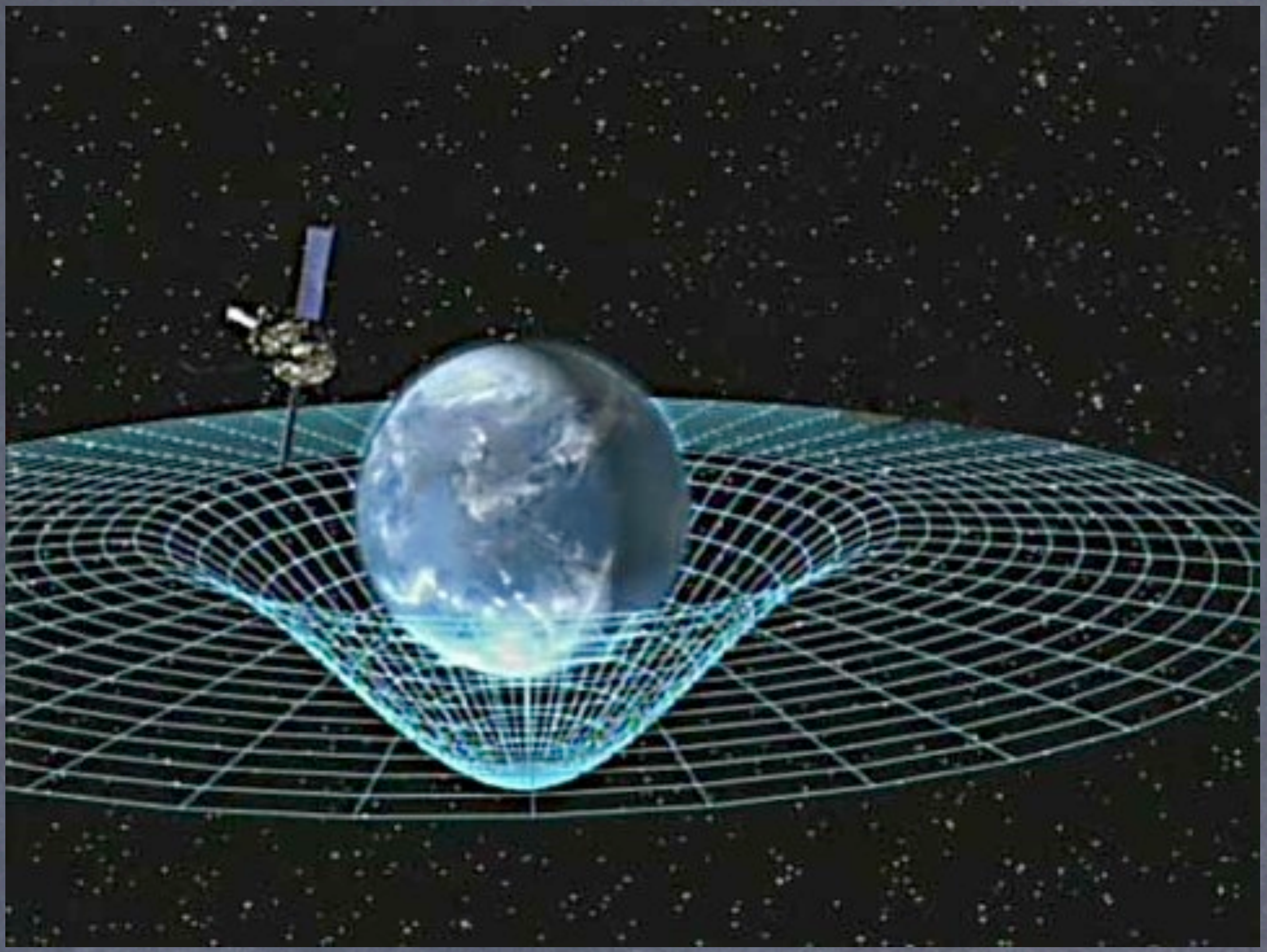


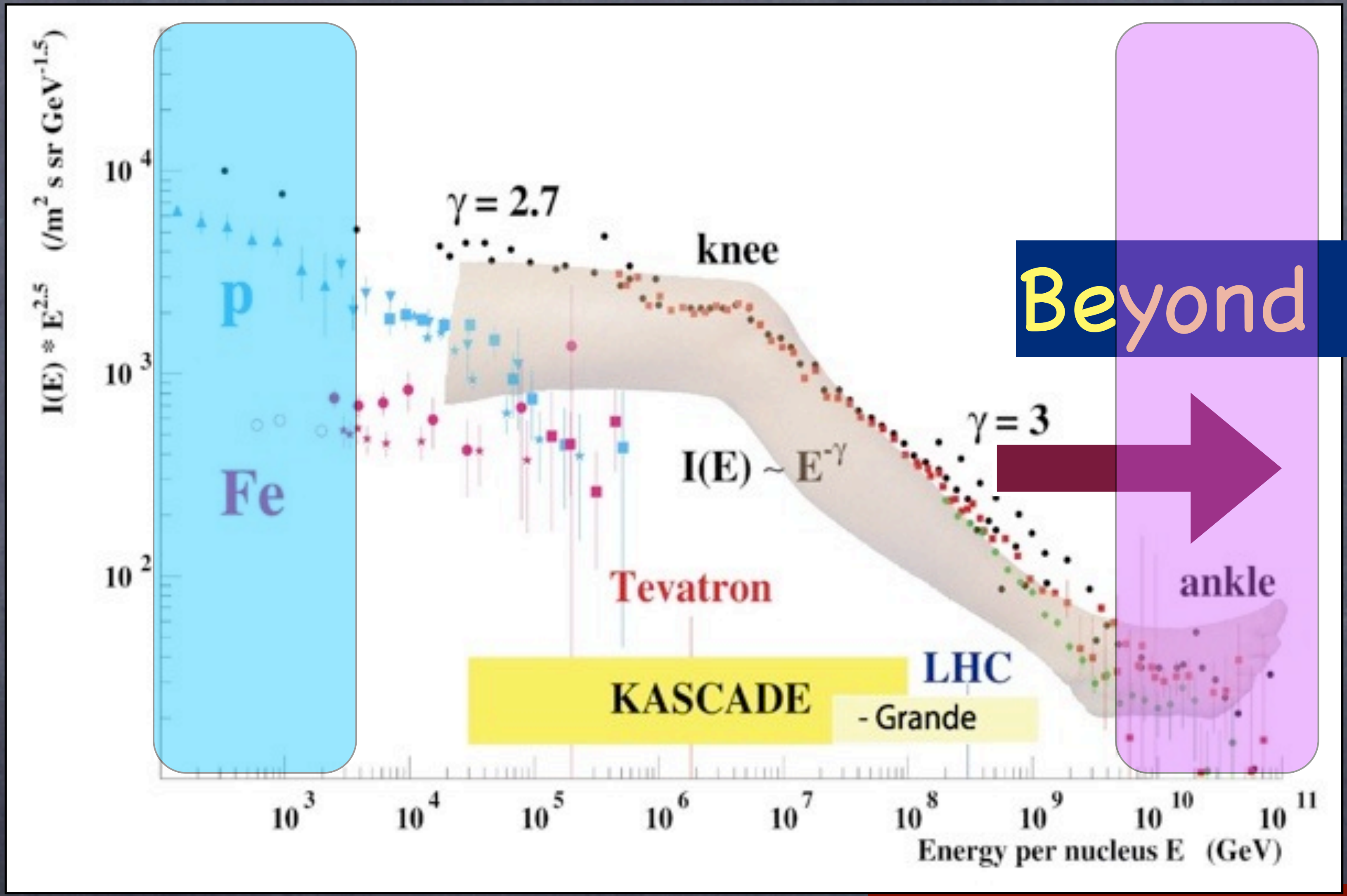
Propagation of galactic Cosmic Rays: recent results and future prospects

Luca Maccione (LMU & MPP, Munich)

Project Review 2011 - MPI - 19 December 2011

Cosmic Ray physics

Deep astrophysical problems: what are the sources? how are they accelerated? how do they propagate?



Beyond LHC !!

Realm of Dark Matter searches

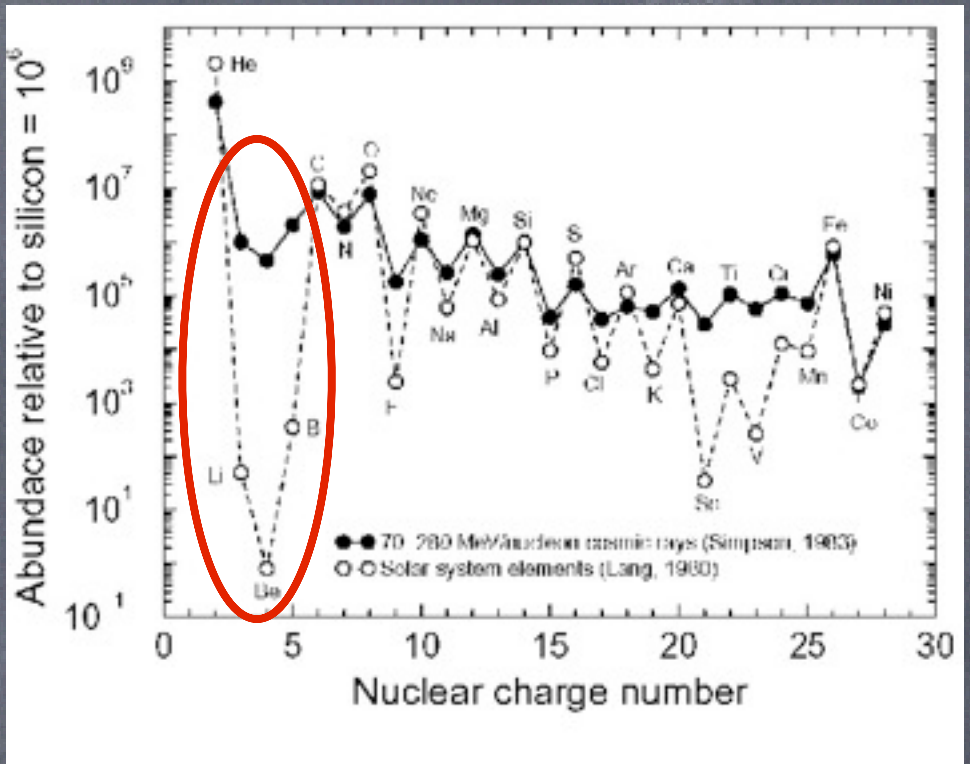
Features:
unavoidable background to Dark Matter searches

Observables:
- spectrum of CRs
- spectrum of their secondaries
- arrival directions

CR abundances

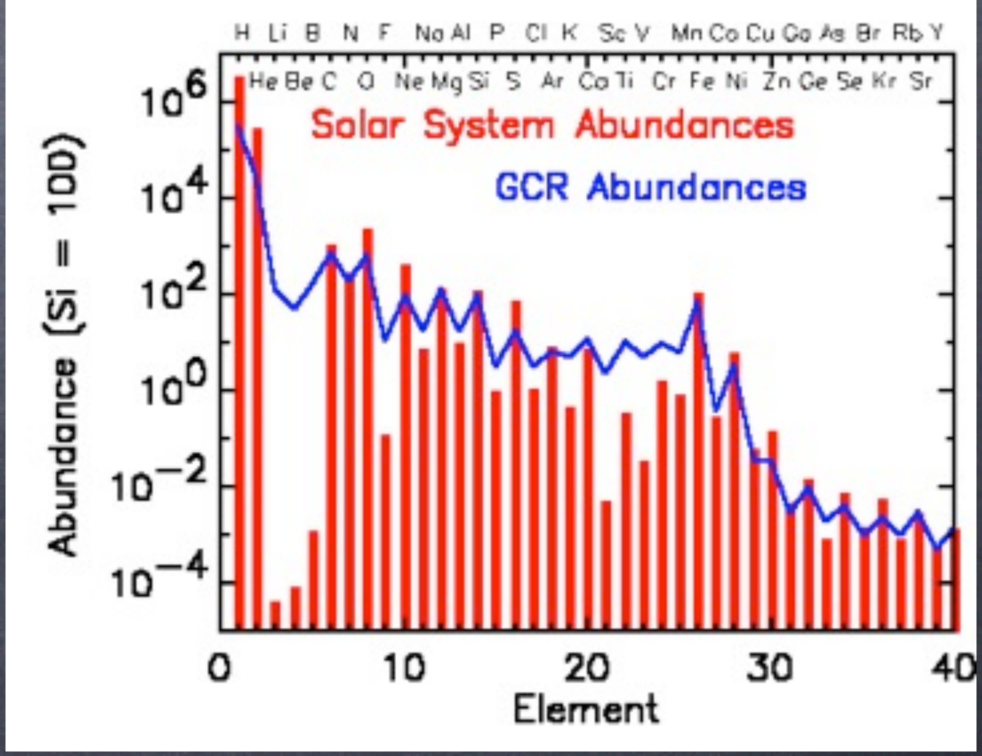
For some nuclei (CNO, Fe) abundances are the same as SSA.
Others (Li,Be,B,F...) are much more abundant.

White points: Solar System abundances
Filled points: CR abundances



J.A. Simpson, Ann. Rev. Nucl. Part. Sci. 33 (1983) 323

Reeves, Fowler & Hoyle (1970):
Li,Be,B are produced by spallation of CRs onto the galactic gas.



In order to reproduce the measured abundances of **stable nuclei**, CRs should have traversed ~ **5 g/cm² material**. Assuming n_{ISM} ~ 1 cm^{-3}, this implies CRs have propagated for **~3 million years** (10 million years if one considers the Galactic Halo).

