V. Lefranc & A. Montanari
ICRC – July 2021

H.E.S.S.

UNIVERSITÉ PARIS SUD

université PARIS-SACLAY

Irfu

ICRC highlights: a selection

About 37th ICRC

- The Astroparticle conference every 2 years
- Online but hosted in Berlin
- 1683 participants from 55 countries
- 1384 contributions (including 674 posters) → 280 hours of talk
- All contribution (slides + recorded videos) available @ https://icrc2021-venue.desy.de/

Outline – Valentin Lefranc

- Facilities : Status and future
- Multi-messenger
- Neutrinos
- High energy cosmic ray spectrum

Facilities : Status and future

Observatories

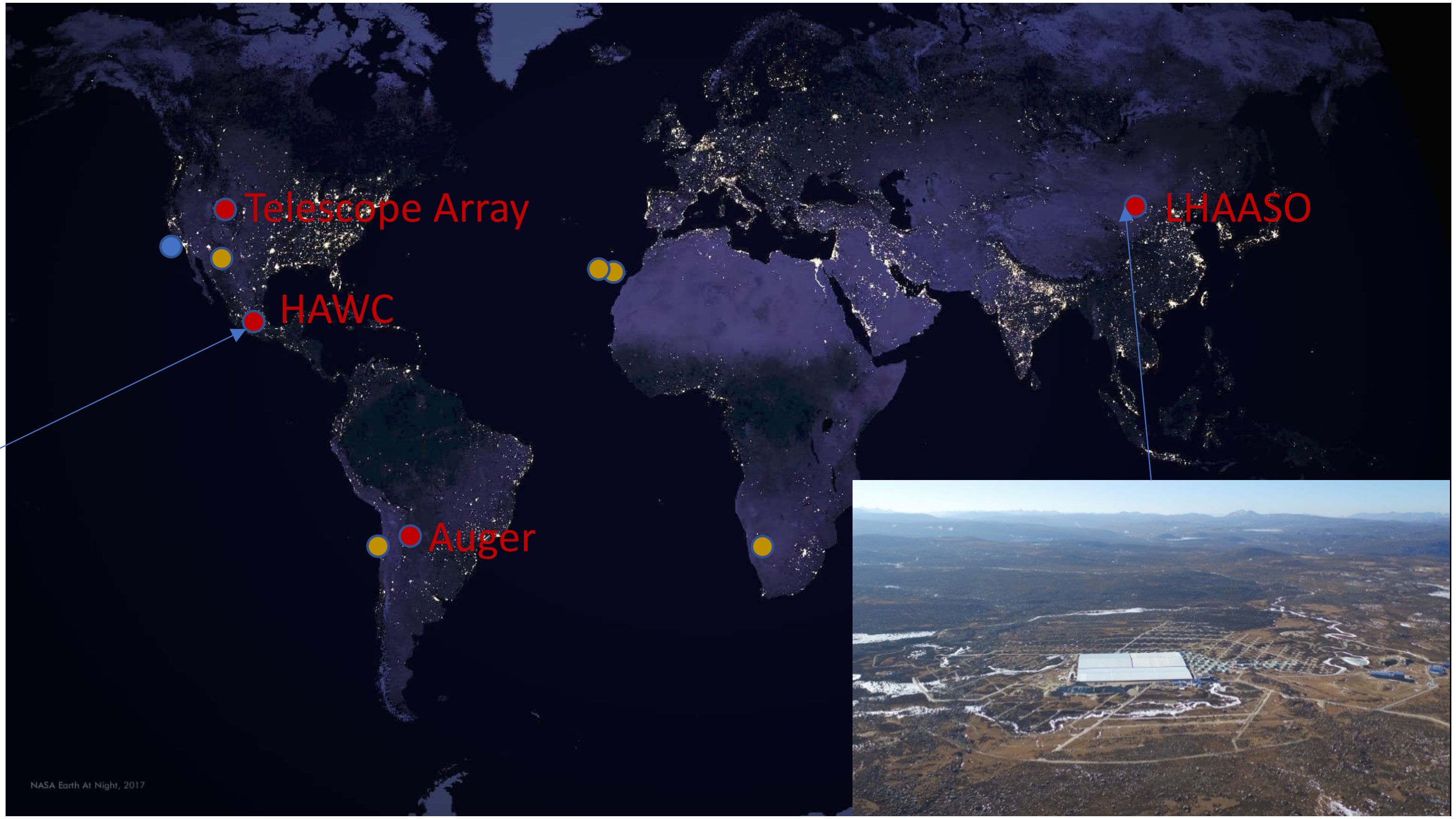
- Ground based
  - Radio : (CHIME, SKA pathfinders MeerKAT , ASKAP) / Optical (ZTF, VRO)

Observatories

- Ground based
  - Radio / Optical (ZTF, VRO)
  - Gamma ray (H.E.S.S. , MAGIC, VERITAS, CTA) future : CTA, TAIGA, TACTIC, MACE

Observatories

- Ground based
  - Radio / Optical (ZTF, VRO)
  - Gamma ray (H.E.S.S. , MAGIC, VERITAS, CTA)
  - UHE (HAWC, LHAASO, Auger TA). future : SWGO



Observatories

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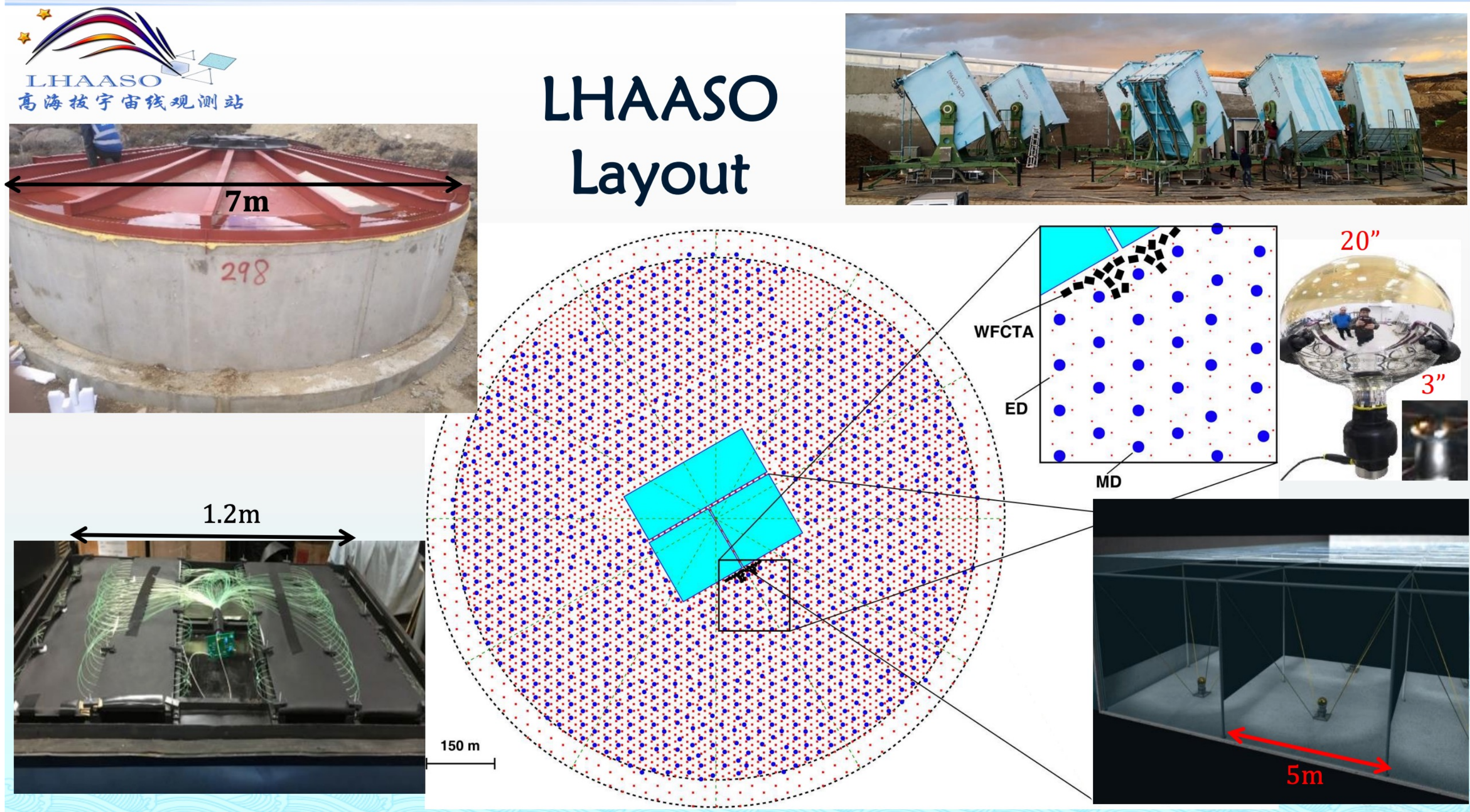
  - Radio / Optical (ZTF, VRO)
  - Gamma ray (H.E.S.S. , MAGIC, VERITAS, CTA)
- LHAASO : China , 4410 m, 1km2
  - Wide FOV air Cherenkov image Telescopes.
  - Water Cherenkov Detector
  - Scintillator detectors
  - burst detectors



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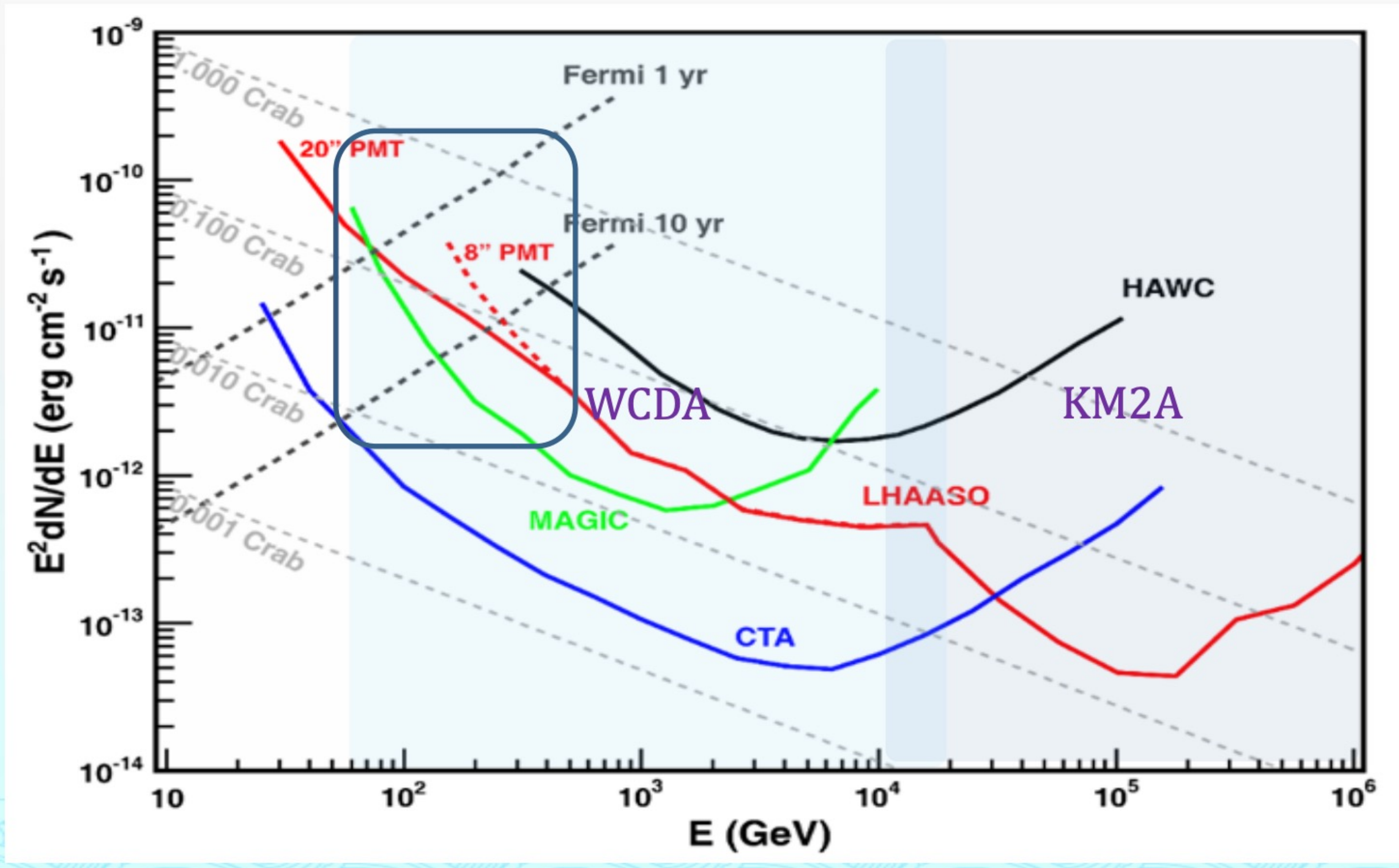

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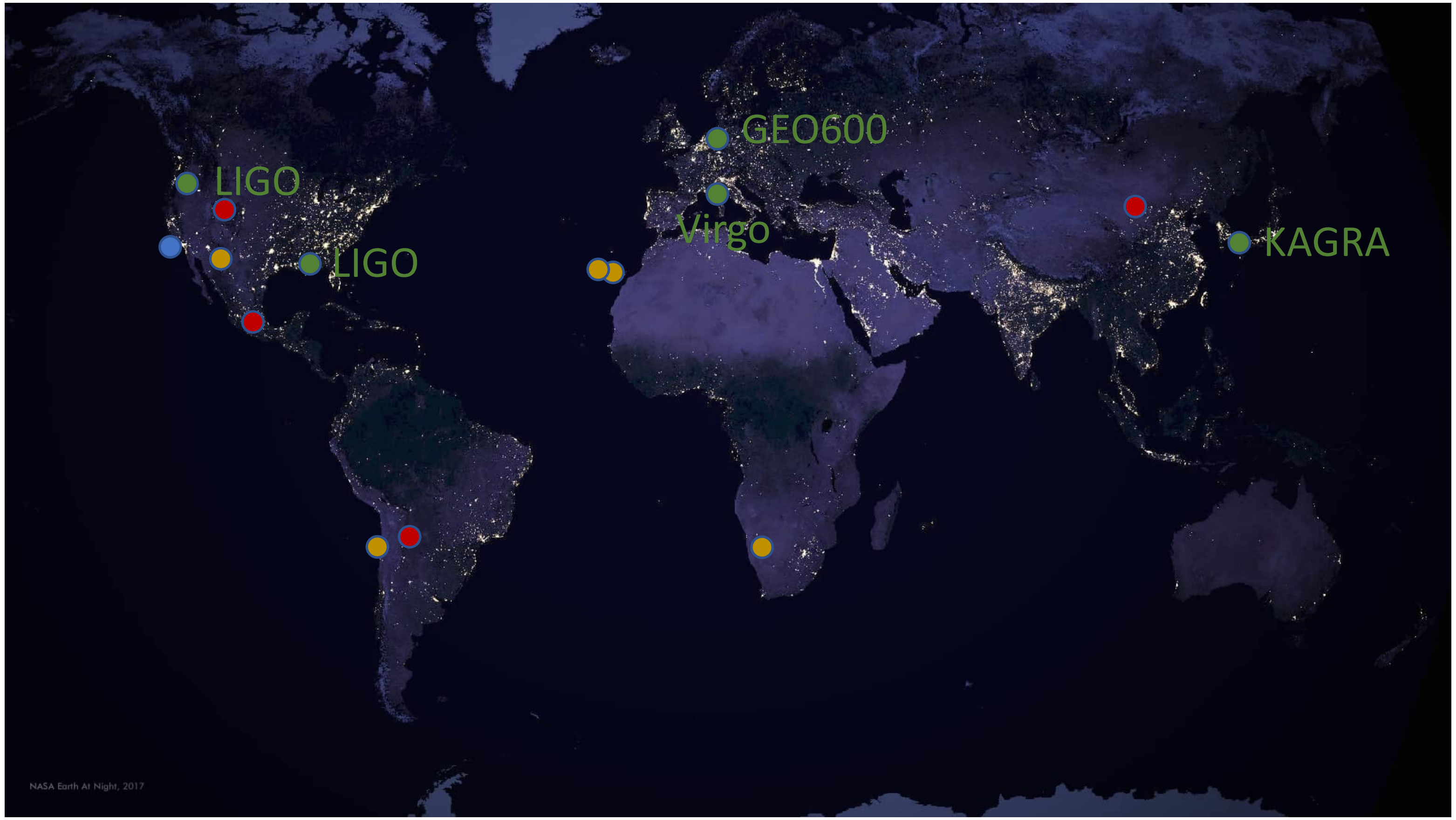
  - GW (LIGO, Virgo, KAGRA) future : LIGO India



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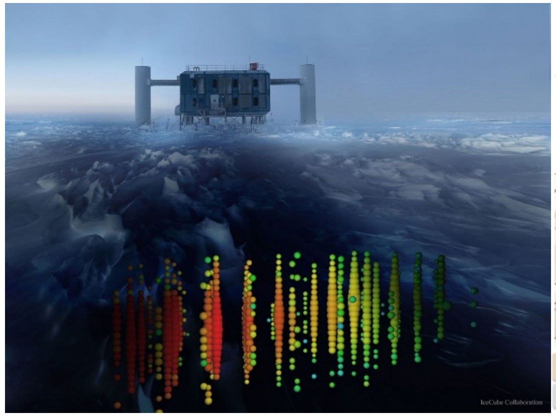
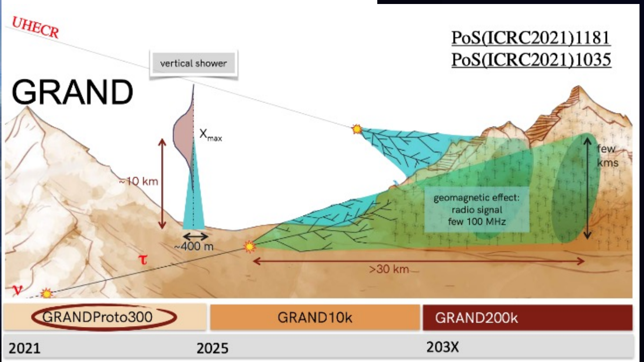
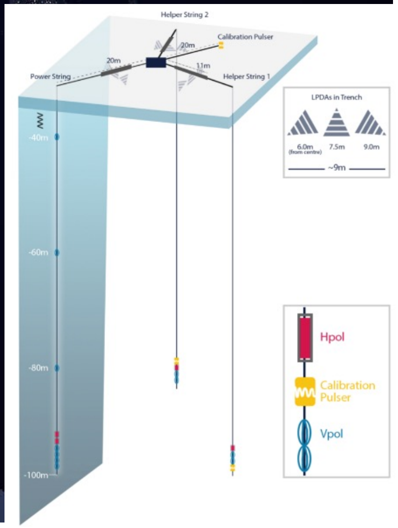
  - UHE (HAWC, LHAASO, Auger, TA)
  - GW (LIGO, Virgo, KAGRA)
  - Neutrino (Ice Cube , Antares, Baikal GVD) future : KM3NET, IceCube (upgrade and Gen2), RNO-G, PUEO, GRAND, BEACON Hyper Kaminokande







Observatories

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  - UHE (HAWC, LHAASO, Auger TA)
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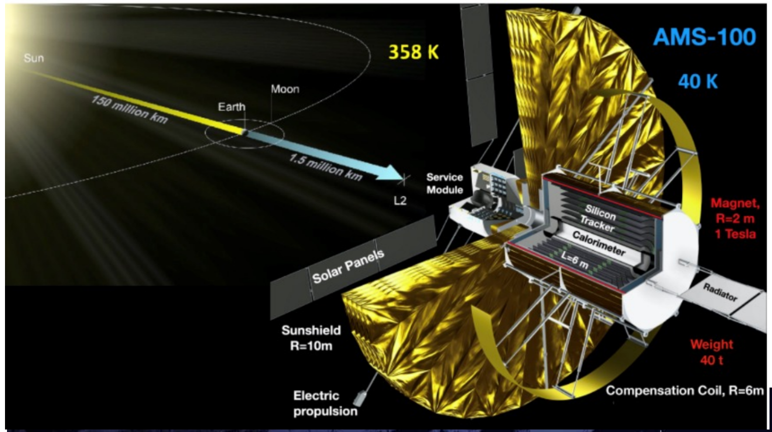
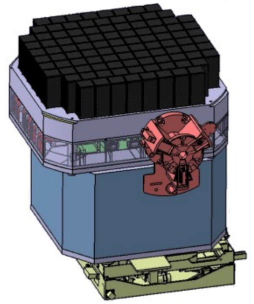
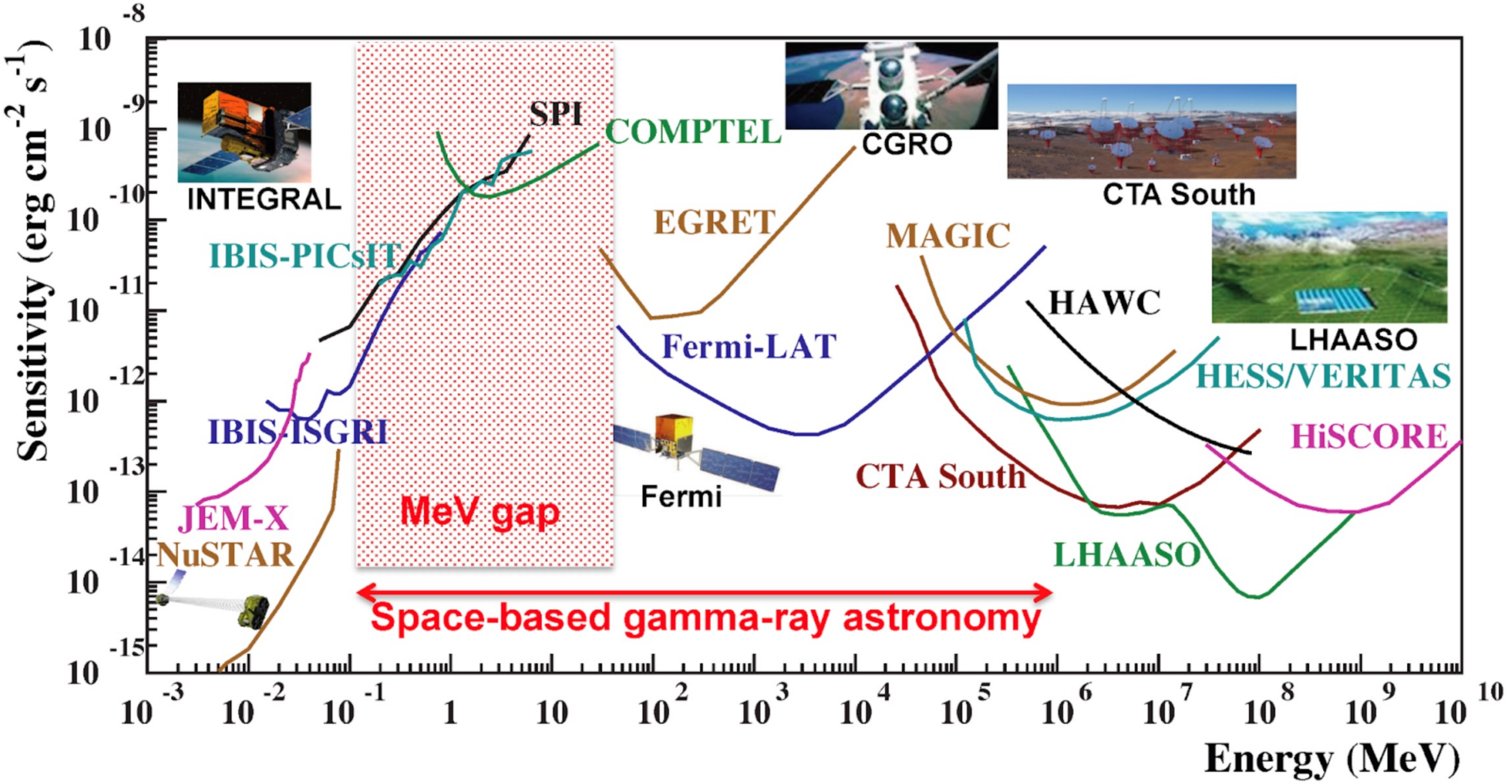
  - Neutrino (Ice Cube , Antares, Baikal GVD)
- Satellites
  - X-rays (Swift, INTEGRAL,SVOM)
  - Gamma rays (Fermi)
  - Cosmic rays : AMS, DAMPE, CALET
- Future Satellites :
  - Gamma ray: ASTROSAT, POLAR-02, GRAINE, SVOM
  - Cosmic rays : GAPS, HERD, HELIX, TIGERIS, AMS100, ALADiNO



GRB Polarization: POLAR-2 (2024)



