Selected topics in

High Energy Astrophysics

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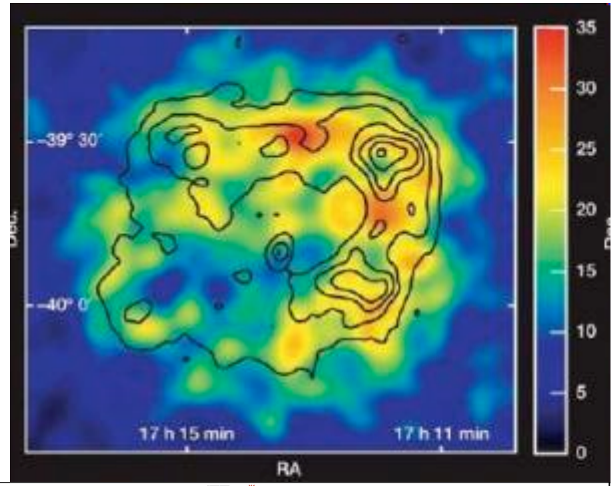
- The gamma-cosmic ray connection
- Dark Matter
- γ propagation (new particles, cosmology)
- Testing fundamental symmetries

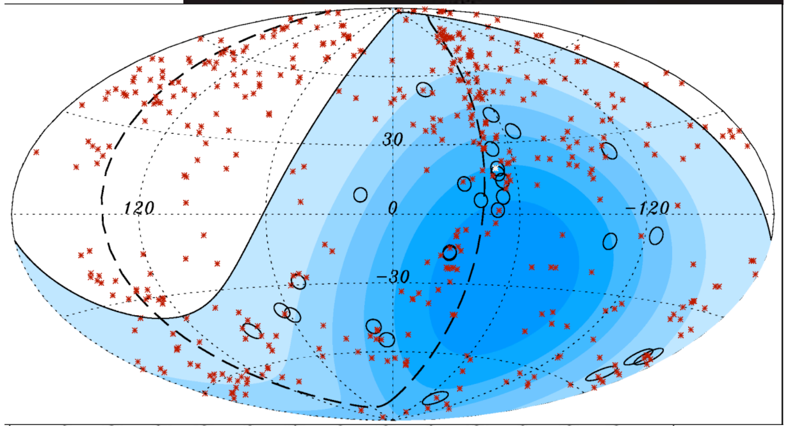
Each topic would be worth a seminar of 1 hour or so…
I am neglecting several subjects like status of detectors…
I am neglecting the most “astronomical” subjects…

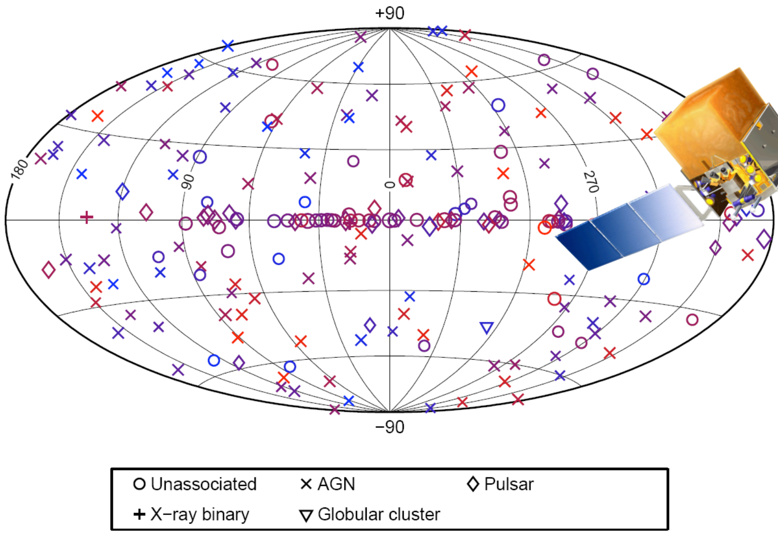
Thanks to S. Casanova, L. Latronico, A. Morselli, M. Persic, …

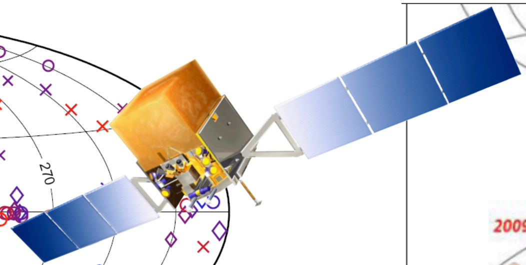
Highlights of the recent years

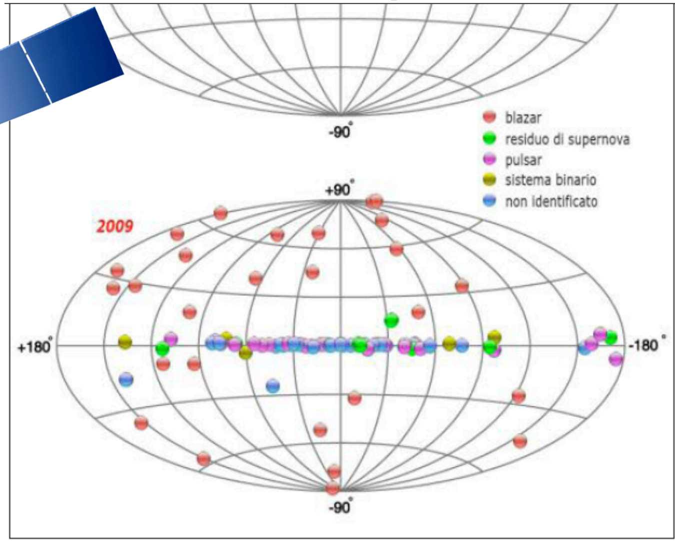
- Imaging of VHE (< 100 GeV) galactic sources (H.E.S.S., MAGIC) and discovery of many new galactic (H.E.S.S., MAGIC) and extragalactic (MAGIC, H.E.S.S.) sources: > 100 papers
  - Correlation of nearby galaxies with UHE CR (Auger)
    - The Pamela excess
- Huge results from Fermi year 1 (about 40 papers published/accepted/submitted, and about 20 in advanced status)
  - Best ever image of the Universe above 100 MeV, and a better one is coming in ~1 month



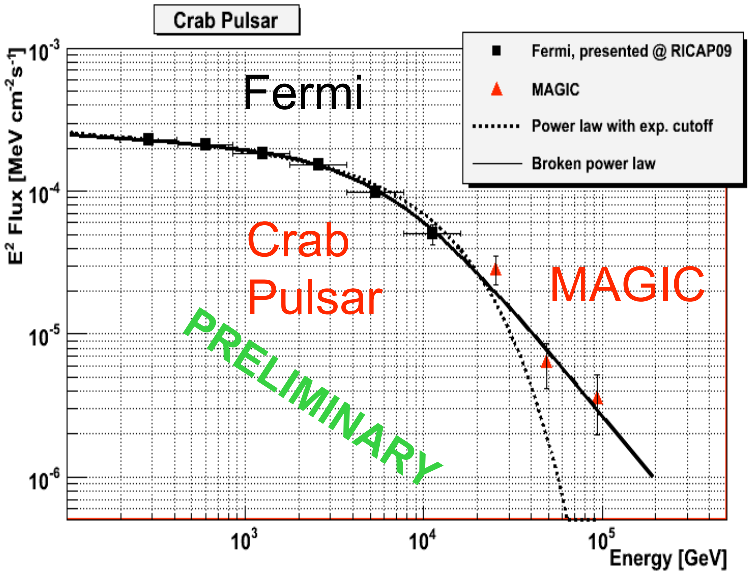


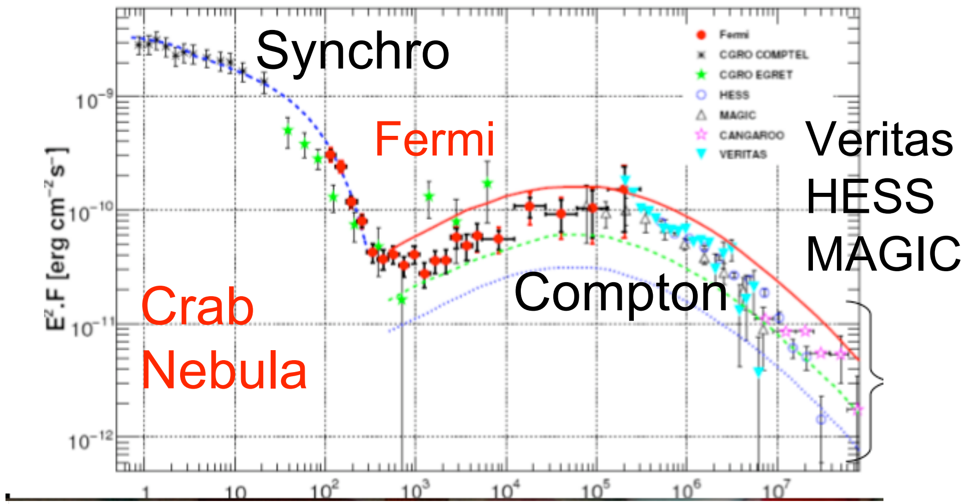


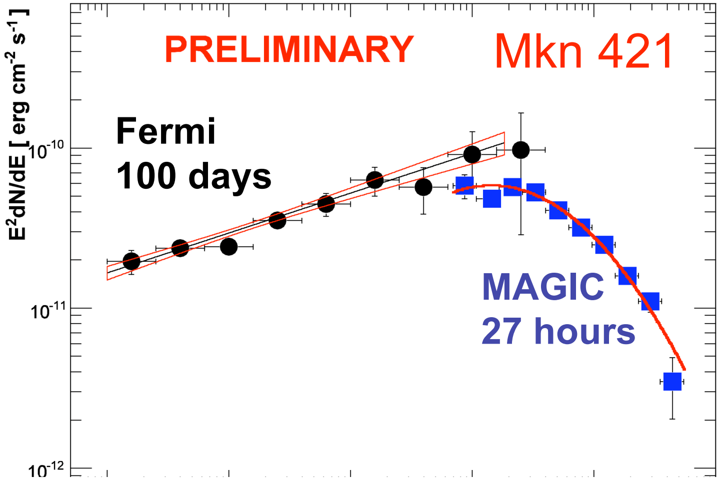


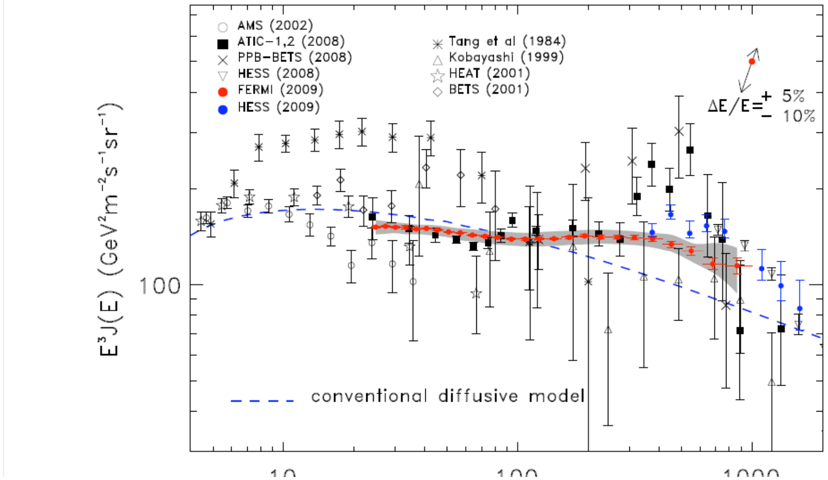


Gamma detectors are complementary (X-cal, X-checks) and complement e^-/e^+ detection





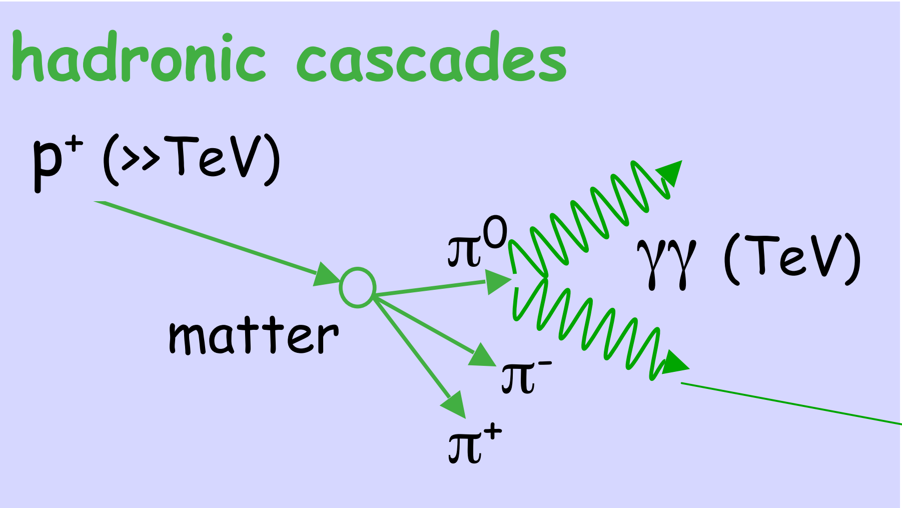


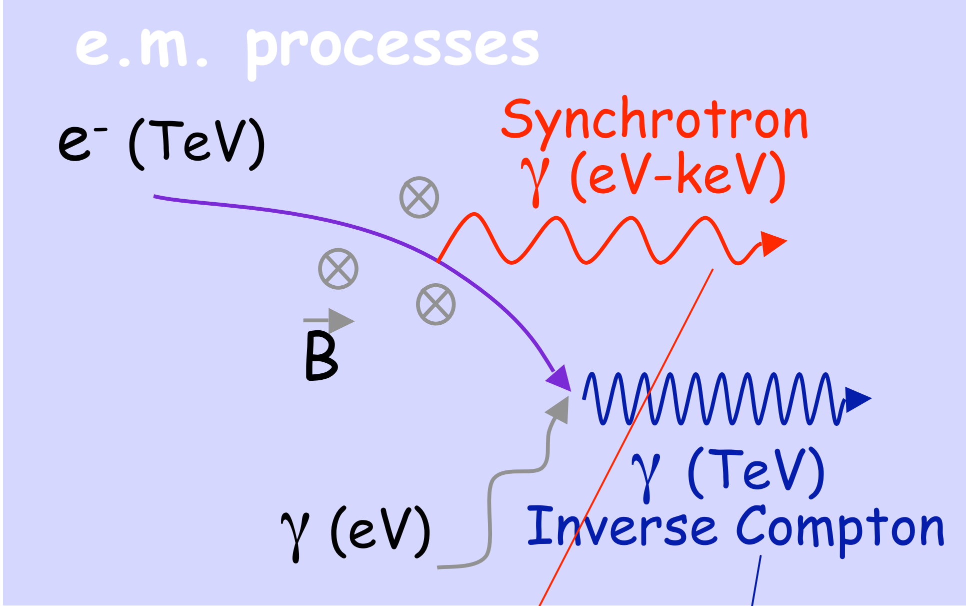


E annoi dell'ienneeffeenne, checcefrega?

Origin of γ rays

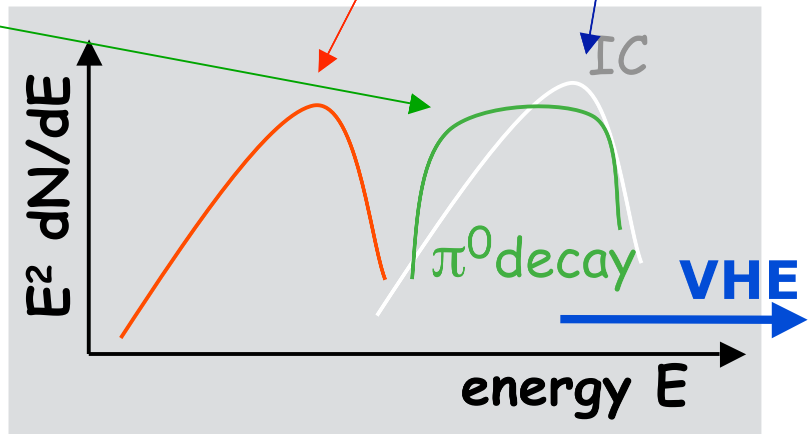
From non thermal extreme dynamic processes:



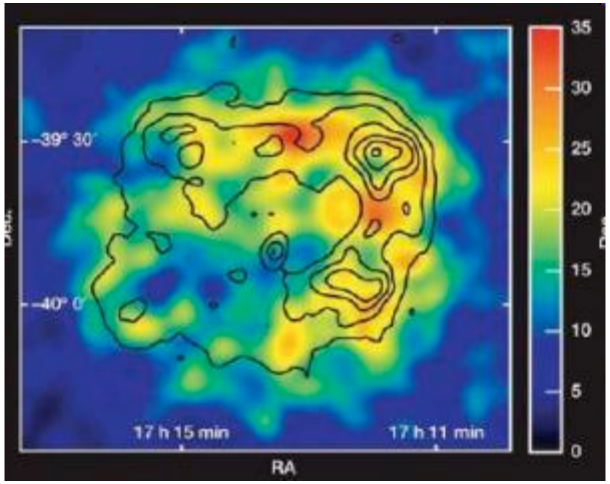


In the VHE region,
$dN/dE \sim E^{-\Gamma}$ (Γ: spectral index)

To distinguish between had/leptonic origin study Spectral Energy Distribution (SED):
(differential flux) · E^2



Evidence for the emission of VHE hadrons by SNR



- Existence of possible mechanisms
  - Consistent w/ energetics
- Morphology
  - Several regions /SSC
  - Statistics of PWN
  - Power law consistent with powering by protons with $\Gamma \sim 2$
- Up to 100 TeV $\rightarrow$ CR at O(1 PeV)

Standard Model of galactic Cosmic Rays

- Galaxy is Leaky Box
  - Energy Dependent Escape of CR from the Galaxy
  - CR source spectra must be $dN/dE = E^{-2.1 \text{ to } -2.4}$ to match $E^{-2.7}$ CR spectrum measured at Earth
- Supernova Remnants accelerate cosmic rays
  - Acceleration of CR in shock produced with external medium that lasts ~1000 years
  - SN rate of 1/30 years means ~30 SNR are needed to maintain cosmic ray flux
  - Gamma fluxes consistent with an energetics of 10^{53} erg -> OK for the detection of galactic neutrinos
  - SN must convert few % of energy of the ejecta into CR
- Model explains most observations, and is consistent with many details

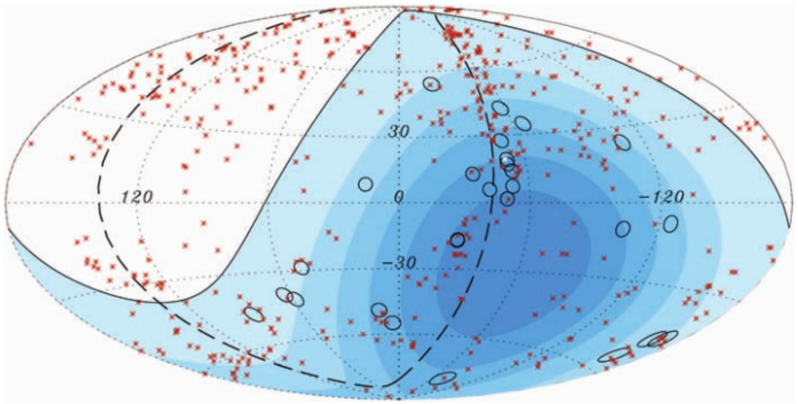
Galactic Gamma Rays

- Localized Sources - Study of target-accelerator systems :Origin of Galactic cosmic rays : pinpointing sources of cosmic rays up to the knee
  - New “fresh” cosmic rays interacting with matter near the source OR electrons up-scattering synchrotron, optical, IR, or CMB photons
  - Sources include
    - Pulsars (up to ~10 GeV)
    - Pulsar Wind Nebulae
    - Supernova Remnants
    - X-ray Binaries
    - Dark Accelerators (gamma-ray sources without counterparts)

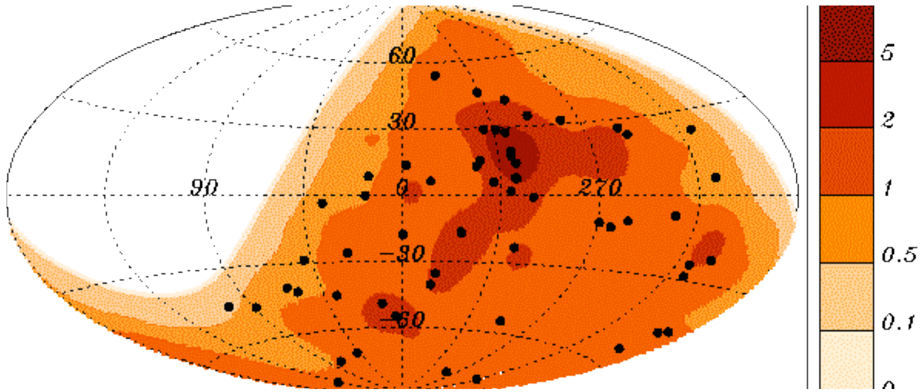
- Diffuse Emission - Study of CR propagation
  - CR “sea” of cosmic rays interacting far from their source OR electrons upscattering photons

Evidence for the emission of EHE hadrons by AGN

- The “direct” measurement by AUGER (E > 60 EeV)



27 events as of November 2007



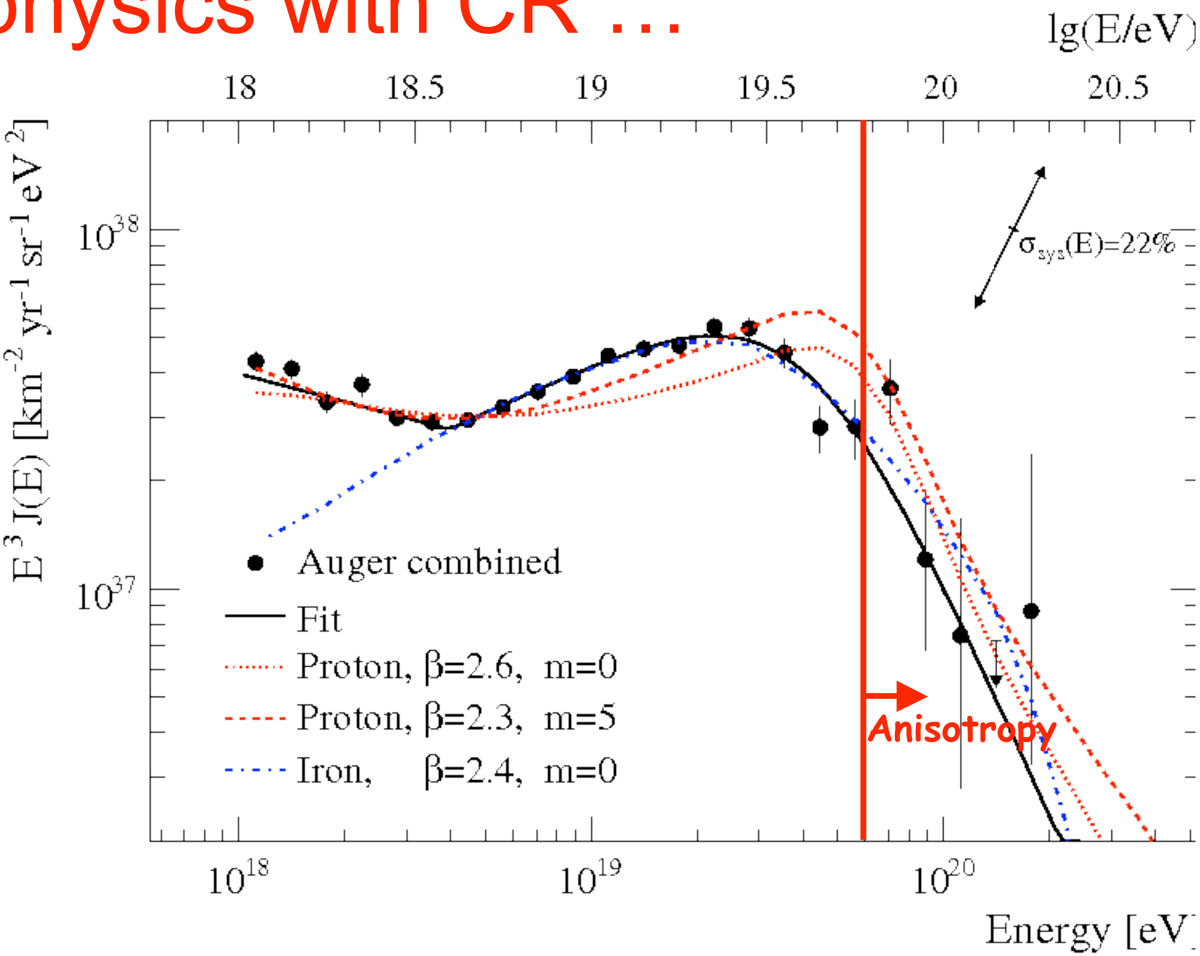
58 events now (with Swift-BAT AGN density map)