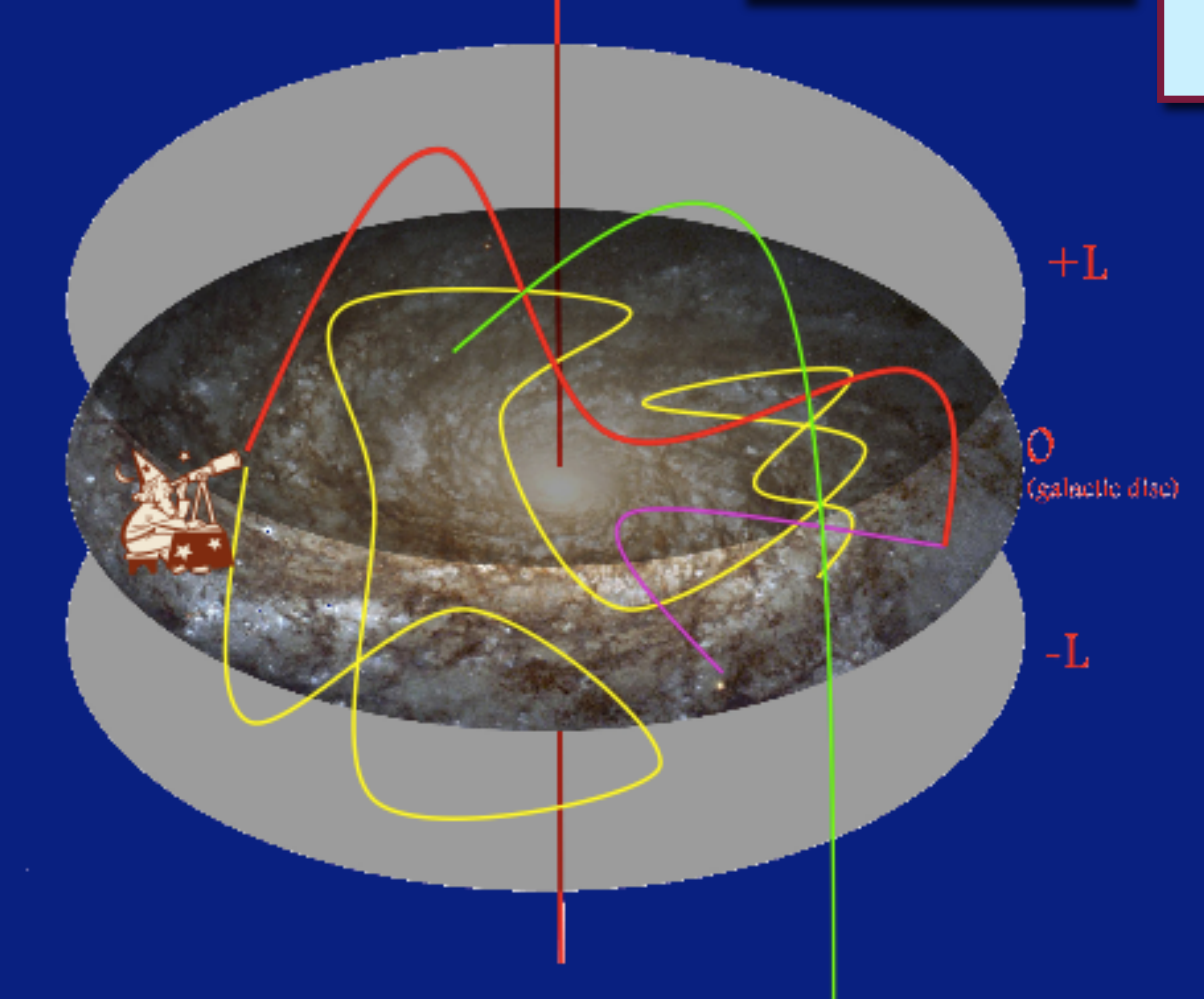
$$L = c\tau \simeq 10^3 \text{ kpc} \gg 15 \text{ kpc}$$

(Galactic radius)

$$n(E,\vec{r}_{\rm obs}) = \int_0^\infty dt \int d^3 r_0 \int dE_0\, q(E_0,\vec{r}_0,t)\, f(E,\vec{r}_{\rm obs};E_0,\vec{r}_0,t)$$

source function

propagation probability function



A complex magnetohydrodynamics problem

The DRAGON code

⇨ Needs simplifications! ~100 coupled PDEs to be solved numerically

$$\frac{\partial N^i}{\partial t} - \nabla \cdot (D\,\nabla - v_c)\,N^i + \frac{\partial}{\partial p}\left(\dot{p} - \frac{p}{3}\nabla \cdot v_c\right)N^i - \frac{\partial}{\partial p}p^2 D_{pp}\frac{\partial}{\partial p}\frac{N^i}{p^2} =$$

$$= Q^i(p,r,z) + \sum_{j>i} c\beta n_{\rm gas}(r,z)\sigma_{ji}N^j - c\beta n_{\rm gas}\sigma_{\rm in}(E_k)N^i$$

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$D(E) = D_0 \, (\rho/\rho_0)^\delta$
$\rho = \text{rigidity} \sim p/Z$

$$\frac{\partial N^i}{\partial t} - \nabla \cdot (D \, \nabla - v_c) \, N^i + \frac{\partial}{\partial p} \left(\dot{p} - \frac{p}{3} \nabla \cdot v_c \right) N^i - \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p} \frac{N^i}{p^2} =$$

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Energy loss

Convection term

$$\frac{\partial N^i}{\partial t} - \nabla \cdot \left(D\,\nabla - v_c \right) N^i + \frac{\partial}{\partial p}\left(\dot{p} - \frac{p}{3}\nabla \cdot v_c \right) N^i - \frac{\partial}{\partial p} p^2 D_{pp} \frac{\partial}{\partial p}\frac{N^i}{p^2} =$$

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Reacceleration
$D_{pp} \propto \frac{p^2 v_A^2}{D}$

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SN source term.
We assume everywhere
a power law energy spectrum

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Spallation cross
section. Appearance
of nucleus i due to
spallation of nucleus j

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Total inelastic cross section.
Disappearance of nucleus i

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The height of the propagation/diffusion region is z_t

$D_0(z) \propto e^{z/z_t}$

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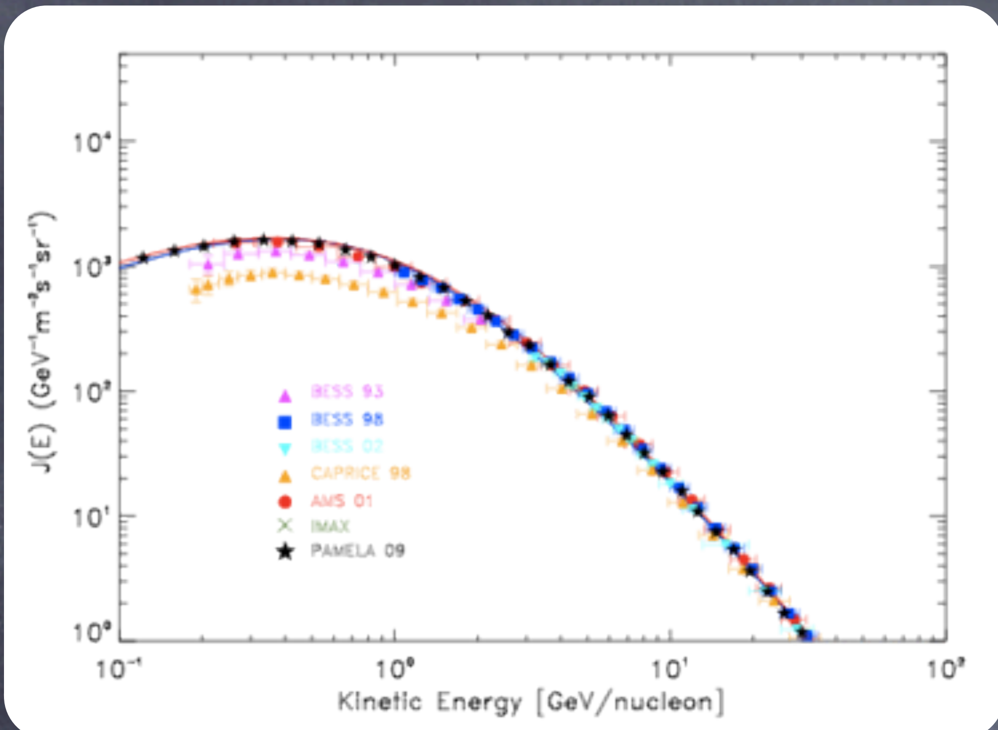
My public numerical (C++) code: **DRAGON**
http://www.desy.de/~maccione/DRAGON/

Cosmic Rays: main results

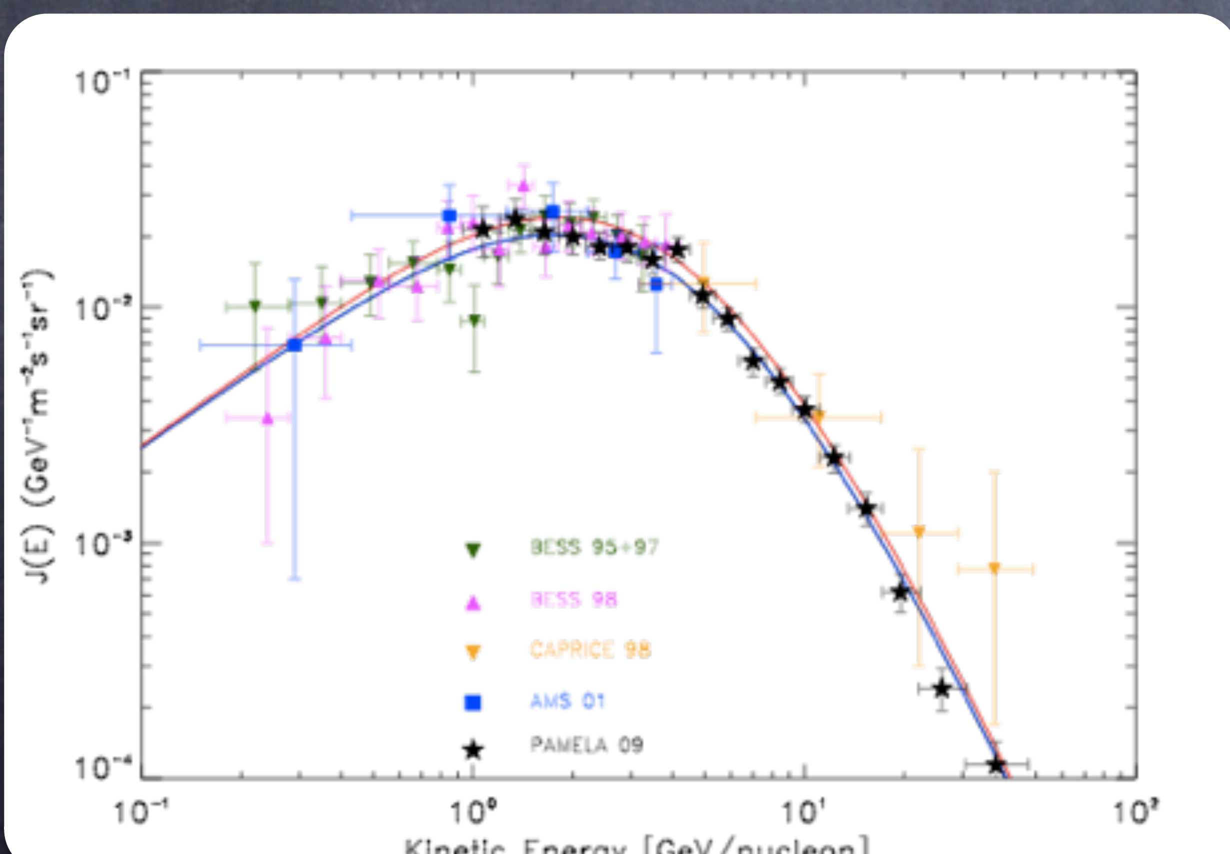


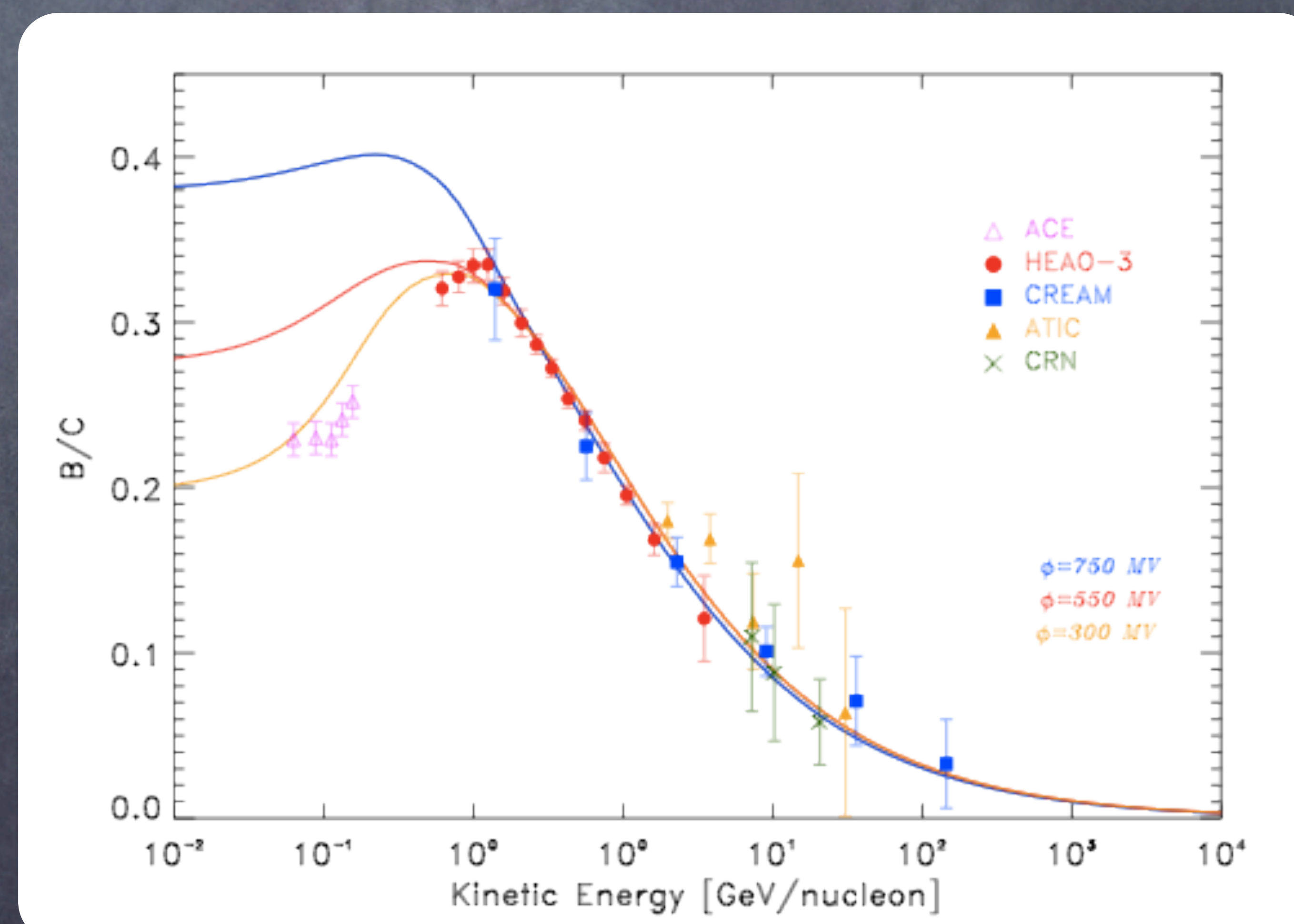
New strategy to pinpoint propagation models by fitting nuclear data

Antiproton spectrum is consistent with astrophysical predictions (no room for dominant DM contribution) !!

