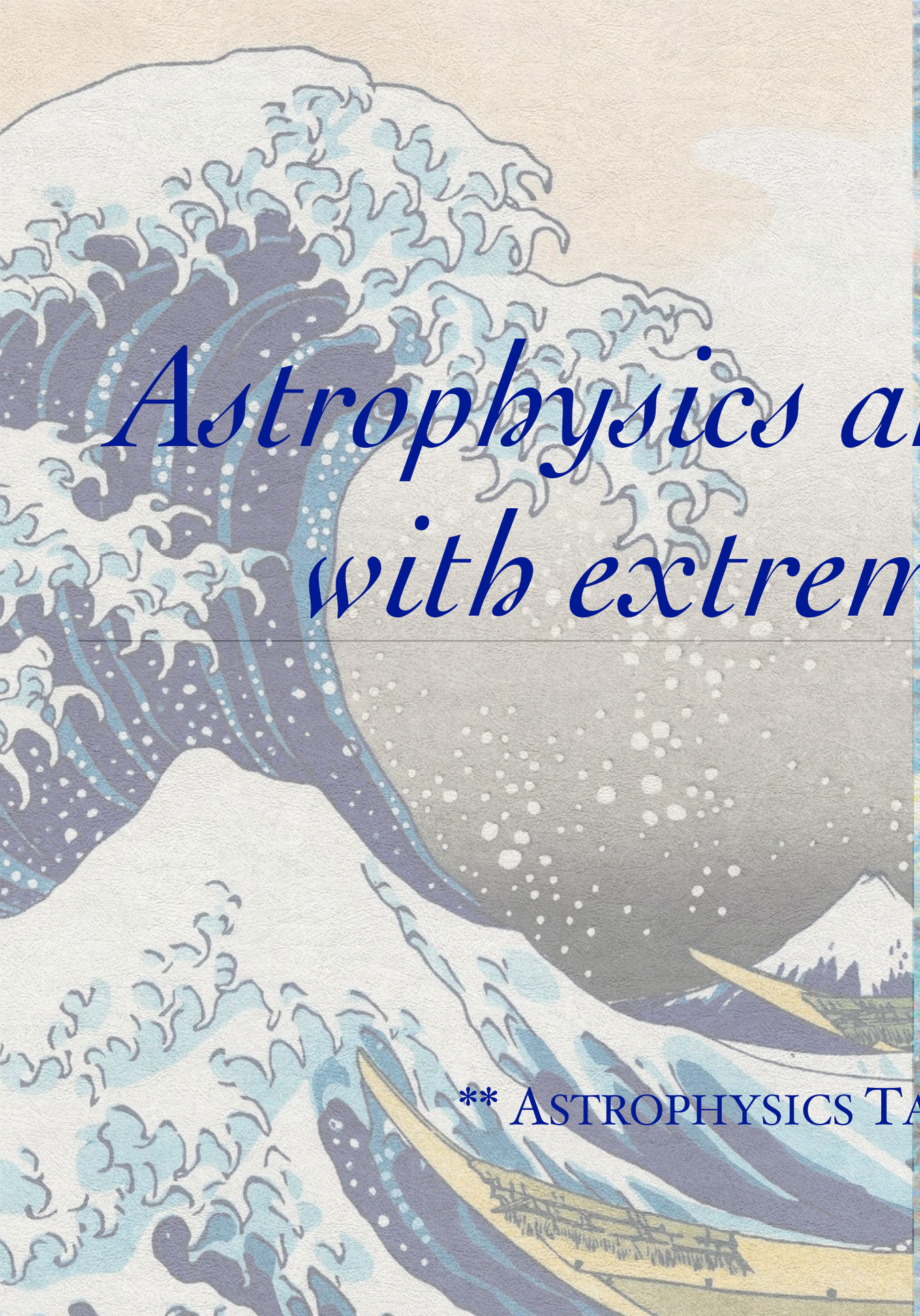
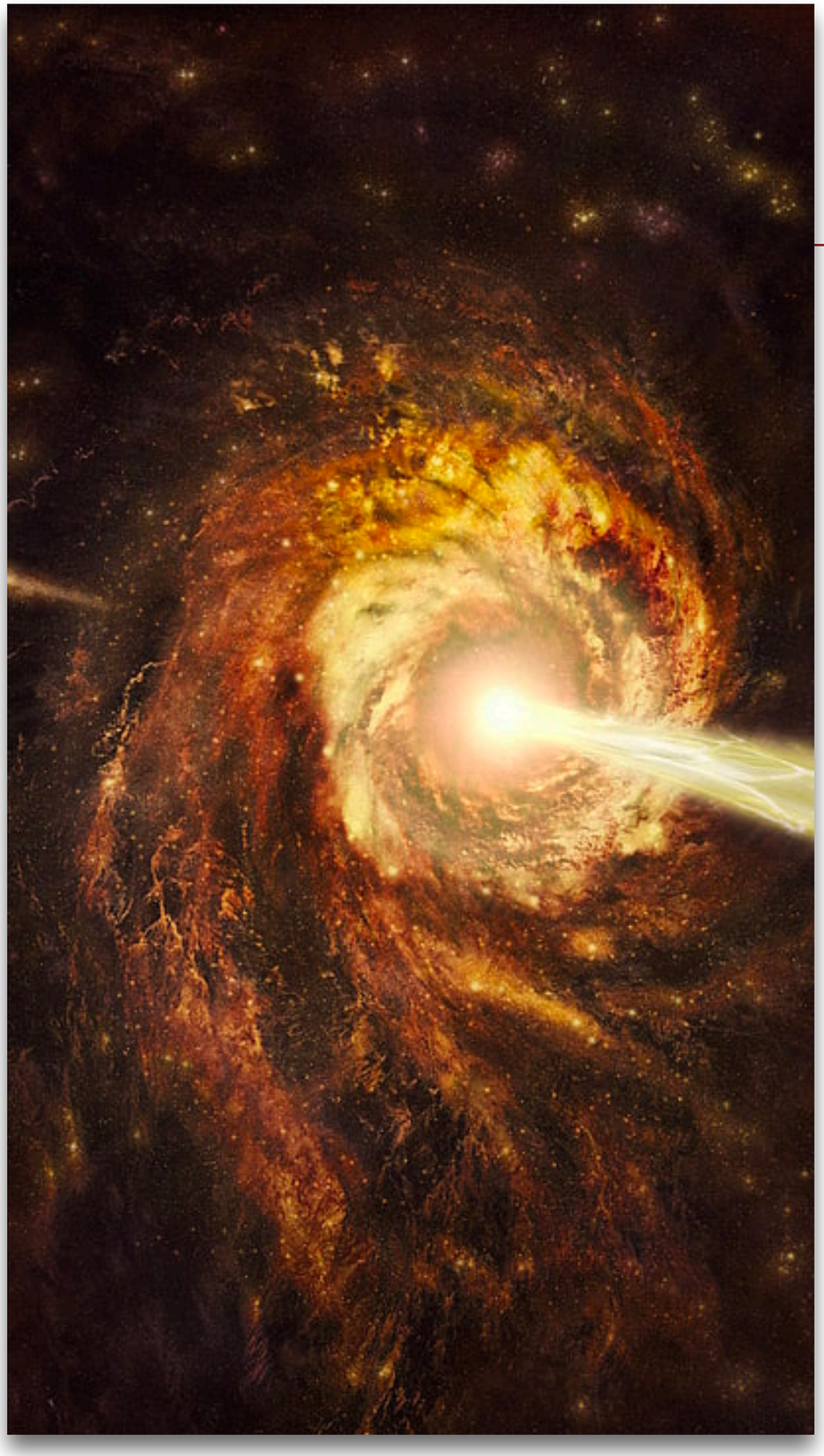


Astrophysics and cosmology with extreme blazars

ELISA PRANDINI (PADOVA U.)

elisa.prandini@unipd.it

** ASTROPHYSICS TALK ** OAS BOLOGNA 16.02.2021



Summary

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- What are extreme blazars?
- MAGIC telescopes: recent results
- The challenge of modeling extreme blazars
- Extreme blazars and cosmology

