Recent highlights of very-high-energy gamma-ray observations by the MAGIC telescopes

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on behalf of the MAGIC Collaboration

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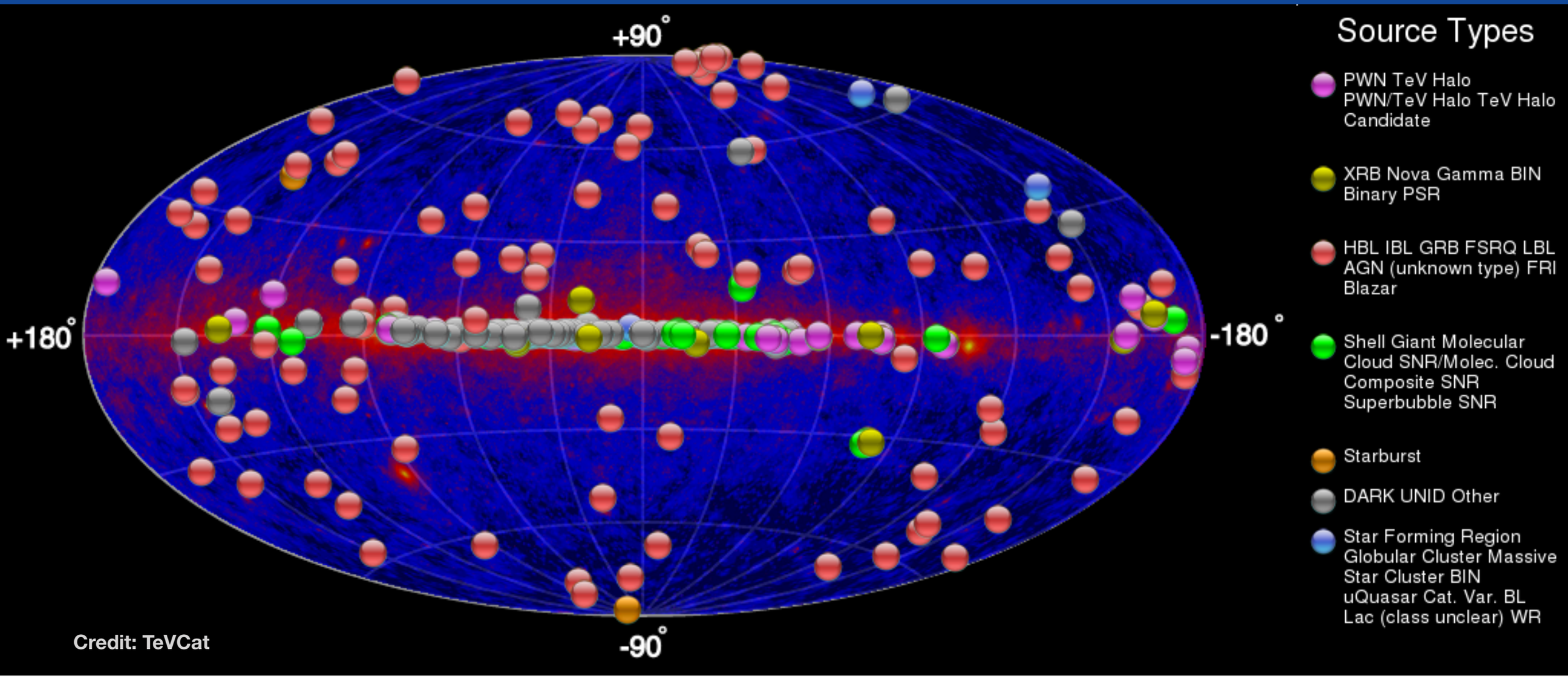
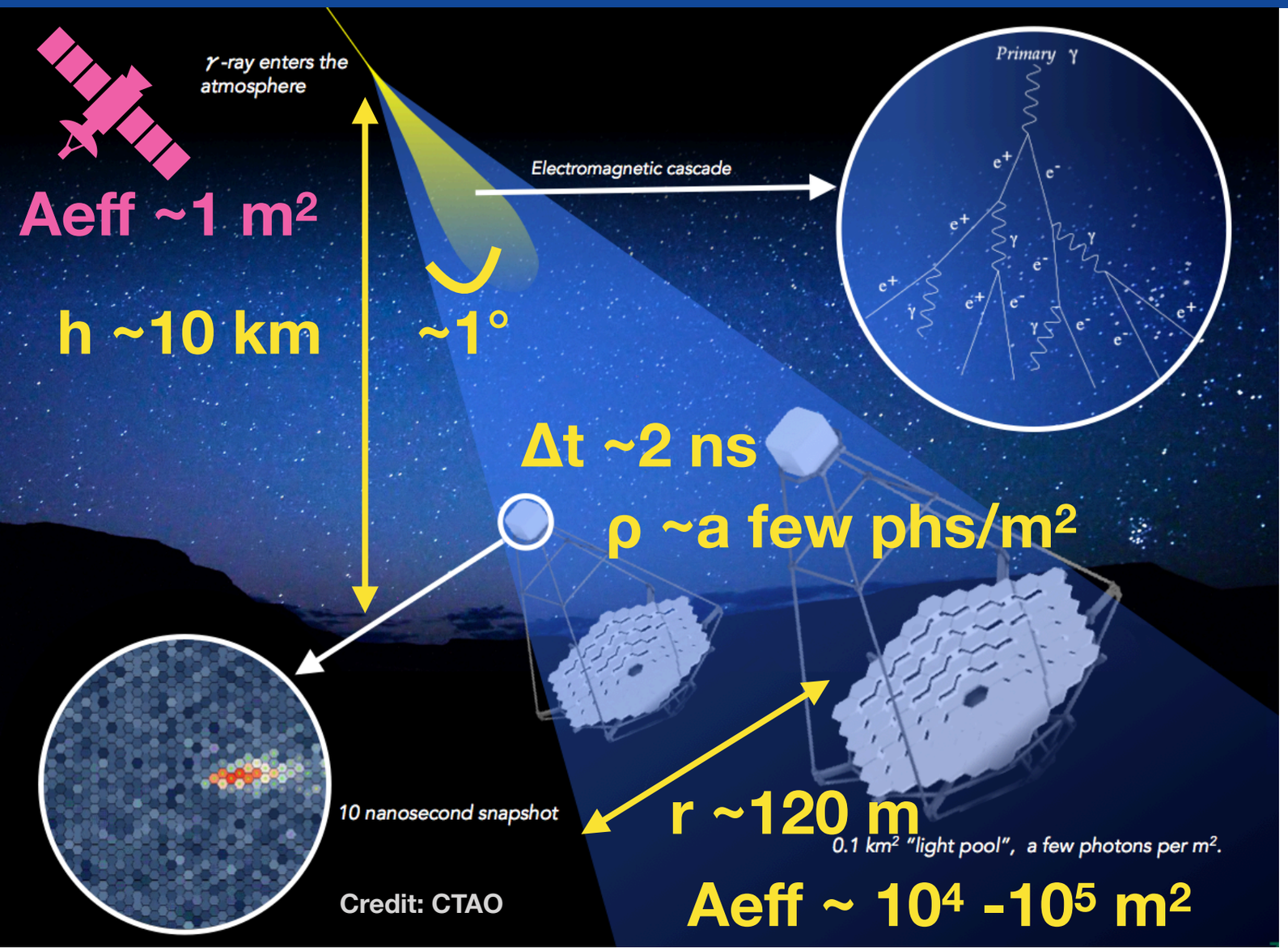
VHE Gamma-ray Sky

