Extreme BL Lacs

probes for cosmology and UHECR source candidates

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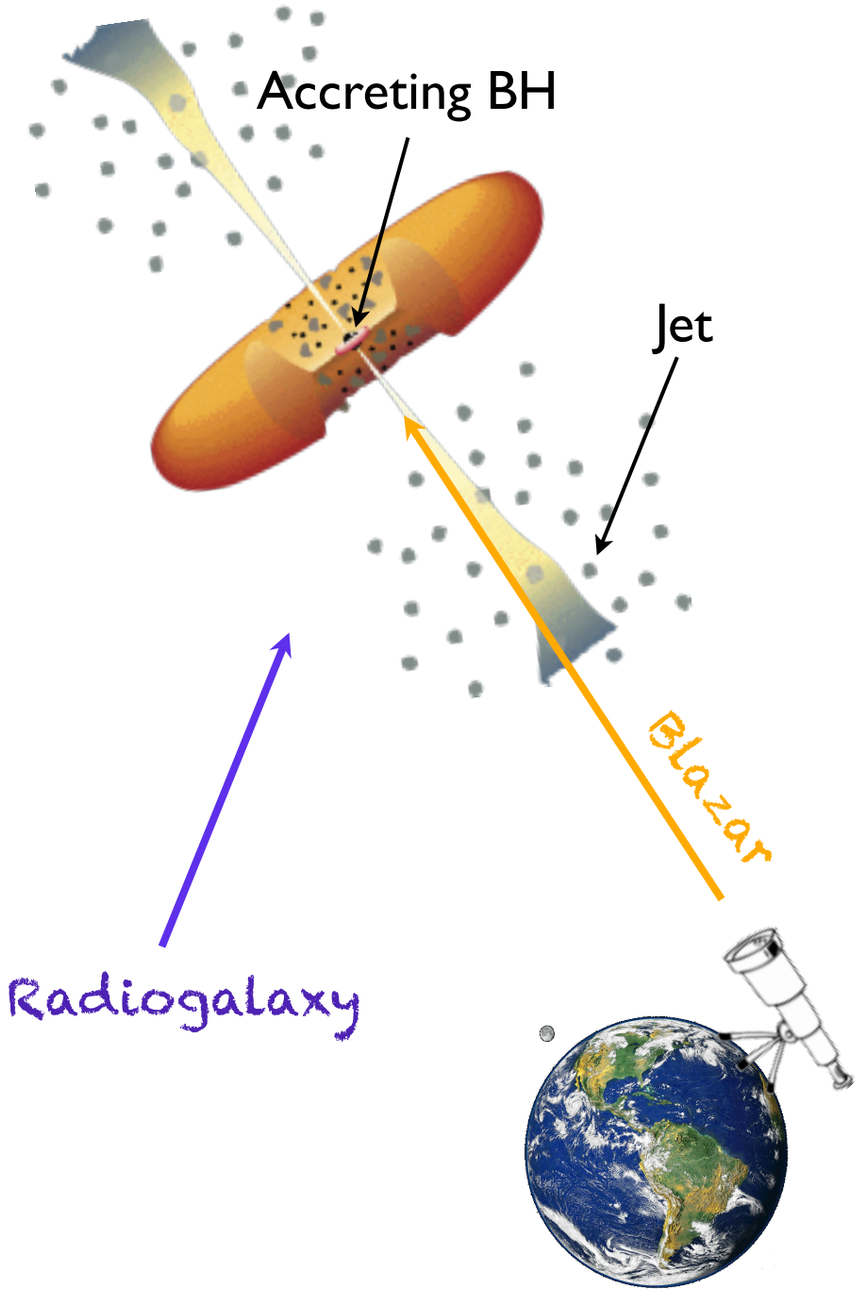
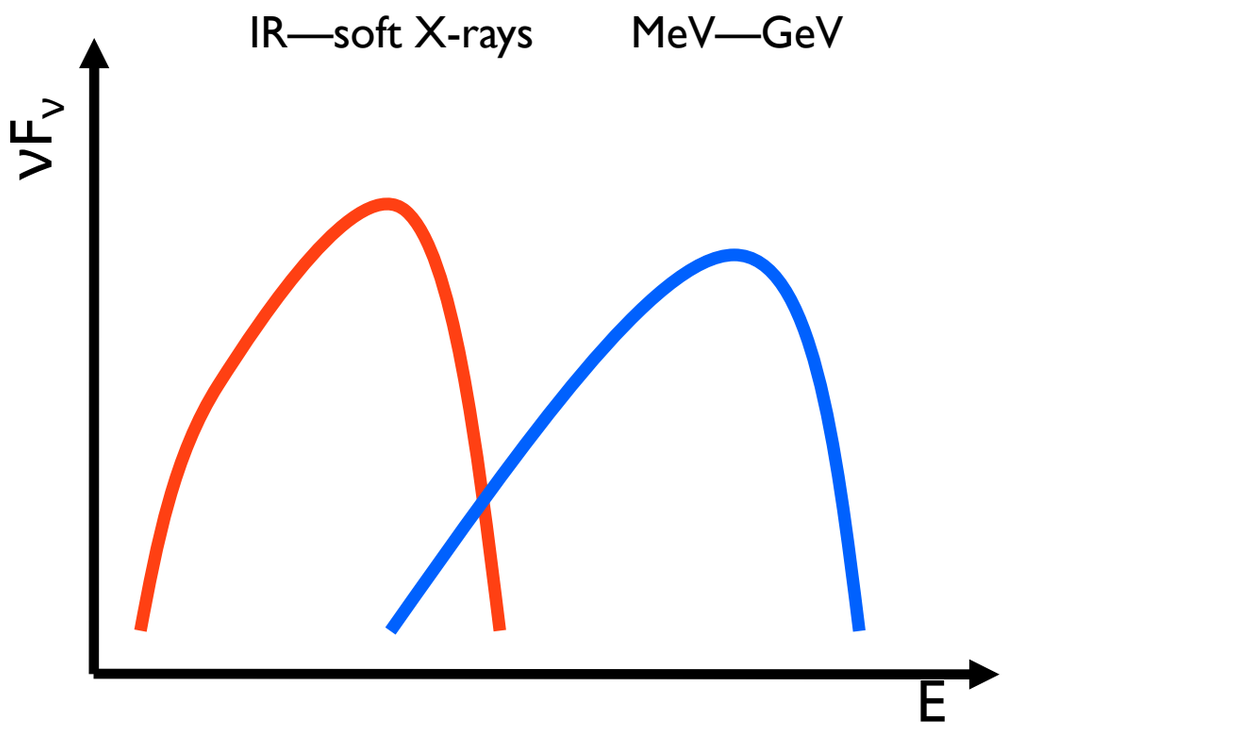
HEPRO V

La Plata, October 6

Jets pointing at us: BLAZARS





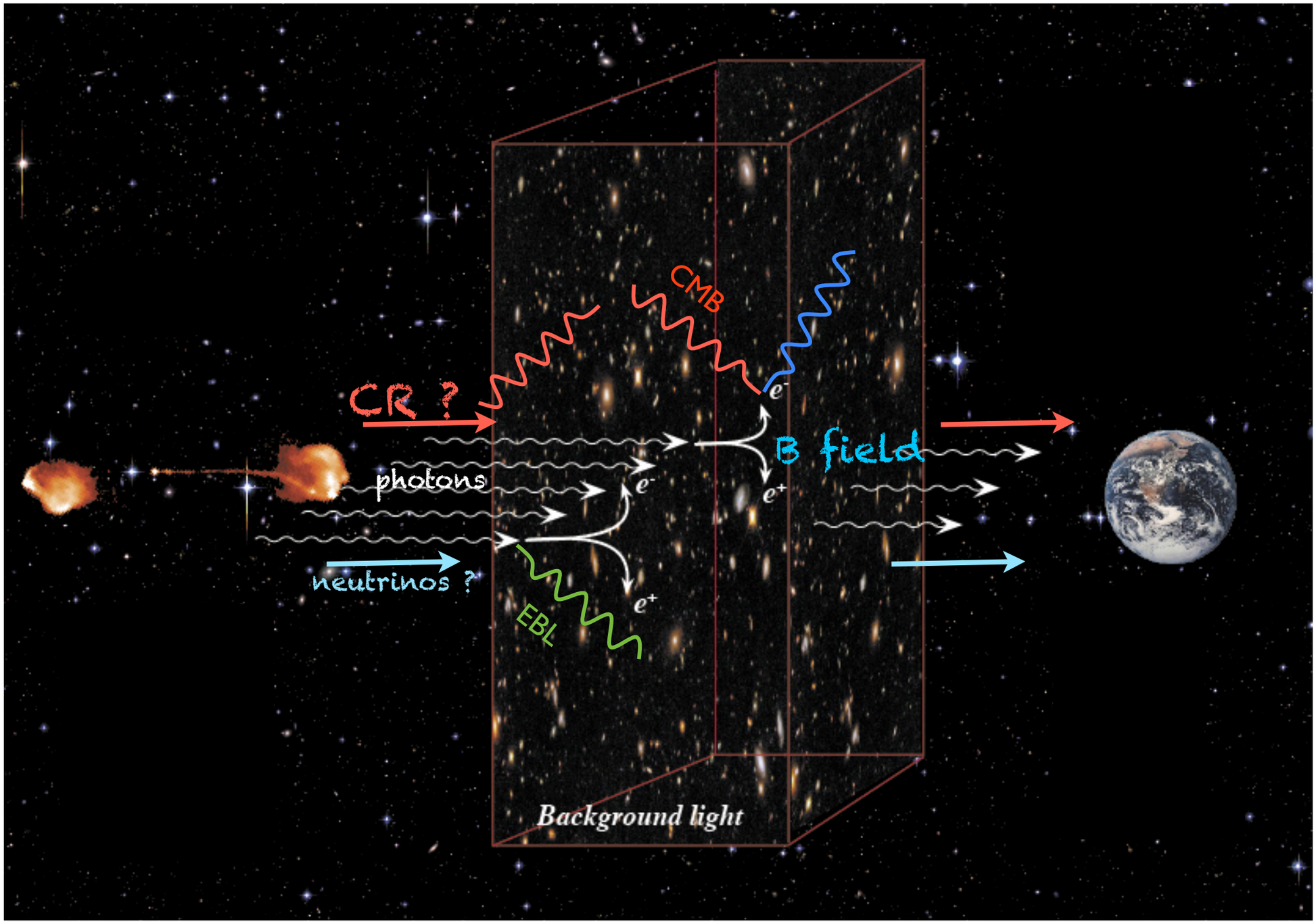
SED dominated by the relativistically boosted non-thermal continuum emission of the jet.

$$L_{\rm obs} = L'\delta^4 \qquad \delta = \frac{1}{\Gamma(1-\beta\cos\theta_{\rm v})}$$

Synchrotron and IC in leptonic models.

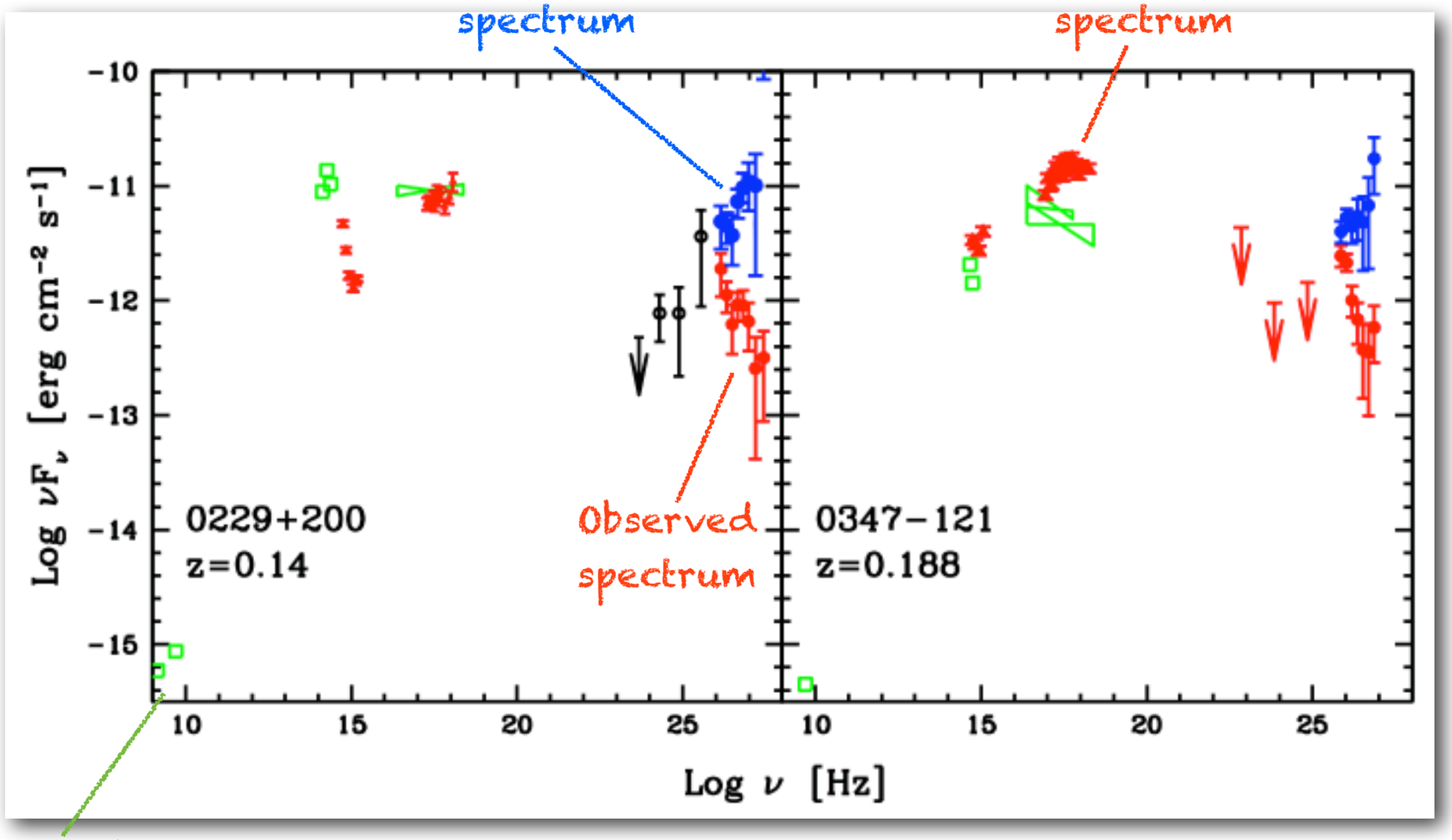
Also hadronic scenarios
(synchrotron or photo-meson emission)

