Neutrinos on ice

3LAC counterparts to IceCube neutrinos above 100 TeV

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Papers in PDF link to journal article, slides available at https://fekrauss.com

Cosmic rays

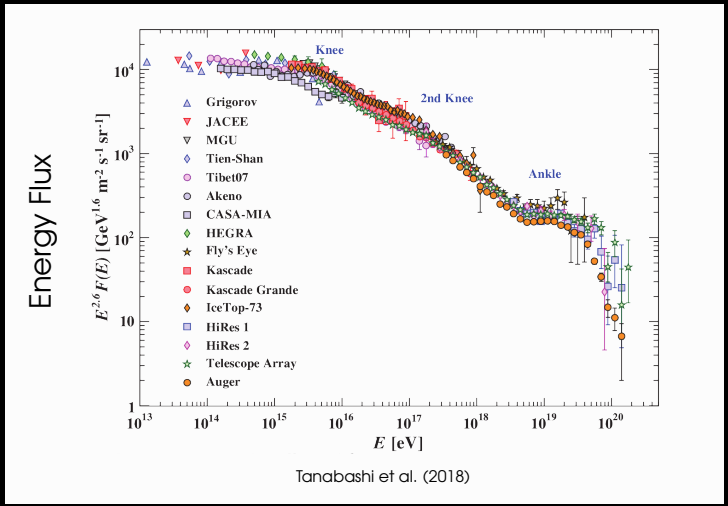
1896: H. Becquerel
discovery of radioactivity

1909: T. Wulf
Eiffel tower and electrometer

1912: V. Hess
balloon flight 5.3 km (17400 feet)

