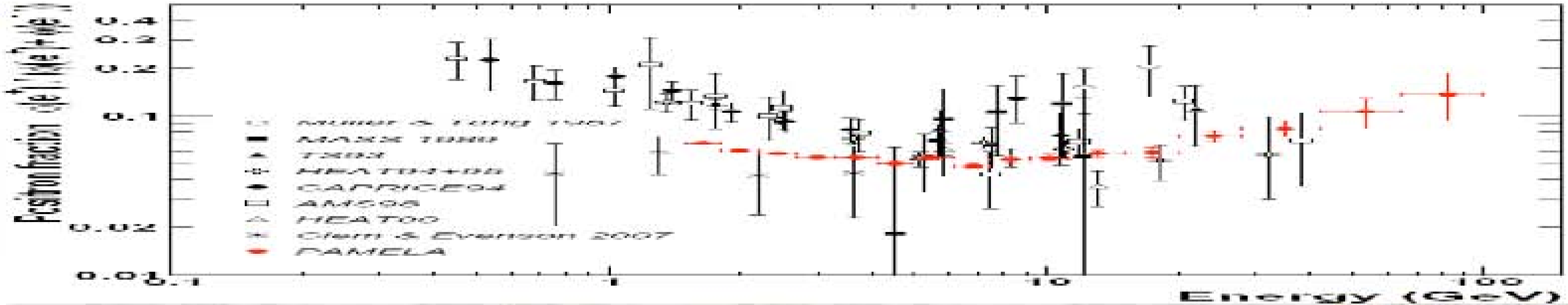
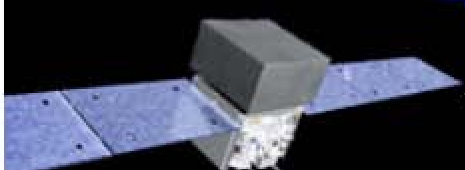


Astrophysics of Cosmic Rays: Turning New Pages

Igor V. Moskalenko (stanford/kipac)



Goal

- To show the place of recent data in astrophysics of cosmic rays

- Target audience: particle and high-energy physicists

There is nothing new to be discovered in physics now. All that remains is more and more precise measurement.

— Lord Kelvin, 1900

The Key Question

Last couple of years the Cosmic Ray and Astrophysical communities were exposed to the overwhelming amount of new and accurate data and are expecting more to come...

It will probably take a few years to fully appreciate the significance of new information, but it is absolutely clear that we are currently on the verge of dramatic breakthroughs in Astrophysics, Particle Physics, and Cosmology and may soon be able to resolve century-old puzzles such as the origin of cosmic rays and dark matter. Hopefully before 100th anniversary of V.Hess flight in 2012!

The key question to answer is how these new discoveries fit or do not fit into the "standard picture" of the Milky Way galaxy

A Particle Physicist's View (pre ~2000)

- An Astronomer does stamp collecting
- An Astrophysicist does engineering
- A Particle physicist does fundamental science

» .....we have been humbled!

– Persis Drell

SLAC NATIONAL ACCELERATOR LABORATORY

Summary Thoughts

- Wealth of data and excitement
  - This is a healthy field!
  - Multiwavelength/Multimessager/Multicultural
- We are bold in our aspirations!
  - Will be a rich field for decades to come
- Astrophysics is an essential part of Particle Physics!!

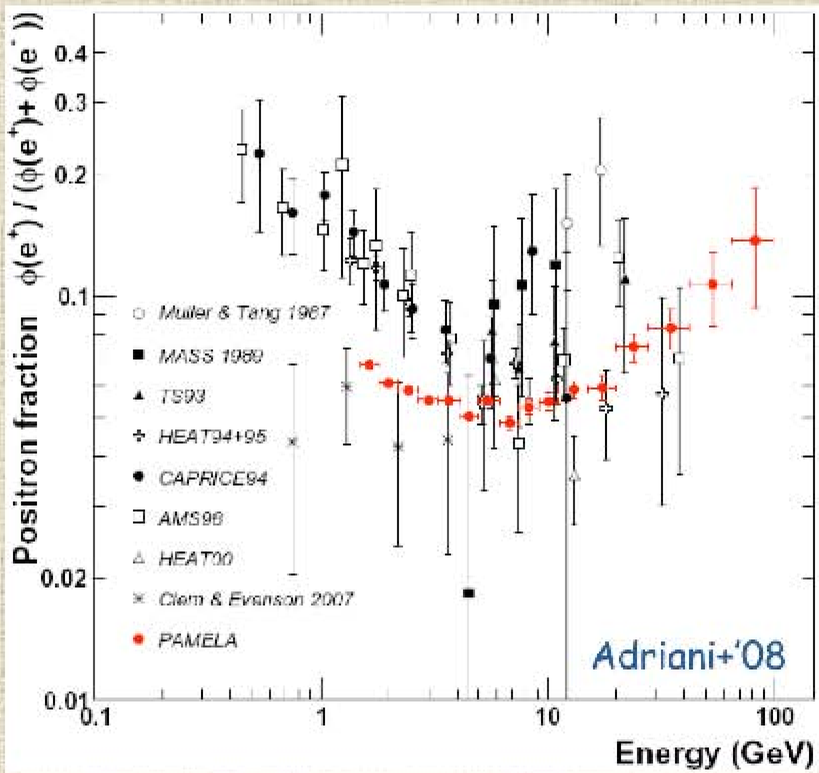
– Persis Drell

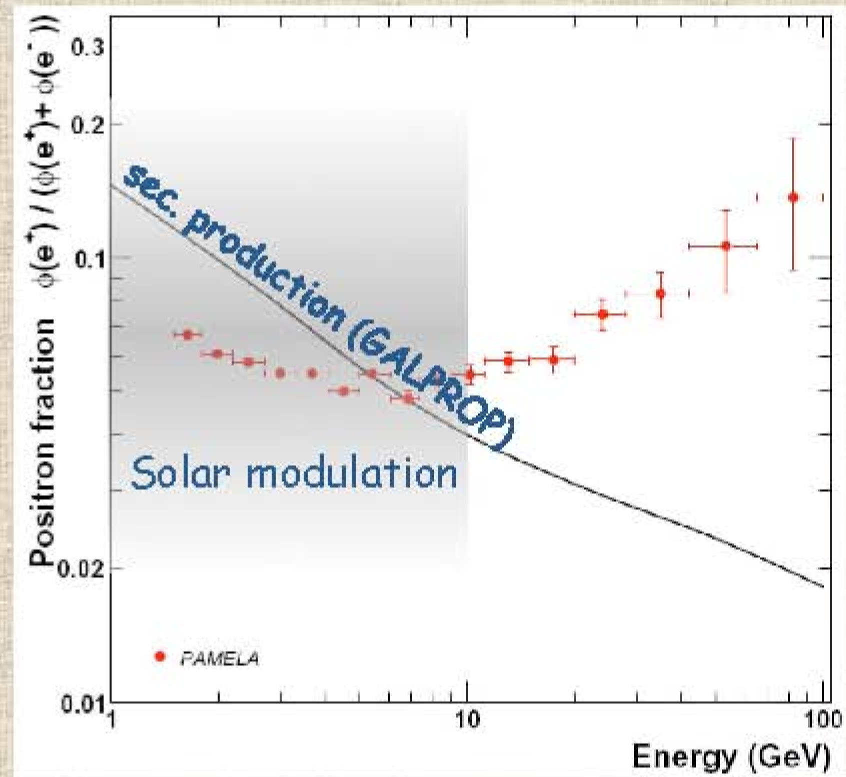
Recent and not Very Recent Past (<2008)

- GeV excess in diffuse gamma rays is "clearly" established
  - Three papers on GeV excess (Hunter+'97, Strong+'00,'04) have received 1000+ citations (NASA ADS). Proposed explanations:
    - Astrophysical sources (SNR, pulsars, unresolved sources…)
    - Fluctuations of CR intensity/spectra throughout the Galaxy
    - Dark Matter
    - Instrumental artifact
- Increase of the CR positron fraction above ~10 GeV
  - Has been known since ~1970s, but the background rejection was not good enough
  - Perhaps first reliable measurement was done by HEAT in 1994-95 flights (Barwick+'97), and then after year 2000 flight was revised down to agree with secondary production within ~2σ
  - Barwick+'97 has received ~110 citations before 2008; exponential rise since 2008
  - Proposed interpretations: pulsars, dark matter, $\gamma\gamma$->ee near the sources, pp-interactions in giant molecular clouds, β^+-decay of SN ejecta…

Current Stage: 2009±1

Positron Fraction





- The excess in the CR positron fraction relative to the predictions of propagation models is confirmed by Pamela and extended to higher energies (up to ~100 GeV)
- Charge sign dependence below ~10 GeV is expected
- Additional positron component?

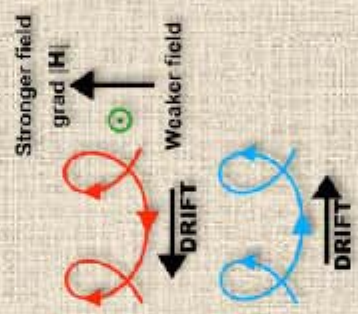
An experiment in nature, like a text in the Bible, is capable of different interpretations, according to the preconceptions of the interpreter. — William Jones, 1781

- There is no deficit in explanations of the PAMELA positron excess (Adriani+08): >370 papers since Oct 2008!
  - Various species of the dark matter (most of papers)
  - Pulsars
  - SNRs
  - Microquasars
  - a GRB nearby
  - ...
- Perhaps we have to discuss a deficit of positrons, not their excess!

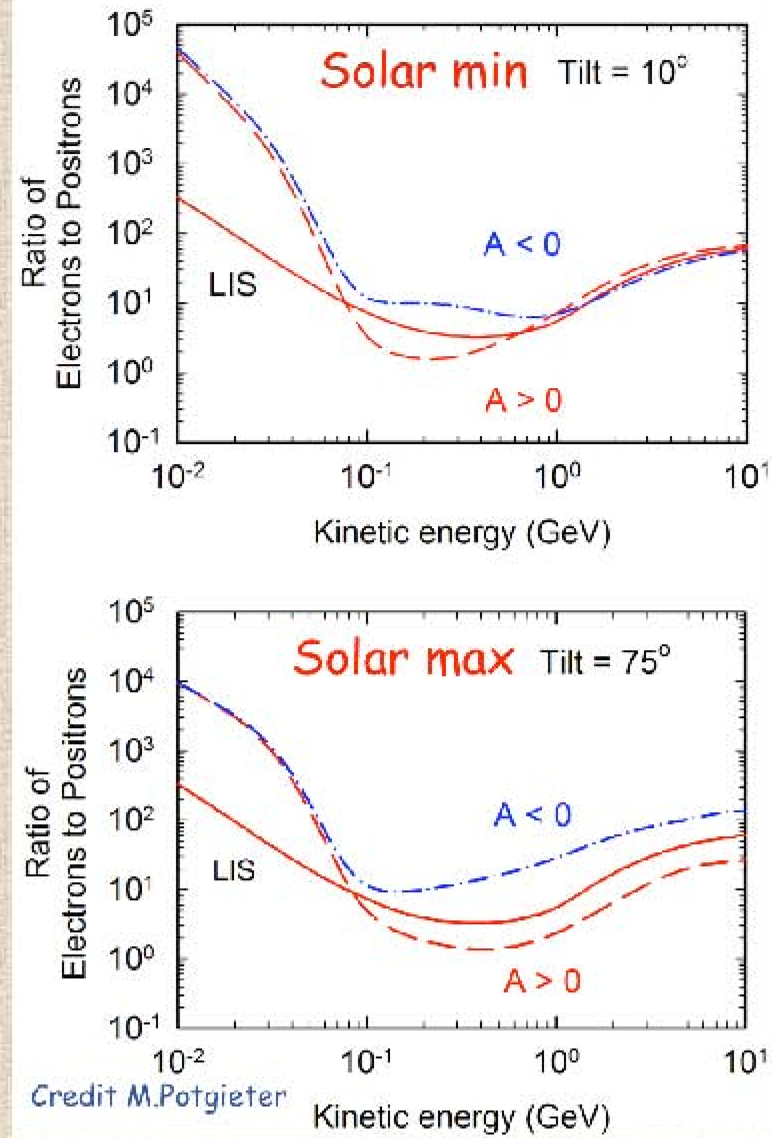
- Unfortunately, >99.7% of these explanations are wrong
- ...Because there is only one correct explanation

Charge-sign dependence

The Parker magnetic field has opposite magnetic polarity above and below the helio -equator, but the spiral field lines are mirror images of each other.

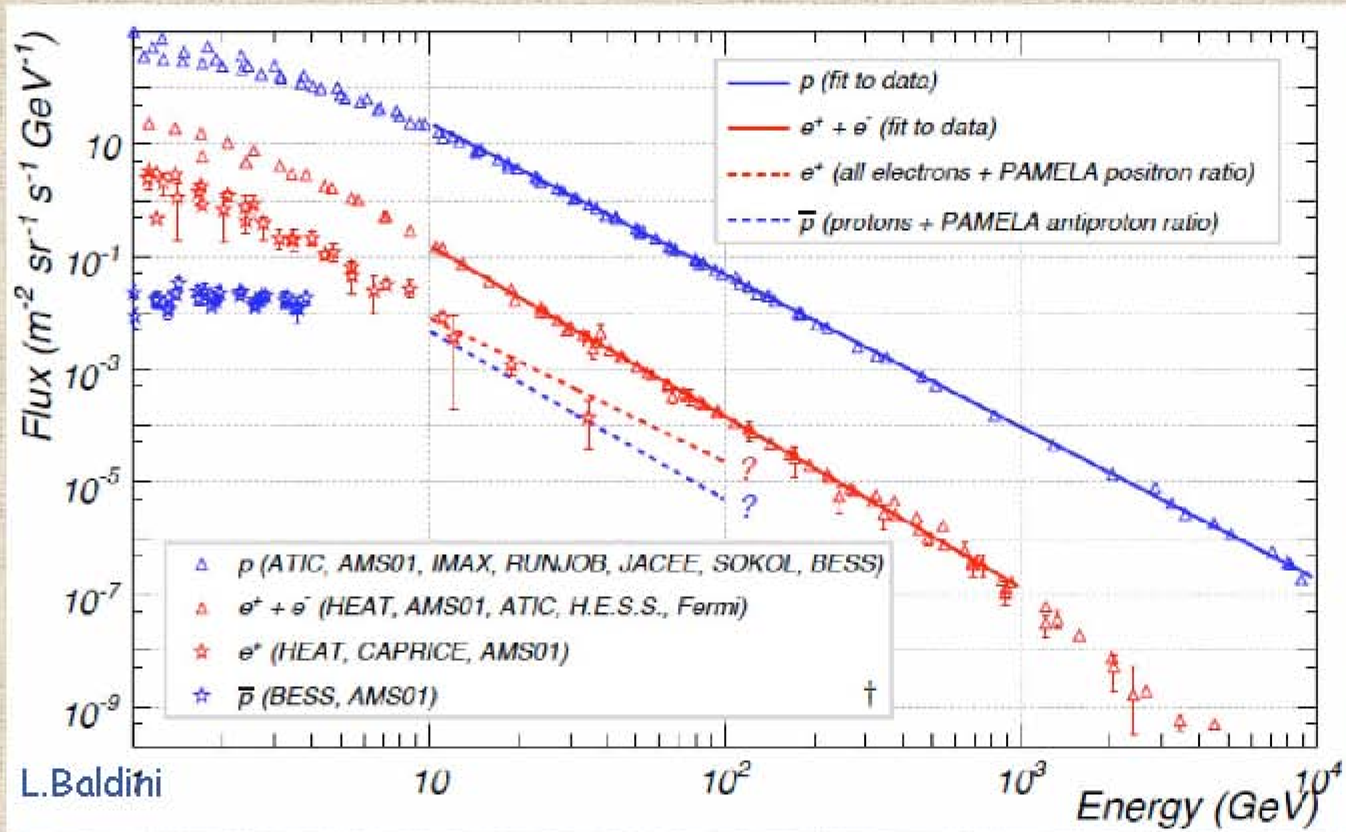


This antisymmetry produces the drift velocity fields that affect the particles of opposite charge in different ways (converge on heliospheric equator or diverge from it).

