36th ICRC Madison - USA - 27.07.2019

MAGIC eyes to the extreme

testing the blazar emission models on EHBLs

E. Prandini (INAF-OAPD and INFN Padova), C. Arcaro, K. Asano, G. Bonnoli, M. Cerruti, F. D'Ammando, V. Fallah Ramazani, L. Foffano, F. Tavecchio for the **MAGIC Collaboration**

AstroFIt 2

OSSERVATORIO ASTRONOMICO DI PADOVA

INFN PADOVA
Istituto Nazionale di Fisica Nucleare
Sezione di Padova

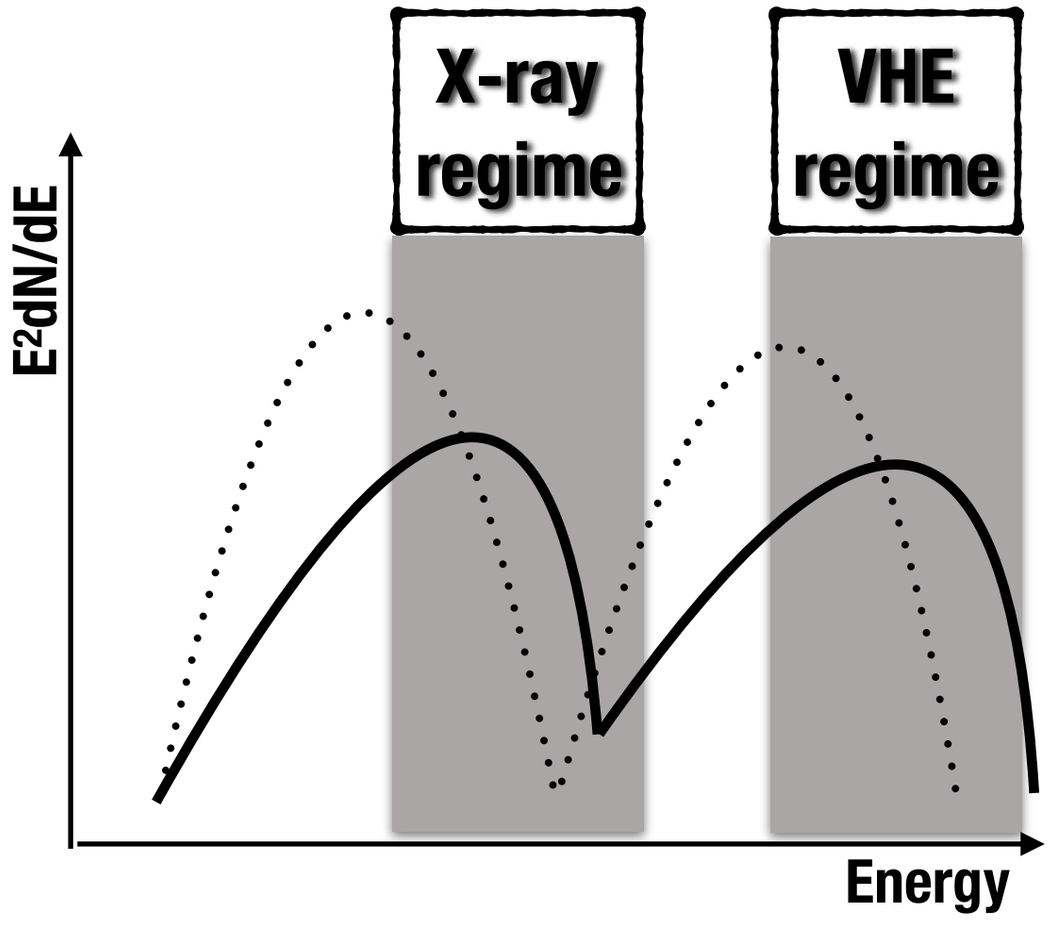
MAGIC
Major Atmospheric Gamma Imaging Cerenkov Telescopes

Extreme blazars: why?

- Extreme blazars aka extreme synchrotron-peaked BL Lac objects — EHBLs — with **synchrotron peak above 10^{17} Hz** (Costamante et al. 2001, Abdo et al. 2010)

- Some objects are also *extreme* at TeV energies (Costamante et al. 2018, Foffano et al. 2019): hard spectrum up to 1 TeV (~10^{26} Hz)

More on extreme blazars as a population:
talk on Monday by L. Foffano GAI7a



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- Hard-TeV extreme blazars are **ideal probes**

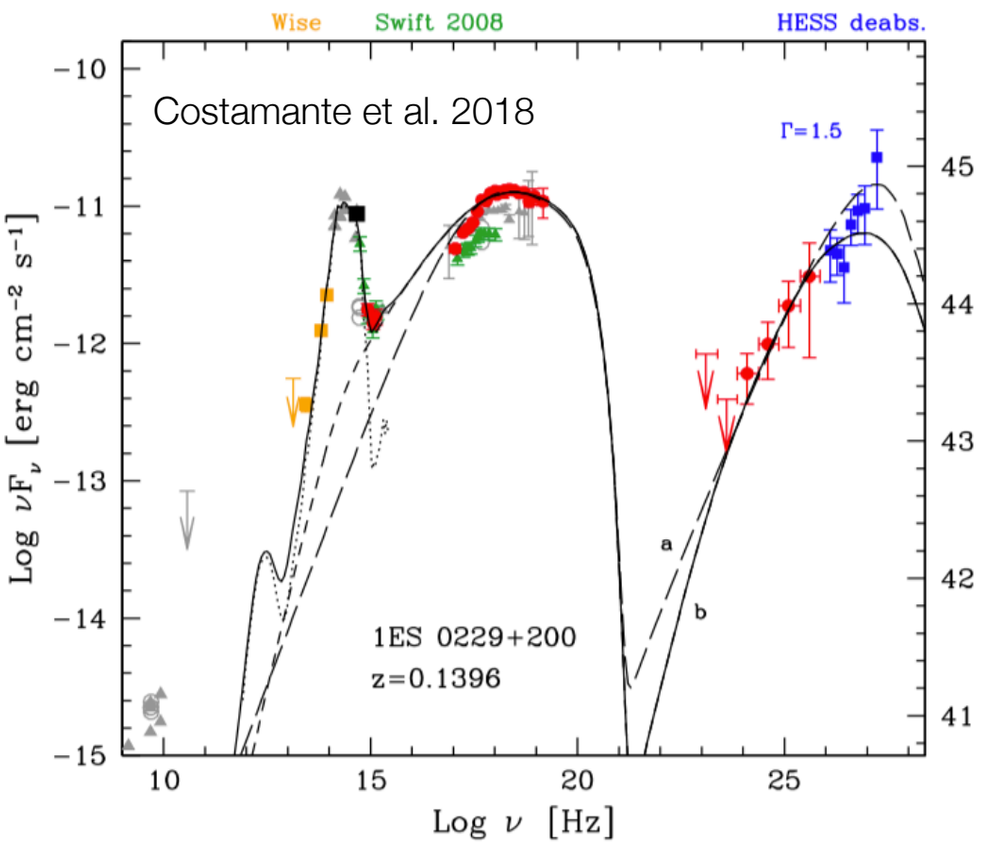
  - Astrophysics of acceleration (e.g. Kaufmann et al. 2011)

  - Cosmology: EBL and IGMF (e.g. Aharonian et al. 2007, Bonnoli et al. 2015, Neronov & Vovk 2010)

  - Cosmic rays (e.g. Tavecchio and Bonnoli 2015)

  - Fundamental physics (e.g. Galanti et al. 2018)

Hard-TeV extreme blazar prototype: 1ES 0229+200



talk later by T. Weisgarber GAI5h

Extreme blazars with MAGIC: selection

- MAGIC: two IACTs on La Palma observing the very-high-energy gamma-ray sky above 60 GeV
- Ten targets selected
  + 1ES 0229+200 as reference source

SOURCE	REDSHIFT	Log_{10} Synchro Peak (*)
TXS 0210+515	0.049	17.3
TXS 0637-128	0.136 (**)	17.4
BZB J0809+3455	0.082	16.6
RBS 0723	0.198	17.8
1ES 0927+500	0.187	17.5
RBS 0921	0.236	17.9
1ES 1426+428	0.129	18.1
1ES 2037+521	0.053	N.A.
RGB J2042+244	0.104	17.5
RGB J2313+147	0.163	17.7
1ES 0229+200	0.140	18.5

(*) From 2WHSP catalog, Chang et al. 2017
(**) new, priv. comm. Simona Paiano

Selection criteria:

1. Hard X-ray spectral index
2. Even marginal detection with *Fermi*-LAT
3. High X-ray-to-radio flux ratio (based on Bonnoli et al. 2015)
4. MWL luminosity (based on Fallah Ramazani et al. 2017)
5. Low redshift favored (< 0.2)

Extreme blazars with MAGIC: 4 detections + 1 hint + 1prototype

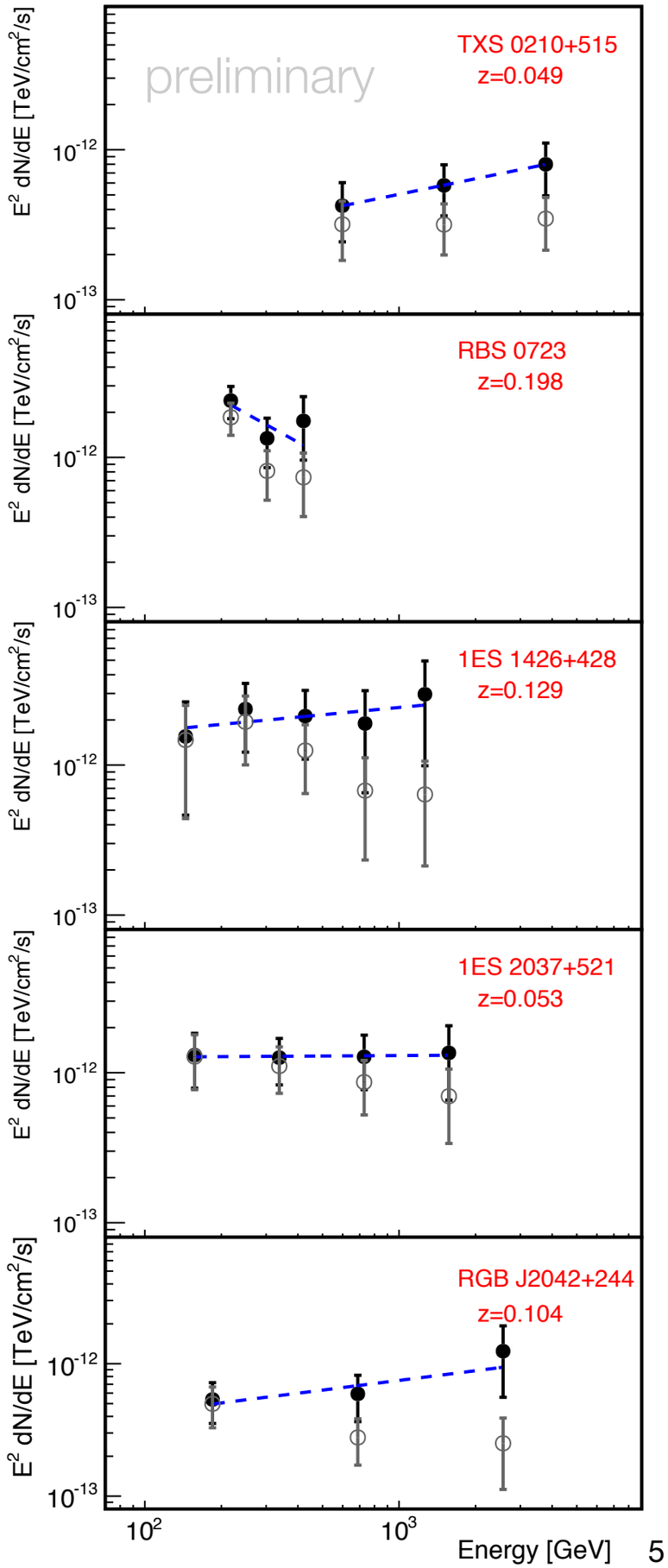
preliminary

Source	Observation period	Time [h]	Signif. [σ]	Spectral index (intrinsic)
TXS 0210+515	2015,2016, 2017	28.6	5.9	1.6 ± 0.3
RBS 0723	2013, 2014	45.3	5.4	2.7 ± 1.2
1ES 1426+428	2012	8.7	6.0	1.8 ± 0.5
1ES 2037+521	2016	28.1	7.5	2.0 ± 0.5
RGB J2042+244	2017	52.5	3.7	1.7 ± 0.6
1ES 0229+200	2013-2017	117.5	9.0	1.8 ± 0.1

- Spectra extending beyond 1 TeV (except for RBS 0723)

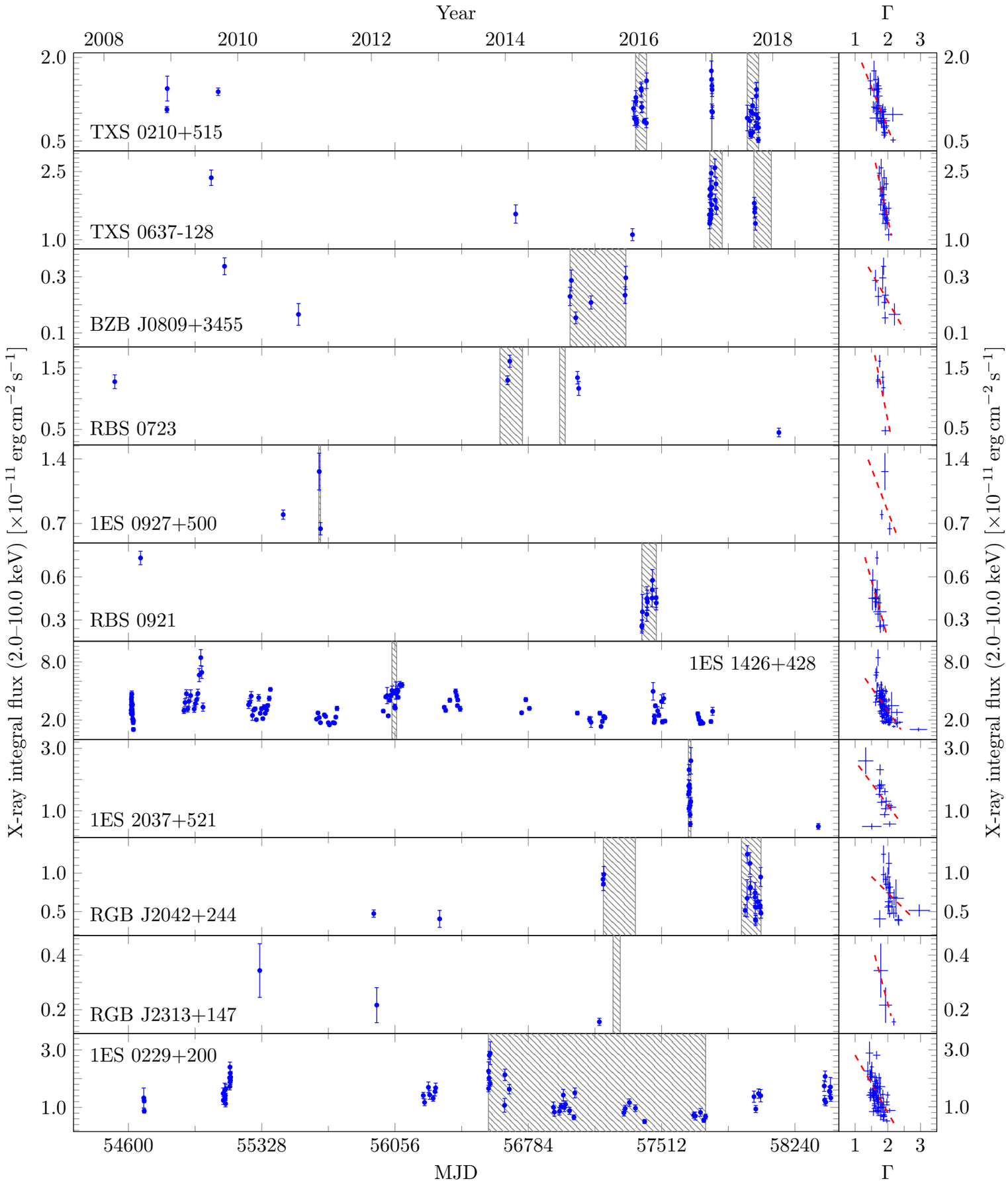
- **Hard intrinsic spectral indices** in all the objects (except for RBS 0723): hard TeV sources; EBL model from Franceschini et al. 2008

See contribution on another EHBL recently discovered with MAGIC: poster by L. Foffano PS2-57, Session 2