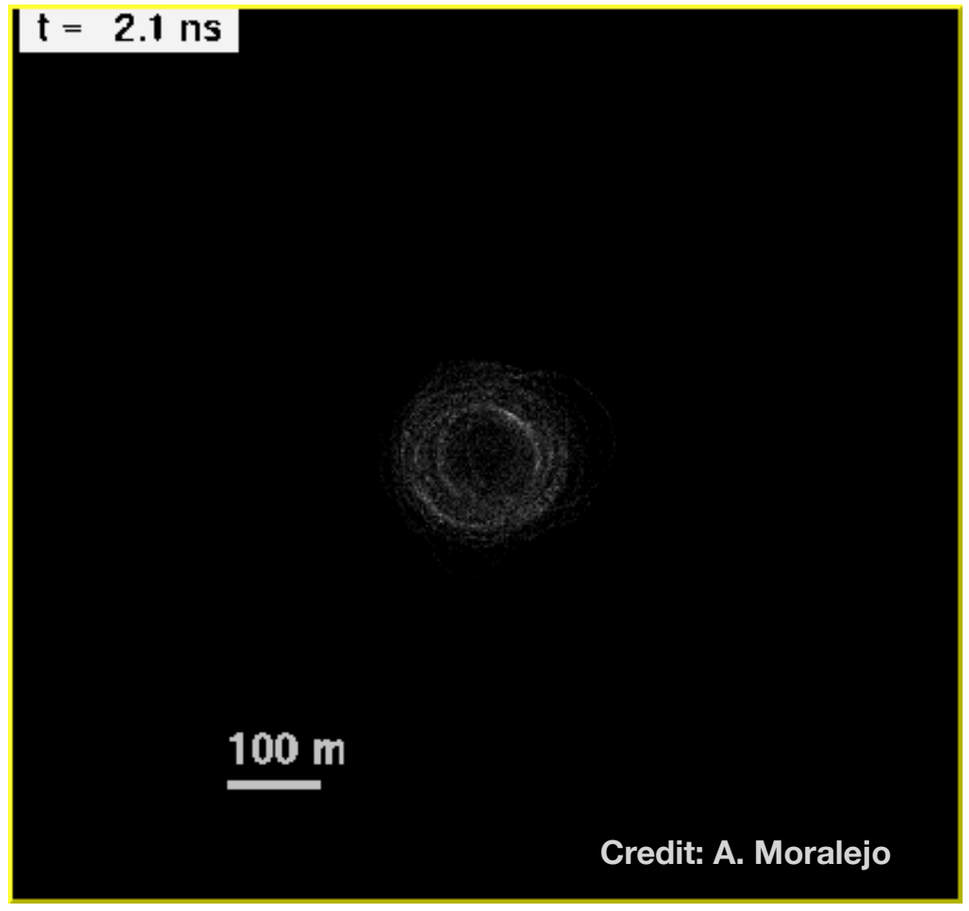


- > 200 very-high-energy (**VHE**, > a few tens of GeV) gamma-ray sources
  - Active Galactic Nuclei, Supernova Remnants, Pulsars, GRBs,..
- Great laboratories to study physics in extreme environments (dense, strong gravity/magnetic field)

Imaging Atmospheric Cherenkov Telescopes (IACTs)



100 GeV γ produced Cherenkov photons at the ground



- IACT = Atmosphere + Big mirror + Ultra high speed camera
- Suitable for detecting VHE gamma rays

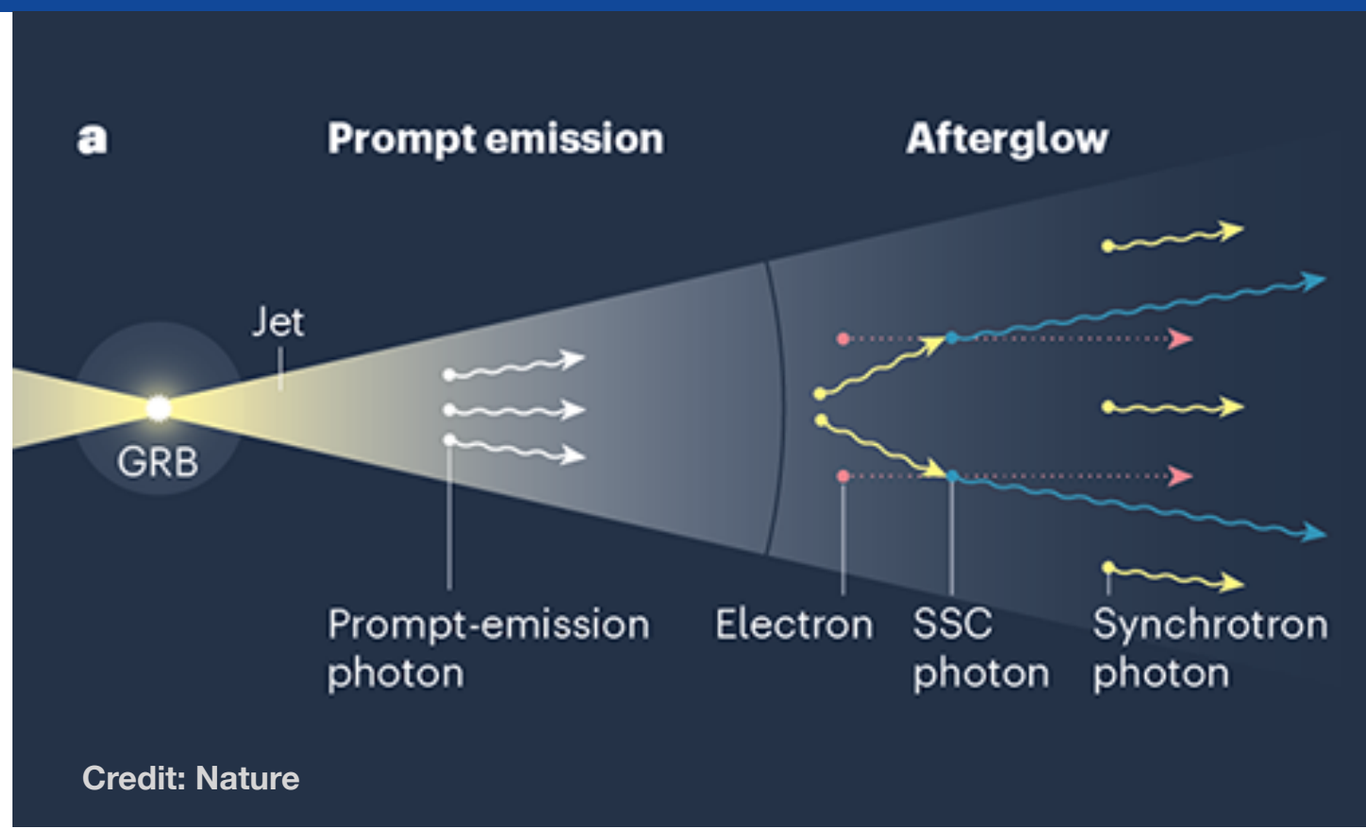
MAGIC Telescopes

1039 pixels (PMT) camera

- Two 17 m IACTs in stereo mode since 2009 (mono 2003) at La Palma, Canaries, Spain. 2200 m a.s.l. **20th anniversary** 🎉
- Energy range: 15 GeV - 100 TeV
- Angular resolution: ~0.1°. Energy resolution: ~15%. FoV: 3.5 deg.
- Fast slewing (~7 deg/s) thanks to the light structure

Gamma-Ray Bursts

Credit: N. Wakabayashi/ICRR

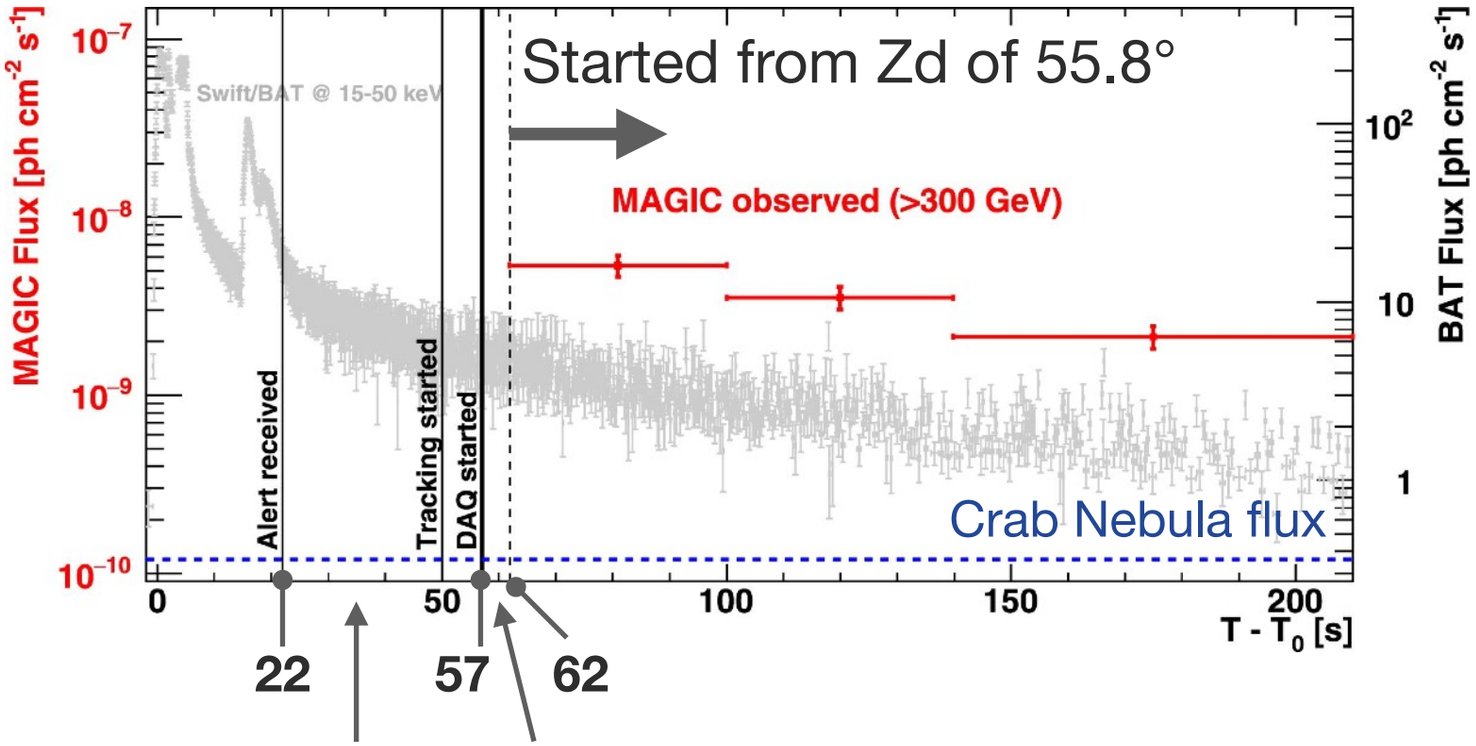


Credit: Nature

- Brightest explosion in the Universe after the Big Bang
- Progenitors: stellar core collapse, binary Neutron Star merger, binary NS-blackhole merger
- Prompt emission: internal shock in jet
  Afterglow: external shock of jet with Interstellar Medium
- Synchrotron Self-Compton (SSC) mechanism in afterglow had been predicted and naturally expected to produce VHE photons
- IACT observations are important to deepen the understanding of GRB emission mechanism

