The Obscuring Torus (3)

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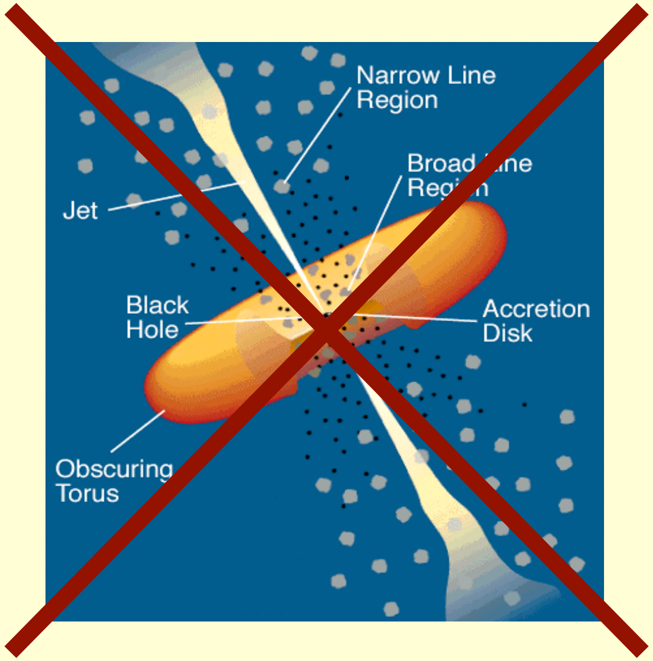
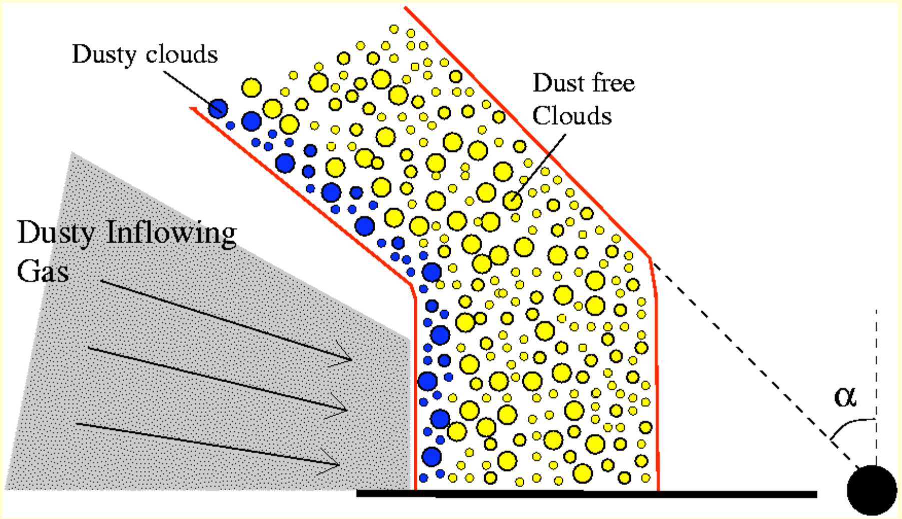
What is the Torus?



