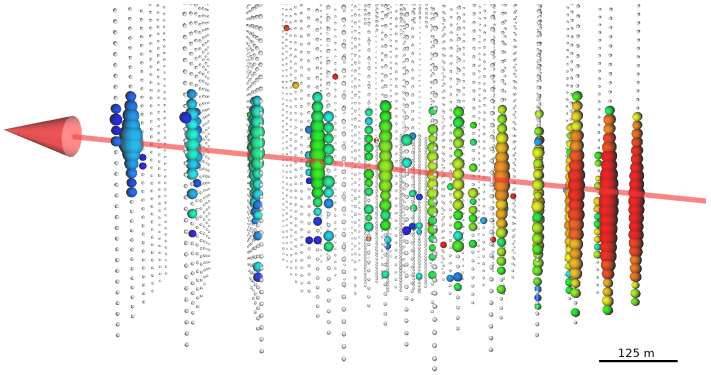
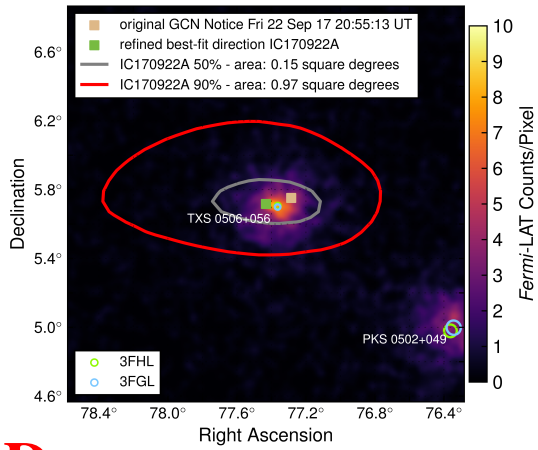
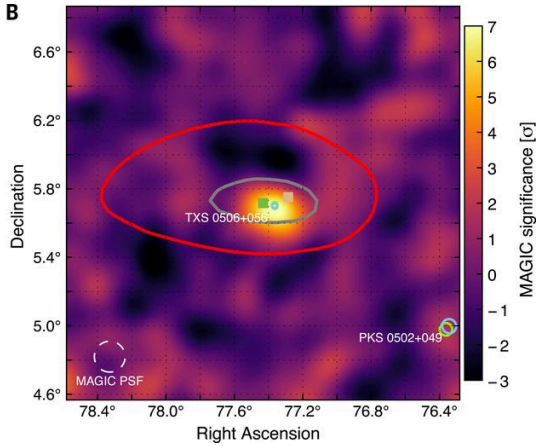
ブレーザー電弱放射の物理

Physics of Electroweak Emission from Blazars

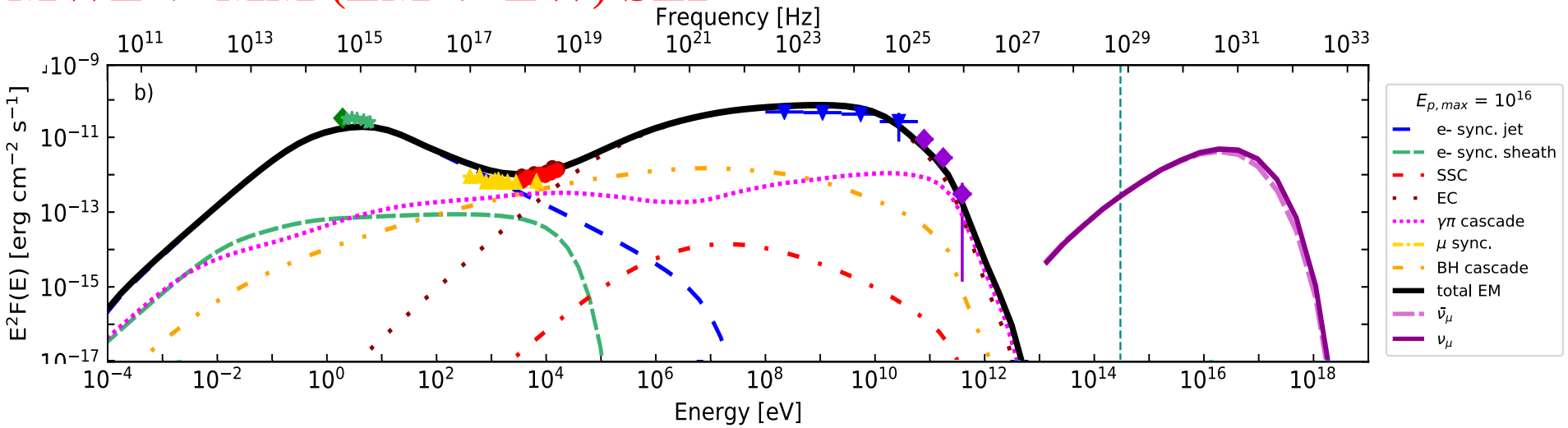
井上 進（理研）







MWL -> MM (EM -> EW) SED



ν / EM observations of IC-170922A / TXS 0506+056

IceCube, Fermi, MAGIC+, 2018, Science 361, eaat1378

IceCube:

- EHE alert: 56.5% probability of being astrophysical ν
- E_ν~290 TeV (183 TeV - 4.3 PeV 90% C.L.) assuming -2.13 spectrum

-> possible cosmic proton accelerator with E_p>~20E_ν~several PeV

(- 2014-2015 flare to be discussed on another occasion)

Fermi-LAT:

- coincident with blazar TXS 0506+056 in bright state (0.5 yr-long)
- significance of association ~3σ

-> possible source of possible astrophysical high-energy neutrino

MAGIC:

- ~6σ detection, steep spectrum (Γ~-3.5 - -4.0) up to 400 GeV
- <day timescale flaring

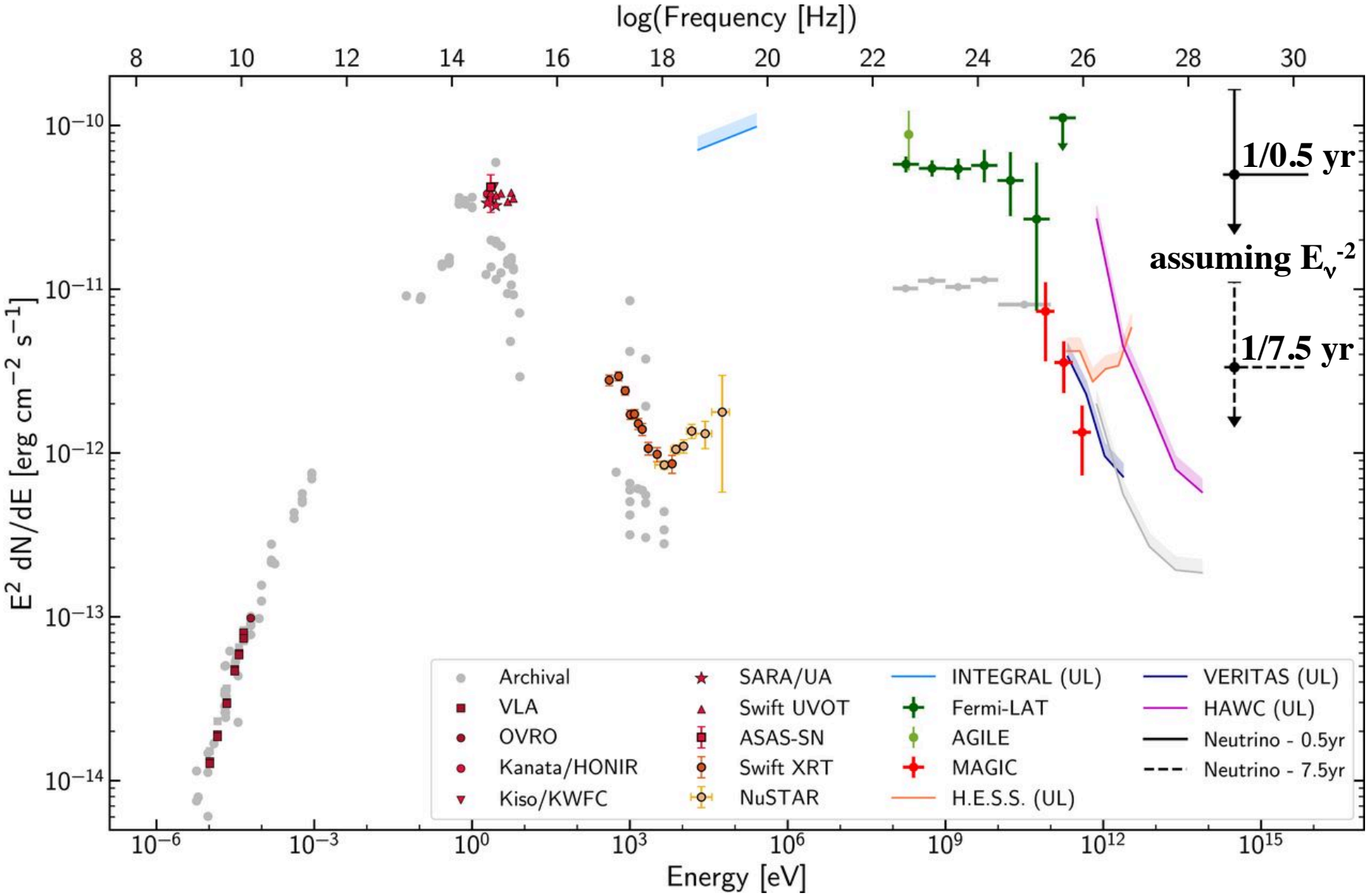
MWL:

- intermediate- or low-frequency peaked BL Lac object
- X-rays (Swift+NuSTAR): sync. - HE crossover
- z=0.3365+-0.0010 Paiano+ 18

Redman's theorem

"A competent theoretician can fit any given theory to any given set of facts."