Di Bernardo, Evoli, Gaggero, Grasso, LM, Astropart.Phys. 34 (2010) 274-283

Evoli, Gaggero, Grasso, LM, JCAP 0810 (2008) 018



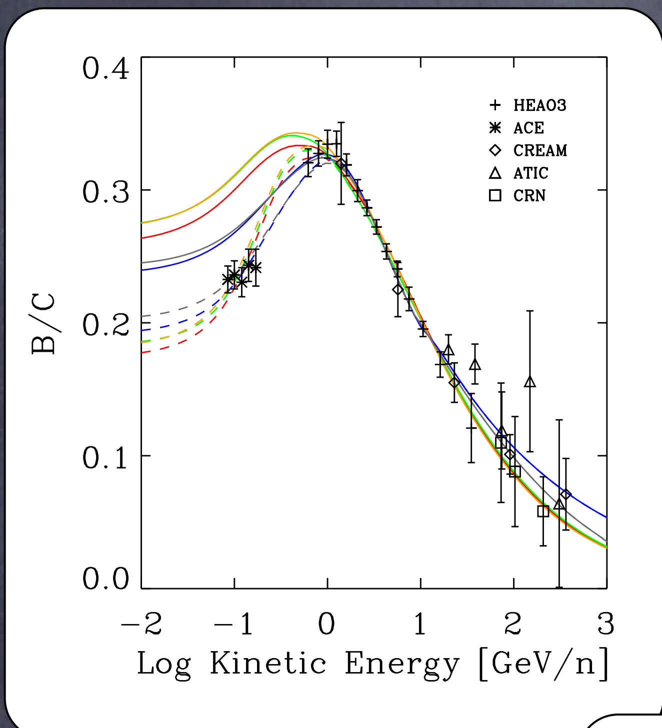


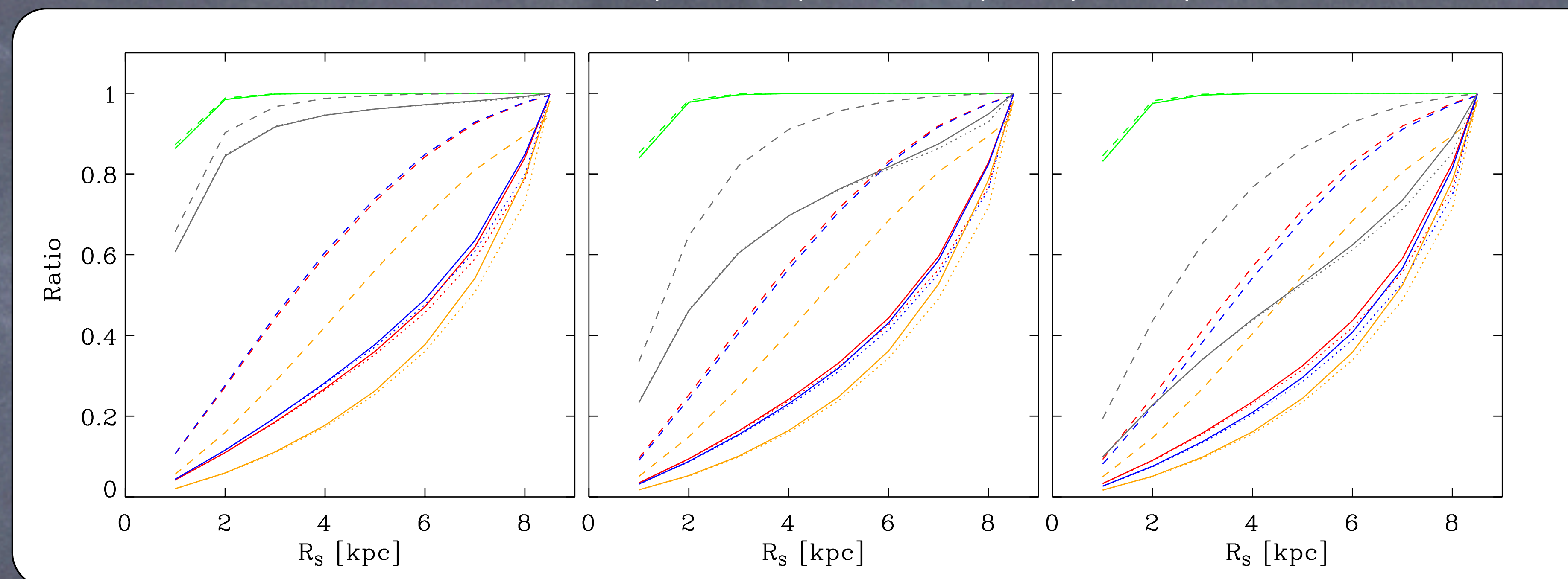
DM constraints: antiprotons

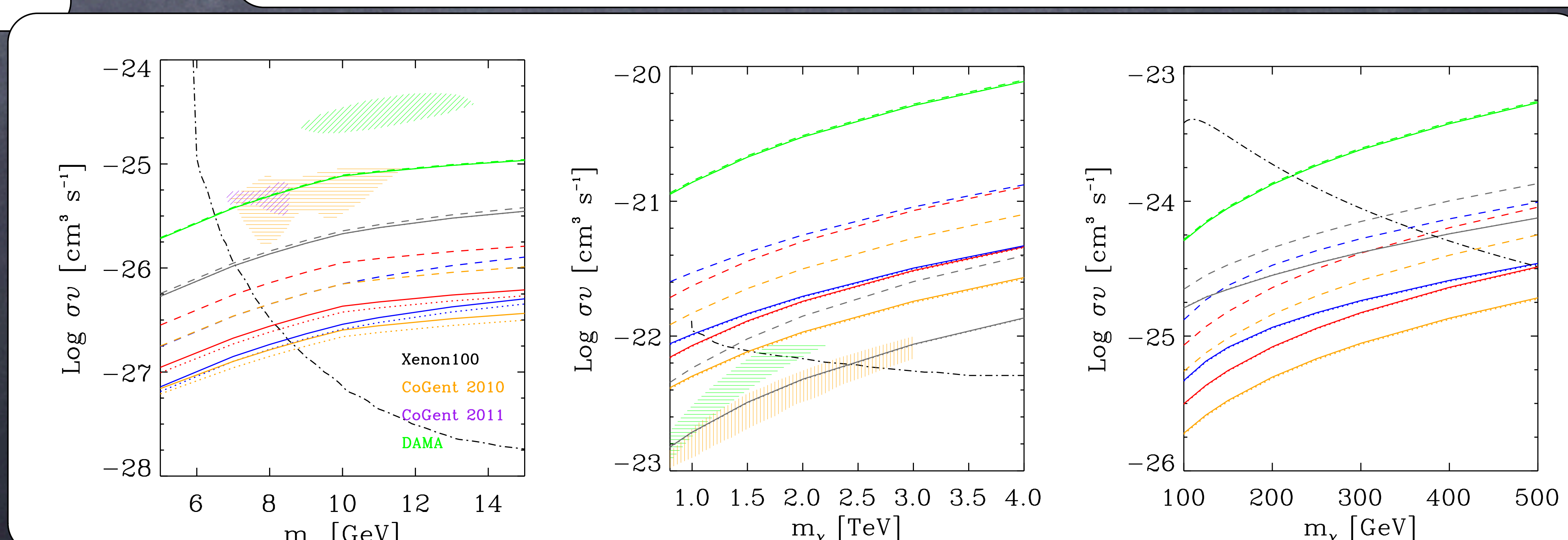
(arbitrary complicate the procedure to get constraints on DM models)

Standard sources are mainly in the galactic plane. DM sources are also present in the halo and at the galactic center. Nuclear CR measurements are not able to constrain effectively the propagation in the halo, therefore we need to test several propagation models to draw meaningful constraints

Evoli, Cholis, Tavakoli, LM, Ullio, arXiv:1108.0664







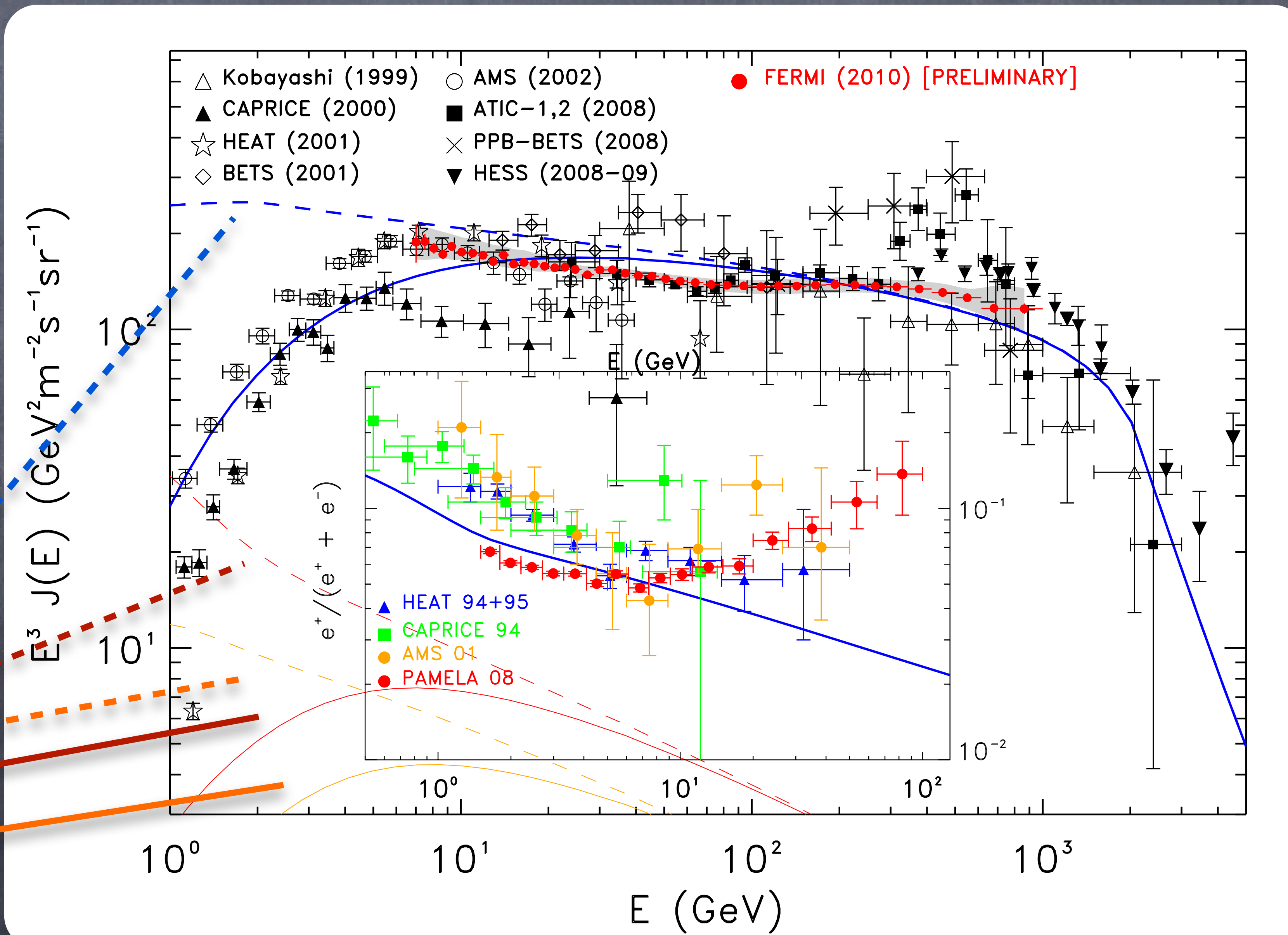
Electron and positron spectra

Single component scenario:

positrons are secondary of pp interactions

$$D(E) \propto E^{\delta}$$

Model parameters:
δ = 0.46
v_A = 15 km/s
γ_0 = 2.0/2.5 (below/above 4 GV)
smooth sources
Φ = 550 MV



non modulated fluxes
sec positrons
sec electrons

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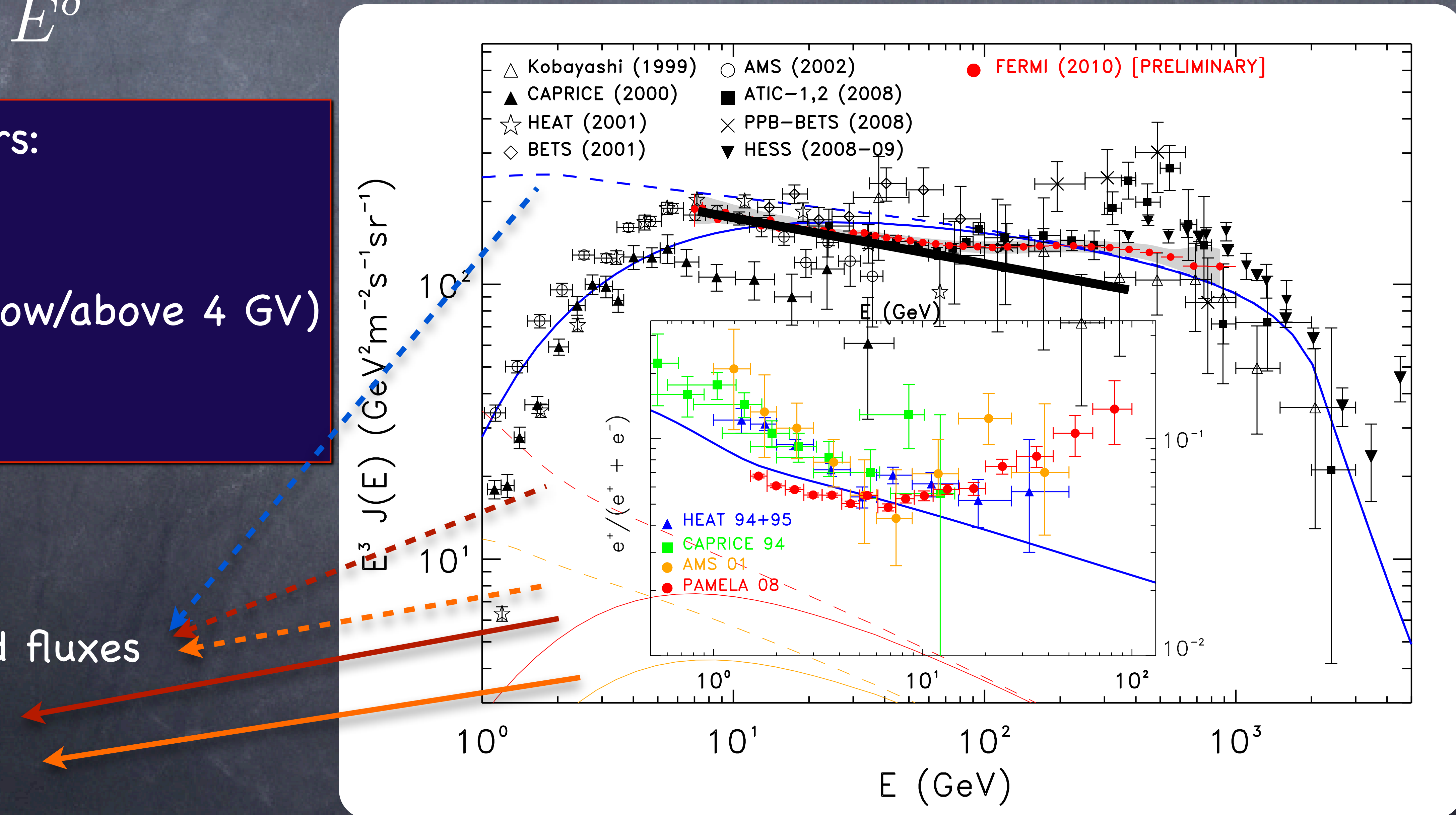