Smooth continuation of the BLR

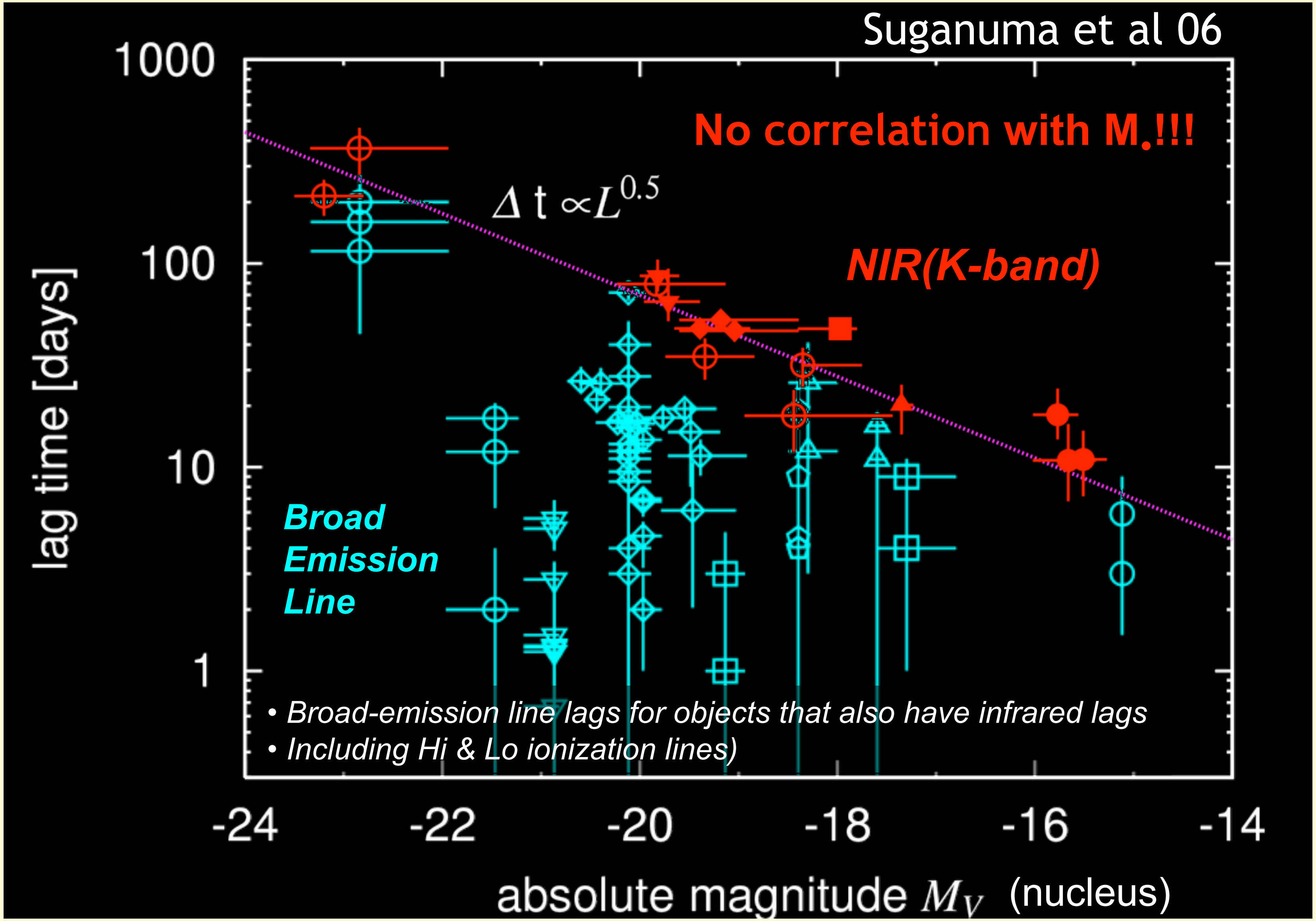
X-ray Obscuration



Risaliti, Elvis & Nicastro 02:

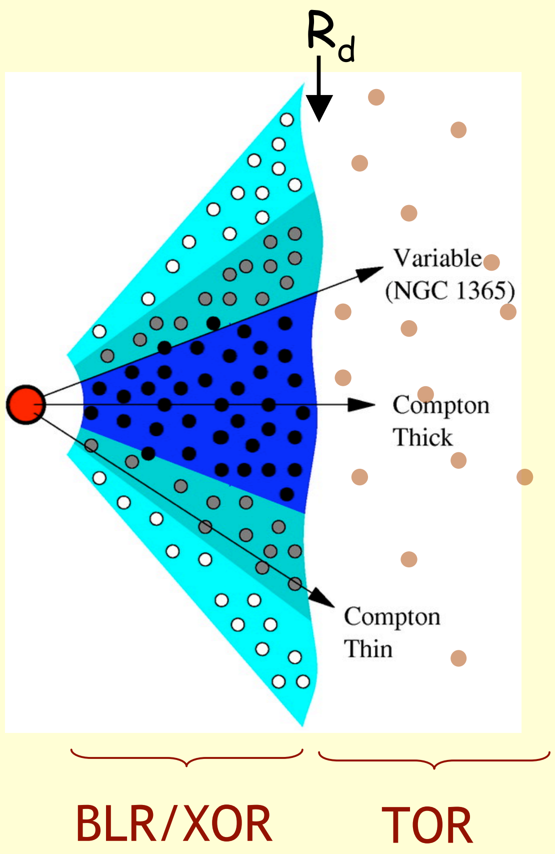
Smooth distribution of dusty and dust-free clouds

Lag Times — BLR and near-IR



BLR is dust bound (Netzer & Laor 93)

The Dust-Sublimation Transition



$r < R_d$ — dust free clouds:

Broad **L**ines **R**egion/
X-ray **O**bscuration **R**egion

$r > R_d$ — dusty clouds:

Toroidal **O**bscuration **R**egion

TOR = Torus

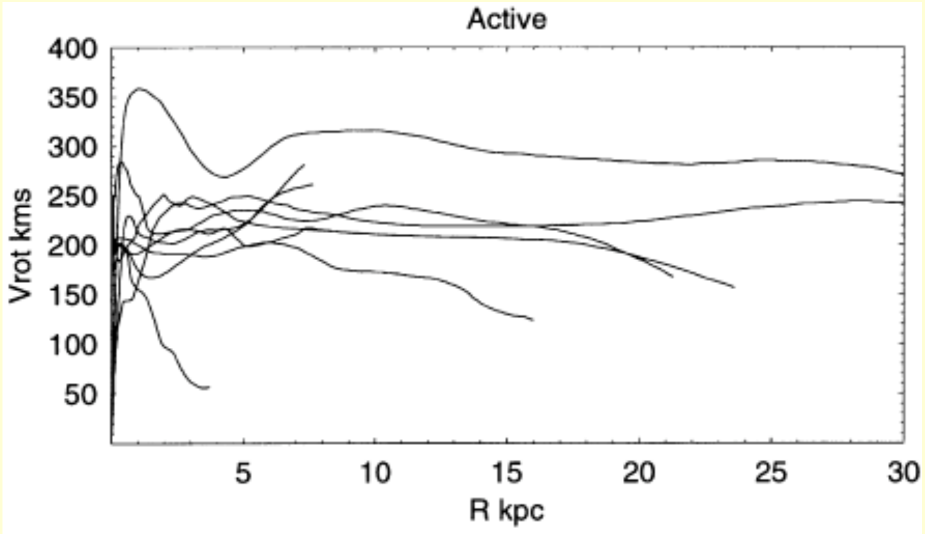
Black-Hole Influence Radius R_{BH}

$$r = R_{BH}: \quad \Omega(R_{BH}) = \Omega_\bullet(R_{BH}) \;\Rightarrow\; M(R_{BH}) = M_\bullet$$

