Structure and Evolution of the AGN Torus and Broad Line Region

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Unification

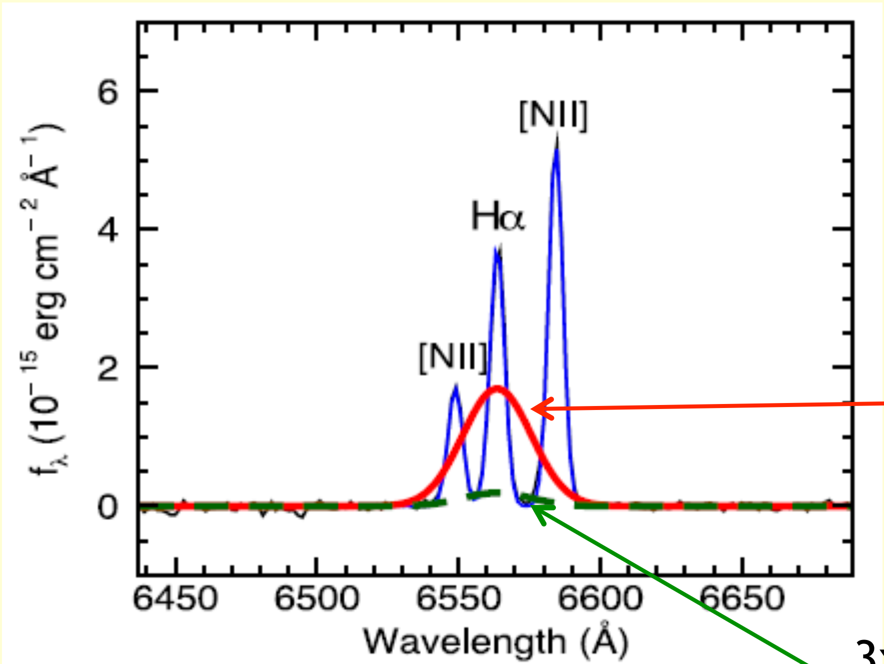
- All AGN are intrinsically the same
  - differences ⇔ viewing direction
- Evolution ⇒ dM/dt decreases
  - When dM/dt = 0, the AGN is gone
- Evolution ⇒ can AGN be intrinsically the same?

Torus Disappearance at Low Luminosities

- Obscuration disappears in
  - FR I (Chiaberge+ 99)
  - Liners (Maoz+ 05)
- No thermal dust emission in
  - M87 (Whysong & Antonucci 04; Perlman+ 07)
  - FR I and some FR II (van der Wolk+ 10)
  - Low Eddington-ratio AGN (Trump+ 11)

BLR Disappearance in LLAGNs

- No BL signature in polarized light (Tran 01, 03)
- "True" type 2 (Panessa & Bassani 02)
  - Even in high Eddington ratios



GSN 069 (Miniutti+ 13)

L = 10^{43} erg s^{-1}

M = 1.2×10^6 M_o

L/L_{Edd} = 0.53

expected Hα

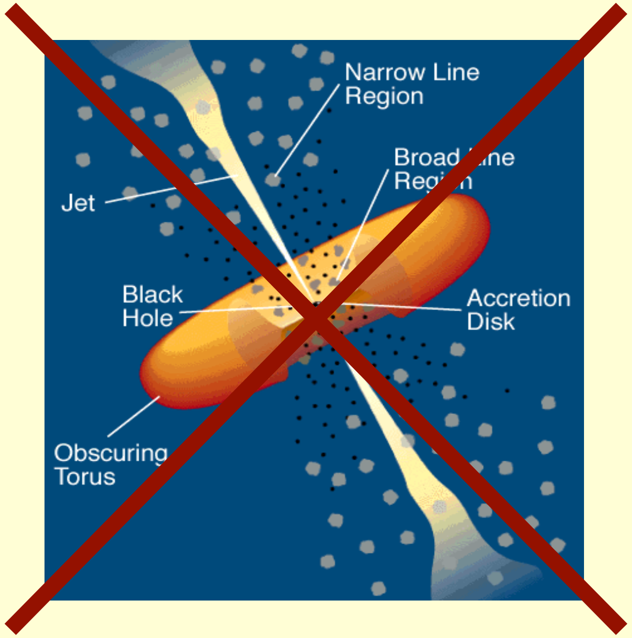
3x residuals (upper limit)
~ 9x less than expected

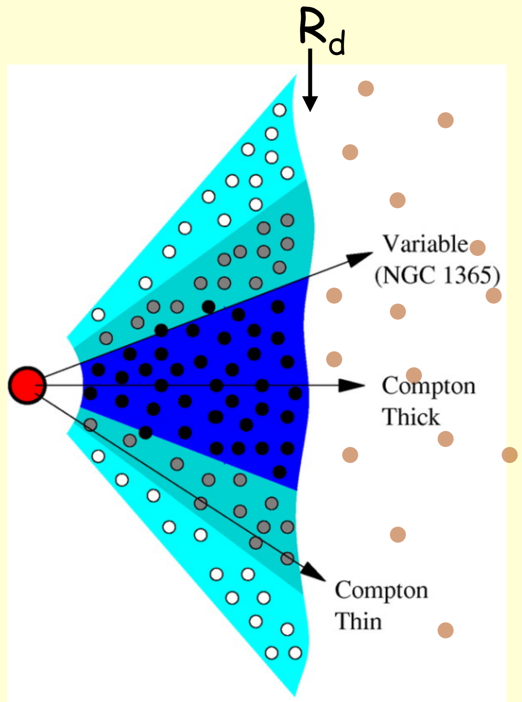
Fundamental Constraint

- Obscuration, broad line emission require minimal column, N_{min}
- $N_R = \int n(R)\, dR$