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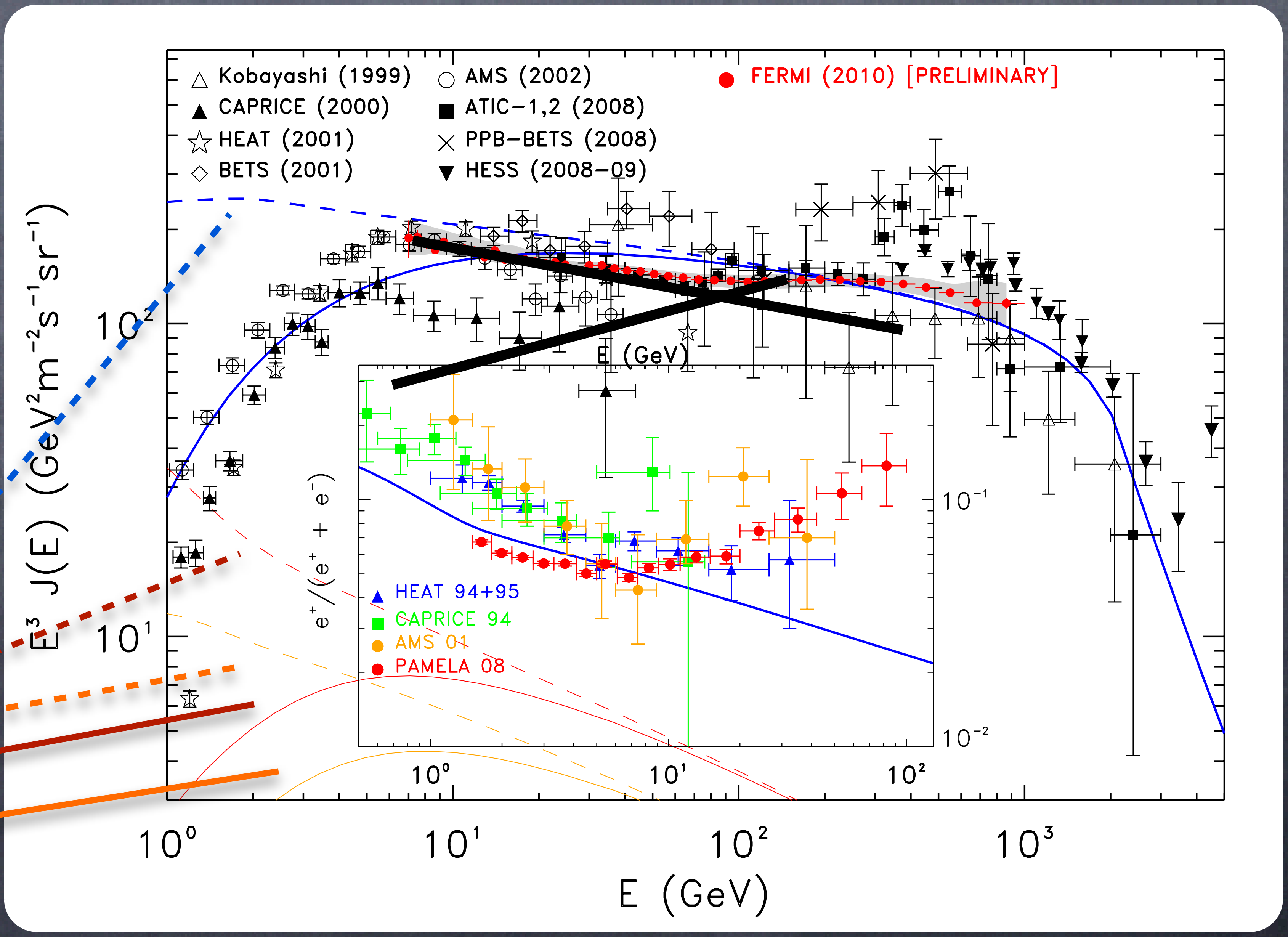


non modulated fluxes
sec positrons
sec electrons

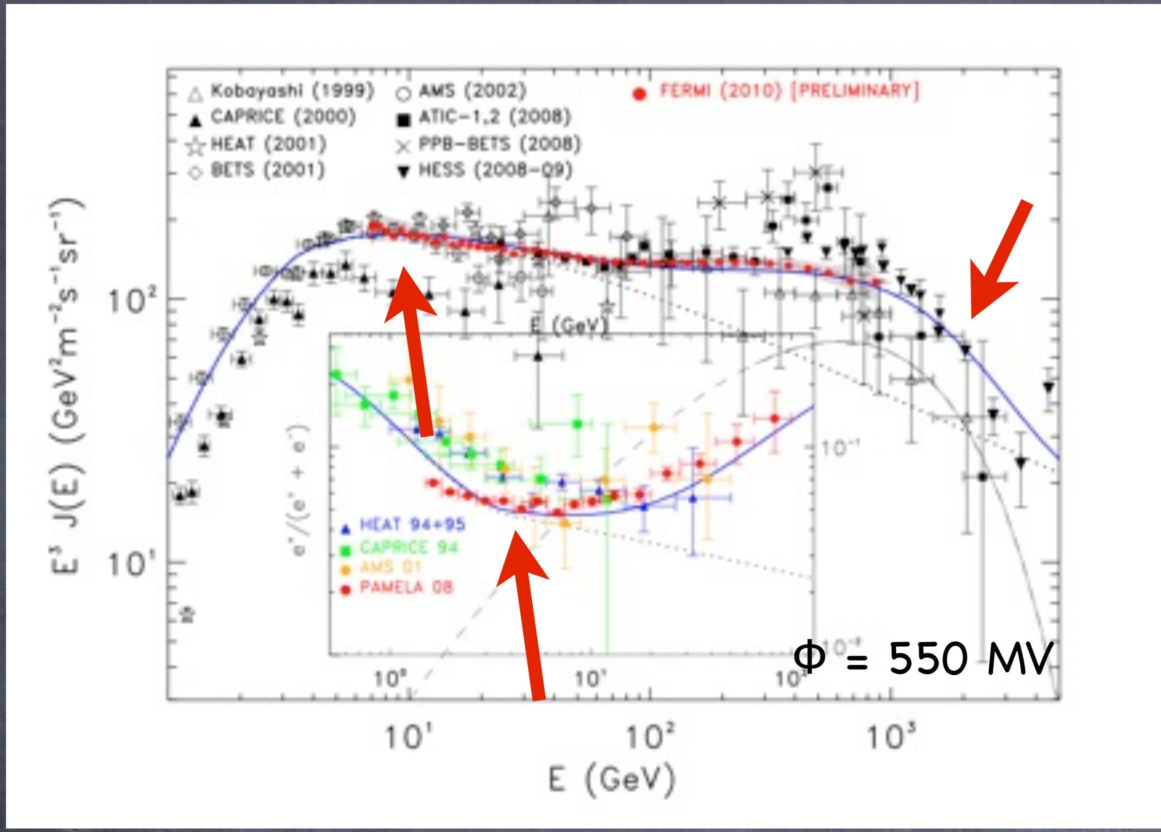
Two components models: main motivations

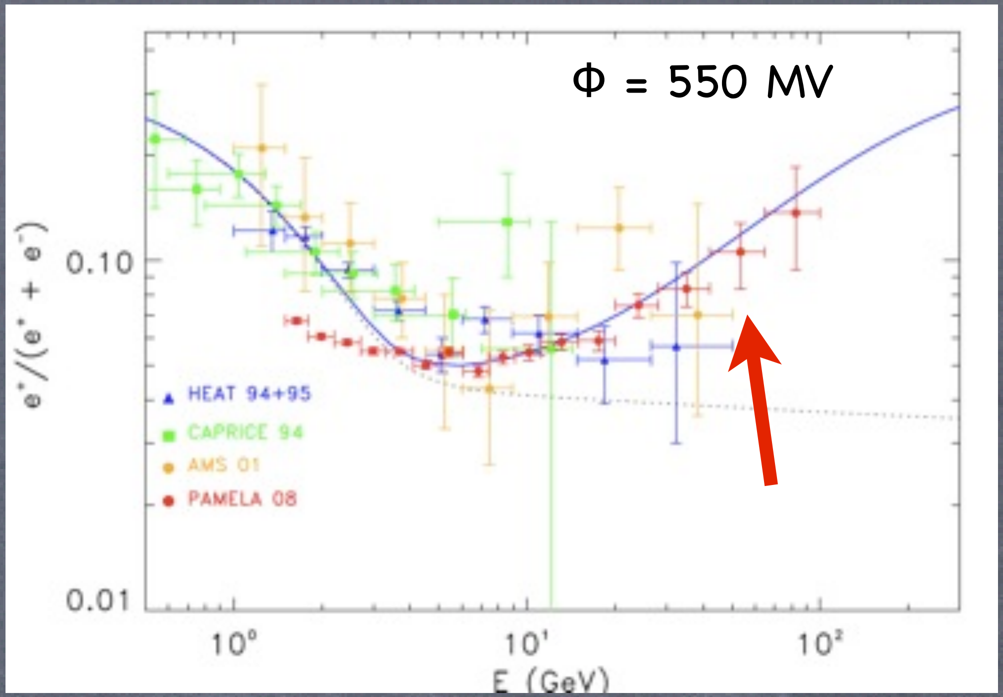
Di Bernardo, Evoli, Gaggero, Grasso, LM, APP 34 (2011)

Toy model with a Galactic $N_{\rm extra} \propto E^{-1.5}\, e^{-E/1\ \rm TeV}$ added to a conv. bkg with

γ_0 = 2.0/2.65 above/below 4 GeV

δ = 0.46

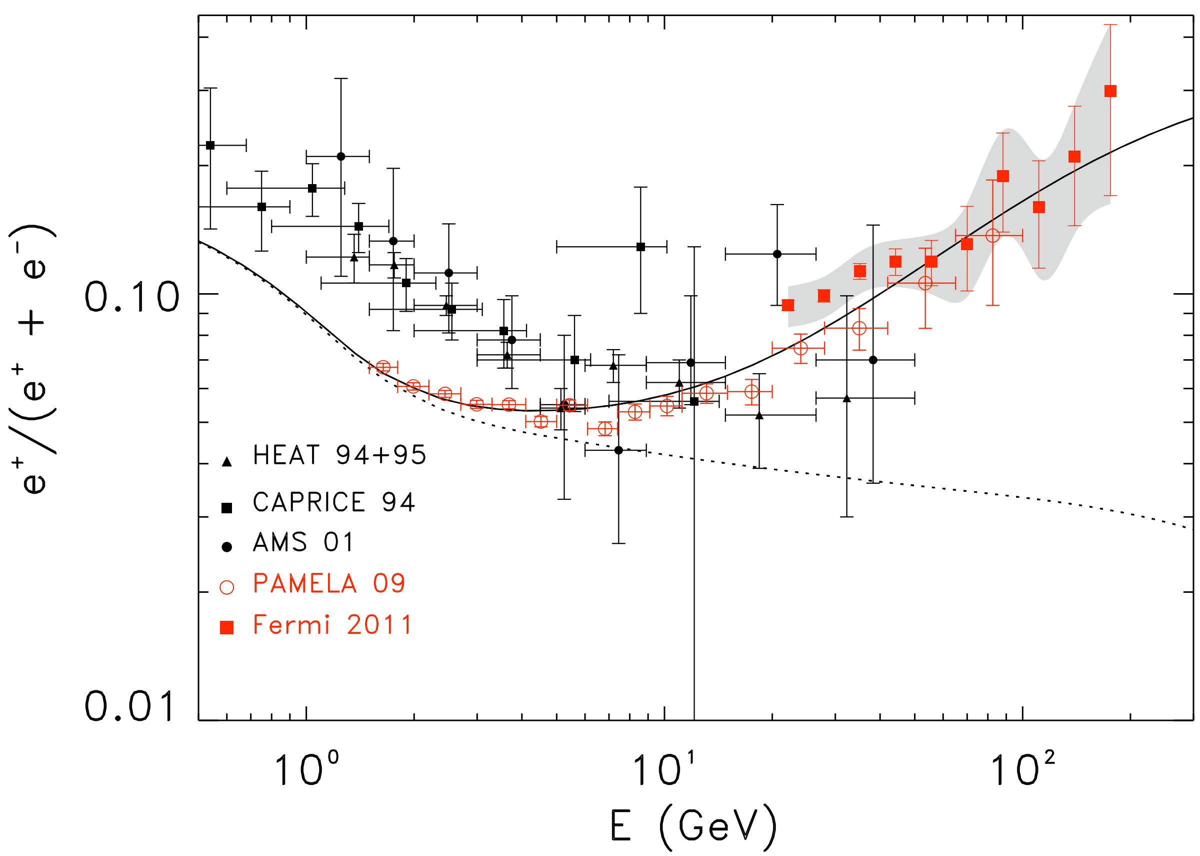


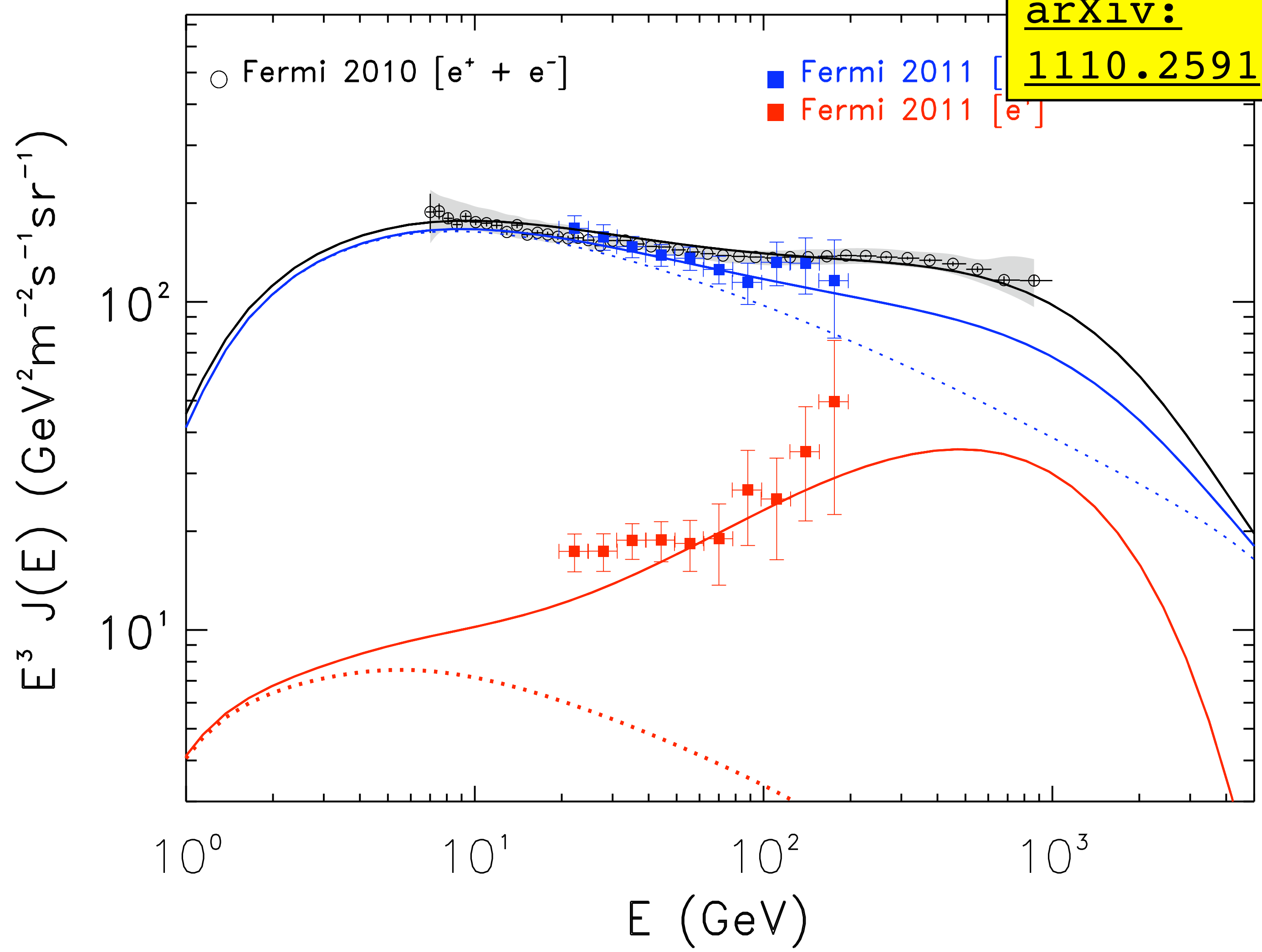


- If the extra component is charge symmetric it allows to match the PAMELA growing ratio above 10 GeV
- Only way to match low energy Fermi and AMS-01 (both taken in a low solar activity phase) without invoking more involved modulation scenarios
- provides a better fit to Fermi-LAT data at high energy as well as HESS data
- under some conditions improve the fit of low energy PAMELA data

