The Violent Universe

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Golden age for astroparticle physics

Results presented at ICHEP2010:

- Cosmic Ray, and UHECR, Gamma-Ray astrophysics
  - Fermi, Veritas, HESS, Milagro, Pamela, Argo, HiRes, Auger, Telescope Array
- Celestial Neutrinos
  - Ice Cube, Antares
- Beyond the Standard model, Dark Matter, and cosmology
  - Pamela, HESS, Veritas, Fermi, CDMS, CJPL, LUX, CAST
- Detection of Gravitational Waves
  - Ligo, Virgo, …
- Coming up soon:
  - AMS-2

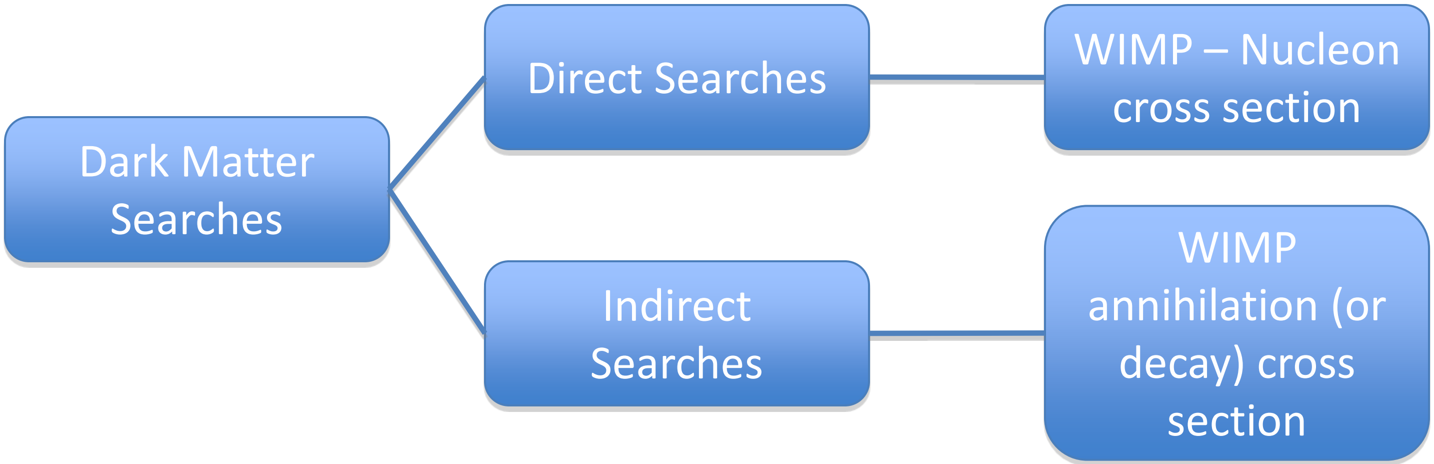
Outline

- Dark matter searches
- Gamma-ray astrophysics
- Cosmic rays
- Multimessengers

Sorry, too many results has been presented…
I had to make some choices to fit in <20 minutes talk!

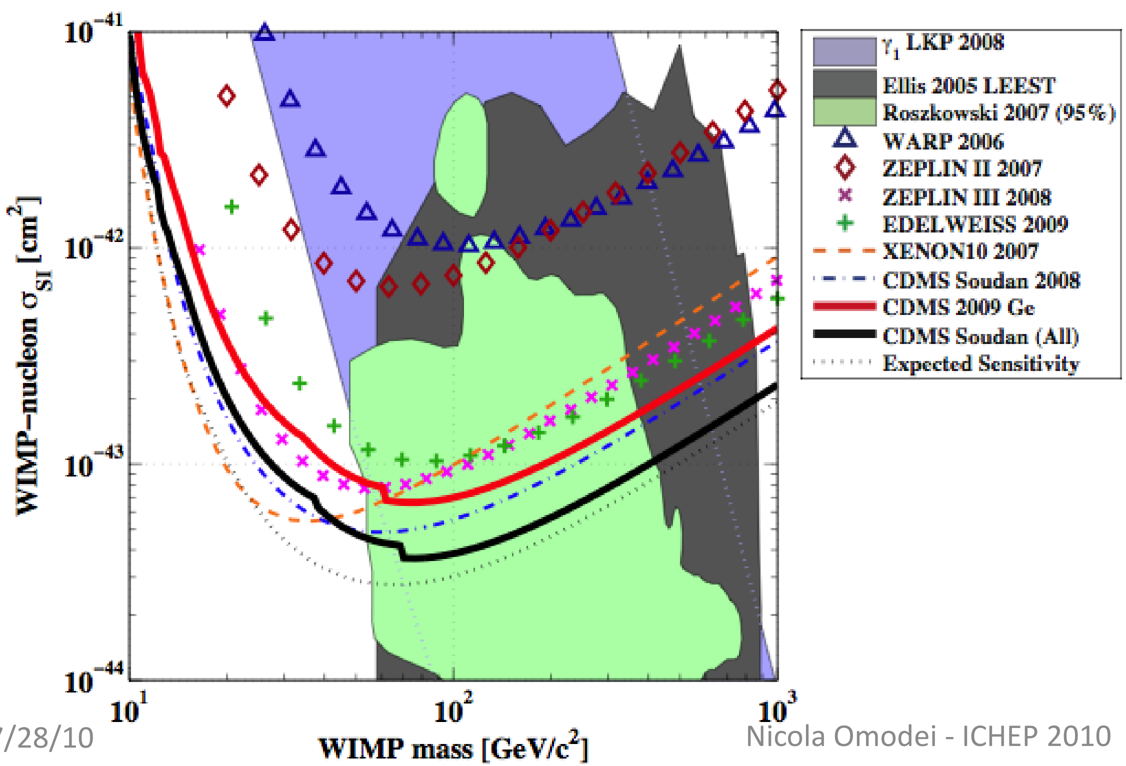
Track for this talk: synergy between experiments, open issues, prospects for the future

Dark Matter Searches



Dark Matter Searches

- Dark Matter Searches
  - Direct Searches → WIMP – Nucleon cross section
  - Indirect Searches → WIMP annihilation (or decay) cross section



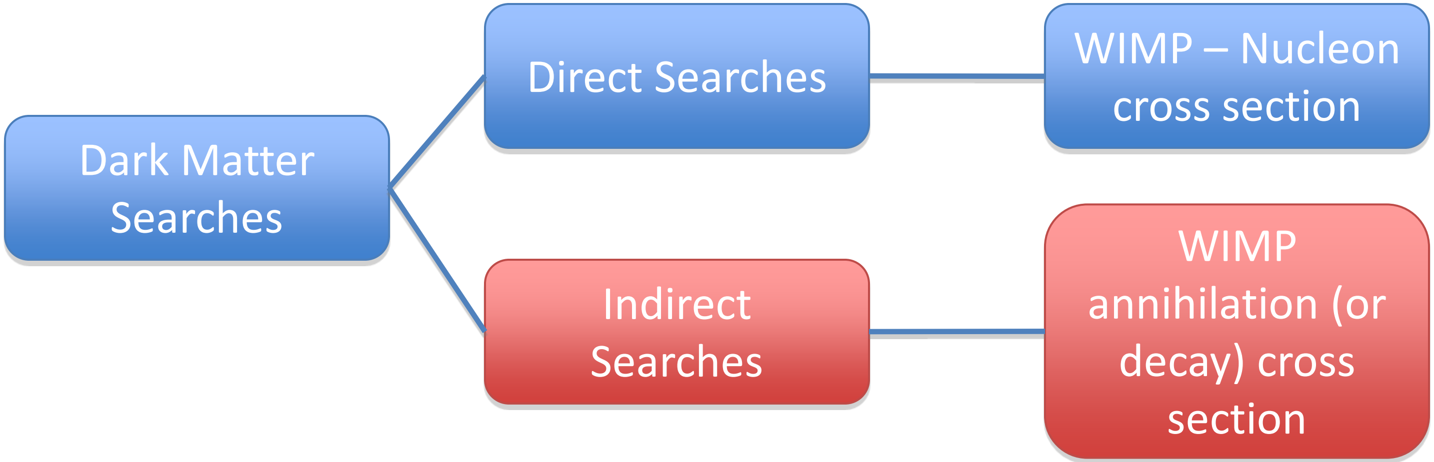
- **CDMSII** (Mark Kos): **no statistically significant detection** (2 events in the signal region (0.8 background))
- World leading limit on spin-independent WIMP-nucleon cross-section

3.8×10^{-44} cm^2 at 90% CL (for 70 GeV/c^2 WIMP mass)

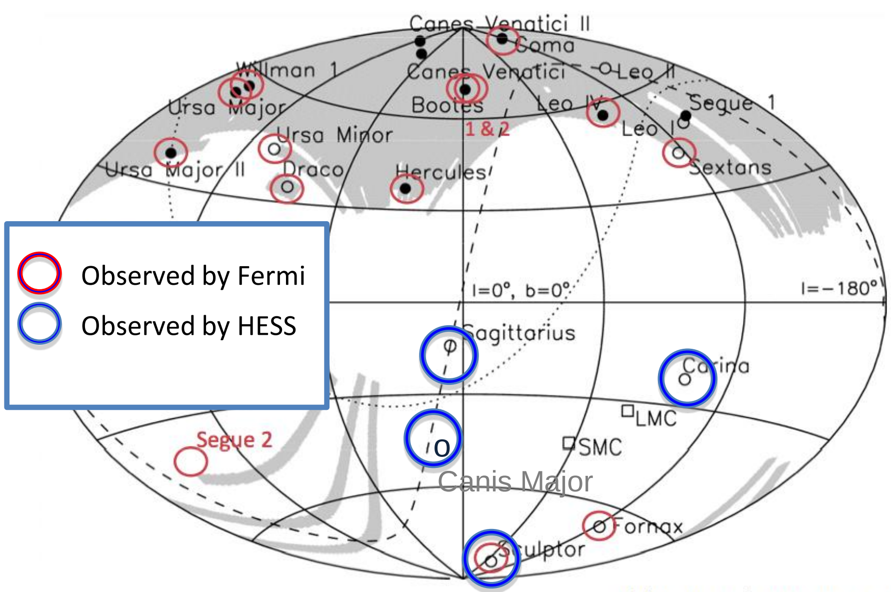
Prospect for the future:

- new **CDMS** (x10),
- **LUX** (Carter Hall)
- **CJPL** (Lin,Shin-Ted)(Germanium detectors): lower energy (WIMP mass <10GeV, sub KeV recoil energy).
- **CAST** (Ferrer-Ribas) - Axions

Dark Matter Searches

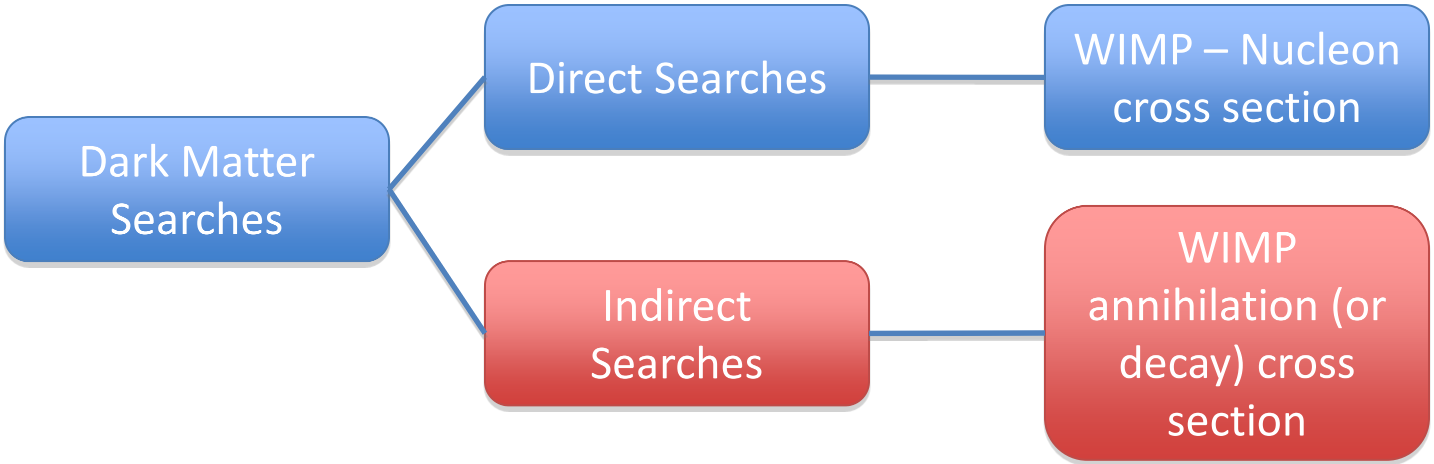


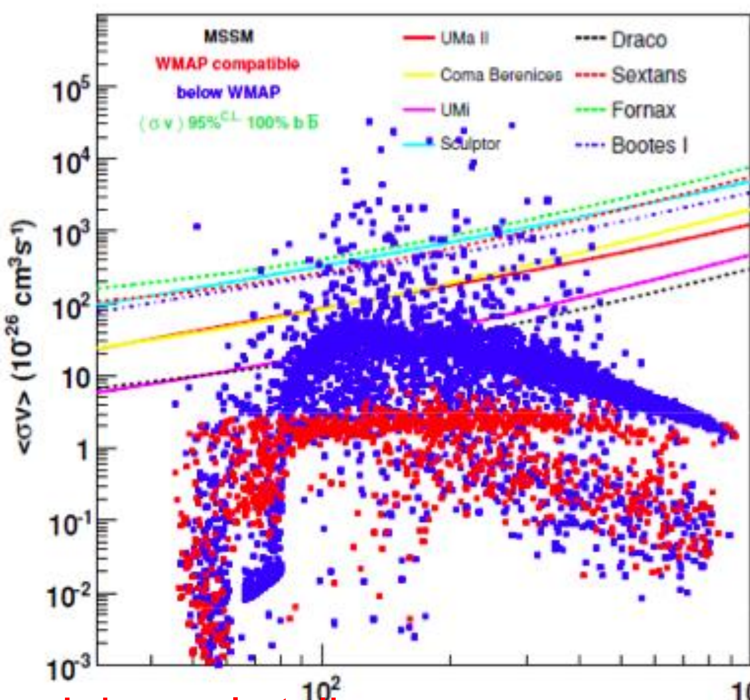
- Celestial gamma rays are a probe to DM signal.
  - Signal over astrophysical "background"
    - Know the astrophysical signal very good
    - Look at non (astrophysical) emitting sources
  - DM candidates (high mass/light, from stellar data), possibly with a dense DM core (NFW)
  - Close sources, Gamma-ray
- An interesting case: dSph's (discovered by SDSS)



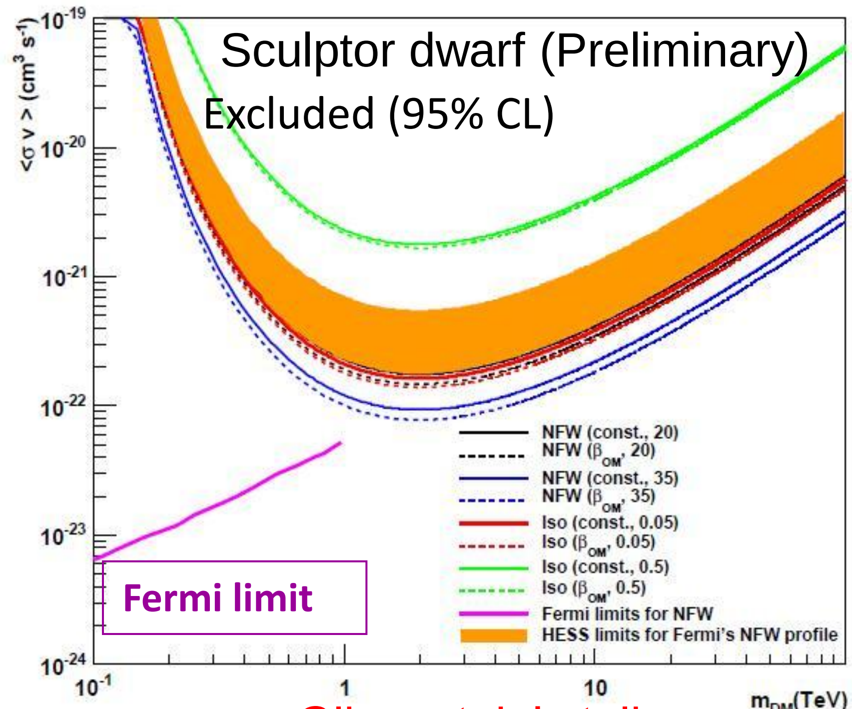
Belokurov, V., et al. 2007, ApJ, 654, 897

