

# Gamma-ray blazars as possible neutrino sources

*Magellan Workshop 2016*

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in collaboration with

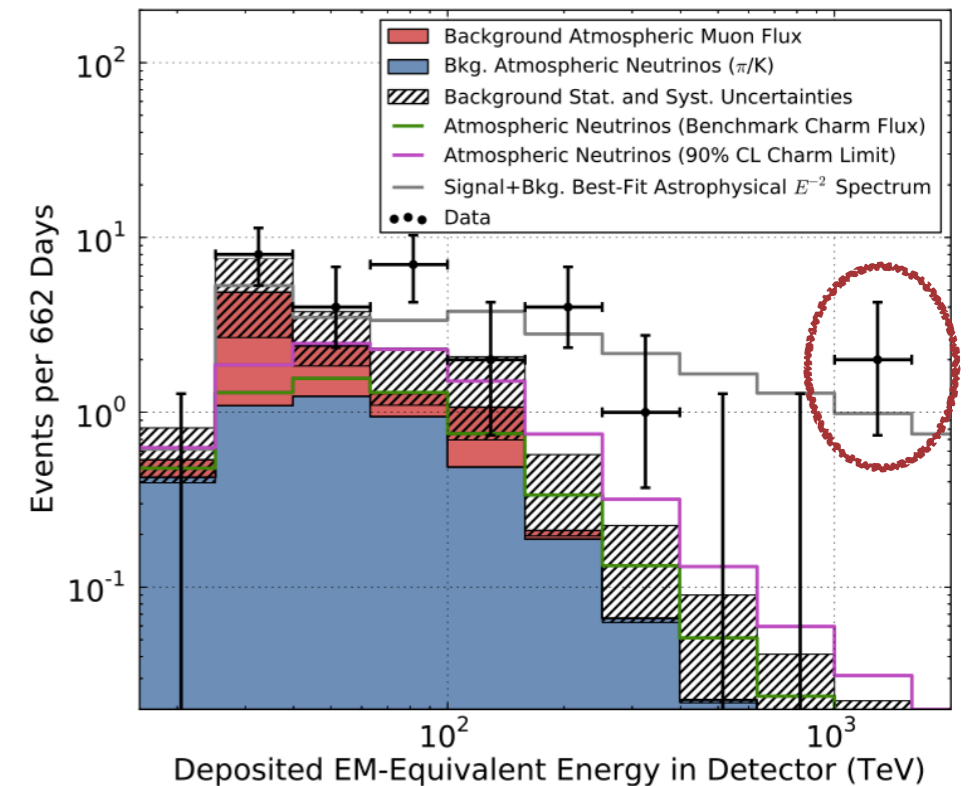
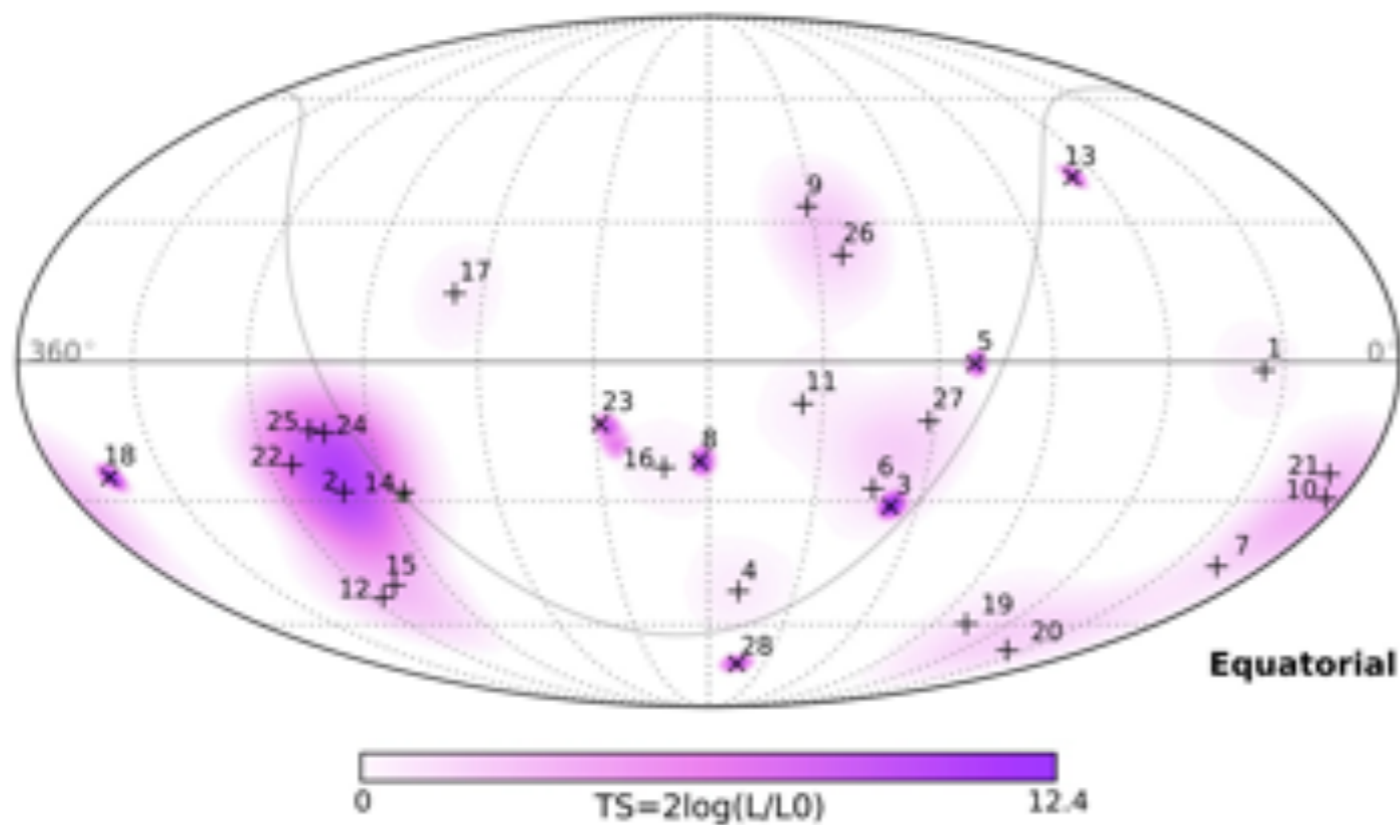
F. Krauß, M. Kadler, K. Mannheim, R. Schulz, J. Trüstedt, J. Wilms (University of Würzburg & Erlangen)

R. Ojha (NASA/GSFC) and the TANAMI Team



# IceCube signal: what are the sources?

IceCube Collaboration 2013, Science 342, 1



but: shower events have typically positional uncertainties of  $\sim 10\text{-}20^\circ$ !

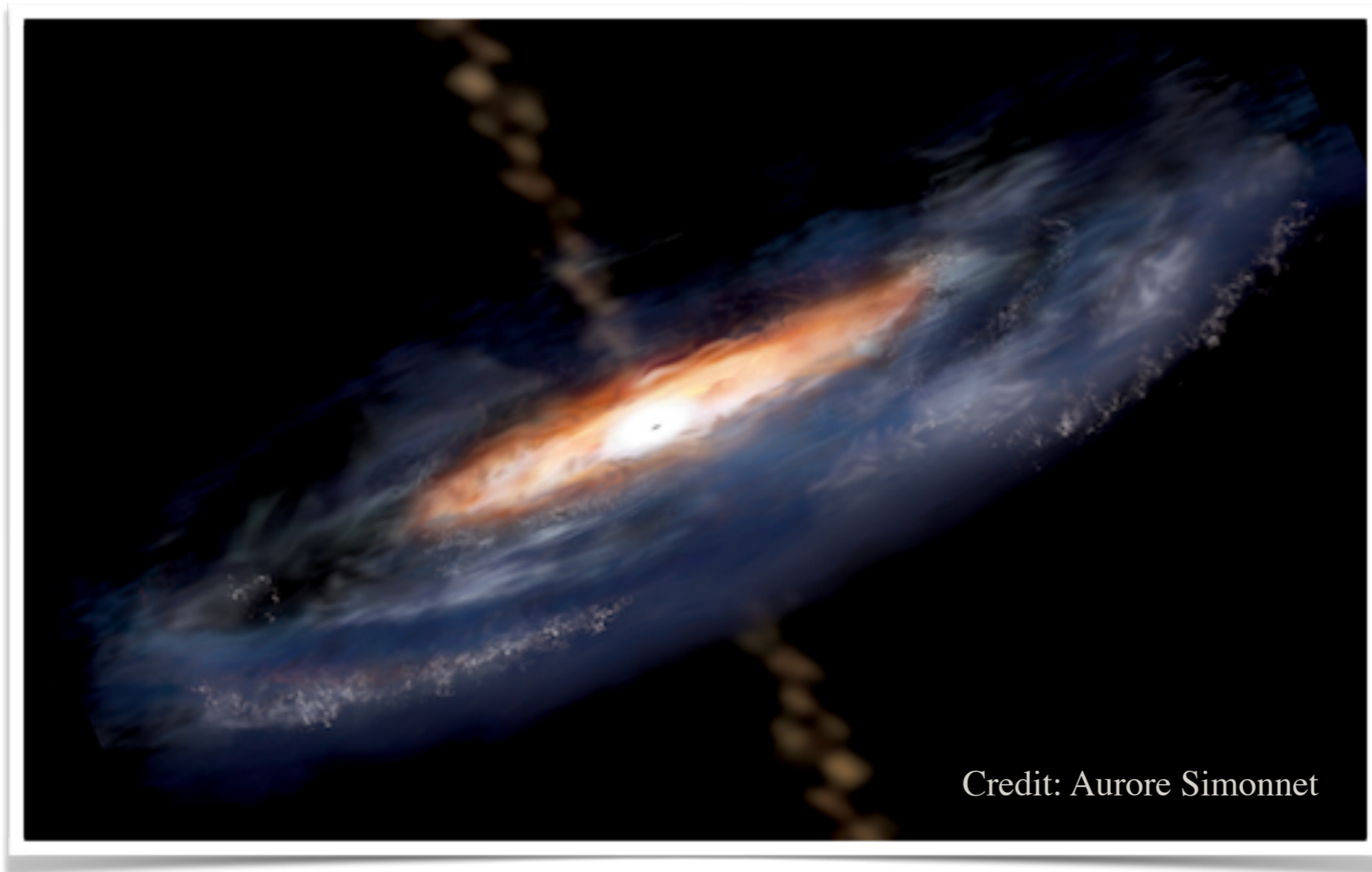
# The idea

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- Earth's opacity => PeV events from southern sky
- neutrino event distribution => **extragalactic**
- contemporaneous multiwavelength data required to probe various source hypotheses
- estimate diffuse neutrino flux in a given large field at a given time

