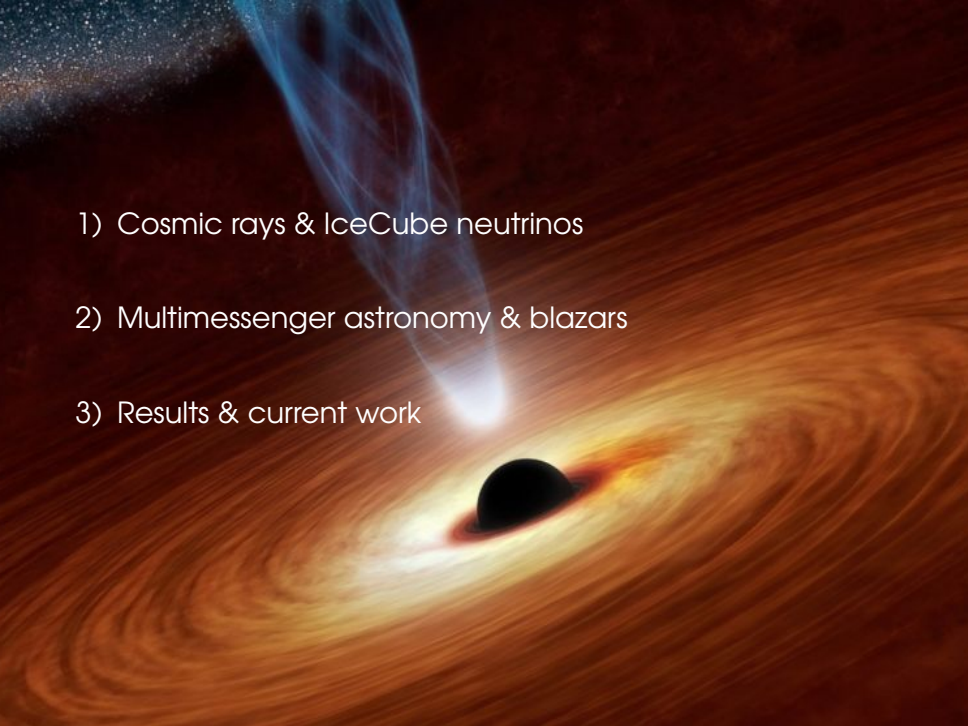


Multimessenger studies of blazars

Felicia Krauß, Matthias Kadler, Karl Mannheim, Joern Wilms •
GRAPPA & API, UvA • Felicia.Krauss@uva.nl

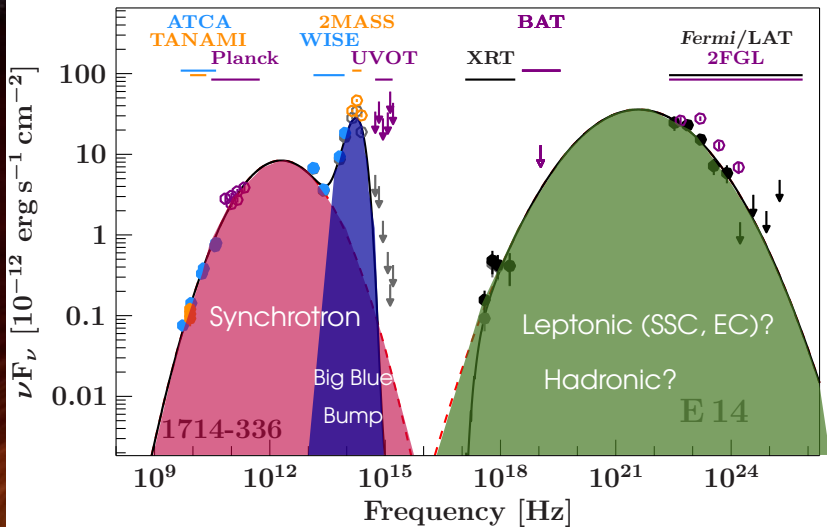


- 
- A black hole is depicted at the bottom center, surrounded by a glowing, swirling accretion disk in shades of orange and yellow. A bright blue jet of light or plasma extends upwards from the black hole, tapering as it rises. The background is a dark, reddish-brown space with faint, concentric ripples emanating from the black hole. In the top left corner, a portion of a galaxy with blue and white stars is visible.
- 1) Cosmic rays & IceCube neutrinos
 - 2) Multimessenger astronomy & blazars
 - 3) Results & current work

