The Blazar Sequence and Accretion Disk Winds

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HAP Workshop | Monitoring the non-thermal universe, Cochem

Outline

- Introduction
- The accretion disk wind as external photon provider
- Blazar Sequence
- Results

Introduction

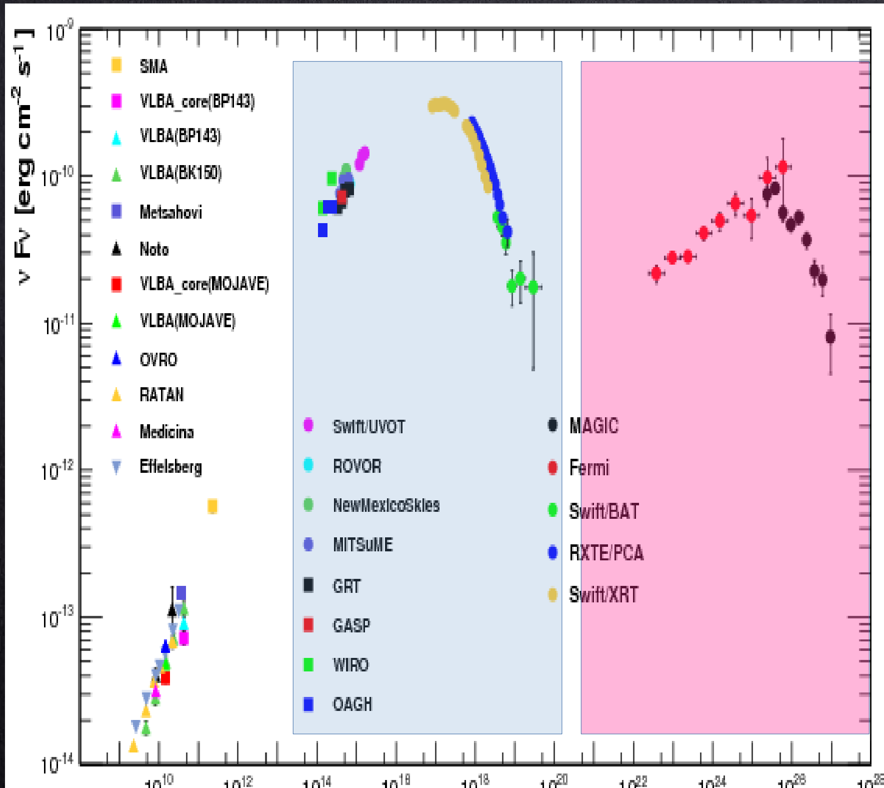
Models

- Leptonic → Synchrotron / Inverse Compton Scatering
- Hadronic → Synchrotron / Hadronic interactions

