Testing the origin of high-energy cosmic rays

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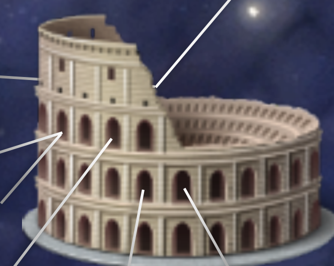
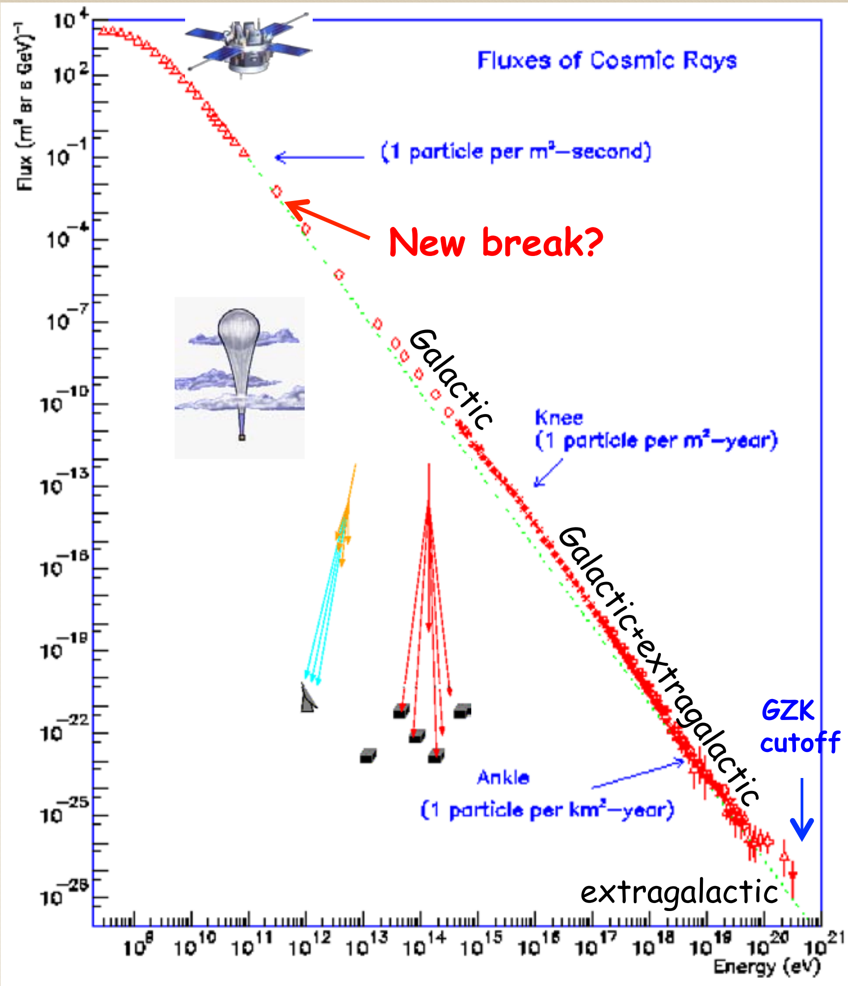


Spectrum of cosmic rays

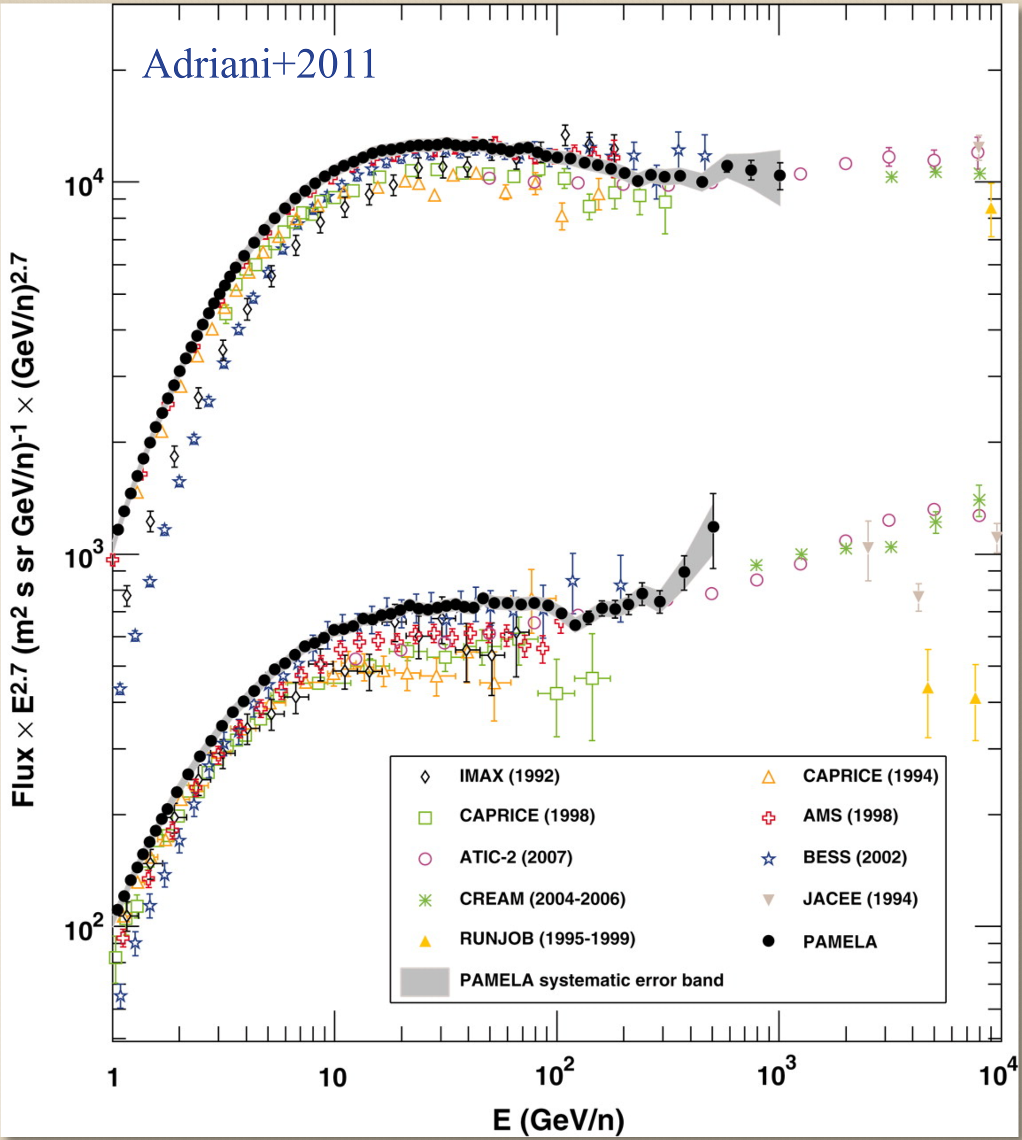


All particle CR spectrum is almost featureless:

- the knee
- the ankle
- GZK cutoff

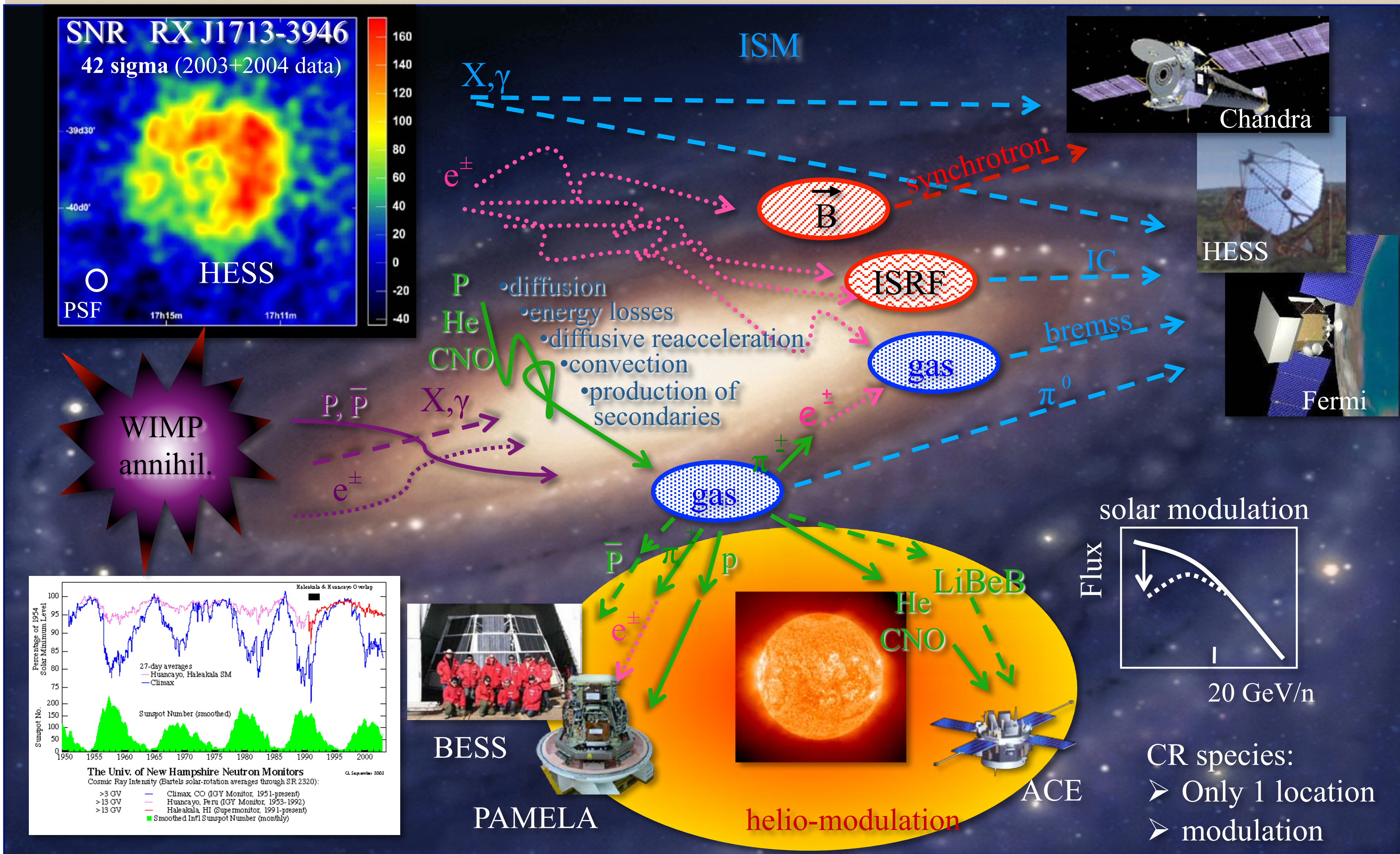
These were the only features in >12 decades in energy and >32 decades in intensity!

Proton and helium absolute fluxes



- Data from three experiments (ATIC, CREAM, PAMELA) are all consistent and indicate spectral hardening above ~100 GeV/nucleon
- He spectrum is clearly flatter than the proton spectrum
- A new break may provide us with a hint on the origin of high energy CRs

CRs in the Interstellar Medium



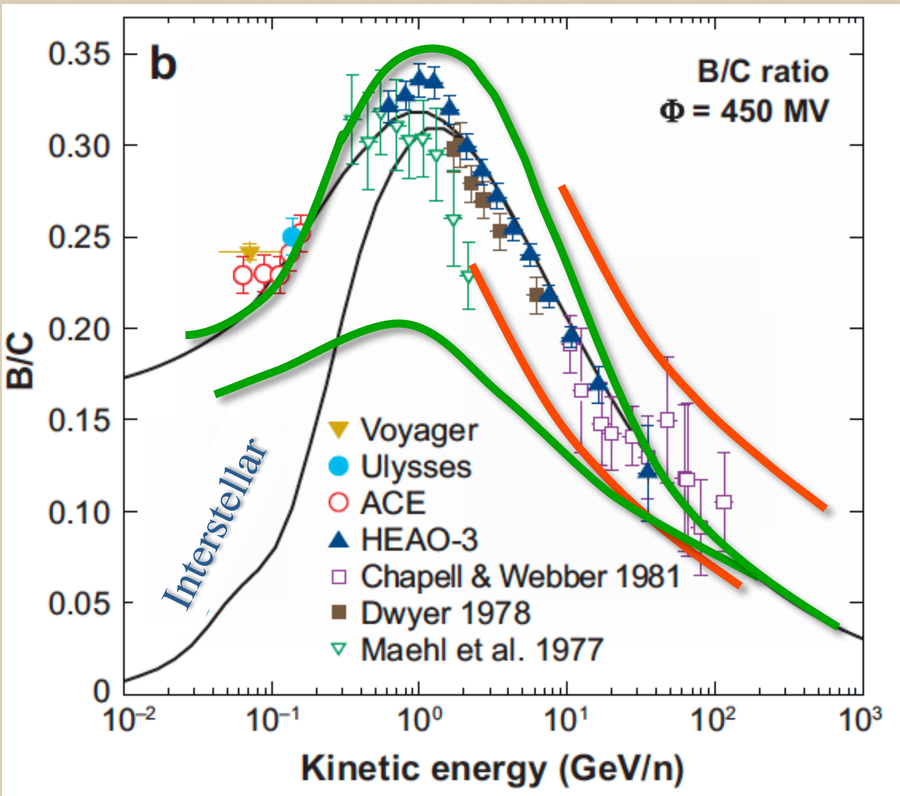
Secondary/primary nuclei ratio & CR propagation