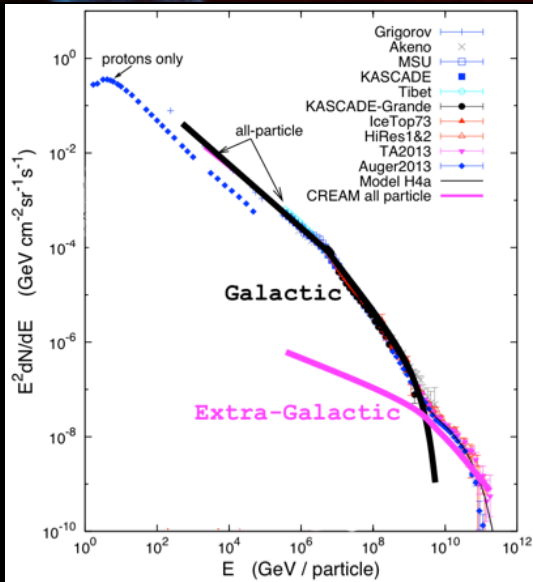
Blazar:
FSRQ/BL Lac



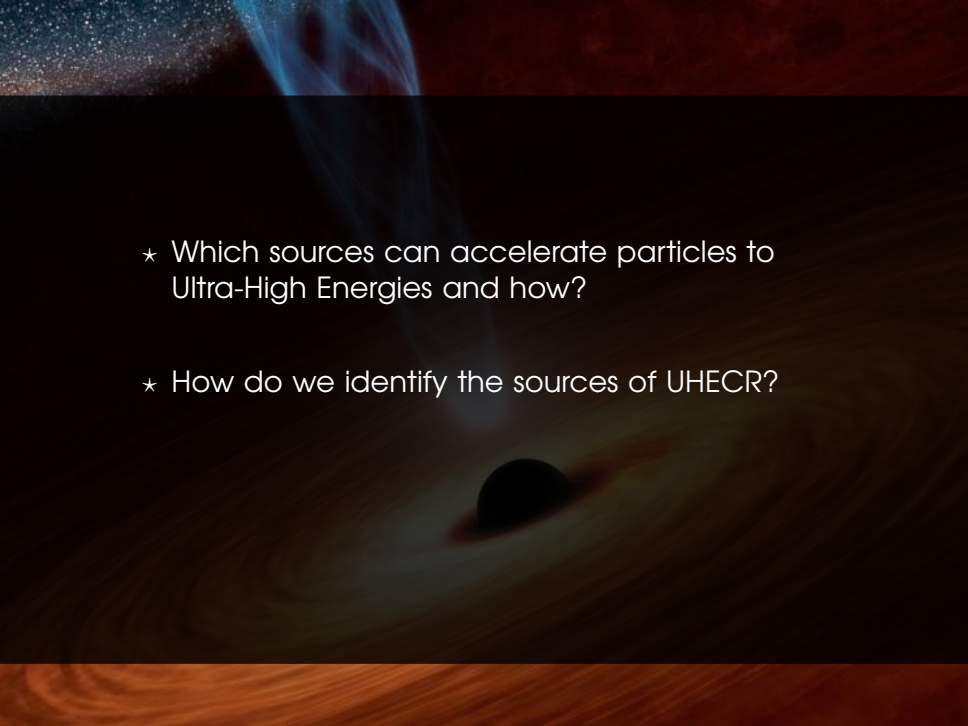
10^{-3} pc

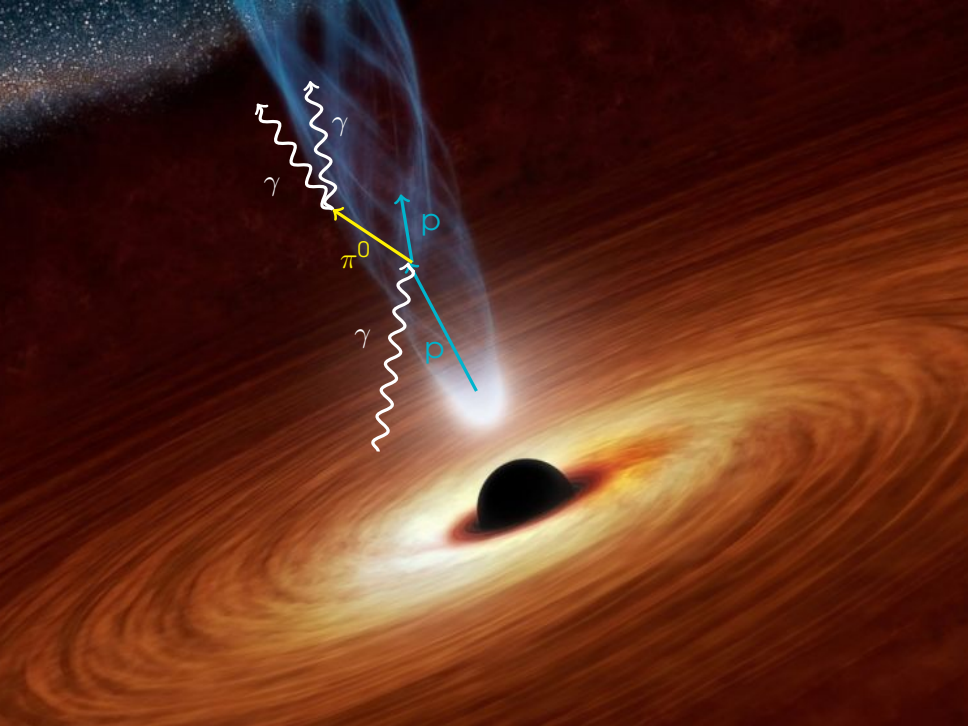


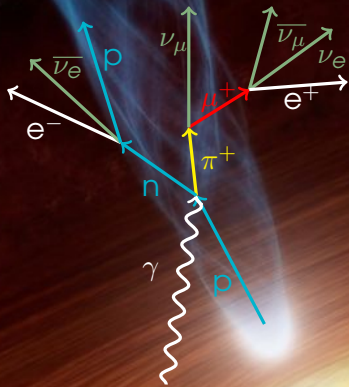
The cosmic ray spectrum



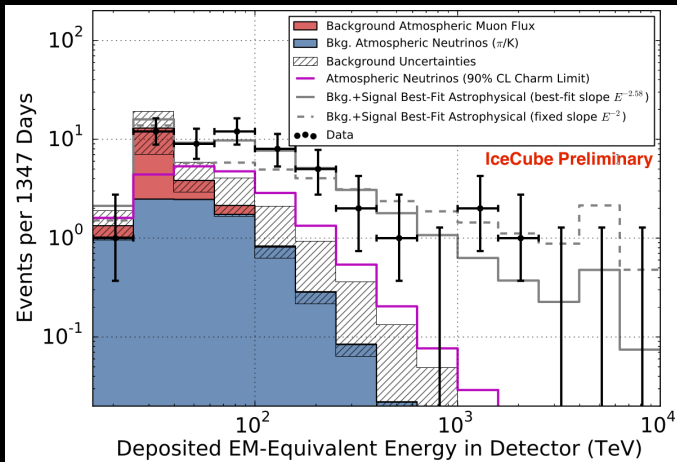
after Hillas 2006

- 
- ★ Which sources can accelerate particles to Ultra-High Energies and how?
 - ★ How do we identify the sources of UHECR?

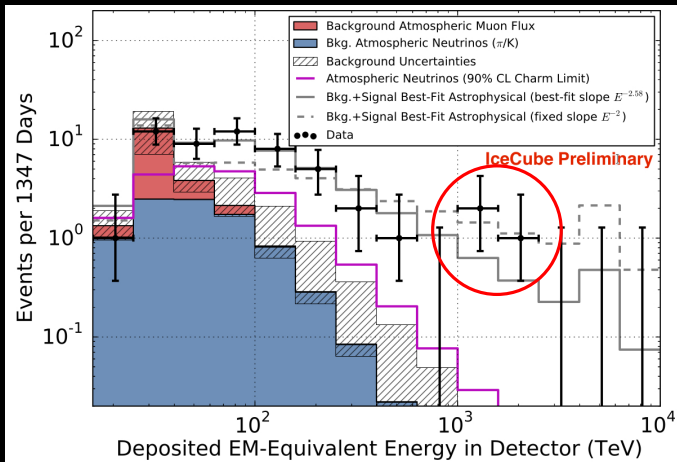




Mannheim (1993), Mannheim (1995)
Mücke (2000)



IceCube Collaboration 2013, 2013, 2014, 2015



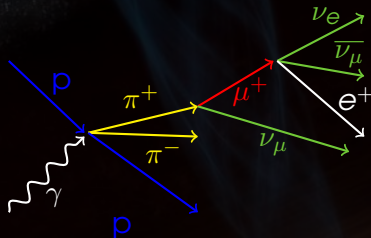
IceCube Collaboration 2013, 2013, 2014, 2015

The background of the slide is a cosmic image. The top portion shows a dark, star-filled space with a blueish-white nebula or jet of light extending downwards. The bottom portion shows a bright, glowing orange and yellow accretion disk or shock front, with a dark, circular silhouette in the center. A solid black rectangular bar is overlaid on the image, containing the text.

