Is the Blazar Sequence related to accretion disk winds?

Stella Boula[1*]

In colaboration: Apostolos Mastichiadis[1]
Demosthenes Kazanas[2]

[1] Department of Physics, University of Athens, Zografos, Greece
[2] NASA Goddard Space Flight Center, Laboratory for High-Energy Astrophysics
*stboula@phys.uoa.gr

Hel.a.S
HELLENIC ASTRONOMICAL SOCIETY
The 2nd Summer School of Hel.A.S.
11-15 July 2016, Athens

Outline

- The anatomy of a Blazar
- SED
- The models
- The accretion disk wind
- Blazar Sequence

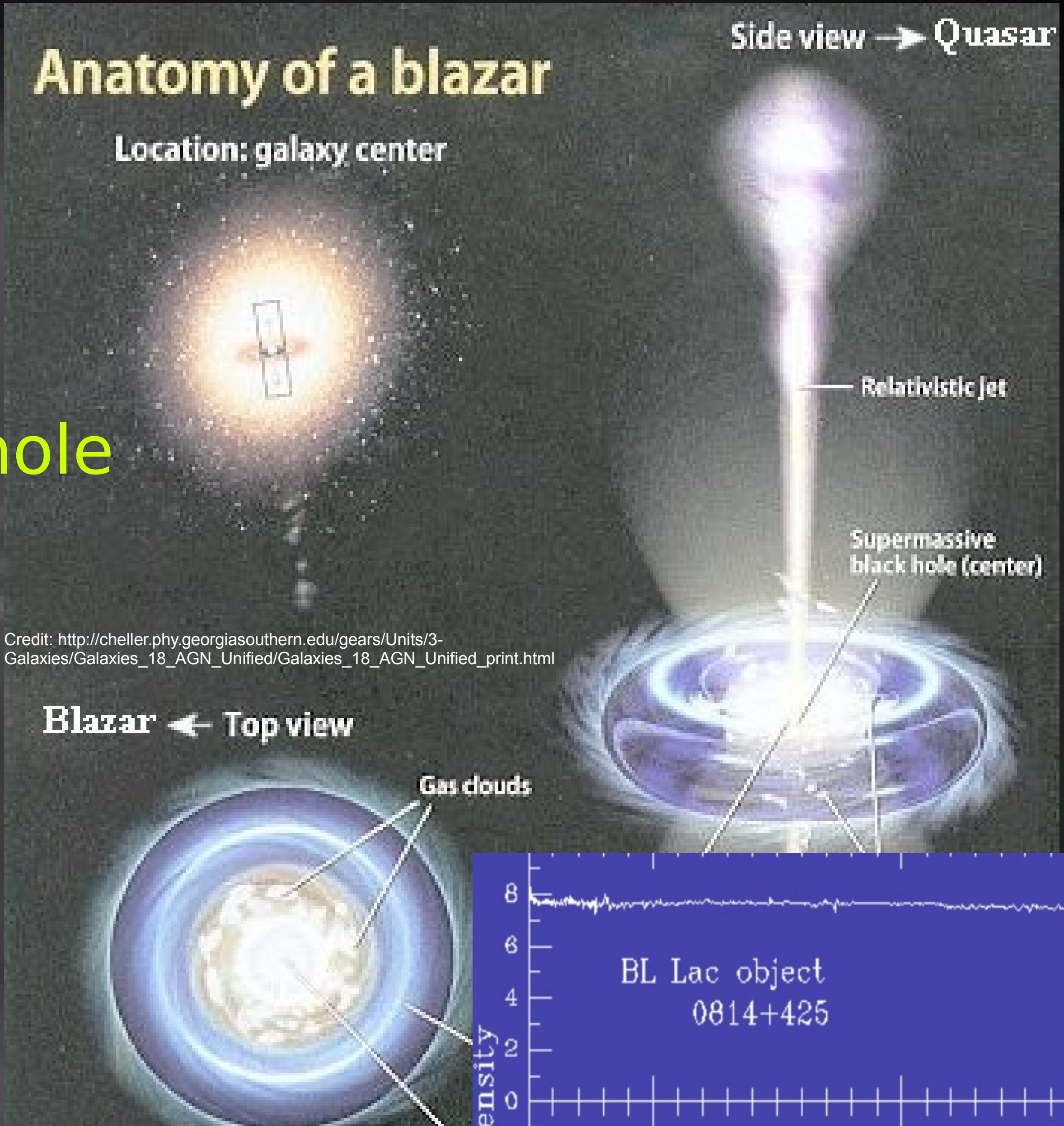
The parts...

