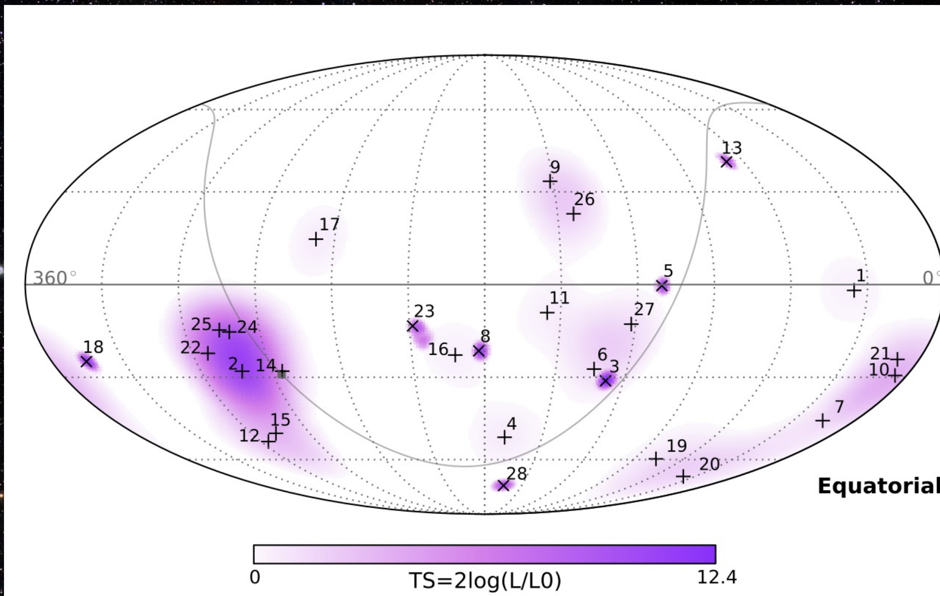
TANAMI Blazars as Possible Sources of the IceCube PeV Neutrinos

Matthias Kadler

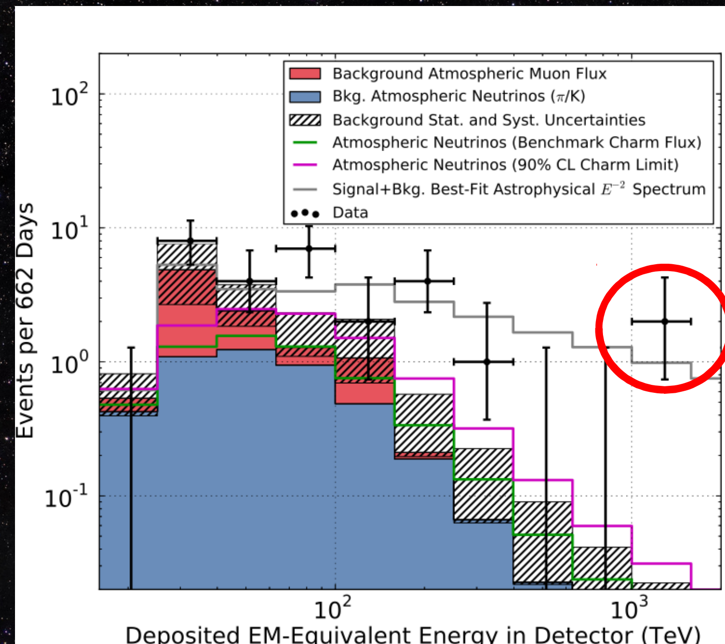
F. Krauß, K. Mannheim, R. Ojha, C. Müller, R. Schulz
for the TANAMI and Fermi-LAT Collaborations

Lehrstuhl für Astronomie
Universität Würzburg

What are the Sources of the IceCube Neutrino Signal?

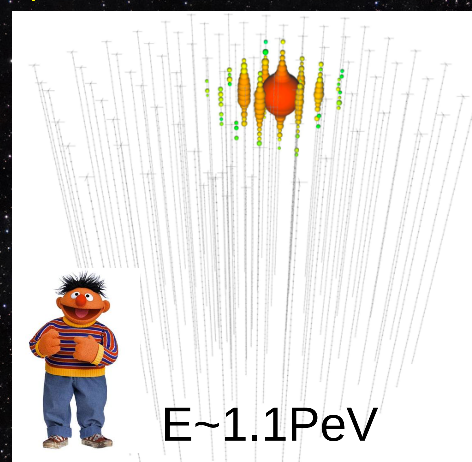


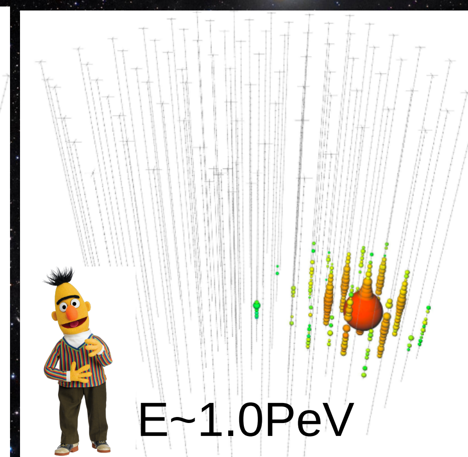
IceCube Collaboration 2013, Science 342, 1