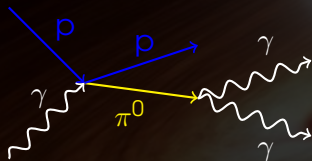
Detection of high-energy photons is not proof for
hadronic processes!

→ Upscattering of Synchrotron photons by relativistic
electrons via Inverse Compton

Pion photoproduction and neutrinos



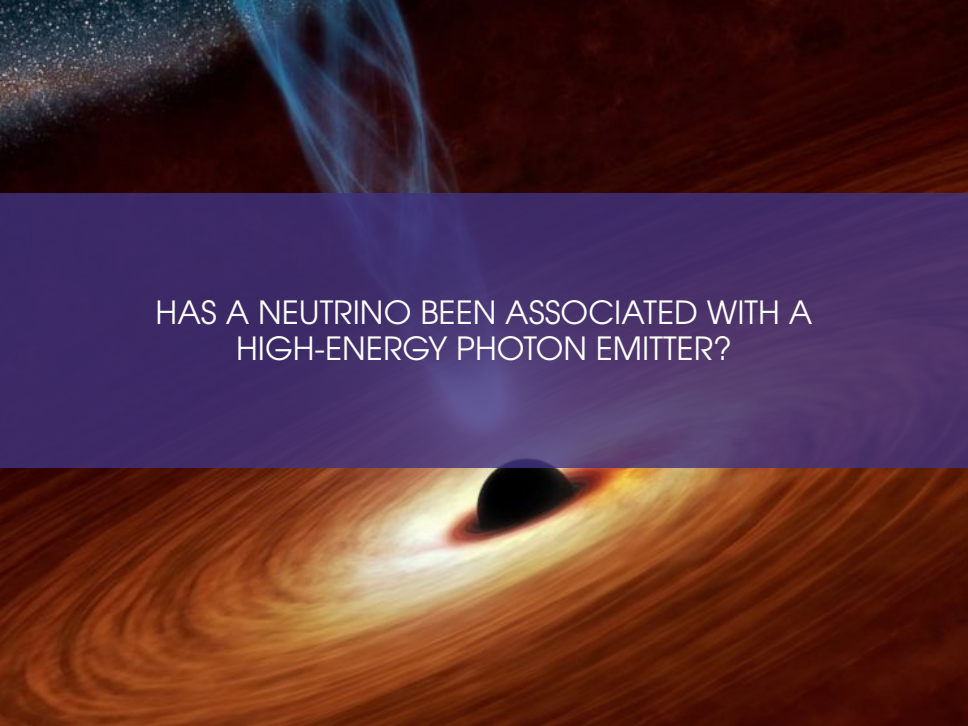
$$F_\nu = \frac{2}{3} \cdot \frac{3}{4} F_\pi = \frac{1}{2} F_\pi$$



$$F_\gamma = \frac{1}{3} F_\pi + \frac{1}{4} \cdot \frac{2}{3} F_\pi = \frac{1}{2} F_\pi$$

Mannheim 1993,1995

Mücke 2000

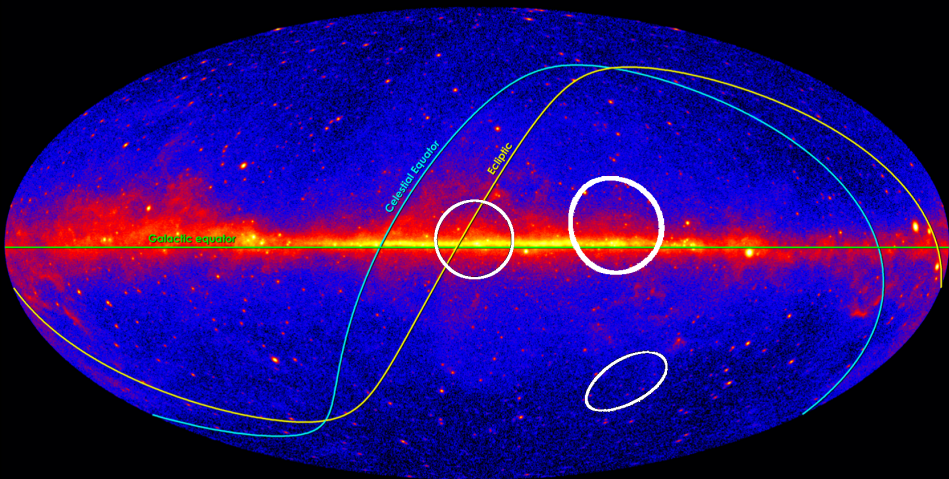
The image features a cosmic background. The top left corner shows a dark, star-filled region. A bright blue, ethereal stream of light or gas flows diagonally from the top left towards the center. A solid purple horizontal band spans the middle of the image, containing white text. Below this band, a bright, glowing yellow and orange ring, resembling an accretion disk or a lensed galaxy, is visible against a dark, swirling background.