ν / EM observations of IC-170922A / TXS 0506+056



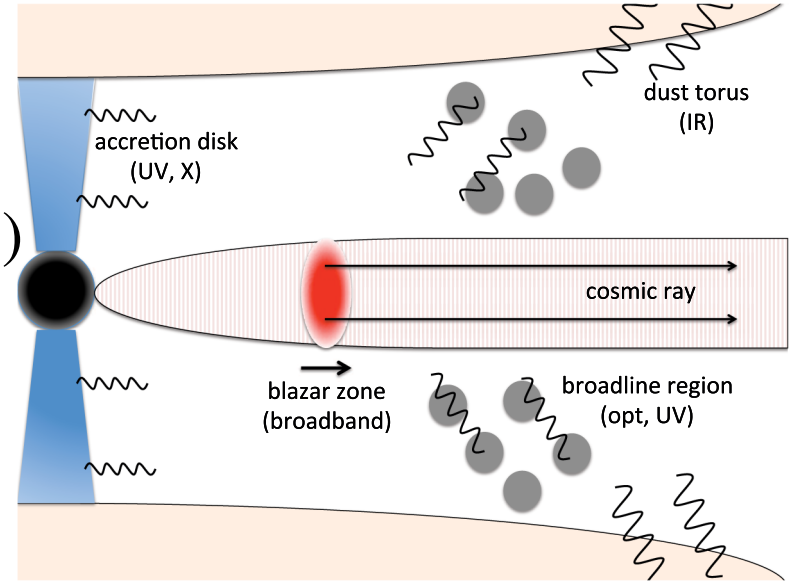
IceCube, Fermi, MAGIC+, 2018, Science 361, eaat1378

neutrino emission from blazars

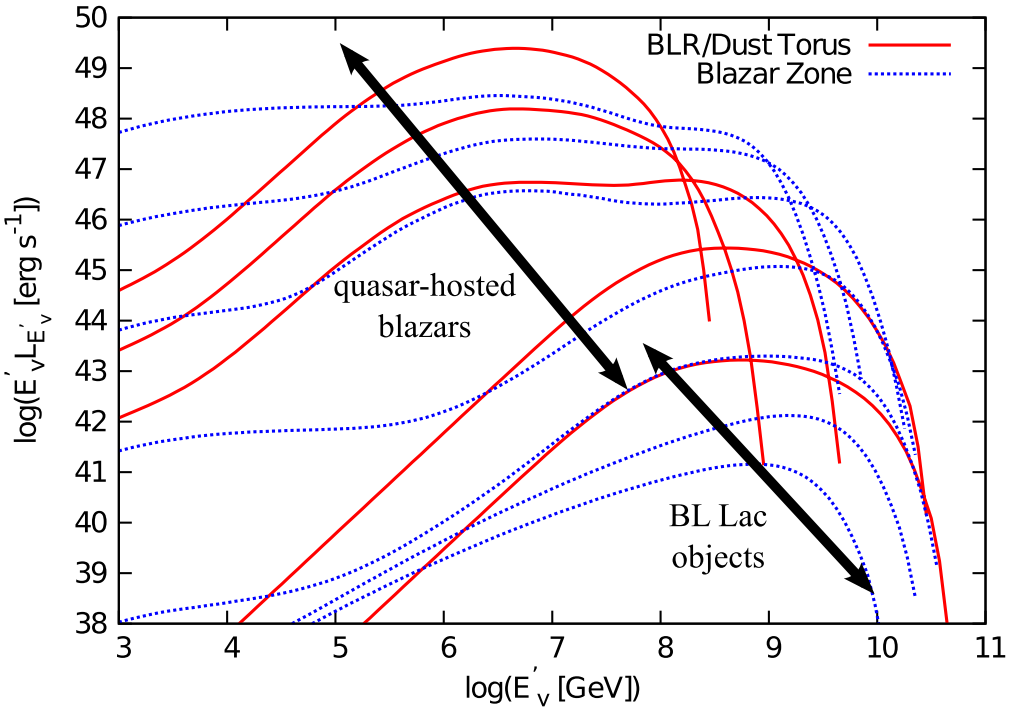
- pγ generally favored over pp in AGN jets
- target γ $\varepsilon'_\gamma > \sim 20 m_\pi m_p c^4 / E_\nu \delta^{-1}$
  ~ 0.4 keV $(E_\nu/300\ \mathrm{TeV})^{-1}$ $(\delta/20)$

- unlike FSRQs, BL Lacs thought to:
  lack bright external γ fields,
  have low internal sync. γ fields
  -> PeV ν production inefficient?

- with internal γ only,
  ν detectable only for high L_p
  Cerruti, Zech, Boisson, Emery,
  SI, Lenain, 1807.04335



Murase+ 14

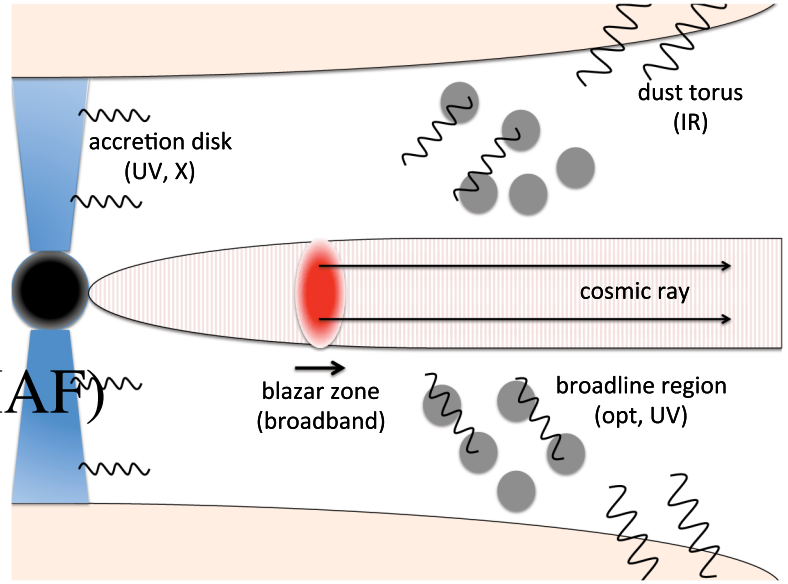


neutrino emission from blazars

- enhanced pγ efficiency via external γ fields in BL Lacs?

I. sync. from sheath in structured jets
MAGIC Coll. 1807.04300

II. radiatively inefficient accretion flow (RIAF)
Righi+ 1807.10506



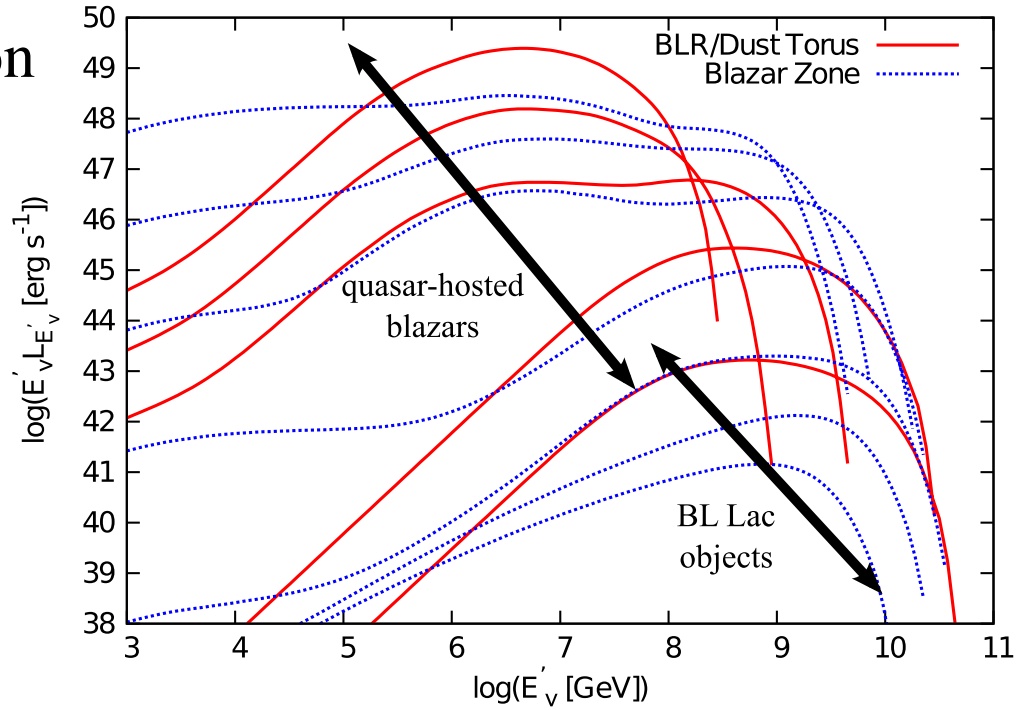
Murase+ 14

- questions

1: accompanying hadronic emission consistent with observed SED?

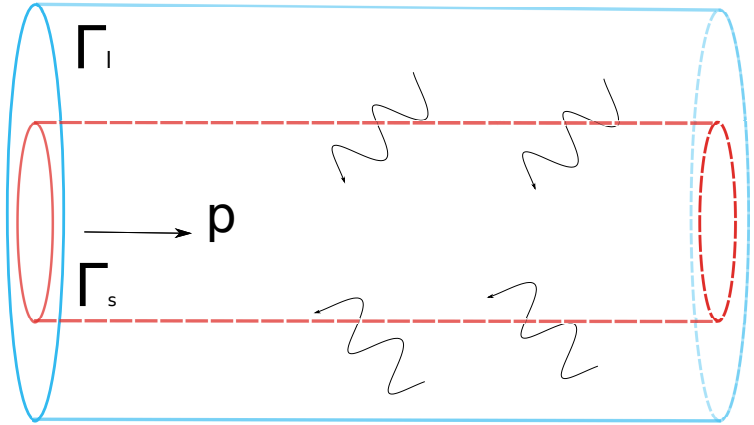
2: accompanying γγ absorption consistent with observed SED?

