Blazars as neutrinos factories

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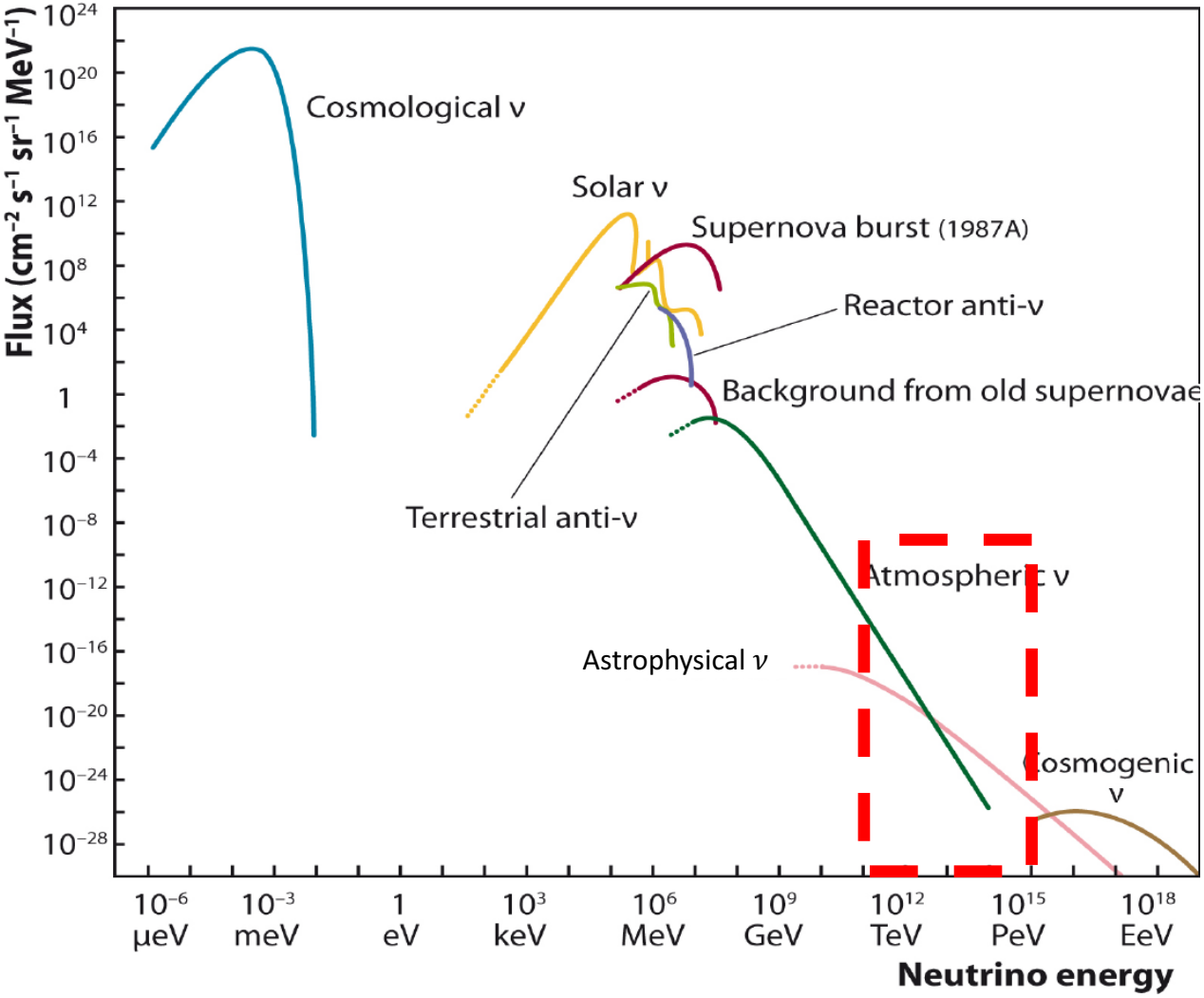
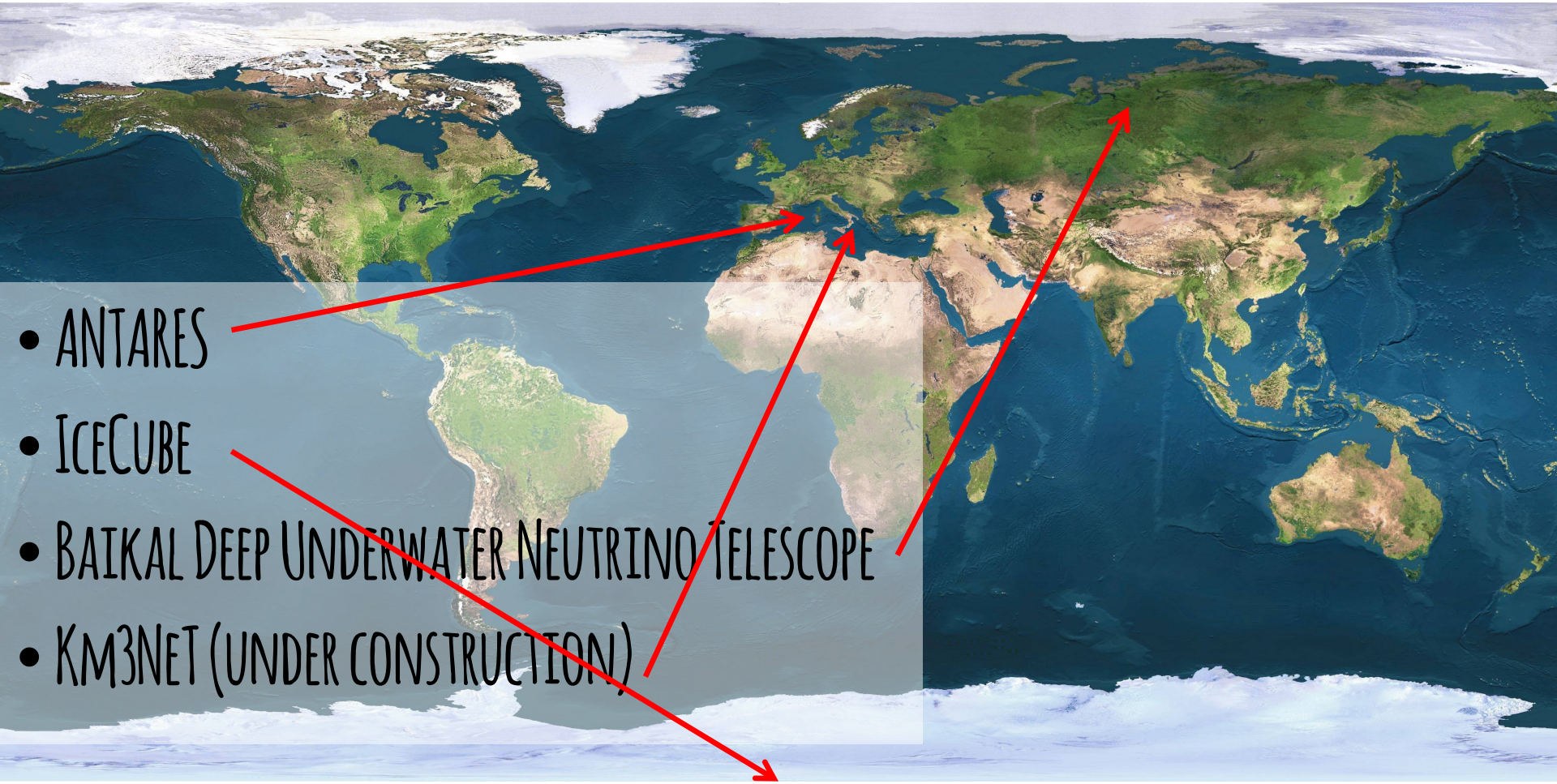
11 December 2018

Neutrino flux

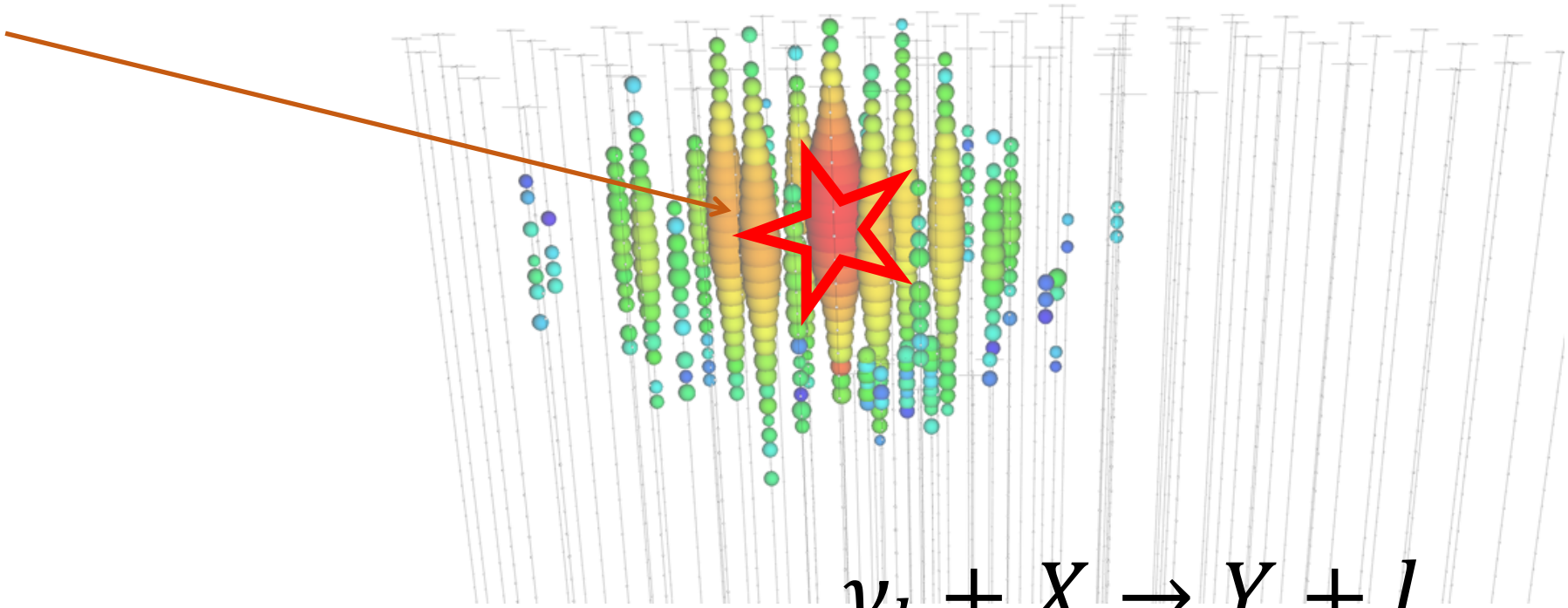


How to observe high-energy neutrinos?



