High-Energy Phenomena and Dark Matter Searches in Galaxy Clusters

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in collaboration with

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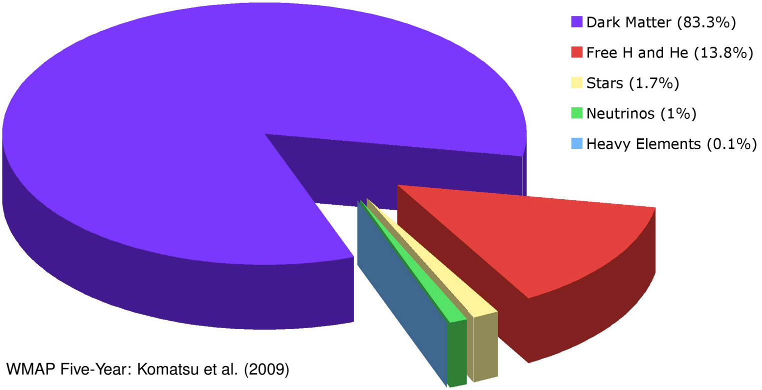
The matter content of the Universe – 2009



WMAP Five-Year: Komatsu et al. (2009)

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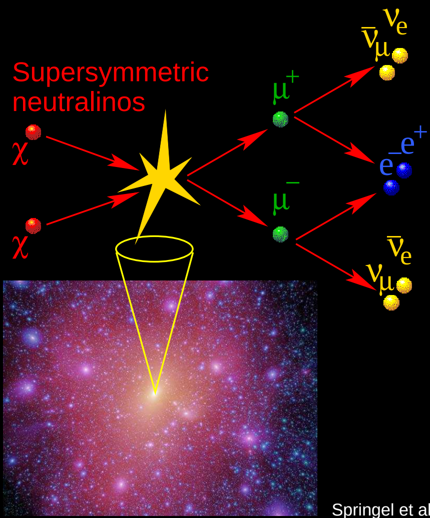
Indirect detection of dark matter



Springel et al. 2008

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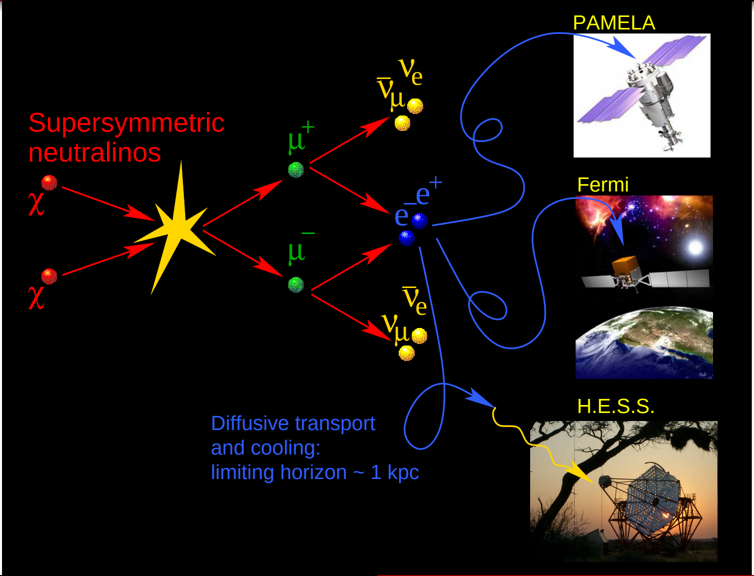
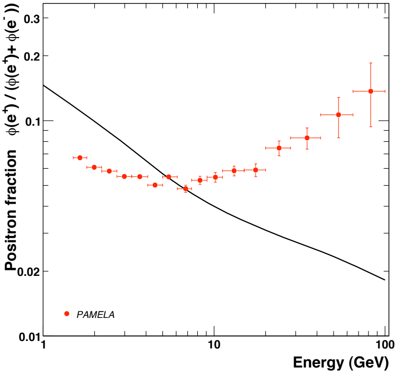
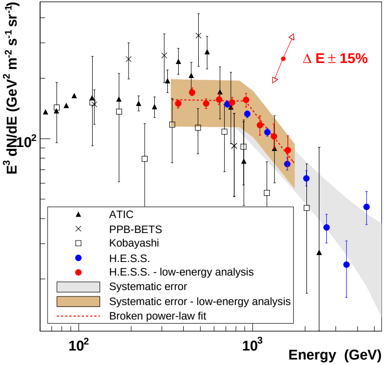