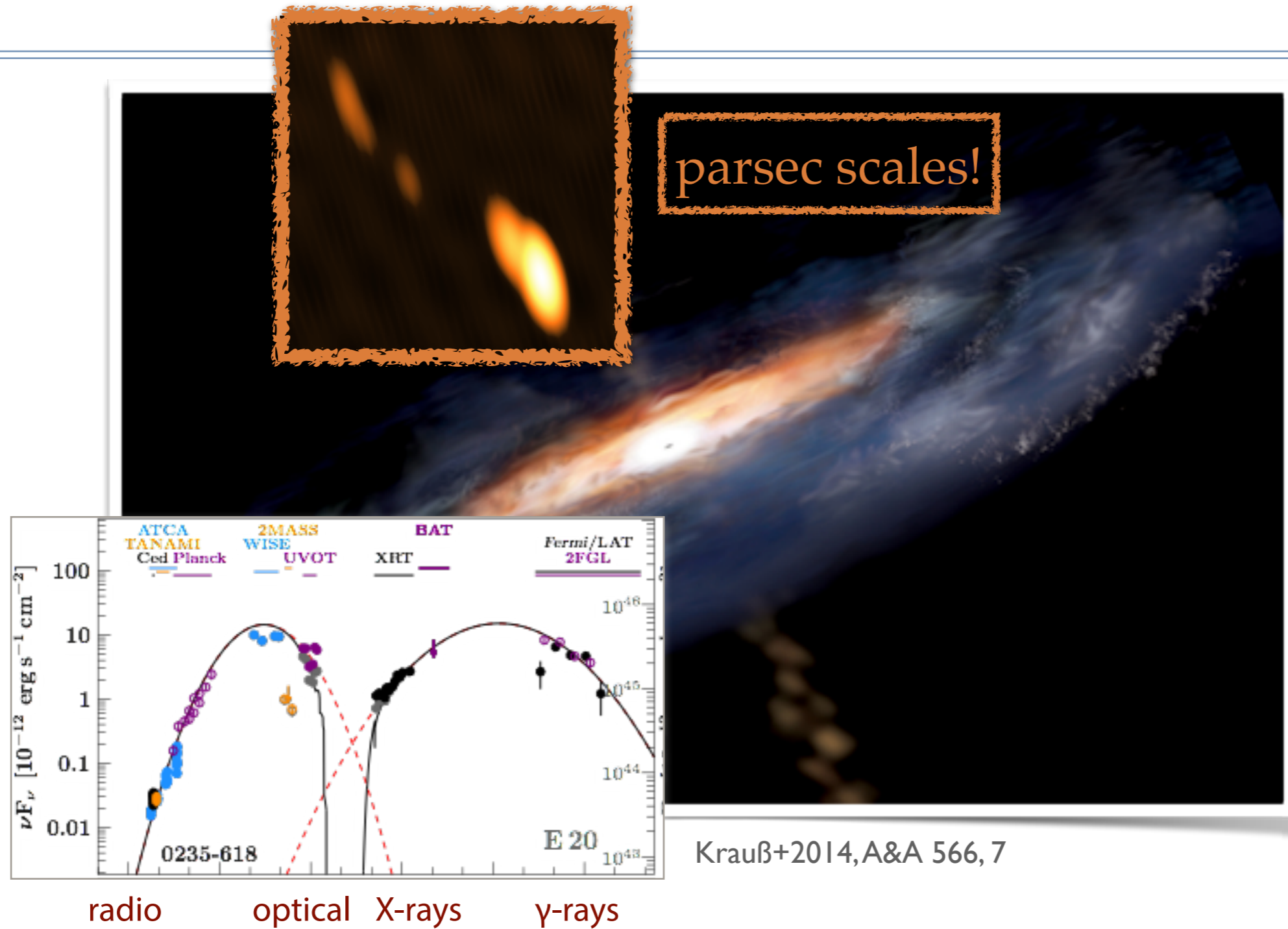
# Blazars = radio-loud AGN

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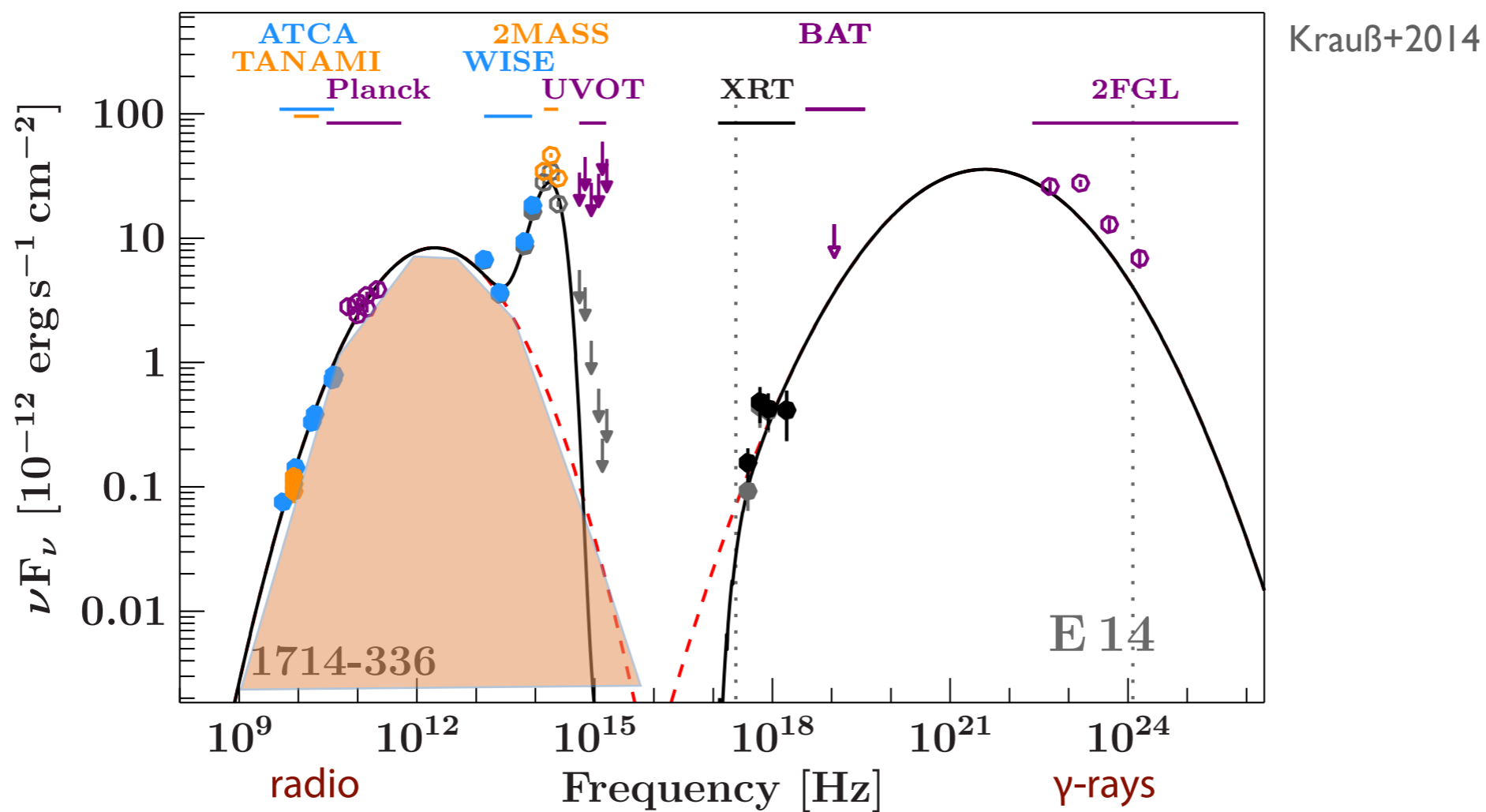
Credit: Aurore Simonnet