- Orphan flares in TeV band (?)
- The production region of gammas from flares in M87 is very close to the BH, where there is abundance of protons
  - If SNRs O(10 SM) can explain CR at O(1 PeV), BH O(10^9 SM) are likely to explain CR up to O(10^{23} eV)

However, one should be careful about astrophysics with CR …

- Auger observations confirm the GZK cutoff

- Role of magnetic fields
  - Galactic astrophysics impossible (B_{MW}~1μG)
  - Extragalactic astrophysics very difficult:



Angular spread observed by Auger ⟶ B ~ 0.5 nG

$$\theta \simeq 0.25^\circ \left(\frac{d}{\lambda}\right)^{1/2} \left(\frac{\lambda}{1\,\mathrm{Mpc}}\right) \left(\frac{\mathrm{B}}{1\,\mathrm{nG}}\right) \left(\frac{10^{20}\,\mathrm{eV}}{E}\right)$$

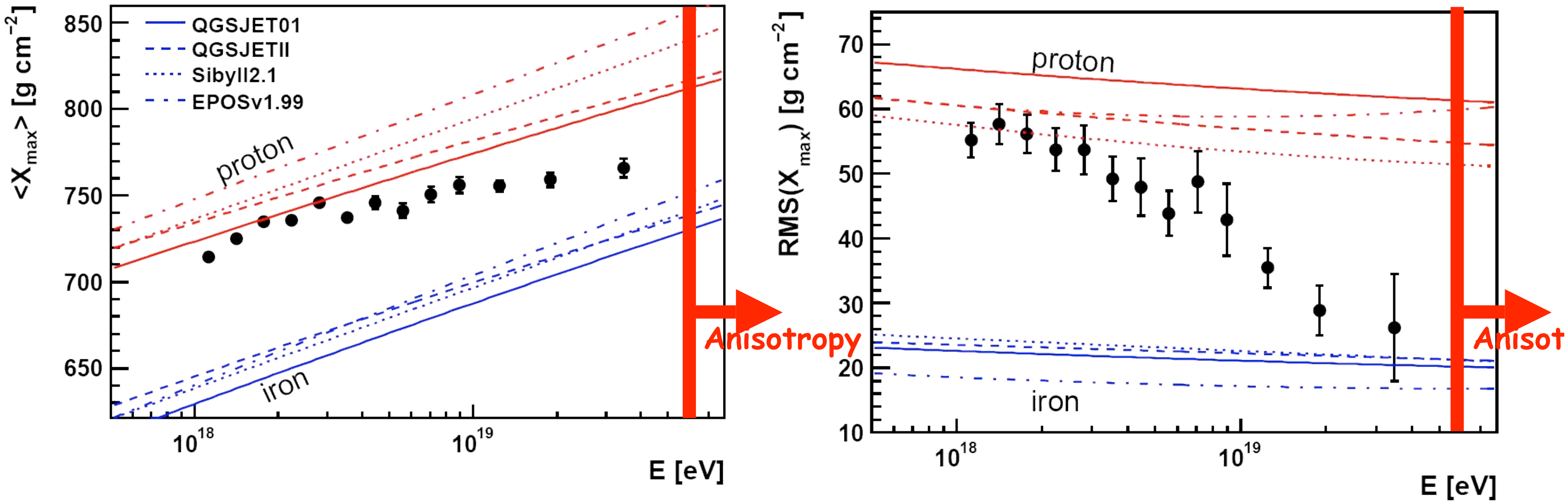
Is 1 cubic kilometer enough for neutrino astronomy?

- If one takes all events compatible with Cen A as coming from Cen A itself (14 Mly, 5 10^7 SM), one could make some modeling to estimate the expected number of neutrinos on a km^2
- …and compare it with the probability to observe it at a gamma detector (flux from Fermi & limits from IACT)

- Theoretical input needed, experimental data are there…Probably a task force should study the problem
  - However, transients are not affected

Auger: Shower Depths of Maximum X_{max}

Bellido, HE 0124



These suggest high cross section and high multiplicity at high energy.

Heavy nuclei?

Or protons interacting differently than expected?

Information lacking for the (anisotropic) trans-GZK energy regime!

What we are learning on CR (great results in the recent years…)

- Thanks to the works of IACTs and Fermi, the mechanism of generation of CR up to the knee by SNR (PWN in particular) has found experimental confirmations
  - Still the “smoking gun” is missing, though
- Auger has found experimental confirmation that CRs up to the ankle come from AGN. Consistent indications from IACTs
  - Something interesting about composition, cross sections
- Auger: GZK cutoff, indications on the intergalactic magnetic fields
  - Astronomy with CR will be extremely difficult
- A way to estimate the neutrino flux from AGN starting from the data by Auger and on gamma detectors
- Gamma astrophysics can be an instrument to study the morphology of CR emitters (mostly Galactic, but not only: M87)

Dark Matter

- Possible astrophysical signatures
  - Gamma line (at suspect clumps), if Majorana
  - Gamma continuum (at suspect clumps or diffuse)
    - And after 5 years of Fermi, a clear picture of the diffuse gamma emission will pinpoint possible clumps
  - Excess of antimatter
  - Effects on the transport of gamma/CR

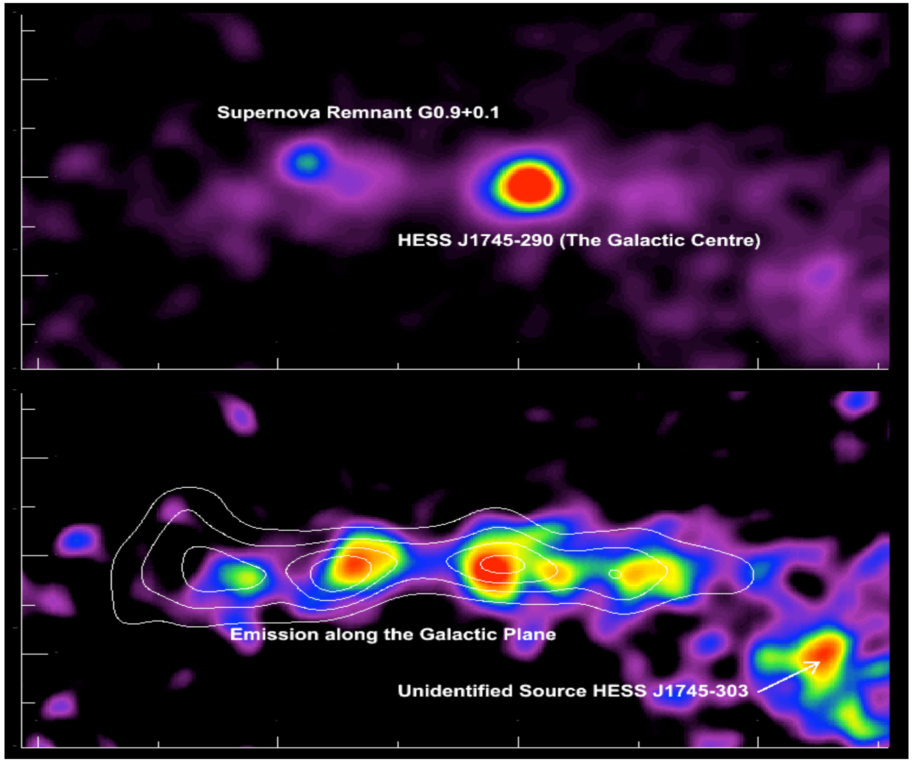
DM search
(Majorana WIMPs)

$$\chi\chi \rightarrow q\bar{q} \rightarrow n \times \gamma$$

$$\chi\chi \rightarrow \gamma\gamma(Z)$$

$$\frac{dN}{dE} = \frac{1}{4\pi} \underbrace{\frac{\langle\sigma v\rangle}{m_{DM}^2} \frac{dN_\gamma}{dE}}_{Particle\ Physics} \times \underbrace{\int_{\Delta\Omega-los} dl(\Omega)\rho_{DM}^2}_{Astrophysics} \times \frac{1}{d^2}$$

Highest DM density candidate:
Galactic Center?
Close by (7.5 kpc)
Not extended



BUT:

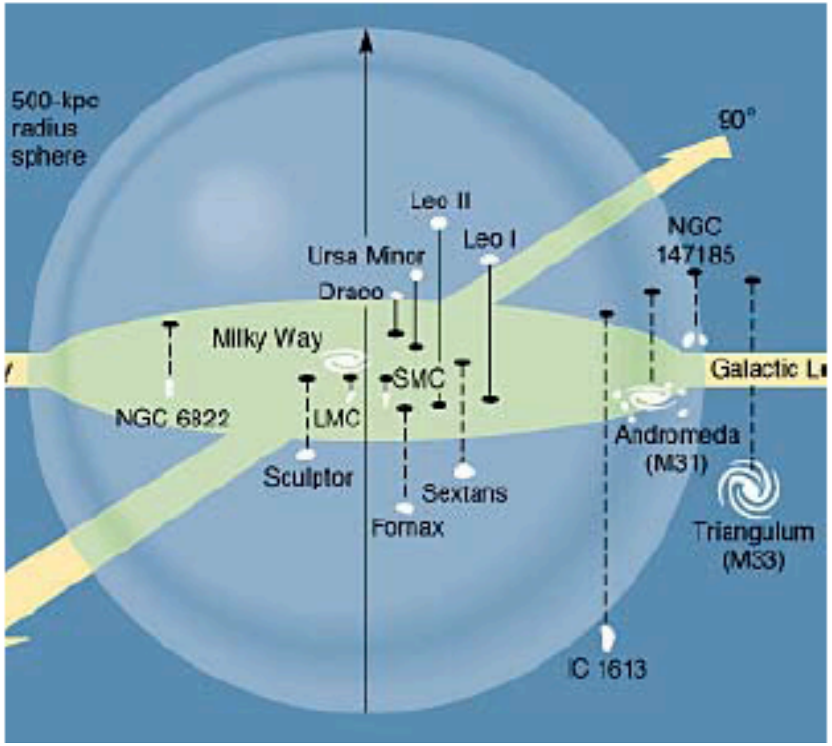
- other γ-ray sources in the FoV
=> competing plausible scenarios
- halo core radius: extended vs point-like

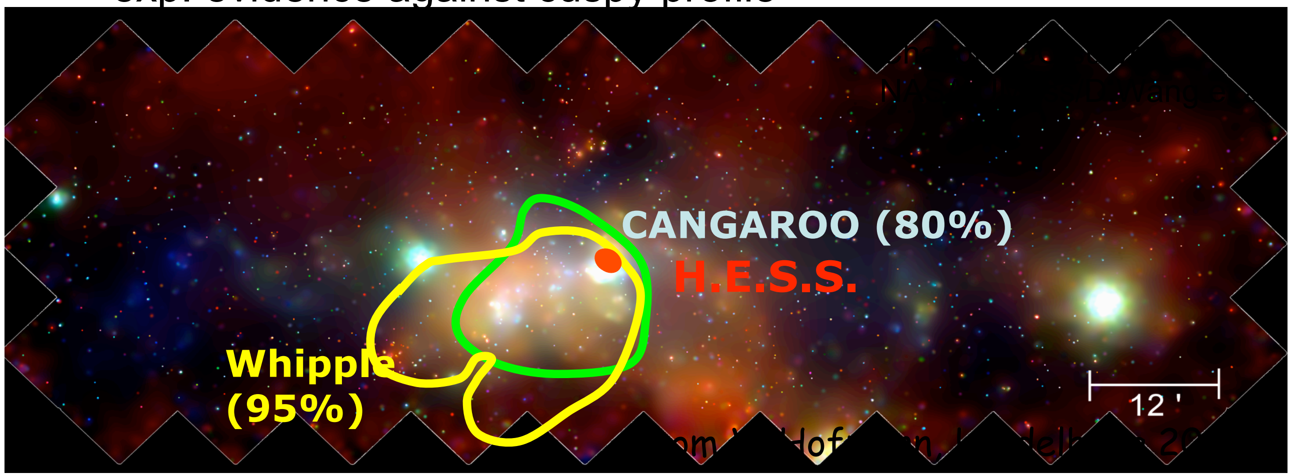
γ-ray detection from the Galactic Center

…and satellite galaxies

- detection of γ-rays from GC by Cangaroo
  Whipple, HESS, MAGIC
- σ_{source} < 3' (< 7 pc at GC)
  - hard $E^{-2.21\pm0.09}$ spectrum
    fit to χ-annihilation continuum
    spectrum leads to: M_χ > 14 TeV
  - other interpretations possible (probab

Galactic Center: very crowded sky region, stron
exp. evidence against cuspy profile





Milky Way satellites
Sagittarius, Draco, Segue, Willman1, Perseus, …

- proximity (< 100 kpc)
- low baryonic content, no central BH (which may change the DM cusp)
- large M/L ratio
- No signal for now…

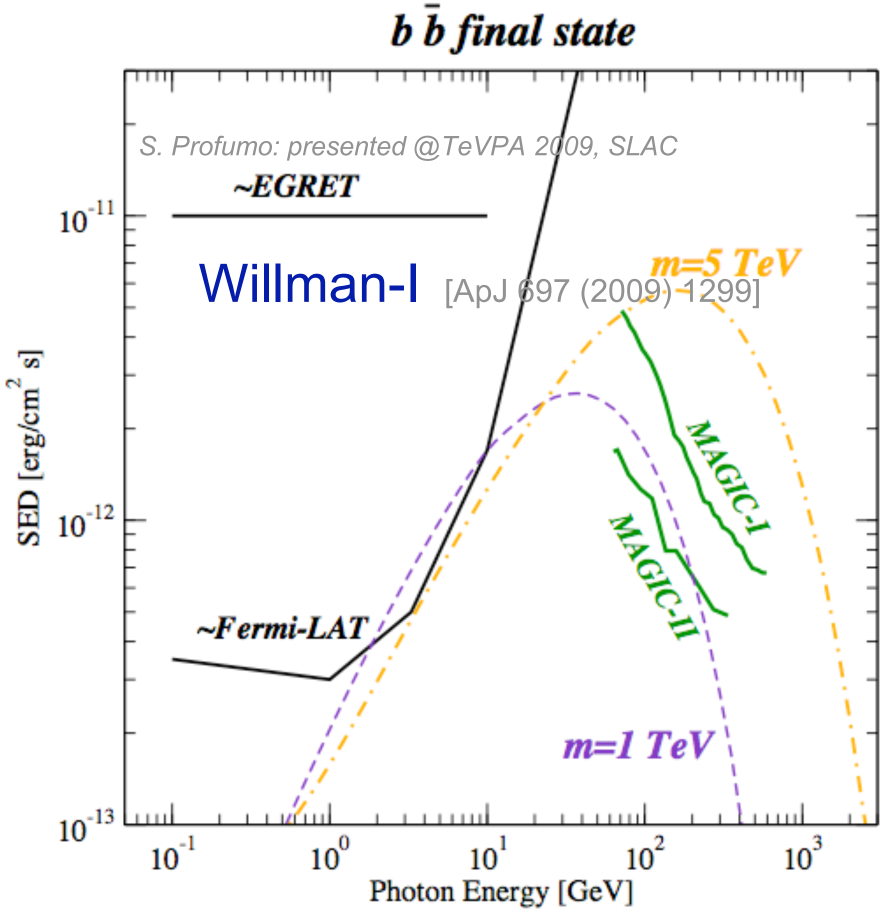
γ ray detection from satellite galaxies

- Cherenkov telescopes play a unique role in identifying DM:

 at **m~1 TeV**, comparable sensitivities for Fermi vs IACTs

 at **m~5 TeV**, IACTs can outperform Fermi

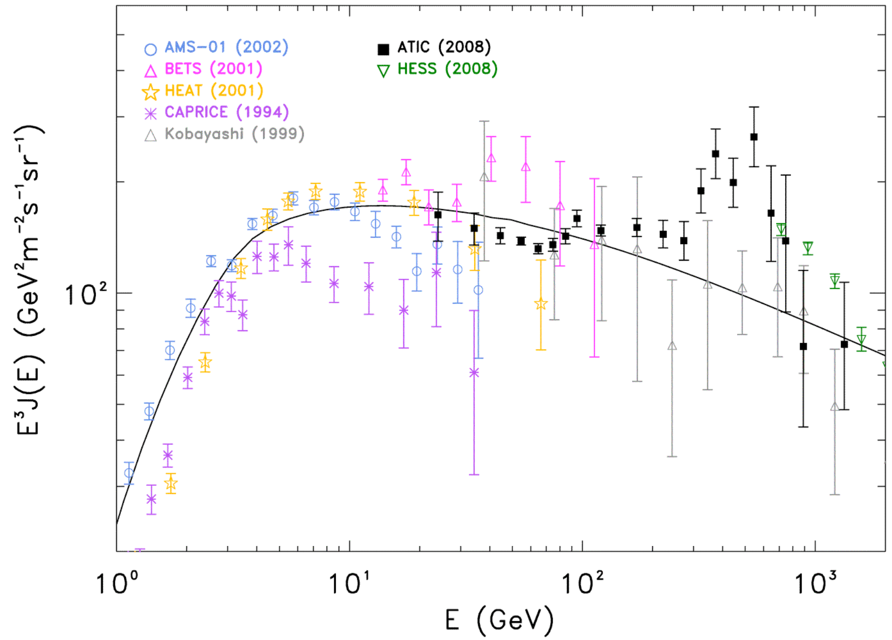
- potential for discovery even in the Fermi era!

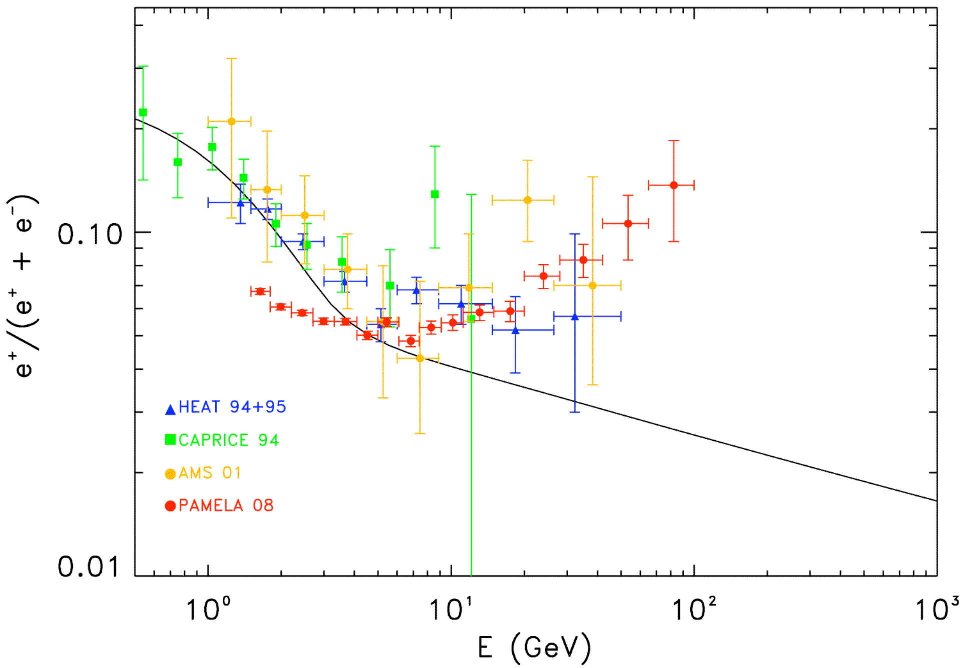


other possible targets:
Intermediate Mass Black Holes, clusters of galaxies

[Perseus: arXiv: 0909.3267]

Unpointed measurements in 2008



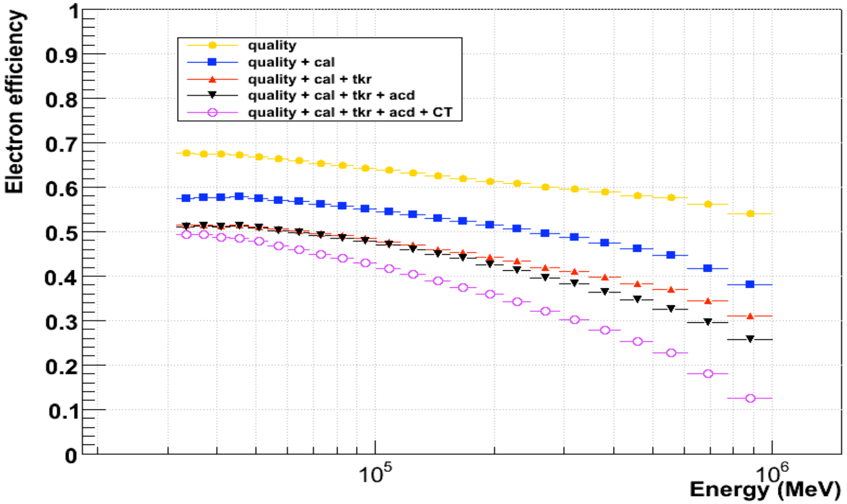


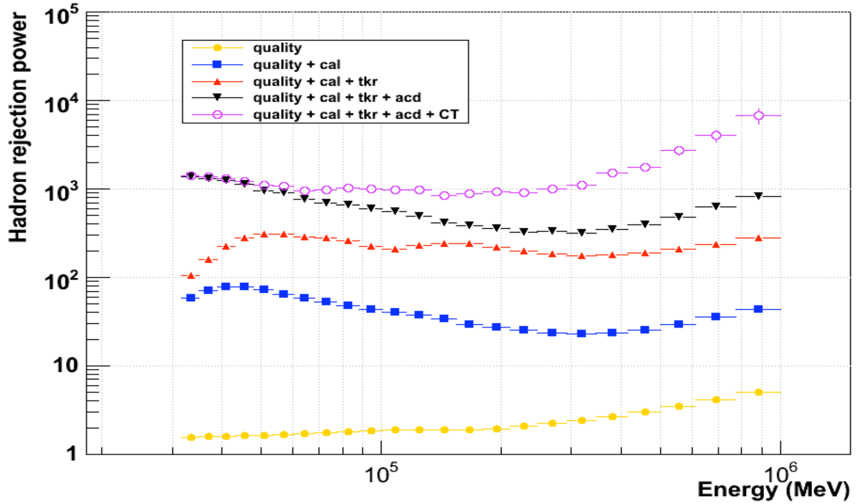
- Spectral features in the $(e^+ + e^-)$ spectrum
  - possible excess around 600 GeV reported by ATIC
  - spectral cutoff measured by H.E.S.S. around 1 TeV
- Pamela reports an increase in the positron fraction

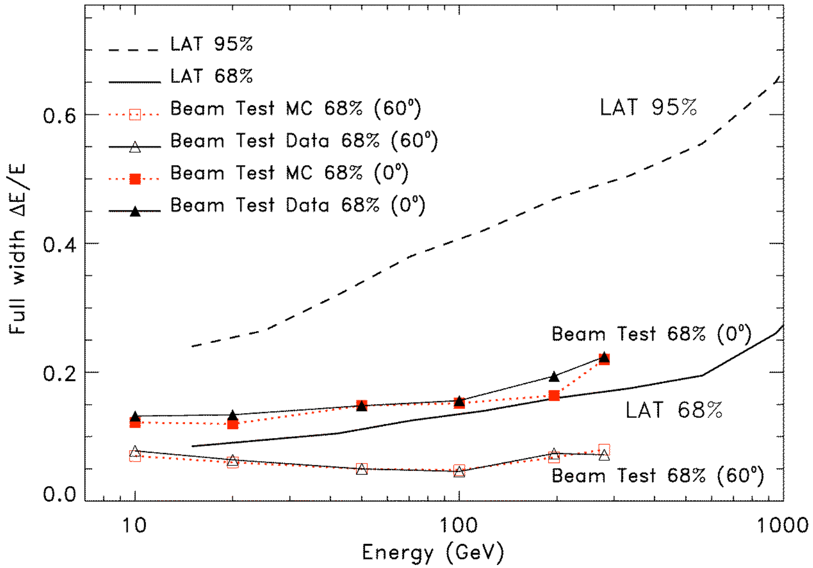
- More than 200 papers in the last year
- Local source of electrons – astrophysical? Dark Matter?

