

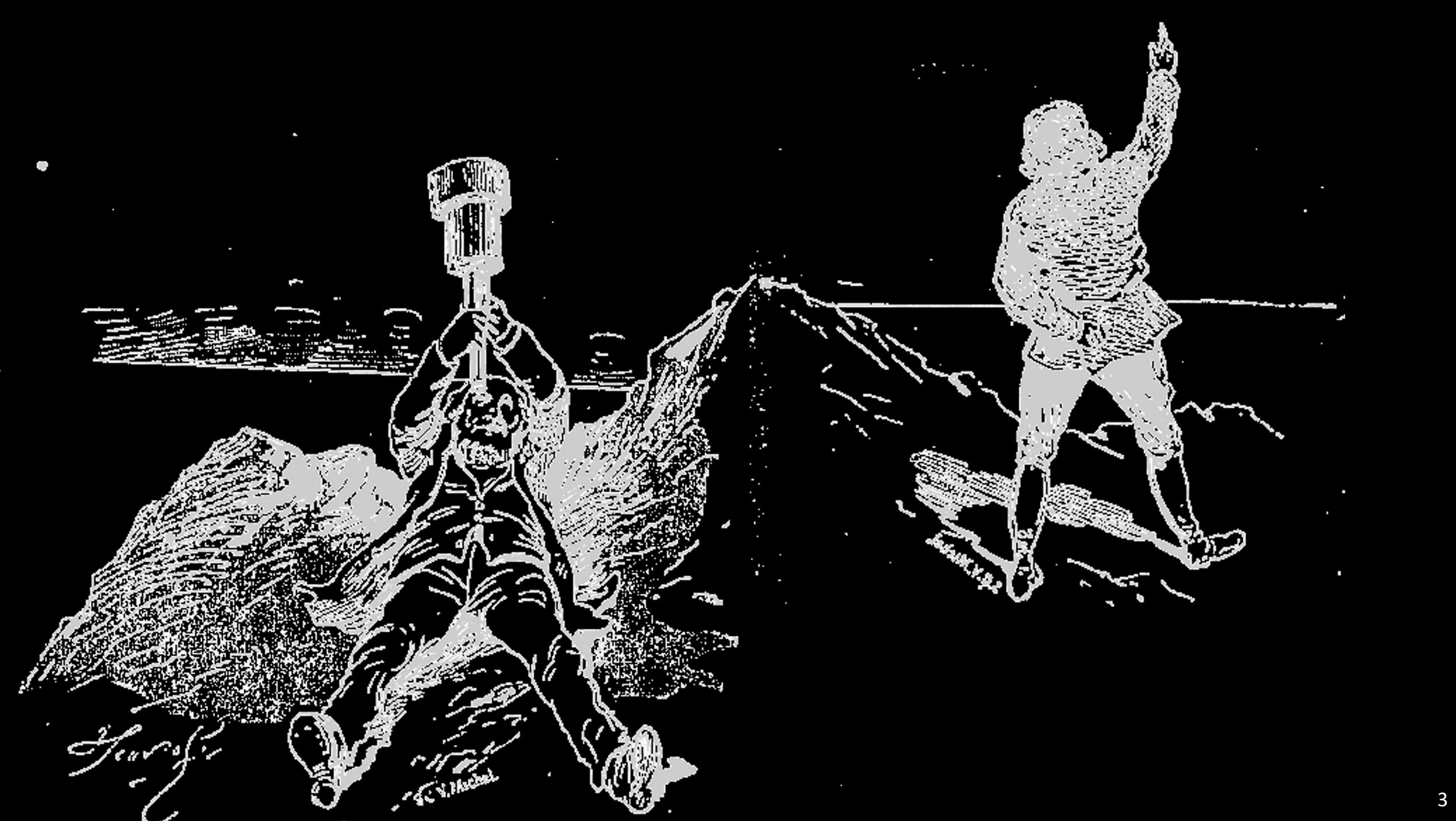


Multi-Messenger Physics

Gwenhael W De Wasseige

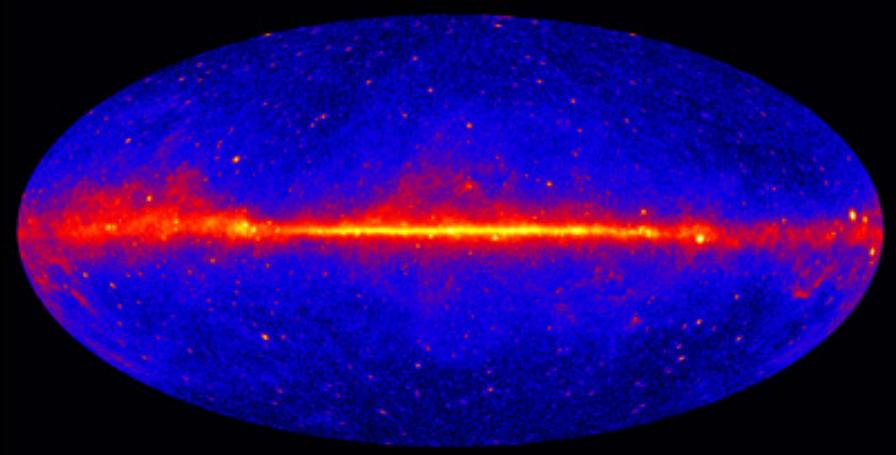


How to study the Universe?



