High-energy electrons, pulsars, and dark matter

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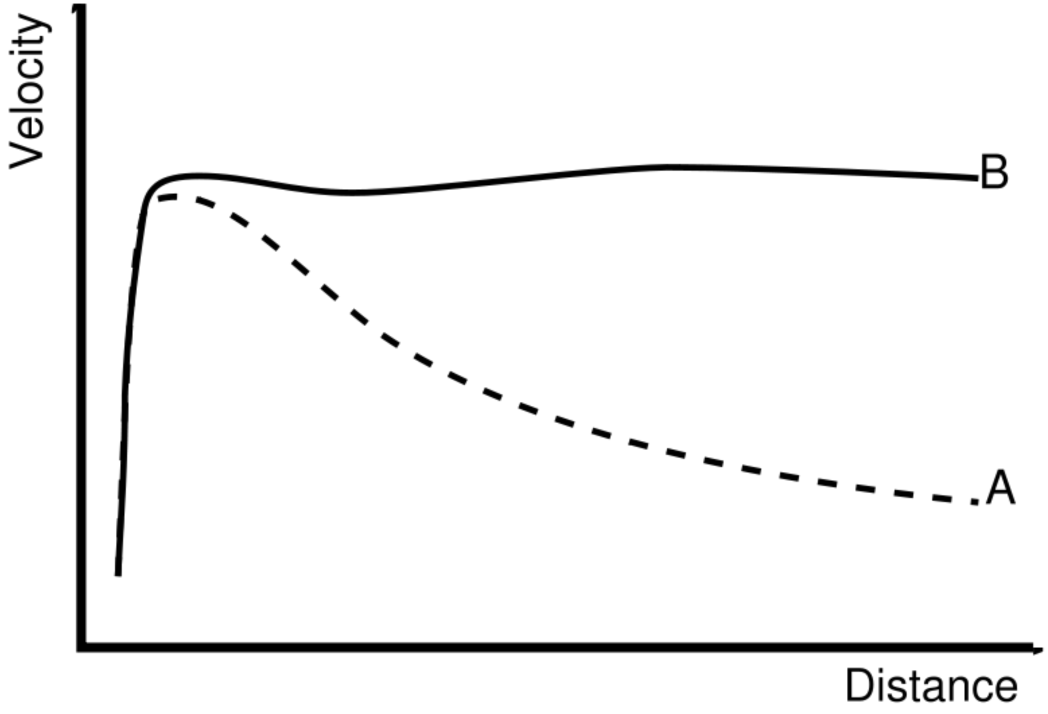
Dark matter

Known for 40 years:

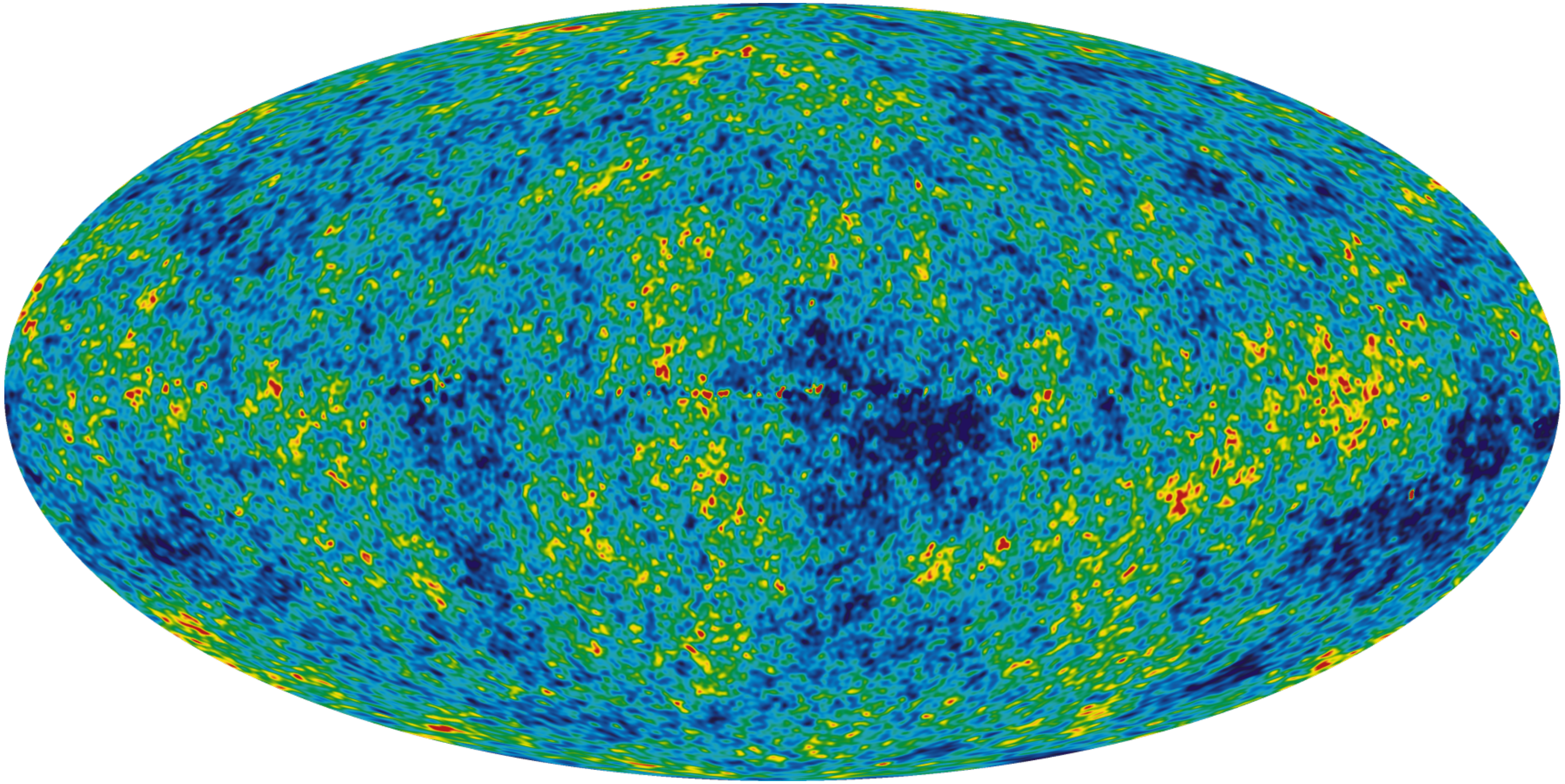
Rotation curves are flatter (B) than expected for observed matter (A)

