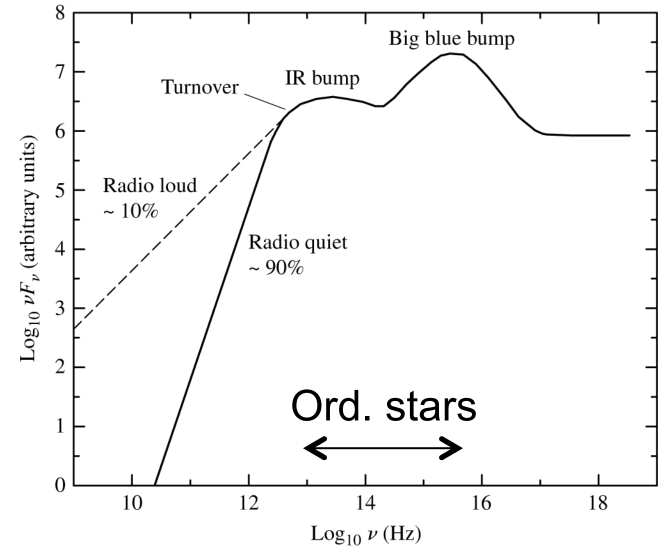
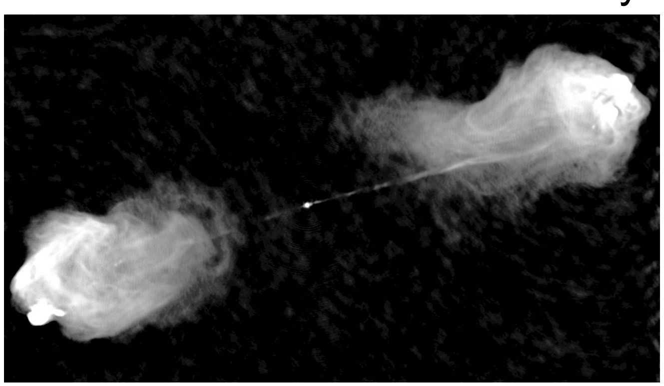
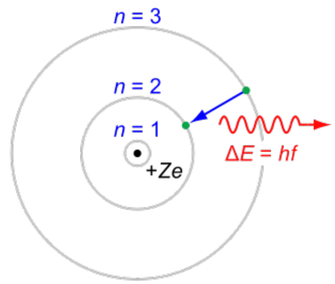
Active Galactic Nuclei