# Blazars



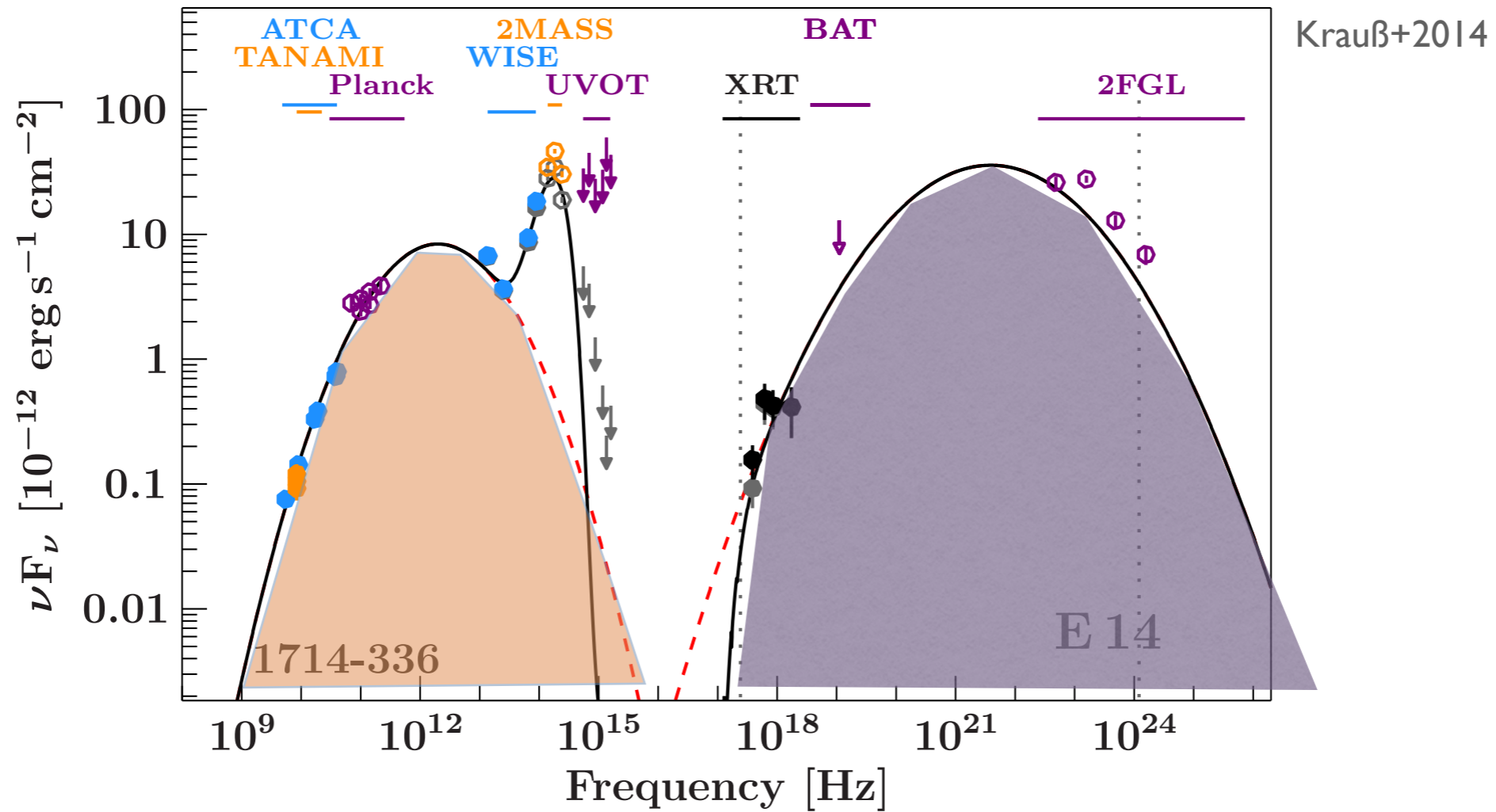
Krauß+2014, A&A 566, 7

# Broadband Spectral Energy Distribution



Synchrotron radiation

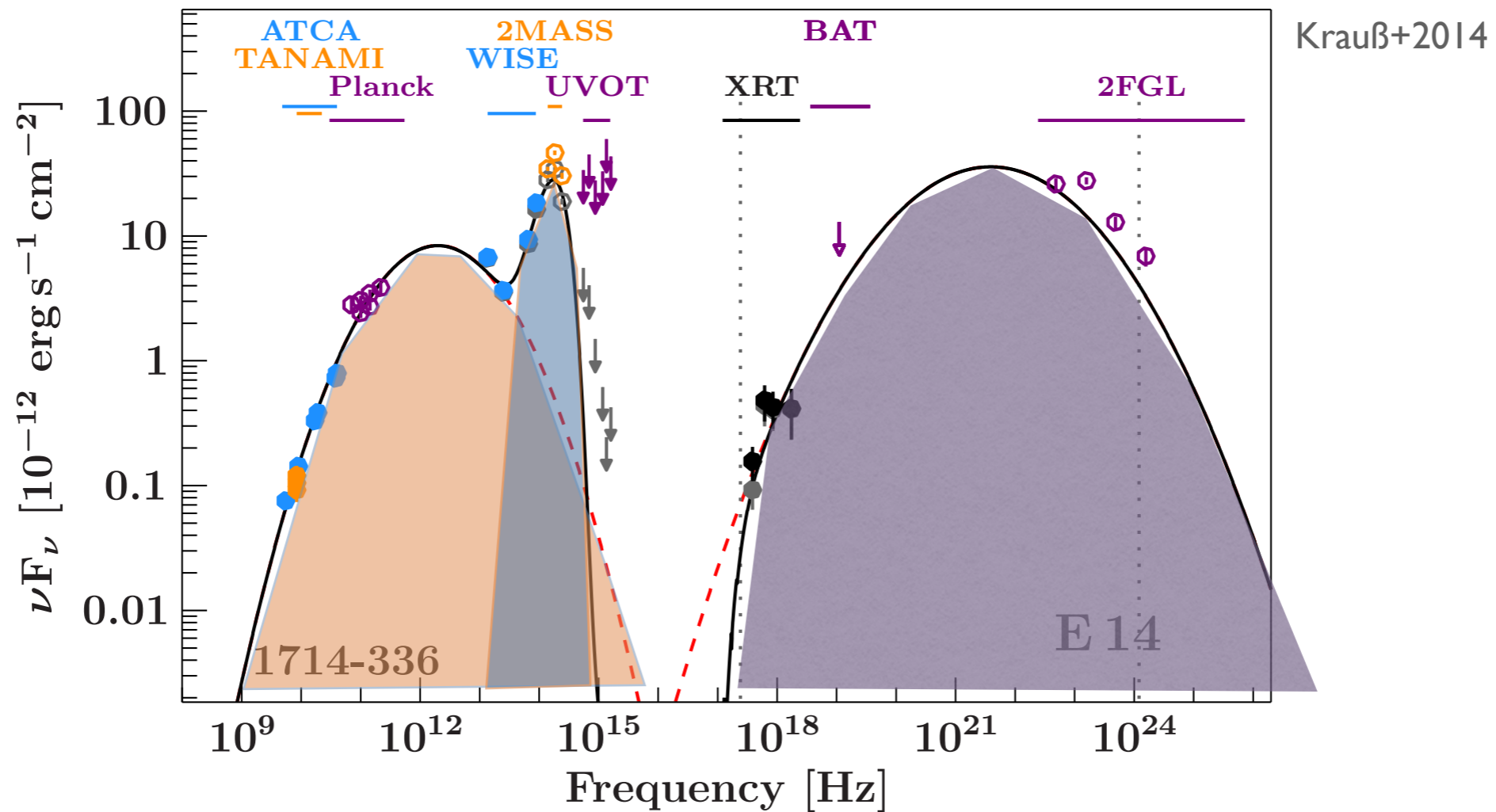
# Broadband SED



Synchrotron radiation

INVERSE COMPTON  
SSC? EC? leptonic? hadronic?

# Broadband SED



Synchrotron radiation

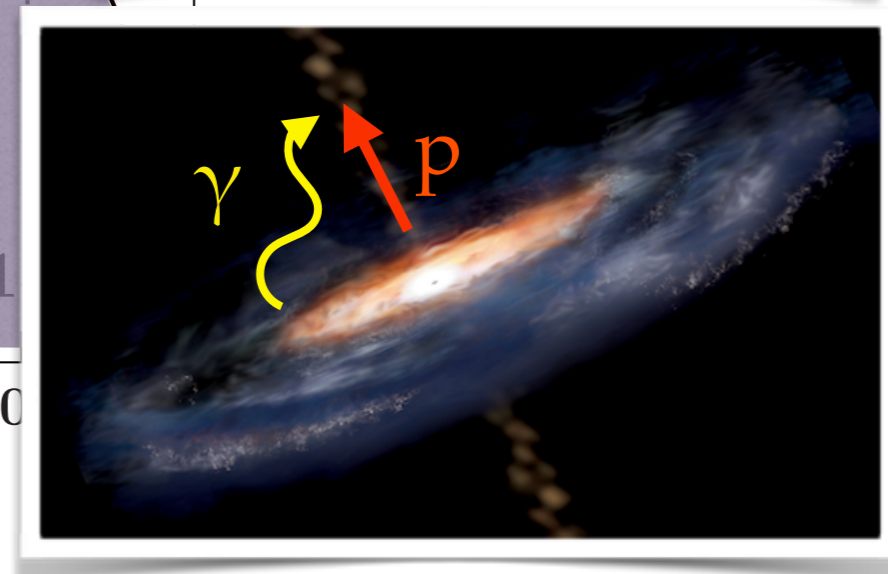
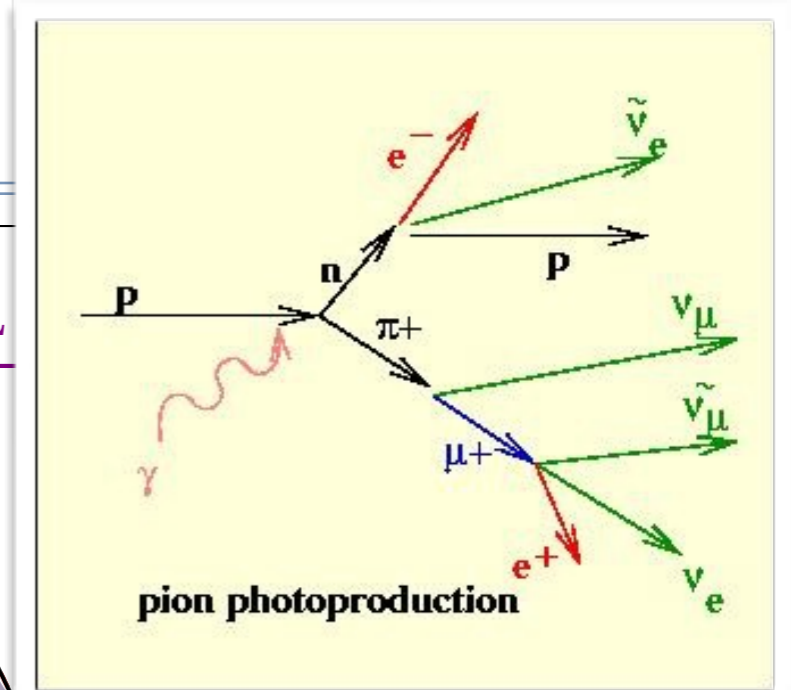
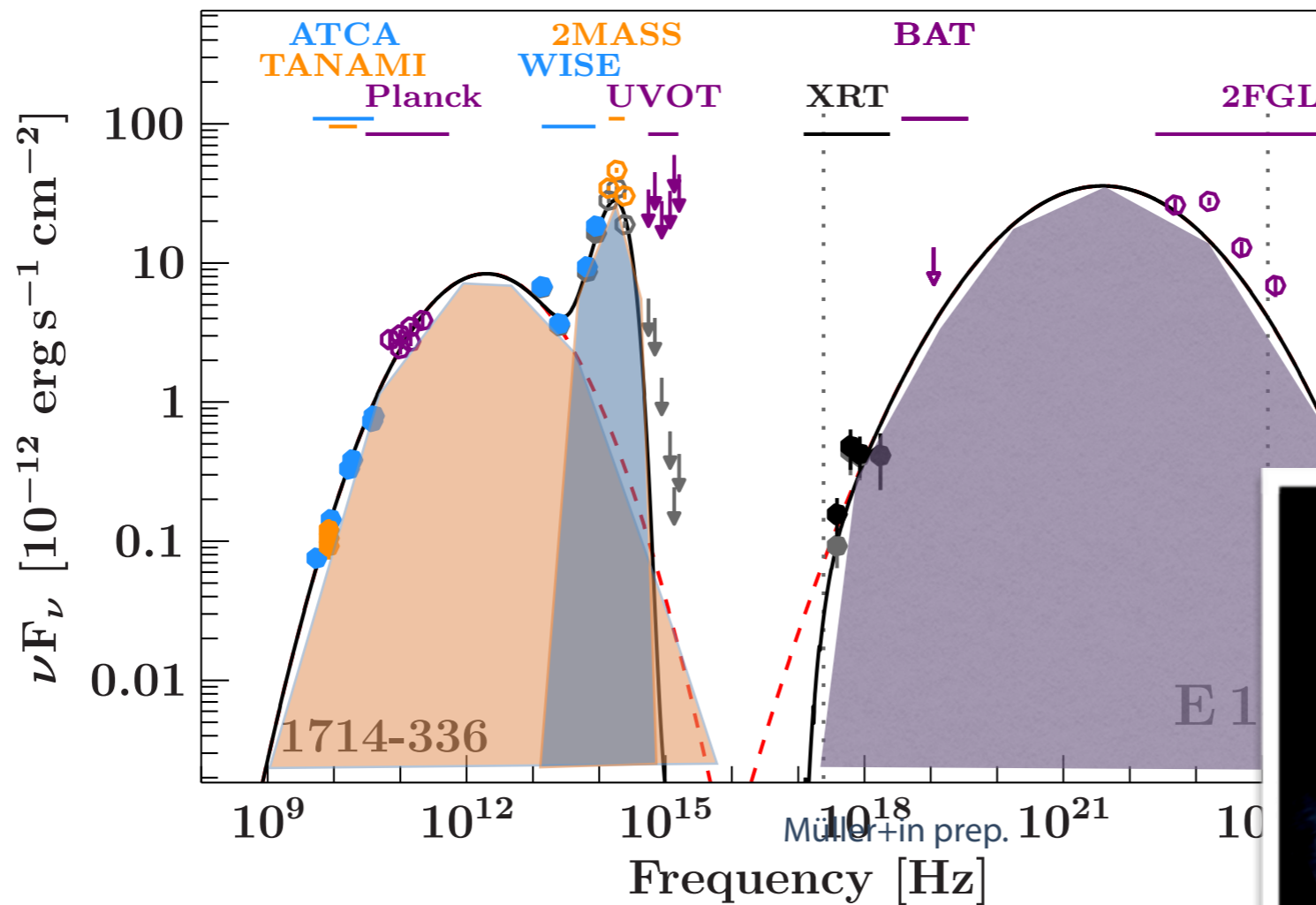
INVERSE COMPTON

SSC? EC? leptonic? hadronic?

