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# MHD Accretion Disk Winds and the Blazar Sequence

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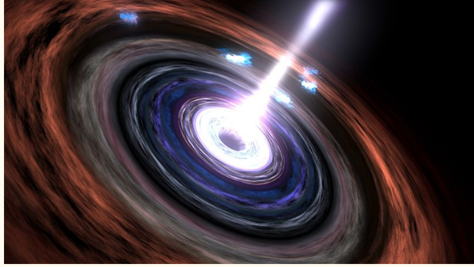
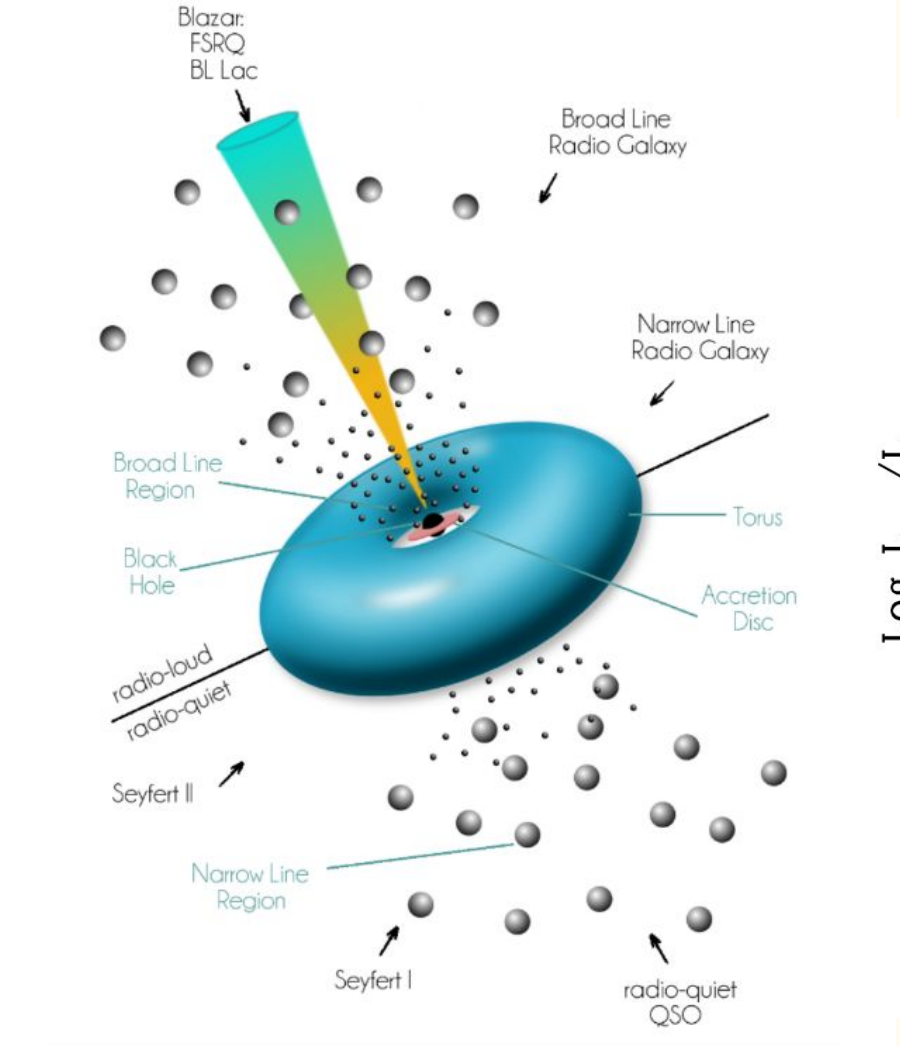
# Outline