Blazars in a nutshell

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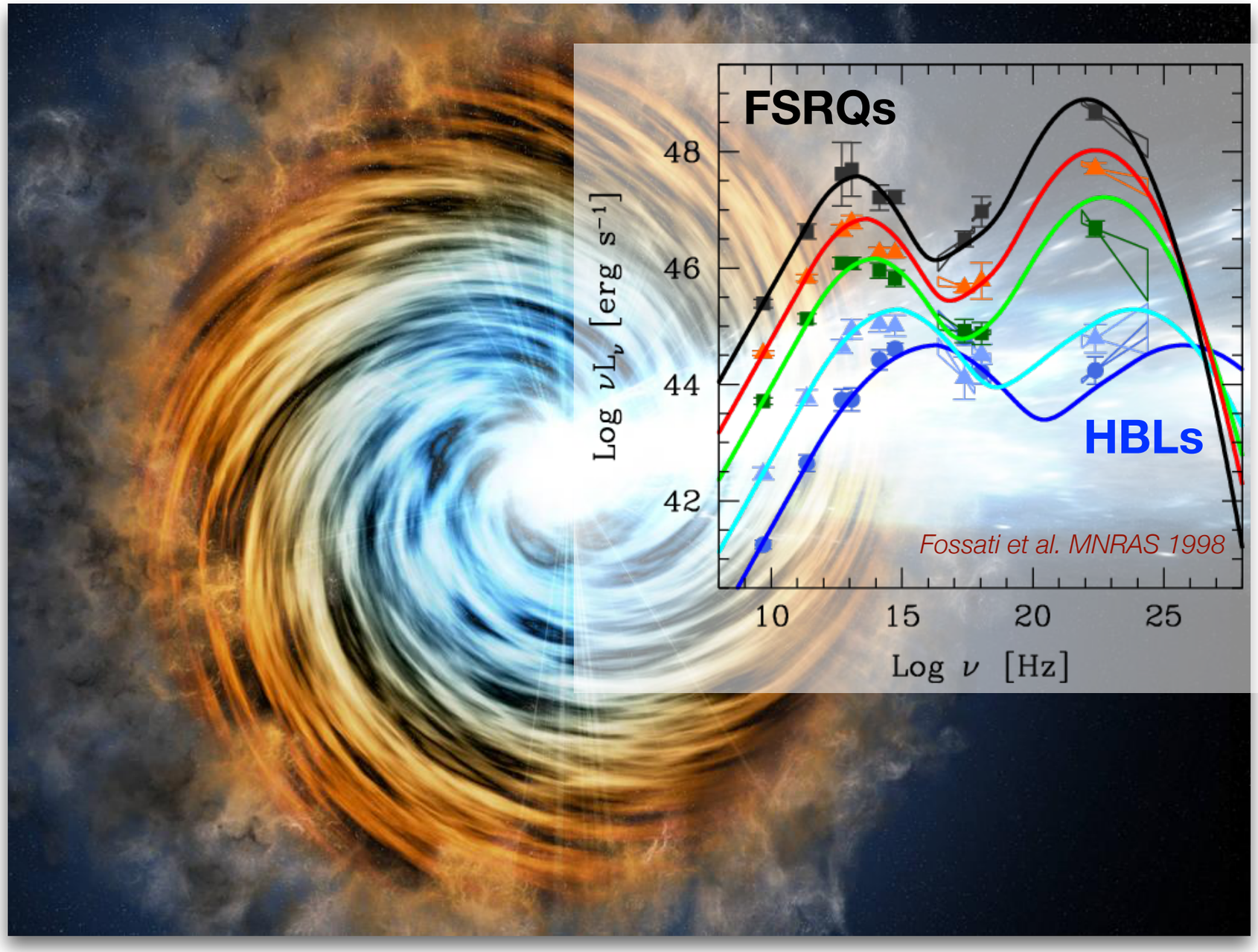
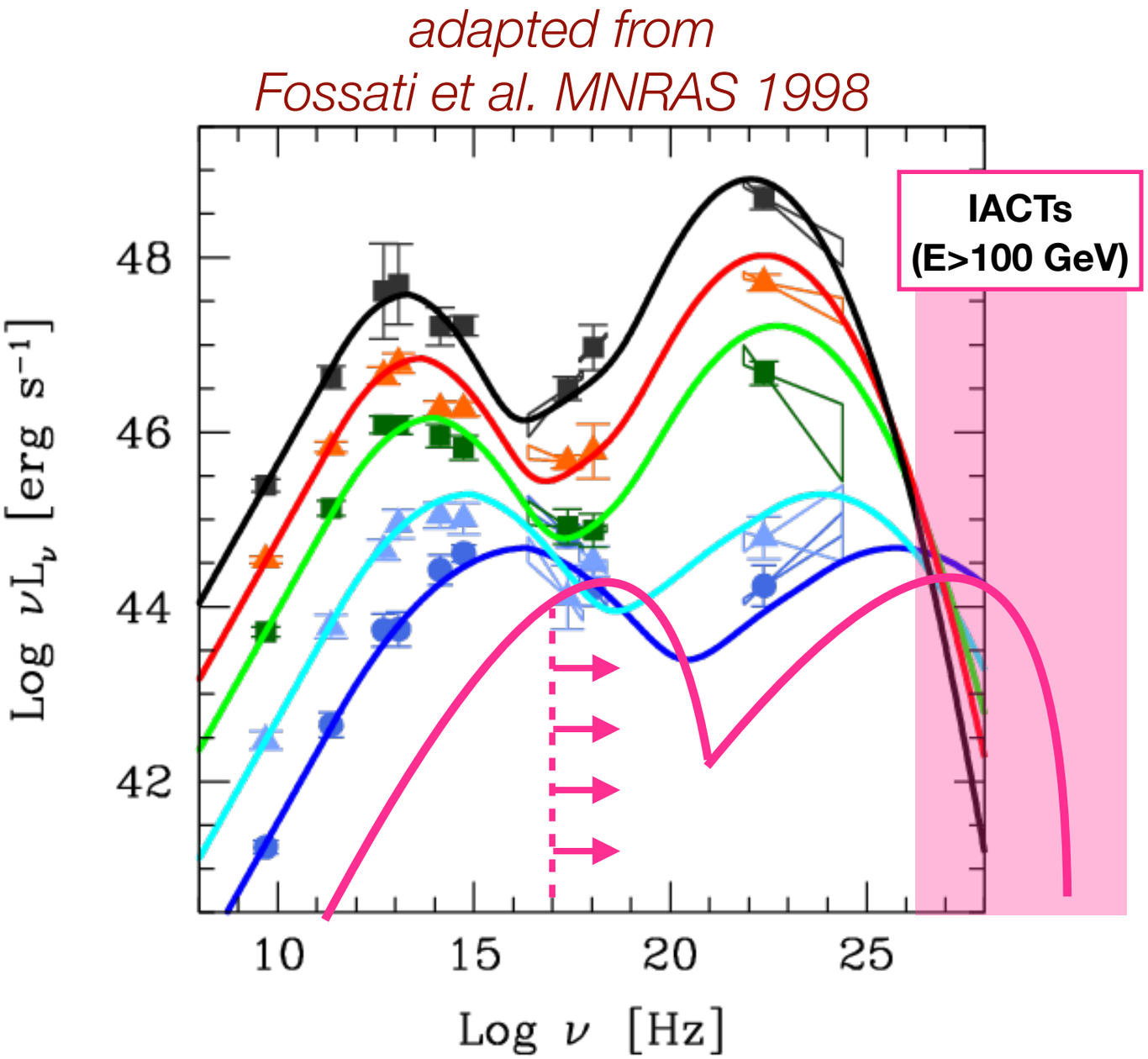
- AGNs
- Electromagnetic radiation: from radio to gamma rays
- Neutrino-emitters (at least one)
- Very likely cosmic-ray accelerators



Extreme Blazars - a classical definition



The classical definition of extreme blazar is based on the synchrotron peak location (> 1 keV)

Early 2000 expectations:

- Extreme (synchro) blazars are ideal targets for Imaging Atmospheric Cherenkov Telescopes (**IACTs**)
- Standard blazar models constraint the high-energy SED **peak below 1 TeV**

The discovery of the hard TeV extreme blazar 1ES 0229+200

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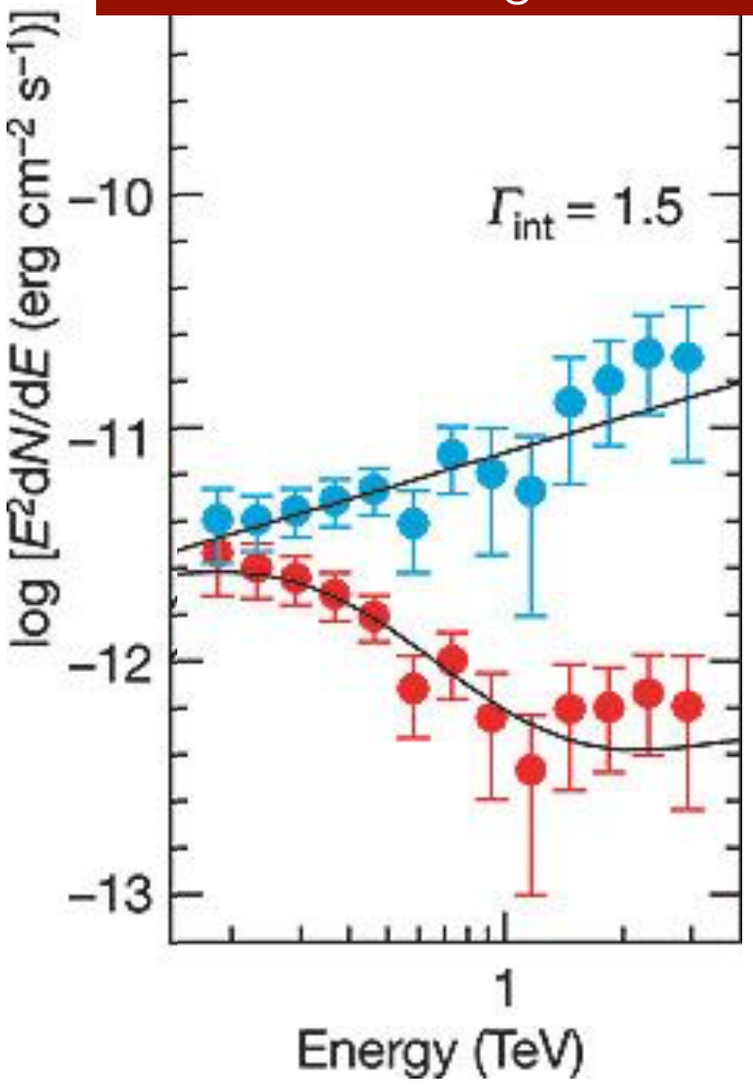
H.E.S.S Coll. Nature 2006

