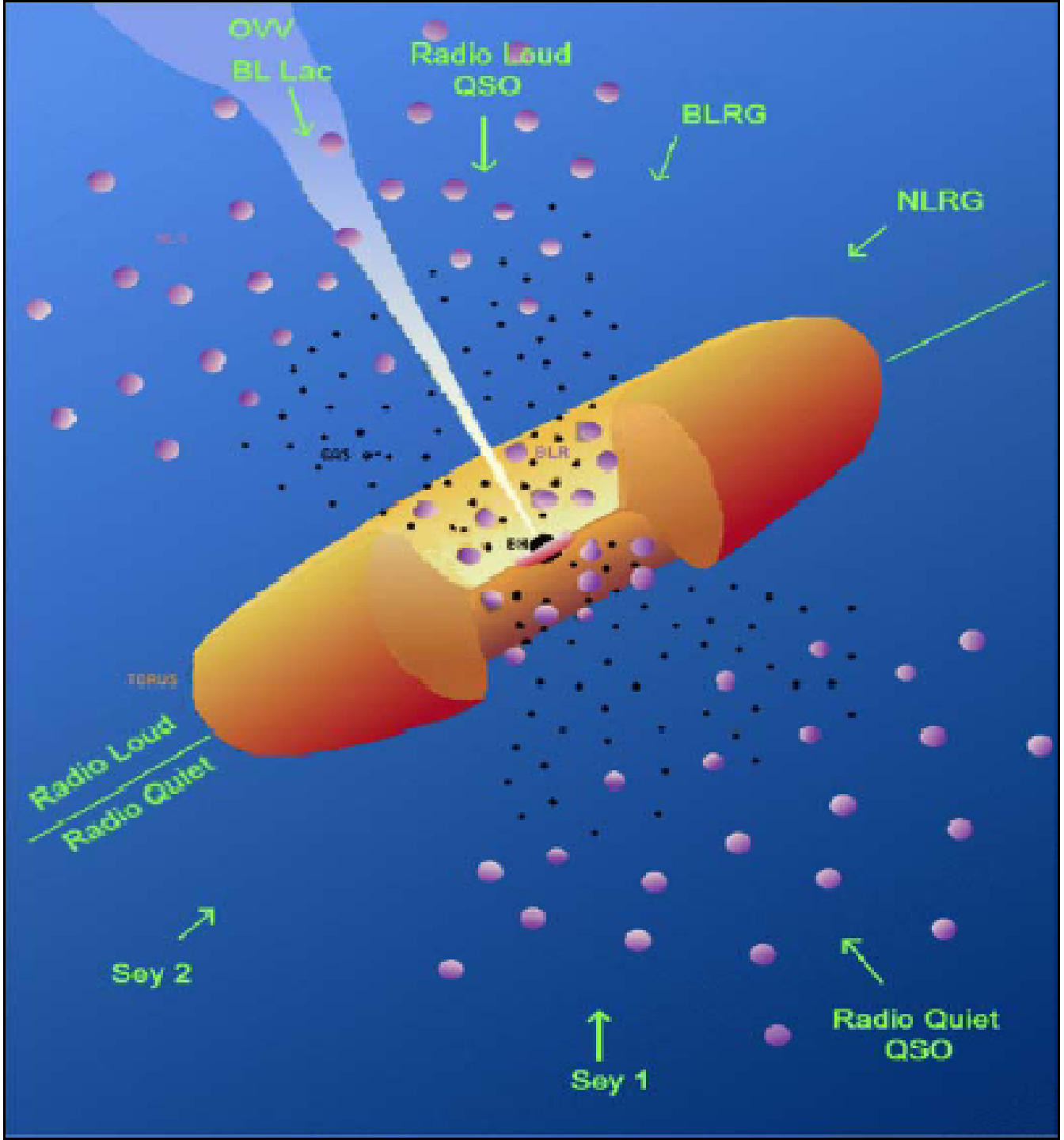
Active Galactic Nuclei

- Very small angular size: point like
- High luminosity: compared to host galaxies
- Broad-band continuum emission: radio to TeV
- Strong emission lines: unlike stars or galaxies
  - Broad lines ($\Delta\lambda/\lambda \sim 0.05$)
  - Narrow lines ($\Delta\lambda/\lambda \sim 0.002$)
- Variability: some are highly variable
- Polarized emission: very high for some
- Radio emission: radio-loud vs radio-quiet