$v_{rot} \sim 100$ km/s

R ~ 100 pc

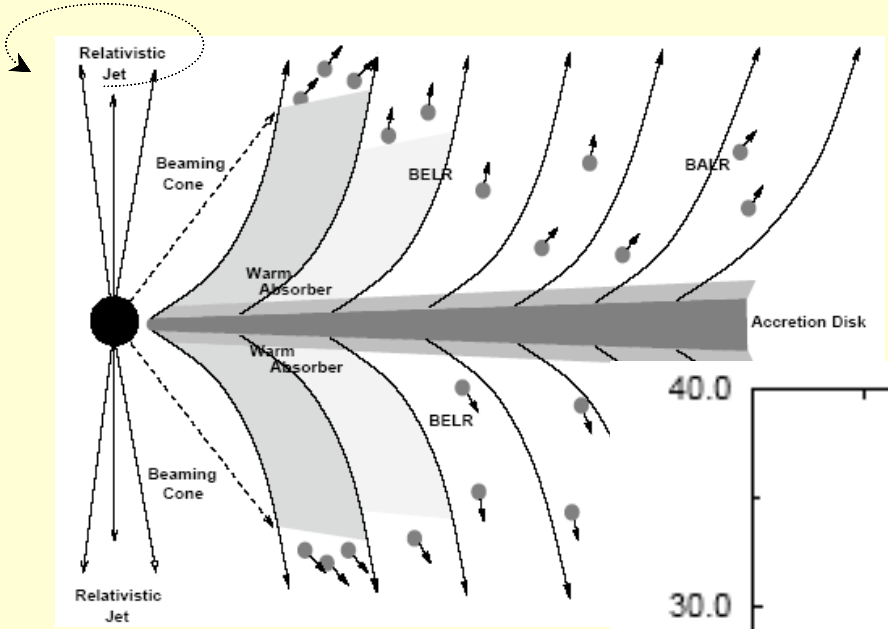
Sofue et al 99



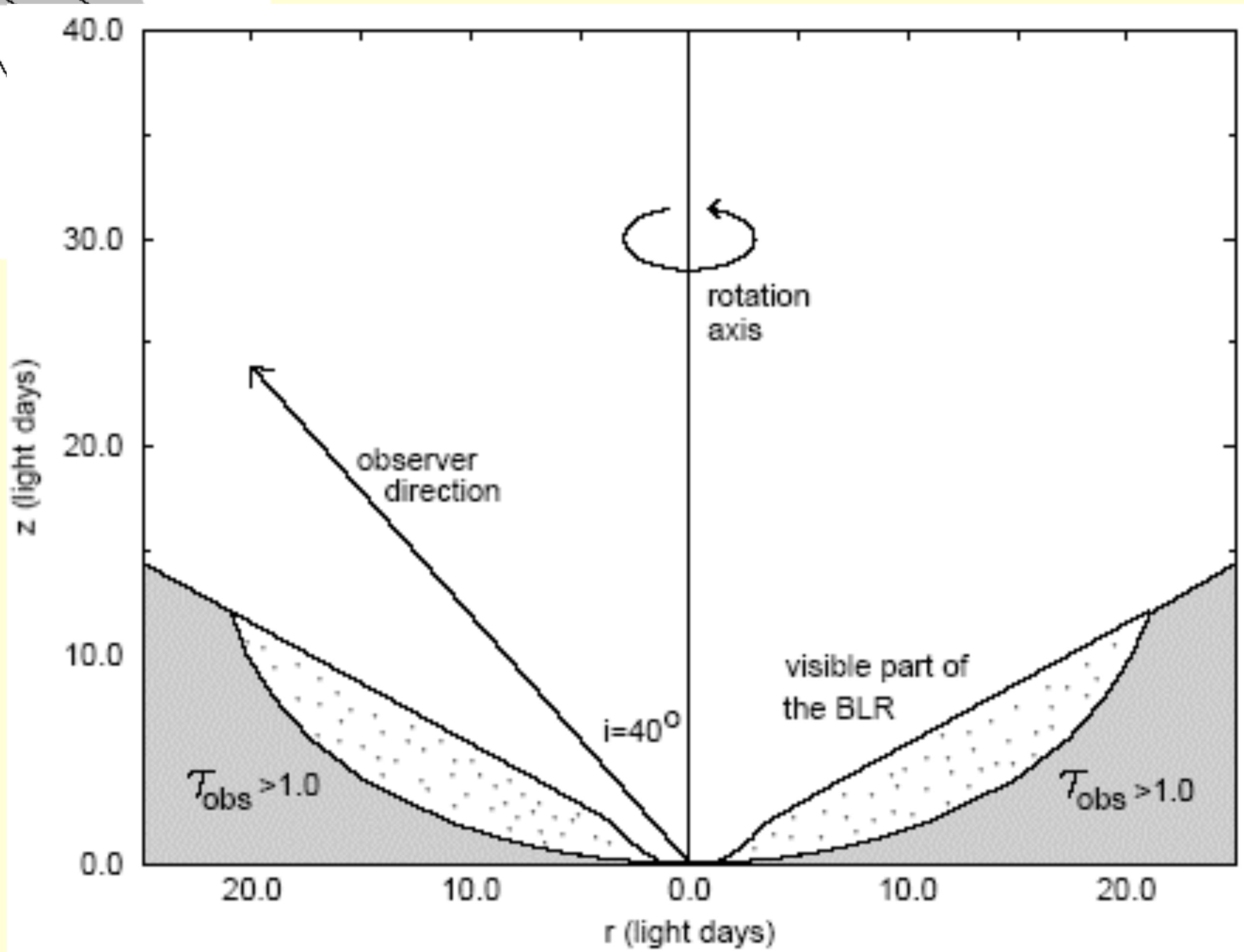
$$\Omega = \frac{v(r)}{r} = \left(\frac{G\,M(r)}{r^3}\right)^{1/2} \sim 1 \text{ km/s/pc}$$

