Julius-Maximilians-
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Counterparts to Single Neutrinos

Matthias Kadler

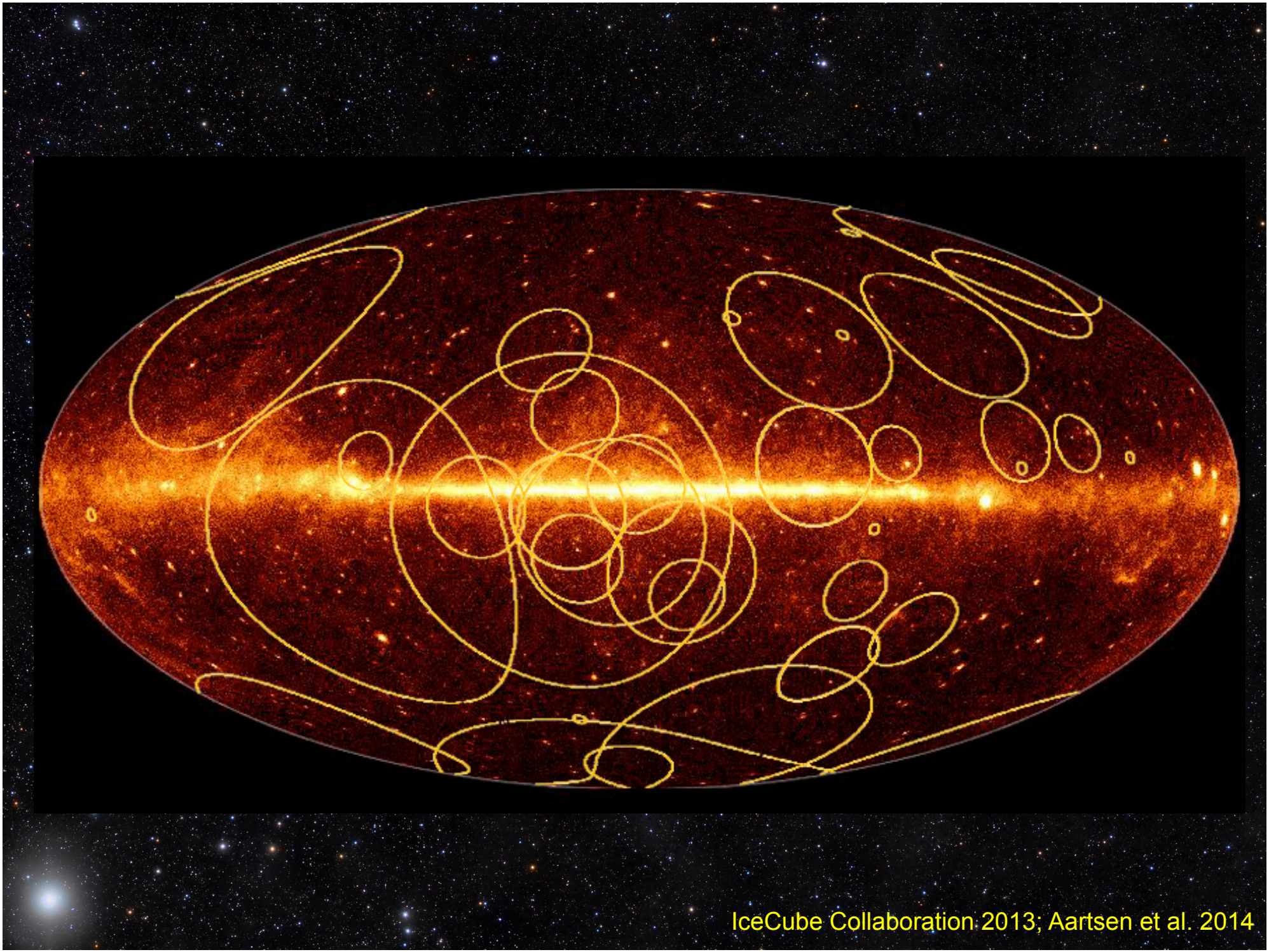
Perspectives on the Extragalactic Frontier, Trieste, May 6, 2016

High-Fluence Blazars as Possible Counterparts to PeV Neutrinos

Matthias Kadler

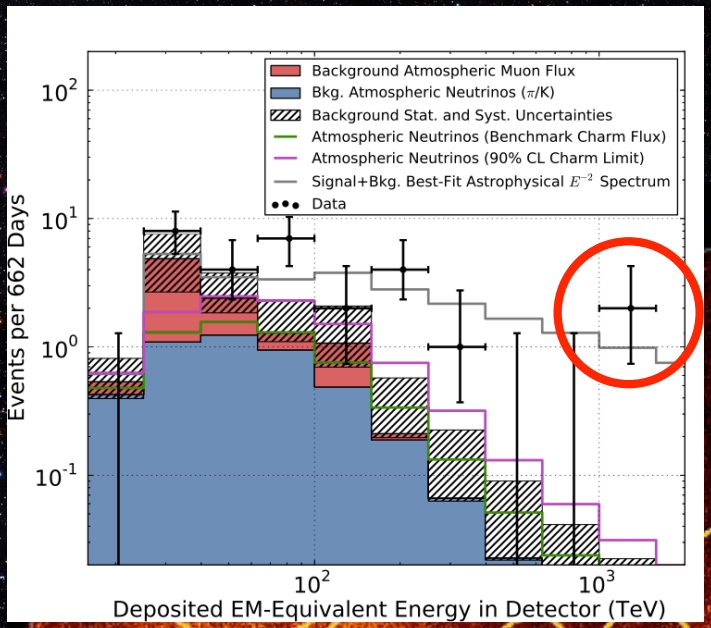
F. Krauß, K. Mannheim, R. Ojha

Perspectives on the Extragalactic Frontier, Trieste, May 6, 2016

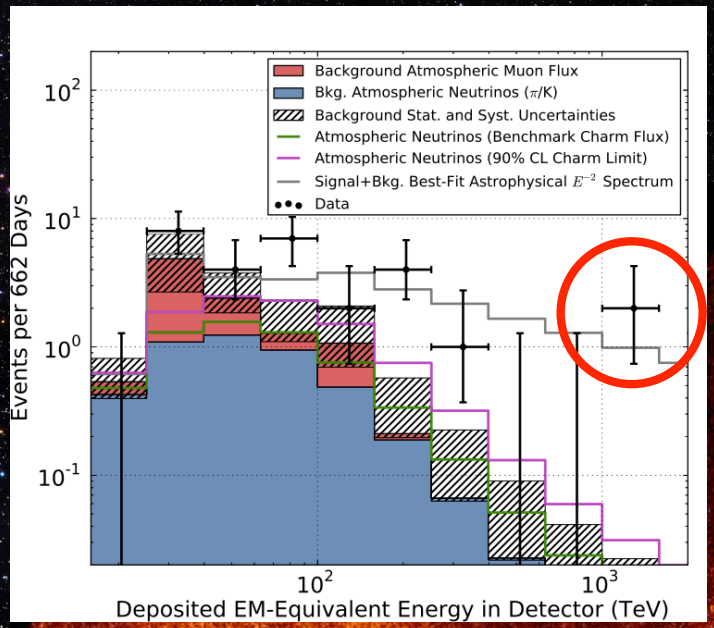

IceCube Collaboration 2013; Aartsen et al. 2014

How to locate astrophysical candidate sources?

1. Reduce the field size
2. Use the most significant events
3. Have a physical model



IceCube Collaboration 2013; Aartsen et al. 2014

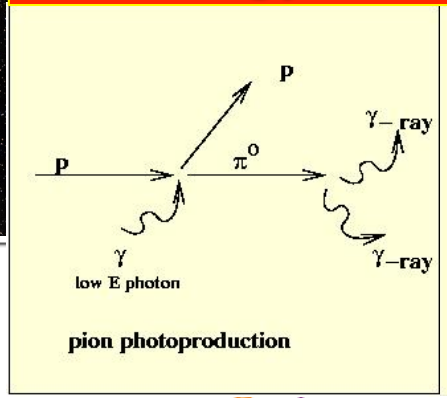


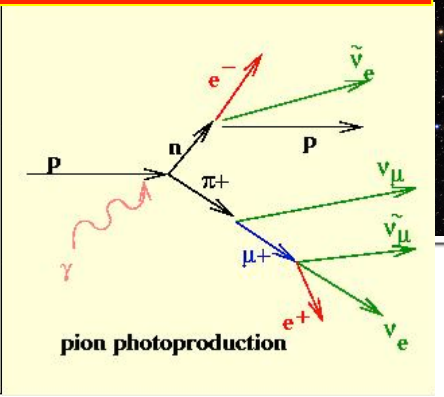
IceCube Collaboration 2013; Aartsen et al. 2014

Ansatz: p-γ in blazar jets

Energy threshold: ~PeV

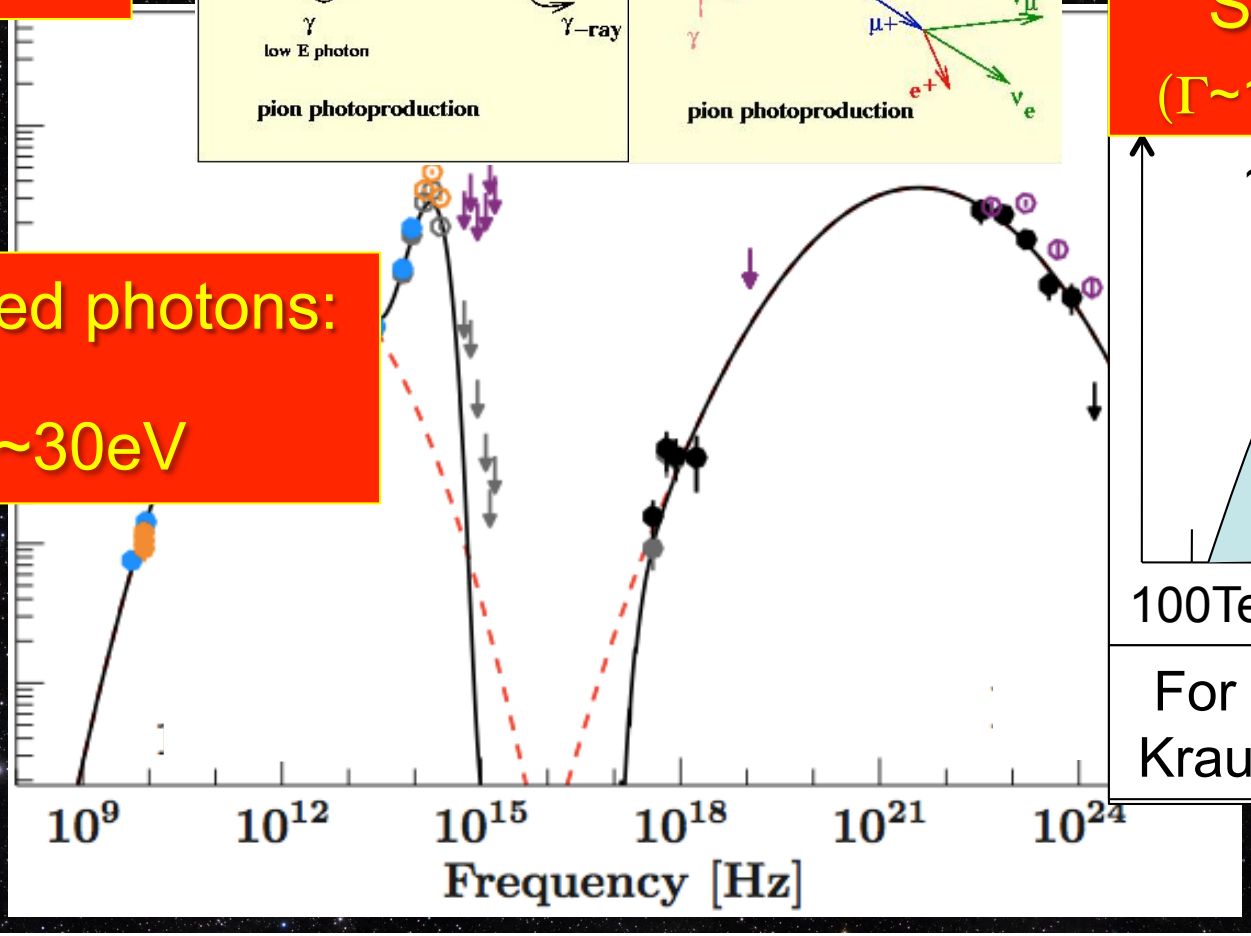
Rel. protons (jet)