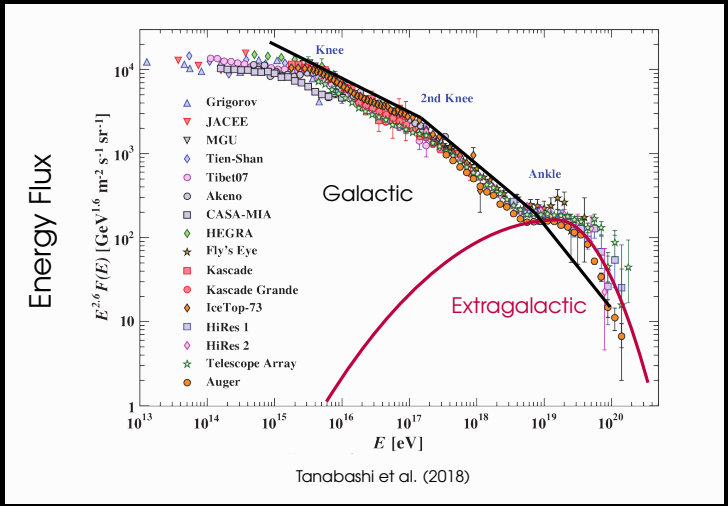
→ Flux of charged particles from space

Cosmic rays

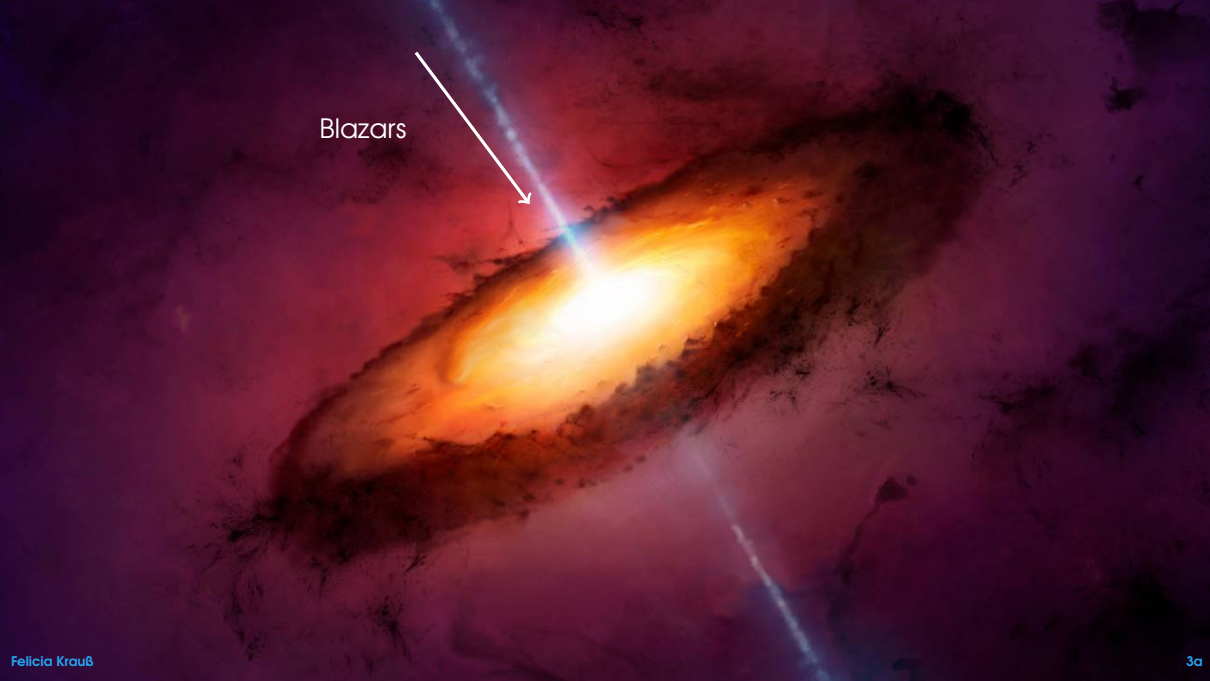


Tanabashi et al. (2018)

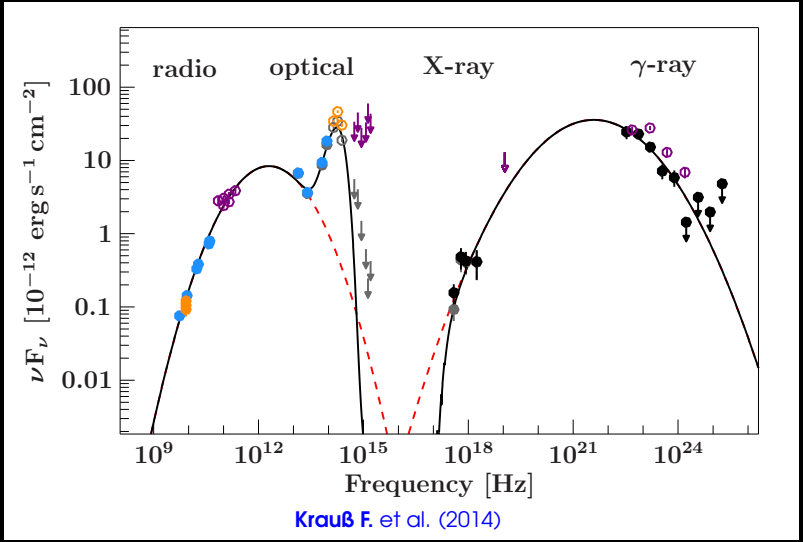
Where are cosmic rays coming from?



Tanabashi et al. (2018)

