The neutrino-BL Lac connection

Fabrizio Tavecchio

INAF-OAB

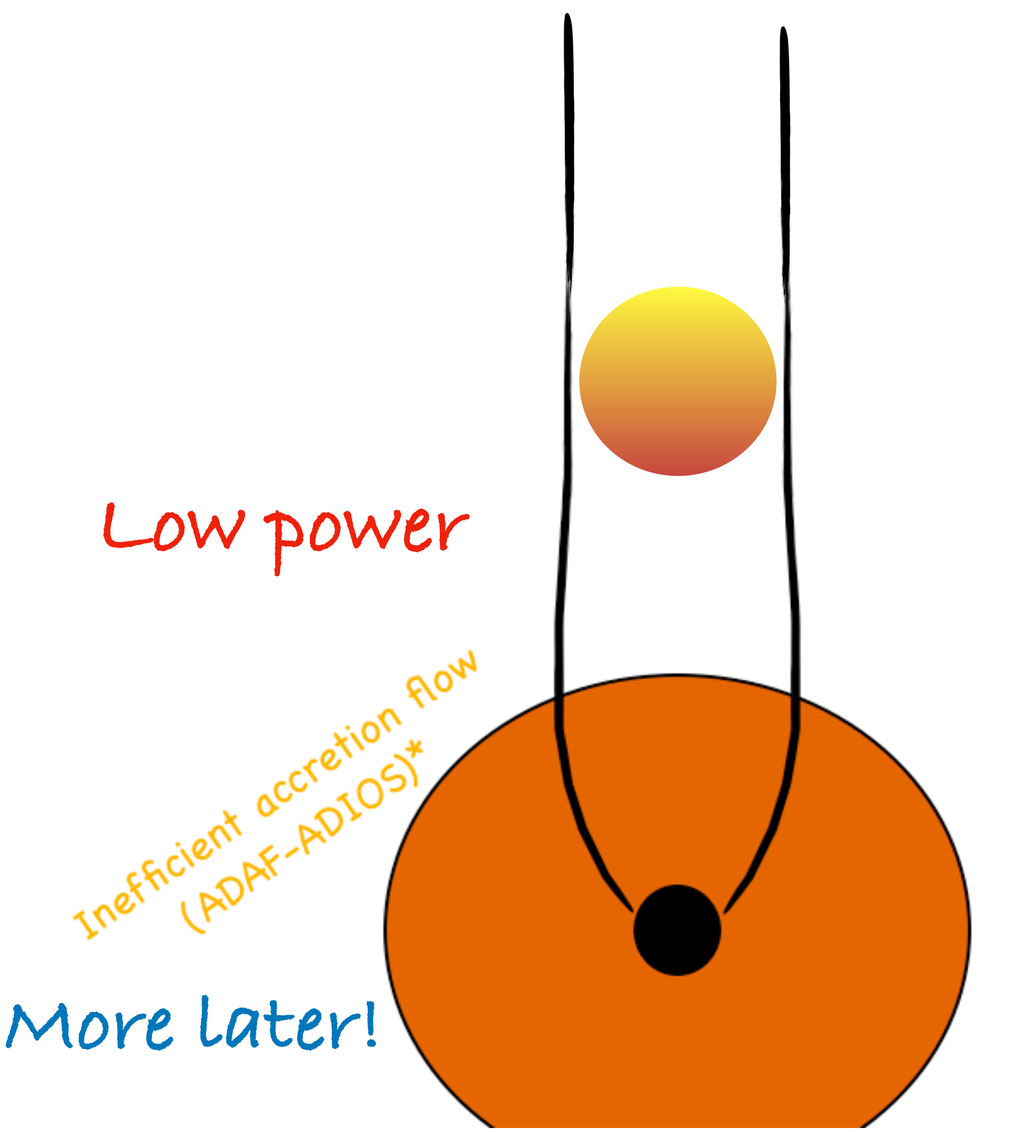
OSSERVATORIO ASTRONOMICO DI BRERA

27–31 August 2018 | Berlin
2018 TeV Particle Astrophysics
TeVPA

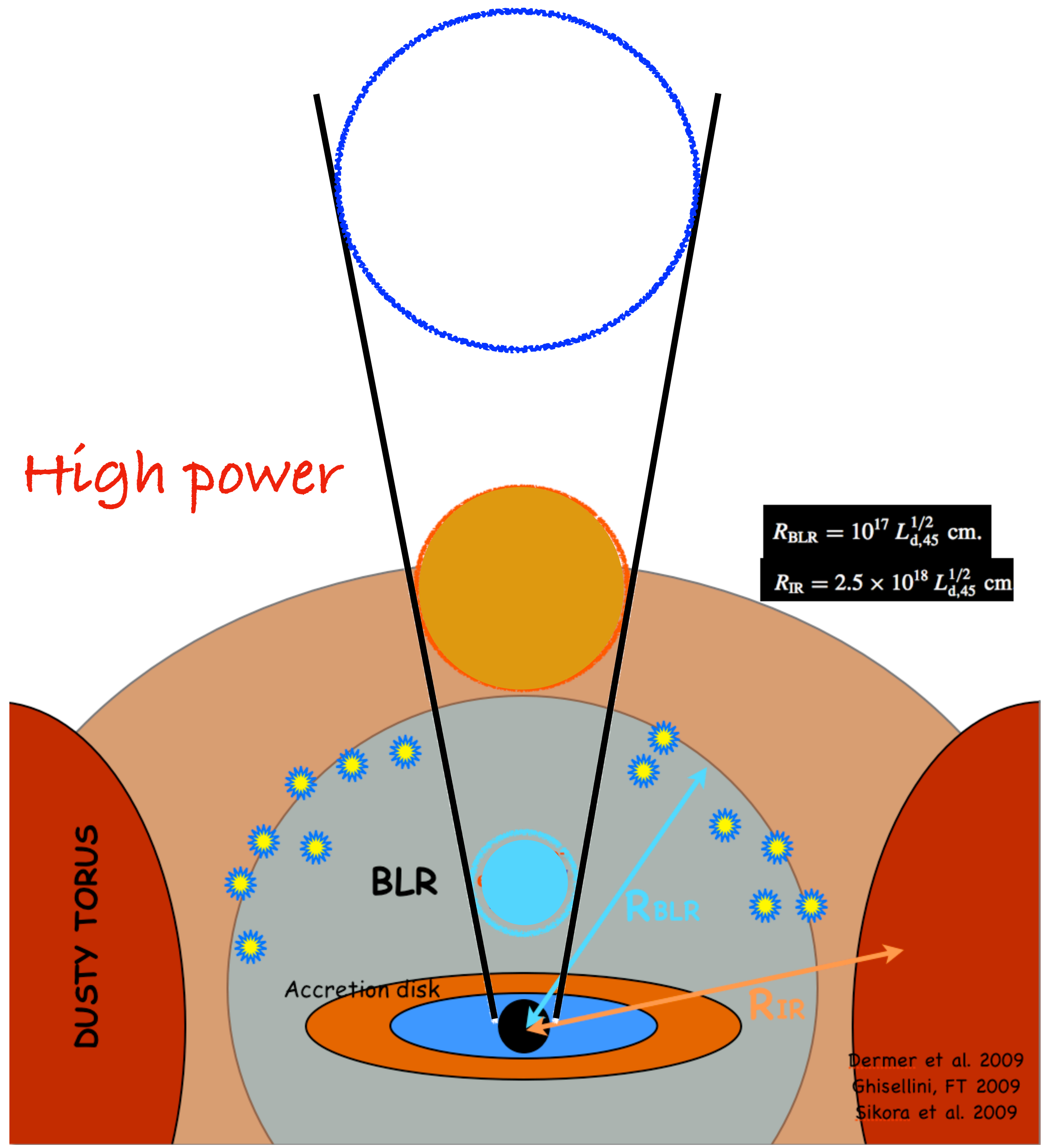
ISTITUTO NAZIONALE DI ASTROFISICA
INAF

Setting the stage

BL Lacs: "naked" jets

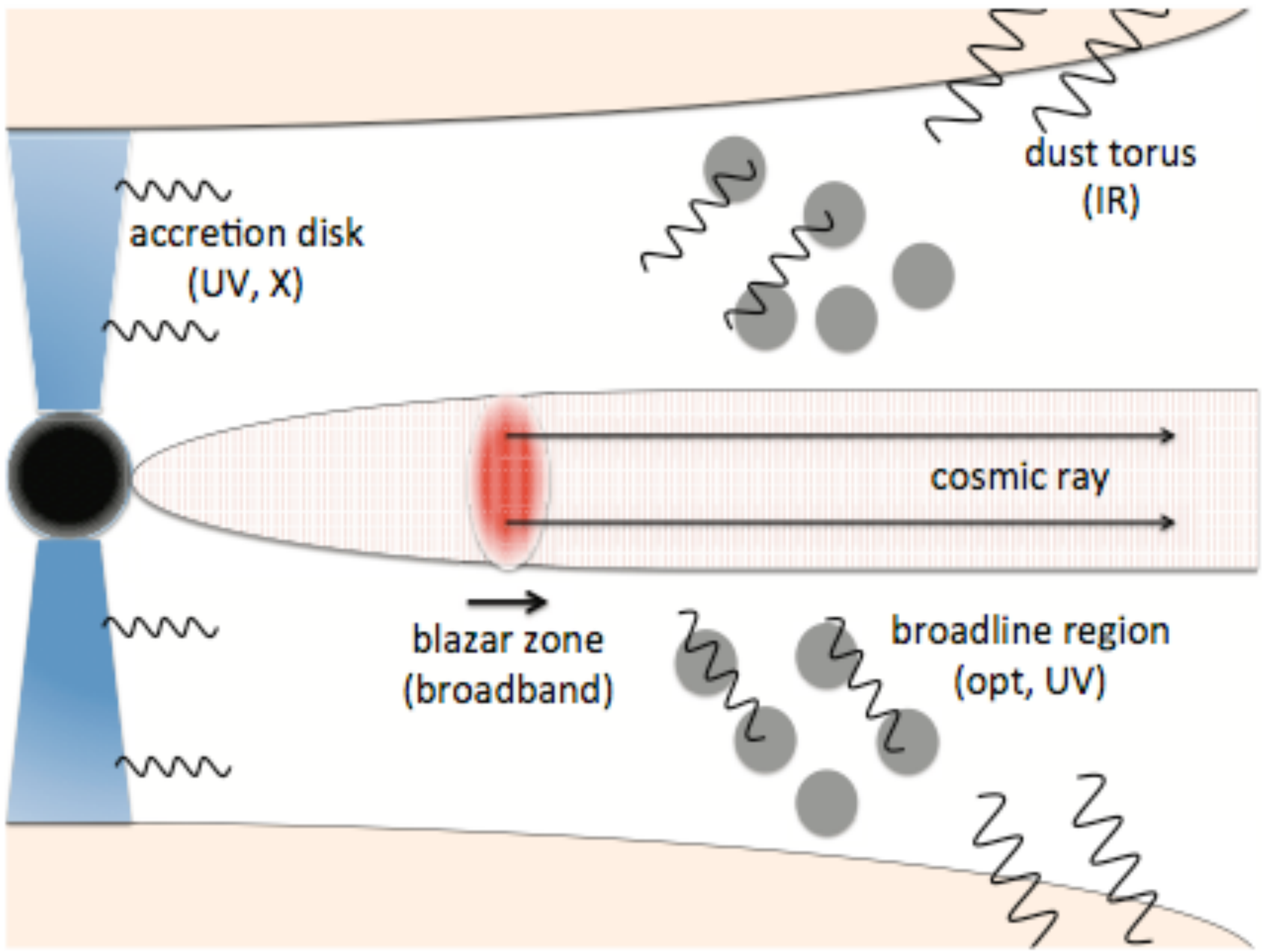


FSRQ: "dressed" jets



Also consistent with unification scheme (radiogalaxies)

Neutrino from FSRQ?