Cosmic particle beams



Extreme BL Lacs

after Costamante et al. 2001



Extreme BL Lacs

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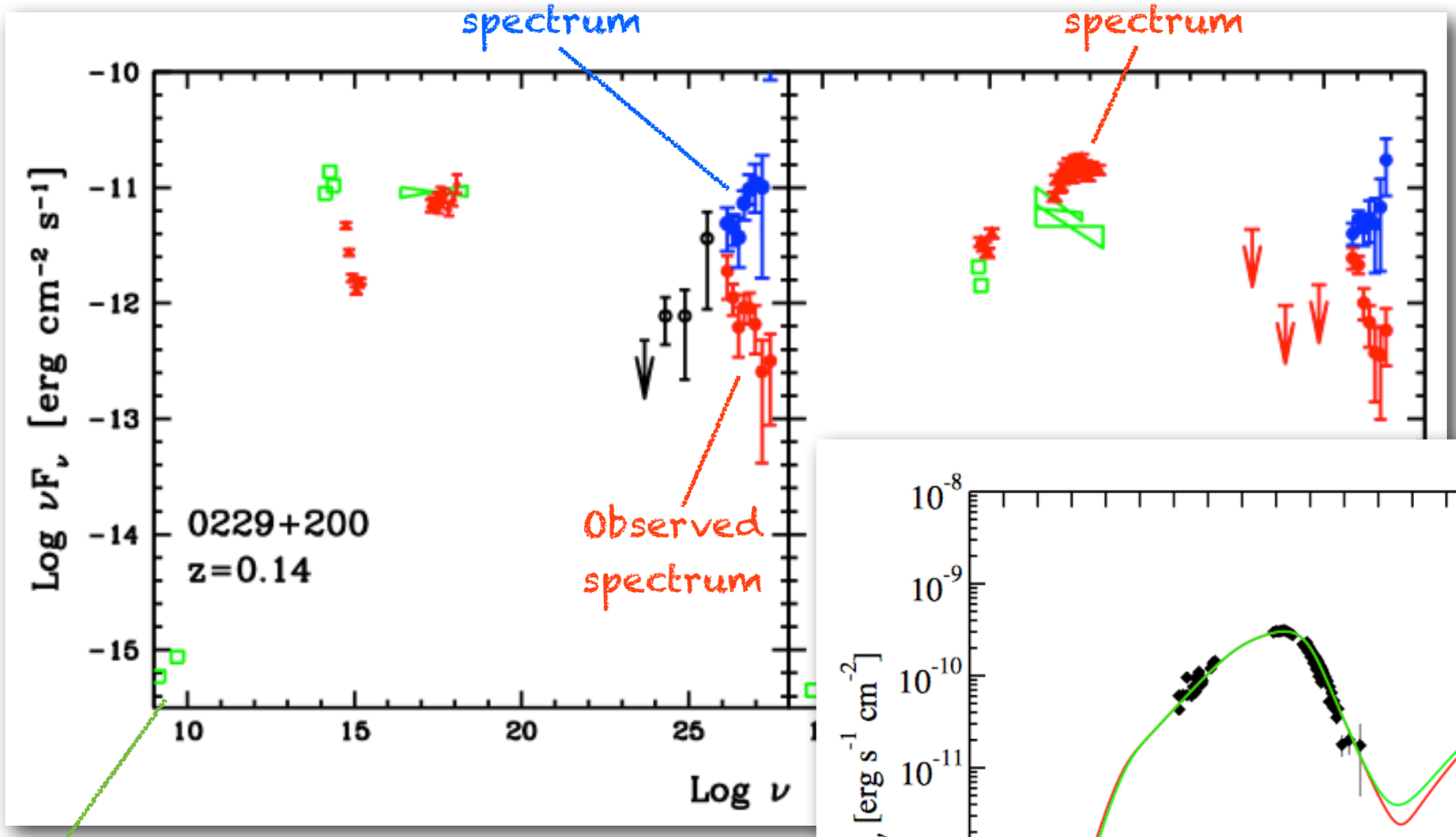

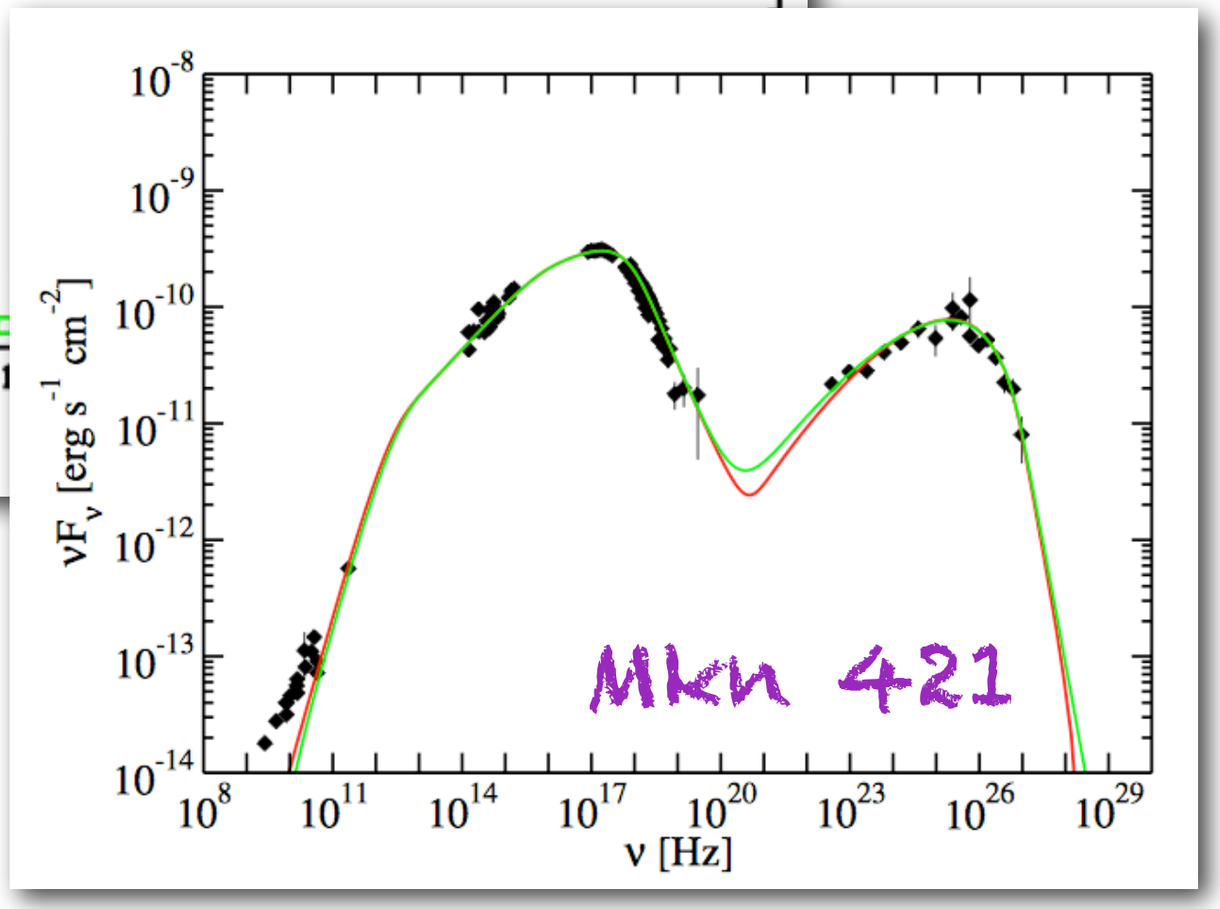

Extreme BL Lacs

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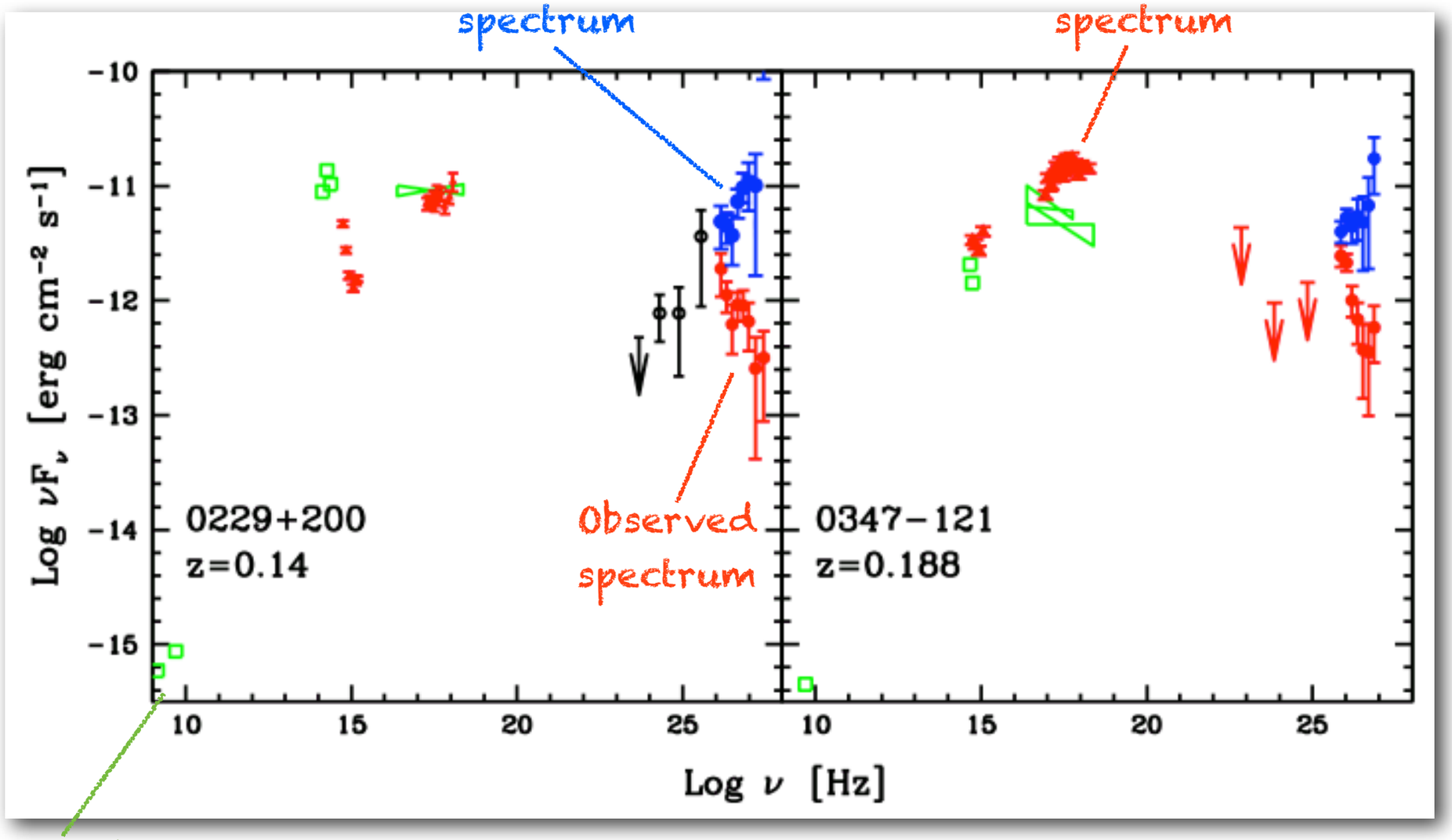


- Very hard X-ray and gamma-ray (deabsorbed) spectra

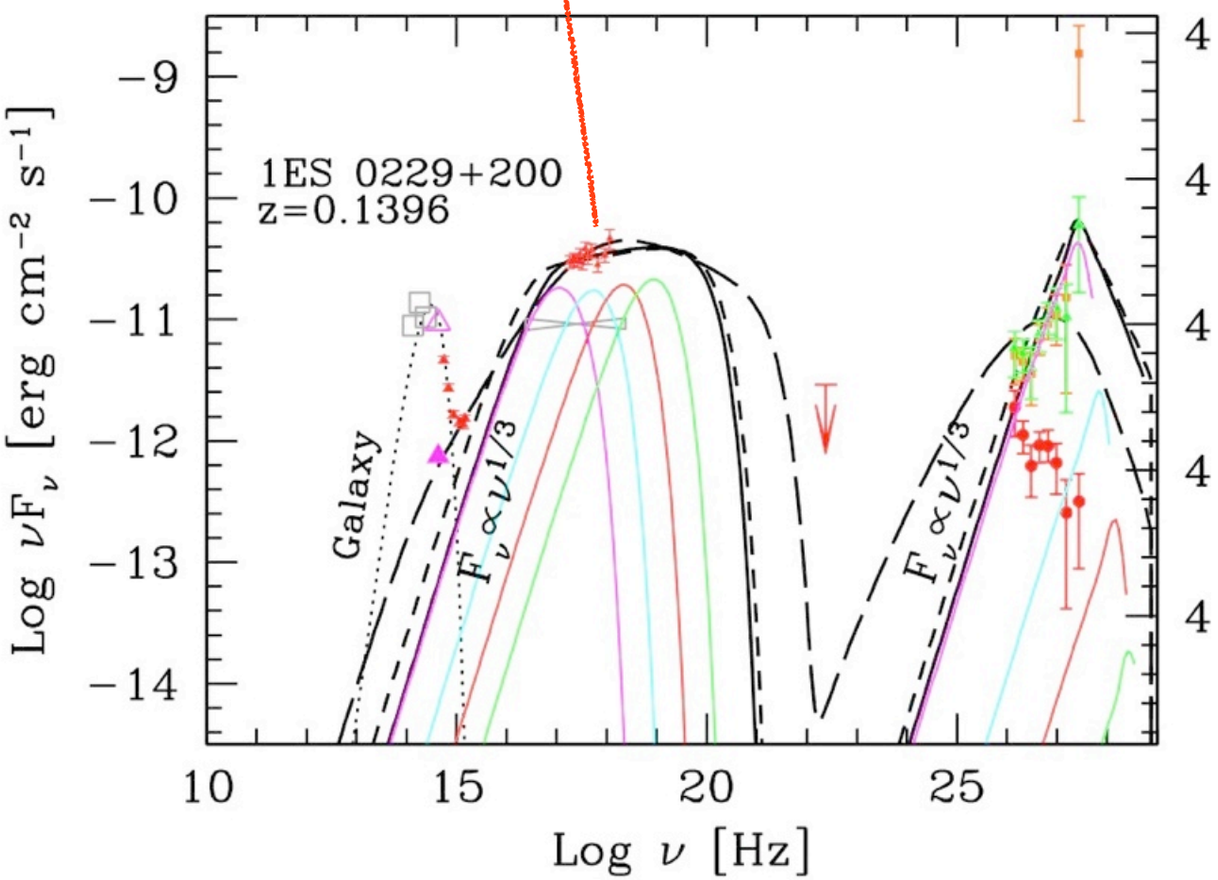
- Rather modest variability at all frequencies

Related topics

- Acceleration/emission mechanism? Katarzynski+2006, Tavecchio+ 2009; Lefa et al. 2011, Zacharopoulou et al. 2011
- far-IR EBL-probes Franceschini+ 2008; Dominguez+ 2011
- Probes for anomalies in EBL opacity:
  - ALPs De Angelis et al. 2011
  - Hadron beams Essey & Kusenko 2010; Murase+ 2012
  - LIV Fairbairn+ 2014, Tavecchio & Bonnoli, submitted
- parent population? "FR0" Baldi et al. 2009, 2015
- Relevance for HE gamma-ray background Inoue & Ioka 2012
- IGMF probes Neronov 2010; Tavecchio+ 2010

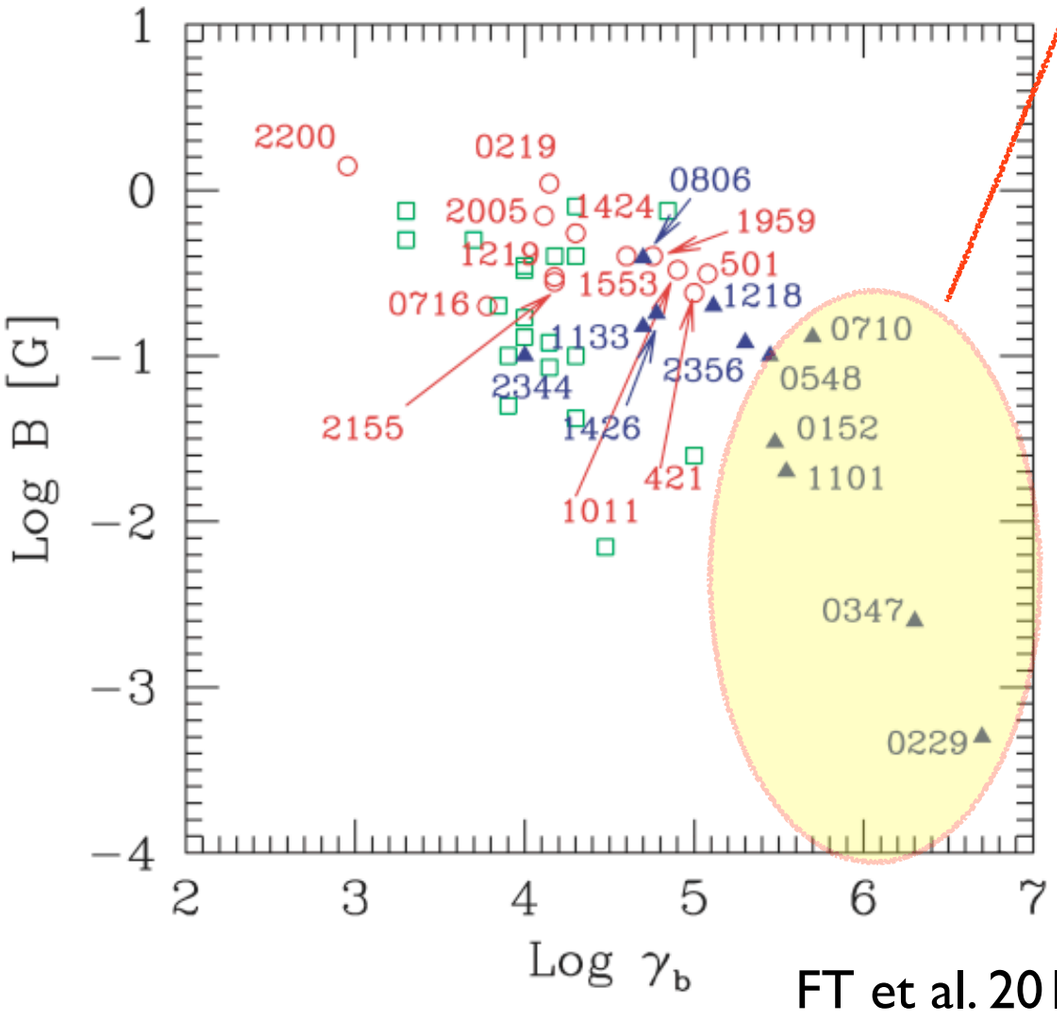
Extreme accelerators?

