Multi-messenger Astrophysics with IceCube

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IceCube Summer School 2023

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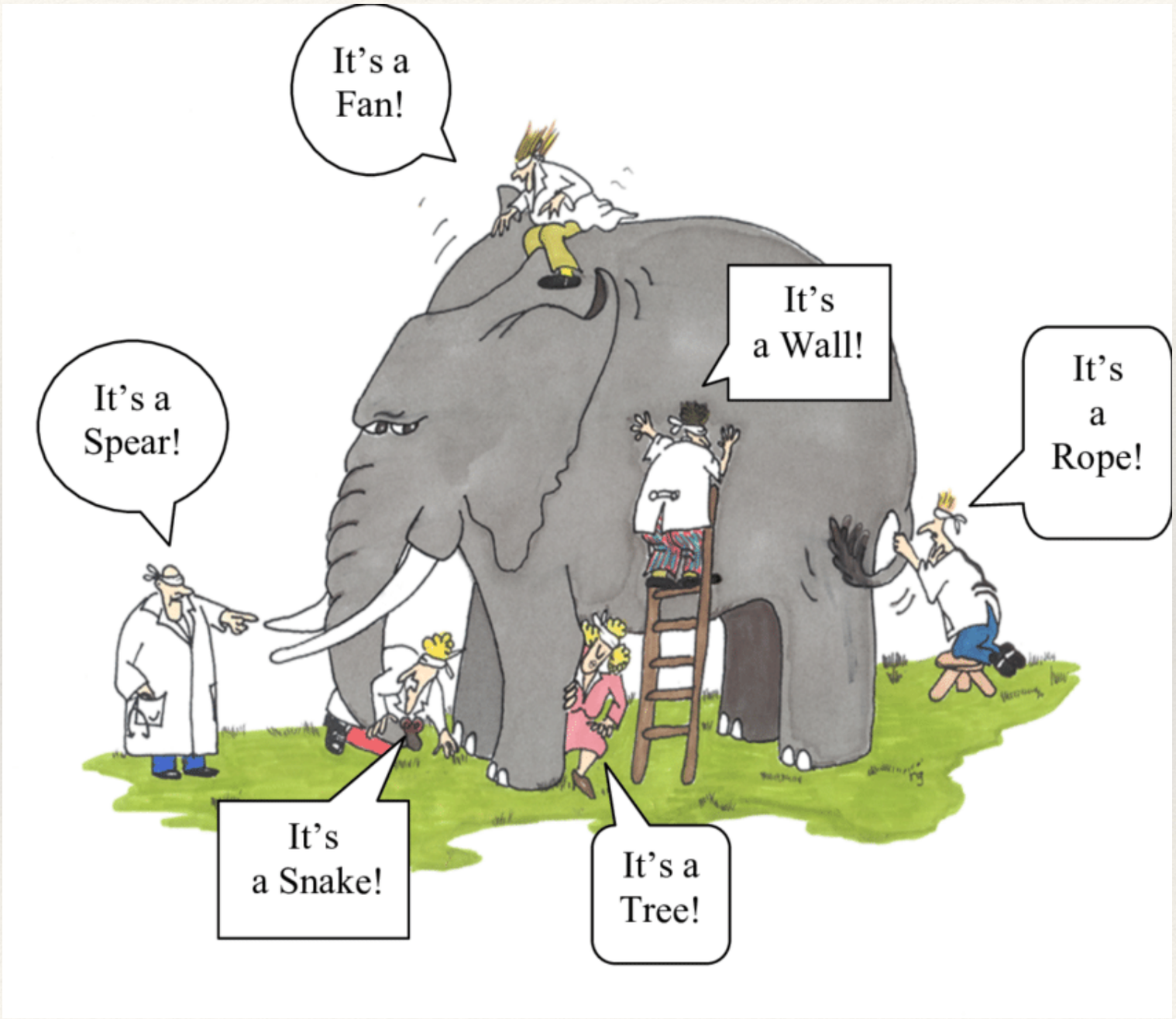
The Multi-messenger Picture