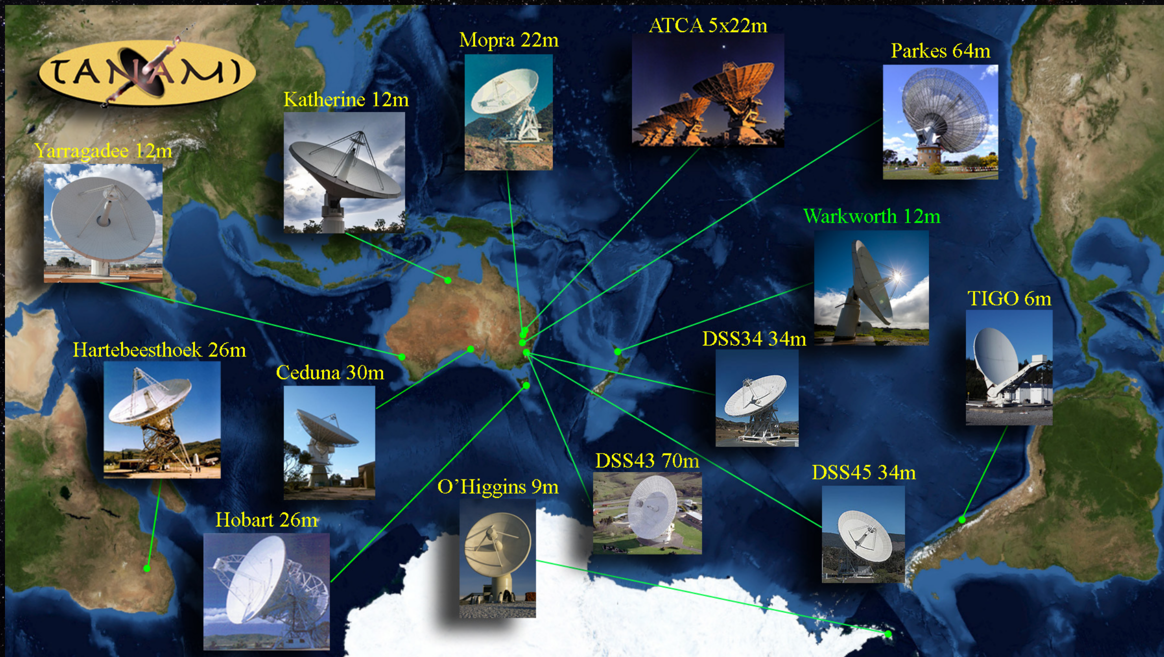


R.A.= 38.3°, Dec=-67.2°, Rerr=10.7°

R.A.=265.6°, Dec=-27.9°, Rerr=13.2°

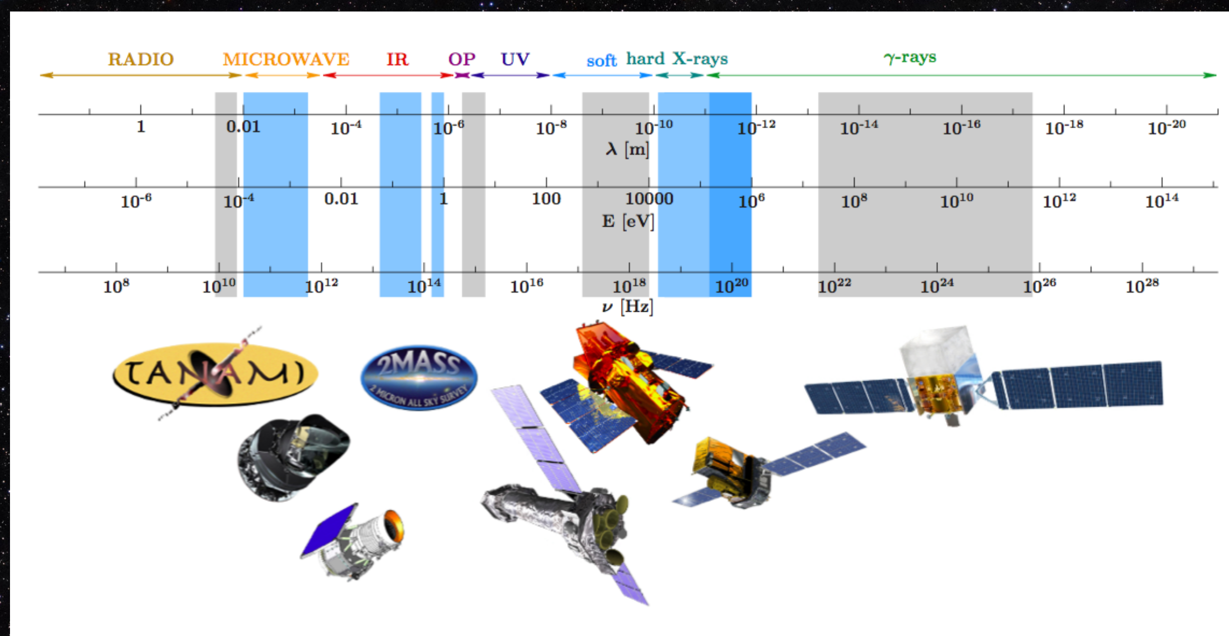




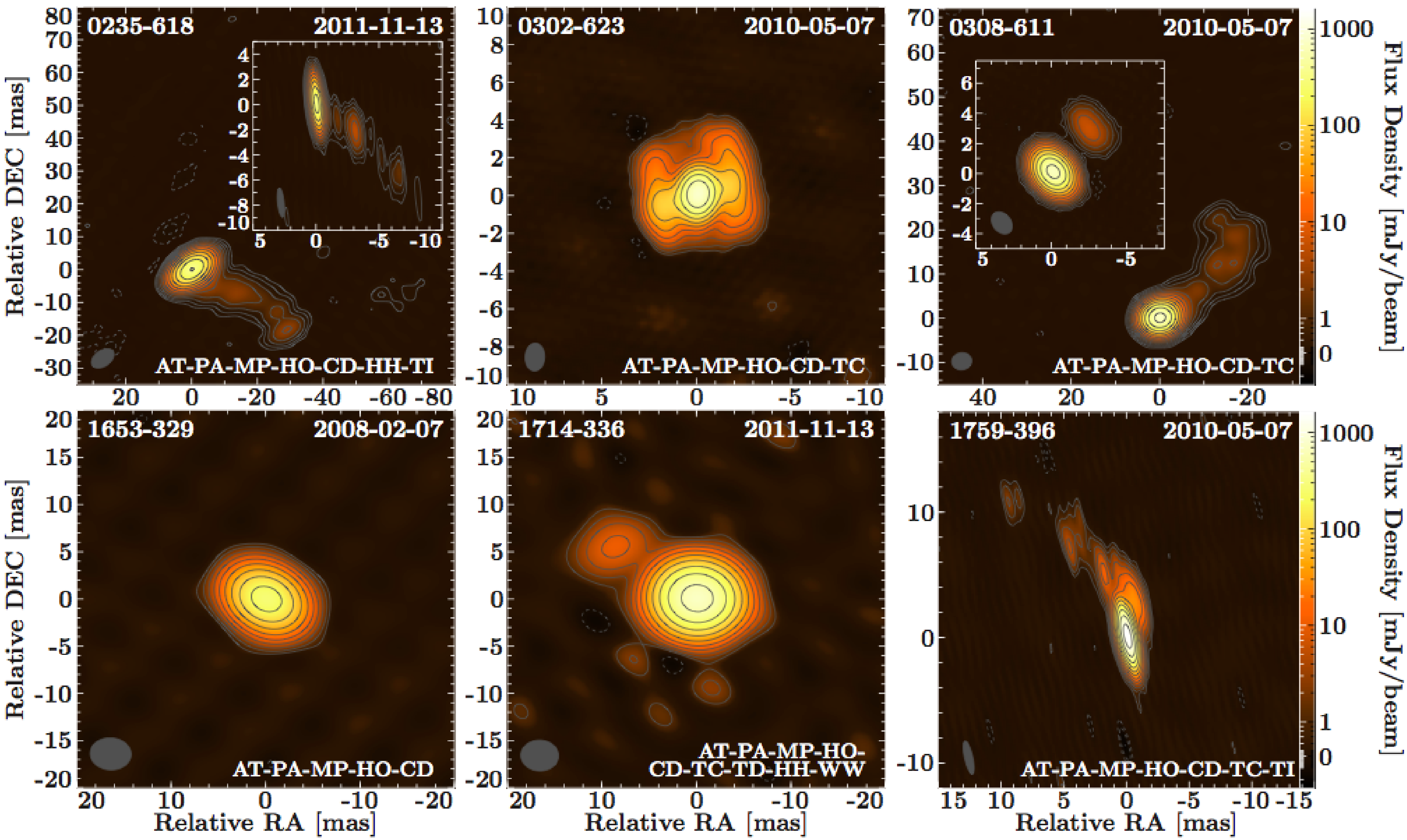


Multiwavelength Monitoring of ~90 AGN Jets South of -30°

Includes the six radio- and γ-ray brightest AGN in the Ernie and Bert fields



TANAMI Blazars in the IceCube PeV Neutrino Fields

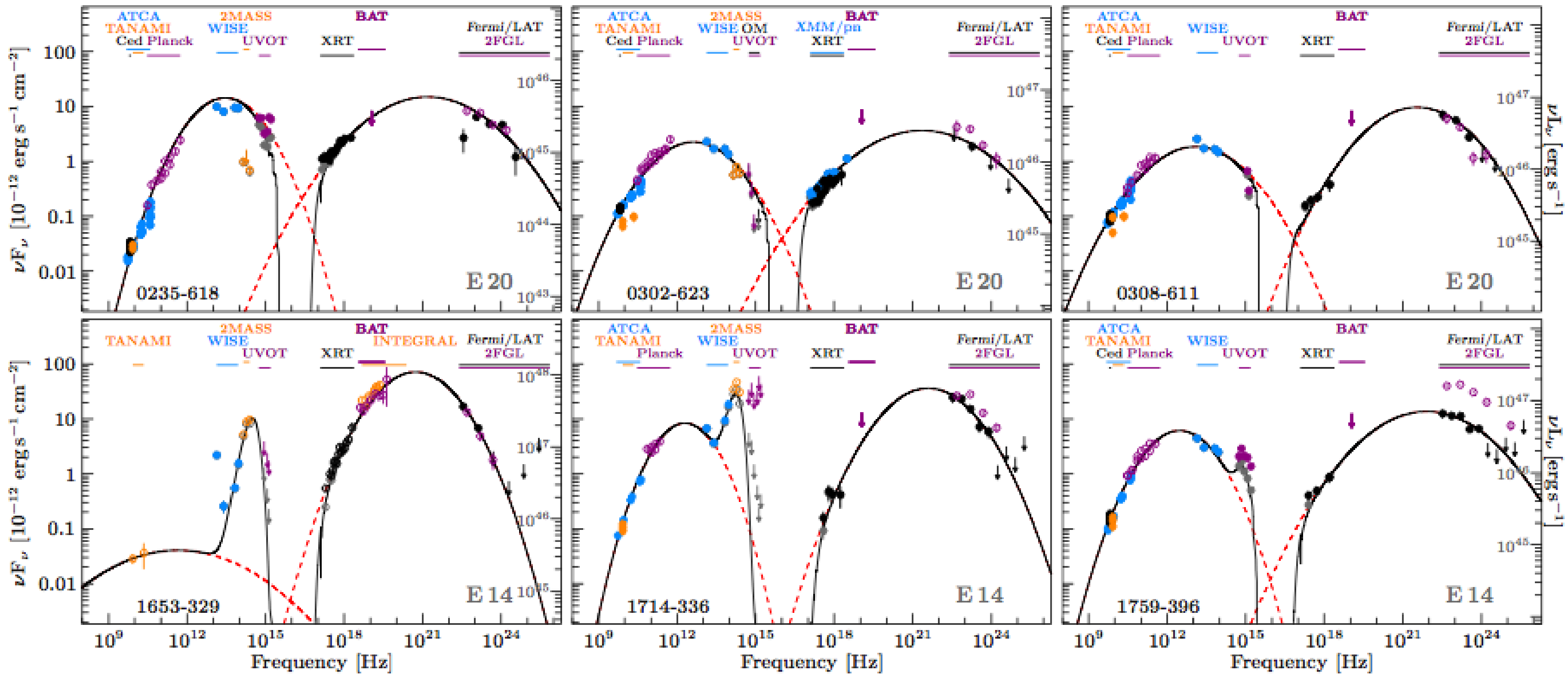


Krauß et al. 2014, A&A 566, L7

TANAMI Blazars in the IceCube PeV Neutrino Fields

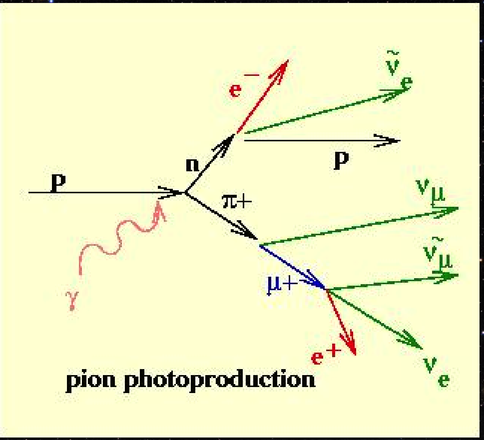
- Classical double-humped blazar SEDs
- Blue bumps in 3 sources

Krauß et al. 2014, A&A 566, L7



Estimate Maximum Neutrino Output

1. Assume presence of accelerated protons (hadronic jet models)
2. Pion photoproduction
3. Estimate neutrino flux from bolometric high-energy flux



$$F_\gamma = 1/3 \cdot F_\pi + 1/4 \cdot 2/3 \cdot F_\pi = 1/2 \cdot F_\pi$$

