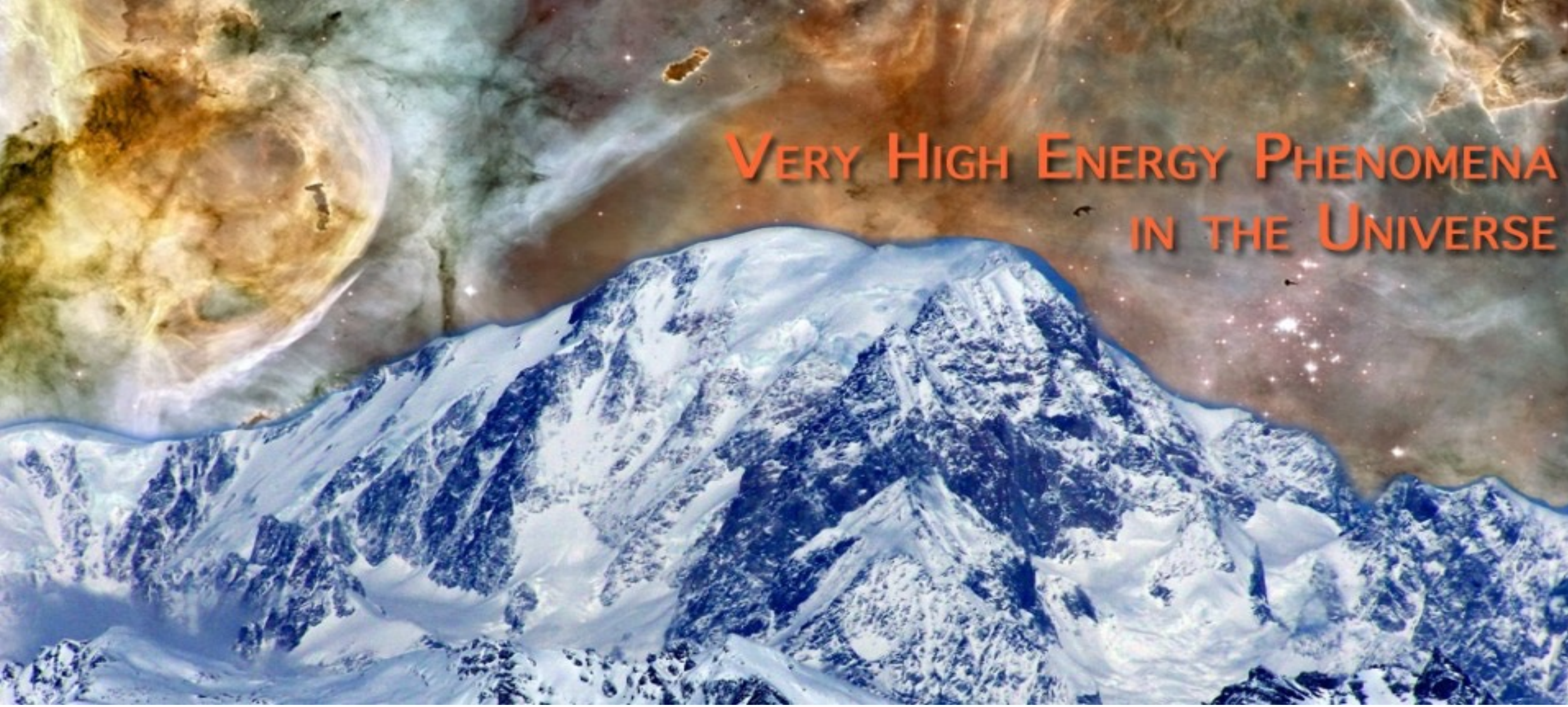

Summary of Moriond VHEPU 2022: a selection

Rencontres de Moriond since 1966

CEA - Saclay

About Moriond VHEPU 2022

- Moriond VHEPU every 4 years.
- About 60 participants
- Topics :
  - Gamma-ray astronomy
  - Neutrinos
  - Cosmic rays
  - Multi-messenger astronomy
  - Dark Matter
- All contributions available :
  https://moriond.in2p3.fr/2022/VHEPU/vhepu-agenda.html

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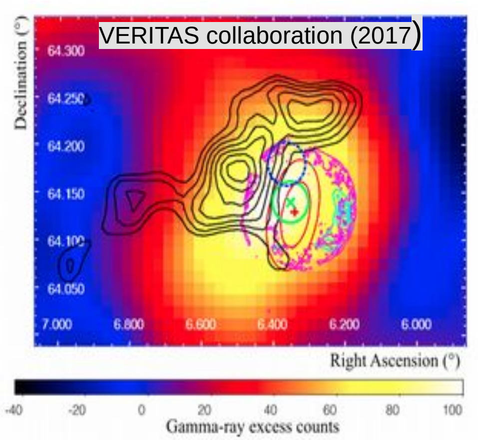
GAMMA-RAY ASTRONOMY

Origin of Galactic Cosmis Rays : Supernova remnants

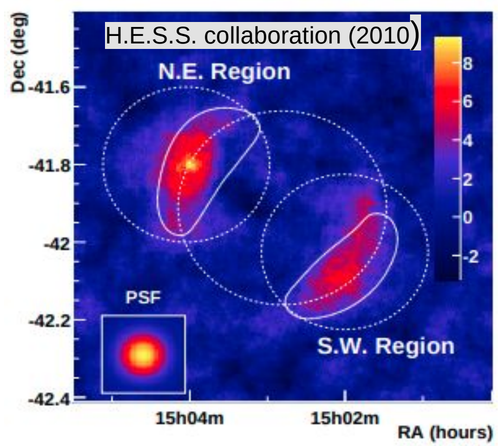
- SNRs as sources of Galactic hadronic CRs
- Historical SNRs detected in VHE gamma rays

Tycho SN (in 1572)



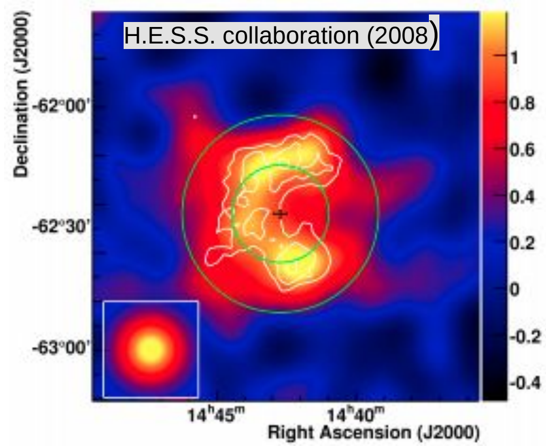
Detected at VHE with VERITAS in 2011 (67 hours)

SN 1006



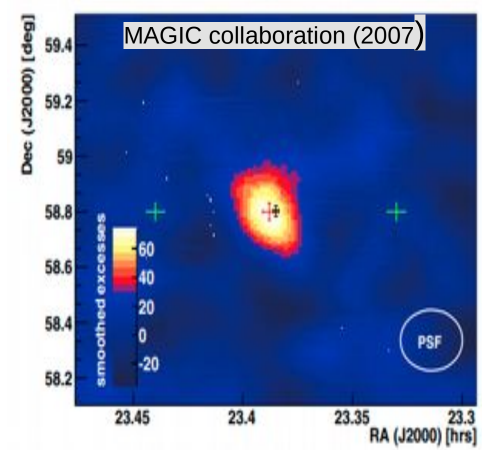
Detected at VHE with H.E.S.S. in 2010 (130 hours)

RCW 86 (SN in 185)



Detected at VHE with H.E.S.S. in 2008 (31 hours)

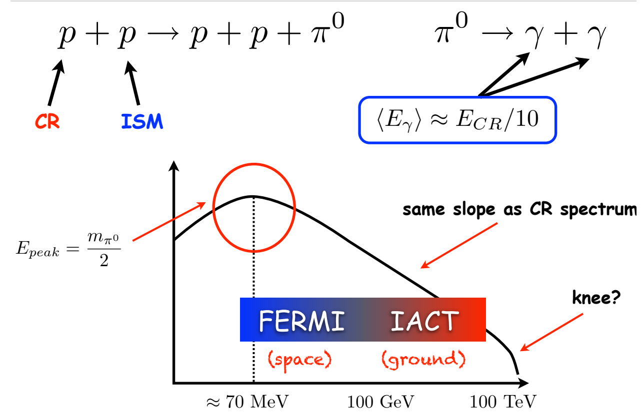
Cas A (SN around 1680)



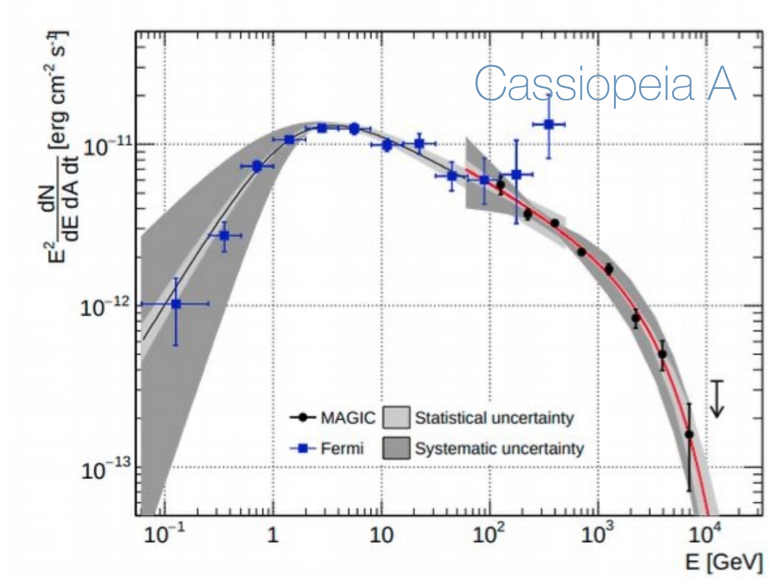
Detected at VHE with HEGRA in 2001 (232 hours)

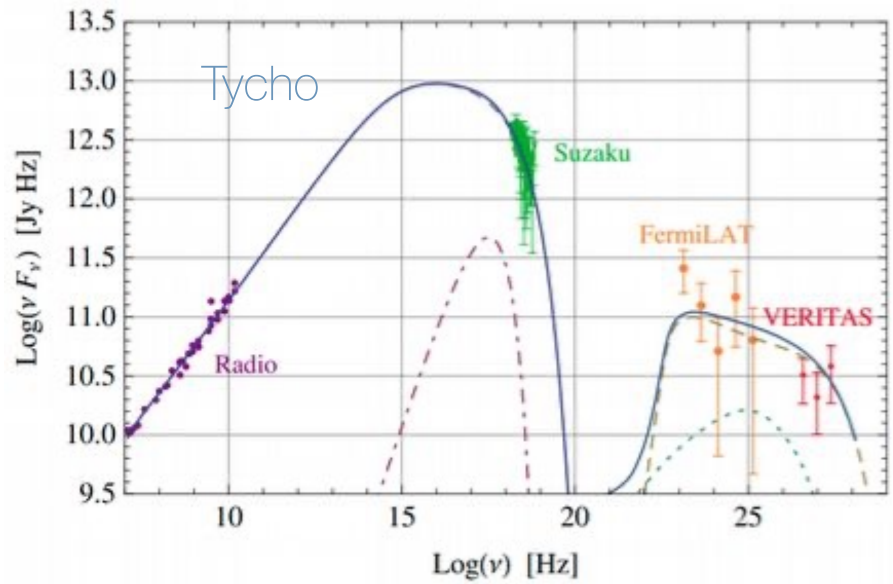
#D. Prokhorov

Origin of Galactic Cosmis Rays : Supernova remnants



- SNRs as sources of Galactic hadronic CRs
- Historical SNRs detected in VHE gamma rays
- Hadronic model (pp interaction)

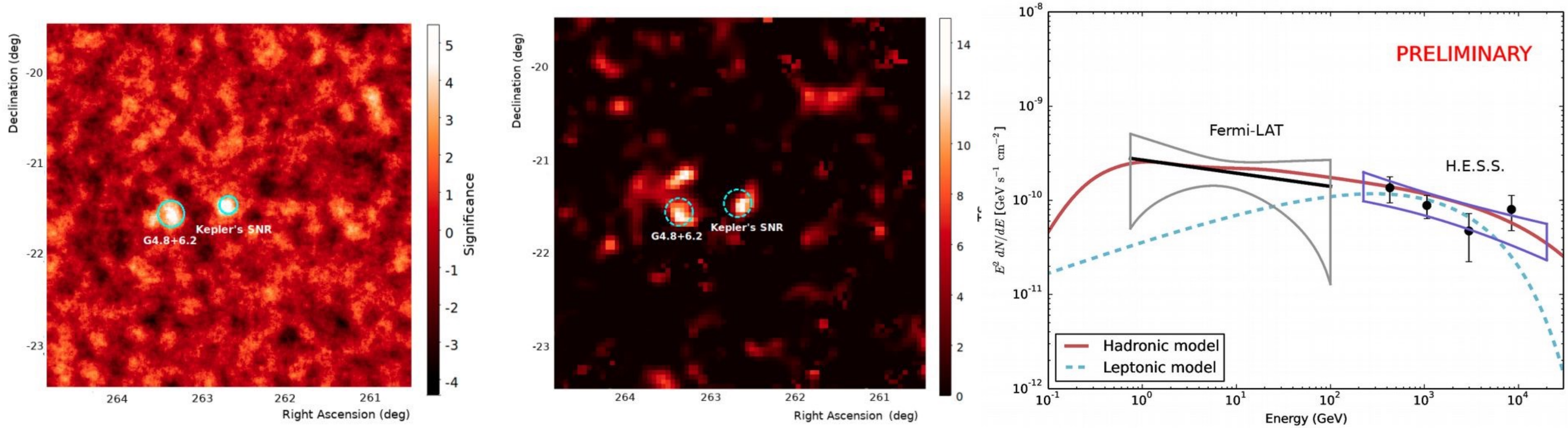




- Significant softening in the energy spectra at the highest energies
  → cannot provide enough CR protons at PeV energies

Origin of Galactic Cosmis Rays : Supernova remnants

- TeV detection of the Kepler's SNR (SN 1604) by H.E.S.S.
- 152 hours of high-quality data since 2004



- Hadronic model can well described the data
  - Cosmic-ray proton spectral index, 2.2
  - Exponential cut-off in the cosmic-ray proton spectrum at 100 TeV

#D. Prokhorov

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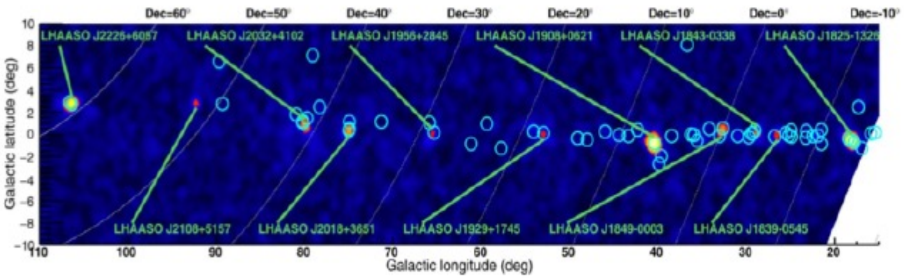
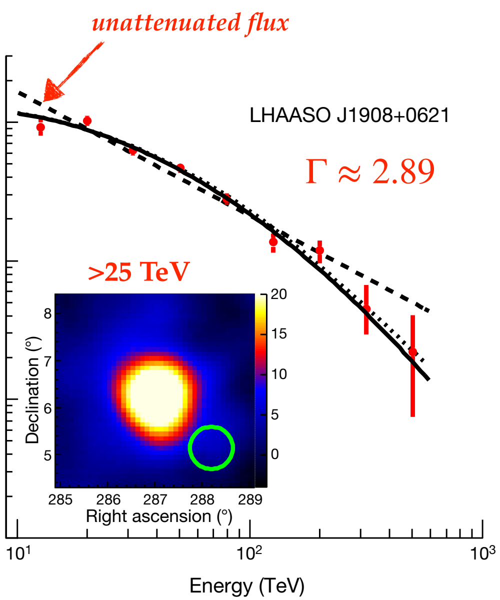
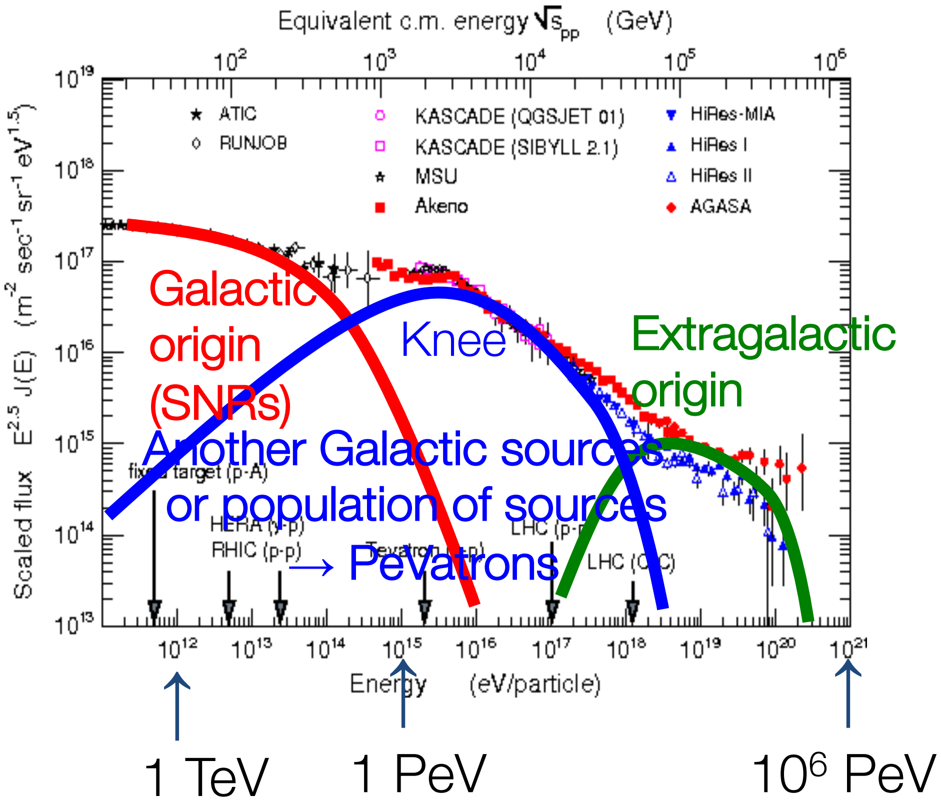
LHAASO: gamma-ray sources above 100 TeV

- 12 sources at > 0.1 PeV
- Most of them are unidentiifed



- The first SNR as PeVatron?





- LHAASO J1908+0621 = SNR G40.5-0.5 ?
- Possible association with MGRO J1908+06 that spatially associate with an Icecube hotspot
- Spectrum suggests >2PeV protons
- Confirmation of association with SNR G40.5-0.5 would be the first evidence of a SNR operating as a pevatron *#G. Siascio*

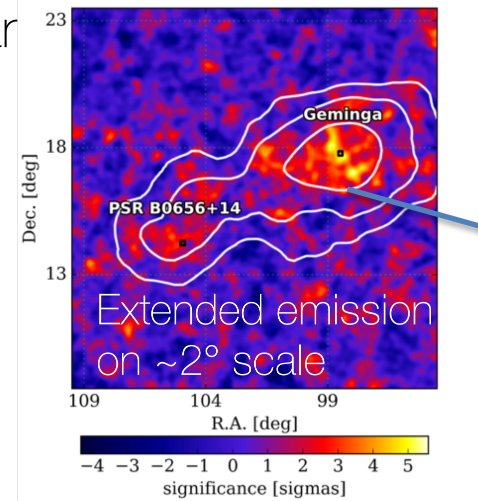
Extended VHE sources: detection of TeV halos

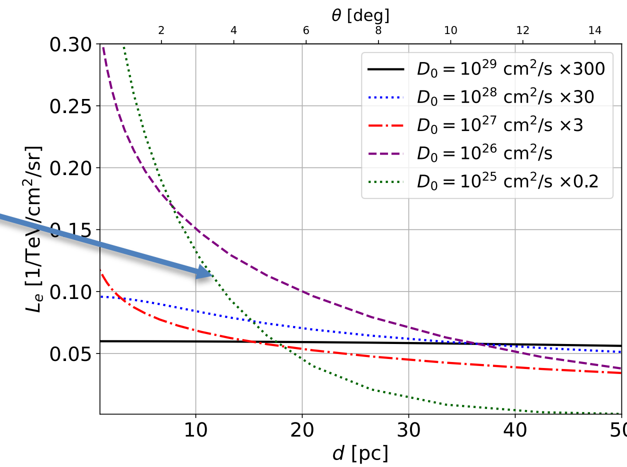
- New source class: Geminga and Monogem pulsars are surrounded by a spatially extended region (~20 pc) emitting multi-TeV gamma-rays

- TeV halos: larger zone in which the pulsar does not dominate the environment: diffusion regime

- Data implied the diffusion coefficient to be two orders of magnitude lower than the one in the Galaxy.