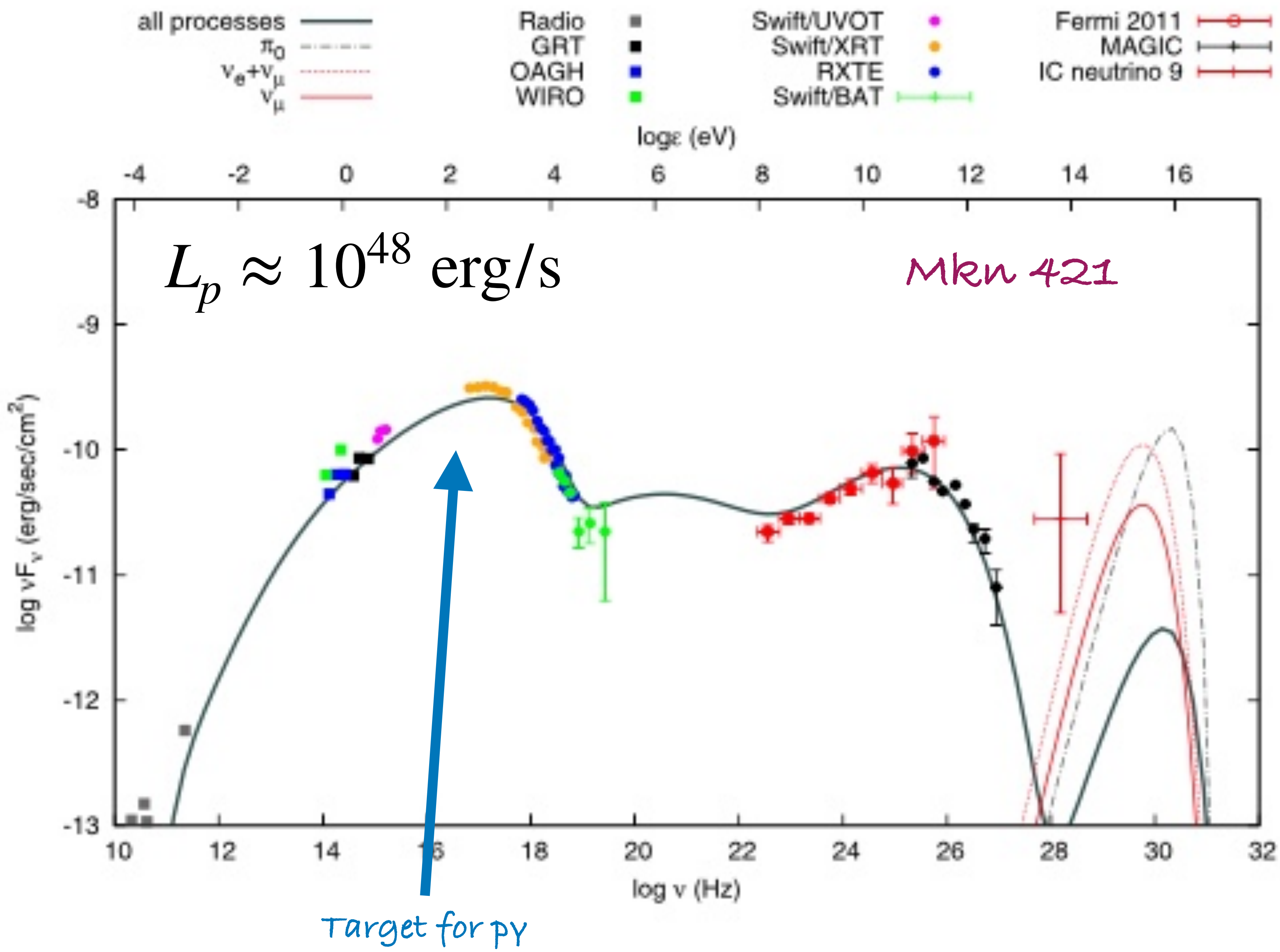


Ideal structure for photo meson production

Murase, Inoue & Dermer 2014
Kadler et al. 2016

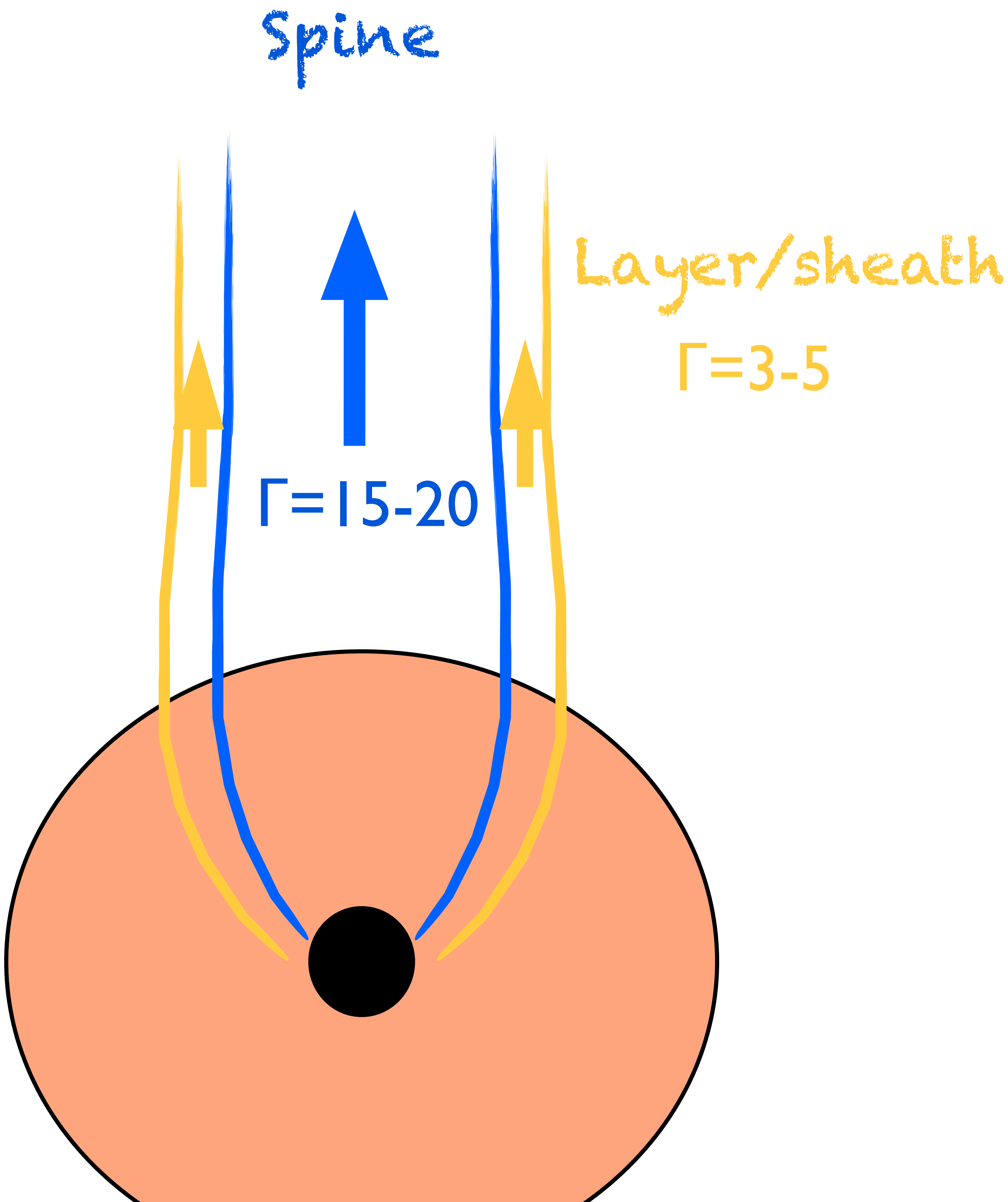
Neutrino from BL Lacs?

One-zone models



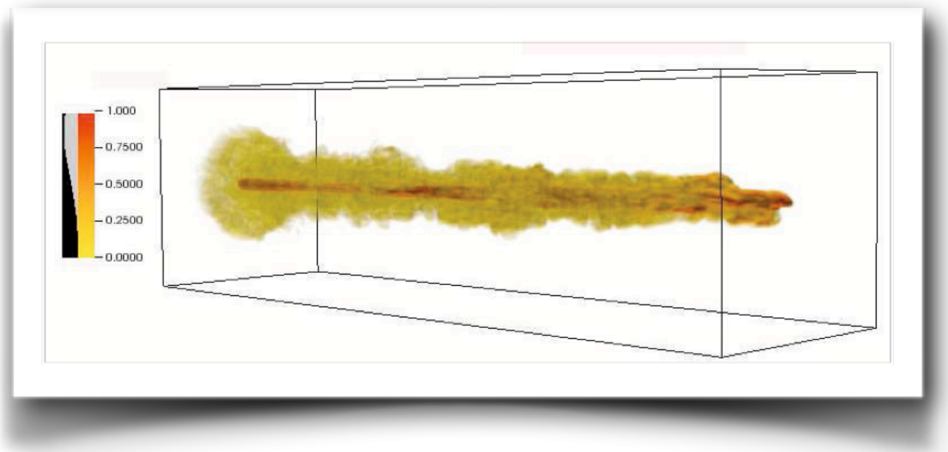
e.g., Petropoulou et al. 2015, 2016

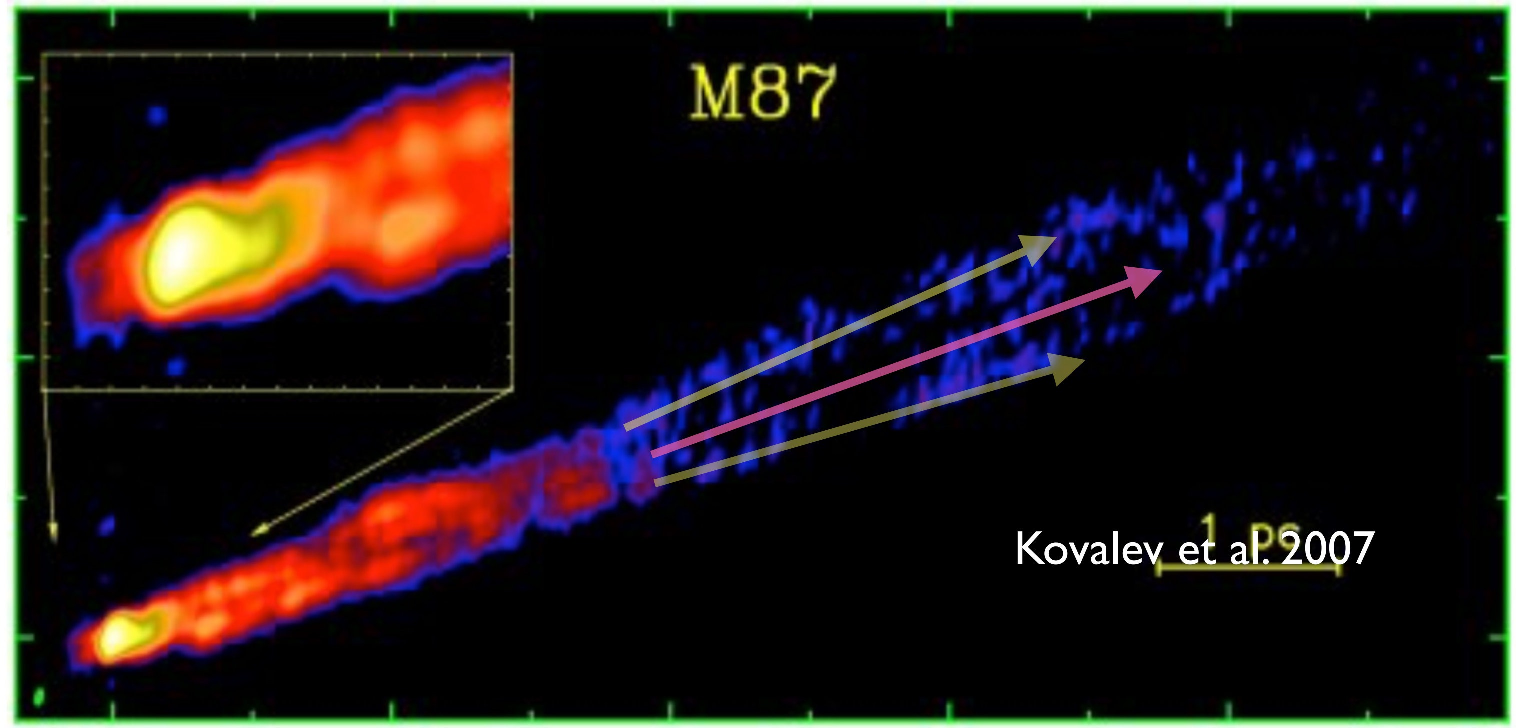
Structured jets in BL Lacs



Ghisellini, FT and Chiaberge 2005
Tavecchio & Ghisellini 2008

Structured jets in BL Lacs





Simulations predict spine-layer structure

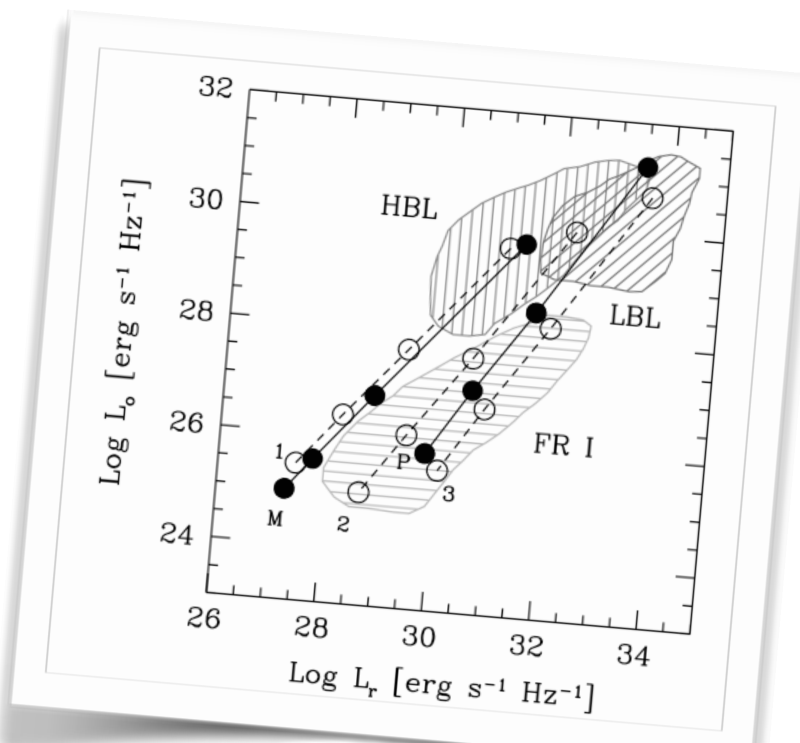
Entrainment/instability e.g. Rossi et al. 2008
Acceleration process e.g. McKinney 2006

Limb brightening
Mkn 501, Mkn 421, M87, NGC 1275

Laing 1996
Giroletti et al. 2004
Piner & Edwards 2014
Pushkarev et al. 2005
Clausen-Brown 2011
Murphy et al. 2013

Unification requires velocity structures

Chiaberge et al. 2000
Meyer et al.
Sbarrato et al. 2014

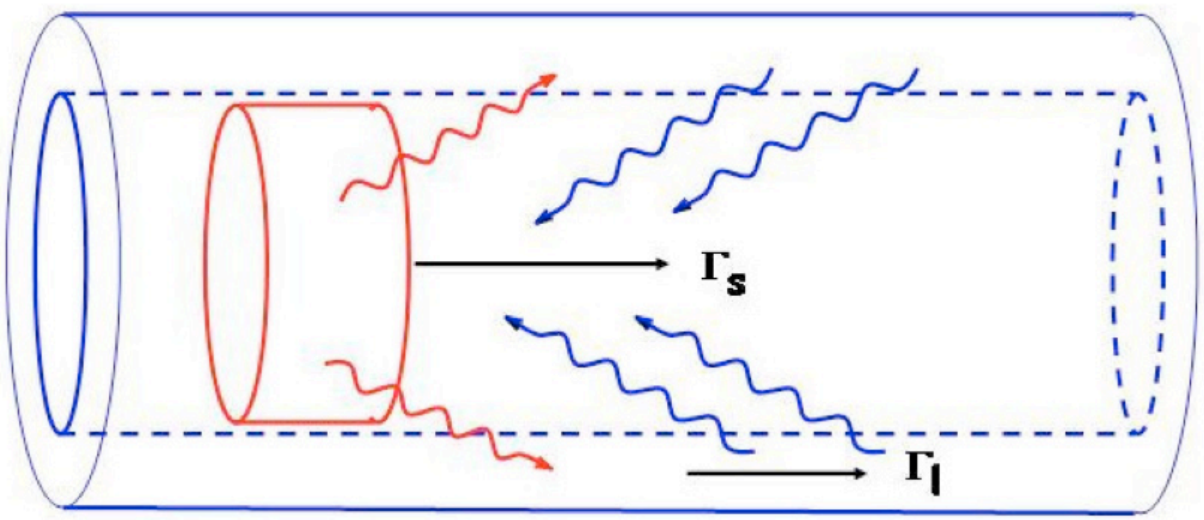


Similar suggestions for GRBs...