Blackbody: Big blue bump



# How blazars could produce neutrinos



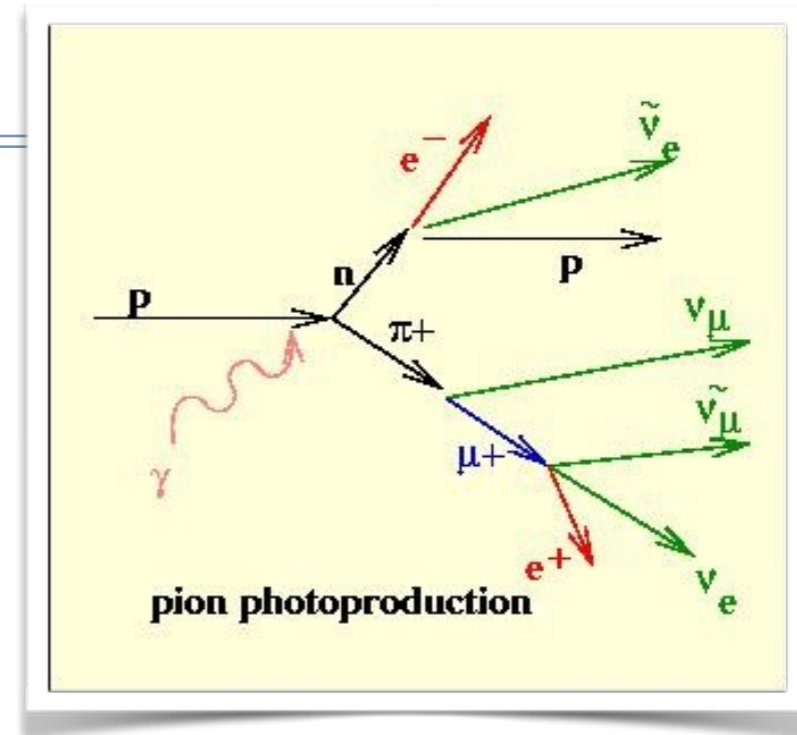
Synchrotron radiation

INVERSE COMPTON

SSC? EC? leptonic? hadronic?

Blackbody: Big blue bump

# Maximum neutrino output

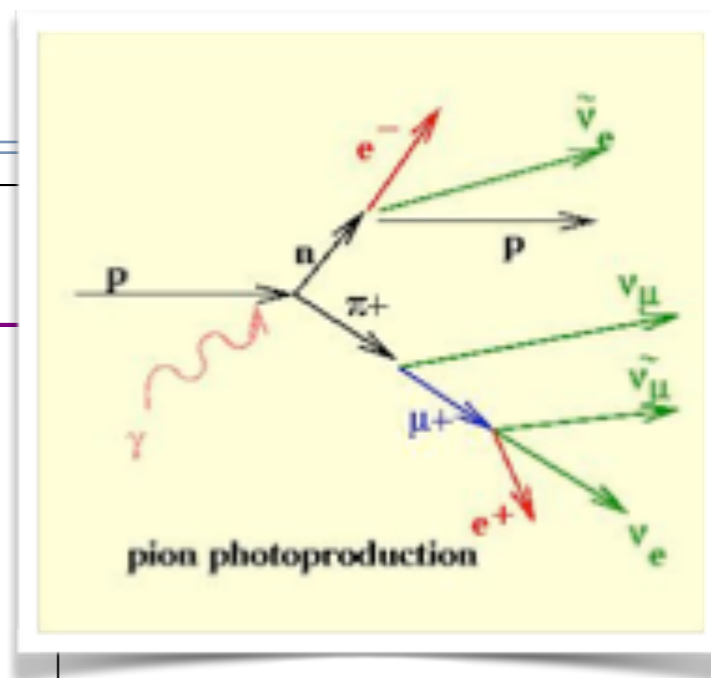
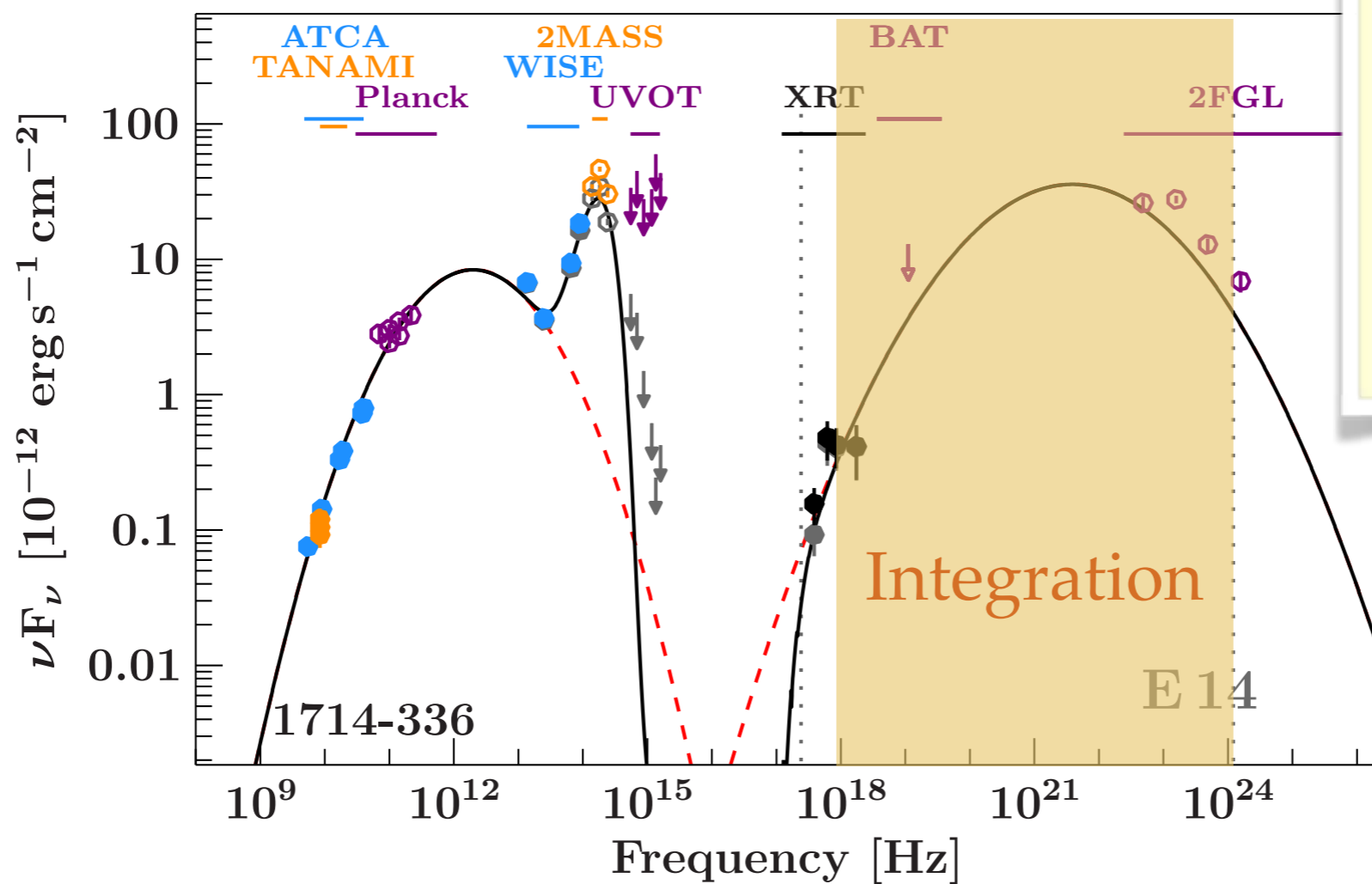


