Multimessenger studies of blazars

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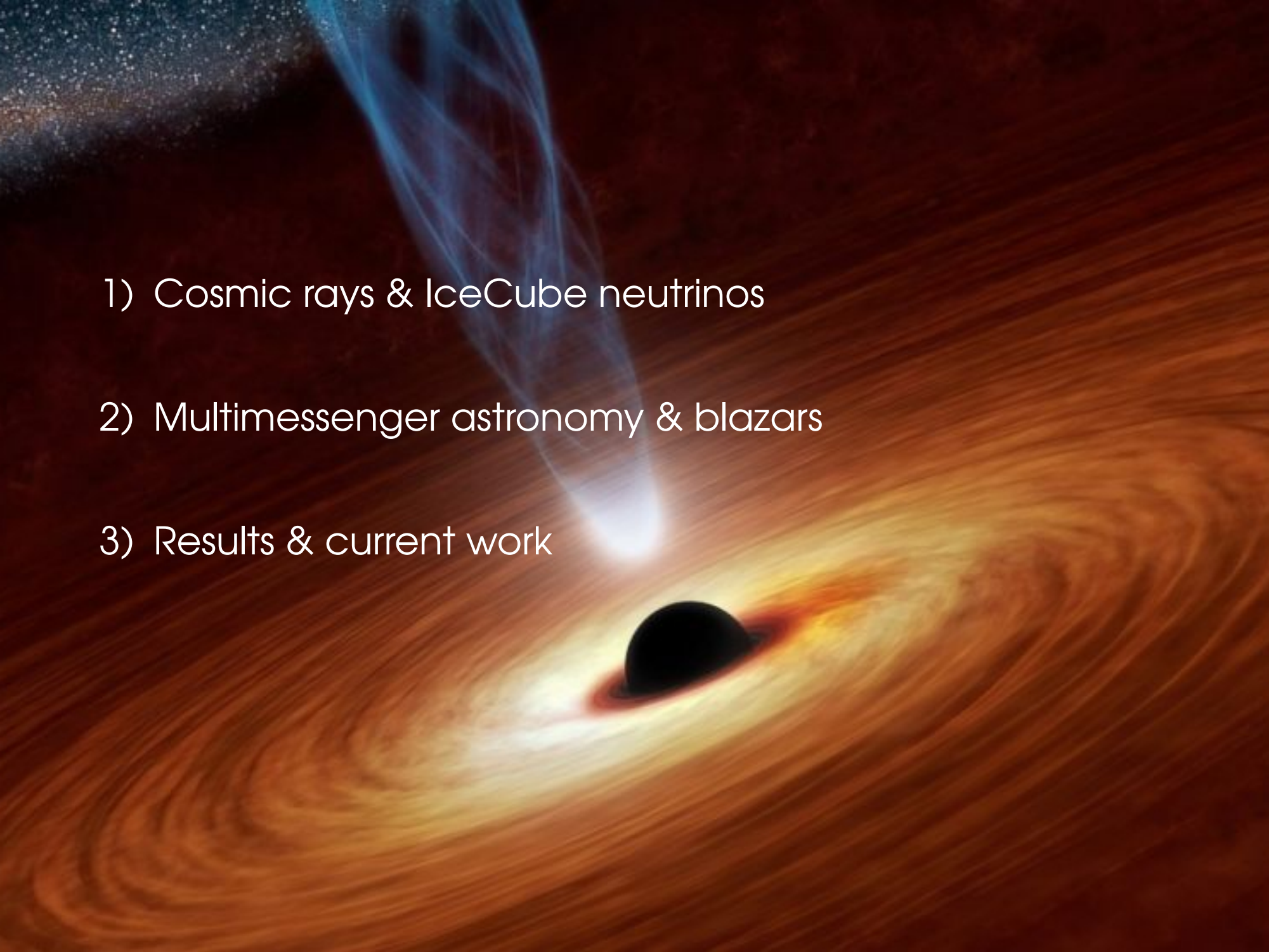
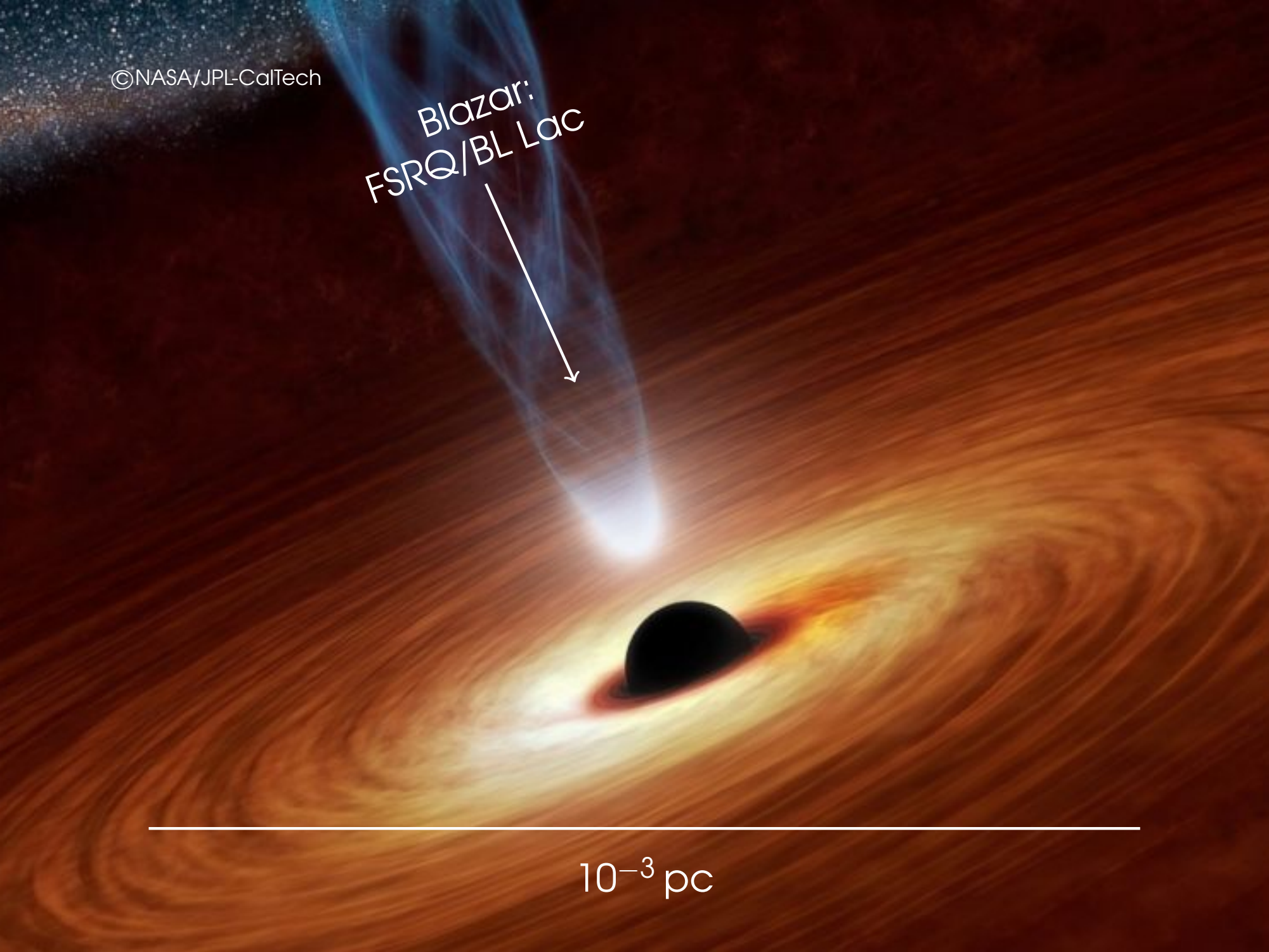
GRAPPA
GRavitation AstroParticle Physics Amsterdam