→ Dark matter

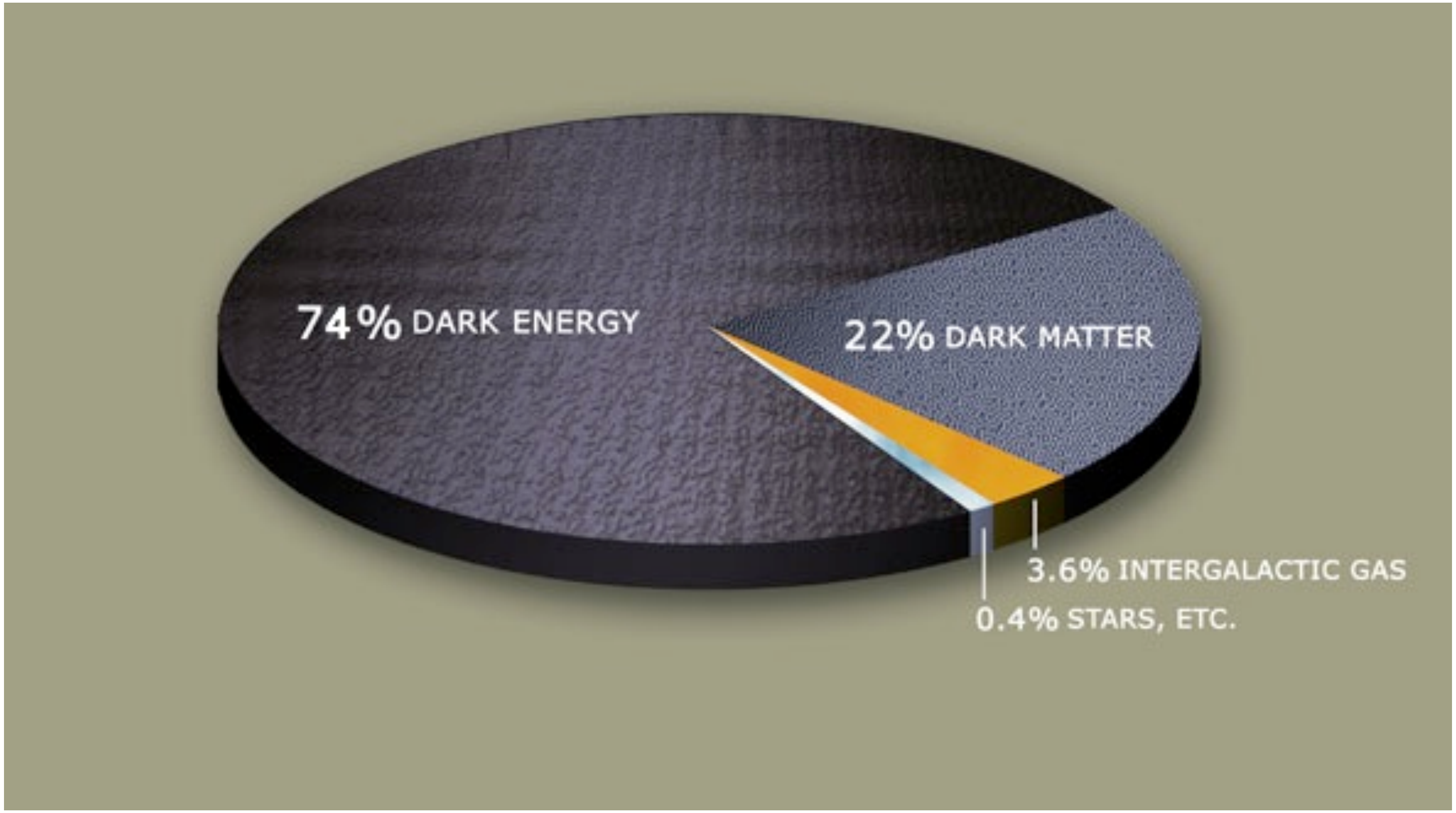


Dark matter

Structure formation ➔ Dark matter must be cold!

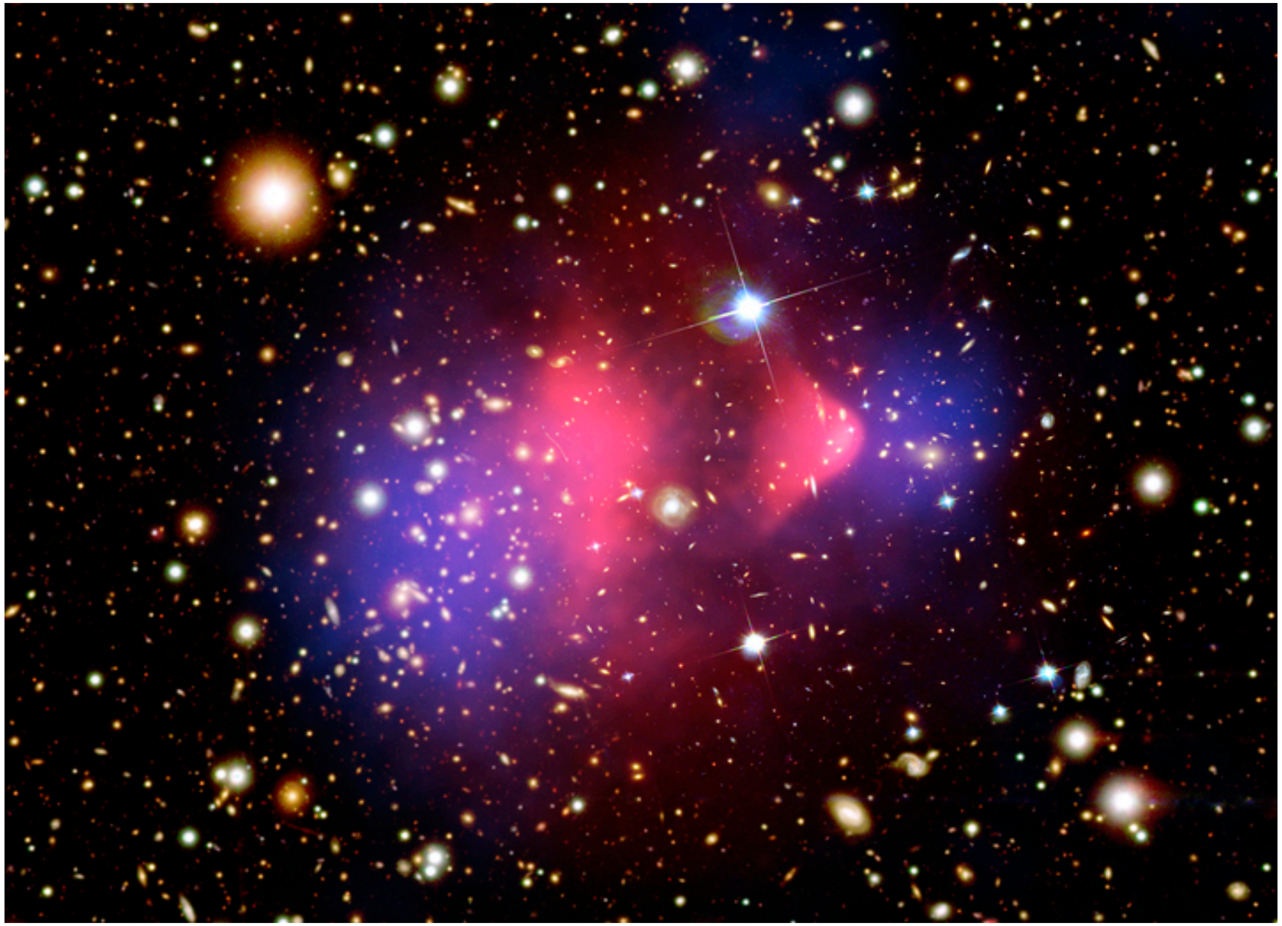


Dark matter


74% DARK ENERGY
22% DARK MATTER
3.6% INTERGALACTIC GAS
0.4% STARS, ETC.

Dark matter

Can’t be gas!



Colliding clusters:

Blue: (dark) matter

Red: (hot) gas

Dark matter

- Direct detection
  - LHC → mass and cross section, but not density
  - Recoil experiments → elastic cross section unknown

- Indirect detection
  - Annihilation into gamma rays or antiparticles
    → will give density distribution
  - Boosting or Sommerfeld enhancement required