$$F_\gamma = 1/3 \cdot F_\pi + 1/4 \cdot 2/3 \cdot F_\pi = 1/2 \cdot F_\pi$$

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

$$F_\nu = F_\gamma$$

# Maximum neutrino output



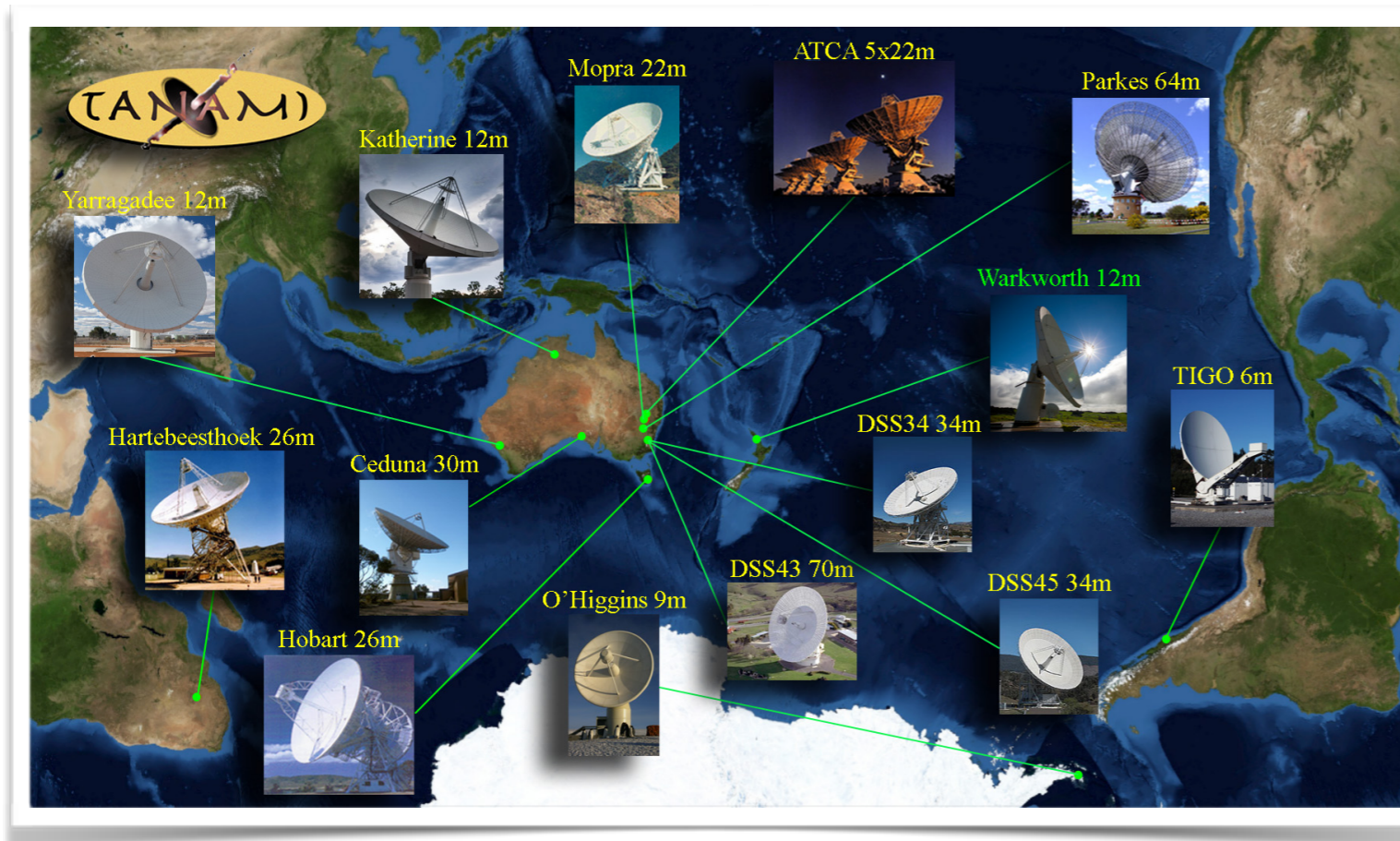
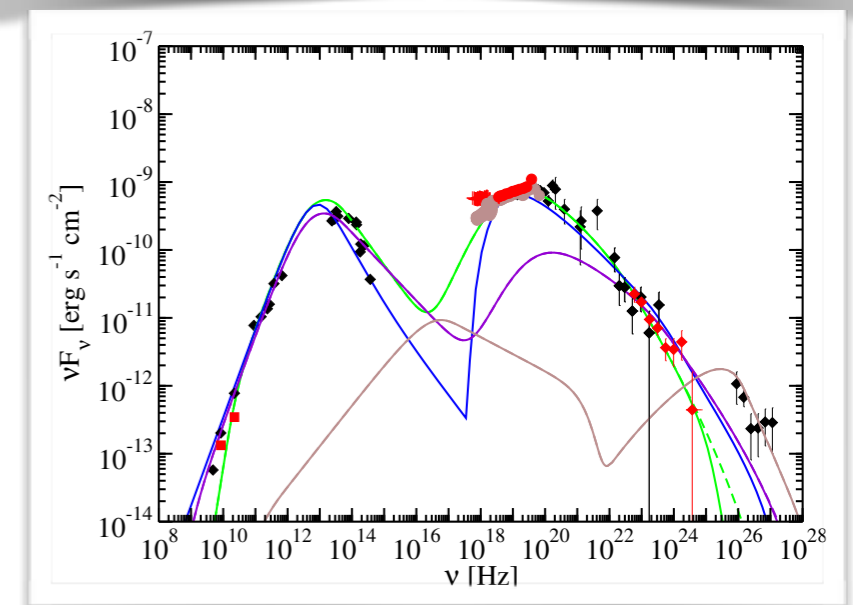
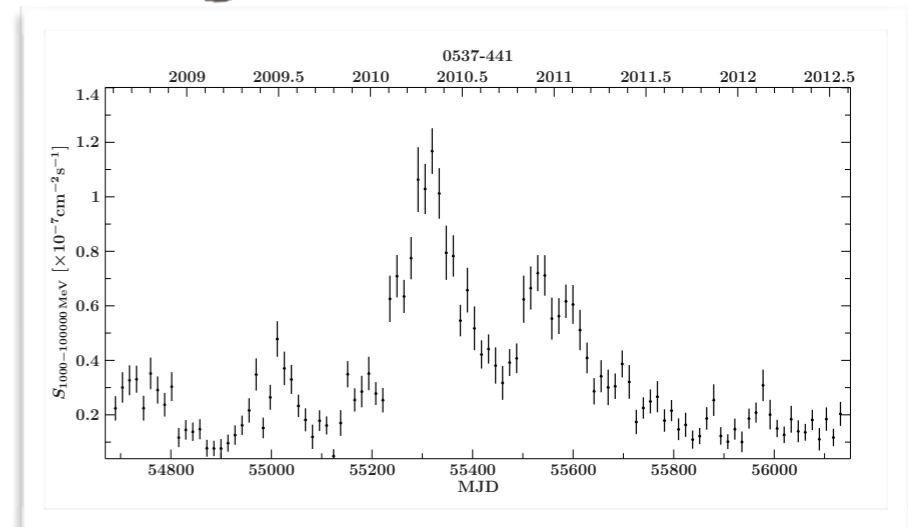
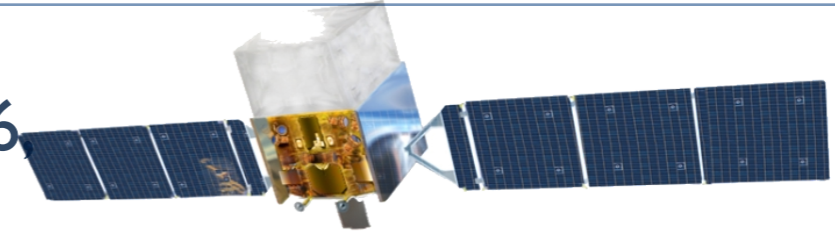
$$F_\gamma = F_\nu$$

# TANAMI



## TRACKING ACTIVE GALACTIC NUCLEI WITH AUSTRAL MILLIARCSECOND INTERFEROMETRY

- Ojha+2010, Kadler & Ojha 2015, Böck+2016
- ~90 extragalactic jets **south** of  $-30^\circ$  declination: **radio &  $\gamma$ -brightest**

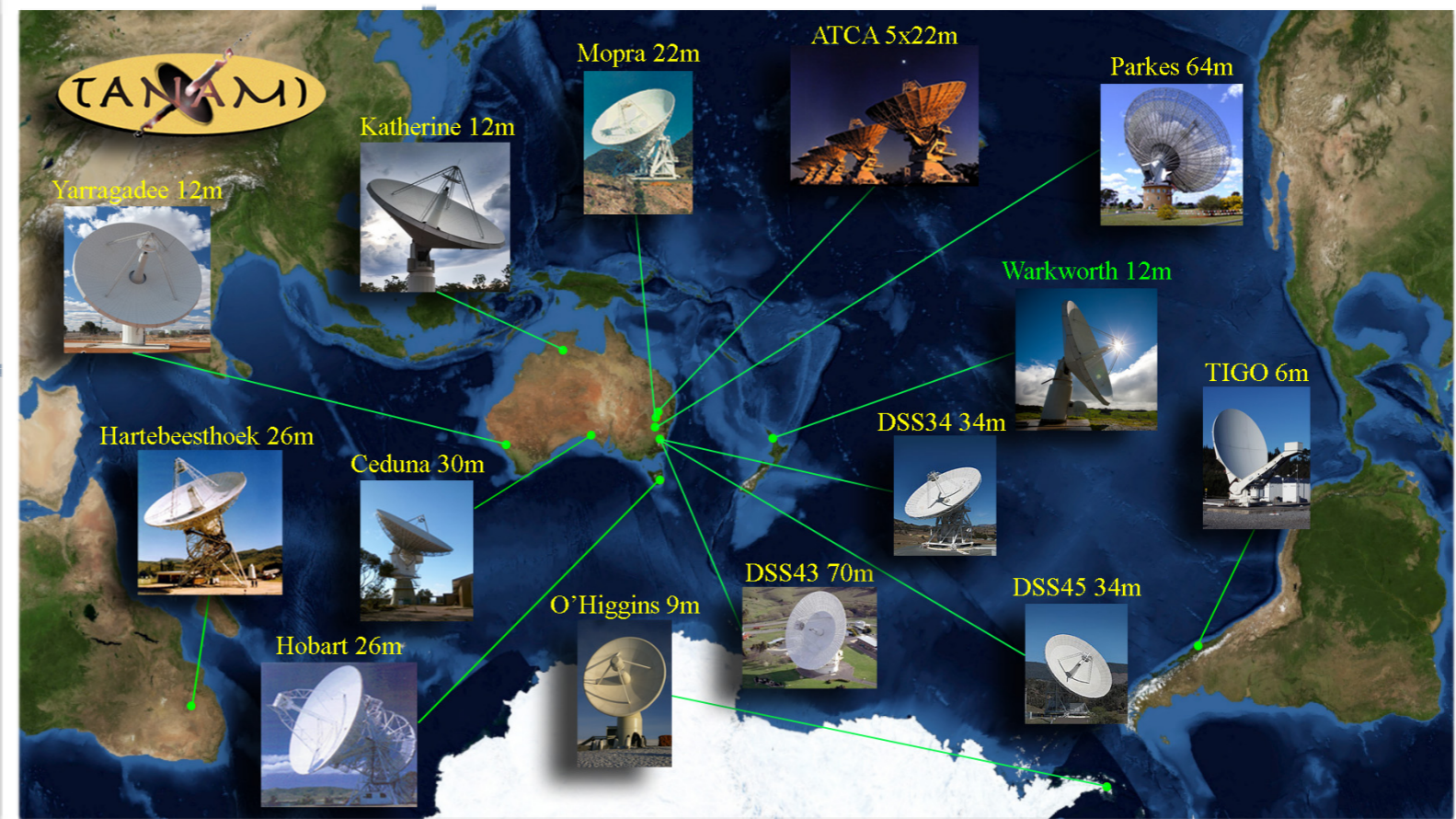
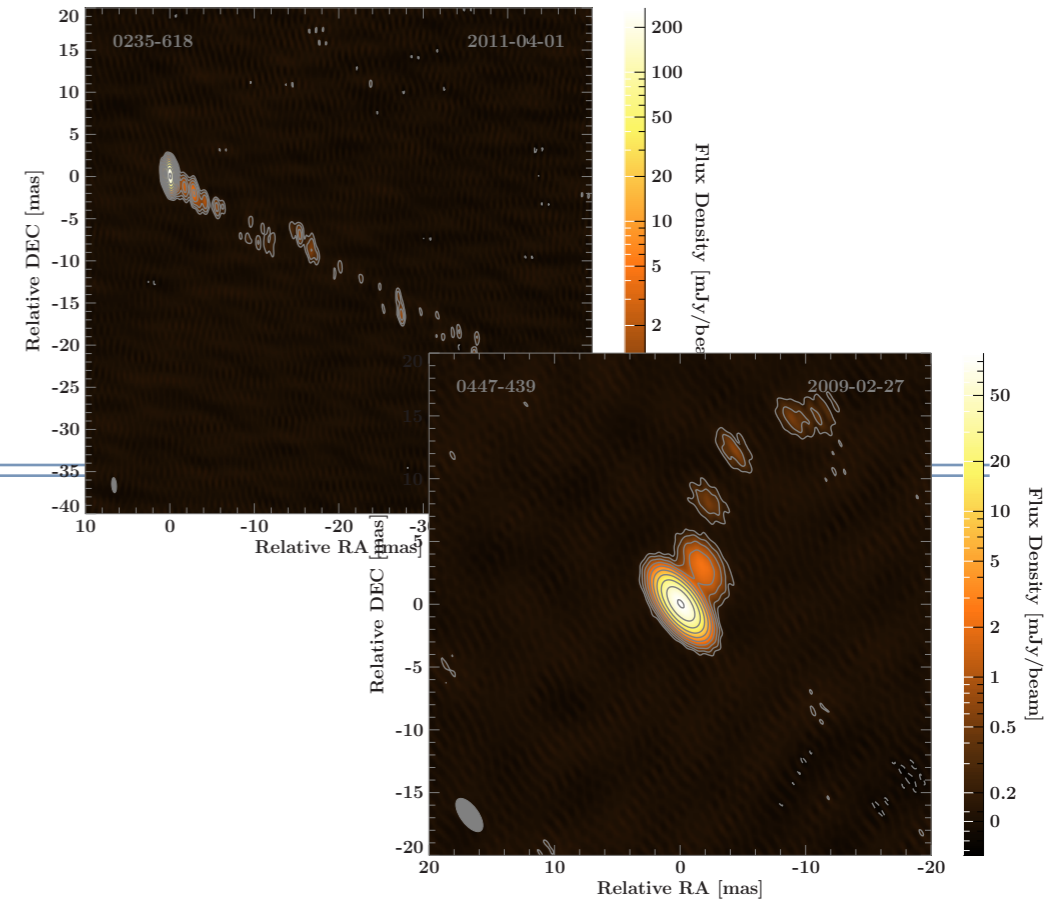


# TANAMI

Very Long Baseline Interferometry:  
(sub-)milliarcsecond resolution

## High-Resolution VLBI Observations

- highest resolved images for most sources
- parsec-scale morphology and kinematics
- spectral index images
- ...