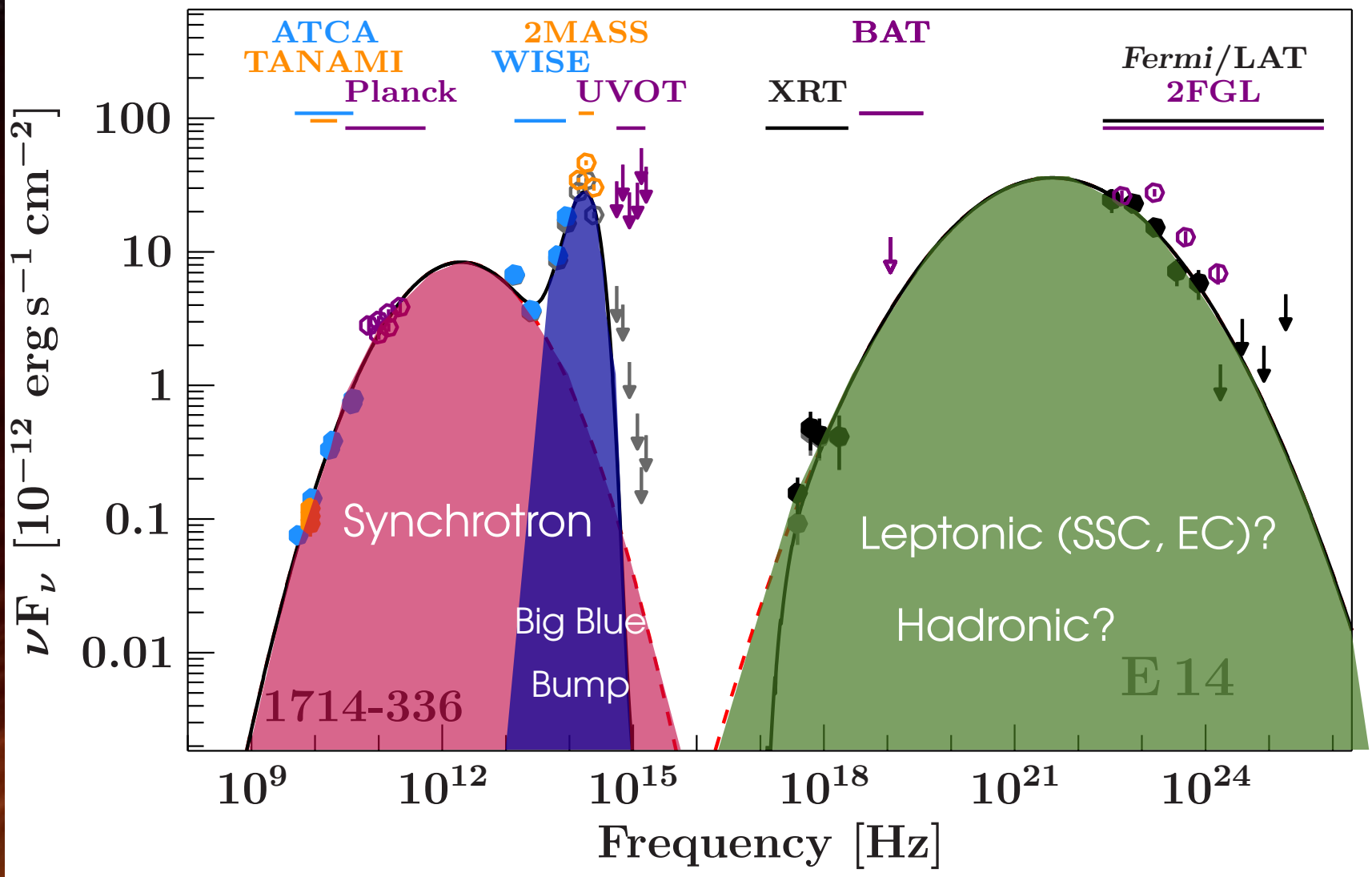
TANAMI

Fermi
Gamma-ray
Space Telescope

@FeKrauss

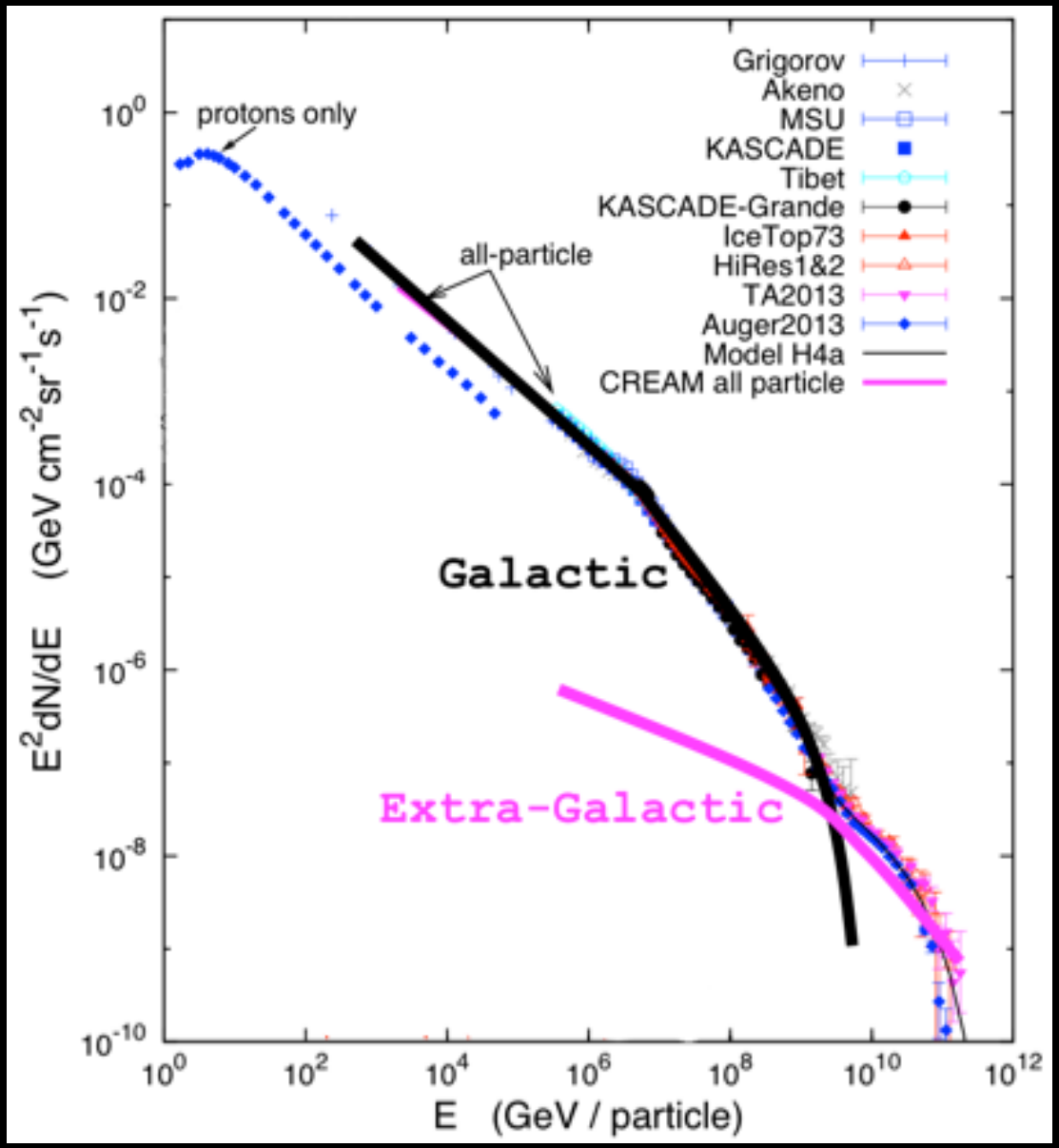

1) Cosmic rays & IceCube neutrinos
2) Multimessenger astronomy & blazars
3) Results & current work