PAMELA and HESS data on electrons and positrons



PAMELA: (Adriani et al. 2009)

rising positron fraction with energy
→ e^- / e^+ pair acceleration source



HESS: (Aharonian et al. 2009)

break in the e^- / e^+ spectrum
→ maximum voltage of accelerator or DM particle mass

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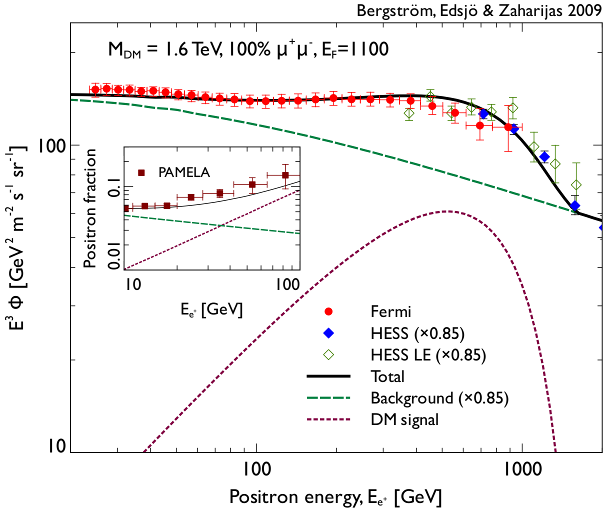
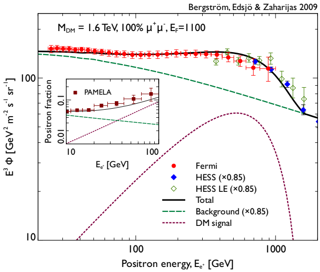
Combining recent electron and positron data

Fermi: excess number of leptons compared to background model (Abdo et al. 2009)



Interpretations of recent electron and positron data

- excess number of leptons compared to background (Fermi/HESS)
- break in the e^-/e^+ spectrum indicates special energy scale (HESS)
- rising positron fraction with energy (PAMELA)



1.) nearby pulsars:
energetics convincing but smoothness of Fermi data remains difficult to model (Harding & Ramaty 1987, Aharonian et al 1995, Malyshev et al. 2009)

2.) DM annihilations:
excellent fit to data but enhancement of cross-section over standard value and muon decay channel necessary (Bergström et al. 2009)

$\rightarrow$ Sommerfeld enhancement: $\langle\sigma v\rangle \sim c/v$ (Arkani-Hamed et al. 2009)

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The key questions

- How can we test this scenario?
- Which are the most promising objects to target?
- What are the cosmological implications of such an effective dark matter annihilation?

I will argue in favor of gamma-ray observations of galaxy clusters being able to scrutinize the DM interpretation of Fermi/HESS/PAMELA data and will end with a surprising cosmological result.

Pinzke, CP, Bergström, arXiv:0905.1948 [astro-ph]