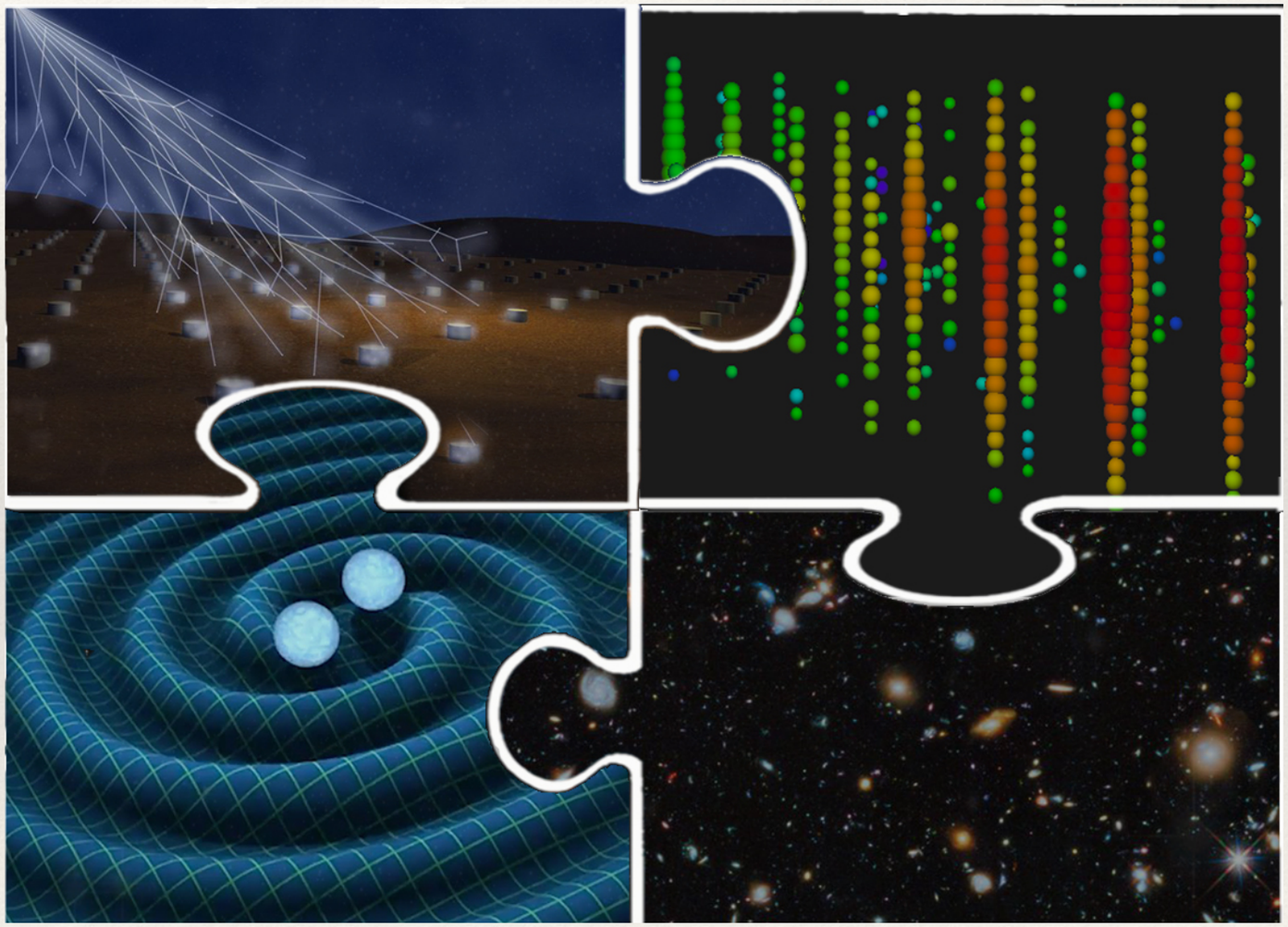
The Blind Researchers And The Elephant



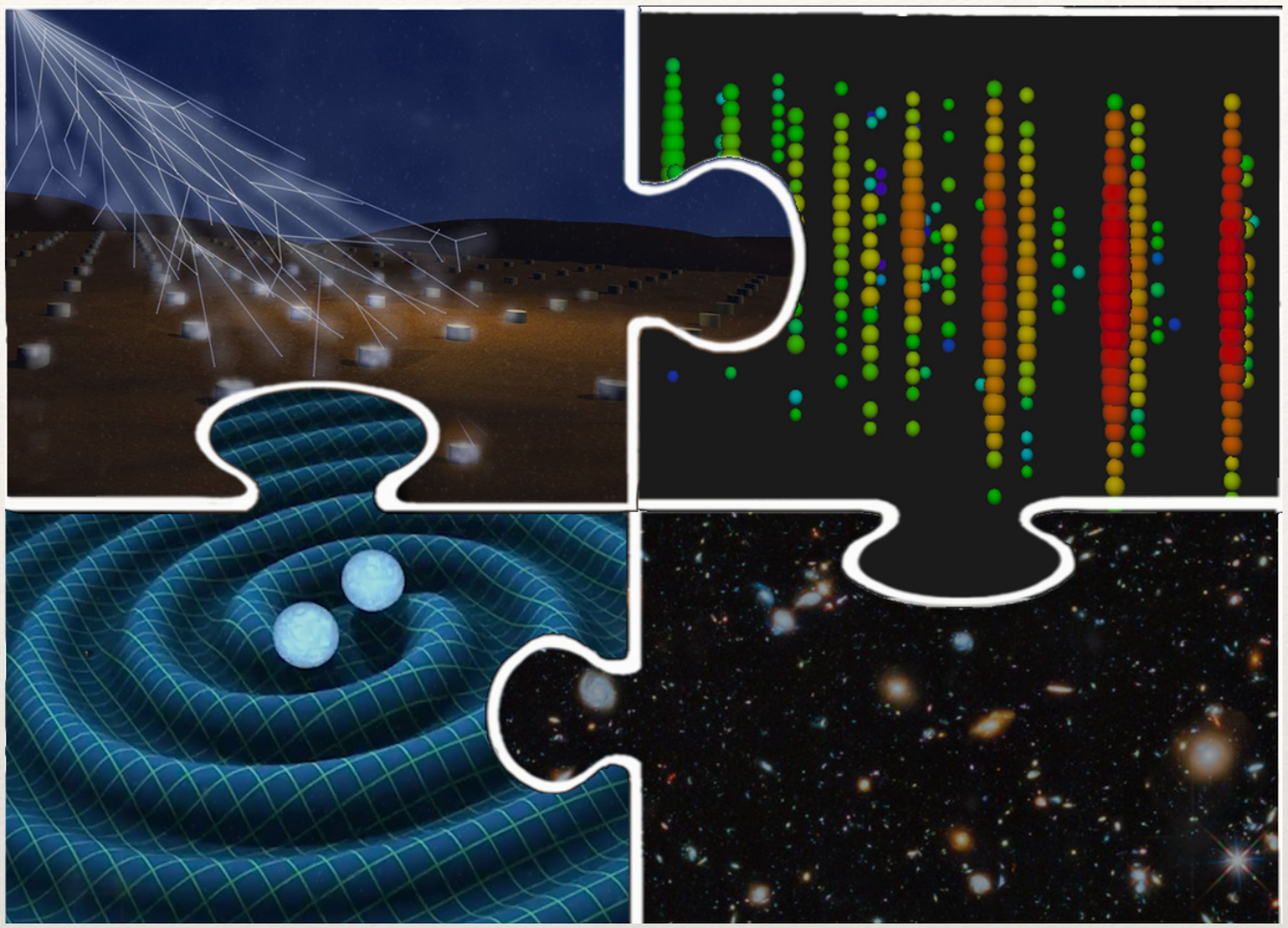
The Multi-messenger Picture

- Definition: Observations of a single source producing distinct signals associated with two or more of the 4 fundamental forces.

Force	Messenger
EM	Photons
Gravity	Gravitational waves
Strong	Protons,Nuclei
Weak	Neutrino



The Multi-messenger Picture



Photons

- The electromagnetic force is responsible for generating visible light as well as radiation in other wavebands not detectable by the human eye.
- The electromagnetic radiation can be thermal or non thermal

The Multi-wavelength Picture

http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/astrophysics/05.html

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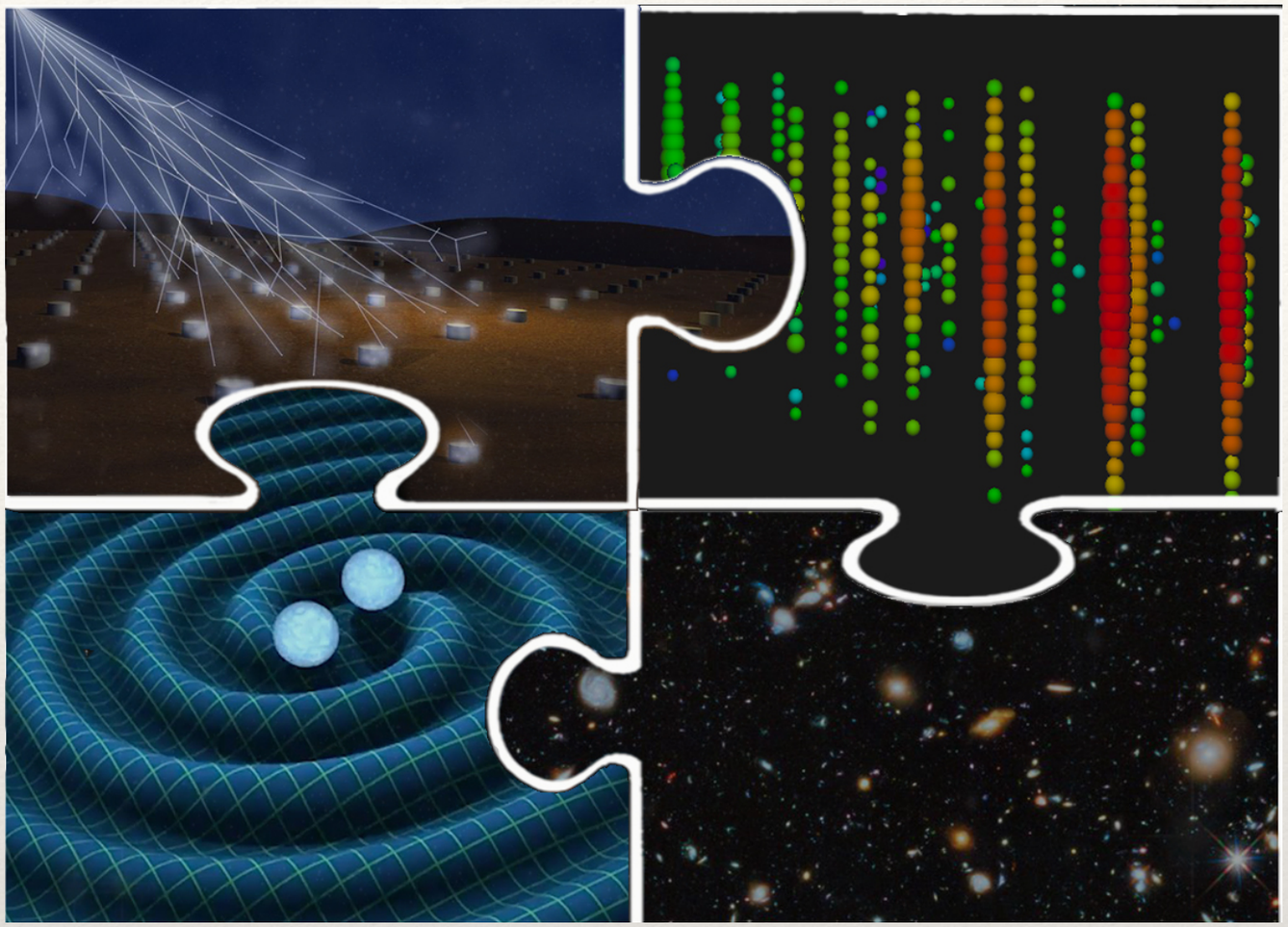
Topics Of Interest:

- Multiwavelength astronomy: http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/index.html

The Multi-messenger Picture

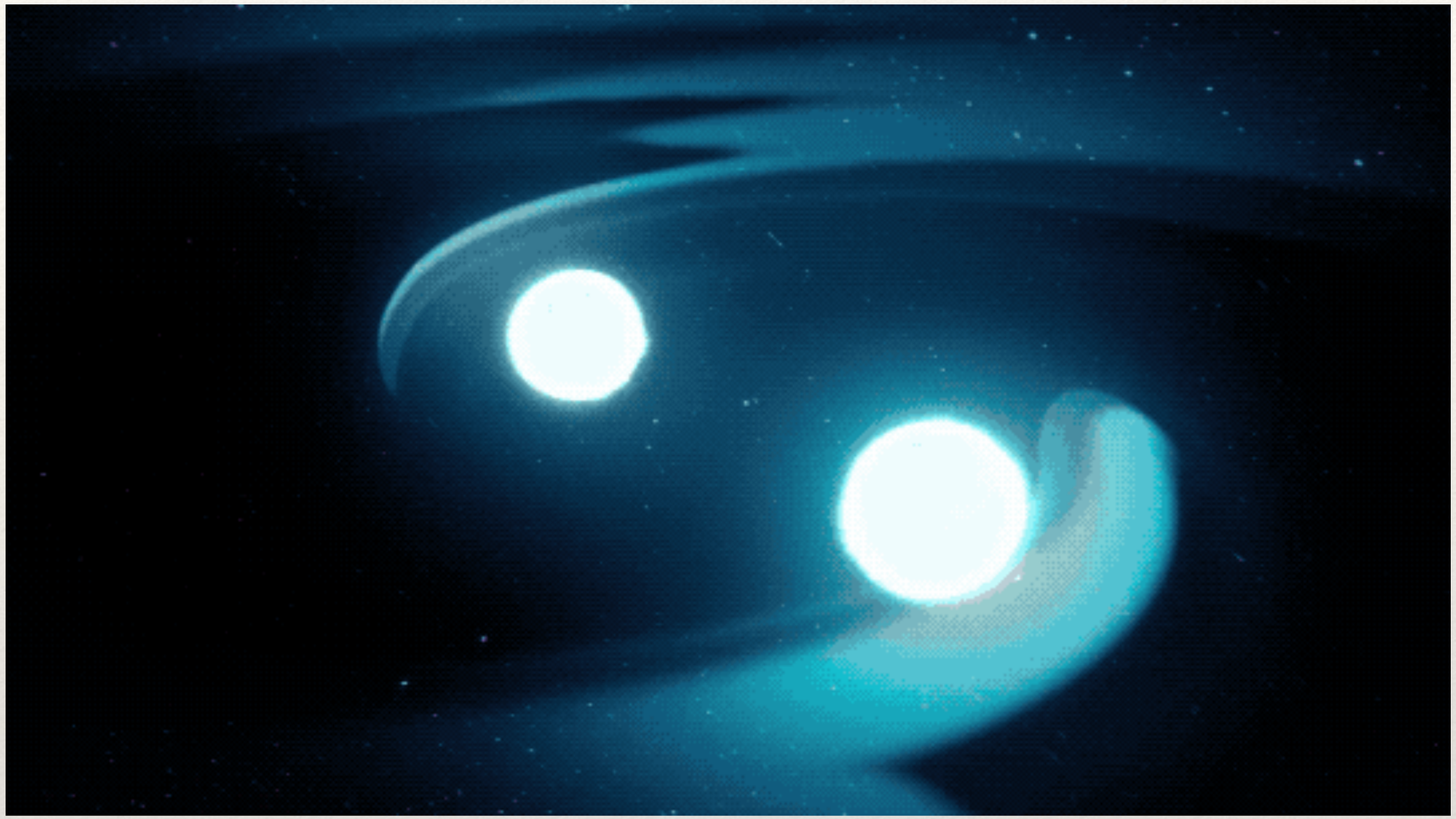
Gravitational Waves



Photons

- According to general relativity, mass causes space-time to curve in a describable manner, manifesting as gravity.
- When masses move, corresponding changes in the gravitational field move through the cosmos as gravitational waves at the speed of light, like ripples across a pond.