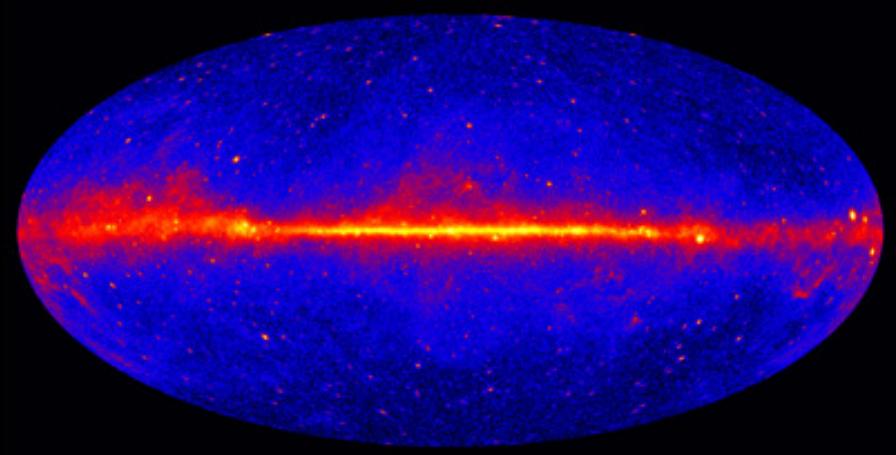
Te
Hau

He
Mata

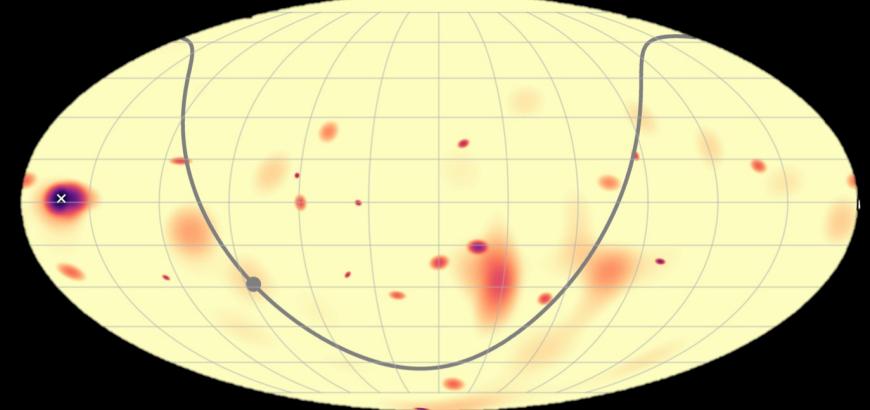


γ

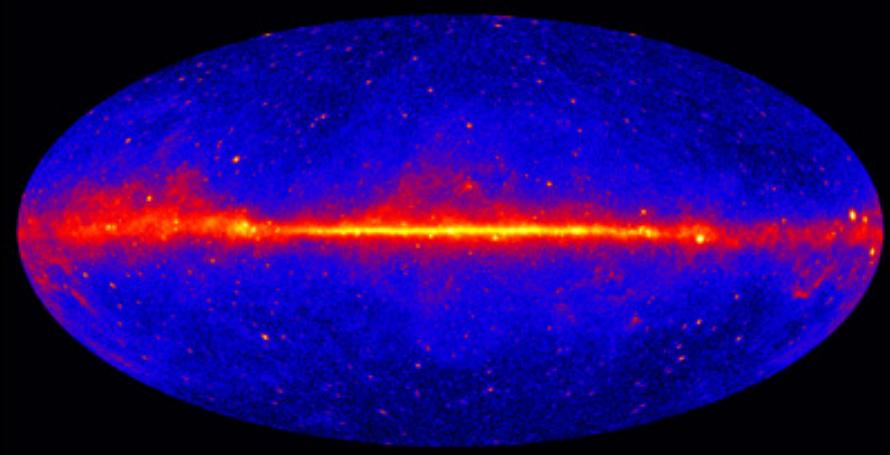
Electromagnetic
waves

 γ

Electromagnetic
waves

 ν

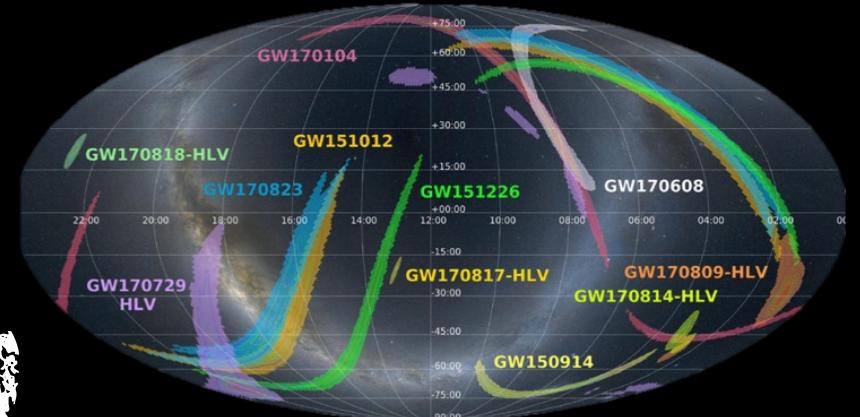
Neutrinos



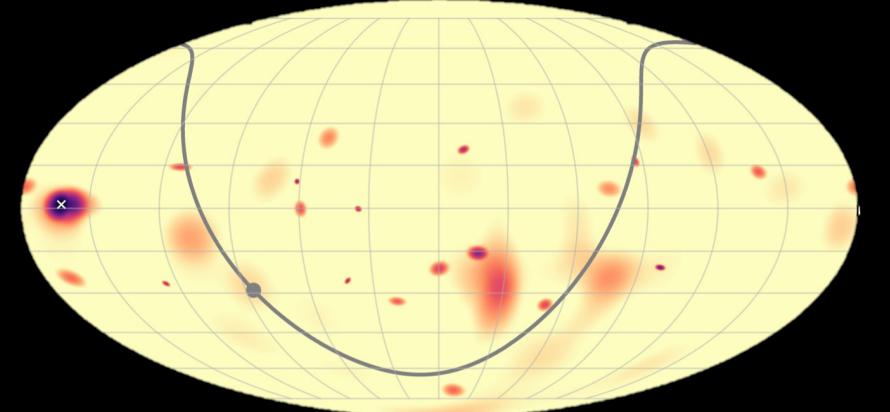
Electromagnetic
waves

γ

GW

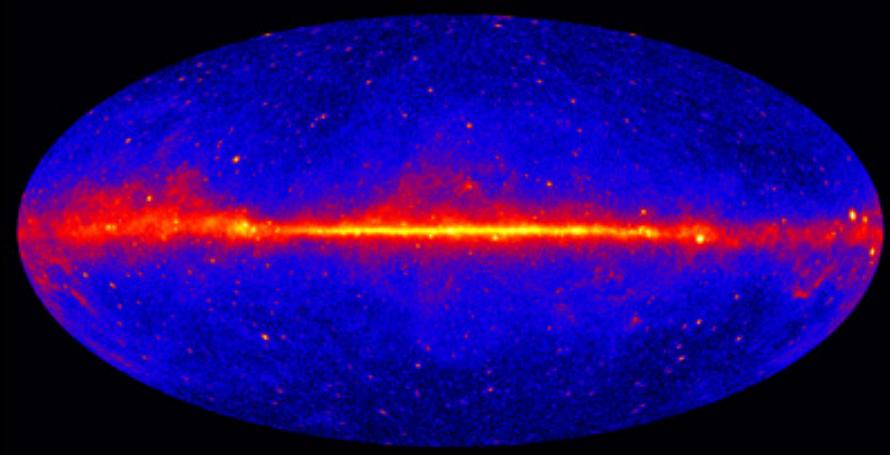


Gravitational
waves



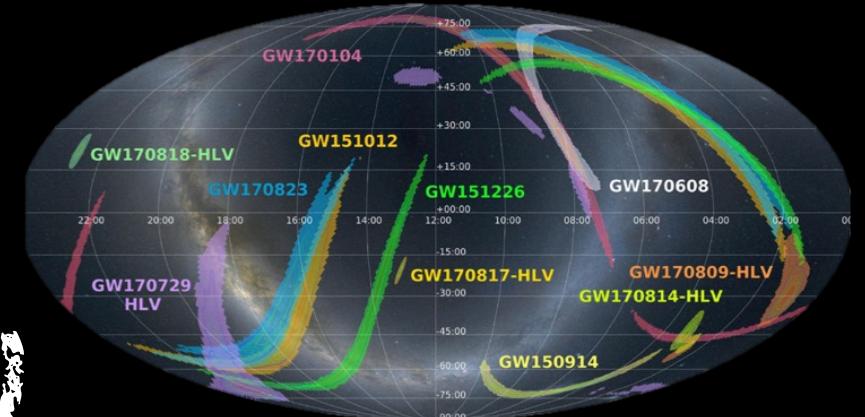
Neutrinos

V



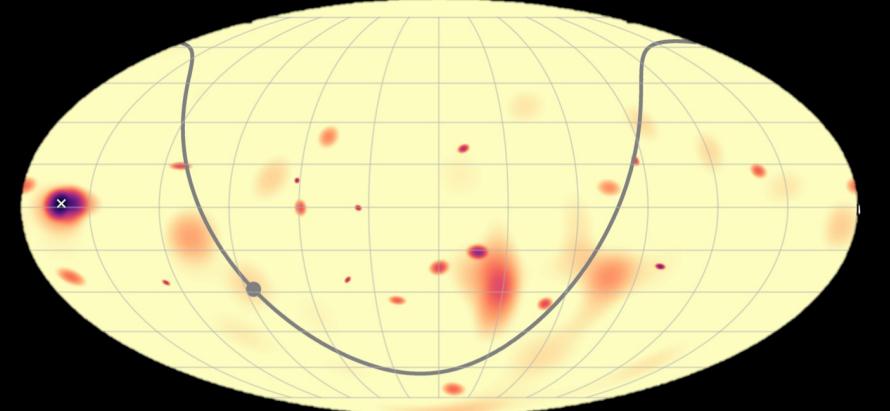
Electromagnetic
waves

γ



Gravitational
waves

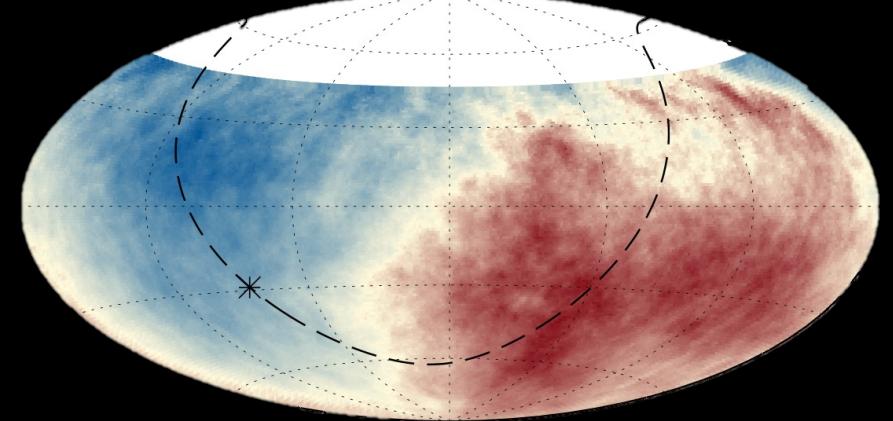
GW



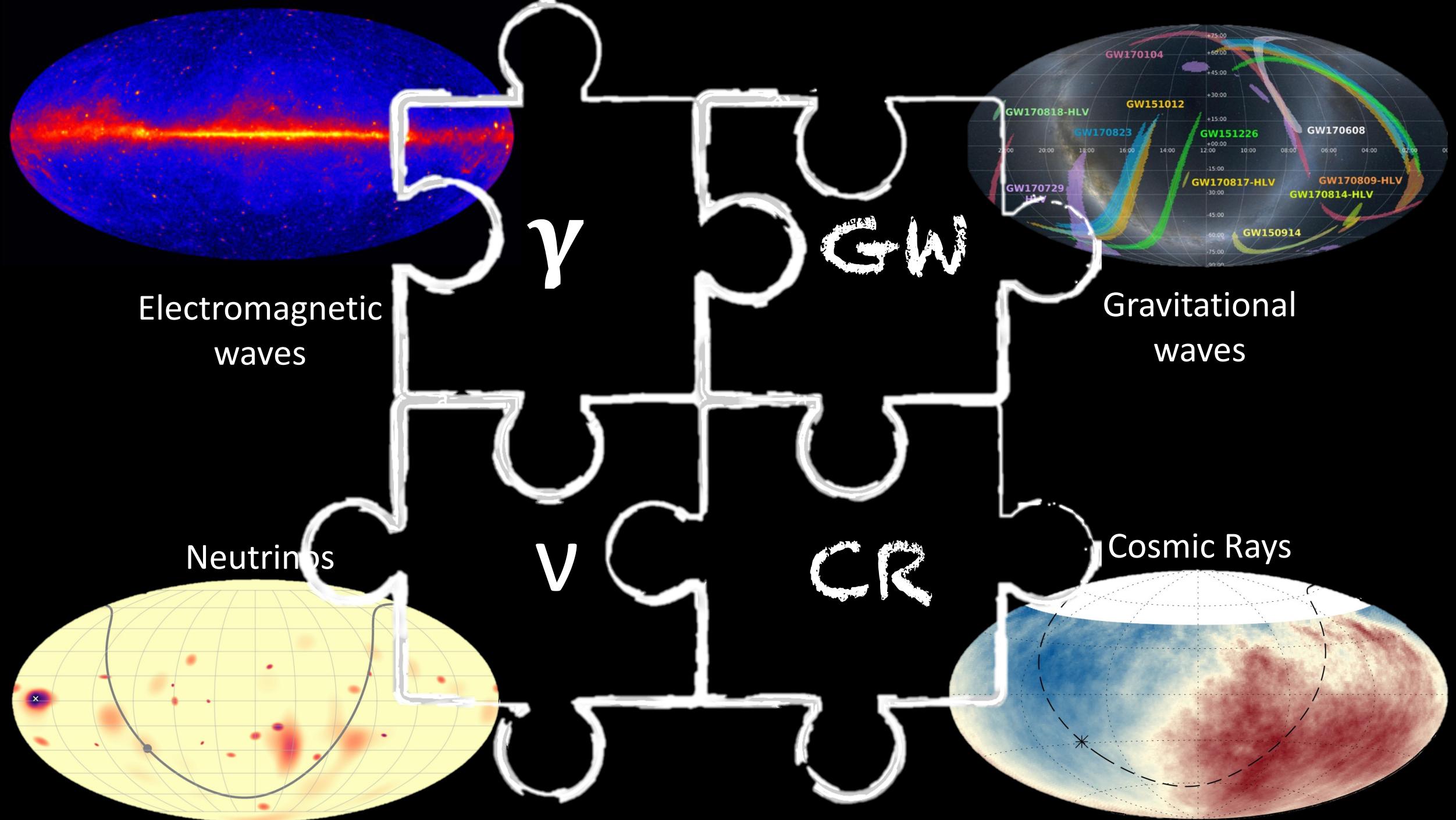
Neutrinos

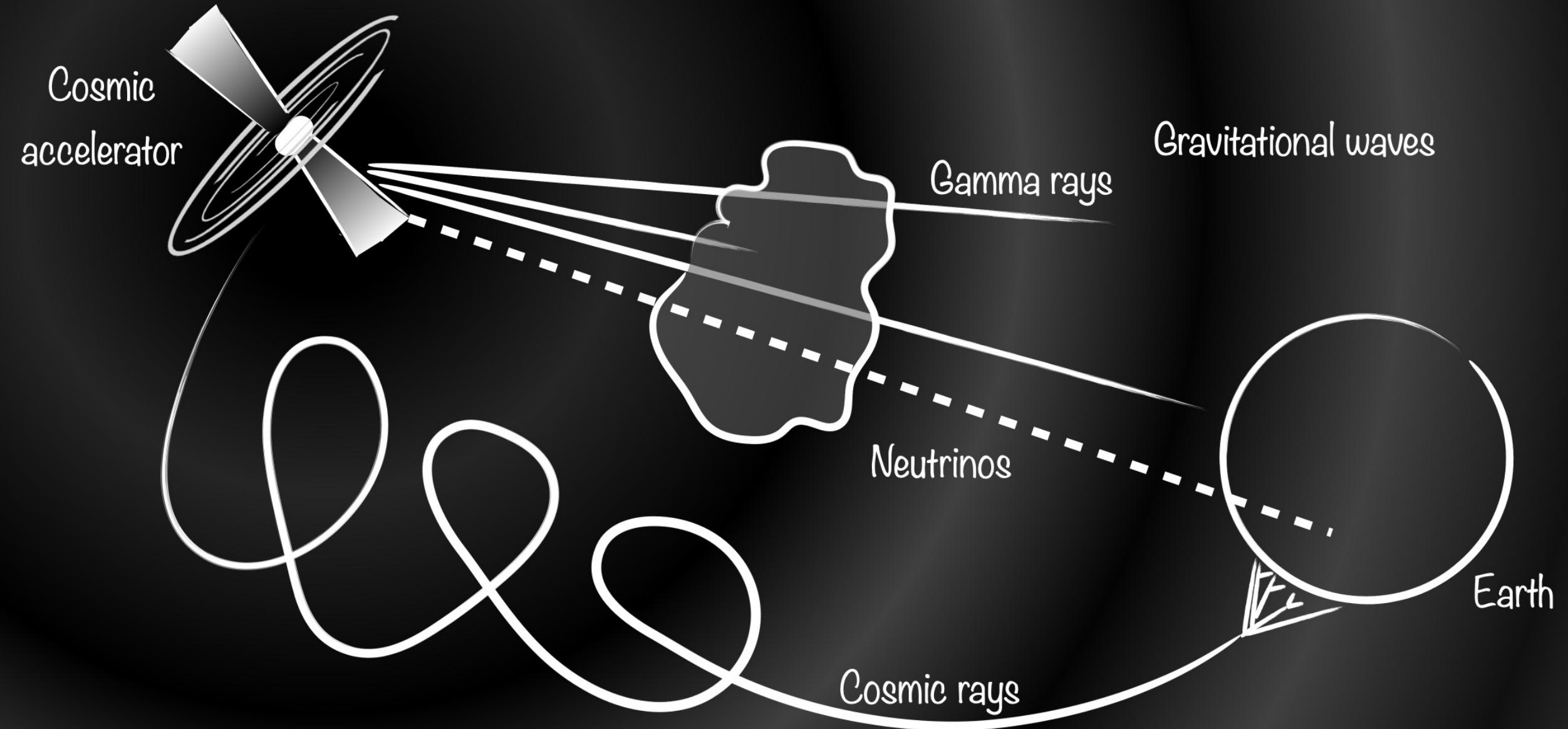
V

CR



Cosmic Rays

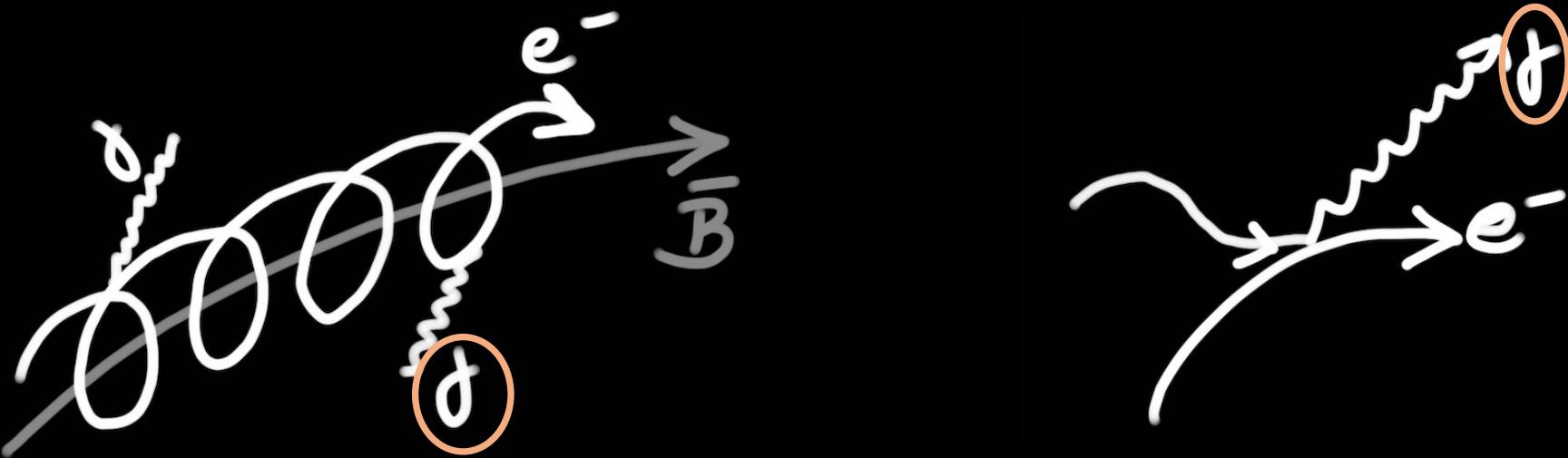






Leptonic processes

(from electron acceleration)