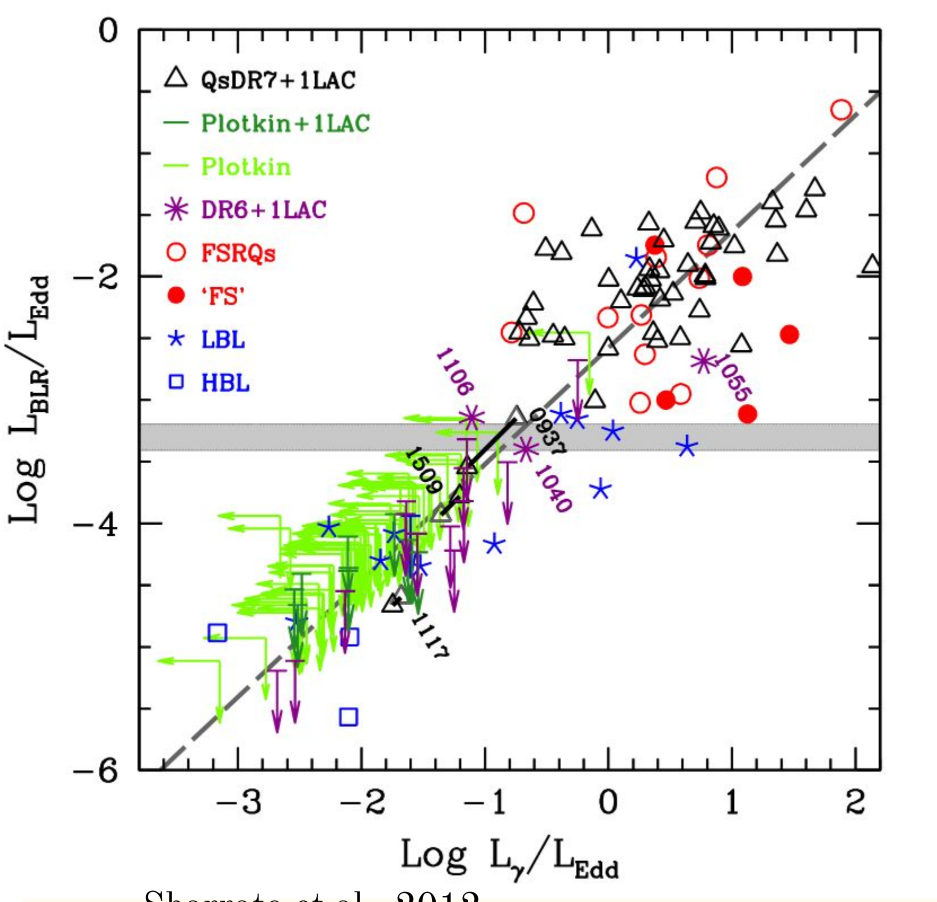
- Introduction
- Modelling the Non-Thermal Emission and External Photon Fields of Blazars
- MHD Accretion Disk Winds
- Blazar Sequence
- A Theoretical Model for the Blazar Sequence
- Results