How to observe high-energy neutrinos?

Interaction inside the detector → High Energy Starting Events (HESE)

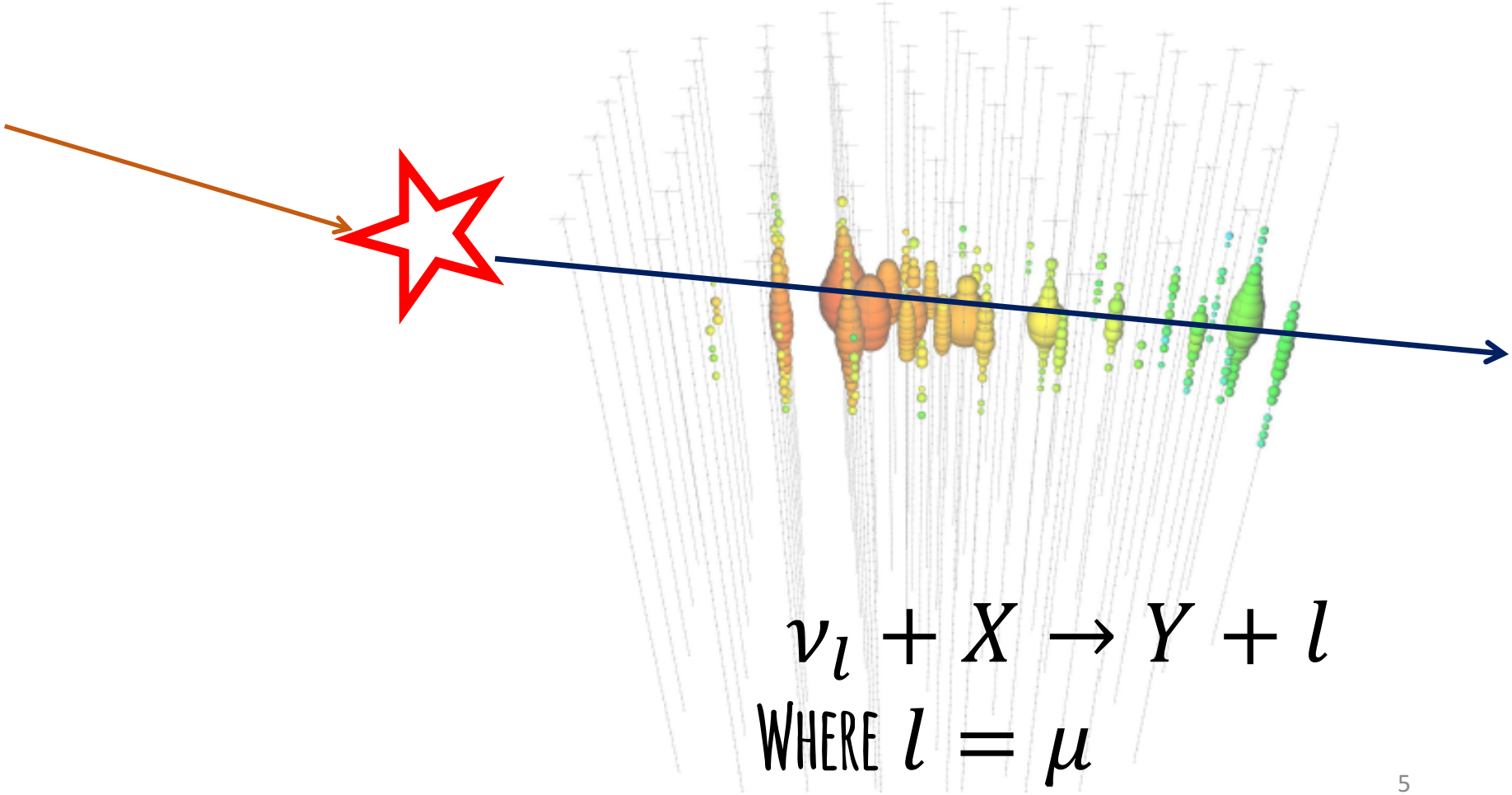


$$\nu_l + X \rightarrow Y + l$$

Where $l = e, \mu, \tau$

How to observe high-energy neutrinos?

