Messages from very high energy γ rays

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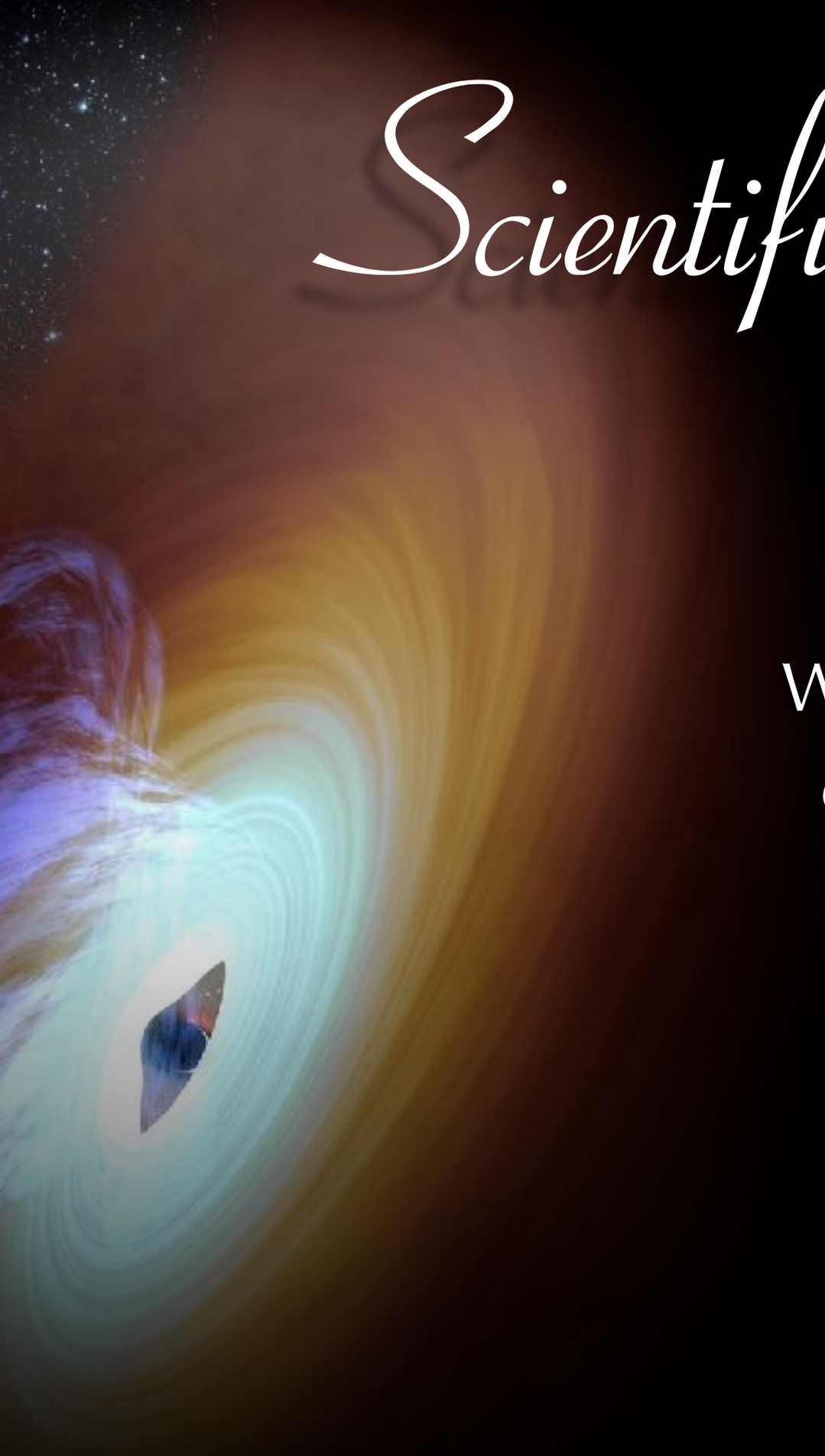
Outline

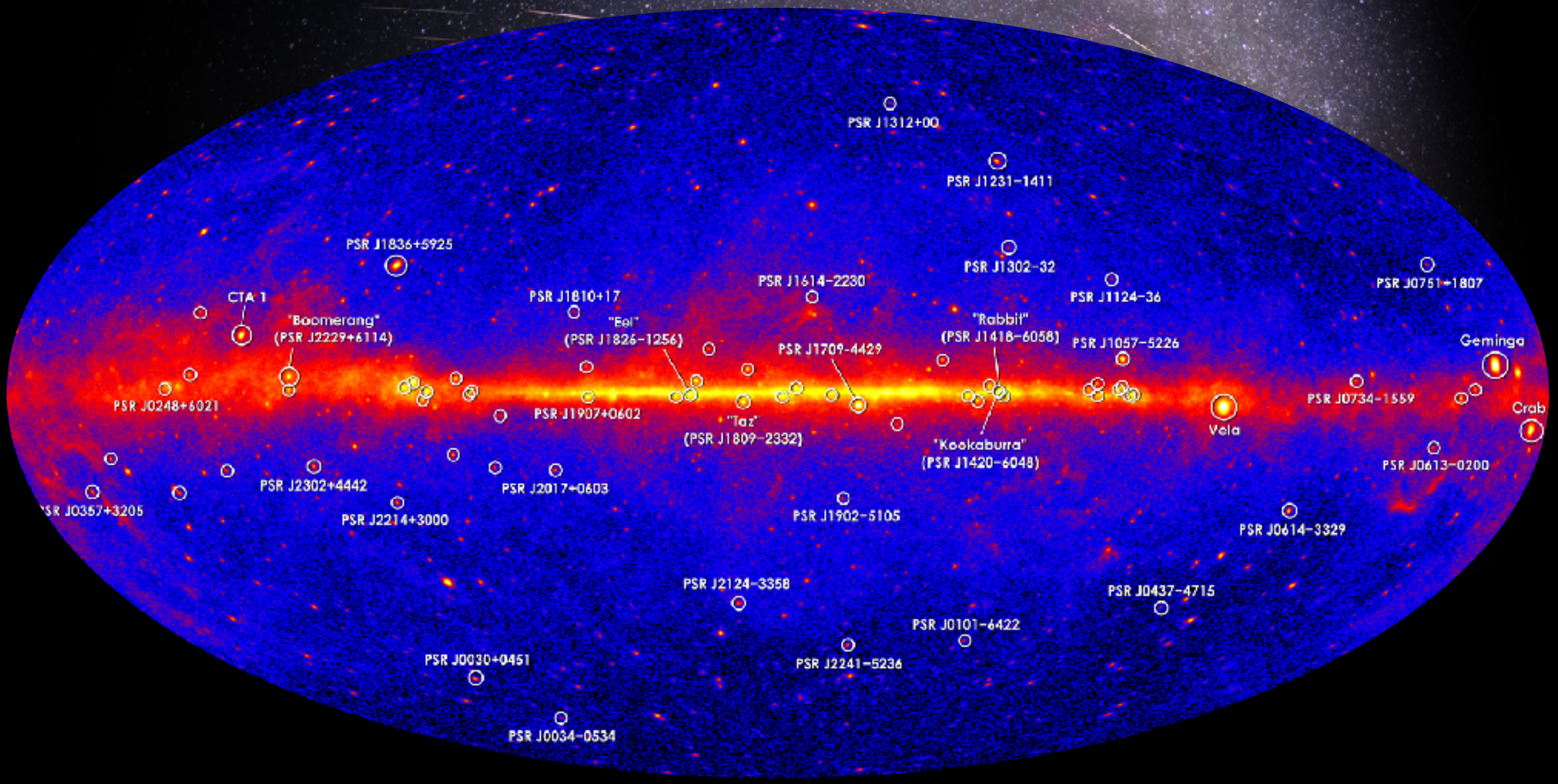
- Introduction and Scientific Motivation
- Biased selection of recent results:
  - Galactic Pevatrons
  - New TeV sources
  - Jets of a microquasar
  - Gamma-ray bursts
  - Flaring quasars
- Conclusions & Outlook

Scientific Motivation



What are the sources of the highest energy particles in the Universe?

Gamma rays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PSR J1231−1411
PSR J1836+5925
PSR J1302−32
PSR J0751+1807
CTA 1
PSR J1810+17
PSR J1614−2230
PSR J1124−36
"Boomerang"
(PSR J2229+6114)
"Eel"
(PSR J1826−1256)
"Rabbit"
(PSR J1418−6058)
PSR J1709−4429
PSR J1057−5226
Geminga
PSR J0248+6021
PSR J1907+0602
PSR J0734−1559
Crab
"Taz"
(PSR J1809−2332)
Vela
"Kookaburra"
(PSR J1420−6048)
PSR J0613−0200
PSR J2302+4442
PSR J2017+0603
PSR J0357+3205
PSR J2214+3000
PSR J1902−5105
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PSR J2124−3358
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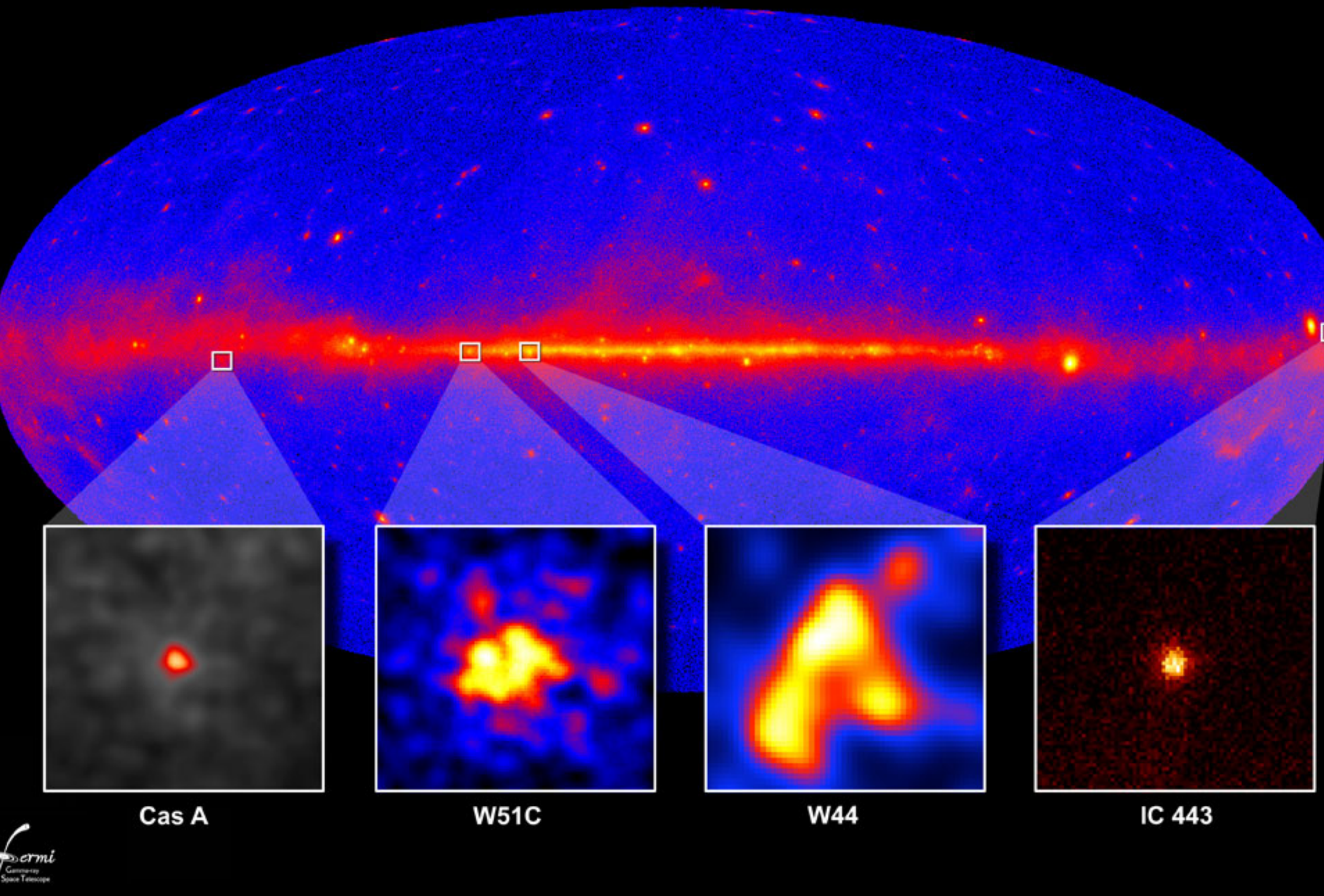
PSR J0034−0534

NASA's Fermi telescope resolves supernova remnants at GeV energies



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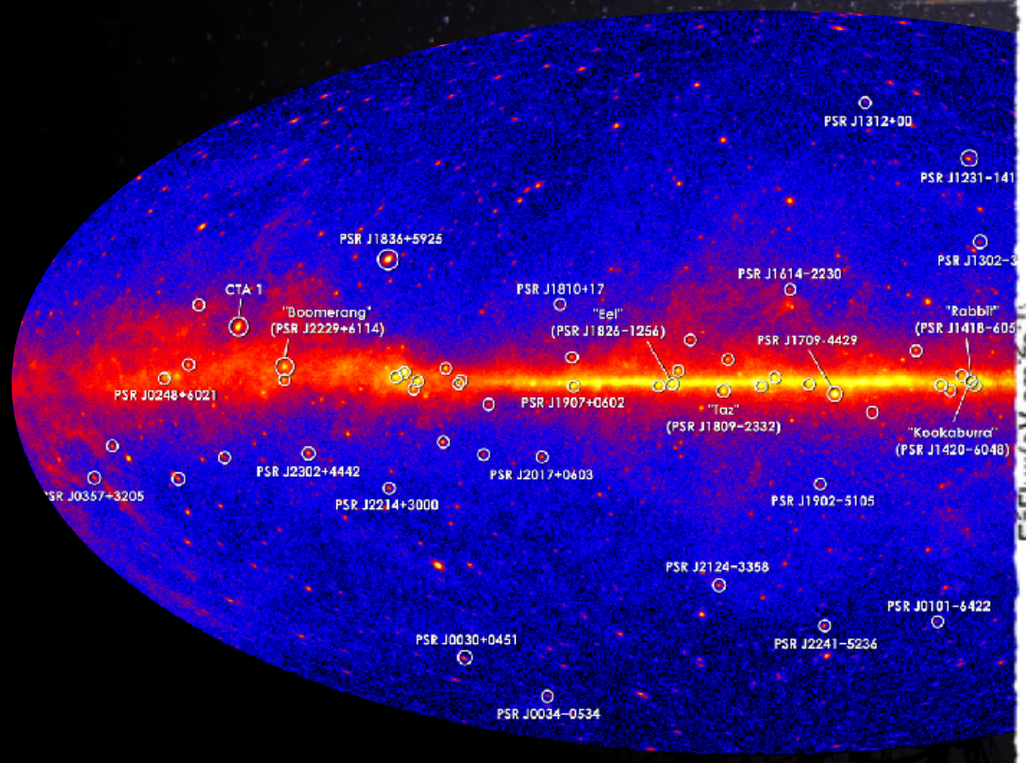
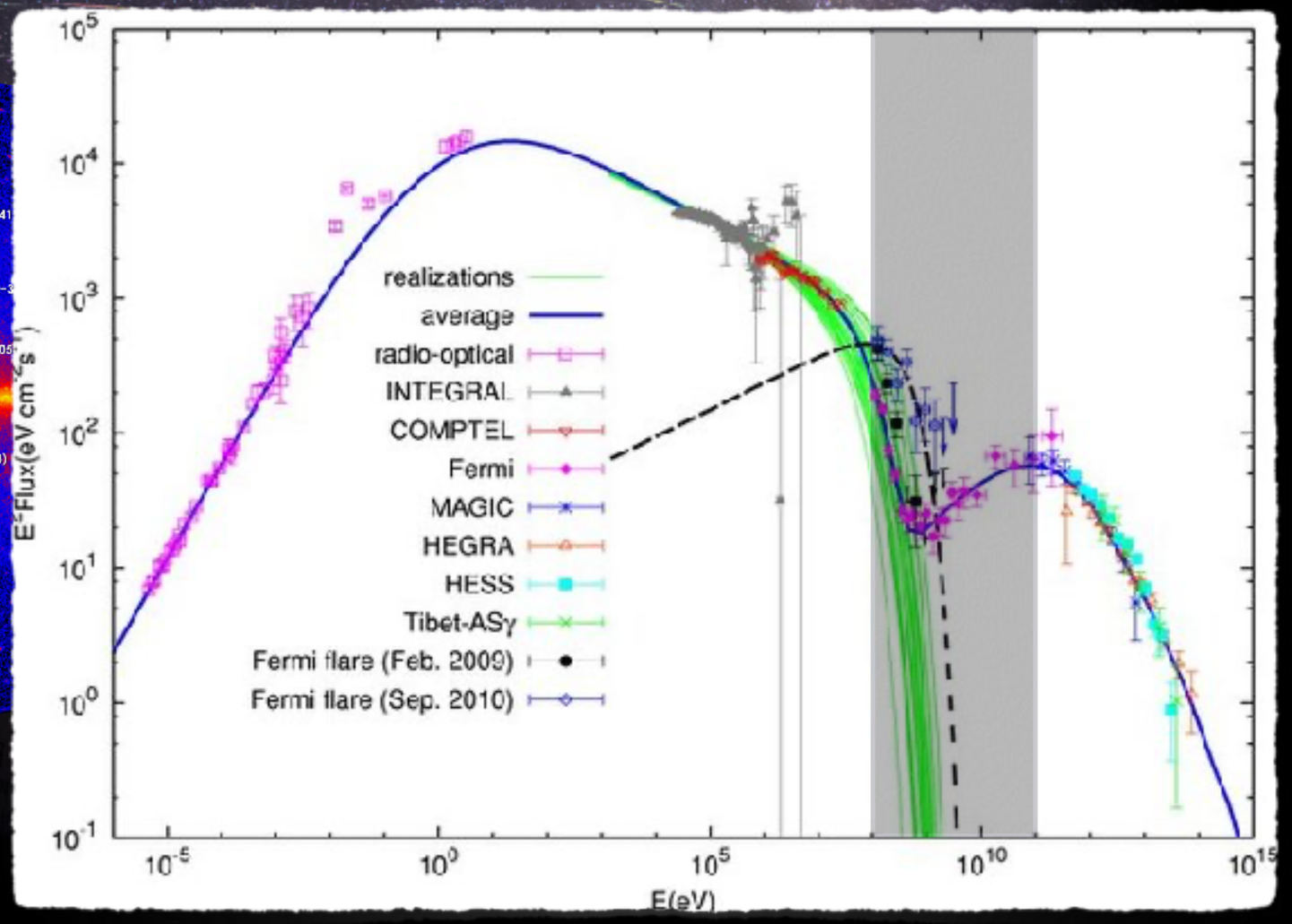
Fermi Gamma-ray Space Telescope