Structured jets in BL Lacs

$$\Gamma_{\rm rel} = \Gamma_{\rm s}\Gamma_{\rm l}(1-\beta_{\rm s}\beta_{\rm l})$$

$$U' \simeq U\Gamma^2_{\rm rel}$$



★ The spine "sees" an enhanced u_{rad} coming from the layer

Rates of processes involving soft photons are enhanced w.r.t. to the one-zone model

Both IC and neutrino emission!

Structured jets in BL Lacs

$$L_\nu \approx \frac{3}{8} f_{p\gamma} L_p$$

$$f_{p\gamma} \propto n_{soft}$$

Increased target density

⇒ Reduced proton luminosity

FT et al. 2014, 2015
Righi FT, Guetta 2017

TXS 0506+056 & IC-170922A

2017 september 22

Fermi-LAT detection of increa
TXS 0506+056, locate
2A

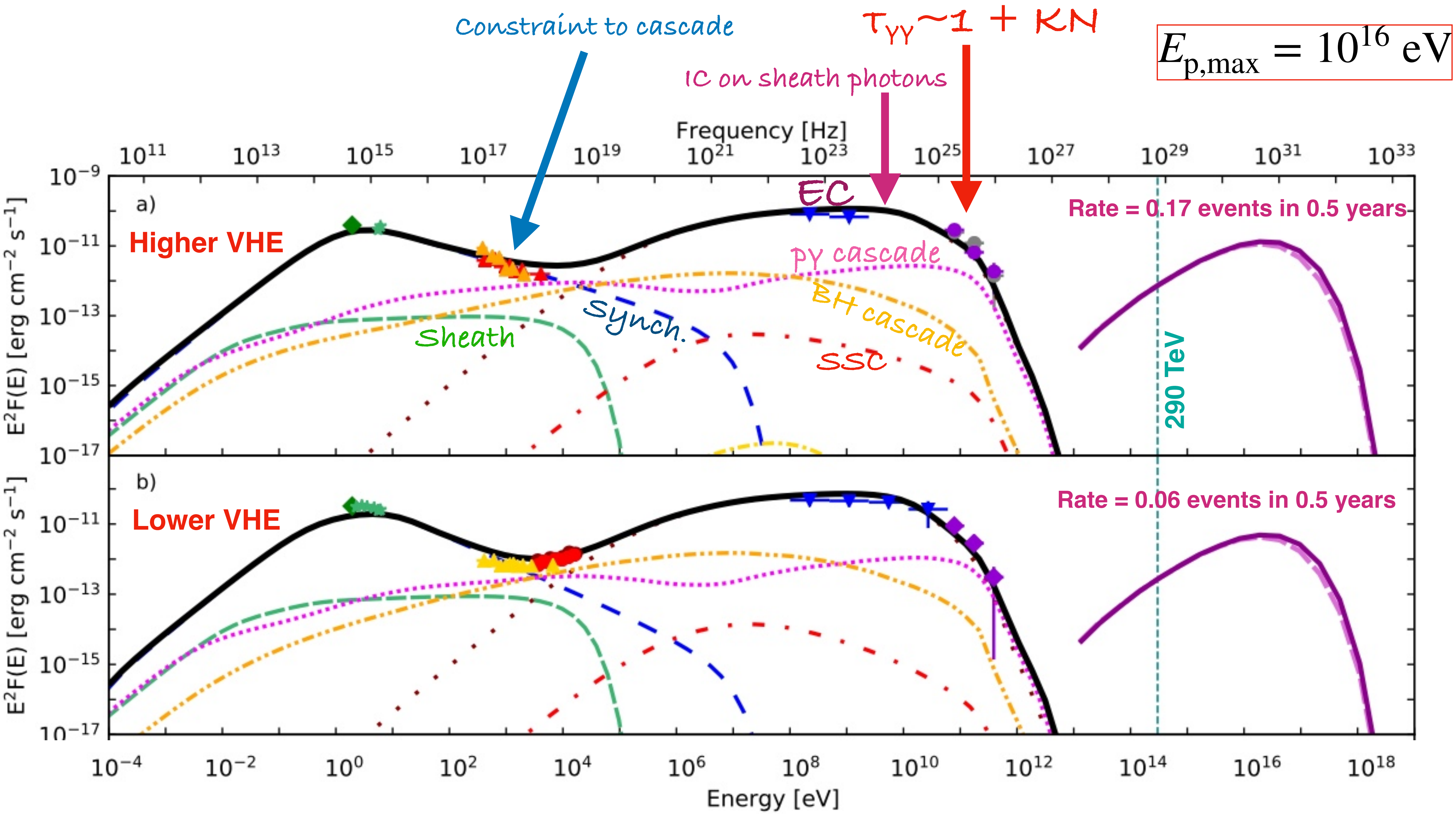
ATel #10791; *Buson (NASA/GSFC), Daniel*
Fermi-LAT collaboration
7; 10:10 UT
Thompson (David.J.Thompson@nasa.gov)

```
TITLE:    GCN CIRCULAR
NUMBER:   21916
SUBJECT:  IceCube-170922A - IceCube observation of a high-energy neutrino candidate event
DATE:     17/09/23 01:09:26 GMT
FROM:     Erik Blaufuss at U. Maryland/IceCube  <blaufuss@icecube.umd.edu>
```

gamma rays by MAGIC from
ion consistent with the recent EHE neutrino
event IceCube-170922A

ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*
on 4 Oct 2017; 17:17 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Jet-sheath model



Numerical model by. W. Bhattacharyya

MAGIC Coll. 2018

Jet-sheath model

MAGIC Coll. 2018

Table 3. Parameters for the jet-sheath model for $E_{\rm p,max}=10^{16}$.

State	MJD 58029-30	Lower VHE
B [G]	2.6	2.6
$E_{\rm min}$ [eV]	3.2×10^8	2.0×10^8
$E_{\rm br}$ [eV]	7.0×10^8	9.0×10^8
$E_{\rm max}$ [eV]	8×10^{11}	8×10^{11}
n_1	2	2
n_2	3.9	4.4
U_e [erg cm^{-3}]	4.4×10^{-4}	3.6×10^{-4}
U_B [erg cm^{-3}]	0.27	0.27
U_p [erg cm^{-3}]	1.8	0.7
P_e [erg s^{-1}]	2×10^{42}	1.6×10^{42}
P_p [erg s^{-1}]	8×10^{45}	3×10^{45}
P_B [erg s^{-1}]	1.2×10^{45}	1.2×10^{45}

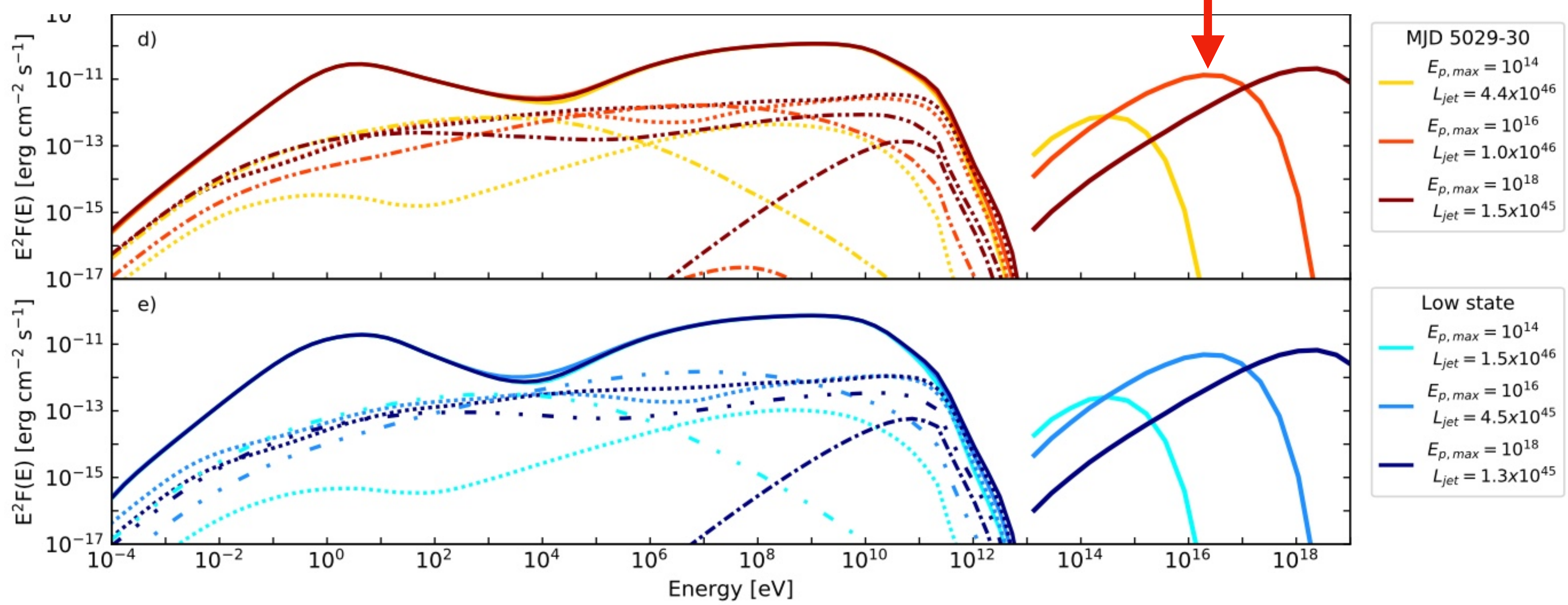
$$P_j \approx 4 \times 10^{45} - 10^{46}\ \mathrm{erg\,s^{-1}}$$

Jet-sheath model

MAGIC Coll. 2018

Effect of maximum proton energy

Constrained by cascade flux in X-rays



Larger Ep —> Lower neutrino rate at 300 TeV

A role for the accretion flow?

Low-luminosity AGNs (including BL Lacs and the parent FRI radiogalaxies) are thought to be powered by an accretion flow with quite small accretion rate

e.g., Rees et al. 1982, Yuan et al. 2003, Di Matteo 2003

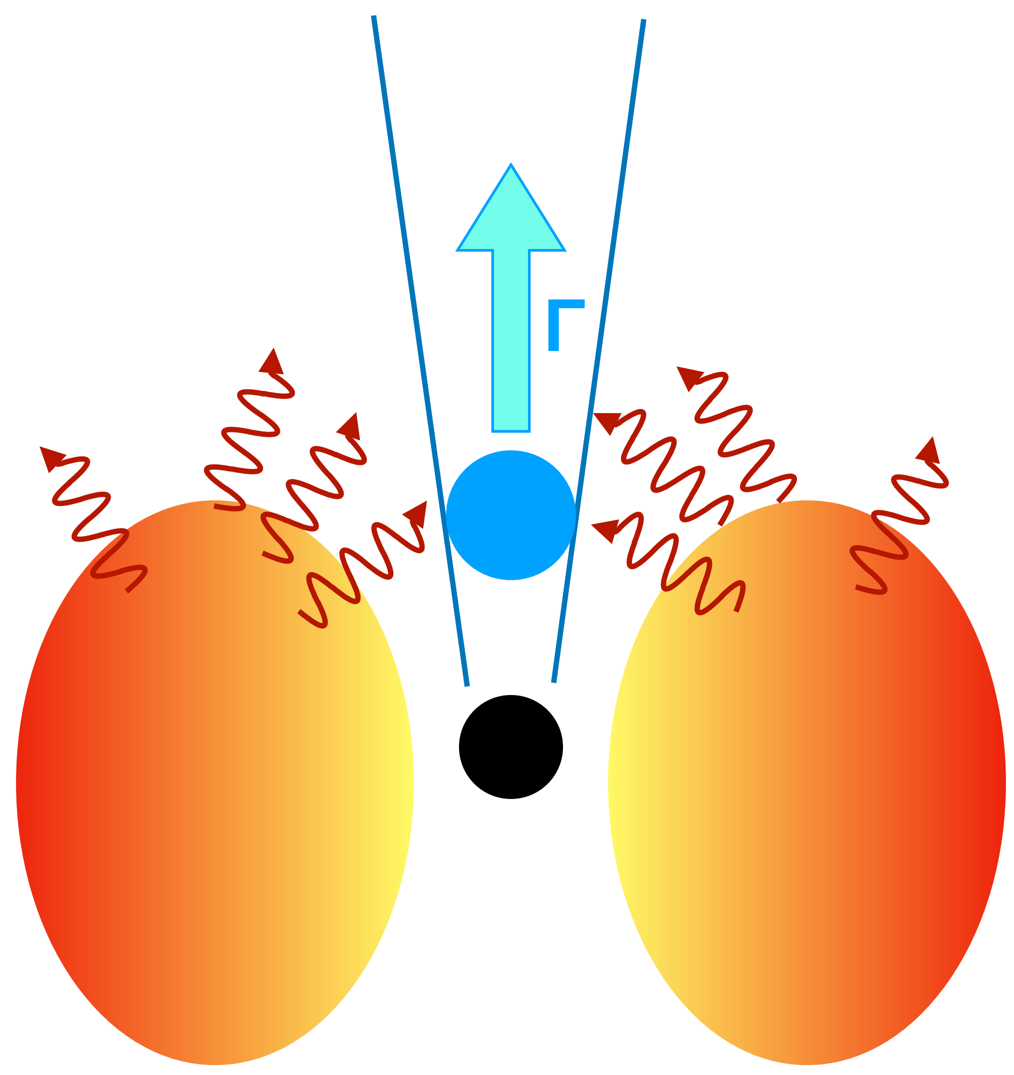
e.g., Ghisellini et al. 2009, 2011, Meyer 2013 for blazars

$$\dot{m} < \alpha^2 \approx 10^{-2}$$

Two-temperature flow (Tp>>Te)
Geometrically thick H~R
Optically thin
Outflow?