HAS A NEUTRINO BEEN ASSOCIATED WITH A
HIGH-ENERGY PHOTON EMITTER?



MAYBE!





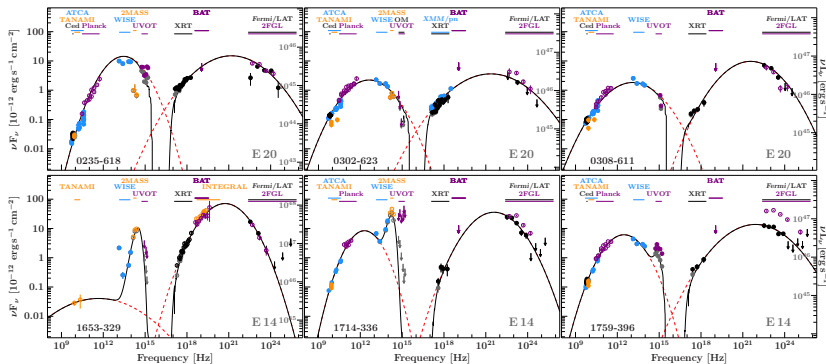
RESULTS

The image is a composite of three astronomical scenes. The top section shows a dark, star-filled space with a bright blue nebula on the left and a blue, wispy stream of gas or dust falling from the top center. A solid purple horizontal band separates this from the middle section. The middle section contains the word 'RESULTS' in white, sans-serif capital letters. The bottom section shows a black hole with a dark, spherical event horizon, surrounded by a glowing, orange-yellow accretion disk. The disk has a bright, white-hot center and is surrounded by a swirling, orange-brown gas cloud.



Blazars & AGN

- ★ Cumulative search: no significant counterparts (Glüsenkamp et al. 2016)
- ★ Contribution from Blazars & Pulsar Wind Nebulae (PWNe; Padovani et al. 2014)?
- ★ Blazars as a class capable of producing observed neutrino flux (Krauss et al. 2014);



Krauss et al. 2014

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	$(3.4^{+0.7}_{-0.7}) \times 10^{-11}$	$0.06^{+0.01}_{-0.01}$
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

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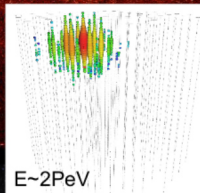
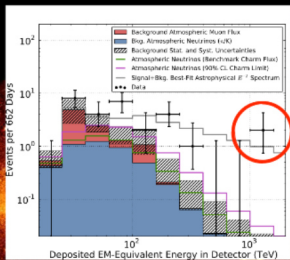
Blazars & AGN

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Blazars & AGN

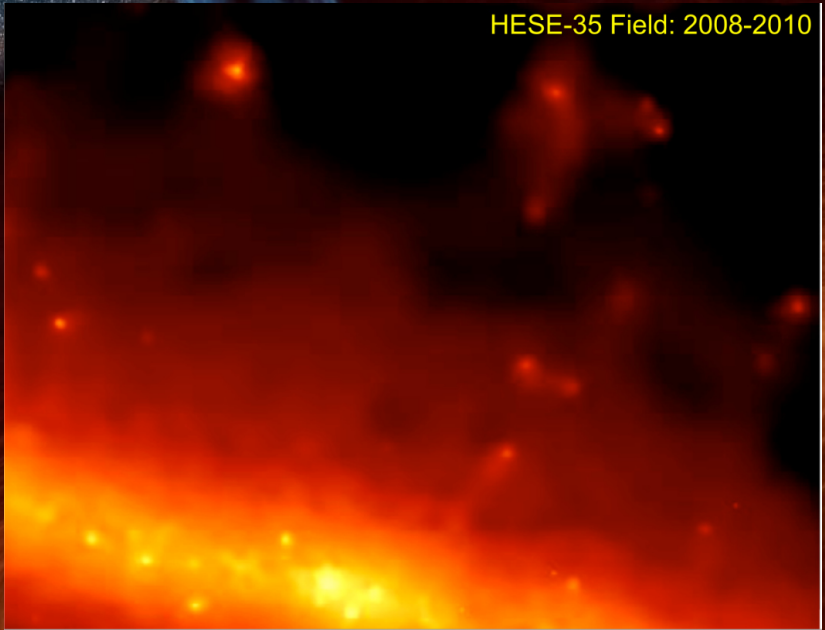
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- ★ Constraints on neutrino spectrum (ANTARES&TANAMI collaborations 2015)
- ★ Coincidence of blazar outburst and high-energy neutrino event (Kadler, Krauss et al. 2016)