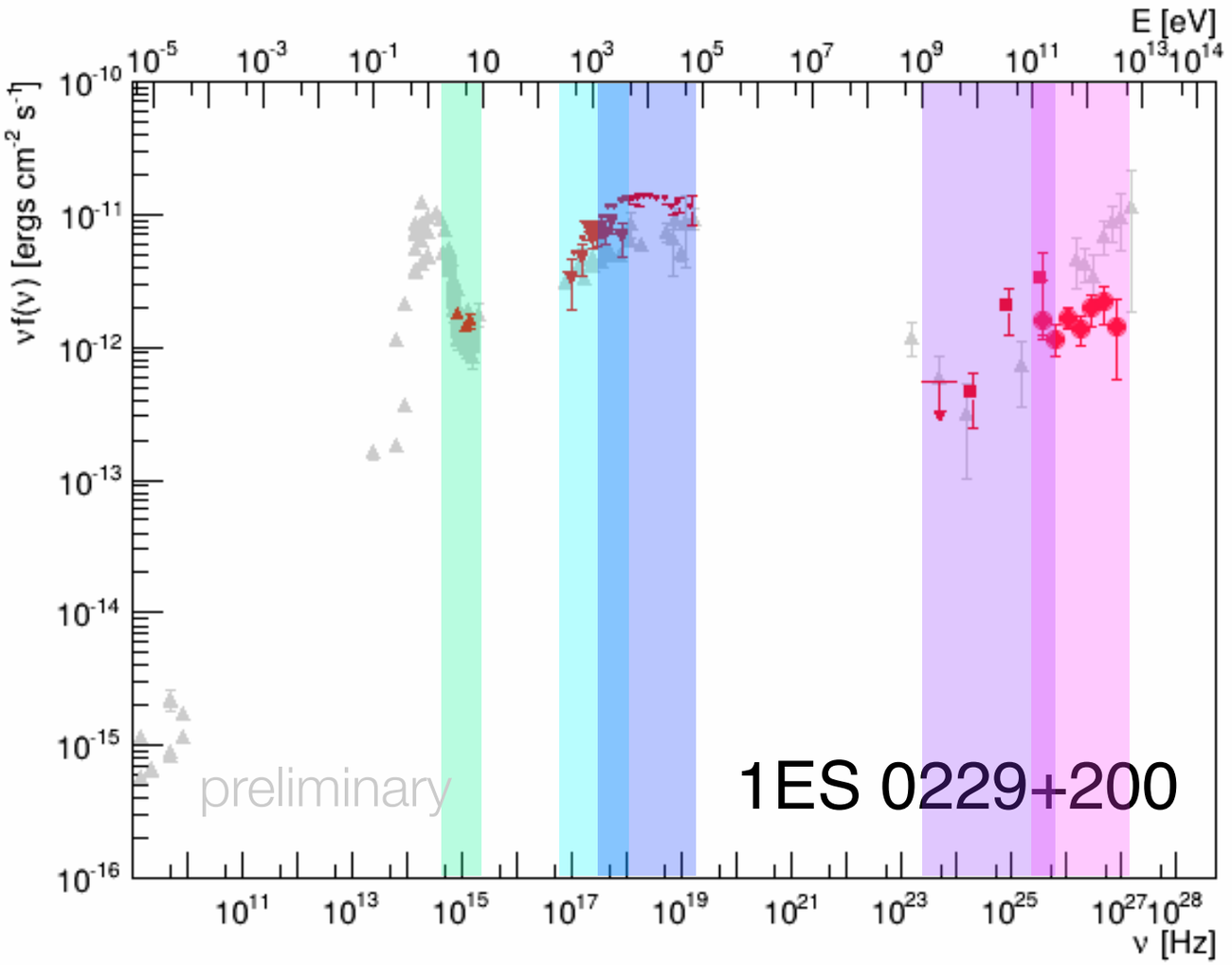
X-ray view

- ***Swift*-XRT** data available for all sources;
- Moderate variability
- Clear **harder-when-brighter** trend usual for BL Lac objects;
- In three cases ***NuSTAR*** observations also available:
  - TXS 0210+515
  - RGB J2312+147
  - 1ES 0229+200 (Costamante et al. 2018)



Broad-band SEDs

- Archival data
- Quasi-simultaneous data:
  - *Swift*-UVOT (1 obs)
  - *Swift*-XRT (1 obs)
  - *NuSTAR* (1 obs)
  - *Fermi*-LAT (averaged)
  - MAGIC (averaged)



NuSTAR data: courtesy of L. Costamante
(Costamante et al. 2018)

Broad-band SEDs

- Archival data
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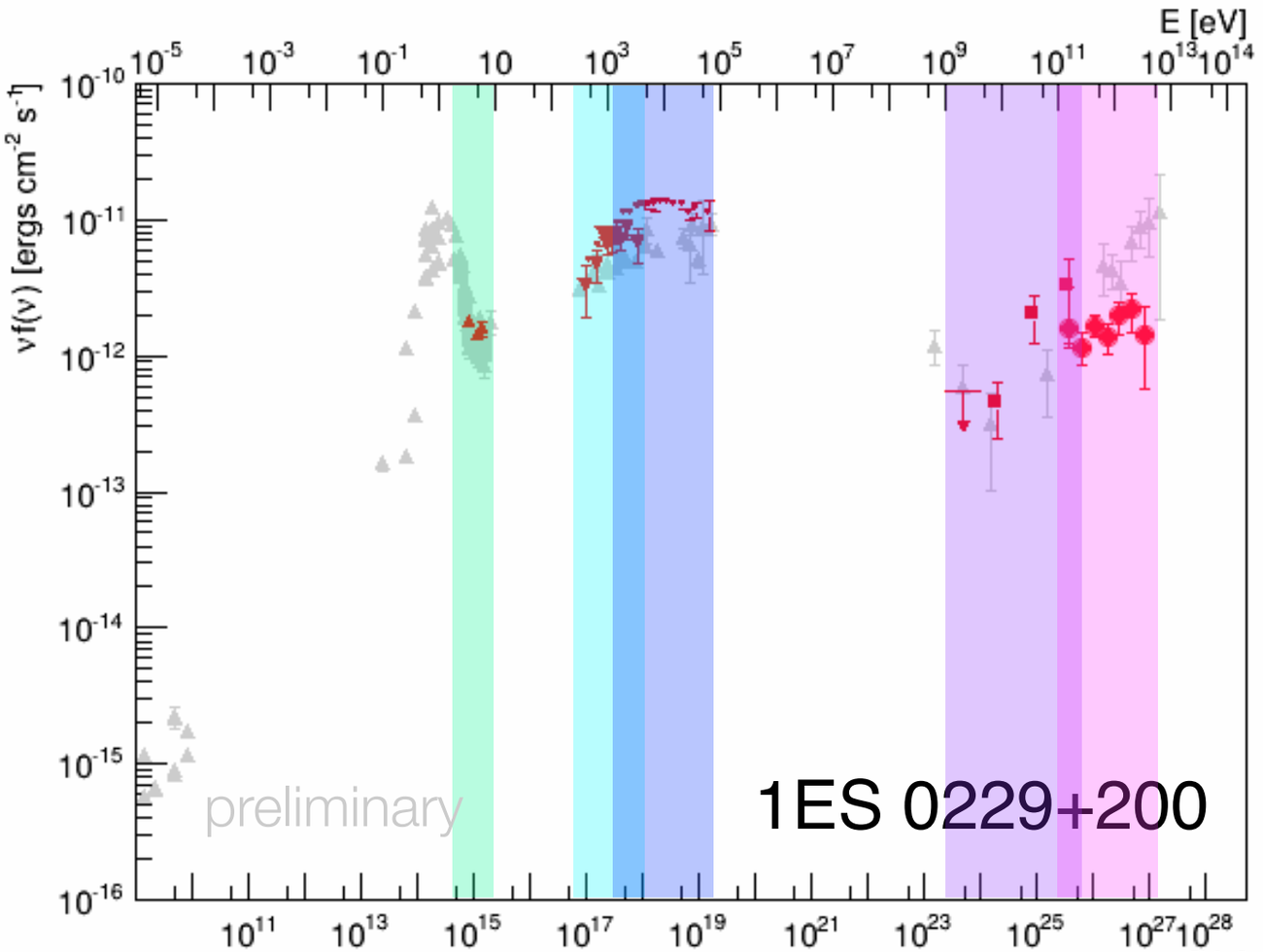
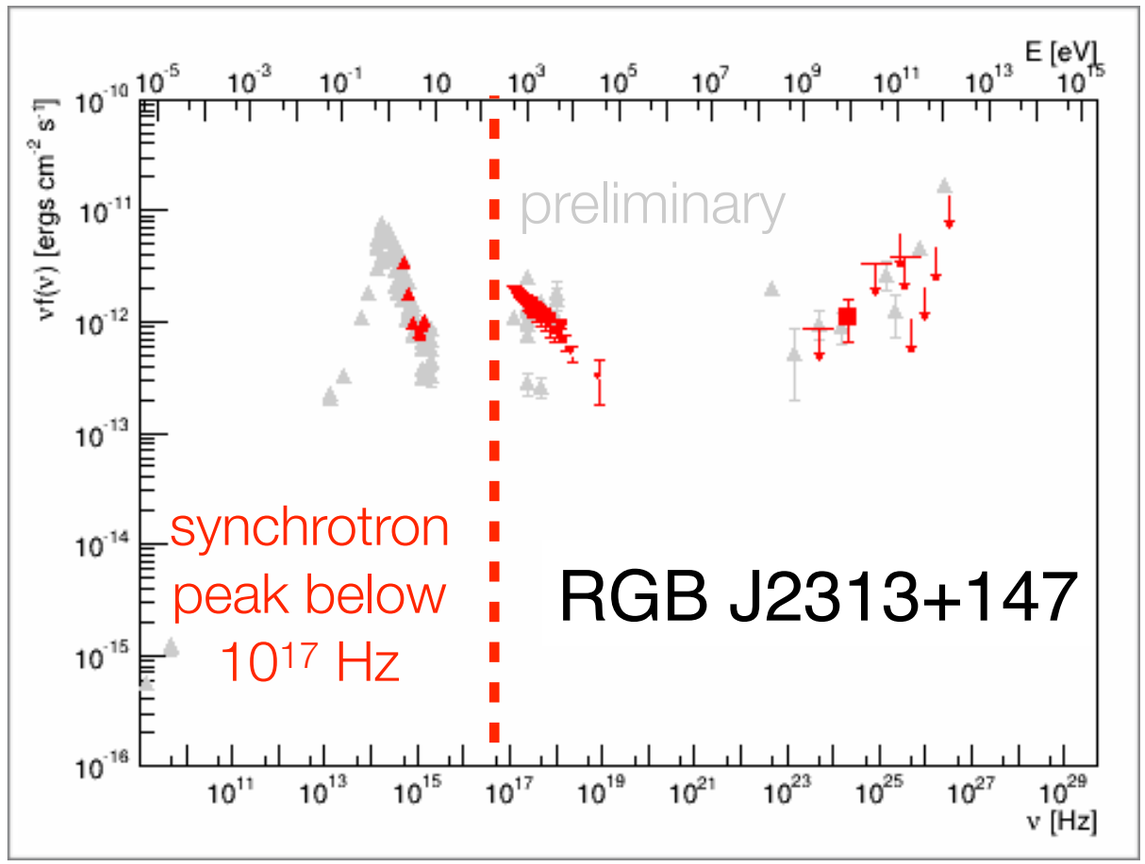
  - ***Swift*-UVOT (1 obs)**
  - ***Swift*-XRT (1 obs)**
  - ***NuSTAR* (1 obs)**
  - ***Fermi*-LAT (averaged)**
  - **MAGIC (averaged)**

