HEASA 2017
Johannesburg, SA

Multi-wavelength and Multi-messenger Modeling of Blazars

Shan Gao

Collaborators : Walter Winter, Martin Pohl, Xavier Rodrigues,
Anatoli Fendynitch and Denise Boncioli

Oct. 04, 2017

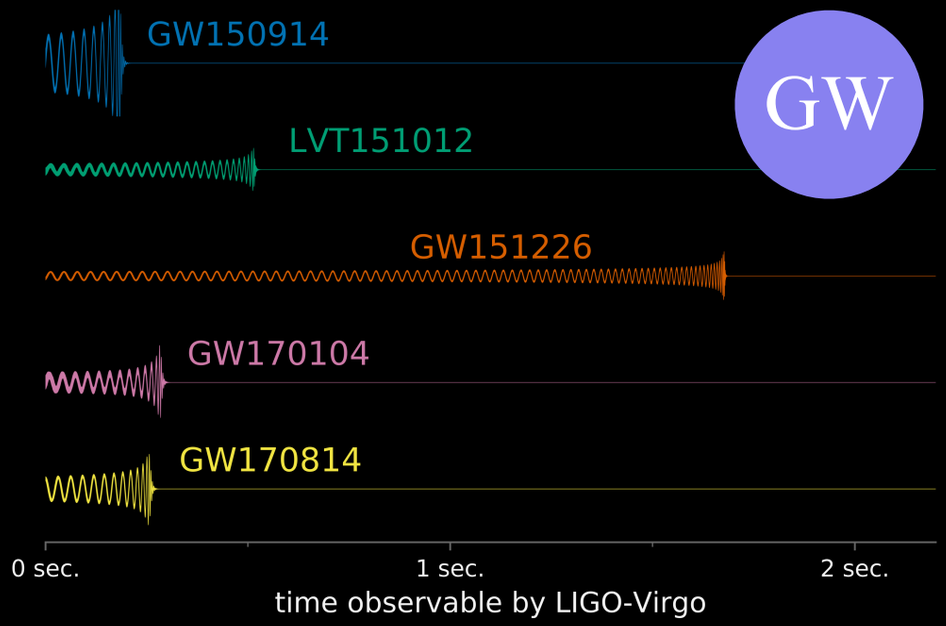


Figure: LIGO/Virgo/B. Farr (University of Oregon)

DM Not yet detected

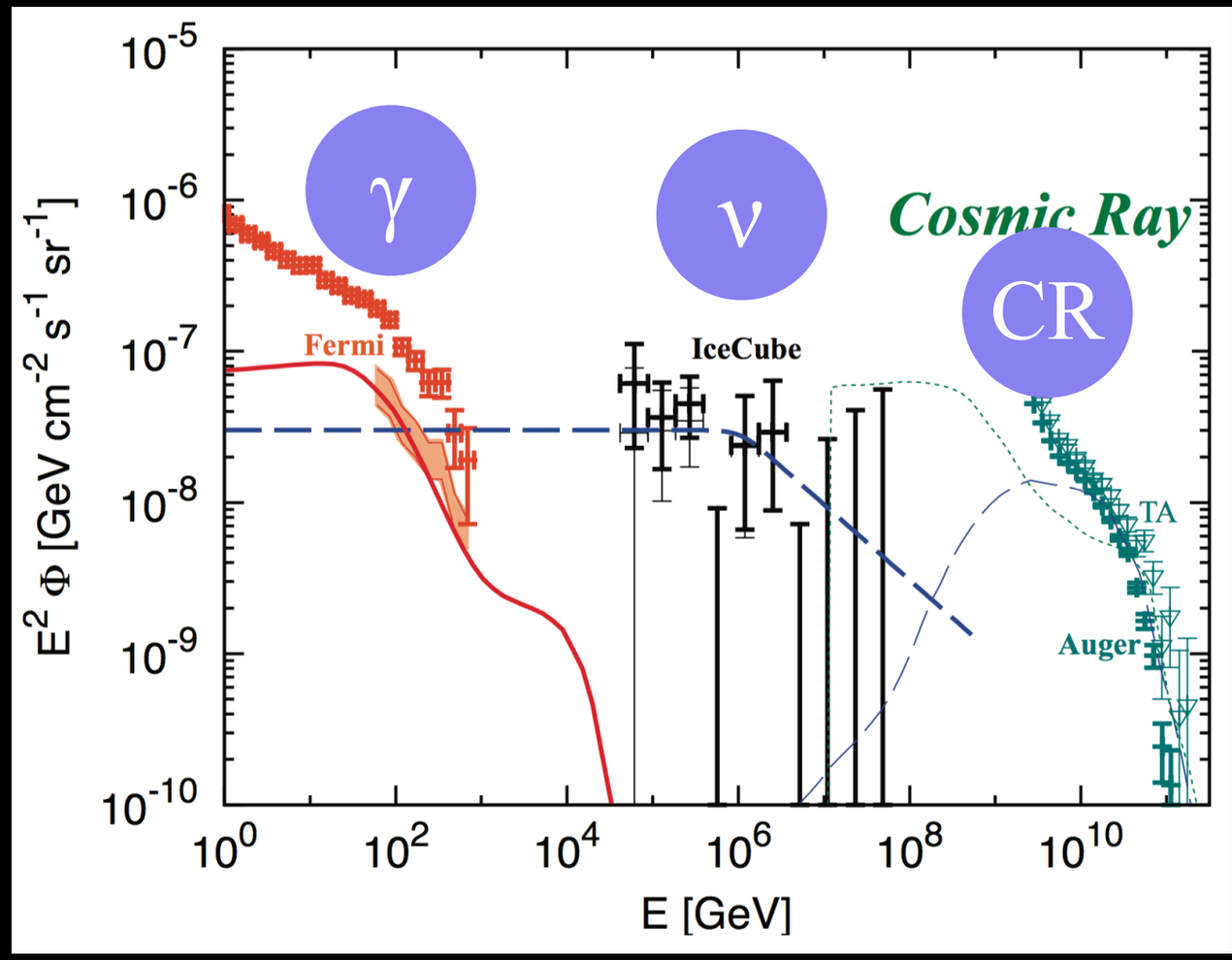


Figure: Murase, Ahlers, Lacki PRD 2014

1. Intro

2. Blazar: SED ν

3. Blazar: ν CR

4. Summary & Outlook

1. Intro

2. Blazar: SED ν

3. Blazar: ν CR

4. Summary and Outlook

γ : Fermi 3FHL Sky Map

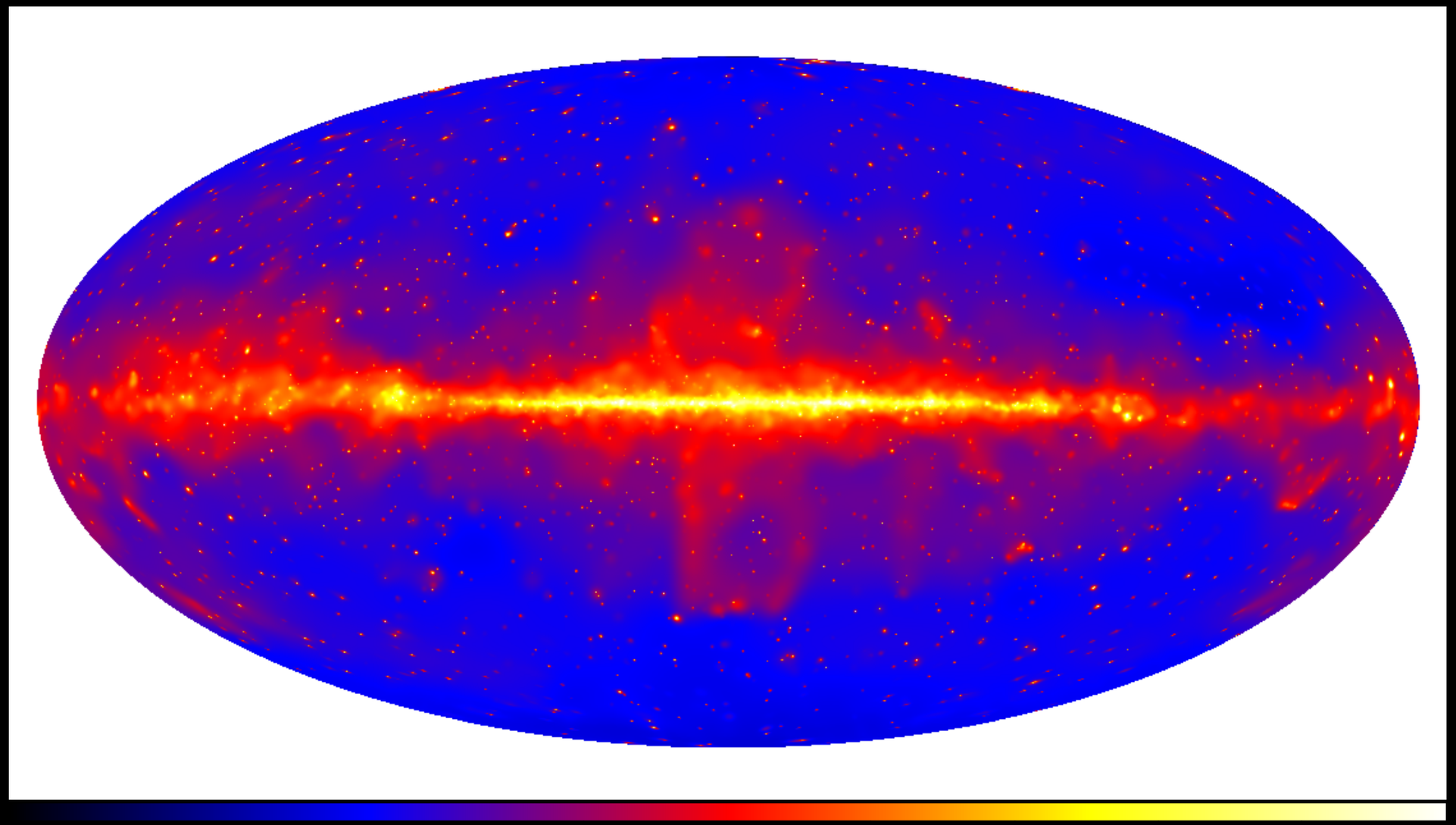
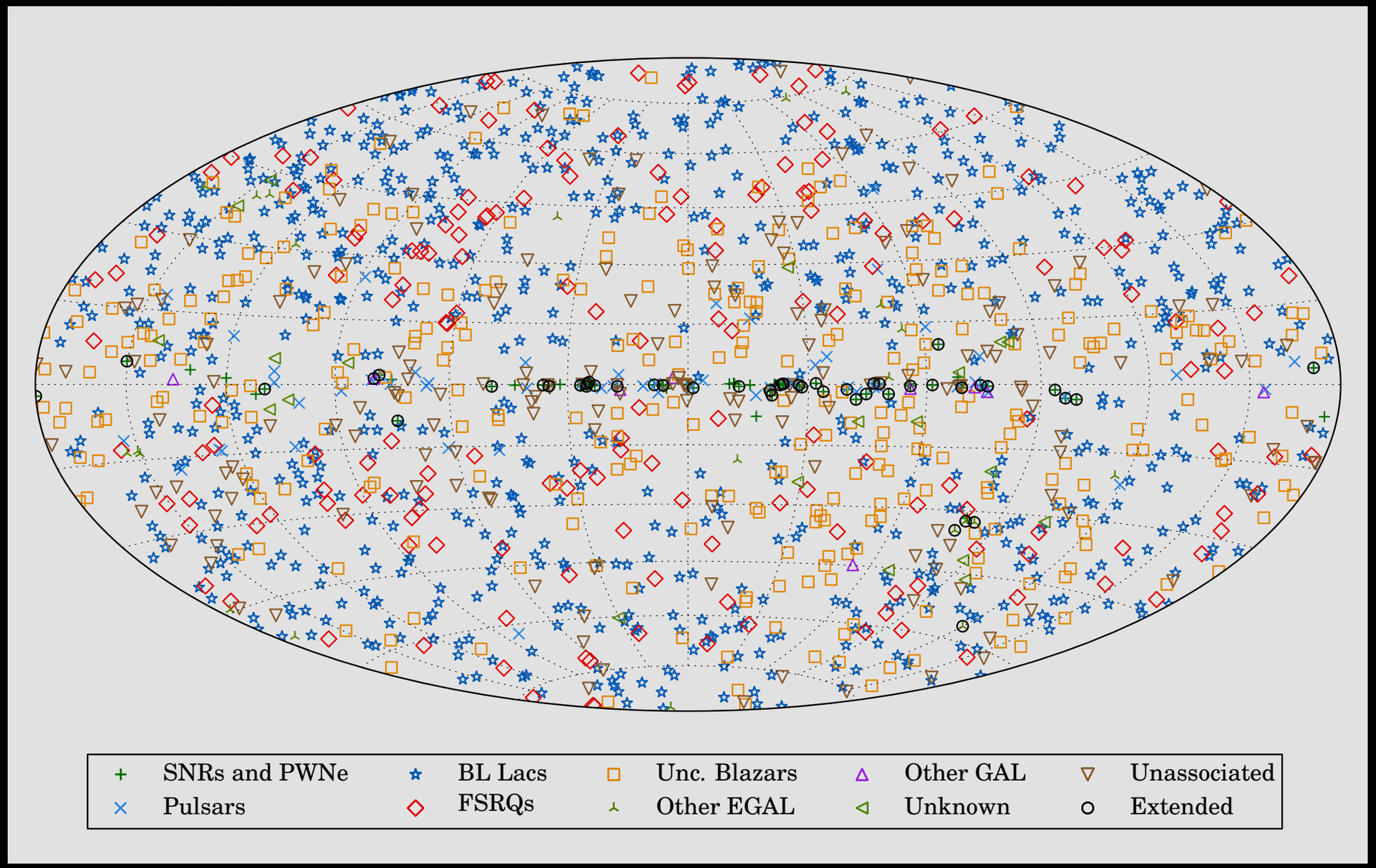


Figure: Dominguez et al. 1702.00664

γ : Fermi 3FHL sources



Most are blazars

Figure: Dominguez et al. 1702.00664

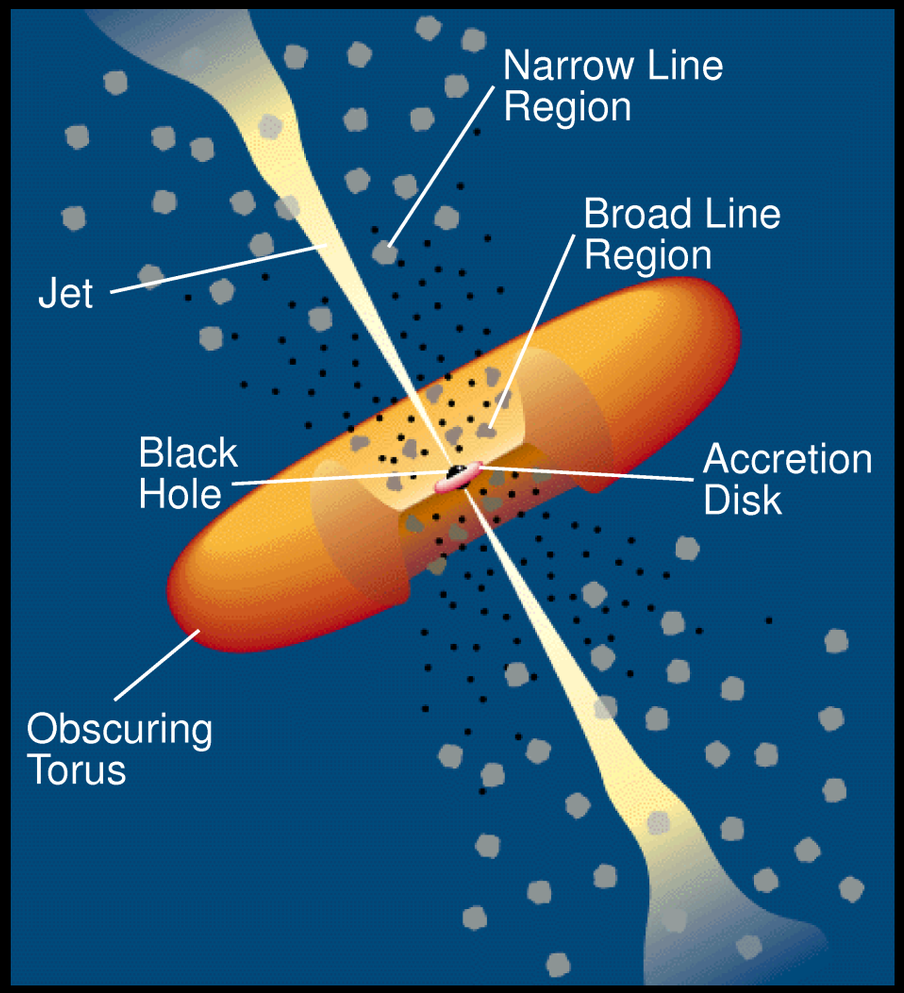
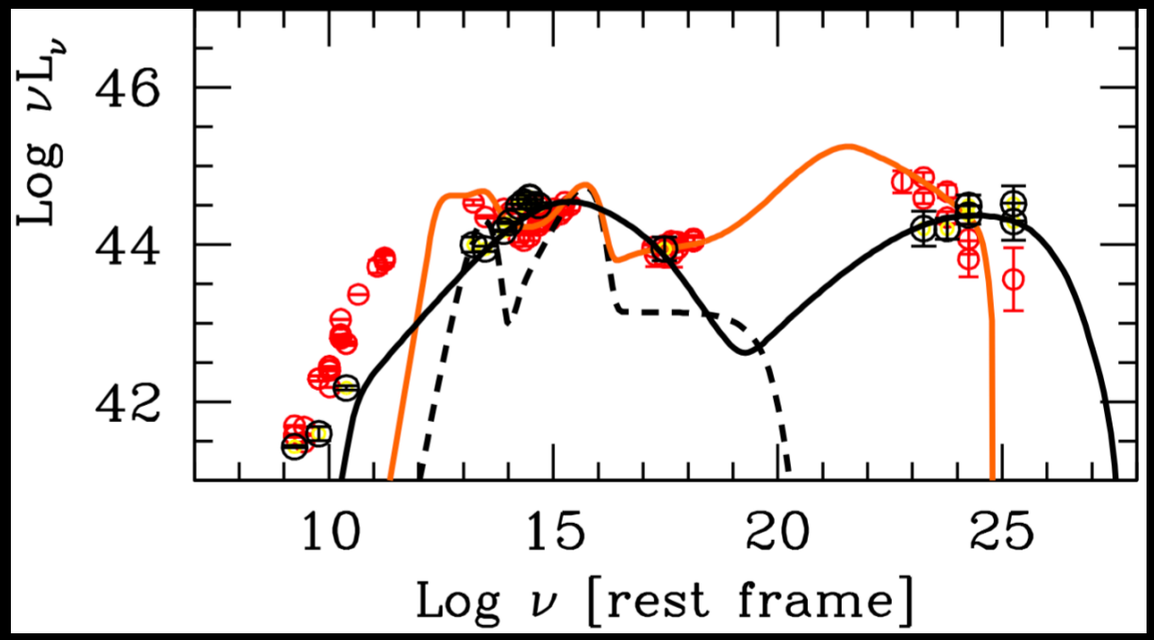