3: role of external Compton relative to SSC?



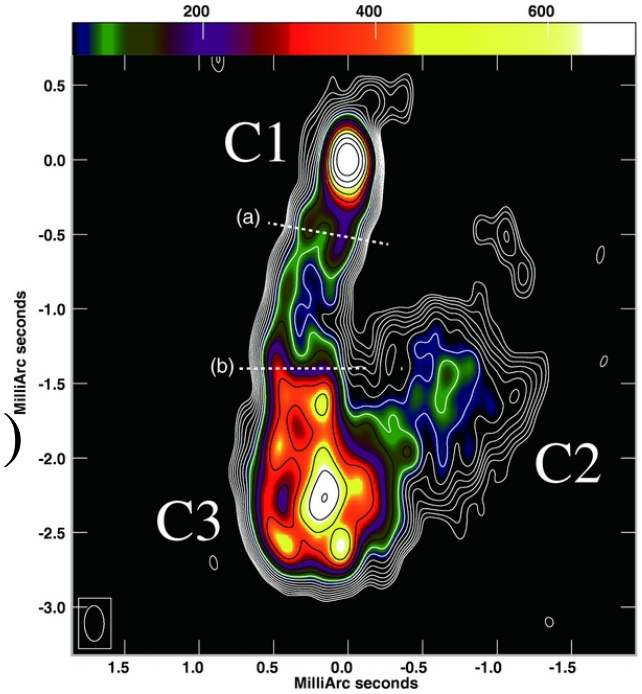
jet-sheath (spine-layer) structure

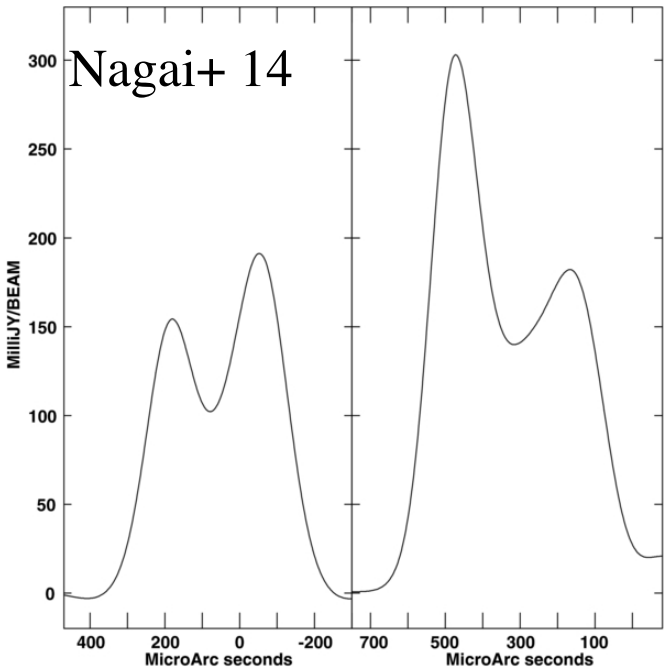
- jet structure with slower sheath (layer) surrounding faster jet (spine)
  -> supported by observations, numerical simulations
- synchrotron photons from sheath seen Doppler boosted in jet frame
  -> enhanced target γ for pγ ν production, EC emission



Tavecchio+ 14, 15
Righi & Tavecchio 17

limb-brightened structure in radio galaxies
e.g. 3C84 (NGC 1275)





model description

follow Tavecchio+ 14, 15

- emission region: cylindrical with radius R, length dR=R, magnetic field B, Lorentz factor Γ_j, viewing angle θ_v
- electron distribution: broken power-law $E_{e,min}$, $E_{e,br}$, $E_{e,max}$, n_1, n_2
- proton distribution: power-law E_p^{-2} with exp. cutoff E_{pmax}
- photons from sheath with Lorentz factor Γ_s, broken power-law spectrum
- leptonic emission: synchrotron, SSC, EC

hadronic emission

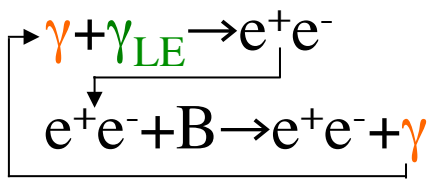
follow Böttcher+ 13, Cerruti+ 15

$p+\gamma_{LE} \rightarrow N+ \pi^0, \pi^{+-}$ photo-meson

$\pi^{+-} \rightarrow \mu^{+-}+\nu \rightarrow e^{+-}+3\nu$ $\pi^0 \rightarrow 2\gamma$

$\mu^{+-}+B \rightarrow \mu^{+-}+\gamma$ muon synchrotron

$p+\gamma_{LE} \rightarrow p+ e^+e^-$ photo-pair (Bethe-Heitler)