$$R_{BH} = 35\text{pc}\,(M_{\bullet 7}/\Omega^2{}_1)^{1/3}$$

The Disk Wind Paradigm

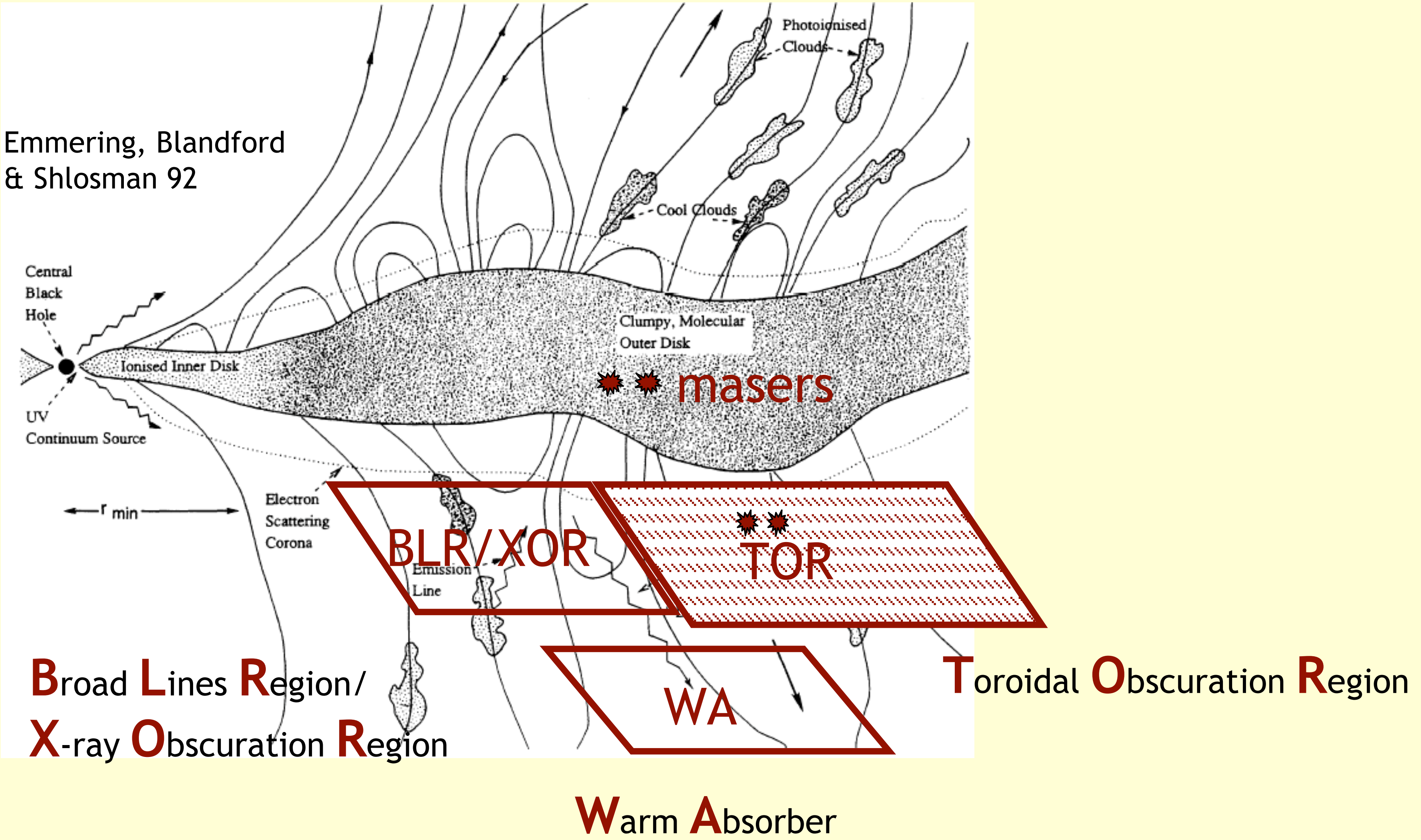


Everett & Konigl '00



Bottorff+ 97

Grand Unification Theory

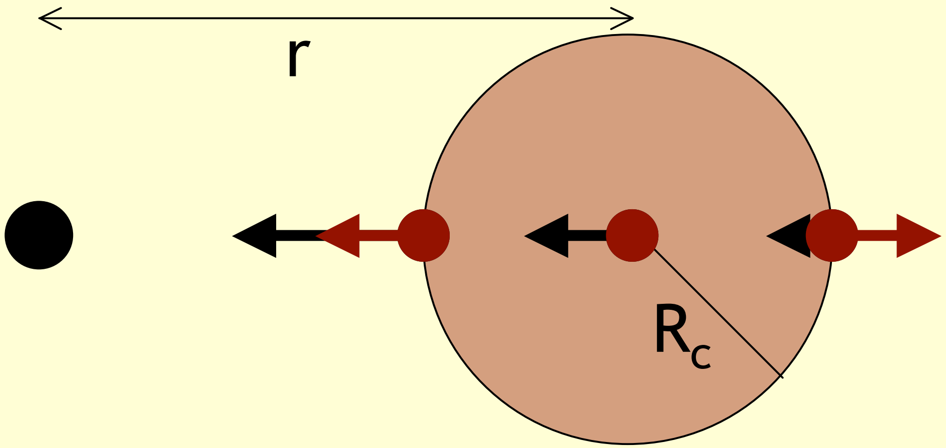


Cloud Properties in TOR Outflow (1)

$\tau_V \sim 20 - 100 \quad \Rightarrow \quad N_H \sim 10^{22} - 10^{23}\ \mathrm{cm}^{-2}$

$N_H = nR;$ $\quad n = ? \quad R = ?$

Tidal Shearing



Tidal force: $$\frac{GM_\bullet}{(r \mp R_c)^2} - \frac{GM_\bullet}{r^2} = \pm 2 \frac{R_c}{r} \times \frac{GM_\bullet}{r^2}$$

Self-gravity glue: $$\frac{GM_c}{R_c^2} = 2\frac{GM_\bullet}{r^2} \times \frac{R_c}{r}$$

$$\frac{M_c}{R_c^3} \sim \frac{M_\bullet}{r^3} \qquad \text{or:} \quad n_c \sim n_\bullet(r)$$

Cloud Properties in TOR Outflow (2)

$\tau_V \sim 20 - 100 \quad \Rightarrow \quad N_H \sim 10^{22} - 10^{23}\ \mathrm{cm}^{-2}$

Resistance to tidal shearing:

$n > 10^7\ M_{\bullet 7} / r_{pc}^3\ \ \mathrm{cm}^{-3}$

$R_c < 10^{16}\ N_{H,23}\, r_{pc}^3 / M_{\bullet 7}\ \ \mathrm{cm}$

$M_c < 7 \cdot 10^{-3}\ N_{H,23}\, R_{c,16}^2\ \ M_\odot$

Confinement?

Cloud Confinement

