Bulletin on the Biggest, Baddest Black Hole on the Block

(SgrA* that is)

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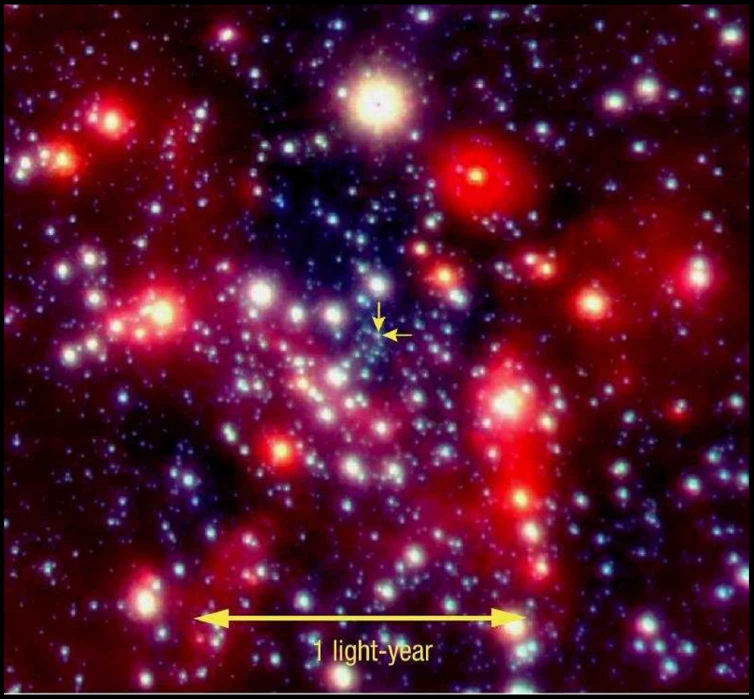
UIUC
CTA Lunch Seminar
September 21, 2005

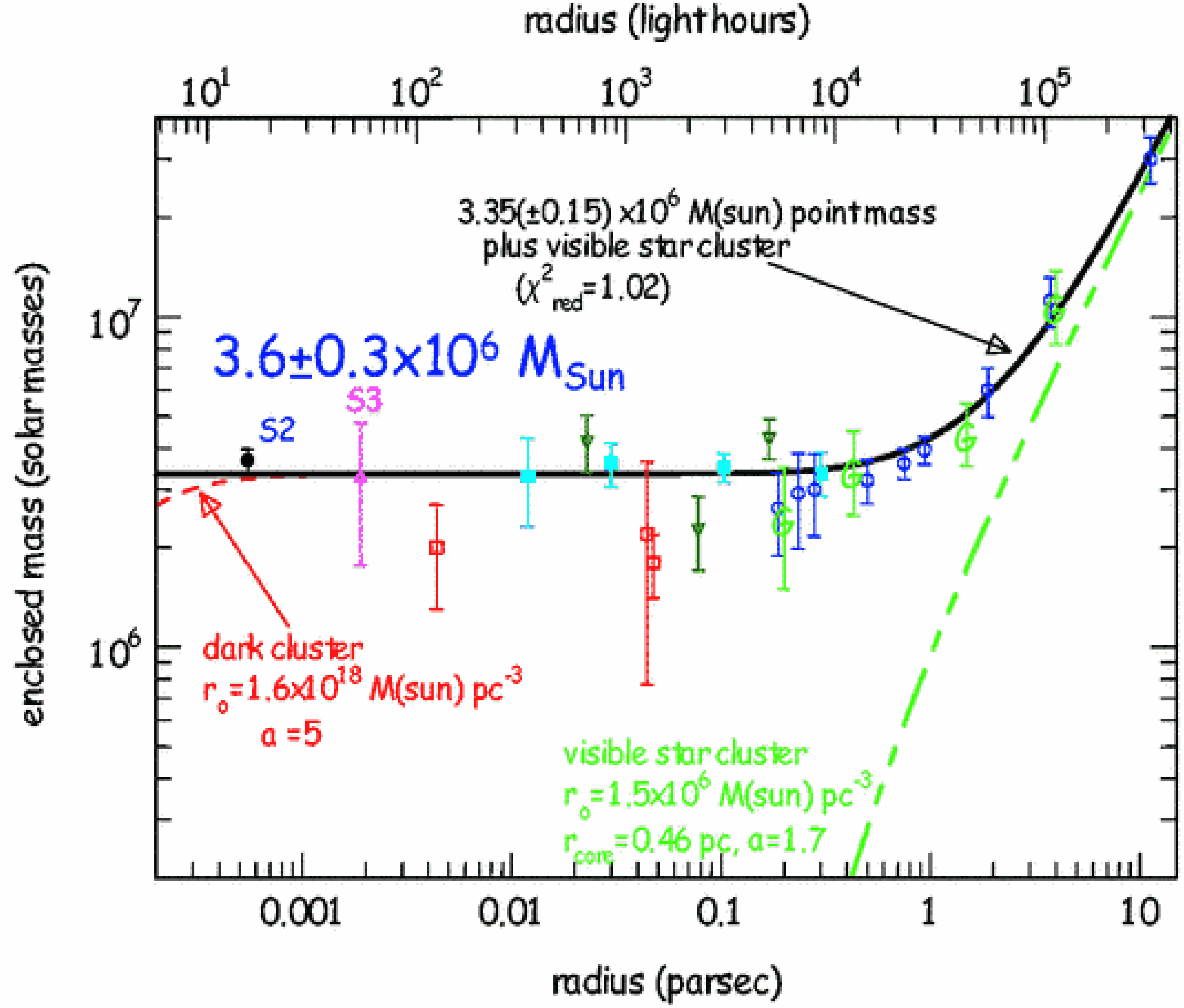


Outline:

- Introduction: How Big and Bad is it? M, R, t_{dyn}, d, etc.
- What can SgrA* do for us?
- Observations: X-rays, IR, Radio and beyond!
- Models: Thin disk, 2-T disks, ADAF, Jet, *CDAF*, *ADIOS*,...
- Future Methods and Trends
- Conclusion

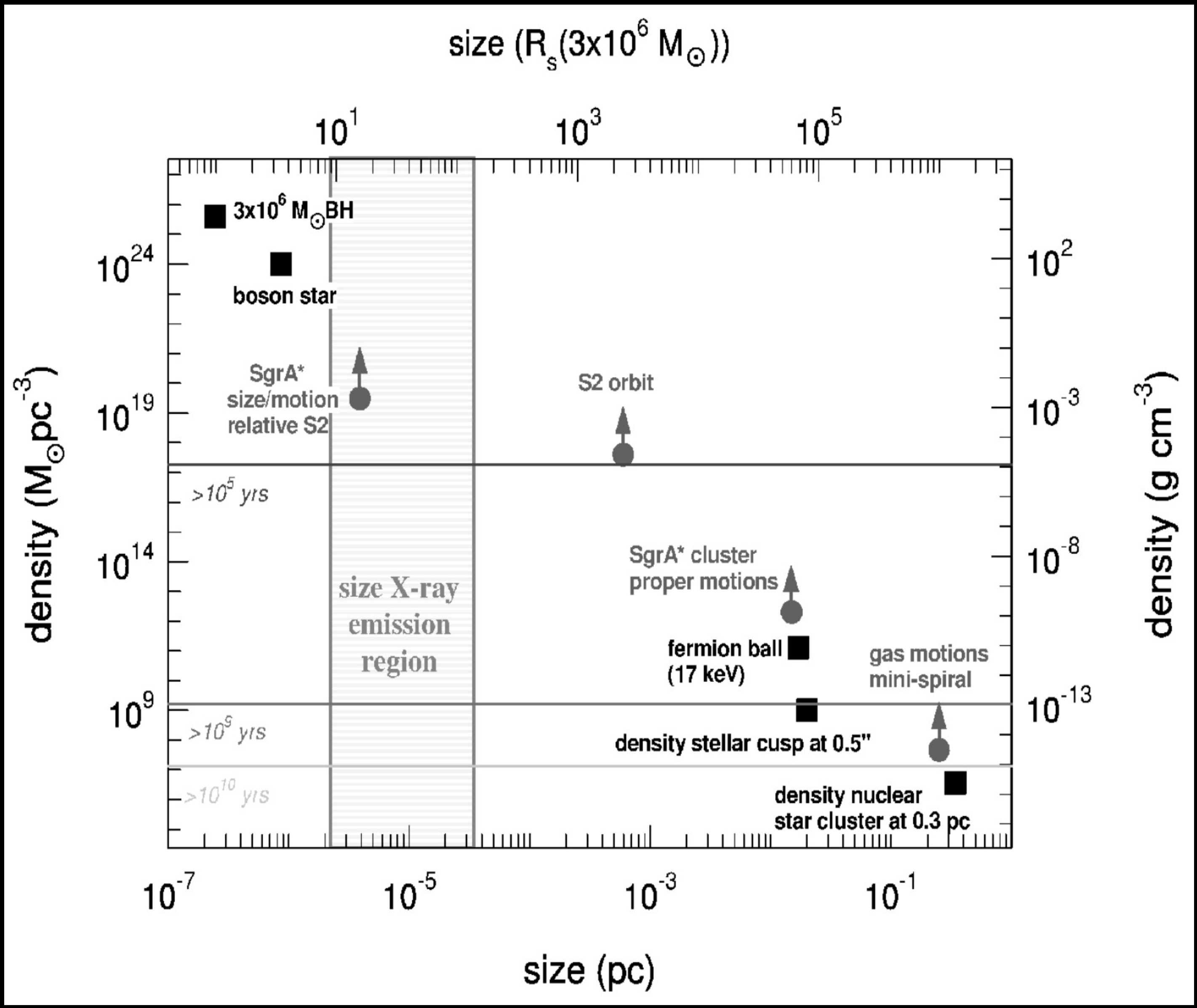
• Alexander 2005 astro-ph/0508106
• SgrA* KITP conference:
http://online.itp.ucsb.edu/online/galactic_c05/

It's a Black Hole, ok?