HAWC Collaboration, Science 358, 911 (2017)





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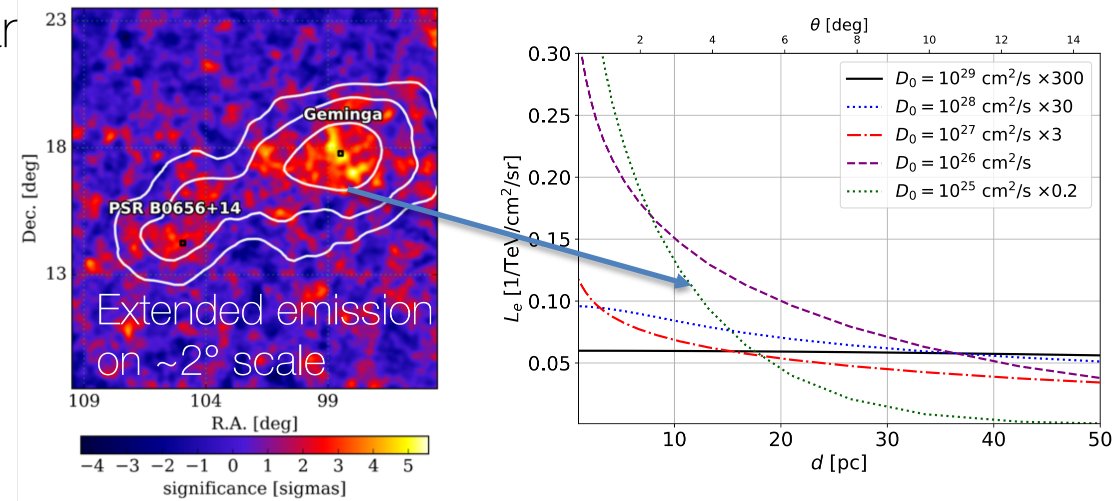
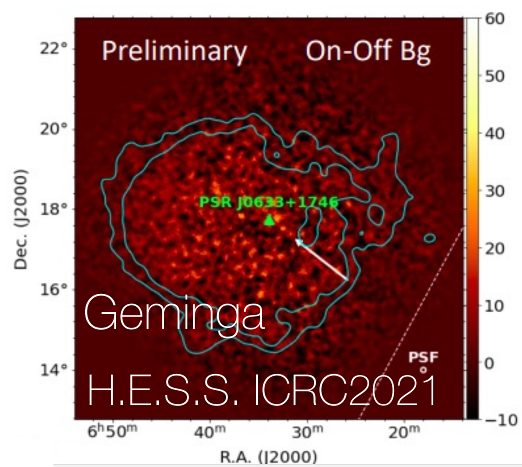


- Understanding transport of particles in the vicintiy of the sources

- Input for understanding the origin of the positrons excess' seen by AMS02



- H.E.S.S observations of Geminga

- More halos candidates seen by LHAASO and TibetAS-γ

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Extended VHE sources: detection of TeV halos

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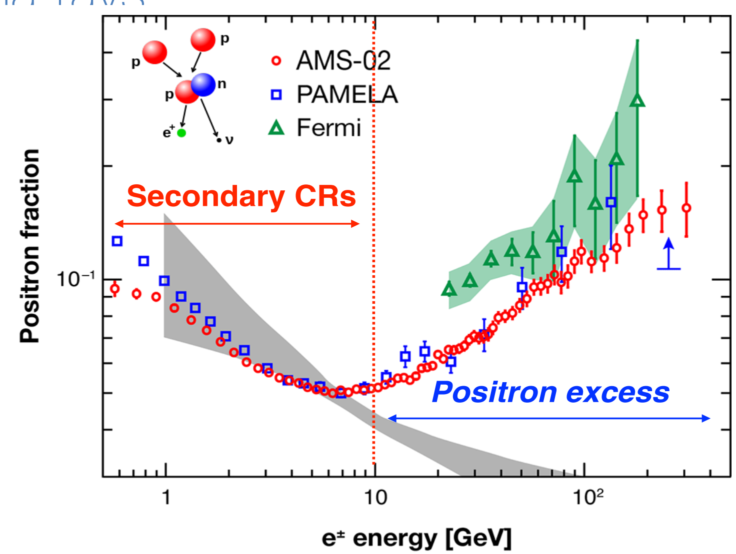
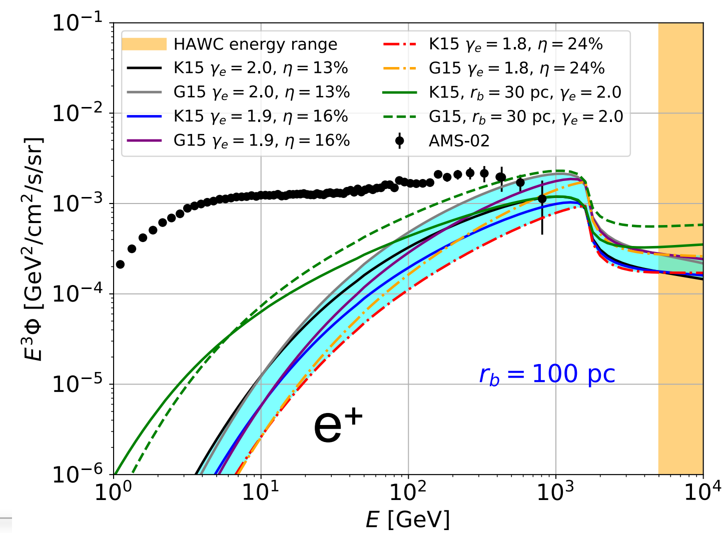


The nearby plusar Geminga alone could contribute to the entire positron excess around 1 TeV.

- The exact contribution depends on the size of the low-diffusion halo
- Other pulsars could contribute as well



#Di Mauro

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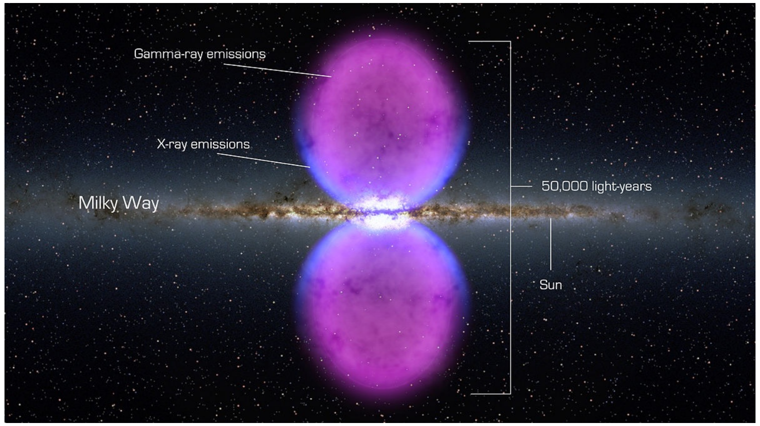
Fermi Bubbles @ VHE ?

- A double-lobe structure observed by Fermi-LAT about a decade ago
  - origin still unknown
  - Counterparts in the X-rays observed by eRosita, and at other wavelengths, e.g., the microwave haze and radio emissions
  - The Fermi Bubbles look like brighter close to GC with an energy spectrum that remains hard ($\sim E^{-2}$) up to ~1 TeV



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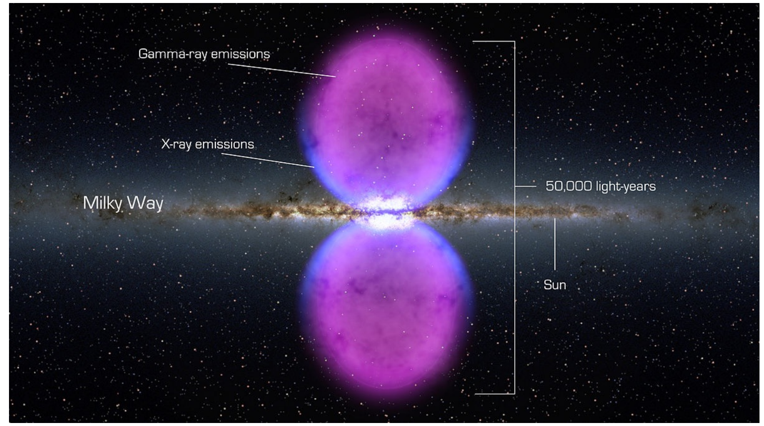
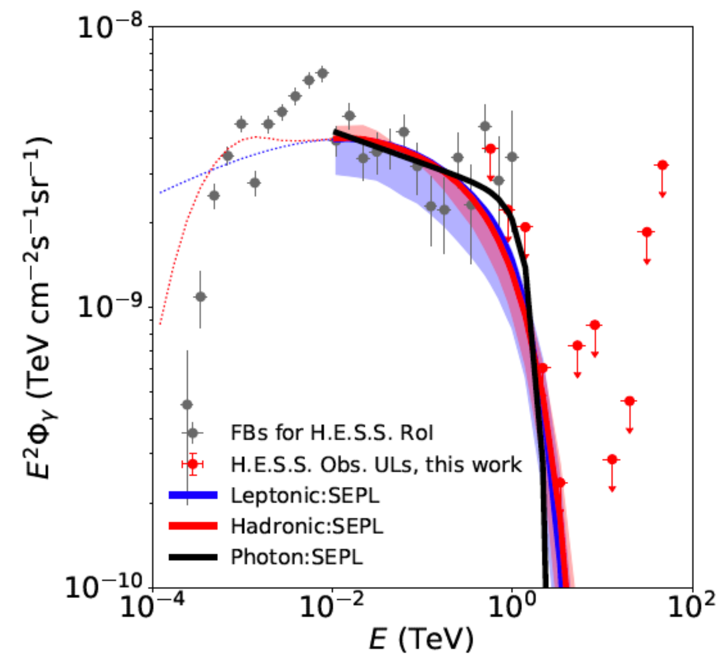


- H.E.S.S. data analysis of 546 hours of high-quality data
  - Differential flux upper limits 95% C.L. UL in the TeV
  - Constraints on model parameters of the injected particle spectrum in leptonic and hadronic scenarios



#A. Montanari

A new class of VHE sources

- Novae – outbursts from accreting binary systems of White Dwarf + massive donor star
- Detected in gamma rays, i.e., Fermi-LAT

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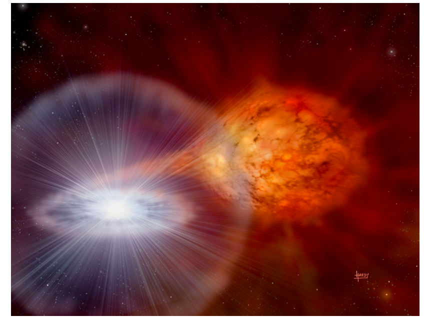
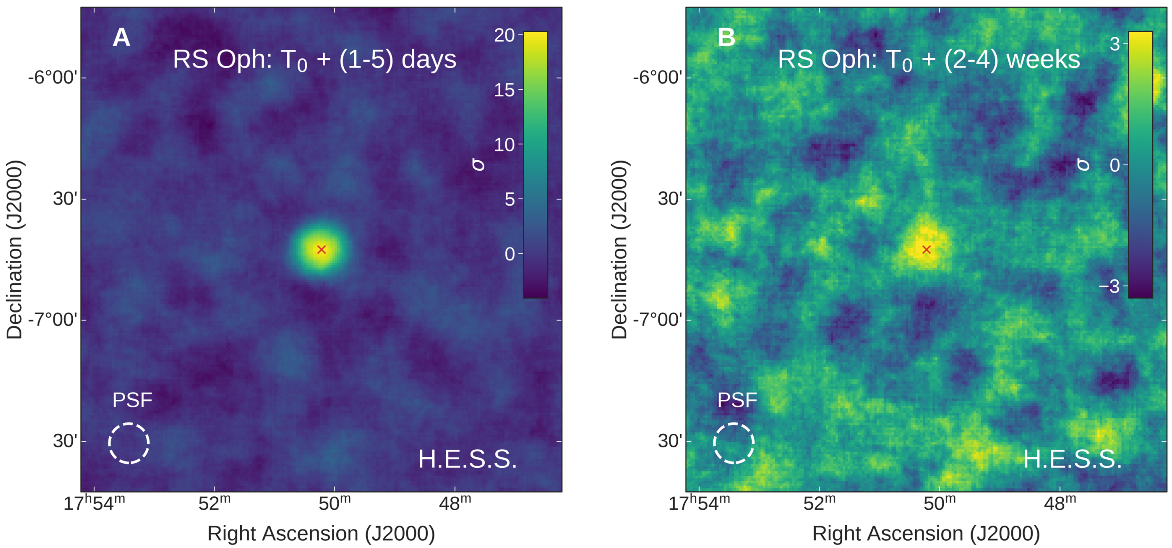
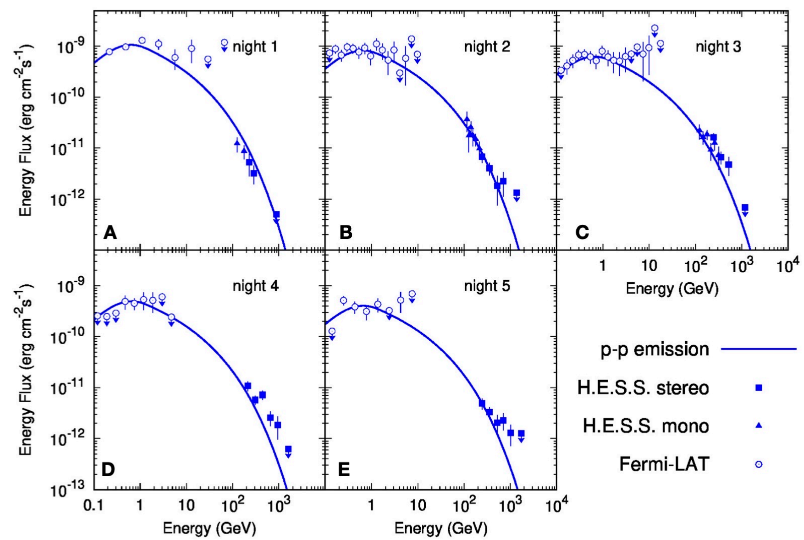


- H.E.S.S. detection of RS Oph





- Detection at > 6 sigma on each night of first five nights
- Hadronic acceleration scenario preferred

#A. Mitchell

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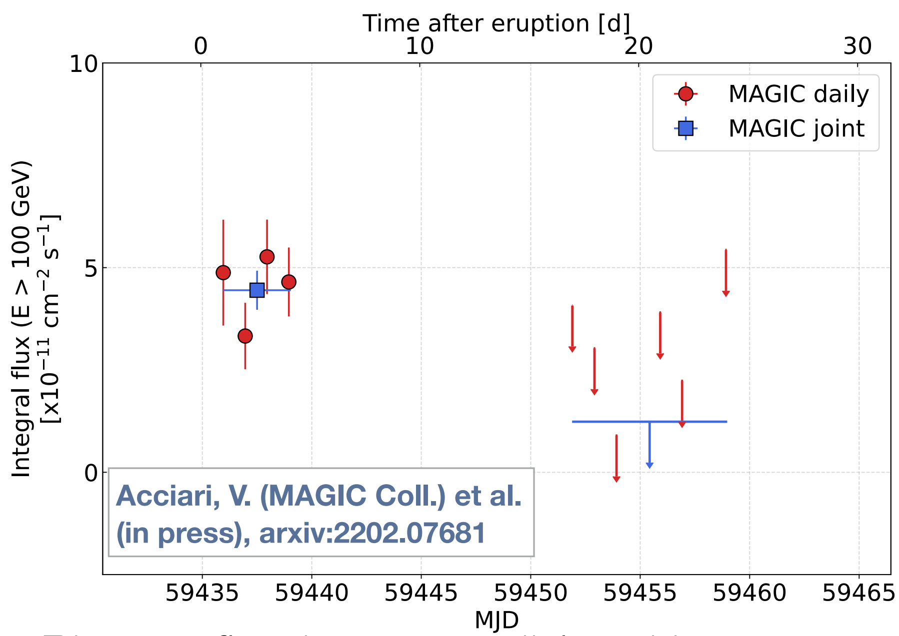
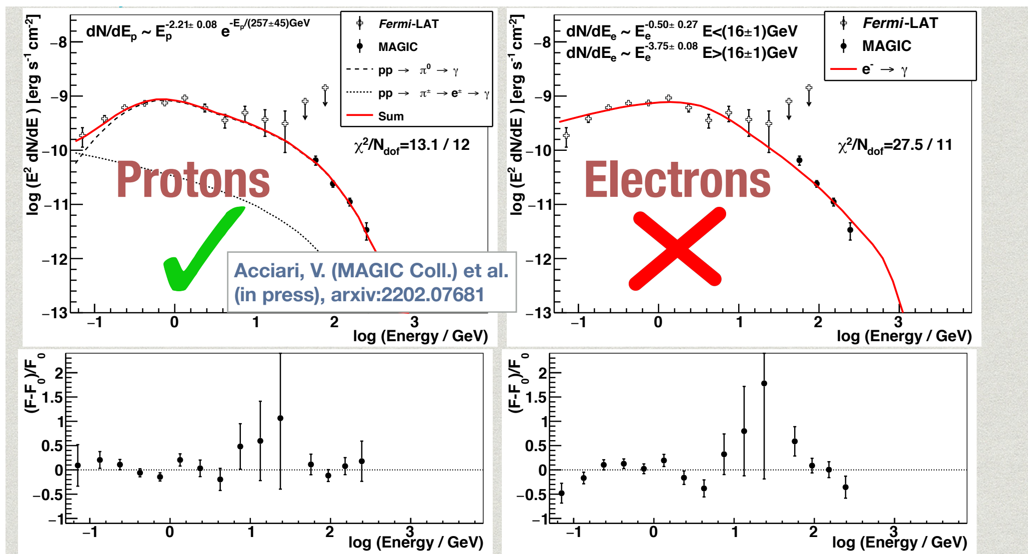
A new class of VHE sources

- Novae – outbursts from accreting binary systems of White Dwarf + massive donor star
- Detected in gamma rays, i.e., Fermi-LAT

- MAGIC detection of RS Oph





- Photon flux is compatible with constant
- Hadronic acceleration scenario preferred

#R. Lopez-Coto

COSMIC RAYS

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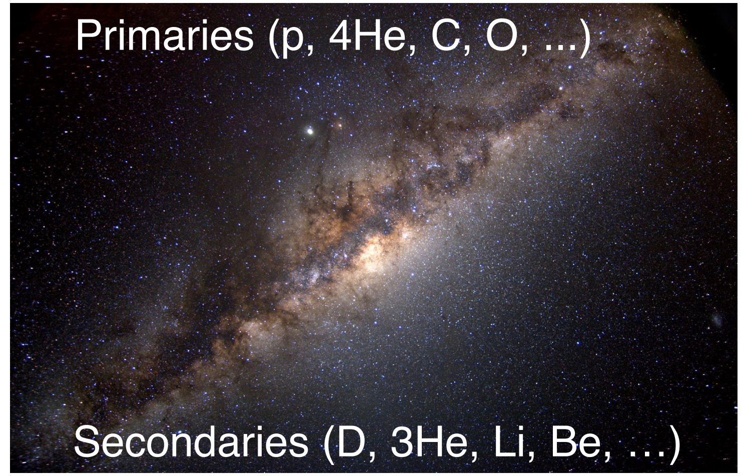
CR nuclei measurements

