

Fermi 130 GeV gamma-ray line as an indirect signal of DM

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Outline

- Dark Matter – the present status
- Dark Matter indirect detection
- Fermi-LAT 130 GeV gamma-ray line as a potential signal of DM annihilations/decays
- Conclusions

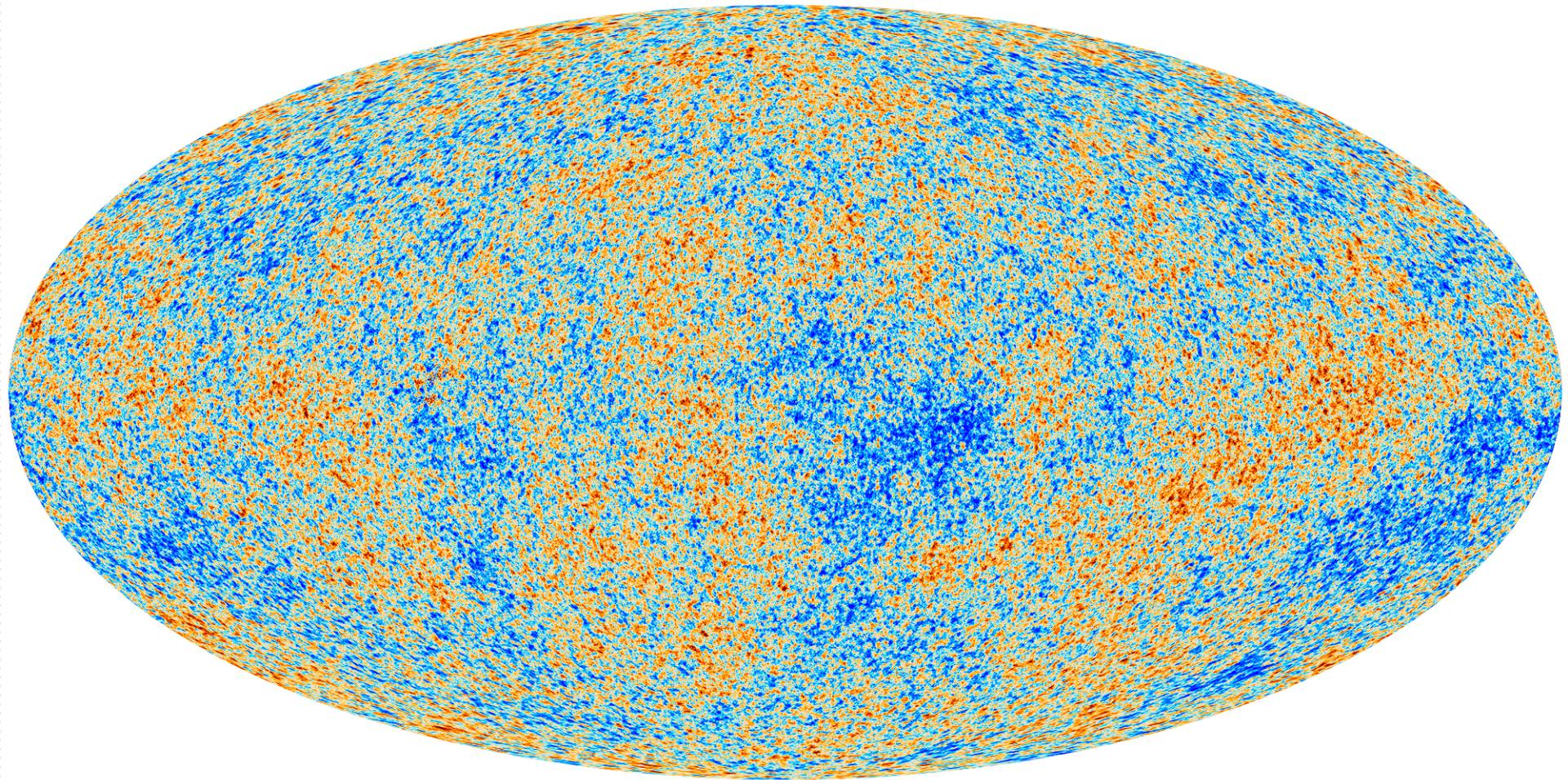
Where is physics beyond the SM?

- The discovery of Higgs proves the SM!
 - LHC: NP can be 20% perturbation around SM
 - Flavour, confinement?

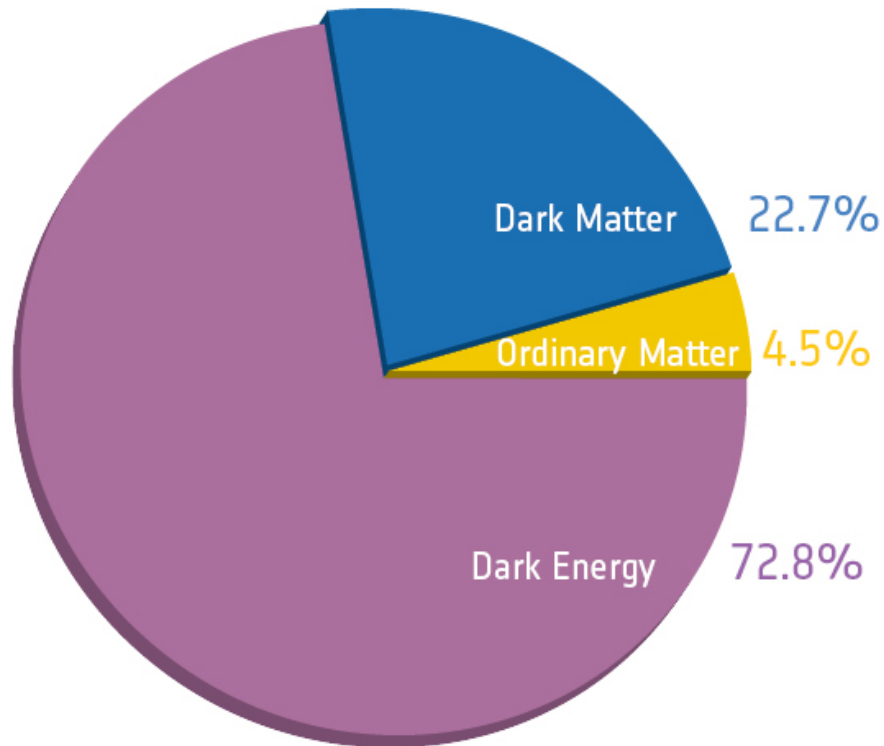
- SM does not have a Cold DM candidate

- Look at the sky!