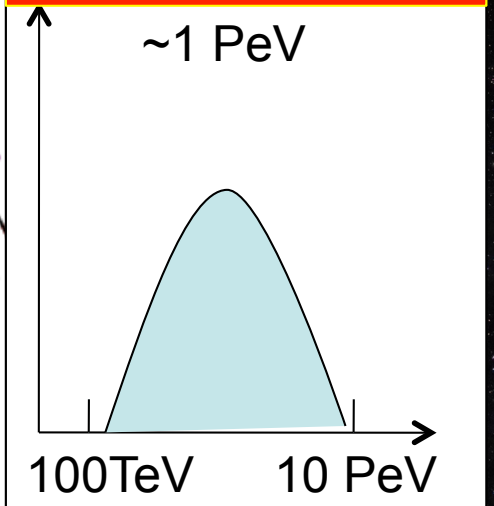
UV seed photons:

ε~30eV



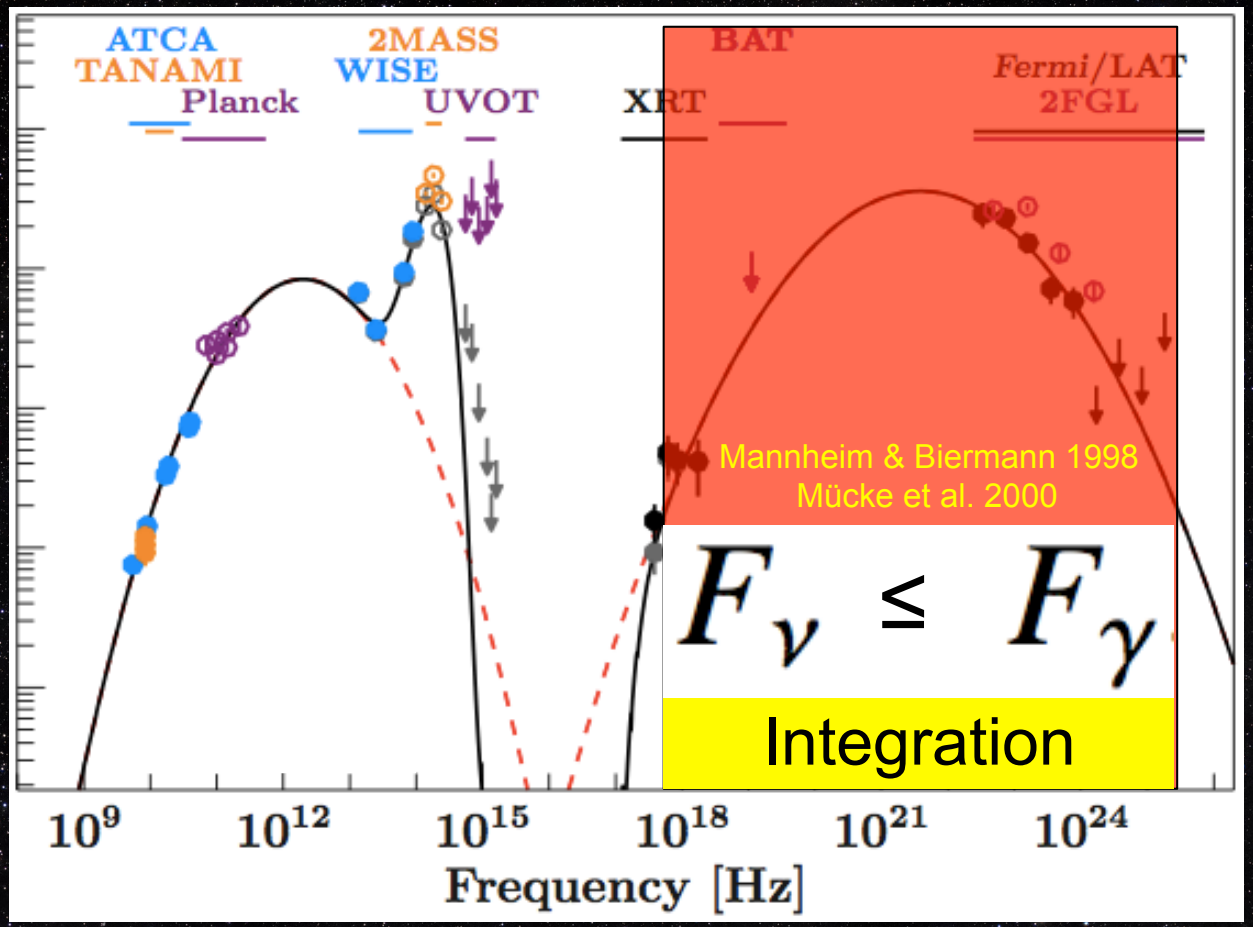
Neutrino Spectrum

(Γ~10, θ varies)

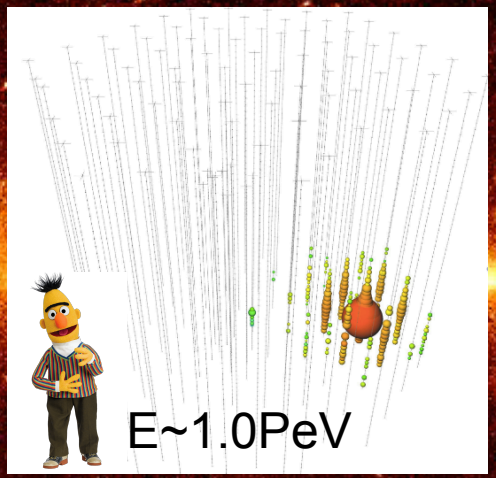


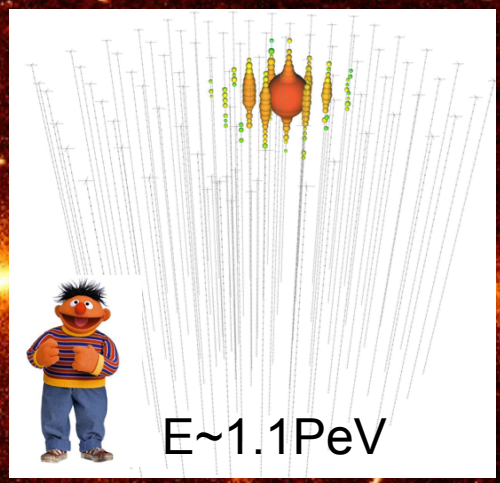
For details, see Krauß et al. 2014

Ansatz: p-γ in blazar jets



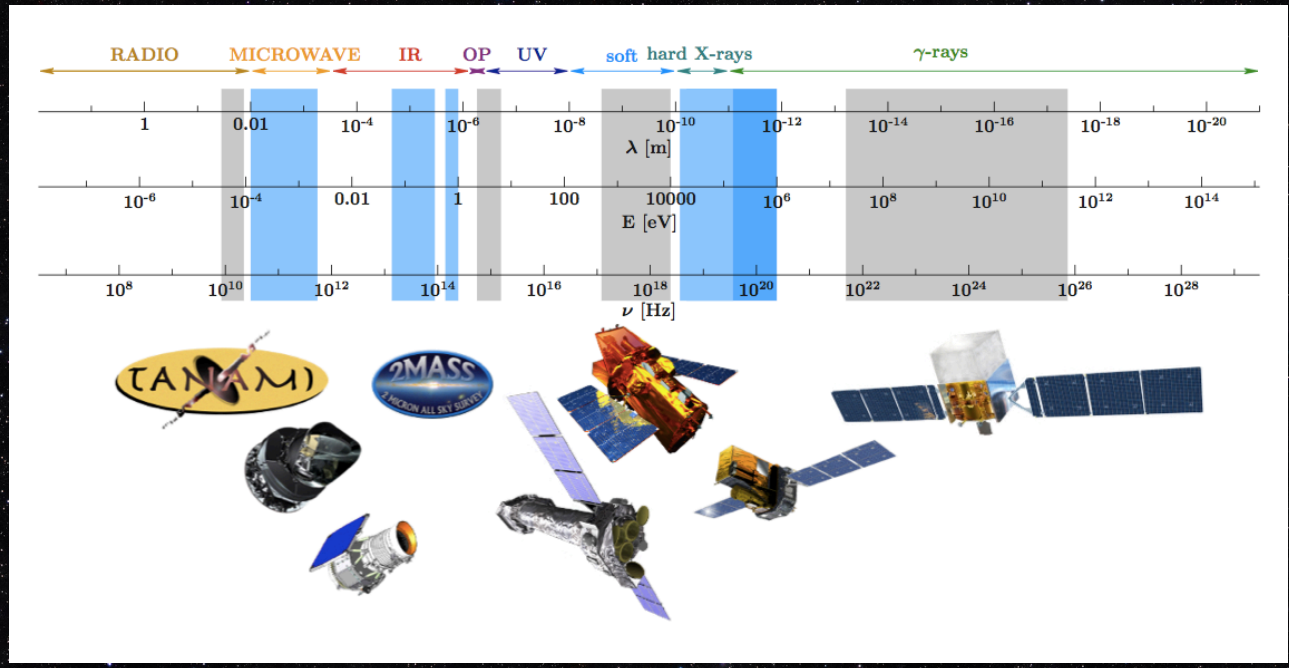
$$N^{\max}_{\nu,\mathrm{PeV}}(\Omega) = A_{\mathrm{eff},\nu_e} \cdot \left(\frac{F_\gamma}{E_\nu}\right) \cdot \Delta t \;\rightarrow\; \underline{\text{need high-fluence FSRQs!}}$$