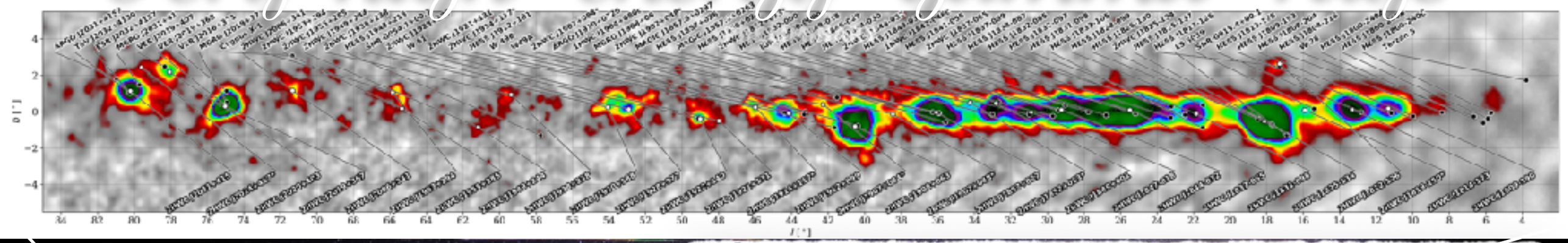
Gamma rays

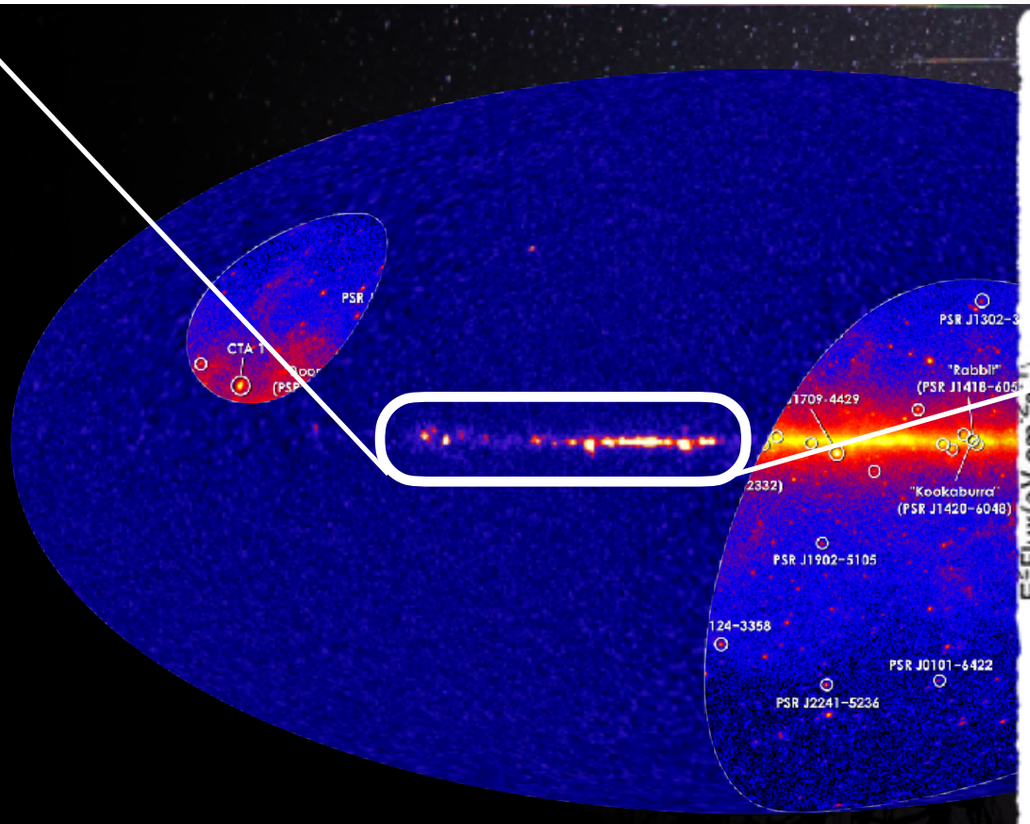


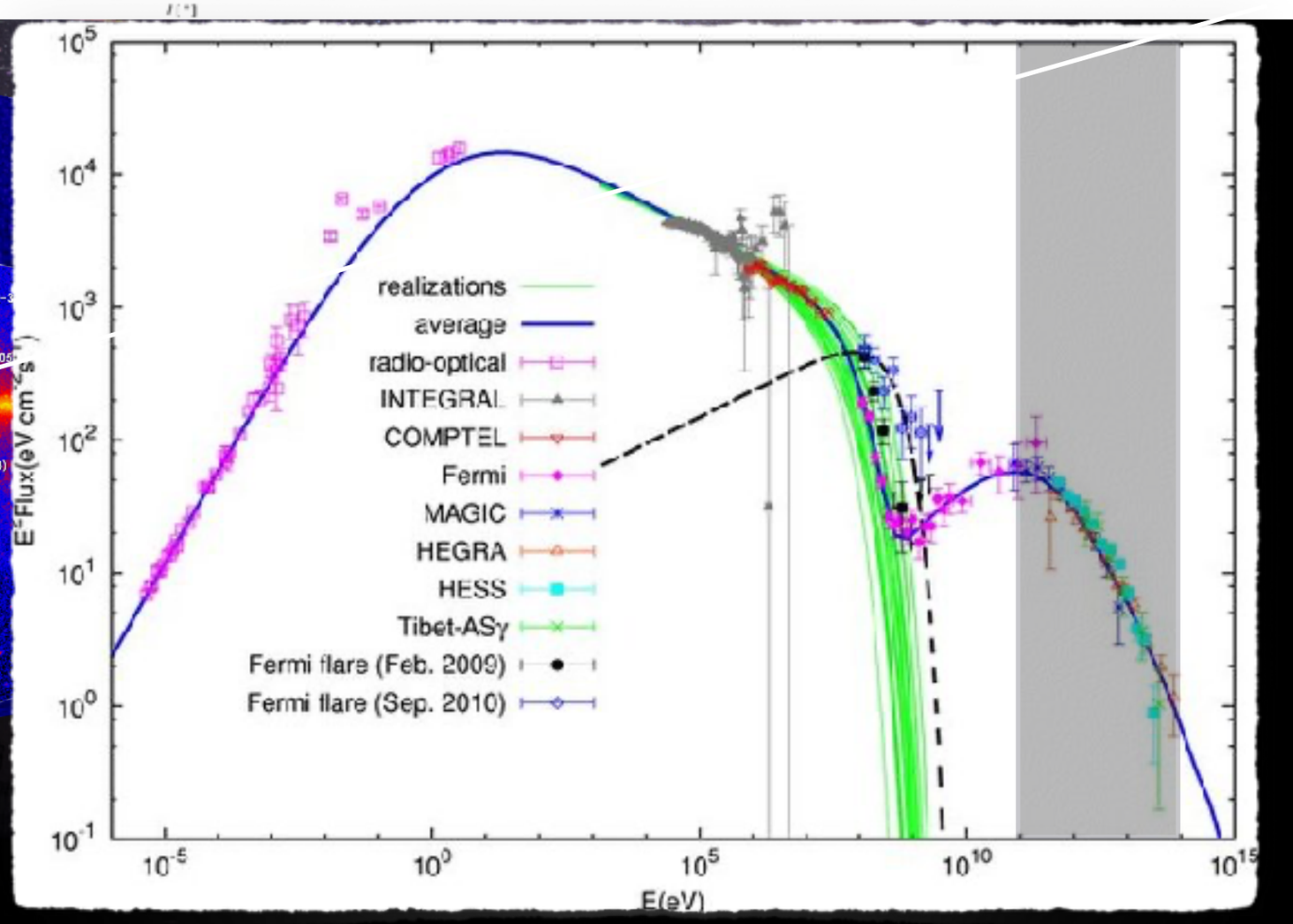


GeV energy range

Very-high energy gamma rays





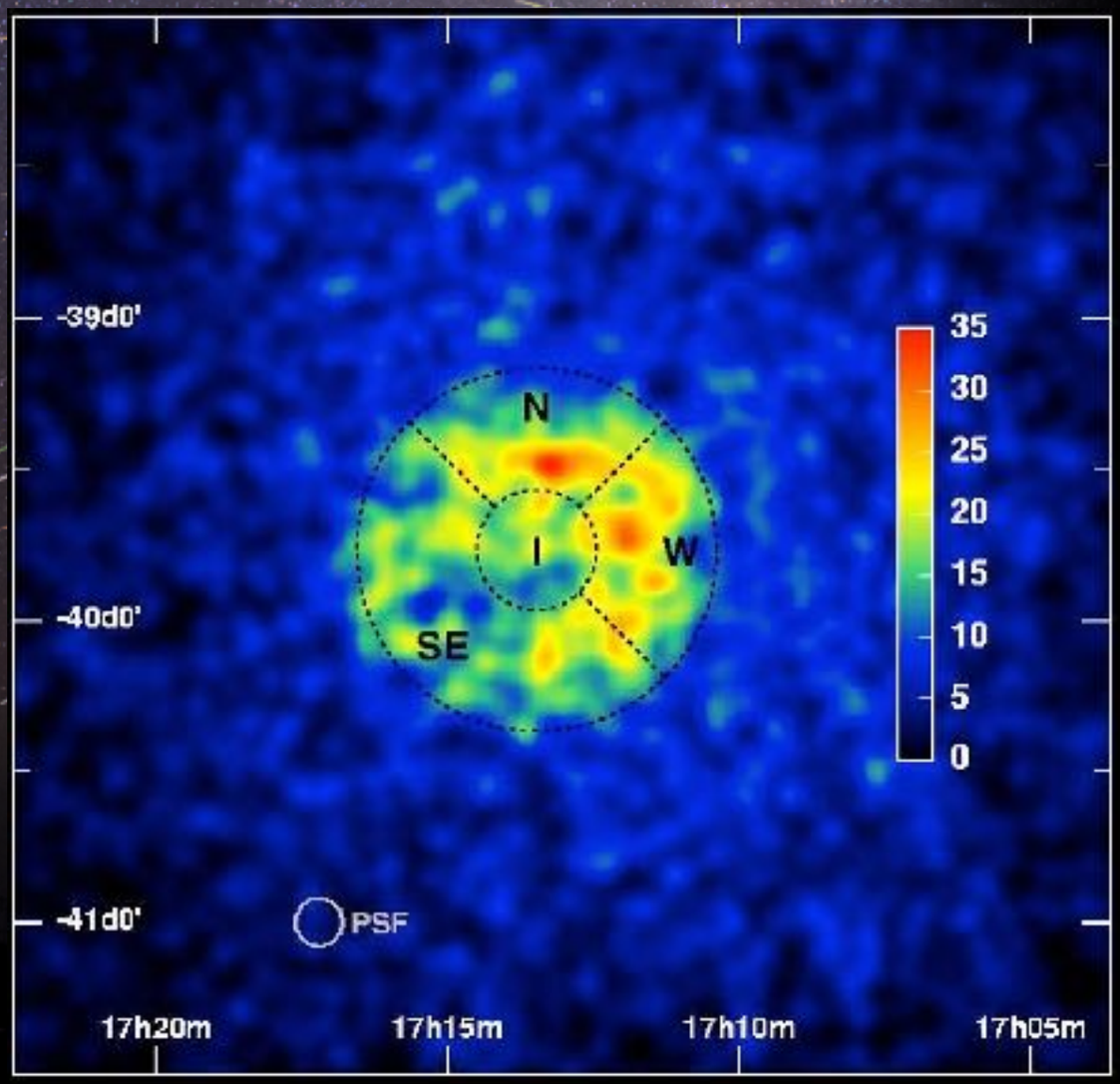


TeV energy range

Accelerating photons

First resolved TeV γ-ray image of a Shell type SNR (Resolution ~10 arcmin)

Acceleration source of cosmic rays, but is it evidence of protons?



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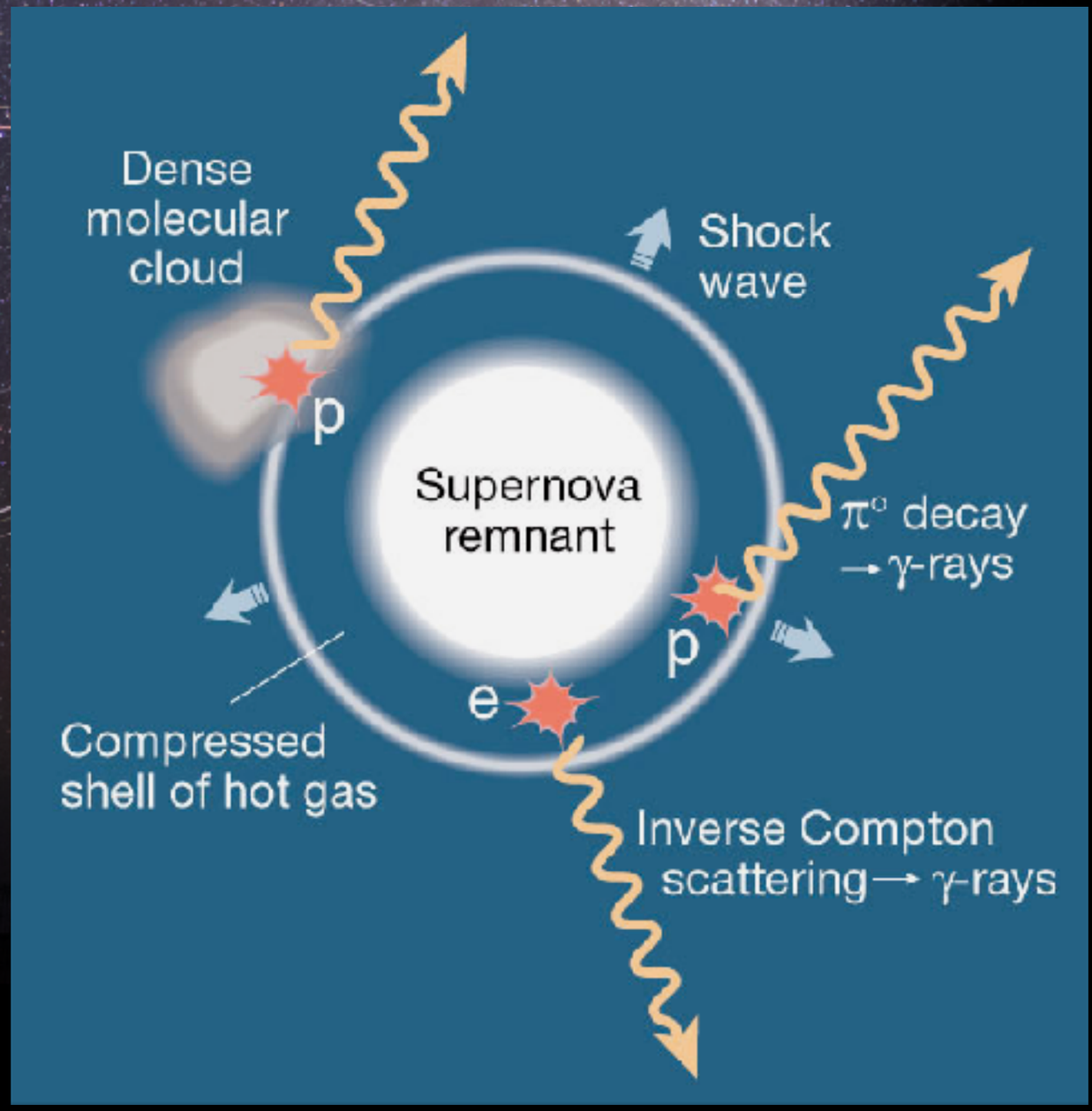