Figure: blazar, Urry & Padovani 95

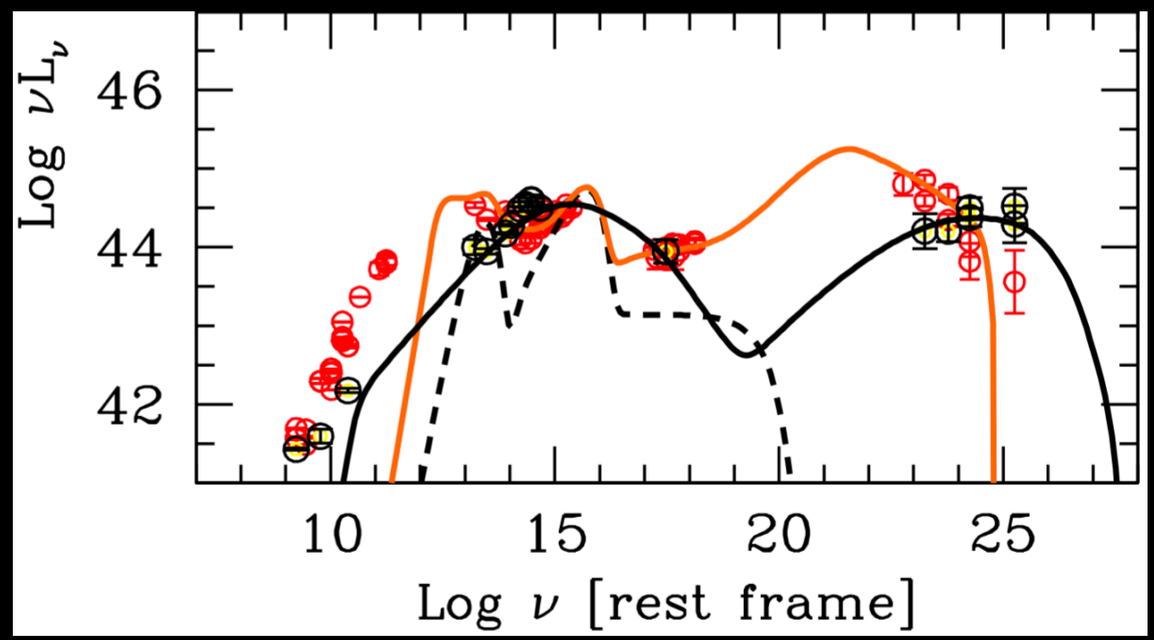


Ghisellini et al, MNRAS 469(2017), arXiv: 1702.02571

Emission from different zones.
Cases for a BL Lac & an FSRQ

Leptonic:

e^- Synchrotron , IC , $\gamma\gamma$-absorption



Ghisellini et al, MNRAS 469(2017), arXiv: 1702.02571

Hadronic (LHπ):

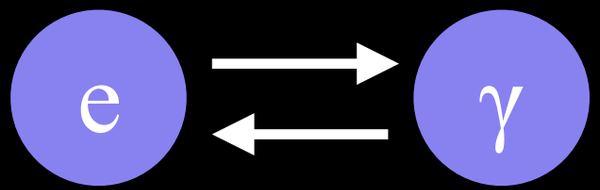
$$p+\gamma(p) \rightarrow \pi + p(n)$$

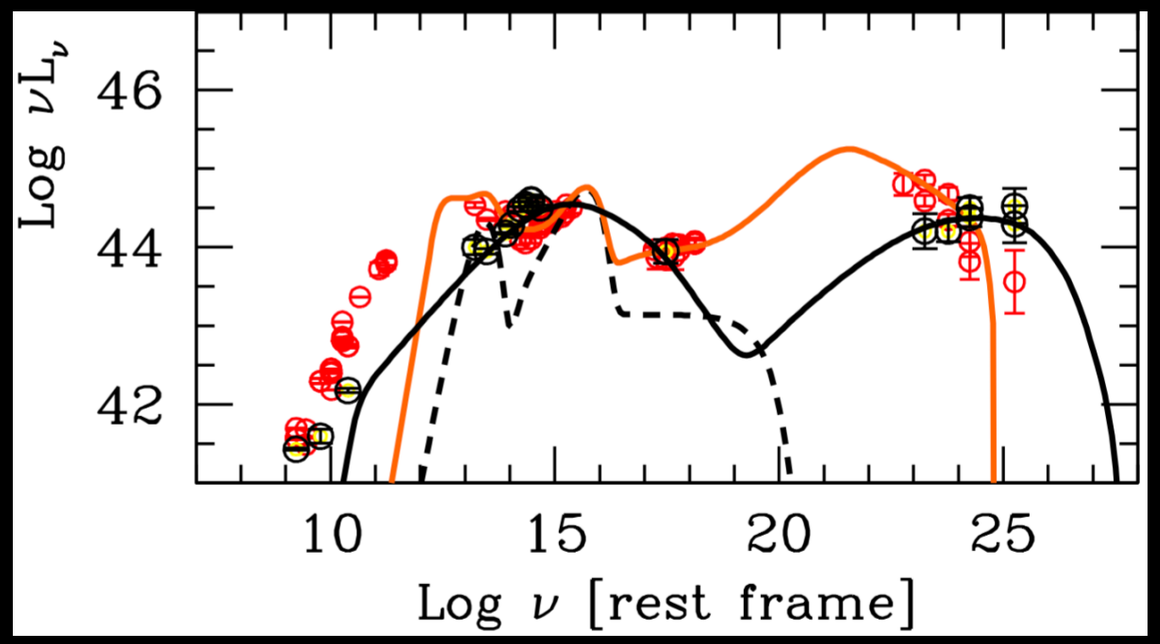
$$\pi^0 \rightarrow \gamma + \gamma$$

$$\pi^+(\pi^-) \rightarrow \nu_\mu + \overline{\nu}_\mu + \nu_e\,(\overline{\nu}_e) + e^+(e^-)$$

Leptonic:

e^- Synchrotron , IC , $\gamma\gamma$-absorption





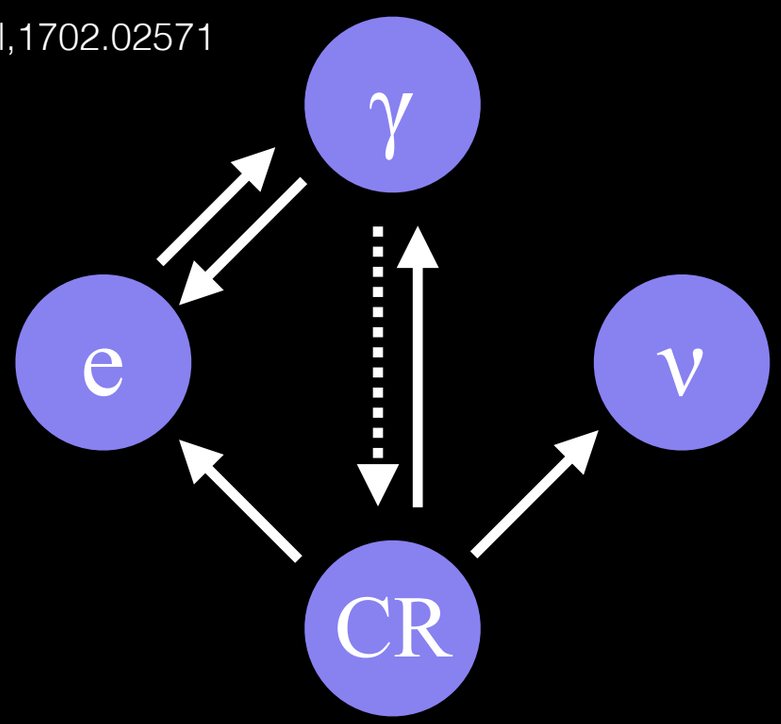
Ghisellini et al,1702.02571

Hadronic (LHπ):

$p+\gamma(p) \rightarrow \pi + p(n)$ **$L\nu \approx L\gamma$**

$\pi^0 \rightarrow \gamma + \gamma$

$\pi^+(\pi^-) \rightarrow \nu_\mu + \bar{\nu}_\mu + \nu_e\,(\bar{\nu}_e) + e^+(e^-)$



Can blazars be:

- All hadronic ? Then sufficient for ν
- Both ν and UHECR source ?

Which type (SED) to look for ?

What composition (UHECR) ?

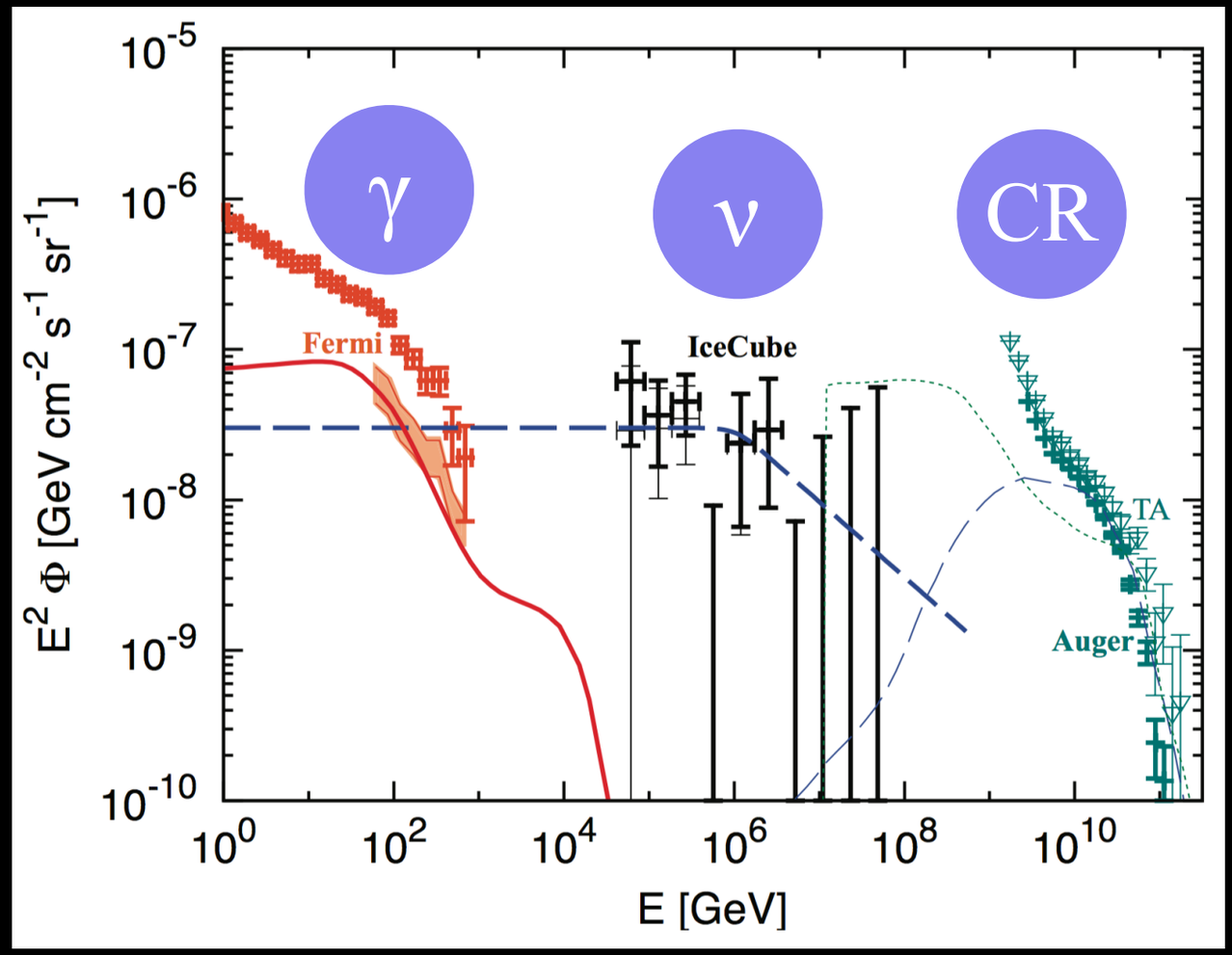


Figure: Murase, Ahlers, Lacki PRD 2014

1. Intro

2. Blazar: SED ν

3. Blazar: ν CR

4. Summary and Outlook

In ν search, why is entire & detailed SED needed ?

