Indirect search for dark matter

Martin Pohl

Why indirect search?

Indirect search can reveal

the abundance and distribution

of dark matter

Provided DM is made of weakly interacting particles

Topics

1. Antiparticles
2. Clumping and the Sommerfeld effect
3. Gamma rays, J factors, and profiles
4. Continuum spectra
5. Line emission

Antiparticles

Dark-matter particles can decay or self-annihilate.

→ antiparticles such as e^+, p^-, etc.

Assuming they were in thermodynamic equilibrium until thermal decoupling,

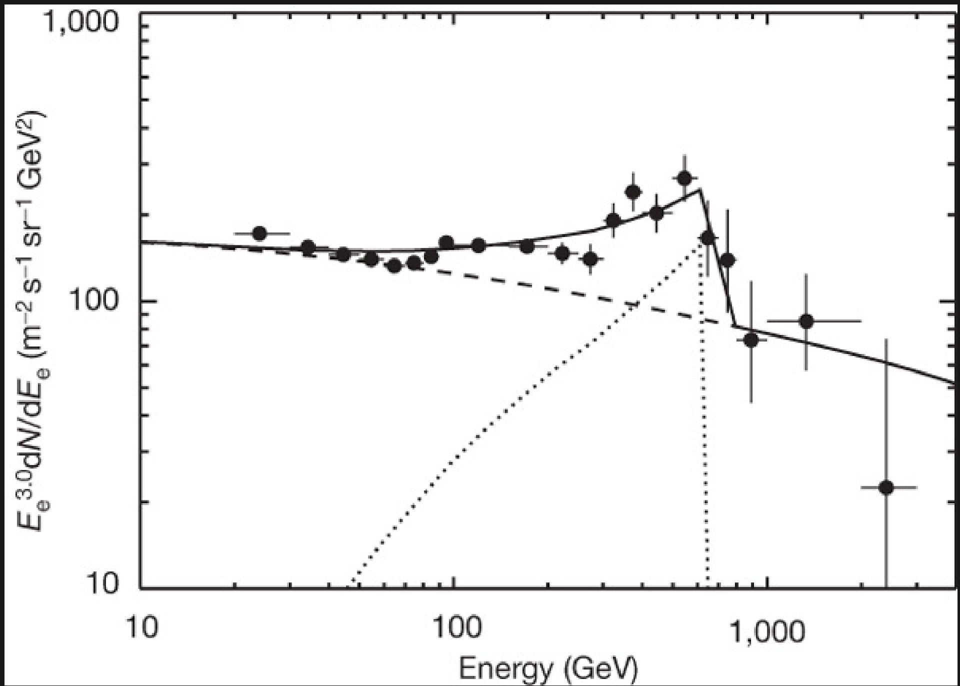
then annihilation cross section should be