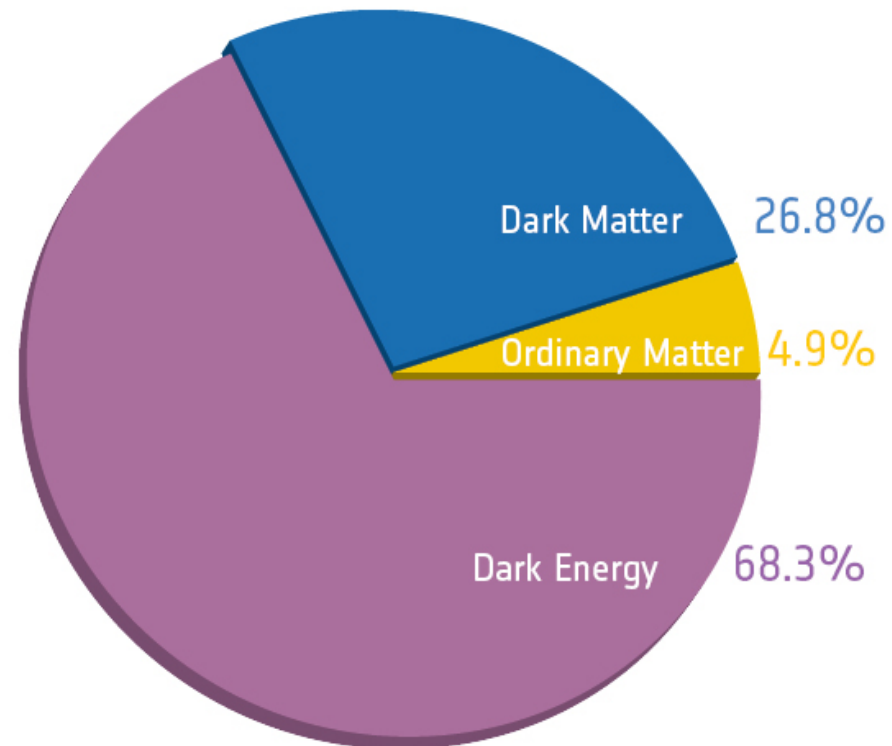
The global picture after Planck Mission (March 2013) - Λ CDM



Energy budget of the Universe



Before Planck

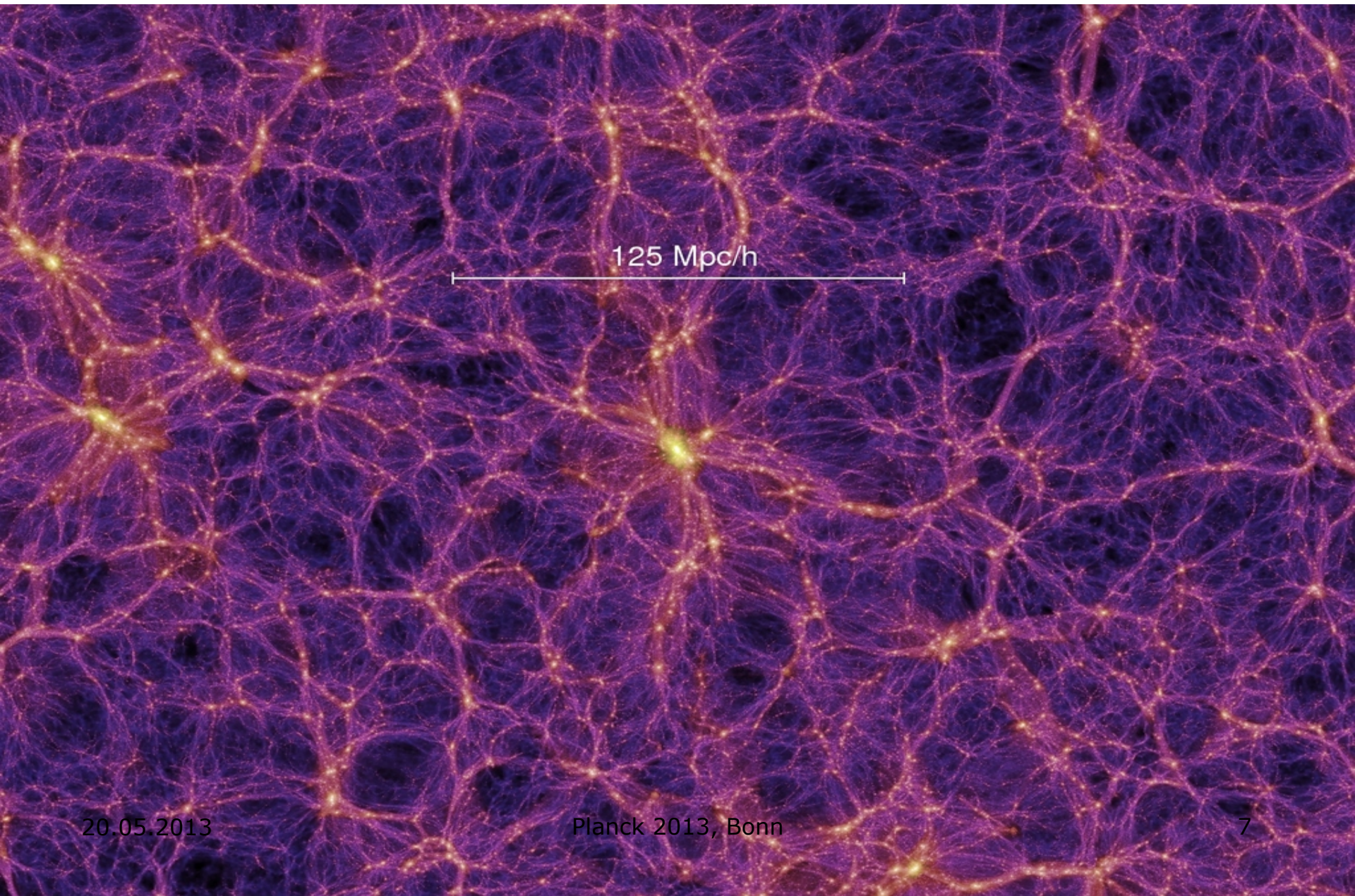


After Planck

What do we know about DM?

- DM does exist!
- Evidence for it is all gravitational
 - Rotation curves of galaxies and clusters
 - Bullet clusters
 - Gravitational lensing
 - Formation of large scale structure
 - Baryon acoustic oscillations
- All the evidences consistent with Λ CDM

Large scale structure of the DM



What is Dark Matter?

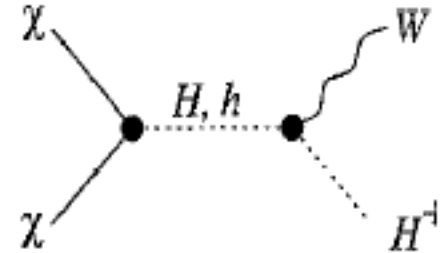
- ❑ No firm particle physics evidence so far
- ❑ Theory: too many candidates
 - ❑ Massive neutrinos (warm DM)
 - ❑ Axions
 - ❑ WIMPs (neutralinos, gravitinos etc)
 - ❑ WIMPZillas
- ❑ Proposed masses vary some 30-40 orders of magnitude

How is dark matter generated?