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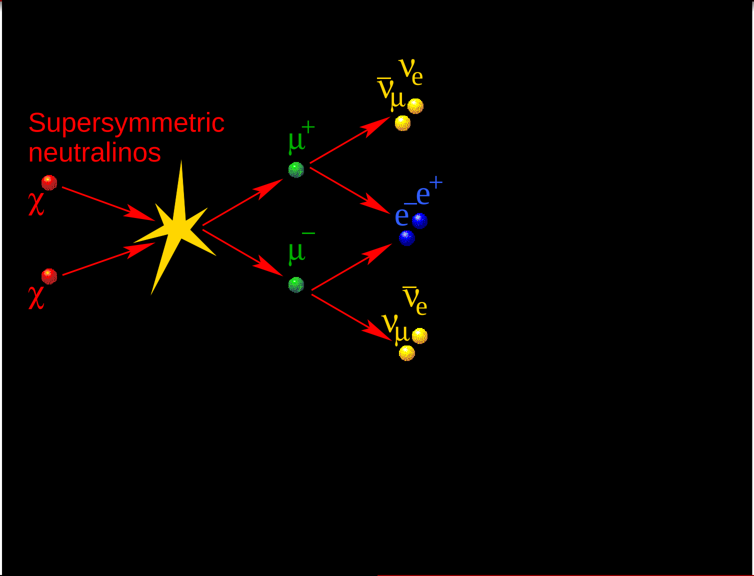
Indirect detection of DM through gamma-rays



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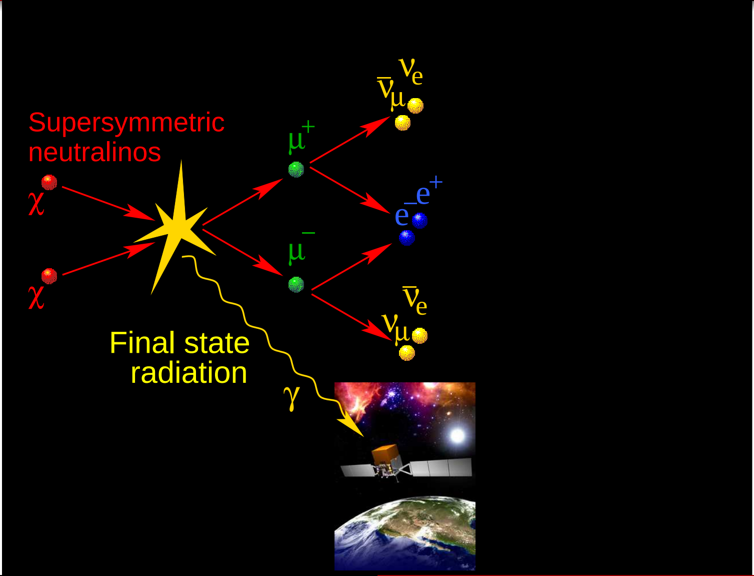
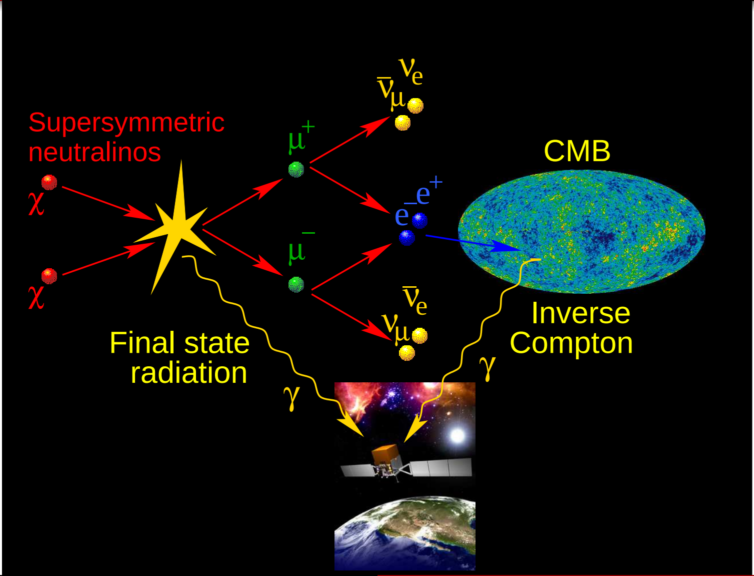
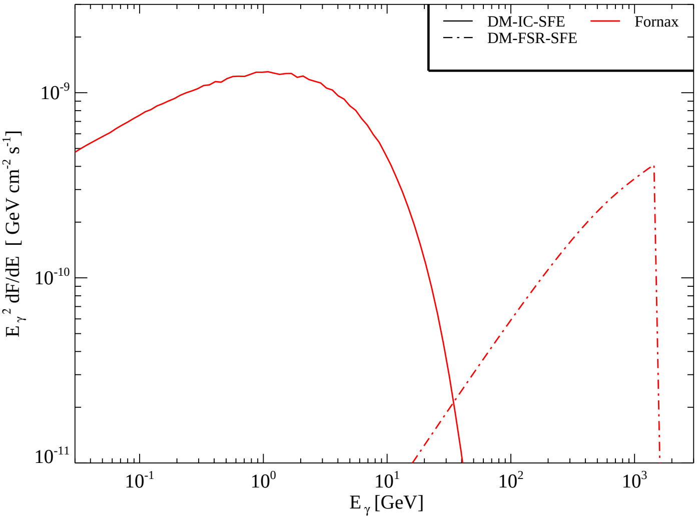


