Stefano Profumo

University of California, Santa Cruz

Santa Cruz Institute for Particle Physics

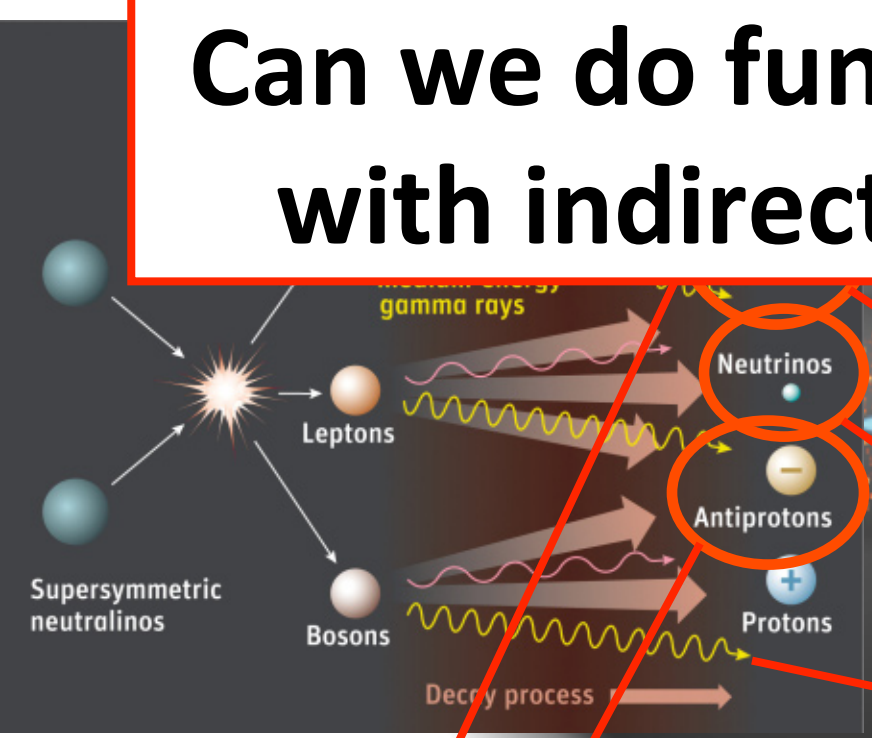
Fundamental Physics from the Sky:
Cosmic Rays, Gamma Rays and the Hunt for Dark Matter

PASCOS 2012

Wednesday June 6, 2012, Merida, Mexico

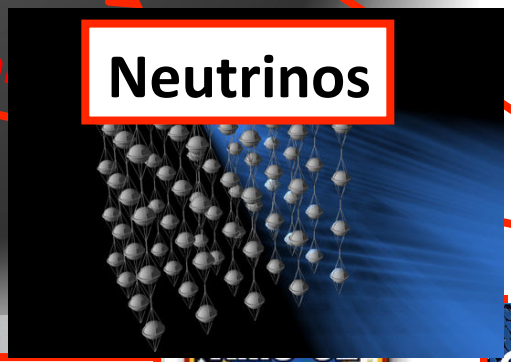
“Indirect” Dark Matter Detection

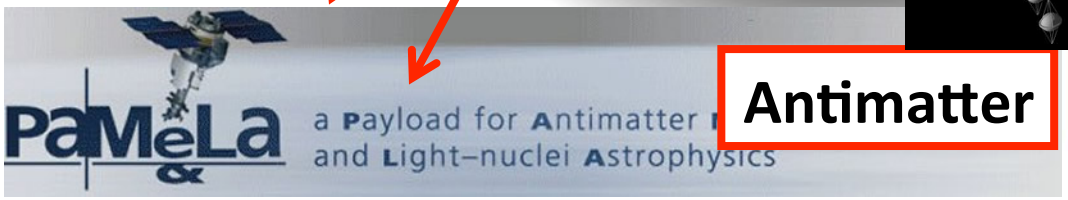
Can we do fundamental physics with indirect DM detection?



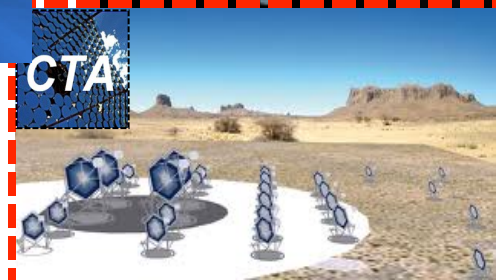
Inverse Compton

HE Neutrinos





Antimatter

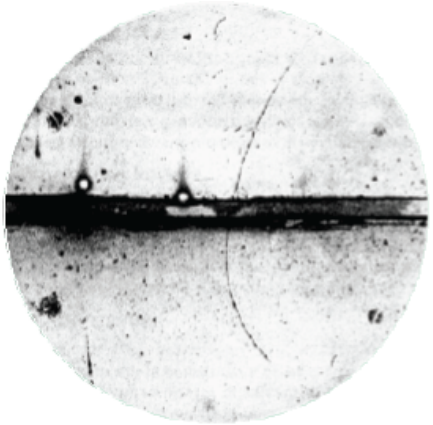


“Indirect” Dark Matter Detection

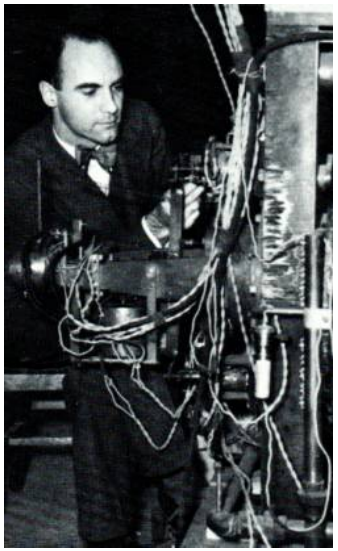
Can we do fundamental physics with indirect DM detection?

“Indirect” Dark Matter Detection

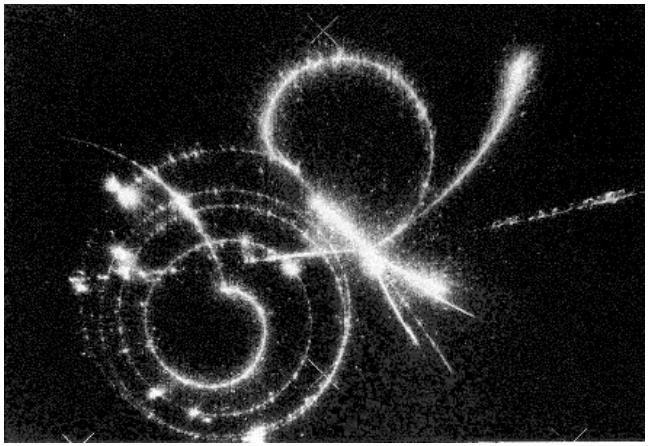
Can we do fundamental physics with cosmic-ray/gamma-ray data?



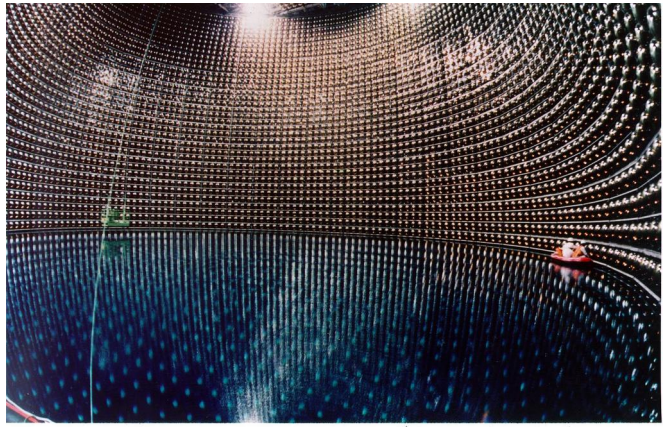
Antimatter
(positron, Anderson, 1932)



Second Generation
(muon, Anderson, 1936)



Pions ("Yukawa" particles)
(Lattes, Powell and
"Beppo" Occhialini)

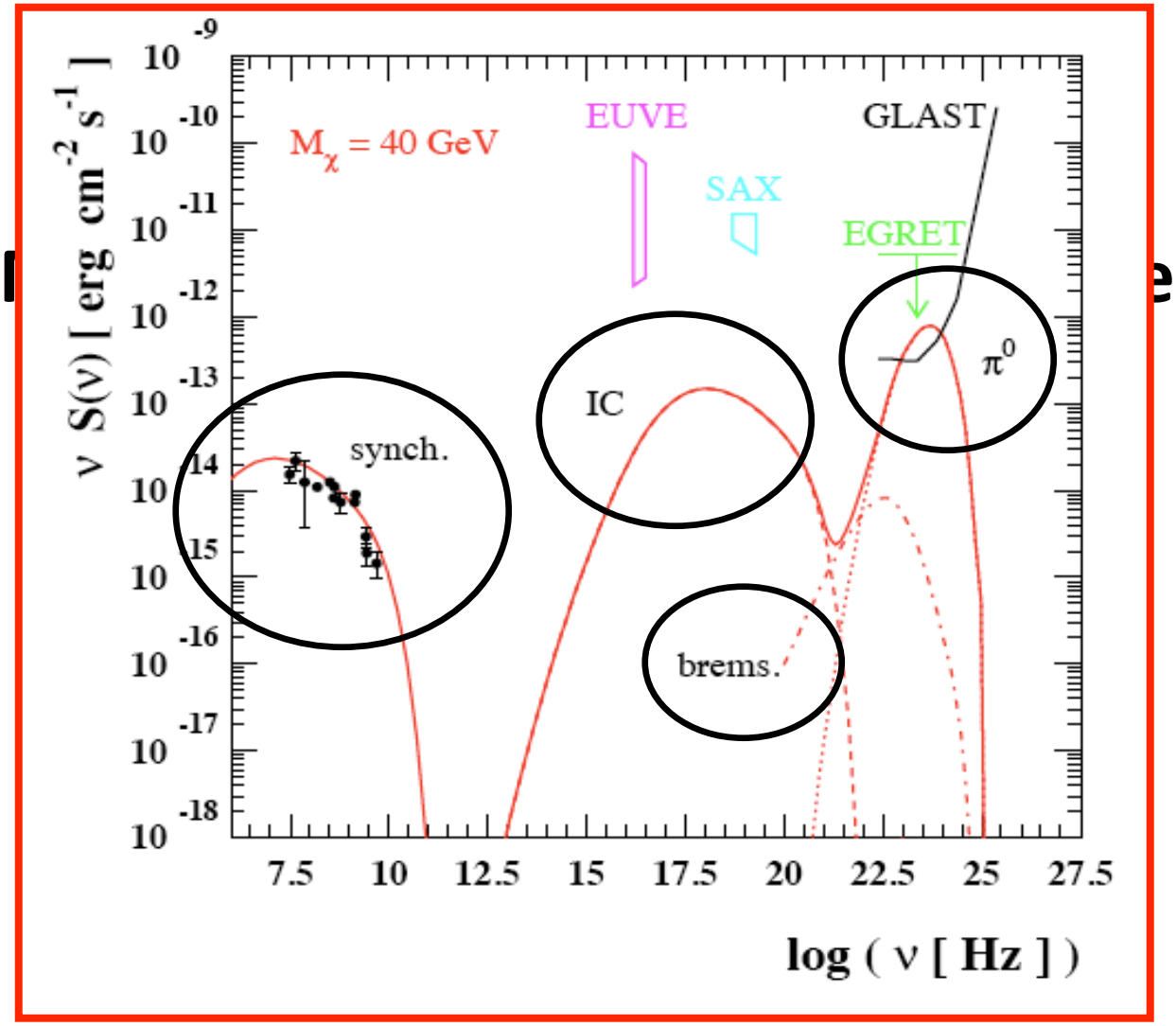


Neutrino Masses

“Indirect” Dark Matter Detection

Multi-wavelength, Multi-messenger

“Indirect” Dark Matter Detection



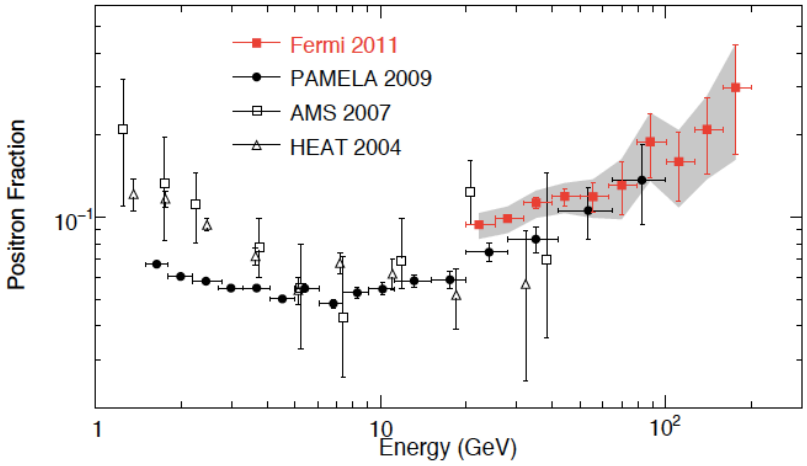
“Indirect” Dark Matter Detection

Multi-wavelength, Multi-messenger

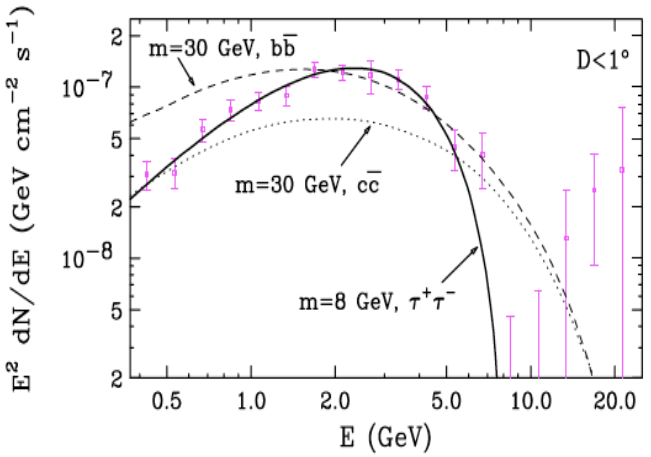
Astrophysical Backgrounds

Worse Astrophysical Backgrounds = Most Exciting Places to Look at!