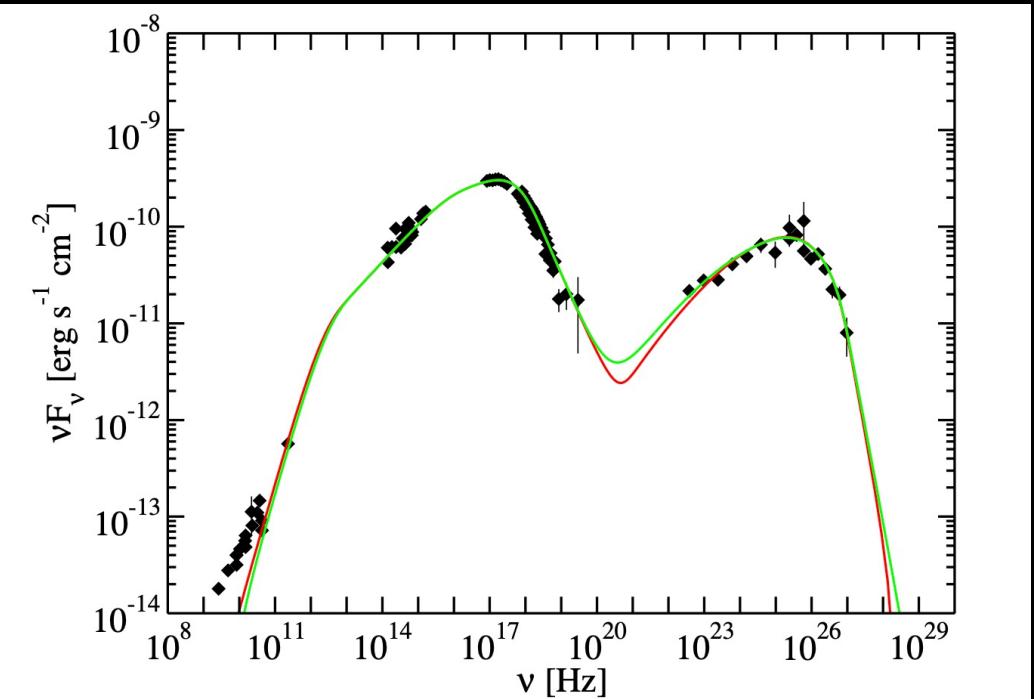


Hadronic processes

(from proton acceleration)

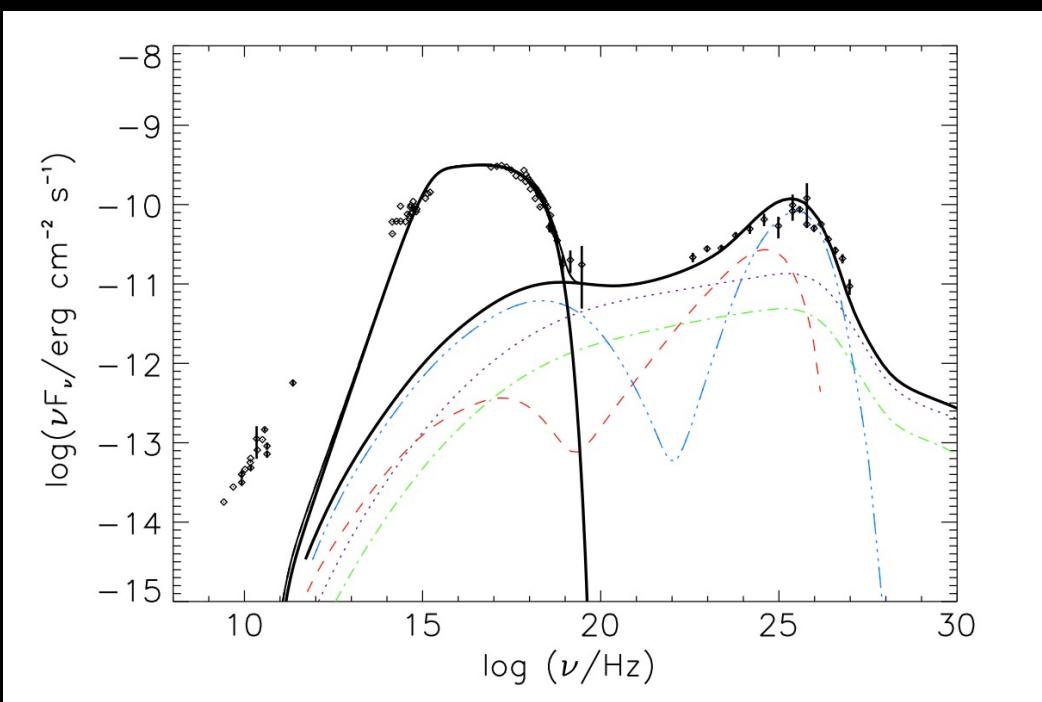
$$P + p/\gamma \rightarrow \left\{ \begin{array}{l} \pi^+ \rightarrow \mu^+ + \bar{\nu}_\mu \\ \quad \downarrow e^+ + \bar{\nu}_e + \bar{\nu}_\mu \\ \pi^0 \rightarrow 2\gamma \end{array} \right.$$

Leptonic processes



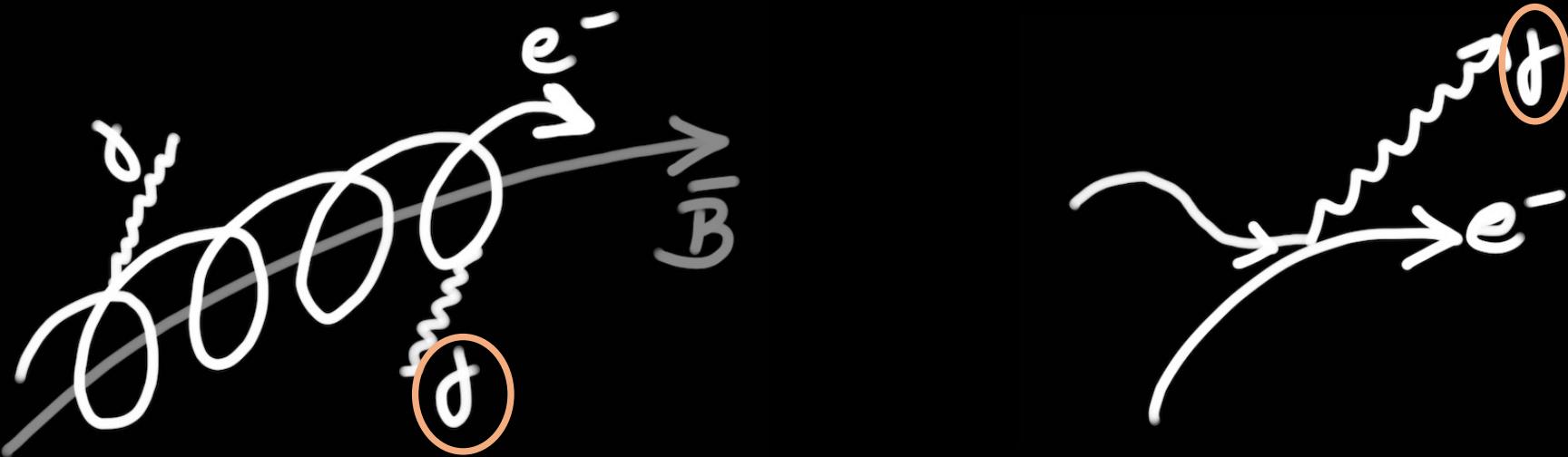
Blazar Markarian 421

Hadronic processes



Leptonic processes

(from electron acceleration)



Hadronic processes

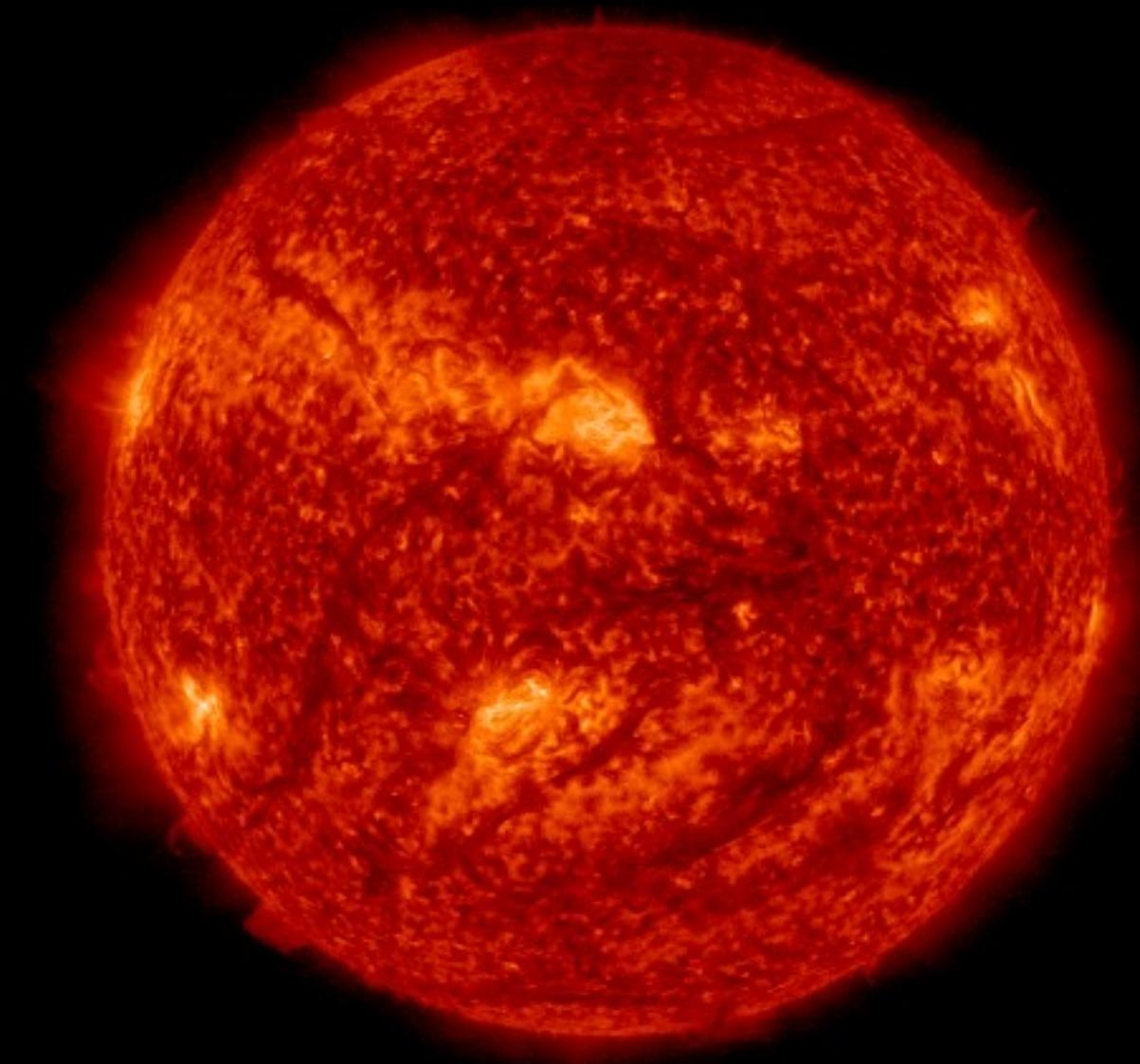
(from proton acceleration)

$$P + p/\gamma \rightarrow \left\{ \begin{array}{l} \pi^+ \rightarrow \mu^+ + \bar{\nu}_\mu \\ \quad \downarrow \\ \pi^0 \rightarrow 2\gamma \\ \pi^0 \rightarrow e^+ + \bar{\nu}_e + \bar{\nu}_\mu \end{array} \right.$$

The equation shows hadronic processes involving protons (P) and photons (γ). It lists three decay channels for the pi^+ particle: 1) pi^+ to mu^+ and an anti-neutrino (nu-bar_mu). 2) pi^0 to two photons (2 gamma). 3) pi^0 to an electron (e^+) and a neutrino (nu_e) plus an anti-neutrino (nu-bar_mu). The mu^+ and nu-bar_mu particles are circled in green, and the e^+ and nu-bar_e particles are also circled in green.

What is the first ever source observed
with multiple messengers?