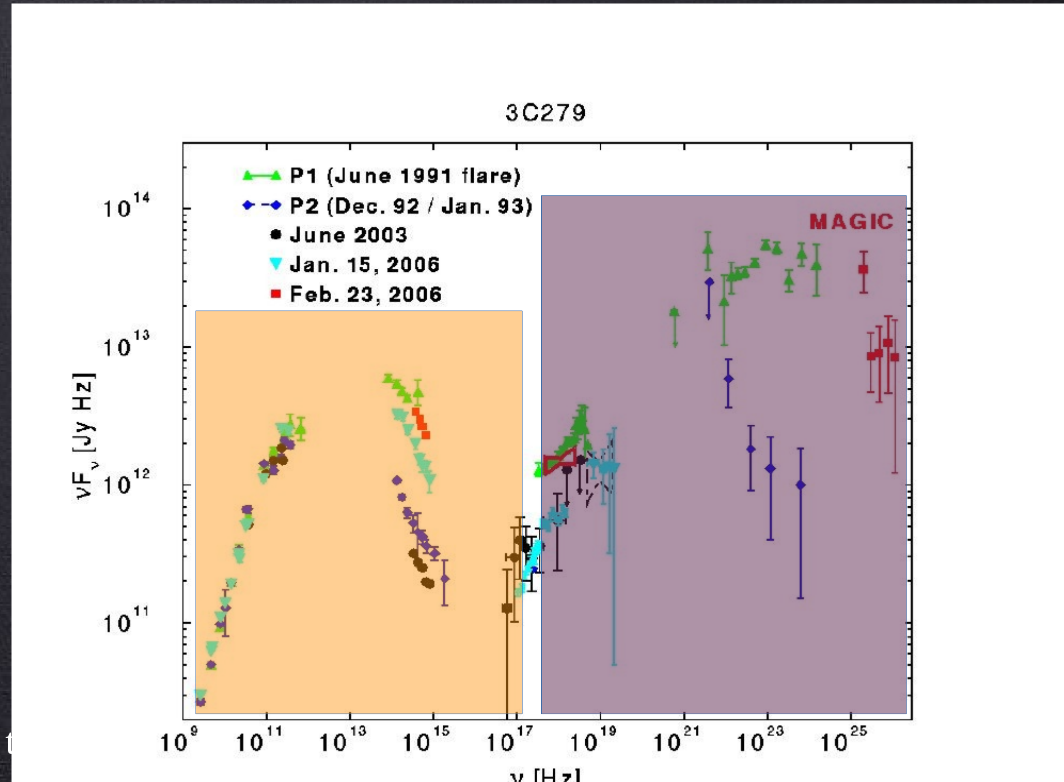
SSC

$$\frac{\partial n_e}{\partial t} = Injection + Losses$$

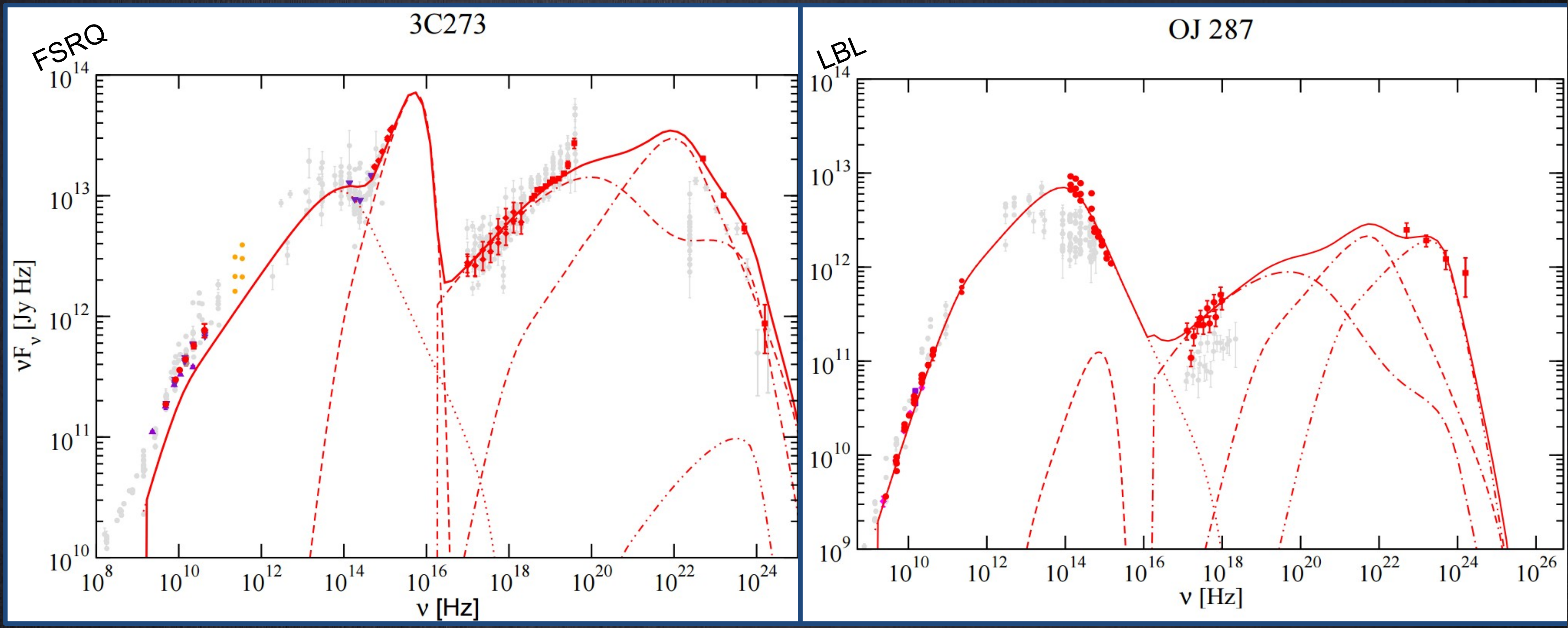
EC



Mrk 421 http://inspirehep.net



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



Bottcher et al. 2013

External Photon Field???

