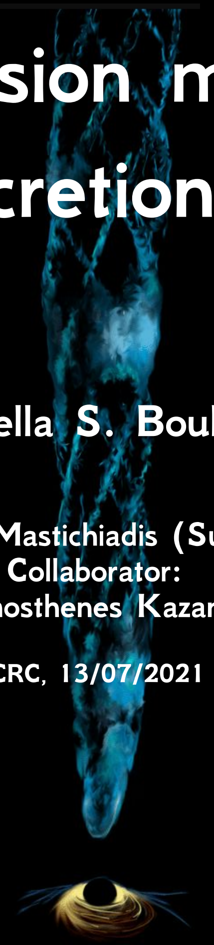
National and Kapodistrian University of Athens
School of Sciences
Department of Physics
Section of Astrophysics, Astronomy & Mechanics

A two-zone emission model for Blazars and the role of Accretion Disk MHD winds



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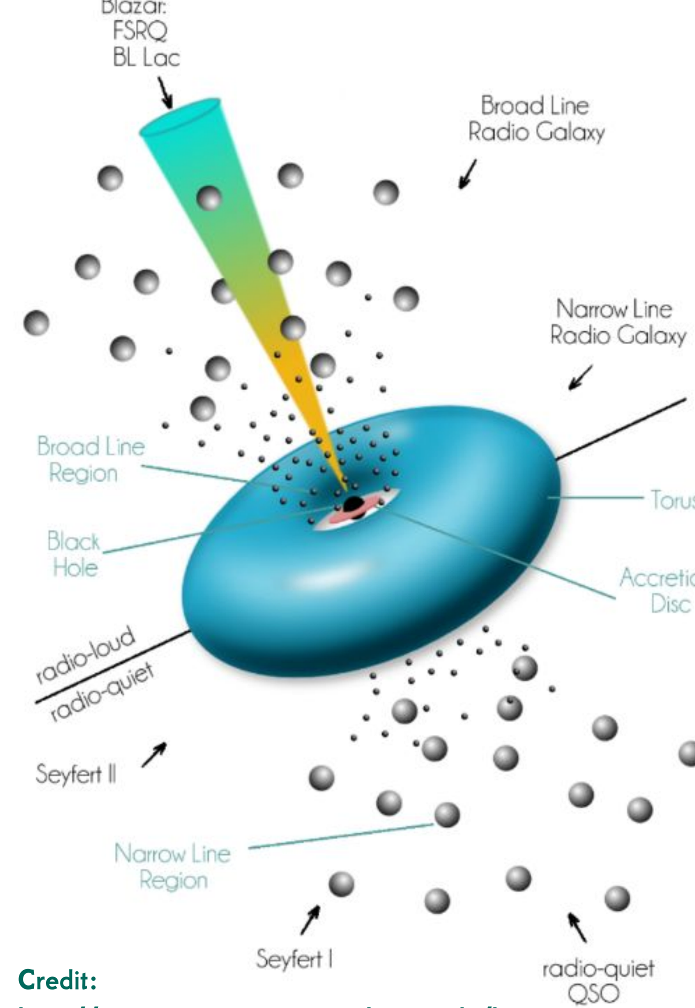
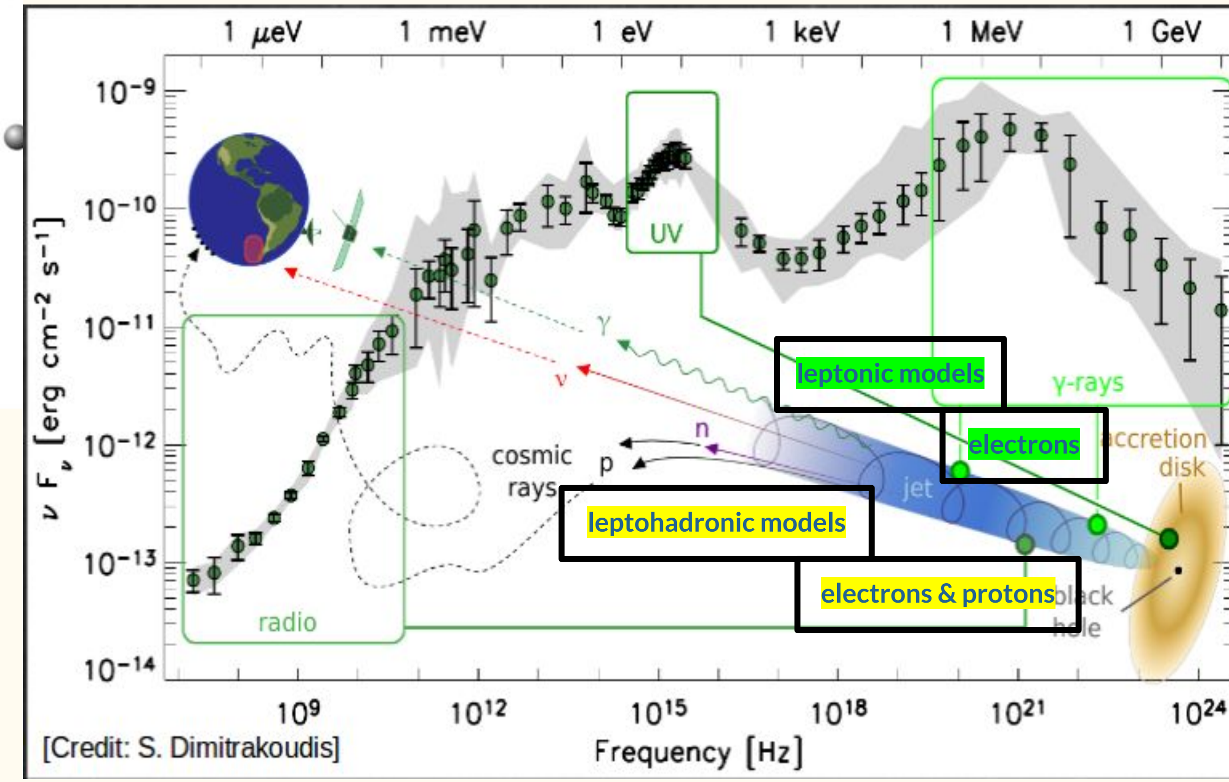
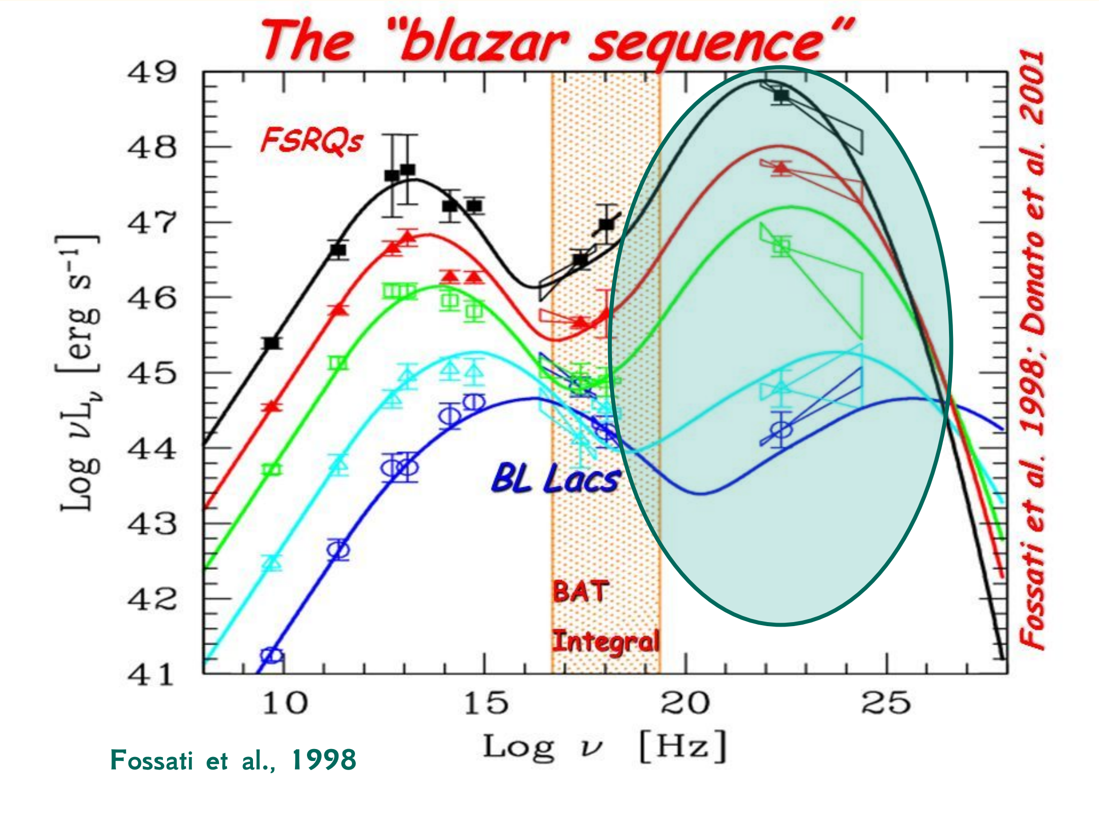


