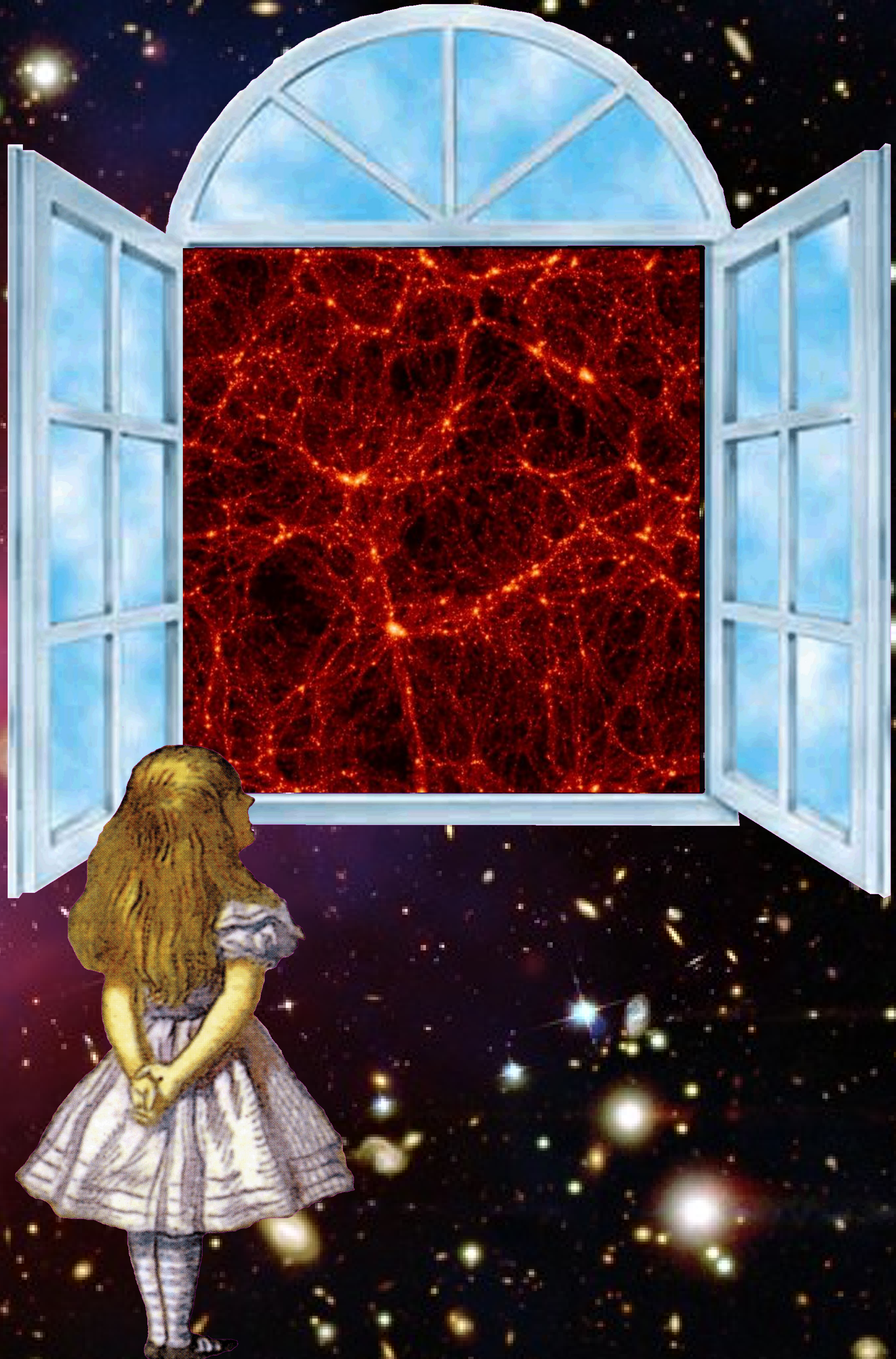
Highlights of GeV and TeV Gamma-ray astronomy and Indirect Dark Matter Searches with the Fermi LAT



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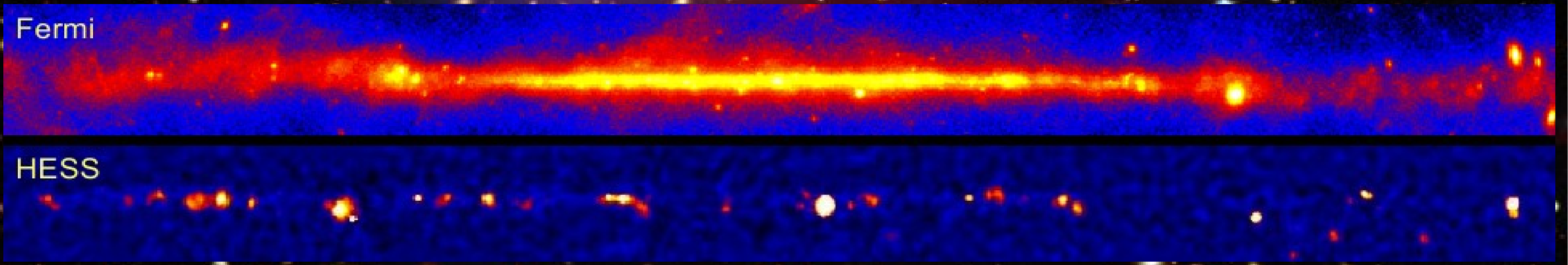
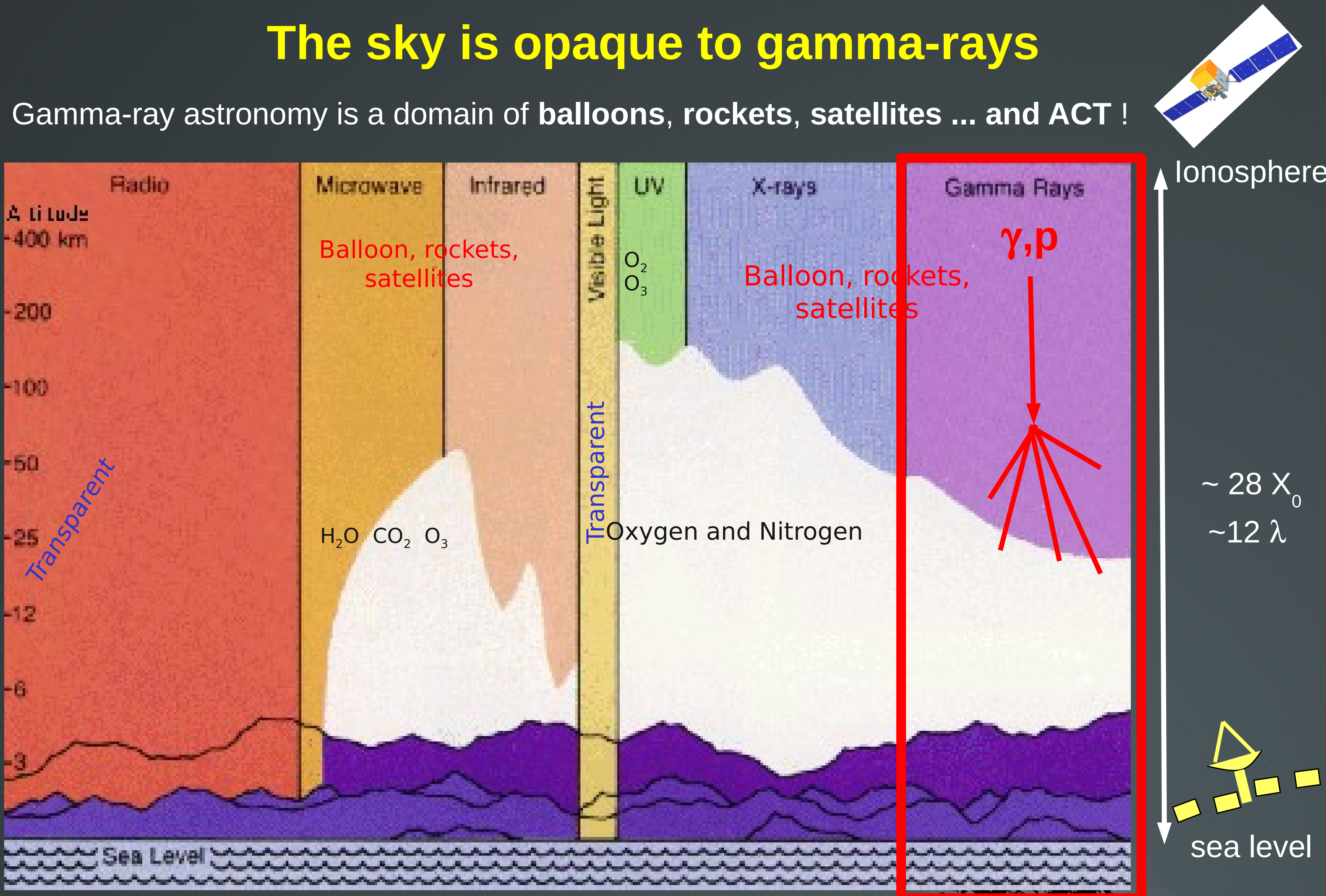
Outline

- Gamma-ray observatory techniques and current experiments
- Selected topics:
  - Overview of GeV/TeV sources
  - Supernova remnants and the origin of Galactic cosmic rays
  - Dark matter searches
  - The future
- Summary and Conclusions



The sky is opaque to gamma-rays

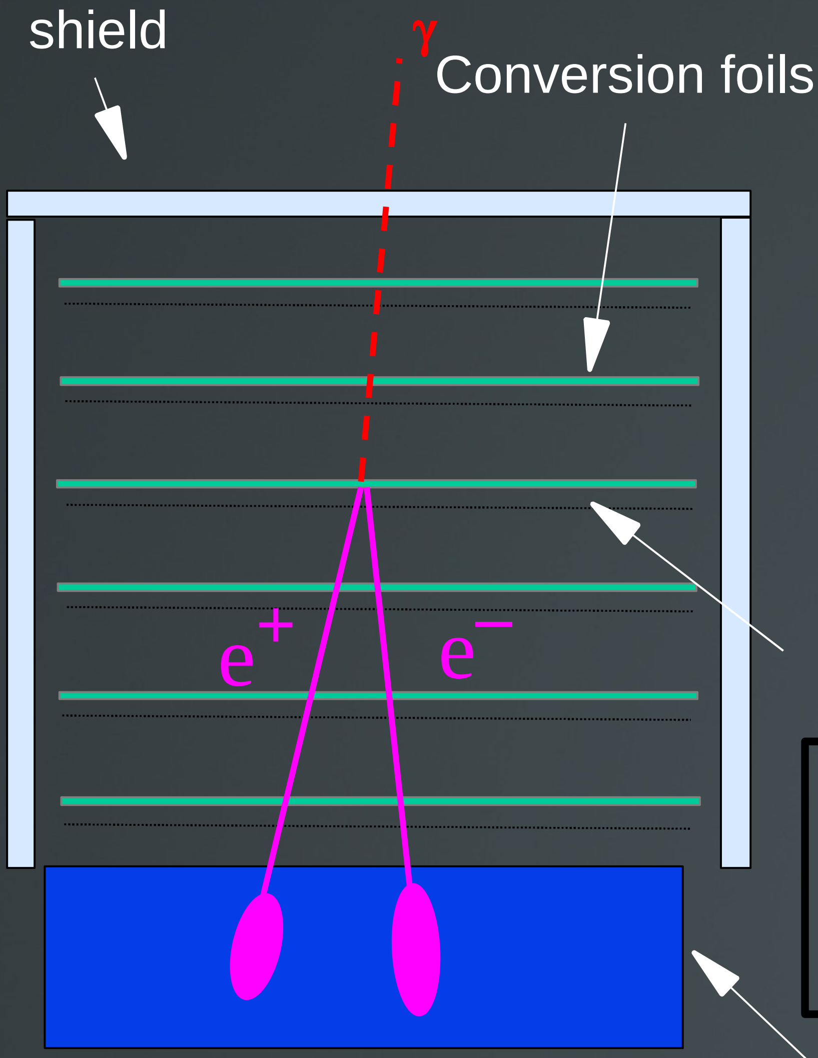
Gamma-ray astronomy is a domain of **balloons**, **rockets**, **satellites ... and ACT** !

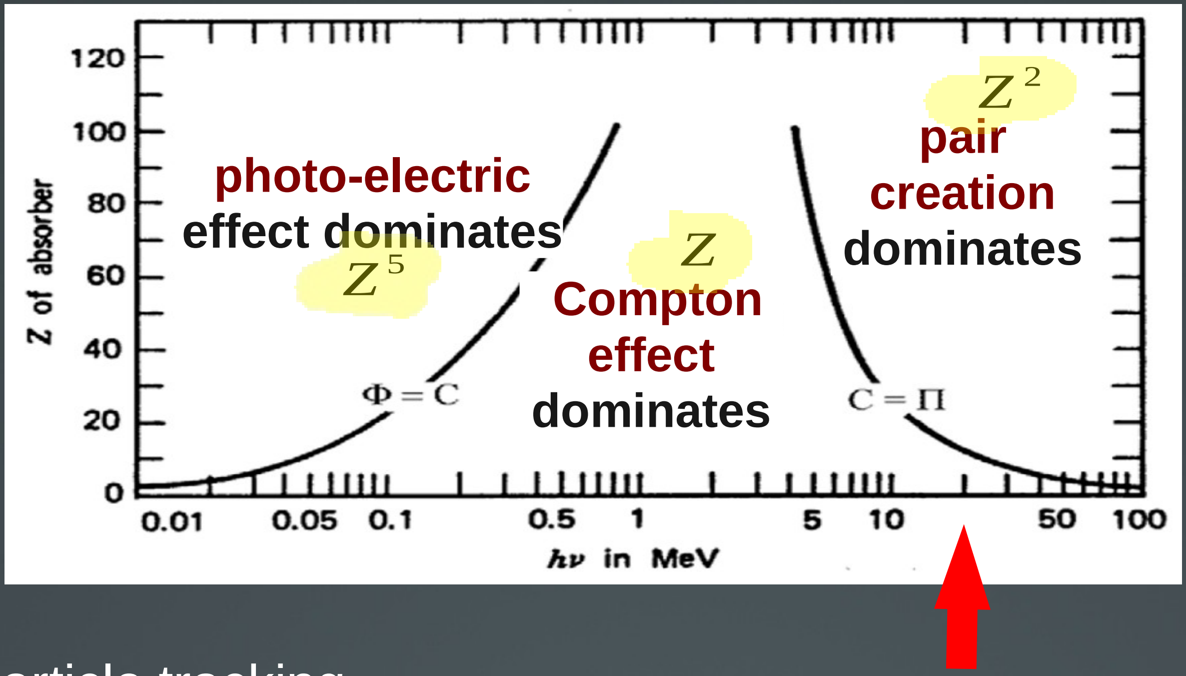


1 X_0 (radiation length) = 37 g/cm^2 of air,

1 λ_I (nuclear inter. length) = 90 g/cm^2 of air

Space based observatory : Pair conversion telescopes technique

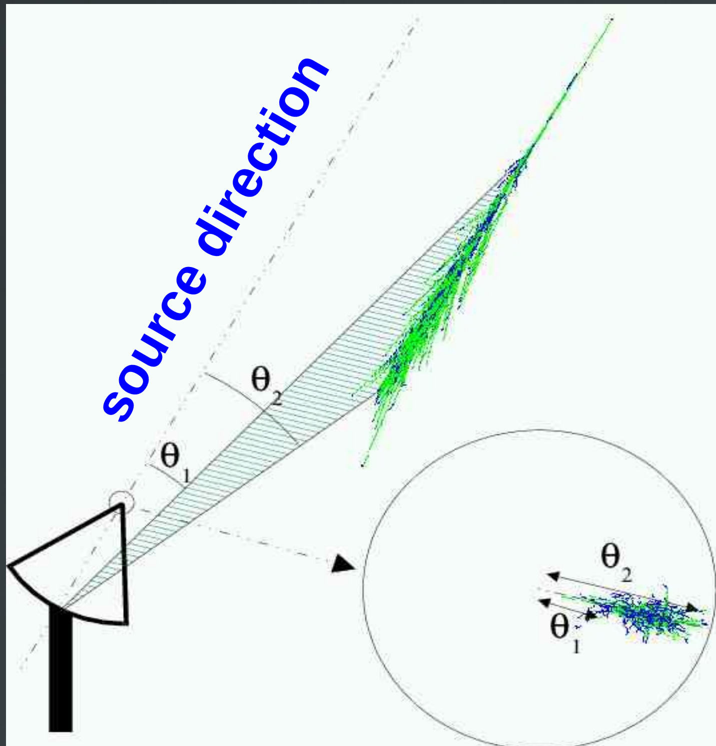




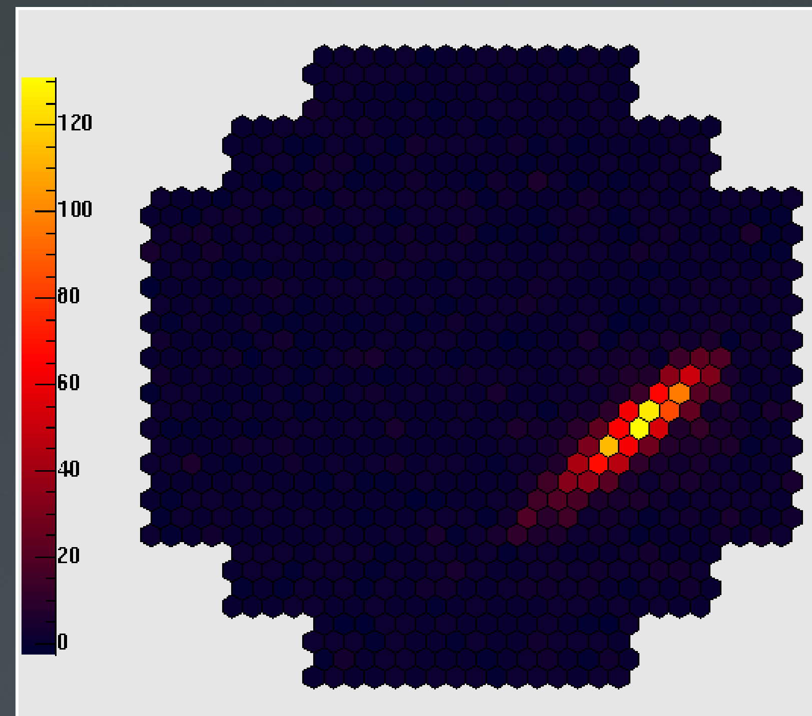
Key characteristics of curent PCT :

- Energy Resolution: ~10% (~5% off-axis)
- PSF (68%) at 100 MeV ~ 5°
- PSF (68%) at 10 GeV ~ 0.1°
- Point Source sens. (>100 MeV): 3×10^{-9} cm^{-2} s^{-1}

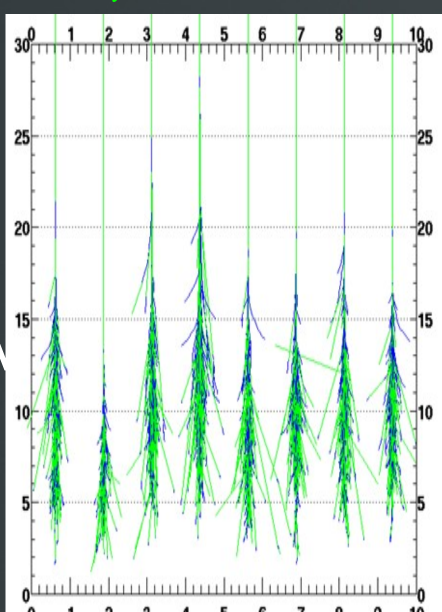
Ground based obserbatory : Imager technique



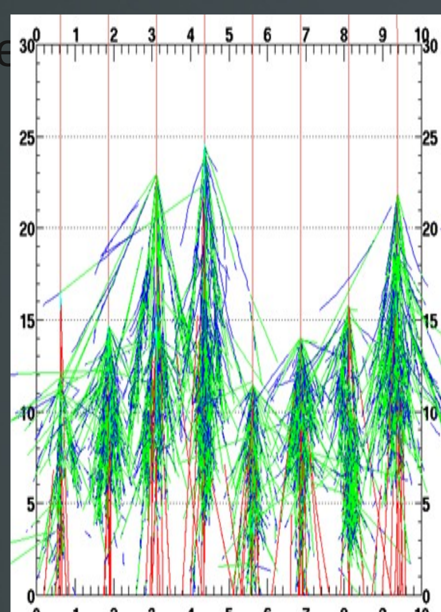
First HESS events taken June 11, 2002



γ, 100 GeV



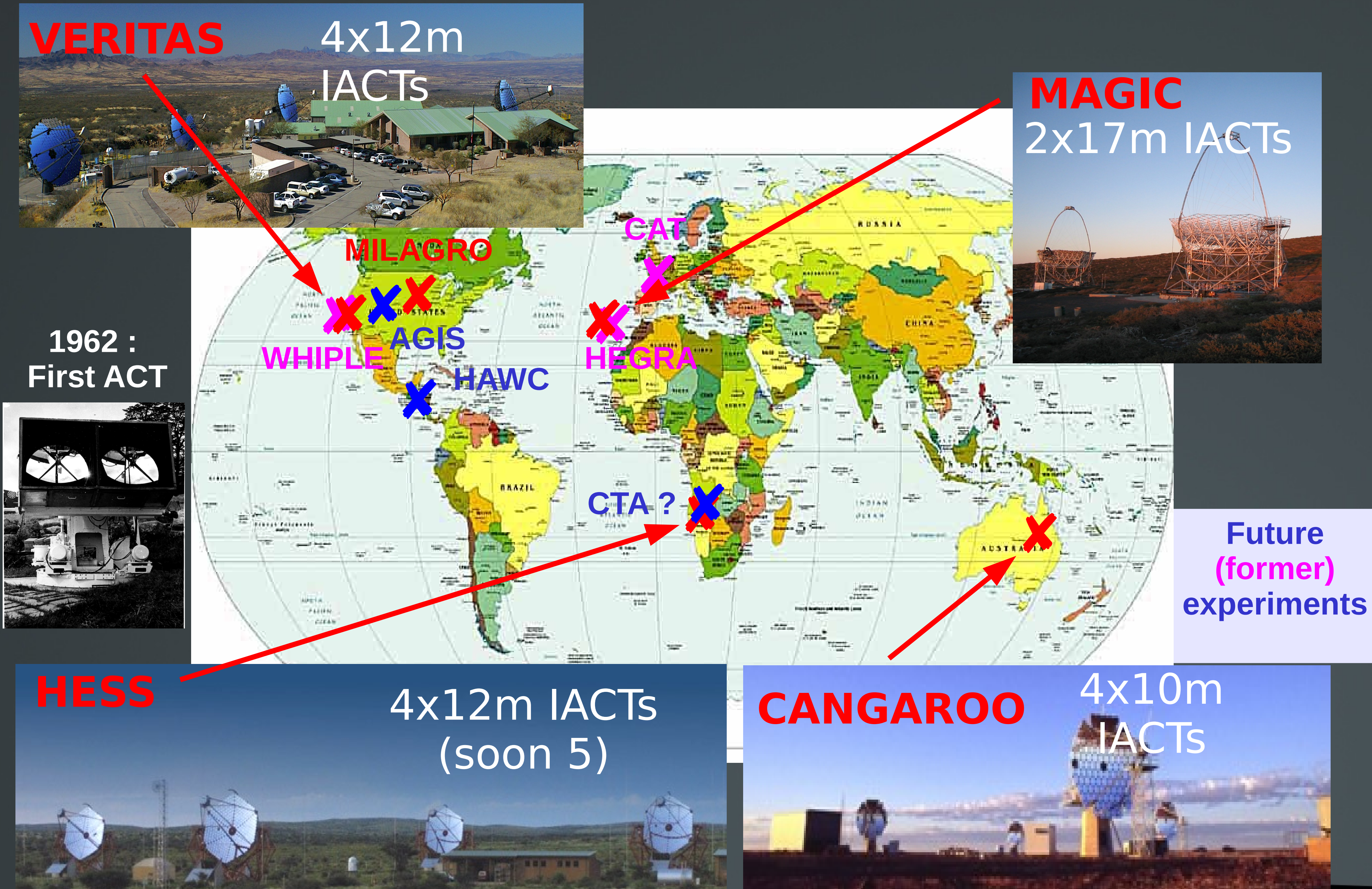
Protons, 500 GeV



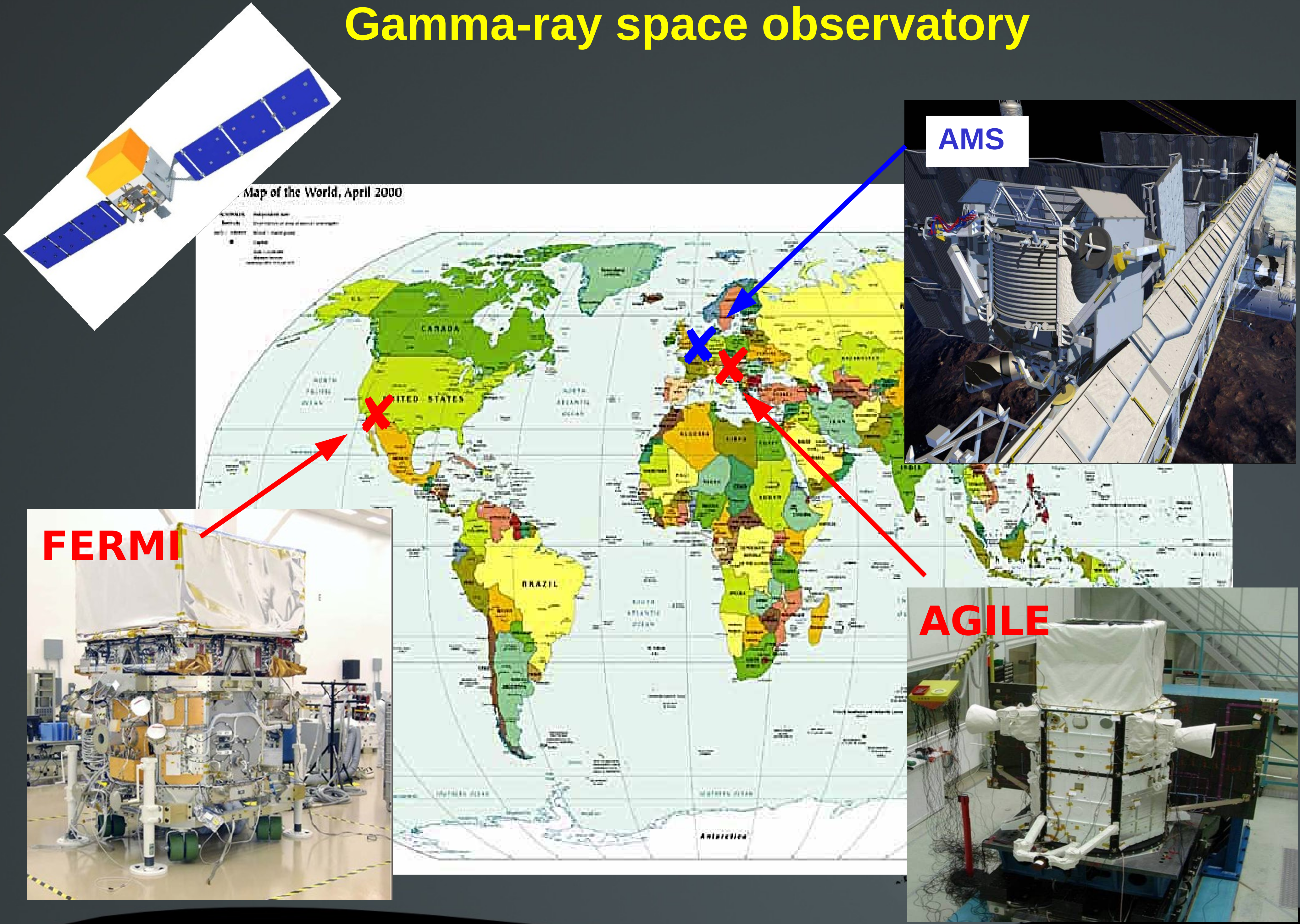
Key characteristics of curents CTA :

- few telescopes ∅ ~ 10 m
- energy threshold ~ 100 GeV -> ~ 10 TeV
- field of view ~ 5°
- energy resolution ~ 15%
- angular resolution ~ 0.1°
- sensibility 1% of the Crab nebula in 25h

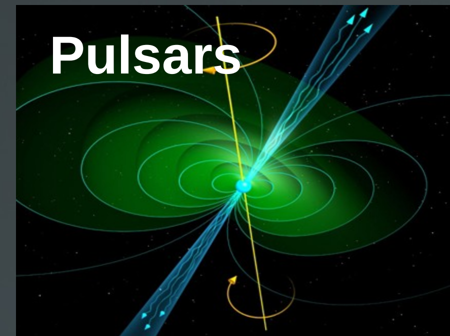
Ground based (imaging) gamma rays observatory

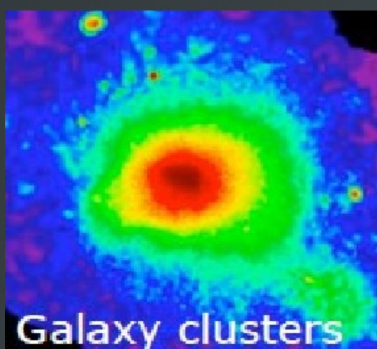


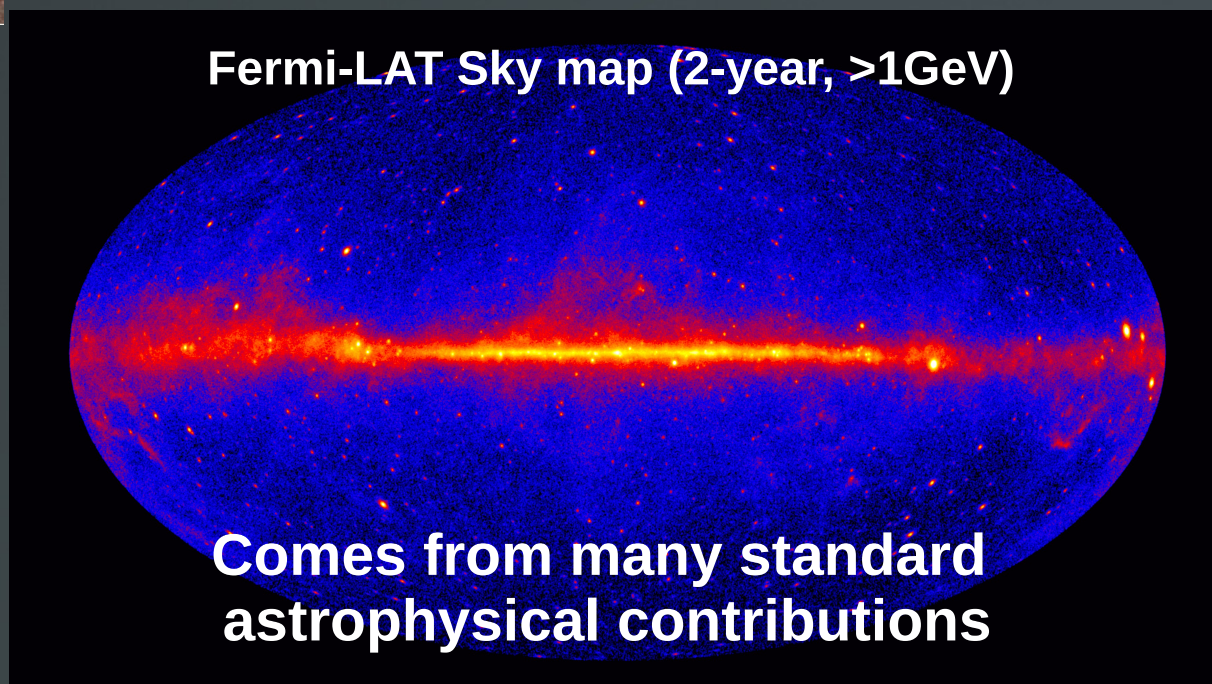
Gamma-ray space observatory



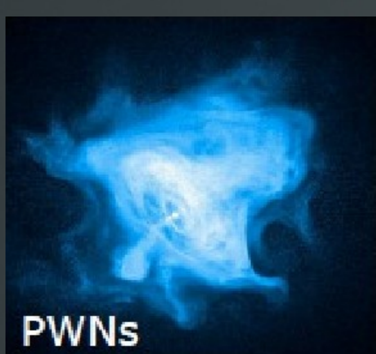
The GeV-TeV Gamma-ray Sky



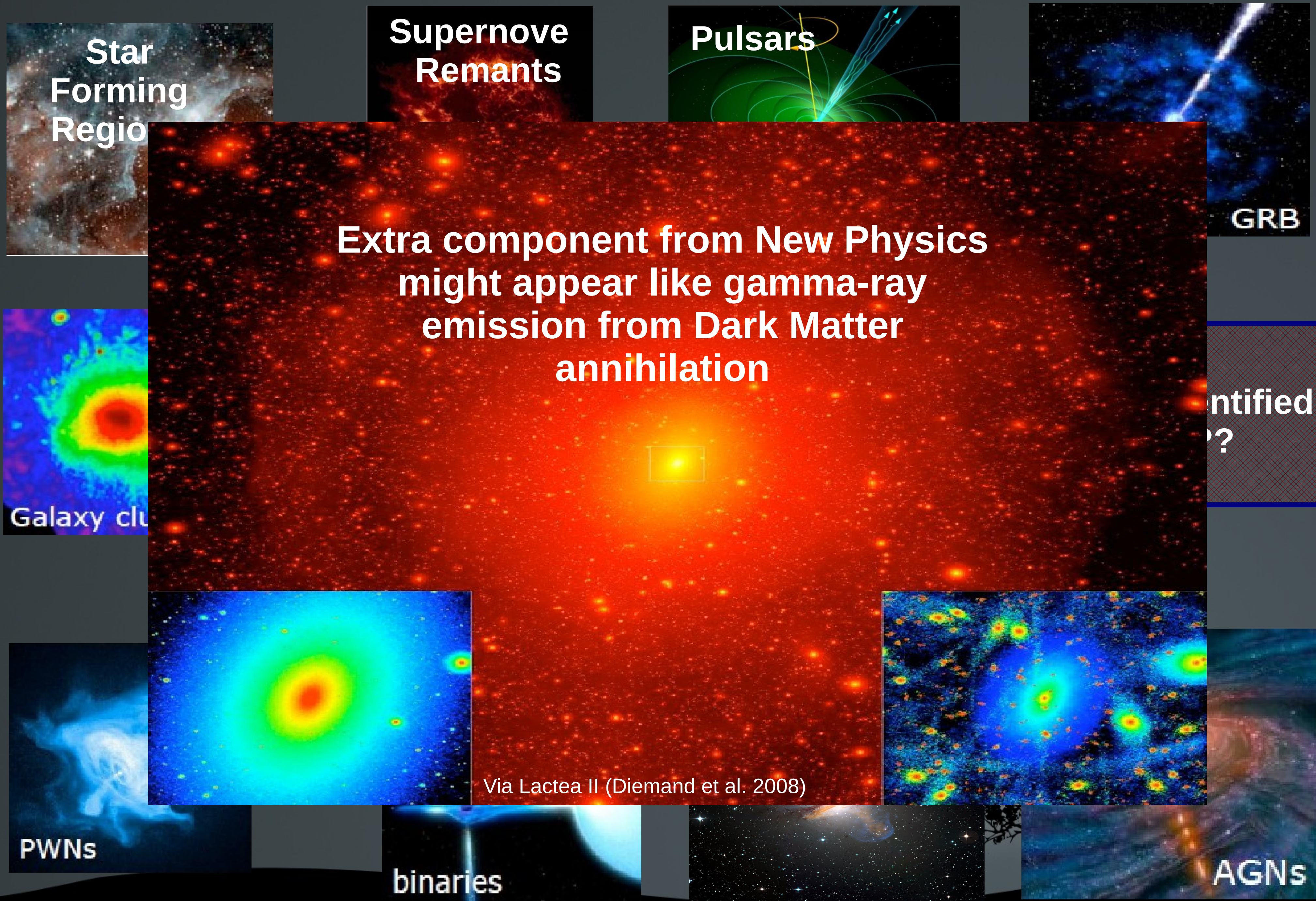




Unidentified ??