Dark Matter Searches





Johnson's talk



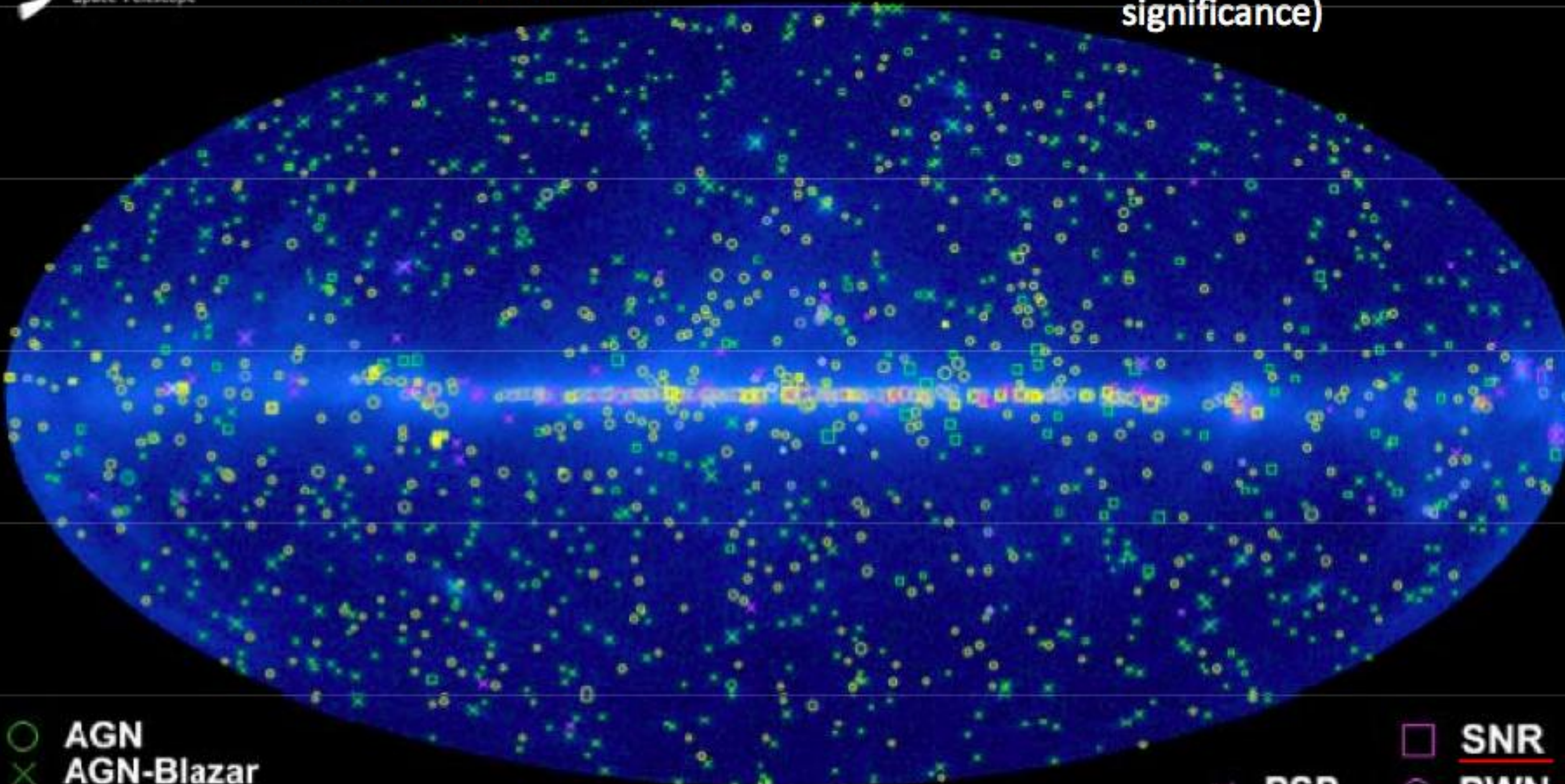
Glicenstein's talk

The Fermi LAT 1FGL Source Catalog

Fermi Gamma-ray Space Telescope

First 11 months of data

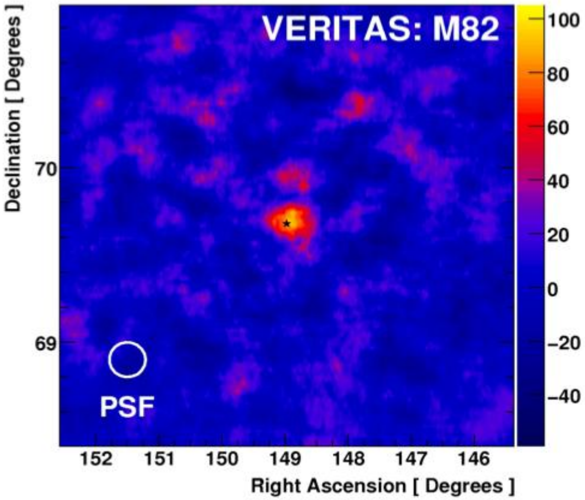
1451 Sources (>4σ significance)



- AGN
- AGN-Blazar
- AGN-Non Blazar
- No Association 630
- Possible Association with SNR and PWN
- Possible confusion with Galactic diffuse emission
- Starburst Galaxy
- Galaxy
- SNR
- PSR
- PWN
- PSR w/PWN
- Globular Cluster
- HXB or MQO

New classes not associated (confidently) with γ-ray sources in 3rd EGRET catalog.

Synergy between experiments



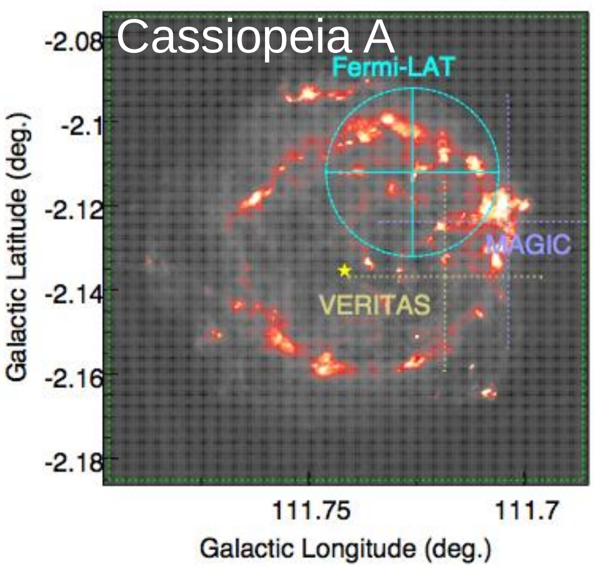
Starburst galaxies discovered in TeV by VERITAS

Detected in GeV by Fermi

New class of high-energy emitter

SN rate ~ Star formation rate: Observation is compatible with the scenario that CR are emitted in Supernovae

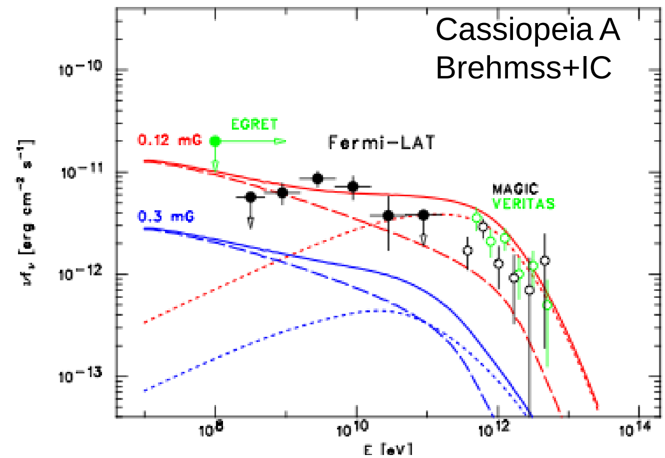
Hanna's talk

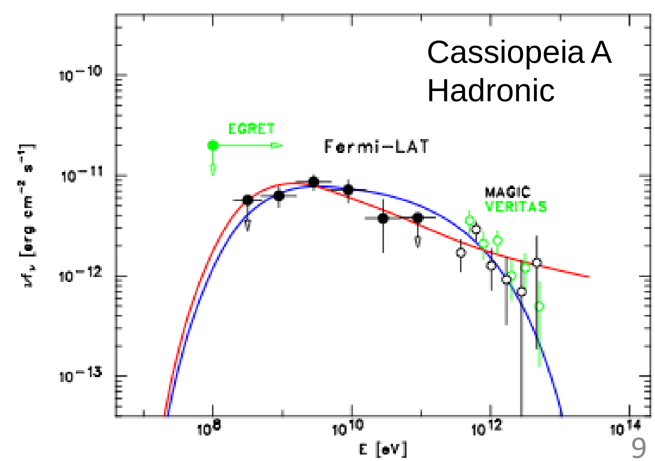


Direct observation of SN

Gamma ray emission compatible with the shocked region in SNR,

Both leptonic models and hadronic models can describe the data. **No "smoking gun" found yet**.



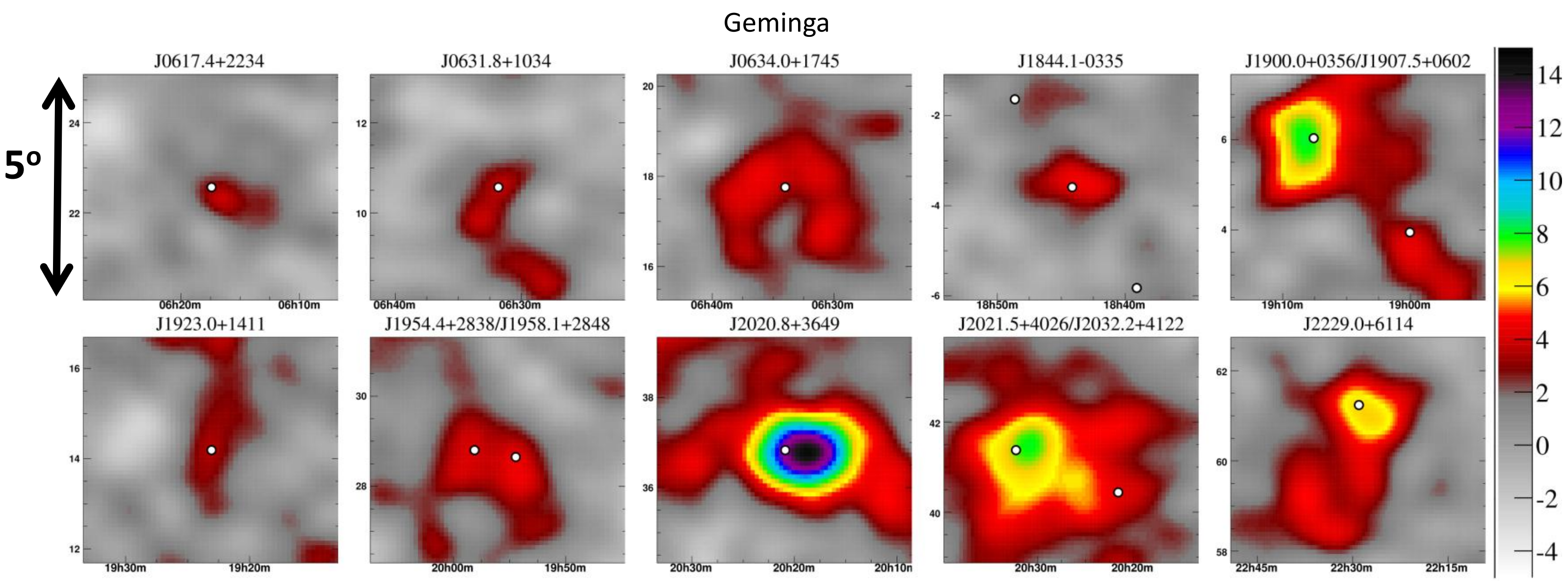


VERITAS: ApJ 714:163-169, (2010)

Fermi: ApJL, 710: L92-L97 (2010)

MILAGRO source associations with Fermi Bright Source List

- All high-significance sources are identified with Fermi pulsars. 'Most' of the low-significance sources are true TeV detections, but cannot be claimed individually.
- Strong evidence for multi-TeV emission associated with Galactic LAT BSL sources "as a class."
- **Emerging picture:** The typical Galactic multi-TeV source is a Pulsar Wind Nebula (PWN) associated with an MeV to GeV pulsar.

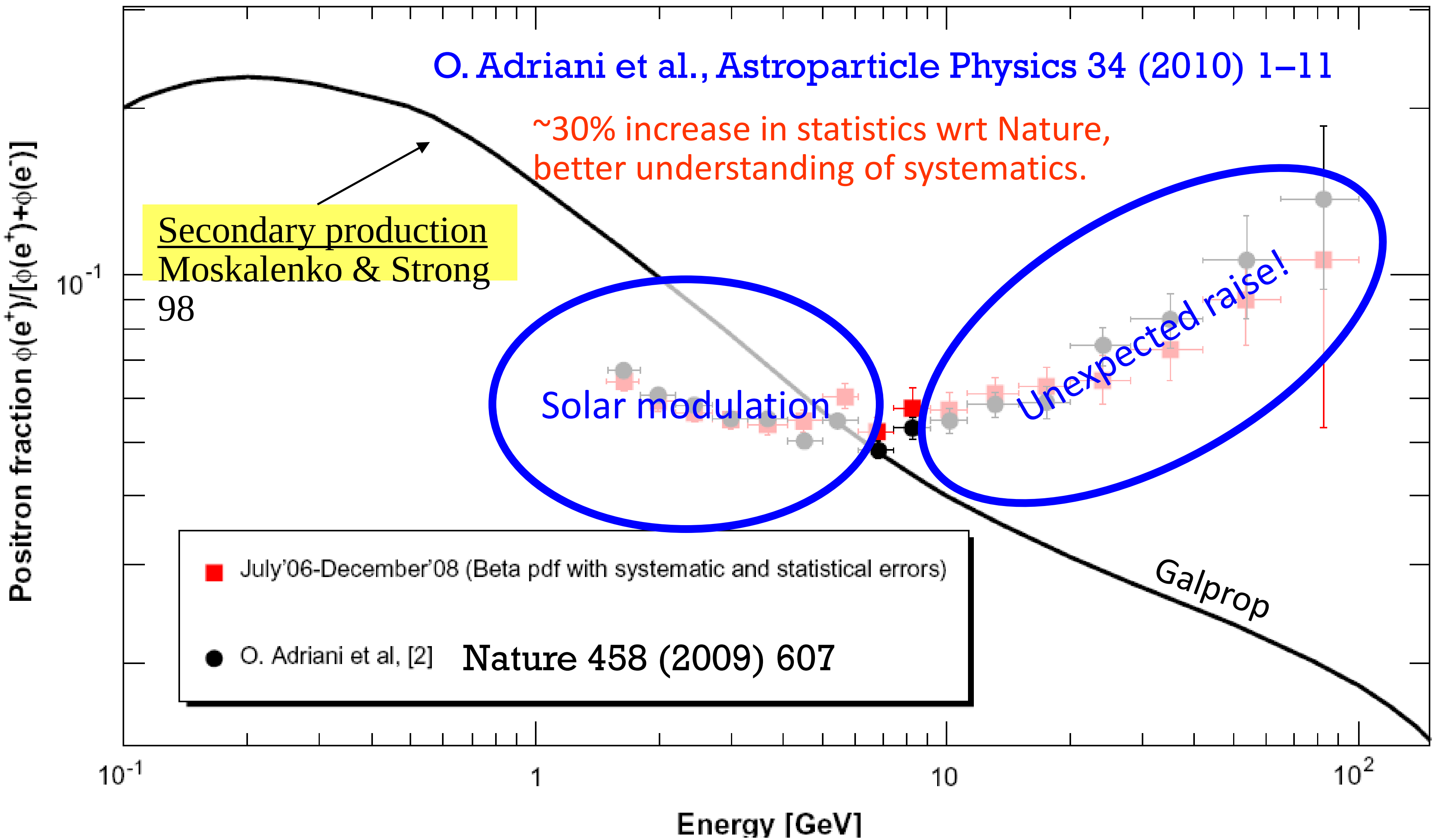


Westerhoff's talk

COSMIC RAYS

PAMELA Positron to all electron ratio

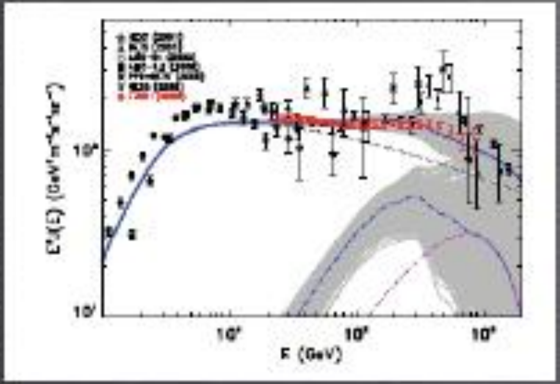
900 days



Adriani's talk

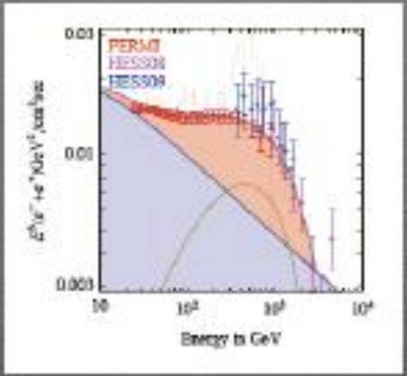
Interpretation

Pulsars



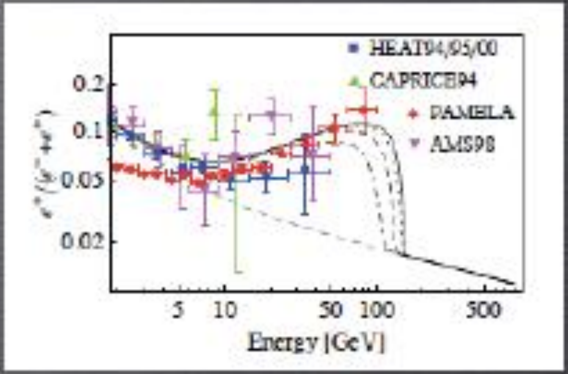
Grasso et al. 2009

DM Annihilation



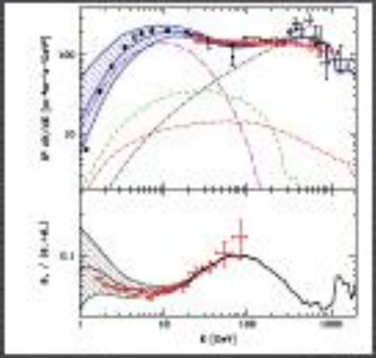
Strumia et al. 2009

DM Decay



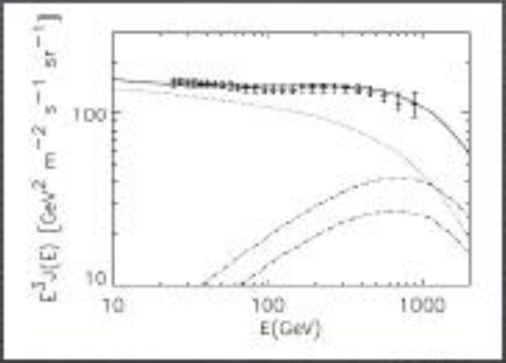
Ibarra et al. 2009

SNRs inhom.



Piran et al. 2009

SNRs 2ndary CR acc.