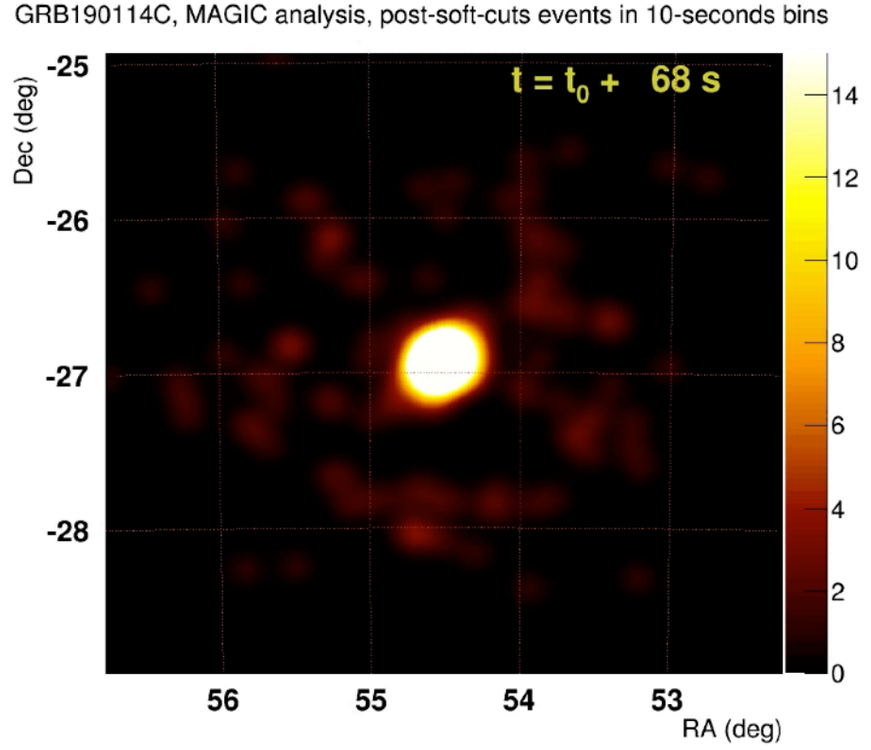
GRB 190114C

Light curves & Timeline

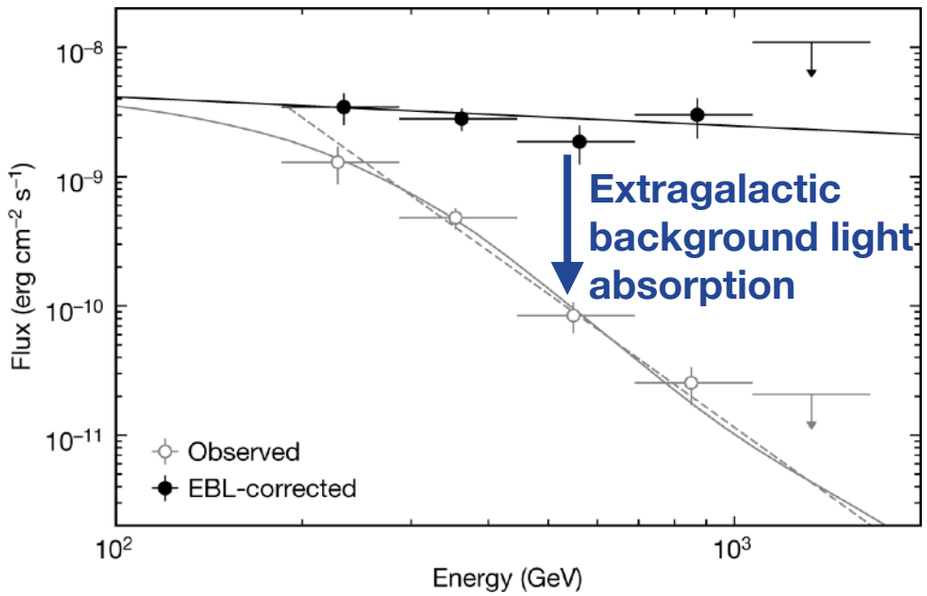


- Bright long GRB at z = 0.42
- First detection of TeV emission from GRB. New type of VHE γ-ray source
- Thanks to the fast repointing & automatic alert system, we could observe it from the early afterglow phase