Large minimum electron energy



Katarzyński et al. 2005
FT et al. 2009

Very low B
Large e energies



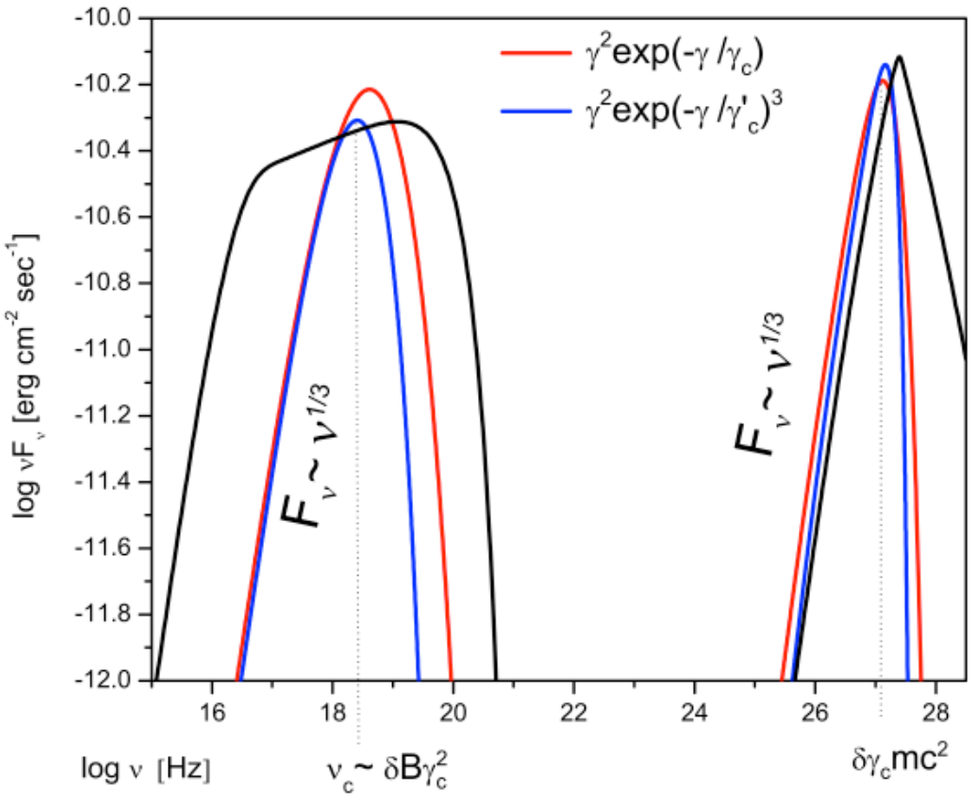
FT et al. 2010,2011

- Acceleration process?
- Why cooling so small?
- Why weakly/slowly variable?

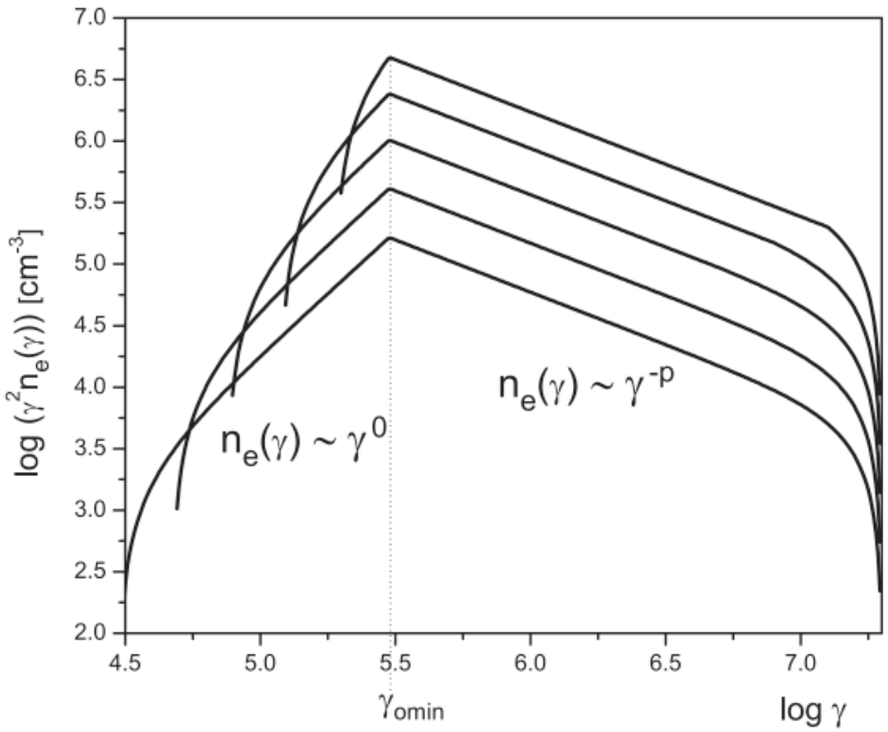
Emission mechanism?

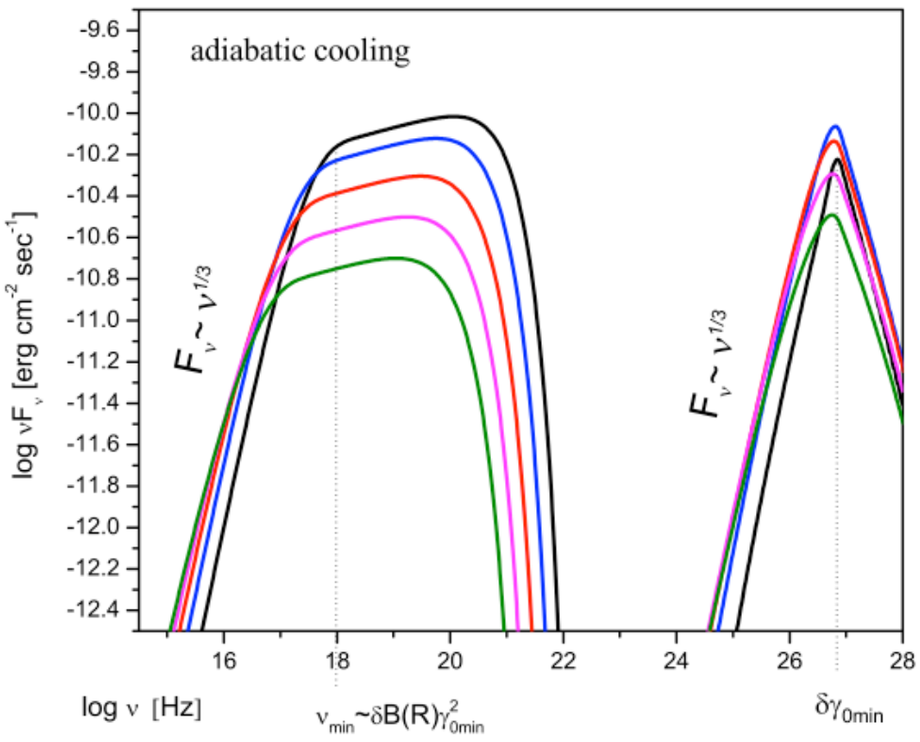
Lefa et al. 2011

Power law or Maxwellian-like distribution?

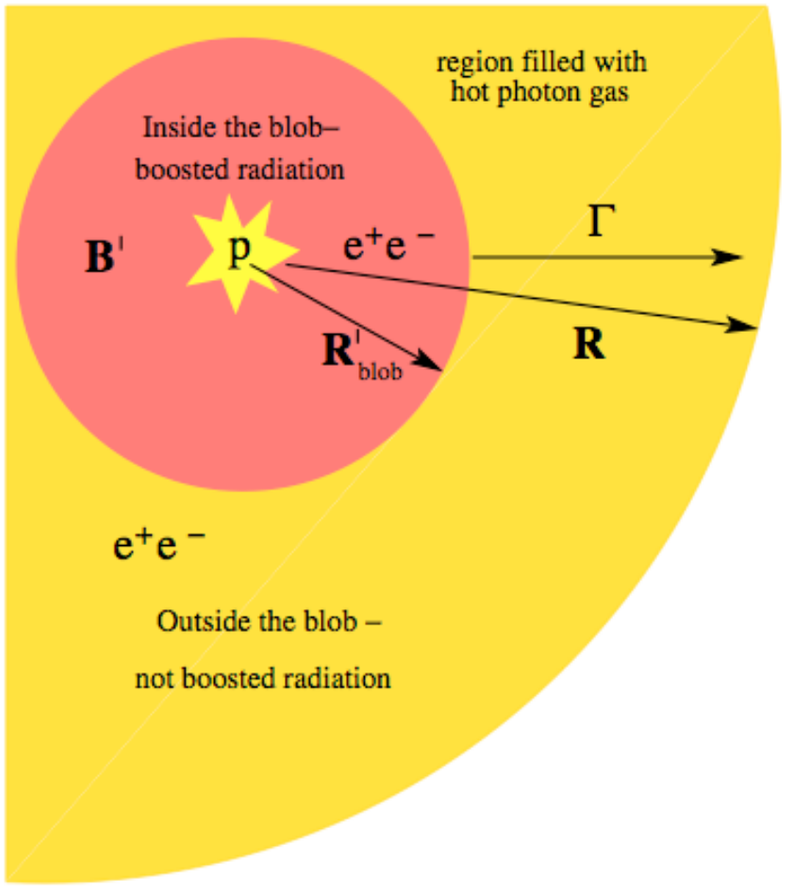


Adiabatic cooling?



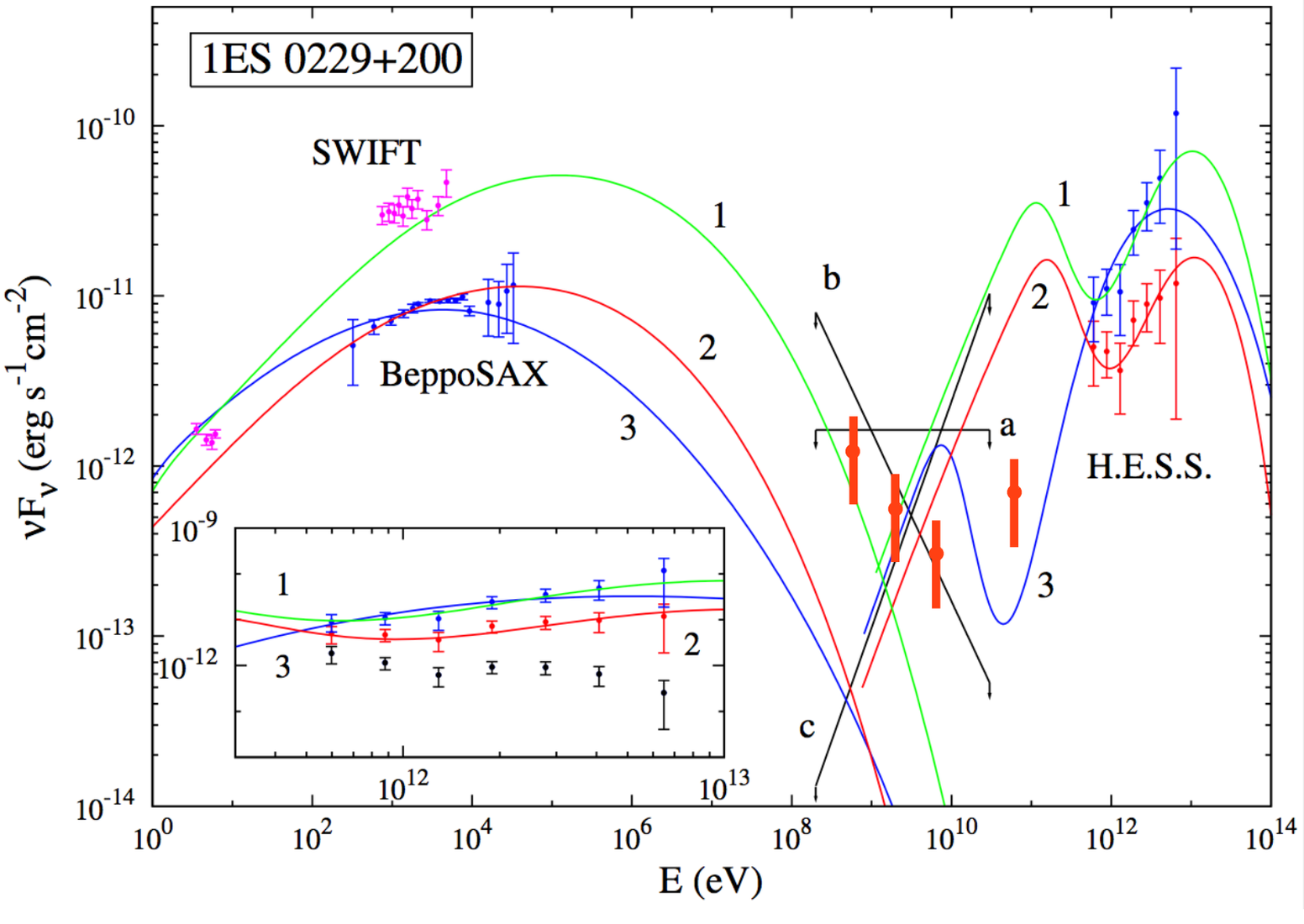


Emission mechanism?

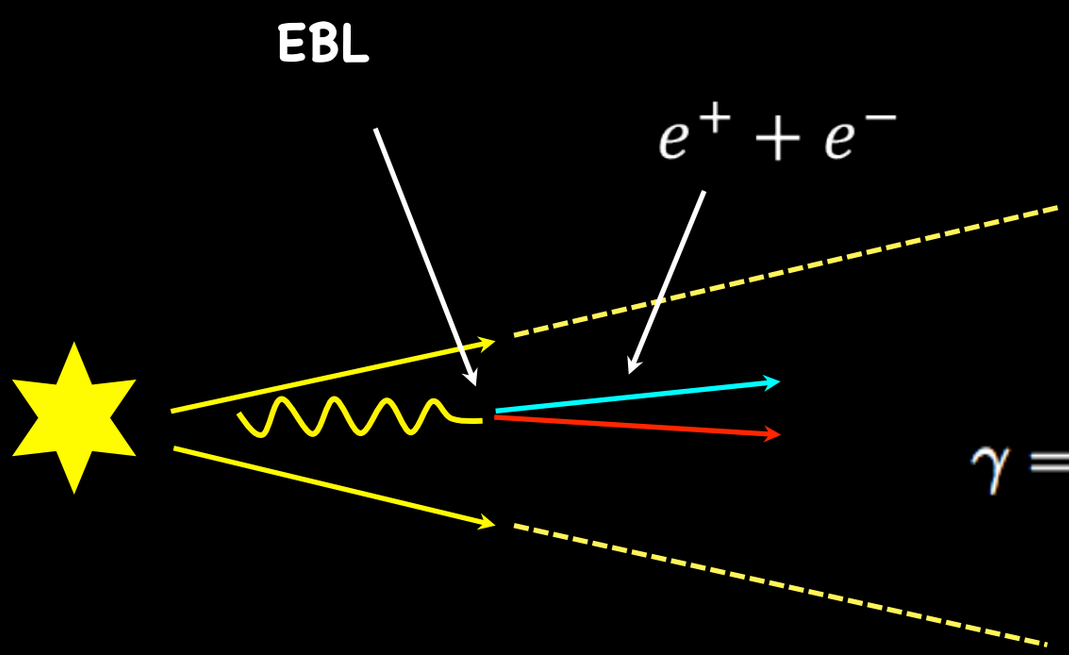


Internal absorption?