Supermassive black hole

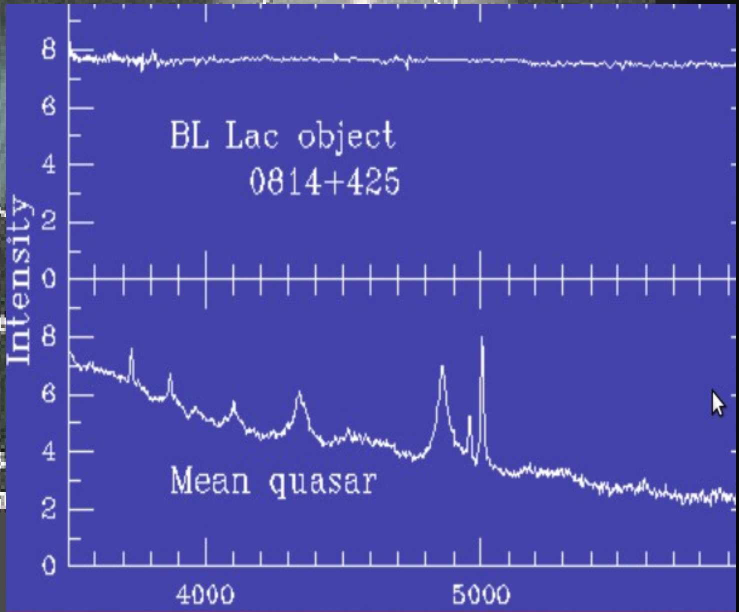
Accretion disk

Relativistic Jet

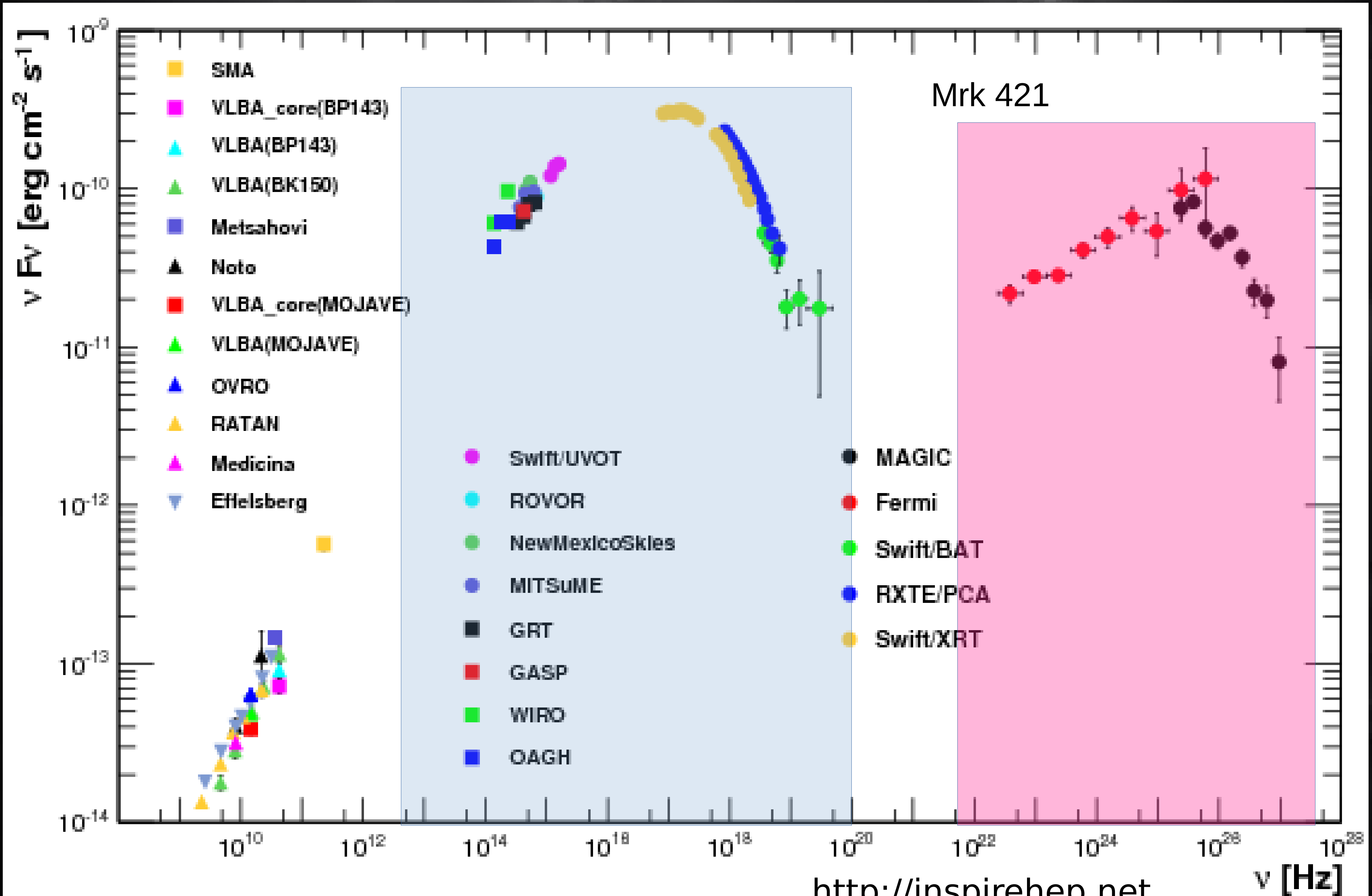
Gas clouds



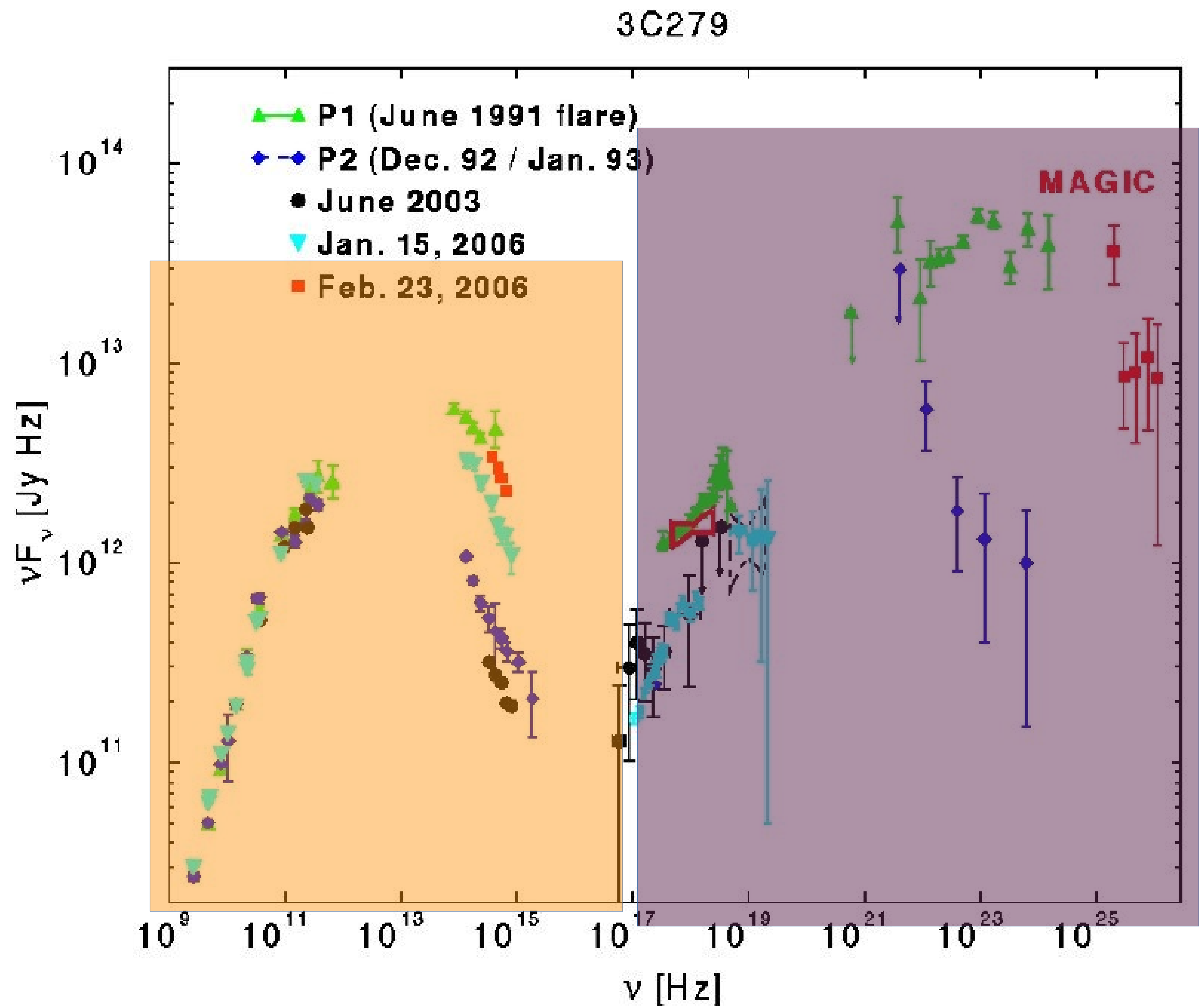
Credit: http://cheller.phy.georgiasouthern.edu/gears/Units/3-Galaxies/Galaxies_18_AGN_Unified/Galaxies_18_AGN_Unified_print.html