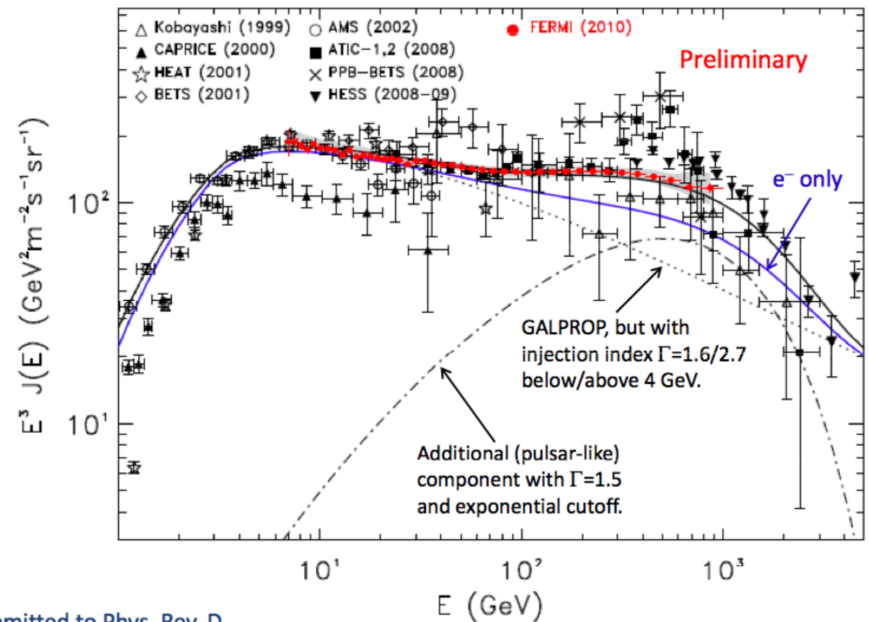
Blasi 2009

Hundreds of citations to Pamela &, Fermi results

From G. Bertone, Plenary Talk at COSMO09 Conference

Cosmic-Ray Electrons (7GeV 1TeV)

- New analysis from Fermi on $e^+ e^-$ presented at this conference:
  - More statistic
  - Low energy extension down to 7 GeV
  - NO anisotropies found
    - Still compatible with an extra component, both pulsar or DM
- PAMELA e^- spectrum also presented (up to 200 GeV)



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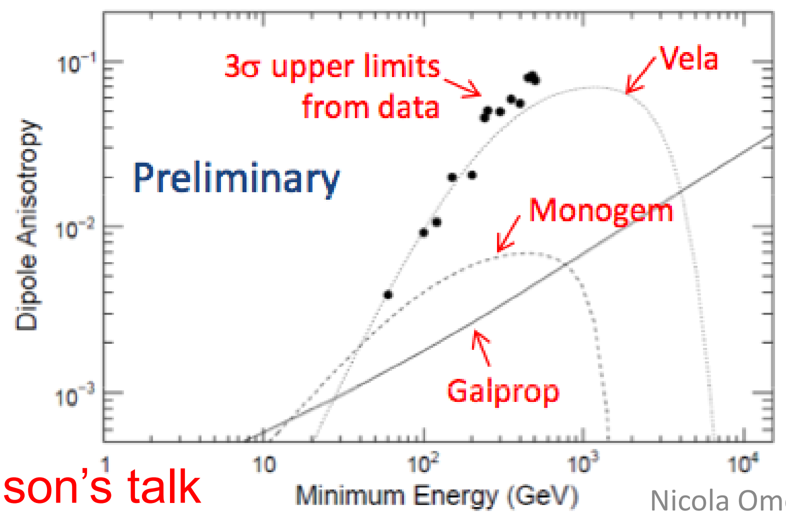
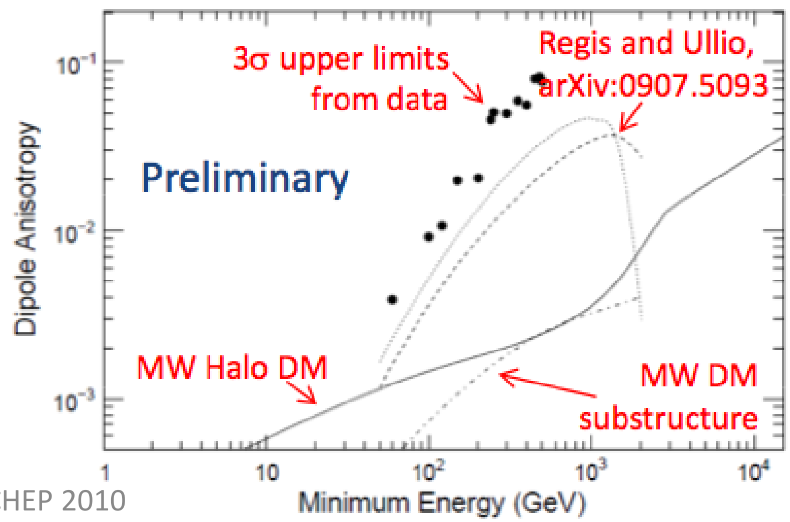
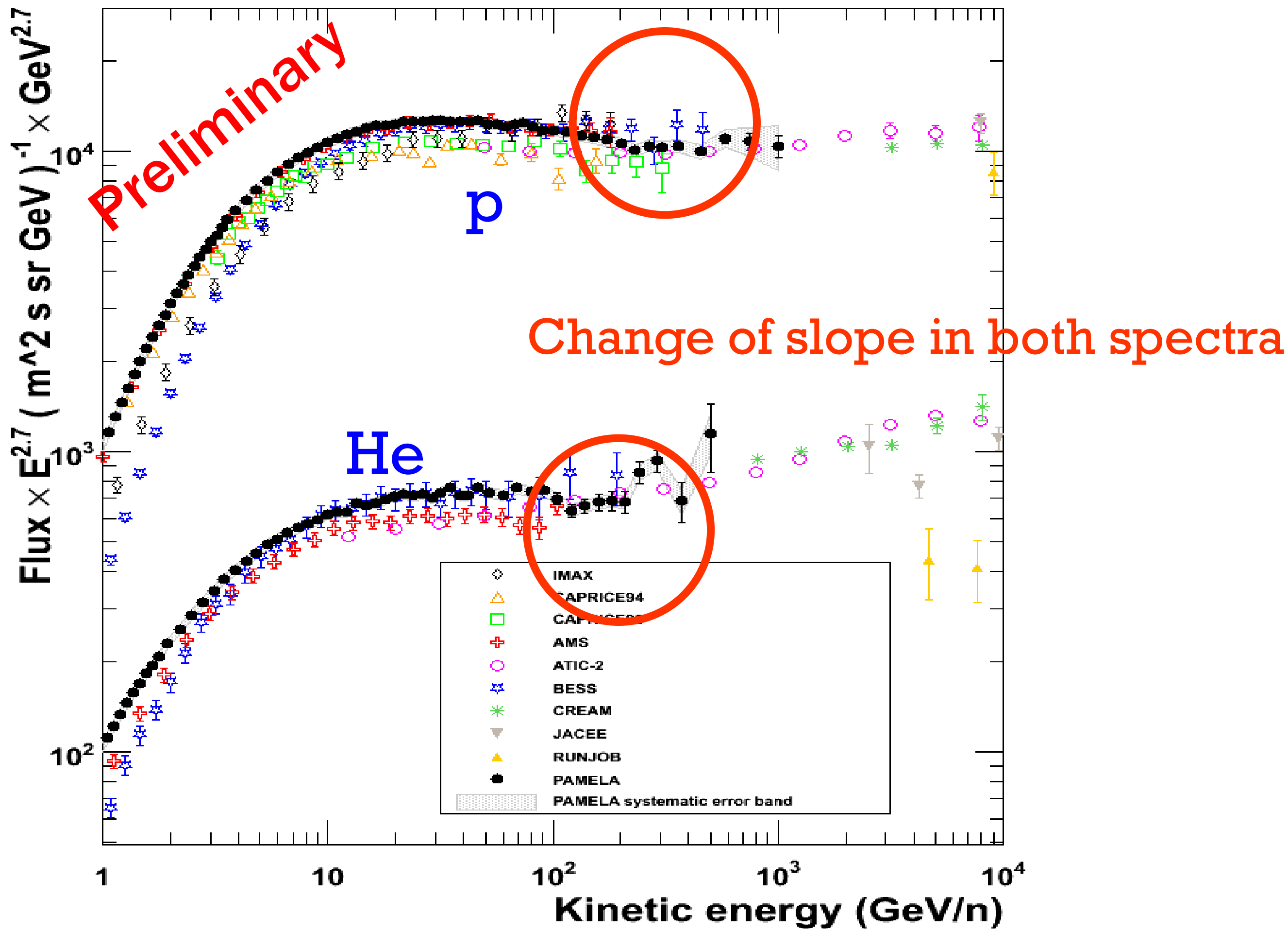




Johnson's talk

PAMELA - Proton and Helium fluxes



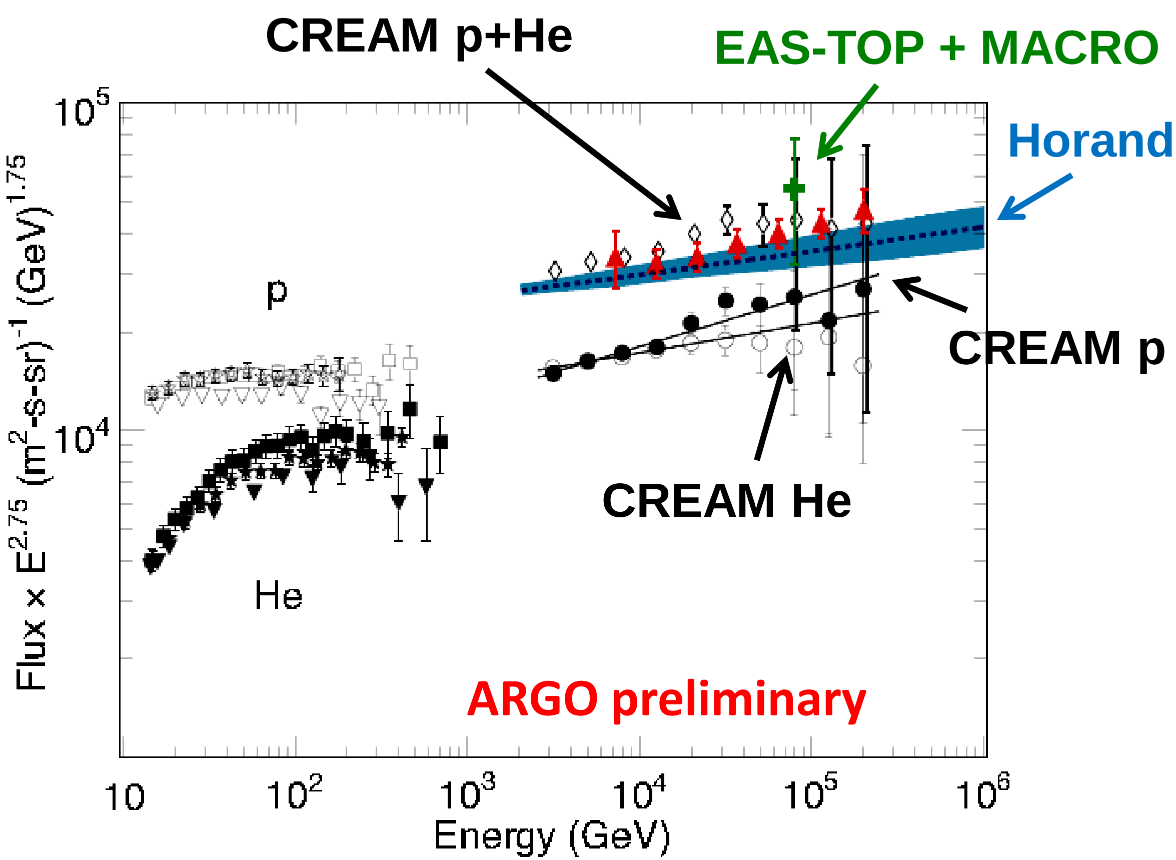
Additional source?

Adriani's talk

At higher energies… ARGO

Measurement of the *light-component* (p+He) spectrum of primary CRs in the energy region (5 – 250) TeV via a Bayesian unfolding procedure

CNO < 2%



ARGO data agree with CREAM results

Evidence that the proton spectrum is flatter than in the lower energy region

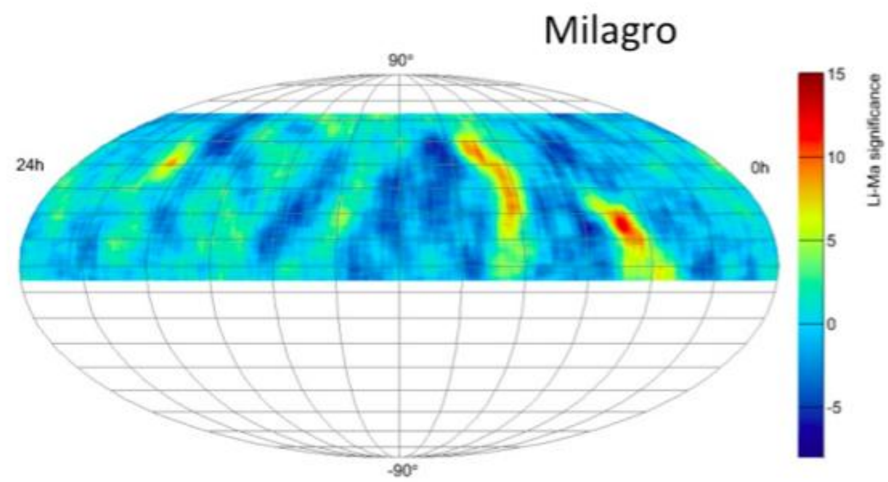
Marsella's talk

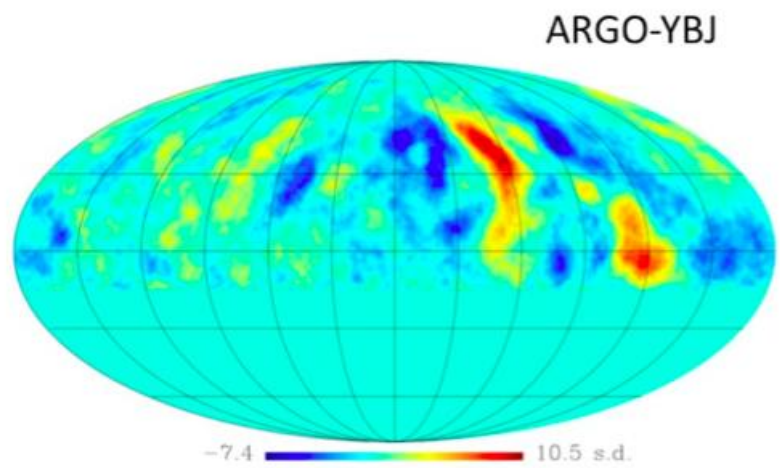
Direction of protons

Hot spots observed in both
Milagro and **ARGO** with high significance
<u>Harder spectrum (flattering)</u>

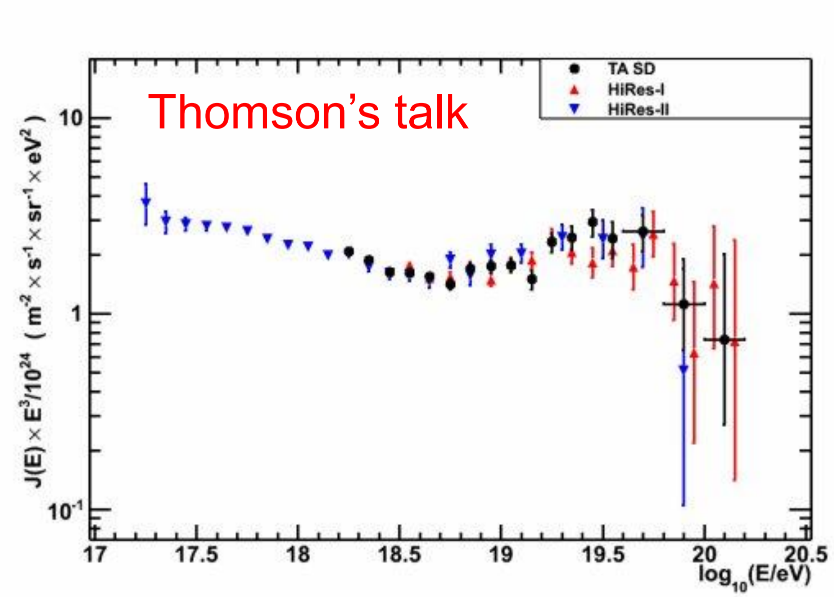
No compelling explanation found yet

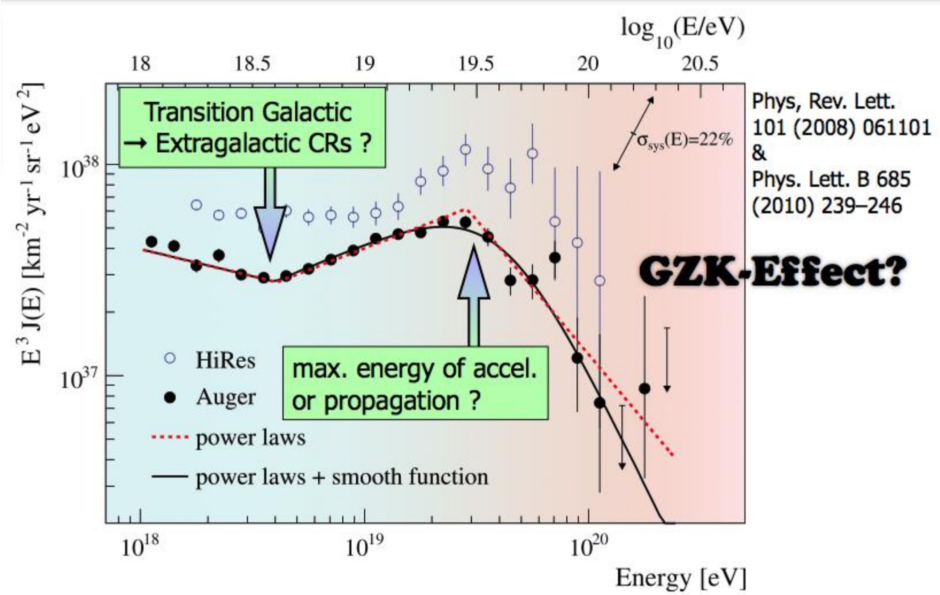
Open issue!