Astrophysics ⟷ High Energy Physics

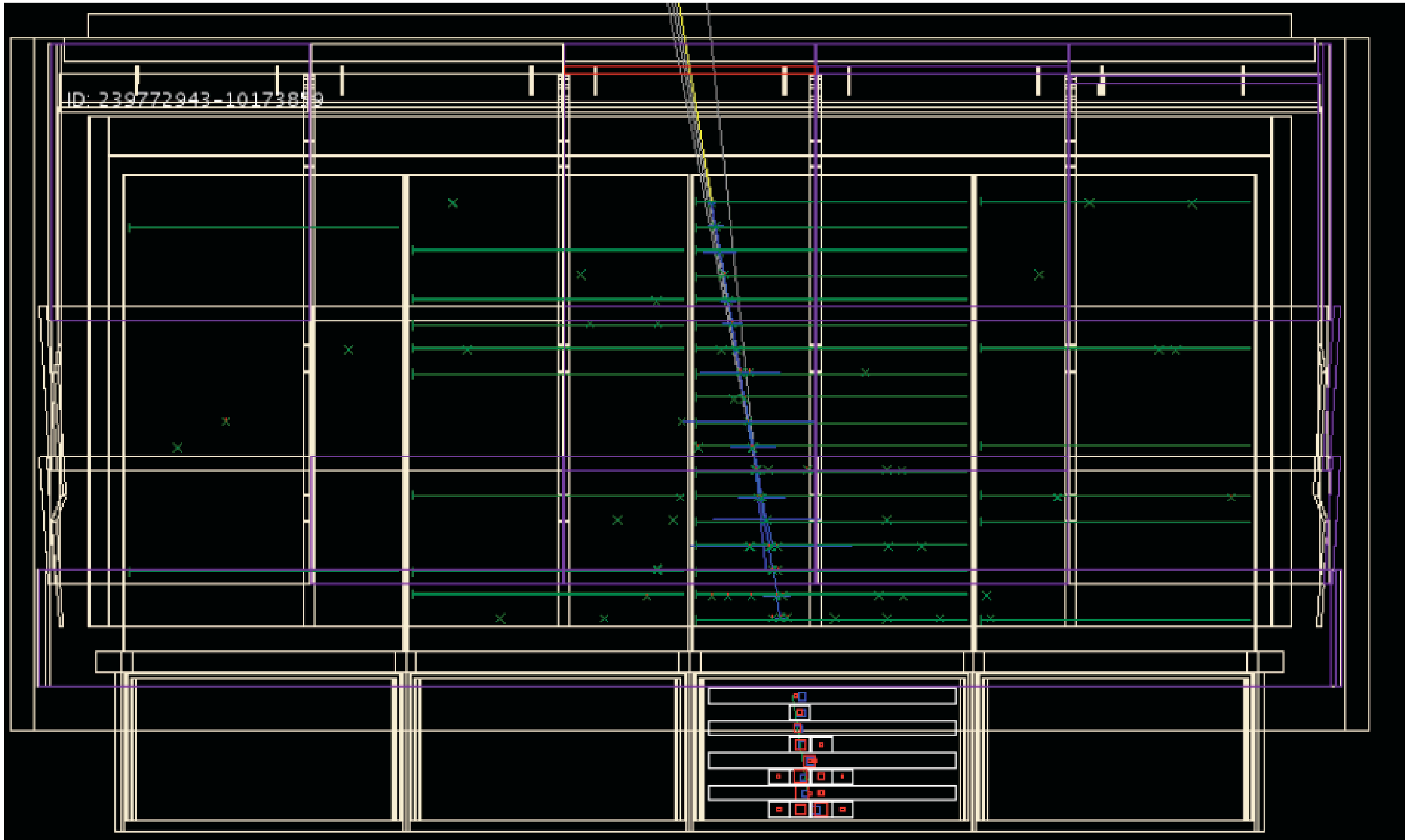
Fermi LAT electron performance







- Performance is a trade-off among:
  - electron-acceptance – hadron contamination - systematics
- Geometry factor
  - ~ 3 m^2sr (50 GeV) to ~ 1 m^2sr (1 TeV)
  - > 10x wrt previous experiments
- Rejection power: ~ $1:10^3$ (20 GeV) to ~ $1:10^4$ (1 TeV)
- Maximum residual contamination ~ 20% (1 TeV)
- Maximum systematic uncertainty ~ 20% (1 TeV)



A candidate electron – 844 GeV

CalEnergyRaw
2.501e+05

CTBBestEnergy
8.443e+05

CTBBestEnergyProb
0.531

TkrNumTracks
5

CalCsIRLn
8.49

CTBBestZDir
-0.986

CTBTKRHEEProb
0.924

CTBCALHEEProb
0.733

CalLRmsAsym
0.0656

CalTrSizeTkrT95
9.73

CalTransRms
23.8

Tkr1CoreHC
29

Tkr1Hits
35

Tkr1ToTTrAve
5.40

AcdTotalEnergy
8.99

AcdTileCount
20

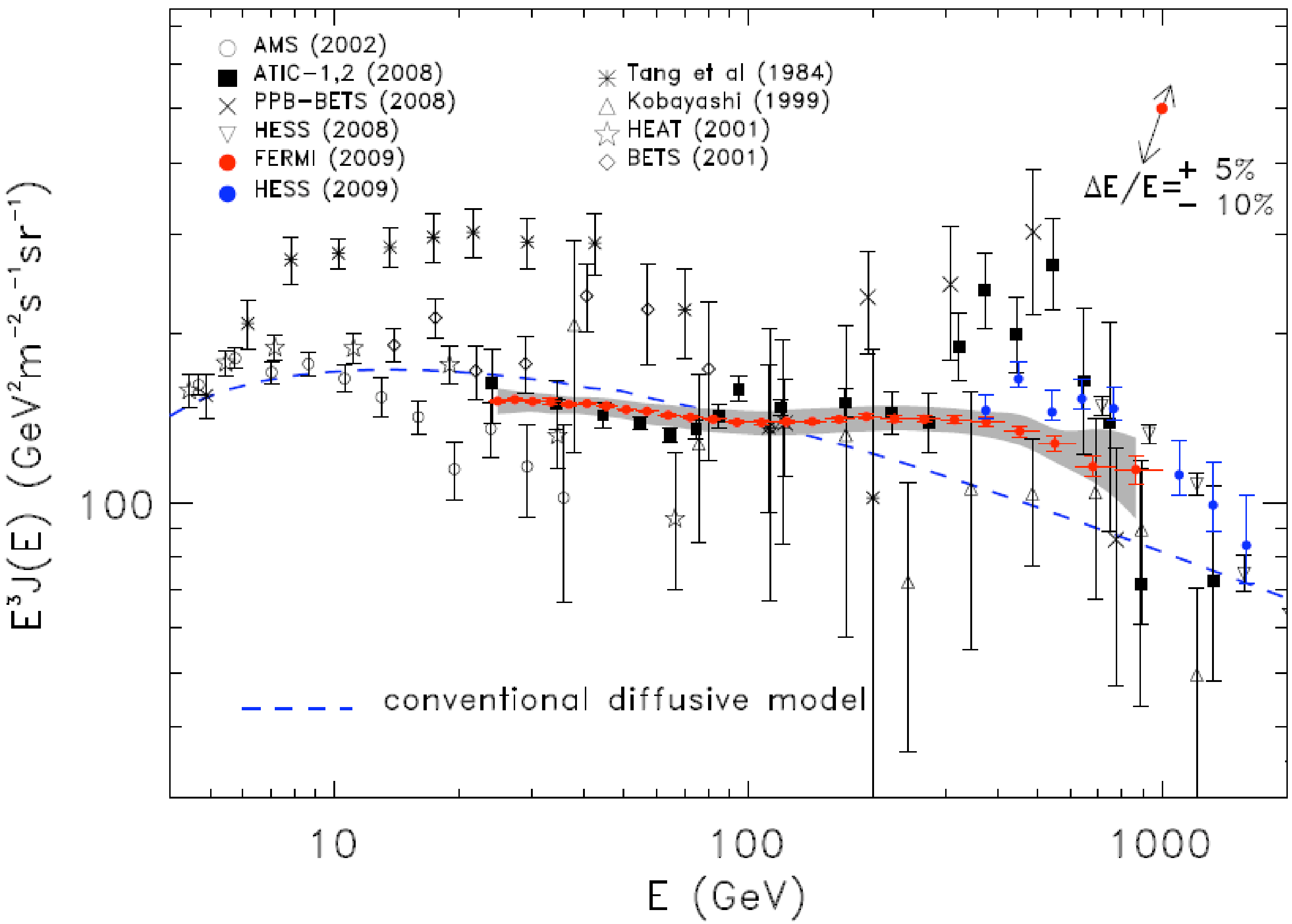
- ACD: few hits in conjunction with track
- TKR: single clean track, extra clusters around main track clusters (preshower)
- CAL: clean EM shower not fully contained in CAL

PRL **102,** 181101 (2009)

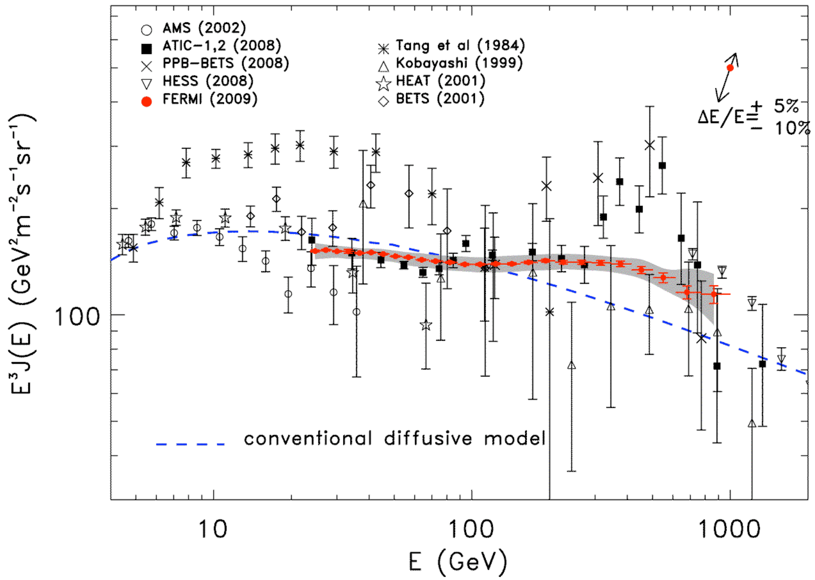
Selected for a Viewpoint in *Physics*
PHYSICAL REVIEW LETTERS

week ending
8 MAY 2009

Measurement of the Cosmic Ray $e^+ + e^-$ Spectrum from 20 GeV to 1 TeV with the Fermi Large Area Telescope



The Fermi-LAT CRE Spectrum



Energy (GeV)	GF (m^2sr)	Residual contamination	Counts
...	...	...	...
291–346	2.04	0.18	7207
346–415	1.88	0.18	4843
415–503	1.73	0.19	3036
503–615	1.54	0.20	1839
615–772	1.26	0.21	1039
772–1000	0.88	0.21	544

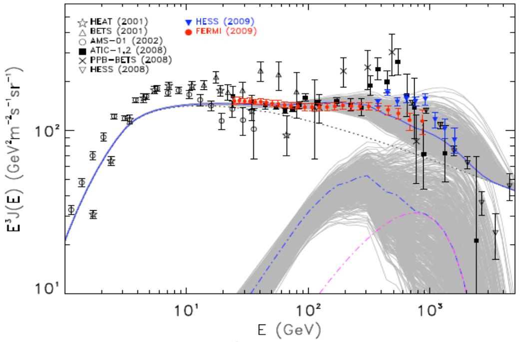
More than 400 electrons in the last energy bin 772-1000 GeV

- High statistics 4.5M events in 6 months
  - systematics dominate but small wrt existing literature
- No evidence of the dramatic ATIC spectral feature
  - Conservative statistical+systematic error allow good fit with a simple power law

Some possible interpretations

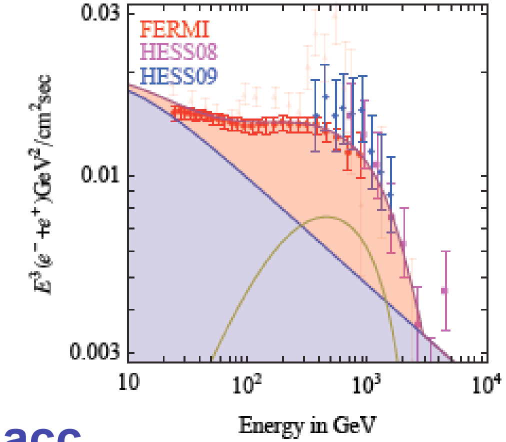
- Several papers already published to explain electron spectrum
  - Together with other observations (positron fraction, diffuse γ-ray)

Pulsars



Grasso et al. 2009

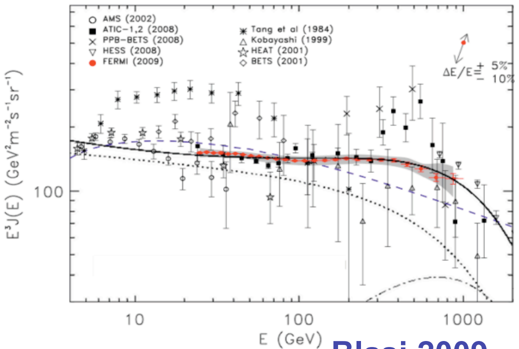
Dark Matter



Strumia et al. 2009

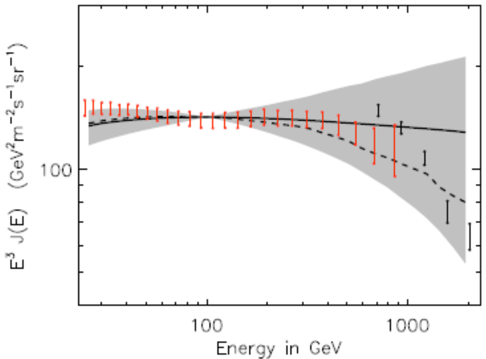
57 citations so far,
~ > 1/day

Secondary CR acc.



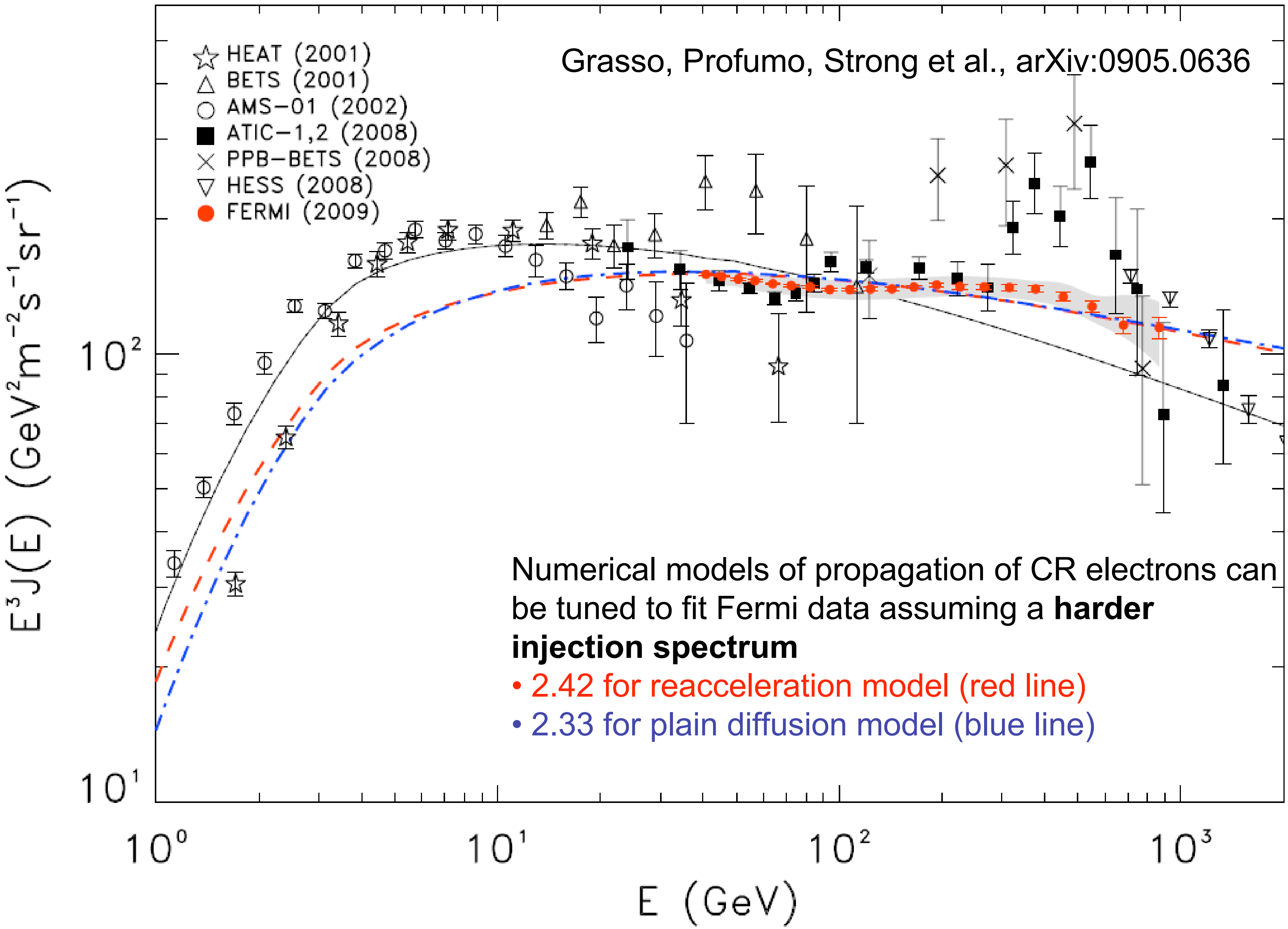
Blasi 2009

Several sources…



Grasso et al. 2009

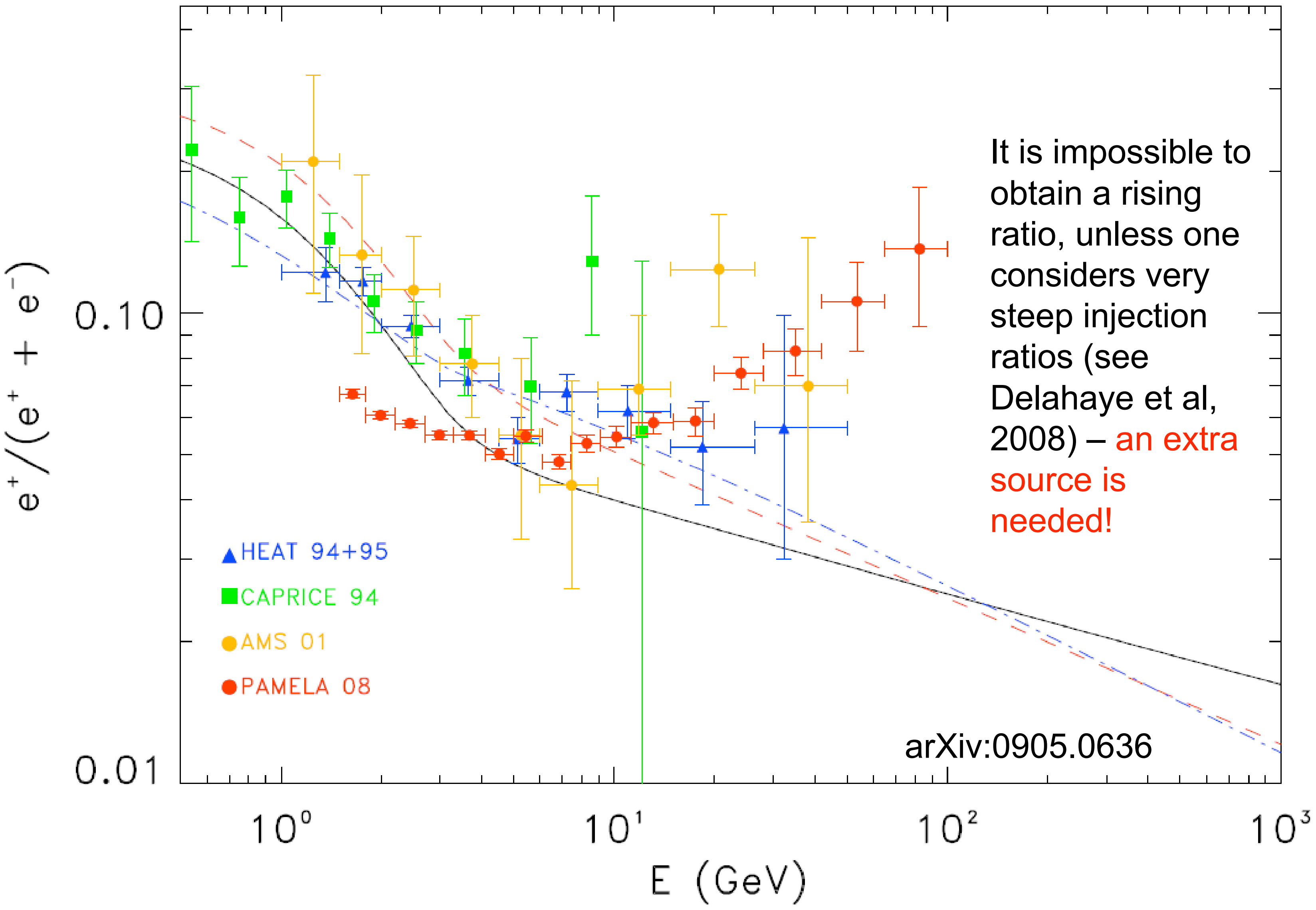
A possible "conservative" interpretation



Numerical models of propagation of CR electrons can be tuned to fit Fermi data assuming a **harder injection spectrum**

- 2.42 for reacceleration model (red line)
- 2.33 for plain diffusion model (blue line)

… does not work for Pamela data



It is impossible to obtain a rising ratio, unless one considers very steep injection ratios (see Delahaye et al, 2008) – an extra source is needed!