$$F_\nu = 2/3 \cdot 3/4 \cdot F_\pi = 1/2 \cdot F_\pi$$

$$F_\nu = F_\gamma$$

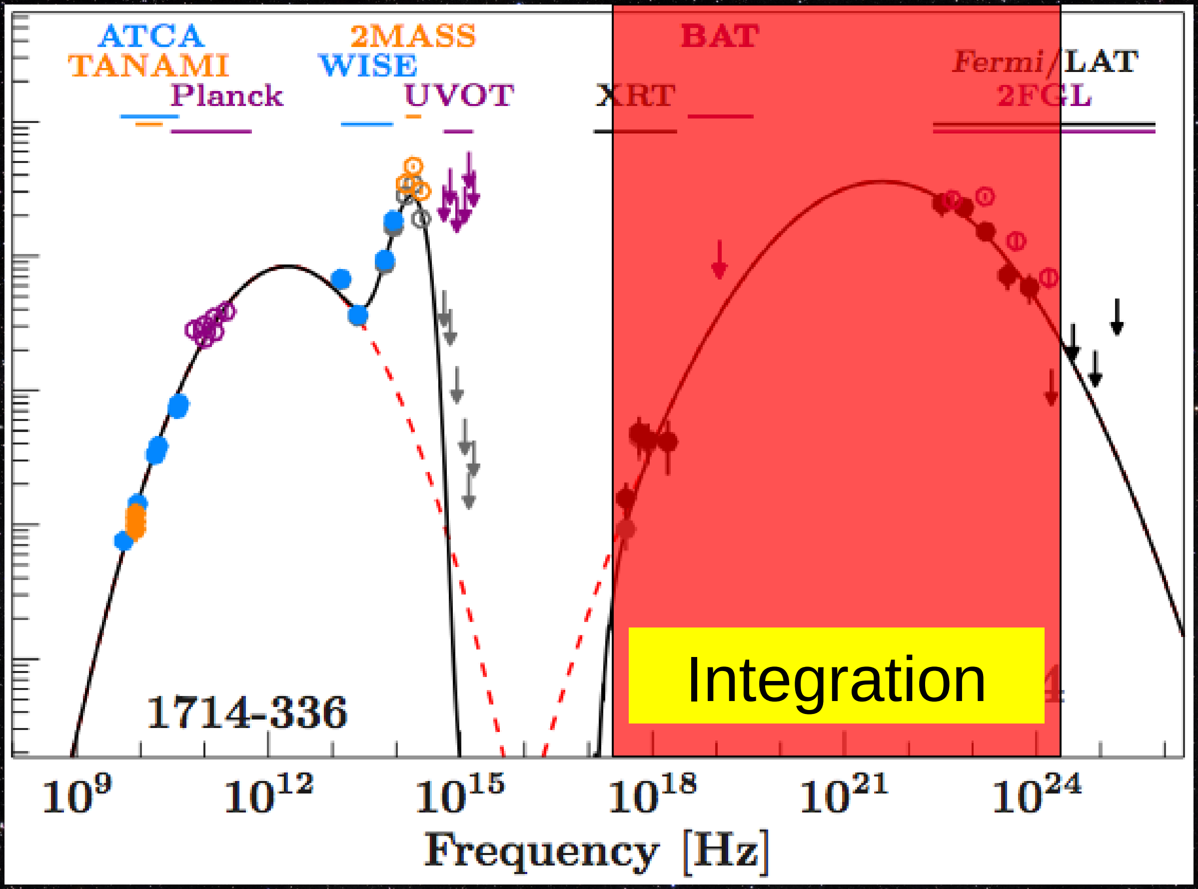
Estimate Maximum Neutrino Output

$$F_\nu = F_\gamma$$

- Fit SEDs with log-parabolas

(plus BB component, absorption)

- Integrate from 1keV to 5GeV



TANAMI Blazars in the IceCube PeV Neutrino Fields

Source	$F_\gamma(\mathrm{erg\,cm^{-2}\,s^{-1}})$	events
0235−618	$\left(1.0^{+0.5}_{-0.5}\right)\times 10^{-10}$	$0.19^{+0.04}_{-0.04}$
0302−623	$\left(3.4^{+0.7}_{-0.7}\right)\times 10^{-11}$	$0.06^{+0.01}_{-0.01}$
0308−611	$\left(7.5^{+2.9}_{-2.9}\right)\times 10^{-11}$	$0.14^{+0.05}_{-0.05}$
1653−329	$\left(4.5^{+0.5}_{-0.5}\right)\times 10^{-10}$	$0.86^{+0.10}_{-0.10}$
1714−336	$\left(2.4^{+0.5}_{-0.6}\right)\times 10^{-10}$	$0.46^{+0.10}_{-0.12}$
1759−396	$\left(1.2^{+0.3}_{-0.2}\right)\times 10^{-10}$	$0.23^{+0.50}_{-0.40}$
Total		1.9 ± 0.4

The six TANAMI blazars are capable of explaining the observed IceCube signal

But:

1. No individual source bright enough for a direct association

⇒ Highest flux from 1653-329 and 1714-336

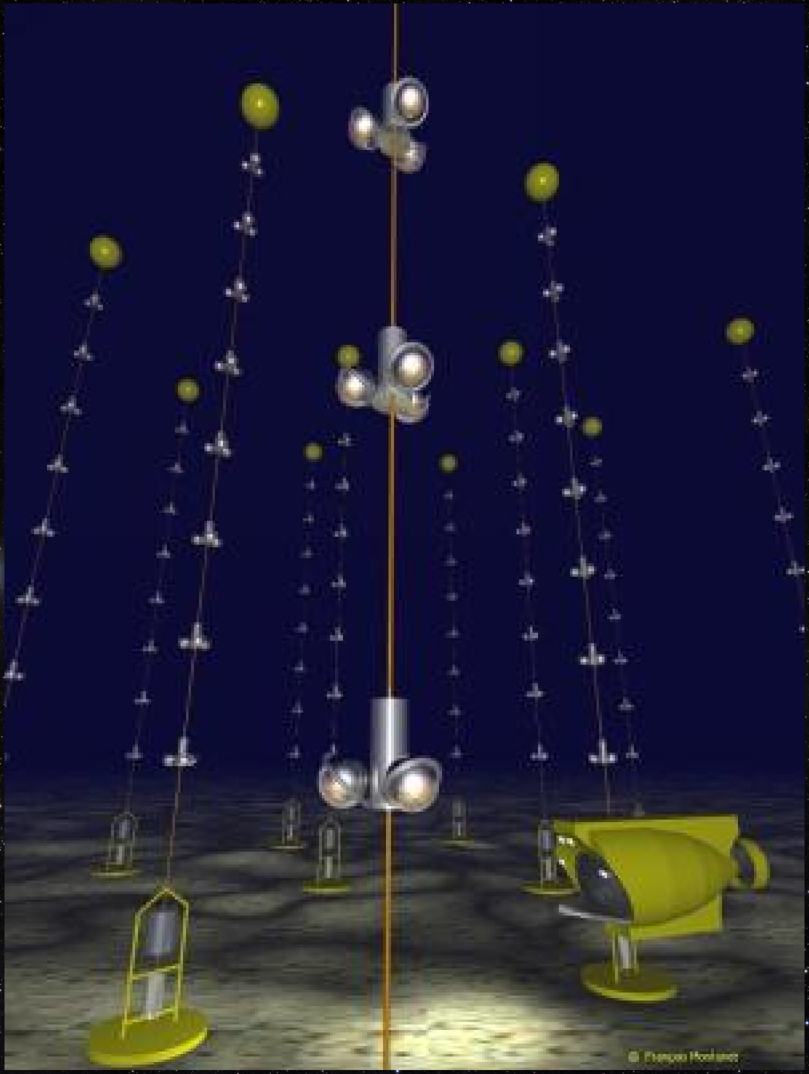
2. Blazar γ-ray luminosity function ~F-2.4

⇒ Substantial contribution of faint, remote sources

⇒ Substantial fudge factor needed

Follow-Up with ANTARES

- Neutrino Telescope in the Mediterranean (Water Ćerenkov Detector)
- In operation since 2008
- 0.01km3
- Highest sensitivity in TANAMI sky region for TeV neutrinos



ANTARES Results

ANTARES Collaboration and TANAMI Collaboration 2015, A&A, 576, L8

Source	$N_{\rm sig}$	p	Limit 10^{-8} GeV^{-1} cm^{-2} s^{-1}	$N_{\nu,IC}=1$	$N_{\nu,IC}=2$	$N_{\nu,IC}=3$	$N_{\nu,IC}=4$
0235–618	0	1	1.3	-2.4	-2.1	-2.0	-1.9
0302–623	0	1	1.3	-2.4	-2.1	-2.0	-1.9
0308–611	0	1	1.3	-2.4	-2.1	-2.0	-1.9
1653–329	1.1	0.10	2.9	<-2.5	-2.5	-2.3	-2.2
1714–336	0.9	0.04	3.5	<-2.5	-2.5	-2.3	-2.2
1759–396	0	1	1.4	-2.4	-2.1	-2.0	-1.8

- 1653-329 and 1714-336: one event, each.

⇒ Consistent with blazar-source hypothesis, but also with background

- Zero events for the other four blazars.

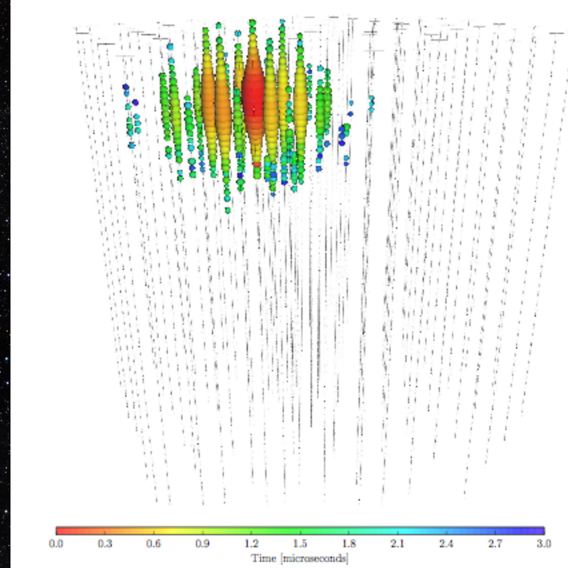
Either:

⇒ Not the sources of the PeV neutrinos, or

⇒ Neutrino spectra flatter than -2.4

Big Bird

- 2PeV event on Dec 4, 2012
  (Aartsen et al. 2014)
- RA = 208.4∘, Dec = −55.8∘ (J2000)
- Median pos. uncertainty: 15.9deg
  ⇒ 17 gamma blazars (2LAC)
  - Again: integral flux sufficient to explain the signal, but this time:

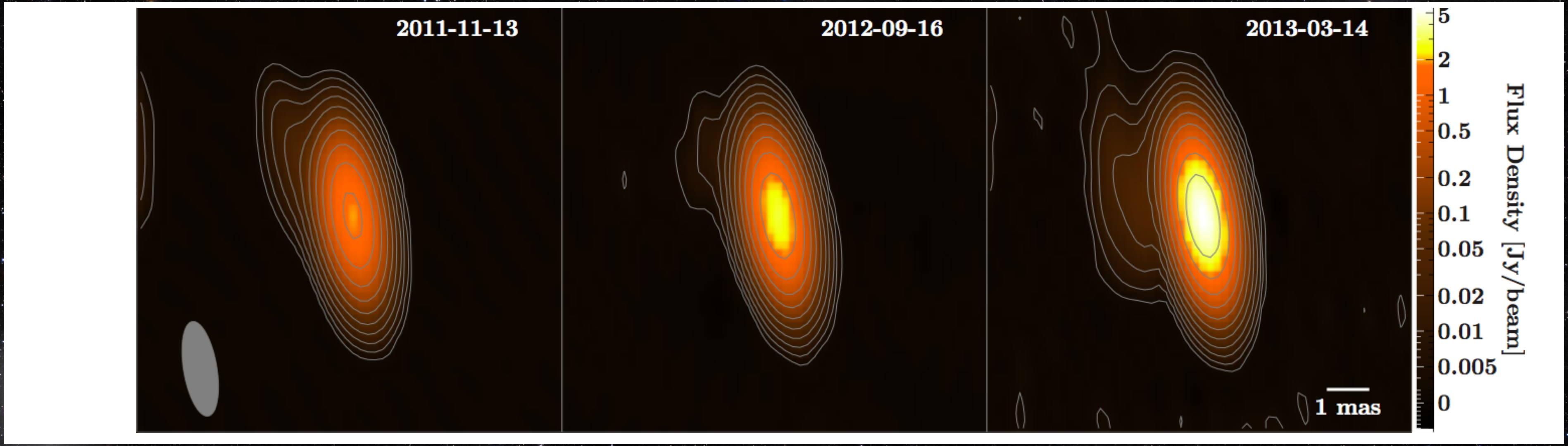


Deposited Energy (TeV)	Time (MJD)	Declination (deg.)	RA (deg.)	Med. Ang. Resolution (deg.)
2004^{+236}_{-262}	56265.1338677	−55.8	208.4	15.9