Unexpected hard spectra from EHBLs: challenge for blazar modeling



Light blue: EBL-corrected spectrum

Red: observed spectrum

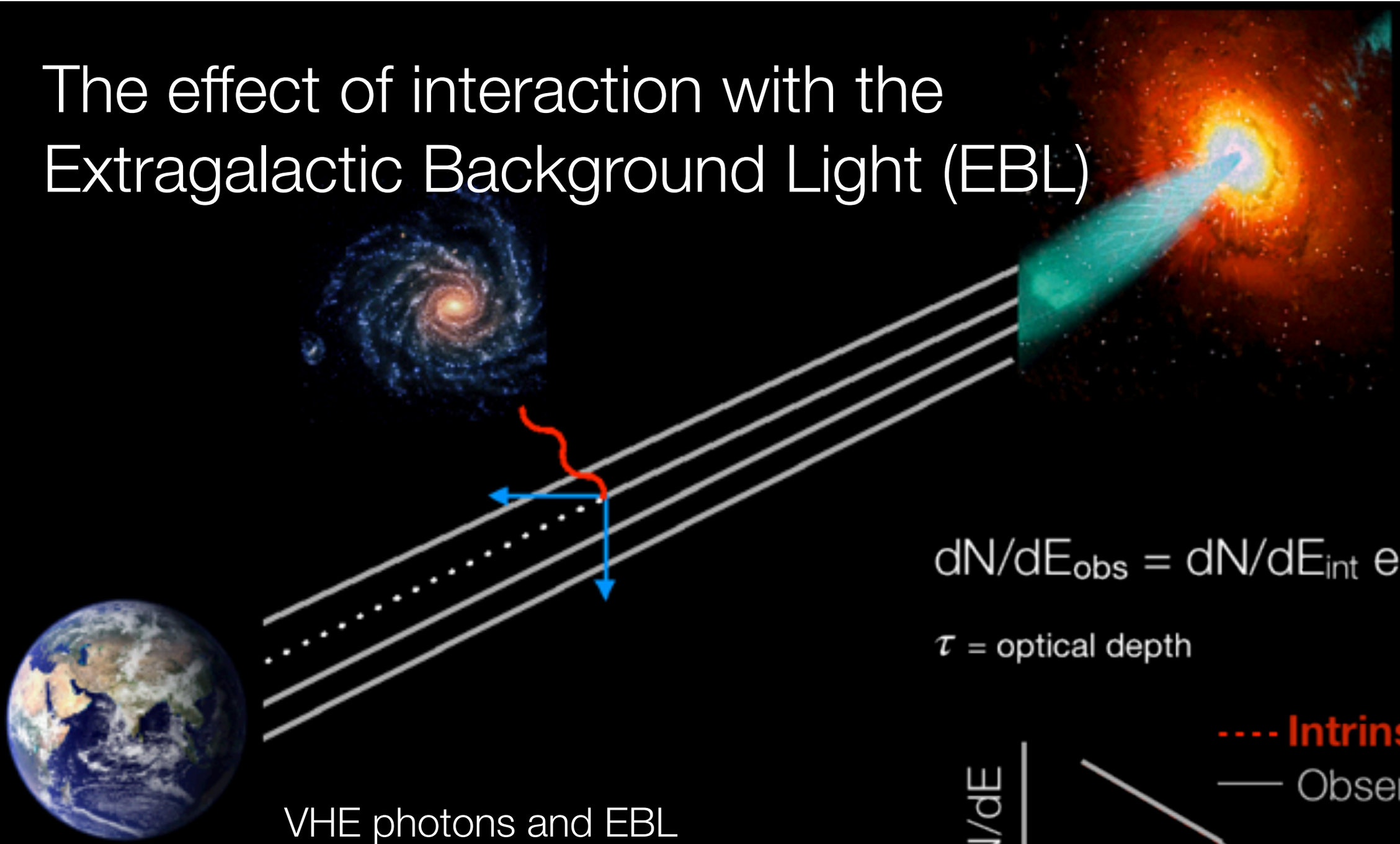
Challenge

- Requires extreme values of the model parameters

Alternatives:

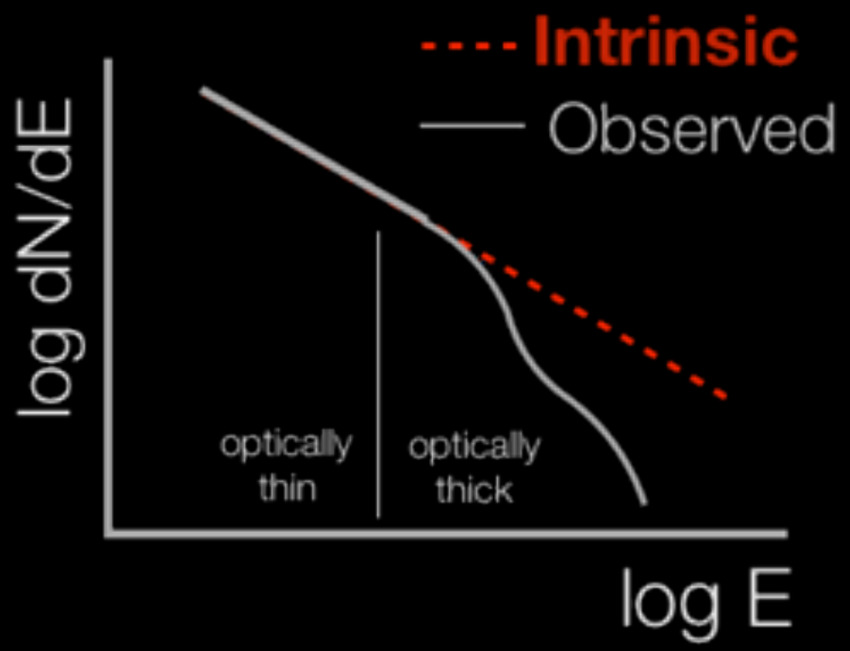
- Change absorption model
- Change propagation
- Change production distance

The effect of interaction with the Extragalactic Background Light (EBL)



$dN/dE_{obs} = dN/dE_{int}\ e^{-\tau(z,E)}$

τ = optical depth



VHE photons and EBL photons: pair creation —> **VHE flux absorption** (e.g. *Franceschini* et al. 2008, A&A)

Spectral signatures of extremeness

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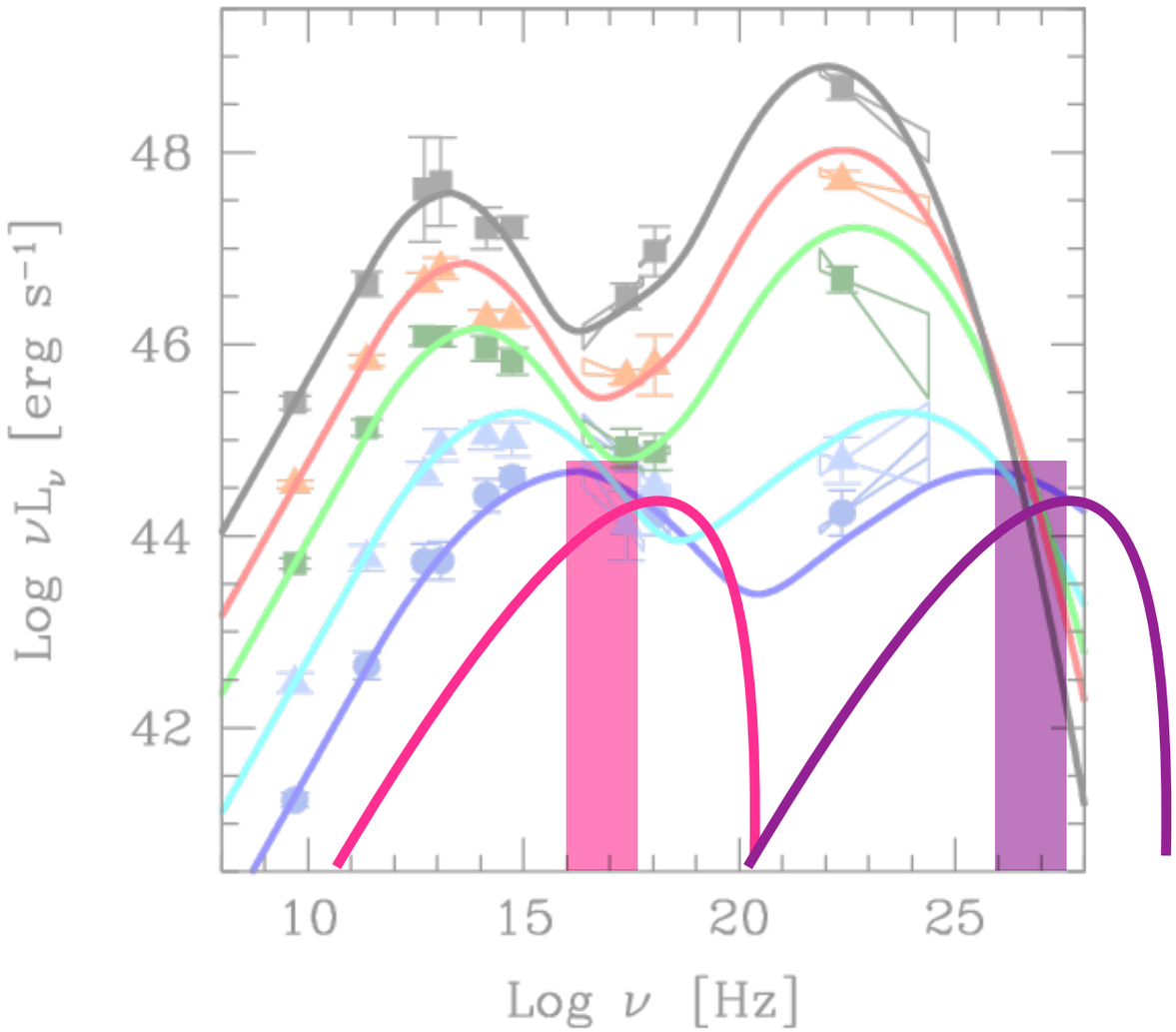
- ***Extreme-synchrotron***
  - synchrotron peak energy E > 1 keV (2.4 x 10^{17}Hz)
  - Signature: hard spectrum in the soft X-ray band (Γ_X<2)
- ***Extreme-TeV***
  - gamma-ray peak energy E > 1TeV (2.4 x 10^{25}Hz)
  - Signature: hard spectrum in the 0.1-1 TeV band (Γ_γ<2)



Examples of extreme blazars

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Biteau, EP, et al. Nature Astronomy 2020

Examples of extreme blazars

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Biteau, EP, et al. Nature Astronomy 2020

extreme synchrotron during short episodes

extreme synchrotron in long-lasting quiescence

extreme TeV

WISE BeppoSAX97 HEGRA CAT97 BeppoSAX99 Whipple CAT HEGRA Swift−NuSTAR HESS XMM01 MAGIC07 3FGL Swift08 Fermi

a) b) c)

16/4/97 7/4/97

Γ≃1.5

Mkn 501 z=0.034

1ES 1426+428 z=0.129

1ES 0229+200 z=0.1396

Log νF_ν [erg cm^{-2} s^{-1}]

Log ν [Hz]

Unlike other BL Lac object classes, the host galaxy is well visible in extreme blazars!