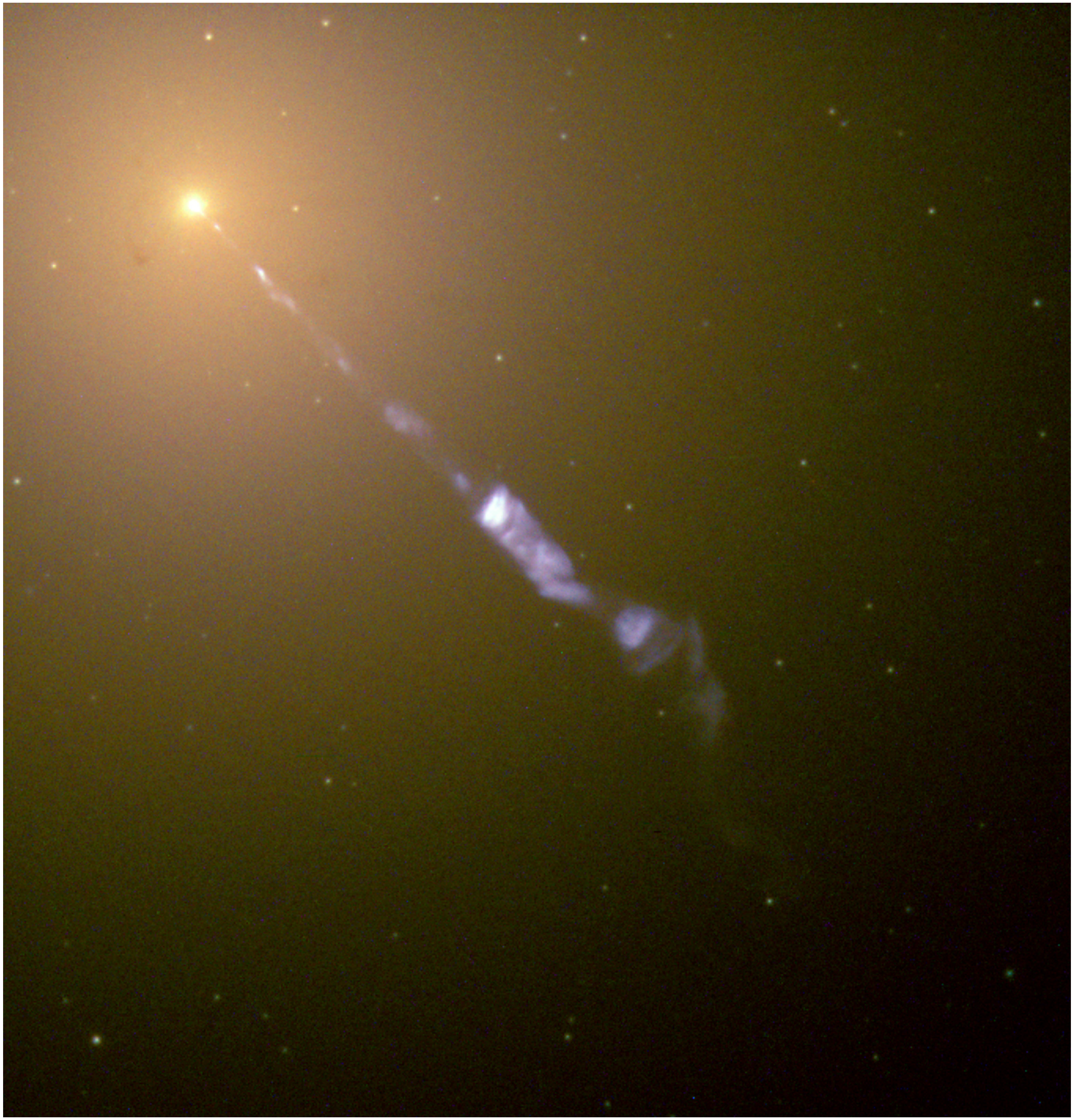


- Many Galaxies, especially younger ones (far away), have extremely bright center (nucleus); can vary over ≈ few days
  - Seyfert Galaxies (typically spiral):
    - Bright nucleus with **emission** lines (instead of absorption as normal)
    - Doppler broadening (Seyfert I), lots of X-rays
    - continuum spectrum (central source) brighter than rest of galaxy
    - (radio loud/quiet - UV, Xray) from extremely hot center
  - Radio Galaxies:
    - Emission mostly at 10 cm; have jets and “radio lobes”
    - Example: Cygnus A (240 Mpc) brighter in radio spectrum than all but sun and 1 nearby supernova remnant ($5 \cdot 10^{37}$ W = 10^{11} suns!)



AGN NGC3079 taken in Hα (Balmer series, λ =656.28 nm) filter.
Picture courtesy Josh Frechem ©





Quasars

- Quasars (quasi-stellar radio sources)
  - Detected in the 60's:
    - Very strongly red-shifted (30-95% c) => far away (?) (100-1000 Mpc)
    - Extremely bright (10^{12-14} suns, up to 10^5 Milky Ways), broad spectra
    - appear star-like in telescope (since nuclei outshine whole galaxy by huge factor)
    - Vary within days/hours - cannot be large (causality argument)
  - initial controversy: Redshift-distance relationship wrong?
  - View now: Early stages of most galaxies, powered by accretion