External Photon Field

Photons from

- Broad Line Regions
- Accretion Disk

or

Wind scattered accretion disk photons

Accretion Disk Wind

MHD equations

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

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

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

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

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

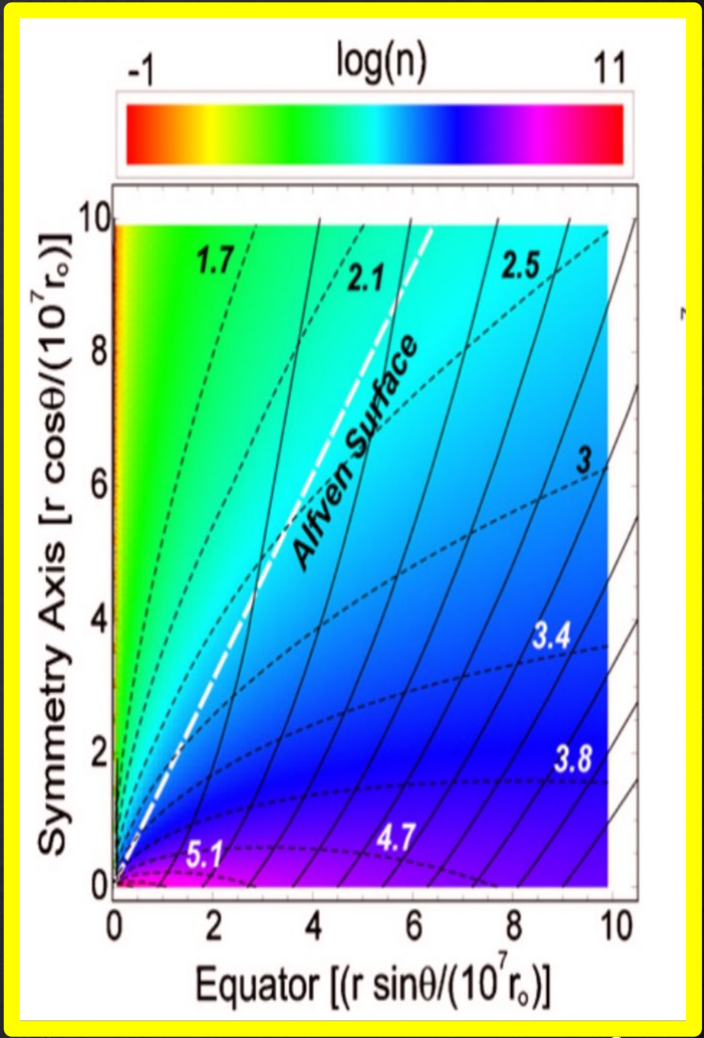
$$\nabla \cdot \boldsymbol{B} = 0$$

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

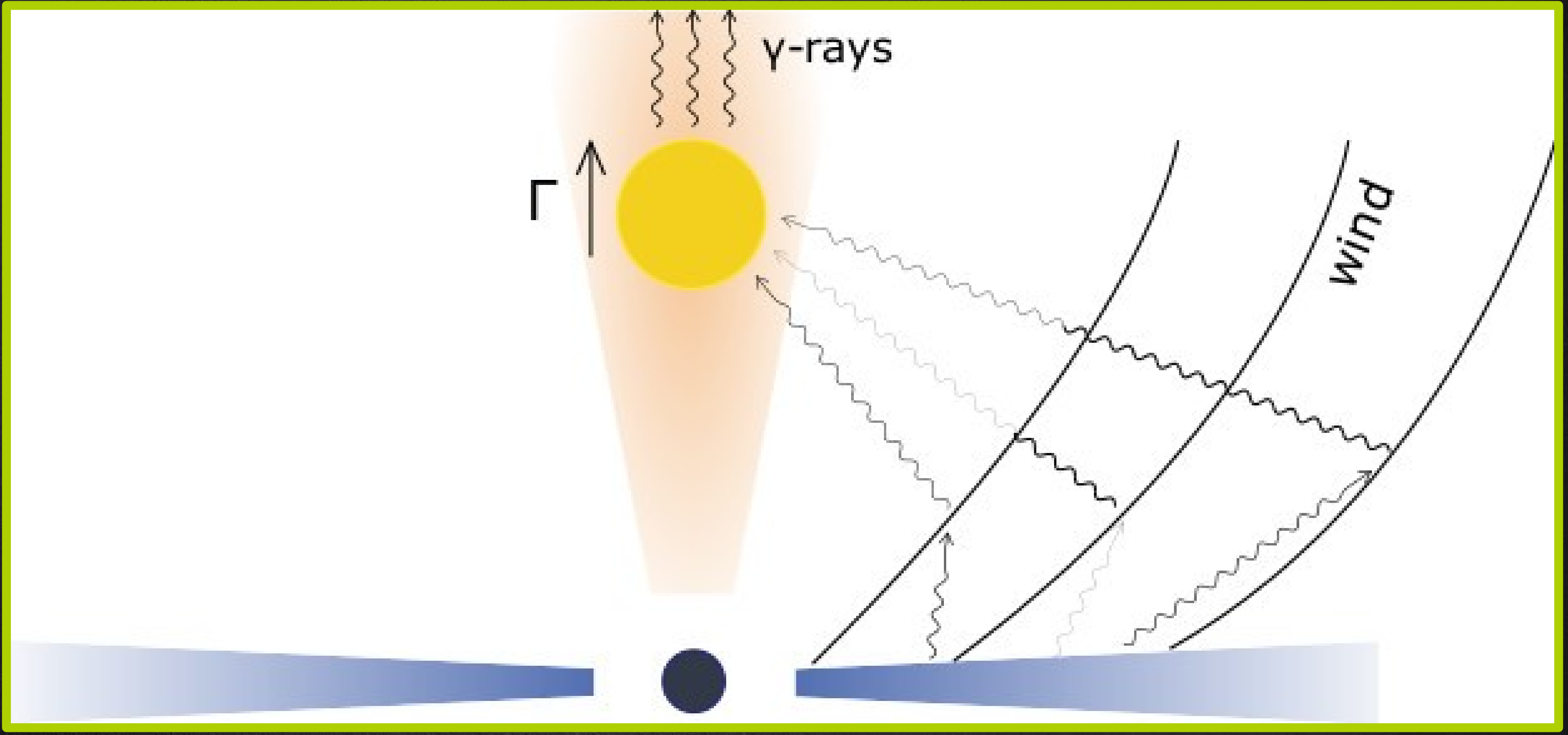
Wind particle density

$$n(r,\theta) \equiv \frac{\rho(r,\theta)}{\mu m_p} = n_0 x^{2q-3} \mathcal{N}(\theta)$$

$$n_0 = \frac{\eta_w \dot{m}}{2\sigma_T R_s}$$



Fukumura et al. 2010


γ-rays
Γ
wind

External Photon Field

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

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

$$R_0 = 3R_s$$

$$\tau_\tau = \frac{\dot{m}}{2} \ln\left(\frac{R_2}{R_1}\right)$$

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

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

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

Other physical quantities...

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

Magnetic Field

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

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

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

$$U_{B_0} = \frac{\eta_b L_{acc}}{A_0 c} \rightarrow \frac{B_0^2 \left(\frac{R_0}{R}\right)^2}{8\pi} = \frac{\eta_b L_{acc}}{A_o c}$$

Electrons luminosity

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

Acceleration

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial \gamma}(f(\gamma)N) + \frac{N}{t_{esc}(\gamma)} = Q_0 \Theta(t) \delta(\gamma - \gamma_0)$$

$$f(\gamma) = \frac{\gamma}{t_{acc}(\gamma)} - \beta_{syn}\gamma^2 - \beta_{ics}\gamma^2$$