The possible role of nearby pulsars

Pulsars are candidate sources of relativistic electrons and positrons (see e.g. Shen 1970, Harding & Ramaty 1987)

- e+/e- pairs believed to be produced in the magnetosphere and re-accelerated in the wind

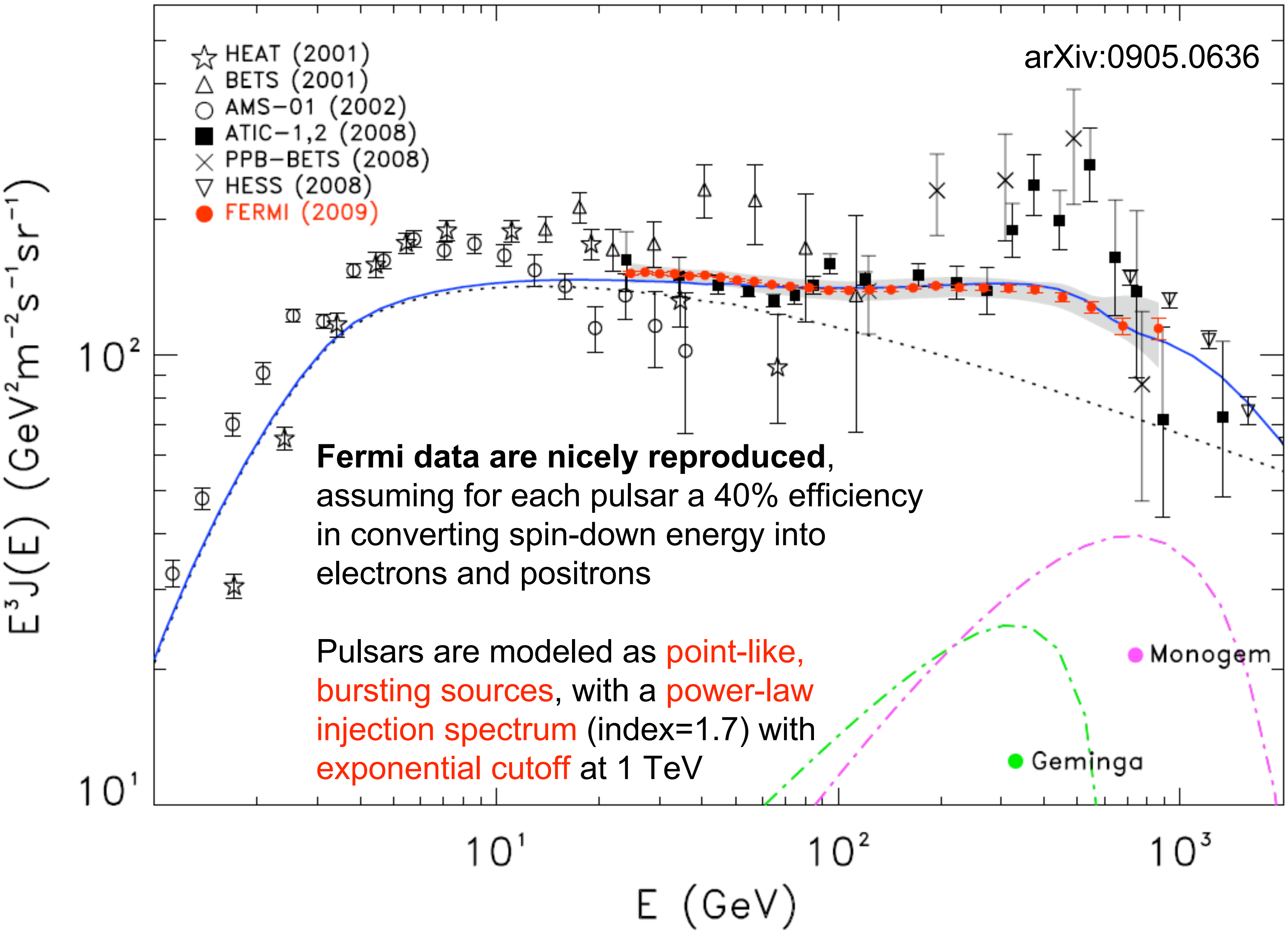
Characteristics needed to explain Fermi/Pamela excesses wrt conventional models

- Nearby, because of synchrotron energy losses
- Mature, because electrons remain confined in the PWN until it merges with the ISM
- But not too old, because old electrons are already diluted in space

Considering distributions of pulsars from the ATNF catalog

- With d<3kpc with age 5×10^4 yr < Y < 10^7 yr
  - Injection index, cutoff energy, e+/e- conversion efficiency, delay between pulsar birth and electron release
- Create different possible summed contributions of all pulsars

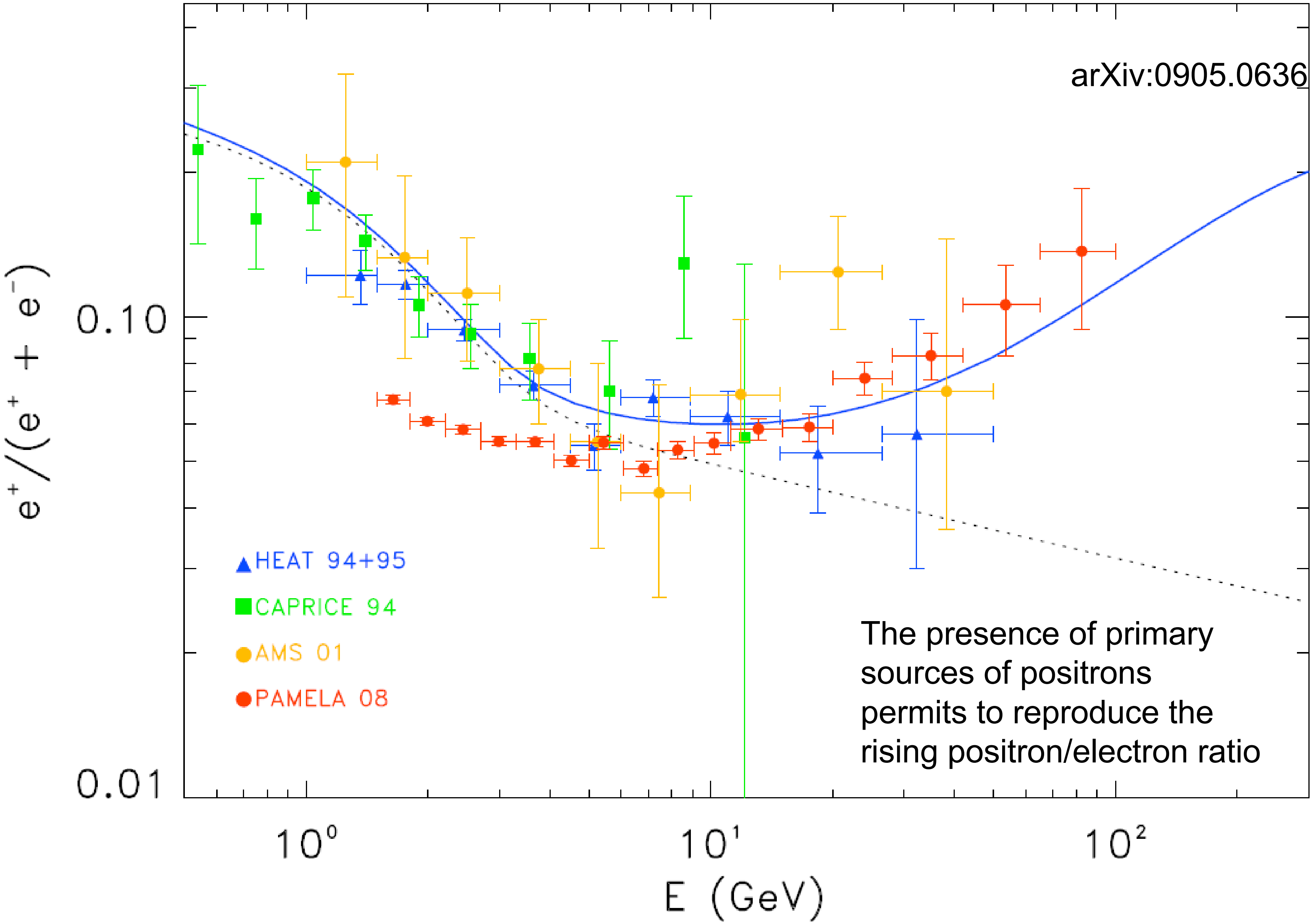
Adding candidate pulsars within 1kpc



Fermi data are nicely reproduced, assuming for each pulsar a 40% efficiency in converting spin-down energy into electrons and positrons

Pulsars are modeled as point-like, bursting sources, with a power-law injection spectrum (index=1.7) with exponential cutoff at 1 TeV

works for Pamela too



The impact of the Fermi CRE data

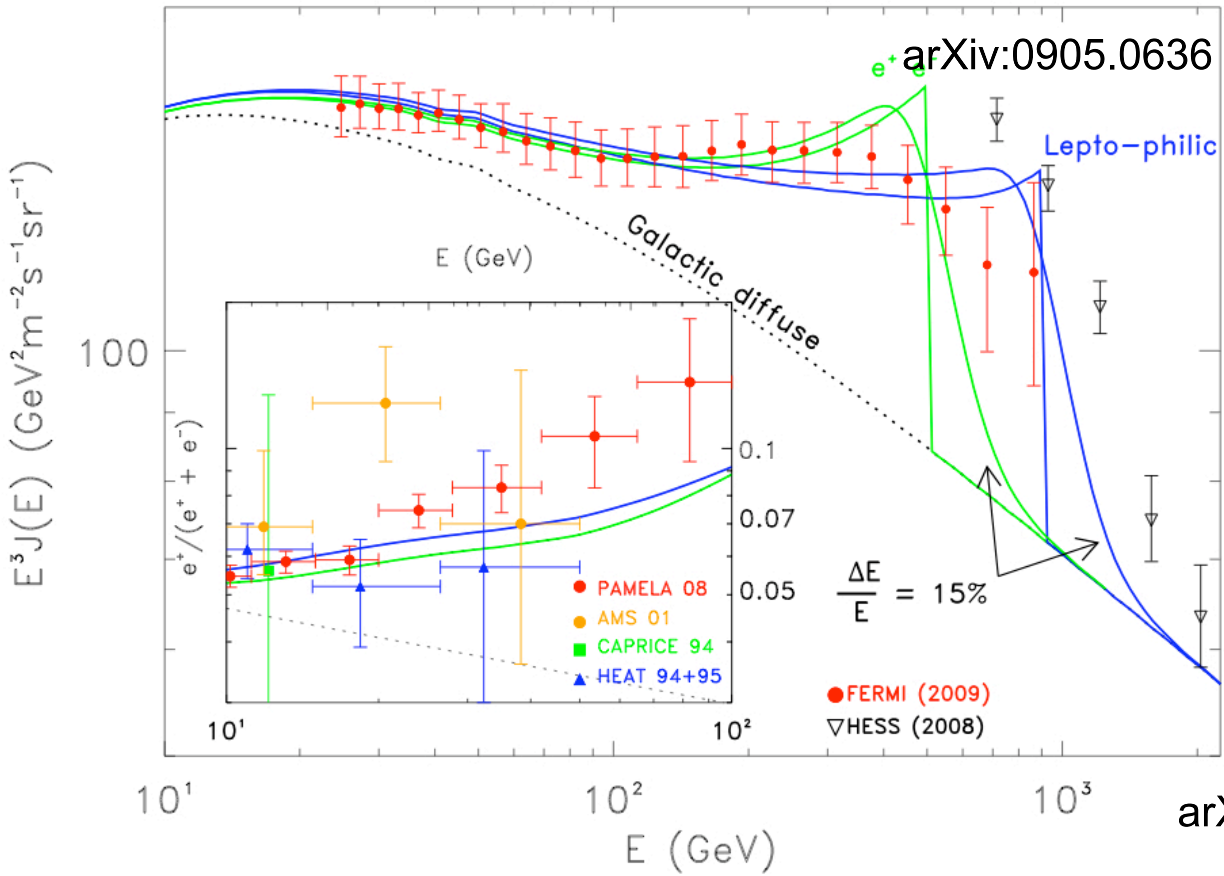
1. Much weaker rationale to postulate a **low DM mass** in the 0.3-1 TeV range (“**ATIC bump**”) motivated by the CR electron+positron spectrum

2. If the Pamela positron excess is from DM annihilation or decay, Fermi CRE data set **stringent constraints** on such interpretation

3. Fermi CRE data are useful to put **limits** on rates for particle **DM annihilation** or **decay (whatever they mean)**

4. We find that a **DM interpretation** to the **Pamela** positron fraction data consistent with the new **Fermi-LAT** CRE is a **viable** possibility

A possible DM interpretation



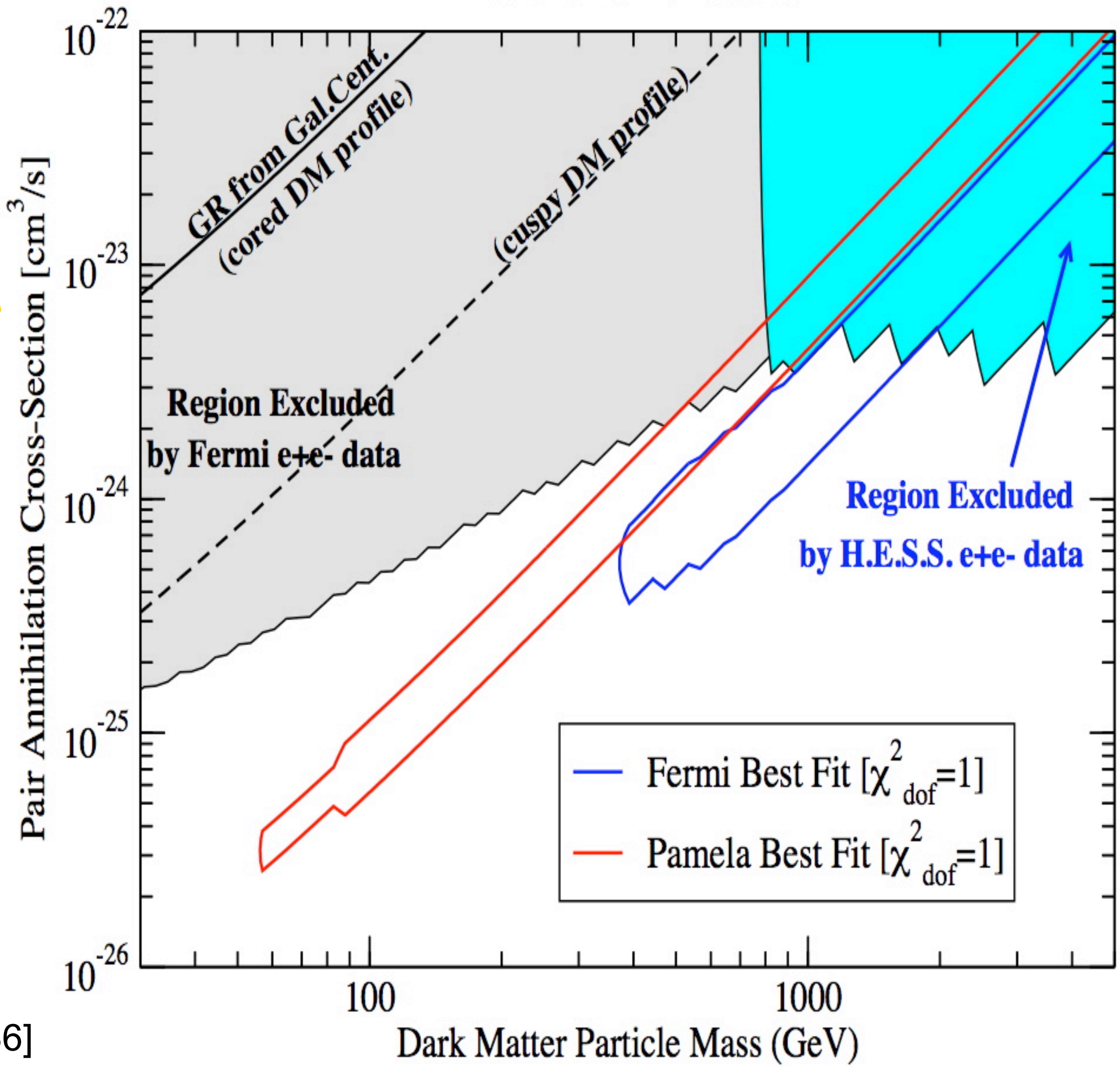
arXiv:0905.0636

Best fit models among two classes

- e+/e- model: DM annihilation into light gauge boson decaying into e+/e-
- Lepto-philic: annihilation into charged lepton species

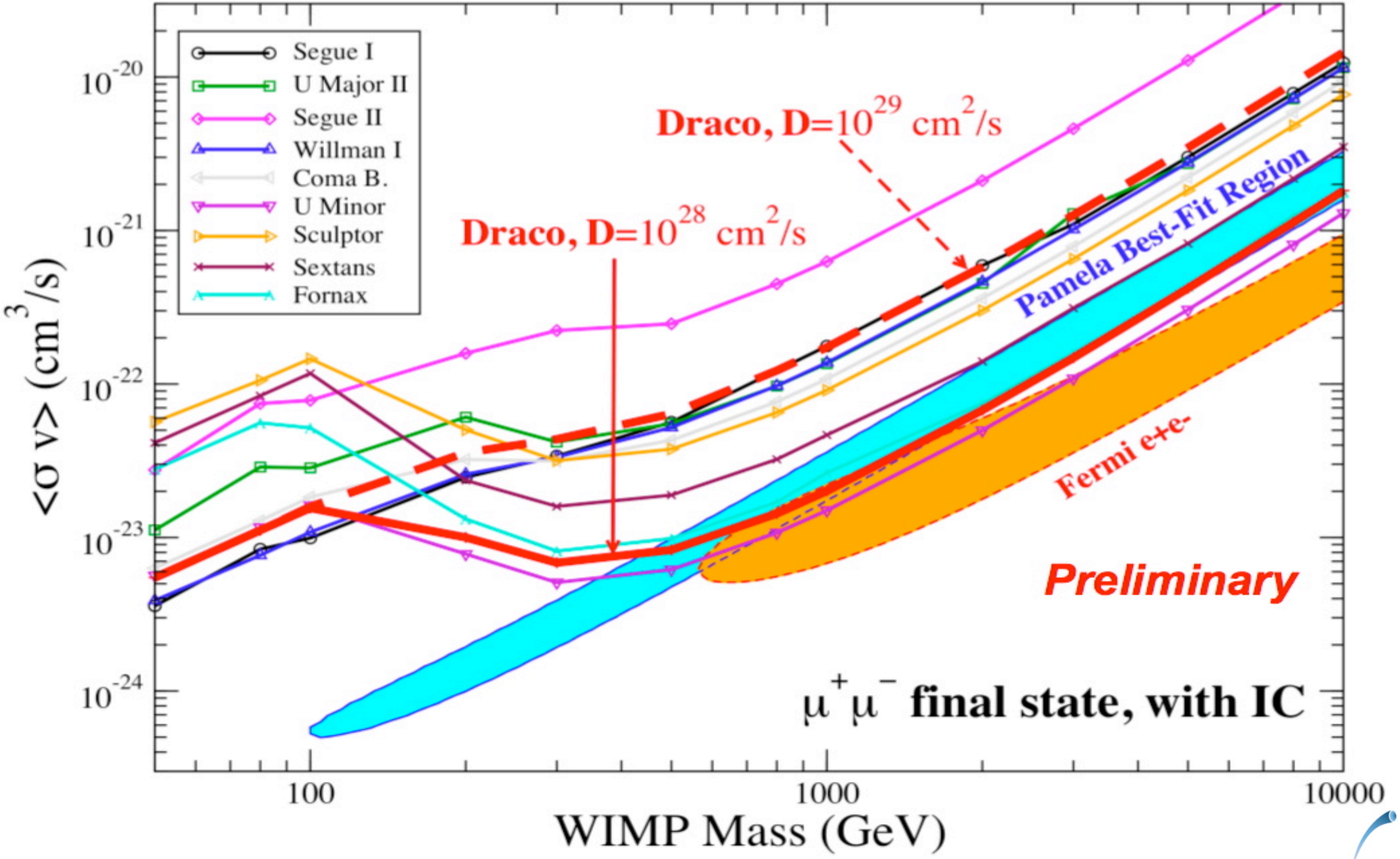
Pure e+e- Models

the dark matter pair annihilation always yields a pair of monochromatic e+e-, with injection energies equal to the mass of the annihilating dark matter particle



[arXiv:0905.0636]

Dwarf spheroidal galaxies: Constraints Including IC Emission

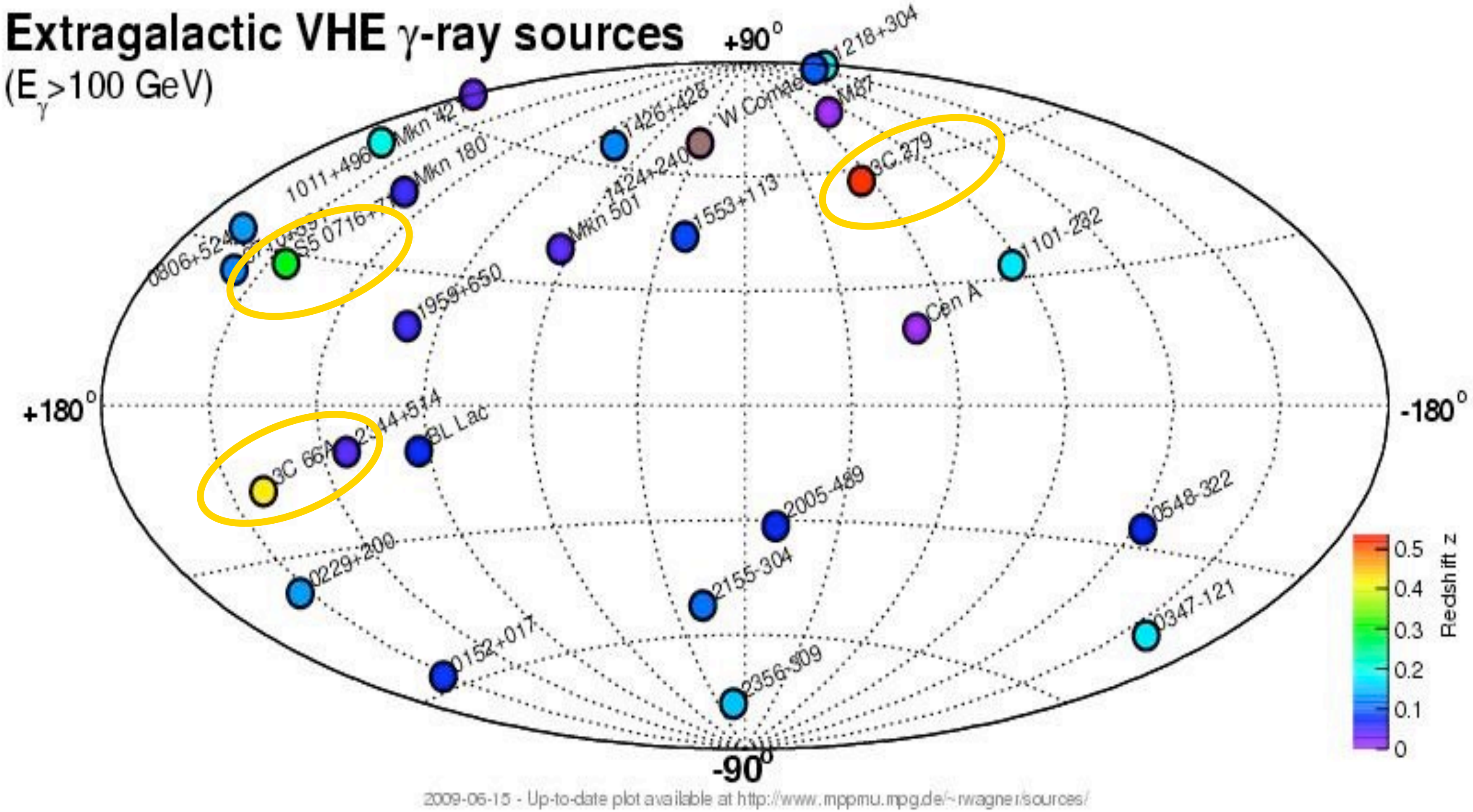


Combined constraints for Final State Radiation (FSR) plus IC with reference diffusion model $D_0 = 10^{28}$ cm^2/s