©NASA/JPL-CalTech
Blazar:
FSRQ/BL Lac
10^{-3} pc

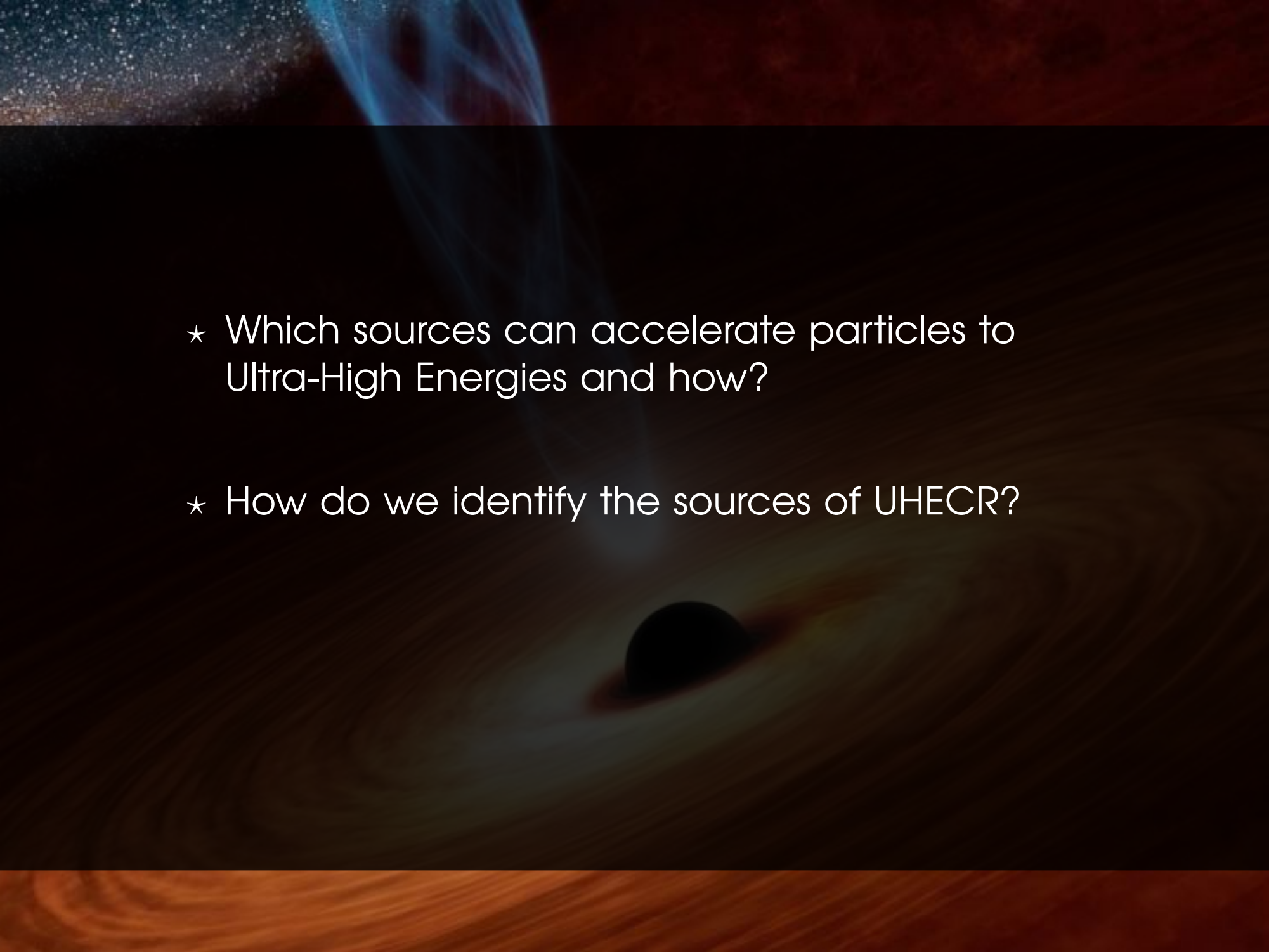


Krauß F., Kadler M., et al., A&A, 2014, 556, L7

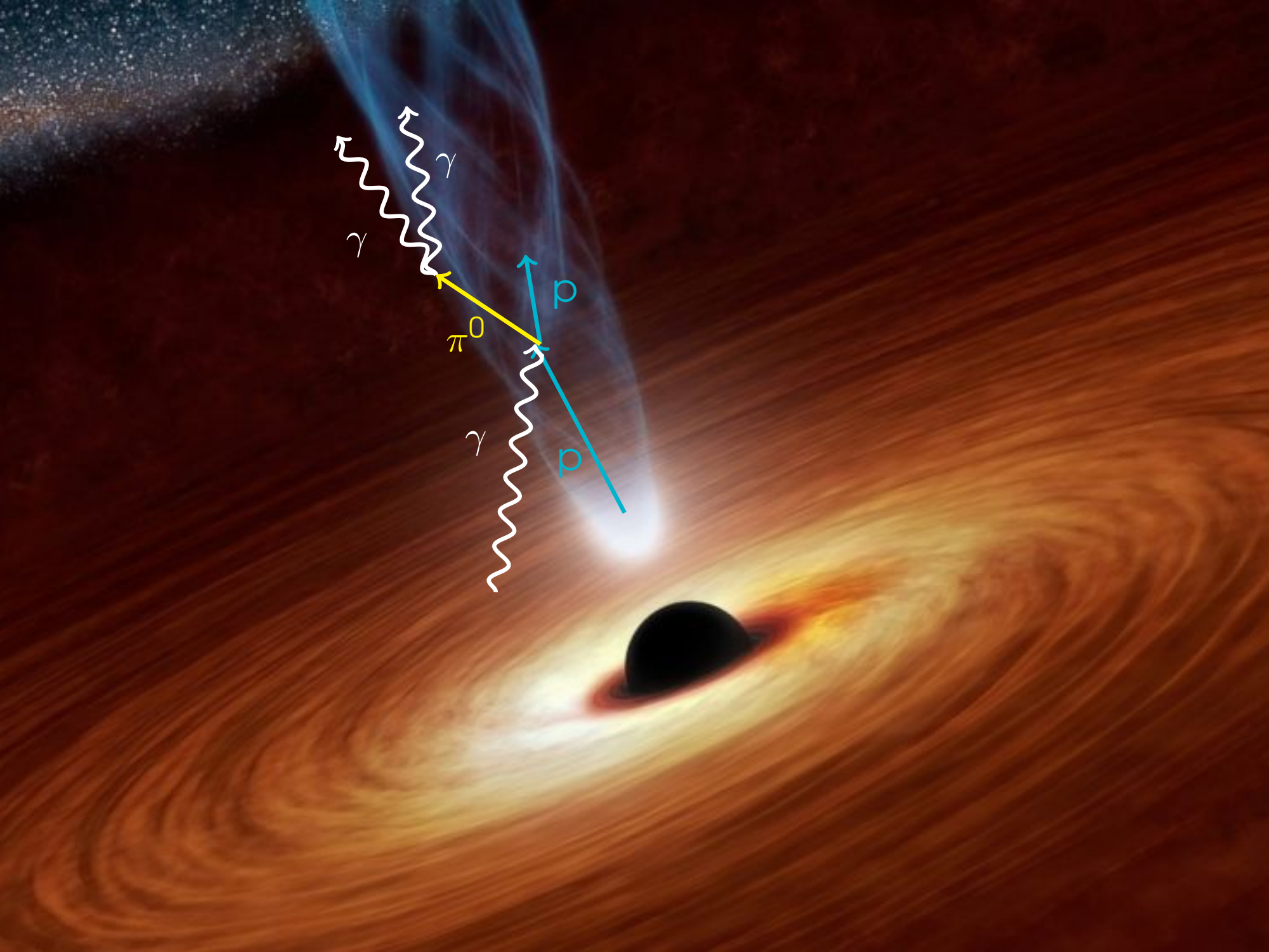
The cosmic ray spectrum

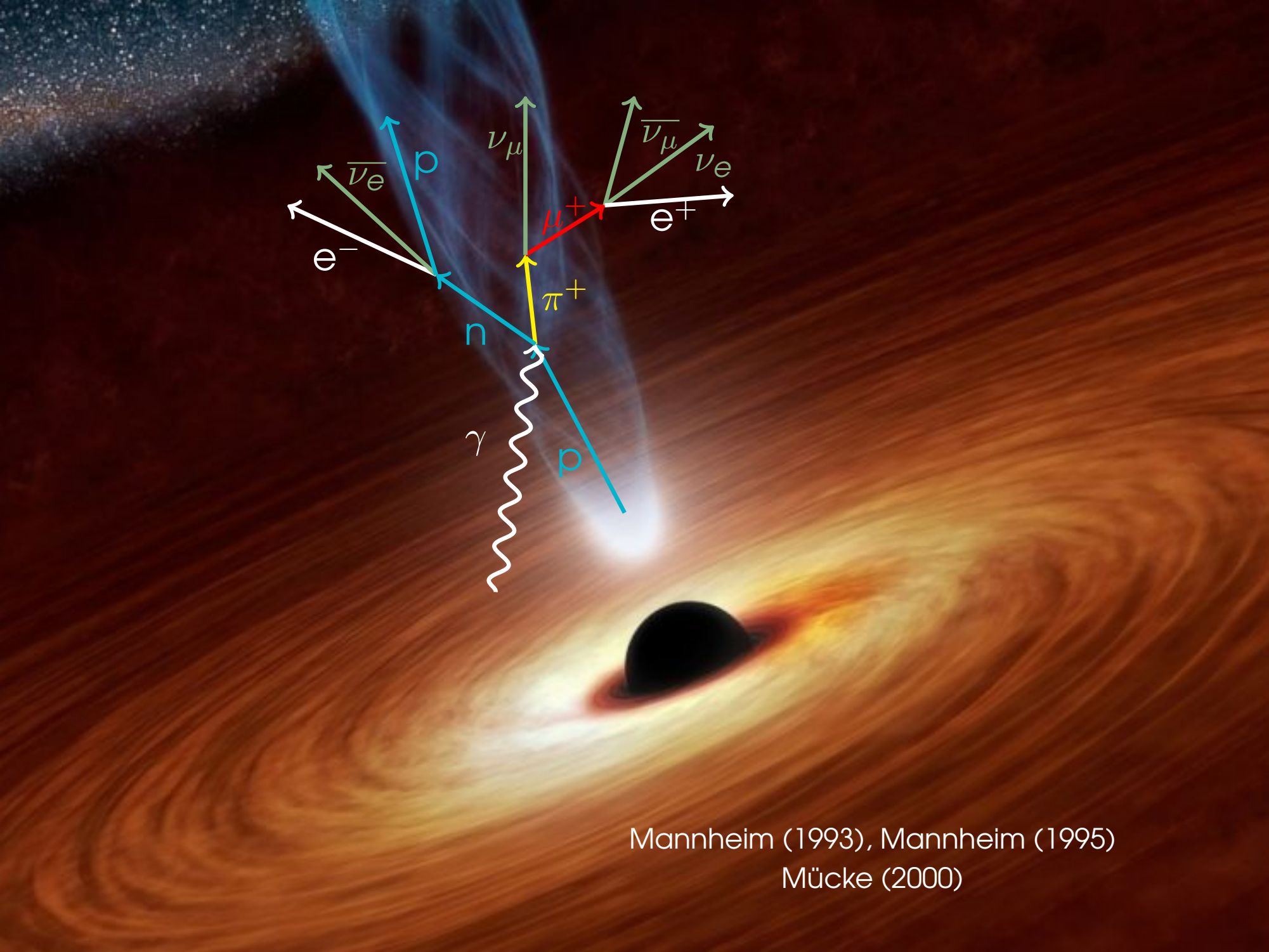


after Hillas 2006

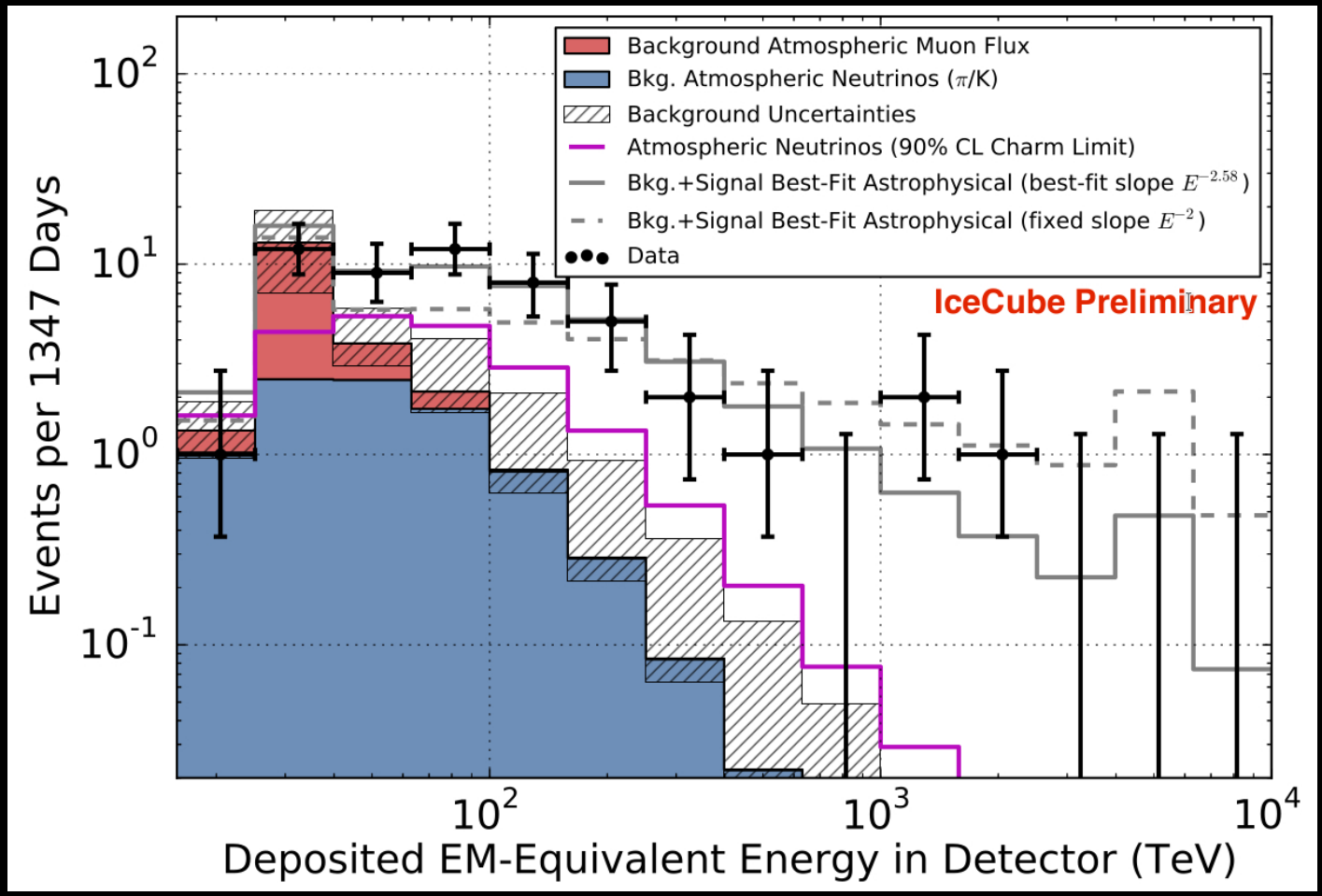


- ⋆ Which sources can accelerate particles to Ultra-High Energies and how?
- ⋆ How do we identify the sources of UHECR?