$$N_R > N_{min}$$

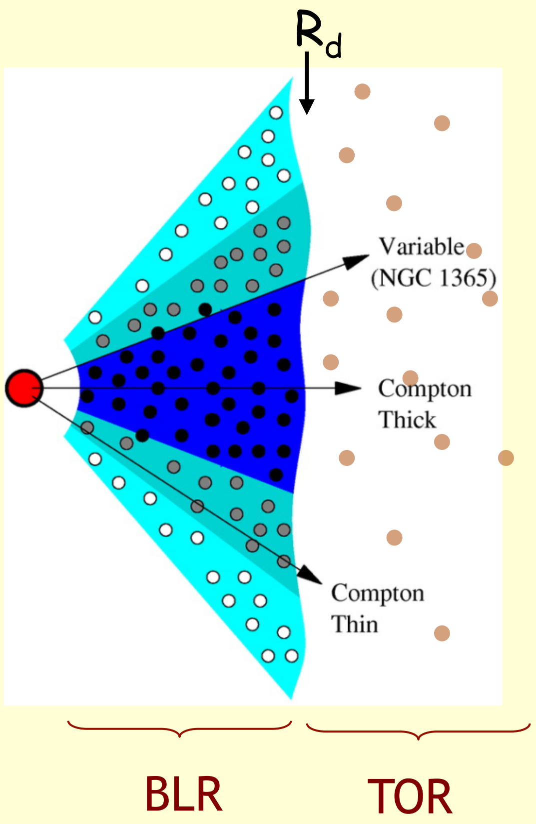
What *ARE* the Torus and BLR?