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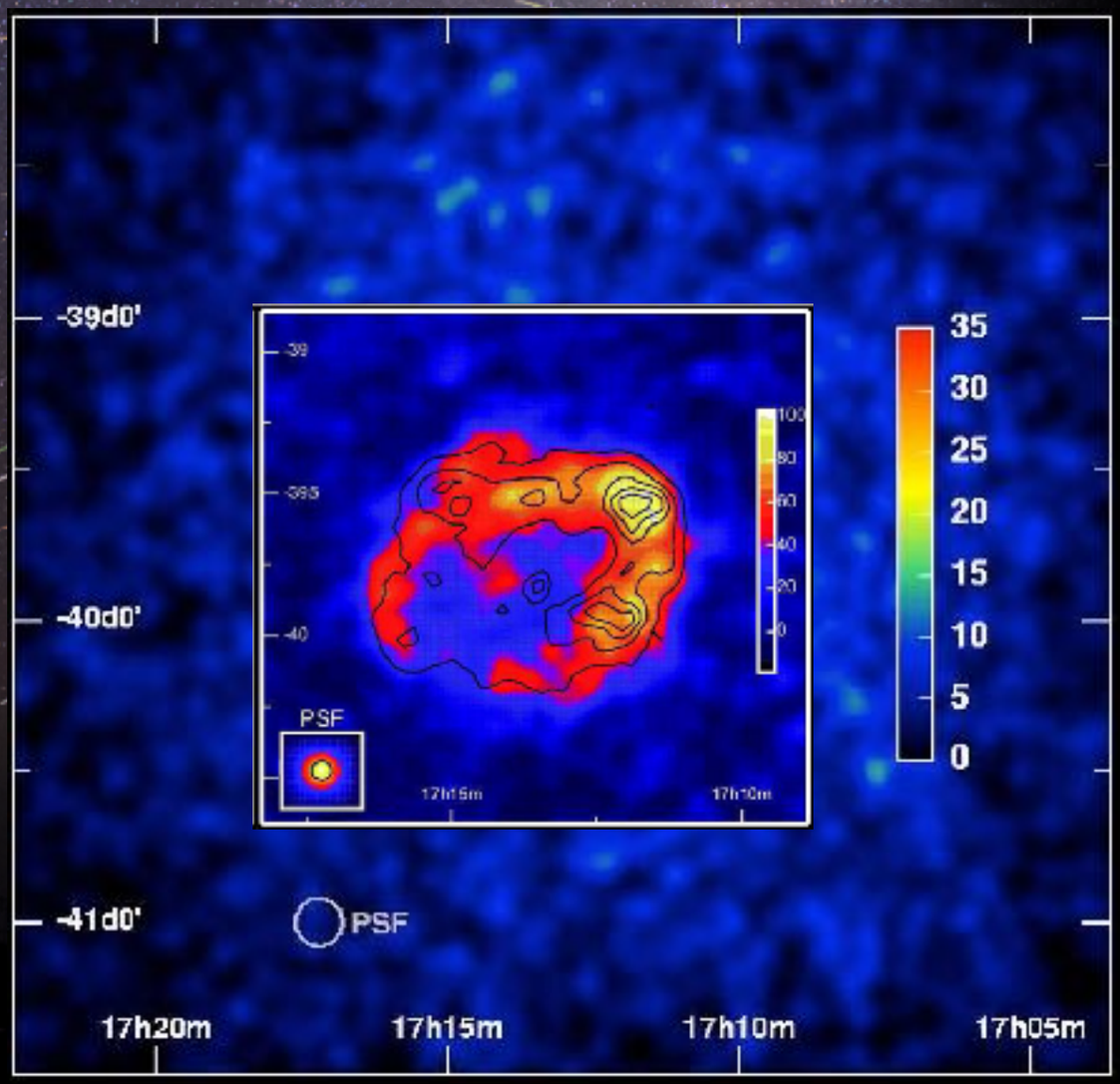
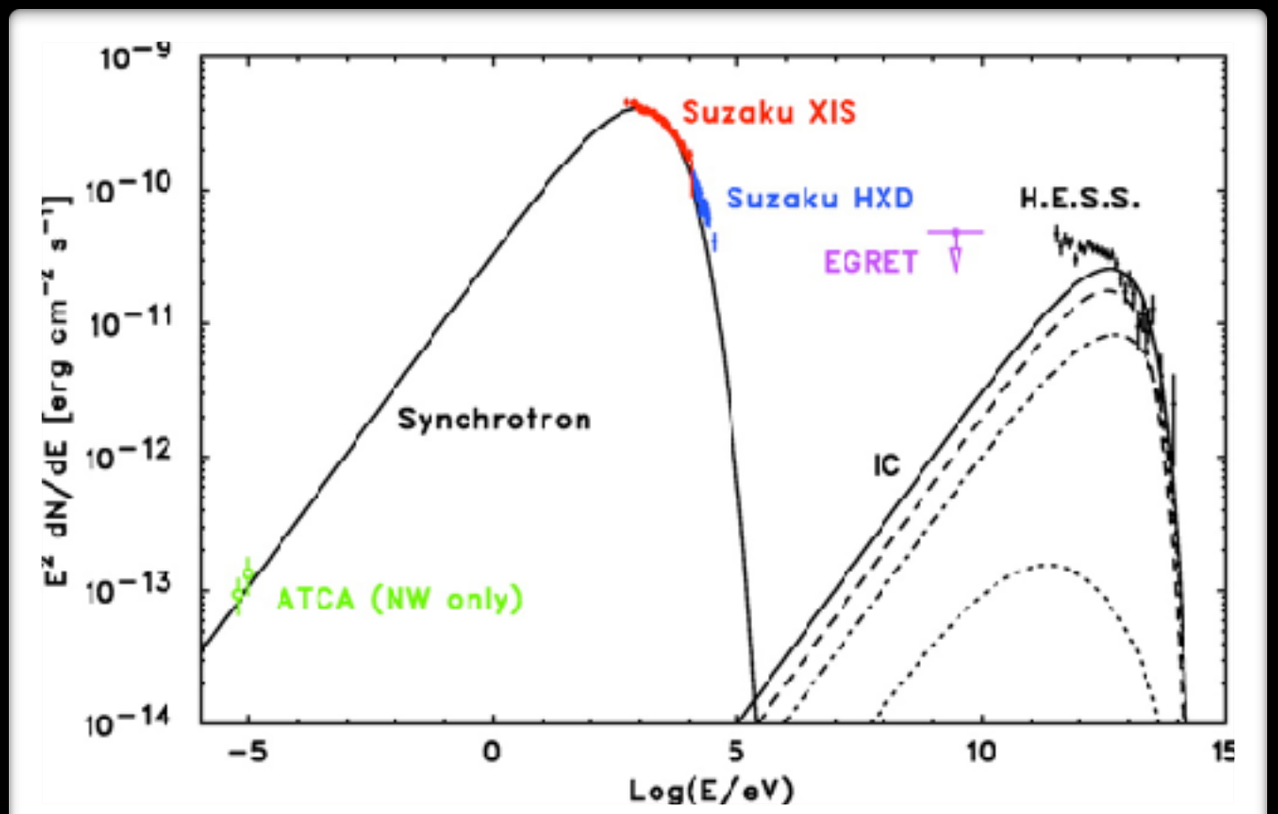
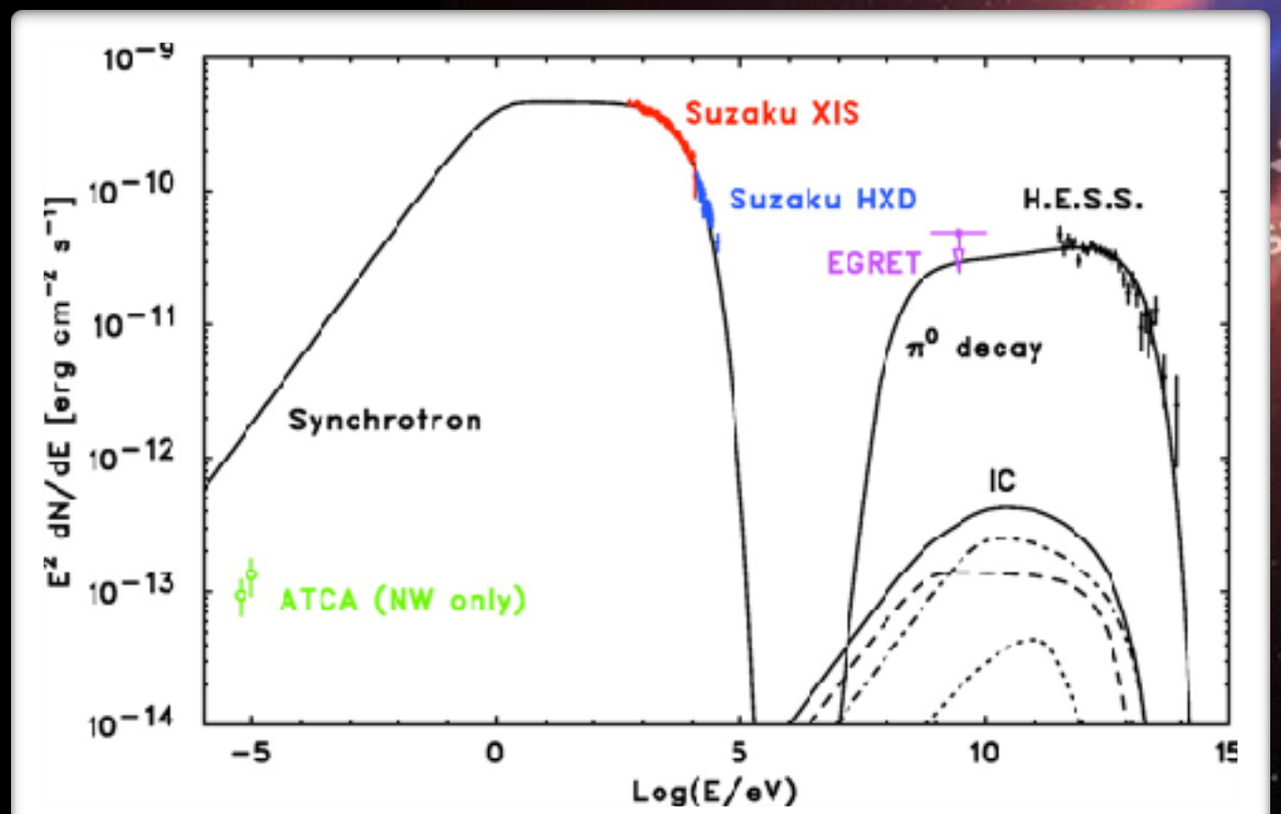


Accelerating photons

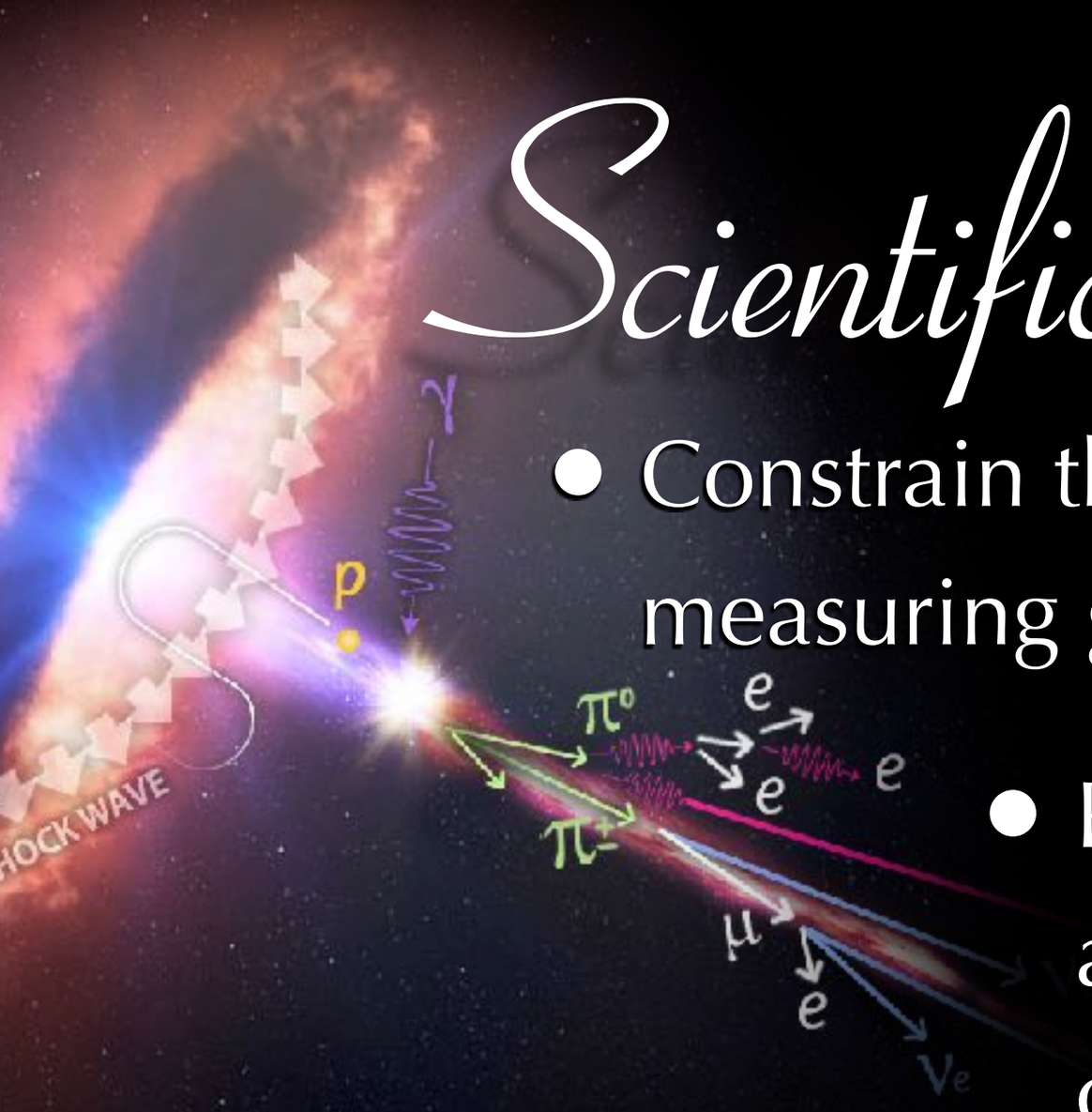
Tanaka et al., The Astrophysical Journal **685** (2008) 988





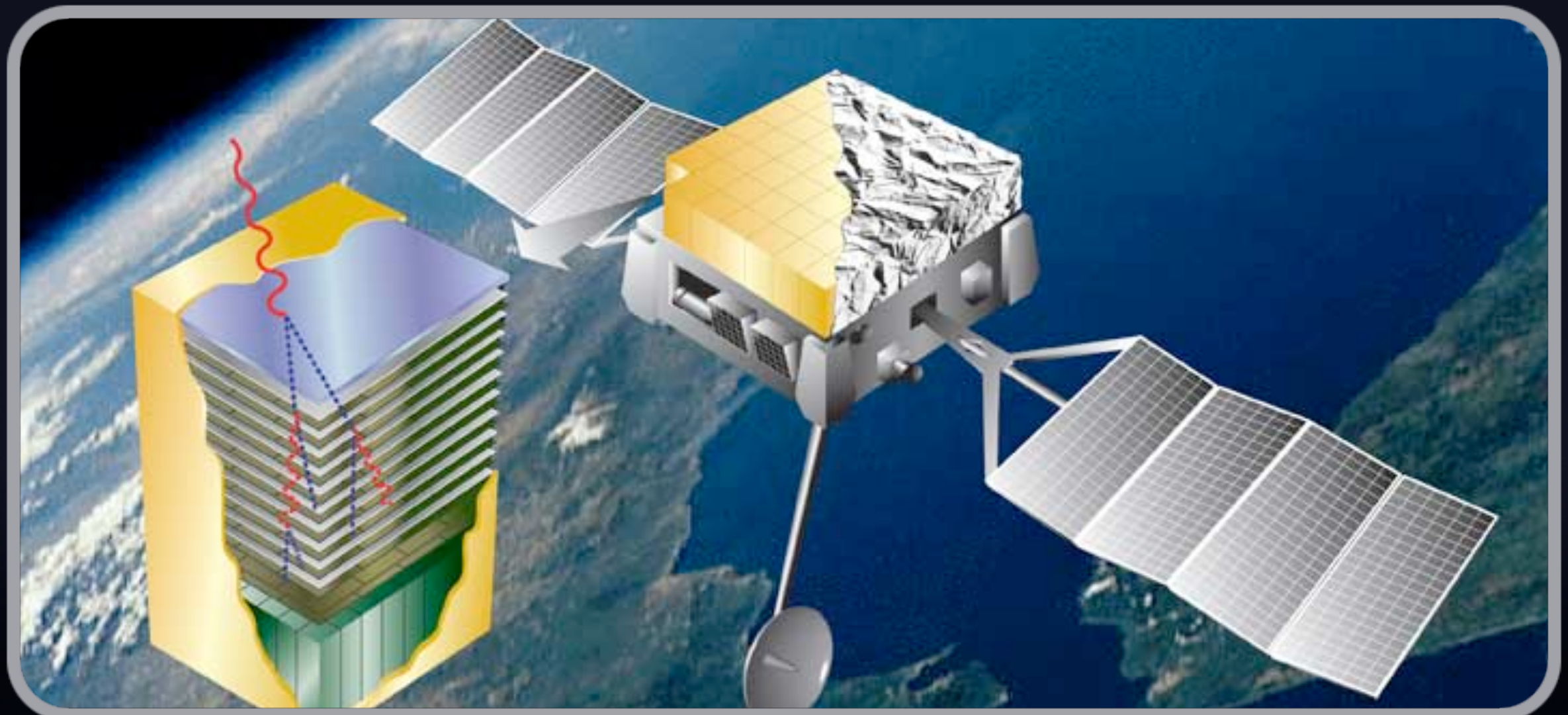
Leptonic origin (i.e., electrons) *vs.* Hadronic origin (i.e., protons)

Scientific motivation



- Constrain the origin of cosmic rays by measuring gamma-ray spectra to 100 TeV.
- Probe particle acceleration in astrophysical objects with a complimentary set of instruments.
- Explore new physics in the TeV energy range.