Interaction outside the detector → Througoing muon events

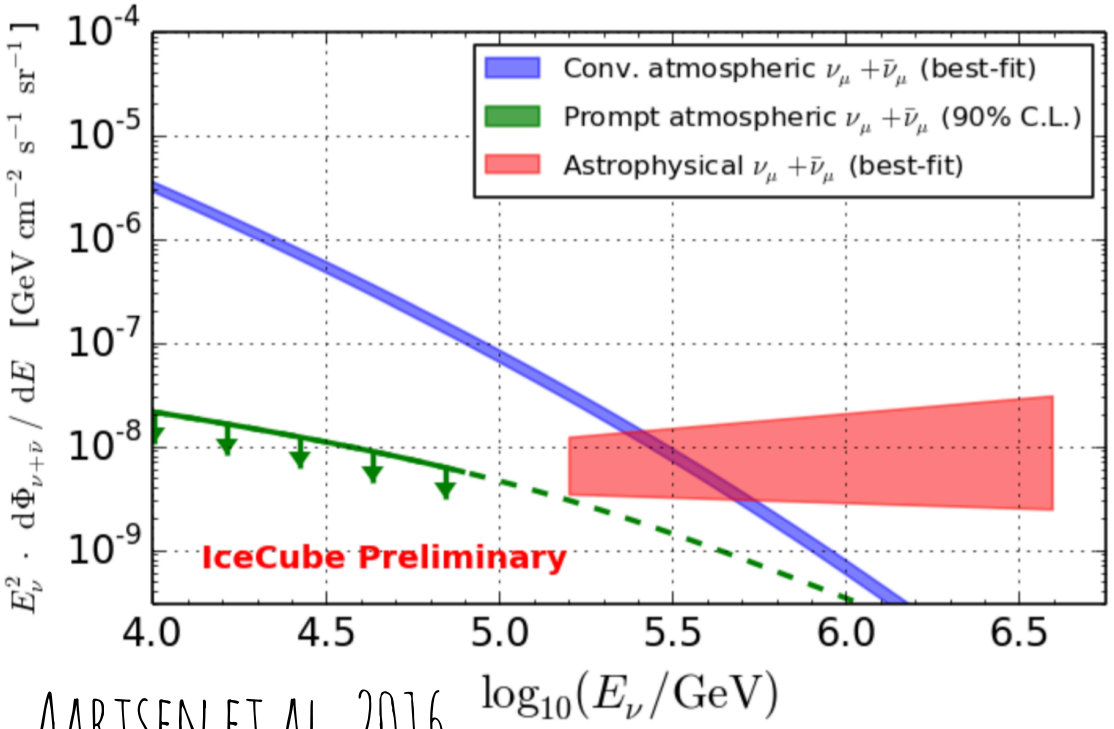


$$\nu_l + X \rightarrow Y + l$$

Where $l = \mu$

Discovery of high-energy neutrinos by IceCube

~80 events since 2010 above 60TeV

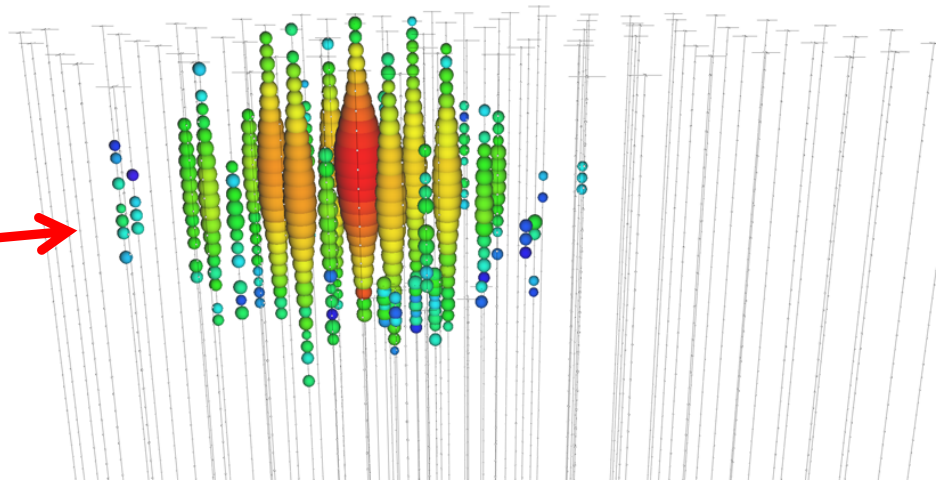


Aartsen et al. 2016

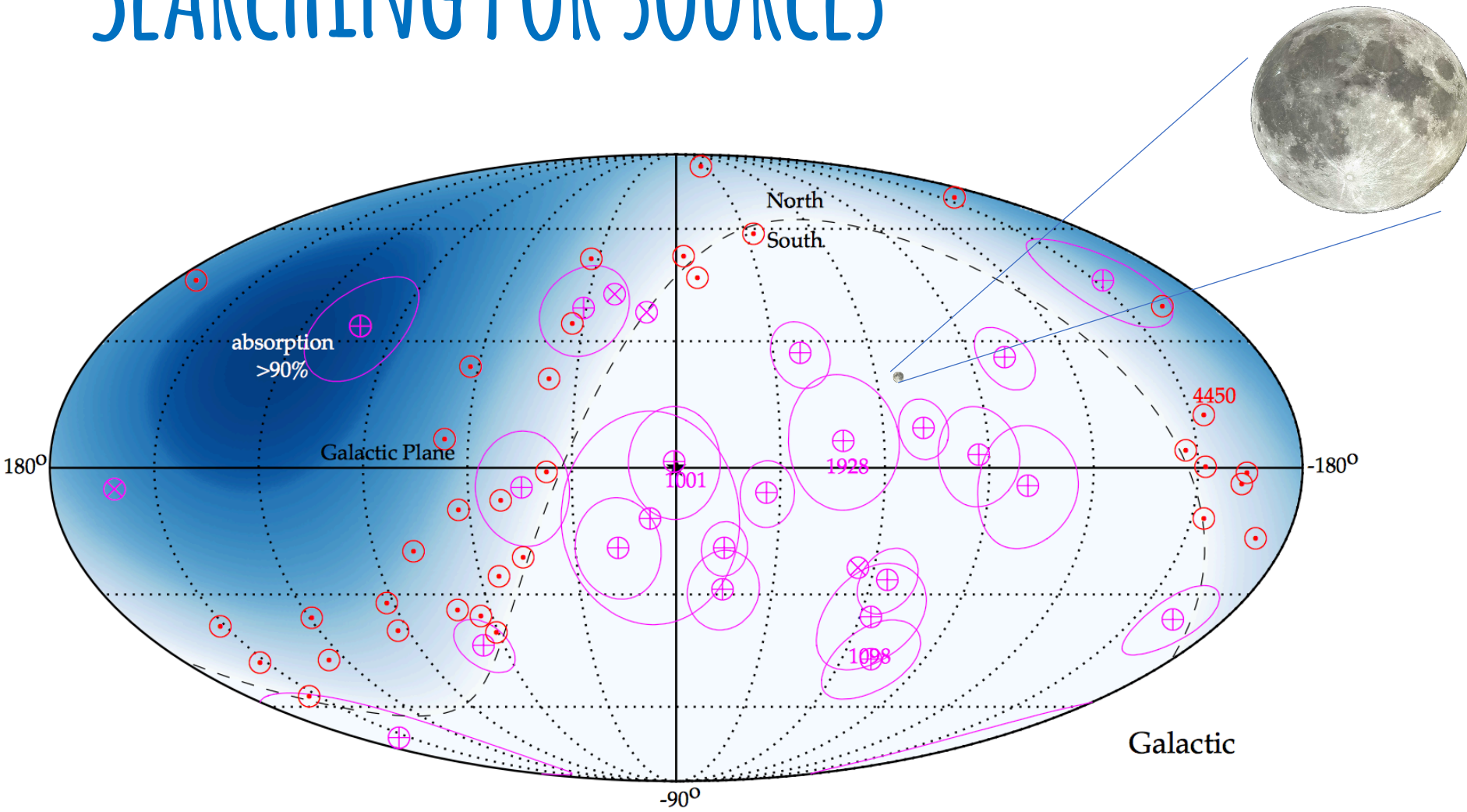
~10 events per year

Discovery of high-energy neutrinos by IceCube

~80 events since 2010 above 60TeV



Searching for sources



We will consider only througoing muons!

High-energy neutrino production

Relativistic protons!!

$$p + p \rightarrow \pi + X \qquad p + \gamma \rightarrow \pi + X$$

$$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu} \rightarrow e^{\pm} + \nu_e + 2\,\nu_{\mu}$$

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

$$E_\nu \sim E_p/20$$

1:1:1
after propagation

High-energy neutrino production

Relativistic protons!!

$$p + p \rightarrow \pi + X$$

$$p + \gamma \rightarrow \pi + X$$

Our galaxy — See M. Cataldo's talk

Star-forming Galaxy

AGN winds

Low-energy radiogalaxies (FR0)

e.g. Ahlers and Murase 2014
Vissani and Palladino 2015

High-energy neutrino production

Relativistic protons!!

$$p + p \rightarrow \pi + X$$

$$p + \gamma \rightarrow \pi + X$$

Our galaxy

Star-forming Galaxy

AGN winds

Low-energy radiogalaxies (FR0)

Protons accelerated inside the SNR escape and interact with intergalactic medium

e. g. Loeb and Waxman 2006
Tamborra et al. 2014

High-energy neutrino production

Relativistic protons!!

$$p + p \rightarrow \pi + X$$

$$p + \gamma \rightarrow \pi + X$$

Our galaxy

Star-forming Galaxy

AGN winds

Low-energy radiogalaxies (FR0)

Protons accelerated inside the AGN wind escape and interact with intergalactic medium

e.g. Lamastra et al. 2016
Lamastra et al. 2017

High-energy neutrino production

Relativistic protons!!

$$p + p \rightarrow \pi + X$$

$$p + \gamma \rightarrow \pi + X$$

Our galaxy
Star-forming Galaxy
AGN winds
Low-energy radiogalaxies (FR0)

Protons accelerated inside the jet escape and interact with intergalactic medium

e.g. Tavecchio et al. 2018

High-energy neutrino production

Relativistic protons!!

$$p + p \rightarrow \pi + X$$

$$p + \gamma \rightarrow \pi + X$$

Our galaxy
Star-forming Galaxy
AGN winds
Low-energy radiogalaxies (FR0)

GRBs
Blazars

e.g. Waxman and Bachall 1997
Atoyan and Dermer 2003
Tavecchio at al. 2014

High-energy neutrino production

Relativistic protons!!

$$p + p \rightarrow \pi + X$$

Our galaxy
Star-forming Galaxy
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Low-energy radiogalaxies (FR0)

$$p + \gamma \rightarrow \pi + X$$

GRBs
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e.g. Waxman and Bachall 1997
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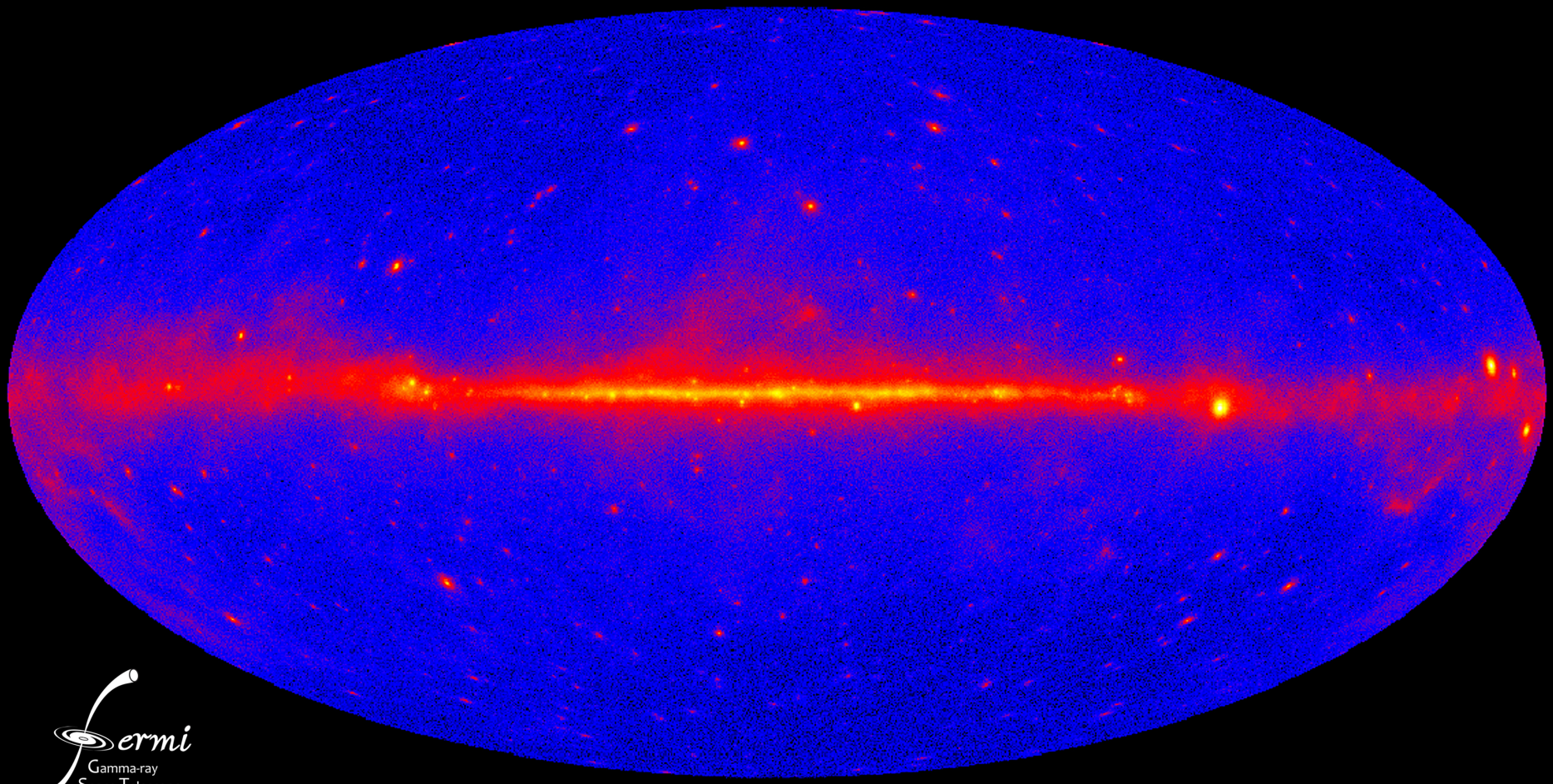
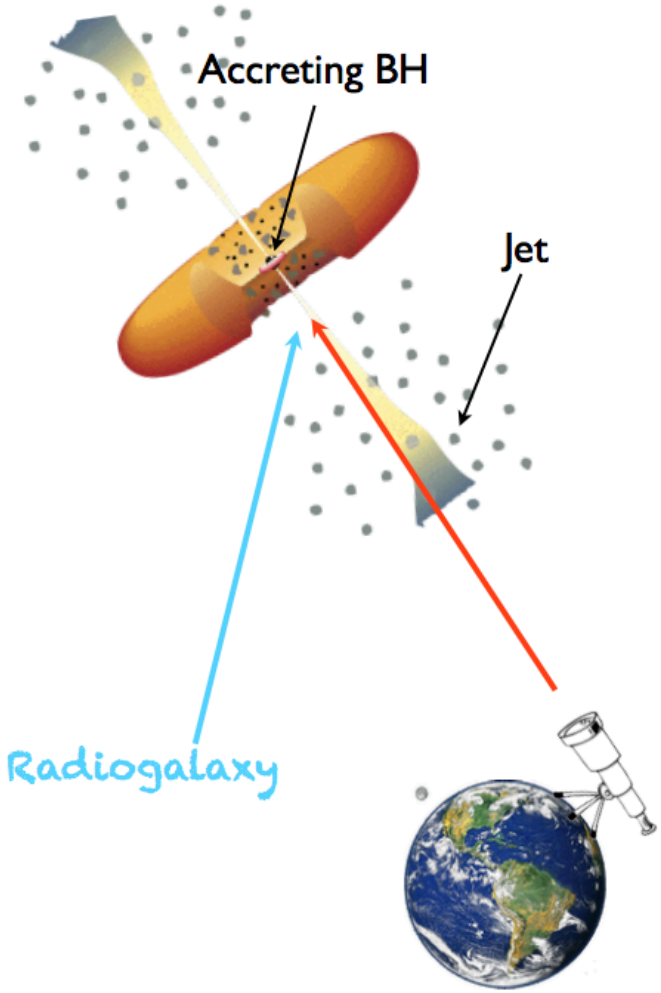
High-energy sky