Indirect detection: cosmic rays

Galactic cosmic rays

Relativistic charged particles

88% p, 10% α, 1% e^-

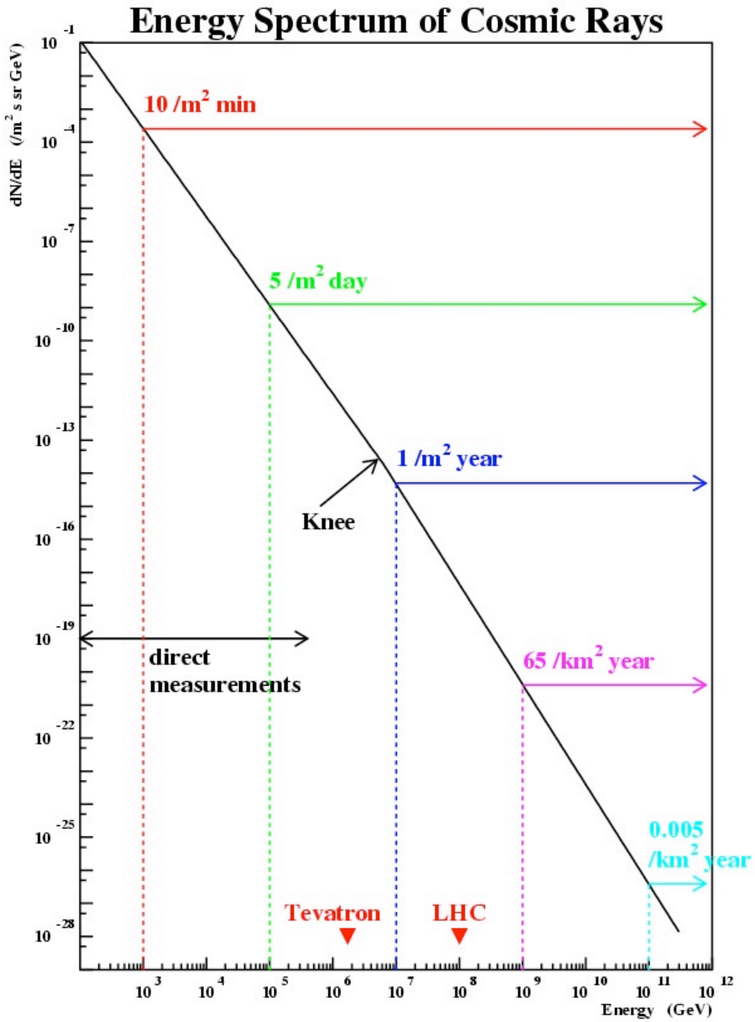
Gamma rays from

$p + p \rightarrow \pi^0 \rightarrow \gamma$

Antiparticles from, e.g.,

$p + p \rightarrow \pi^+ \rightarrow e^+ + \nu$

Also from dark matter



Cosmic-ray electrons

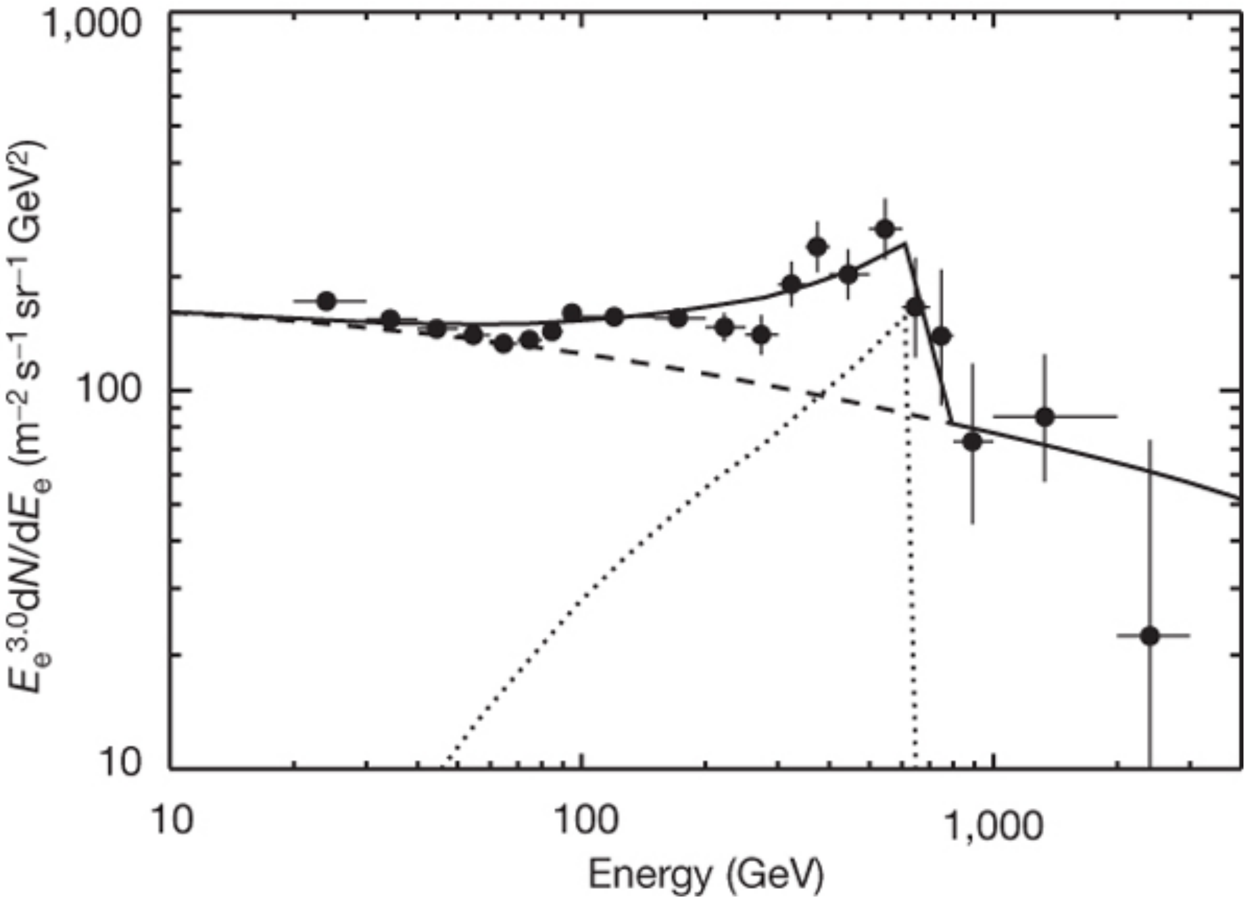
Excess at 500 GeV

Dashed line:
Normal CR electrons

Dotted line:
Kaluza-Klein DM

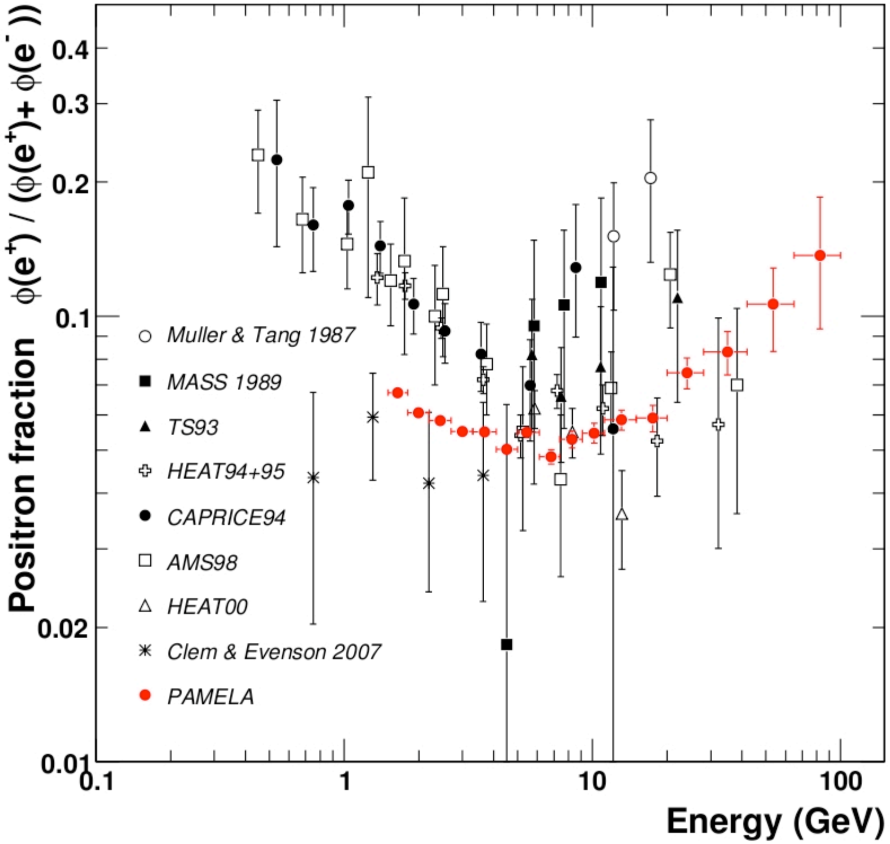
Needs boost by ~200

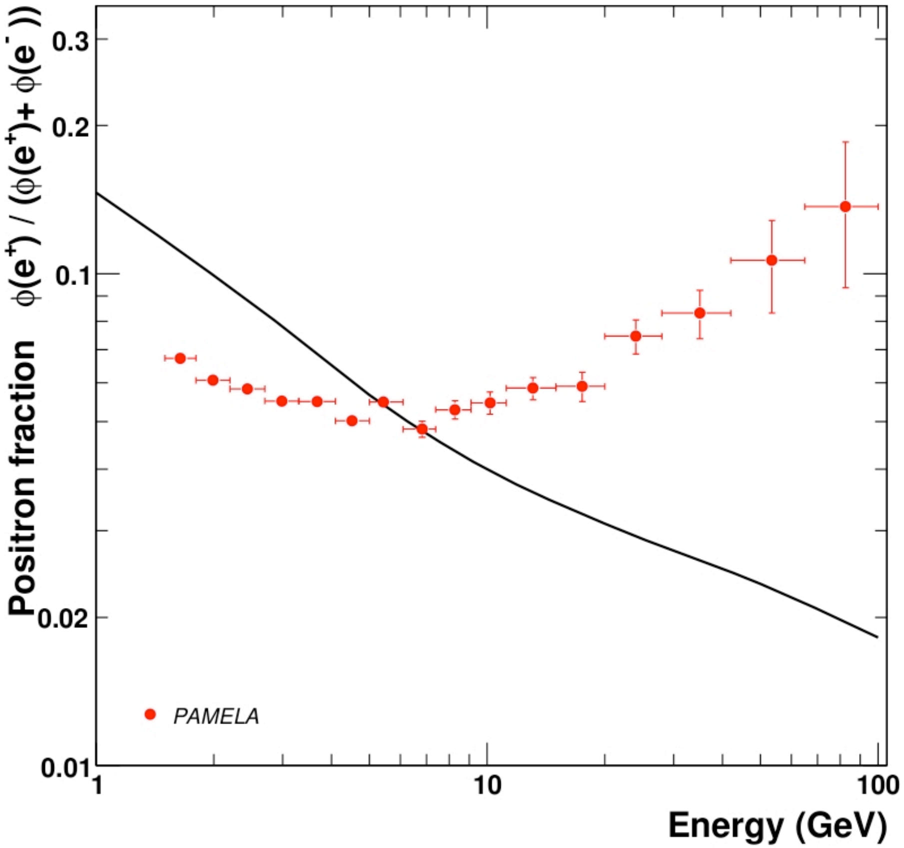
ATIC: cosmic-ray electrons



Positrons with Pamela

May be a new source of electron-positron pairs





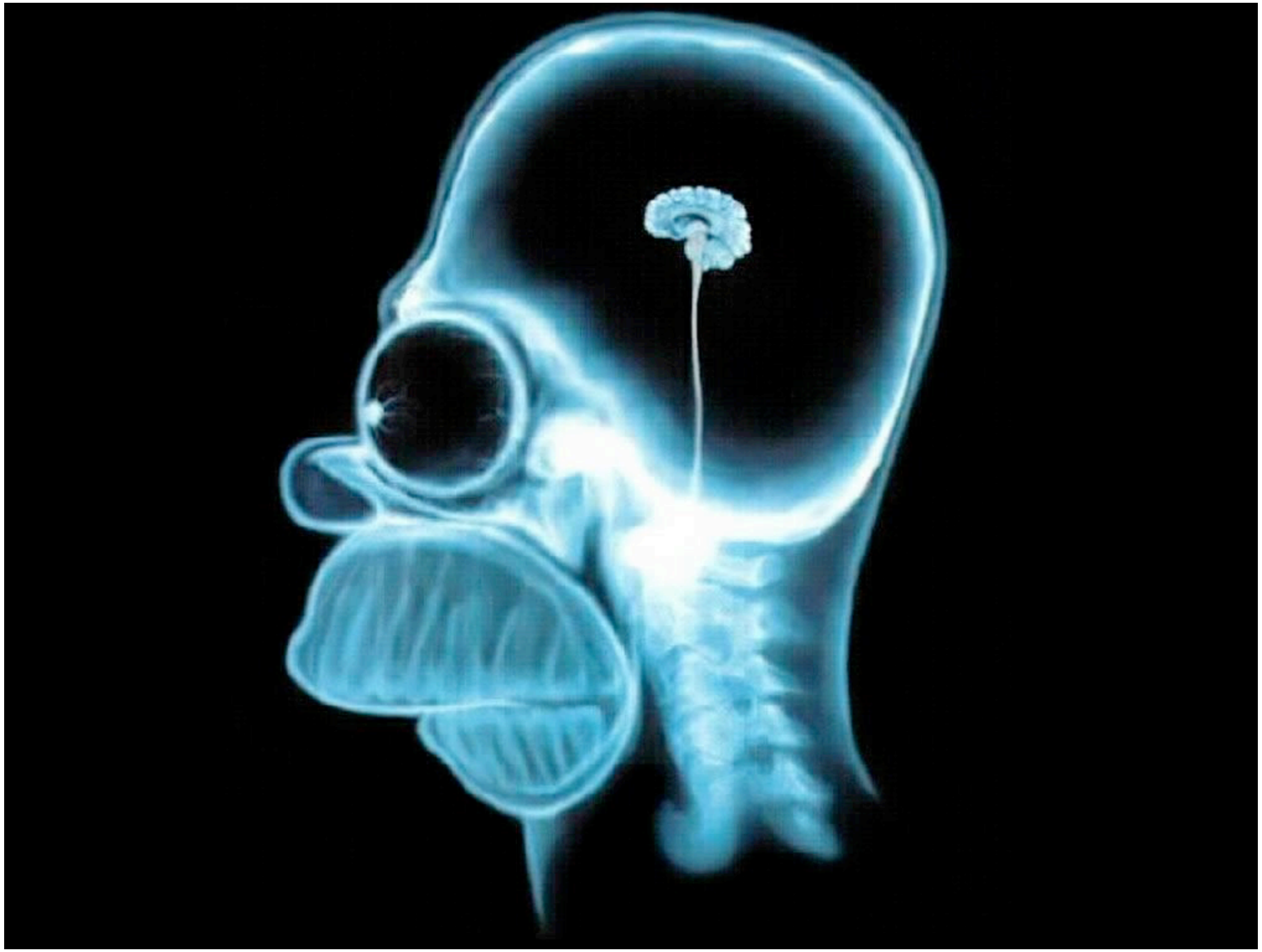
Kaluza-Klein dark matter

- Interest: Could be dark matter!
    - Needs boost factor of ~200
    - Needs e+/e- pairs as main decay channel

- Kaluza-Klein dark-matter
    - Produces monoenergetic pairs
    - Supports theories with extra dimensions

- Electron spectrum modified by propagation

How can we make sense of this?



The transport equation

Consider differential electron density

$$N = \frac{dN}{dVdE} = \frac{4\pi}{\beta c} I$$

$$\frac{\partial N}{\partial t} - \frac{\partial}{\partial E}\left(b\ E^2 N\right) - D\ E^a \nabla^2 N = Q$$

Energy loss diffusion injection

Two classes of models:

pure diffusion a=0.6

reacceleration a=0.33

Dark matter: depends on clump density

Boosting required ➔ clumps

Realistic case: mass spectrum $\frac{dn}{dM} = n_0 \, M^{-b}$

But electron source rate: $Q \propto \rho_0^2 \, r_0^3 \propto M^d \, , \quad d \approx 1$