Smooth Continuation

The Dust-Sublimation Transition



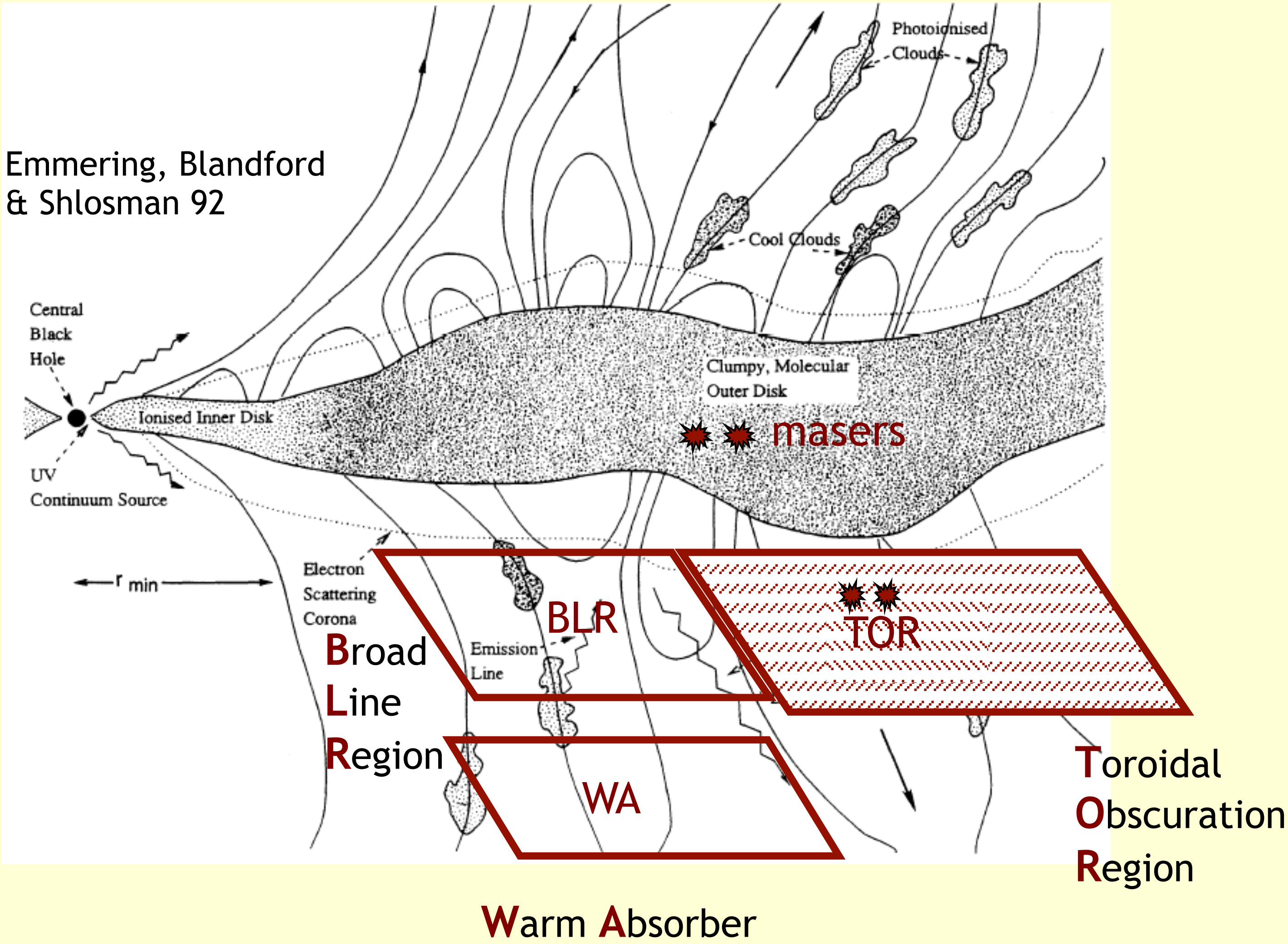
$R_d = 0.4\ L^{1/2}_{45}$ pc

$r < R_d$ – dust free clouds:
Broad **L**ine **R**egion

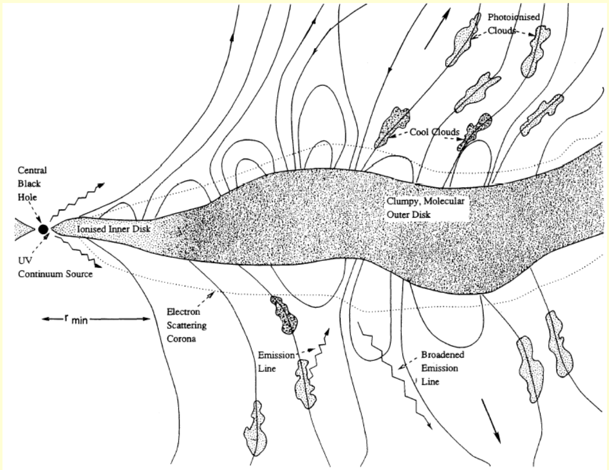
$r > R_d$ – dusty clouds:
Toroidal **O**bscuration **R**egion

TOR = Torus

The Disk-Wind Scenario



Geometry



- Clouds rise and expand $\Rightarrow$
- Column density decreases ($nR \propto M/R^2$) $\Rightarrow$
- <u>*Toroidal structure for both BLR, TOR and X-ray obscuration*</u>

Mass Continuity

$$N_w \equiv \frac{\dot{M}_w}{4\pi m_p R_d v_{Kd}} = I N_R$$

$R_d \propto L^{1/2}$ $\qquad v_{Kd} = v_K(R_d)$ $\qquad N_R = \int n \, dR$

$$I = \int (v_z/v_K)(R/R_d)^{1/2} \, n dR / N_R$$

BLR or TOR:

$$N_R = N_w/I > N_{min}$$

Obscuration and Broad Line Emission

$$N_w > IN_{min}$$

$$N_w = \frac{\dot{M}_w}{4\pi m_p R_d v_{Kd}}$$

$$L = \varepsilon \dot{M} c^2$$

Obscuration and Broad Line Emission

$$N_w > IN_{min}$$

$$N_w = \frac{\dot{M}_w}{4\pi m_p R_d v_{Kd}}$$

$$L = \varepsilon \dot{M} c^2 = \varepsilon r \dot{M}_w c^2$$

$$r = \dot{M}/\dot{M}_w$$

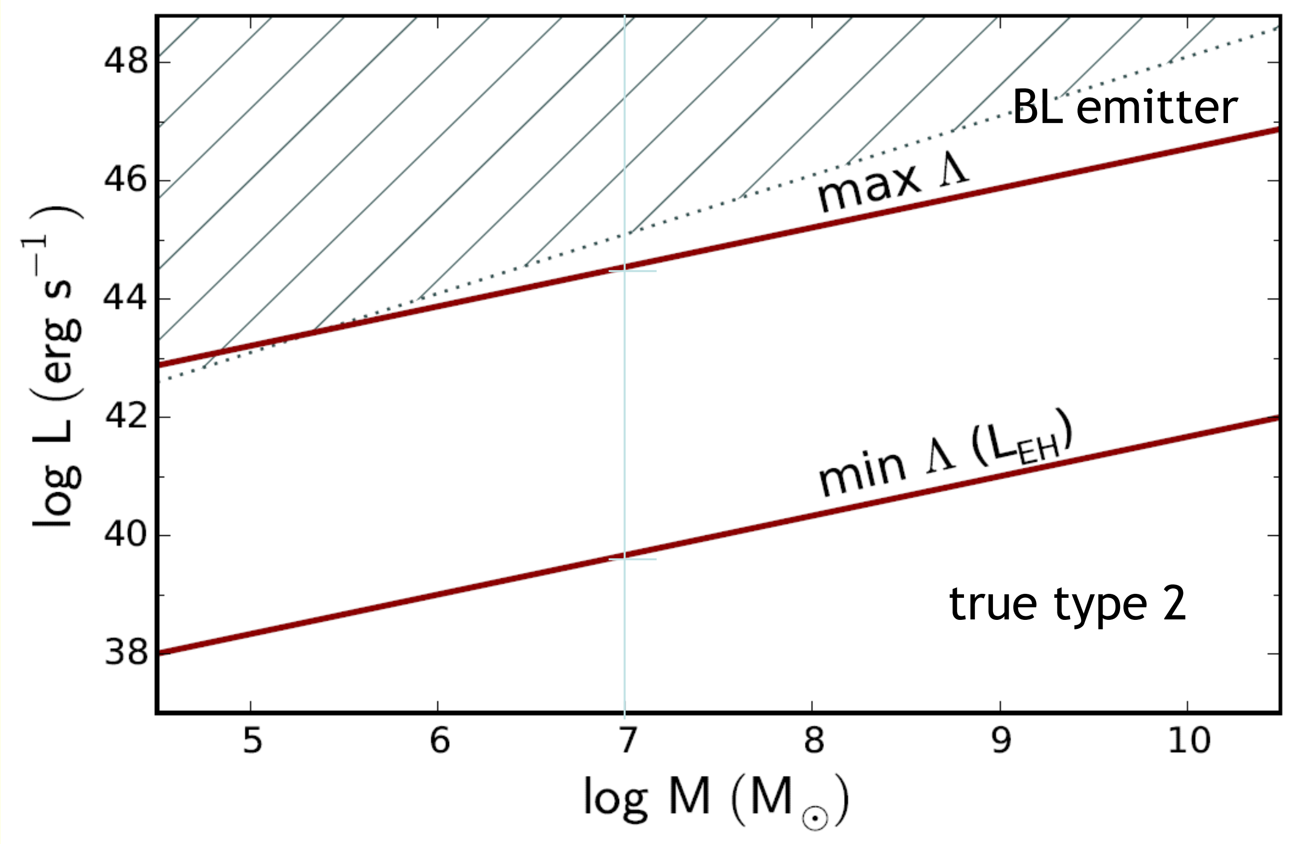
$$L > L_{min} = \Lambda M_7^{2/3}$$

$$\Lambda = 3.3\text{x}10^{45} (\varepsilon r I)^{4/3} \text{ erg s}^{-1}$$

BLR/TOR must disappear at small L!

Elitzur & Shlosman '06

Broad Line Emission Constraint

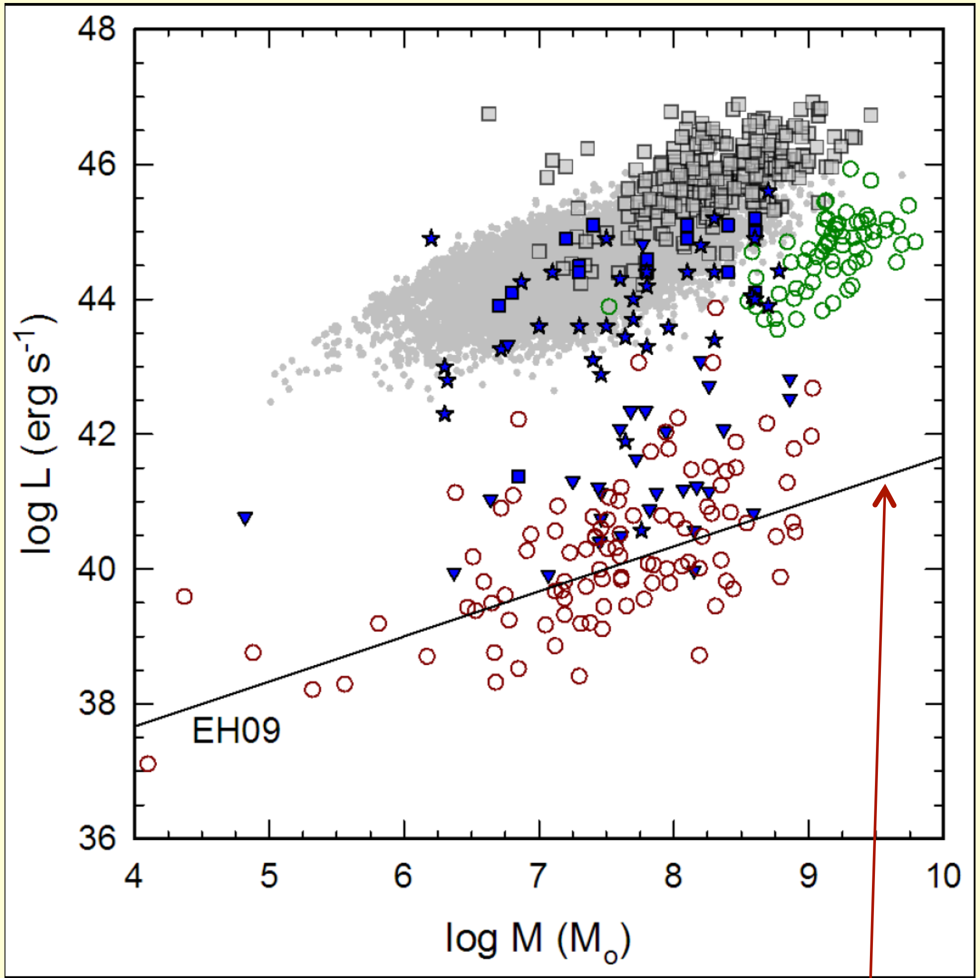


$L > L_{min} = \Lambda M_7^{2/3}$ $\Lambda = 3.3x10^{45} (\varepsilon r l)^{4/3}$ erg s^{-1}