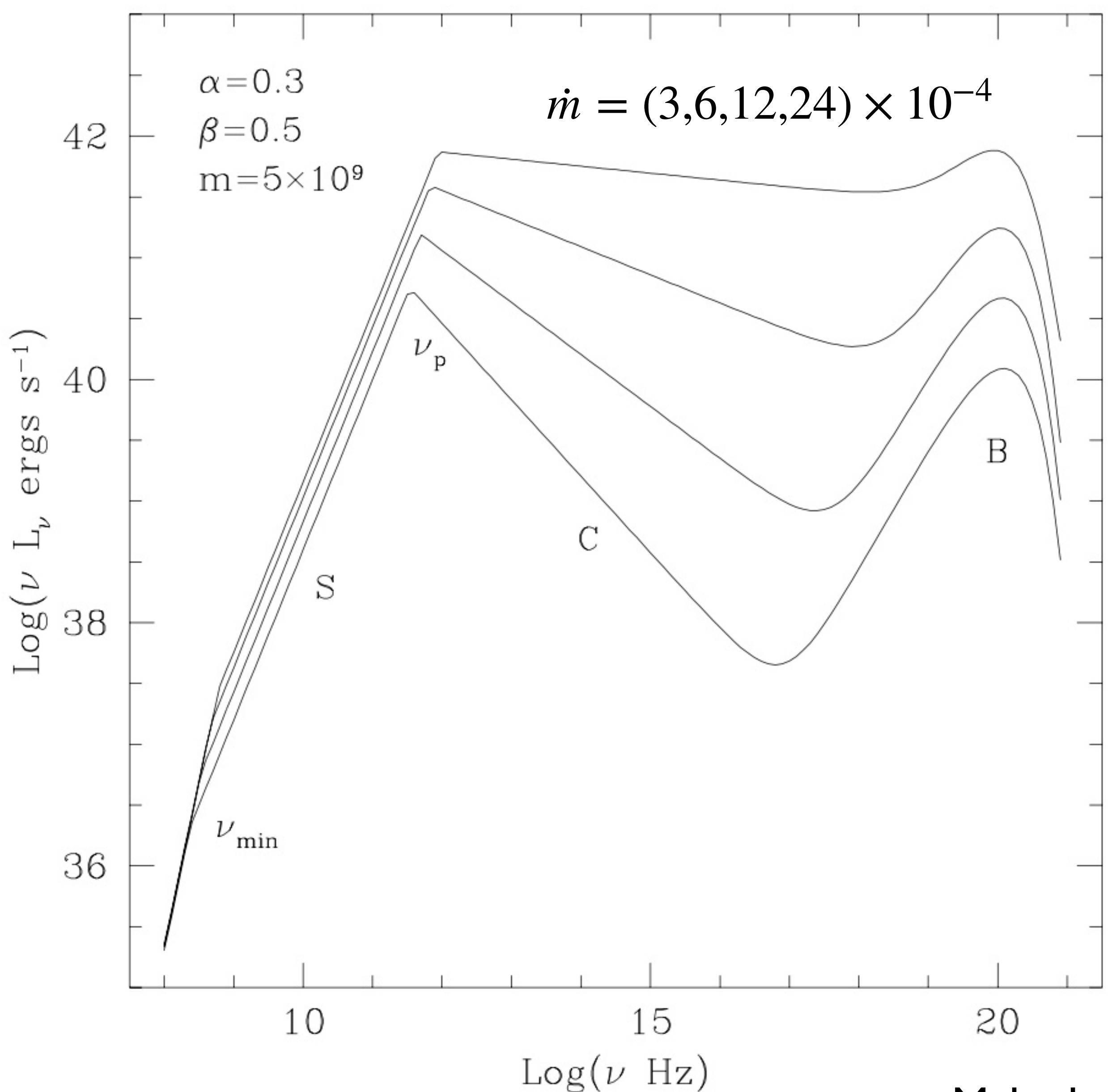
Ichimaru 1977, Rees et al. 1982, Narayan & Yi 1994, 1995, Blandford & Begelman 1999

A role for the accretion flow?



A role for the accretion flow?

Advection dominated accretion flow



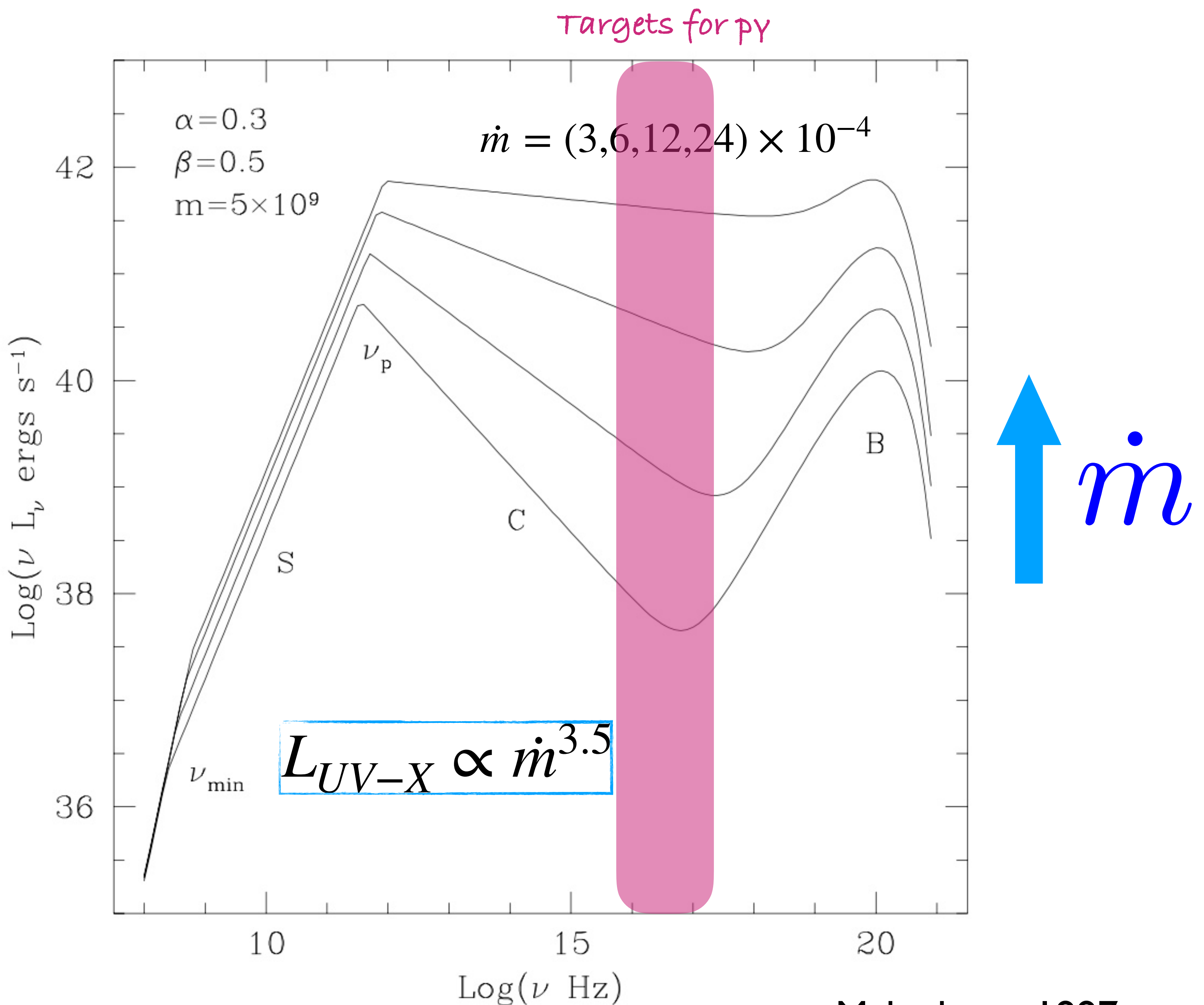
$\dot{m}$

Mahadevan 1997

Total spectrum!

A role for the accretion flow?

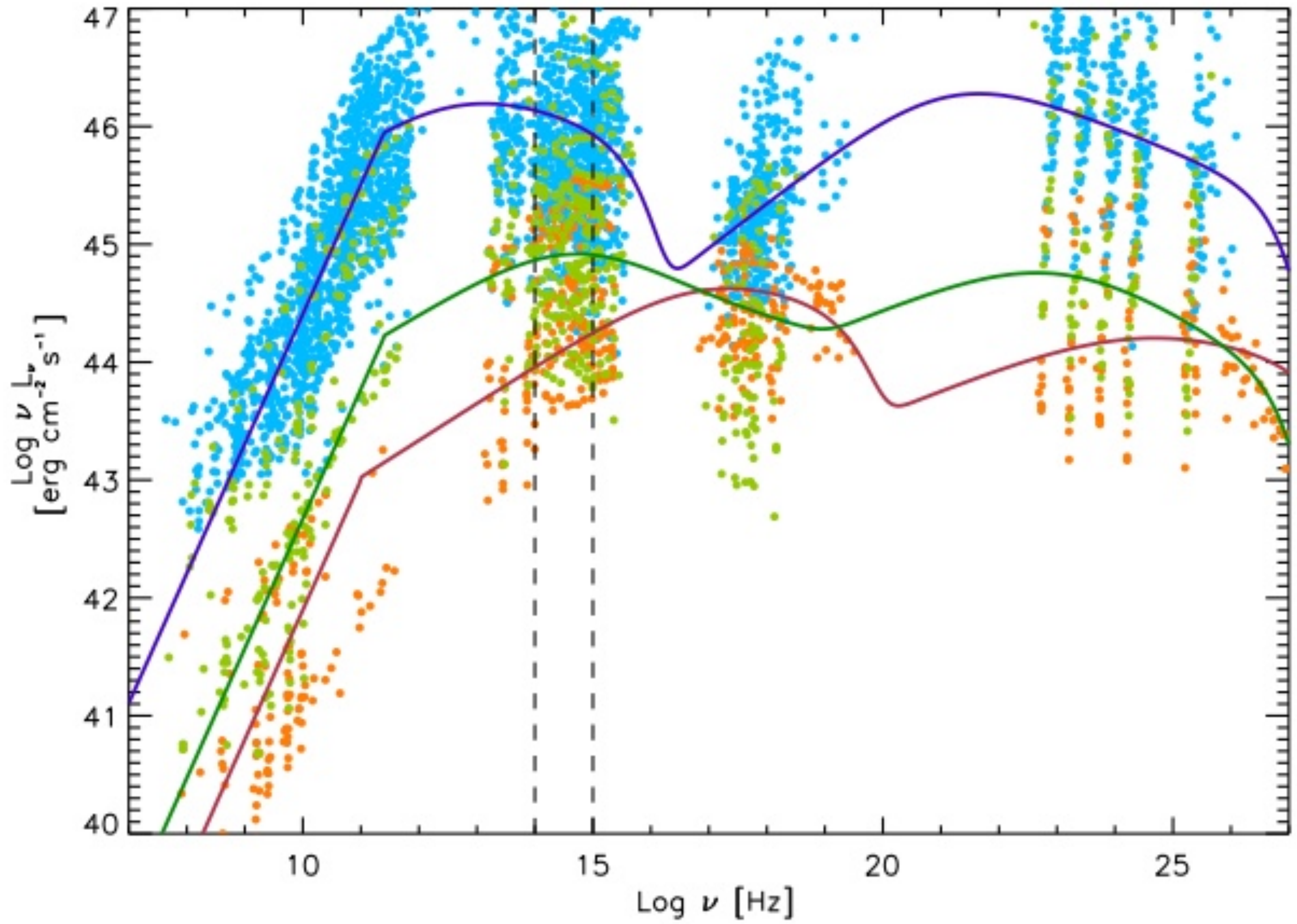
Advection dominated accretion flow



Mahadevan 1997

A role for the accretion flow?