# Introduction



Credit: NASA/Goddard Space Flight Center Conceptual Image Lab

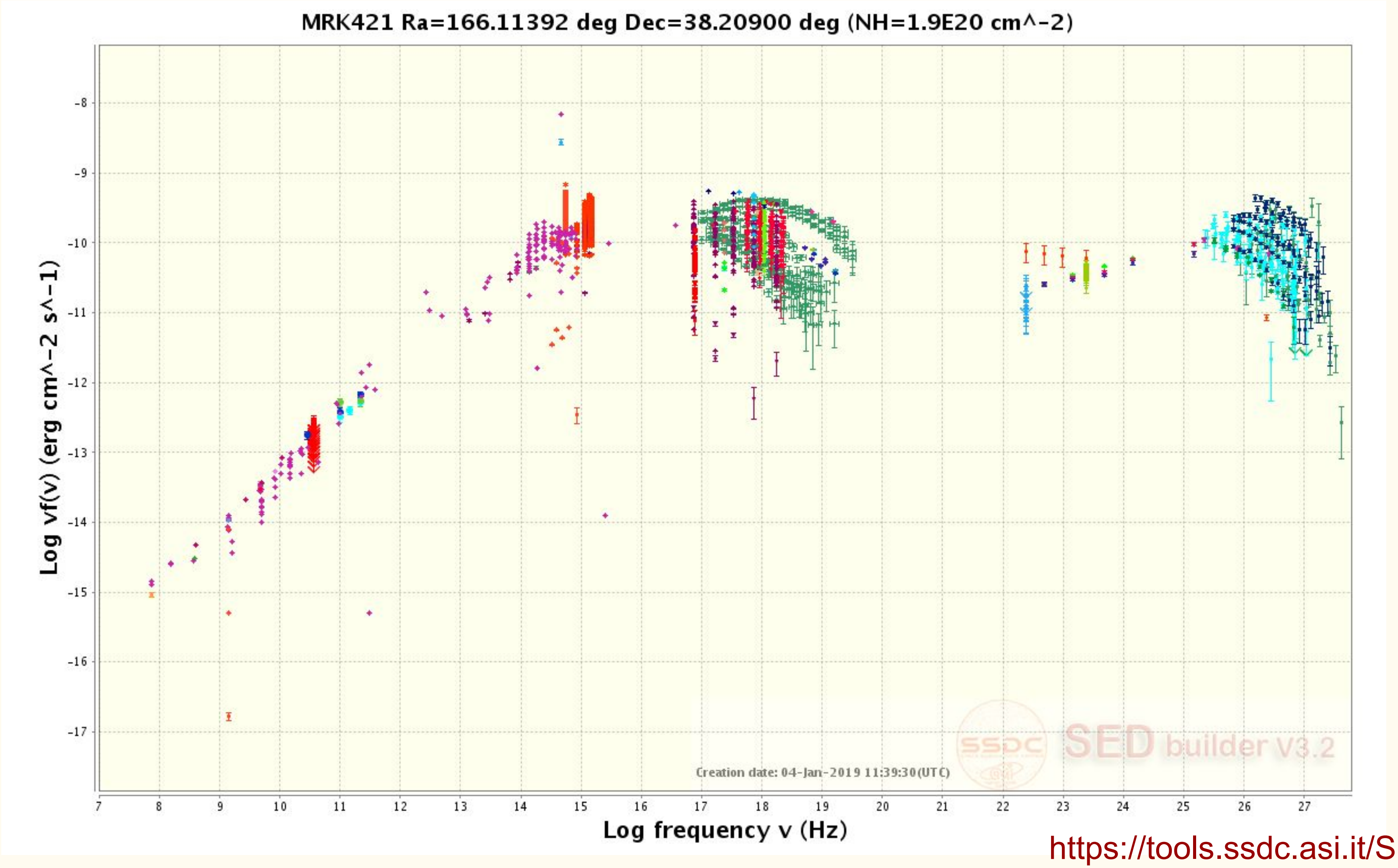



Sbarrato et al., 2012

Credit: http://www.sternwarte.unierlangen.de/ krauss.

# Modelling the Non-Thermal Emission of Blazars

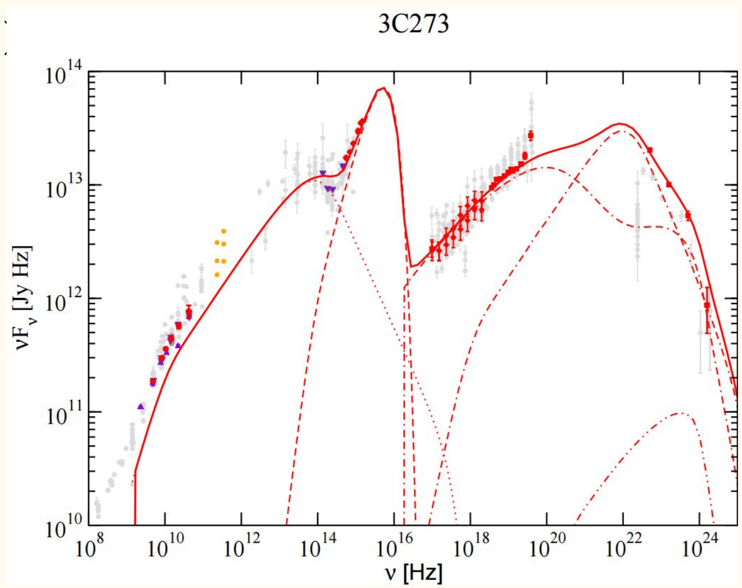


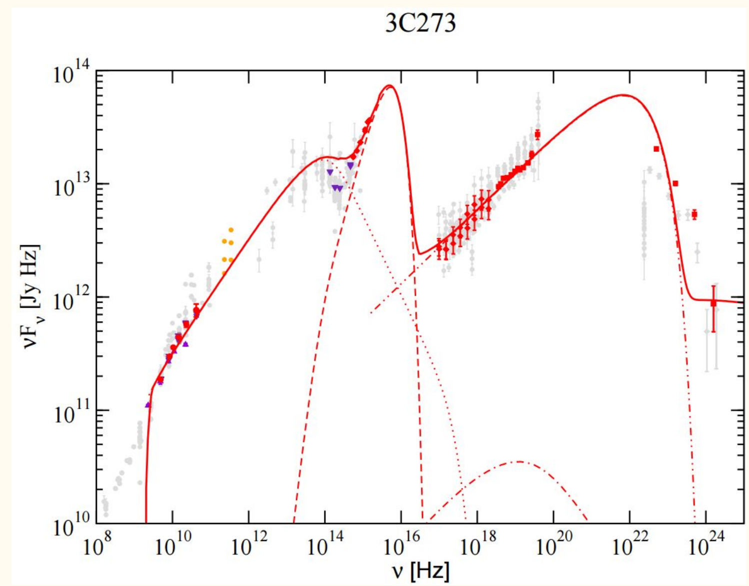

https://tools.ssdc.asi.it/SED/

# Models

Leptonic (Mastichiadis and Kirk, 1997,Weidinger and Spanier, 2010, Kataoka et al., 2000, Krawczynski et al., 2002, Sikora et al., 2001, Bottcher and Chiang, 2002, Ghisellini and Tavecchio, 2009, Acciari and Aliu, 2009, ++)

Hadronic (Mannheim and Biermann, 1992, Dimitrakoudis et al., 2014, Petropoulou et al., 2014, Padovani et al., 2015, Petropoulou et al., 2016, Zech et al., 2017, Padovani et al., 2018, Keivani et al., 2018 ++)