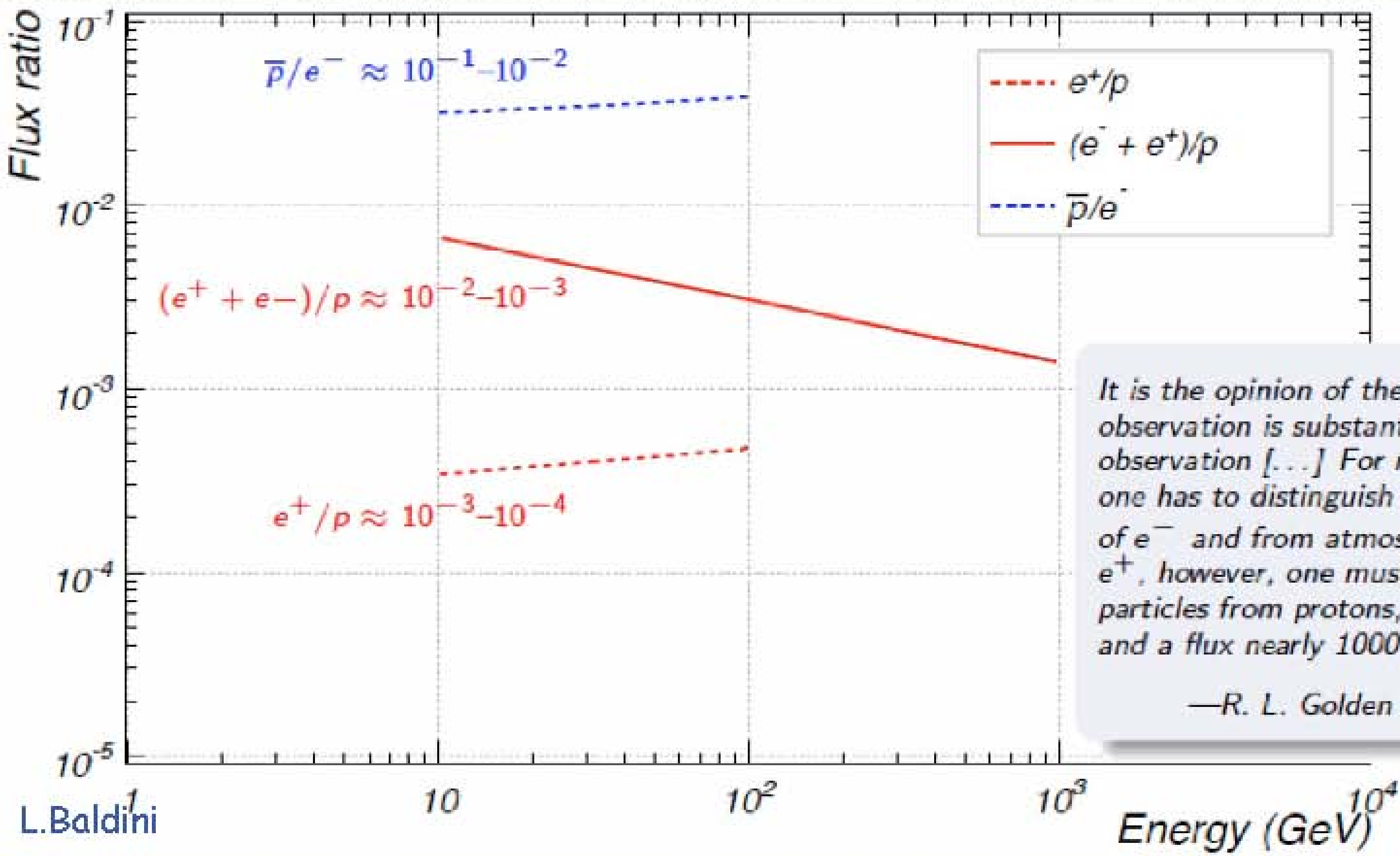


Credit M.Potgieter

Spectra of CR Species



CR Measurements and Backgrounds

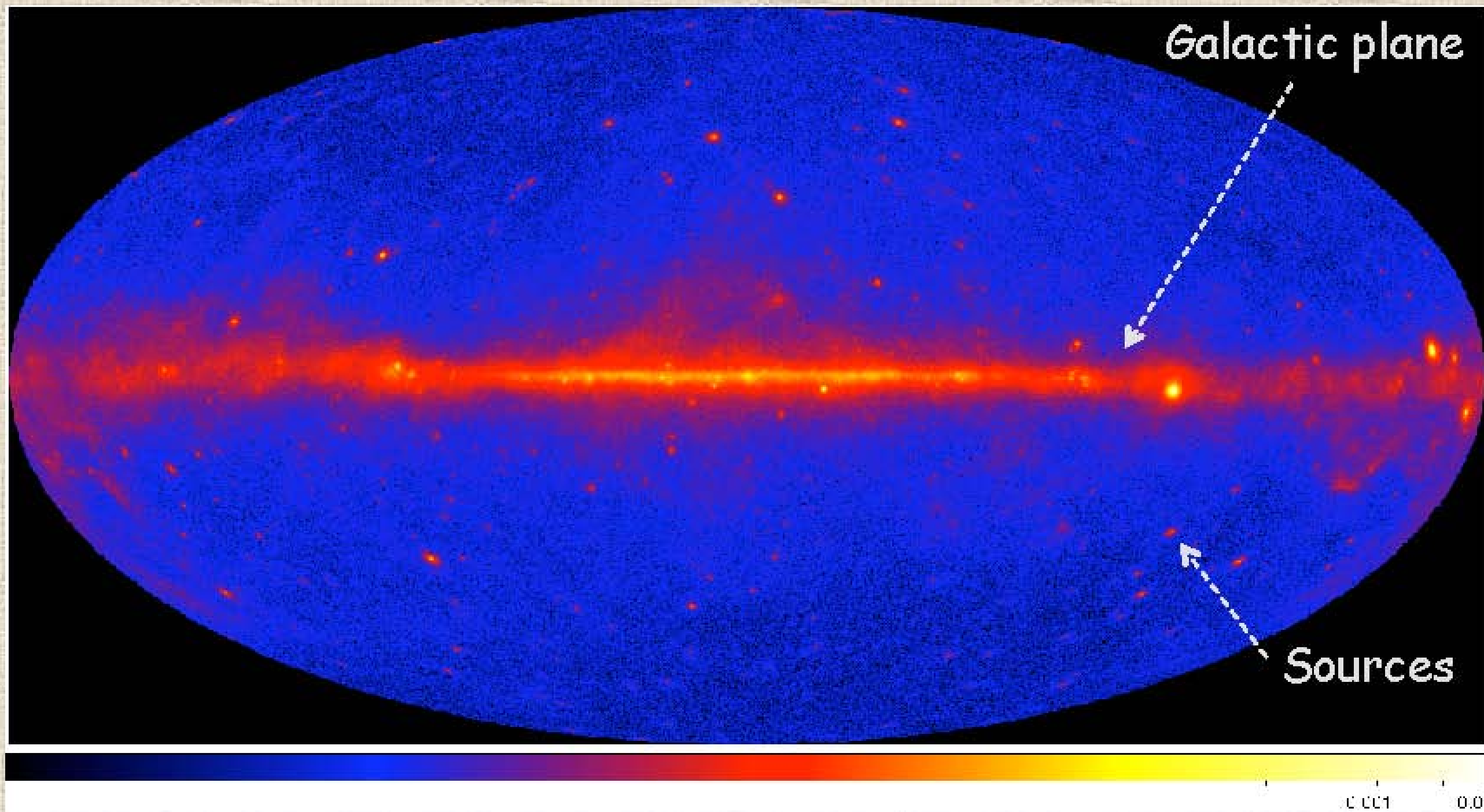


L.Baldini

It is the opinion of the investigators that the e^+ observation is substantially more difficult than the $\bar{p}$ observation [...] For negatively charged particles one has to distinguish $\bar{p}$ from a 20 times higher flux of e^- and from atmospheric mesons. In the case of e^+, however, one must separate the desired particles from protons, which have the same charge and a flux nearly 1000 times as great.

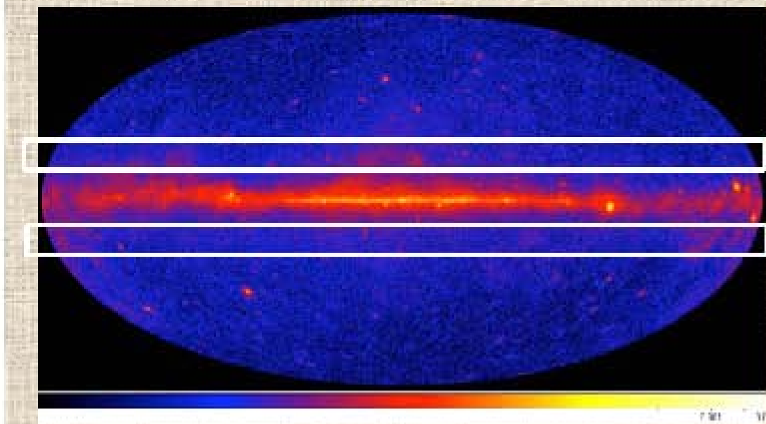
—*R. L. Golden et al., A&A* **188**, *145 (1987)*

Fermi-LAT 1-year Gamma-Ray Skymap

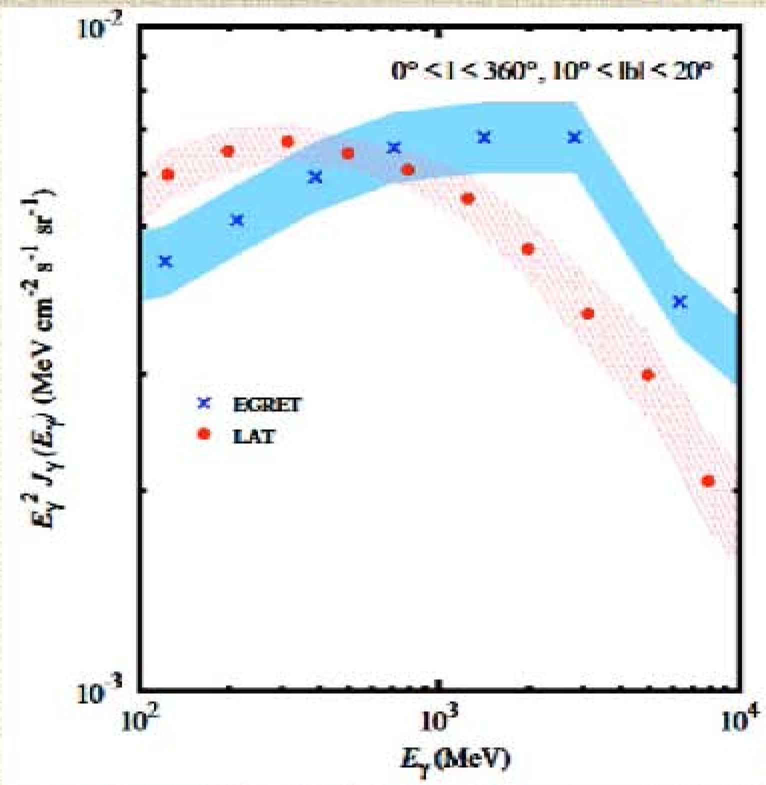


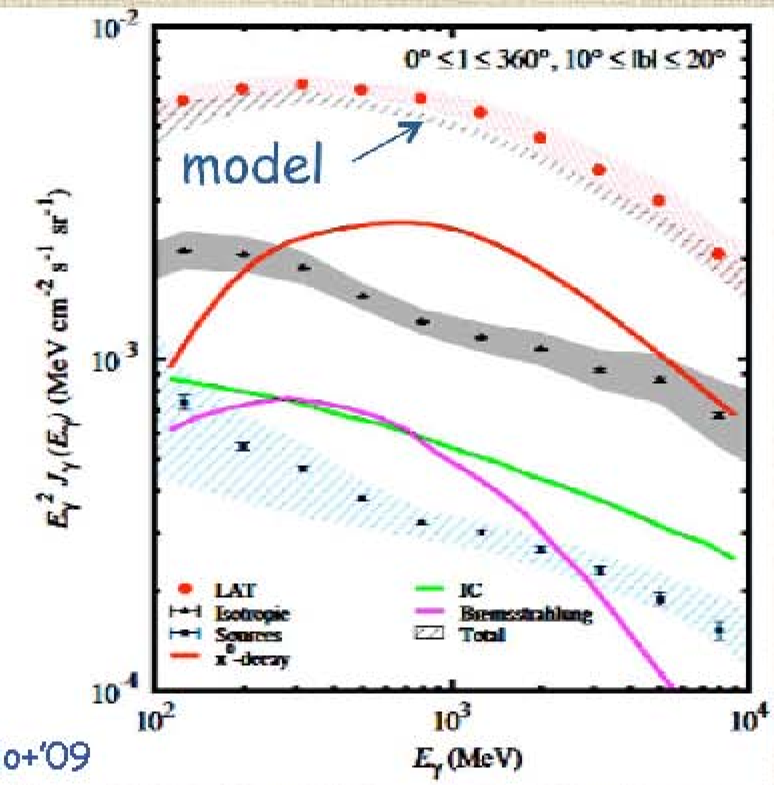
~80% of gamma-rays are produced by CR interactions with interstellar gas and radiation field! – therefore, the diffuse Galactic gamma rays trace CR proton and electron spectra throughout the Galaxy