Zacharopoulou et al 2011



Probes of IGMF



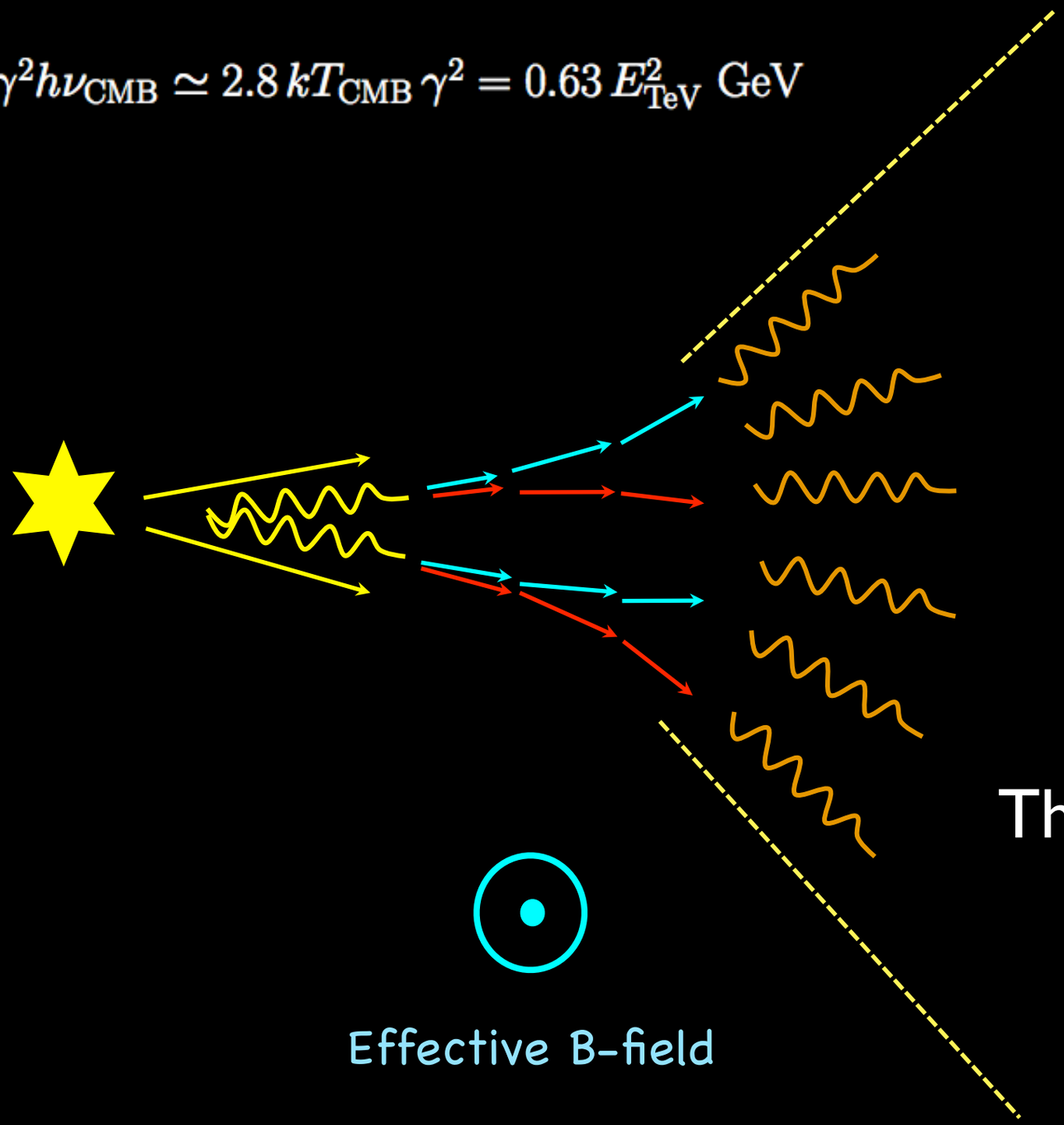
$$\gamma = \frac{E}{2m_e c^2} \simeq 10^6 E_{\mathrm{TeV}}$$

$$\gamma_1 + \gamma_2 = e^- + e^+$$

Probes of IGMF

$$\epsilon = \gamma^2 h\nu_{\rm CMB} \simeq 2.8\, kT_{\rm CMB}\, \gamma^2 = 0.63\, E^2_{\rm TeV}\ {\rm GeV}$$

$$\theta_\gamma = \frac{ct_{\rm cool}}{r_{\rm L}} = 1.17\, B_{-15}\, \gamma_6^{-2}\ {\rm rad}$$

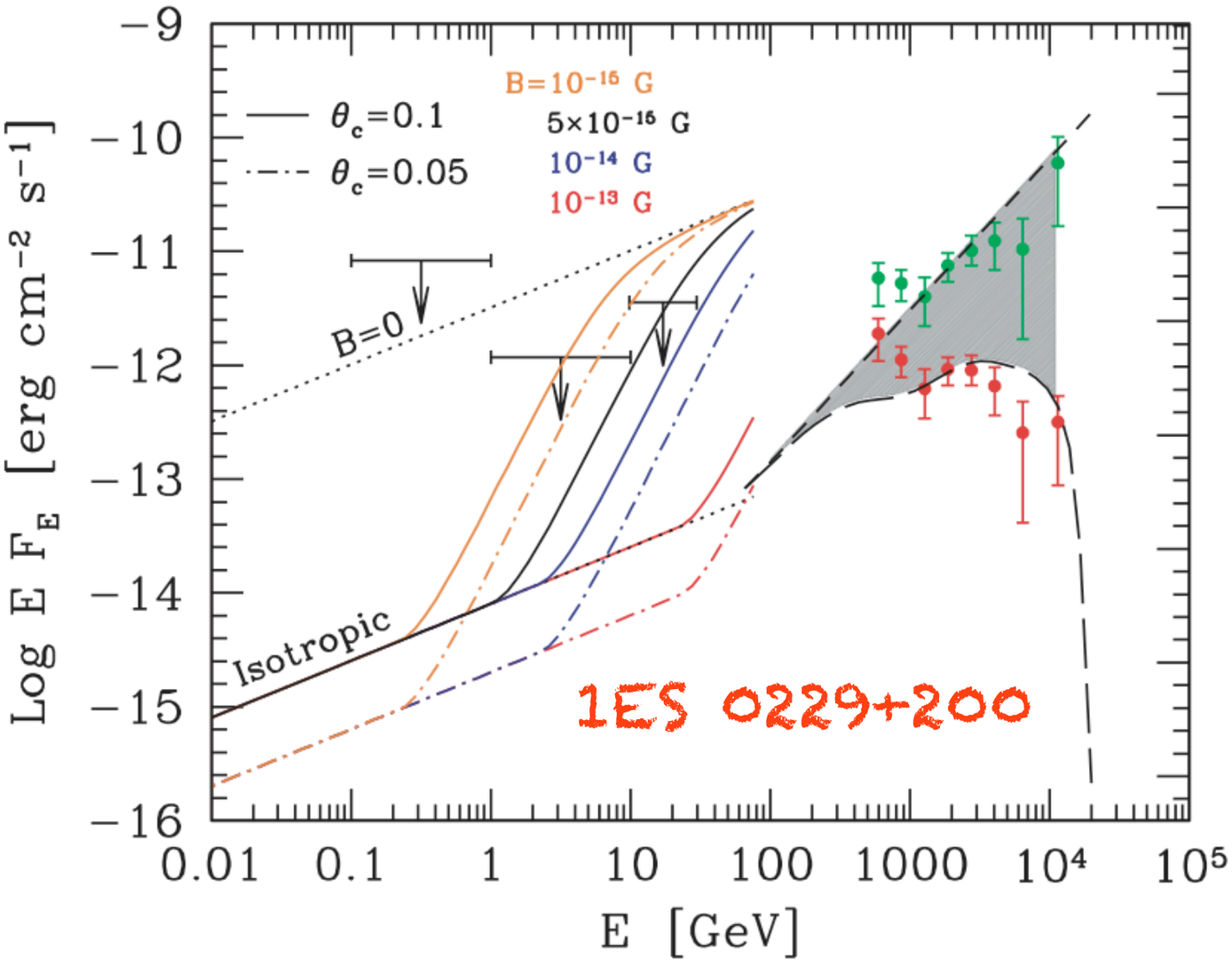


The reprocessed flux is diluted within a larger solid angle

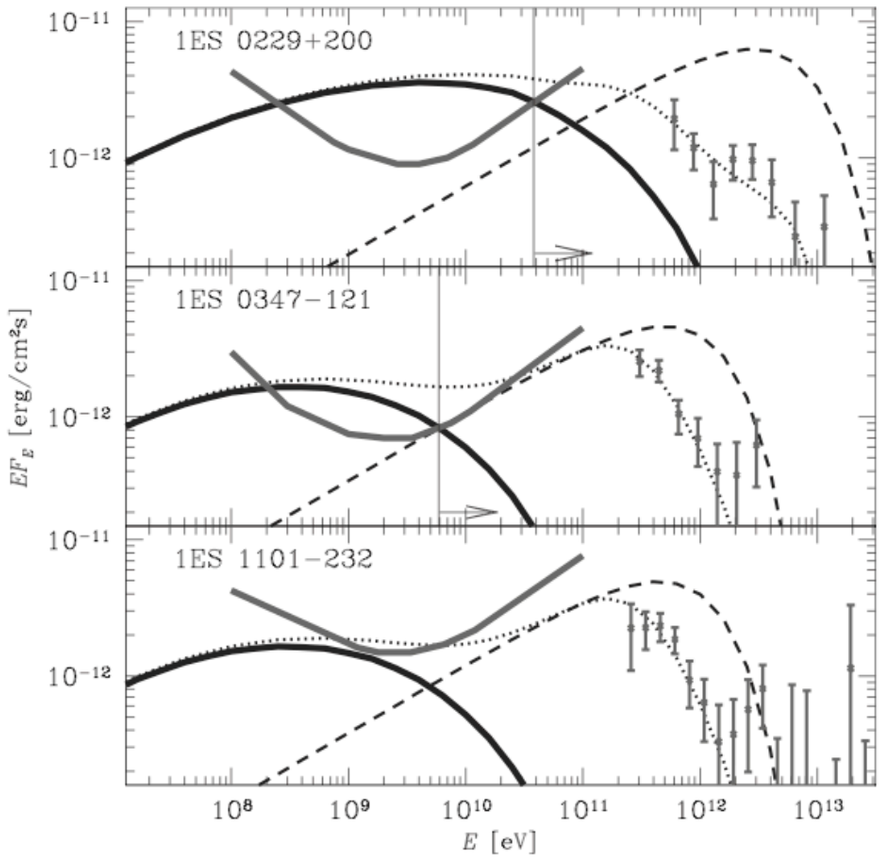
Probes of IGMF

$B > 10^{-18}$–10^{-15} G

FT et al. 2010,2011

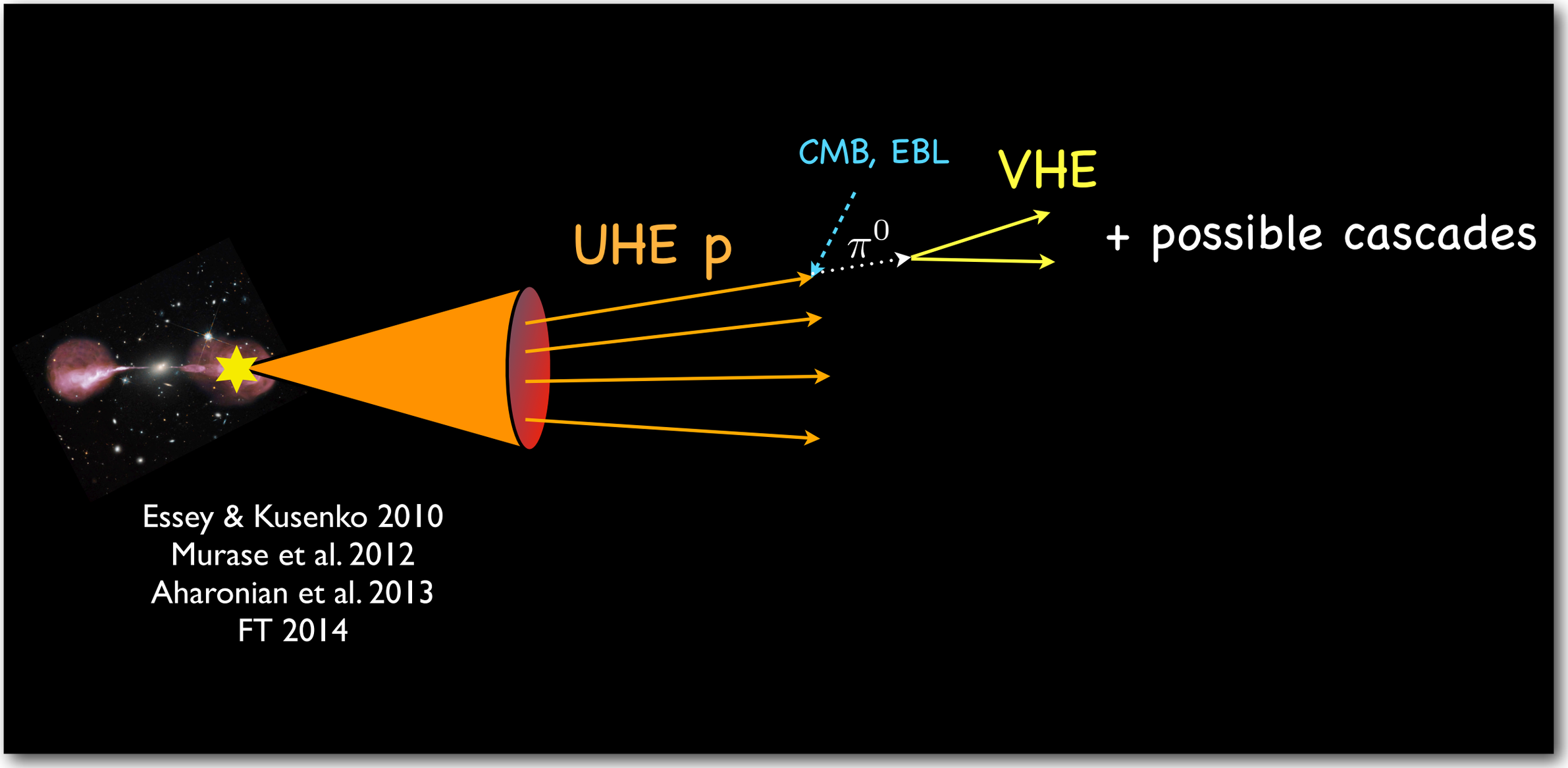


Neronov & Vovk 2010



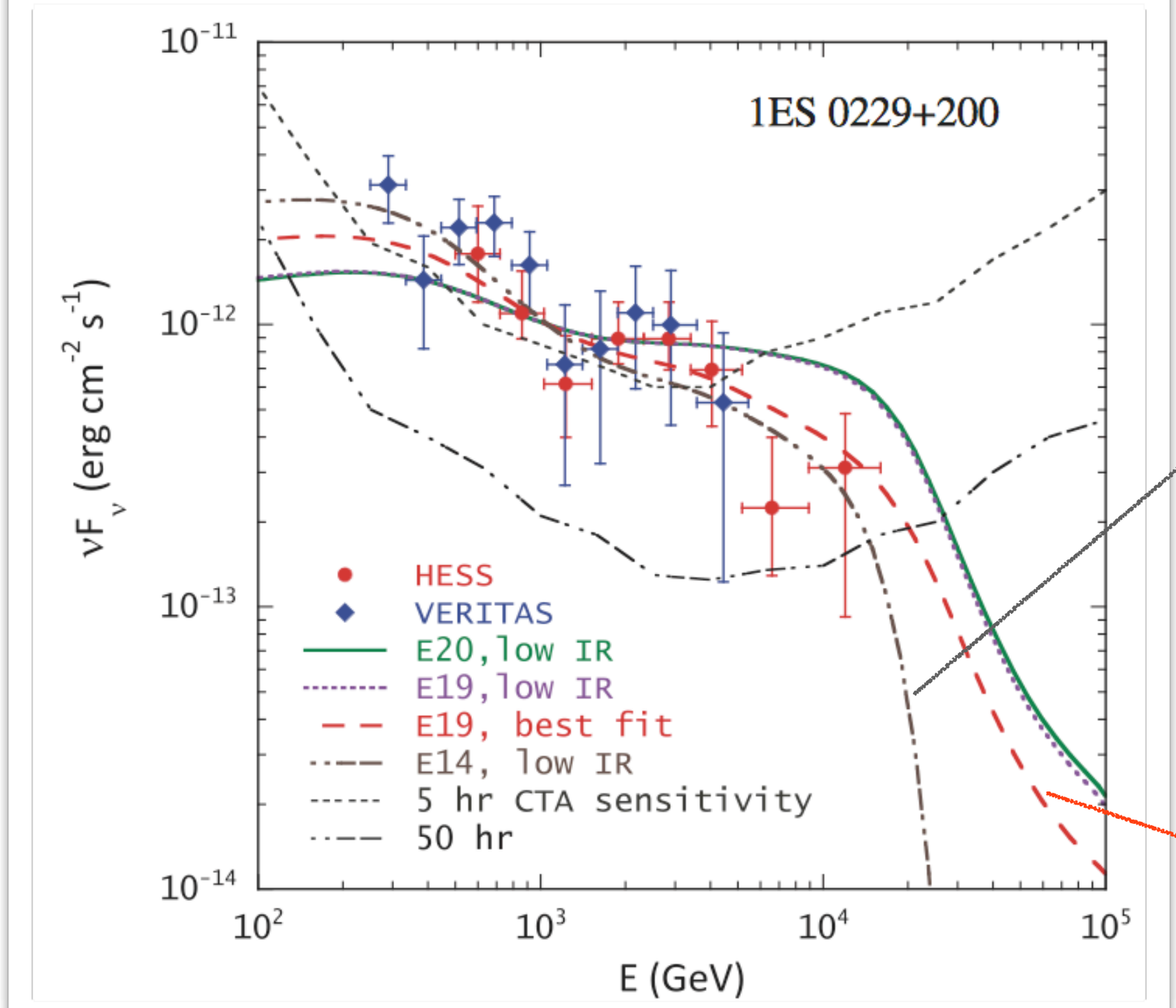
Also Dolag et al. 2011, Dermer et al. 2011, Taylor et al. 2012 ...