HBLs and extreme blazars: statistics

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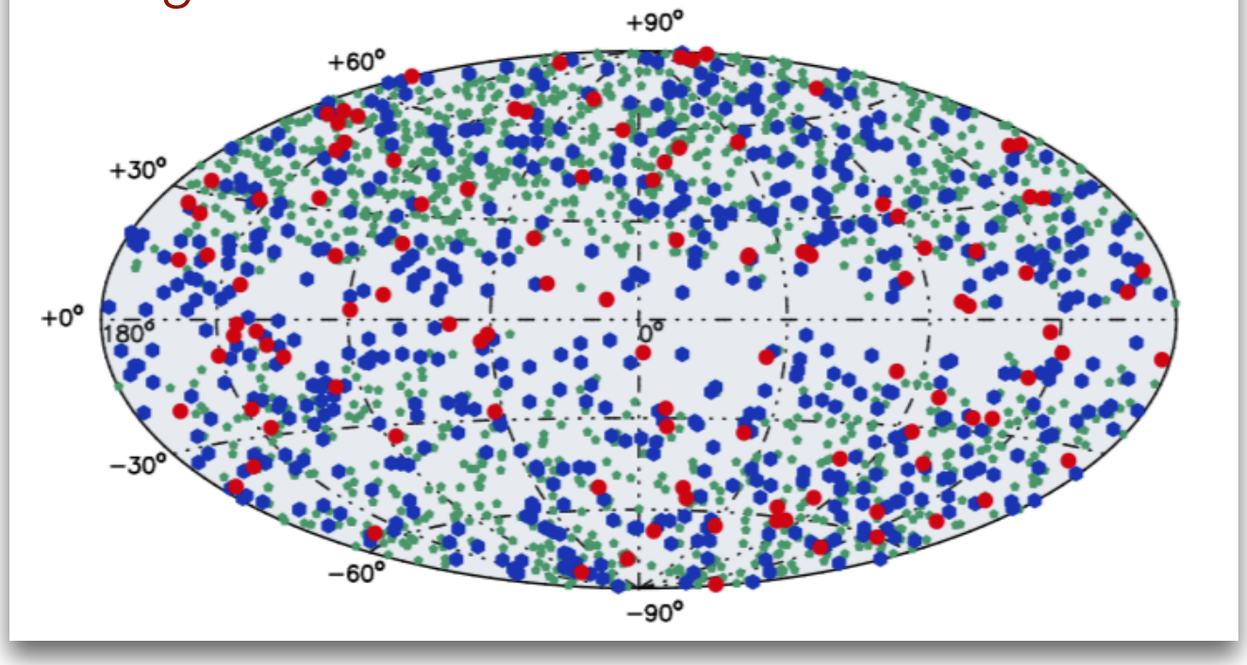
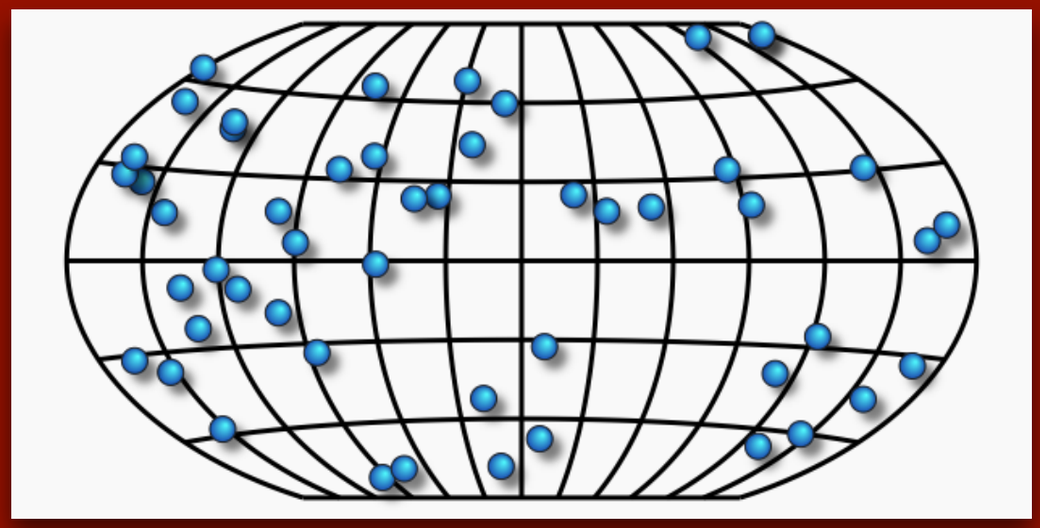
Chang et al. A&A 2019



3HSP catalog: 2'011 HBLs, **199** are extreme *synchrotron* blazars

TevCat catalog:
53+1 HBLs
detected at TeV,
24+1 are extreme
blazars
http://tevcat2.uchicago.edu



Cherenkov Telescopes at the Roque de los Muchachos Observatory (La Palma)

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Latest results from MAGIC

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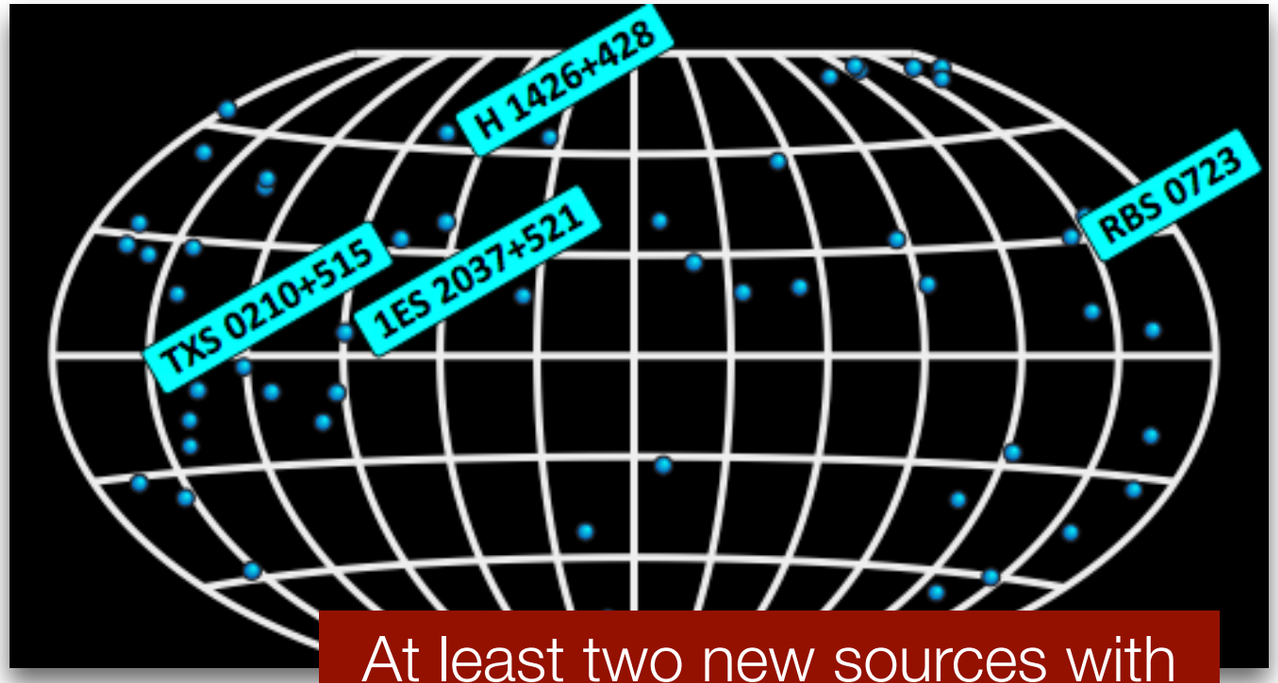
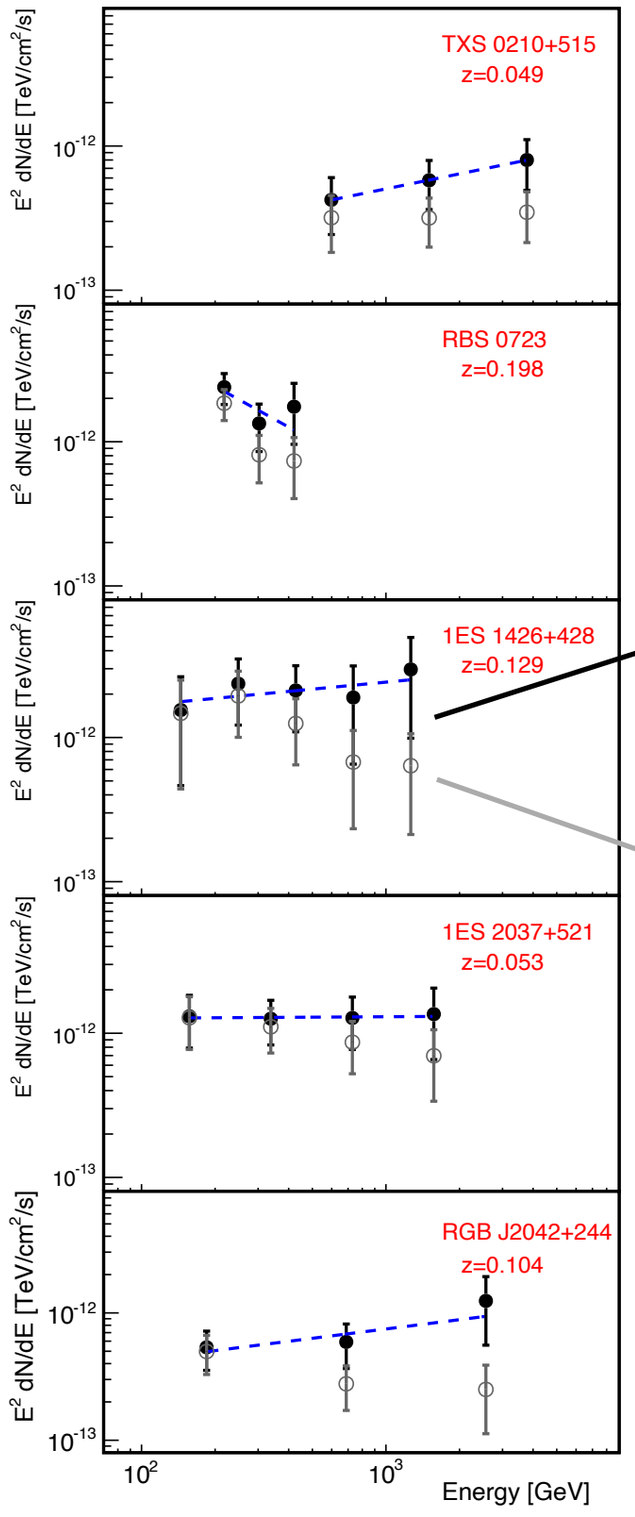
MAGIC Coll. ApJS 2020

- **260 hours** devoted to this program from 2010 to 2017, 10 sources observed.
- Four sources firmly detected and one hint-of-signal