High energy cosmic ray spectrum

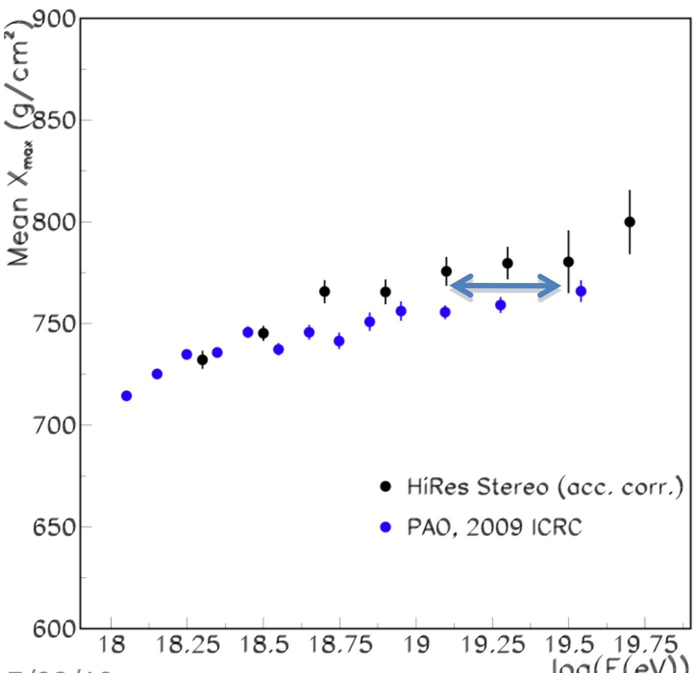


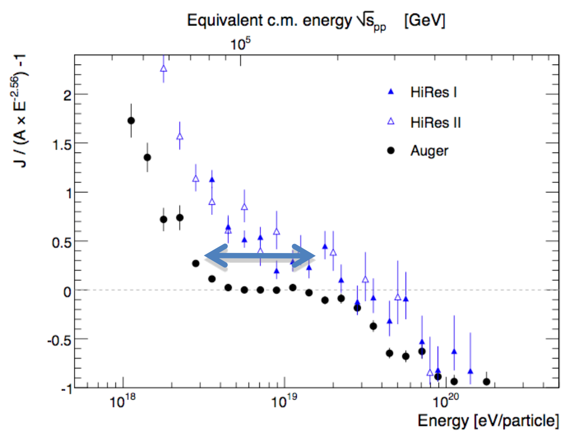


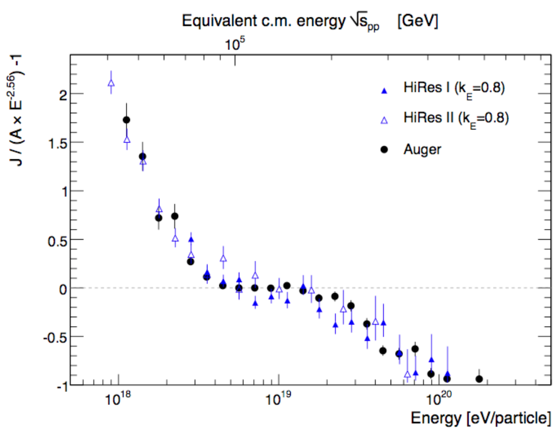
- From HiRes (Sokolsky'talk): GZK suppression at 5.3s. No anisotropy found.
- From Pierre Auger Observatory (Kampert): suppression significance >20 s, but could also be consistent with the suppression of the spectrum at the source
  - E> 55 EeV correlation with AGN, no longer high significant (0.3% by chance)

Composition

- Much better understanding of the development of the shower in the atmosphere
- Composition of the cosmic rays as a function of the energy.
- Compositions between HiRes and Auger do not seem to agree but… (Farrar's talk)
  - Uncertainty in the respective energy scales



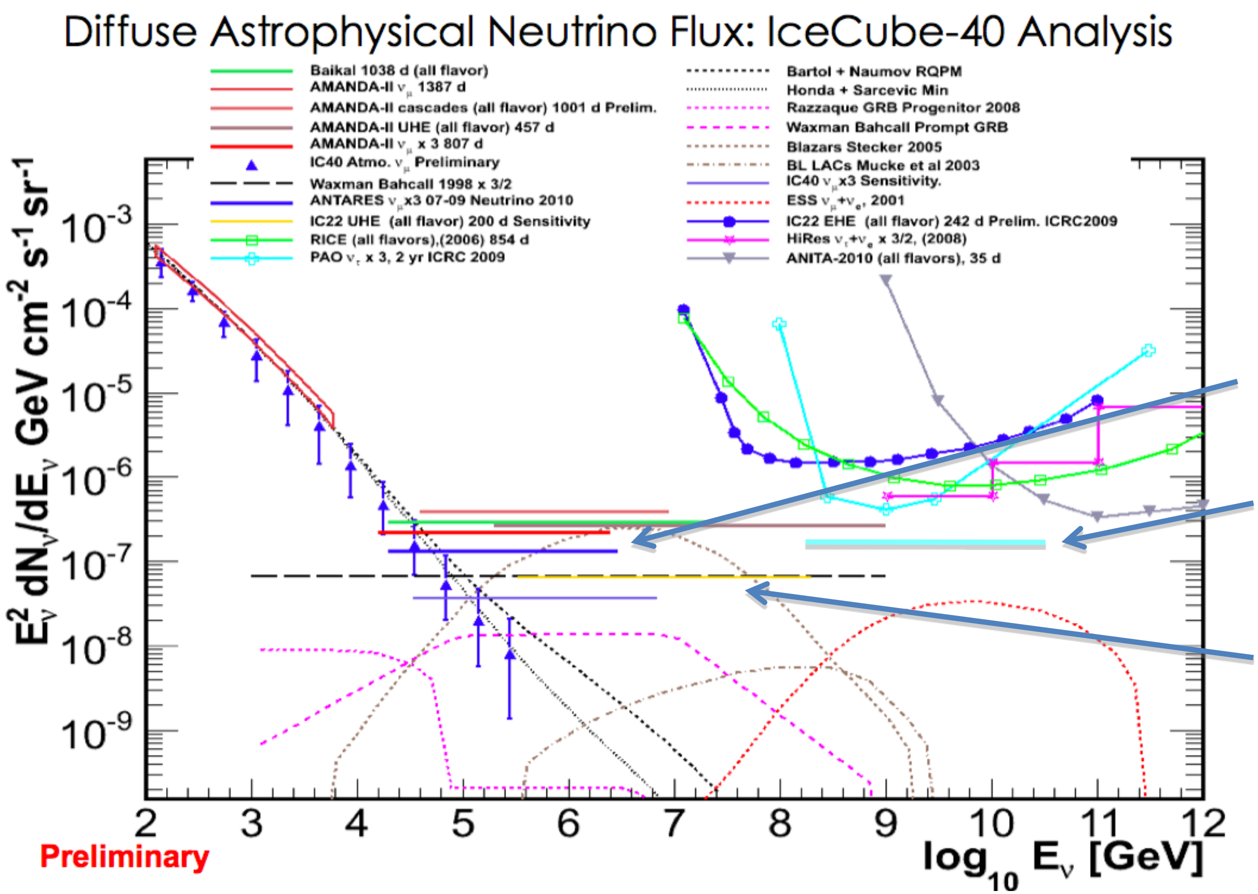




MULTIMESSENGERS

Diffuse astrophysical Neutrino

- Contribution from celestial sources dominates the atmospheric neutrino flux at high energy
- Energy estimators to reduce the background
- Set upper limits on diffuse neutrino emission
  - Start to constrain models



Antares
Spurio's talk

Auger
Kampert's talk

IceCube
Finley's talk

UL on point sources also presented

Gravitational Waves Detector

A bit of history

First generation (2001-2008)

- Infrastructure setup
- **Design sensitivity** has been **reached**
- **Upper limits** on event rates
- **No detection**

Enhanced Detectors (2009-2011)

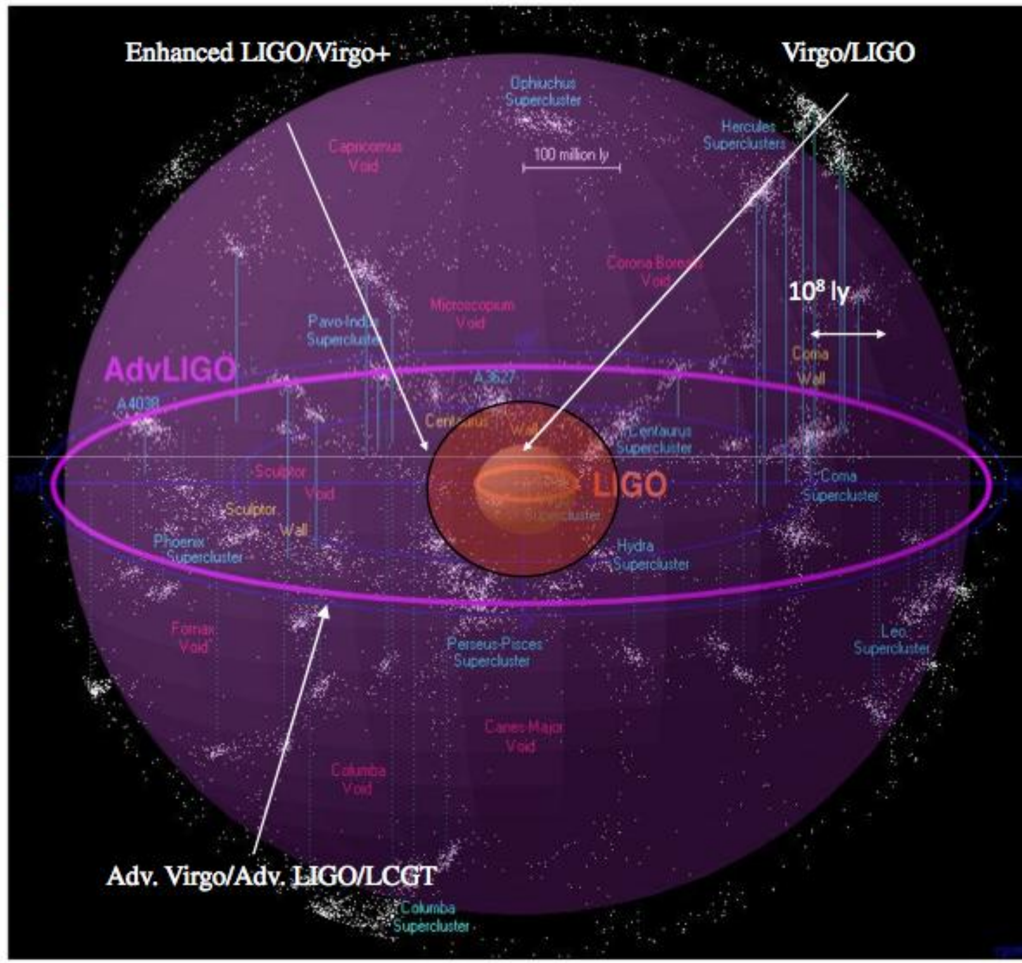
- **Sensitivity increased** by a factor **2-3**
- Use of some Advanced detector technologies
- **Detection still unlikely** but surprises are always possible

Advanced Detectors (2011-2020)

- **Sensitivity gain** by factor **10** compared to first generation
- Visible **Universe volume** increased by **1000**
- **10-100 events per year** ?

Third Generation (>2017)

- **Gain** by factor **100** compared to first generation



Credit: R.Powell, B.Berger

Cavalier's talk

Presented Results

- DATA SHARING!
- Limit on Coalescing Binaries
  - [8.7×10^{-3} (BNS), 2.2×10^{-3} (BHNS), 4.4×10^{-4} (BBH)] events/yr/L_{10} (BBH, BHNS,BNS)
- Limit on Pulsars:
  - spins down limit reached for 3 pulsars (aka: Spin down not only due to GW)
- Stochastic gravitational-wave background:
  - $Omega_0 < 6.9 \times 10^{-6}$
- GW burst
- GW burst in association with GRBs

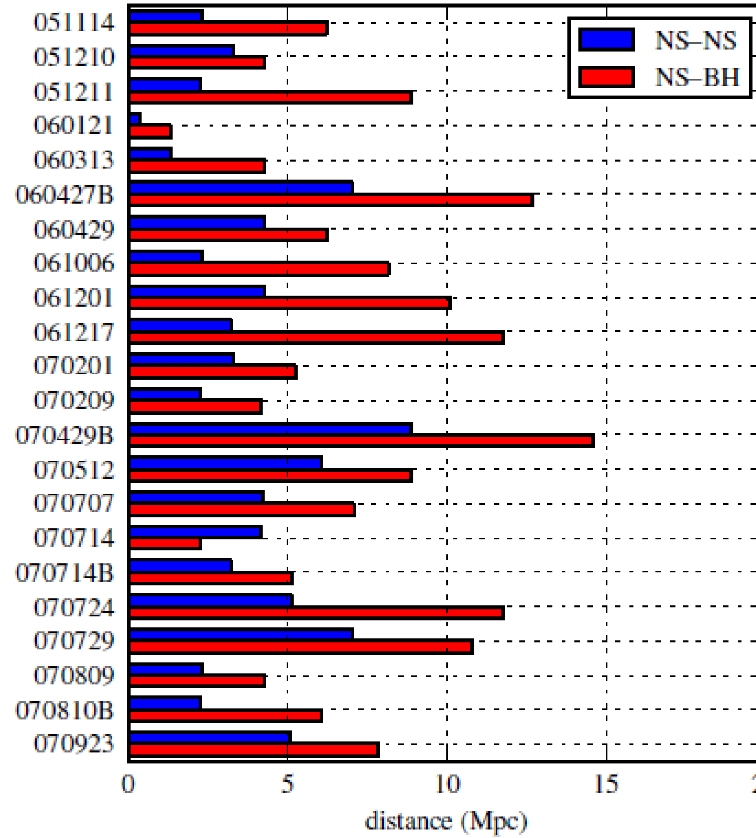


Figure 2. Lower limits on distances at 90% CL to putative NS–NS and NS–BH progenitor systems, as listed in Table 2 and explained in Section 3.2.

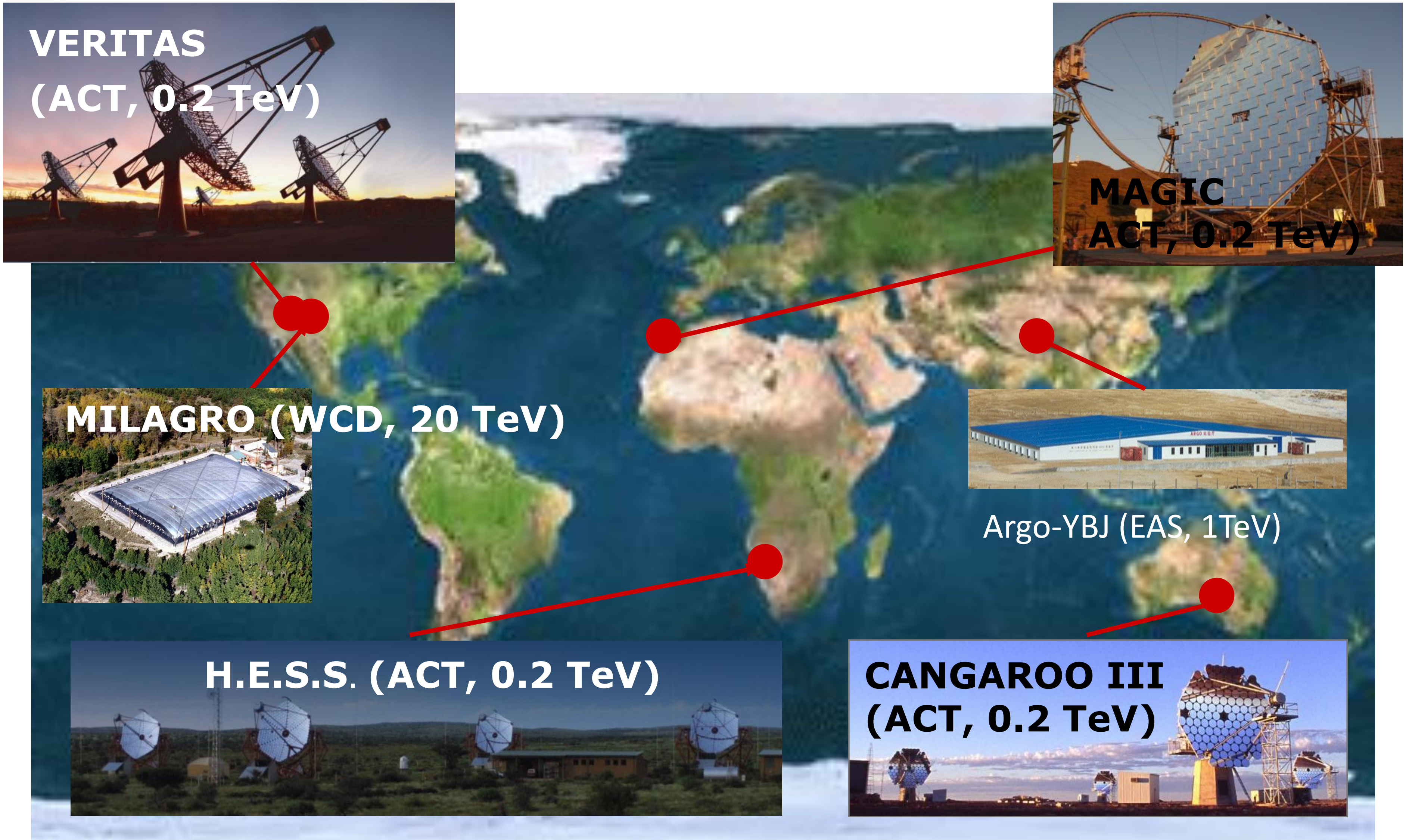
Conclusions

- Golden age for atroparticle physics
- Big boost given by Fermi
  - Path finder, high statistics of sources
  - Synergy between experiments important
- DM searches start to provide interesting results, reaching the “interesting” phase space
  - A discovery at LHC will be a revolution for astroparticle a well!
- Cosmic-ray physics reach of new data
  - Hardening of the e+/(e- e+) spectrum still need an explanation.
  - Proton spectrum might point to extra components, no association with any celestial object yet
- UHECR
  - New data on shower development in atmosphere points either to increasingly heavier composition or rapidly increasing p-air cross section with energy
- Neutrino astrophysics:
  - Extraterrestrial neutrinos are probably in the data, to now
  - Limits on the flux of celestial neutrinos start to constrain models
- Interplay between different instruments and facilities opens a huge discovery space
  - quick alerts and sharing information are crucial for turn an “observation” into a “discovery”…