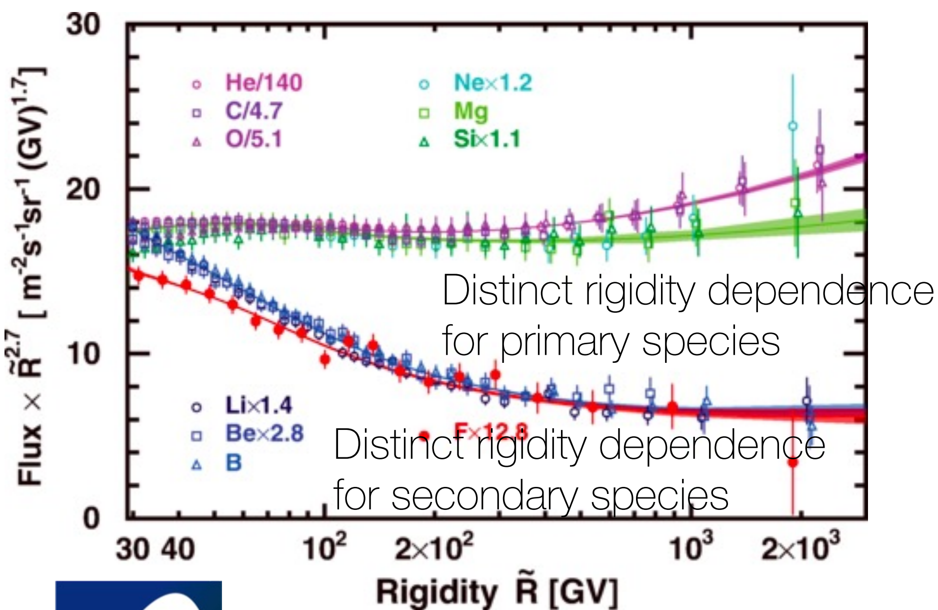


- Primaries are produced and accelerated at the sources. $\Phi_P \propto \frac{q}{K} \propto R^{-\alpha-\delta}$

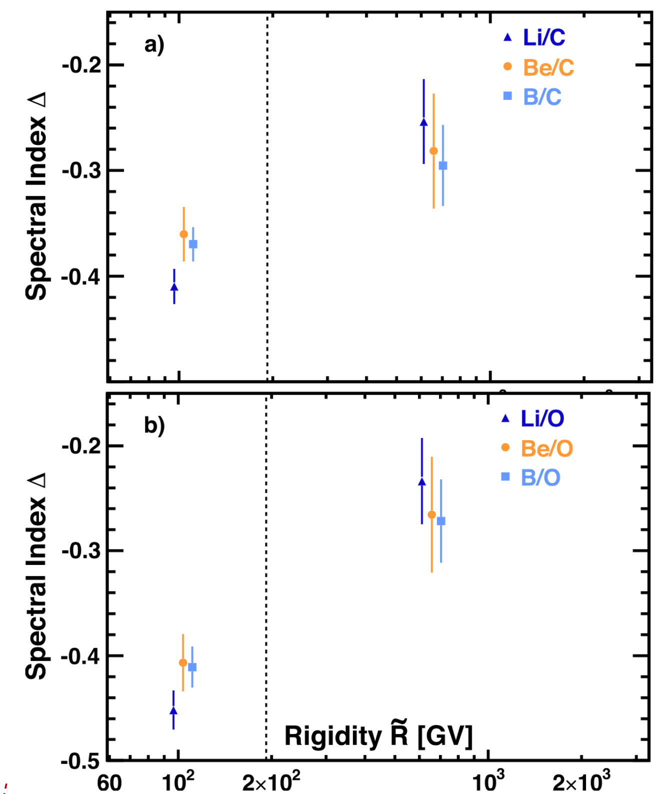
- Secondaries are produced by the collisions of primaries with the interstellar medium (ISM).

$$\Phi_S \propto \frac{\Phi_P}{K} \propto R^{-\alpha-2\delta}$$

q(R) is the source term (a power-law in rigidity)
K(R) is the diffusion coefficient (a power-law in rigidity)

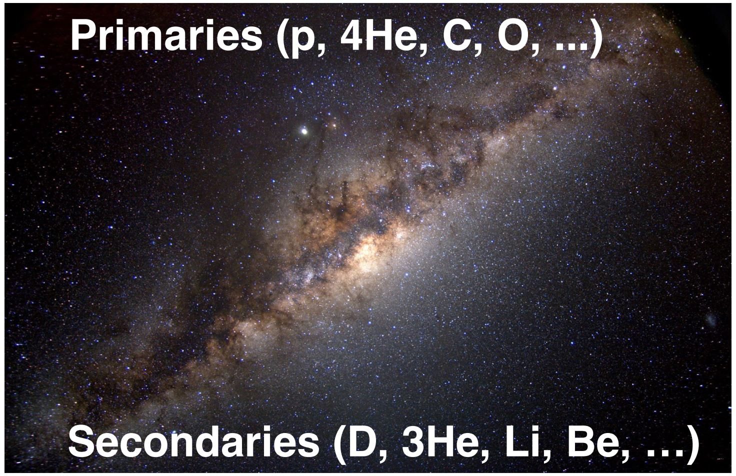


AMS provides evidence for a break in the B/C



#M. Vecchi

CR nuclei measurements



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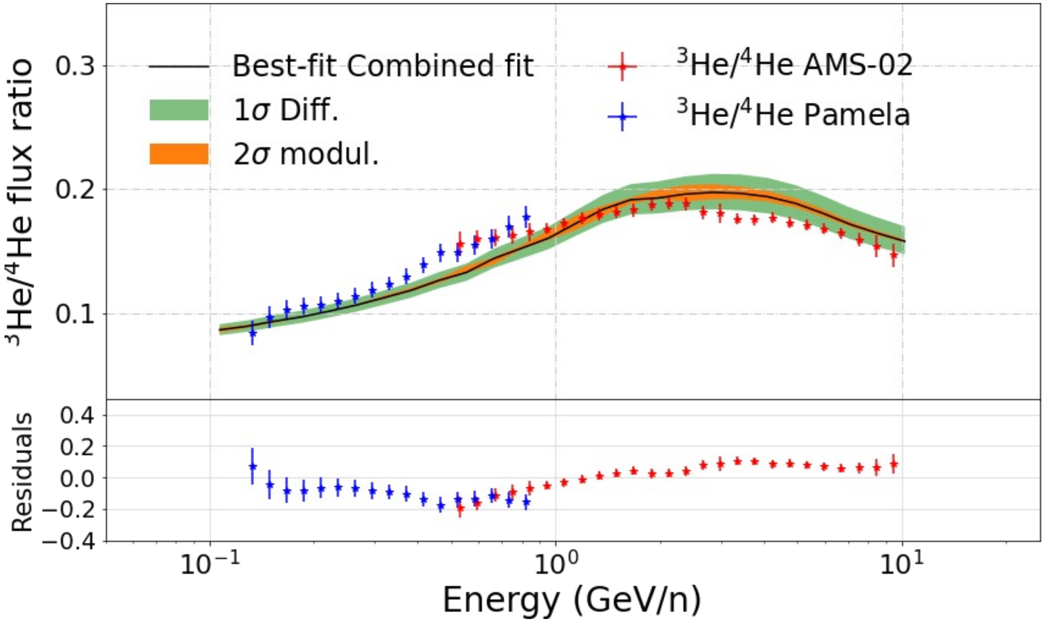
q(R) is the source term (a power-law in rigidity)
K(R) is the diffusion coefficient (a power-law in rigidity)

- Computation of cross sections is a limitation for most of the analyses of propagation of charged particles in the Galaxy

#P. de la Torre Luque



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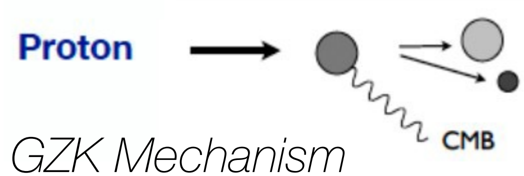
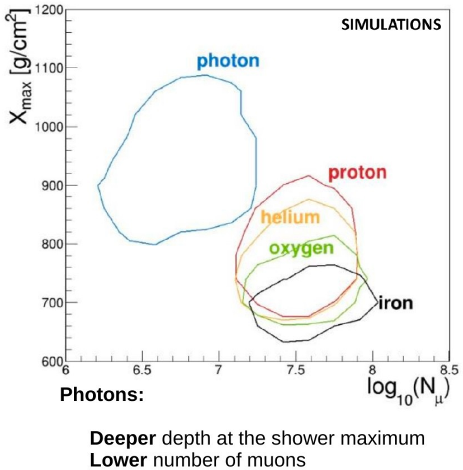
UHECR and neutral CR measurements

- Measurements of neutrals
  - expected from propagation



GZK Mechanism



- Photon shower different from CR nuclei ones
  - Larger Xmax (maximum closer to the ground)
  - Lower number of muons (but not 0 due to photo-nuclear interactions)
  - Best identification using Xmax and Nμ

UHECR and neutral CR measurements

- Measurements of neutrals
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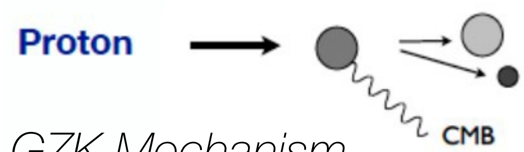

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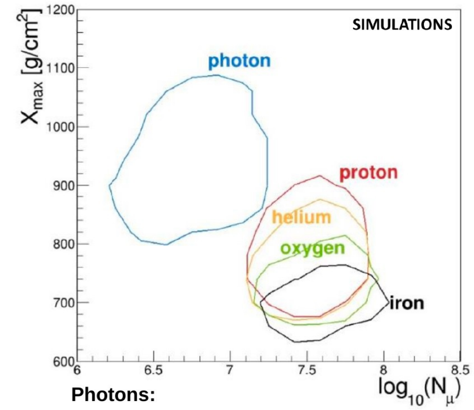

Deeper depth at the shower maximum
Lower number of muons

- Photon shower different from CR nuclei ones
  - Larger Xmax (maximum closer to the ground)
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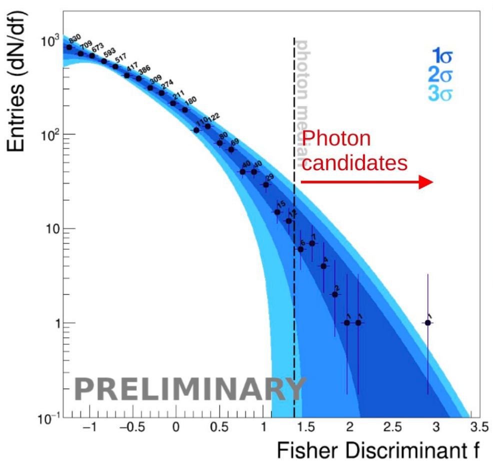
  - Best identification using Xmax and Nμ

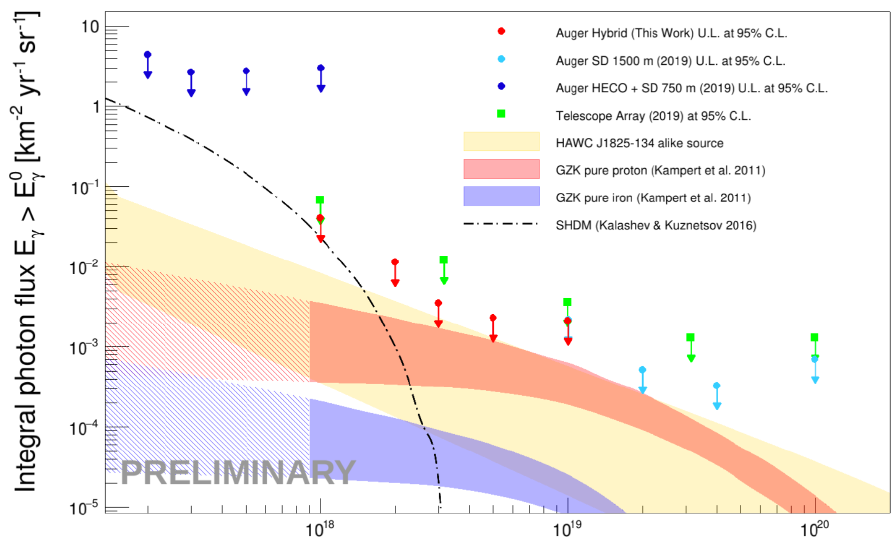


estimated events above median:
$N_{exp}(E > 10^{18.0}$ eV) = 30 ± 16

Candidates found:
$N_{obs}(E > 18.0$ eV) = 22

Median of the photon distribution derived as **photon selection cut** from the study of the background extrapolation.

Photons identified as excess with respect to the expected background



PAO starts constraining the most optimistic models of cosmogenic photon production by protons

#T. Pierog

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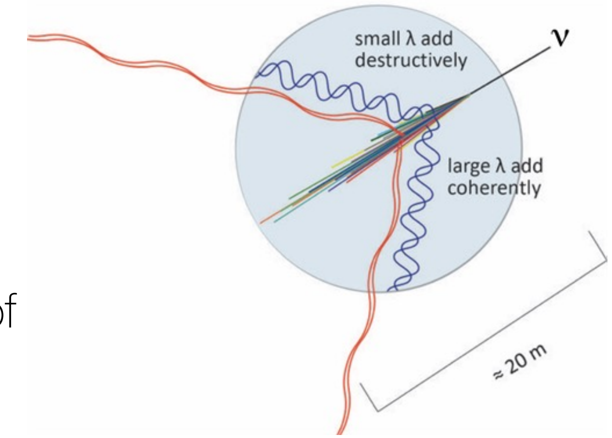
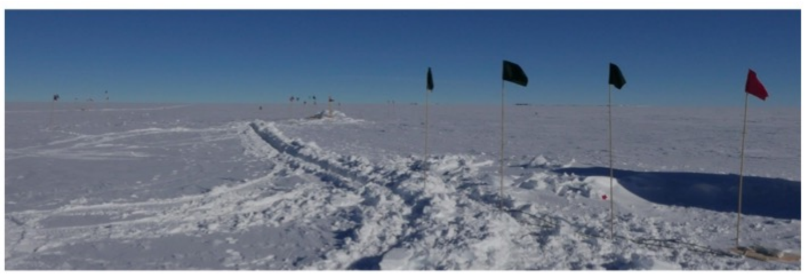
UHE neutrino search with radio

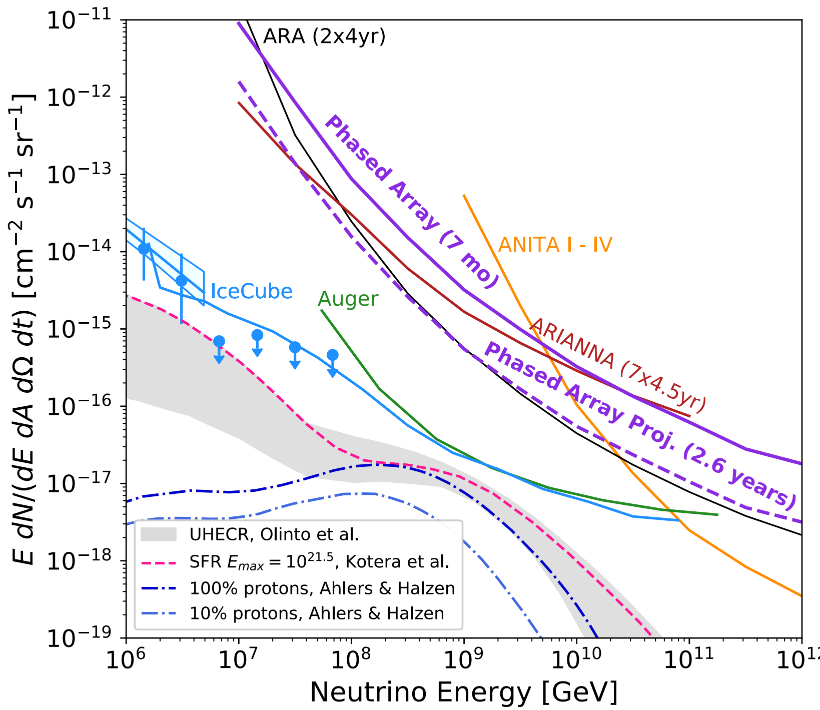


- Askaryan effect: predicted in 1960s and demonstrated in early 2000s
  - particle shower with negative charge excess
  - Cherenkov Radiation: coherent for wavelengths > lateral width of the shower
  - In ice, this coherent radiation is radio waves!
  - Radio attenuation length in ice is ~ 1 km; detectors can be sparely instrumented

- The Askaryan Radio Array (ARA)
  - 5 independent stations spaced 2 km apart
  - Located at the South Pole



  - 208 days of livetime from 2019



#K. Hughes

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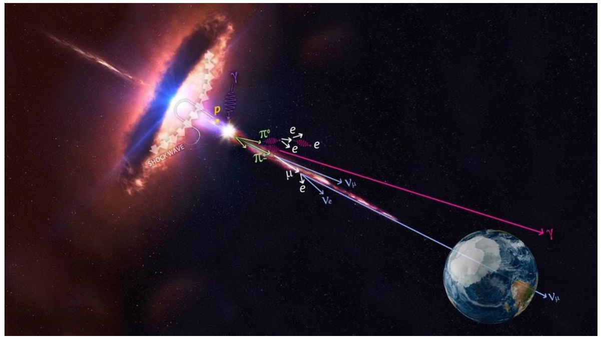
MULTI-MESSENGER ASTRONOMY

Neutrino alerts and VHE gamma-ray follow-up



- Space and time correlations would provide ”smoking gun” signal for joint emission processes
  => CR interaction/acceleration

- Neutrino alert emission
  - Event-by-event estimation of Astro probability
    - Bronze/Gold alert streams (30%/50% astrophysical probability)
  - Follow-ups by IACTs, see TXS 0506+056 for single–neutrino alert

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Neutrino alerts and VHE gamma-ray follow-up

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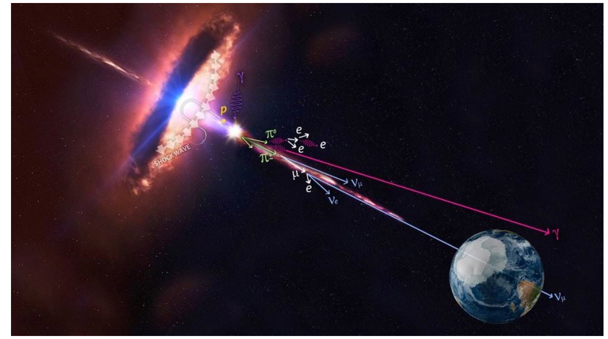
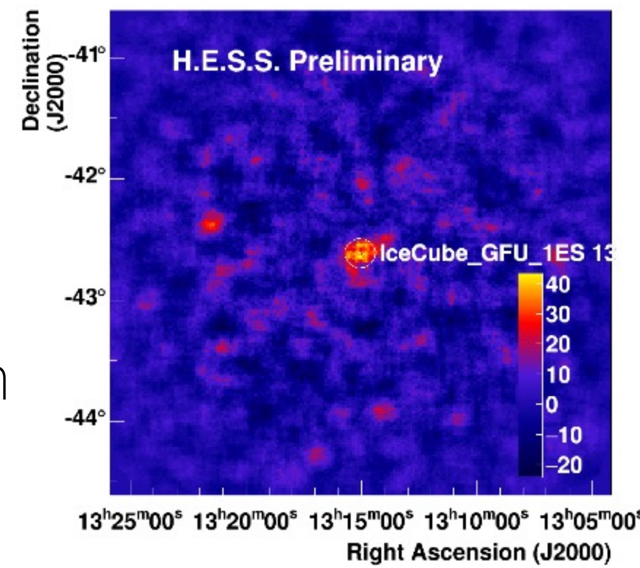


