

Neutrino-Astronomie: Ein neues Bild des Hochenergie- Universums

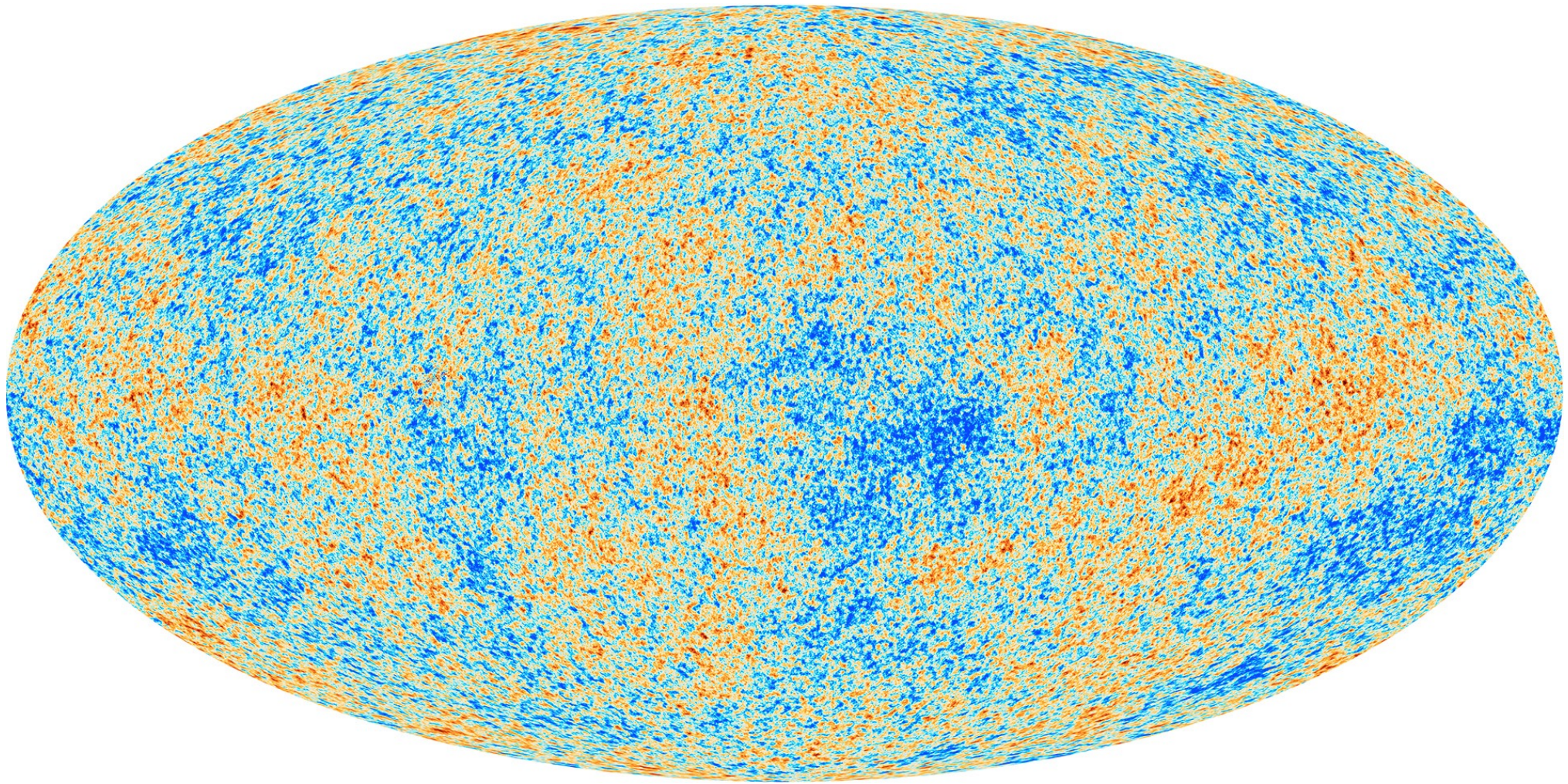
Marek Kowalski
Humboldt-Universität zu Berlin & DESY

Ask an expert
Berlin, 28.9.2022

The energy frontier

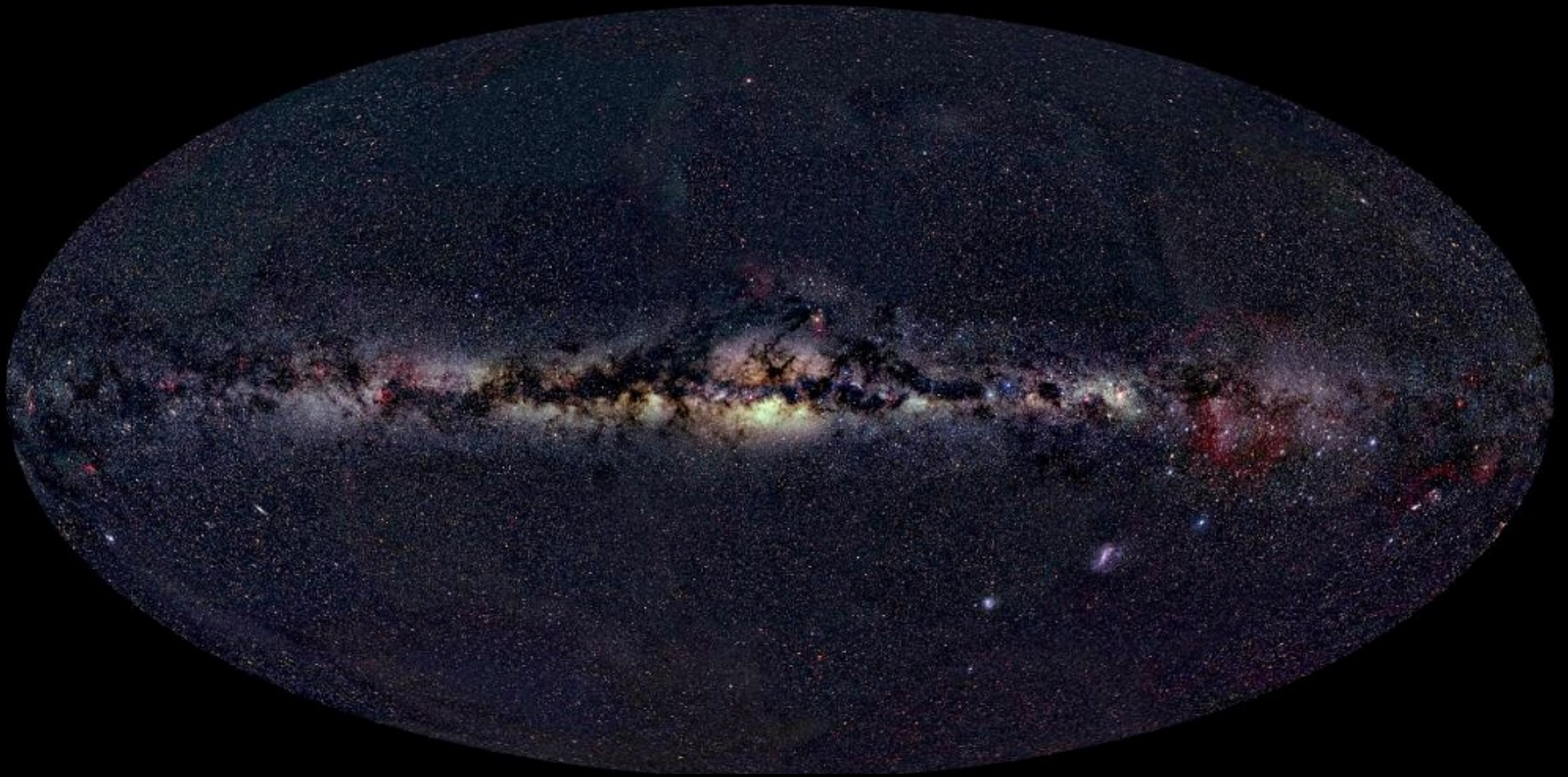
Cosmic Horizons – Microwave Radiation

380.000 years after the Big Bang



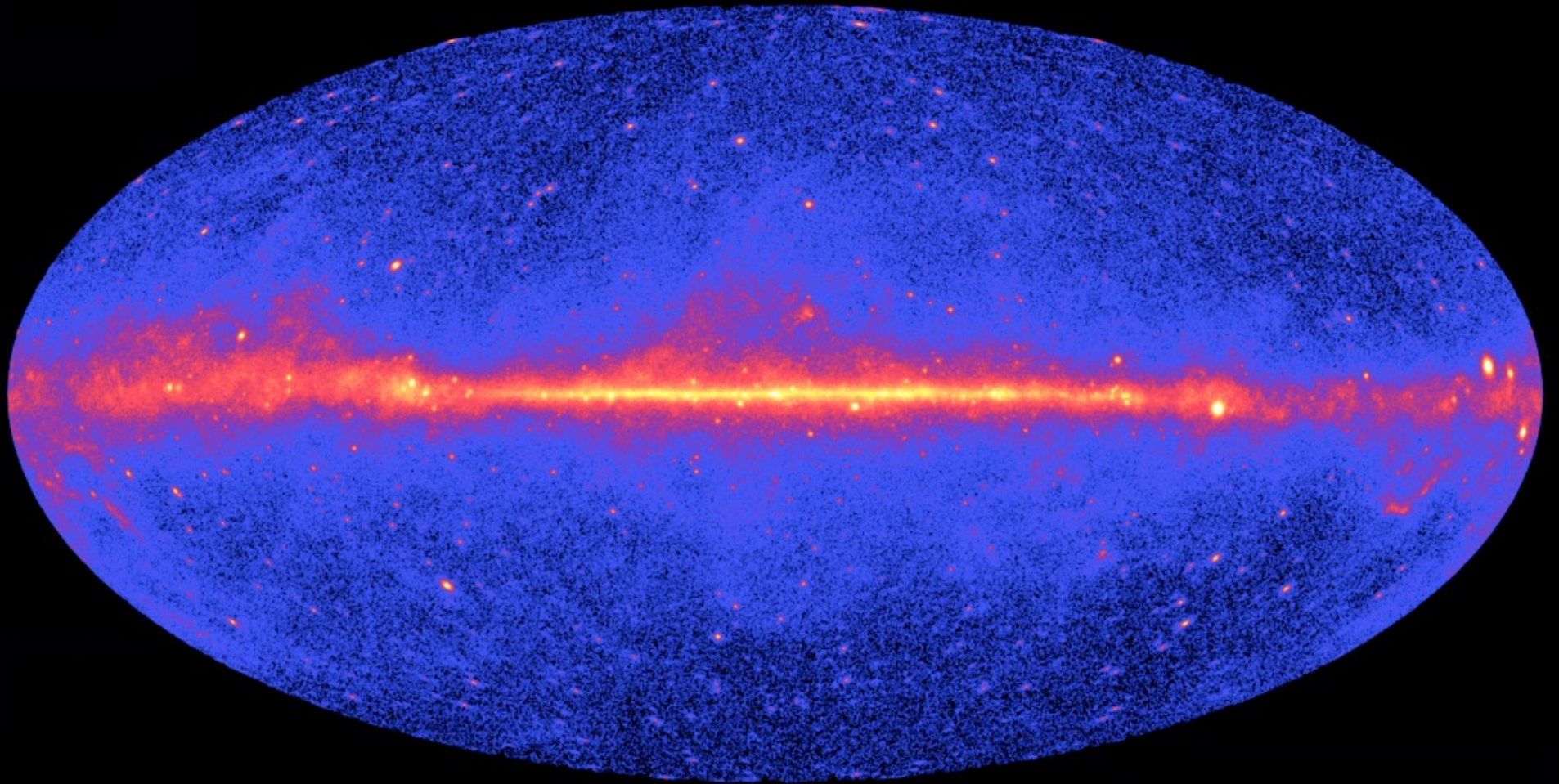
$$\lambda = 1 \text{ mm} \Leftrightarrow E = 10^{-4} \text{ eV}$$