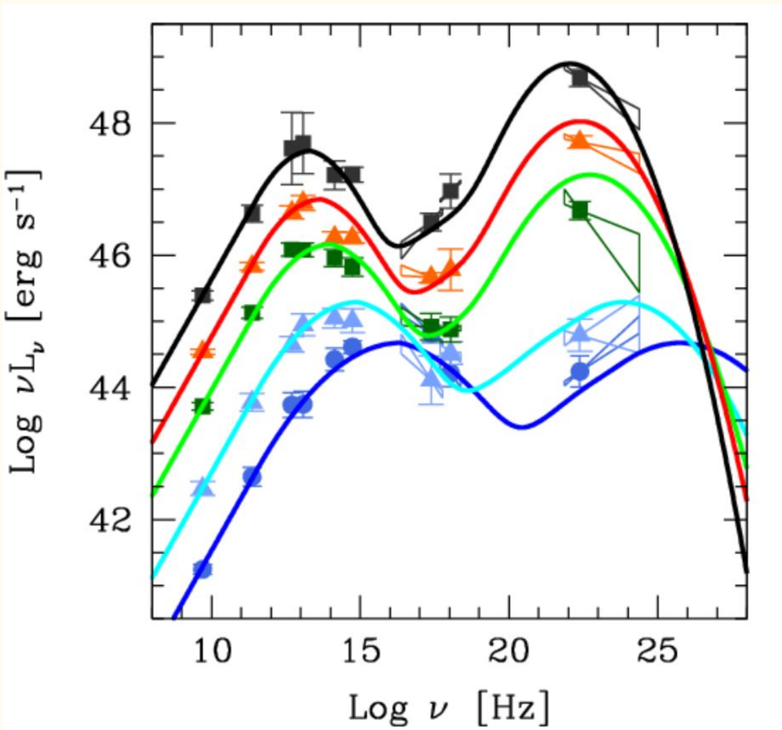




Bottcher et al, 2013

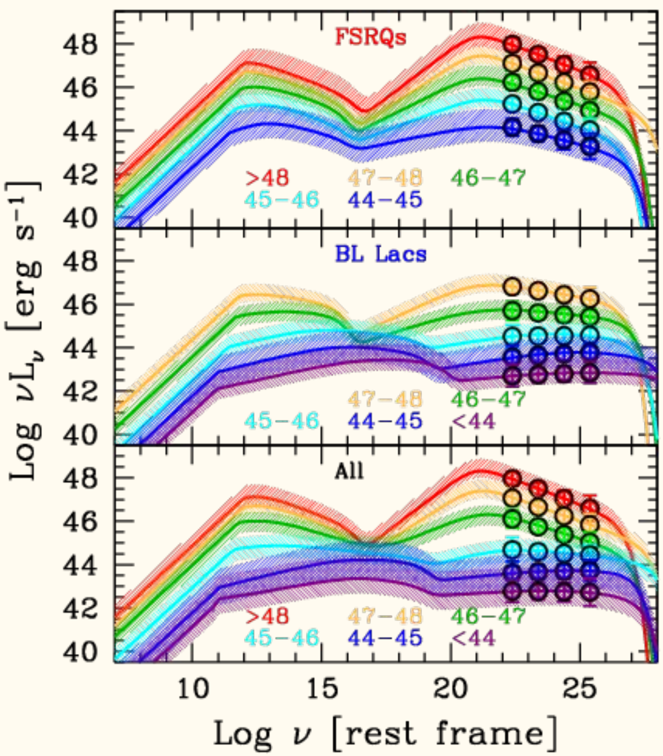
**See Florou's talk tomorrow**

# Does the Blazar Sequence exist?

(Giommi et al., 1999, Georganopoulos et al., 2001, Cavaliere and D'Elia, 2002, Padovani et al., 2003, Maraschi and Tavecchio, 2003, Nieppola et al., 2006, Padovani, 2007, Nieppola et al., 2008, [Xie et al., 2007, Ghisellini and Tavecchio, 2008, Ghisellini and Tavecchio, 2009, Meyer et al., 2011, Chen and Bai, 2011, Giommi et al., 2012, Finke, 2013, Xiong et al., 2015, Xiong et al., 2015b, Raiteri and Capetti, 2016, Ghisellini et al., 2017, Boula et al., 2019).




Fossati et al, 1998




Ghisellini, 2017

# Photon Fields

- Accretion Disk Photons (Dermer et al., 1992, Dermer and Schlickeiser, 1993 ++)
- Broad Line Region (Sikora et al., 1994, Blandford and Levinson, 1995, Ghisellini and Madau, 1996, Dermer et al., 1997, Finke, 2013 ++)
- Photons from torus (Blazejowski et al., 2000)
- Synchrotron emission from other regions of the jet ( Georganopoulos and Kazanas, 2003, Ghisellini and Tavecchio, 2008)
- Photons which are scattered on Accretion Disk Wind particles (Boula et al., 2019)

- Synchrotron Photons (Marscher and Gear, 1985, Maraschi et al., 1992, Bloom and Marscher, 1996 ++)