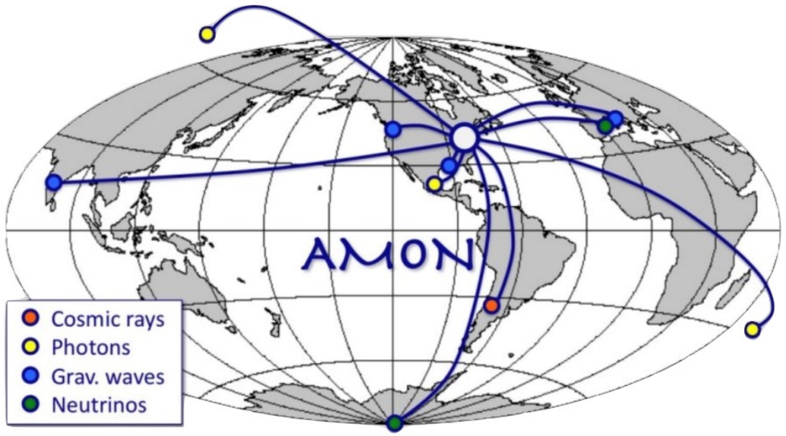
All together



Multi Messenger Astronomy

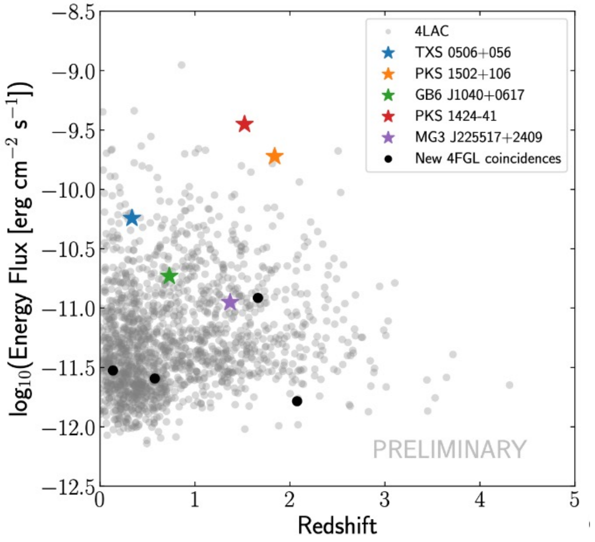
Real time and network

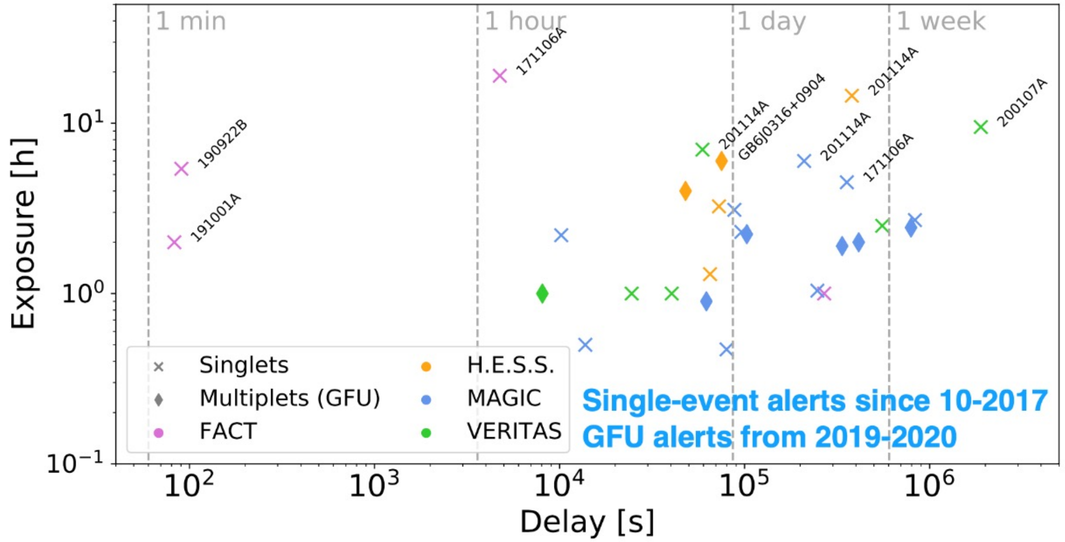
- Observatories have to work close together and provide fast reliable informations to hope coincident observation.
- Neutrino Alert system : Baikal, IceCube, Antares
- AMON network
  - Real time alerts :Searching for HE gamma-ray and neutrino coincidences
- Astro-COLIBRI
  - Use all channel (AMON, VoEvents, GW, FERMI, INTEGRAL …) and provide a easy readable web interface (also available as an app with notifications)
  - Ask me or Fabian for more infos ! Contribution : https://pos.sissa.it/395/935



Neutrino follow ups

- Number of alerts increases : Ice Cube 3x more alerts/week in 2 years
  - Used over 50 times (GRBs, FRBs, blazar flares, ...) no significant detection.
  - Current limits constrain nearby bright transients and future ones aim to constrain populations of sources
- Fermi-LAT : follow-up observations of real time high-energy neutrino detections have identified 7 candidate counterparts
- IACTs observational strategies:
  - Fast reaction (<1day)
  - Deep exposures (HESS, VERITAS) Fabian is responsible of the HESS observations of this contribution
  - Follow-up of many alerts (MAGIC)

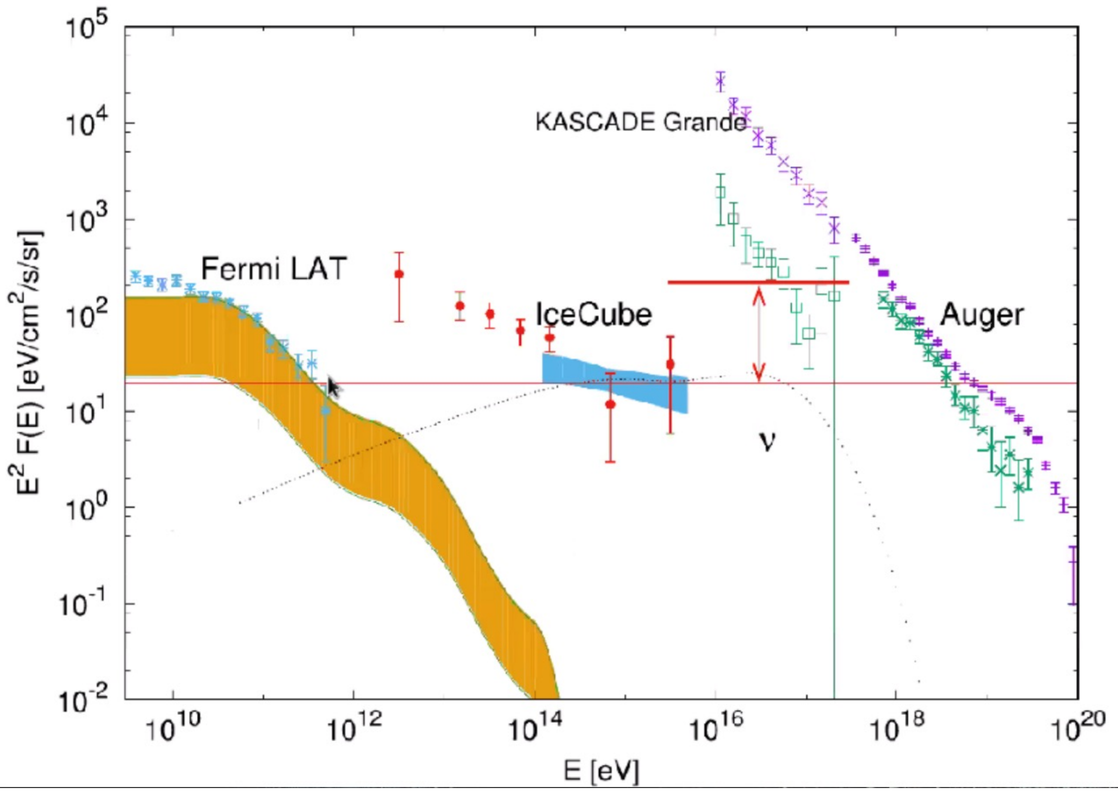




Konstancja Satalecka, PoS 960. See Olga Sergijenko, PoS 975, Andrea Bulgarelli, PoS 937, Roberta Zarin, PoS 005 for CTA alert & follow-up systems.

Blazars

- Blazars represents 80% of the gamma rays sky as seen with Fermi but can only explain maximum 30% of the neutrino diffuse flux
- More sources contribution must explain the gap between gamma / neutrino and neutrino / CRs



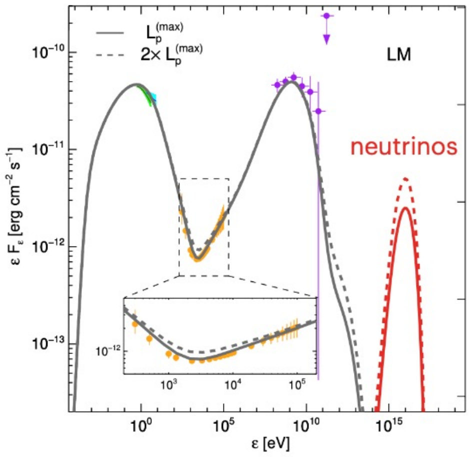
Blazars & Neutrinos

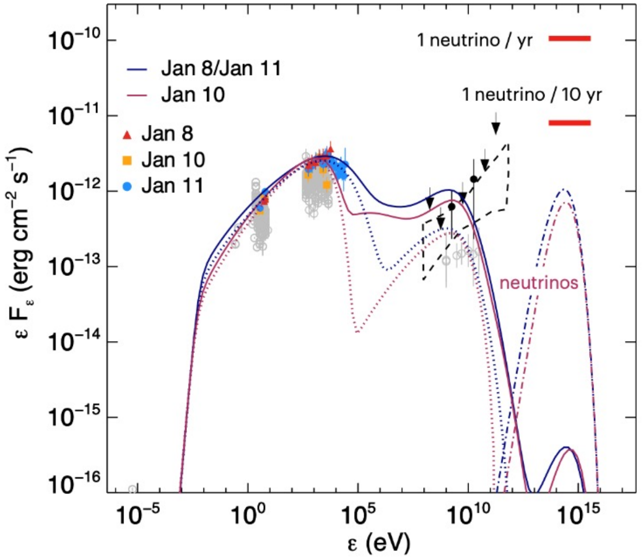
- **TXS 0506+056**
  - Neutrino Event : IC170922A
  - Detected in GeV and TeV during a flaring period that overlapped with the arrival of the neutrino event but other lower energy neutrino event not correlated with GeV activity.
  - Modelisation of the emission not compatible with the Neutrino flux alternative model are investigated. (Different production area for neutrino and gammas)

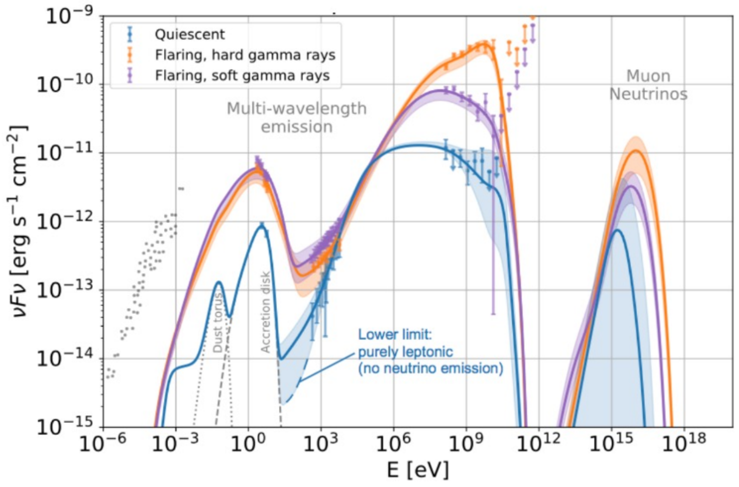
- **3HSP J095507**
  - Neutrino Event : IC200107A 300 TeV
  - Hard X rays shorly after the neutrino arrival
  - Modelisation of the emission not compatible with the Neutrino flux

- **PKS 1502+106**
  - Detected in a quiescent state of weak gamma-ray activity at the time of neutrino arrival.
  - More Neutrinos should be detected when flaring

Keivani et al. 2018, ApJ, 864, 84

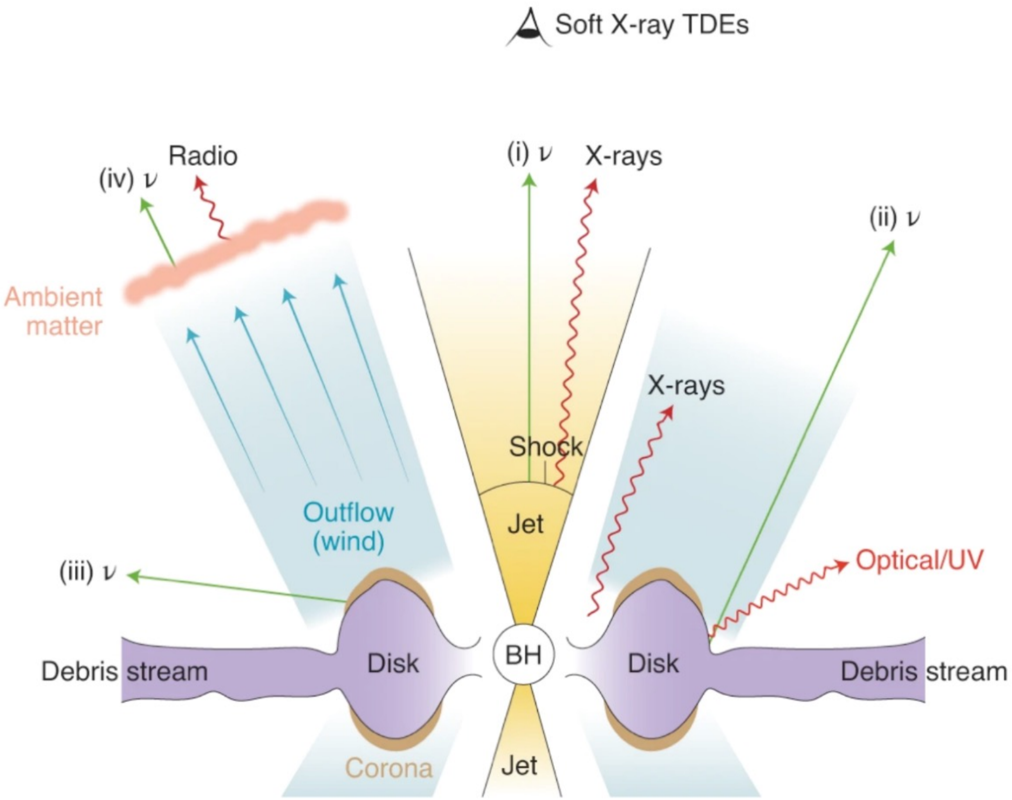






Tidal distruption event

- ZTF telescope detected his 2nd brightest events.
  - Neutrino detected 175 days after discovery (0.2 PeV).
- Neutrinos from TDEs could contribute up to 26% to diffuse neutrino flux
- Second event, AT 2019fdr, coincident with another neutrino event (IC200530A, 80 TeV)
- We are entering a new era for the detection of TDEs, does this have implications on neutrino detection?
- Where are the neutrinos produced?
- Need to improve on our understanding of the TDE population.

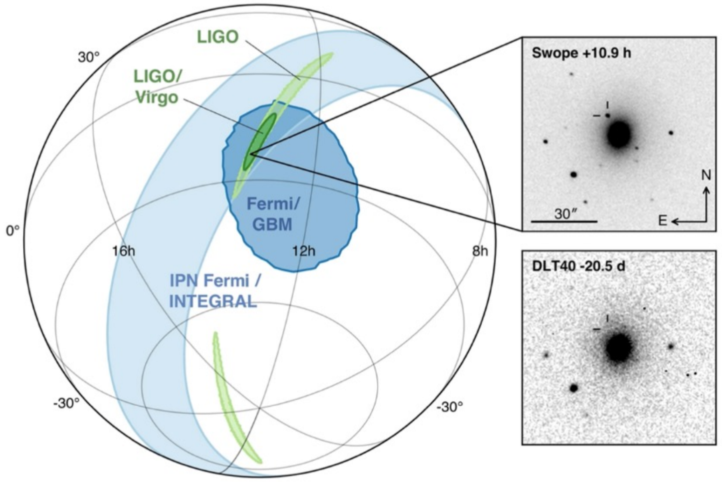


Nat Astron **5** 436–437 (2021)
Hayasaki

Robert Stein, PoS 009. Winter & Lunardini, PoS 997

Compact binary mergers

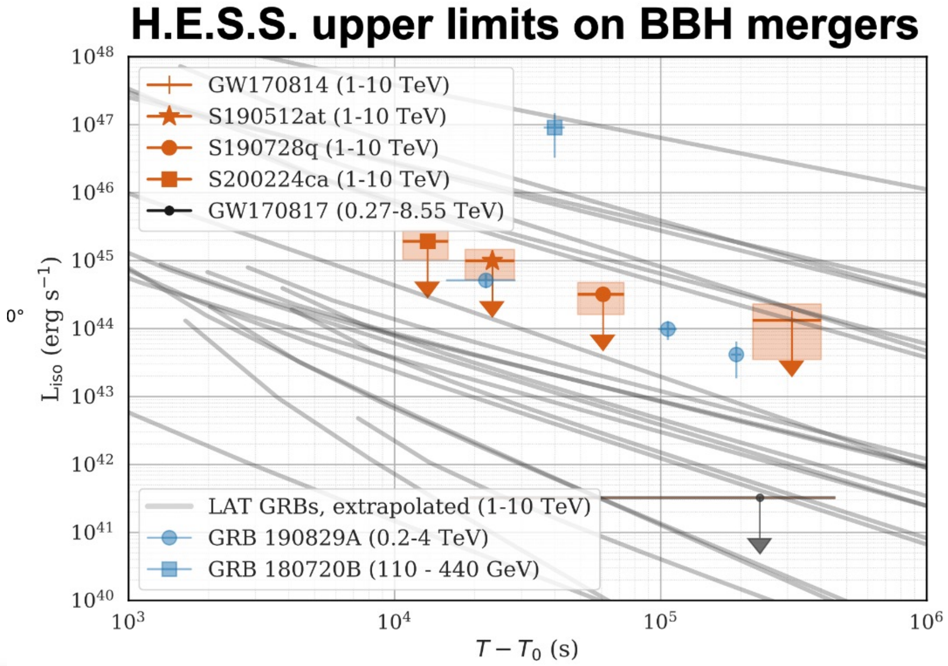
- **GW 170817**
  - First joint detection EM and GW
  - Associated with GRB 170817A
  - Possible other EM counterpart : **AT2017gfo ?**
  - 3.4 years later: X-rays are still there



- Neutrino Observatories : Upper limits

- IACTs : Possible short GrBs,
  - H.E.S.S. follow up 4 BBH and set up Upper limits**. (2 contributions by Halim Ashkar** pos.sissa.it/395/943 and pos.sissa.it/395/936**)**
  - **CTA will be a key (north and south)**

- Need to get ready for expected larger number of multi-messenger detections

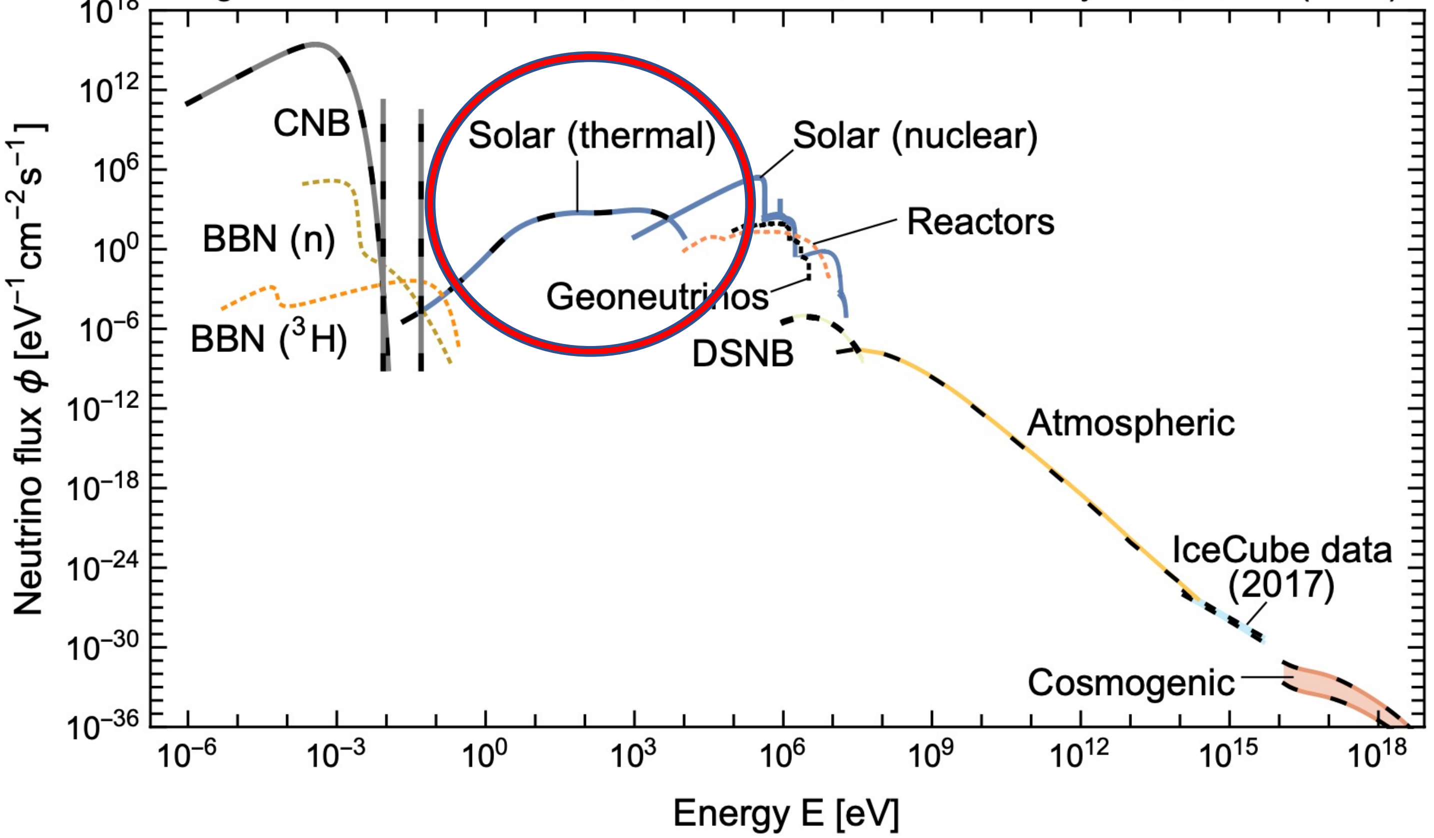


Neutrinos

The world of Neutrinos

- Borexino sees first evidence for CNO neutrinos.
- All other searches at this point still compatible with background
- JUNO has the potential to resolve B8

Vitagliano, Tamborra and Raffelt, 1910.11878, Rev. Mod. Phys. 92, 45006 (2020)