News from Fermi

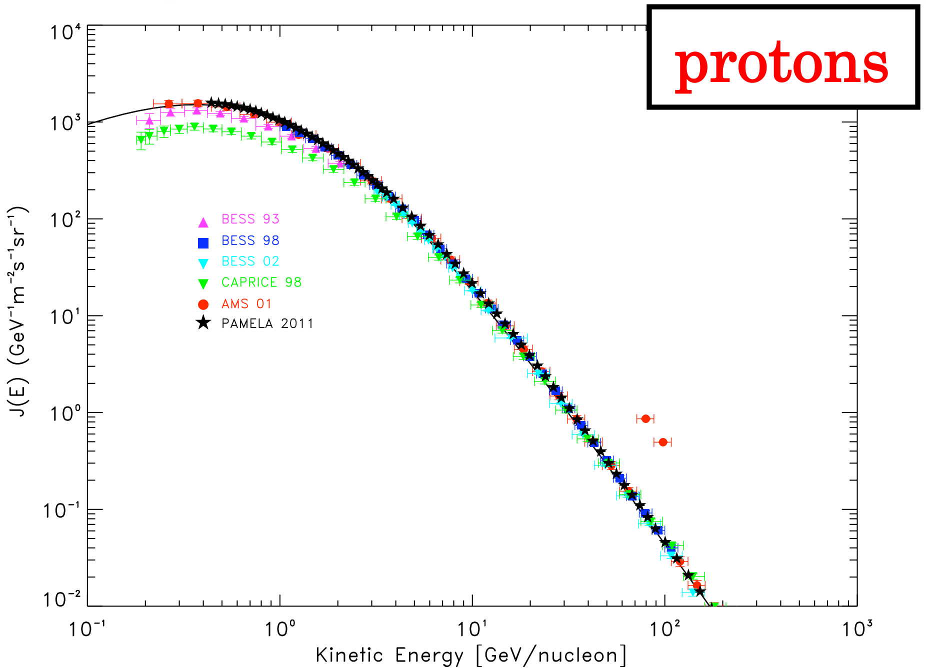
NEW!
arXiv:
1110.2591

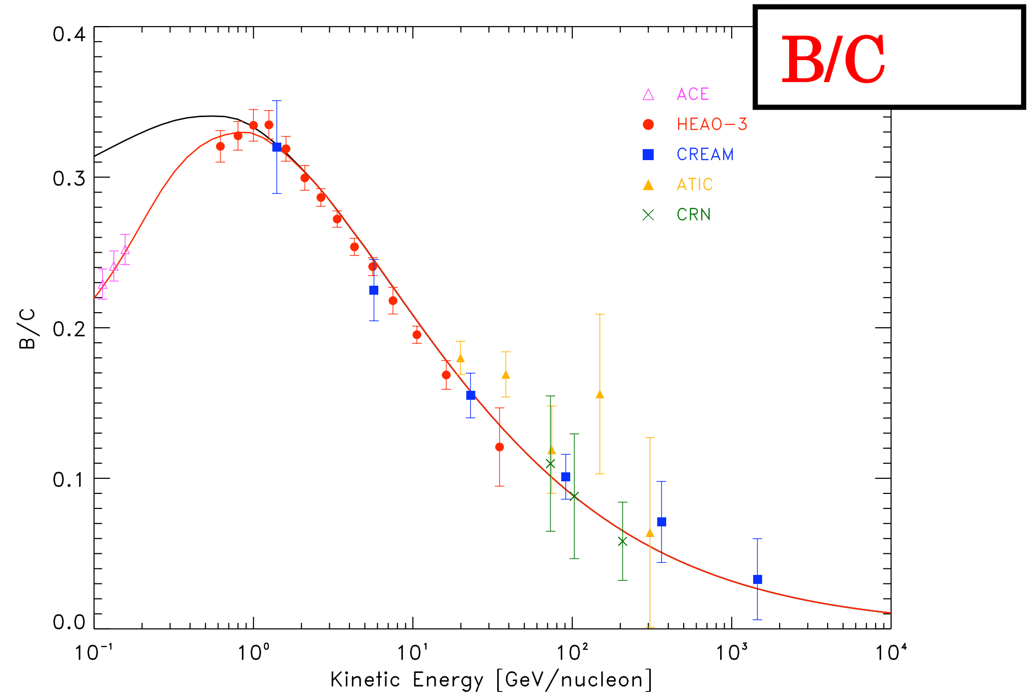


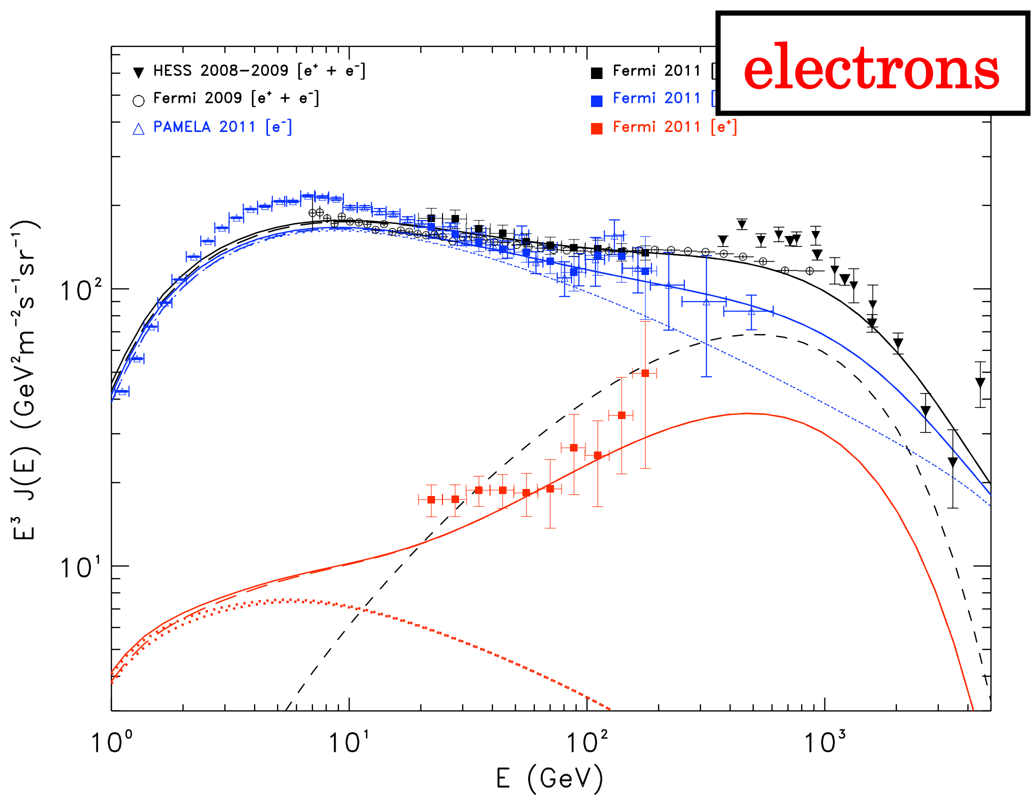


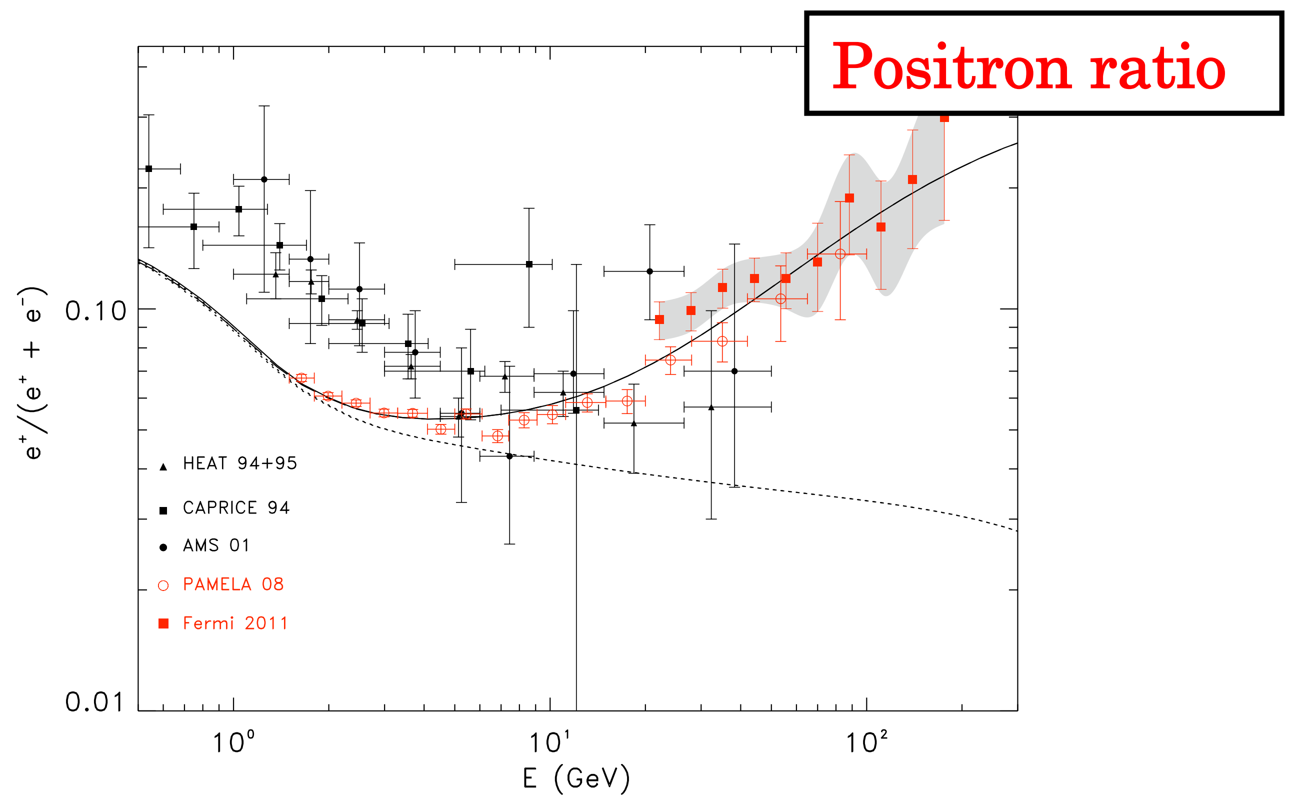
Notice how a double component scenario with Kraichnan-like diffusion setup is self-consistent and compatible with most CR observables:

primary nuclei, secondary/primary ratios, electrons, positrons.