Fermi-LAT: Diffuse Gammas



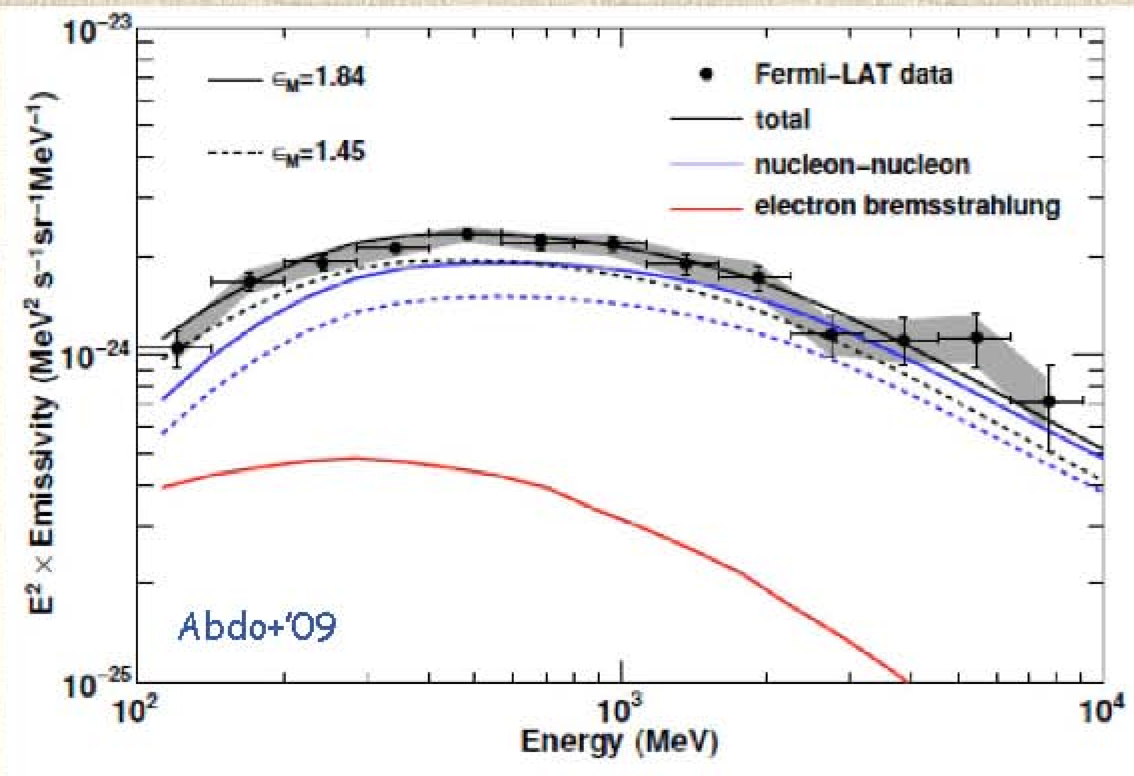
- Conventional GALPROP model is in agreement with the Fermi-LAT data at mid-latitudes (mostly local emission)
- This means that we understand the basics of cosmic ray propagation and calculate correctly interstellar gas and radiation field, at least, locally





Abdo+'09

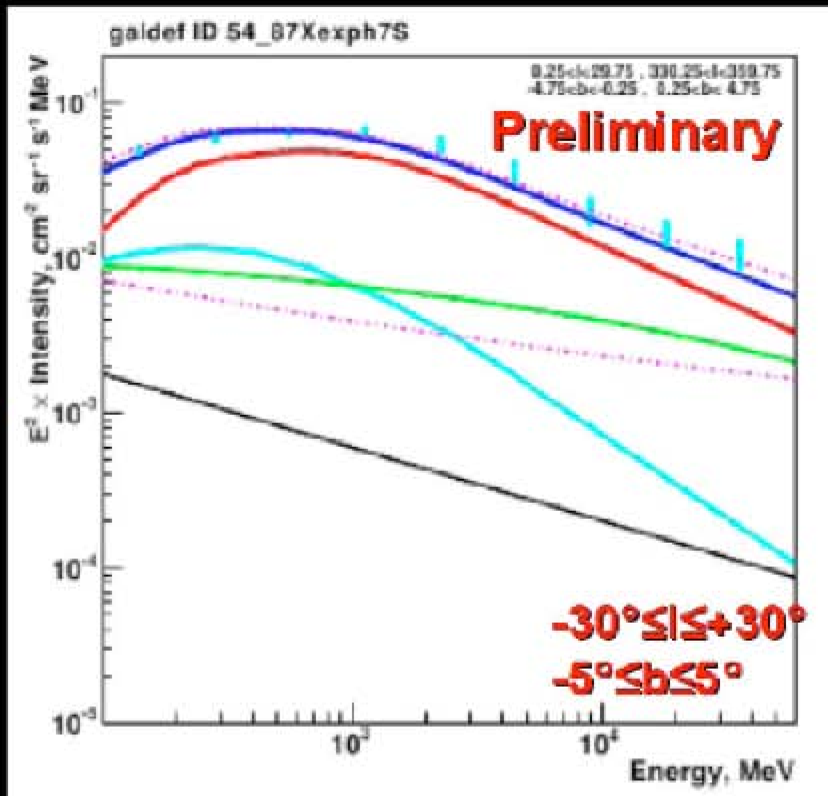
Diffuse gammas - Local Spectrum

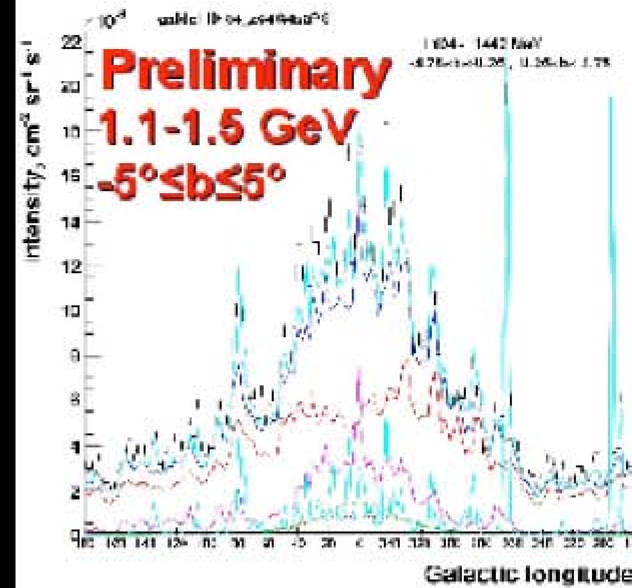


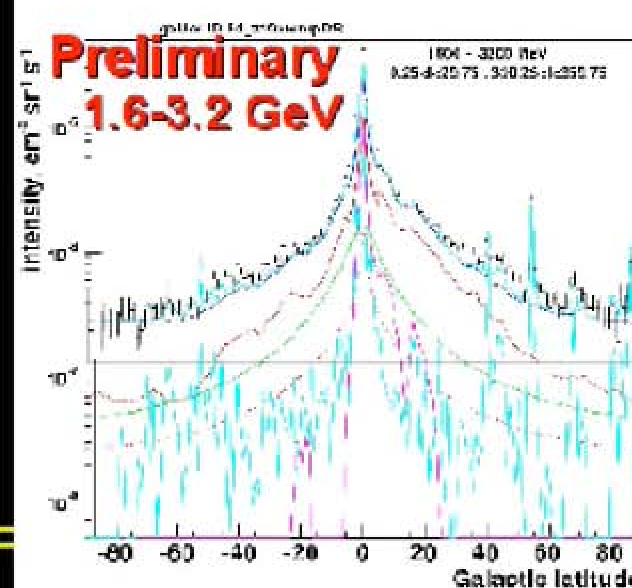
- The spectrum of the local gas, after the subtraction of the IC emission, agrees well with the model
- Confirms that the local proton spectrum is similar to that from direct measurements

Diffuse Galactic Emission: Spectrum, Longitude, and Latitude Profile

IC:
Total
OPT
IR
CMB
π^0-decay
Brem
Catalogue sources
Model total







HI
H_2
IC
Model
Model + Sources

Model describes large-scale diffuse emission over whole sky within 10%

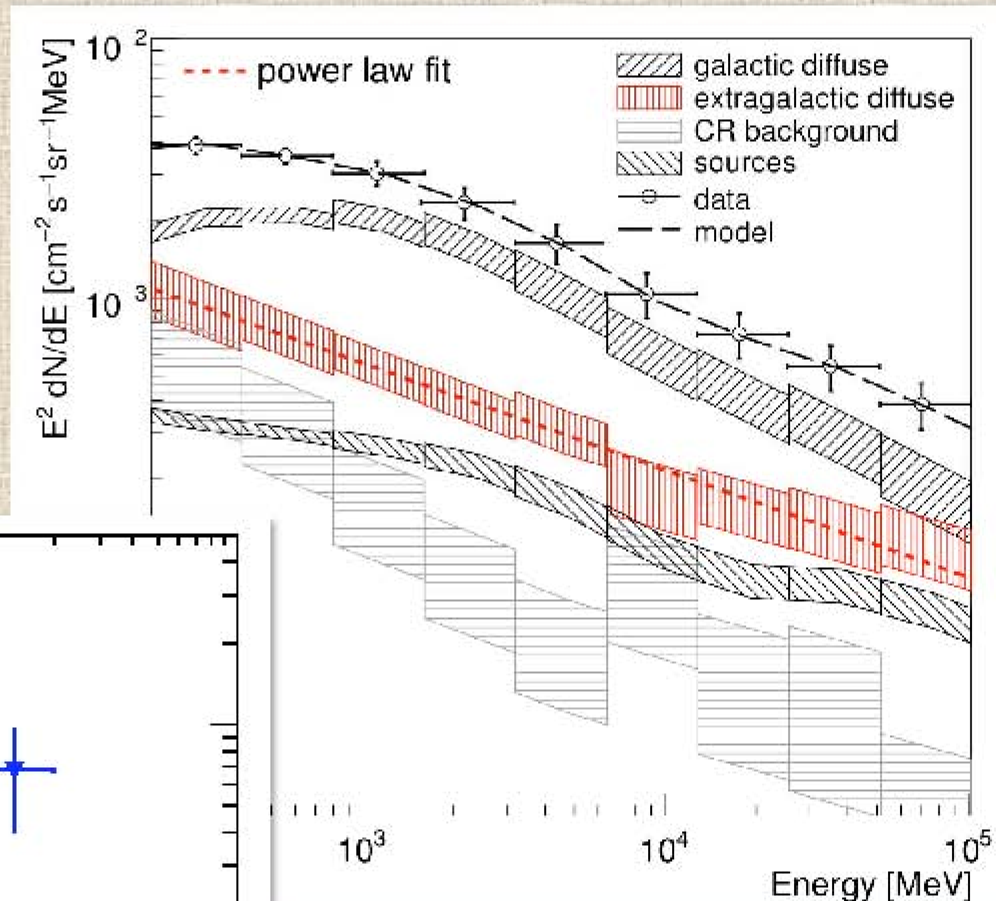
T.Porter

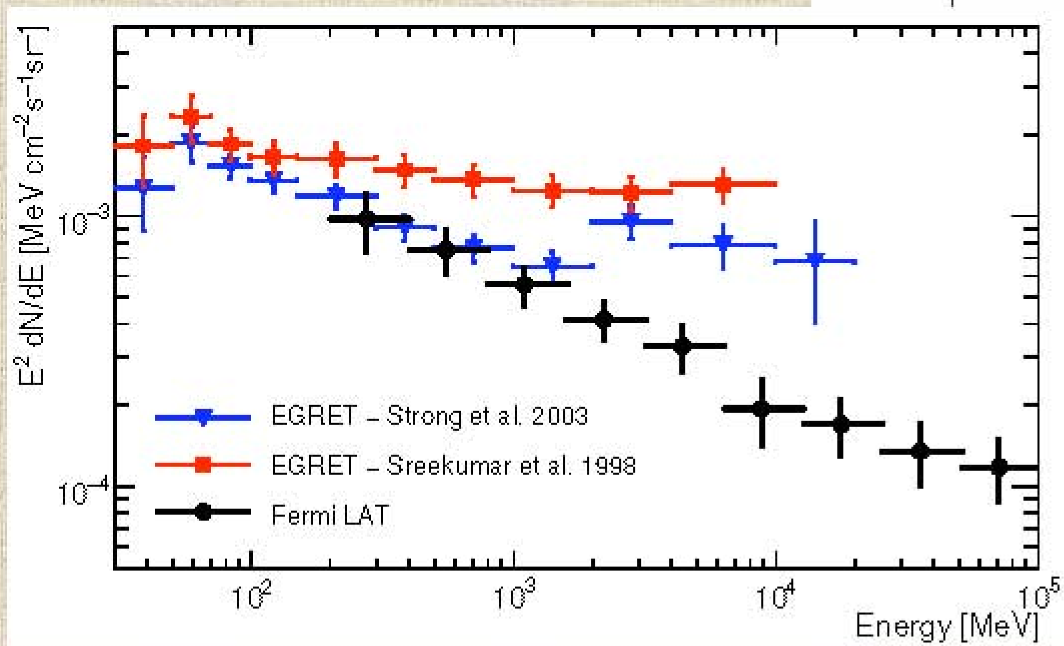
November 2nd, 2009

Fermi-LAT: Isotropic Gamma-Ray Background

The isotropic gamma-ray background seems to be featureless and agree (<1 GeV) with the one derived from the EGRET data

(submitted to PRL)