Credit: http://www.sternwarte.unierlangen.de/krauss.





Target 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 ++)

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 $\Gamma = (1-\beta^2)^{-1/2}$
- Doppler factor $\delta = [\Gamma(1-\beta\cos\theta)]^{-1}$

Related to the mass accretion rate

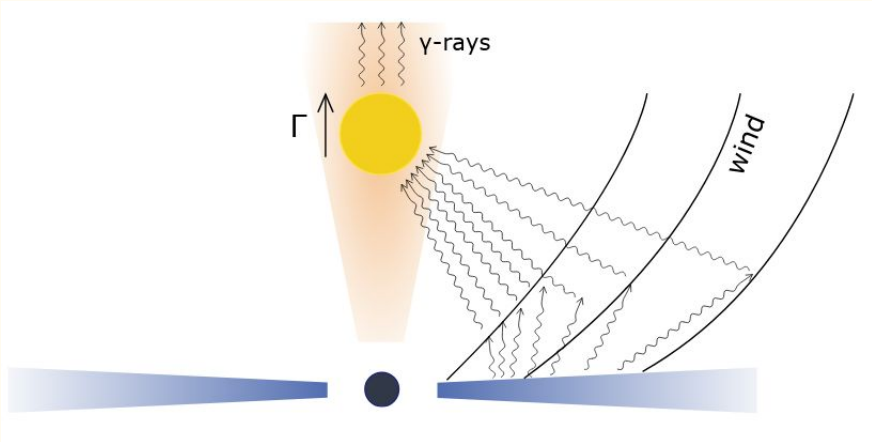


Image credit: S. Dimitrakoudis

External Photon Field

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

$$n(r,\theta) = n_0 (r_s/r)$$

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

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

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

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

Accretion Power of the source:

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

Magnetic Field

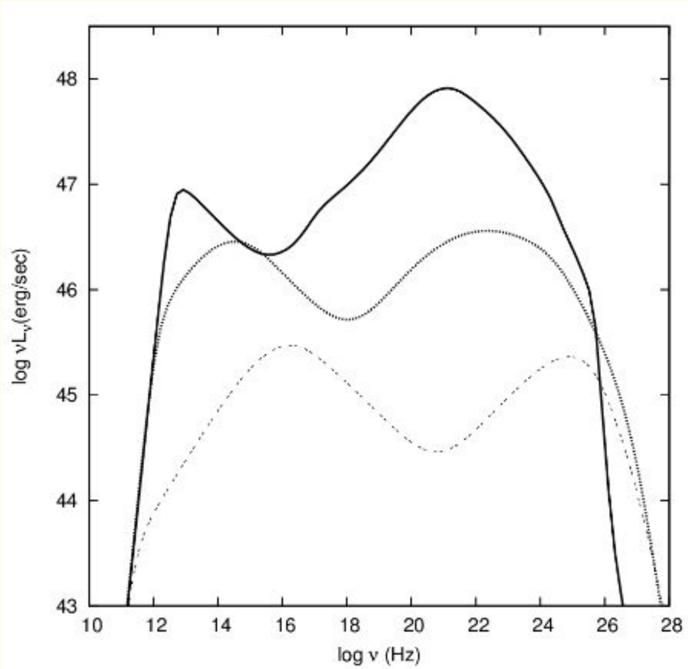
$$U_{\rm B_0} = \frac{\eta_b P_{\rm acc}}{4\pi(3r_{\rm s})^2 c}, \ B = B_0\left(\frac{z_0}{z}\right)$$