- DM is symmetric thermal relic

$$\text{DM} + \text{DM} \rightarrow \text{SM} + \text{SM}$$

- The WIMP miracle
- The annihilations should occur also today

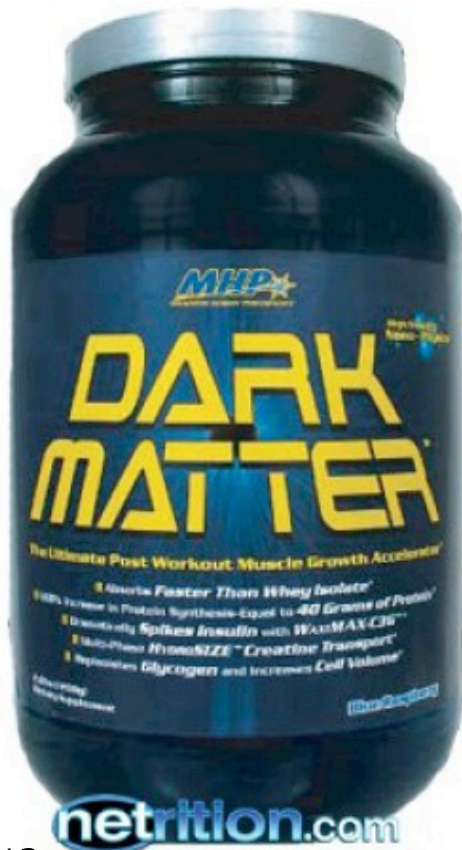


- DM is due to asymmetry

$$X \rightarrow \text{SM} + \text{DM}$$

- DM abundance related to baryon asymmetry of the Universe
- $\Omega_{\text{DM}} = 5 \Omega_{\text{b}}, m_{\text{p}} = 1 \text{ GeV} \rightarrow M_{\text{DM}} = 5 \text{ GeV}$

DM available in internet for the reduced price!



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How to detect Dark Matter of the Universe?

The main ways to detect WIMPs

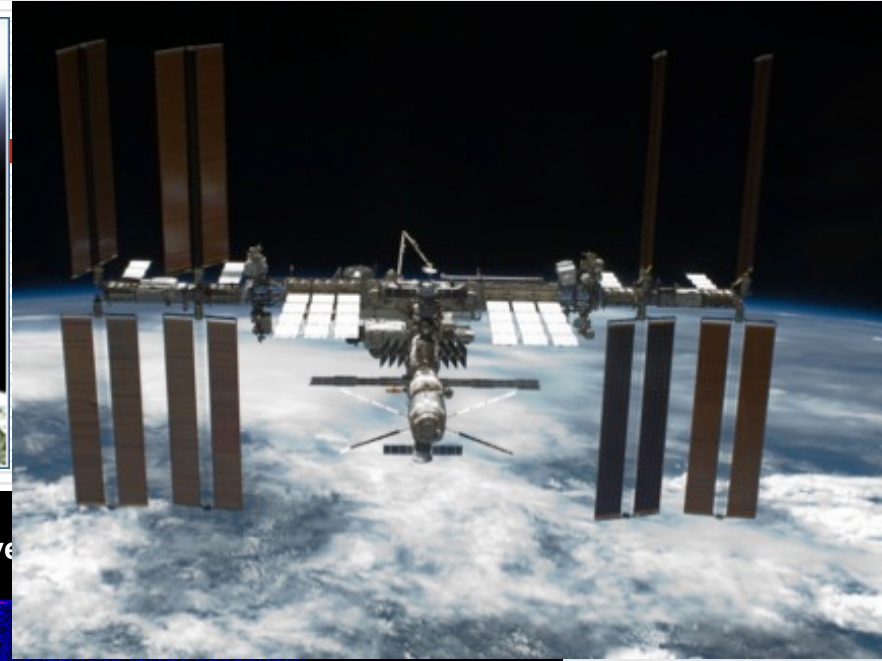
□ Direct detection

- Search for DM recoils on nuclei in very sensitive underground experiments
- XENON, CDMS, DAMA, COGENT, LUX etc
- Search for DM particles at the LHC experiments

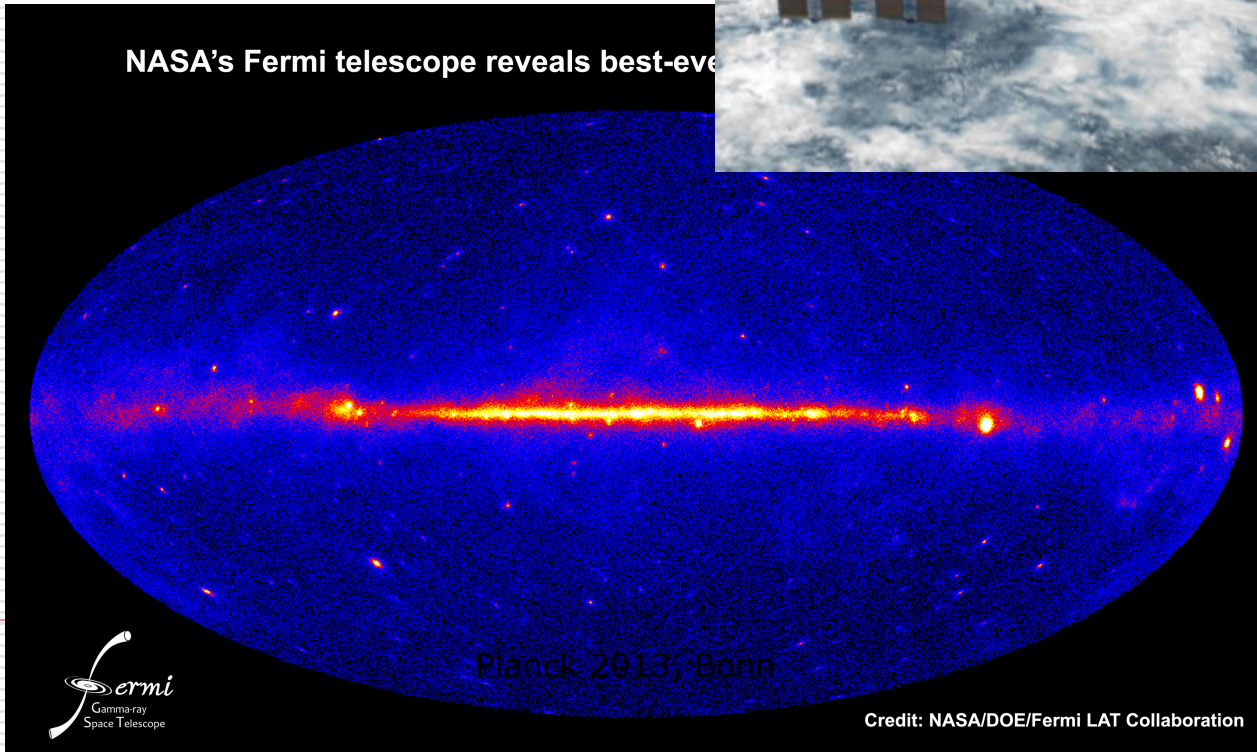
□ Indirect detection

- Search for cosmological signals of DM annihilations/decays today
- PAMELA, FERMI, AMS02, ATIC, HESS

Astroparticle physics – new HEP



NASA's Fermi telescope reveals best-ever



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Credit: NASA/DOE/Fermi LAT Collaboration