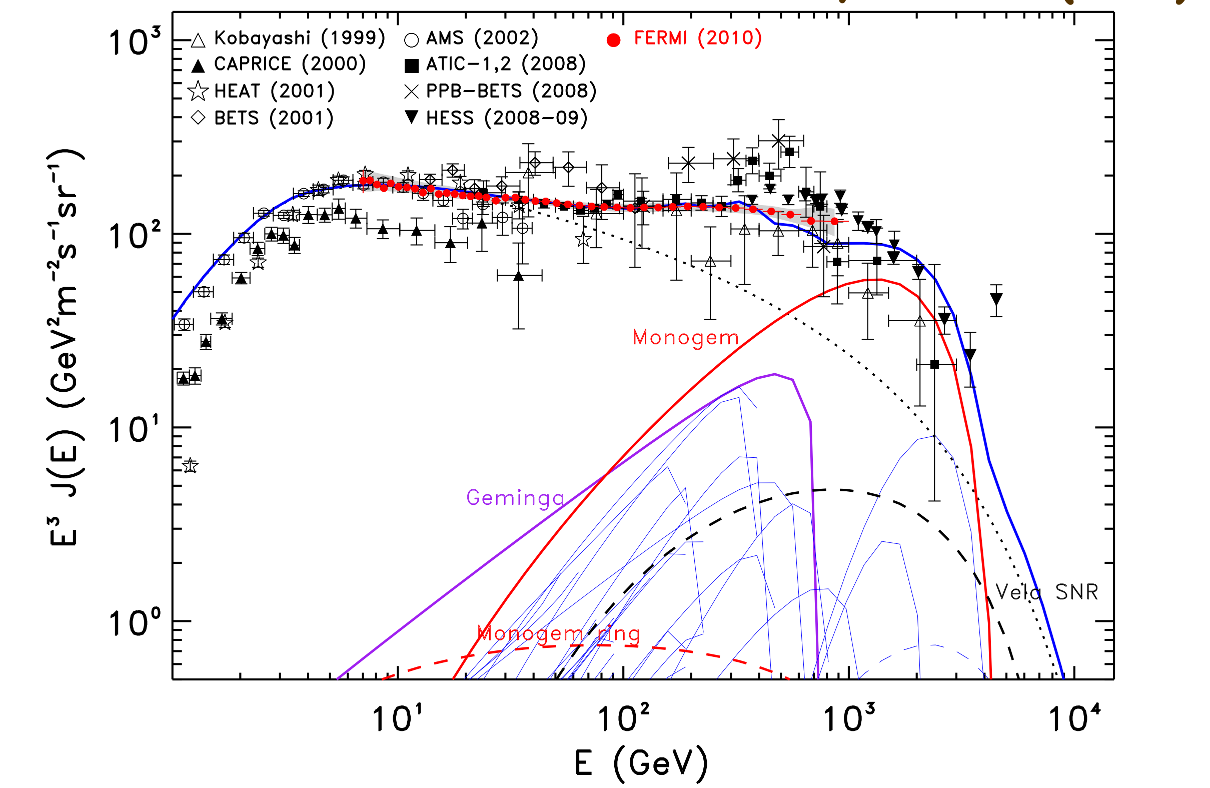


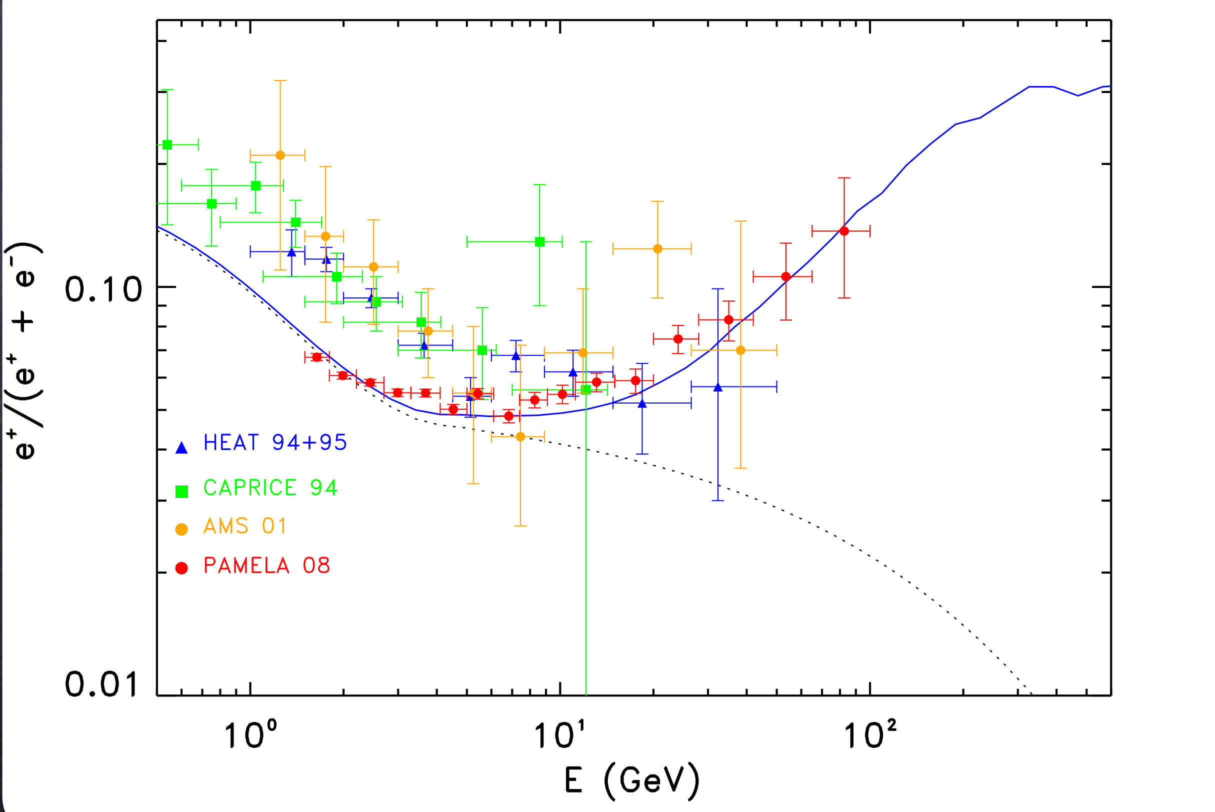


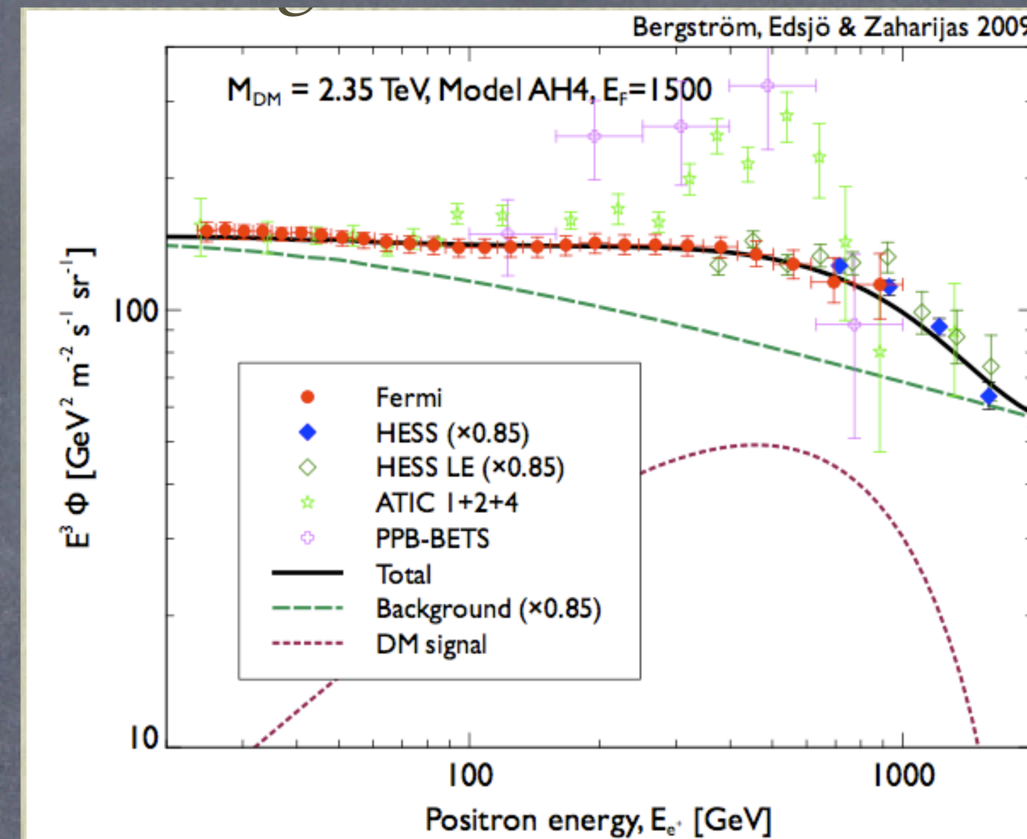


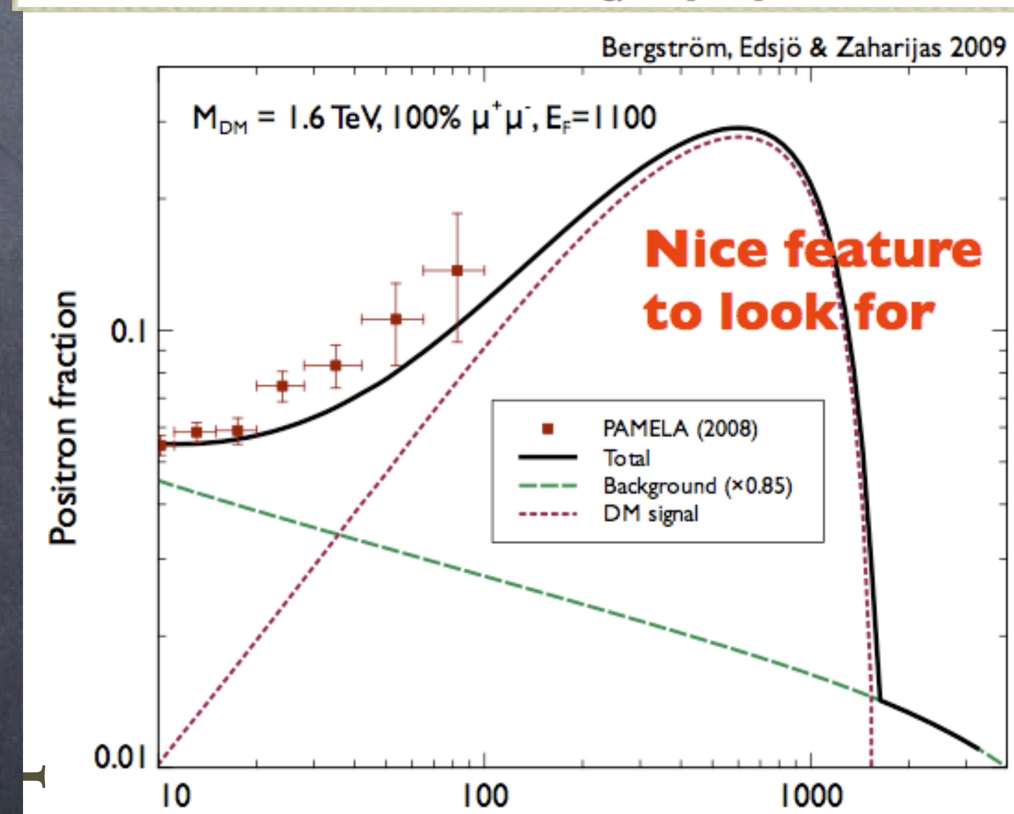
Dark Matter vs Astrophysics

Di Bernardo et al, APP 34 (2011)









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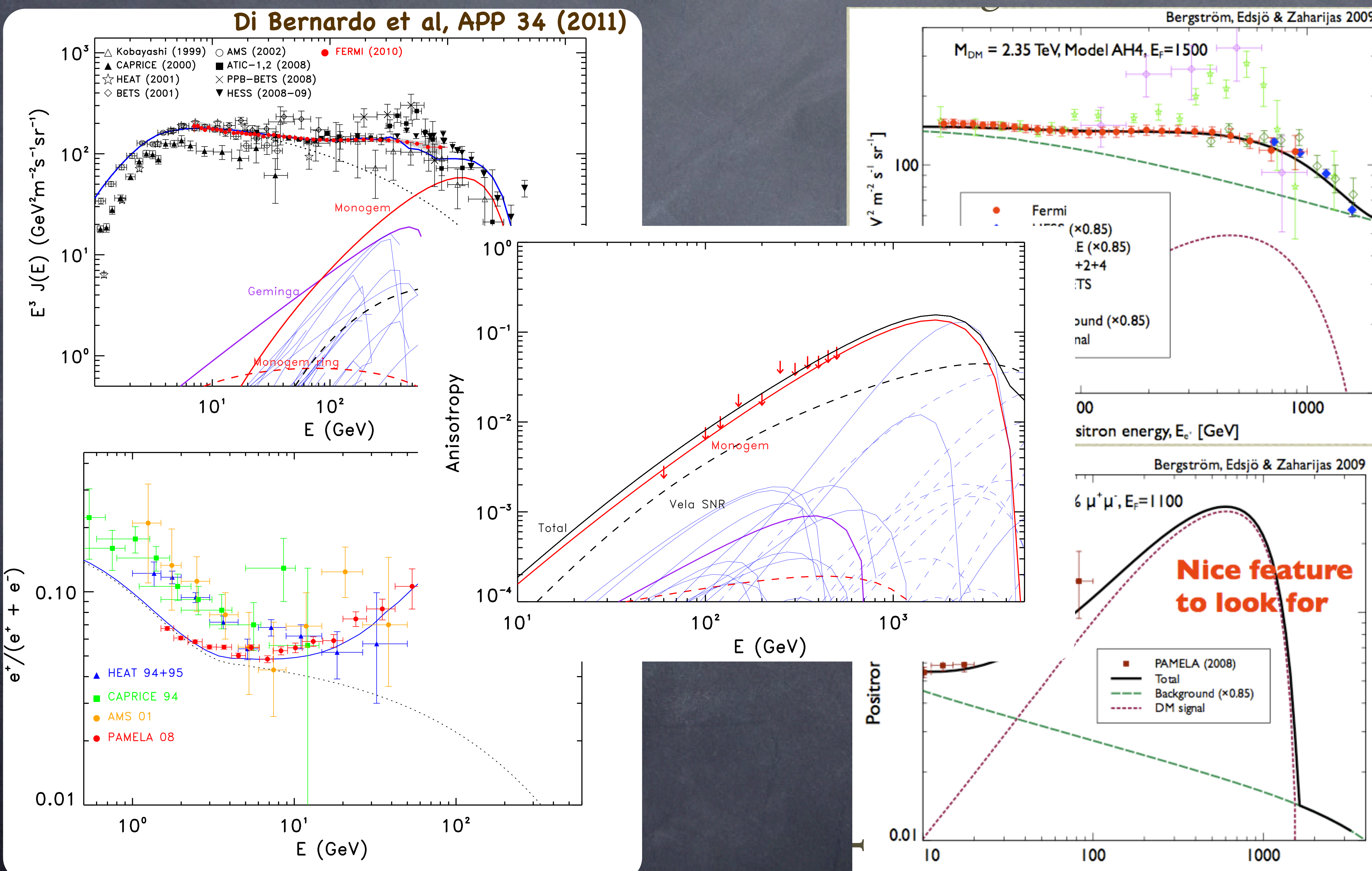