Gravitational Waves



- However gravity is an extremely weak force so even the sources of the biggest gravitational waves, like the cataclysmic collisions of black holes, would only produce the tiniest of wiggles by the time they reached Earth.
- Using detectors like LIGO these tiny gravitational waves wiggles as detected as messengers

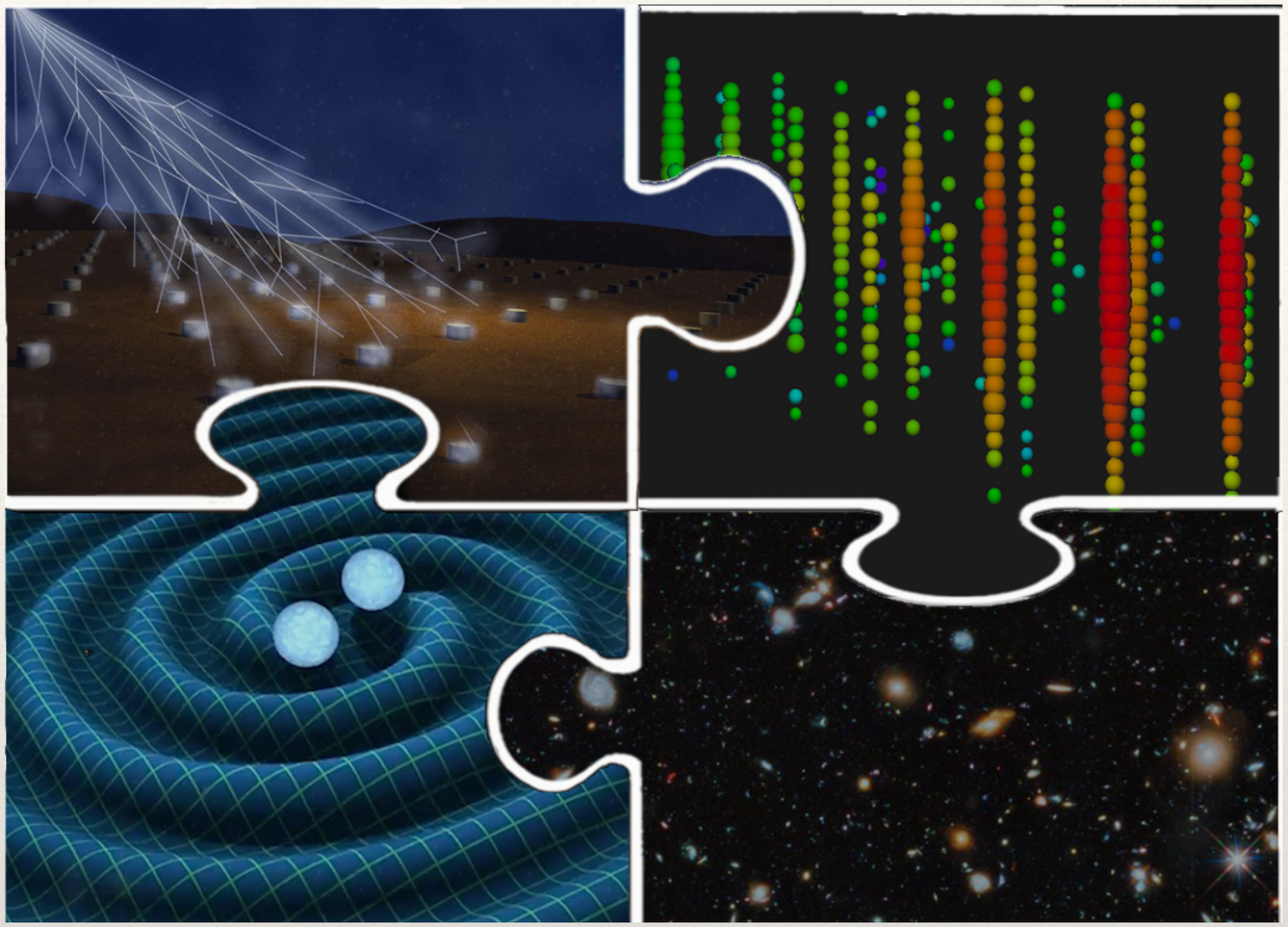
Topics Of Interest:

- Multiwavelength astronomy: http://ecuip.lib.uchicago.edu/multiwavelength-astronomy/index.html
- Gravitational Waves: https://youtu.be/hhbMpe17fzA

The Multi-messenger Picture

Cosmic Rays

Gravitational Waves



Photons

- Cosmic Rays are high energy particles that move through space at nearly the speed of light.
- These particles come from outer space and from our own Galaxy. Scientists first called these particles “rays” because they thought they were a form of electromagnetic radiation.