Cosmic Horizons – Optical Sky



$$\lambda = 10^{-6} \text{ m} \Leftrightarrow E = 1 \text{ eV}$$

Cosmic Horizons – Gamma Radiation

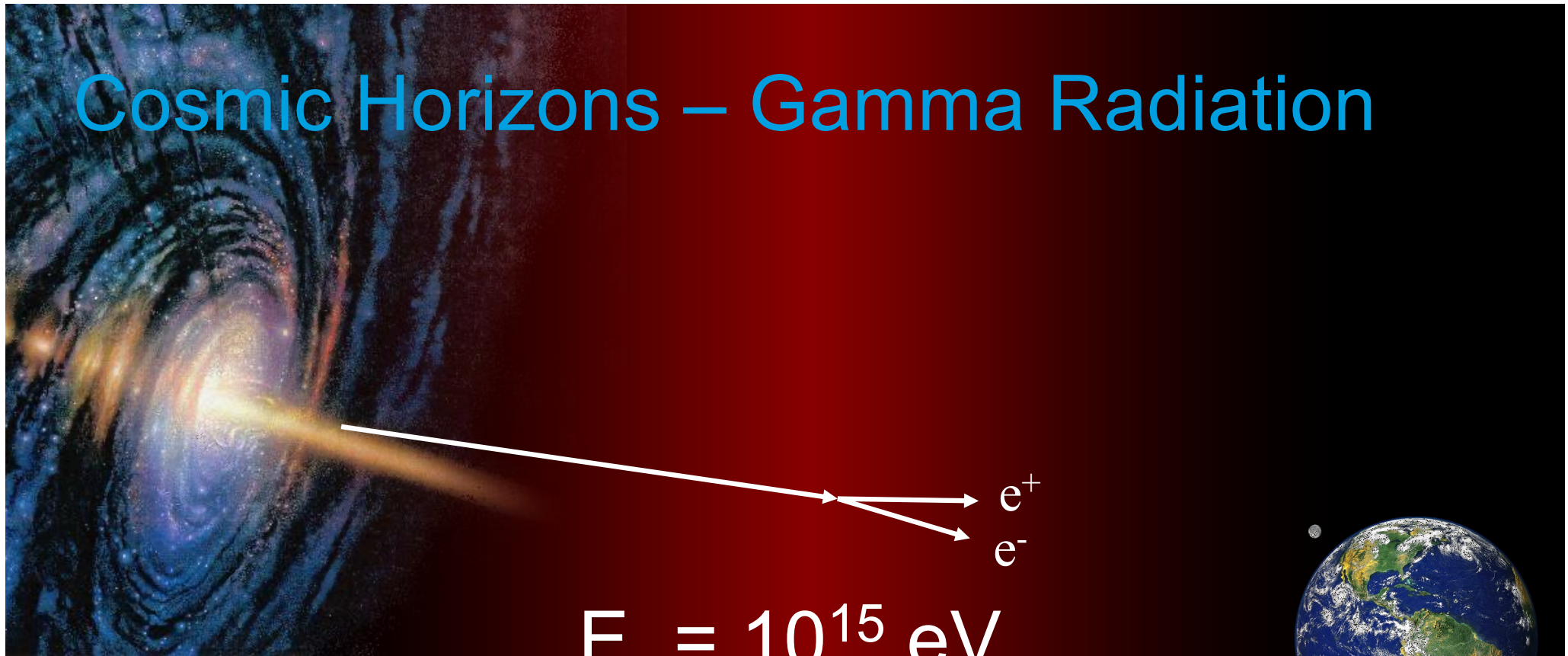


$$\lambda = 10^{-15} \text{ m} \Leftrightarrow E = 10^9 \text{ eV}$$

Cosmic Horizons – Gamma Radiation

$$E_{\gamma} = 10^{15} \text{ eV}$$

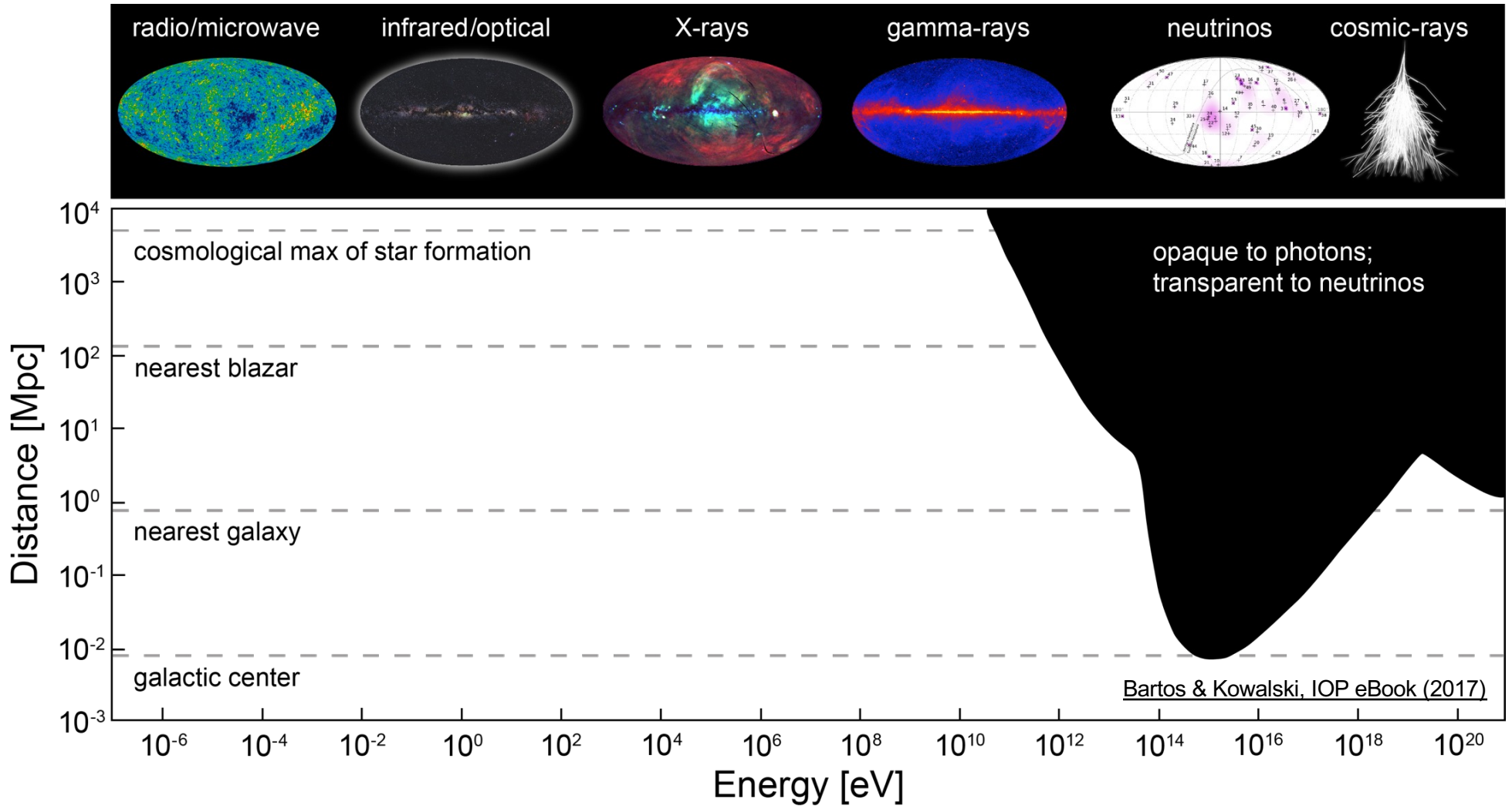
Cosmic Horizons – Gamma Radiation



$$E_{\gamma} = 10^{15} \text{ eV}$$

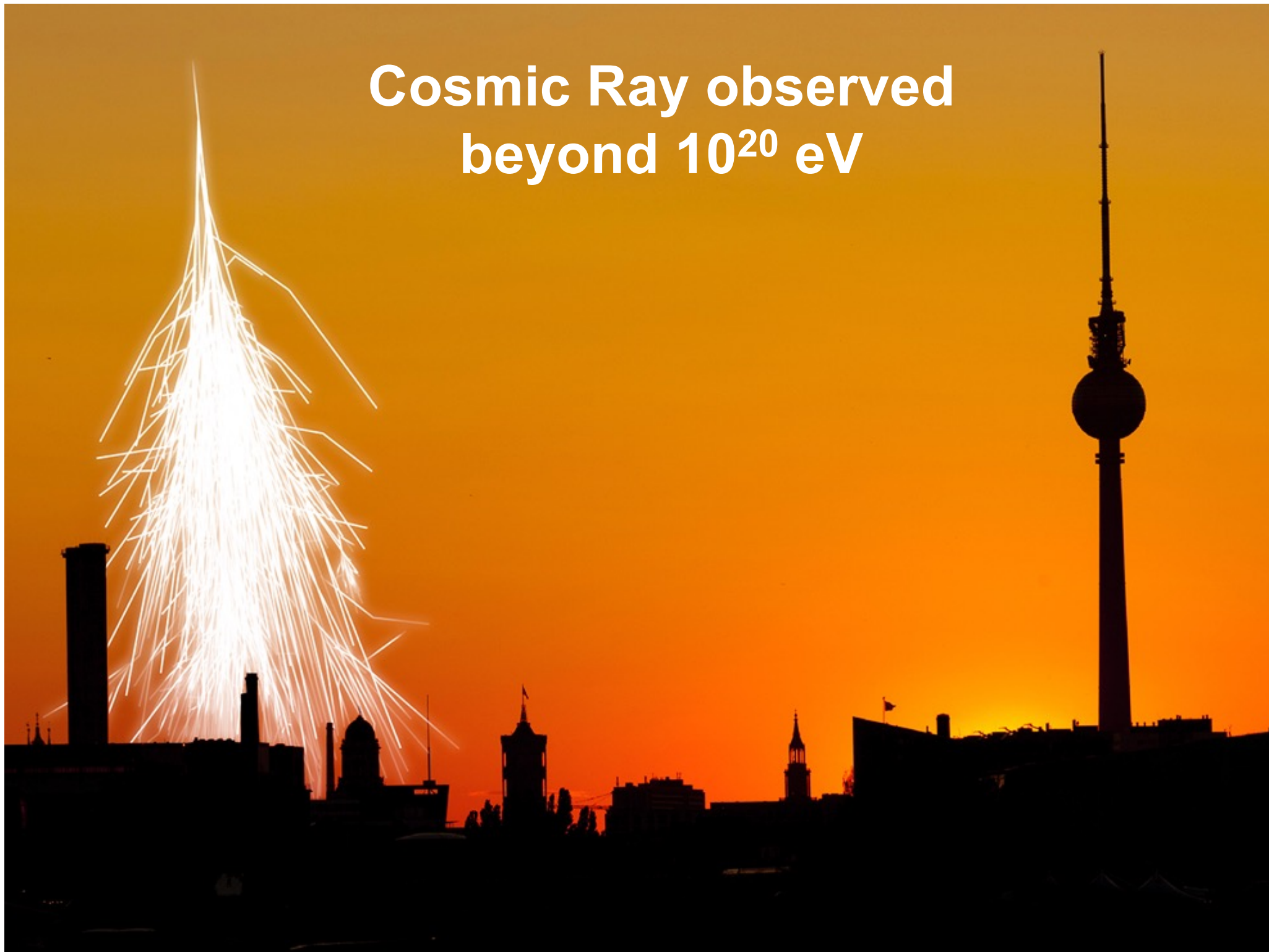
γ absorption by cosmic
microwave background