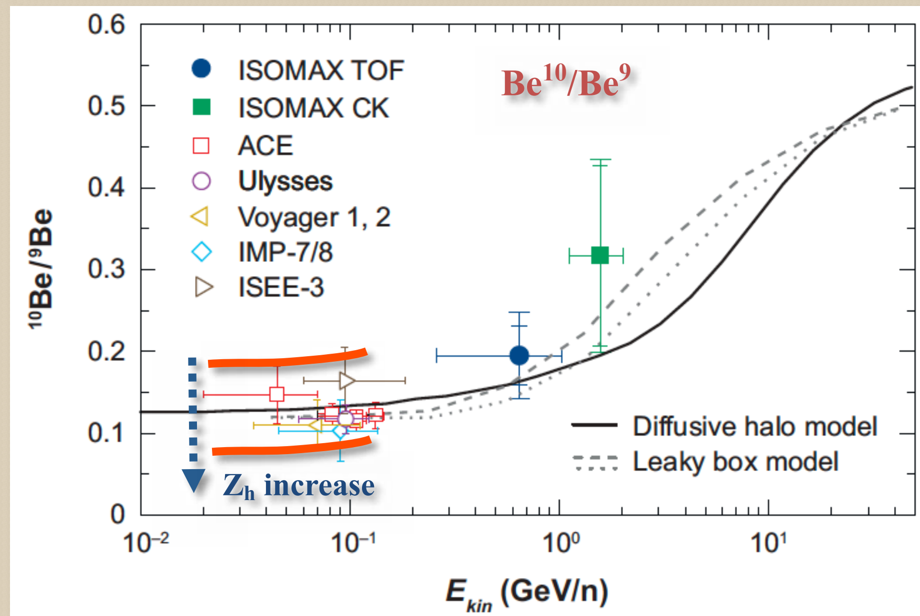
Typical parameters (model-dependent):

$D \sim 10^{28} (\rho/1\ GV)^{\alpha}\ cm^2/s$

$\alpha \approx 0.3\text{-}0.6$

$Z_h \sim$ 4-6 kpc; $V_A \sim$ 30 km/s

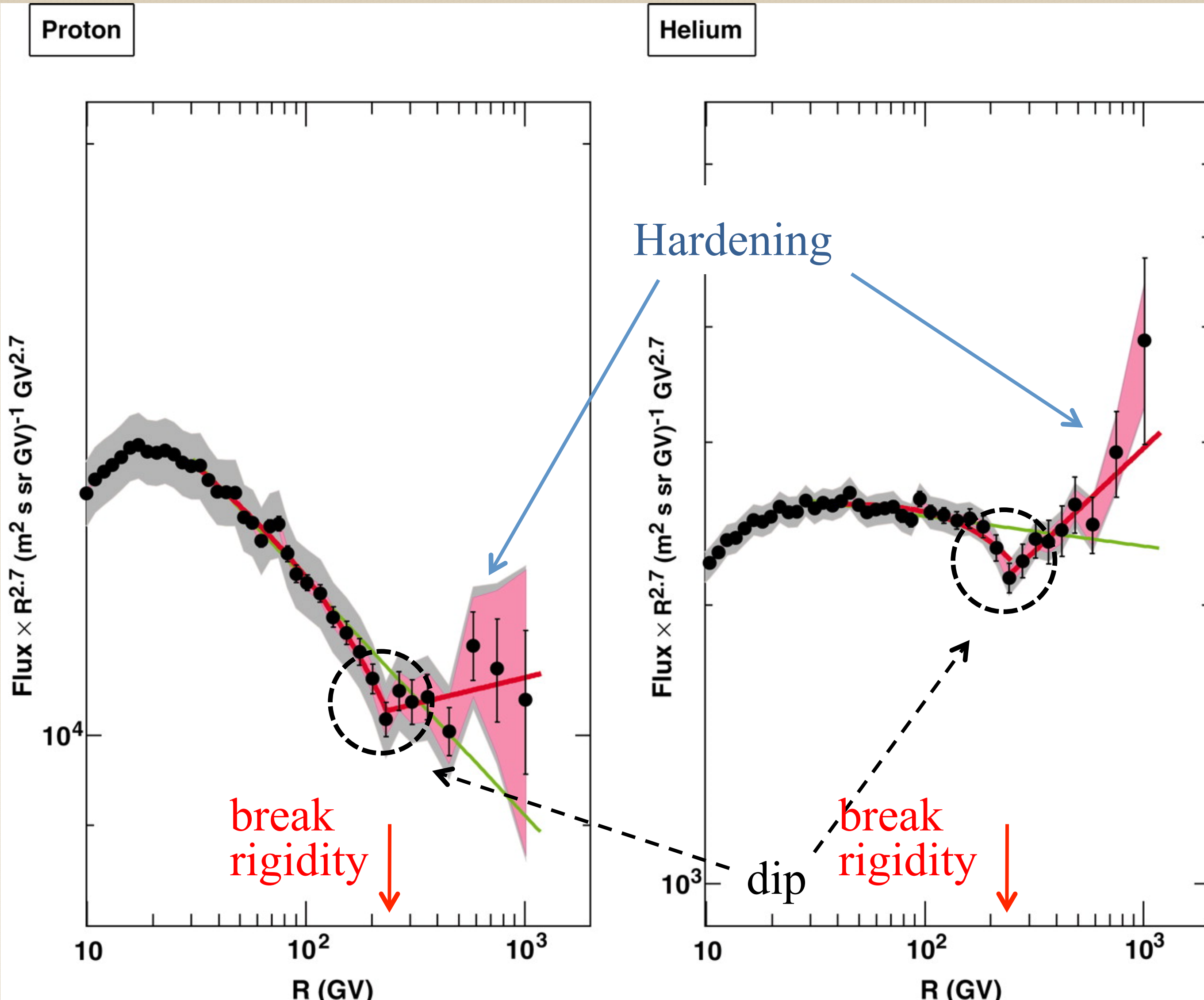




Using secondary/primary nuclei ratio (B/C) & radioactive isotopes (e.g. Be^{10}):