- Searches for neutrino multiplets (“flares”) in the IC online data stream
  - Neutrino multiplet from 1ES 1312-423
  - H.E.S.S. ToO observations => re-detection of the source (~4sigma)
  - No significant change in the non-thermal emission during the ToO neutrino multiplet from 1ES 1312-423

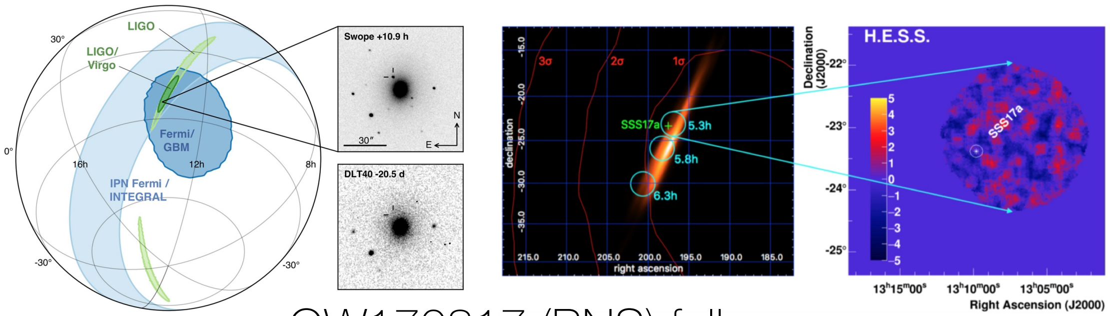


#F. Schussler

CEA - Saclay

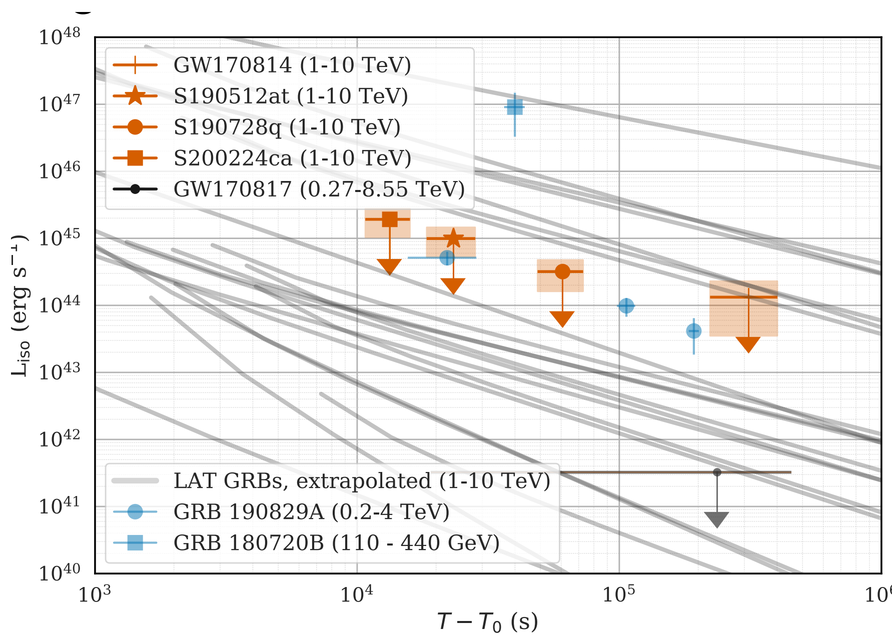
Gravitational wave follow-up with H.E.S.S.

- Since 2017 H.E.S.S successfully followed in total 5 GW events: 1 BNS and 4 BBH.



GW170817 (BNS) follow-up

- BBH follow-up
  - No significant VHE emission found for GW170814, GW190512, GW190728 and GW200224
  - Comparison with VHE GRBs: GRB 180720B & 190829A
  - GRBs could be detectable by H.E.S.S. if produced by BBH mergers
  - more prompt opportunities during O4 with deeper observations



#H. Askar

CEA - Saclay

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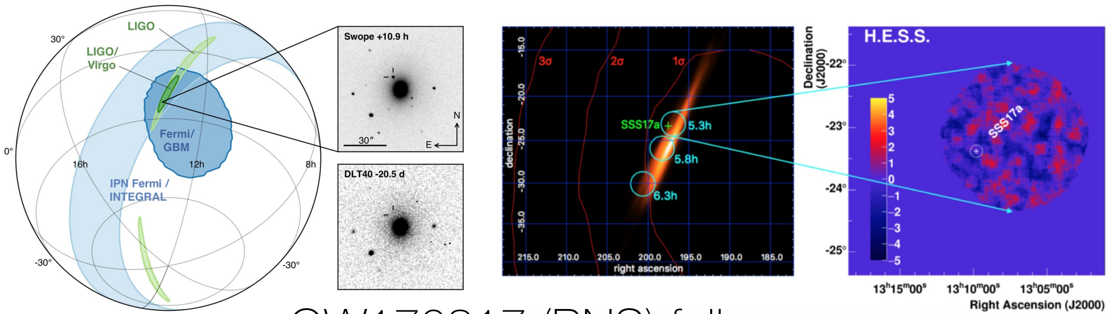

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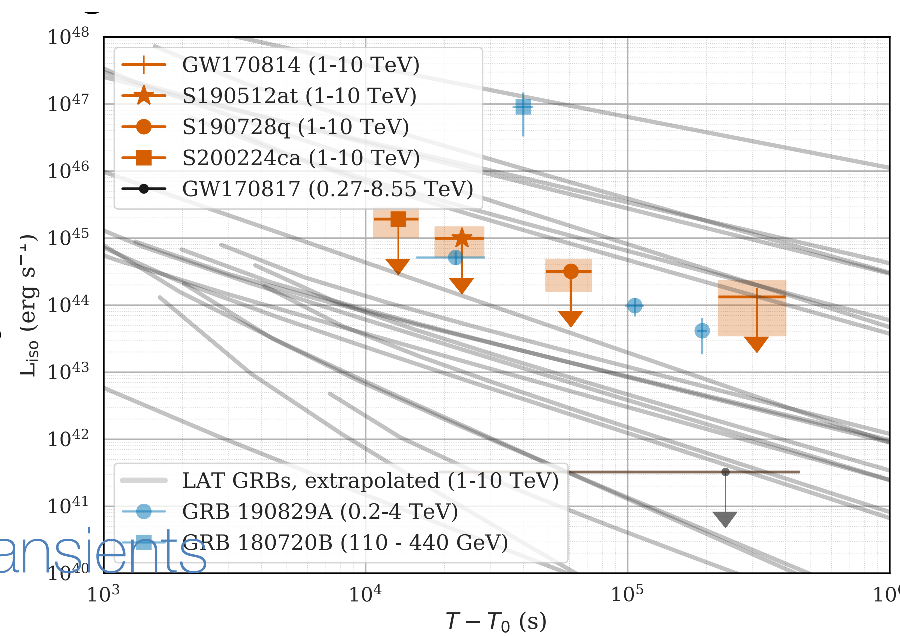


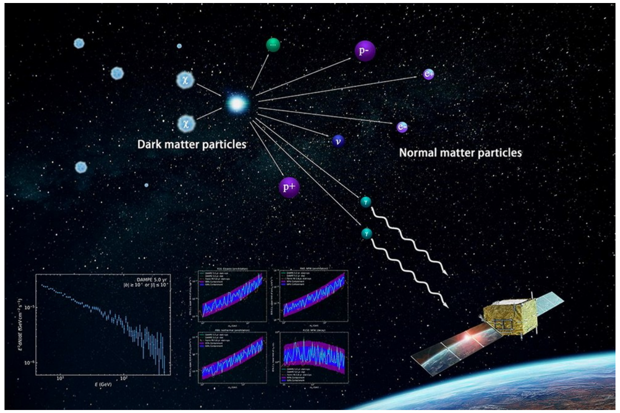
- Astro-COLIBRI for easy access to main transients

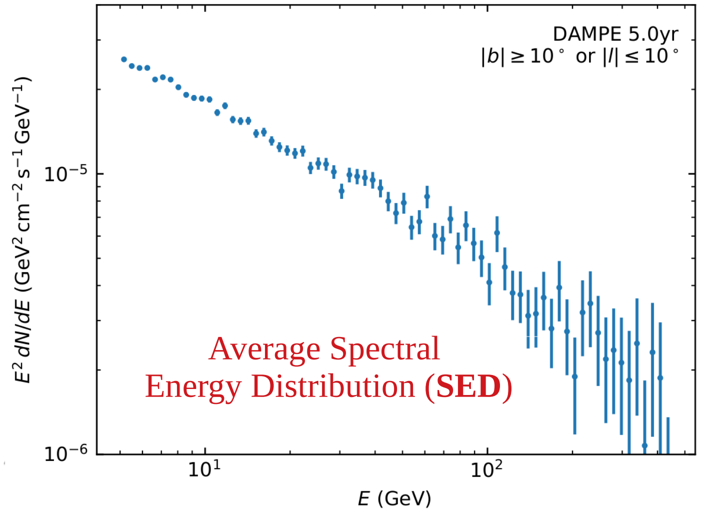
#V. Lefranc

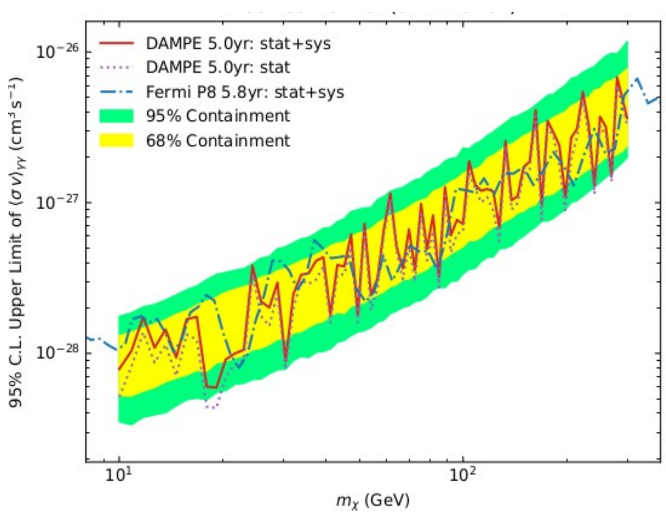
DARK MATTER

Dark matter line search with DAMPE

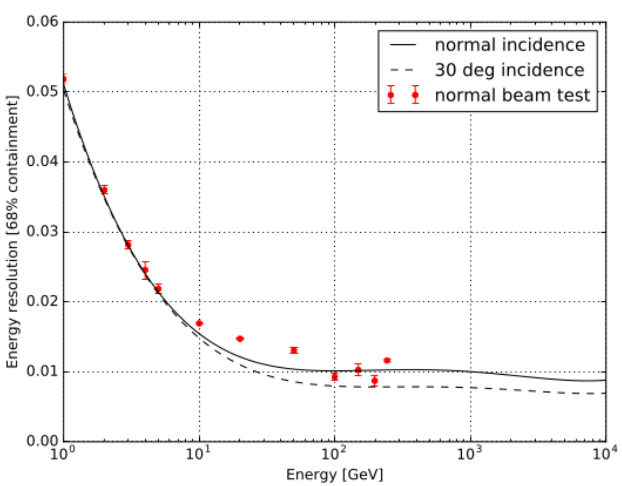
- DAMPE was successfully launched on December 17th 2015 from the Jiuquan Satellite Launch Center
- 5 years of data: 2016 – 2020, Energy range: [5 – 450] GeV, DMDM –> $\gamma\gamma$ search







DAMPE energy resolution for photons and electrons/positron ~ 1% for E>10 GeV



- No obvious line-like structure can be found
- DAMPE 5-year results comparable with 5.8-year results of Fermi-LAT

#F. Alemanno

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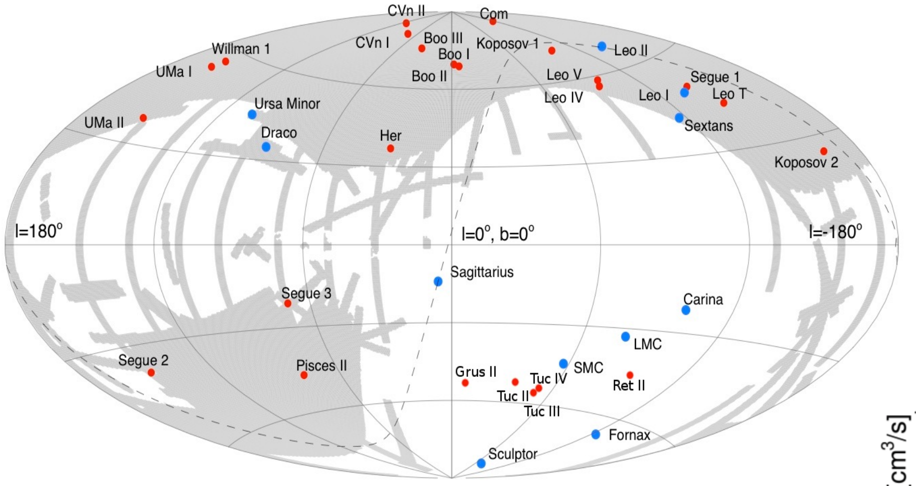
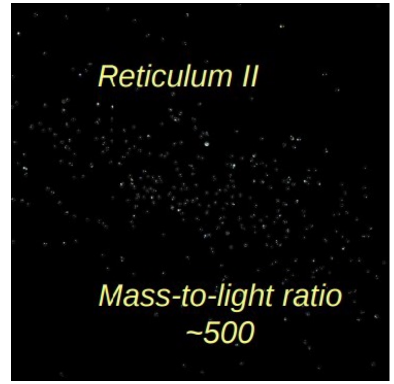
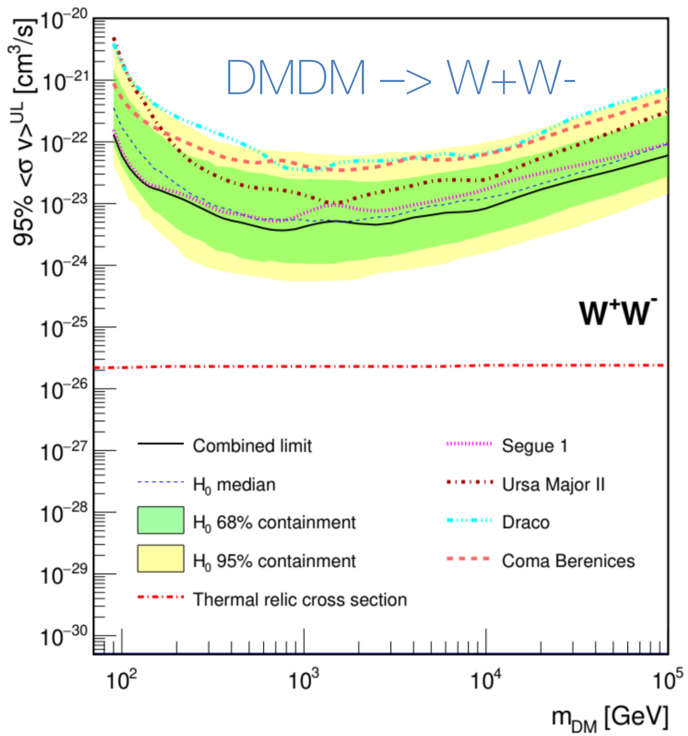
Dwarf galaxy satellites of the Milky Way



- DM-dominated objects
- No recent star formation
- Very low gas amount

→ they could give unambiguous detection





MAGIC combined analysis :
Segue 1 (158 h), Ursa Major II (95 h), Draco (52 h), and Coma Berenices (50h) with a total exposure of 355 h

- Searches on specific DM models, e.g., Wino, Higgsino, branons, …
- Combined dark matter searches towards dwarf spheroidal galaxies with Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS

#T. Miener

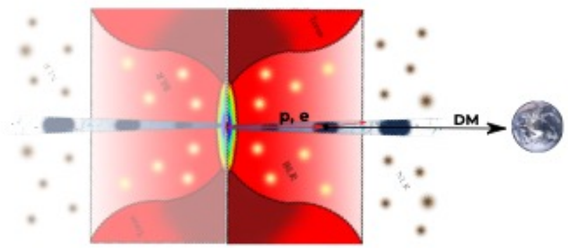
CEA - Saclay

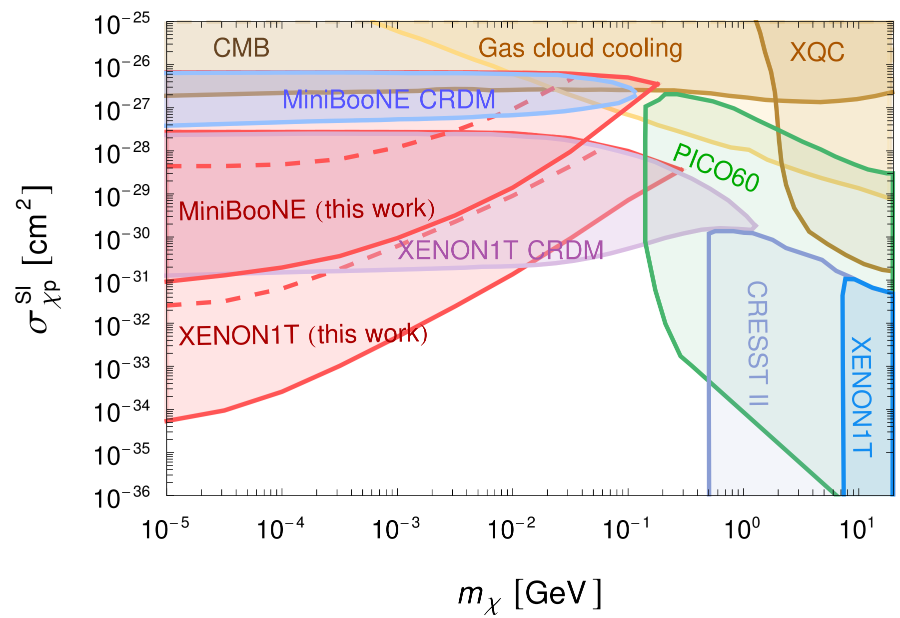
Boosted dark matter

- CR-boosted DM scenarios
  e.g., galactic Cosmic Rays (CRs) boosting local DM particle (CRDM scenario)

- Blazar-Boosted Dark Matter (BBDM):
  the possibility of protons and electrons in the jet of a blazar boosting the neighboring DM particles to Earth.
  -> constraints on the DM-proton and DM-electron cross-sections
  - Hadronic model for TXS 0506+056
  - The null detection of BBDM signals at XENON1T gives very competitive constraints on $\sigma_{\chi\text{-}p}$