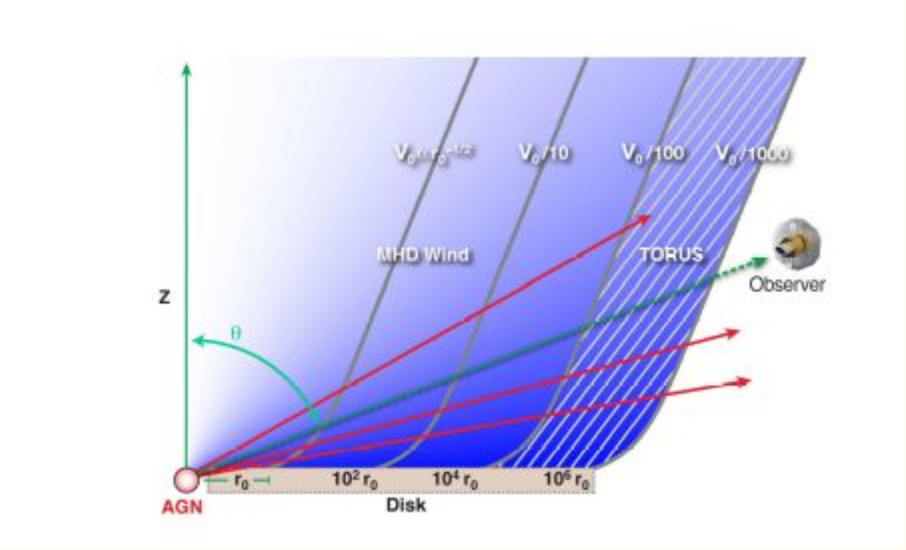
# MHD Accretion Disk Winds

- Winds driven by an accretion disk threaded by a poloidal magnetic field.

- At latitudes above the Alfven point the field lines become toroidal and the flow is almost radially out.

- The magnetic field permeates the entire disk, out to $\sim 10^6$ $R_s$, so these winds extend across many decades in R along the disk surface.

$$\mathbf{B}(\mathbf{r},\theta) \equiv x^{-(s+1)/2}\tilde{\mathbf{B}}(\theta)B_o\ ,$$
$$\mathbf{v}(\mathbf{r},\theta) \equiv x^{-1/2}\tilde{\mathbf{v}}(\theta)v_o\ ,$$
$$p(r,\theta) \equiv x^{-(s+1)}\mathcal{P}(\theta)B_o^2\ ,$$
$$n(r,\theta) \equiv x^{-s}\tilde{n}(\theta)B_o^2v_o^{-2}\ ,$$




Fukumura et al., 2010 (based on Contopoulos & Lovelace, 1994)

# A Theoretical Emission Model

Basic Parameters of a Leptonic Model

- Magnetic Field Strength
- Electrons luminosity
- Electrons Distribution
- Energy Density of the External Photon Field
- Bulk Lorentz factor
- Doppler factor