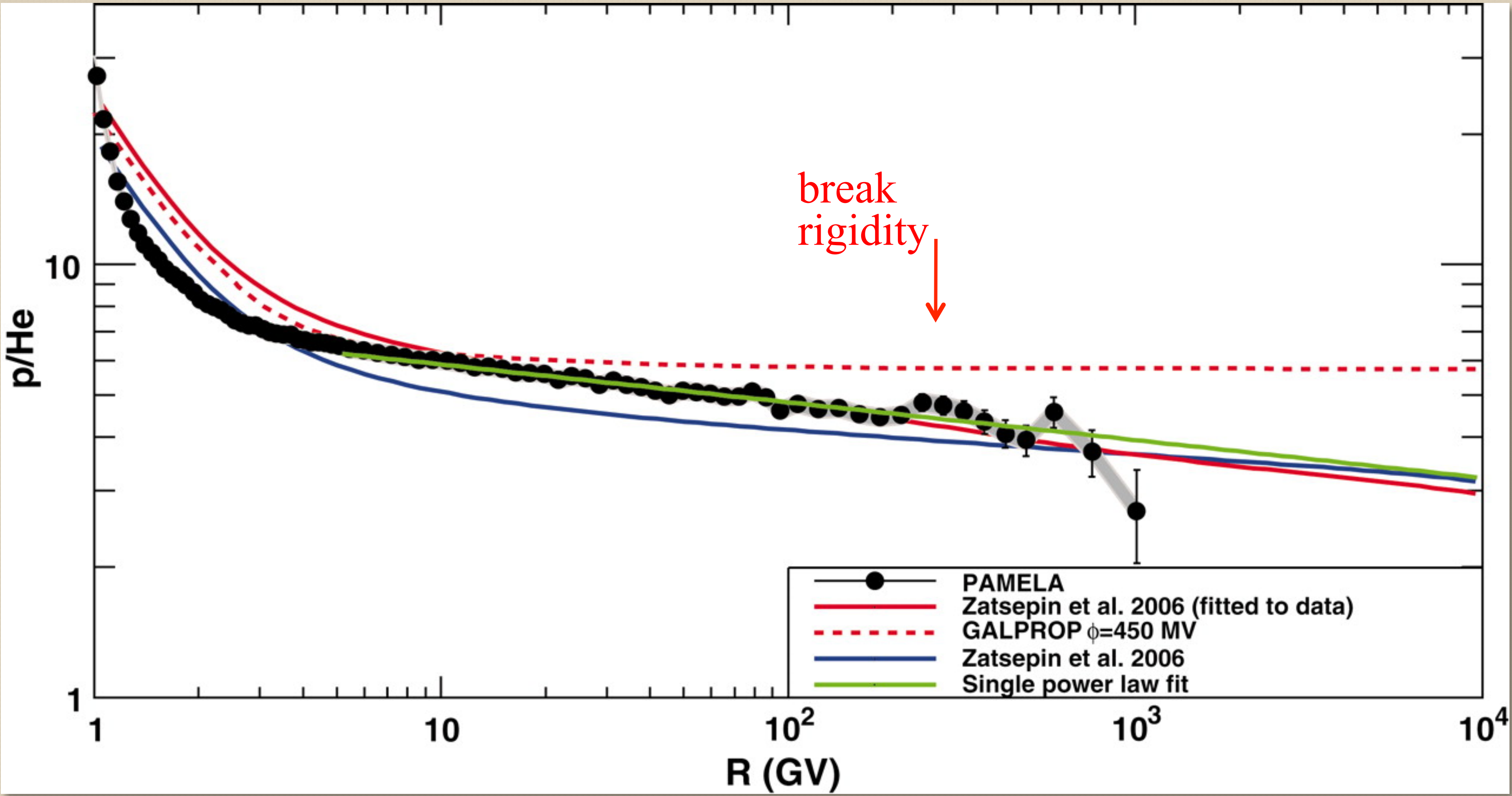
- ✧ Diffusion coefficient and its index
- ✧ Galactic halo size Z_h
- ✧ Propagation mode and its parameters (e.g., reacceleration V_A, convection V_z)
- ✧ Propagation parameters are model-dependent

PAMELA: Proton and helium spectra



- The same break rigidity for p and He ~240 GV
- The spectrum becomes flatter above the break
- Spectral softening near the break, the "dip"
- The differences between p and He spectral indices $\Delta = \delta_p - \delta_{He}$ are about the same below and above the break