$5x10^{39}$ erg s^{-1} <~ Λ <~ $4x10^{44}$ erg s^{-1}

Elitzur & Netzer '15

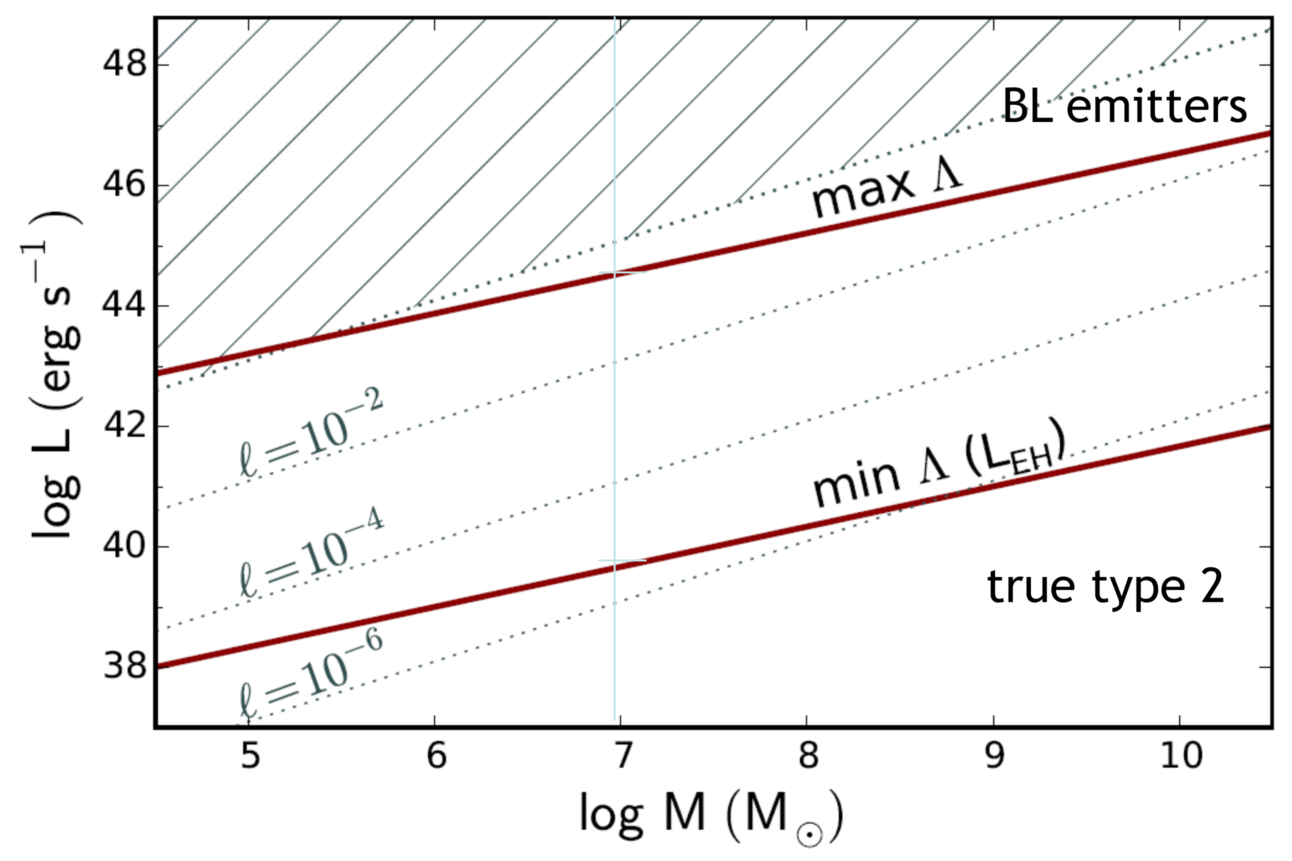
Broad Line Disappearance



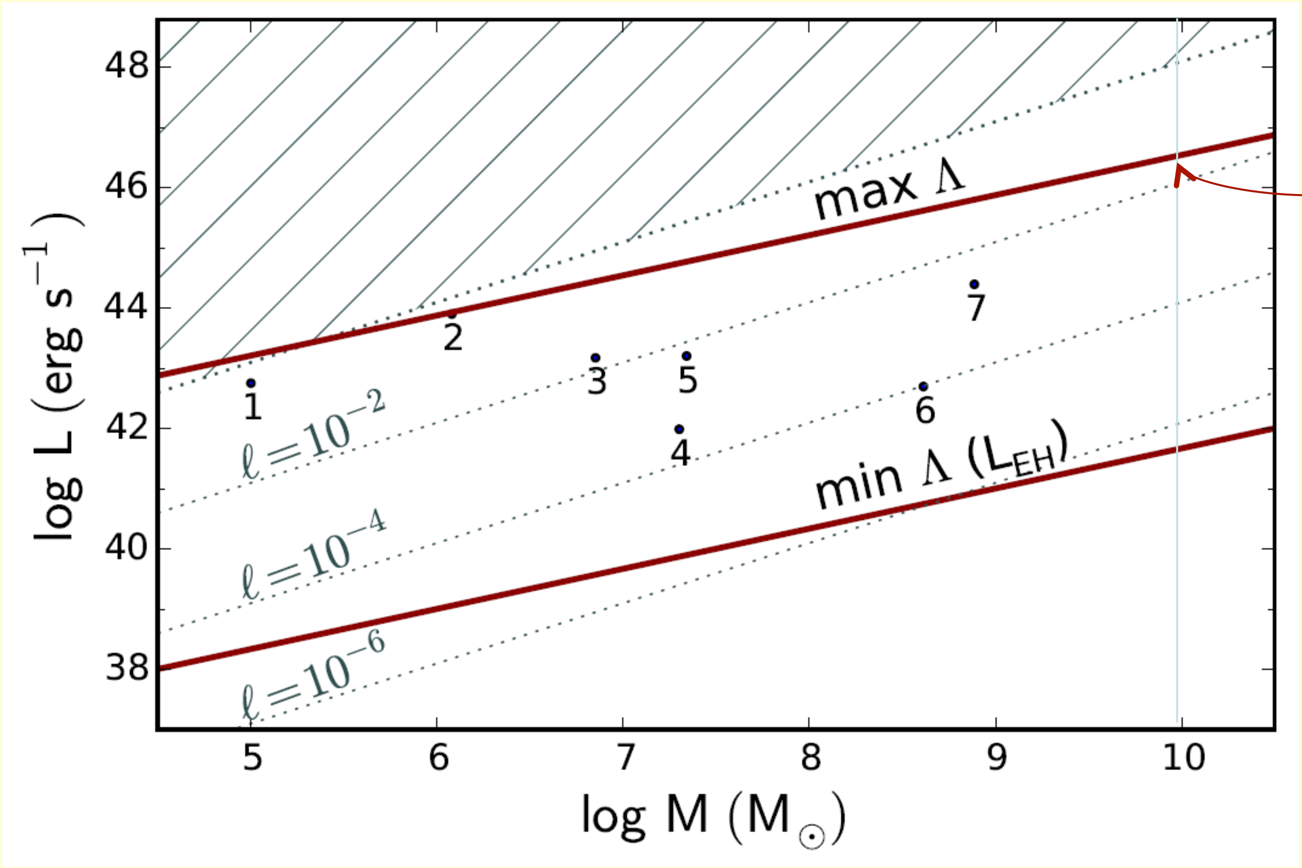
$L = 5\times10^{39}\, M_7^{2/3}$ erg s^{-1}

Elitzur & Ho '09

BL Emission & True Type 2



BL Emission & True Type 2



Confirmed True Type 2:

1 – Ho+12
4 – Shi+10, SL12
3, 6, 7 – Bianchi+12

2 – Miniutti+13