Experimental Techniques



- **Space-based detectors**
  - Low energy threshold
  - EGRET, Fermi-LAT

Experimental Techniques

- ✓ Background free
- ✓ Large duty cycle
- ✓ Large aperture

- \- Small area

- **Space-based detectors**
  - Low energy threshold
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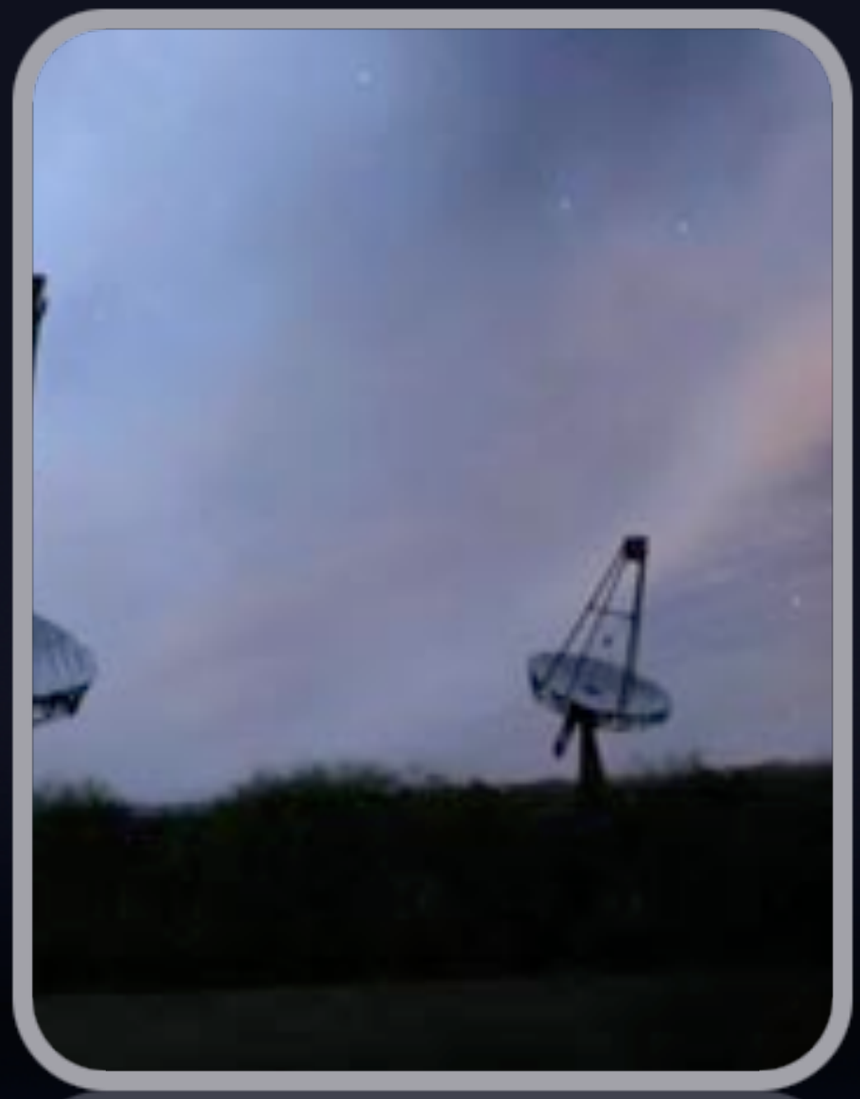
Experimental Techniques

- **Imaging Atmospheric Cherenkov Telescopes**
  - High sensitivity
  - HESS, MAGIC, VERITAS, CTA

Experimental Techniques



✓ Large effective area

✓ Excellent background rejection

- Small aperture
- Low duty cycle

- **Imaging Atmospheric Cherenkov Telescopes**

  High sensitivity

  HESS, MAGIC, VERITAS, CTA

Experimental Techniques

- **Ground array of air-shower particle detectors**
  - Large aperture + High duty cycle
  - Milagro, Tibet, ARGO, HAWC, LHAASO