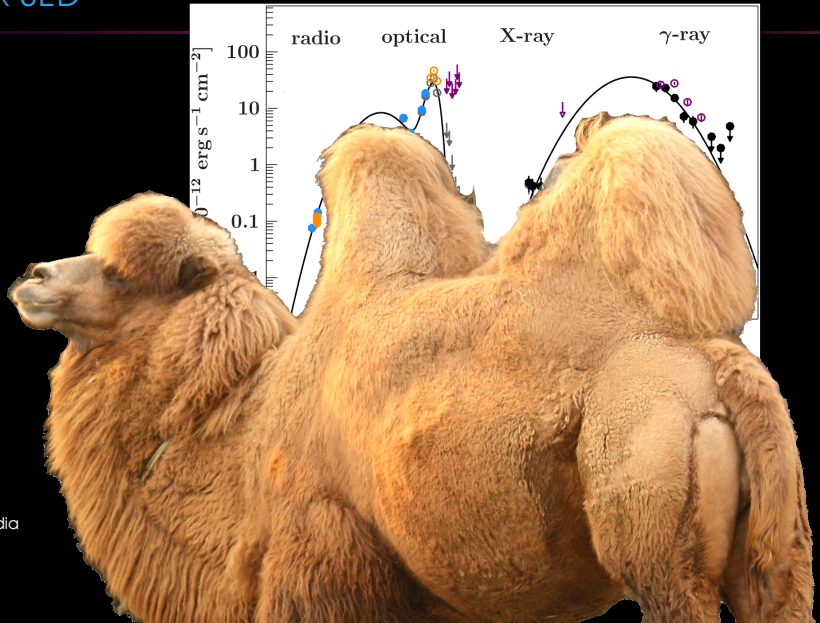

Blazars

Blazar SED



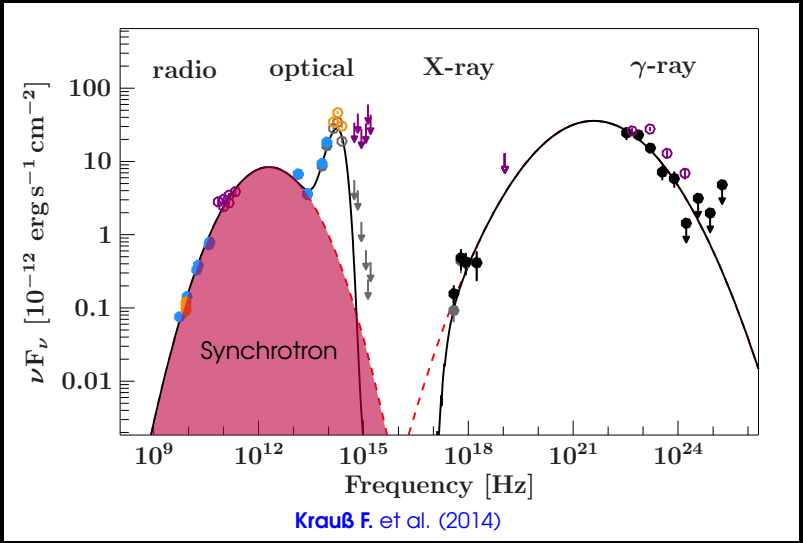
Krauß F. et al. (2014)

Blazar SED



©Wikipedia

Blazar SED



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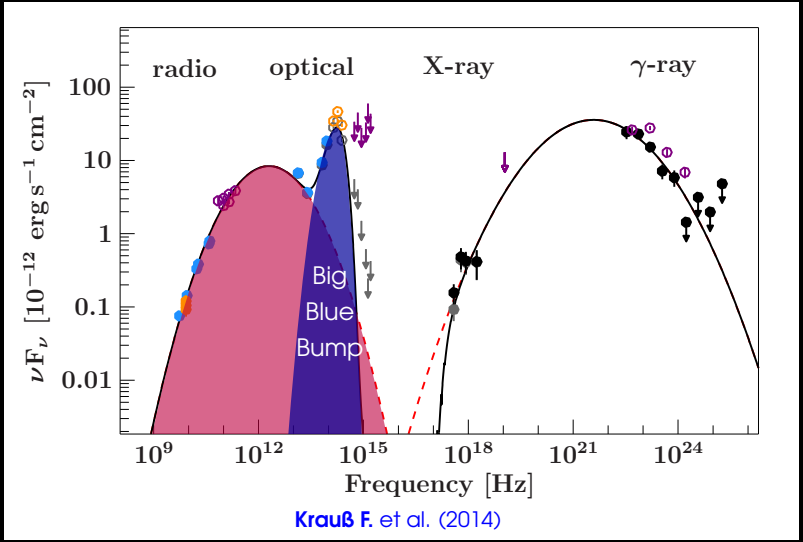
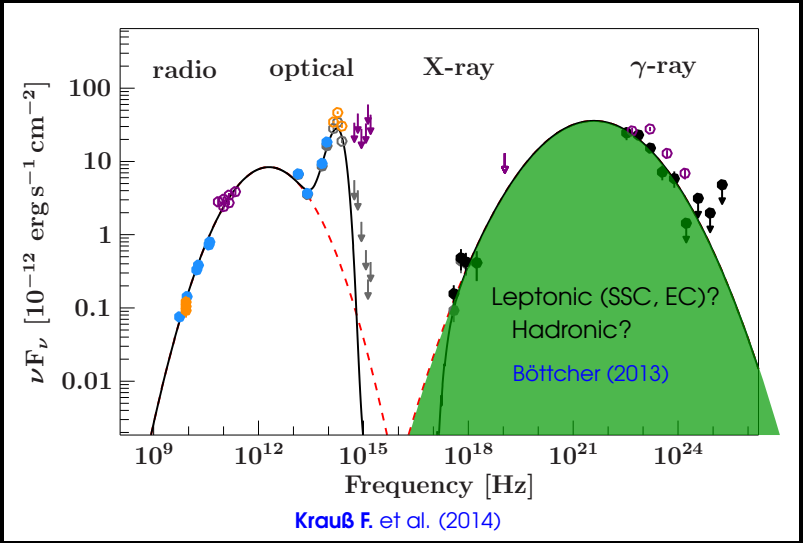


Krauß F. et al. (2014)

Blazar SED



Krauß F. et al. (2014)

How hadronic are blazars?

