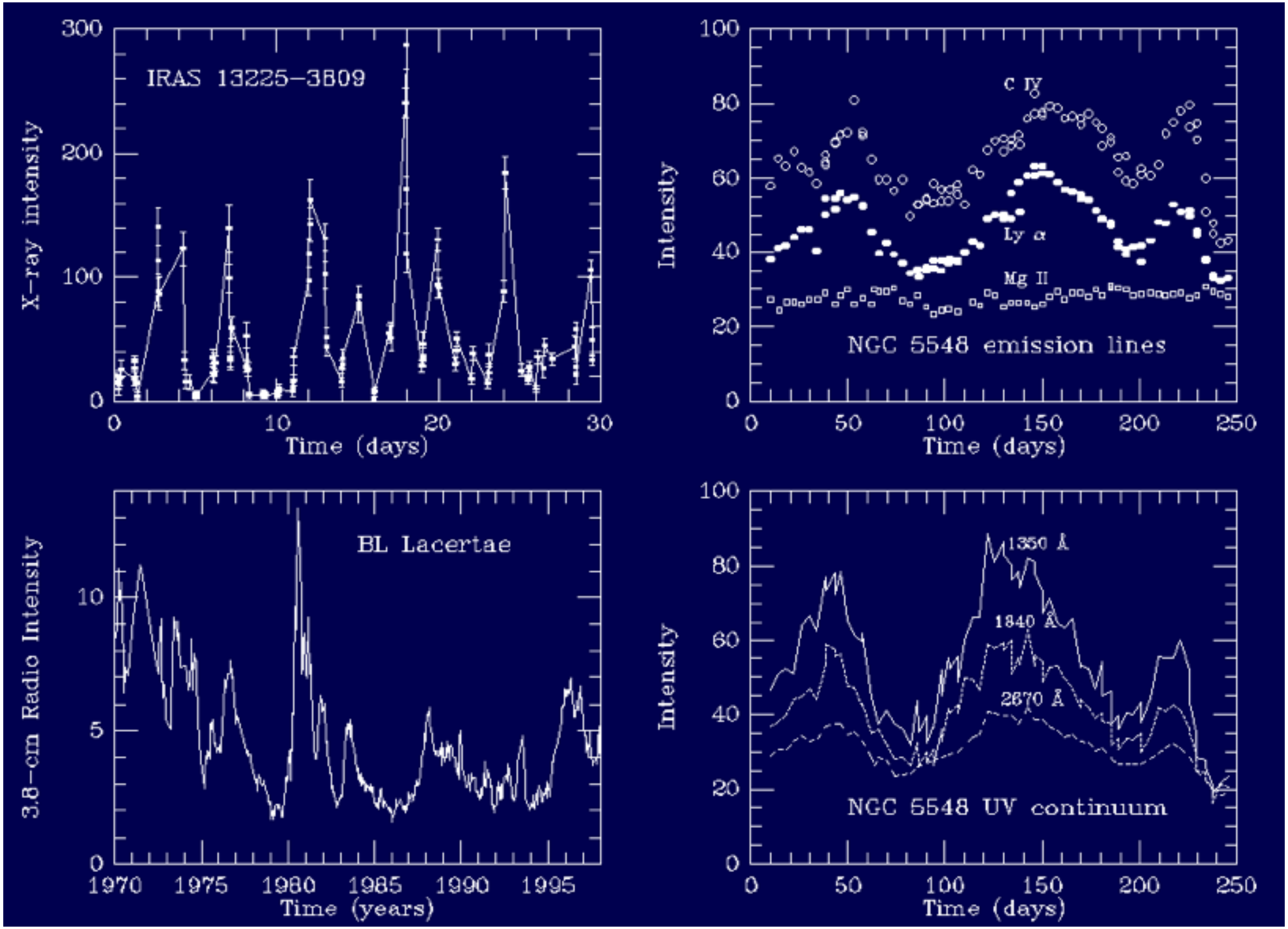

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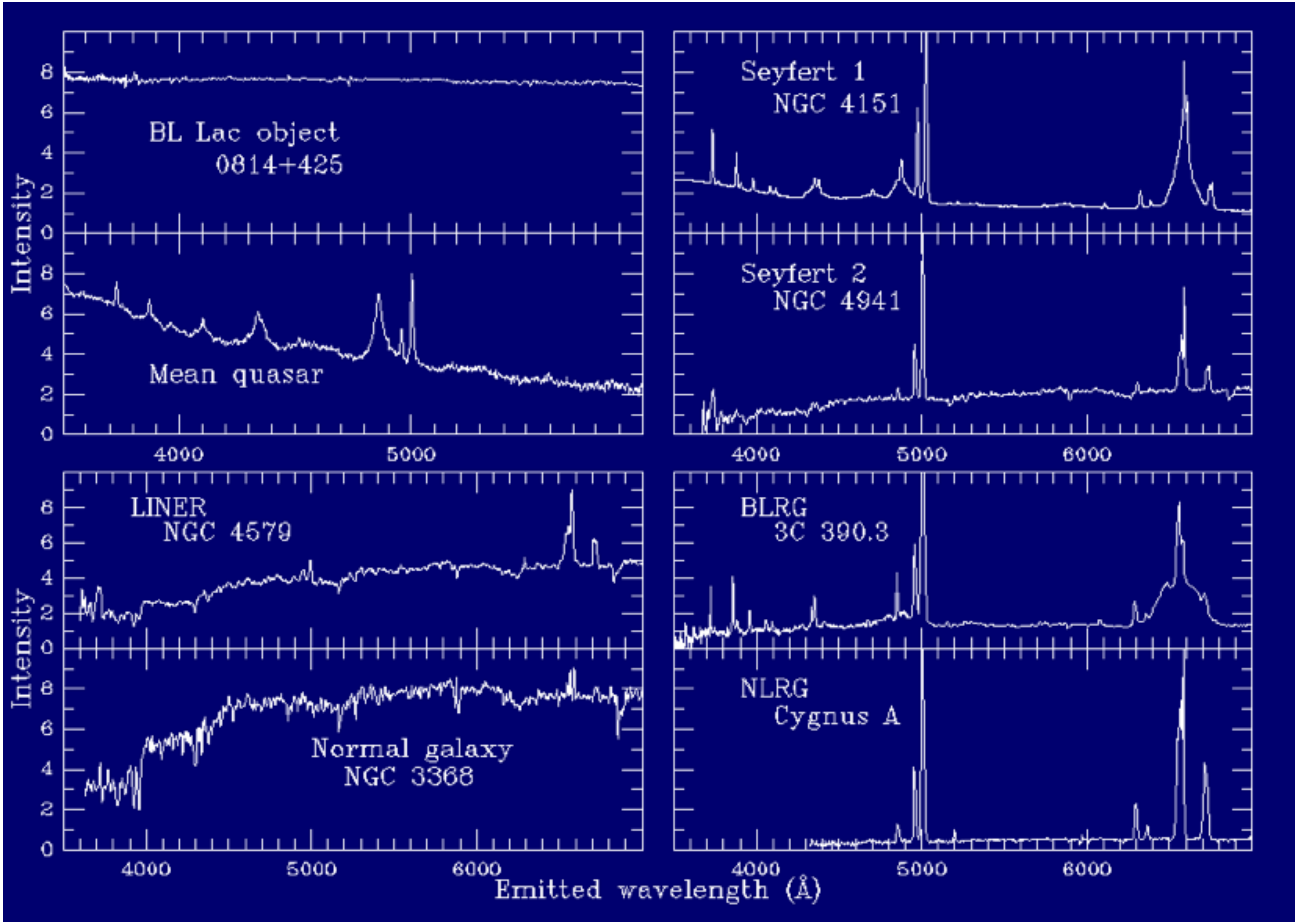