$$\frac{dQ}{d\log M} \propto M^{1+d-b}$$

d+1-b > 0 ➔ Dominated by few massive clumps

Dark matter: depends on clump density

Pure diffusion model

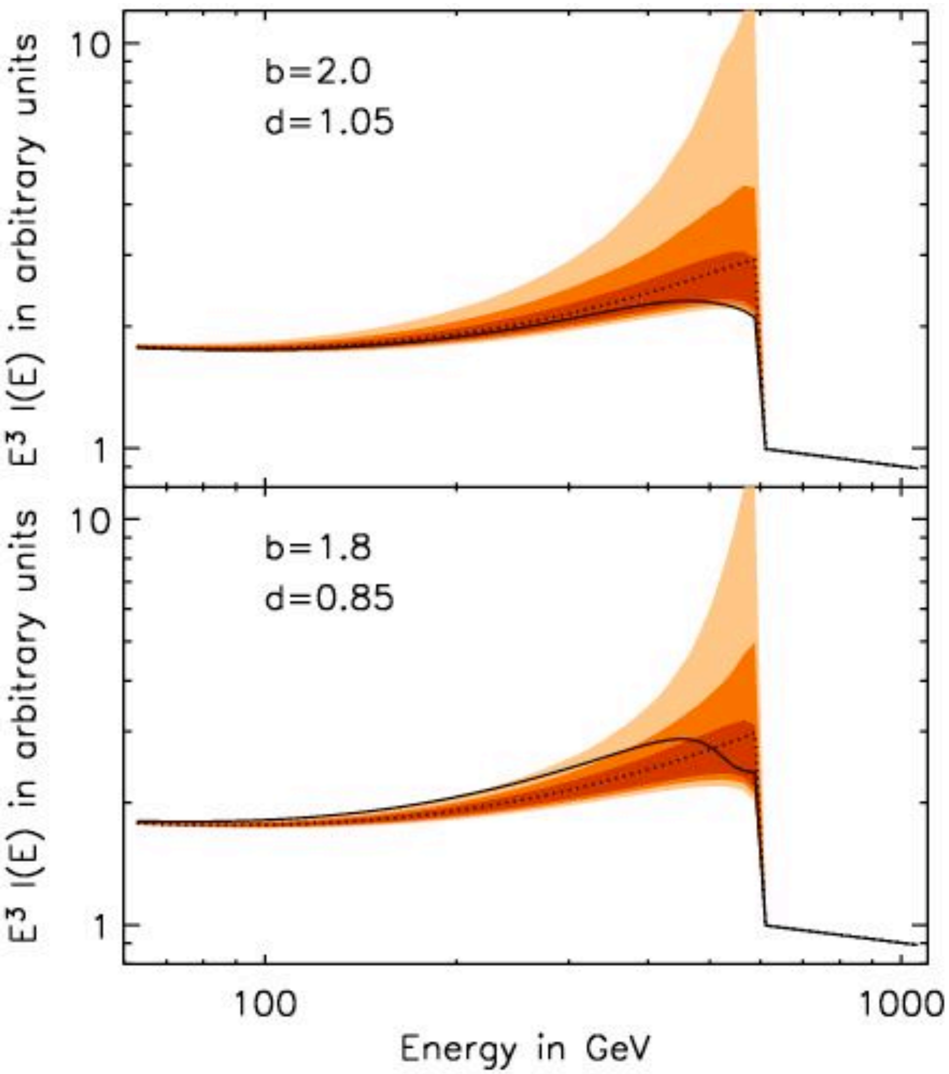
added to normal electron flux

Dotted line:
average spectrum

Dashed line:
randomly selected spectrum

Color shades:

- **Light: 68%**
- **Medium: 90%**
- **Dark: 99%**



Pulsars may also leak pairs …

Source spectrum (dotted)

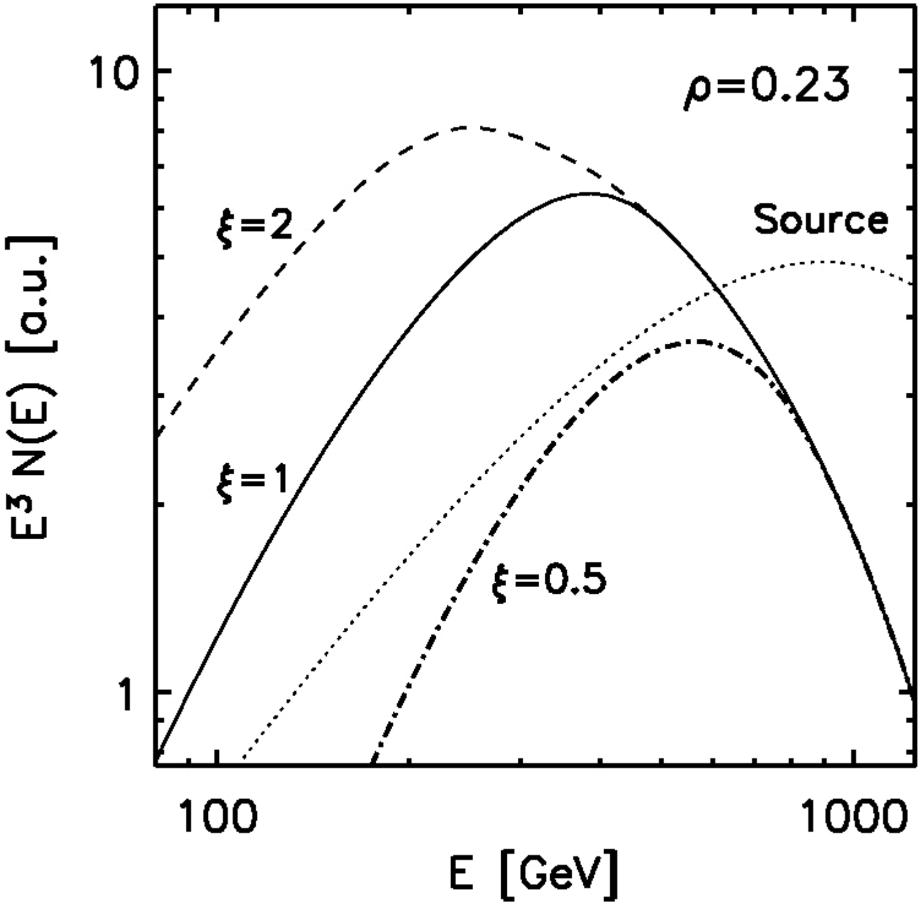
$$Q(E) \propto E^{-1.5} \exp\left(-\frac{E}{E_0}\right)$$

Age in units of energy-loss time at 600 GeV:

$$\xi = 1 \quad \leftrightarrow \quad t = 140{,}000 \text{ yrs}$$

Distance in units of diffusion distance at 600 GeV

$$\left(\frac{\rho}{0.23}\right) = \left(\frac{r}{700 \text{ pc}}\right)^2$$



The riddle: which is which?