Schödel et al. 2002, 2003, Ghez et al. 2003, Eisenhauer et al. 2003, 2005

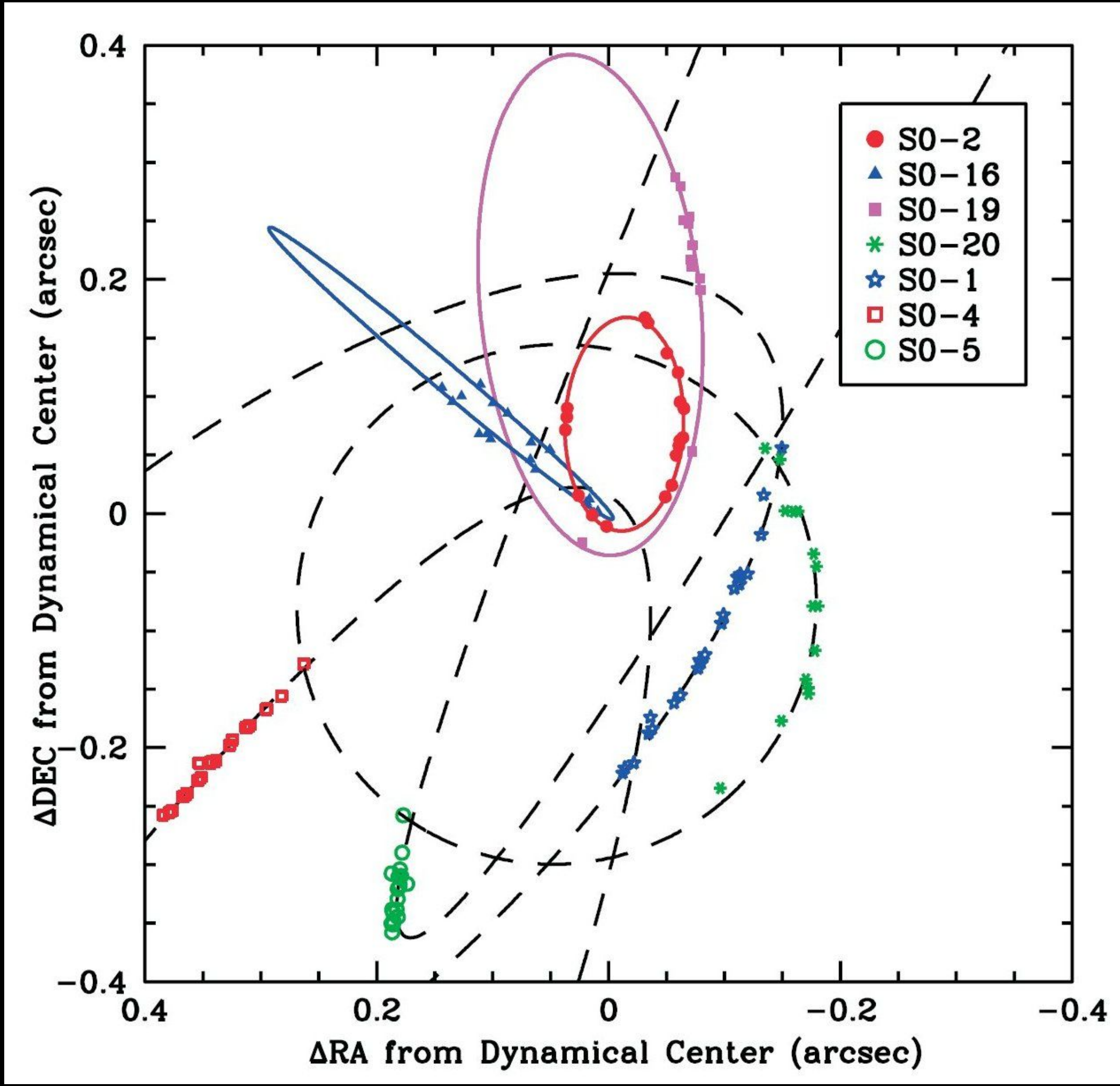
It's a Black Hole, ok?



- Very few possible compact sources
- Who's seen a scalar boson anyway?
- Spectra fits well with jet & accretion models
- Some spectra features seem to indicate variability < 10 R_s
- Dark star clusters are short lived

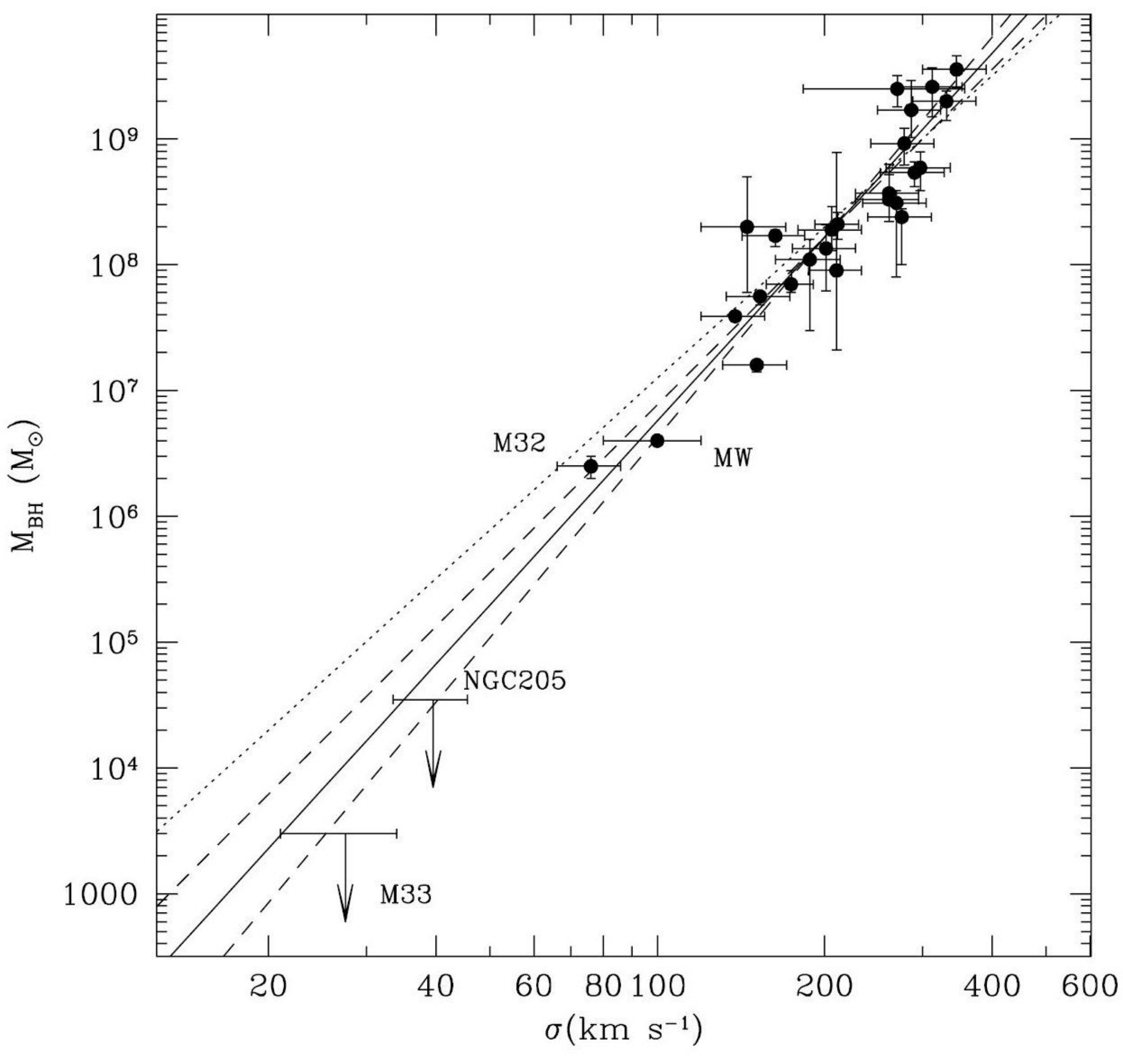
How Big is it?

- Ghez et al. 2005 (UCLA)
  - New Keck diffraction limited observation, adaptive optics
  - Simultaneous 6-orbit fit
  - $M_{SgrA*} = 3.7 \pm 0.2 \times 10^6\ M_{Sun}$
- Genzel et al., Nature, 2003
- Eisenhauer et al. 2005 (MPE/UCB)
  - ESO/VLT, adaptive optics
  - $M_{SgrA*} = 3.6 \pm 0.3 \times 10^6\ M_{sun}$
  - $R_o = 7.6 \pm 0.3$ kpc
  - Biggest black hole on the sky!!!
  - $R_{SgrA} = 1\times10^{12}\,cm = 3.6\times10^{-7}\,pc = =0.07\,AU =$



Ghez et al. 2005

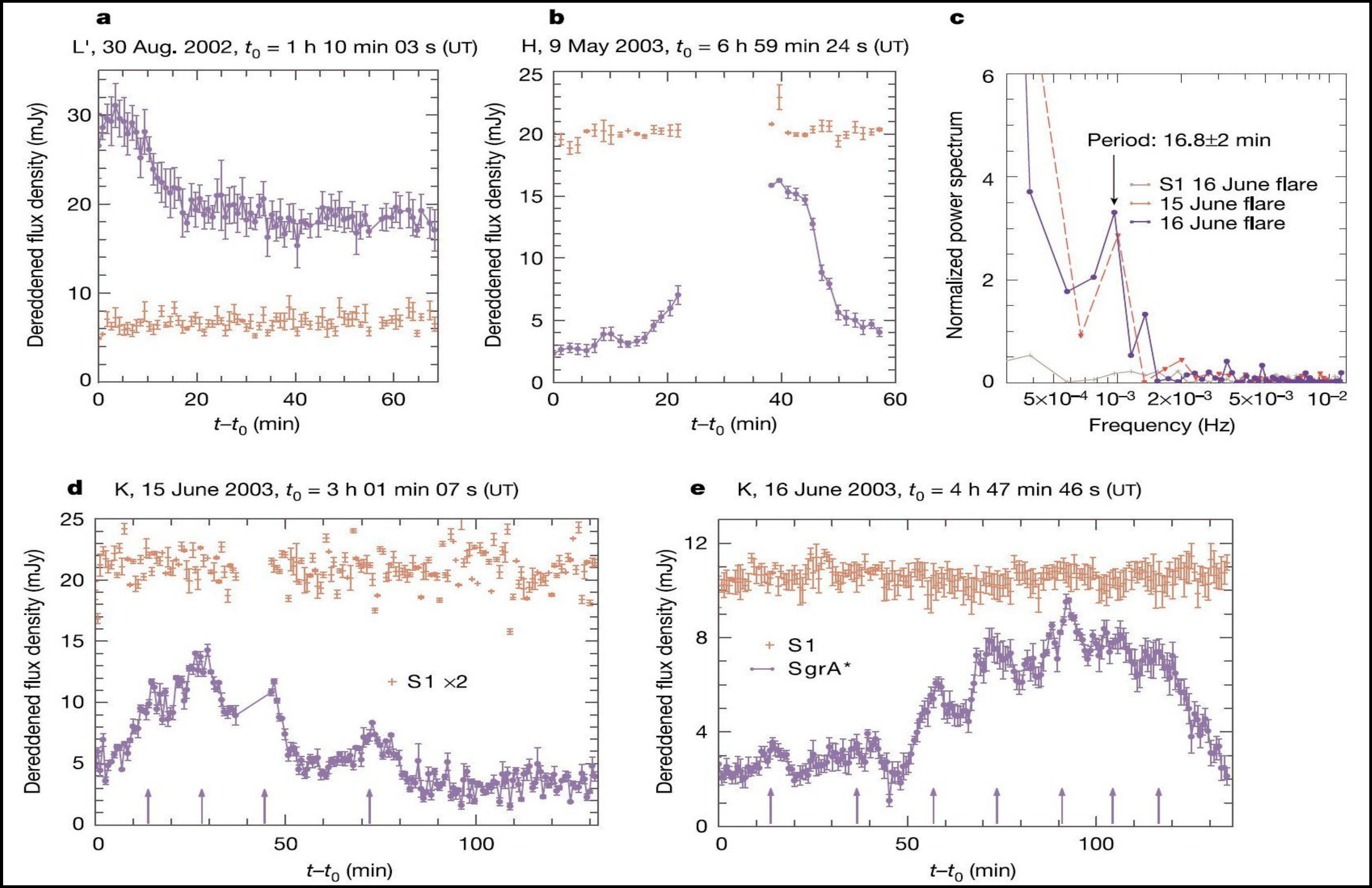
How Bad is it?