Output dominated by a single source: PKS B1424-418

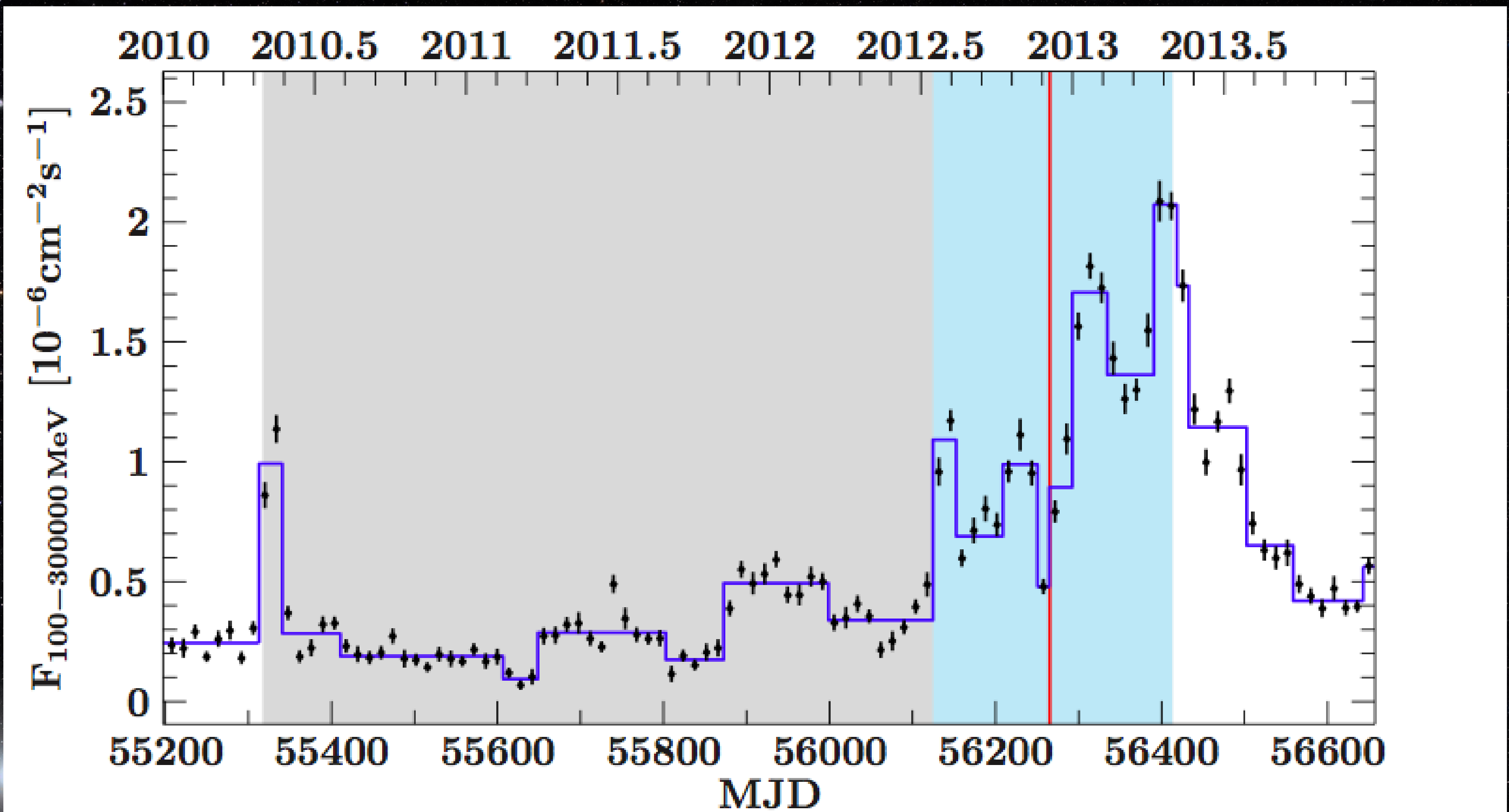
PKS B1424-418: Radio Outburst

- Radio core flux density increased from 1.5Jy to 6Jy in late 2012 to early 2013
- Strongest outburst ever seen by TANAMI