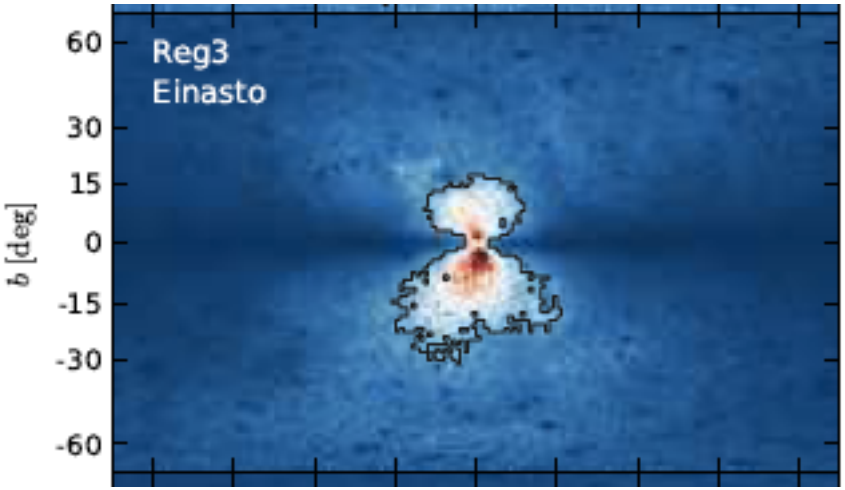
Cosmic Ray Electrons and Positrons: the Pamela Anomaly

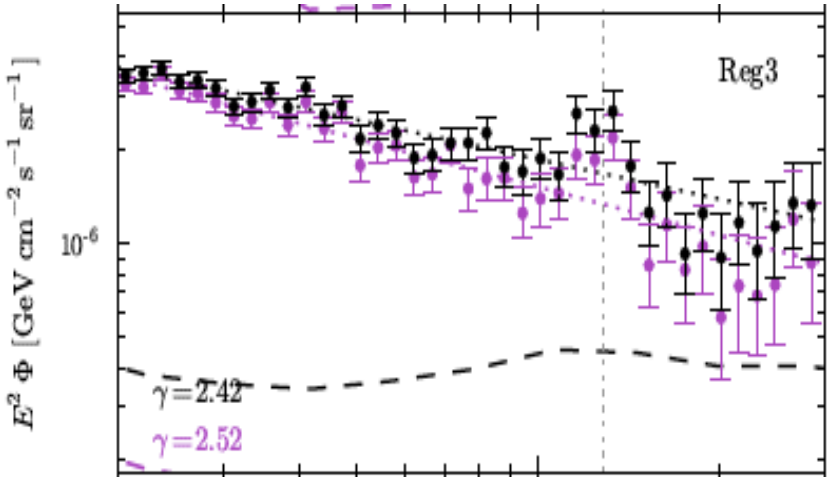


Dark Matter annihilation in the Galactic Center?

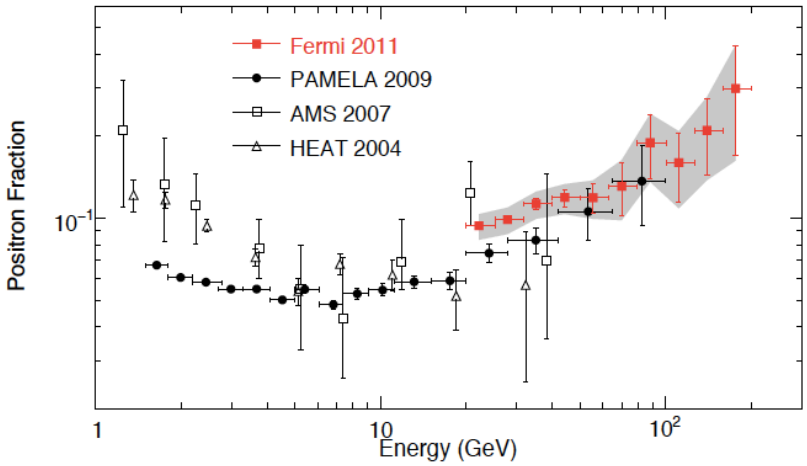


A 130 GeV Gamma-Ray Line?

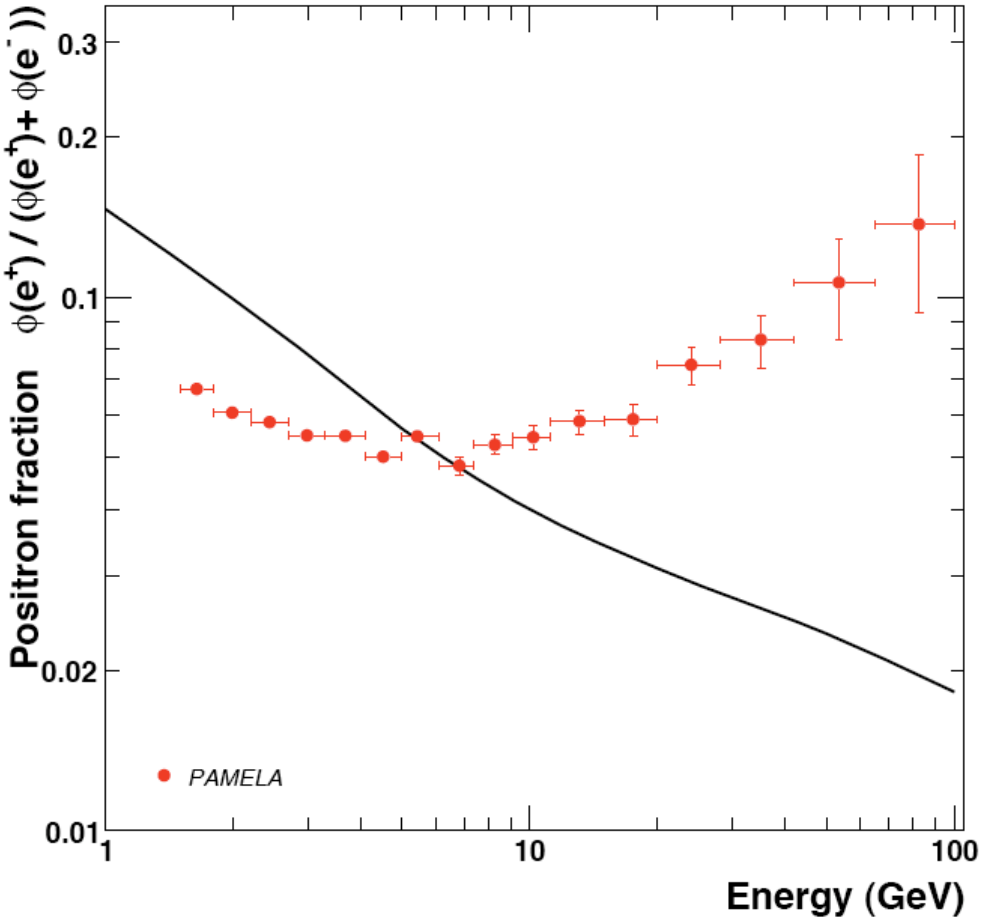




Cosmic Ray Electrons and Positrons: the Pamela Anomaly



PaMeLa
a Payload for Antimatter Matter Exploration
and Light-nuclei Astrophysics



Adriani et al, Nature, 2009, 900+ citations!

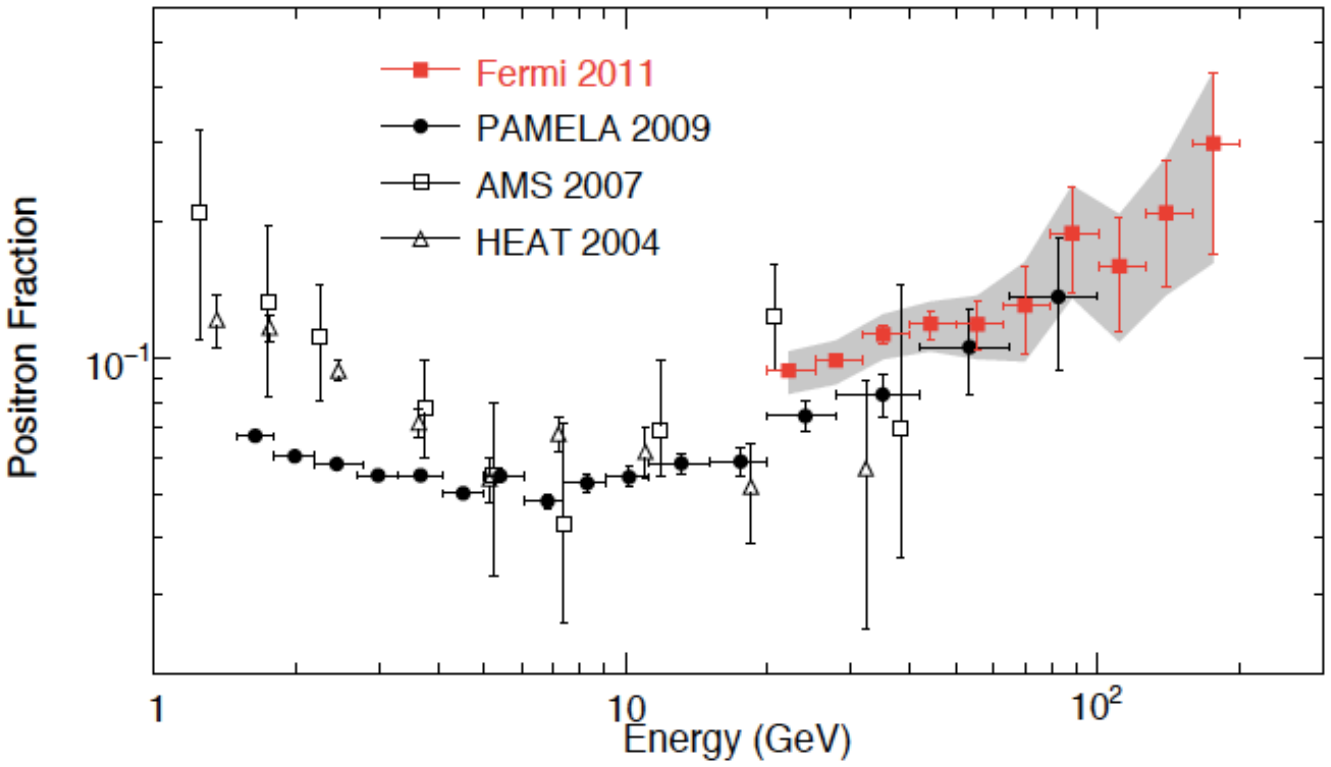
is this real?

Experimentalists get ignored if they are right, and **hugely cited** if they are **wrong**.