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Cosmic Rays

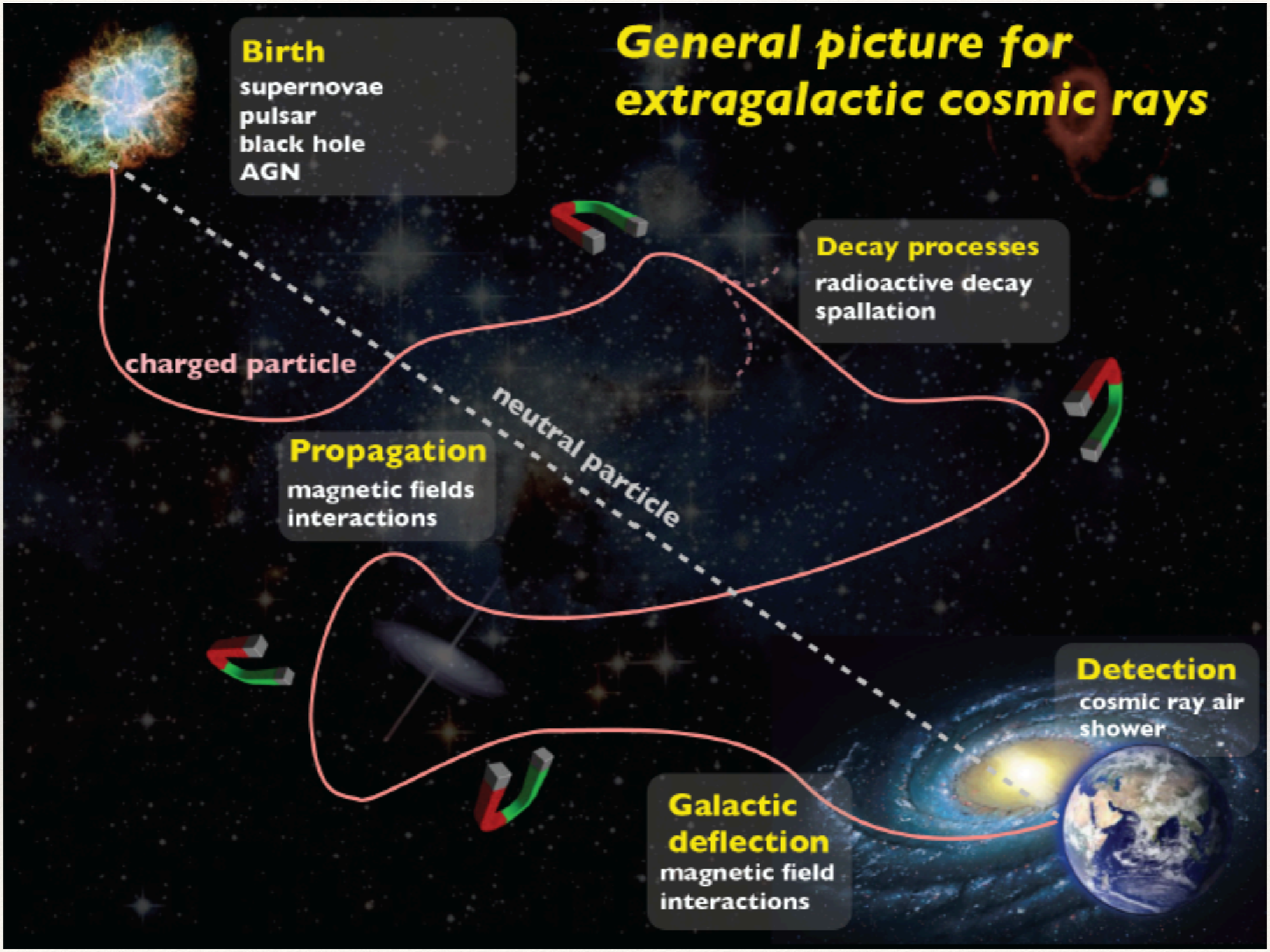

Image courtesy Daniel Kuempel

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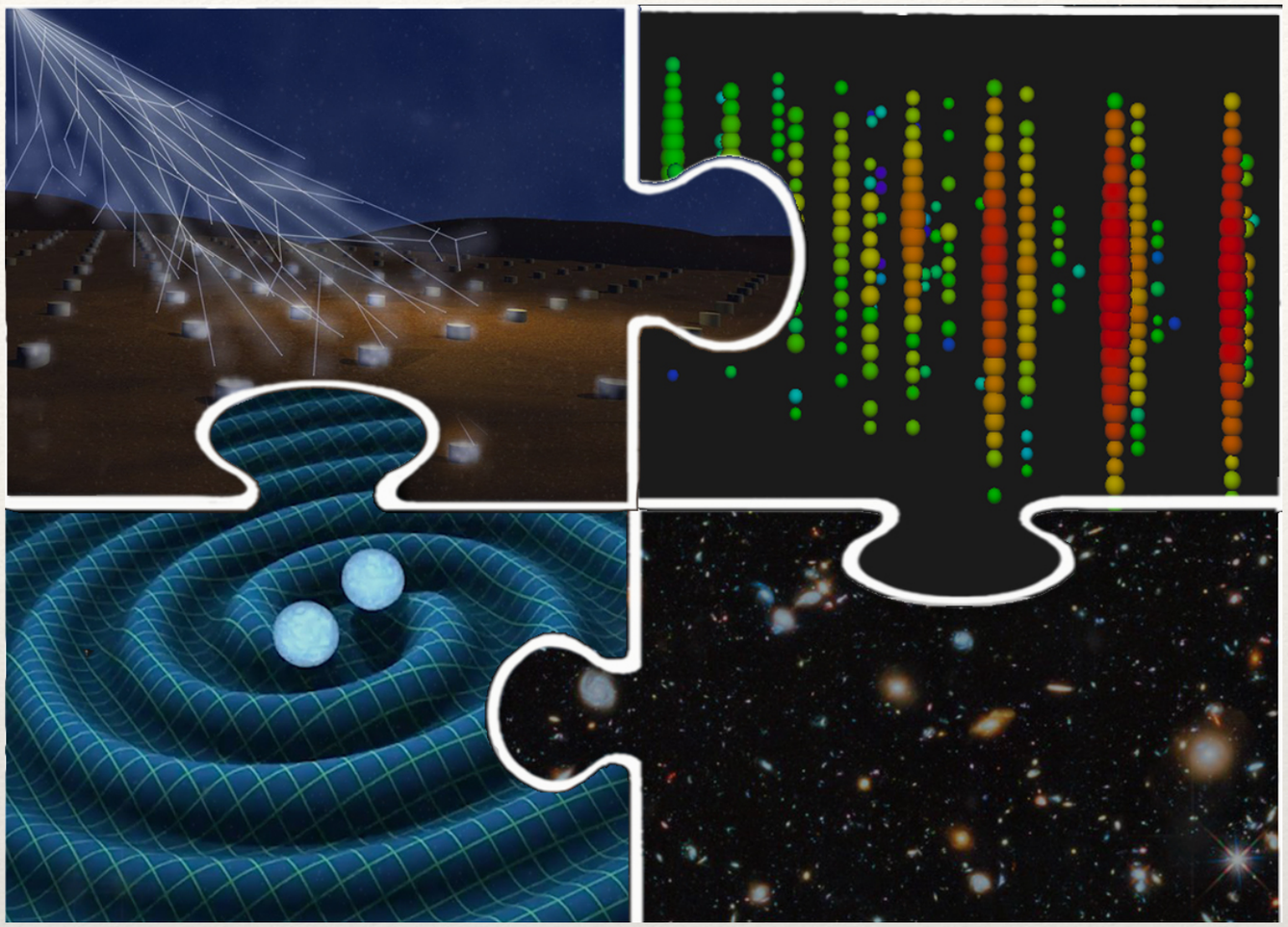
- Gravitational Waves: https://youtu.be/hhbMpe17fzA
- Cosmic Rays: https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=11209

The Multi-messenger Picture

Cosmic Rays

Gravitational Waves



Neutrinos

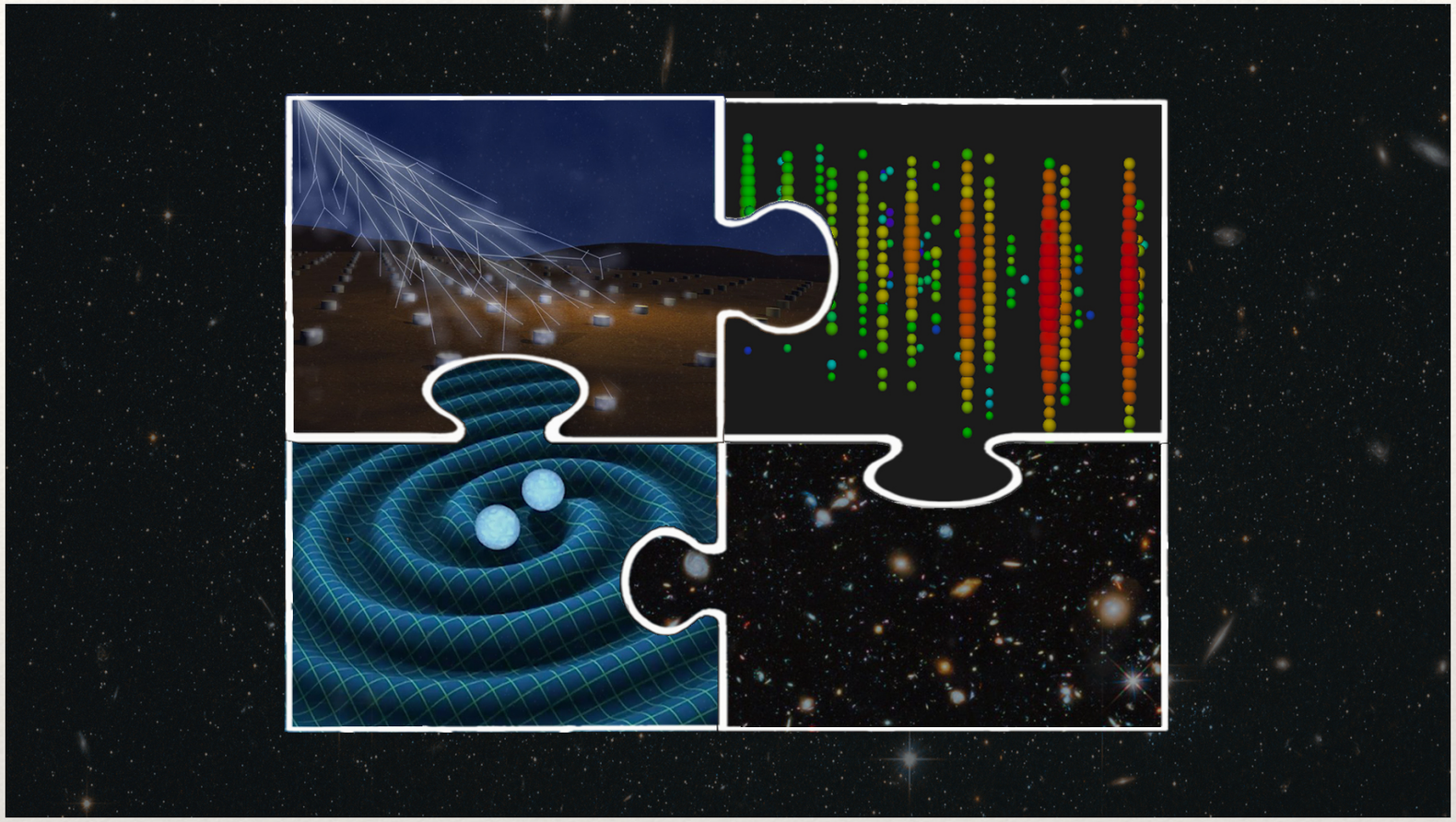
Photons

- Neutrinos are nearly massless and have no electric charge. Therefore, unlike the other particles, they only interact via the weak nuclear force.
- Since the weak nuclear force only acts at shot ranges, neutrinos can pass through massive objects without interacting with them.