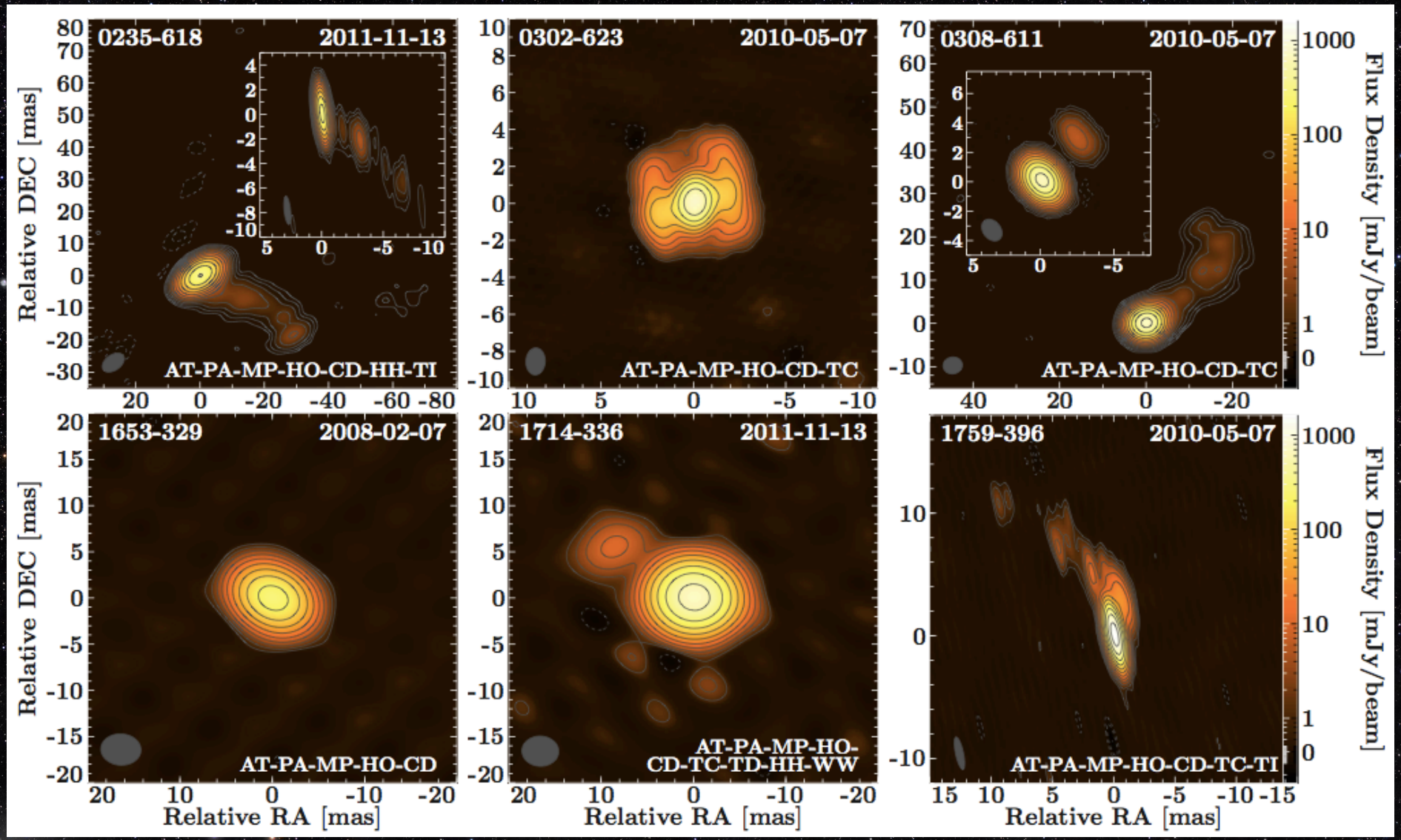

E~1.0PeV


E~1.1PeV


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

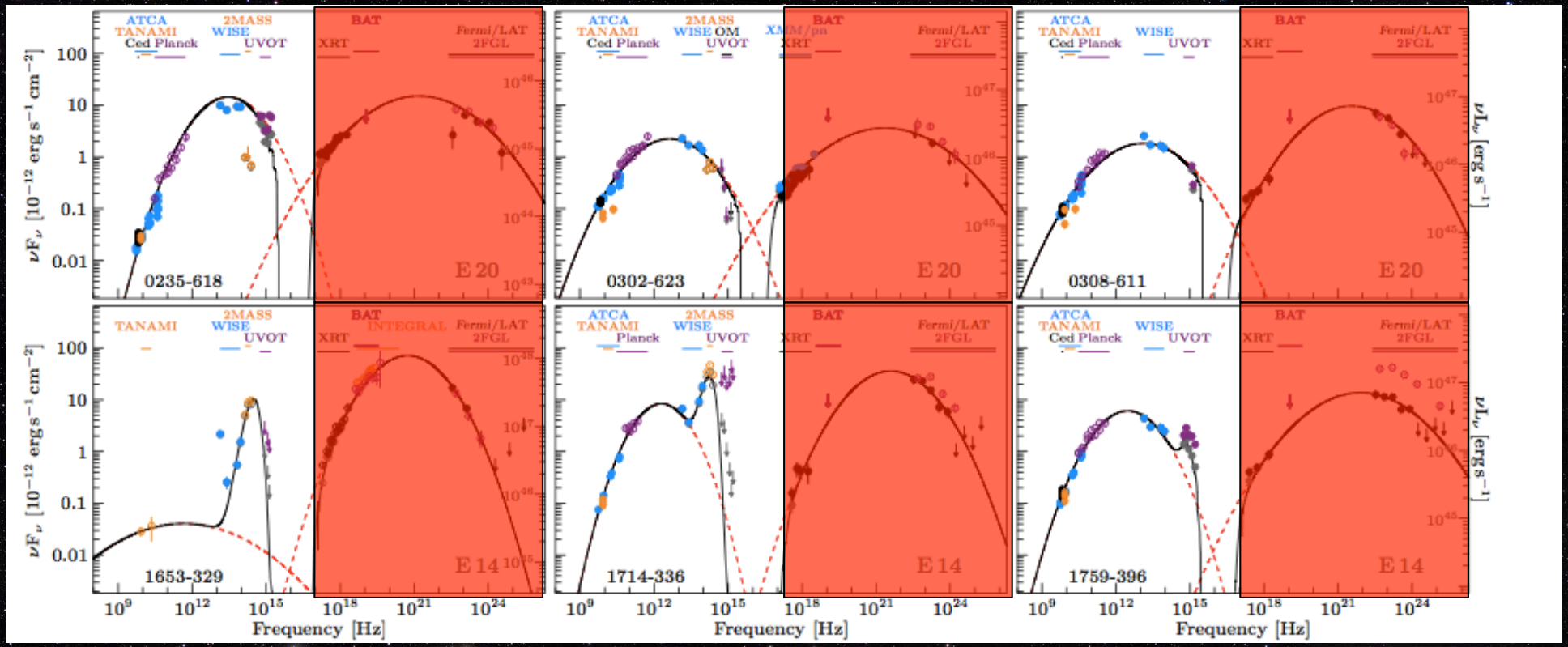
TANAMI


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

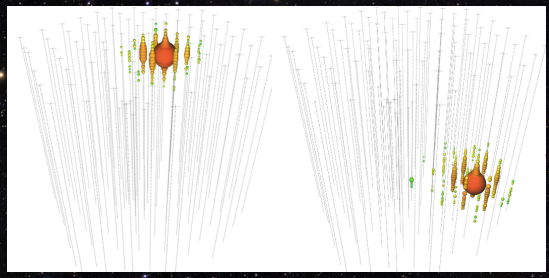


Krauß et al. 2014, A&A 566, L7

Krauß et al. 2014, A&A 566, L7



$$N^{\max}_{\nu,\mathrm{PeV}}(\Omega) = 0?.?$$

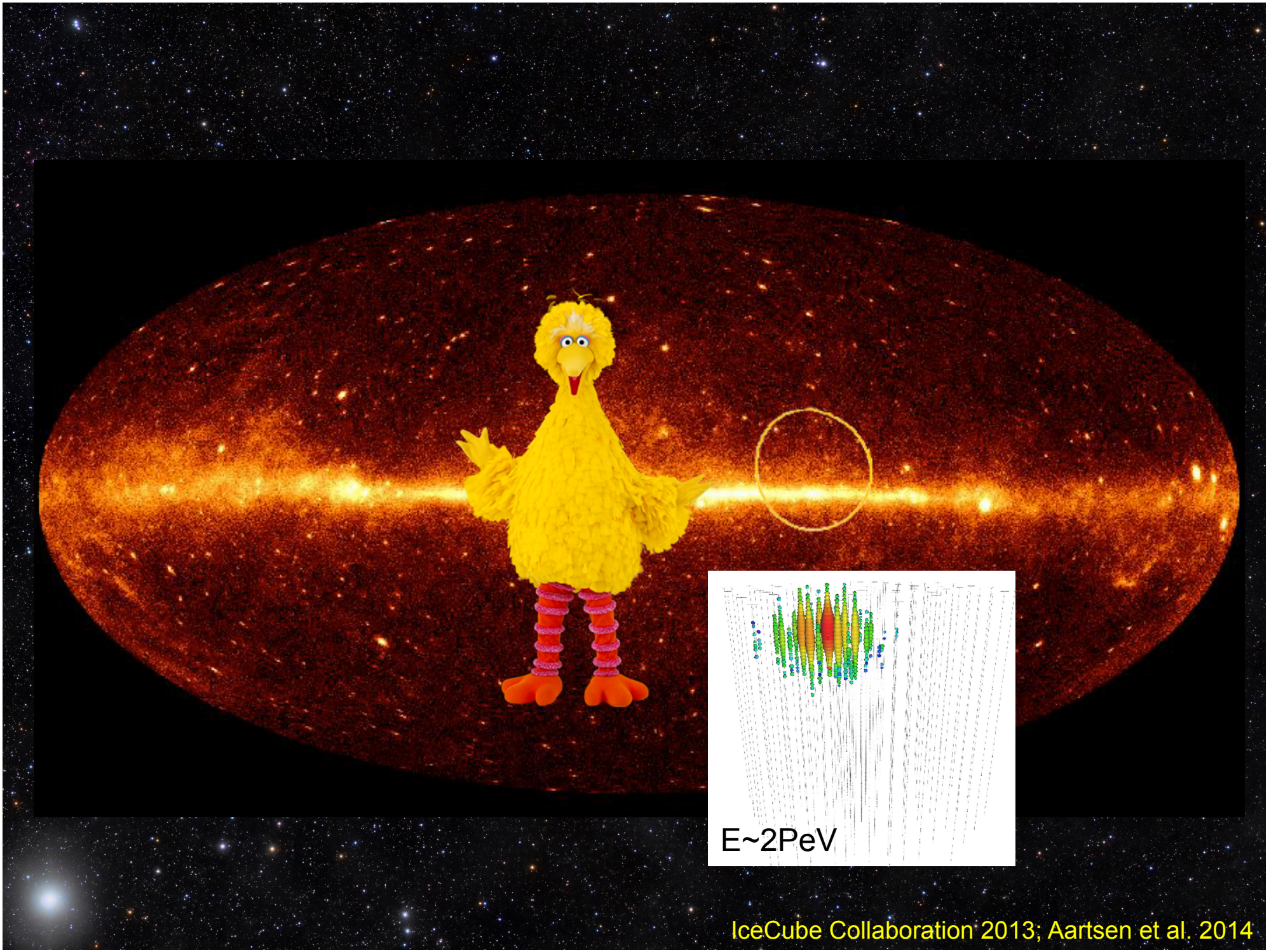


The six TANAMI blazars are capable of explaining the observed IceCube PeV flux via p-γ!