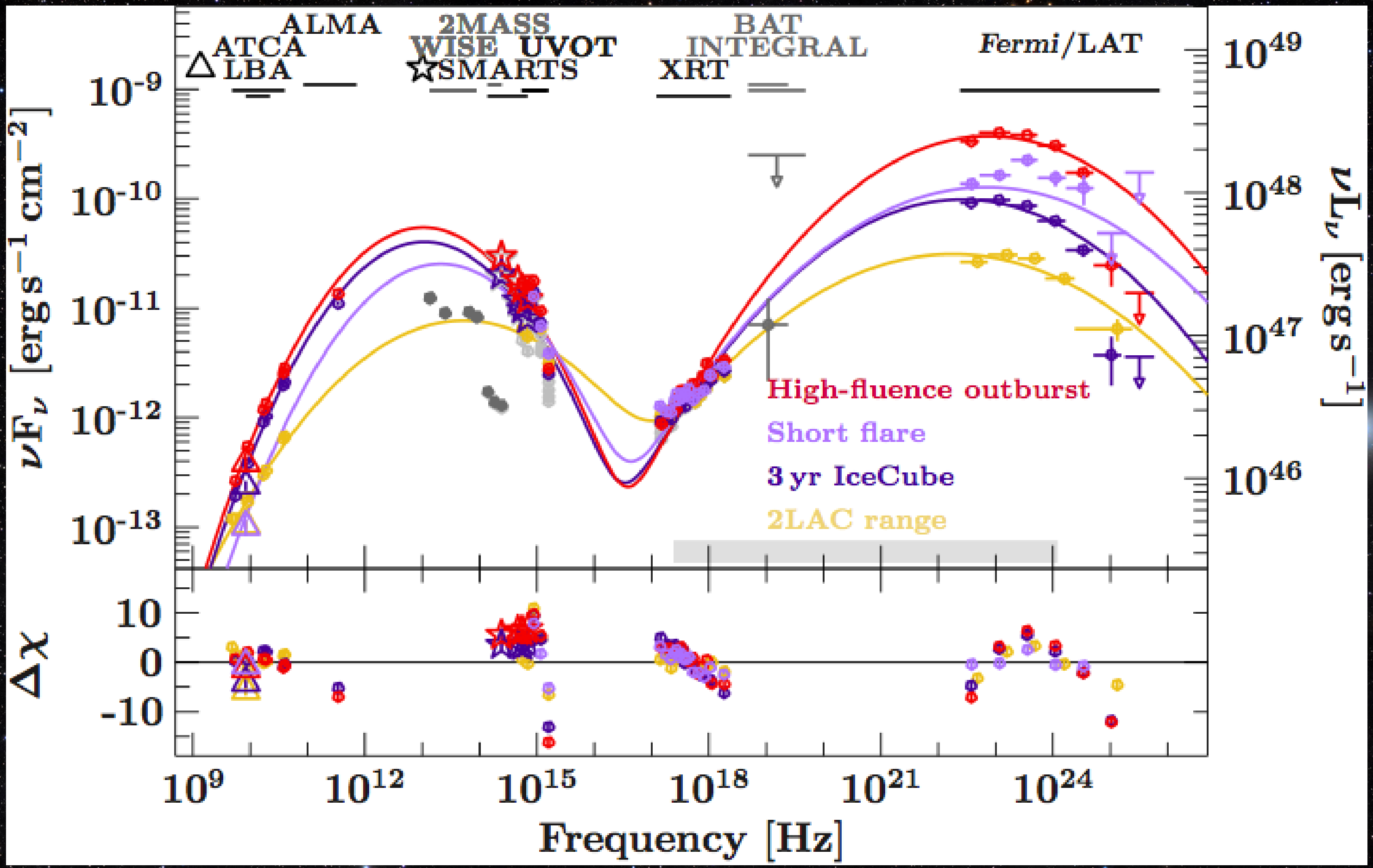
PKS B1424-418: Gamma Outburst

Outburst coincident with BigBird arrival time

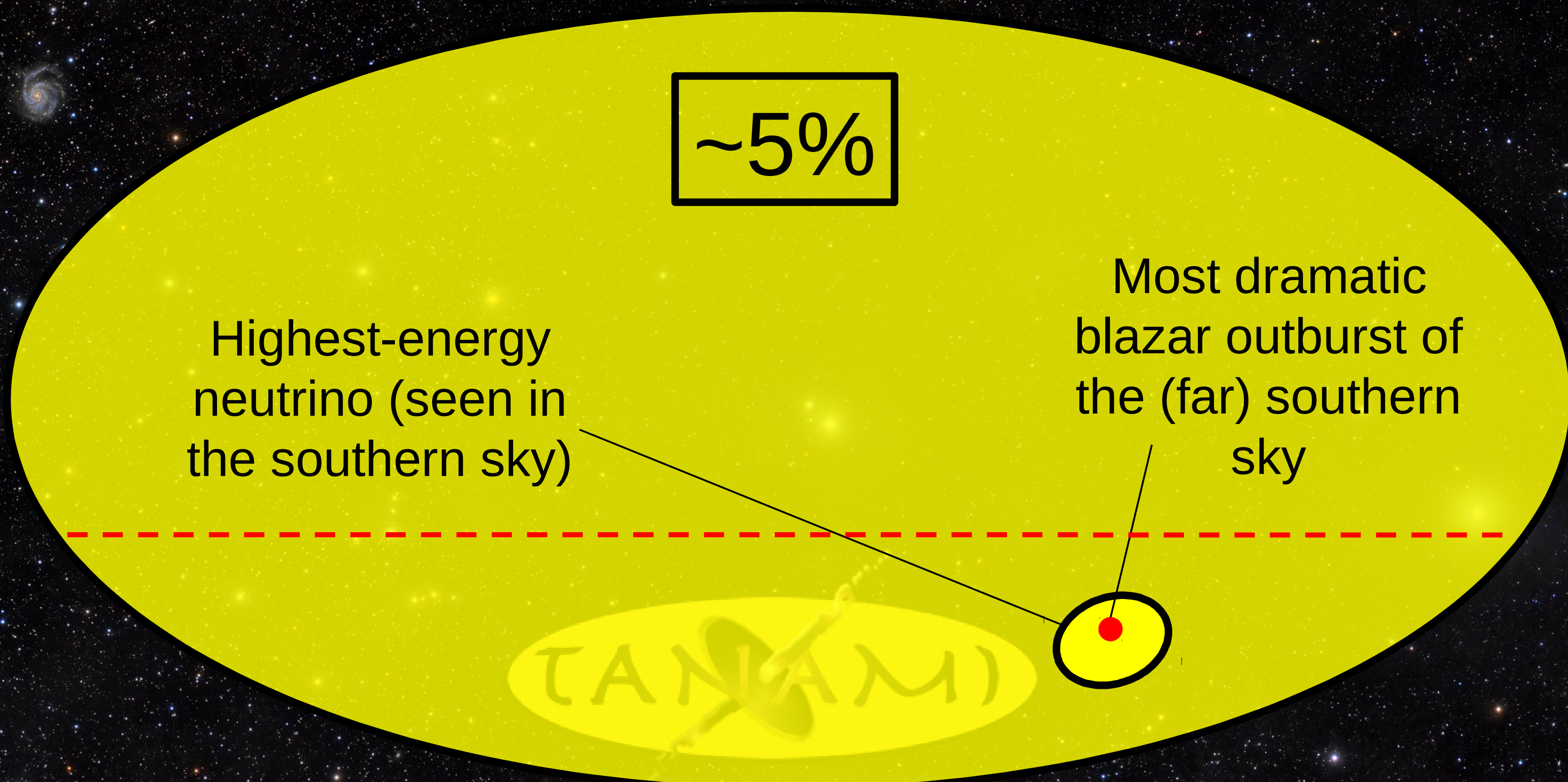


PKS B1424-418: Outburst SED

Predicted Neutrino Output: 2.2 Events

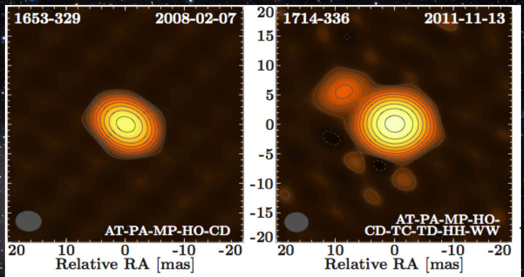


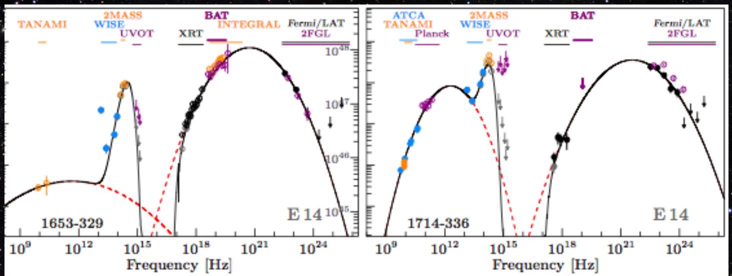
Chance Coincidence?

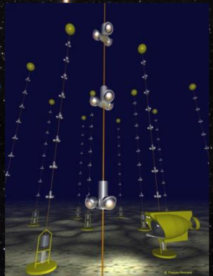


Summary I

- Integrated flux of blazars can explain the IceCube signal
- Follow-up with ANTARES finds two neutrinos coincident with the two brightest candidates (still consistent with background)
- Assume an association ⇒ Rather flat neutrino spectra



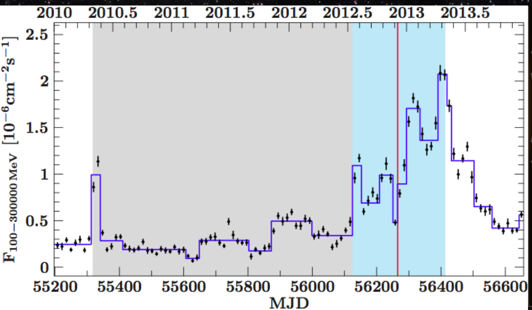


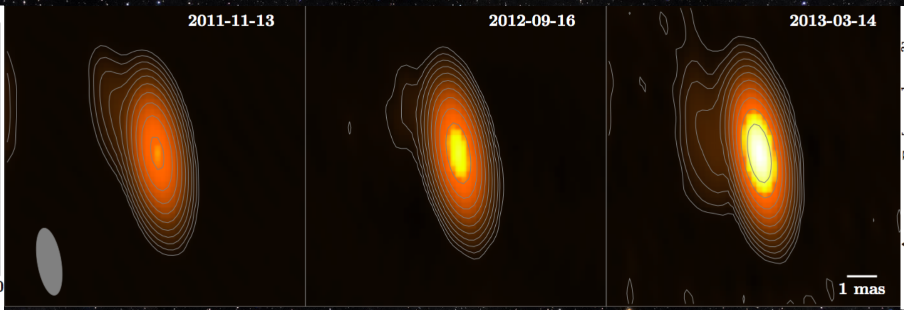


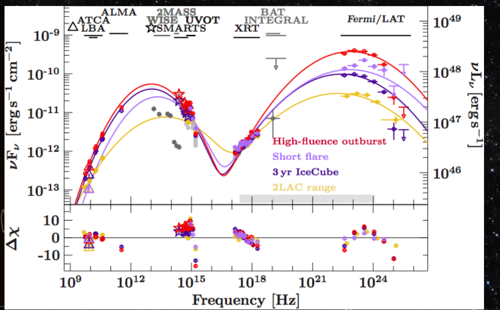
Source	F_γ(erg cm^{-2} s^{-1})	events
0235−618	$(1.0^{+0.5}_{-0.5}) \times 10^{-10}$	$0.19^{+0.04}_{-0.04}$
0302−623	$(3.4^{+0.7}_{-0.7}) \times 10^{-11}$	$0.06^{+0.01}_{-0.01}$
0308−611	$(7.5^{+2.9}_{-2.9}) \times 10^{-11}$	$0.14^{+0.05}_{-0.05}$
1653−329	$(4.5^{+0.5}_{-0.5}) \times 10^{-10}$	$0.86^{+0.10}_{-0.10}$
1714−336	$(2.4^{+0.5}_{-0.6}) \times 10^{-10}$	$0.46^{+0.10}_{-0.12}$
1759−396	$(1.2^{+0.3}_{-0.2}) \times 10^{-10}$	$0.23^{+0.50}_{-0.40}$
Total		1.9 ± 0.4