Experimental Techniques

✓ Large aperture

✓ Excellent background rejection

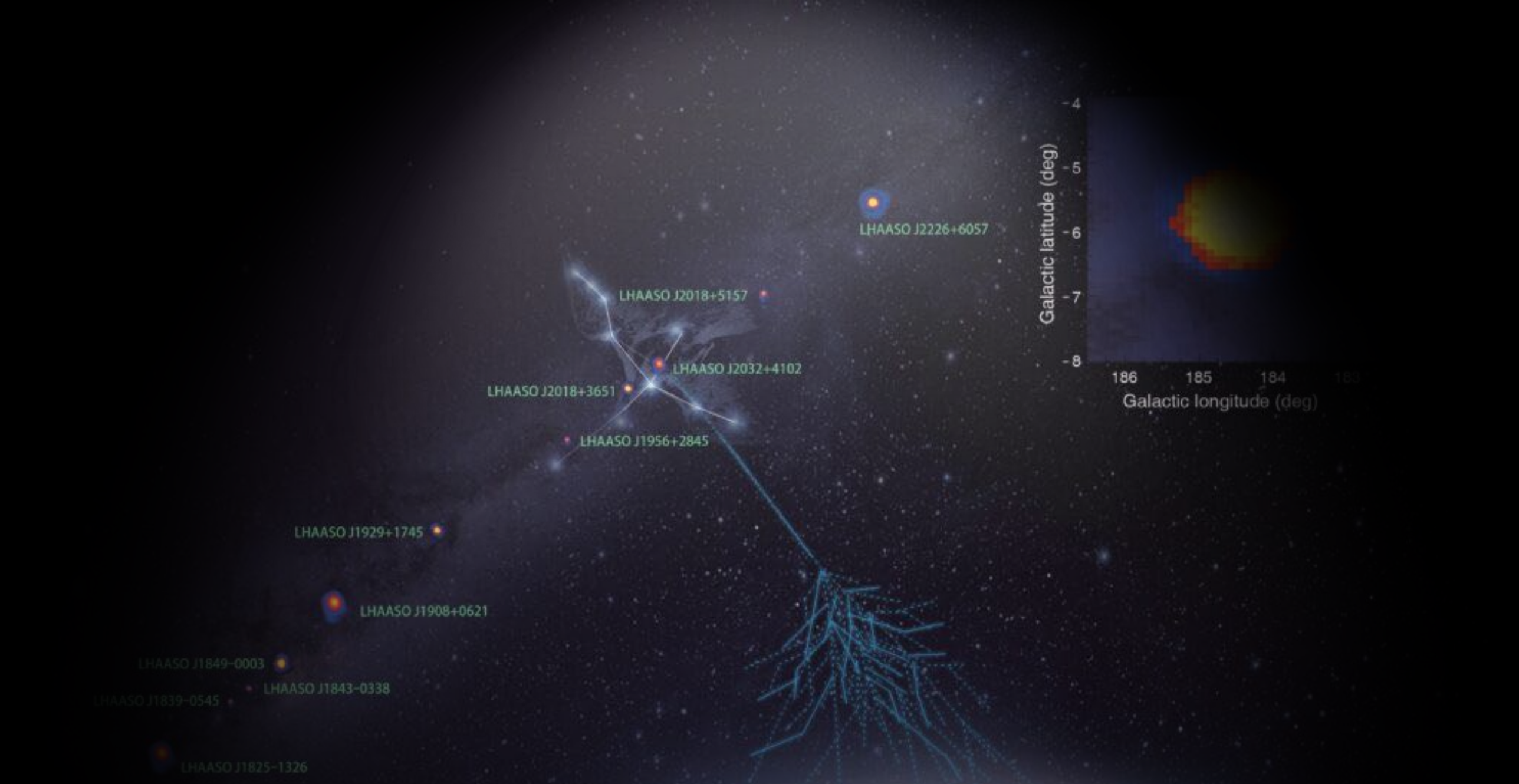
✓ Large duty cycle

- Moderate area

- **Ground array of air-shower particle detectors**

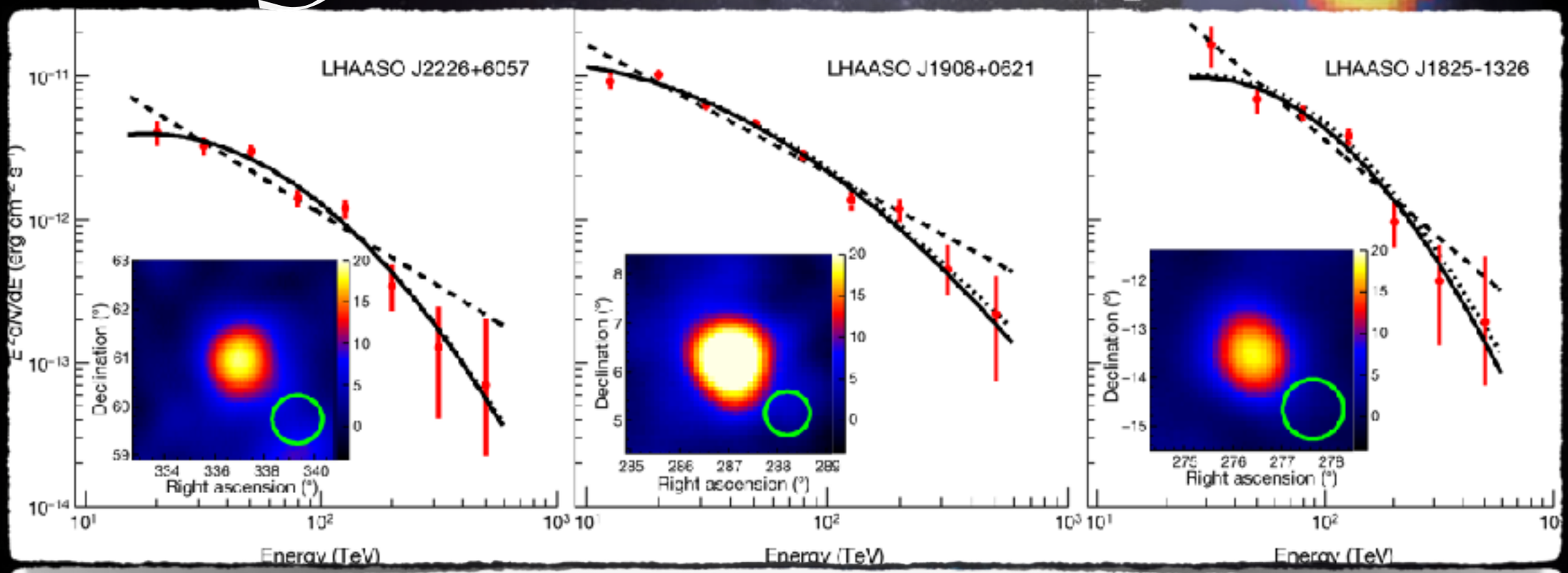
  Large aperture + High duty cycle

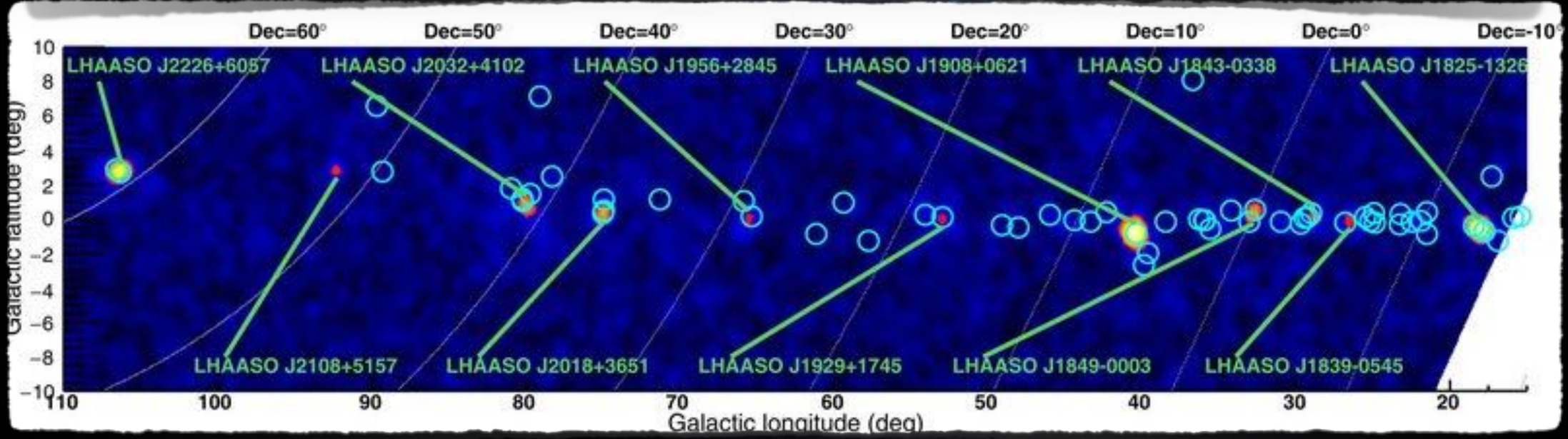
  Milagro, Tibet, ARGO, HAWC, LHAASO



Selected Results

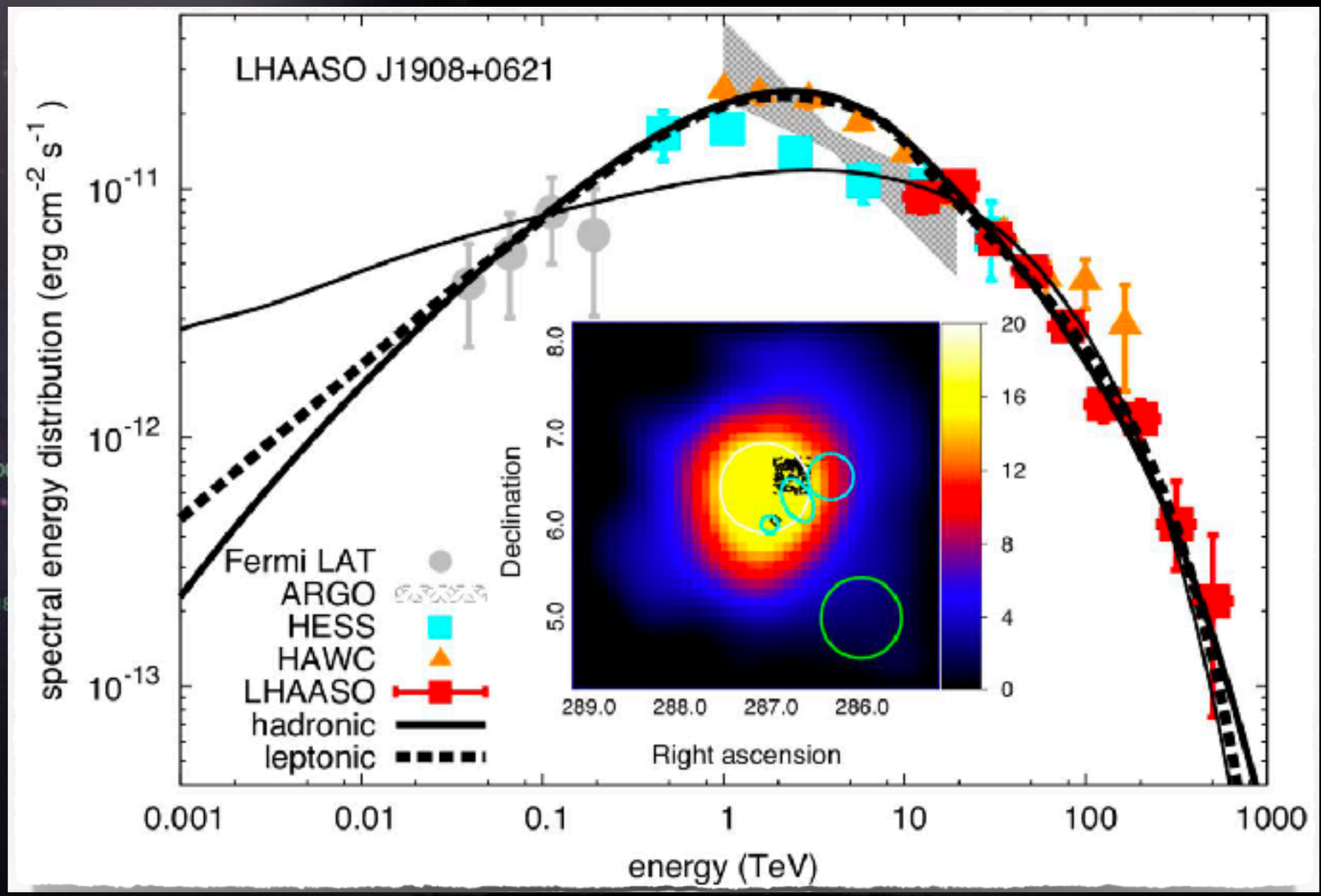
Galactic Pevatrons





Cao *et al* [LHAASO] Nature **594** (2021) 33-36

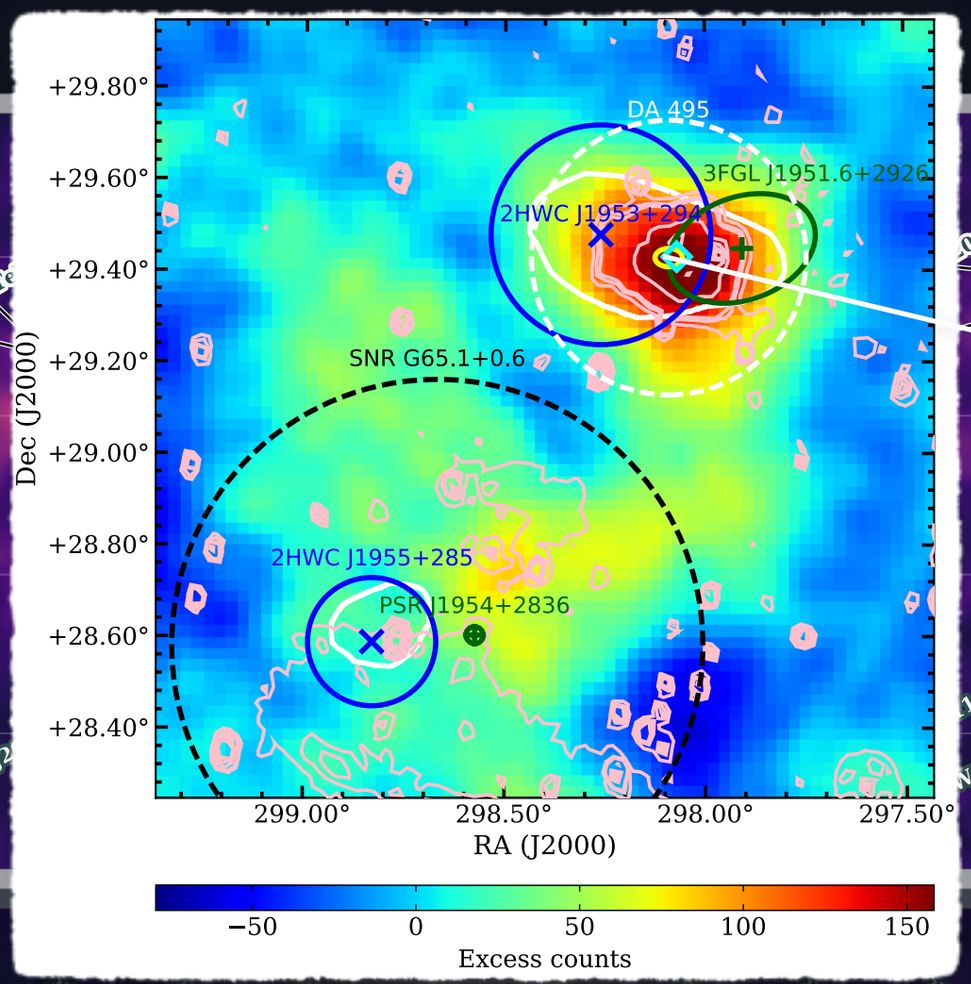
Galactic Pevatrons



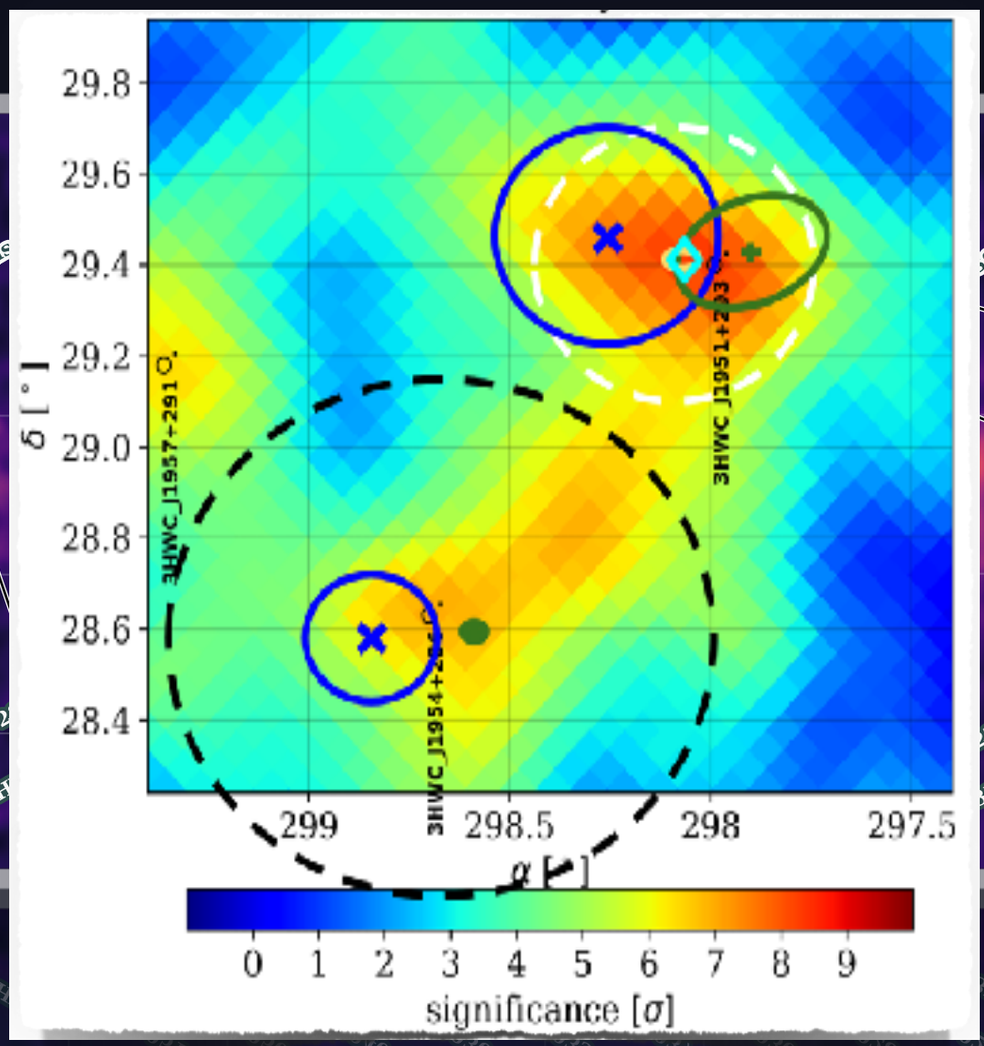
Cao *et al* [LHAASO] Nature **594** (2021) 33-36

Albert *et al* [HAWC] ApJ **905** (2020) 76

New TeV sources



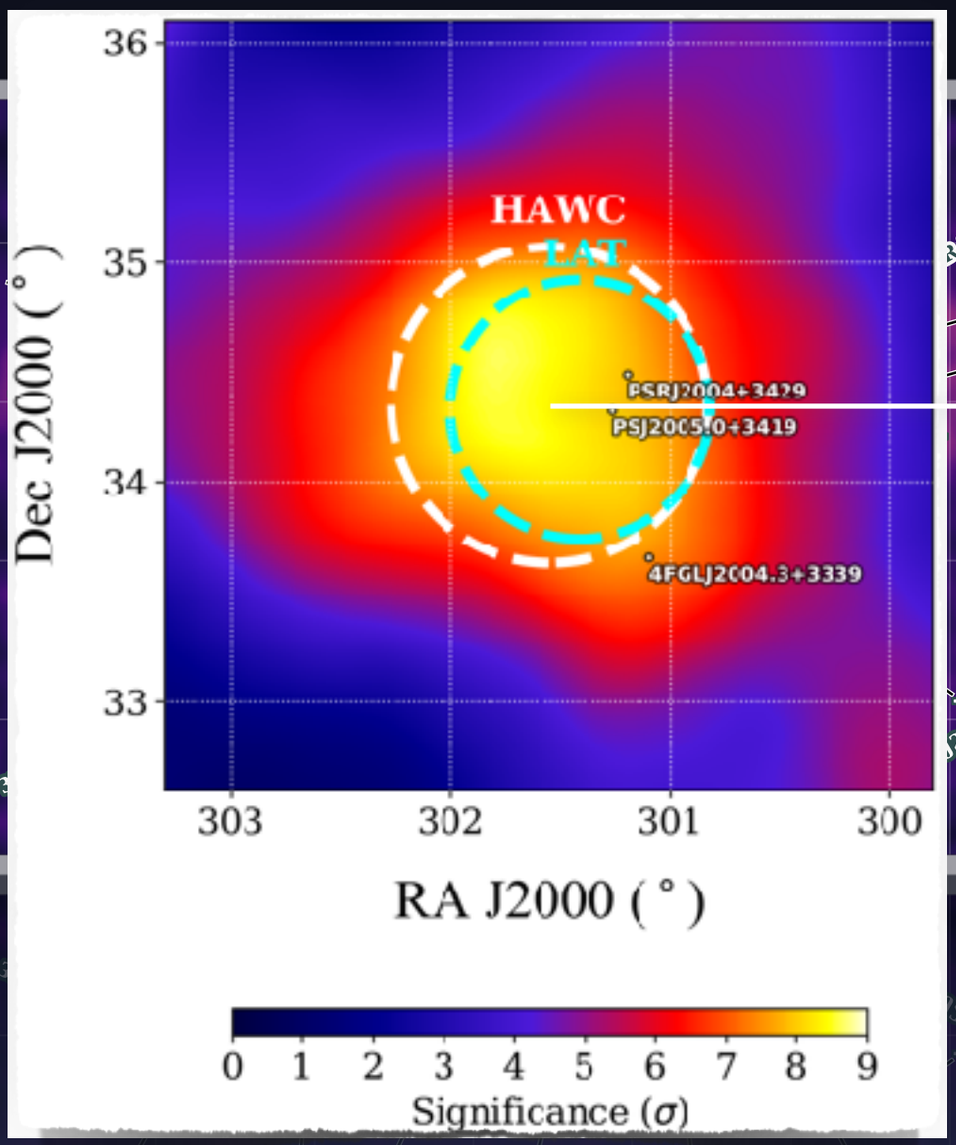
VERITAS counts map



3HWC significance map

[VERITAS+Fermi-LAT+HAWC] ApJ **866** (2018) 24

New TeV sources



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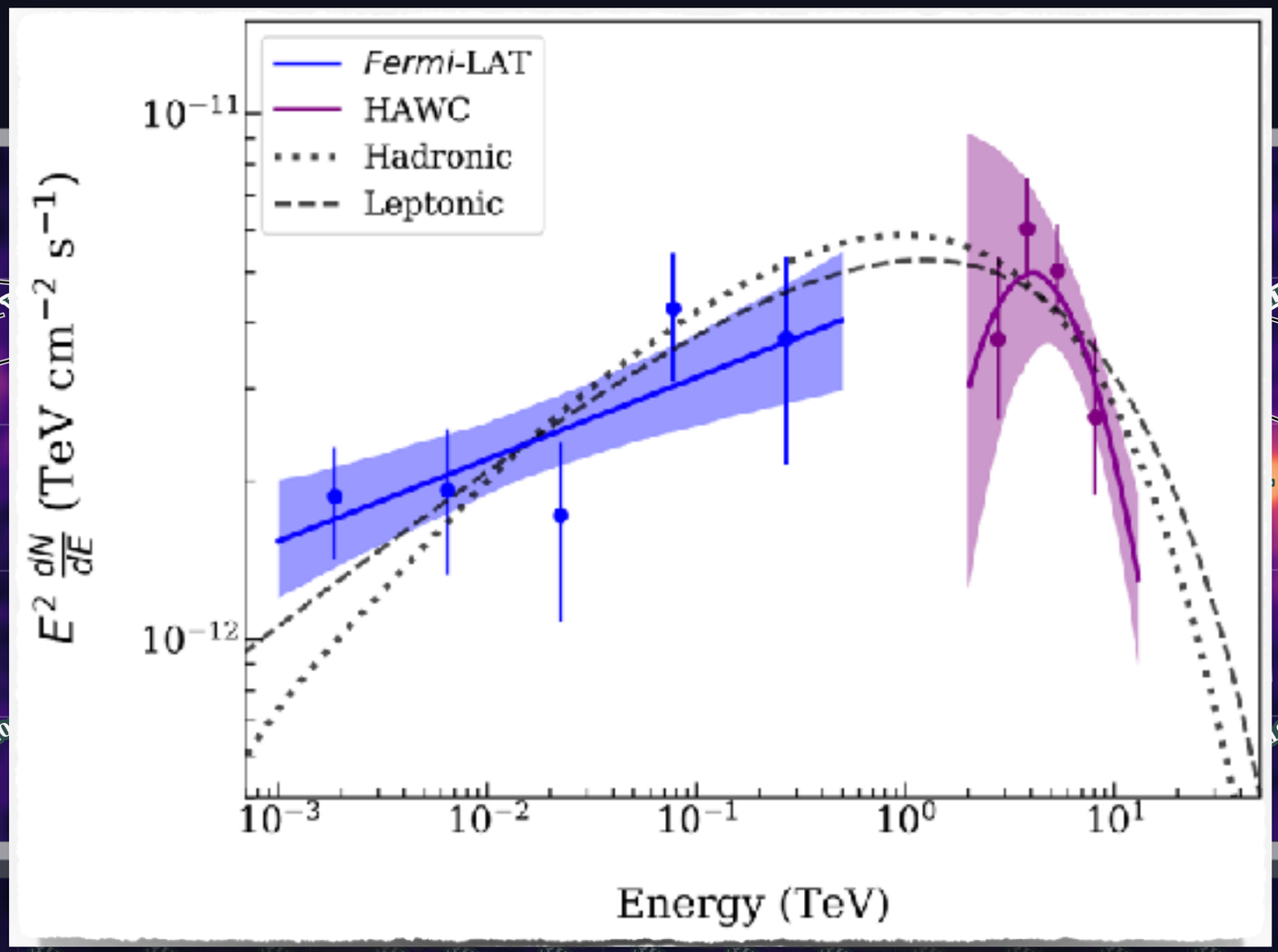
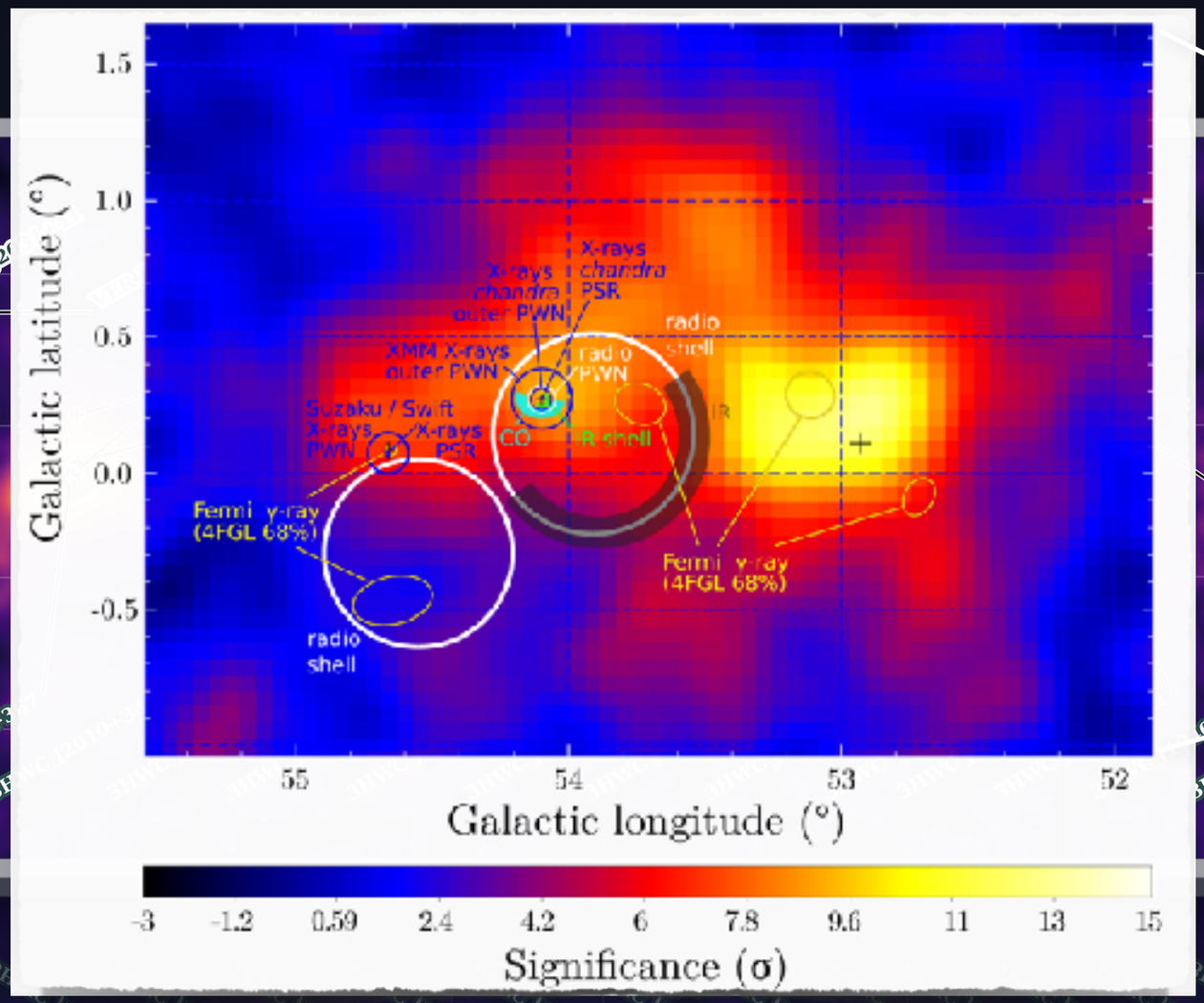