Case: FSRQ *PKS B1424-418*

Fermi: Burst Phase 2012.6 - 2013.3

IceCube 2PeV event: 2012.12 (IC35)

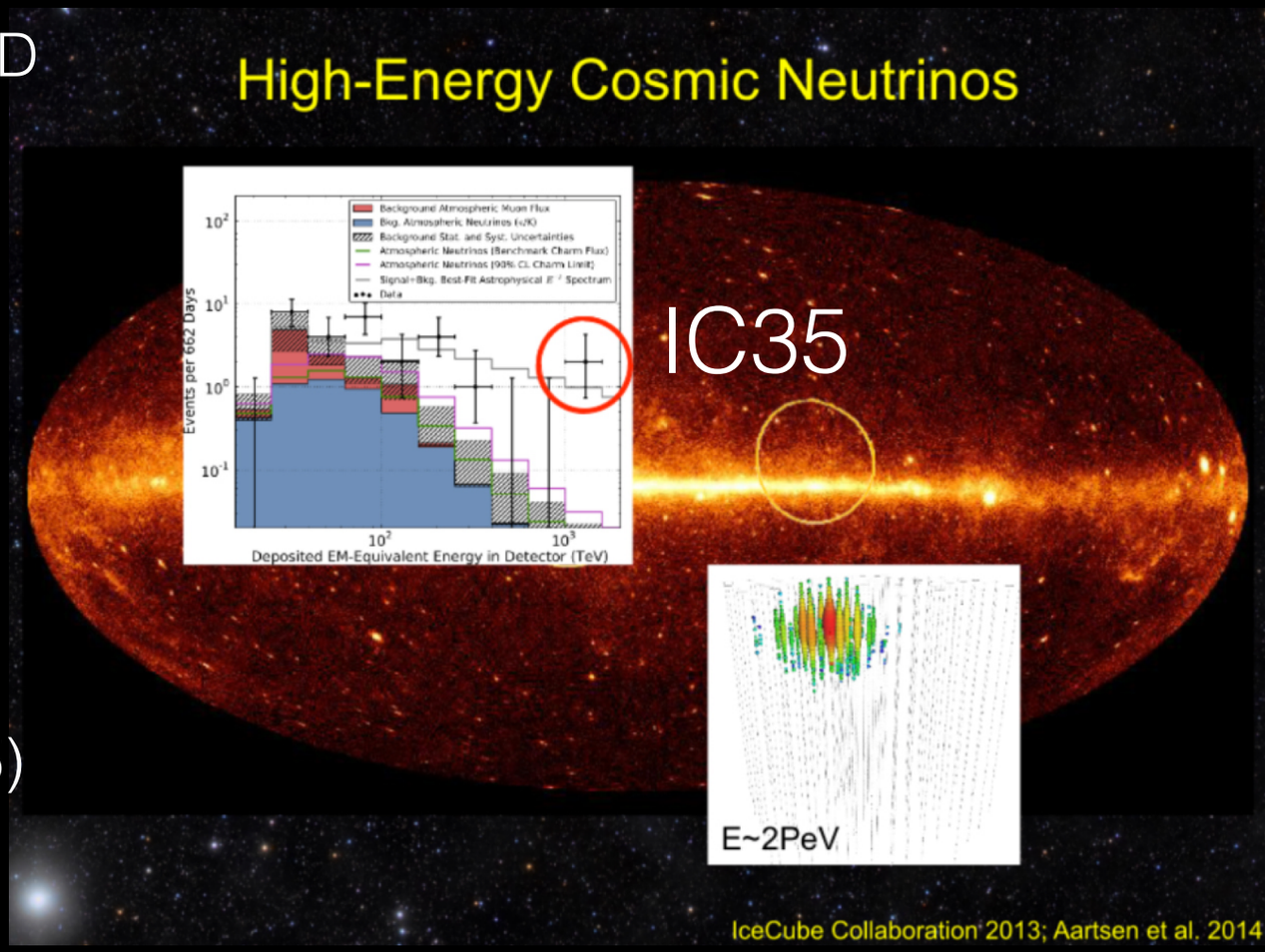


Figure: Krauss, F. 2016 HAP workshop, Cochem

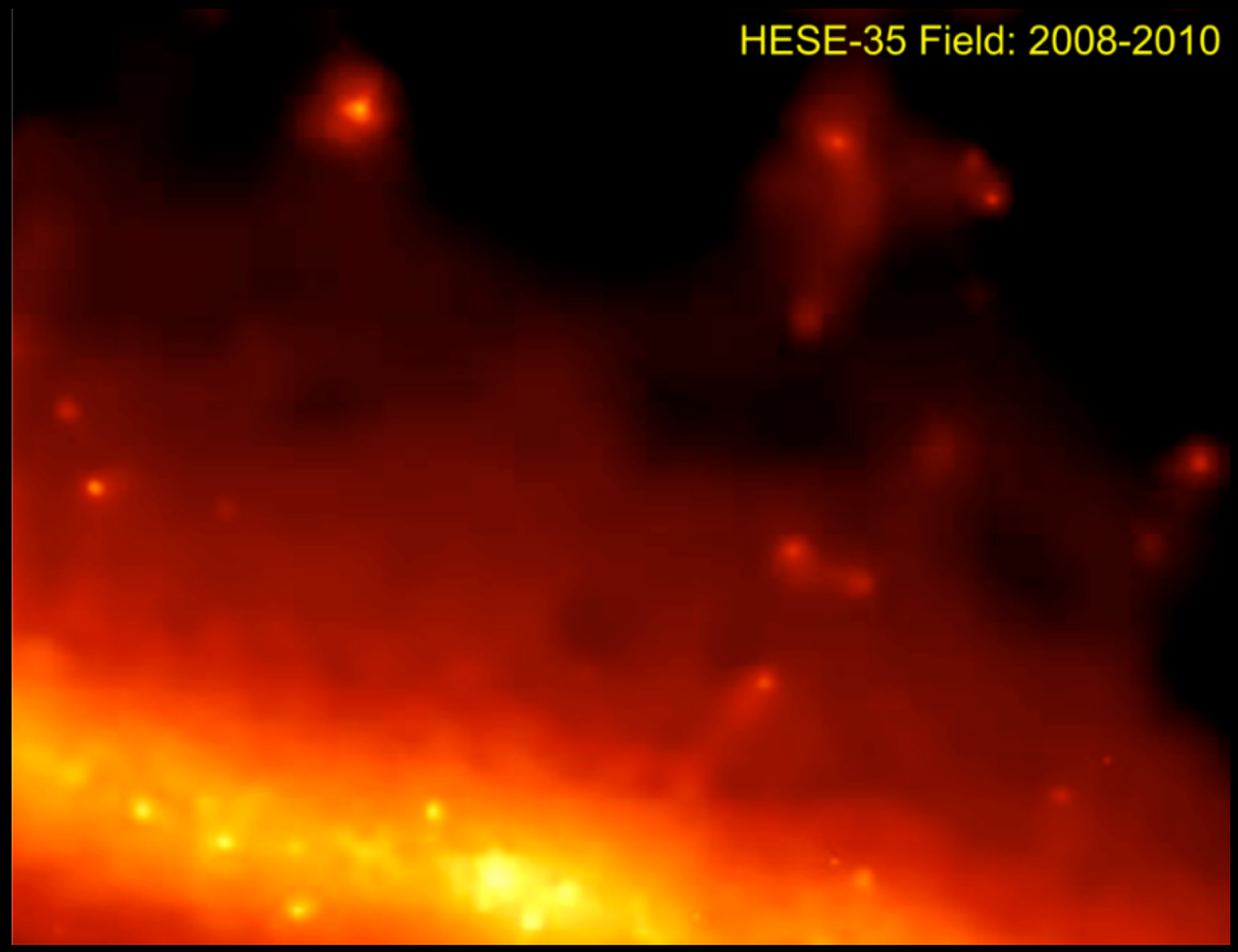


Figure: Krauss, F. 2016 HAP workshop, Cochem

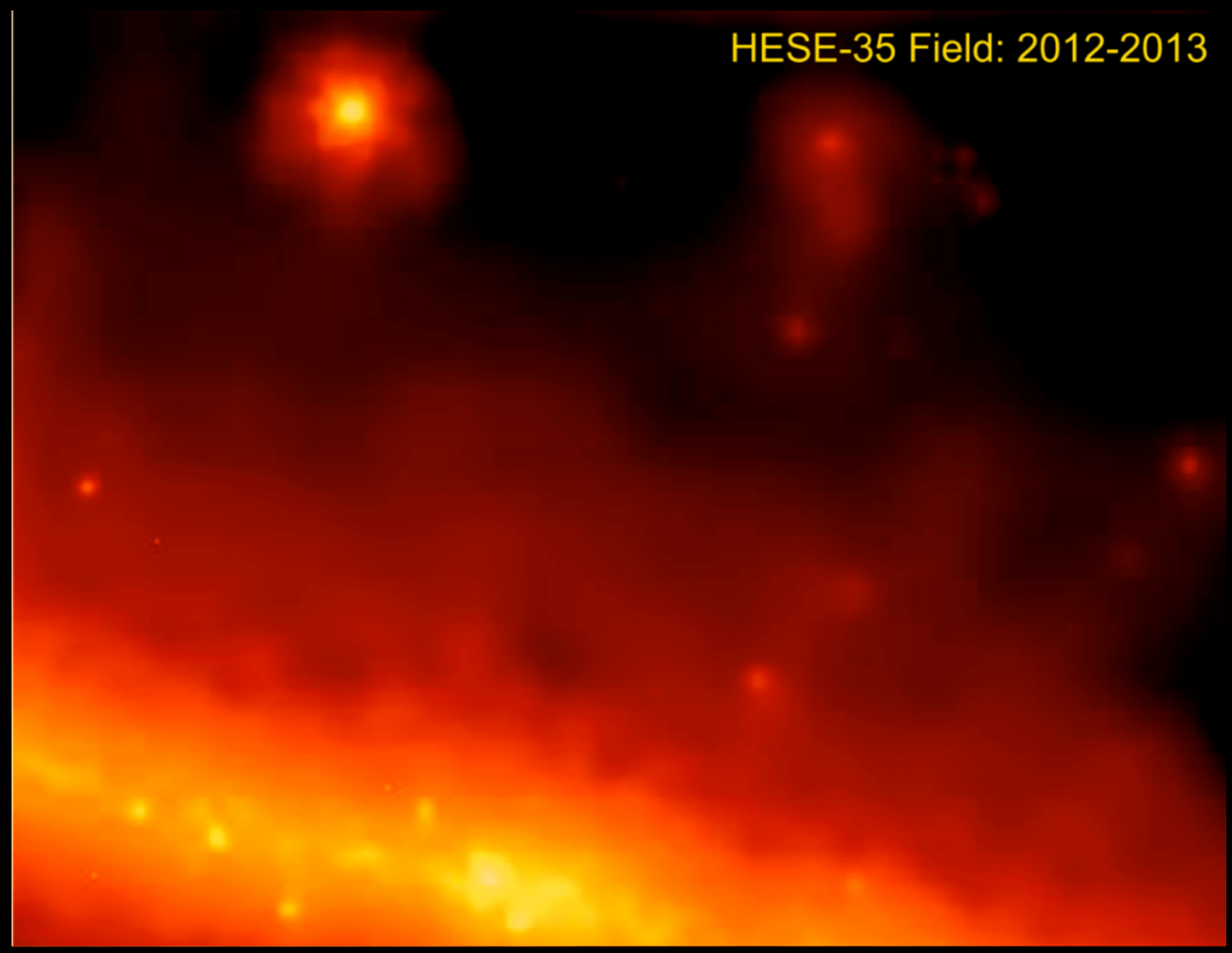


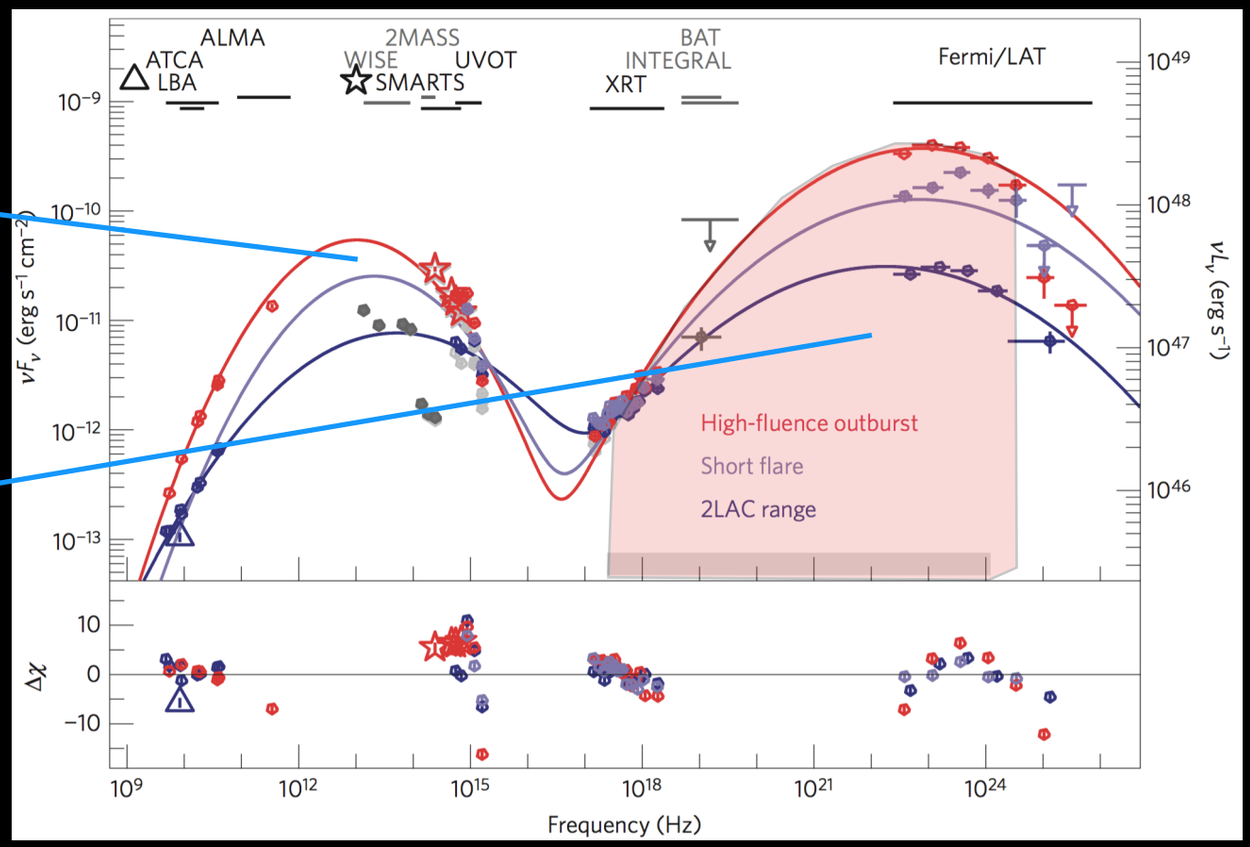
Figure: Krauss, F. 2016 HAP workshop, Cochem

e⁻ syn.

SSC

p syn

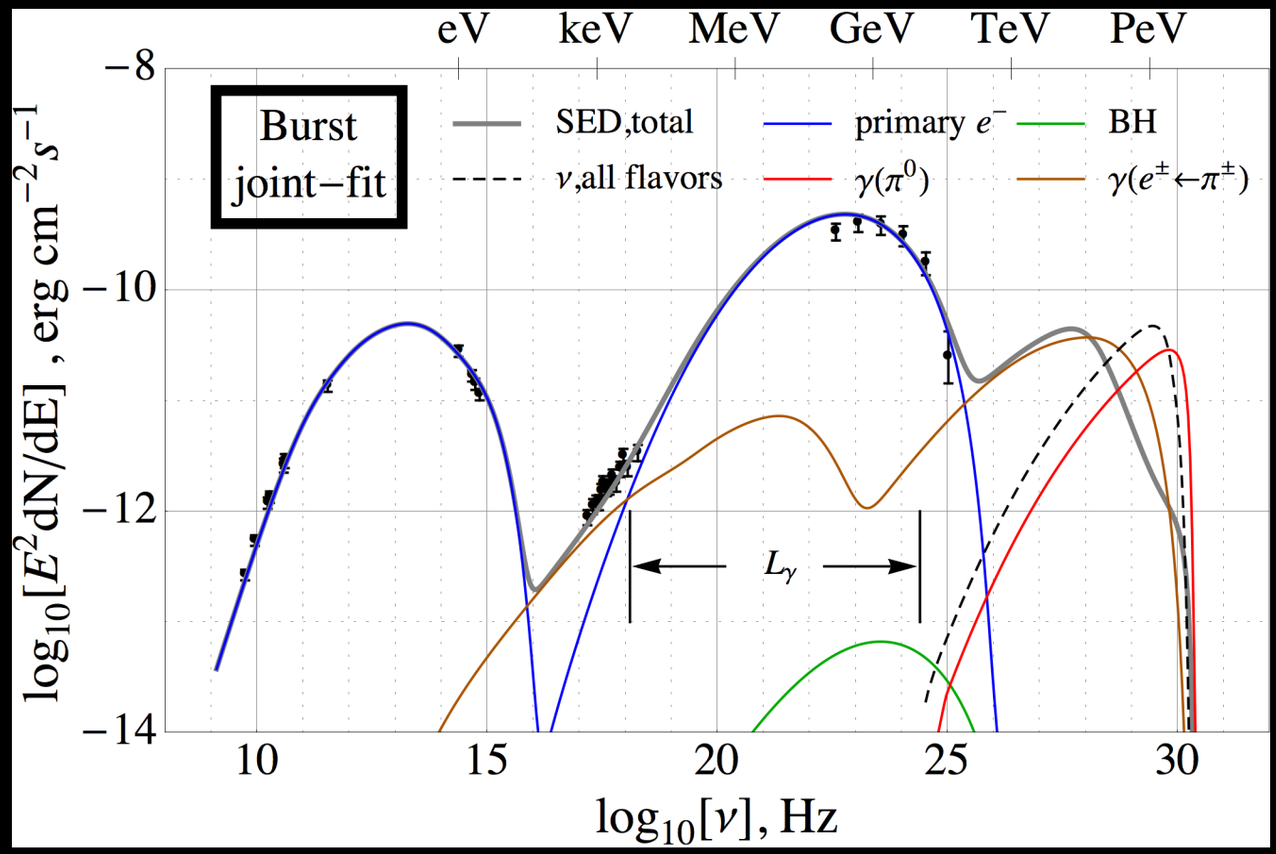
π^0 decay



Kadler et al, Nature Phys. 2016

π^0 decay → $L\nu \sim L\gamma \longrightarrow$ 4.5 ν in PeV

- LHπ not applicable for PKS B1424
- SSC dominates
- X-ray range : hadronic

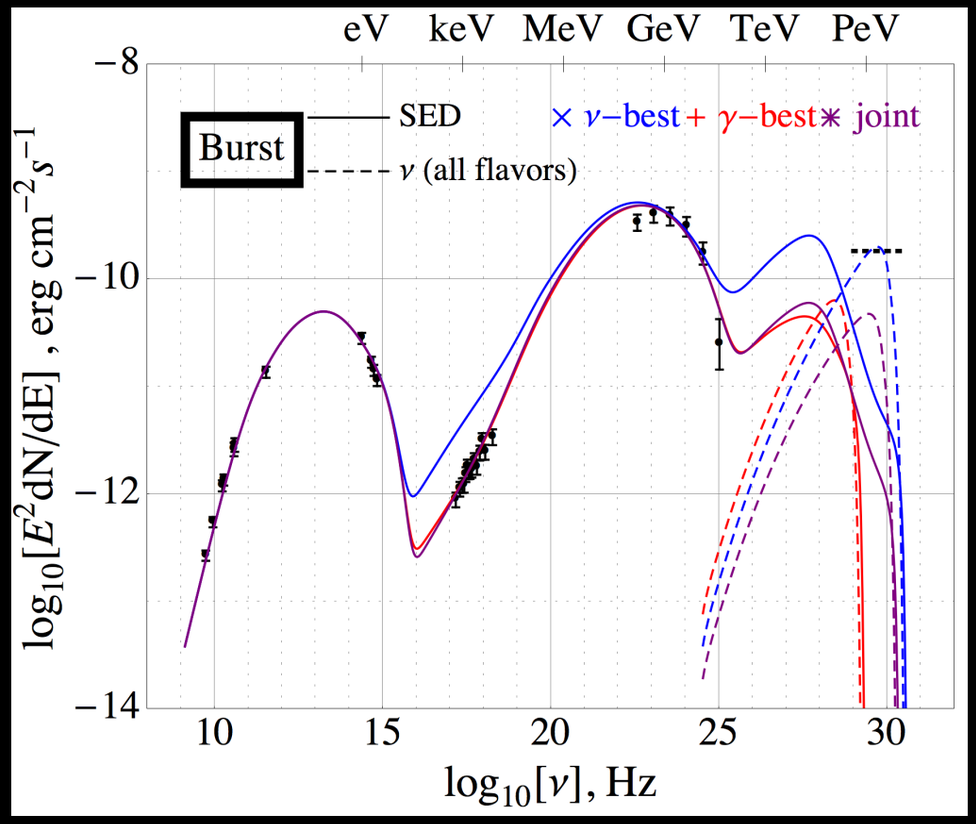


SG, Pohl and Winter, 1610.05306, ApJ 2017

Parameter Scan (Lp, $E_{p,max}$)