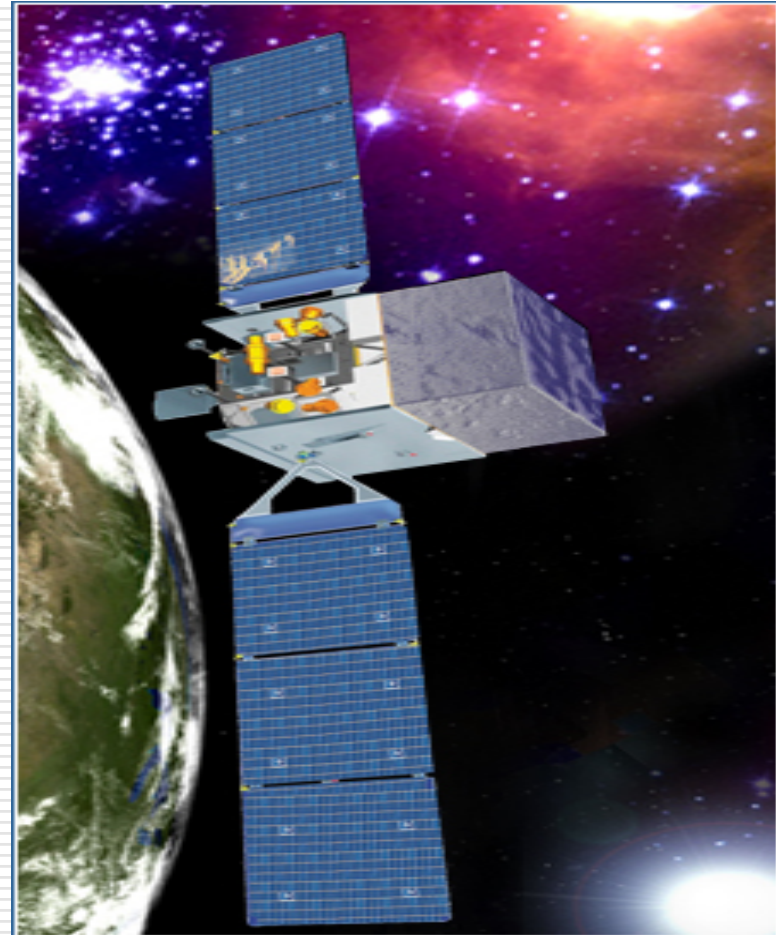
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DM indirect detection

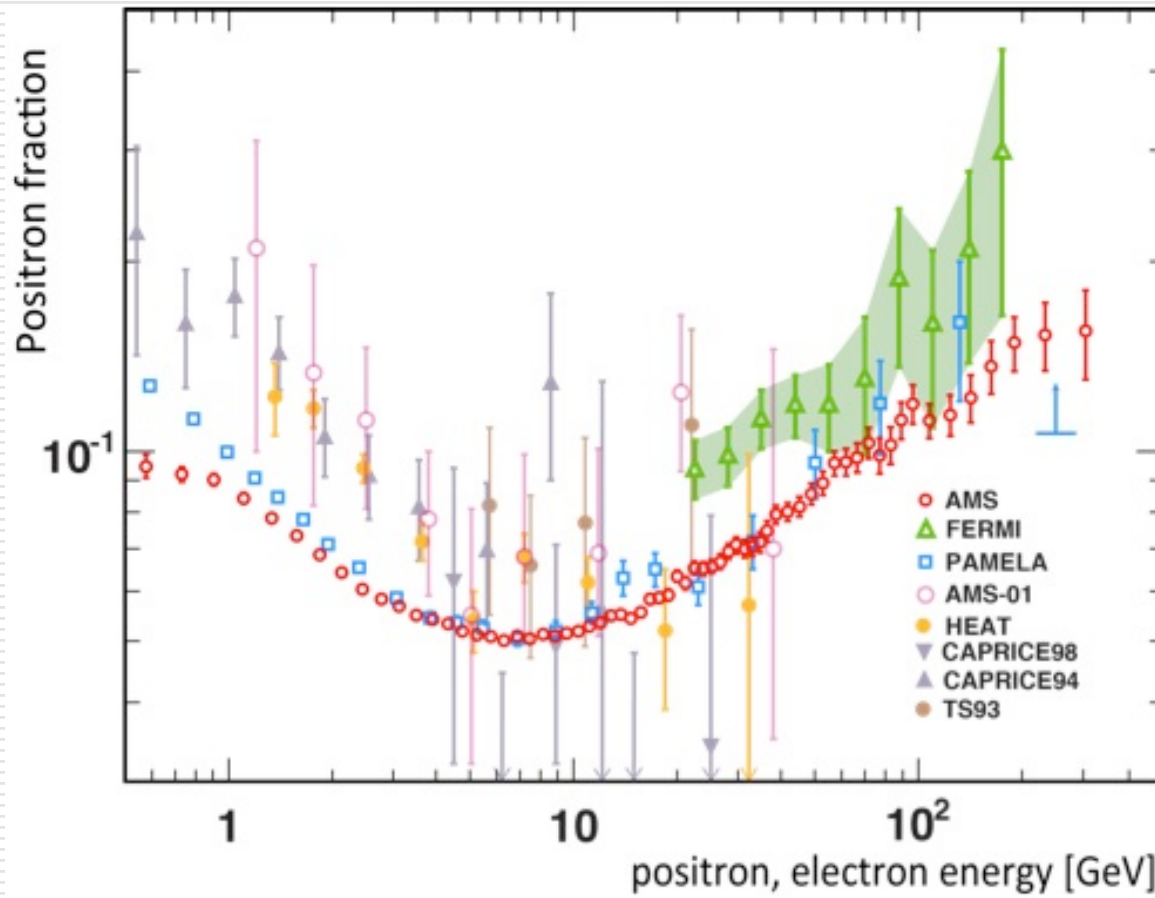
- Indirect search – look for DM annihilation/decay products today
- Detect anti-particles in cosmic rays
 - Loose both energy and direction
- **Photons** are easily detectable
 - Show the direction of the source
 - May exhibit spectral features
- Look at dense DM objects like Galactic Center, galaxy clusters, LSS filaments