SED



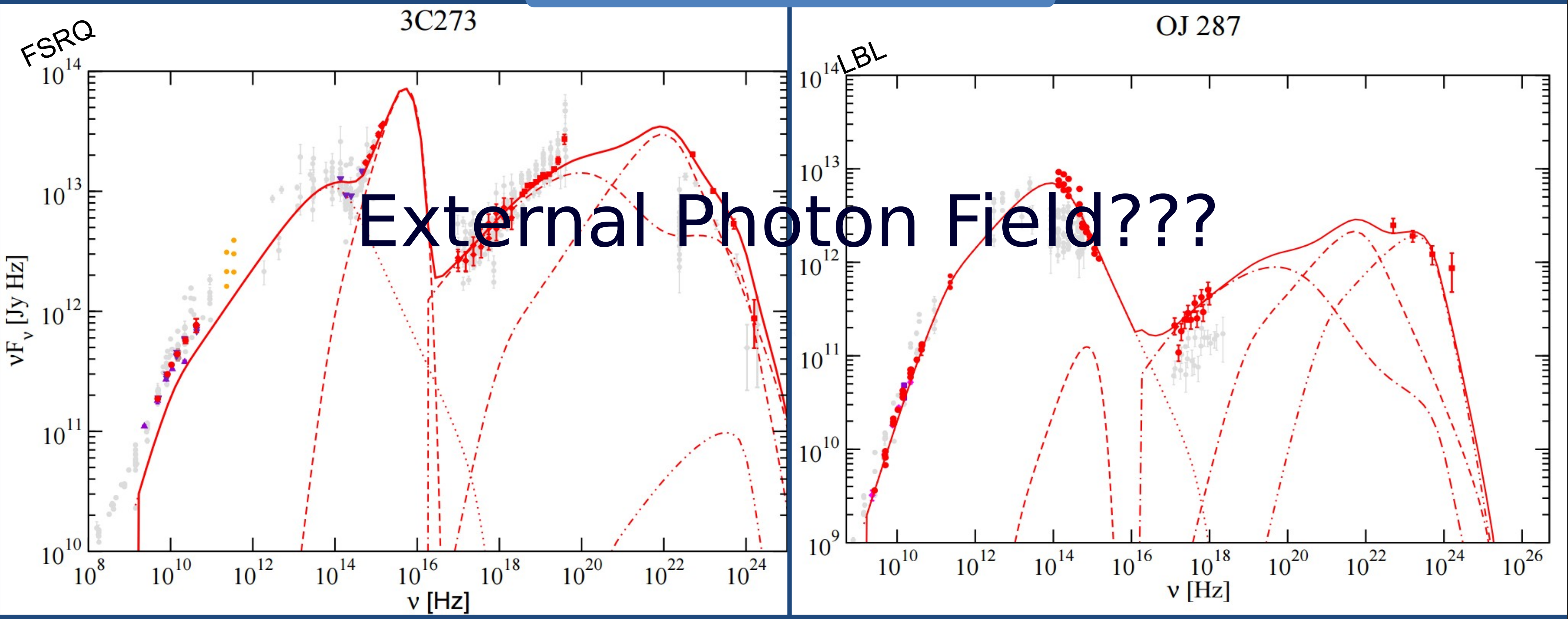
http://inspirehep.net



http://www.phy.ohiou.edu/

The leptonic model...

$$\frac{\partial n_i}{\partial t} + \frac{n_i}{t_{esc}} = L_i + Q_i$$



Bottcher et al, ApJ, 2013, arXiv:1304.0605

Accretion Disk Wind

$$\nabla \cdot \rho \boldsymbol{v} = 0$$

$$\nabla \times \boldsymbol{B} = \frac{4\pi}{c}\boldsymbol{J}$$

$$\boldsymbol{E} + \frac{v}{c} \times \boldsymbol{B} = 0$$

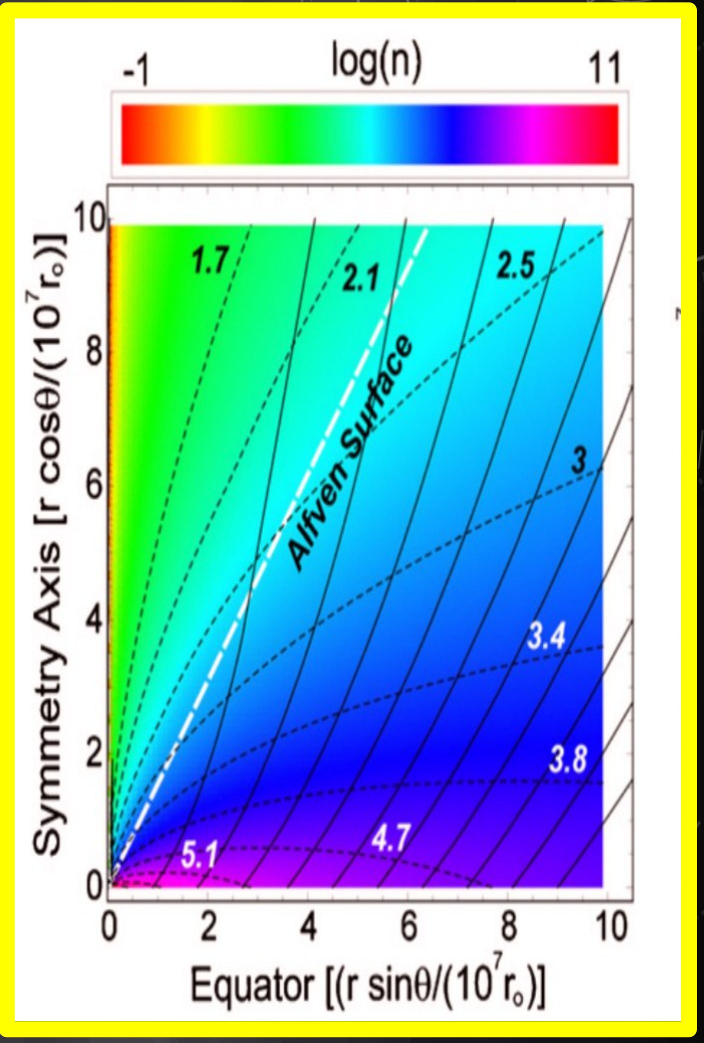
$$\nabla \times \boldsymbol{E} = 0$$

$$\rho(\boldsymbol{v} \cdot \nabla)\boldsymbol{v} = -\nabla \boldsymbol{p} - \rho \nabla \boldsymbol{\Phi}_g + \frac{1}{c}(\boldsymbol{J} \times \boldsymbol{B})$$

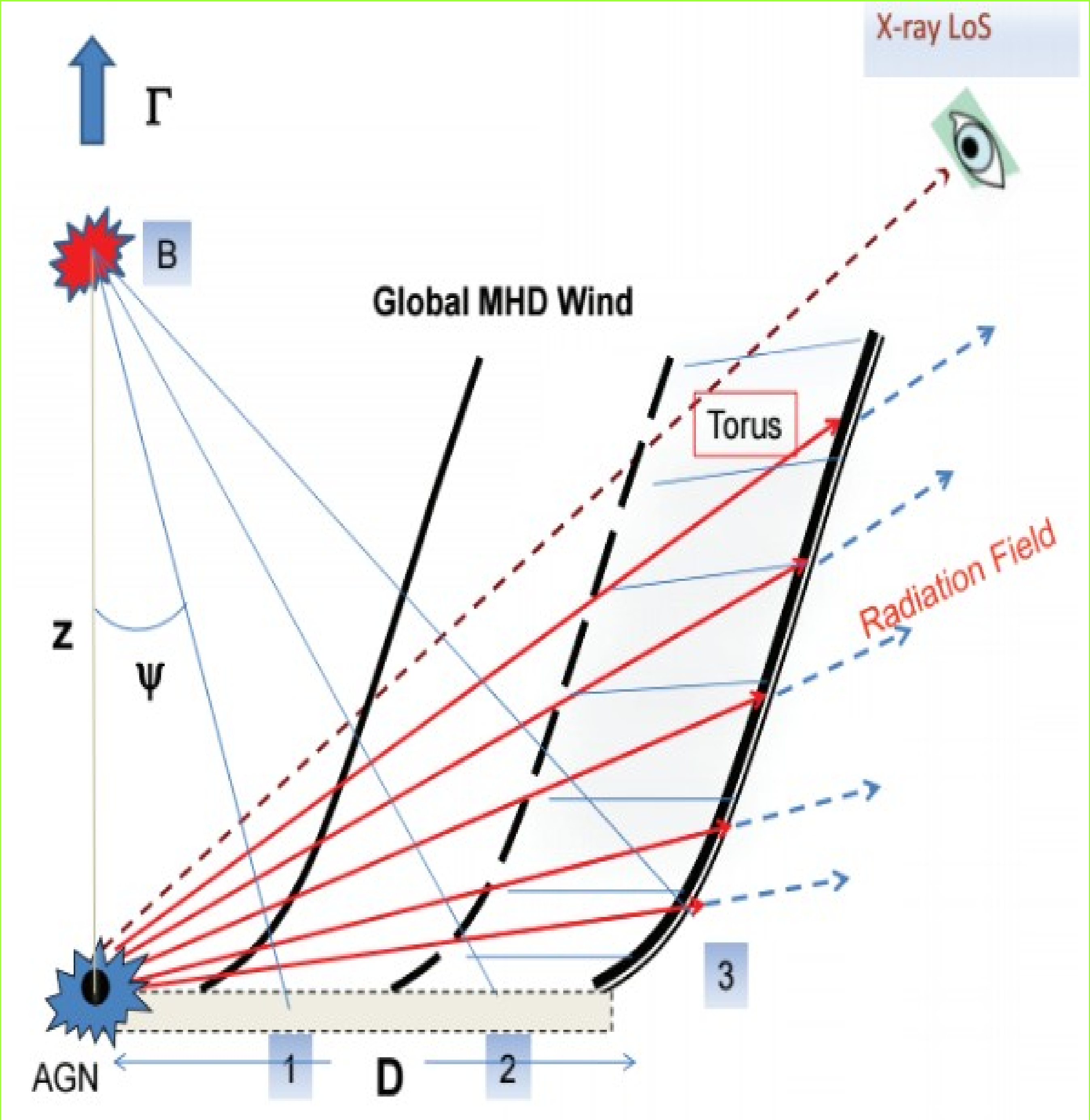
$$\nabla \cdot \boldsymbol{B} = 0$$

$$p = K\rho^{\Gamma}$$

$$n(r,\theta) \equiv \frac{\rho(r,\theta)}{\mu m_p} = n_0 x^{2q-3} \mathcal{N}(\theta) \quad n_0 = \frac{\eta_w \dot{m}}{2\sigma_\tau R_s}$$