- ν-best : overshoots X-ray
- SED-best : no PeV ν

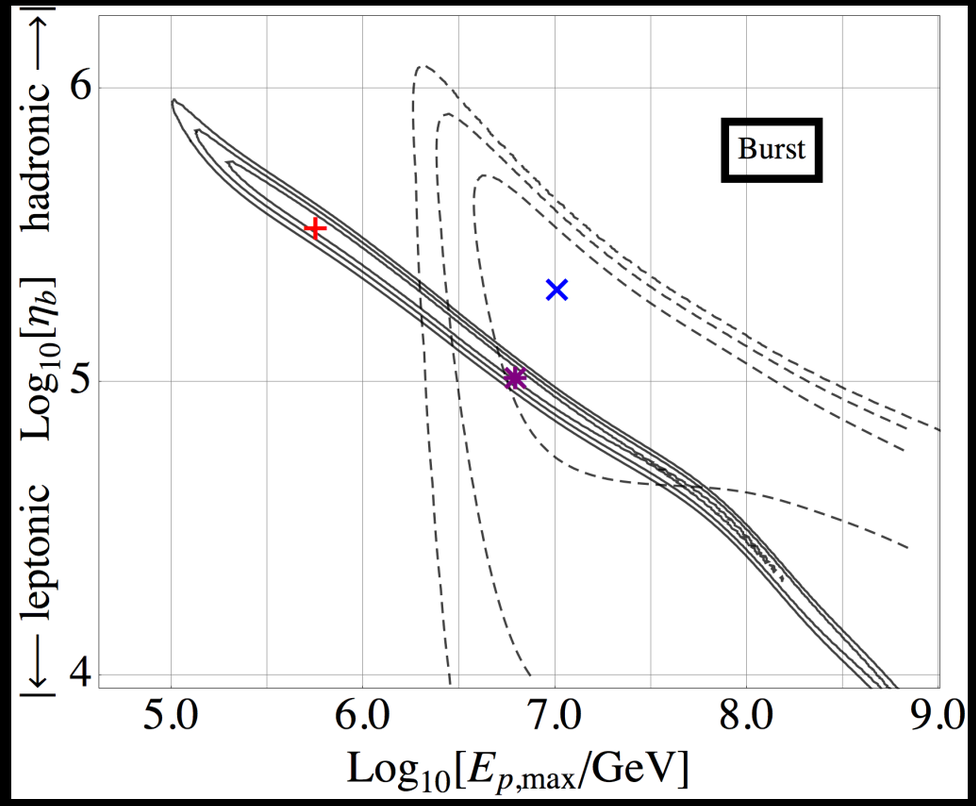
! Tension between ν and SED



Results

- ν-SED joint-best : 3.2% chance to fit IC35
- Low state (2 yr before IC35) : 5.7 % chance

IC 35 and Burst: correlation insignificant



SG, Pohl and Winter, 1610.05306, ApJ 2017

Hadronic (LHπ) model

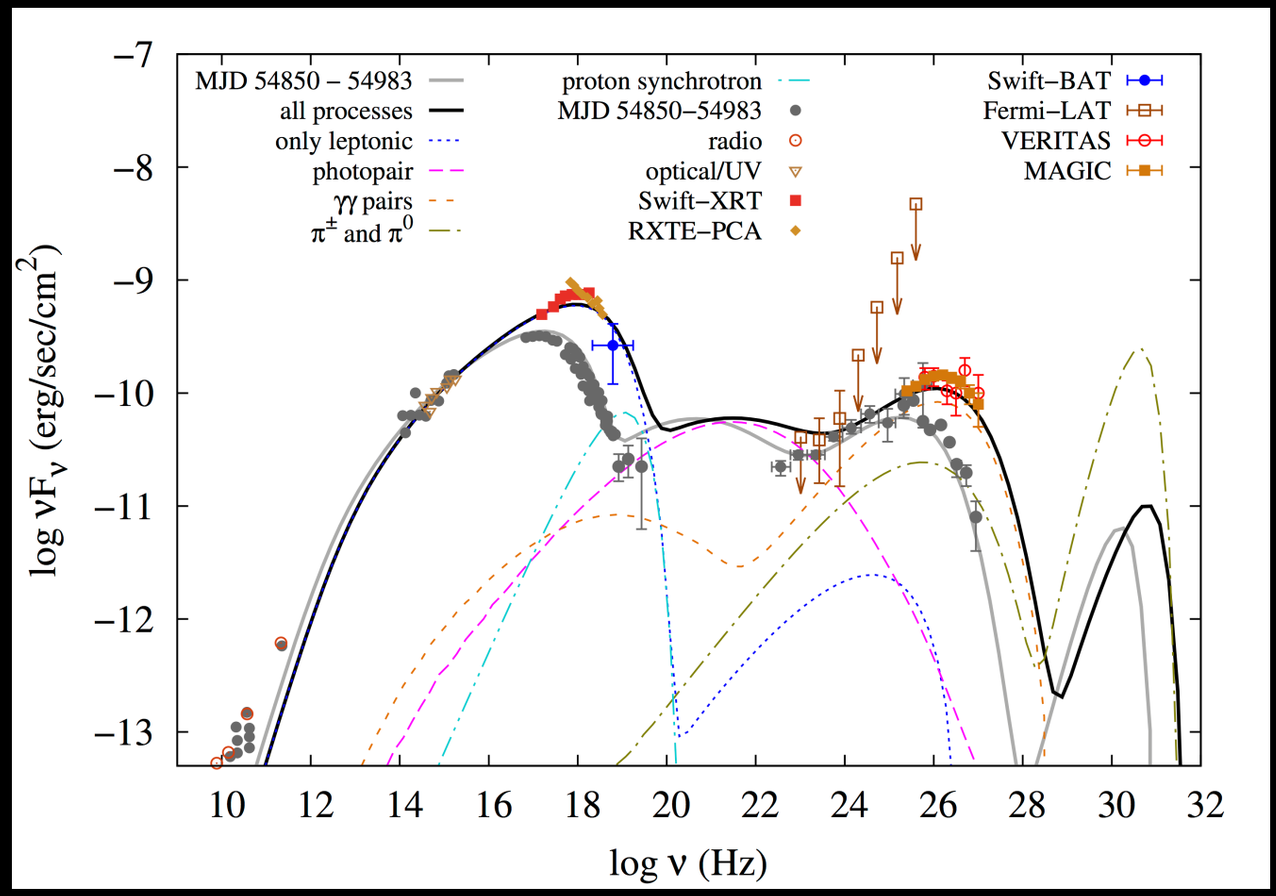
- Works for some blazars

  e.g. Mrk 421, HBLs

- 1PeV-10PeV ν

- Boost of detection rate

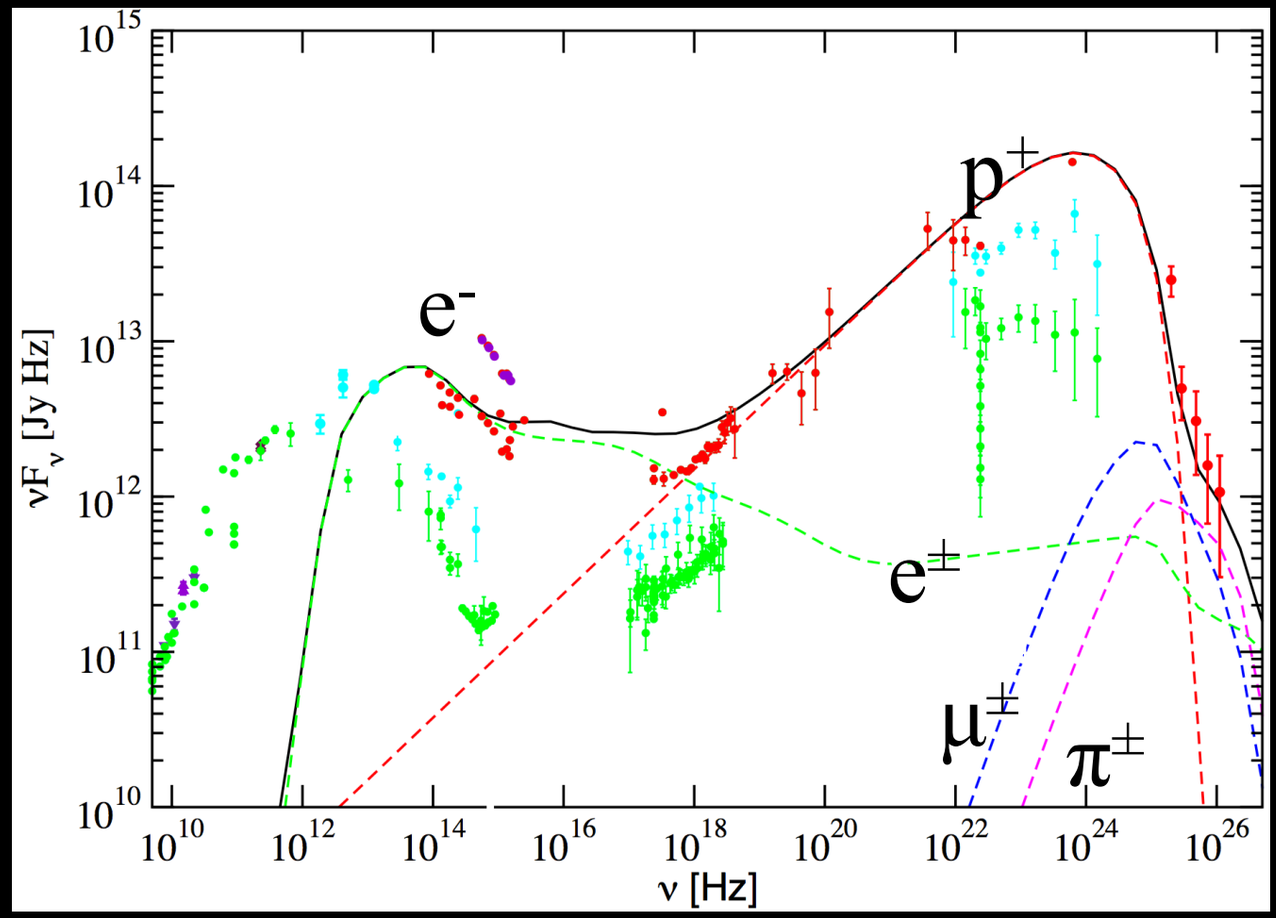
  insignificant : earth absorption



Petropoulou et al. Astropart. Phys. 2016

Proton syn model

- 3C 279. Needs high mag. field (~150G this case)
- 300 PeV ν, but not efficient
- emission from mesons produces TeV



Diltz, Böttcher and Fossati, ApJ 2015

1. Intro

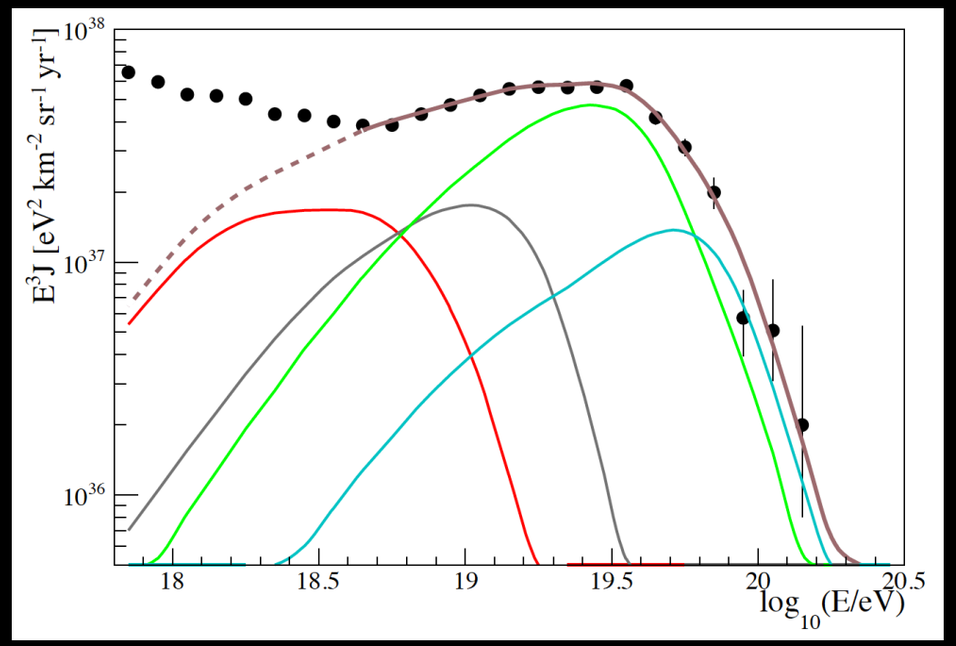
2. Blazar: SED ν

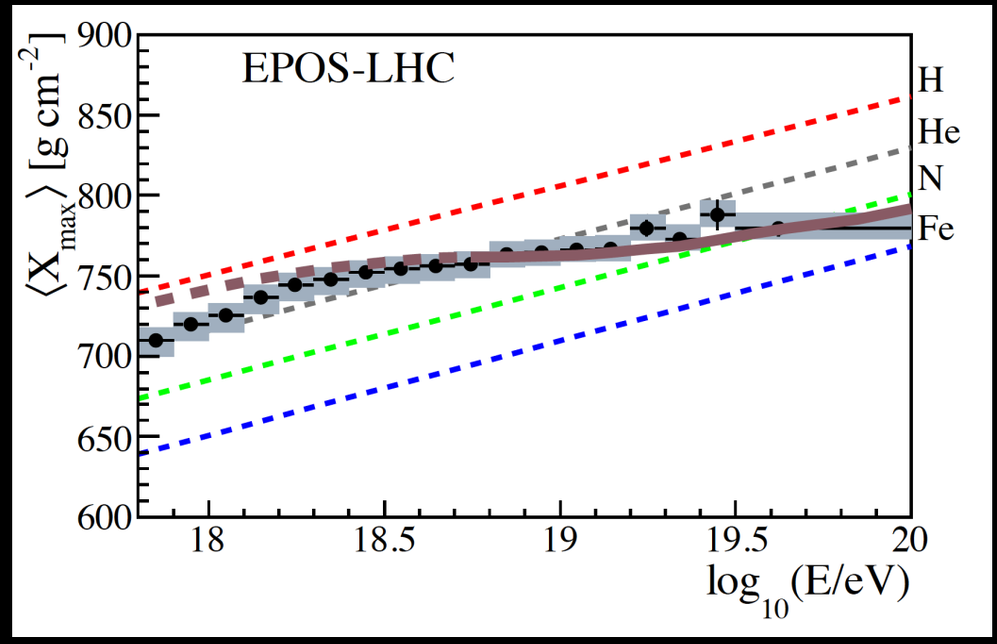
3. Blazar: ν CR

4. Summary & Outlook

Blazars and UHECR

- Auger indicates a heavy composition
- If blazars are sources of UHECR, consequences of injecting nuclei in AGN ?
- consistent with IceCube ν ?