Fermi-LAT gamma-ray data is publicly available

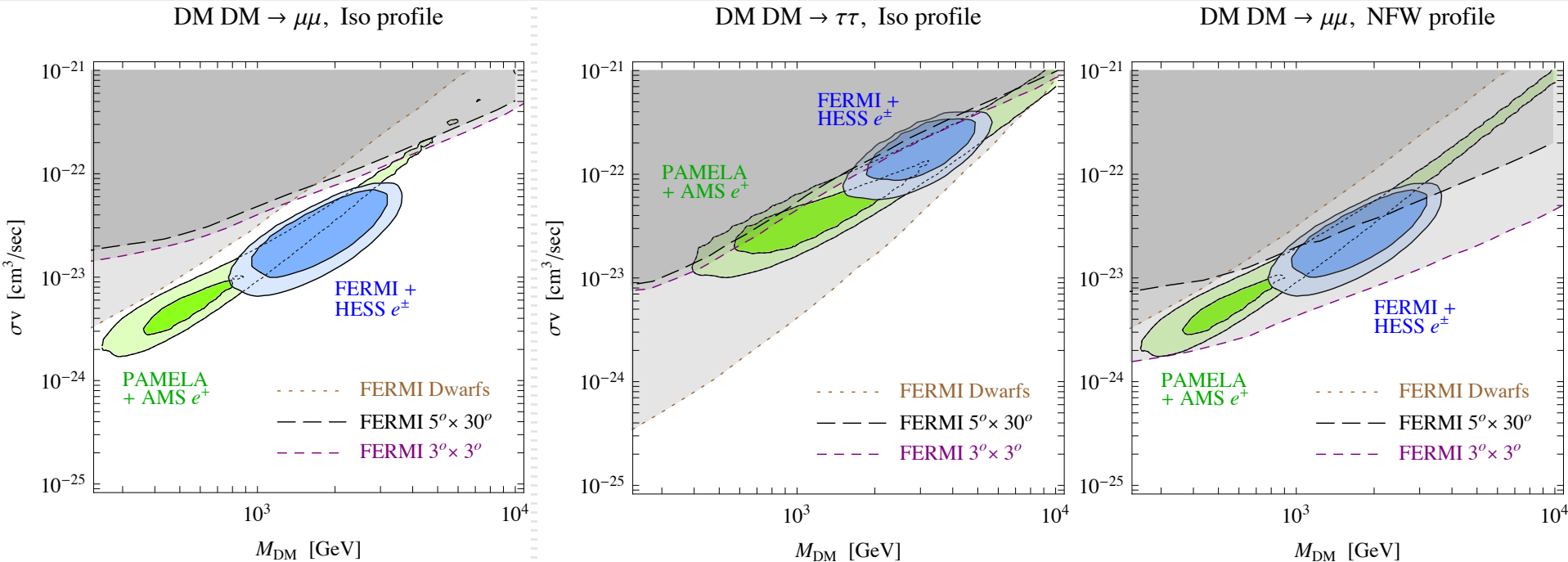
- ❑ Detects cosmological objects
- ❑ Can check the PAMELA, Fermi, AMS positron excess with associated **secondary** photons
- ❑ Can look for new excesses and spectral features in **primary** gamma-rays



AMS02 – confirms PAMELA, Fermi



Global status of DM annihilations after AMS02 – strongly constrained

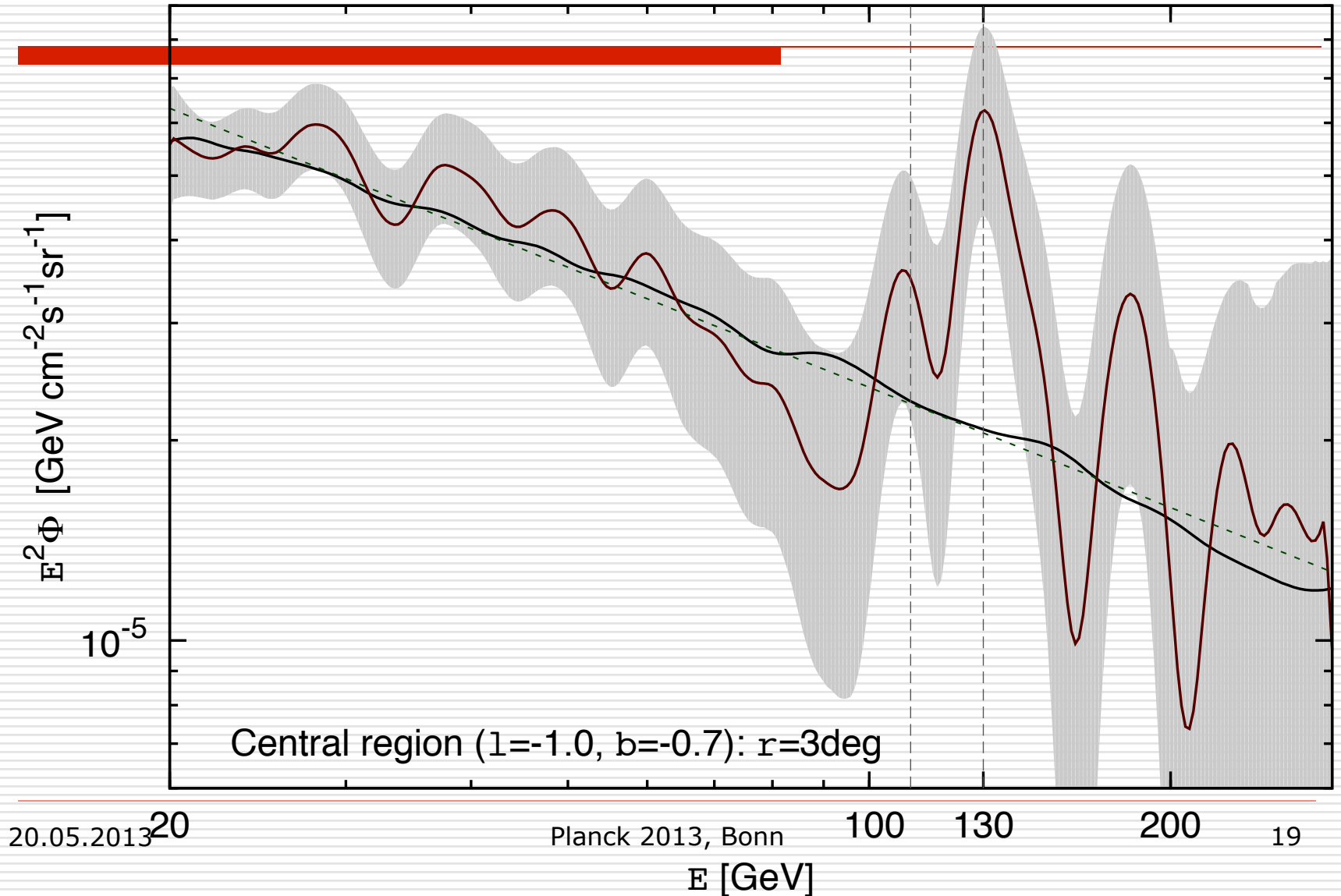


- No aniprotons – requires **leptophilia**
- Cross section must be **1000x enhanced**
- New non-standard approach/view on the problem needed