Self-gravitating clouds: $\sigma^2 = \dfrac{2GM_c}{R_c}$

$M_c = 7 \cdot 10^{-3}\ M_\odot$, $R_c = 10^{16}$ cm $\Rightarrow$ $\sigma = 0.1$ km s^{-1}

Measly Confinement!

Magnetic confinement: $\dfrac{B^2}{8\pi} = \frac{1}{2} n m_H \sigma^2$

$B \sim 1.5\ \sigma_{km/s}\ n_7^{1/2}$ mG

Cloud Properties in TOR Outflow

$N_H \sim 10^{22} - 10^{23}\ cm^{-2}$

$n > 10^7\ M_{\bullet 7} / r_{pc}^3\ \ cm^{-3}$

$R_c < 10^{16}\ N_{H,23}\, r_{pc}^3 / M_{\bullet 7}\ \ cm$

$M_c < 7 \cdot 10^{-3}\ N_{H,23}\, R_{c,16}^2\ \ M_\odot$

$B \sim 1.5\ \ \sigma_{km/s}\, n_7^{1/2}\ \ mG$

Elitzur & Shlosman 06

TOR Scale Height

- Clouds rise and expand
- $M \sim nR^3 = nR \times R^2 \;\; \Rightarrow \;\; N_H \propto M/R^2$
- Crossing the TOR — factor ~10 expansion
- $\sigma \sim 1$ km s^{-1} $\quad v_K = 208\,(M_7/r_{pc})^{1/2}$ km s^{-1}

  $\Rightarrow H \sim r$

TOR Energy Outflow Rate

$$L_w = \int \tfrac{1}{2} M_c v_c^2 \times n_c v_c \, dA$$

Estimate at the wind base — disk surface

Outflow: $v \geq v_{turb} \sim 10$ km s^{-1}

$$L_w = 7 \times 10^{35} \, L_{45}^{1/2} \, N_{H,23}^{T} \, v_6^3 \cdot I_3 \quad \text{erg s}^{-1}$$