Theorists get ignored if they are wrong, but a **Nobel** Prize if they are **right**.*

Superluminal Neutrinos @ OPERA:
>200 theory papers

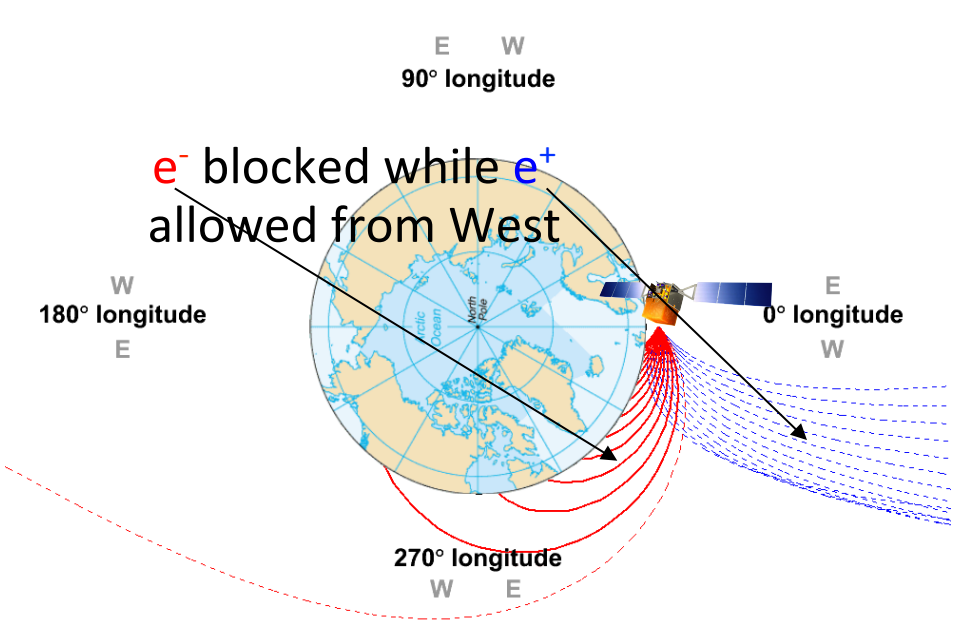
* quoted from the Guardian

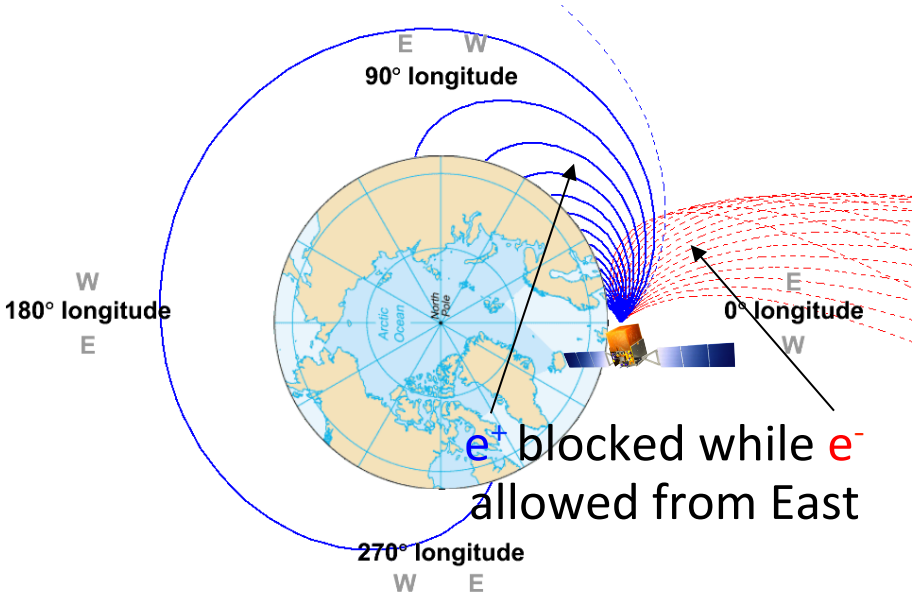


How does **Fermi** tells **e^+** apart from **e^-**?

Fermi-LAT Collaboration, 1109.0521

Geomagnetic field + solid **Earth** shadow = directions from which only electrons or **only positrons** are allowed





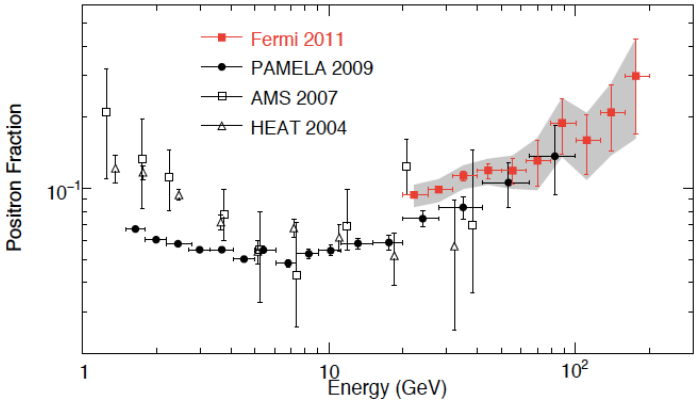
For particular directions, electrons or positrons are completely forbidden

Pure e^+ region looking West and pure e^- region looking East

Regions vary with **particle energy** and **spacecraft position**

Slide concept: Justin Vandenbroucke

Why is this measurement **important**?



1. For **every** (50 GeV) **cosmic-ray positron**,
10 electrons and **10,000 protons**!

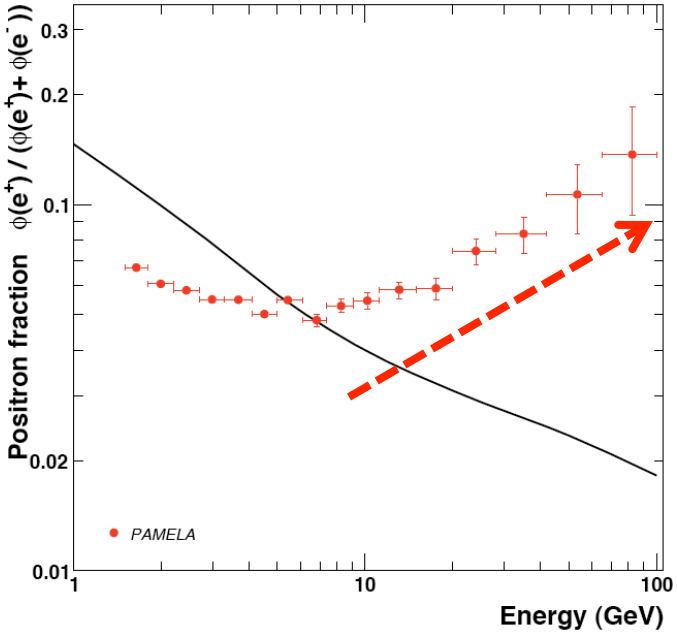
2. Extends Pamela results to **higher energy**, E=200 GeV

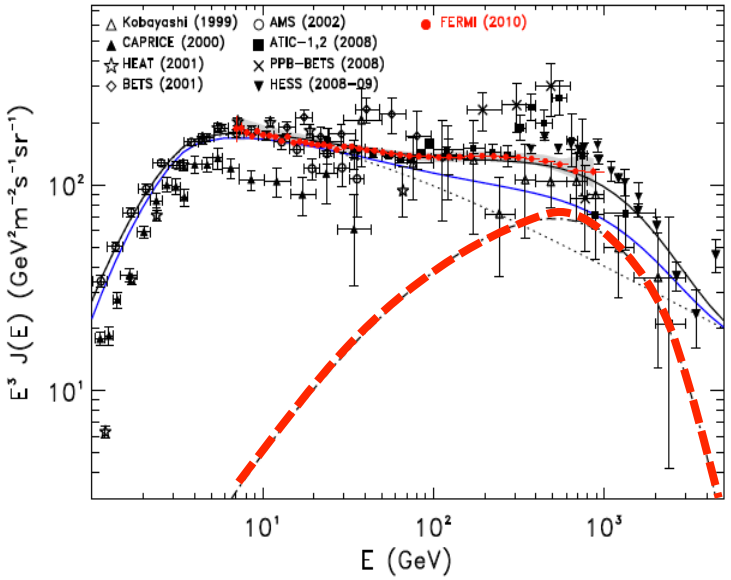
3. **Rules out** certain **models** for positron fraction excess (SNR inhomogeneity, Shaviv et al 2009)

it probably is real

but what is it then?

Solution: postulate **additional source**
of (high-energy) electrons and positrons:





What is the nature of this
new powerful electron-positron **source**??

700/850 papers advocate Dark Matter

…**despite** some obvious and significant **issues**:

(i) Need very **large annihilation rates**
($\langle\sigma v\rangle \sim 10^2$-$10^3 \times 10^{-26}\ cm^3/s$)

(ii) Need rather **large masses** (~TeV)

(iii) Need special annihilation or decay modes
(suppress **antiprotons** + have a hard spectrum)
e.g.: $\mu^+\mu^-$, or 4μ

interesting **riddle** to test a **theorist's creativity**!

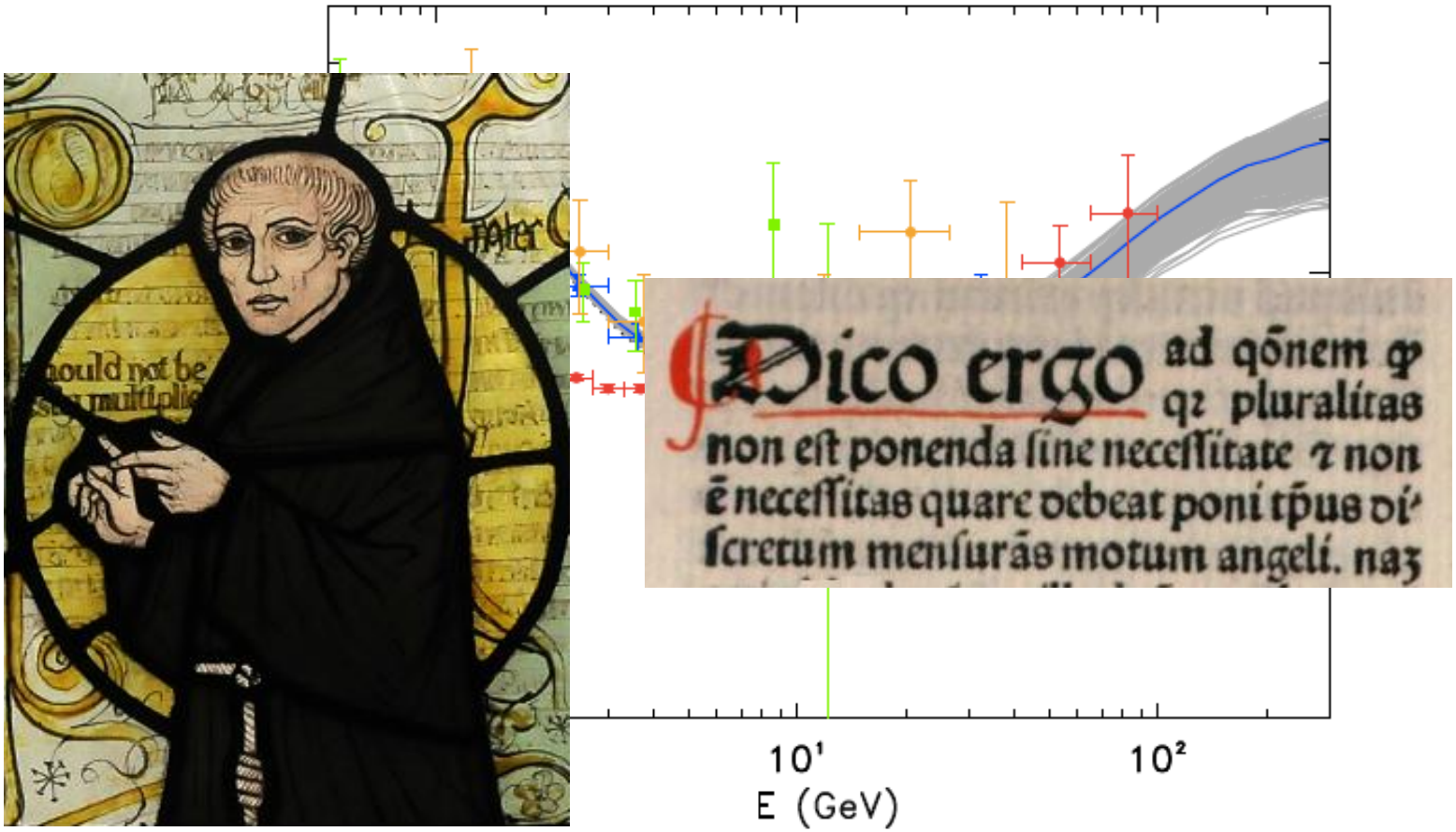
Redman's Theorem

"Any competent theoretician can fit any given theory to any given set of facts" (*)

Roderick O. Redman
(b. 1905, d. 1975)
Professor of Astronomy
at Cambridge University

(*) Quoted in M. Longair's "High Energy Astrophysics", sec 2.5.1 "The psychology of astronomers and astrophysicists"

"Dissecting Pamela with **Occam's Razor**:
existing, well-known Pulsars naturally account for the "anomalous" Cosmic-Ray Electron and Positron Data"



Profumo, 0812.4457; Grasso, Profumo, 0905.0636

…plus, radio-quiet **gamma-ray** pulsars!