The Sun

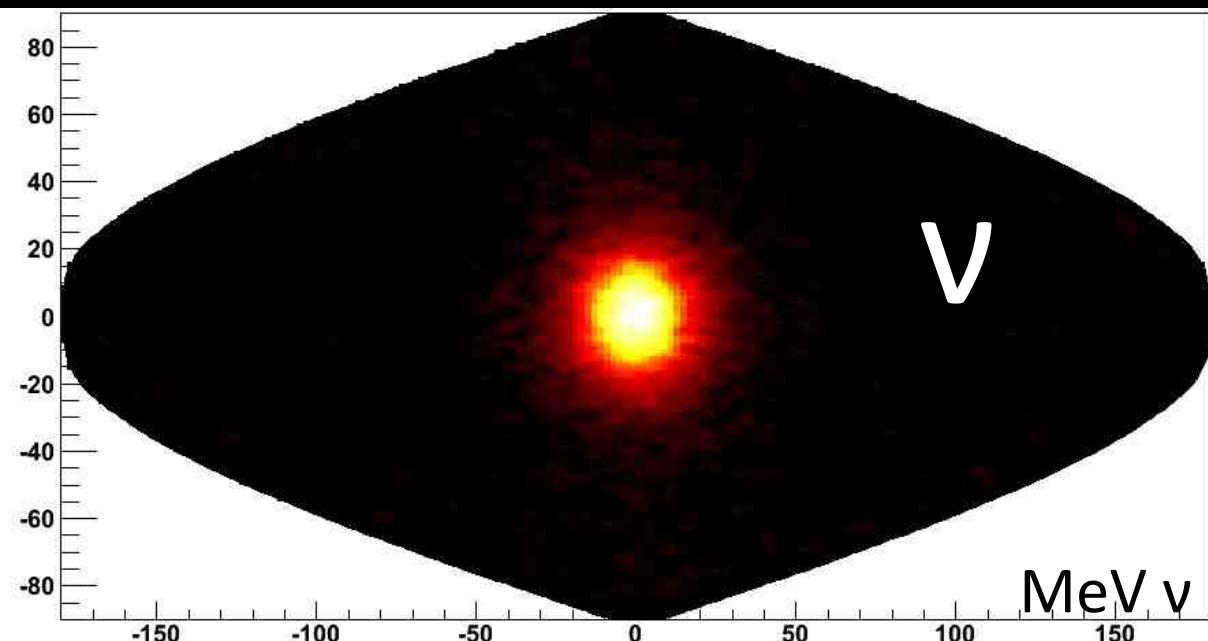


SDO/AIA 304 2022-07-11 15:19:06 UT



The Sun

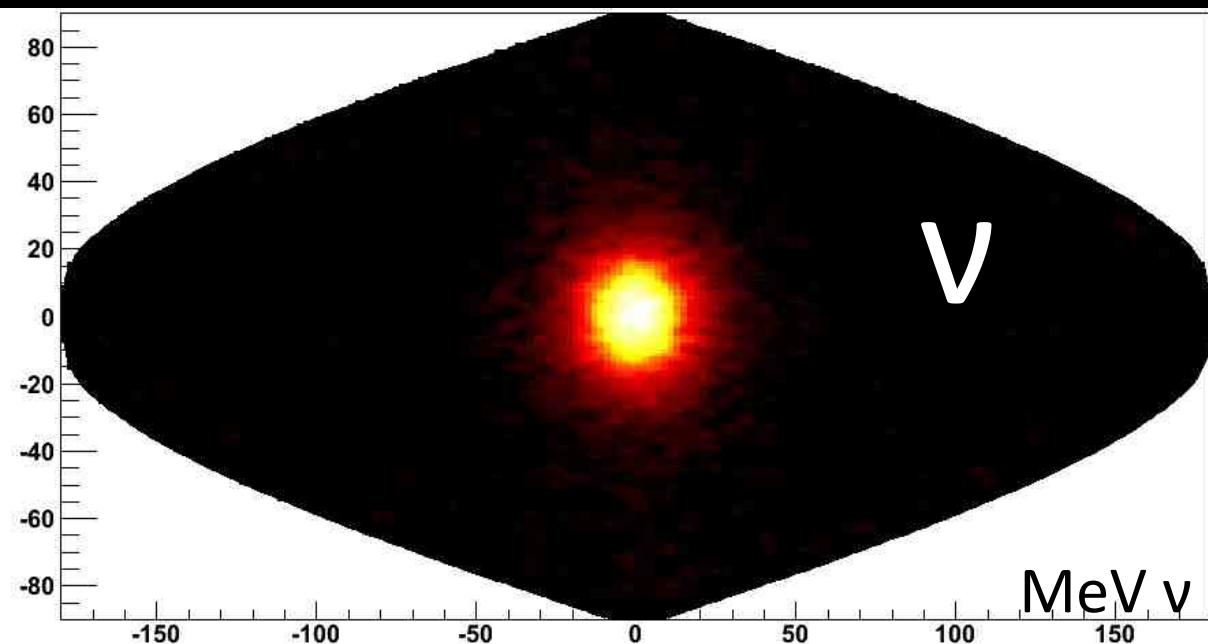
The Sun



The Sun

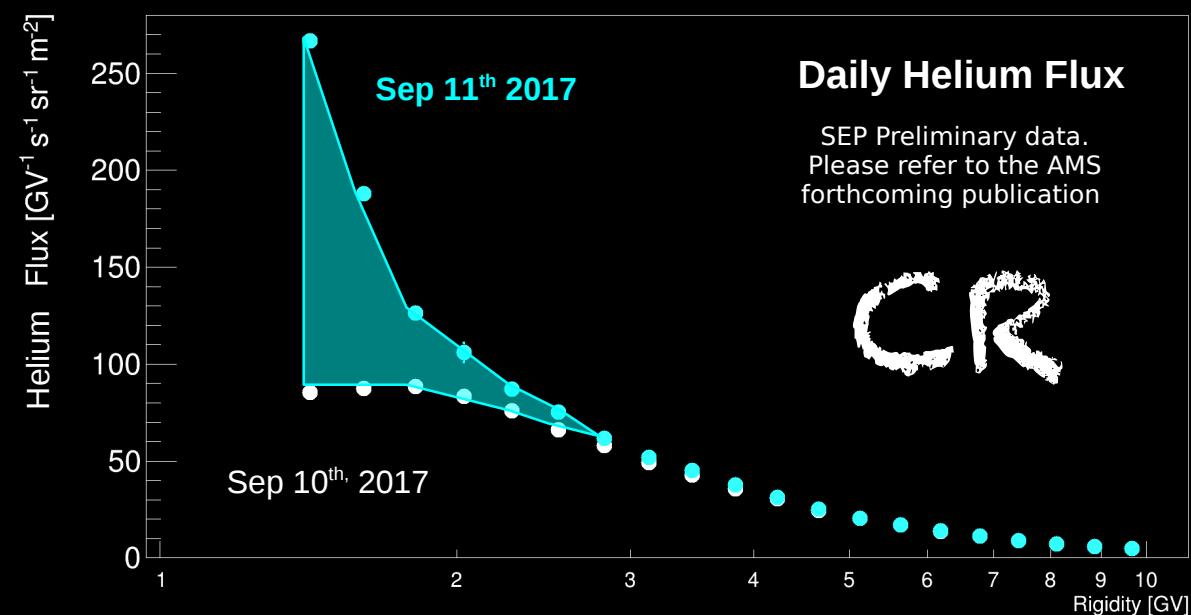


γ



MeV v

September 2017 Event AMS SEP Helium Fluxes



Daily Helium Flux

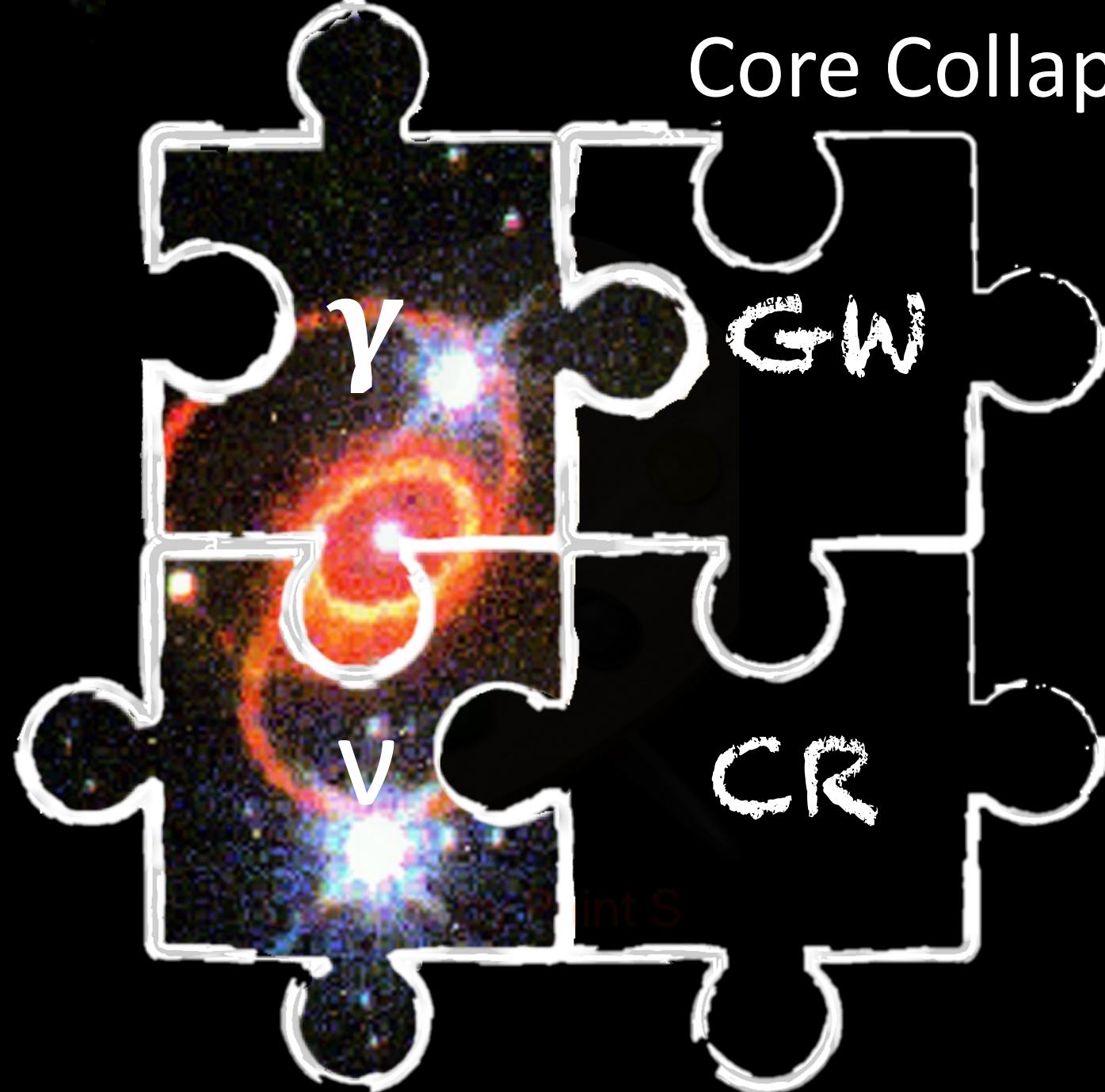
SEP Preliminary data.
Please refer to the AMS
forthcoming publication

CR

Core Collapse Supernova

SN1987A

1987



Observation of a Neutrino Burst from the Supernova SN1987A

K. Hirata,^(a) T. Kajita,^(a) M. Koshiba,^(a,b) M. Nakahata,^(b) Y. Oyama,^(b)
N. Sato,^(c) A. Suzuki,^(b) M. Takita,^(b) and Y. Totsuka^(a,c)
University of Tokyo, Tokyo 113, Japan

T. Kifune and T. Suda
Institute for Cosmic Ray Research, University of Tokyo, Tokyo 118, Japan

K. Takahashi and T. Tanimori
National Laboratory for High Energy Physics (KEK), Ibaraki 305, Japan

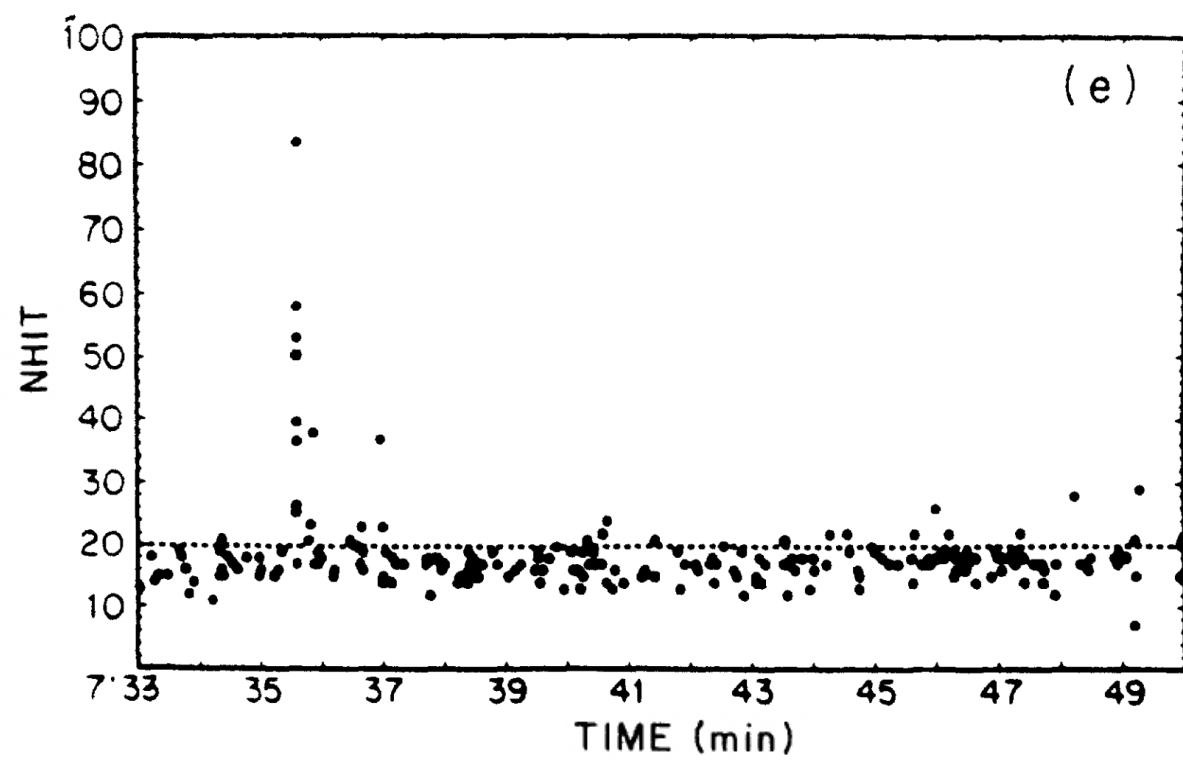
K. Miyano and M. Yamada
Department of Physics, University of Niigata, Niigata 950-21, Japan

E. W. Beier, L. R. Feldscher, S. B. Kim, A. K. Mann, F. M. Newcomer, R. Van Berg, and W. Zhang
Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104

and

B. G. Cortez^(d)
California Institute of Technology, Pasadena, California 91125
(Received 10 March 1987)

A neutrino burst was observed in the Kamiokande II detector on 23 February 1987, 7:35:35 UT (± 1 min) during a time interval of 13 sec. The signal consisted of eleven electron events of energy 7.5 to 36 MeV, of which the first two point back to the Large Magellanic Cloud with angles $18^\circ \pm 18^\circ$ and $15^\circ \pm 27^\circ$.