Indirect detection of DM through gamma-rays



Gamma-ray spectrum from DM annihilations



Galaxy clusters vs. dwarf galaxies

1. The DM annihilation luminosity of the smooth halo component scales as $F \sim \int \mathrm{d}V \rho^2 / D^2 \sim M/D^2$ assuming a universal density scaling[1]: the smooth component of dwarfs and galaxy clusters are equally bright!
2. Substructure in dark matter halos is less concentrated compared to the smooth halo component (dynamical friction, tidal heating and disruption): the DM luminosity is dominated by substructure at the virial radius, IF present!
   $\rightarrow$ these regions are tidally stripped in dwarf galaxies
   $\rightarrow$ galaxy clusters are dynamically 'young' and their subhalo population can boost the DM luminosity by up to 200 (Springel et al. 2008).

[1] A more refined argument that takes into account the different halo formation epochs breaking scale invariance yields the same result.

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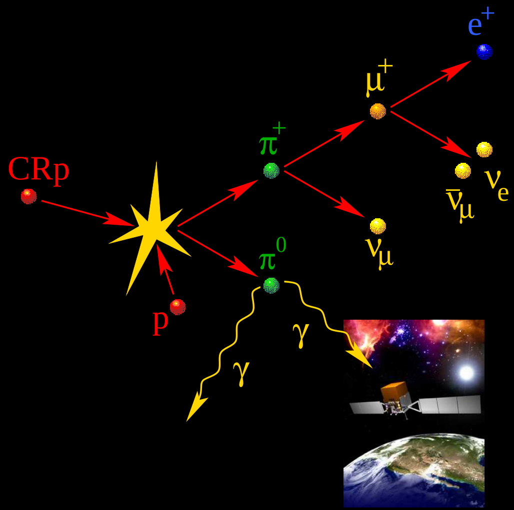
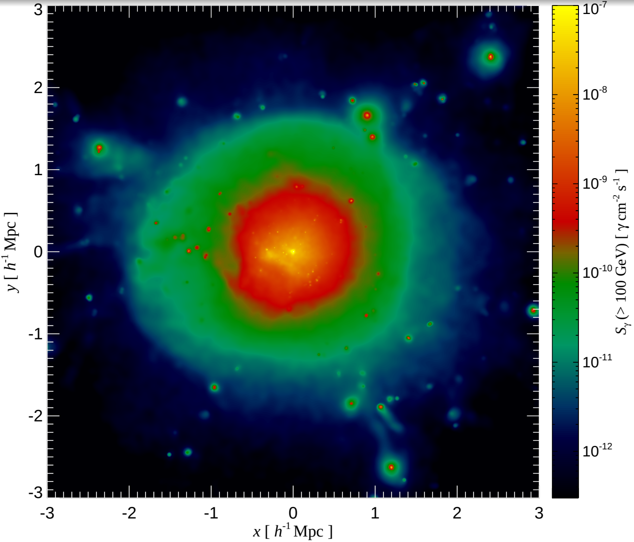
Hadronic cosmic ray proton interaction