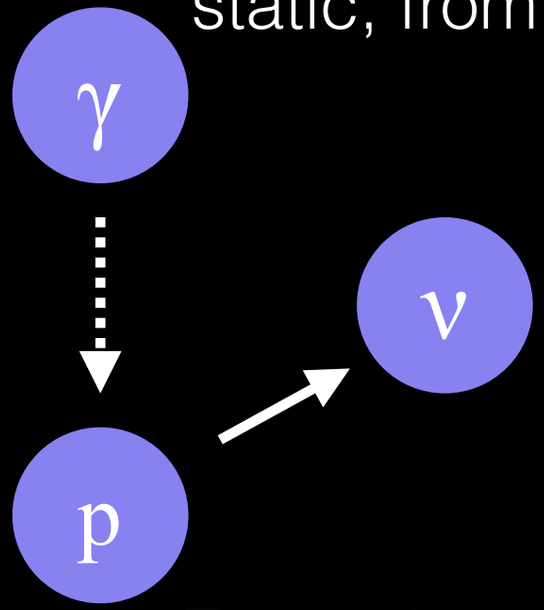




Auger global fit, 1612.07155

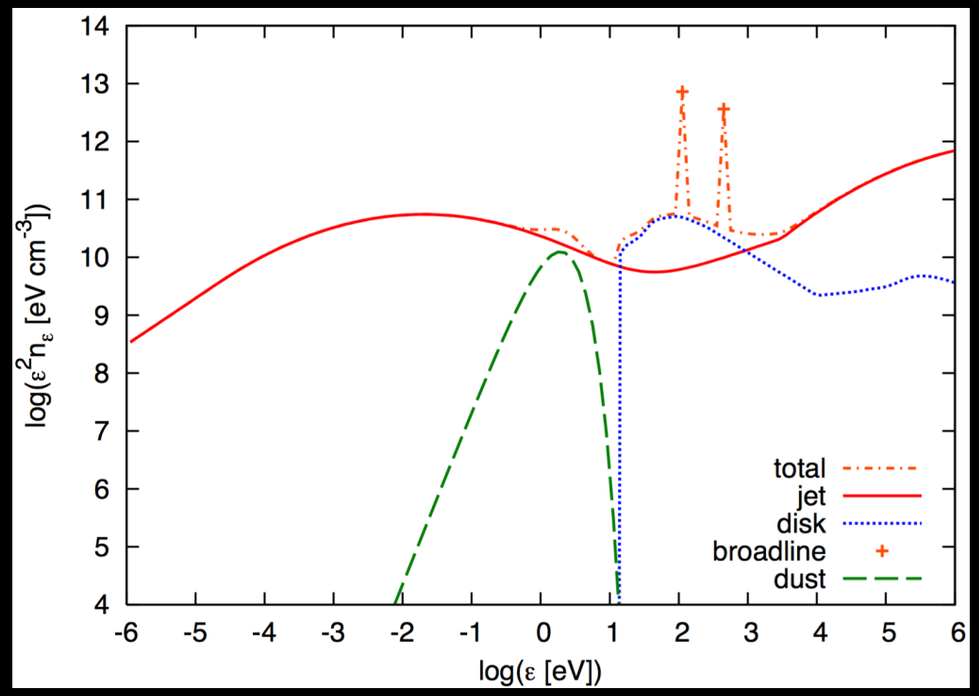
Start with a Proton model

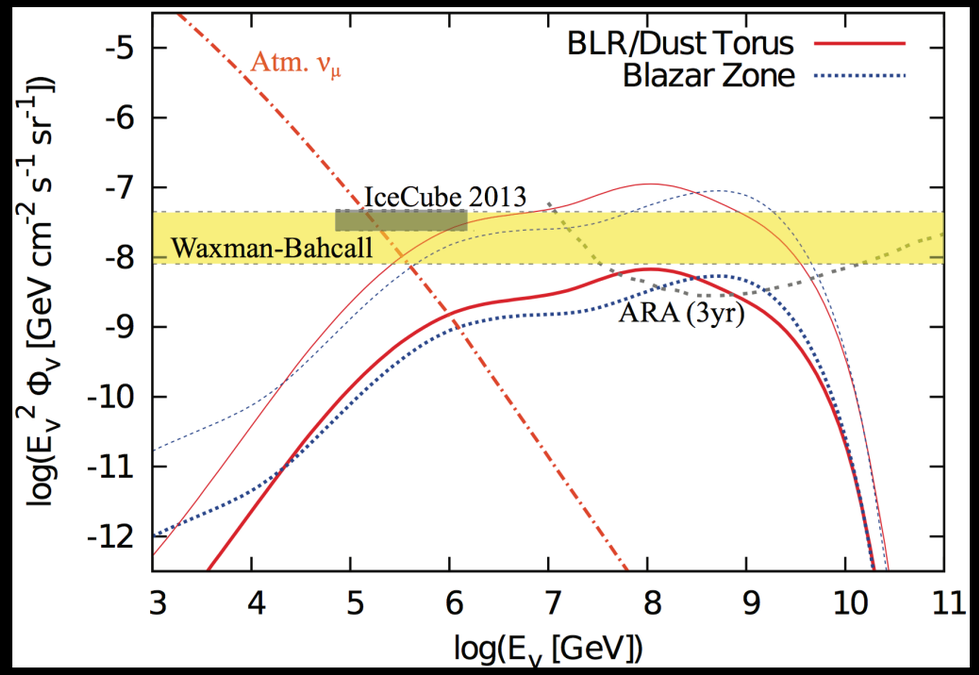
static, from obs.



E_{max} self-consistant

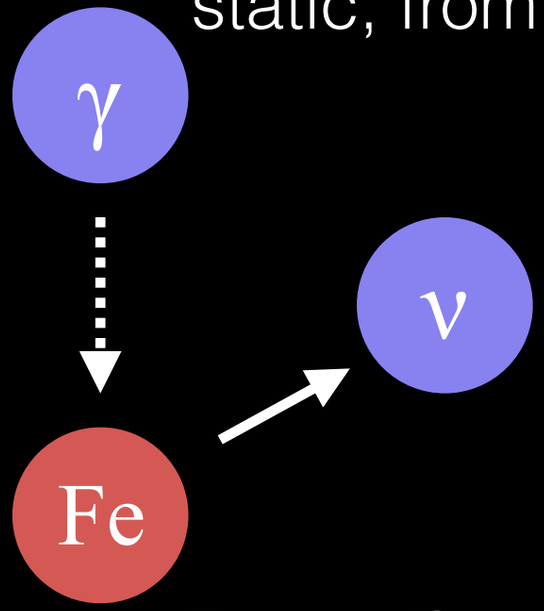
too many high energy ν





Murase et al, 1403.4089, PRD 14

Nuclear model

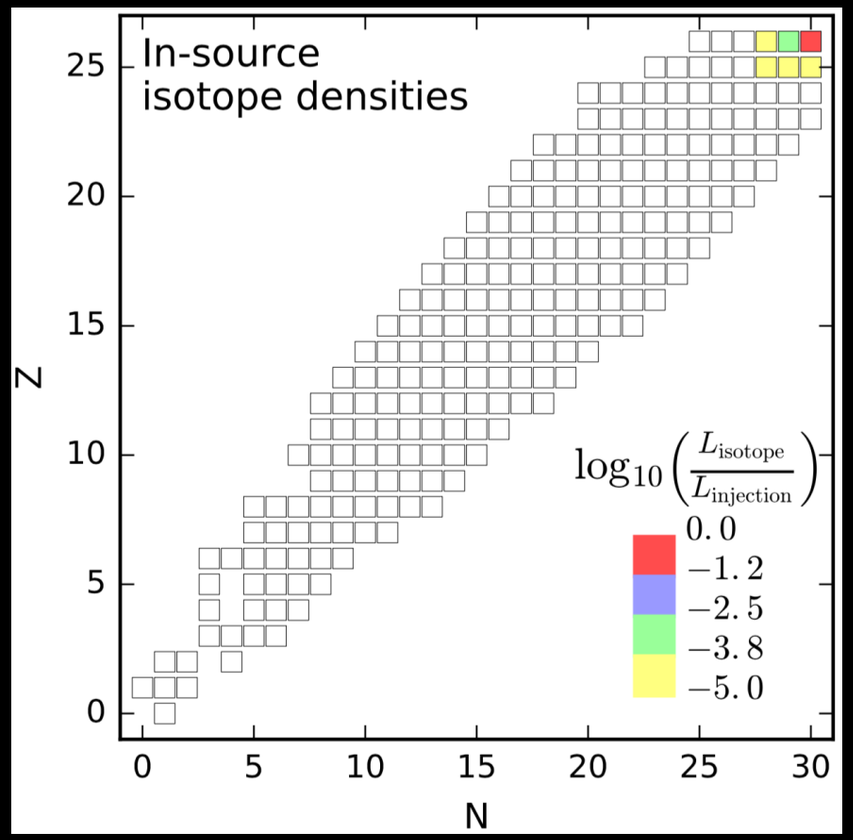


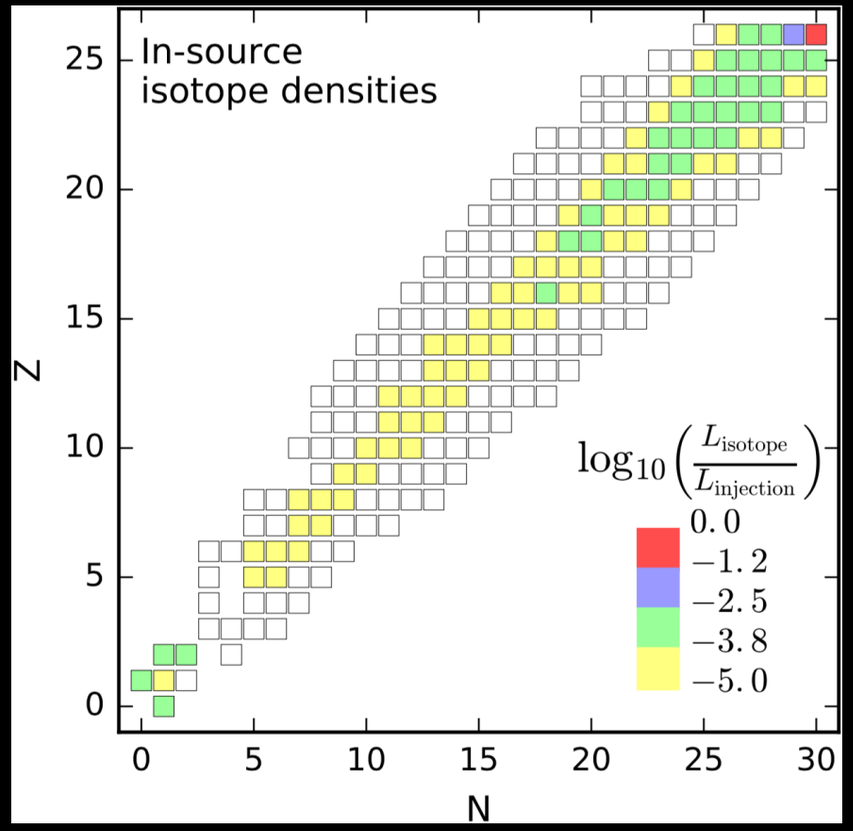
static, from obs.

E_{max} self-consistant

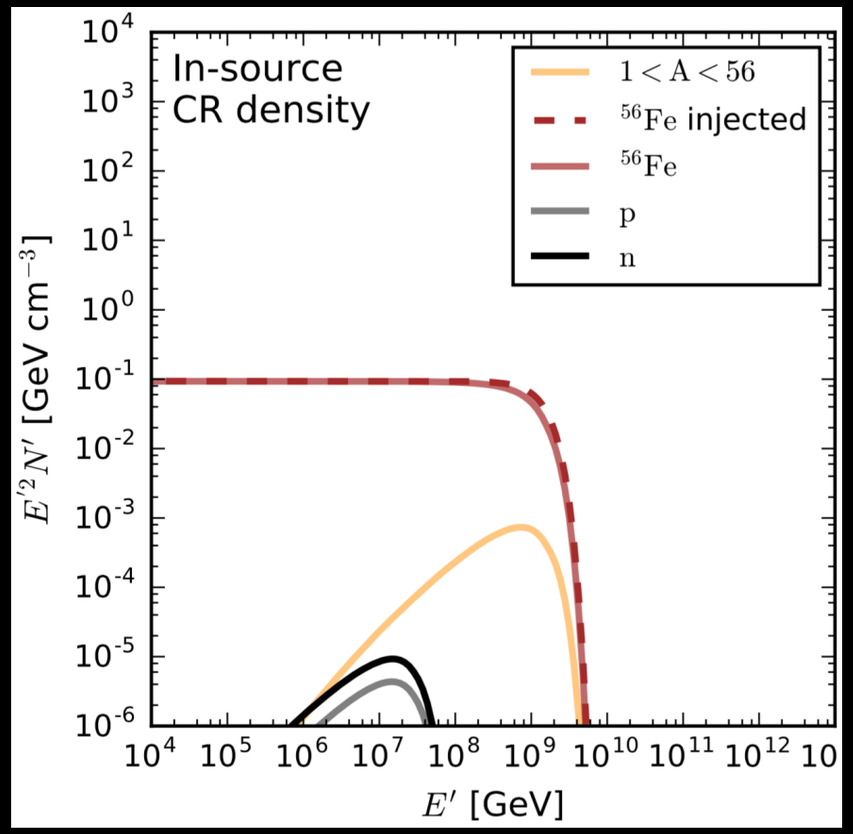
Photo-disintegration

Rodrigues, Fedynitch, SG, Boncioli, Winter, to appear soon.