Fermi
Gamma-ray
Space Telescope

>60% extragal due to Blazar!

What is a Blazar?

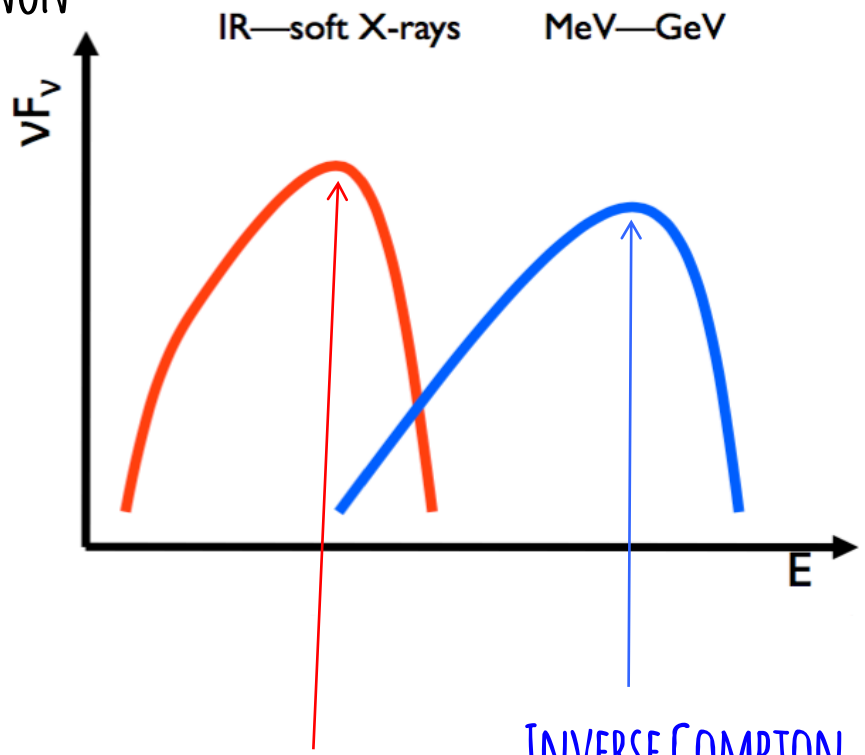


Jet pointing to us:

Outshines any other isotropic emission component associated to AGN (disk, dust) or to the host galaxy.

Blazars

Spectral Energy Distribution (SED) dominated by the relativistically boosted non-thermal continuum emission of the jet.



Models

Leptonic

Synchrotron

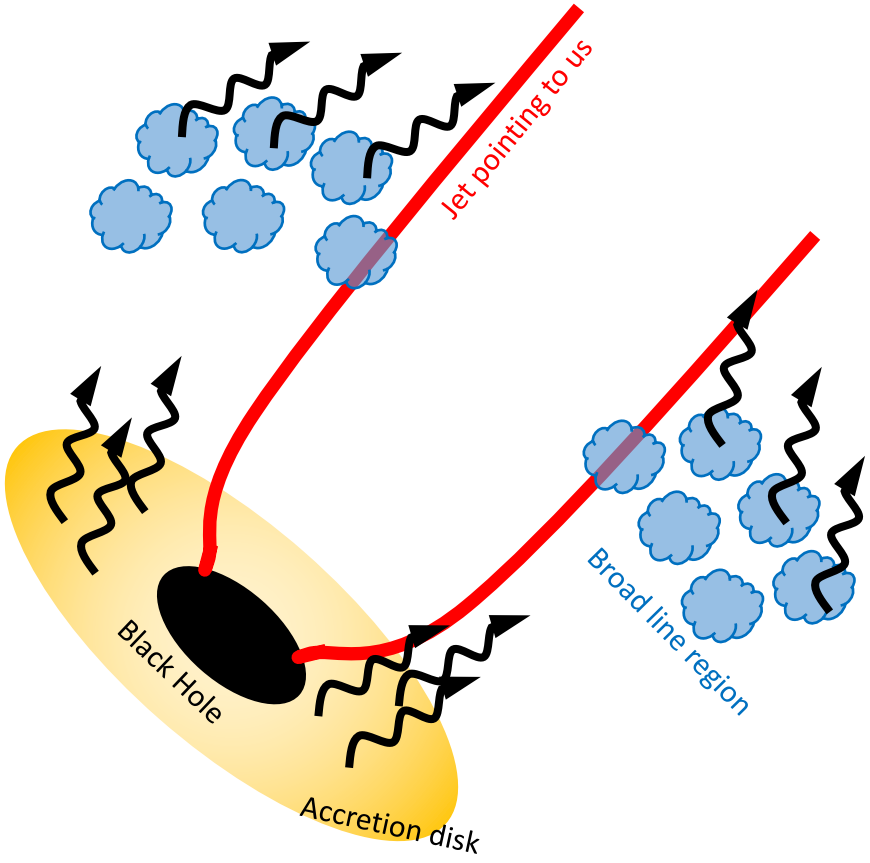
Inverse Compton

Hadronic

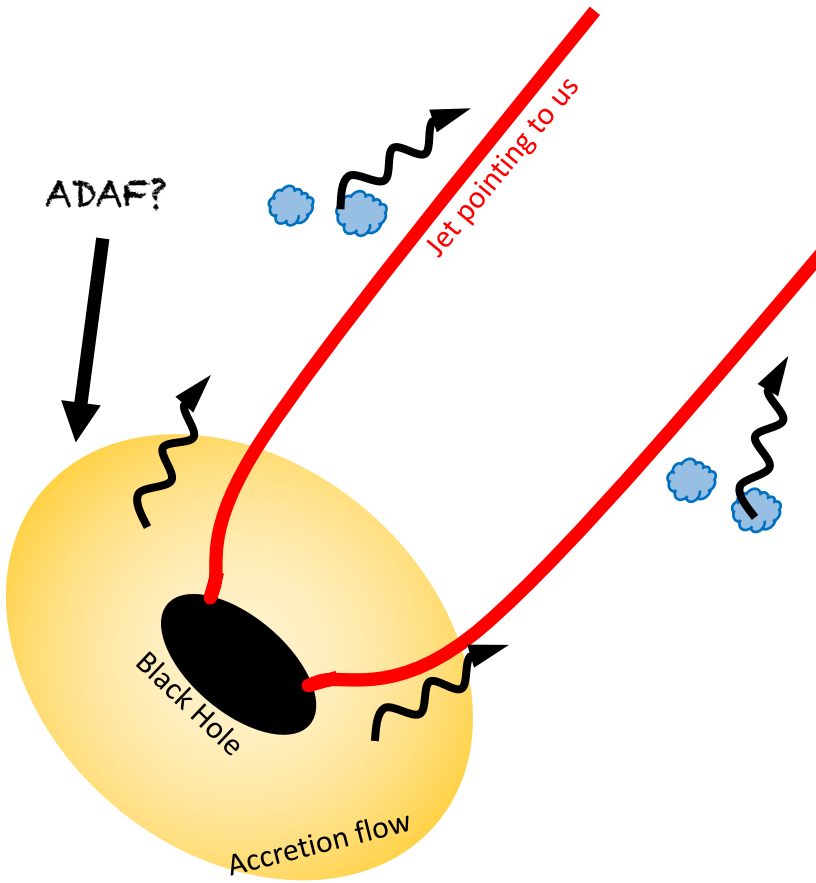
Reprocessed photo-meson products or synchrotron (protons)