Hadronic γ-ray emission, $E_\gamma > 100$ GeV



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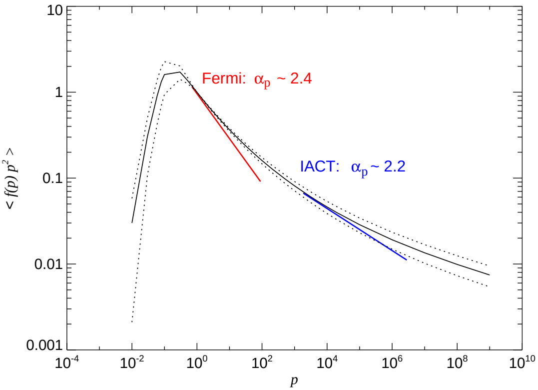
Universal CR spectrum in clusters



Normalized CR spectrum shows universal concave shape → governed mainly by hierarchical structure formation and adiabatic CR transport processes. (Pinzke & CP, in prep.)

→ very promising for disentangling the dark matter annihilation signal!

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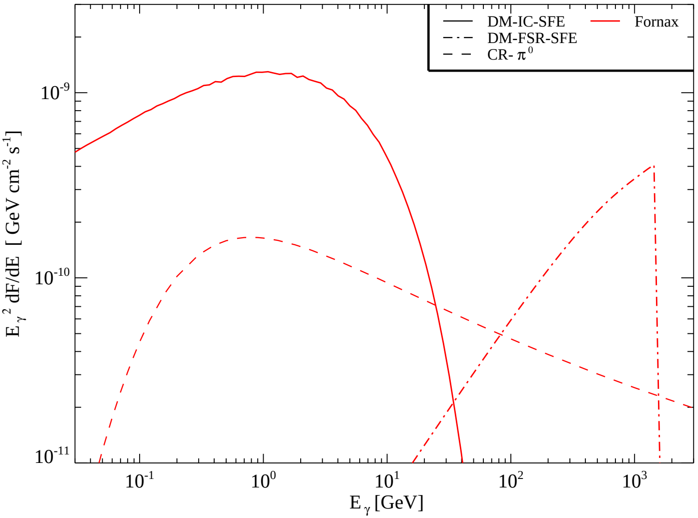
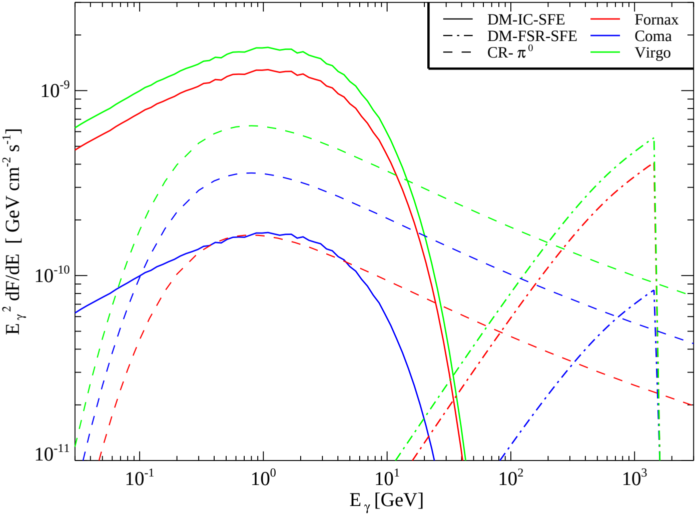
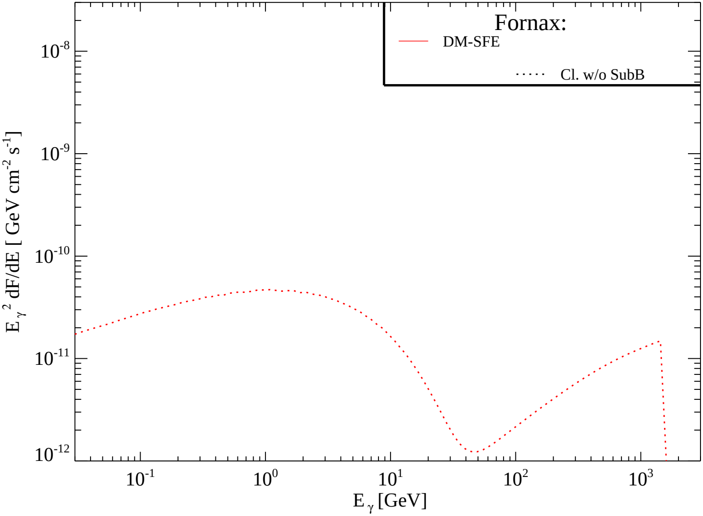
Gamma-ray spectrum from DM vs. CR interactions