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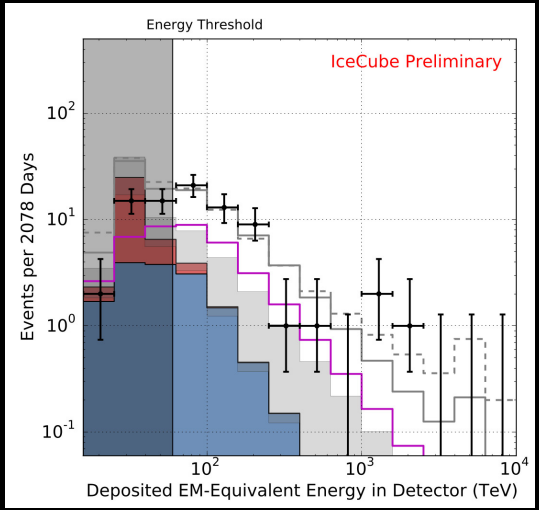

IceCube collaboration (2018)

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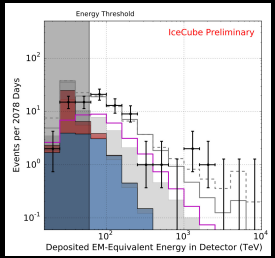
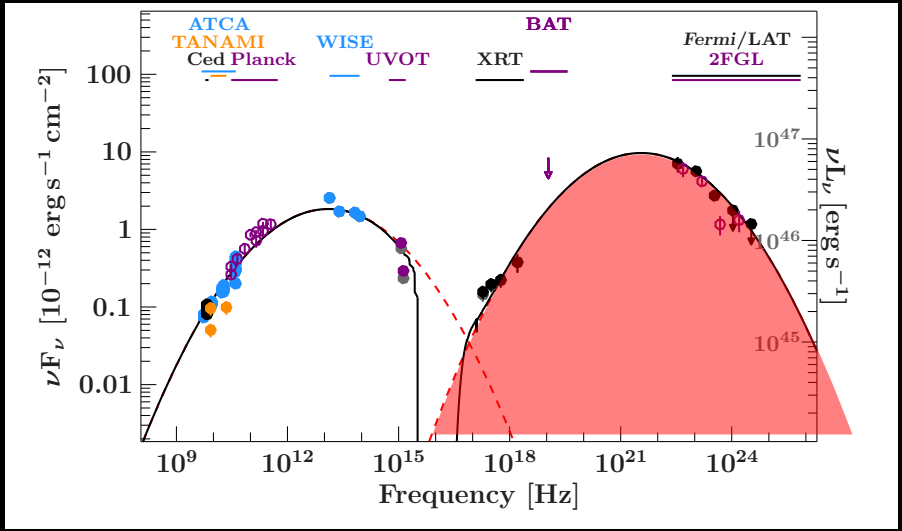


Consistent with IceCube?

What is the hadronic contribution?



Krauß F. et al. (2014)

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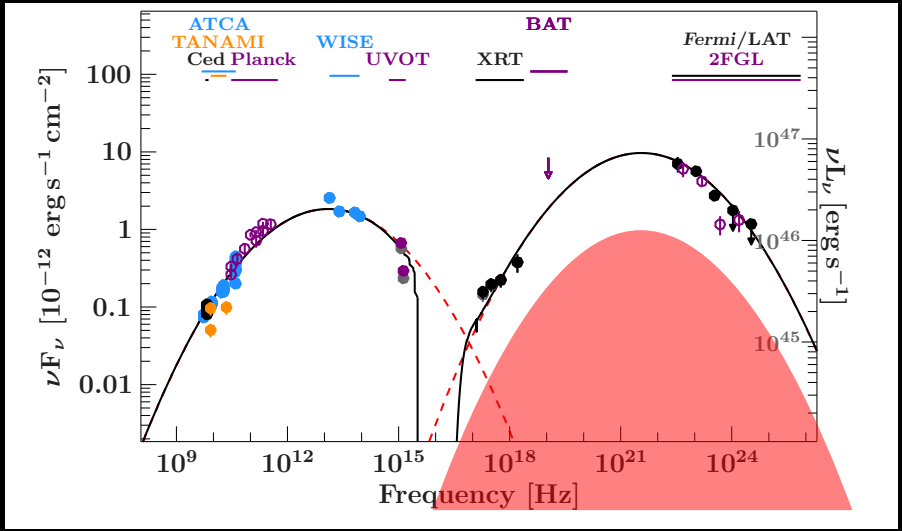