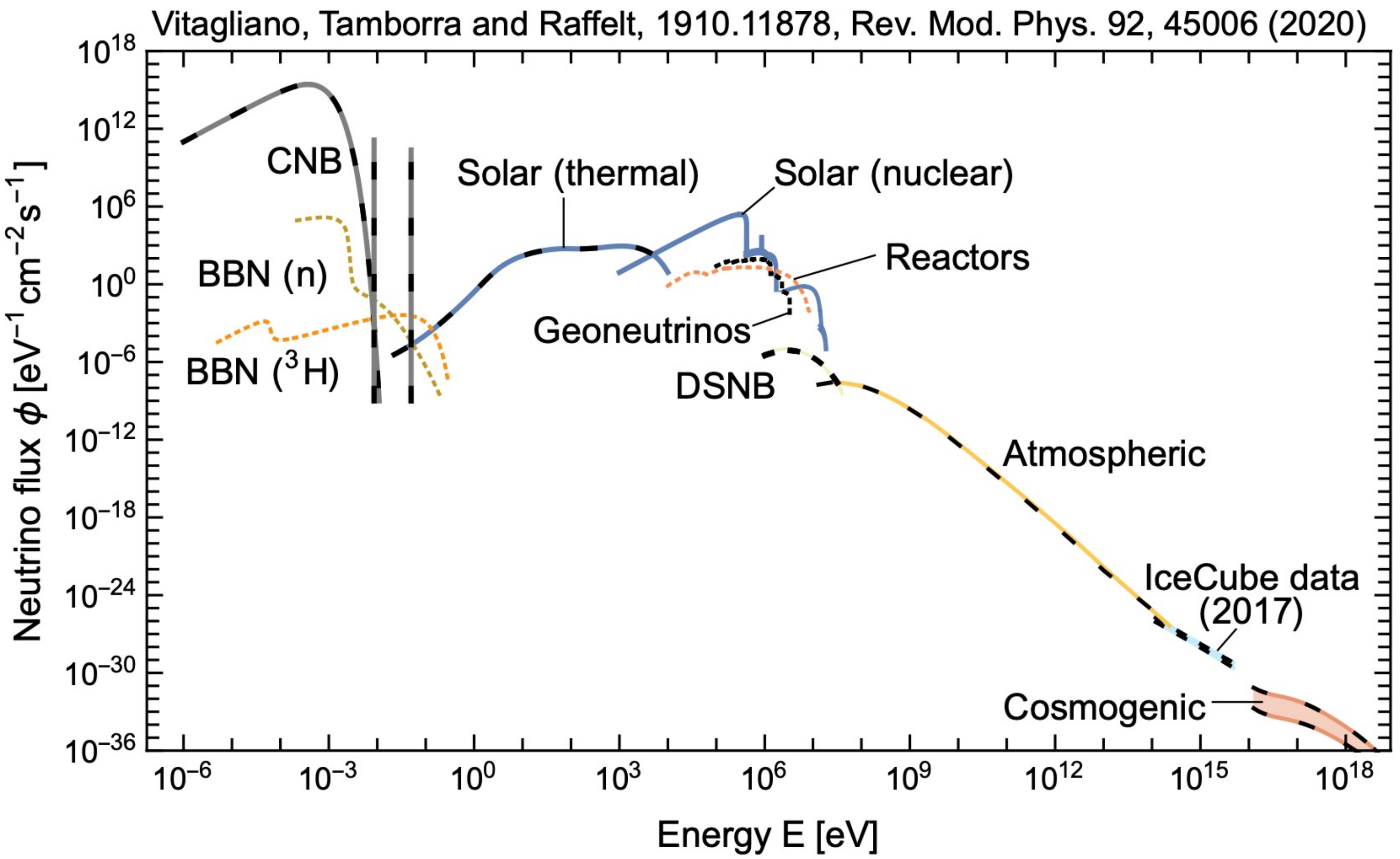


The world of Neutrinos

Supernovae

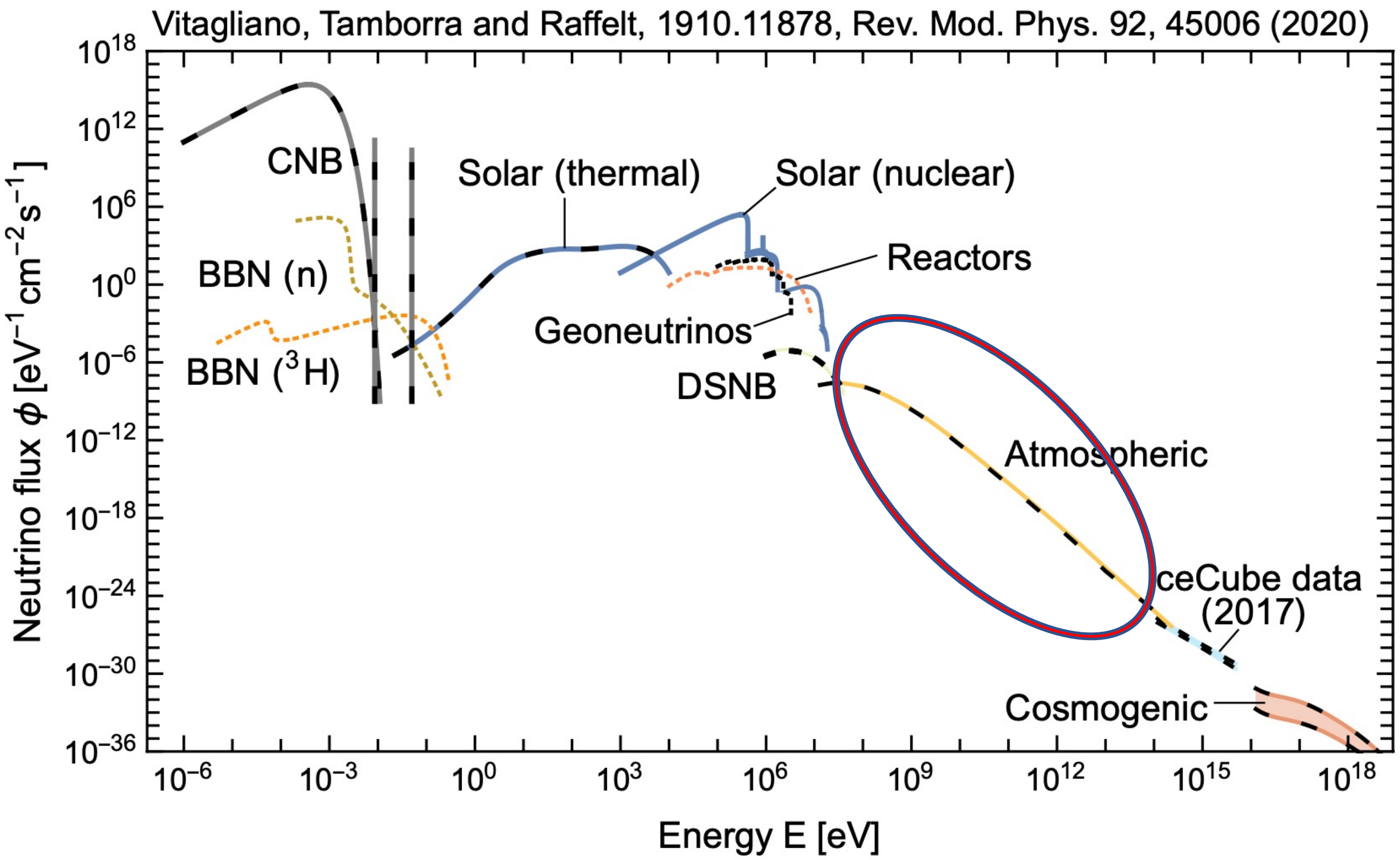
- Still waiting for the ONE

- Supernova Early Warning System will alert the astronomical community to what is coming, many neutrino telescopes are (in the process of) joining forces



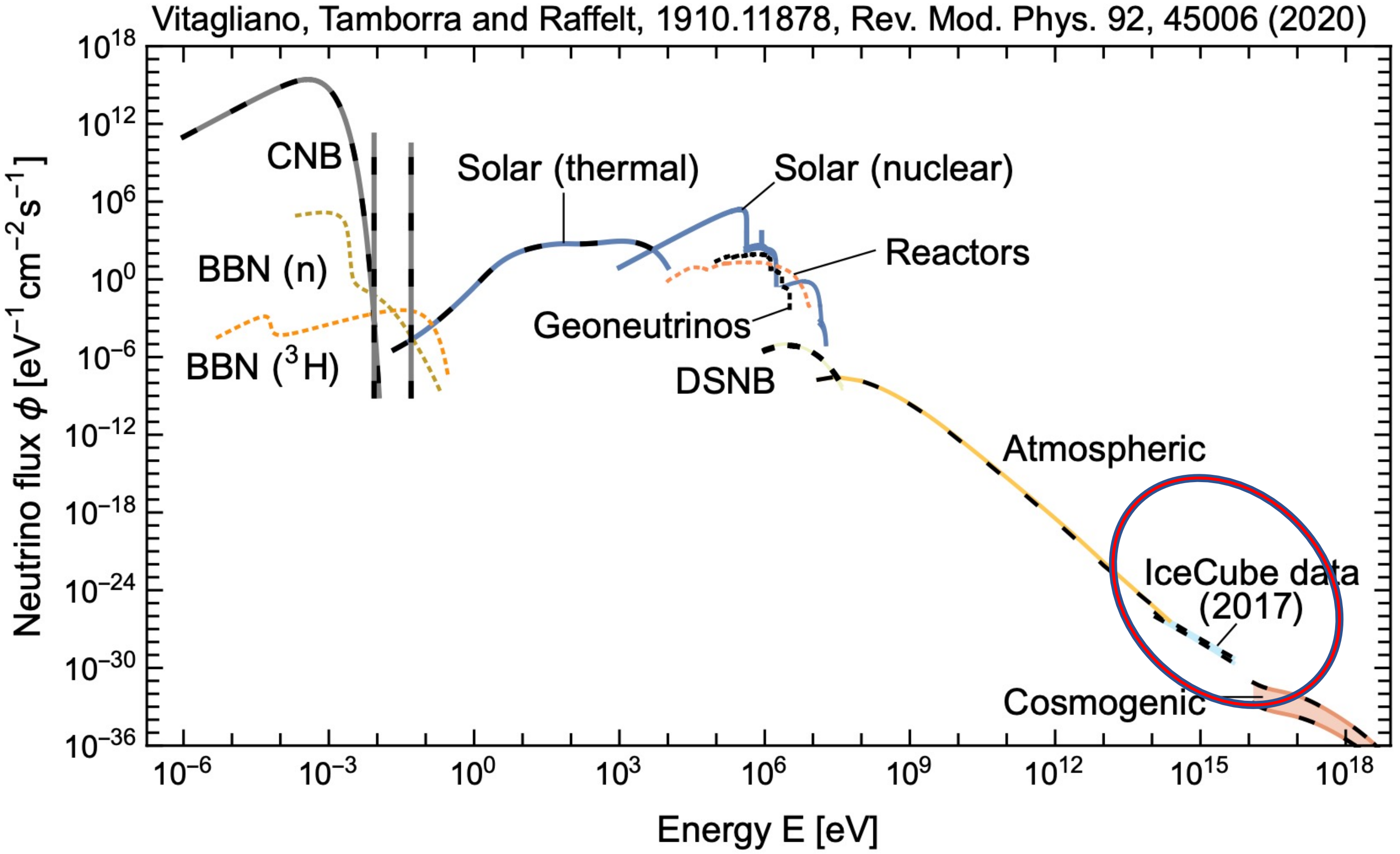
The world of Neutrinos

- Atmospheric spectra keeps improving so are results on oscillations physics and other properties



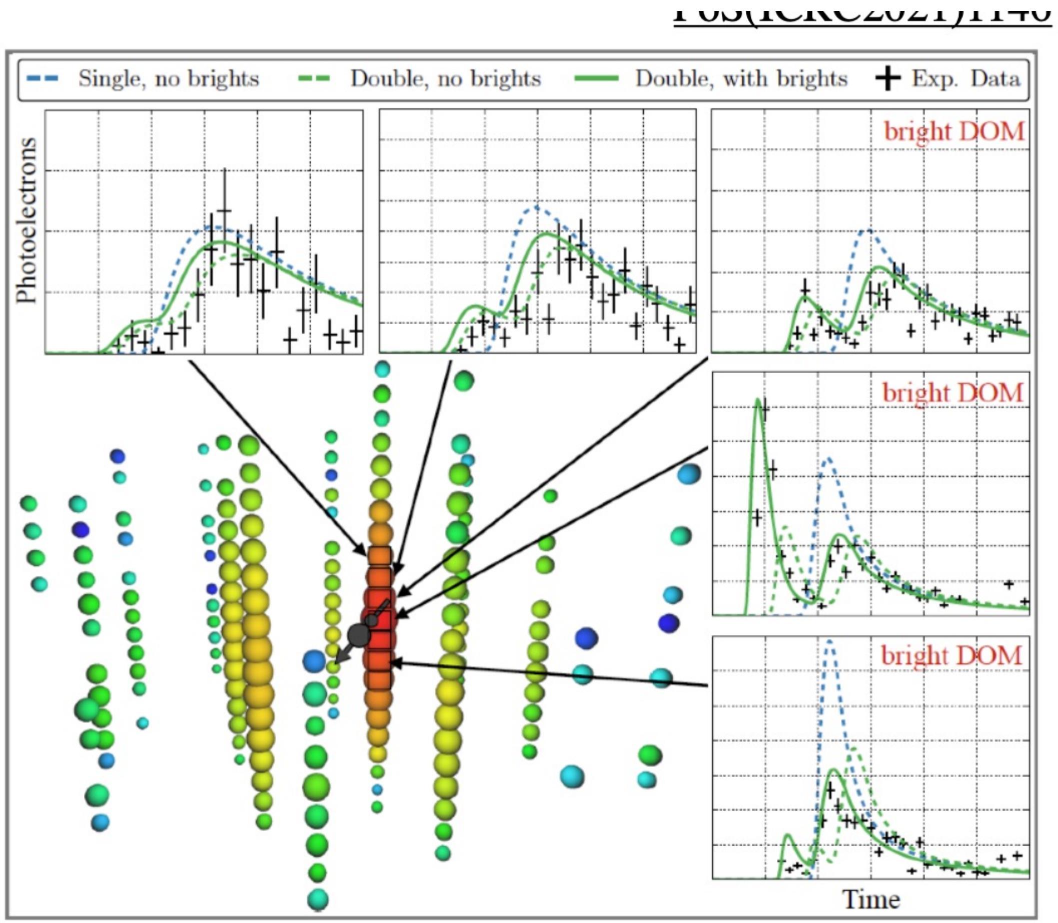
The world of Neutrinos

- Need more statistics
- KM3NET and Baikal almost there



The world of Neutrinos

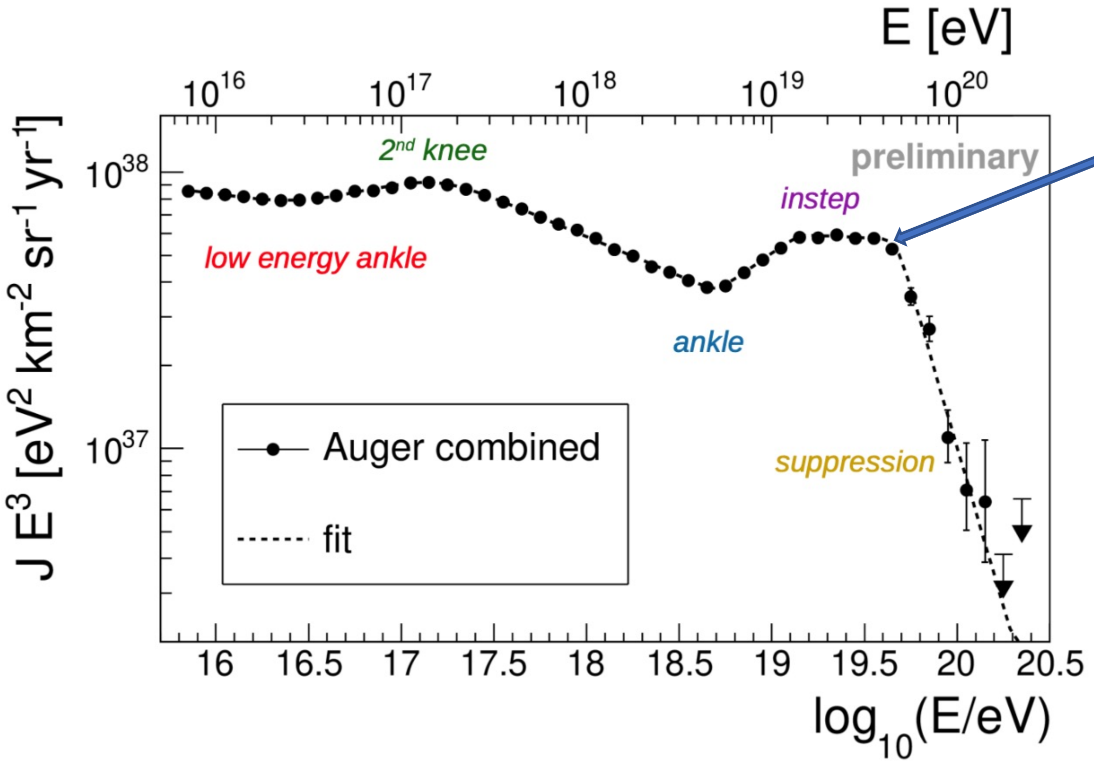
- Need more statistics
- KM3NET and Baikal almost there
- IceCube
  - First identifiable electron-anti-neutrino
  - First identifiable tau neutrino



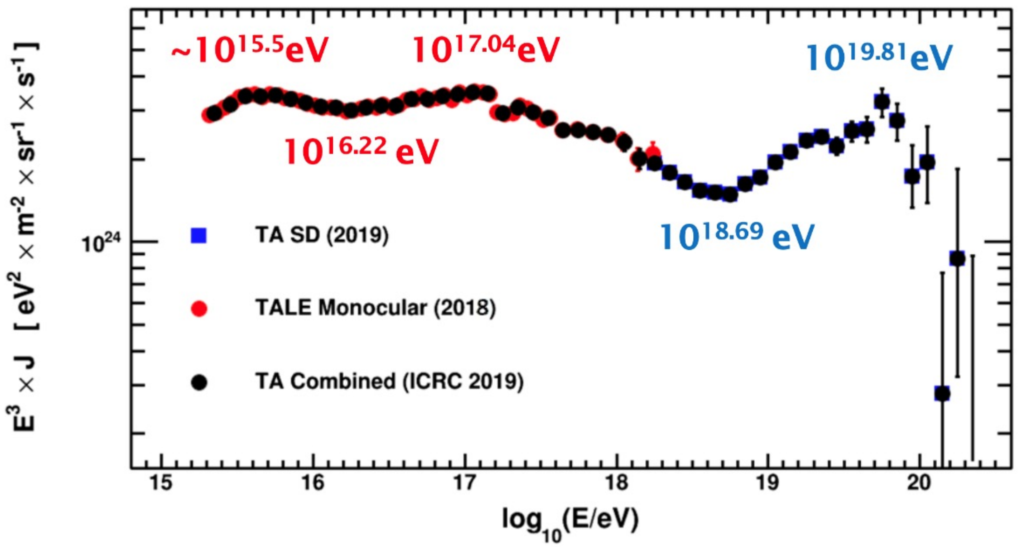
Cosmic rays indirect

Cosmic rays indirect

- **Pierre Auger and TA main results :**
  - Thanks to a lower threshold a low ernergy break was discovered.
  - Five breaks in the energy spectrum are now reported.

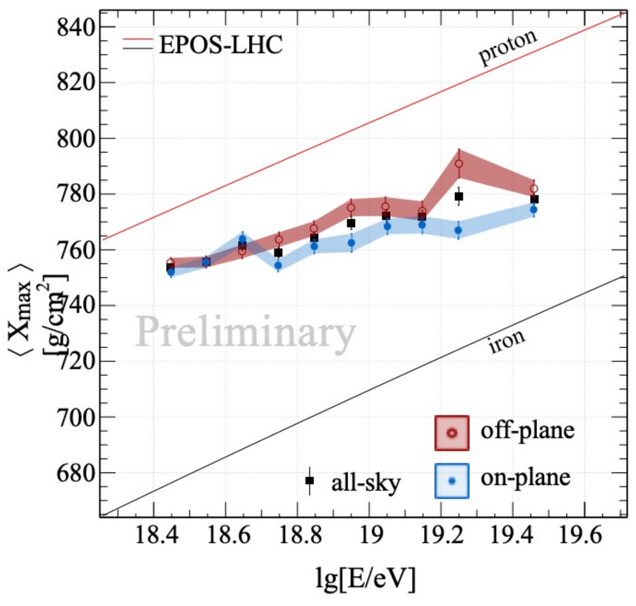


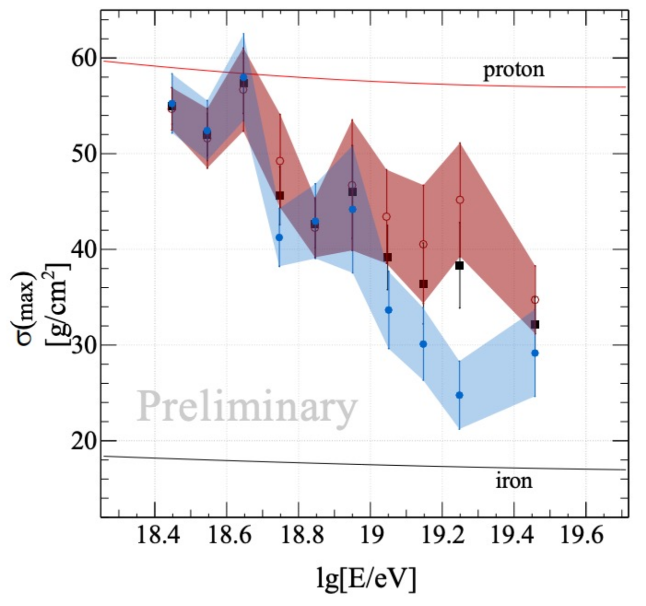
Harder spectrum in the 10^19-19.5 eV range => Confirmed by TA

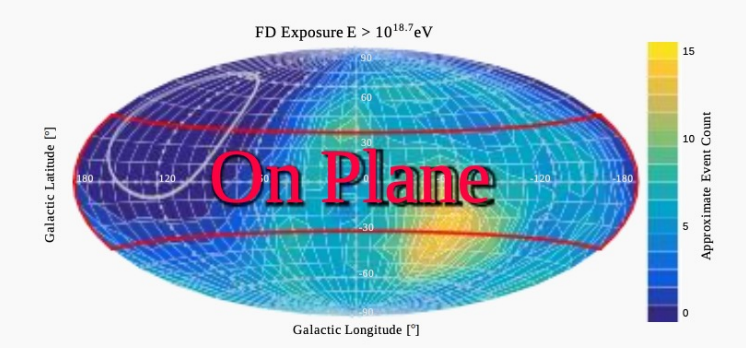


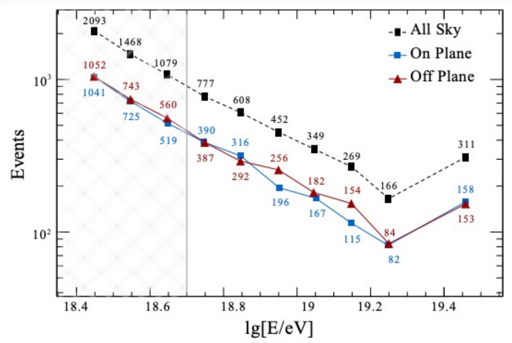
Cosmic rays indirect

- **Pierre Auger and TA main results :**
  - Thanks to a lower threshold a low ernergy ankle was discovered.
  - Five breaks in the energy spectrum are now reported.
  - Auger reported a different mass composition differences between ON / OFF planes.



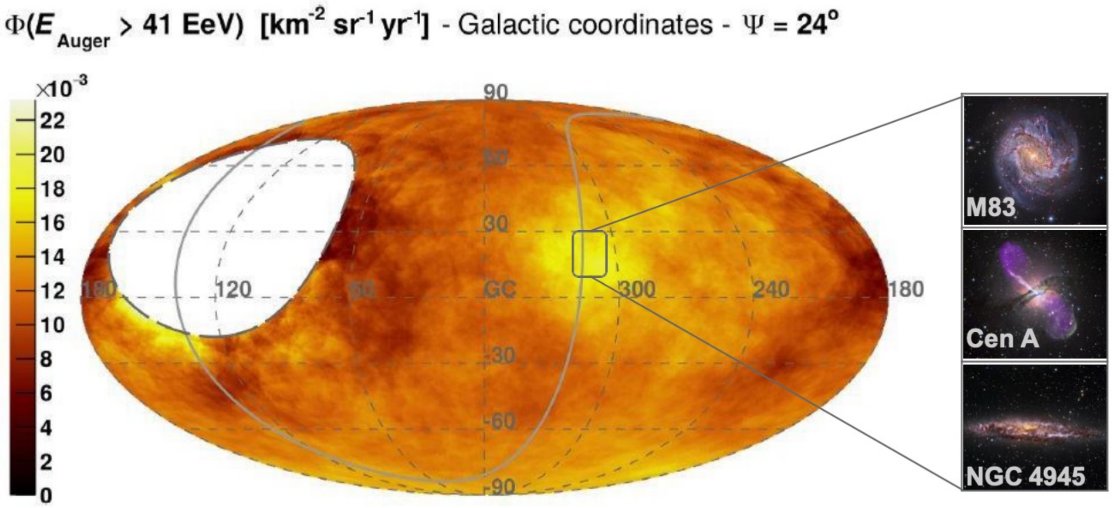


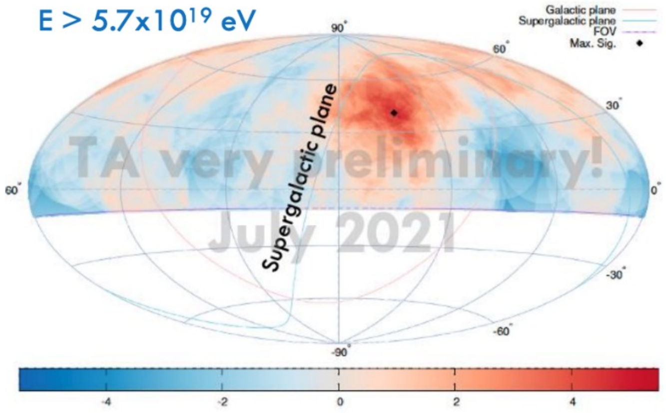


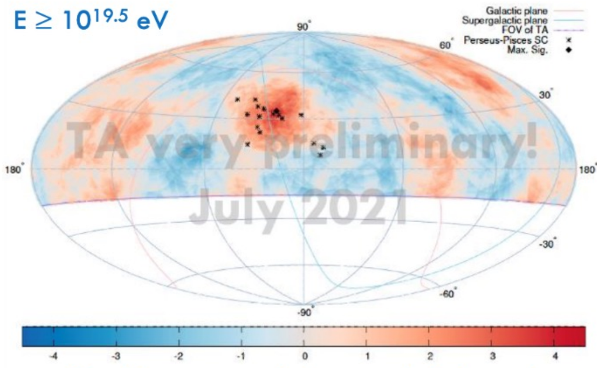


Cosmic rays indirect

- **Pierre Auger and TA main results :**
  - Thanks to a lower threshold a low ernergy ankle was discovered.
  - Five breaks in the energy spectrum are now reported.
  - Auger reported anisotropy between ON / OFF planes, different species from different regions ?
- Anisotropy searches inthe top region (>32 EeV)
  - Auger : 4σ from centaurus region confirmed by catalog based search
  - TA : 3.2 and 3.7 hot spots in the direction of Ursa Major and Perseus super cluster.