Fukumura et al, 2010


X-ray LoS
Γ
B
Global MHD Wind
Torus
Radiation Field
z
ψ
3
AGN
1
D
2

External Photon Field

$$L \simeq \epsilon \dot{m}^2 L_0 \hat{M} = 2\pi\epsilon\dot{m}^2 \frac{R_s m_p c^3}{\sigma_T}$$

$L_0 = 1.5 \times 10^38\ erg\ sec^{-1}$

$$\tau_T = \int_{R_1}^{R_2} n(r)\sigma_T \mathrm{dr} = \int_{R_1}^{R_2} \sigma_T \mathrm{n_0} \left(\frac{\mathrm{R_0}}{\mathrm{r}}\right) = \sigma_T \mathrm{n_0 R_0} \ln\left(\frac{\mathrm{r}}{\mathrm{R_o}}\right)$$

$R_0 = R_s$

$$\tau_T = \frac{\dot{m}}{2} \ln\left(\frac{r}{R_s}\right)\Big|_{R_1}^{R_2}$$

$$L_{ext} = L_{disk}(1 - e^{-\tau_T})$$

$$L_{ext} \overset{\tau_T << 1}{=} \tau_T L_{disk} = \tau_T \eta_d L_{acc}$$

Other physical quantities..

Magnetic Field

$$B \propto \frac{1}{R}$$

$$\Gamma = (1 - \beta^2)^{-1/2}$$

$$\delta = [\Gamma(1 - \beta\cos\theta)]^{-1}$$

$$U_{B_0} = \frac{\eta_b L_{acc}}{A_0 c}$$

$$R_0 = 3R_s$$

$$A_0 = 4\pi R_0^2$$

$$\frac{B_0^2 \left(\frac{R_0}{R}\right)^2}{8\pi} = \frac{\eta_b L_{acc}}{A_o c}$$

Electrons luminosity

$$L_e = \eta_e L_{acc}.$$

Energy density of EF

$$U_{ext} = \frac{L_{ext}}{4\pi R_2^2 c}.$$

Maximum electrons Lorentz Factor

$$\gamma_{max} = \frac{3 m_e c^2}{4 \sigma_T t_{acc} c (U_B + U_{ext} + U_{SSC})}$$

Acceleration time

$$\tau_{FI} \gtrsim 6 \left(\frac{c}{u_s}\right)^2 \frac{\lambda}{c} \sim 6 \frac{r_{gyr} c}{u_s^2} = 6 \frac{\gamma m_e c^2}{eB} \frac{c}{u_s^2}$$

Electrons Distribution

$$Q_e = q_e \gamma^{-s} e^{-\gamma/\gamma_{max}} \text{ για } \gamma_{min} \leq \gamma \leq \gamma_{max}$$

or

$$Q_e = \begin{cases} k_{e_1} \gamma^{-p} & \text{για } \gamma_{min} \leq \gamma \leq \gamma_{br} \\ k_{e_2} \gamma^{-q} e^{\gamma/\gamma_{max}} & \text{για } \gamma_{br} \leq \gamma \leq \gamma_{max} \end{cases}$$

Acceleration

Acceleration

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial \gamma}\left[\left(\frac{\gamma}{t_{acc}} - \beta_s \gamma^2\right) N\right] + \frac{N}{t_{esc}} = Q\delta(\gamma - \gamma_0)$$

$$\beta_s = \frac{4}{3}\frac{\sigma_T}{m_e c}\frac{B^2}{8\pi}$$

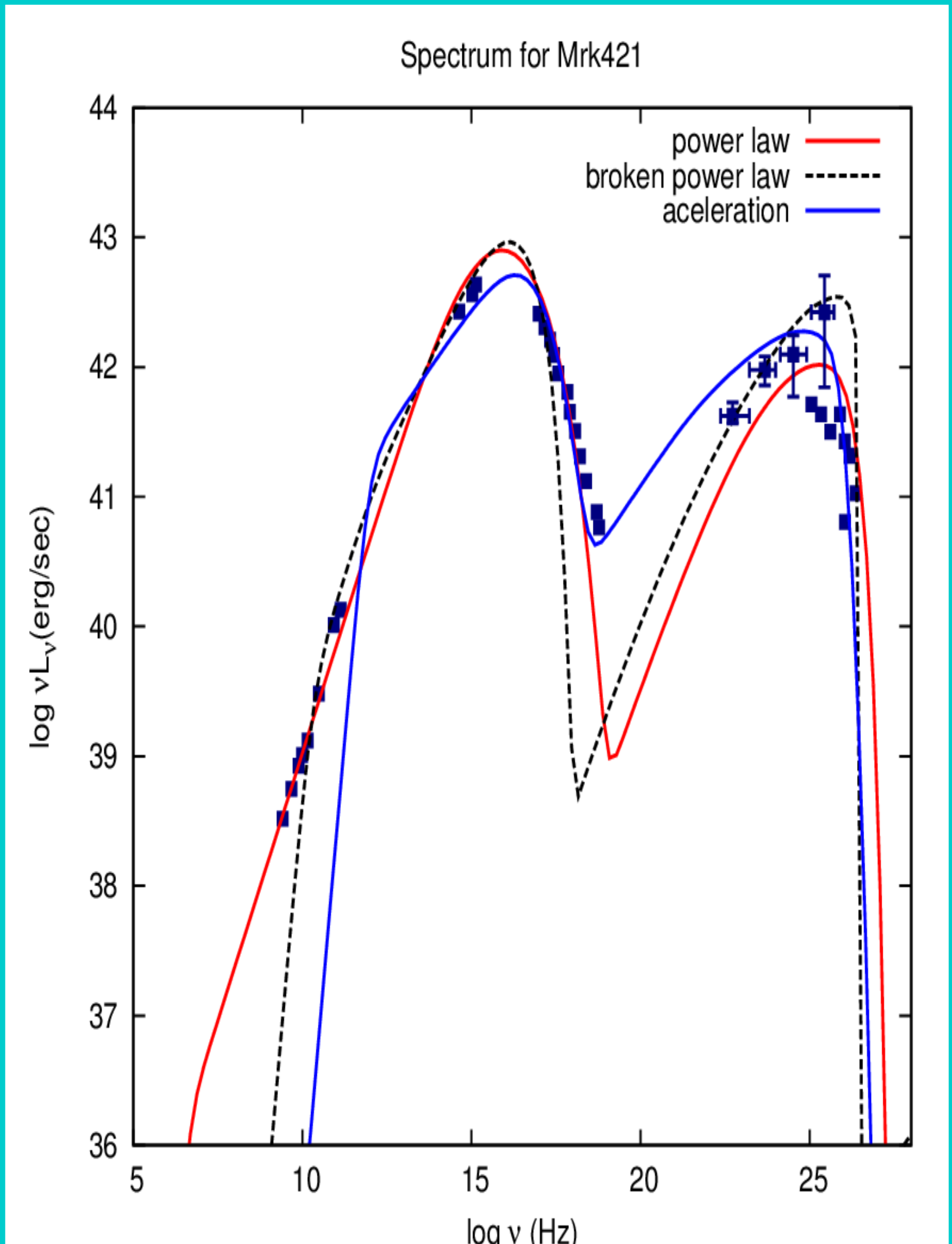
$$N(\gamma, t) = \alpha \frac{1}{\gamma^2}\left(\frac{1}{\gamma} - \frac{1}{\gamma_{max}}\right)^{(t_{acc}-t_{esc})/t_{esc}} \Theta(\gamma - \gamma_0)\Theta(\gamma_1(t) - \gamma)$$

$$\alpha = Q_0 t_{acc} \gamma_0^{t_{acc}/t_{esc}} \left(1 - \frac{\gamma_0}{\gamma_{max}}\right)^{-t_{acc}/t_{esc}}$$

$$\gamma_1(t) = \left(\frac{1}{\gamma_{max}} + \left[\frac{1}{\gamma_0} - \frac{1}{\gamma_{max}}\right] e^{-t/t_{acc}}\right)^{-1}$$