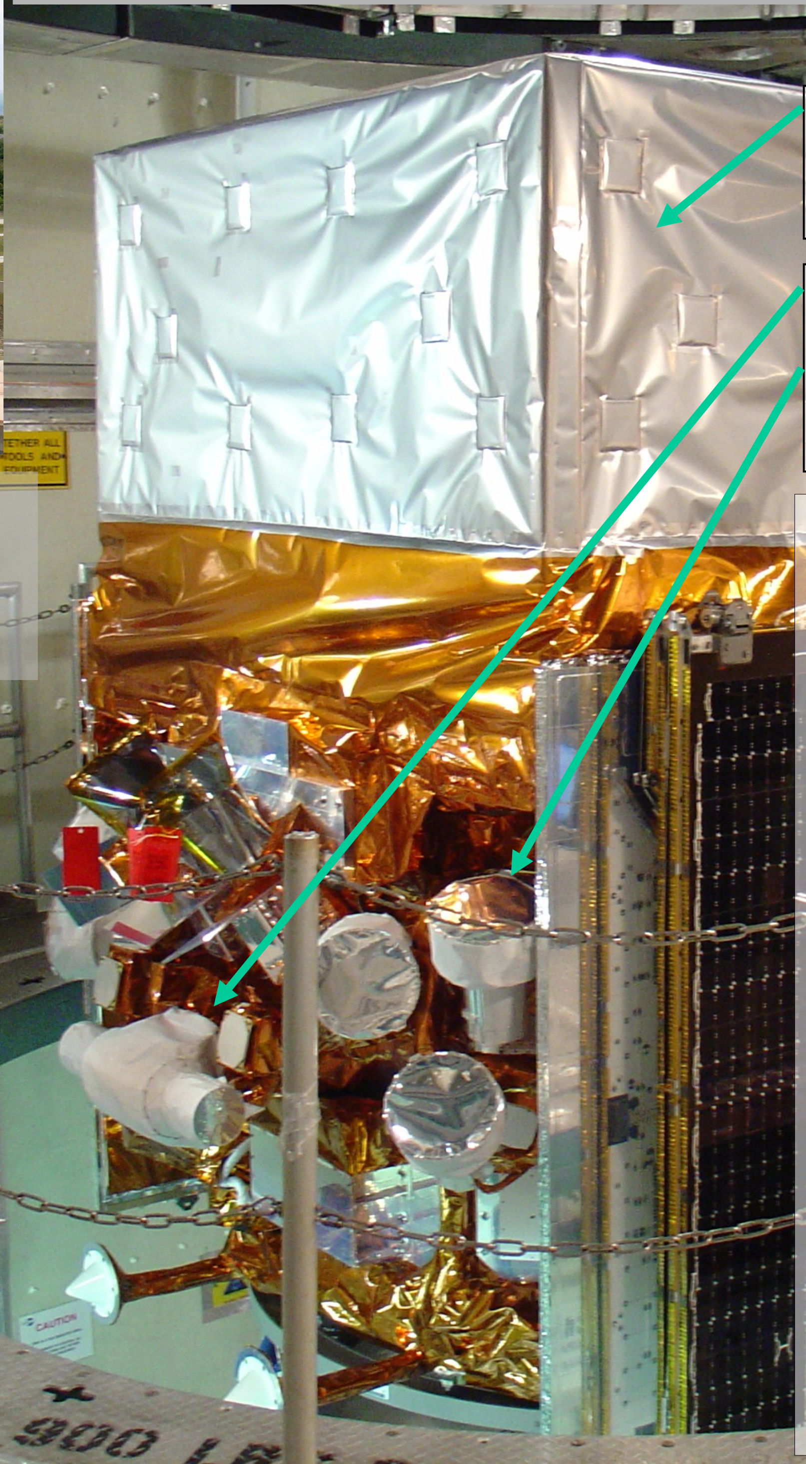


The GeV-TeV Gamma-ray Sky



The Fermi-LAT observatory

Launch :
June 11 2008
Nominal operations:
Aug 4 2008



Large AreaTelescope (LAT)
20 MeV - >300 GeV

Gamma-ray Burst Monitor (GBM)
NaI and BGO Detectors
8 keV - 30 MeV

KEY FEATURES

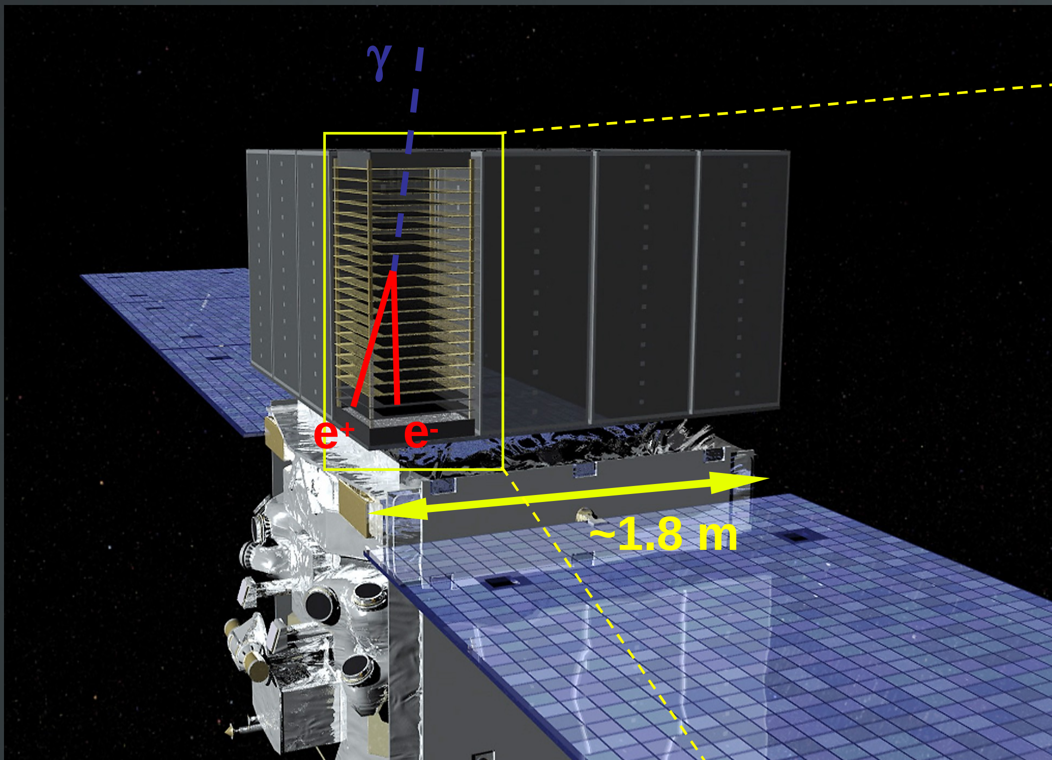
- **Huge field of view**
  - **LAT: 20% of the sky at any instant; in sky survey mode, expose all parts of sky for ~30 minutes every 3 hours. GBM: whole unocculted sky at any time.**
- **Huge energy range, including largely unexplored band 10 GeV - 100 GeV.**

Total of >7 energy decades !

Currently no other telescope covering this energy range

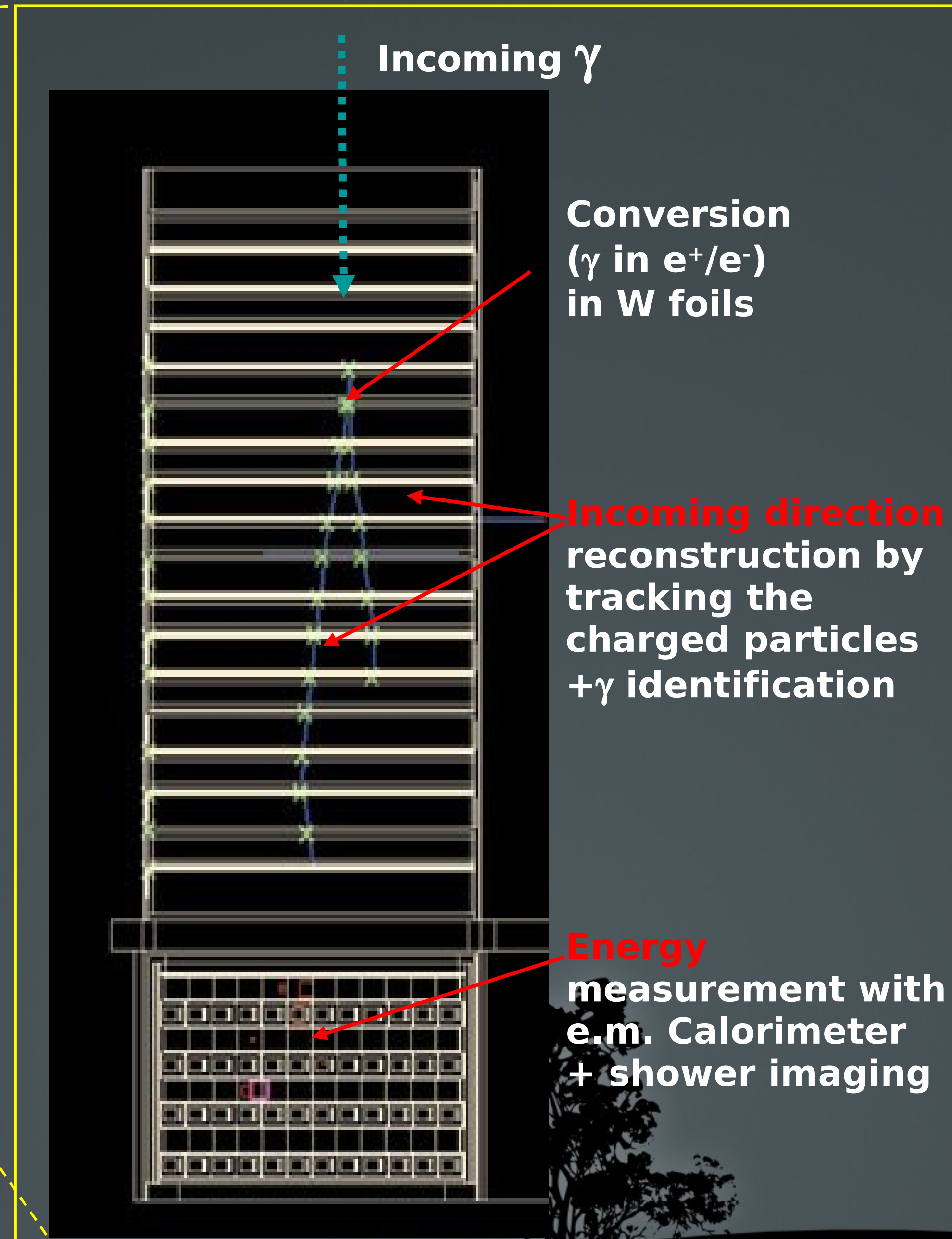
- **Large leap in all key capabilities. Great discovery potential.**

The LAT



- **Precision Si-strip tracker :**
  Si-strip detector, W converter foils,
  80 m^2 of Si active area,
  1.5 radiation lengths on-axis.
- **Hodoscopic CsI calorimeter :**
  array of 1536 CsI(Tl) crystals in 8 layers.
  8.6 radiation lengths on-axis.
- **Segmented Anti-Coincidence Detector :**
  89 plastic scintillator tiles and 8 ribbons.
  charged particles veto (0.9997 average detection efficiency).

Modular pair-conversion telescope
4 x 4 array of identical towers



Fermi LAT Collaboration, APJ 697, 1071 (2009)

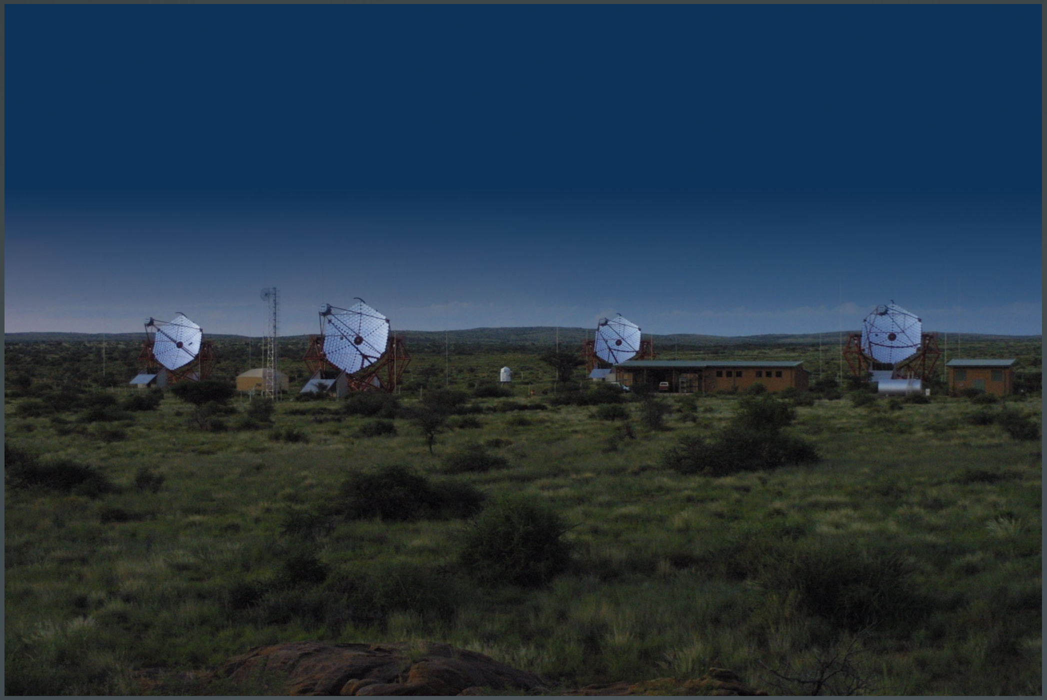
The HESS Cherenkov telescope array

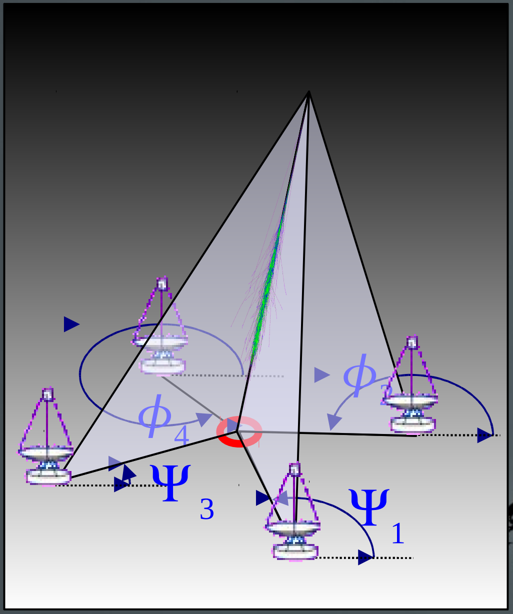
- High Energy Stereoscopic System located in Namibia, latitude=-23°, altitude=1800 m
  ~180 physicists, 35 institutes

- 4 telescopes, 120 m spacing , D=13m
  107 m^2 mirror surface
  cameras 960 PMT
  FOV= 5°
  energy threshold ~ 200 GeV
  energy resolution <15%
  angular resolution ~0.1°
  sensitivity (5σ) :
  5% of Crab in 1 h
  1% of Crab in 25 h
  HEGRA: 5% Crab in 100 h

- New analysis techniques
  (MVA and likelihood reconstruction)
  provide up to a 2x improvement in
  flux sensitivity

- full array running > january 2004
  5th telescope installed in 2010-2011
  mirror: 600m^2, 2048 PMT,
  FOV=3.5°, trigger threshold=20 GeV

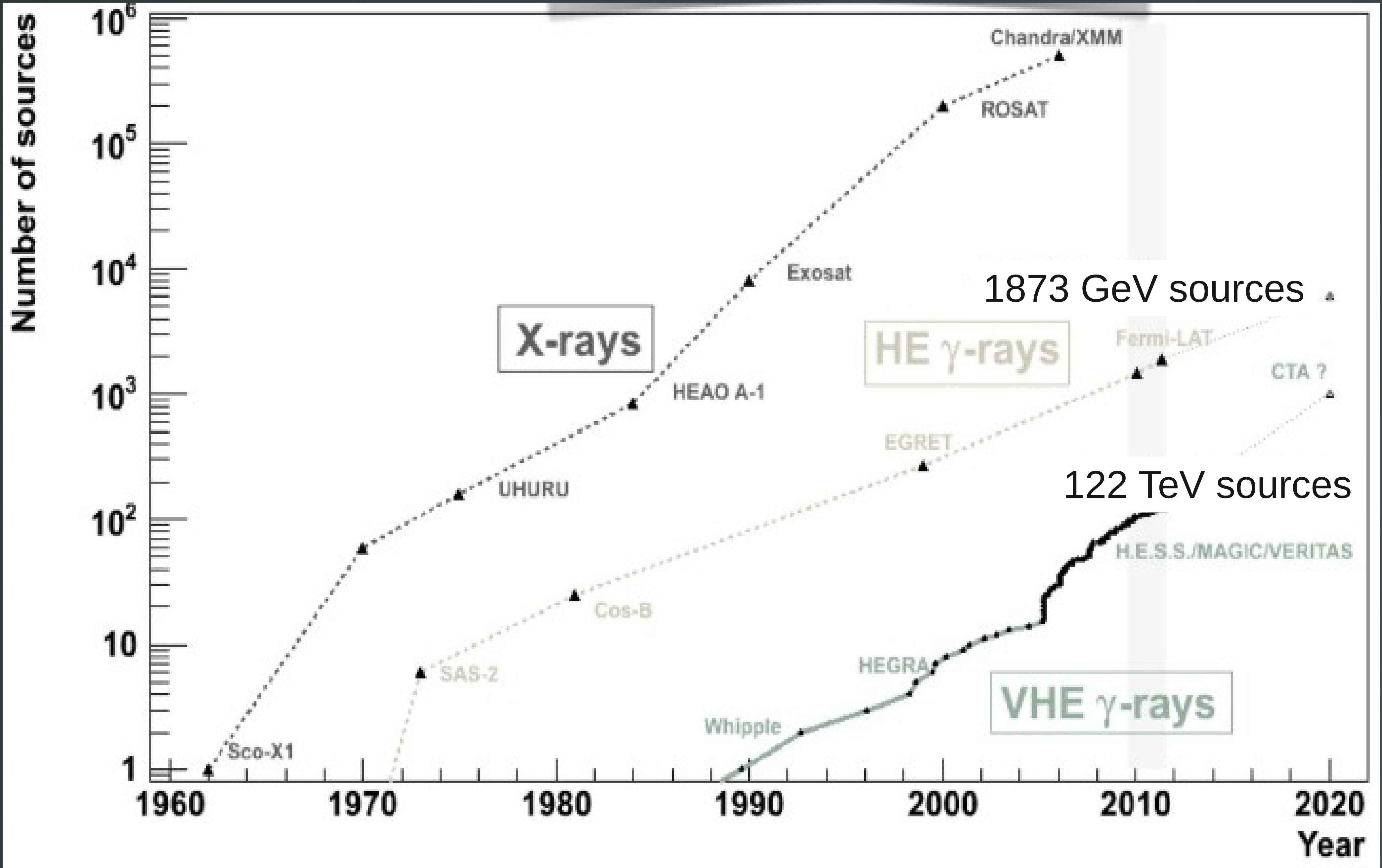




Steroscopy :

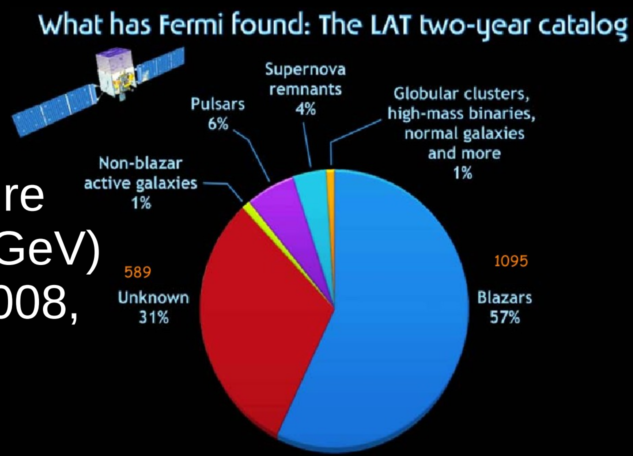
- cosmic ray background rejection
- improved gamma ray reconstruction

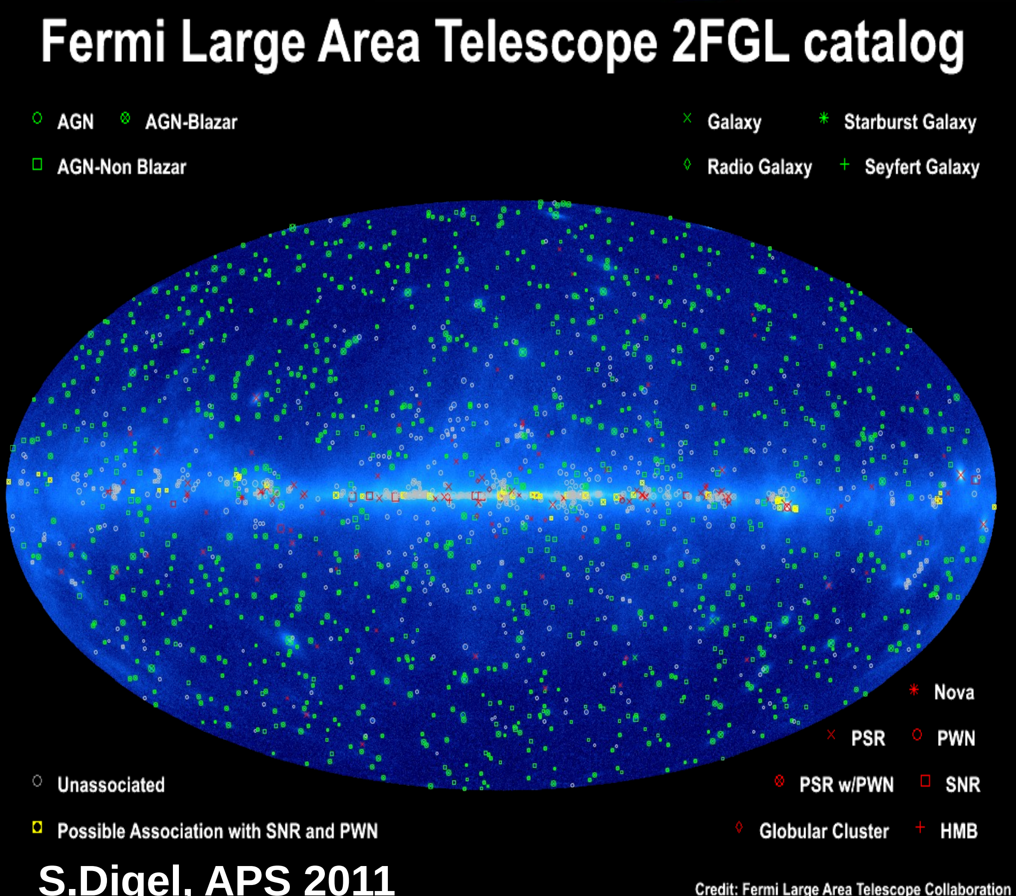
The “Kifune plot” ...



GeV versus TeV gamma-ray sky

FERMI- LAT :
1,873 sources, arXiv:1108.1435
integrated exposure (100 MeV to 100 GeV)
From August 4, 2008, to July 31, 2010.
TS > 25

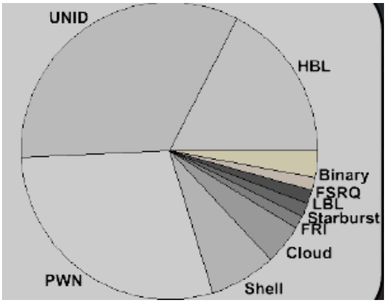




S.Digel, APS 2011

Current IACT :

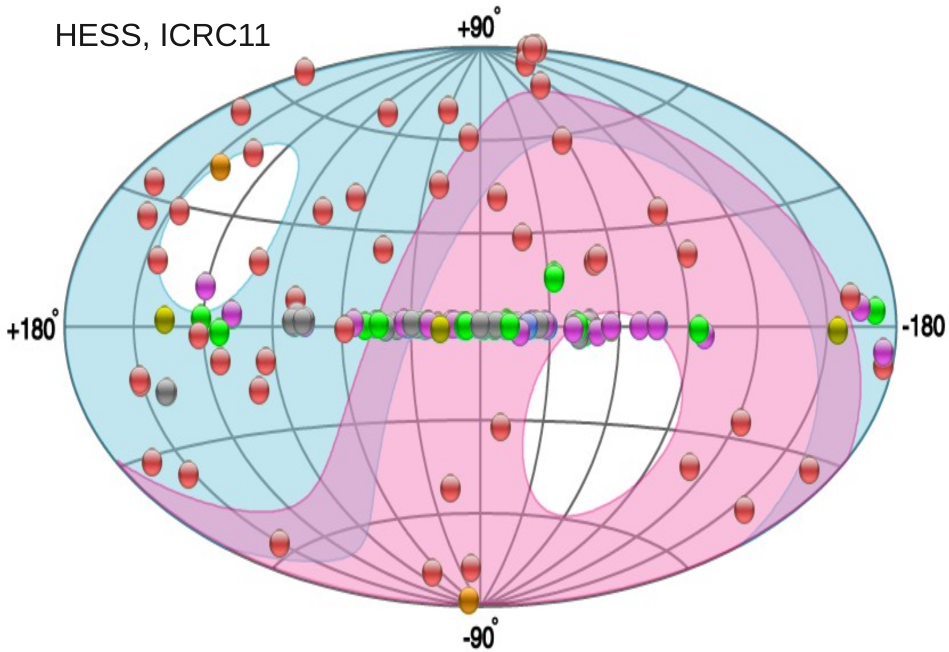
122 sources (75 Galactic + 47 Extragalactic), as of June 2011



HESS, ICRC11

Source Types

25	PWN
4	XRB PSR Gamma BIN
45	HBL IBL FRI FSRQ LBL AGN (unknown type)
17	Shell SNR/Molec. Cloud
2	Starburst
25	DARK UNID Other
4	uQuasar Star Forming Region Cat. Var. Massive Star Cluster BIN WR



http://tevcat.uchicago.edu/

GeV versus TeV gamma-ray sky

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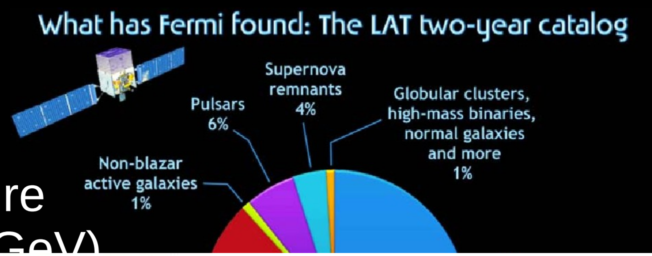

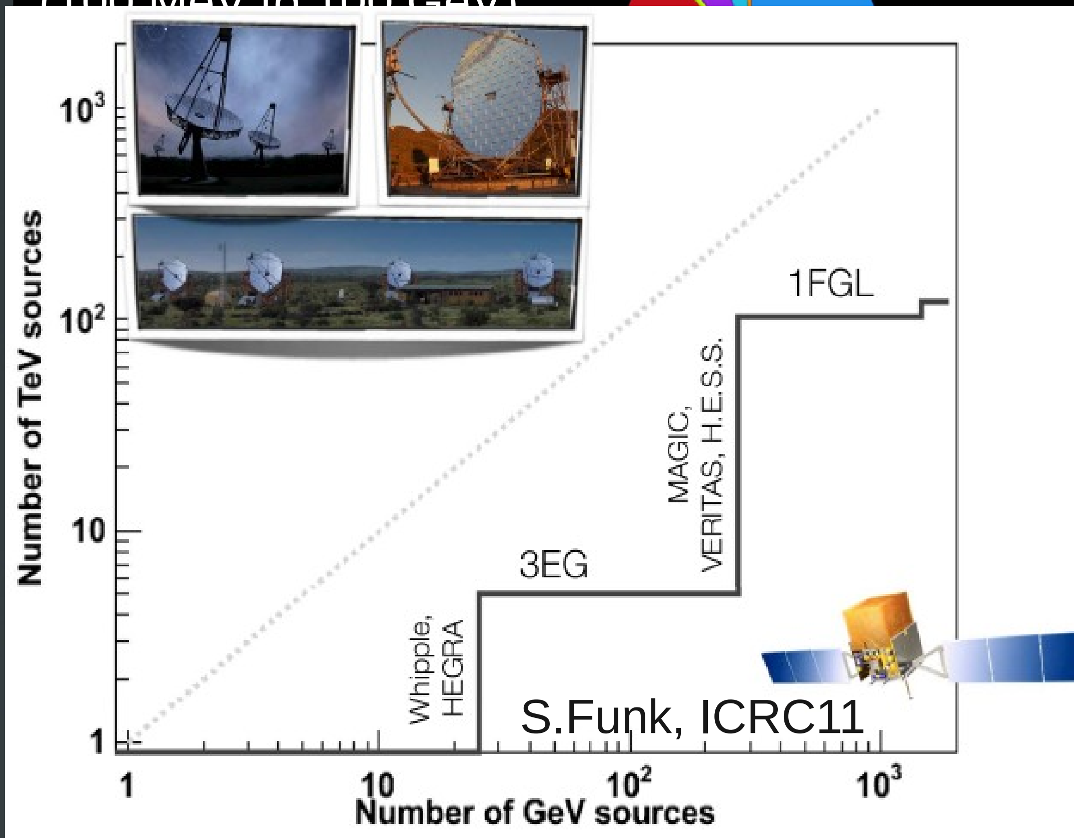

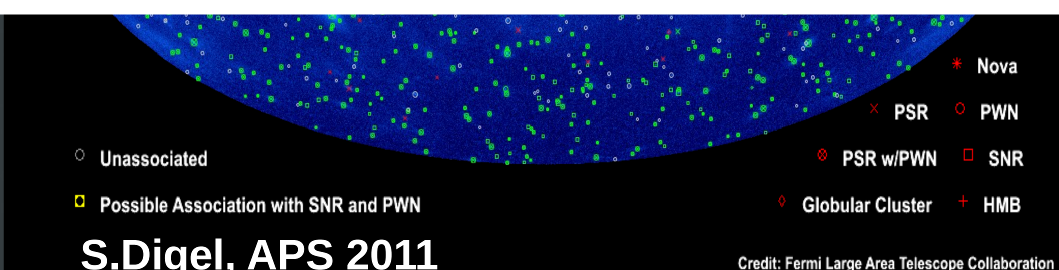

S.Digel, APS 2011

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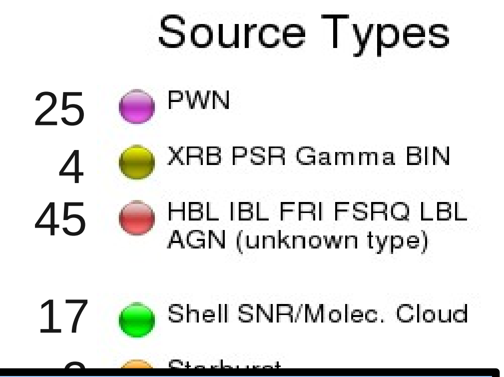
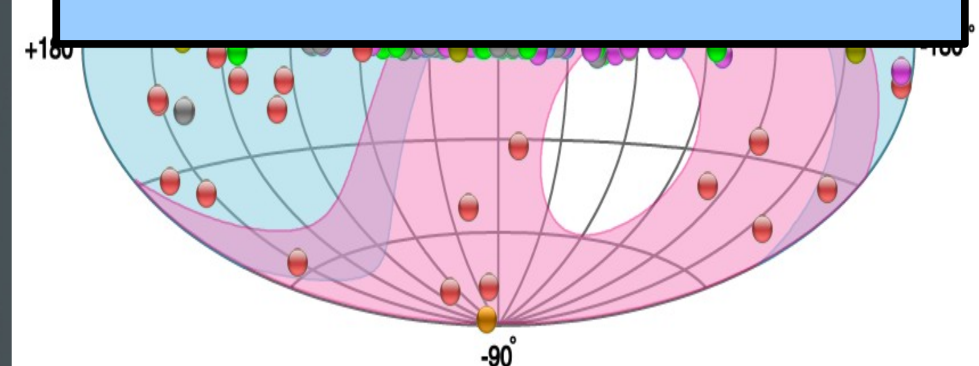


85 sources with 2FGL counterparts:

39/45	TeV AGNs
16/25	TeV PWNe
4/5	TeV SNR/Molec. Cloud
5/10	TeV Shell type SNR
2/2	TeV Starburst
2/4	TeV HMBs
17	TeV UNID

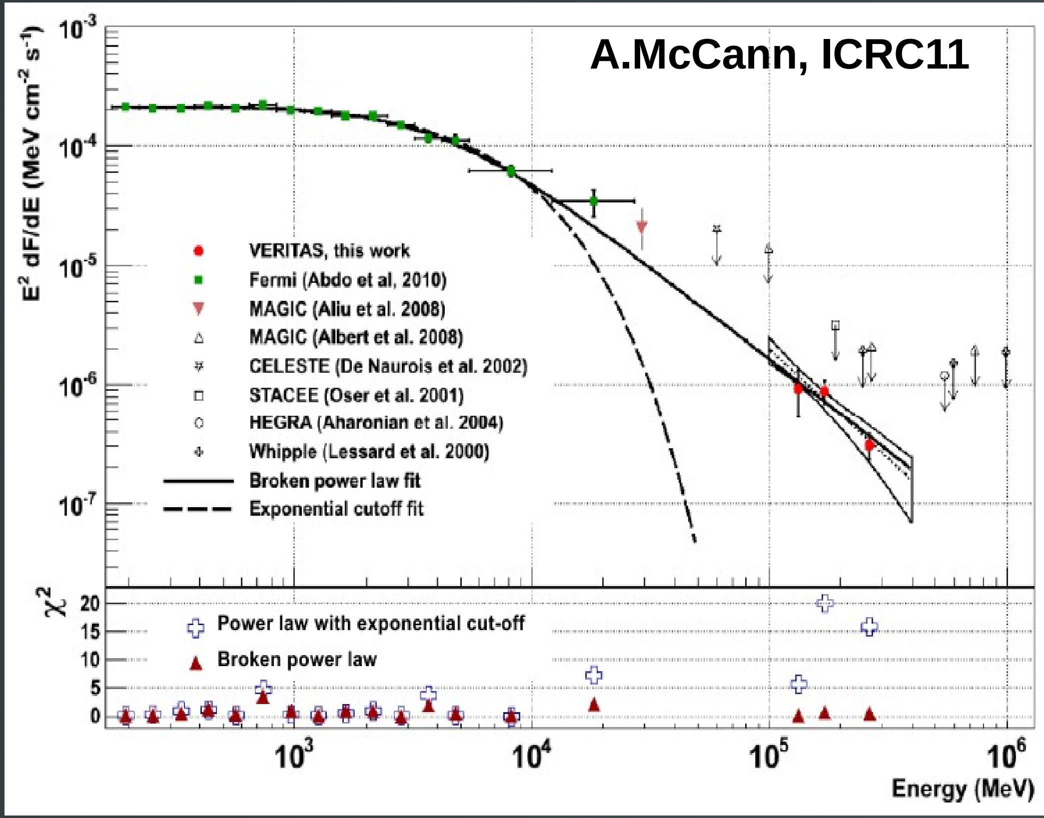


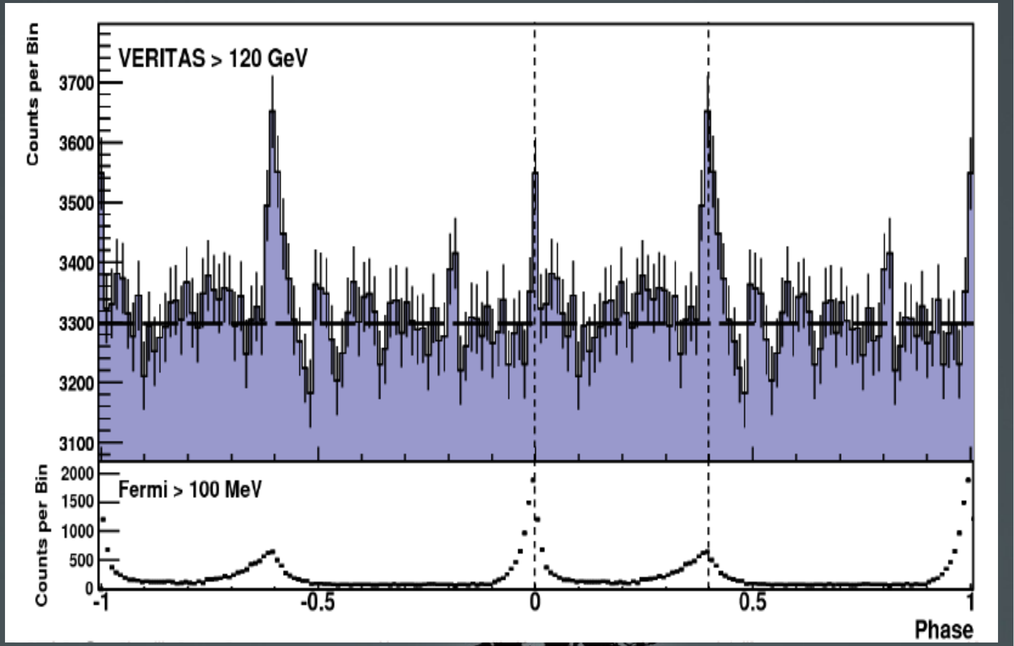
http://tevcat.uchicago.edu/

In late 2009, we were reasonably confident that we understand the Crab rather well : VERITAS Detection of the Crab Pulsar above 100 GeV

- Remnant of historic supernova observed in 1054 A.D.
- Distance 2 kpc.
- Spin-down luminosity is 4.6 x 10^{38} erg/s.
- One of the brightest at Fermi energies.
- Powerhouse behind the VHE standard candle, the Crab Nebula.
- 107 hours of data,
- analysis threshold of 120 GeV

First (6 σ !) detection of pulsed emission above 100 GeV !