At least two new sources with hard-TeV spectrum



Corrected for extinction on EBL

Observed

Latest results from MAGIC

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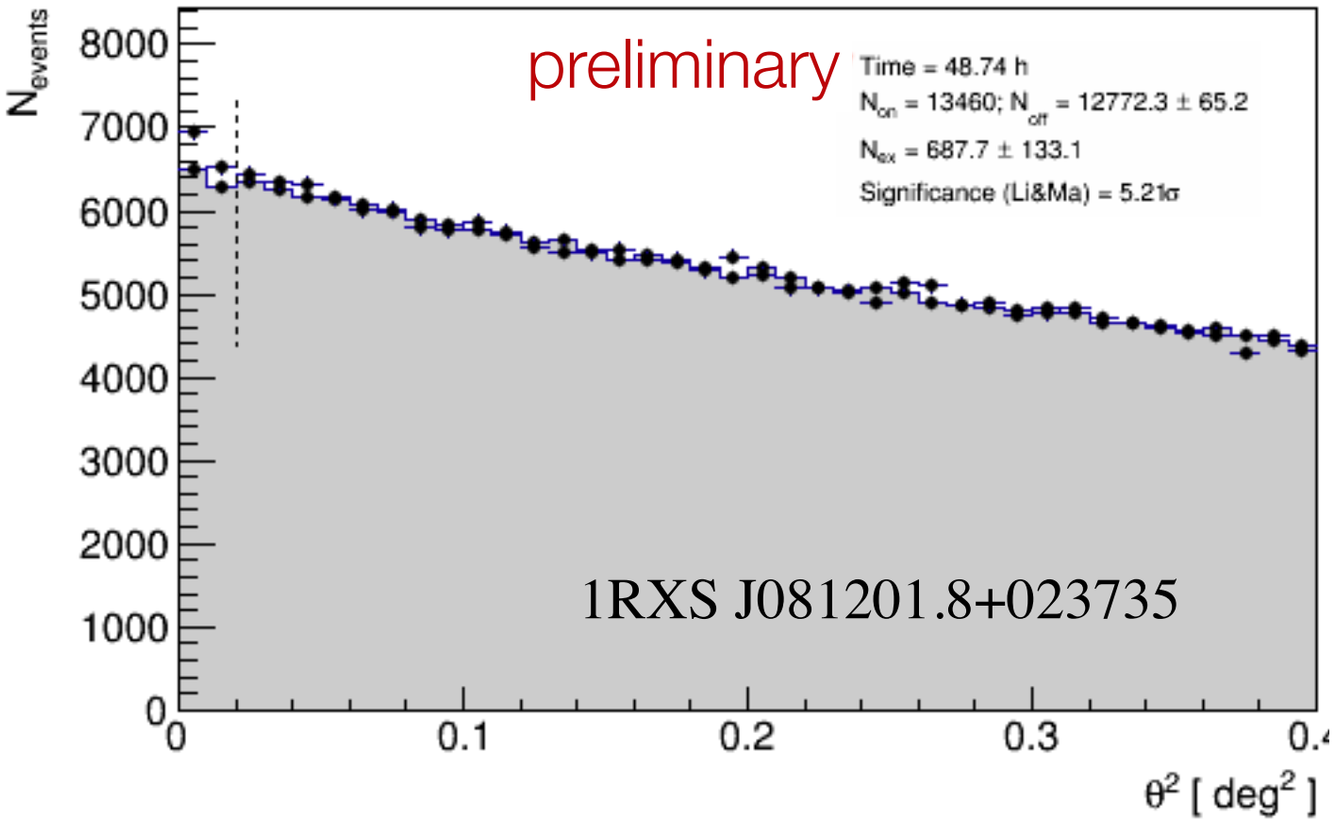
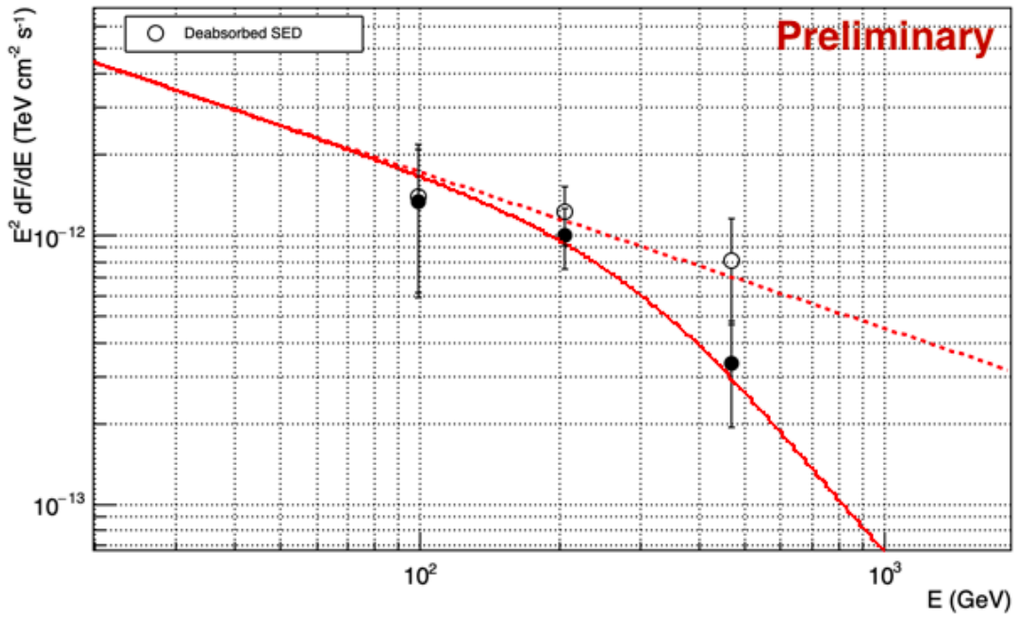
S. Ventura et al. COSPAR 2021



Yet another new extreme (synchrotron) blazar

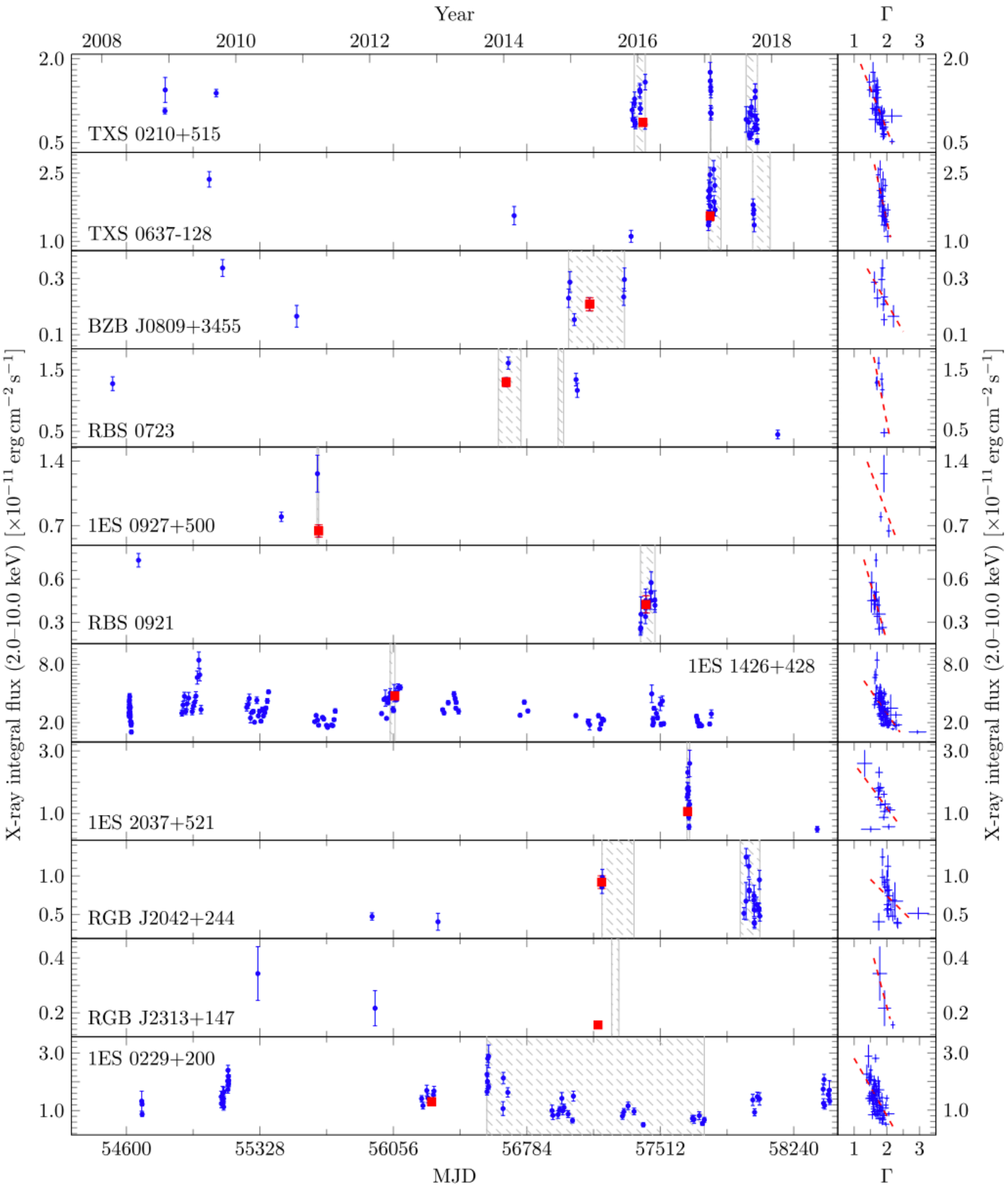
- Faint emission (5 sigma in ~50 hours)
- Extreme synchro