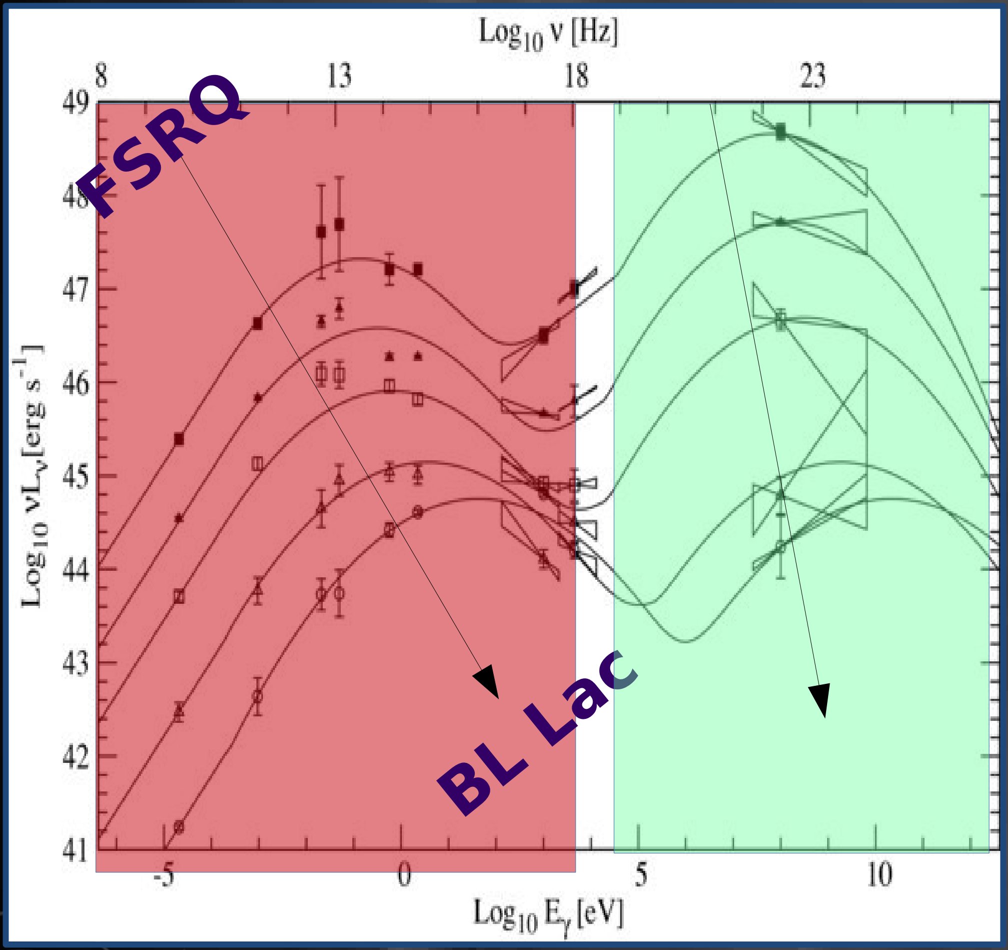
$$\gamma_{max} = (\beta_s t_{acc})^{-1}$$

Mrk 421 SED

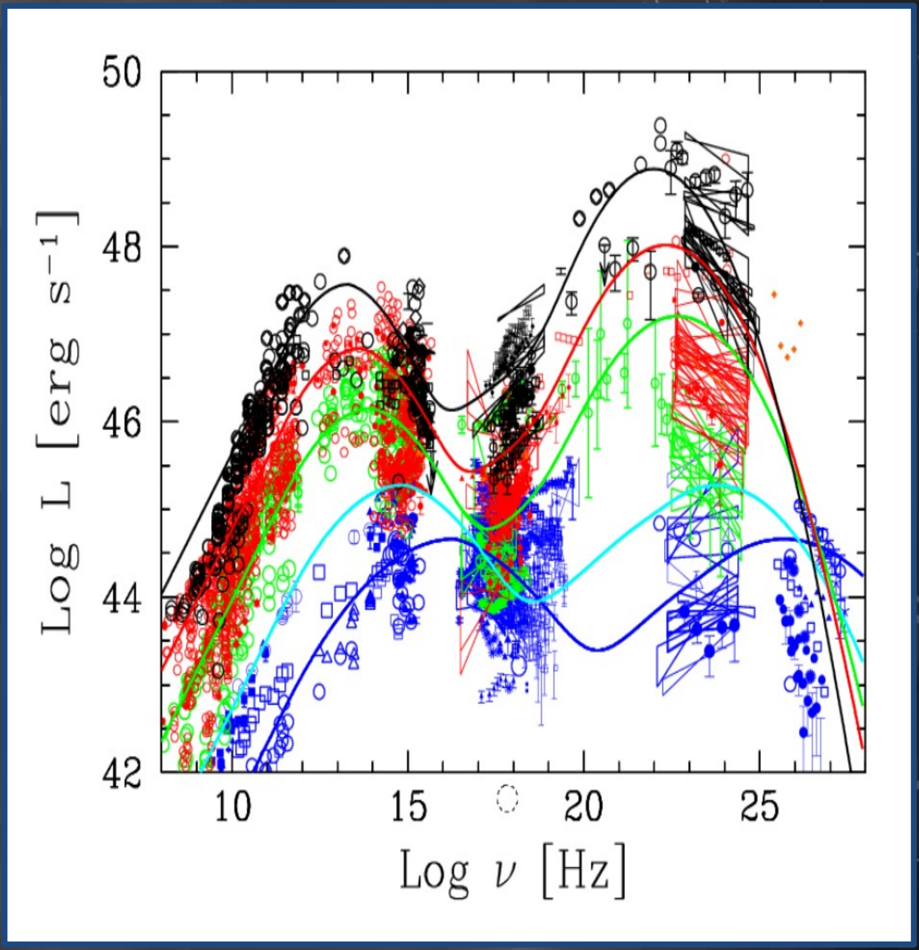


Μοντέλο	R_b	B (G)	$\log \gamma_{max}$	$\log l_e$	$\log l_{ext}$	δ
Απλός Νόμος Δύναμης	16.3	0.07	5.0	-5.9	-8.5	10
Σπασμένος Νόμος Δύναμης	16.7	0.03	4.2	-4.7	-8.5	7
Επιτάχυνση	15.0	0.65	-	-	-8.5	10