Negligible in the energy budget

TOR Mass Outflow Rate

$$\dot{M}_{out} = 0.02\, L_{45}^{1/2}\, N_{H,23}^{T}\, v_6 \cdot I_1 \quad M_{\odot}\, yr^{-1}$$

$$\dot{M}_{acc}^{BH} = \dot{M}_{acc}^{TOR} - \dot{M}_{out} = \alpha \dot{M}_{acc}^{TOR} \qquad \alpha < 1$$

$$L = \eta \dot{M}_{acc}^{BH} c^2 = \varepsilon \dot{M}_{acc}^{TOR} c^2 \qquad \varepsilon = \eta\alpha \sim 0.01\,(?)$$

$$\dot{M}_{acc}^{TOR} = 0.02\, L_{45} / \varepsilon \quad M_{\odot}\, yr^{-1}$$

$$\frac{\dot{M}_{out}}{\dot{M}_{acc}^{TOR}} = \frac{1}{L_{45}^{1/2}}\, \varepsilon N_{H,23}^{T}\, v_6 \cdot I_1$$

Torus disappears at L <~ 10^{42} erg s^{-1} !

Torus Disappearance at Low Luminosities

- Nucleus visible in FR I radio galaxies (Chiaberge+ 99)
- … and LINERs too (Maoz+ 05)
- LINER 1 & 2 UV colors similar (A_V <~ 1)
- No torus dust emission in M87 (Whysong & Antonucci 04; Perlman+ 07)
- No torus dust emission in FR Is and ~ half of FR IIs (Guido van der Wolk+ 07)

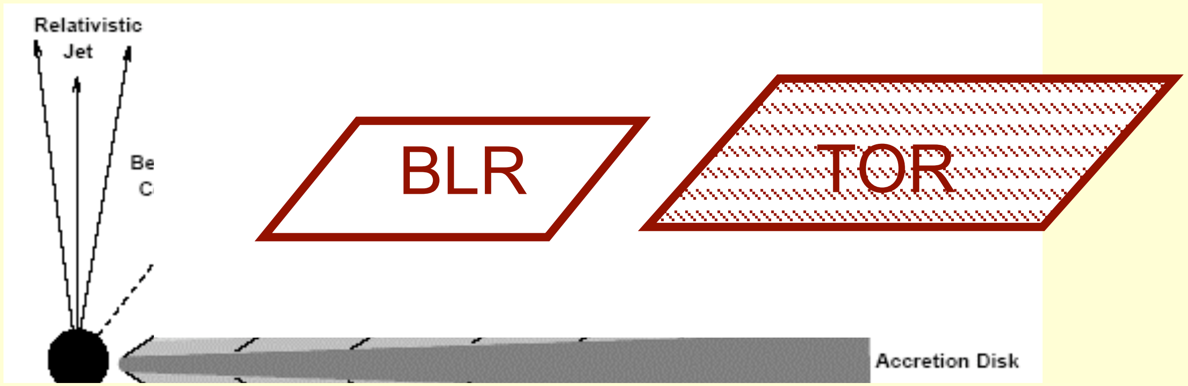
If only TORUS is removed, all low-luminosity AGN become type 1

HOWEVER

- Both type 1 and type 2 LINERs do exist (Maoz et al 05)
- "true" type 2 AGN exist at $L < 10^{42}$ erg s^{-1} (Panessa & Bassani 02; Laor 03)

THEREFORE

BLR must disappear at some lower L



- Wind diminishes — mass outflow directed to jets (?)
- Ho '02, Sikora et al '07: Radio loudness (L_{rad}/L_{opt}) varies *inversely* with $\dot{M}_{acc}$!
- Similar effect in X-ray binaries

The Maiolino Conjecture

The relevant parameter is not L, but L/L_{Edd}

Mid-IR Spectroscopy of Radio Galaxies and Quasars

Patrick Ogle (SSC/Caltech)

SSC Spitzer Science Center

D. Whysong (NRAO), R. Antonucci (UCSB)

UCSB

Xi’an 2006

Mid-IR Spectroscopy of Radio Galaxies and Quasars

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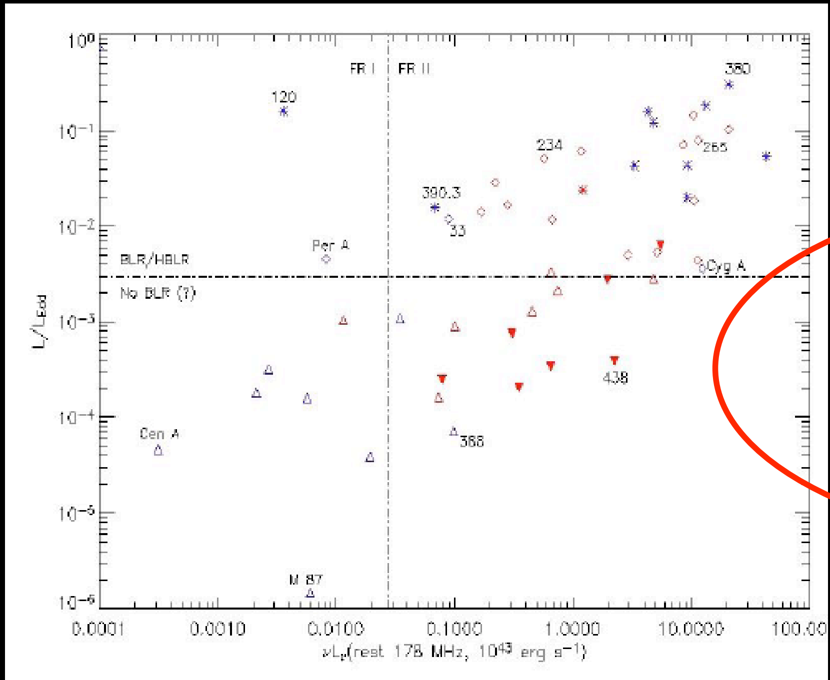
D. Whysong (NRAO), R. Ar