Skymap



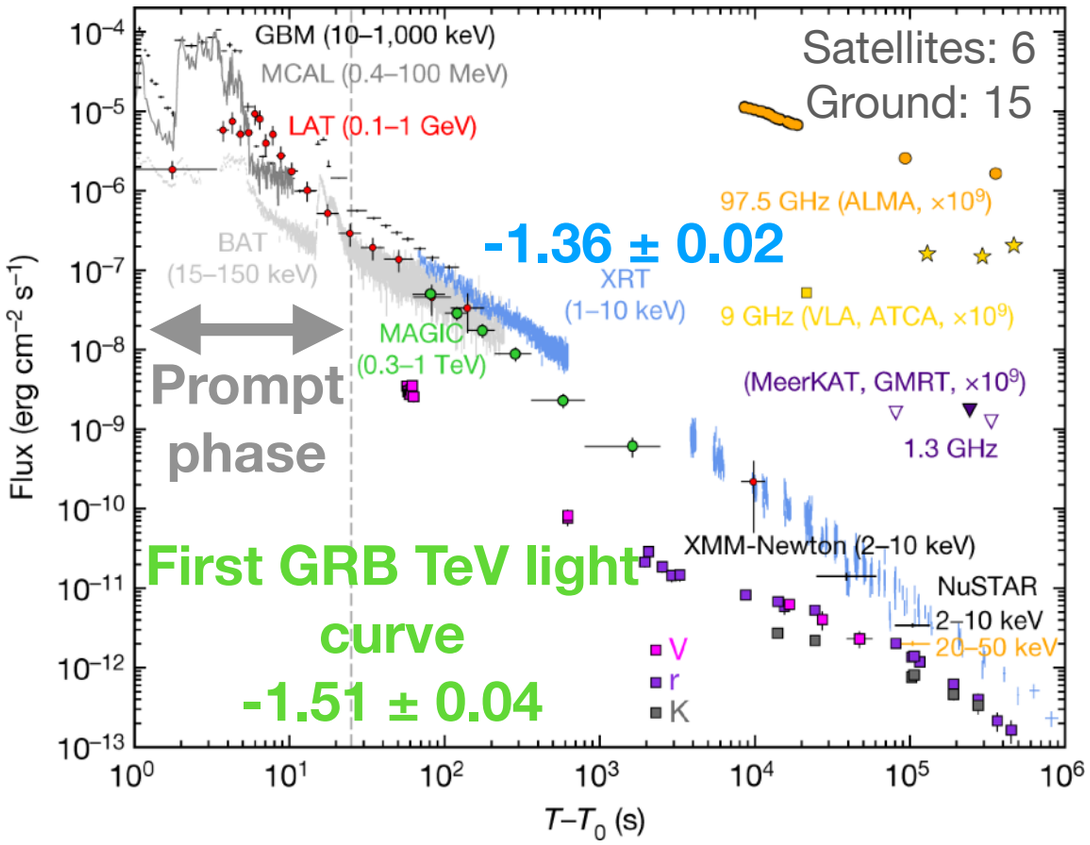
Spectral Energy Distribution



MAGIC Coll. Nature 575 (2019) 455

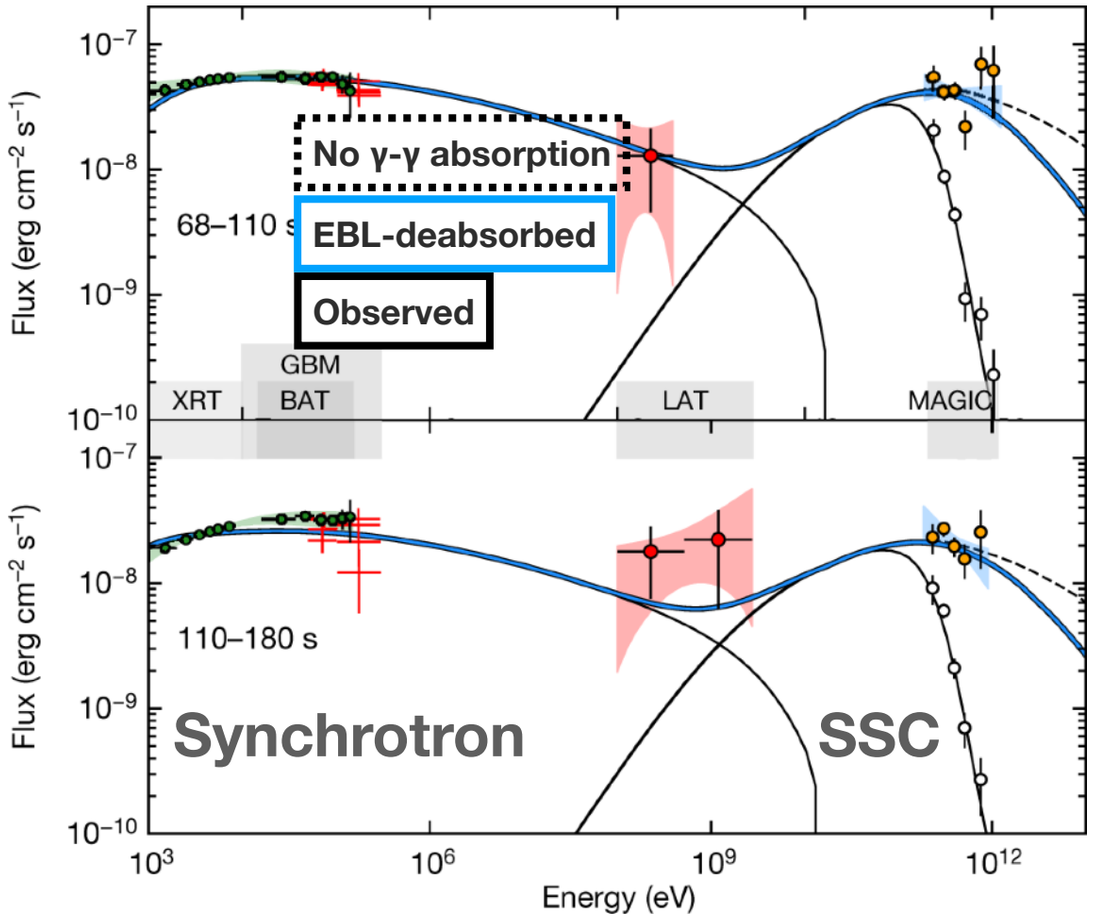
GRB 190114C - Science

Extensive Multiwavelength Campaign



- Similarity in X/GeV/TeV afterglow slope
  → Common emission mechanism
- Synchrotron emission excluded, SSC favored
- Testing Lorentz Invariance Violation:
  competitive limits on the quadratic leading order of speed of light modification

SED & Modeling



MAGIC Coll et al. Nature 575 (2019) 459

E-dep. arrival time delay

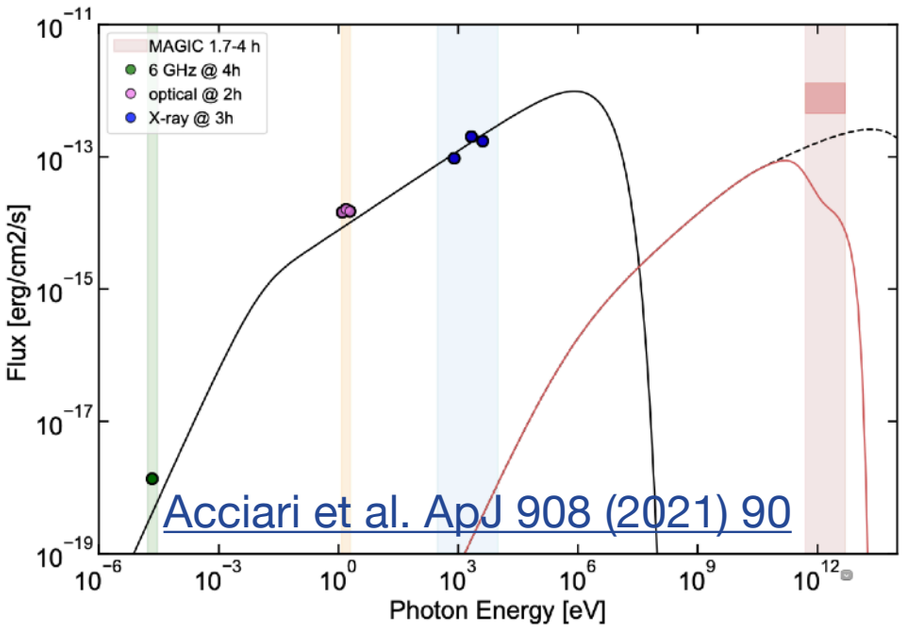
$$\Delta t = s\,\frac{n+1}{2}\,D_n(z)\left(\frac{\Delta E}{E_{\mathrm{QG,n}}}\right)^n$$