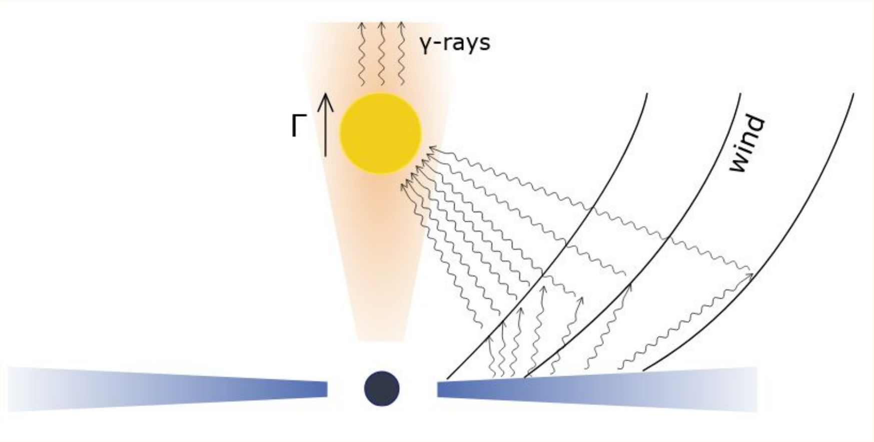



Image credit: S. Dimitrakoudis

# Theoretical Emission Model

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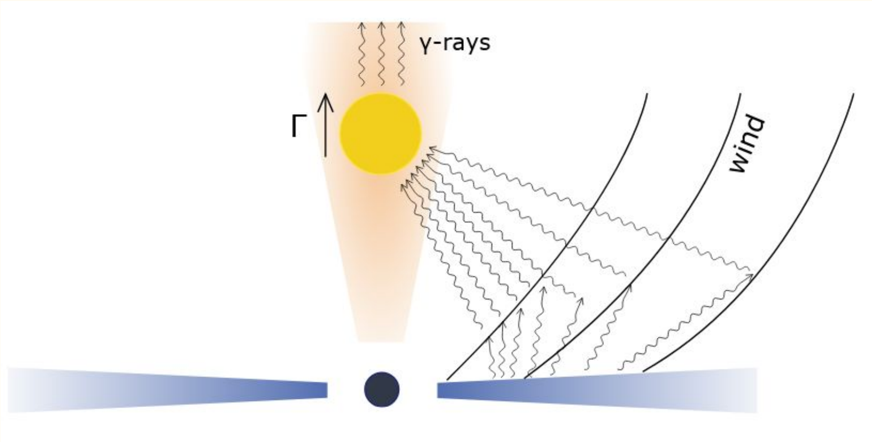



Image credit: S. Dimitrakoudis

**Related to the mass accretion rate**

# Accretion Power of the source:

$$P_{\mathrm{acc}} = \dot{m}\mathcal{M}L_{\mathrm{Edd}}$$

# Magnetic Field

$$U_{\mathrm{B}_0} = \frac{\eta_b P_{\mathrm{acc}}}{4\pi(3r_{\mathrm{s}})^2 c}$$

$$B = B_0(z_0/z)$$

# Electron Injection

$$Q_{\mathrm{e}} = \begin{cases} k_{\mathrm{e}_1}\gamma^{-s} \text{ for } \gamma_{\mathrm{min}} \leq \gamma \leq \gamma_{\mathrm{br}}, \\ k_{\mathrm{e}_2}\gamma^{-q}\mathrm{e}^{-\gamma/\gamma_{\mathrm{max}}} \text{ for } \gamma_{\mathrm{br}} \leq \gamma \leq \gamma_{\mathrm{max}} \end{cases}$$

$$L^{e}_{\mathrm{inj}} = m_{\mathrm{e}}c^2 \int_{\gamma_{\mathrm{min}}}^{\gamma_{\mathrm{max}}} Q_{\mathrm{e}}(\gamma)\gamma\,\mathrm{d}\gamma = \eta_{\mathrm{e}} P_{\mathrm{acc}}$$

$$\gamma_{\mathrm{br}} = \frac{3m_{\mathrm{e}}c^2}{4\sigma_\tau c t_{\mathrm{dyn}} U_{\mathrm{tot}}}$$

# External Photon Field

$$n(r,\theta) = n_0 (r_s/r)^p \, e^{5(\theta-\pi/2)} \quad n_0 = \frac{\eta_w \dot{m}}{2\sigma_T r_s}$$

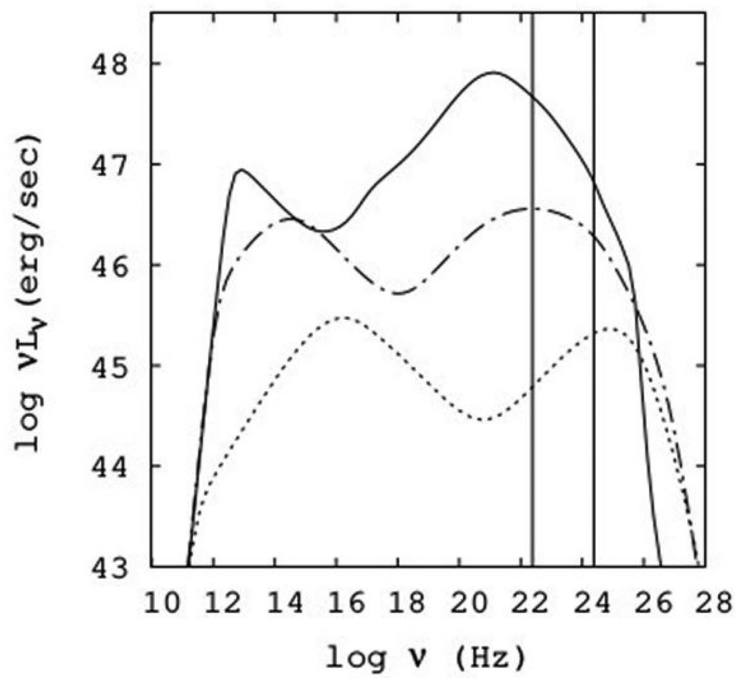
$$\tau_\tau(R_1, R_2) = \int_{R_1}^{R_2} n(r)\sigma_T \mathrm{dr} = n_0 \sigma_T r_s \ln(R_2/R_1)$$