AGN Classification

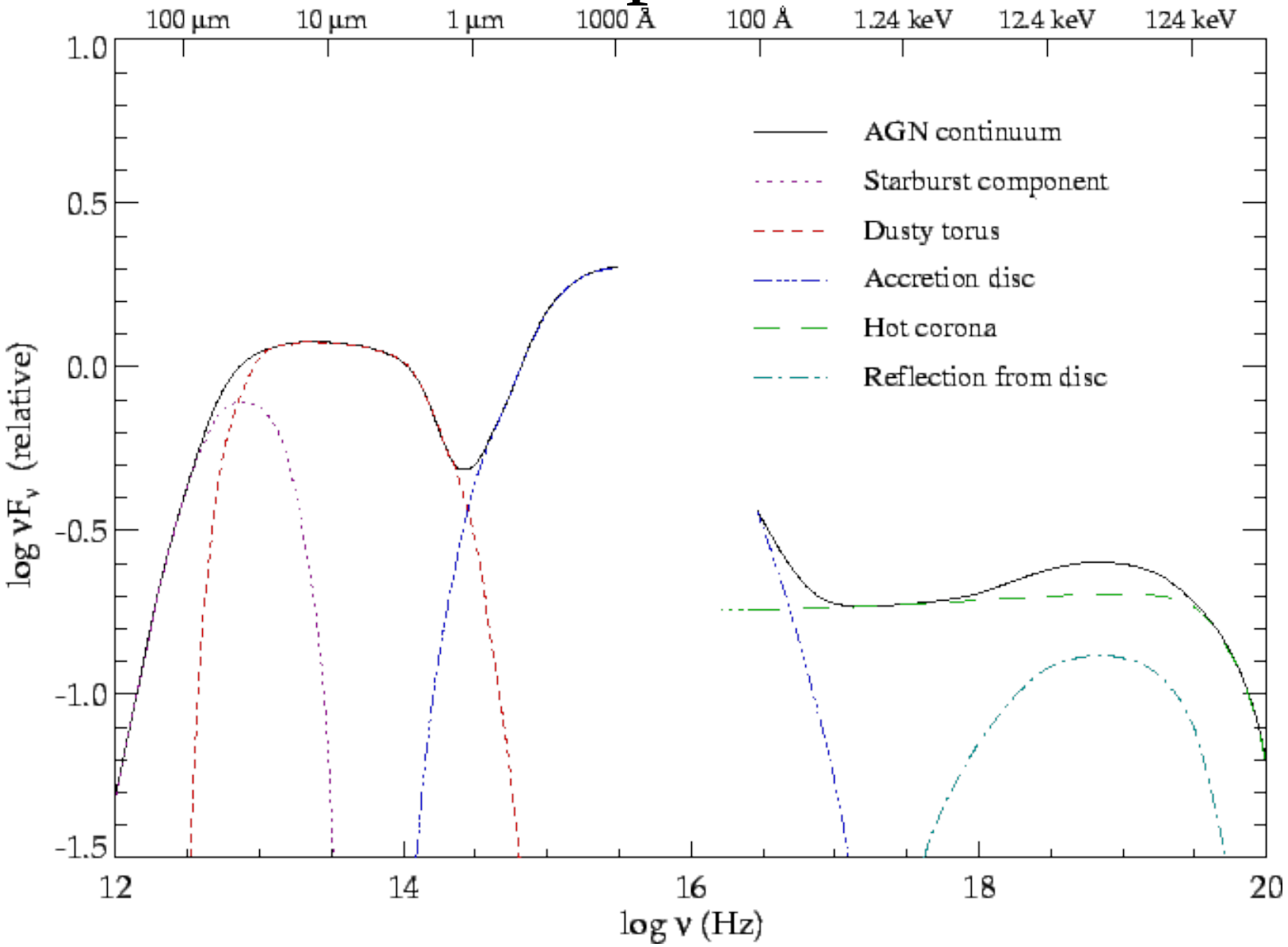
- Radio-Quiet AGN (~90%)
  - Radio-quiet quasars
  - Seyfert galaxies
    - Seyfert 1: both narrow and broad emission lines
    - Seyfert 2: only narrow emission lines
  - LINERs
- Radio-Loud AGN (~10%)
  - Radio-loud quasars: core dominated vs lobe dominated
  - Radio galaxies
    - Faranoff-Riley type 1 (FR 1): only narrow emission lines
    - FR 2: both narrow and broad emission lines
  - BL Lac Objects: very weak emission lines (blazars)
  - Optically Violent Variables (OVV)