The Multi-messenger Picture

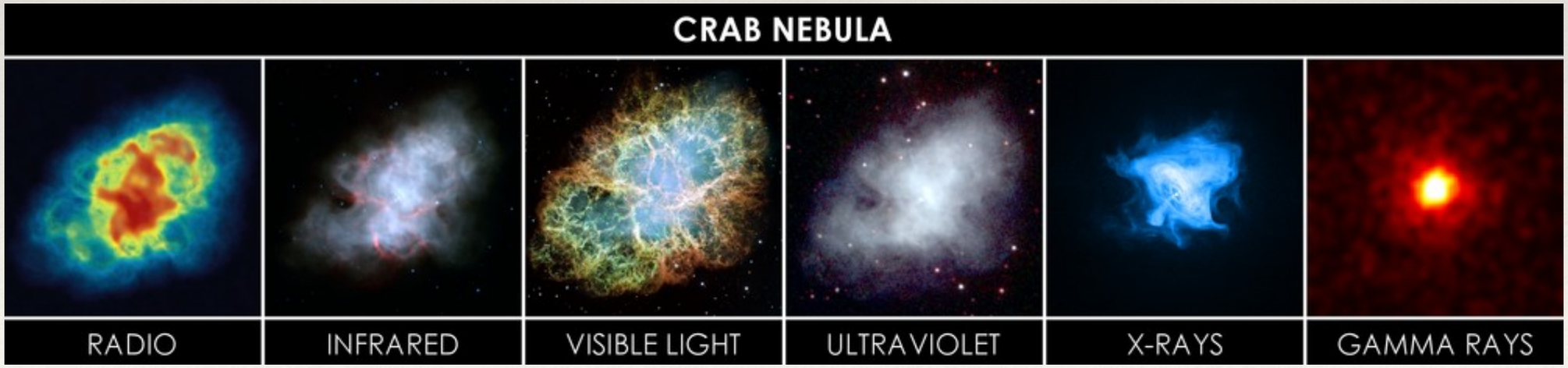
Cosmic Rays

Gravitational Waves



Neutrinos

Photons



Multi-wavelength Observations

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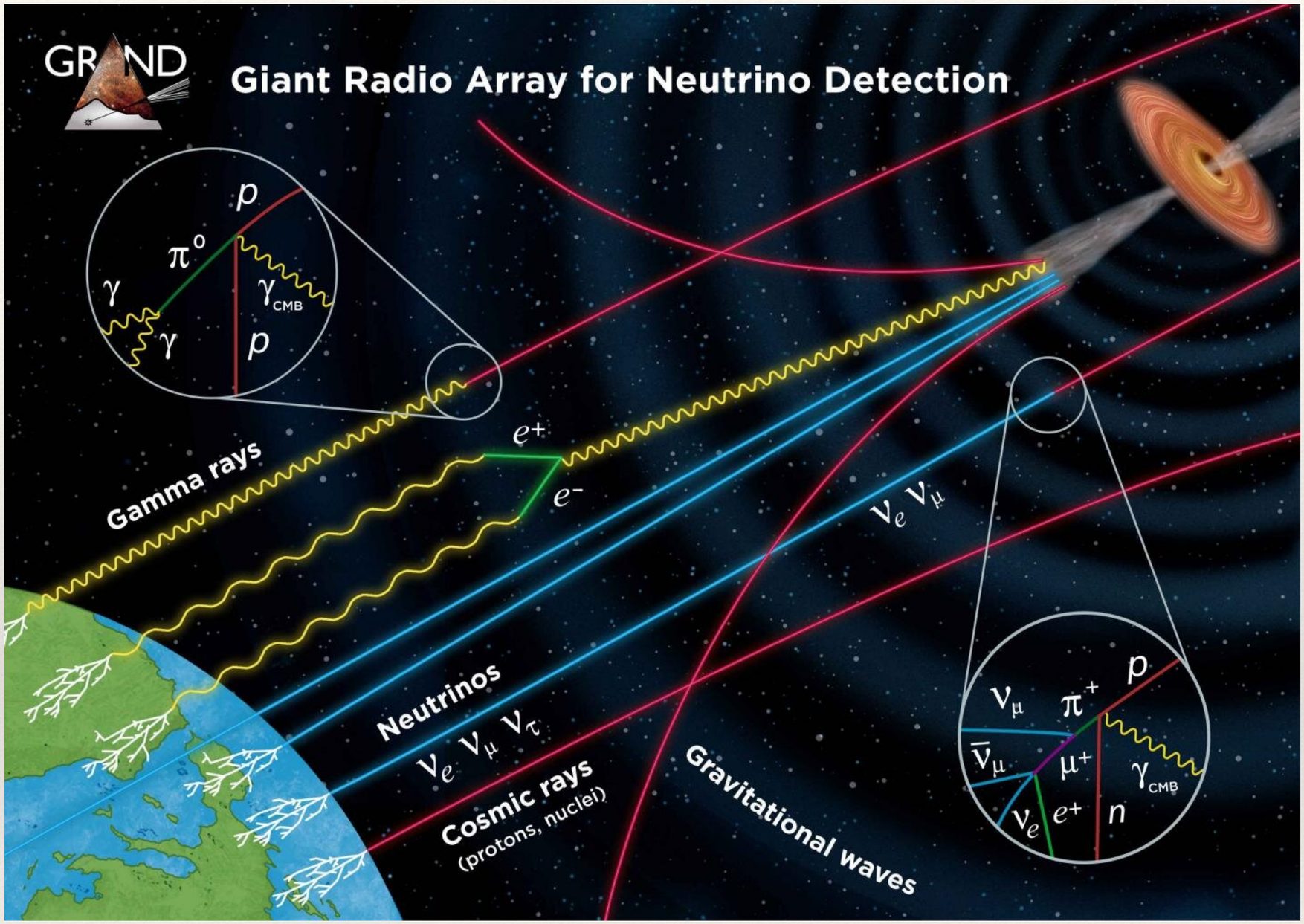
The Multi-messenger Picture



Creation and propagation of ultra-high energy particles in the Universe.
Credit: Science China Press

Diffuse Background

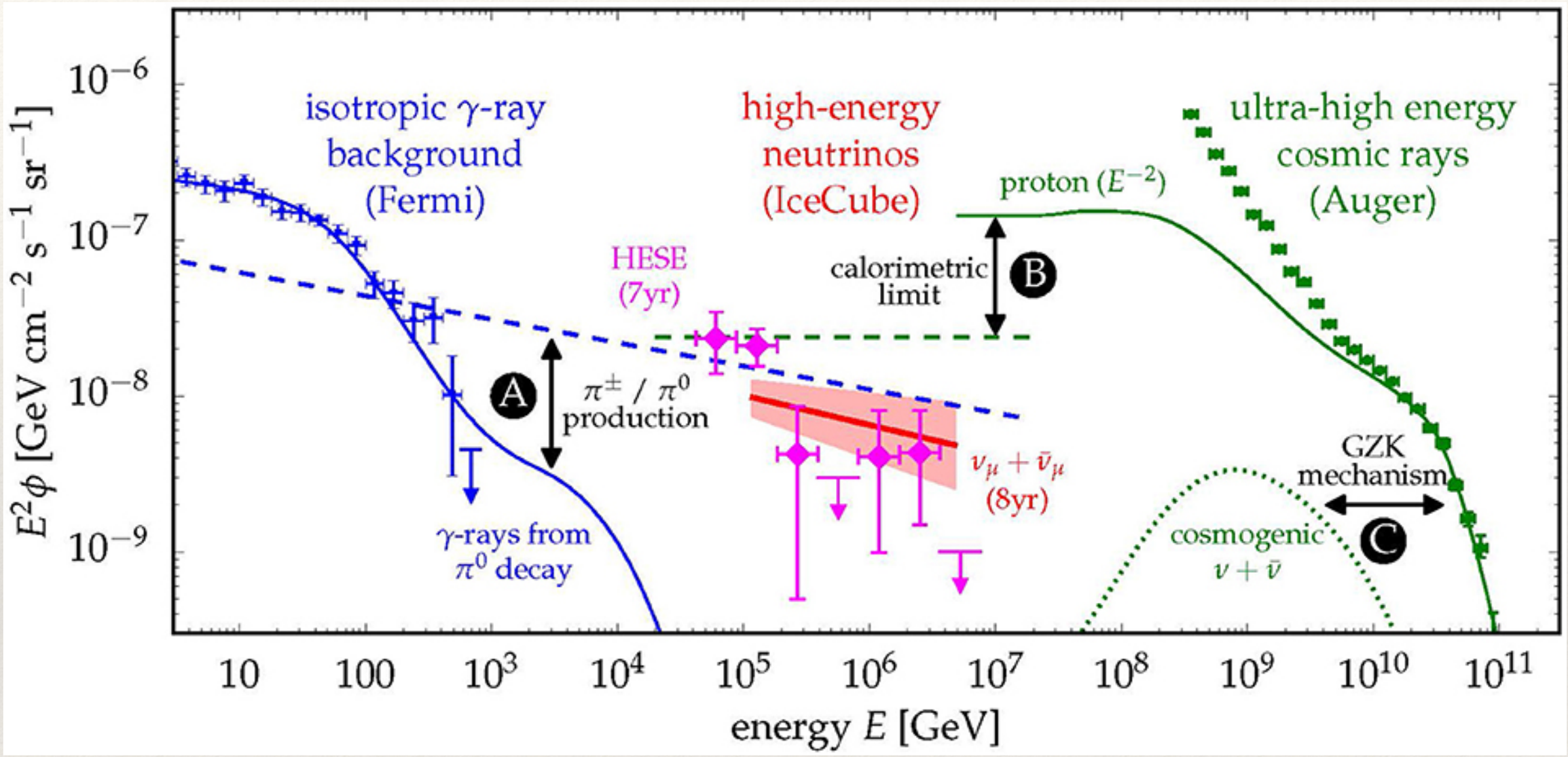


Figure from Ahlers and Halzen (2018)

Diffuse Background

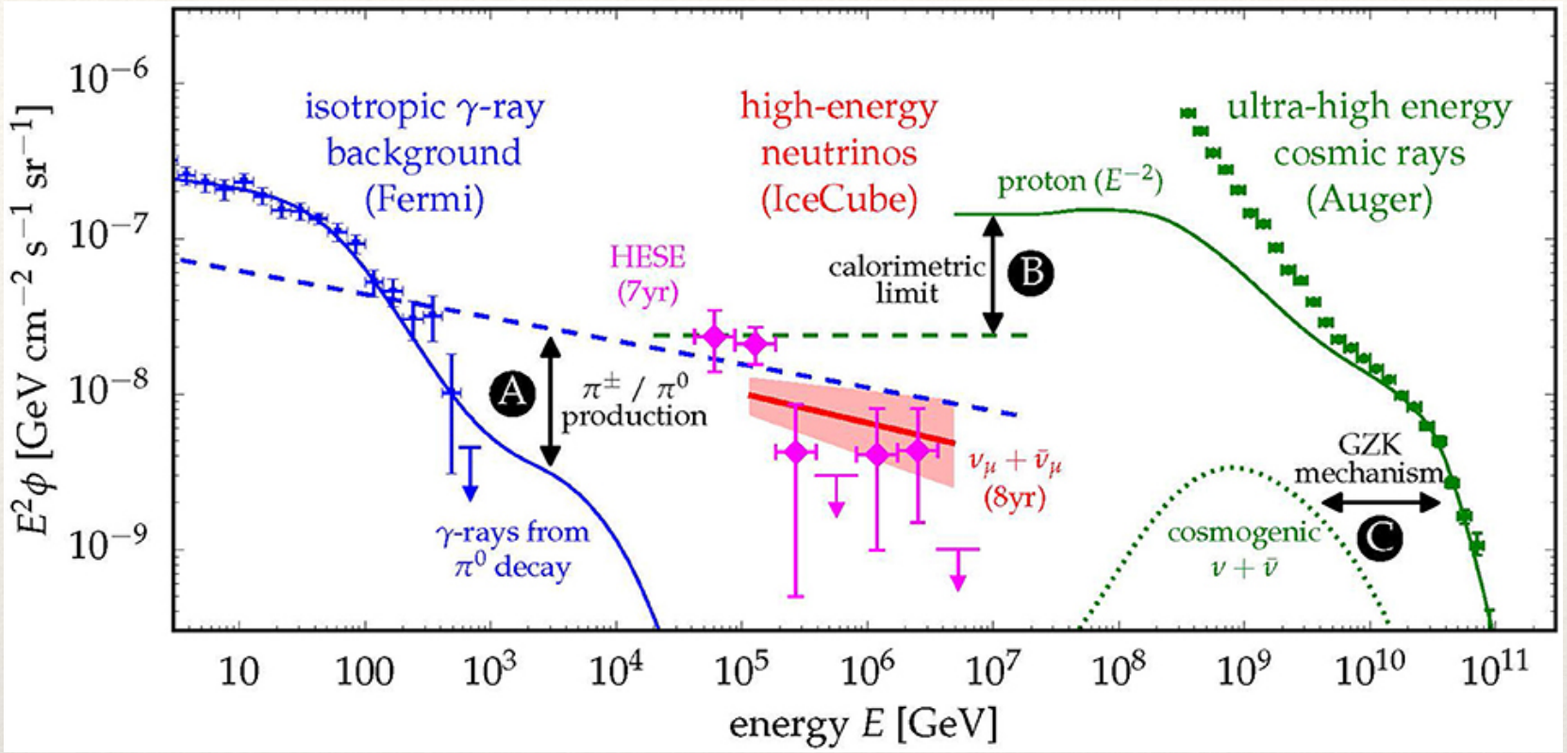


Figure from Ahlers and Halzen (2018)