5 – Tran+11, SL12

Potential true type 2!

True Type 2 AGN

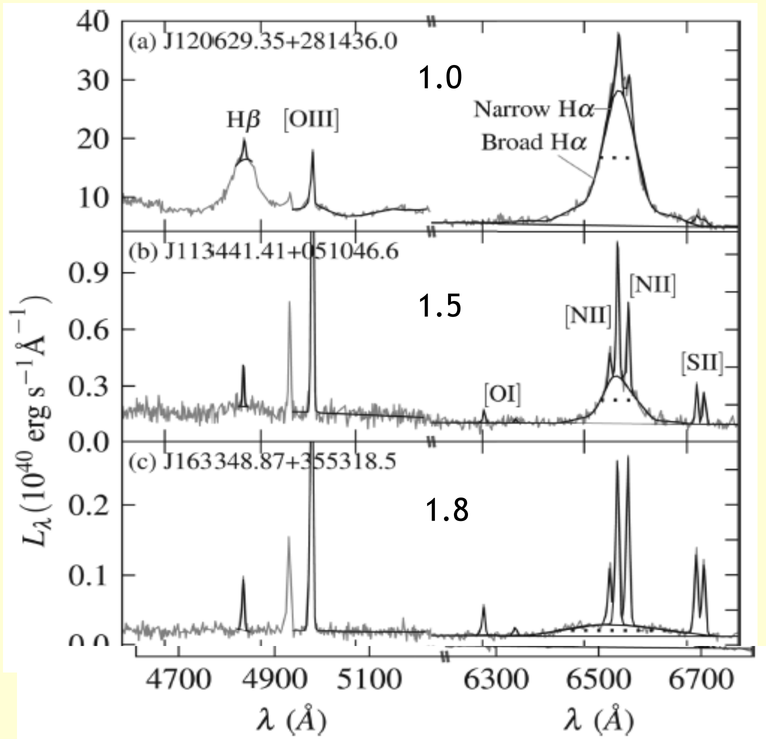
- Can occur at any Eddington ratio
- Can occur at luminosities >~ 10^{46} erg s^{-1}
- Highest luminosity true 2 requires
  - Fast spinning black hole (high ε)
  - Shallow density profile (high l)
  - Small fractional mass outflow rate (large r)
- All AGN with $L < L_{EH}$ are true type 2