The energy frontier



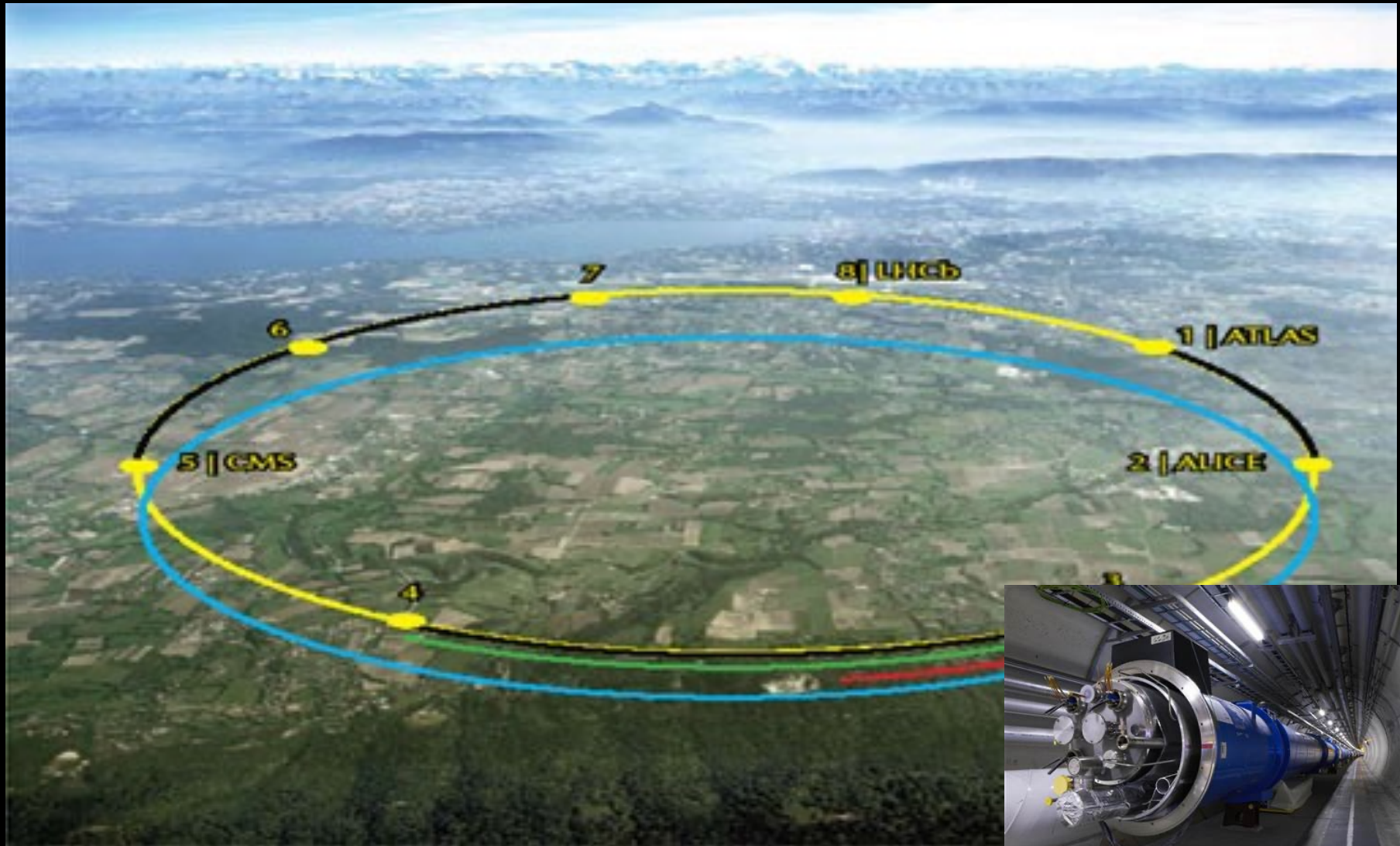
The Universe is opaque to photons for $\frac{1}{4}$ of the spectrum

**Cosmic Ray observed
beyond 10^{20} eV**

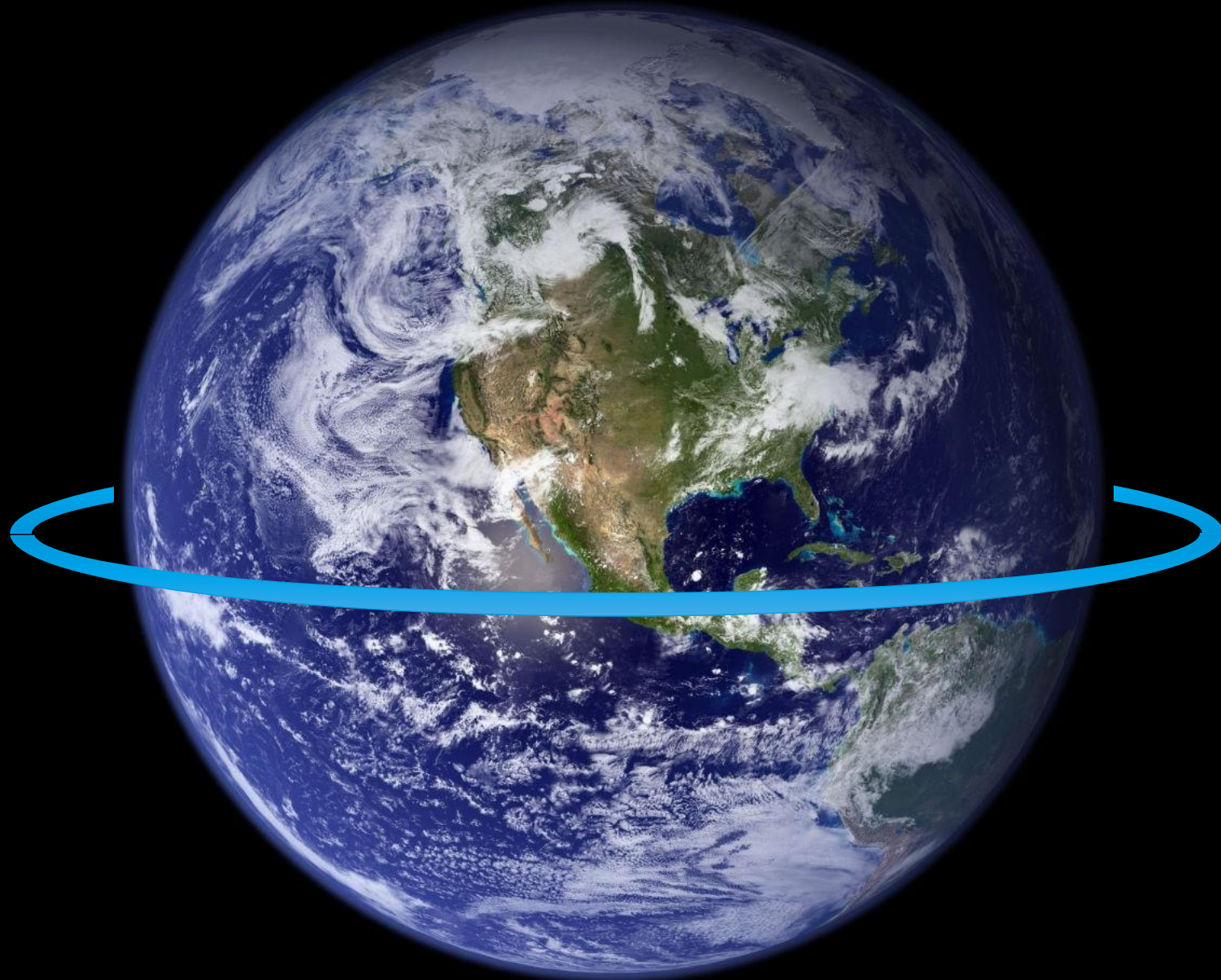


Large Hadron Collider:

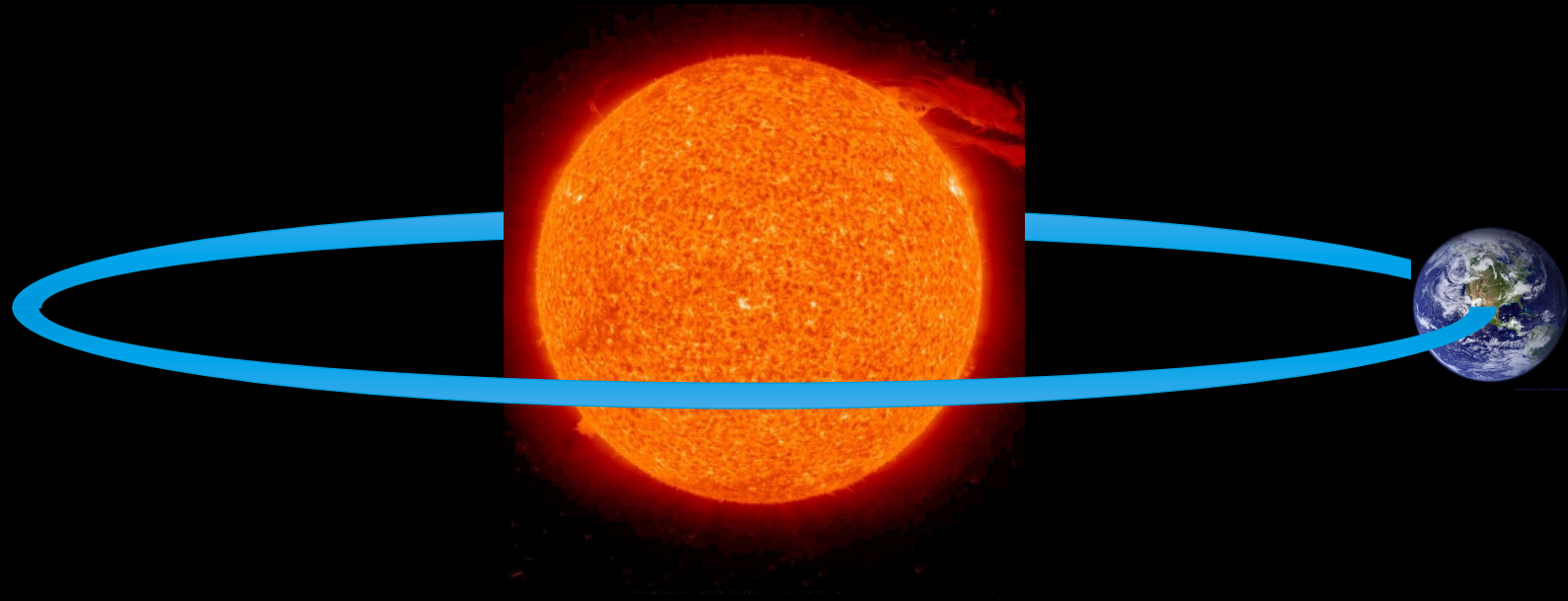
$$E_{\max} = c \cdot e \cdot B \cdot R = 7 \times 10^{12} \text{ eV}$$