# Multiwavelength ...

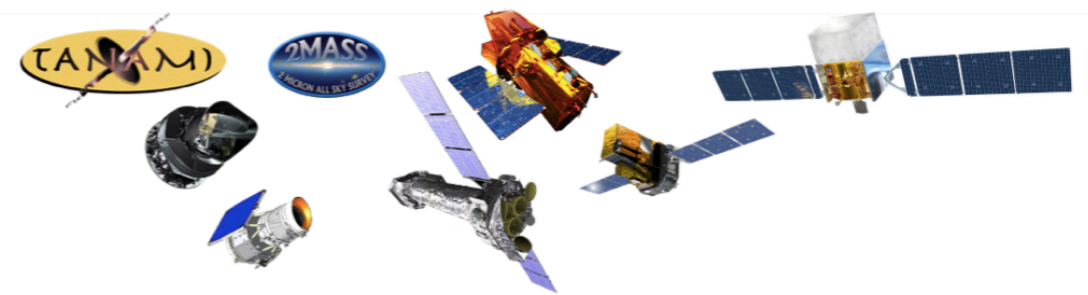
## High-Resolution VLBI Observations

- highest resolved images for most sources
- parsec-scale morphology and kinematics
- spectral index images
- ...



## Multiwavelength Monitoring

- Fermi/LAT all-sky monitoring
- quasi-simultaneous broadband coverage
- broadband variability and SEDs
- multimessenger astronomy
- ...



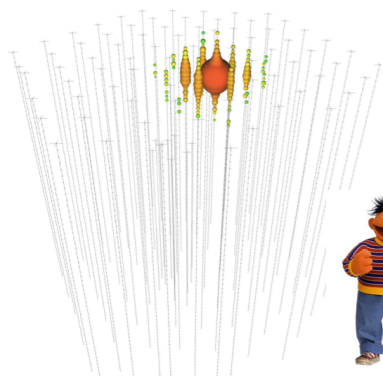
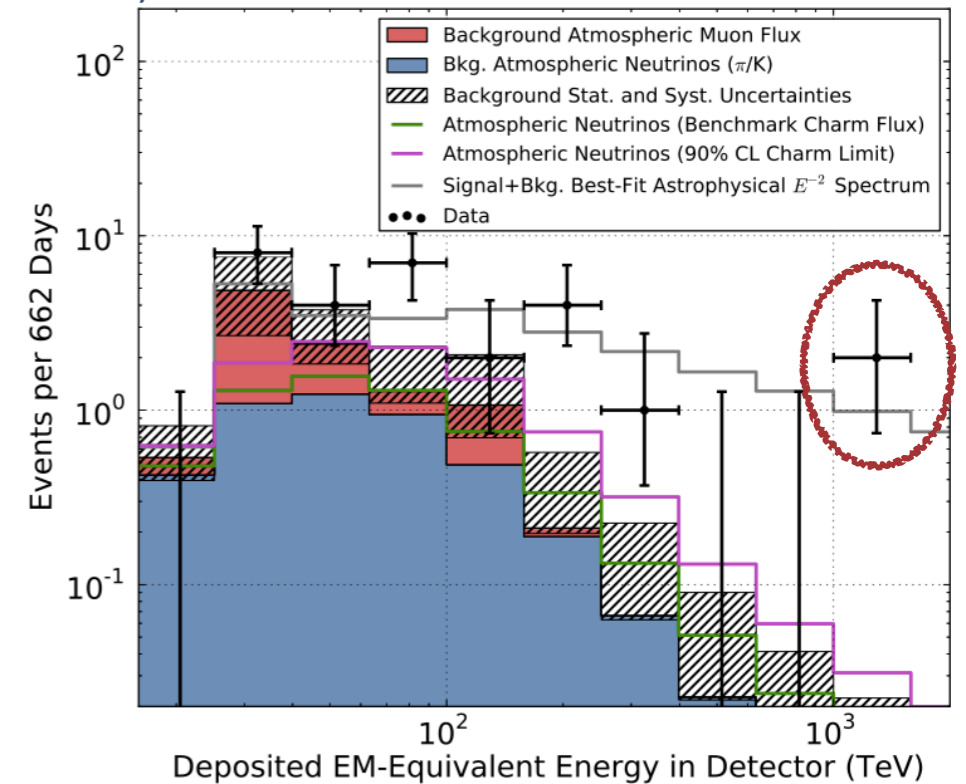
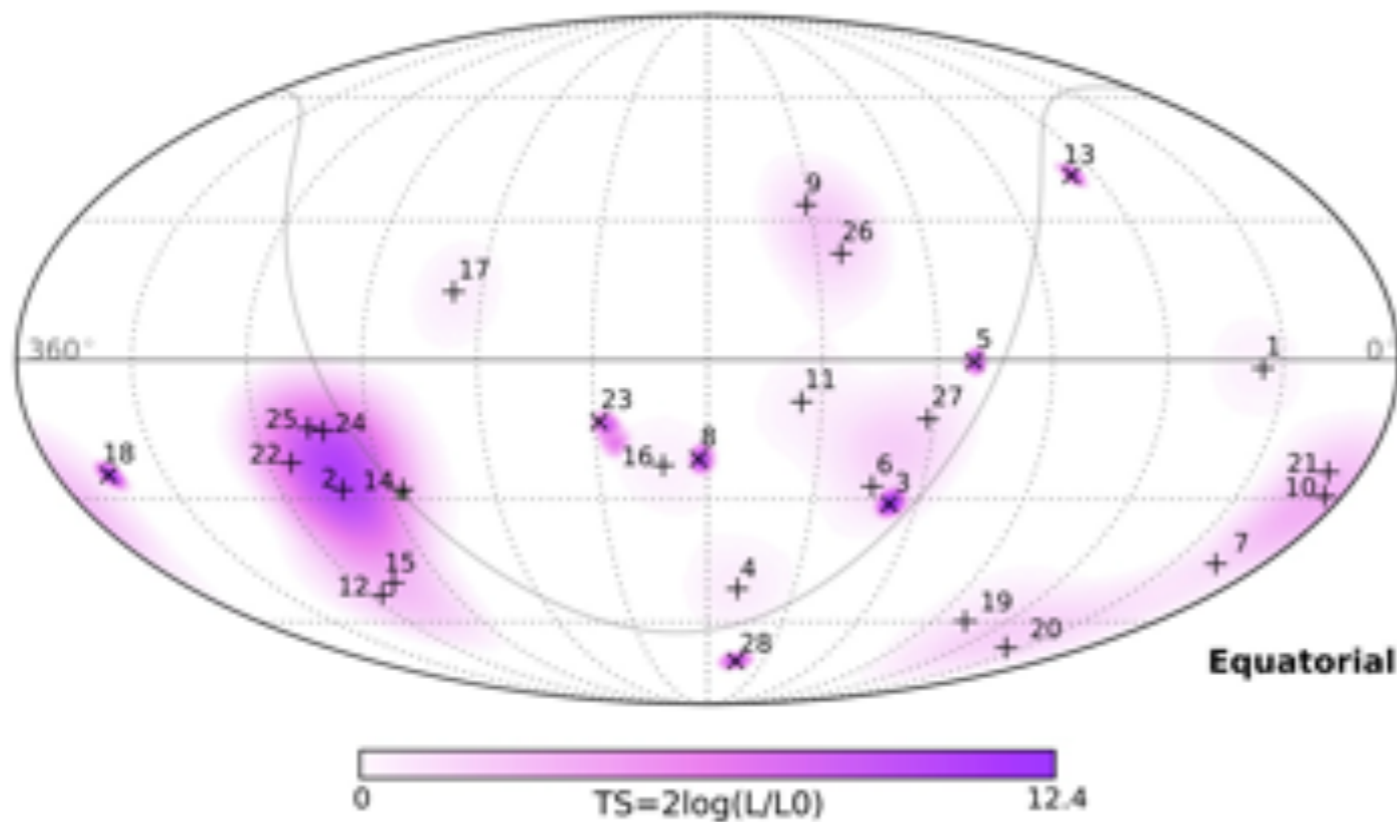
# ... to Multimessenger Astronomy:

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## Are radio-loud AGN neutrino emitters?

# IceCube signal: what are the sources?

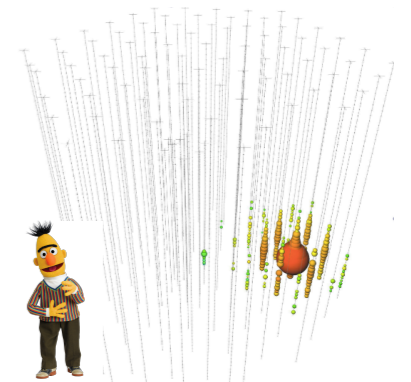
IceCube Collaboration 2013, Science 342, 1



HESE-20

Cornelia Müller

Ernie: R.A.= 38.3°, Dec=-67.2°,  $R_{err}=10.7^\circ$   
 Bert: R.A.=265.6°, Dec=-27.9°,  $R_{err}=13.2^\circ$