SED from HAWC and LAT data

[HAWC+Fermi-LAT] ApJL **903** (2020) L14

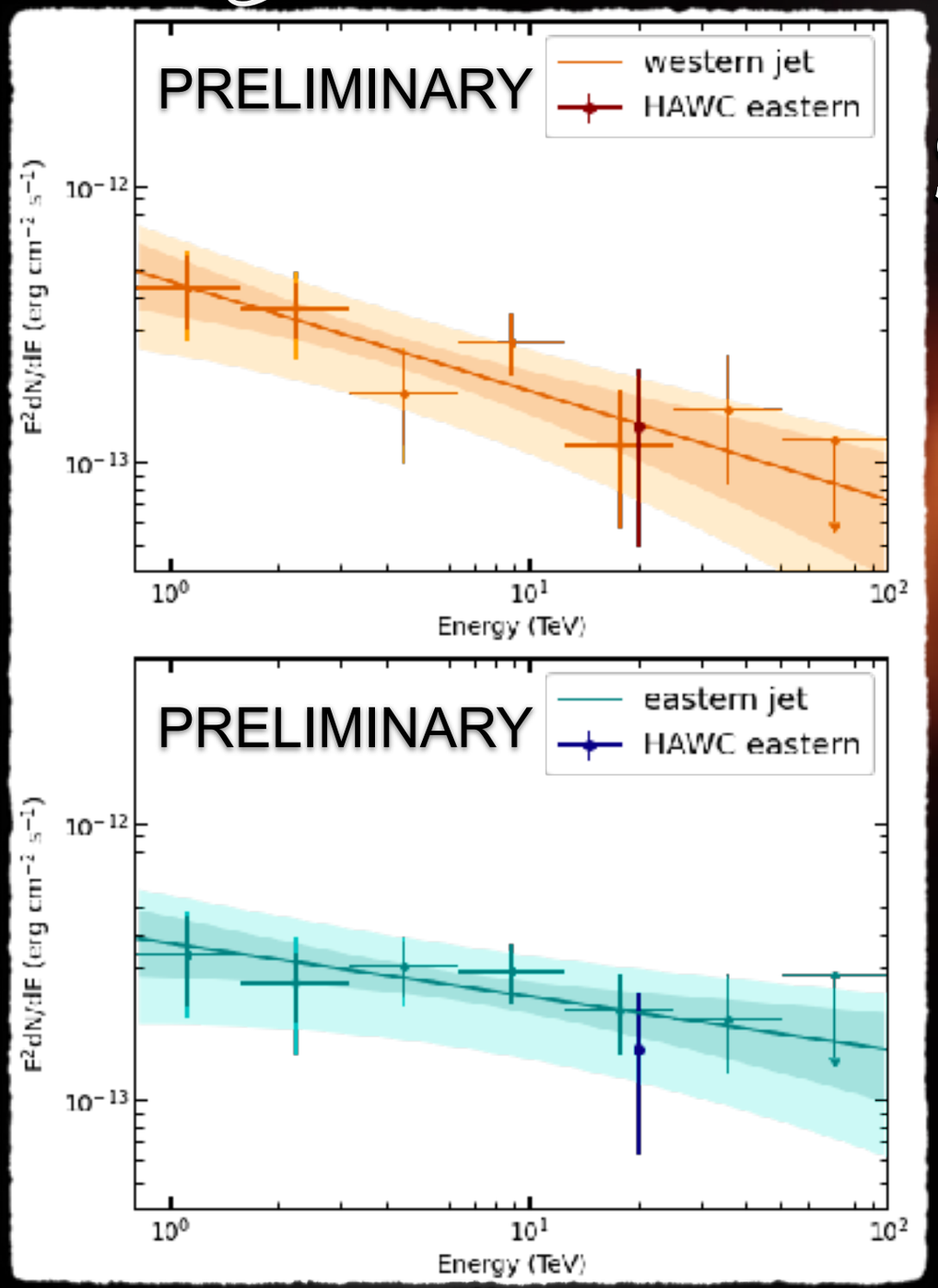
New TeV sources

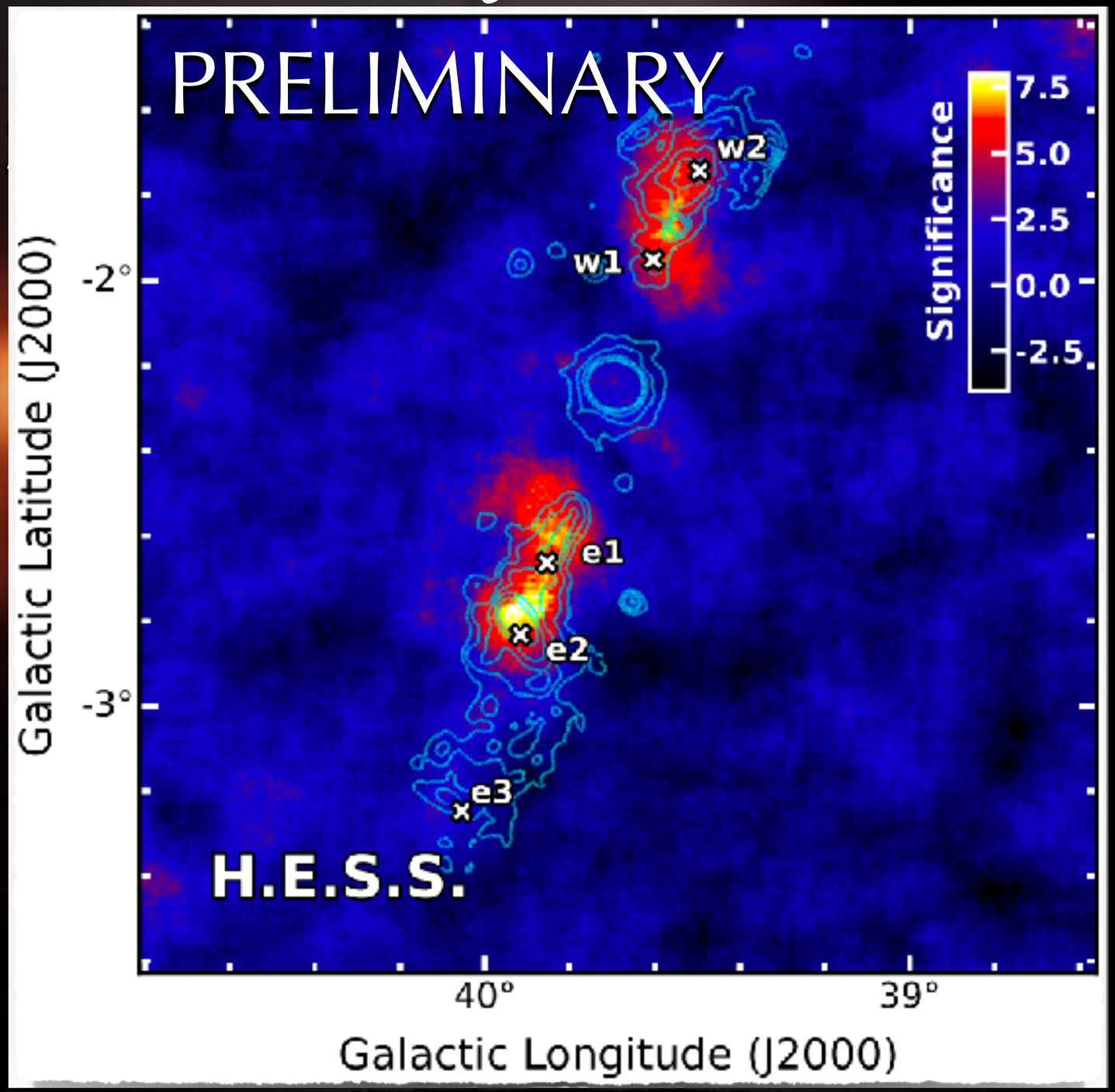


Detailed analysis of the TeV γ-ray sources 3HWC J1928+178, 3HWC J1930+188 and the new source HAWC J1932+192

Albert *et al* [HAWC] accepted for publication in *The Astrophysical Journal*

Jets of a Microquasar

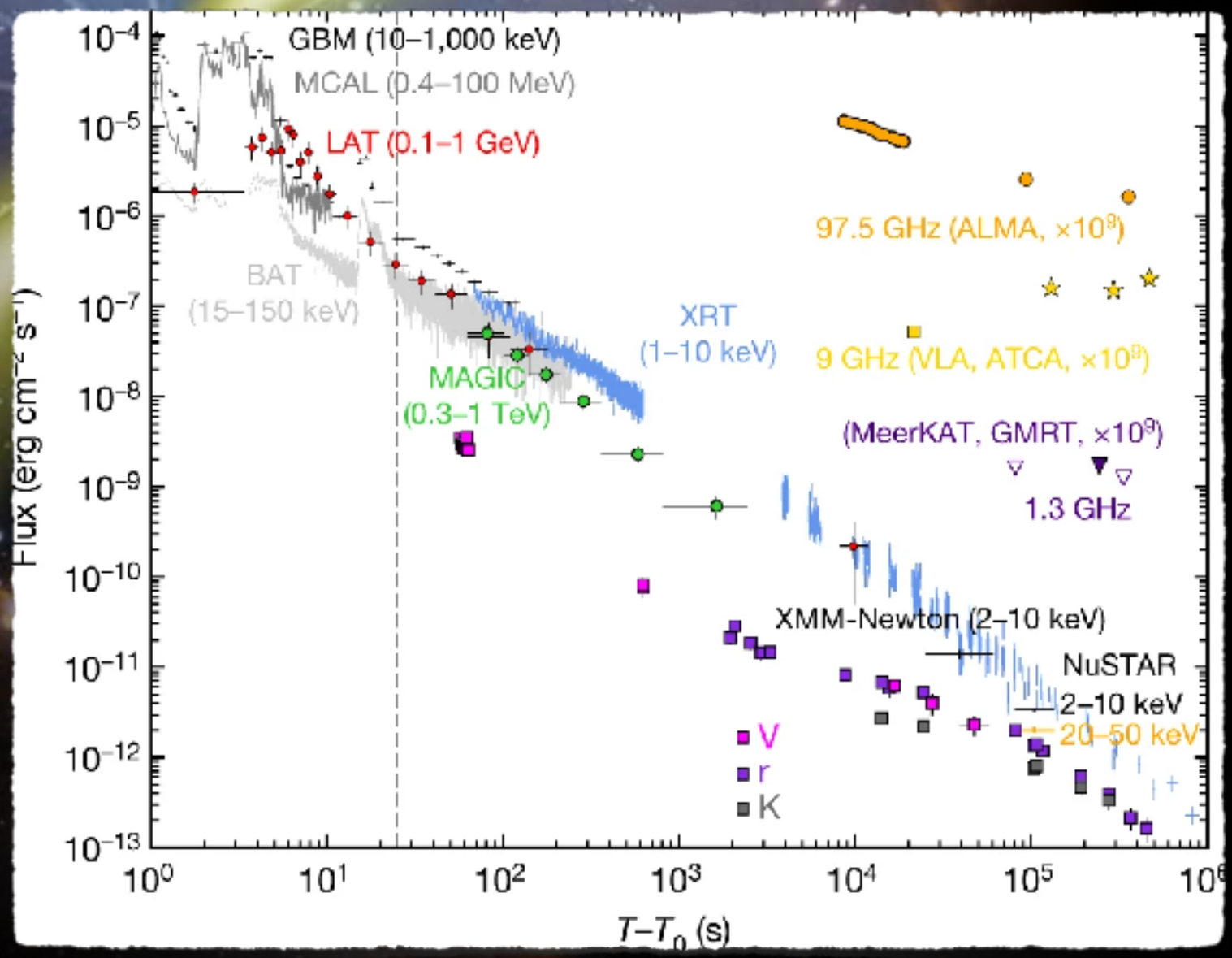




Gamma Ray Bursts

GRB190114C: 1st detection of VHE emission!

- Brightest VHE γ-ray source!
- Long GRB (T_{90}~6 min)
- Observations started < 1 min after BAT trigger



Acciari *et al* [MAGIC] Nature **575** (2019) 459

Gamma Ray Bursts

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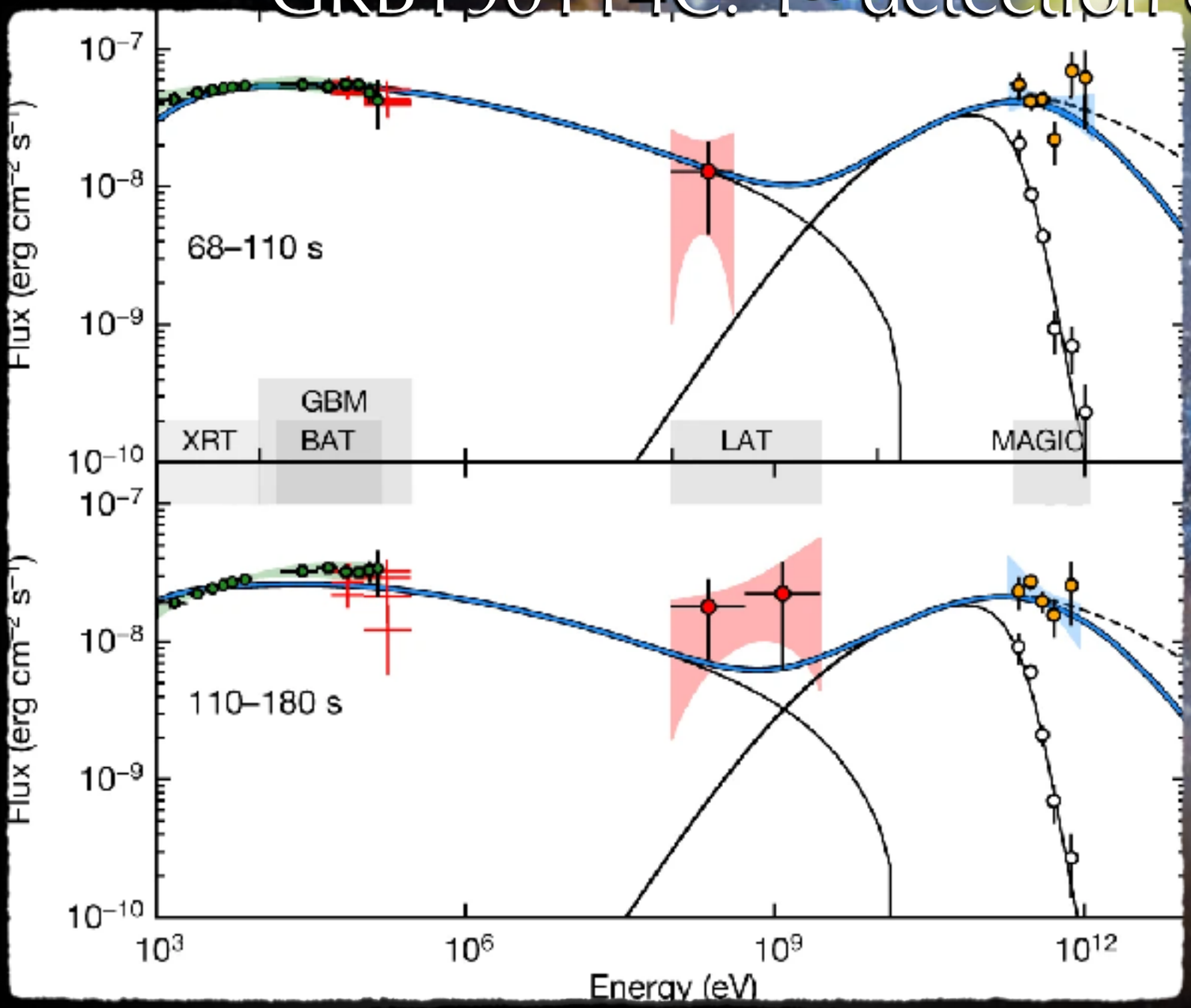