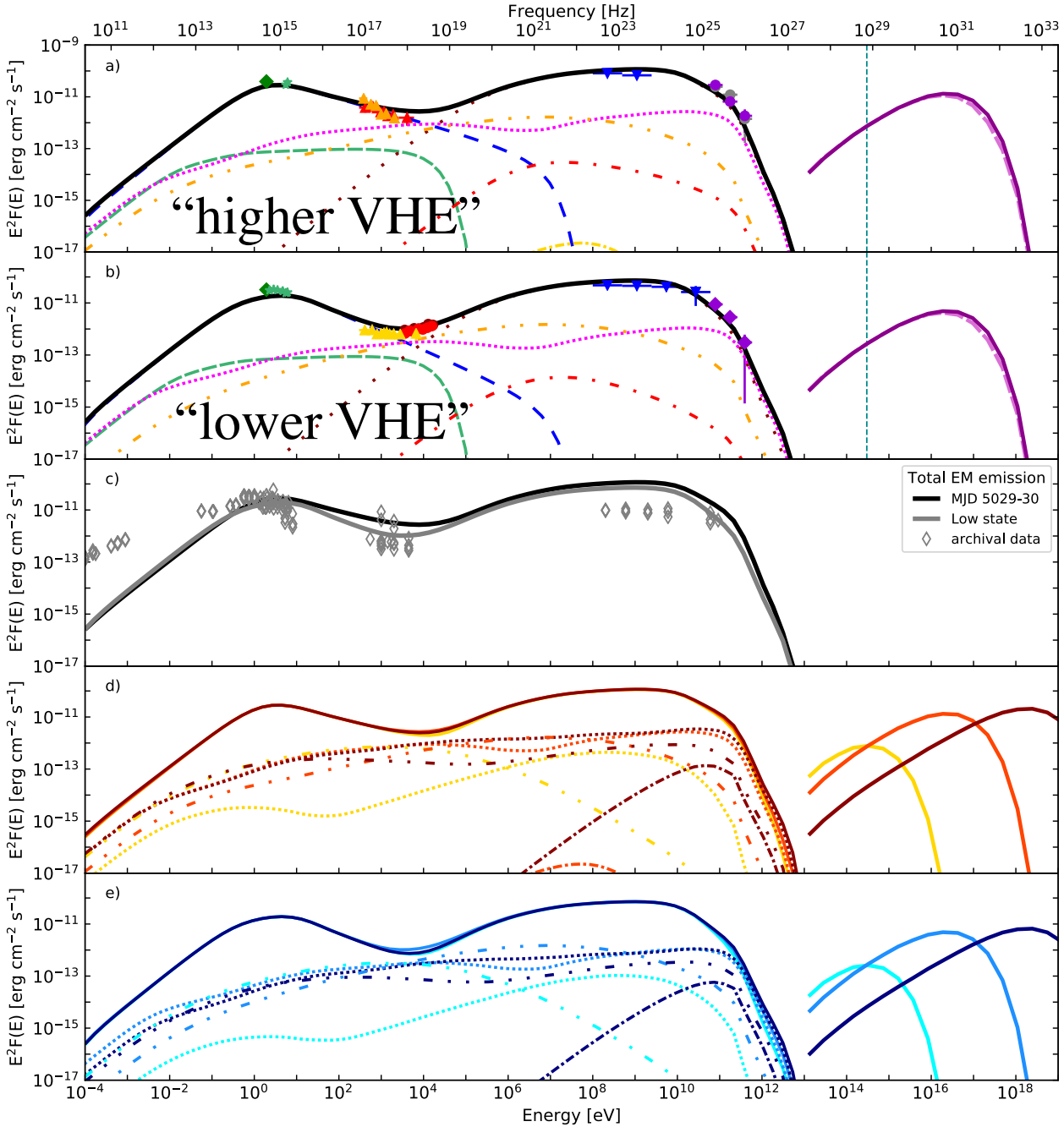


electron-positron sync. cascade

Mannheim 93
Mücke+ 02,03
Aharonian 00…

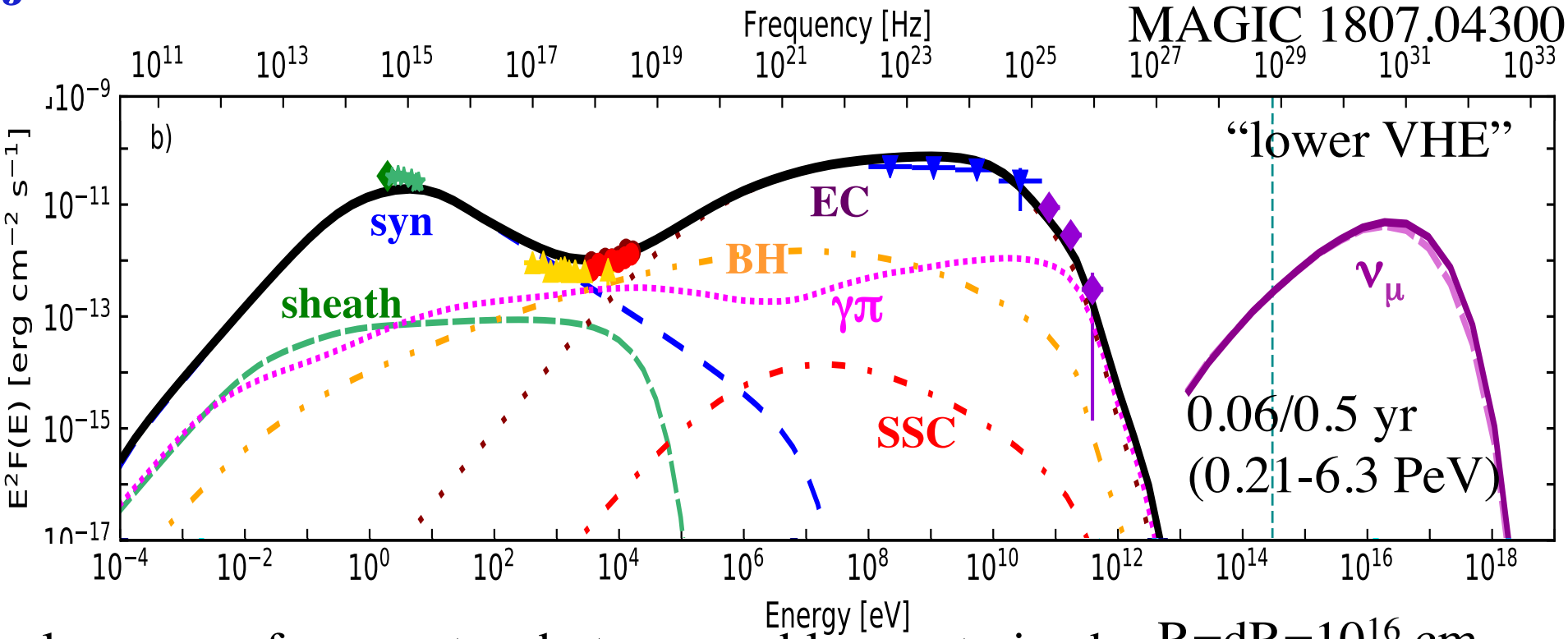
$p+B \rightarrow p+\gamma$ proton synchrotron

jet-sheath model for electroweak emission



MAGIC Coll.
ApJ 863, L10
1807.04300
(E. Bernardini
W. Bhattacharya
SI
K. Satalecka
F. Tavecchio)
M. Cerruti

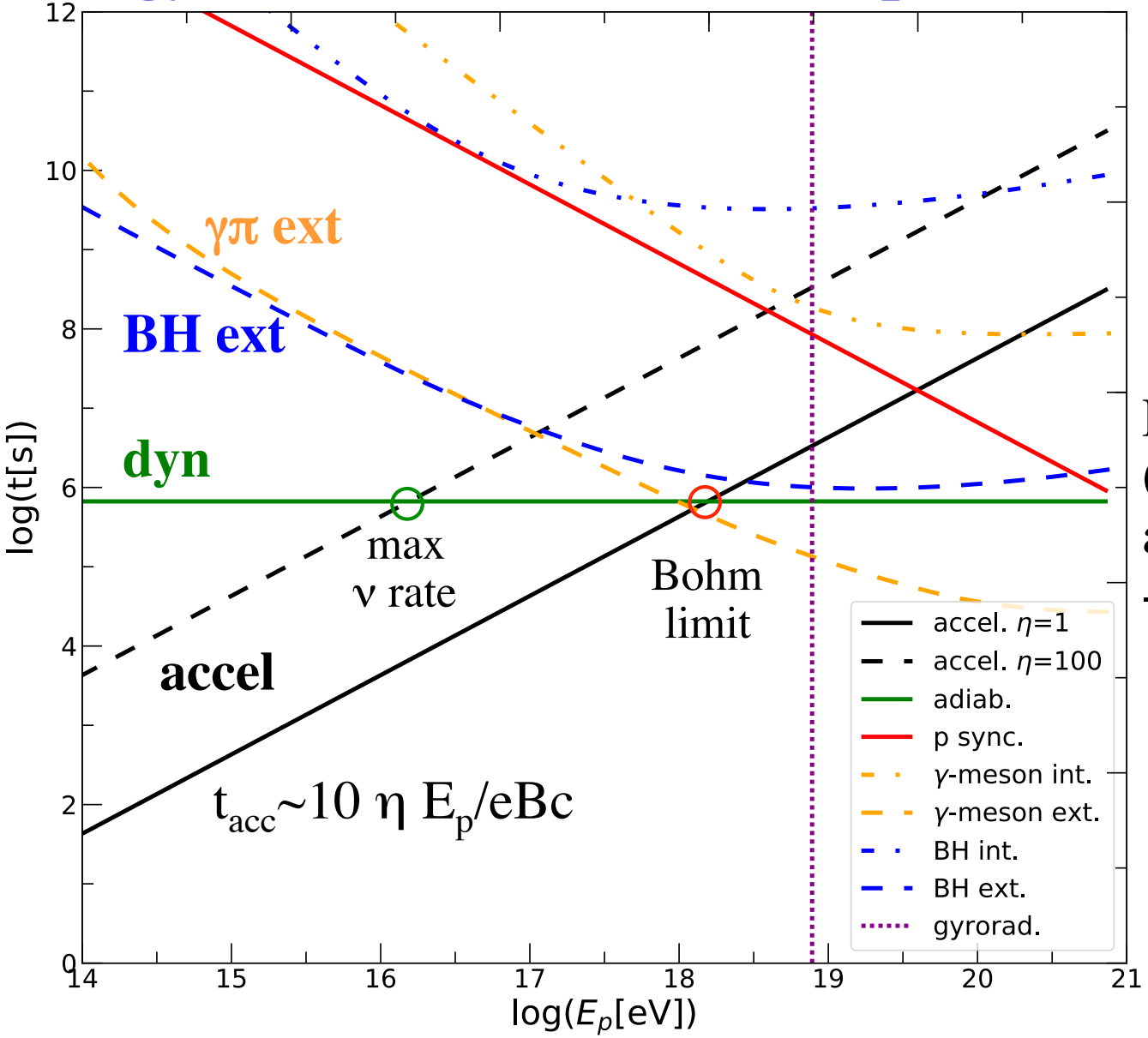
jet-sheath model for electroweak emission



- large no. of parameters but reasonably constrained
- SED predominantly leptonic with γ-rays EC
- photopion+BH cascade subdominant
  but non-negligible in X (+VHE)
  -> crucial constraint on proton population
- photopion efficiency $f_{p\gamma}(E_p\sim6$ PeV$)\sim10^{-4}$
  -> $\tau_{\gamma\gamma}(E_\gamma\sim12$ GeV$)\sim0.1$ -> $\tau_{\gamma\gamma}(E_\gamma\sim100$ GeV$)\sim1$
  consistent with observed GeV-TeV break

$R=dR=10^{16}$ cm
$B=2.6$ G
$\Gamma_j=22$, $\Gamma_s=2.2$
$\theta_v=0.8°(\delta_j=40)$
$E_{pmax}=10^{16}$ eV
$L_e=1.6\times10^{42}$ erg/s
$L_p=3\times10^{45}$ erg/s(?)
$(L_B=1.2\times10^{45}$ erg/s)

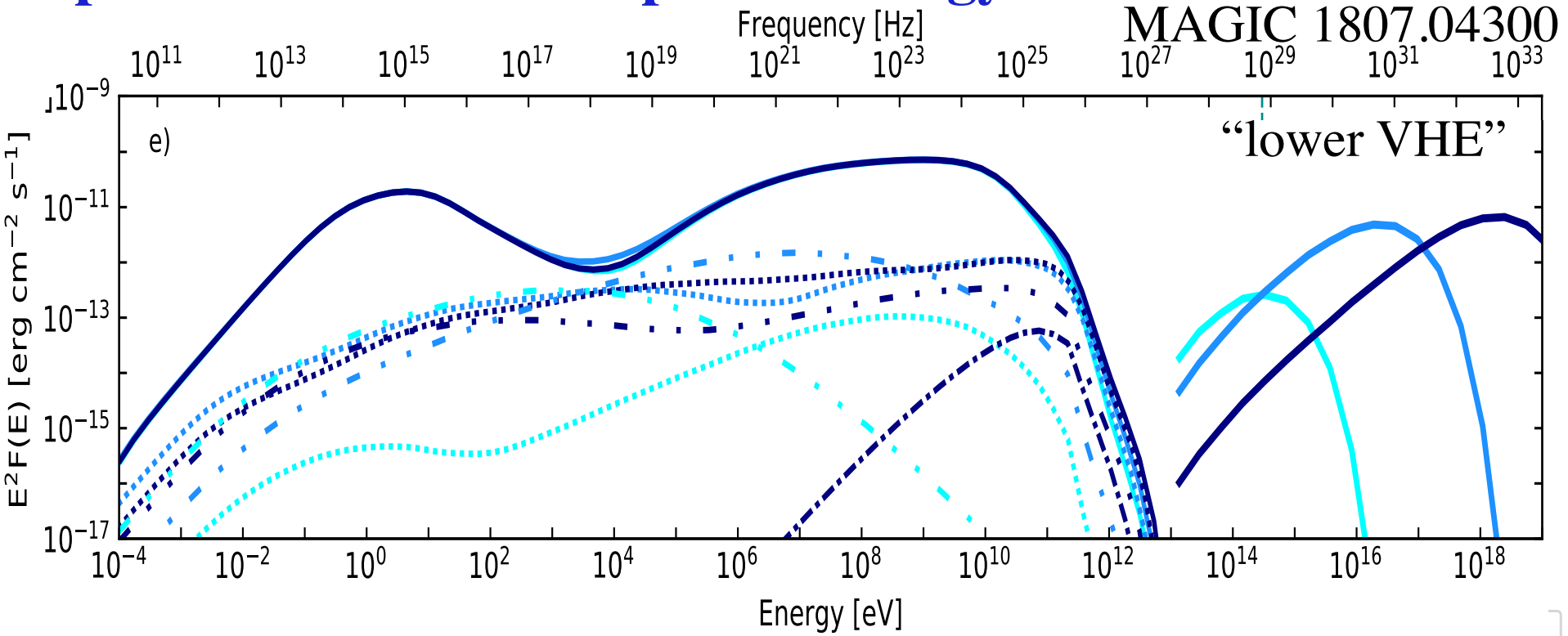
energy loss/accel. timescale comparison (comoving frame)