Conclusions on the excess of e/gammas

- Fermi excess can be explained with e.g.
  - A background model with less steep electron injection spectrum. Does not fit Pamela, though
  - Nearby astrophysical sources like pulsars, reacceleration at old SNRs, localized SNRs, ... Could explain Fermi and Pamela data
  - Dark matter. Could explain Fermi and Pamela data. Or maybe there is no excess, the diffusion model is wrong
- We need more data (Pamela, Fermi, AMS, Planck, ...) and understanding to distinguish these scenarios
- Cherenkov telescopes can help – measurements of HE electrons have already been published, and positron measurements using the shadow of the moon and the geomagnetic field are difficult but not impossible
- Potential of HEA larger than accelerators. However, astrophysical uncertainties are such that, if DM is not found, limits are much less reliable than limits at the accelerators

Farther out…

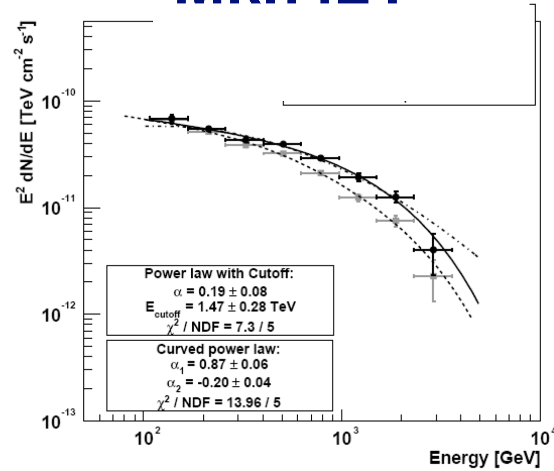

Extragalactic VHE γ-ray sources
(E$_\gamma$>100 GeV)
+90°
-90°
+180°
-180°
1218+304
W Comae
M87
1426+428
1424+240
Mkn 421
1011+496
Mkn 180
0806+524
S5 0716+714
3C 279
1553+113
Mkn 501
1101-232
1959+650
Cen A
2344+514
BL Lac
3C 66A
2005-489
0548-322
0229+200
2155-304
0347-121
0152+017
2356-309
Redshift z
0.5
0.4
0.3
0.2
0.1
0
2009-06-15 - Up-to-date plot available at http://www.mppmu.mpg.de/~rwagner/sources/

Variability

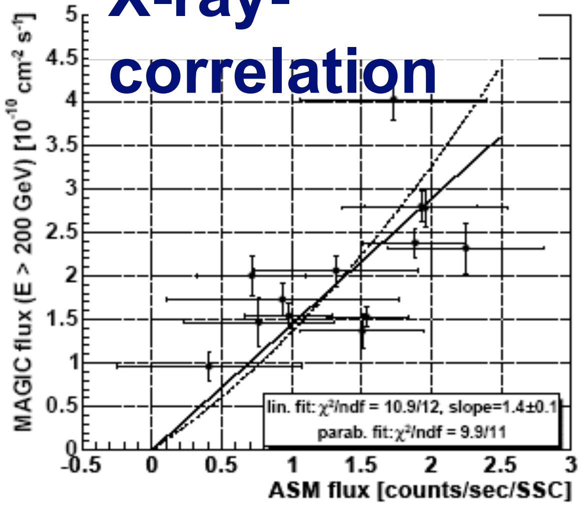
Variability: Mkn 421, Mkn501

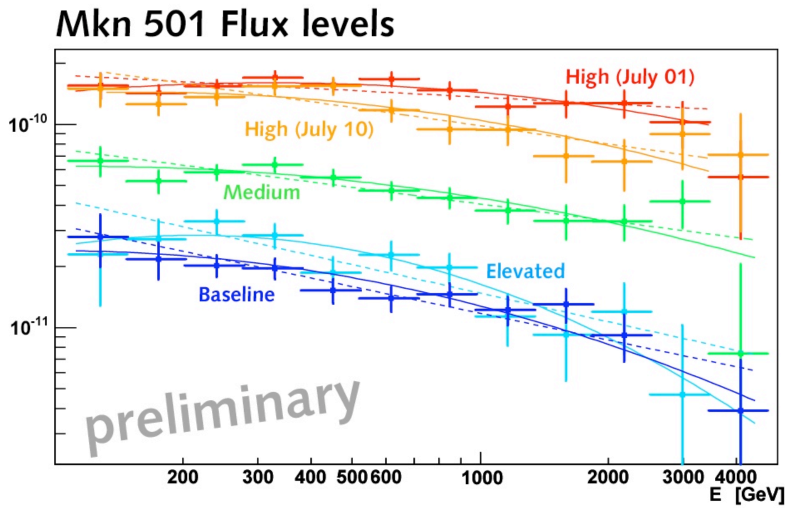
- Two very well studied sources, highly variable
  - Monitoring from Whipple, Magic…
  - TeV-X Correlation
    - No orphan flares…
      - See neutrino detectors

Mkn421



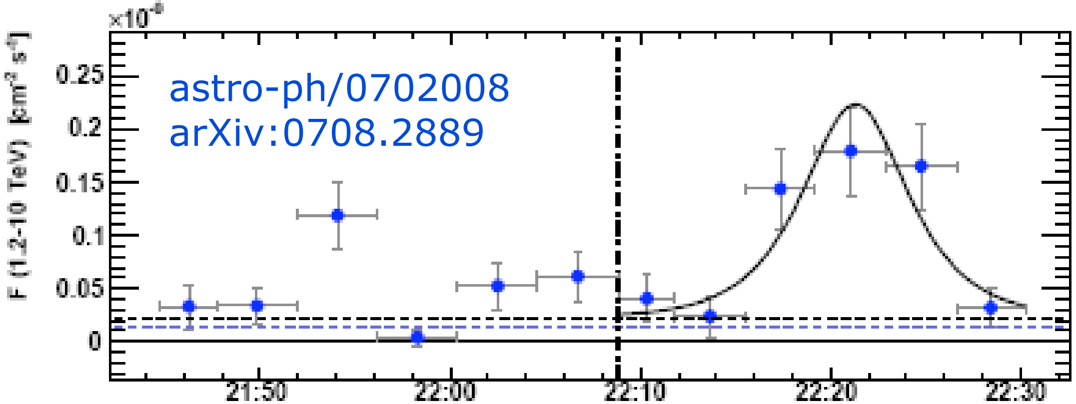
Mkn421 TeV-X-ray-correlation



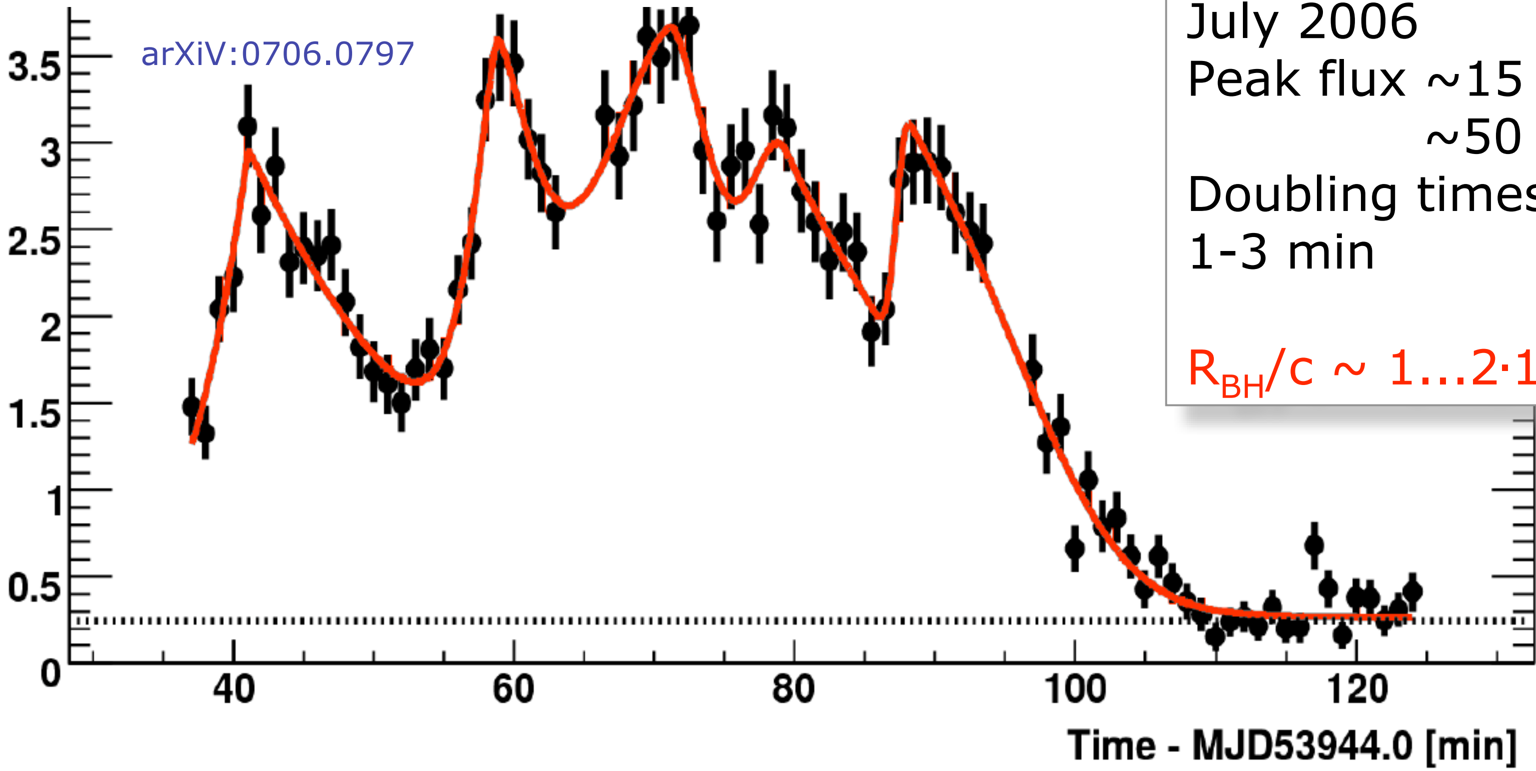


However, recently Fermi/HESS saw no correlation in PKS 2155

Rapid variability



MAGIC, Mkn 501
Doubling time ~ 2 min



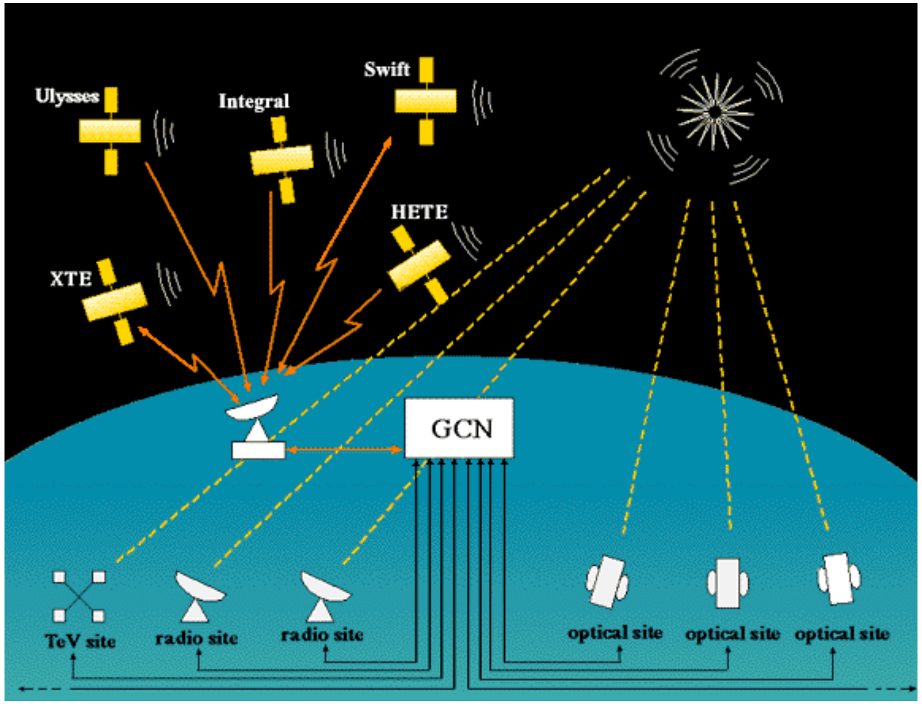
HESS PKS 2155
z = 0.116

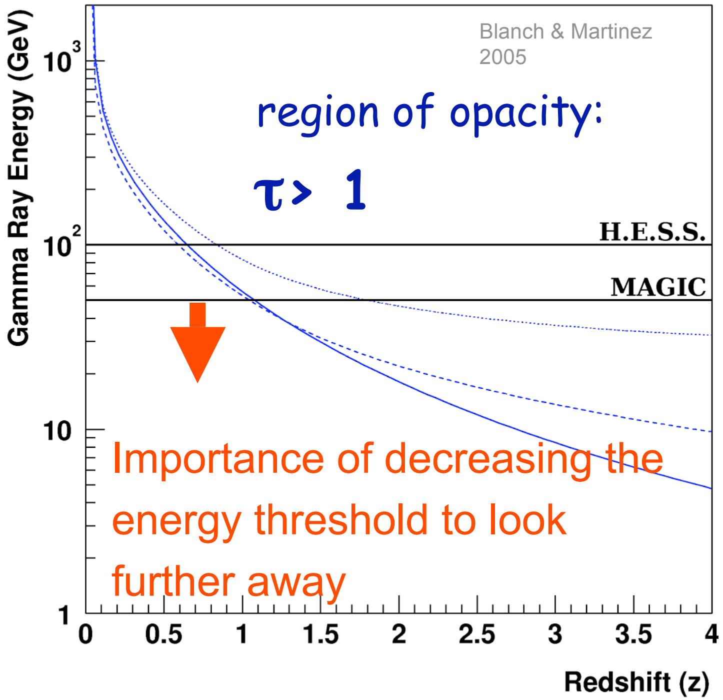
July 2006
Peak flux ~15 x Crab
~50 x average
Doubling times
1-3 min

$R_{BH}/c \sim 1...2\cdot10^4$ s

GRBs
Another probe

- Interesting for astrophysical reasons, for propagation physics, for rapid variability
- Fermi is changing our view, due to its unprecedented range, self-pointing, dedicated instrument
- MAGIC is the best IACT, due to its fast movement & low threshold





No VHE γ emission from GRB positively detected yet...
(all other observed GRB very short or at very high z)

Violation of the Lorentz Invariance?

Light dispersion expected in some QG models, but interesting "per-se"

$$V = c\,[1 \pm \xi\,(E/E_{s1}) - \xi_2\,(E/E_{s2})^2 \pm \ldots]$$

1st order $$(\Delta t)_{\rm obs} = \frac{\Delta E}{\mathbf{E_{s1}}} H_0^{-1} \int_0^z \frac{(1+z)dz}{\sqrt{\Omega_\Lambda + \Omega_m (1+z)^3}},$$

MAGIC Mkn 501, PLB08

$E_{s1} \sim 0.03\ M_P$

$E_{s1} > 0.02\ M_P$

HESS PKS 2155, PRL08

$E_{s1} > 0.06\ M_P$

GRB X-ray limits:

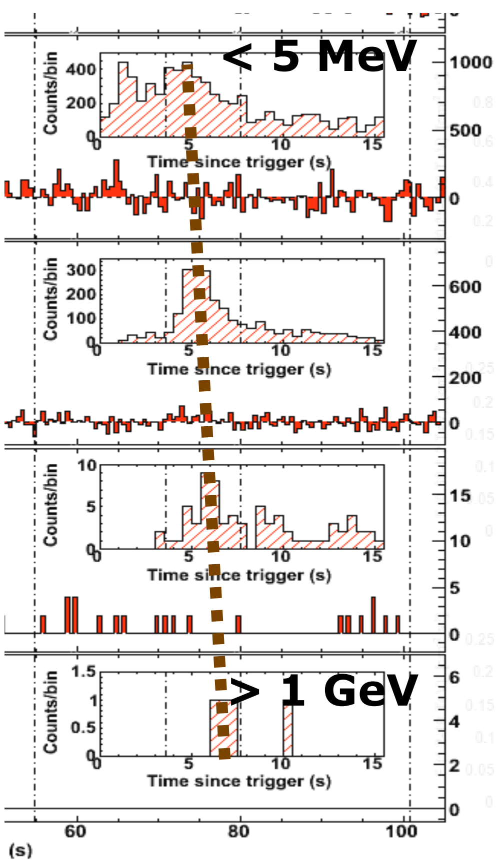
$E_{s1} > 0.11\ M_P$ (Fermi, but…)

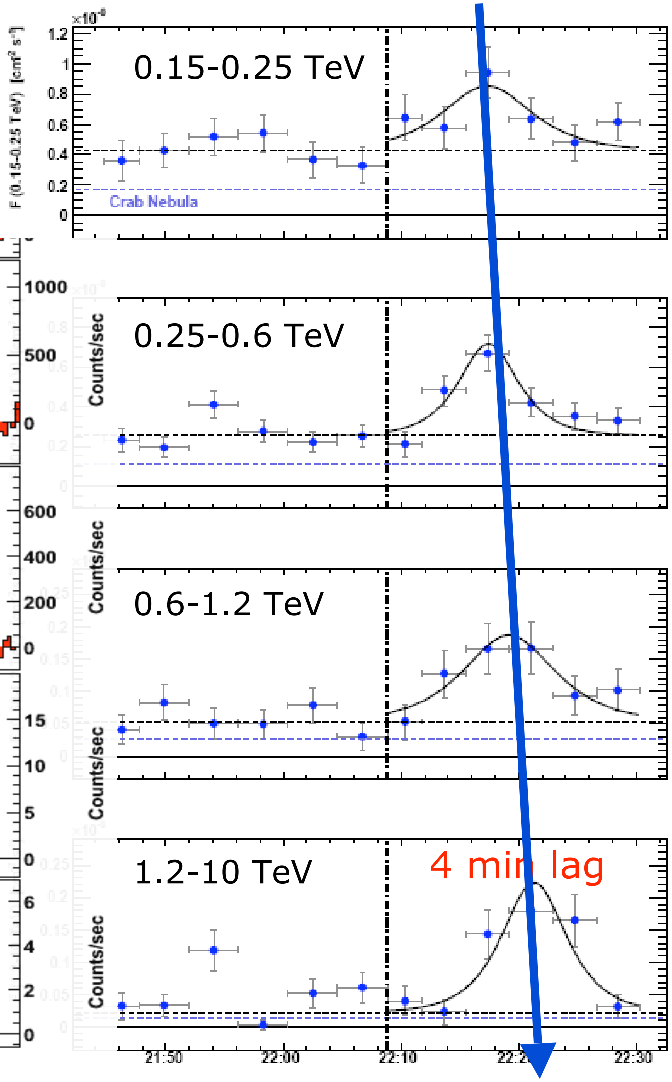
anyway in most scenarios

$\Delta t \sim (E/E_{s\alpha})^\alpha$, $\alpha>1$

▶ VHE gamma rays are the probe

▶ Mrk 501: $E_{s2} > 3 \cdot 10^{-9}\ M_P$, $\alpha=2$





LIV in Fermi vs. MAGIC+HESS

- GRB080916C at **z~4.2** : 13.2 GeV photon detected by Fermi **16.5 s** after GBM trigger. At 1st order

$$(\Delta t)_{\rm obs} = \frac{\Delta E}{\mathbf{E_{s1}}} \mathrm{H}_0^{-1} \int_0^z \frac{(1+z)dz}{\sqrt{\Omega_\Lambda + \Omega_m (1+z)^3}}, \qquad \sim z$$

- The MAGIC result for Mkn501 at z= 0.034 is Δt = (0.030 +- 0.012) s/GeV; for HESS at z~0.116, according to Ellis et al., Feb 09, Δt = (0.030 +- 0.027) s/GeV
- Δt ~ (0.43 ± 0.19) K(z) s/GeV

Extrapolating, you get from Fermi **(26 +- 11) s** (J. Ellis et al., Feb 2009)

SURPRISINGLY CONSISTENT:

DIFFERENT ENERGY RANGE

DIFFERENT DISTANCE

Fermi: GRB 090510

- $z = 0.903 \pm 0.003$
- prompt spectrum detected, significant deviation from Band function at high E
- High energy photon detected: 31 GeV at T_o + 0.83 s [expected from Ellis & al. (12 ± 5) s]
- tight constraint on Lorentz Invariance Violation:
  - M_{QG} > several M_{Planck}

GRB 090902

[arXiv:0909.247v1]

- $z = 1.8 \pm 0.4$
- one of the brightest GRBs observed by LAT
- after prompt phase, power-low emission persists in the LAT data as late as 1 ks post trigger:

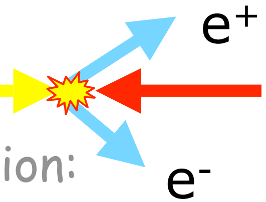
  highest E photon so far detected: 33.4 GeV, 82 s after GBM trigger [expected from Ellis & al. (26 ± 13) s]
- much weaker constraints on LIV E_s (EBL constraints)

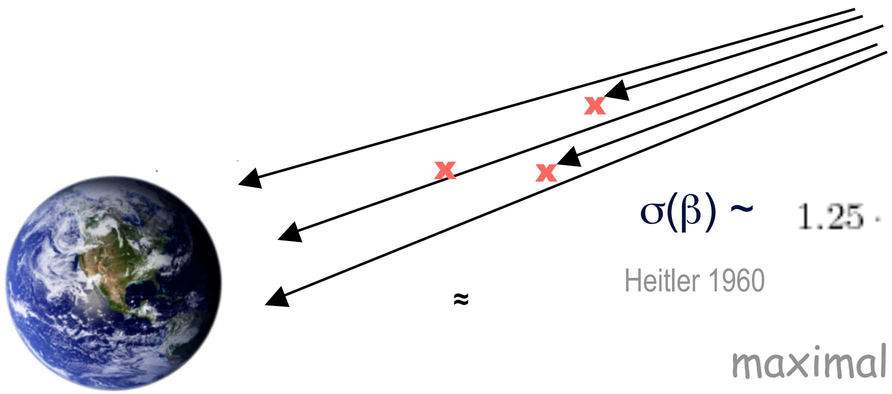
Interpretation of the results on rapid variability

- The most likely interpretation is that the delay is due to physics at the source
  - By the way, a puzzle for astrophysicists

- However
  - We are sensitive to effects at the Planck mass scale
  - More observations of flares will clarify the situation
  - 2nd order effects?