- *NuSTAR* data: one source has no extreme synchrotron peak during the observations
  - RGB J2313+147



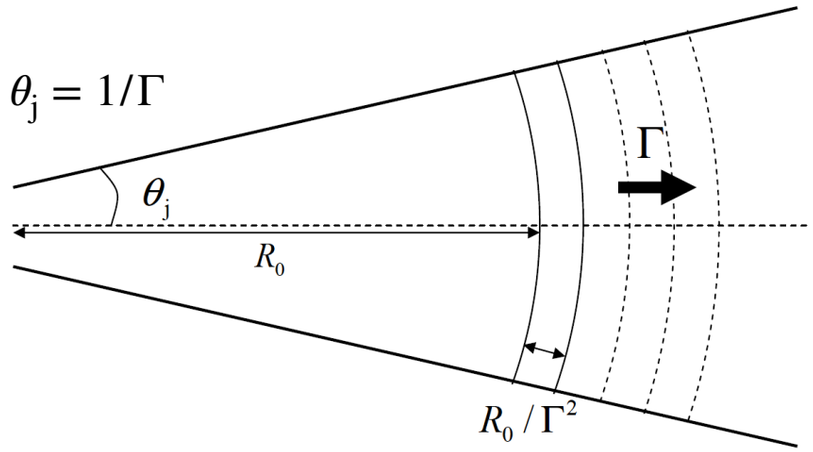


Broad-band SEDs: modeling

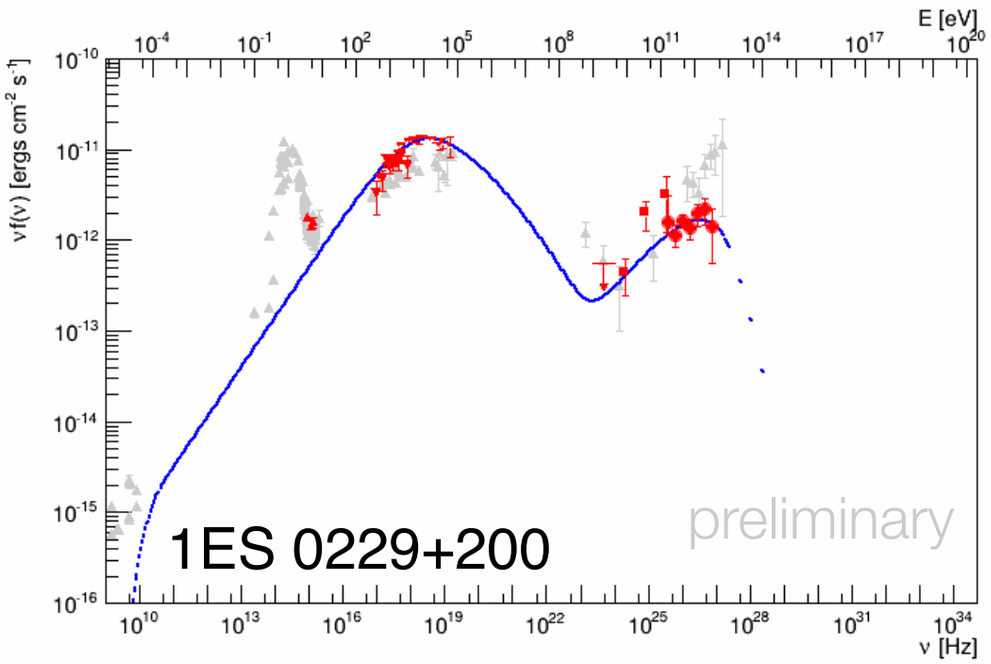
Models considered:

- **SSC conical-jet model (Asano et al. 2014)**
- SSC spine-layer model (Ghisellini et al. 2005)
- Lepto-hadronic model (Cerruti et al. 2015)

Similar to BLAZAR code in Moderski et al. 2003



- Steady outflow
- Electron injection starting from R_0 and continuing during the dynamical timescale $R_0/(c\Gamma)$ in the plasma rest frame