Cosmic Rays and DM searches

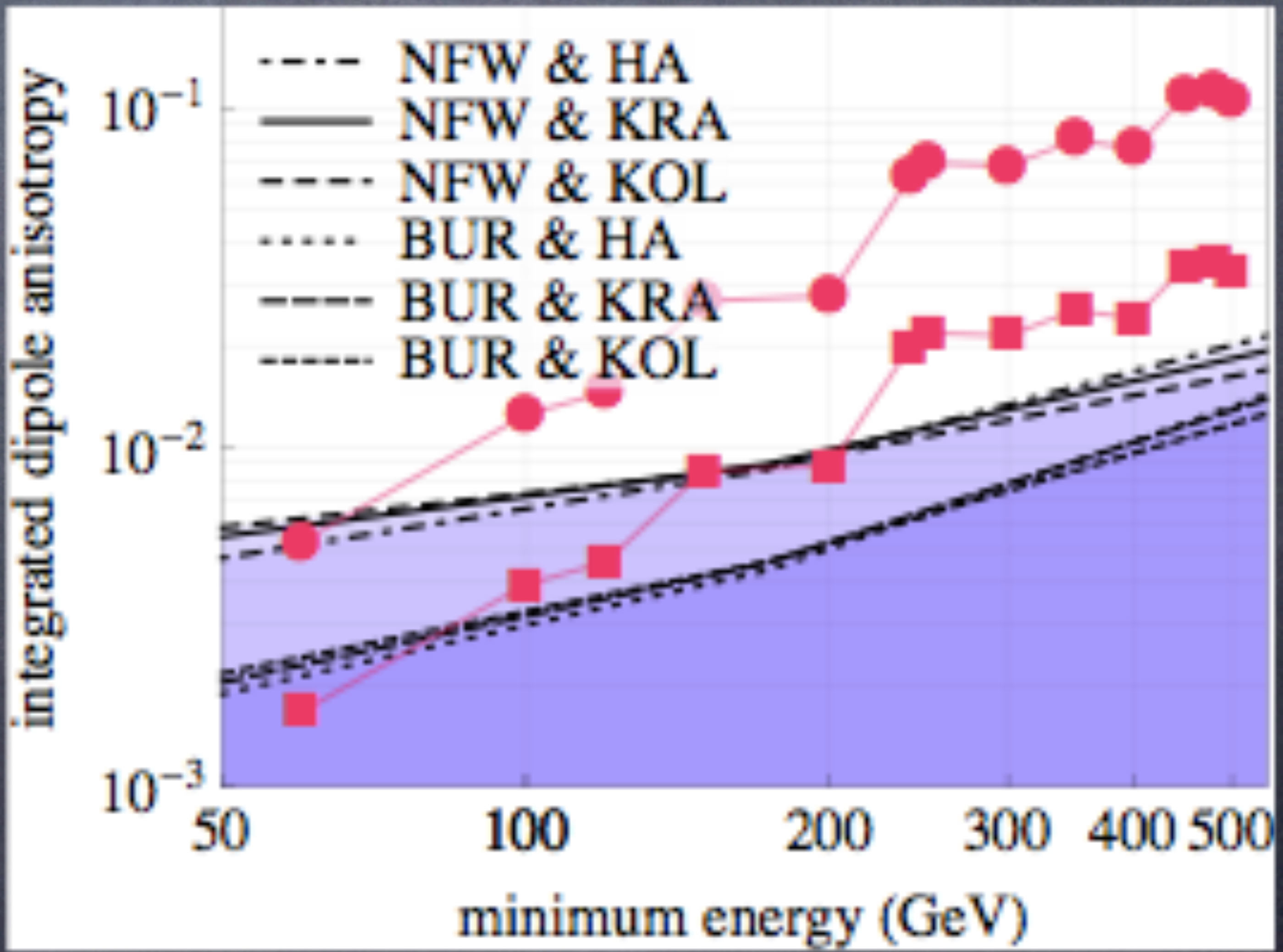
Typical problems:

- DM fluxes predictions are **model dependent**
- background predictions are **model dependent**

A **model independent observable**, the dipole anisotropy

Borriello, LM, Cuoco, arXiv: 1012.0041

$$\delta \propto \frac{|\vec{\nabla}\phi|}{\phi}$$

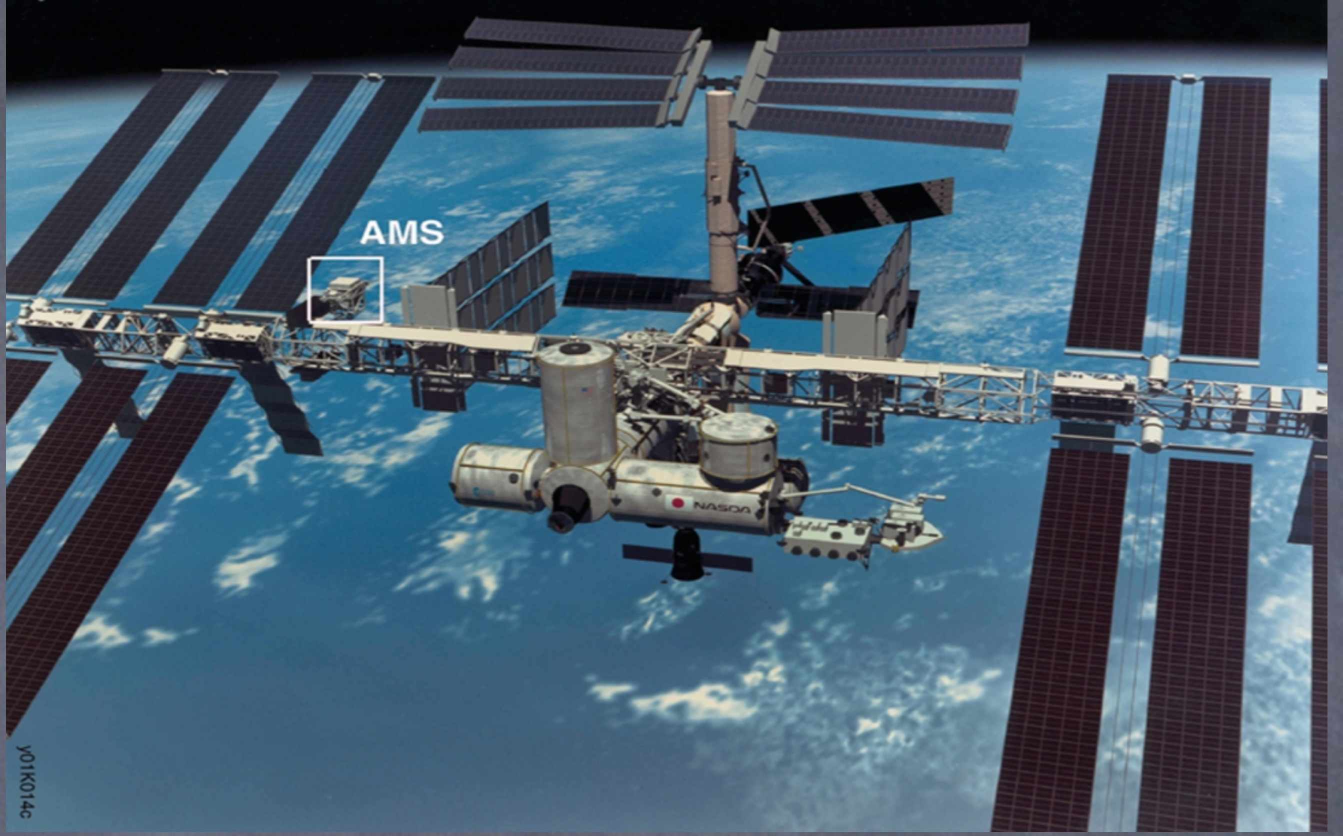


A **simple yet powerful** criterion to disentangle DM from astrophysical contributions

Open problems

- Electron/positron spectra still to be understood
- what does the steep injection spectrum mean?
- what about the extra component:
  - pulsars?
  - enhanced secondary production in sources?
  - Dark Matter?
- smoking guns ?

Get ready to interpret new AMS-02 data!



Markov Chain Montecarlo (MCMC) may be a very useful tool to perform complete statistical analyses on large parameter spaces (in order to include convection, reacceleration, diffusion-related parameters…)

There is WORK IN PROGRESS at Karlsruhe Institute of Technology (KIT) on this field!!!

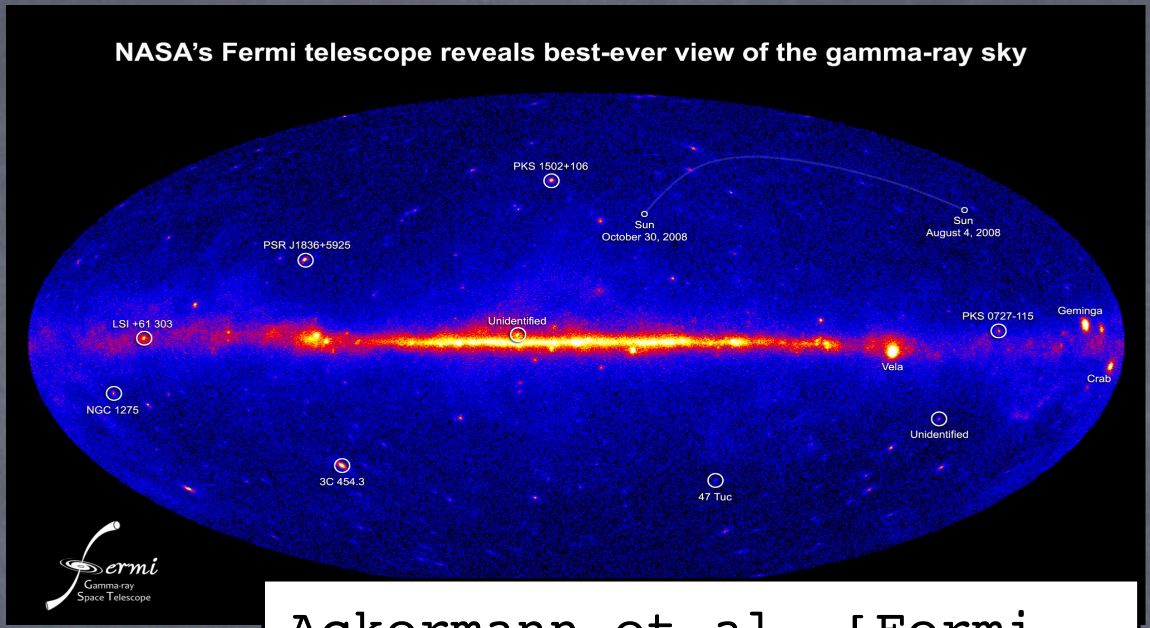
A markov chain monte carlo interface for Dragon

KIT Karlsruhe Institute of Technology

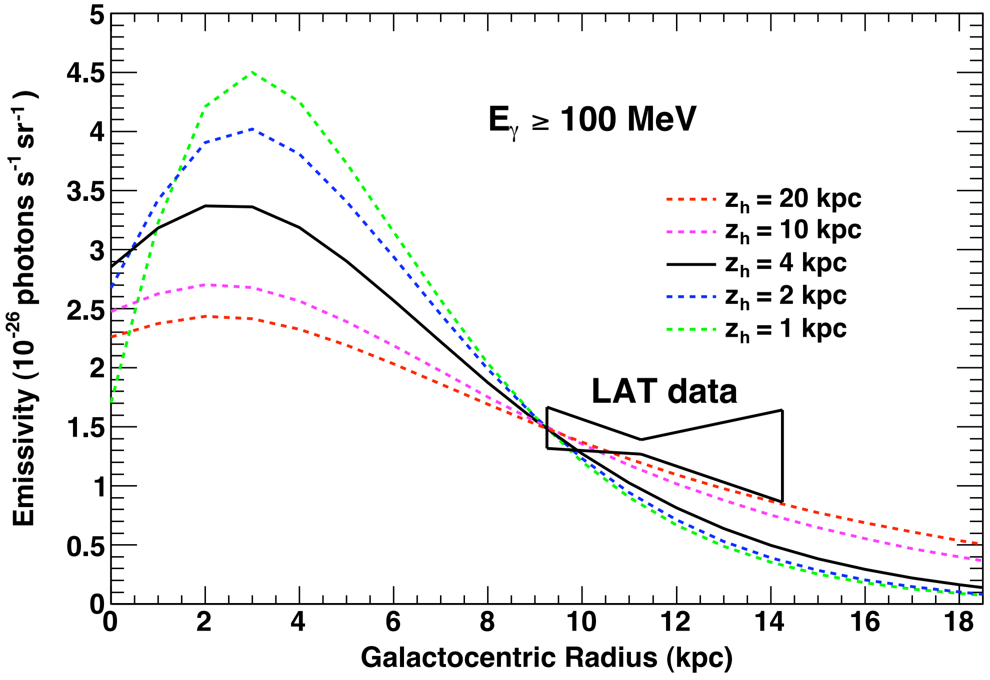
- MTM and MH has been implemented into a small package called DMCMC. In the case of MTM the programm runs parallel using standard C posix threads (gcc-4.4 not available on all clusters, so C++ threads cannot be used).
- DMCMC can be easily adapted for use with Galprop/any other code
- DMCMC is tested and stable
- allocation of computing ressources is currently underway, first physics runs are running

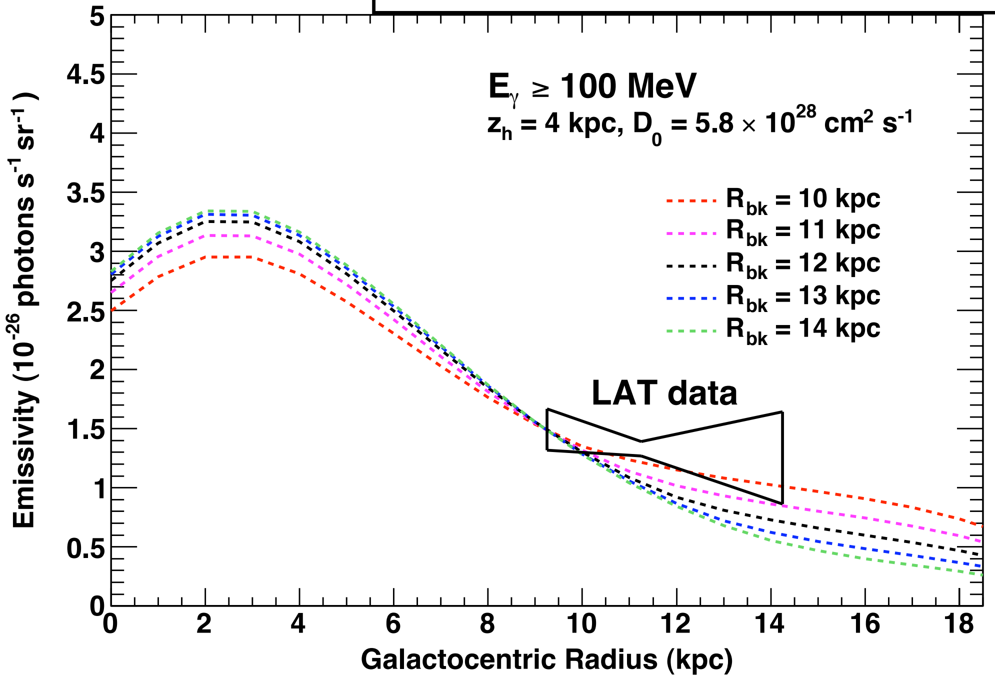
by Iris Gebauer

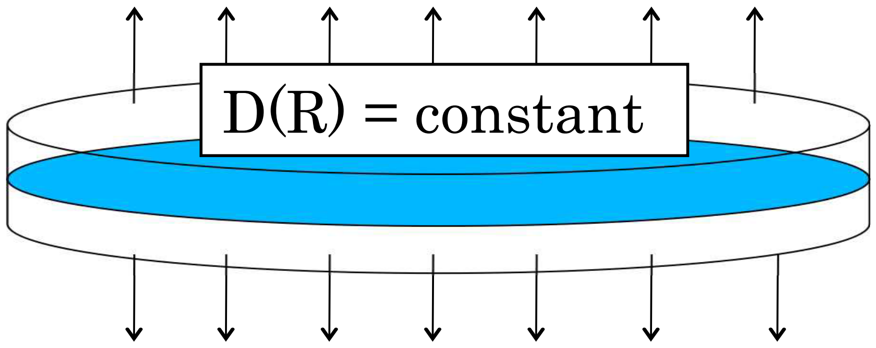
Hints of non-standard propagation scenarios? The gradient problem