VERITAS and LAT combined

- **Broken power-law fits data.**
- **Exponential cut-off excluded.**

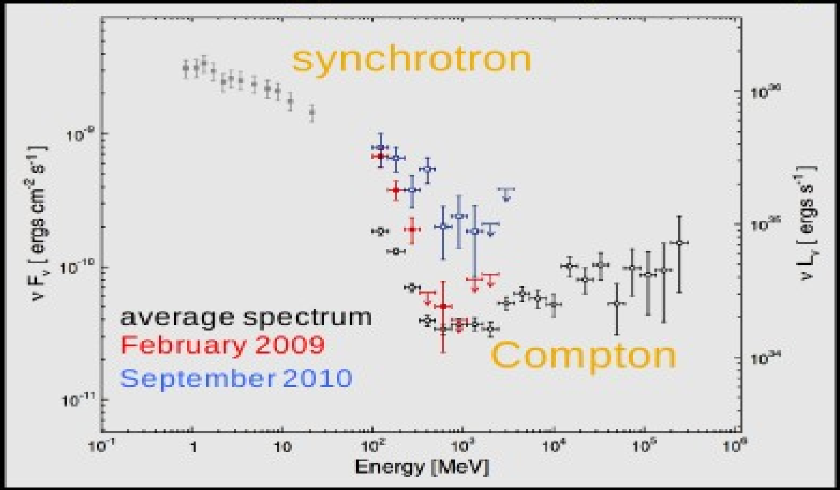
In late 2009, we were reasonably confident that we understand the Crab rather well : γ-ray flares of the Crab ...

©-ray flares from the Crab Nebula

Science **331,** 817 (2010); also seen by AGILE

1st reports of variability of high-energy gamma-ray emission from Crab nebula

Spectral energy distribution (25 months)

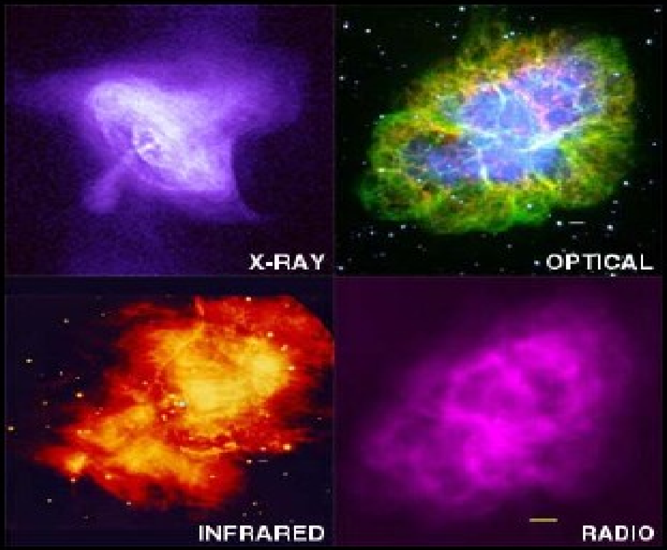


flare time scales (4 days) imply compact flaring region:

$L < Dct < 1.4 \times 10^{-2}$ pc

(1.5 arcsec)

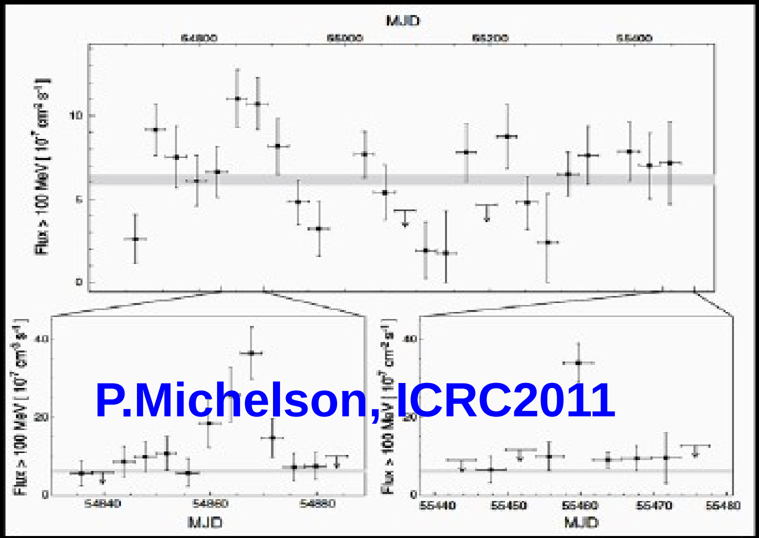
Structures this small only found in inner part of nebula, close to pulsar wind termination shock, base of the jet, or the pulsar.



spectrum and short flare time scales imply **emission is synchrotron radiation** (electron cooling timescales for IC emission & bremsstrahlung ≥ 10^7 yr.)

detection of synchrotron photons up to ≥ 1 GeV implies electrons accelerated to ≥ 1 PeV in the nebula.

efficiency of synchrotron losses requires a strong electric field to compensate; severe difficulties for diffusive shock acceleration mechanism.



P.Michelson, ICRC2011

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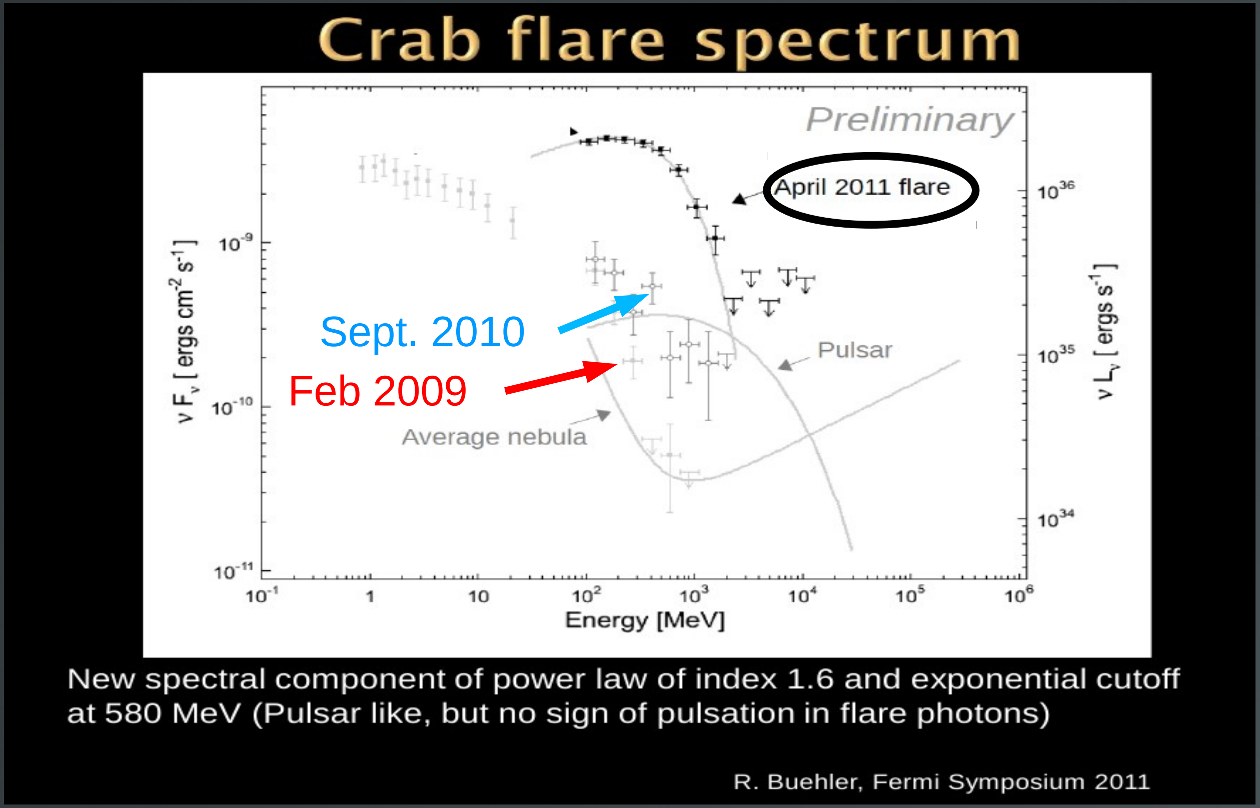
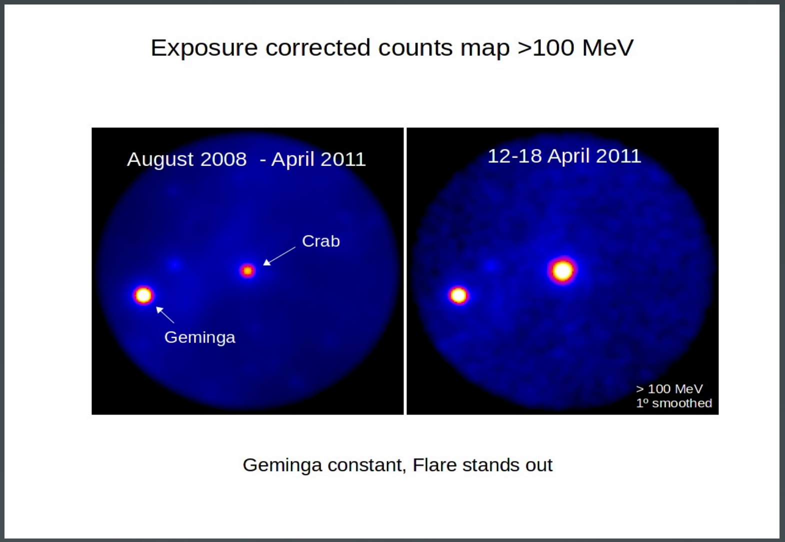
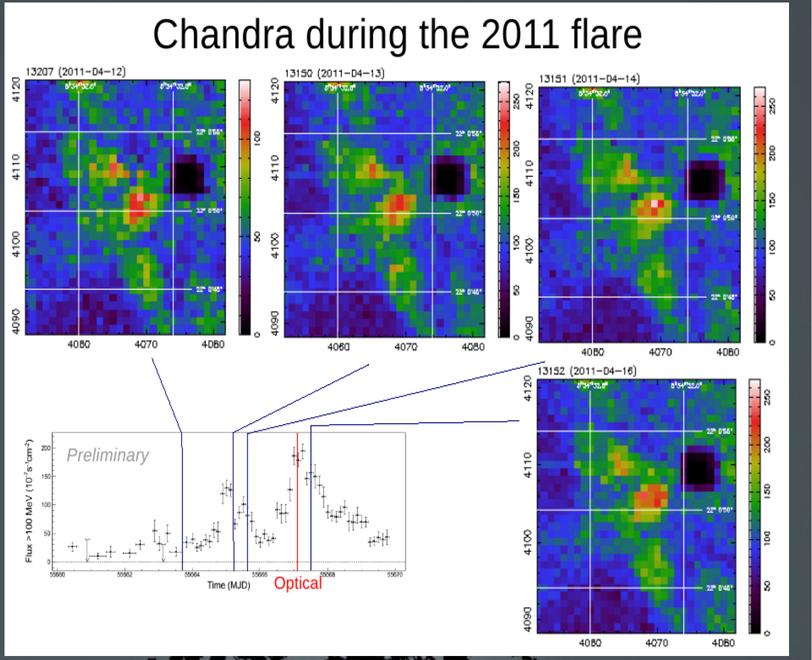






- Fermi-LAT "superflare" in April 2011 :
  flux increased by factor ~30 (!) in the synchrotron component (IC stable)
- Points to > 1 PeV electrons.
  Accelerated in a few hours !
  Shock acceleration seems not feasible
- Chandra observation during flare : no change

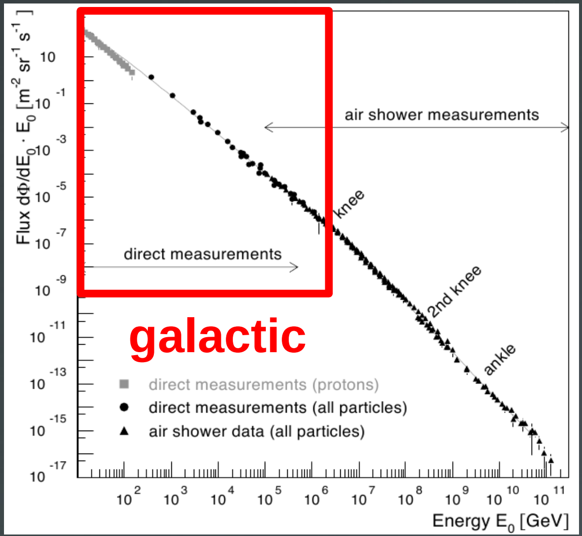
Flares and >100 GeV pulsed emission from the Crab are a surprising discovery, which gives us look into the "unknown" pulsar wind region.

Galactic Supernova Remnants (SNRs) : the source of Cosmic Rays (CR) ?

SNRs are the main candidates as sources of Galactic CR.
Requirements :

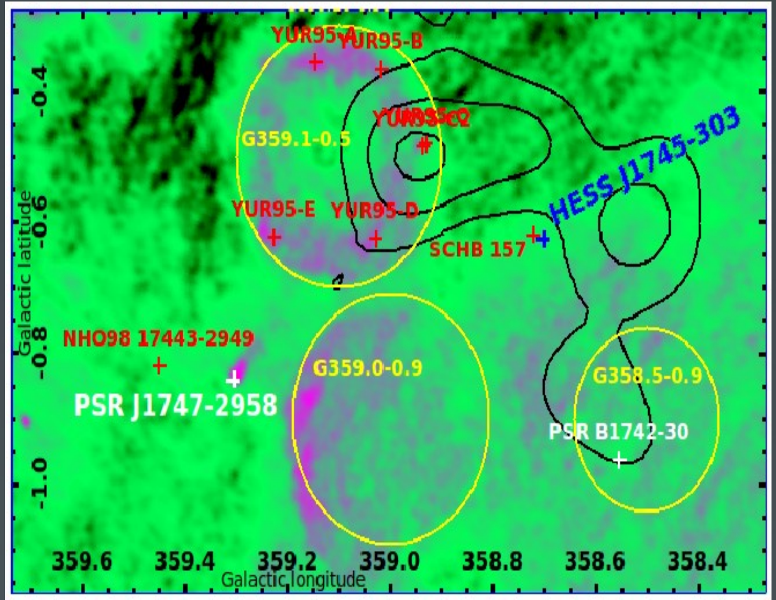
- E_{CR} ~10% E_{SN} (10^{51} ergs)
- 2.84 ± 0.6 Sne/century
- Multi TeV (e,p) energies
- both e and p are accelerated

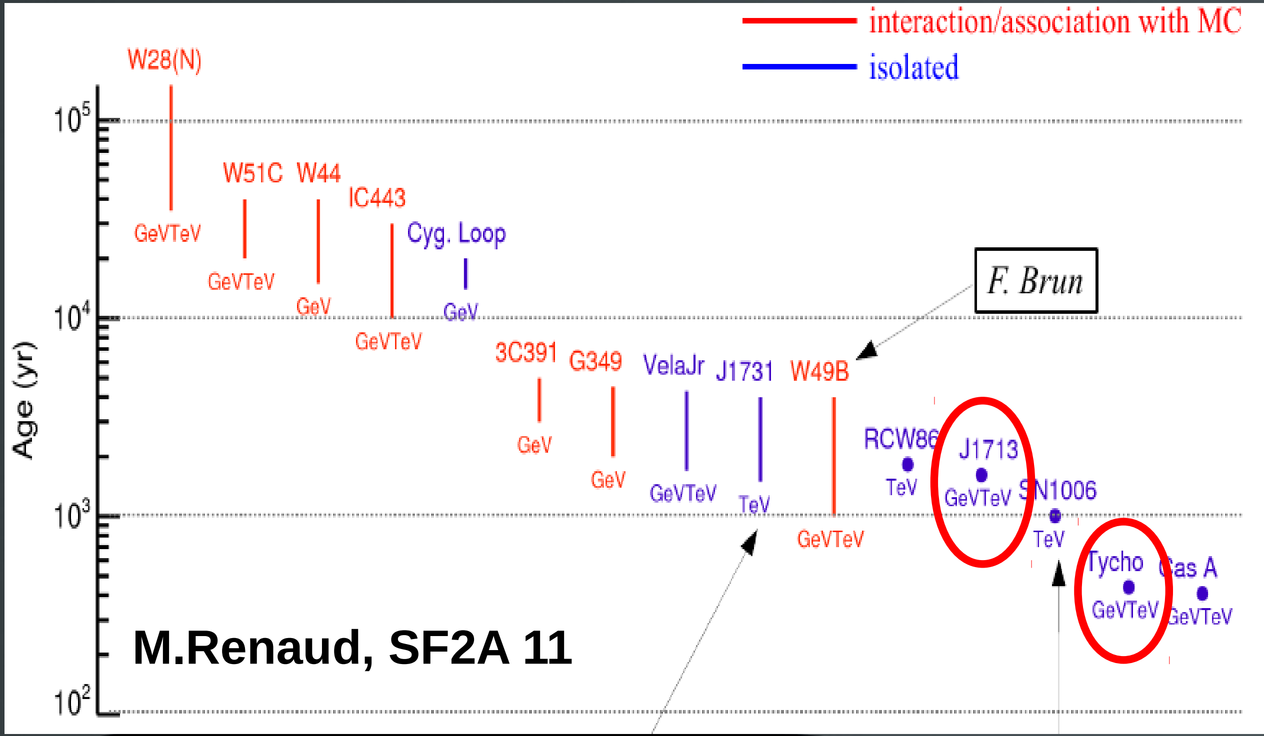
GeV/TeV γ-rays can test underlying CR acceleration scenarios

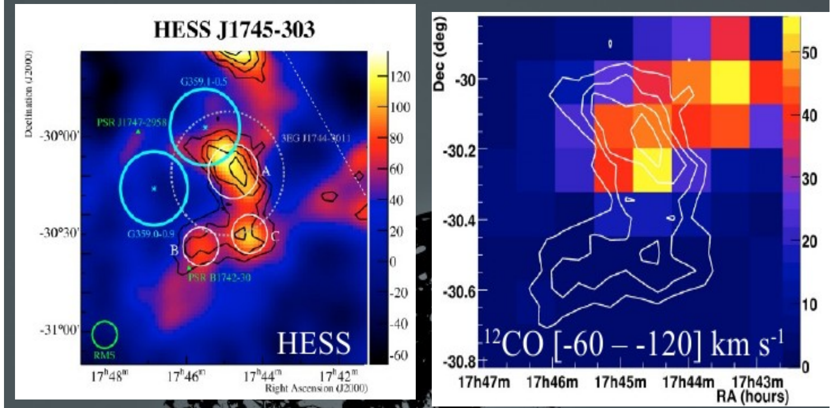


VLA 300Mhz image of the confuse HESS J1745-303 region :

L.Falletti, Fermi Symp. 11



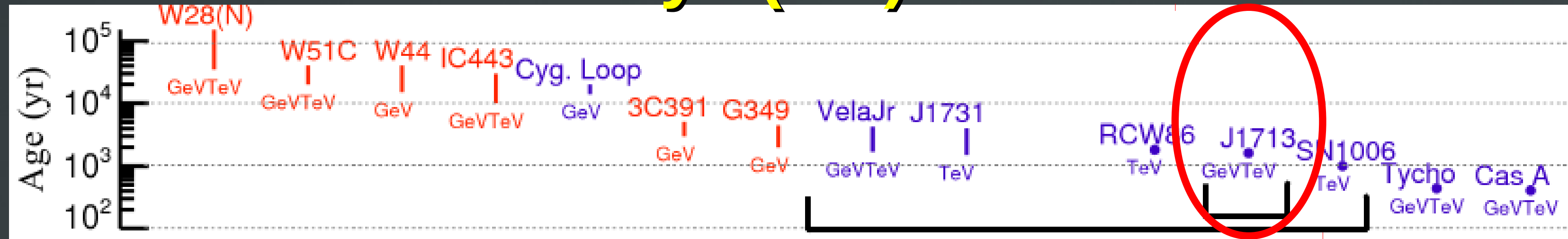




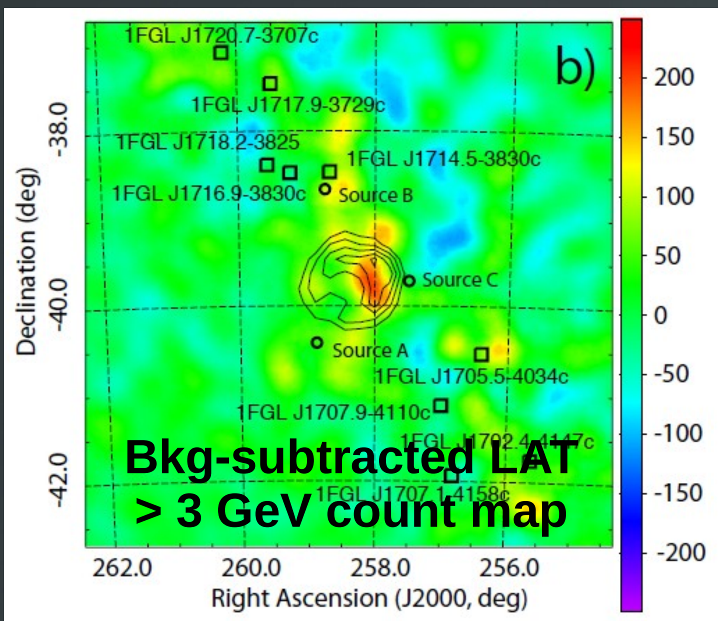
Aharonian et al. 2008

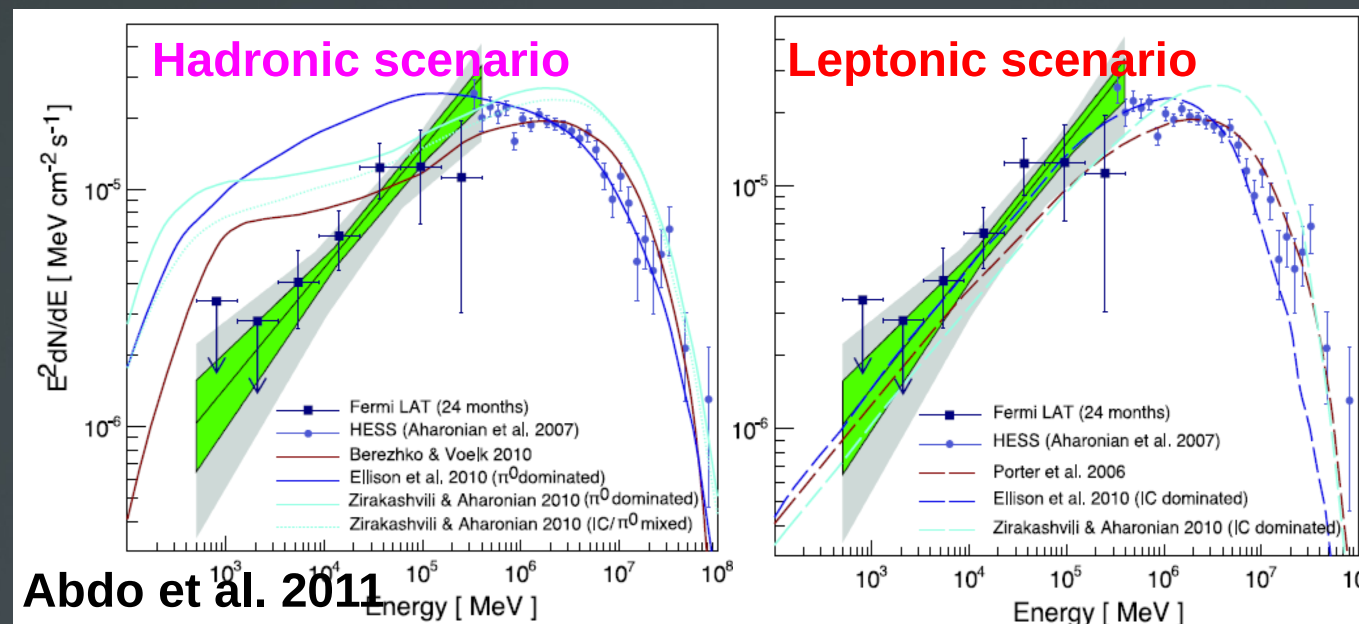
Galactic Supernova Remnants (SNRs) : the source of Cosmic Rays (CR) ?

RX J1713.7-3946



- 100 MeV – 100 TeV gamma-rays
- Direct evidence for GeV – multi TeV (e,p) being accelerated at the shock fronts





Abdo et al. 2011

Hadronic scenarios

Predicted slope unconsistent with observations ...especially for the brightest NW region thought to undergo MC-interaction (Moriguchi et al. 2005)

$\xi_{CR} \sim 2\, E^{-1}_{51}\, n^{-1}_{0.1\,cm\text{-}3}\, d^2_{1kpc}$ to fulfill $n_{X\text{-}ray} < 0.1$ cm^{-3}

$\xi_{CR} \sim 0.3\, E^{-1}_{51}\, n^{-1}_{0.1\,cm\text{-}3}\, d^2_{1kpc}$ compatible with GeV UL

Leptonic scenarios

Predicted slope consistent with observations

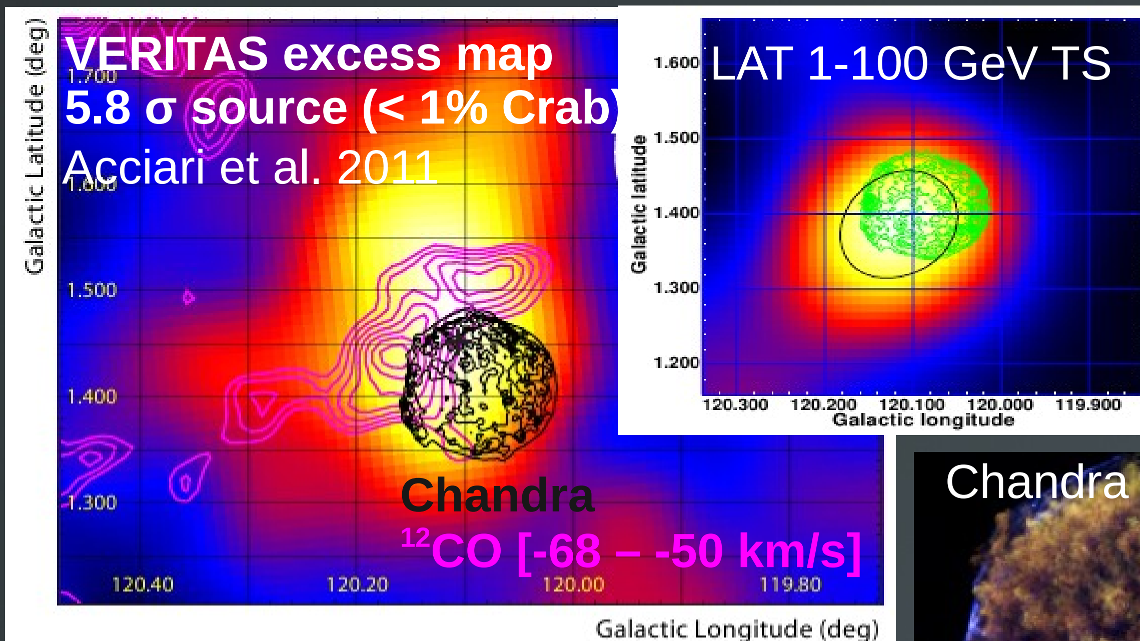
$B_2 \sim 10$ µG... how to reconcile with X-ray filaments and intermittent hotspots (Bykov et al. 2008)?

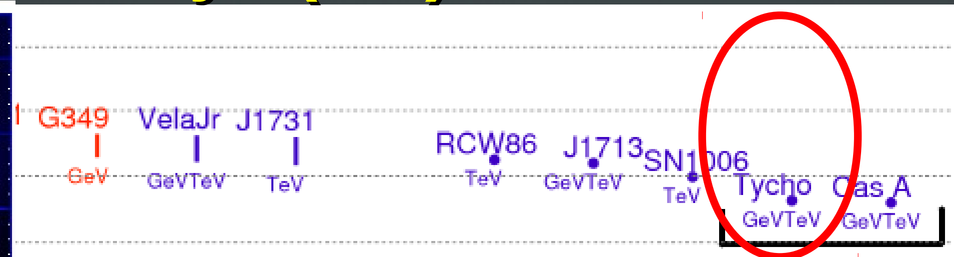
Difficult to explain both the low- & high-E domains

Efficient CR acceleration does not lead necesserely to a bright GeV/TeV source ...

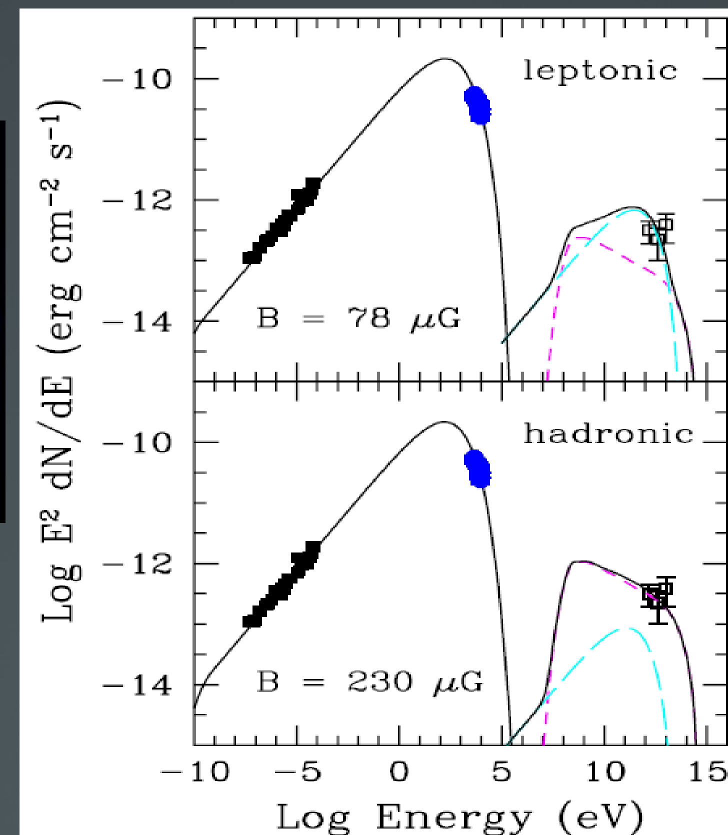
M.Renaud, SF2A 11

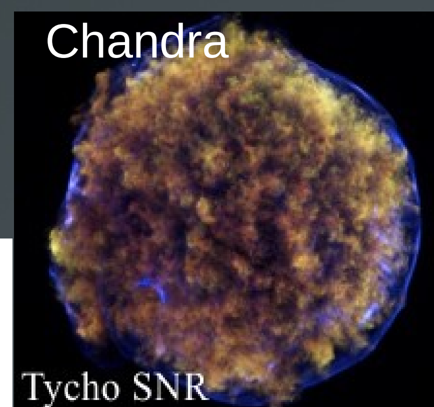
Galactic Supernova Remnants (SNRs) : the source of Cosmic Rays (CR) ? Tycho

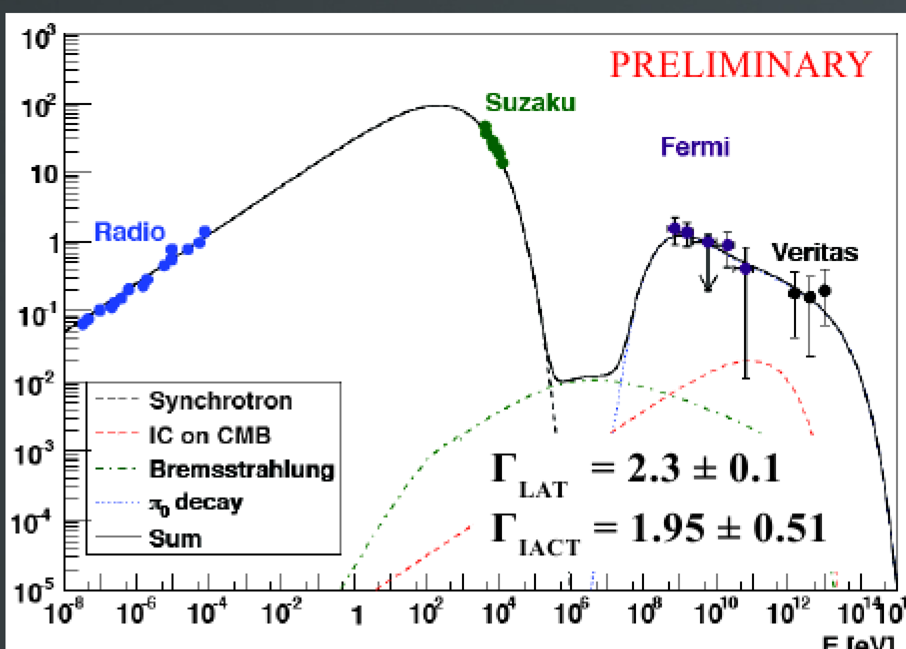




Acciari et al. 2011





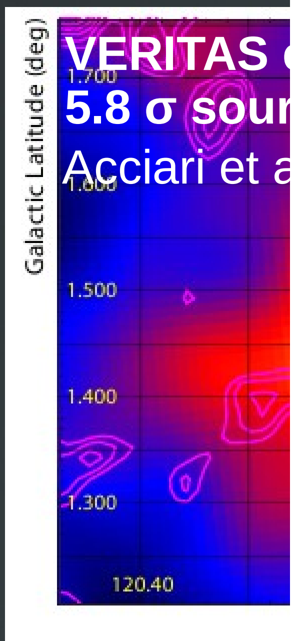


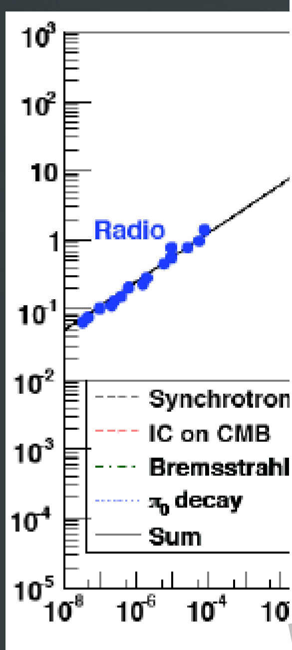
Naumann-Godo et al. 2011, Fermi collab. in prep.

Good evidence for hadronic acceleration
6-8% of E_{SN} transferred to CR acceleration.