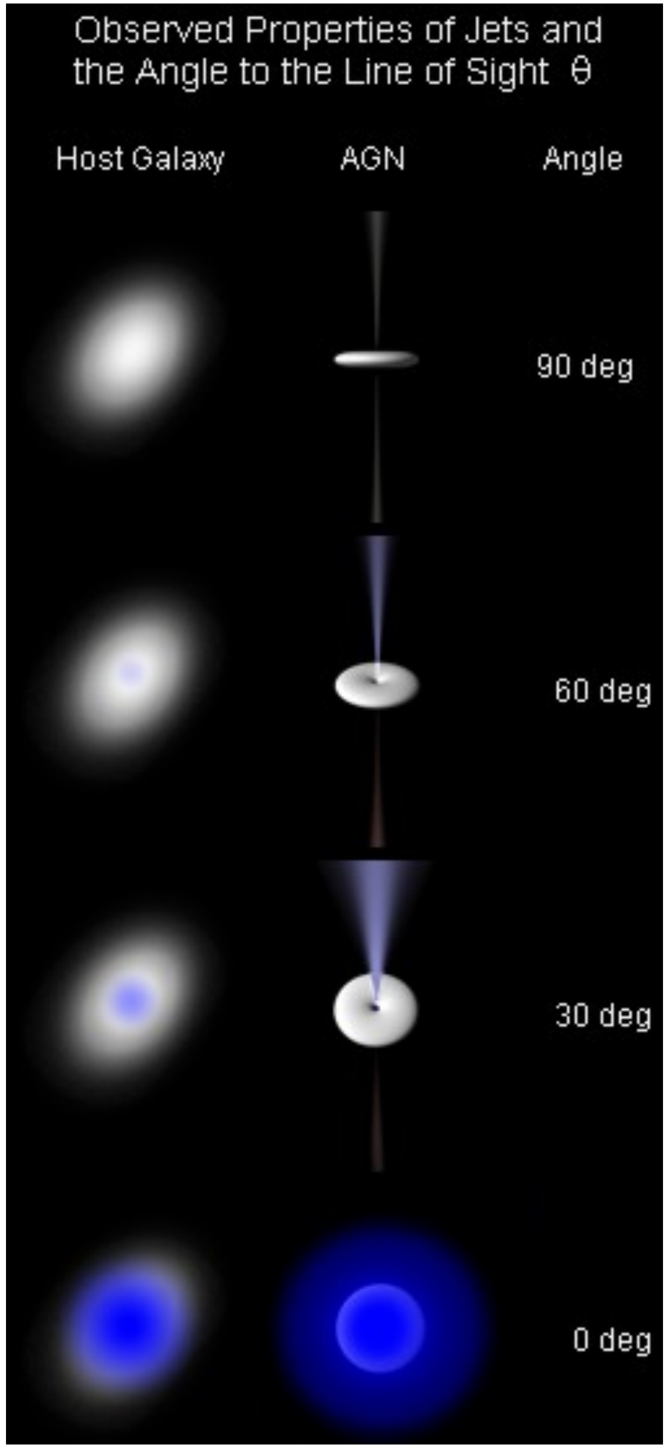

QSO B0957+0561

Engine for all these AGNs: Supermassive Black Holes

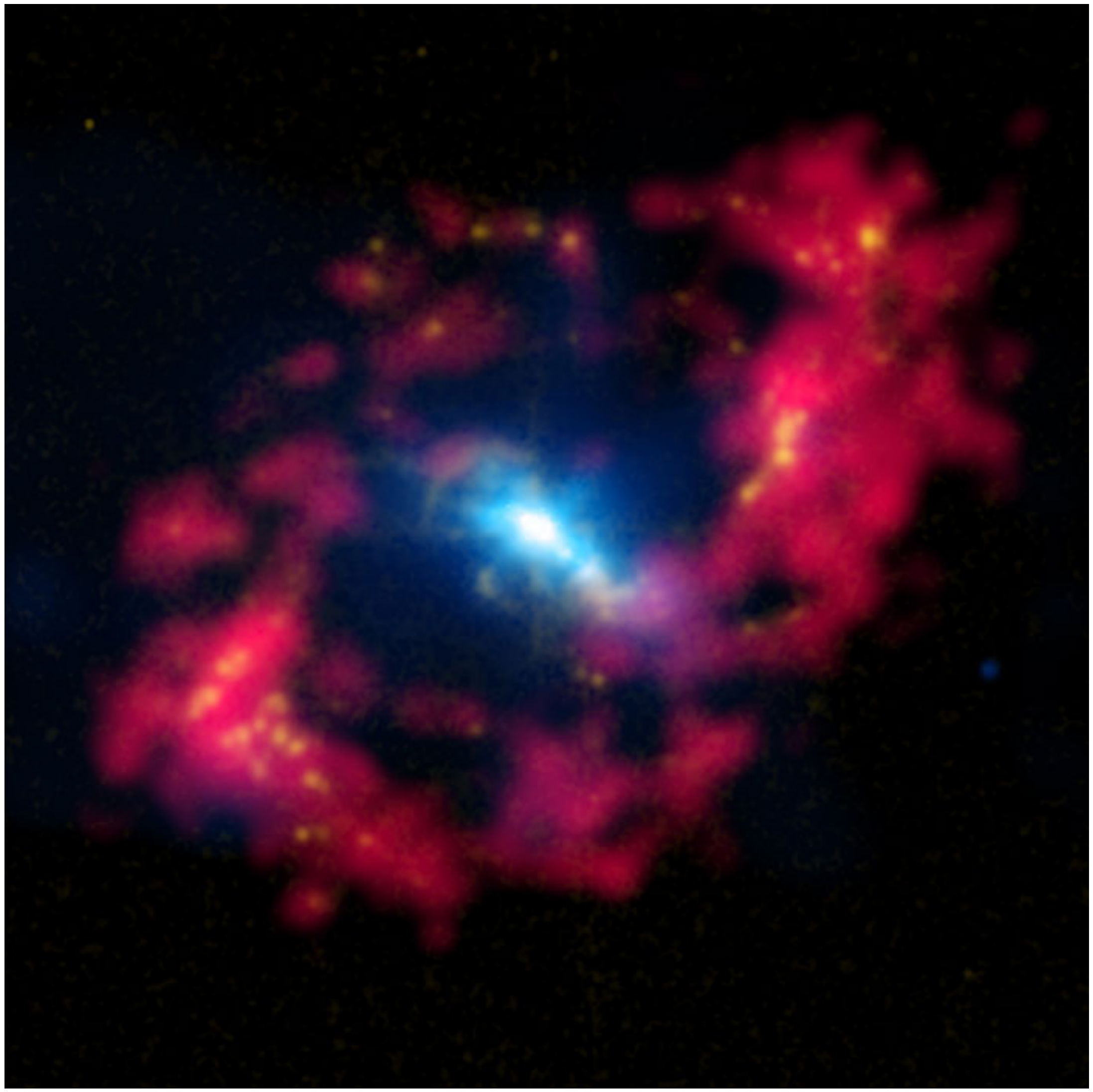
- Size:
  - Cannot be much larger than t_{var} x c (illuminated sphere) => 1 hr implies 7 AU
- Mass: Eddington limit
  - Energy flux density: $F = \dfrac{L}{4\pi r^2}$ Momentum Flux: $F_p = \dfrac{L/c}{4\pi r^2}$
  - Radiation Force on electrons: (Thompson cross section $6.7 \cdot 10^{-29}$ m^2) $F_{r.p.} = \dfrac{L}{4\pi r^2 c}\sigma_e\,; \quad \kappa = \dfrac{1}{m_H / \sigma_e}$
  - …must be < grav. force on proton (attached to e^- in plasma): $F_{grav} = \dfrac{GMm_p}{r^2}$
  - => yields max. Lumi: $L_E = \dfrac{4\pi GMc}{\bar{\kappa}} = \dfrac{4\pi GMm_p c}{\sigma_e} = 3.3 - 3.8 \cdot 10^4 L_{sun} \dfrac{M}{M_{sun}}$
  - => $M > 3 \cdot 10^8\ M_{sun}$ for $10^{13}\ L_{sun}$
  - Schwarzschild radius $9 \cdot 10^8$ km = 6 A.U. => Consistent!