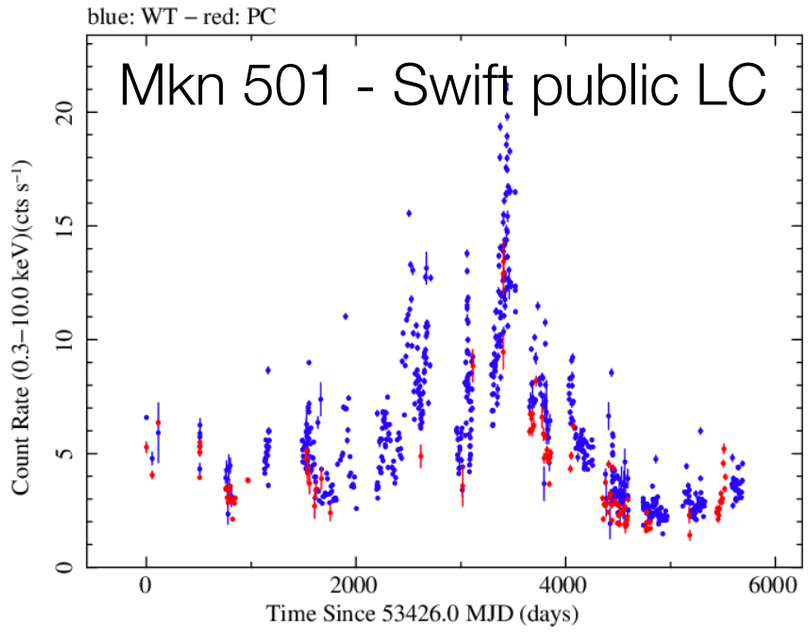


X-ray light curve of a sample of extreme blazars

MAGIC Coll. ApJS 2020

Moderate variability in X-ray

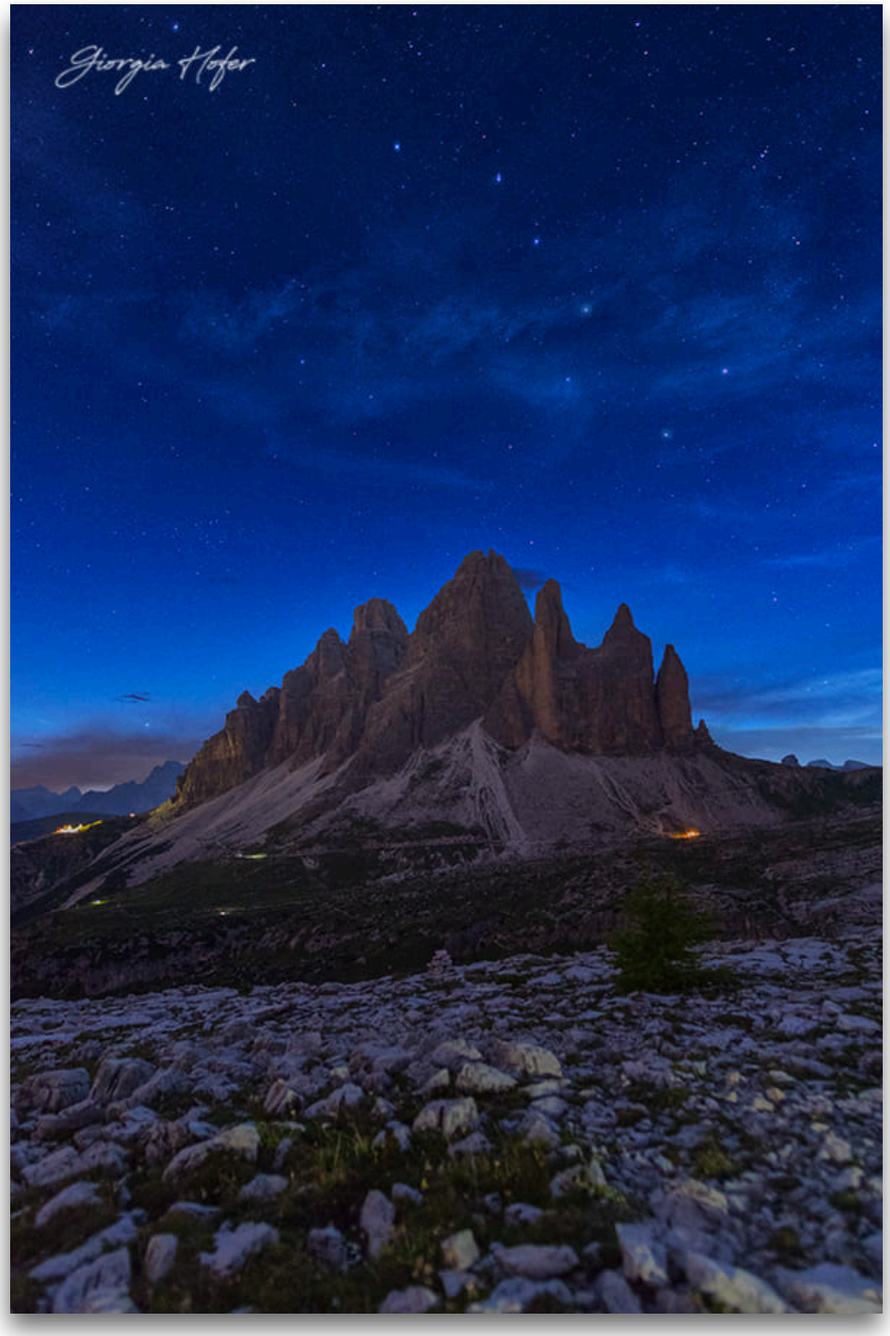




https://www.swift.psu.edu/monitoring/

Modeling extreme blazars

- **Extreme synchrotron emission is not problematic:**
  - spectral energy distribution (SED) well fitted by Synchrotron Self-Compton models
  - represent the high-energy tail of the blazar population.
- **Extreme TeV emission is *challenging:***
  - **Hardness** of the 0.1 - 1 TeV spectrum $\Gamma_\gamma<2$
    - Implies a hard accelerated particle spectrum (competition between energy gain and loss, usually spectra indices ~ 2)
    - Many scenarios: shock acceleration, turbulent acceleration, shear acceleration, reconnection
  - **Peak of radiation** at energies > 1 TeV



Phenomenological models for extreme TeV blazars: leptonic models

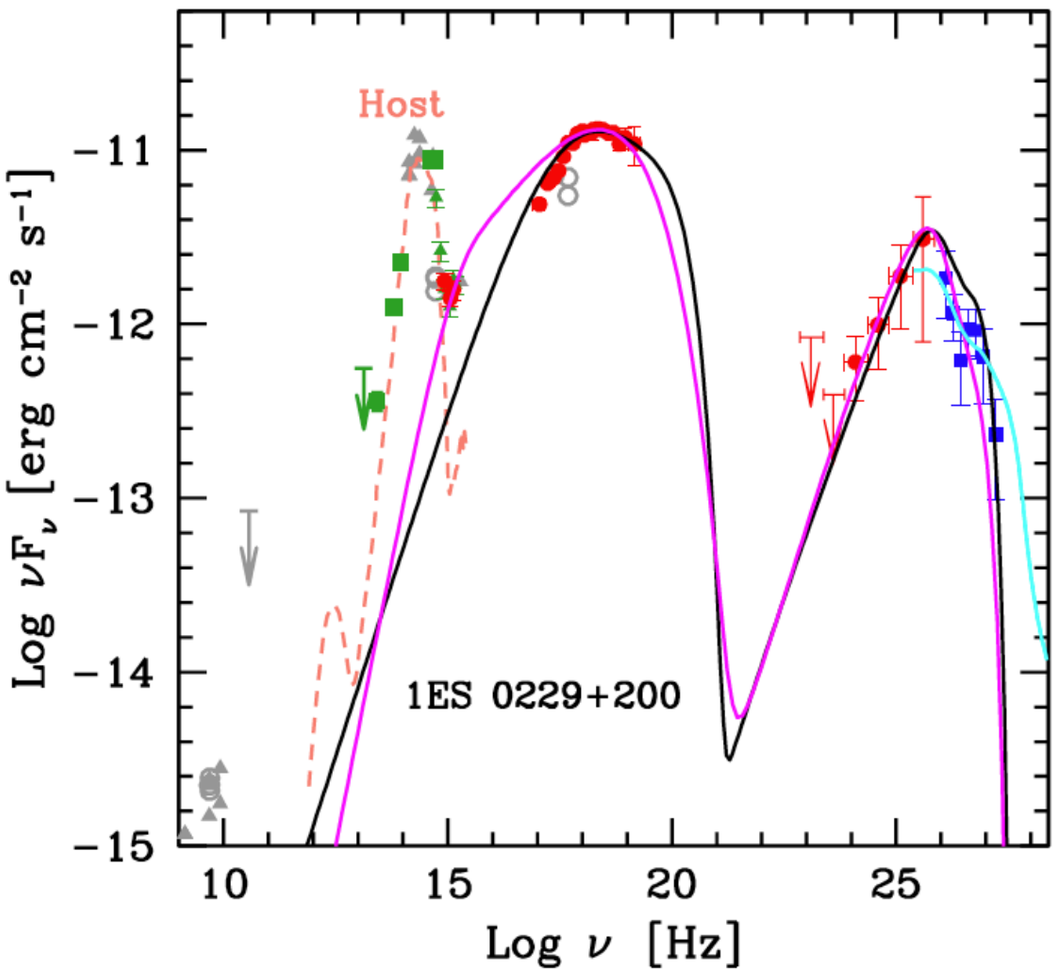
Università degli Studi di Padova

Leptonic:

Synchrotron Self Compton - SSC:

extremely high minimum Lorentz factors (γ_{min} ~10^4 - 10^5) + very low magnetic field (< mG)

black line: SSC leptonic model



SSC possible signature:

X-ray and VHE gamma-ray simultaneous variability

Phenomenological models for extreme TeV blazars: hadronic models

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Hadronic:

Proton Synchrotron:

requires a high B and high proton power

External Cascade:

gamma rays from secondary radiation produced outside the source

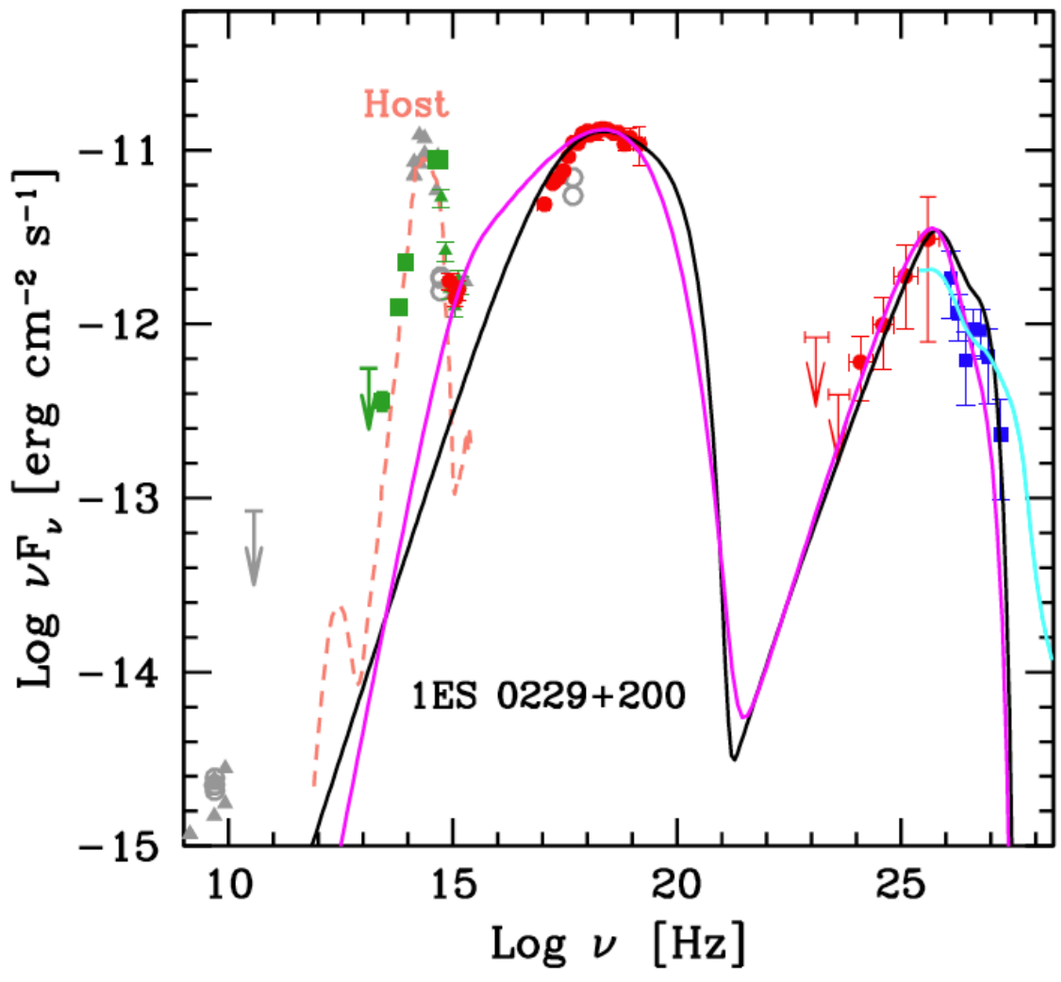
Hadronic models possible signatures:

External cascade: no sub-yearly scale variability allowed

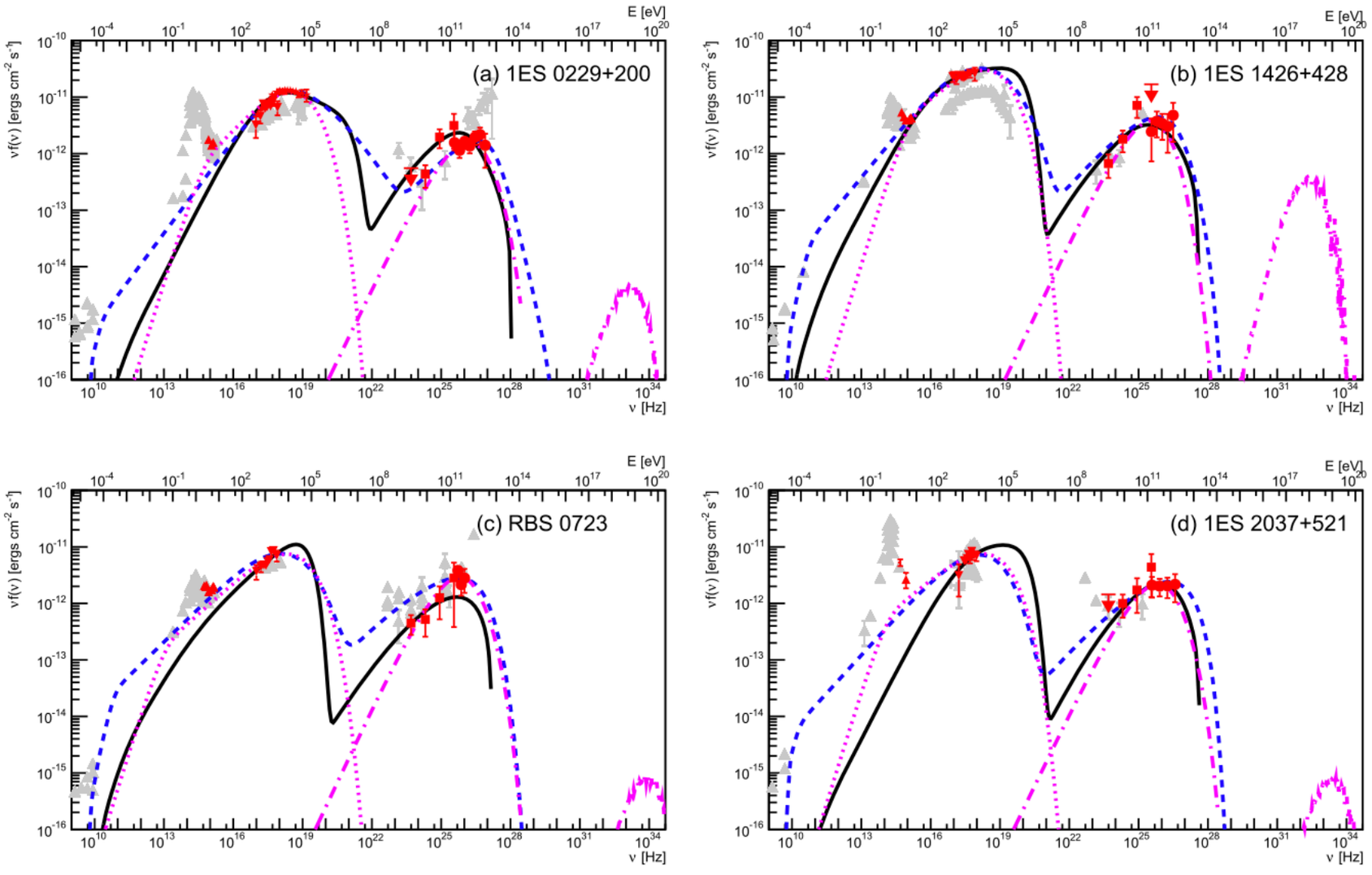
Proton synchrotron: no sub-day variability, (low) neutrino flux

magenta line: proton-synchrotron model

cyan line: external cascade model



Modeling the MAGIC sample



MAGIC Coll. ApJS 2020

- 3 models tested an none is favoured

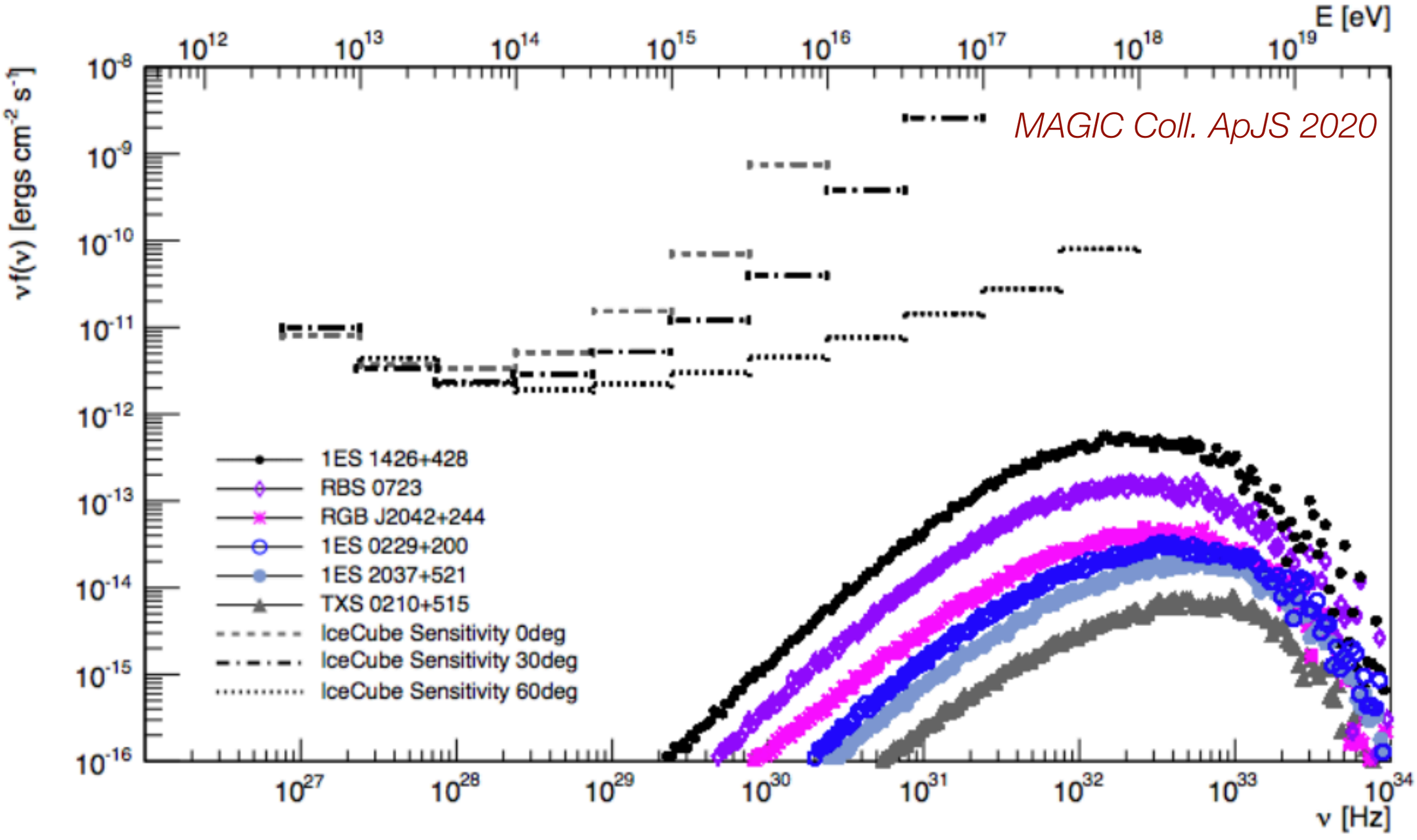
- More data needed in particular in both the hard X-ray and VHE gamma-ray regimes