QG energy scale

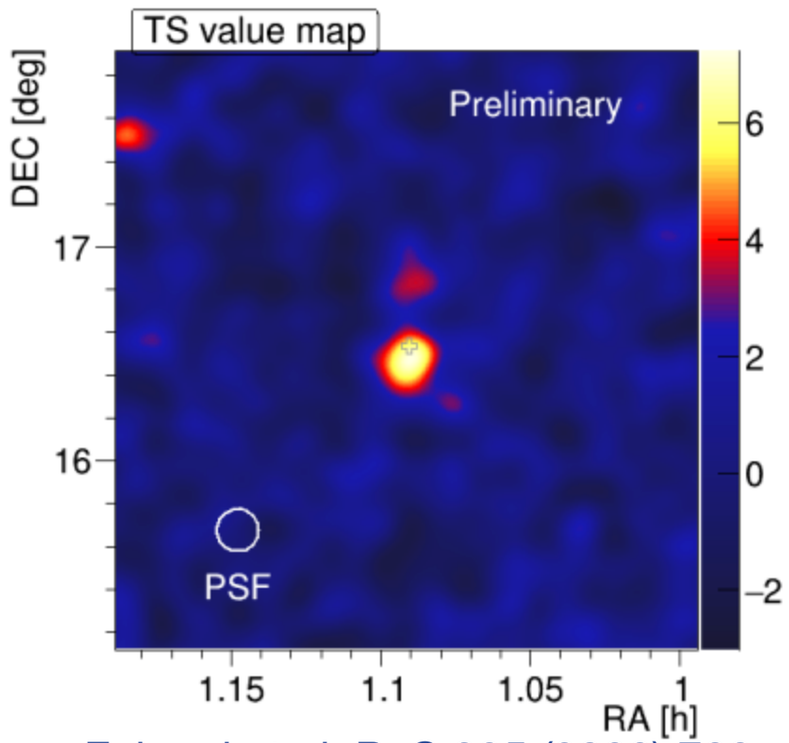
Acciari et al. PRL 125 (2020) 021301

Other GRBs

SED of GRB 160821B



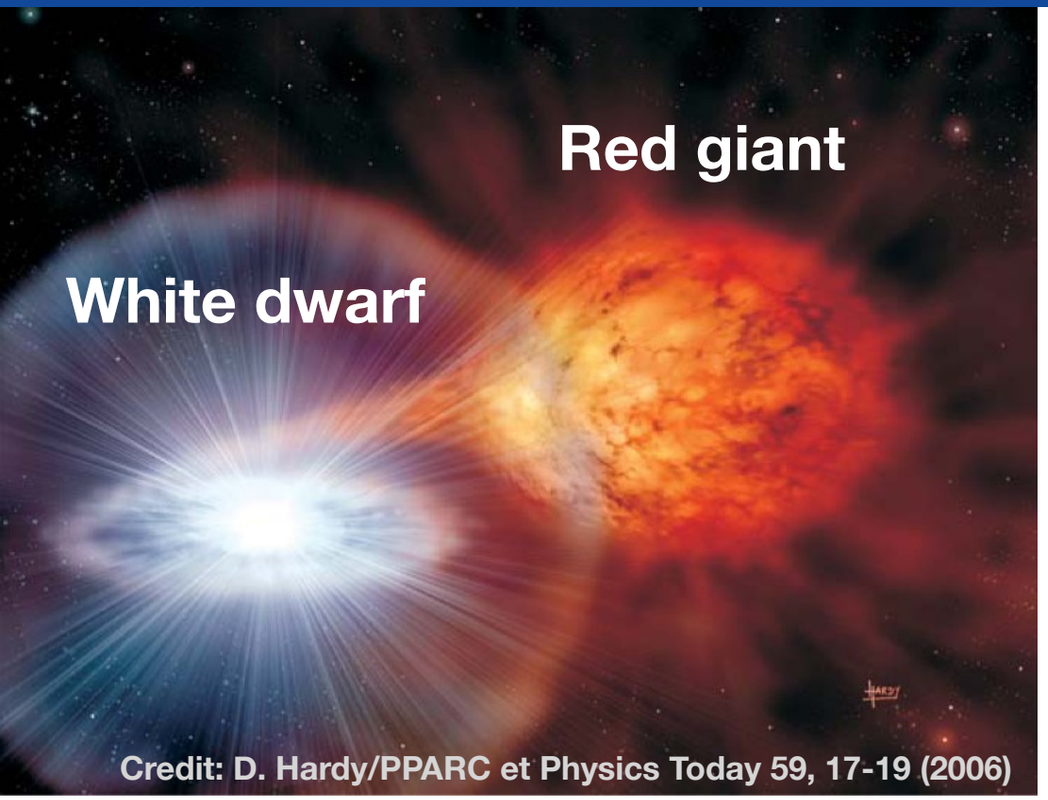
Skymap of GRB 201216C



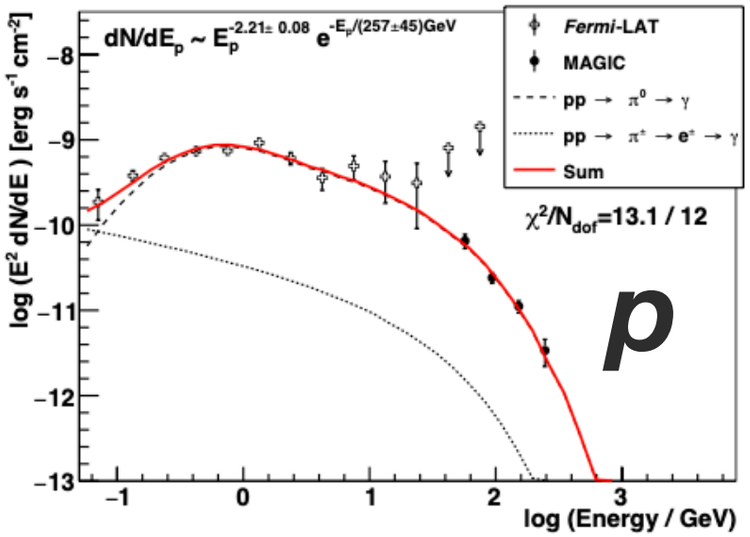
Fukami et al. PoS 395 (2022) 788

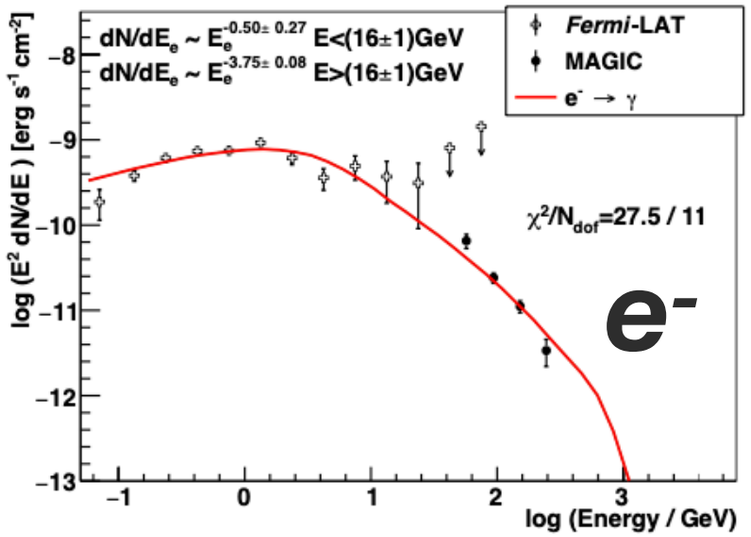
- **GRB 160821B**: short GRB associated to a kilonova
  - 3σ hint of gamma-ray emission
  - If detected, challenging to explain with one-zone SSC models
- **GRB 201015A**: relatively low luminosity long GRB
  - 3σ hint of gamma-ray emission
    Suda et al. PoS 395 (2022) 797
  - 10^3 less energetic, but at similar distance as GRB 190114C
- **GRB 201216C**: long GRB at z = 1.1
  - >5σ detection. Farthest IACT source ever
- The can is open. More to come!

RS Ophiuchi



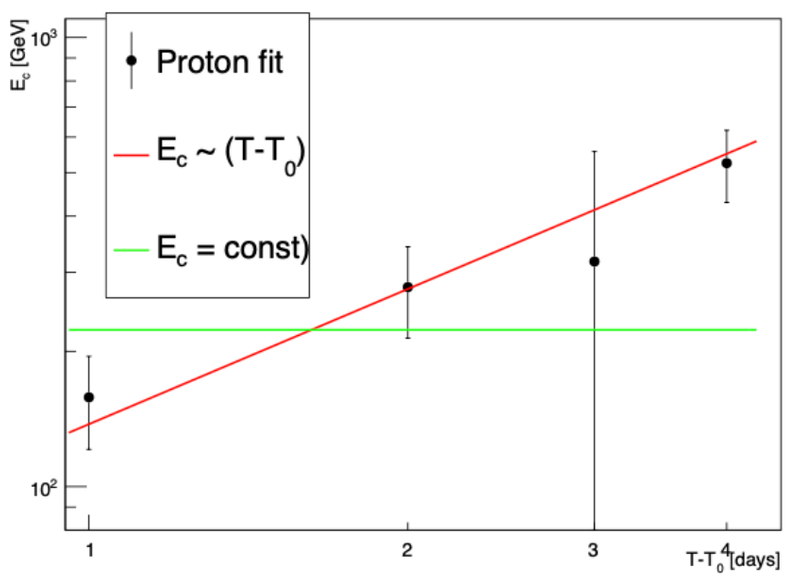
Fermi-LAT + MAGIC spectra strongly favors proton acceleration in the nova shock





- A recurrent nova (~15 yrs) in the Milky Way
  - Accumulation of hydrogen → thermonuclear explosion → …
- First VHE nova detection (Aug. 2021). New type of VHE gamma-ray source
- Minor contribution to Galactic cosmic rays

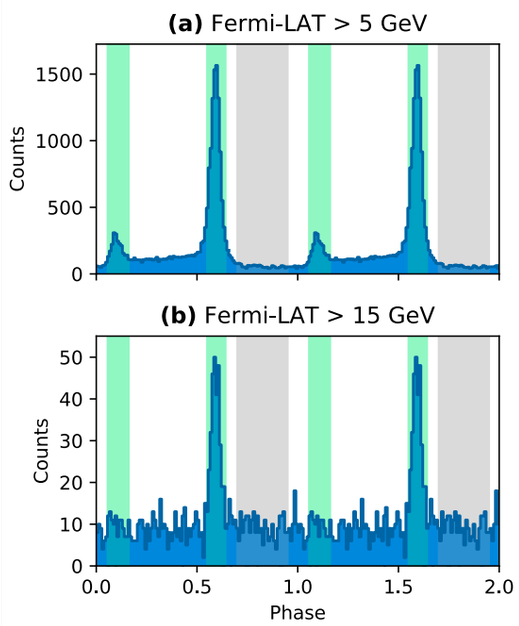
$E_{cut\text{-}off}$ fits to the E_{Max} achieved in proton acceleration