- Photons are inevitably produced in association with neutrinos when accelerated cosmic rays produce neutral and charged pions.
- The pionic gamma rays should then accompany neutrinos at the site of production. However, since they undergo EBL absorption, they will appear at lower energies.
- Multimessenger interface **(A)** The joined production of charged pions and neutral pions in cosmic-ray interactions leads to the emission of neutrinos (dashed blue) and gamma rays (solid blue), respectively.

Diffuse Background

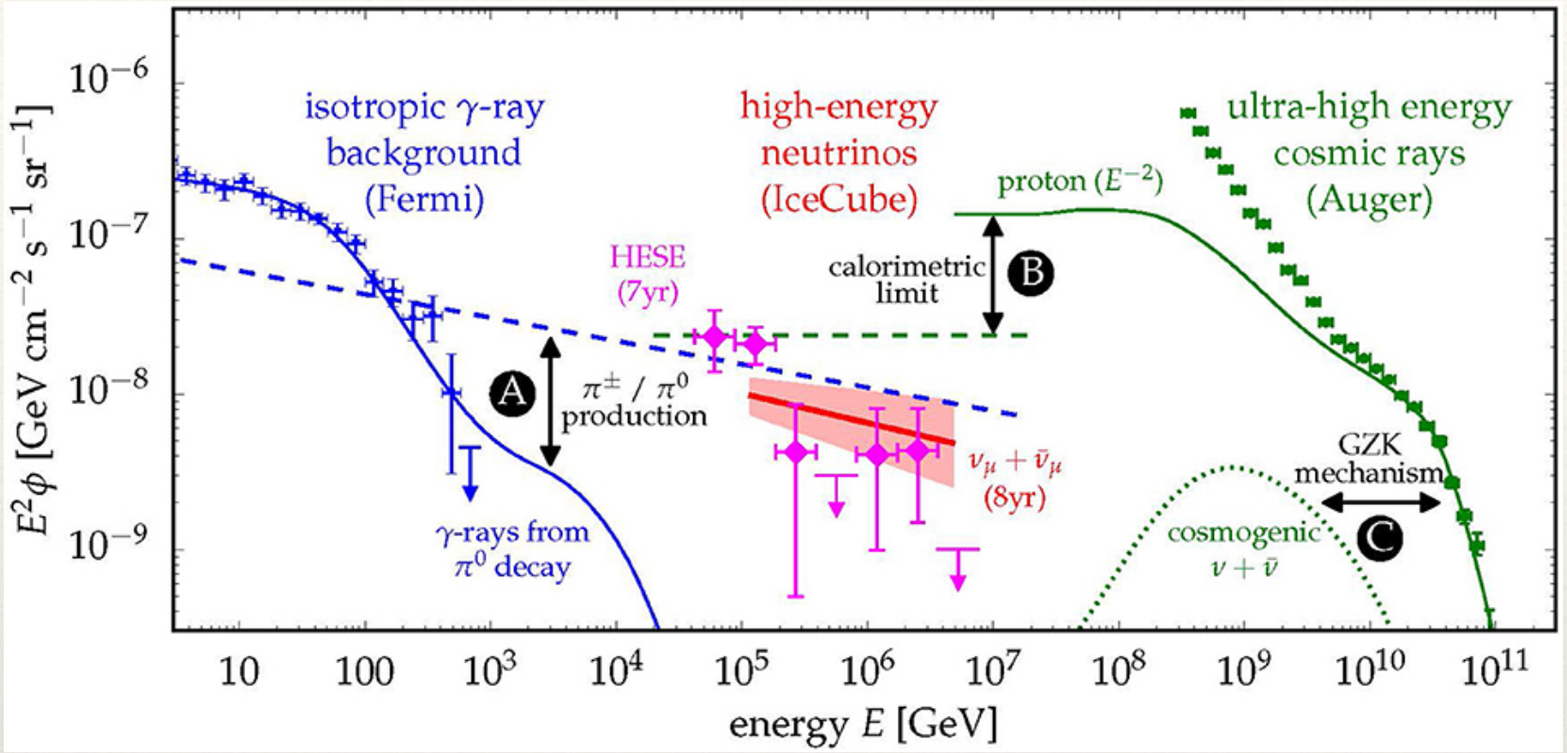


Figure from Ahlers and Halzen (2018)

- Multimessenger interface **(B)** Cosmic ray emission models (solid green) of the most energetic cosmic rays imply a maximal flux (calorimetric limit) of neutrinos from the same sources (green dashed).
- Multimessenger interface **(C)** The same cosmic ray model predicts the emission of cosmogenic neutrinos from the collision with cosmic background photons (GZK mechanism).
- Neutrinos with higher energies are expected from the Greisen Ztsepin Kuzmin (GZK) effect, namely the interaction of ultrahigh-energy cosmic rays (UHECRs) with the cosmic microwave background (CMB) and the extragalactic background light (EBL), but have not yet been detected

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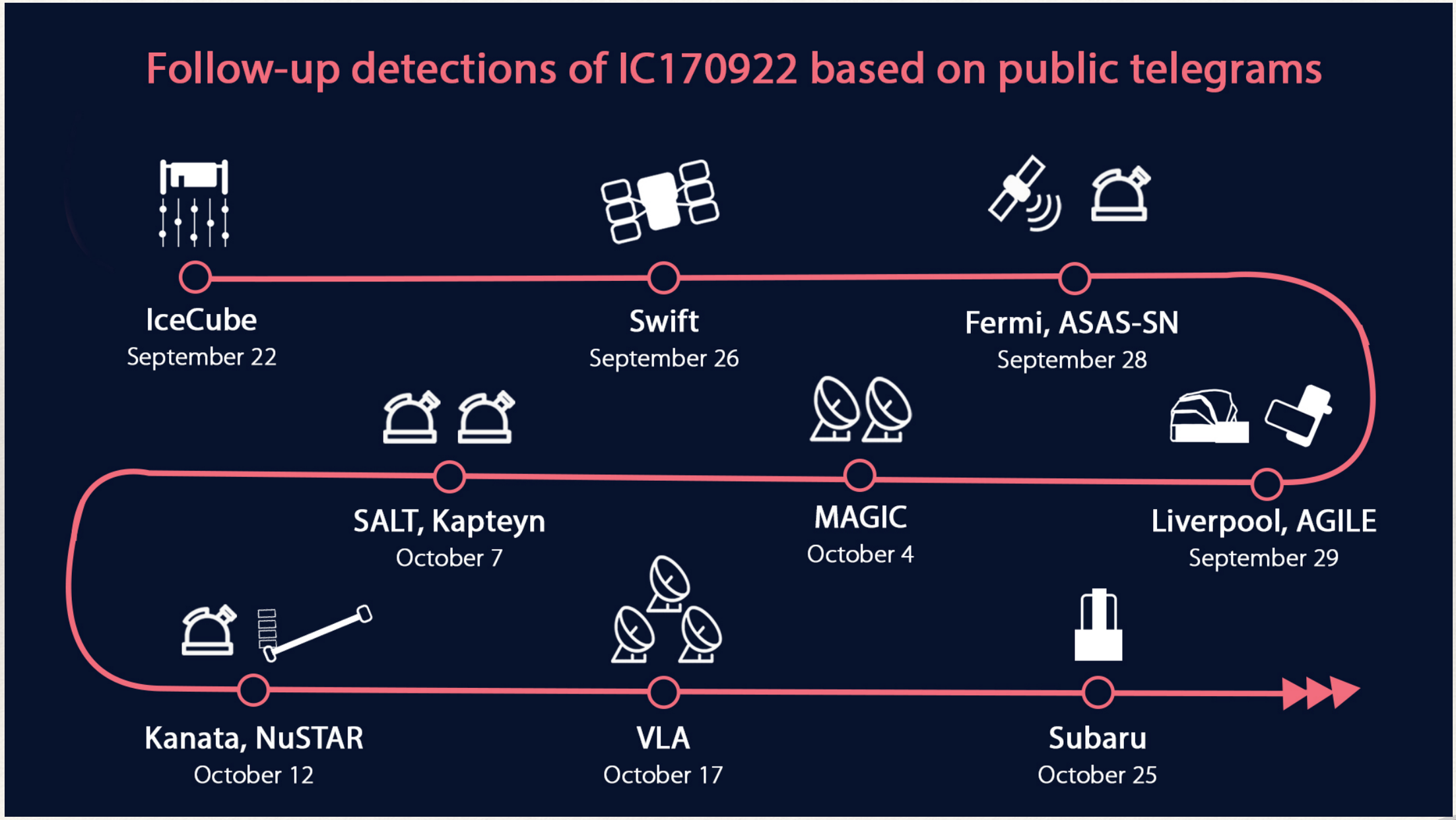
- Cosmic Rays: https://svs.gsfc.nasa.gov/cgi-bin/details.cgi?aid=11209
- Must read for all that is discussed today and more: https://www.frontiersin.org/articles/10.3389/fspas.2019.00032/full