Hadron beams?



Hadron beams?

Murase et al. 2012



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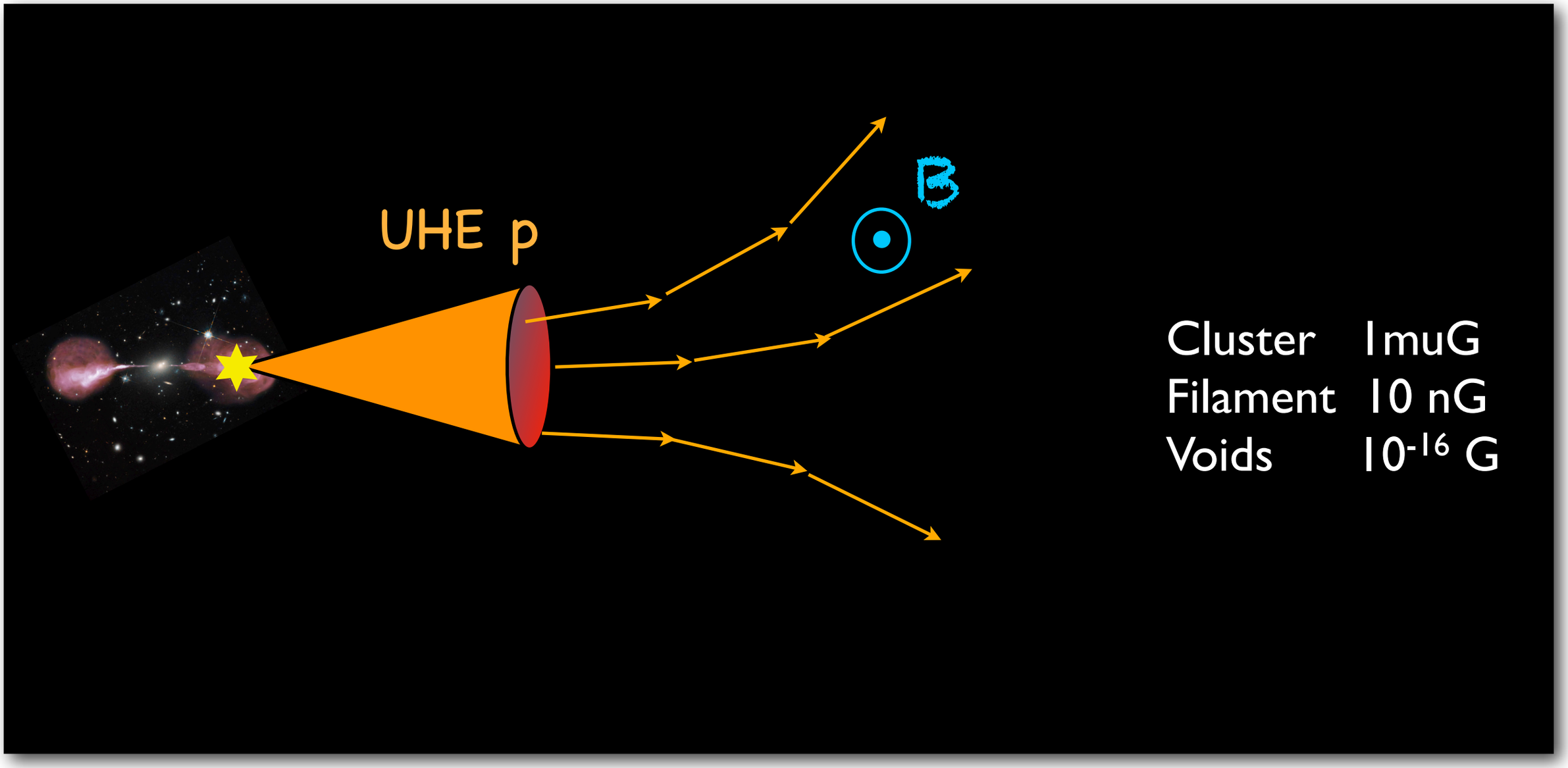

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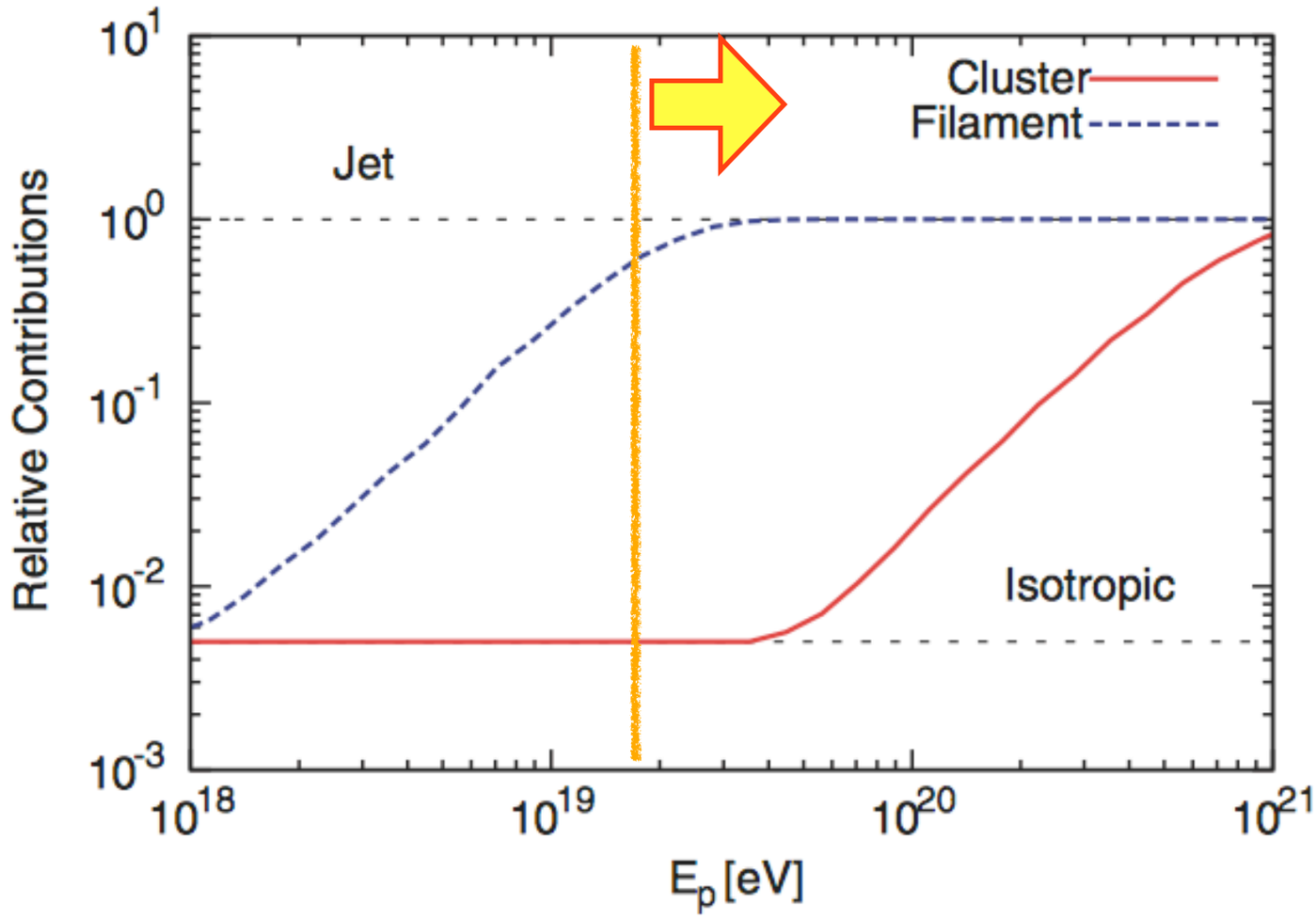


$$L_{\rm CR} \approx 10^{45} - 10^{46}\ {\rm erg\ s^{-1}}$$

$$P_{\rm CR} = L_{\rm CR}\ \frac{\Delta\Omega}{4\pi}$$

$$\theta_{\rm CR} \approx \frac{\sqrt{2\lambda_{\rm coh} l}}{3r_L} \simeq 8^\circ Z E_{A,19}^{-1} B_{\rm EG,-8} \left(\frac{\lambda_{\rm coh}}{0.1\,{\rm Mpc}}\right)^{1/2} \left(\frac{l}{\rm Mpc}\right)^{1/2}$$

$$\theta_{\rm j} \approx 5^\circ$$

Hadron beams?

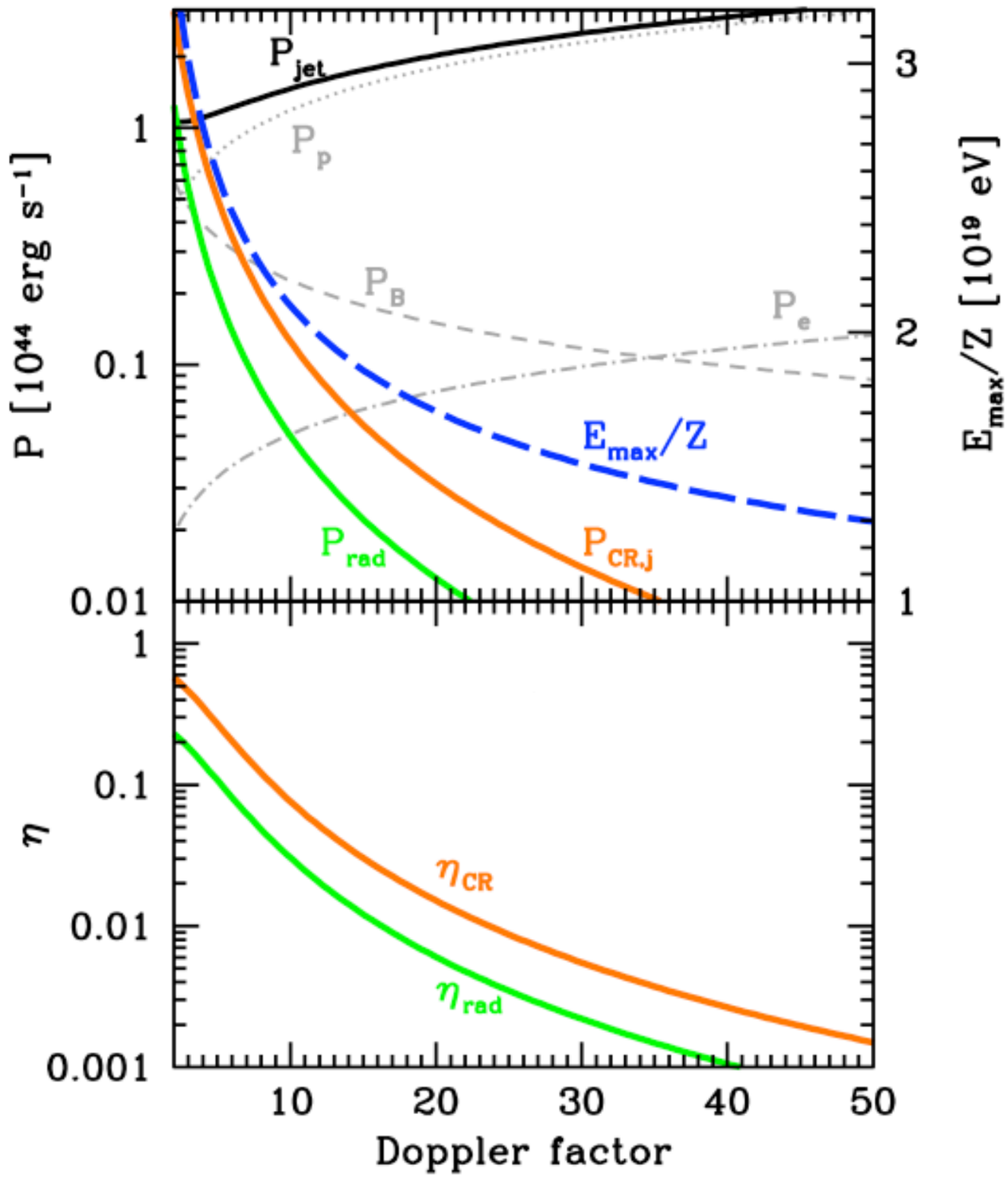
Gyroradius < source size

Hillas 1984

$$E_{\max} = ZeBR\Gamma$$

Emission model

Tavecchio 2014

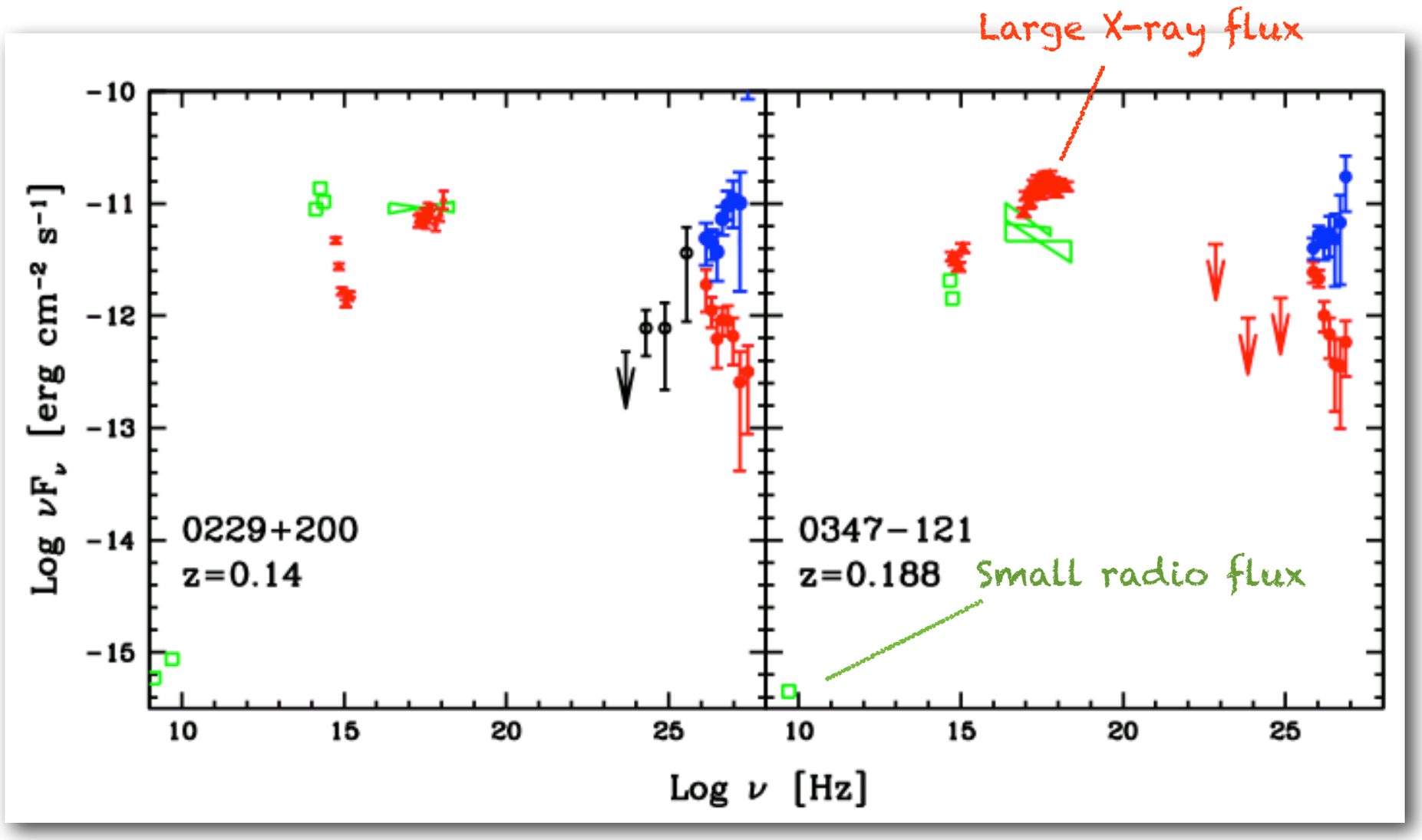


Looking for EHBL

Quite interesting sources, but only a few

Population?
Impact on gamma-ray background?
Evolution?
Parent population?