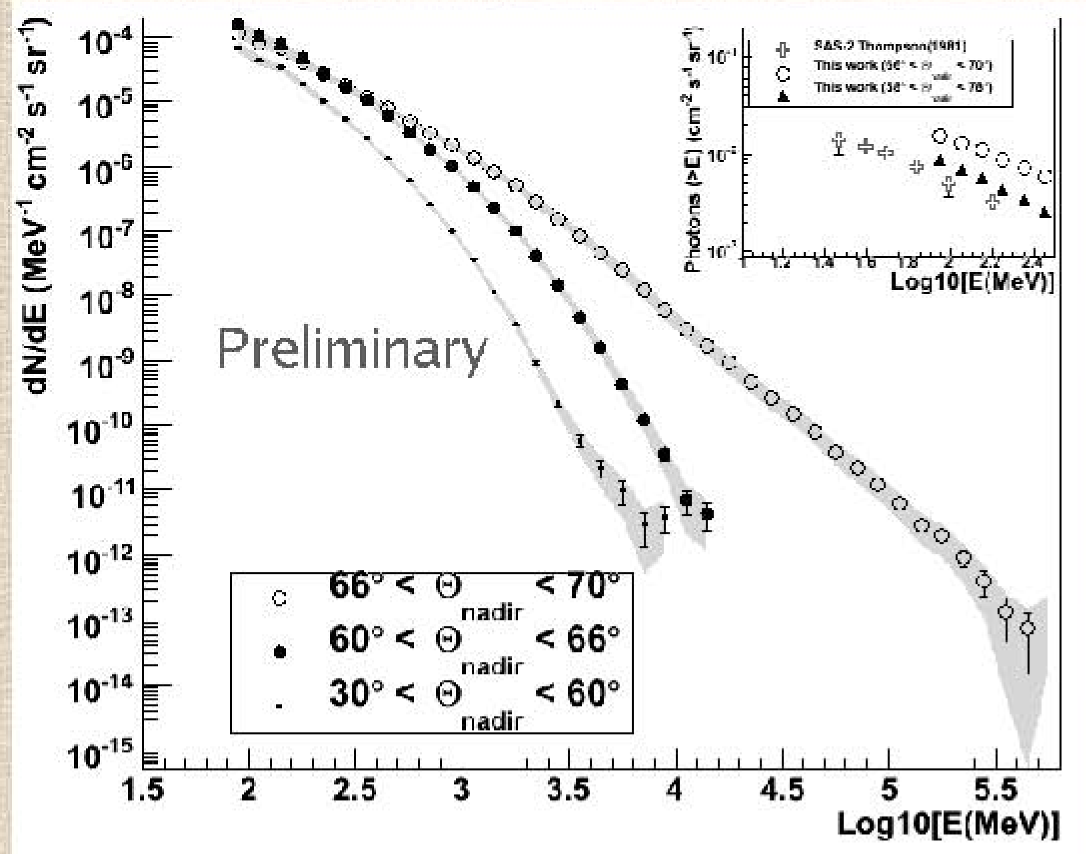


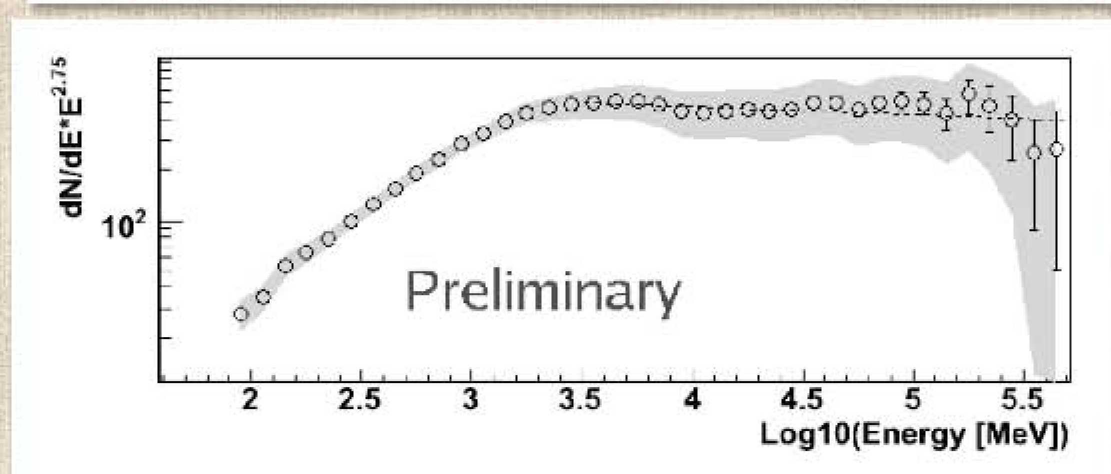
Note that the LAT PSF and the effective area are energy dependent and they are "folded" into the derived spectrum

Fermi-LAT:
The Earth's Albedo

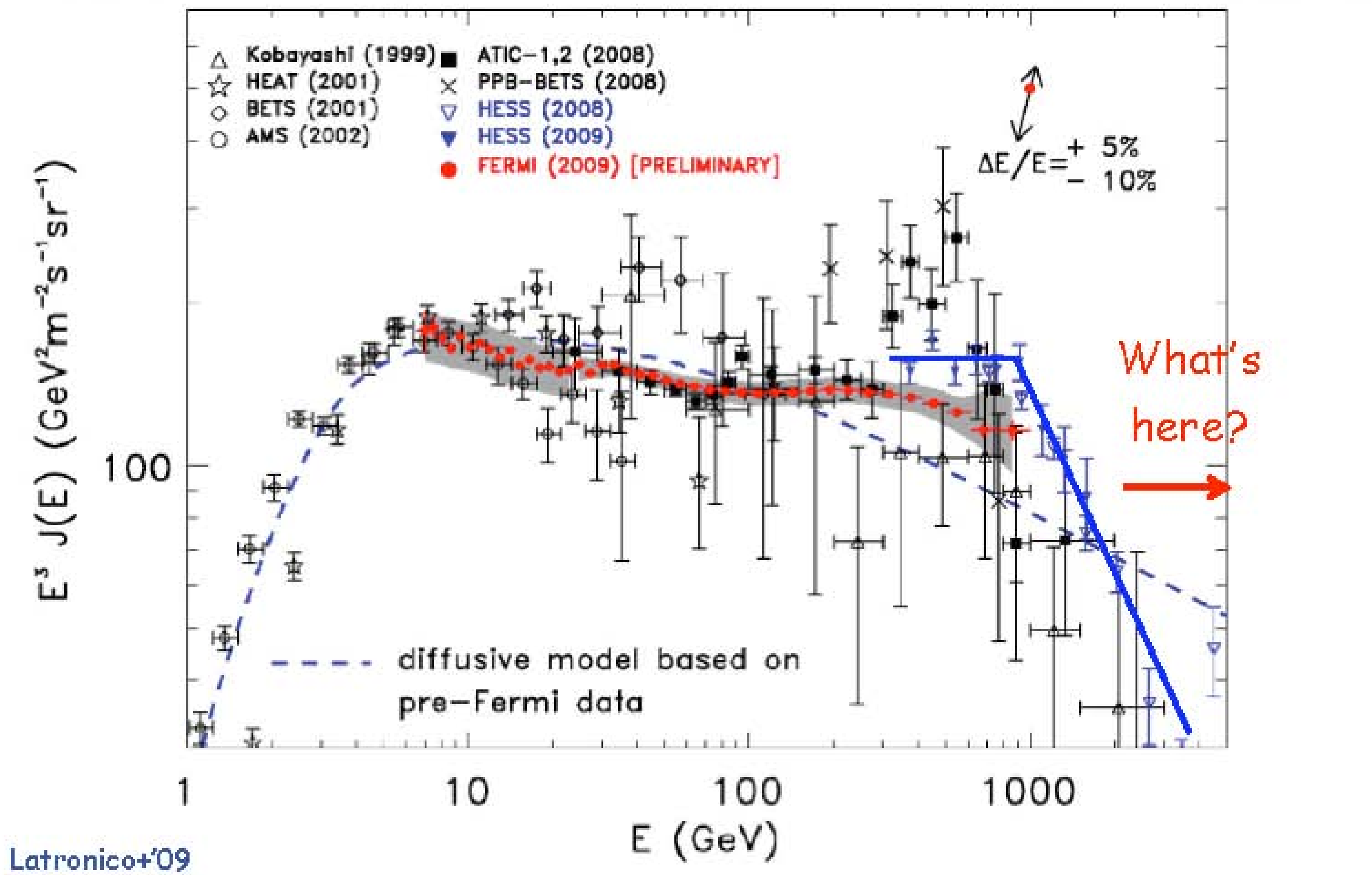
A test of on orbit calibration of the LAT can be done using the Earth limb albedo spectrum - produced by CR interactions with the Earth's atmosphere (PRD, in press).

The spectral index of the albedo is close to the spectral index of ambient CRs.





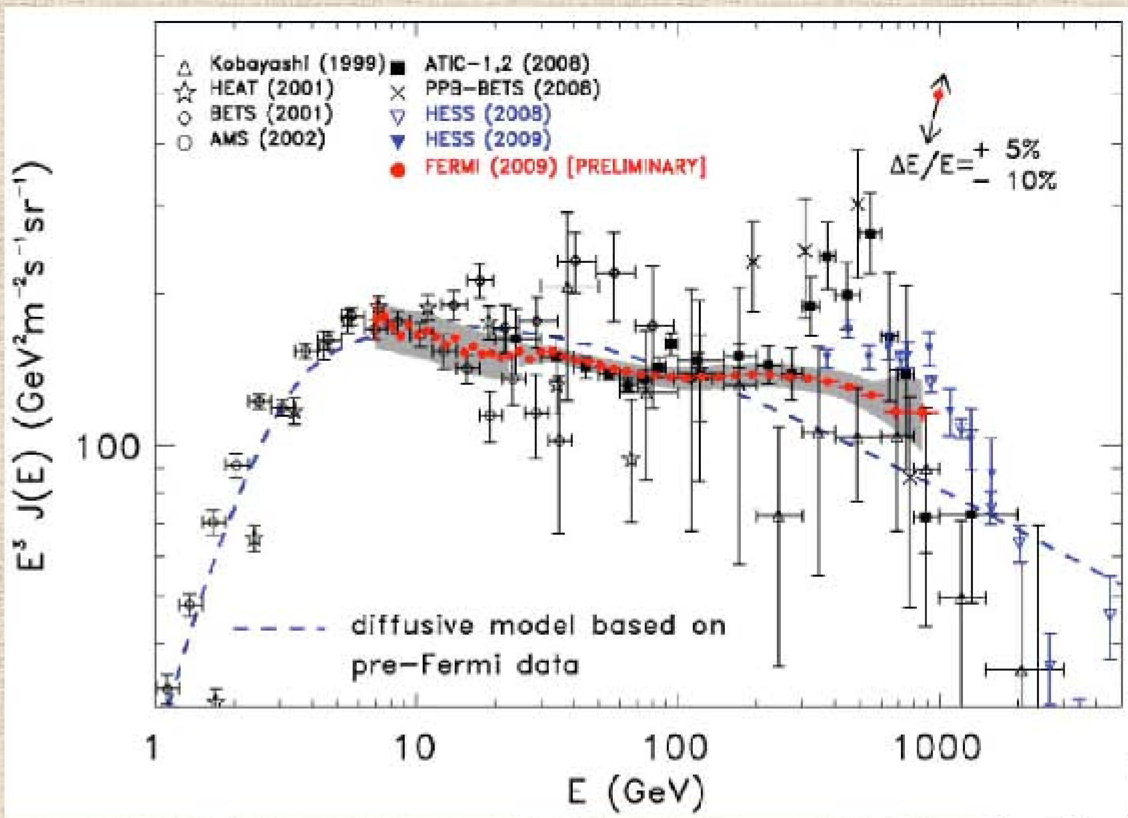
Cosmic Ray Electrons



Extended Energy Range (7 GeV – 1 TeV) – One year statistics (8M evts)

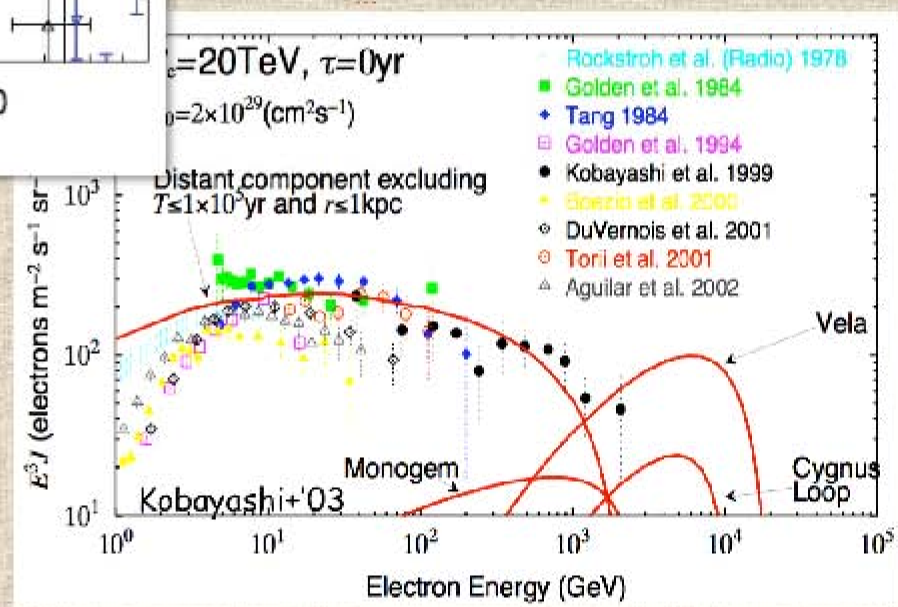
Fermi LAT measurements of CR electrons

Interpretation of CR Electron Data



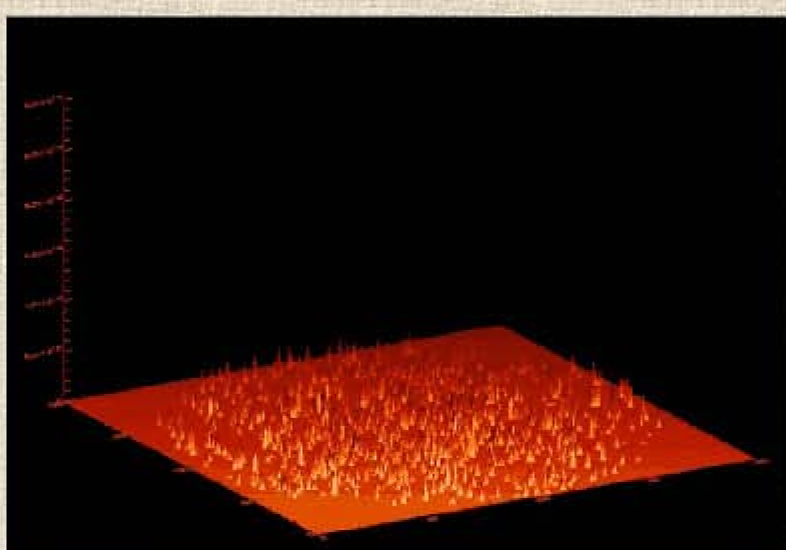
- CR electron spectrum is consistent with a single power-law with index -3.05
- Can be reproduced well by the propagation models
- Multi-component interpretation is also possible
  - Dark matter contribution
  - Astrophysical sources (SNR, pulsars)
  - …