$$\langle v\sigma \rangle \cong 3 \cdot 10^{-26}\ \mathrm{cm^3 s^{-1}}$$

Antiparticles

Bumpology

Total electron + positron spectrum



Modeled as resulting from Kaluza-Klein particles

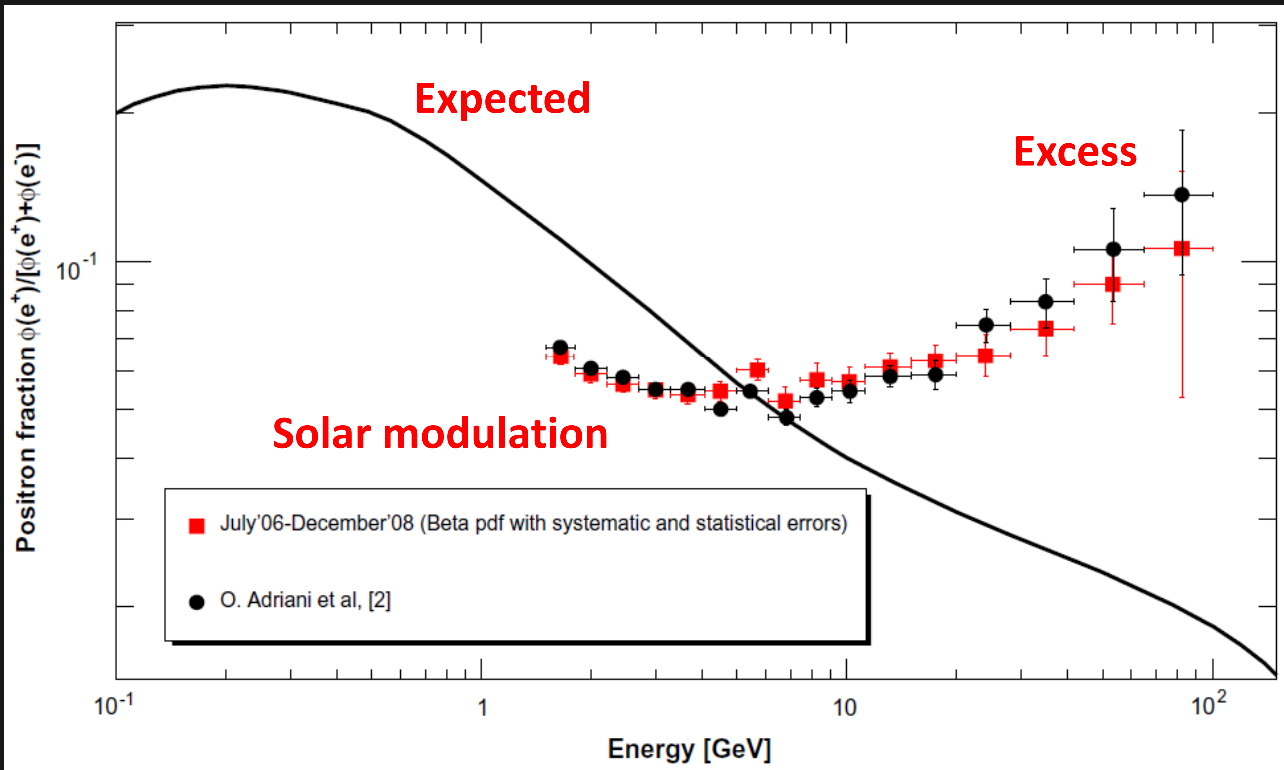
Strong boosting required, factor ~100

Propagation is key issue

Need to discriminate from ordinary astrophysics

Antiparticles

Positron fraction measured with PAMELA



Confirmed by Fermi LAT

Combine with

bump in total e+/e- flux

→Dark matter particles

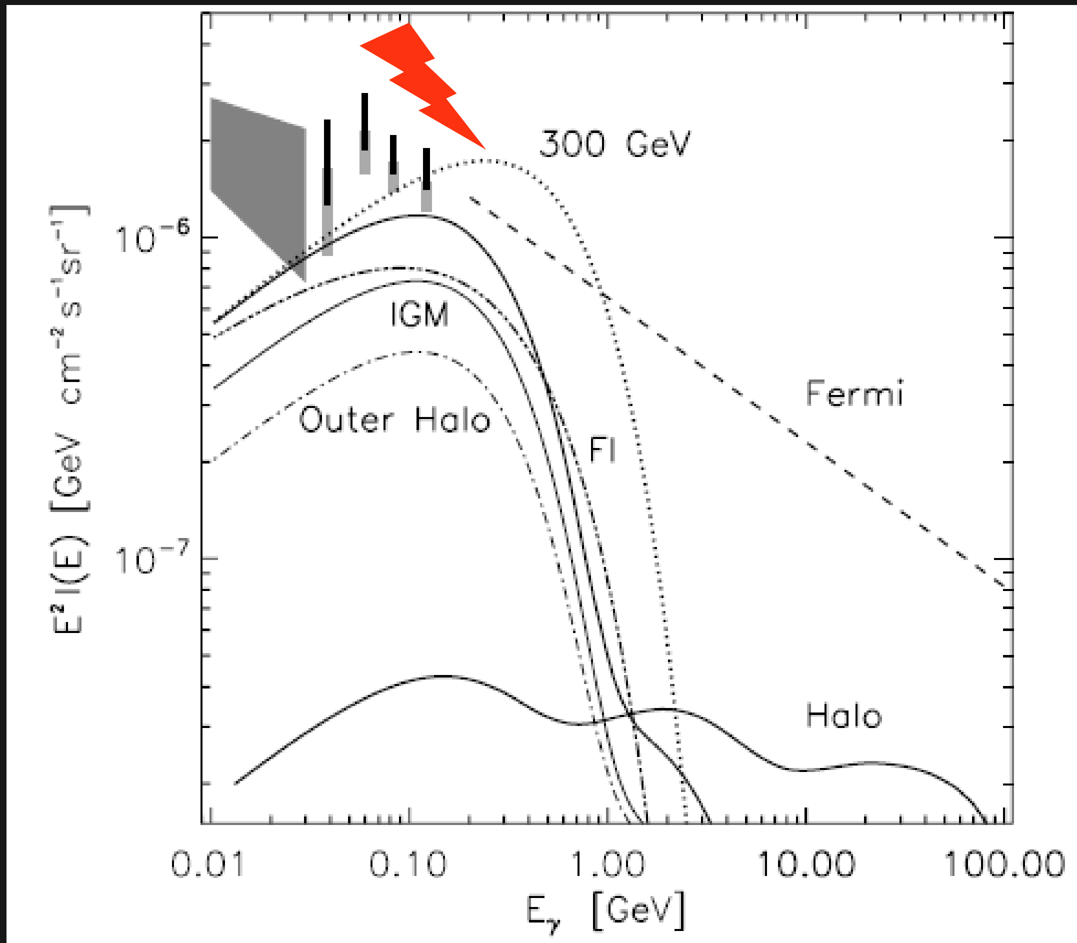
with mass ~600 GeV

Decay?

Decay scales with density

Inverse-Compton emission would exceed extragalactic gamma-ray background

Similar limits for annihilation are generally model dependent



Boosting

Sommerfeld effect:

Originally a resonance effect with environment

Now distortion of wave functions of incoming particles

If particle momentum, p, matches size of potential well, r,

$p \approx h / r$ → Resonance, large value of $|\psi|^2$ at the center

Huge enhancement of cross section, but high mass required

$$m = \frac{p}{v} = \frac{h}{v\lambda} \approx \frac{h}{\sqrt{v}\sqrt{v\sigma}} \cong 1\,\mathrm{TeV/c^2}$$

Boosting

Clumping $\langle \rho^2 \rangle >> \langle \rho \rangle^2$

Careful with Parseval's Theorem $\int d^3x \, \rho_x^2 = \int d^3k \left| \tilde{\rho}_k^2 \right|$

Need to measure density spectrum everywhere!

Clumps can be destroyed in haloes by, e.g., tidal interactions

Boosting

Consider the mass spectrum, $$\frac{dn}{dM} = n_0 M^{-b} , \;\; b \cong 2$$

the source rate per clump, $$Q \propto \rho_0^2 r_0^3 \propto M^d , \quad d \approx 1$$

and the total rate $$\frac{dQ}{d\log M} \propto M^{1+d-b} , \quad 1 + d - b \approx 0$$

If dominated by small clumps, then quasi-homogeneous distribution.