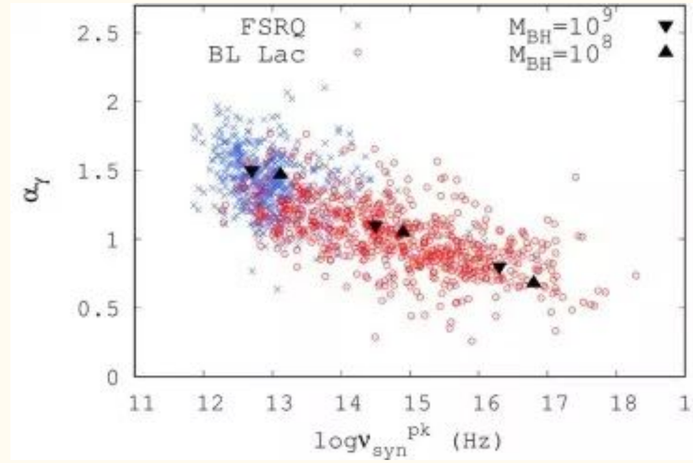
Electron Injection

$$Q_{\rm e} = \begin{cases} k_{\rm e_1}\gamma^{-s} & \text{for } \gamma_{\rm min} \le \gamma \le \gamma_{\rm br}, \\ k_{\rm e_2}\gamma^{-q}e^{-\gamma/\gamma_{\rm max}} & \text{for } \gamma_{\rm br} \le \gamma \le \gamma_{\rm max}, \end{cases}$$

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

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





$\dot{m}$	B(G)	$U_{\rm ext}$ $\left(\frac{\rm erg}{\rm cm^3}\right)$	$L_{\rm e}^{\rm inj}$ $\left(\frac{\rm erg}{\rm sec}\right)$	$\gamma_{\rm br}$	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

values are in logarithmically scale

$$U_{\rm B} \propto \frac{\dot{m}}{\mathcal{M}},$$

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

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

$$L_{\rm e}^{\rm inj} \propto \dot{m}\mathcal{M}$$

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

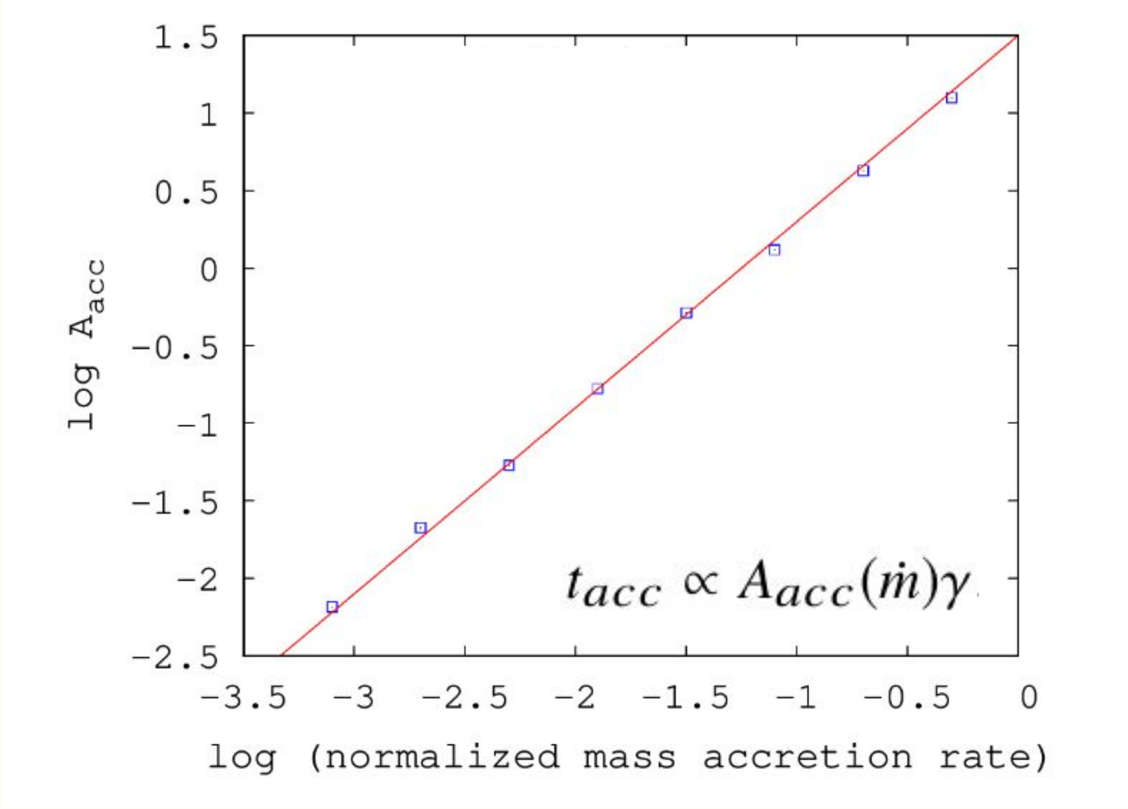
Boula, Kazanas & Mastichiadis, 2019 (MNRASL)

Particle Acceleration

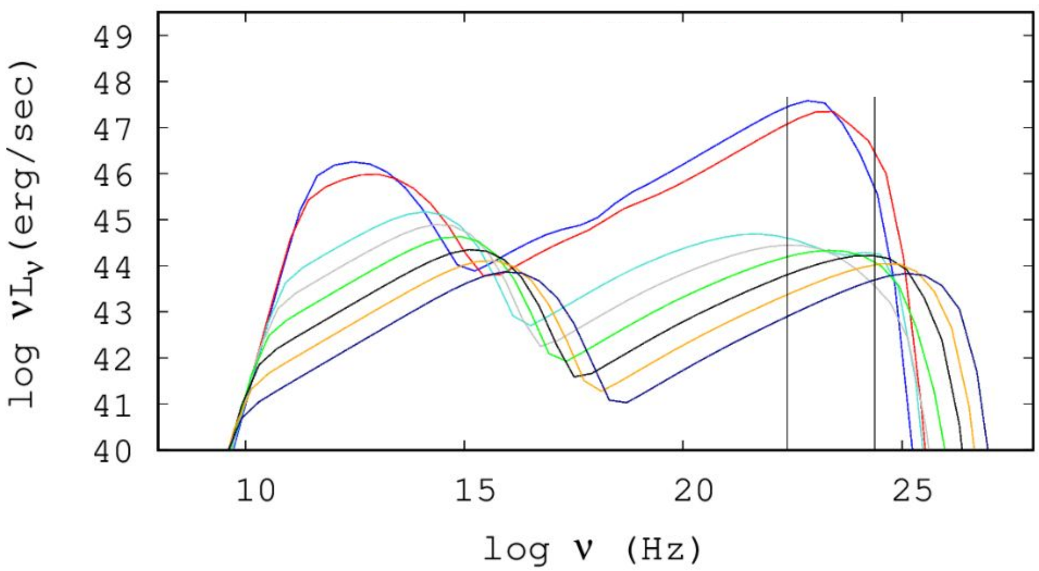
$$\frac{\partial n_e(\gamma,t)}{\partial t} + \frac{n_e(\gamma,t)}{t_{esc}(\gamma)} + \frac{\partial}{\partial \gamma}\left(\frac{\gamma}{t_{acc}(\gamma)}\right) n_e(\gamma,t) = \mathcal{L}_e(\gamma,t)$$

$$t_{acc_{FI}} \geq 6\left(\frac{c}{u_s}\right)^2 \frac{\lambda}{c} \simeq 6\frac{r_g c}{u_s^2},$$