Eddington Luminosity

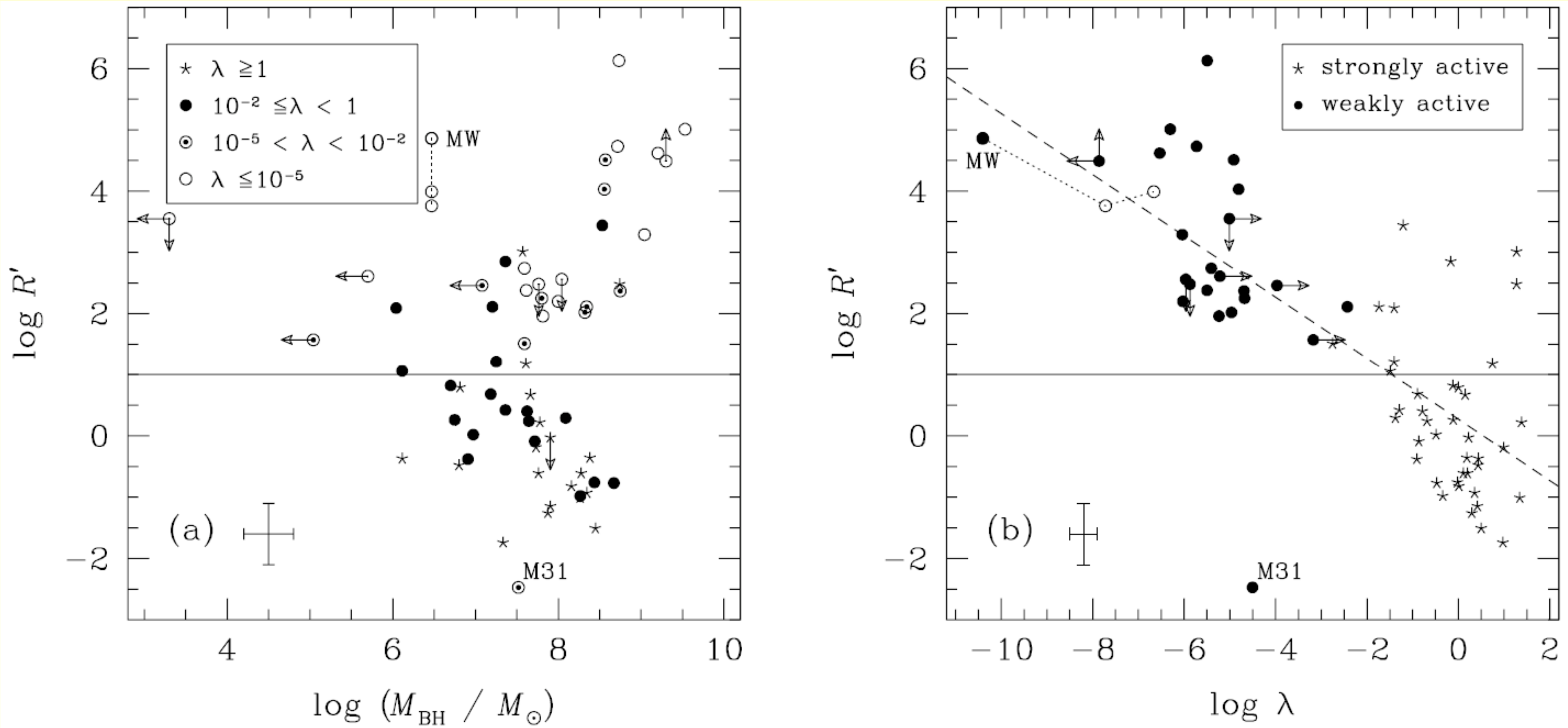


Ogle et al. 2006, ApJ, 647, in press

- Mbh estimated from σ or K band luminosity of bulge.
- L=1.7 L(15μ) / 0.6
- All sources with broad Balmer lines have L/Ledd > 3E-3
- Most FR Is and 50% of FR IIs have L/Ledd < 3E-3.