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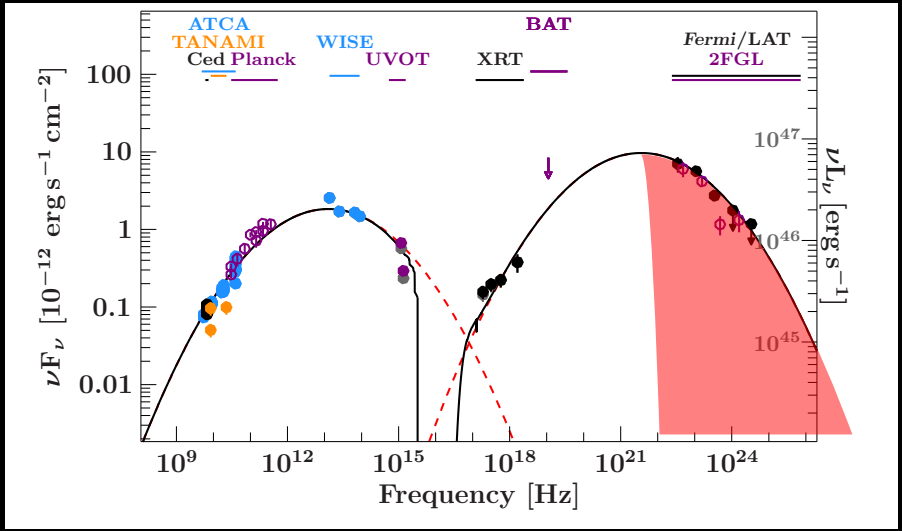

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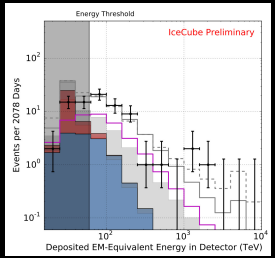

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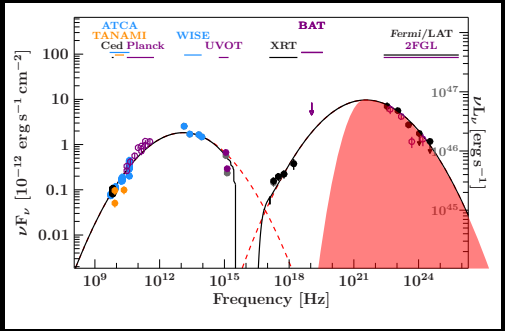
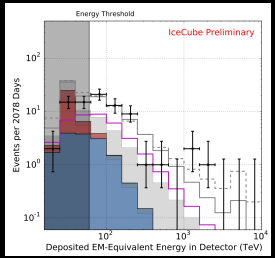


Contribution to the high-energy spectrum

How hadronic are blazars?



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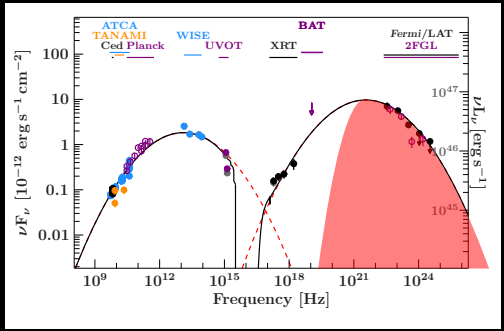


Contribution to the high-energy spectrum

Similar for all sources?