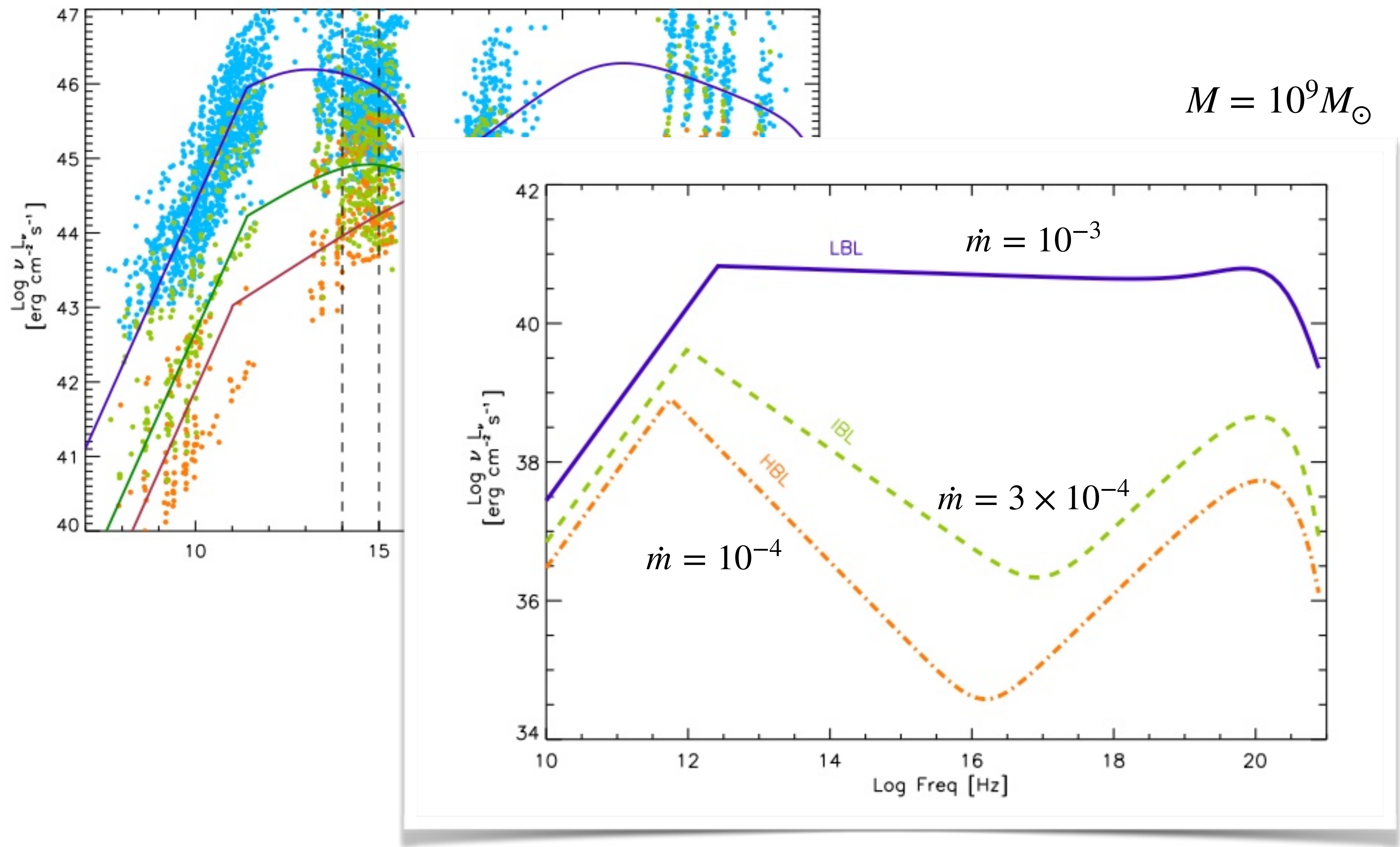
BL Lac section of the "blazar sequence"



Righi, FT, Inoue et al. 2018

A role for the accretion flow?

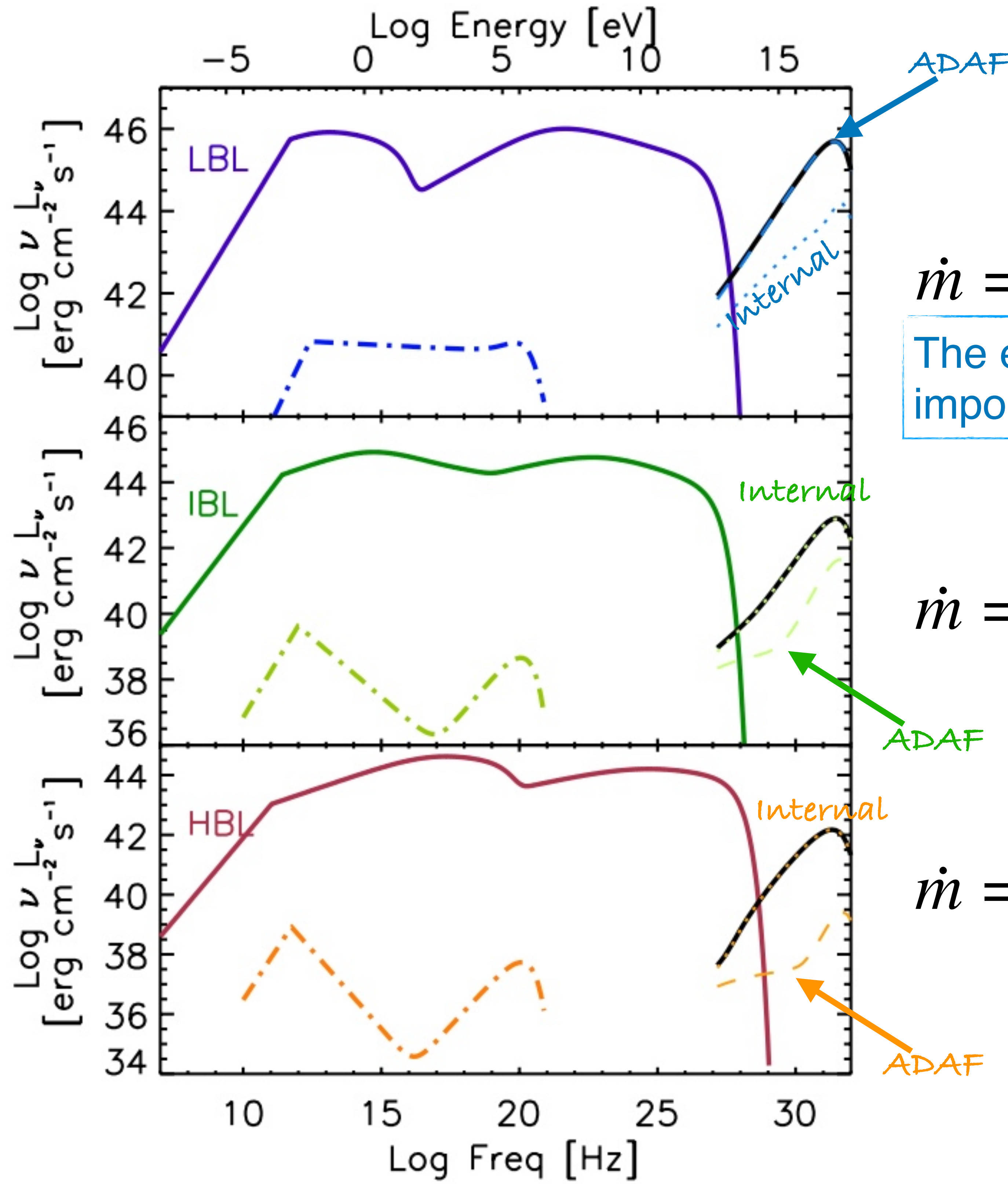
BL Lac section of the "blazar sequence"



Righi, FT, Inoue et al. 2018

A role for the accretion flow?

$L_p \propto P_{jet}$



$\dot{m} = 10^{-3}$

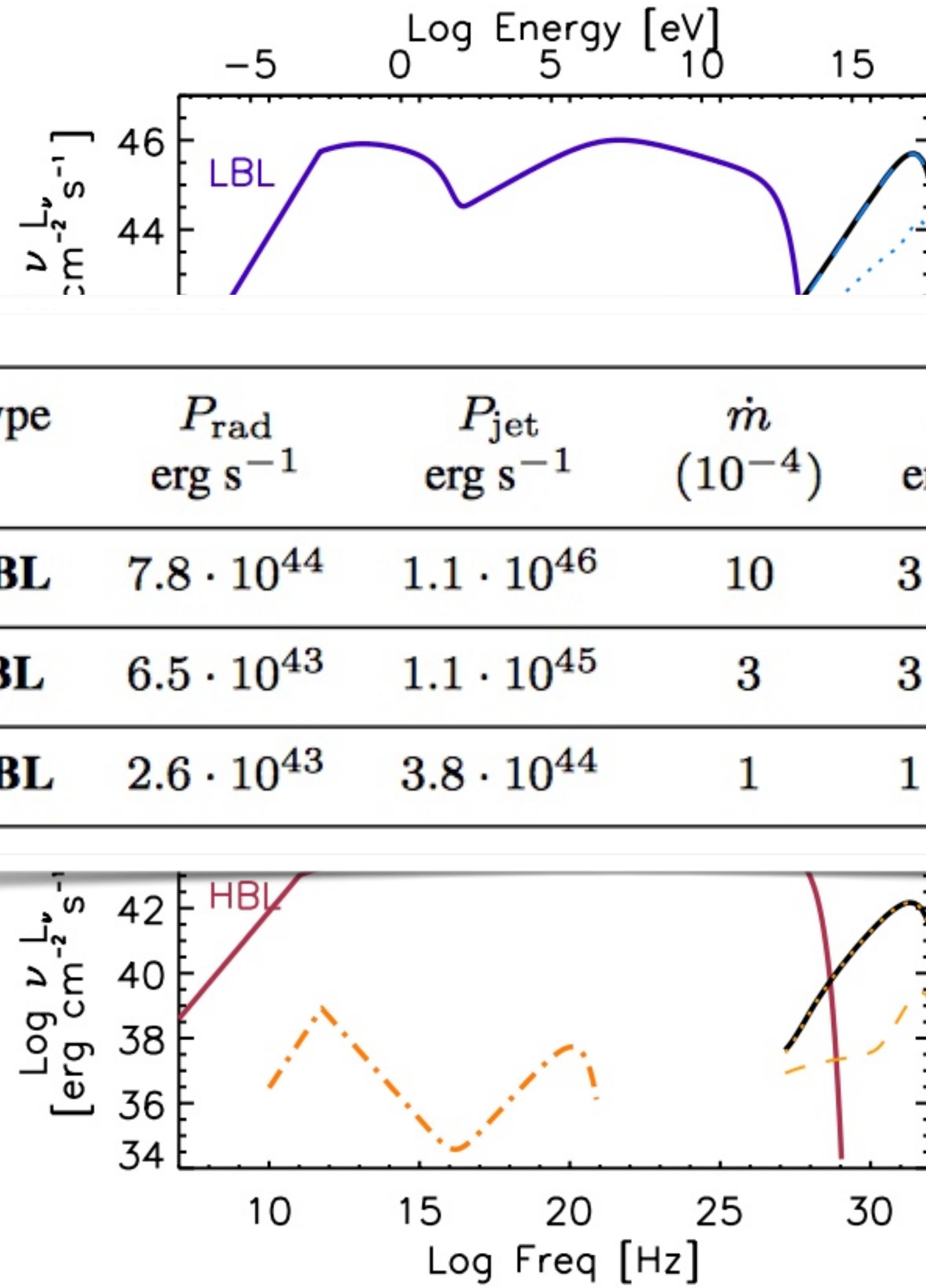
The external field is important for LBL only

$\dot{m} = 3 \times 10^{-4}$

$\dot{m} = 10^{-4}$

Righi, FT, Inoue et al. 2018

A role for the accretion flow?



Type	$P_{\rm rad}$ erg s^{-1}	$P_{\rm jet}$ erg s^{-1}	$\dot{m}$ (10^{-4})	$L'_{\rm p}$ erg s^{-1}	R_{ν_μ} 7 yr
LBL	$7.8 \cdot 10^{44}$	$1.1 \cdot 10^{46}$	10	$3 \cdot 10^{45}$	1
IBL	$6.5 \cdot 10^{43}$	$1.1 \cdot 10^{45}$	3	$3 \cdot 10^{44}$	$3 \cdot 10^{-5}$
HBL	$2.6 \cdot 10^{43}$	$3.8 \cdot 10^{44}$	1	$1 \cdot 10^{44}$	$9 \cdot 10^{-6}$

$\dot{m} = 10^{-4}$

Righi, FT, Inoue et al. 2018

Take home messages

The astrophysical setting is relevant! Environment could play an important role

External photons can help to keep the jet power below 10^{47} erg/s

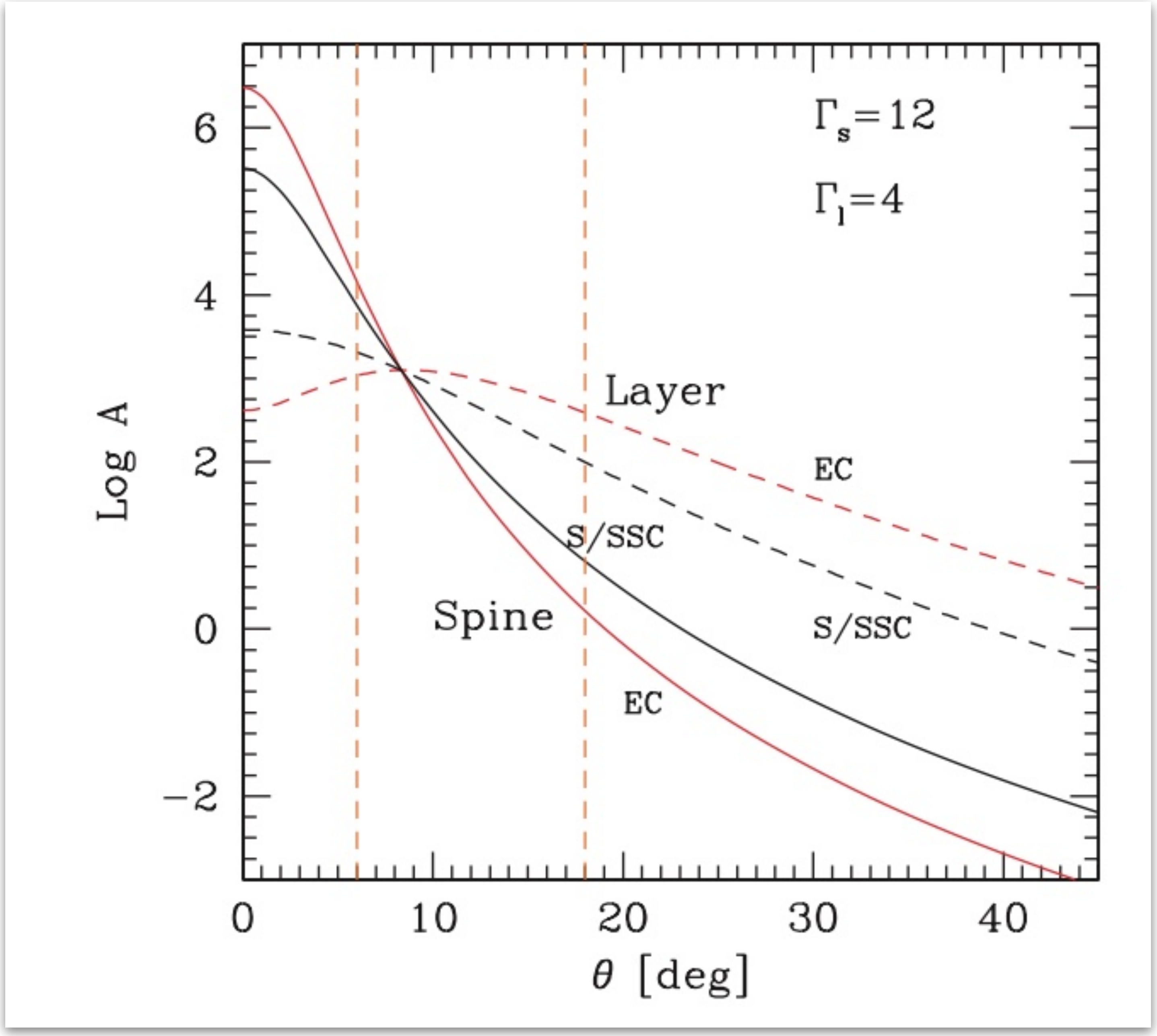
Fits using the structured jet scenario allow us to determine several parameters in a self-consistent way (but several parameters!)