OVV
BL Lac
Radio Loud
QSO
BLRG
NLRG
BLR
TORUS
Radio Loud
Radio Quiet
Sey 2
Sey 1
Radio Quiet
QSO

AGN Unified Scenario

- Supermassive black hole
- Thin accretion disk – emission peaks in UV, optically thick
- Disk corona – produces X-ray/hard X-ray emission, optically thin
- Dusty torus – essentially outer part of accretion disk, optically thick, produces IR emission
- High-velocity clouds – located near BH, produce broad optical emission lines, electron density above 10^{7} cm^{-3} (due to lack of forbidden lines), ionized by disk/corona
- Low-velocity clouds – located near/outside of torus, produce narrow optical emission lines which are collisionally excited, have a range of ionization levels, filling factor is small ~ 10^{-3}, material seems to be mainly outflowing
- Relativistic jets and radio lobes – extend parsecs to 100s kpc, detected up to X-rays, contain highly energetic particles

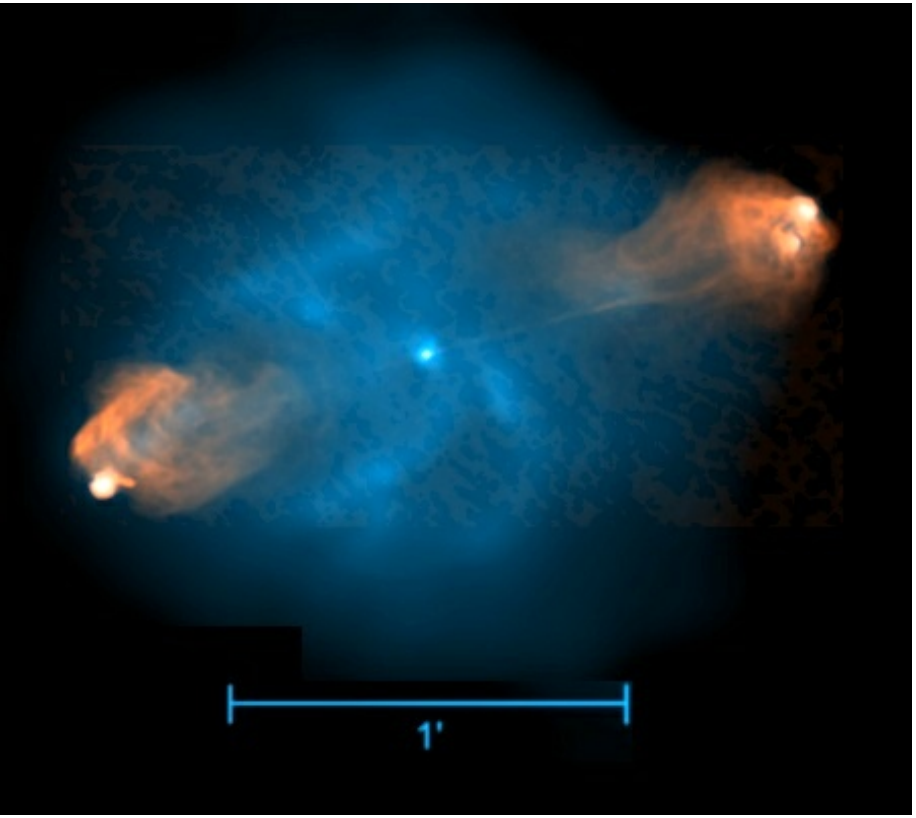
AGN Spectrum



Black Hole Mass

- High luminosity and rapid variability suggest accretion onto black holes
- Estimate mass of black hole:
  - $\eta Mc^2 = L\Delta t$
  - Δt = lifetime – estimate from size and expansion rate of radio lobes ~ 10^8 years
  - $\eta \sim 0.1$, $L \sim 10^{45}$ erg/s
  - Then $M \sim 3\times10^{40}$ gm ~ $10^7 M_\odot$