Particle accelerator around the Earth : 10^3 x LHC

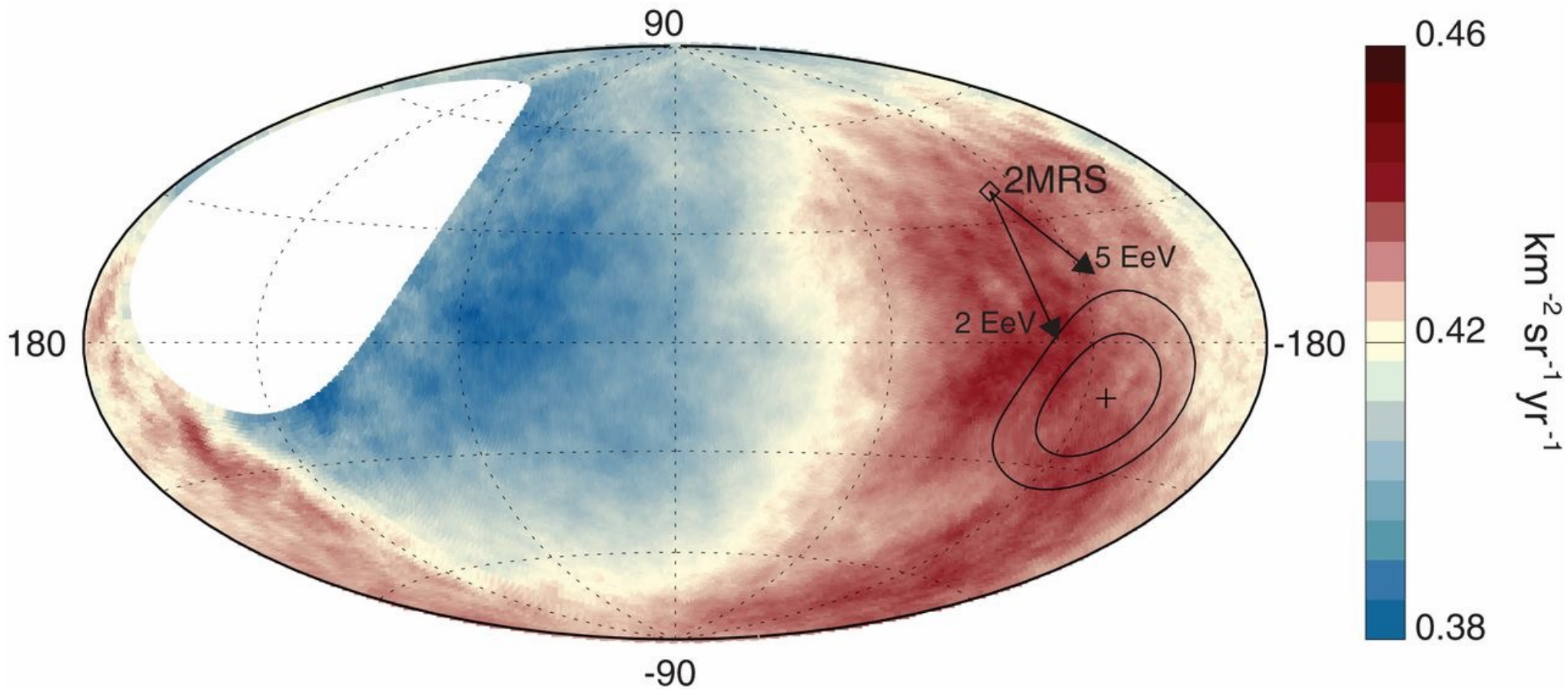


Particle accelerator around the sun: 10^7 x LHC

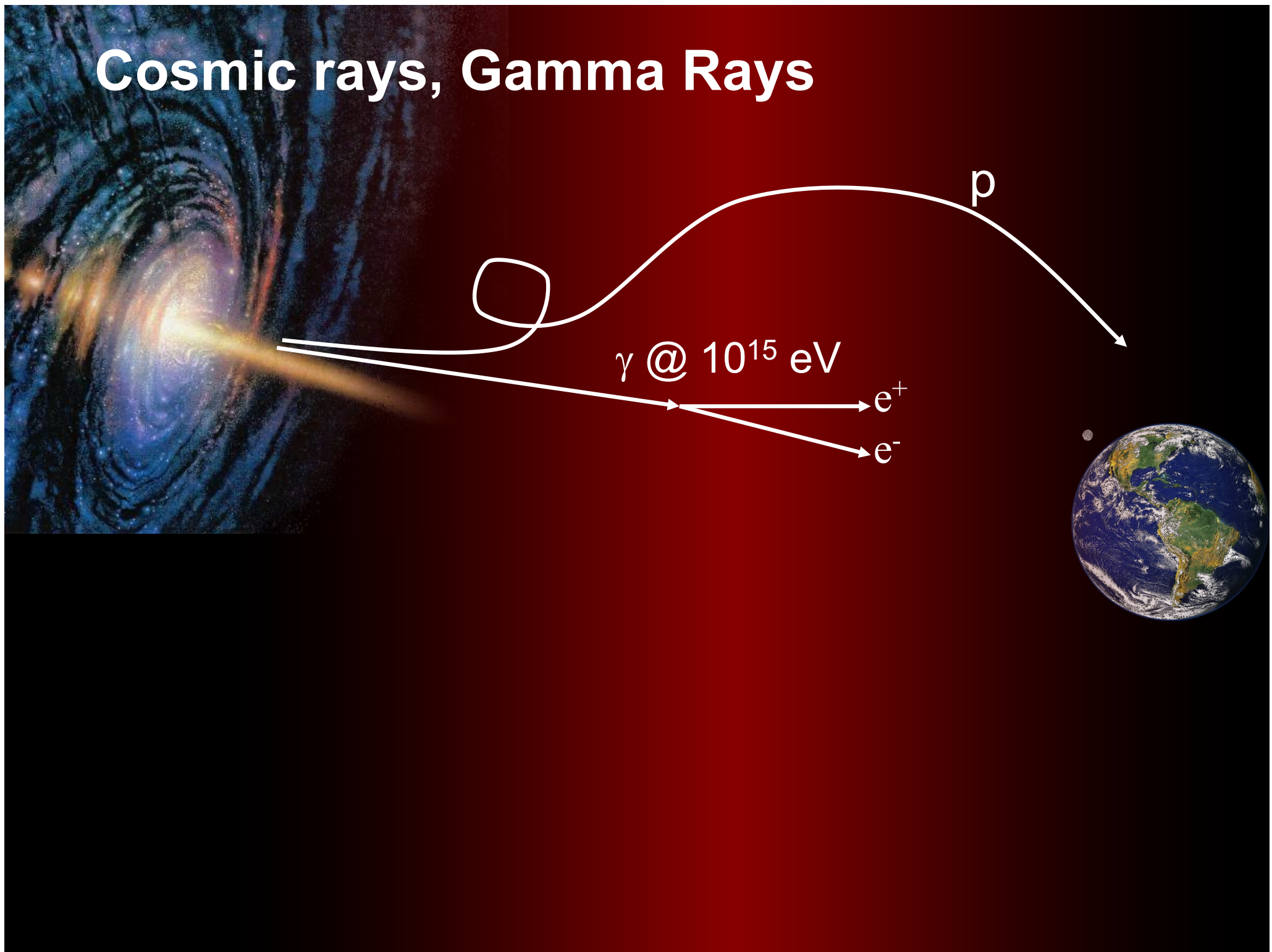


Cosmic Rays

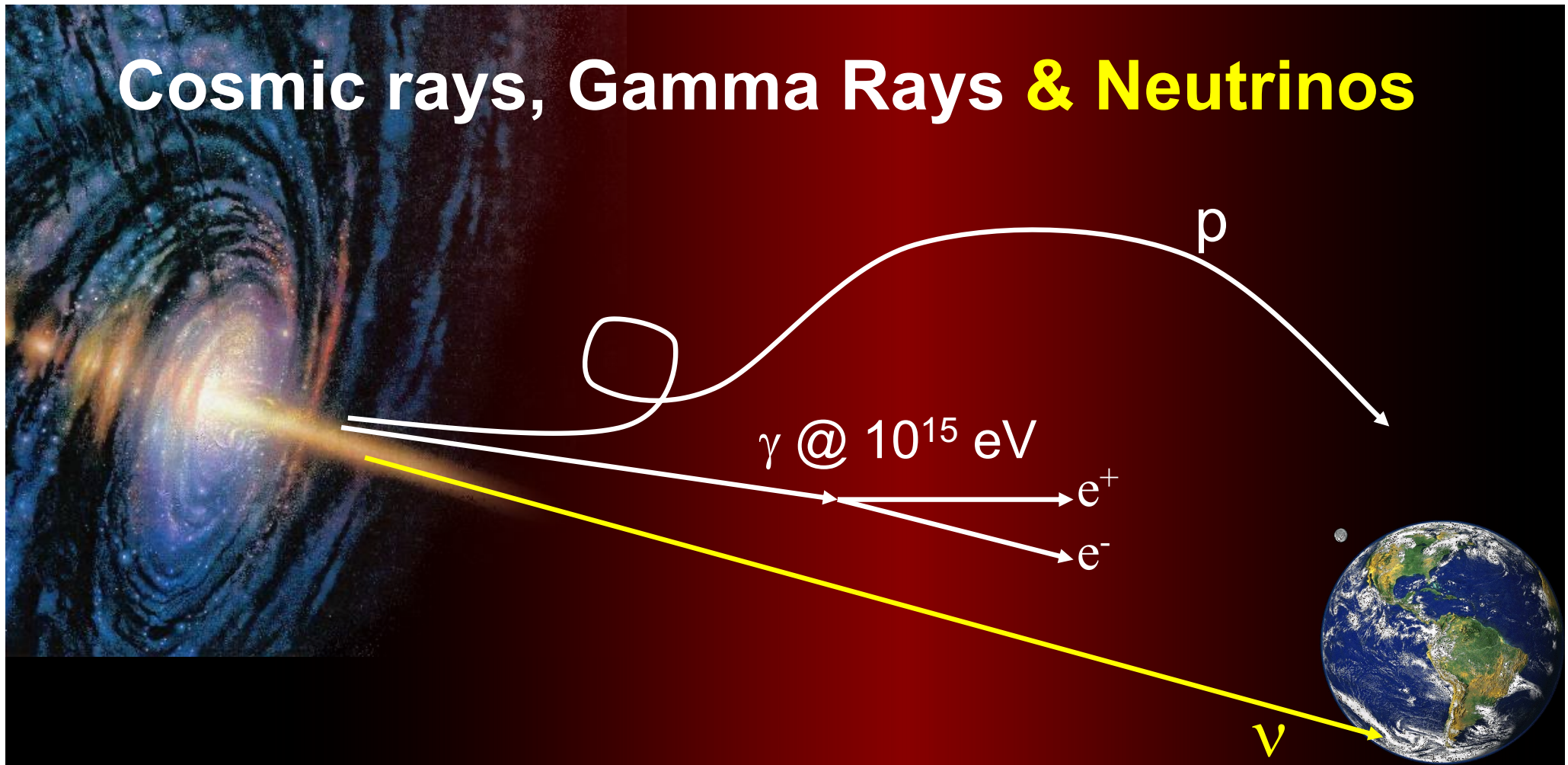
5.2 σ discovery of dipole pattern
in cosmic rays with $E > 8$ EeV
 \Rightarrow **extra galactic sources**
Auger, Science 357 (2017) 1266



Cosmic rays, Gamma Rays



Cosmic rays, Gamma Rays & Neutrinos



Neutrinos interact only weakly – they escape from regions where even X-rays are absorbed