But:

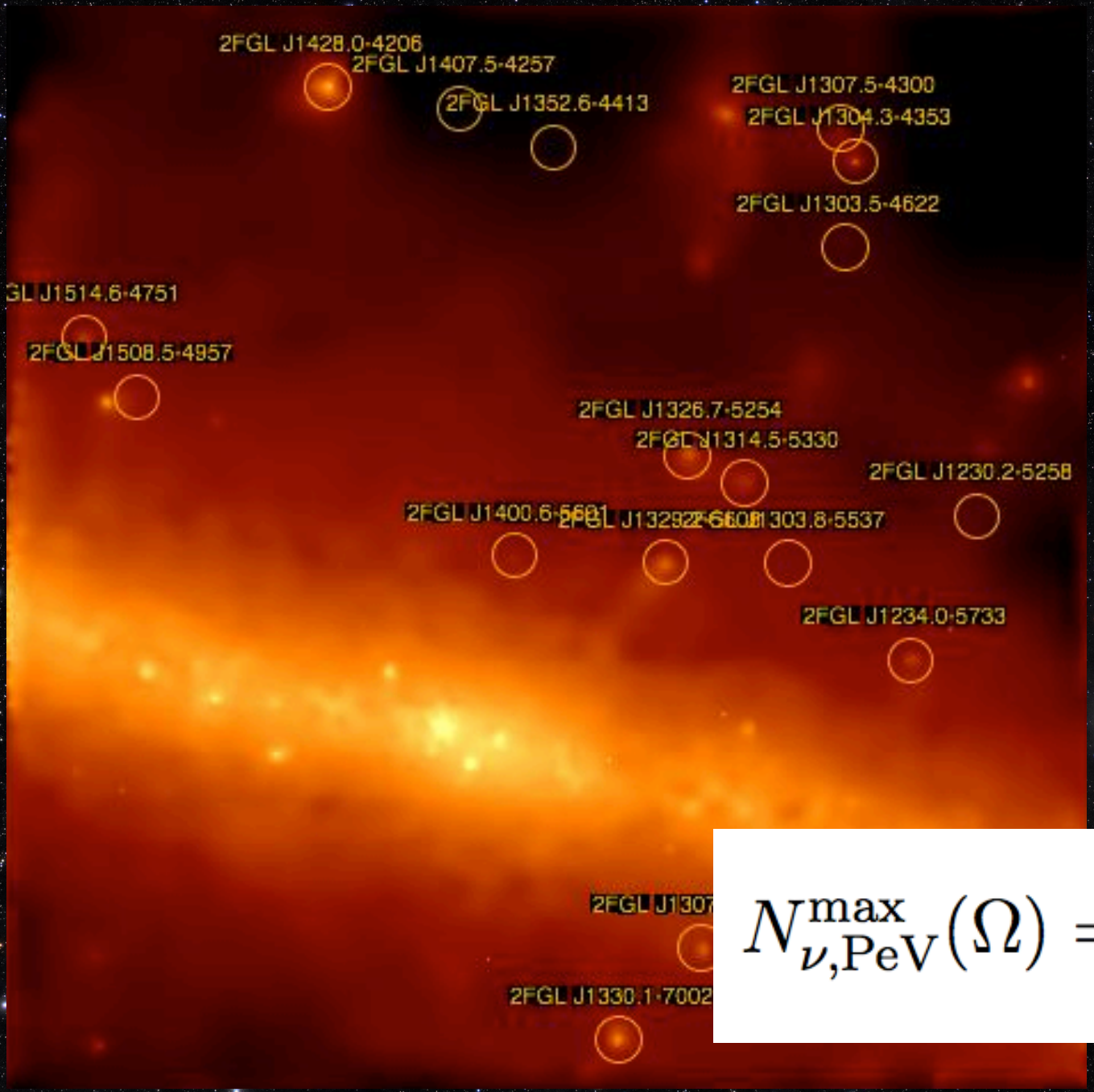
- **No individual source bright enough**
- **Scaling factor?**

$$N_{\nu,\mathrm{obs,PeV}} = f \cdot N_{\nu,\mathrm{max,PeV}}$$

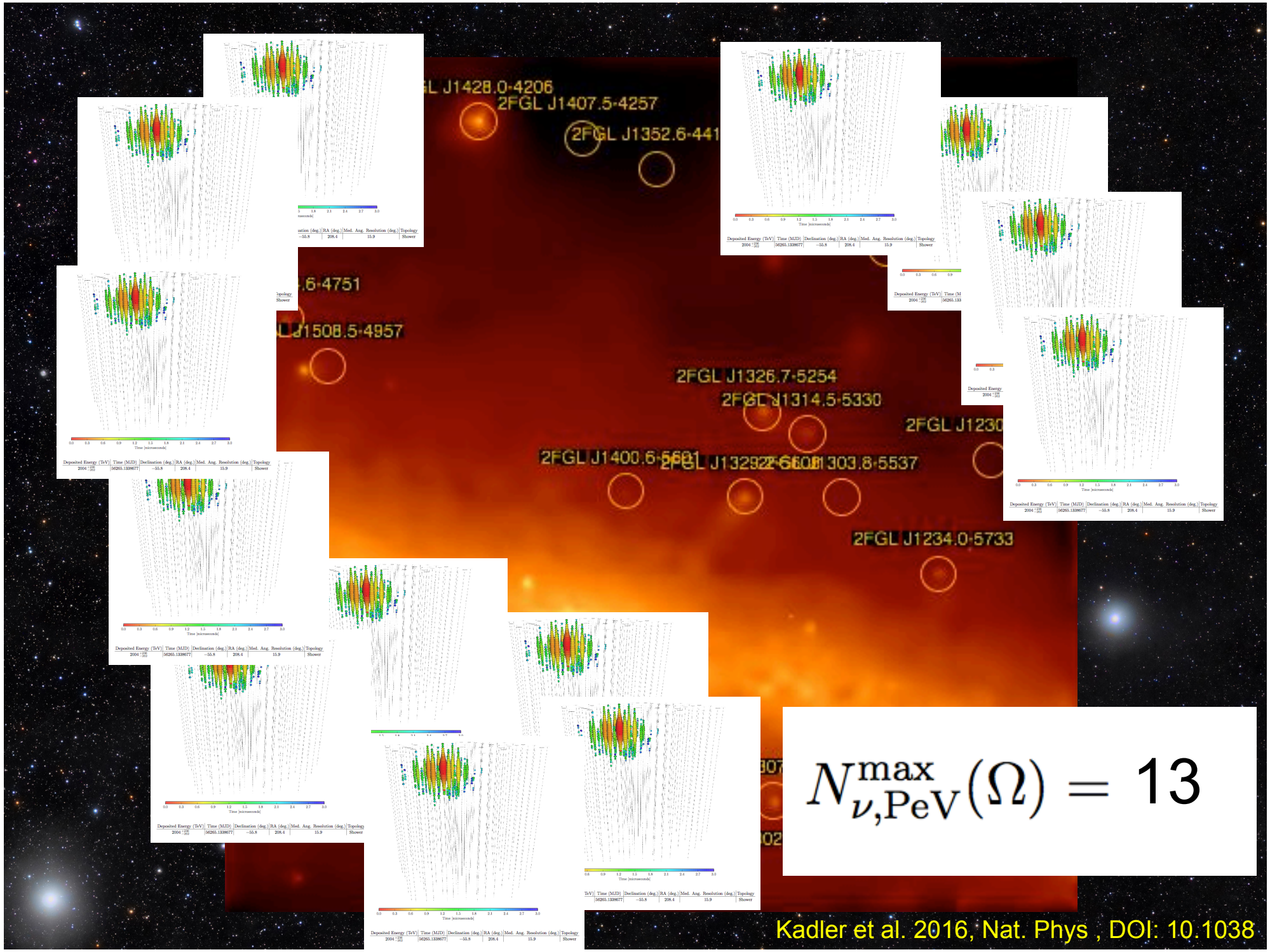


IceCube Collaboration 2013; Aartsen et al. 2014

Kadler et al. 2016, Nat. Phys , DOI: 10.1038



$$N^{\max}_{\nu,\mathrm{PeV}}(\Omega) = \ ?$$



Kadler et al. 2016, Nat. Phys , DOI: 10.1038

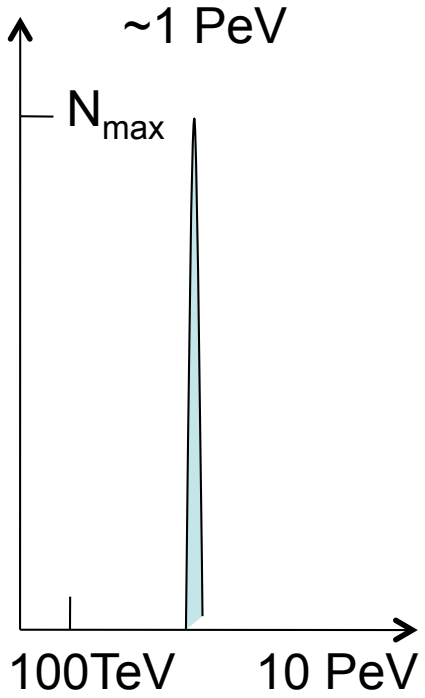
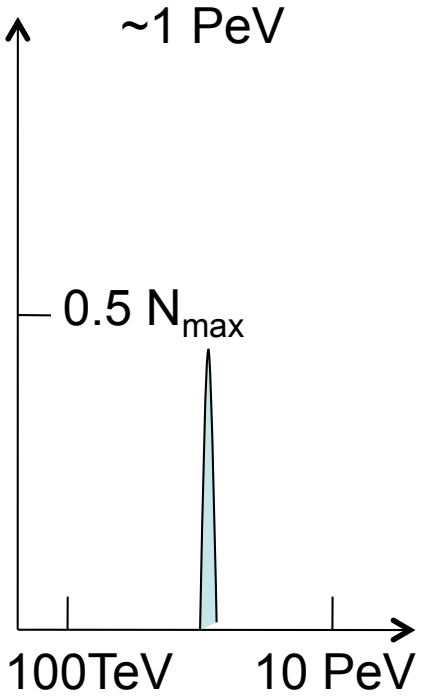
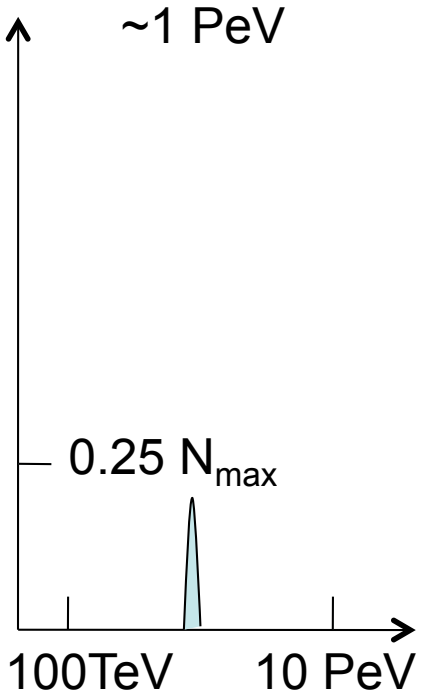
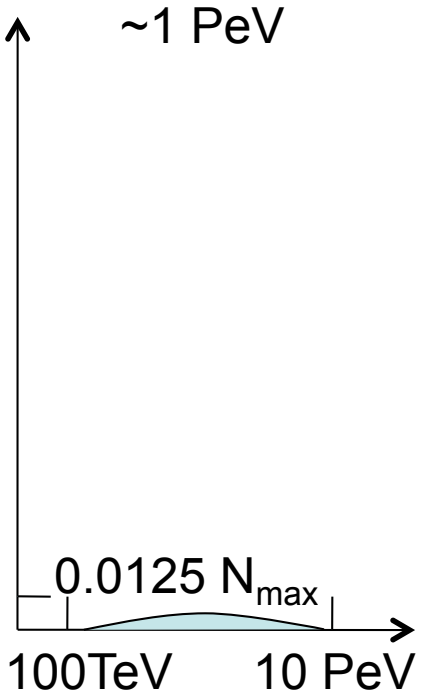
Empirical Scaling Factor