PAMELA: p/He ratio



- The p/He ratio is smooth and does not have a feature at the break rigidity

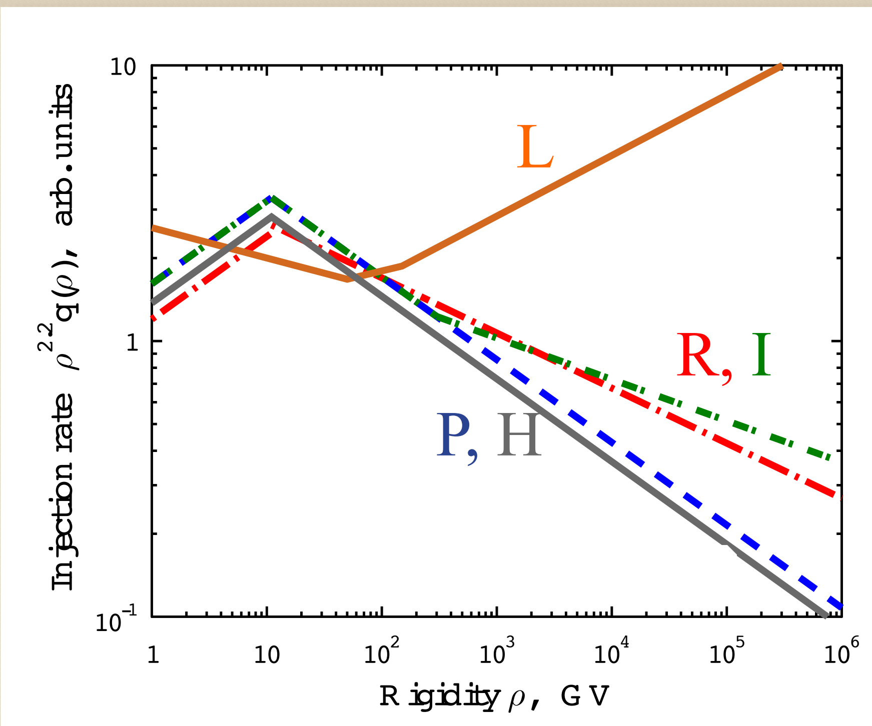
Rationale

- **Scenario P:** interstellar **P**ropagation effects
  - Change in CR transport: $D \sim \rho^{\delta}$, $\delta = 0.3/0.15$ below/above the break
- **Scenario I(a):** CR **I**njection effects, a source with spectral break
  - Breaks in the injection spectrum of CR sources
- **Scenario I(b):** CR **I**njection effects, a composite source
  - Two types of CR sources (soft and hard) uniformly mixed in the Galaxy
- **Scenario L:** local **L**ow energy source
  - High energy CRs are produced by sources distributed in the Galaxy
  - Low energy CRs are coming from a local source
  - No reacceleration, $\delta = 0.67$ below/above the break
- **Scenario H:** local **H**igh energy source
  - Low energy CRs are produced by sources distributed in the Galaxy
  - High energy CRs are coming from a local source
- **Scenario R:** **R**eference model
  - Tuned to pre-PAMELA CR data

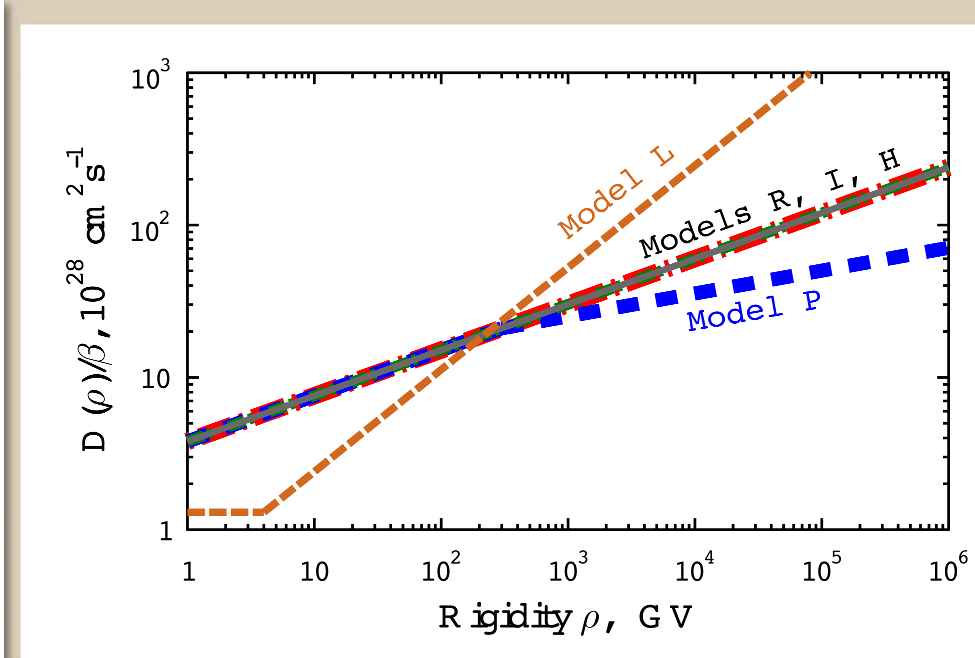
- Calculations employ GALPROP Webrun: http://galprop.stanford.edu