My work

FSRQ



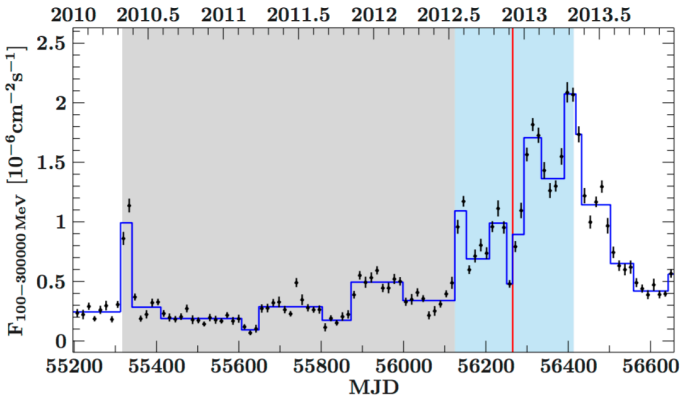
BL Lac



Are Blazars detectable by IceCube?

FSRQ

✔ Possible correlation between one neutrino event and a γ-ray flare of a FSRQ object (Kadler et al. 2016).



✗ EM-ν emission can't be exclusively hadronic (Gao et al. 2017)

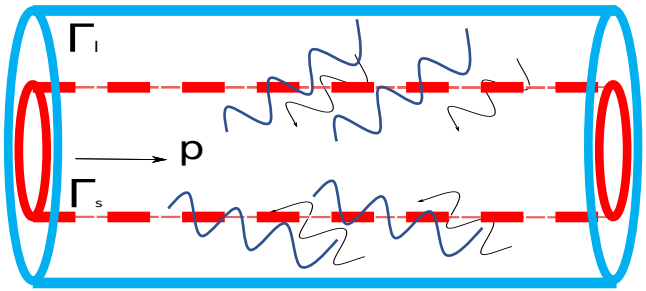
✗ Murase and Waxman 2016

✗ p+γ reaction with UV photons of BLR produce neutrino spectra harder than that "IceCube spectrum"

BL Lac

✔ Padovani et al. 2016 (spatial correlation with γ -ray BL Lacs detected above 50GeV)

✔ Tavecchio et al. 2014 efficient neutrino production (spine-layer model only for high-energy emitting BL Lacs)



Ghisellini et al. 2005

Fermi 2FHL catalogue (sources emitting above 50GeV) is a good representation of these sources

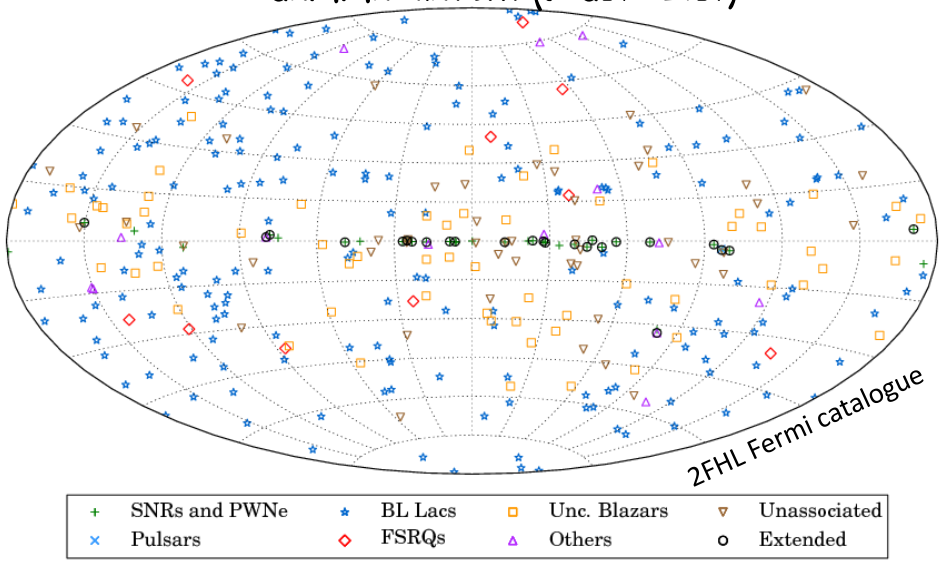
The model

Righi et al. 2017 a

Assumption 1:

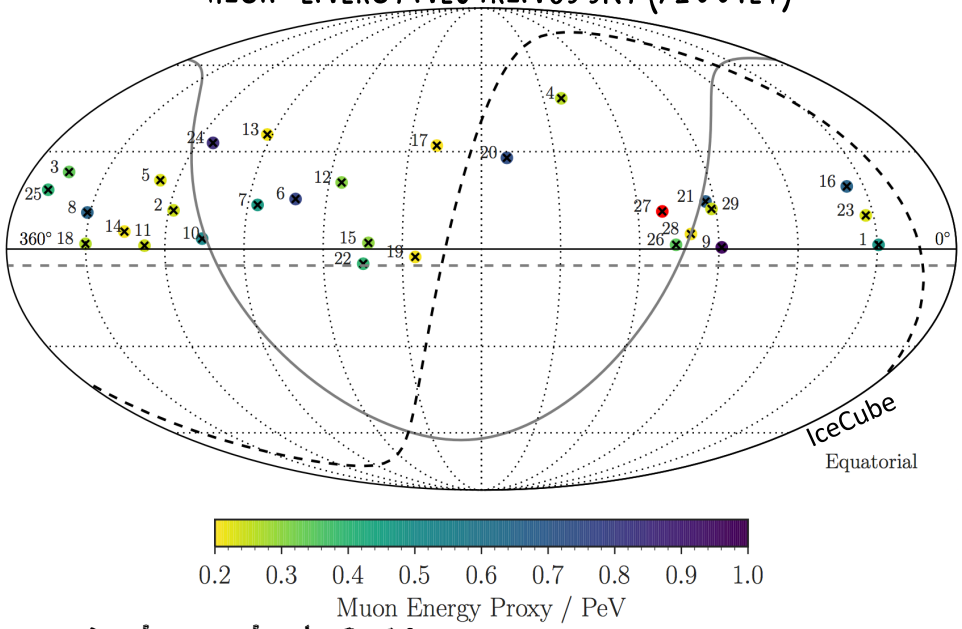
Only BL Lac objects of 2FHL catalogue contribute to ν_μ IC events.

Gamma-ray sky (50GeV–2TeV)



Ackermann et al. 2015

High-energy neutrinos sky (>200TeV)



Aartsen et al. 2016

The model

Righi et al. 2017 a

Assumption 1:

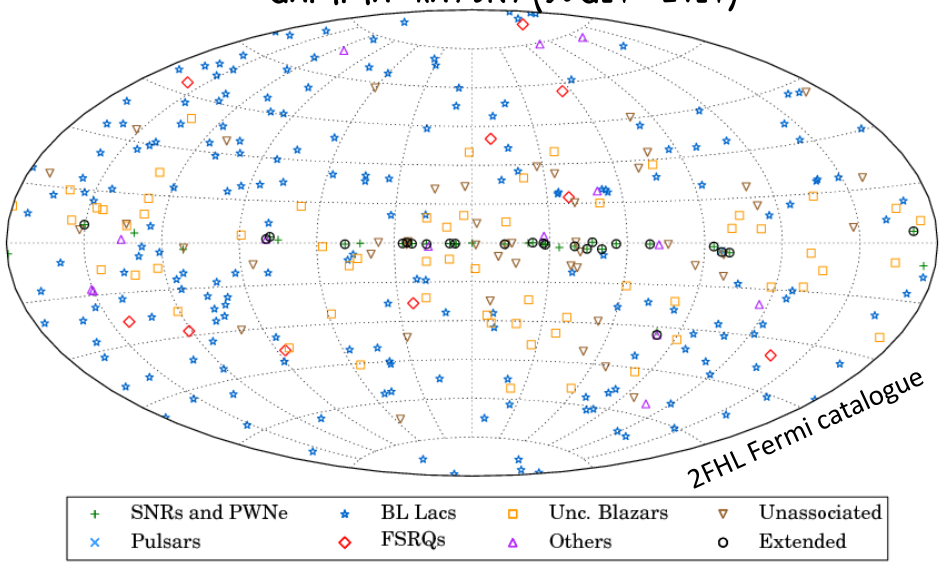
Only BL Lac objects of 2FHL catalogue contribute to ν_μ IC events.