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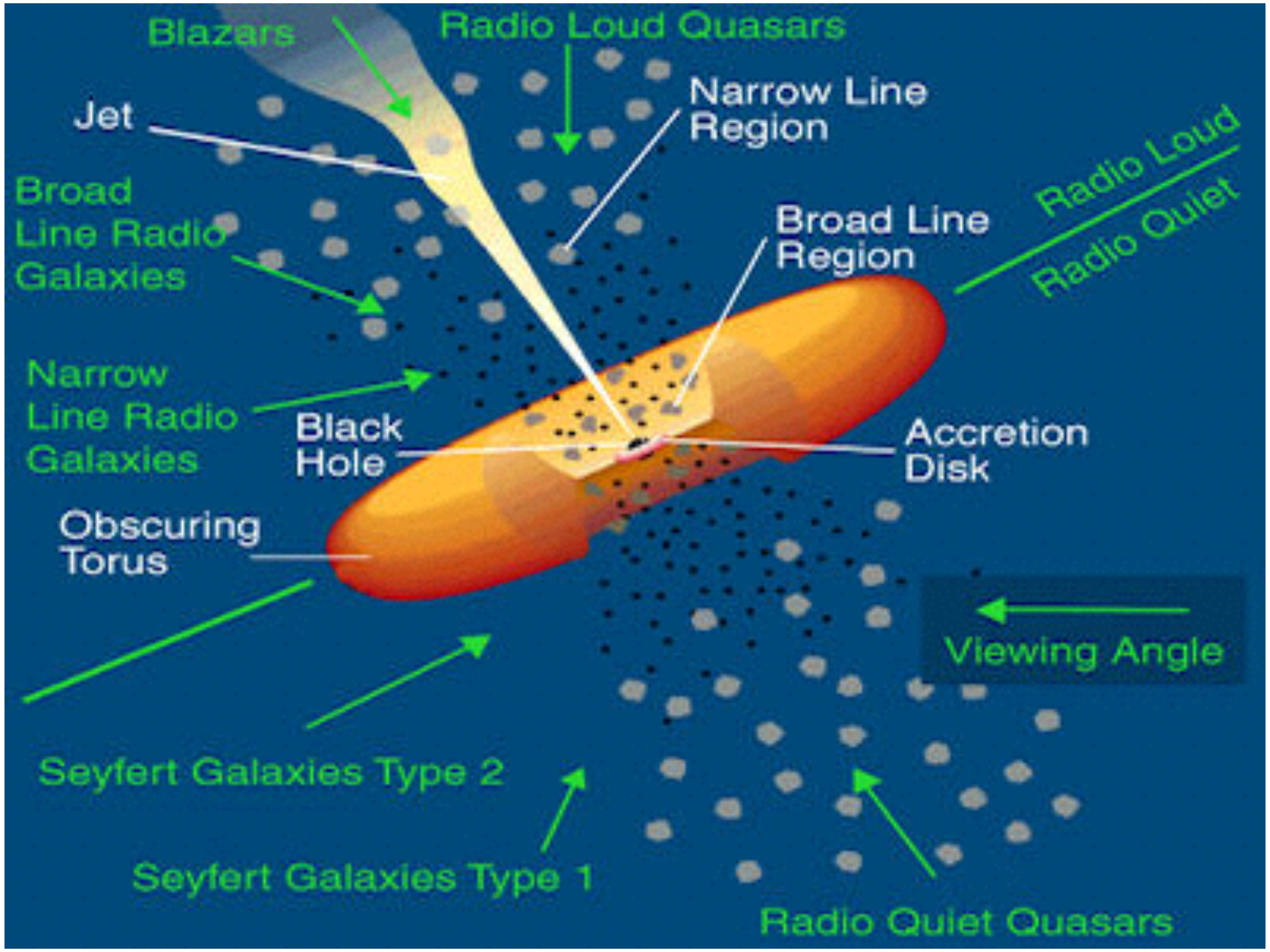
III. AGN zoo and unification