#A. Granelli





Caveat : DM distribution around the SMBH of the balzar…

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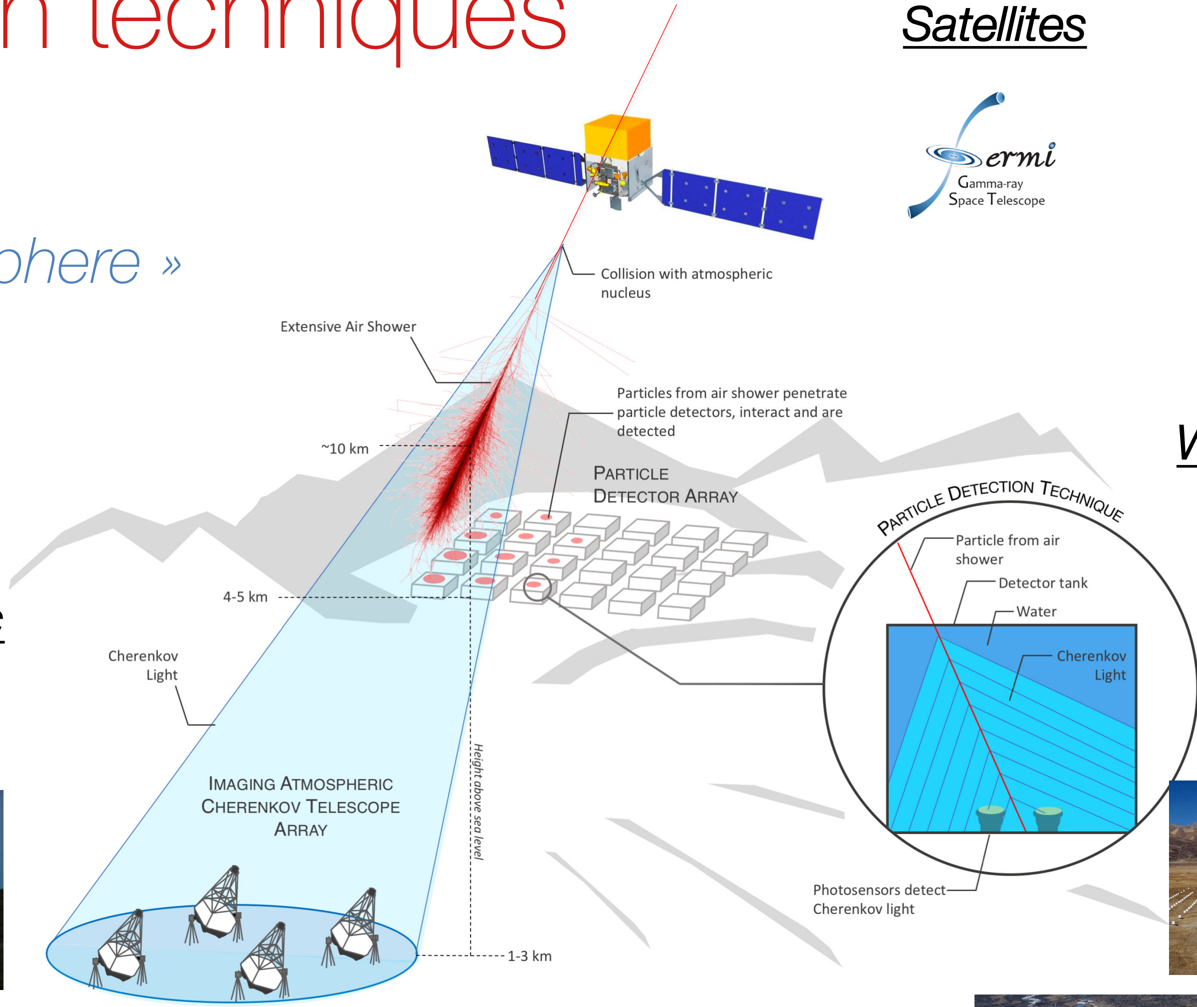
THANKS

Detection techniques

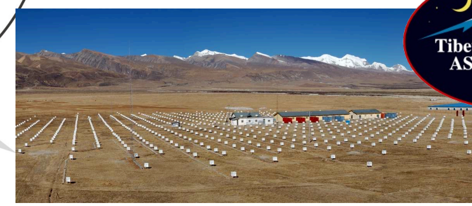
« Blocked by the atmosphere »

Satellites



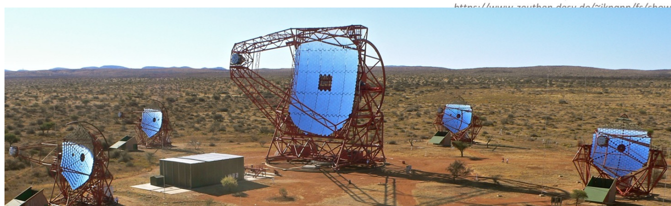
Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005,

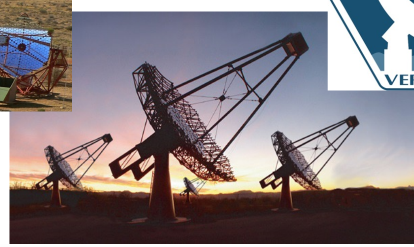
Water Cherenkov Detectors



Combination of Water Cherenkov Detectors, Scintillators

Imaging Atmospheric Cherenkov Telescopes (IACT)



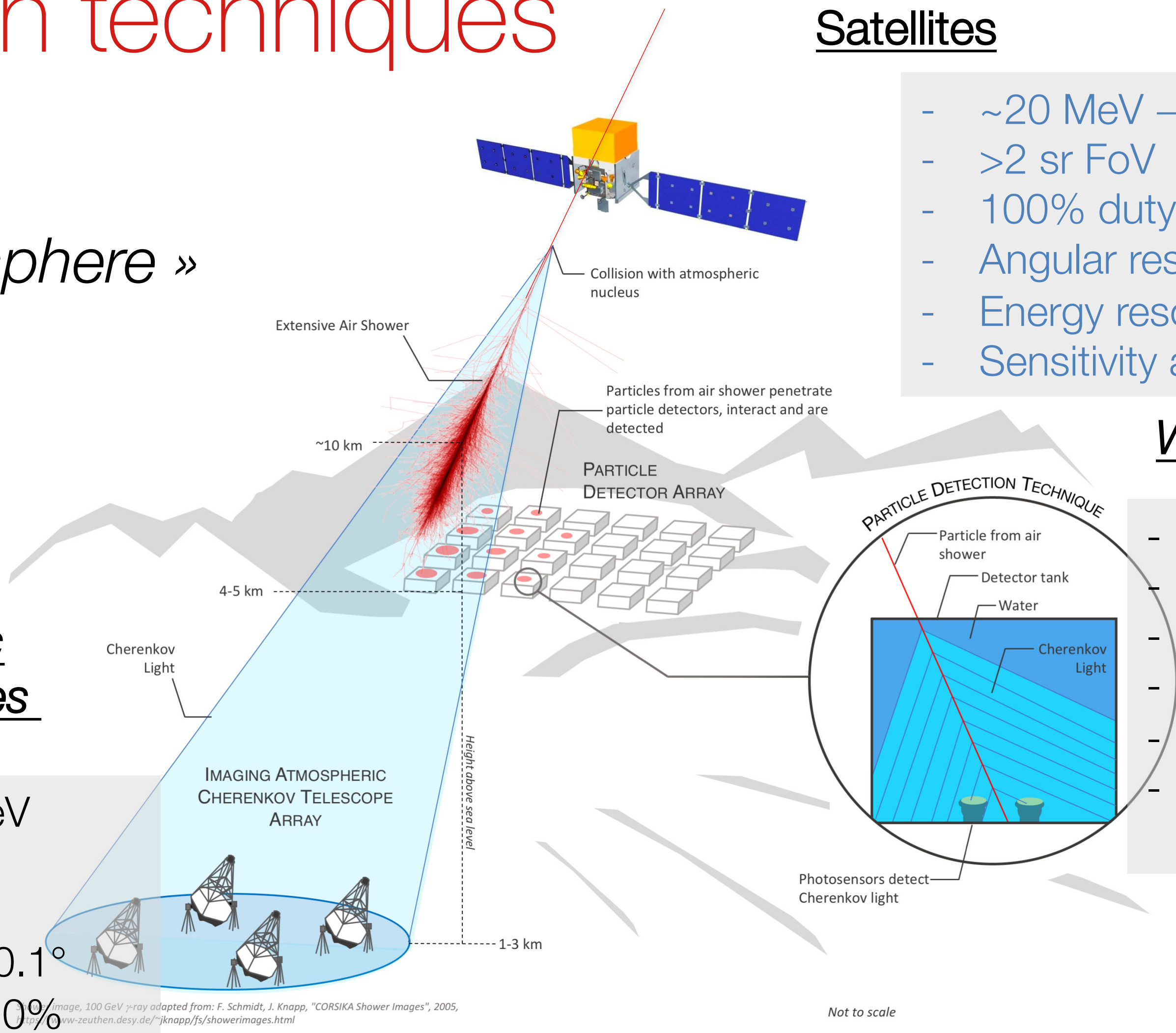


Detection techniques

« Blocked
by the atmosphere »

Satellites

- ~20 MeV → 300 GeV
- >2 sr FoV
- 100% duty cycle
- Angular resolution 0.15-3.5°
- Energy resolution ~10%
- Sensitivity a few % Crab flux



Water Cherenkov Detectors

- ~100 GeV → 1 PeV
- 90% duty cycle
- ~sr FoV
- angular resolution 0.2 - 0.8°
- energy resolution ~50%
- sensitivity 5-10% Crab flux

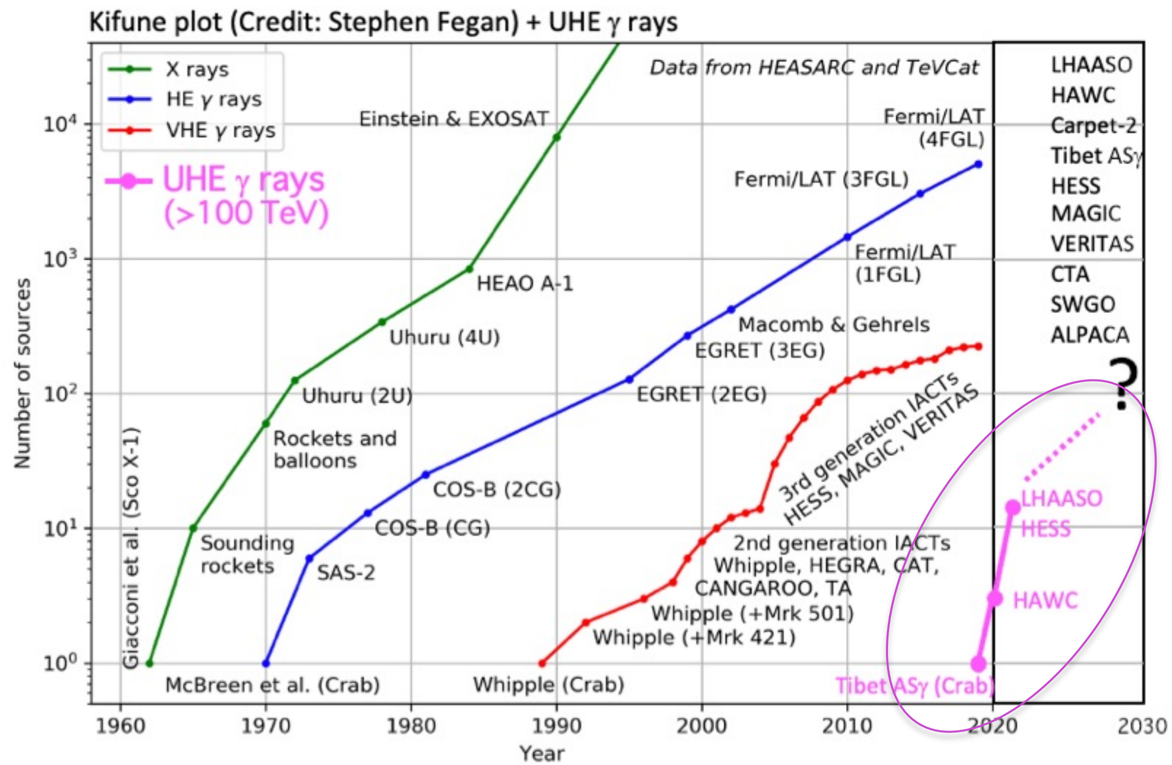
Imaging Atmospheric Cherenkov Telescopes

- ~30 GeV → ~100 TeV
- Small FoV : ~ 5°
- Duty-cycle: 10-15%
- Angular resolution <0.1°
- Energy resolution ~10%
- sensitivity 1% Crab flux

Galactic Pevatrons and VHE gamma rays

PeVatron - UHE gamma-ray source ($E_\gamma \gtrsim 100$ TeV)

- What is a PeVatron?
  - Only hadronic accelerators?
  - "Leptonic PeVatrons"?
- When is it no longer a candidate?
  - Clear accelerator
  - Confirmed hadronic
    - Coincident neutrino

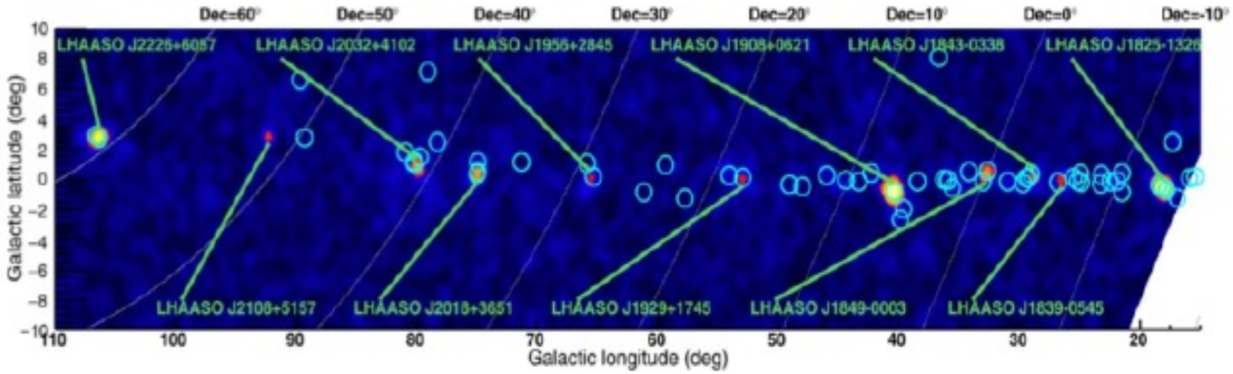


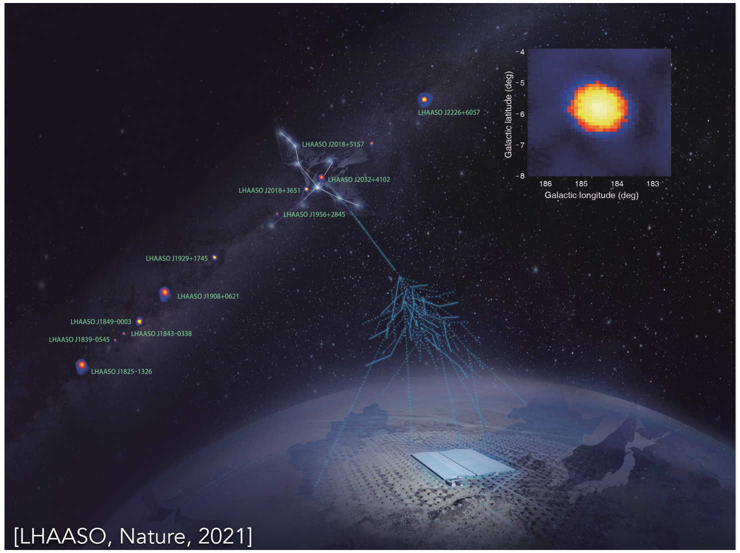
- How many PeVatrons do we know so far?

LHAASO detection of 12 Galactic Pevatrons

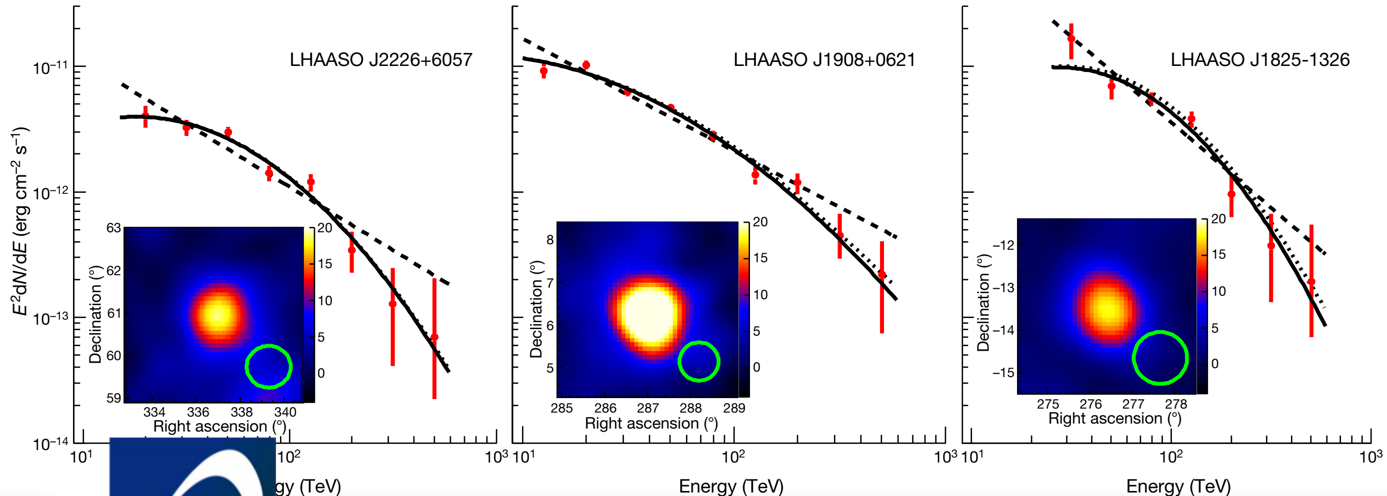
- 12 sources at > 0.1 PeV
- TeV-PeV gamma rays from unidentified sources

LHAASO sky map at energies above 100 TeV:





[LHAASO, Nature, 2021]



- Three brightest sources show no sign of cut-off – PeVatrons
- Extreme accelerators, proton-vs-elecron origin not settled yet

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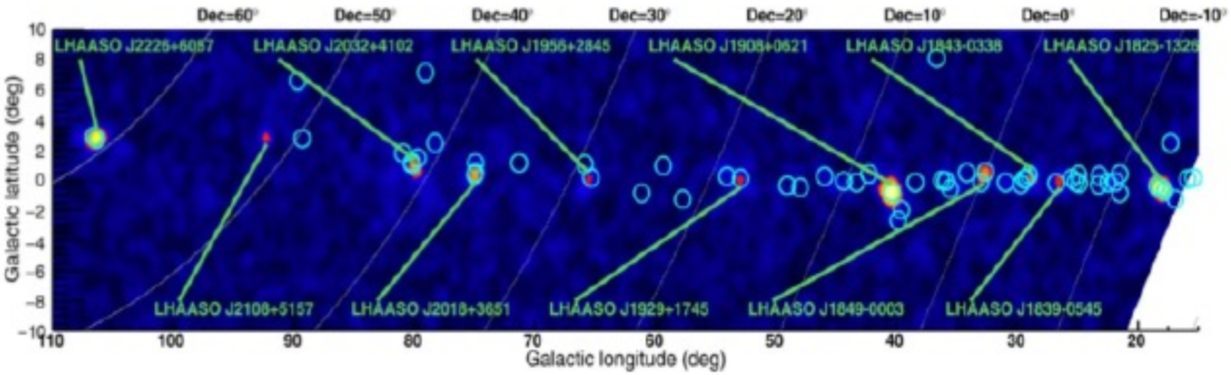
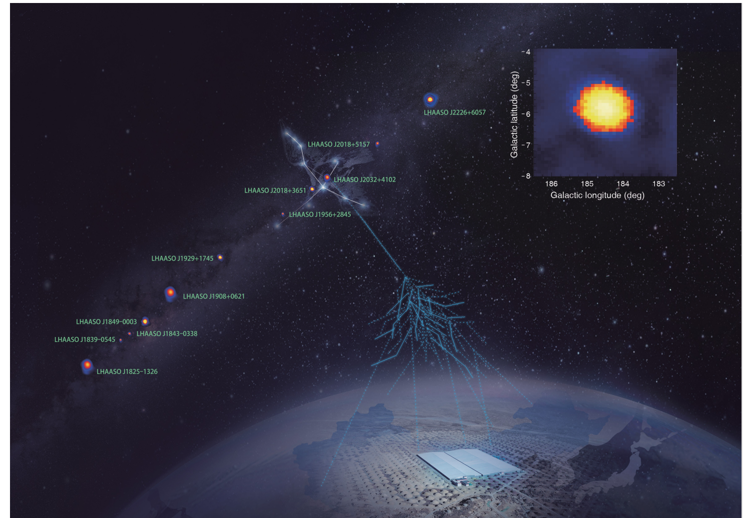
LHAASO detection of 12 Galactic Pevatrons