Solid: Ferrarese & Ford (2005)
Dotted: Tremaine et al. (2002)

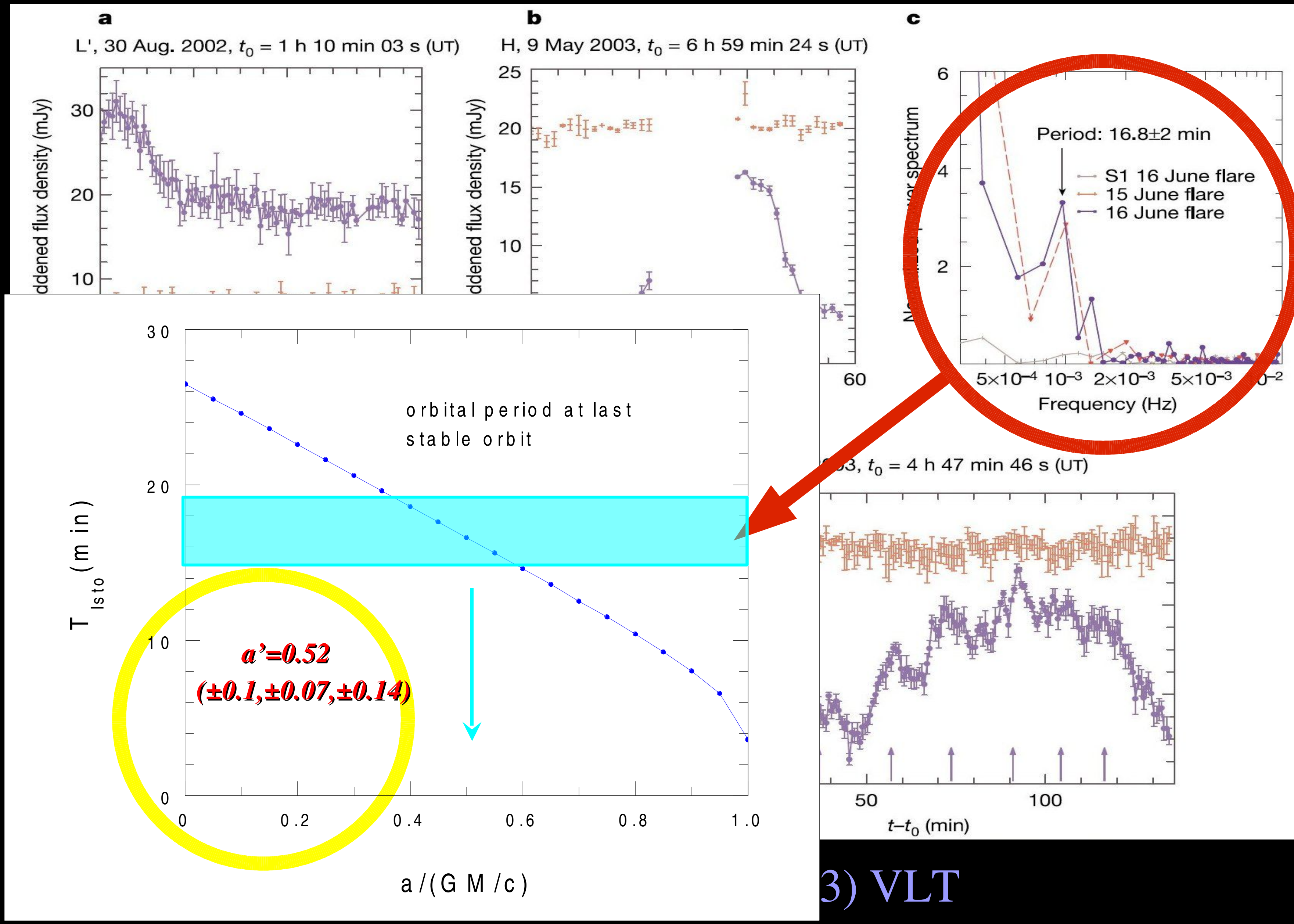
- Only sources where Sphere of Influence is resolved.
- SgrA* shows other spectral similarities to LLAGN

IR Observations



Genzel et al, Nature (2003) VLT

IR Observations

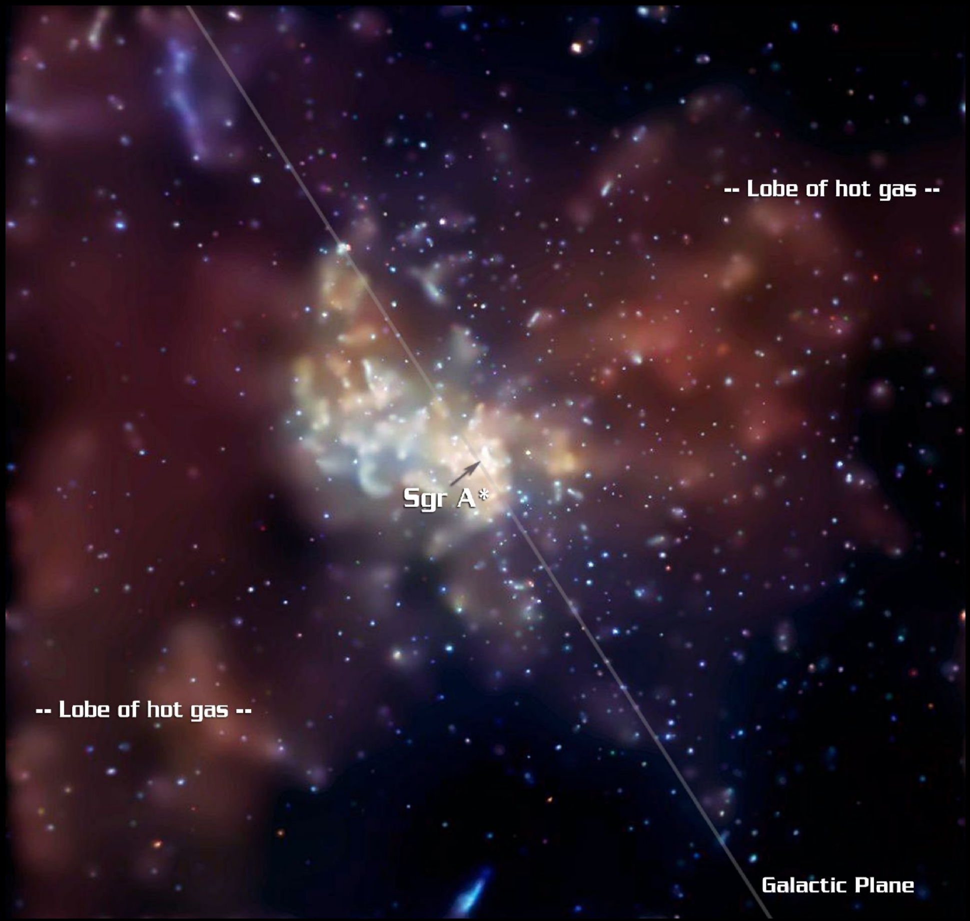


3) VLT

X-Ray Observations

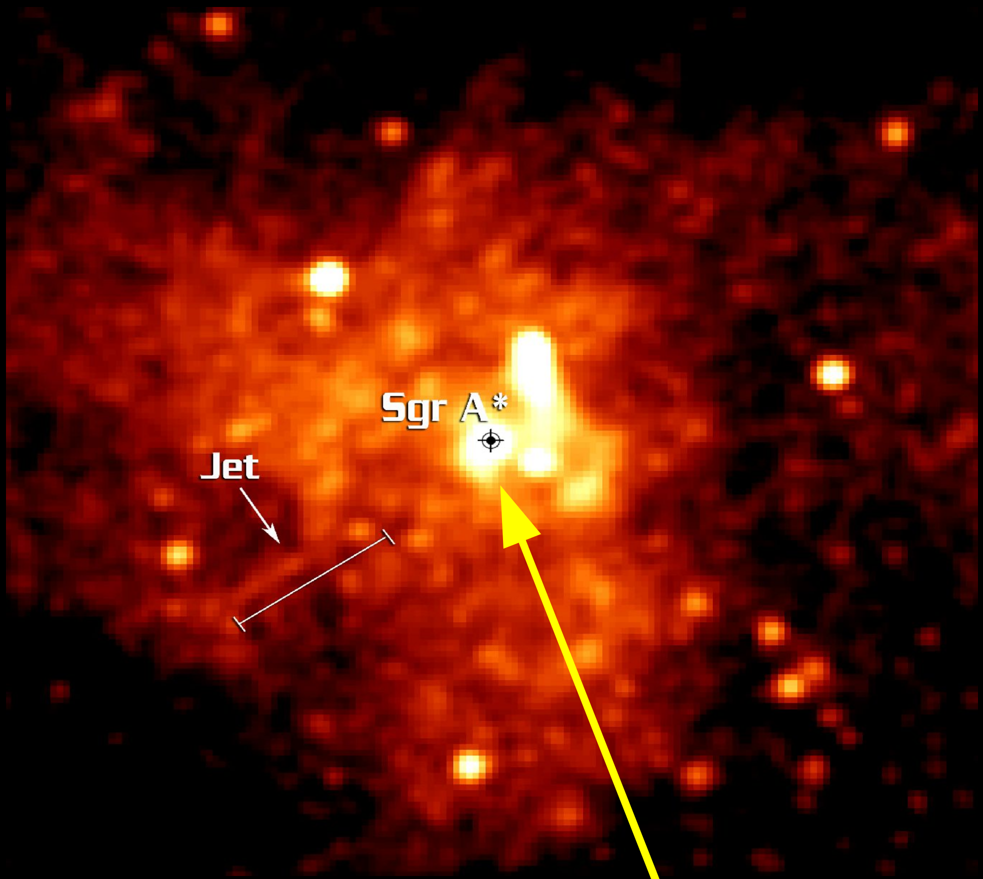
NASA/UMass/D.Wang et al. (Chandra)
120x48 arcmin or 900x400 light-year

X-Ray Observations



8.4 arcmin

1.23 arcmin



1.4 arcsec

NASA/CXC/MIT/ F.K. Baganoff et al.