Potential galactic sources of cosmic rays

$$E_{\max} = c \cdot e \cdot B \cdot R \sim 10^{15} \text{ eV}$$



Supernova-Remnants

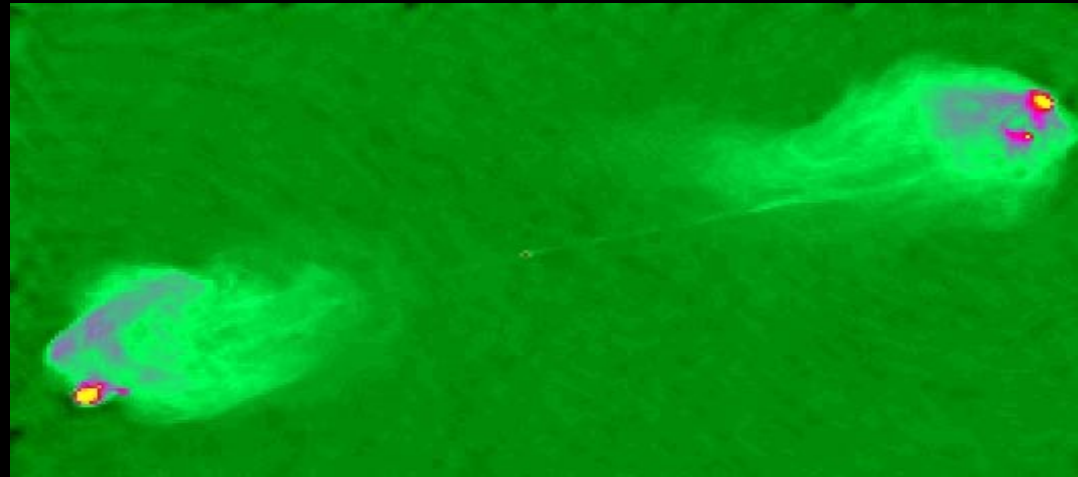
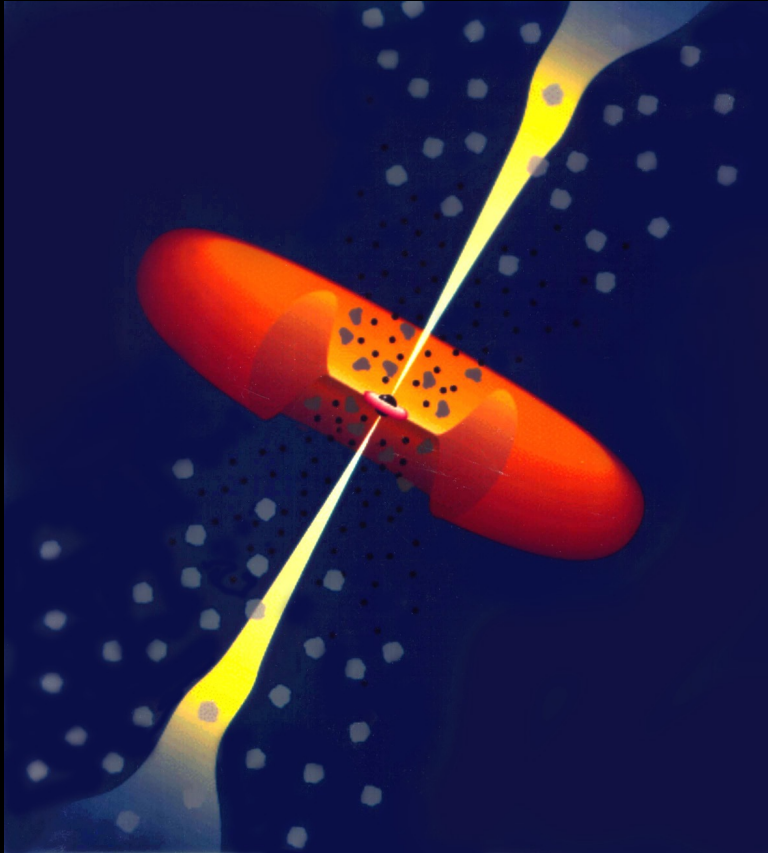
Microquasars

Pulsars

...

Potential extra-galactic sources of cosmic rays

$$E_{\max} = c \cdot e \cdot B \cdot R \sim 10^{20} \text{ eV}$$



Active Galactic Nuclei / Blazars

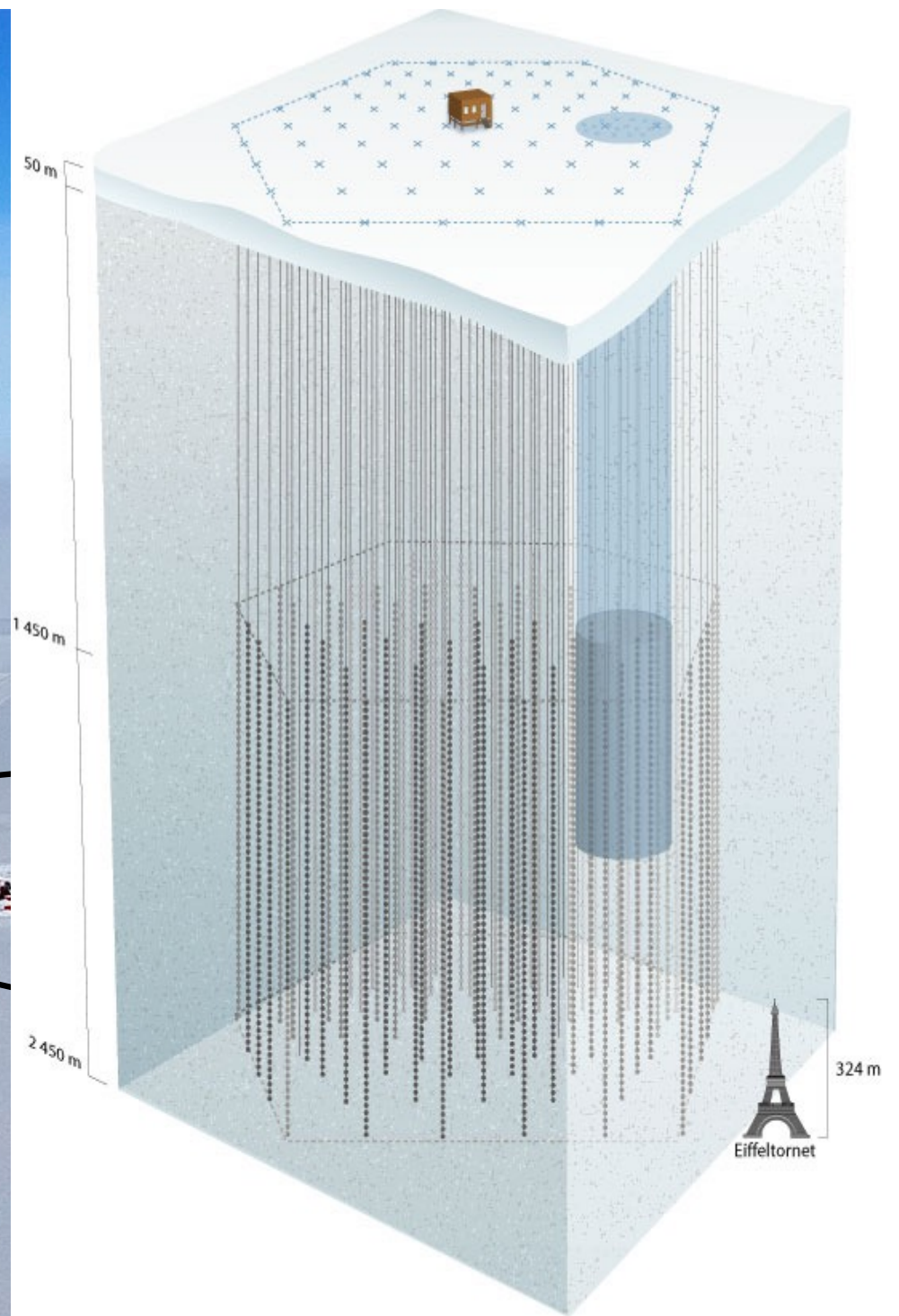
Tidal Disruption Events

...

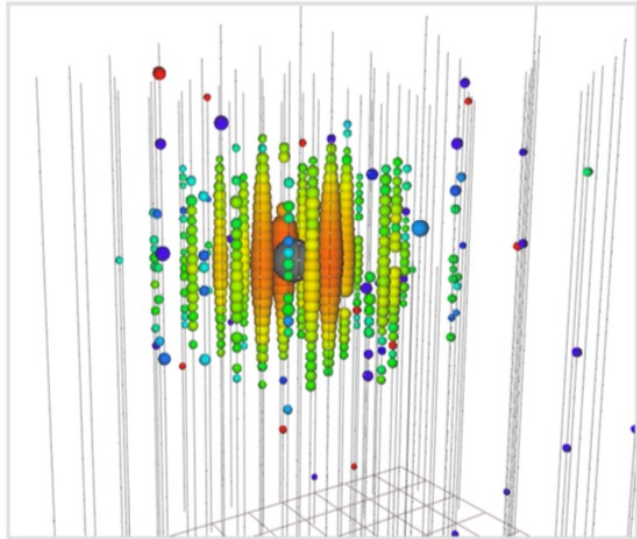
IceCube - a cubic-kilometre large neutrino observatory



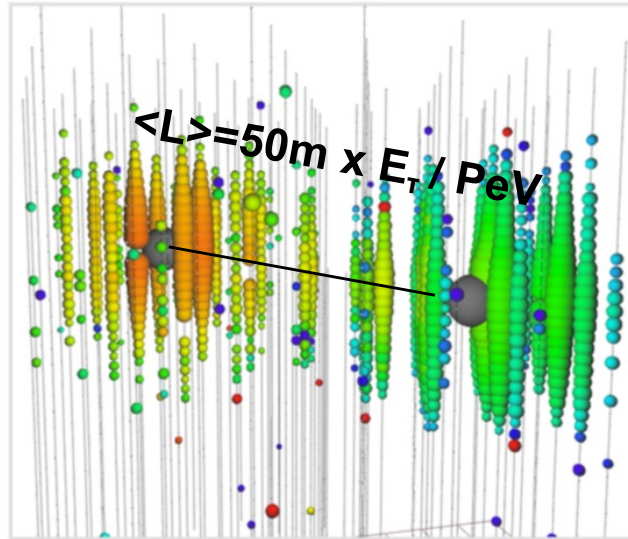
IceCube - a cubic-kilometre large neutrino observatory