If not, the location of a few clumps is decisive factor.

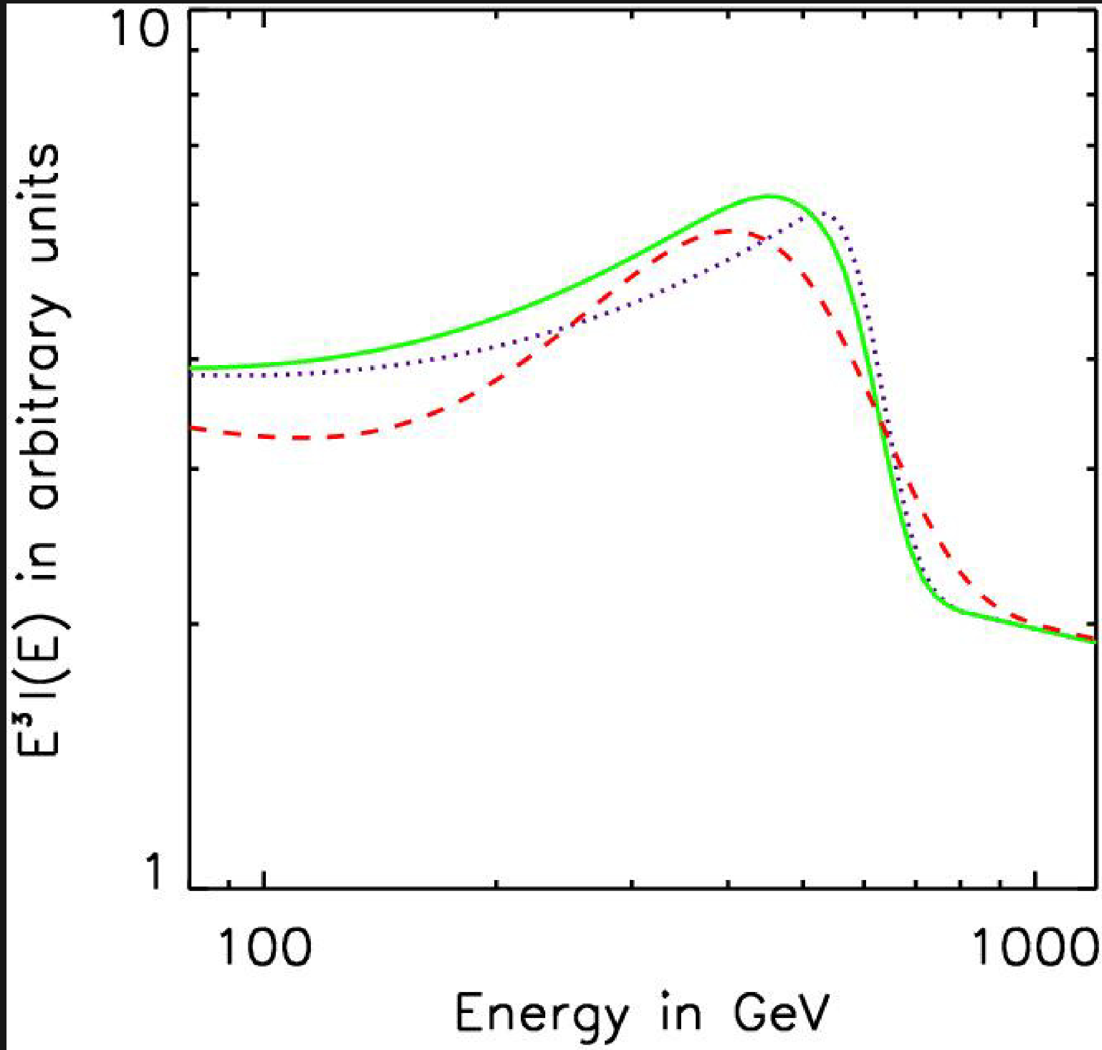
The riddle: e^+/e^- flux

Which is which?

All 8% energy resolution

1. Homogeneous dark matter
2. Clumpy dark matter
3. Pulsar

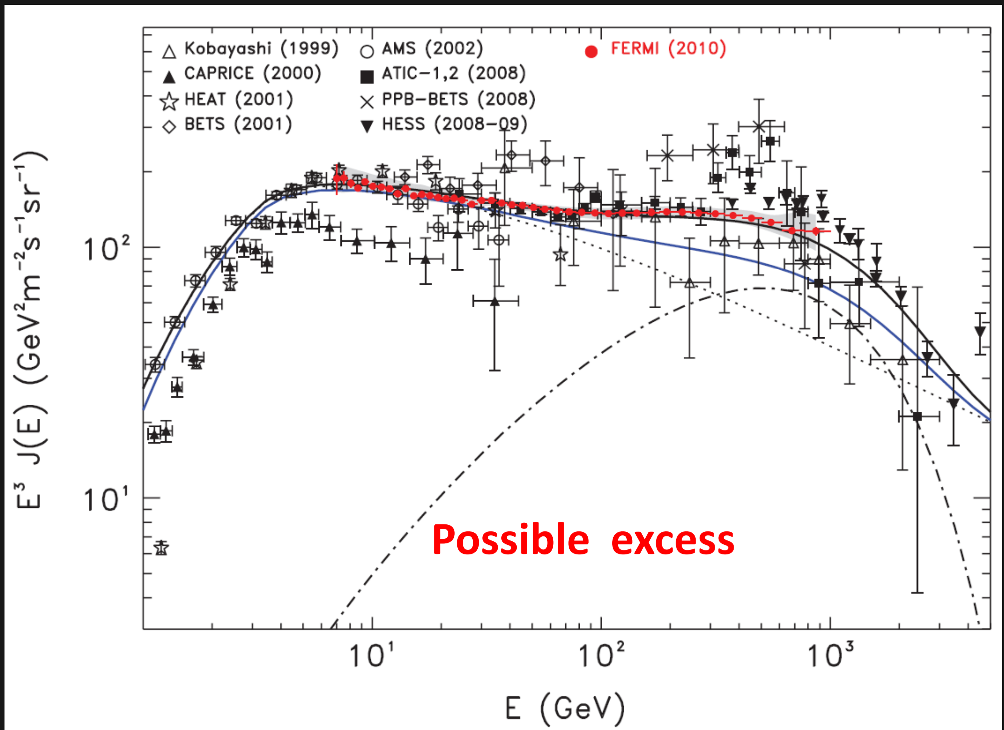
   Distance 1.1 kpc
   Start time 70 kyr
   End time 14 kyr