CR injection spectra and the diffusion coefficient in different scenarios

Injection spectra

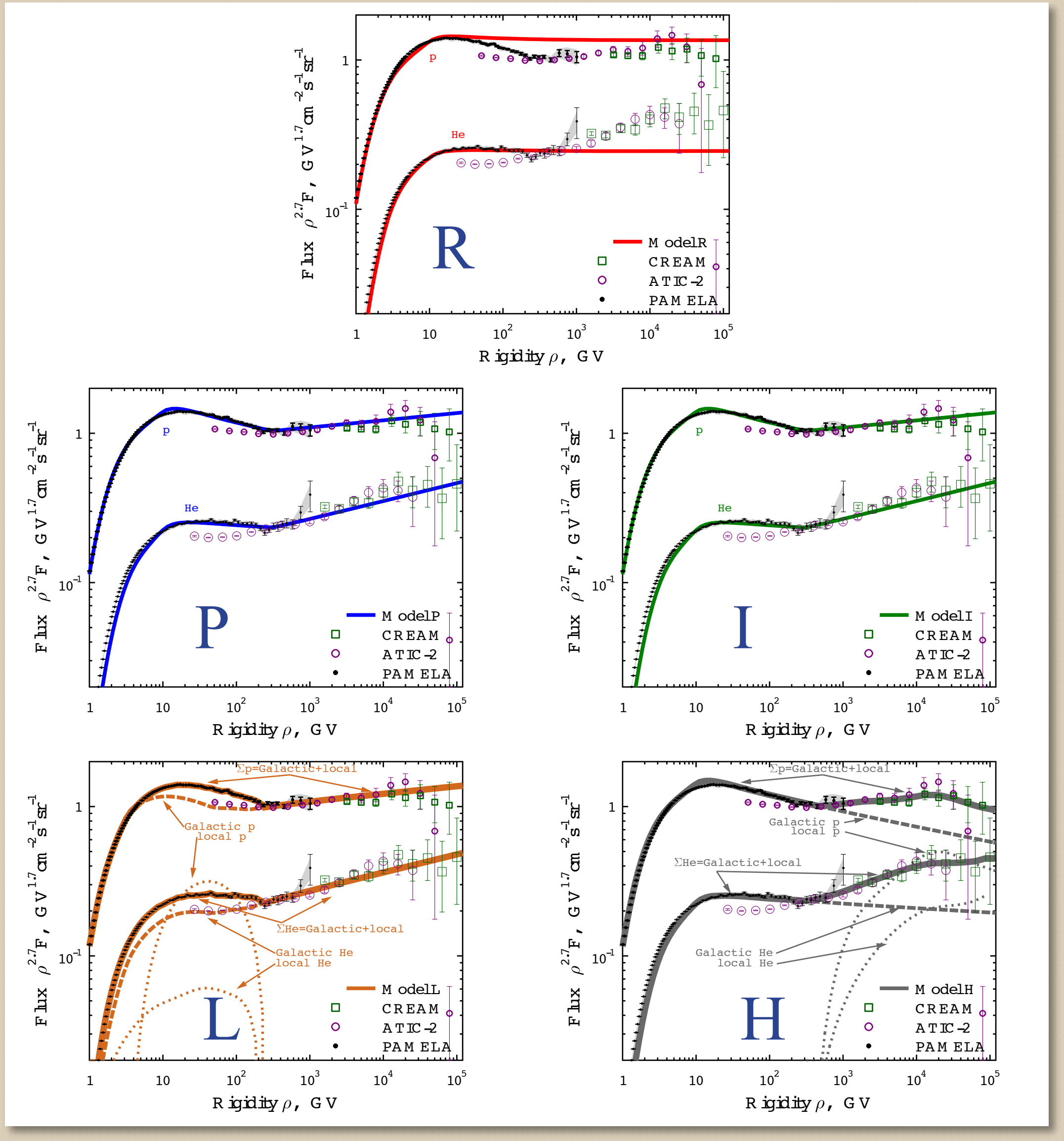


Diffusion coefficient



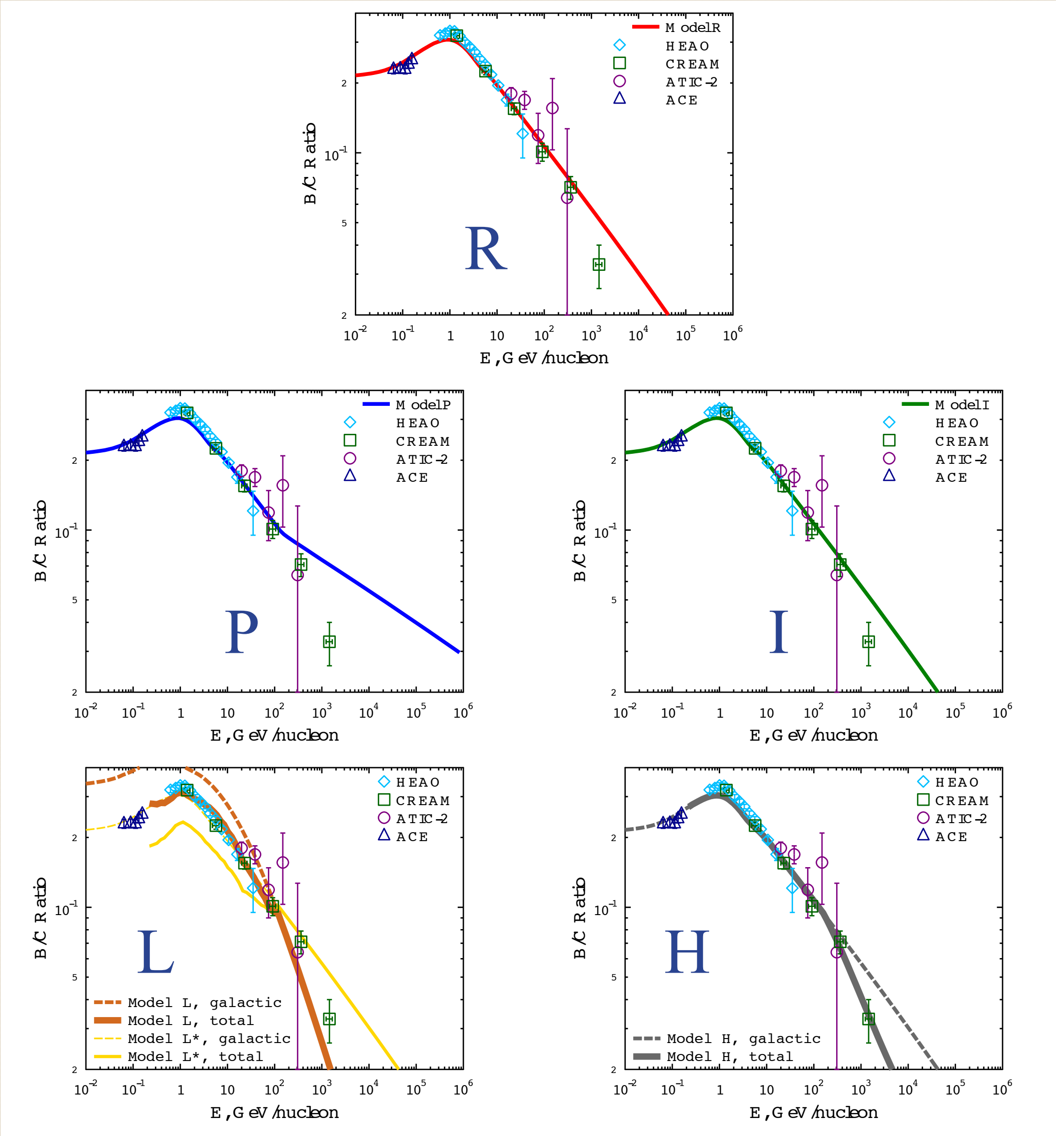
Propagation: stochastic reacceleration model, except scenario L

P and He spectra in different scenarios



- All scenarios are tuned to the data, except the Reference scenario
- Scenarios L and H: the local source component is calculated by the subtraction of the propagated Galactic spectrum from the data
- The local source is assumed to be close to us, so no propagation; only primary CR species