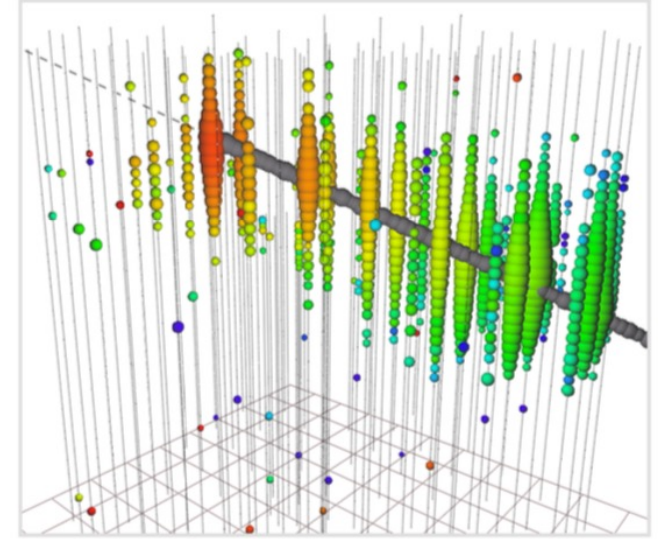
Neutrino Signatures in IceCube



Electron neutrinos:
isolated cascades

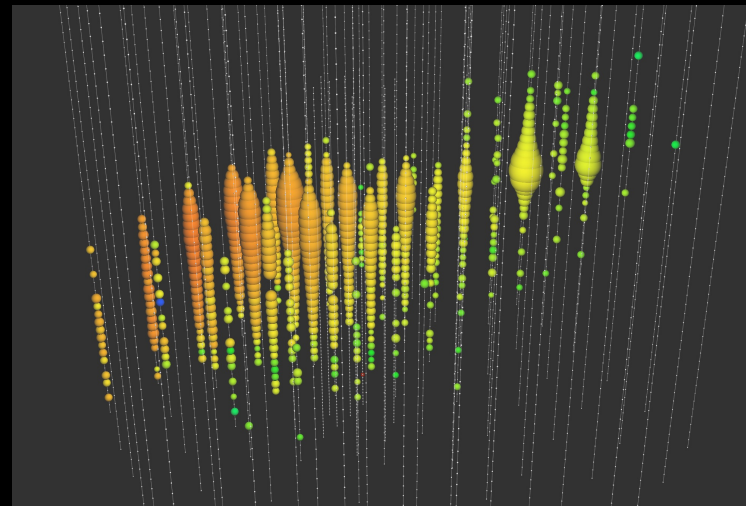
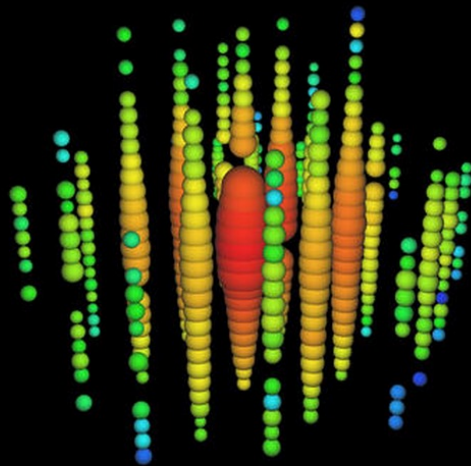
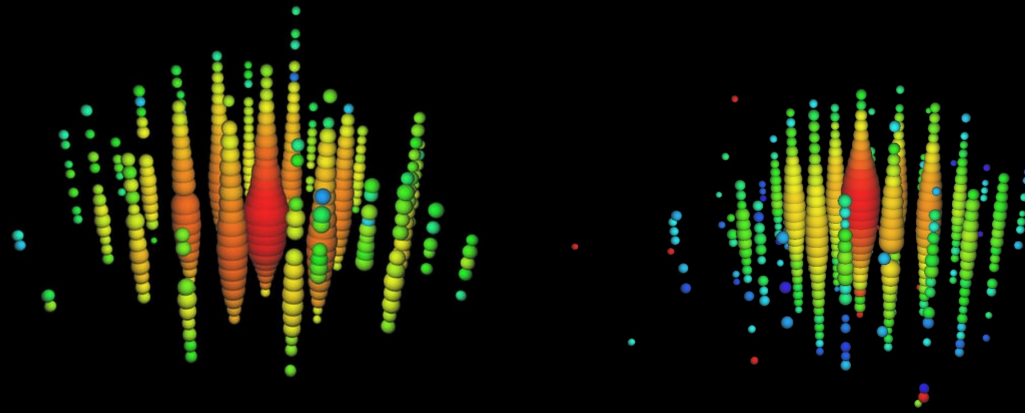


Tau neutrinos:
"double bang"



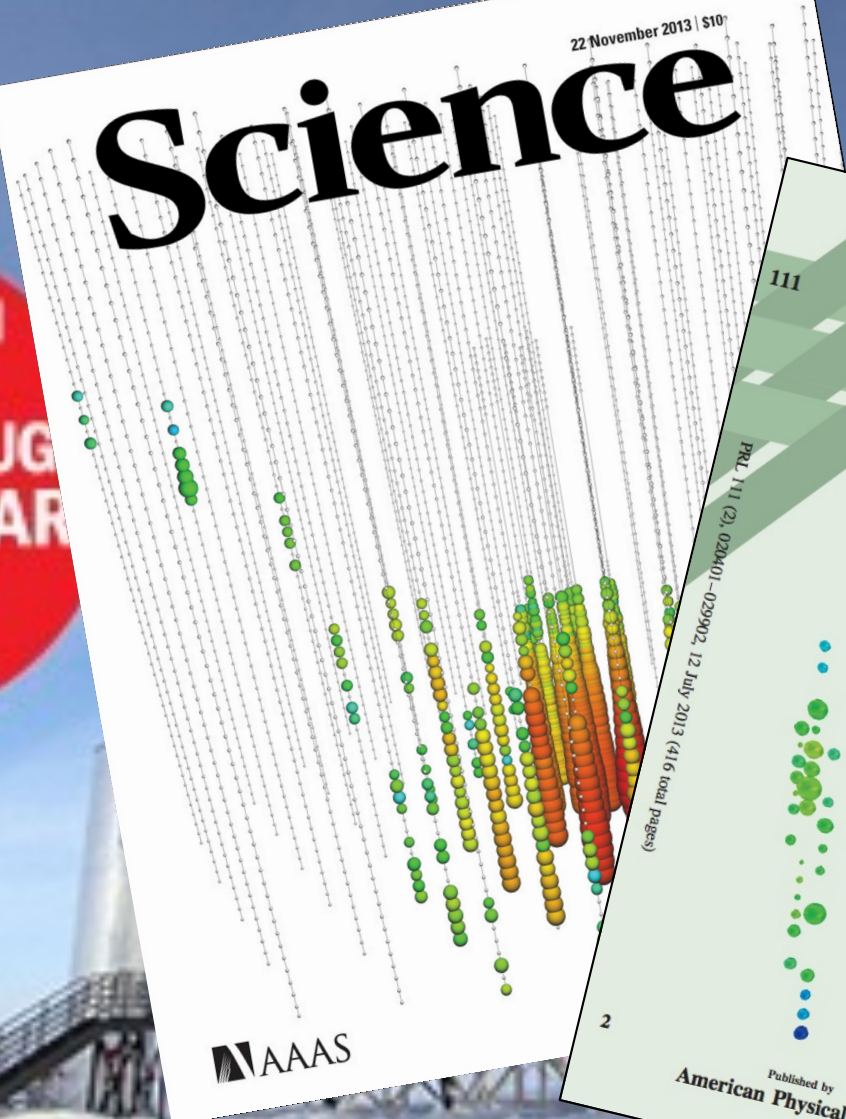
Muon neutrinos:
track-like events

Cosmic Neutrinos!



22 November 2013 | \$10

Science



AAAS

111

PHYSICAL REVIEW LETTERS

Articles published week ending 12 JULY 2013

PRL 111 (2), 020401–029902, 12 July 2013 (416 total pages)

2

Published by
American Physical Society.