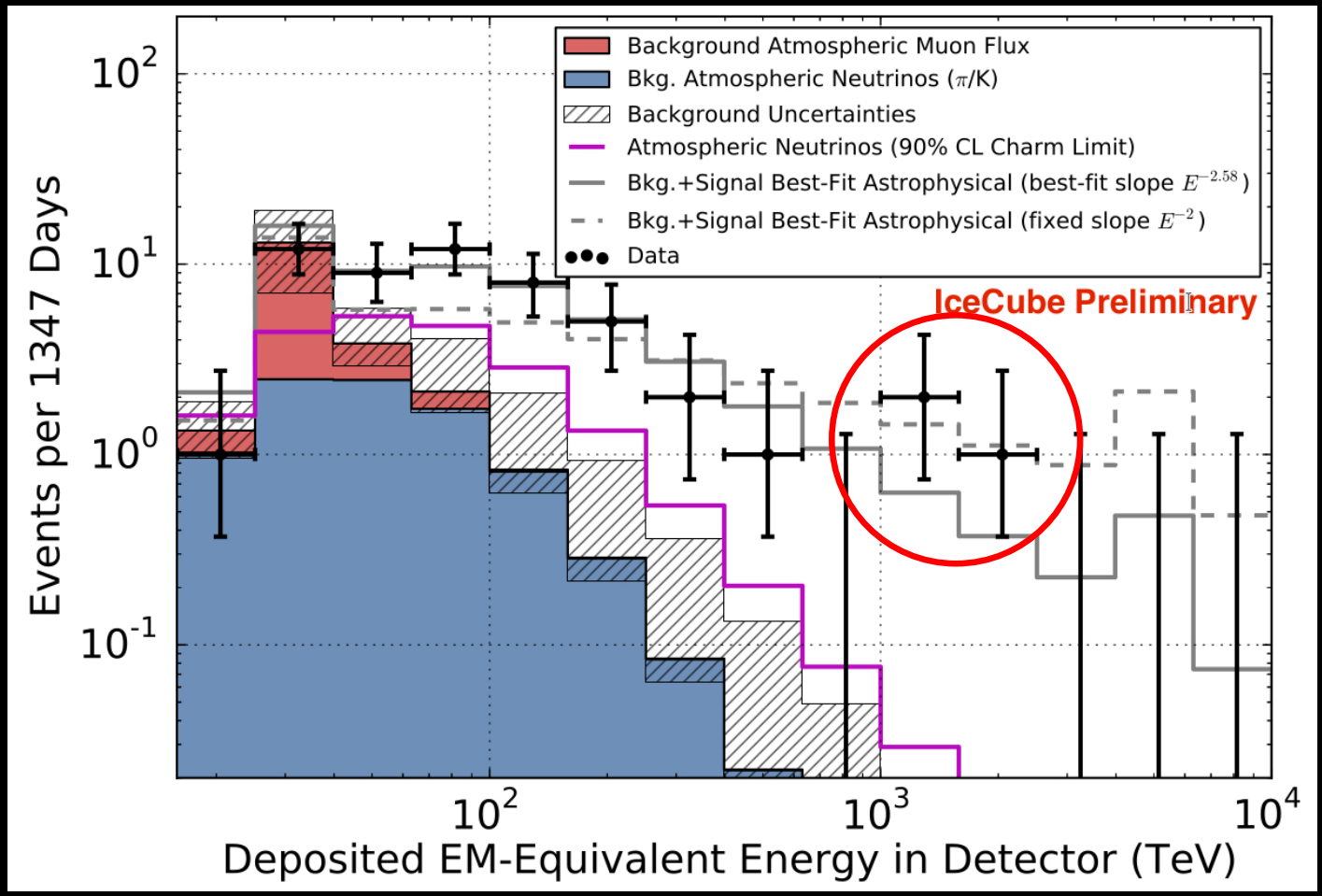

γ
γ
p
π0
γ
p



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



IceCube Collaboration 2013, 2013, 2014, 2015

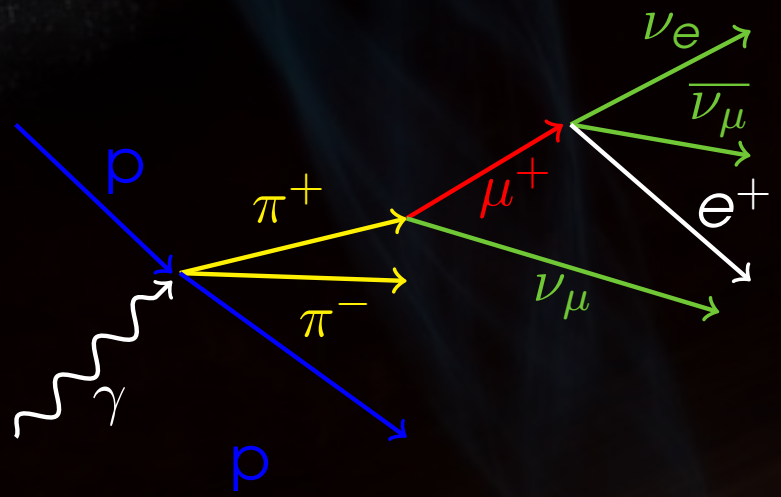


IceCube Collaboration 2013, 2013, 2014, 2015

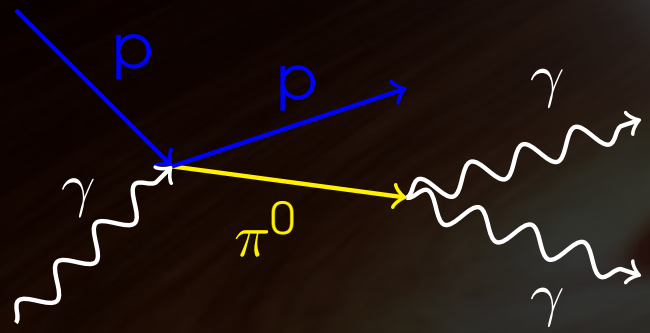
Detection of high-energy photons is not proof for hadronic processes!

$\rightarrow$ Upscattering of Synchrotron photons by relativistic electrons via Inverse Compton

Pion photoproduction and neutrinos



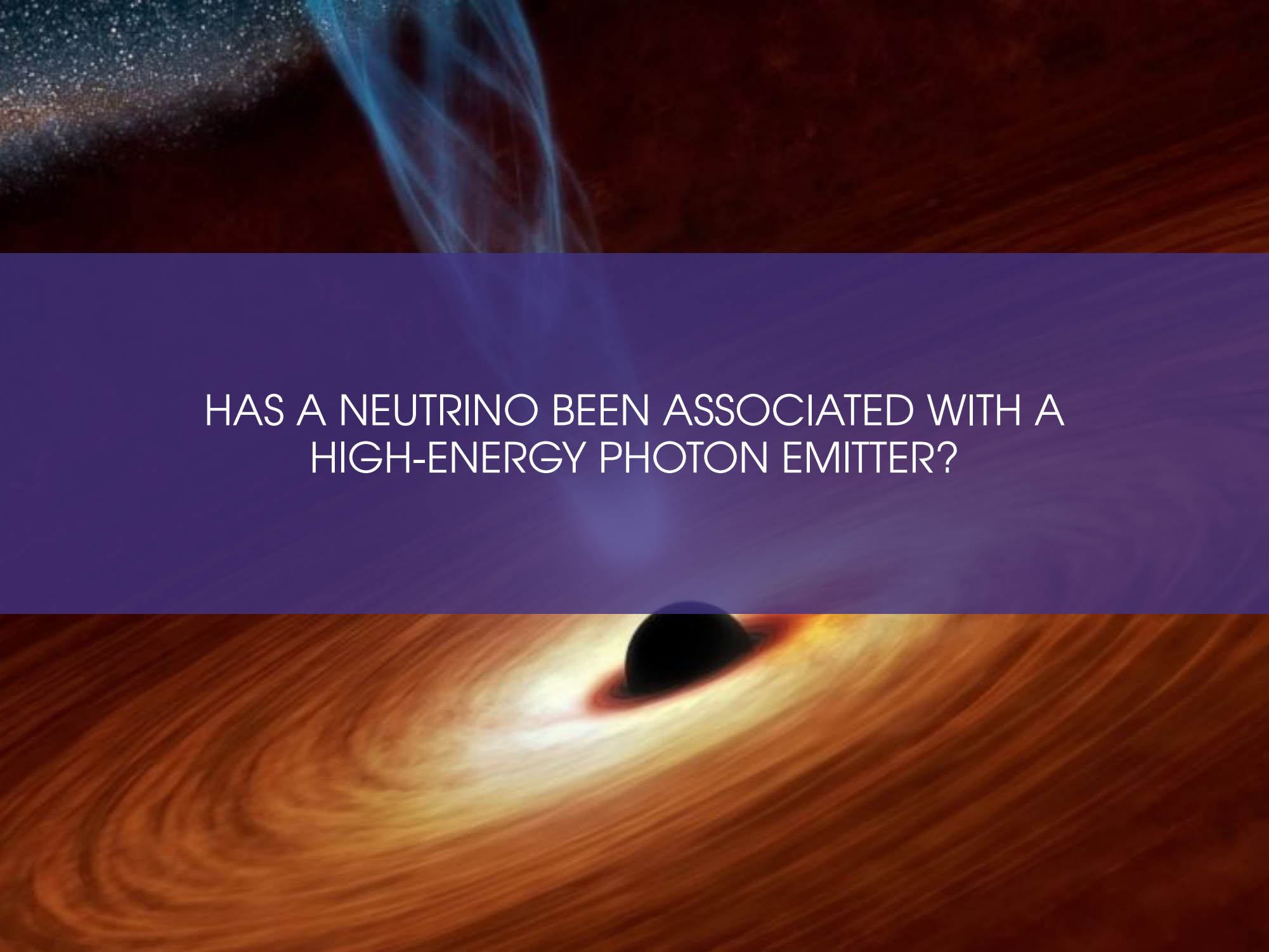
$$F_\nu = \frac{2}{3} \cdot \frac{3}{4} F_\pi = \frac{1}{2} F_\pi$$