Gamma-ray spectrum for various galaxy clusters



DM gamma-rays: without substructure



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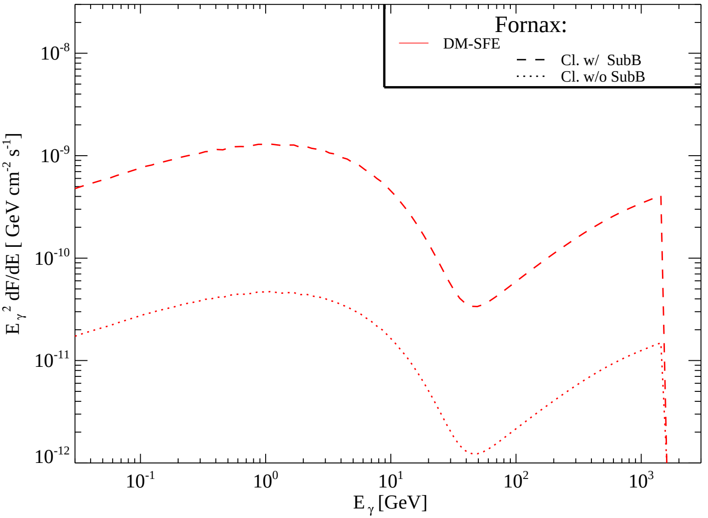
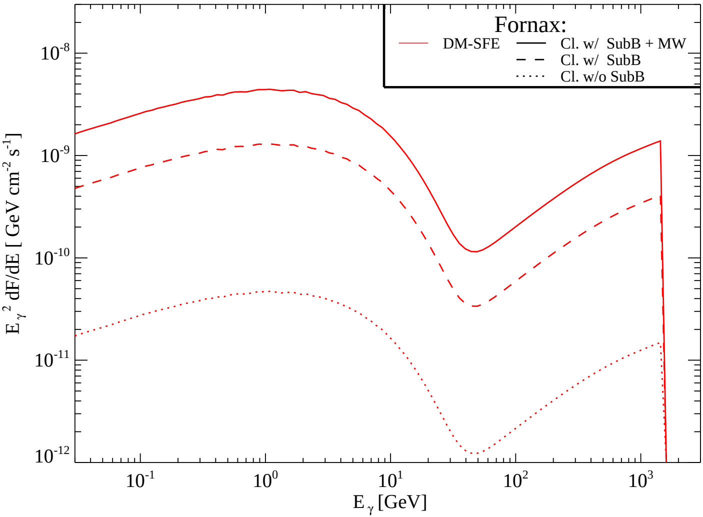