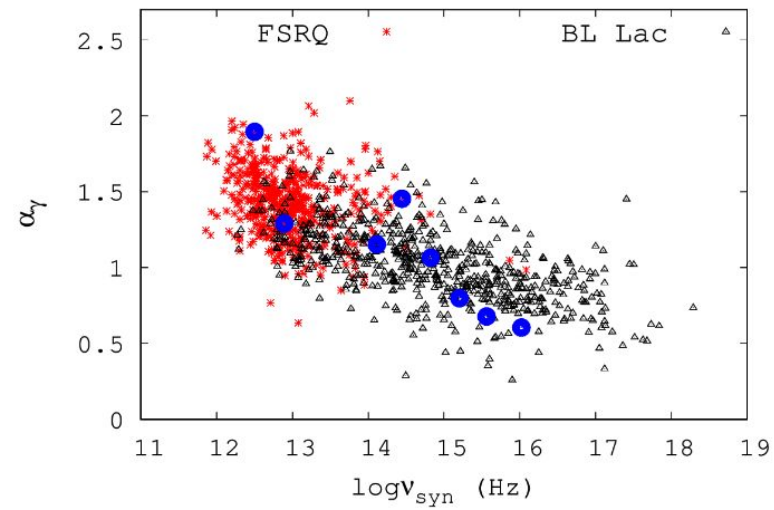
$$r_g = \frac{\gamma m c^2}{eB}.$$



We assume next that the particles gain energy and the electrons energy distribution is calculated self-consistently



log νLν(erg/sec)
log ν (Hz)

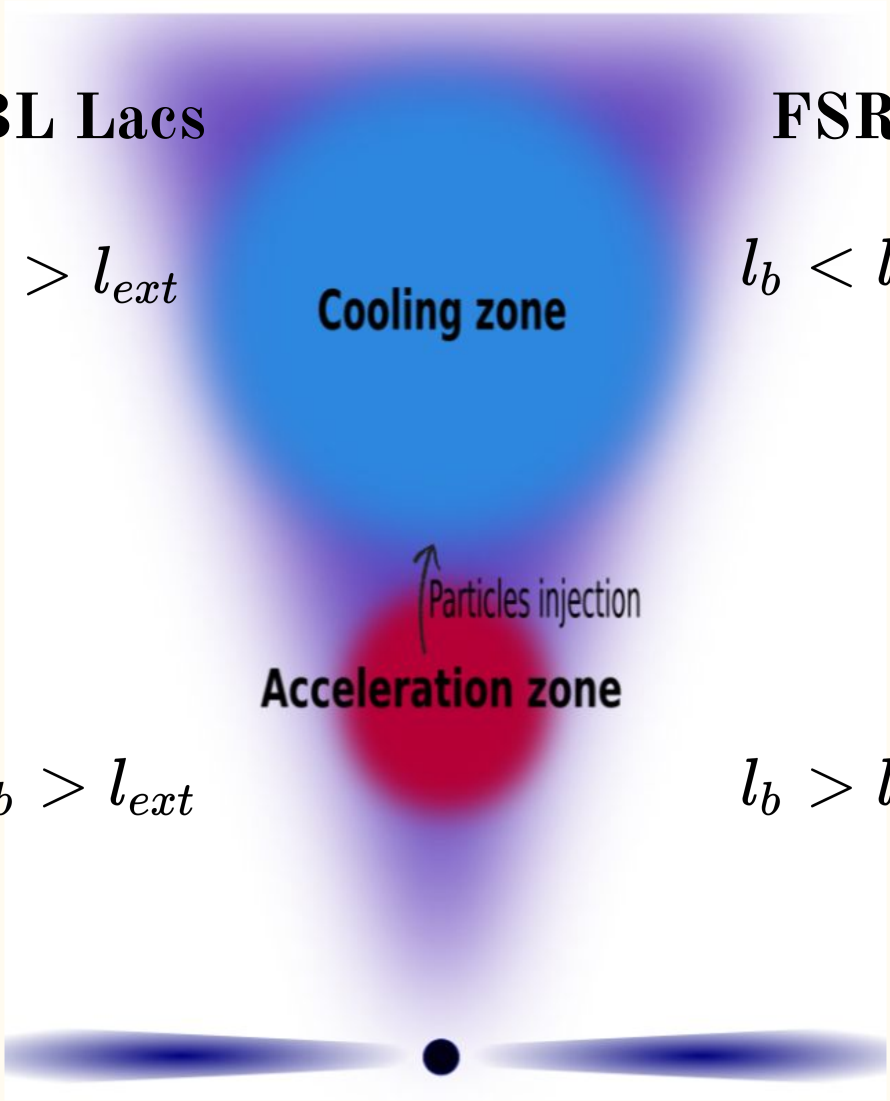


FSRQ
BL Lac
αγ
logνsyn (Hz)

The idea:

BL Lacs — **FSRQs**

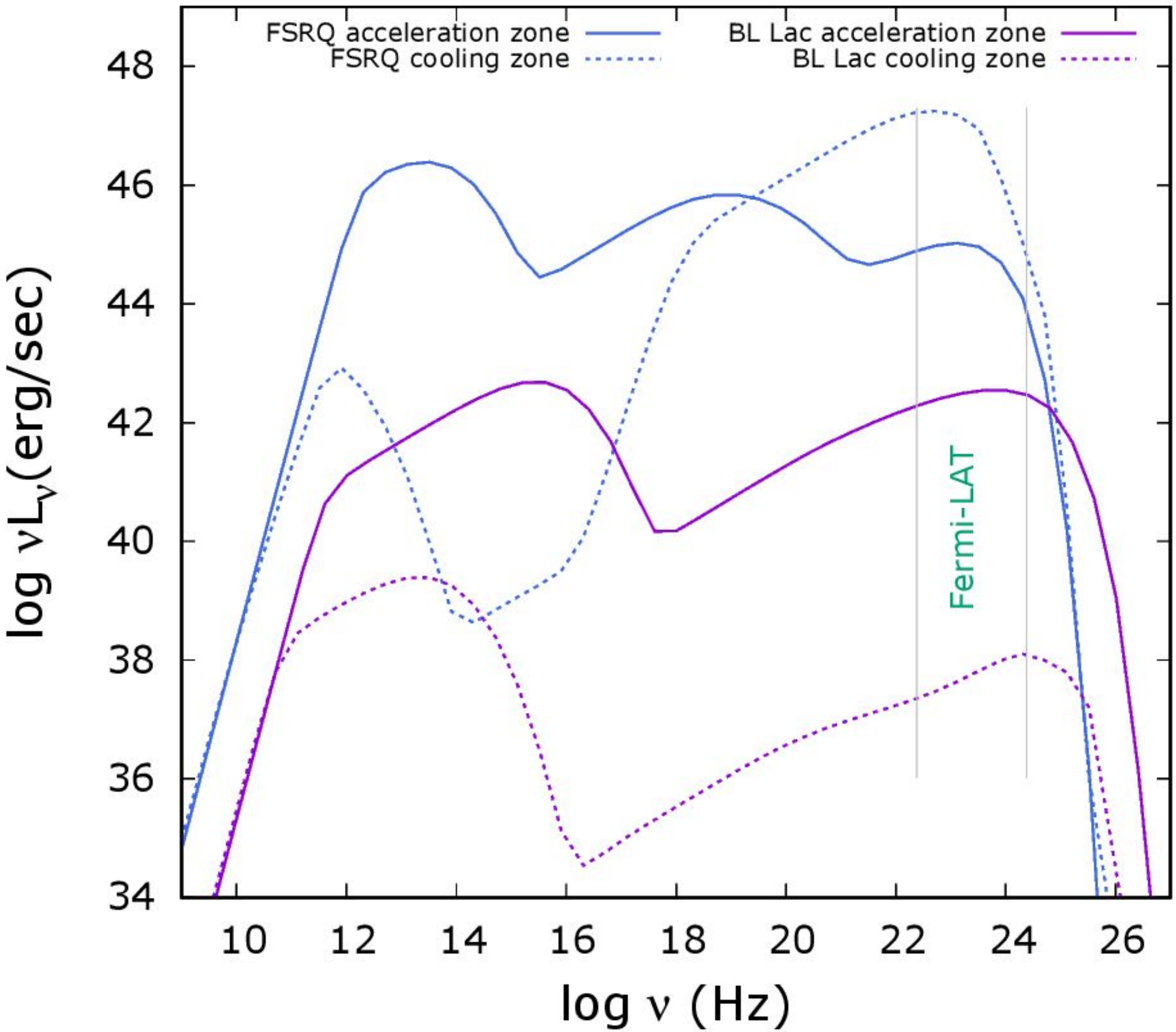
$l_b > l_{ext}$ — $l_b < l_{ext}$



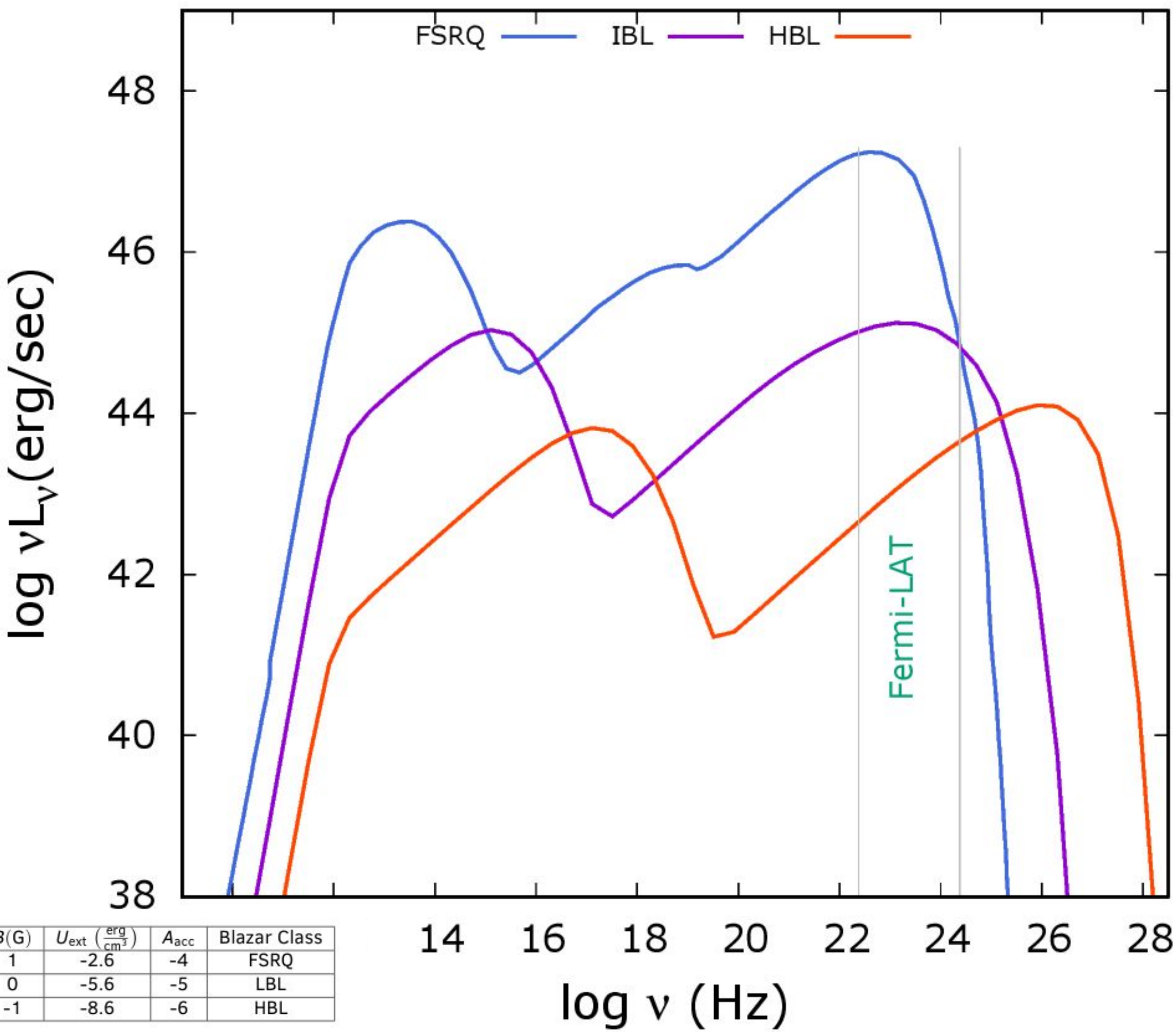
$l_b > l_{ext}$ — $l_b > l_{ext}$

$$l_b = \frac{\sigma_T R_b U_b}{m_e c^2}, l_{ext} = \frac{\sigma_T R_b U_{ext}}{m_e c^2}$$