Assumption 2:

Linear relation between γ-ray emission and neutrino emission.

$$F_{\gamma i} = k F_{\nu i}$$

Gamma-ray sky (50GeV–2TeV)



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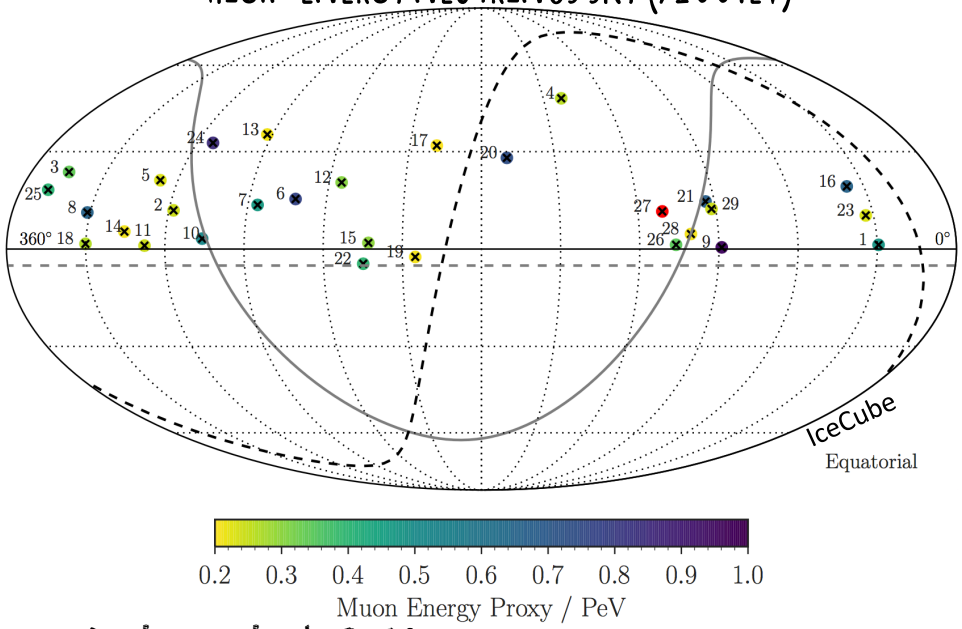
High-energy neutrinos sky (>200TeV)



Aartsen et al. 2016

The model

Righi et al. 2017 a

Assumption 1:

Only BL Lac objects of 2FHL catalogue contribute to ν_μ IC events.

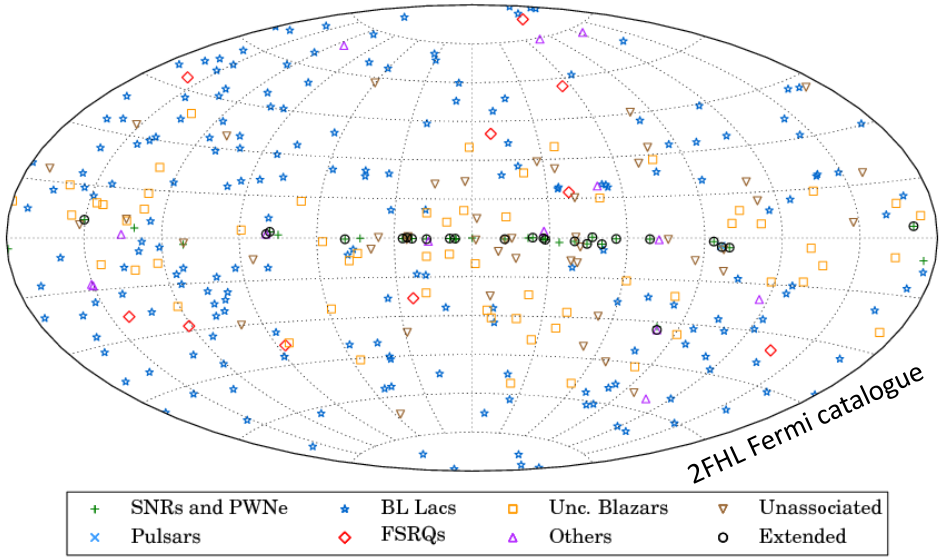
Assumption 2:

Linear relation between γ-ray emission and neutrino emission.

$$F_{\gamma i} = k F_{\nu i}$$

It's the same for all BL Lacs

Gamma-ray sky (50GeV–2TeV)



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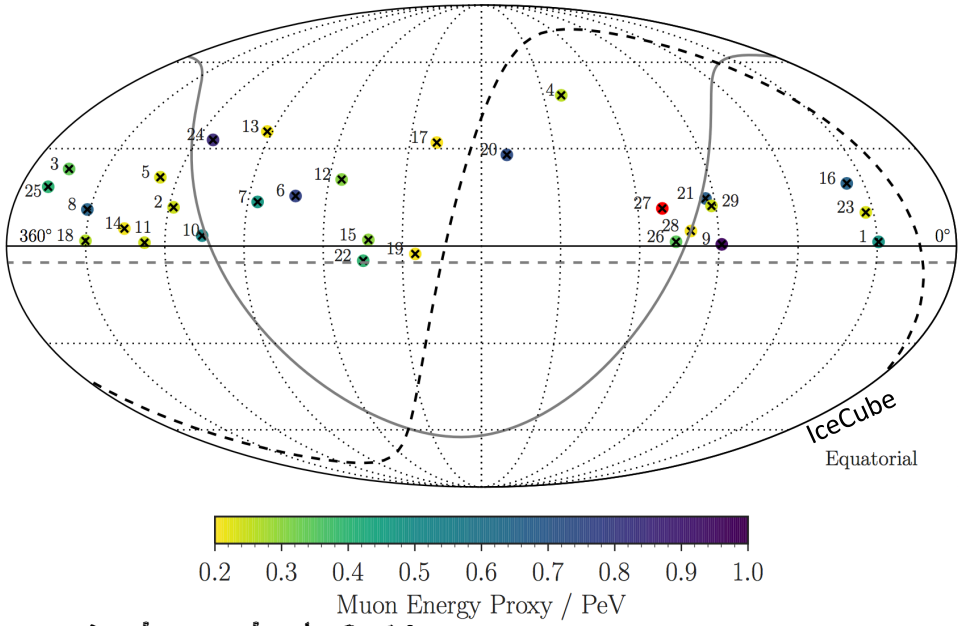
High-energy neutrinos sky (>200TeV)



Aartsen et al. 2016

RESULTS

Righi et al. 2017 a

$$N_\nu = \dot{N}_\nu T_{\rm exp} = T_{\rm exp} \int_{E_1}^{E_2} A_{\rm eff}(E_\nu)\Phi_i(E_\nu)dE_\nu$$

IceCube

	Name	FLUX	#ν
	$60° < \delta < 90°$		
1	1ES1959+650	1.38	0.27
2	1ES0502+675	1.14	0.22
3	S50716+71	0.44	0.08
4	1RXSJ013106.4+61203	0.25	0.05
5	4C+67.04	0.25	0.05
6	Mkn180	0.24	0.05
7	MS0737.9+7441	0.13	0.02
8	RXJ0805.4+7534	0.08	0.02
9	S40954+65	0.07	0.01
10	S41749+70	0.07	0.01
	$30° < \delta < 60°$		
11	Mkn421	8.77	4.89
12	Mkn501	3.41	1.90
13	PG1218+304	0.92	0.52
14	3C66A	0.87	0.49
15	1H1013+498	0.87	0.49
16	1ES0033+595	0.82	0.46
17	1ES2344+514	0.69	0.39
18	1ES1215+303	0.52	0.29
19	B32247+381	0.37	0.21
20	B30133+388	0.35	0.19
	$0° < \delta < 30°$		
21	PG1553+113	1.89	2.47
22	PKS1424+240	1.00	1.30
23	PG1218+304	0.92	1.20
24	TXS0518+211	0.87	1.14
25	1ES0647+250	0.75	0.99
26	1ES1215+303	0.52	0.69
27	RXJ0648.7+1516	0.45	0.59
28	1RXSJ194246.3+10333	0.41	0.54
29	RBS0413	0.32	0.42
30	1H1720+117	0.25	0.33

10^{-8} GeV/cm^{2}s yr^{-1}

KM3NeT (prediction)

	Name	F_ν	R_ν	Visibility at horizon	R_ν	Visibility at 10°
1	Mkn421	8.77	4.59	0.30	5.80	0.39
2	PKS2155-304	2.15	2.23	0.60	2.53	0.69
3	Mkn501	3.41	1.65	0.28	2.26	0.39
4	PG1553+113	1.89	1.42	0.44	1.66	0.51
5	PKS0447-439	0.76	0.87	0.67	1.02	0.79
6	PKS1424+240	1.00	0.67	0.39	0.79	0.46
7	PKS2005-489	0.51	0.63	0.72	0.75	0.86
8	TXS0518+211	0.87	0.59	0.39	0.72	0.48
9	PG1218+304	0.92	0.55	0.34	0.69	0.44
10	1ES0647+250	0.75	0.47	0.36	0.60	0.46
11	3C66A	0.87	0.38	0.25	0.54	0.36
12	1RXSJ054357.3-55320	0.80	0.40	0.78	0.52	1.00
13	PKS0301-243	0.43	0.44	0.59	0.49	0.66
14	1H1914-194	0.45	0.44	0.57	0.49	0.63
15[a]	1H1013+498	0.87	-	-	0.48	0.32
15[b]	1RXSJ194246.3+10333	0.41	0.32	0.45	-	-
16	PKS1440-389	0.36	0.41	0.66	0.47	0.76
17	1ES0347-121	0.39	0.35	0.53	0.40	0.60
18	1ES1215+303	0.52	0.31	0.34	0.39	0.44
19	1RXSJ101015.9-31190	0.32	0.34	0.60	0.39	0.69
20	RXJ0648.7+1516	0.45	0.33	0.42	0.38	0.49