$$N^{\max}_{\nu,\,\mathrm{PeV}}(2\pi) = 13 \cdot \frac{2\pi}{\Omega_{\mathrm{IC\,35}}} \sim 336$$

$$f_{\mathrm{emp}} = \frac{N^{\mathrm{obs}}_{\nu,\,\mathrm{PeV}}(2\pi)}{N^{\max}_{\nu,\,\mathrm{PeV}}(2\pi)} \sim \frac{3}{336} \sim 0.009$$

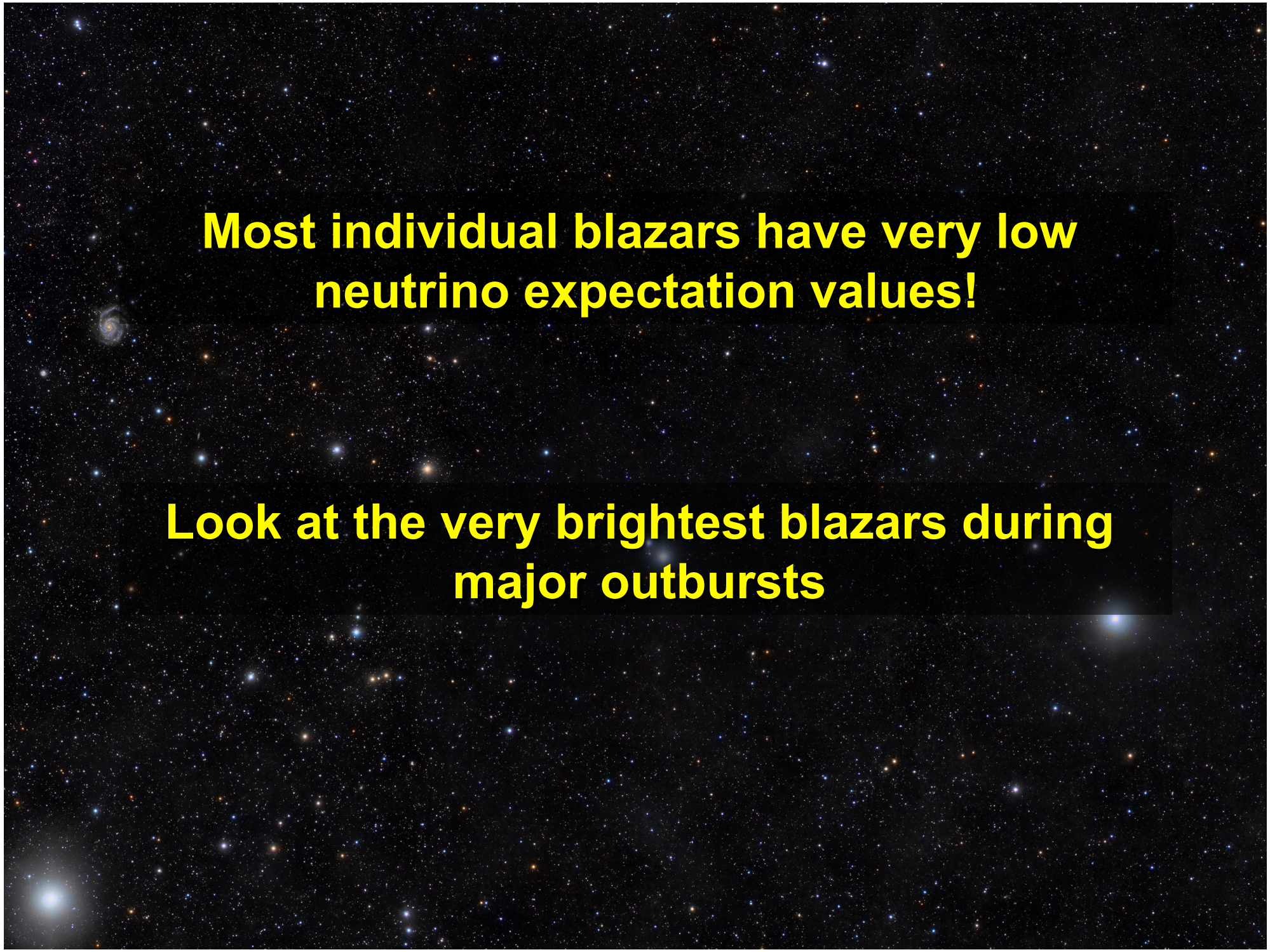
Kadler et al. 2016, Nat. Phys , DOI: 10.1038

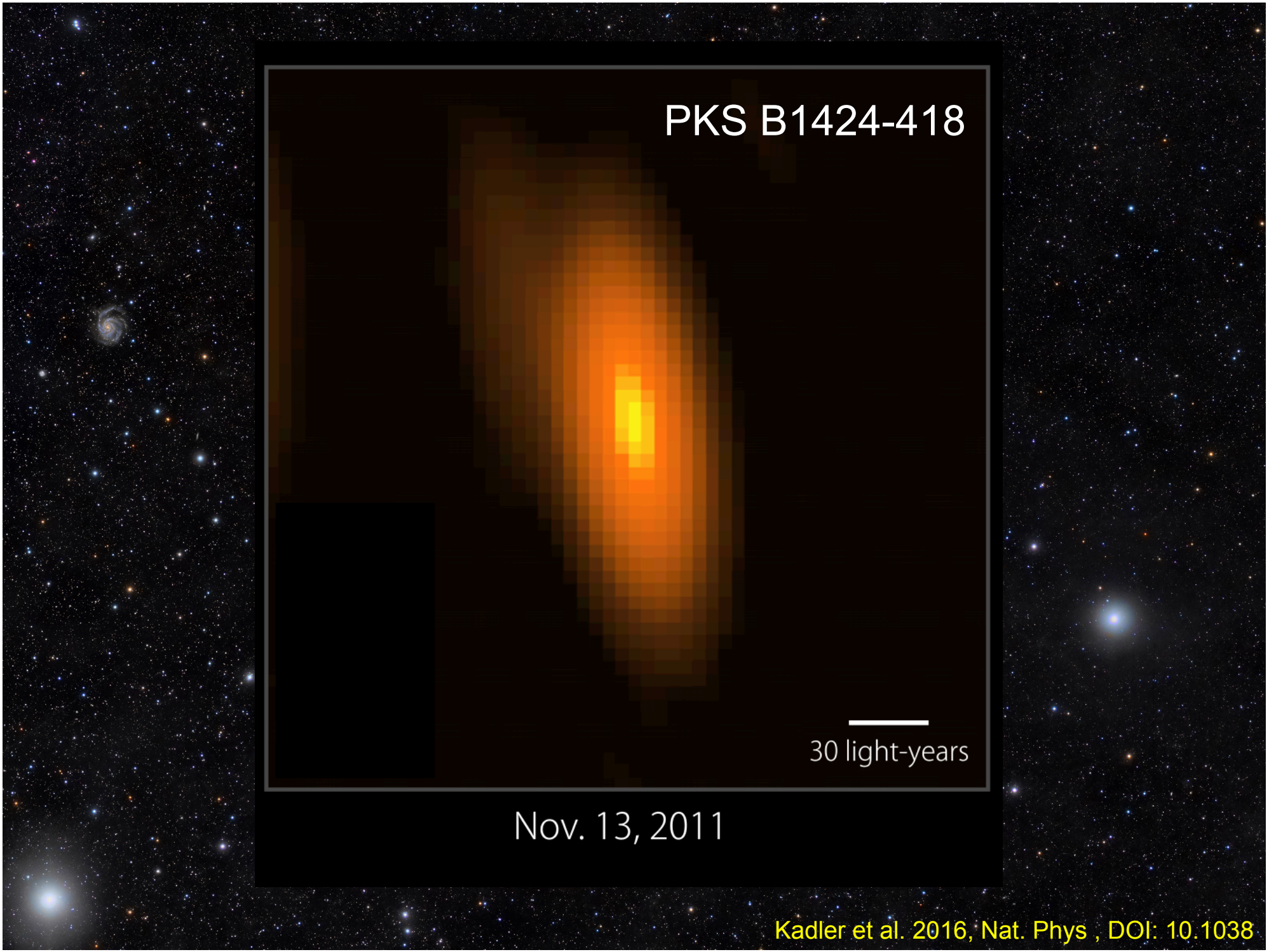
Theoretical Scaling Factor

Maximum	Flavor Corrected	FSRQ Fraction	Predicted
			

$$f_{\rm th}\, f_{\rm th} = 0.5 \cdot 0.5 \,).05 \sim 0.0125$$

Kadler et al. 2016, Nat. Phys , DOI: 10.1038


Most individual blazars have very low neutrino expectation values!
Look at the very brightest blazars during major outbursts