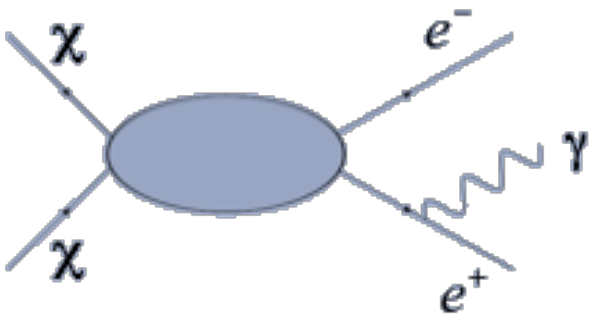
Gendelev, SP and **Dormody**
JCAP 1002 (2010) 016

Dark Matter: a "**Universal**" Phenomenology

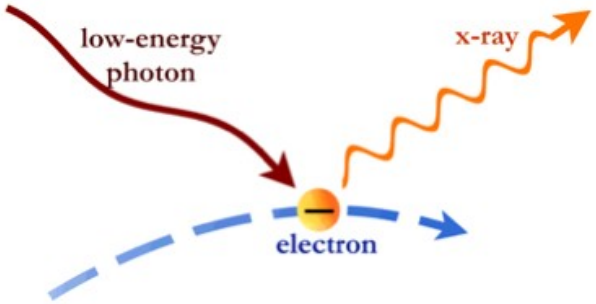
Large **annihilation rates**

Large **masses**

Hard **charged leptons**



Final State Radiation

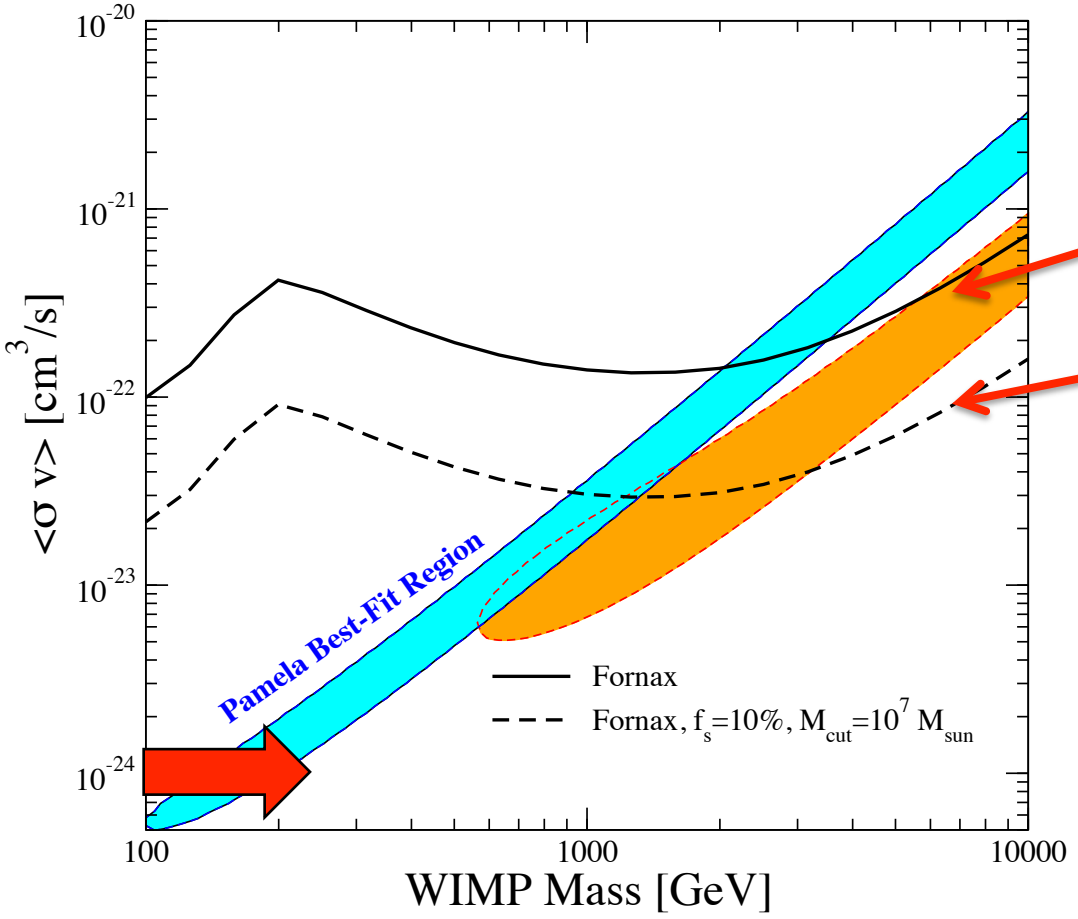


Inverse Compton

Gamma-Ray Searches from **Galaxy Clusters**

Jeltema, Profumo & Fermi-LAT Collaboration, JCAP 2010, arXiv: 1001.4531

Gamma-Ray Searches from **Galaxy Clusters**

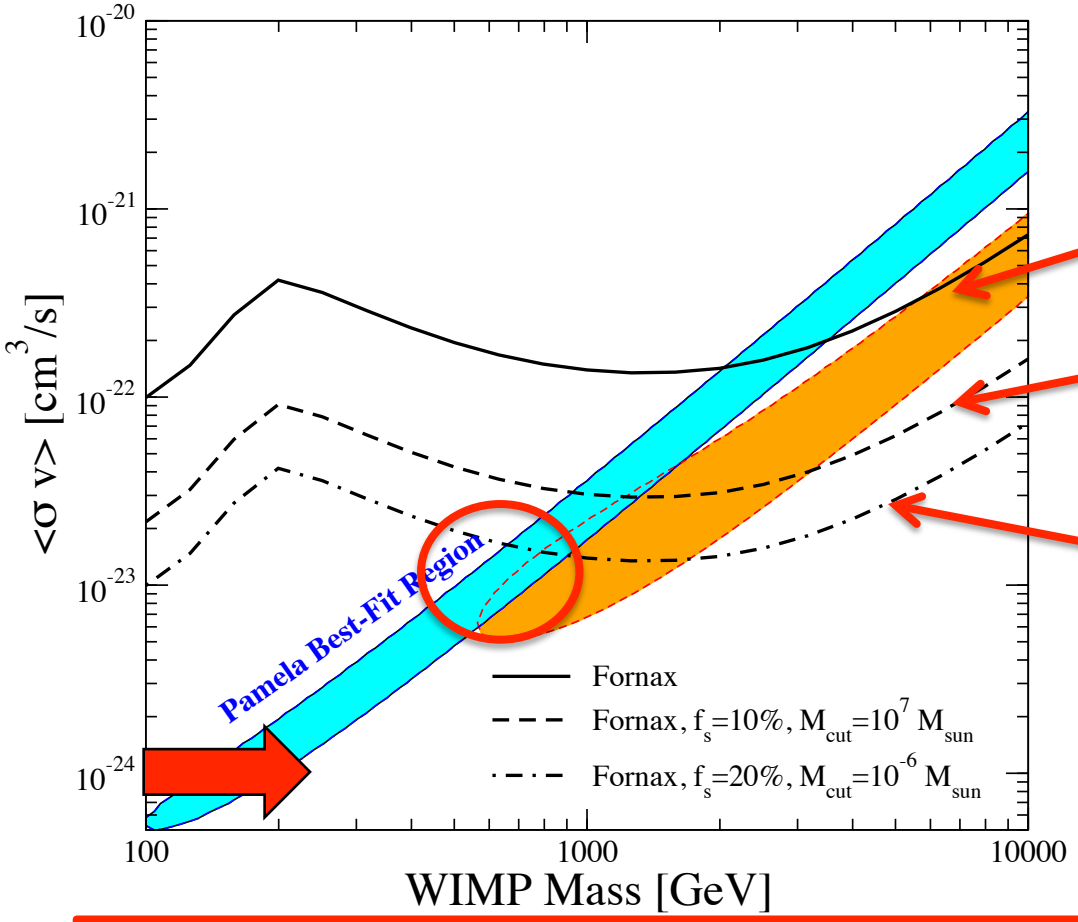


no substructure

galaxies only

Jeltema, Profumo & Fermi-LAT Collaboration, JCAP 2010, arXiv: 1001.4531

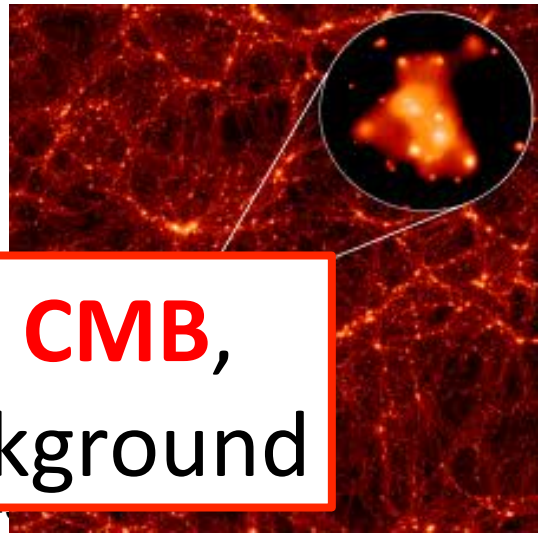
Gamma-Ray Searches from **Galaxy Clusters**



no substructure

galaxies only

substructure with M > 10^{-6} M_{Sun}



Additional constraints from **CMB**, extragalactic **gamma-ray** background

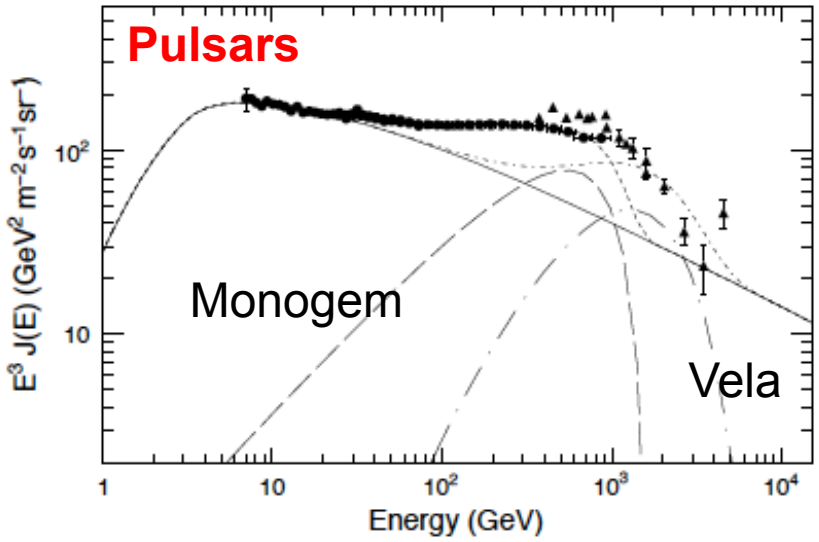
Jeltema, Profumo & Fermi-LAT Collaboration, JCAP 2010, arXiv: 1001.4

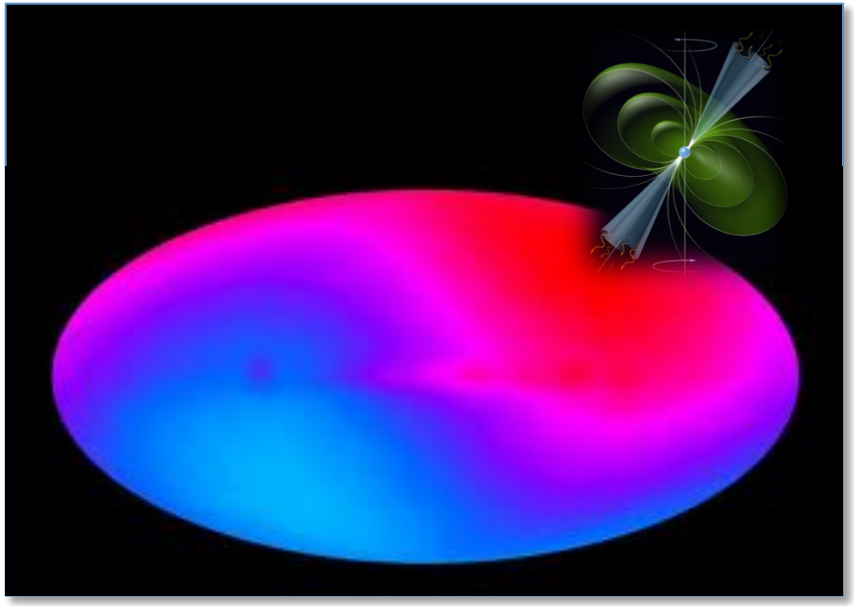
can we **discriminate** between

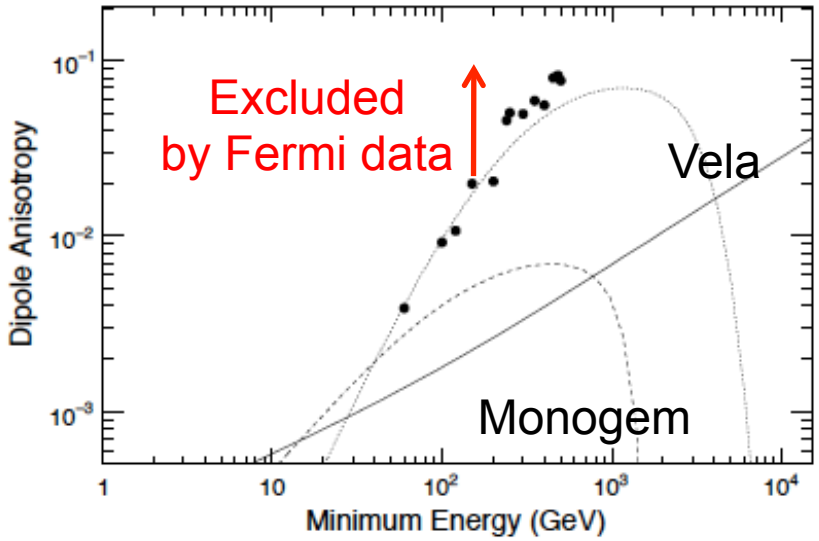
dark matter and **pulsars**?