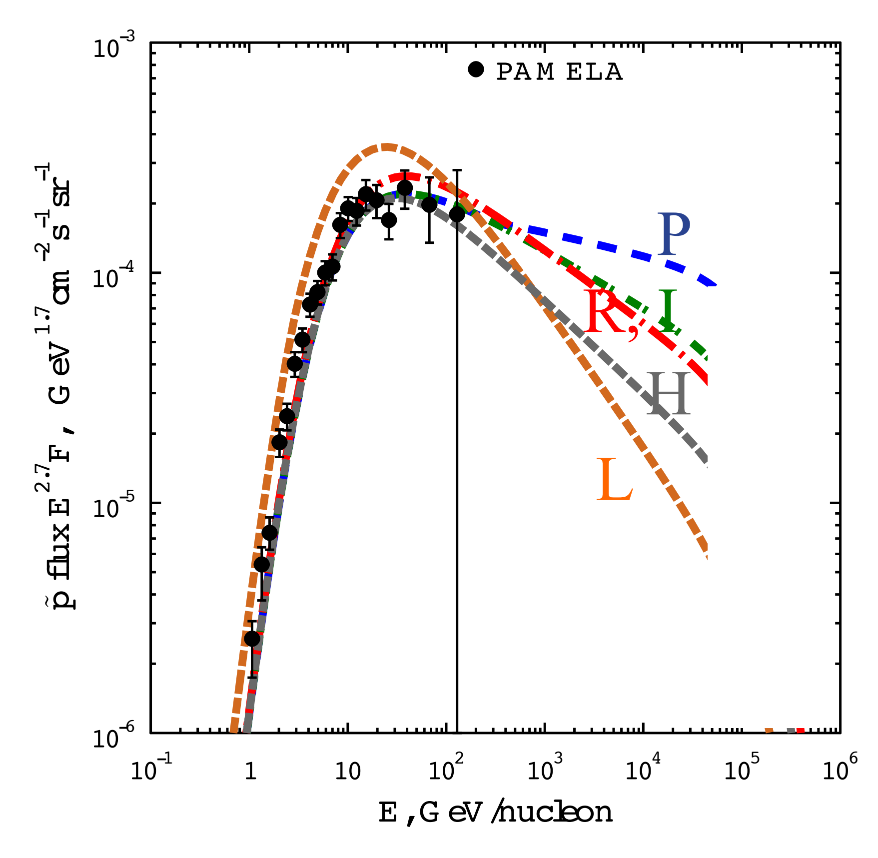
B/C ratio in different scenarios



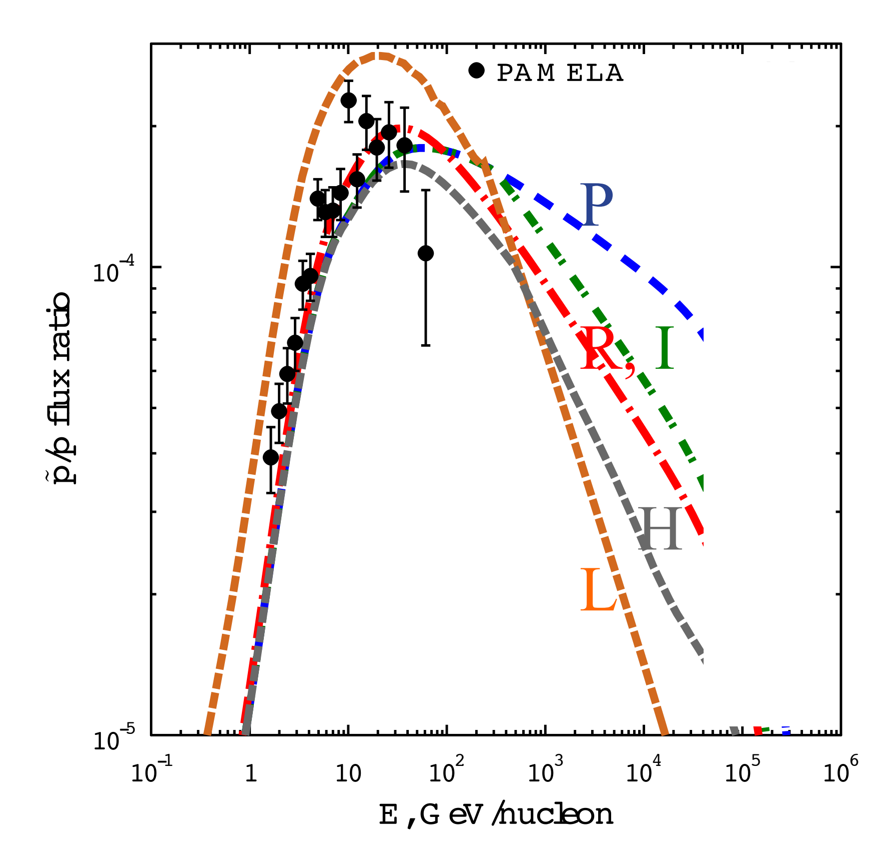
- B/C is flatter in Scenario P
- Local sources are assumed to produce primary isotopes only
- B/C is steeper in scenario L and H, but due to the different reasons
  - Scenario L: P-L index of the diffusion coefficient steepens to 0.67
  - Scenario H: there is no Boron in the local source, but there is Carbon