X-Ray and Bondi

Modelling it as kT~1.3keV hot, optically-thin emission:

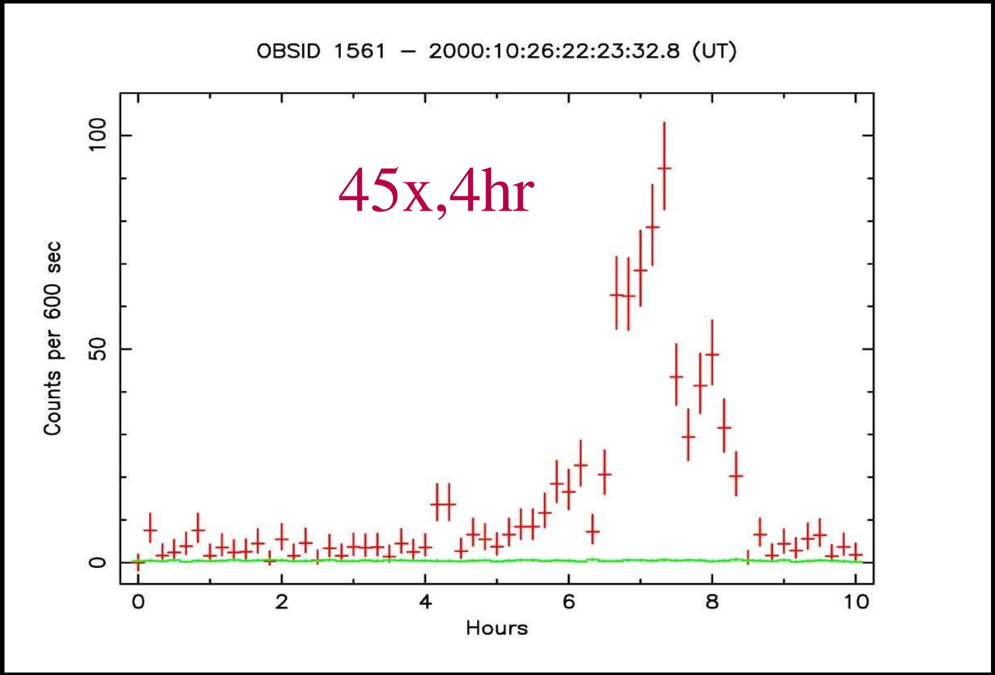
$$n_e = 30\,cm^{-3}$$

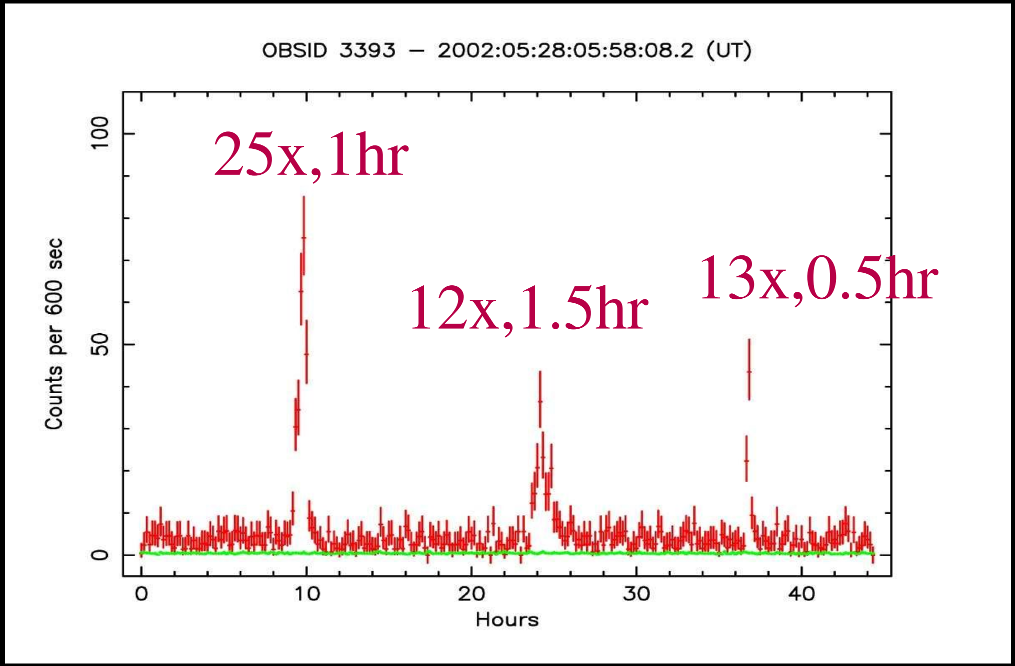
$$c_s^2 = \gamma\, k\, T / \mu\, m = 550\, km/s = v_{wind}$$

$$R_B = 2\,G\,M_{SgrA}/c_s^2 = 0.1\,pc = 2.7\,arcsec.$$

$$\rightarrow \quad R_B = 2\,R_{X-rays}$$

X-Ray Variability

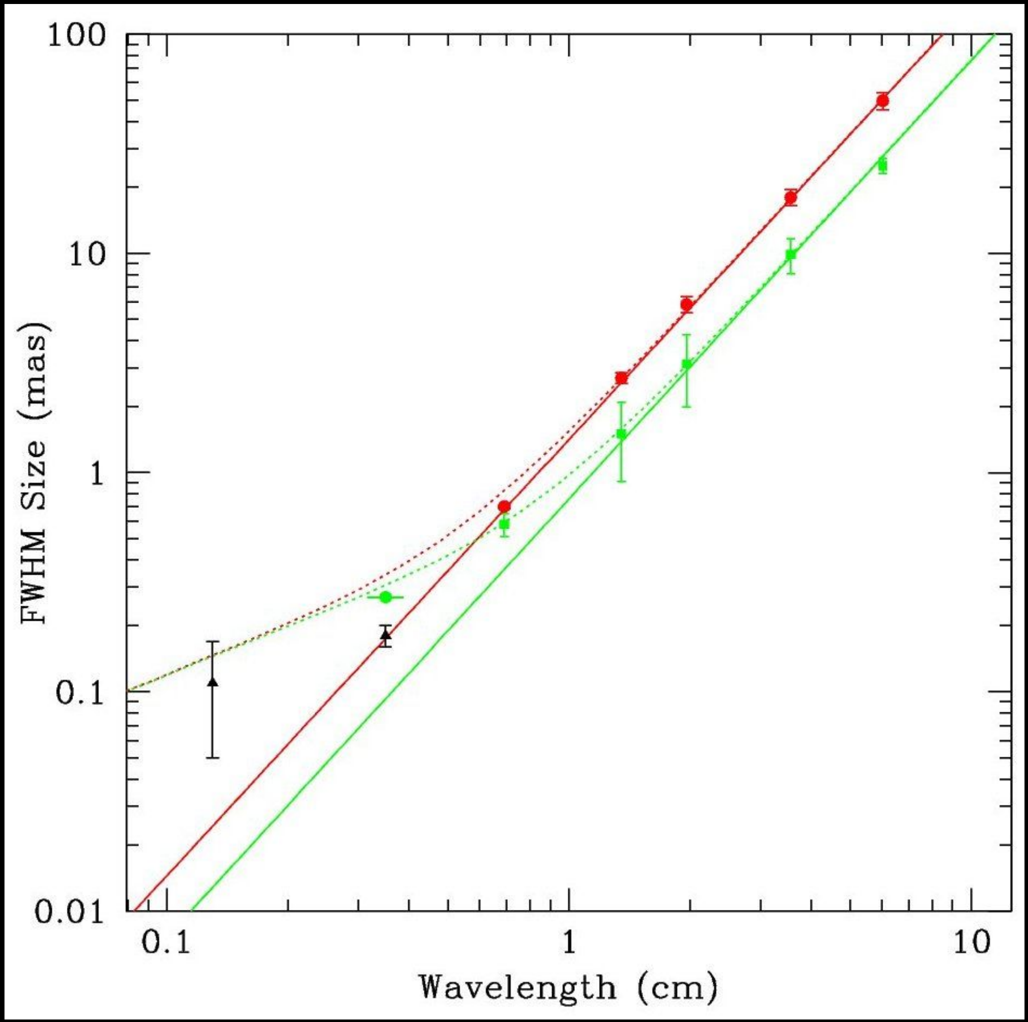


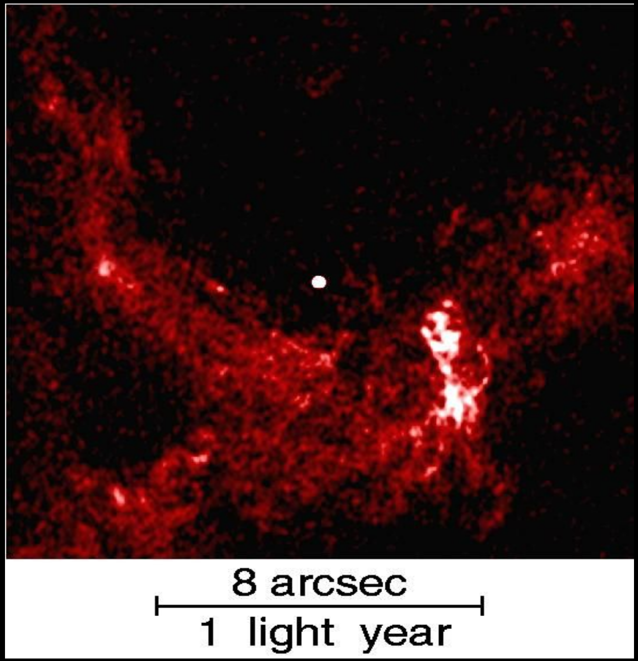


1hr variability --> ~20 R_s

Baganoff et al. (2000-2003)