Collaboration for simulation ongoing

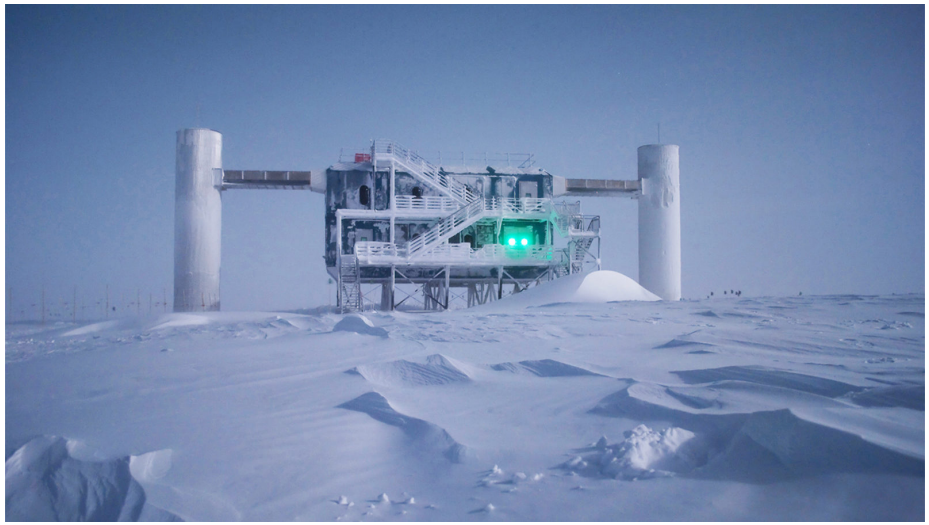
The case of TXS0506+056

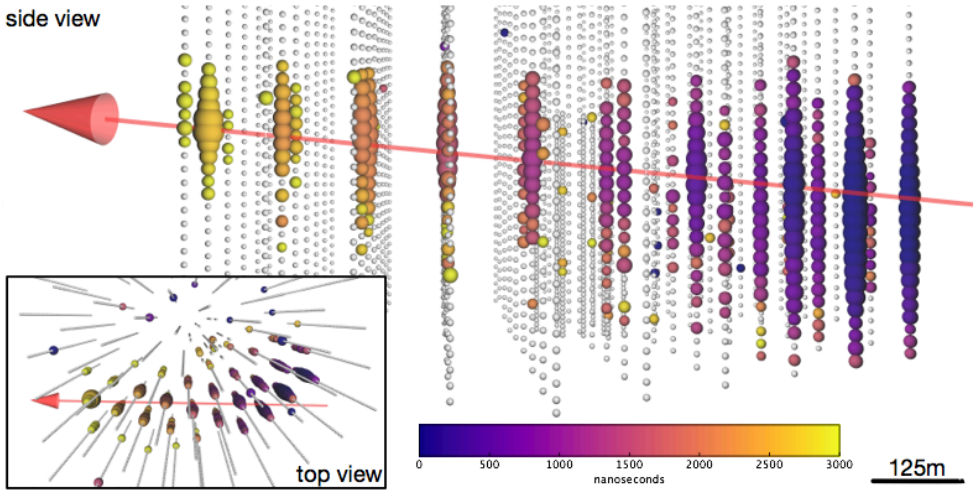
TXS 0506+056 & IC-170922A

2017 september 22

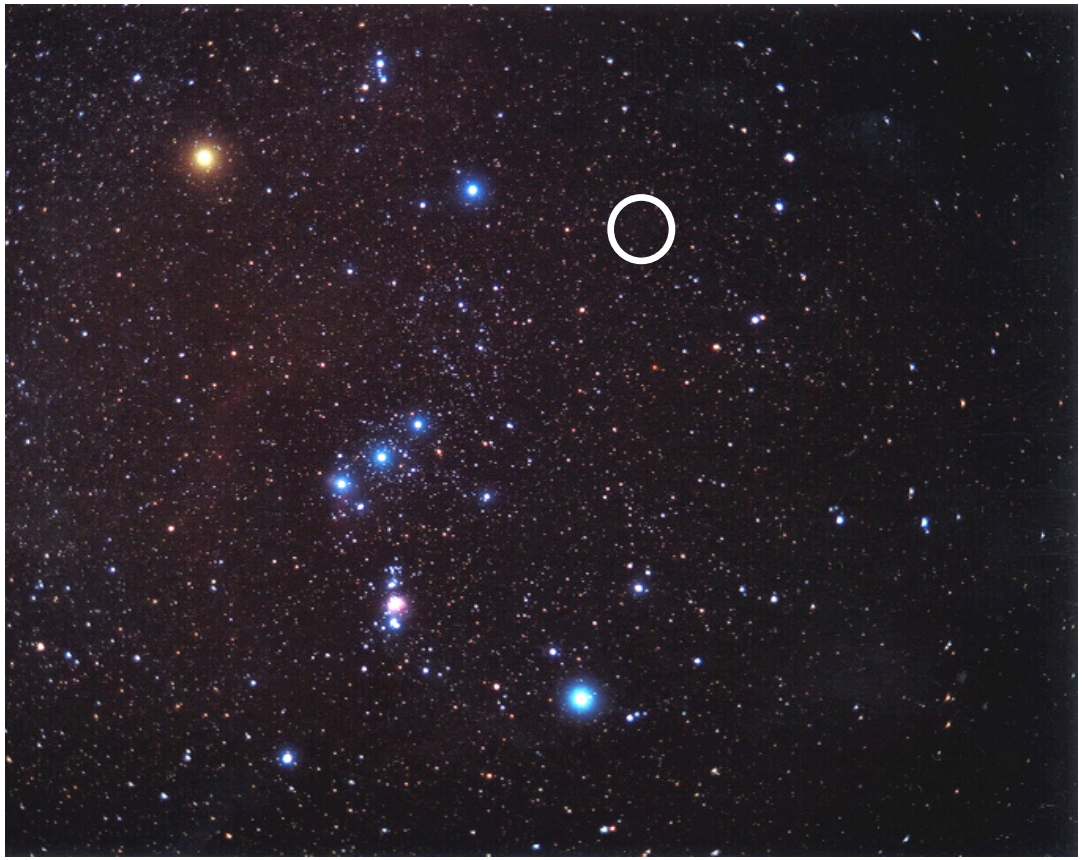
TXS 0506+056

22 Settembre 2017





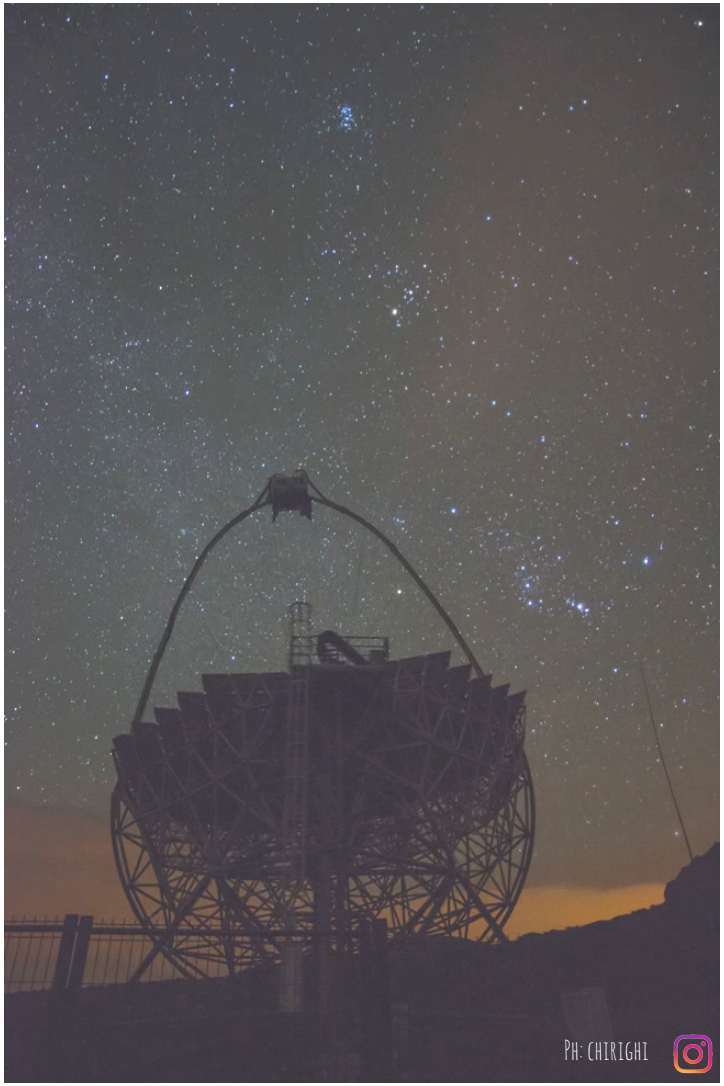
TXS 0506+056



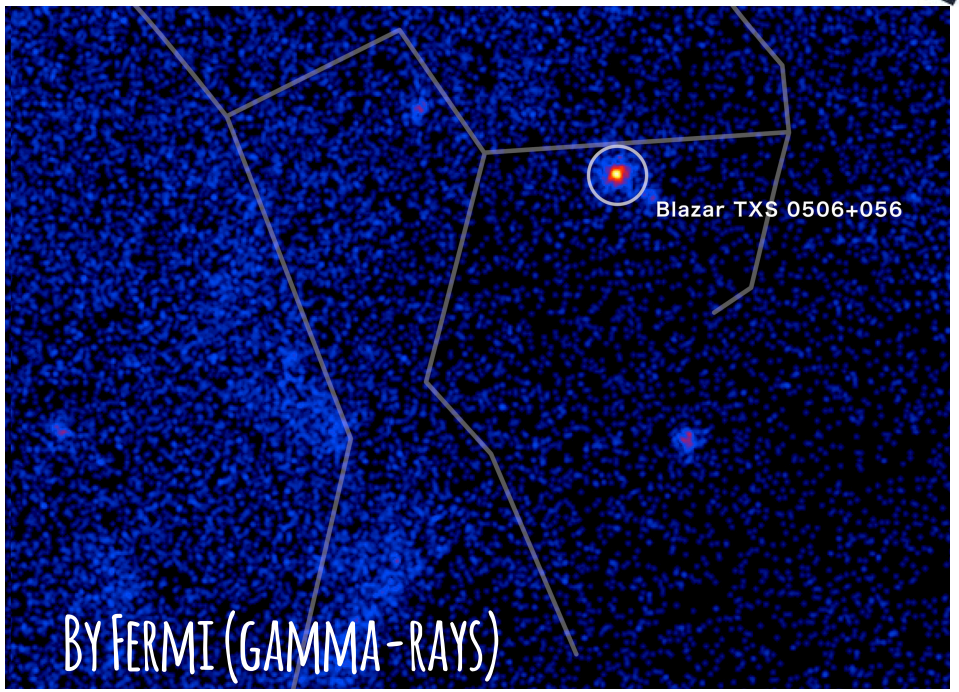
TXS 0506+056

MAGIC telescopes

High-energy gamma-ray via Cherenkov radiation

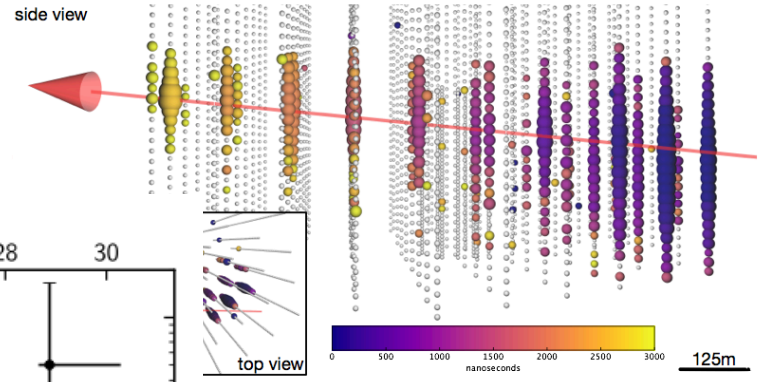


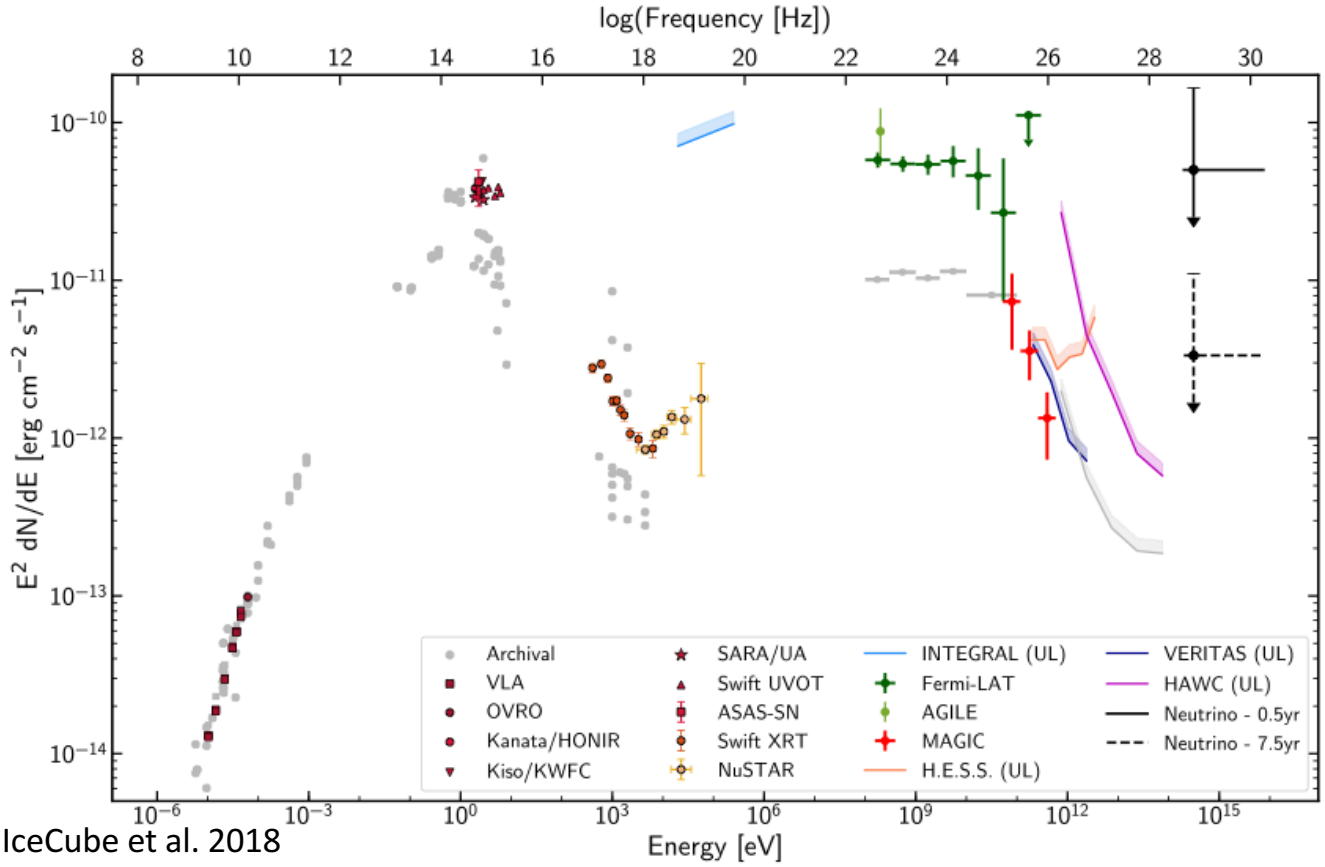
TXS 0506+056



IC170922A and TXS0506+056