$\xi_{CR} \sim 0.06\, E^{-1}_{51}\, n^{-1}_{0.3cm-3}\, d^{2}_{2.8kpc}$

Galactic Supernova Remnants (SNRs) :





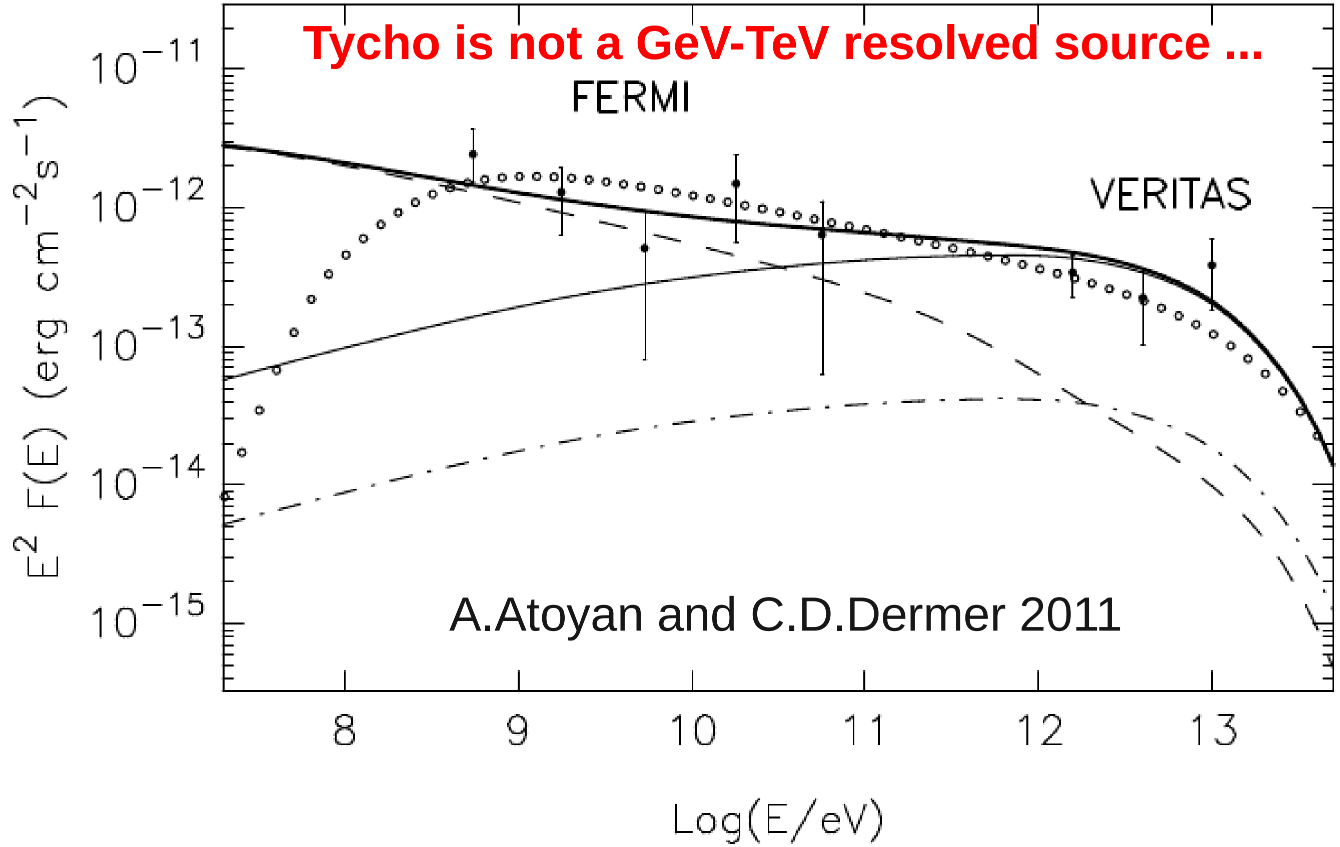
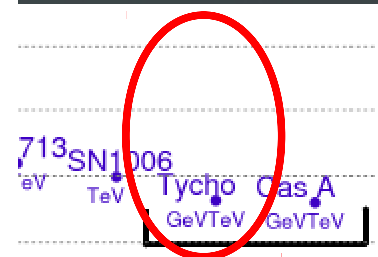


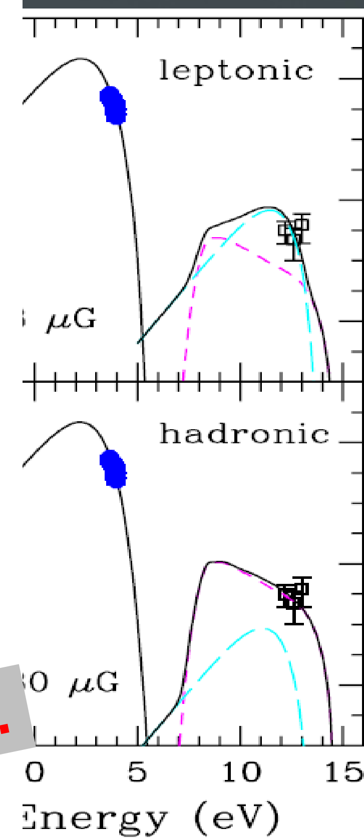
FIG. 2: The γ-ray fluxes produced in the two-zone model. The heavy solid line shows the total flux of leptonic origin. The total bremsstrahlung and Compton radiation fluxes are shown by dashed and solid (thin) lines, respective… are predominantly produced in zone 2. … the Compton flux contributi… …also shown (dot-dashed line). Th… dots show a possible fit to data b… model (see text).

We are still looking for the « Smoking-gun » SNR ...

Tycho



t al. 2011



celeration
cceleration.

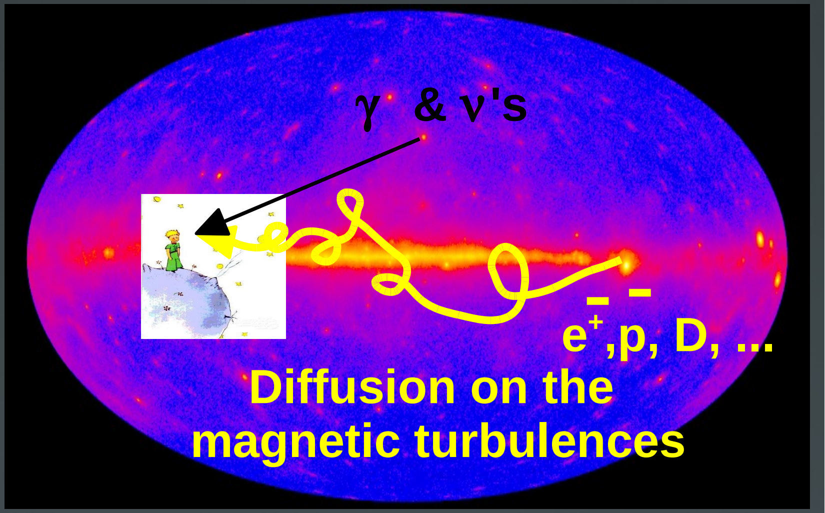
Naumann-Godo et al. 2011, Fermi collab. in prep. $\zeta_{CR} \sim 0.06\ E_{51}\ n_{0.3cm-3}\ d_{2.8kpc}$

Indirect Dark Matter searches from gamma-rays

E.Nuss
LPTA, University of Montpellier 2

Indirect Detection of Dark Matter : The General Framework

- A wealth of observational evidences
- Many theoretical hints and « natural » candidates
- Tools : Direct detection / Indirect detection / Colliders



1) WIMP Annihilation

Typical final states include heavy fermions, gauge or Higgs bosons

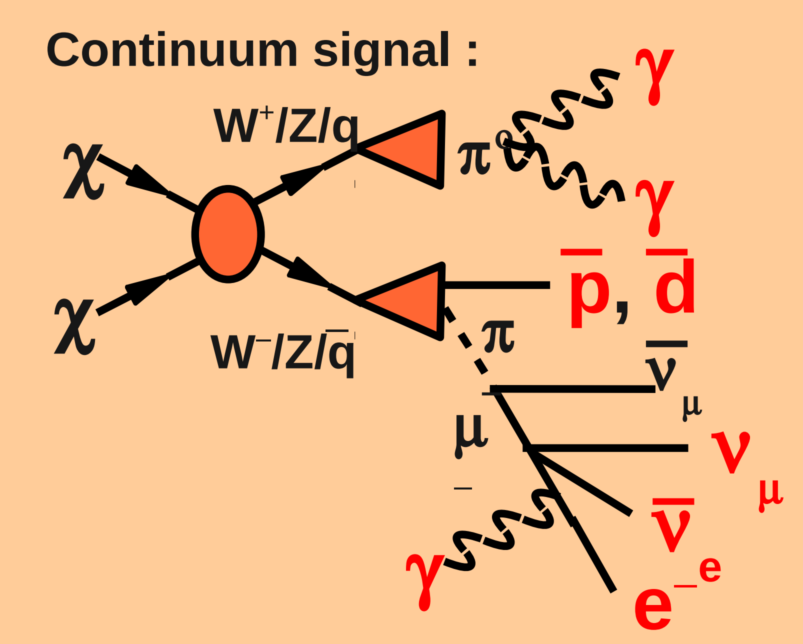
2) Fragmentation / Decay

Annihilation products decay and/or fragment into some combination of

charged : electrons, protons, deuterium, ...
neutral : neutrinos and gamma rays

3) Synchrotron and Inverse Compton

Relativistic electrons up- scatter starlight to MeV – GeV energies, and emit synchrotron photons via interactions with magnetic fields



Indirect detection rates :

$$\frac{d\Phi_\gamma}{dE_\gamma} = \frac{1}{4\pi} \underbrace{\frac{\langle \sigma v \rangle}{2m_\chi^2} \sum_f \frac{dn_\gamma^f}{dE_\gamma} B_f}_{\text{Particle Physics}} \underbrace{\int_{\Delta\Omega} \int_{l.o.s} \rho^2(l) \; dl(\psi) \; d\Omega}_{\text{Astrophysics}}$$

« J-factor »

How to Disentangle the Dark Matter puzzle ?

☺ Advantages
☹ Challenges

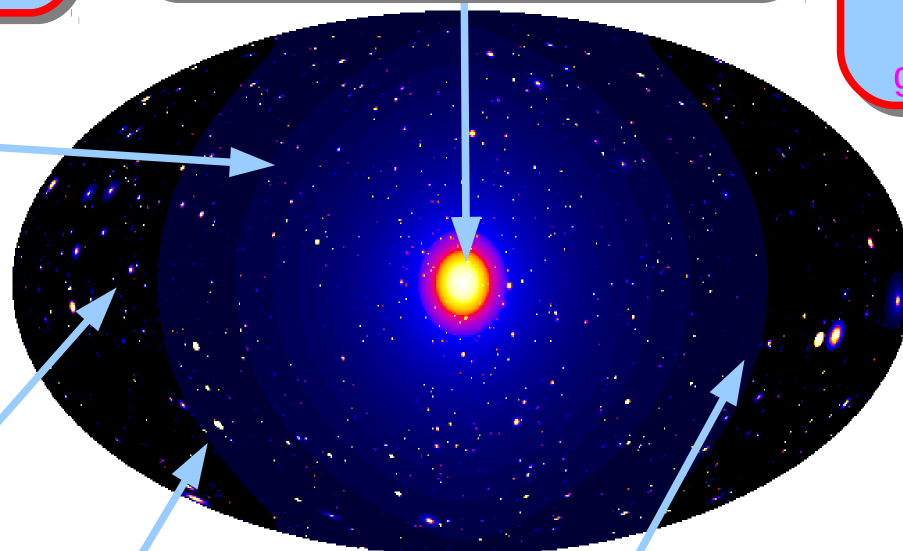
1) DM hunting targets

Spectral lines
No astrophysical uncertainties
Good source identification
Low statistics

Galactic center
Large Statistics (?)
Large uncertainties in the DM profile
Source confusion
Diffuse background

Extra-galactic
Large Statistics
Isotropic
Very model dependent limit
Astrophysics and
galactic diffuse background

Galactic Halo
Good sensitivity
Complicated by diffuse
ϒ-rays from cosmic rays



Anisotropies

Galaxy clusters
High signal level
High background

Cosmic-ray electrons and positrons
Experimental hints,
large statistic
DM models discrimination
Astrophysical background
Diffusion models

Point sources (NS)
Known location
Low statistics

DM Subhalos
Low background
Low statistics
Unknown location

Nearby Galaxies
Low background,
good source identification
Low statistics

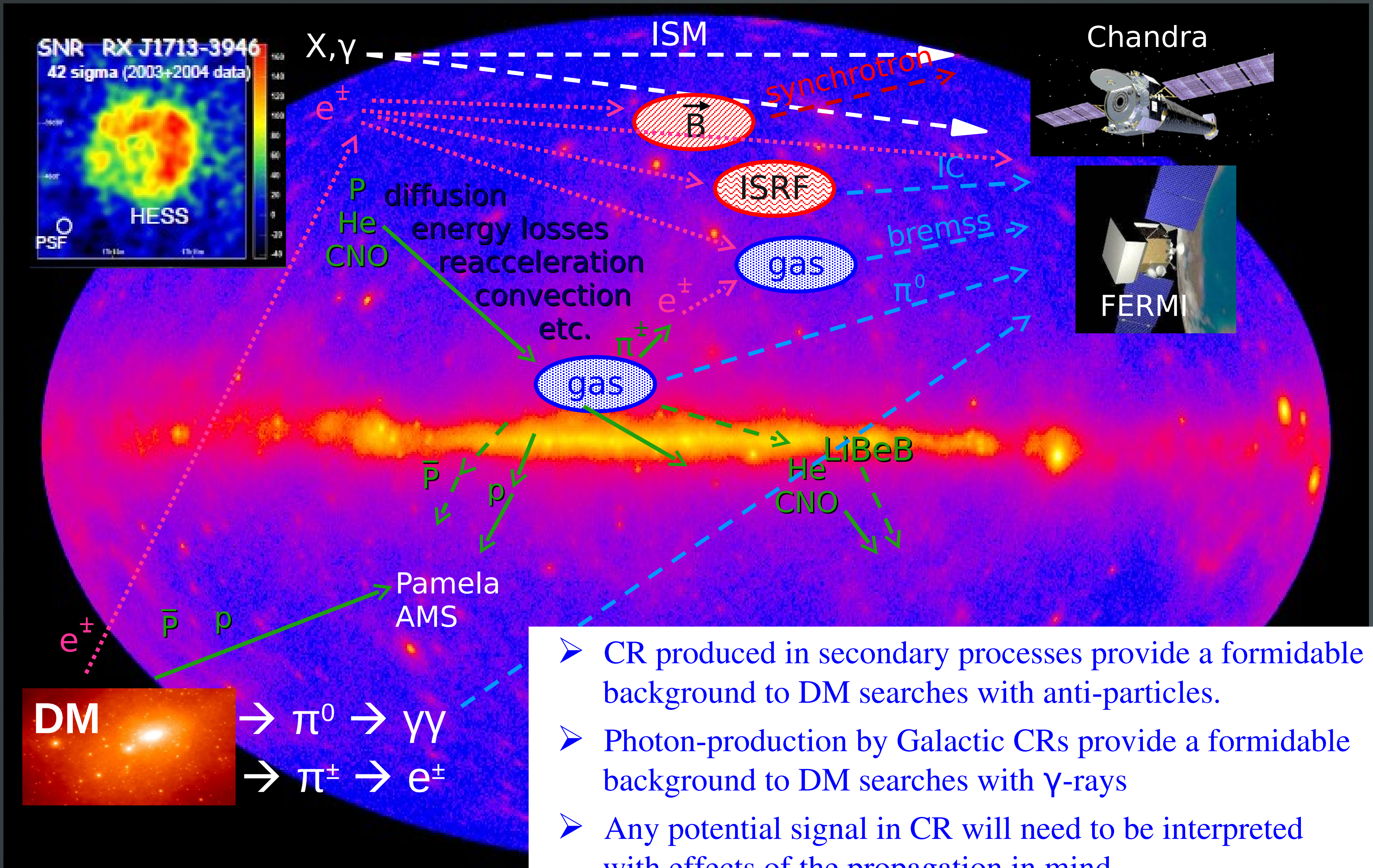
The sun

Pre-launch sensitivities published in Baltz et al. JCAP07 (2008) 013

2) Good understanding of galactic and extragalactic diffuse emission

No Dark Matter detected so far

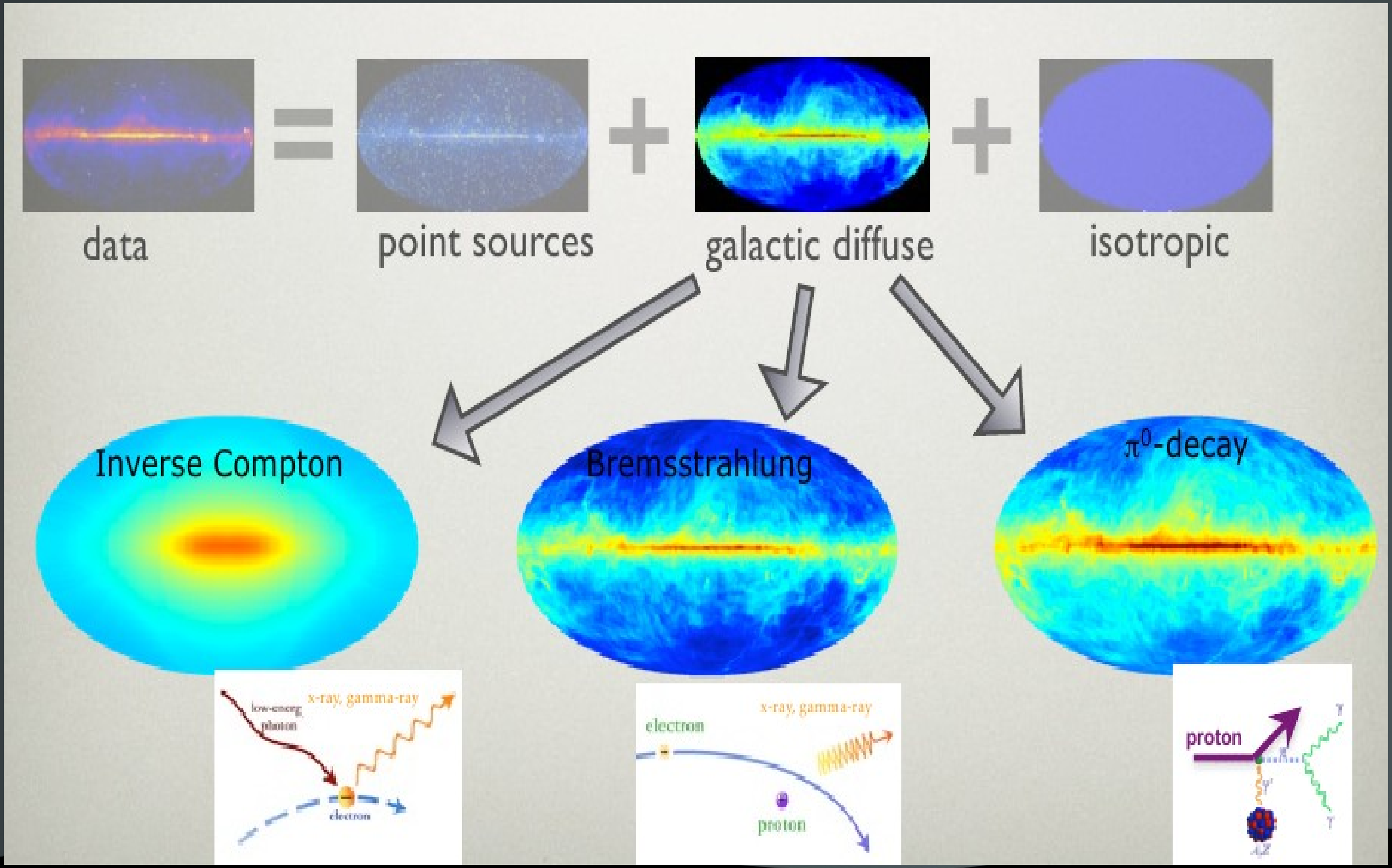
Cosmic rays progagation in the galaxy



- CR produced in secondary processes provide a formidable background to DM searches with anti-particles.
- Photon-production by Galactic CRs provide a formidable background to DM searches with γ-rays
- Any potential signal in CR will need to be interpreted with effects of the propagation in mind

Galactic Diffuse Emission

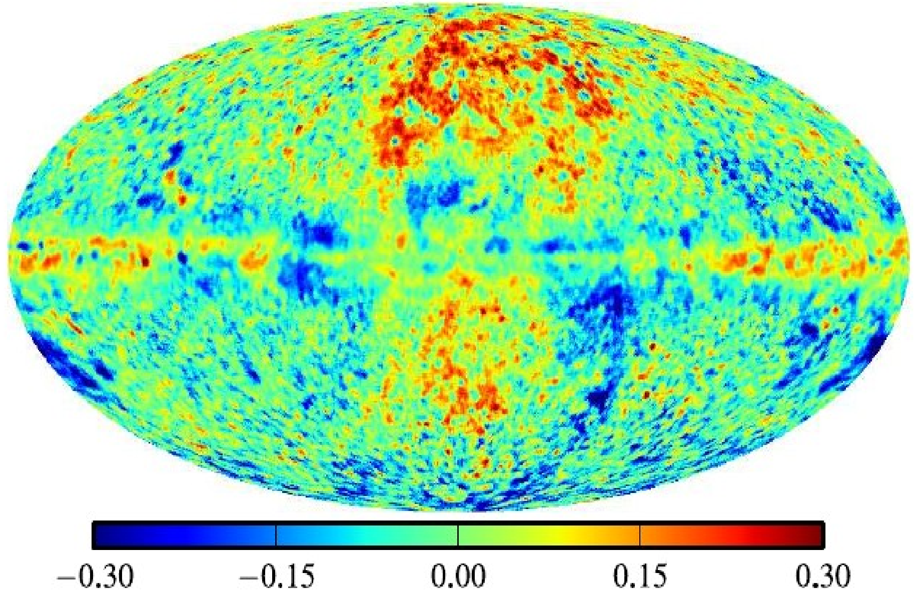
- The diffuse gamma-ray emission from the Milky Way is produced by cosmic rays interacting with the interstellar gas and radiation field and carries important information on the acceleration, distribution, and propagation of cosmic rays.

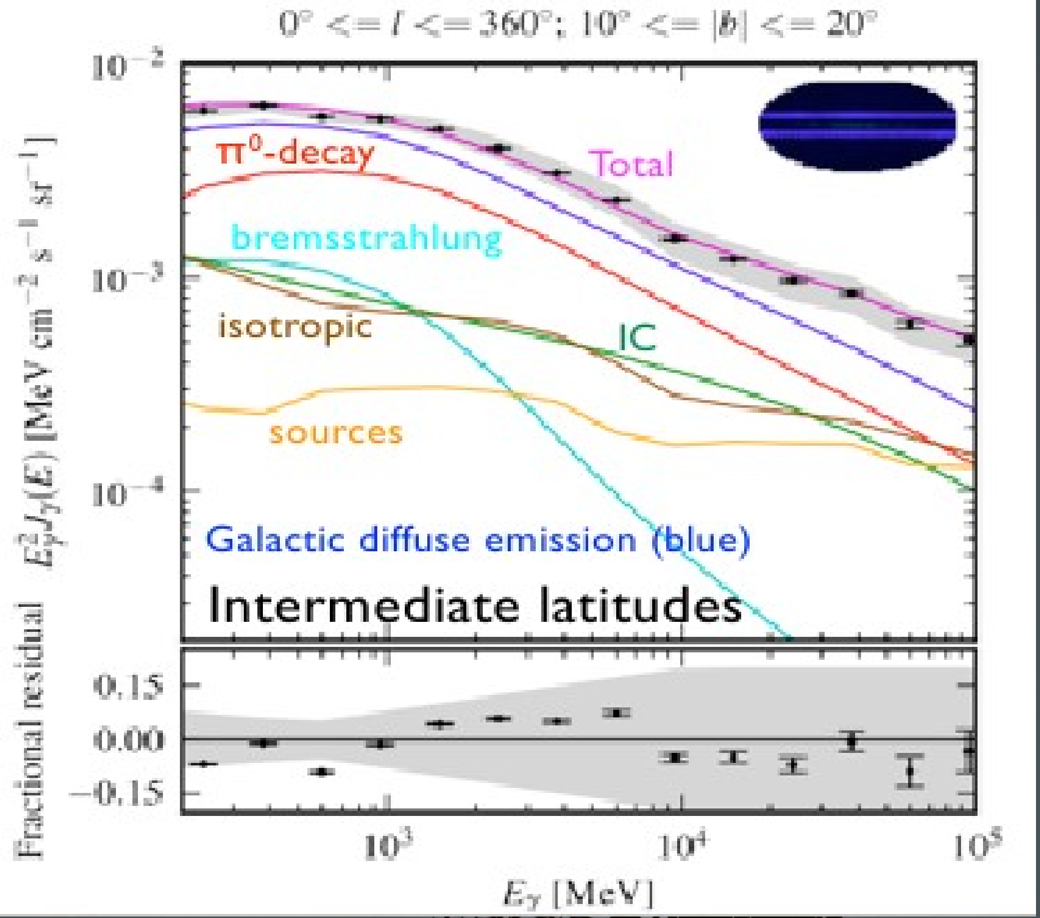


Galactic Diffuse Emission

- The diffuse gamma-ray emission from the Milky Way is produced by cosmic rays interacting with the interstellar gas and radiation field and carries important information on the acceleration, distribution, and propagation of cosmic rays.
- Cosmic ray origin, propagation, and properties of the interstellar medium can be constrained by comparing the data to predictions.
- Generate models (in agreement with CR data) varying CR source distribution, CR halo size, gas distribution and compare with Fermi LAT data (21 months, 200 MeV to ~100 GeV)

(Fermi data – prediction)/prediction
200 MeV – 100 GeV





On a large scale the agreement between data and prediction is overall good, however some extended excesses stand model out.

Fermi LAT Collaboration, arXiv:1202.4039 (to appear in ApJ)

Galactic Diffuse Emission

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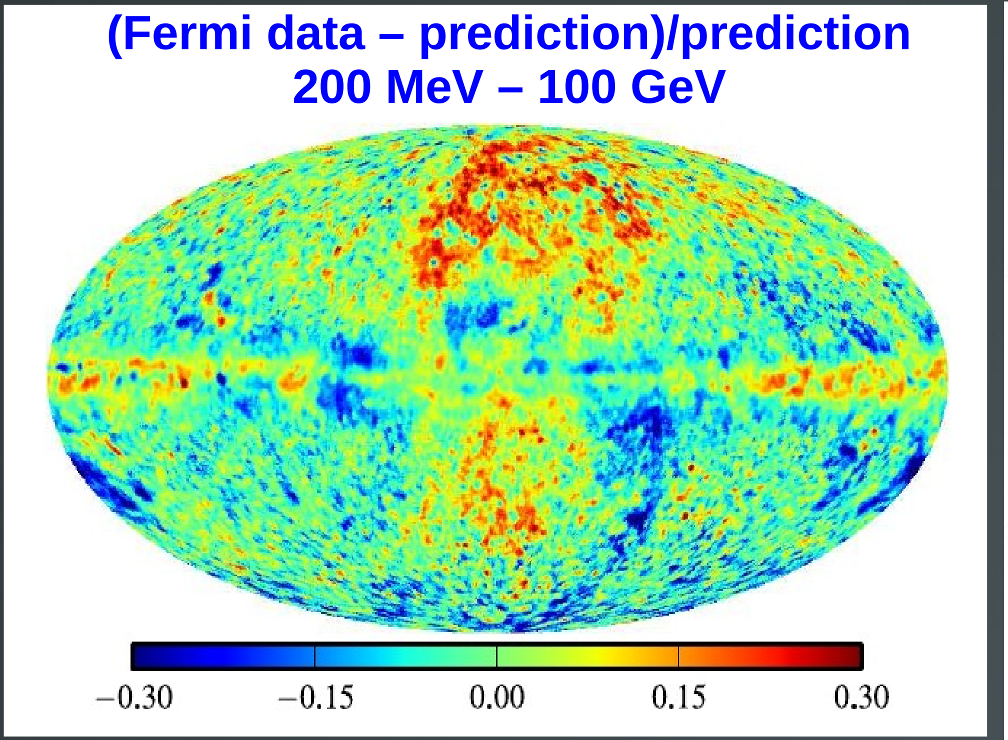

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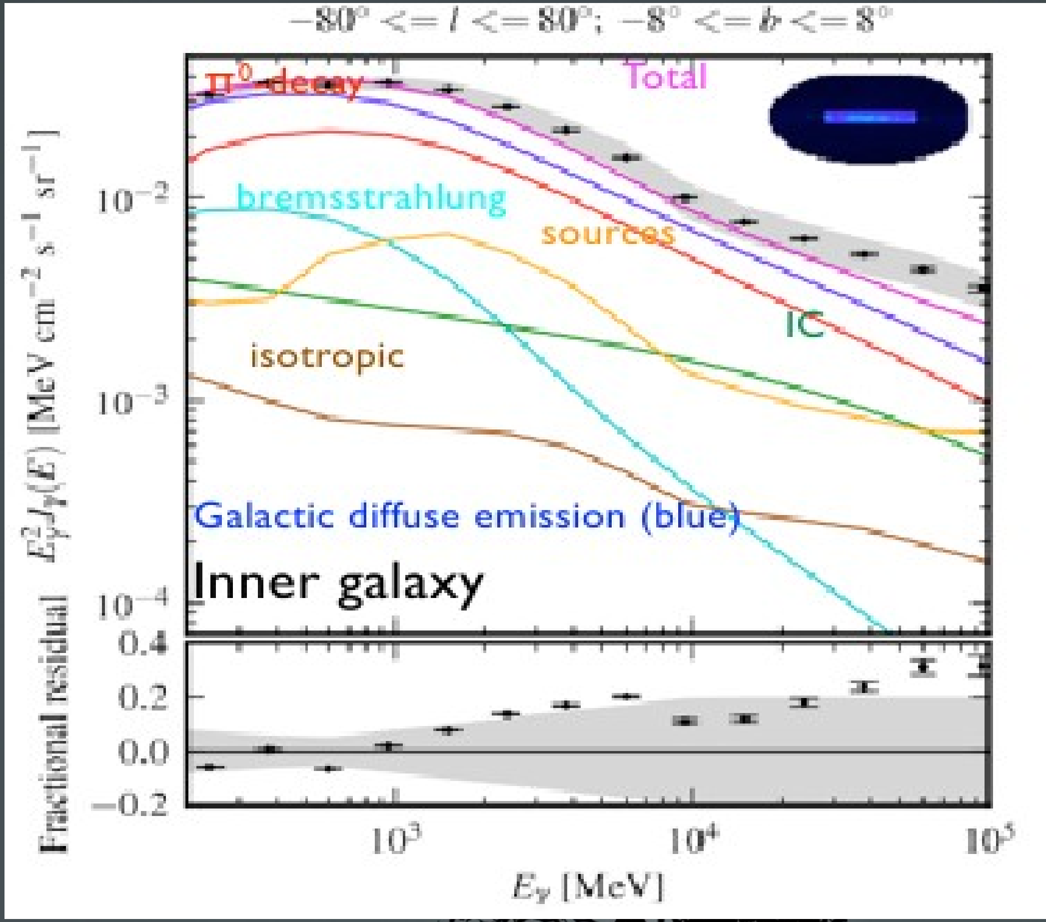
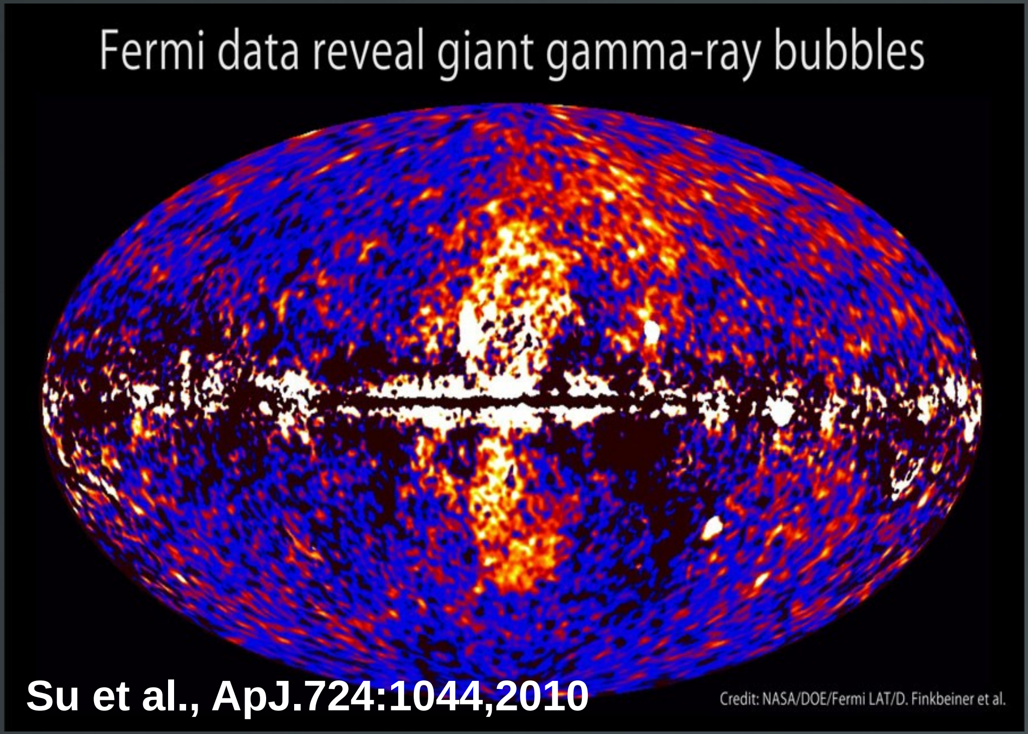


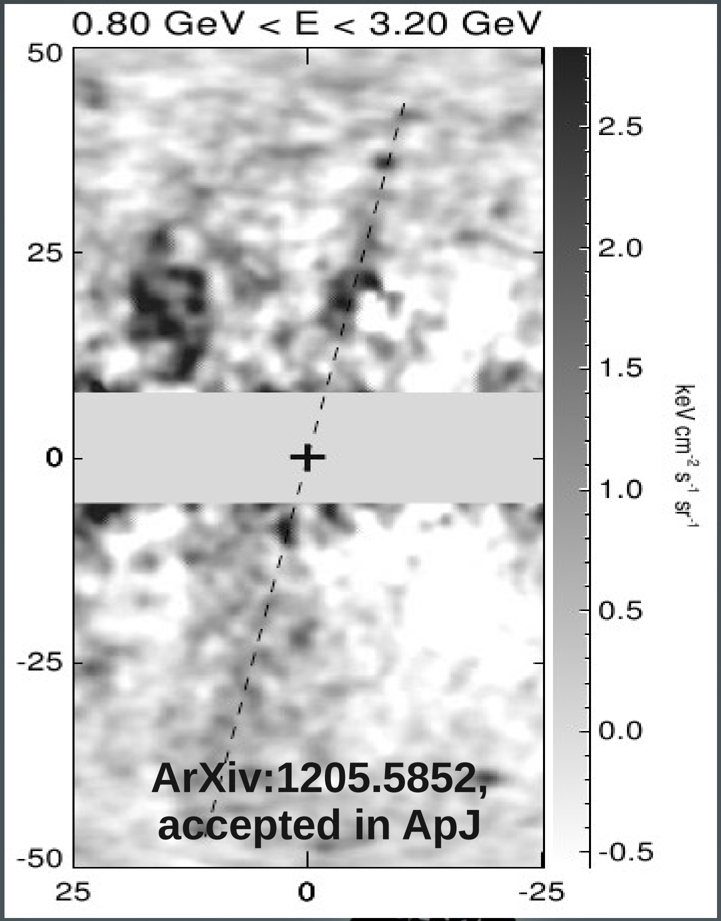
Fermi LAT Collaboration, arXiv:1202.4039 (to appear in ApJ)

Extended lobe-like features in the Fermi sky

- « Gamma-ray lobes » (Su, Slatyer, and Finkbeiner 2010 & 2012) :
  - very extended (~ 50° from plane)
  - hard spectrum (~E^{-2}, 1-100 GeV)
  - sharp edges
  - possible counterparts in microwave (WMAP), X-ray (ROSAT)

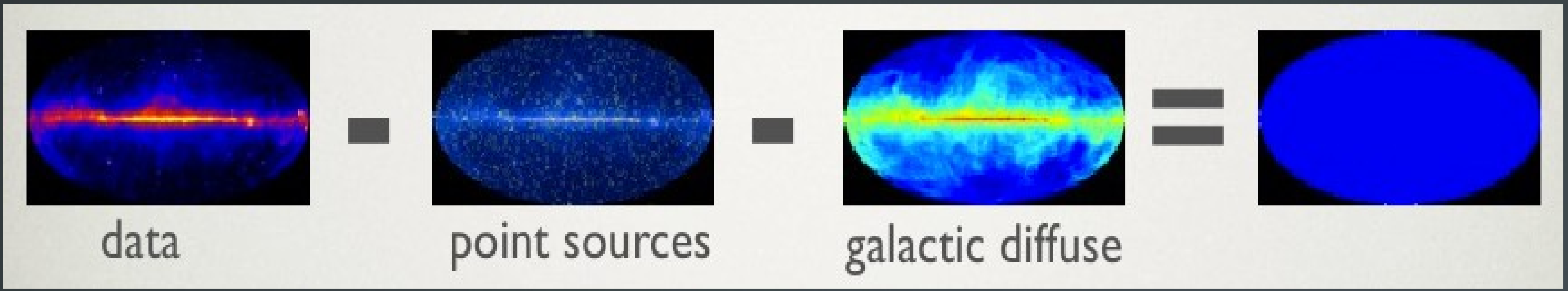


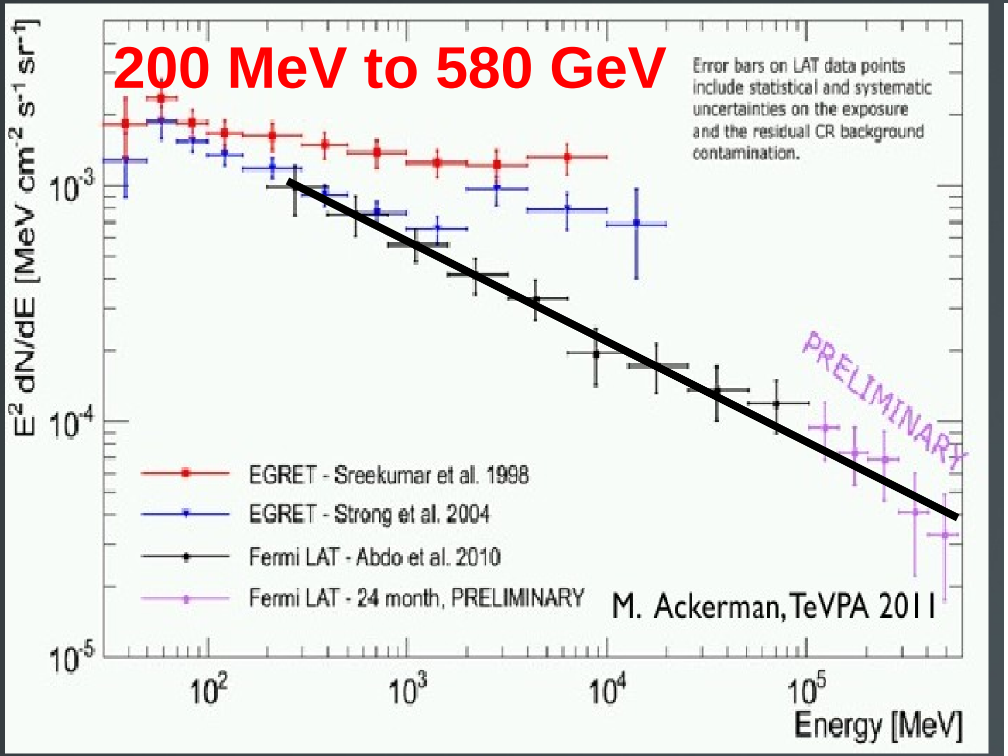
Possible jet like feature.
If confirmed : the first resolved gamma-ray jets ever seen !