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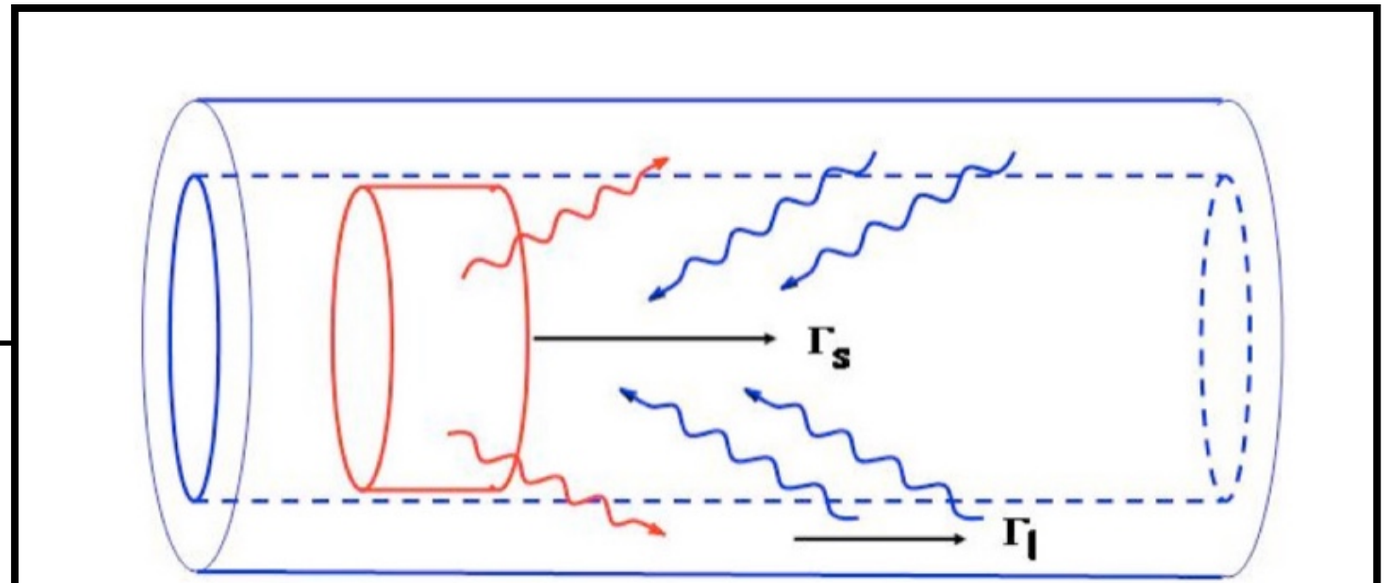
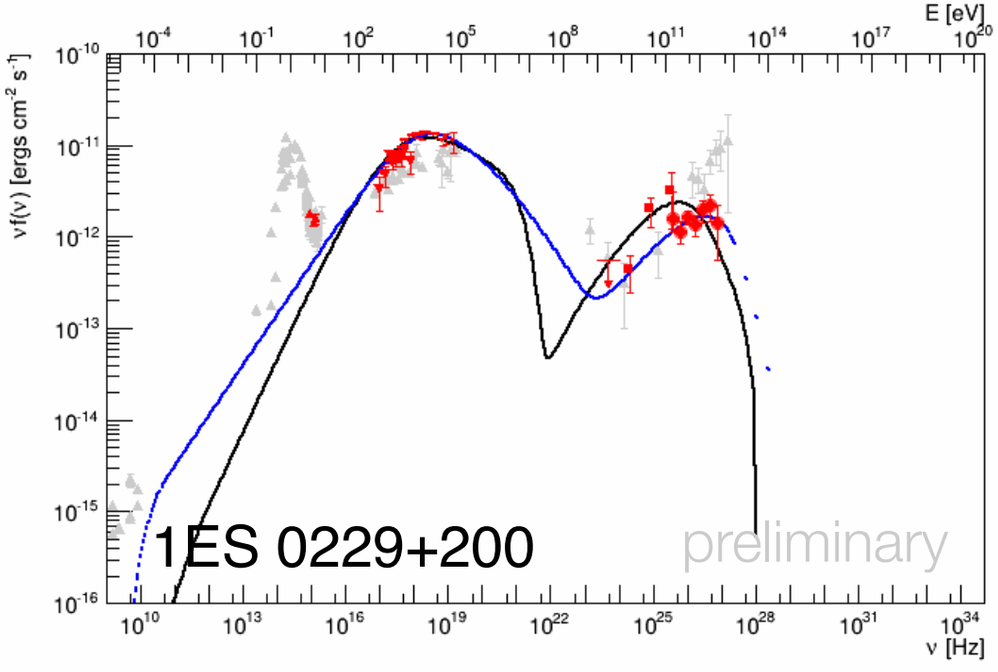


- Jet with two regions: fast, inner core and a slow, external layer
- Synchrotron and high-energy components are decoupled
- Large number of free parameters



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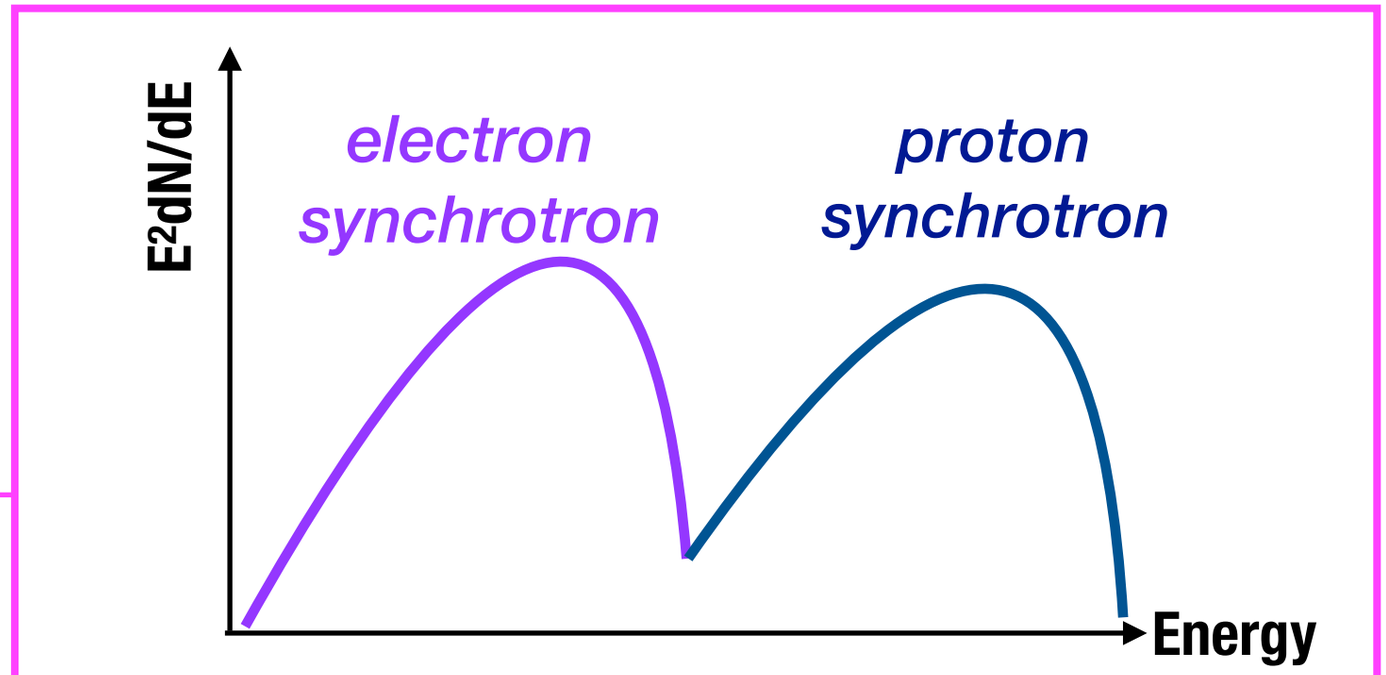
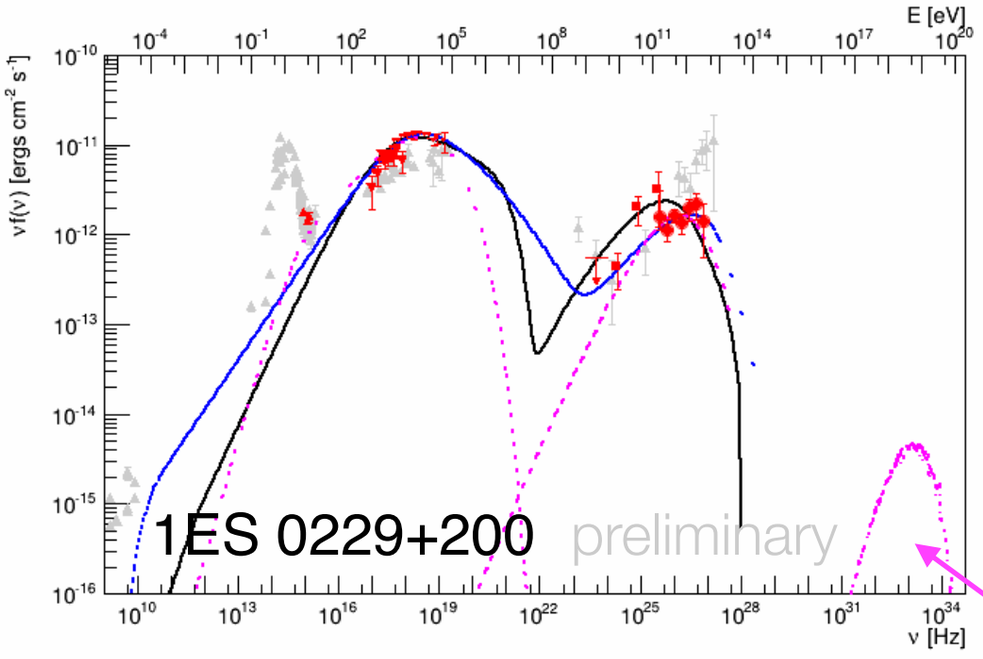
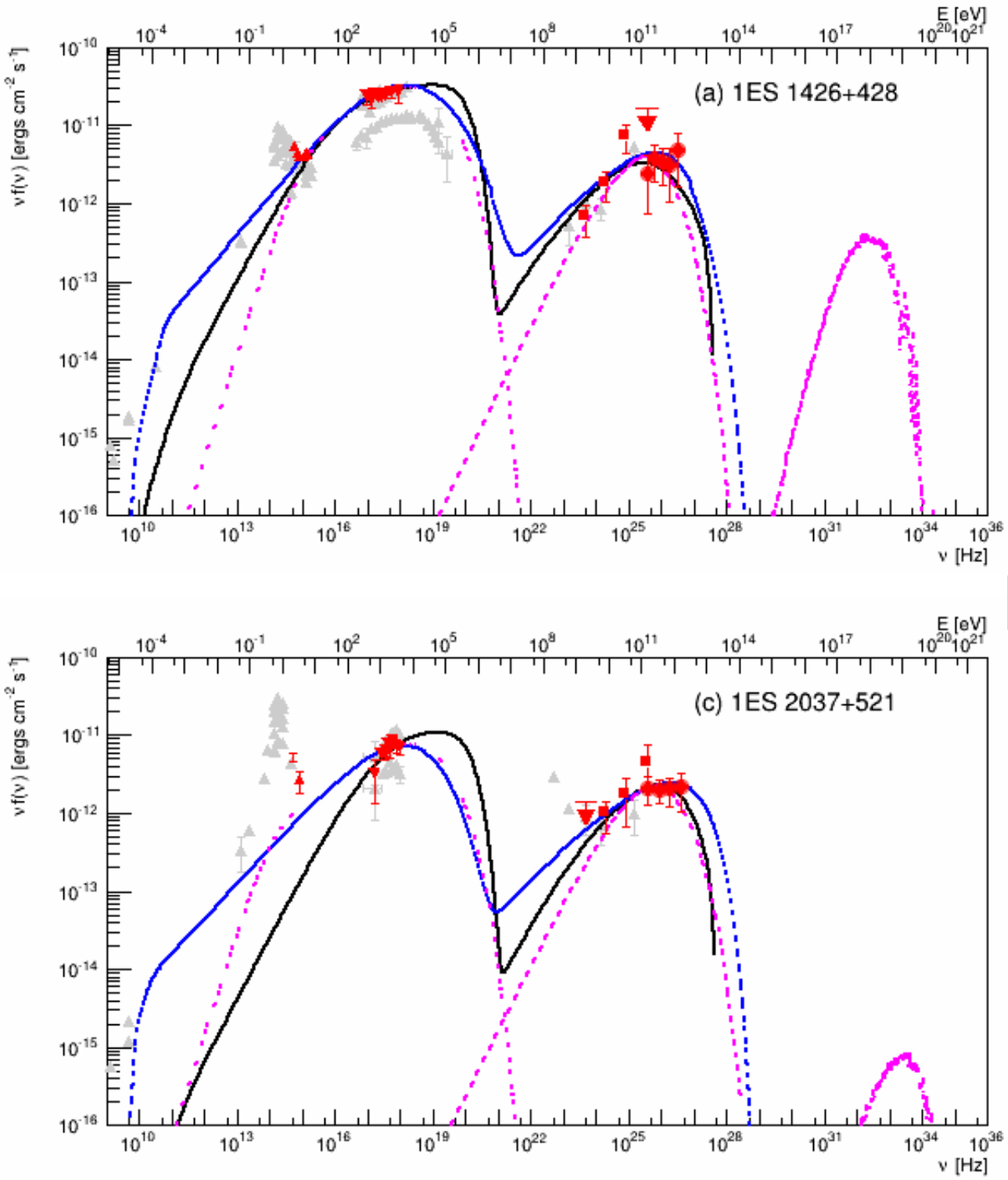