$B \propto 1/z, \ U_{ext} = constant$

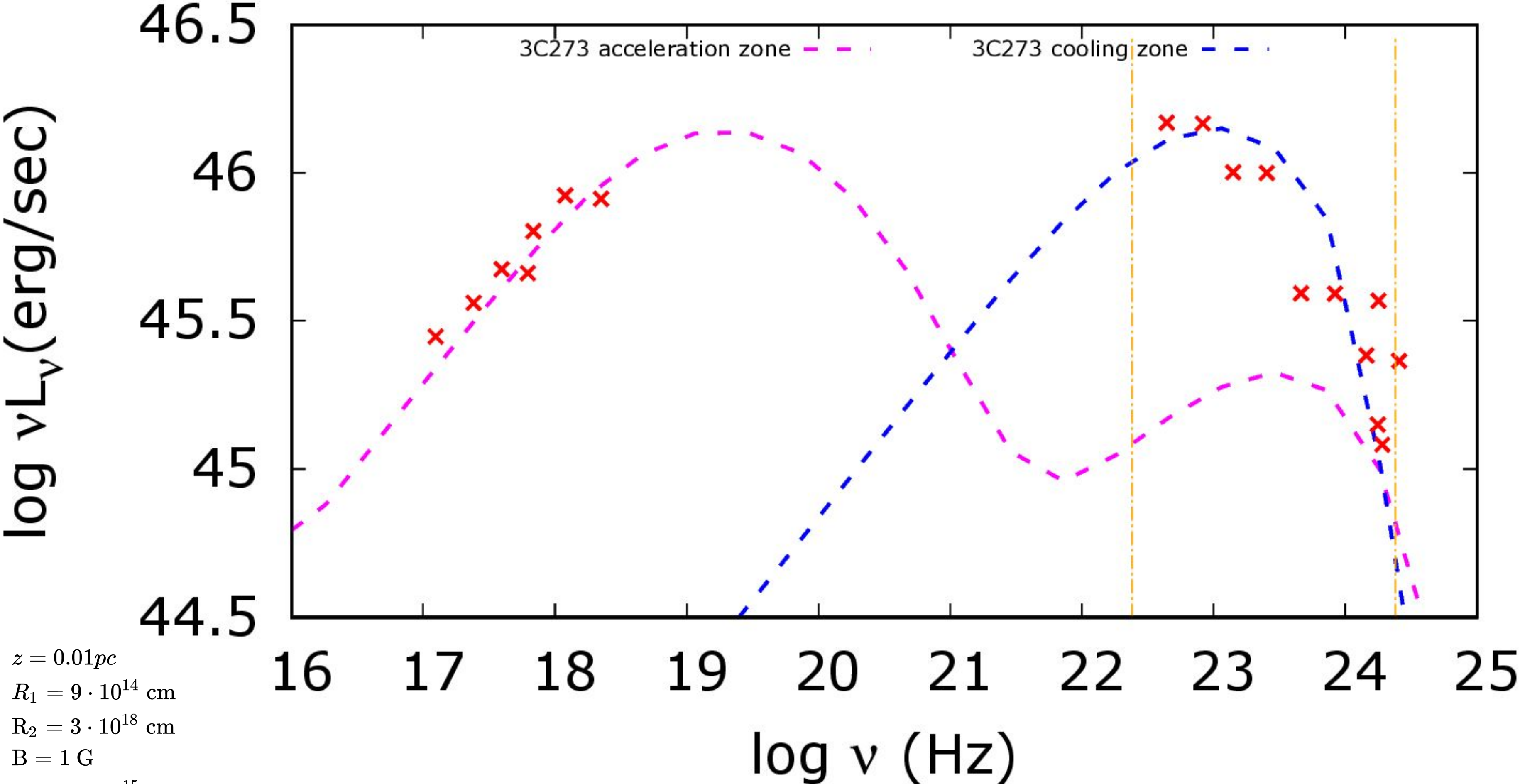


FSRQ acceleration zone
FSRQ cooling zone
BL Lac acceleration zone
BL Lac cooling zone
Fermi-LAT
log νL$_ν$(erg/sec)
48
46
44
42
40
38
36
34
10
12
14
16
18
20
22
24
26
log ν (Hz)



$\dot{m}$	B(G)	U_{ext} $\left(\frac{erg}{cm^3}\right)$	A_{acc}	Blazar Class
-0.5	1	-2.6	-4	FSRQ
-1.5	0	-5.6	-5	LBL
-2.5	-1	-8.6	-6	HBL

Application to 3C273



$z = 0.01pc$

$R_1 = 9 \cdot 10^{14}$ cm

$\mathrm{R}_2 = 3 \cdot 10^{18}$ cm

$\mathrm{B} = 1$ G

$\mathrm{R} = 5 \times 10^{15}$ cm

$\mathrm{A_{acc}} = 0.0001$

$\mathrm{U_{ext}} = 10^{-2.6} \ \frac{\mathrm{erg}}{\mathrm{sec}}$

$\Gamma = 30$

$\delta = 15$

$\mathrm{T_{disk}} = 3 \cdot 10^5 \mathrm{K}.$

Take home messages

- MHD Accretion Disk Winds are fundamental in reproducing the LAT Blazar phenomenology (Blazar Sequence) which appears to be a one parameter family.
- We obtain the theoretical Blazar Sequence by varying only one parameter, the mass accretion rate .
- The spread of the distribution depends on the other parameters.

Thank you!

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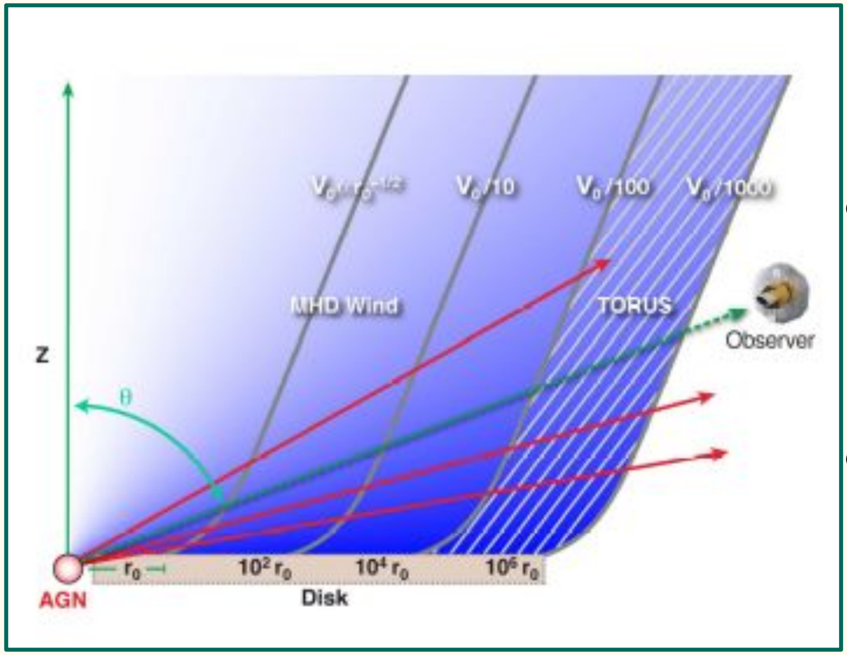
Back up slides