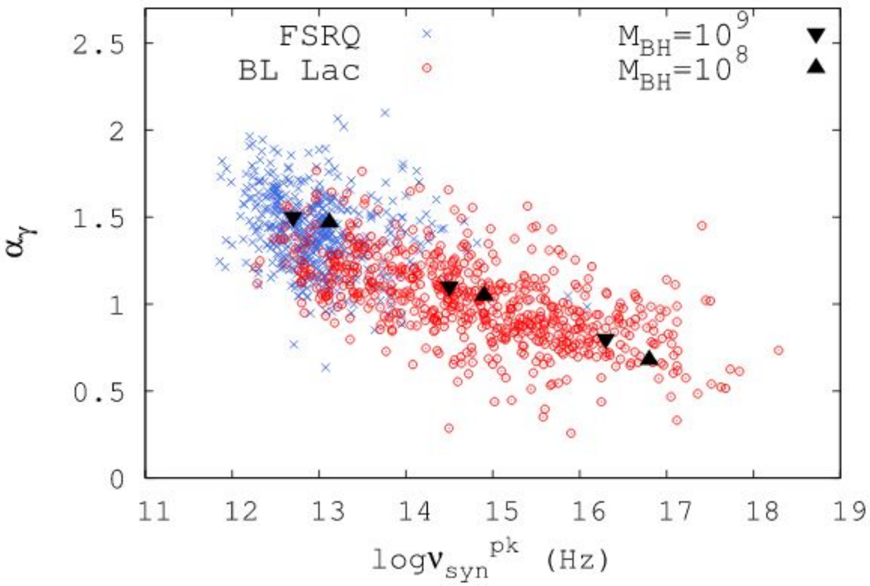
$$L_{\rm disc} = \begin{array}{ll} \epsilon \dot{m} \mathcal{M} L_{\rm Edd} & \text{for } \dot{m} \gtrsim 0.1 \\ \epsilon \dot{m}^2 \mathcal{M} L_{\rm Edd} & \text{for } \dot{m} \lesssim 0.1 \end{array}$$

$$U_{\rm sc} = \frac{L_{\rm disc}\tau_T}{4\pi R_2^2 c}$$

$$U_{\rm ext} = \Gamma^2 U_{\rm sc}$$

# Results



(In comparison with 3LAC results)

$$U_B \propto \frac{\dot{m}}{\mathcal{M}}$$

$$U_{ext} \propto U_{sc} \propto \frac{\dot{m}^{\alpha+1}}{\mathcal{M}} \quad \alpha = 1 \text{ for } \dot{m} \geq 0.1 \text{ and } \alpha = 2 \text{ for } \dot{m} < 0.1$$

$$L_e^{inj} \propto \dot{m}\mathcal{M}$$

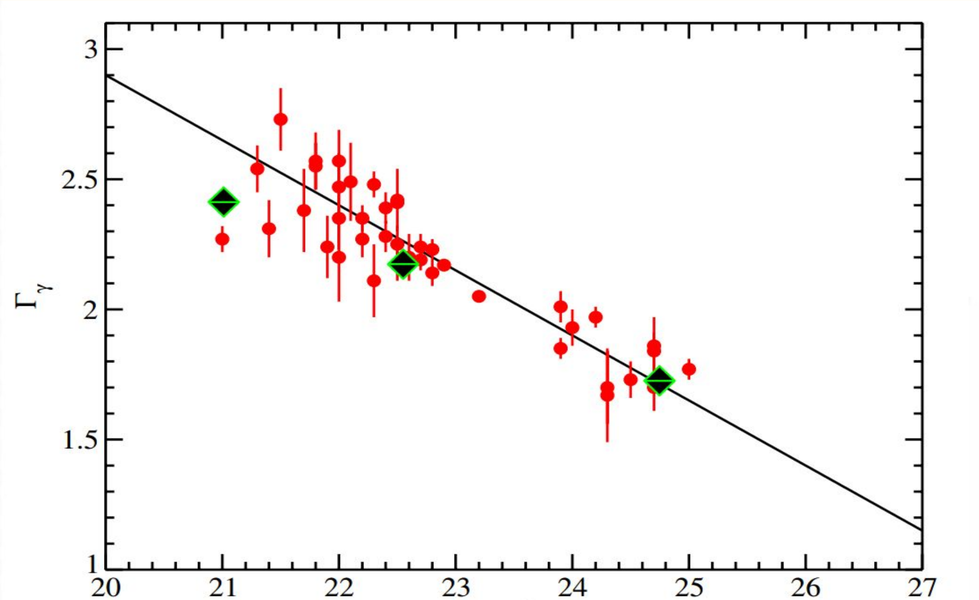
$$\gamma_{br} \propto \dot{m}^{-1}(1+\dot{m}^{\alpha})^{-1}$$

$$\nu_{pk}^{syn} \propto \mathcal{M}^{-1/2}\dot{m}^{-3/2}/(1+\dot{m}^{\alpha})^2$$