- A Zoo of AGN classes
- **Unification scheme** — putting everything in one picture



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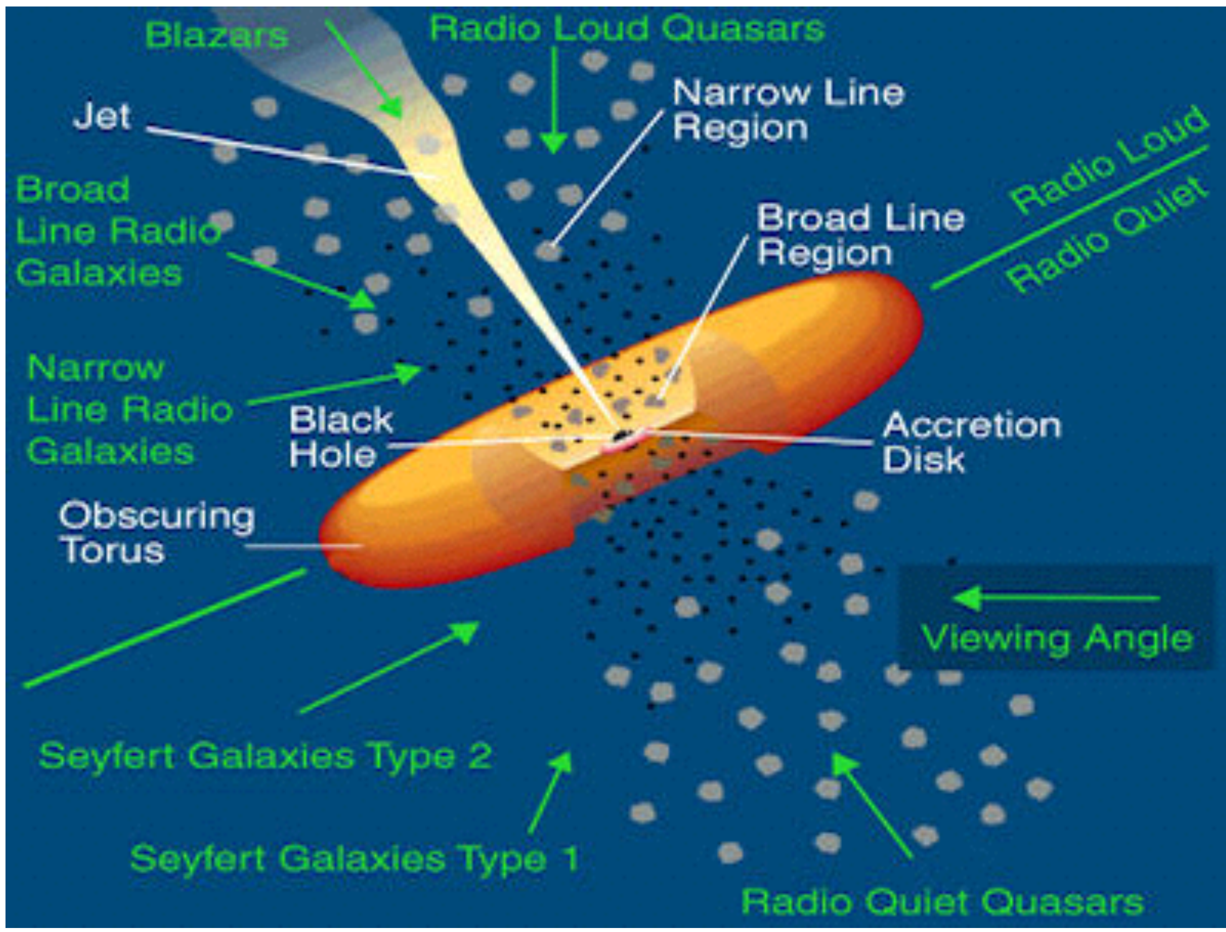