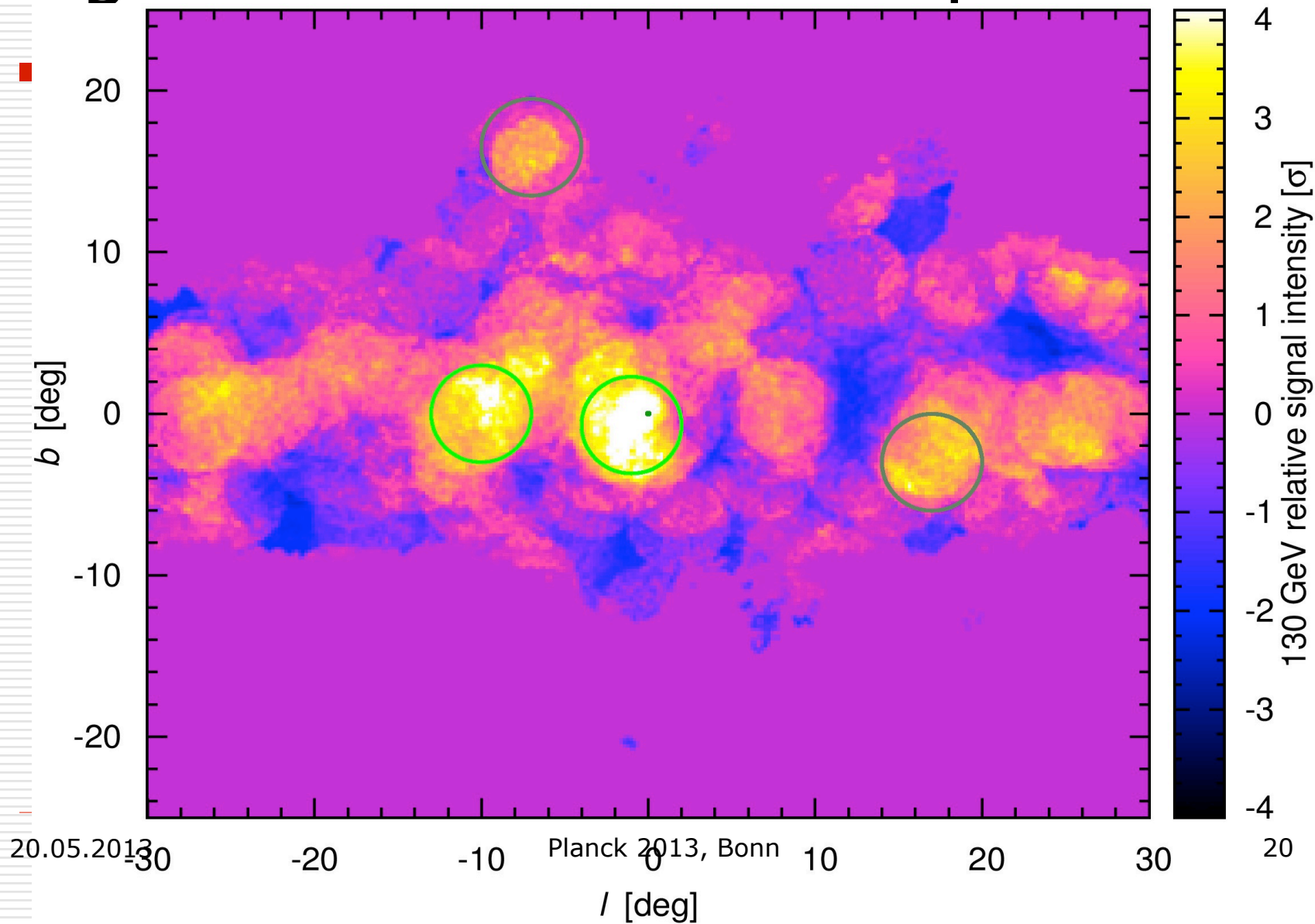
A surprise – 130 GeV gamma-ray line in public Fermi data from GC

- The line was discovered by Bringmann, Huang, Ibarra, Vogl, and Weniger
- Shortly confirmed by Tallinn (Hektor, Raidal, Tempel) and Harvard (Finkbeiner, Su) groups
- Questions of its origin:
 - Is it associated with known cosmological mechanism like creation of Fermi bubbles?
 - If it signals DM annihilations, what is the particle physics behind it?

Double peak, significance varies between $4.5-6.5\sigma$



Signal originates from the GC! The brightest centre little displaced!