Observation of a Neutrino Burst from the Supernova SN1987A

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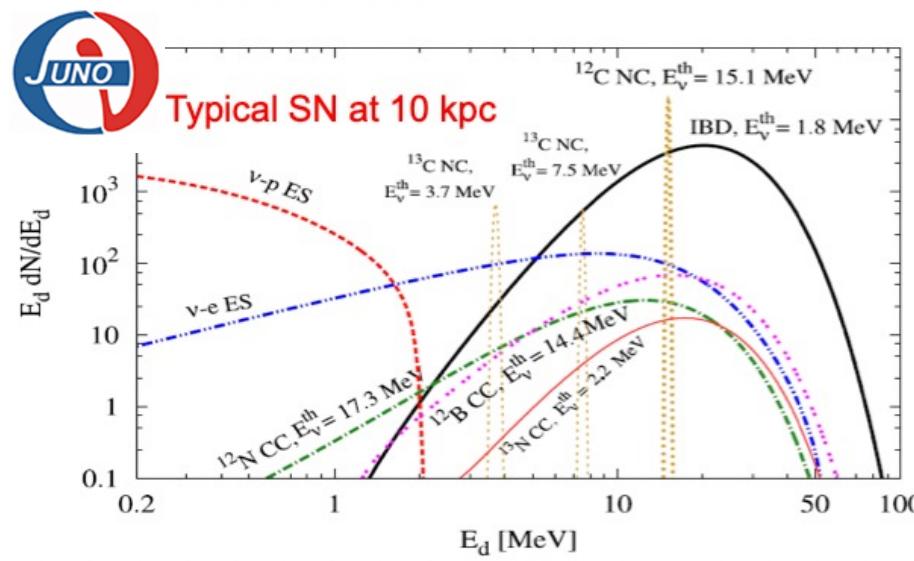
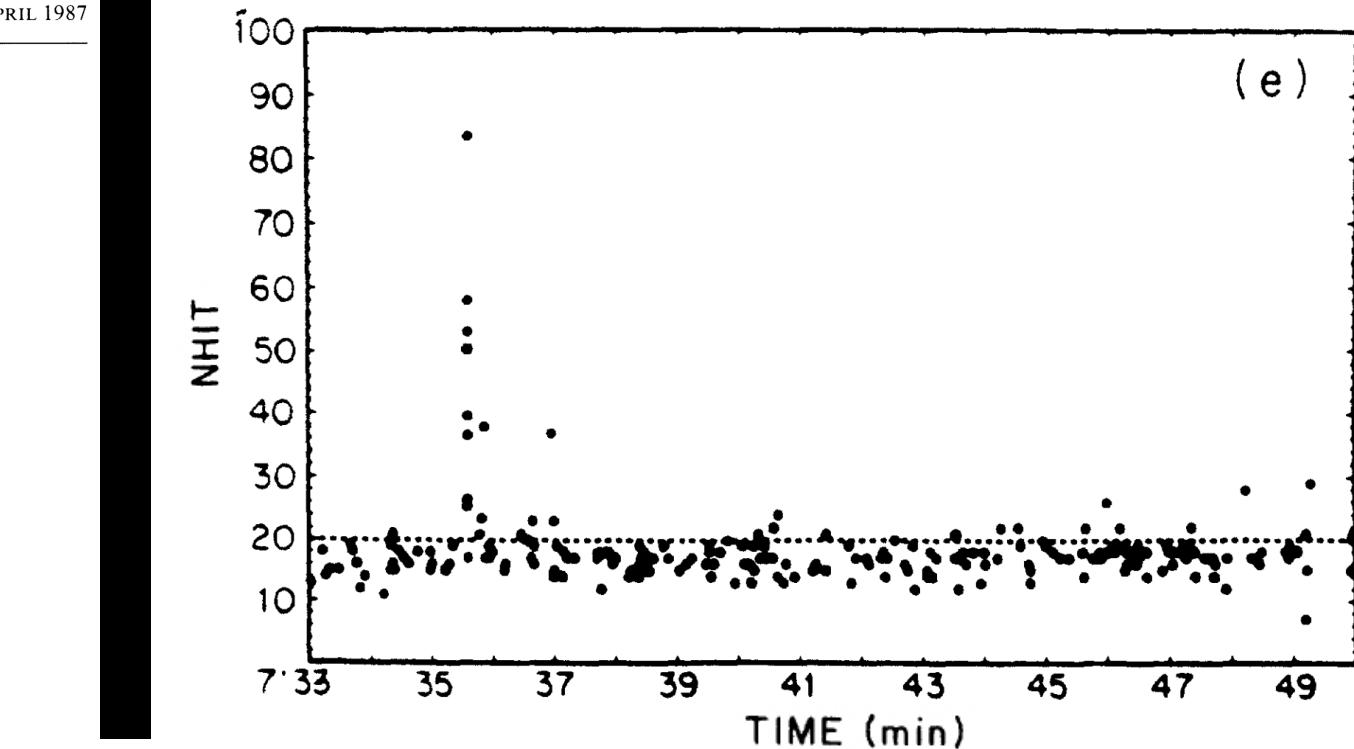
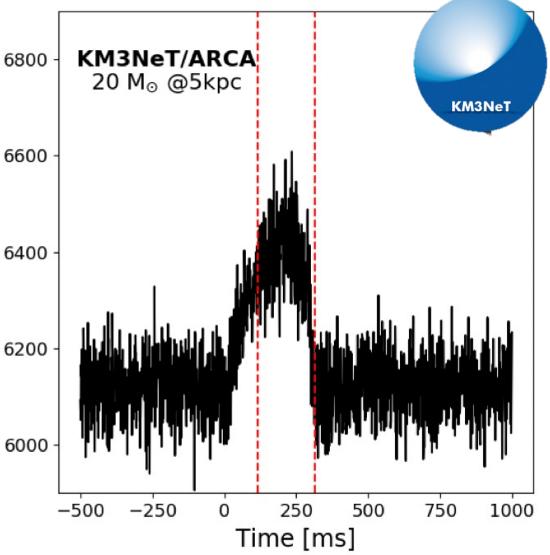
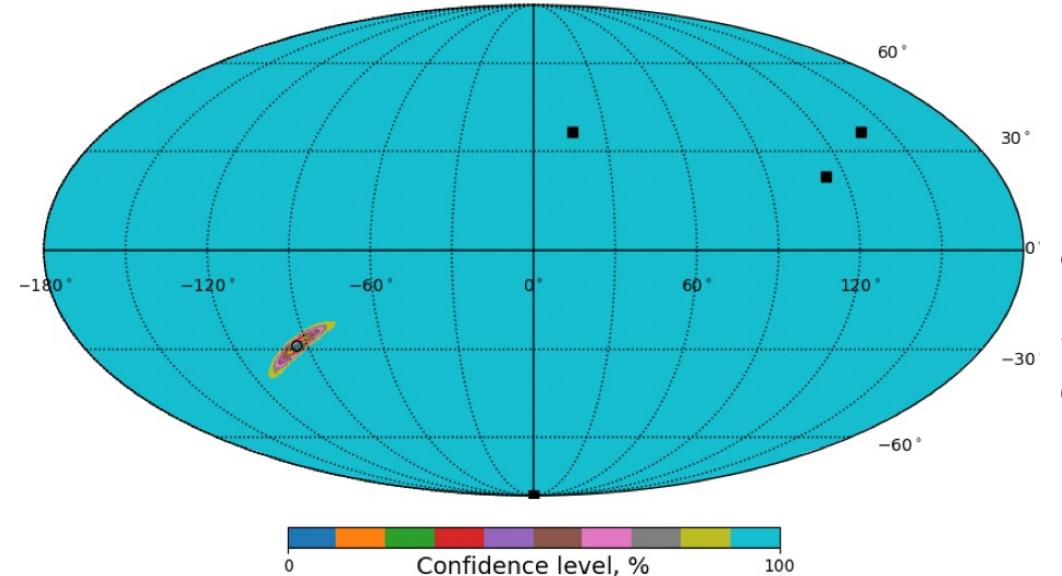
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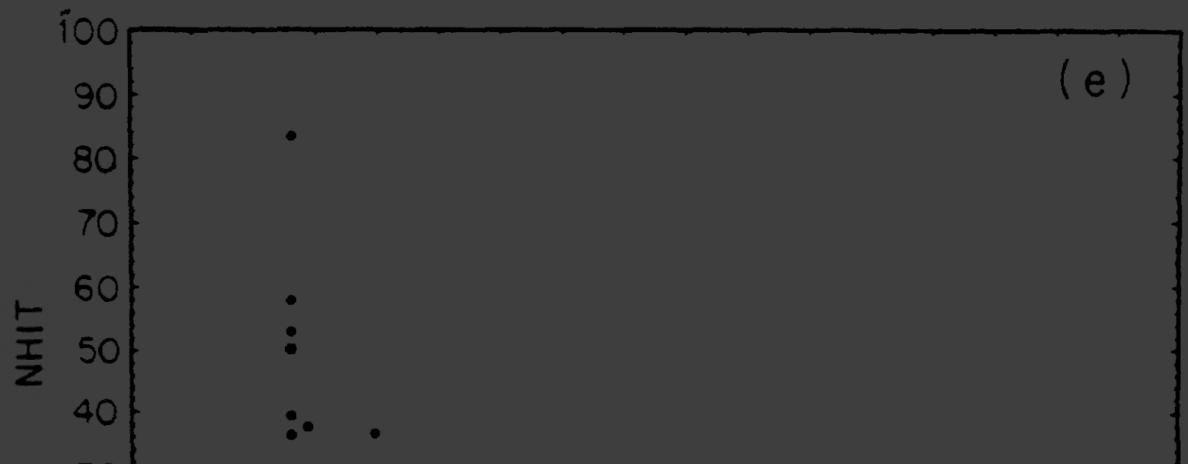
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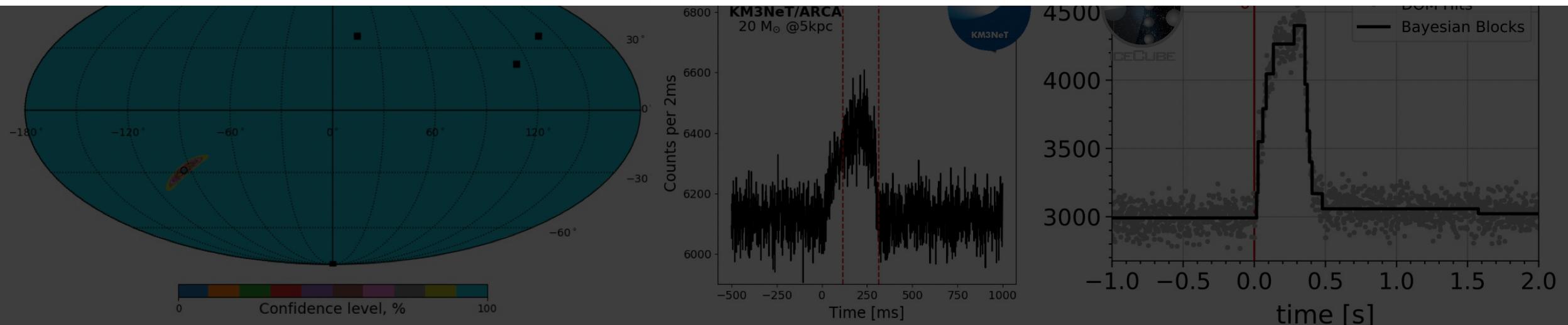
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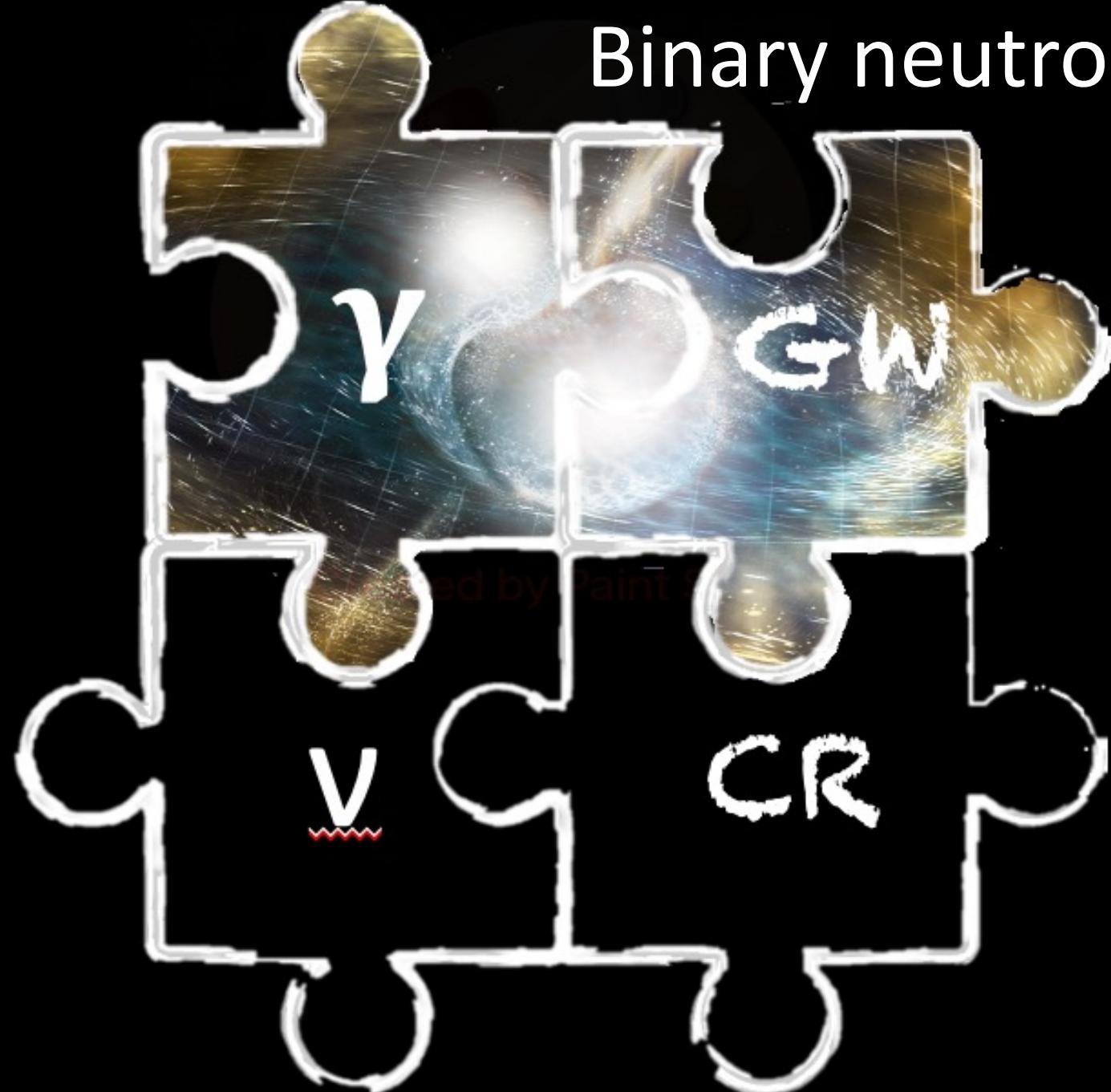