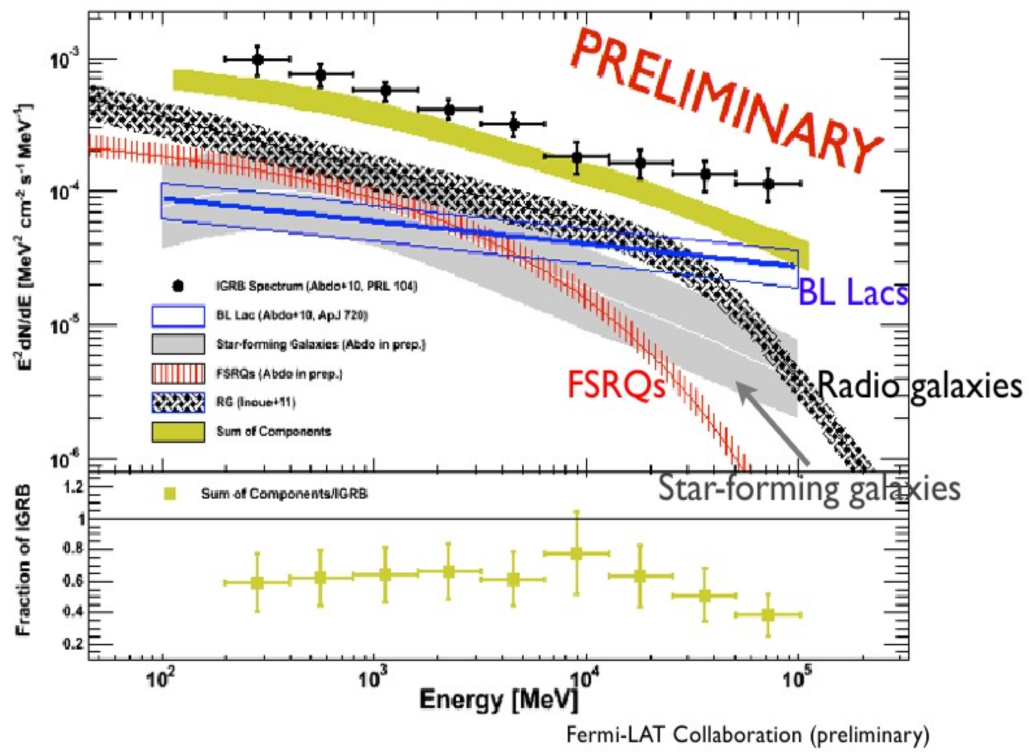
- Possible interpretations :
  - Symmetry suggest relation to GC.
  - Outflow from the center of the Milky Way: jets from the supermassive black hole ?
  - Starburst ?
  - Protons or electrons ?
  - "Lobes" with sharp edges difficult to explain with DM annihilation/decay

Extragalactic Diffuse Emission





M. Ackerman, TeVPA 2011

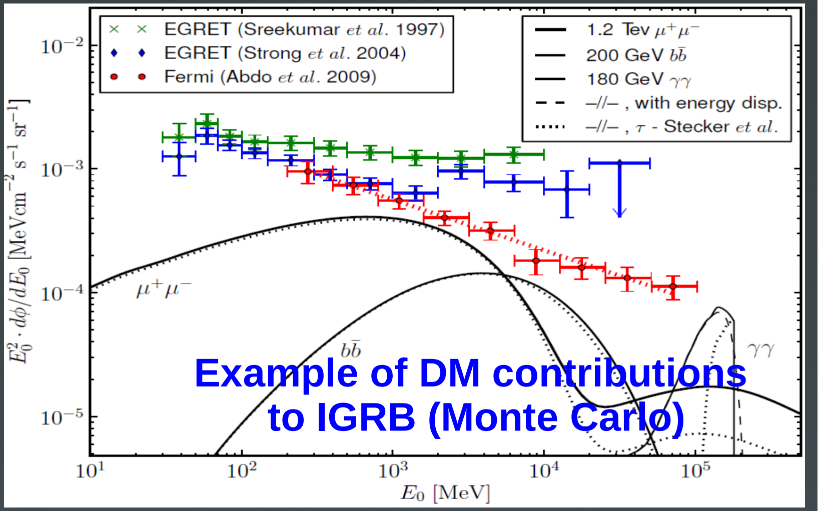


M. Ajello, Fermi Symposium 2011

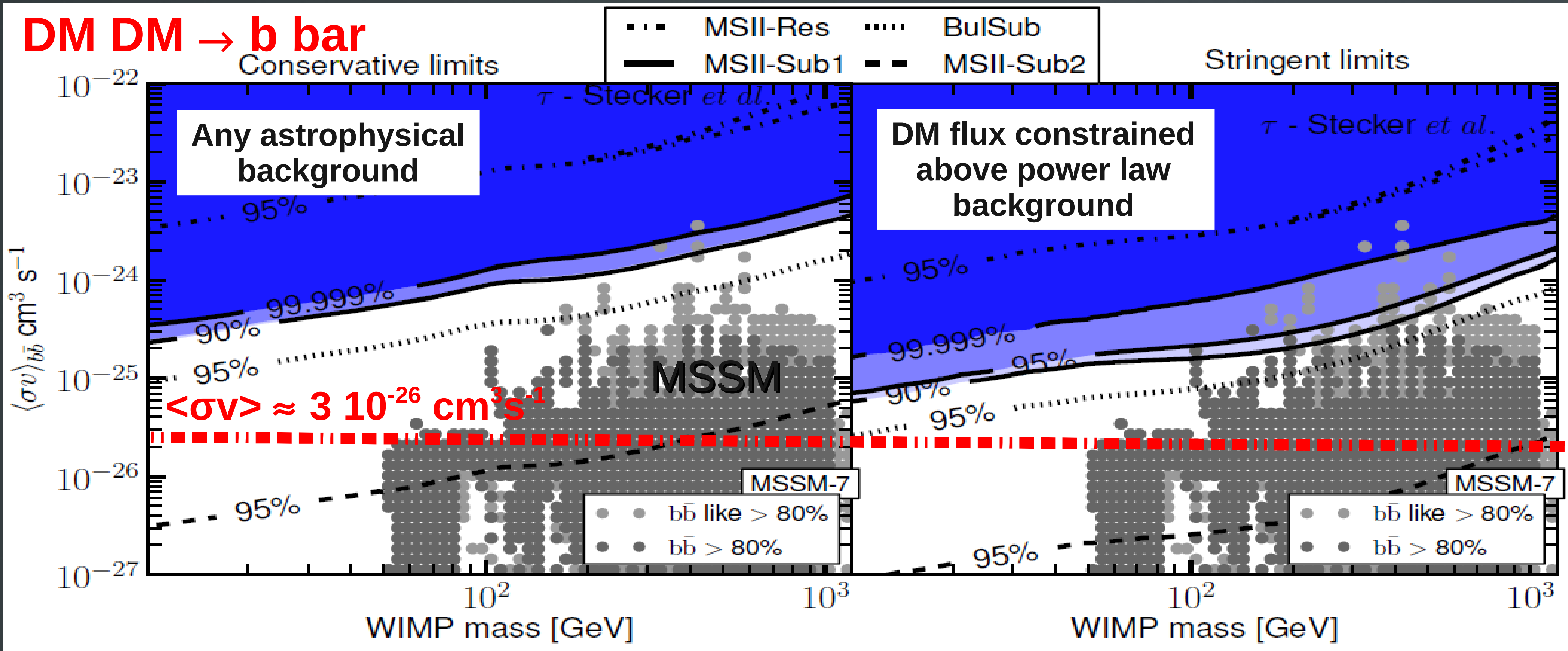
EGB spectrum compatible with a feature-less PL spectrum below 100GeV. Indications of spectral softening above 100 GeV

Search for Cosmological DM

- Limits based on Fermi's measurement of the isotropic diffuse gamma-ray emission
- Search for a DM annihilation signal from all halos at all redshifts



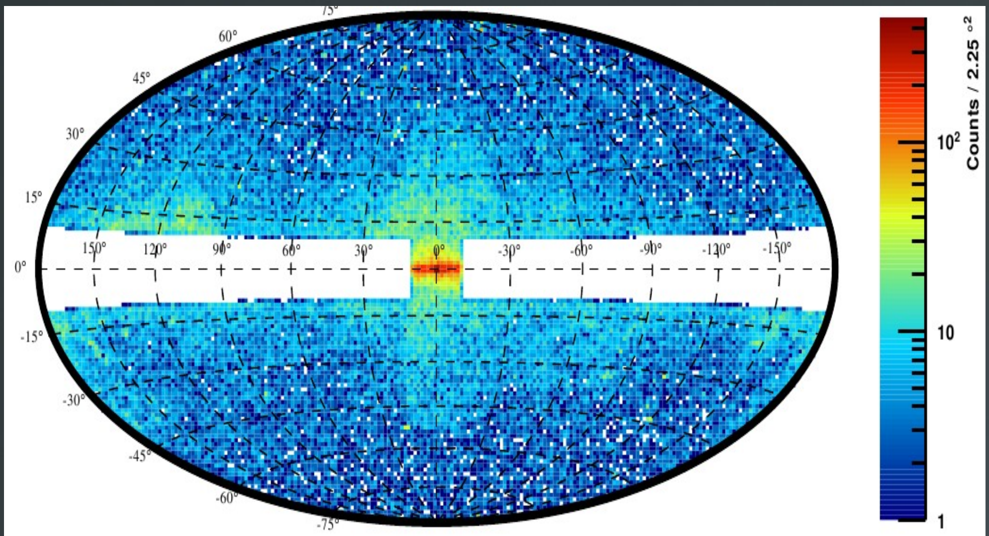
Abdo et al. (Fermi-LAT) JCAP 1004 (2010) 014

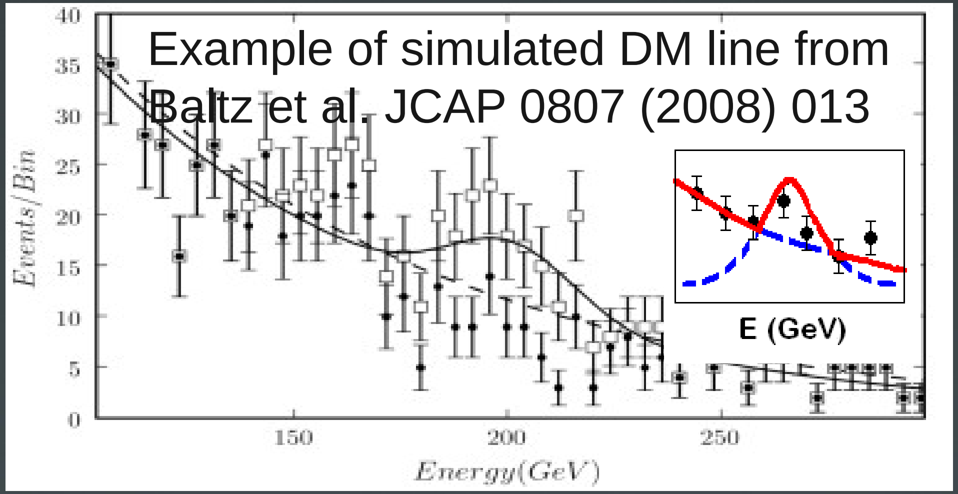


Limits can be very constraining for many DM interesting models, however the uncertainties on the evolution of the DM structure are large.

Search for Spectral Lines : The « Smoking Gun »

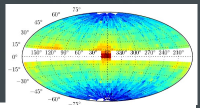
Region of Interest :

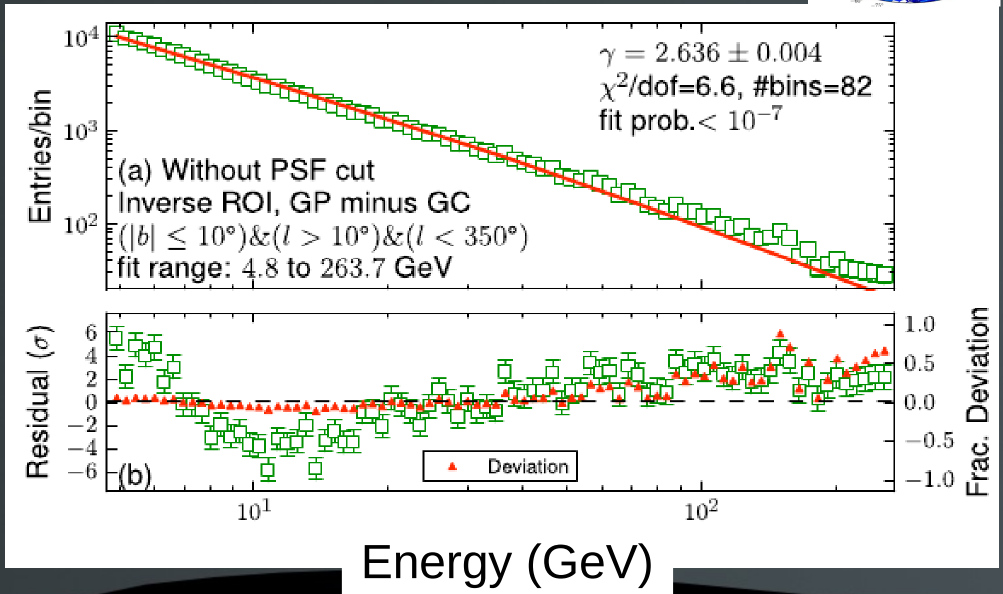




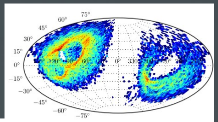
- 2 years of data from high galactic latitude and the galactic center (increased statistics)
- Inclusive photon spectrum 4.8-264 GeV (remove photons from point sources)

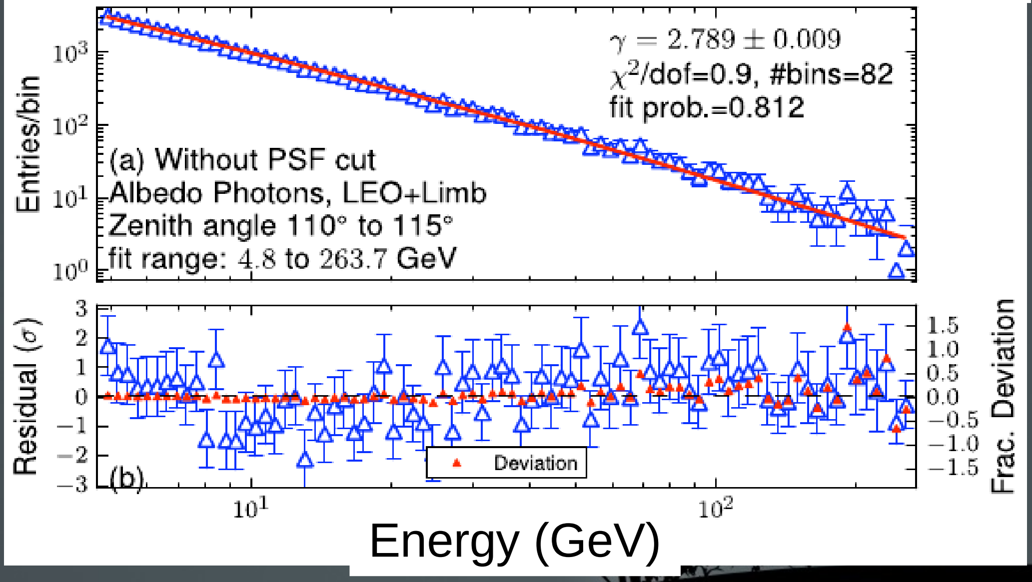
Photon Line dataset :





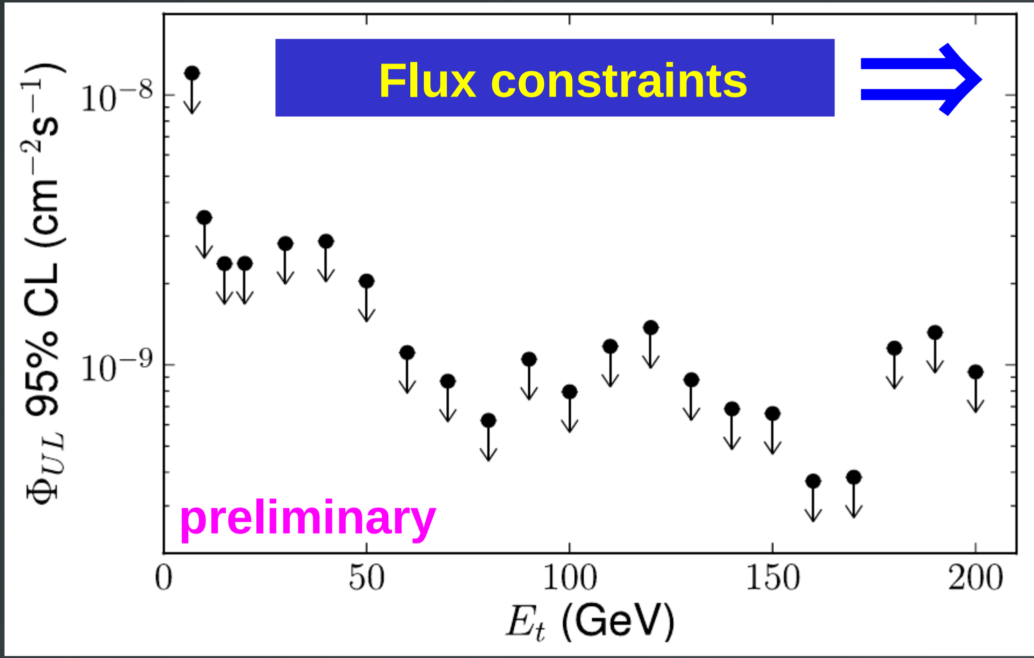
Earth Albedo :

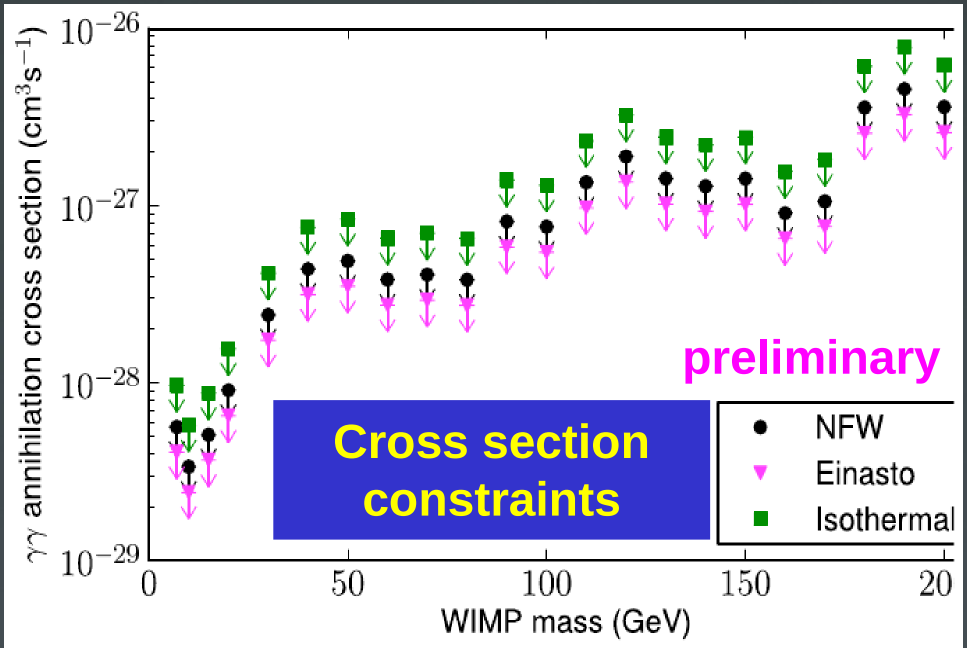


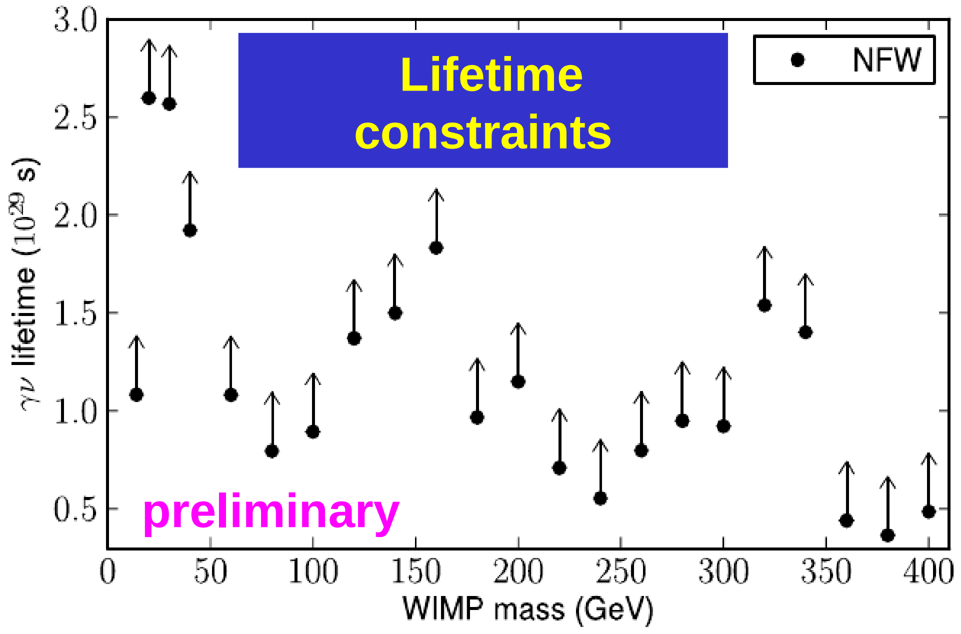


Ackermann, M. et al., accepted in Phys. Rev. D (2012)

Search for Spectral Lines : The « Smoking Gun »





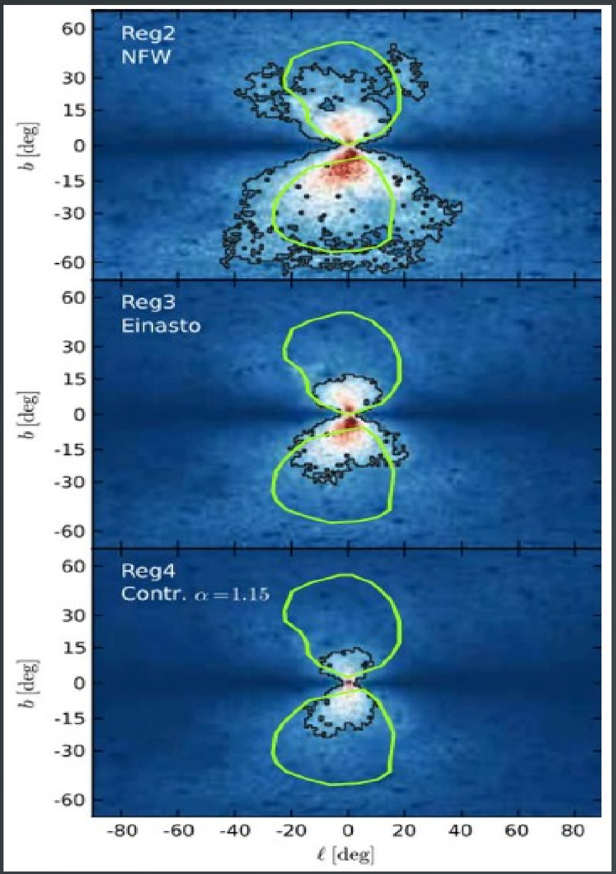


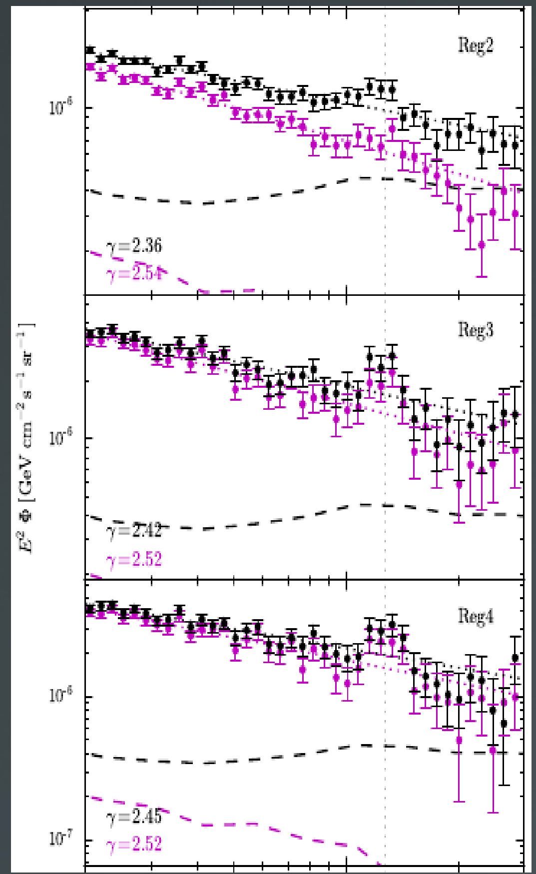
No line detection, 95% CL flux upper limits are evaluated.
Assuming dark matter density distributions, we extracted constraints on the dark matter annihilation cross-section (or lifetime for decaying dark matter)

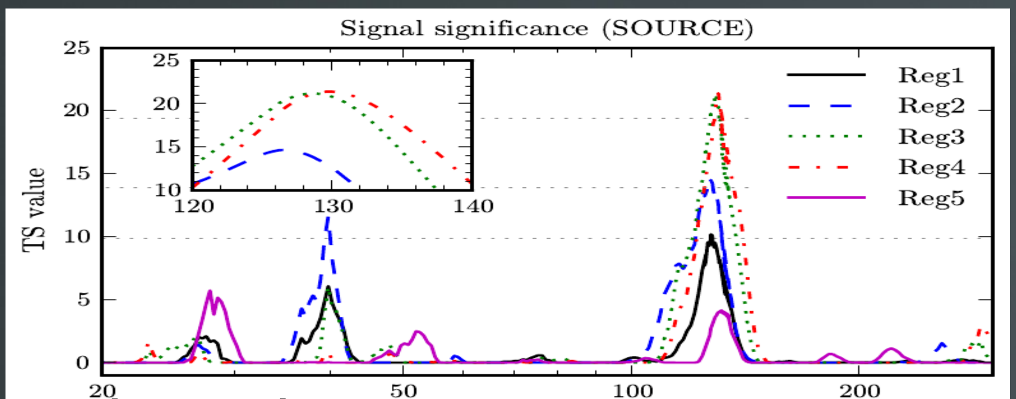
Ackermann, M. et al., submitted to Phys. Rev. D (2012)

Other Searches for Spectral Lines in Fermi data

- Possible Evidence for 130 GeV Dark Matter Annihilation Line ?
- 4.6s or 3.3s when taking into account “look elsewhere” effect







Weniger, arXiv:1204.2797

Fermi limits are in some contention with the recent results of Weniger

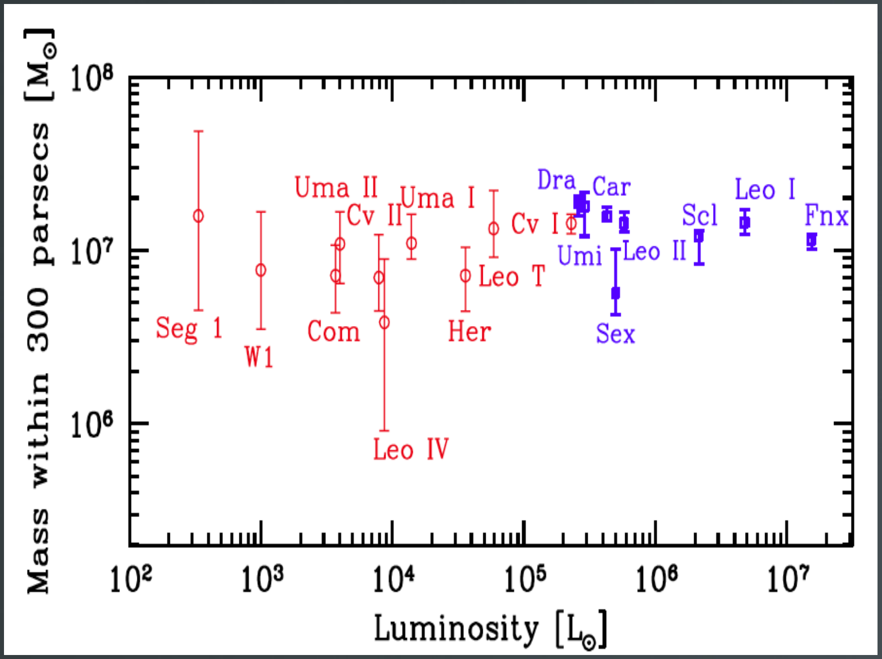
Updated analysis using Pass 8 will be upcoming. This greatly increases both the energy resolution and high-energy effective area of the Fermi-LAT

Currently, an exciting topic of study ! Weniger et al., Profumo & Lindden, Bringman et al .

Search for DM in Dwarf Spheroidal Galaxies

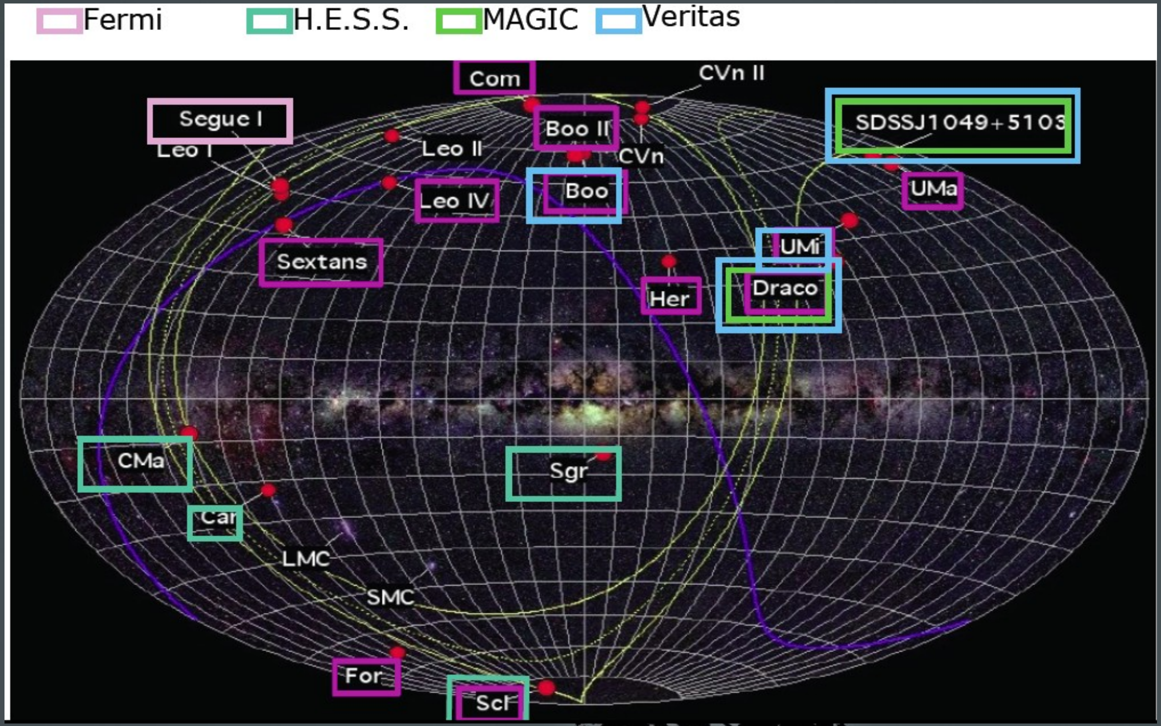
dSphs are excellent DM targets of opportunity :

- Very large M/L ratios : ~10 to 1000 (M/L ~ 10 for Milky Way)
- Most of them are expected to be free from any other astrophysical gamma source and have low content in dust/gas, very few stars
- More promising targets could be discovered by currentand upcoming experiments ! (SDSS, DES, PanSTARRS, ...)