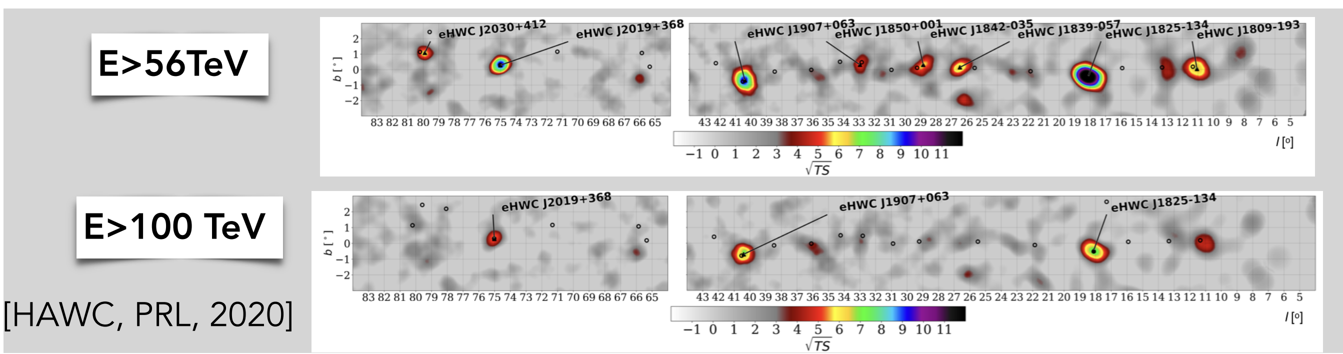
- LHAASO detected 12 sources at > 0.1 PeV
- TeV-PeV gamma rays from unidentified sources



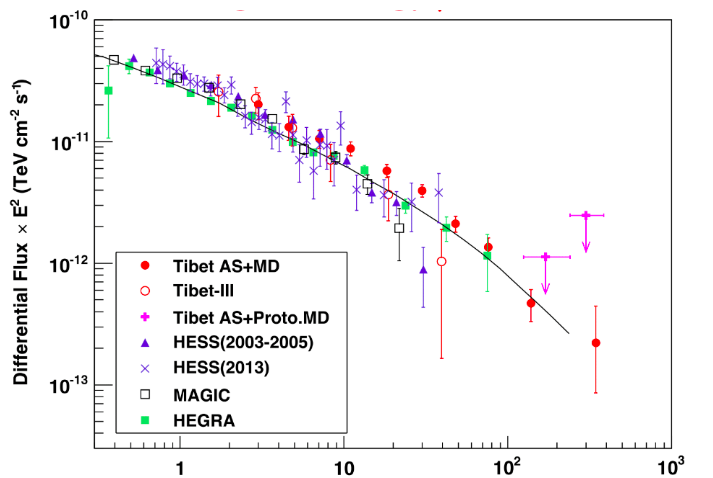


[LHAASO, Nature, 2021]

- Gamma rays >100 TeV also observed by HAWC, Tibet ASg



[HAWC, PRL, 2020]



Amenomori et al., PRL (2

- 9 Sources seen by Tibet ASg coincident with LHAASO UHE sources

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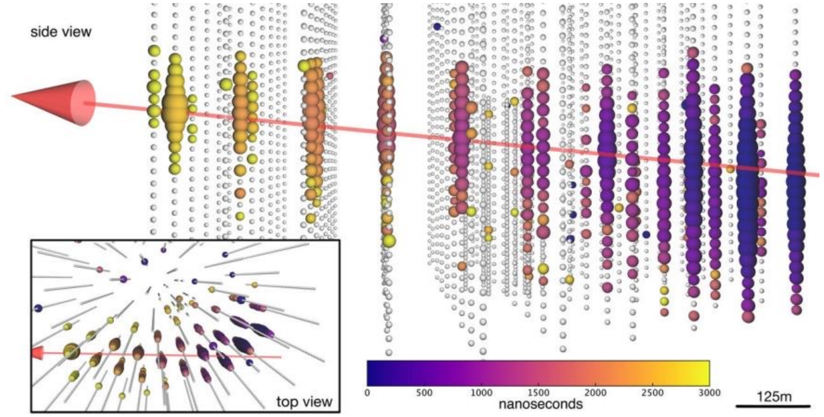
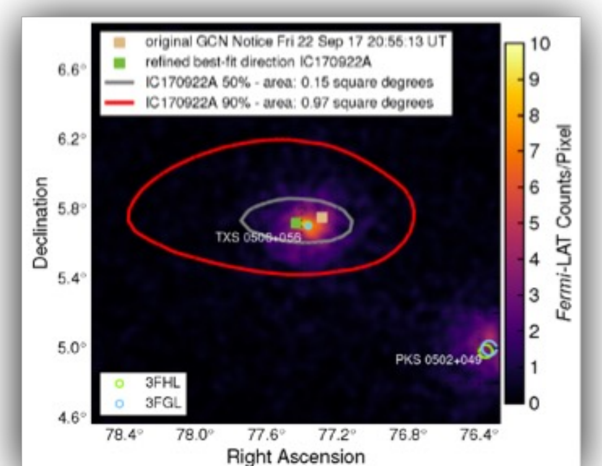
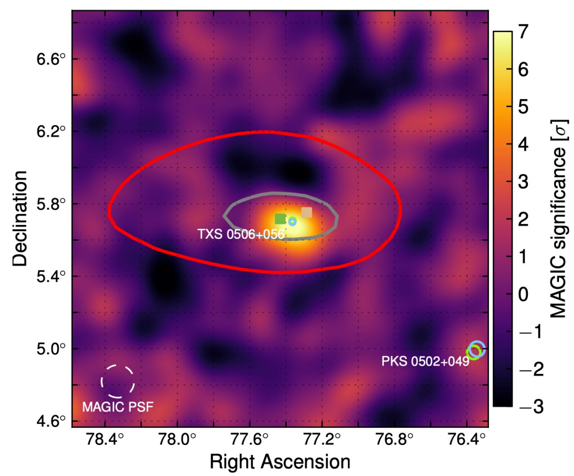
Multi-messenger extragalactic astronomy

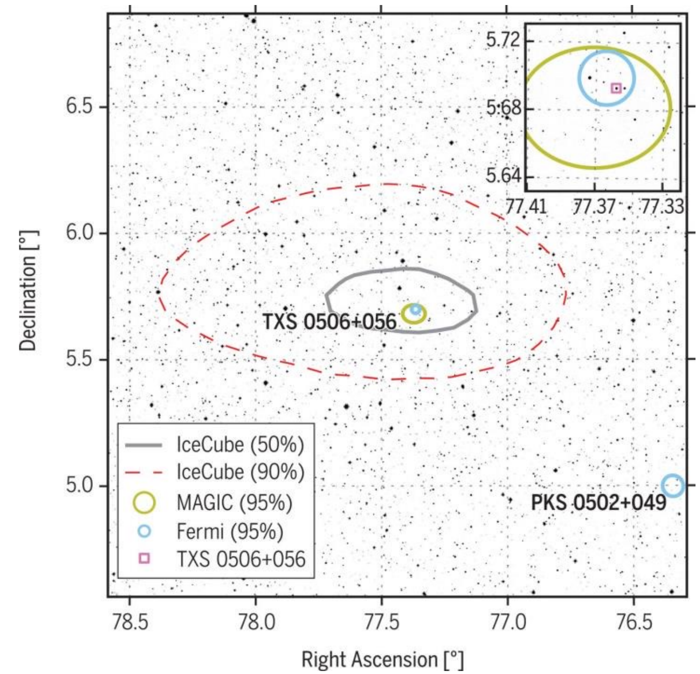
- 2017: a neutrino with energy ~290 TeV (IC170922) detected in coincidence with the balzar TXS 0506+056 during enhanced gamma-ray activity



- Follow-up observations by a myriad of instruments: Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/NuSTAR, VERITAS, VLA, ...







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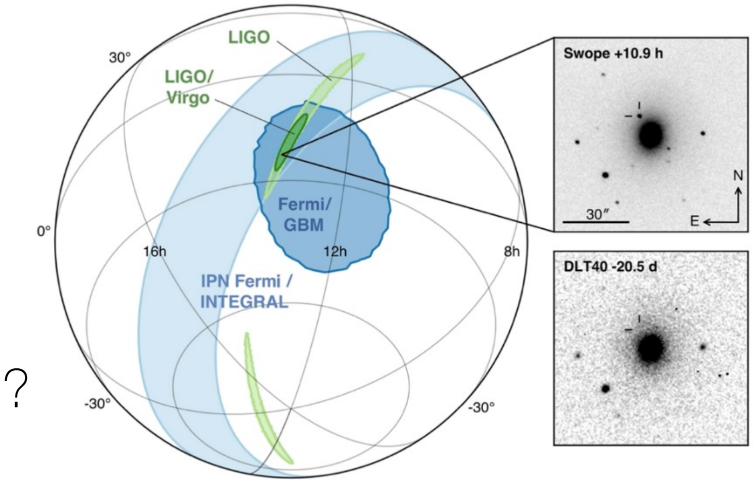
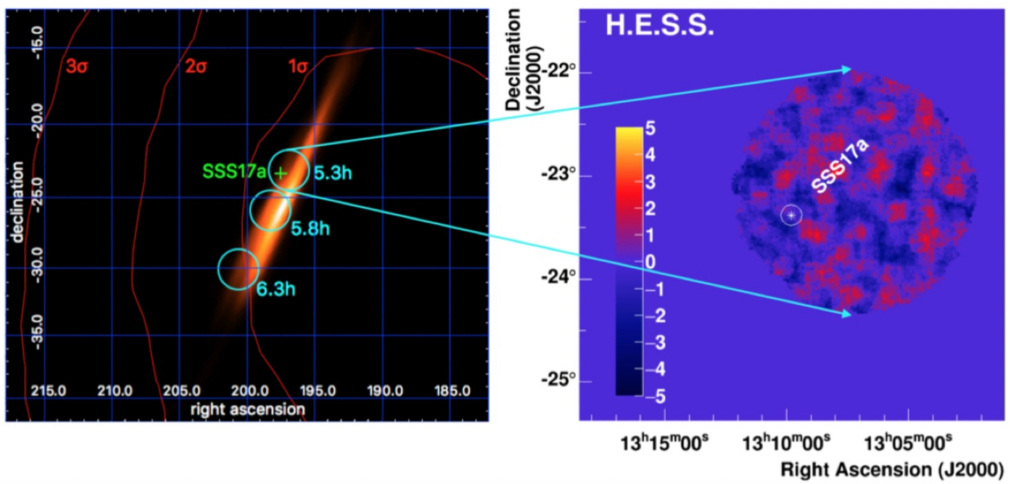
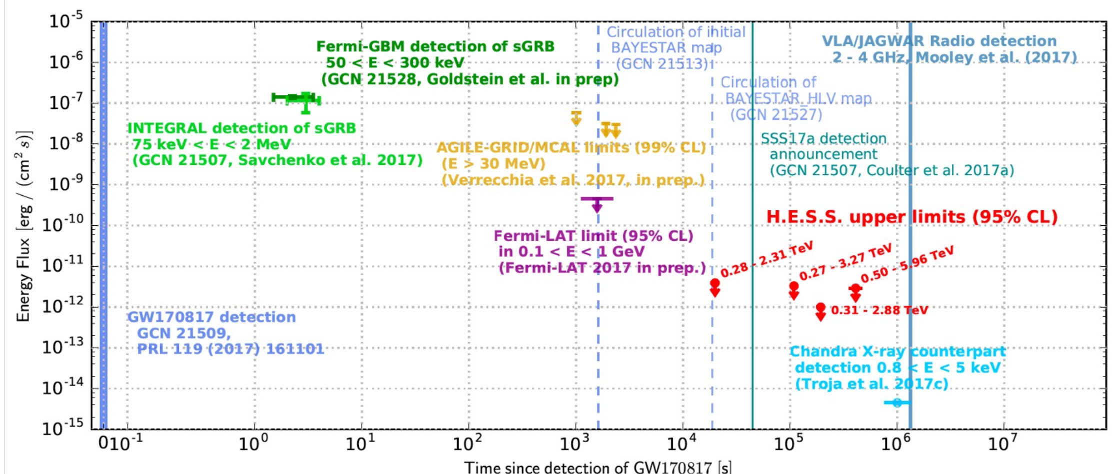
Compact binary merger follow-up

- LIGO GW170817: smoking gun – relation between GW events (BNS mergers) and short GRBs
  - First joint detection EM and GW
  - Associated with GRB 170817A
  - Possible other EM counterpart : AT2017gfo ?



- Short term follow-up: stringent upper limits on the VHE emission from a BNS merger





See H. Ashkar talk@VHEPU 2022

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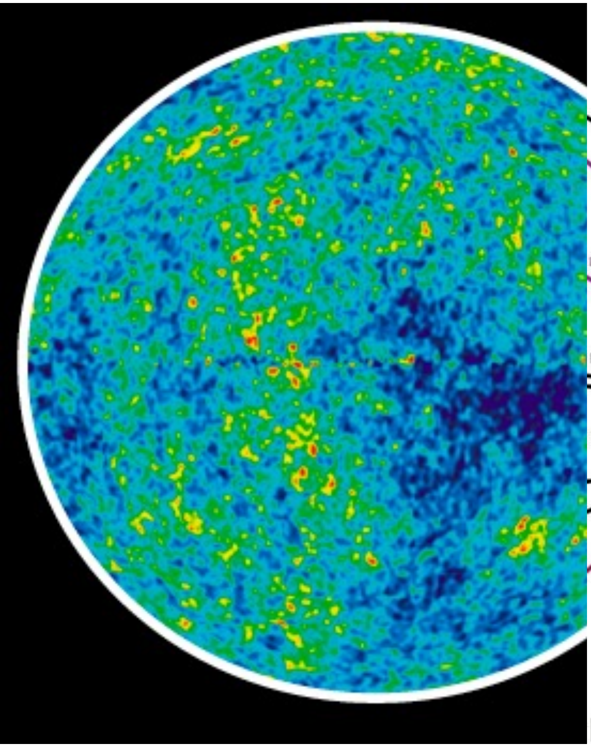
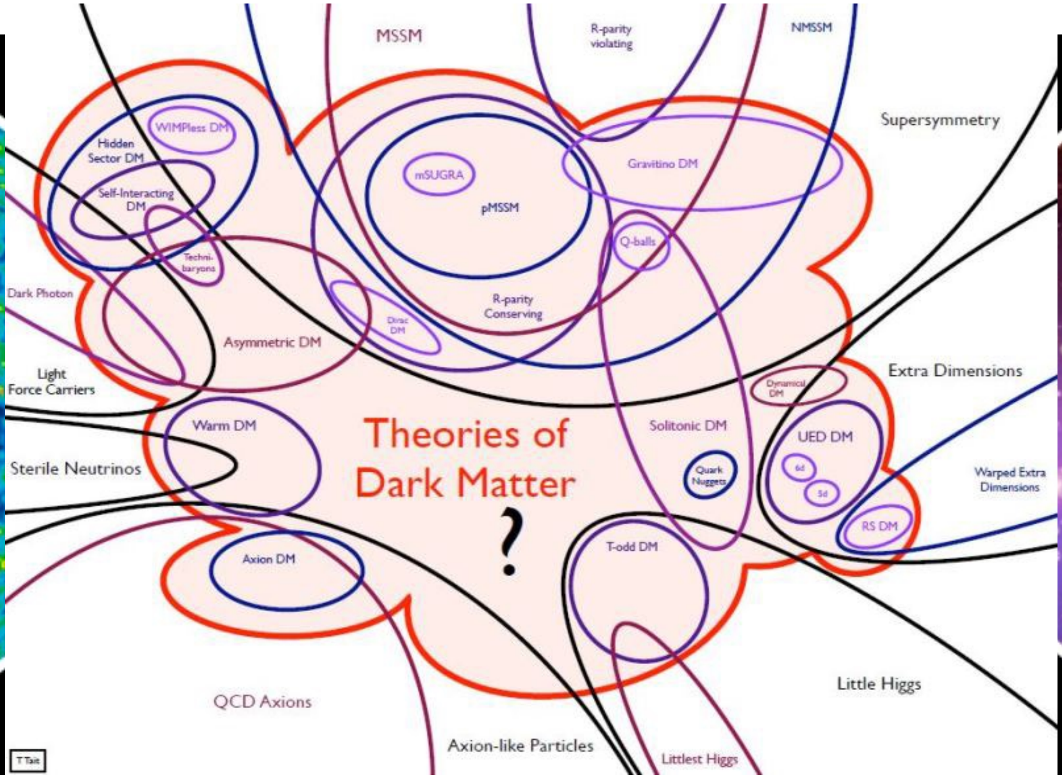
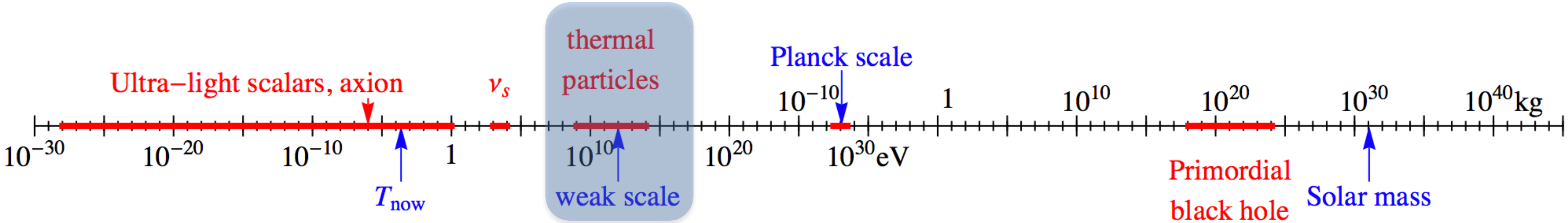
Dark Matter : what we don't know







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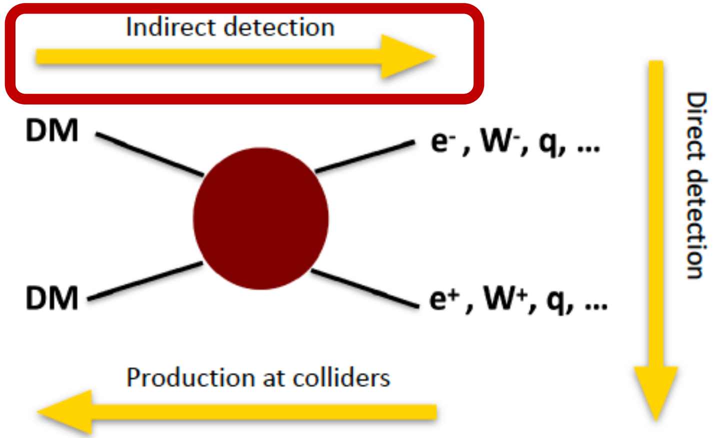
Dark Matter - search in VHE gamma rays

- Classical WIMP searches



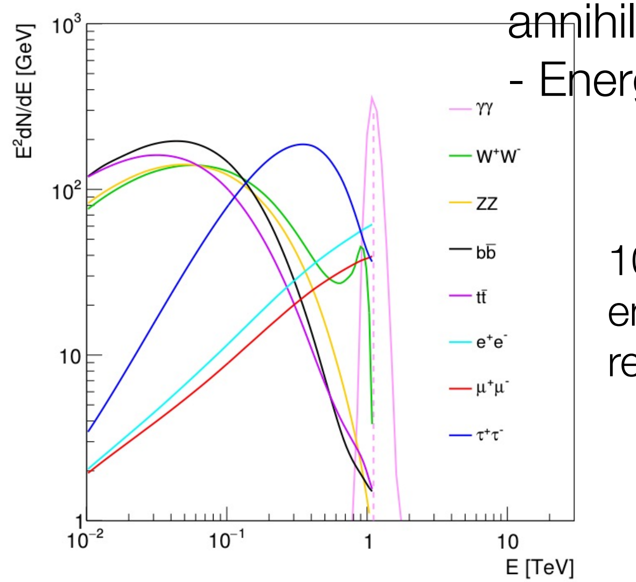
- Many realisations in BSM : Wino, Higgsino, …
- Look for Standard Model particles - electrons/positrons, photons, neutrinos, protons/antiprotons - produced when DM particles collide or decay.