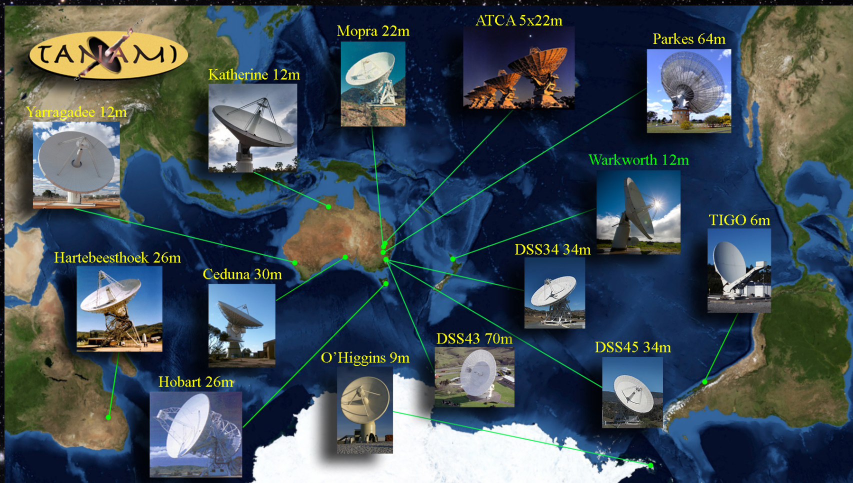
Summary II

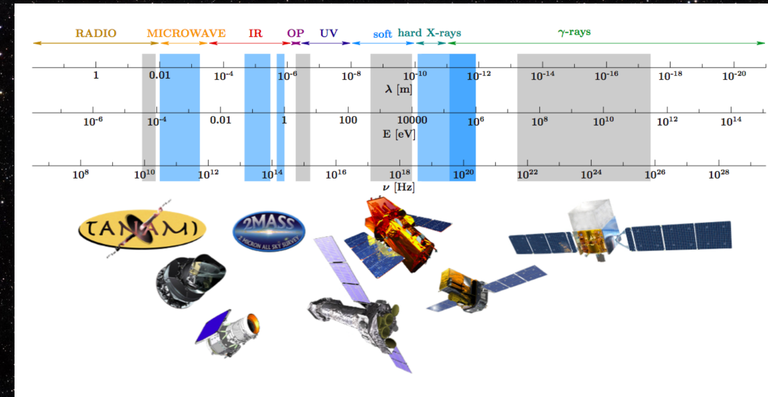
- First time that a single blazar can explain an individual PeV neutrino
- Comparable blazar outbursts had substantially lower-sensitivity IceCube coverage
- Still ~5% chance coincidence

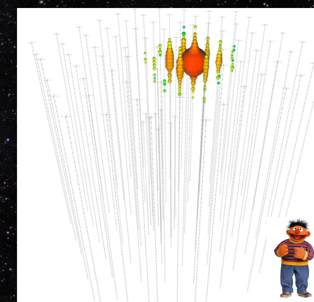


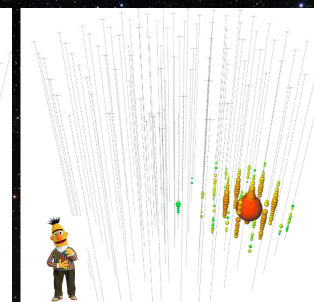


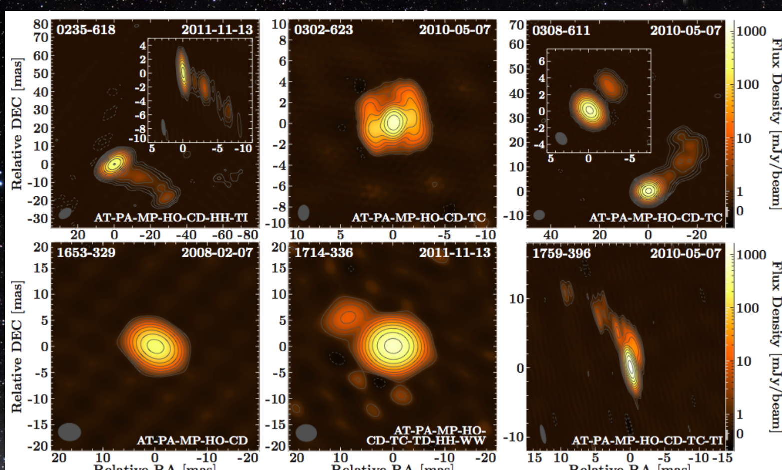


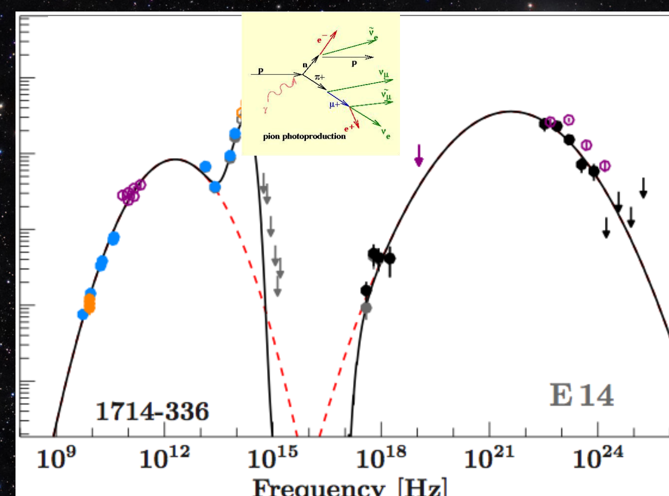

TANAMI
Yarragadee 12m
Katherine 12m
Mopra 22m
ATCA 5x22m
Parkes 64m
Warkworth 12m
TIGO 6m
DSS34 34m
Hartebeesthoek 26m
Ceduna 30m
DSS43 70m
DSS45 34m
O'Higgins 9m
Hobart 26m


RADIO
MICROWAVE
IR
OP
UV
soft
hard X-rays
γ-rays
λ [m]
E [eV]
ν [Hz]
TANAMI
2MASS






0235-618
2011-11-13
AT-PA-MP-HO-CD-HH-TI
0302-623
2010-05-07
AT-PA-MP-HO-CD-TC
0308-611
2010-05-07
AT-PA-MP-HO-CD-TC
1653-329
2008-02-07
AT-PA-MP-HO-CD
1714-336
2011-11-13
AT-PA-MP-HO-CD-TC-TD-HH-WW
1759-396
2010-05-07
AT-PA-MP-HO-CD-TC-TI
Relative DEC [mas]
Relative RA [mas]
Flux Density [mJy/beam]