Propagation of γ-rays





dominant process for absorption:

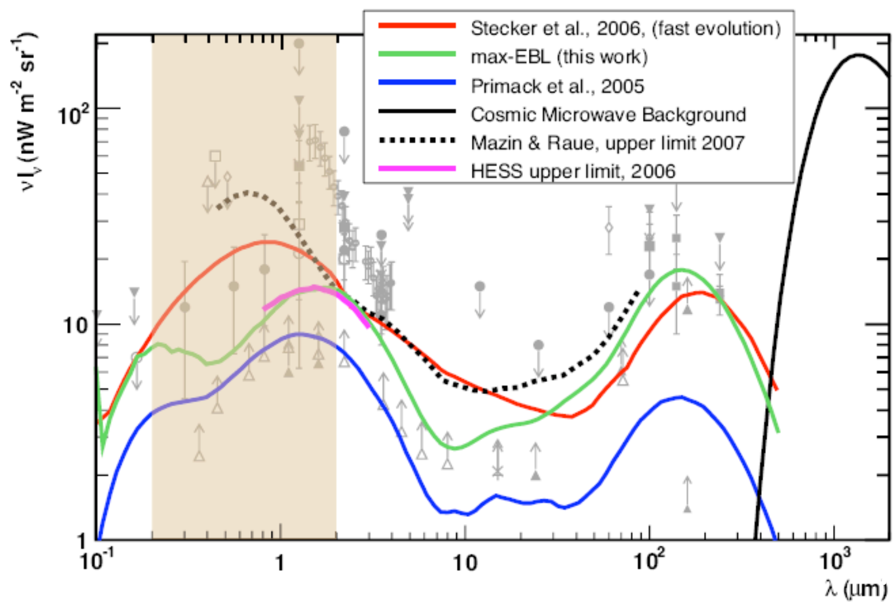
$\gamma_{VHE}\gamma_{bck} \rightarrow e^+e^-$

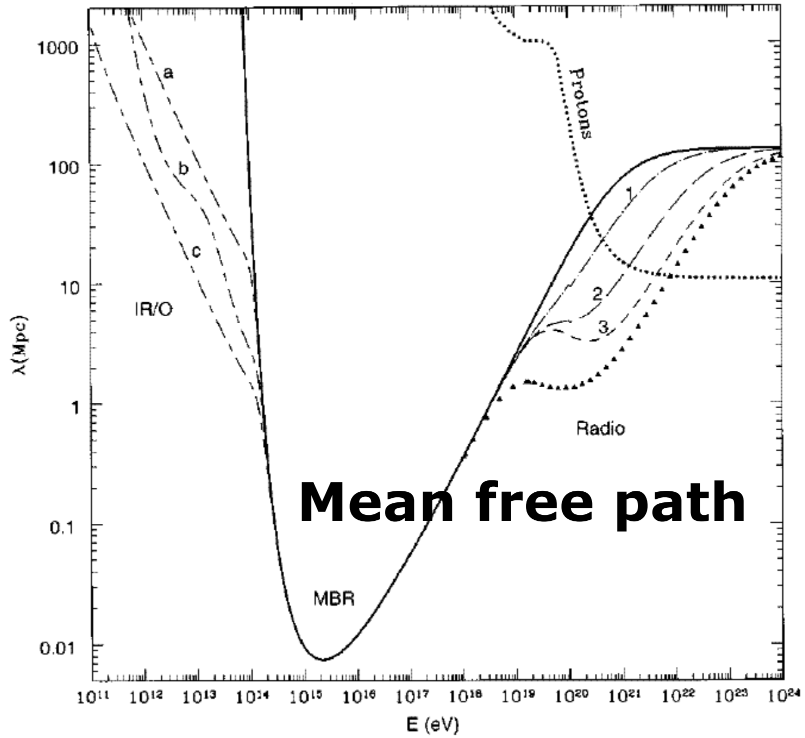
$$\sigma(\beta) \sim 1.25 \cdot 10^{-25}(1-\beta^2) \cdot \left[2\beta(\beta^2-2) + (3-\beta^4)\ln\left(\frac{1+\beta}{1-\beta}\right)\right] \mathrm{cm}^2$$

Heitler 1960

maximal for: $\epsilon \simeq \frac{2m_e^2c^4}{E} \simeq \left(\frac{500\ \mathrm{GeV}}{E}\right)\mathrm{eV}$

- For γ–rays, relevant background component is optical/infrared (EBL)
- different models for EBL: minimum density given by cosmology/star formation

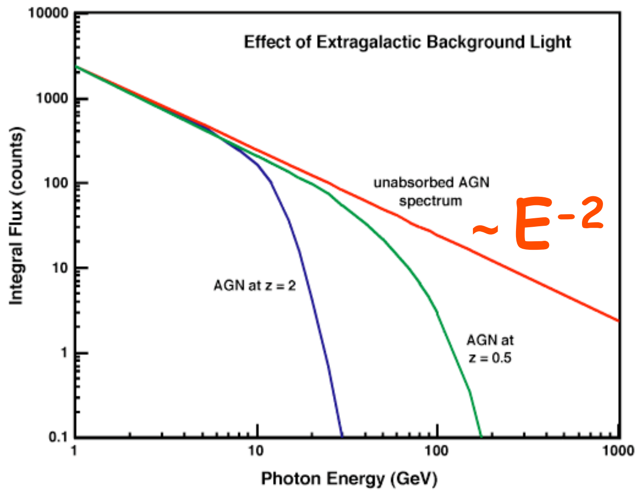




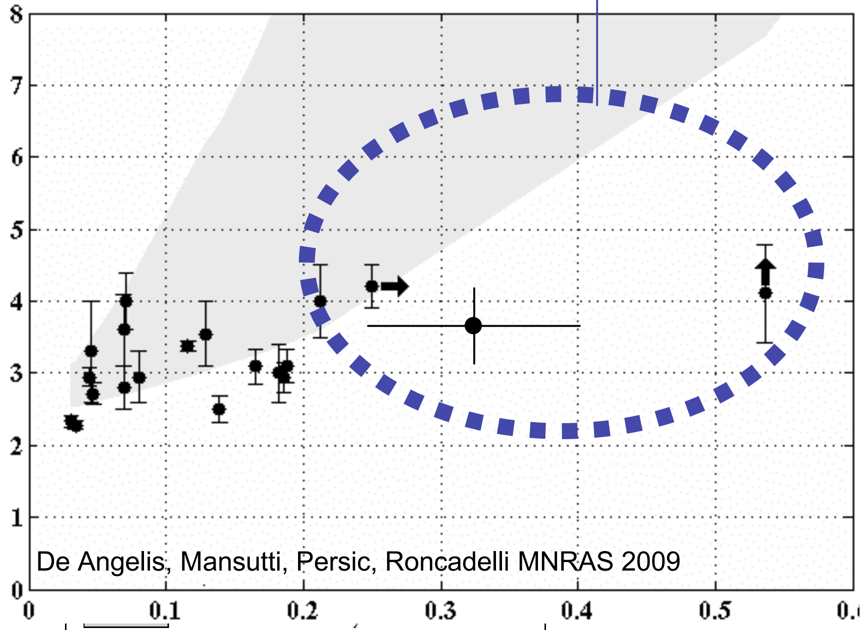
Are our AGN observations consistent with theory?

Selection bias?
New physics ?

Measured spectra affected by attenuation in the EBL:

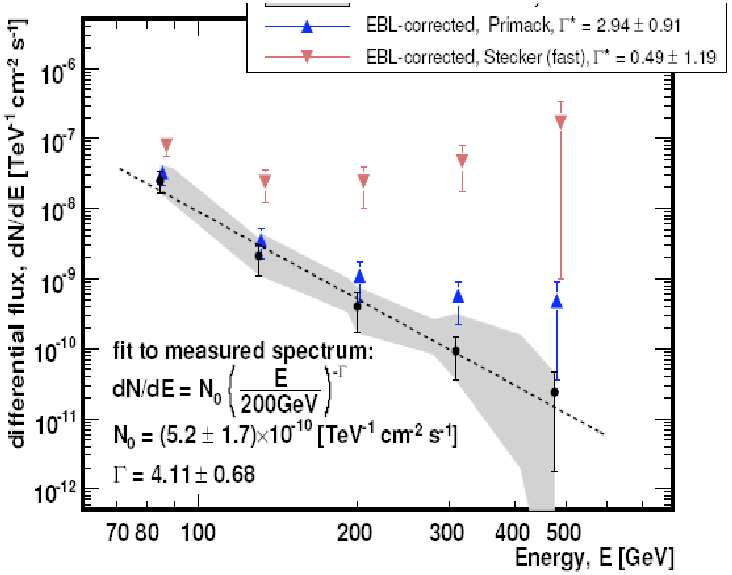


~ E^{-2}



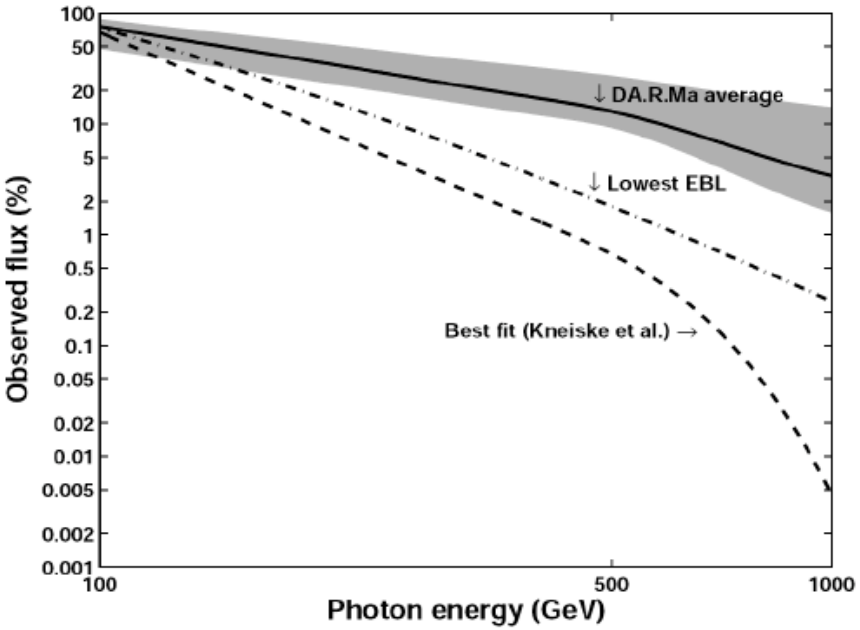
observed spectral index

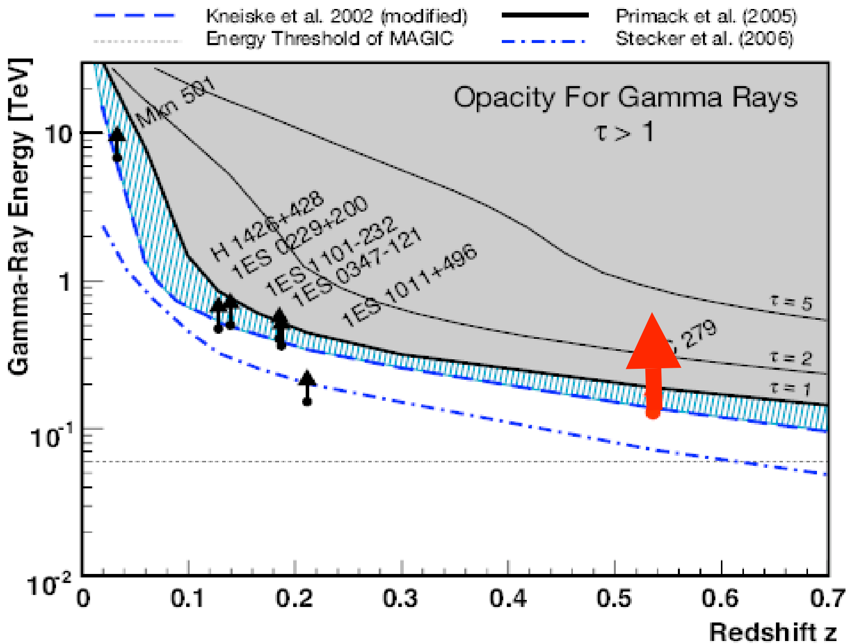
redshift



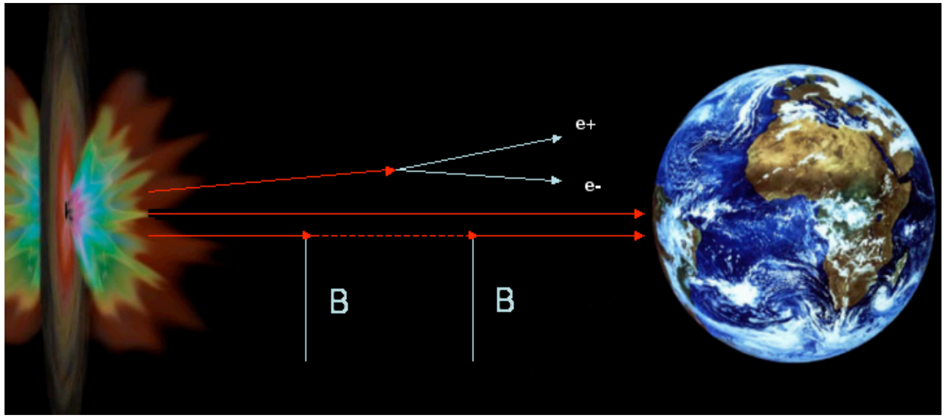
The most distant:
MAGIC 3C 279
(z=0.54)

Could it be seen?





- Explanations go from the standard ones
  - very hard emission mechanisms with intrinsic slope < 1.5 (Stecker 2008)
  - Very low EBL
- to possible evidence for new physics
  - Oscillation to a light “axion”? (**DA**, **R**oncadelli & **MA**nsutti [**DARMA**], PLB2008, PRD2008)
    - Axion emission (Hooper et al., PRD2008)

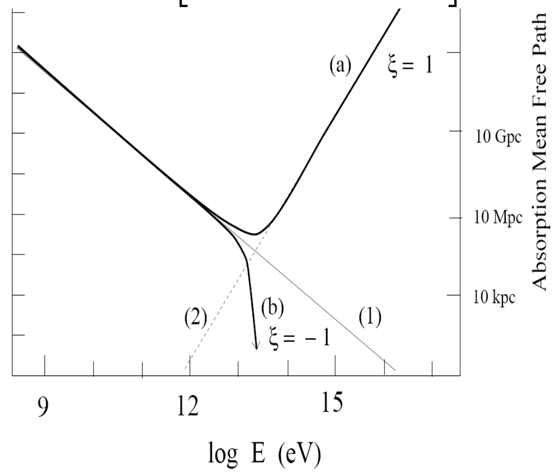


We are (maybe) making two extraordinary claims

- *A possible relation between arrival time and energy*
- Signal from sources far away hardly compatible with EBL

- We should keep in mind that
  - Extraordinary claims require extraordinary evidence
    - New Scientist, SciAm blog/news, …, and then?
  - Claims must be followed up
    - If we see this in such sources, what else do we expect?
    - Fundamental implications of unexpected findings?
    - Are we seeing a part of the same big picture?

$$c^2 p^2 = E^2 \left[1 + \xi \frac{E}{E_s} + O\left(\frac{E}{E_s} \right)^2 \right]$$



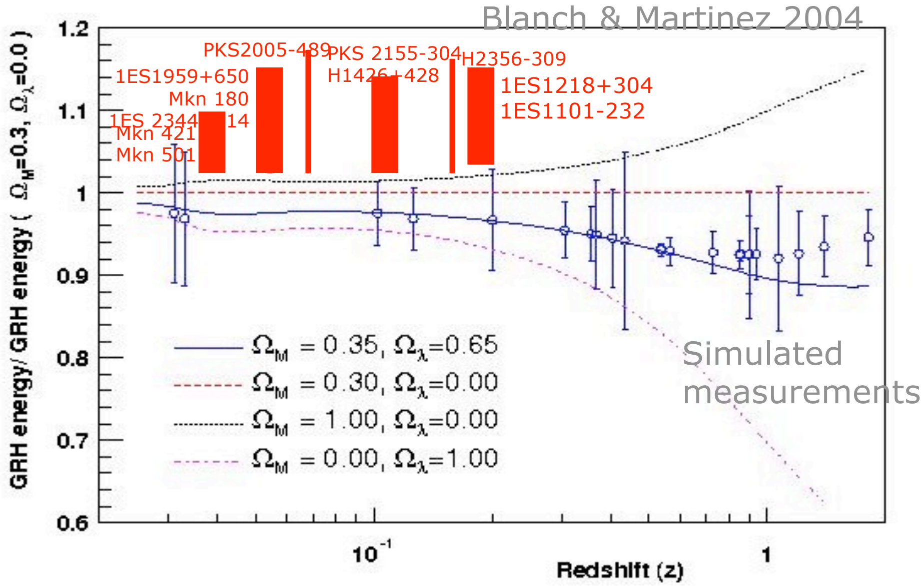
A no-loss situation: if propagation is standard, cosmology with AGN

GRH depends on the γ–ray path and there the **<u>Hubble constant and the cosmological densities</u>** enter => if EBL density is known, the GRH might be used as a **distance estimator**

$$\frac{dl}{dz} = c \cdot \frac{1/(1+z)}{H_0\left[\Omega_M(1+z)^3 + \Omega_k(1+z)^2 + \Omega_\lambda\right]^{1/2}}$$

GRH behaves differently than other observables already used for cosmology measurements.

EBL constraint is paving the way for the use of AGNs to fit Ω_M and Ω_Λ …



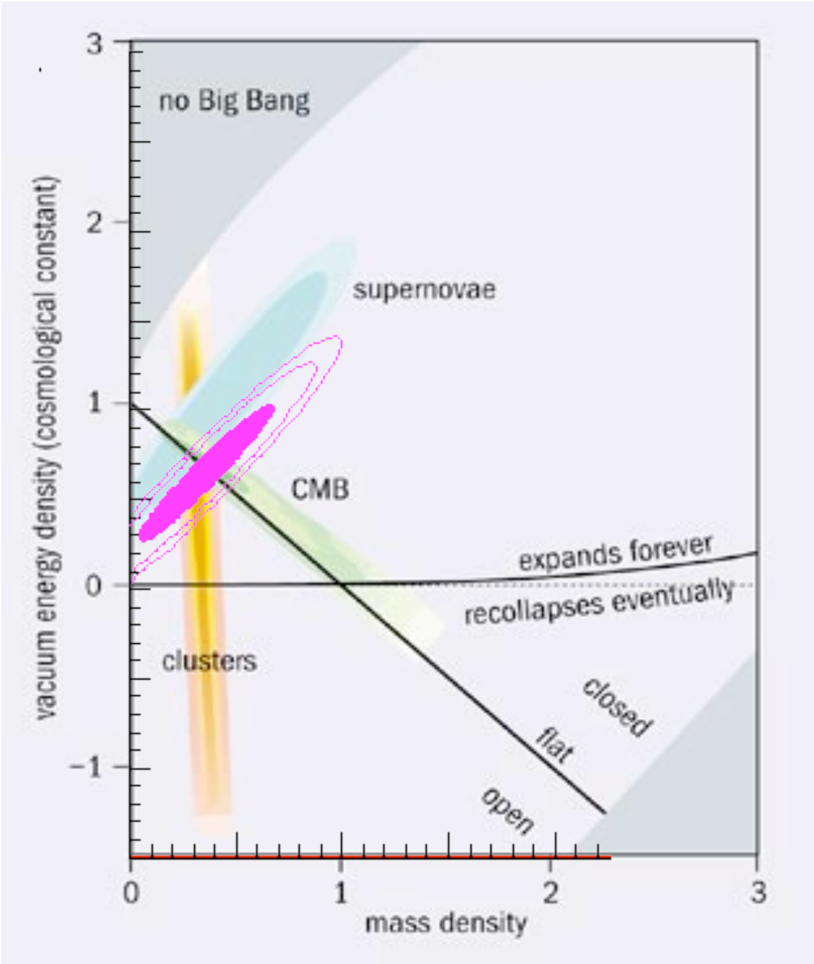
Determination of H_0, Ω_M and Ω_λ

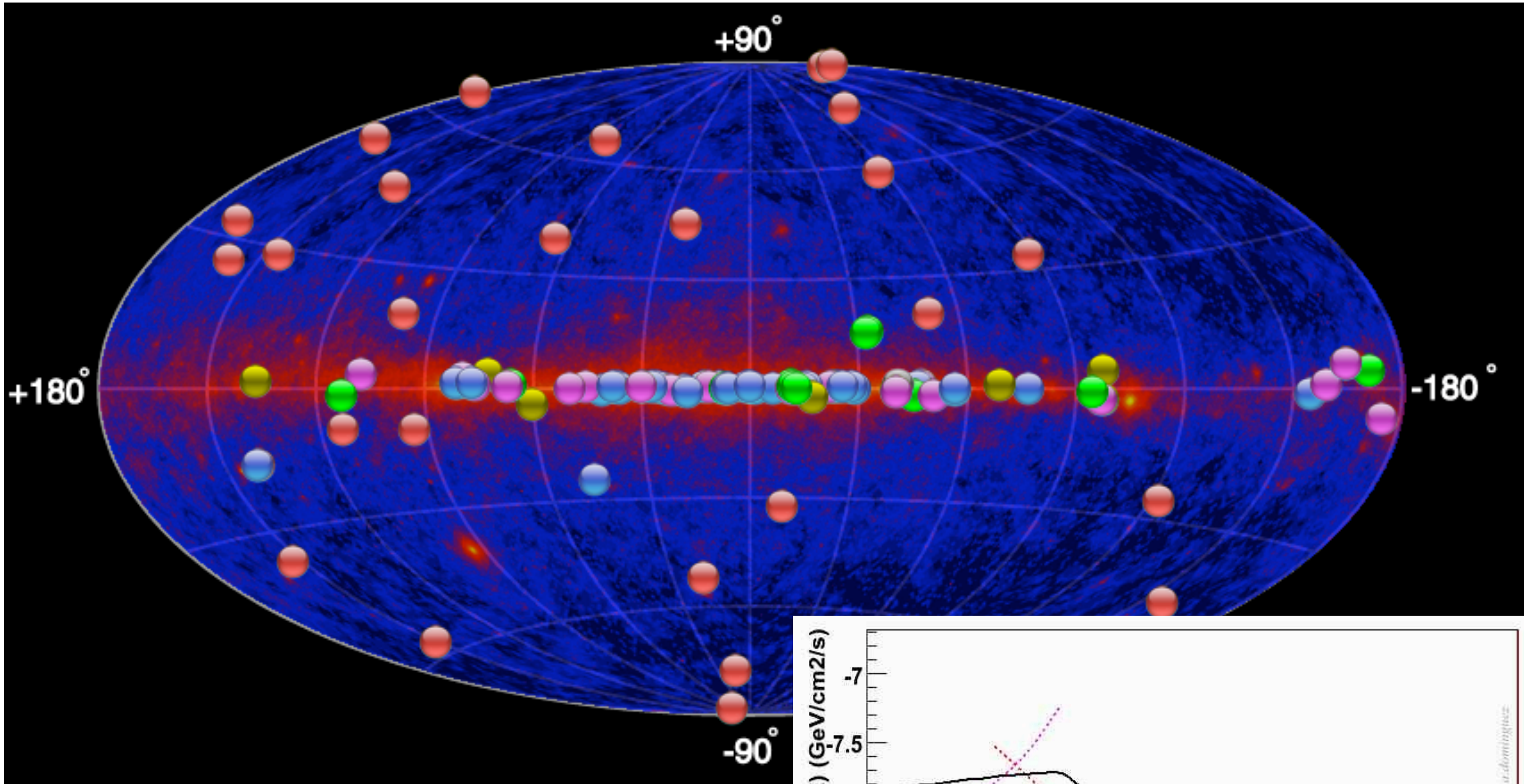
Using the foreseen precision on the GRH measurements of 20 extrapolated EGRET AGNs, the COSMOLOGICAL PARAMETERS can be fitted.