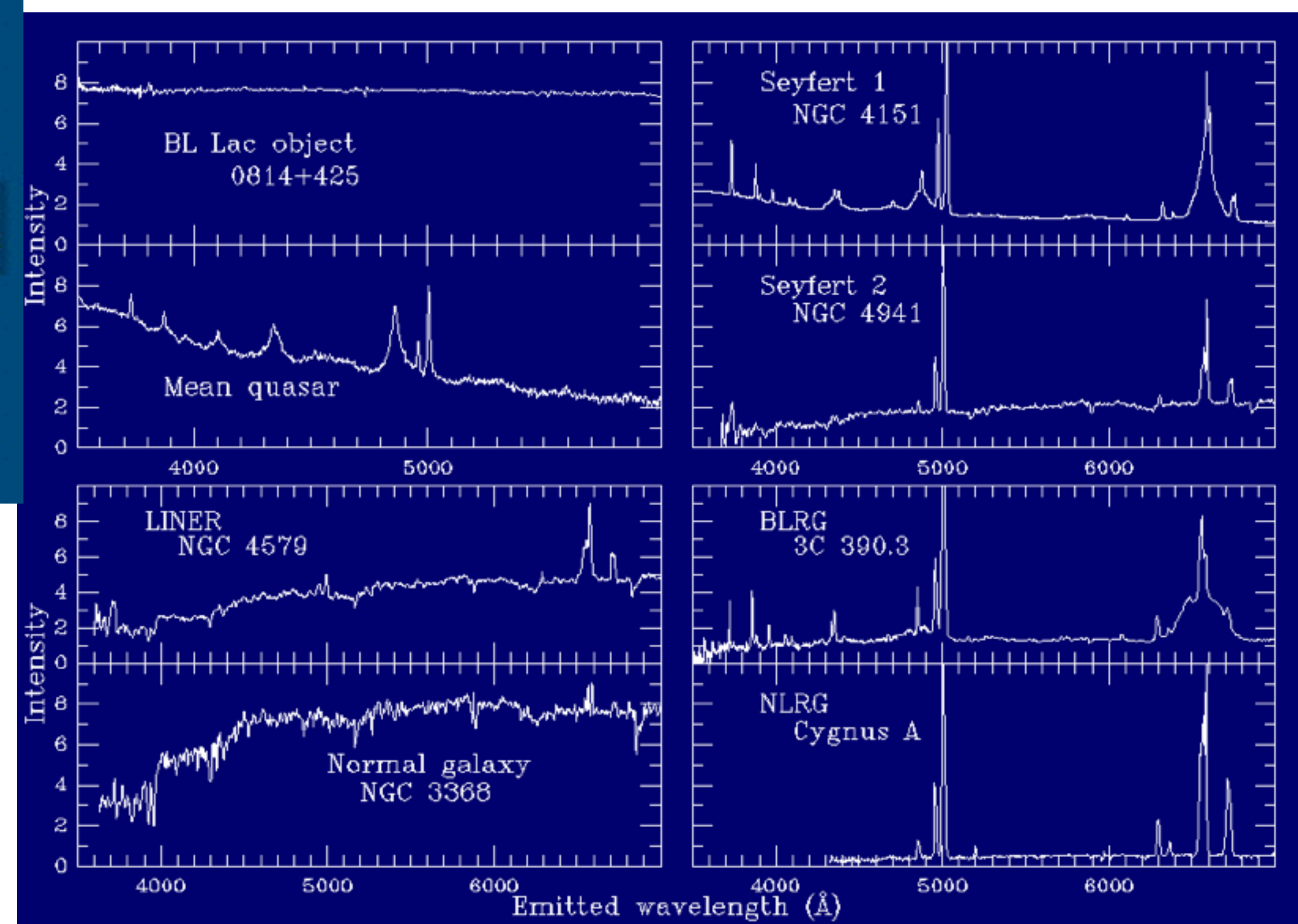

IV. The dusty torus

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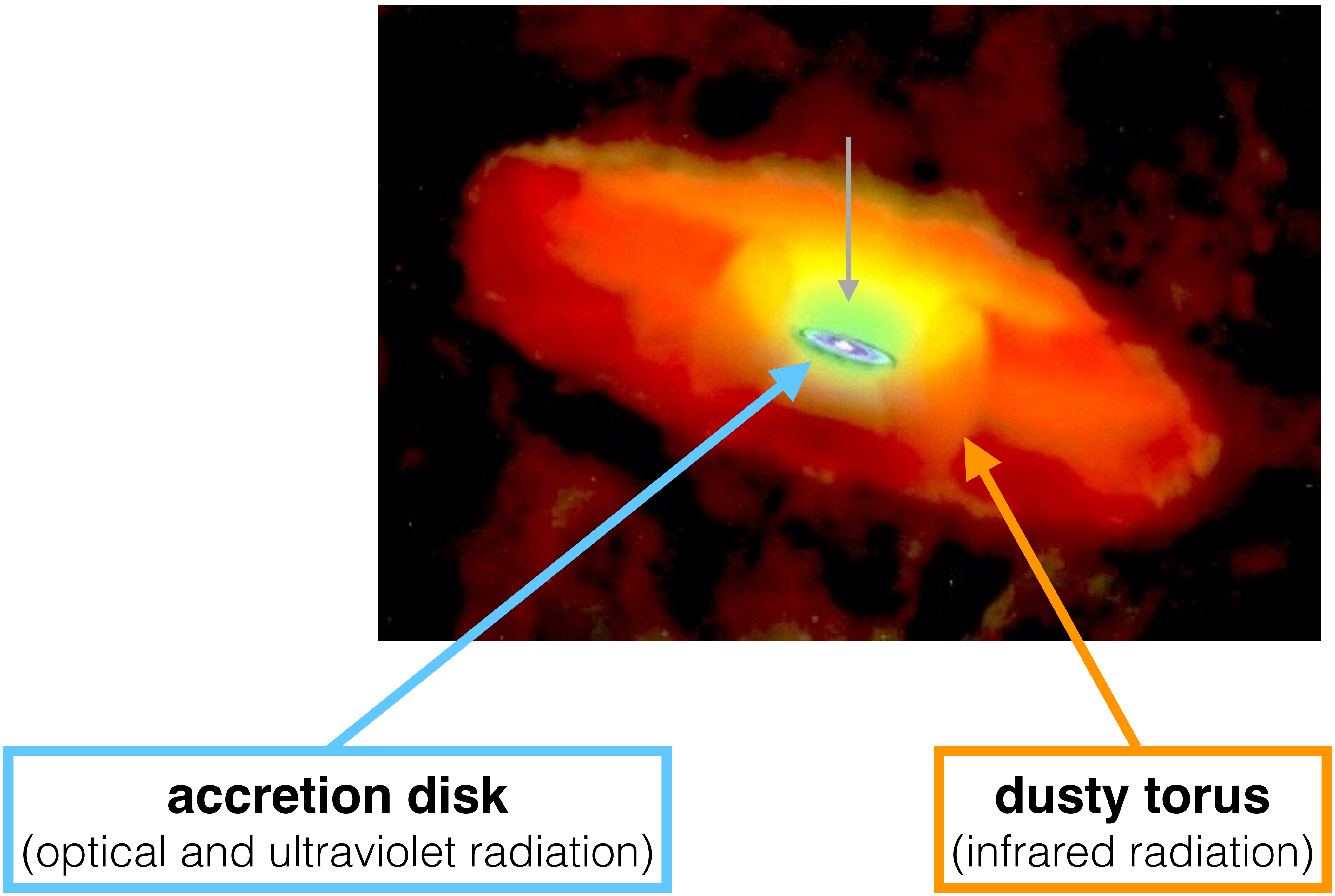
- Let's simplify a bit