Thank you!

Structured jets

"Dermer effect"

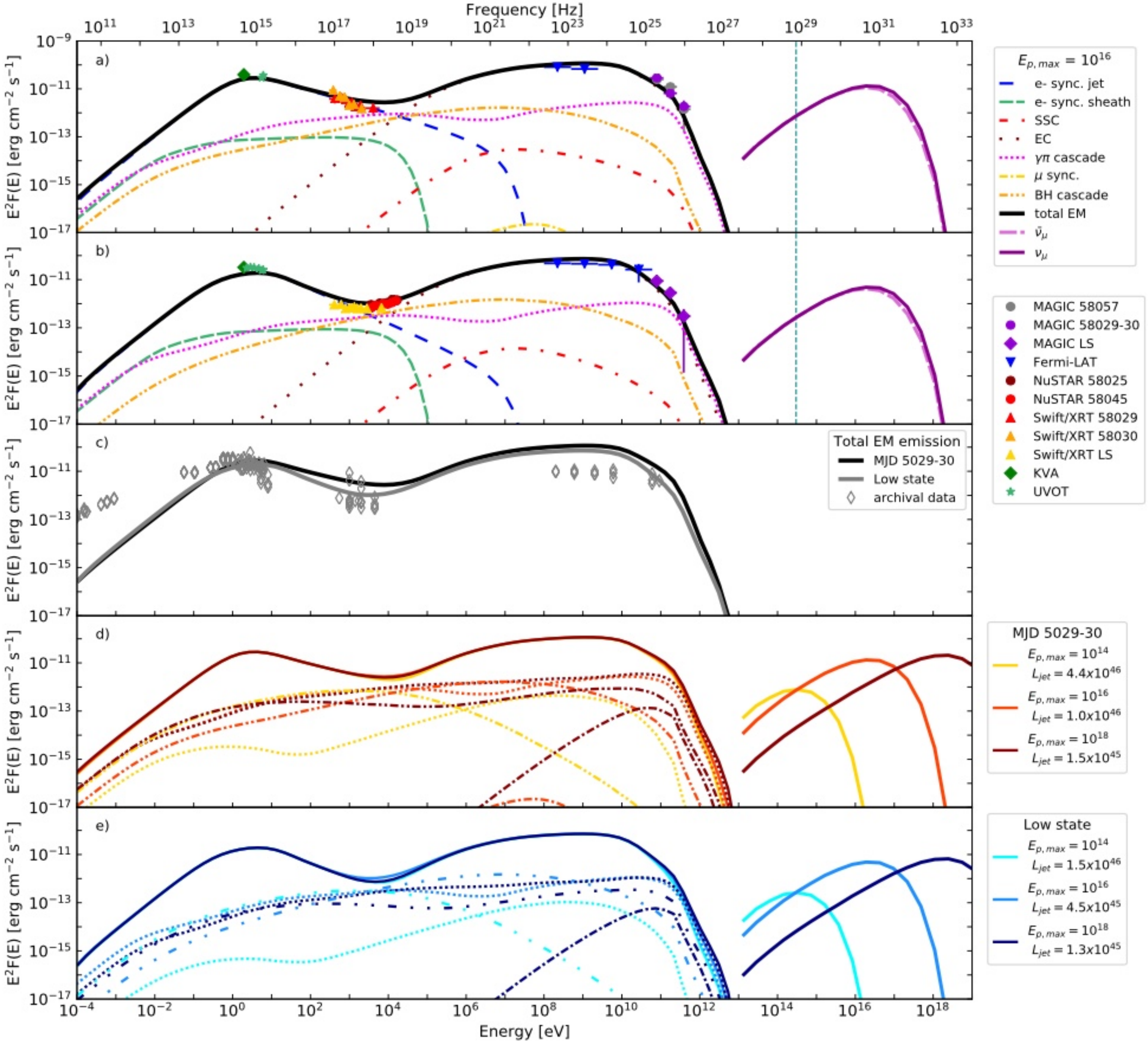
Dermer 1995



Tavecchio and Ghisellini 2008

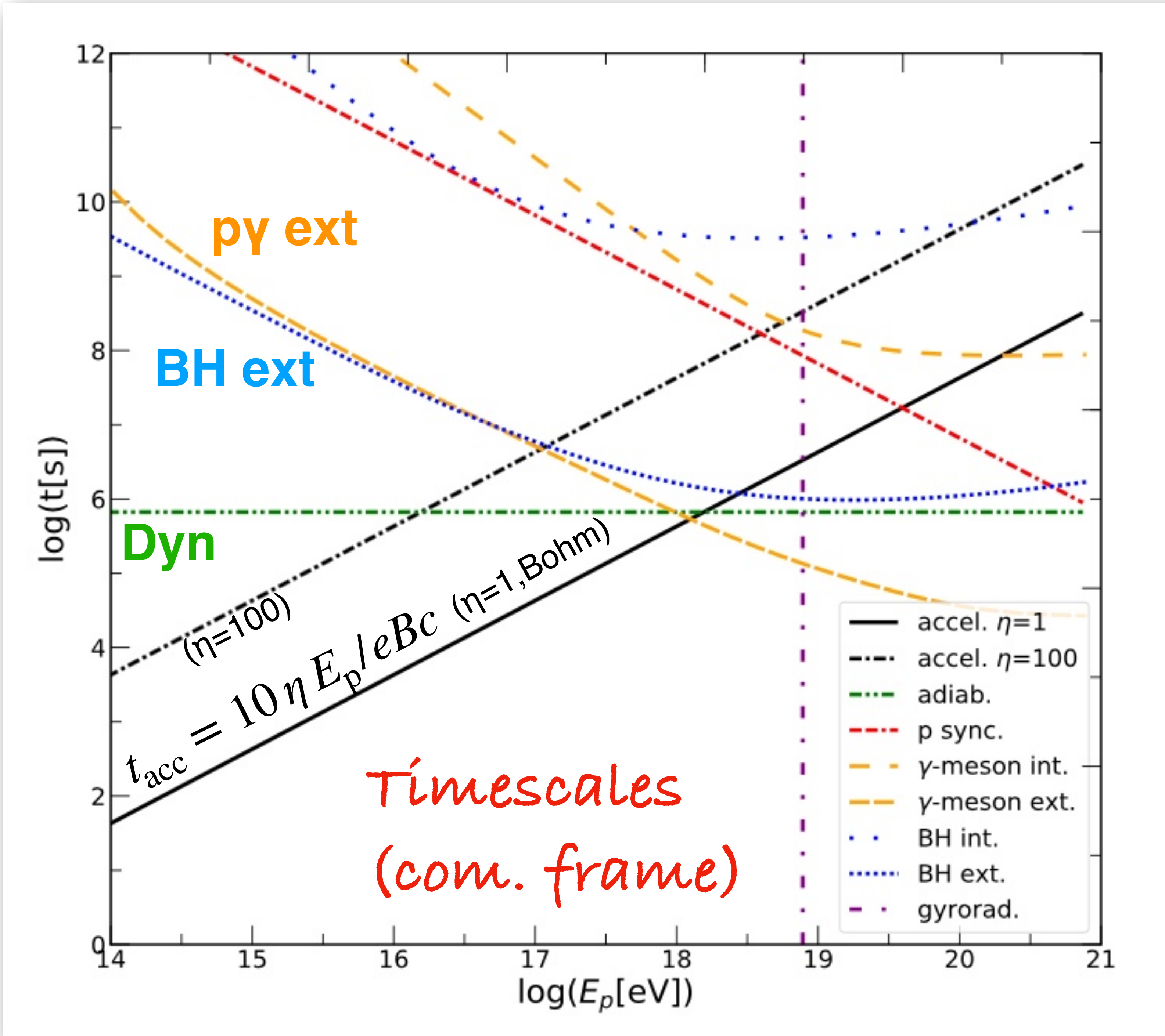
Jet-sheath modeling of TXS

MAGIC Coll. 2018



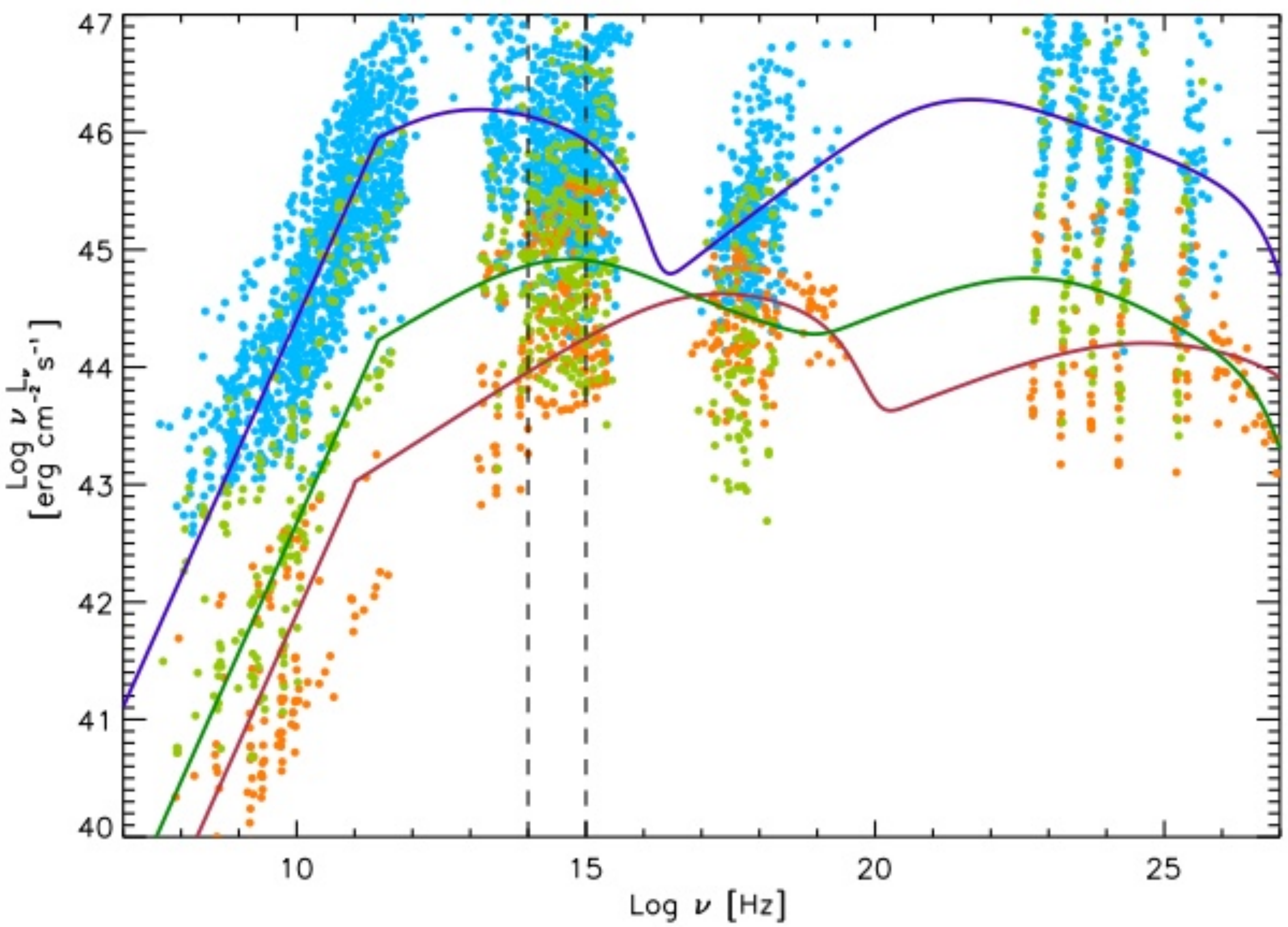
Jet-sheath model

MAGIC Coll. 2018



A role for the accretion flow?