We take the scenario where Ho is known from other experiments at the level of 4 km/ s Mpc (Hubble project).

$$H_0 = 68.5 + 1.6 - 1.6\, km/s\, Mpc$$
$$\Omega_M = 0.35 + 0.21 - 0.20$$
$$\Omega_\lambda = 0.65 + 0.24 - 0.25$$

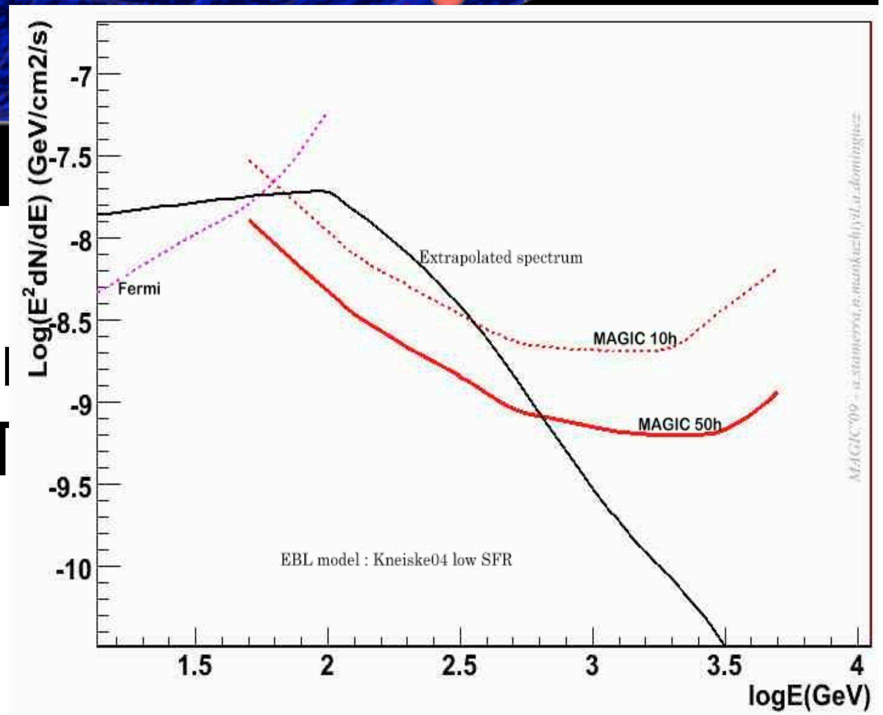
=> The $\Delta\chi^2$=2.3 2-parameter contour improves by more than a factor 2 the 2004' Supernovae combined result !





⇒Perfect trigger for IACT

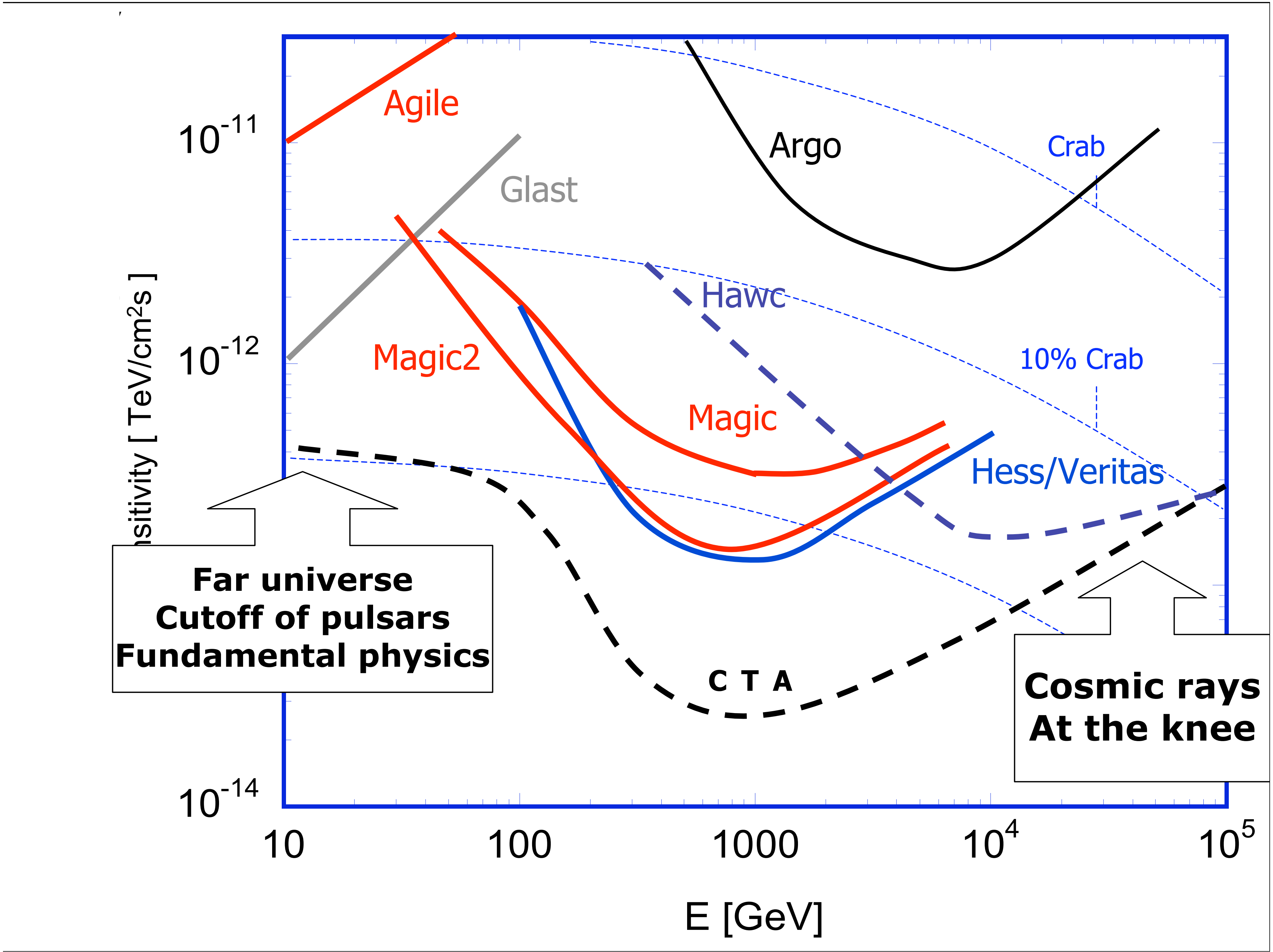
⇒By 2010, a map of the U
between 1 GeV and 10 T



AND THEN?

Still looking for

- Sample of sources not suffering selection bias
- Proof that SNR quantitatively account for galactic CRs
- Tracking propagation of VHE CRs via diffuse emission
- Understanding of processes around galactic compact objects
- Understanding of energy conversion in pulsar winds
- …
- Deep understanding of particle (& matter) acceleration in AGN
- Cosmic rays in and VHE gamma rays from starburst galaxies
- Cosmic rays in VHE gamma rays from clusters of galaxies
- VHE gamma rays from GRB
- …
- Real cosmology with gamma rays
- Signs of Dark Matter
- Violation of Lorentz invariance



Agile
Argo
Crab
Glast
Hawc
10% Crab
Magic2
Magic
Hess/Veritas
C T A
nsitivity [TeV/cm²s]
Far universe
Cutoff of pulsars
Fundamental physics
Cosmic rays
At the knee
10^-11
10^-12
10^-14
10
100
1000
10^4
10^5
E [GeV]

SciNeGHE 2009
Gamma Ray Physics
in the LHC Era
Gran Hotel Assisi, Assisi, PG, Italy
ASSISI
October 7-9, 2009
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HE Astronomy/astrophysics: Summary / future

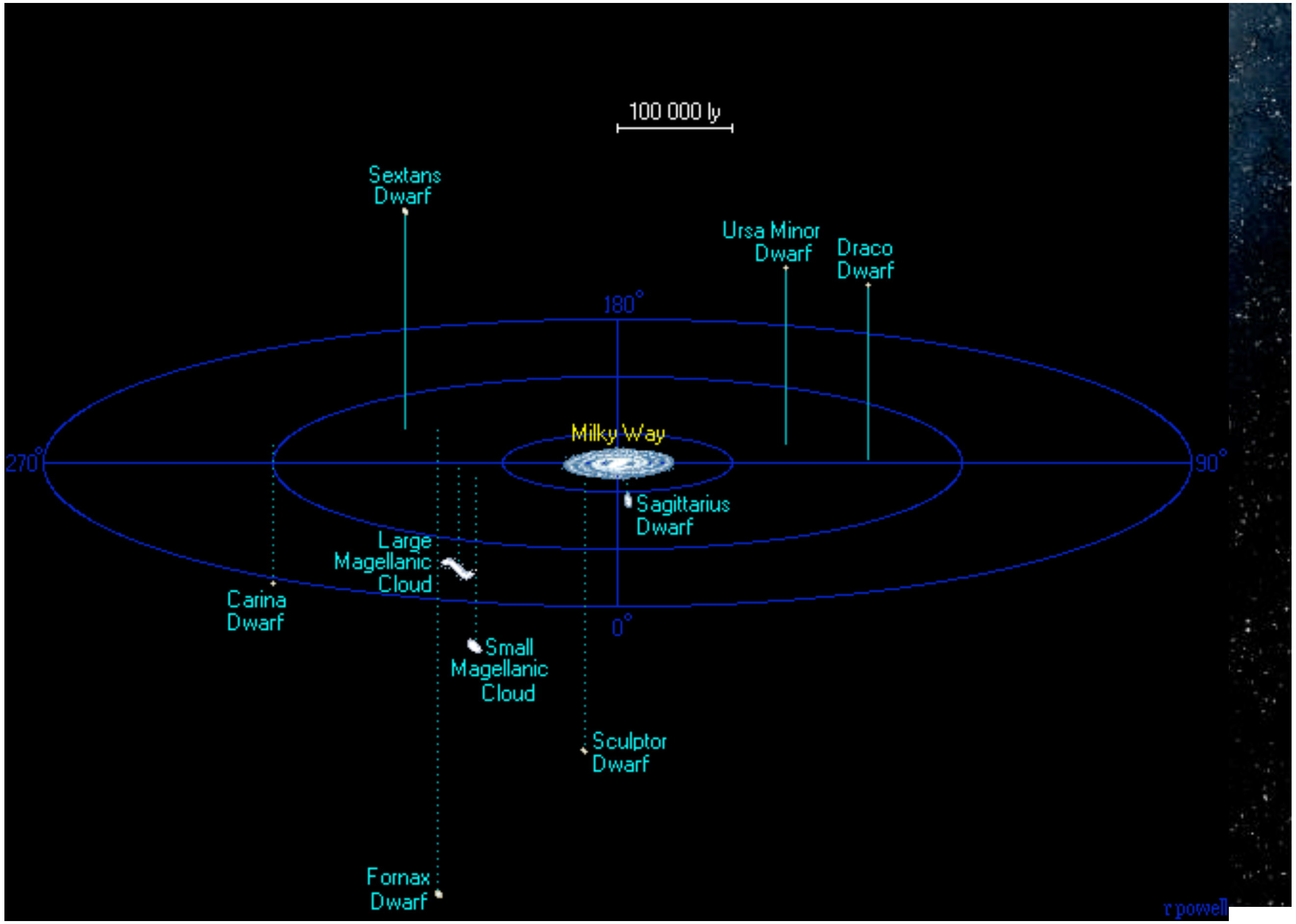
- Probably the main new results in the last years come from Fermi and the IACT (but I don't forget Auger and Pamela)
- Cosmic Rays:
  - SNR as galactic sources established
  - AGN as sources established
  - Astronomy with charged CR will be difficult
  - Estimates of neutrino flux start to be possible (they should be done)
- Still no detection of DM
  - Interesting results from Pamela and Fermi need further study
  - And the information from no detection is not as good as for accelerators
- A few things still not explained
  - Photon propagation
  - CR spectra
- Safe fundamental science (and astronomy/astrophysics) from gamma rays – room for easy improvement
- HEA can explore regions beyond the reach of accelerators

BONUS MATERIAL

Where to look for Cold Dark Matter in our neibourghood ?

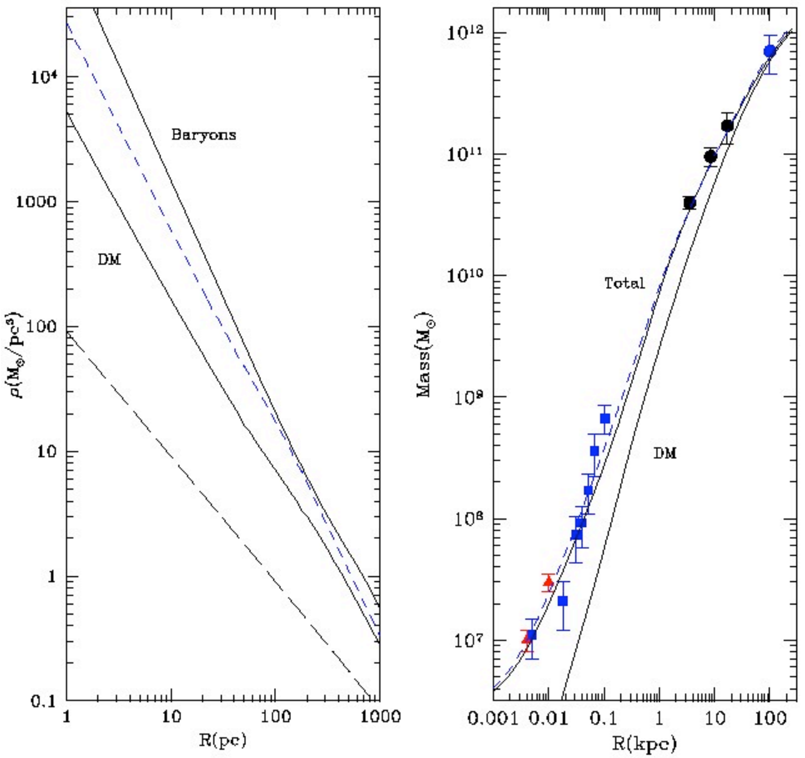
WIMPs would constitute the galactic halo and would concentrate at

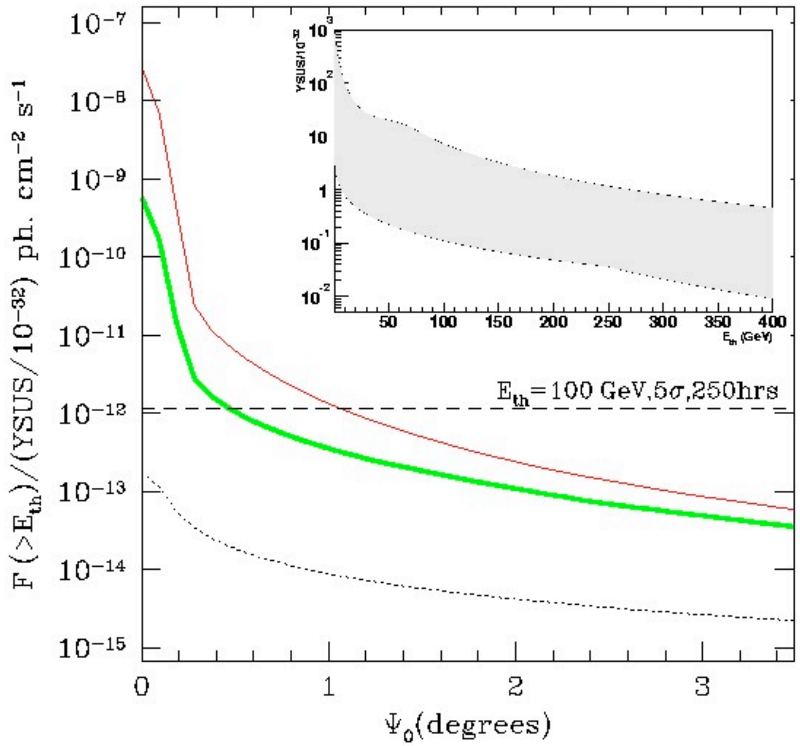
- the galaxy center
- dark matter clumps
- visible satellites
- invisible satellites
- nearby galaxies (M31)



Best targets for Dark Matter searches

Galactic Center:



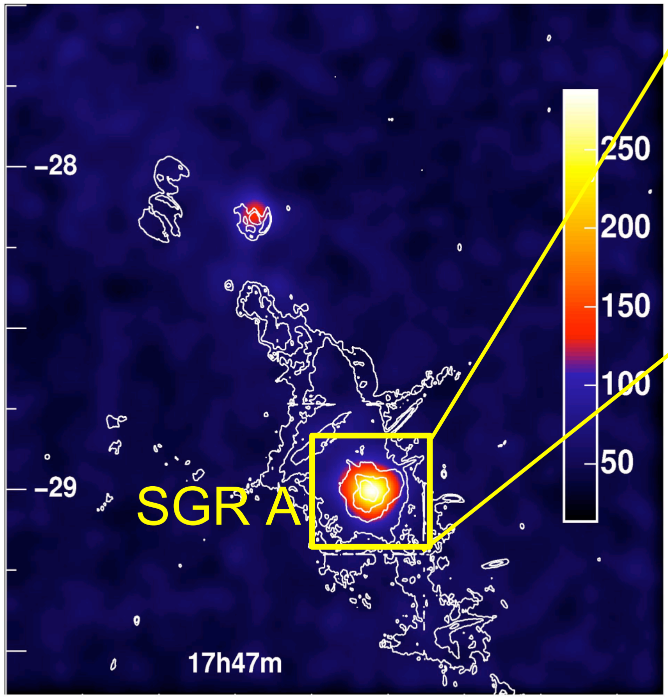


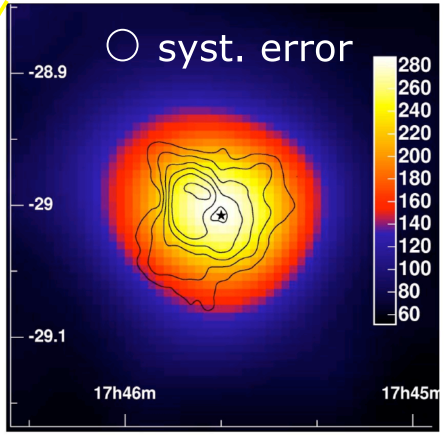
Density and mass profiles

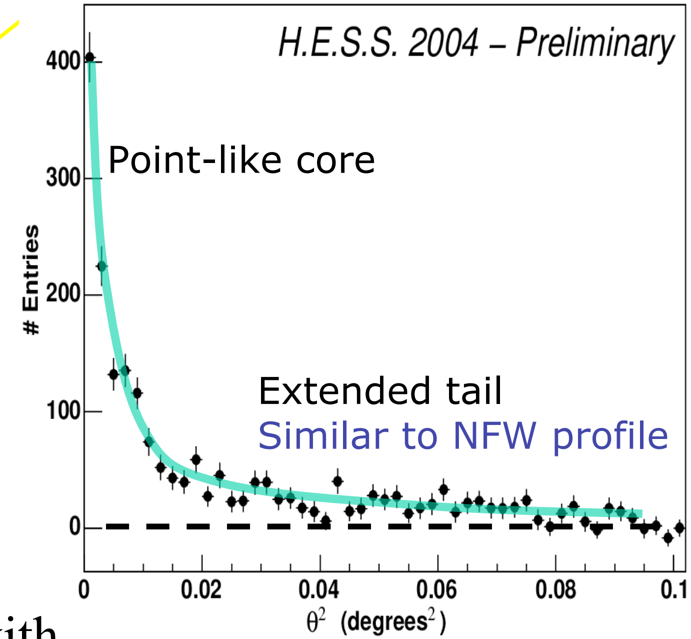
γ-ray flux from χ annihilation

Flix, Klypin, Martinez, Prada, Simonneau

Galactic Center



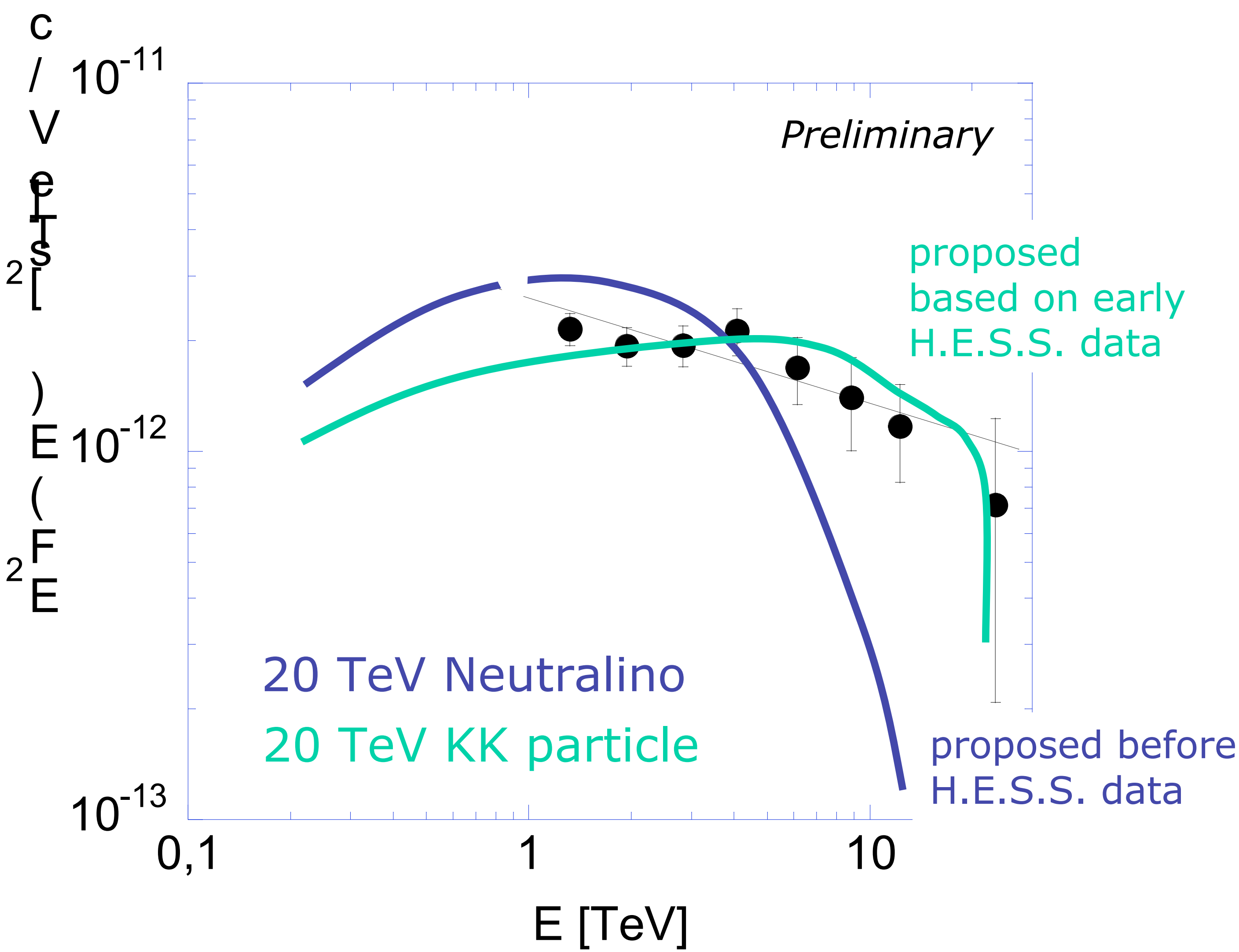




-> Consistent with
SGR A* to 6’’ and slightly extended.