Ackermann et al. [Fermi Collaboration] 2010







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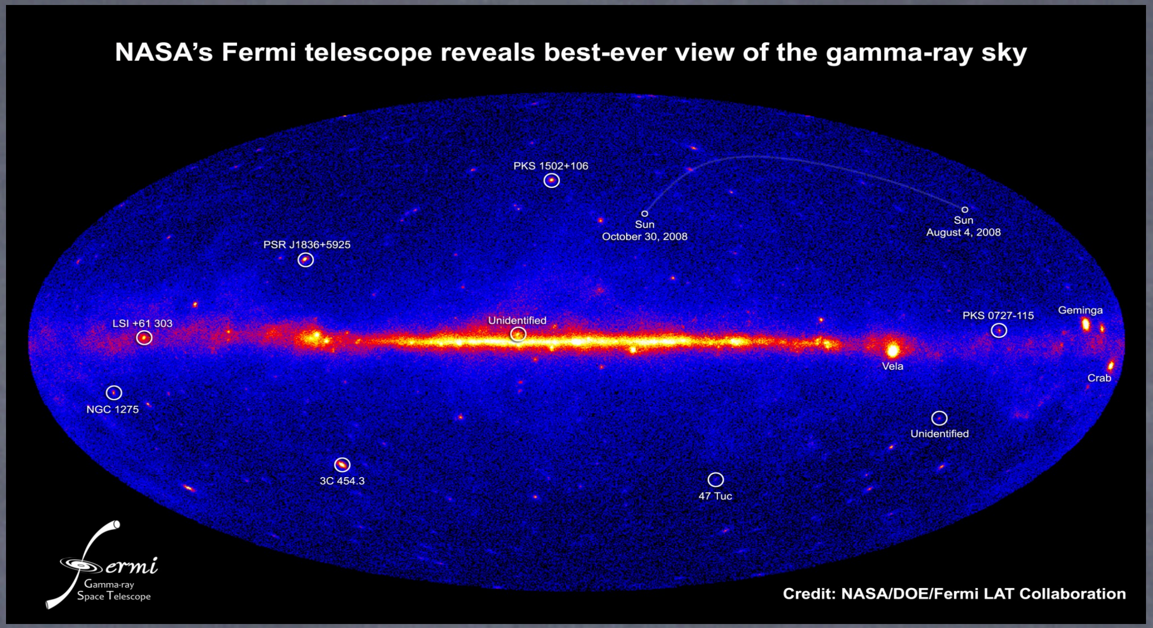
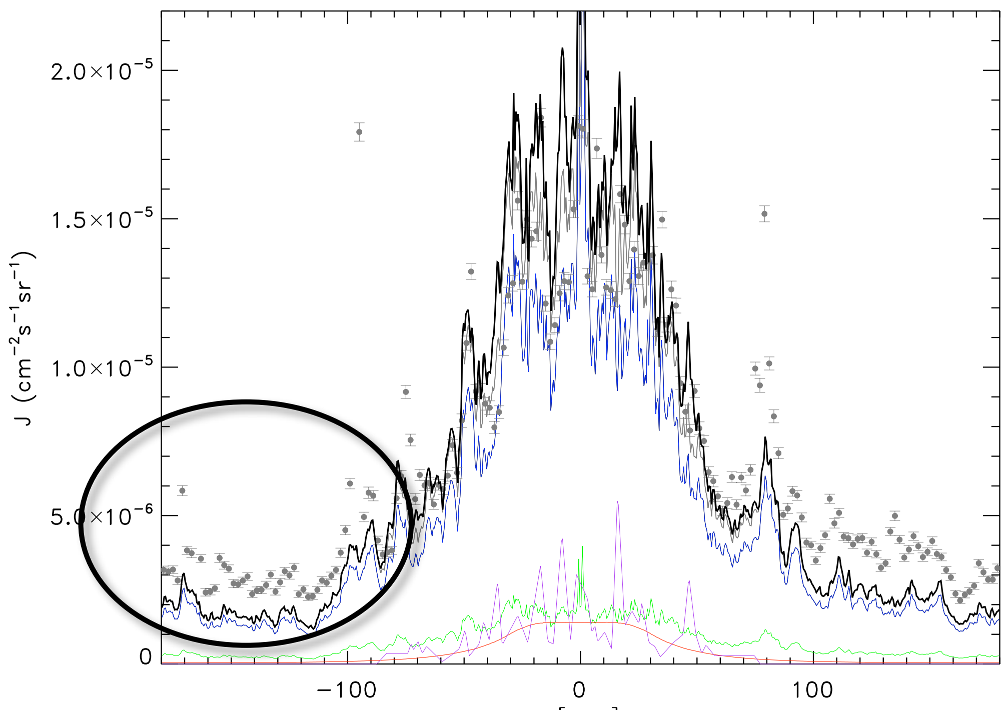
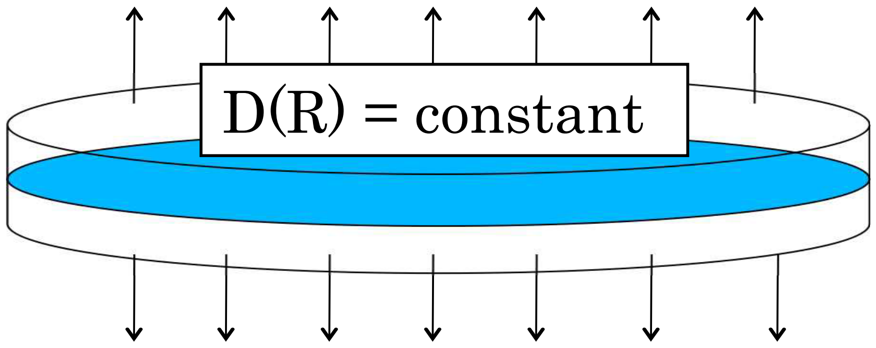
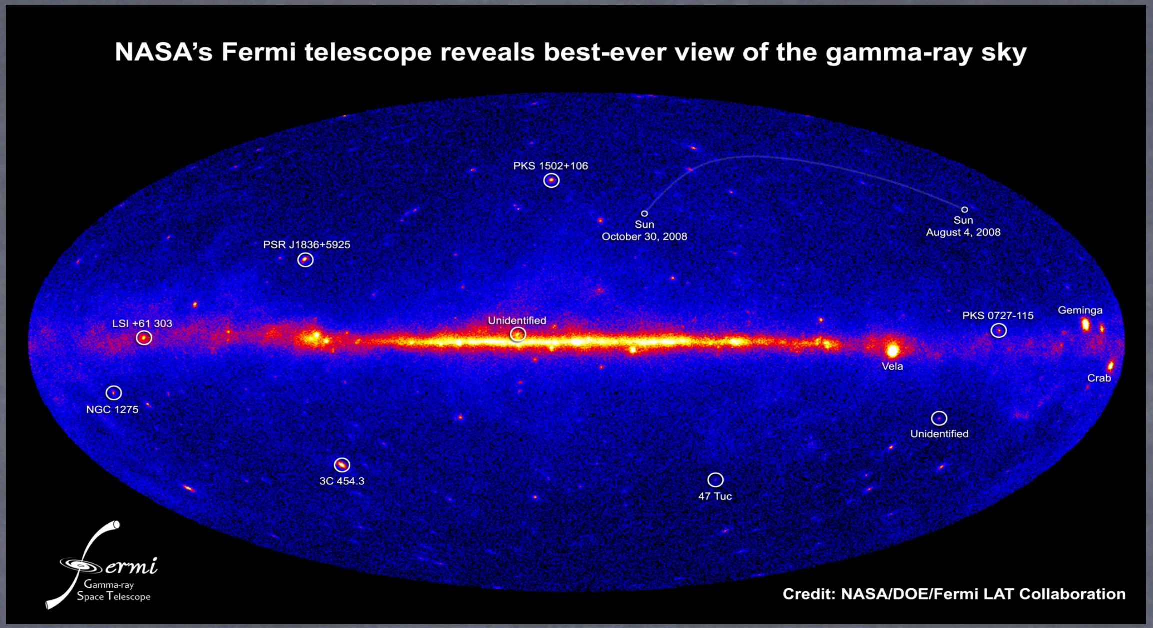
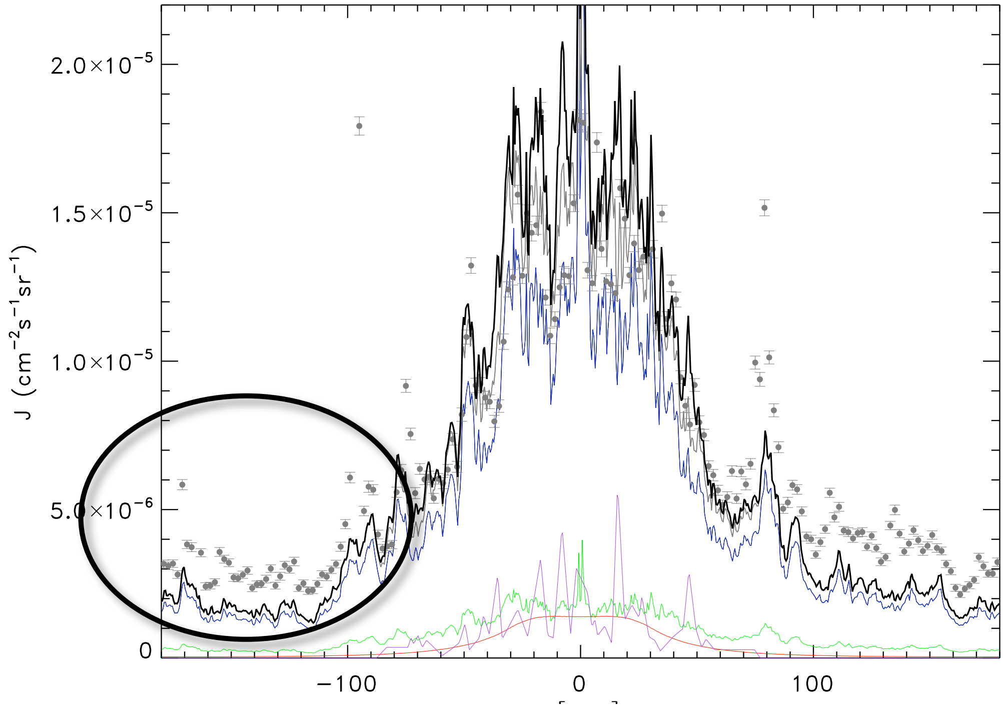


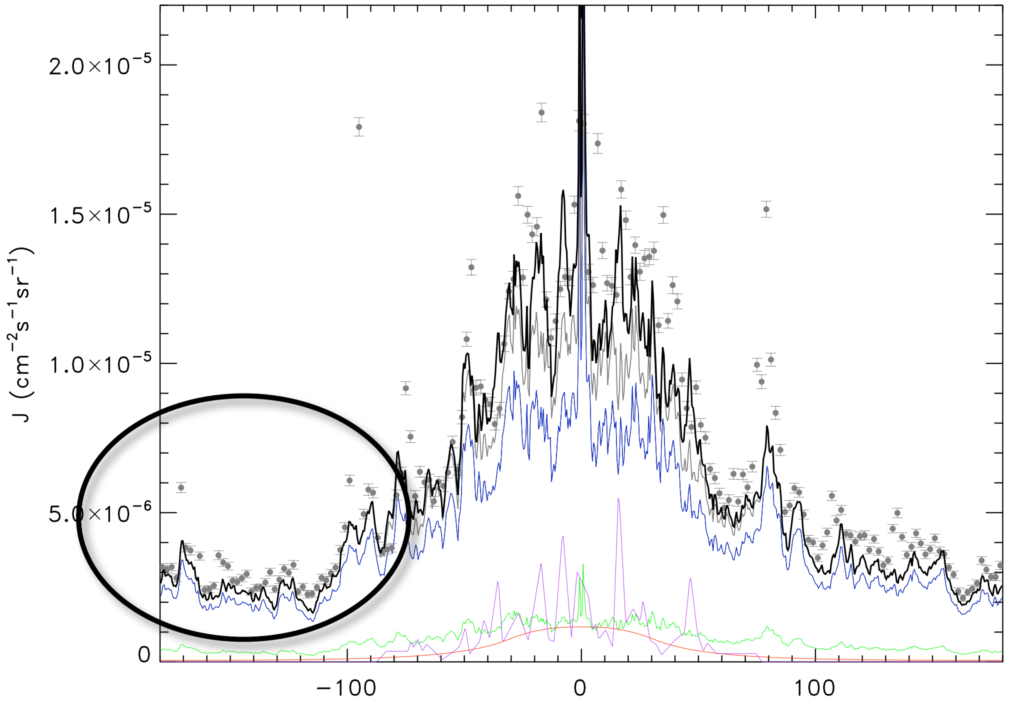


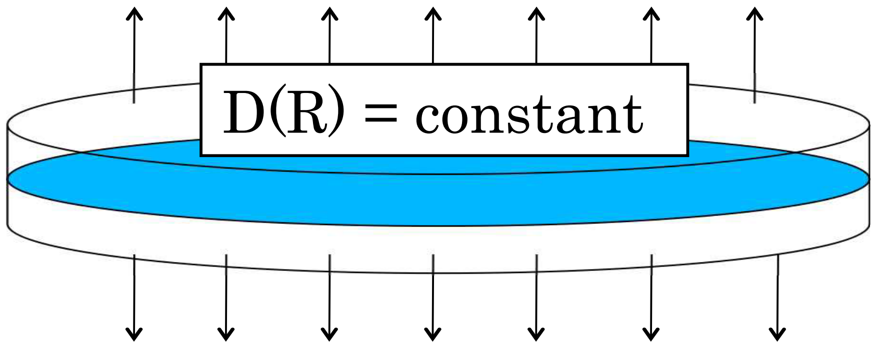


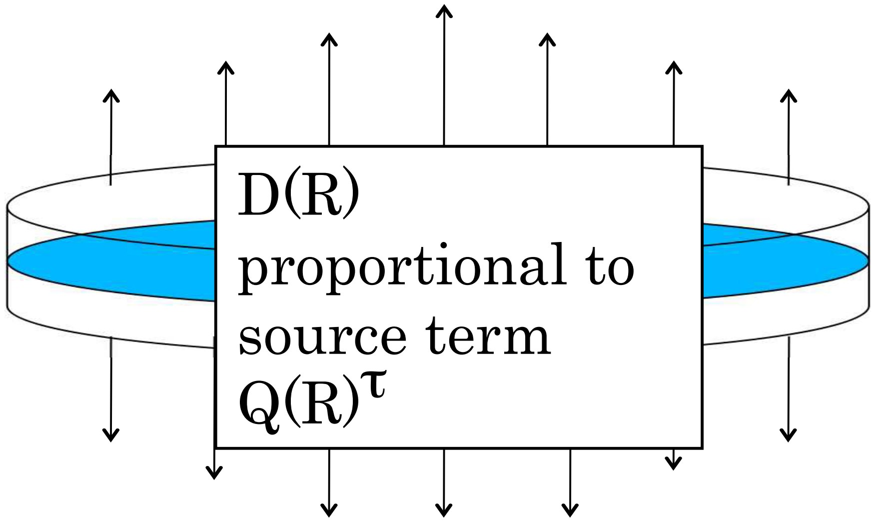
Hints of non-standard propagation scenarios? The gradient problem











Hints of non-standard propagation scenarios? The gradient problem