Intermediate Seyferts (1.x)

LnHα/LbHα increases from < 0.1 (Sy 1) to > 0.3 (Sy 1.8)

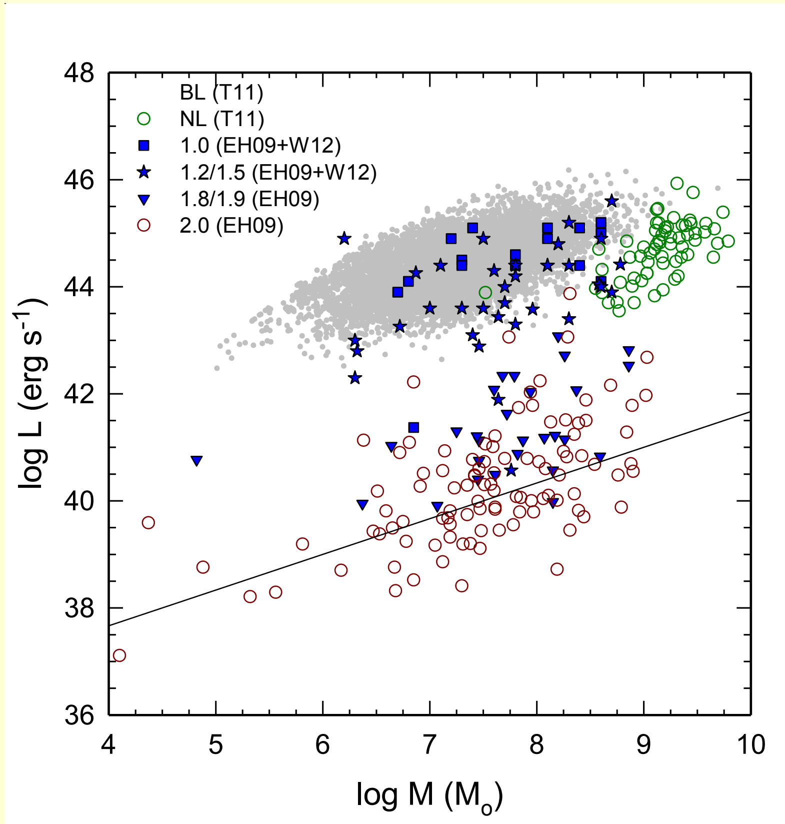
Stern & Laor (2012a,b):

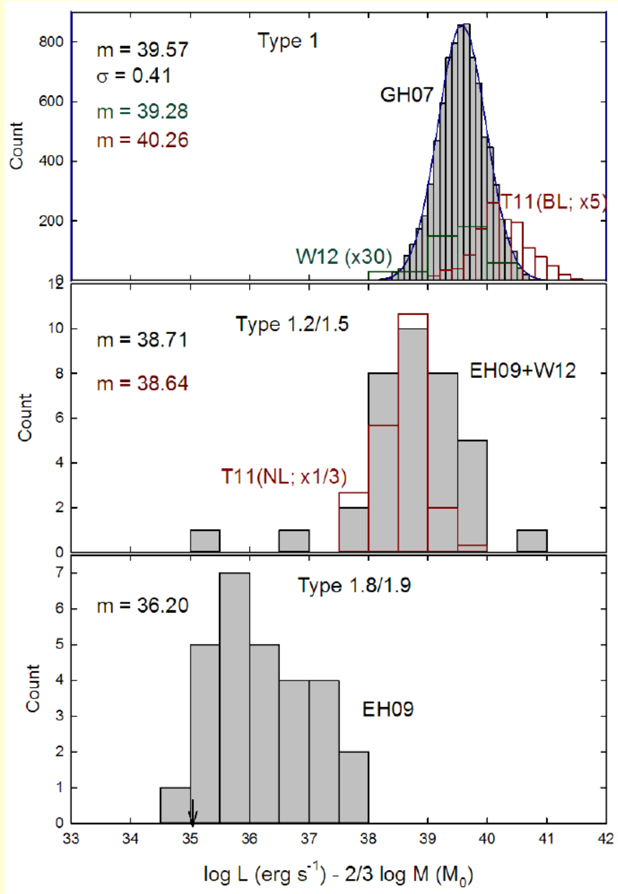
- 1.0: LbHα ~ 10^{43} erg s^{-1}
- 1.5: LbHα ~ 10^{42} erg s^{-1}
- 1.8: LbHα ~ 10^{41} erg s^{-1}



At low luminosity most broad-line AGN are intermediate

An Evolutionary Sequence!