Cyg A radio/x-ray lobes

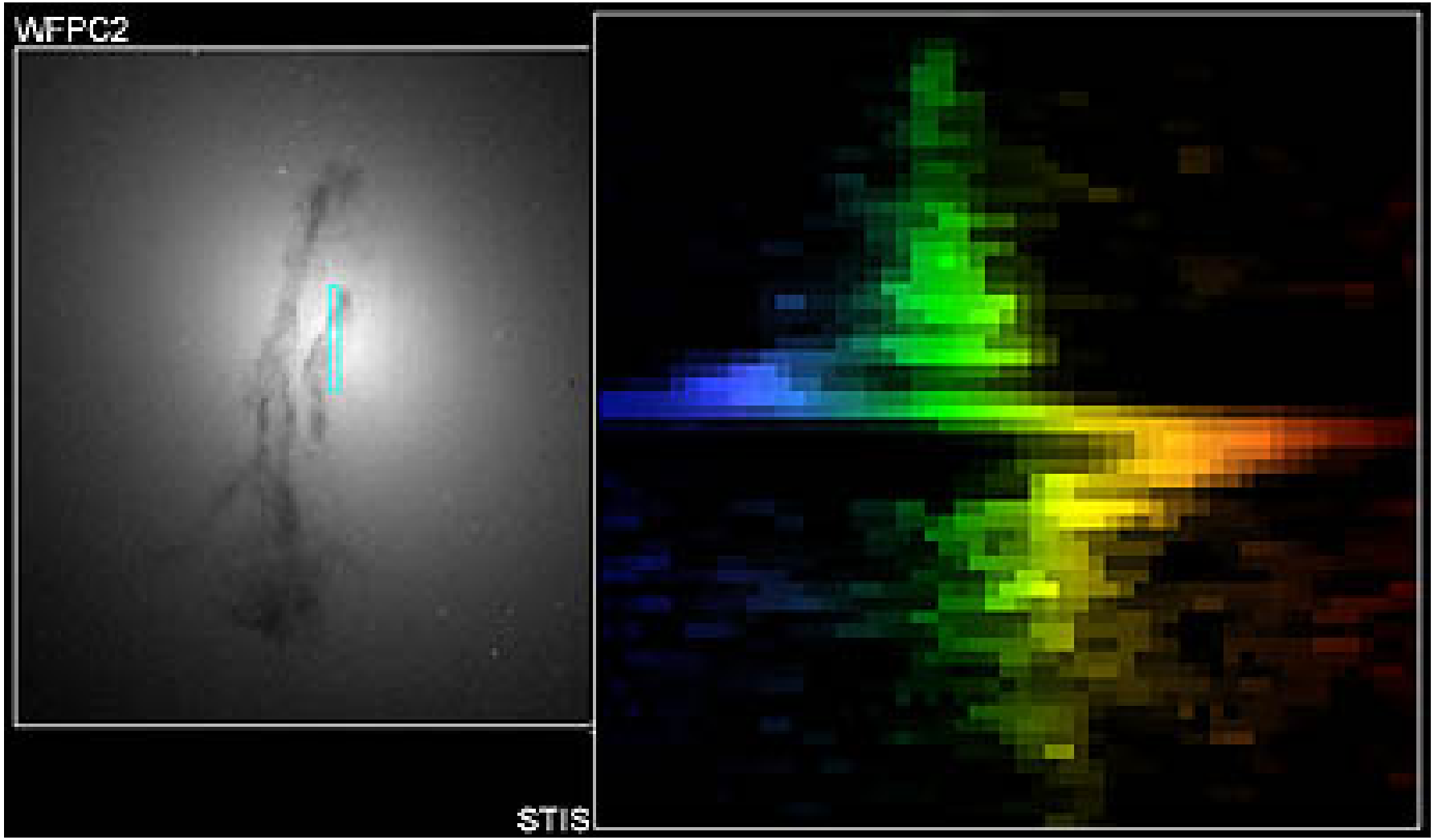


Lobe separation ~ 100 kpc,
speed ~ 1000 km/s

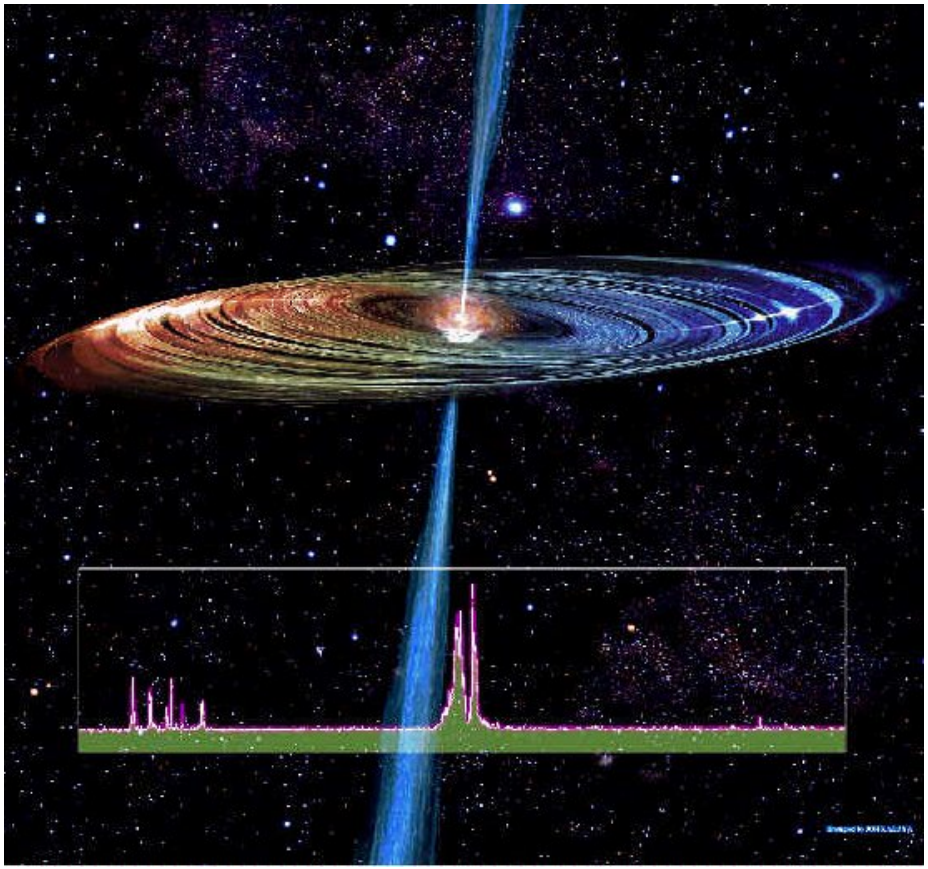
$\Rightarrow$ age $\Delta t \sim 10^8$ years

Alternate way to estimate active lifetime of AGN is
Δt ~ (galaxy lifetime)(duty cycle)
~ (10^{10} years)(1% of galaxies are active) ~ 10^8 year

Mass Determination



Water Maser in NGC 4945



Water maser emission (at 1.3 cm) from radii between 0.14 and 0.29 pc.