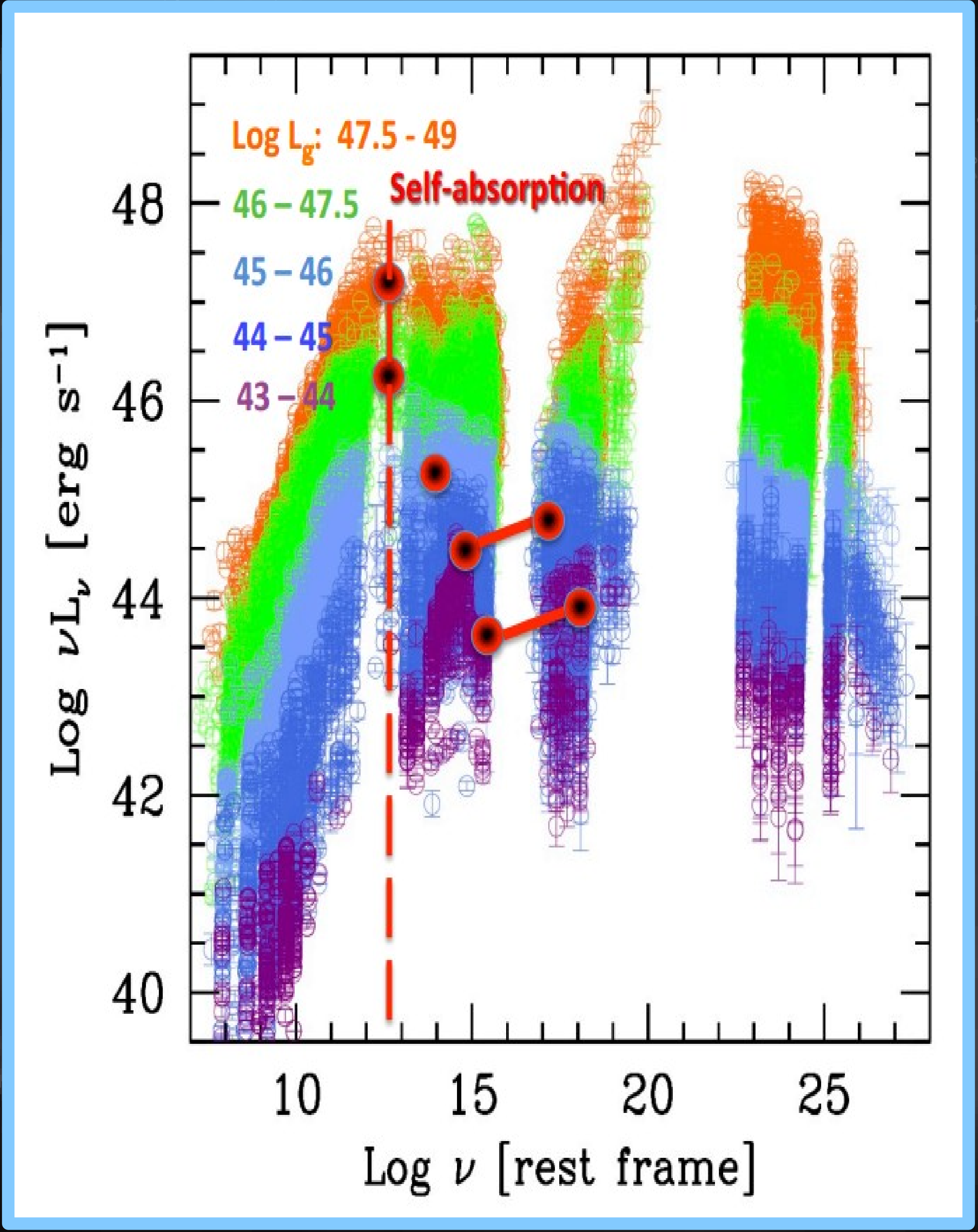
Blazar Sequence



Fossati et al, 1998



Ghisellini 2013, Granada, Spain



Ghisellini 2016, Malaga Spain

The role of the accretion mass rate

$$U_B \propto \dot{m}^2$$

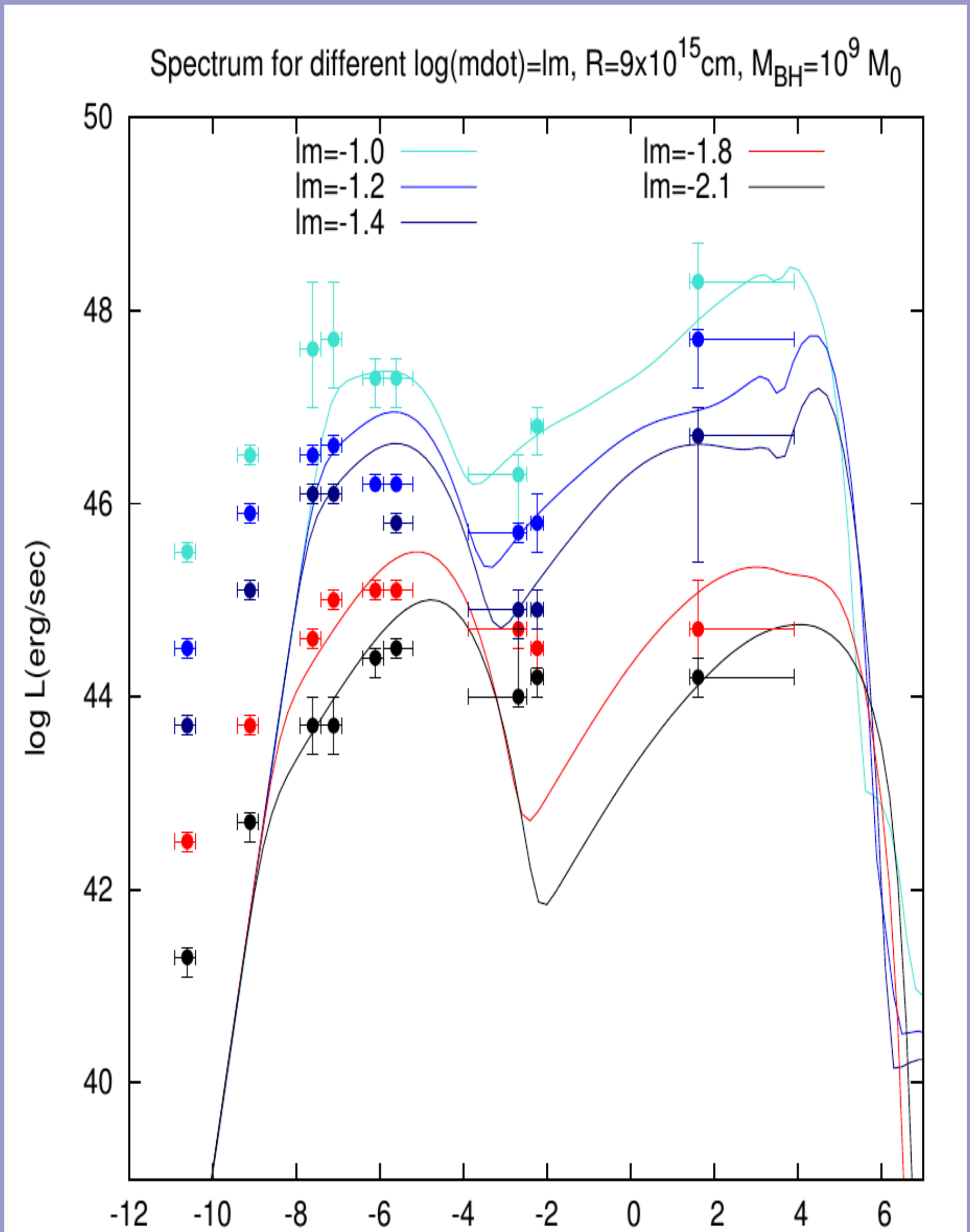
$$U_{ext} \propto \dot{m}^3$$

$$\gamma_{max} \propto \dot{m}^{-2}(1+\dot{m})$$

$$L_e \propto \dot{m}^2$$

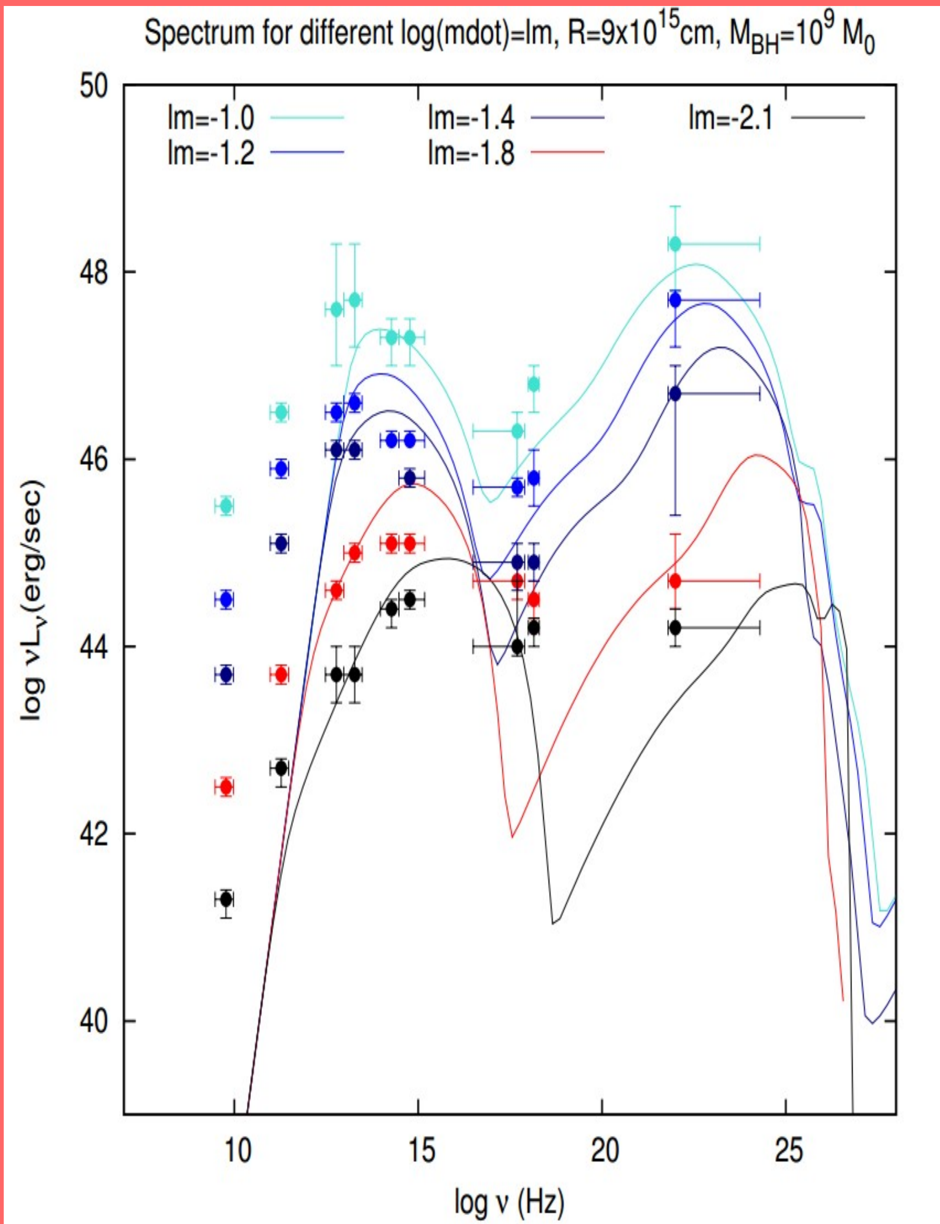
$$t_{acc} \propto \dot{m}^0$$

BS - PL