Nearby **Pulsar** → Anisotropy in the arrival direction *(sufficient, not necessary)*

Dark Matter → Diffuse secondary component *(observetionally tricky)*





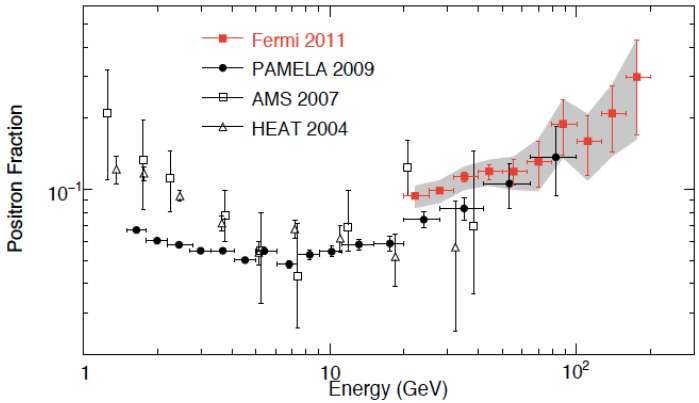


No Anisotropy observed in the Fermi e+e- E>60 GeV data

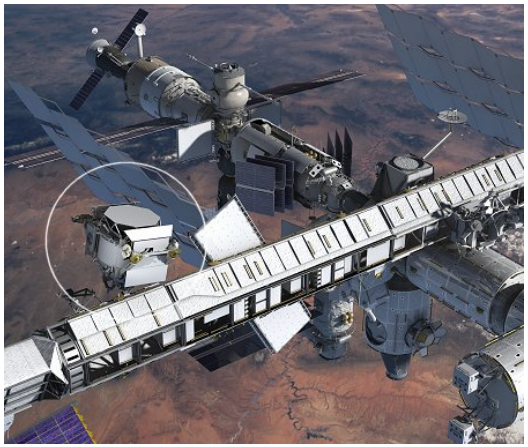
Pulsar interpretation entirely **consistent** with **all data**

Fermi-LAT Collaboration, PRD, 1008.5119

The origin of the **positron excess** is still unsettled



Pulsars explanation is **fine**;
Dark Matter is a **viable**,
though highly **constrained**, option



What Next?

Update on **AMS**

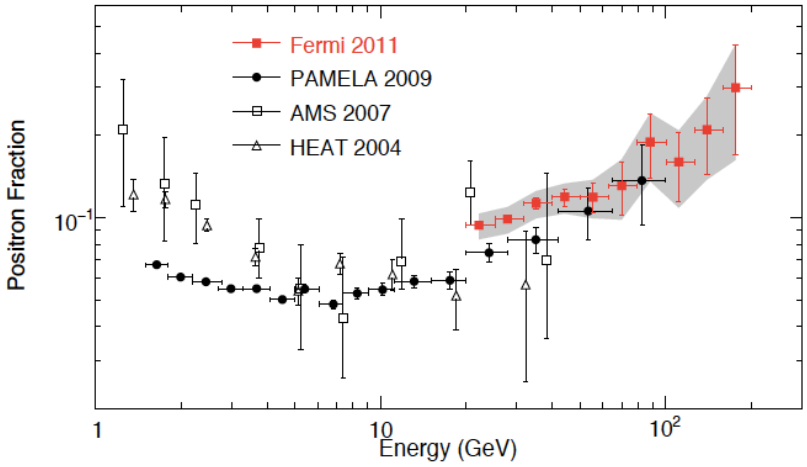
Launched 5/16/2011
Installed on ISS 5/19/2011

- Ongoing **Calibration** & Alignment
- **Jan 2013**: $e^+/(e^+ + e^-)$; analysis by two independent groups within Collaboration*
- Next priority: **antiprotons**; then, high-Z

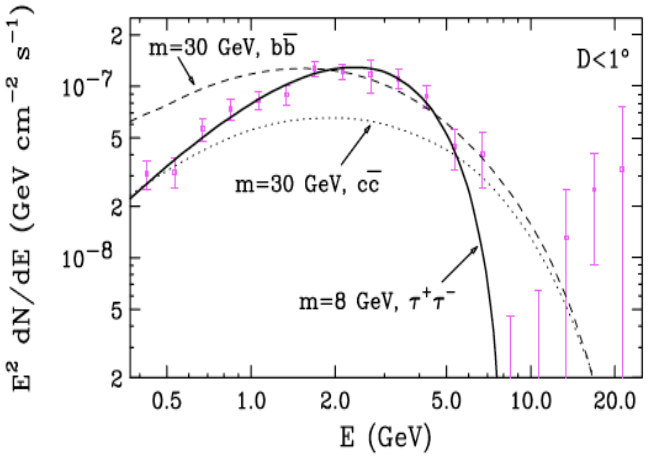
* Iris Gebauer, private communication

the problem with the **Galactic Center**: "**under-fitting**" versus "**over-fitting**"

Cosmic Ray Electrons and Positrons: the Pamela Anomaly



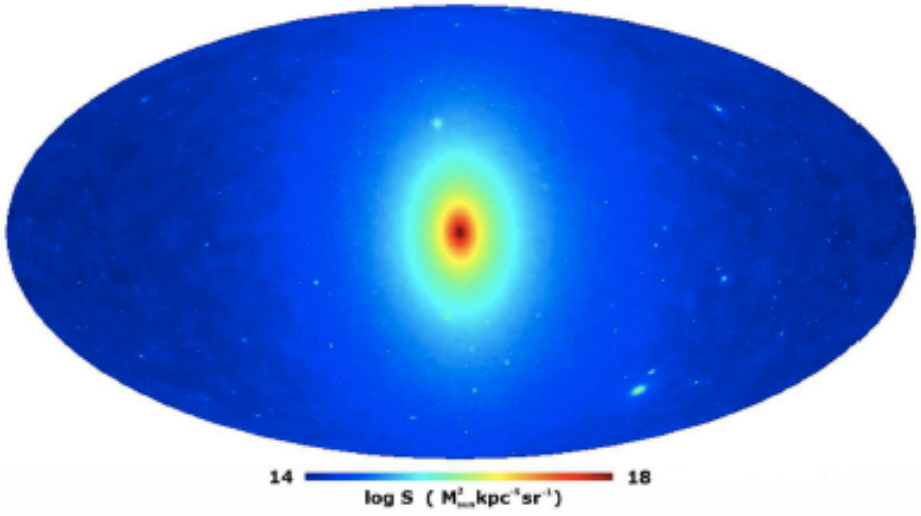
Dark Matter annihilation in the Galactic Center?



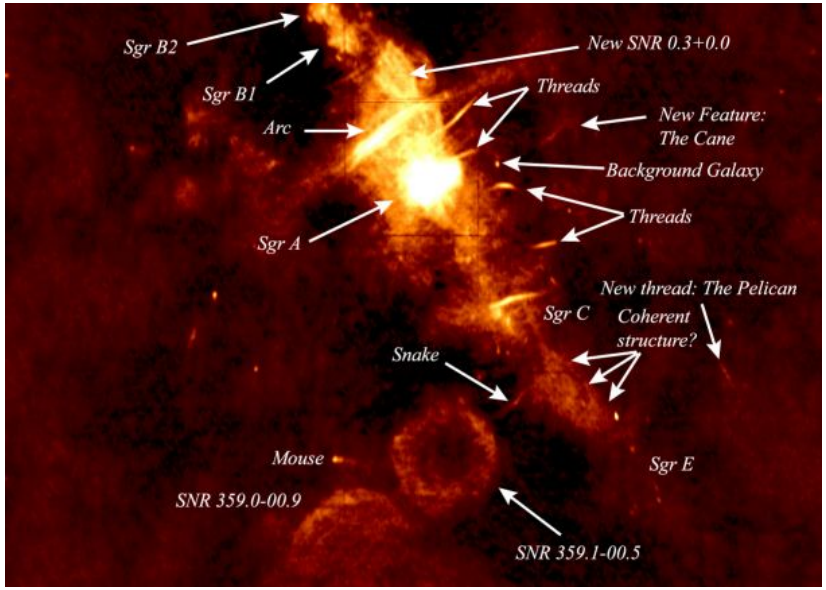
The **Galactic Center** Region: a Holy Grail or a Hornet's Nest?

- Largest **Cosmic Ray** Density
- Largest **Gas** and **Radiation** Densities
- Largest concentration of Galactic **Gamma Ray sources**

Largest (known) Galactic **Dark Matter** Density



Springel et al, 2009



Kassim et al, 1999

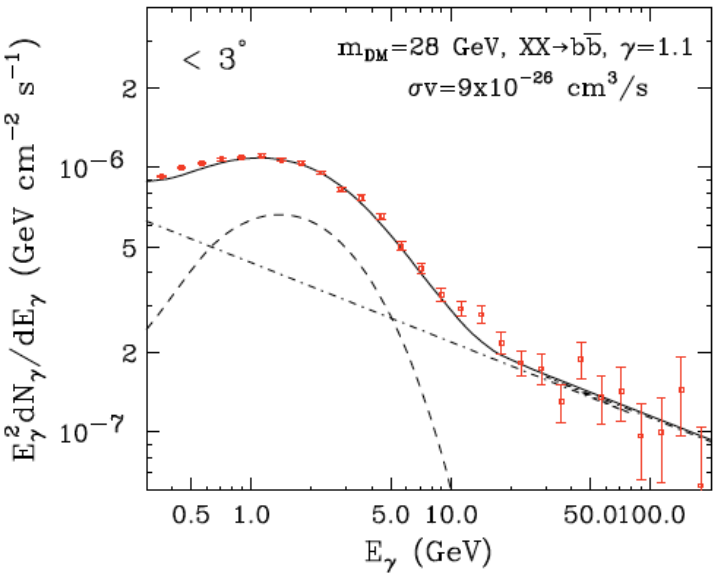
Background **Dark Matter particle**

Oct. 2009

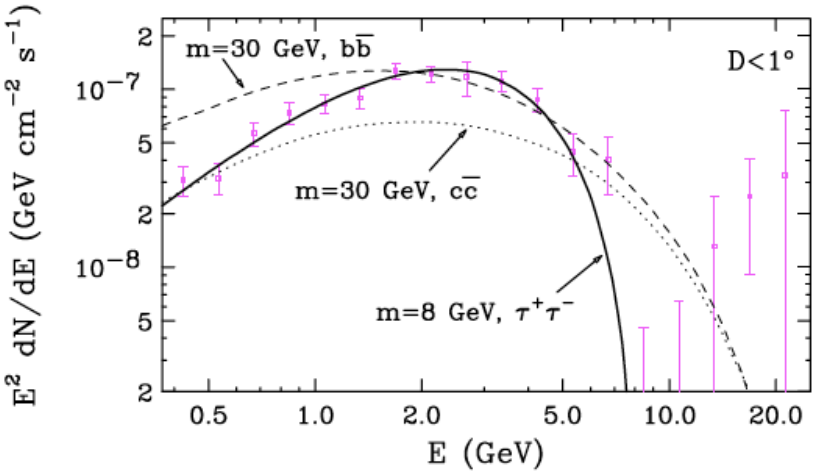
Goodenough, Hooper

Exponential angular fall-off
Power-law spectrum

28 GeV, bb quark



	Background	Dark Matter particle
Oct. 2009 Goodenough, Hooper	*Exponential angular fall-off* *Power-law spectrum*	*28 GeV, bb quark*
Oct. 2010 Hooper, Goodenough	$r^{-1.55}$ *fall-off* Spectrum: extracted from >2deg region	*8 GeV,* $\tau^+\tau^-$



the danger of background “**under-fitting**”:

may end up with a “**Goodenough Hooperon**”