Strigari et al. Nature 2009

Dwarfs probed in gamma-rays :

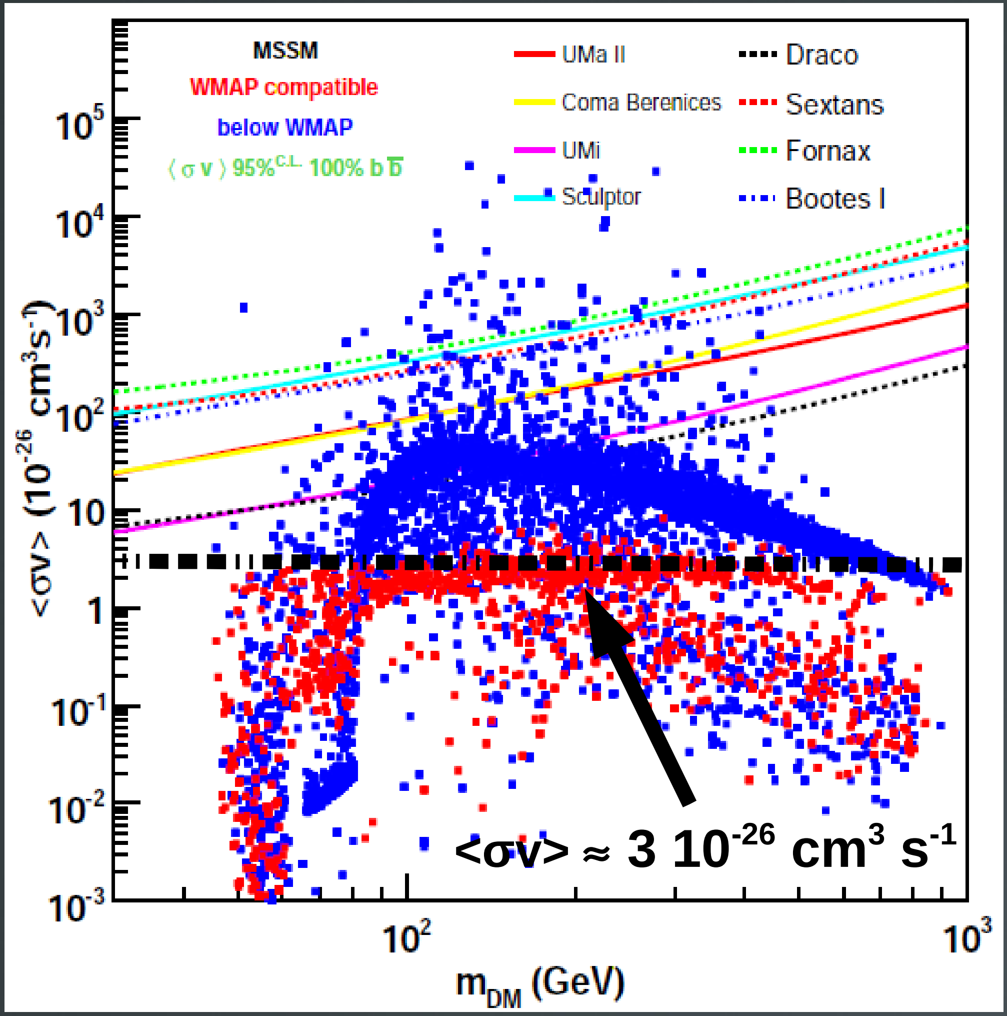


J-factors (DM signal) and their uncertainties can be calculated from stellar kinematical data of the dwarfs

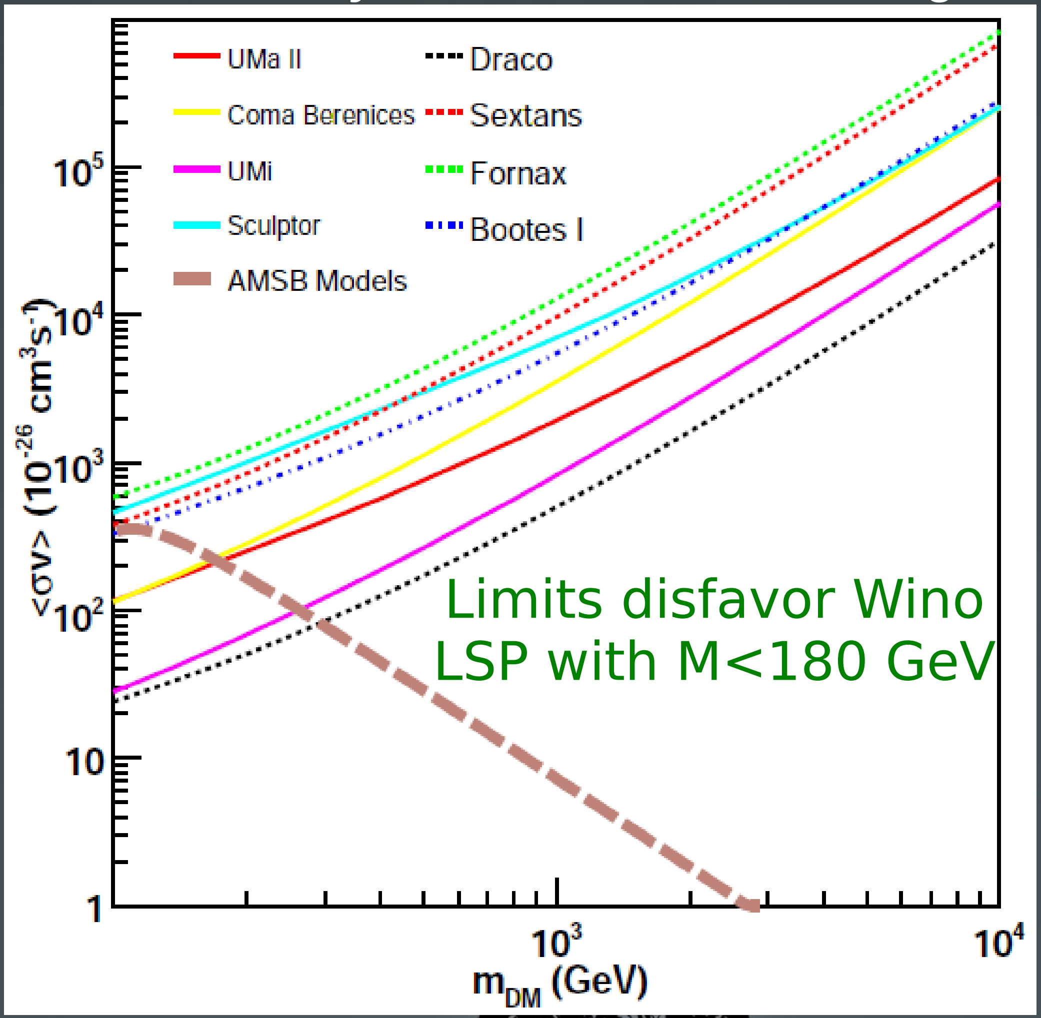
Step 1 : Search for DM in dSphs galaxies with Fermi

Select 10 dSphs wih relatively large "astrophysical factor" J (8 for individual study; +2 for stacking analysis)

« Constrained » MSSM



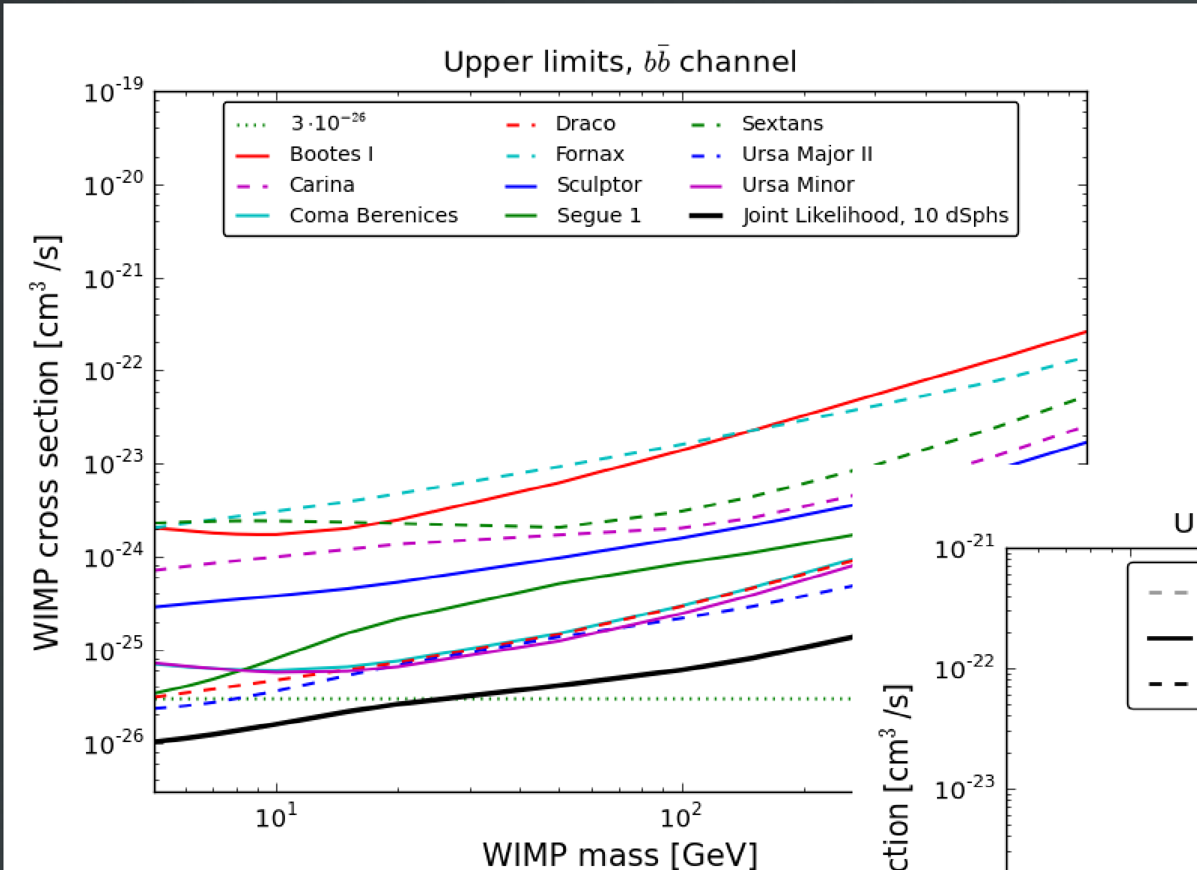
Anomaly mediated SUSY breaking



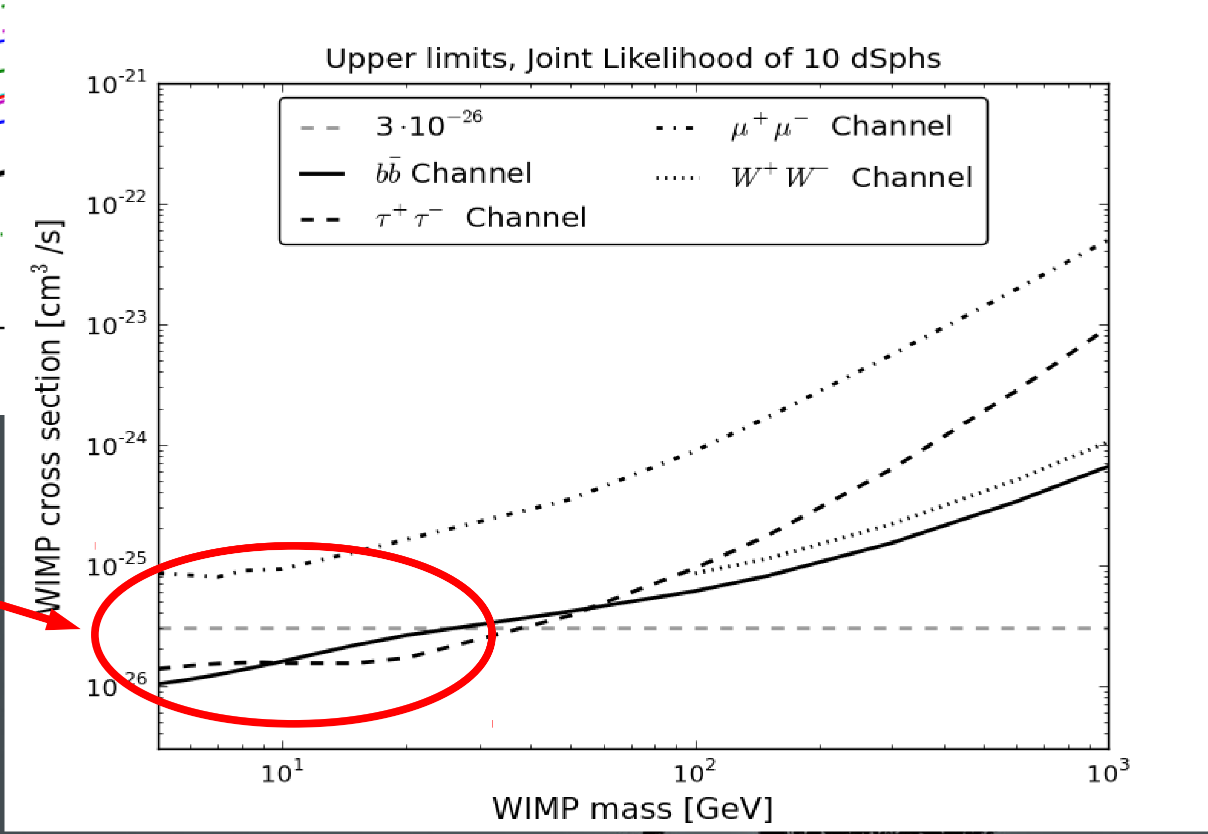
Fermi LAT Collaboration, ApJ 712 147 (2010)

Exclusion regions cutting into interesting parameter space for some WIMP models (NFW, no substructure).

Step 2 : Combining Fermi dSph limits



- No detection of dSph with 24 month of data.
- The method implements a product of likelihoods from the single dwarfs, instead of the usual multiple source stacking.
- Statistical stacking of 10 dSphs.



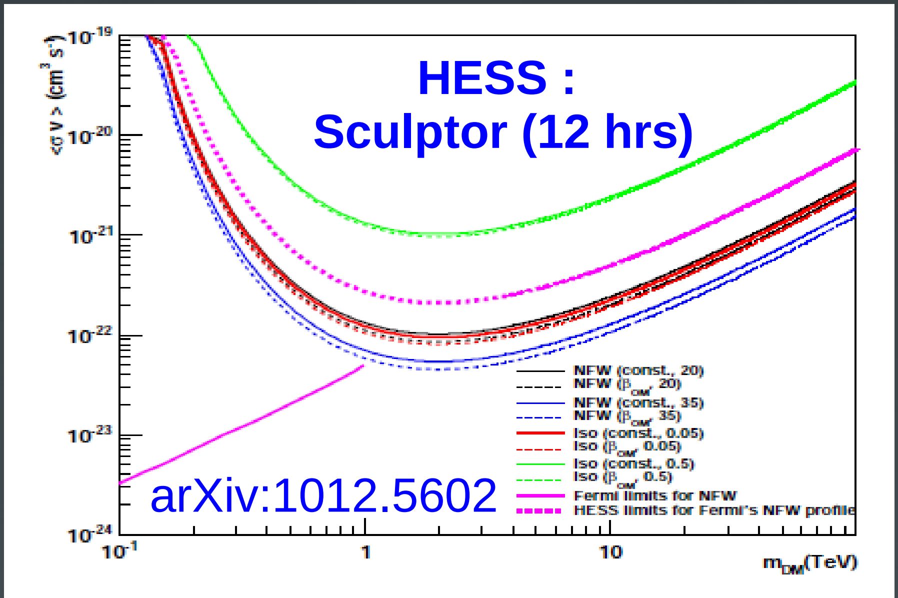
Thermal WIMP cross section
$<\sigma v> \approx 3\ 10^{-26}$ cm³ s⁻¹

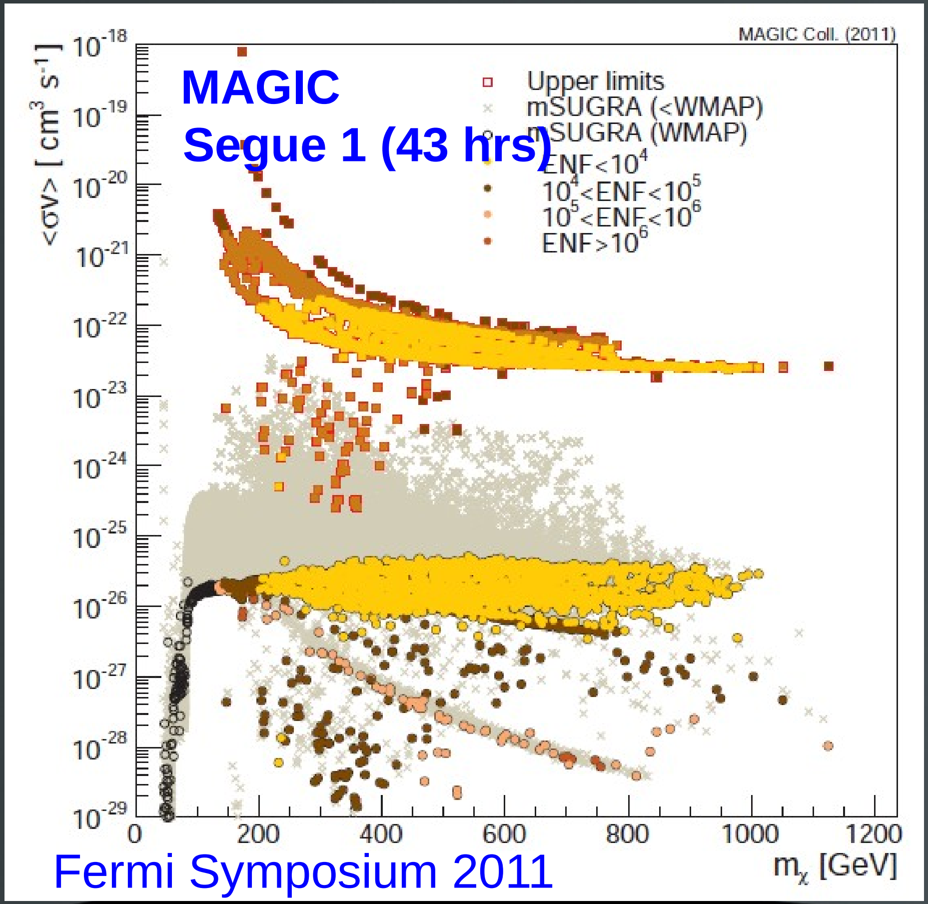
Now exlusion regions getting to very interesting sensitivity ranges !

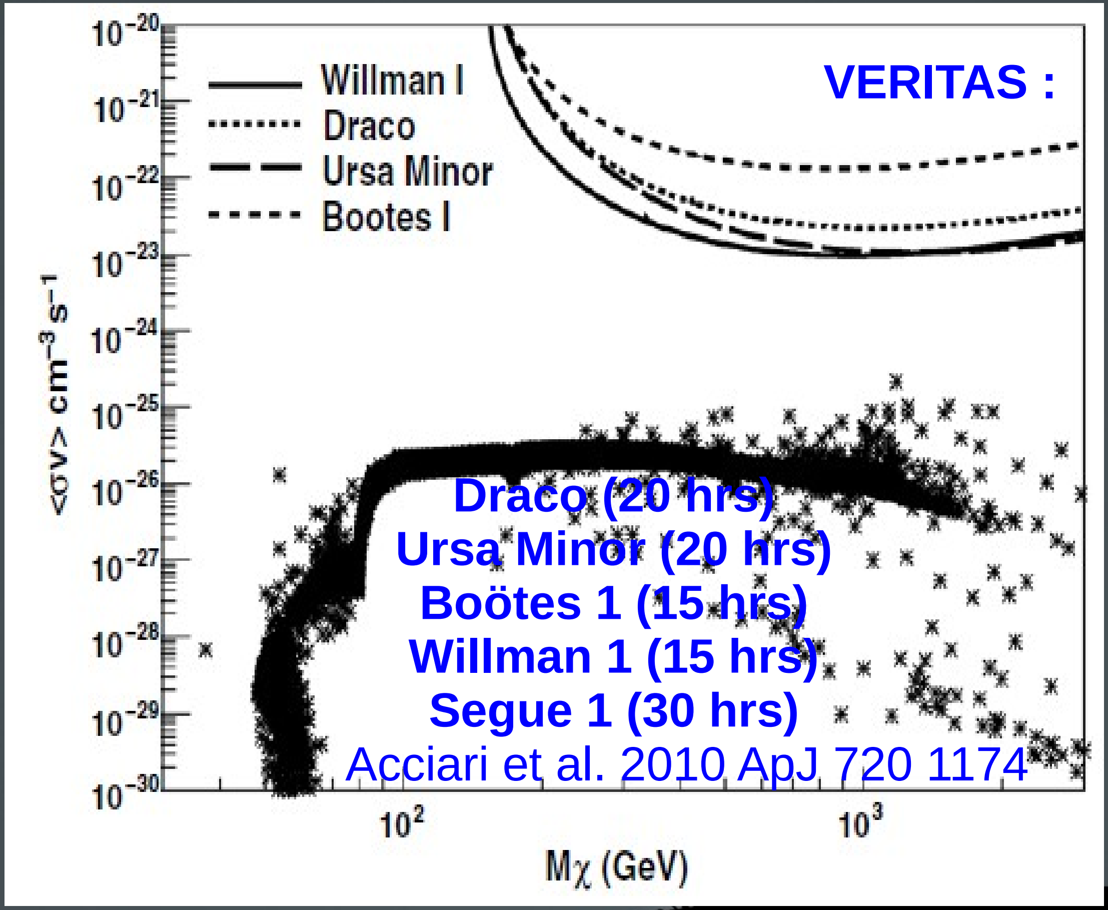
Fermi-LAT collaboration, PRL 107, 241302 (2011)
Alex Geringer-Sameth, Savvas M. Koushiappas, arXiv:1108.2914v2

dSphs observations with ACT

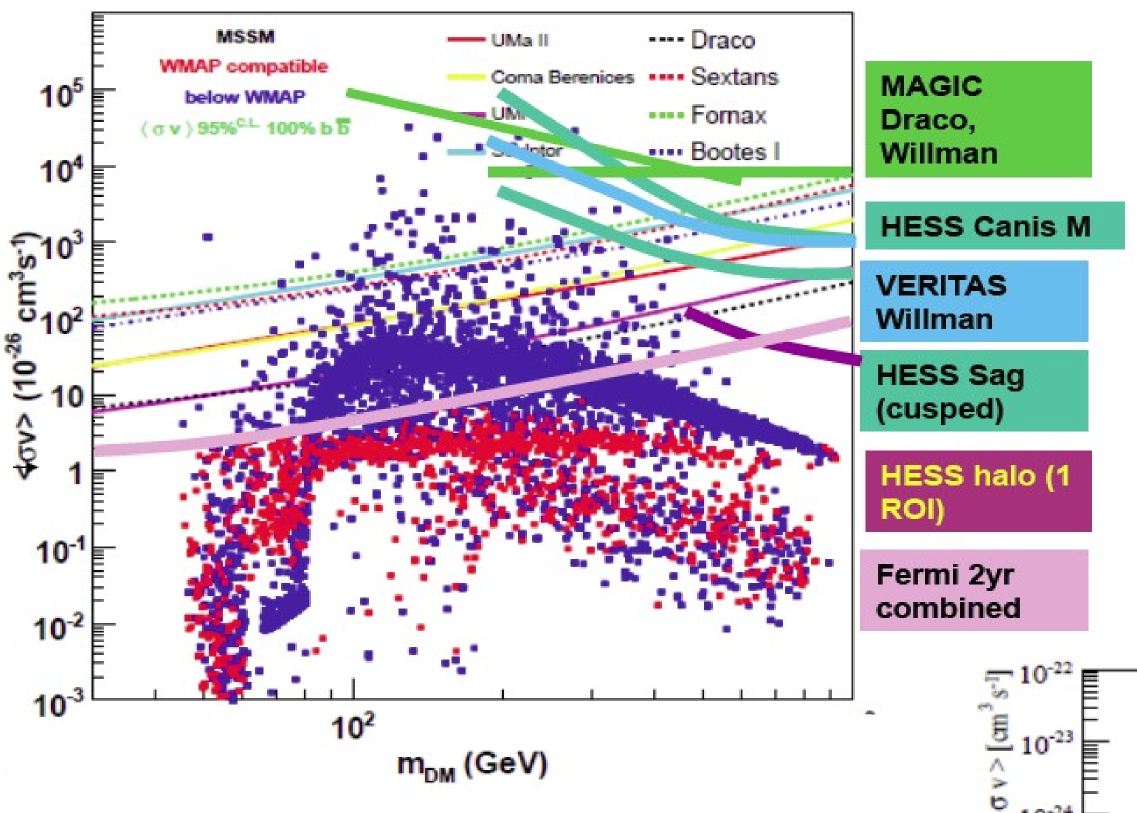
- Dedicated observations of a number of dSphs galaxies
- No significant excess in any of the observations
- Set constraints on the annihilation cross section







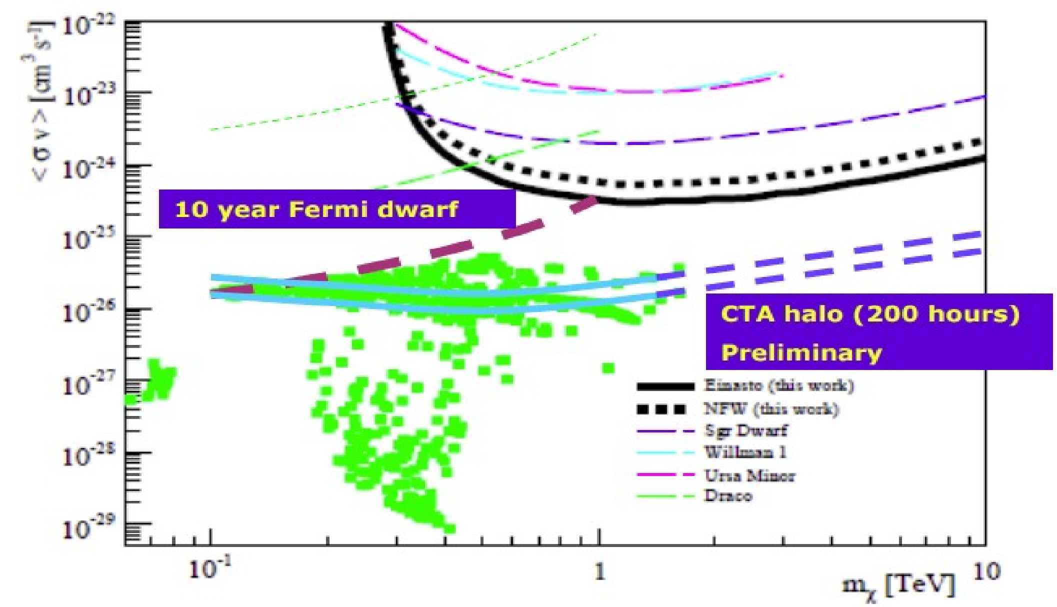
Fermi and Cherenkov telescopes in comparison and some projection to the future



At the moment CTs limits are competitive with Fermi only above ~1 TeV due to the CTs' high energy threshold.

CTA will be ~10x more sensitive than current instruments and extend lower energy threshold

Figure adapted from: *Fermi-LAT: Astrophys.J.712:147-158,2010*
By J.Conrad, IDMS 2011



Seems that dSph's are good for constraints, but not necessarily for discovery.

Abramowski et. al. PRL.106 (arXiv:1103.3266)

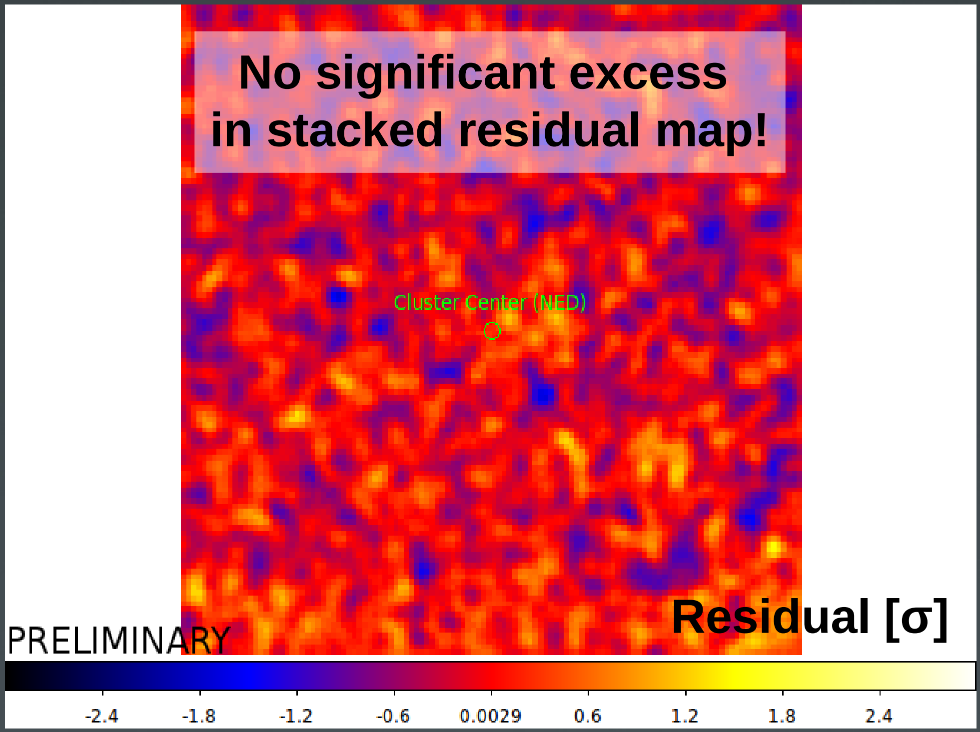
Clusters of galaxies with Fermi

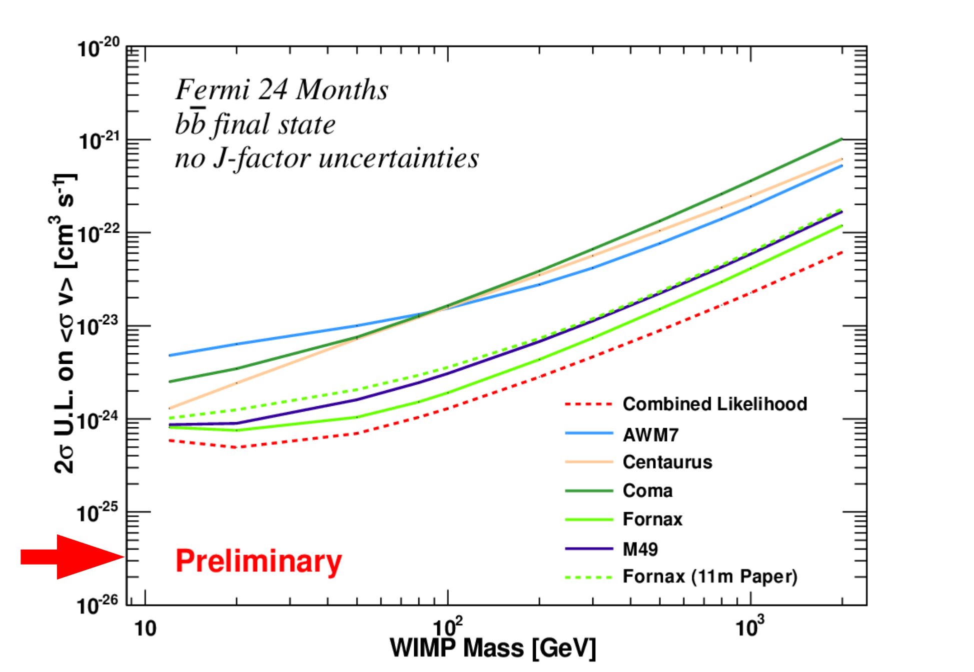
- Largest virialized and most massive structures in the universe :
  - Radio emission suggests rel. cosmic ray (CR) population
  - Lensing and X-Ray observations indicate large dark matter (DM)

- Data analysis :
  - 24 Months of Fermi-LAT data, p6v11 Diffuse class Events
  - Binned analysis, 10 deg ROI, 20 Energy bins from 200 MeV to 100 GeV
  - Clusters modeled as point sources !

- Combined Likelihood Approach :

  In both cases, CR and DM have common parameter in all clusters (Annihihilation cross section or decay time and maximum Injection efficiency)



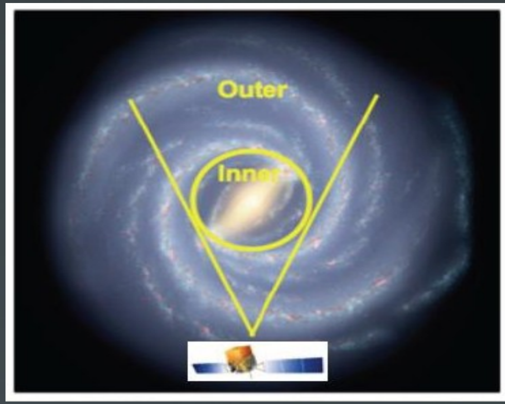


No observational evidence for γ-rays so far.

A paper with details on careful modeling of clusters as extended sources considering both CR- and DM-induced γ-ray signals is in the works

S.Zimmer and J.Conrad for the Fermi-LAT collaborat, Fermi Symposium 2011

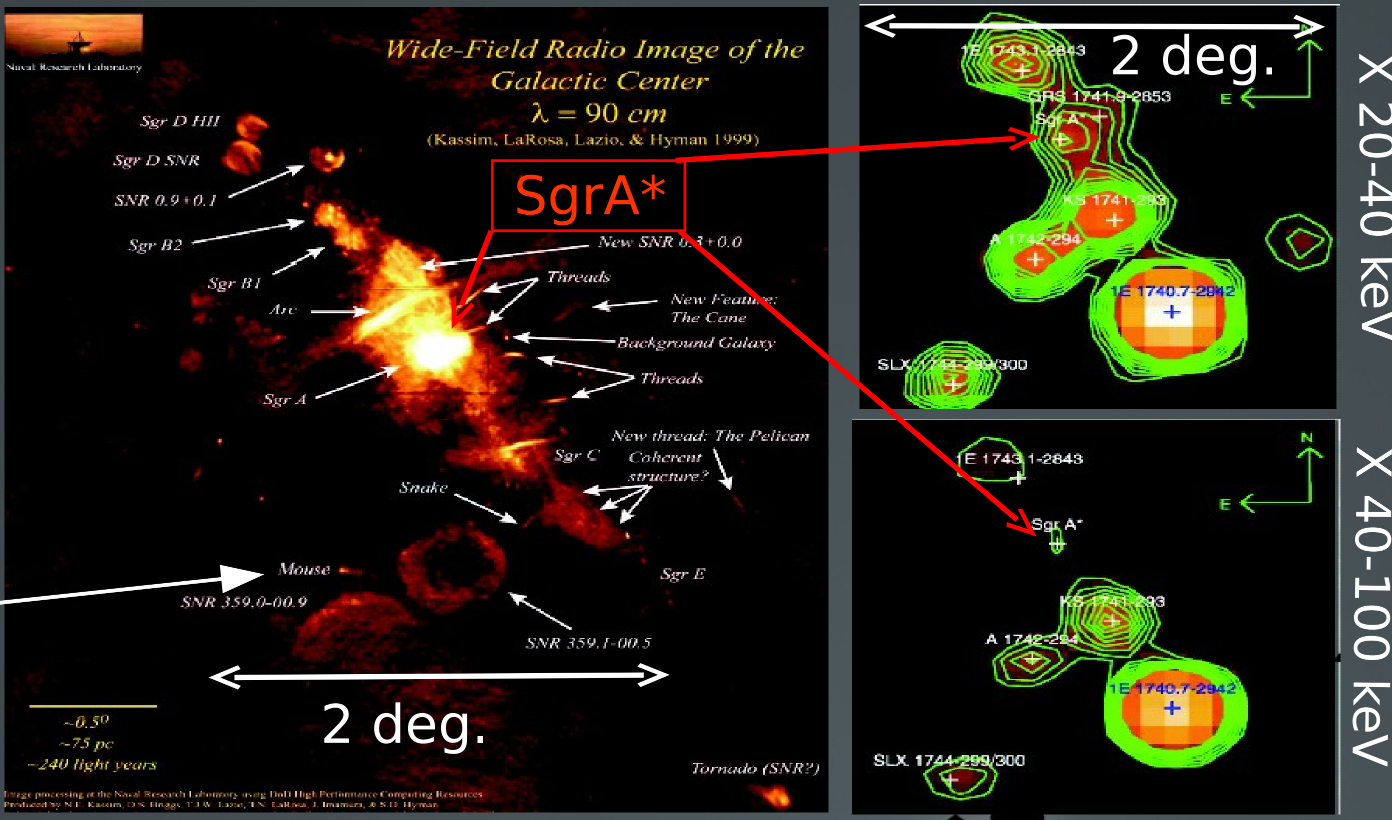
The Galactic center as one of the most fascinating (and complex ...) region in the sky ...



MWL source in the central parsecs of our Galaxy emitting from radio to TeV γ-rays. From radio to X-rays: originates from the SMBH Sgr A* but several possible counterparts for the hard X-rays / GeV / TeV γ-ray emissions

- **Huge pp emissivity due to CRs streaming through very dense clouds (CMZ)**
- **SNRs and PWNs...**
- **Large Pulsar population !**
  Deneva et al. 09 :
  3 pulsars detected near SgrA*. Inferred population of ~2000 active radio Pulsars !