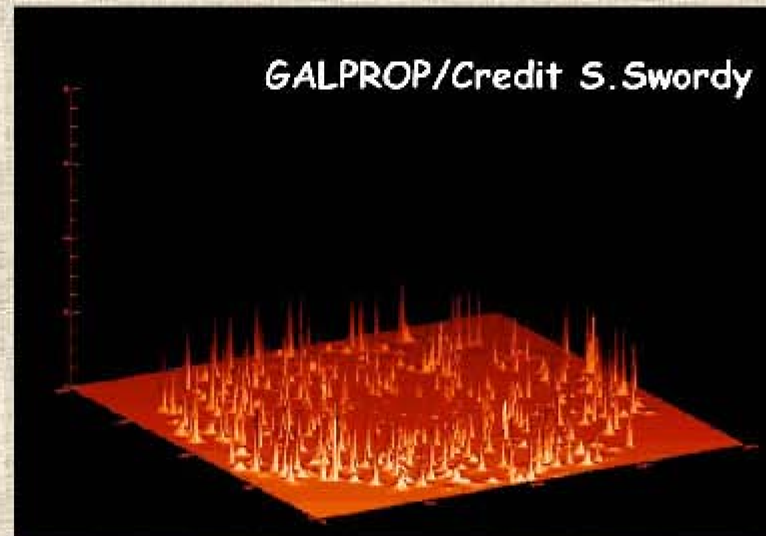
The key in understanding of the electron spectrum (local vs global) is the origin of the positron excess and the diffuse gamma-ray emission



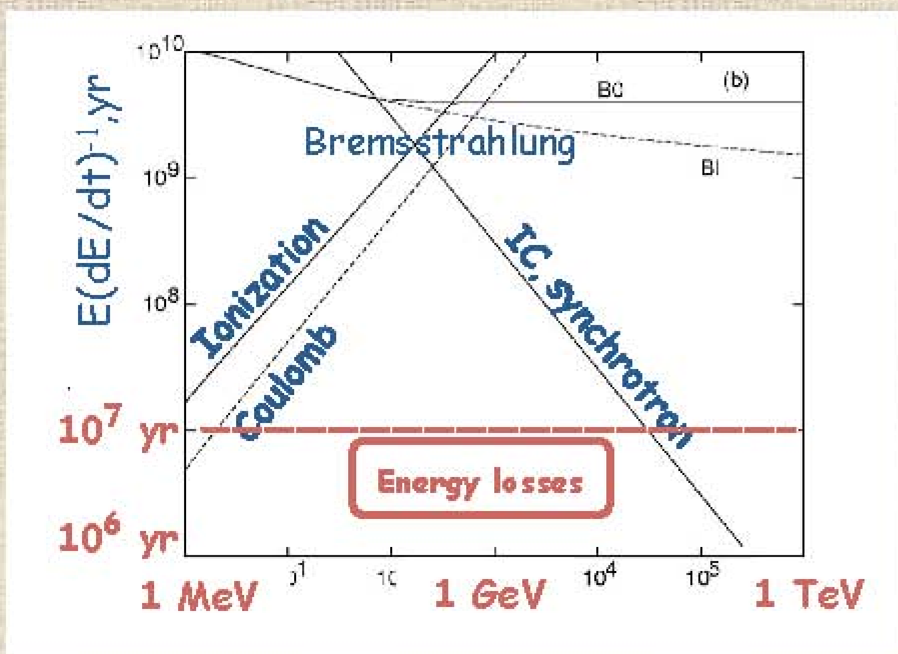
Electron Fluctuations/SNR Stochastic Events

GeV electrons





100 TeV electrons



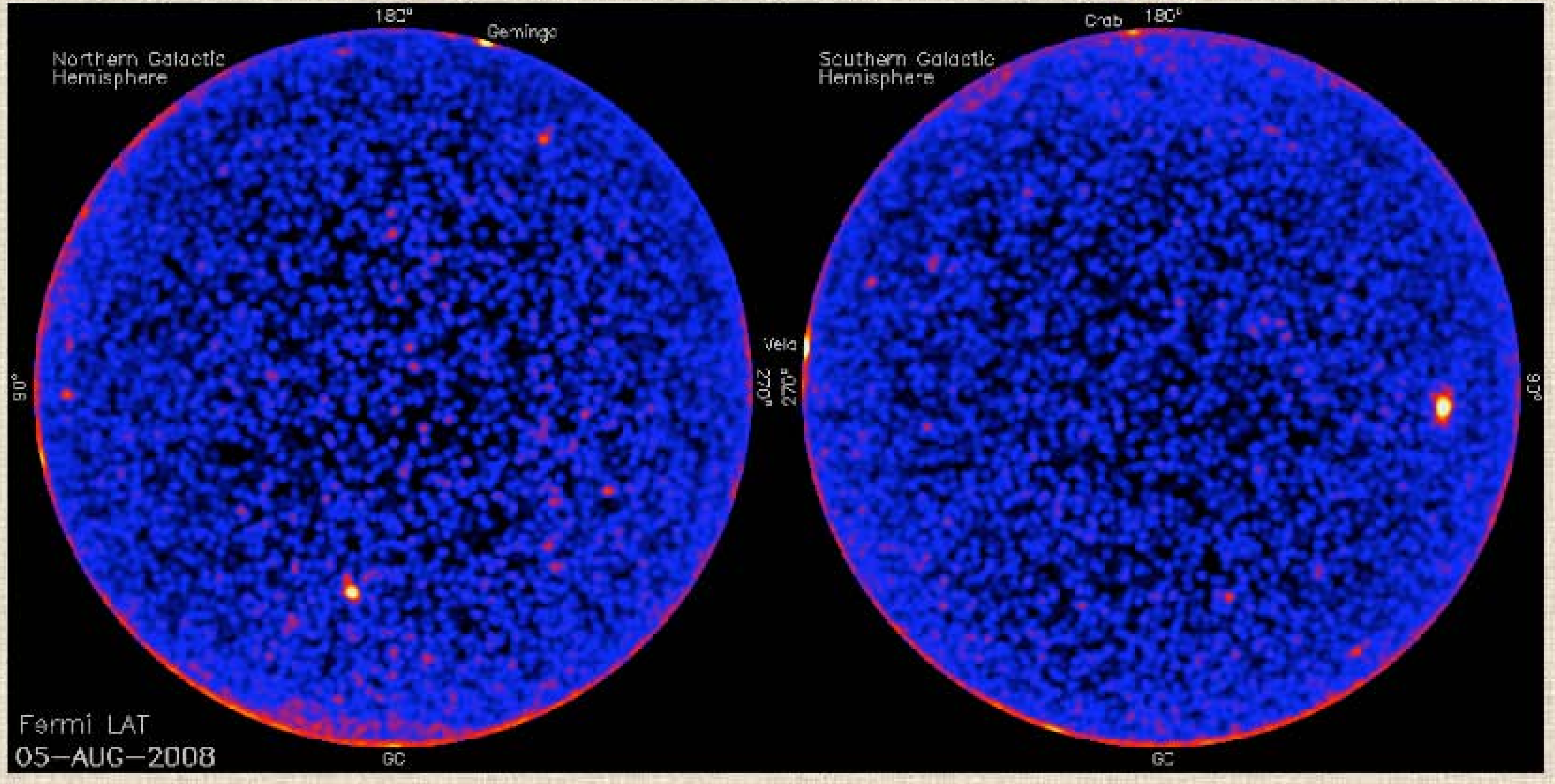
Electron energy loss timescale:

1 TeV: ~300 kyr

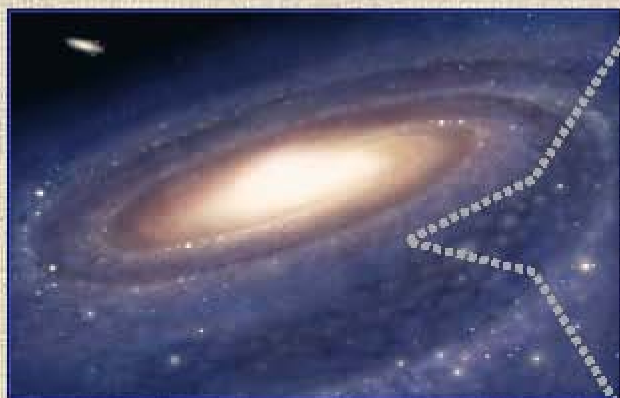
100 TeV: ~3 kyr

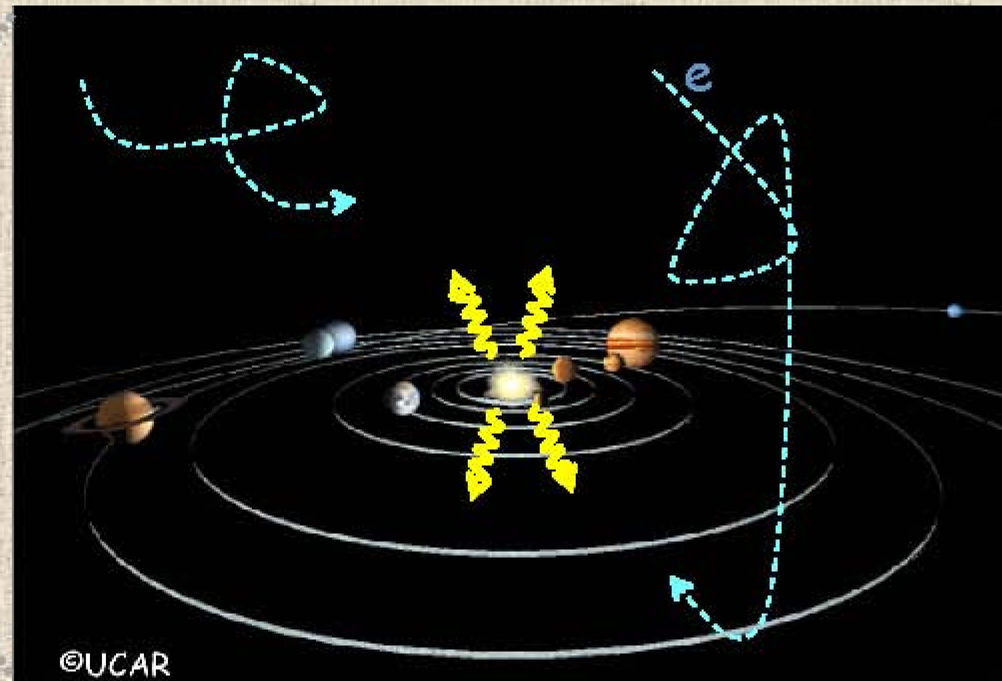
Compare with CR lifetime ~10 Myr

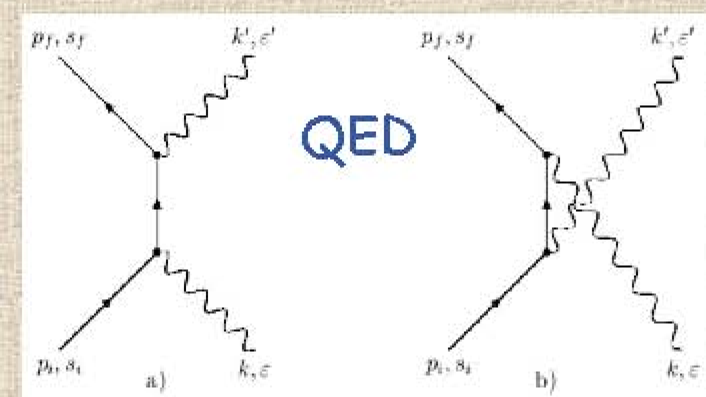
Fermi-LAT:
First Movie Ever Shot in Gamma Rays



An Alternative Way to Measure CR Electrons





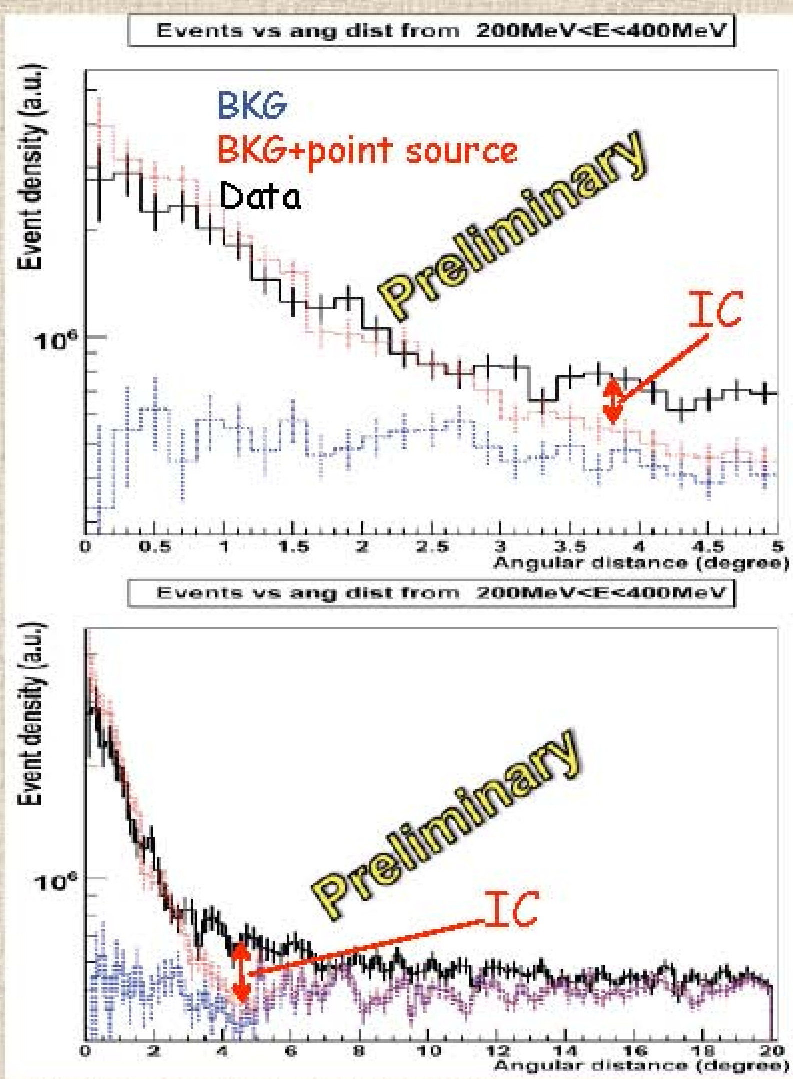


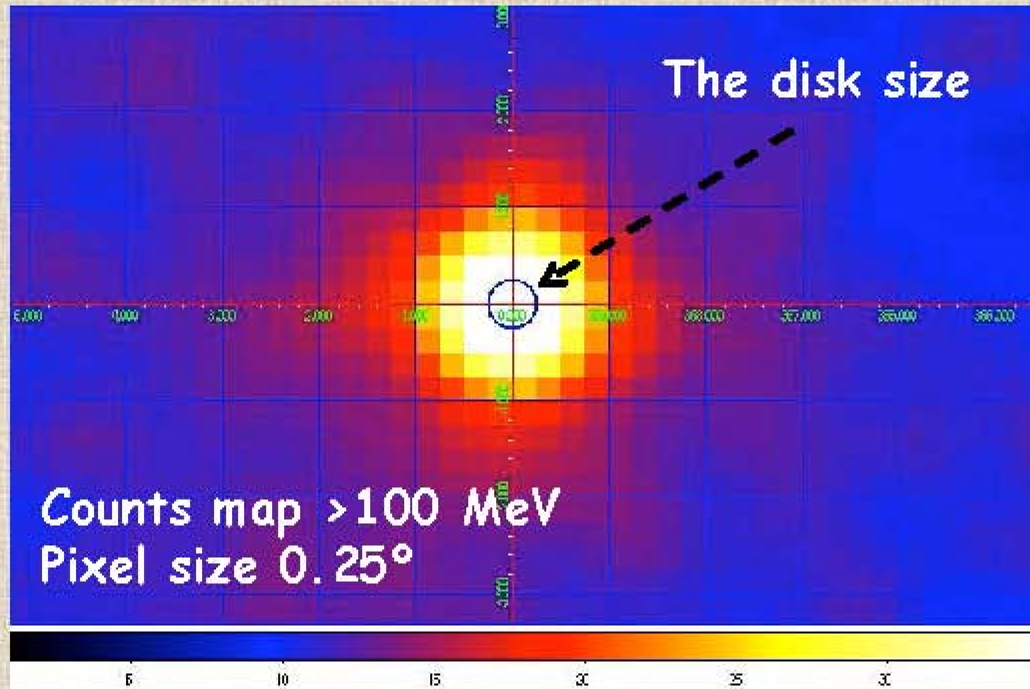
The heliosphere is filled with Galactic CR electrons and solar photons -> inverse Compton scattering