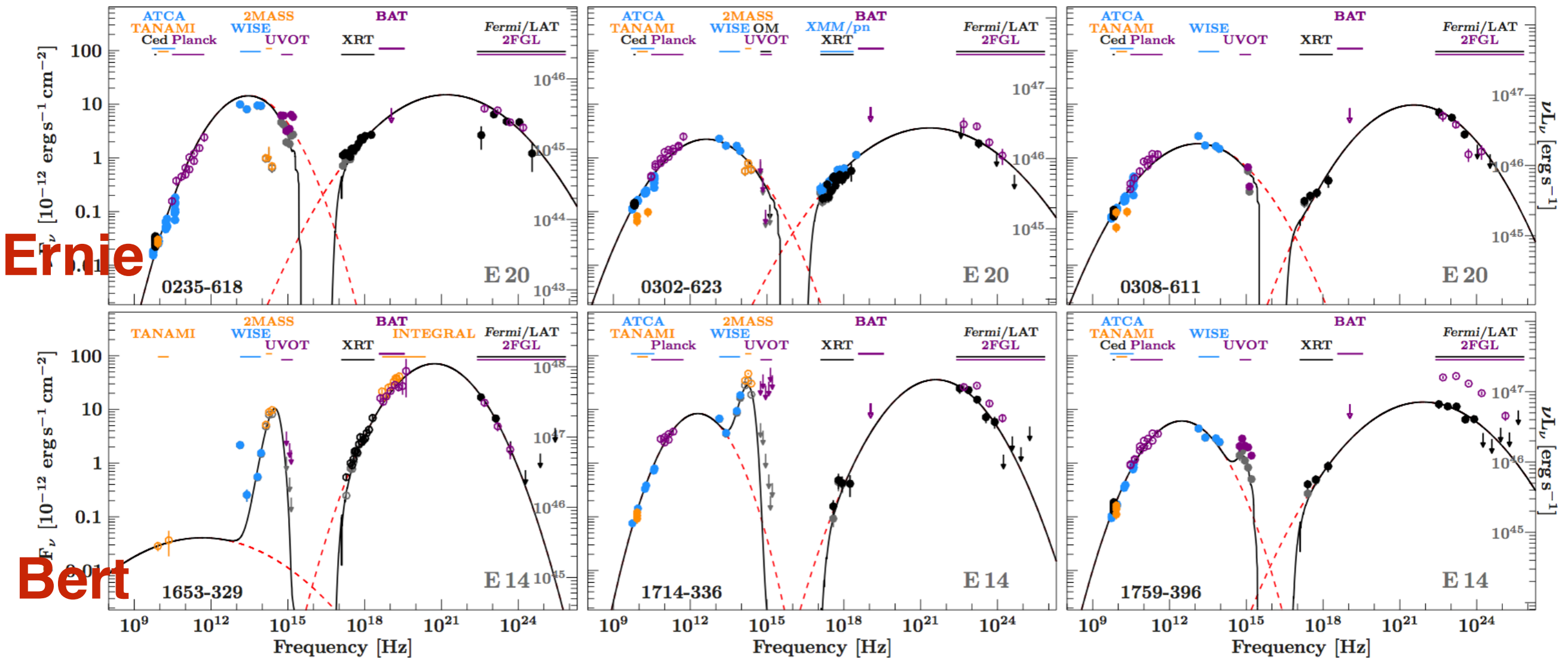


HESE-14

Magellan Workshop 2016



# TANAMI blazars in the IceCube PeV neutrino fields



Krauß+2014, A&A 566, 7

# Result for TANAMI blazars in Ernie & Bert fields

The energy output of these six TANAMI blazars can explain the observed IceCube signal!

Source	$F_\gamma(\text{erg cm}^{-2} \text{s}^{-1})$	events
0235–618	$(1.0^{+0.5}_{-0.5}) \times 10^{-10}$	$0.19^{+0.04}_{-0.04}$
0302–623	$(3.4^{+0.7}_{-0.7}) \times 10^{-11}$	$0.06^{+0.01}_{-0.01}$ <b>Ernie</b>
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	$(2.4^{+0.5}_{-0.6}) \times 10^{-10}$	$0.46^{+0.10}_{-0.12}$ <b>Bert</b>
1759–396	$(1.2^{+0.3}_{-0.2}) \times 10^{-10}$	$0.23^{+0.50}_{-0.40}$
Total		$1.9 \pm 0.4$

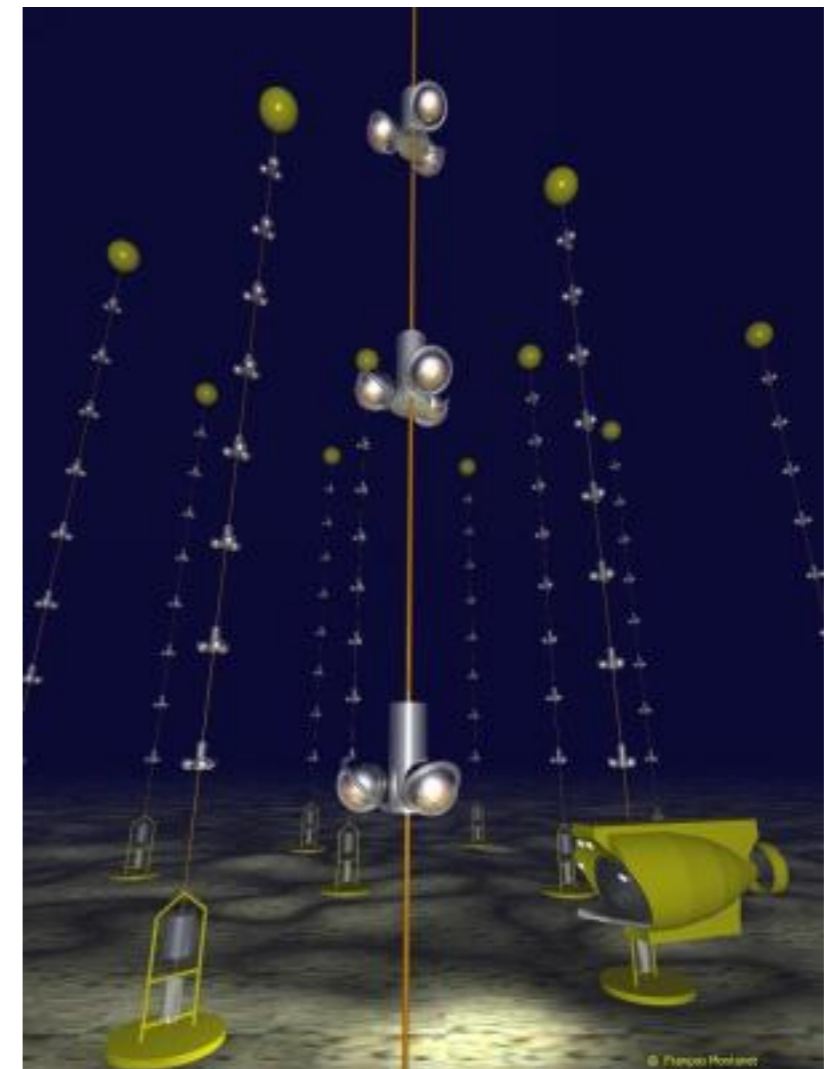
Krauß+2014, A&A 566, 7

# Antares follow-up

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



- Neutrino Telescope in the Mediterranean (Water Cherenkov Detector) operating since 2008
- Angular resolution:  $0.4^\circ$
- Highest sensitivity in TANAMI sky region for TeV neutrinos



# Antares follow-up

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

Source	$N_{\text{sig}}$	$p$	Limit $10^{-8} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1}$	$N_{\nu,IC} = 1$	$N_{\nu,IC} = 2$	$N_{\nu,IC} = 3$	$N_{\nu,IC} = 4$
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 & 1714-336 both 1 event
  - consistent with blazar hypothesis, but also consistent with background
  - non-detection for other sources
- **constrain neutrino spectrum: flatter than -2.4**