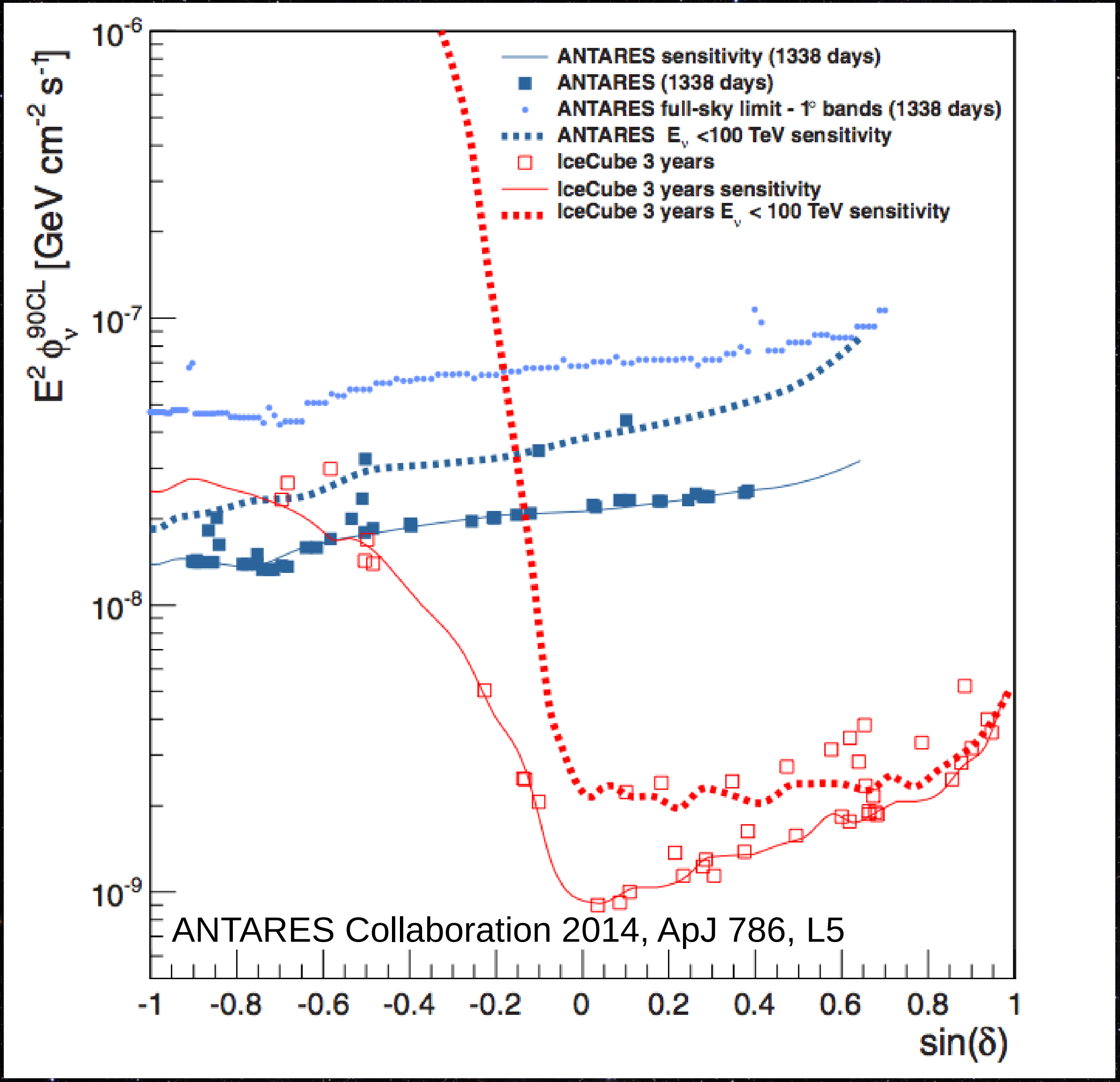

pion photoproduction
1714-336
E 14
Frequency [Hz]

Neutrino Telescope Sensitivities

- Main limitation: atmospheric background

⇒ Look down through Earth

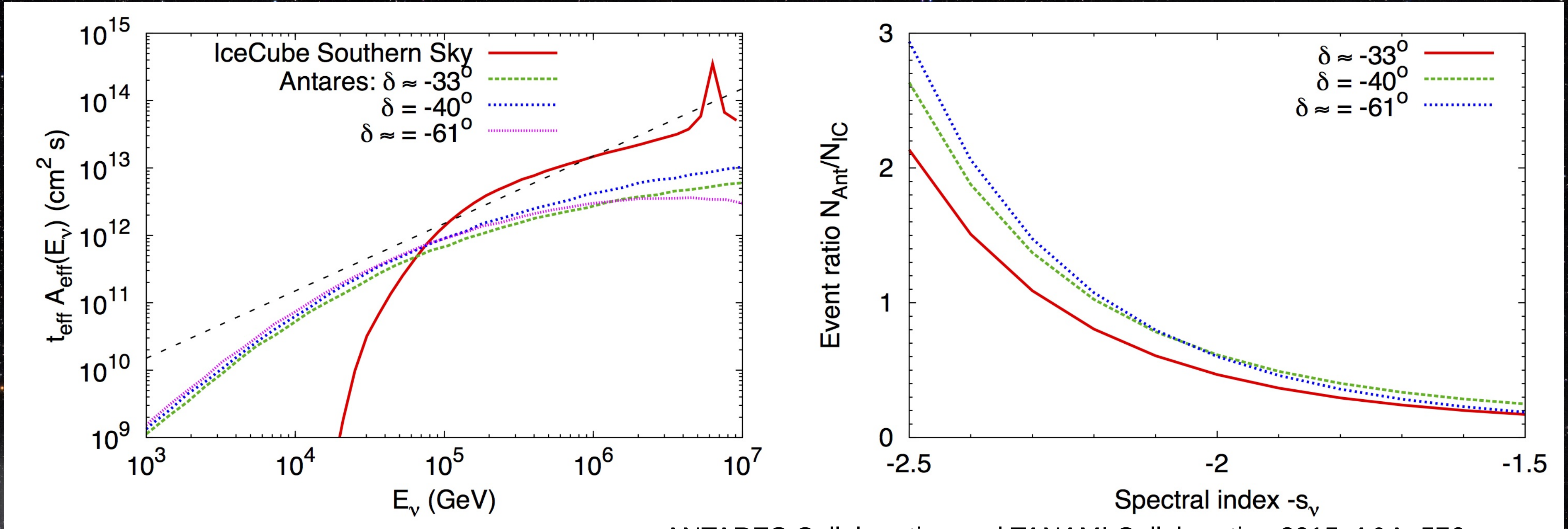
⇒ At E<100TeV: Southern sky accessible only for ANTARES



Expected ANTARES Response

Steep spectra: 2-3 events,Flat spectra: 0.2-0.3 events

⇒ ANTARES constrains the possible neutrino spectra for the candidate sources



ANTARES Collaboration and TANAMI Collaboration 2015, A&A, 576,

What are the Sources of the IceCube Neutrinos?

- Single Galactic-Center source excluded (ANTARES Collaboration 2014, ApJ 786, L5)
- Sky distribution consistent with isotropy
  - Gamma-ray bursts excluded (IceCube 2012, ANTARES 2014)
  - AGN jets (Mannheim 1995, Learned & Mannheim 2000)?

TANAMI Blazars in the IceCube PeV Neutrino Fields

The six radio- and γ-ray brightest AGN in the Ernie and Bert 1σ uncertainty regions:

Source	R.A.[°]	De.c[°]	z	Class.	Θ [°]
0235–618	39.2218$^{\triangle}$	−61.6043$^{\triangle}$	0.47$^{\blacklozenge}$	FSRQ$^{\blacklozenge}$	5.61
0302–623	45.9610†	−62.1904†	1.35$^{\blacklozenge}$	FSRQ$^{\blacklozenge}$	5.98
0308–611	47.4838†	−60.9775†	1.48$^{\blacklozenge}$	FSRQ$^{\blacklozenge}$	7.39
1653–329	254.0699$^{\triangle}$	−33.0369$^{\triangle}$	2.40$^{\diamond}$	FSRQ$^{\diamond}$	11.18
1714–336	259.4001*	−33.7024*	?	BL Lac$^{\blacktriangle}$	7.87
1759–396	270.6778$^{\bullet}$	−39.6689$^{\bullet}$	1.32$^{\blacksquare}$	FSRQ$^{\blacksquare}$	12.50

Are they capable of producing the two PeV neutrinos?