High-Energy Cosmic Neutrinos

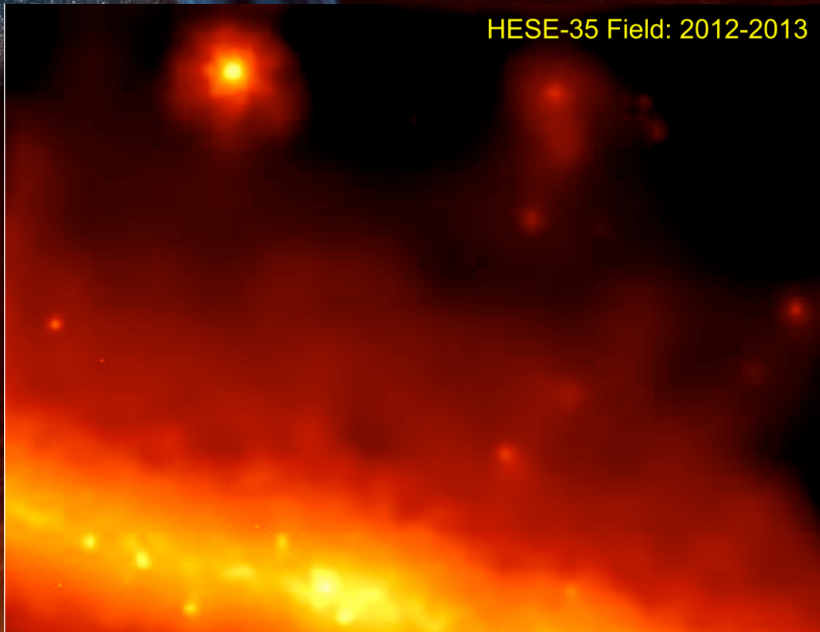


IceCube Collaboration 2013; Aartsen et al. 2014

HESE-35 Field: 2008-2010

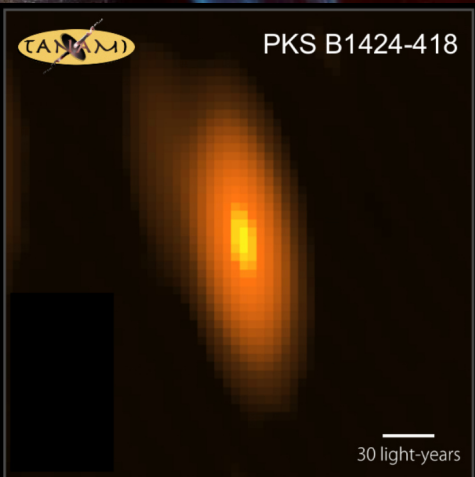


HESE-35 Field: 2012-2013





PKS B1424-418

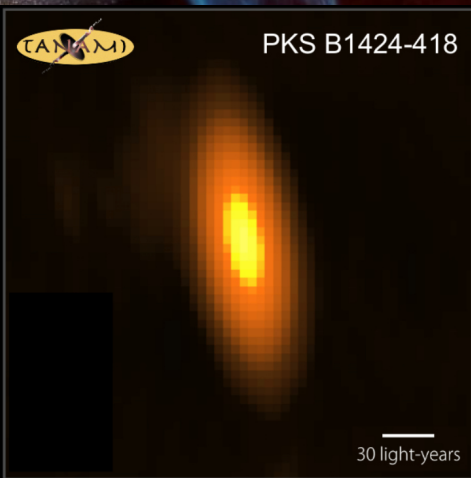


30 light-years

Nov. 13, 2011



PKS B1424-418



Sept. 16, 2012

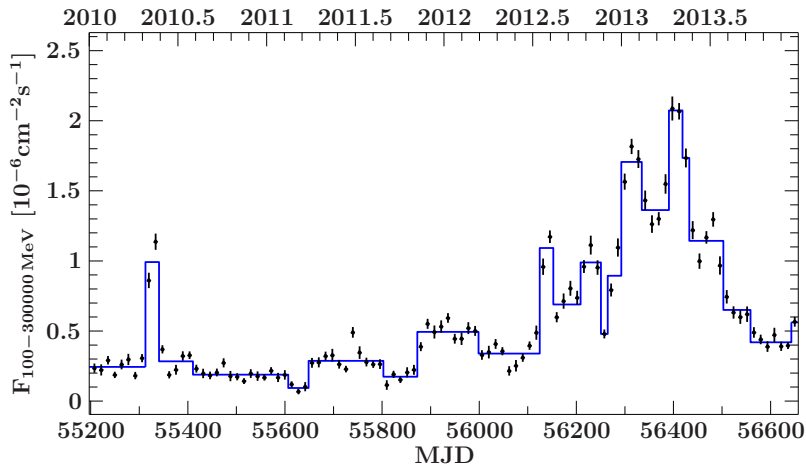


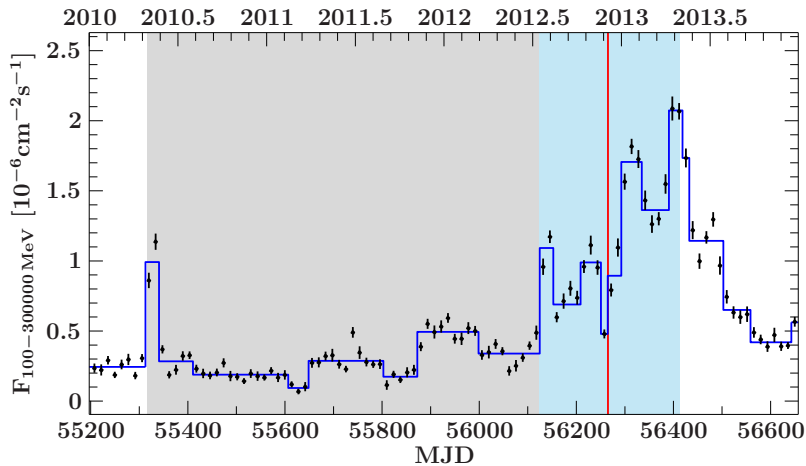