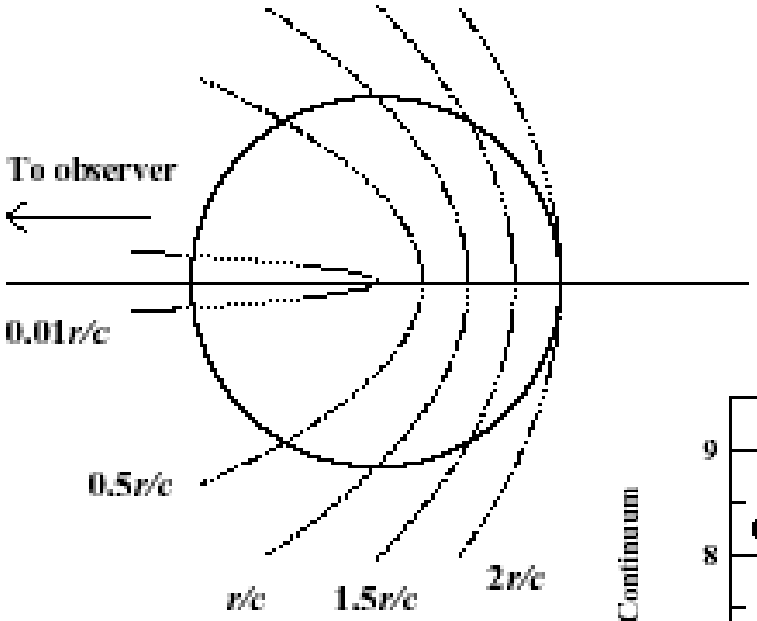
Extent is a few milliarcseconds and can be mapped in the radio.

Measured black hole mass is $3.9 \times 10^7 M_\odot$

Masers are also the best direct evidence for accretion disks.

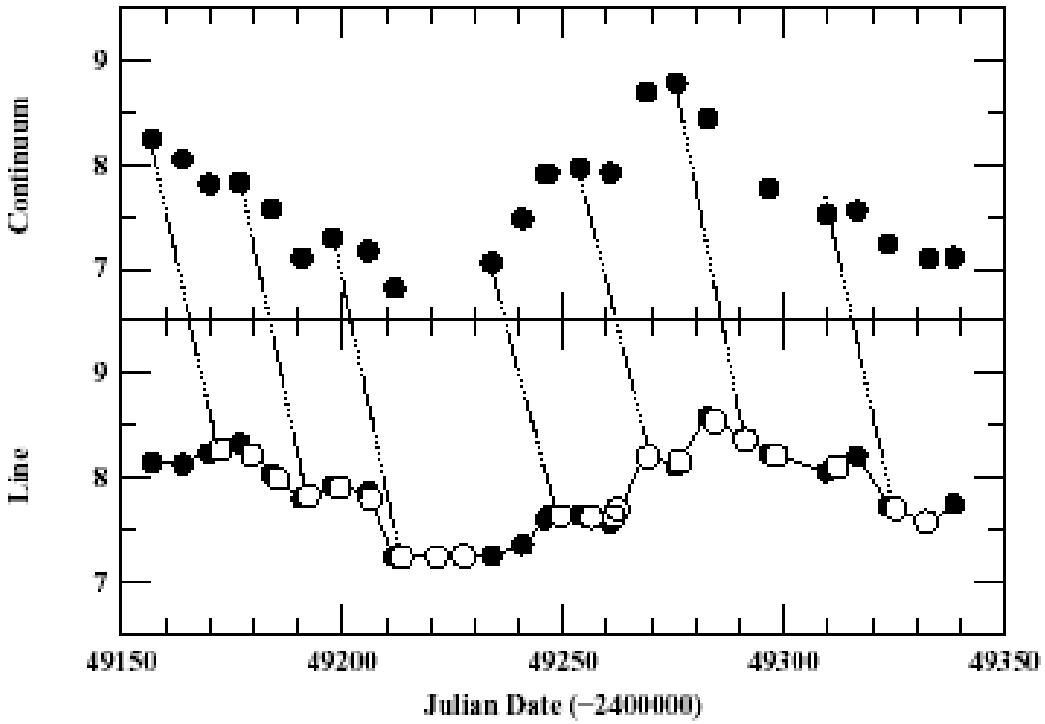
The disks are geometrically thin, but warped.

Reverberation mapping



$$M = \frac{f r \sigma^2}{G}$$

r = size, σ = velocity dispersio



AGN Accrete from the ISM

- Via Bondi accretion

$$\dot{M} \simeq (1.4\times10^{11}\,\mathrm{g/s})\left(\frac{M}{M_\odot}\right)^2\left(\frac{\rho}{10^{-24}\,\mathrm{g/cm^3}}\right)\left(\frac{c_s}{10\,\mathrm{km/s}}\right)^{-3}$$