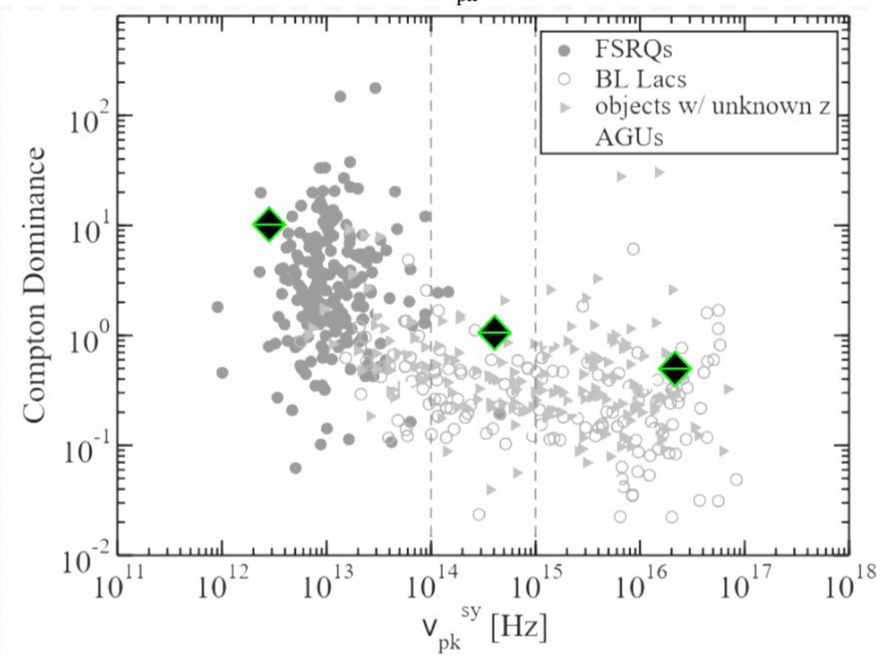
| $\dot{m}$ | $B$(G) | $U_{ext}$ $\left(\frac{erg}{cm^3}\right)$ | $L_e^{inj}$ $\left(\frac{erg}{sec}\right)$ | $\gamma_{br}$ | Blazar class |
|---|---|---|---|---|---|
| −0.5 | −0.3 | −1.4 | 45.2 | 2.3 | FSRQ |
| −1.5 | −0.8 | −4.6 | 44.2 | 3.3 | LBL |
| −2.5 | −1.3 | −7.6 | 43.2 | 6.5 | HBL |

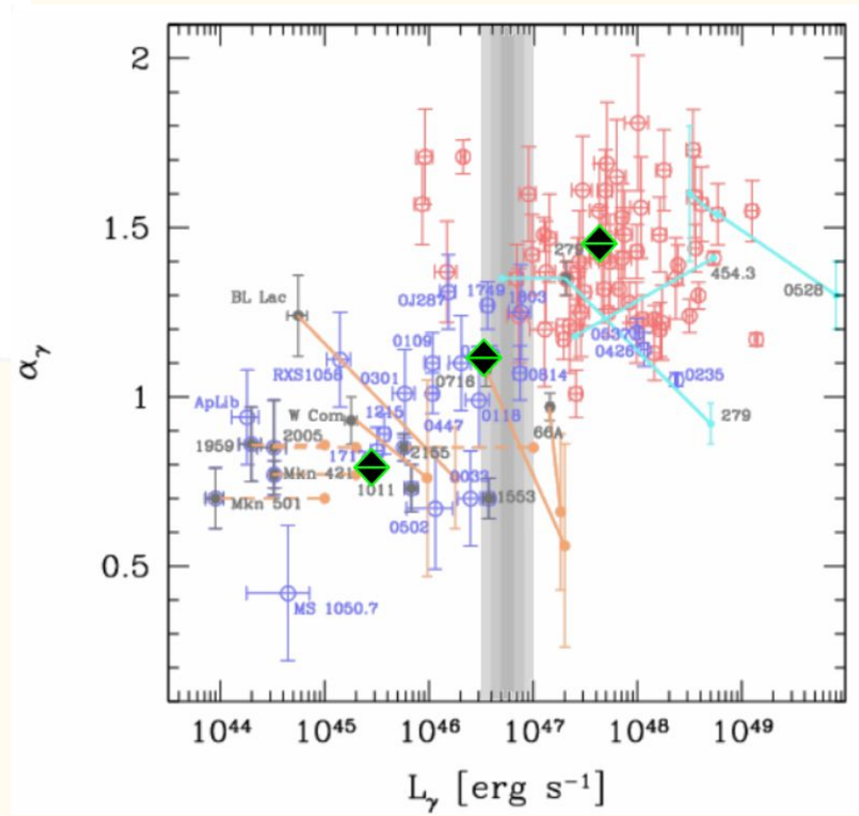
(logarithmic values)

Boula, Kazanas, Mastichiadis, 2019




Finke 2013




Ghisellini et al., 2009

# Take home messages

- MHD Accretion Disk Winds might be related to Blazars SED.
- We obtain the theoretical BS by varying only one parameter.
- The spread of the distribution depends on the other parameters.

# Thank you!

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