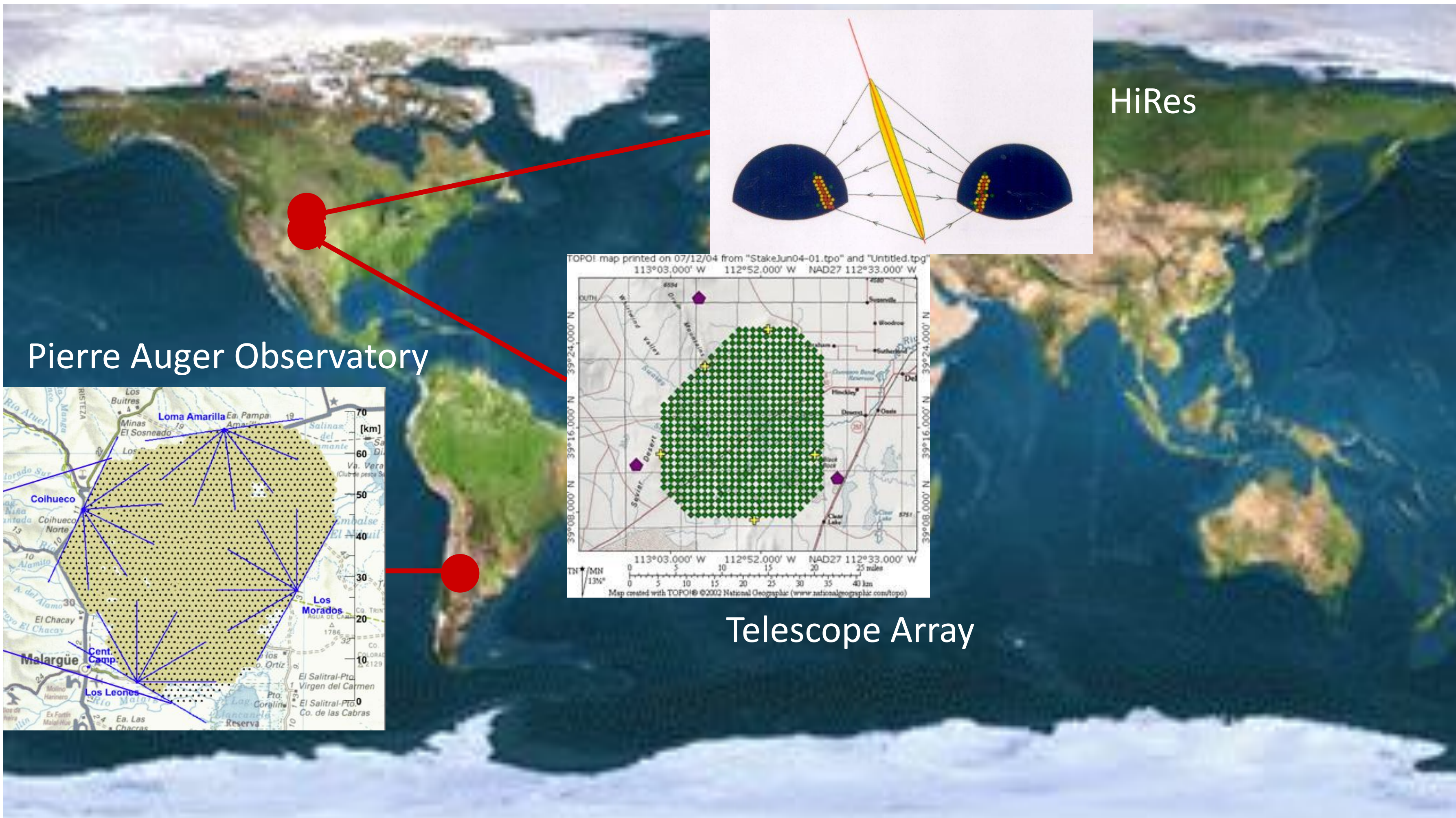
Yellow slide means Backup

Ground-based VHE gamma-ray instruments

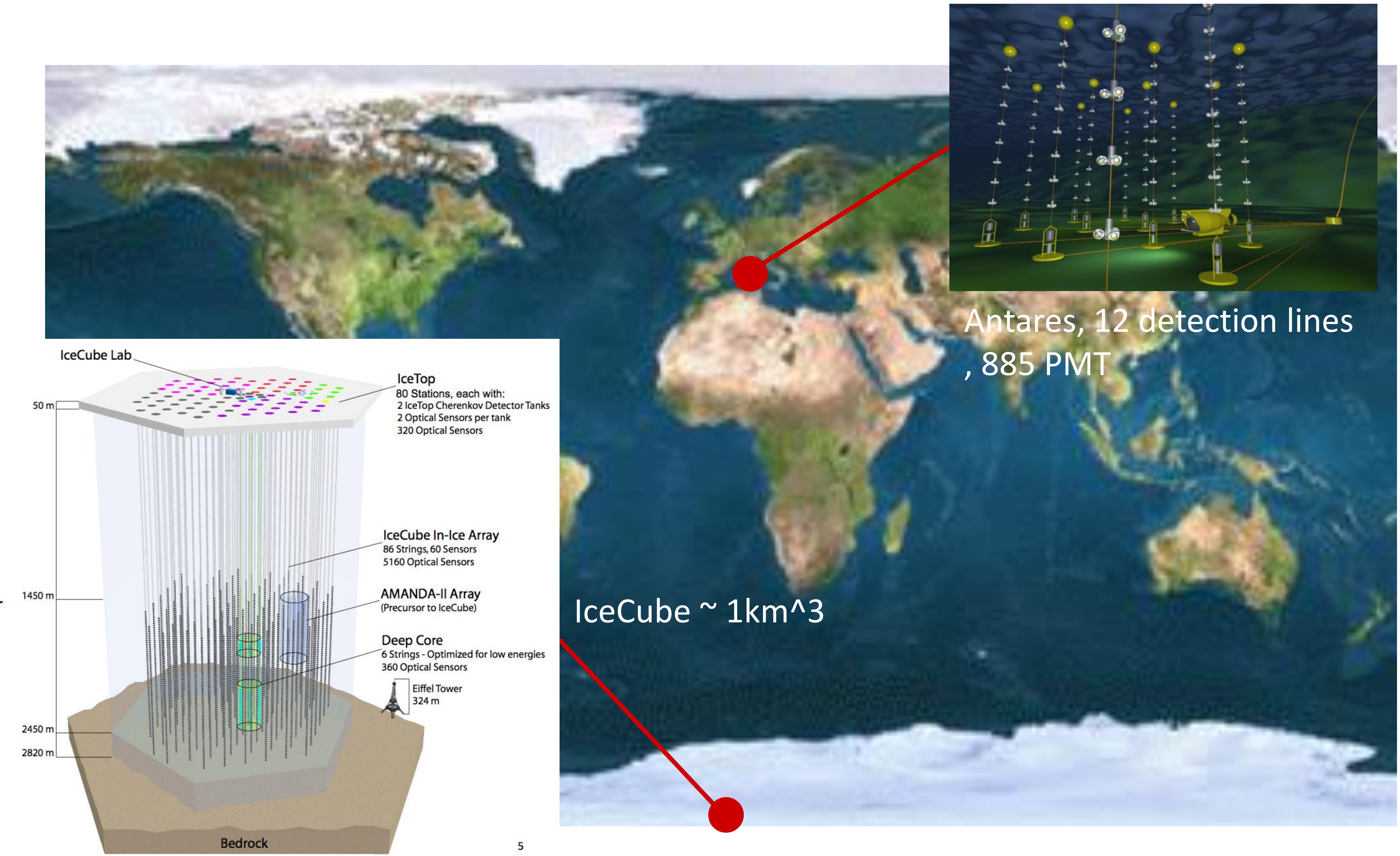
ICHEP PARIS 2010



Ground Based UHECR detectors



Celestial Neutrino detector

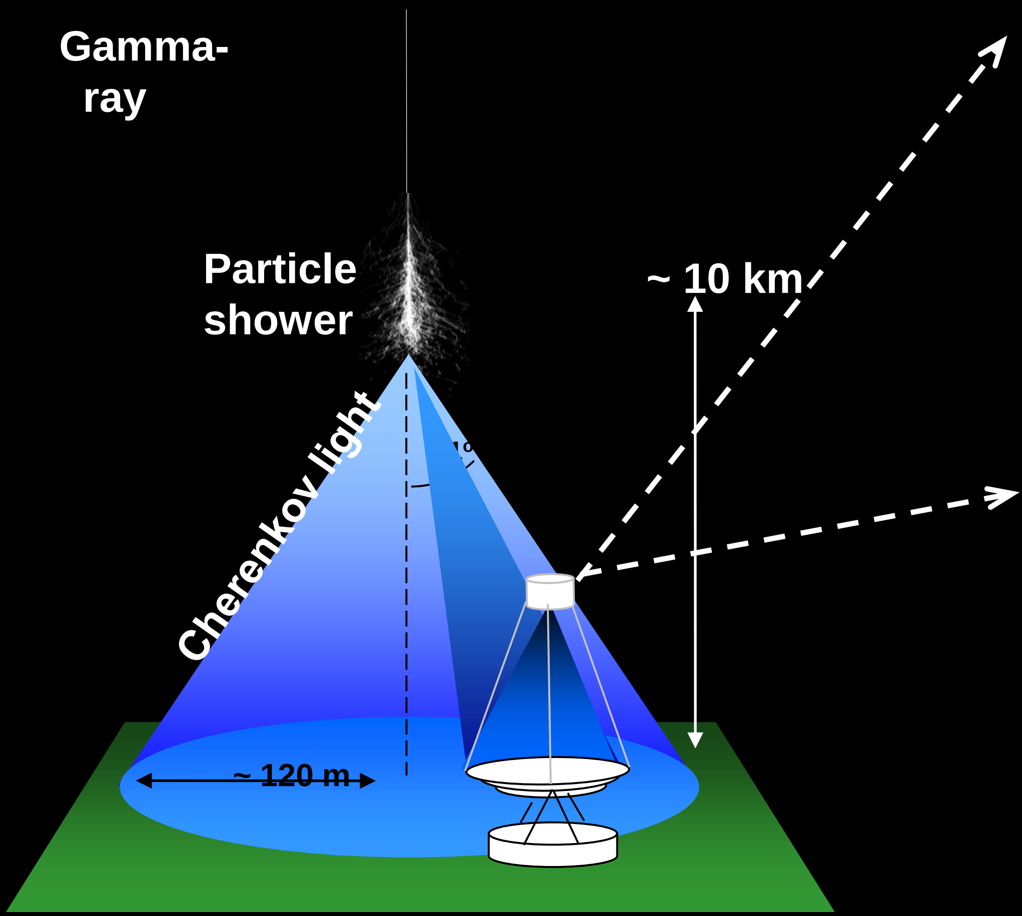


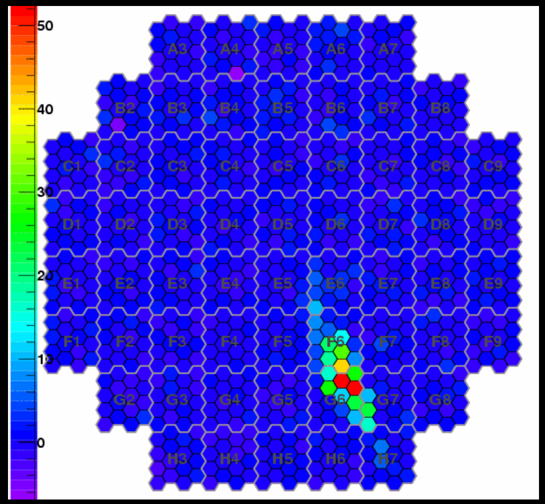
Gravitation Wave Detectors

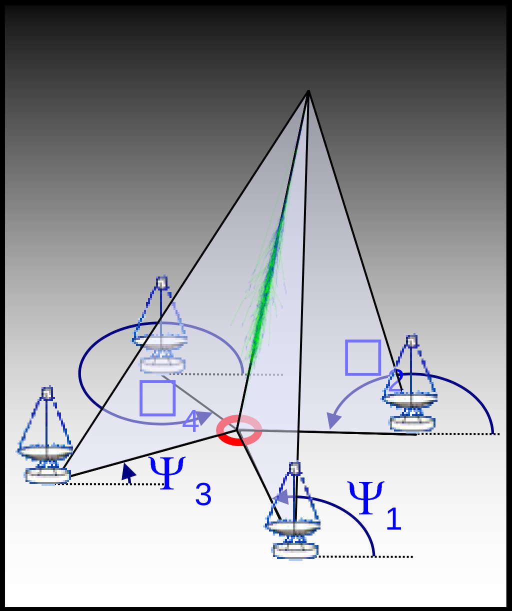
Gamma Ray Detectors

	Gamma Ray Energy	Field of View (sr)	Point Spread Function	Sensitivity (erg/cm^2/sec)
Fermi	**0.1 GeV**	**4 □**	**0.04°**	**$1 \cdot 10^{-12}$**
Veritas / HESS	**0.2 TeV**	**0.002**	**0.05°**	**$0.2 \cdot 10^{-12}$**
Milagro	**20 TeV**	**2 □**	**0.7°**	**$2 \cdot 10^{-12}$**

Imaging atmospheric Cherenkov telescopes





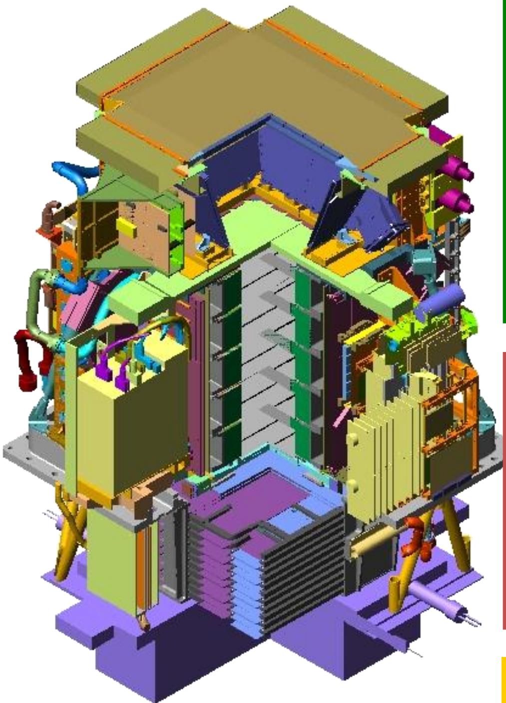


- brief flash ~3 ns
- **steroscopy**:

cosmic ray background rejection
improved gamma ray reconstruction

PAMELA detectors

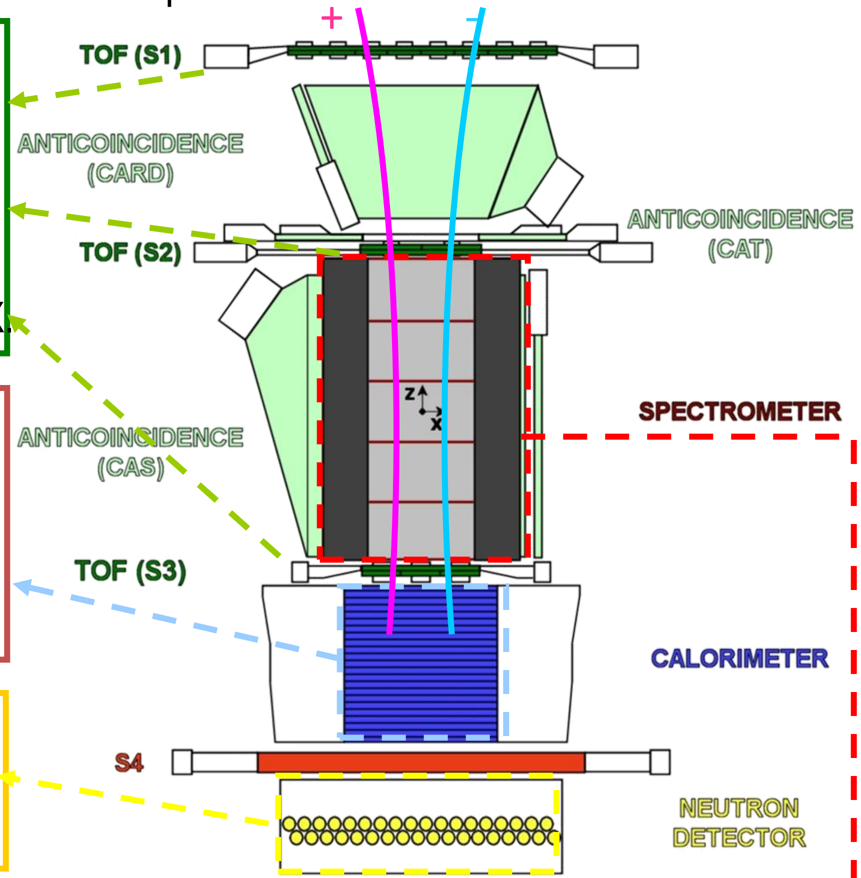
Main requirements → high-sensitivity antiparticle identification and precise momentum measurement



Time-Of-Flight
plastic scintillators + PMT:
- Trigger
- Albedo rejection;
- Mass identification up to 1 GeV;
- Charge identification from dE/dX