- electrons are isotropic
- photons have a radial angular distribution

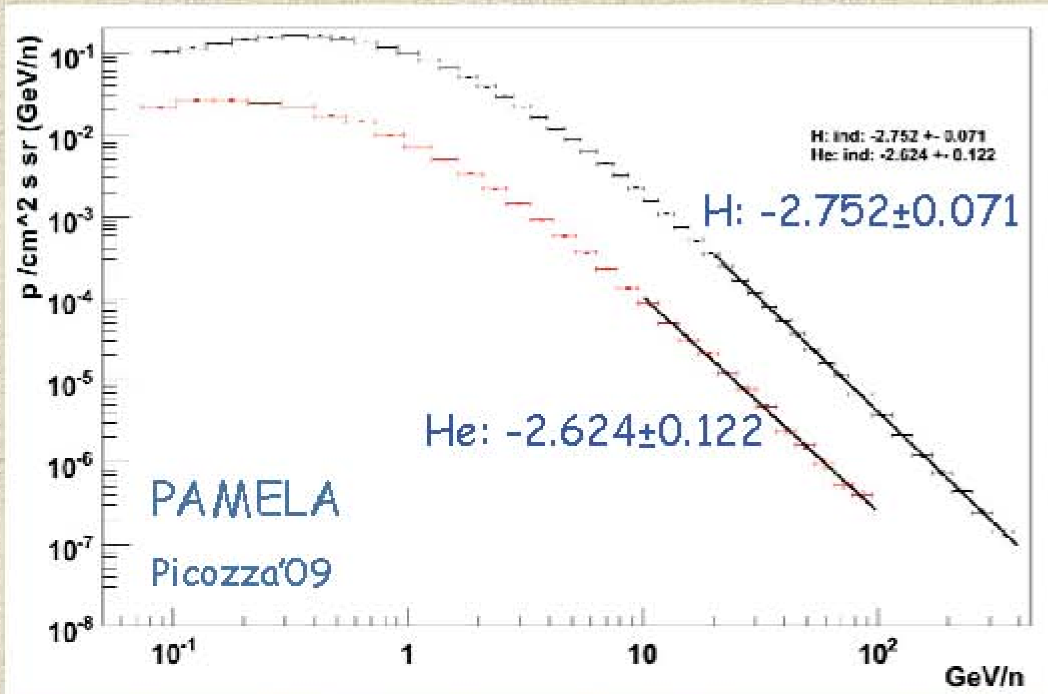
IM+'06, Orlando&Strong'07

IC Scattering on Solar Photons





- >40σ detection
- IC scattering flux $(1.1 \pm 0.3) \times 10^{-6}\ cm^{-2}\ s^{-1}$ for $\theta < 10^\circ$



CR Protons & He

- The CR proton and He spectra by Pamela agree well with previous measurements
- No surprises for production of secondary particles and diffuse gammas

protons He

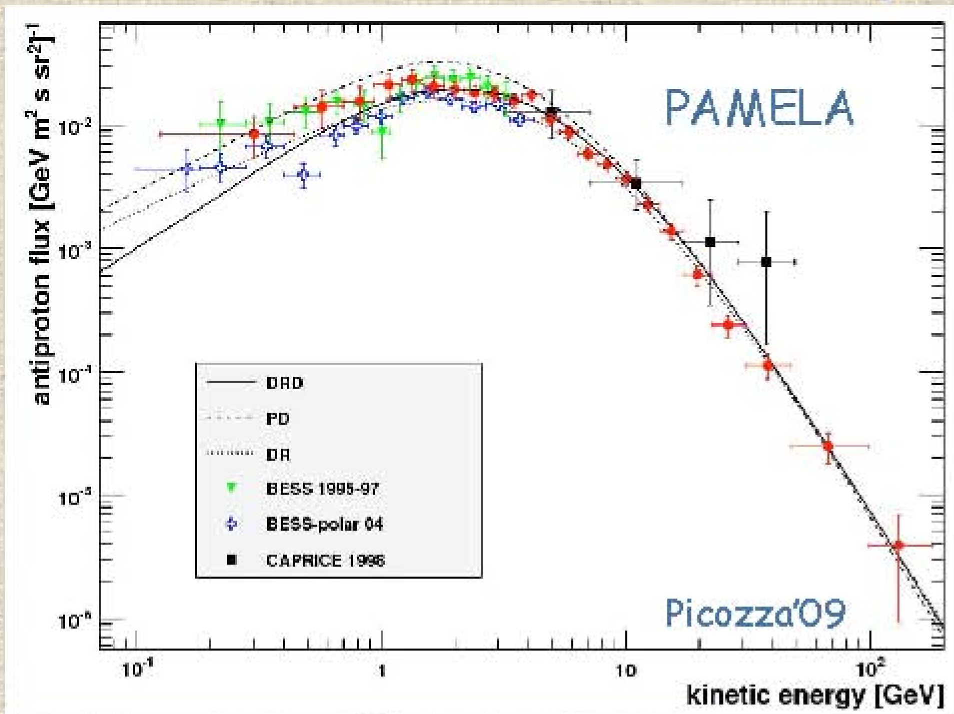
Instrument	Fitting Interval E_{kin} (GeV)	Normalization $(m^2\ s\ sr\ GeV)^{-1}$	Power-Law Index	Fitting Interval E_{kin} $(GeV\ nucleon^{-1})$	Normalization $(m^2\ s\ sr\ GeV\ nucleon^{-1})^{-1}$	Power-Law Index
LEAP....................	20–100	...	2.69 ± 0.04	10–100	...	2.69 ± 0.09
MASS2	20–100	$(1.93 \pm 0.15) \times 10^4$	2.82 ± 0.03	10–50	686 ± 130	2.79 ± 0.07
IMAX	20–200	$(1.08 \pm 0.15) \times 10^4$	2.66 ± 0.04	10–125	600 ± 120	2.70 ± 0.07
CAPRICE..............	20–200	$(1.55 \pm 0.19) \times 10^4$	2.80 ± 0.03	10–100	590 ± 124	2.73 ± 0.07
AMS	20–200	$(1.82 \pm 0.21) \times 10^4$	2.79 ± 0.03	10–100	653 ± 56	2.72 ± 0.03
BESS	20–120	$(1.61 \pm 0.13) \times 10^4$	2.75 ± 0.03	10–50	640 ± 139	2.67 ± 0.07
Weighted average...		$(1.58 \pm 0.08) \times 10^4$	2.76 ± 0.01		641 ± 53	2.72 ± 0.01

[a] Assuming power law in kinetic energy LIS spectrum.

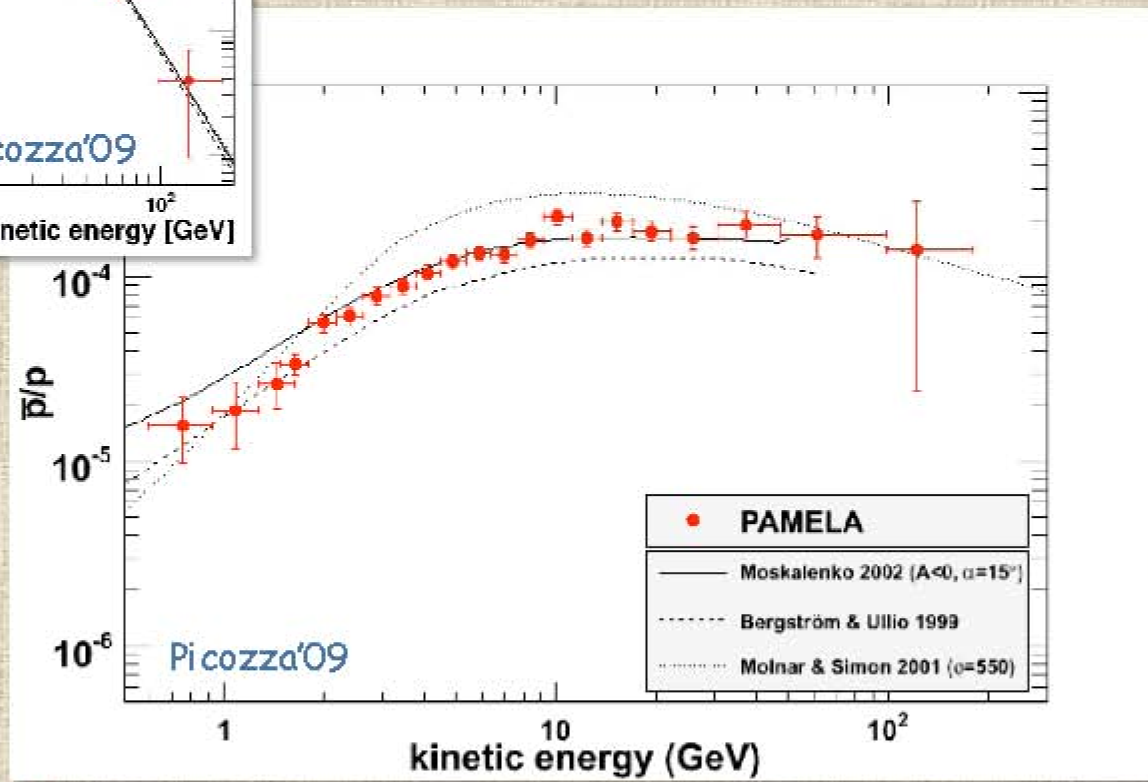
References.—(1) Seo et al. 1991. (2) Belotti et al. 1999. (3) Menn et al. 2000. (4) Boezio et al. 1999. (5) Alcaraz et al. 2000a. (6) Sanuki et al. 2000.

IM+'02

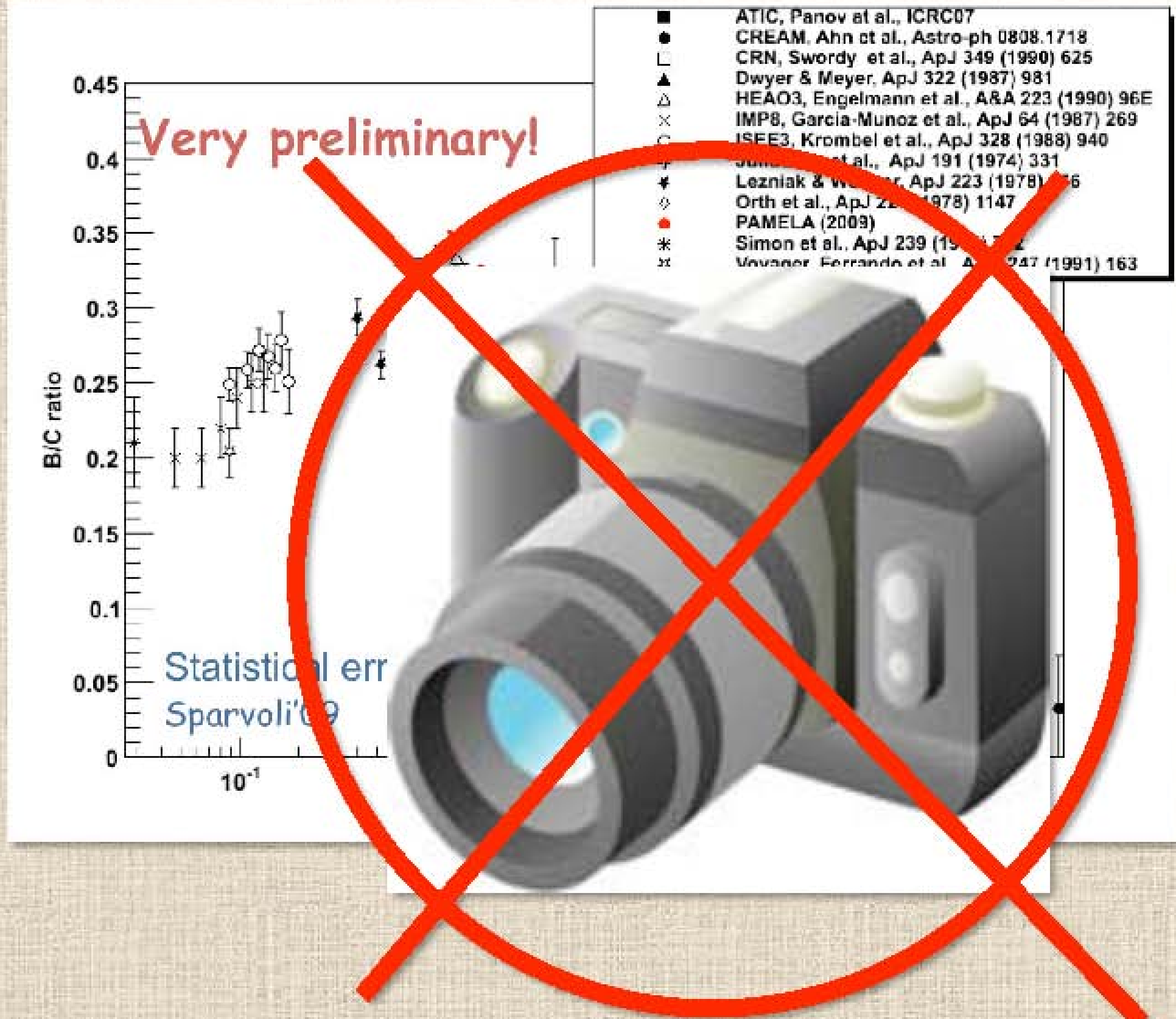
Antiprotons



- Antiprotons in CRs (BESS, Pamela) <100 GeV are in agreement with secondary production