Mannheim 1993,1995

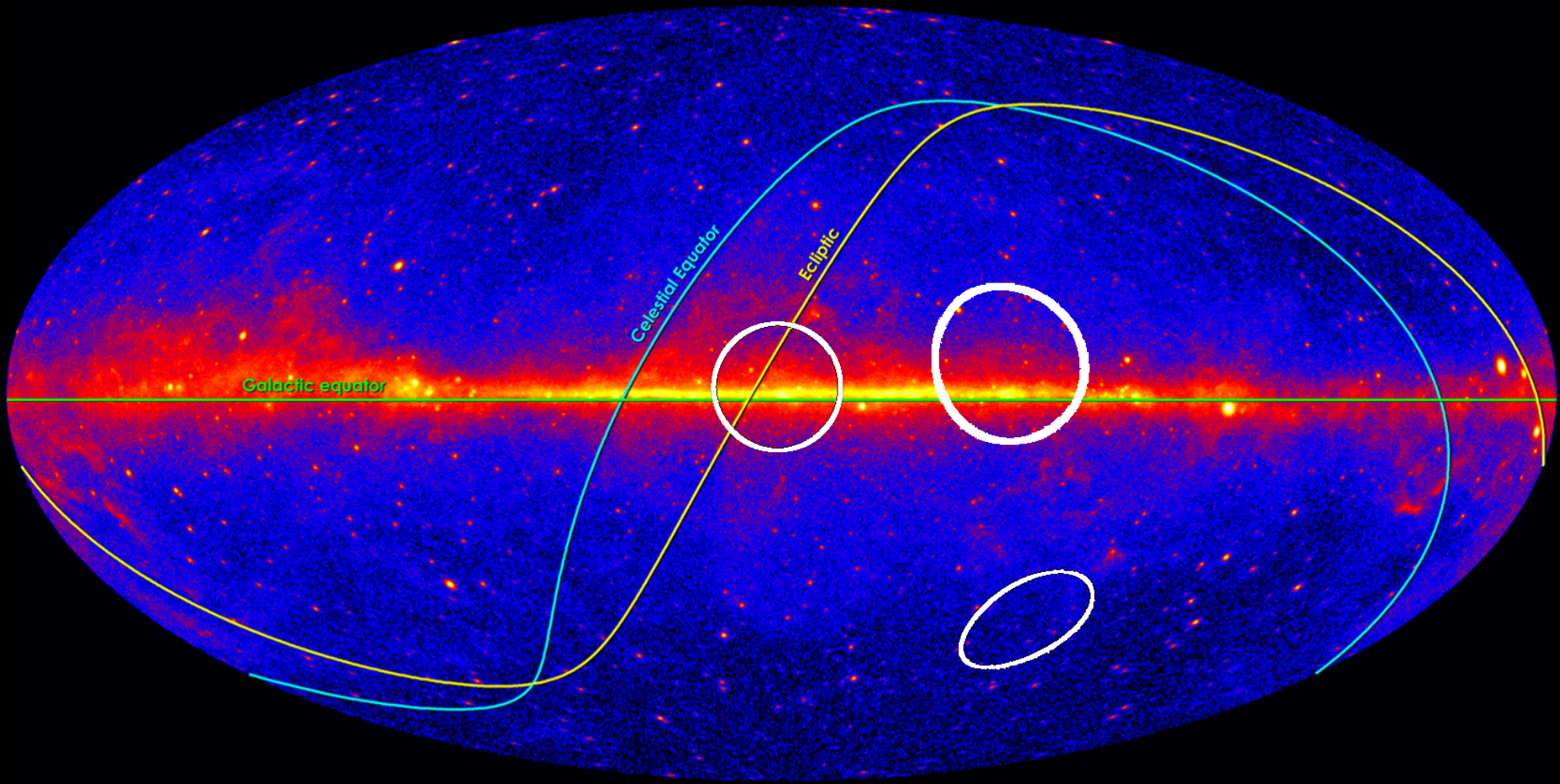
Mücke 2000

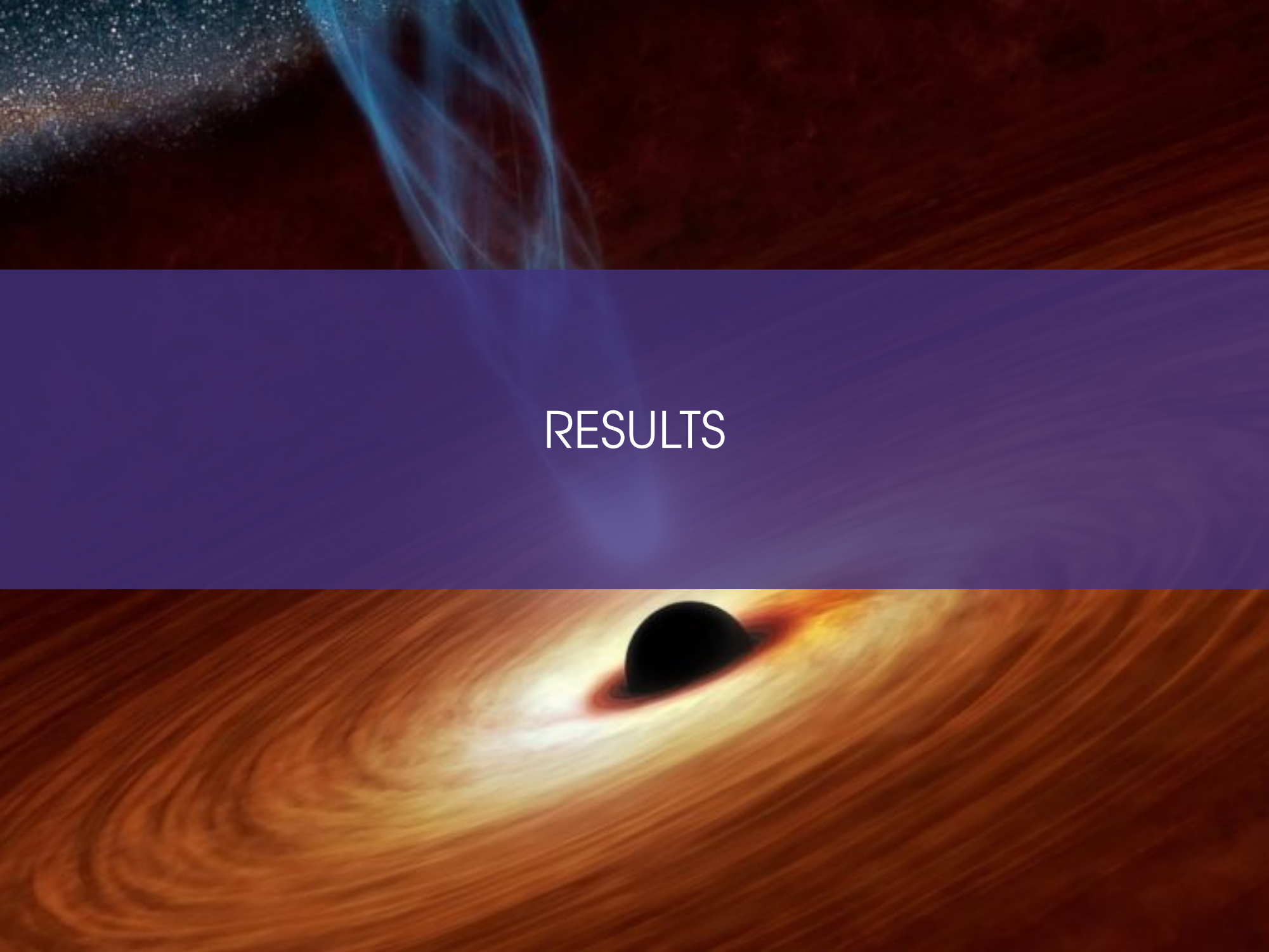
$$F_\gamma = \frac{1}{3} F_\pi + \frac{1}{4} \cdot \frac{2}{3} F_\pi = \frac{1}{2} F_\pi$$



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


MAYBE!

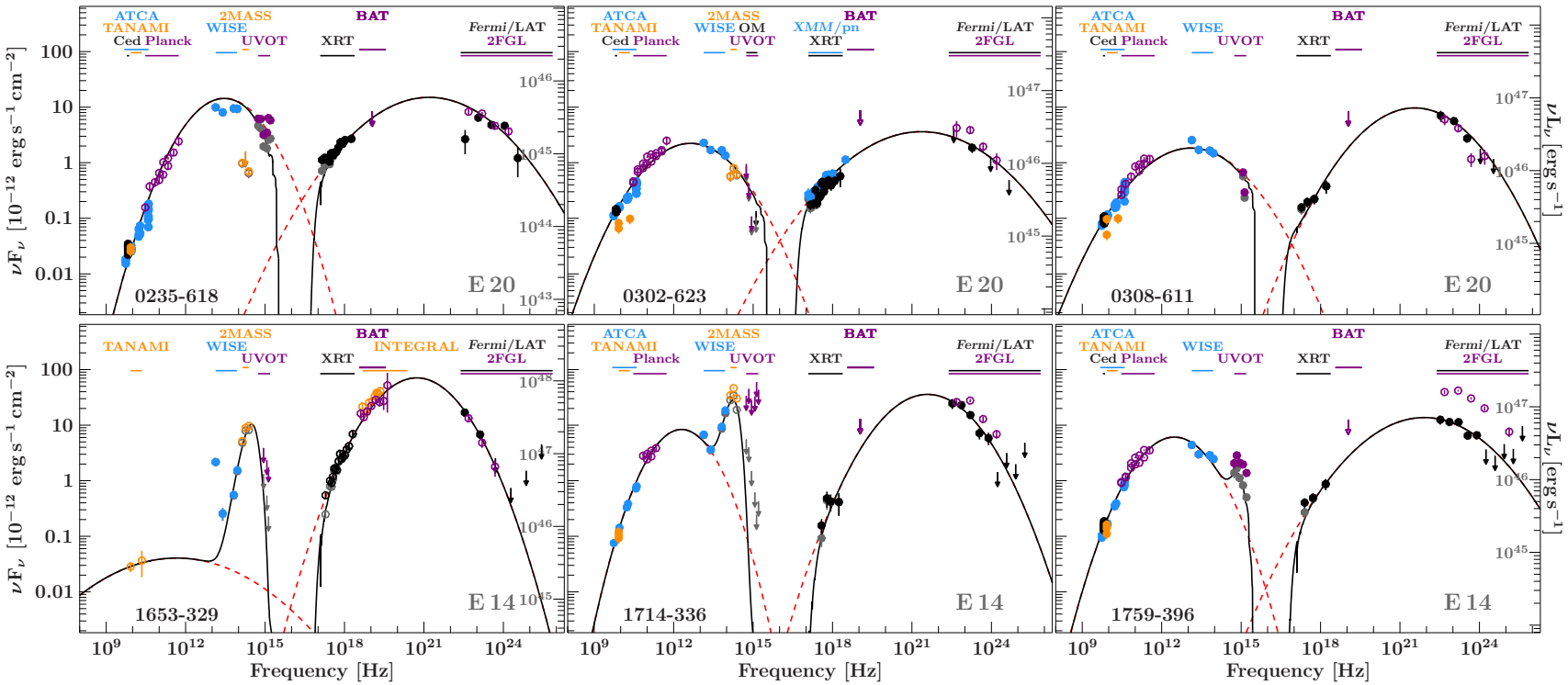

Celestial Equator
Ecliptic
Galactic equator



RESULTS

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	$F_\gamma(\mathrm{erg\,cm^{-2}\,s^{-1}})$	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

Krauss et al. 2014

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- ⋆ Constraints on neutrino spectrum (ANTARES&TANAMI collaborations 2015)

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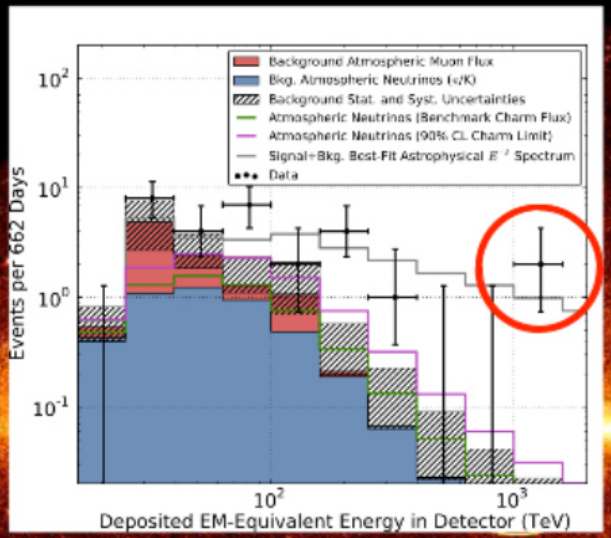
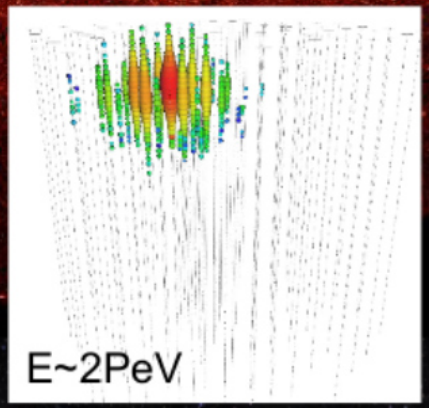
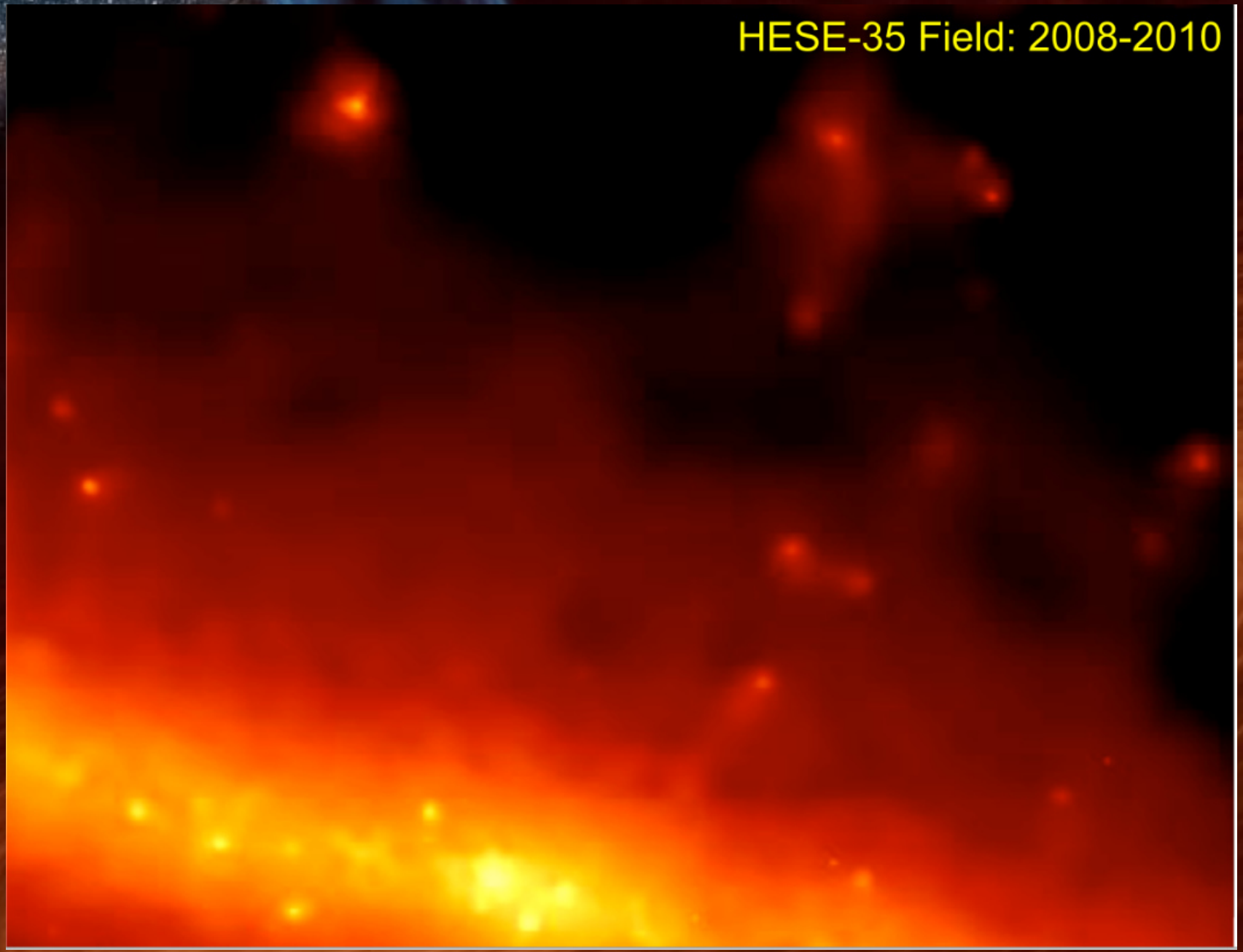
- ⋆ Constraints on neutrino spectrum (ANTARES&TANAMI collaborations 2015)
- ⋆ Coincidence of blazar outburst and high-energy neutrino event (Kadler, Krauss et al. 2016)