PKS B1424-418

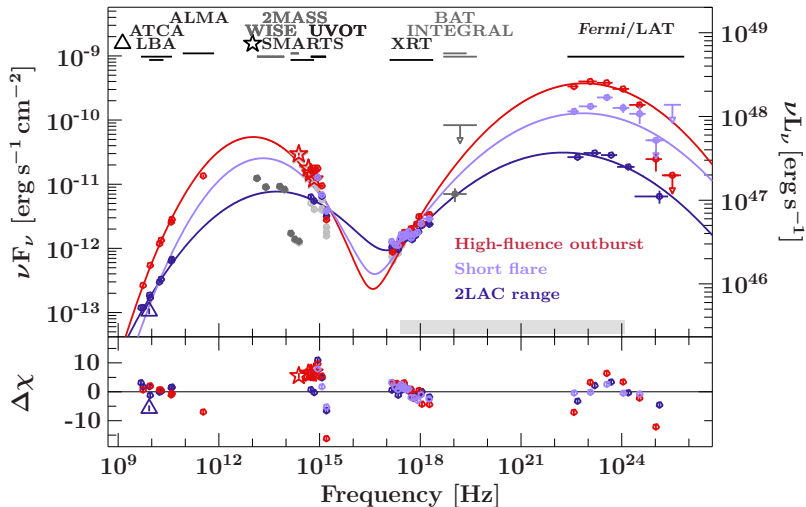


30 light-years

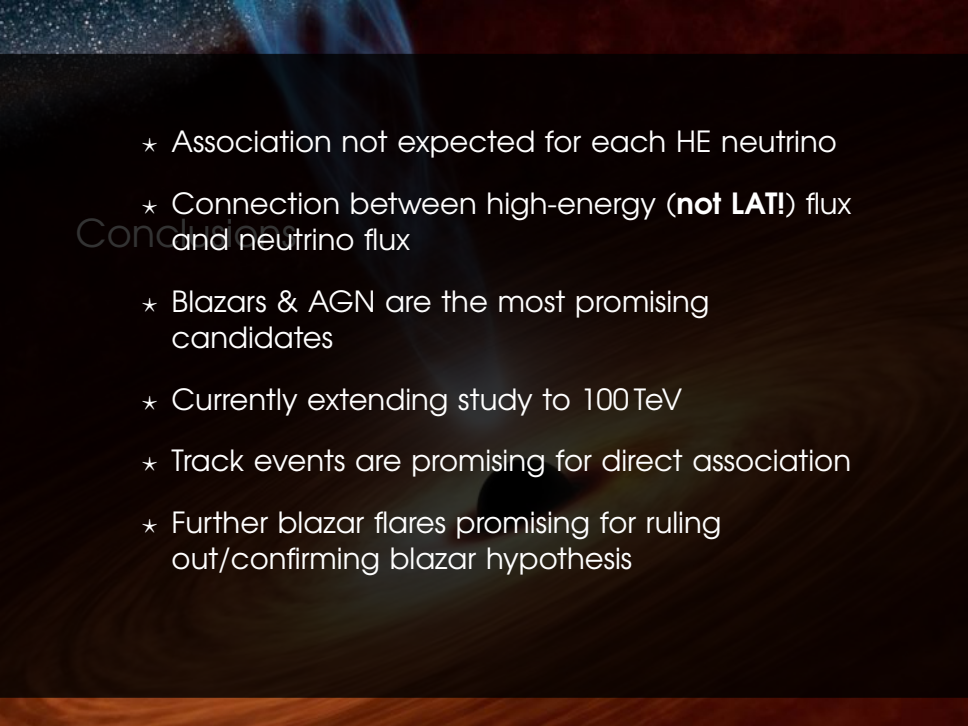
March 14, 2013







Variability as indicator for association!

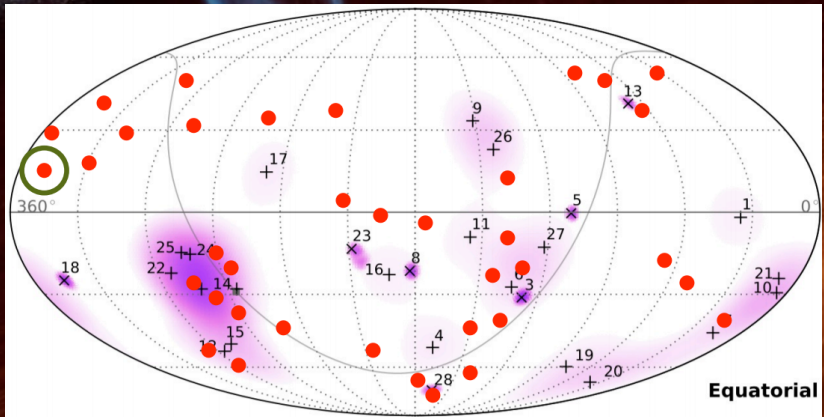
- 
- ★ Association not expected for each HE neutrino
 - ★ Connection between high-energy (**not LAT!**) flux and neutrino flux
 - ★ Blazars & AGN are the most promising candidates
 - ★ Currently extending study to 100 TeV