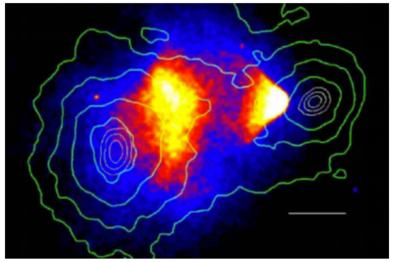
Outline – Alessandro Montanari

- Dark Matter (DM)
  - WIMPs – direct detection, indirect detection
  - PeV decaying dark matter
  - Dark matter searches with cosmic rays and neutrino
- Very high energy (VHE, >100 GeV) gamma rays and extended sources
  - Halos and extended VHE sources
  - Ultra-High-Energy (UHE, >100 TeV) gamma-ray sources
  - Cosmic-ray models in the Galaxy
- VHE cosmic-ray spectra
  - Positron, electron, proton spectra
- Conclusions

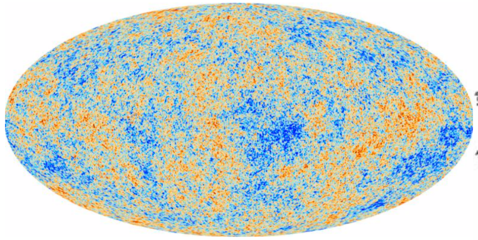
Dark Matter

Dark Matter

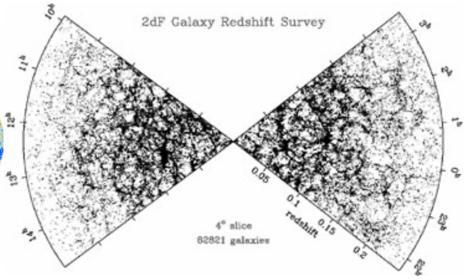
Evidence



Bullet cluster

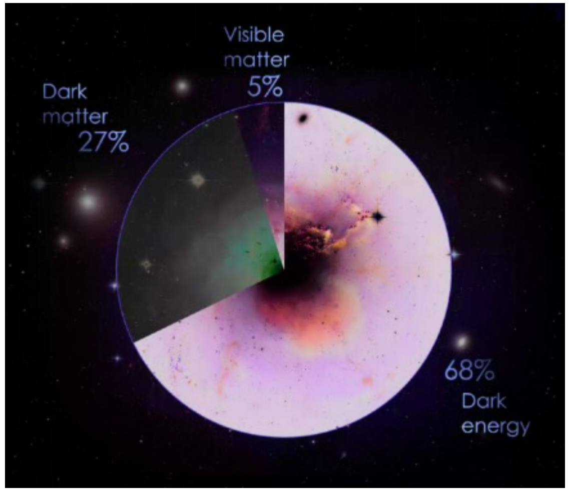


CMB



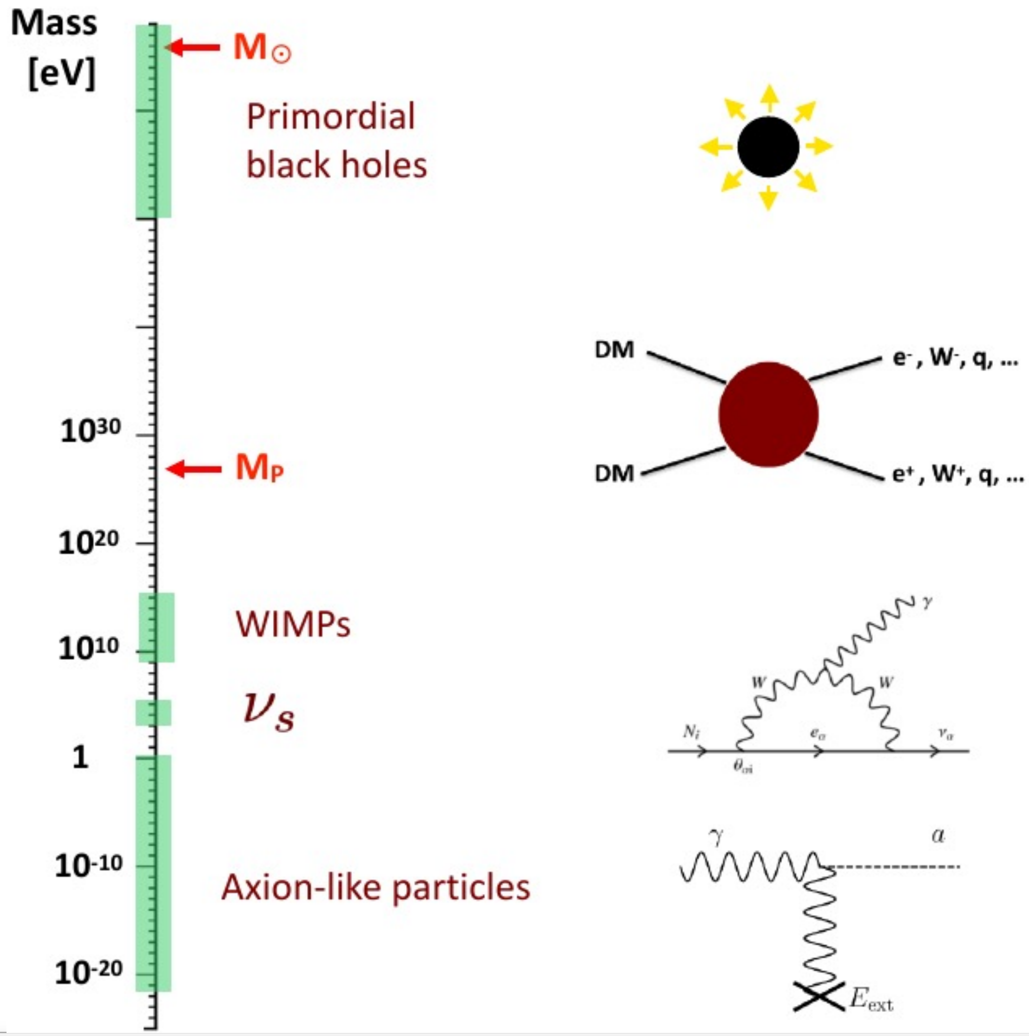
LSS

....

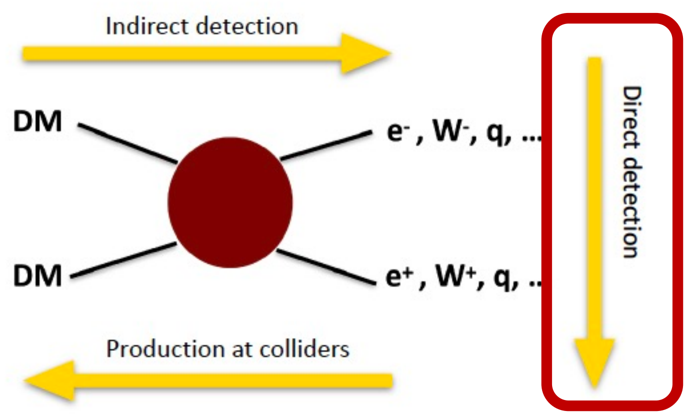


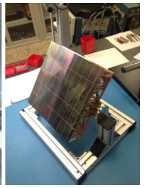
- Doesn't scatter/emit/absorb light
- Does have mass (and hence gravity).
- Is ~84% of the matter in the universe.
- Forms the primordial "scaffolding" for the visible universe
- Forms "halos" around galaxies
- Interacts with other particles weakly or not at all (except by gravity)

Candidates ...



WIMPs – direct detection status



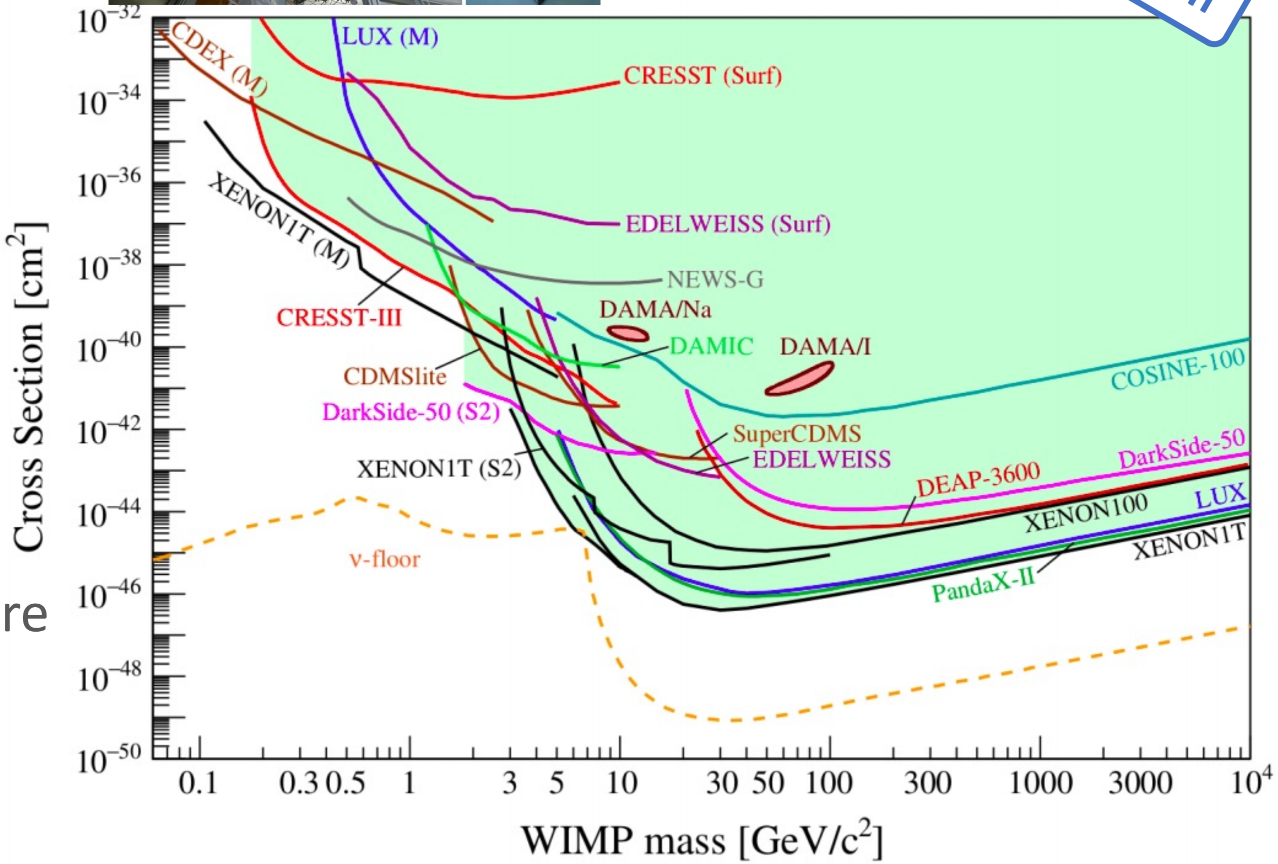


M. Schumann

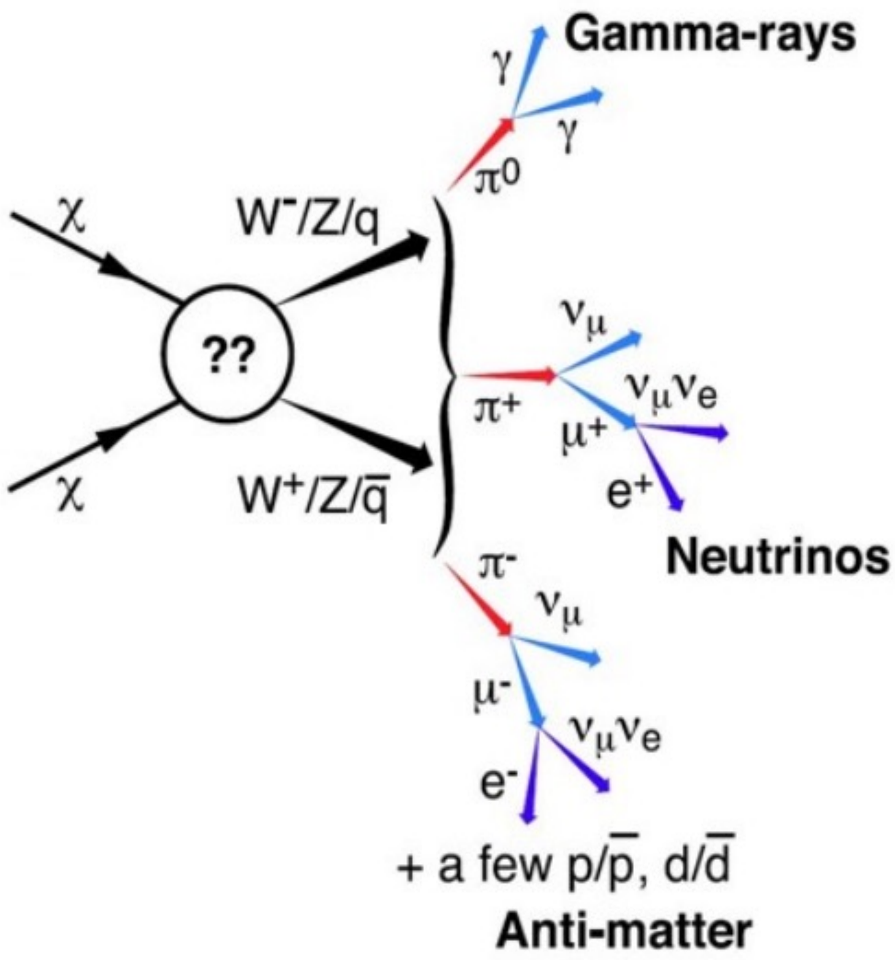
- **Elastic scattering of WIMPs off target nuclei**
  - Spin independent WIMP-nucleon
  - Sub-GeV masses start to be probed
  - Getting closer to the neutrino-floor

NEW

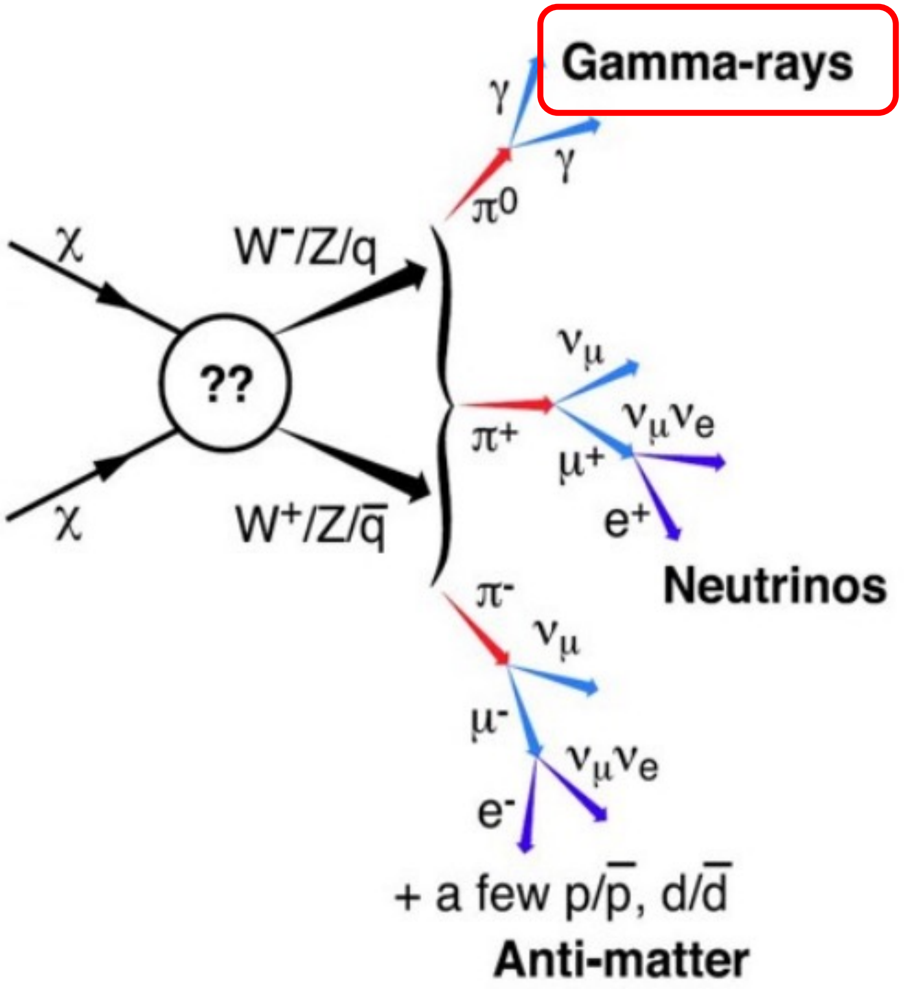
ANAIS (NaI) 3 years data: 314 kg x y exposure
Data consistent with no modulation: incompatible with DAMA at 3.3σ
PRD 103, 102005 (2021)



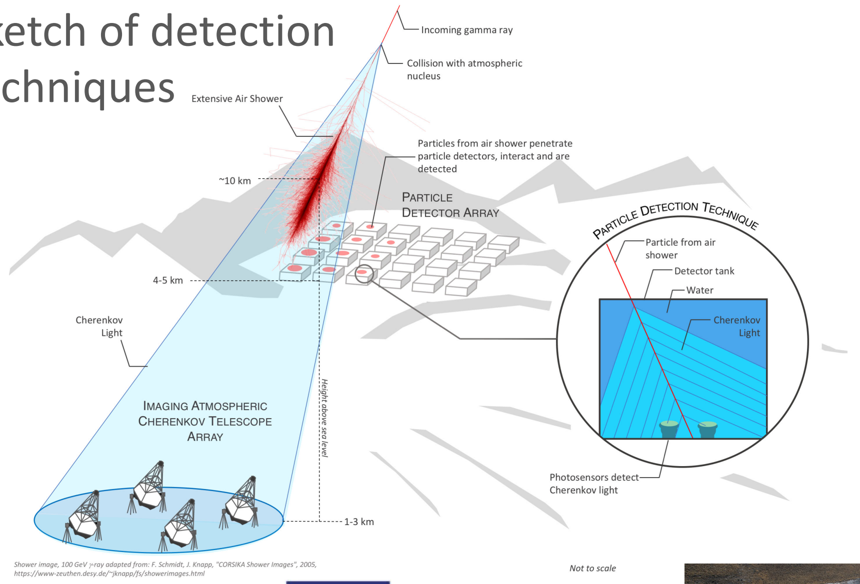
WIMPs – indirect detection

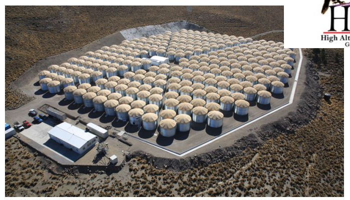


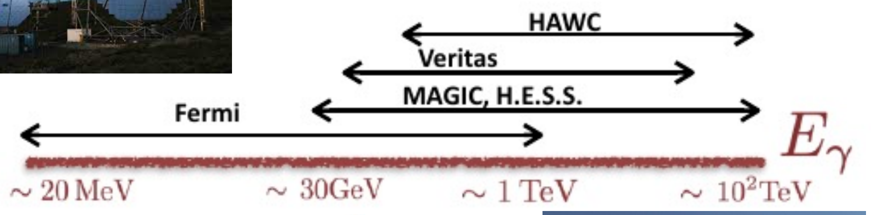
WIMPs – indirect detection



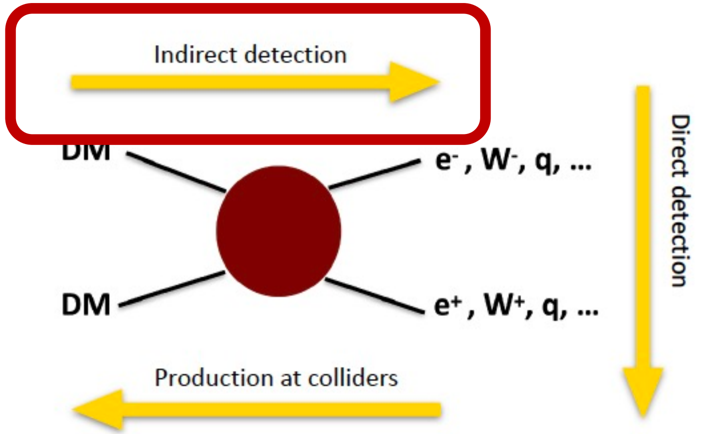
Sketch of detection techniques

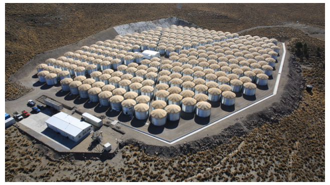






WIMPs – gamma-ray indirect detection

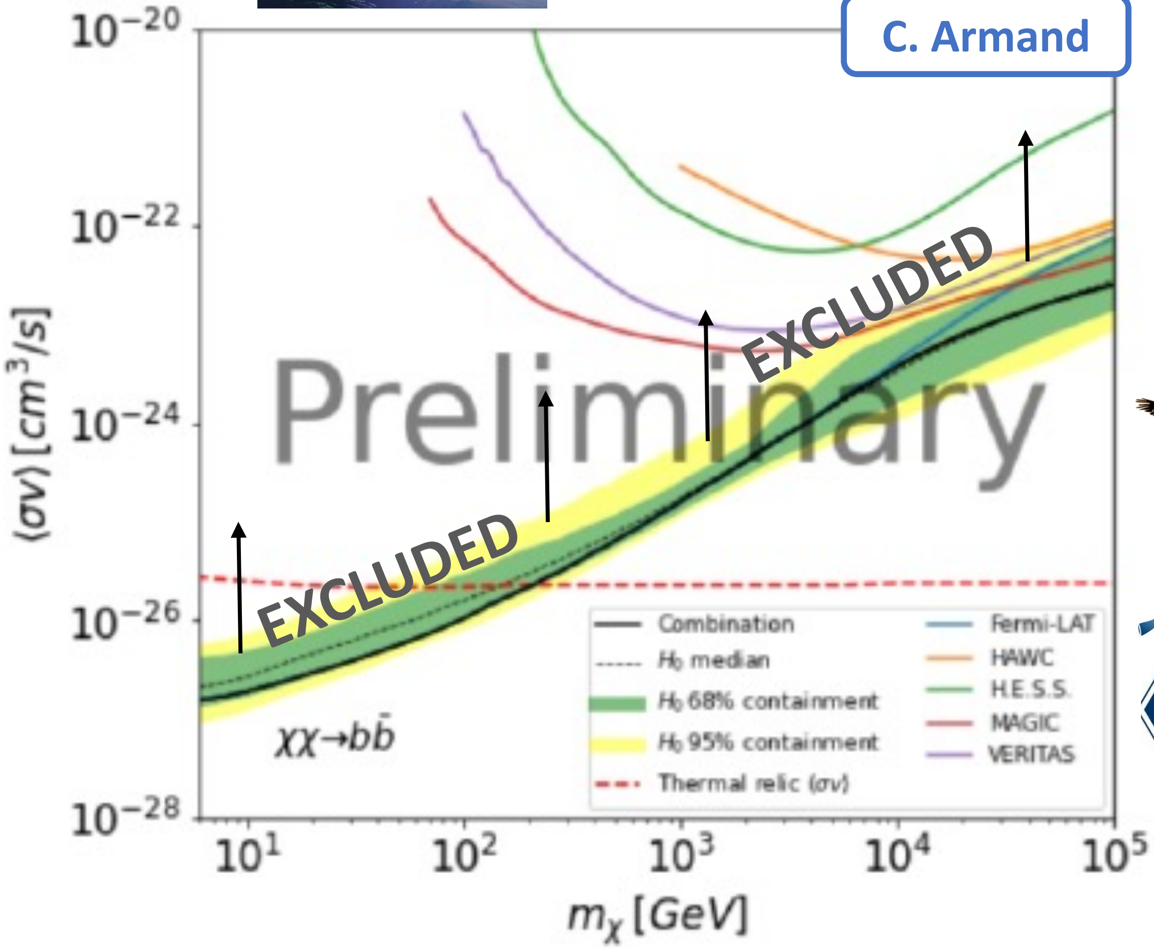




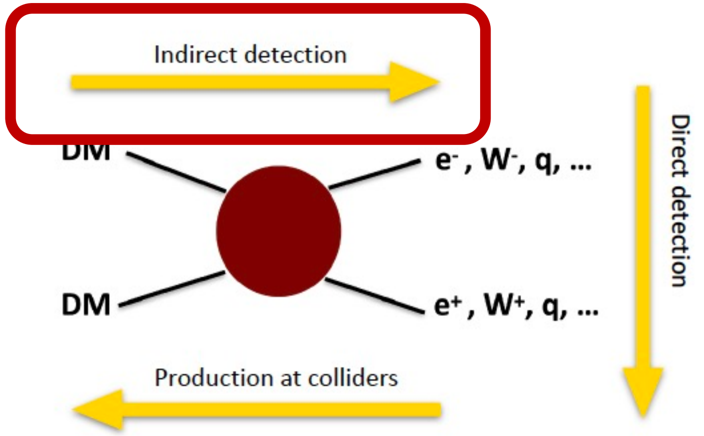
C. Armand

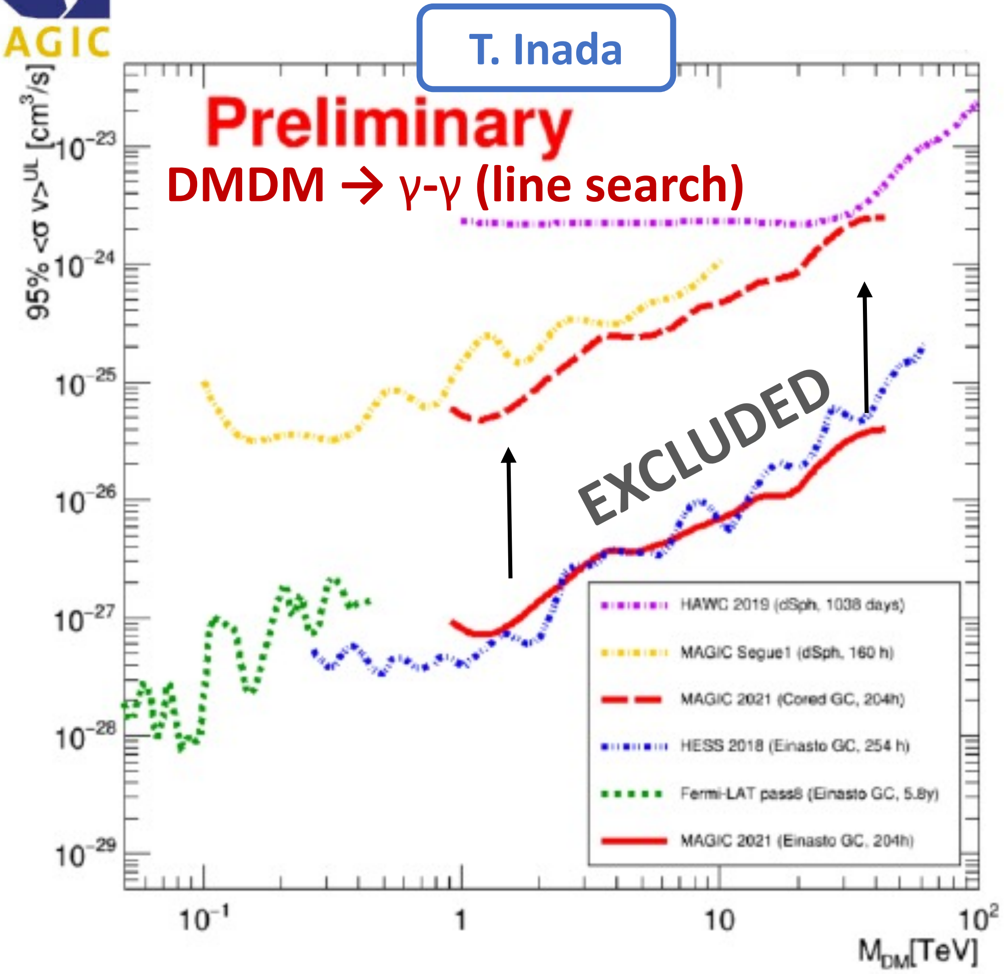
- **Observations of overall 20 dwarf spheroidal galaxies by five instruments**
  - No overall excess in the stacked dataset
  - Different J-factors computation and uncertainties tested
  - Common analysis procedure