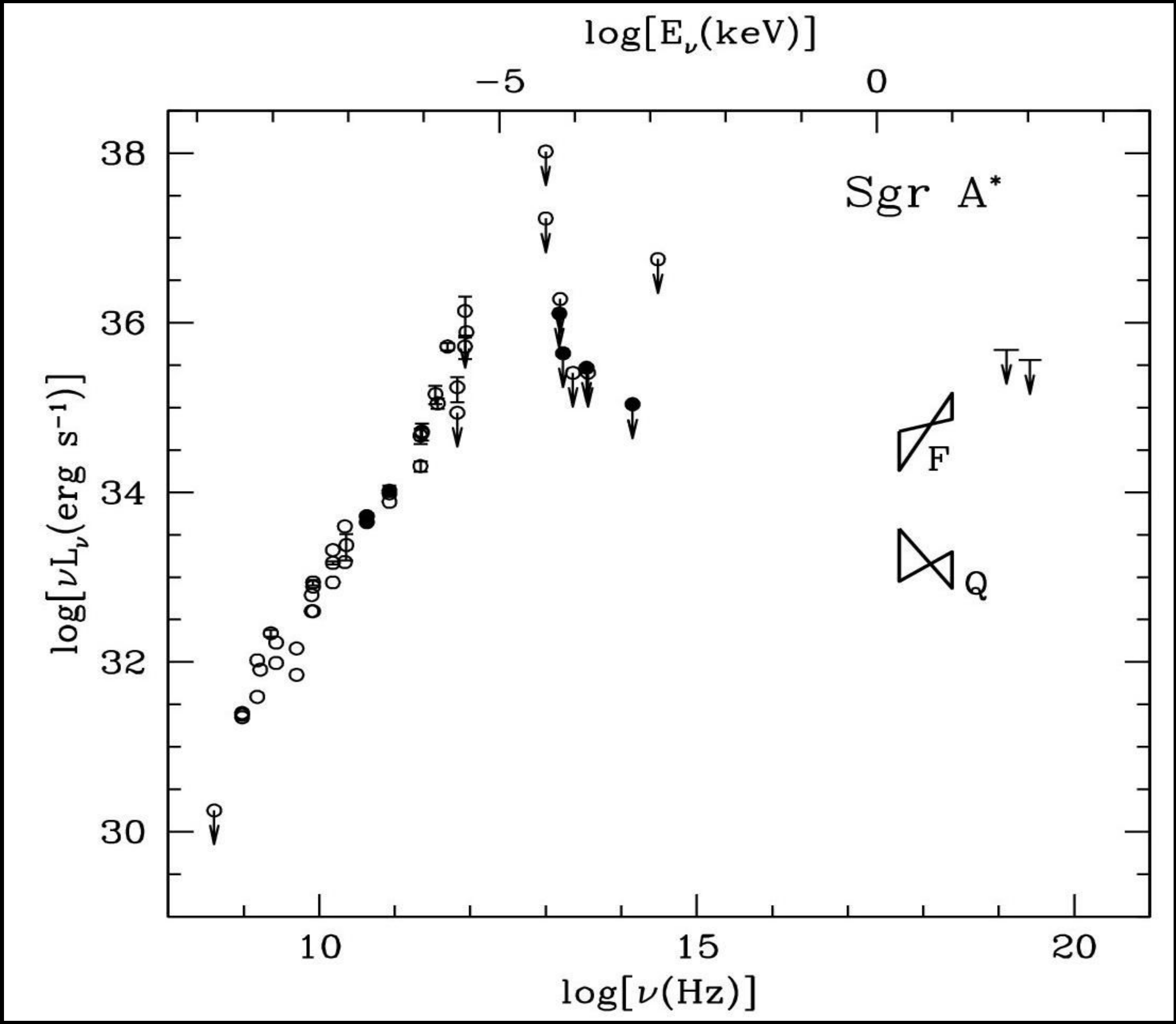
Radio (VLBA)





- Position best determined in radio (best res. on the planet)
- Visible Size ~ 1/ν
- Optically thin at ~submm λ —> horizon images

Composite Spectrum



The Luminousity Problem

$$L_{SgrA} = 10^{36}\, erg/s$$

$$L_{Edd} = 4\pi c G M \mu_e / \sigma_T = 1.51\times 10^{38} (M/M_{sun})\, erg/s$$

$$L_{Edd}(M_{Sgr}) = 5.44\times 10^{44}\, erg/s$$

$$\rightarrow \quad L_{Sgr} = 10^{-8} L_{Edd}$$

$$\dot{M}_{X-rays} = 4\pi R_B^2 \rho c_s = 4\times 10^{-5} M_{sun}/yr$$

$$\rightarrow \quad L = \eta c^2 \dot{M}_{X-rays} = \eta\; 2.1\times 10^{43}\, erg/s$$

The Luminousity Problem

$$\rightarrow \quad L_{SgrA} = 5\times 10^{-6} L_{thin}$$

Radio Linear Polarization contraints:

$$\dot{M} = 10^{-3}\dot{M}_{X-rays} \rightarrow \eta = 10^{-3}\eta_{thin}$$

The Luminousity Problem

$$\rightarrow \quad L_{SgrA} = 5\times10^{-6} L_{thin}$$

Radio Linear Polarization contraints:

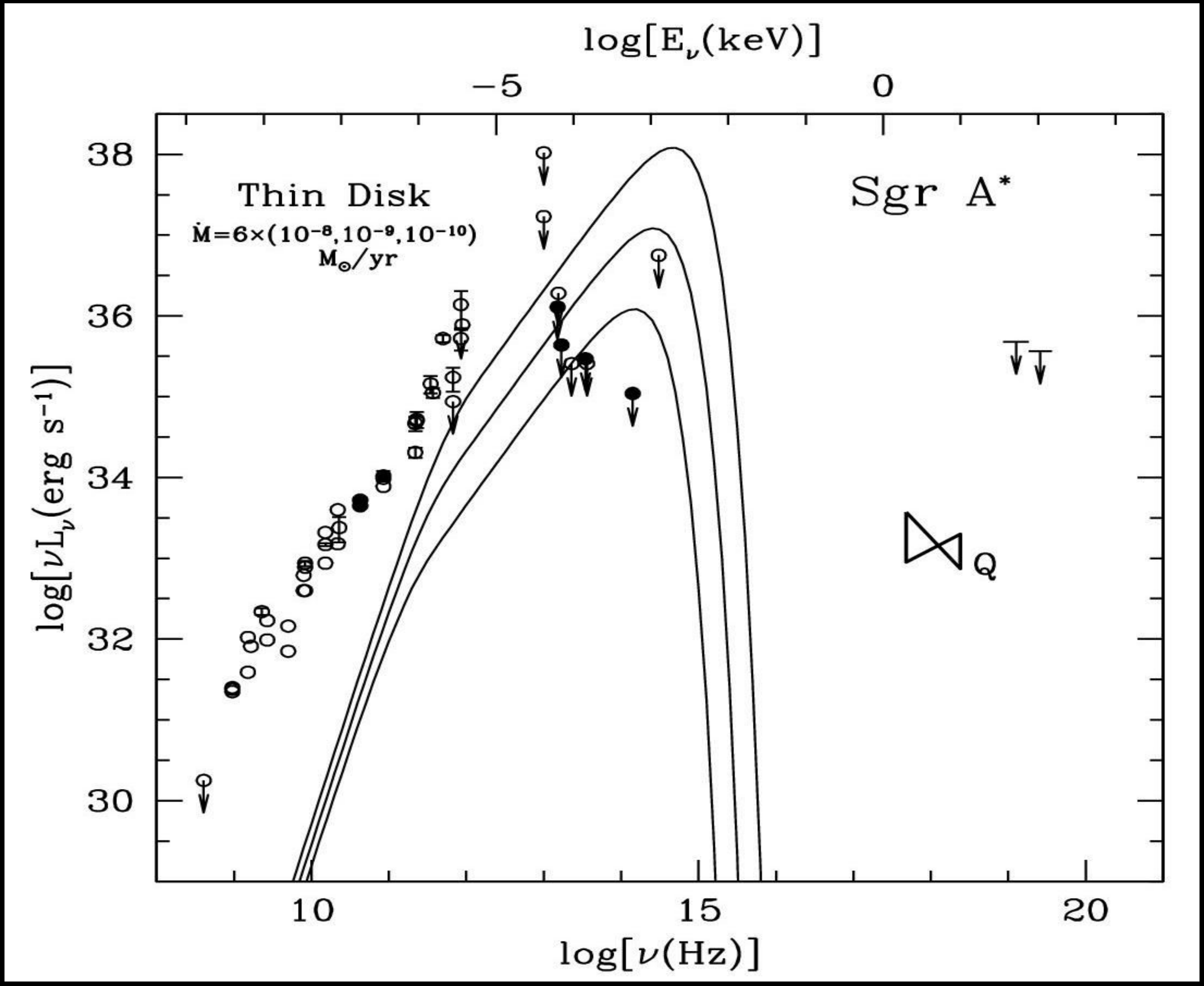
$$\dot{M}=10^{-3}\dot{M}_{X-rays} \rightarrow \eta=10^{-3}\eta_{thin}$$

No thermal thin disk emission

?