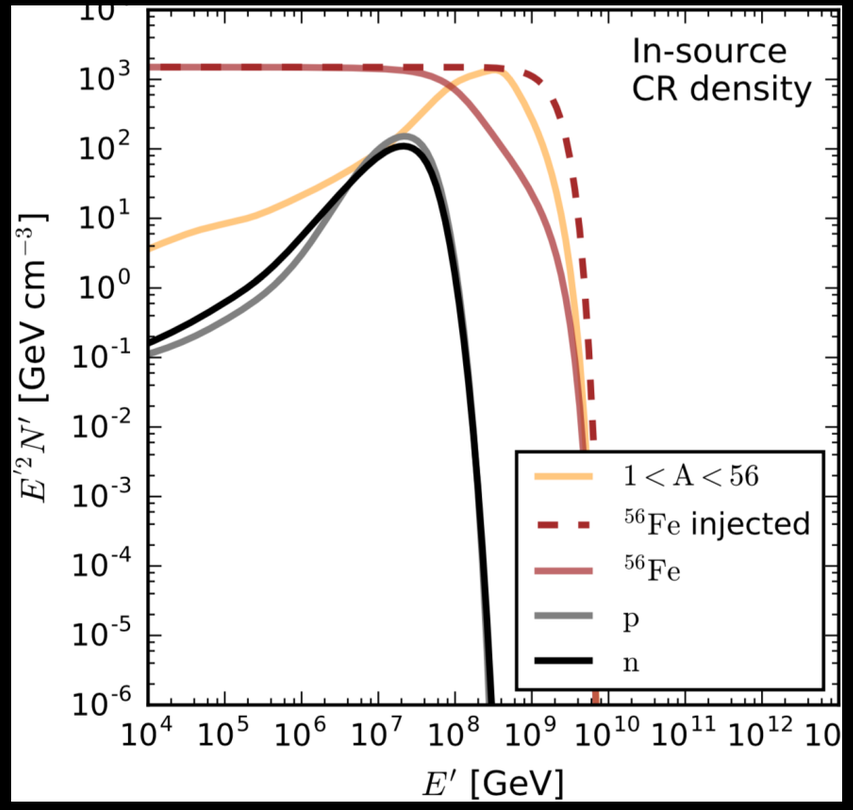




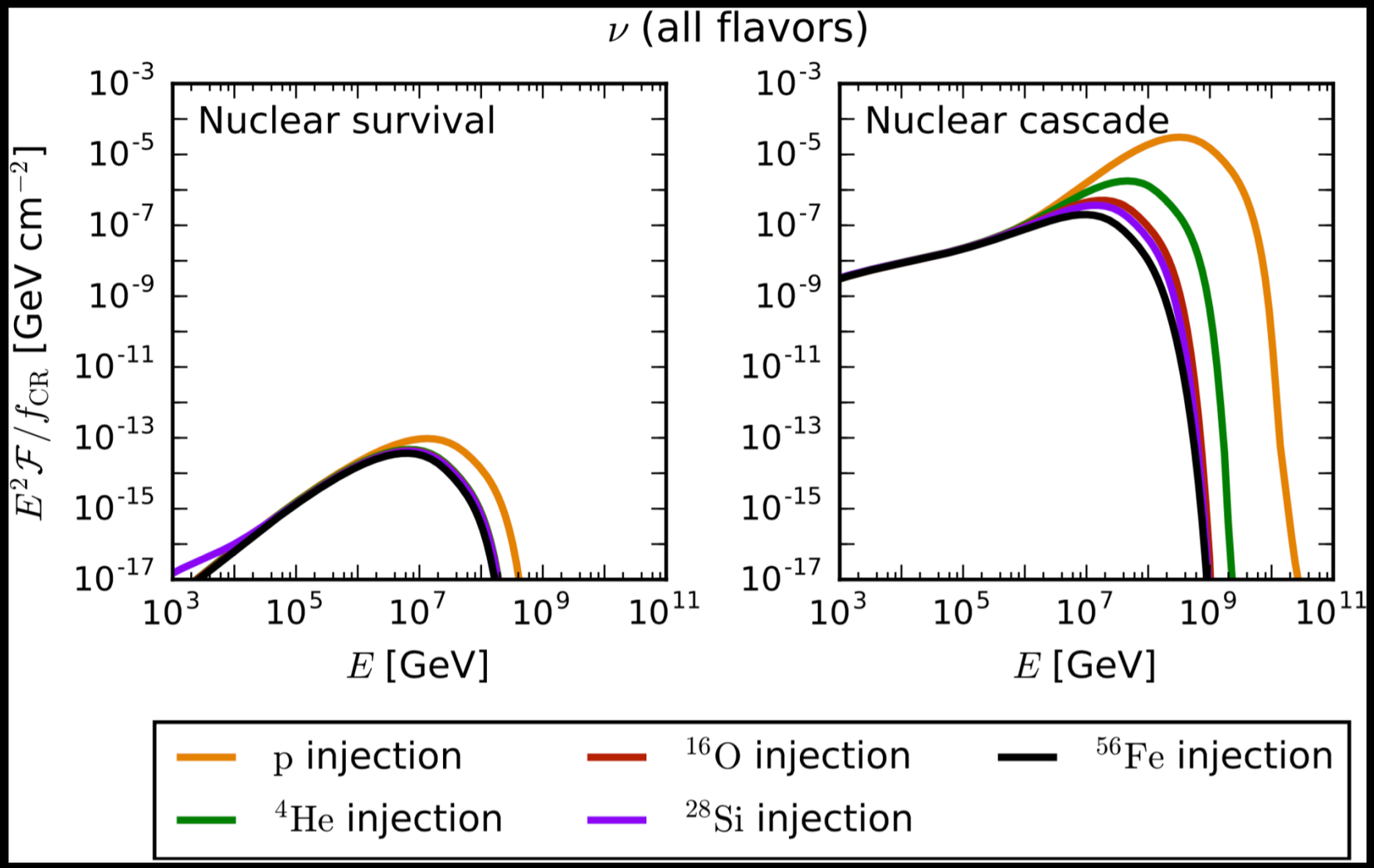
Low reaction rates
nuclear survival
(in low-luminosity BL Lac)



High reaction rates
nuclear cascade
(in high-luminosity FSRQ)



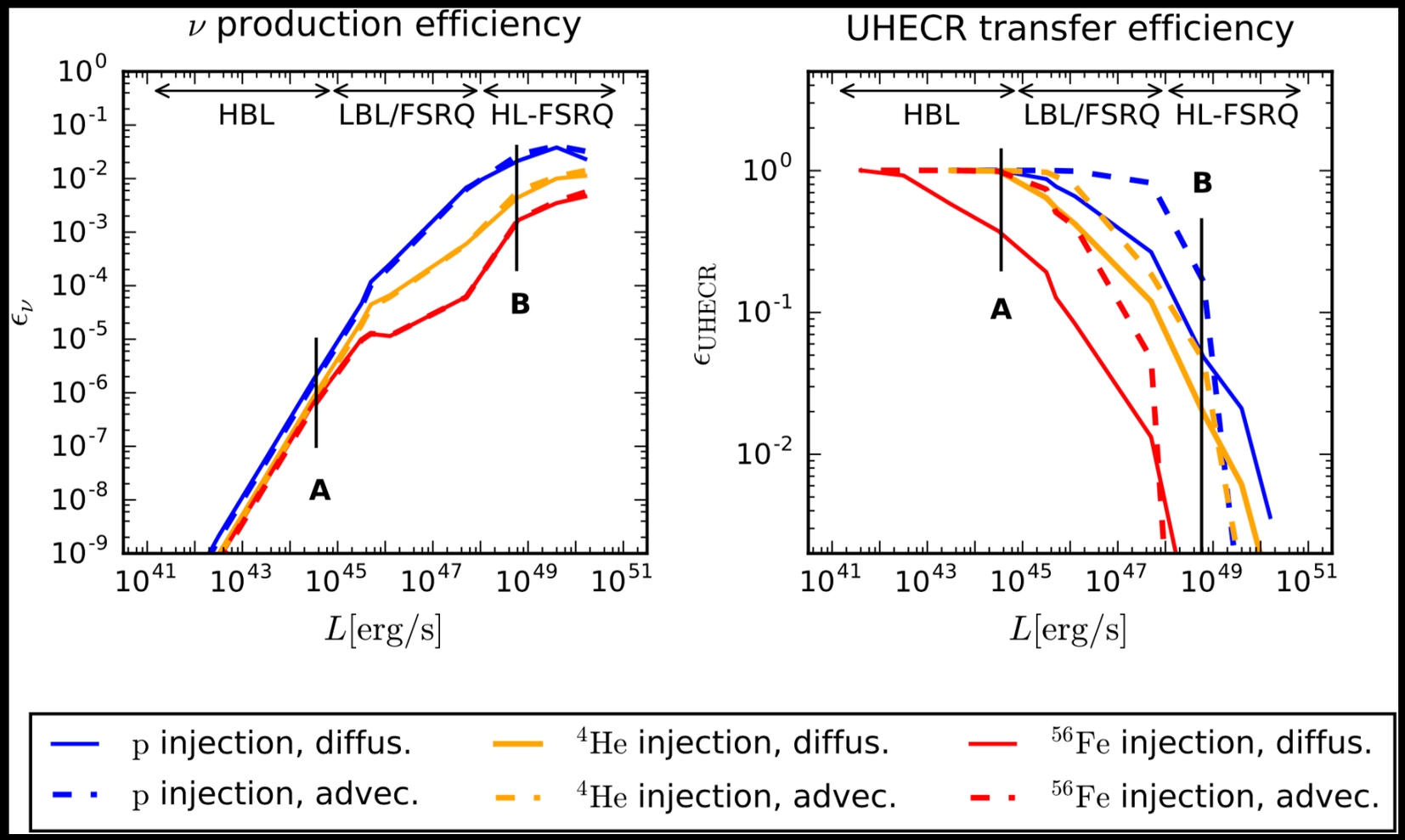
Rodrigues, Fedynitch, SG, Boncioli, Winter,
to appear soon.



Rodrigues, Fedynitch, SG, Boncioli, Winter, to appear soon.

ν spectrum
as a function of
injecting composition

$E_{\nu,\max}$ shifts to lower :
better compatibility with IceCube



Rodrigues, Fedynitch, SG, Boncioli, Winter, to appear soon.

ν CR

production efficiency as a function of blazar luminosity

Opposite trends:

High Lum. FSRQ → ν emitter

Low Lum. BL Lacs → UHECR emitter

Summary

- SED of blazar strongly constrains ν and CR; All blazars cannot be hadronic ($L\nu \neq L\gamma$)

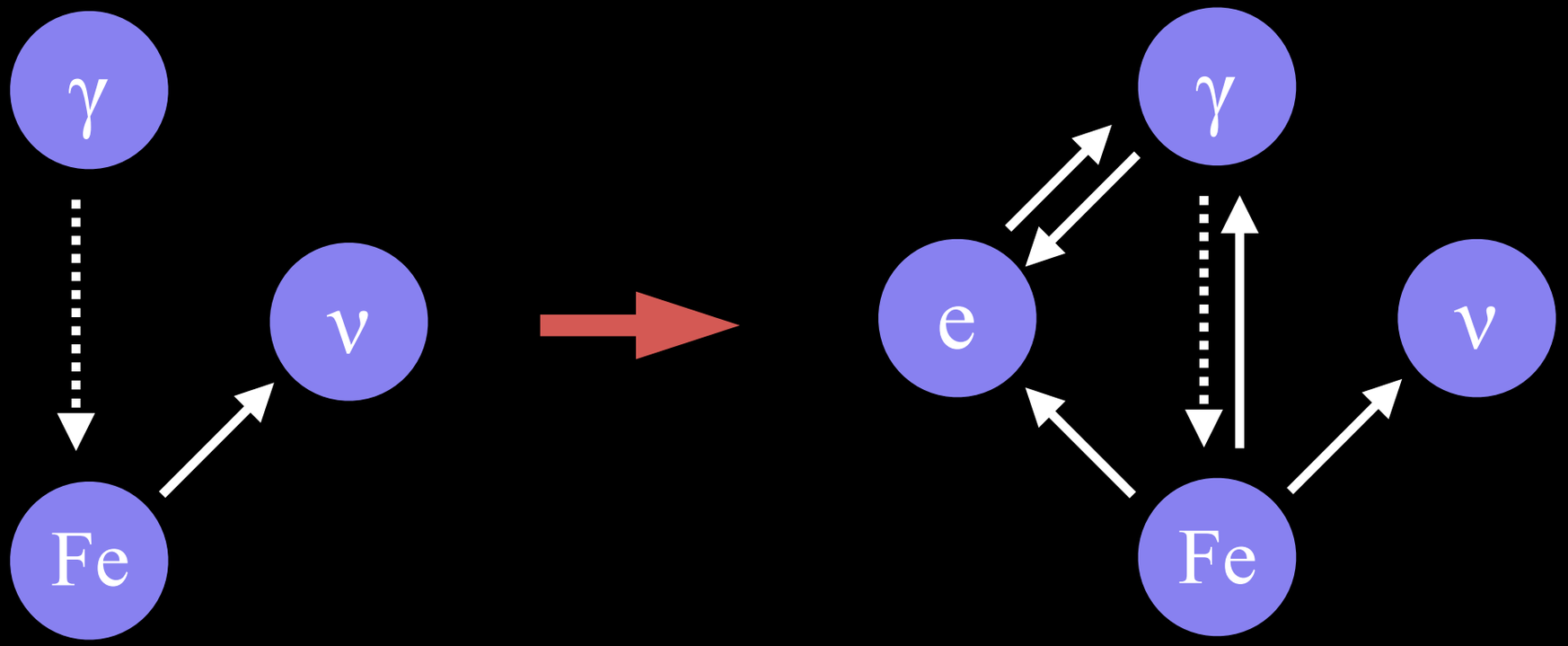
- Nuclear blazar, compared with proton models, yields better ν compatibility with IceCube.

- Opposite trends between ν and CR emissivity along the blazar sequence (different $L\gamma$) : FSRQ - ν; HBL - CR;

- Future: identify gamma-ray signals CTA; to reveal if blazars can be both ν and UHECR sources (incl. diffuse sources). Time-domain; new observables (polarization, PSD, …)

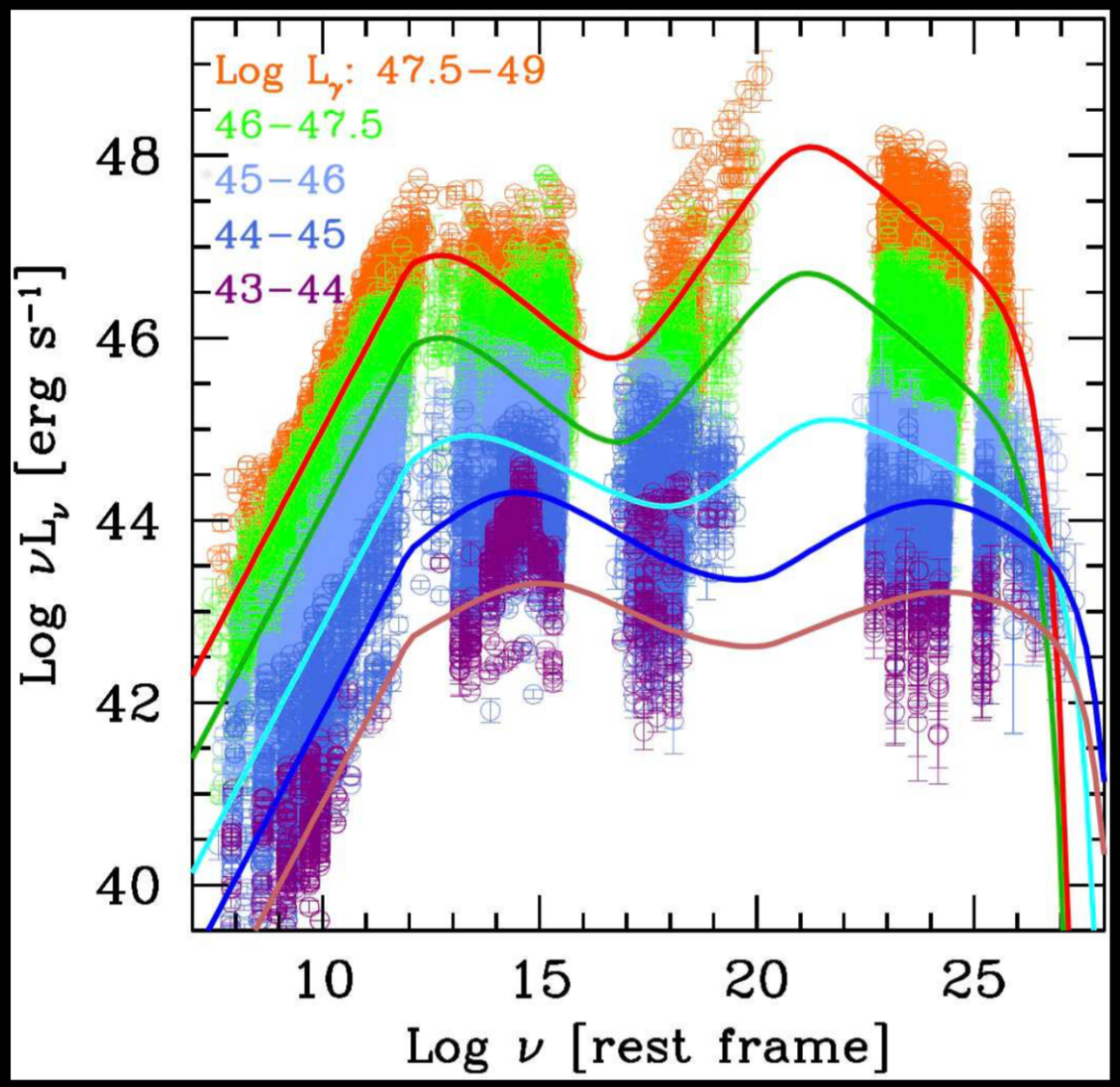
backup

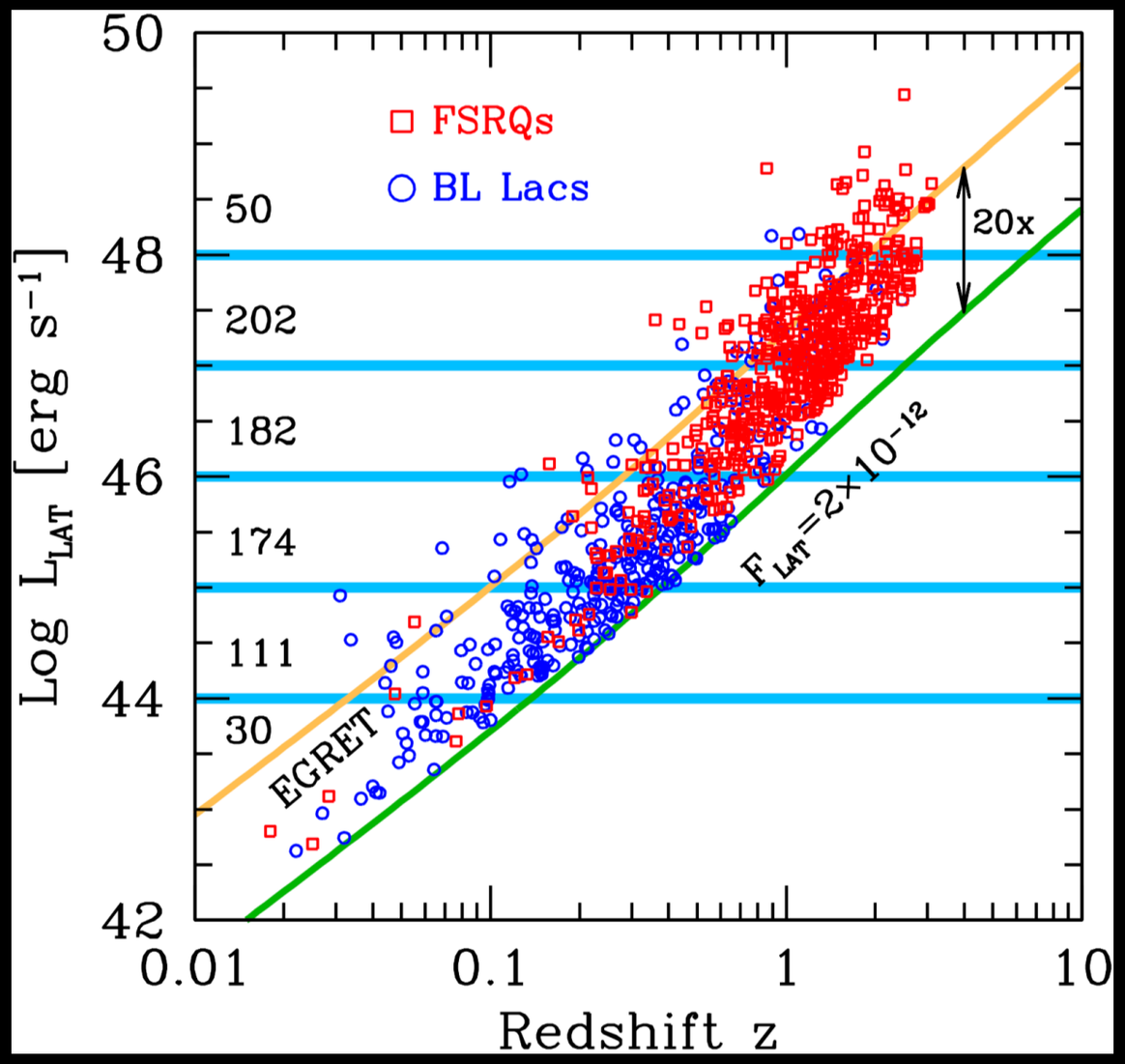
Nuclear feed back to the system, self-consistent



γ signatures of nuclear interactions, TeV ? CTA ?