→ **2-3 times more constraining limits than individual analyses.**



WIMPs – gamma-ray indirect detection

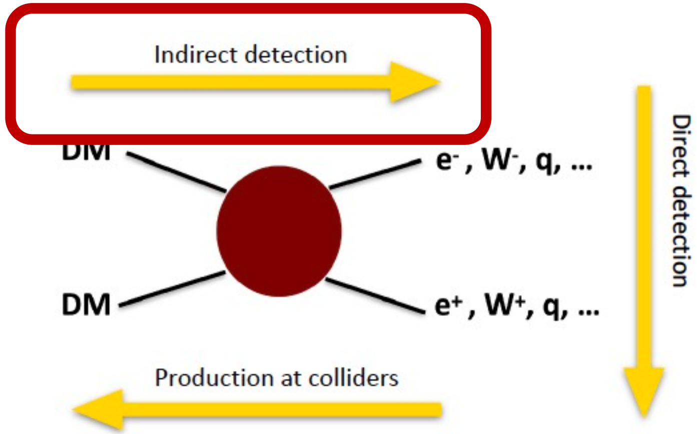




- **<u>NEW</u> observations of the Galactic Center (GC) region for line spectral features search with MAGIC (204 hours)**
  - No significant excess
  - Large energy threshold due to high zenith angle observations
  - Reach H.E.S.S. 2018 limits above ~1TeV

→ **Upper limits on the annihilation cross section of DM particles**

WIMPs – gamma-ray indirect detection



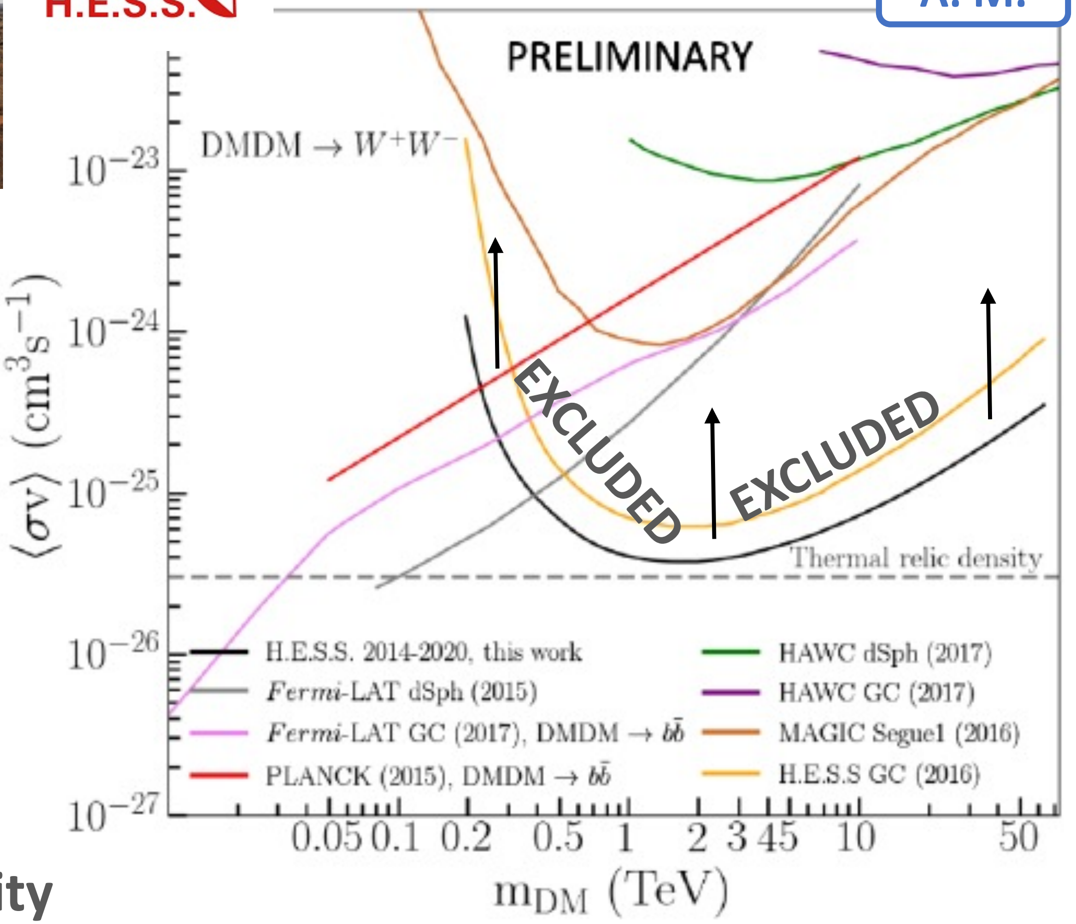
H.E.S.S.

- <u>NEW</u> observations of the GC region with the 5-telescope H.E.S.S. array (546 hours)
  - First ever conducted survey at TeV energies of the GC
    - Inner Galaxy Survey (IGS)
  - No significant excess

→ **Upper limits on the annihilation cross section of DM particles**

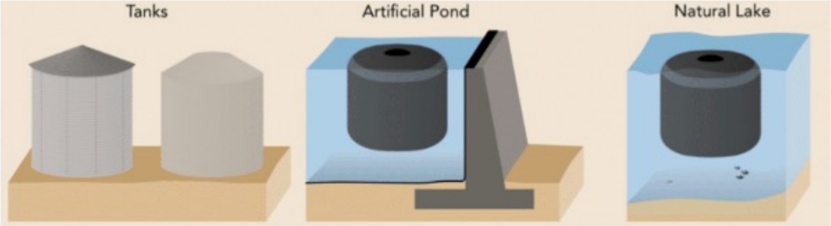
→ **Present constraints can challenge DM thermal relic density**

A. M.



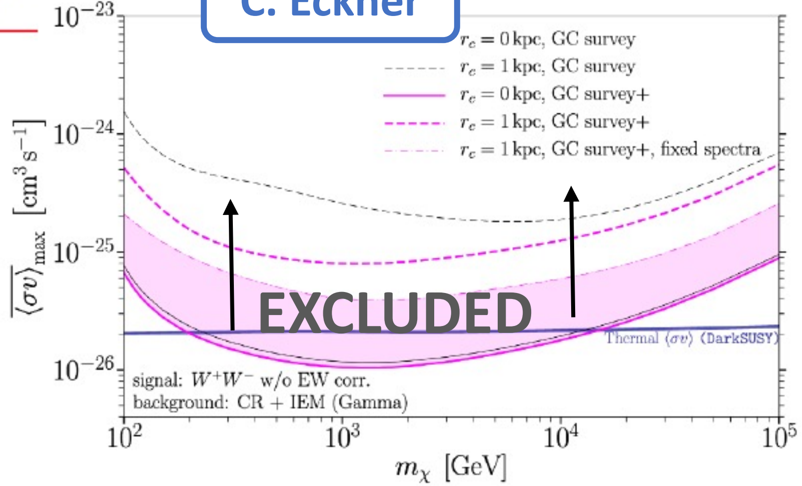
WIMPs – gamma-ray indirect detection - prospects

cherenkov telescope array

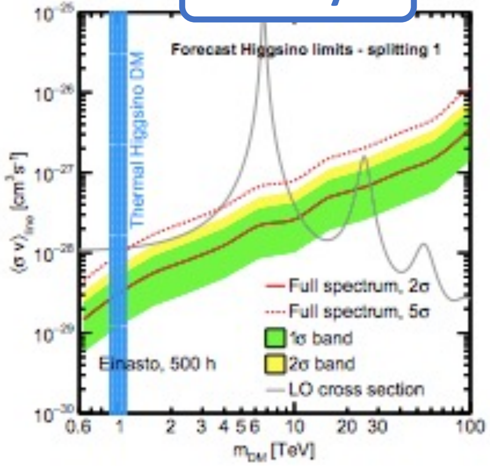


SWGO The Southern Wide-field Gamma-ray Observatory

C. Eckner

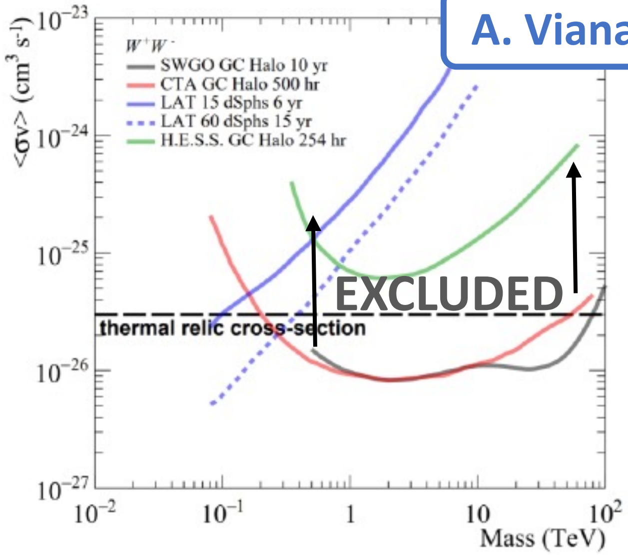


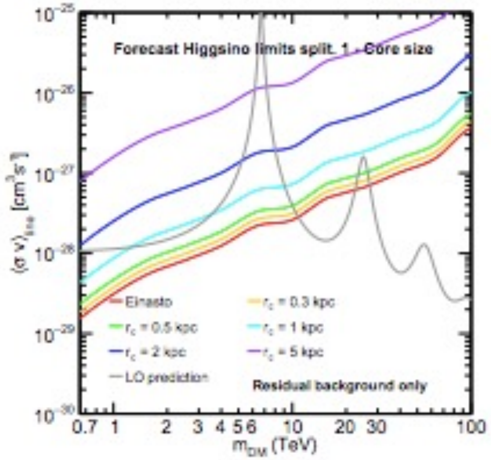
T. Slatyer



W+W- channel

A. Viana





- **Sensitivity <u>prospects</u> with observations of the GC region**
  - CTA: array of Cherenkov telescopes (500 hours)
  - SWGO: ground based gamma-ray detector (10 years)

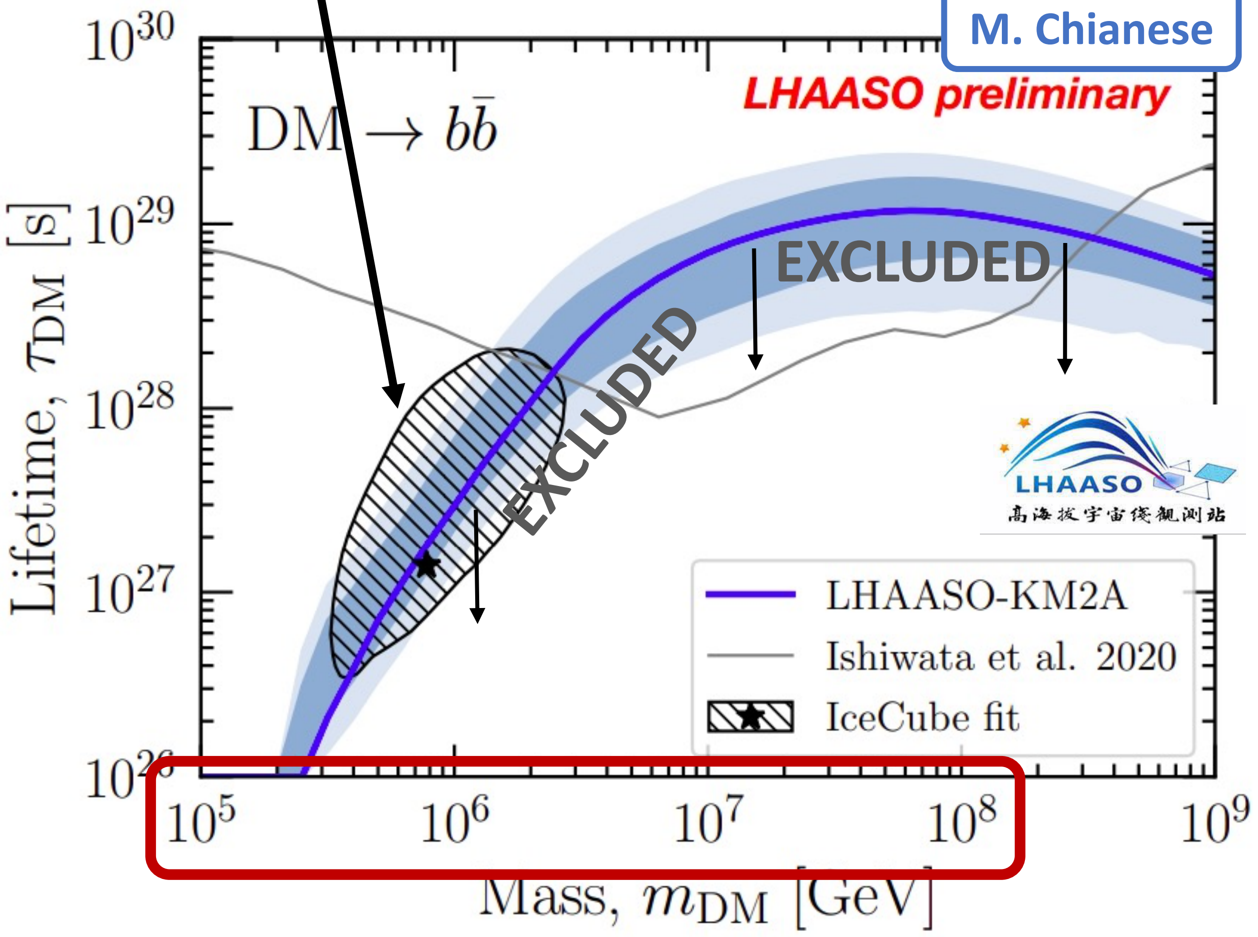
Constraints will challenge
→ thermal relic density
→ canonical DM models such as Wino and Higgsino

Decaying DM with LHAASO

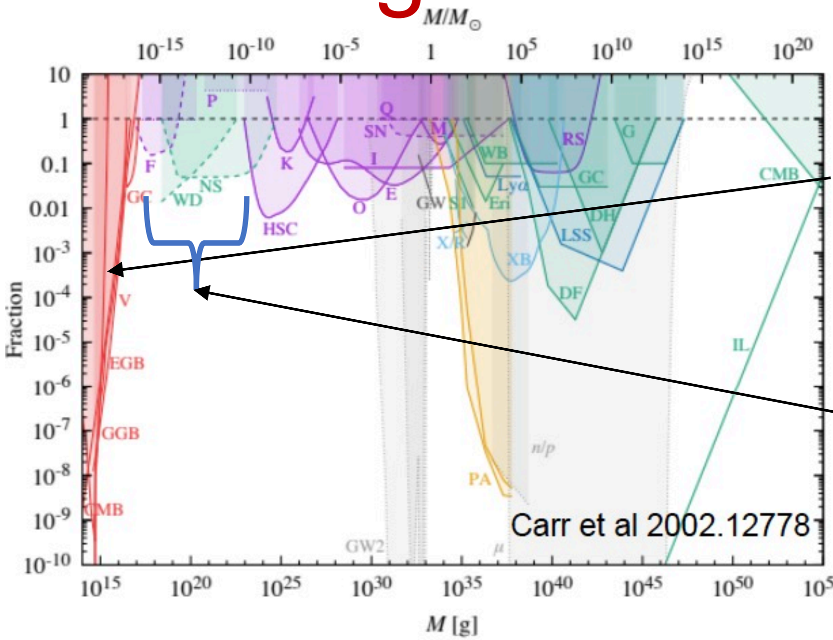
- <u>NEW</u> **observations of the GC region with LHAASO (340 days)**
  - First results on DM with LHAASO
  - → **Lower limits on the lifetime of DM particles**
  - → **Challenge the HE IceCube events as PeV DM**

Explanation of HE IceCube neutrinos as PeV DM

M. Chianese

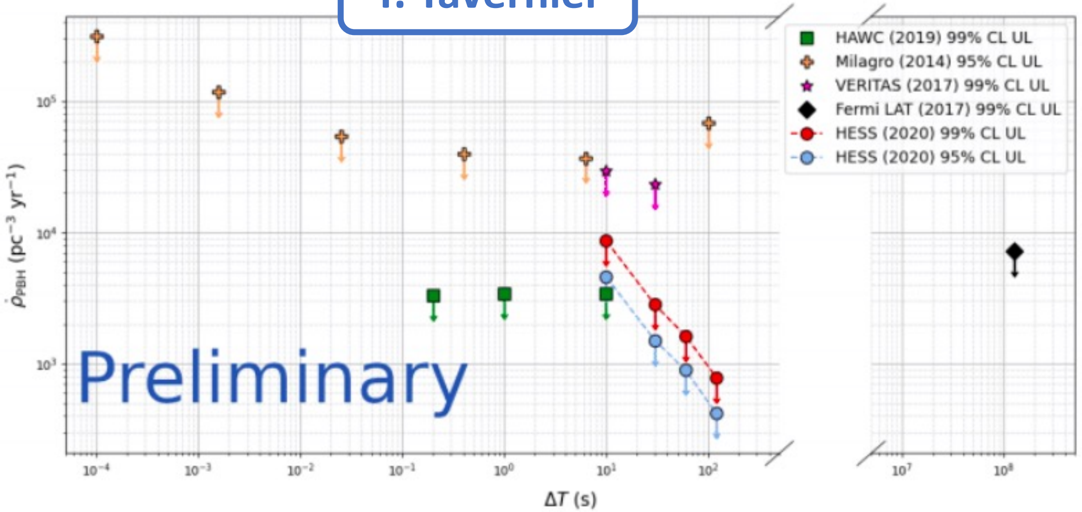


Photon signals from PBHs



- Bounds from PBH evaporation
- Open window in the mass range $10^{17} - 10^{23}$ g (Dashed lines → debated constraints)

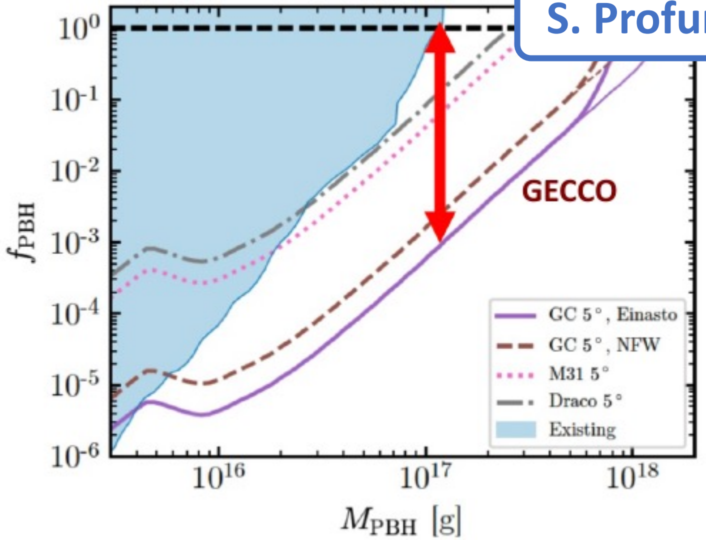
T. Tavernier



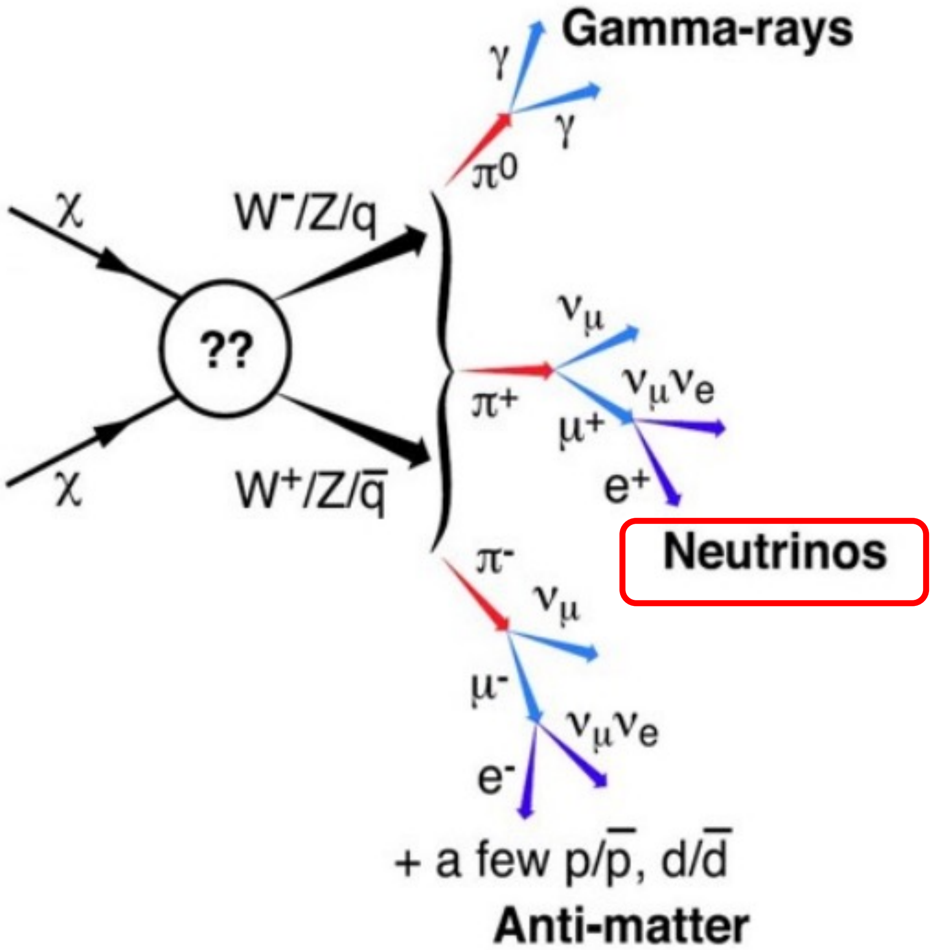
- **Observations of PBHs with H.E.S.S. (4924 hours)**
  - NEW limits on the evaporation rate
  - PBHs are unlikely to participate significantly in the missing mass of the universe

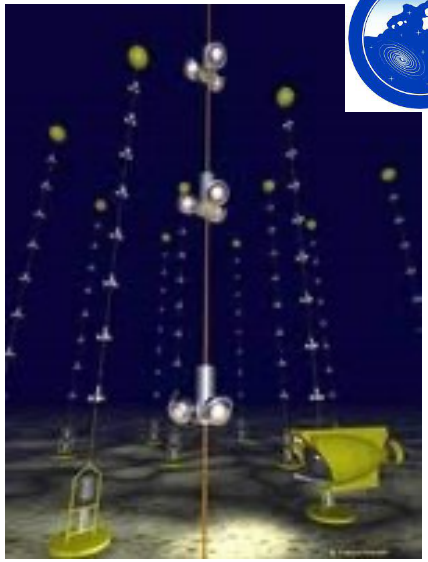
- **Sensitivity prospects of MeV satellite**
  - Probing part of the open window
  - Constraining the fraction of PBHs as DM