# Big Bird

Aartsen et al. 2014

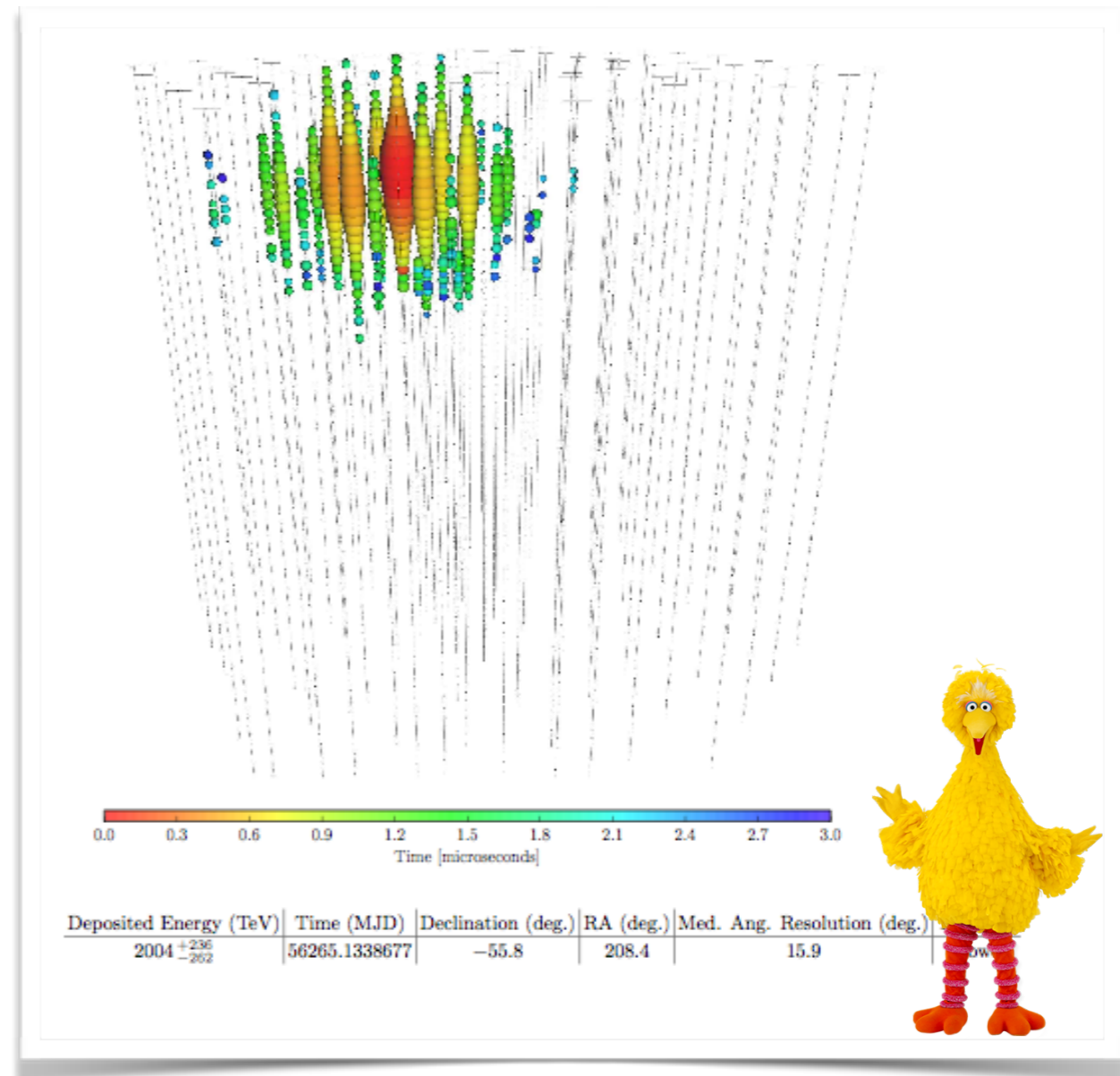
HESE-35 „**Big Bird**“

Dec 4, 2012

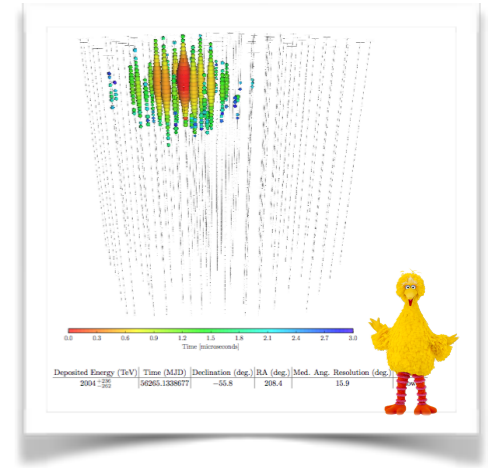
2PeV

R.A. =  $208.4^\circ$ , Dec =  $-55.8^\circ$

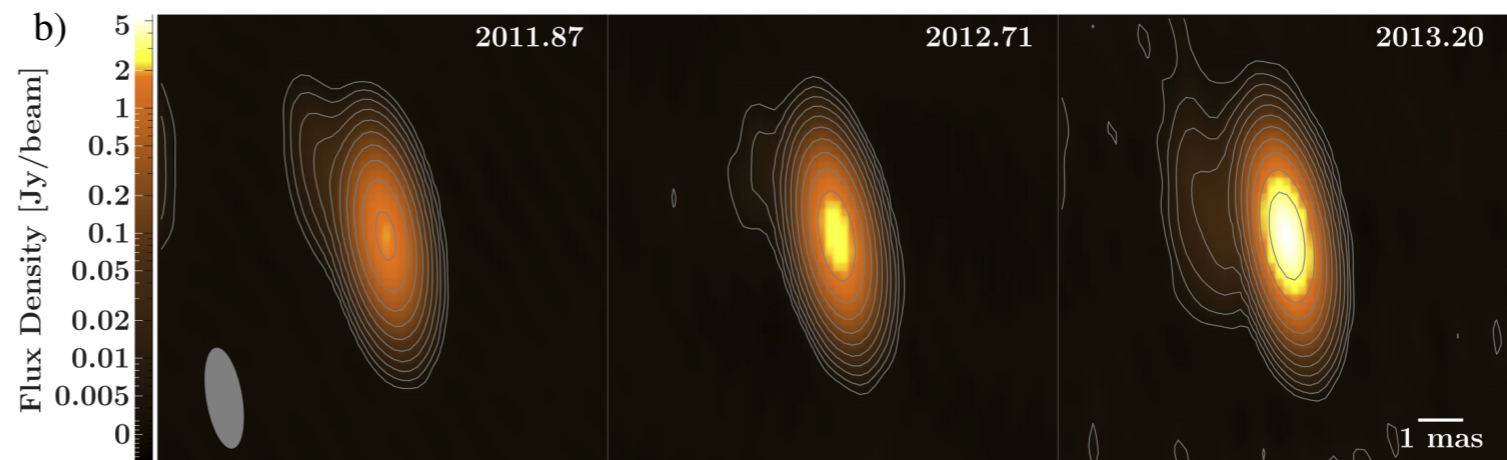
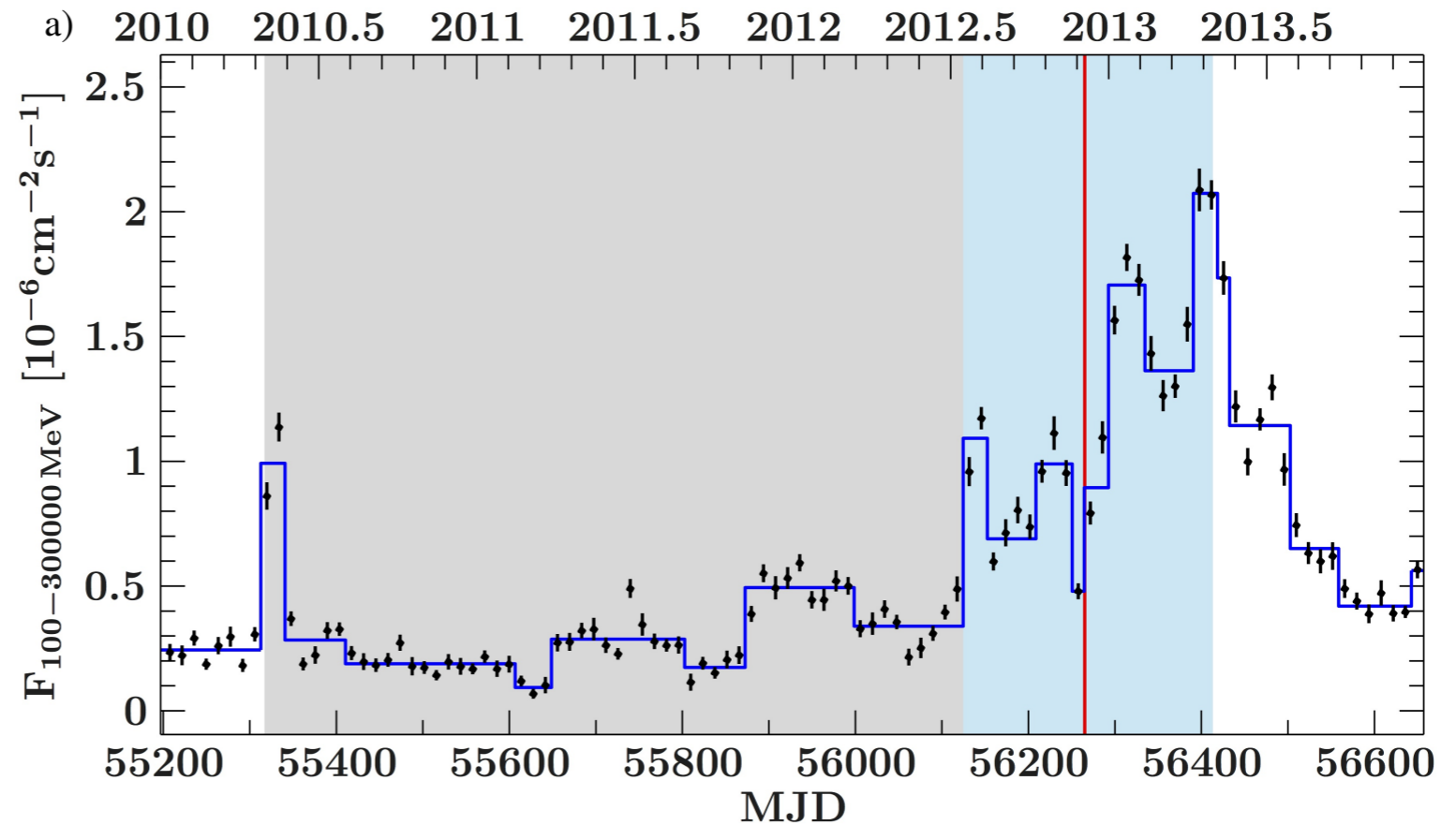
$R_{\text{err}} = 15.9^\circ$



# Big Bird

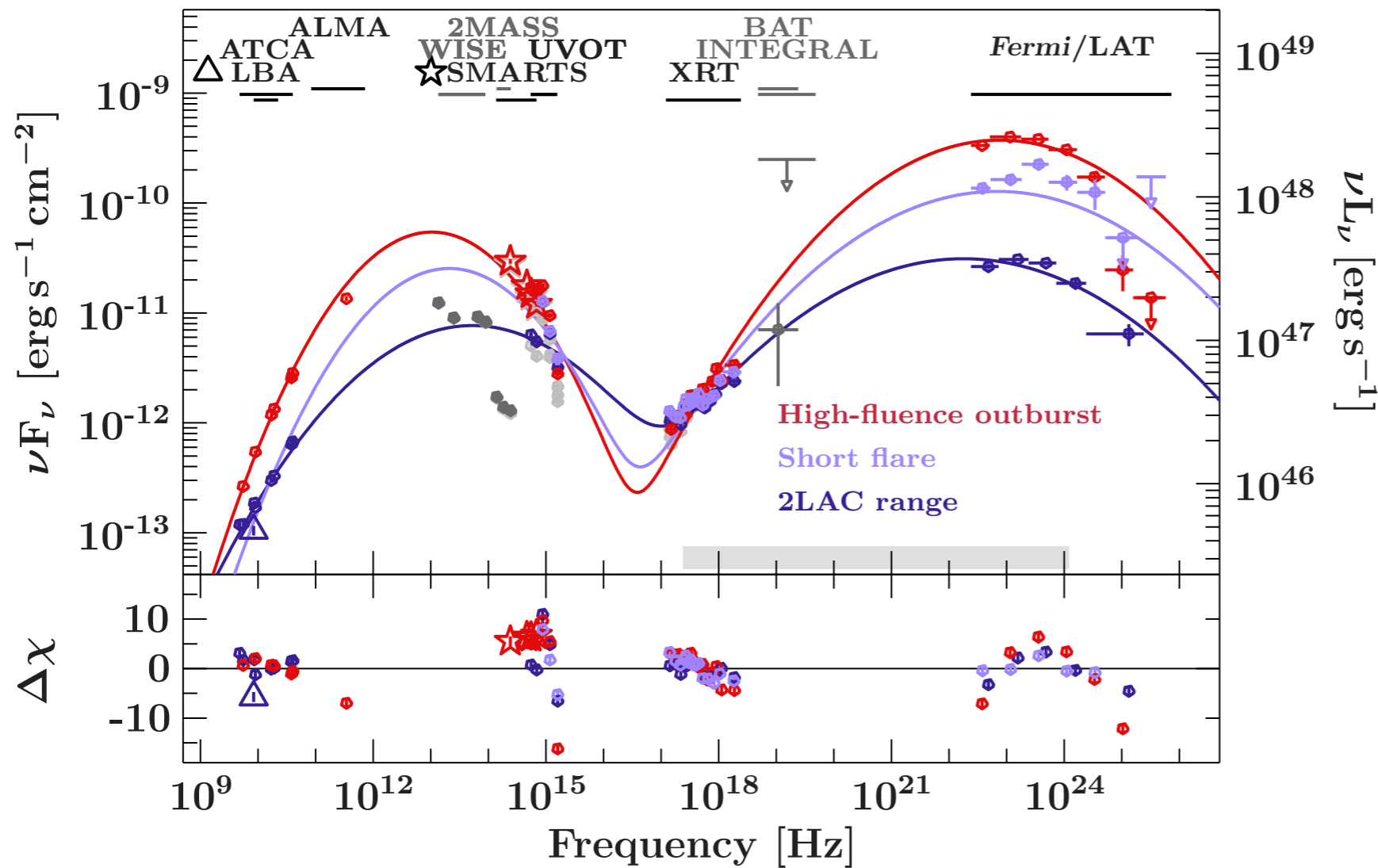
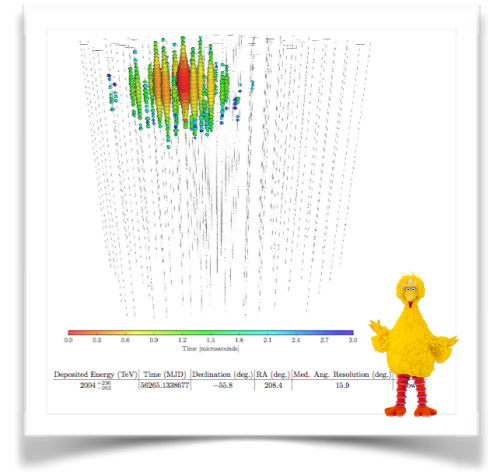


**PKS B1424-418:**  
 Gamma-ray outburst  
 coincident with arrival time  
  
 => highest  $\gamma$ -ray fluence of  
 all extragalactic sources  
 in 9 month period  
 (July 2012-April 2013)



Kadler+2016, Nature Physics

# Big Bird



Energy output during outburst can explain observed PeV event

but: 5% chance coincidence

Kadler+2016

# Summary & Conclusions

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- Integrated flux of blazars can explain the IceCube signals
  - ANTARES follow-up: flat neutrino spectrum
  - Third PeV event („Big Bird“) can be explained by one single blazar outburst
  - but: 5% chance coincidence
- ➔ Future analysis of track events (smaller error circles), improved statistics & continued multiwavelength monitoring