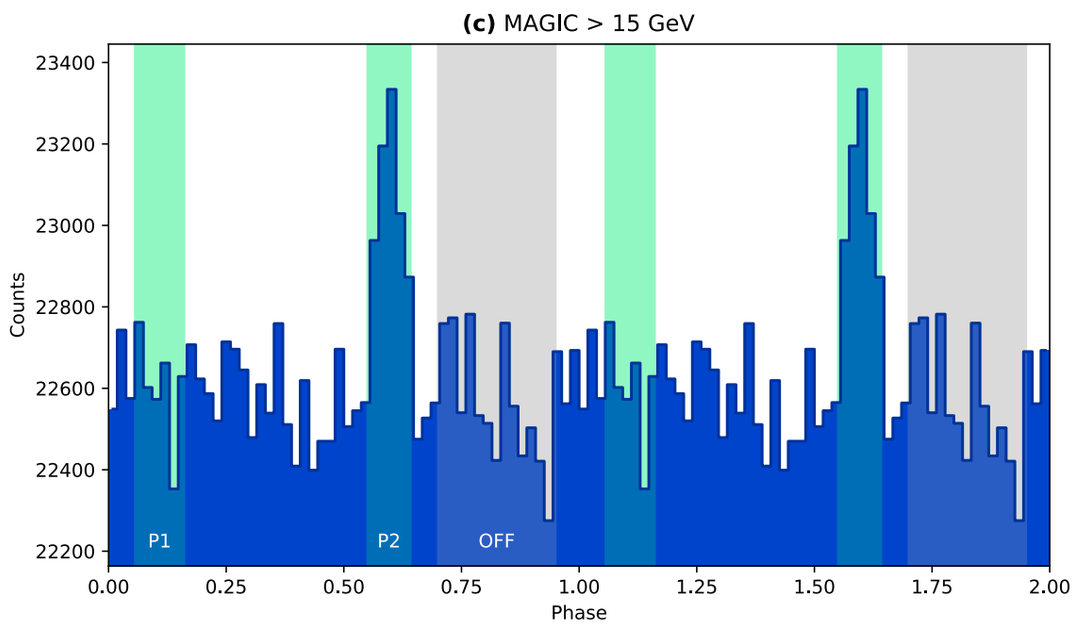


Acciari et al. Nature Astronomy, 6 (2022) 689

Geminga Pulsar

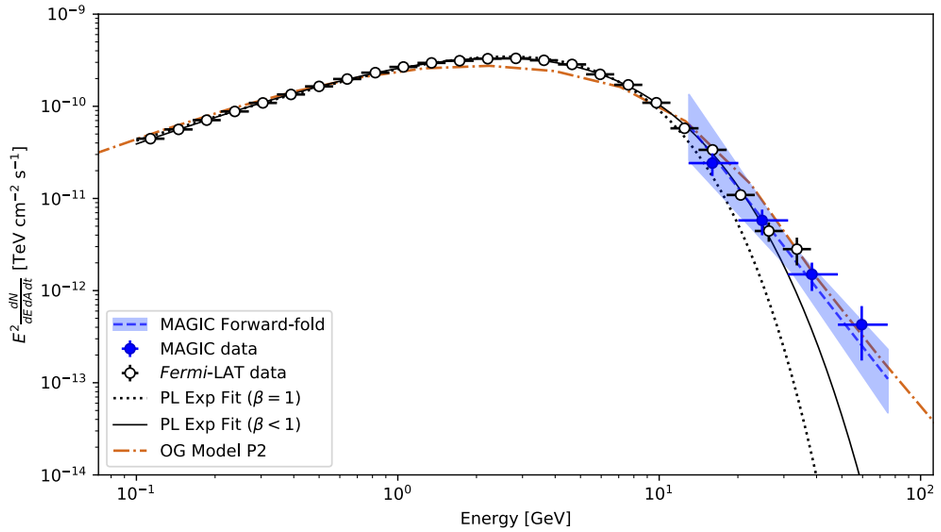
Light curves





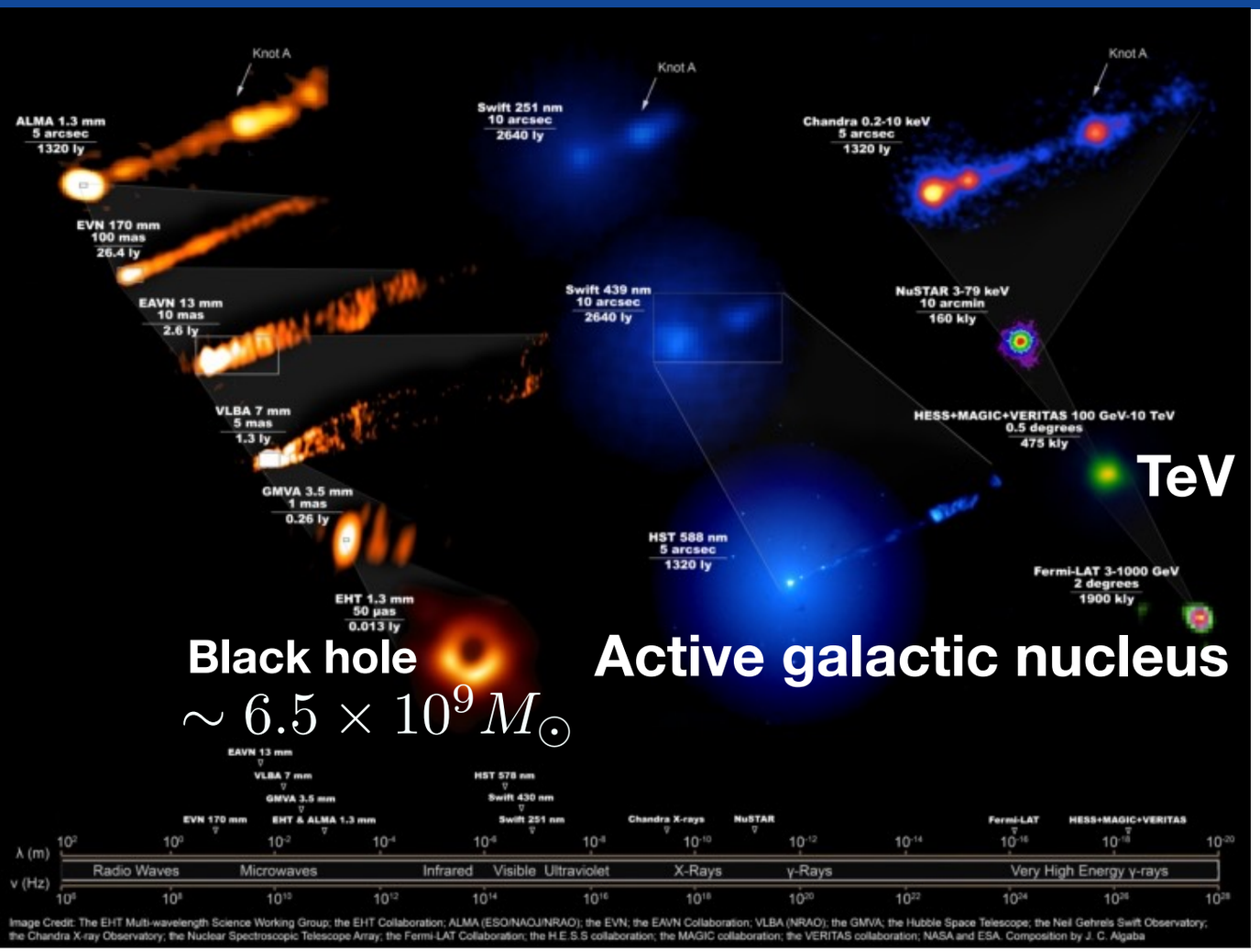
- First detection of a middle-aged pulsar and the 3rd pulsar detected by IACTs
- Detection between 15 GeV and 75 GeV thanks to excellent low-E capabilities with special trigger (Dazzi et al., IEEE TNS 68 (2021) 7)
- Power-law tail emission interpreted as the transition from curvature radiation to inverse Compton scattering