S. Profumo

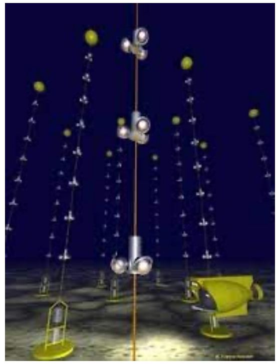


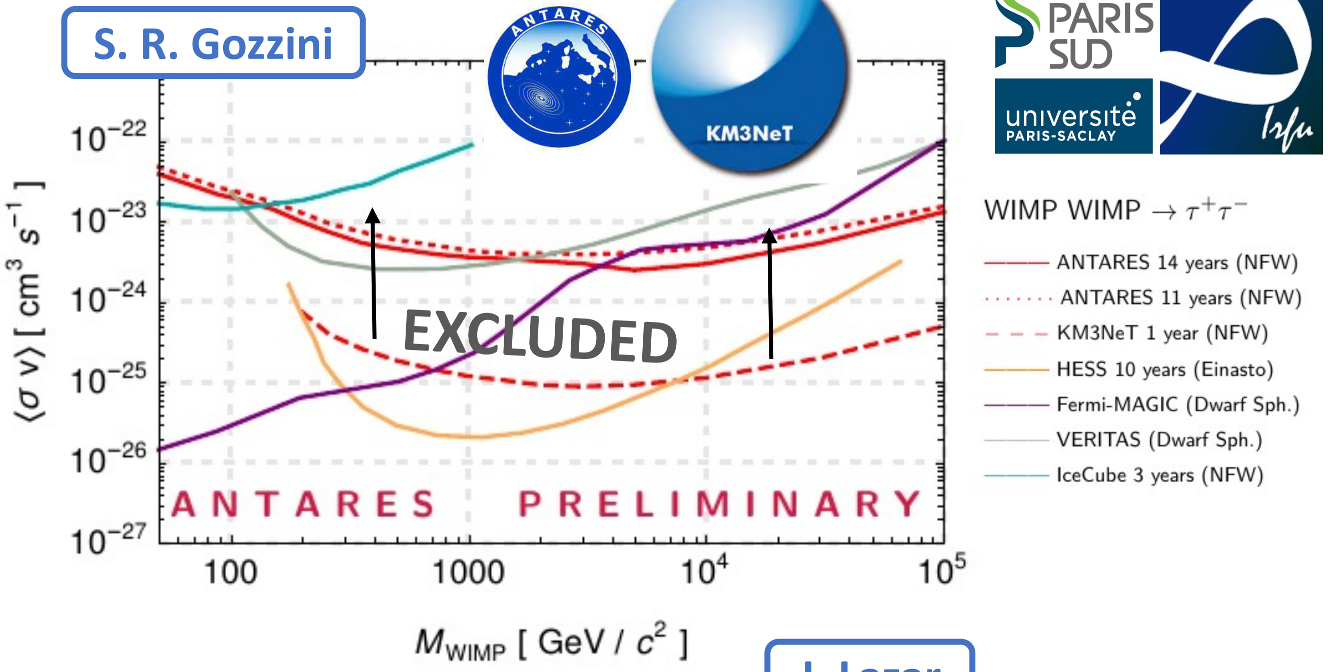
WIMPs – indirect detection



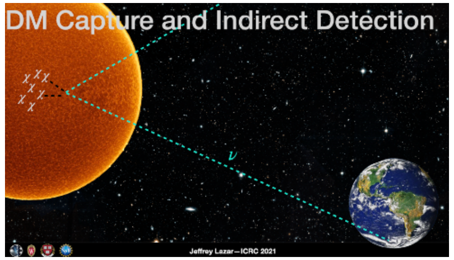


Neutrinos





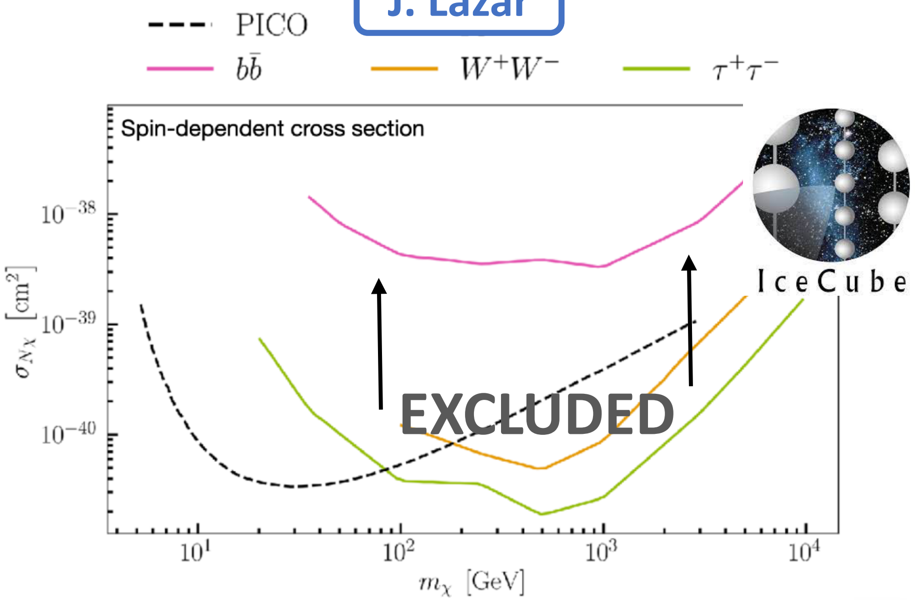
- **Observations of the GC region**
  - ANTARES data (14 years), sensitivity prospect with KM3NeT (1 year)
  - → **Upper limits on the annihilation cross section of DM particles**



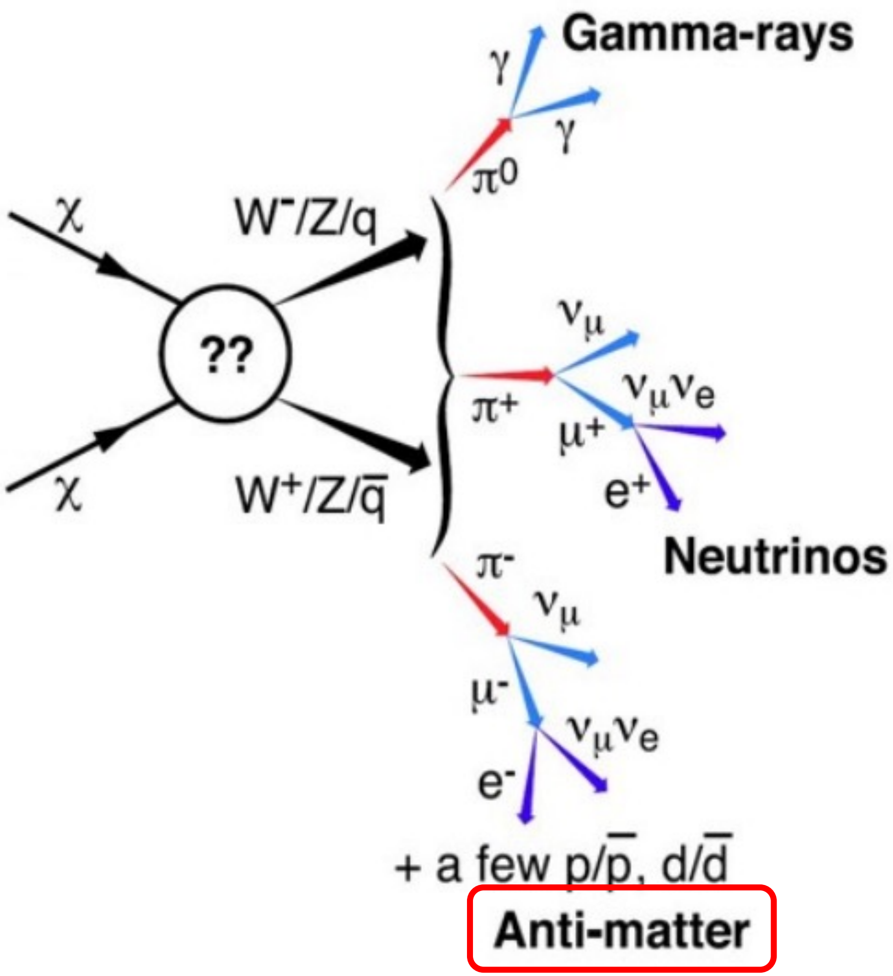
$$\frac{\Gamma_A}{2} = C_C \propto \sigma_{\chi N}$$

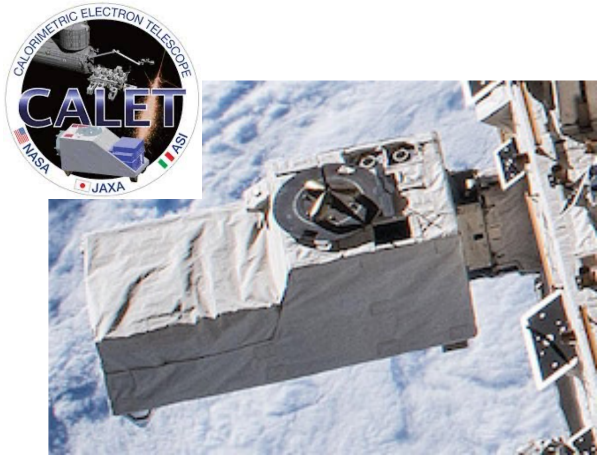
- **Neutrinos from the Sun**
  - IceCube data

→ **Upper limits on the SD annihilation cross section of DM particles**

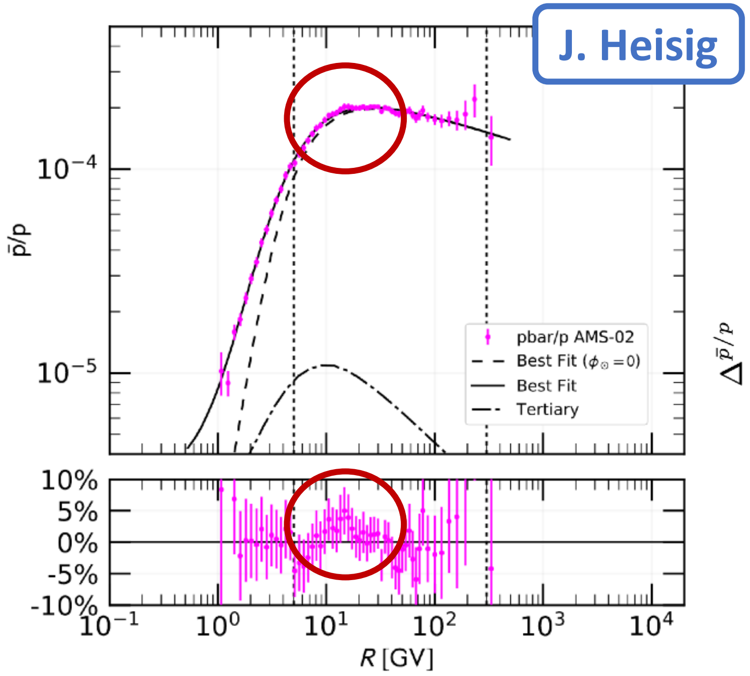


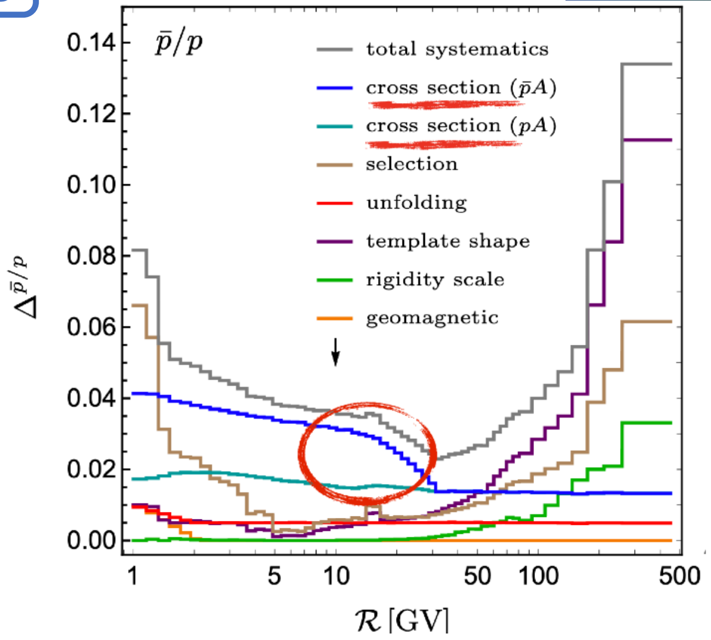
WIMPs – indirect detection





Charged cosmic rays – antiprotons, positrons

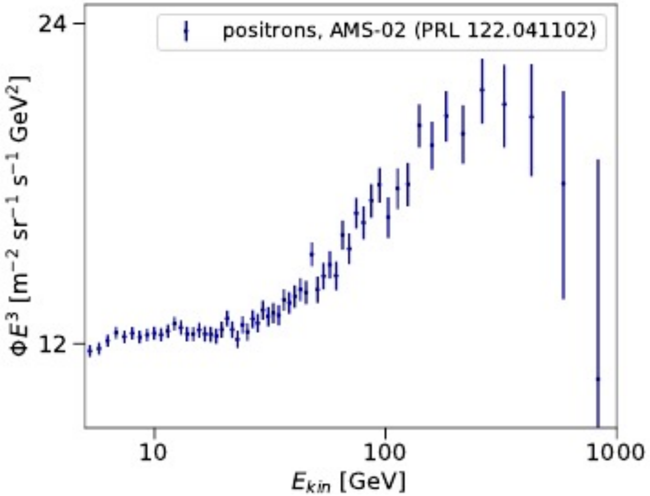


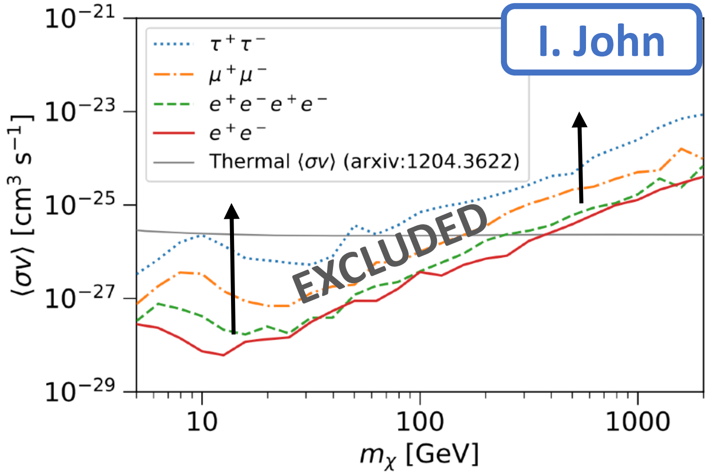


Cosmic ray data from AMS-02

- **Antiprotons:**
  - Hint for an excess in anti-p data compatible with DM
  - <u>**NEW**</u> studies: systematic uncertainties at few % level are important
- **Positrons:**
  - Most of the signal can be explained by nearby pulsars

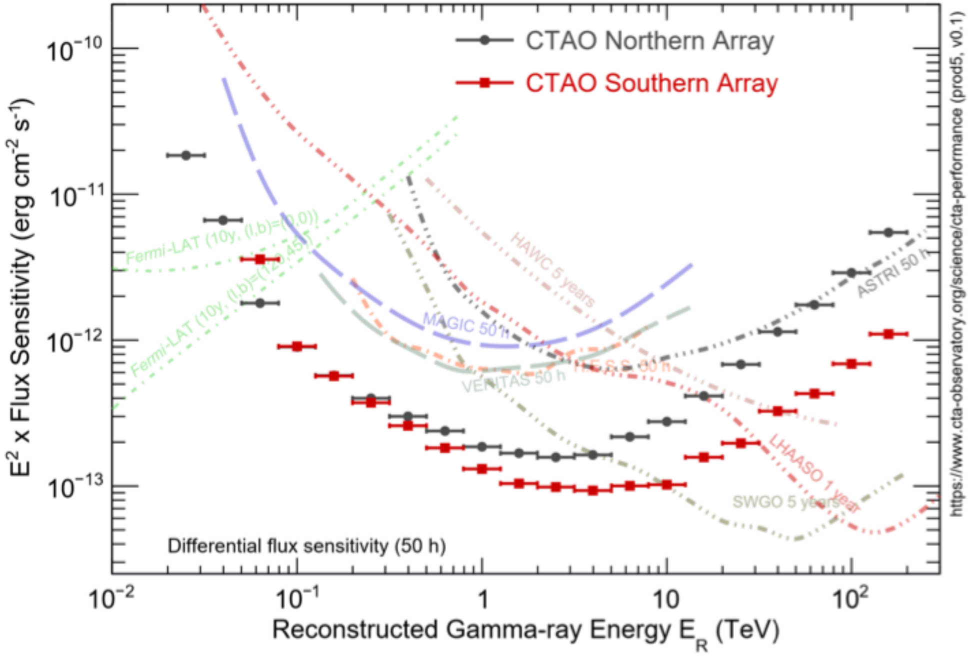
  → **Latest constraints on DM**

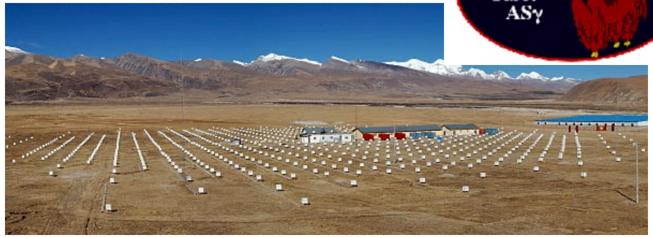




Gamma ray very-high-energy and extended sources

Gamma ray very-high-energies and extended sources





LHAASO 高海拔宇宙线观测站

Tibet ASγ

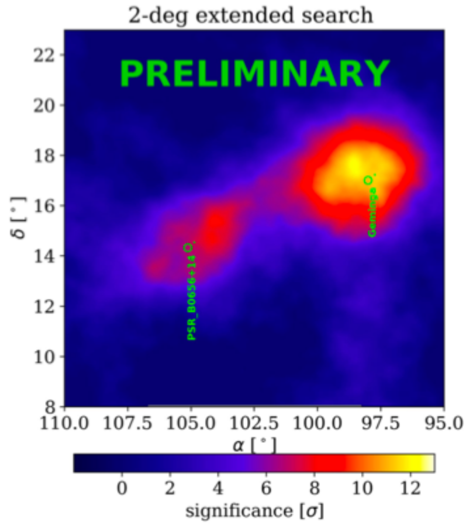
DARK MATTER PARTICLE EXPLORER DAMPE

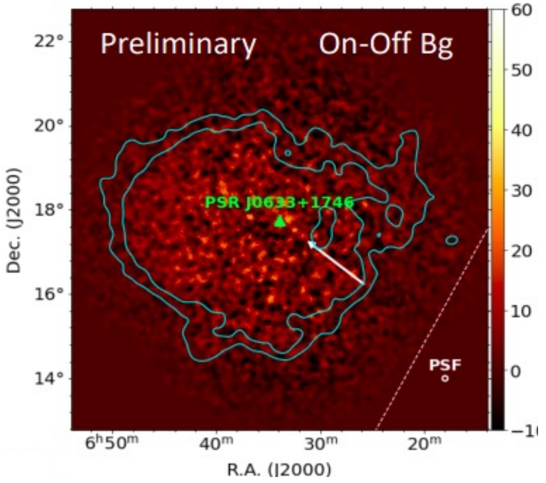
H.E.S.S.

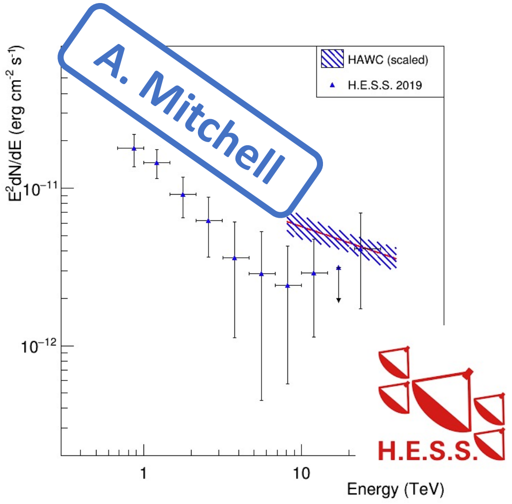
Fermi Gamma-ray Space Telescope

Pulsar Wind Nebulae and halos: Geminga

- **HAWC measurements around Geminga**
  - Diffusion coefficient a factor 100 lower than from local measurements



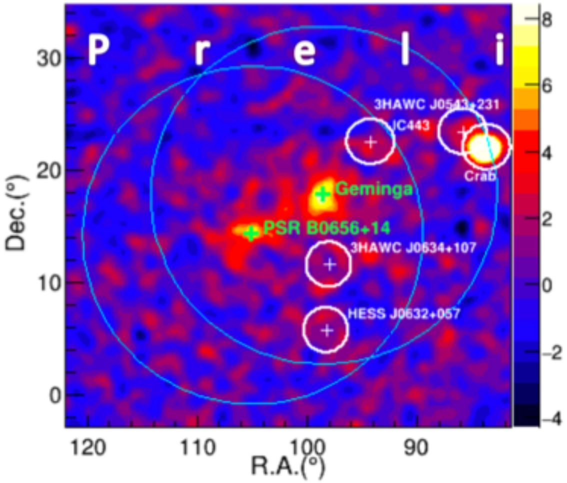


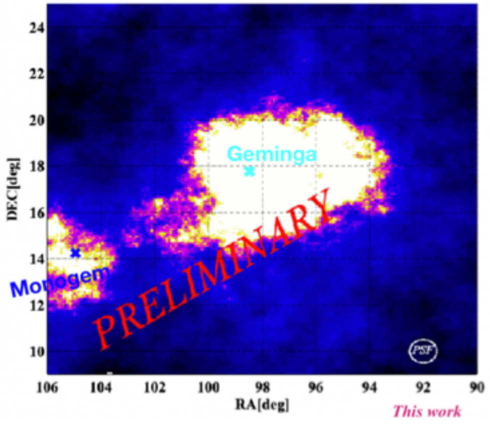


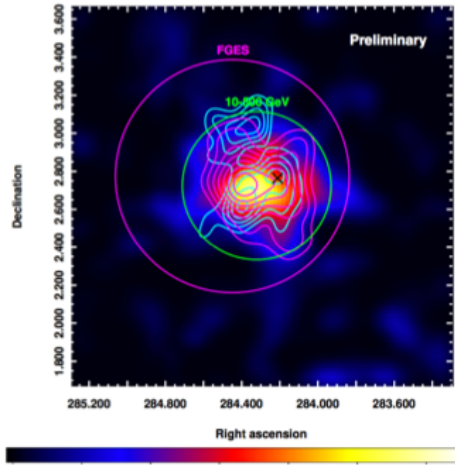
- <u>NEW</u> **Improvements in the data analysis of H.E.S.S. measurements around Geminga**

- Diffusion suppressed in halo regions?

- **More halos candidates seen by LHAASO and TibetAS-γ**







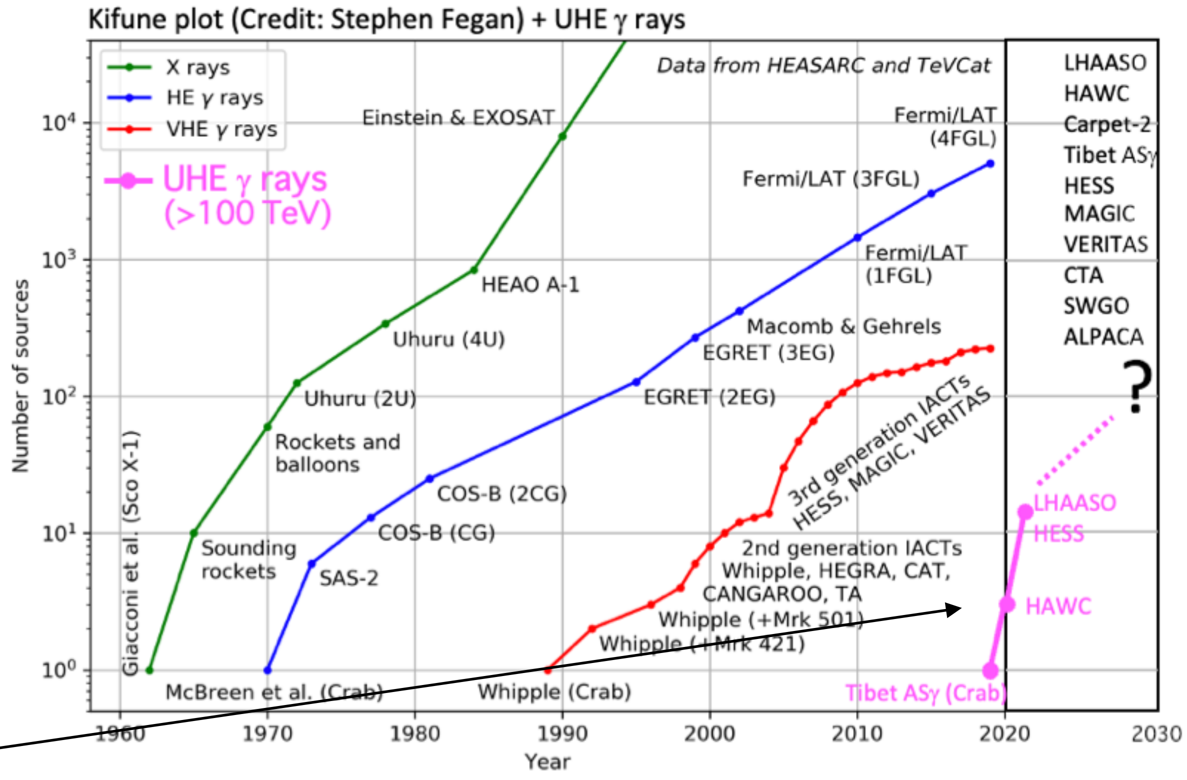
VHE gamma rays and PeVatrons

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

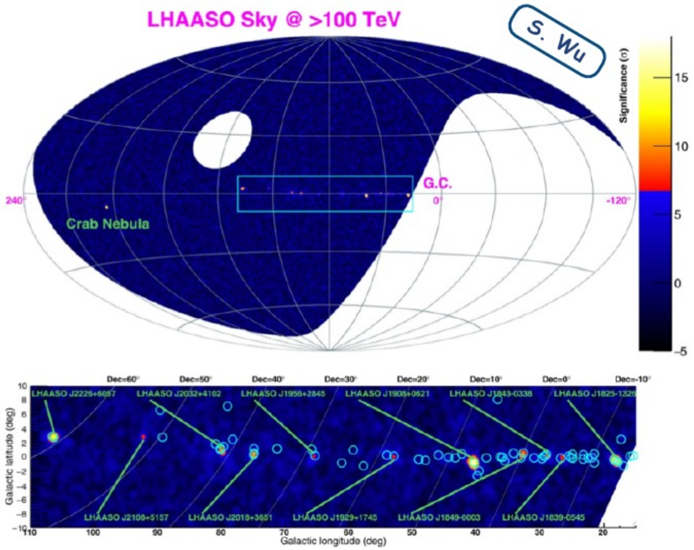
- **What is a PeVatron?**
  - Only hadronic accelerators?
  - “Leptonic PeVatrons”?