Mouse pulsar
PSRJ1747-2958
Abdo et al.
ApJ 187 460 (2010)



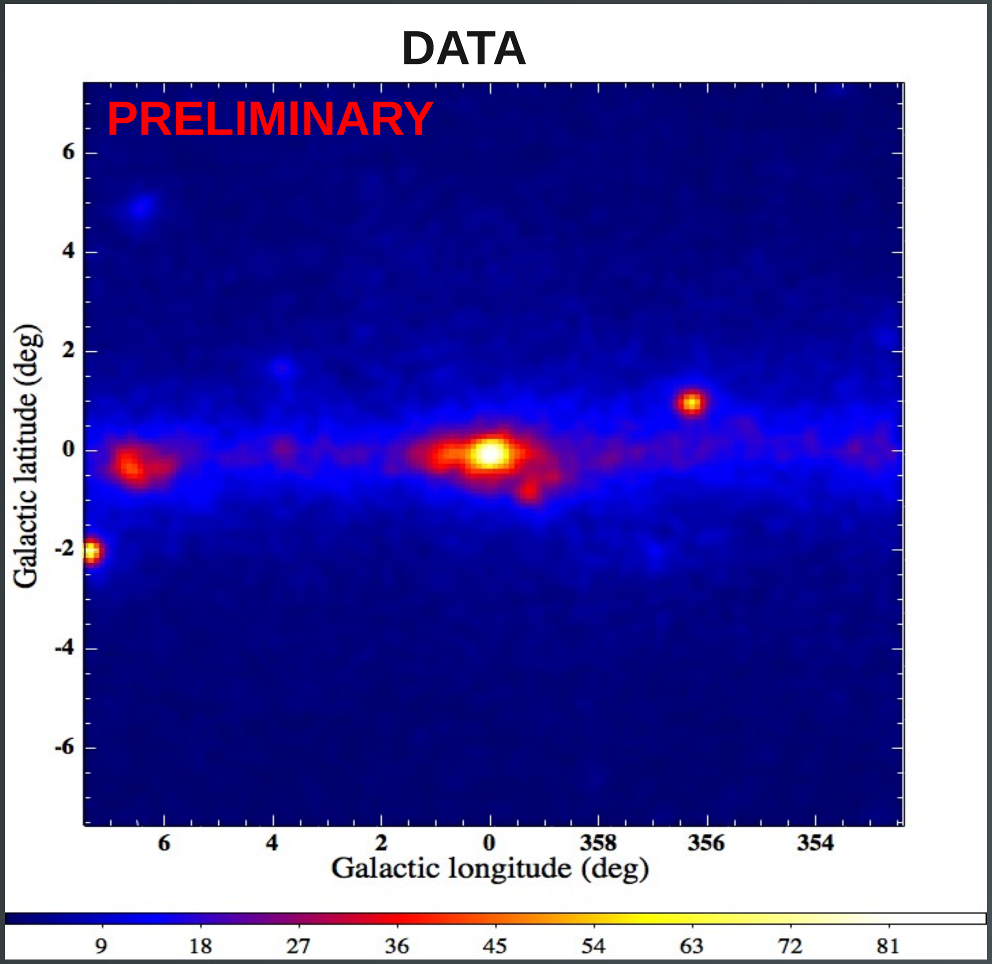
Search for DM in the GC :

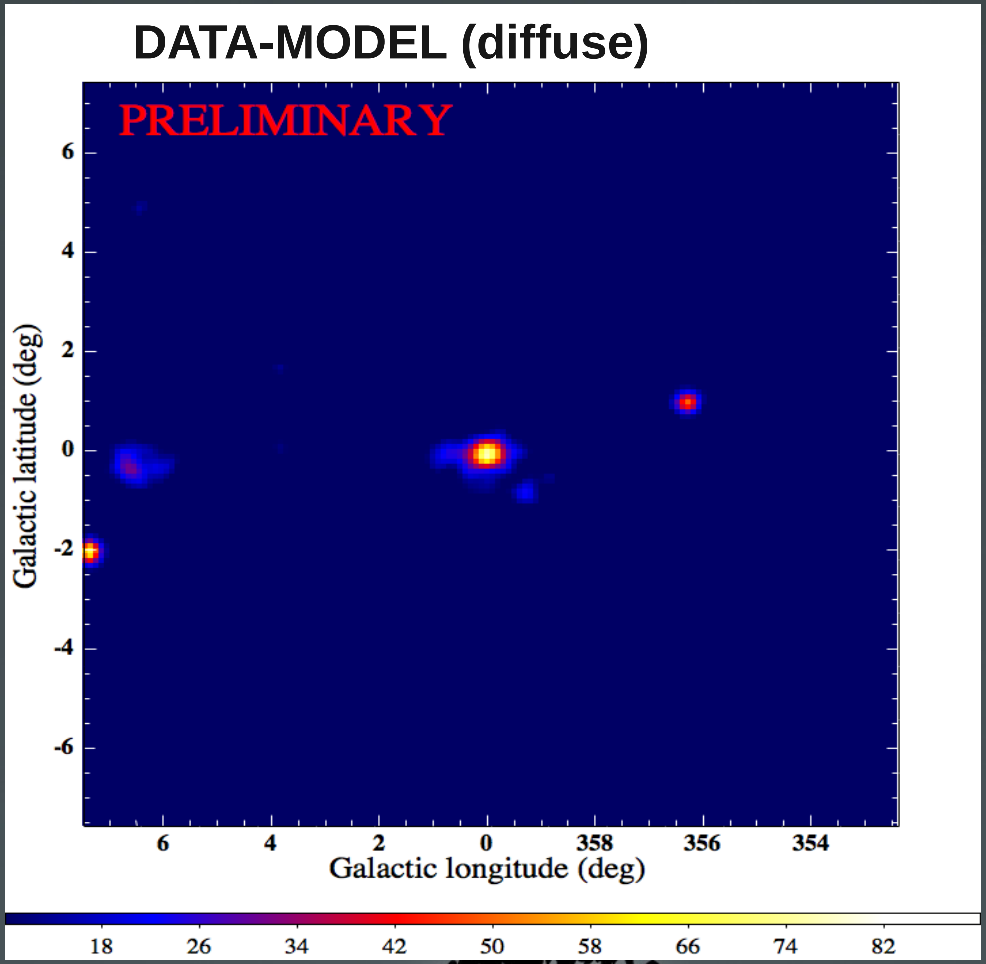
☺ **Expect large DM annihilation/decay signal due to possible steep DM profiles**

☹ **Caveats : Good understanding of the astrophysical background is crucial to extract a potential DM signal from this complicated region of the sky : source confusion / diffuse emission modeling (very difficult !)**

Fermi's View of the Inner Galaxy (15°x15° region)

Fermi LAT preliminary results with 32 months of data, E>1 GeV (P7CLEAN_V6, FRONT) :

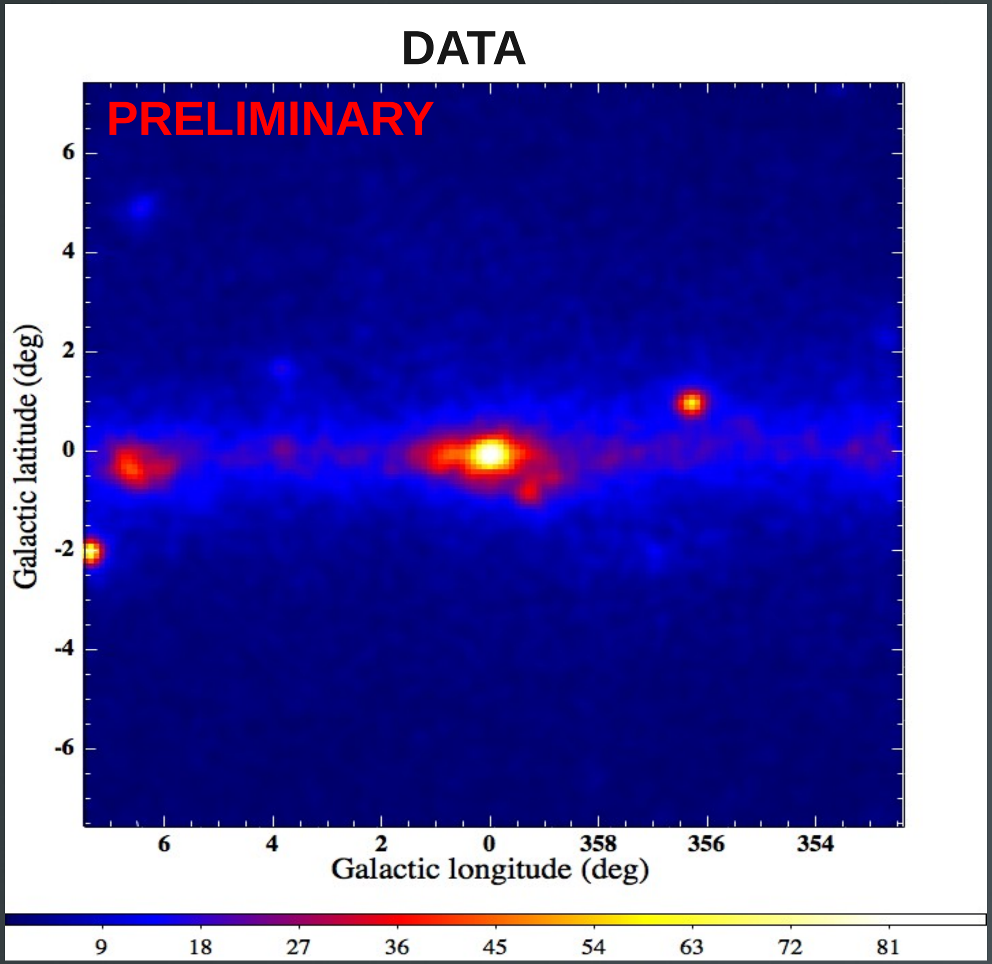


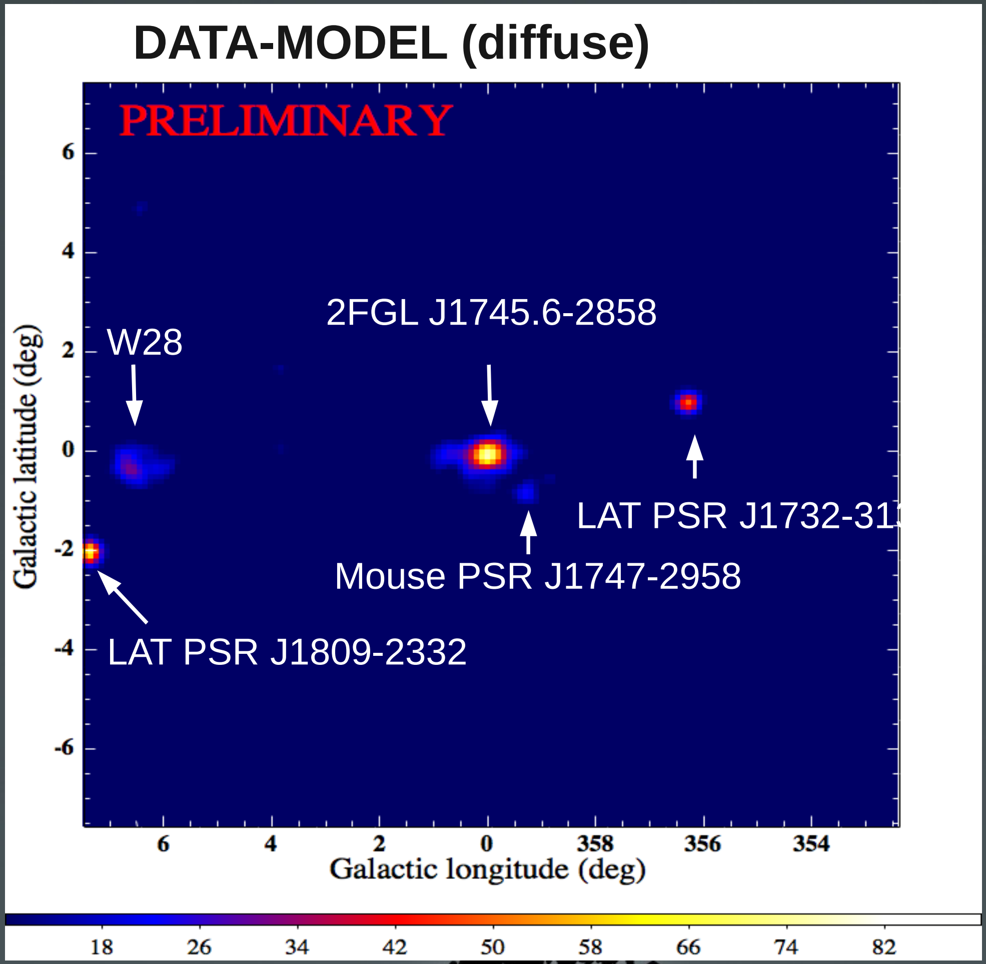


- **Galactic diffuse emission model: all sky GALPROP model tuned to the inner galaxy**

Fermi's View of the Inner Galaxy (15°x15° region)

Fermi LAT preliminary results with 32 months of data, E>1 GeV (P7CLEAN_V6, FRONT) :

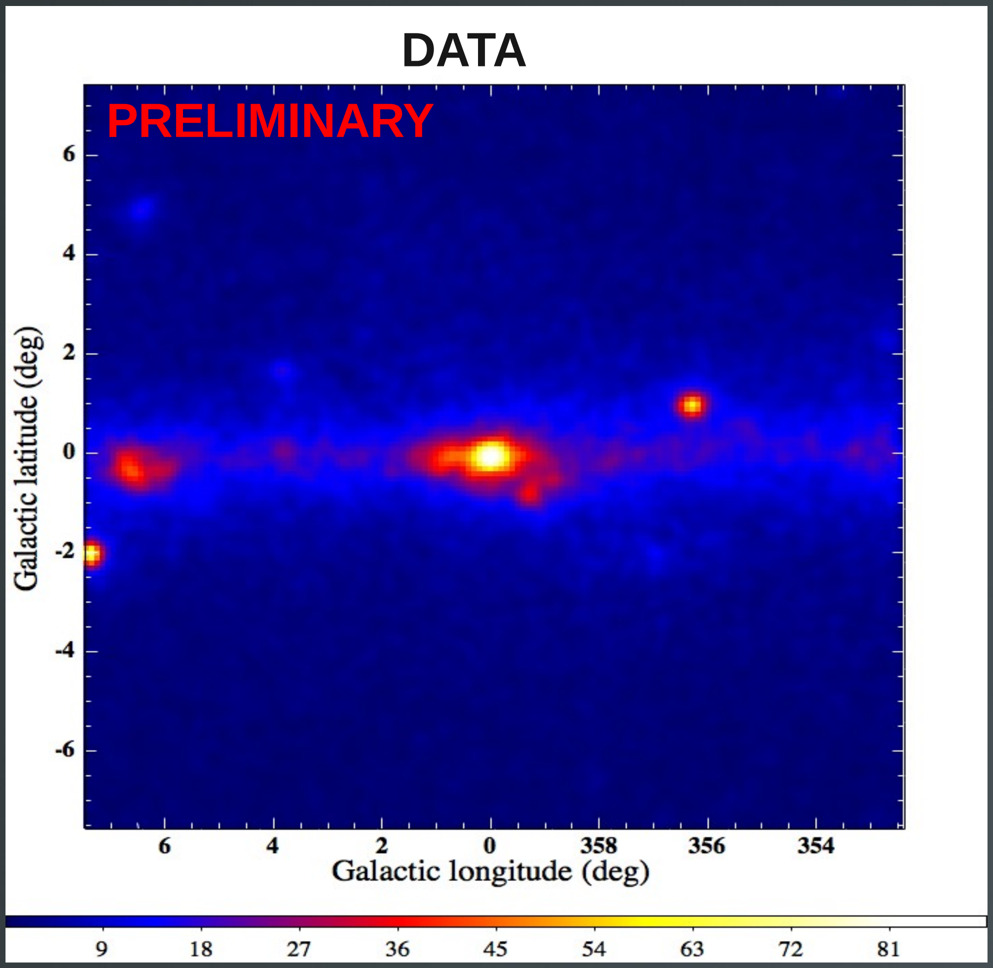


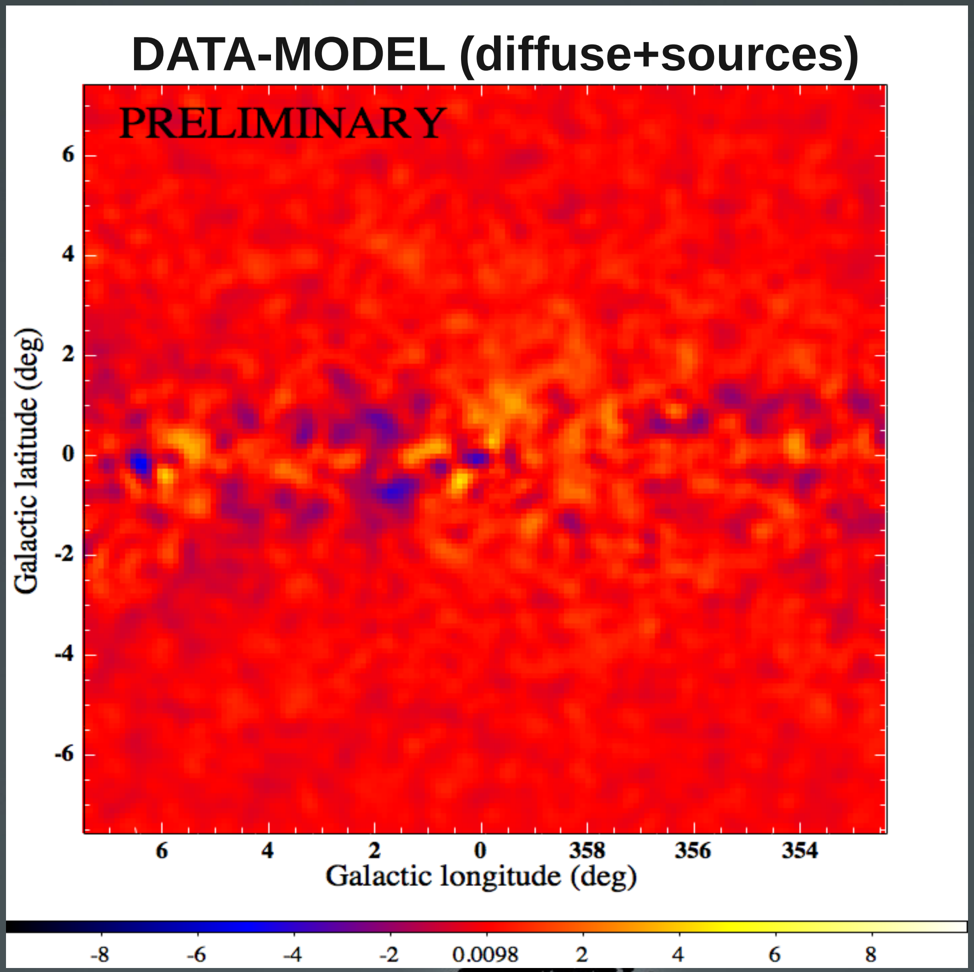


- Galactic diffuse emission model: all sky GALPROP model tuned to the inner galaxy
- Bright excesses after subtracting diffuse emission model are consistent with known sources.

Fermi's View of the Inner Galaxy (15^{o}x15^o region)

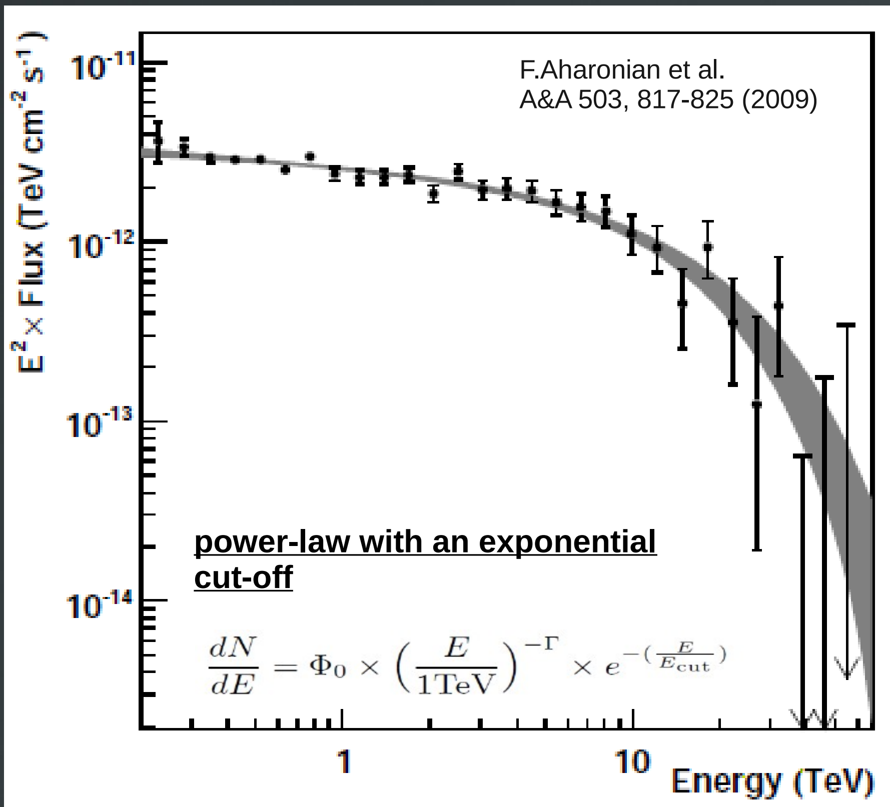
Fermi LAT preliminary results with 32 months of data, E>1 GeV (P7CLEAN_V6, FRONT) :

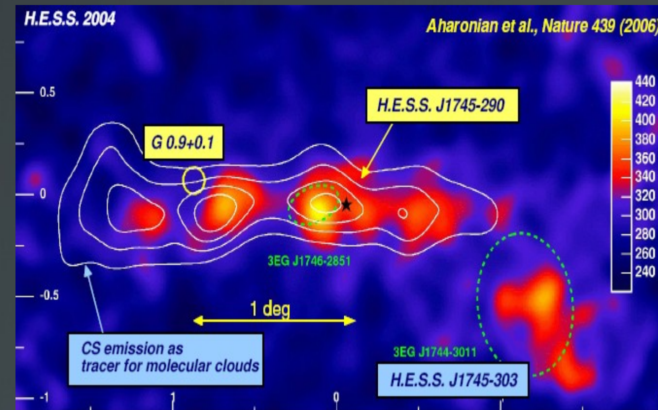


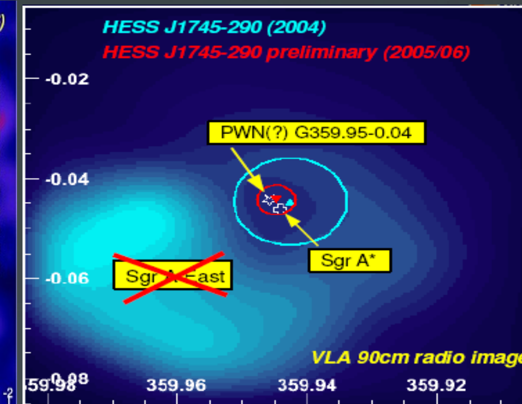


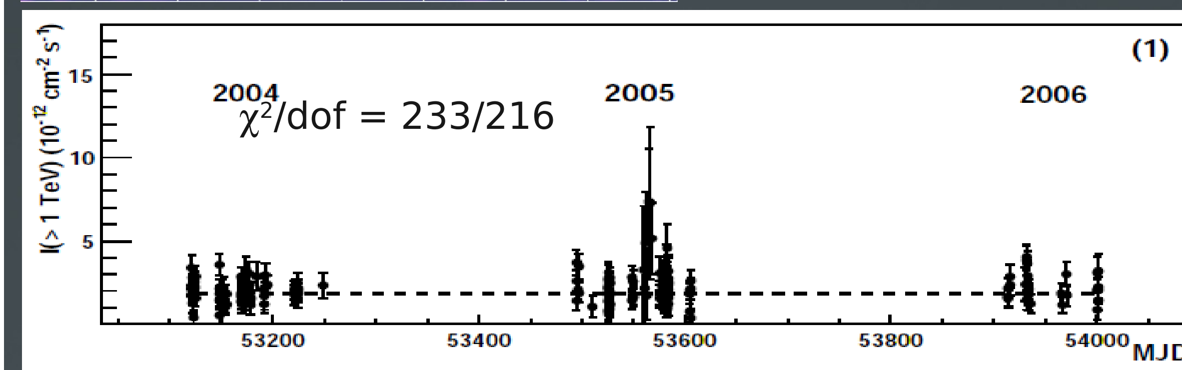
Diffuse emission and point sources account for most of the emission observed in the region.
Papers are forthcoming and will include dark matter results.

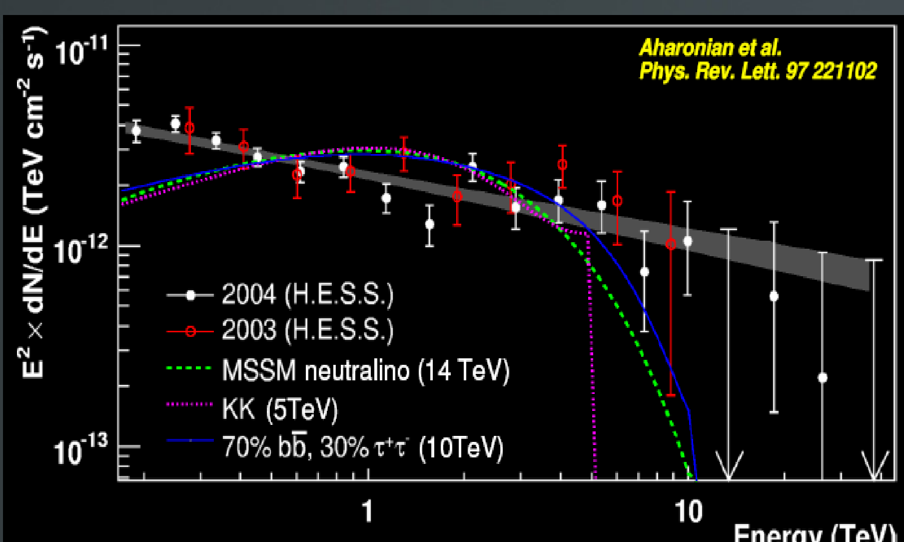
TeV Galactic center as seen by HESS









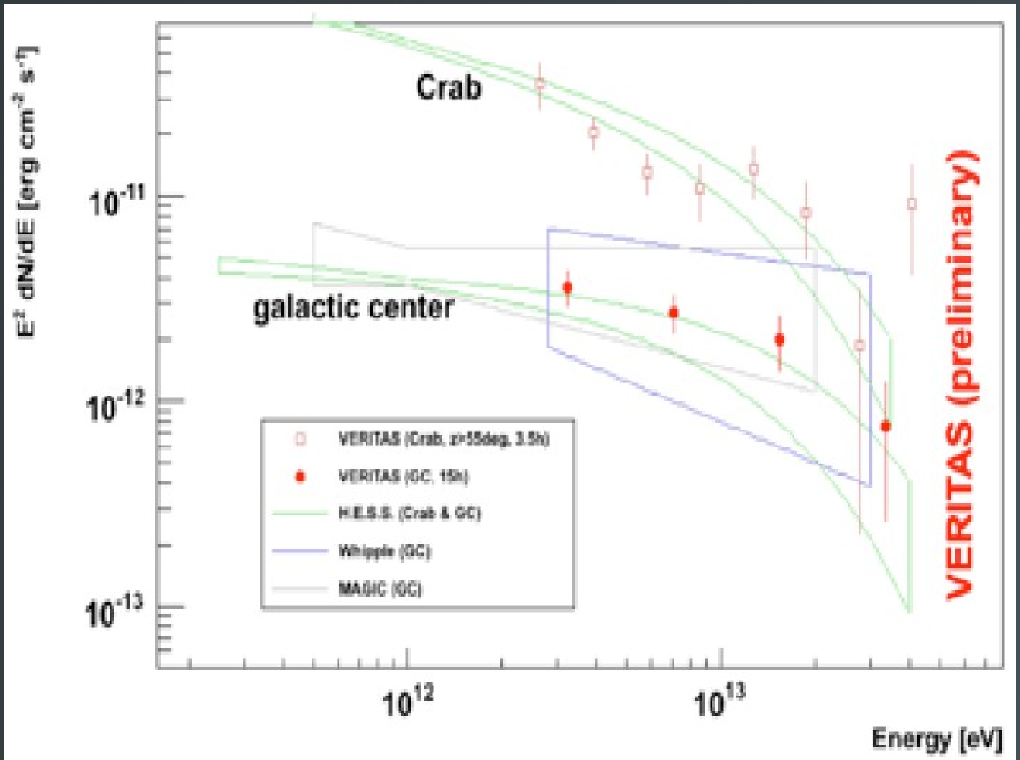


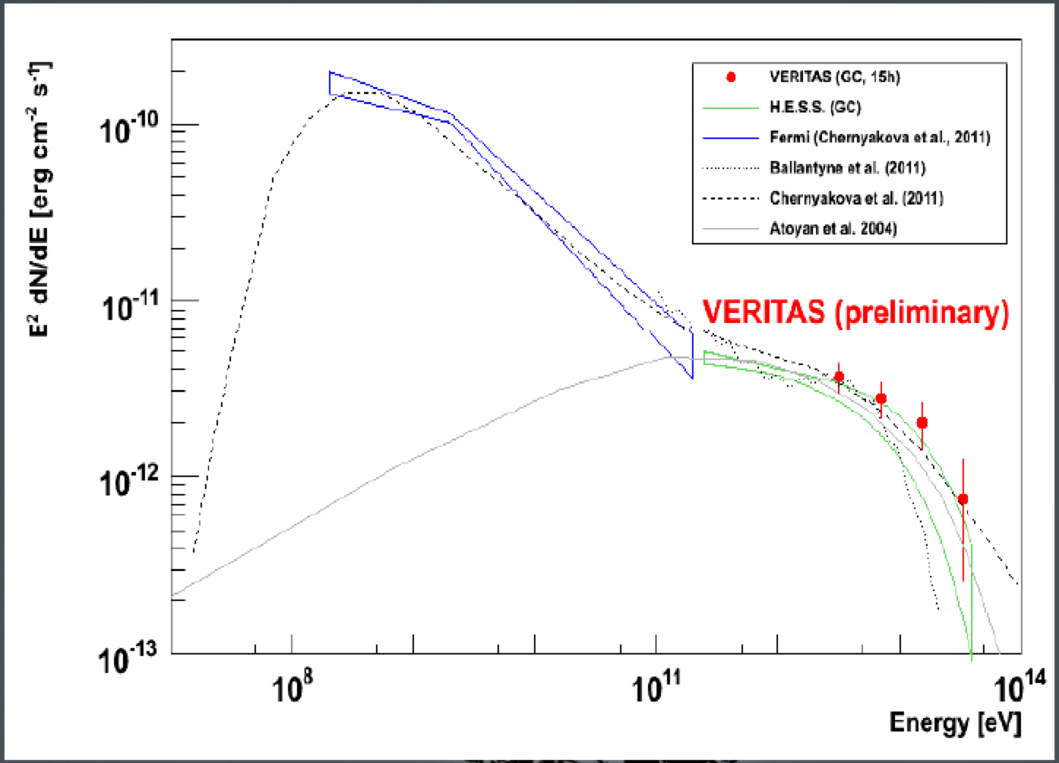
- 3 years data analysis ~100hrs
- First deviation from a simple PLspectrum
- No significant flux variation is found.
  Run by run light curves (28') compatible with a constant
- Sgr A East excluded at 7σ C.L.
- Remaining candidates : SgrA*, PWN cand. G359.95-0.04 (Wang et al. 06), others....
- Spectrum incompatible with DM particle annihilations.

The fits are bad in the low & high energy parts.

Galactic Center Source : GeV/TeV

- Consistent spectrum observed by HESS (>100 hrs), MAGIC and VERITAS (~ 25 hrs, large zenith angle observations)
- GeV/TeV spectrum compatible with gamma-ray production from protons accelerated in Sgr A* and diffusing in the interstellar medium
- GC source spectrum consistent with astrophysical particle accelerators

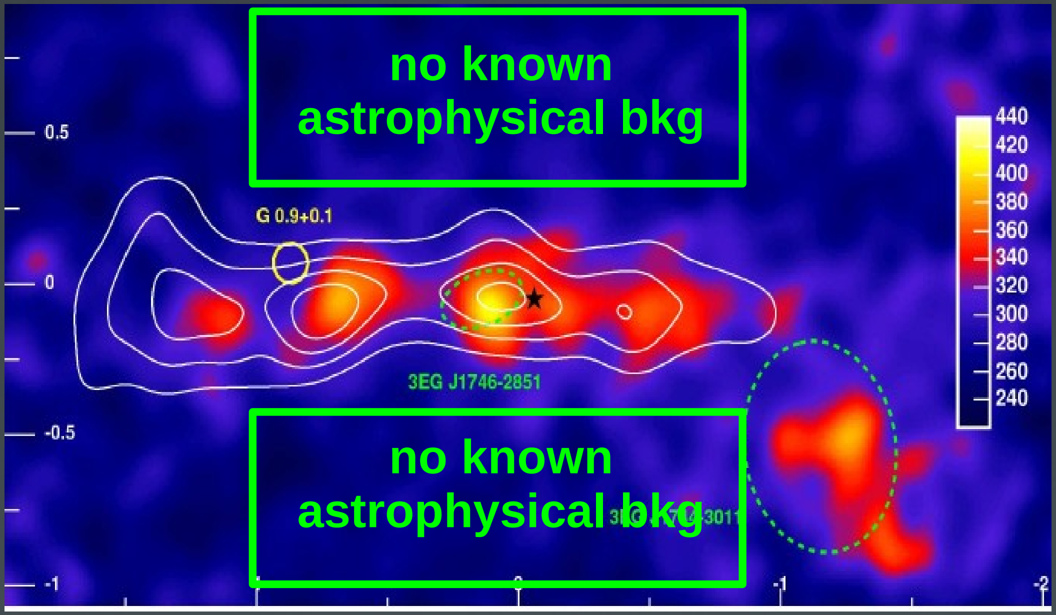


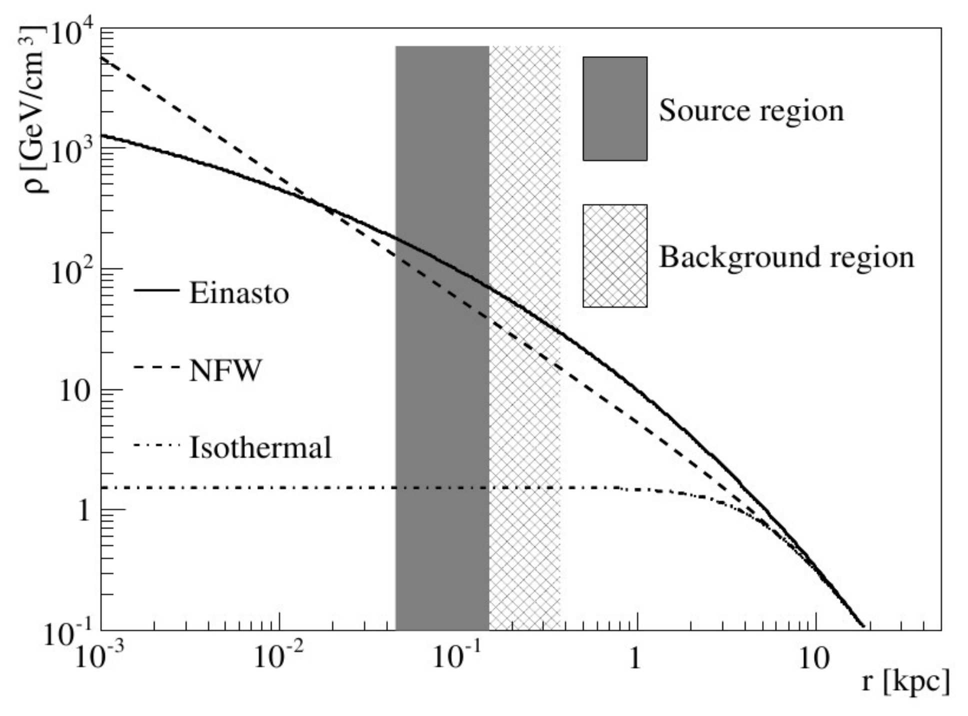


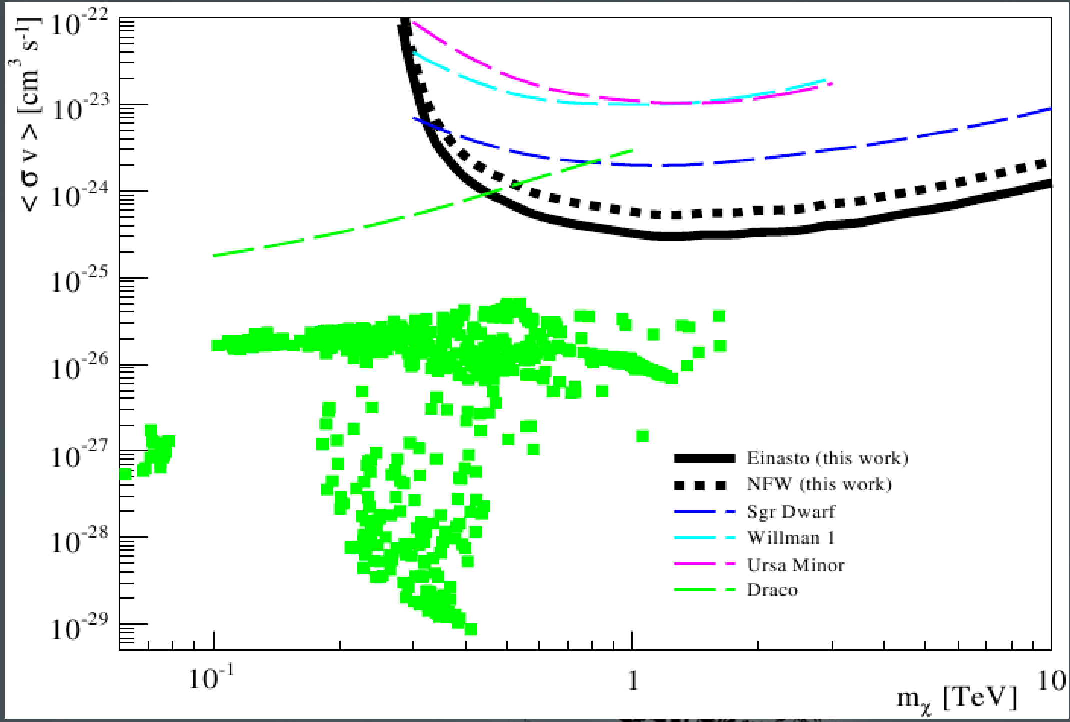
R.Ong, TeVPA 2011

Constraints from Galactic Halo with HESS data

- Galactic Center observations ~ 150 hrs
- Galactic Halo observations ~112 hrs
- high flux expected and ~ well understood profile.
- Best limits for Cherenkov telescopes.
- Still enhancements factors ~ 100 needed

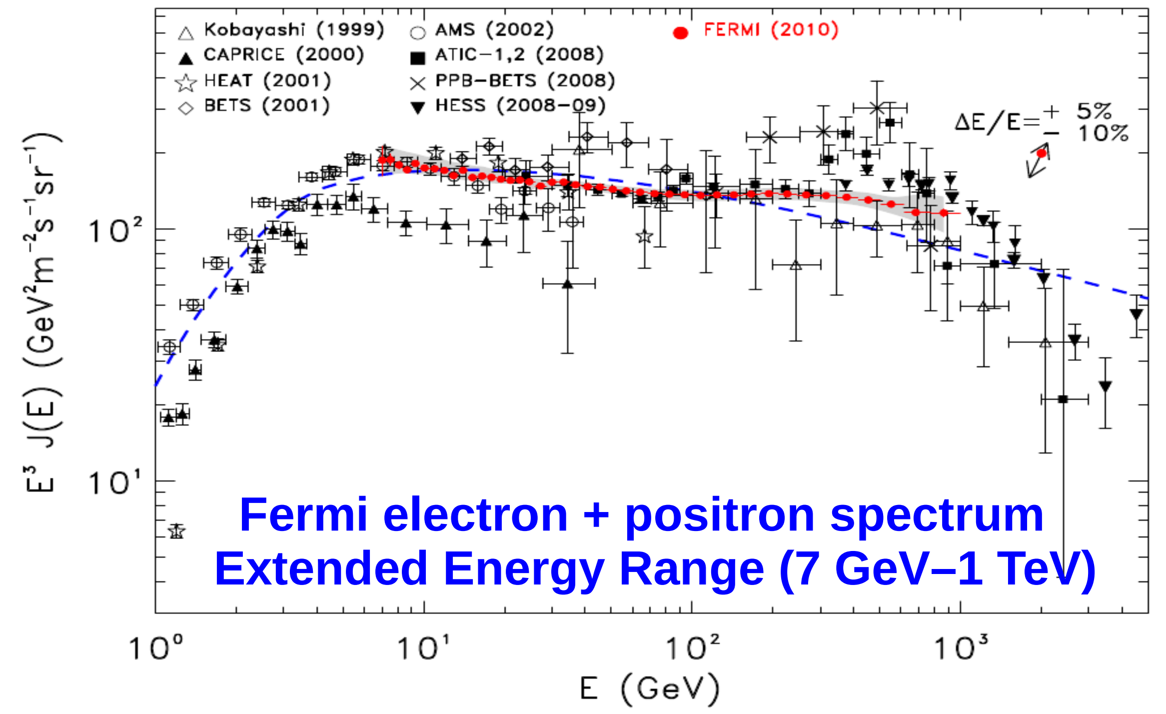






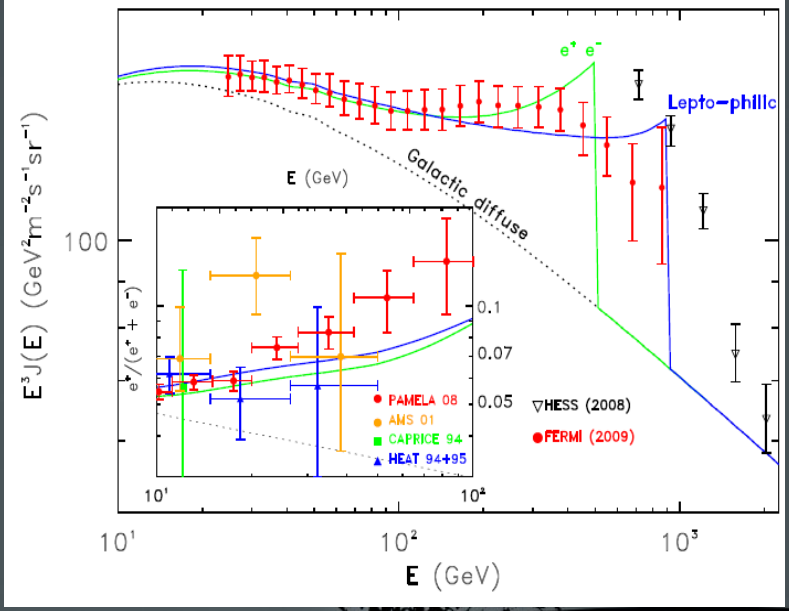
Abramowski et. al. Phys.Rev.Lett.106

Unexpected Features in the Cosmic-Ray e± Spectra ?