Highest energy emission strongly absorbed by EBL

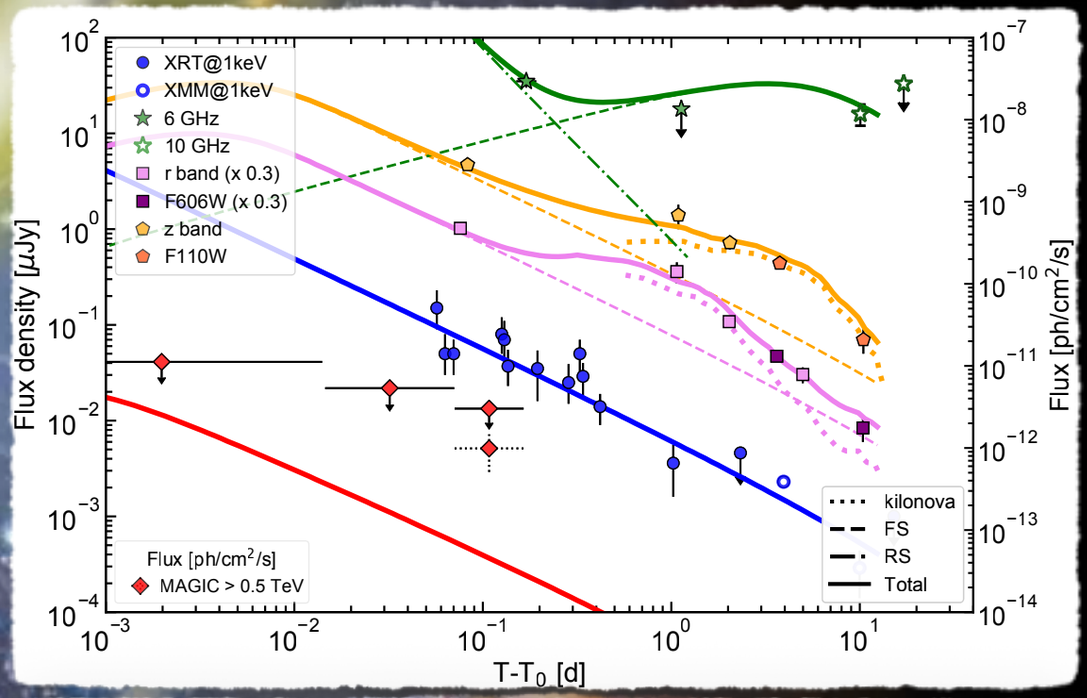
VHE γ-ray emission can be modeled in SSC scenario

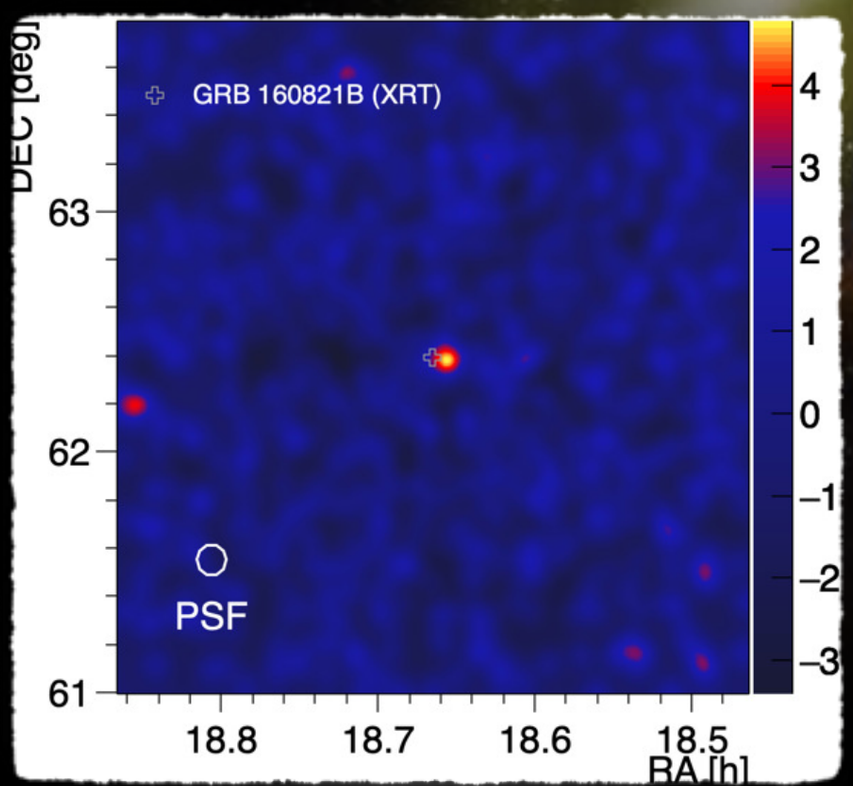
Acciari *et al* [MAGIC] Nature **575** (2019) 459

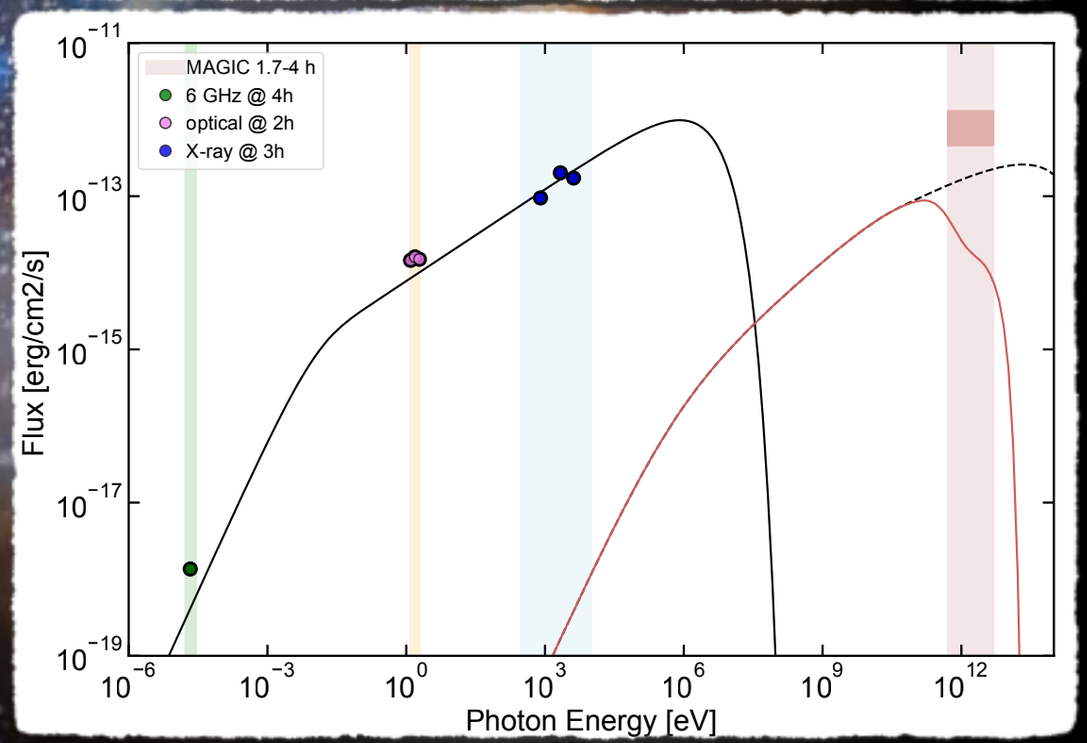
Gamma Ray Bursts

GRB160821B: ~3σ evidence of γ-ray emission above ~ 0.5 TeV

One-zone models of SSC emission have a hard time explaining the putative TeV flux





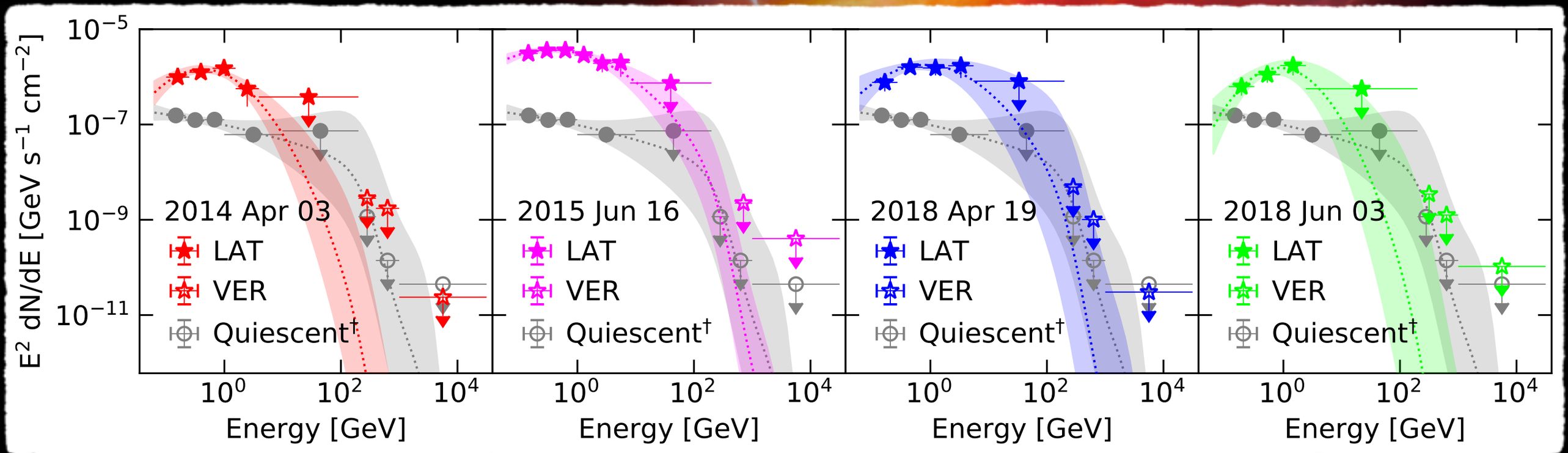


Acciari *et al* [MAGIC] ApJ **908** (2021) 90

Flaring quasars

γ-ray variability and spectral characteristics of FSRQs during bright GeV flares

Flux upper limits on 3C 279



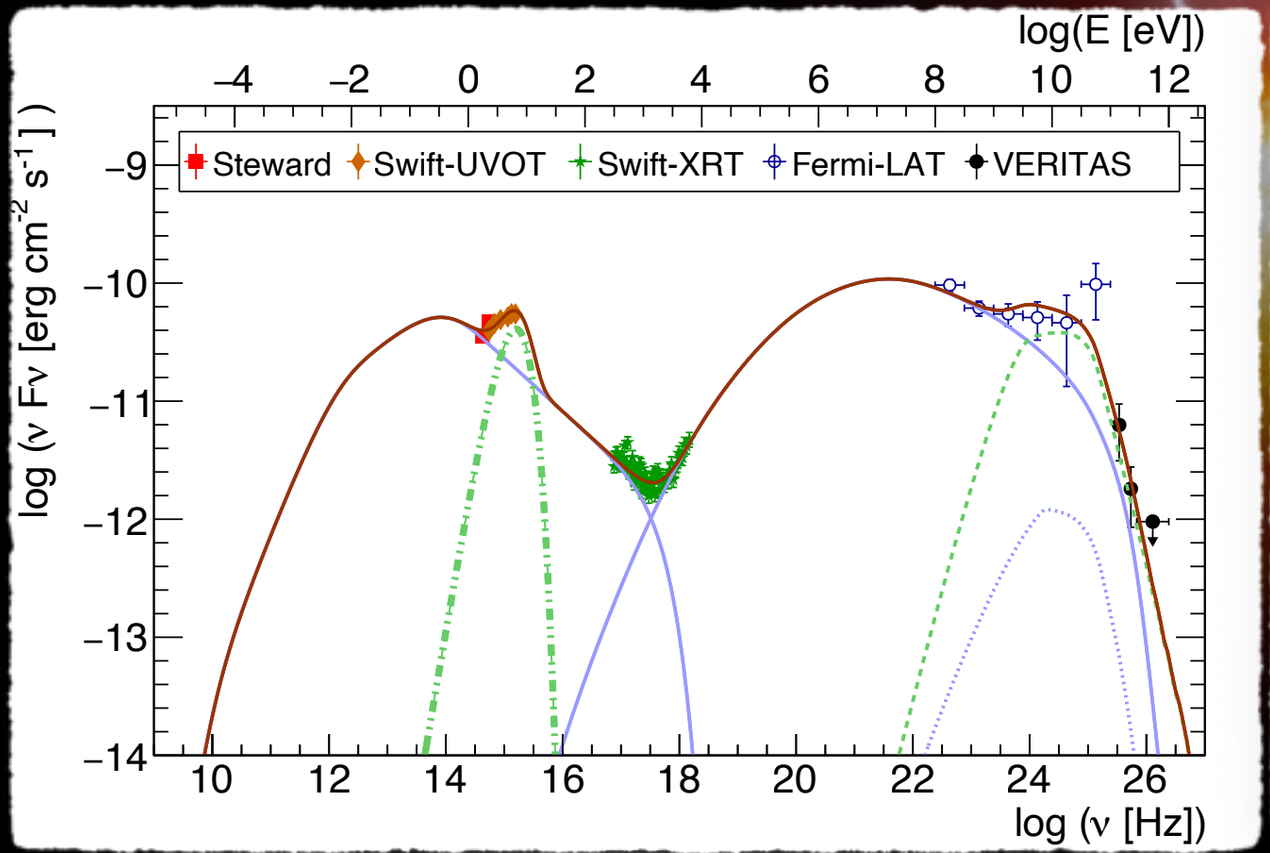
100 h of VERITAS observations over 10 y + LAT data

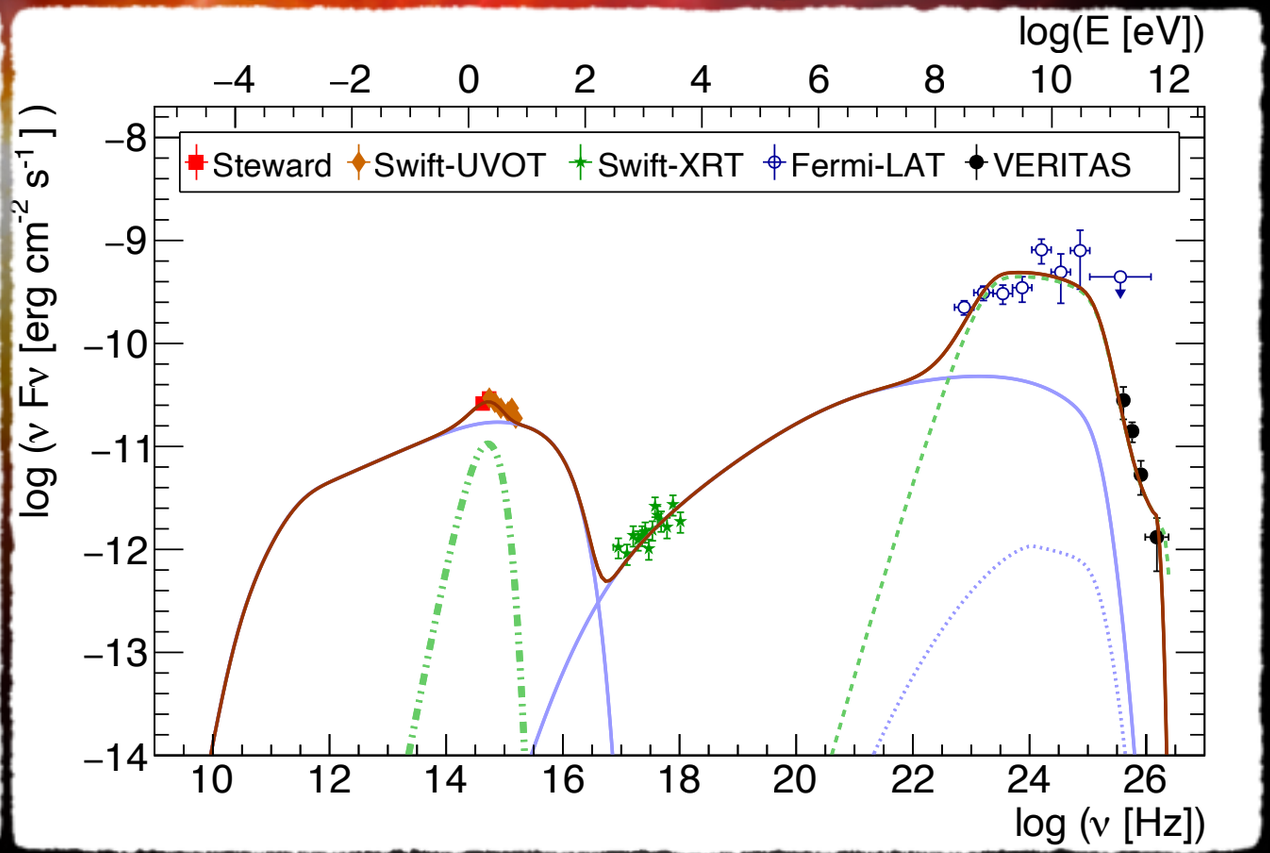
Adams *et al* [VERITAS+Fermi-LAT] ApJ **924** (2022) 95

Flaring quasars

γ-ray variability and spectral characteristics of FSRQs during bright GeV flares

Both PKS 1222+216 and TON 599 detected by VERITAS during flaring states!