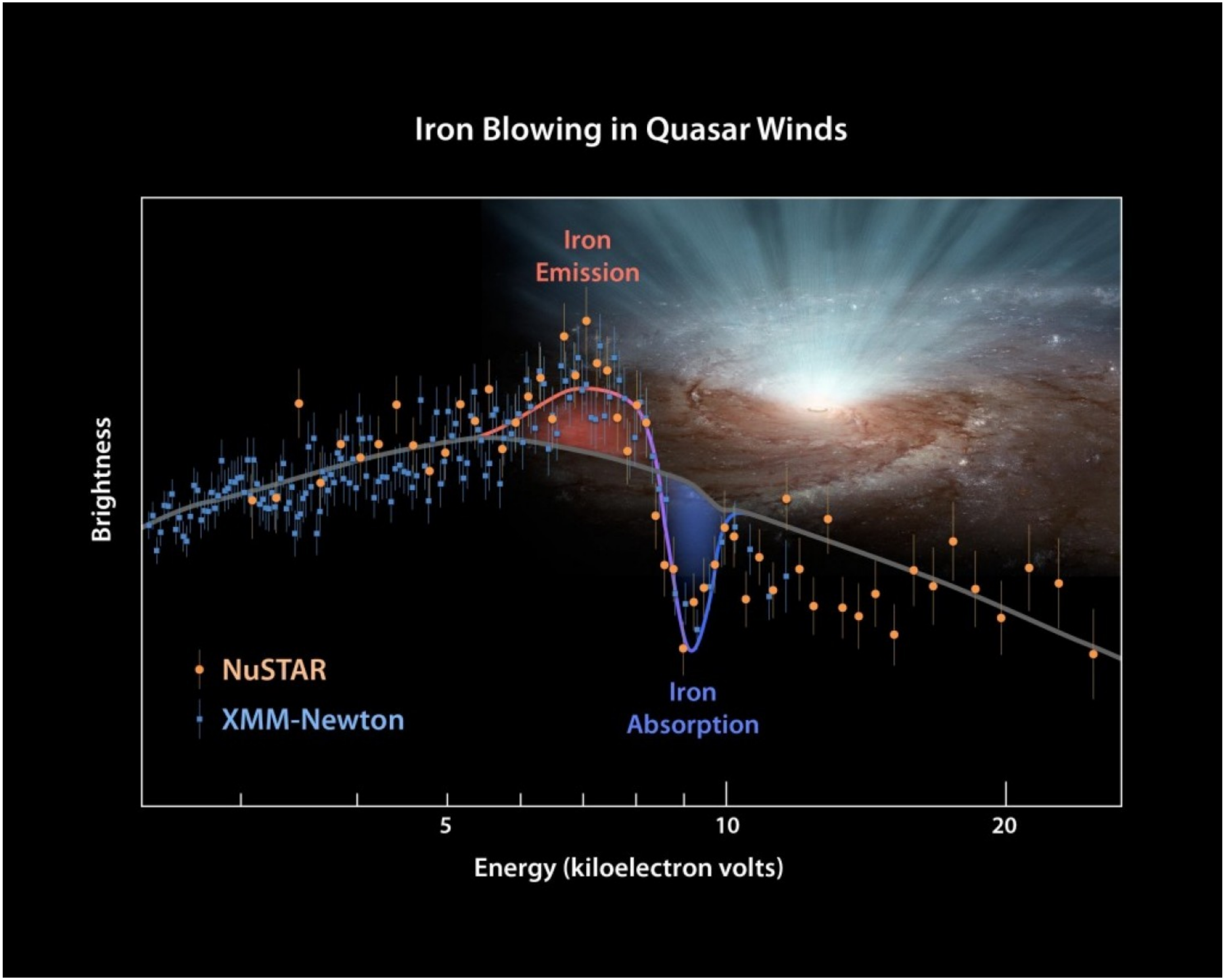
Luminosity via Accretion

- Straight-line infall - mass-energy disappears and simply makes black hole bigger (
- Accretion disk (rotating) - lots of gas, “friction” => most of gravitational energy change converted into heat => luminosity
- Non-rotating BH -> smallest orbit = $3R_S$, expect grav. binding energy = 1/6 mc^2 but in fact only 5.7% available (= efficiency)
- Rotating BH -> can get up to 42% (some energy rotational)
- Assume efficiency η = 10% on average
- $L = \eta \, \mathrm{d}M/\mathrm{d}t \; c^2$
- => $\mathrm{d}M/\mathrm{d}t = 7\ M_{sun}$/yr for $L = 10^{13}\ L_{sun}$
  - Compare nuclear: η = 0.7% => req. $10^{11}\ M_{sun}$ in 1 B years
- Maybe explains history: after a few10^9 yrs, BH creates maximum L; later it runs out of fuel - see later…


Observed Properties of Jets and
the Angle to the Line of Sight θ
Host Galaxy
AGN
Angle
90 deg
60 deg
30 deg
0 deg

AGN NGC 4151




Iron Blowing in Quasar Winds
Iron
Emission
Iron
Absorption
NuSTAR
XMM-Newton
Brightness
5
10
20
Energy (kiloelectron volts)

Galactic Evolution

- Looking at far-away galaxies we see young galaxies (as they were a long time ago)
  - Example: Quasar with redshift z = 6.4 (meaning $\lambda_{obs}/\lambda_{em}$ = 7.4) => light we see was emitted when Universe was only 2 Gyr old
    - at that time, quasar was 3.7 Gyr·*c* away
    - Now it's 27 Gyr·*c* away
  - Luminosity requires accretion of 200 M_{sun}/yr
  - Do that for 10 Gyr => $2 \cdot 10^{12}$ M_{sun}! No black holes that large have ever been seen (plus where should that mass come from?
  - Back then, 1 in 1000 galaxies was a quasar
  - Today: 1 in 10^6 galaxies is a quasar
  - Possible reasons:
    - fuel is all gobbled up or blown away, BHs still around but "hibernating"
    - Much more food around in the past: colliding galaxies (higher density)

Galactic Evolution II

- General observation: Oldest stars only a few Gyr younger than Universe, most in galaxies
- Most elliptical galaxies (and bulges) probably were formed after 3 Gyr (did the disks come later?)
  - Possible precursors: “weirdly shaped” irregulars that later merged (see Hubble Deep Sky survey)
- Initially high star forming activity, many giants -> relatively high luminosity, blue color
- Later smaller stars dominate, more reddish color
- Spiral galaxies: continue to make new stars - plenty of gas left
- Elliptic galaxies: May have used up their gas quickly; due to larger initial density fluctuation?
  - or because of wind from central BH? or are they due to collisions Summary: Evolution is complicated and not yet fully understood
  - collisions in the early Universe play a big role!