If you are interested in being notified about the occurrence of a neutrino burst from SNEWS, please [sign up for our alert list](#).



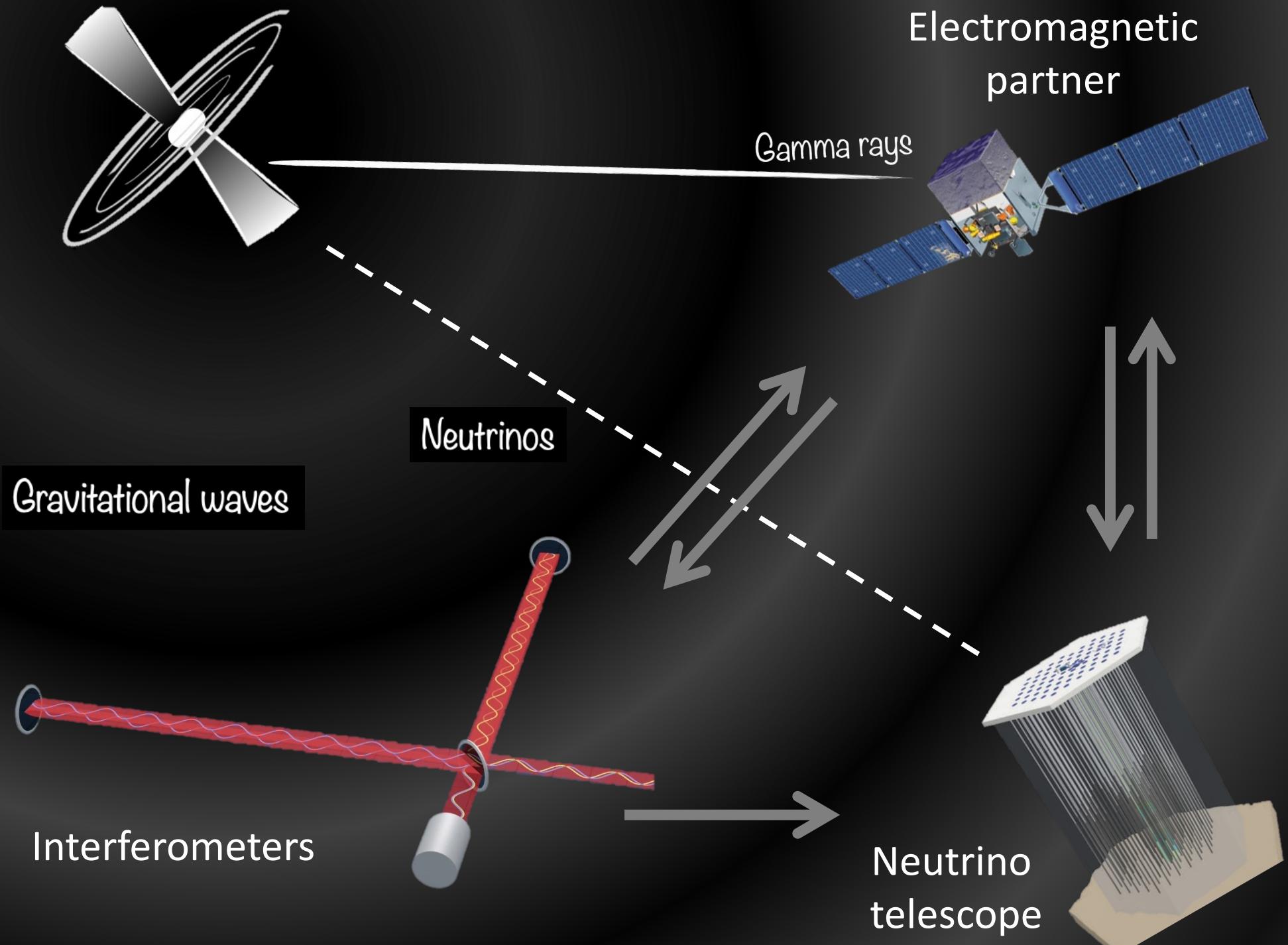
Binary neutron star merger

2017



GW170817

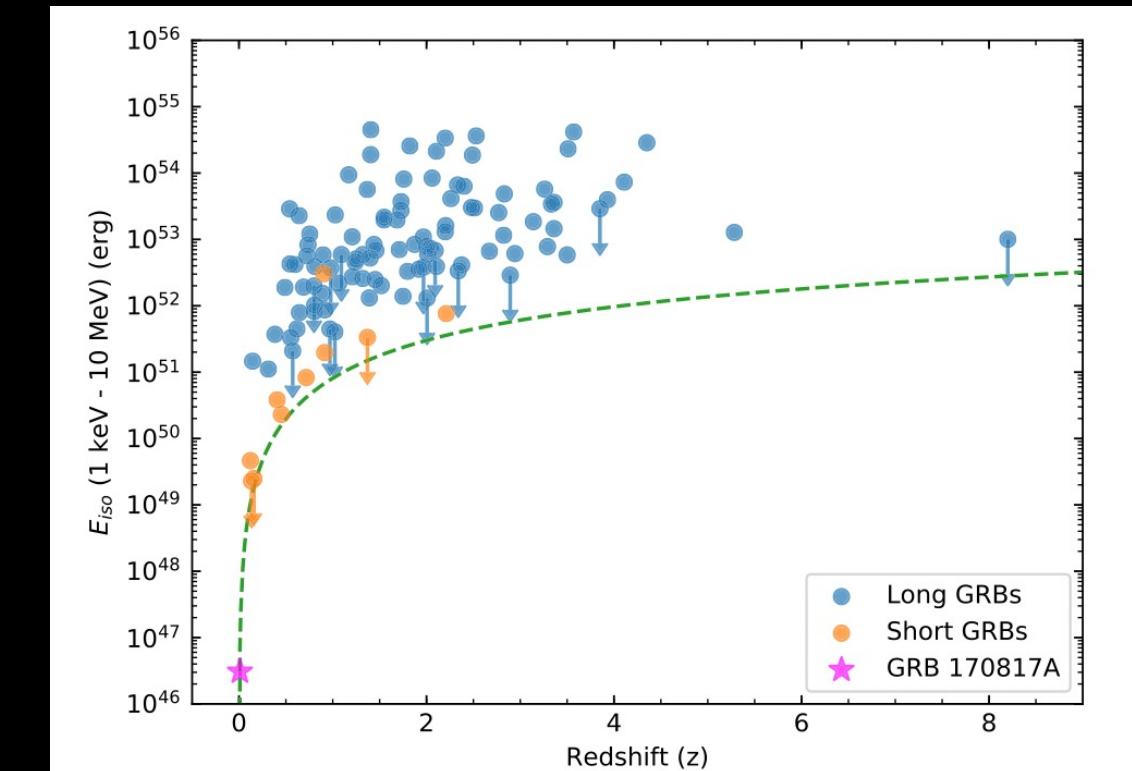
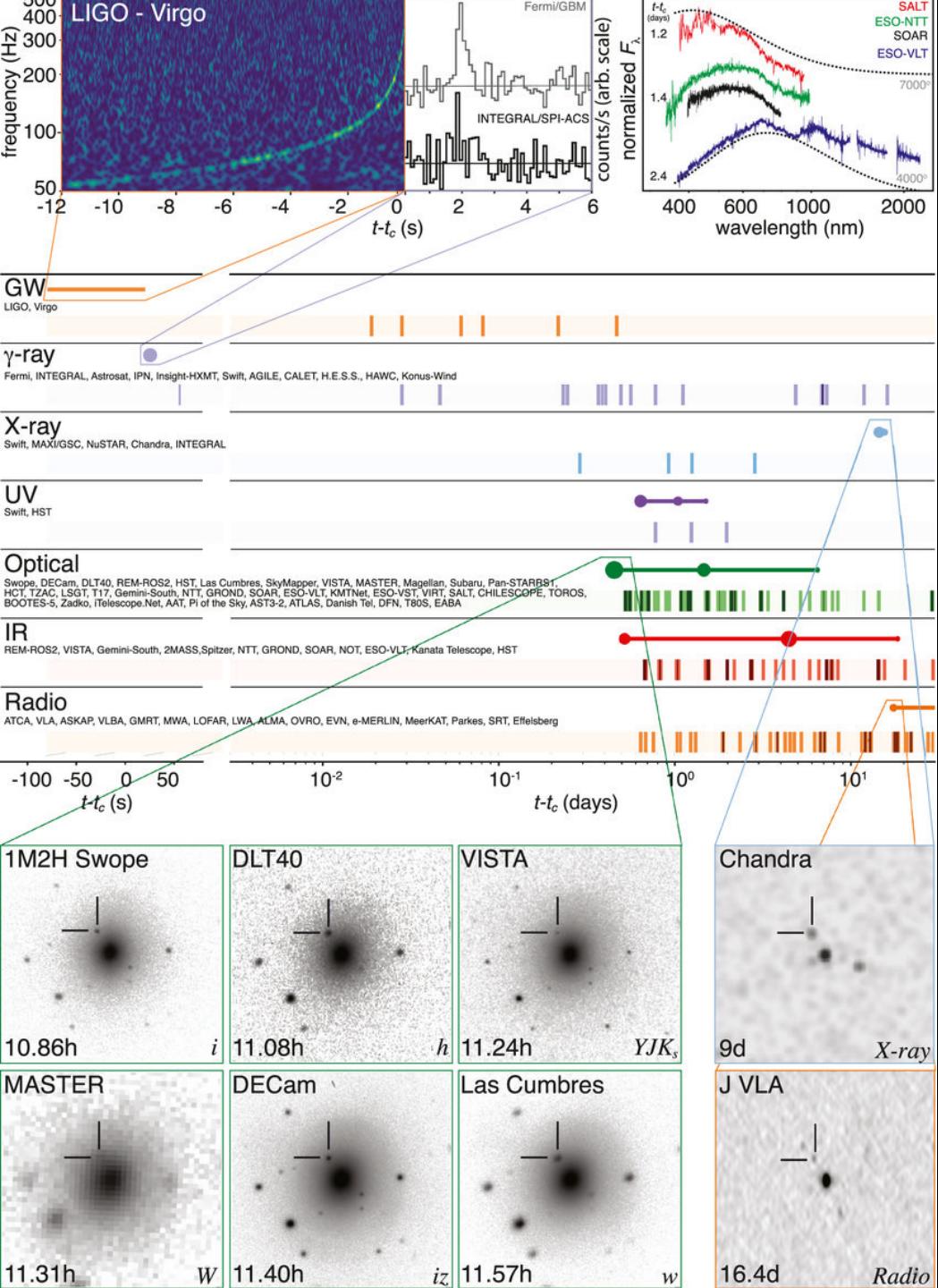
GRB170817A