The BL Lac and FSRQ families

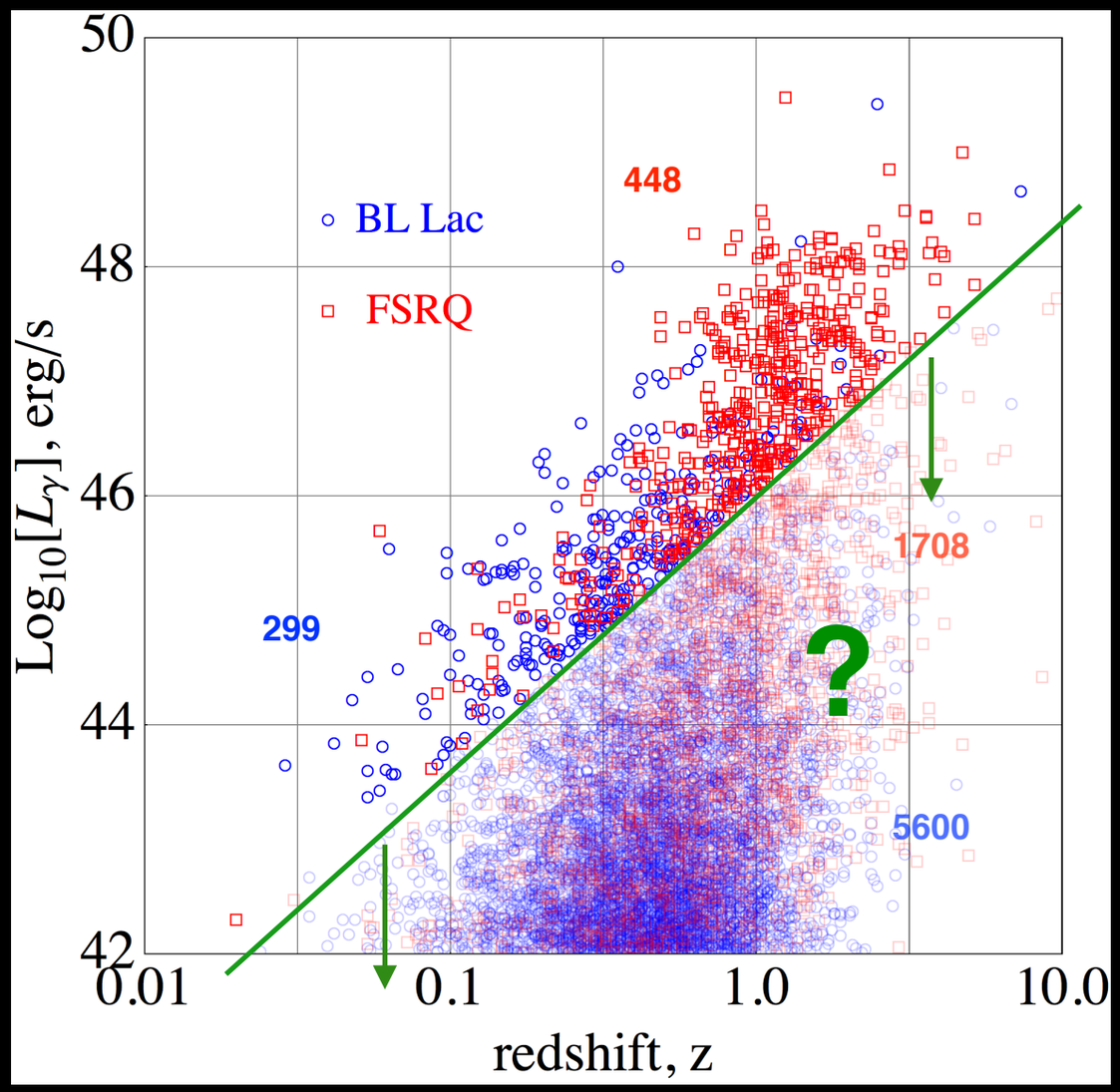




Figures: Ghisellini et al, MNRAS 469(2017), arXiv: 1702.02571

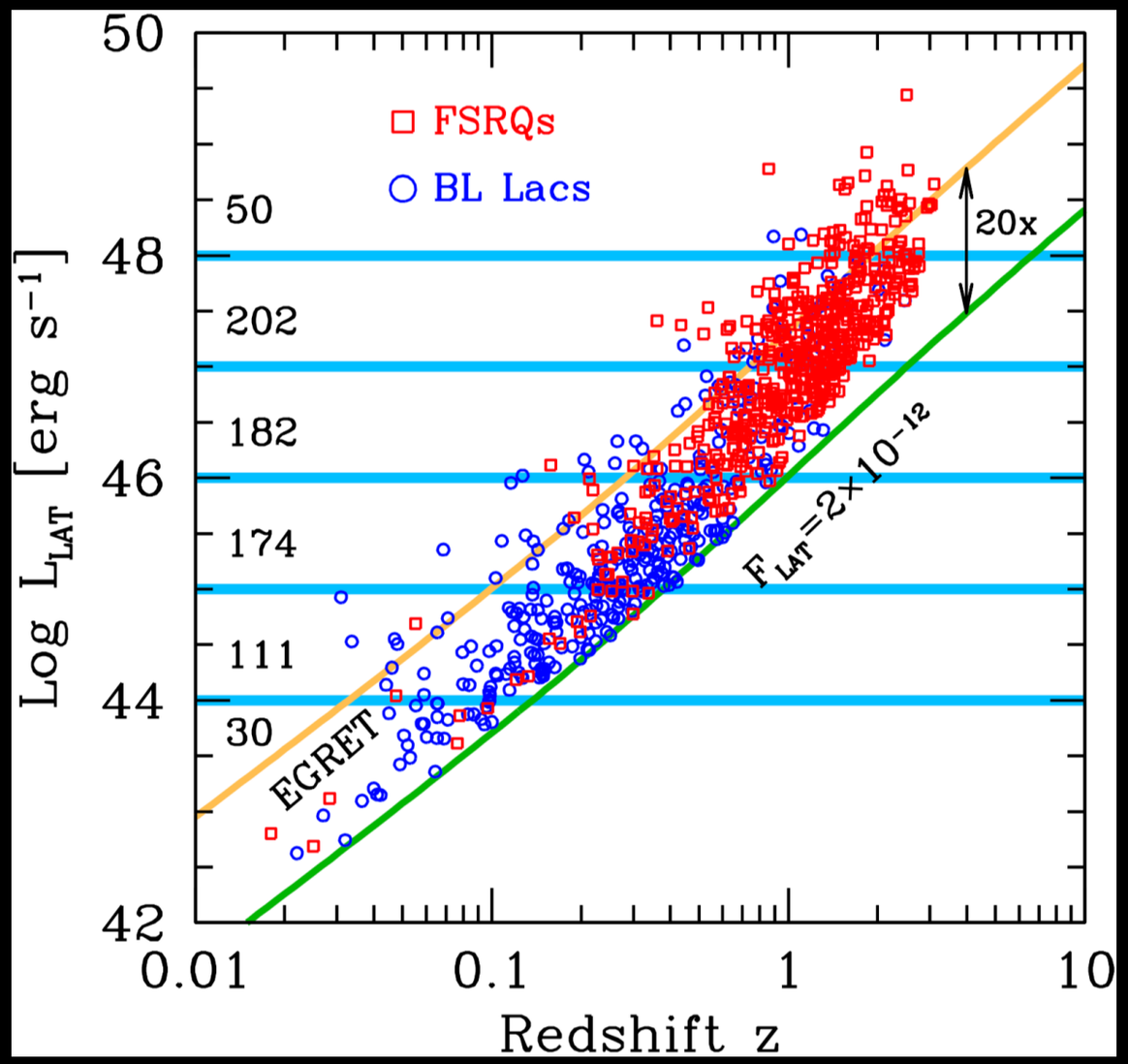
Cannot be all hadronic…

Simulated, from $f(L,z)$



SG, Pohl, Winter. In prep.

Observed



Ghisellini et al, MNRAS 469(2017), arXiv: 1702.02571

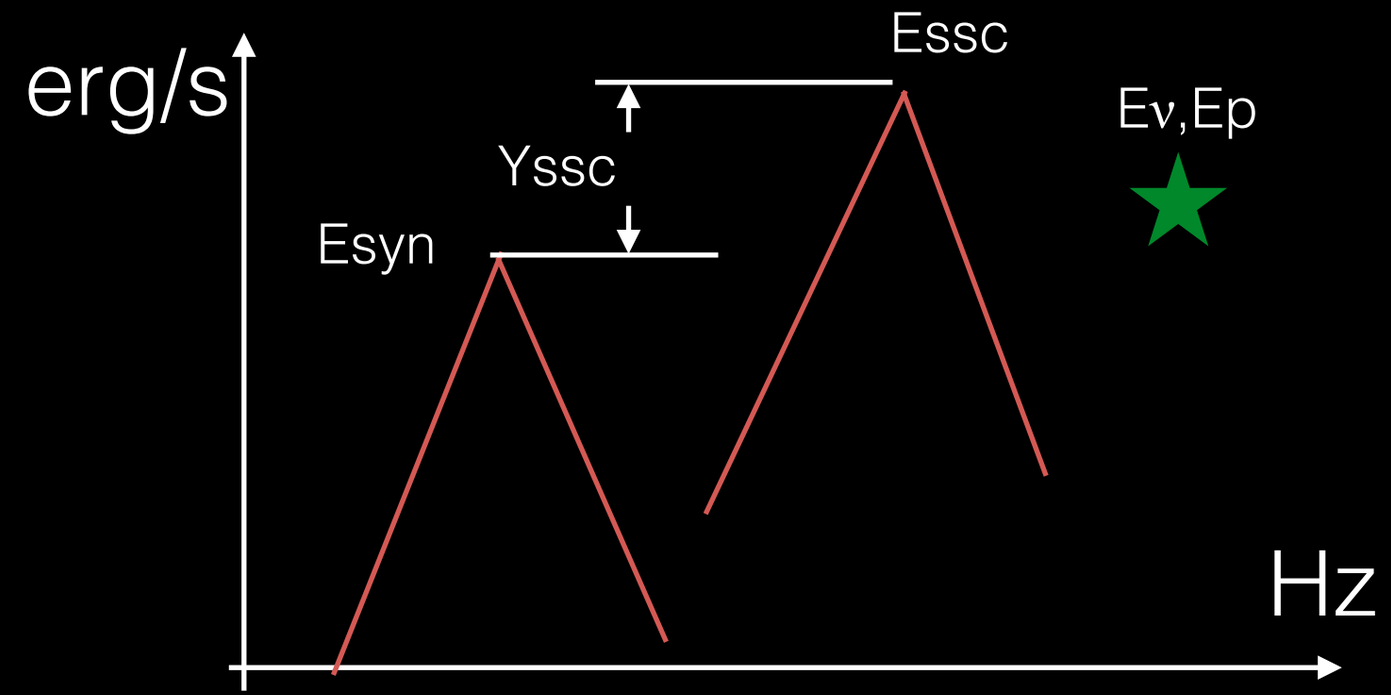
Sub-threshold sources ?

New observables

- ξ Polarization
- t Time-domain, flare, correlation, PSD
- ...

Analytical arguments

- Each constraints -> allowed parameterregions on Γ and B
- No overlaping region that satisfies all: hadronic model ruled out
- A similar approach kills p-syn model



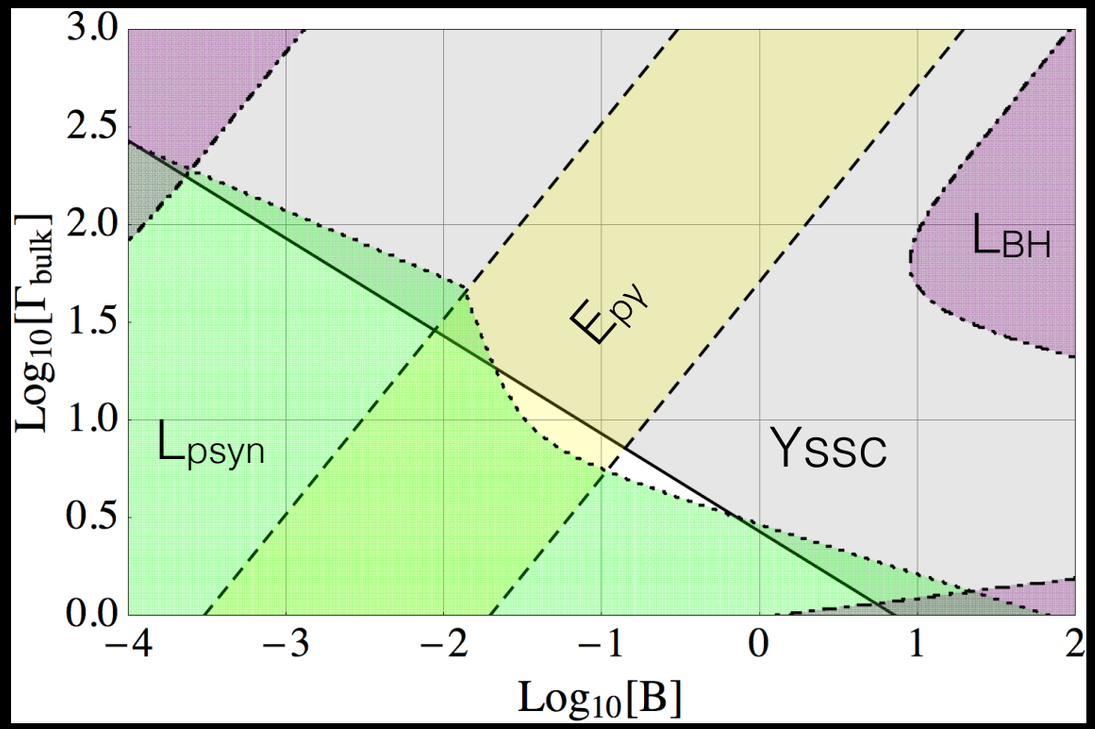


Figure: SG, Pohl, Winter, ApJ 2017

Neutrino production

Astro Source Dissipation → Particle Acceleration → pp, pγ Interaction → Propagation → Earth Detector Response