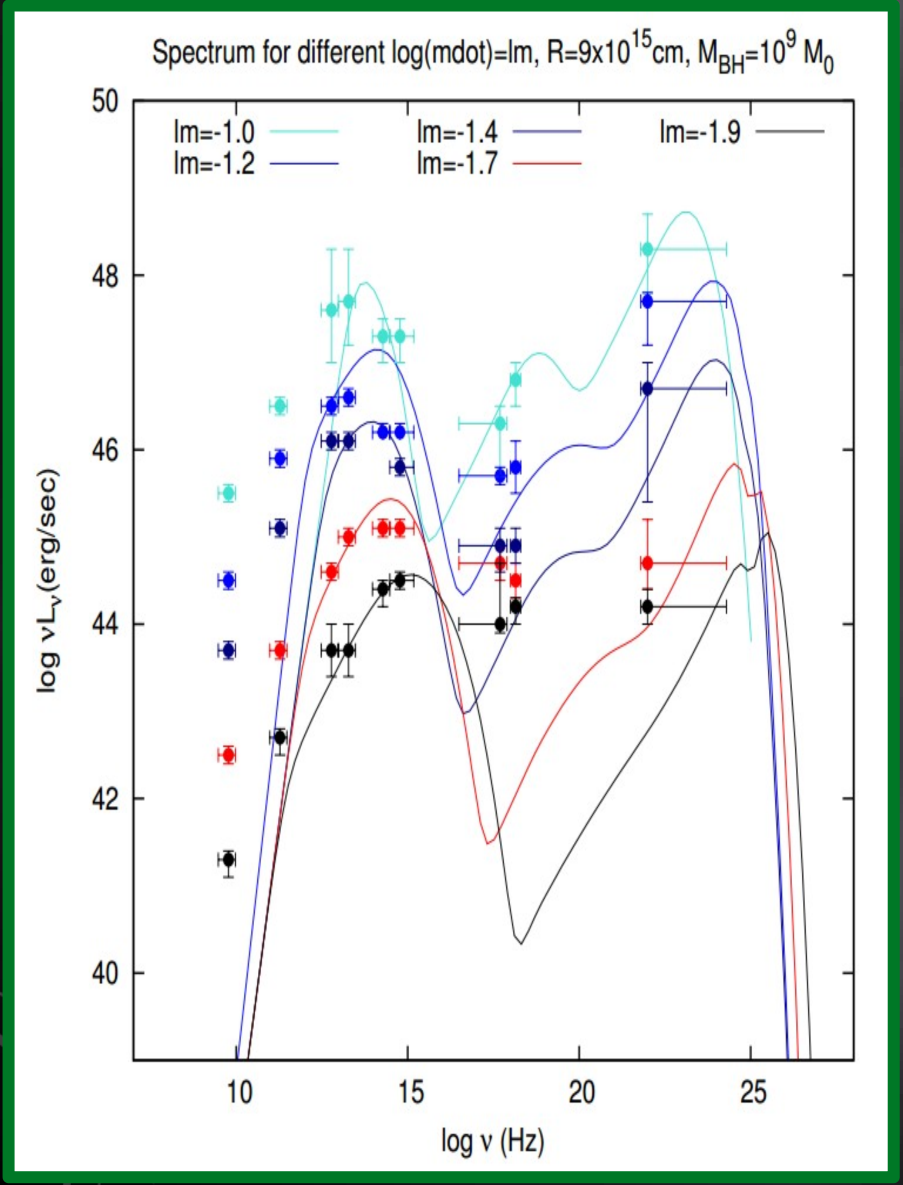
$\log \dot{m}$	B (G)	$\log \gamma_{max}$	$\log l_{ext}$	$\log l_e$
-1.0	1.00	3.3	-1.85	-2.6
-1.2	0.47	3.6	-2.70	-3.2
-1.4	0.30	3.8	-3.22	-3.6
-1.8	0.09	4.2	-4.70	-4.6
-2.1	0.06	4.4	-5.30	-5.0

BS-BPL



$\log \dot{m}$	B (G)	$\log \gamma_{br}$	$\log l_{ext}$	$\log l_e$
-1.0	2.40	2.90	-2.0	-1.9
-1.2	1.51	3.01	-2.1	-2.3
-1.4	0.95	3.16	-2.5	-2.7
-1.8	0.38	3.50	-3.4	-3.5
-2.1	0.19	3.60	-4.5	-4.1