- Proton-synchrotron radiation mostly responsible for the gamma-ray component (+ cascade components)
- Direct link with neutrinos
- Slower cooling time-scale



neutrino emission

SED and models of the TeV-detected sources



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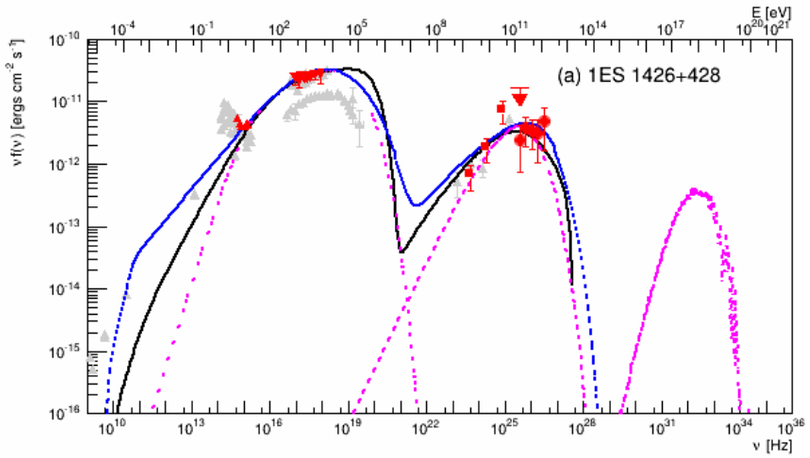
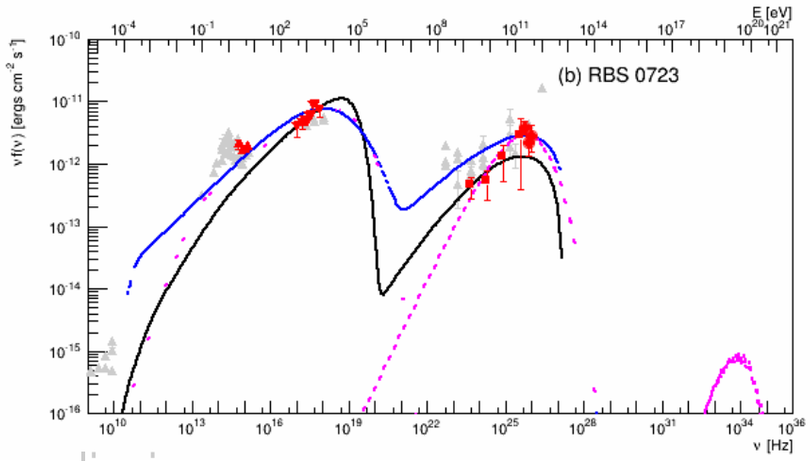
SSC conical-jet model

Asano et al. 2014

- Klein-Nishina effect is crucial in these sources
- Compton dominance is quite constant





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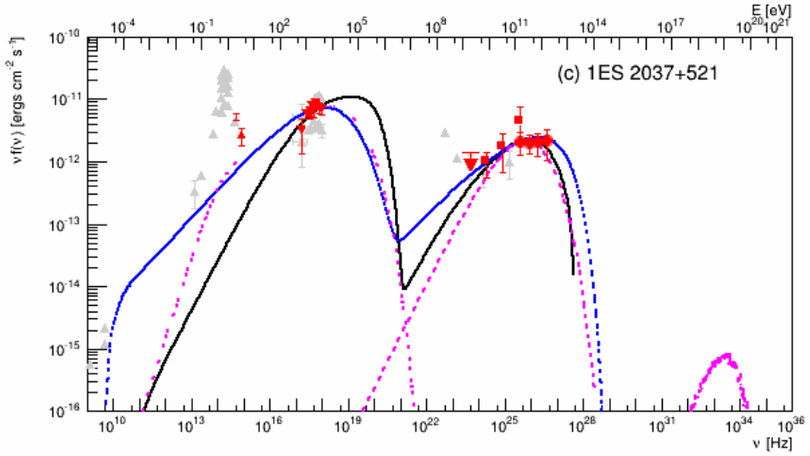