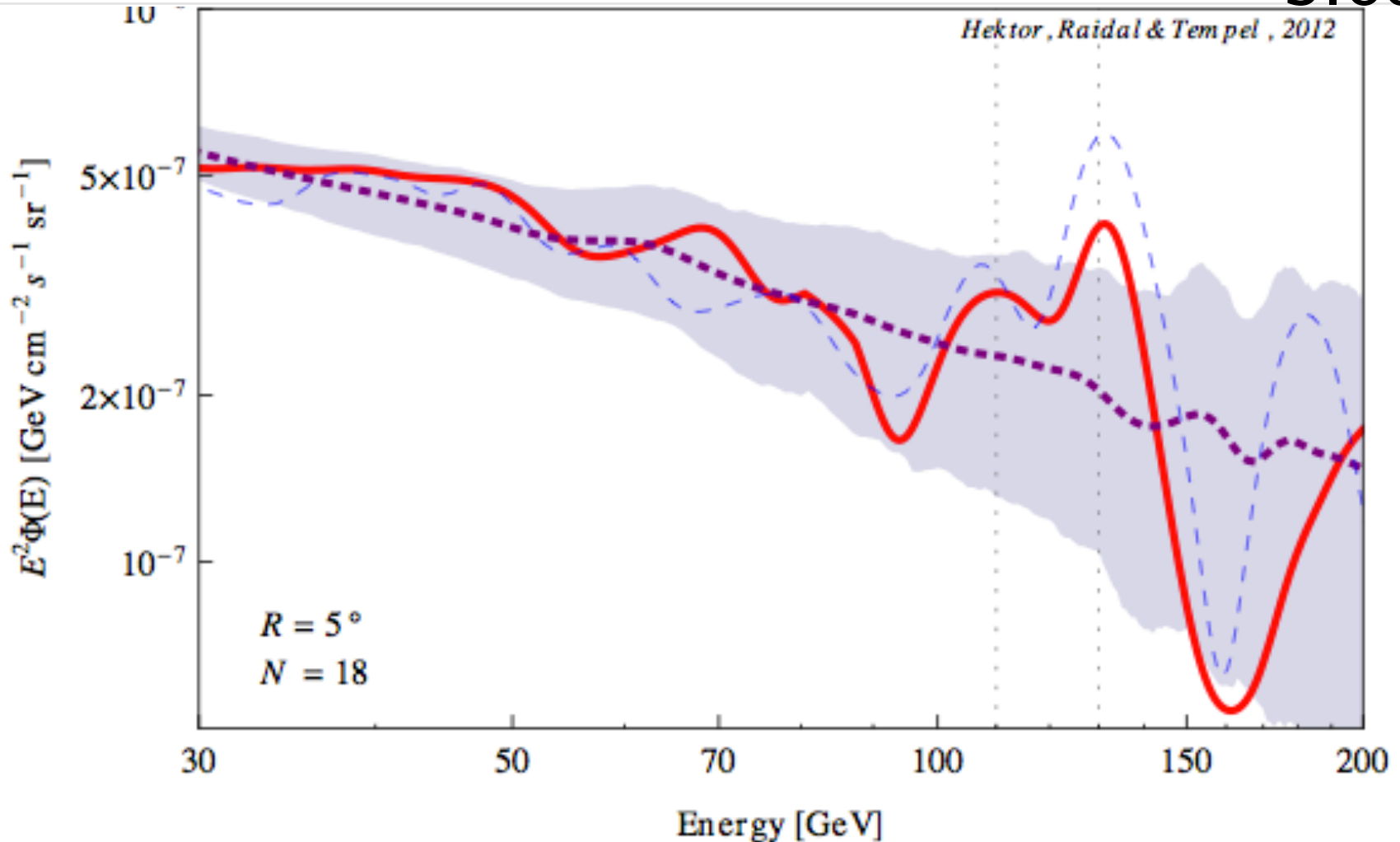


Look for signal from other DM rich objects – the galaxy clusters

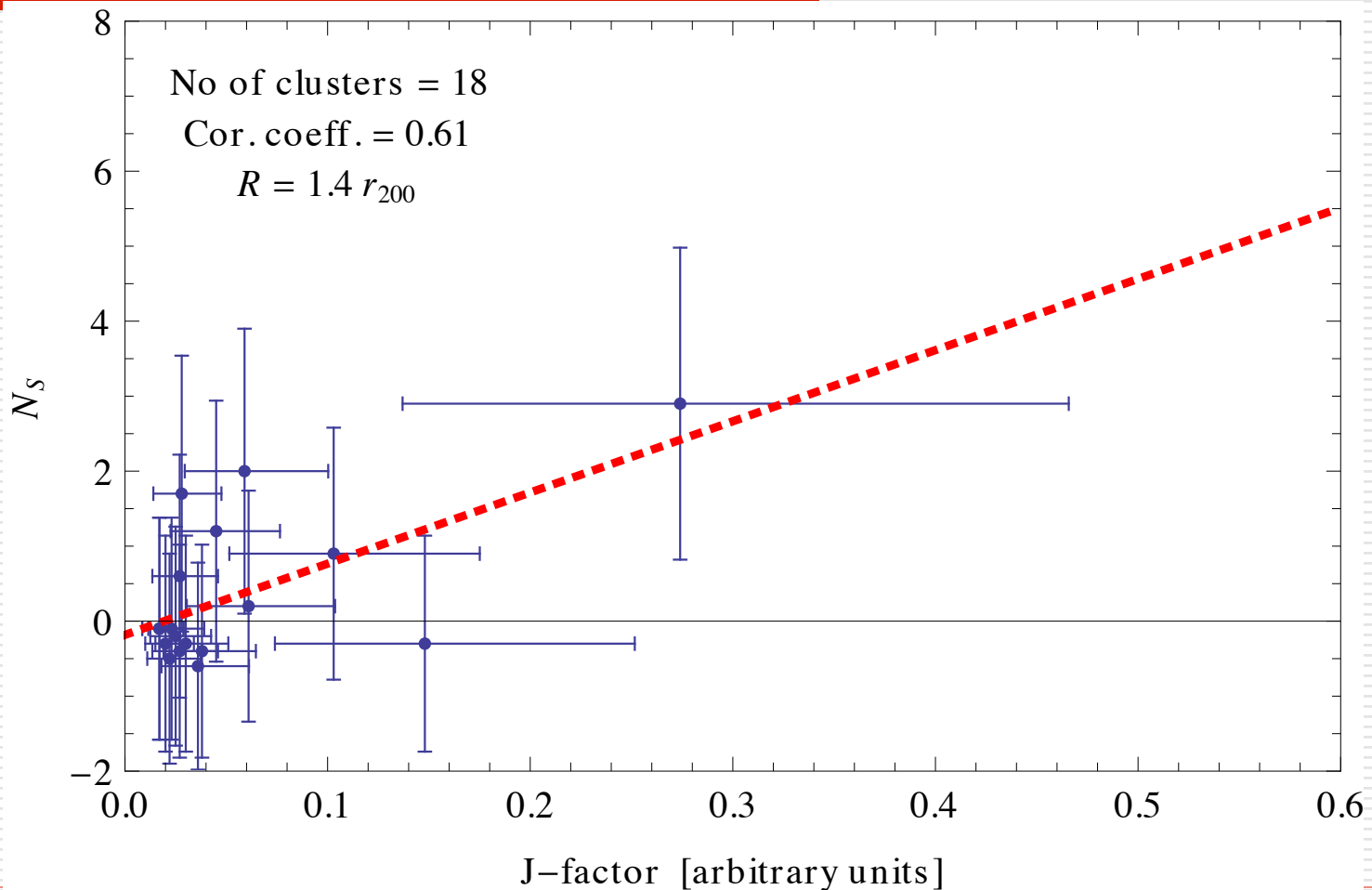
- Galaxy clusters should be ideal for looking for DM annihilations due to the **boost of the signal induced by the DM substructure**
- We studied the signal from the brightest nearby galaxy clusters