Mastichiadis & Kirk, 1995

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

$$t_{acc} \geq 6 \frac{\gamma m_e c^2}{eB} \frac{c}{u_s^2}$$

The role of the accretion mass rate

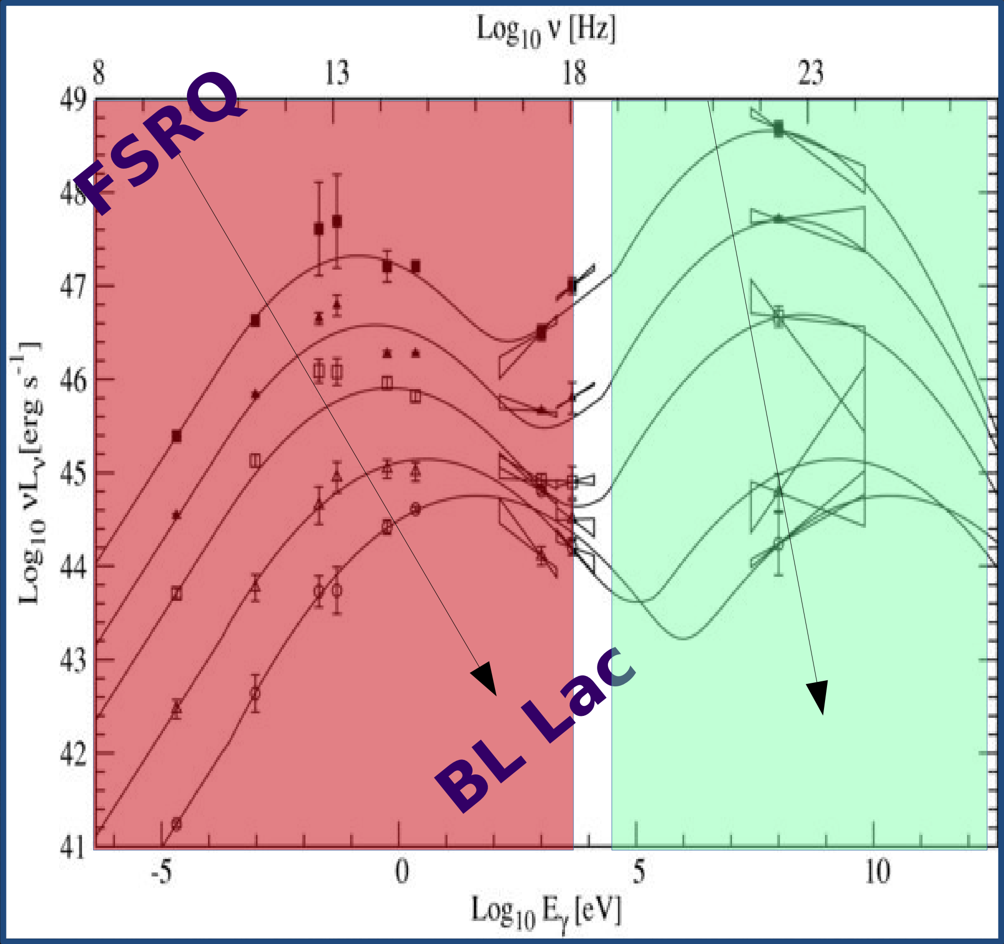
$$U_B \propto \dot{m}^2$$

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

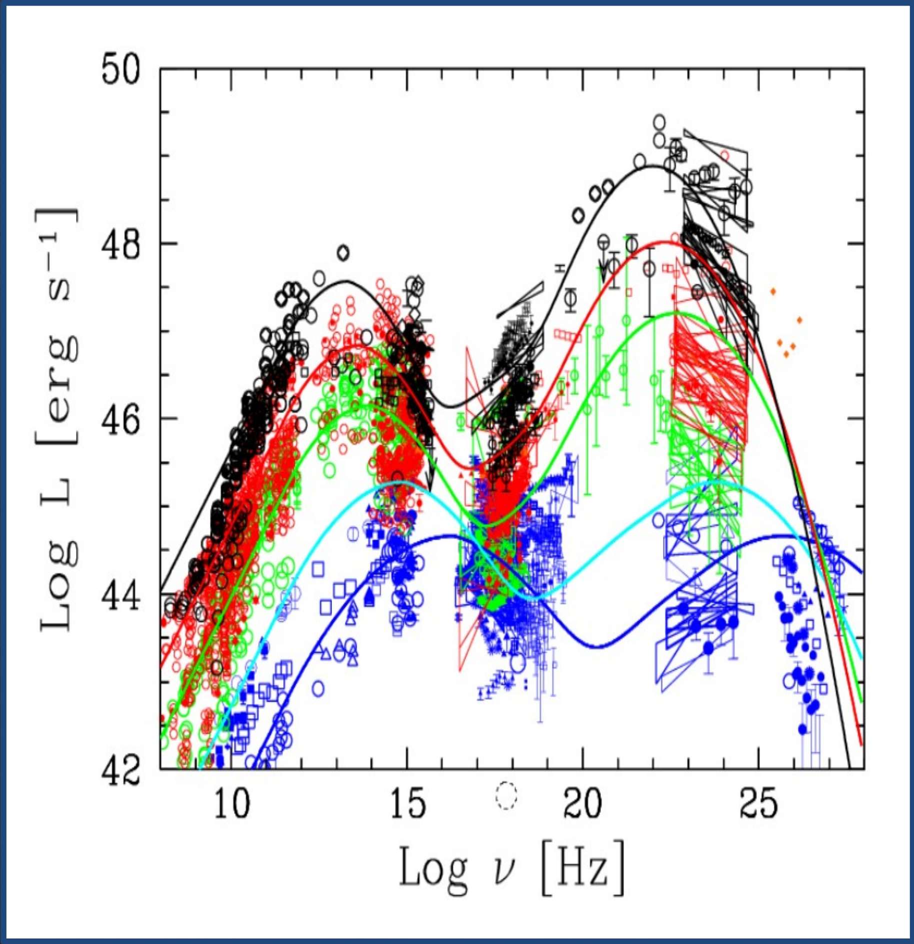
$$\gamma_{max} \propto \dot{m}^{-2}(1+\dot{m})$$