B/C ratio



- The B/C ratio <30 GeV/nucleon is measured by Pamela (no surprises)

One Good Experiment is Worth Thousand Theories…

- ATIC electrons: 270+ citations (in ~1 yr)
- PPB-BETS electrons: 150+ citations (in ~1 yr)
- Fermi LAT electrons: 170+ citations (in <1 yr)
- HESS electrons: 100+ citations (in <1 yr)
- PAMELA positron fraction: 370+ citations (in ~1 yr)
- PAMELA antiprotons: 150+ citations (in <1 yr)
- BESS program (only journal papers): 1000+ citations

Of course, most of citations are coming from particle physics

★ using NASA ADS

A Summary to This Part

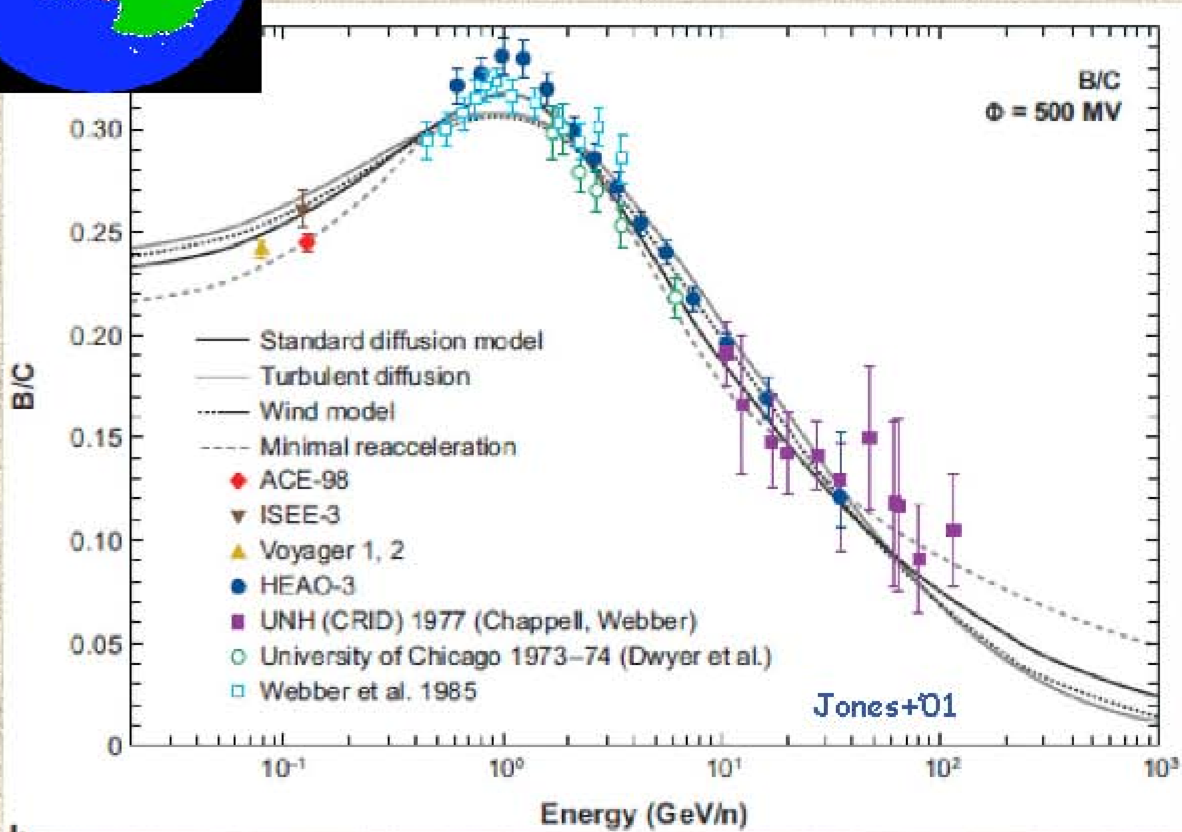
- No much new on CR nuclei species
- The spectrum of CR electrons and the positron fraction are two surprises
- Q: Could new measurements of CR electron spectrum and positron fraction affect our current understanding of CRs?
- A: Yes and No
  - They indicate how little we know about our local Galaxy
  - Diffuse emission agrees well with the predictions based on the conventional model (<10 GeV) – means that the CR propagation (based on CR nuclei species) is understood correctly
  - The key is to study the diffuse emission at high energies where the IC component becomes comparable to the gas component

Near Future: >2010

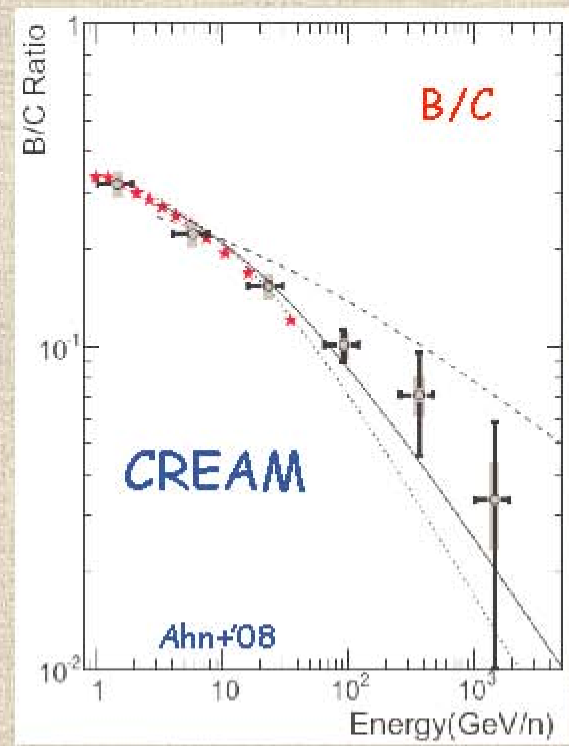
Successfully launched on Dec. 1, 2009 – Ultra Long Duration Balloon

CREAM-V

http://cosmicray.umd.edu/cream/



- Different propagation models are tuned to fit the low energy part of sec./prim. ratio where the accurate data exist

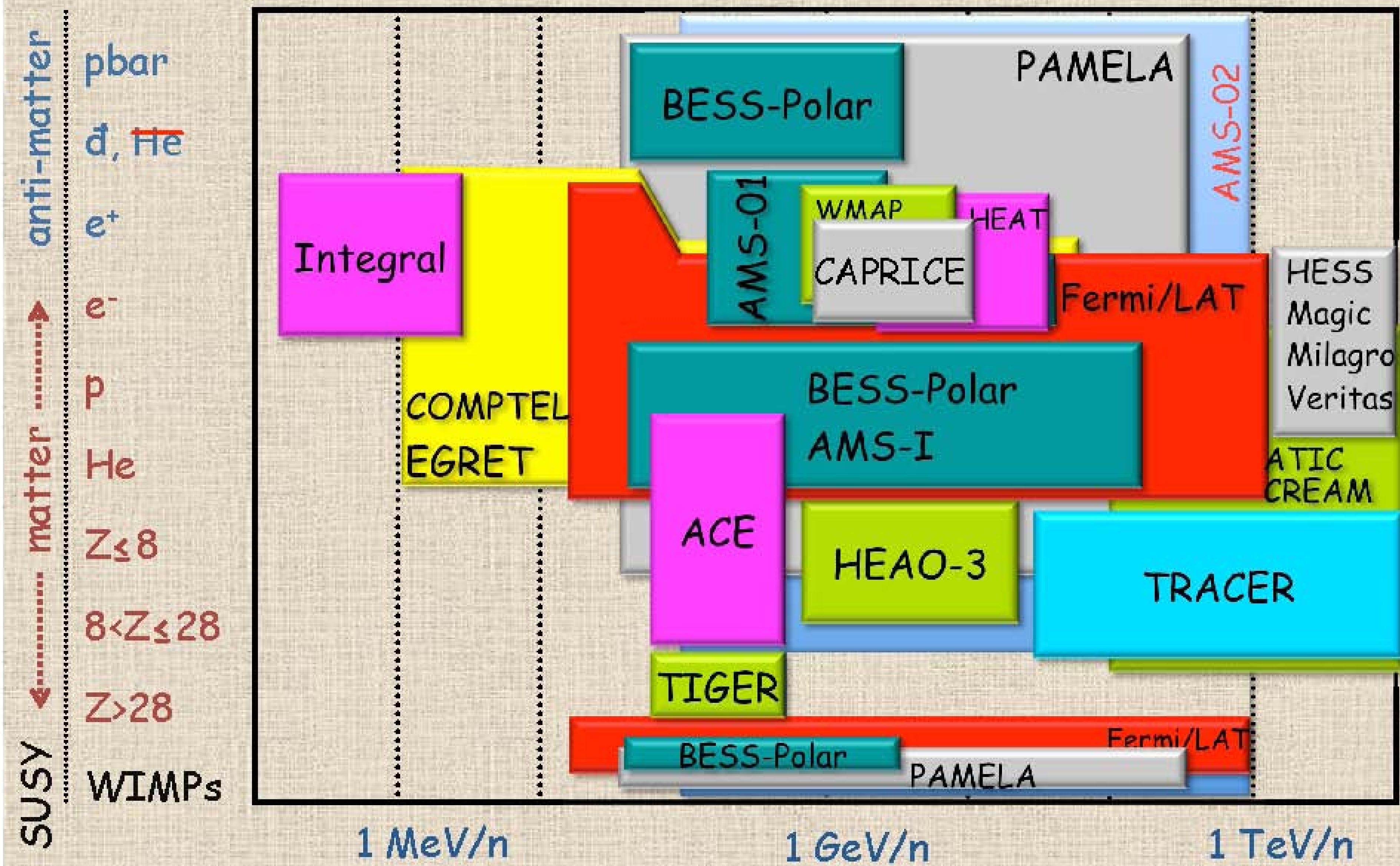


- However, they differ at high energies which will allow to discriminate between them when more accurate data are available (hopefully after CREAM V flight)

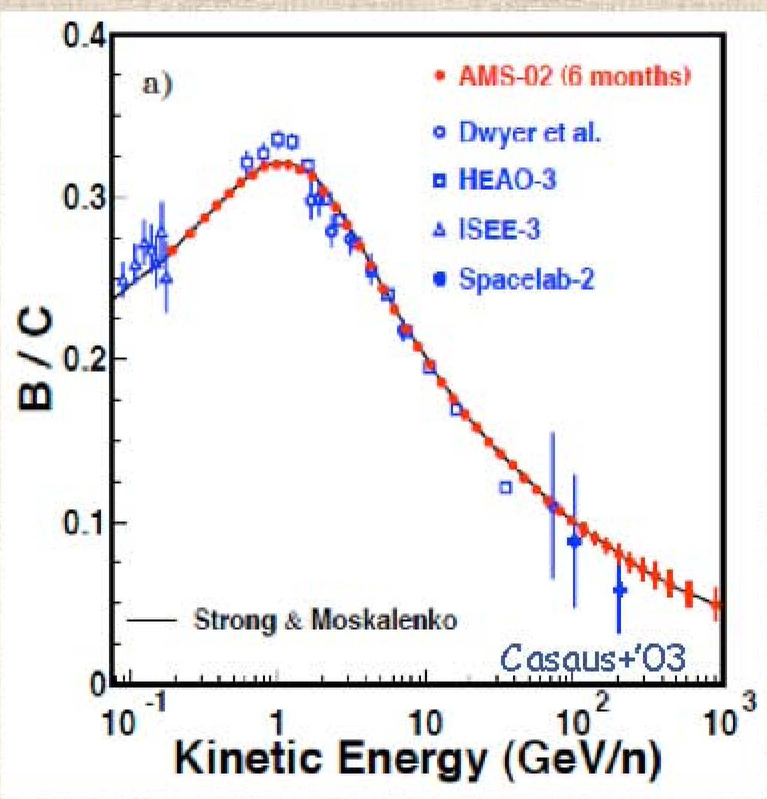
AMS-02

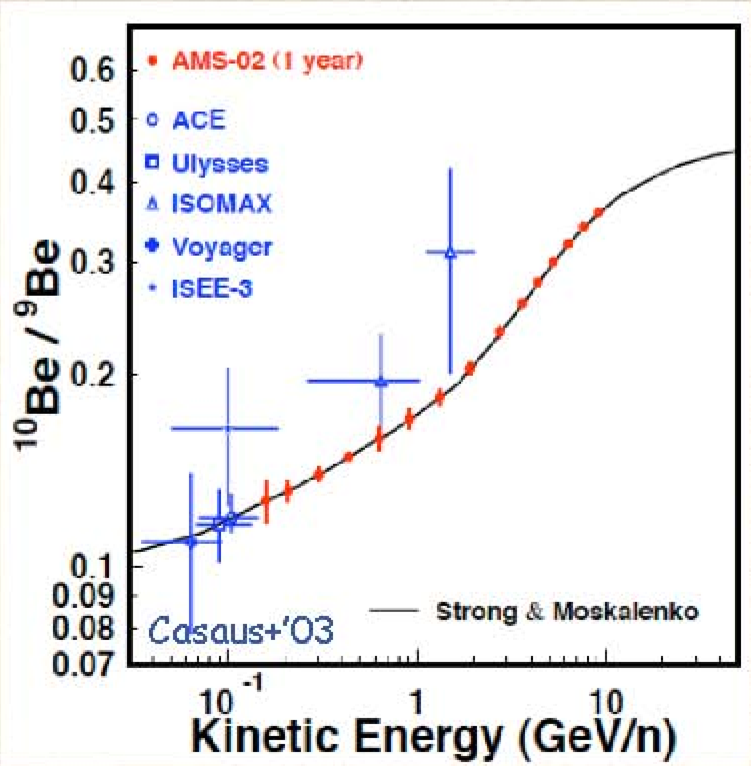
- AMS is on track for a flight on July 29, 2010
- Will be able to provide us with excellent quality CR data in the range from some 100 MeV – 1 TeV