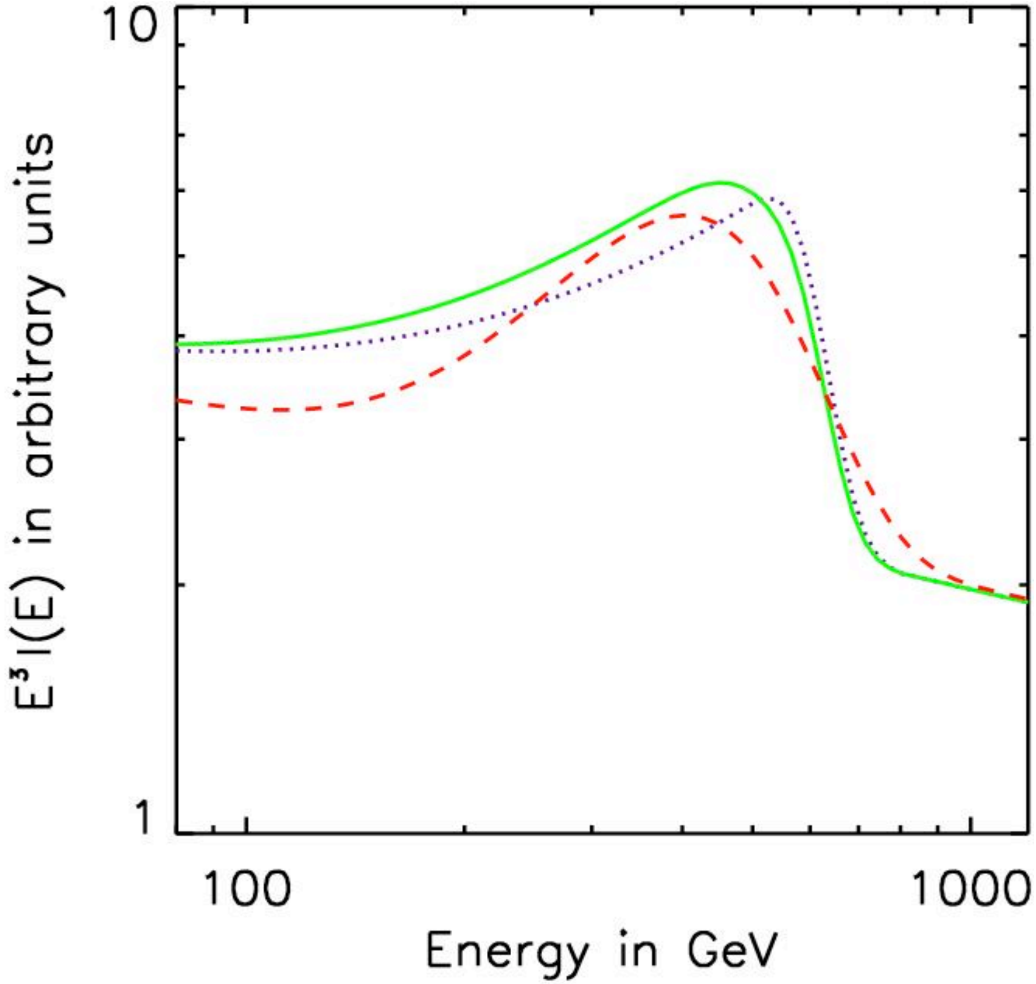
All 8% energy resolution

A)Homogeneous dark matter

B)Clumpy dark matter

C)Pulsar

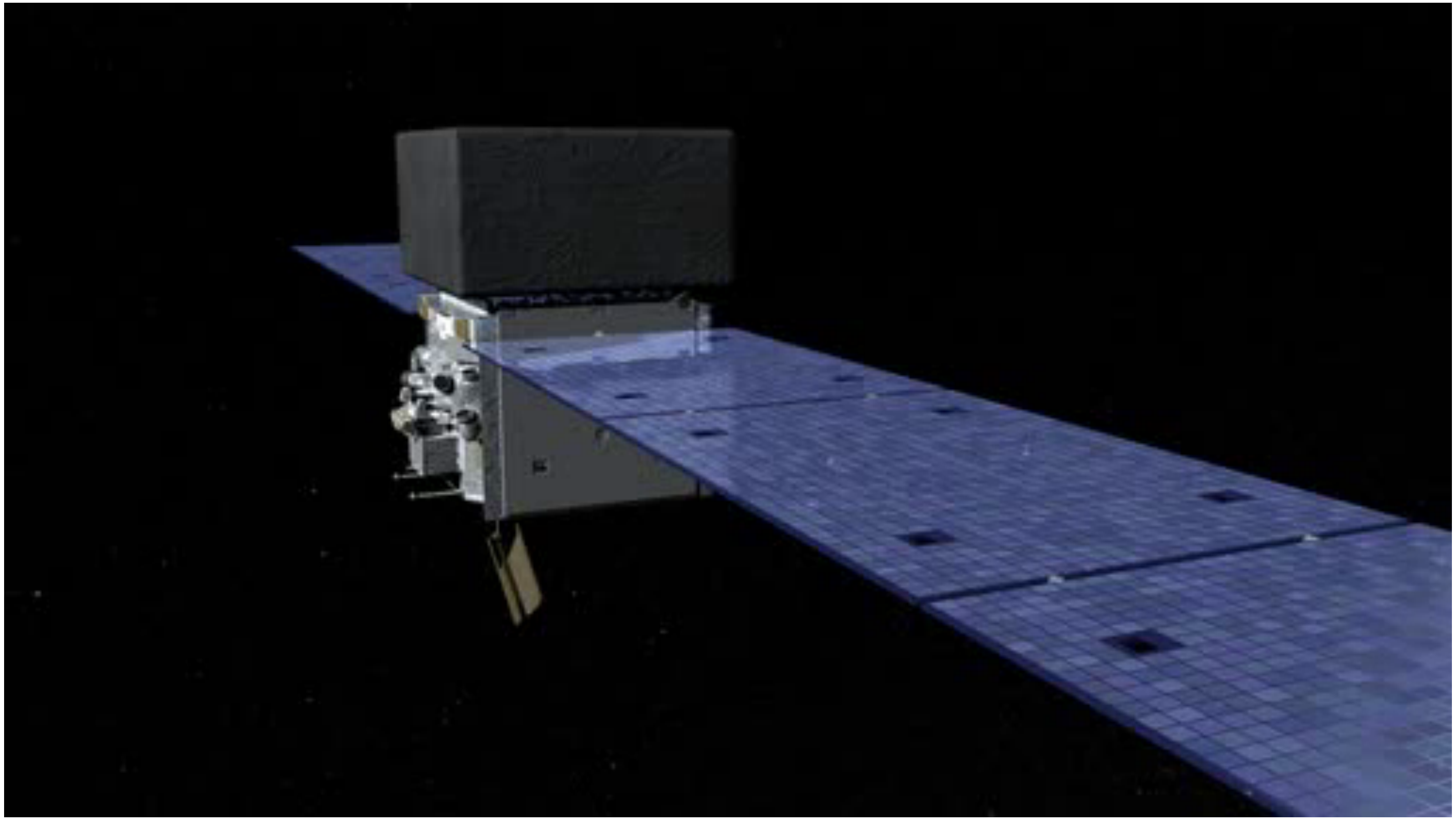
Distance 1.1 kpc
Start time 70 kyr
End time 14 kyr



MP, PRD 79, 041301 (2009)

What will GLAST/Fermi add?

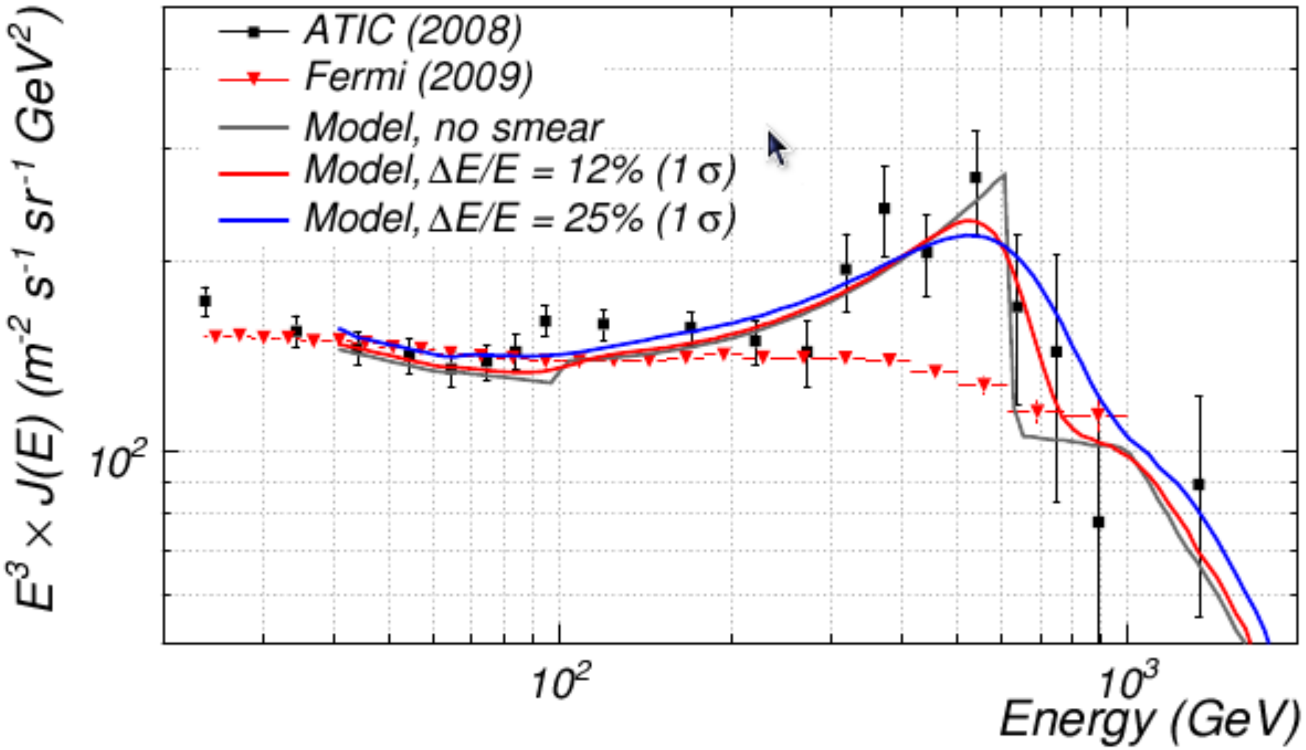
Designed to measure gamma rays, but can also measure electrons



LAT data and other sources

LAT data: much weaker excess (Abdo et al. 2009)

Narrow peak would have been seen!