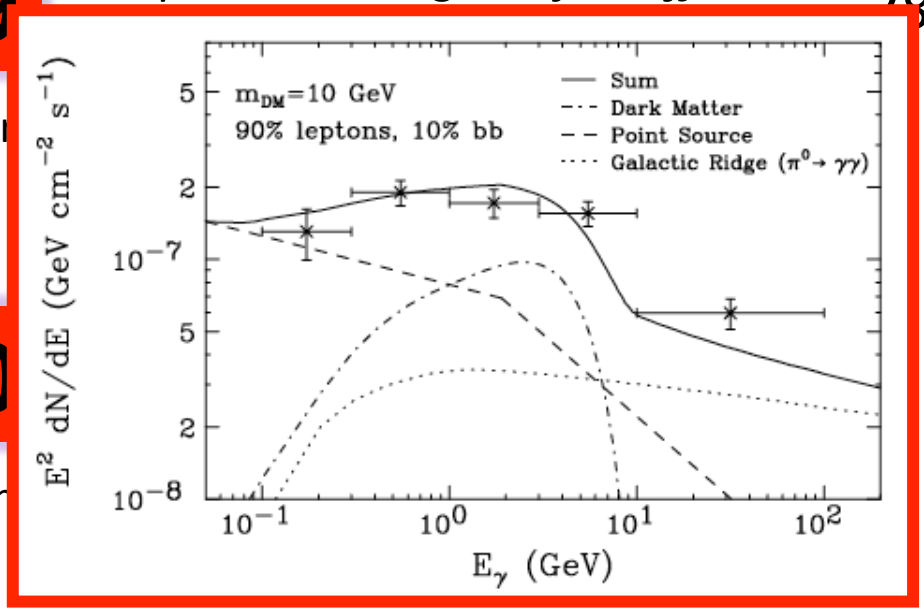
Background **Dark Matter particle**

Oct. 2009

Goodenough, Hooper

Exponential angular fall-off

28 GeV, bb quark



Oct. 2010

Hooper, Goodenough

8 GeV, $\tau^+\tau^-$

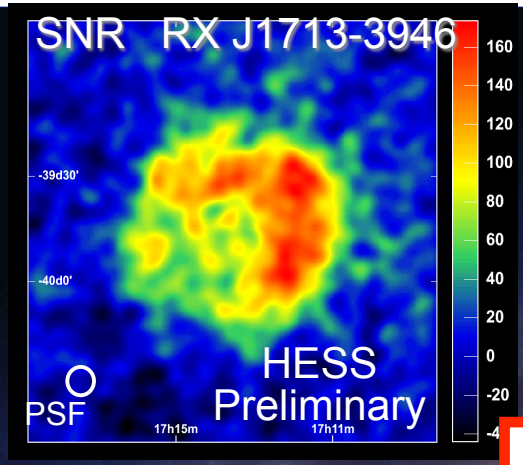
Oct. 2011

Linden, Hooper

Angular distrib: gas maps
Spectrum from: π^0 decay
plus point-source

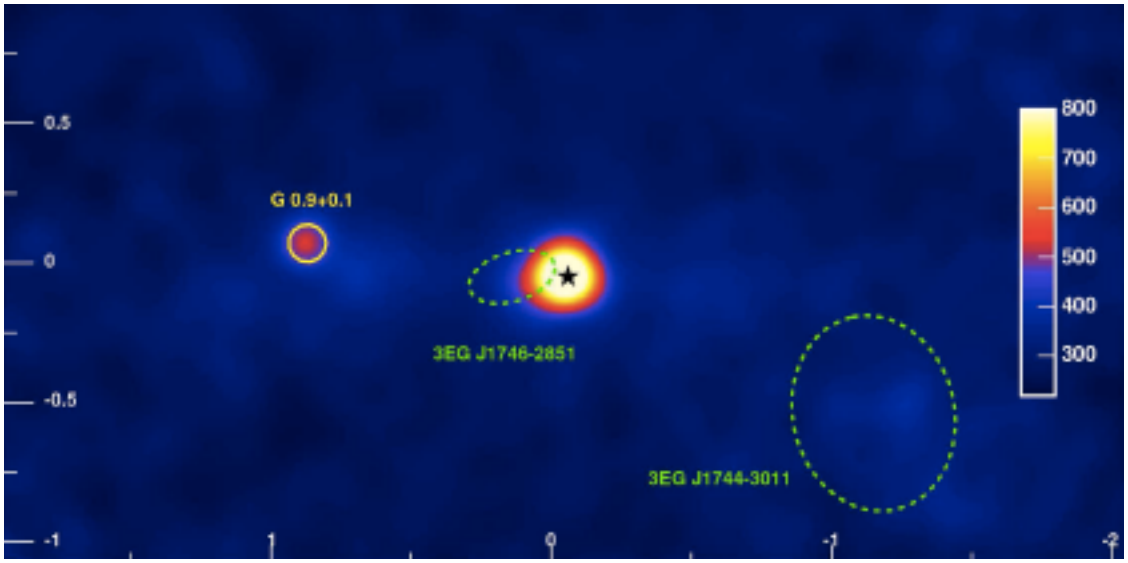
~10 GeV,
$\tau^+\tau^-$ or bb,
or generic
diffuse excess

“Over-fitting”



[slide from Igor Moskalenko]

One of the elephants in the room: **Sgr A***

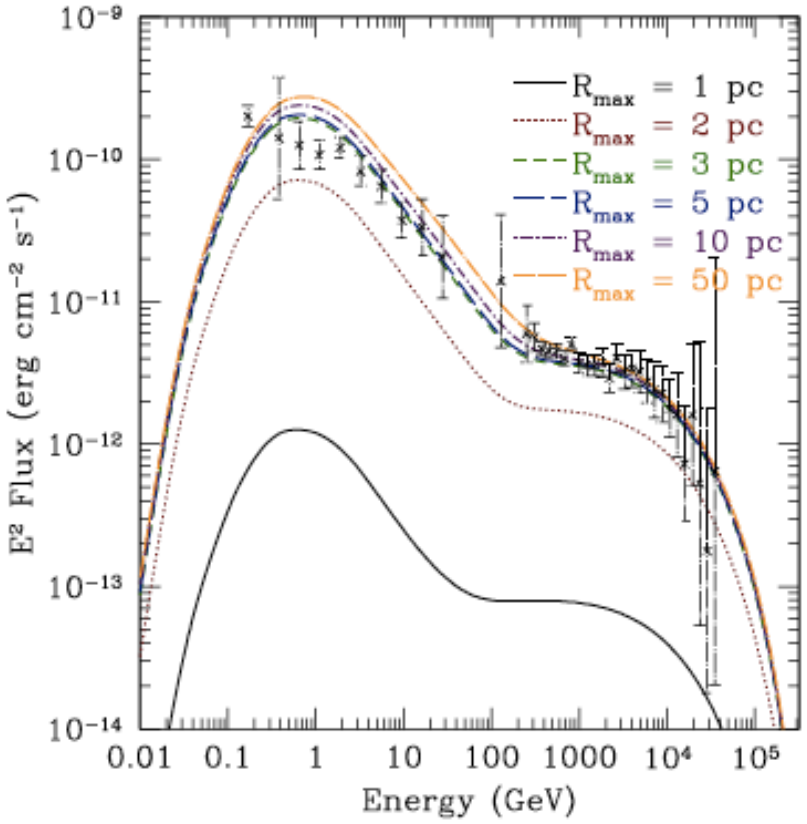


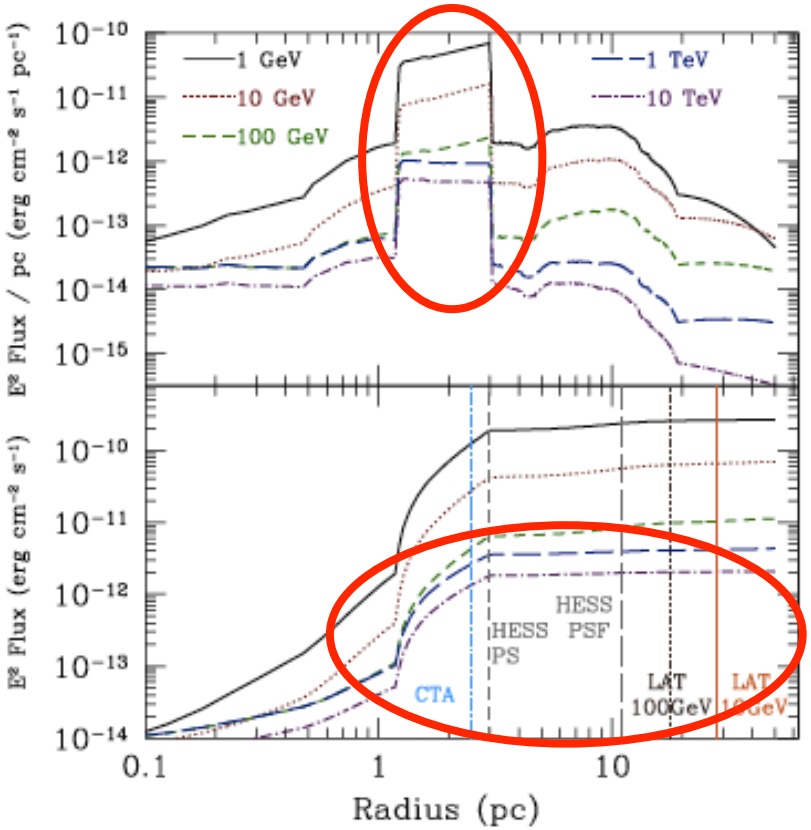
Source can be **protons** accelerated by central supermassive black hole Sagittarius A*

Key **diagnostic**: gamma-ray source **morphology** secondary (**leptonic**) emission

Linden, Lovegrove and SP, 1203.3539 and in prep.

One of the elephants in the room: **Sgr A***





FUNDING AGENCIES: WE WILL NEED CTA!!!

Linden, Lovegrove and SP, 1203.3539 and in prep.

a **case** for **~10 GeV dark matter**?

Galactic Center

Direct Detection

Radio Filaments

WMAP/Planck haze

ARCADE-2 excess

(I'm a competent theoretician, so
I can fit any given theory to any given data…
favorite model: **lepton-specific 2HDM+singlet**
Boucenna and Profumo, 2011)

a **case** for **~10 GeV dark matter**?

Galactic Center

Radio Filaments

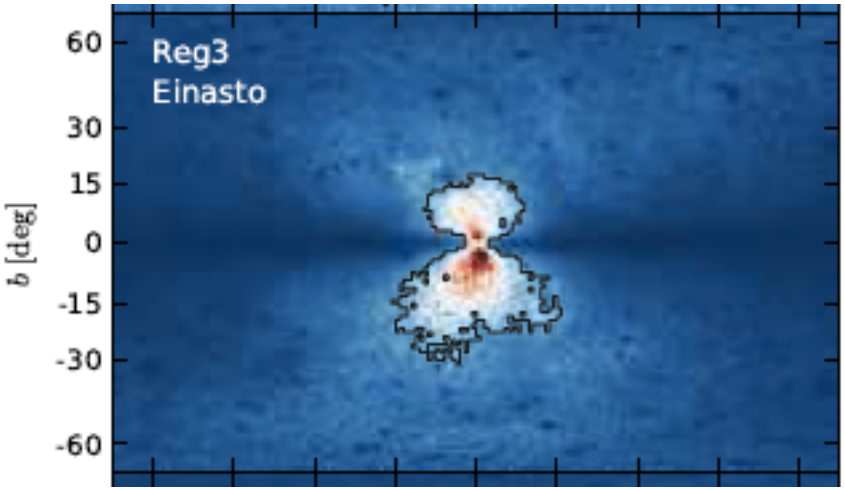
WMAP/Planck haze

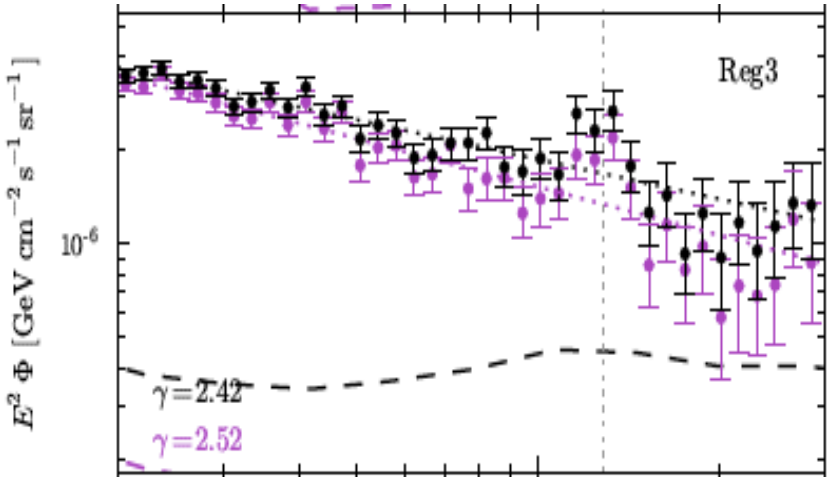
Direct Detection

ARCADE-2 excess

- **interesting** possibility, investigate **case-by-case**
- **theoretically** + **observationally**, 10 GeV just **fine**
  (*WIMPs >40 GeV from silly theory prejudice!*
  Fermi results from stacked dSph have limited applicability)
- **no conclusive evidence** of "non-standard" physics so far

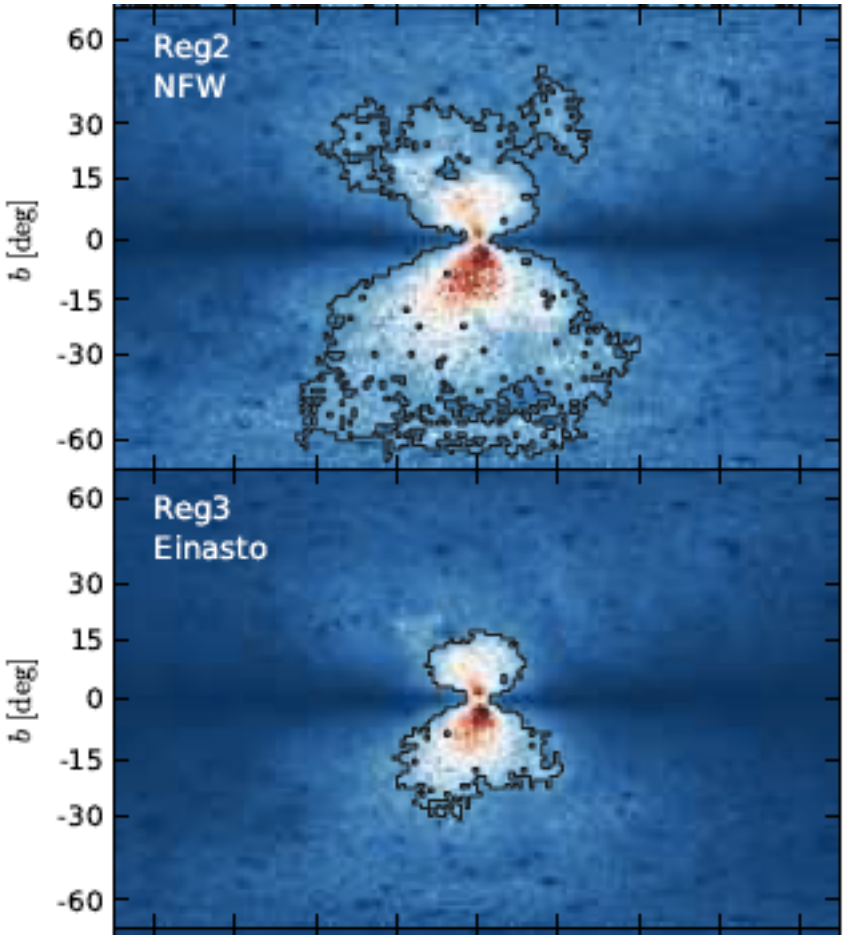
A 130 GeV Gamma-Ray Line?