MAGIC 1807.04300

E'_{pmax} ~10^{18} eV
(comoving)
achievable in principle
-> UHECR?

implications: maximum proton energy



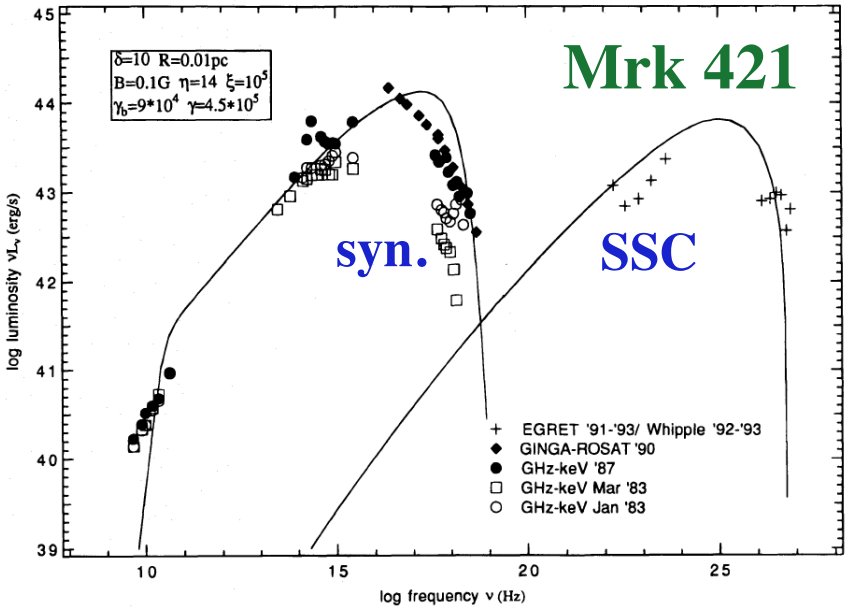
E_{pmax} dependence
- maximum ν yield for $E'_{pmax} \sim 10^{16}$ eV (comoving)
- $E'_{pmax} \sim 10^{16}$-10^{18} eV: higher $E_{\nu pk}$, lower L_p from X-ray limits
  lower ν rate, but not too low to be ruled out (>~0.01/0.5yr)
  -> unclear whether UHECR accelerator or not

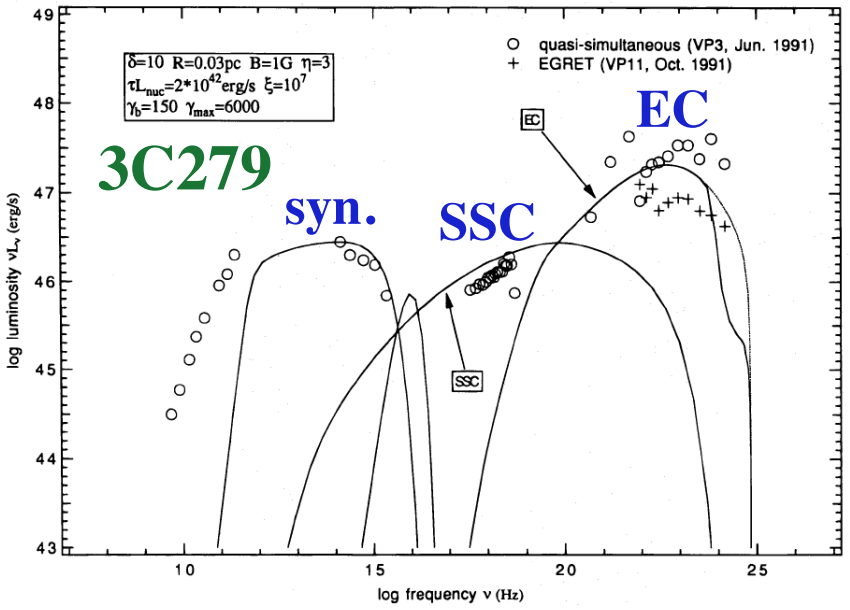
implications: energy balance in jet-sheath model

	lower VHE	higher VHE
L_e [erg/s]	1.6×10^{42}	2×10^{42}
L_p [erg/s]	3×10^{45}(?)	8×10^{45}(?)
L_B [erg/s]	1.2×10^{45}	1.2×10^{45}
U_p/U_e	1700	3600

- SSC insignificant -> U_B~(<)U_p near equipartion, U_e subdominant
  c.f. Ghisellini+ 05 potentially consistent with B-dominant jets!
- proton/electron U_p/U_e~(<)m_p/m_e

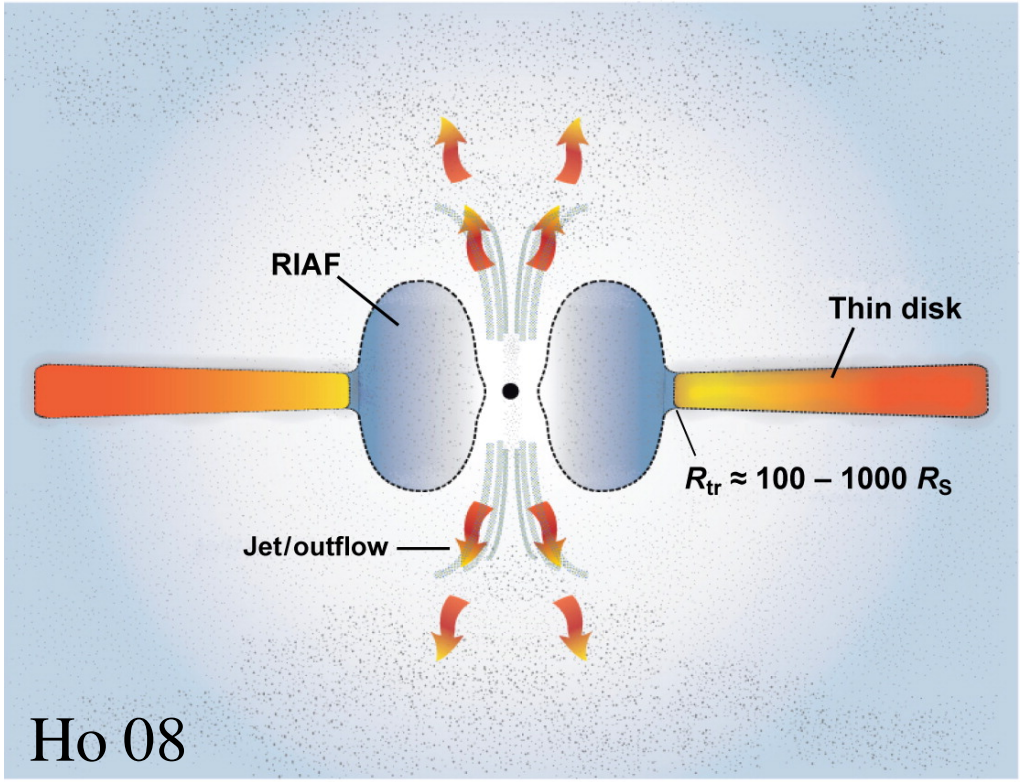
old (but prevalent) view: SI, Takahara 96

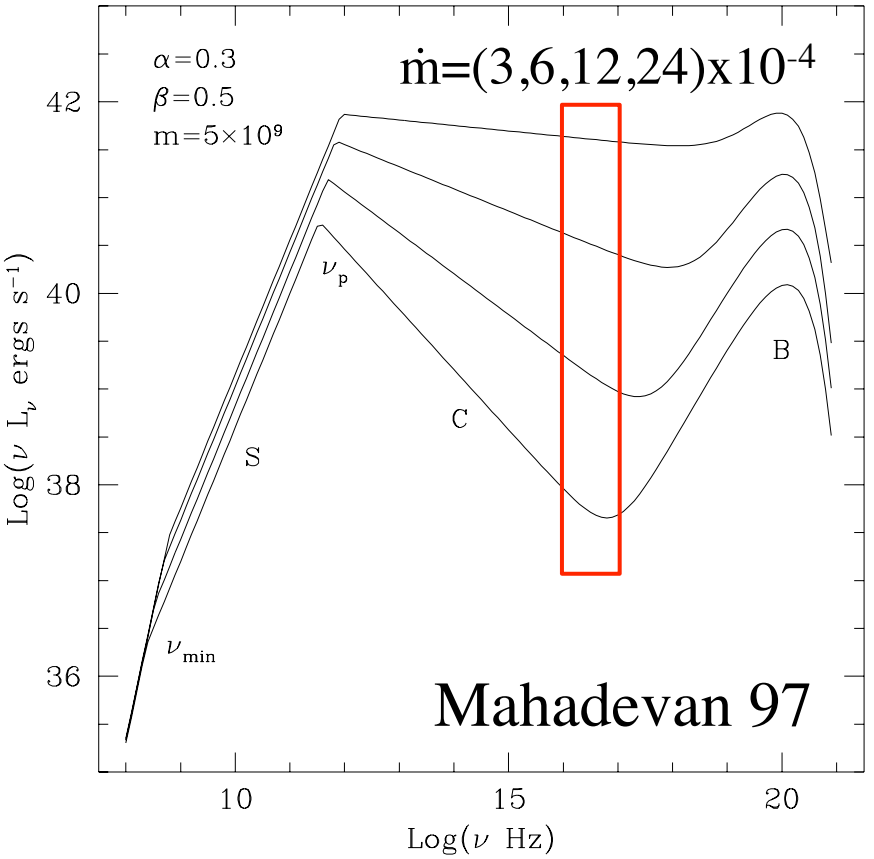




radiatively inefficient accretion flow (RIAF)