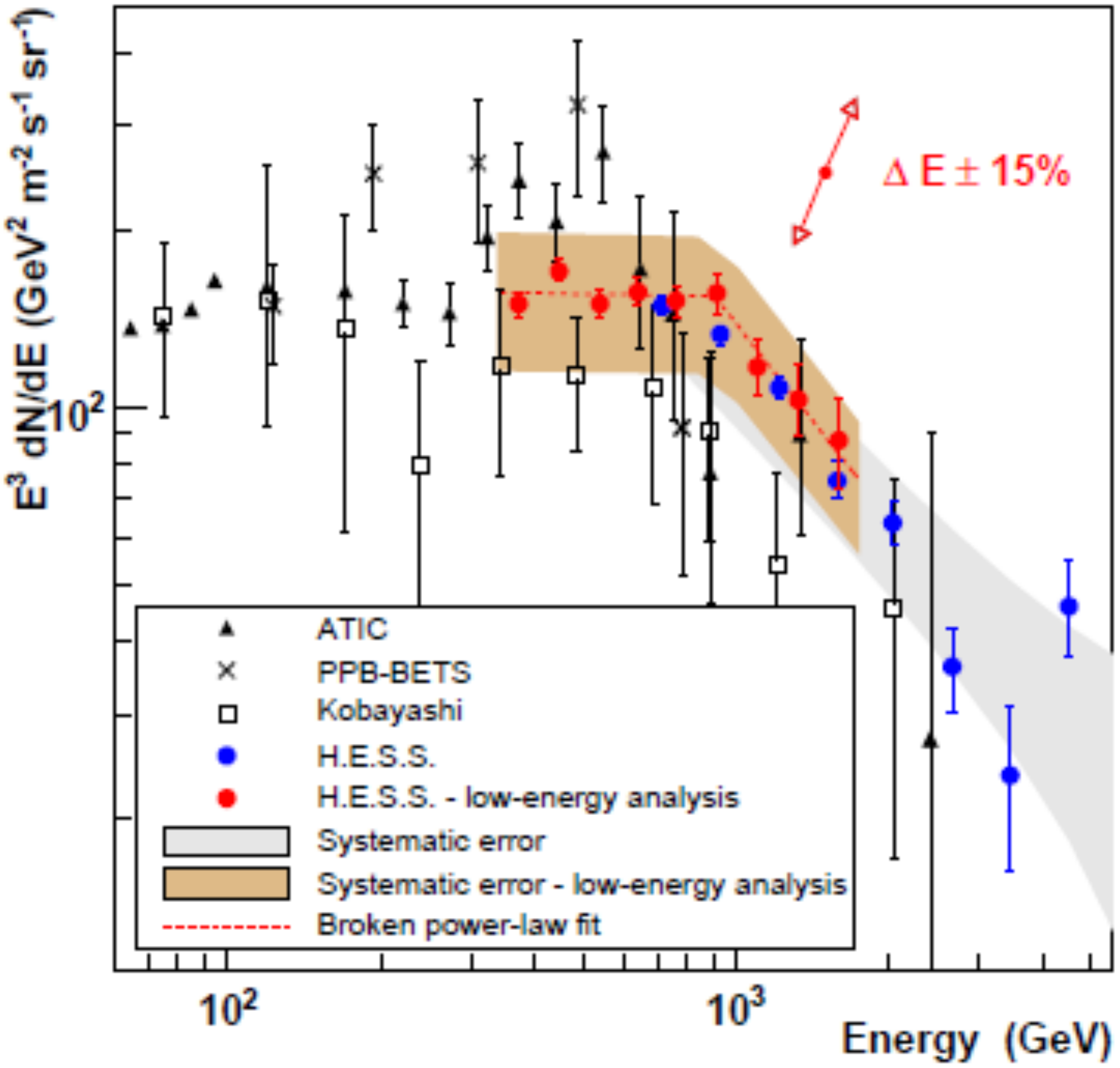


No bump?

Low-energy analysis

of HESS data

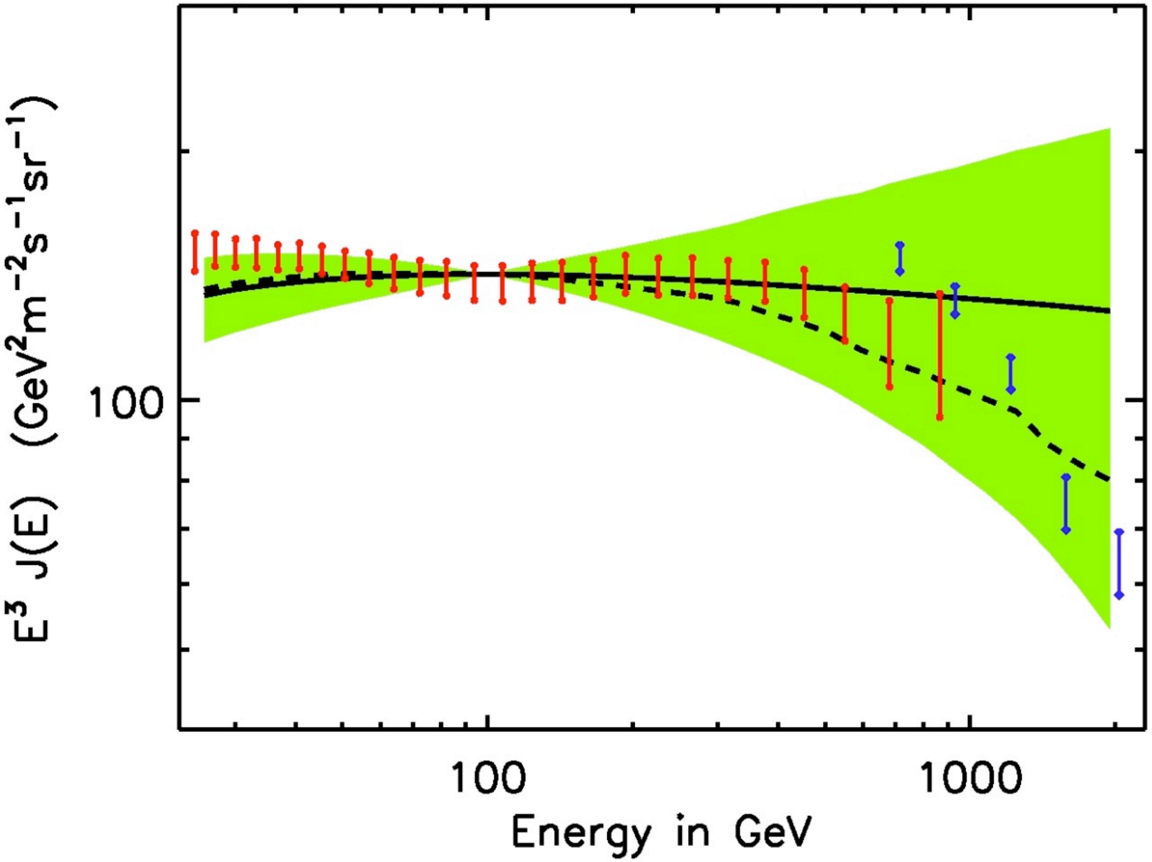
→ No bump!



LAT data and other sources

Uncertainty in power-law index much smaller

than local fluctuations (Grasso et al. 2009)



Assume SNR as

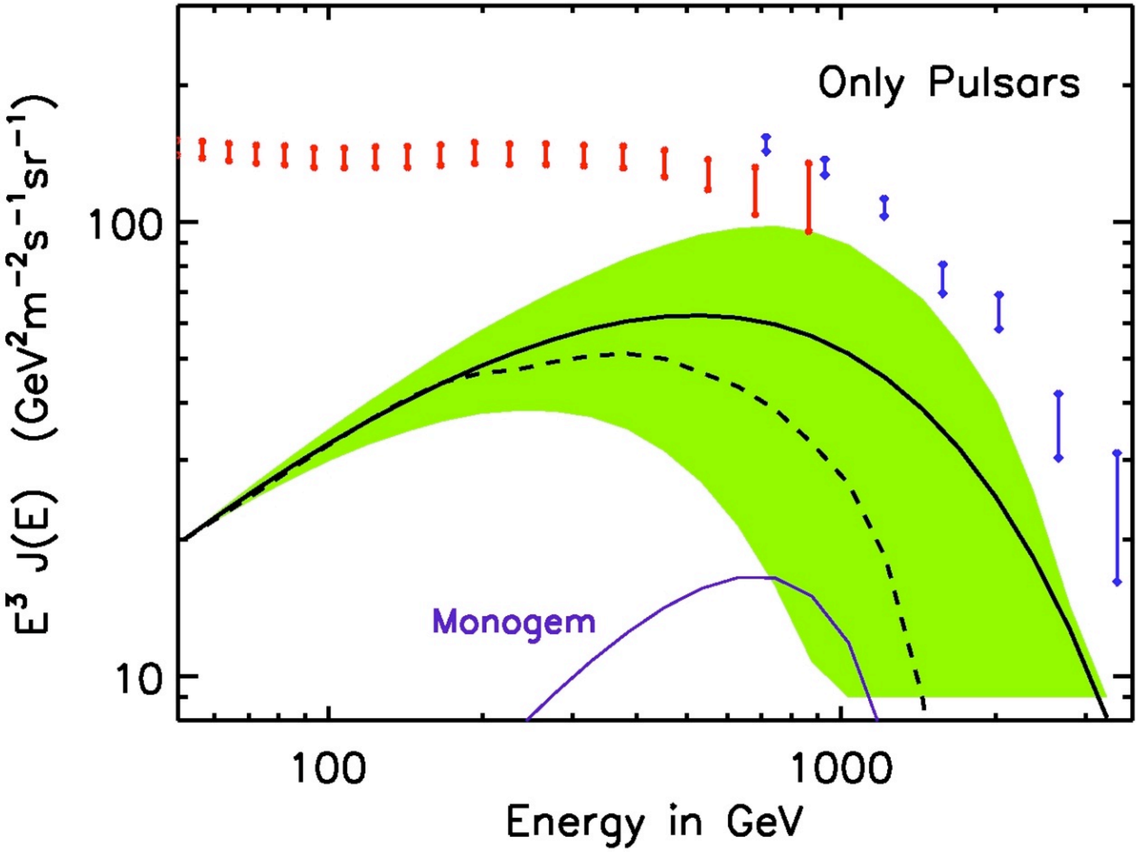
electron sources

(following
MP+ Esposito 98;
MP et al. 03)