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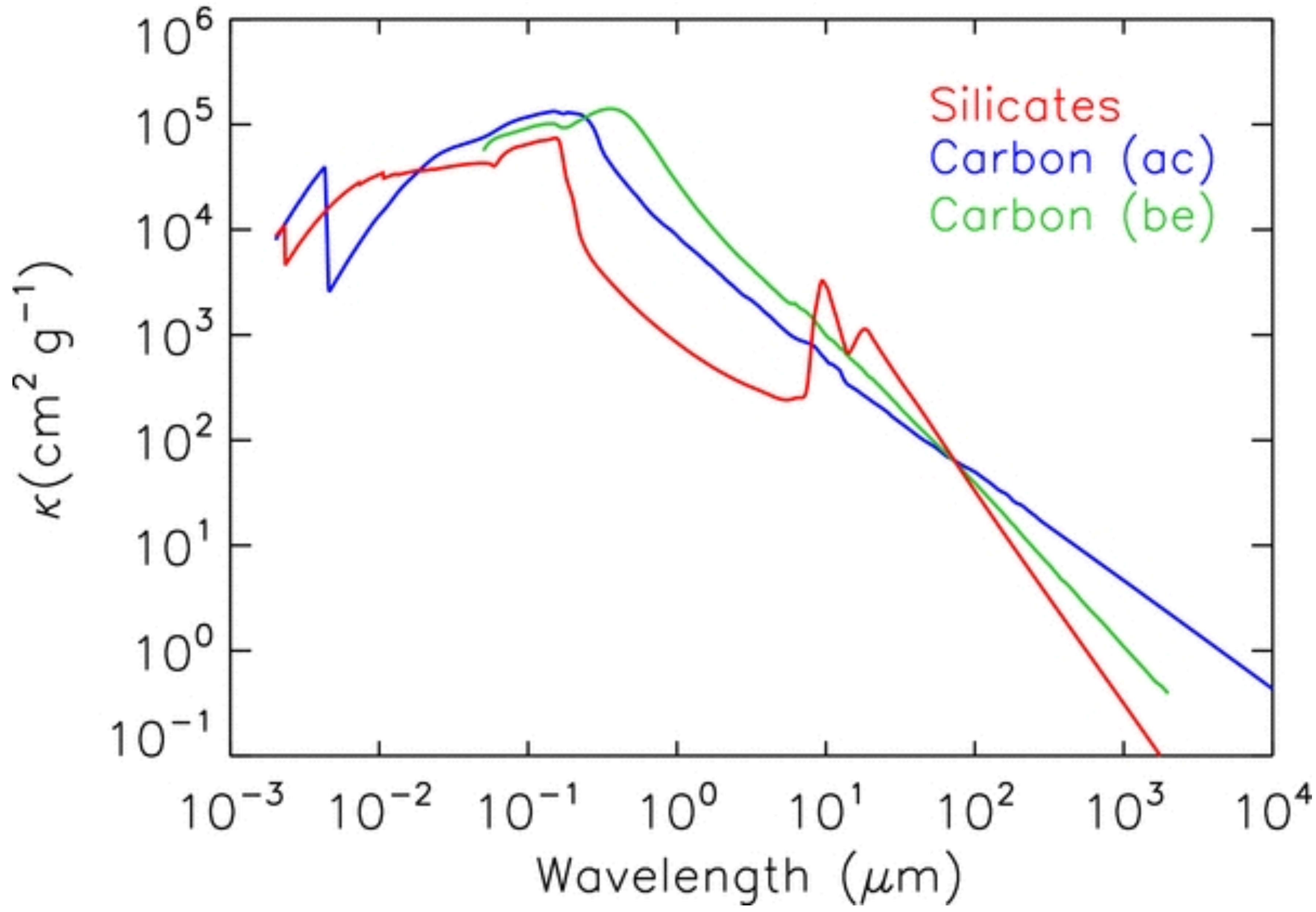
- How is the **IR emission** coming together?
- **Dust** absorbs in the optical/UV



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$$r_{\mathrm{sub}} \approx 0.2\,\mathrm{pc} \times \left(\frac{L}{10^{45}\,\mathrm{erg/s}}\right)^{1/2} \cdot \left(\frac{T_{\mathrm{sub}}}{1500\,\mathrm{K}}\right)^{-2} \cdot \left(\frac{\epsilon_s}{1.0}\right)^{-1/2}$$

→ the torus is parsec-scaled (=mas in nearby AGN)

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- **mass supply** to AGN:

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- **AGN phase** ~ $10^{7\text{-}8}$ years

→ torus must be constantly refilled!!!