magenta line: proton-synchrotron model

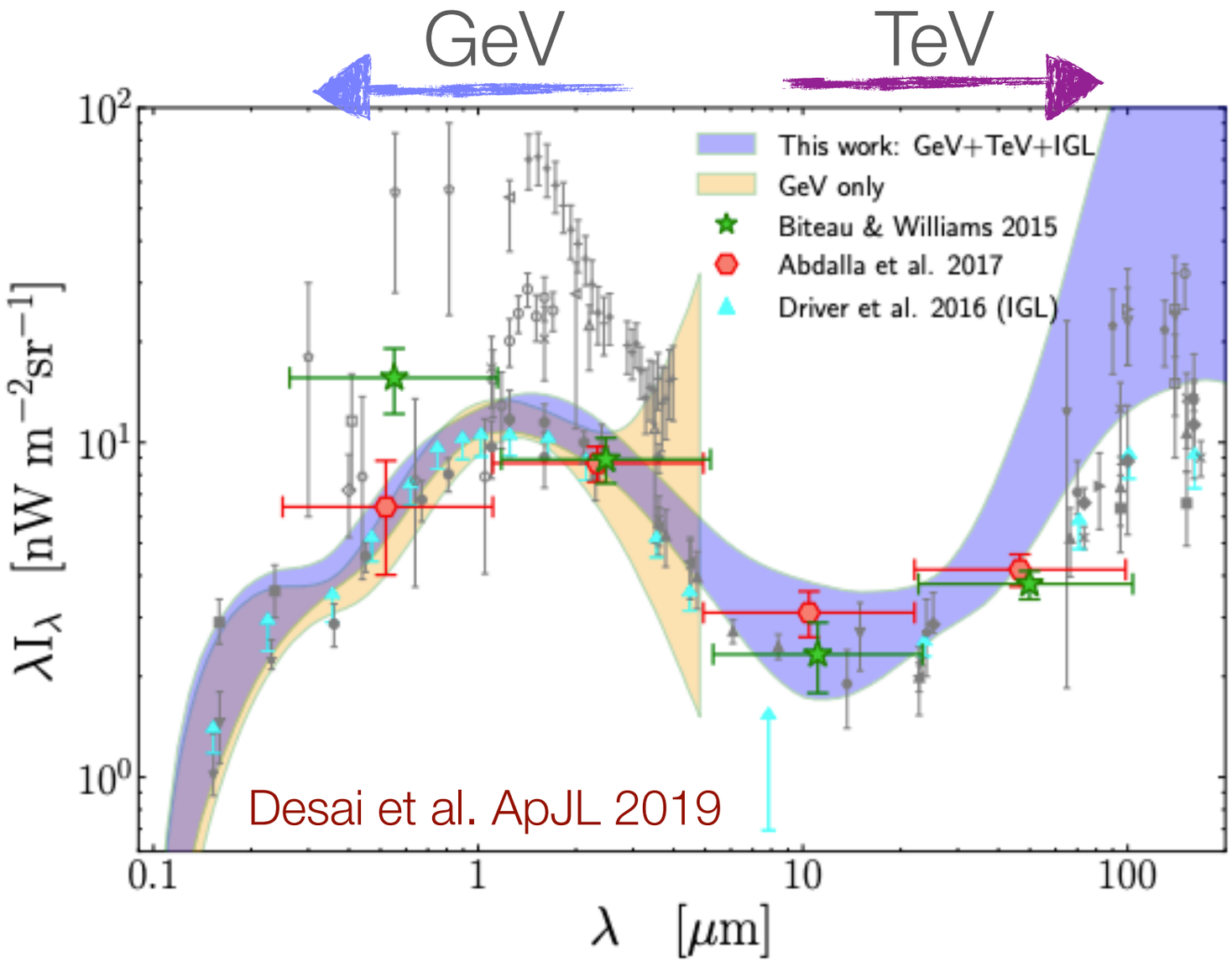
Blue line: SSC model

Black line: alternative leptonic model (spine-layer)

Neutrinos from extreme blazars?

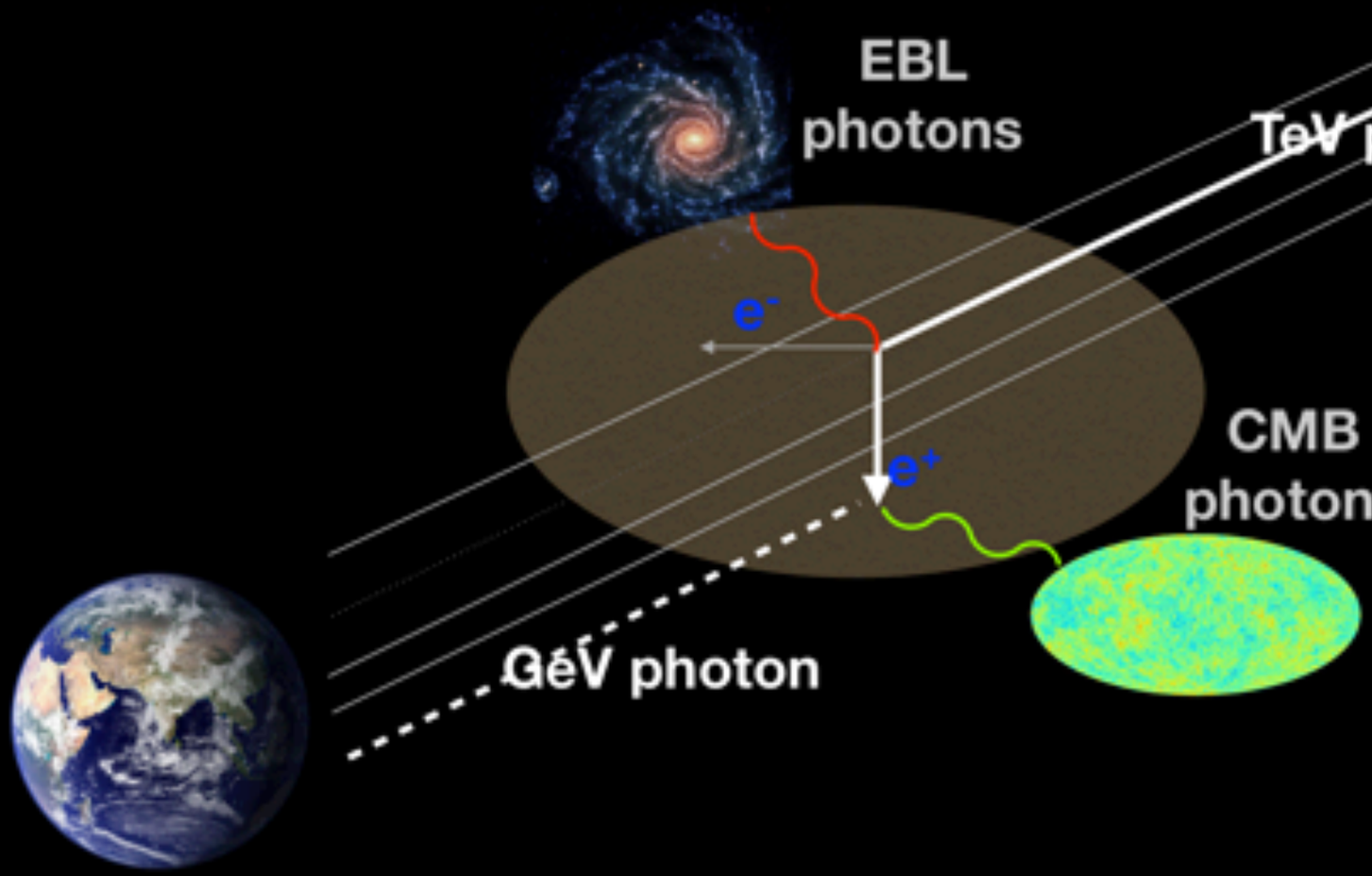


Cosmological probes: EBL



Hard spectra: extreme blazars are ideal to probe **EBL at IR wavelengths**, in particular above 10 microns (H.E.S.S. Coll. 2007 A&A)

Cosmological probe: InterGalactic Magnetic Field (IGMF)



Pairs deflected by IGMF may up-scatter CMB photons → reprocessed signal in the lower energy band (GeV)

E (absorbed)	E(reprocessed)
5 TeV	20 GeV
8 TeV	50 GeV
10 TeV	80 GeV

Neronov & Vovk 2010, Science, 328, 73;
Tavecchio et al. 2010, MNRAS, 4141, 4;
Dermer et al. 2010, ApJL 733,2

Limits on the Intergalactic Magnetic Field (IGMF)

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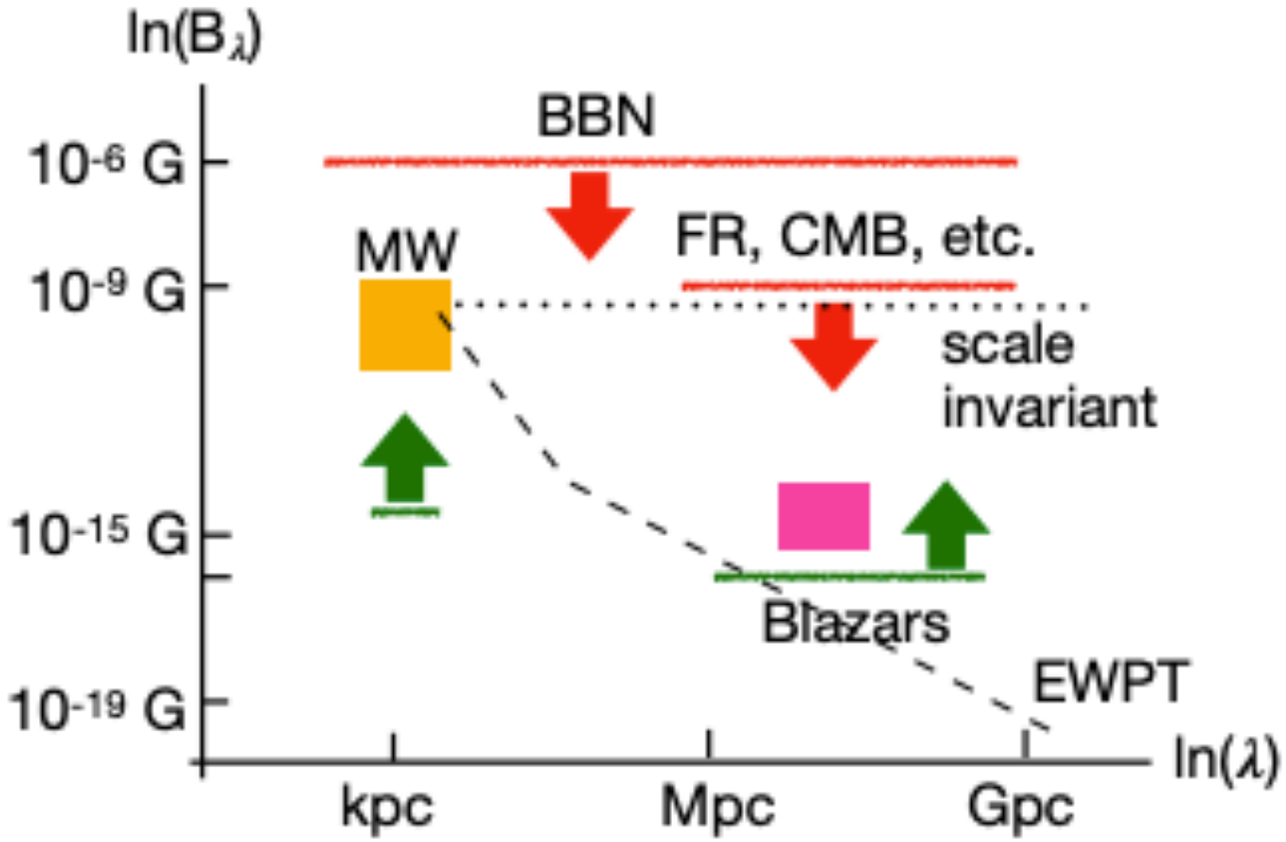
Vachaspati arXiv:2010.10525

- Lower limits from blazars observations are the most constraining limits on the IGMF
- Detection of reprocessed (extended) emission would represent a detection of IGMF



Future perspectives

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1. Population studies
2. Emission mechanisms
3. Jet hadronic content
4. Cosmology

Very promising progresses expected in the next decade!

eROSITA
IXPE
AMEGO / eASTROGAM
CTA
LHAASO
SWGO
SVOM
IceCube-Gen2
KM3NeT
AugerPrime
TAx4

thank you!