Binary neutron star merger

GW170817

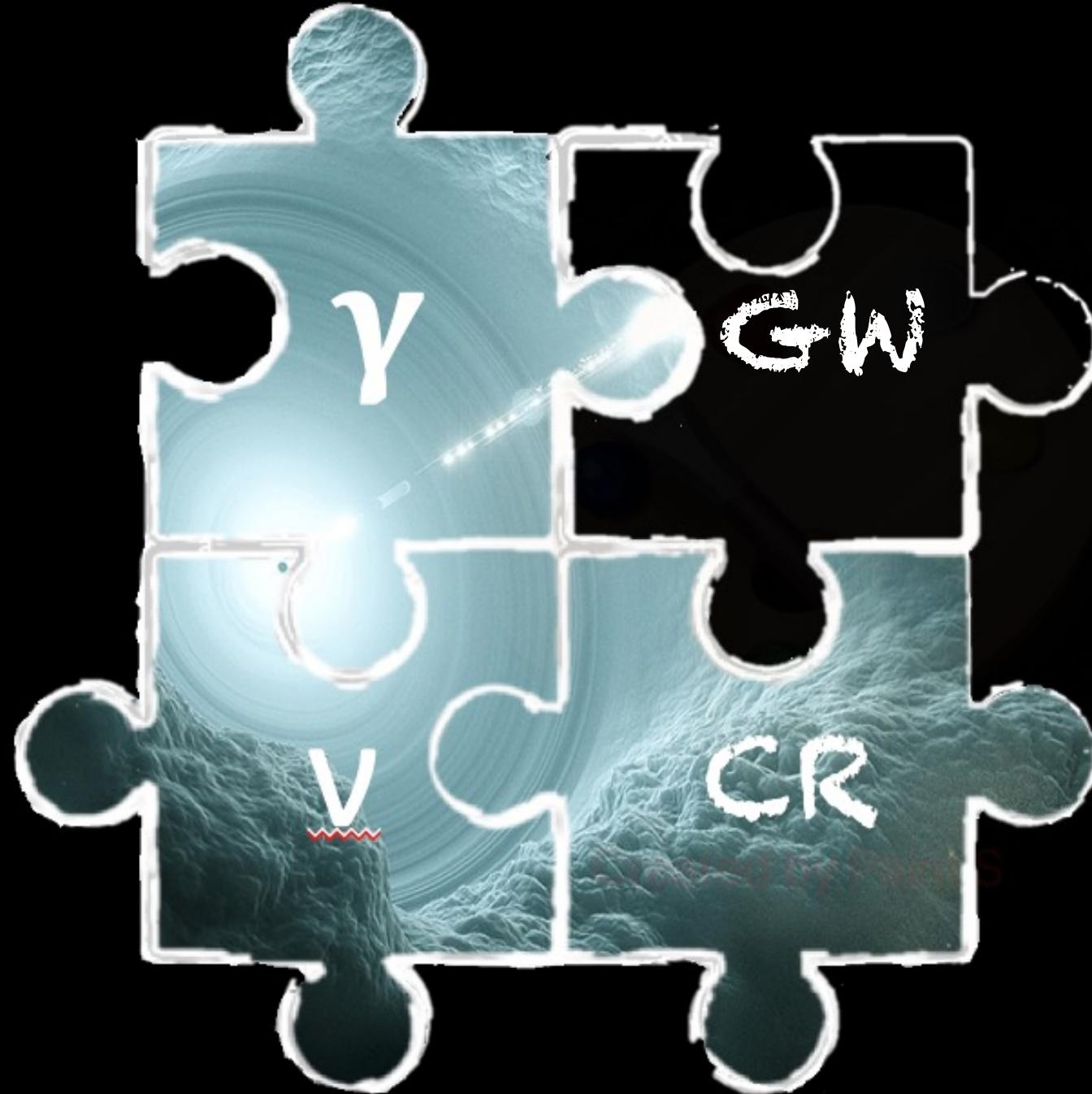
GRB170817A



[arXiv:1710.05834](https://arxiv.org/abs/1710.05834)

Flaring blazar TXS 0506+056

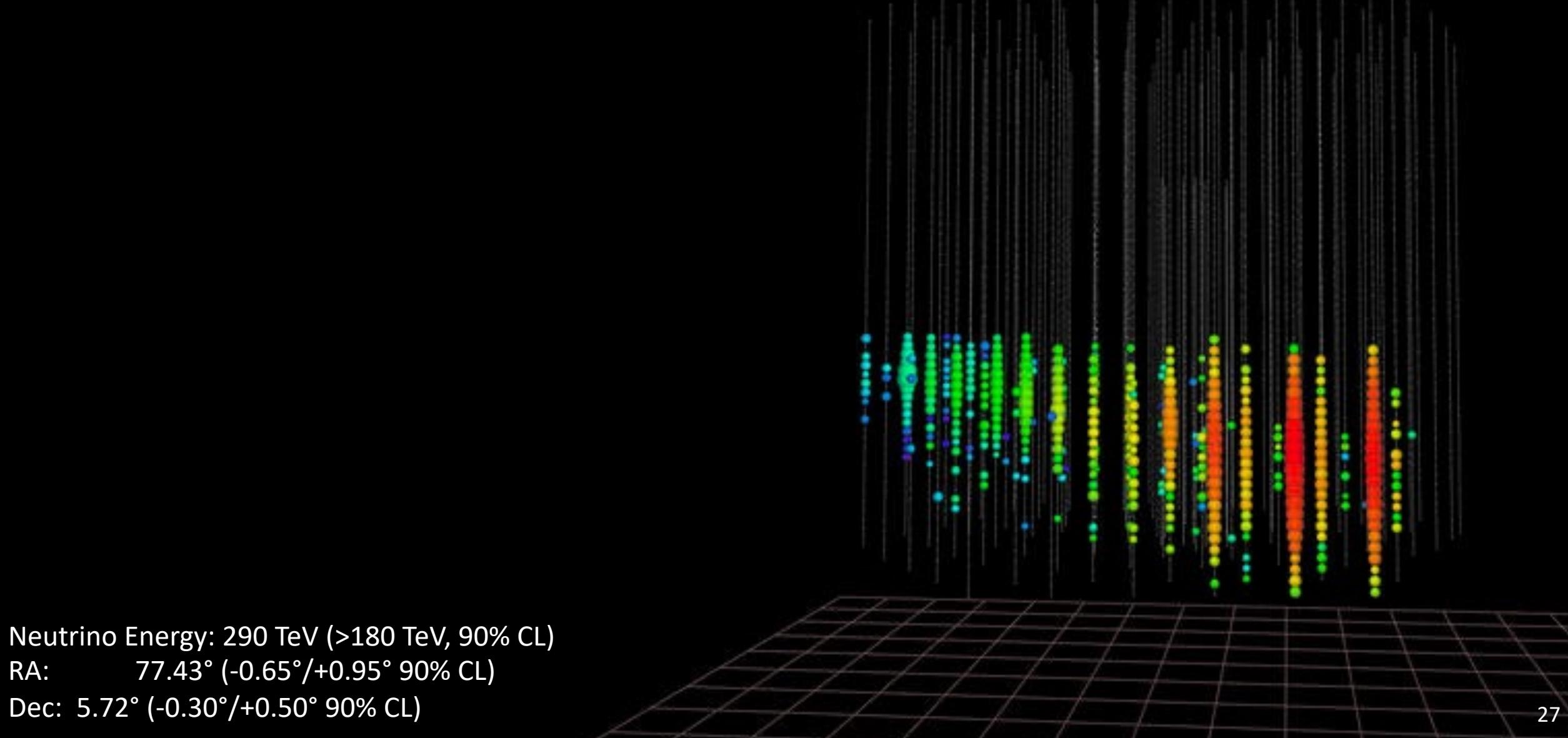
2017



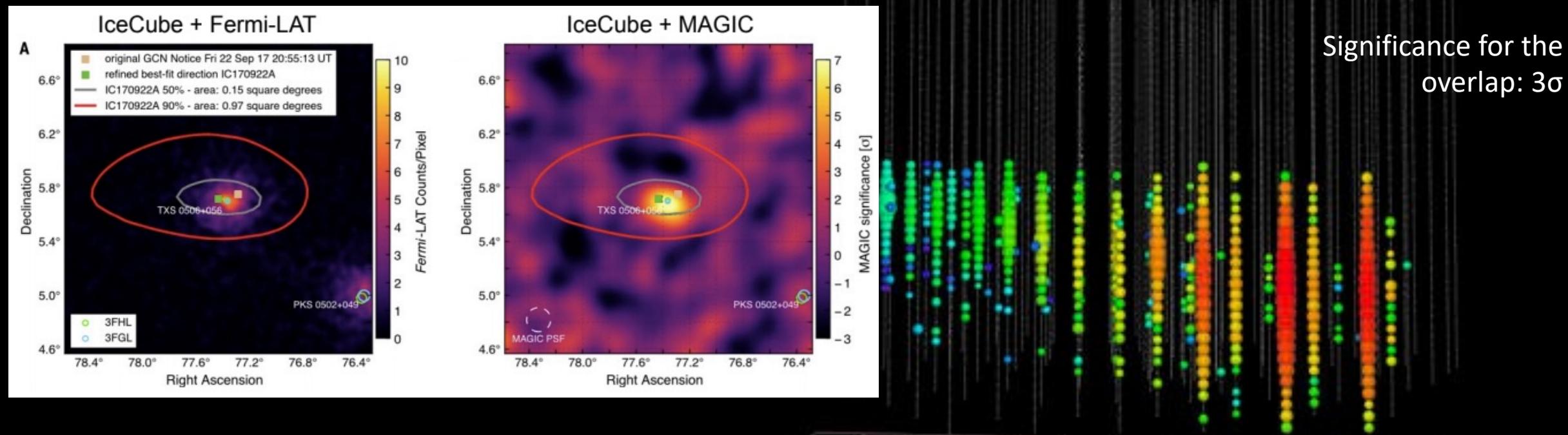
<https://arxiv.org/pdf/1807.08816>

<https://arxiv.org/abs/1807.08794>

22 September 2017
IceCube-170922A

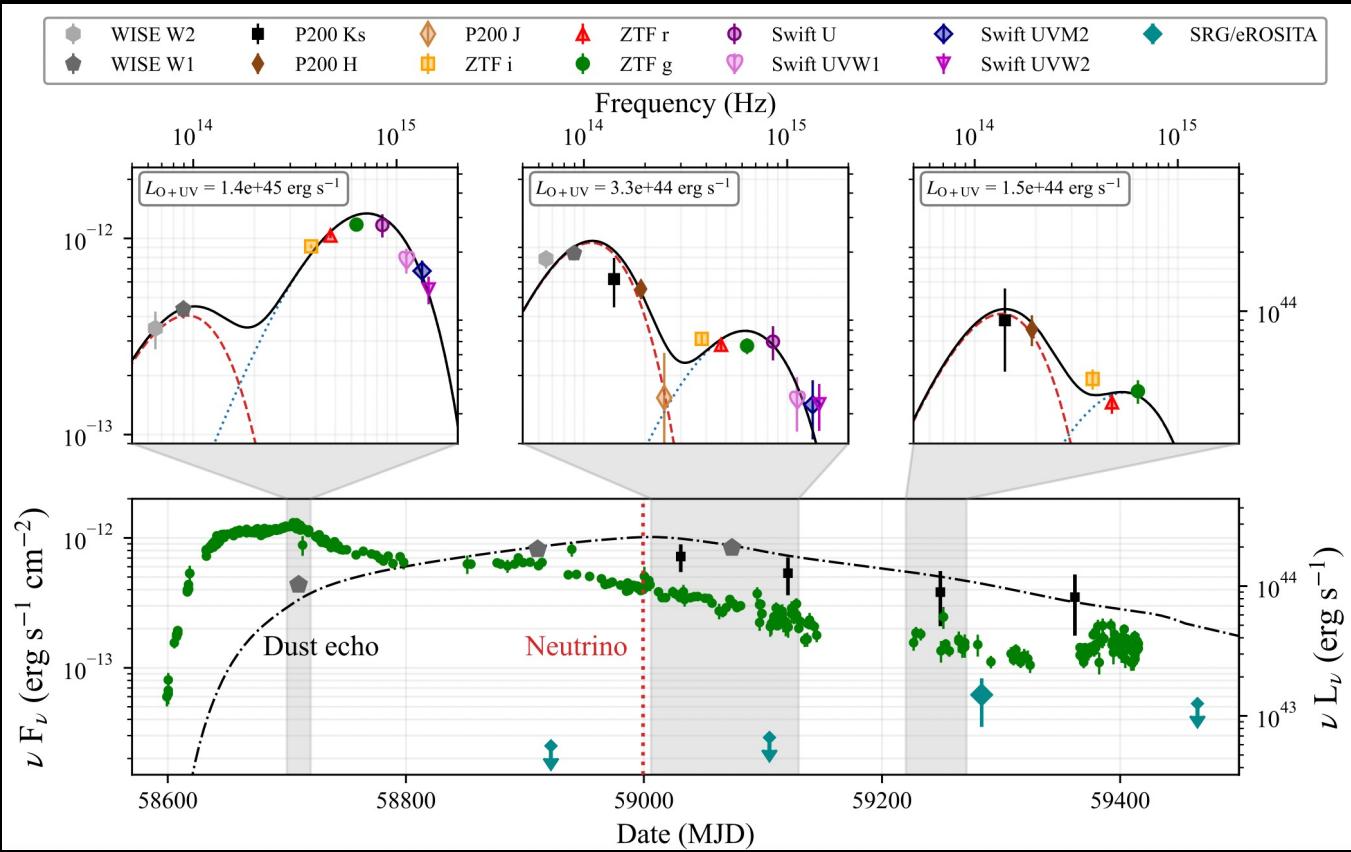


- Fermi observations of a known blazar TXS 0506+056, in a state of enhanced gamma-ray emission
- MAGIC detection of > 400 GeV gamma rays from the blazar