DM gamma-rays: with substructure and Milky Way



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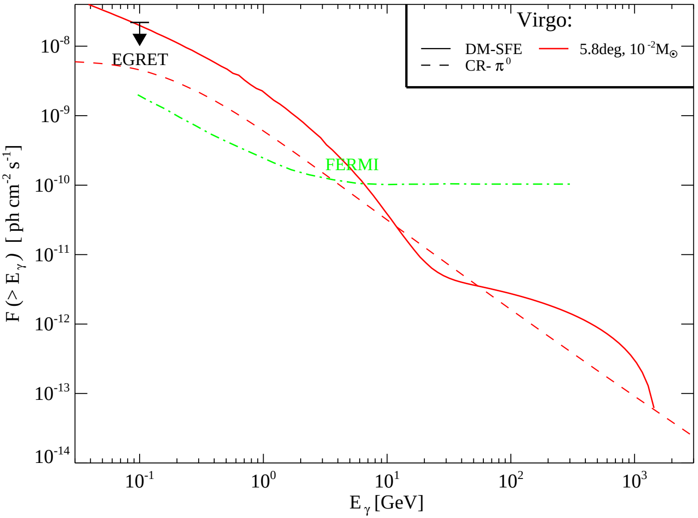
Probing small scales with gamma-rays



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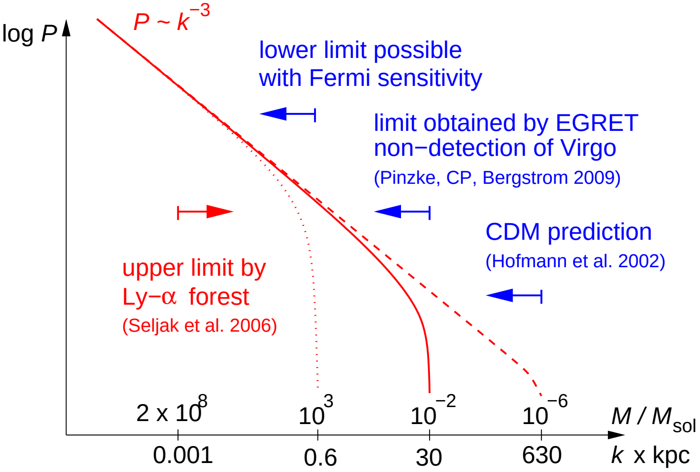
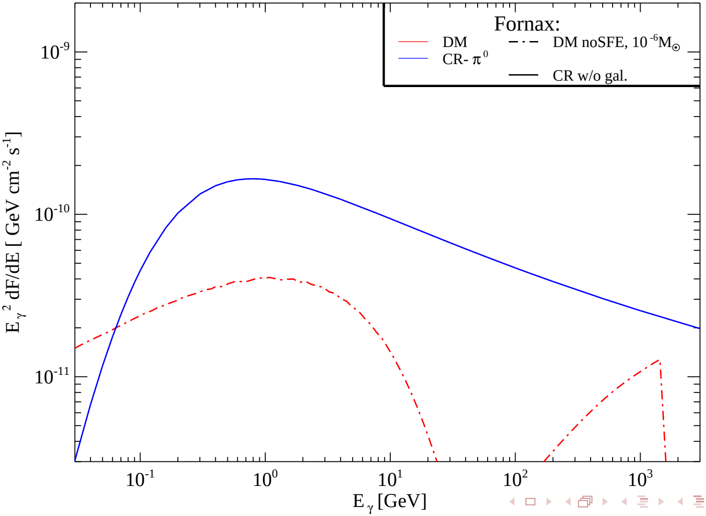
Implications for cosmological structure formation

Probing the linear power spectrum on the smallest scales



Bright prospects without Sommerfeld enhancement

CR induced emission does not completely swamp the DM annihilation signal



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Conclusions

- Gamma-ray observations of galaxy clusters by Fermi will test the DM interpretation of the Fermi/HESS/PAMELA data in the next years.
- If the DM interpretation is correct, then we either live in a warm dark matter Universe or there is a new dynamical effect during non-linear structure formation that wipes out the smallest structures.
- Gamma-ray observations might be the most sensitive probes of the smallest cosmological structures.
- The very distinctive spectral features of the DM-induced gamma-rays and the universality of the CR spectra provides hope that even in the absence of Sommerfeld enhancement, we are able to detect the DM annihilation in the future.

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