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{DM}^2}\frac{dN_\gamma}{dE_\gamma} \times \int_{\Delta\Omega} d\Omega \int_{l.o.s} \rho^2(r[s])ds$$

Particle physics:

- Cross sections
- Differential photon yield
- DM particle mass

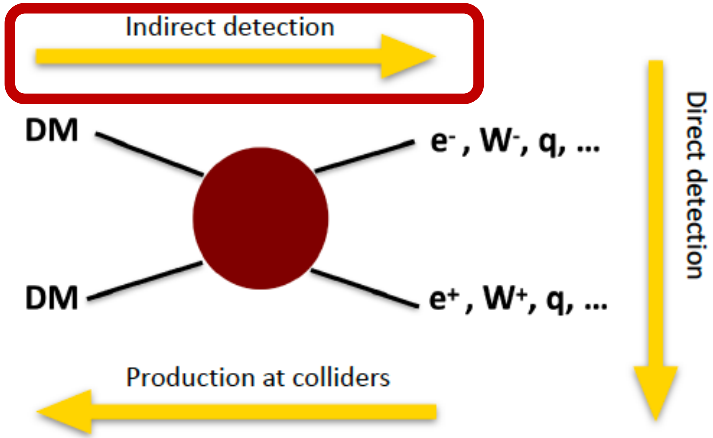
Annihilation spectra for m_{DM}=1 TeV per annihilation
- Energy cutoff at m_{DM}



10% energy resolution

Dark Matter - search in VHE gamma rays

- Classical WIMP searches



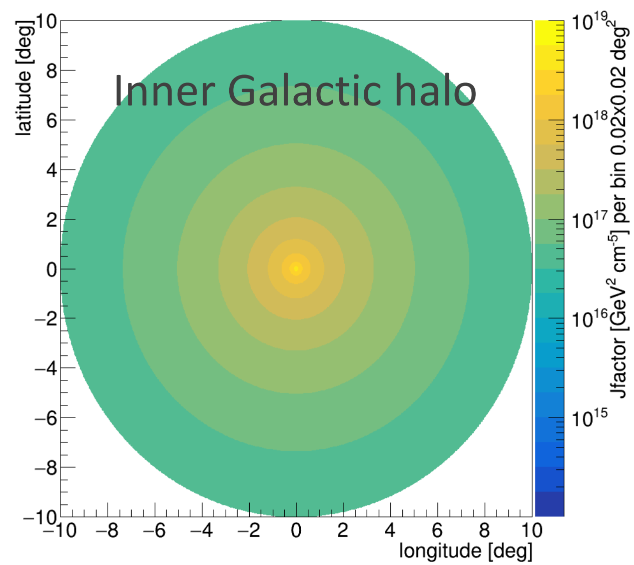
$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{4\pi}\frac{\langle\sigma v\rangle}{2m_{DM}^2}\frac{dN_\gamma}{dE_\gamma} \times \int_{\Delta\Omega} d\Omega \int_{l.o.s} \rho^2(r[s])ds$$

Astrophysics: J-factor

$$J(\Delta\Omega) = \int_{\Delta\Omega}\int_{\rm los} \rho^2(r(s,\theta))\mathrm{d}s\mathrm{d}\Omega.$$

depends on the DM density distribution ρ in the object :

- Look for Standard Model particles - electrons/positrons, photons, neutrinos, protons/antiprotons - produced when DM particles collide or decay.



Dark Matter targets in VHE gamma rays

Aquarius, Springel et al. Nature 2008

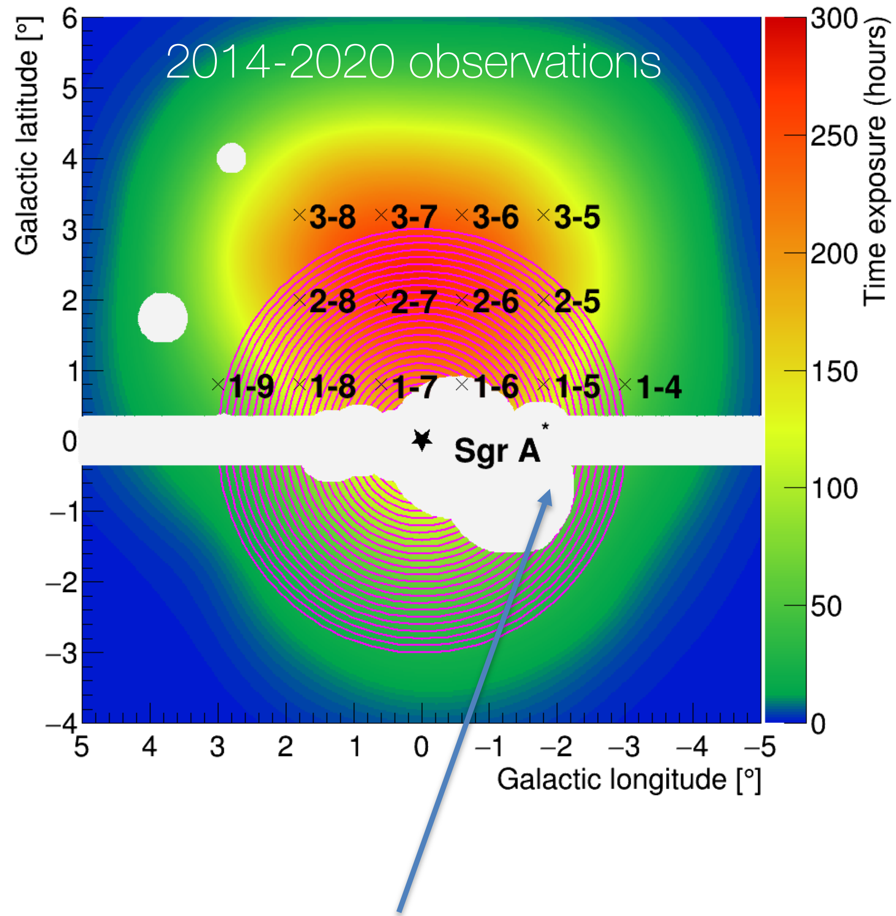
→ Maximize the quantity of DM signal (close distance and large DM density) wrt background (astrophysical sources)

Central region of the Milky Way

- H.E.S.S. is performing a survey of the inner few degrees of the Galactic Centre region since 2015
  - → provide unprecedented sensitivity to dark matter
  - → study in greater details the central diffuse emission
  - → search for TeV outflows from the Galactic Centre

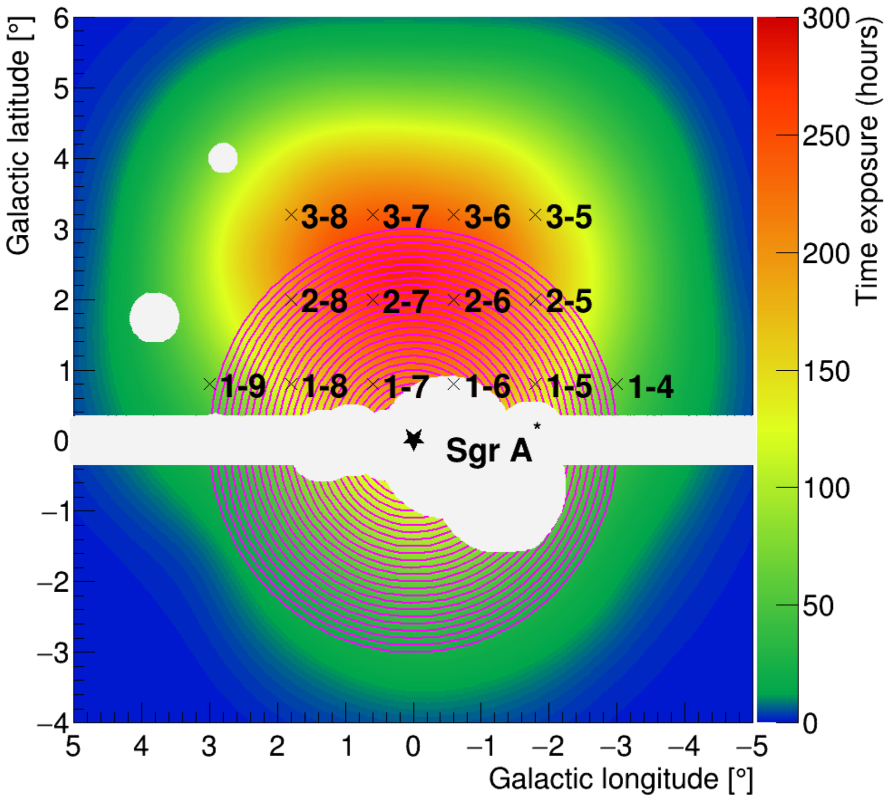
- The first ever conducted VHE gamma-ray survey of the Galactic Center (GC) region.

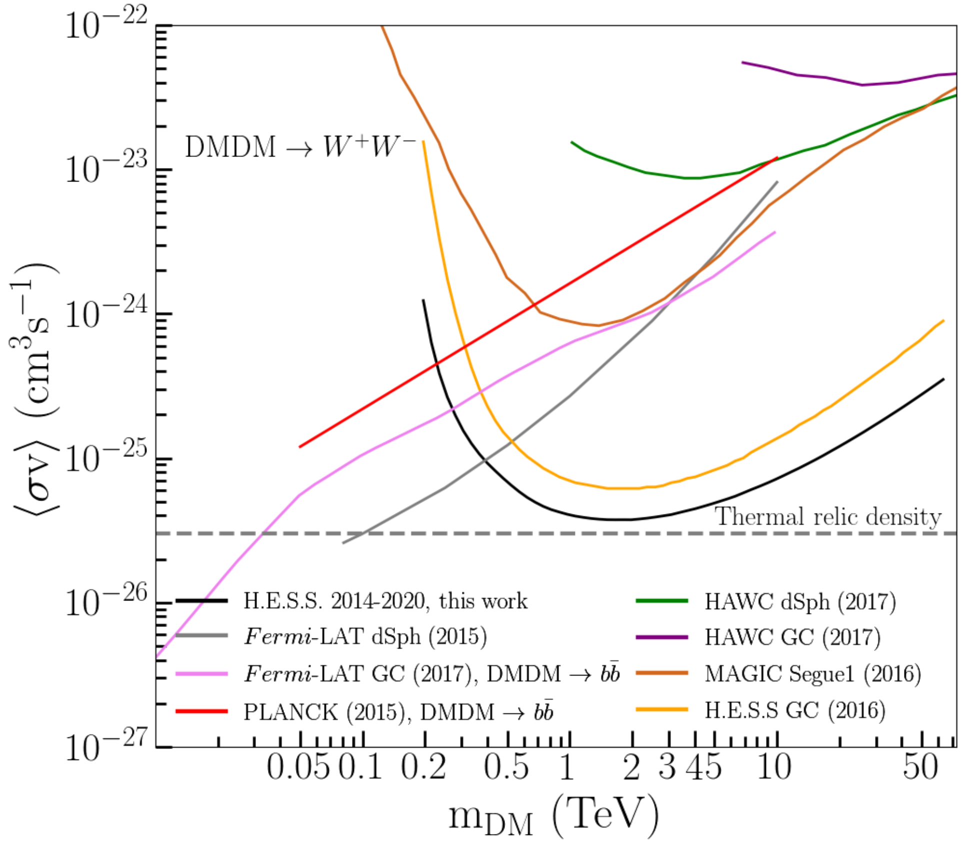
- 2014-2020 exposure map with IGS pointing positions: exposure up to b ≈ 6°;



Set of exclusion regions for DM search to mask conventional gamma-ray emission

Central region of the Milky Way

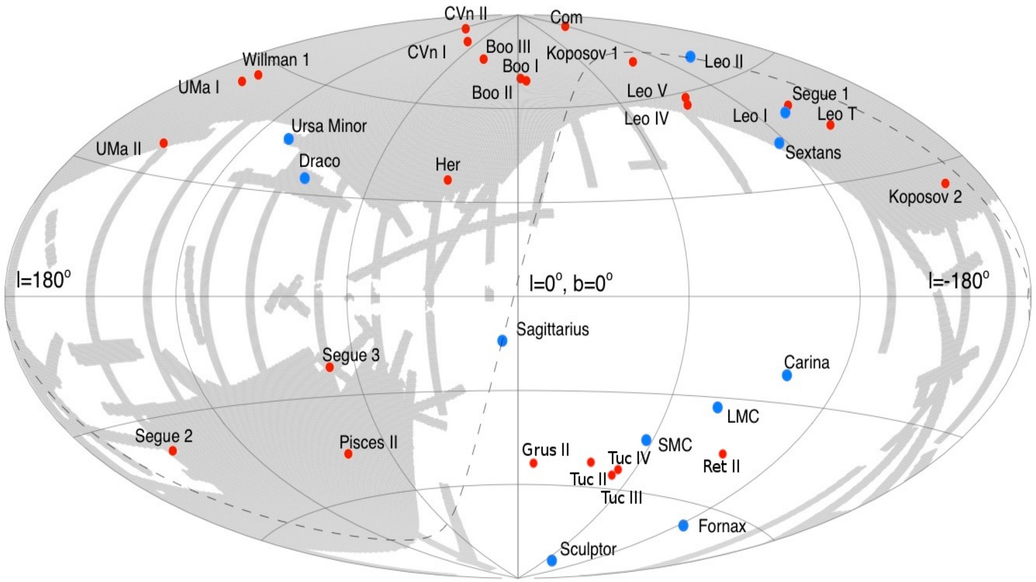




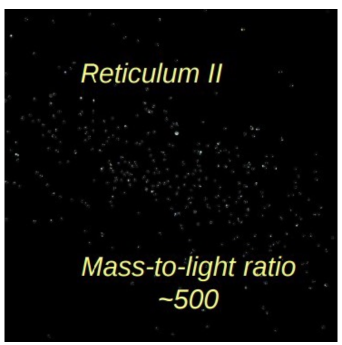
- Comparison with Fermi-LAT dSph and GC, HAWC dSph and GC, MAGIC Segue 1, PLANCK CMB, H.E.S.S. GC (2016) and this work.

→ Most constraining limits in the TeV-mass range

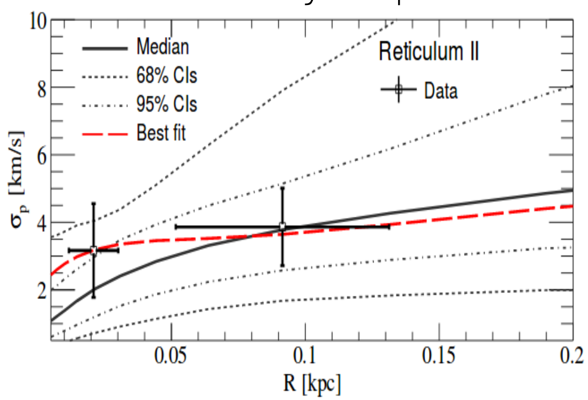
Dwarf galaxy satellites of the Milky Way

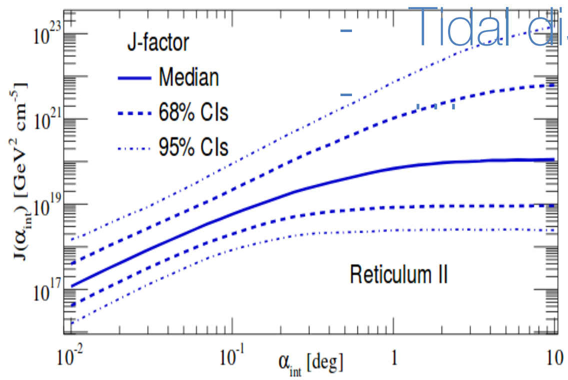


- Determination for the ultra-faint dwarf spheroidal galaxy Reticulum II:



Stellar velocity dispersion -> large J-factor

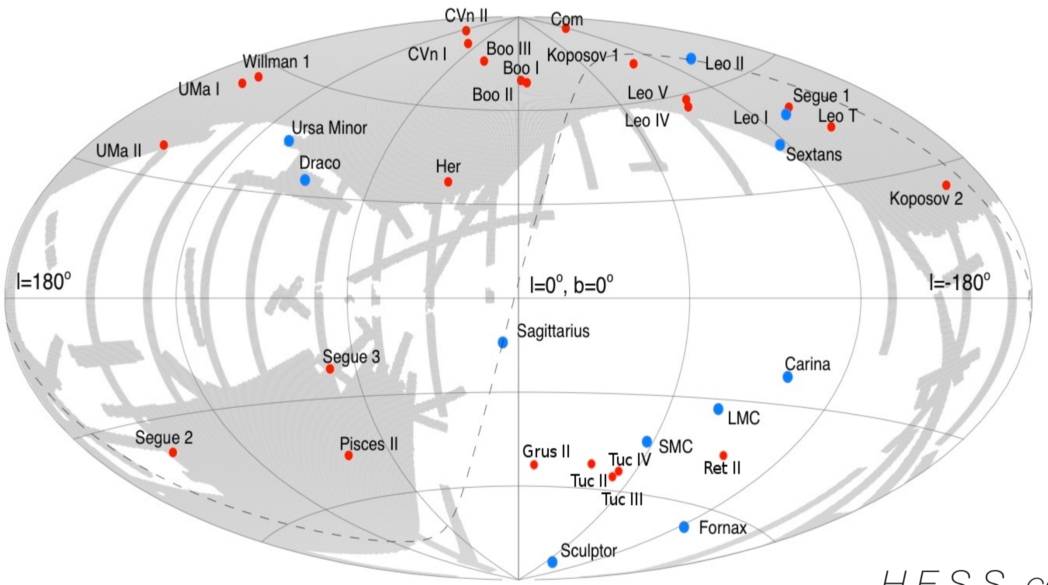




- Modelling of the DM distribution:
  - Pressure-supported systems
  - Use of kinematic tracers of the gravitational potential
  - Works very well in the DM-dominated environments, e.g., dwarf galaxies, via the Jeans equation modelling
- J-values discussion:
  - Impact of triaxiality on halos
  - Stellar membership probability
  - Multiple stellar population
  - Tidal disruption

Evans et al., PRD 69, 123501 (2004)

Dwarf galaxy satellites of the Milky Way



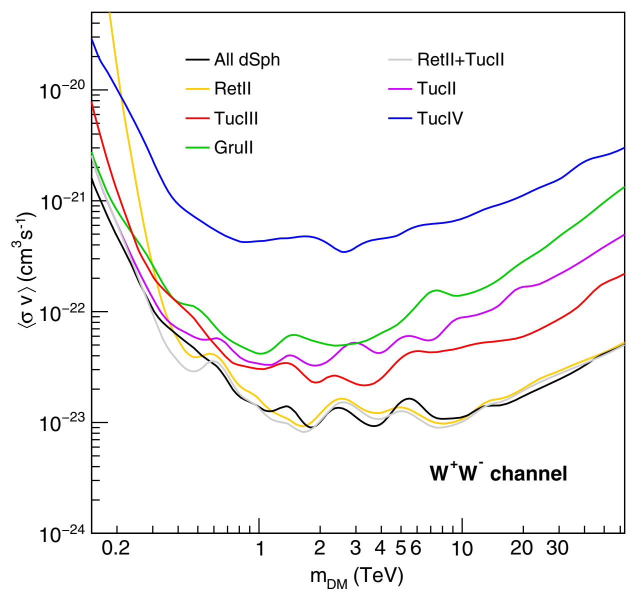
H.E.S.S. observations – 80 hours

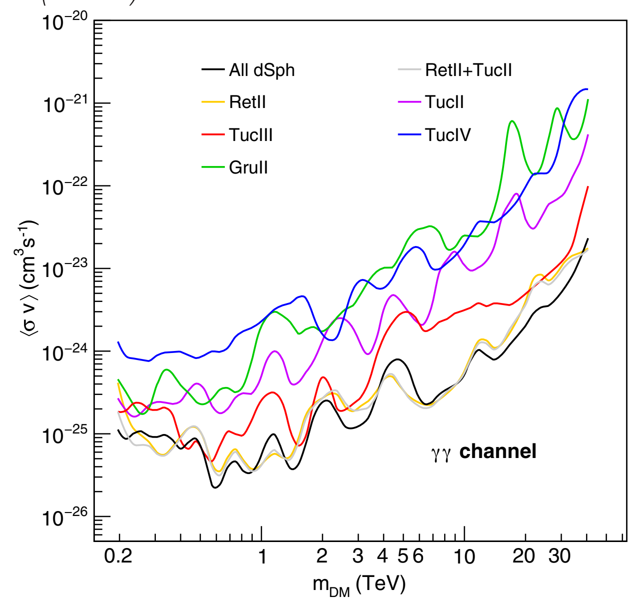
- A selection of Milky Way ultra-faint satellites by the Dark Energy Survey (DES)