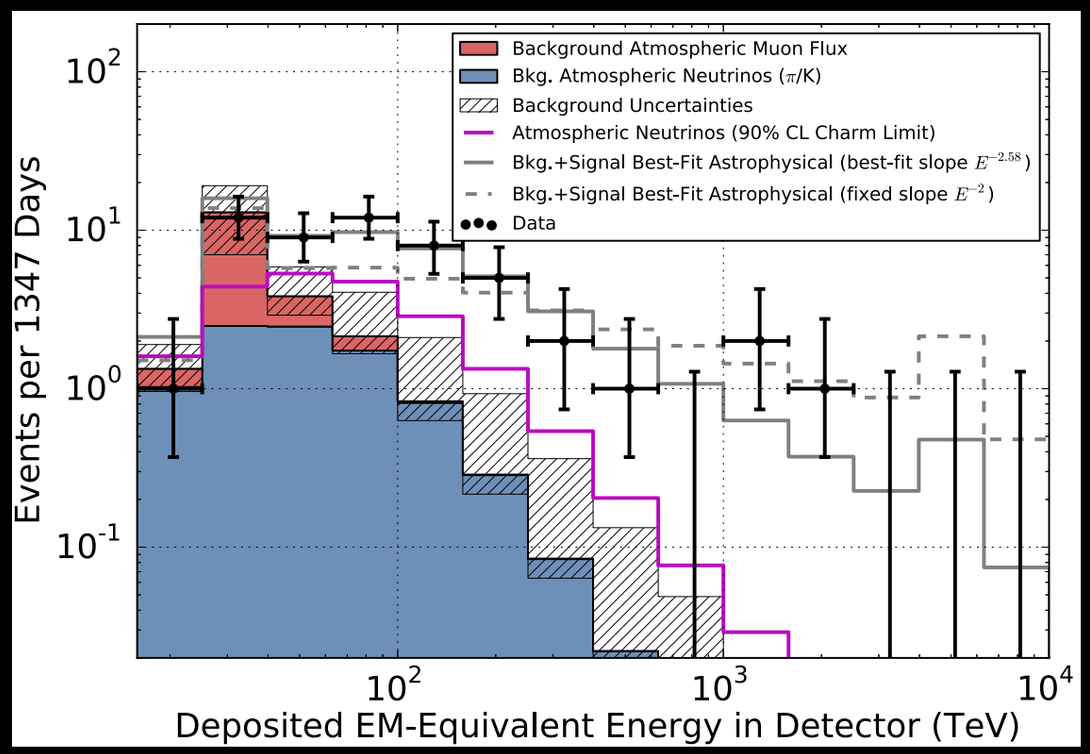
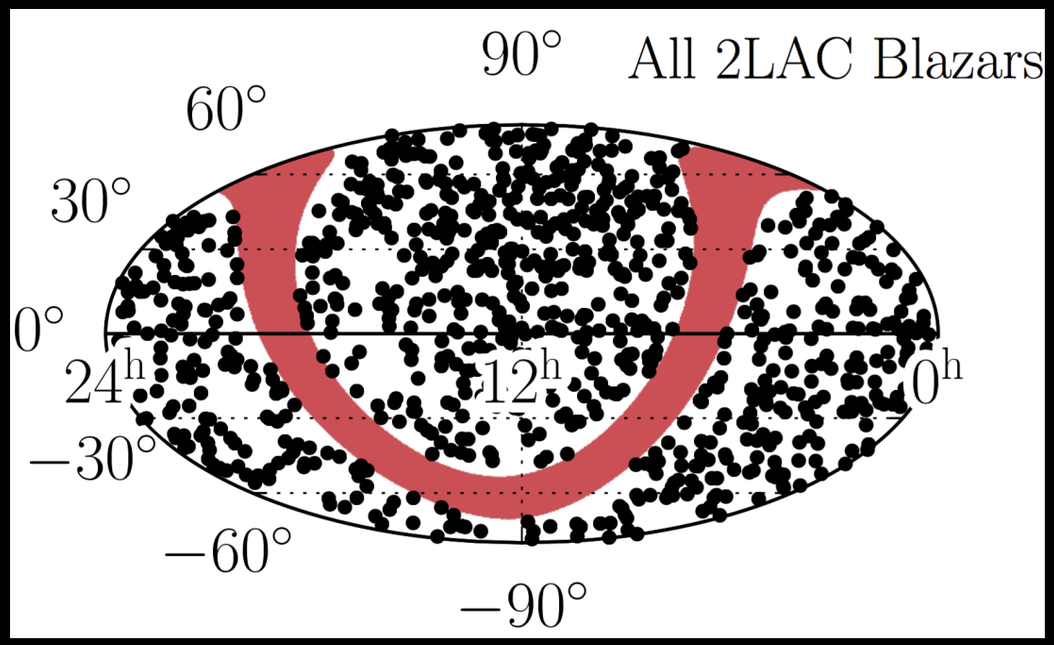
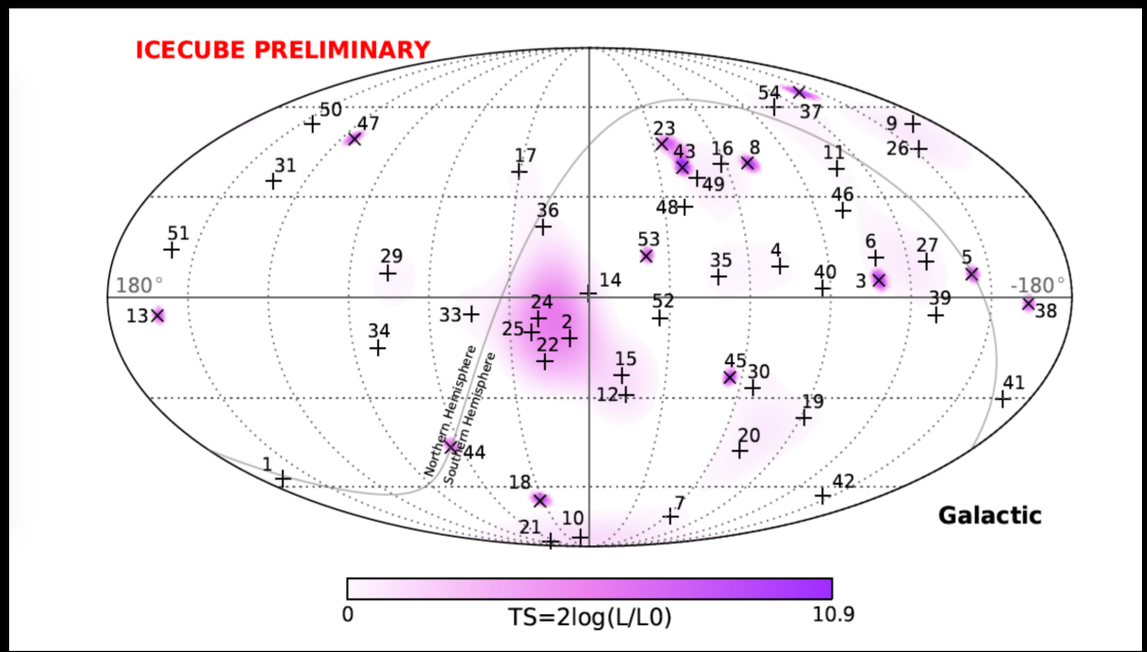


Figure: IceCube collaboration

IceCube analysis 2LAC blazars





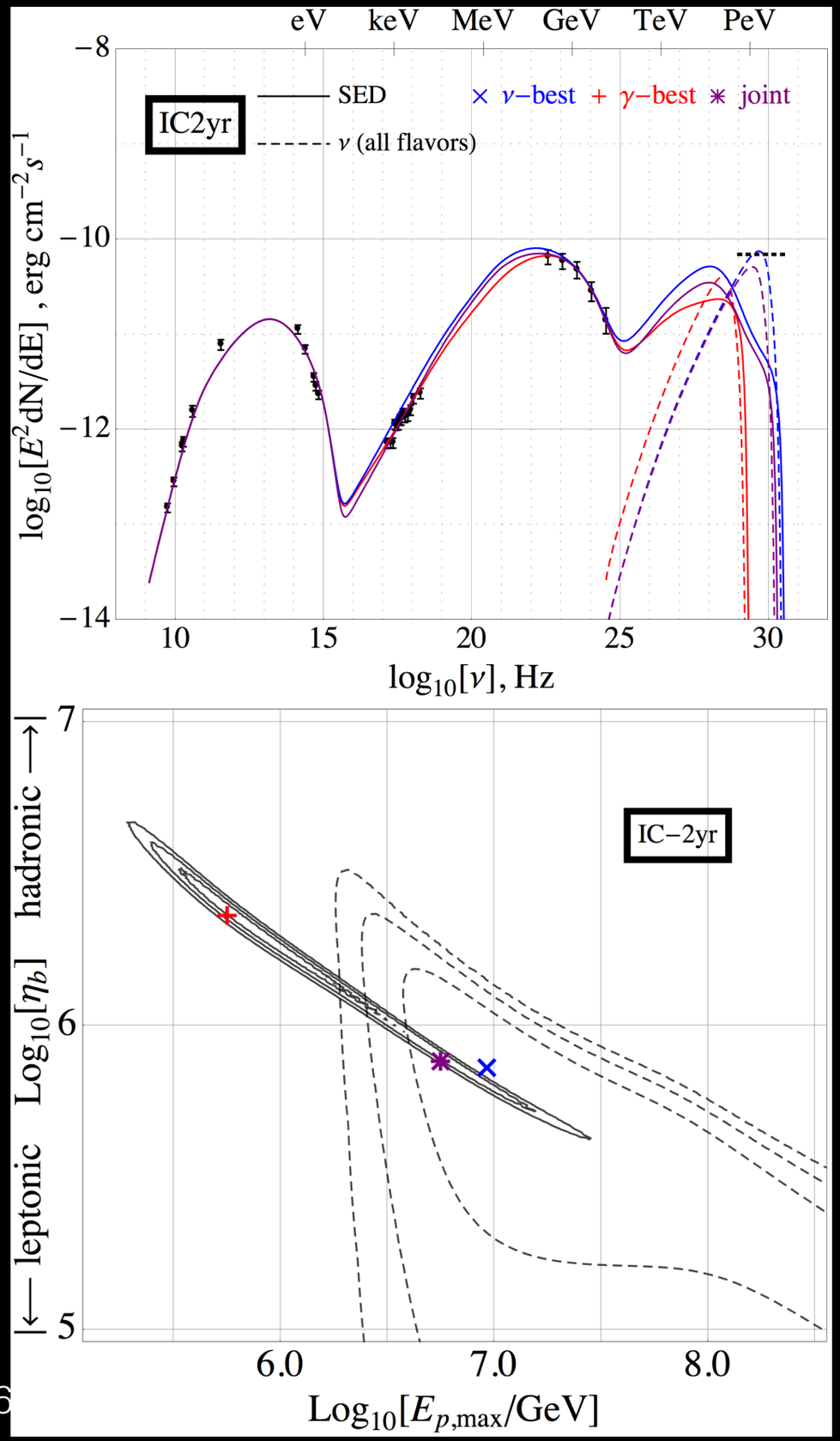
IceCube collaboration
1611.03874

+ Spatial correlation study

Lν=Lγ (each source)	Assumption	F(Lν)=F(Lγ) (entire pop.)
Up to ~10% flux	Conclusion	Up to ~ 30% flux

Low-state result

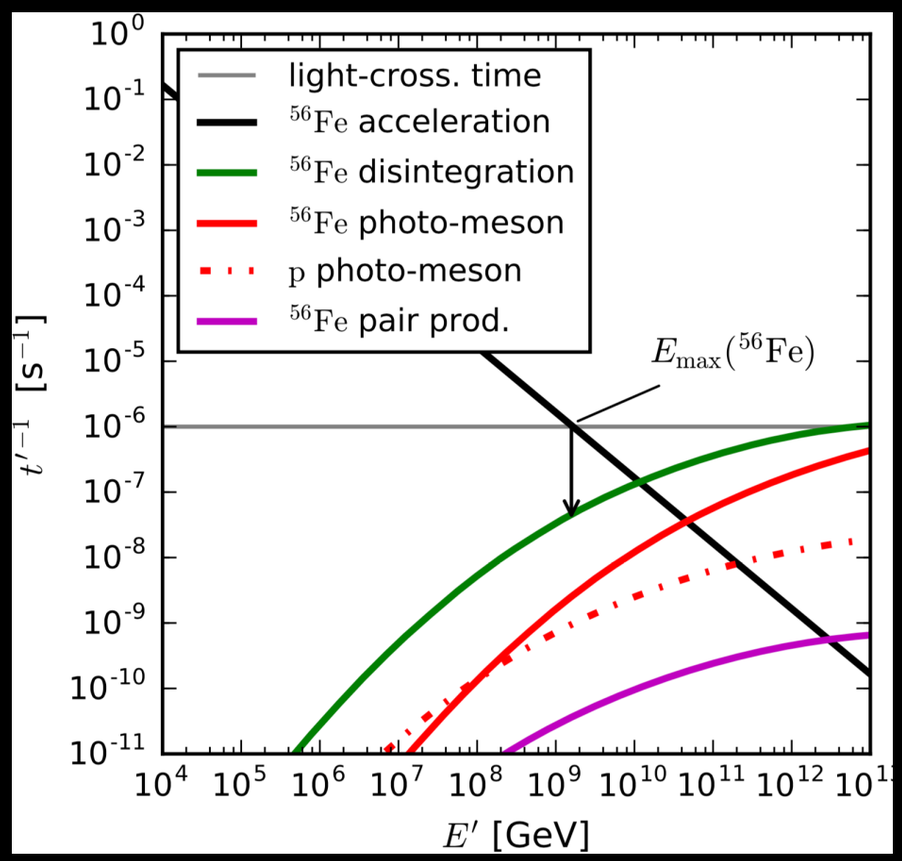
- Results are similar
- Low-state duration is longer (2yr)
- SED-NU joint best-fit is better

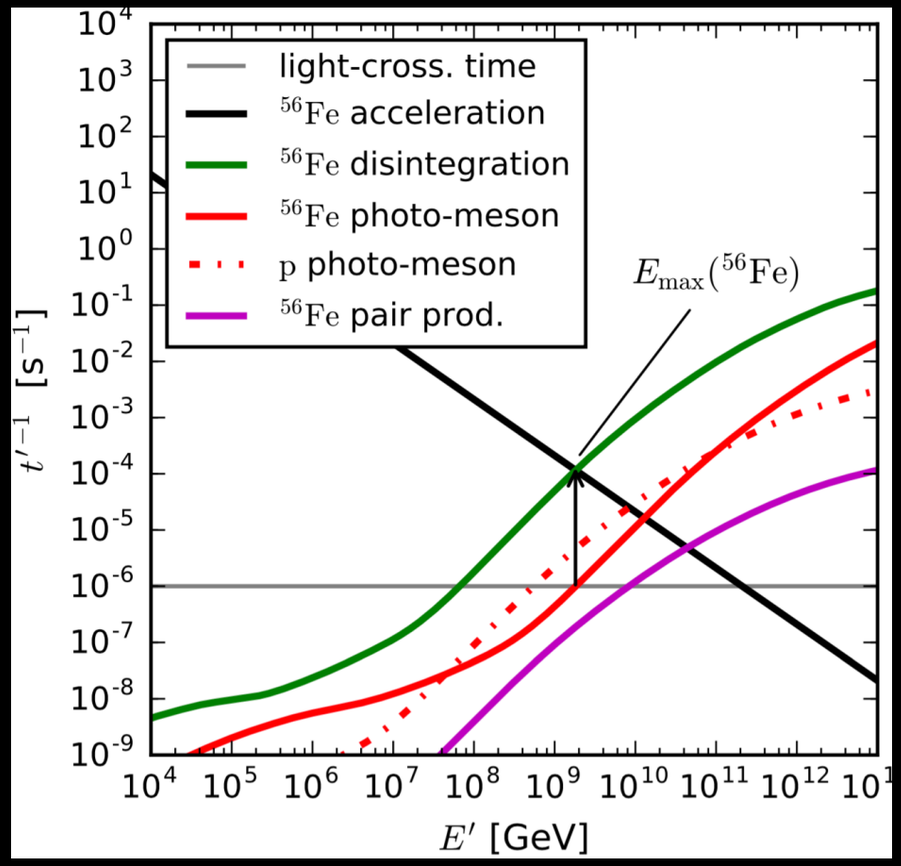


Conclusion

- SED is leptonic dominated for PKS B1424-418
- Low and Burst state modeled self-consistently by perturbing Le and Lp
- Low-state has an even better probability to observe PeV NU

	Low (2yr)	Burst
Lp	baseline	0.5 x
Le	baseline	2.5 x
Pν	5.7%	3.2%


light-cross. time
^{56}Fe acceleration
^{56}Fe disintegration
^{56}Fe photo-meson
p photo-meson
^{56}Fe pair prod.
$E_{\rm max}(^{56}{\rm Fe})$
t'^{-1} [s^{-1}]
E' [GeV]


light-cross. time
^{56}Fe acceleration
^{56}Fe disintegration
^{56}Fe photo-meson
p photo-meson
^{56}Fe pair prod.
$E_{\rm max}(^{56}{\rm Fe})$
t'^{-1} [s^{-1}]
E' [GeV]