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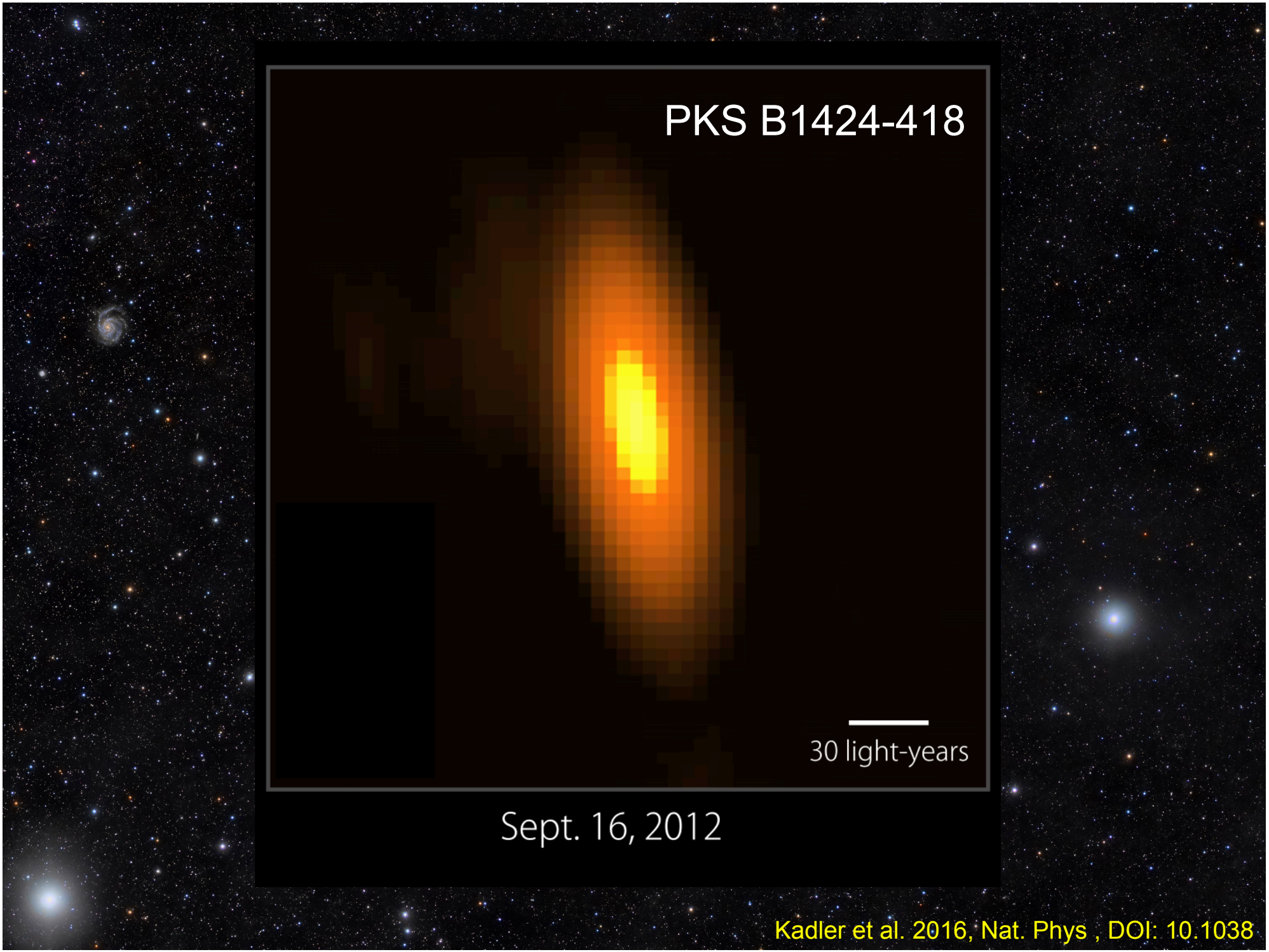

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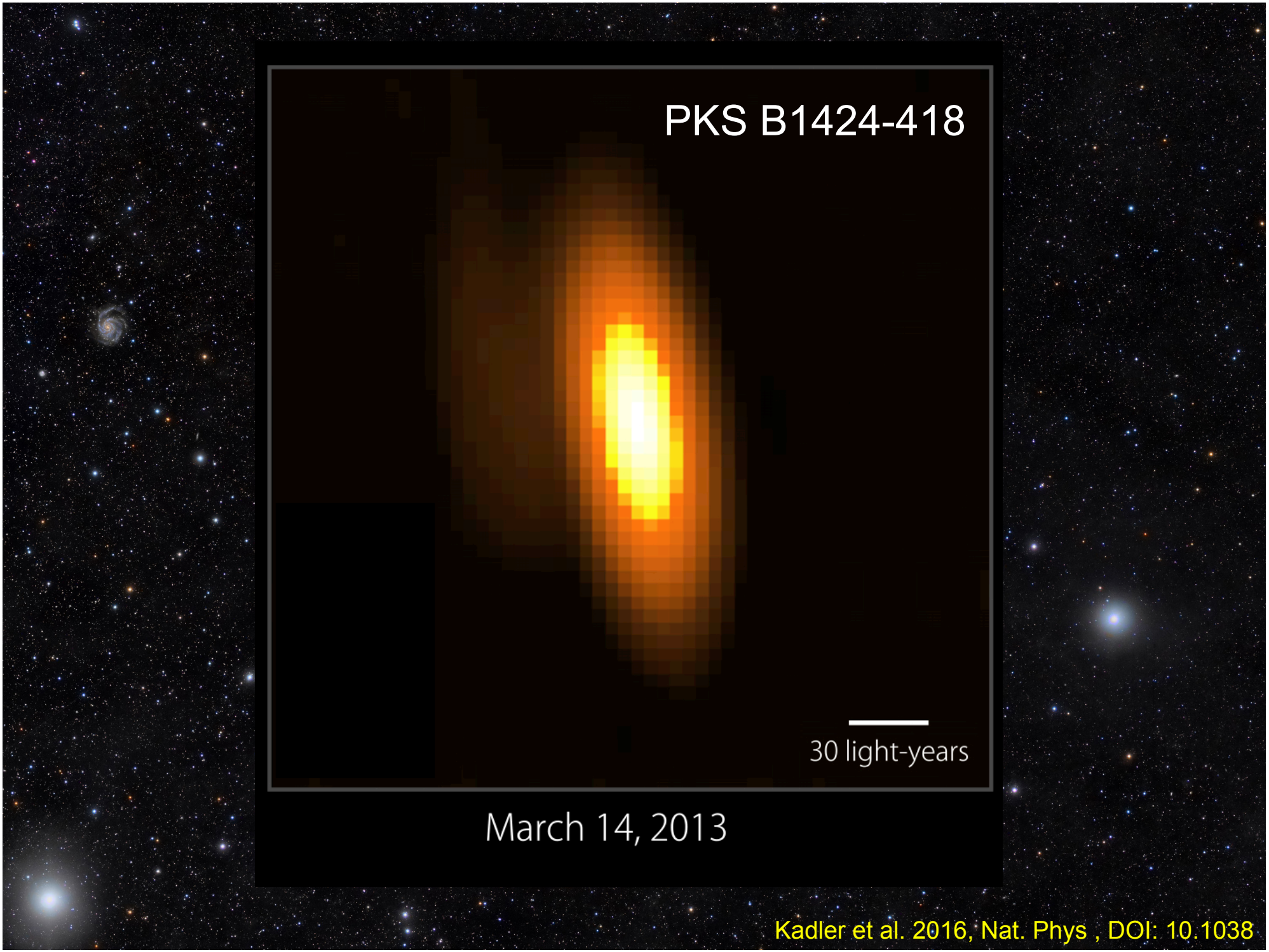

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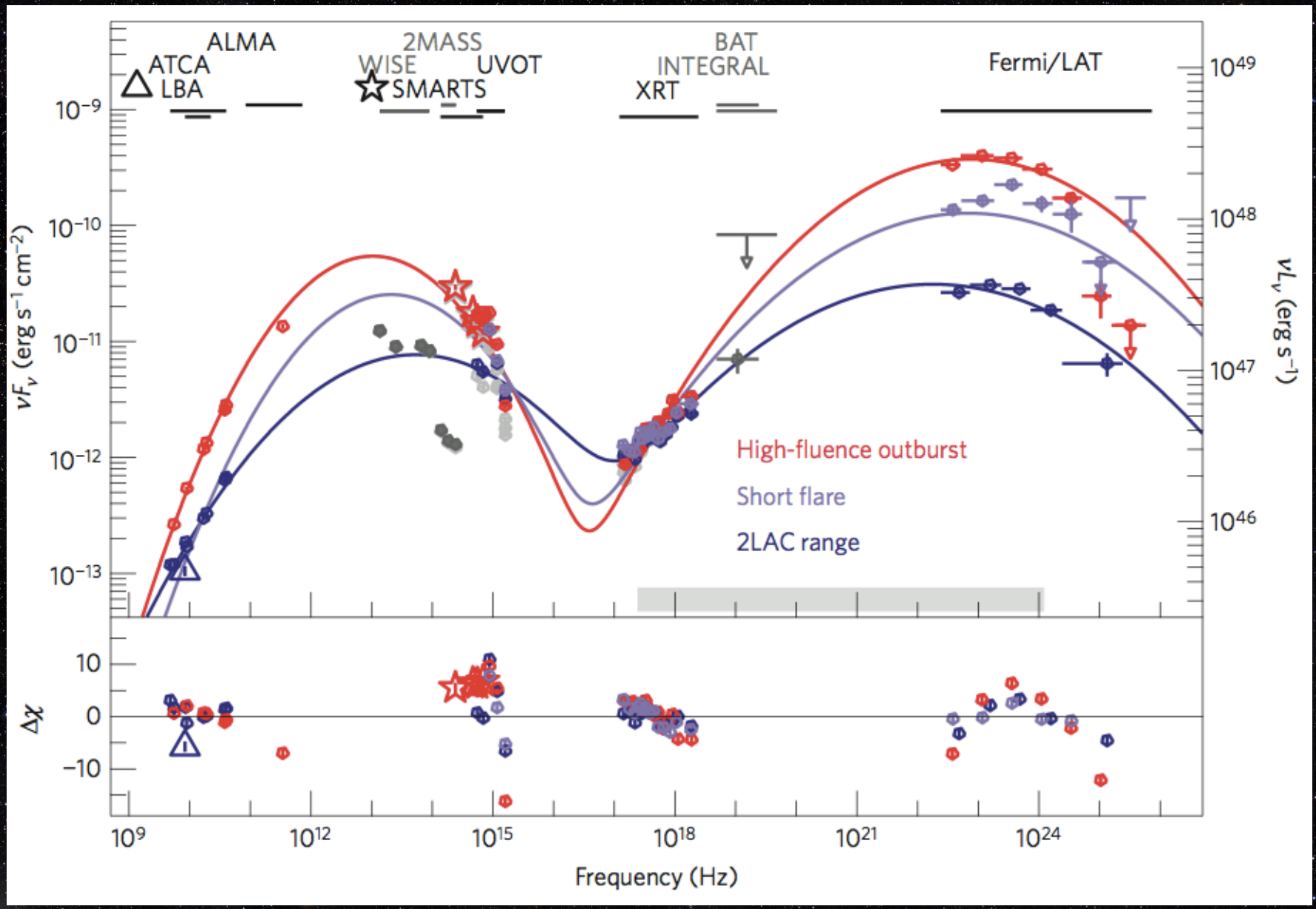