- expected at low accretion rates ($\dot{m}=\dot{M}/\dot{M}_{Edd}\sim<0.01$), inferred for SMBHs hosting BL Lacs
- radiatively inefficient -> hot, geometrically thick, optically thin <-> standard accretion disk for high $\dot{m}$
- broadband spectrum from radio to X-rays
- strong dependence of UV-soft X intensity on $\dot{m}$

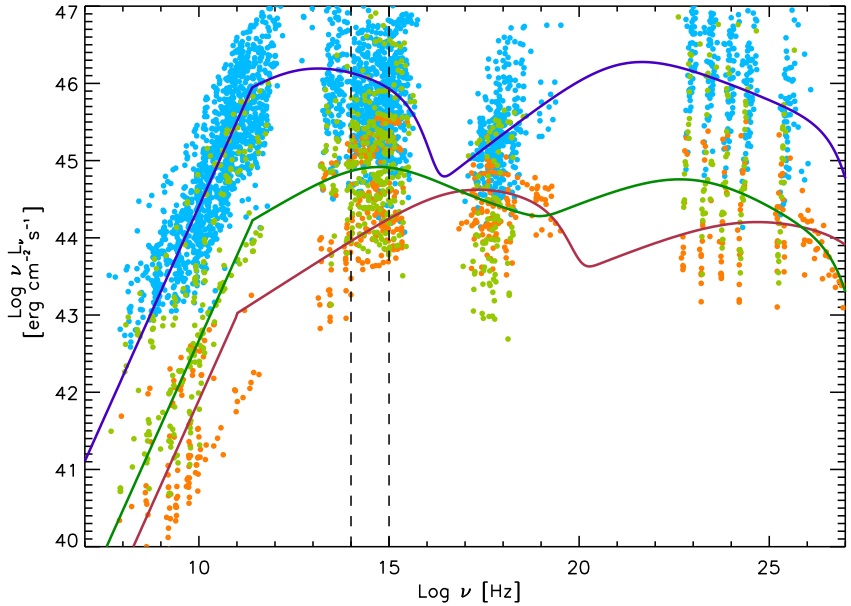


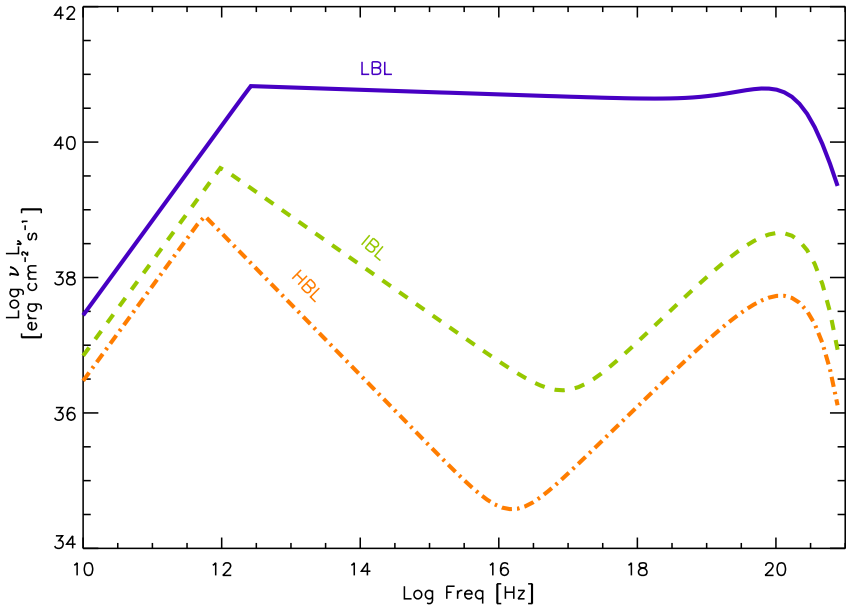


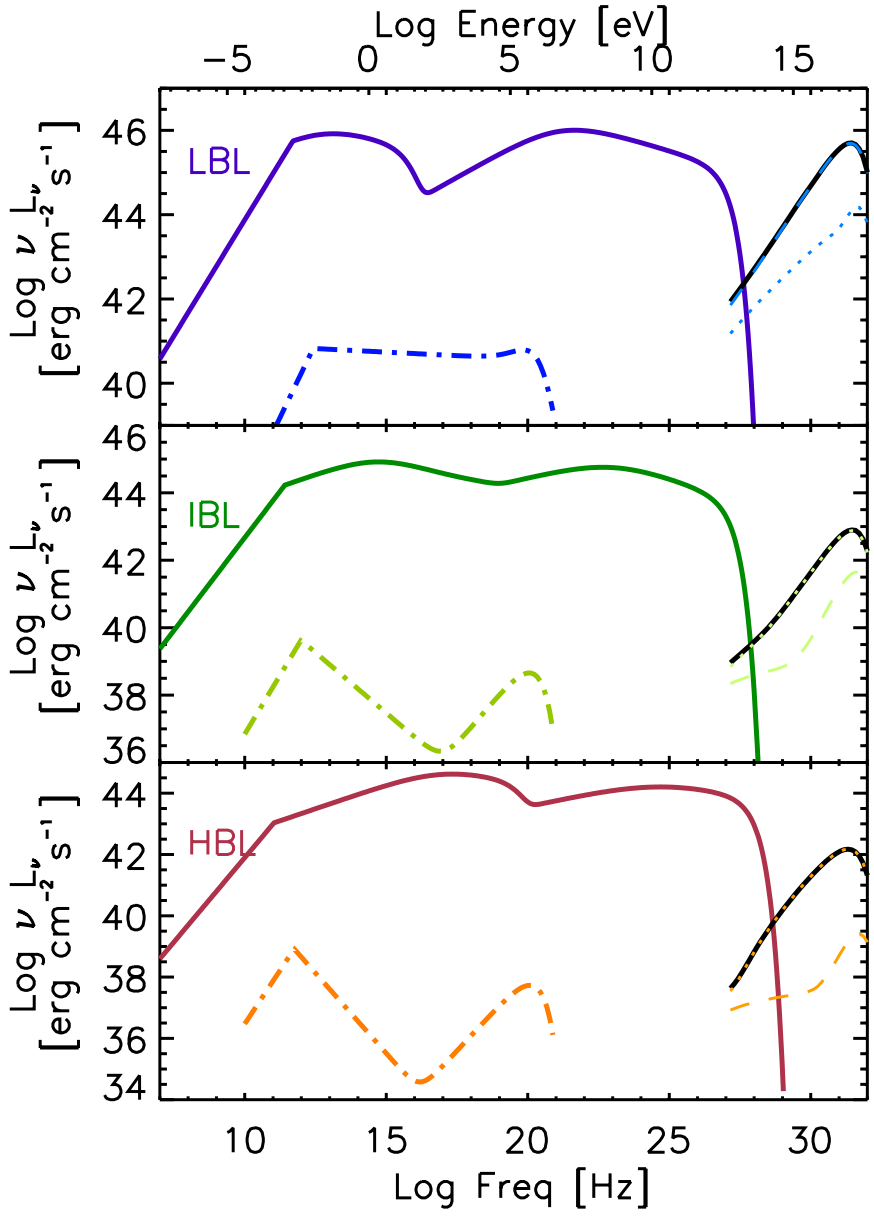
RIAF model for electroweak emission

Righi, Tavecchio, SI 1807.10506

- RIAF spectra well-defined, important for pγ only for LBLs
- potential explanation for why TXS 0506+056, not Mrk 421/501