Current status

An extension of the excess to ~600 GeV?

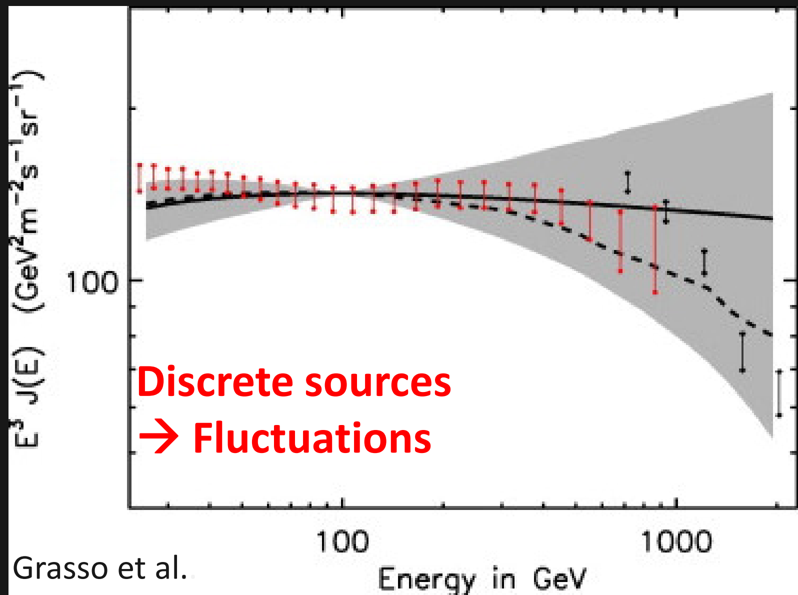
Total e^+/e^- spectrum, Fermi LAT



Requires very soft electron source spectrum

Could be dark matter or pulsars or ...
... nothing

Be careful:
Bumps in electron spectrum are natural!



Gamma rays

Direct production of gamma rays → **observe angular distribution**

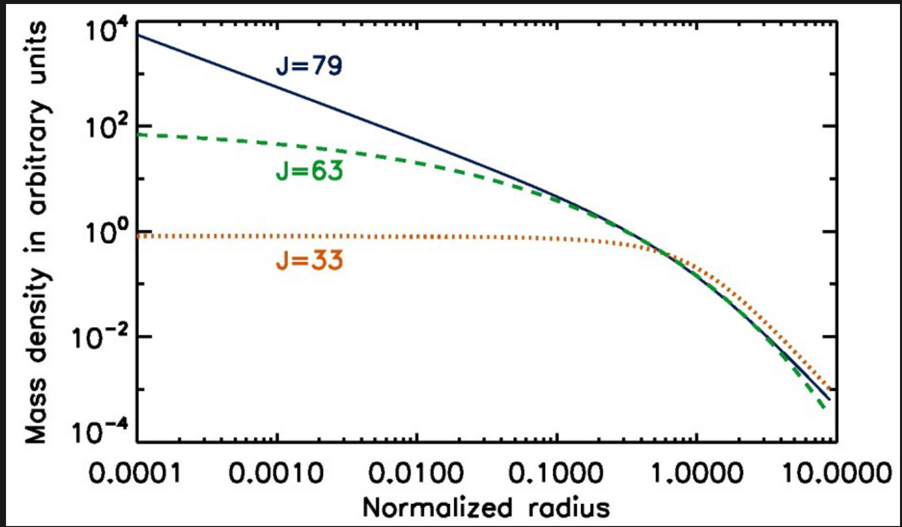
$$I = \frac{\langle v\sigma \rangle}{8\pi\, m_x^2} F \frac{dN}{dE} \;, \qquad F(r_p) = \int_{LOS} dl\, \rho^2 \;, \qquad J = \int_{\Delta\Omega} d\Omega'\, F\left[r_p(\Omega')\right]$$

Choice of density profiles:

NFW, Einasto, and Burkert

Same mass within unit radius

A central cusp or not?