Weniger (1204.2797)

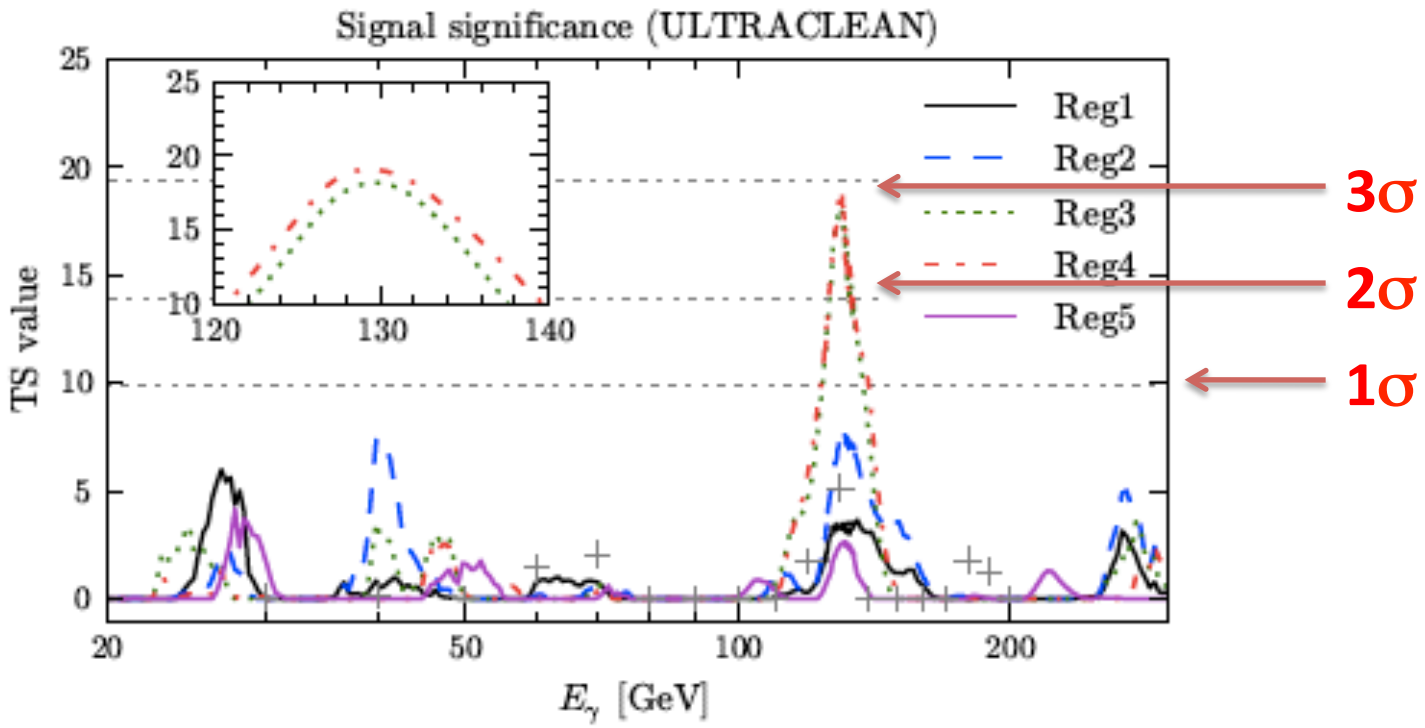
Key novelty: **optimized** Regions of Interest



Signal: ~$(\rho_{DM})^2$

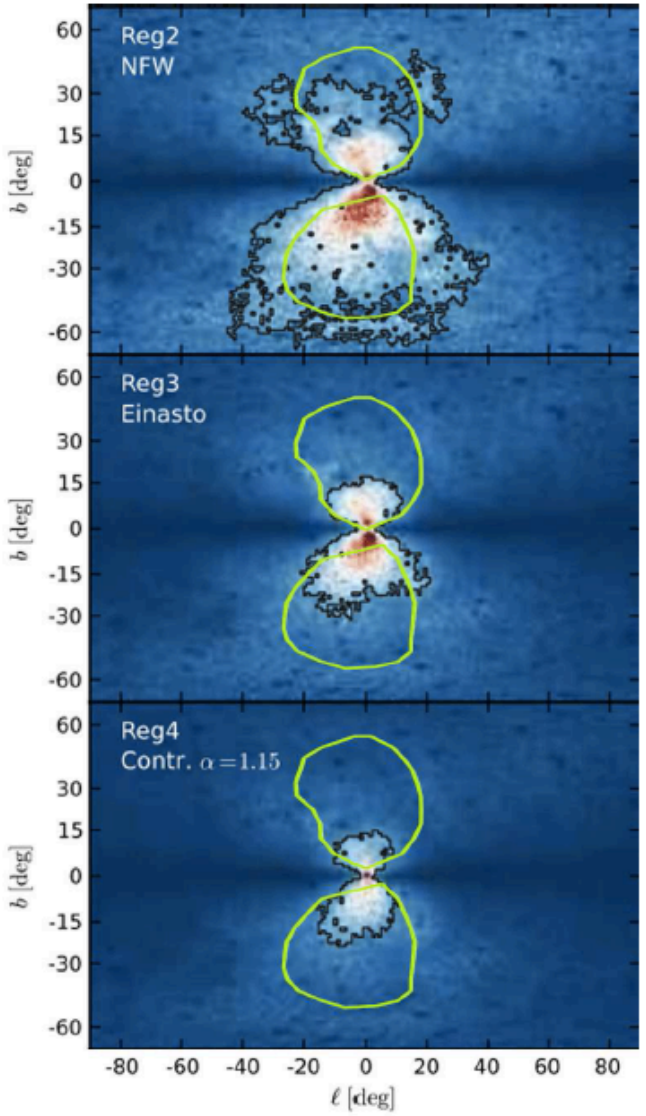
Noise: (1-20 GeV sky)$^{1/2}$

(almost) 3σ effect, E_γ=130 GeV look-elsewhere effect accounted for



Two key points*

(1) ROI's overlap with **Fermi bubbles**: photons from bubbles are important **background**

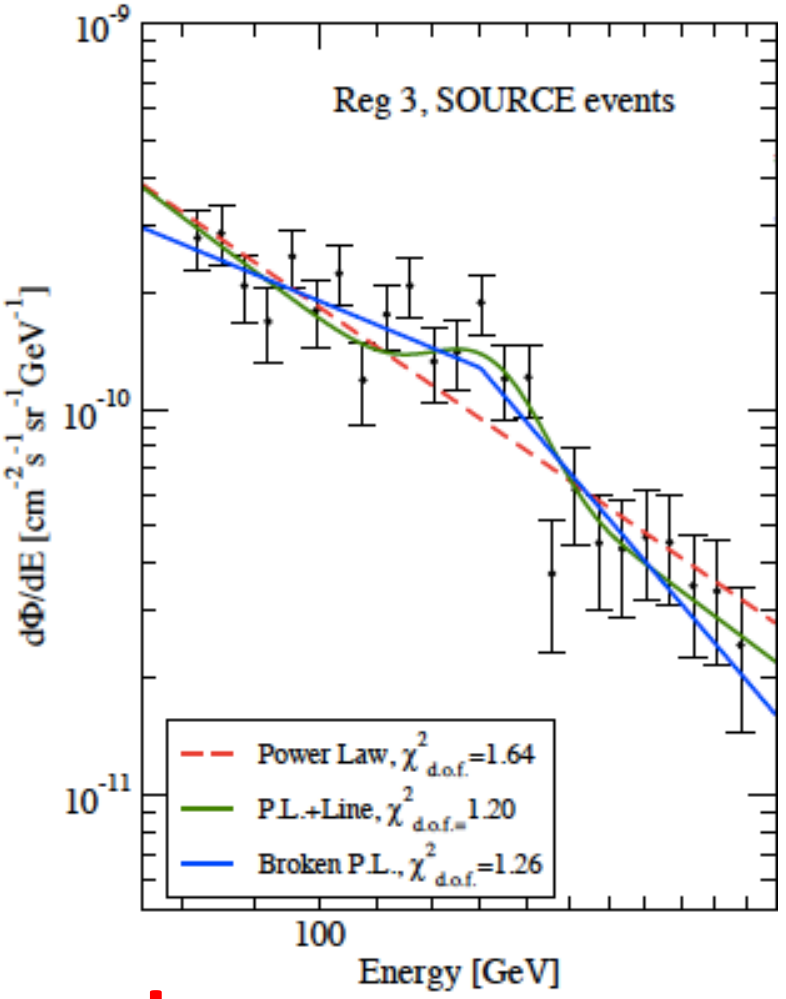


* Profumo and Linden, "Gamma-Ray Line in the Fermi Data: is it a Bubble?"

Two key points*

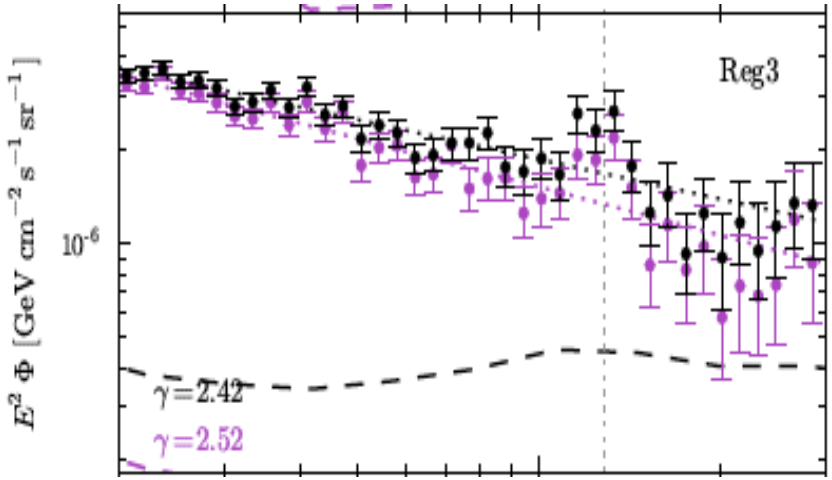
(1) ROI's overlap with **Fermi bubbles**: photons from bubbles are important **background**

(2) broken power-law could be **mistaken** for a **line** - Fermi bubbles have **broken power-law spectrum**



* Profumo and Linden, "Gamma-Ray Line in the Fermi Data: is it a Bubble?"

could it be an
instrumental effect?