Ackermann, M. et al., Phys. Rev. D 82, 092004 (2010)

- Rise in local e+ fraction above ~10 GeV disagrees with conventional model for CRs
- Unexpected bump in total electron + positron spectrum measured by ATIC
- Less prominent feature seen in Fermi cosmic ray e+/e- spectrum but the spectrum is harder than in pre-Fermi GALPROP model (Γ ~ 3.08)



D.Grasso et al., Astropart.Phys.32:140,2009

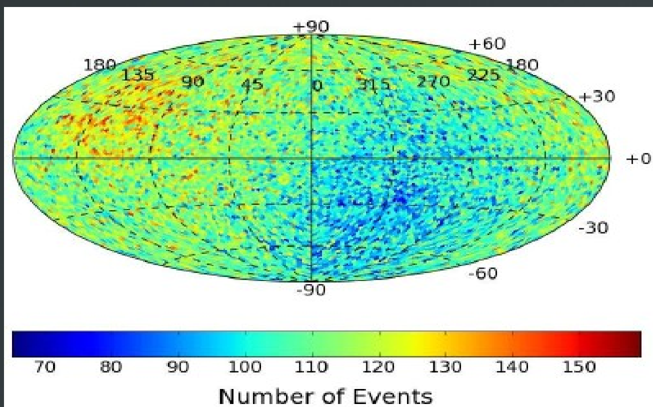
- Diffusive models don’t reproduce spectral features ...
  Hints of a dark matter signal ?
- Possible interpretations :
  - revised diffusion model
  - and/or (local?) extra component (astrophysical or DM)
- DM contribution is not required, however cannot be ruled out

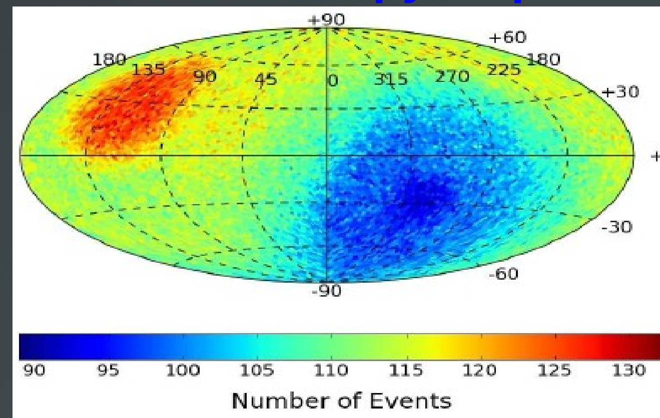
Search for Anisotropies in the CRE Flux

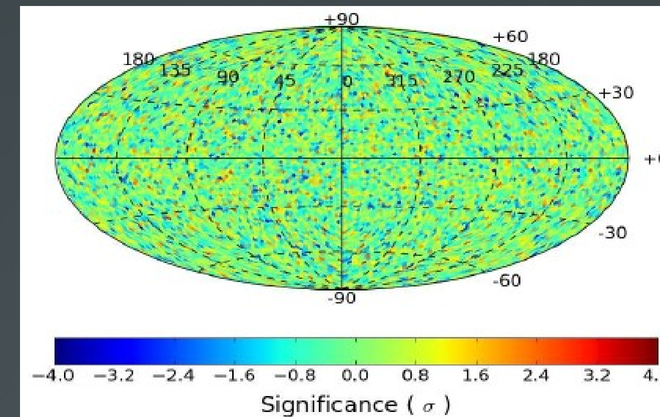
Provides an information on :

Local CR sources and their distribution in space, propagation environment, heliospheric effects, presence of dark matter clumps producing e+ e-

Count map | **No-anisotropy map** | **Significance map**

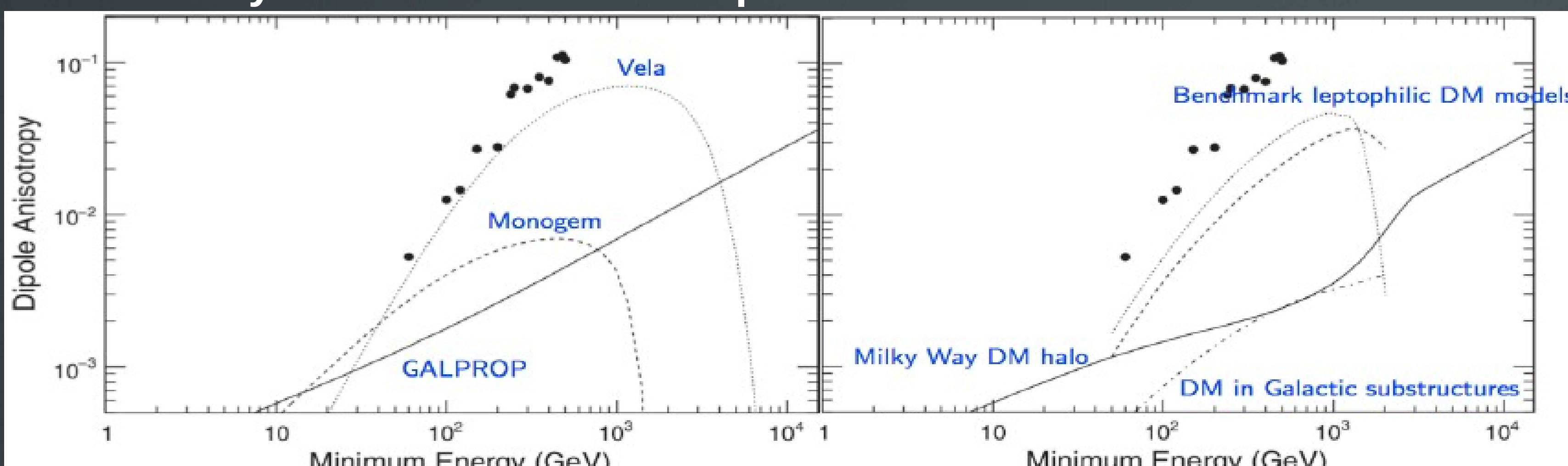






E>60 GeV

- **> 1.6 M candidate electrons above 60 GeV in the first year of the mission**
- **Entire sky searched for anisotropies in Galactic coordinates**



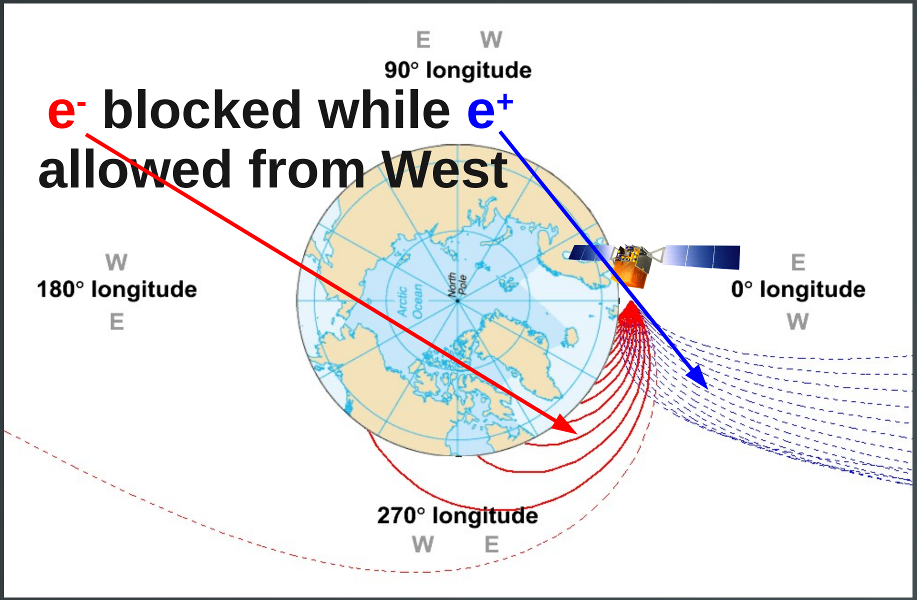
Ackermann, M. et al., Phys. Rev. D 82, 092003 (2010)

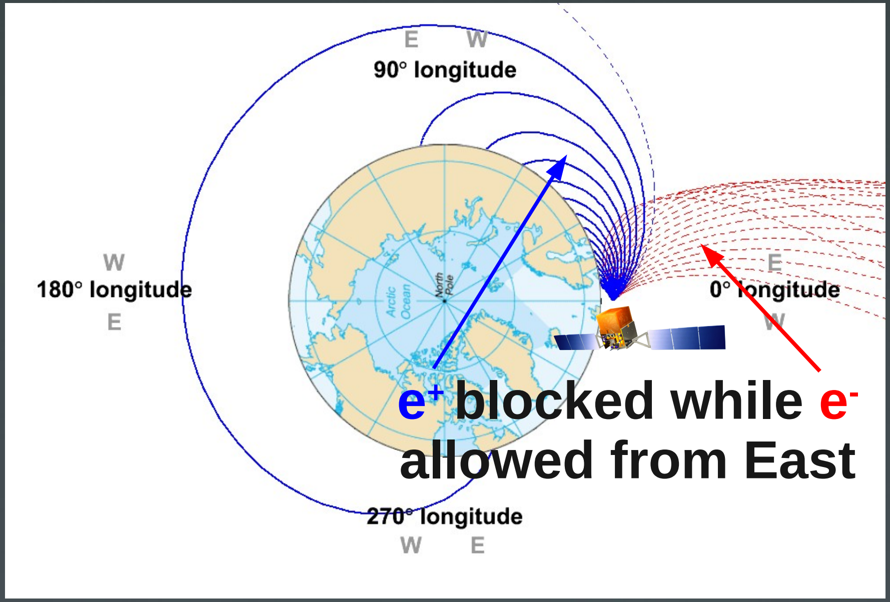
No anisotropies found.

Upper limits for the dipole case ranging from 0.5% to 10%. comparable to the values expected for a single nearby source dominating the high-energy electron spectrum

Fermi – LAT Positron fraction measurement

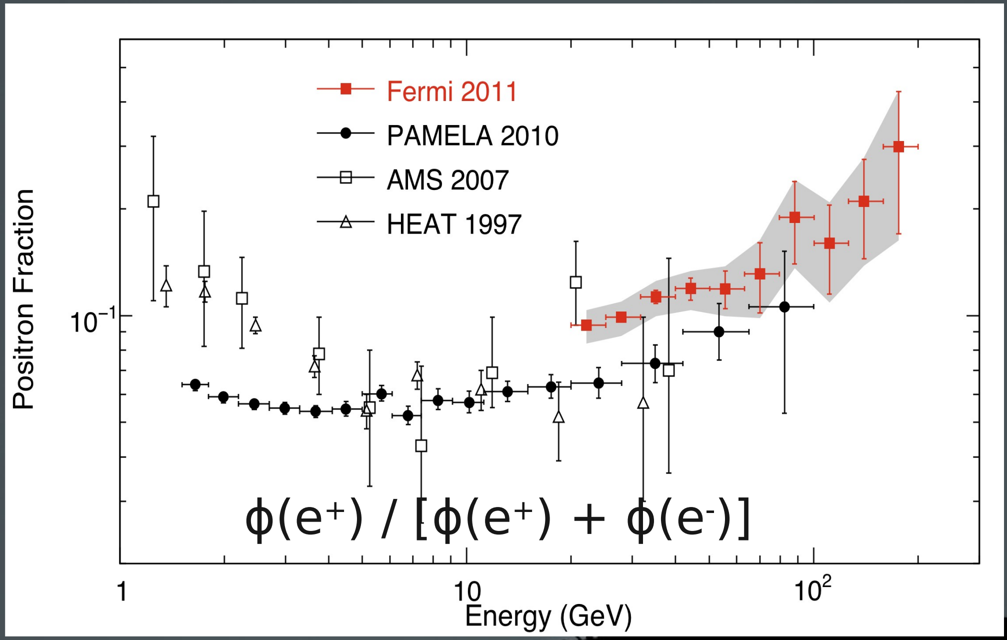
« Unfortunately », the LAT doesnt' carry a magnet, therefore, we cannot discriminate the particle charge … except if we use the earth magnetic field to distinguish e+ from e- !





- Pure e+ region in the West and pure e- region in the East
- Regions vary with particle energy and spacecraft position
- To determine regions, use code by Smart and Shea, which numerically calculates particle's trajectory in geomagnetic field

We find that the positron fraction increases with energy between 20 and 200 GeV, consistent with results reported by PAMELA.



Fermi LAT Collaboration, PRL 108, 011103 (2012)

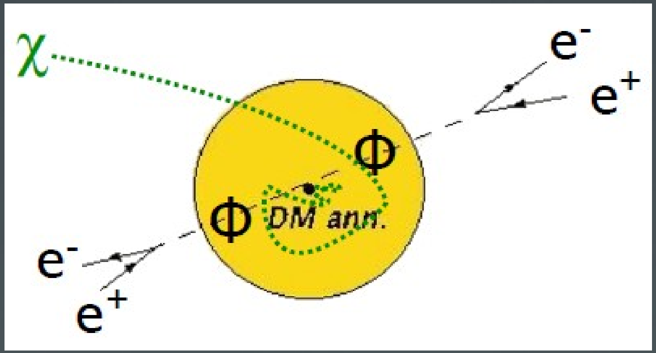
Fermi Dark Matter Limits from the Sun

- In the last decades the searches for a dark matter (DM) signal from the Sun were performed looking for possible excesses of neutrinos or gamma rays associated with the Sun's direction.

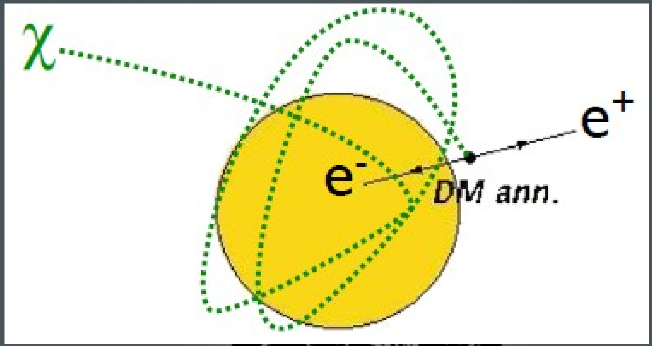
- Several DM models that have been recently developed to explain various experimental results also imply an associated solar flux of high-energy cosmic-ray electrons and positrons (CREs).

- In particular, Schuster, Toro, Weiner, Yavin 2010 discuss 2 scenarios in which DM annihilation leads to cosmic-ray electron and positron (CRE) fluxes from the Sun :

  - **Intermediate state scenario :** Dark matter annihilates in the center of the Sun into an intermediate state Φ which then decays to CREs outside the surface of the Sun



  - **iDM scenario :** Inelastic dark matter (iDM) captured by the Sun remains on large orbits, then annihilates directly to CREs outside the surface of the Sun



As no known astrophysical mechanisms are expected to generate a significant high-energy CRE (> 100 GeV) from the Sun we searched for a CRE flux excess correlated with the direction of the Sun to constrain these DM models

Constraints on Inelastic DM from Fermi UL on CRE from the Sun

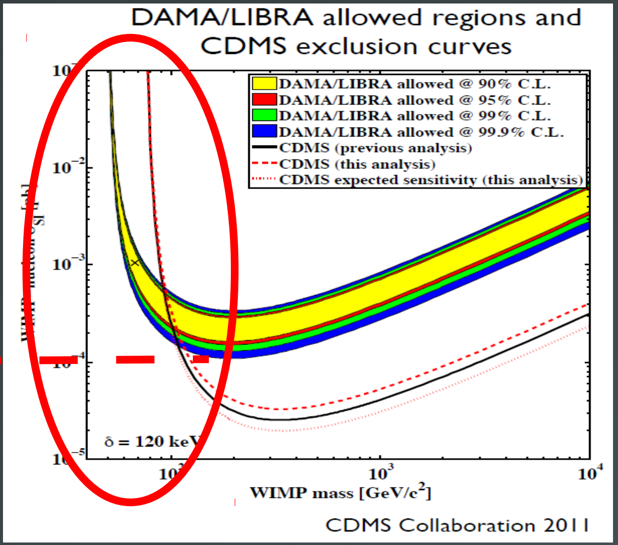
Parameter space compatible with DAMA/ LIBRA and CDMS

⇓

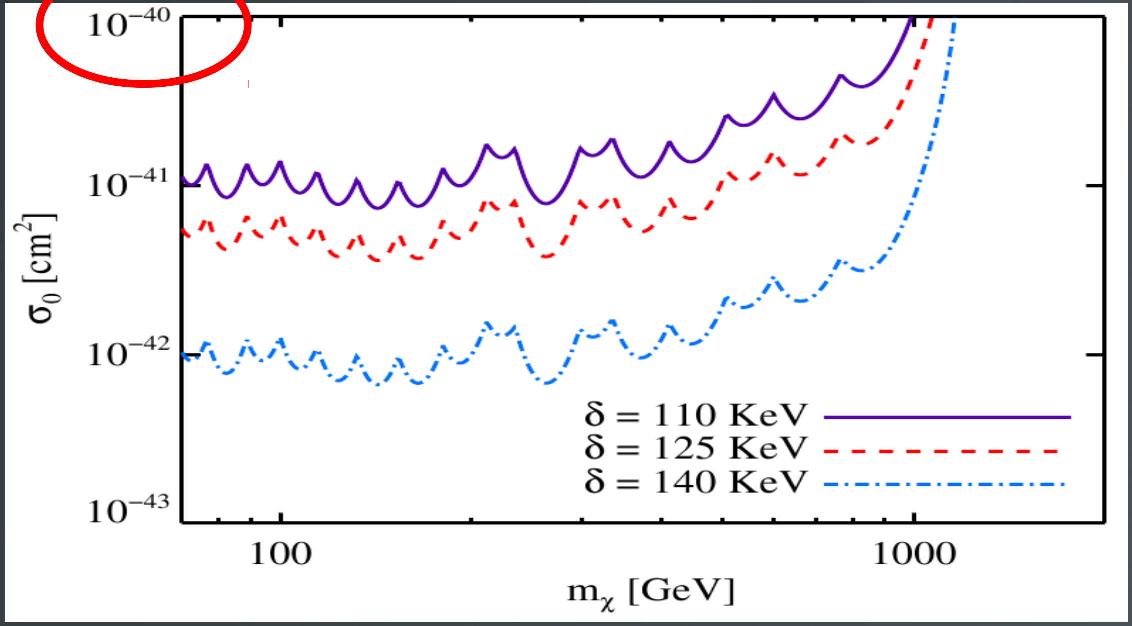
$m_\chi \lesssim 100$ GeV

$\sigma_{SI} \sim 10^{-39} - 10^{-40}$ cm^2

10^{-40} cm^2



Inelastic dark matter (iDM) models could naturally explain such observations as the 511 keV line observed by INTEGRAL/SPI and the apparently inconsistent results of DAMA/LIBRA and CDMS if the DM scattered inelastically and thereby transitioned to an excited state with a slightly heavier mass.



Parameter space above curves excluded at 95% CL for CRE final state

Data selection :

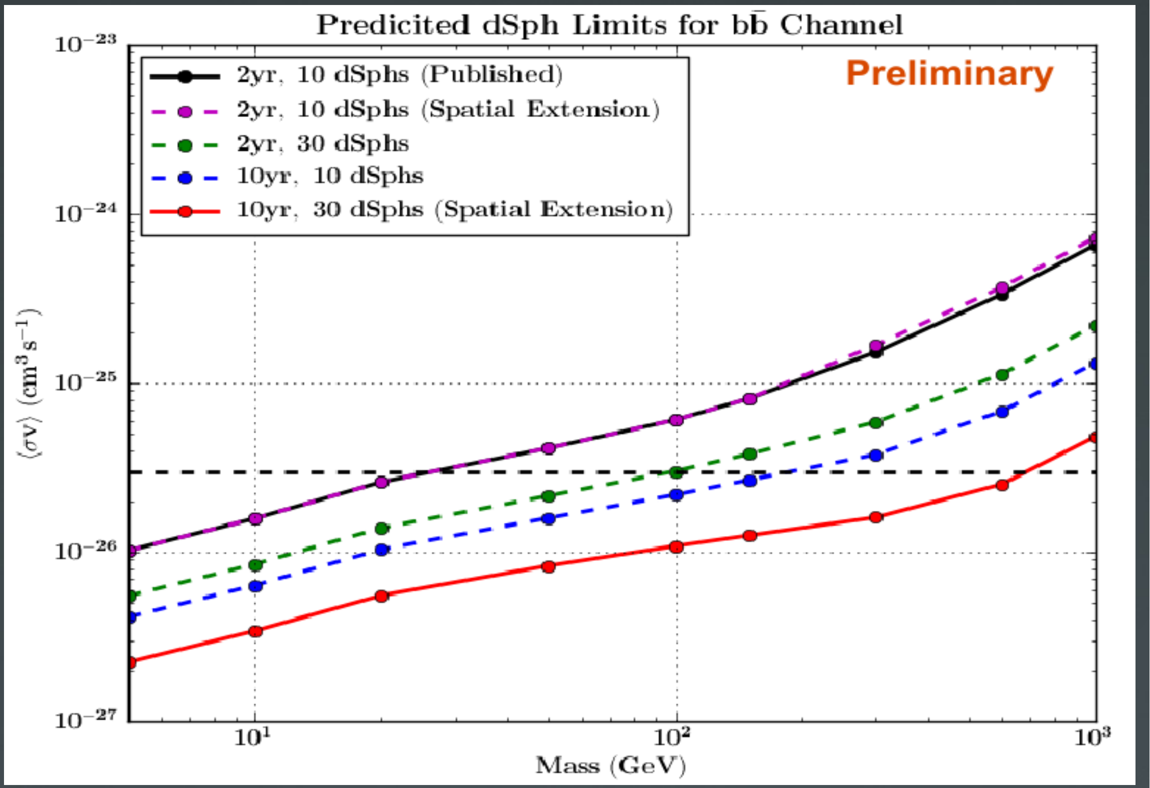
- ~10^6 CRE events (E > 60 GeV), from 1st year of operation
- analysis performed in ecliptic coordinates, in reference frame centered on the Sun

The bounds we derive exclude the relevant cross sections by 1–2 orders of magnitude → The parameter space of models preferred by DAMA/LIBRA can be ruled out for m >70 GeV for annihilation to e+e-

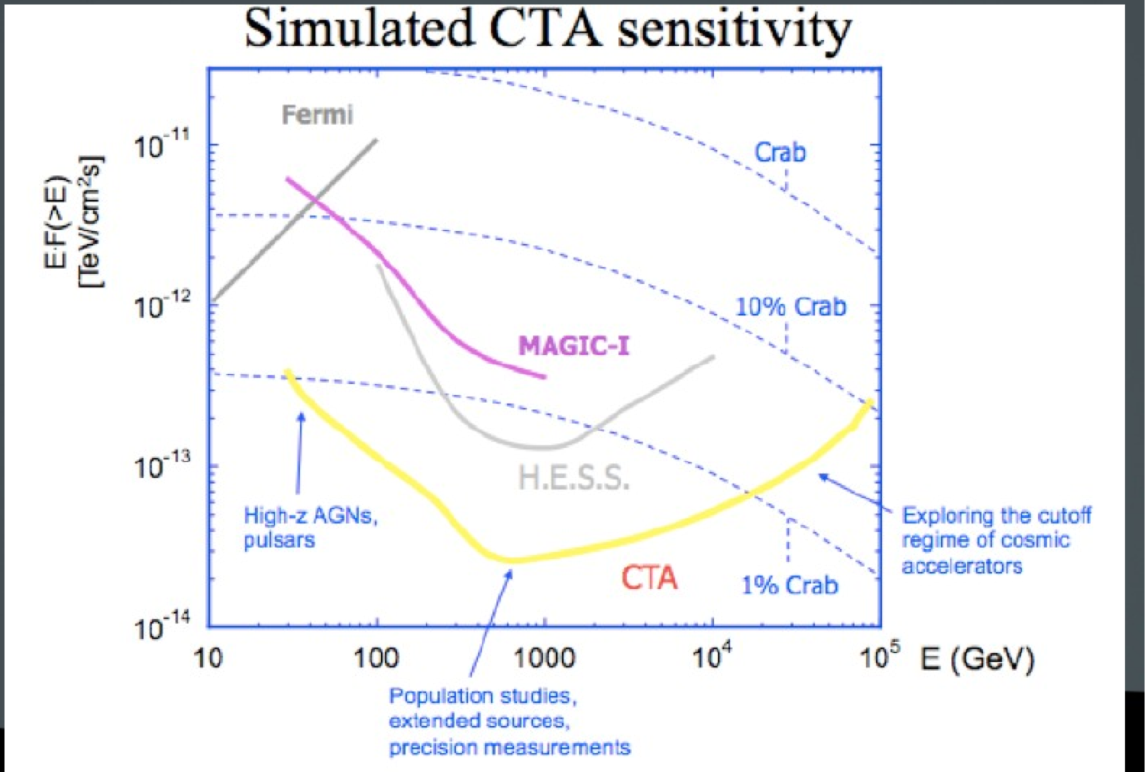
Fermi LAT Collaboration, Phys. Rev. D 84, 032007 (2011)

Examples of future prospects

- Future dwarf spheroidal limits :
  – Increased observation time
  – Discoveries of new dwarfs
  – Gains at high energy



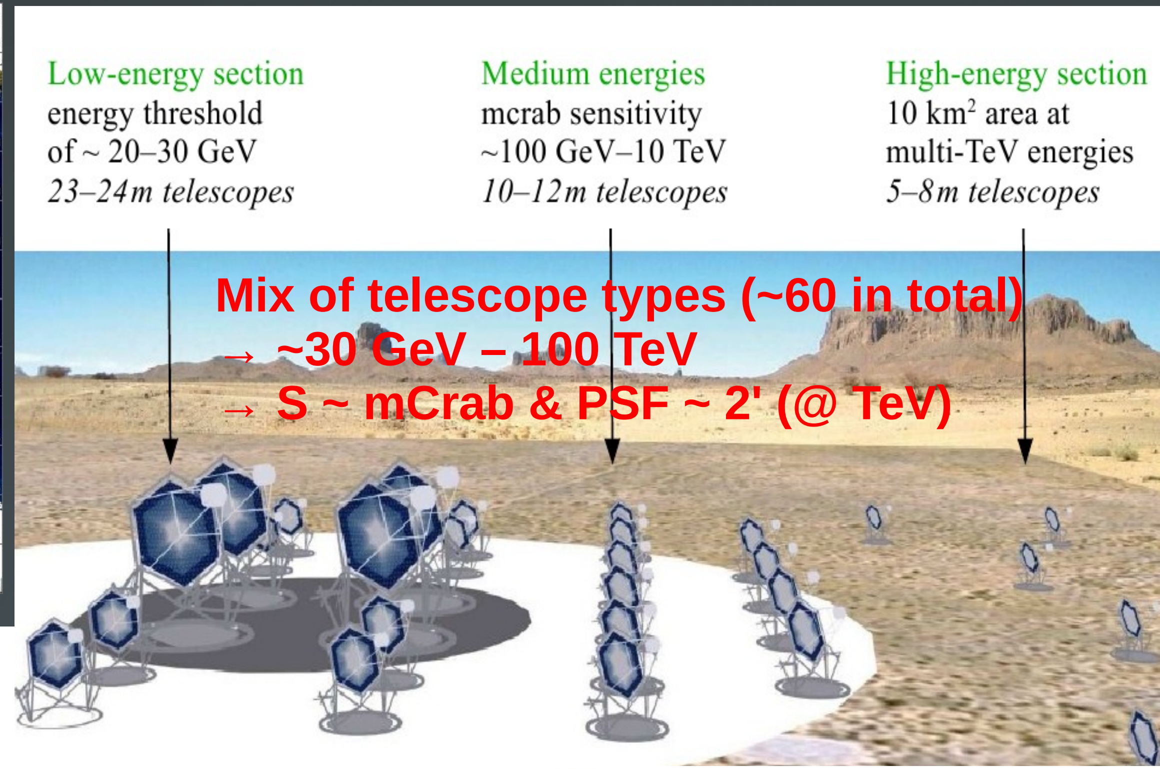
- Complementarity with next generation of IACTs : Cherenkov Telescope Array (CTA ~ 2014)
  Mix of telescope types (~60 in total)
  ~30 GeV – 100 TeV
  S ~ mCrab & PSF ~ 2' (@ TeV)



- Complementarity with
  Direct detection and
  Accelerator
  experiments is very exciting.

Next generation of IACTs: Cherenkov Telescope Array (CTA ~ 2014)

Selection of sites by 2012, 10 km2 flat area, 1.5-4.0 km altitude, minimum cloud cover, easiest access, ...



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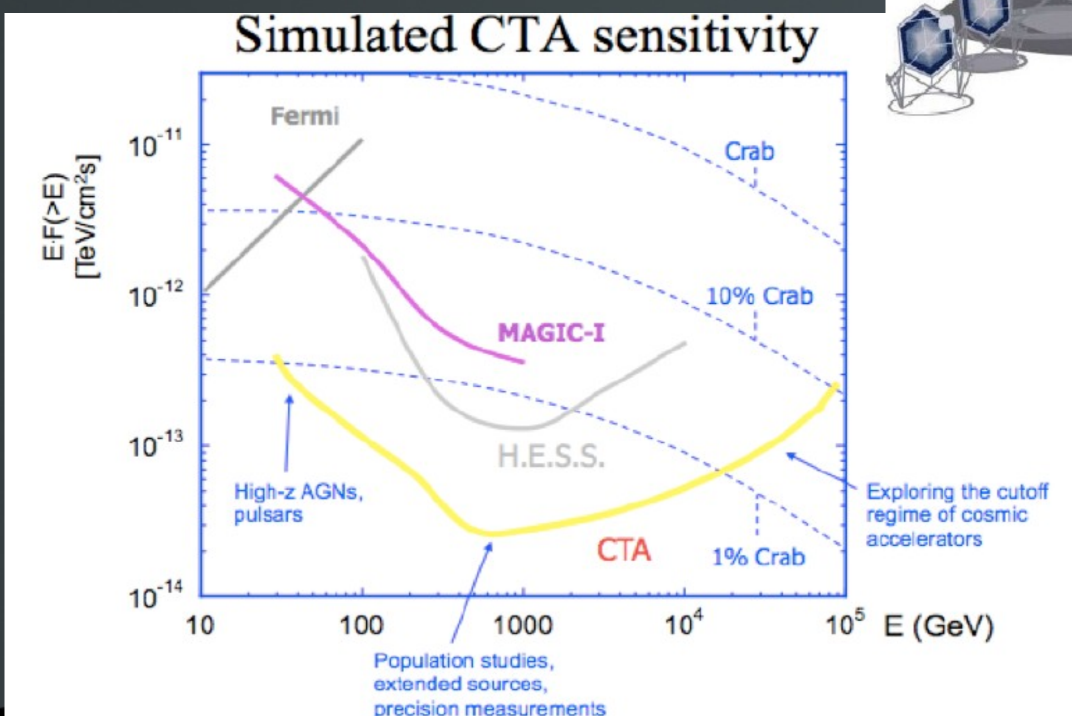
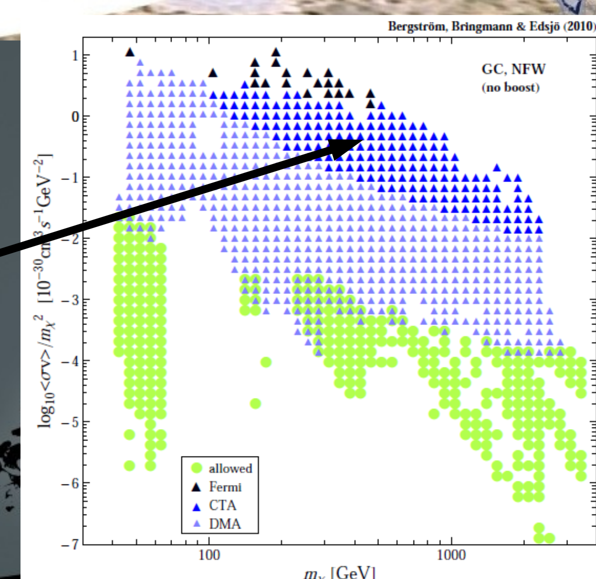


Projected CTA sensitivity for dark matter searches



The CTA project

Higher sensitivity	→ 1000 sources? Pop. studies	~mCrab, 5σ, 50h @ TeV
Wider energy coverage	Spectr(o-imaging)al parameters	30 GeV – 300 TeV
Better angular resolution	Source identification & morphology	~2 arcmin @ TeV
Better energy resolution	Cutoffs & spectral features	rms < 10% @ TeV
Wider field-of-view	Extended sources & survey	6 – 8 degrees

A ~200 M€ International Project
>700 scientists & engineers in >100 institutes in 25 countries
Design 2008–11, Prototyping 2011–13, Construction 2013–18

CTA as an Open Observatory

« Design Concepts for CTA » arXiv:1008.3703

EU funded 5.2 M€
Preparatory Phase 10/2010–10/2013

Summary and Conclusions

- Fermi is working very well and carrying out a wide variety of astrophysical measurements improving our understanding of the high energy Universe and the processes that govern it.

Many exciting results and some unexpected discoveries !

- New window for indirect searches for DM have been opened and we explore many complementary searches for DM signal. Even if no significant detections have been made, robusts and significant limits on the nature of DM have been placed, starting to probe the interesting region :

Best current Fermi limits below thermal WIMP cross section for m<25GeV
$\langle\sigma v\rangle \approx 3\ 10^{-26}\ cm^3/s$ (dSph's stacking)

- Our knowledge of the astrophysical background have been improved but an even better understanding of the background is essential. In addition to accumulation of data, it will allow us to improve constrains on DM models.

- IACTs are all upgrading their instruments which will increase the overlap with Fermi-LAT.

Hopefully more exciting results to come !