LAT data plus pulsars

Assume pulsars provide extra positrons to fit PAMELA @ 50 GeV

Injection spectrum $Q \propto E^{-1.5} \exp\left[- \mathrm{E}/\left(600\,\mathrm{GeV}\right)\right]$



Other pulsars

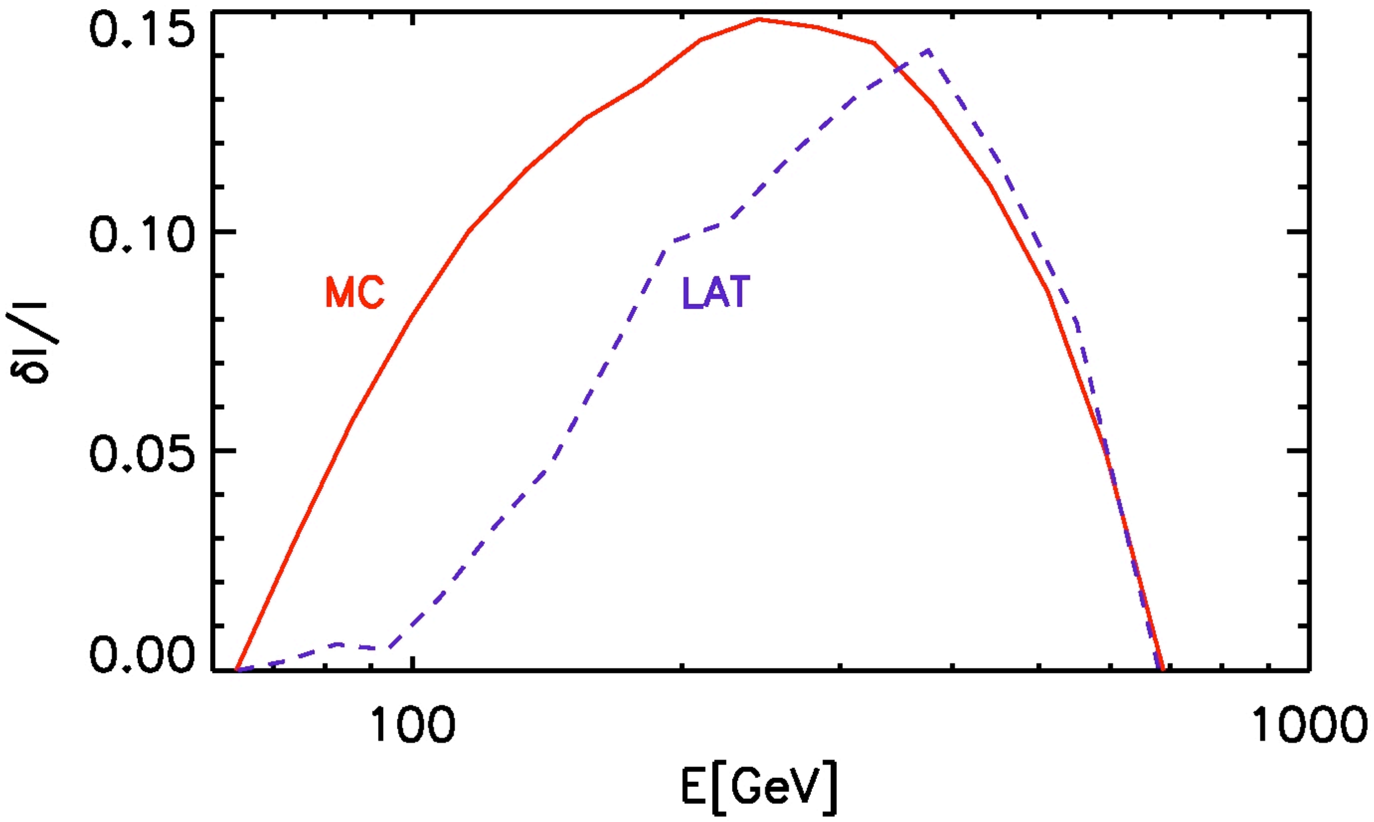
are important!

→ Broad bump

Careful:
Here D ~ $E^{0.33}$

Bumpyness for SNR origin

Compare with power law between 65 GeV and 680GeV



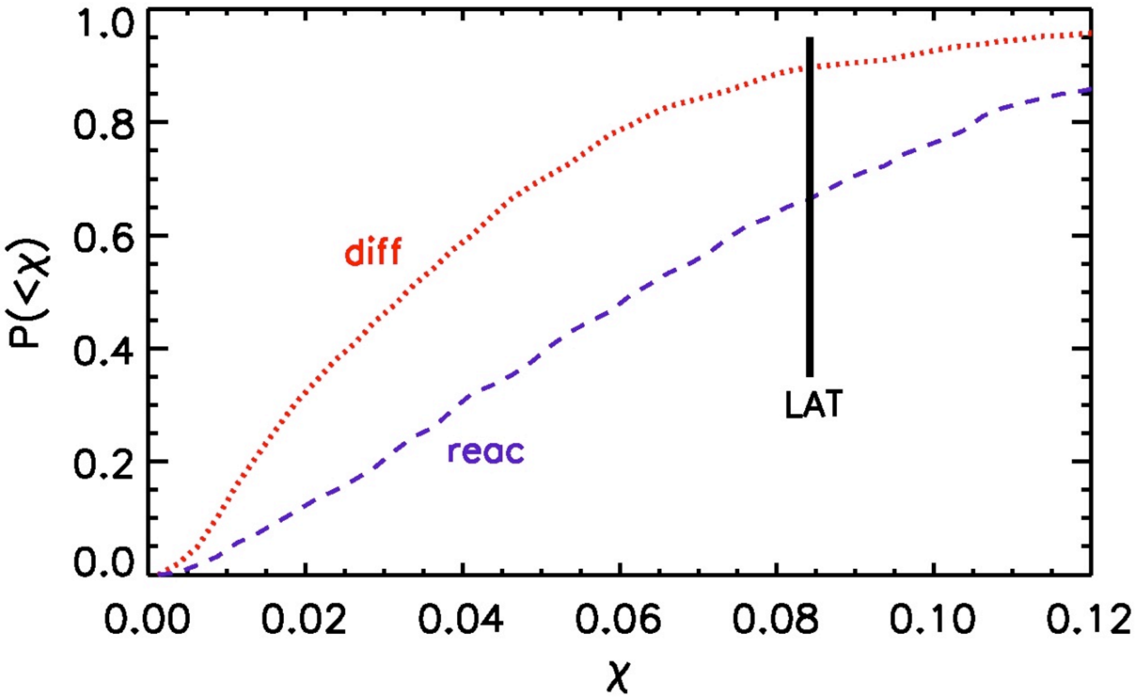
Bumpyness for SNR origin

Average fluctuation level

I data

J power-law

$$\chi = \sqrt{\frac{1}{N}\sum^{N}\frac{\left(I - J_{PL}\right)^2}{J_{PL}^{\;2}}}$$



Fluctuations in LAT data enhanced by errors

→ no evidence for additional sources

Conclusions

- Cosmic-ray spectra may carry DM signature
  - Dark matter interpretation requires boosting
  - Particle spectra can’t discriminate between DM and pulsar
- Fermi and HESS data do not confirm ATIC bump
  - Relatively featureless electron spectrum up to 1 TeV
  - Positron excess still unresolved issue
  - If real, pulsars or leptophilic dark matter possible
- Bumpyness (LAT) as expected for normal CR sources