Looking for EHBL



Look for BL Lacs with large X-ray/radio flux ratio and weak gamma-ray emission

Looking for EHBL

Bonnoli, FT et al. 2015

71 BL Lacs form SDSS+FIRST
(Plotkin et al. 2011)
+
z<0.4 (small EBL absorbtion)
+
X-ray detection

50 BL Lacs

Looking for EHBL

Bonnoli, FT et al. 2015

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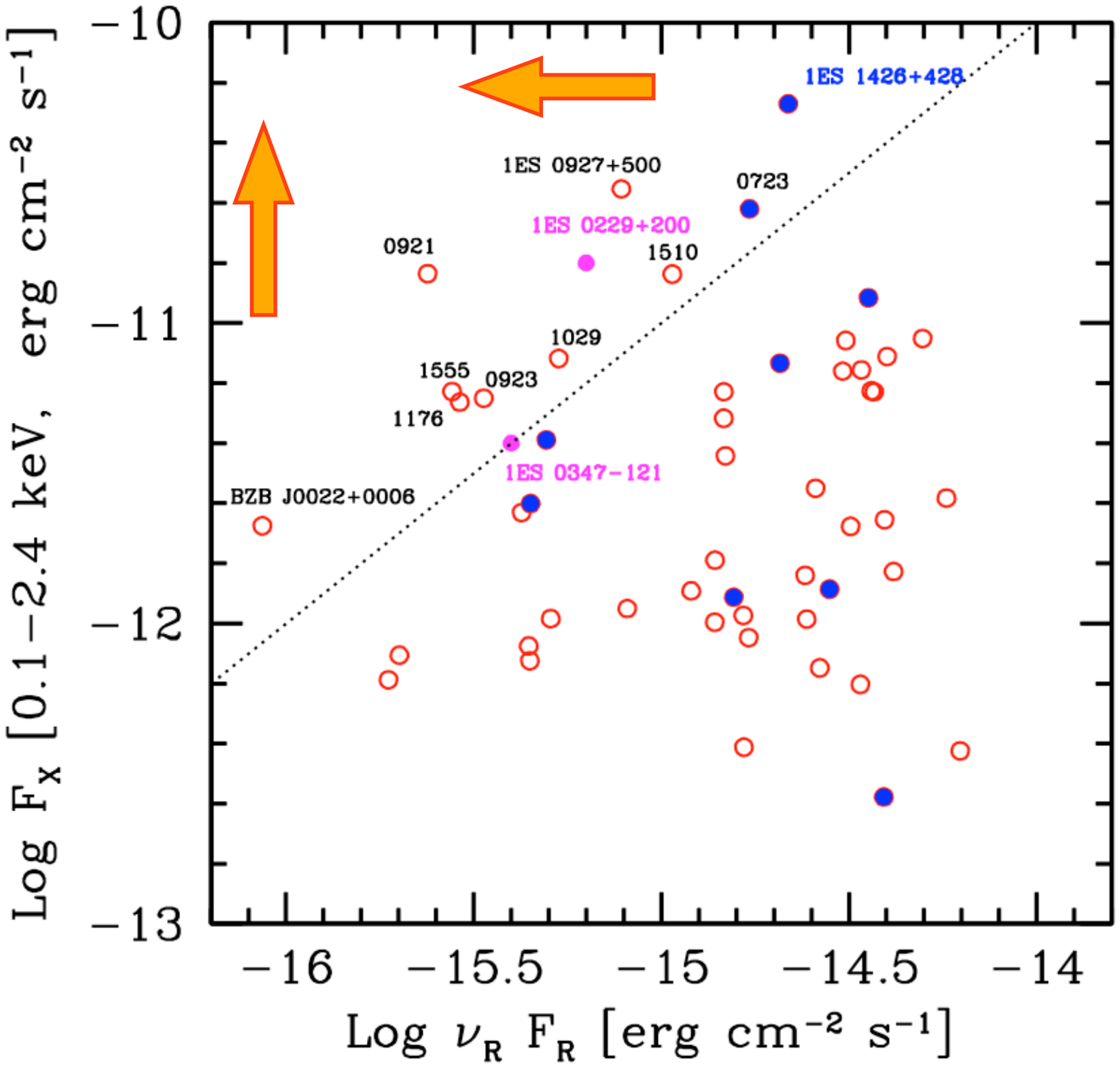


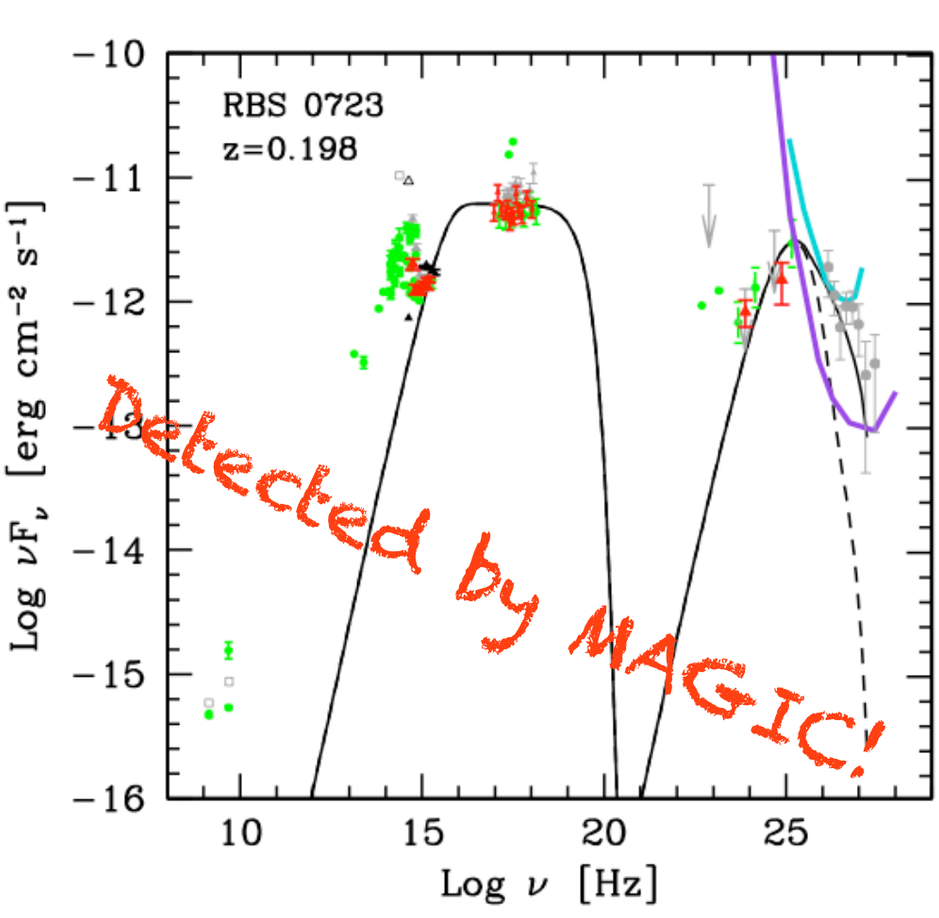
Looking for EHBL

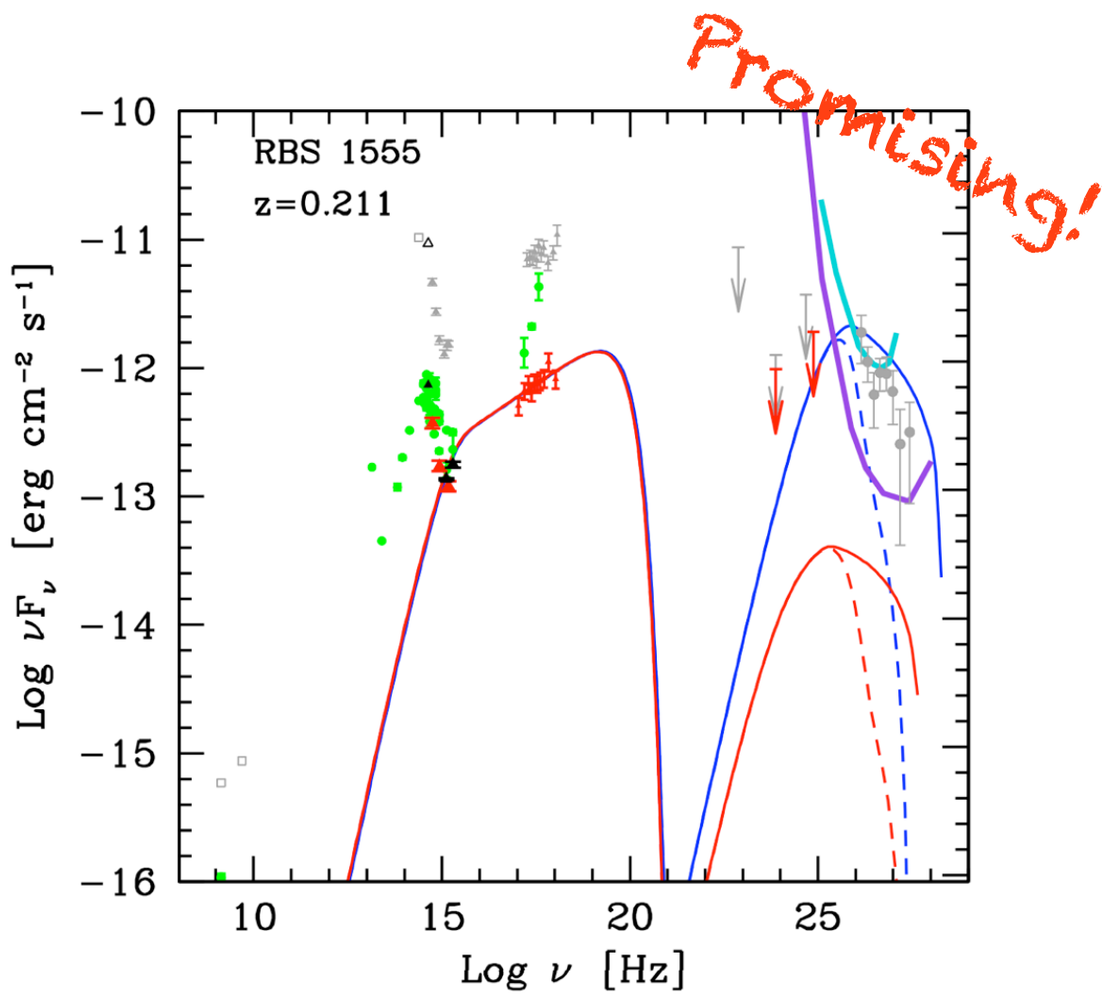
Source Name	R.A.(J2000)	δ(J2000)	l	b	Redshift	A_B
BZB J0022+0006	5.5040	0.1161	107.18	−61.85	0.306	0.108
RBS 0723	131.8039	11.5640	215.46	30.89	0.198	0.093
1ES 0927+500	142.6566	49.8404	168.19	45.71	0.187	0.073
RBS 0921	164.0275	2.8704	249.28	53.28	0.236	0.178
RBS 0923	164.3462	23.0552	215.96	63.91	0.378	0.088
RBS 1029	176.3963	−3.6671	273.11	55.34	0.168	0.130
RBS 1176	193.2540	38.4405	121.36	78.68	0.371	0.083
RBS 1510	233.2969	18.9081	29.21	52.05	0.307	0.210
RBS 1555	241.3293	54.3500	84.35	45.60	0.212	0.041

9 candidates

Swift (UV-X-ray) observations

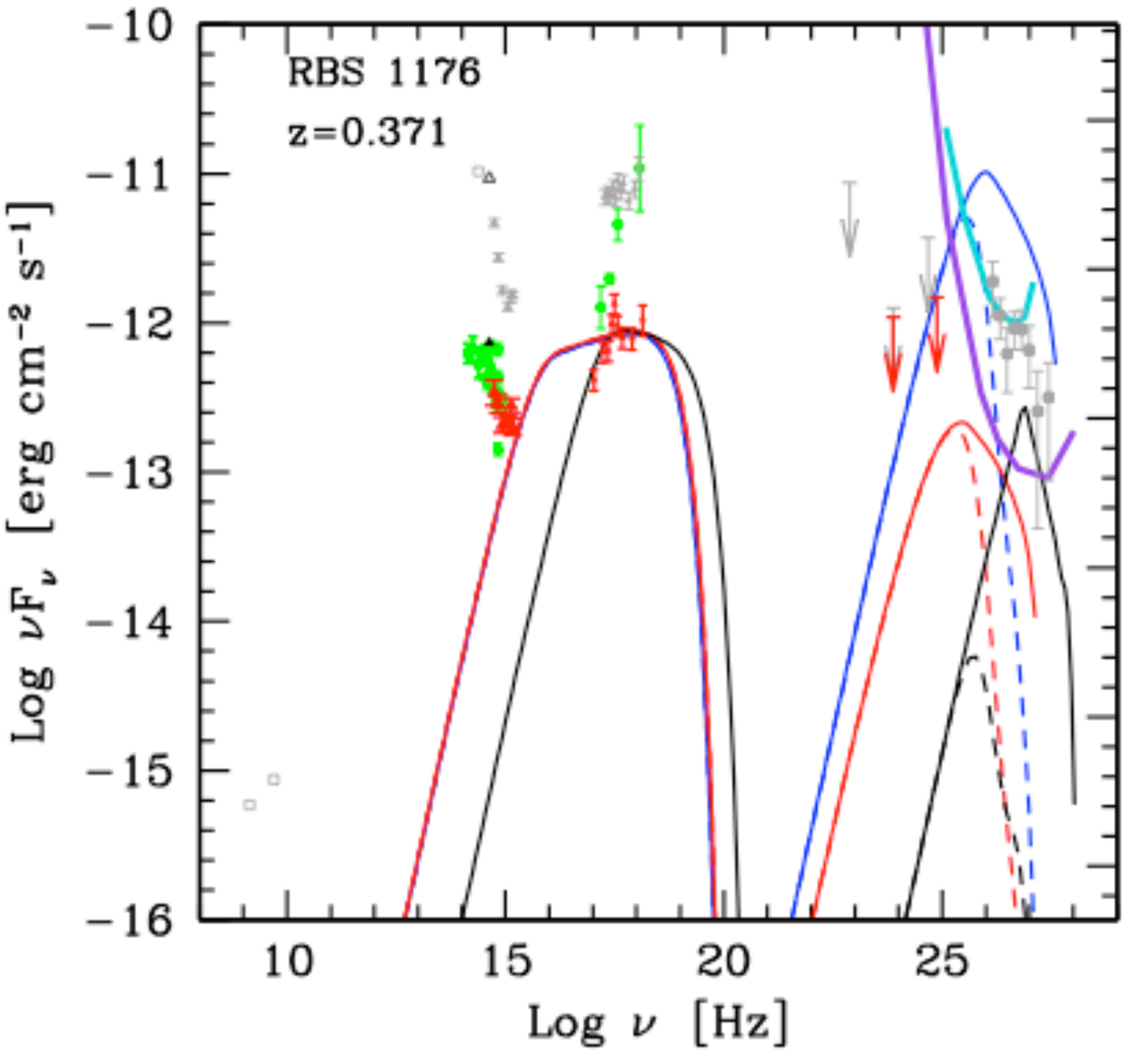
Confirmation





Looking for EHBL

RBS 1176: an ultra-extreme HBL?