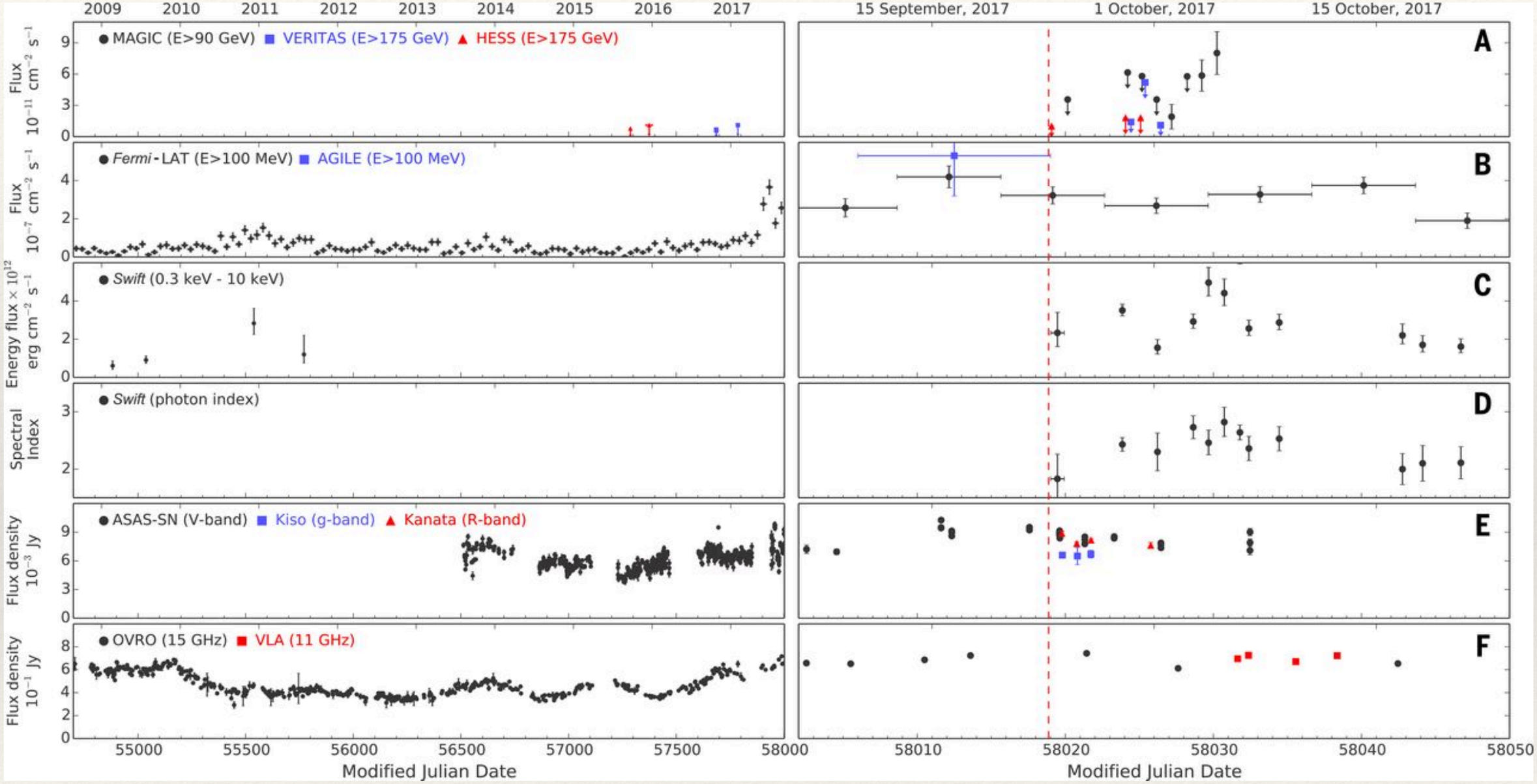
Neutrinos and Photons

- Or Why TXS0506+056 is so famous?



Neutrinos And Photons: TXS 0506+056

- Neutrino Alert: IC-170922A (Red dashed line)



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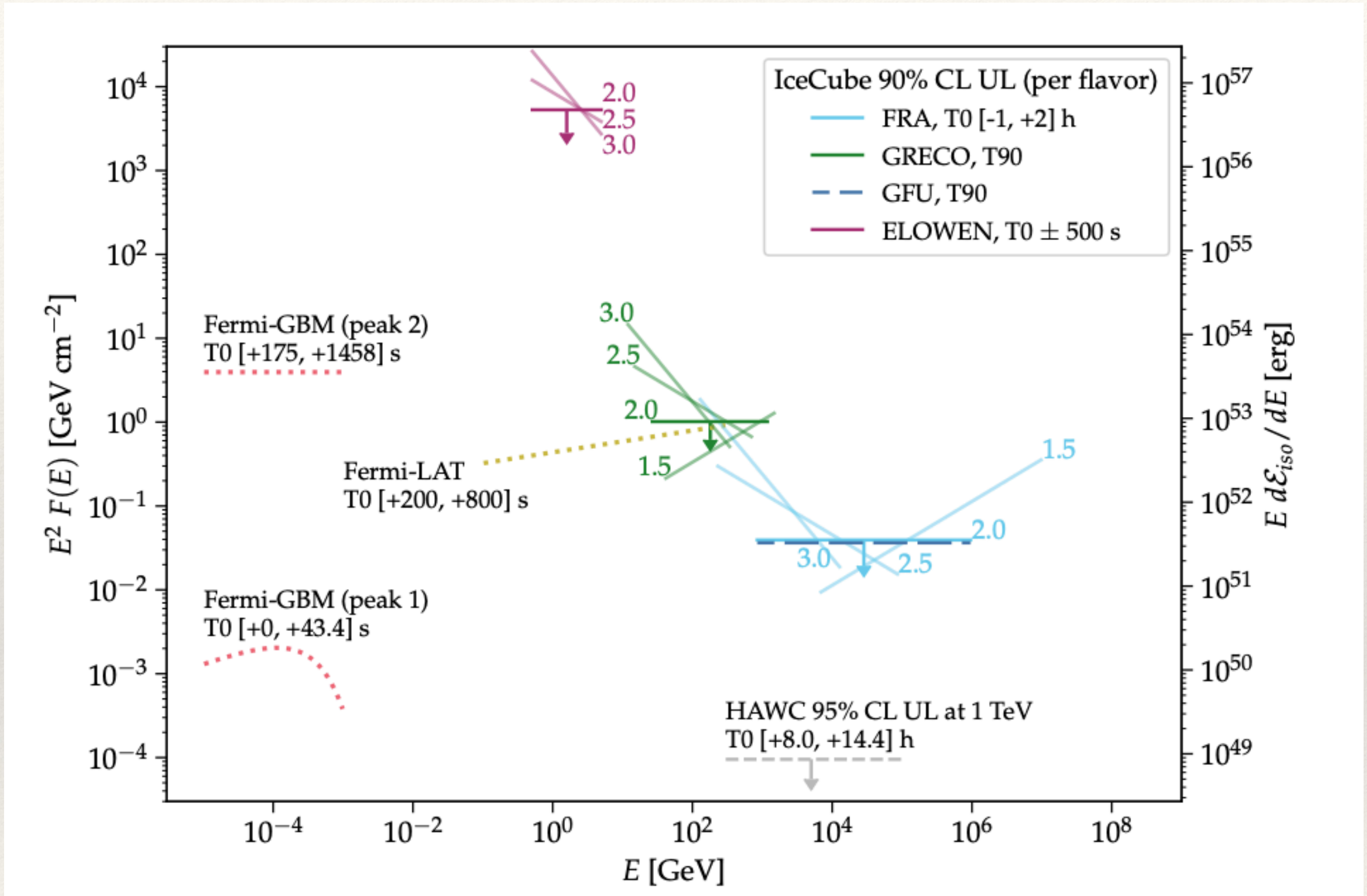
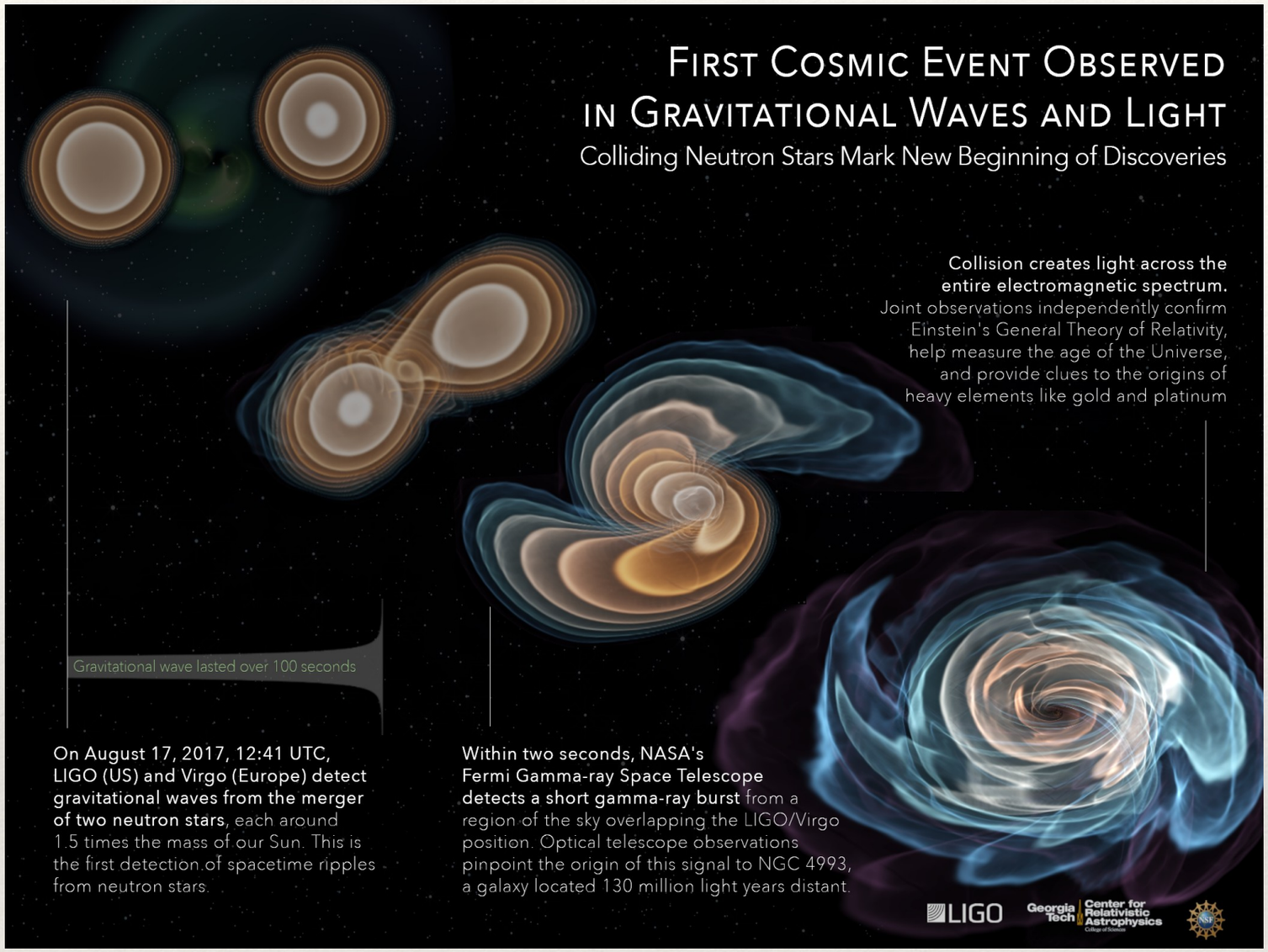