Galactic centre vs. galaxy clusters

3.6 σ



Number of signal photons vs. brightness of the galaxy cluster



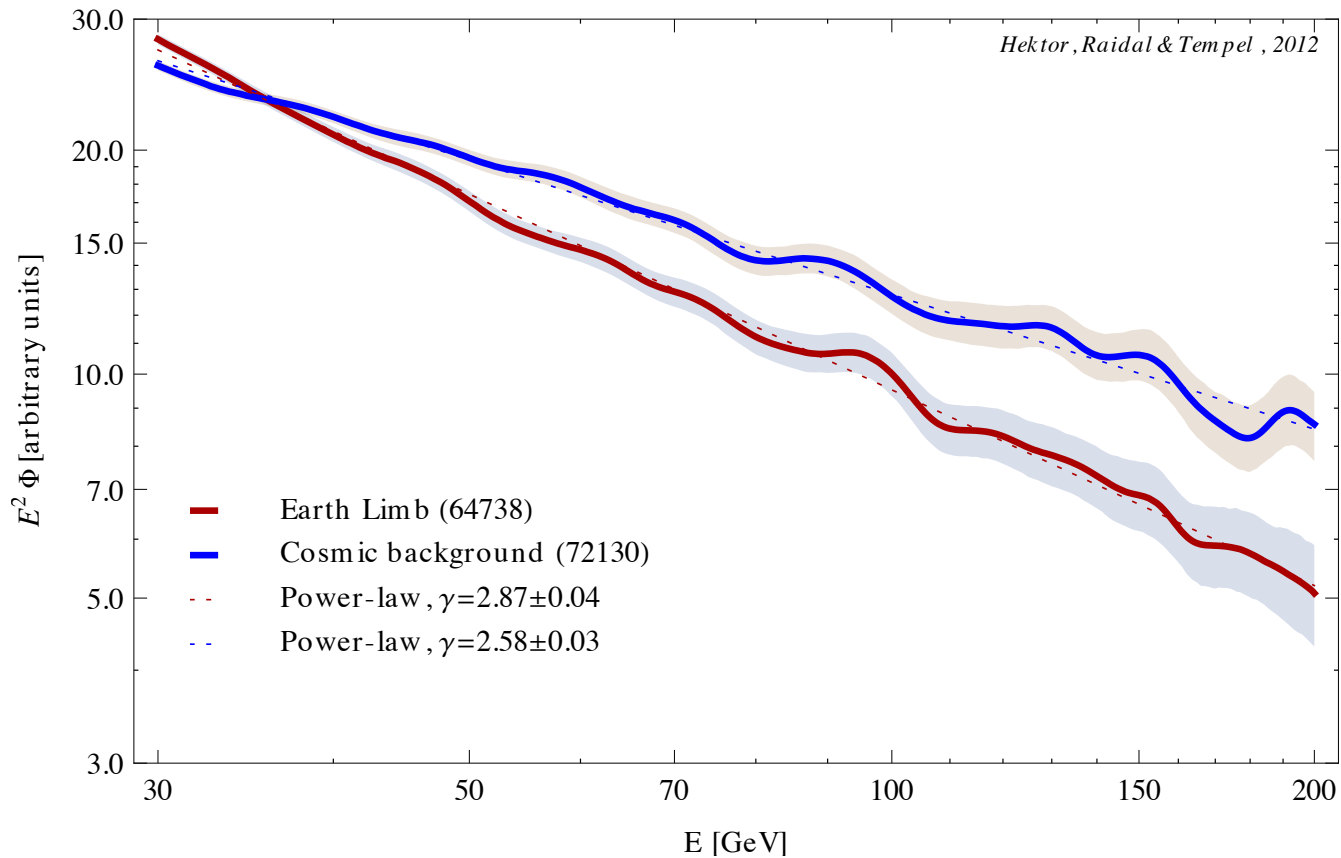
Particle physics interpretation

- ❑ DM vs. astrophysics? – **the DM!**
 - ❑ The double peak refers to $\gamma\gamma$, γZ , γH final states
- ❑ DM annihilations preferred over decays
 - ❑ Morphology of the GC signal ρ^2 (Weniger)
 - ❑ Boost factor 10^{2-3} from the galaxy clusters
- ❑ Annihilation xs **$0.1 \sigma v$, too big for a loop**
 - ❑ Internal bremsstrahlung, $DM+DM \rightarrow SM+SM+\gamma$
 - ❑ Large anomalies (DM “almost” charged)
 - ❑ **Natural** annihilation into intermediate states X , $DM+DM \rightarrow X X$, followed by $X \rightarrow \gamma\gamma$, γZ with 10%

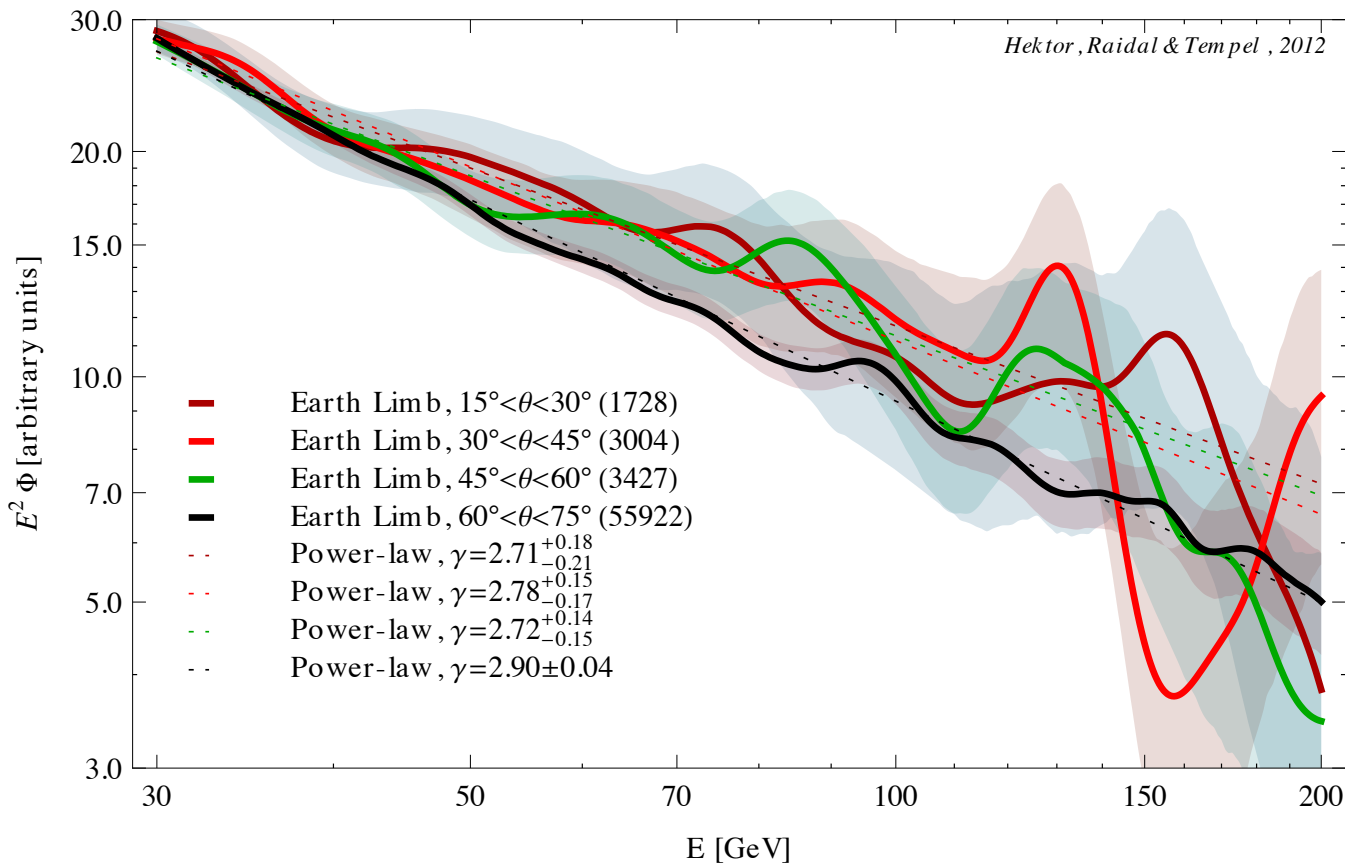
Fermi Symposium 2012 – an important milestone

- ❑ Fermi-LAT Collaboration finally confirmed the excess but:
 - ❑ With smaller statistical significance
 - ❑ Using re-processed data (not publicly available)
- ❑ No official claim by the Collaboration but
 - ❑ The excess shifts to higher energy, 135 GeV
 - ❑ Similar excess in the Earth Limb data
- ❑ If Earth Limb data is taken as region of interest for comparison, the GC excess reduces

Cosmic diffuse background vs. Earth limb – all available data



Subset of Earth limb data shows an excess without the double peak



Is it fake detector effect or real signal of DM?

- We, theorists, can work only with publicly available data
- Check the **consistency** of the data for
 - Different regions of interest
 - For different detector parameters such as the incidence angle θ
- No obvious effects are seen in data
 - The excess seen only in special regions
 - We see no anomalous dependences on θ

Detector effects continued ...

- We believe there are good reasons behind the pessimism of the Fermi-LAT Collaboration
- Those are not obvious when working with the publicly available data
- Wait for the recalibrated Fermi-LAT data
- The 130 GeV excess should be cross-checked by AMS02 and new experiments

Present status of the 130 GeV gamma-ray excess

- Double peak signal is seen from GC and from galaxy clusters (5σ and 3.5σ)
- The double peak, morphology of GC signal, boost from galaxy clusters favor DM annihilations as the interpretation
- If confirmed, DM properties must be strange since DM is expected be “dark”
- Fermi Collaboration has confirmed the excess but not the interpretation