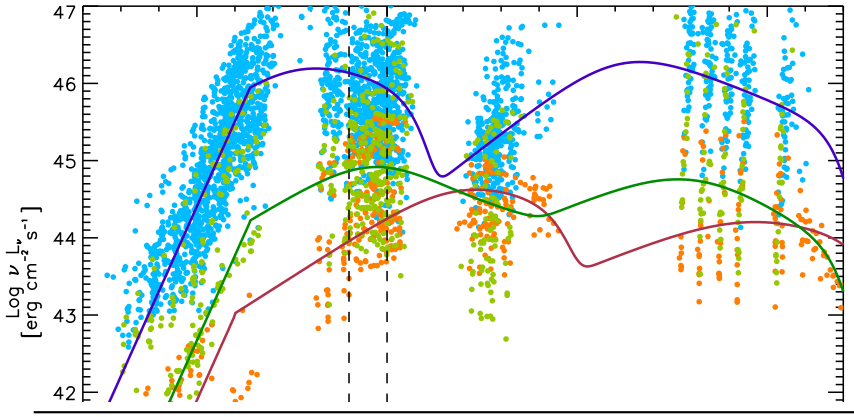




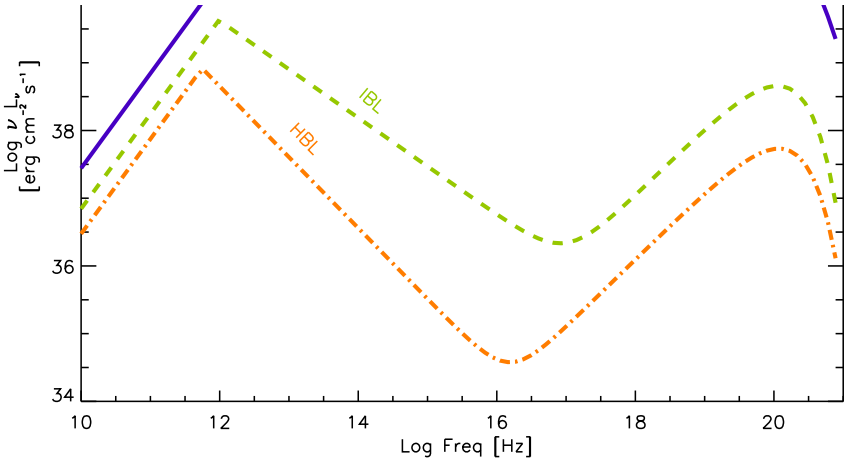
RIAF model for electroweak emission

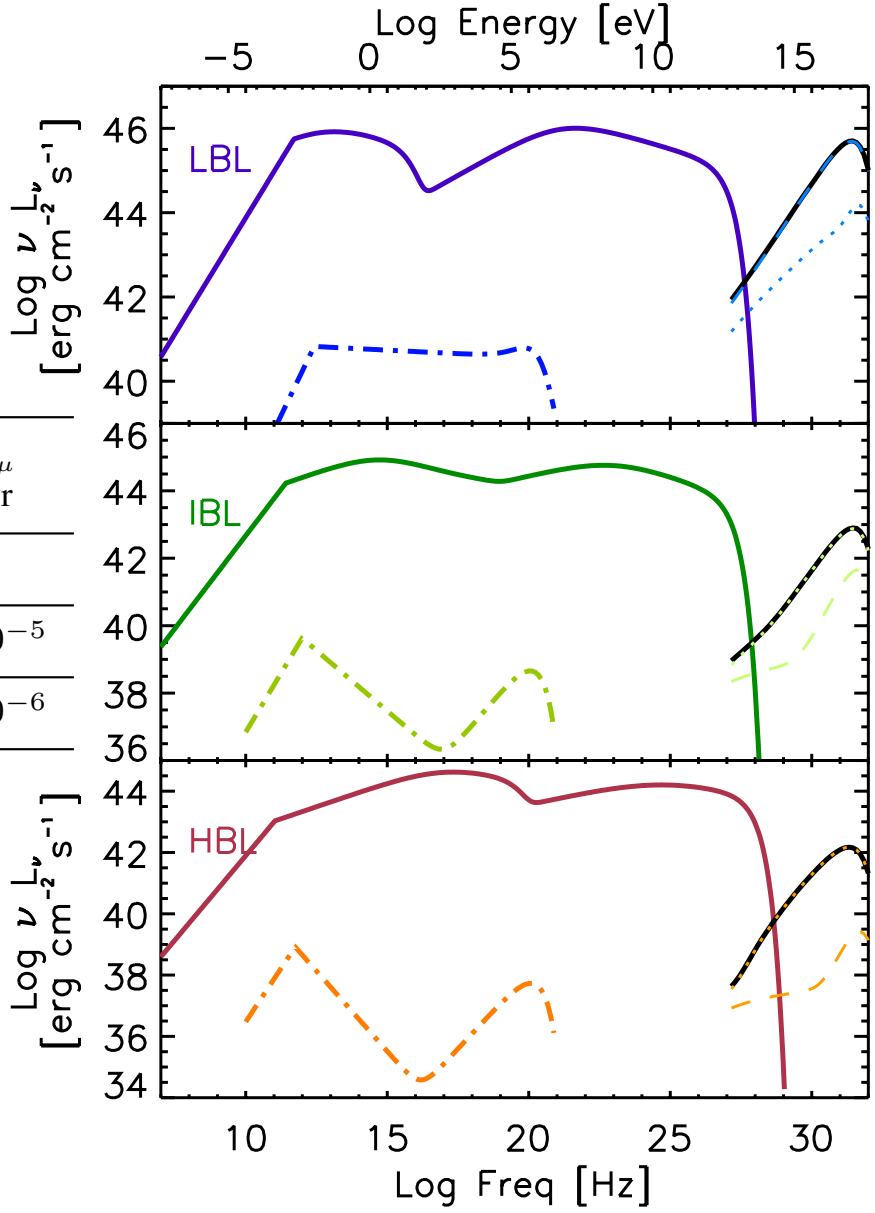
Righi, Tavecchio, SI 1807.10506

- external RIAF photons important only for LBL subclass
- potential explanation for why TXS 0506+056, not Mrk 421/501



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	$1 \cdot 10^{44}$	$9 \cdot 10^{-6}$





summary electroweak emission of TXS 0506+056

- scenarios with internal photons only require very high proton power
- consistent one-zone interpretation possible in terms of
  electron+proton co-acceleration + “external” photons from jet sheath
- observed SED predominantly leptonic (sync.+external Compton)
  hadronic subdominant, constrained by X-ray (+VHE)
- GeV-TeV break consistent with $\gamma\gamma$ absorption entailed by
  $p\gamma$ production of ~300 TeV neutrino
- proton maximum energy $\sim<10^{18}$ eV (comoving) possible in principle
  but not well constrained -> may or may not be UHECR accelerator
- RIAFs alternative source of external photons, important only for LBLs
- dawn(?) of electroweak astronomy:
  addition of single neutrino to MWL SED provides crucial new insight

questions

- relation to other blazars: why TXS 0506+056 and not HBLs, FSRQs?
- origin of 2014-2015 neutrino flare during low gamma-ray state (if real)
- contribution to diffuse flux, origin of dominant source(s)

…

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questions

- re **The transition has begun: MWL -> MM astronomy,** ;?
- or **electromagnetic -> electroweak observations!** :al)
- contribution to diffuse flux, origin of dominant source(s)

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questions

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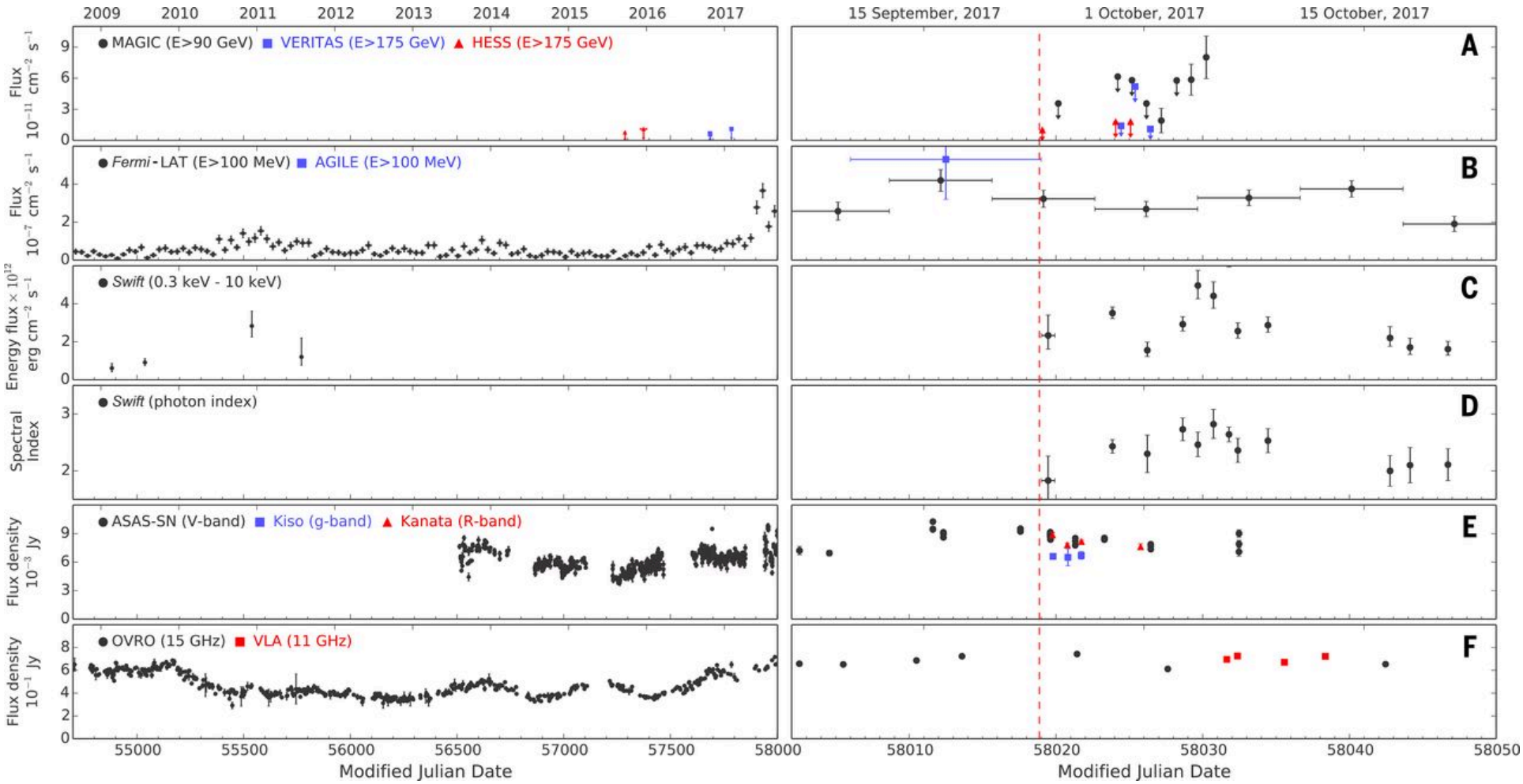
The transition has begun: MWL -> MM astronomy,
electromagnetic -> electroweak observations!
The future: -> +CRs: grand unified observations,
-> +GWs: observations of everything!

l)