Looking for EHBL

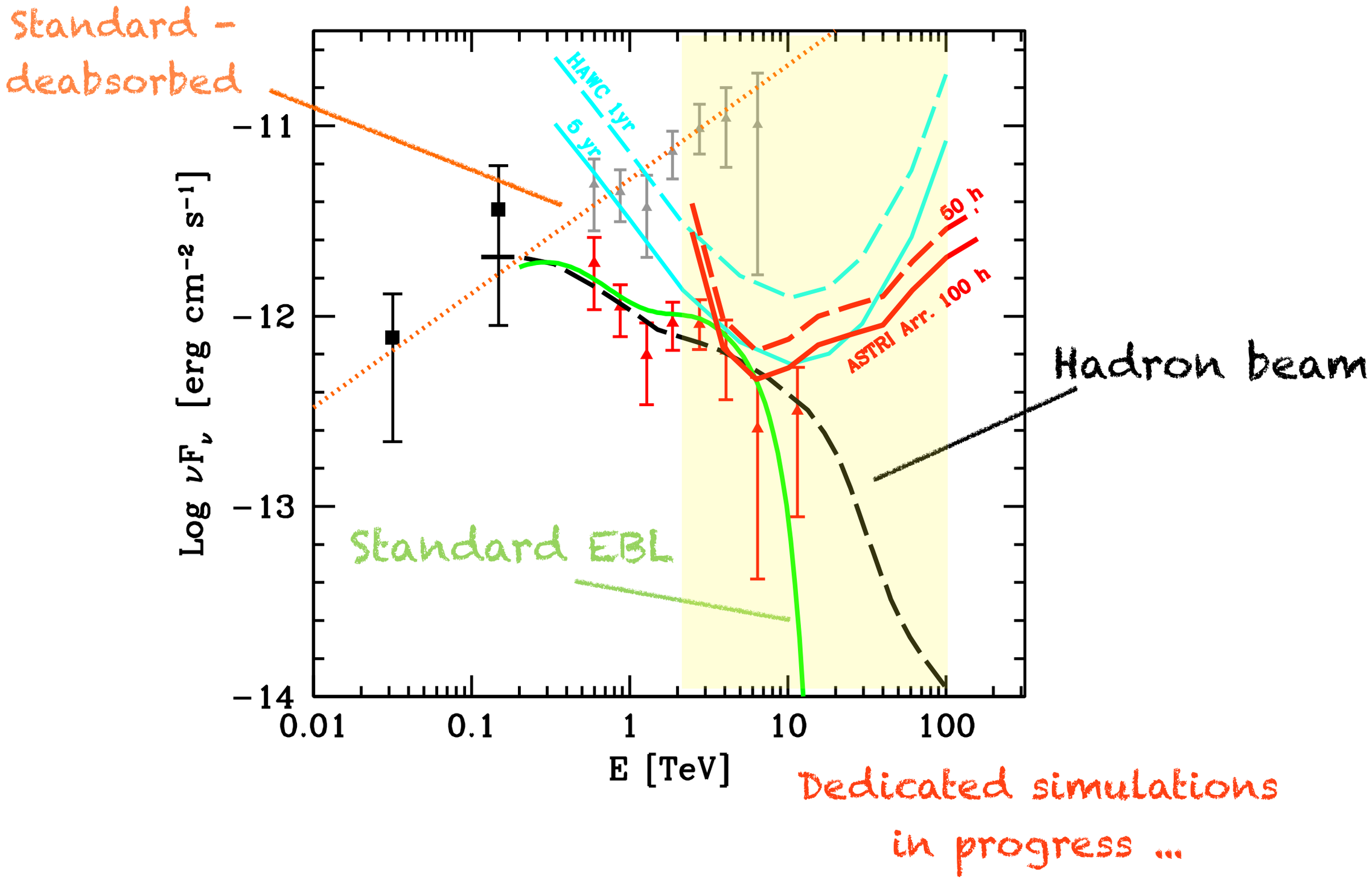
We start to extend the selection

Rosat Bright Survey
+
FIRST (1.4 GHz)
+
No 3FGL

14 new + 4 in Bonnoli 2015

Thank you!

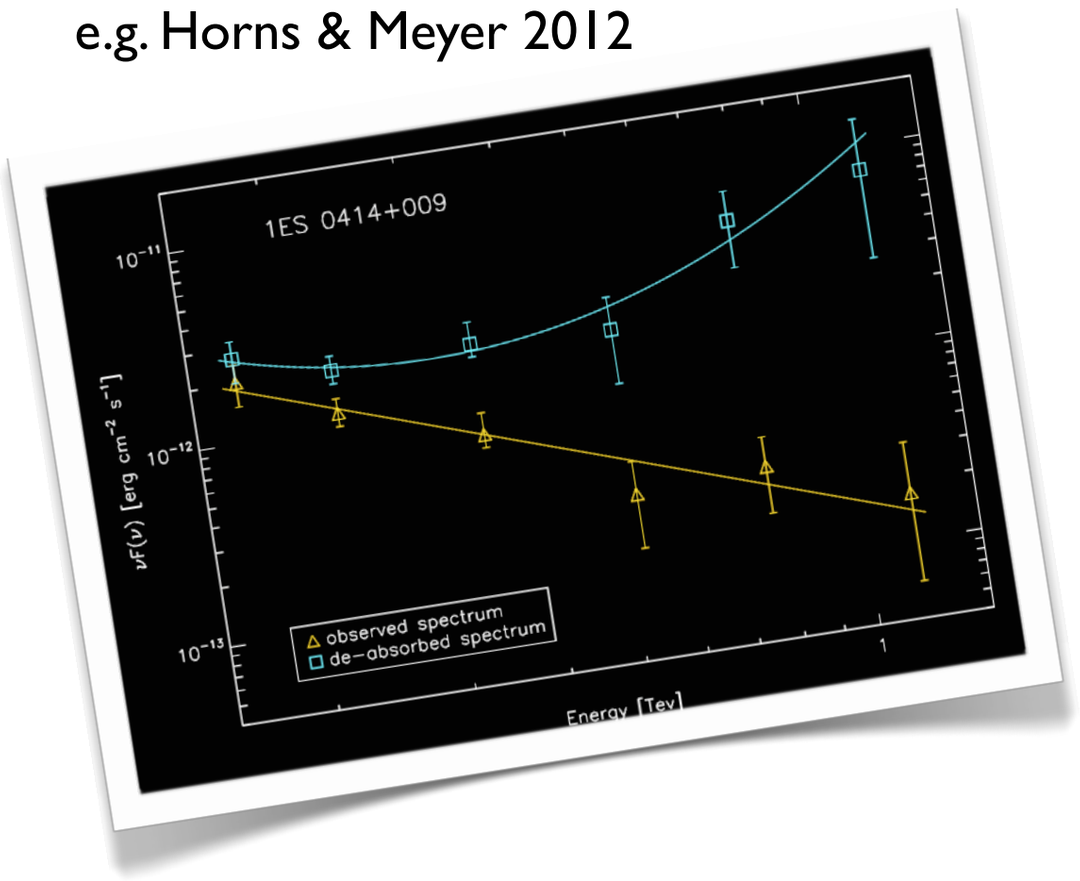
Even before CTA completion!



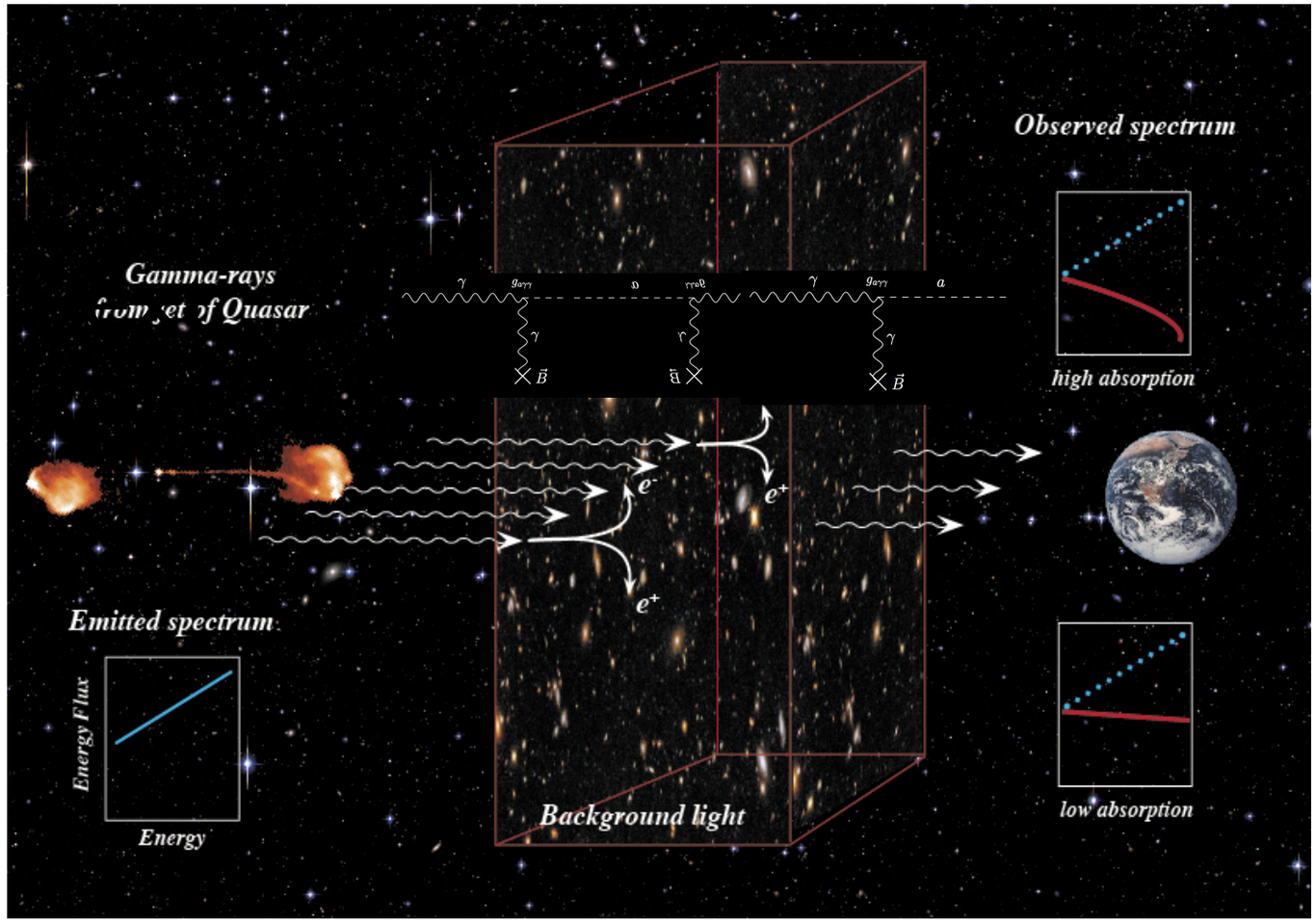
Dedicated simulations in progress ...

Cosmic opacity anomaly: ALP

e.g. Horns & Meyer 2012



e.g. De Angelis et al. 2011



Cosmic opacity anomaly: LIV

LIV induces an affective mass for the photon

$$\beta_\gamma = 1 - \left(\frac{E_\gamma}{M_{LVn}}\right)^n \quad ; \quad m_\gamma^2 = -\frac{E_\gamma^{2+n}}{M_{LVn}^n},$$

Modification of threshold for pair production at high E

LIV induces suppression of EBL-opacity

ASTRI/CTA Mini-Array

Fairbairn+ 2014

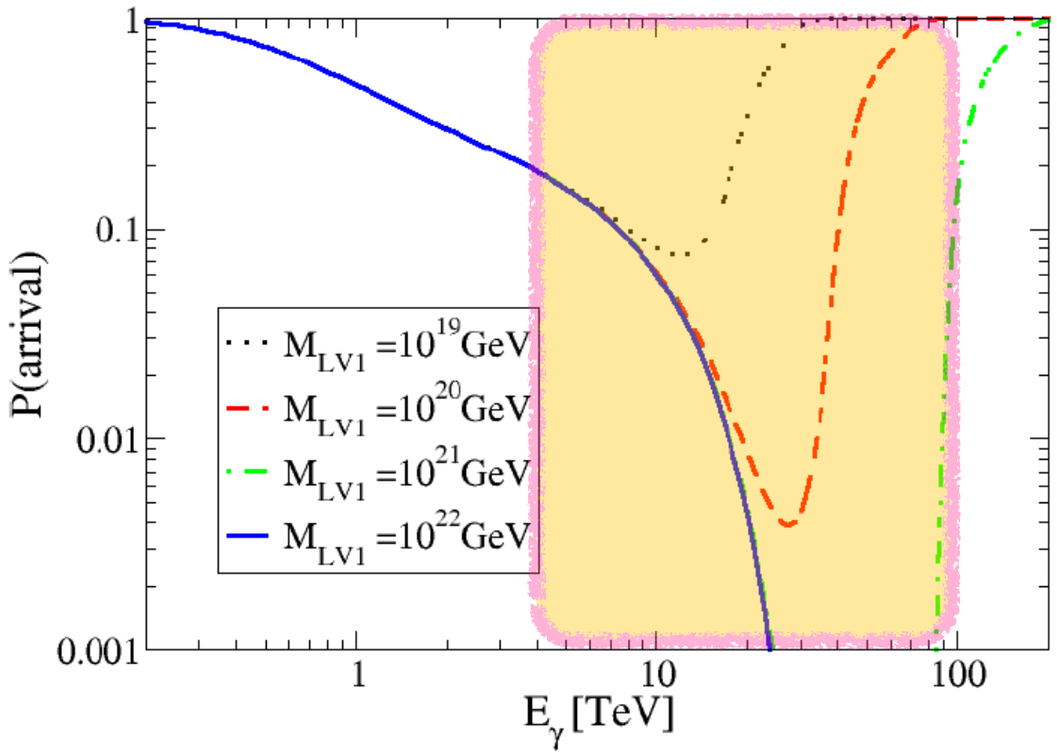
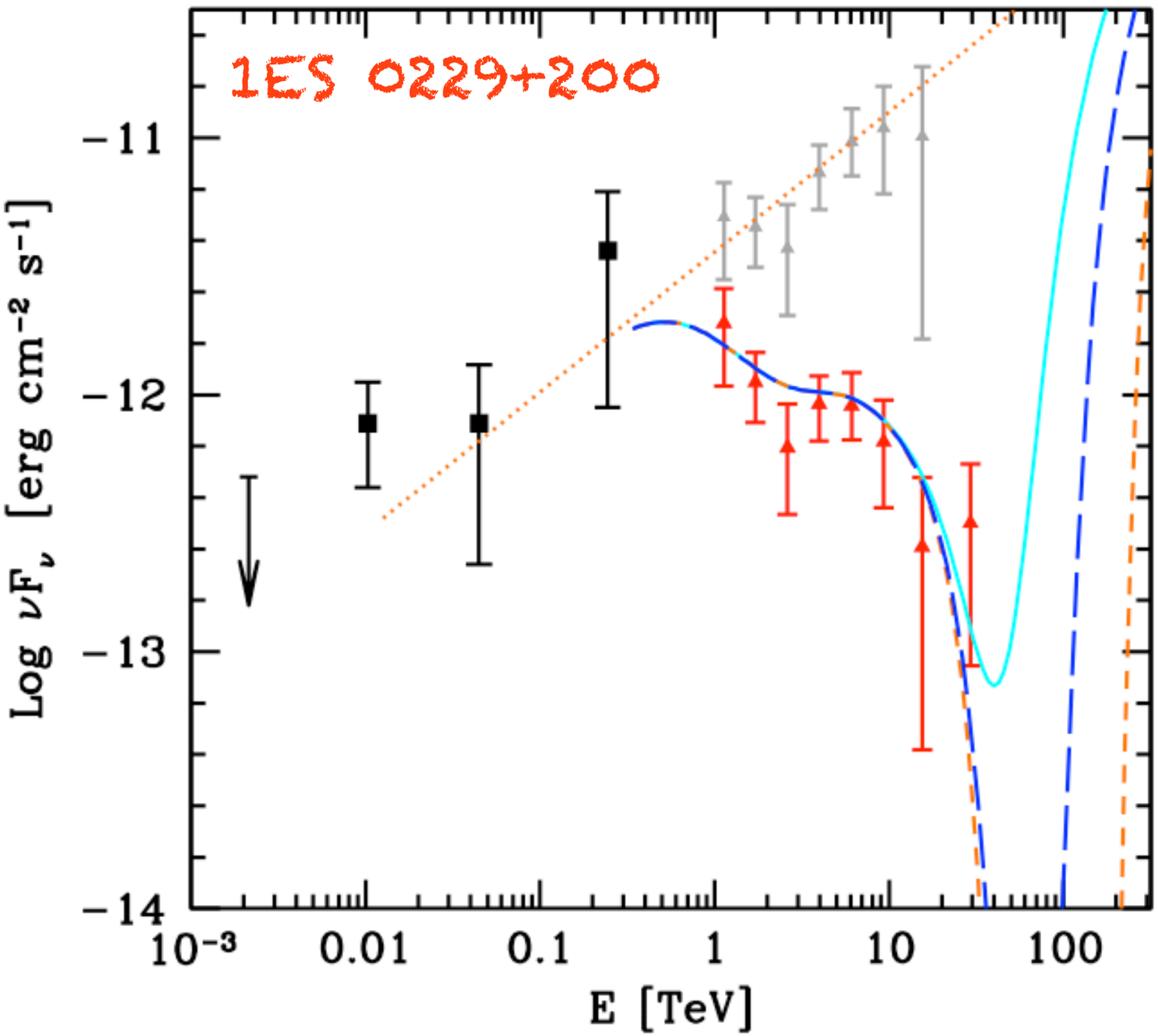