BL Lac section of the "blazar sequence"



$$P_{\rm rad} = \eta_{rad} P_{\rm jet}$$

$$P_{rad} \approx \frac{L_{rad}}{\Gamma^2}$$

Nemmen et al. 2012
Celotti & Ghisellini 2008
Ghisellini et al. 2010

$$\eta_{\rm rad} \approx 0.1$$

$$P_{\rm jet} \simeq \eta_j \dot{M} c^2$$

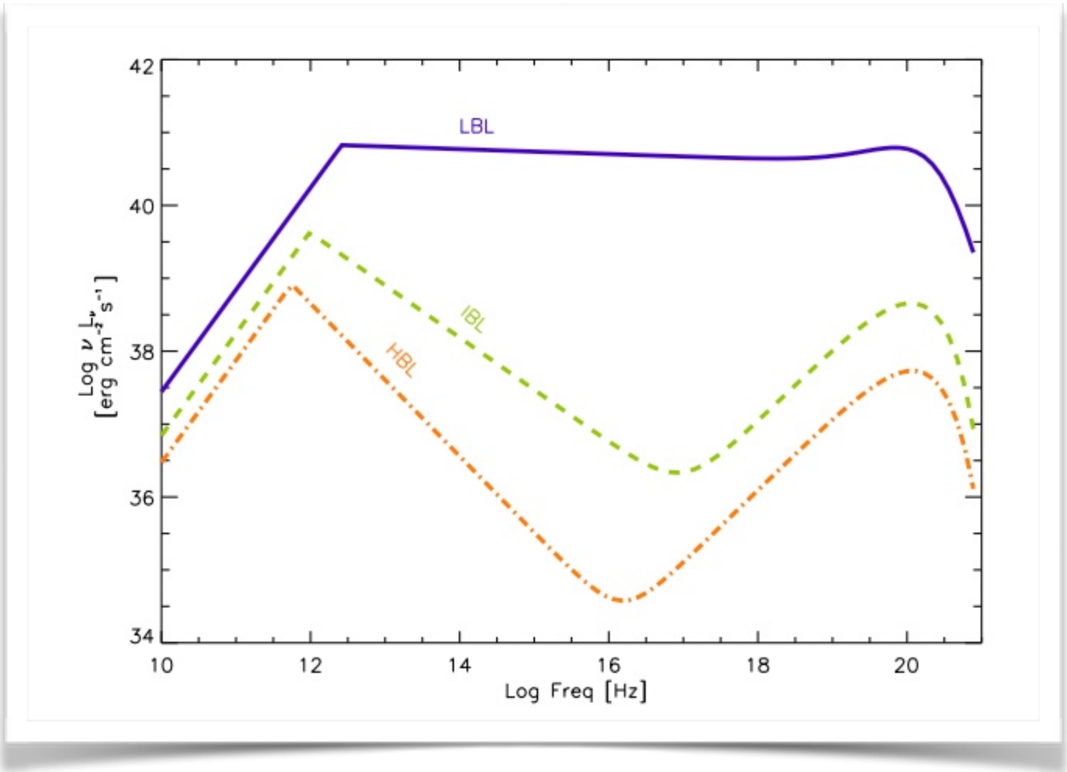
$$\eta_{\rm j} \approx 1$$

Ghisellini et al. 2010, 2014

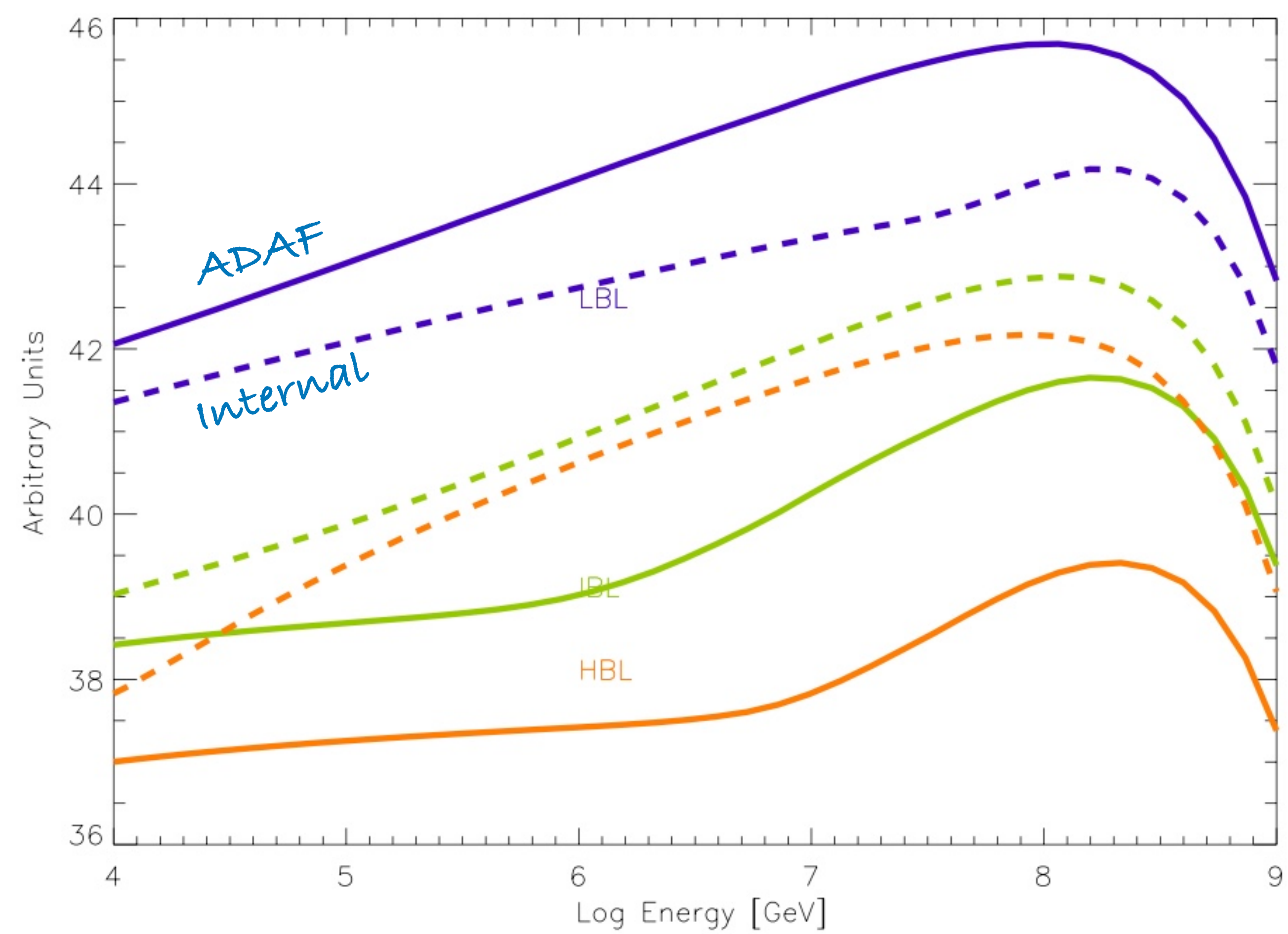
$$\dot{m} = \frac{P_{\rm rad}\eta_{acc}}{L_{\rm Edd}} \frac{\eta_{rad}}{\eta_j}$$

Righi, FT, Inoue et al. 2018

Neutrino emission



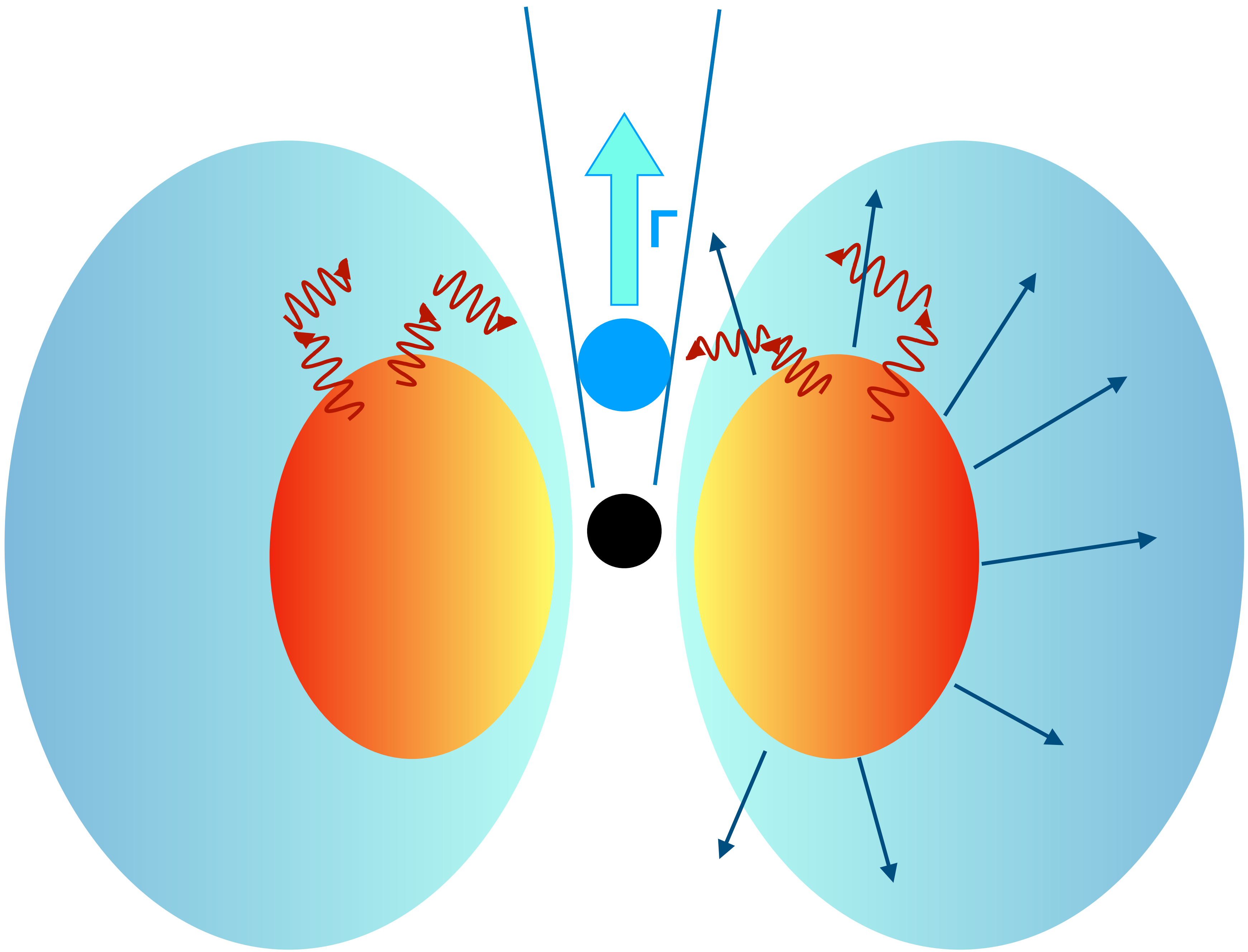
Fixed proton luminosity



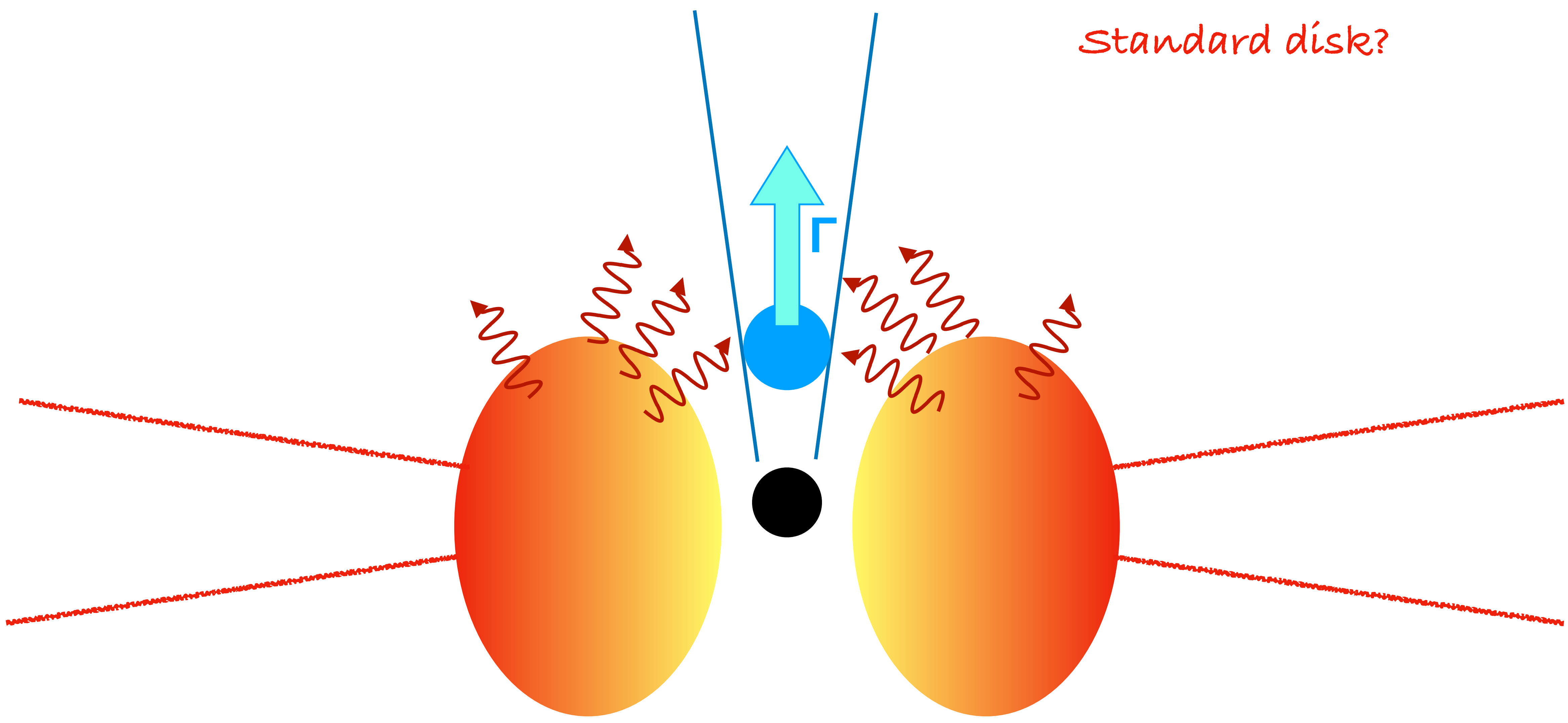
The external field is important for LBL only!