High-Energy Cosmic Neutrinos

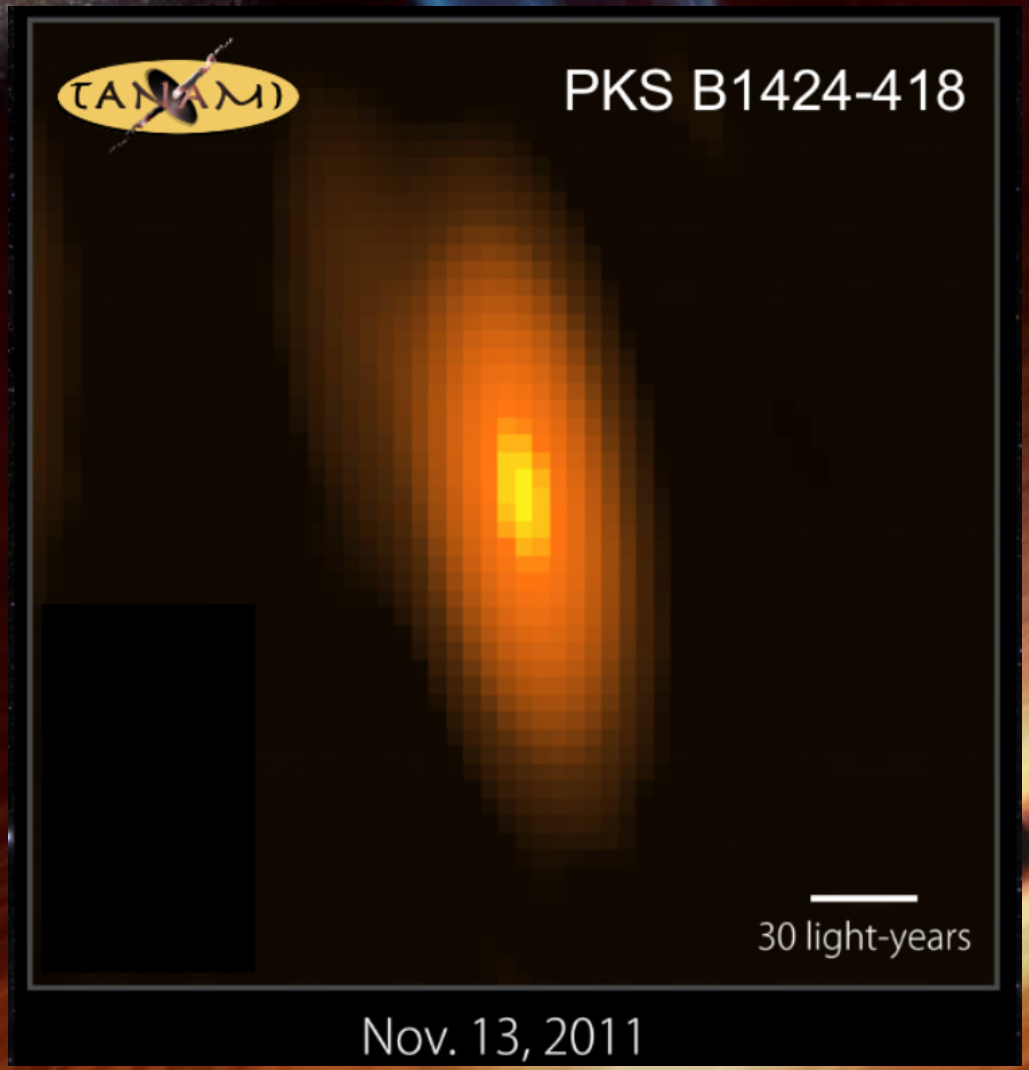


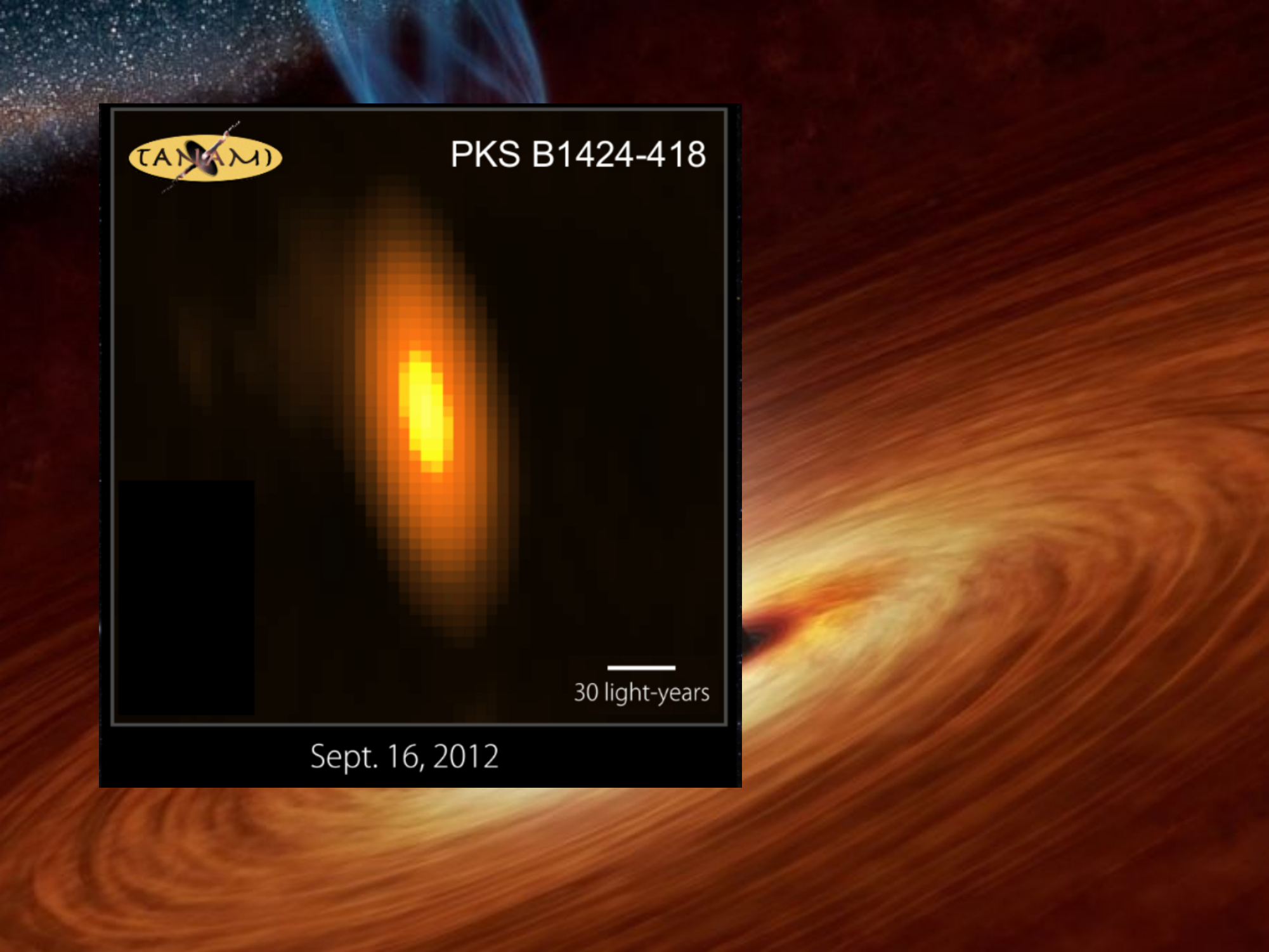


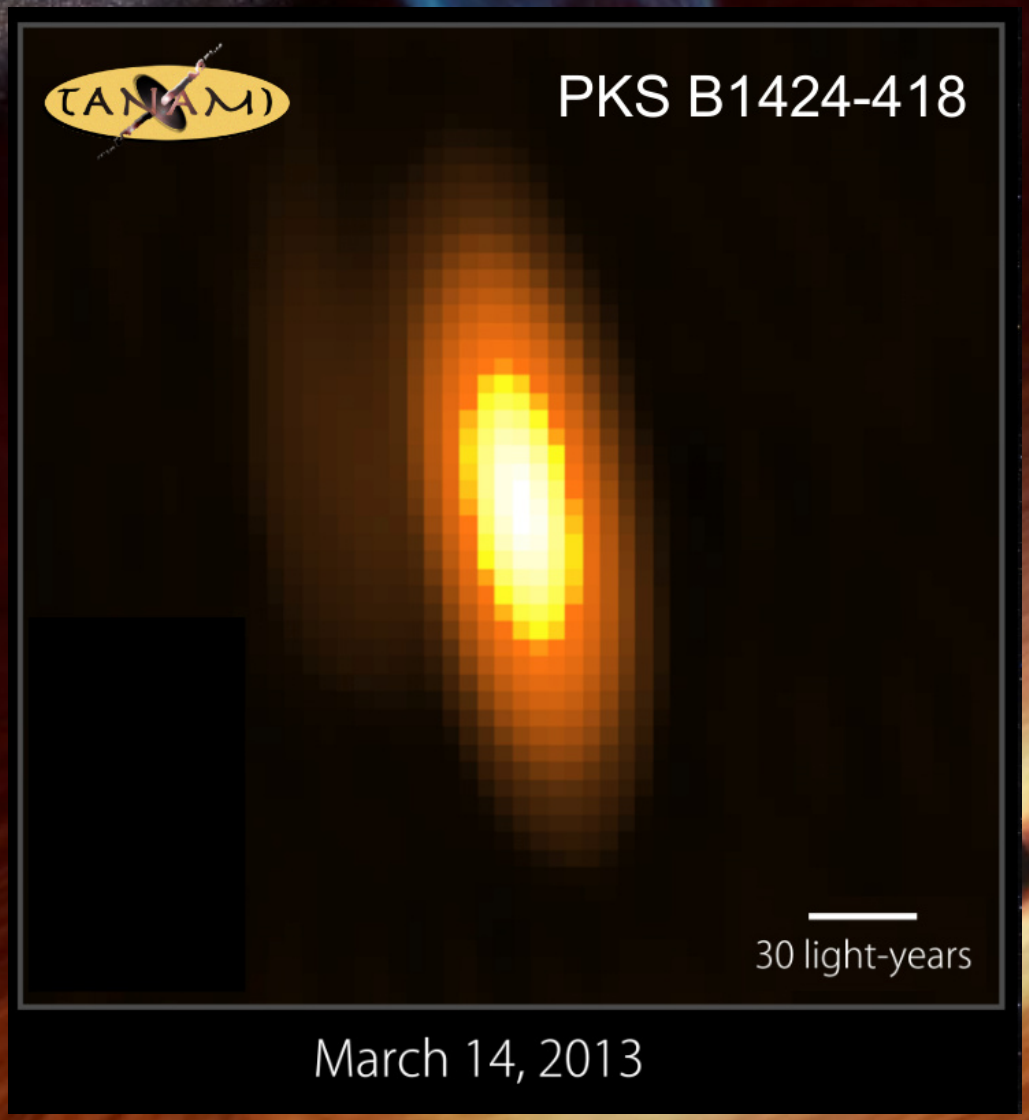
IceCube Collaboration 2013; Aartsen et al. 2014