Neutrino Energy: 290 TeV (>180 TeV, 90% CL)
 RA: 77.43° (-0.65°/+0.95° 90% CL)
 Dec: 5.72° (-0.30°/+0.50° 90% CL)

Tidal Disruption Event AT2019fdr

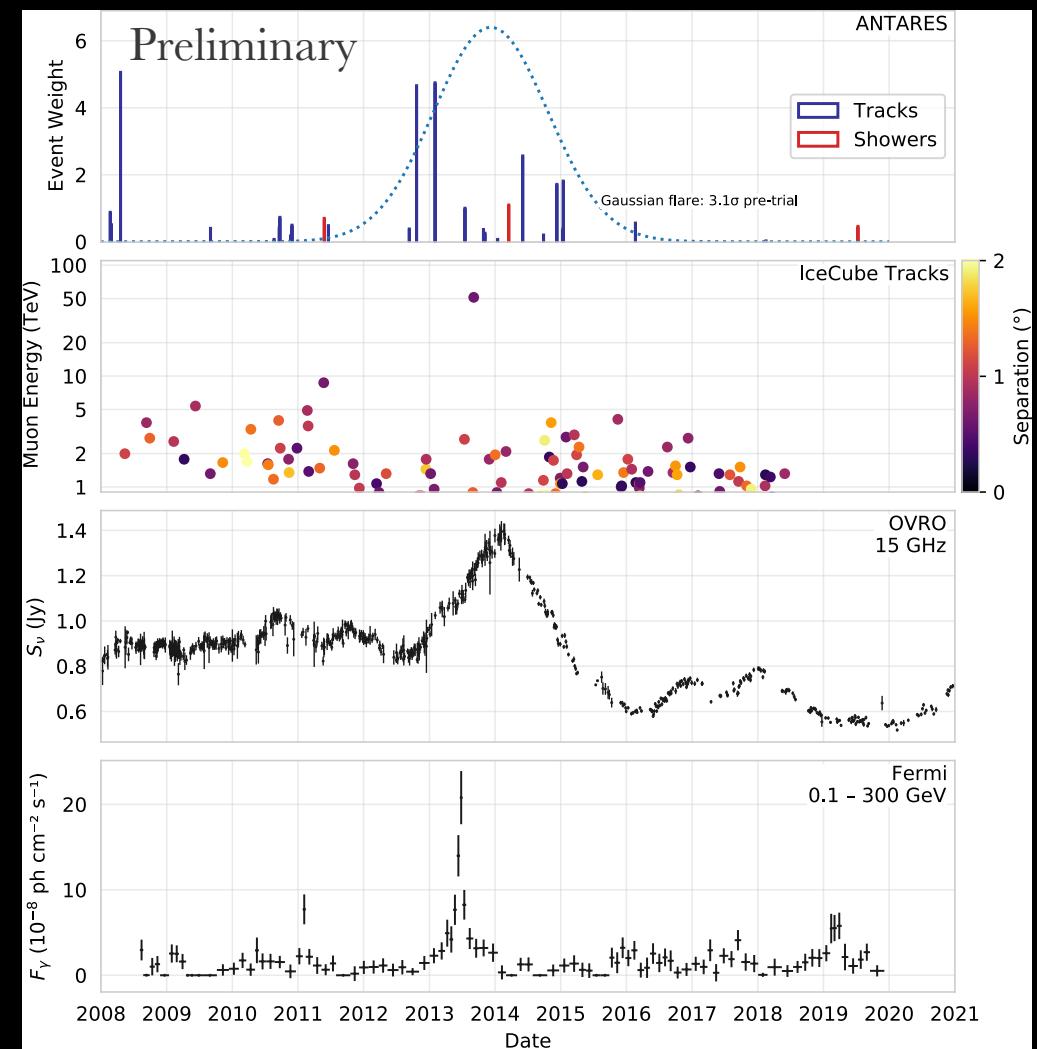


Following previous observation from AT2019dsg

arXiv:2111.09390

Nat Astron 5, 510–518 (2021)

Radio-bright blazar PKS 0239+108



Neutrino2022, G. Illuminati and A. Plavin

Alert systems
Coordination in between
instruments Joint
analysis



Independent
development of
calibration,
reconstruction,
event selection,...

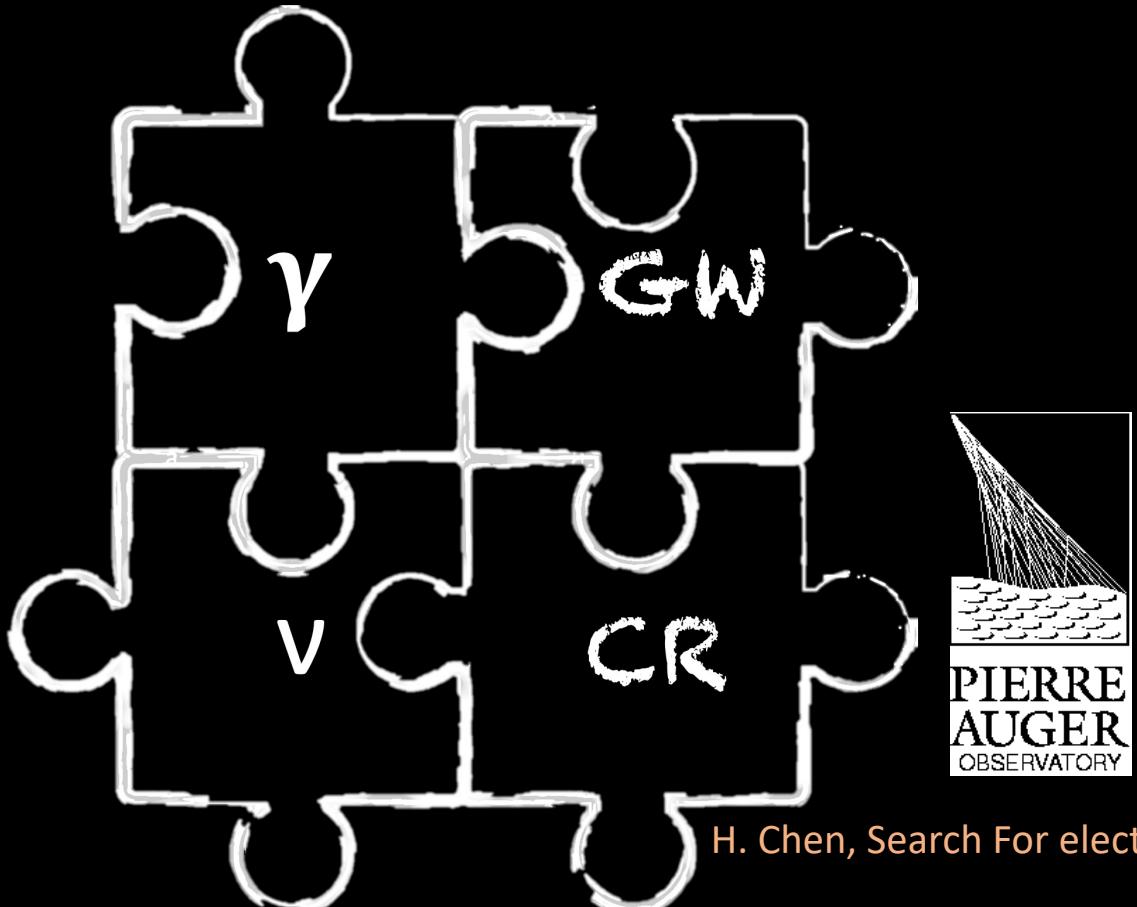
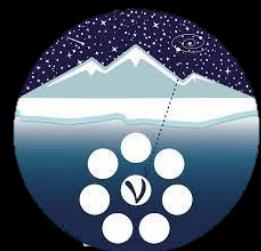
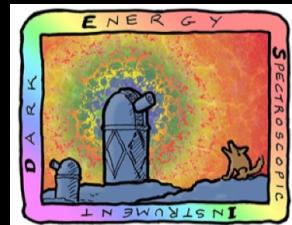
(Prioritization of
candidates)

Interpretation

t

Not to scale

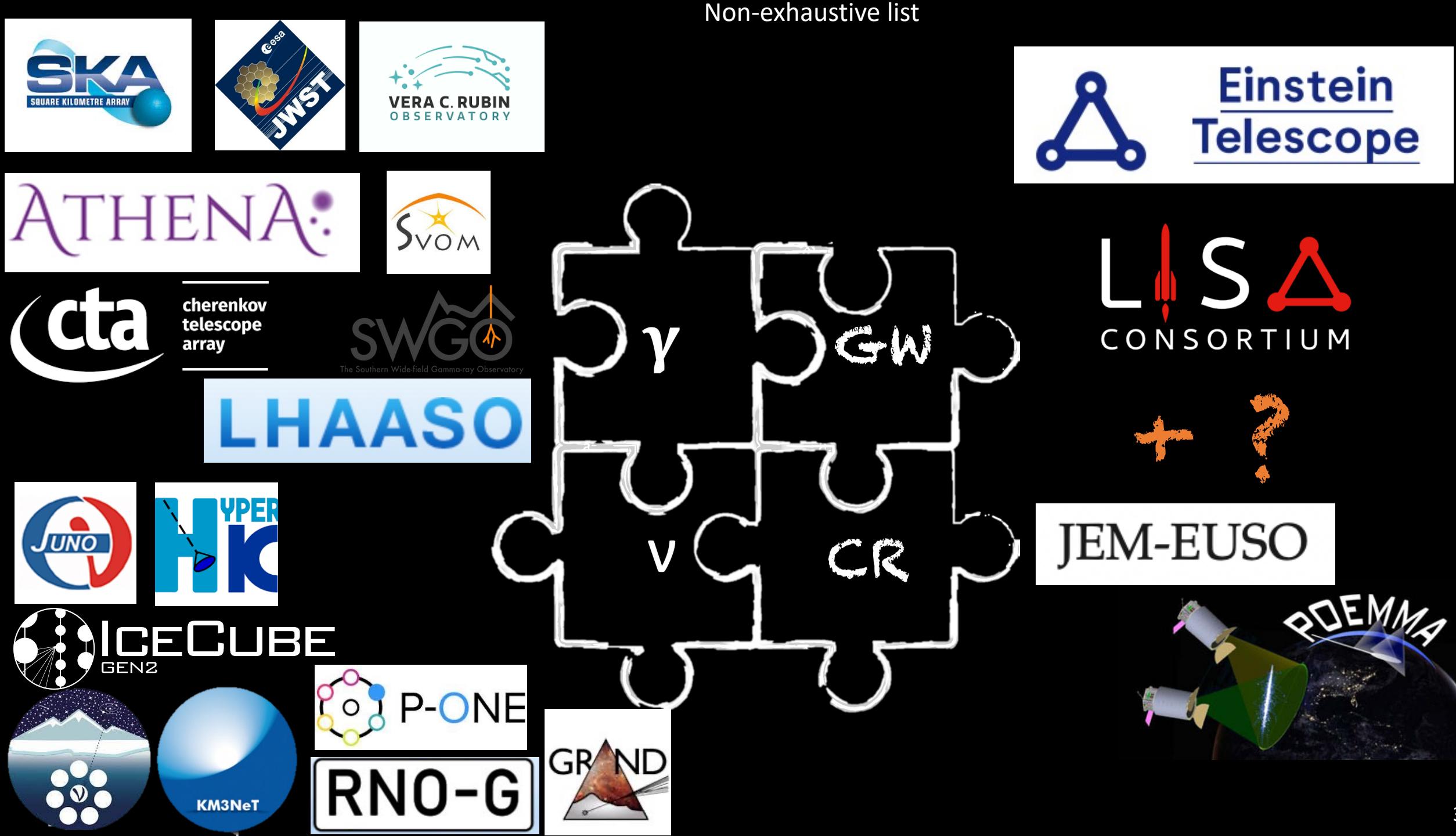
Non-exhaustive list



- H. Chen, Search For electron-antineutrinos associated with GW events at Daya Bay
- P. Kalaczynski, Prospects and recent results from KM3NeT/ARCA
- M. Mastrodicasa MM with Pierre Auger Observatory
- A. Palmese, MM studies with DESI
- M. Spurio, Highlights from the ANTARES neutrino telescope

What will multi-messenger look like
when ICHEP will be held again in Italy?

Non-exhaustive list



Take-home message

- Multi-messenger is a tool to explore the Universe
- Real-time astronomy already led to the identification of multi-messenger sources
- This field requires coordination, synchronisation, and coverage in every wavelength / messenger
- The future is bright in all messengers!

We are just at the beginning of the story!

Thanks!