MHD
Accretion Disk Winds

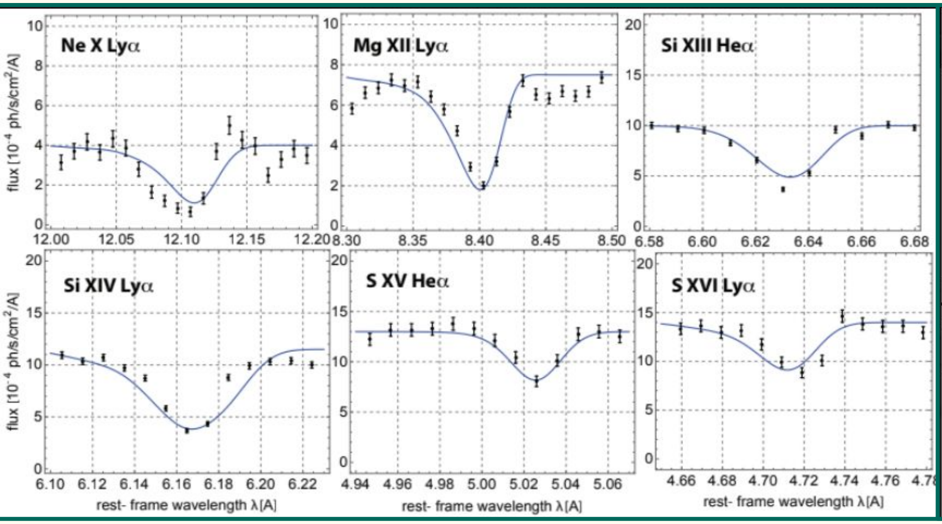


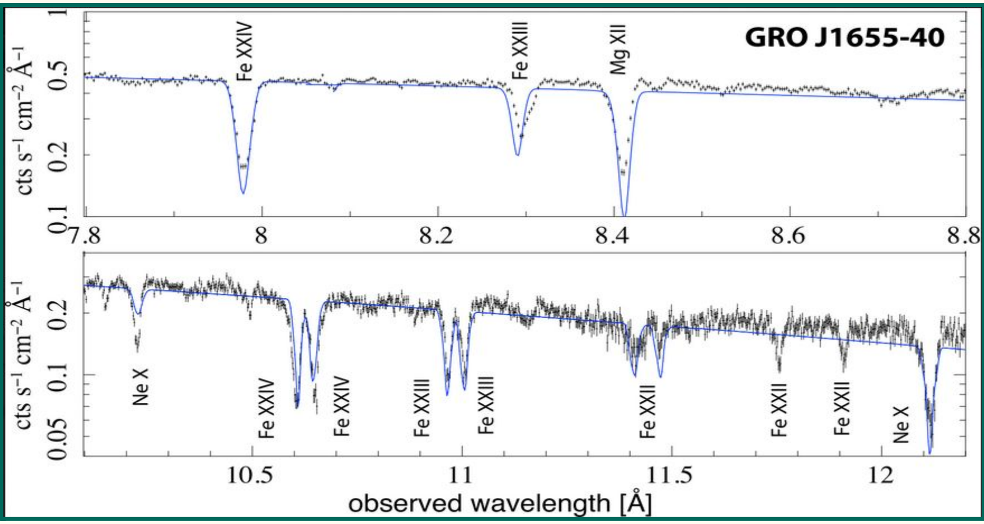
- Winds driven by an accretion disk threaded by a poloidal magnetic field.
- At latitudes above the Alfven point the field lines become toroidal and the flow is almost radially out.
- The magnetic field permeates the entire disk, out to ~10^6 R_s

Contopoulos & Lovelace, 1994
Fukumura et al., 2010

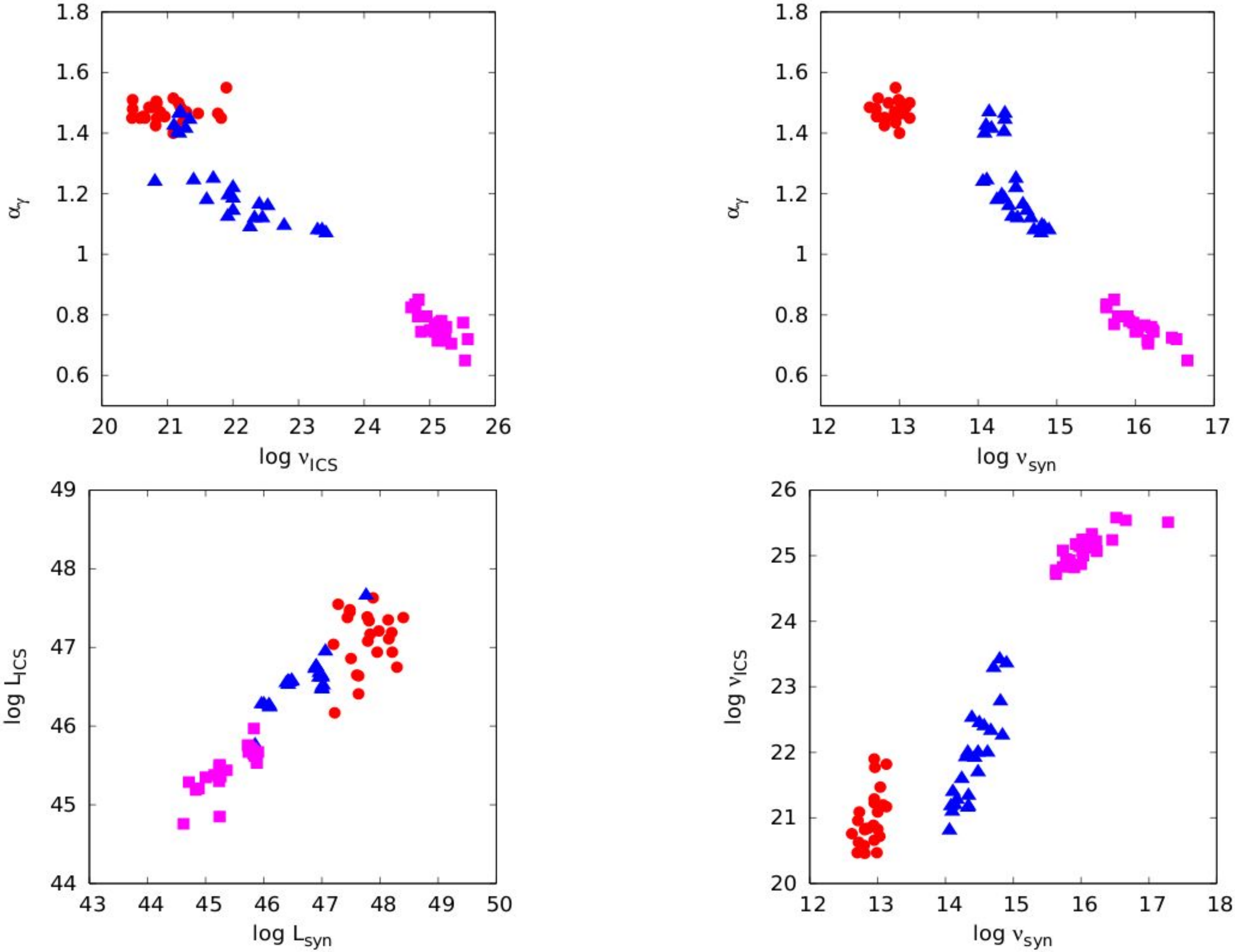
Galactic and extragalactic applications of the wind