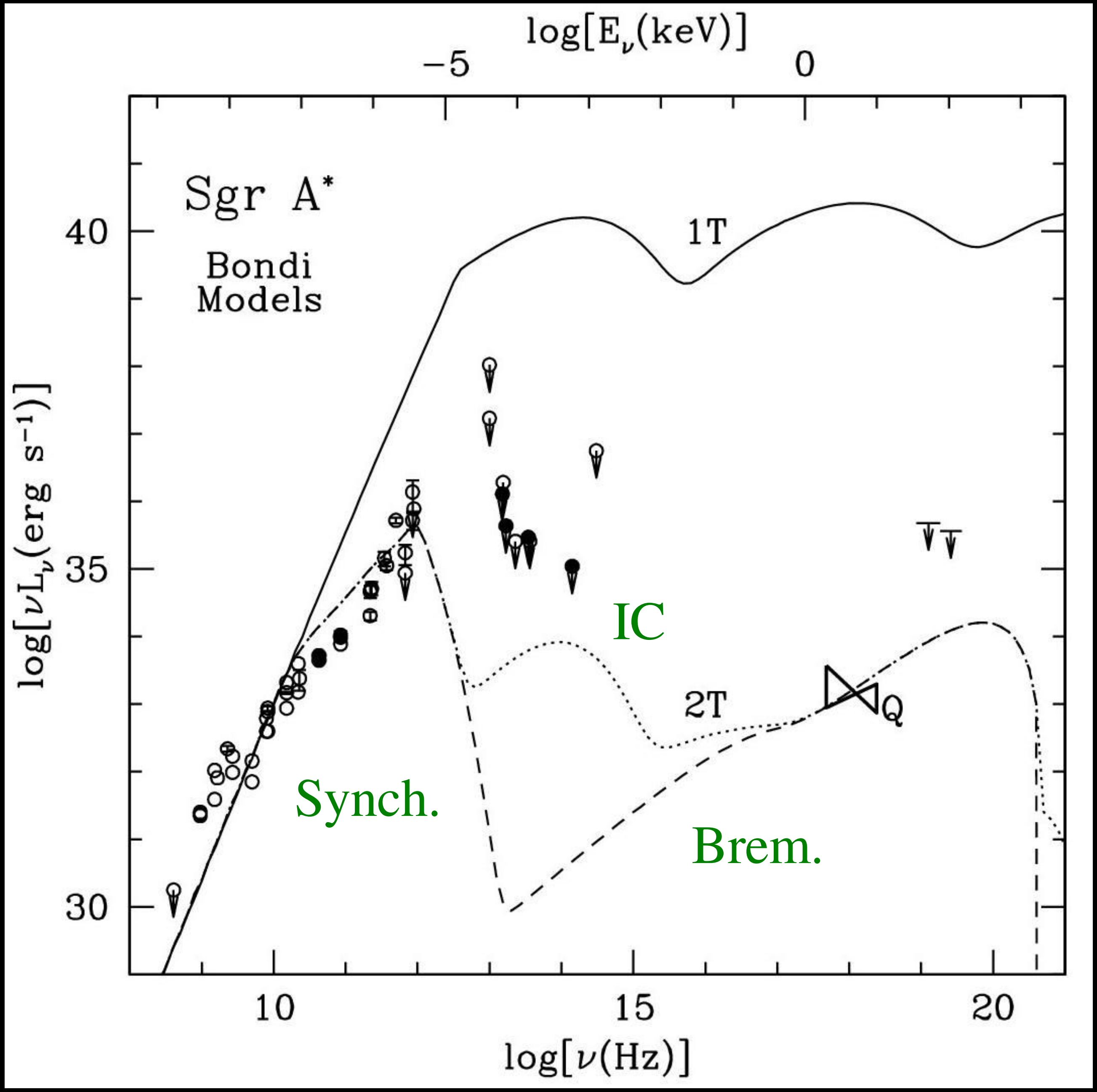
Bad!

Plain BB Bondi Spectrum (more B's!)



Narayan astro-ph/0201260

Realistic Bondi Spectrum



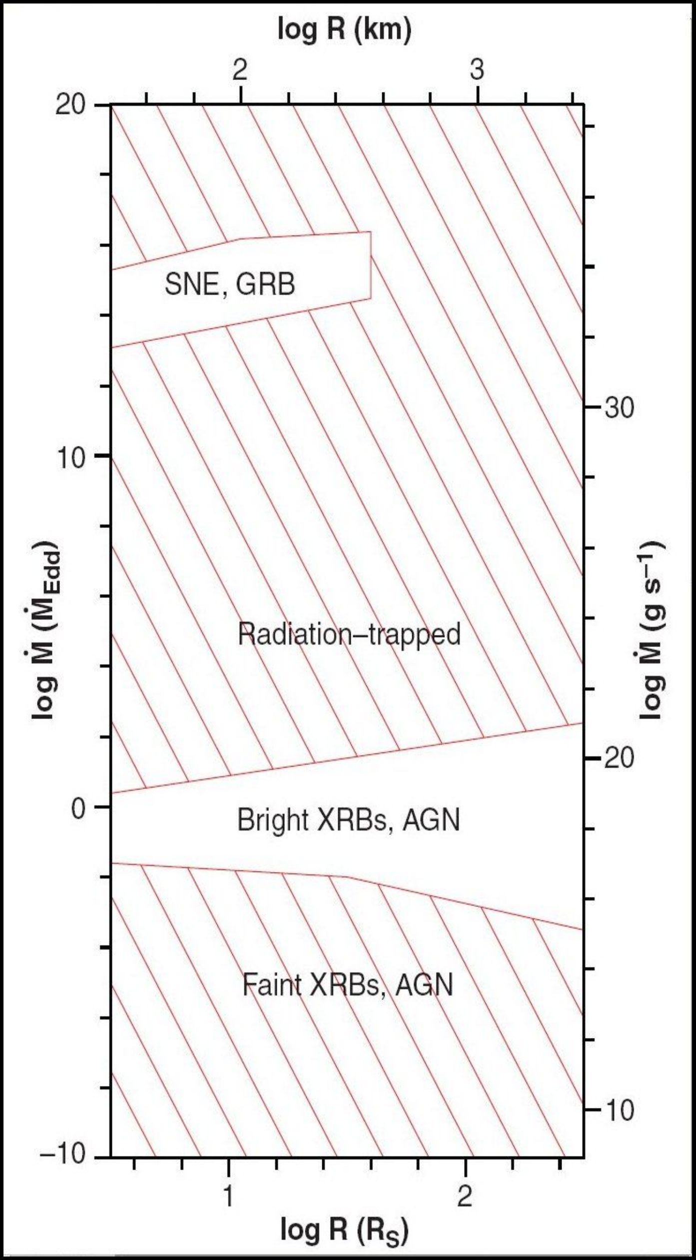
- Including Synch., Bremsstrahlung (+IC)
- At low ρ, e's & ions decouple since

$$t_{Coulomb} > t_{infall}$$

- Shapiro, Lightman, & Eardley (1976)

Narayan astro-ph/0201260

RIAF's (Radiatively Inefficient Accretion Flows)



- **ADAF's (Advection Dominated Accretion Flows)**:
- Narayan & Yi (1994-5), Yuan et al. (2003-4)
  - "At least I didn't name them Type II accretion flows!", Narayan, KITP SgrA* Conf. 2005

$$Q_{diss} > Q_{rad.} \qquad \rho \;\alpha\; r^{-3/2}$$

  - 2-T flows, ala Shapiro et al., advection stabilizes
  - Thick disks, ~spherical
  - Convectively unstable

CDAF's & ADIOS's

$$\rho \; \alpha \; r^{-3/2+s} \qquad \dot{M}_{in} = \dot{M}_{out} \left(R_{in} / R_{out} \right)^{s}$$

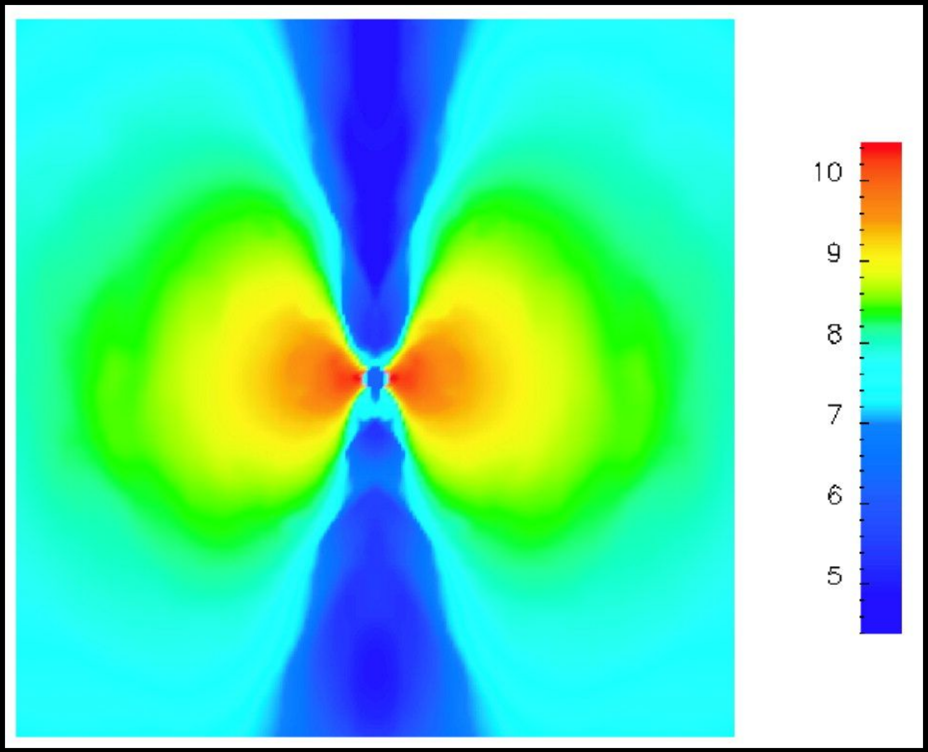
$$0 < s < 1$$

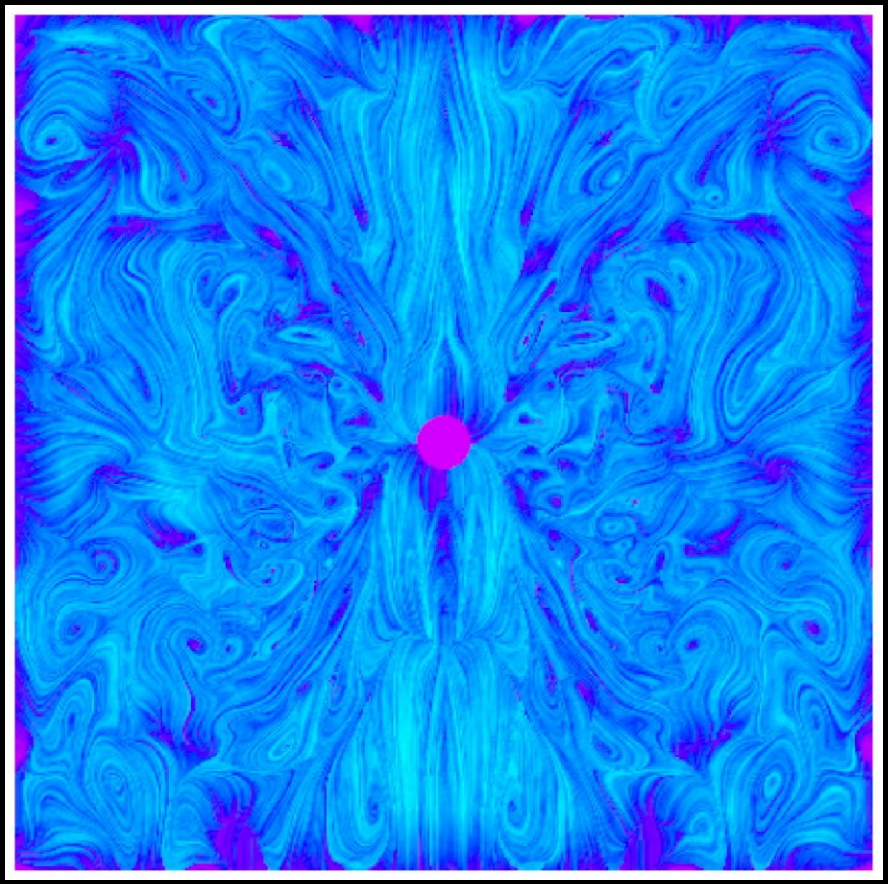
- **ADIOS (Advection Dominated Inflow/Outflow Sol's)**
  - Blandford & Begelman (1999)
    - Much of the energy is blown away in a wind

$$s = 1$$

- **CDAF (Convection-Dominated Accretion Flows)**
  - Quataert & Gruzinov (2000)
    - Ang. Mom. Transported inward
    - Energy Transported outward
    - Weakest accretion of the RIAF's