Summary

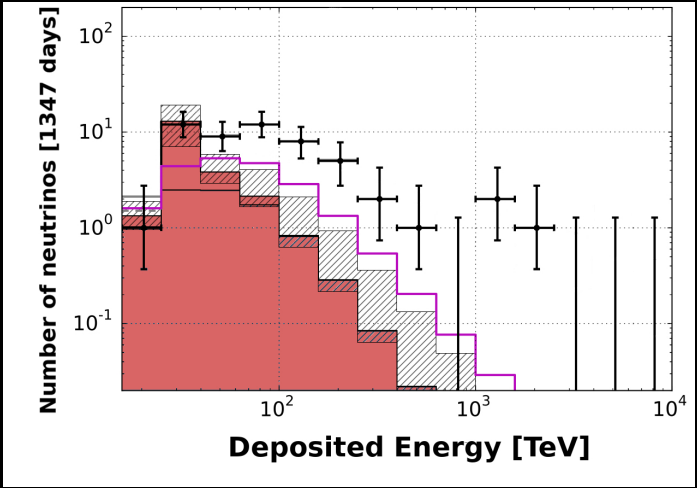
What is the average percentage of hadronic emission?

4%

Are all sources equally hadronic?

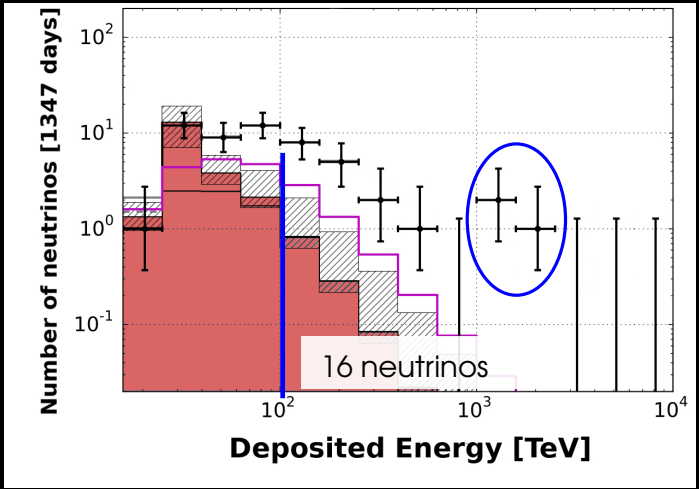
?

METHOD



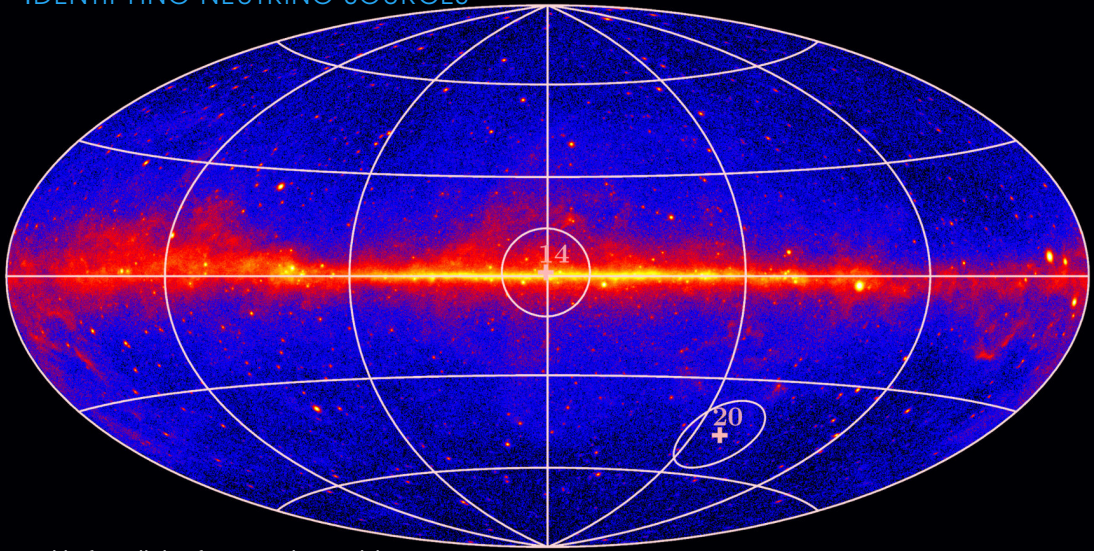
IceCube Collaboration (2013, 2013, 2014, 2015)

METHOD



IceCube Collaboration (2013, 2013, 2014, 2015)