AGN

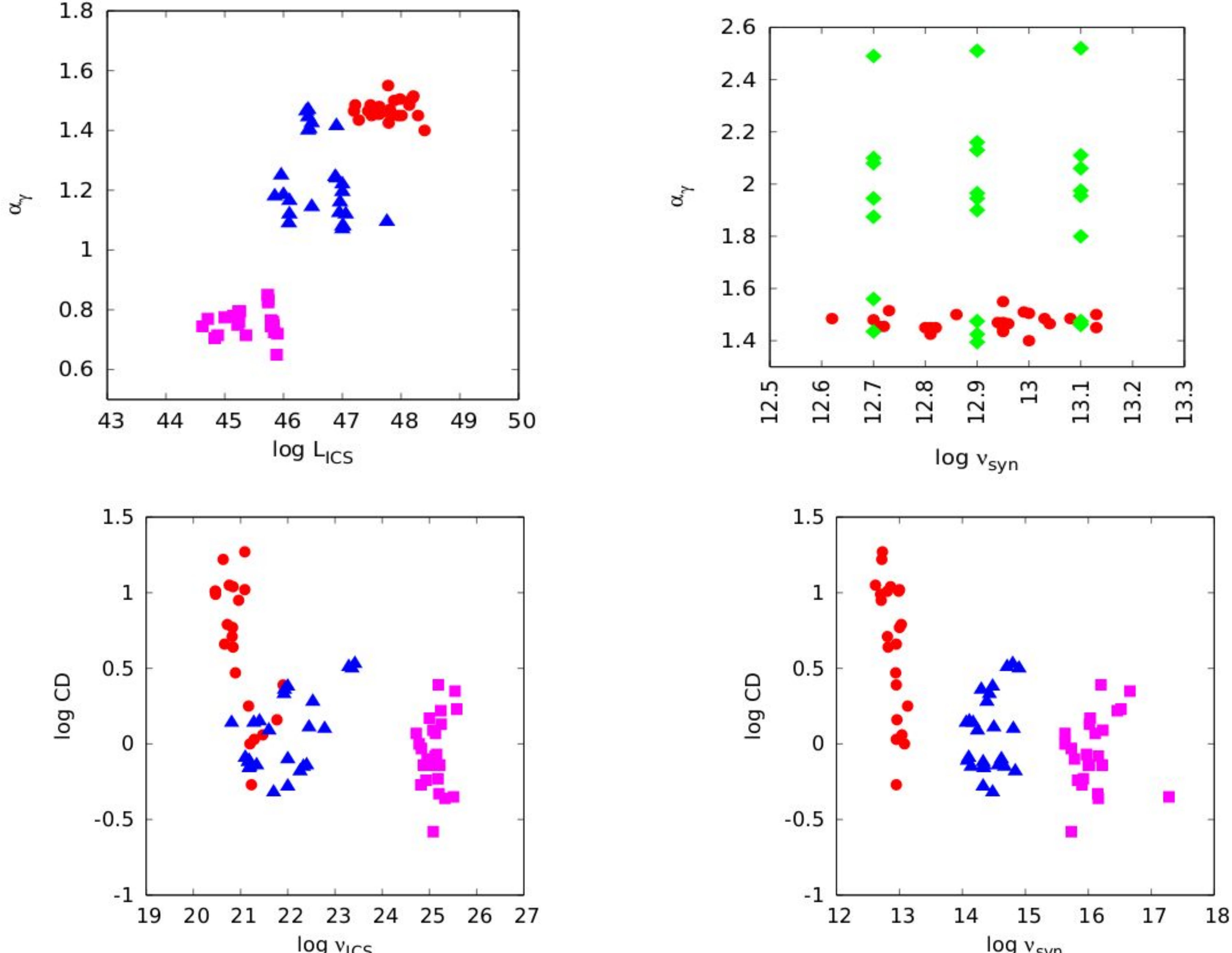




Fukumura et al., 2018,2019



1.8
1.6
1.4
1.2
1
0.8
0.6
α_γ
20 21 22 23 24 25 26
log ν_{ICS}
12 13 14 15 16 17
log ν_{syn}
49
48
47
46
45
44
log L_{ICS}
43 44 45 46 47 48 49 50
log L_{syn}
26
25
24
23
22
21
20
log ν_{ICS}
12 13 14 15 16 17 18
log ν_{syn}



1.8
1.6
1.4
1.2
1
0.8
0.6
α_γ
43 44 45 46 47 48 49 50
log L_{ICS}
2.6
2.4
2.2
2
1.8
1.6
1.4
α_γ
12.5 12.6 12.7 12.8 12.9 13 13.1 13.2 13.3
log ν_{syn}
1.5
1
0.5
0
-0.5
-1
log CD
19 20 21 22 23 24 25 26 27
log ν_{ICS}
1.5
1
0.5
0
-0.5
-1
log CD
12 13 14 15 16 17 18
log ν_{syn}