- IceCube Collaboration et al 2023

Gravitational Waves



Gravitational Waves and Photons

- We are now working on performing the fast response analysis and sending out alerts for gravitational waves reported in real-time. (Ask Jessie Thwaites or Aswathi Balagopal for more info)

Multimessenger With IceCube

- Powerful real time follow-up program at IceCube targets the detection of transient sources.
- This multimessenger program sends alerts of single and clusters of high-energy neutrino events (multiplets), typically within one minute of the event detection.
- In collaboration with other observatories, IceCube aims to identify the electromagnetic counterpart of a rapidly fading source or coincident gravitational waves. Single event alerts are distributed publicly as GCN alerts, while multiple alerts are distributed through individual agreements with optical, X-ray, and gamma-ray observatories.
- Searches for bursts of low-energy neutrinos from nearby supernovas are performed, and above threshold detection is announced rapidly within the SNEWS network.

Taken from the IceCube Science Highlights Page

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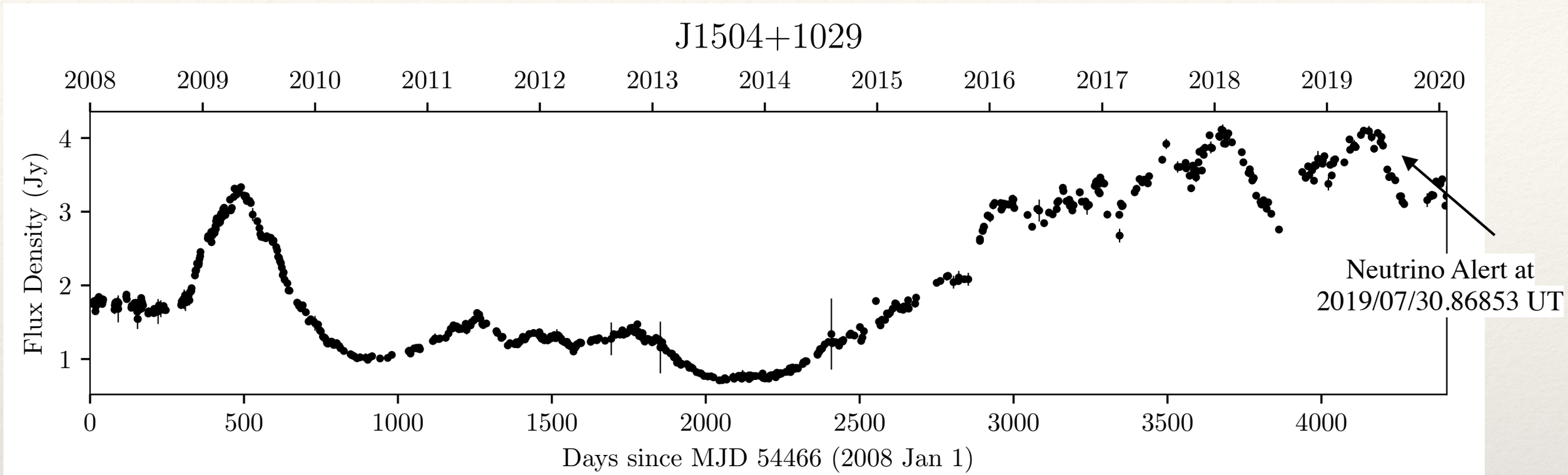
- IceCube Multimessenger Highlights: https://icecube.wisc.edu/science/highlights/neutrino_astronomy

Questions?

or

Comments!

Exiting Research Work In Progress

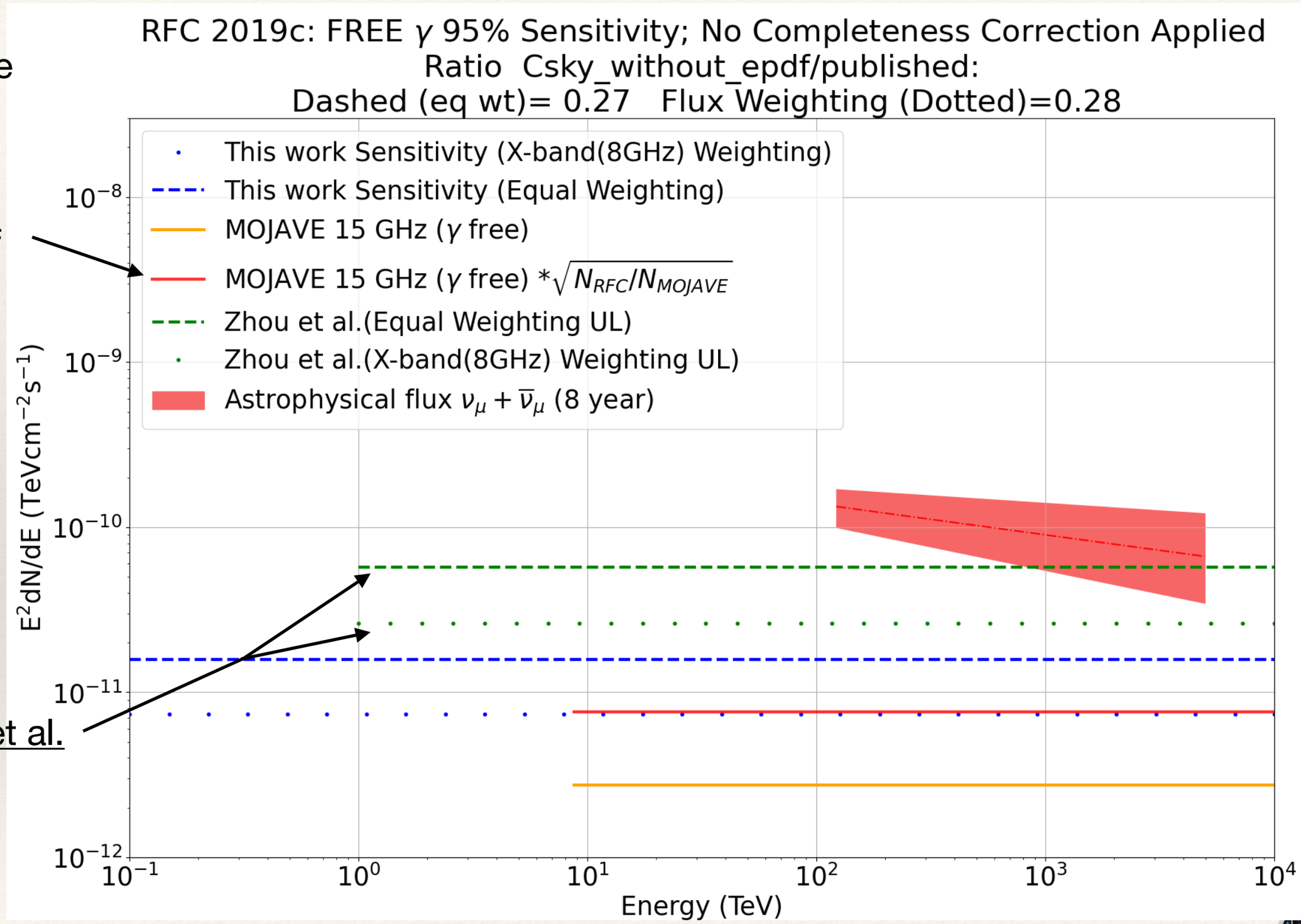


Data taken from the OVRO 40-m monitoring program (Richards, J. L. et al. 2011, ApJS, 194, 29) Link

- The Blazar PKS1502+106 was found to be possibly correlated with an Iceube alert (IC190730A)
- At the time of the alert, the radio observations of the FSRQ were seen reaching an all time peak flux of 4 Jy (S. Kiehlmann et.al. The Astronomer's Telegram 12996, 1 (2019).) (See Below)
- Moreover, positive correlations would help us better understand the neutrino production processes in AGN (as also discussed in Plavin et al 2020)

Some results

Check done to see if sensitivity scales as function of number of sources.



See Zhou et al. 21

AGN models:

- Model of Rodriguez et al 21 is used as example here.
- Test case of a 10 day flare with flux rising by a factor of 10