Volume 111, Number 2

physicsworld
**BREAKTHROUGH
OF THE YEAR
2013**

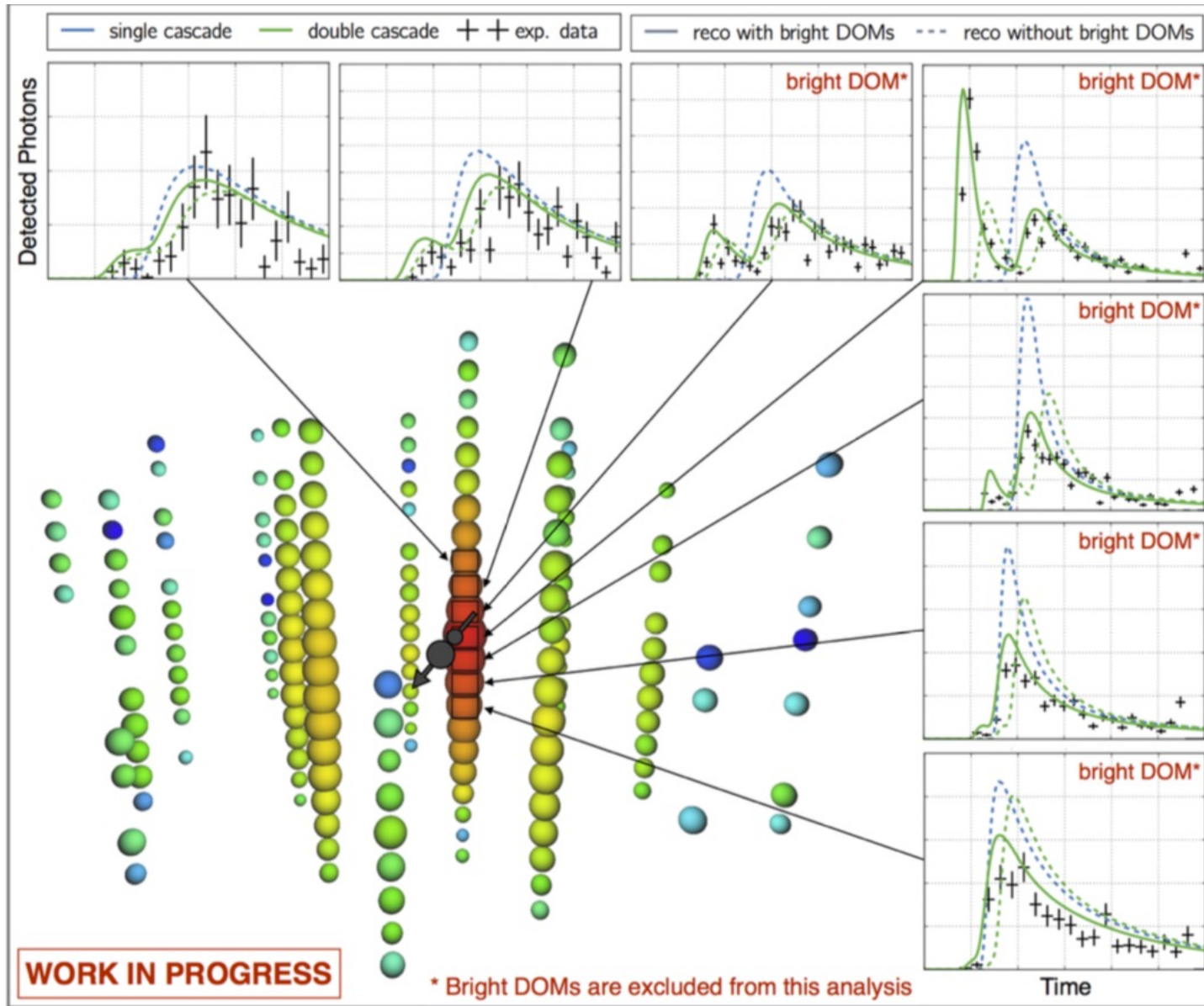


ICECUBE



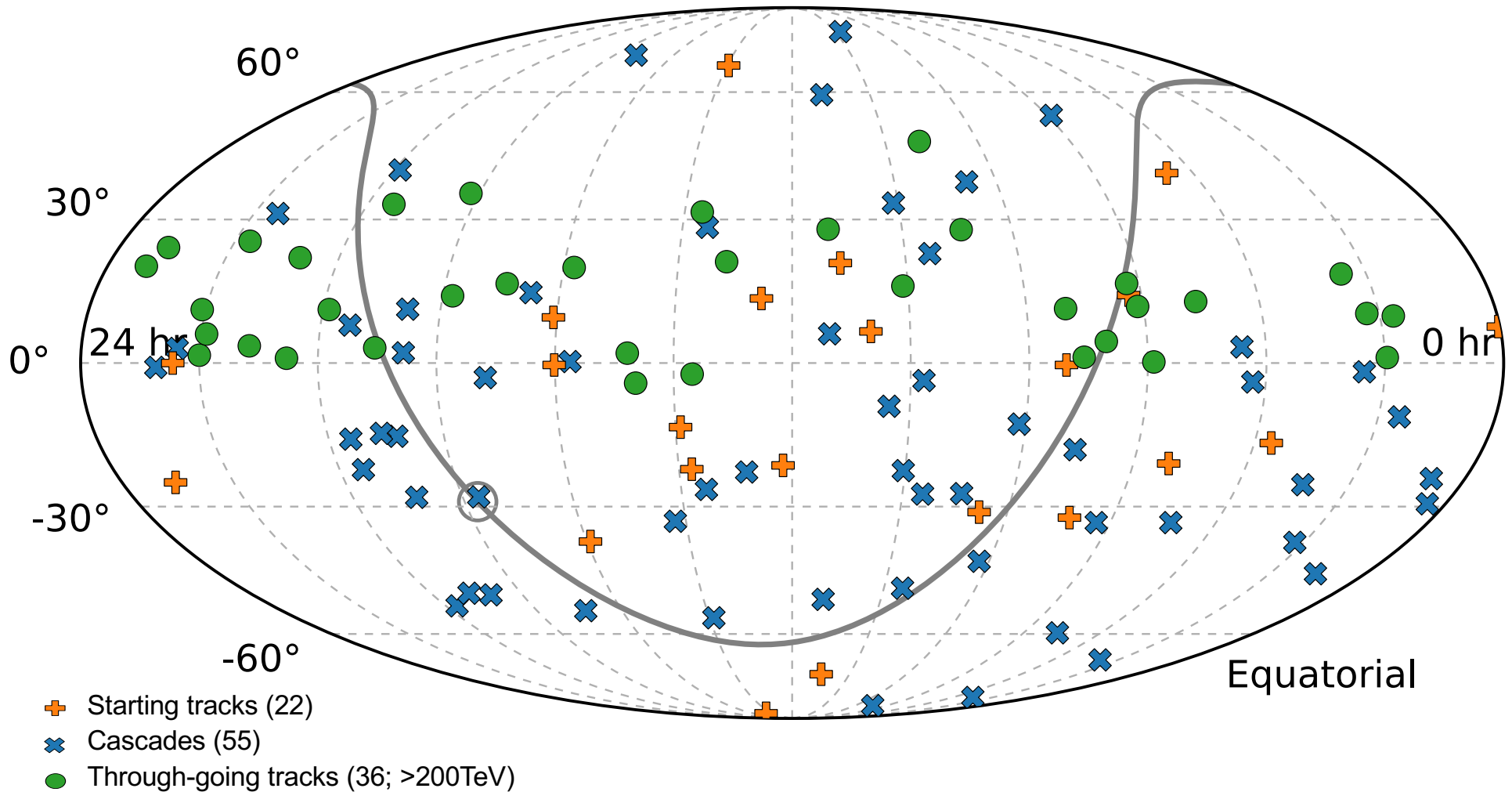
NSF

A first candidate tau neutrino event



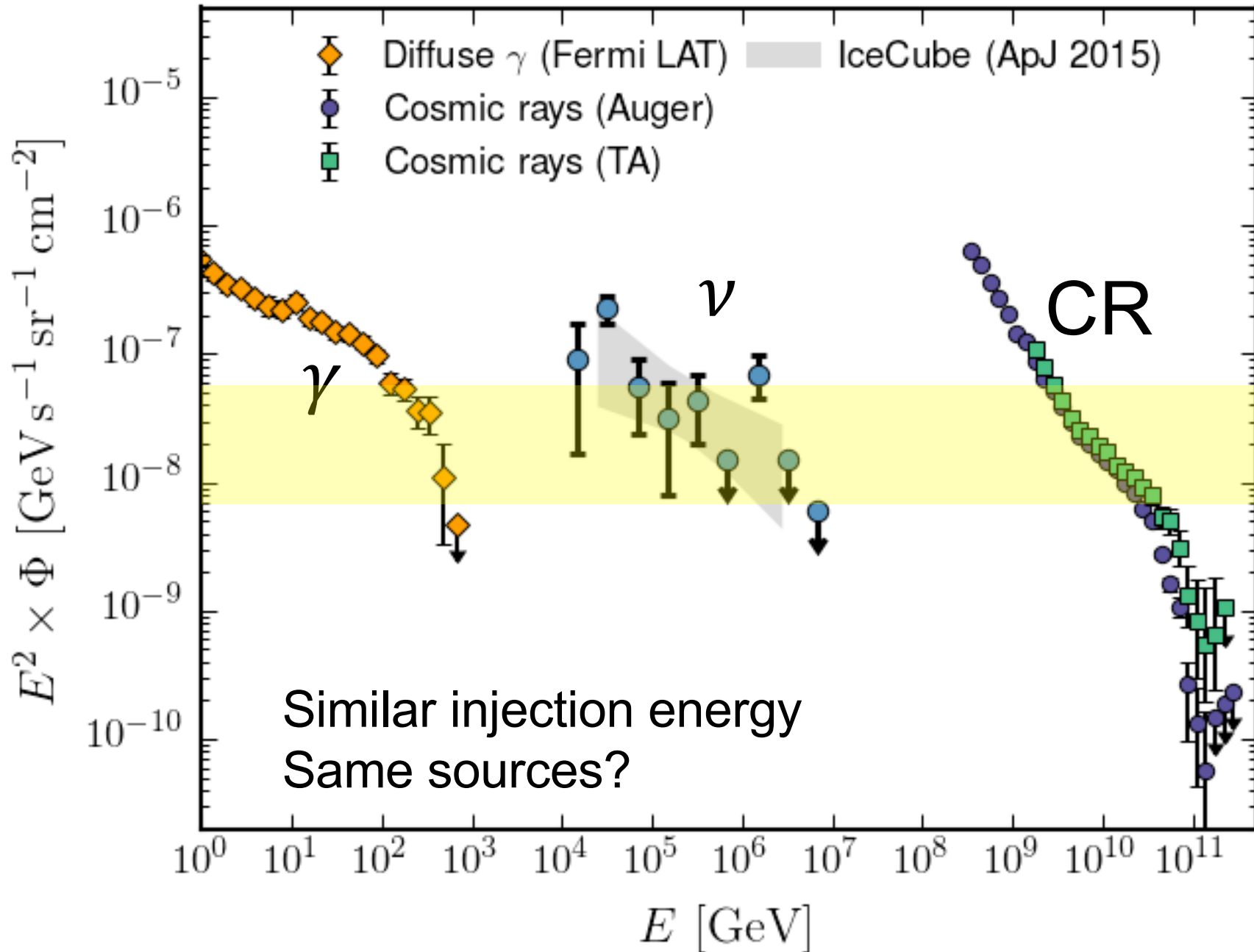
J. Stachurska, DESY

Astrophysical neutrinos



mostly isotropic \Rightarrow neutrinos of extragalactic origin

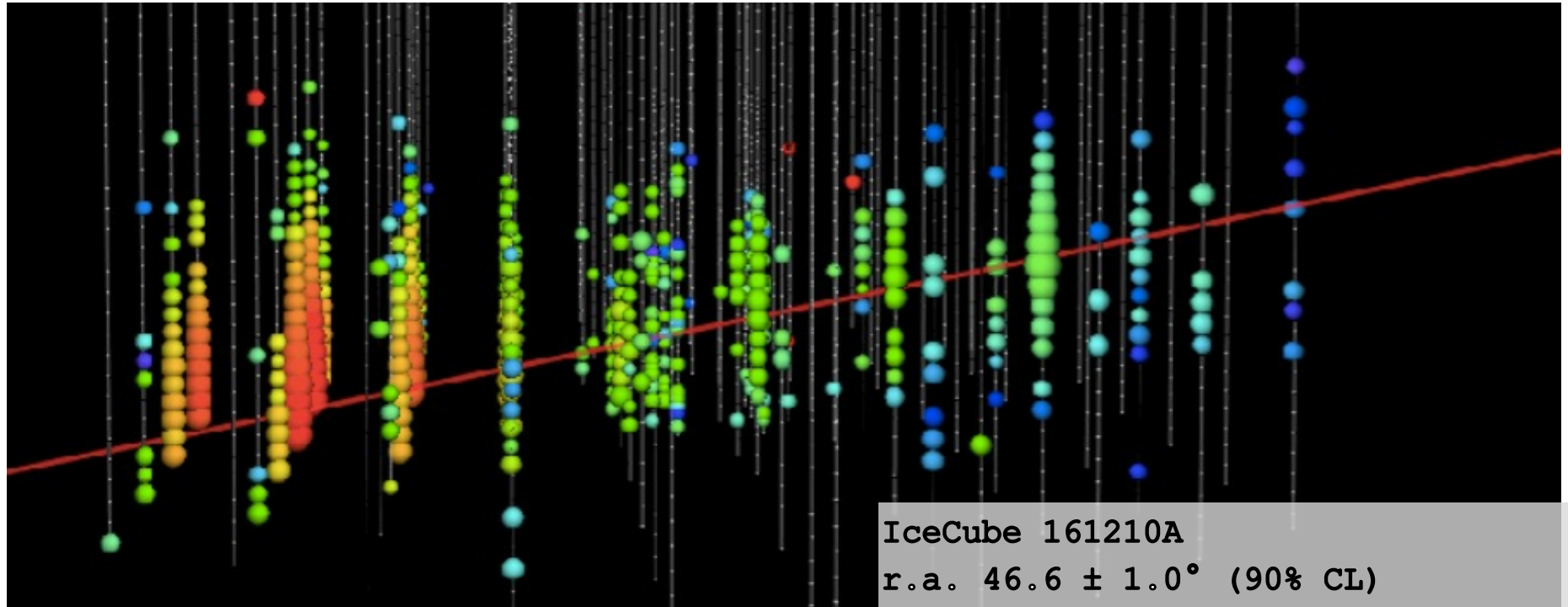
Multimessenger Spectroscopy



**What are the sources
of our high-energy
neutrinos?**

Realtime high-energy neutrino alerts

Public alert stream running since April 2016, so far ~100 alerts



IceCube 161210A

r.a. $46.6 \pm 1.0^\circ$ (90% CL)

dec $15.0 \pm 0.4^\circ$ (90% CL)

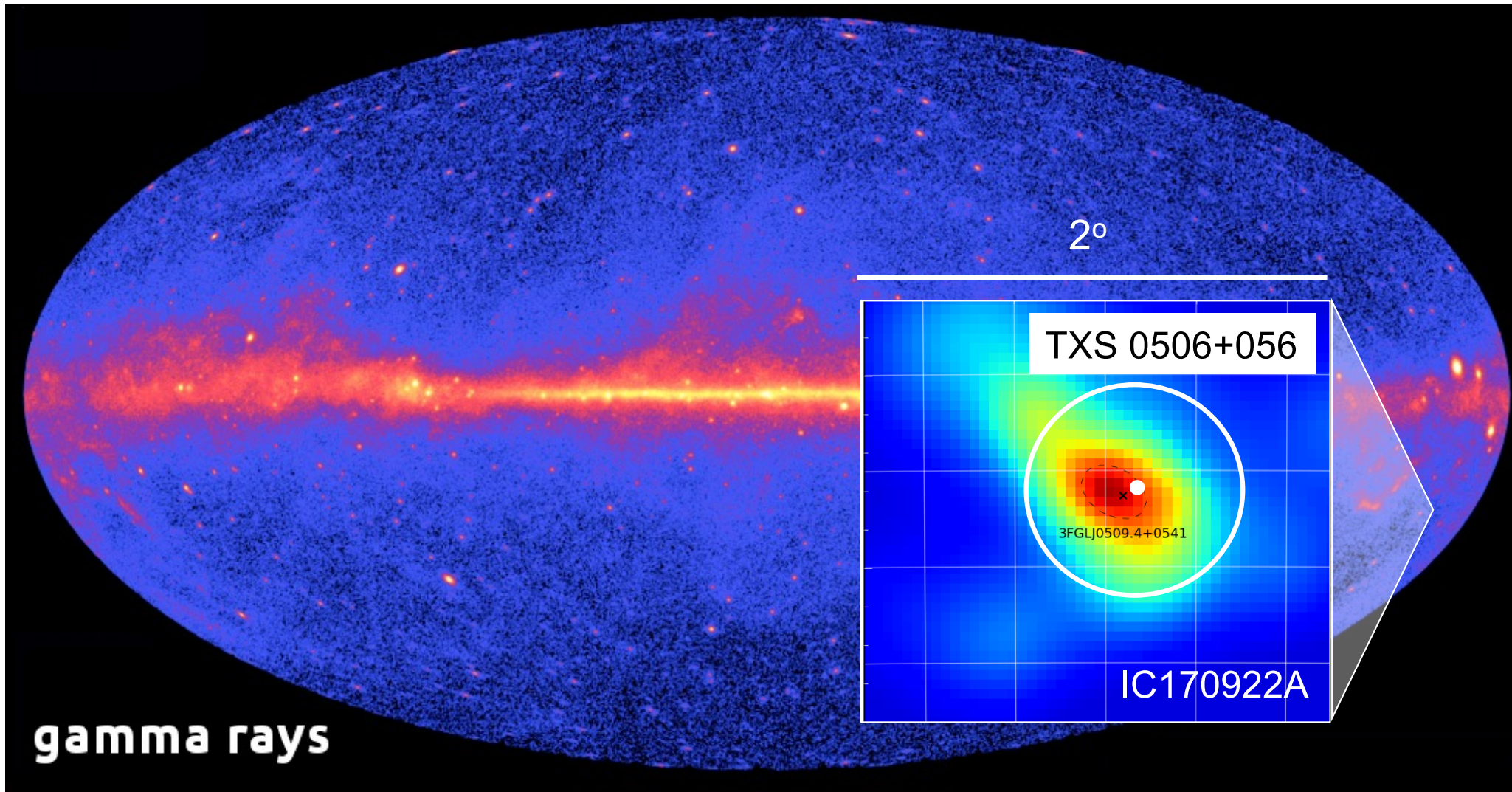
Energy: ~ 100 TeV

Astrophysical signal probability:
49%

https://gcn.gsfc.nasa.gov/other/icecube_161210.gcn3

Realtime high-energy neutrino alerts

Alert #10: IceCube 1709922A



Event coincident with known GeV gamma-ray emitting Blazar

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

ATel #10791; *Yasuyuki T. Tanaka (Hiroshima University), Sara Buson (NASA/GSFC),*