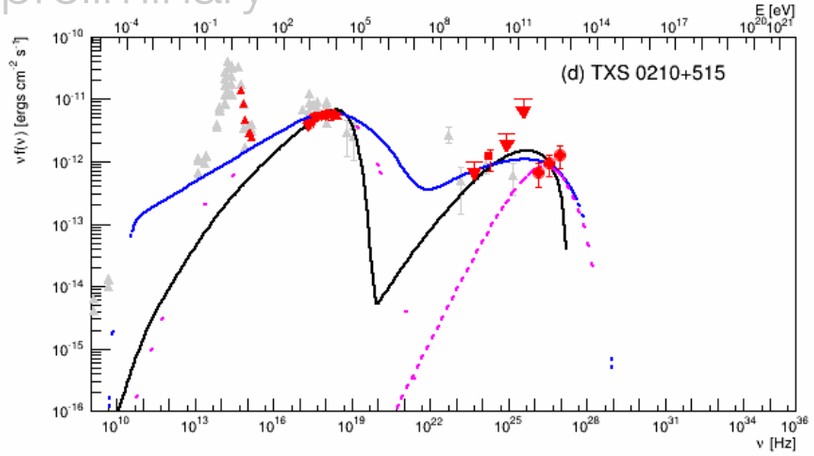

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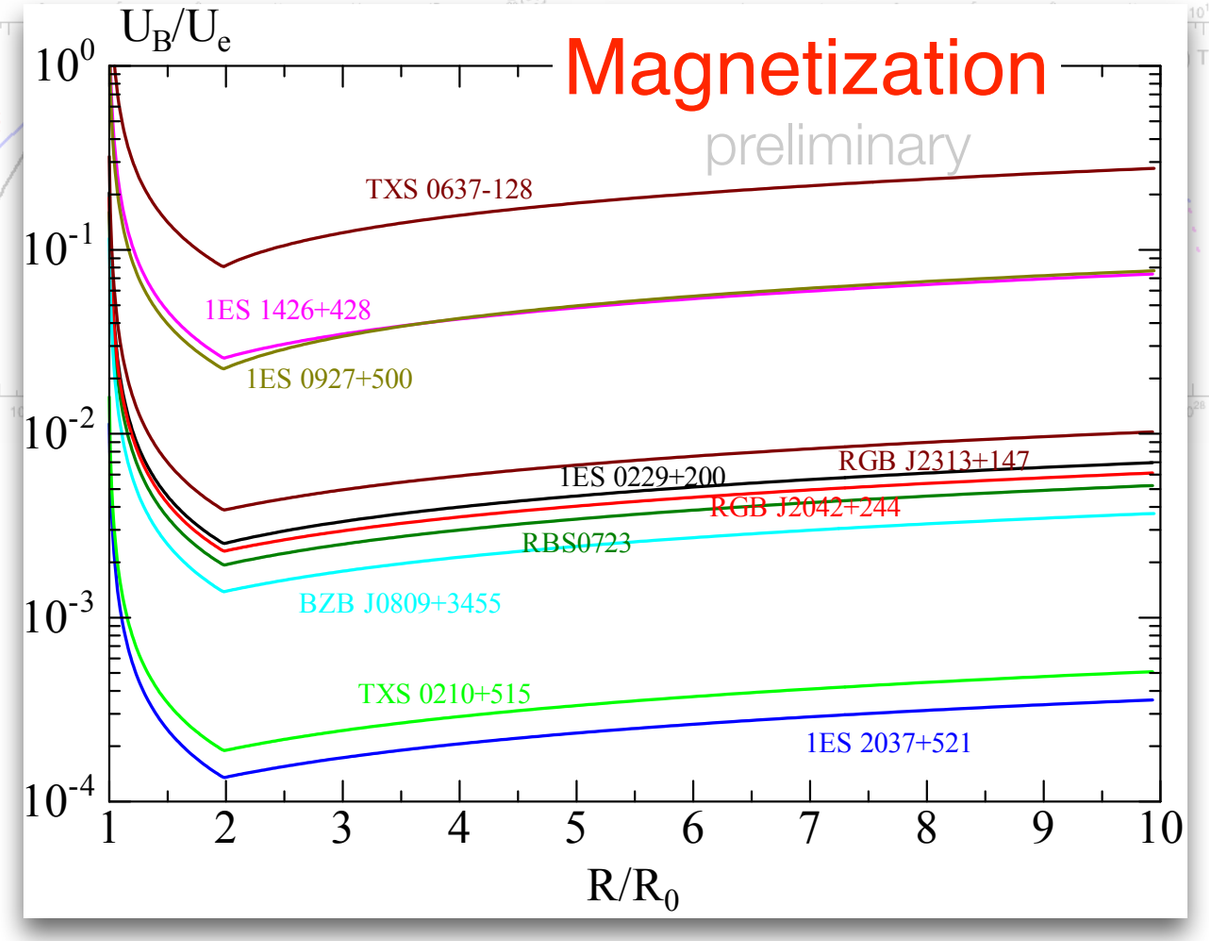
Magnetization commonly small: problem with the magnetic-reconnection models and magnetically driven jet model

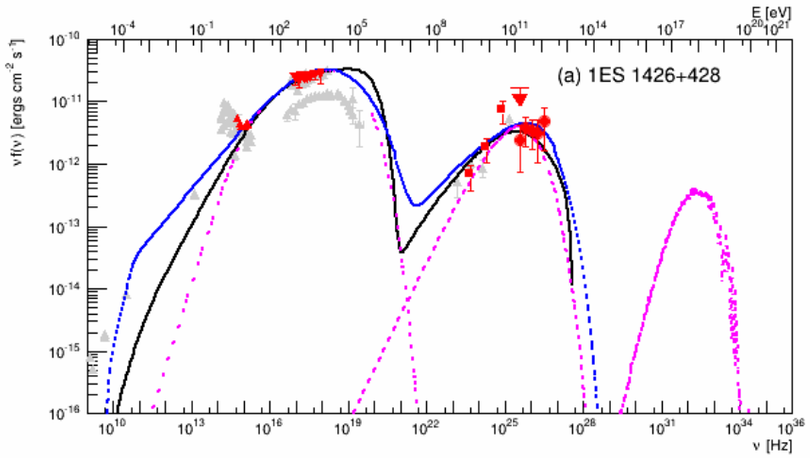
- ~10^{-3} in our sample
- Mkn 421 ~3 x 10^{-2} (Asano & Hayashida 2018)

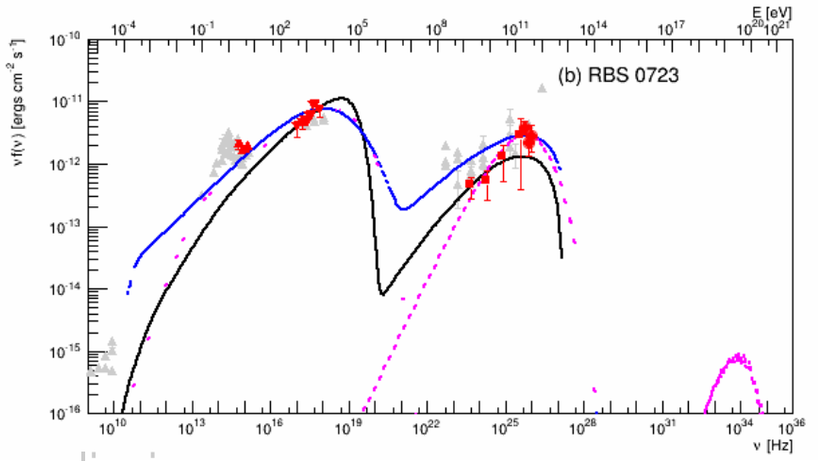


Spine Layer model

Ghisellini et al. 2005, Tavecchio et al. 2008

- Larger set of parameters
- <u>Lower jet power</u> among models
- B ranges from 0.15 to 0.4 G (one order of magnitude larger than in conical-jet SSC model)