Electromagnetic calorimeter
W/Si sampling (16.3 X0, 0.6 λI)
- Discrimination e+ / p, anti-p / e-
(shower topology)
- Direct E measurement for e-

Neutron detector
^{3}He Tubes:
- High-energy e/h discrimination



GF: 21.5 cm^2 sr
Mass: 470 kg
Size: 130x70x70 cm^3
Power Budget: 360W

Spectrometer
microstrip silicon tracking system + permanent magnet
It provides:
- *Magnetic rigidity* → R = pc/Ze
- *Charge sign*
- *Charge value from dE/dx*

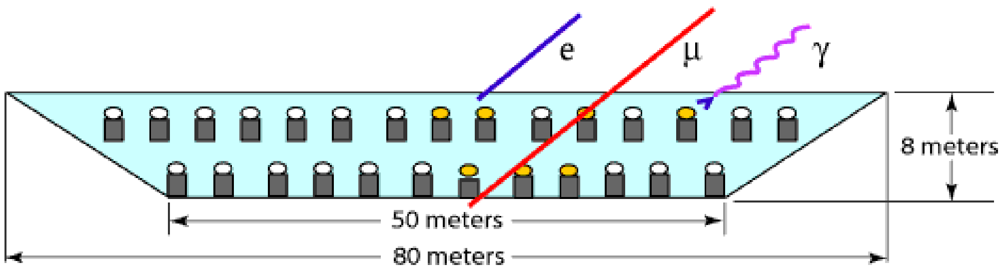
The Milagro Detector

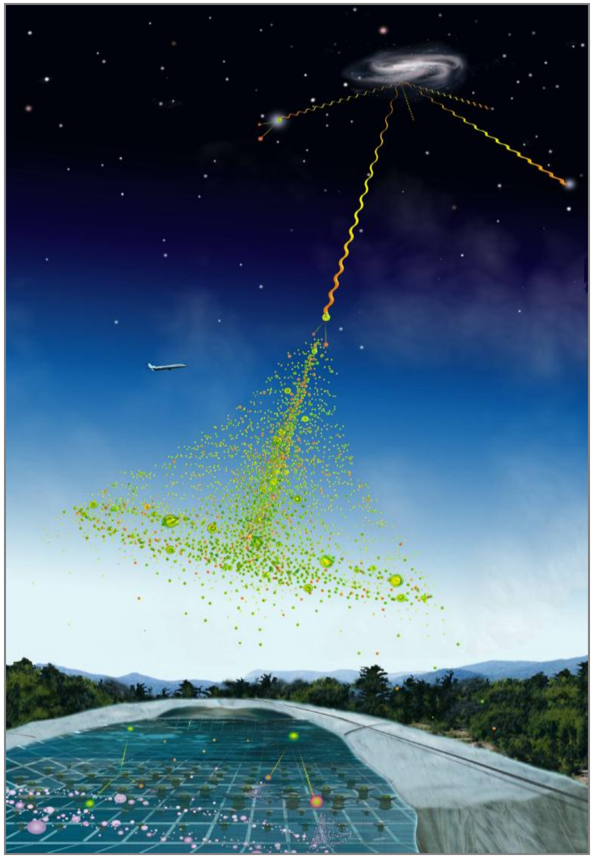
- First generation water Cherenkov detector for gamma rays and cosmic rays at TeV energies with…
  - … large field of view.
  - … 100% duty cycle.

- Location: Jemez Mountains (near Los Alamos) at 2630 m altitude, 36º N.

- Detector:
  - 60m × 80m water-filled pond with light-tight cover and 723 8'' photomultiplier tubes.
  - Sparse 200m × 200m array of 175 outrigger tanks (with one photomultiplier each) surrounding the pond.

Detection Principle

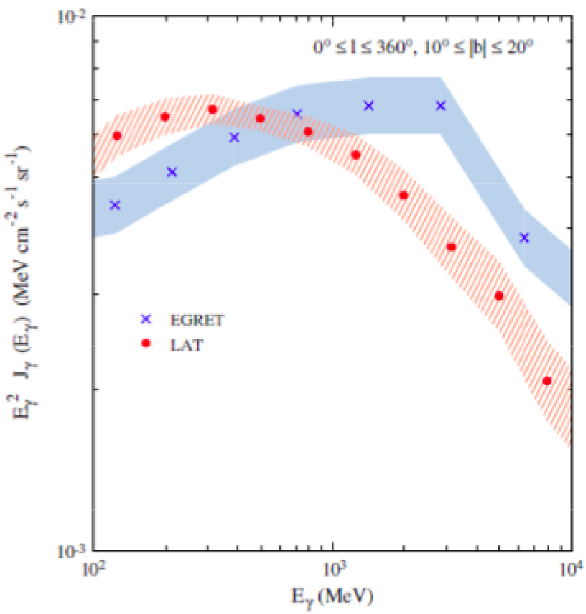


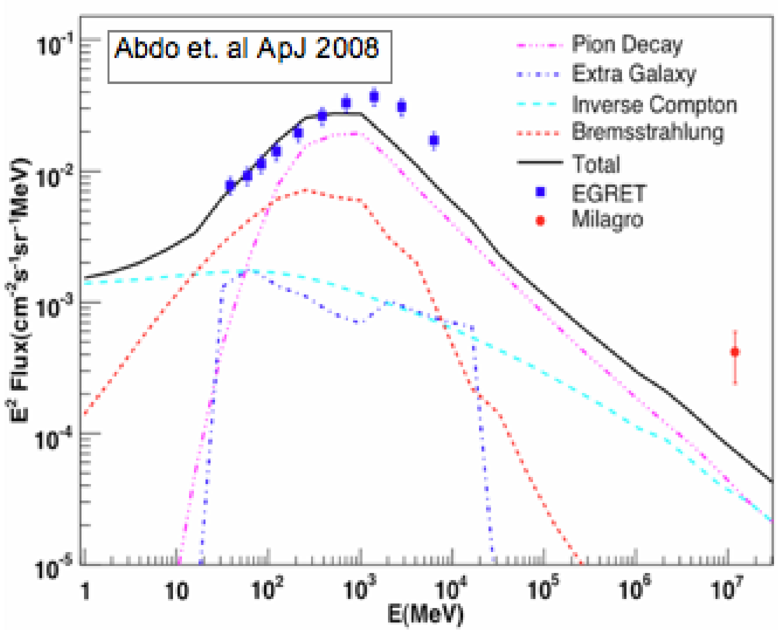


- Pond is instrumented with two layers of photomultipliers (PMTs):
  - Air shower layer: 450 PMTs at 1.4m depth ⇒ accurate measurements of air shower particle arrival times, used for arrival direction reconstruction and triggering.
  - Muon layer: 273 PMTs at 6m depth ⇒ detection of penetrating muons and hadrons, used for rejection of cosmic ray background.

- Outrigger array (added in 2003) ⇒ improvement of angular resolution, providing longer lever arm for event reconstruction.

Resolved GeV excess, unresolved TeV Excess…

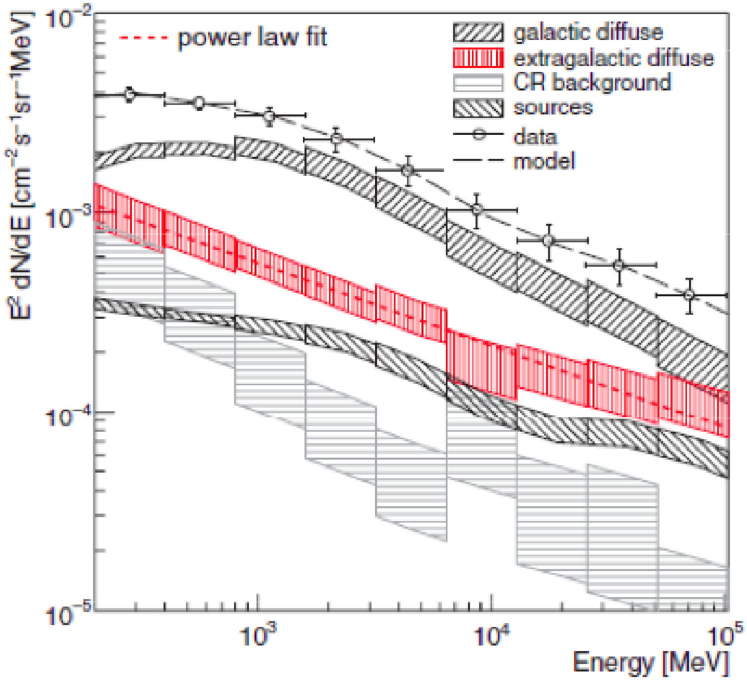




- *Fermi: EGRET GeV excess <u>not</u> confirmed*
- *Study of the Cygnus region with MILAGRO:*
  - Even after excluding MGRO J2019+37, the TeV gamma ray flux from the Cygnus region exceeds that predicted from models of cosmic ray production and propagation.
  - Flux is 8 times higher than conventional GALPROP predictions.

- Excess could be due to unresolved gamma ray sources or hard-spectrum cosmic ray or electron accelerators.

Isotropic (Extragalactic) Diffuse Emission



|b|>10°

- Spectral Index γ=2.41 $\pm$ 0.05
- Intensity (E>100 MeV)= $(1.03 \pm 0.17)\times10^{-5}$ $cm^{-2}\, s^{-1}\, sr^{-1}$

PRL **104**, 101101 (March 2010)

A recently published analysis has extracted the isotropic flux of gamma rays (believed to be primarily extragalactic) by reducing and understanding the residual CR background.

- Based on Fermi measurements of the blazar luminosity function (arxiv:1003.0895), unresolved AGN can account for up to 30% of this diffuse.
- Star forming galaxies *may* be able to account for most of the rest (Fields et al., arxiv:1003.3647).

Fermi
Gamma Ray
Space Telescope

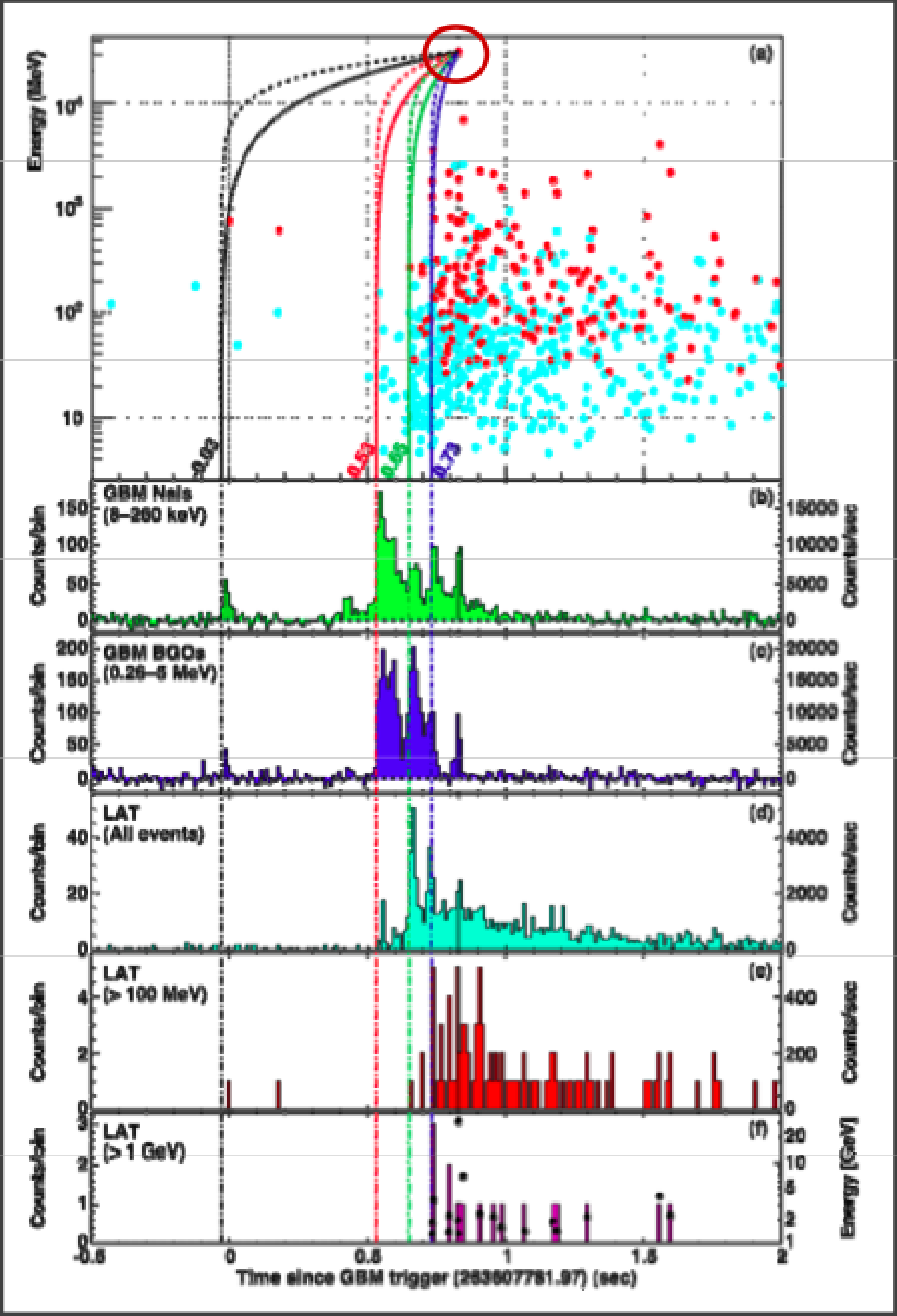
GRB 090510

Interesting constraint on Quantum Gravity ideas:

Some quantum gravity "theories" predict that high energy photons should travel slightly more slowly than low-energy photons.

In this GRB we see a 31 GeV photon less than 1 second after the first X-ray photons, after traveling >7 billion light years.

This requires the quantum-gravity mass scale to be at least ***1.2 times the Planck mass.***



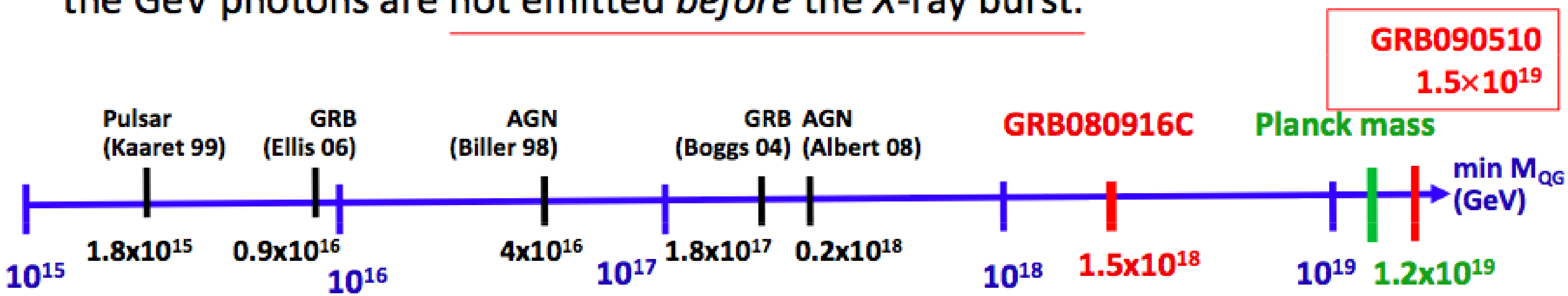
Nature **462**, pp 291, 331.

Limits on Lorentz Invariance Violation

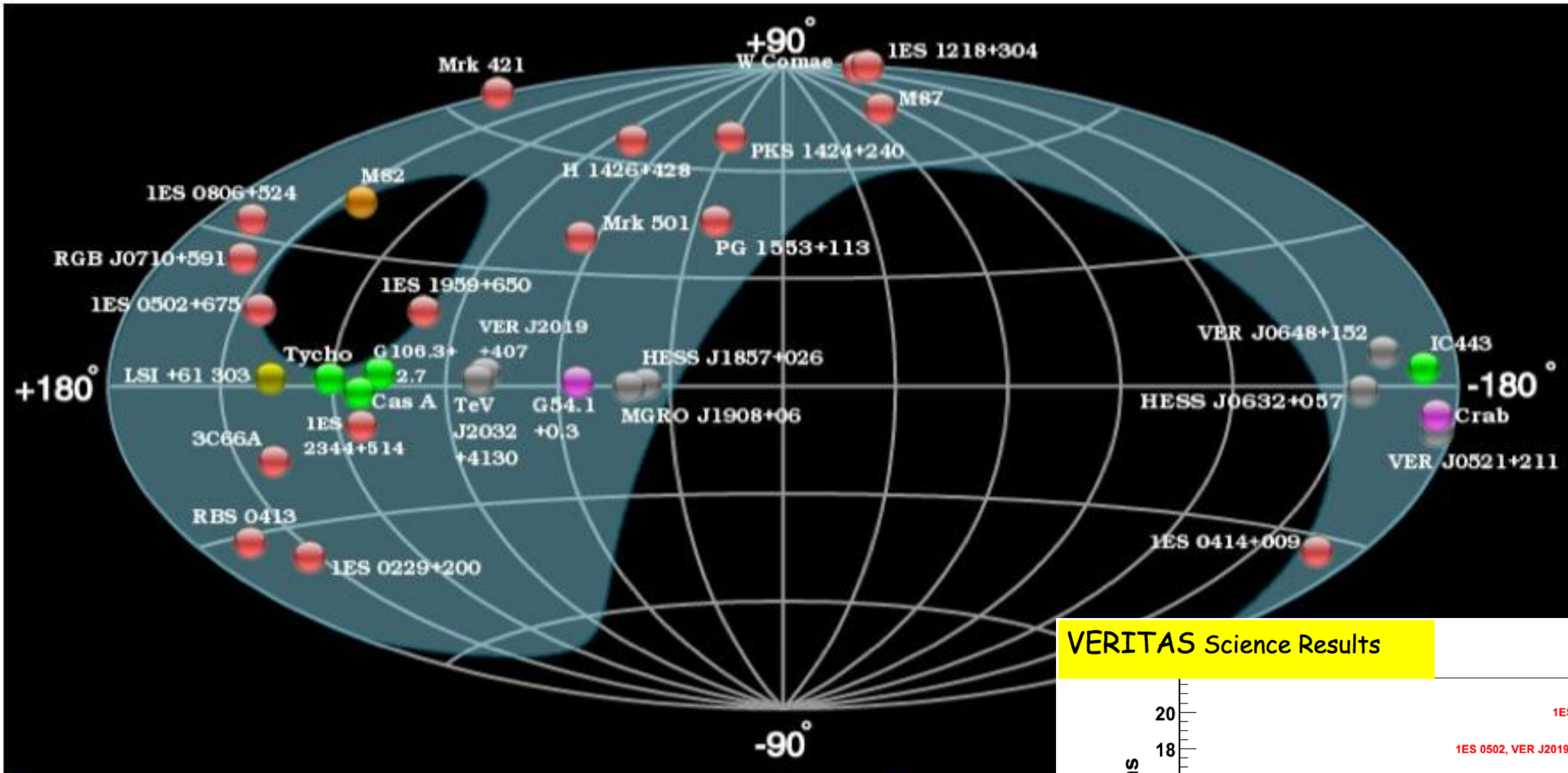
- Assume dispersion: $v = \delta E/\delta P \sim c\,(1-(E/E_{QG})^n)$ with $n=1$
- Cosmological distance:

$$\Delta t = \frac{(1+n)}{2H_0}\frac{E_h^n - E_l^n}{(M_{\mathrm{QG},n}c^2)^n}\int_0^z \frac{(1+z')^n}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}}\,dz'$$

- In GRB 080916C (z=4.2) the highest energy photon, 13.2 GeV, was detected 16.5 s after the GBM trigger.
- In GRB 090510 (z=0.90) the 31 GeV photon was detected only 0.83 s after the GBM trigger.
- The time delay due to quantum gravity cannot be more than this, assuming that the GeV photons are not emitted *before* the *X*-ray burst.