Further Swift-XRT observations of IceCube 170922A

ATel #10792; *P. A. Evans (U. Leicester) A. Keivani (PSU), J. A. Kennea (PSU), D. B. Fox (PSU), D. E. Cowen (PSU), J. P. Osborne (U. Leicester), and E. F. Marshall*

ASAS-SN optical light-curve of blazar TXS 0506+056, located inside the IceCube-170922A error region, shows increased optical activity

ATel #10794; *A. Franckowiak (DESY), K. Z. Stanek, C. S. Kochanek, T. A. Thompson (OSU), T. W. S. Holoian, B. J. Shappee (Carnegie Observatories), J. J. Prieto*

AGILE confirmation of gamma-ray activity from the IceCube-170922A error region

ATel #10801; *F. Lucarelli (SSDC/IASI and INAF/OAR), G. Piano (INAF/IAPS), C. Pittori, F. Verrecchia (SSDC/IASI and INAF/OAR), M. Tavani (INAF/IAPS, and Univ. Roma Tor Vergata), A. Bulgarelli (INAF/IASF-Bo), P. Munar-Adrover, G. Minervini, A. Ursi (INAF/IAPS), S. Vercellone (INAF/OA-Brera), I. Donnarumma (ASI), V. Fioretti, A. Zoli (INAF/IASF-Bo), E. Striani (CIFS and INAF/IAPS), M. Cardillo (INAF/OA-Astropis and INAF/IAPS), F. Ciampi, M. Toffi (INAF/IASF-Bo)*

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*

Joint Swift XRT and NuSTAR Observations of TXS 0506+056

ATel #10845; *D. B. Fox (PSU), J. J. DeLaunay (PSU), A. Keivani (PSU), P. A. Evans (U. Leicester), C. F. Turley (PSU), J. A. Kennea (PSU), D. F. Cowen (PSU), J. P. Osborne (U. Leicester), M. S. Smith (U. Leicester), and E. F. Marshall (PSU)*

MAXI/GSC observations of IceCube-170922A and TXS 0506+056

ATel #10838; *H. Negoro (Nihon U.), S. Ueno, H. Tomida, M. Ishikawa, Y. Sugawara, N. Isobe, R. Shimomukai (JAXA), T. Mihara, M. Sugizaki, S. Nakahira, W. Iwakiri, M. Shidatsu, F. Yatabe, Y. Takao, M. Matsuoka (RIKEN), N. Kawai, S. Sugita, T. Yoshii, Y. Tachibana, S. Harita, K. Morita (Tokyo Tech), A. Yoshida, T. Sakamoto, M. Serino, Y. Kawakubo, Y. Kitaoka, T. Hashimoto (AGU), H. Tsunemi, T. Yoneyama, M. Mori, A. ...*

VLA Radio Observations of the blazar TXS 0506+056 associated with the IceCube-170922A neutrino event

ATel #10861; *A. J. Tetarenko, G. R. Sivakoff (UAlberta), A. E. Kimball (NRAO), and J. C.A. Miller-Jones (Curtin-ICRAR) on 17 Oct 2017; 14:08 UT*

High energy neutrino alerts

Aartsen et al, Science 361 (2018)

p-value $\sim 10^{-3}$

2°

TXS 0506+056

3FGLJ0509.4+0541

IC170922A

TeV gamma-ray emitting Blazar

MULTIMESSENGER ASTRONOMY

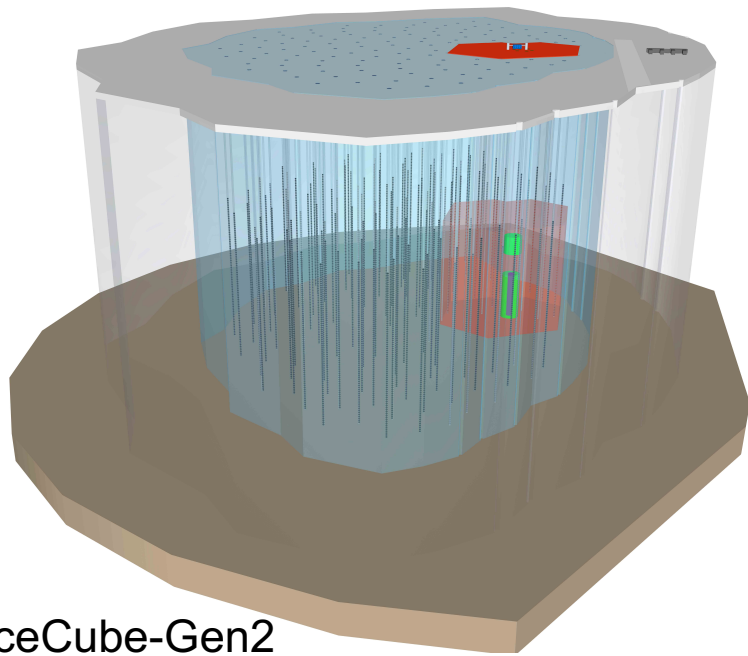


Artists impression of TXS056+56

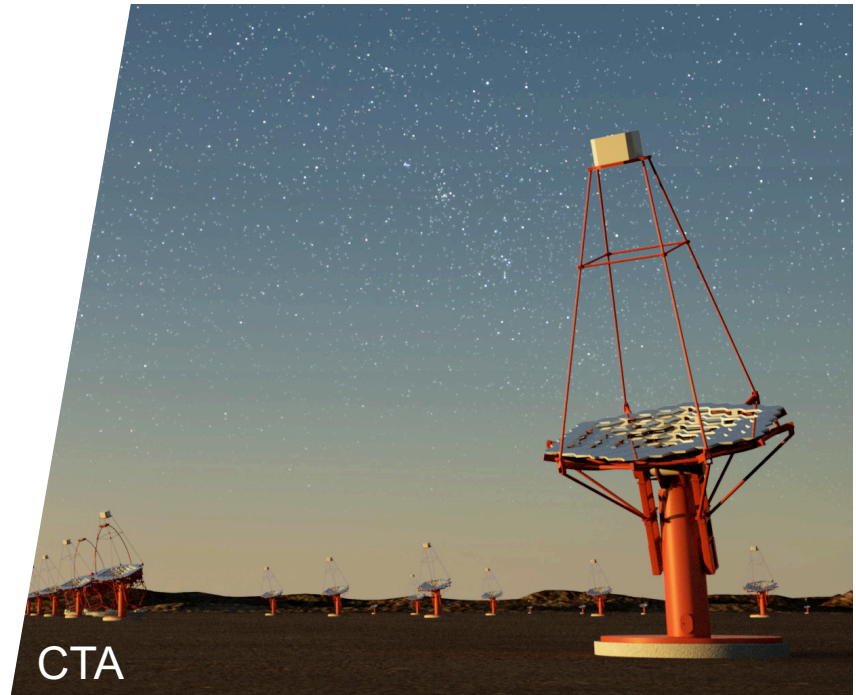
More evidence for sources: Two neutrino alerts point to Tidal Disruption Events (TDEs)

p-value = 2×10^{-3}

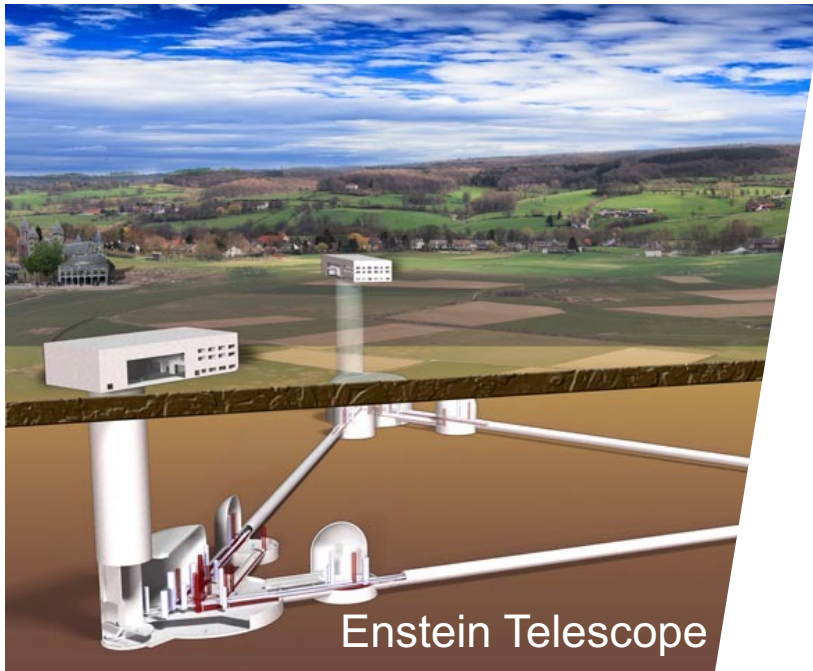




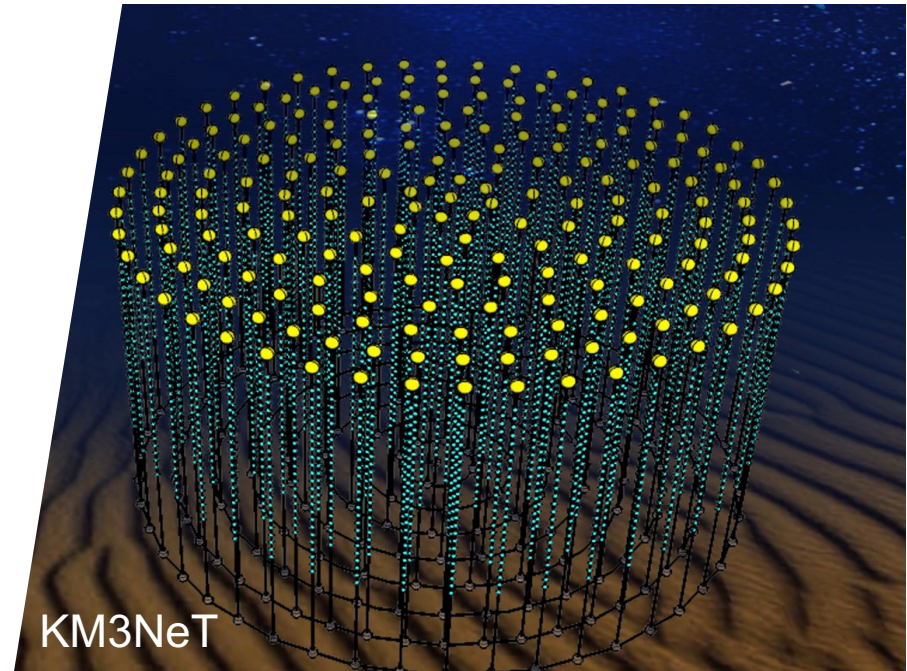
IceCube-Gen2



CTA



Einstein Telescope



KM3NeT

Conclusion

- After the first detection of high-energy cosmic neutrinos a decade ago, we are now identifying first likely sources
- Multimessenger techniques and instruments continuously improving, more detections expected, further inter-connecting the field
- A rapidly evolving field, with broad implications for physics and astronomy