Antiprotons and pbar/p ratio in different scenarios

Antiprotons

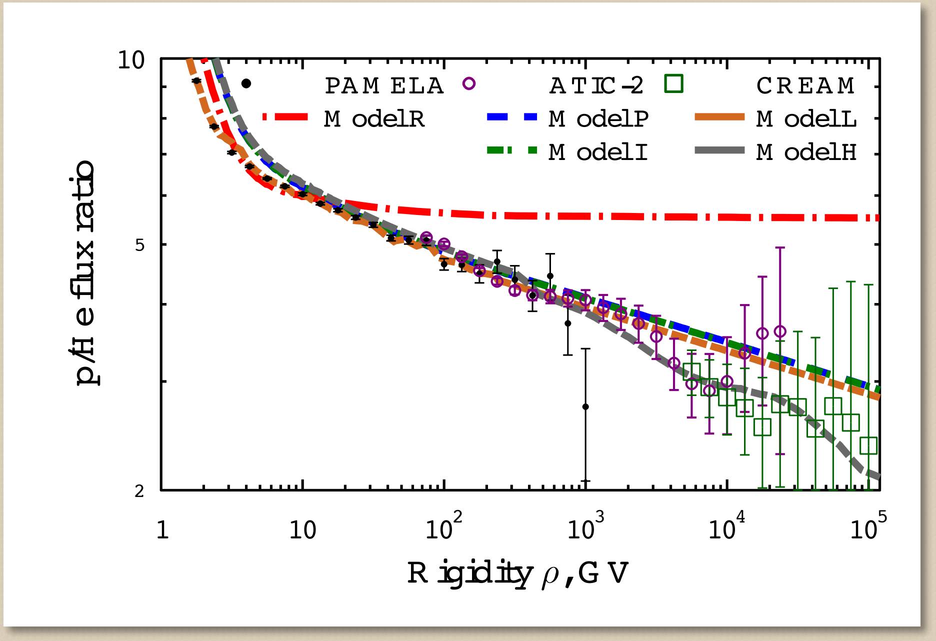


pbar/p ratio

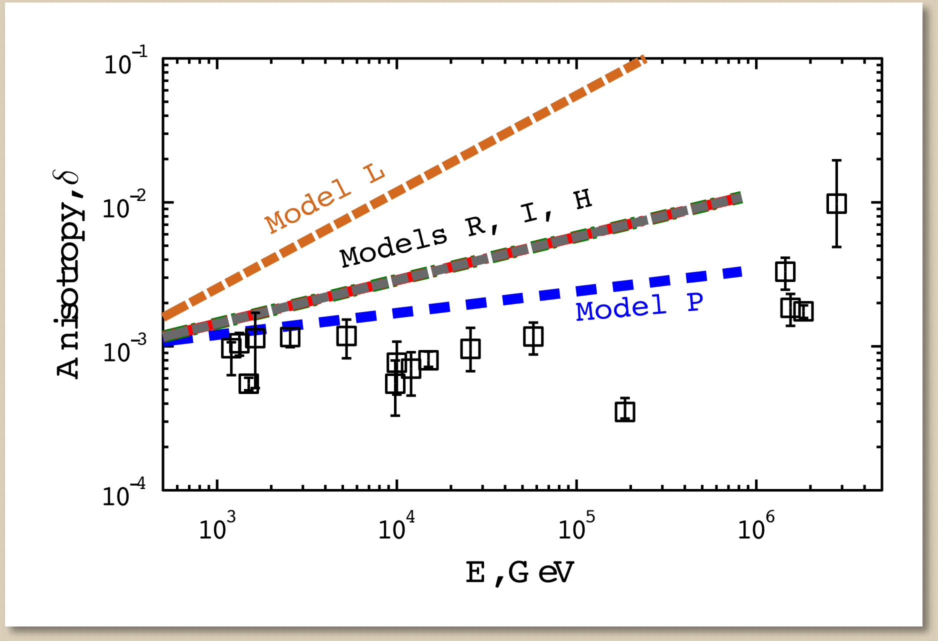


p/He ratio and CR anisotropy ratio in different scenarios

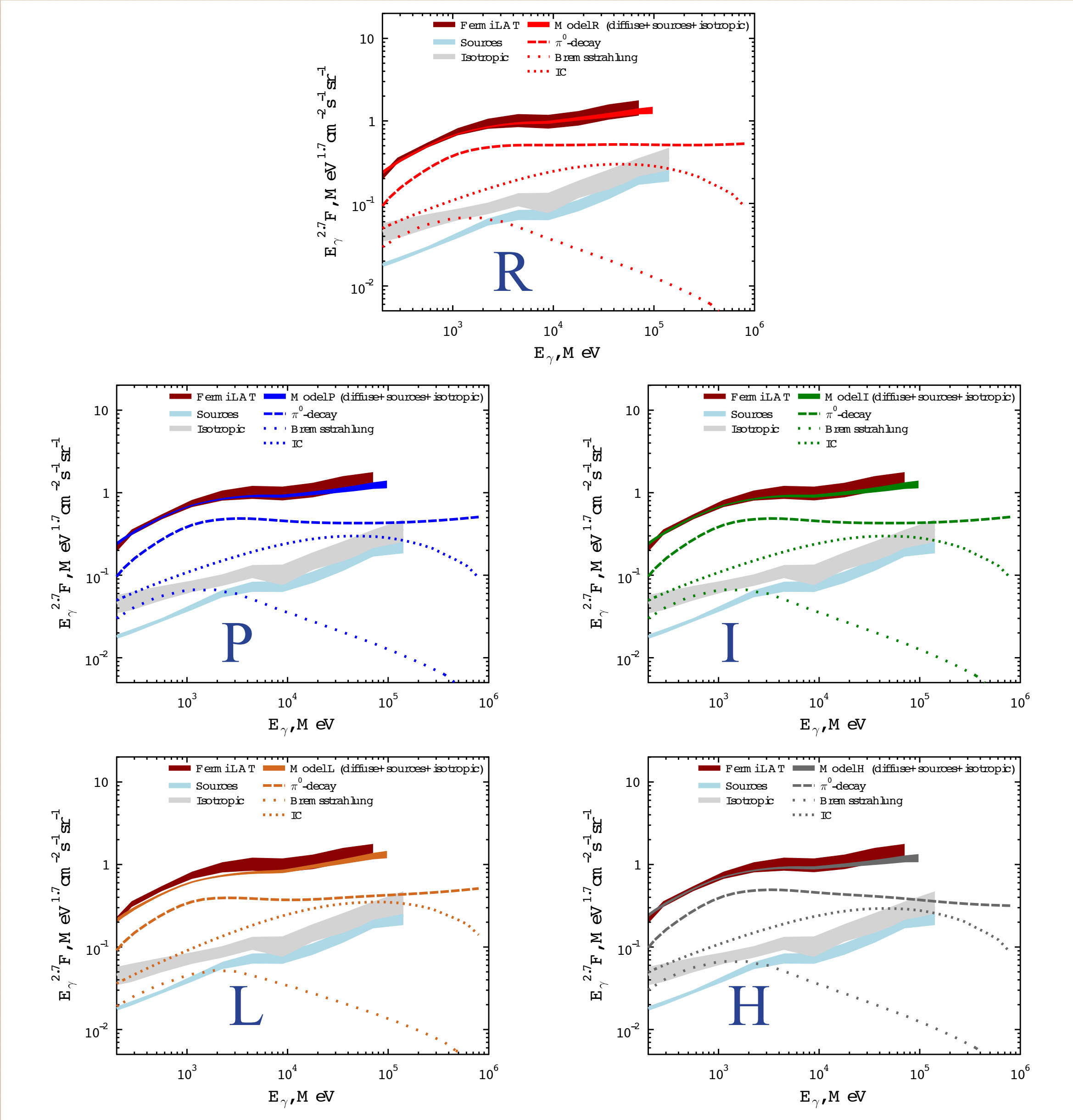
p/He ratio



CR anisotropy



Mid-latitude diffuse emission in different scenarios



- All scenarios are consistent with the Fermi -LAT data
- There are small differences at TeV energies, but the chances of detecting them are slim

Conclusions

- The model predictions can be tested by current or near future experiments
- Scenario P (interstellar propagation effects) is the favorite scenario, although other scenarios can't be ruled out yet
- Important issue is the reality of the "dip" feature, which can only be understood in Scenario L
- Scenario L (plain diffusion model) seems to be ruled out on the base of pbar and anisotropy arguments

- Submitted to ApJ (will be posted to the arXive soon)