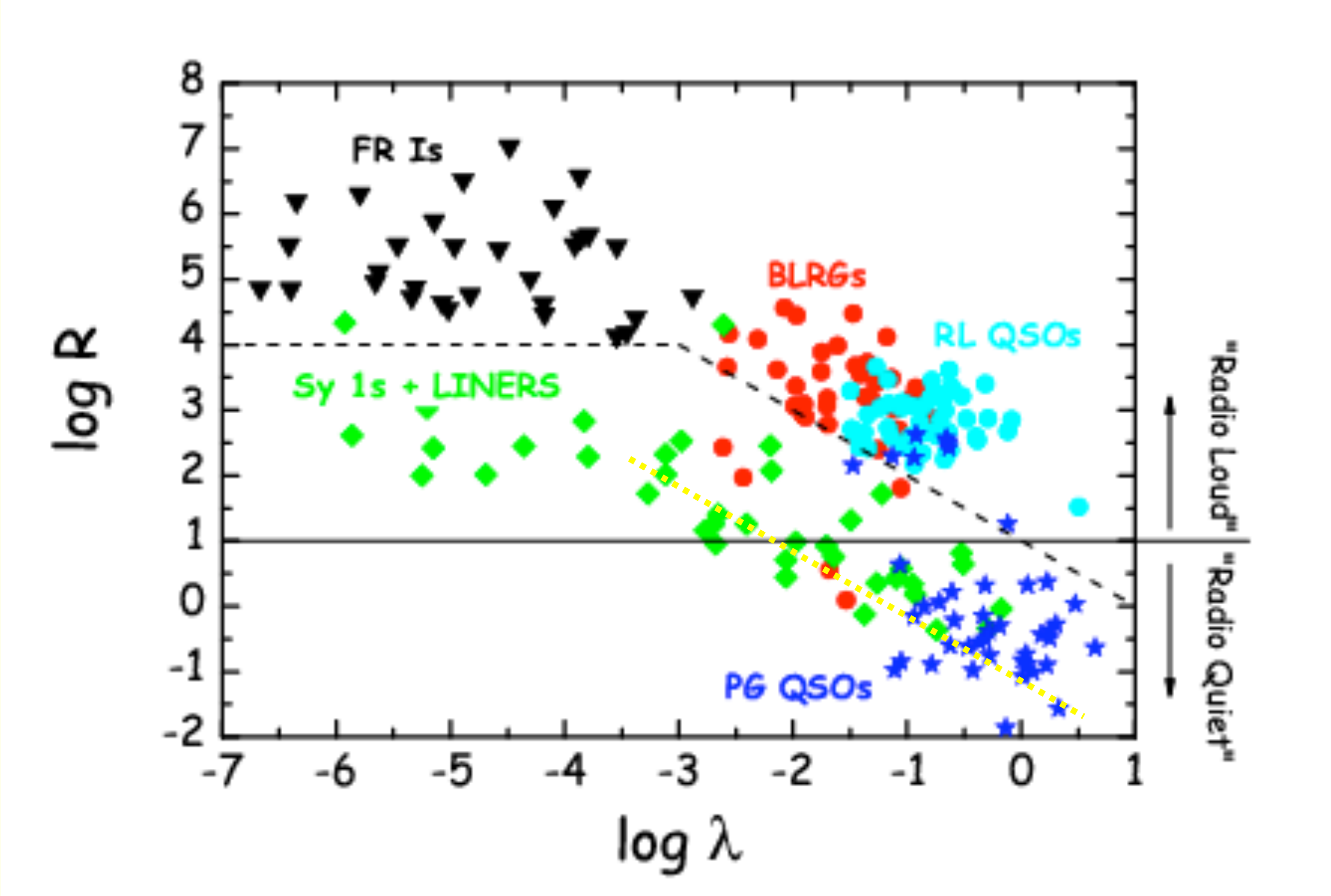
Jets may be powered by radiatively inefficient accretion and/or black hole spin.

Radio-loudness; Ho '02



$R' = L_{rad}/L_{opt}$ $\lambda = L/L_{Edd}$

Radio-loudness; Sikora+ '07



R = L_{rad}/L_{opt} $\lambda = L/L_{Edd}$

$$\log \mathcal{R} > \log \mathcal{R}^* = \begin{cases} -\log\lambda + 1 & \text{for } \log\lambda > -3 \\ 4 & \text{for } \log\lambda < -3 \end{cases} .$$

The Maiolino Conjecture — Implications

- Torus disappears at $L/L_{Edd} <\sim 10^{-3}$,
  i.e., $L <\sim 10^{42}\, M_{\bullet 7}$ erg s^{-1}
- TOR outflow: $\dot{M}_{out}/\dot{M}_{acc}{}^{TOR} \propto (L_{Edd}/L)^{1/2}$
  namely, $\varepsilon \sim 0.03\, L_{Edd}{}^{1/2}$ $[\times f(L/L_{Edd})]$
- Radiation pressure?

High

Accretion Rate (L/L_{Edd})

Low

Full Unification Scheme;

both type 1 & 2

molecular outflow extinguished

Torus disappears; type 1 only

atomic outflow extinguished

BLR disappears; “true” type 2

Low

Radio Loudness

High

Final Speculation

- With $\eta \sim 0.1$, the required accretion rate is

  $\dot{M}_{acc} \sim 0.1\, L_{45}\, M_{\odot}\, yr^{-1}$

- The AGN phase lasts ~ $10^7 - 10^8$ yrs

- Overall accreted mass ~ $10^6 - 10^7\, L_{45}\, M_{\odot}$

Is the whole Seyfert phenomenon the accretion of just a single GMC?

Things to Ponder

- It's all probabilities!
- UV/optical vs X-ray torus properties
- f_2 decrease at high L – N_H or σ?
- Low-luminosity end of AGN:
  - TOR disappearance – IR emission
  - BLR disappearance
  - Switch from outflow to jets