Gamma rays

The density profile $\rho(r)$ matters

Astrophysical foreground matters as well

Pick your target:

Galactic center	Very large J	Huge foreground
Cluster of galaxies	Large J	Extended, AGN?
Dwarf galaxies	Large J, uncertain	Little foreground

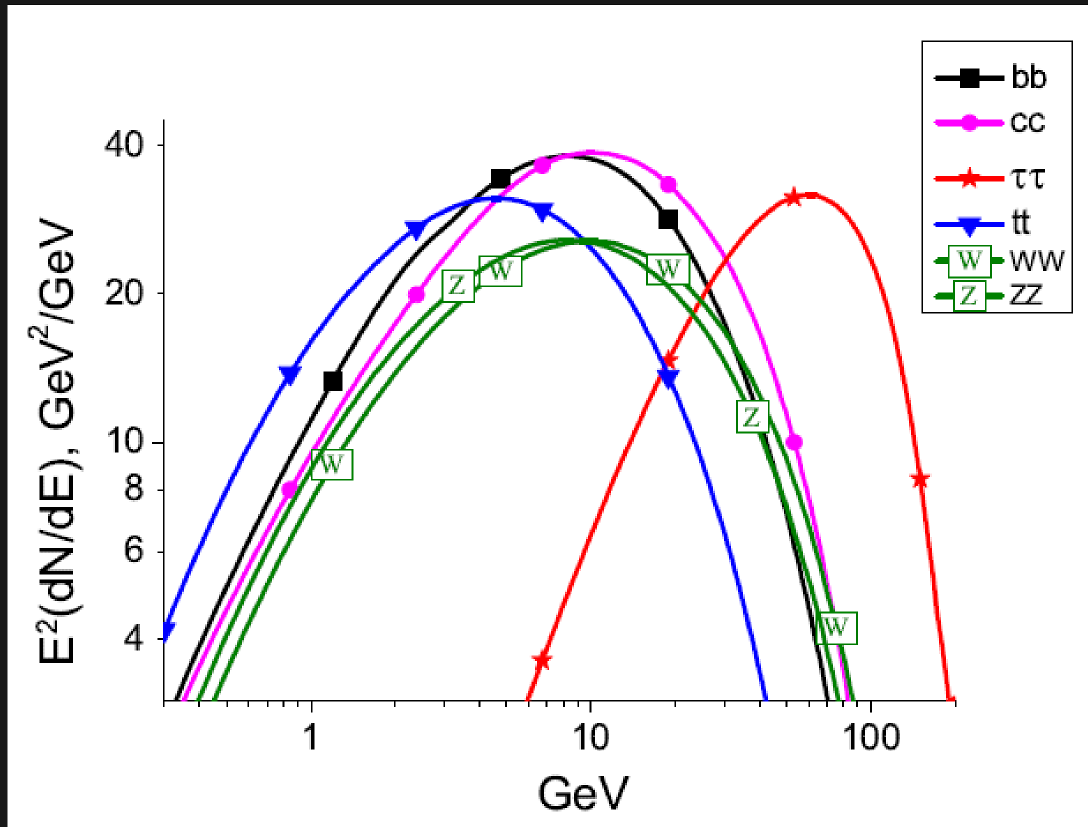
Gamma rays

Example: m_x=200 GeV

Pick your spectral model

Combine with profile

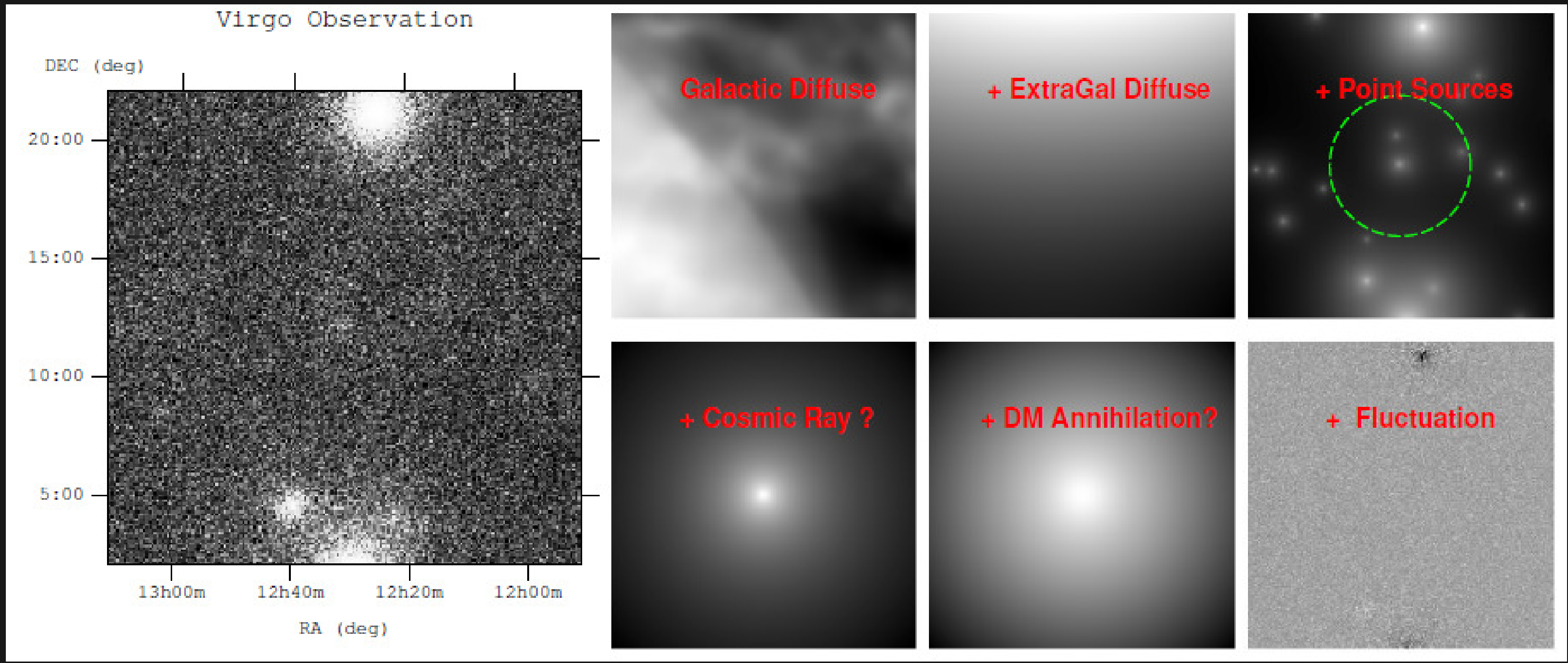
Analyze data (Fermi-LAT, or HESS, MAGIC, VERITAS)



Gamma rays

Continuum gamma rays from nearby clusters   Han et al.