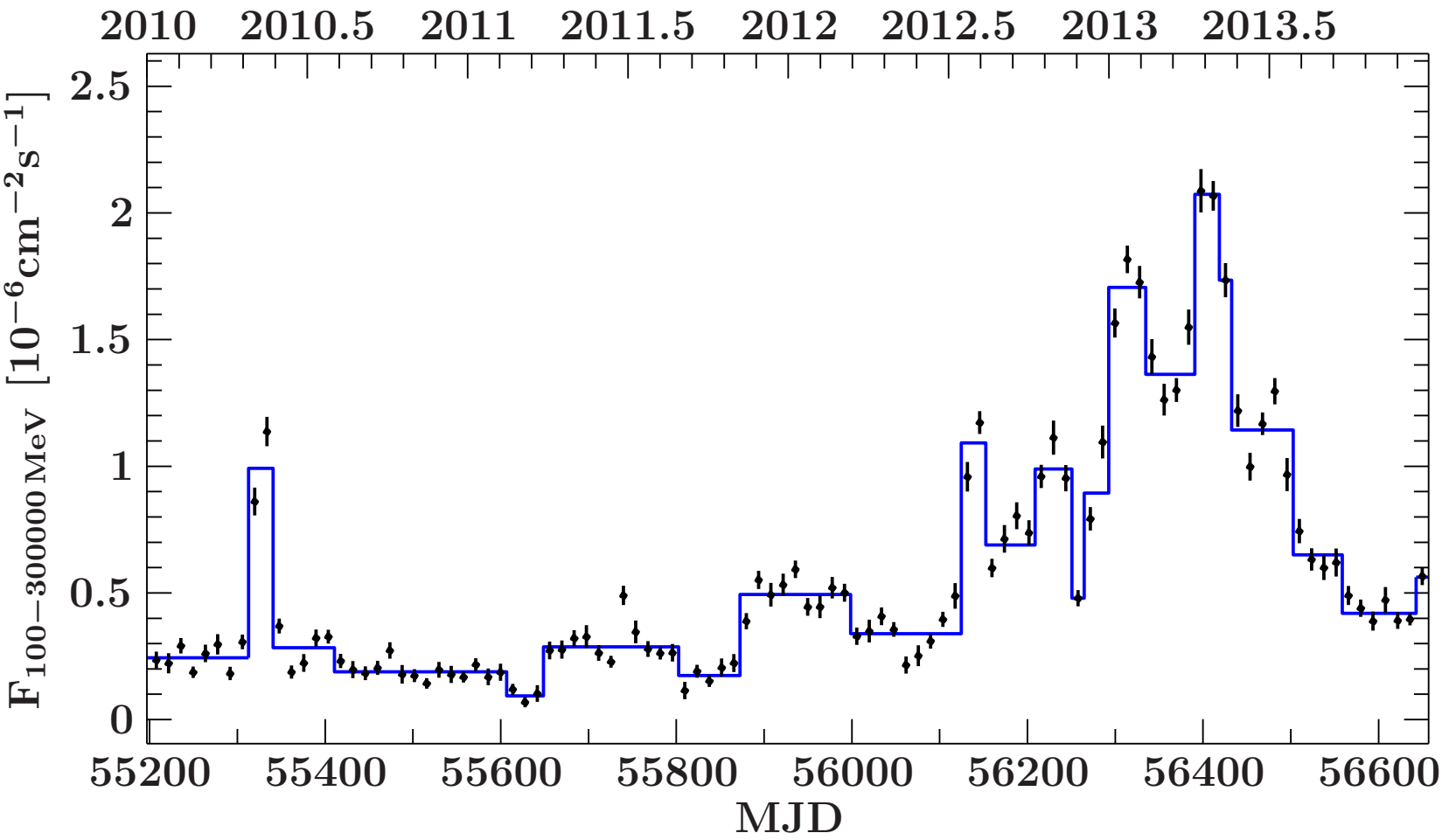

HESE-35 Field: 2008-2010

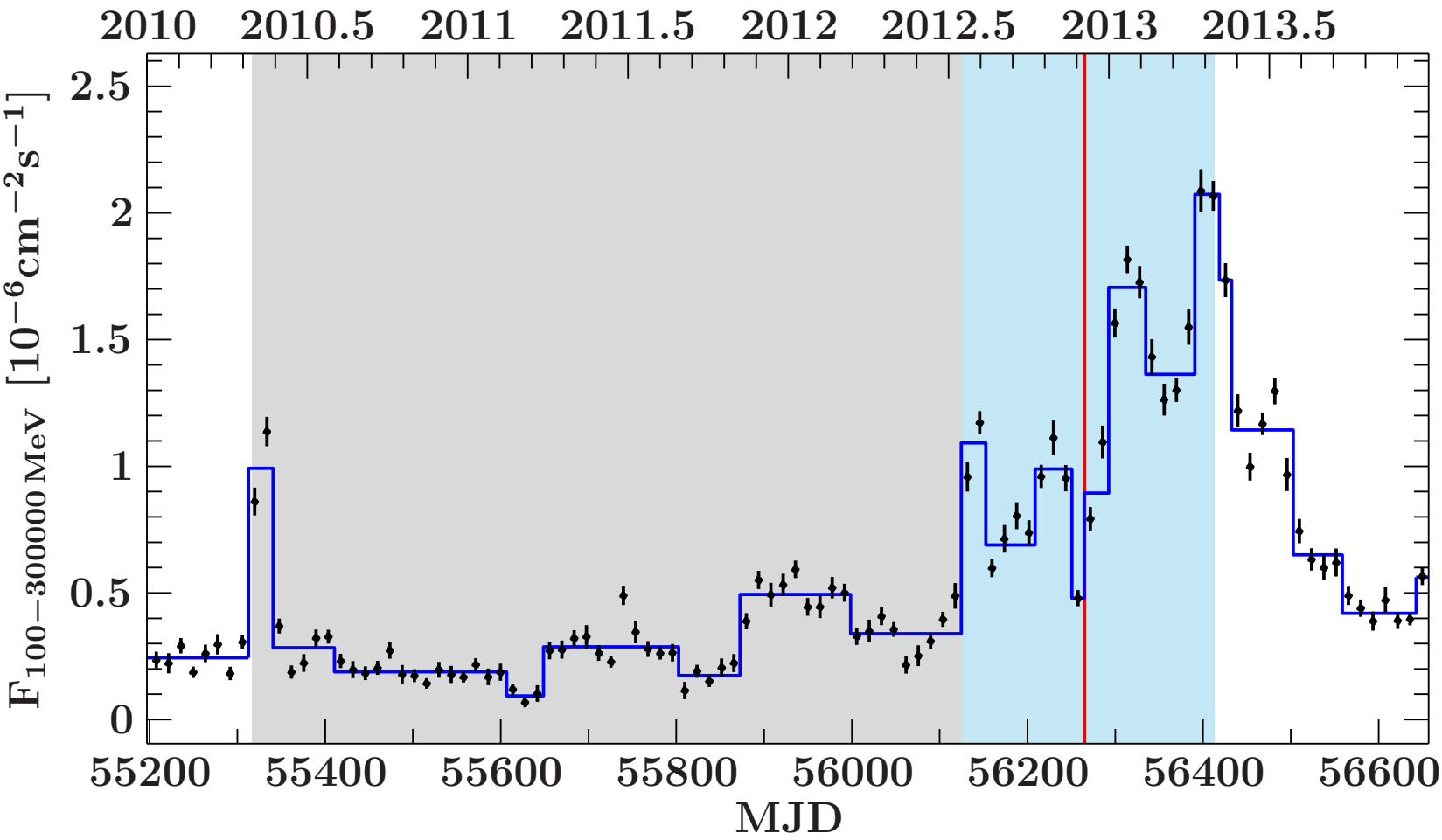

HESE-35 Field: 2012-2013

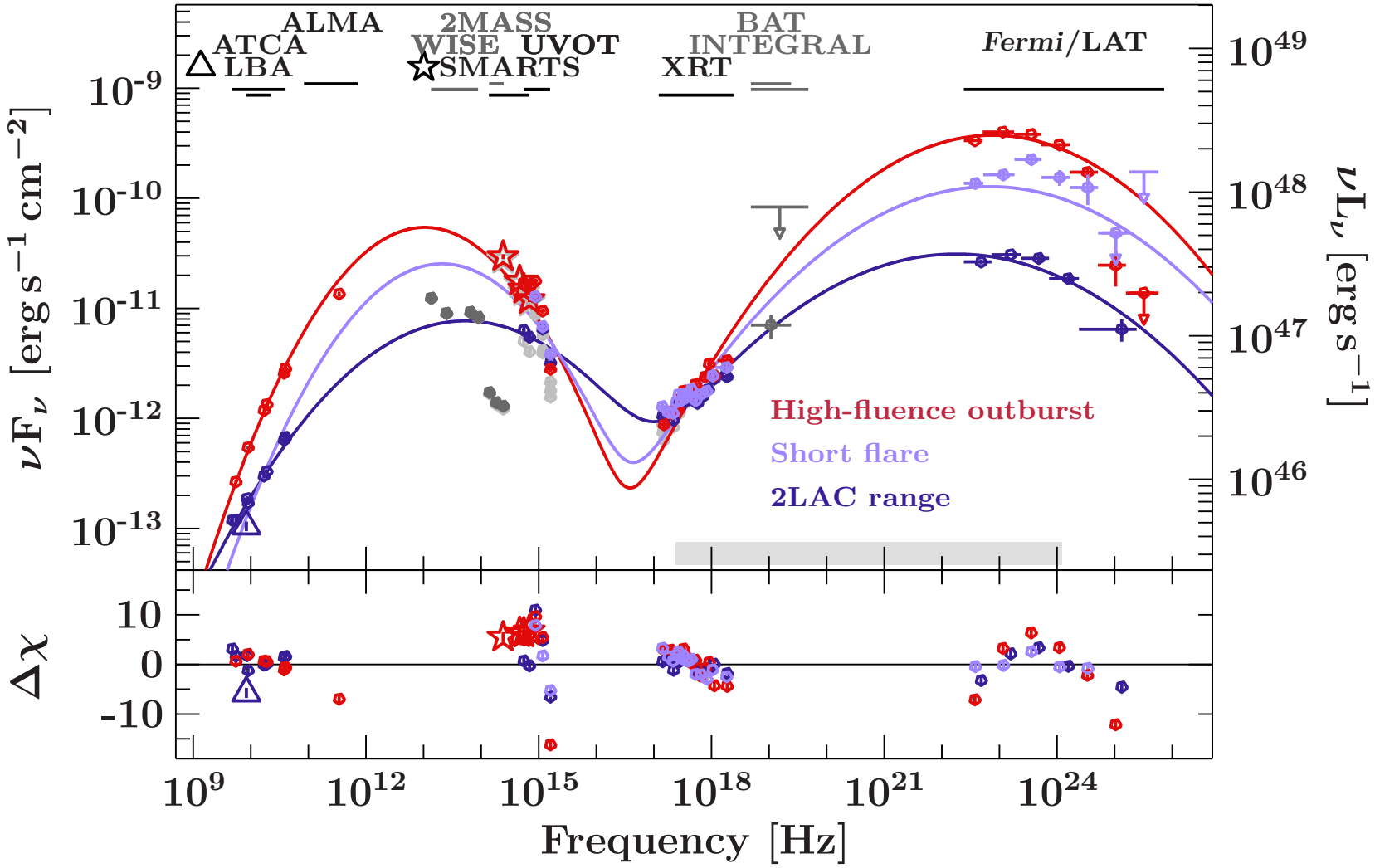

TANAMI
PKS B1424-418
30 light-years
Nov. 13, 2011


PKS B1424-418
30 light-years
Sept. 16, 2012


TANAMI
PKS B1424-418
30 light-years
March 14, 2013


2010
2010.5
2011
2011.5
2012
2012.5
2013
2013.5
2.5
2
1.5
1
0.5
0
$F_{100-300000\,\mathrm{MeV}}$ $[10^{-6}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$
55200
55400
55600
55800
56000
56200
56400
56600
MJD


2010
2010.5
2011
2011.5
2012
2012.5
2013