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

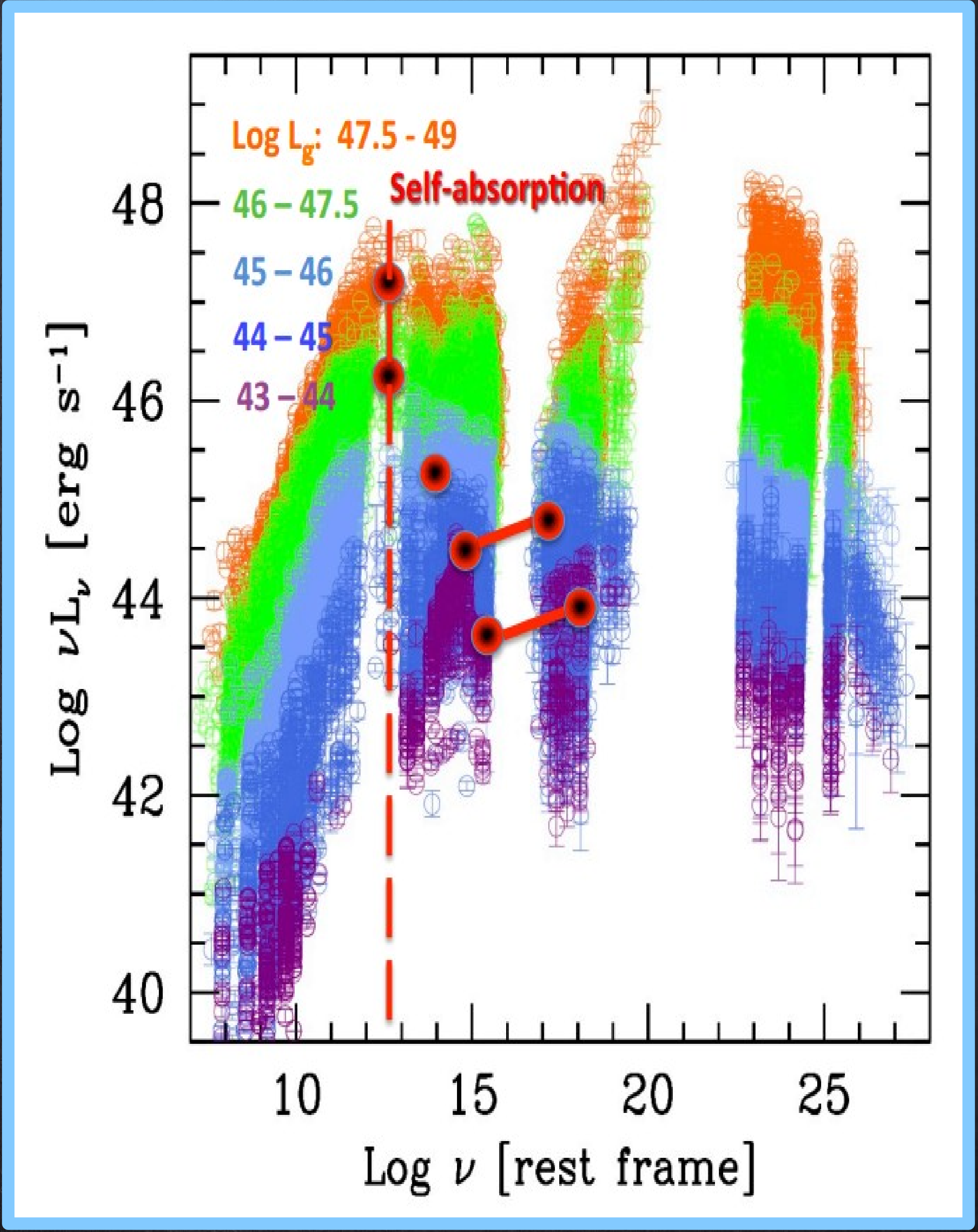
Blazar Sequence



Fossati et al. 1998

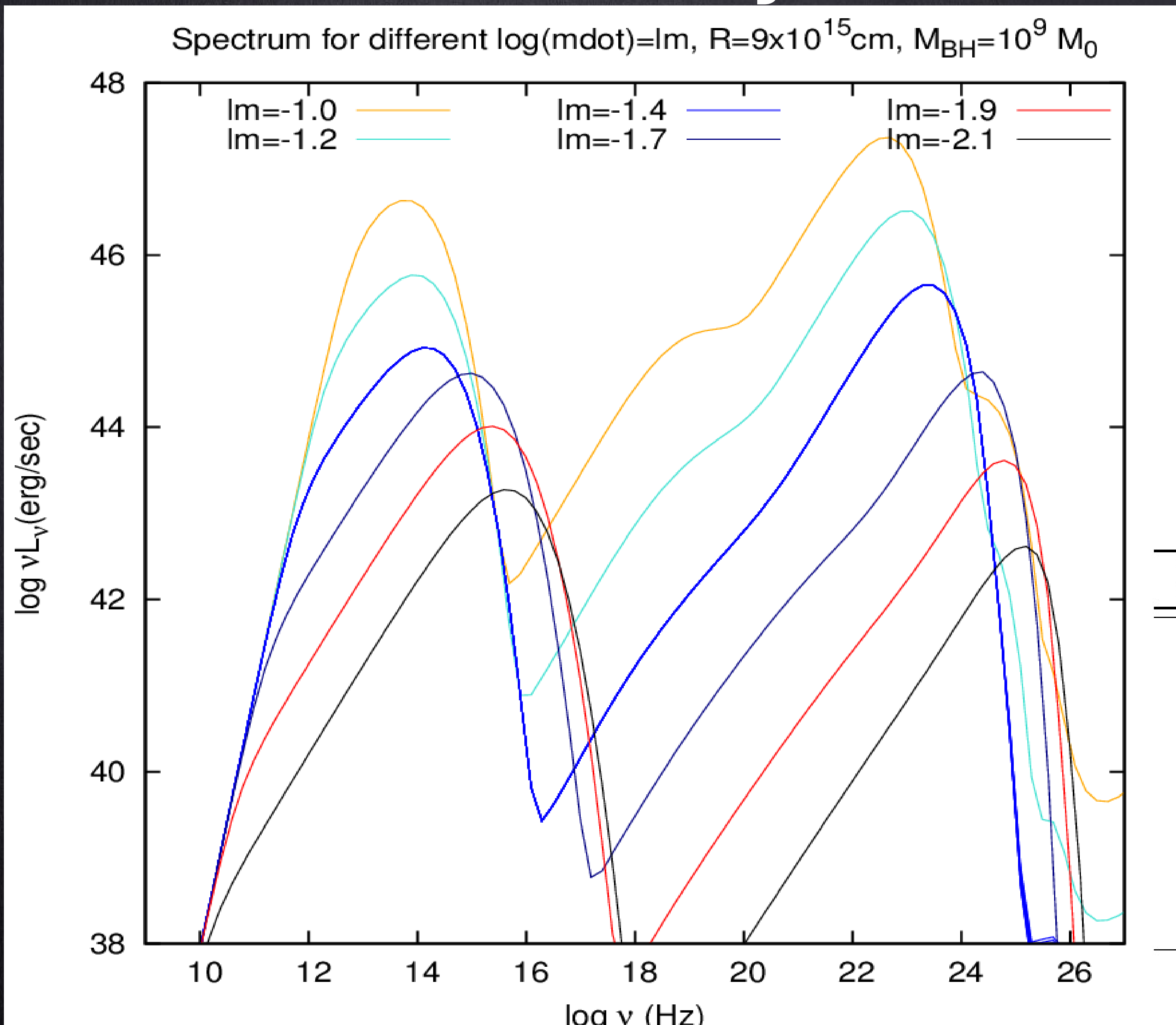


Ghisellini, 2013



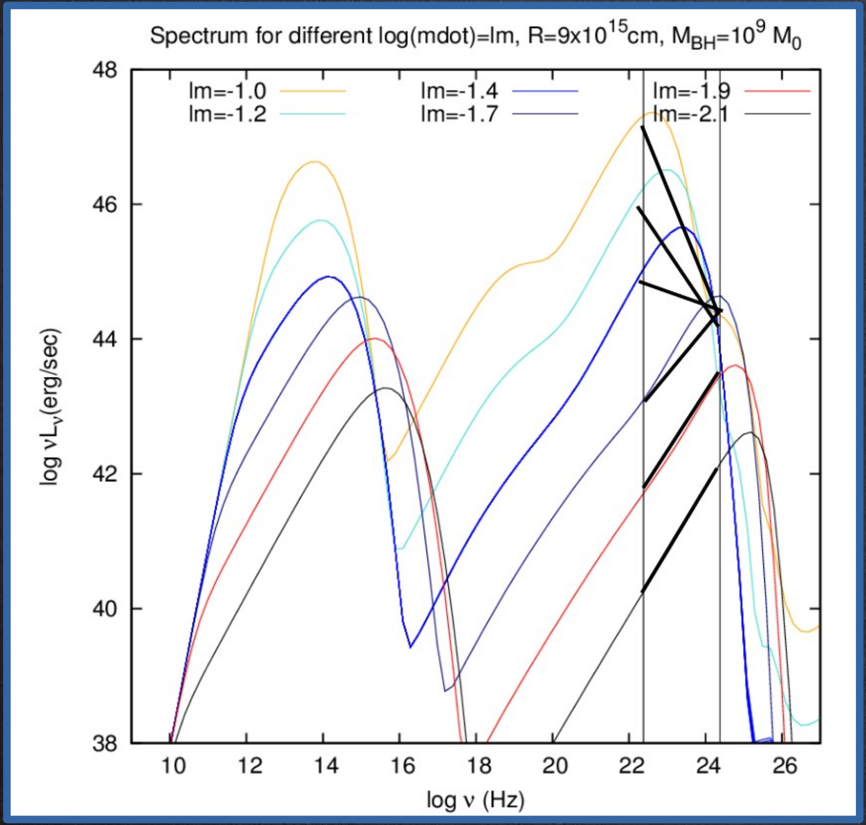
Ghisellini, 2016

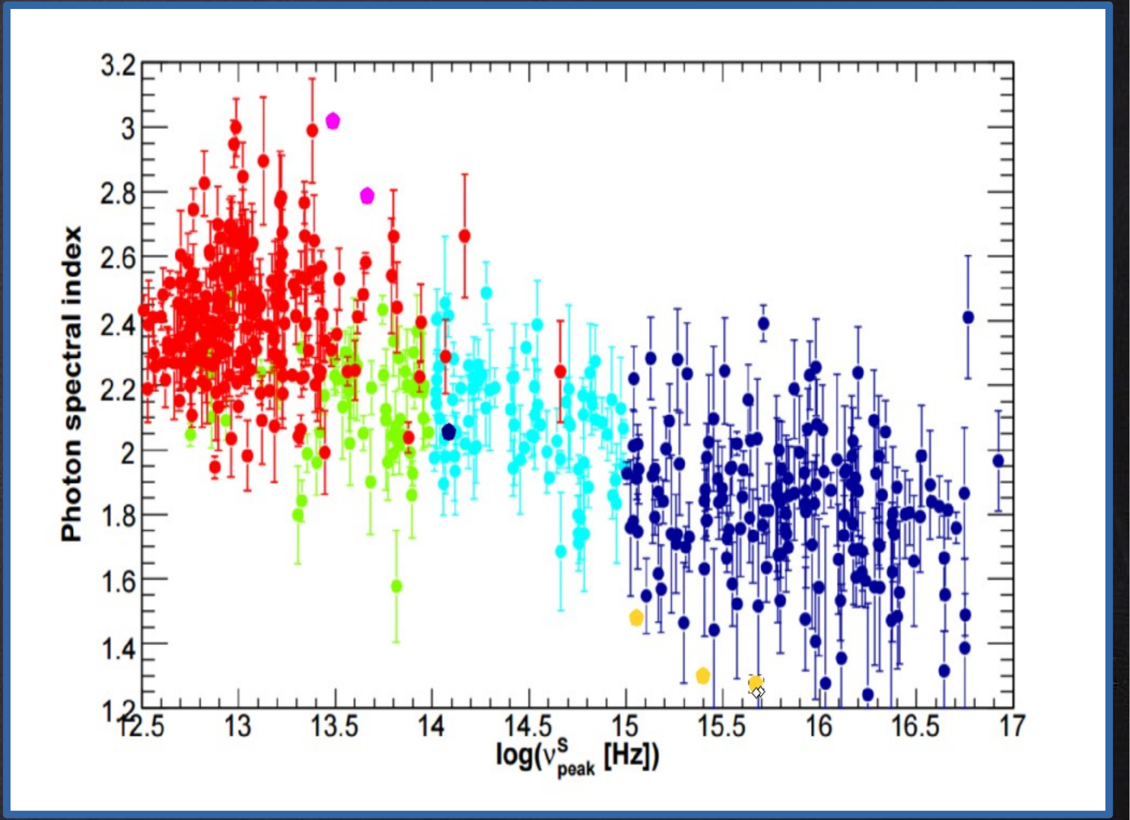
Preliminary results



$$R_b = 9 \times 10^{15}$$
$$z = 3 \times 10^{16}$$
$$R_1 = 9 \times 10^{14}$$
$$R_2 = 3 \times 10^{17}$$
$$\delta = 30$$
$$\Gamma = 30$$

$\log \dot{m}$	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
-2.1	0.19	5.0





Ackermann et al. 2011

Conclusion

- Leptonic model + particle acceleration
- External photon field: scatterd accretion disk photons from 1/r wind particles
- Preliminary results in agreement with the observations

Take message home

- This accretion disk wind model can describe the Blazar Sequence by varying only one parameter, the mass accretion rate.

Thank you!