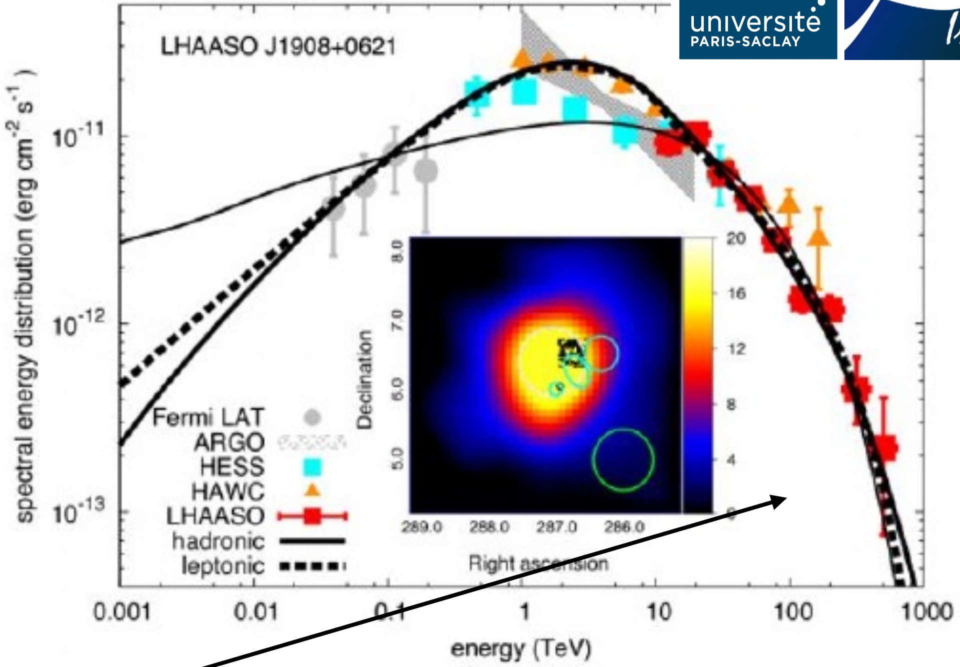
- **When is it no longer a candidate?**
  - Clear accelerator
  - Confirmed hadronic
    - Coincident neutrino

- **How many PeVatrons do we know so far?**
  - 14 UHE sources

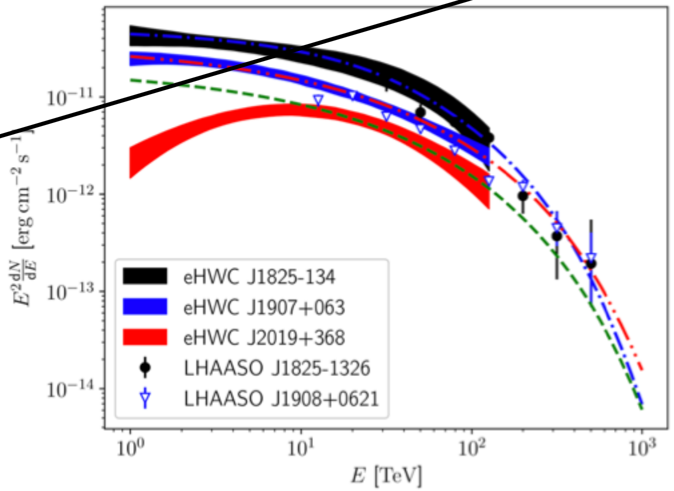


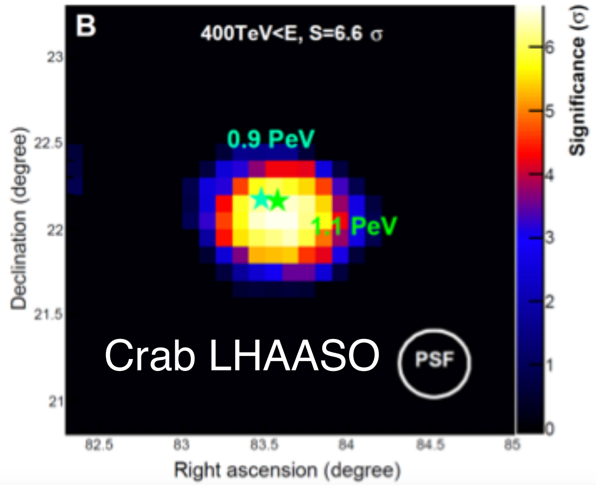
LHAASO UHE photons (E>100 TeV)





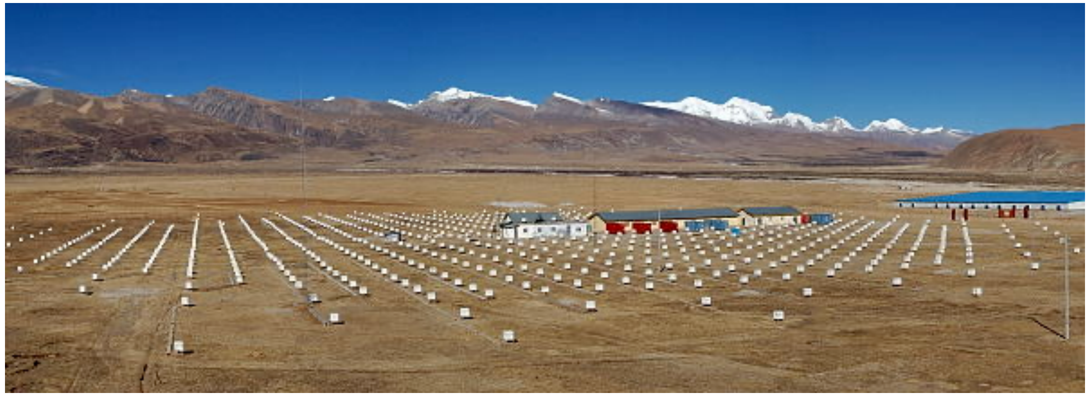
- **<u>NEW</u> observations of Galactic sources with LHAASO**
  - Detection of UHE sources
  - More than 7σ at >100 TeV
  - Spectra with photons at ~PeV energies



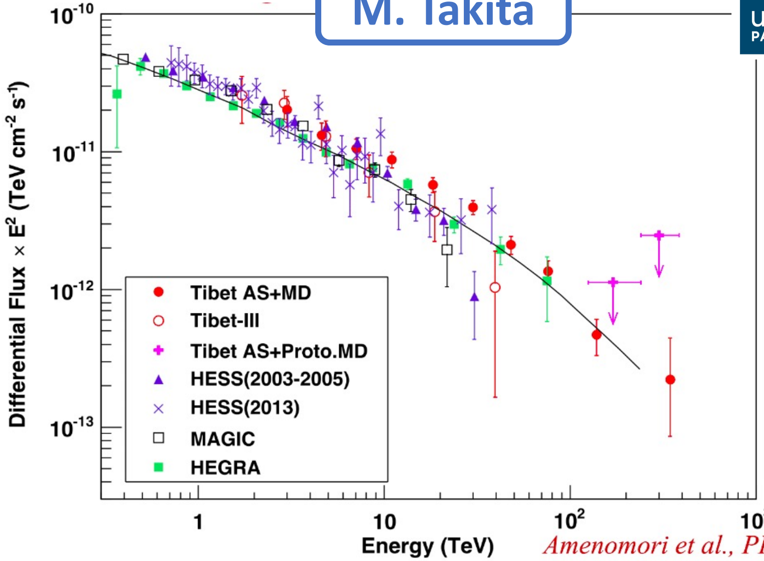


→ First PeVatrons after the H.E.S.S. PeVatron detection (*Nature* 531, 476–479 (2016))

TibetAS-γ VHE photons sources



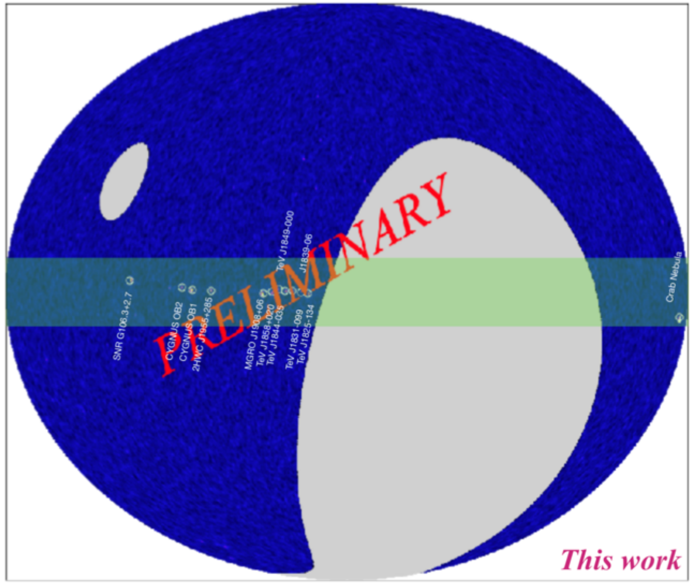
M. Takita



Amenomori et al., PRL (2019)

- **Observations of Galactic sources with TibetAS-γ**
  - Detection of VHE sources
  - More than 5σ at >100 TeV
  - Photon at 450 TeV from the Crab Nebula

→ ~9 coincident with LHAASO UHE sources



X. Chen

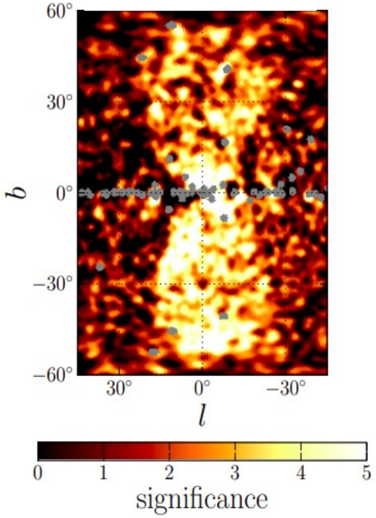
Associated Source	RA[deg]	Dec[Deg]
Crab	83.65	22.02
TeV J1825-134	276.52	-13.4
TeV J1831-099	277.58	-9.84
TeV J1840-055 TeV J1837-065	279.91	-6.03
TeV J1844-035	280.92	-3.58
TeV J1849-000	282.84	0.03
TeV J1857+026	284.70	2.66
MGRO J1908+06	287.01	6.20
2HWC J1955+285	298.87	28.63
Cygnus OB1	305.02	36.77
Cygnus OB2	308.01	41.19
SNR G106.3+2.7	336.77	60.88

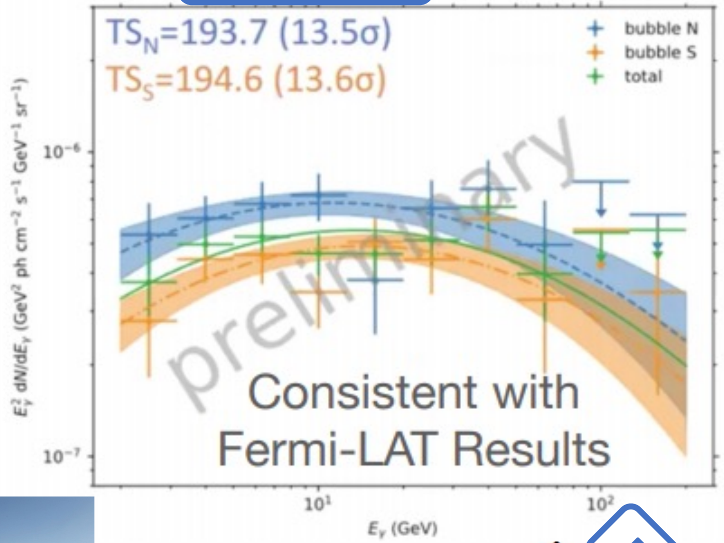
This work

Extended VHE gamma-ray sources

Z. Q. Shen

- Fermi Bubbles, close to the GC region
    - Previously detected by *Fermi*-LAT



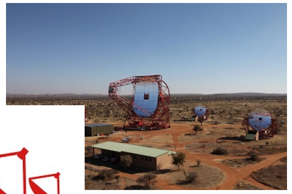


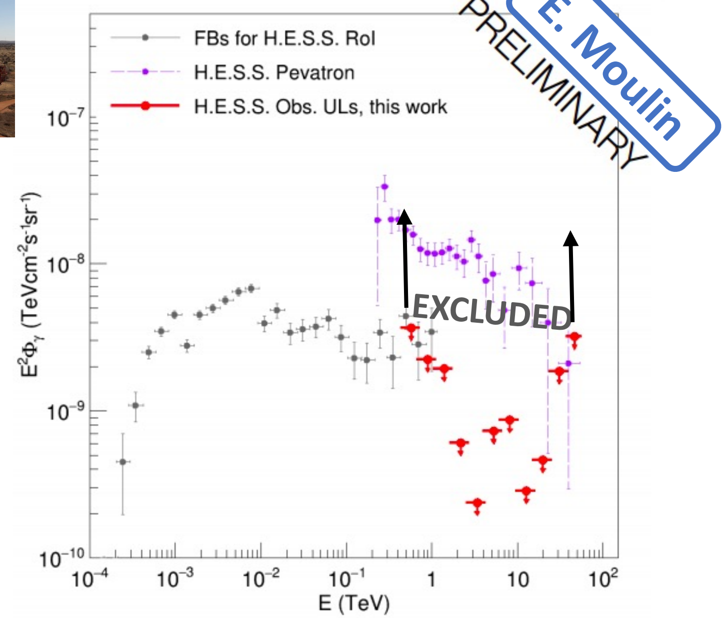
- **Search for the Fermi Bubbles emission**
    - Extended source at GeV and TeV energies
    - Understanding the properties of the parent-particle population

→ NEW DAMPE flux points consistent with *Fermi*-LAT measurements (with 4.8 year dataset)

→ NEW H.E.S.S. upper limits at the base of FBs (with 546 hours - IGS)

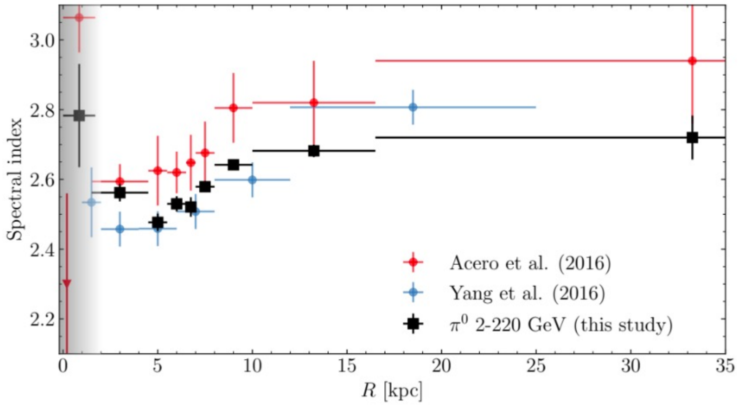
→ strong constraints on the energy cutoff in spectra of parent-particle population!





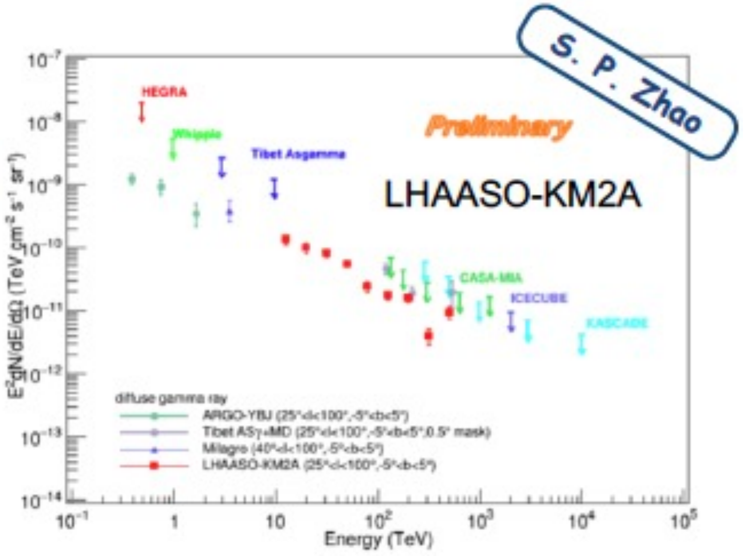
Cosmic ray distribution models in the Galaxy

- Does the cosmic ray spectrum harden towards the GC as seen from gamma-ray measurements?



Prothast, Gaggero, Strom, Weniger, 2018

  - NEW *Fermi*-LAT measurements of the hardening



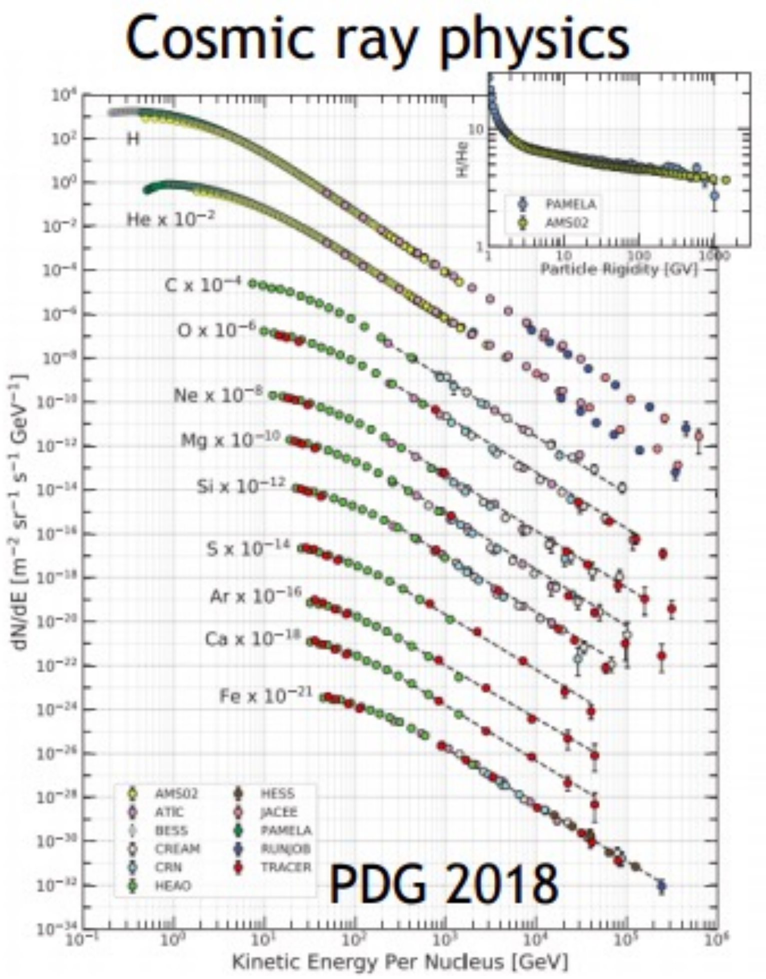
- **NEW observations in the Galaxy**
  - Complementary facilities

→ Present data cannot distinguish between scenarios with and without hardening towards the GC

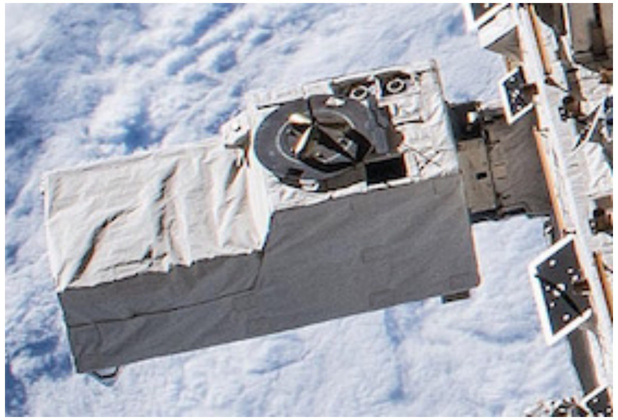
→ Need more data

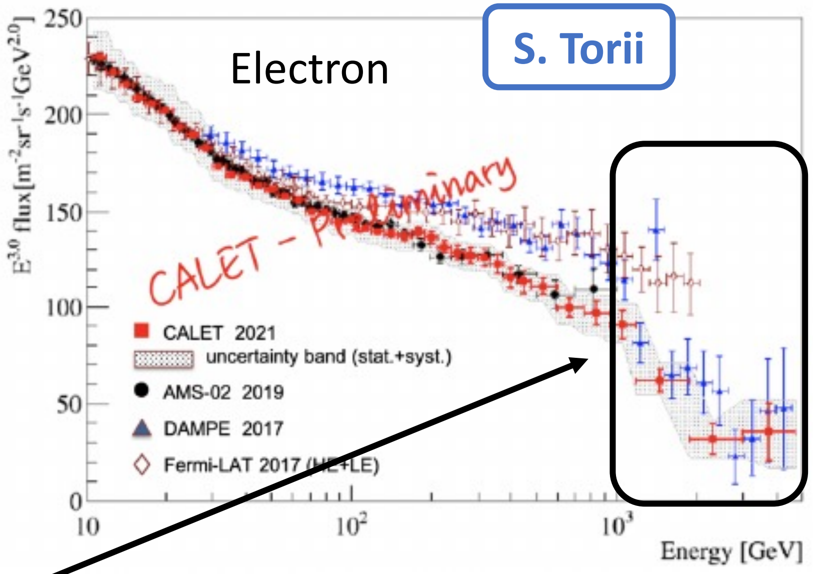
Cosmic ray spectra and anisotropies

Cosmic ray spectra and anisotropies

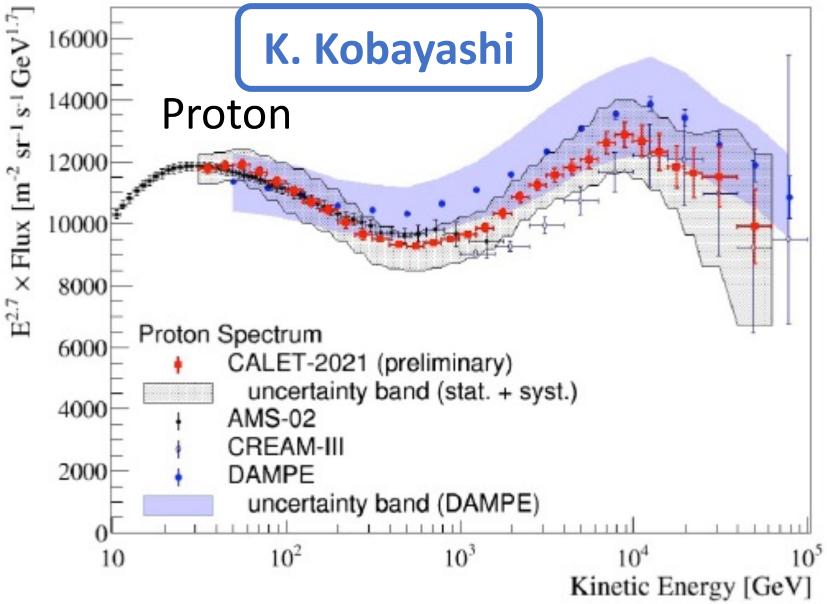


CALET electron/positron and proton spectra



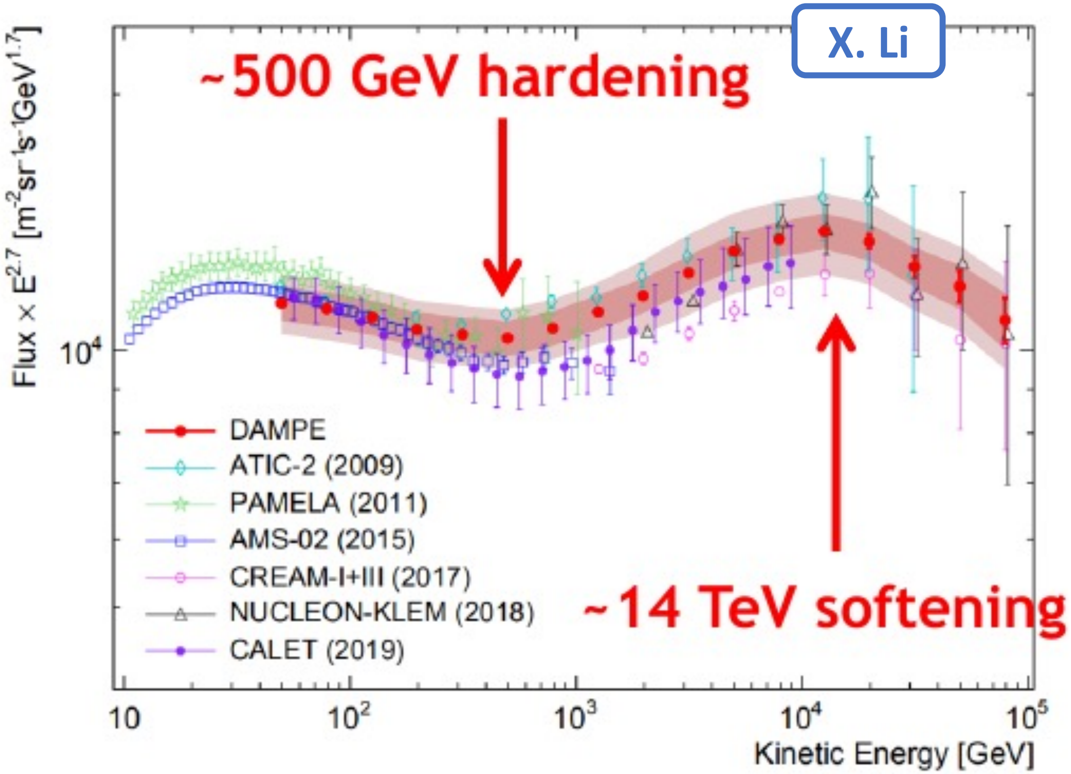


- <u>NEW</u> **cosmic rays spectra measured with CALET**
  - Electron and positron spectra, in agreement with AMS
    - Suppression over 1 TeV at >6.5σ
  - Proton spectrum, in agreement with DAMPE
    - Progressive hardening up to TeV energies