Elitzur, Ho & Trump '14

As $L/M^{2/3}$ decreases:

Type 1 → 1.2/1.5 → 1.8/1.9 → "true" Type 2

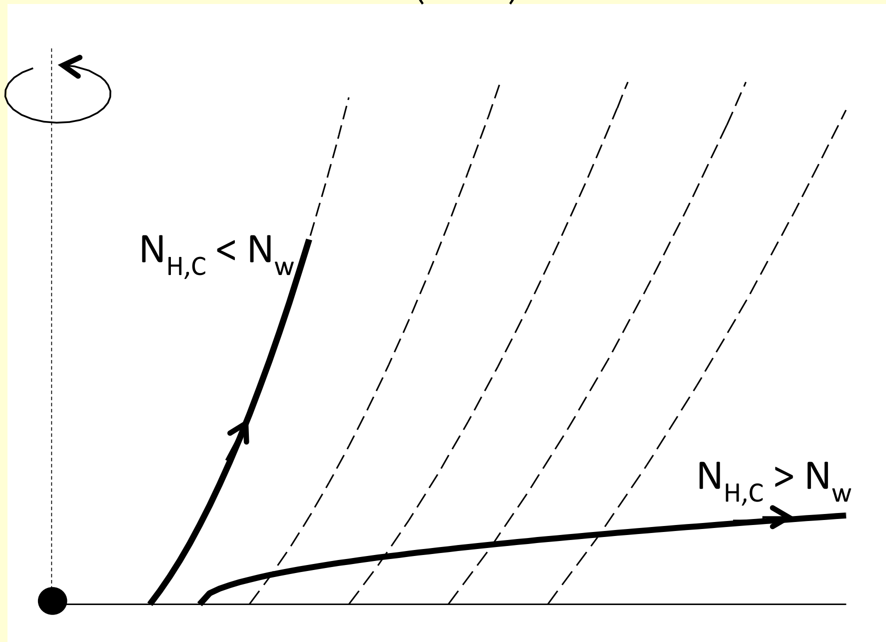
BLR Low-Luminosity Evolution

- Spectral type 1 $\rightarrow$ 1.2/1.5 $\rightarrow$ 1.8/1.9 $\rightarrow$ 2 is an evolutionary sequence:
  - Evolution governed by $L/M^{2/3}$
  - Broad line "covering factor" decreases
  - Double-peaked profiles emerge

Cloud Trajectories

Force on a cloud = Wind ram pressure – Gravity

$$\frac{F_{grav}}{F_{ram}} \sim \left(\frac{r}{R_d}\right)^{1/2} \frac{N_{H,C}}{N_w}$$



Kartje+ '99
Elitzur+ '12

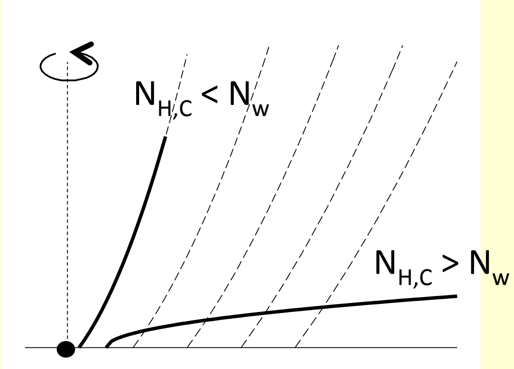
A mix of "wind" + "disk" populations

A Two-Component BLR

BL Emission: $N_{H,C} > N_{min} \sim 5 \cdot 10^{21}$ cm^{-2}

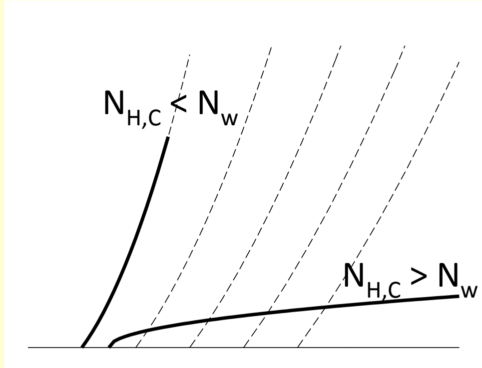
"wind" : $N_{min} < N_{H,C} < N_w (R_d/R)^{1/2}$

"disk": $N_w (R_d/R)^{1/2} < N_{H,C}$



- As L decreases, N_w ($\sim L/M^{2/3}$) decreases
- More clouds become supercritical — "wind" → "disk", but not the other way!
- Less central luminosity is intercepted
- Double-peaked profiles emerge

BLR Evolution



Controlled by L/L_{min} (N_w/N_{min})

and $0.02 <\sim l <\sim 0.07$

- $L/L_{min} > 1/l$ ($N_w/N_{min} > 1$): 'Standard Unification'
- $1 < L/L_{min} < 1/l$ ($N_w/N_{min} < 1$): Intermediate Seyferts
- $L/L_{min} < 1$ ($N_w/N_{min} < l$): True type 2

Summary

- BLR (and TOR) disappearance — inherent to disk winds
  - Independent of wind properties (just mass conservation!)
  - True type 2 at any Eddington ratio & L as high as ~$4x10^{46}$ erg s^{-1}
- Evolution controlled by L/L_{min} ($\propto L/M^{2/3}$)
- Seeding wind with clouds explains Sy1.x
- Lower "covering factor" together with double peaks
- Same property, N_w, controls both mass conservation and cloud motions

The I-factor

$$I = \int (v_z/v_K)(R/R_d)^{1/2}\, n dR/N_R \;\sim\; 0.1 \int (R/R_d)^{1/2}\, n dR/N_R$$