NFW density profile with strong boosting in outer halo

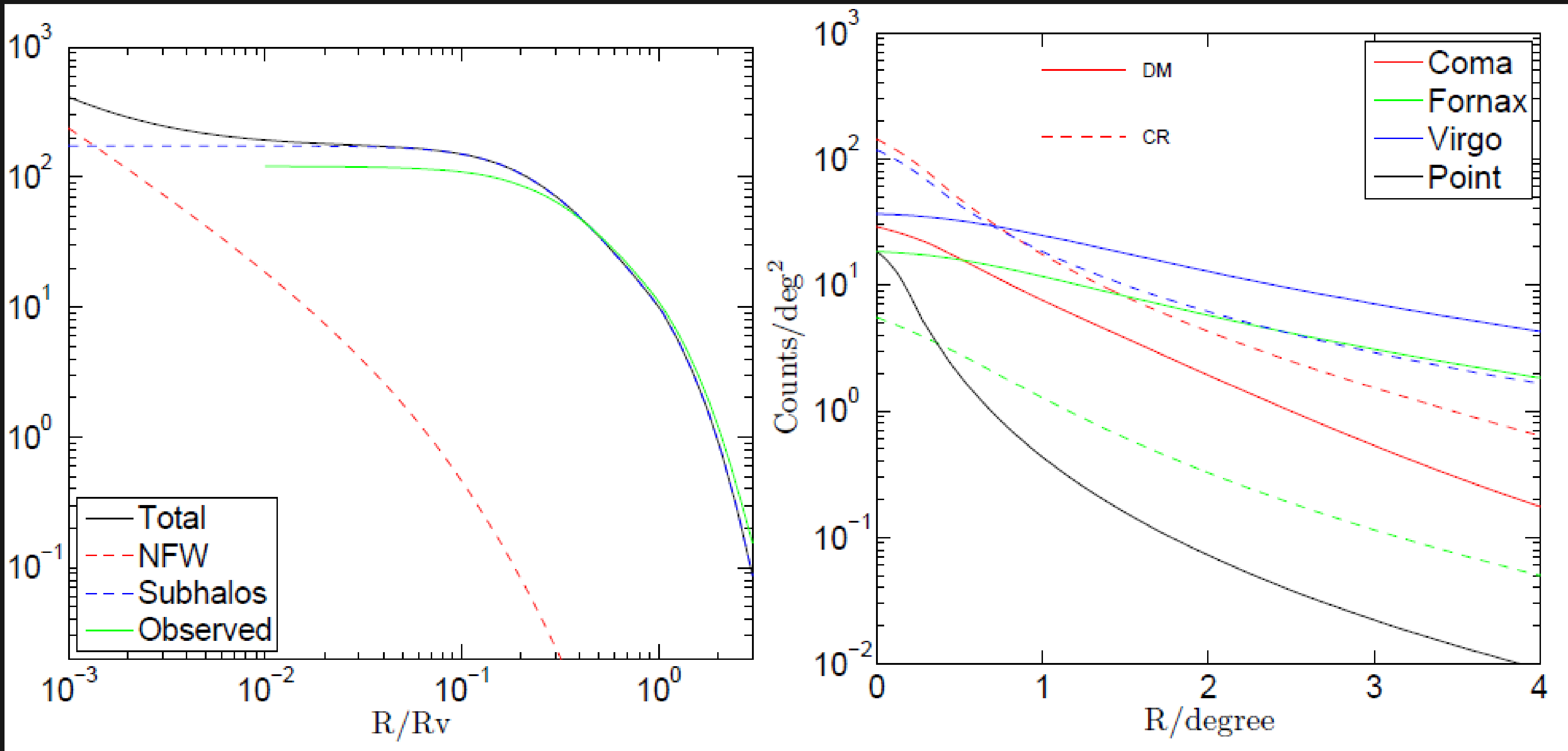


Gamma rays

Boosting of clumps dominates signal

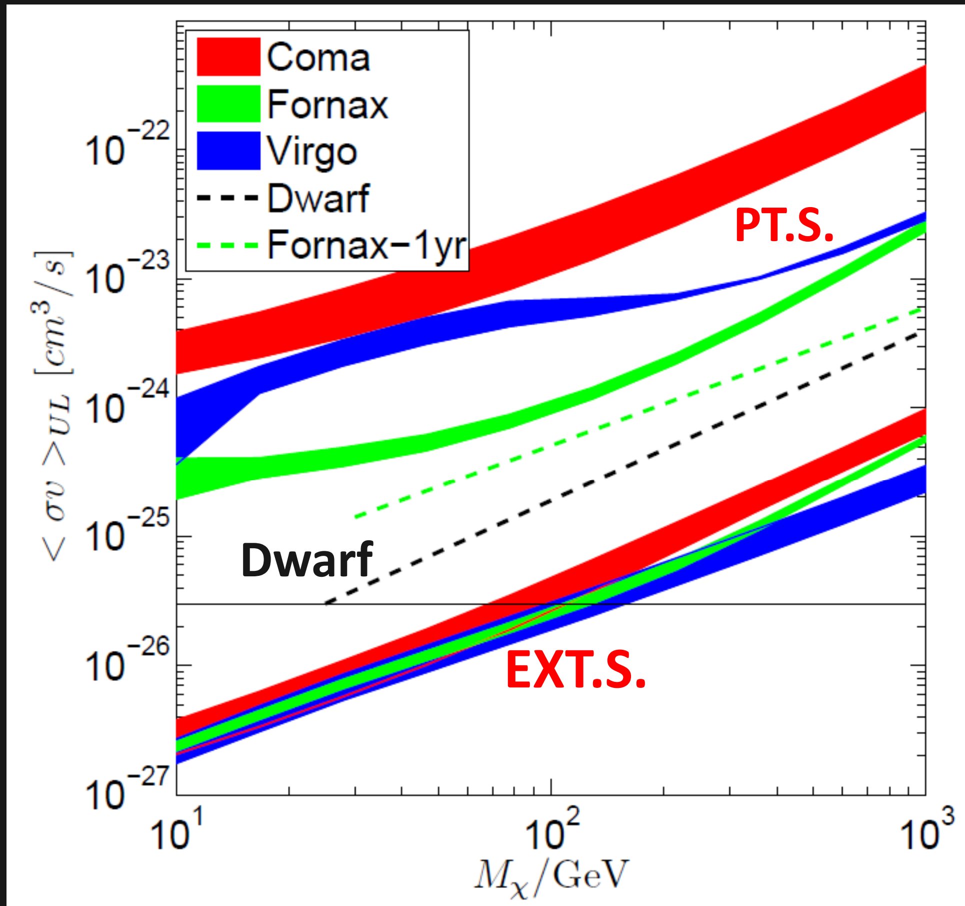
Trial factor?