Identifying neutrino sources



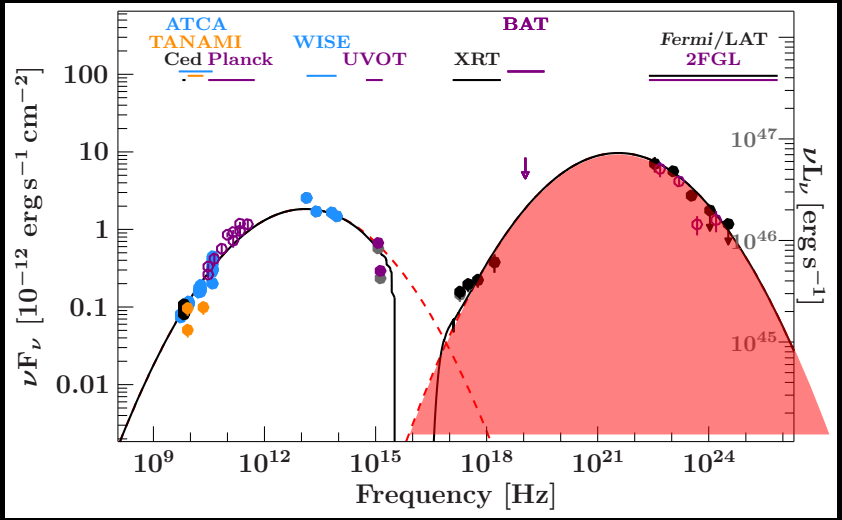
Unfeasible for most neutrinos

Calculate neutrino emission for large number of sources

Previous results

- Calorimetrically blazars can explain IceCube events
  Krauß et al. (2014)
- First coincidence of blazar outburst and neutrino: PKS 1424−418 and IC 35
  Kadler, Krauß et al. (2016), Nature Physics
- (TXS 0506+056 and IC 170922A)

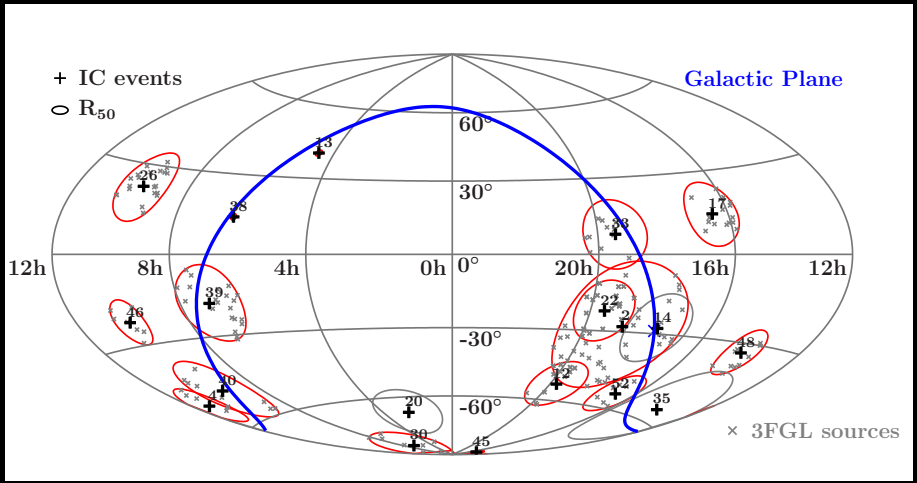
Identifying neutrino counterparts



Mannheim (1993), Mannheim (1995), Mücke (2000)

$$\int F_\nu(E_\nu)\,\mathrm{d}E_\nu = \int F_\gamma(E)\,\mathrm{d}E$$

Neutrinos > 100 TeV



Krauß et al. (2018)

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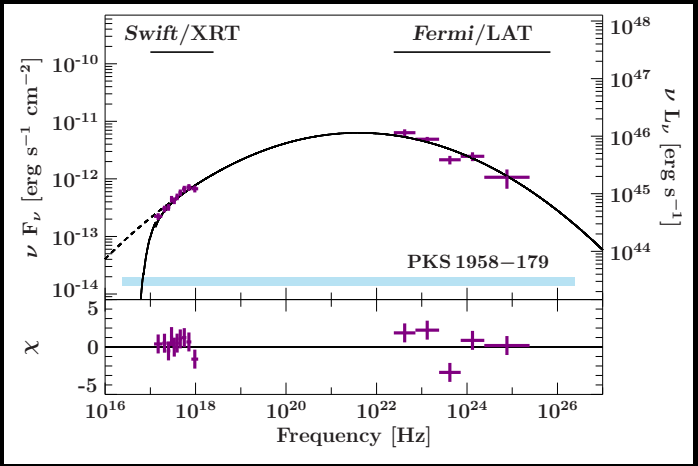