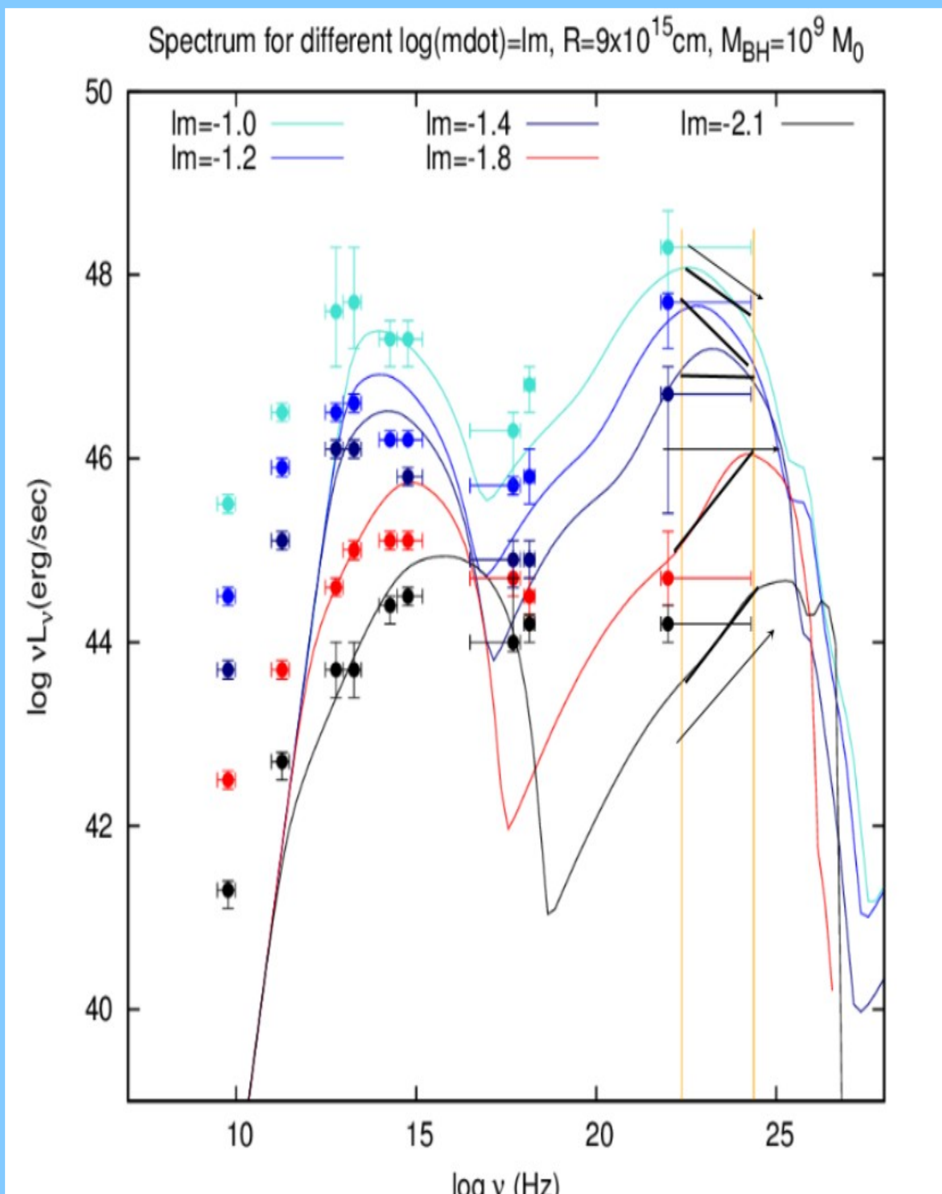
BS-Acceleration

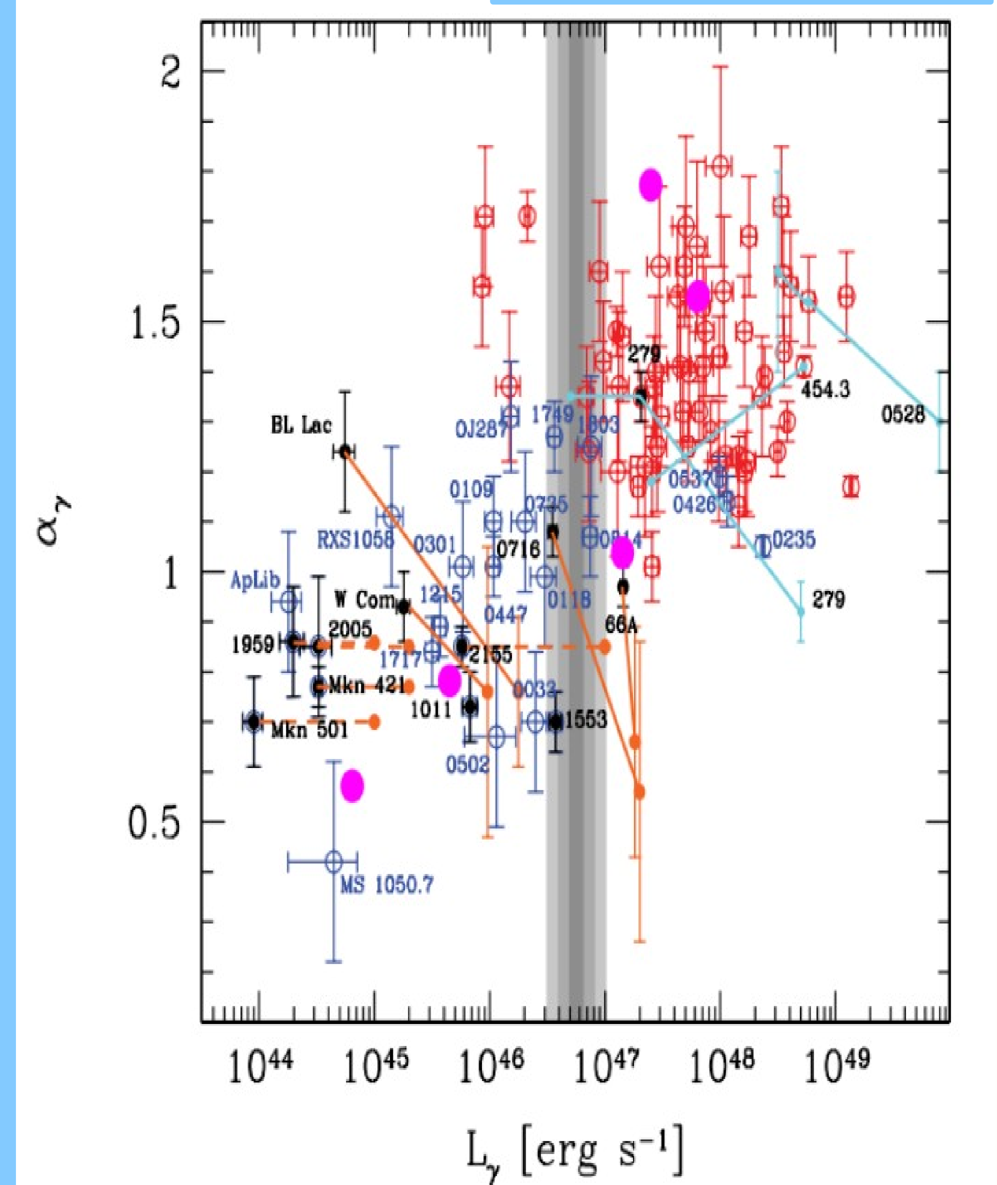


$\log \dot{m}$	B (G)	$\log l_{ext}$
-1.0	2.40	-1.7
-1.2	1.51	-2.5
-1.4	0.95	-2.1
-1.7	0.48	-3.7
-1.9	0.30	-4.4

α_γ-L_γ

$1-\alpha_\gamma$	α_γ	Γ_γ	$\log(L_\gamma)$ (erg/sec)
-0.28	1.28	2.28	48.1
-0.30	1.30	2.30	47.7
-0.05	1.05	2.05	47.2
0.24	0.76	1.76	46.0
0.45	0.55	1.55	44.7





Ghisellini et al, 2009

Take message home

- The wind could be a physical explanation for the BS

Thank you!