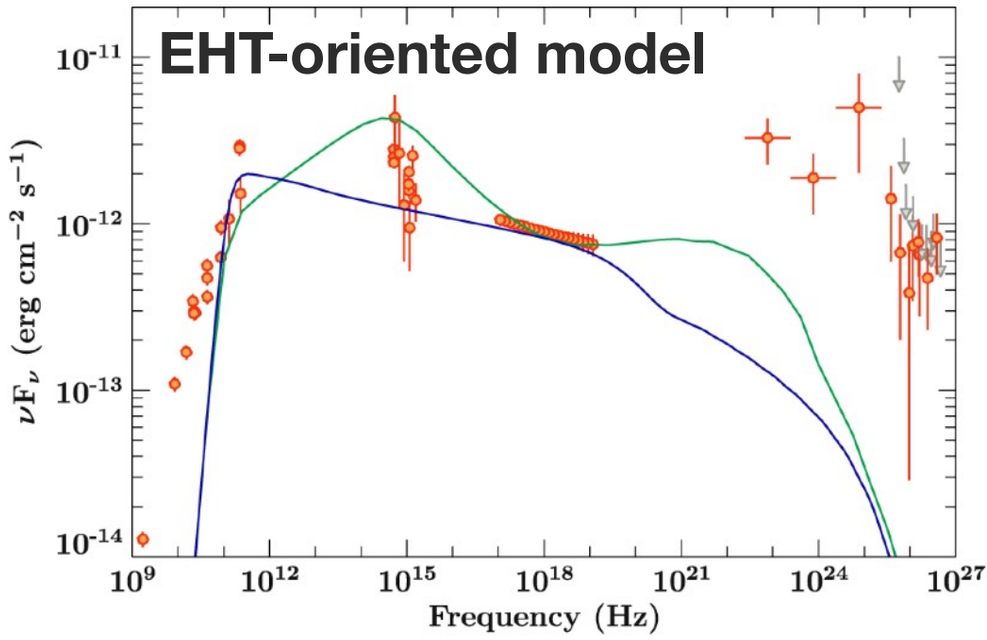
SED of P2



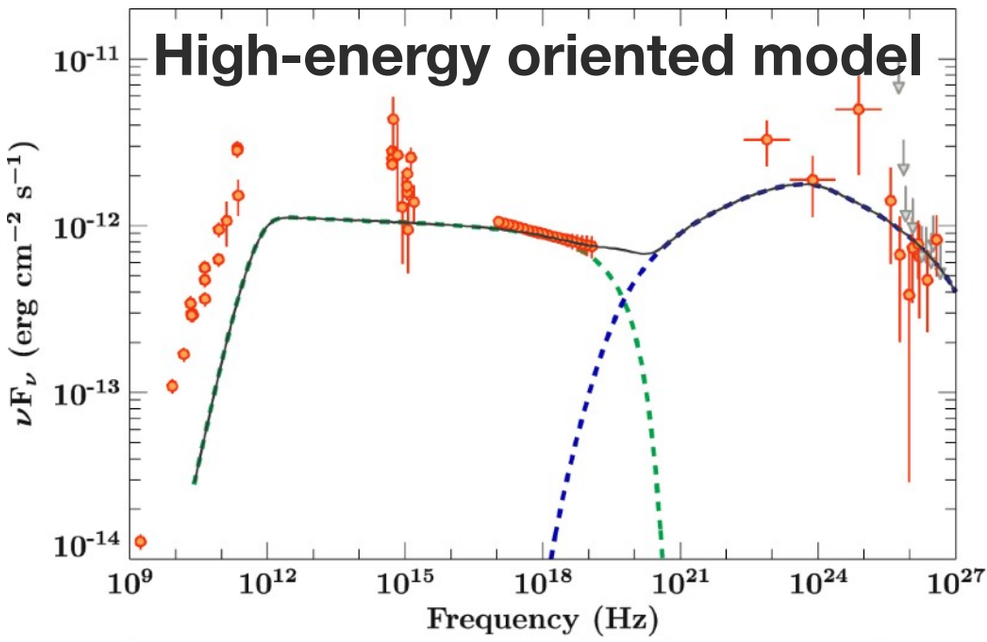
MAGIC Coll et al. A&A 643 (2020) L14

M87





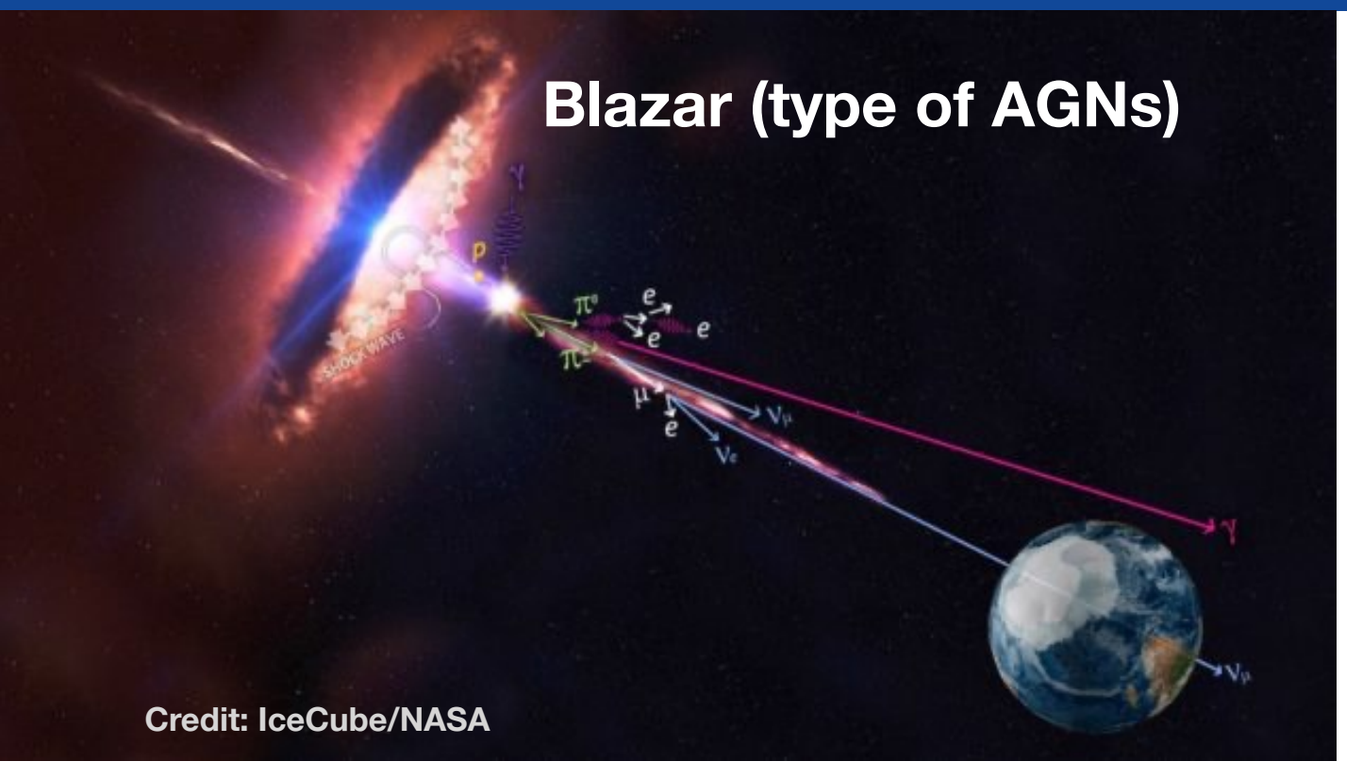
mm-radio Opt. UV X γ **TeV**



- Broadband observations during the 2017 Event Horizon Telescope Campaign
- High energy emission cannot be originated at the same location as mm-band. γ-rays can only be produced in the inner jets (HST-1)

Algaba et al. ApJL 911 (2021) L11

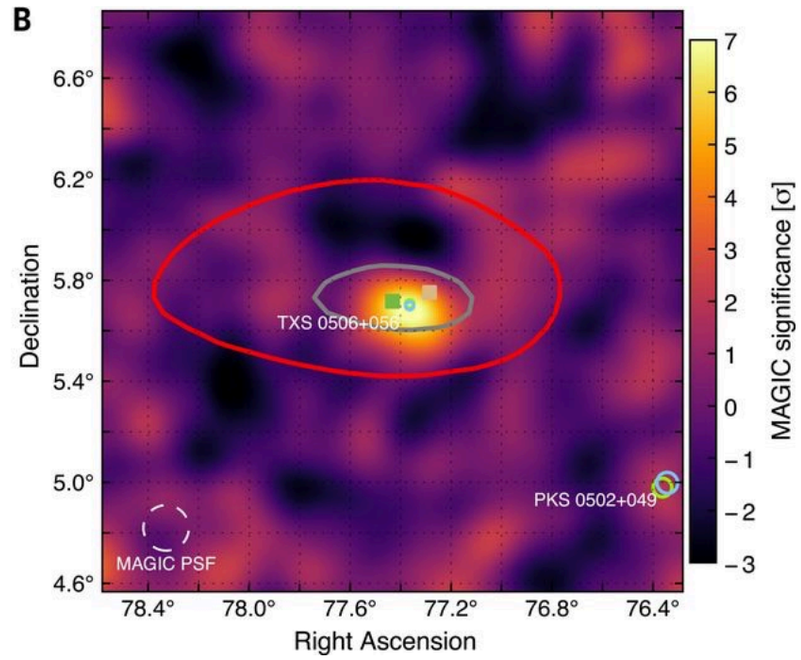
TXS 0506+056



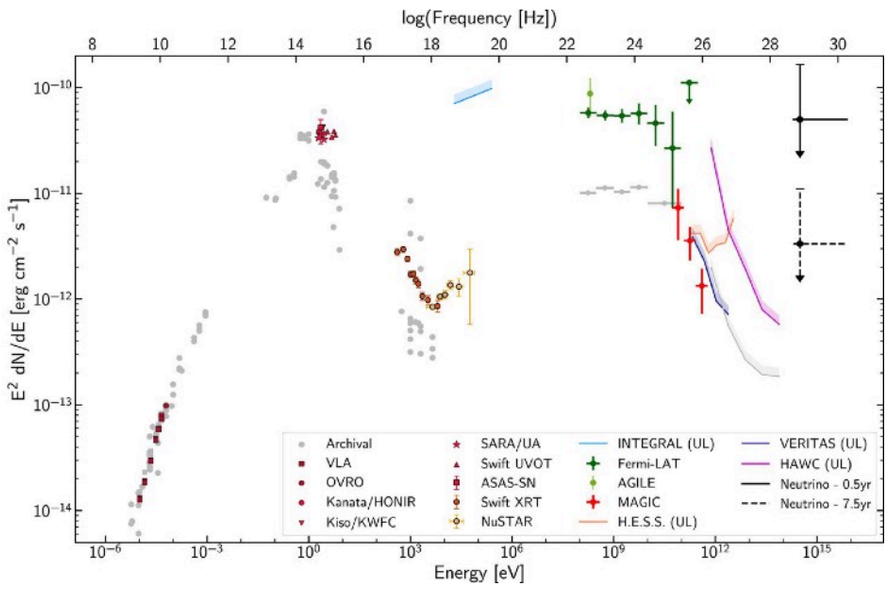
- Multimessenger (EM+ν) observations of a flaring γ-ray blazar
- Smoking gun of the presence of highly relativistic hadrons in AGN jets.
  AGNs as ultra-HE cosmic-ray accelerators
- Multiwavelength campaign (2017-2021) with several flares seen by MAGIC without ν counterpart

(Acciari et al. ApJ 927 (2022) 197, Satalecka et al. PoS 395 (2022) 875)