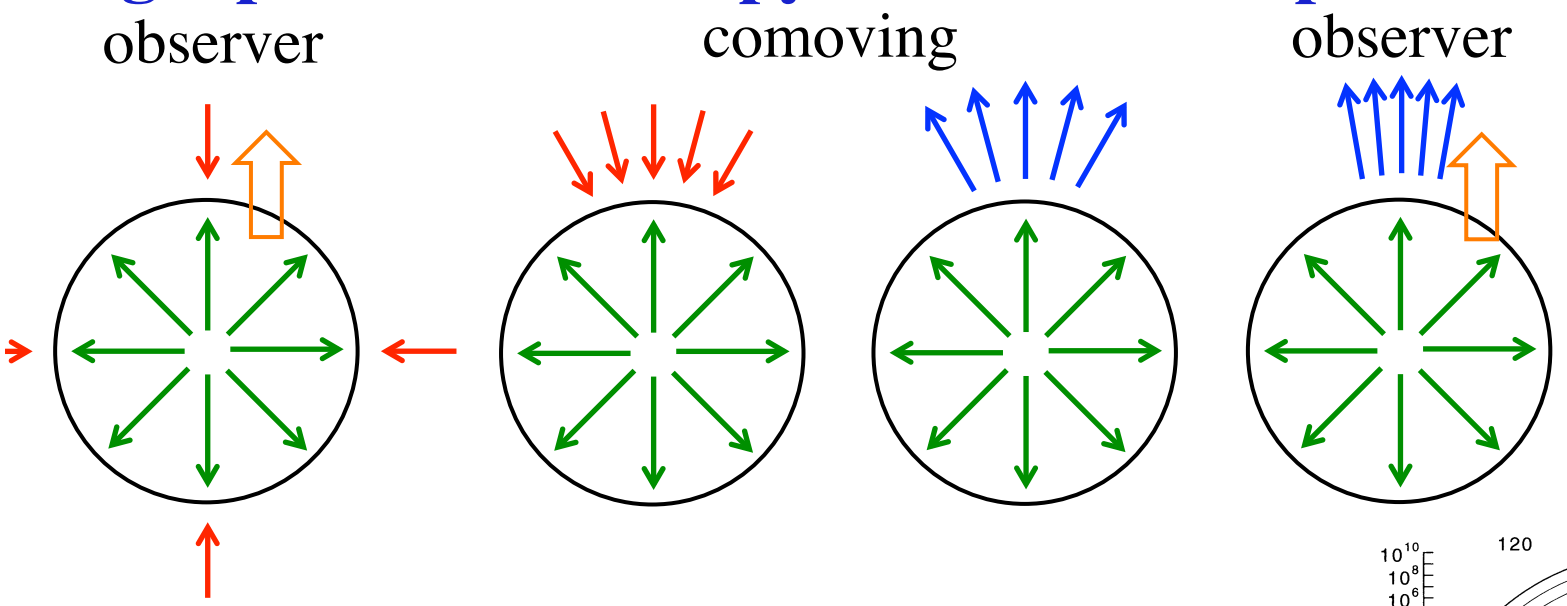
backup slides

ν + EM observations of IC-170922A / TXS 0506+056



IceCube, Fermi, MAGIC+, 2018, Science 361, eaat1378

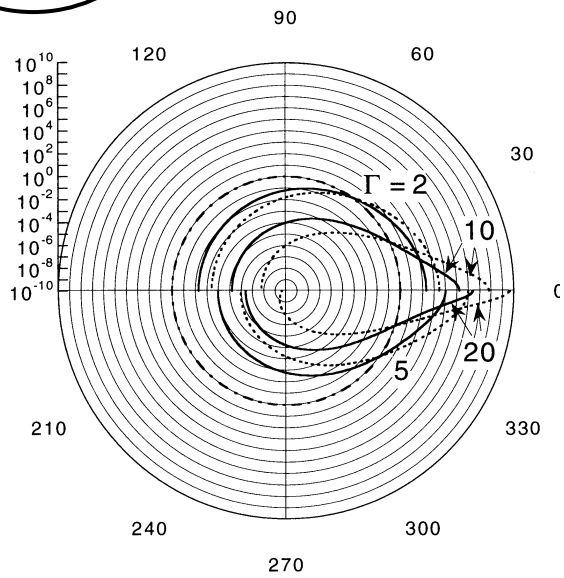
target photon anisotropy: external Compton



$L_{syn}, L_{SSC} \sim \propto \delta^4$

$L_{EC} \sim \propto \delta^6$

Dermer 95



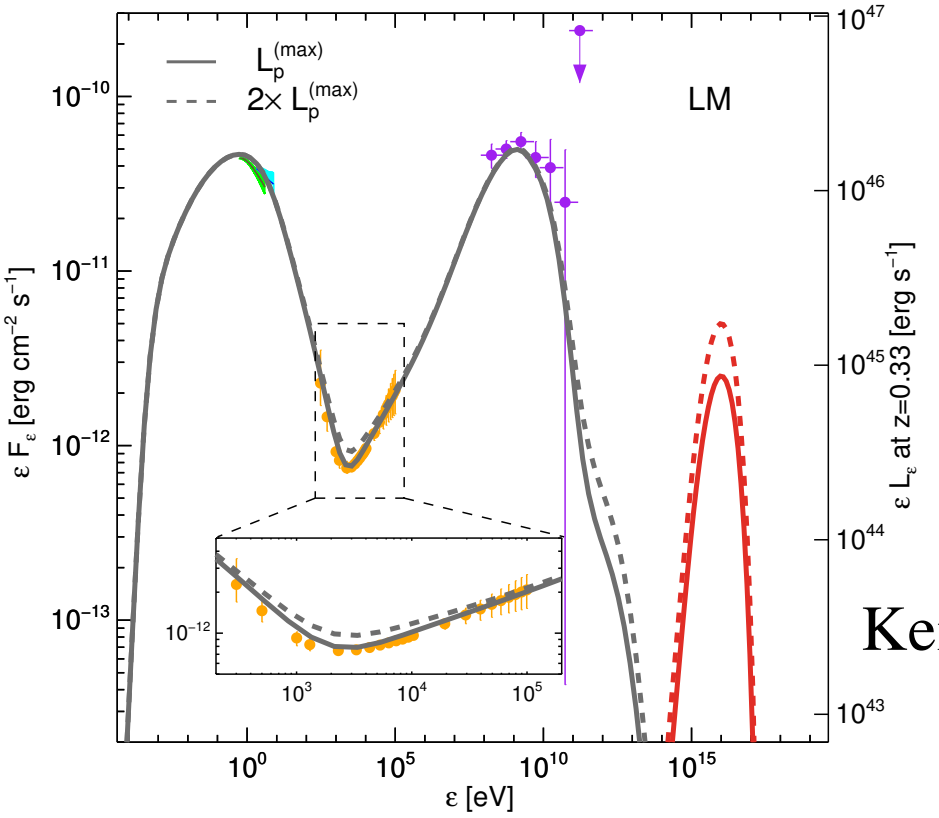
target photon anisotropy: pγ neutrinos vs cascade

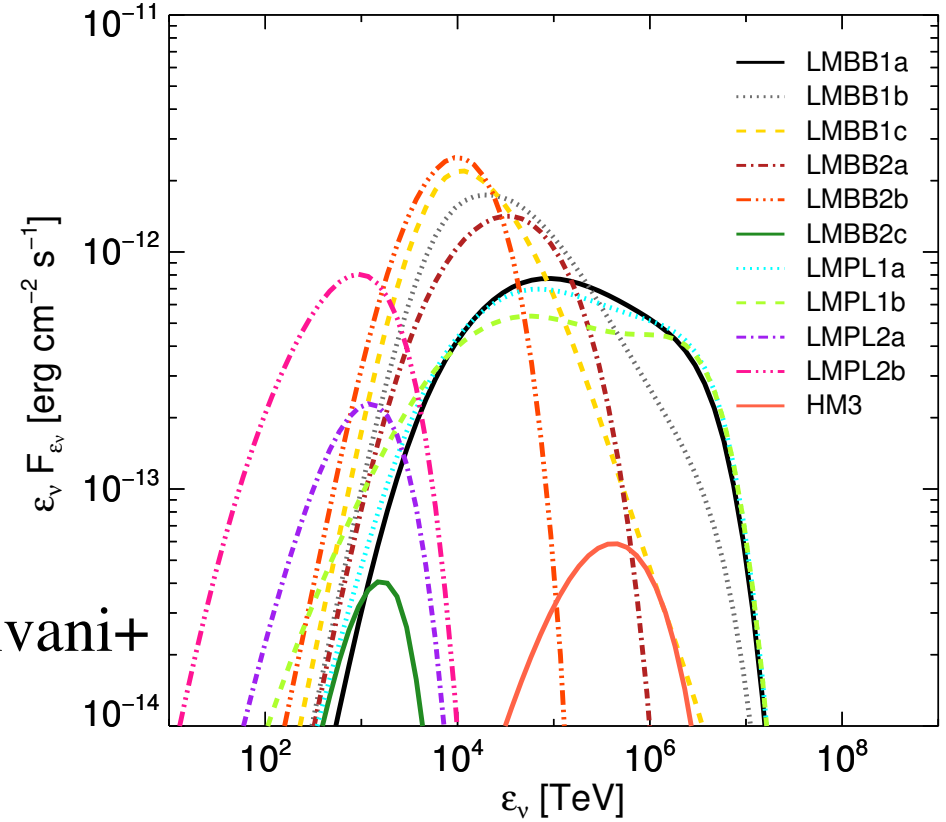
$L_\nu \sim \propto \delta^6$?

$L_{cas} \sim \propto \delta^4$?

other recent work on TXS 0506+056 / IC-170922A

- internal/external photon scenarios
  Keivani+ 1807.04537, Murase+ 1807.04748, Zhang+ 1807.11069
- internal photon scenarios
  Gao+ 1807.04275, Cerruti+ 1807.04335
- pp scenarios Liu+ 1807.05113





Keivani+