Righi, FT, Inoue et al. 2018

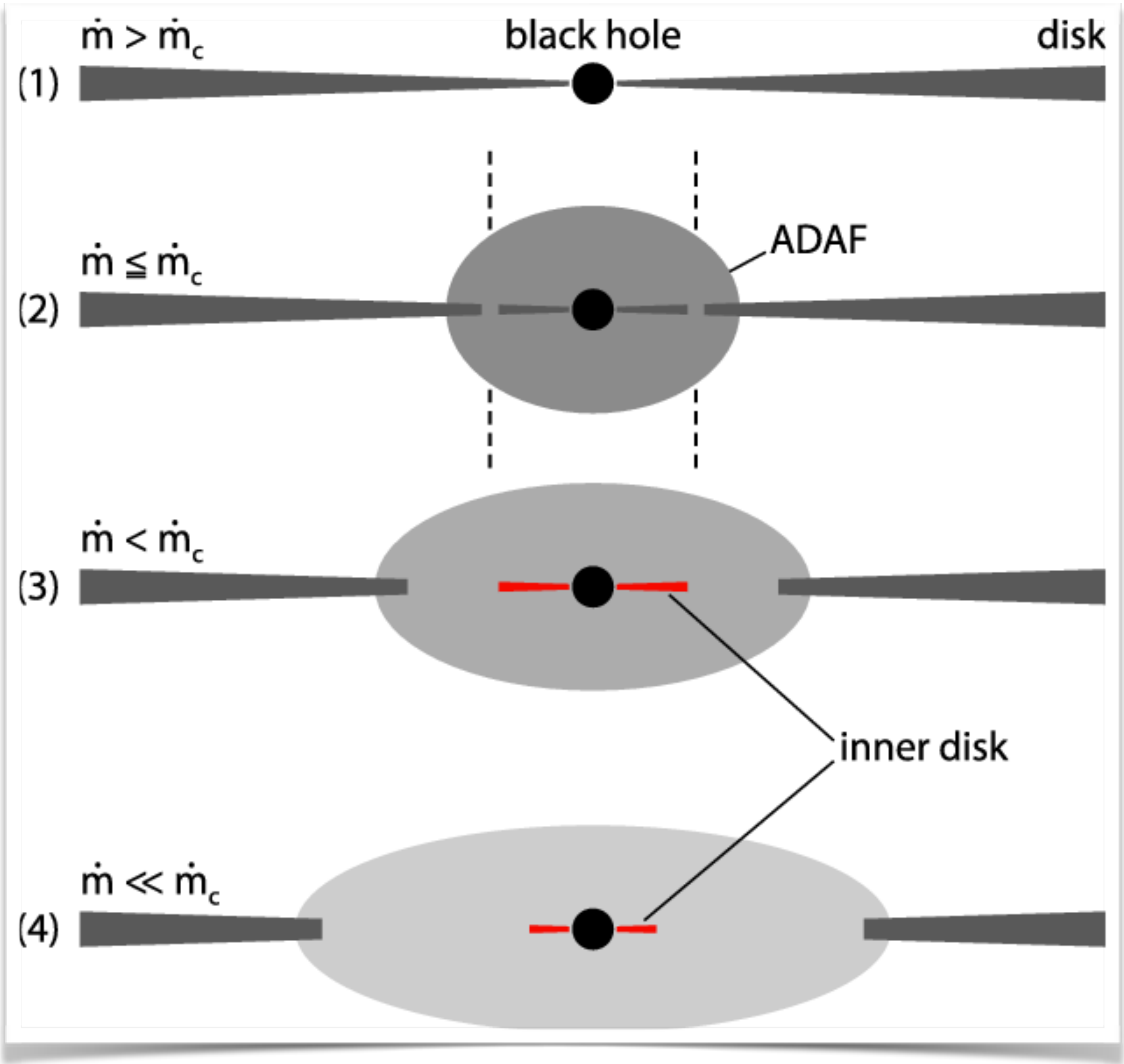
A role for the accretion flow?



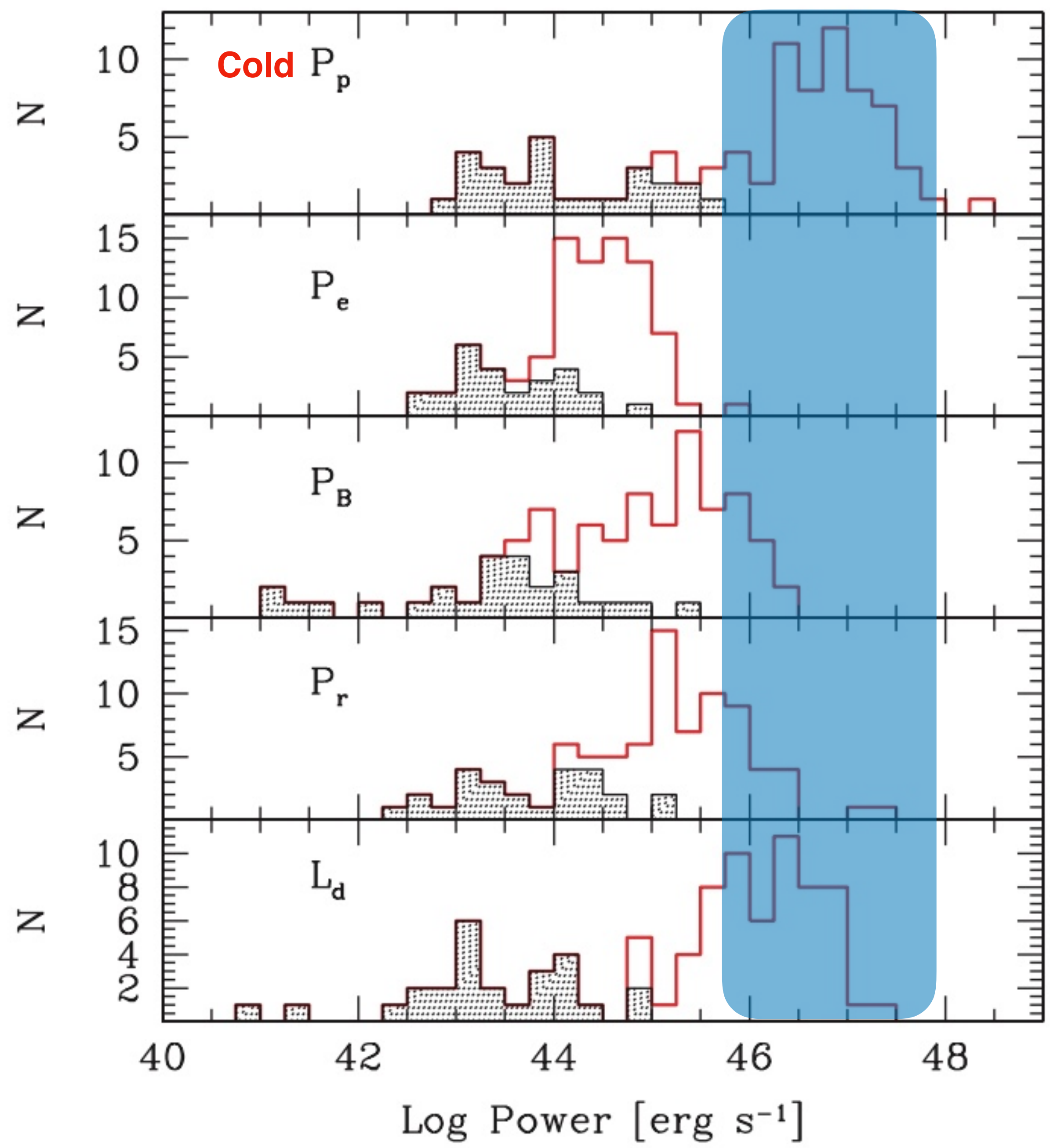
Caveats & Complications



Caveats & Complications



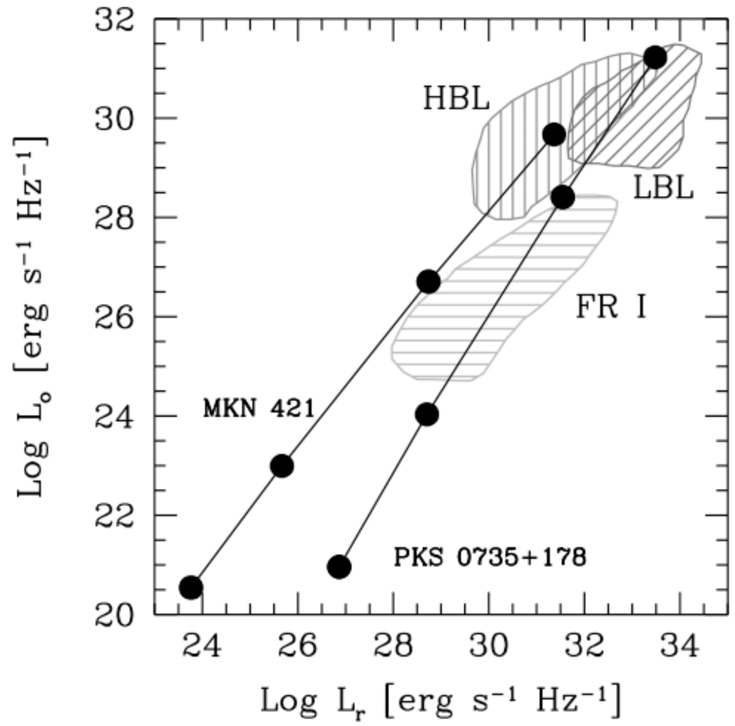
Jet power



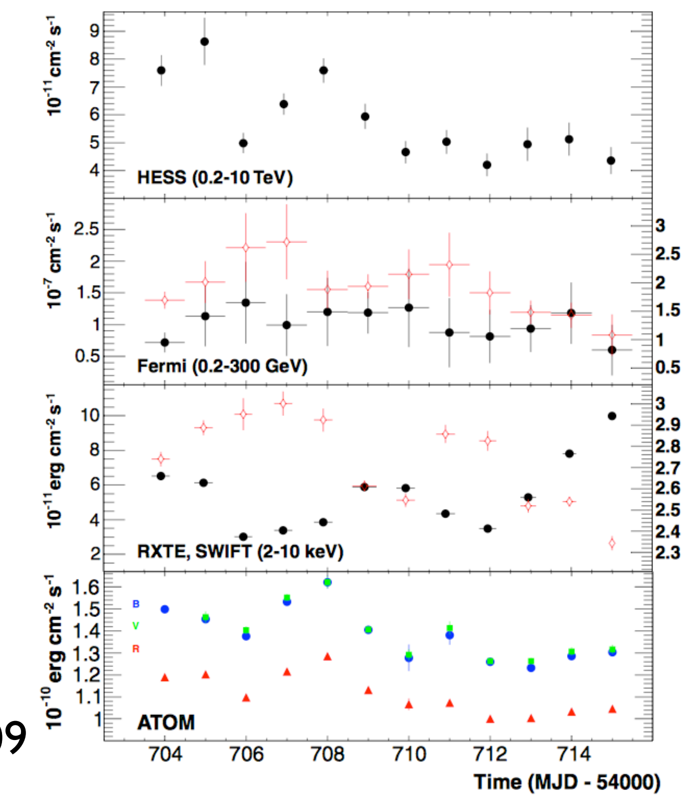
Some problems with BL Lacs

Unification

Chiaberge et al. 2000
Meyer et al. 2011
Sbarrato et al. 2014
Georganopoulos & Kazanas 2004
Henry & Sauge' 2006



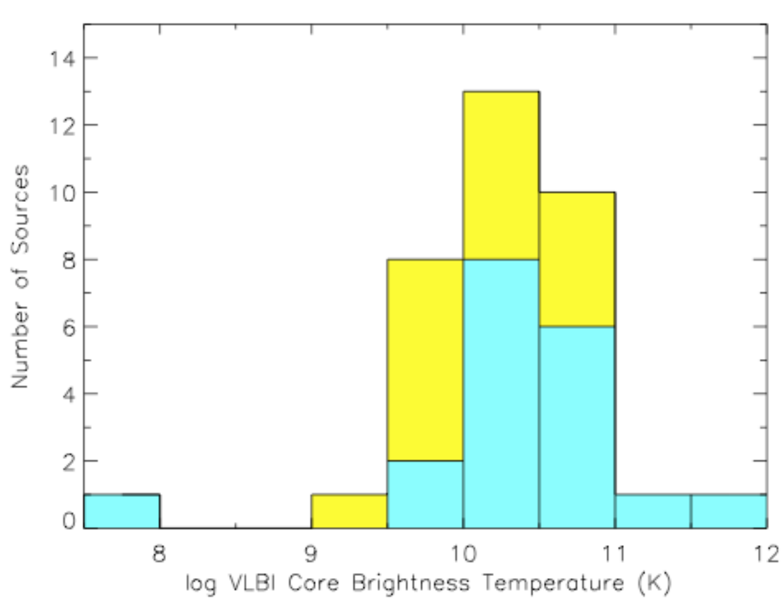
X-ray/TeV connection



Aharonian et al. 2009
Aleksic et al. 2015

Velocity discrepancy

Contraddiction between large delta and small (v<c) VLBI apparent speeds and brightness T



Piner & Edward 2004, 2014
Georganopoulos & Kazanas 2004