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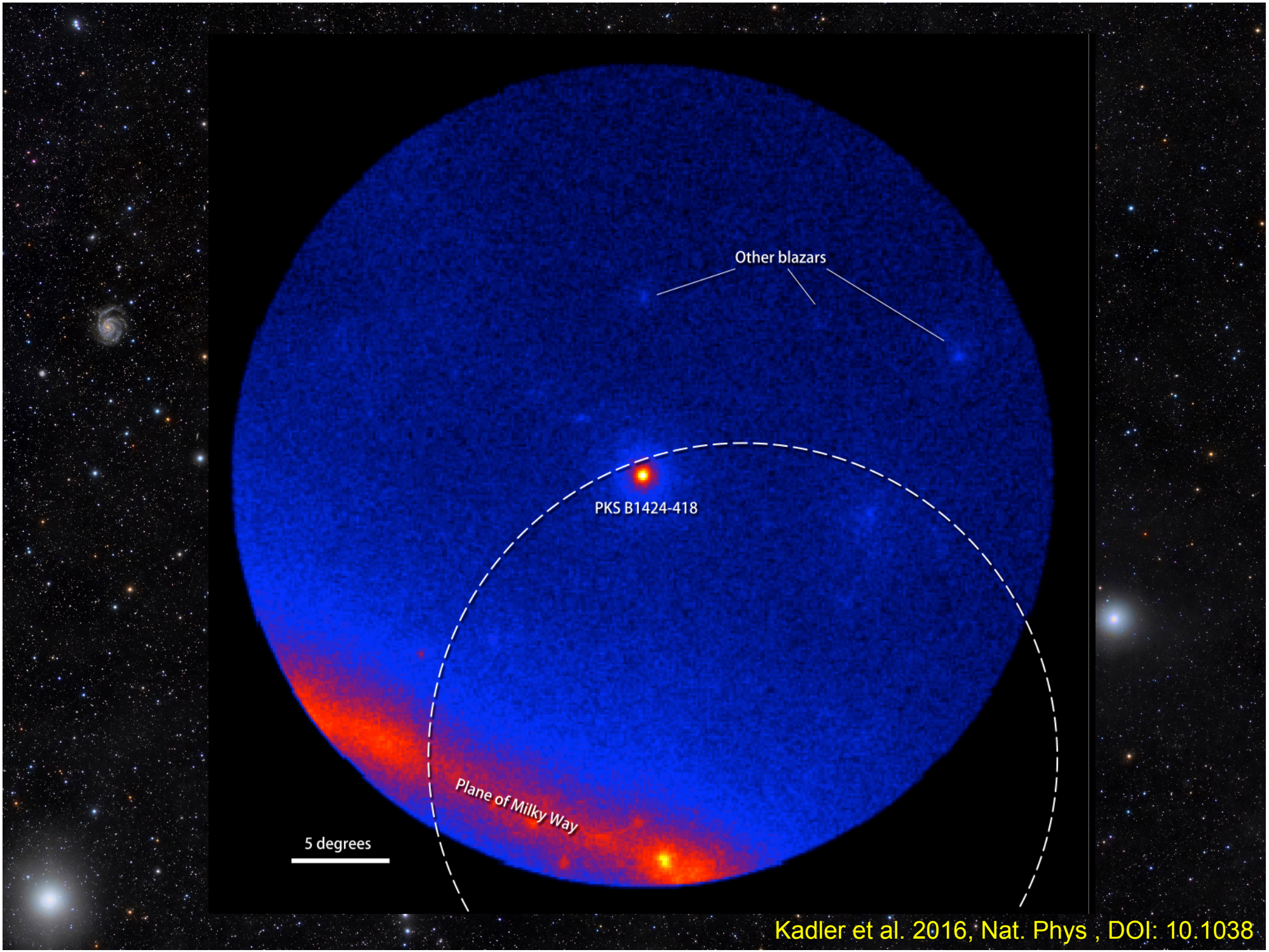

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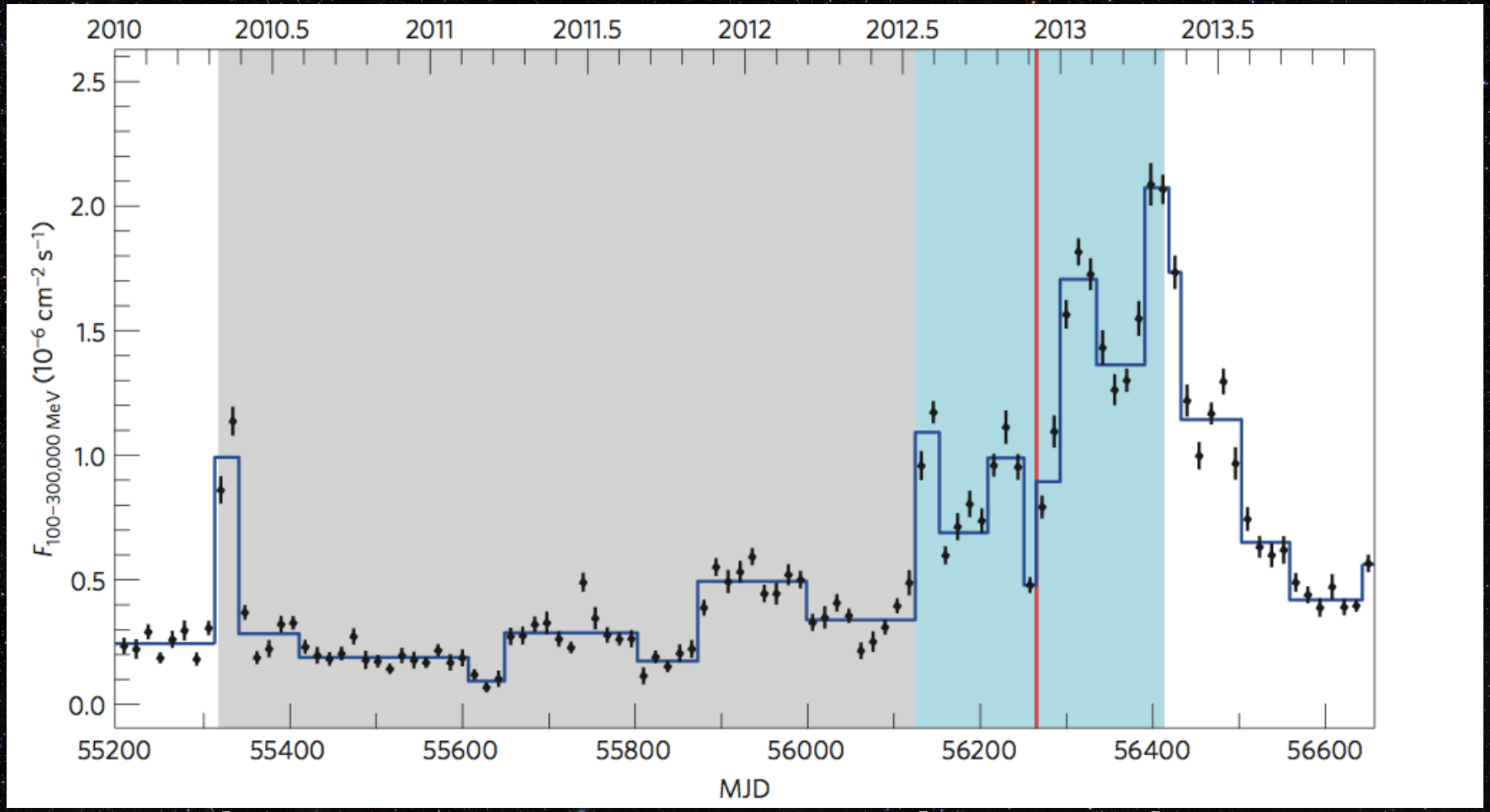
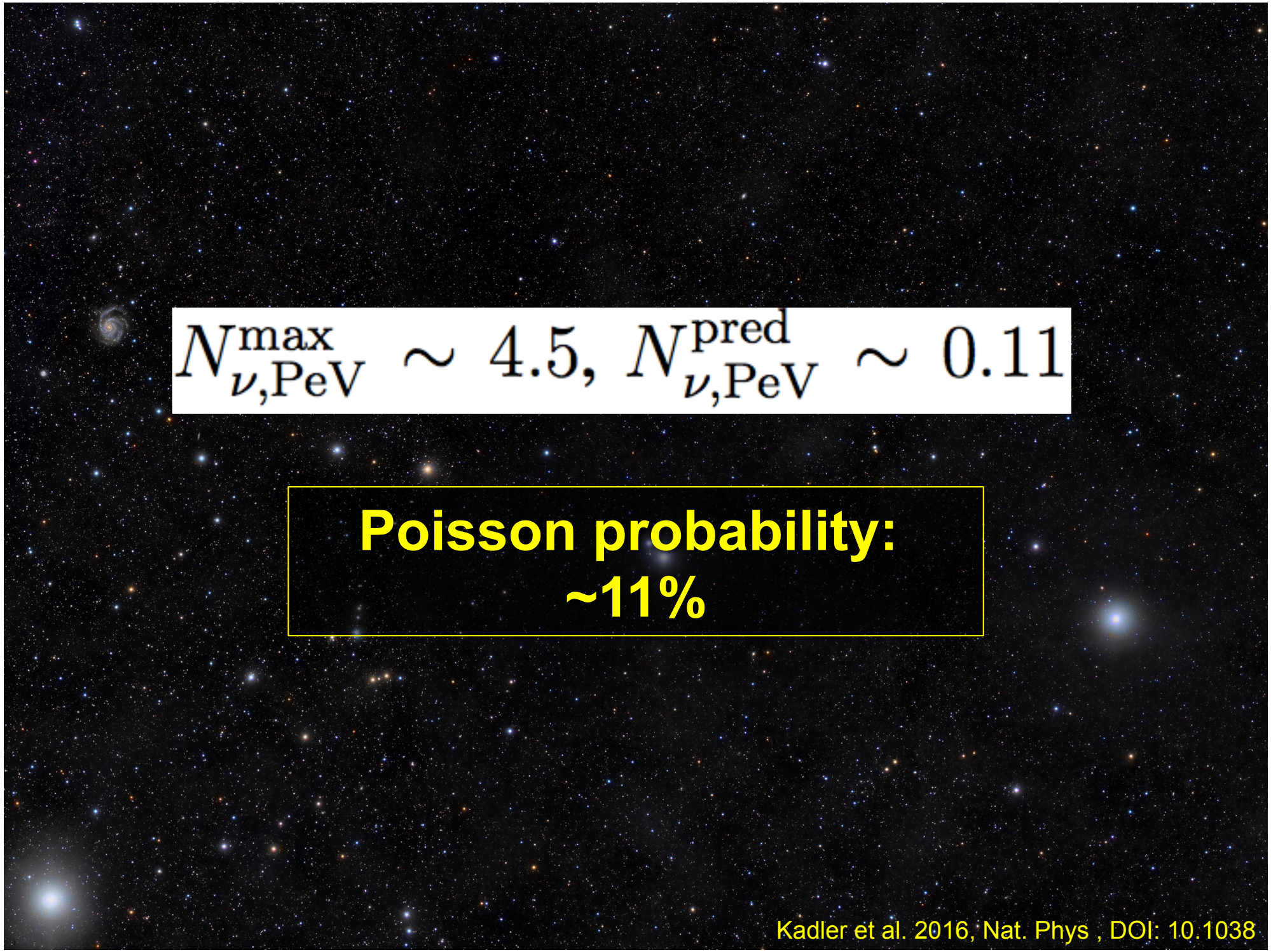