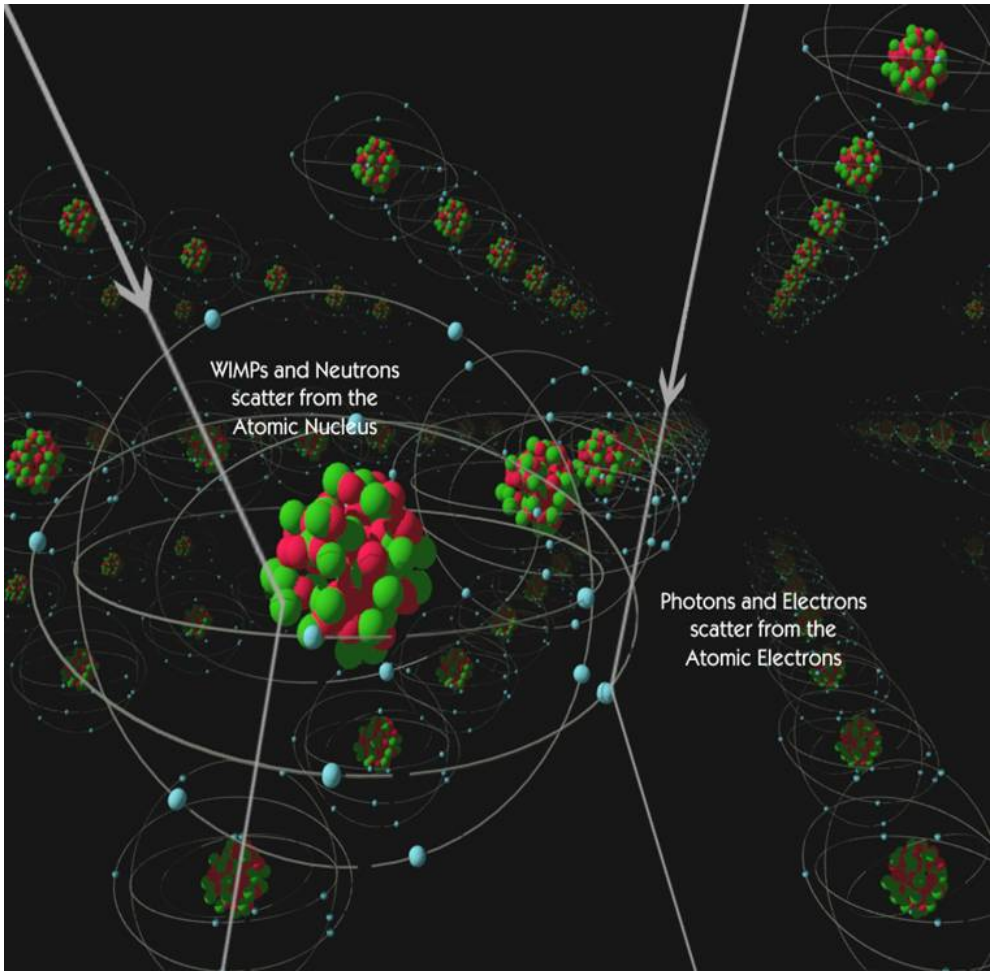
Culprit could be **energy reconstruction**:
E>130 GeV mis-read as E=130 GeV event!
…**under investigation** by Fermi Collaboration

If not instrumental, potentially **very interesting**
wait for **more statistics** (so far ~50 photons)!


THE
WAY
FORWARD

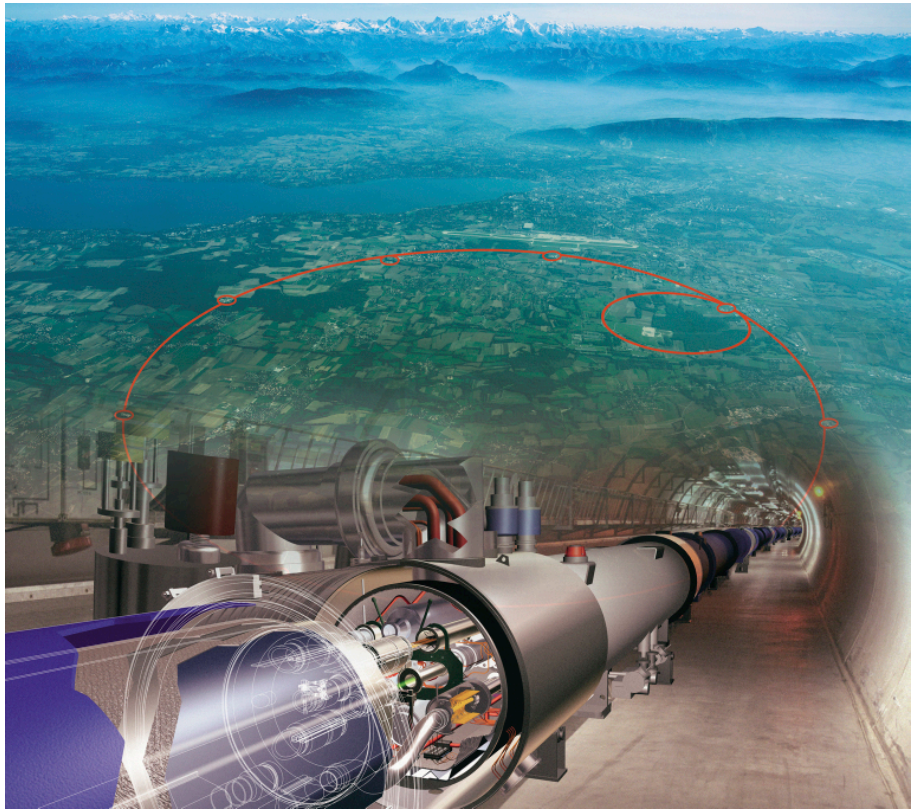
➢ **direct** dark matter **detection**

- Tapping into **low-mass** region
- Carving into interesting WIMP **parameter space** regions
- See Paolo's talk on Friday!



- **direct** dark matter **detection**
- **model-building** guidance from **LHC**

- **Sharpening predictions** for certain DM models (e.g. UED)
- Will provide **clues** of correct beyond-the Standard Model physics



- ➢ **direct** dark matter **detection**
- ➢ **model-building** guidance from **LHC**
- ➢ cosmic-ray results from **AMS-02**

- **CR propagation!**
- More info on CR antimatter, including e^+, anti-p, **antideuterons**

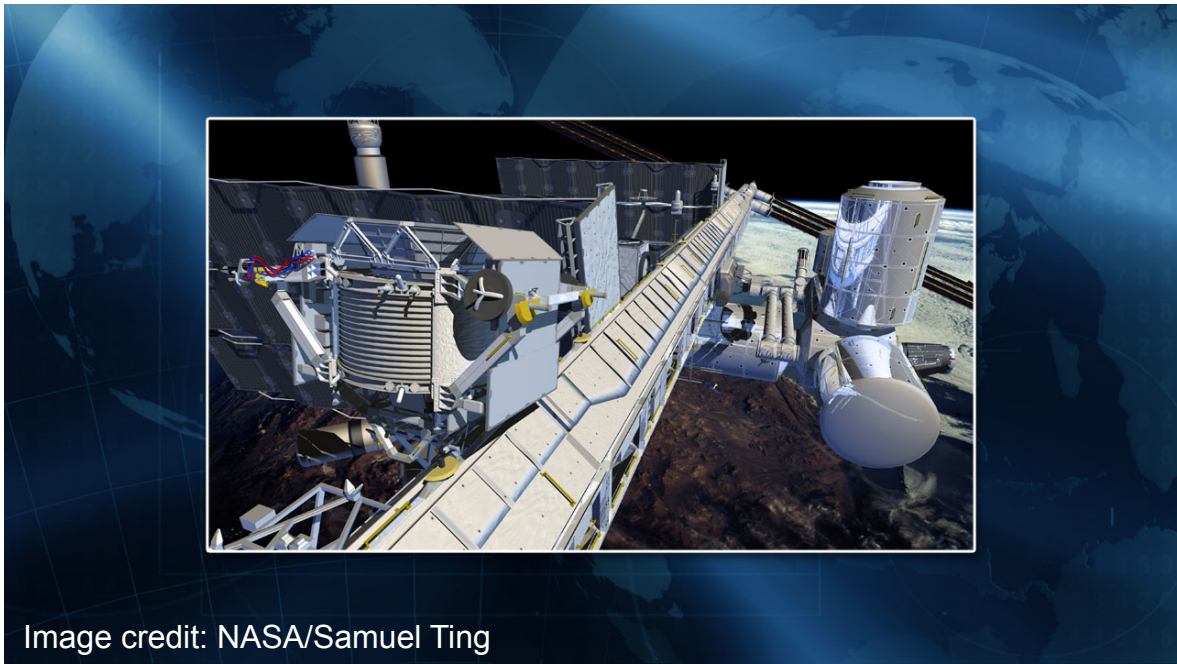
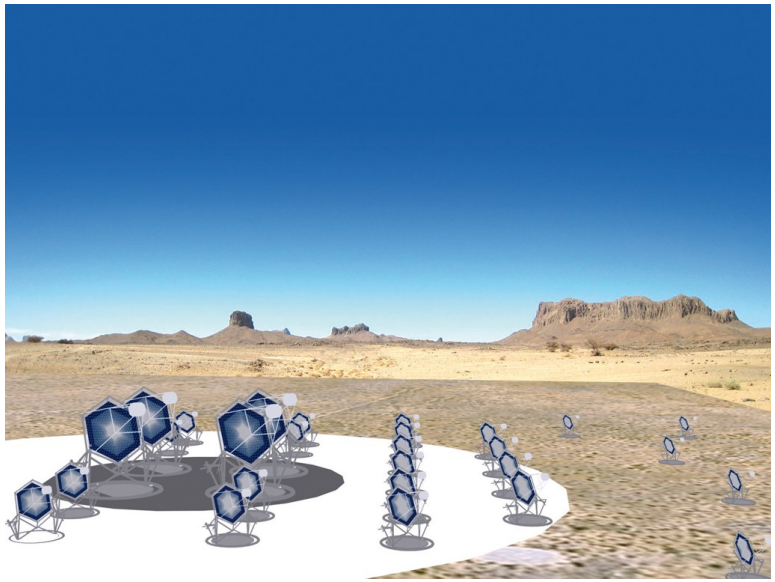


Image credit: NASA/Samuel Ting

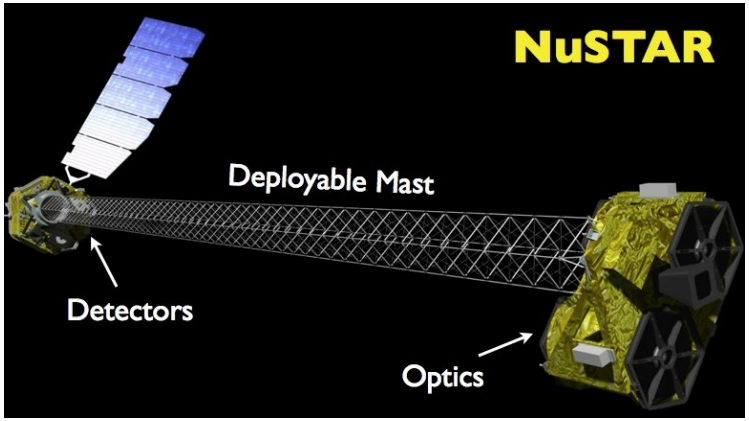
- **direct** dark matter **detection**
- **model-building** guidance from **LHC**
- cosmic-ray results from **AMS-02**
- post-Fermi **high-energy** telescopes



High-mass dark matter:
Cherenkov Telescope array
(preparatory phase >> 2013)

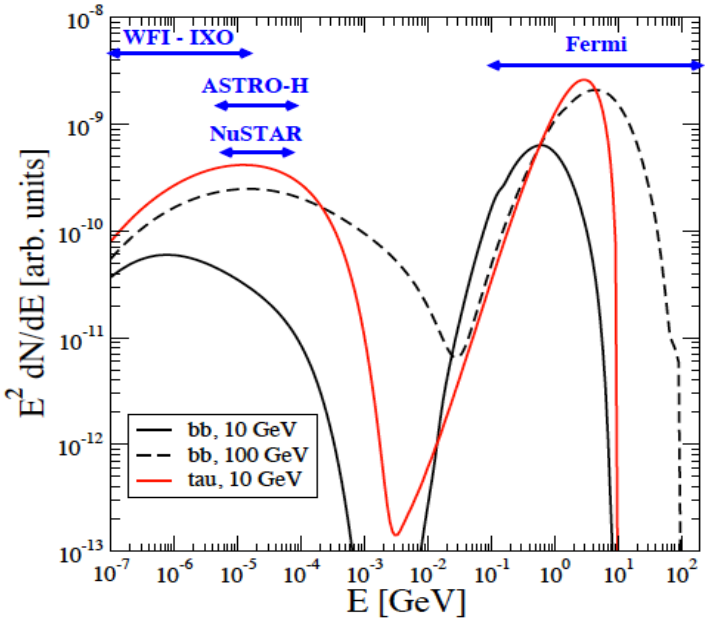
- **direct** dark matter **detection**
- **model-building** guidance from **LHC**
- cosmic-ray results from **AMS-02**
- post-Fermi **high-energy** telescopes

Low-mass dark matter:
Hard X-ray telescopes
(NuSTAR, eROSITA, IXO)



- **direct** dark matter **detection**
- **model-building** guidance from **LHC**
- cosmic-ray results from **AMS-02**
- post-Fermi **high-energy** telescopes

Low-mass dark matter:
Hard X-ray telescopes
(NuSTAR, eROSITA, IXO)



Jeltema & Profumo, 2011

- **direct** dark matter **detection**
- **model-building** guidance from **LHC**
- cosmic-ray results from **AMS-02**
- post-Fermi **high-energy** telescopes

The promenades of Euclid

an appropriate adagio for
indirect dark matter detection :

"Everything we see
hides another thing,

we always want to see
what is hidden
by what we see"

R. Magritte

[slide concept: Pasquale Serpico]