- Some without spectroscopic J-values

H.E.S.S. coll. Phys. Rev. D 102, 062001 (2020)

Stacking datasets of Ret. II, Tuc; II. Tuc; III, Tuc. IV, and Grus II from H.E.S.S. observations

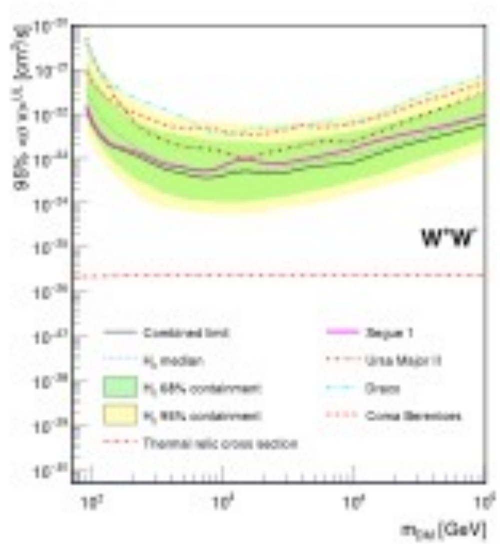




Dwarf galaxy satellites of the Milky Way

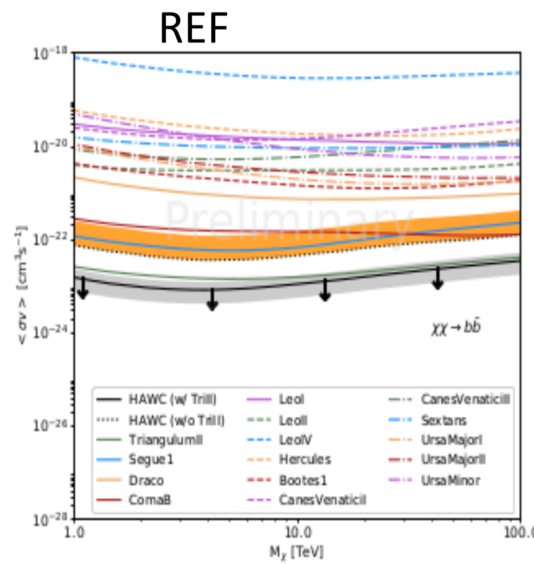
MAGIC observations of 4 dSphs:
Segue 1, Ursa Major II, Draco, Coma Berenices

- A combined analysis of 4 dSph datasets for a total of 354.3 h

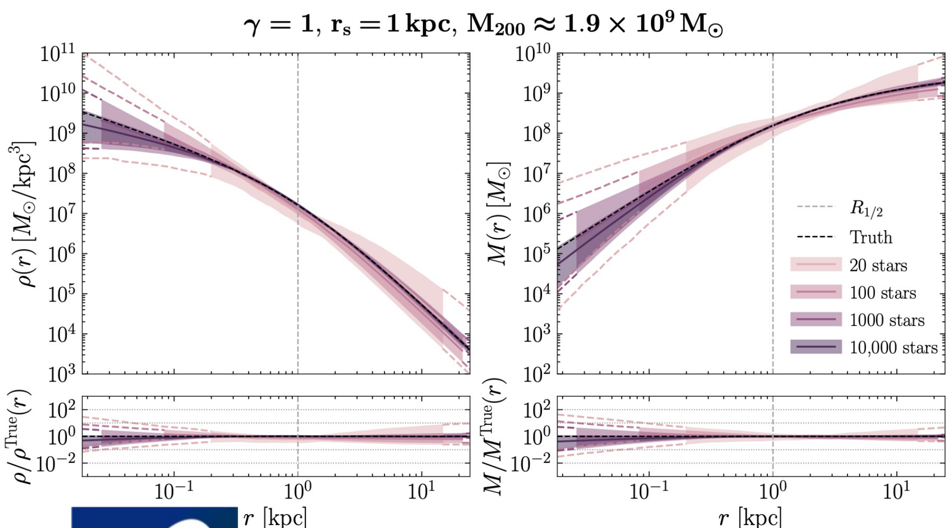


HAWC obseervations of 15 dSphs
- Combination in a joint likelihood analysis, 507 days of observations

REF



- Core vs. Cusp. DM profiles in dSphs…



Chang&Necib 2021

Even for classical dSph galaxies like Fornax. (avout thousanbd stars detected) we may be lacking iof data to disentangle. Between core and. Cusp profiles

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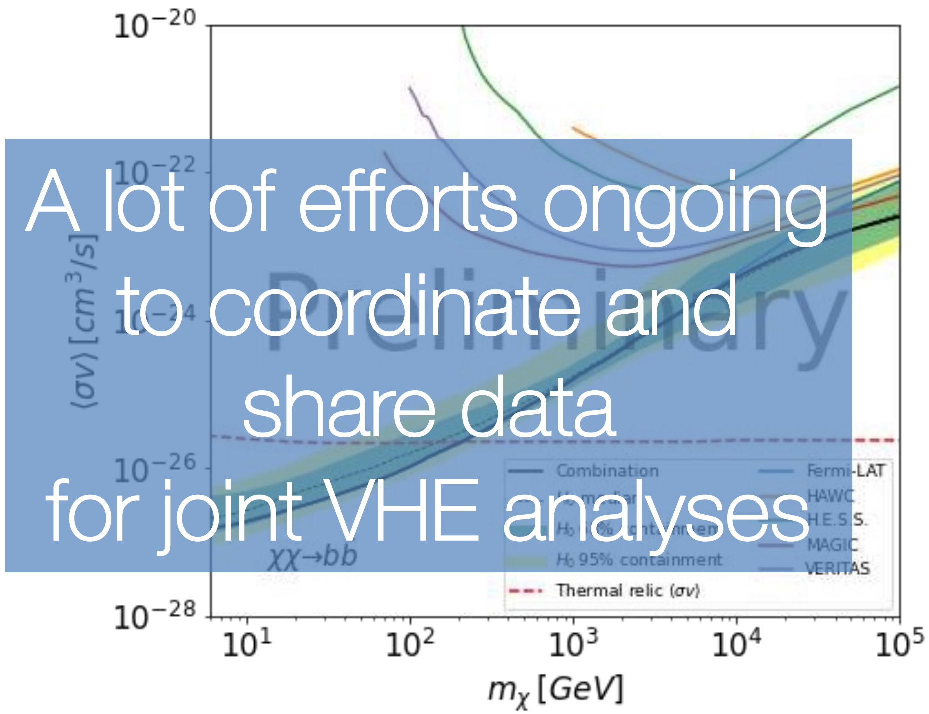
Combining all dSph observations

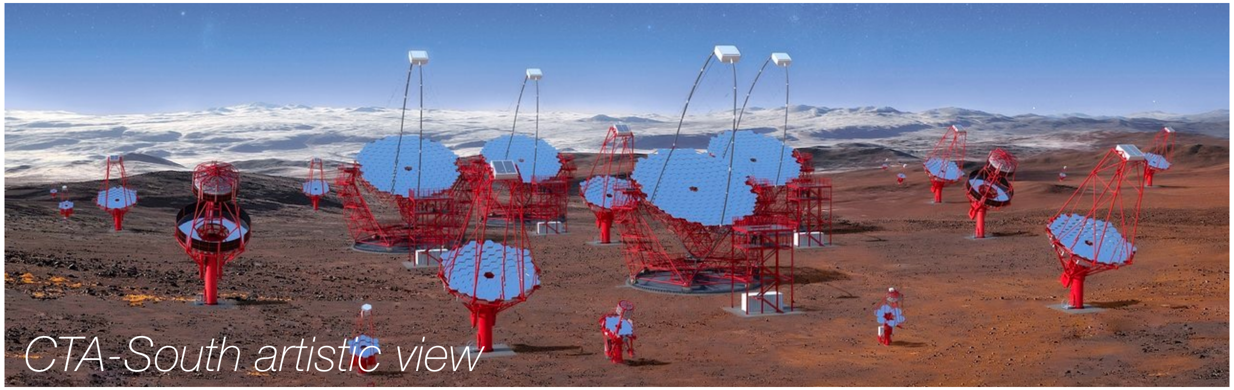
- Combination of the observation results towards 20 dwarf spheroidal galaxies (dSphs)
  - Significant increase of the statistics -> Increase the sensitivity to potential dark matter signals
  - Cover the widest energy range ever investigated : 20 MeV – 80 TeV

- Common elements :
  - Agreed model parameters
  - Sharable likelihood table formats
  - Joint likelihood test statistic



A lot of efforts ongoing to coordinate and share data for joint VHE analyses

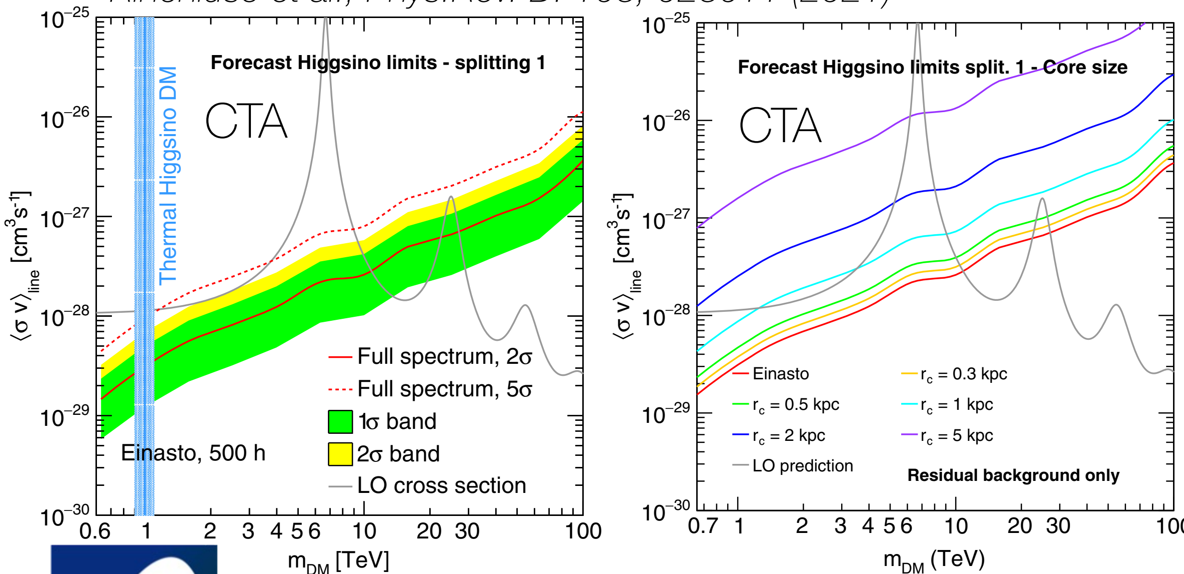
Prospects for annihilating Dark Matter



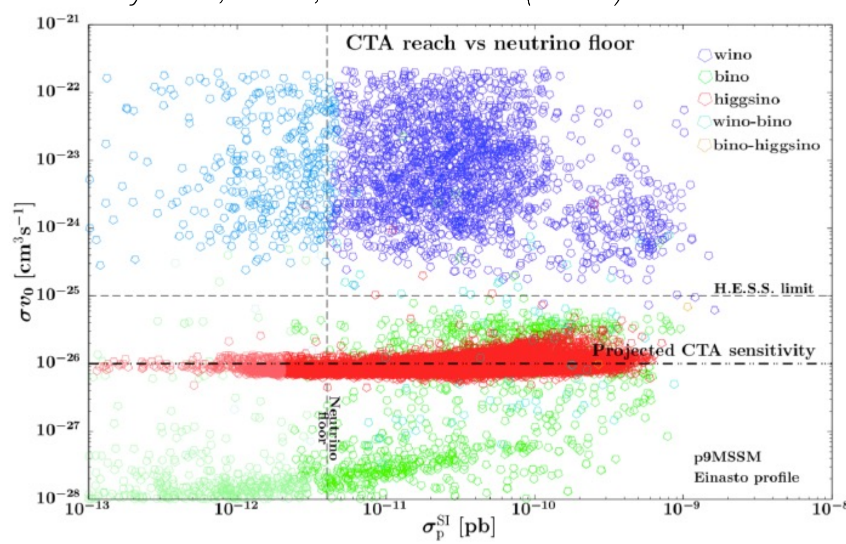
- 2 sites: La Palma/ Chile
- A factor ~10 increase in flux sensitivity
- Energy coverage 30 GeV – 300 TeV
- Arcminute angular resolution
- Energy resolution up to 5% in the TeVs

- Some of the simplest classic WIMP models remain unconstrained
  - DM could still interact through the W and Z bosons!

Rinchiuso et al., Phys.Rev. D. 103, 023011 (2021)



Hryczuk, et al., JHEP 1910 (2019) 043

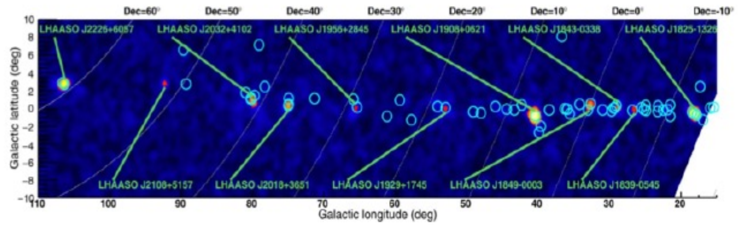


CEA - Saclay

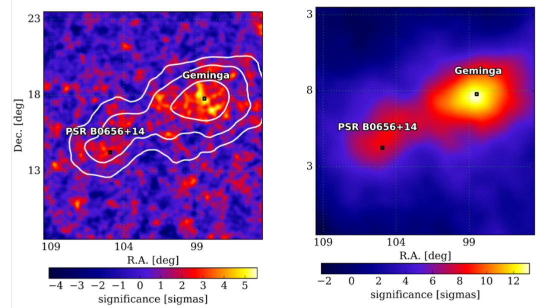
Summary

VHE gamma astrophysics is a lively field :
HESS, MAGIC, VERITAS, HAWC, LHASSO, …

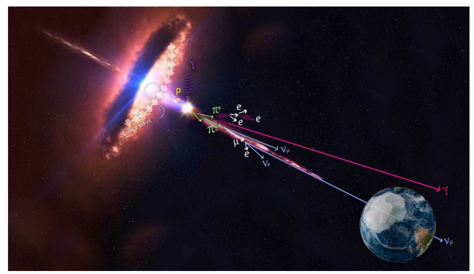
- Many Galactic Pevatrons being detected !



- TeVhalos : probing CR diffusion nearby sources

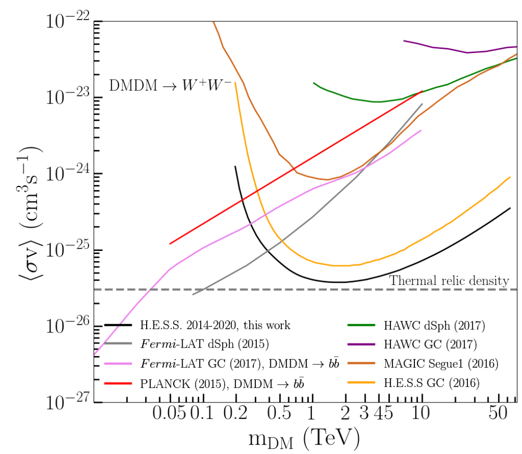


- Novae: a new class of TeV emitters

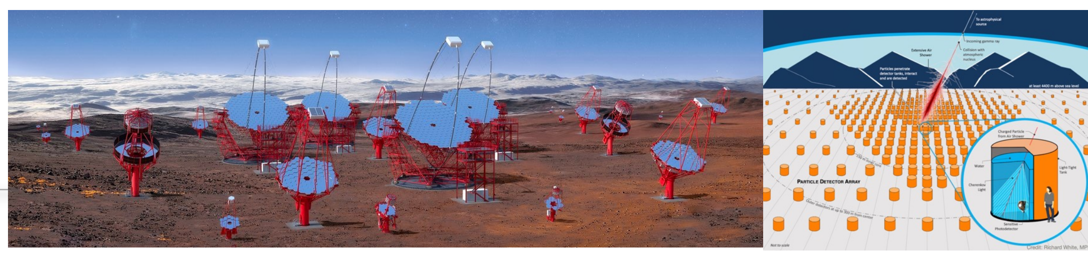


- Birth of multimessenger astronomy : n/gamma coincident detection

- TeV WIMP uncharted parameter space being probed



- Stay tuned with upcoming facilities : CTA , SWGO

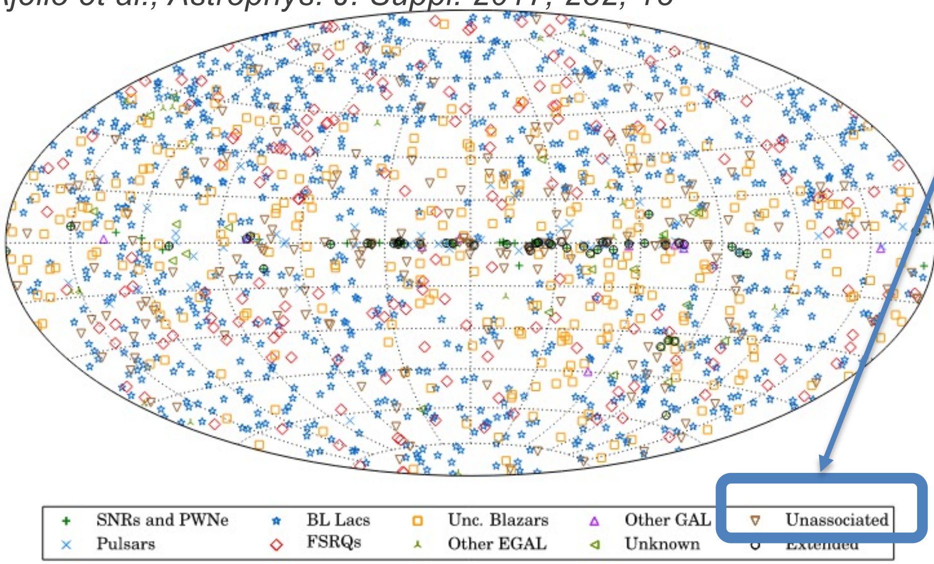


An alternative: selected Unidentified Fermi-LAT Objects as Dark matter subhalos

Dark Matter subhalos in the Galactic halo

- Lower signal than the GC region
- No astrophyiscal background
- Location not known …

Ajello et al., Astrophys. J. Suppl. 2017, 232, 18



200 unassociated over 1556 sources in the catalogue;

→ these sources are classified as Unidentified Fermi Objects (UFOs);
→ Selection through the Third catalog of Hard *Fermi*-LAT sources (3FHL) to obtain the most promising UFOs for the IACT observations.

An alternative: selected Unidentified Fermi-LAT Objects as Dark matter subhalos