2013.5
$F_{100-300000\,\mathrm{MeV}}$ $[10^{-6}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$
2.5
2
1.5
1
0.5
0
55200
55400
55600
55800
56000
56200
56400
56600
MJD



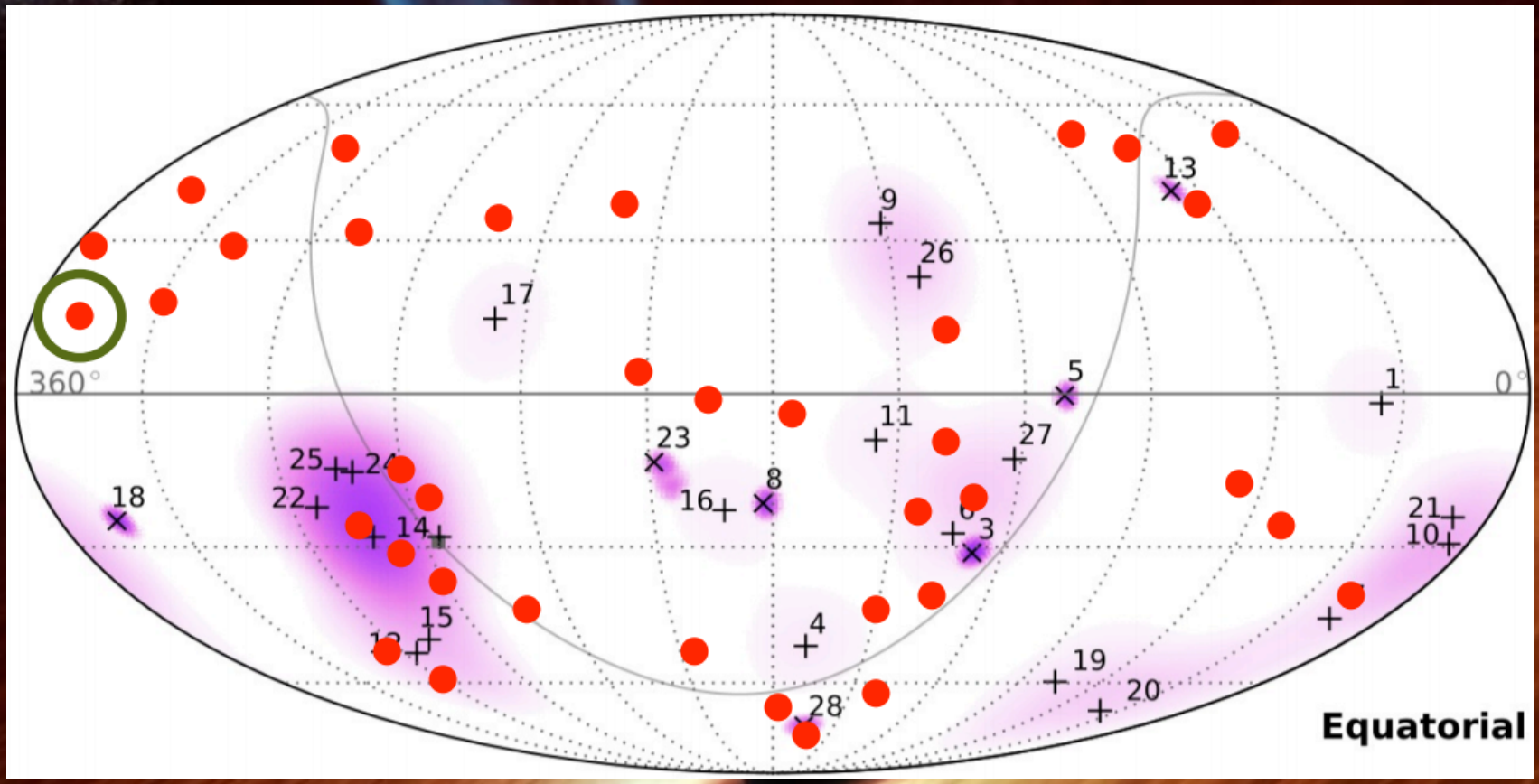
Variability as indicator for association!

Conclusions

- ⋆ 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

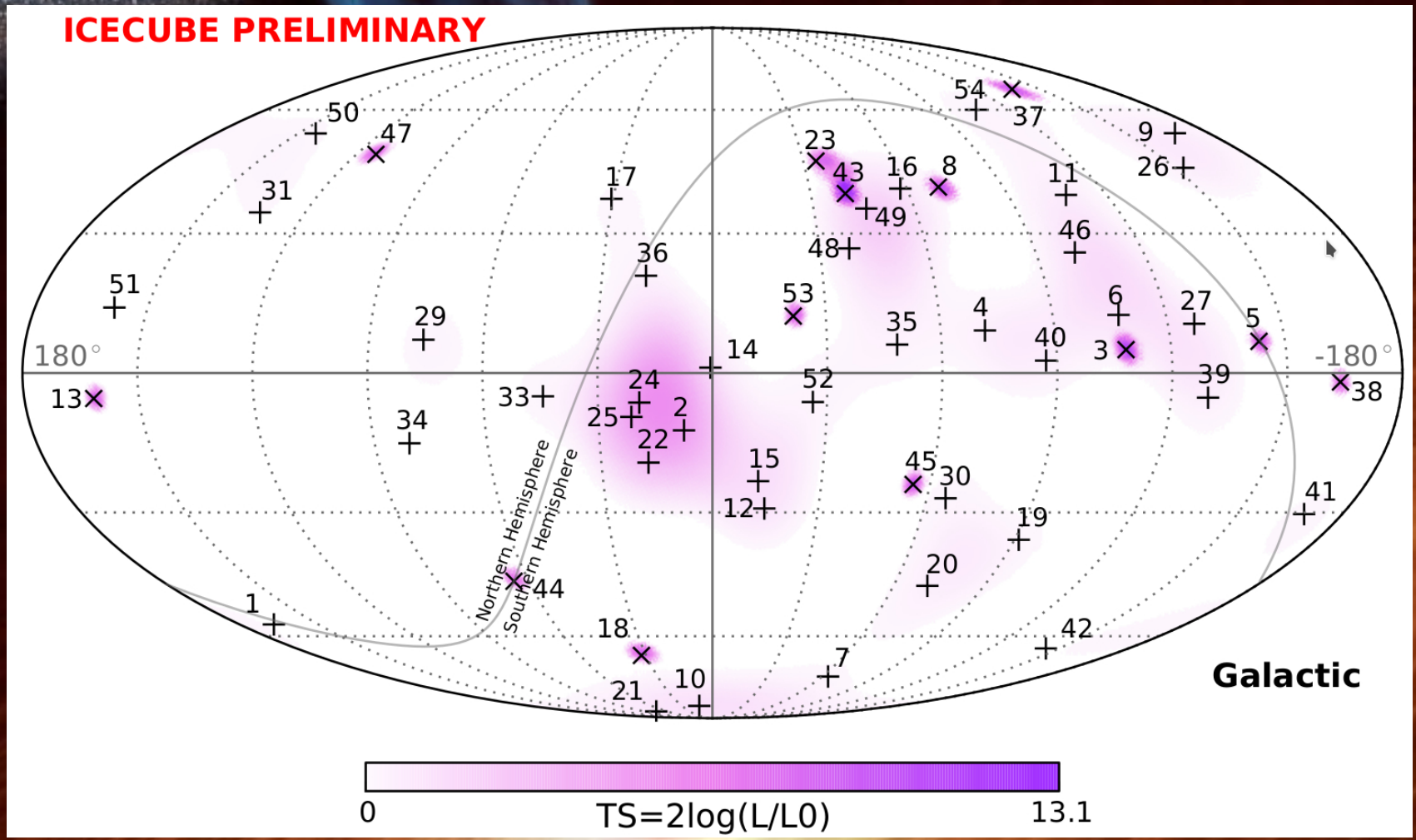
BACKUP

37 LAT photons



(after IceCube Collaboration 2014)

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



(IceCube Collaboration 2014, 2015)

→ Extragalactic origin consistent with isotropic distribution