3.5σ association of a high-E ν (290 TeV) with a VHE γ-ray source

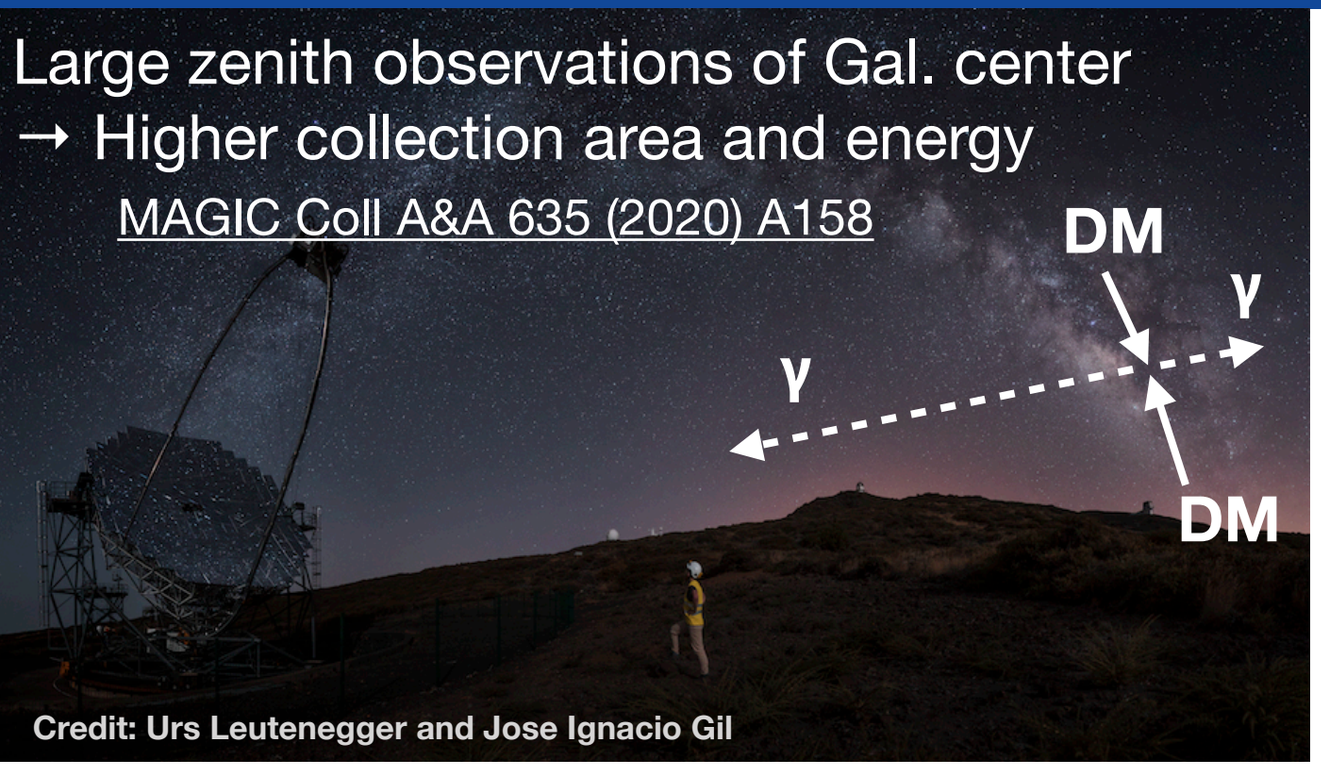


First multi-messenger SED



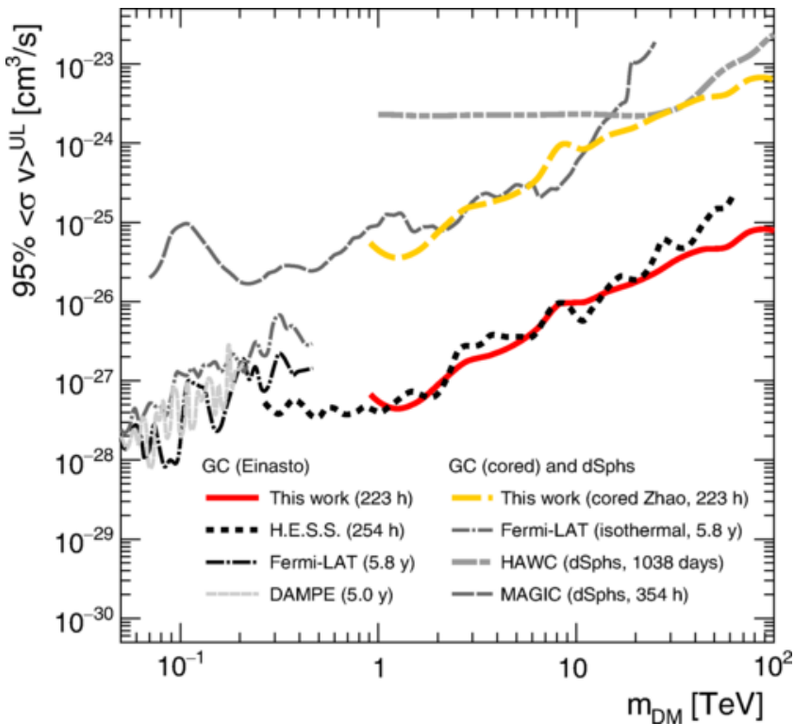
IceCube Coll et al. Science 361 (2018) 6398

Dark Matter



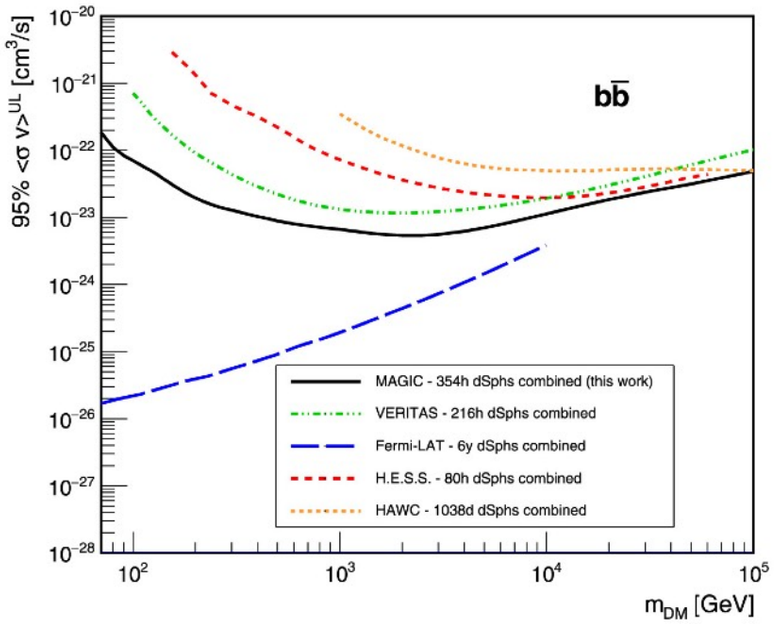
- Galactic Center: Best limits for $\chi\chi \rightarrow \gamma\gamma$ in the 20-100 TeV DM mass range
- dSphs: Best limits for 9 annihilation channels in the multi-TeV DM mass range with IACTs

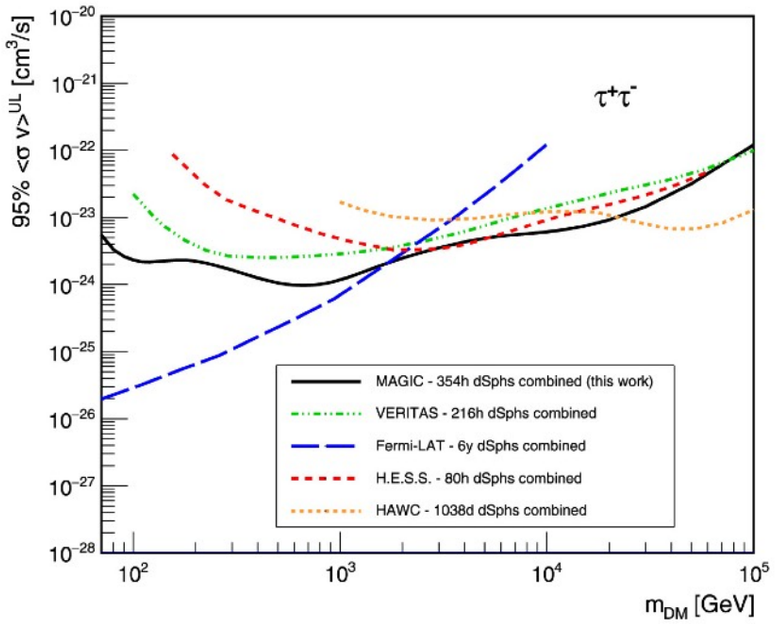
DM γ-ray lines in the Galactic Center



MAGIC Coll et al. PRL 130 (2023) 061002

Combined searches for DM in dwarf spheroidal galaxies





MAGIC Coll. PDU 35 (2022) 100912

Summary & Prospect

- MAGIC providing unique information about physics in extreme environments since 2003 (20th anniversary!)
  - Discovery of new types of VHE γ-ray sources
  - Understanding particle acceleration and radiation mechanism
  - Testing LIV and searching for DM

- MAGIC collaborating with its younger brother CTA LST-1 to perform joint observations which improve sensitivity significantly