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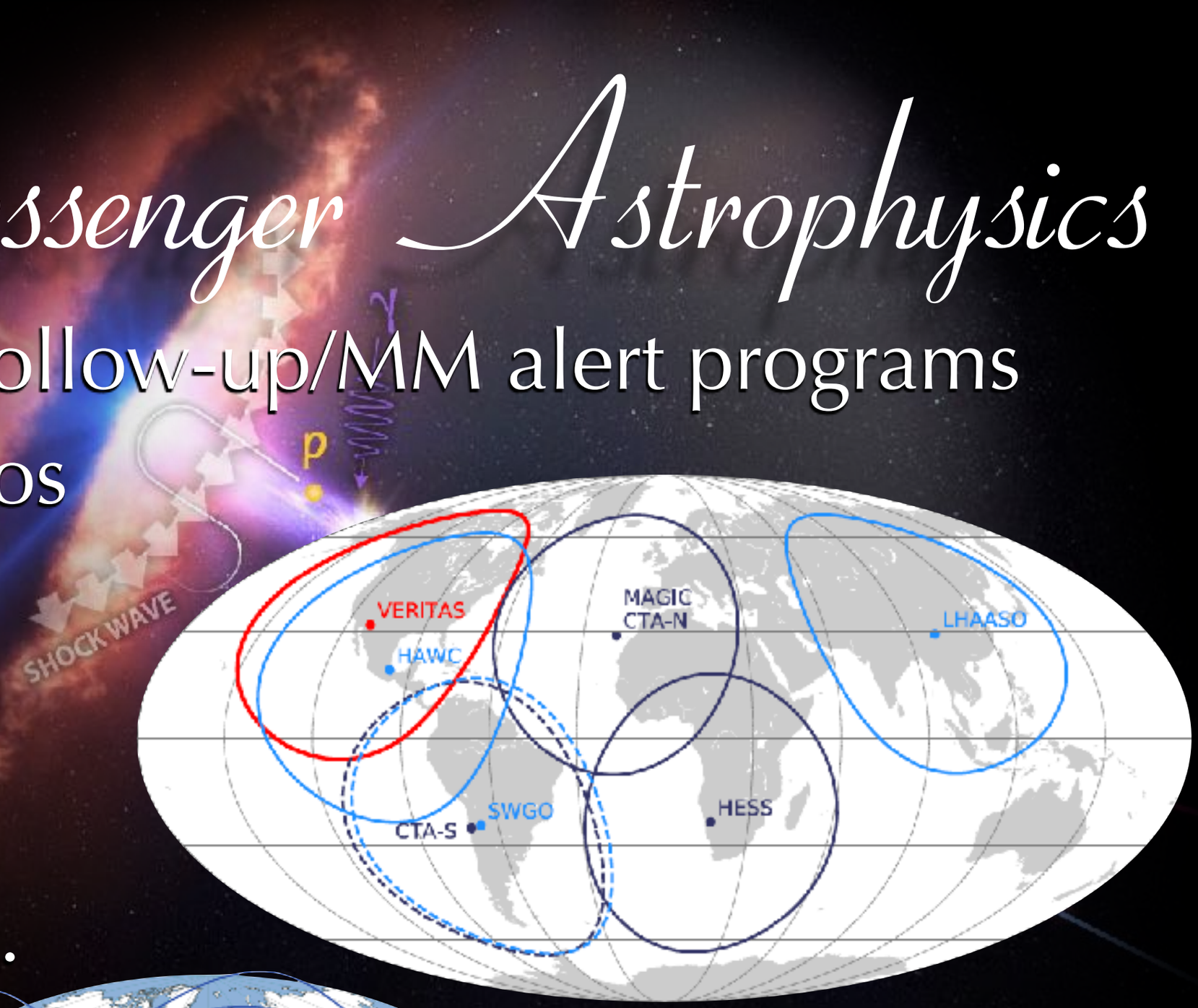
Multimessenger Astrophysics

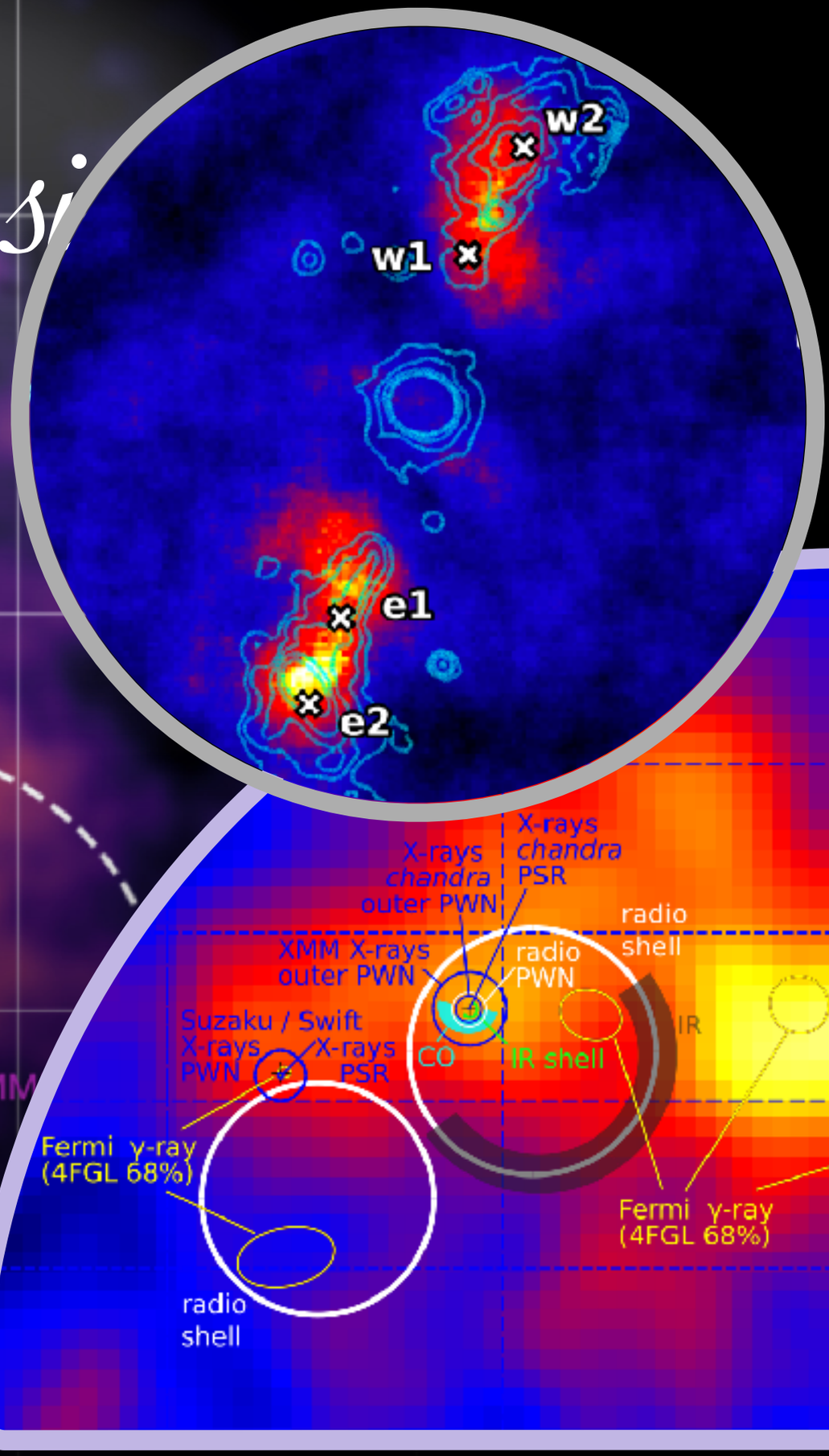
Extensive follow-up/MM alert programs

- Neutrinos
- GWs
- FRBs
- GRBs
- etc., etc.

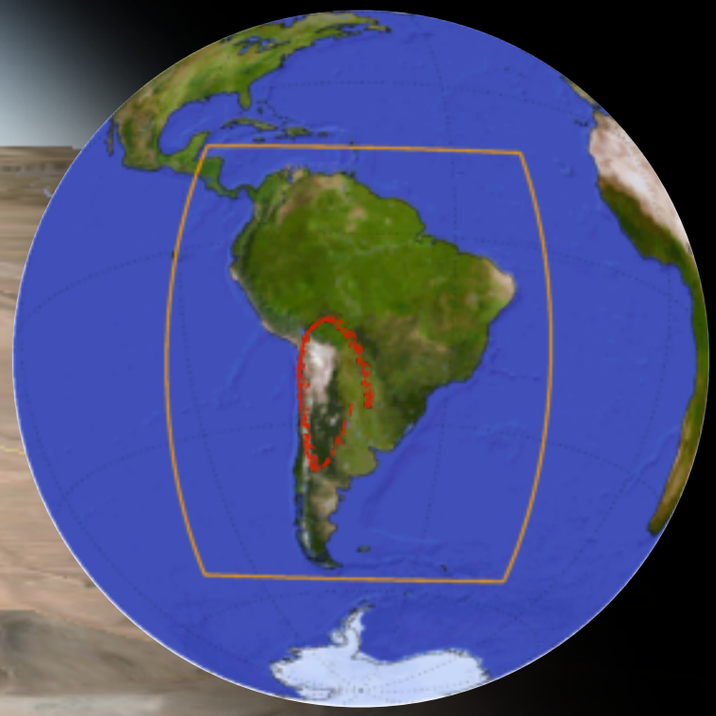


Conclusi

Discoveries from HAWC, H.E.S.S., MAGIC, LHAASO, and VERITAS

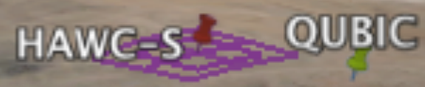


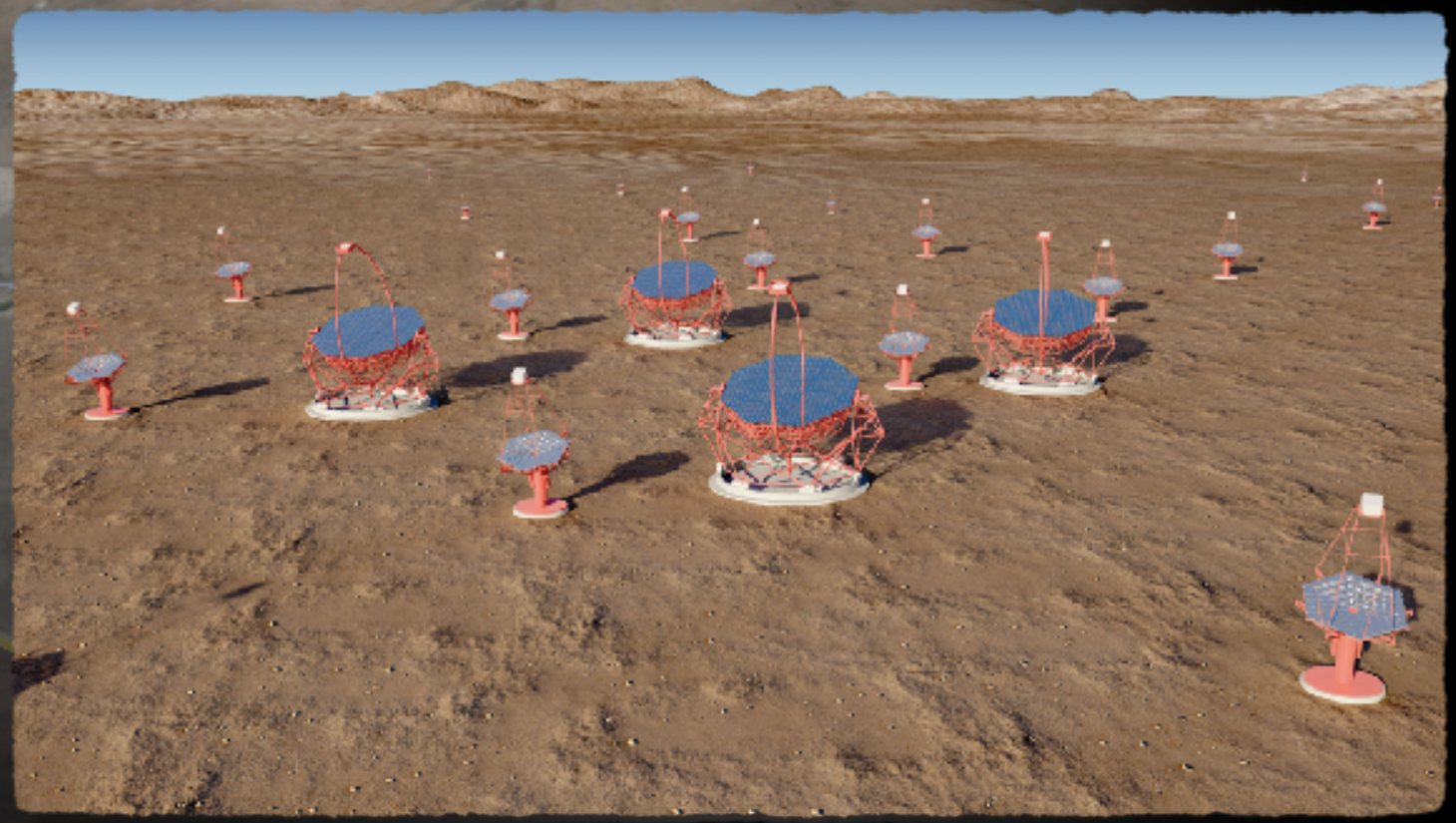
Conclusions



Discoveries from HAWC, H.E.S.S., MAGIC, LHAASO, and VERITAS

Next-generation experiments!



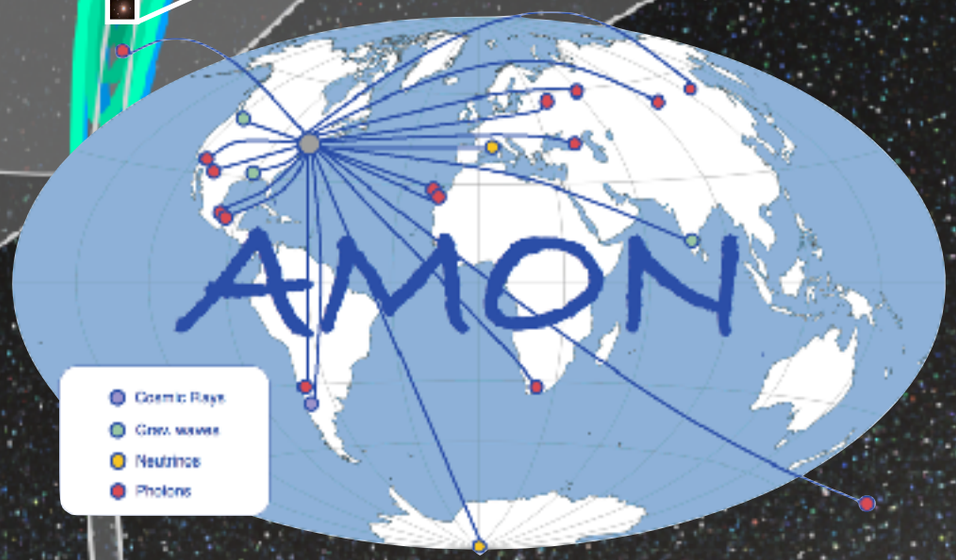


Conclusions

Discoveries from HAWC, H.E.S.S., MAGIC, LHAASO, and VERITAS

Next-generation experiments!

New Era of Multimessenger Astrophysics



Thank you very much!