Synergy between experiments



VERITAS catalog June 2010

(tevcat.uchicago.edu S Wakely & D Horan)

Fermi is a "path finder"

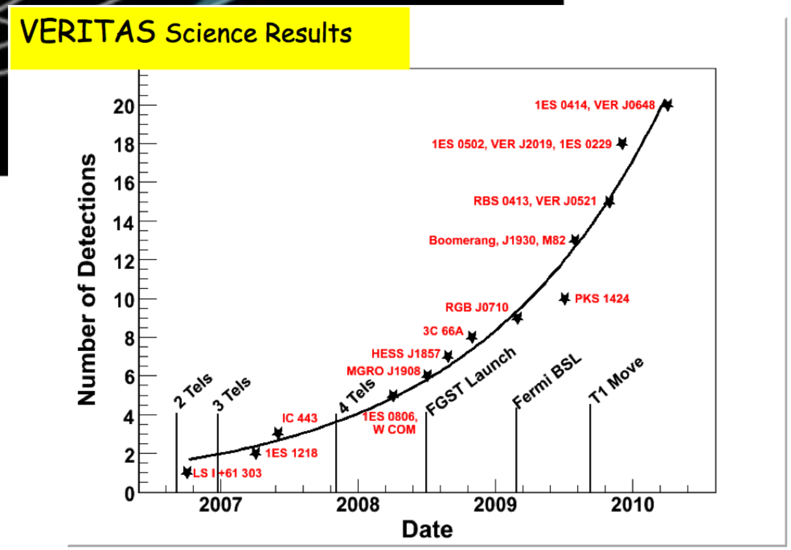
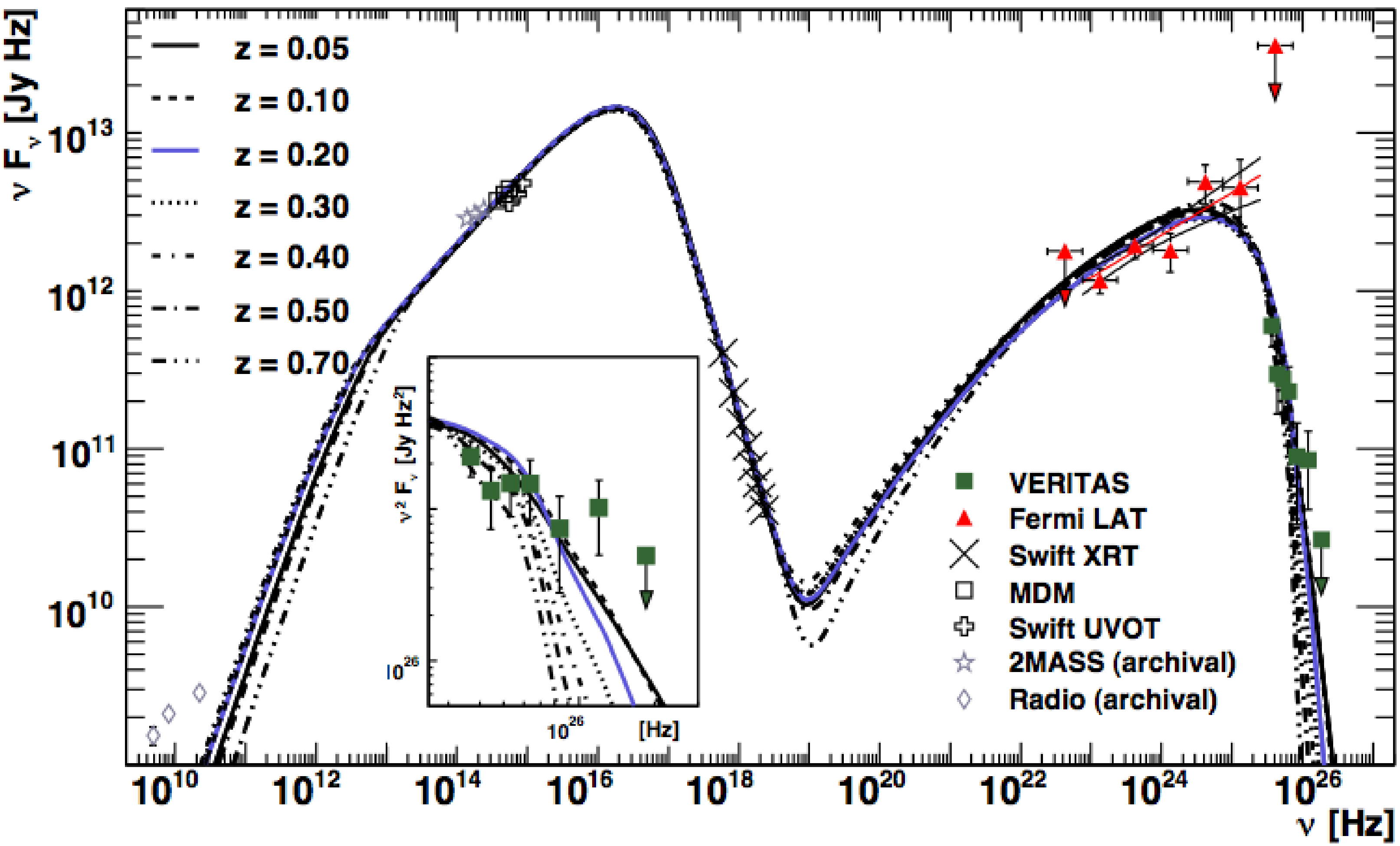


Fig: Dr Andy Smith, Argonne National Laboratory

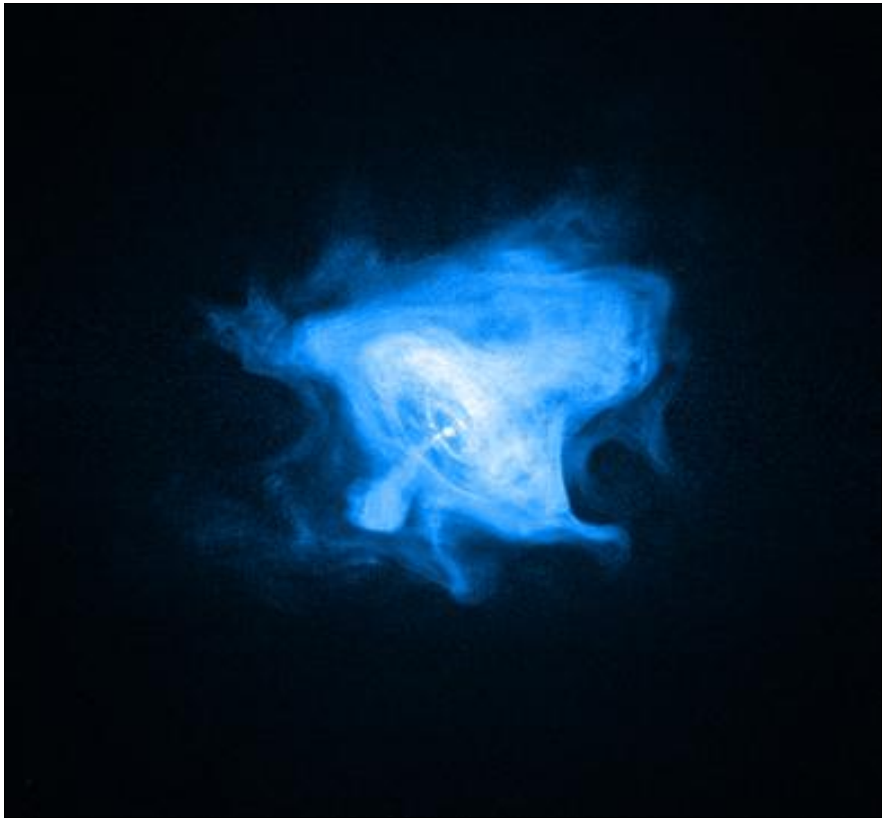
PKS 1420+240



ν F_ν [Jy Hz]
ν [Hz]
z = 0.05
z = 0.10
z = 0.20
z = 0.30
z = 0.40
z = 0.50
z = 0.70
VERITAS
Fermi LAT
Swift XRT
MDM
Swift UVOT
2MASS (archival)
Radio (archival)
ν² F_ν [Jy Hz²]
[Hz]

Pulsar Wind Nebula

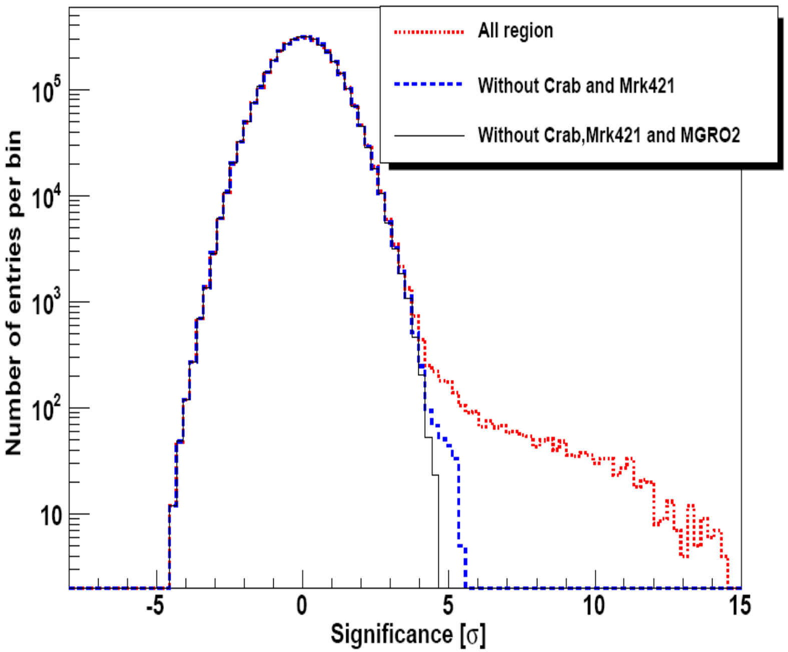
- *Emerging picture:*
  - The typical Galactic multi-TeV source is a Pulsar Wind Nebula (PWN) associated with an MeV to GeV pulsar.
  - ‘Wind’ driven by electrons from the central pulsar.
  - Shocks where 'wind' meets ISM give additional electron acceleration.
  - Gamma-rays are from electron inverse-Compton of local photons.

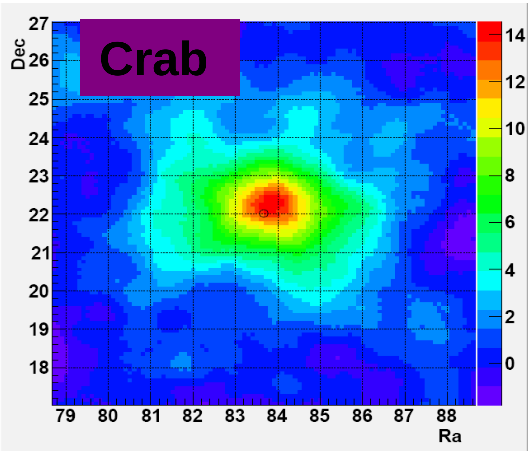


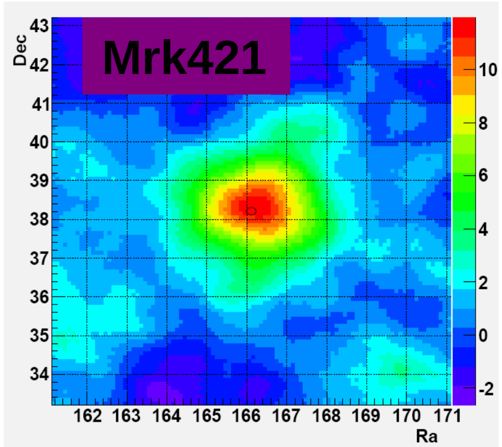
Chandra X-ray image of the Crab

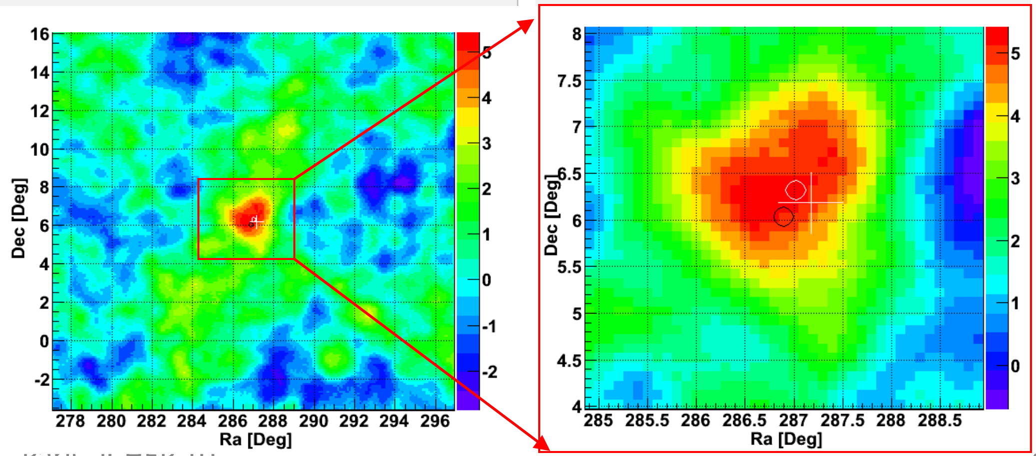
ARGO, all sky survey result

- Method: Direct Integral method to estimate background.
- 3 sources with significance >5σ
- Crab 14.5 σ,Mrk421 11.9 σ, MGRO1908+06 5.4 σ









Mrk421: June 2008 flares

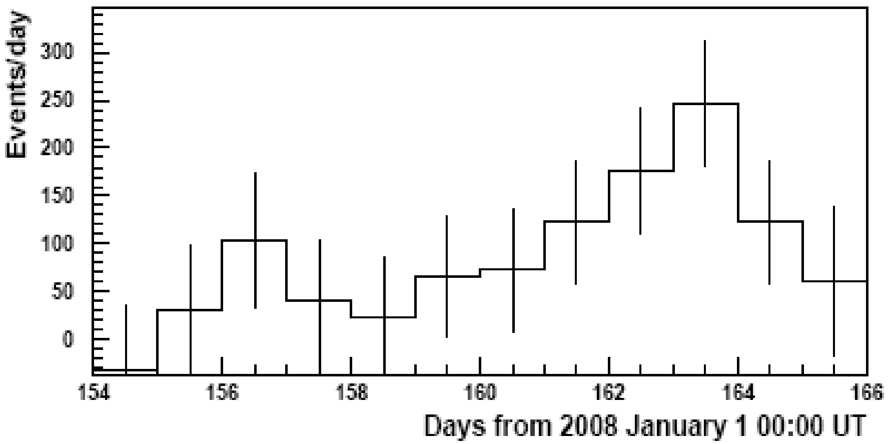
Observed from optical to TeV energies

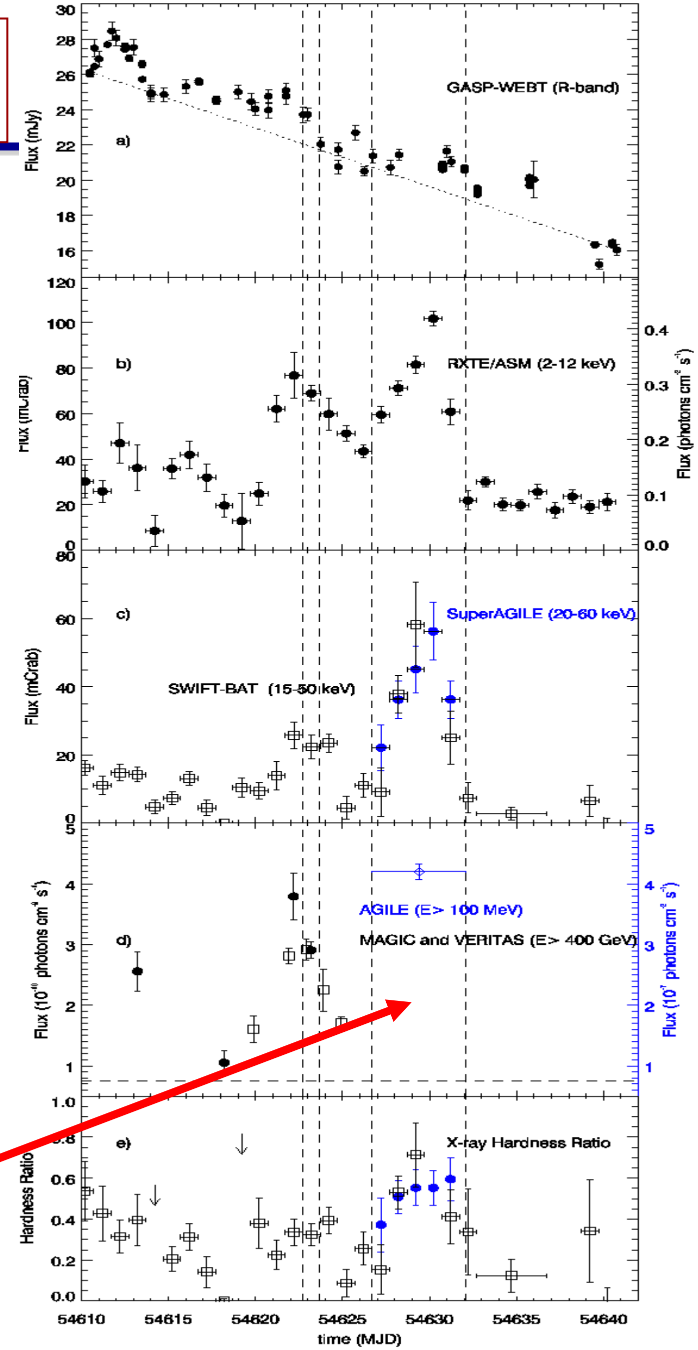
Donnarumma et al. ApJ 691 (2009) L13, data from:

- 3)
-
-
- ;

c

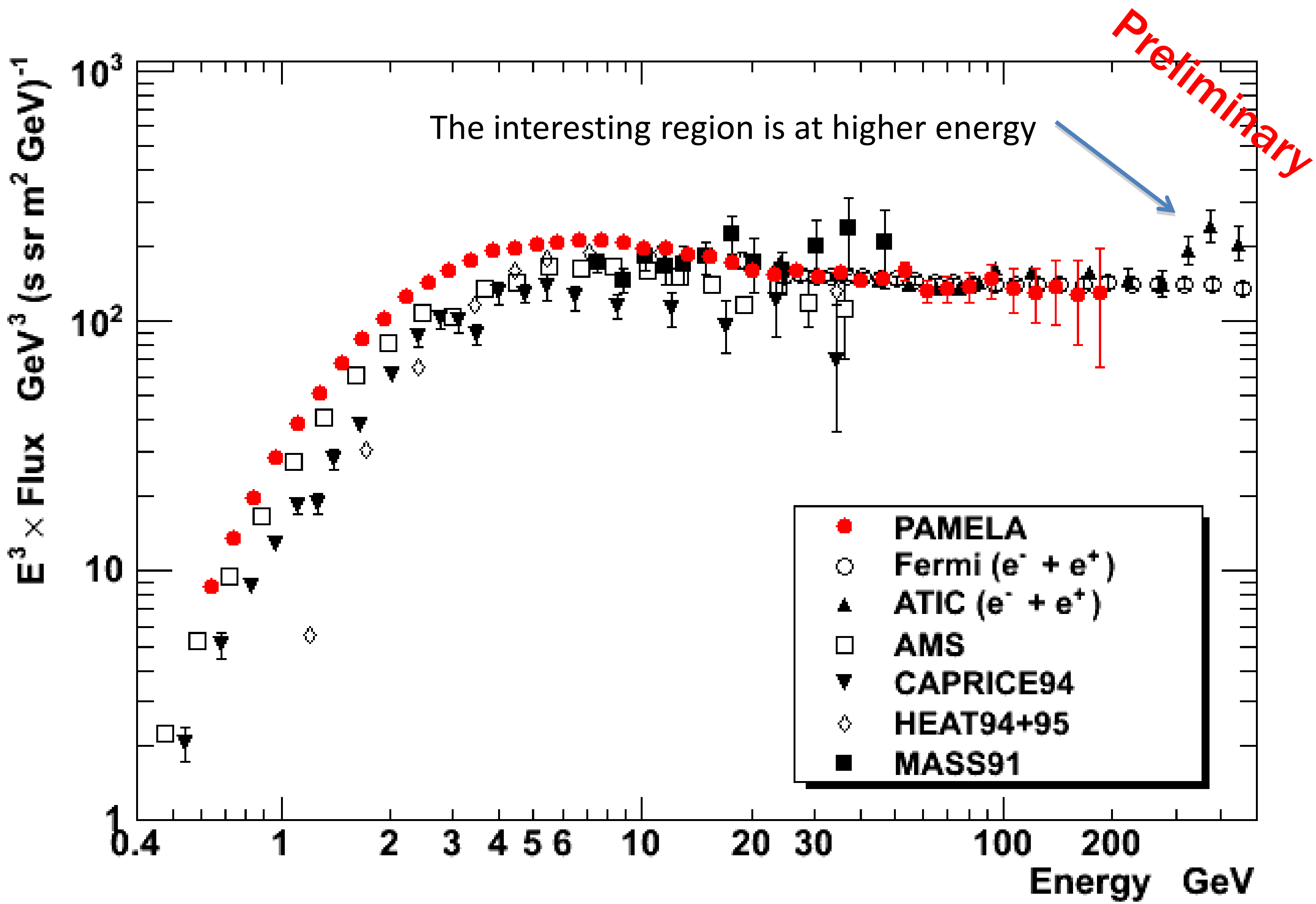
RossiXTE/ASM (2-12 keV) and Swift/BAT (15-50 keV)





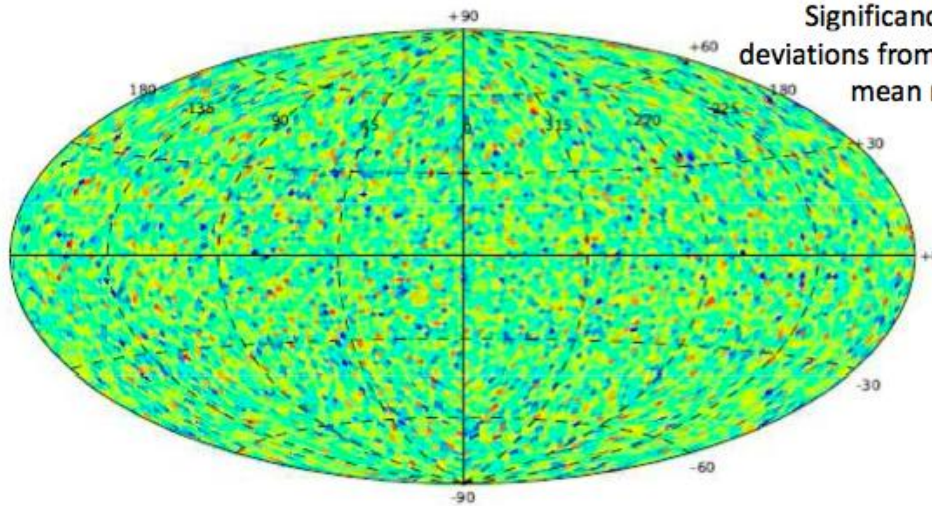
No VHE Cerenkov data after June 8

PAMELA Electron (e-) Spectrum (x E3)

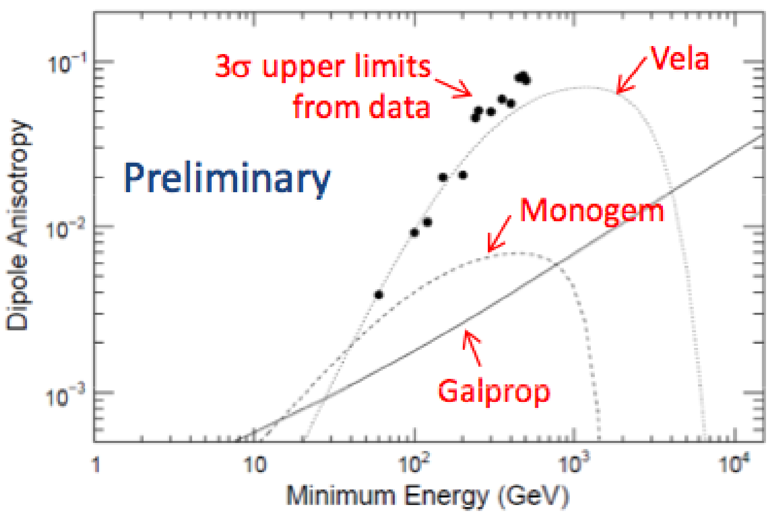


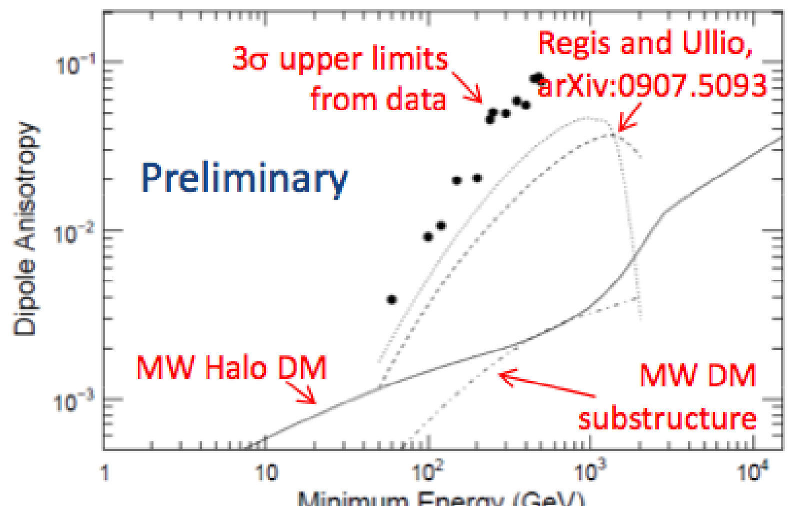
Looking at the anisotropy

- No significant detection of anisotropy in Fermi electrons
- Still compatible with an extra component, both pulsar or DM



Significance of deviations from the mean rate.

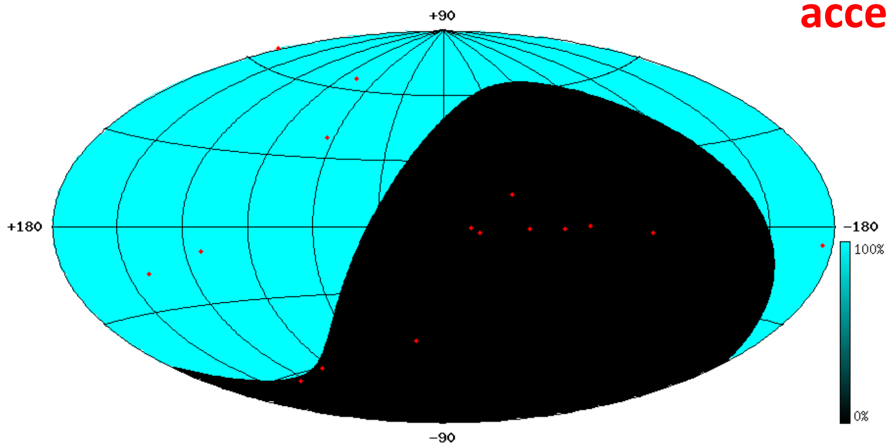


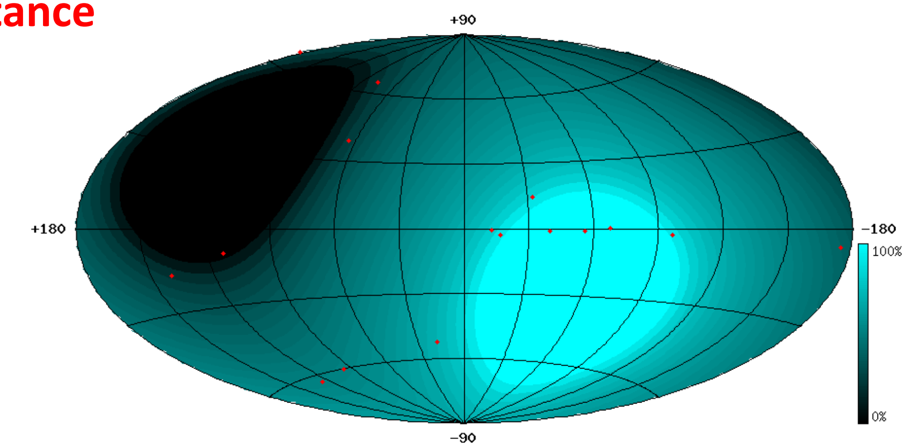


sky view (galactic coordinates)

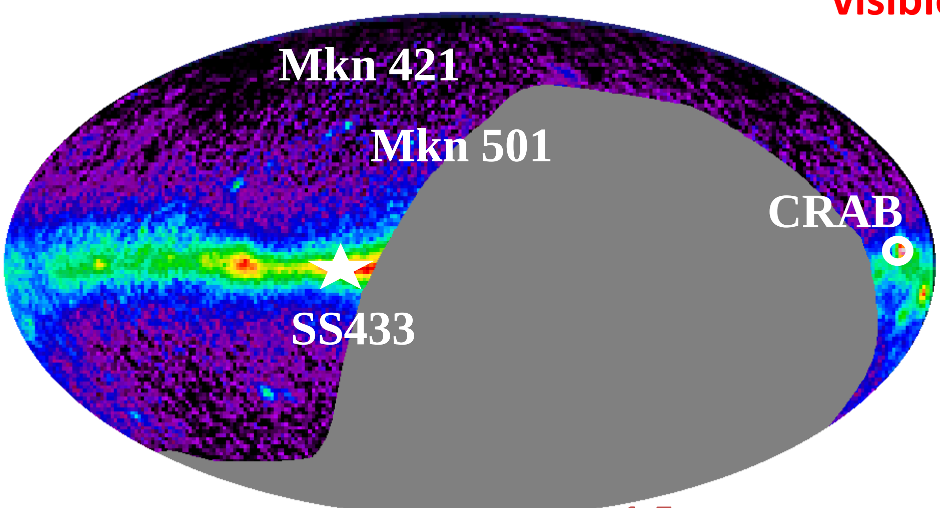
AMANDA / IceCube (South Pole) | **ANTARES (43° N)**

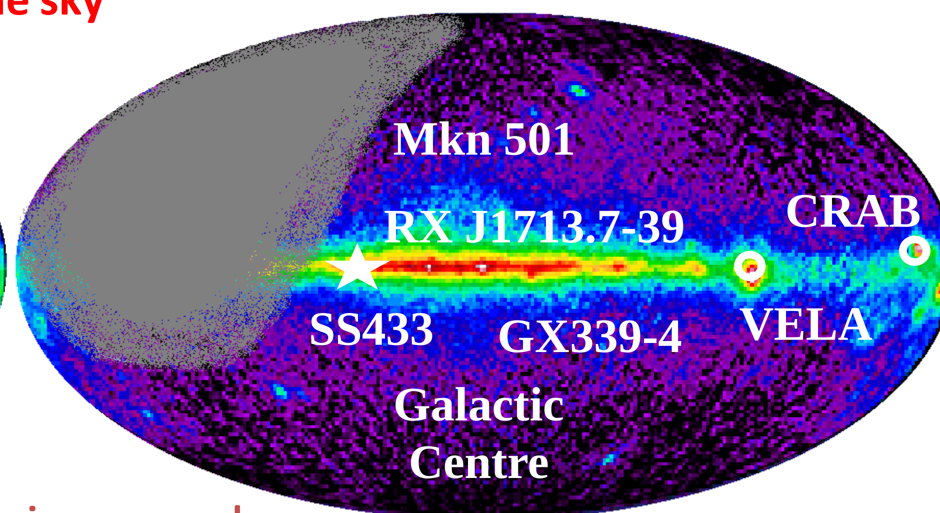
acceptance





visible sky



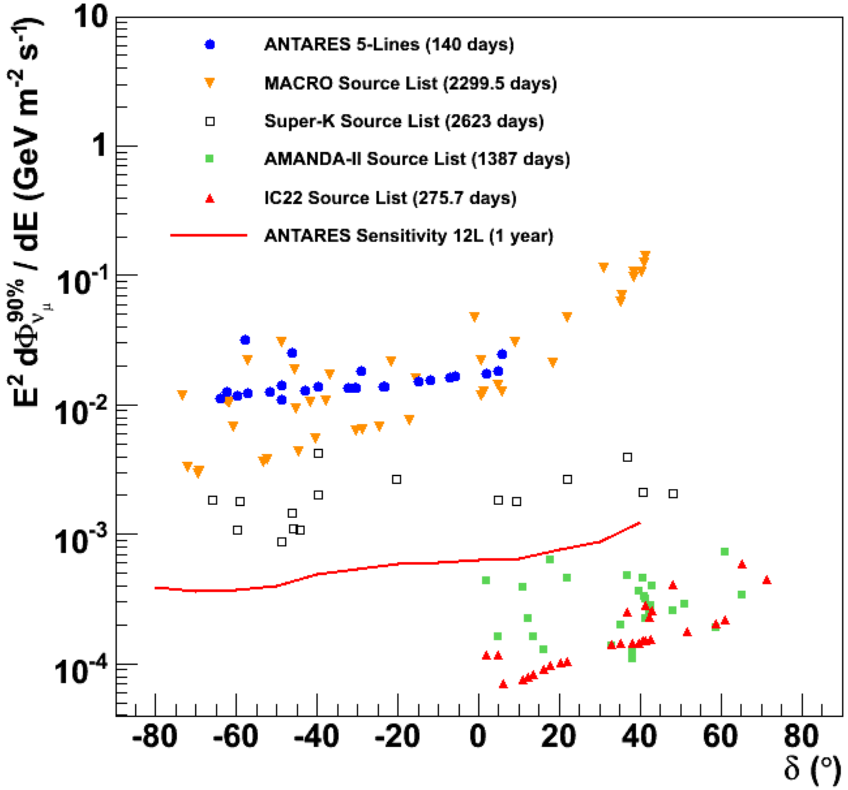


1.5 π sr common view over a day

Neutrinos for celestial point sources UL from Antares and IC-40

Looking at the position of selected point sources
No significant clustering in the sky

Spurio's talk



Finley's talk