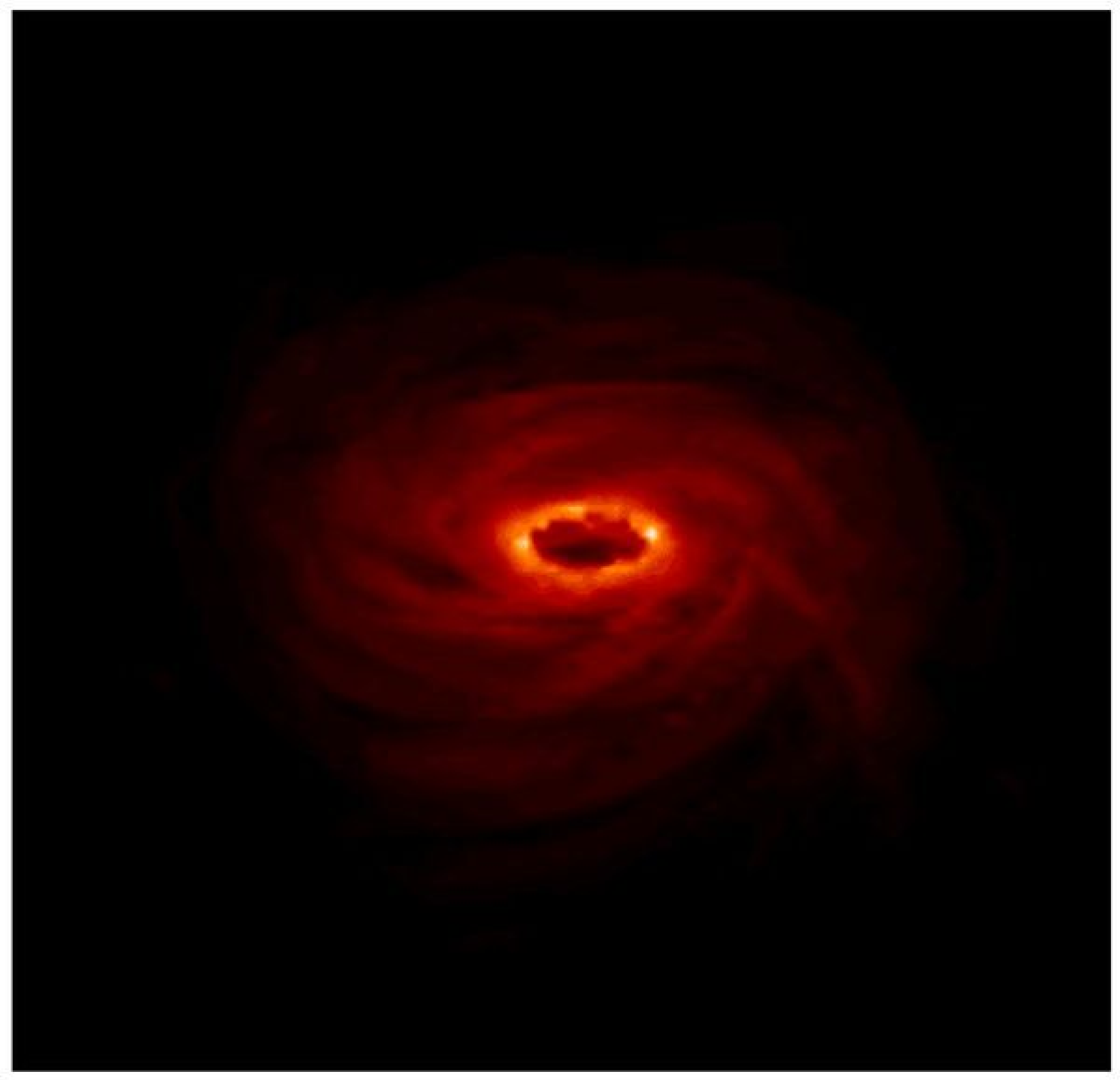
RIAF Simulations





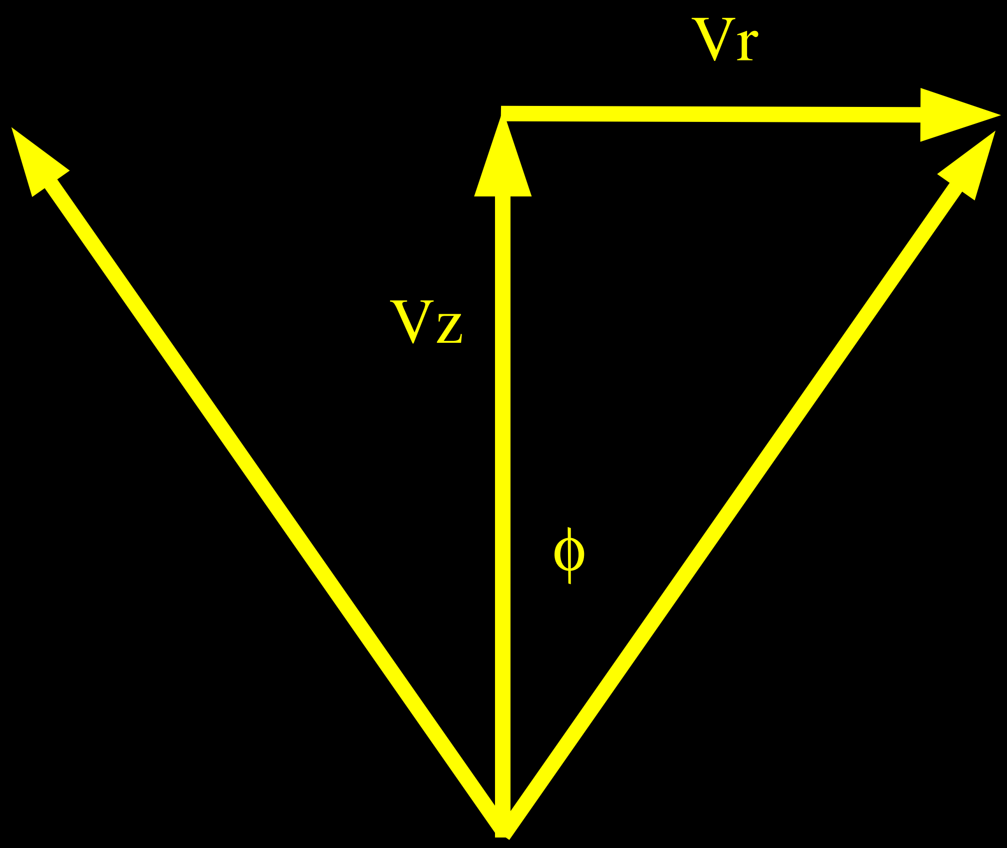
- Igumenshchev, Narayan, Abramowicz (2003)
- 3D, MHD, Paczynski & Wiita Pot., Viscous, Resistive
- Toroidal B fed in from outer boundary
- Similar $\rho \sim 1/R$ close to analytic CDAF

RIAF Simulations



- Goldston, Quataert, Igumenshchev (2005)
- 3D RIAF Sim. as before
- $T_e = a\, T_{tot}$
- n_e ~ Maxwellian + PLT
- Opt. thin at 450 GHz
- t_{orbit} timescale for opt. thin emission
- > t_{orbit} timescale for opt. thick emission

Jet Models



- Falcke et al (1995-now)
- Blandford & Konigl (1979)
- Free expanding, rel. jet
- Conical confinement due to rel. vel.
- Jet fed at constant rate

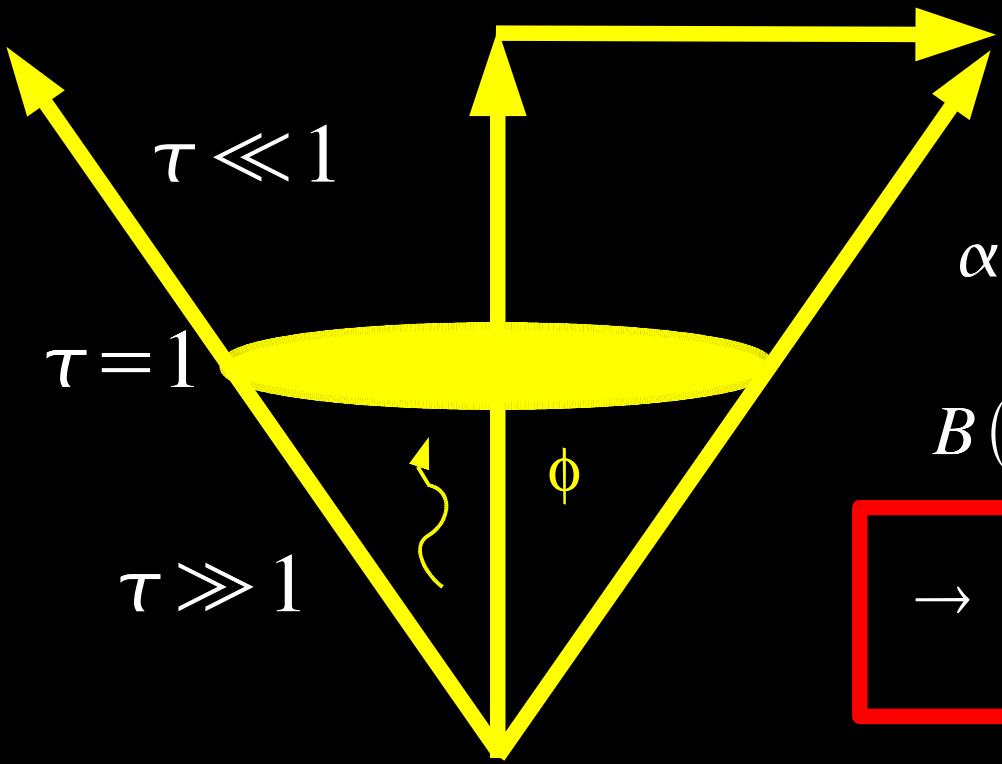
$$v_z = \gamma \beta c \quad , \quad v_r = \gamma_s \beta_s c$$

$$\phi = 1/M = v_r / v_z (small)$$

$$\dot{M}_{jet} = \rho v A = m_p n(r) \gamma \beta c \pi r^2 \rightarrow n(r) \alpha 1/r^2$$

$$\dot{E}_{B,\, jet} = \rho_B v A = B^2(r) \gamma \beta c \pi r^2 \rightarrow B(r) \alpha 1/r$$