→ Improvement in the statistics → more data
→ Extended energy reach to ~ 60 TeV
→ Systematic uncertainties being worked out

DAMPE proton spectrum



- <u>NEW</u> cosmic rays spectrum measured with DAMPE
  - Proton spectrum
  - In agreement with CALET
  - Measured hardening at ~500 GeV and softening at ~14 TeV

Conclusions

- **Contributions from new observatories**
- **Networks for coincident observations**
- **Blazars and neutrinos events**
- **More neutrino alerts**
- **New results on Dark Matter**
- **PeV era just started!**
- **Analyses of extended TeV sources and propagation/distribution of cosmic rays**
- New detectors with different operating modes and complementary techniques
- More community open tools

→ **Plenty of exciting results**

→ **Stay tuned for the upcoming <u>TeV-PeV astrophysics</u>!**


ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
Thank you!
Danke
Merci
Obrigada
Gracias
ありがとう
Dank u
Grazie
Takk
Спасибо
Dankie
谢谢
감사합니다
Teşekkürler
شكرا
Hvala
Dzięki
icrc2021.desy.de
धन्यवाद
תודה

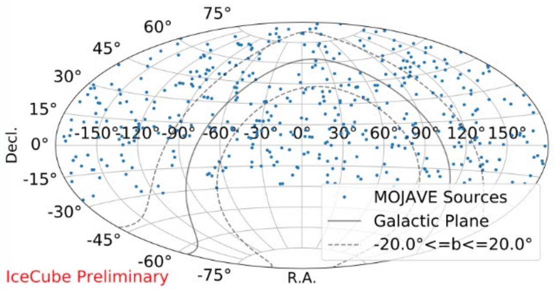
Backup slides

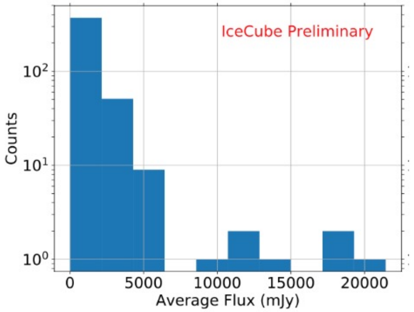
Blazars & Neutrinos

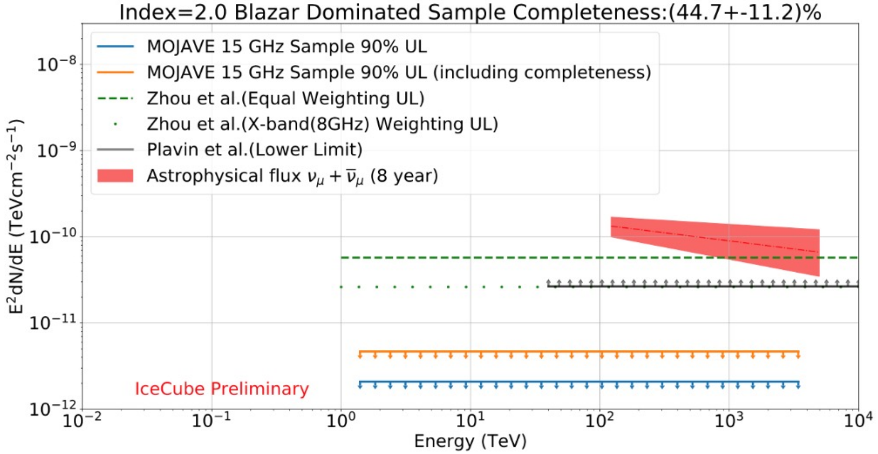
- Interesting correlation between Blazar high radio state and neutrino arrival time.
- Hints that gamma-rays and neutrinos may be produced in different regions of blazars and are not directly related.
- Models statistically consistent with the detection of neutrinos but require extreme parameters, atypical of the blazar population.
- Need to move beyond one-zone model as well as investigate time variability.

Blazars & Neutrinos

Correlation analysis between AGN radio observations reported in the MOJAVE XV catalog and 10 years of **IceCube** data

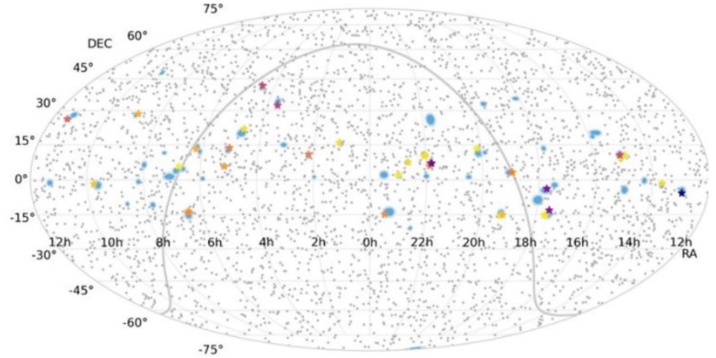


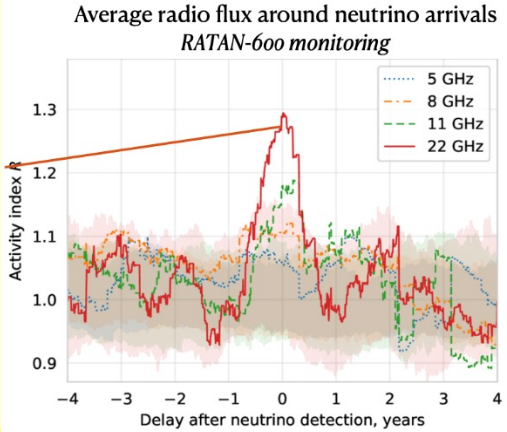




Radio loud AGN can not explain more than 6% of the diffuse neutrino flux.

Correlation analysis between VLBI sample with 10 years of **IceCube** data

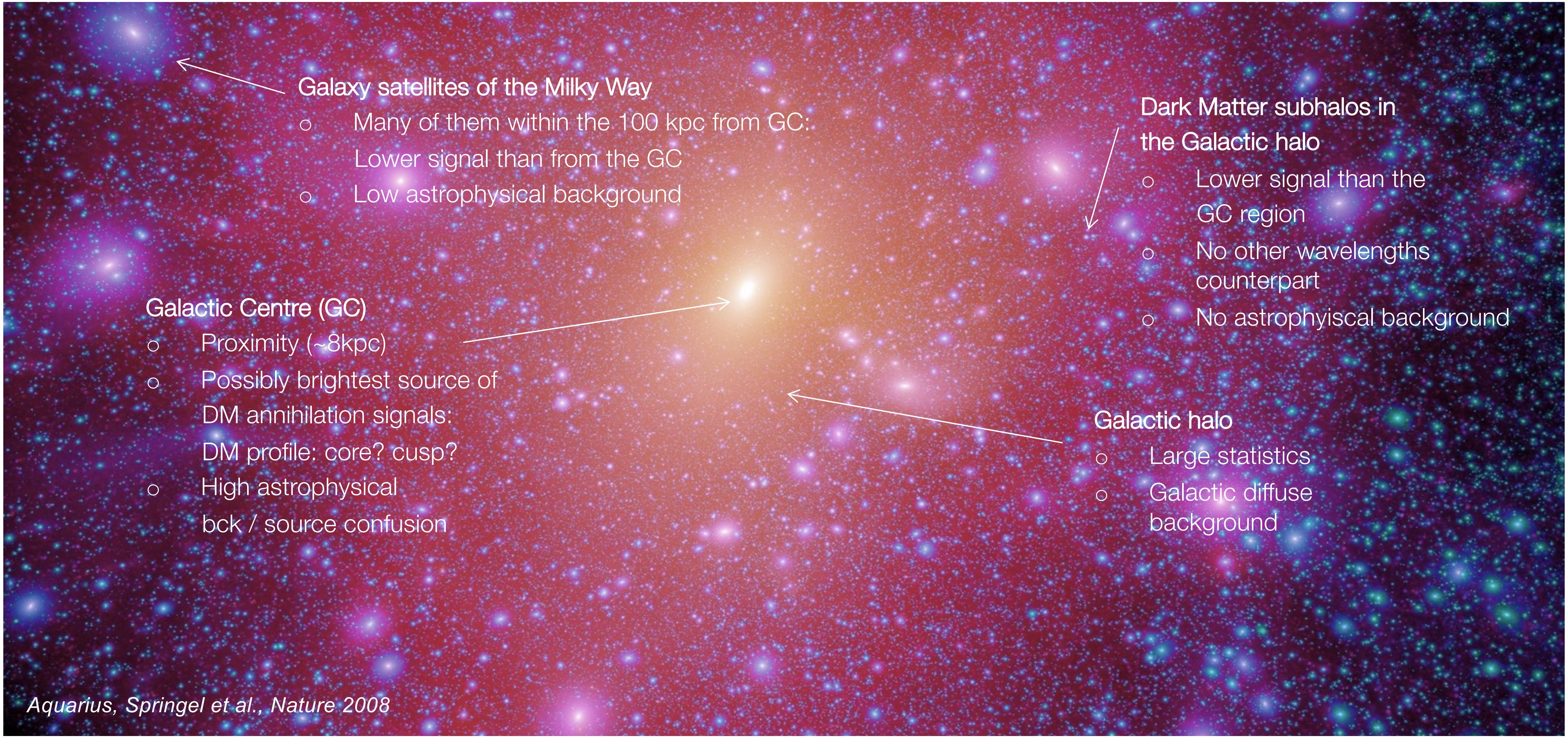




Neutrinos arrive when blazars are brighter in radio (strong effect for PKS 1502+106)

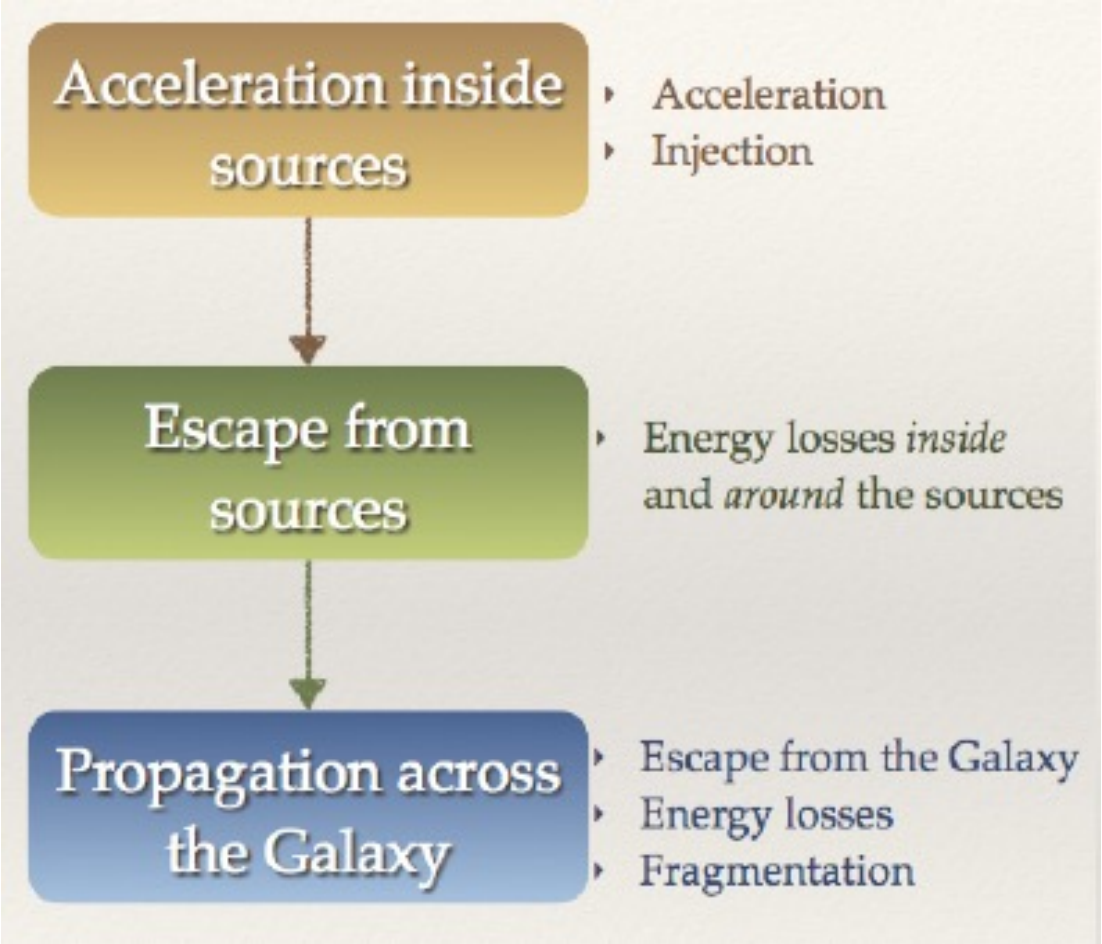
Hints that gamma-rays and neutrinos may be produced in different regions of blazars and are not directly related.

Dark Matter targets in gamma rays

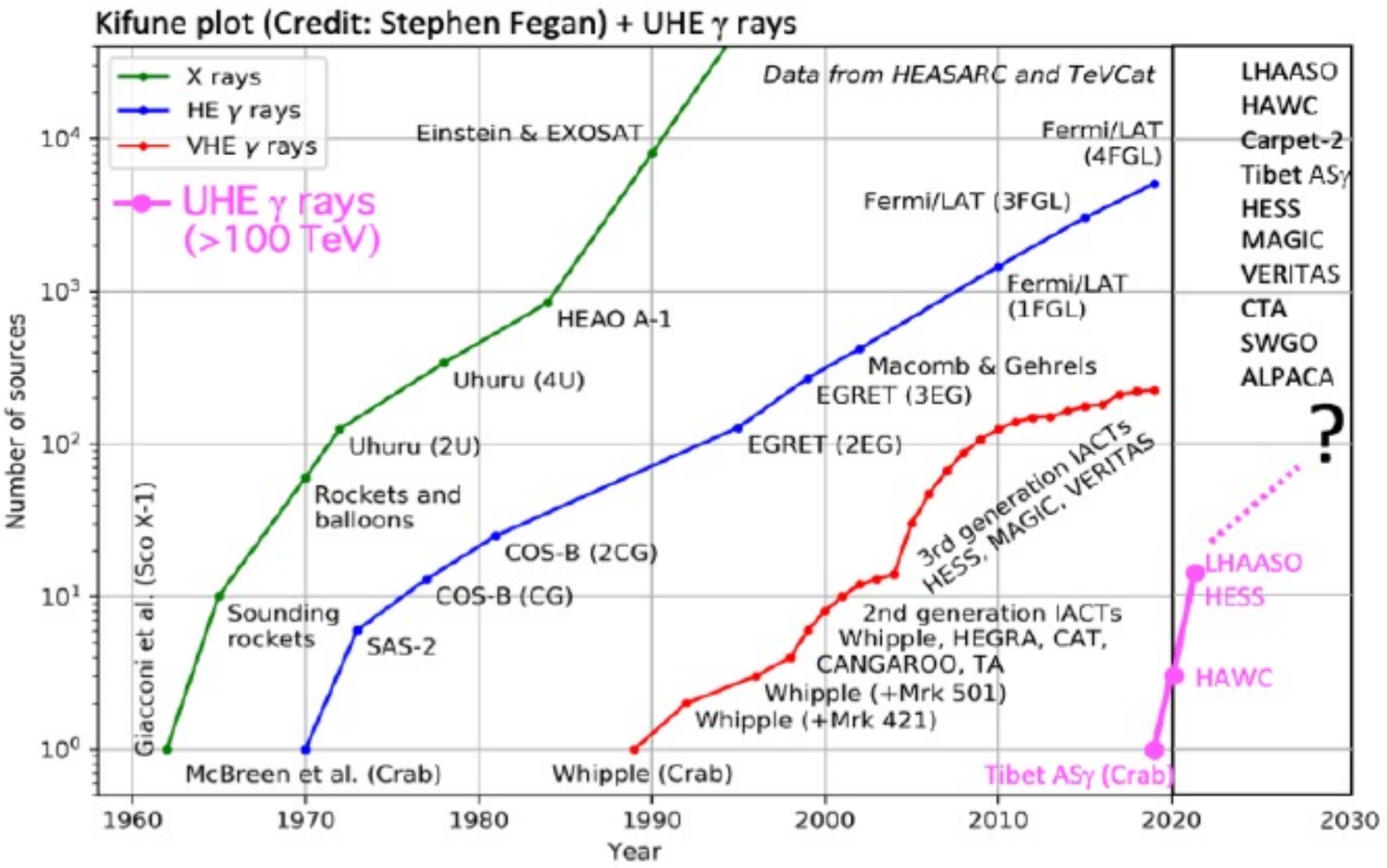


Aquarius, Springel et al., Nature 2008

Origins of Galactic Cosmic Rays

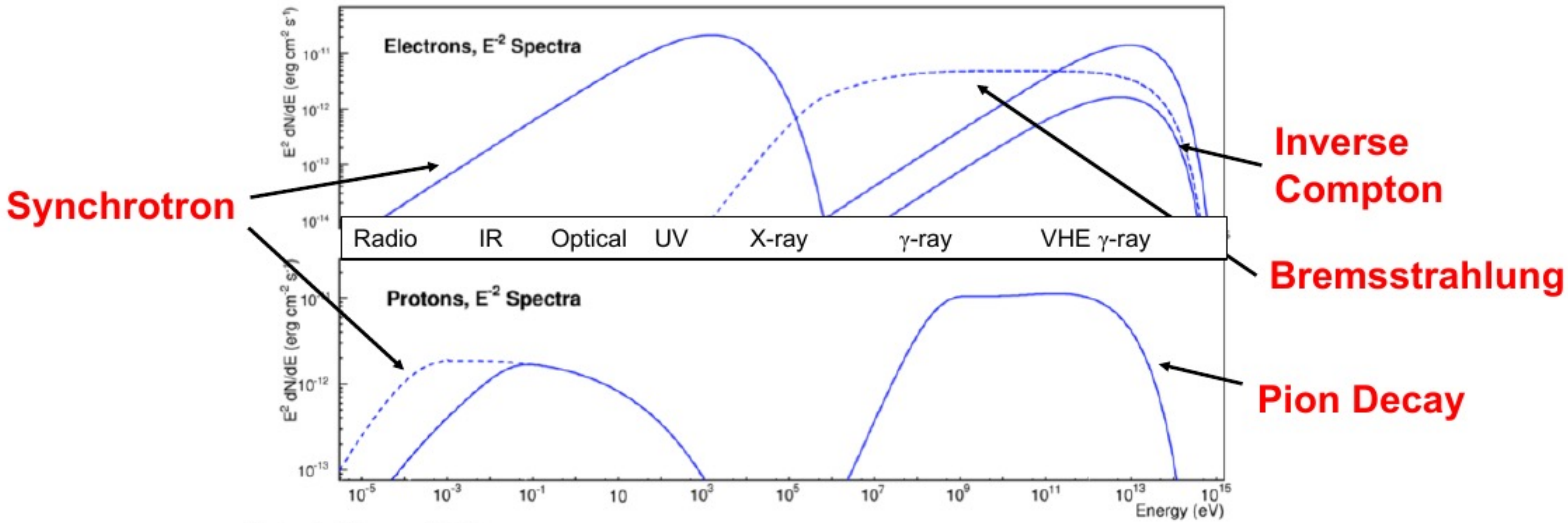


Ultra High Energy gamma-ray sources



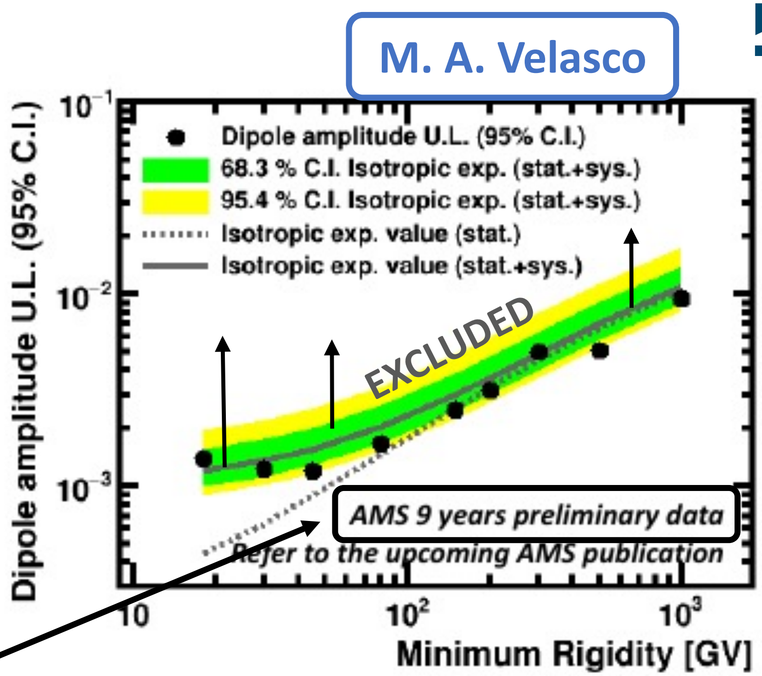
Gamma-ray emission mechanism

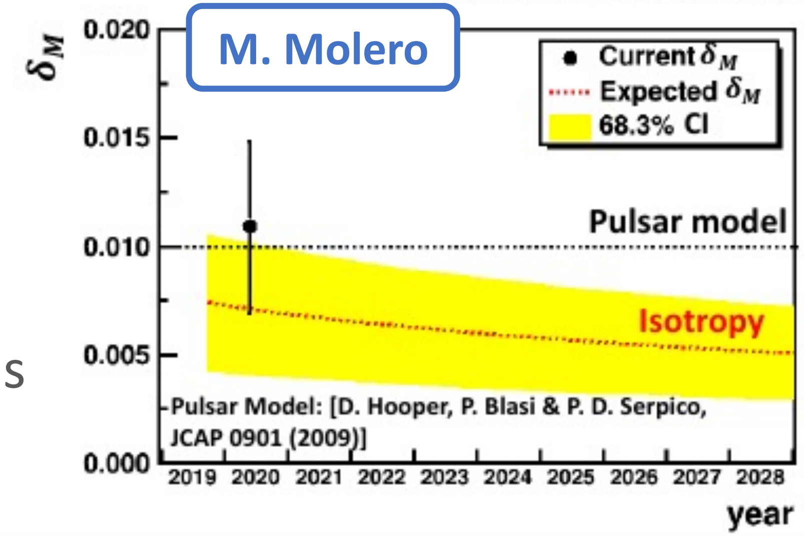
Hadronic vs Leptonic



Hinton & Hofmann (2009)

Anisotropies with AMS





- **Dipole anisotropy of the cosmic rays spectra measured with AMS (9 years)**
  - Measured anisotropy on the proton flux with current AMS data
  - Projected amplitude to 2028 on the positron and electron fluxes
    - sensitivity to the level predicted by pulsar models