2017 September 22



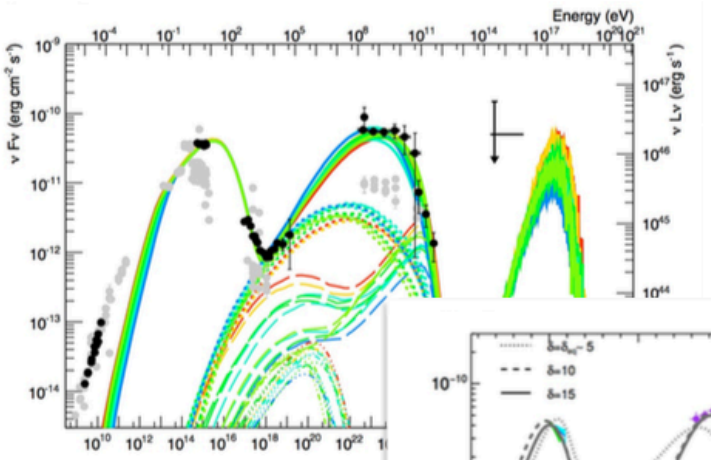


IceCube et al. 2018

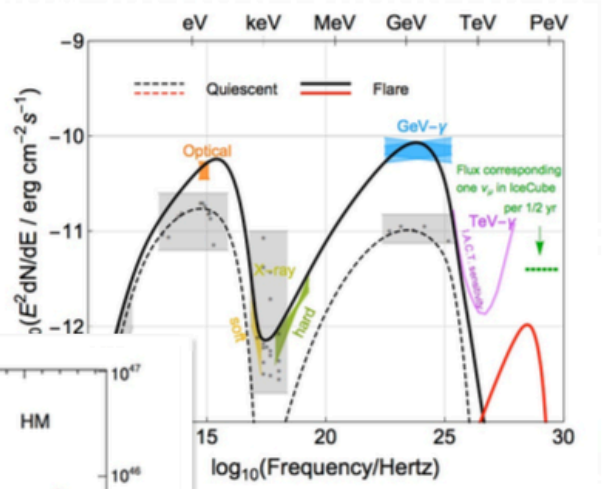
MODELS

THE COMMUNITY IS STILL WORKING ON THIS

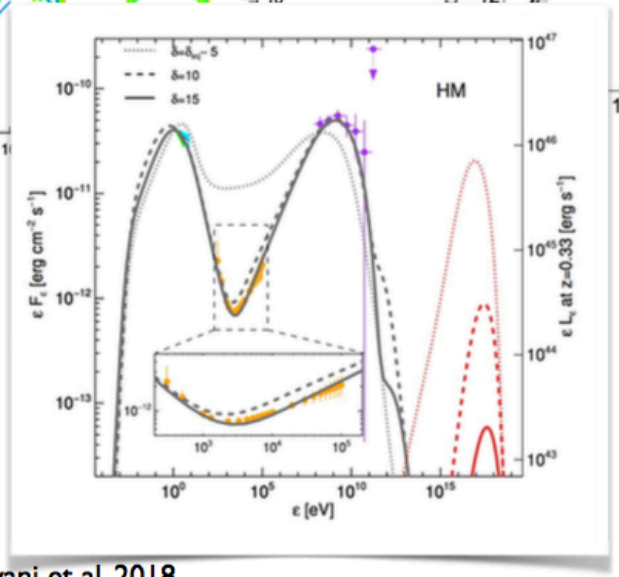
A burst of models …



Cerruti et al. 2018



Gao et al. 2018



Keivani et al. 2018

But the jet power is very large!

Take home messages

- High-energy neutrinos is a field to explore
- Blazar are good candidates to produce high-energy neutrinos (the case of TXS 0506+056)
- Waiting for new detection and new detector

How to observe high-energy neutrinos?