Jet Models (Synchrotron Absorption)



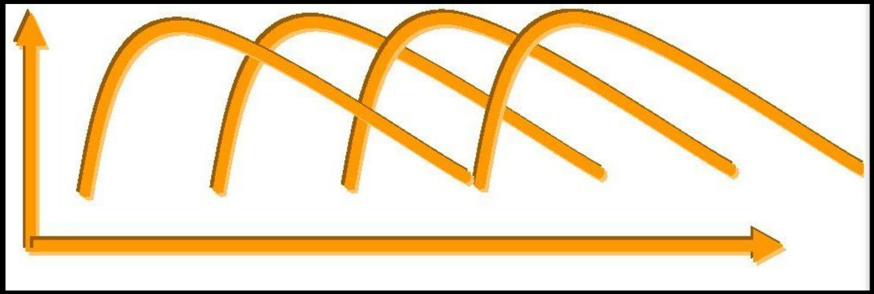
- Photons are free to go past the $\tau = 1$ surface

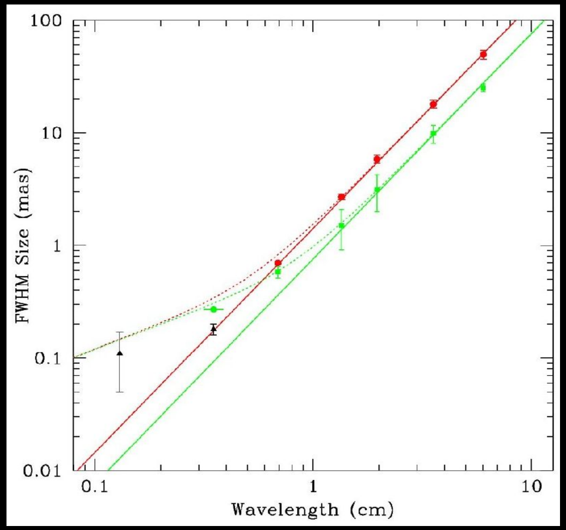
$$\alpha_{sync} \ \alpha \ B^4 \nu^{-3} \qquad \tau \ \alpha \ r\,\alpha_{sync}$$

$$B(r) \ \alpha \ r^{-1} \qquad \rightarrow \ \tau \ \alpha \ r^{-3} \nu^{-3}$$

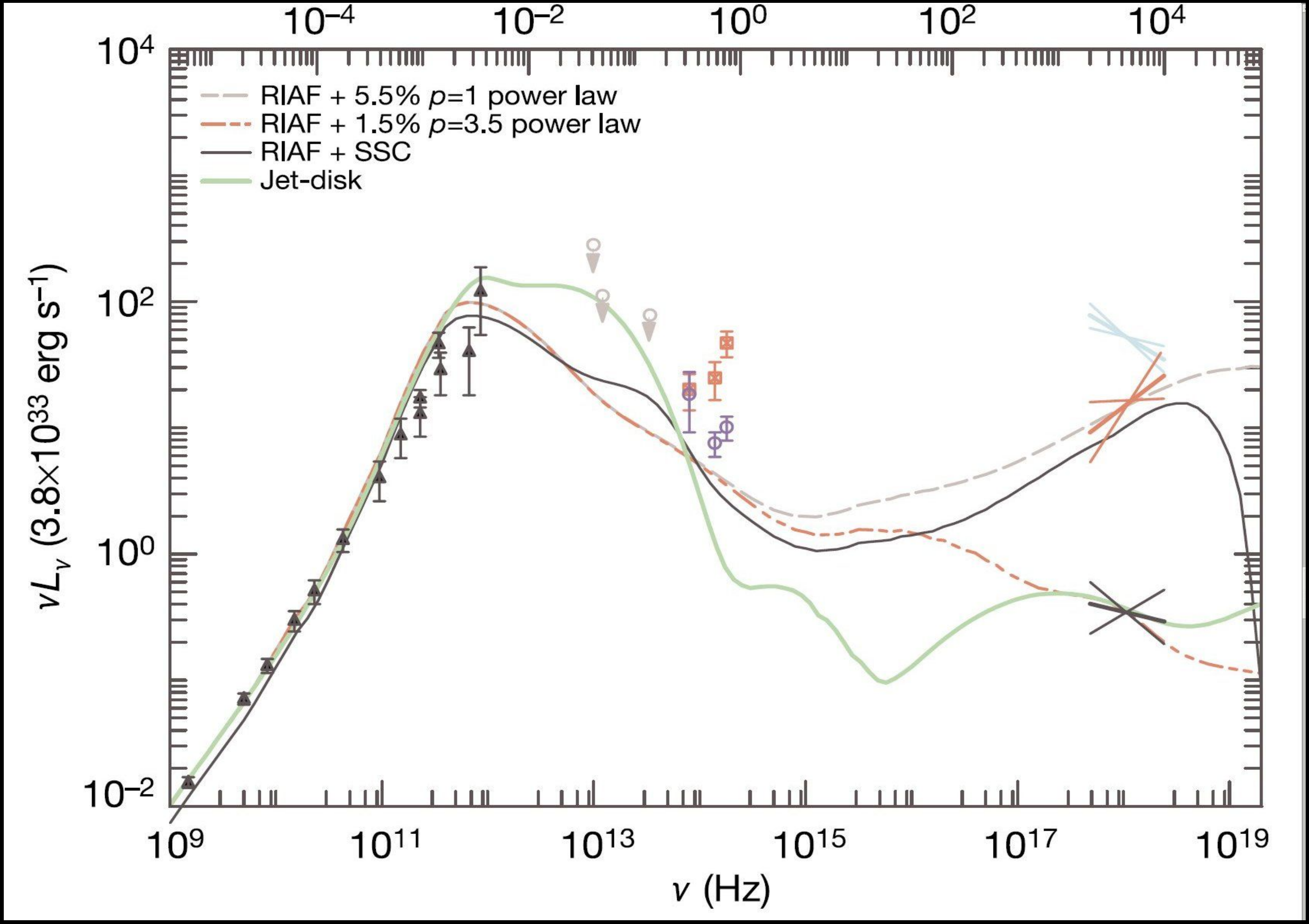
$$\rightarrow \ r_{\tau=1} \ \alpha \ \nu^{-1}$$

- Get a flat spectrum





Composite Spectrum (comparison)

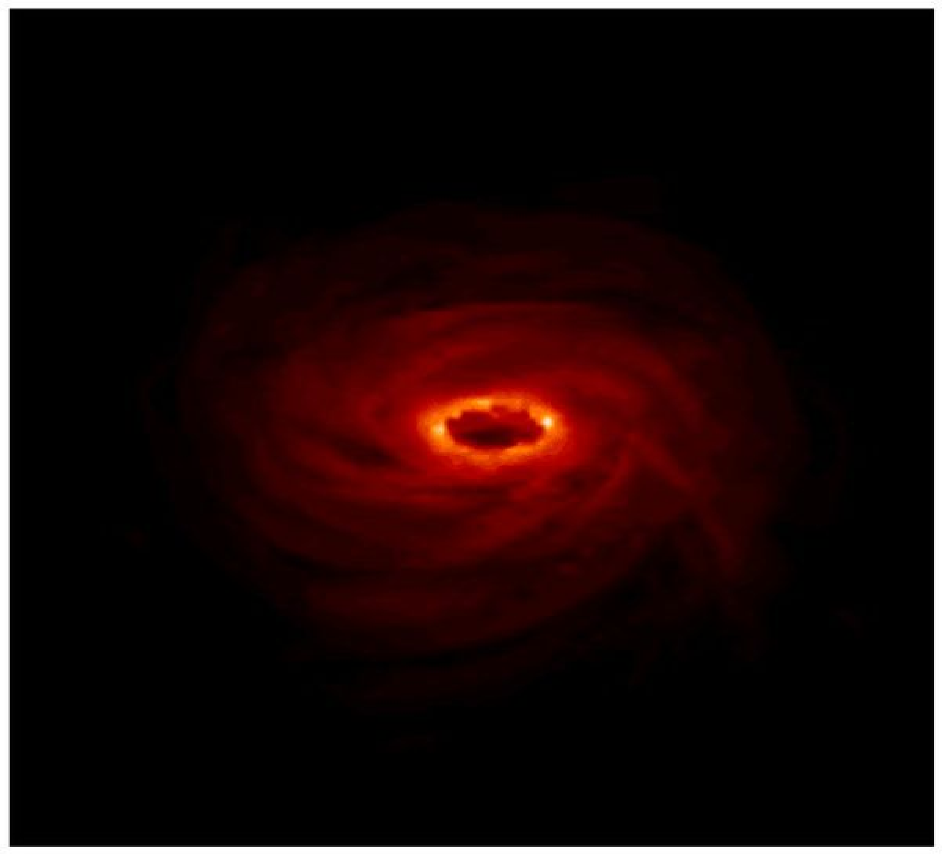


- RIAF's have problem with var. of brem. since $R_{brem} \sim 10^5 R_s$
- Instead, add PL n_e gives hard IC/SSC photons
- Solves Radio under-lum.
- Modern RIAF's have many parameters, need better constraints: simult. wide-freq. survey, submm VLBI

- Jets lack a mechanism, no launching mechanism
- Reliant on a disk model of some type
- Can it predict X-ray flare state?
- SgrA* may have been more active in the past...?

Conclusion?

Not until submm VLBI and see



or