V. AGN in the cosmological context

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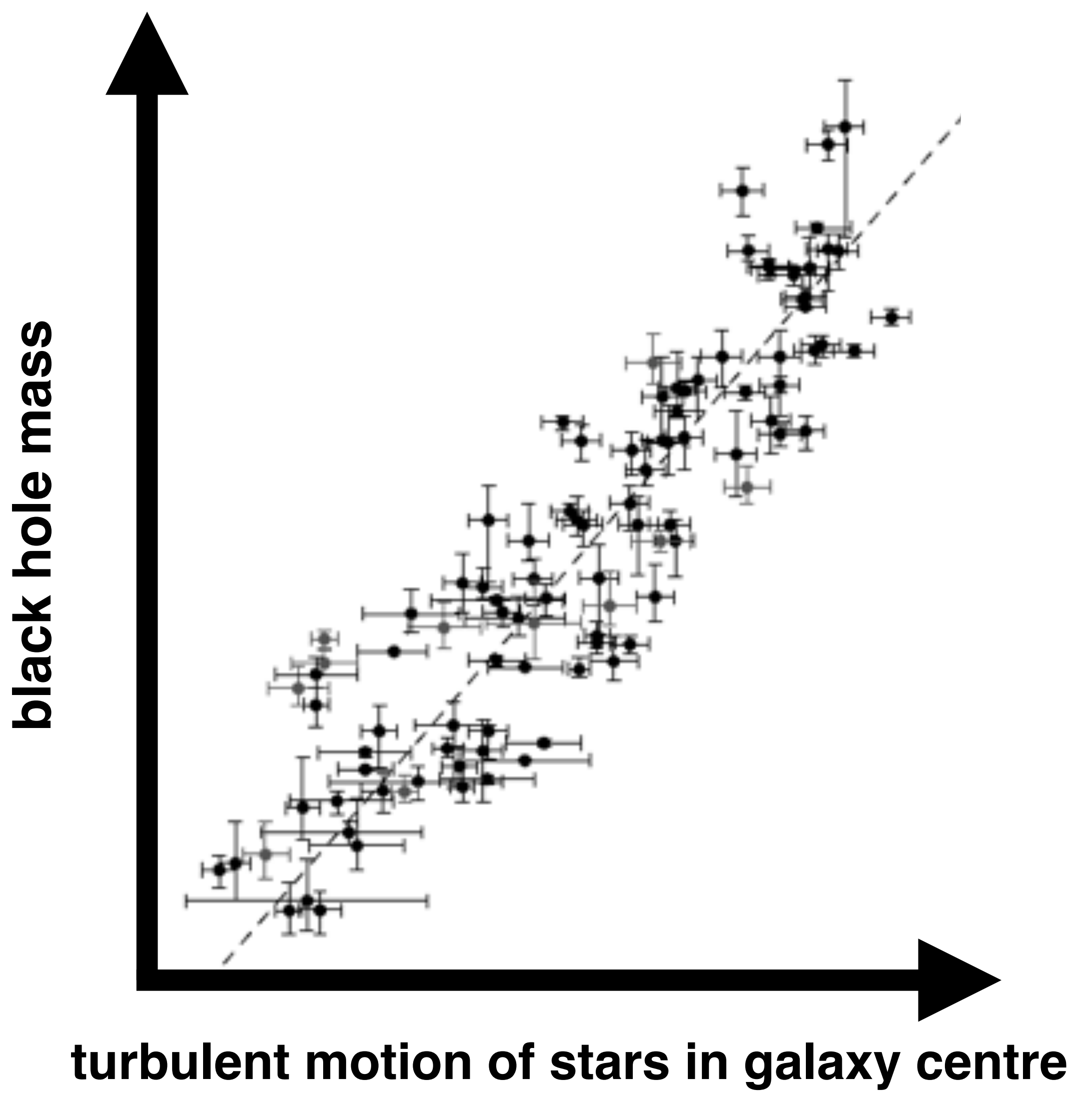
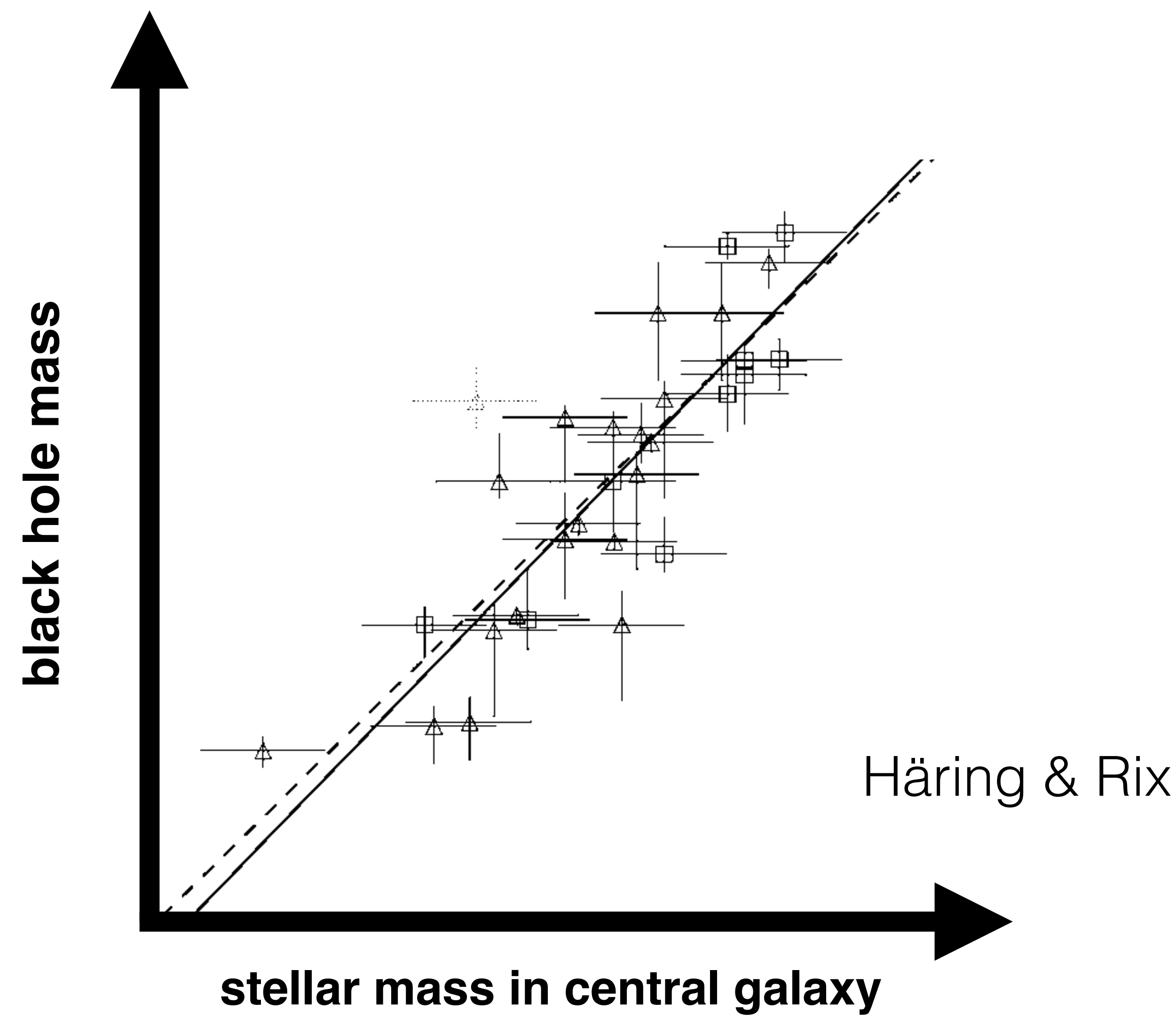
- supermassive black hole **< 1% of mass of galactic bulges**