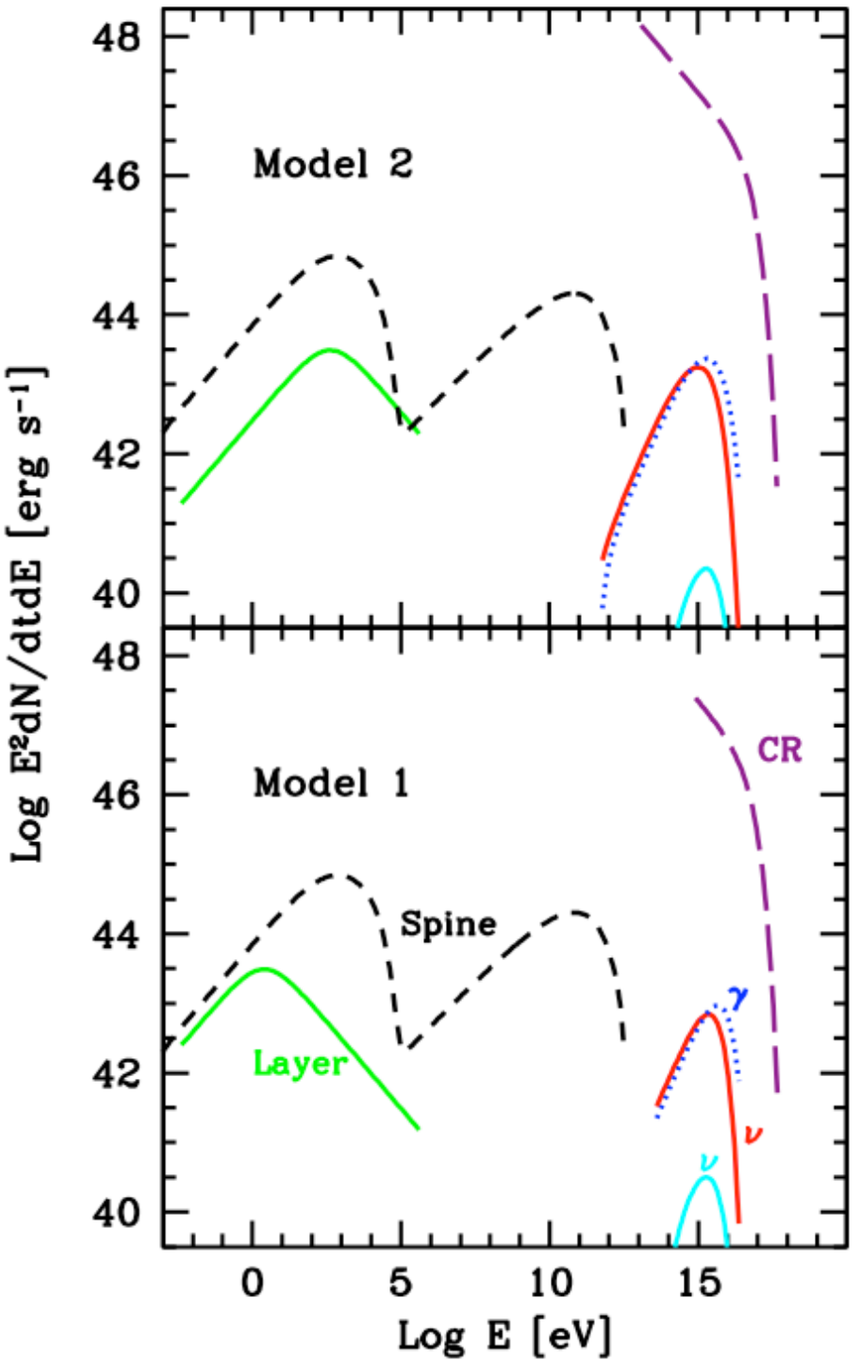
Figure 2. *The arrival probability of a photon emitted from a hypothetical source at redshift $z = 0.05$ as a function of energy. The different curves represent different values of the Lorentz-violating scale M_{LV1}. VHE photons with energies $\gtrsim 100$ TeV can travel through the CMB effectively unimpeded.*

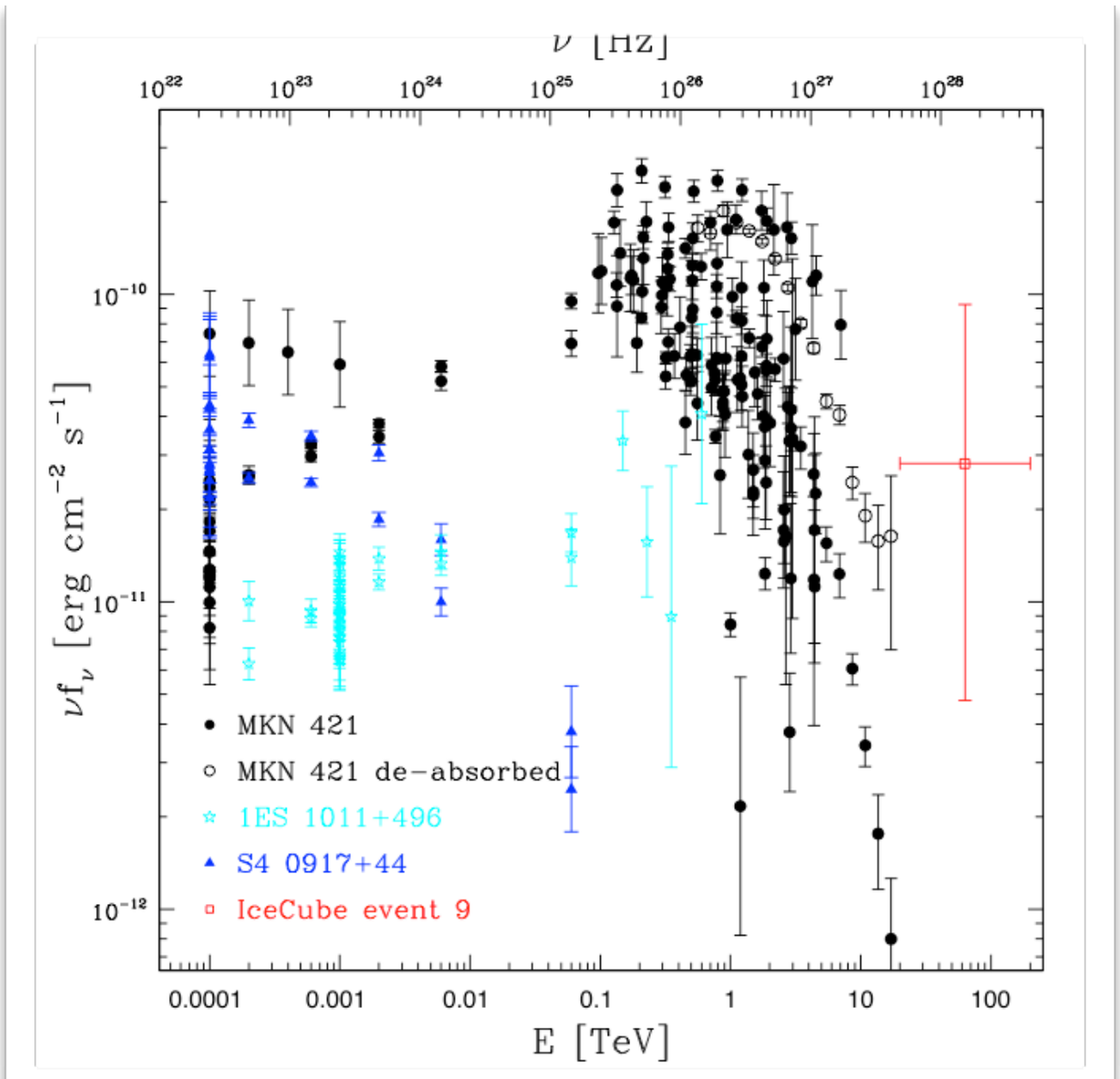
Cosmic opacity anomaly: LIV



Structured jets: neutrinos

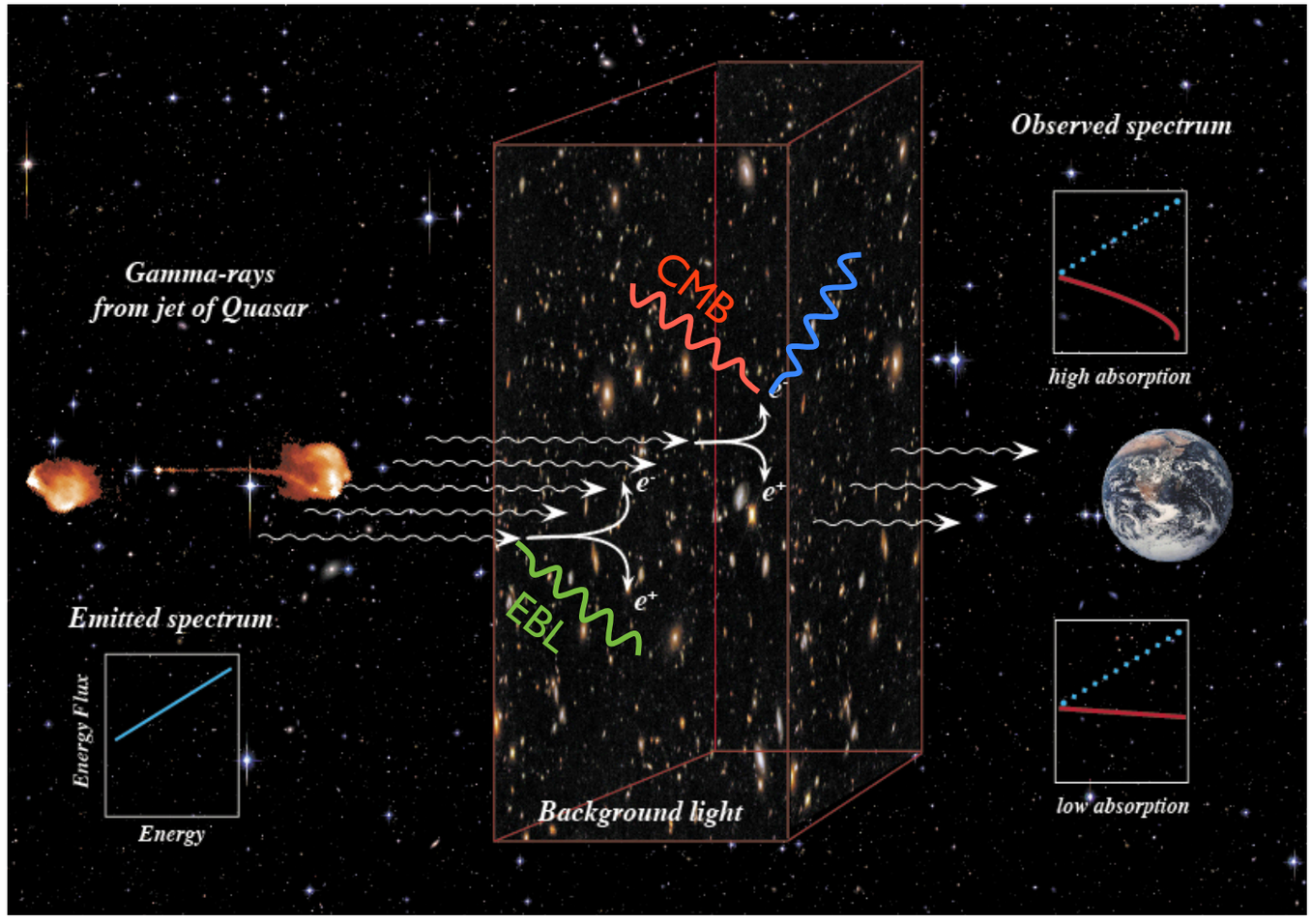
FT et al. 2014

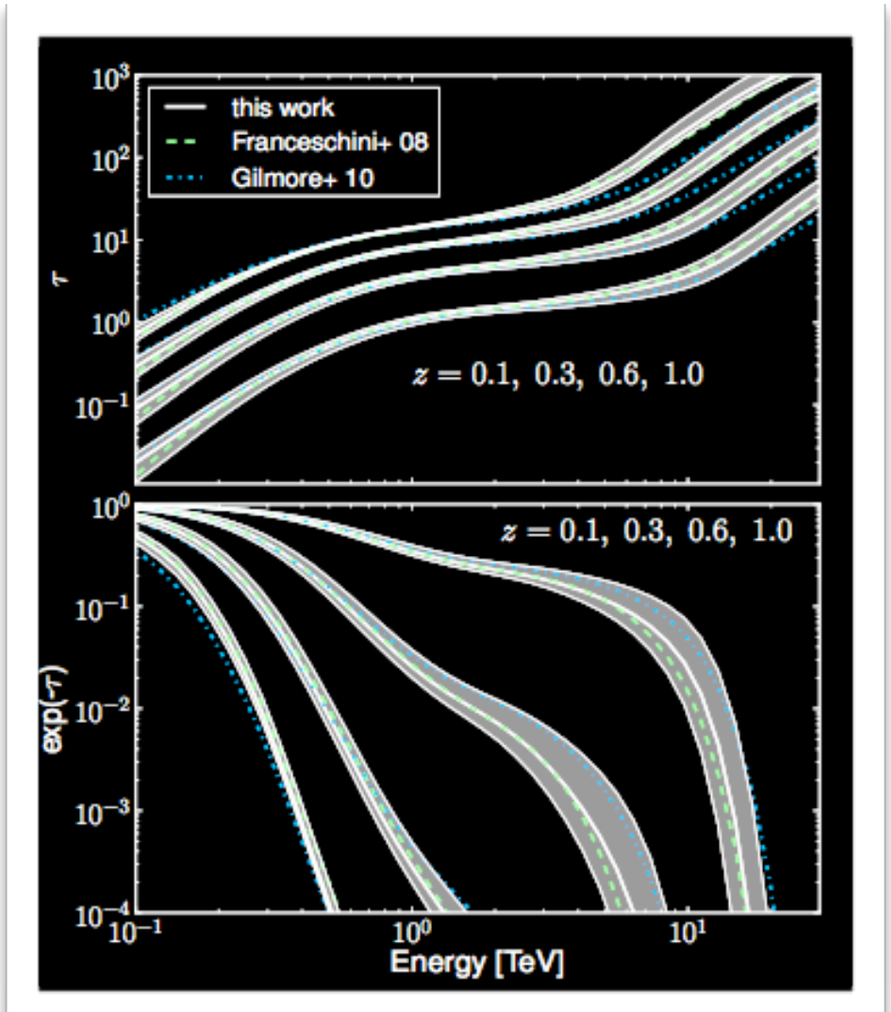




Padovani & Resconi 2014

Propagation: EBL absorption





Dominguez et al. 2011