×179

Krauß et al. (2018)

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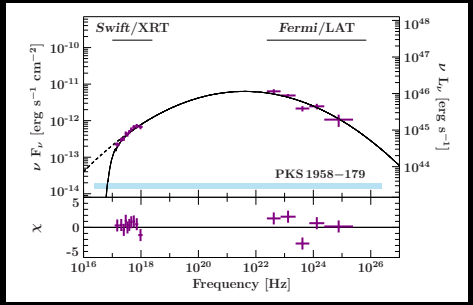

$\times$ 179

$N_{\nu,\mathrm{all}} = 178 \gg 10$ cosmic neutrinos

Kadler, **Krauß F.** et al., Nature Physics (2016)
Krauß F. et al. (2018)

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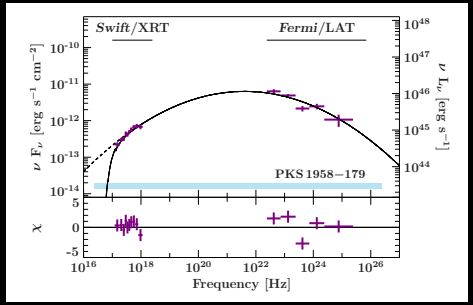

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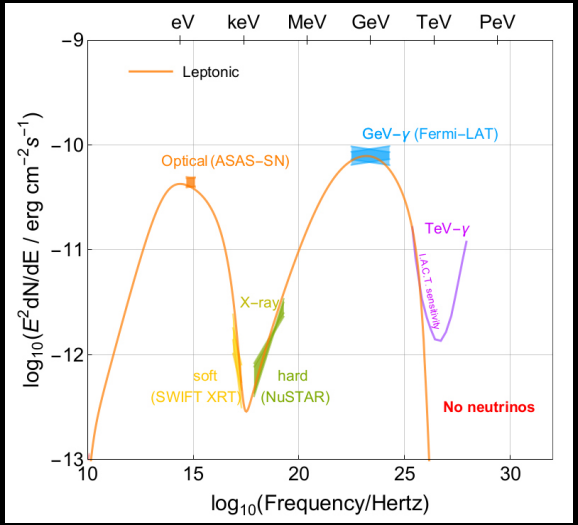
$N_{\nu,\mathrm{all}} = 178 \gg 10$ cosmic neutrinos

$\leq 4\%$ of emission hadronic

First constraint on hadronic contribution to SED

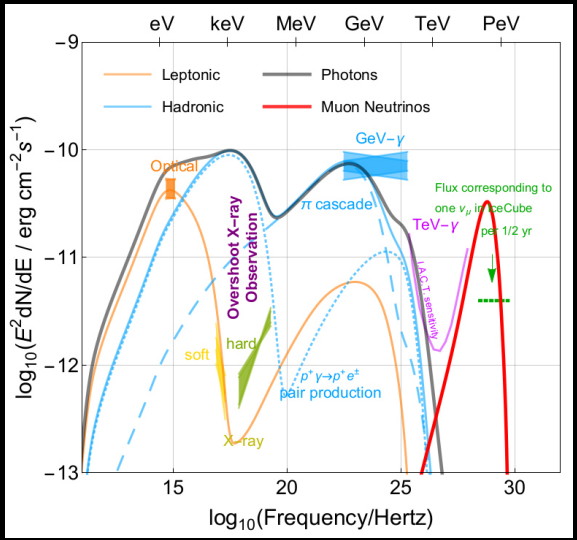
Multiwavelength modeling of TXS 0506+056



Leptonic model

(Gao et al., 2018; Keivani et al., 2018)

Multiwavelength modeling of TXS 0506+056



Felicia Krauß Hadronic model

(Gao et al., 2018; Keivani et al., 2018)

Conclusion

- Blazars on average $\sim$ 4% hadronic
- No 5σ associations yet!
- Unclear whether different sources are less/more hadronic