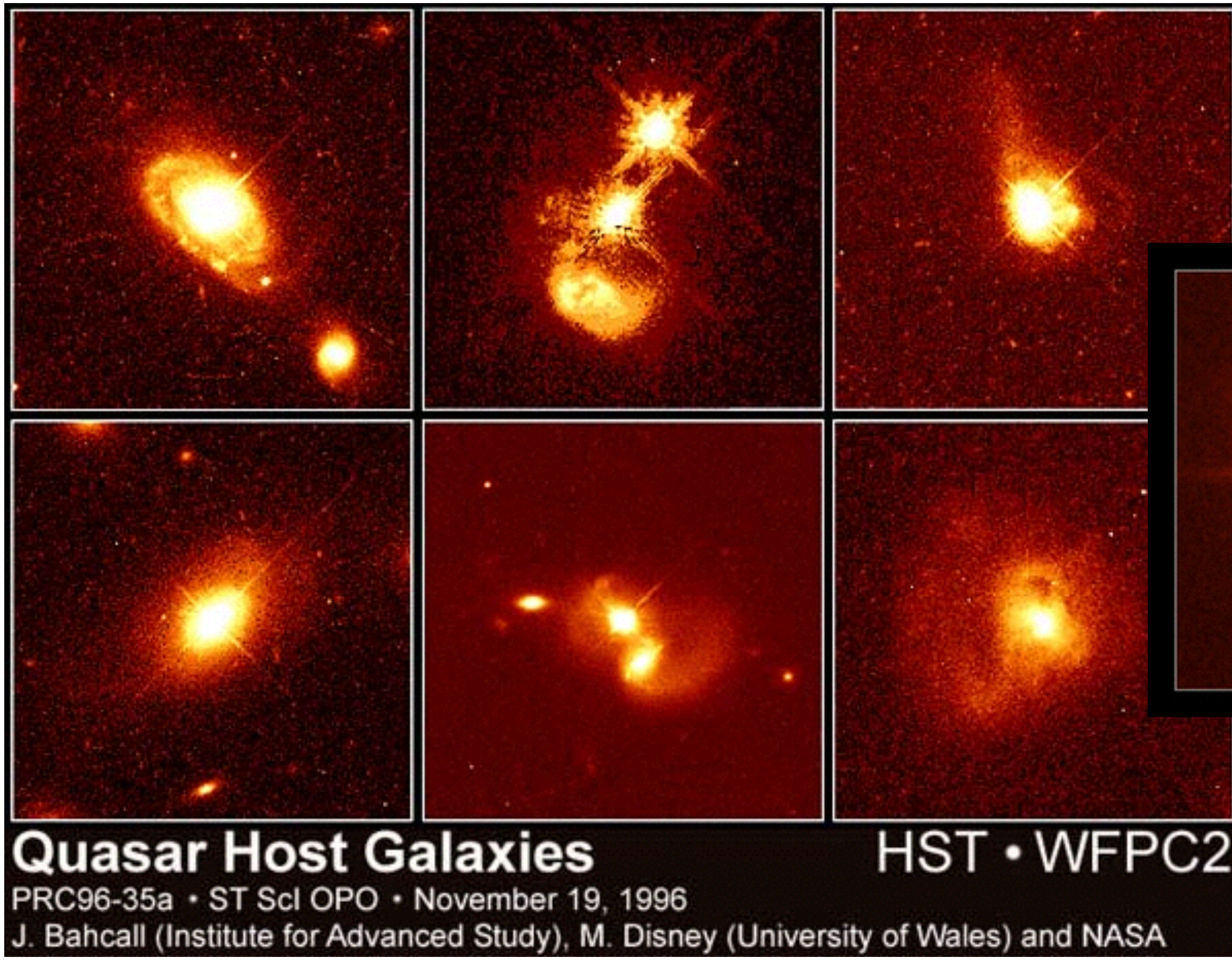




→ AGN and galaxies coevolve

V. AGN in the cosmological context

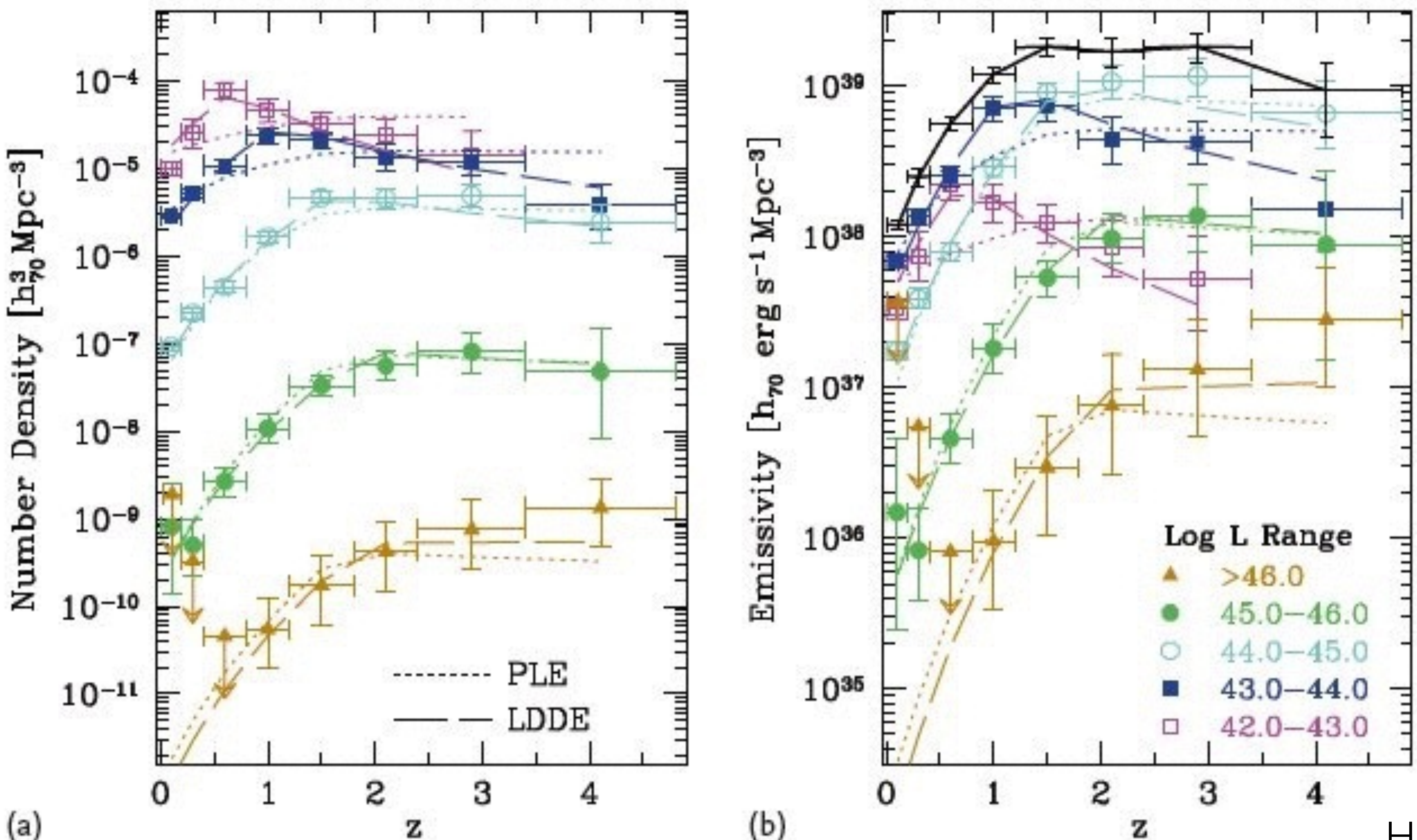
- supply and suppression via star formation



→ **very luminous AGN are in starburst galaxies**

V. AGN in the cosmological context

- luminosities evolve over time



Hasinger

→ highest masses first!?!?

V. AGN in the cosmological context