F



Gamma rays

Marginal detection → Treat as upper limit



Model dependence:
Unteresting
if boosting is weak

Need much more A_{eff}
beyond 20 GeV

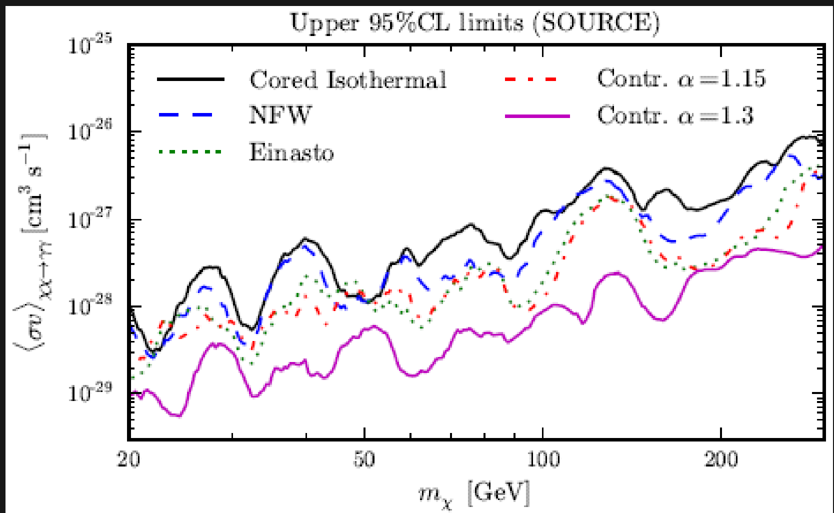
→ **CTA**

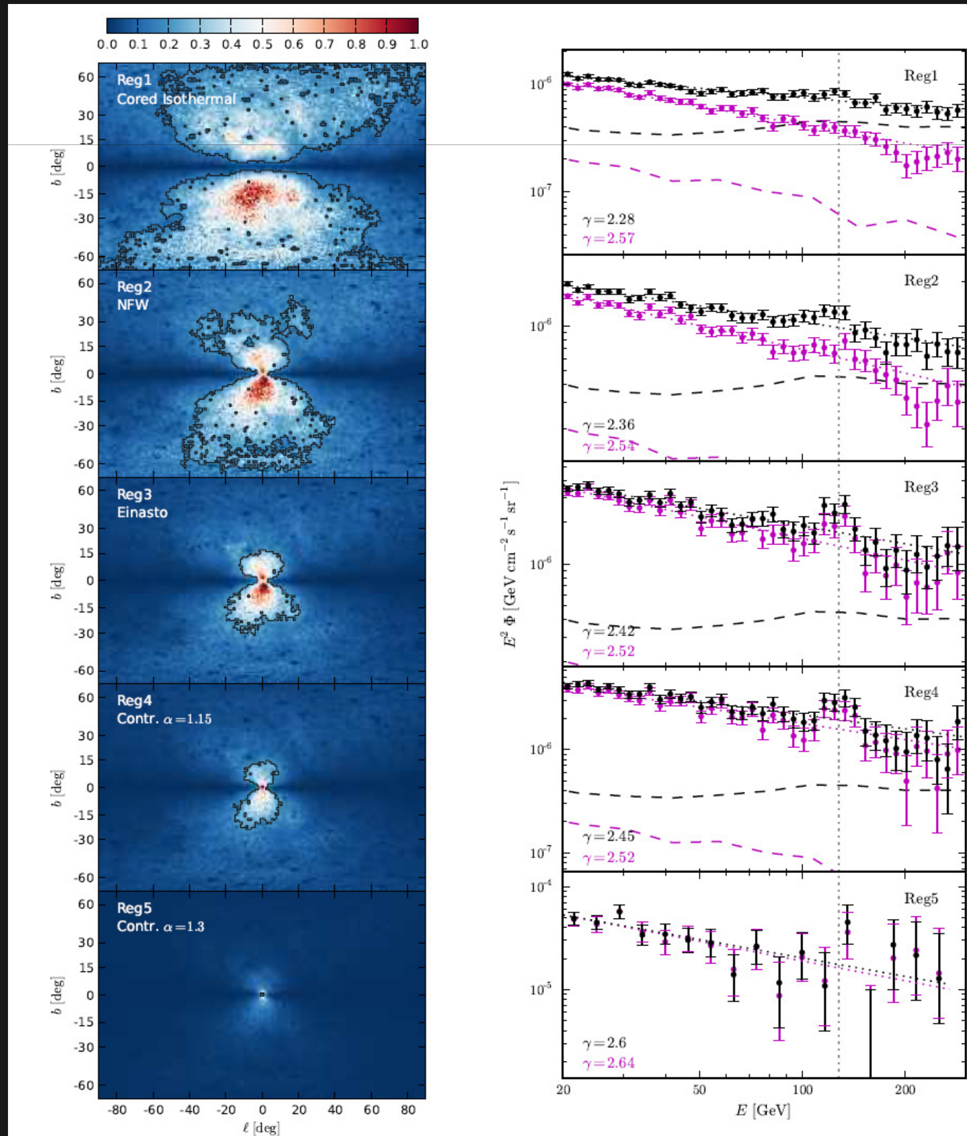
Gamma rays

Suppose annihilation channel into photon pair → line at m_x

or 3 bodies with 1 photon (internal bremsstrahlung) → Bump below m_x (Weniger)

Marginal result → Upper limit





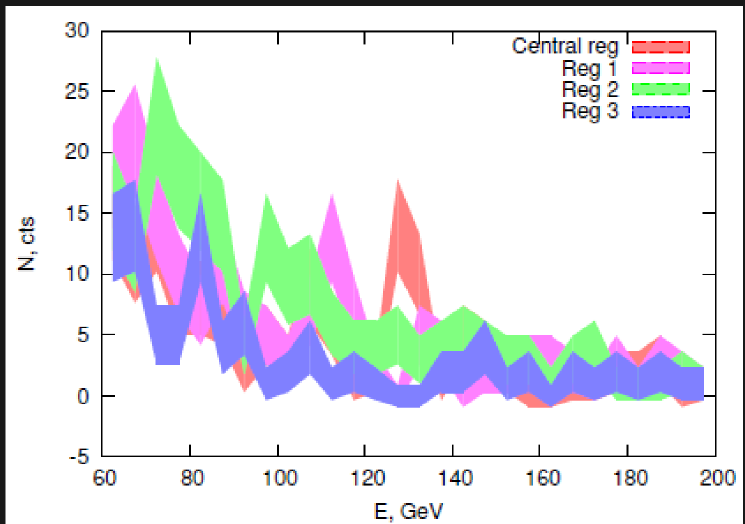
Gamma rays

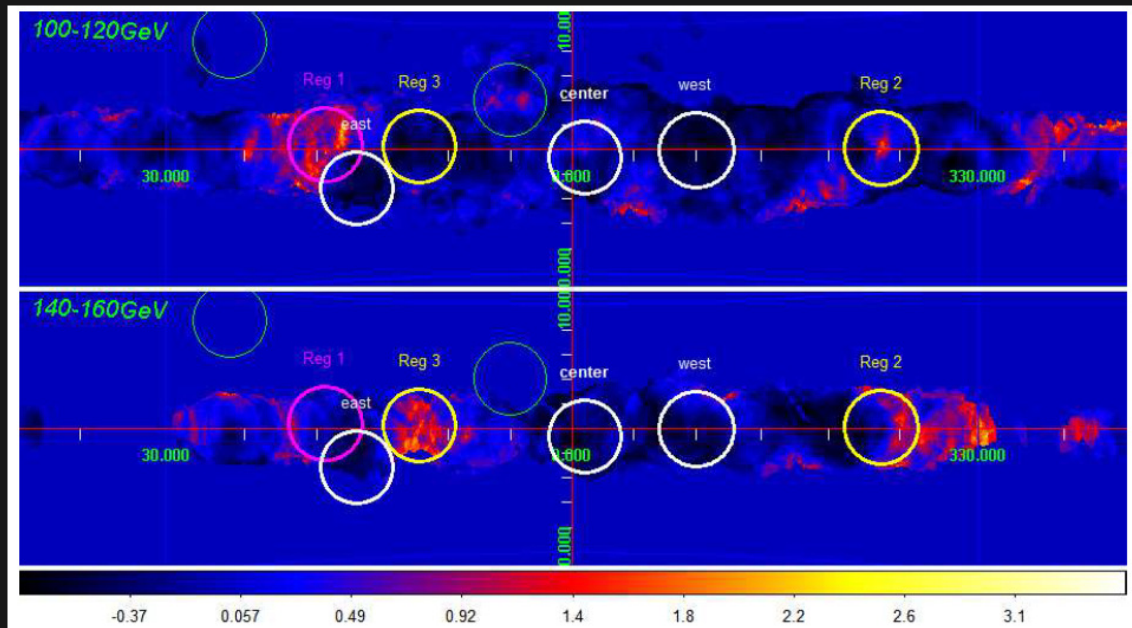
Careful: upper limit includes branching ratio

$$\langle v\sigma\rangle \to \zeta\langle v\sigma\rangle\ , \quad \zeta \approx 10^{-4}$$

There should be no gamma-ray lines beyond 1 GeV **but spectral bumps?**

Excess over background and spectra (Boyarsky et al.)





Conclusions

No indirect detection of dark matter thus far

What are the issues?

- Trials, systematics, background
- Upper limits approach interesting levels

What can we improve?

- Need to go lower in intensity → background
- Need UL without boosting
- Need large FOV and large A_{eff} → CTA
- Or simply need luck