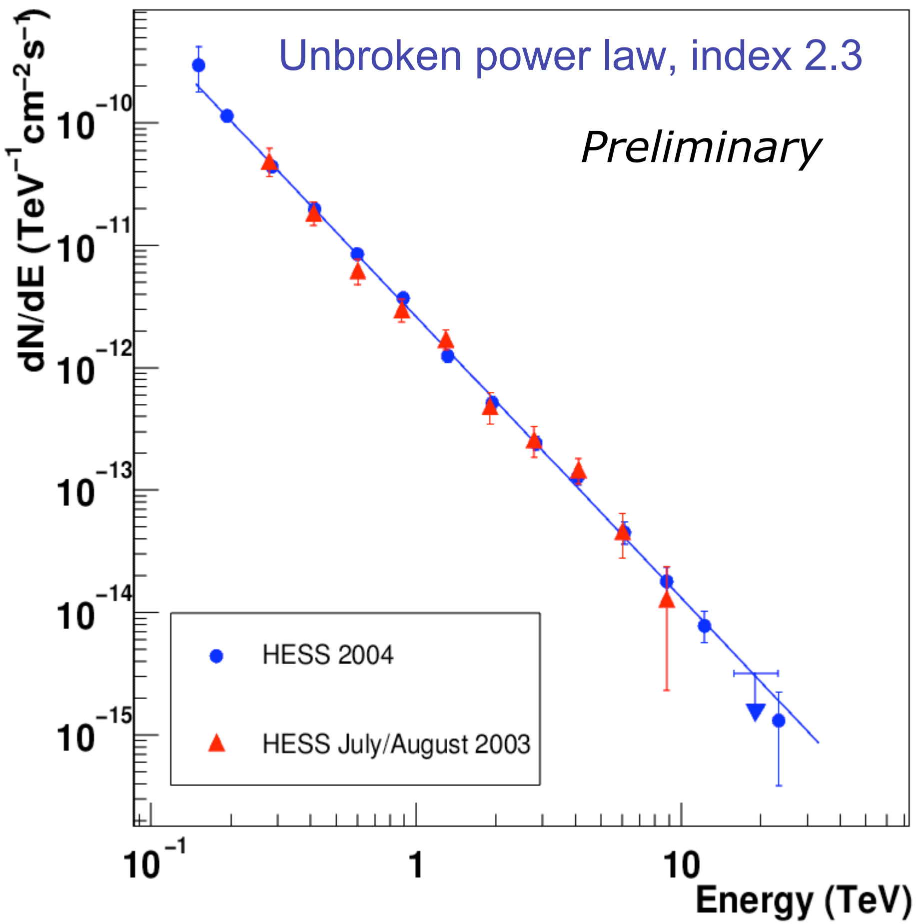
-> No significant variability from year to minute scales (in ~40 h obs. time distributed over 2 years)

Dark matter annihilation ?

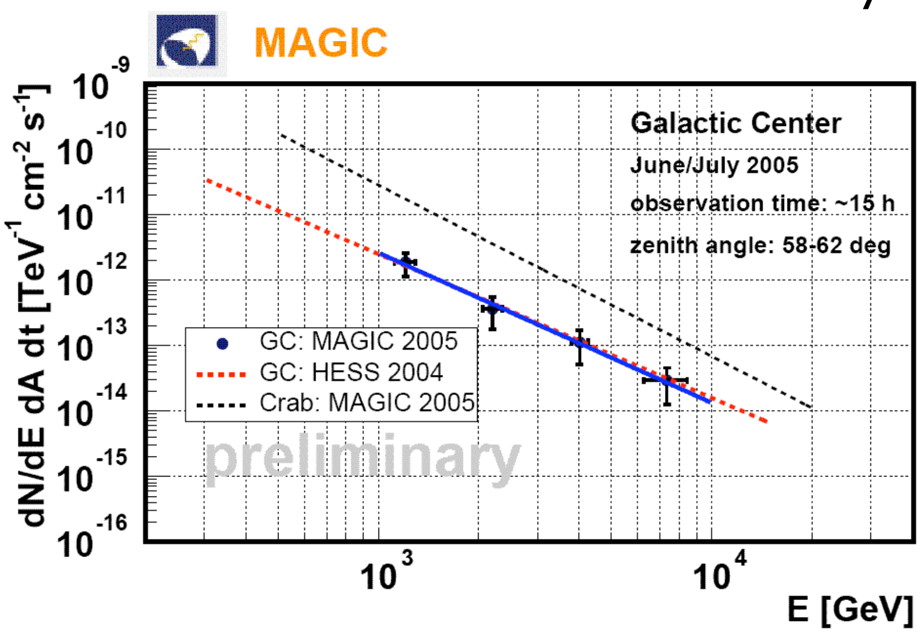


⏩ J. Ripken ICRC 2005

Gamma ray spectrum



Preliminary

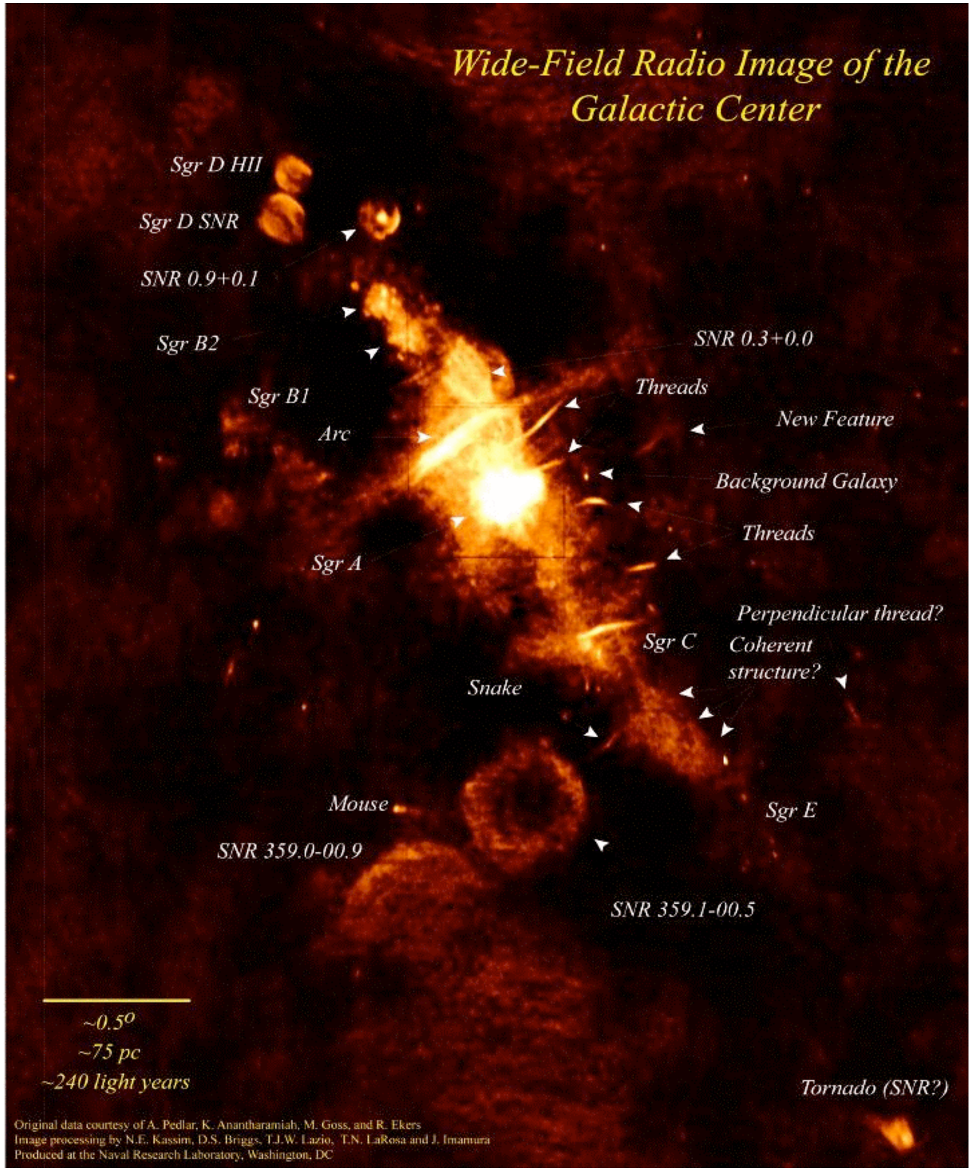


Good agreement between HESS and MAGIC (large zenith angle observation).

⇒**Very unlikely to be dark matter.**

⇒**Presence of a strong gamma-ray source outshines any possible DM signal**

The Galactic Center region



Proximity (~8 kpc) and possibly high DM concentration

BUT

Extreme environment

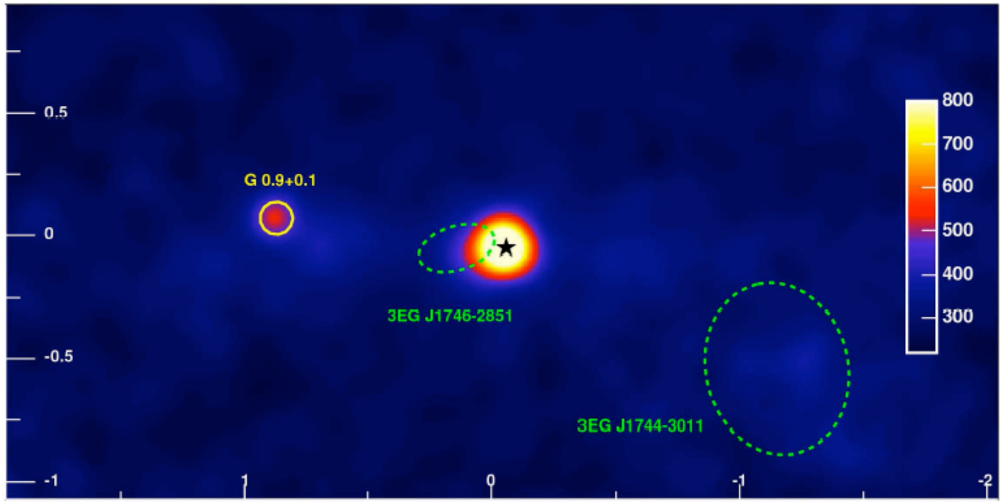
Totally obscured in the Optical
Only visible from Radio to IR and high energies

GC contains:

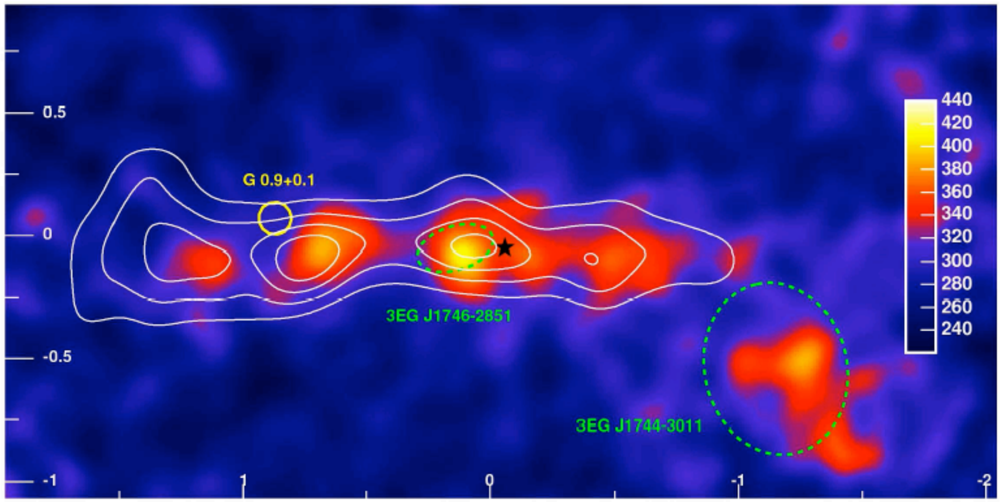
10 % of galactic interstellar medium
[giant molecular clouds]
Host the nearest [hypothetical] super-massive BH
Variety of VHE emitters: SNRs, Molecular Clouds, non-thermal arcs...

The Galactic Centre Ridge

HESS



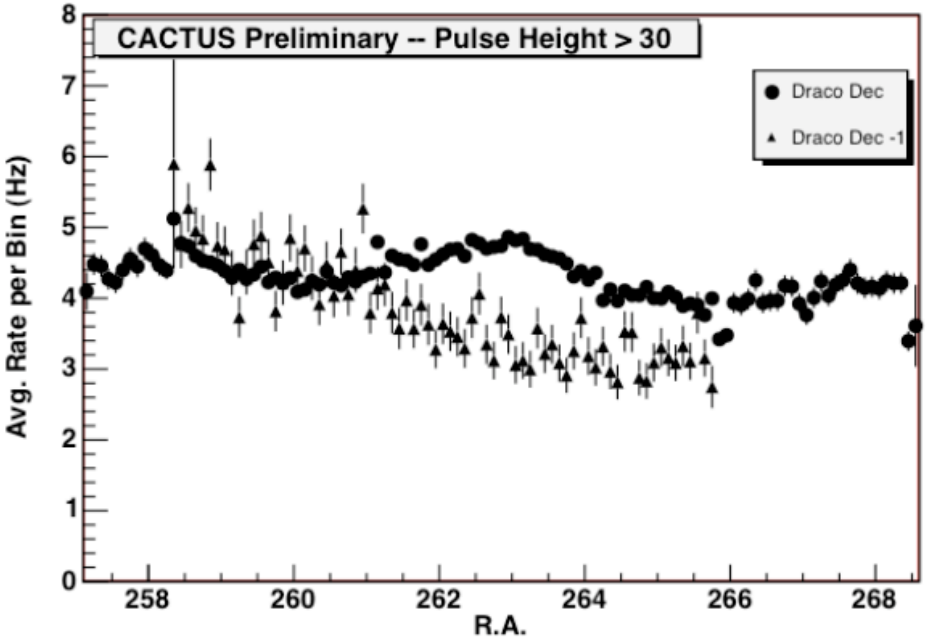
Galactic Centre gamma-ray count map



Same map after subtraction of two dominant point sources =>
Clear correlation with molecular gas traced by its CS emission

Best targets for Dark Matter searches

- Dwarf spheroidal galaxies with M/L ~ 100-200:



- **DRACO**: Θ_{cul} ~ 30º

  RA15 08.2 - DEC +67 23

  D = 82 Kpc.

  CACTUS claim under scrutiny.

- **Ursa Minor**: Θ_{cul} ~ 40º

  RA17 19.2 - DEC +57 58

  D = 69 Kpc.

7 hours → 30‘000 excess events above the background. Angular region extending approximately 1 degree around the center of Draco.

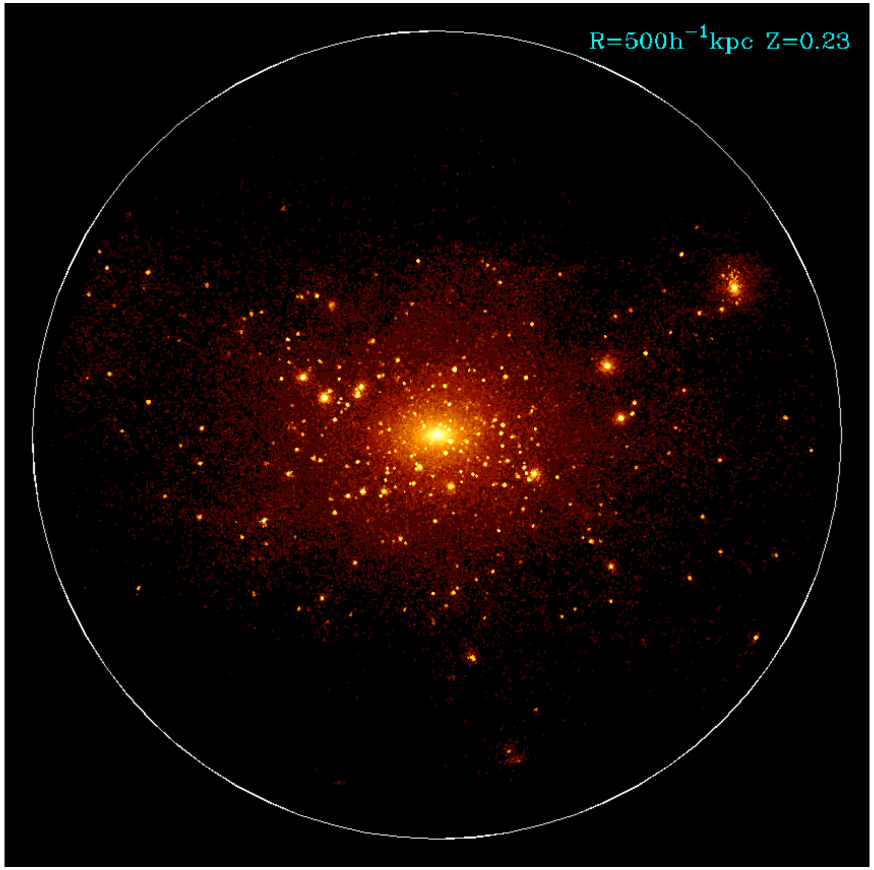
DRACO dwarf galaxy

CACTUS telescope has a rather poor angular resolution of 0.3º [Crab nebula].

Most of the excess events are low energetic, between 50 GeV and 150 GeV.

Best targets for Dark Matter searches

- Dark Matter halo substructure:



Anatoly Klypin

- **Compact High Velocity Clouds.**

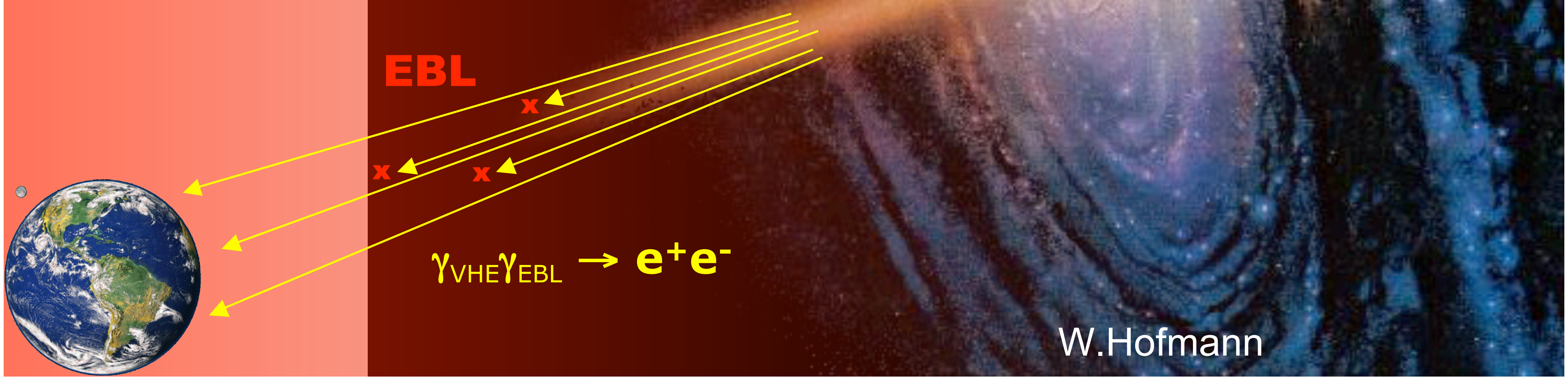
  (as “missing” satellites)

- **as gamma diffuse background.**

Simulation of
local group:
~300 satellites
with V_{circ} > 10 km/s

Extragalactic TeV astronomy

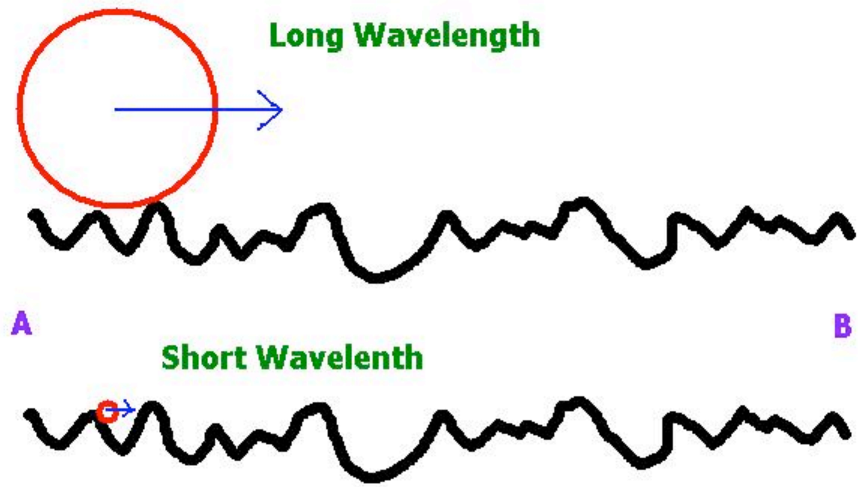
- Space is filled with diffuse extragalactic background light: sum of starlight emitted by galaxies through history of universe
- Gamma Rays absorbed by interaction with Background radiation fields



Energy dependence of the Speed of light

• Space-time at large distances is "smooth" but, if Gravity is a quantum theory, at very short distances it might show a very complex ("foamy") structure due to Quantum fluctuations.

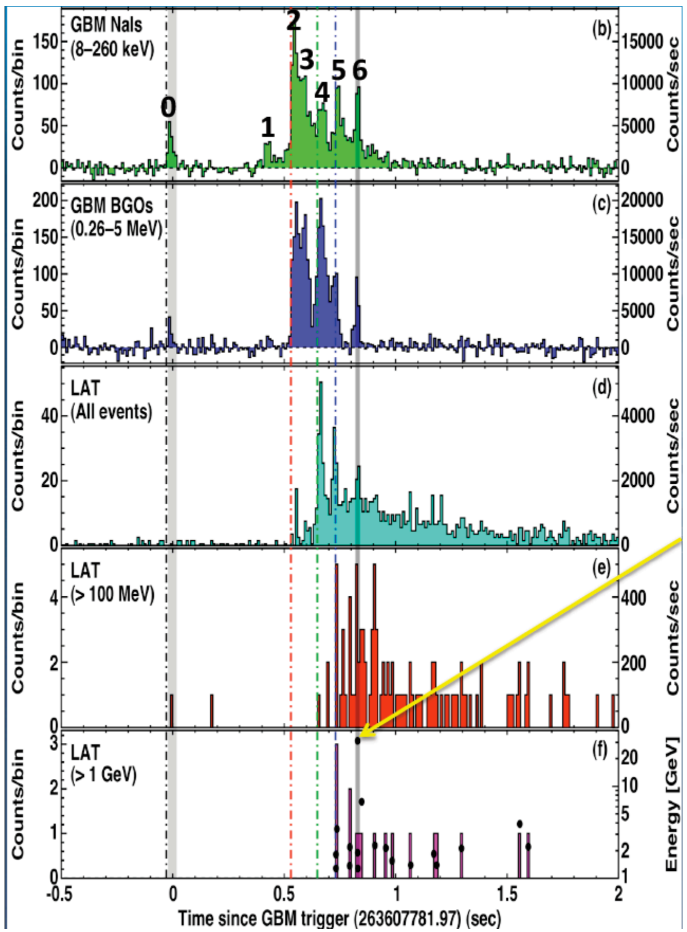
• A consequence of these fluctuations is the fact that the speed of light in vacuum becomes energy dependent.



• The energy scale at which gravity is expected to behave as a quantum theory is the Planck Mass

$$E_{QG} = O(M_P) = O(10^{19})\ \mathrm{GeV}$$

However: Fermi GRB 090510



- LAT emission delayed
- Spectral evolution
  - High energy emission starts at 2° GBM peak
  - > 1GeV emission starts at 4° GBM peak
  - Highest energy photon (31 GeV) located on 6° GBM peak
- Clear power law spectral component at high energy → deviation from Band function
- Powerful outflow
  - $\Gamma_{Lorentz} \approx 1000$
- Lorentz InVariance test
  - M_{QG} > several M_{planck}

ArXiv 0908.1832, accepted by Nature