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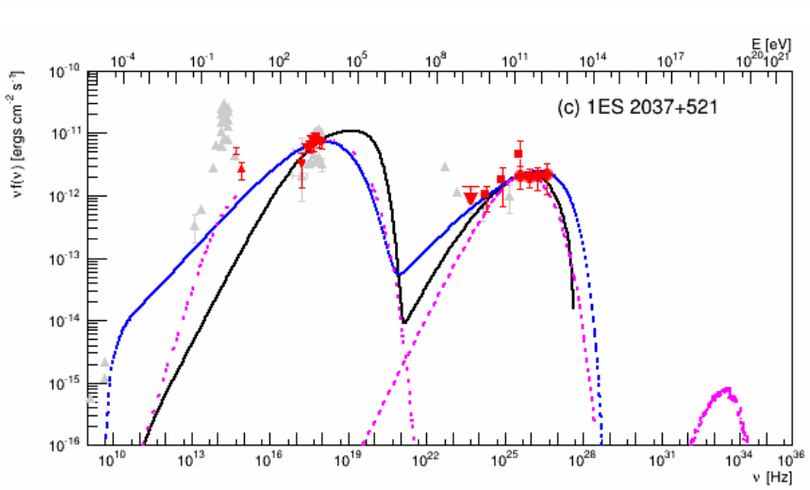
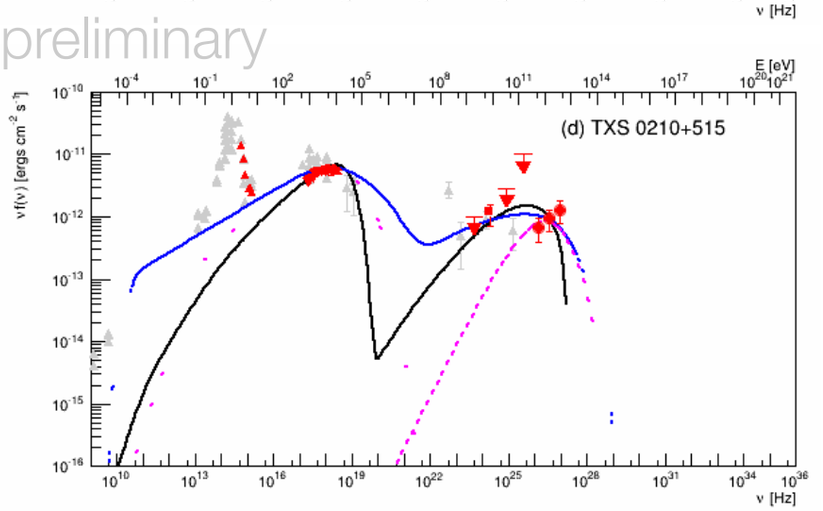




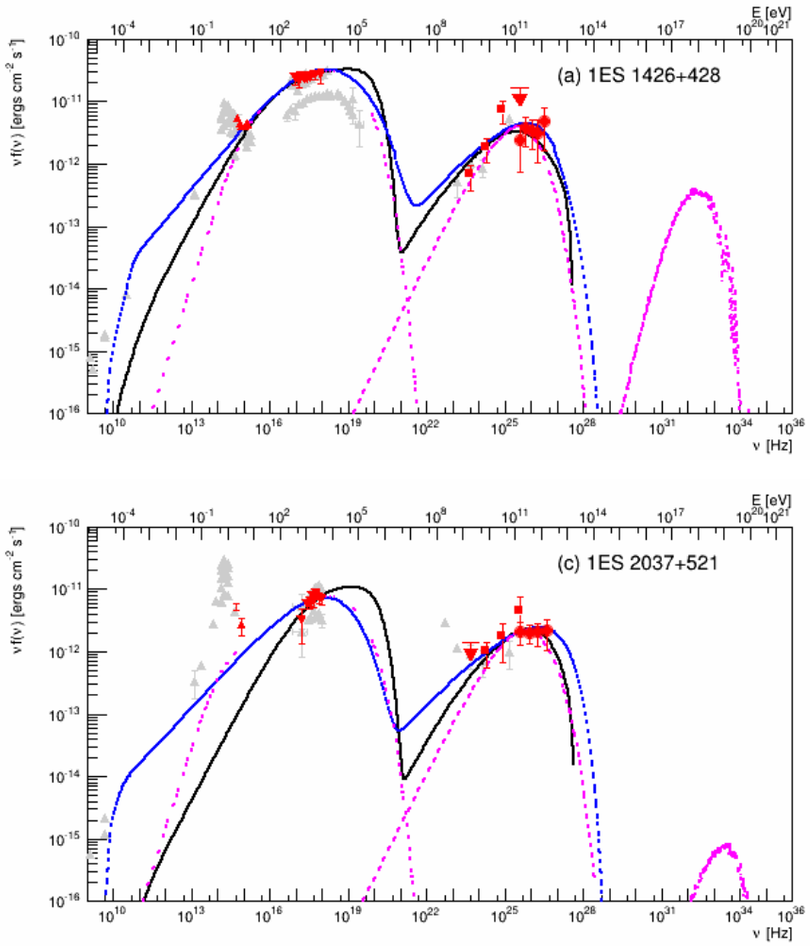
Equipartition ($U_B/U_e \sim 1$) in all the sources considered

Lepto-hadronic model

Cerruti et al. 2015

Scan of the parameter space (only best-fit solution shown)

- Large set of parameters —> degeneracy
- Luminosity not problematic: only a <u>fraction of the Eddington luminosity</u>
- <u>Magnetically-dominated</u> jet
- Unusual parameter: <u>hard particle-injection index</u> (~ 1.1–1.3)



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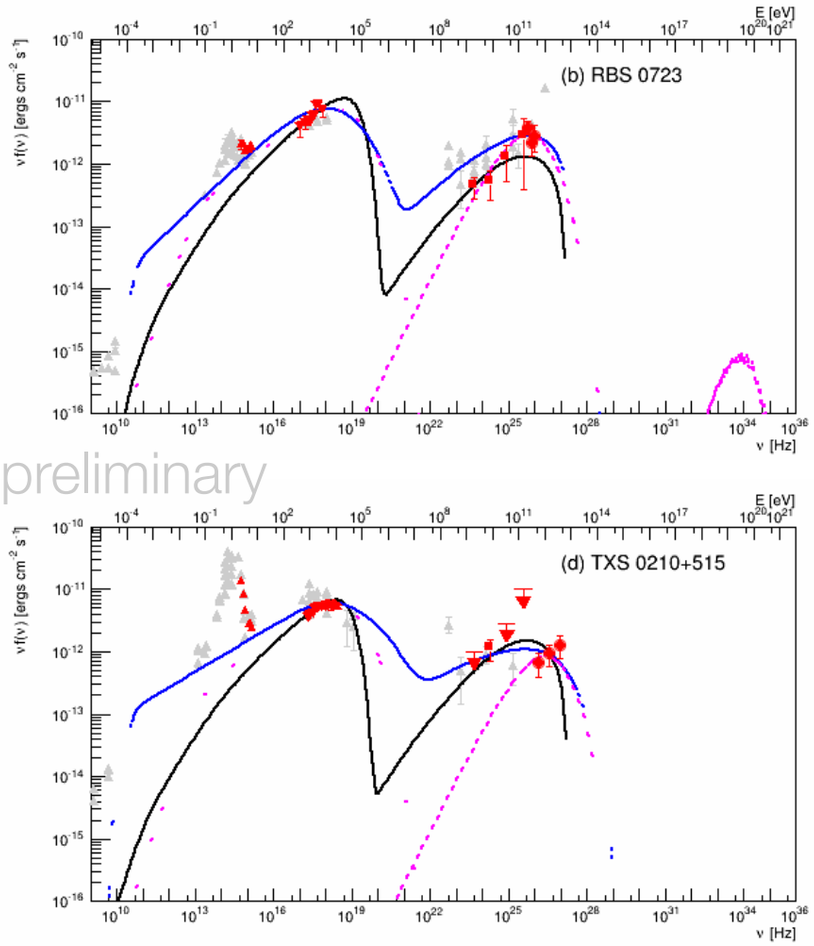

Neutrino emission predicted: 1ES 1426+428 has the strongest neutrino emission; still below detectability

Conclusions

Search for extreme blazars: one of the MAGIC multi-year programs.
Very **successful program**: 3 new TeV emitters (over 9 "new" sources), 1 known source, 1 hint-of-signal source.

MWL observations

- **In X-rays:** modest variability in soft X-rays, harder-when-brighter trend. One source has no extreme synchrotron peak (at least when observed).
- **In gamma rays:** faint signals. 4 sources are hard-TeV EHBLs; promising for further observations.

Modeling

- SSC conical-jet: very low magnetization
- Spine-layer: equipartition, low jet power.
- Lepto-hadronic: strongly magnetized jet, unusual particle-injection spectrum. No detectable neutrino emission predicted.

Questions for the future

Observations of new and known objects are fundamental

- Are extreme blazars a single population?
  - Probably not! talk on Monday by L. Foffano GAI7a
  - Also: how do they connect with the HBL class? talk later by A. Arbet-Engels GAI5f
- What is the maximum synchrotron and high-energy peak energy?
- Are hard-TeV blazars variable at TeV?
  - Only modest variability seen in 1ES 0229+200 (VERITAS Coll., 33rd ICRC, 2015)

talk later by O Gueta GAI5d

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Thank you!

Credits: C. Righi