 - ★ Track events are promising for direct association
 - ★ Further blazar flares promising for ruling out/confirming blazar hypothesis



BACKUP



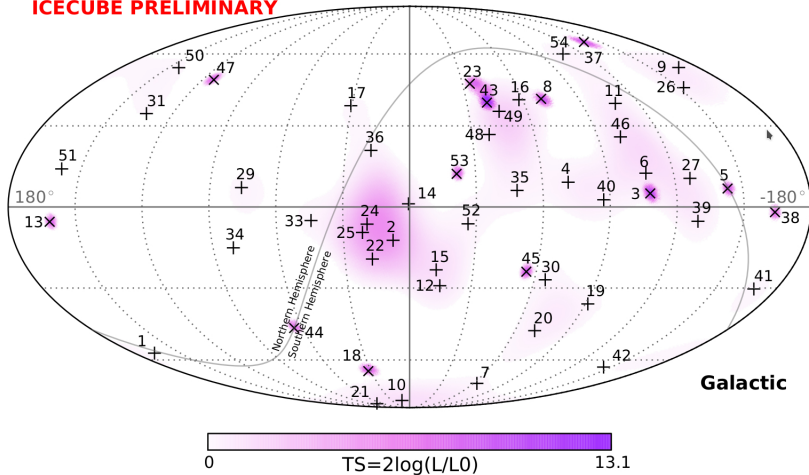
37 LAT photons



(after IceCube Collaboration 2014)

→ Only 1 photon associated with a resolved source, a blazar

ICECUBE PRELIMINARY



(IceCube Collaboration 2014, 2015)

→ Extragalactic origin consistent with isotropic distribution