$N^{\max}_{\nu,\mathrm{PeV}}(\Omega) = 1.2$

$N^{\max}_{\nu,\mathrm{PeV}}(\Omega) = 4.5$

Kadler et al. 2016, Nat. Phys , DOI: 10.1038



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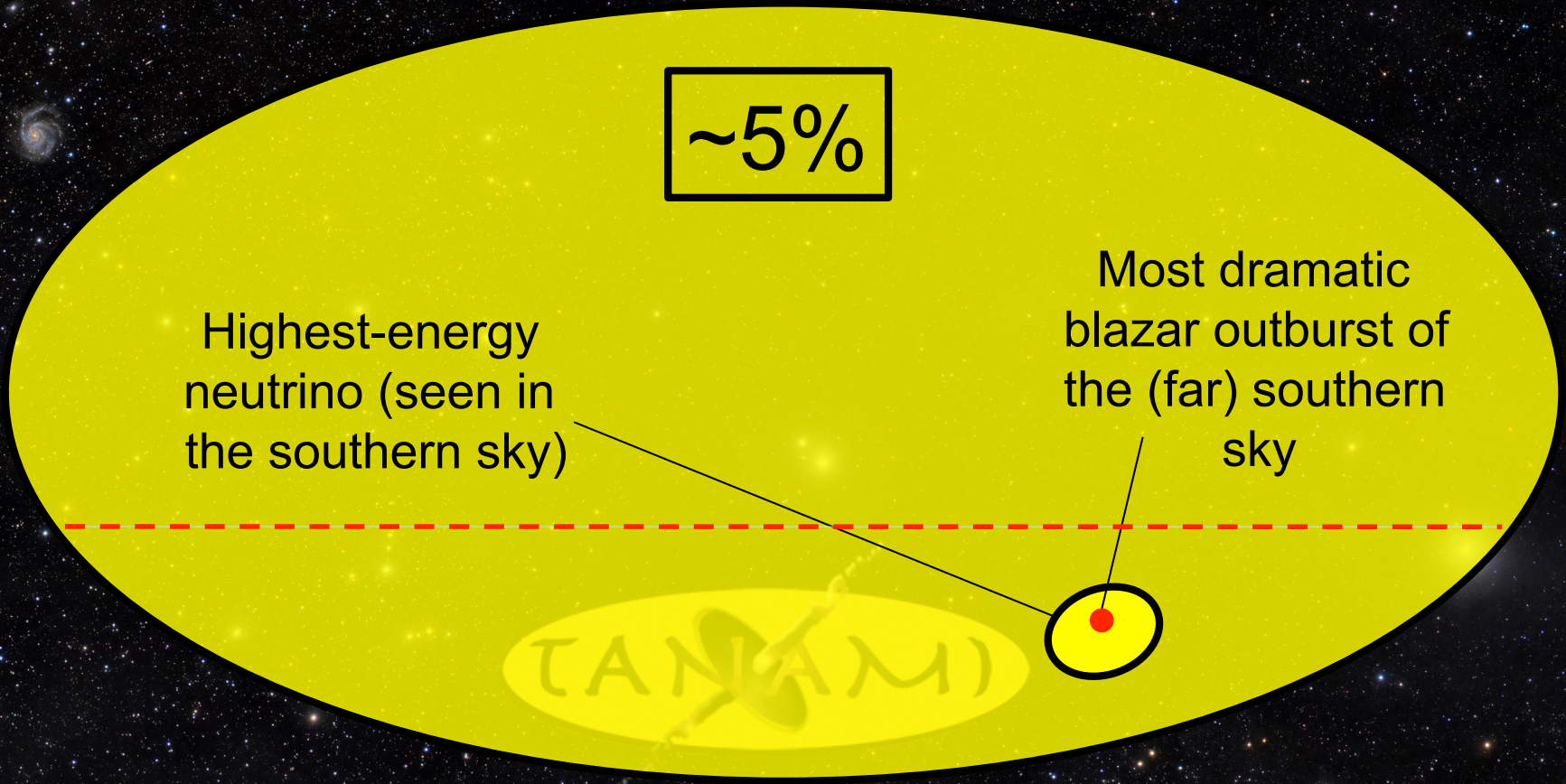
Self-consistent model:

1. Based on measured keV-GeV blazar fluences
2. Explains all-sky PeV neutrino flux
3. Predicts peaked PeV spectra
   - ➢ no problem with TeV overprediction
4. Association of BigBird with a single blazar
5. Small chance probability

Chance Coincidence?



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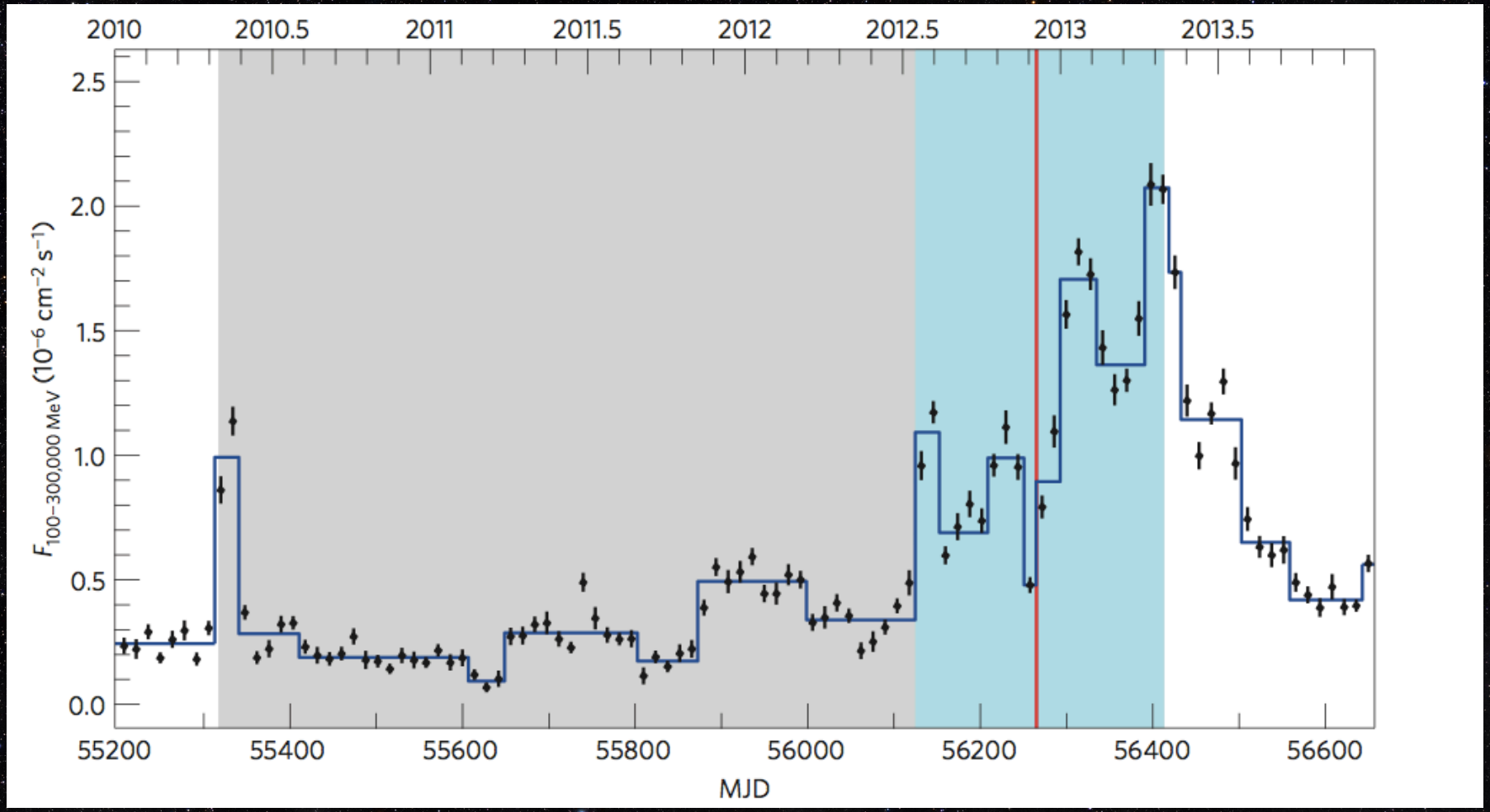
Fundamental Implications

(with the 5% kept in mind)

- Hadronic blazar emission models
- High-energy cosmic rays
- Neutrino velocity
  - ➢ Lorentz invariance
  - ➢ Equivalence principle

Kadler et al. 2016, Nat. Phys , DOI: 10.1038



$$(v - c)/c \lesssim \mathcal{O}(10^{-11})$$

Kadler et al. 2016, Nat. Phys , DOI: 10.1038

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(with the 5% kept in mind)

- Hadronic blazar emission models
- High-energy cosmic rays
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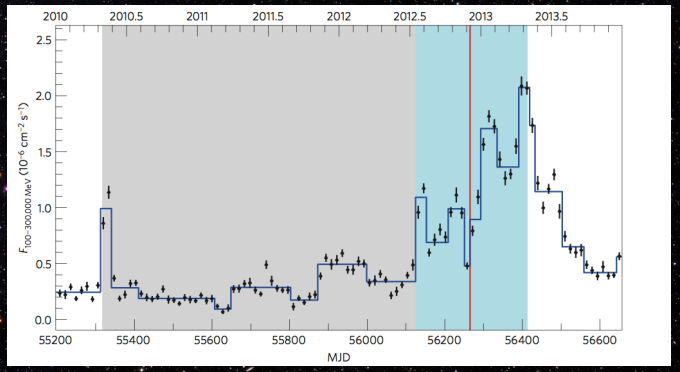
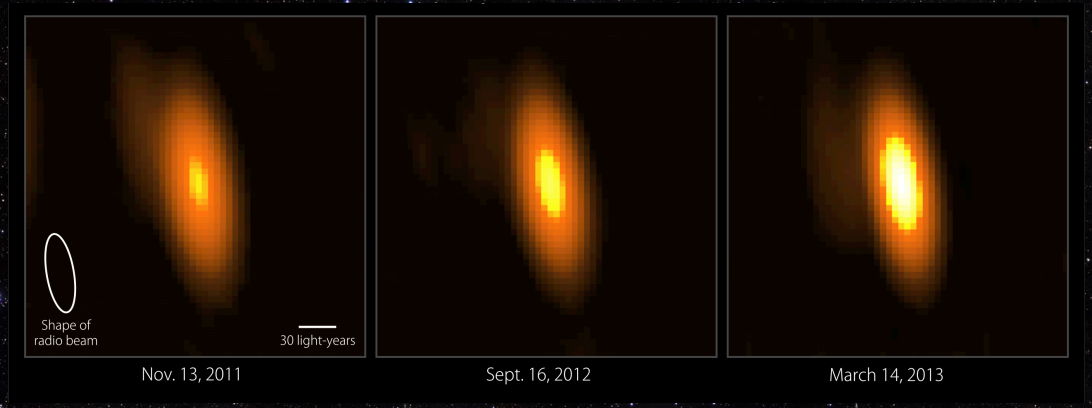
Kadler et al. 2016, Nat. Phys , DOI: 10.1038; Wang et al. 2016, arXiv:1602.06805; Wei et al. 2016, arXiv:1603.07568





$$(v-c)/c \lesssim \mathcal{O}(10^{-11})$$