A Constellation of CR and gamma-ray (also CR!) instruments



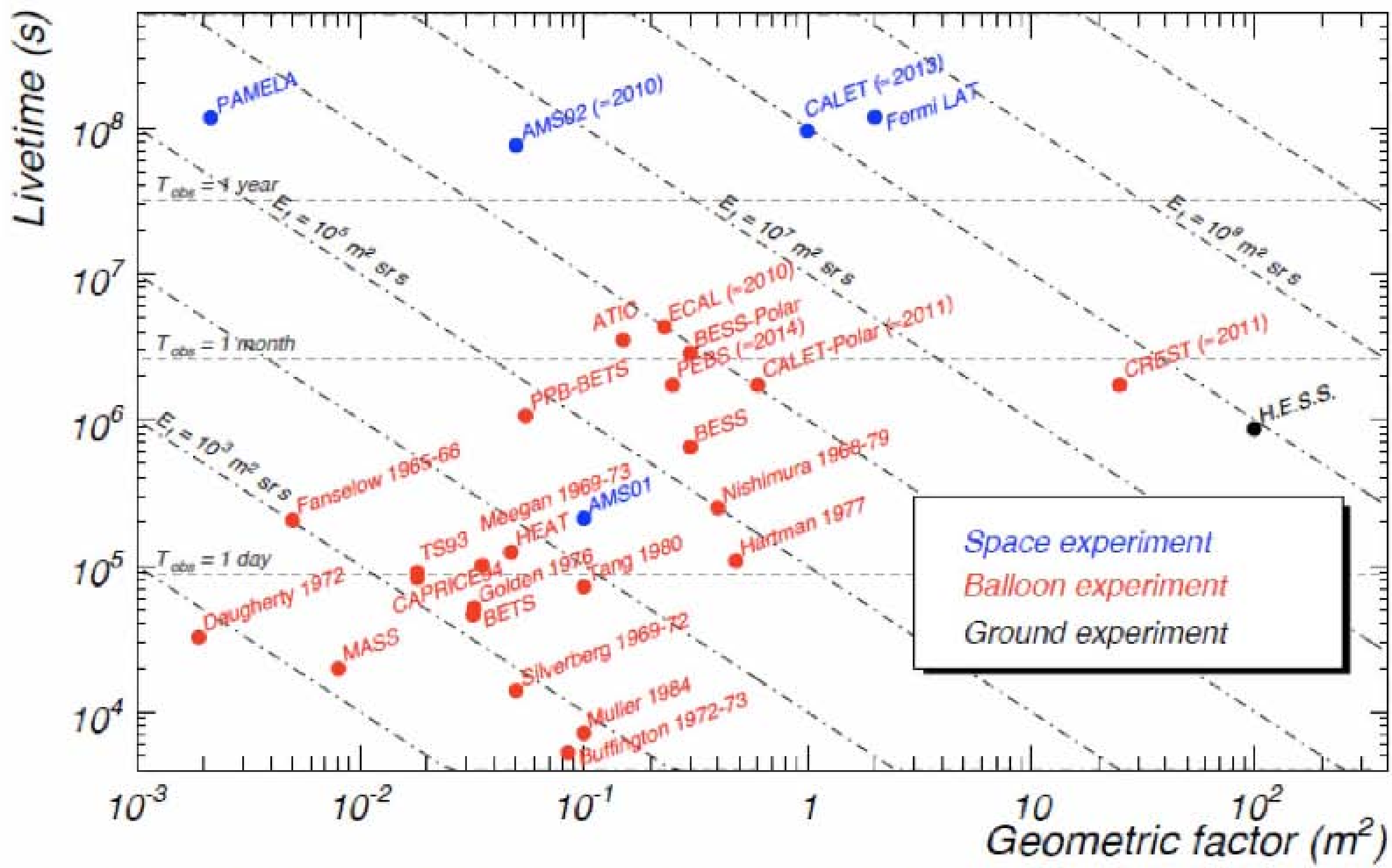
Simulations of AMS-02 Data





- The large statistics and accuracy of AMS-02 data will allow one to study CR propagation with unprecedented detail

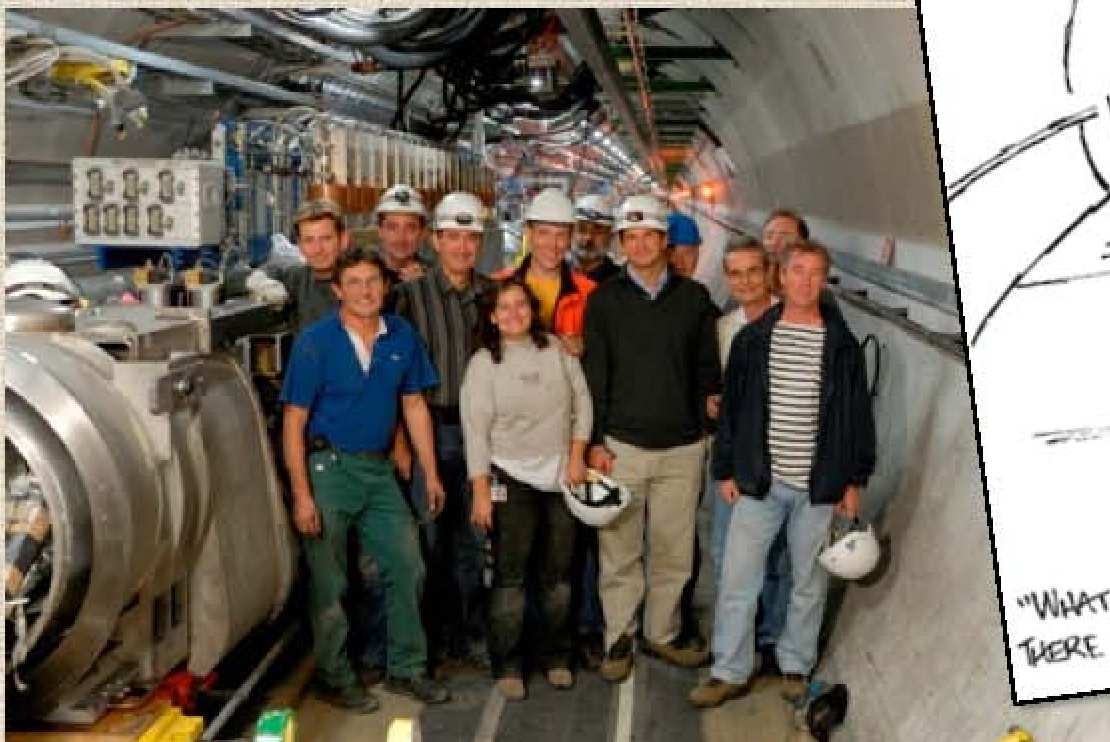
Exposure of Different Experiments

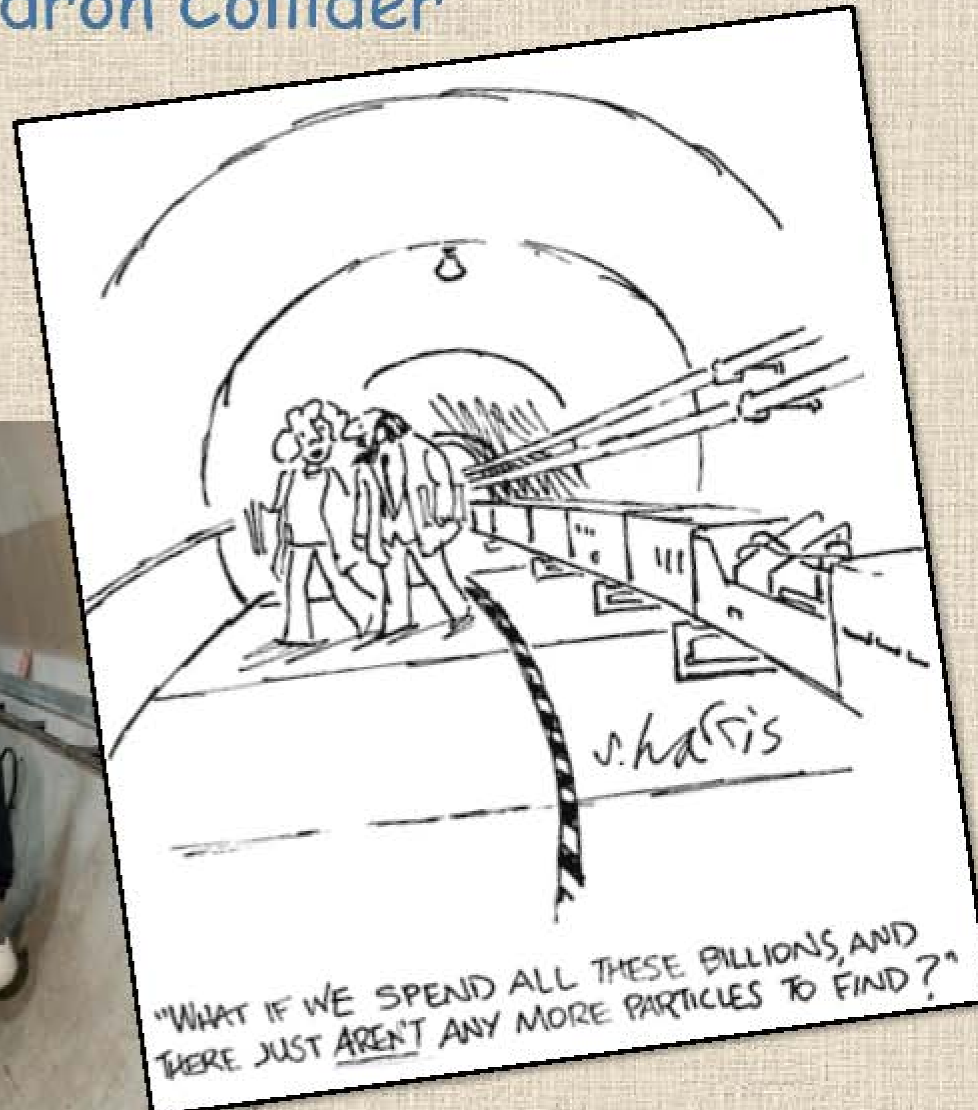


- The exposure factor determines the statistics.
- Imaging calorimeters (vs. spectrometers) feature larger G_f.
- Space (vs. balloon) experiments feature longer livetime.

Large Hadron Collider

Nov 30: 1.18 TeV beams!





Fermi LAT

- Better measurement of the CR electron spectrum, possibly up to higher energies
- Better statistics will allow us to better constrain CR propagation and the diffuse emission model
- Especially important the diffuse emission at HE – possible DM signatures and key to understanding leptons in CRs

Morphology of the Diffuse Emission @ 150 GeV

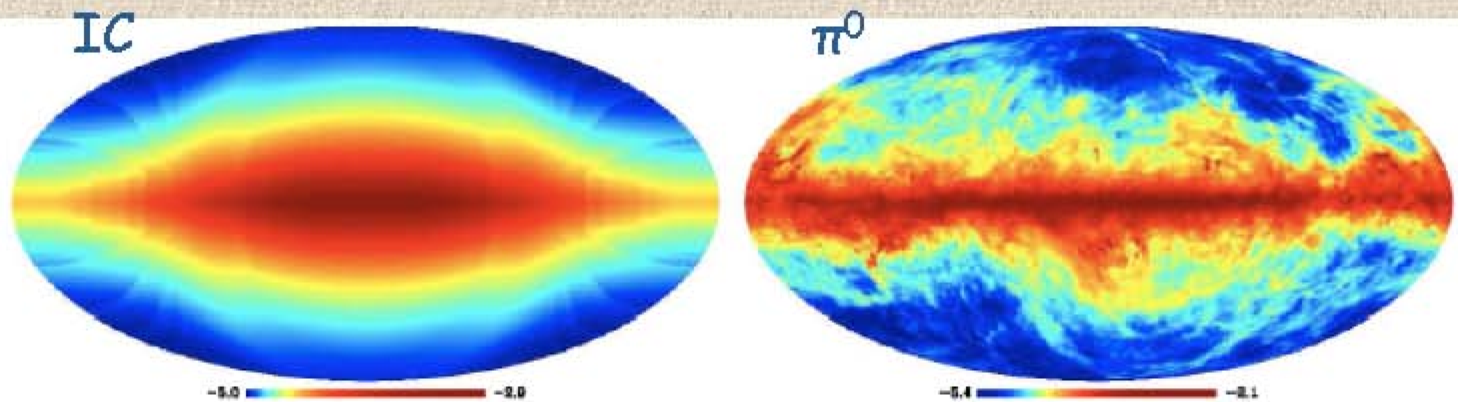
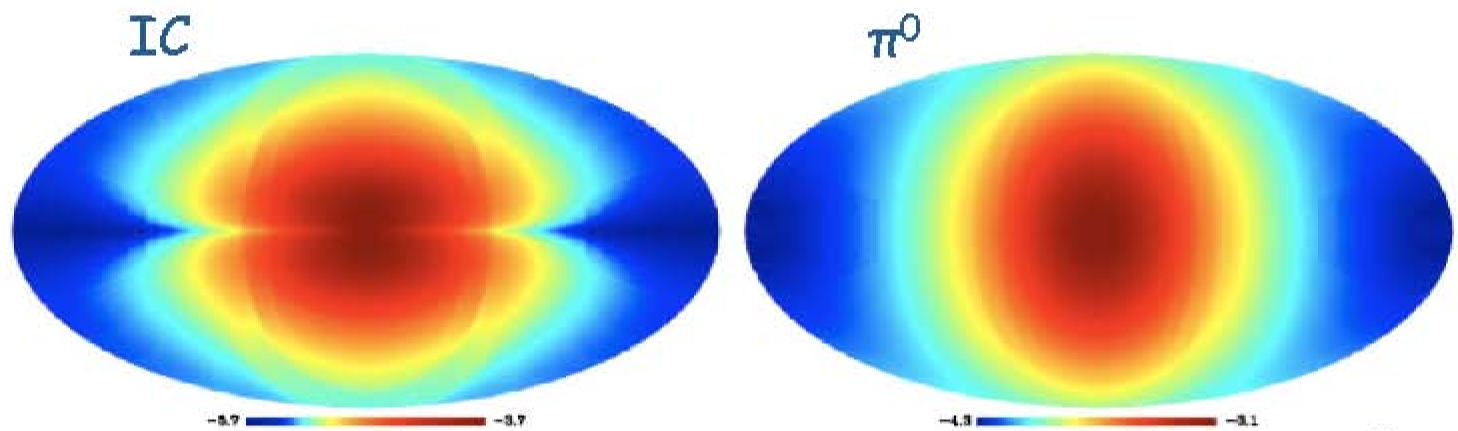


FIG. 9: Sky-map at 150 GeV of the emissions associated to Galactic primary+secondary CRs in the "conventional" model B0. The intensity is shown in logarithmic scale and units [MeV cm^{-2} s^{-1} sr^{-1}]. *Left Panel*: Inverse Compton radiation. *Right Panel*: π^0-decay emission.



Regis&Ullio'09

FIG. 10: Sky-map at 150 GeV of the emissions induced by WIMP annihilations in the propagation model B0. The intensity is shown in logarithmic scale and units [MeV cm^{-2} s^{-1} sr^{-1}]. *Left Panel*: Inverse Compton radiation in the DMe scenario. *Right Panel*: π^0-decay emission in the DMτ scenario.

Milagro: TeV Observations of Fermi Sources

Many γ-ray sources show extended structures at HE - thus they are also the sources of accelerated particles (CRs)

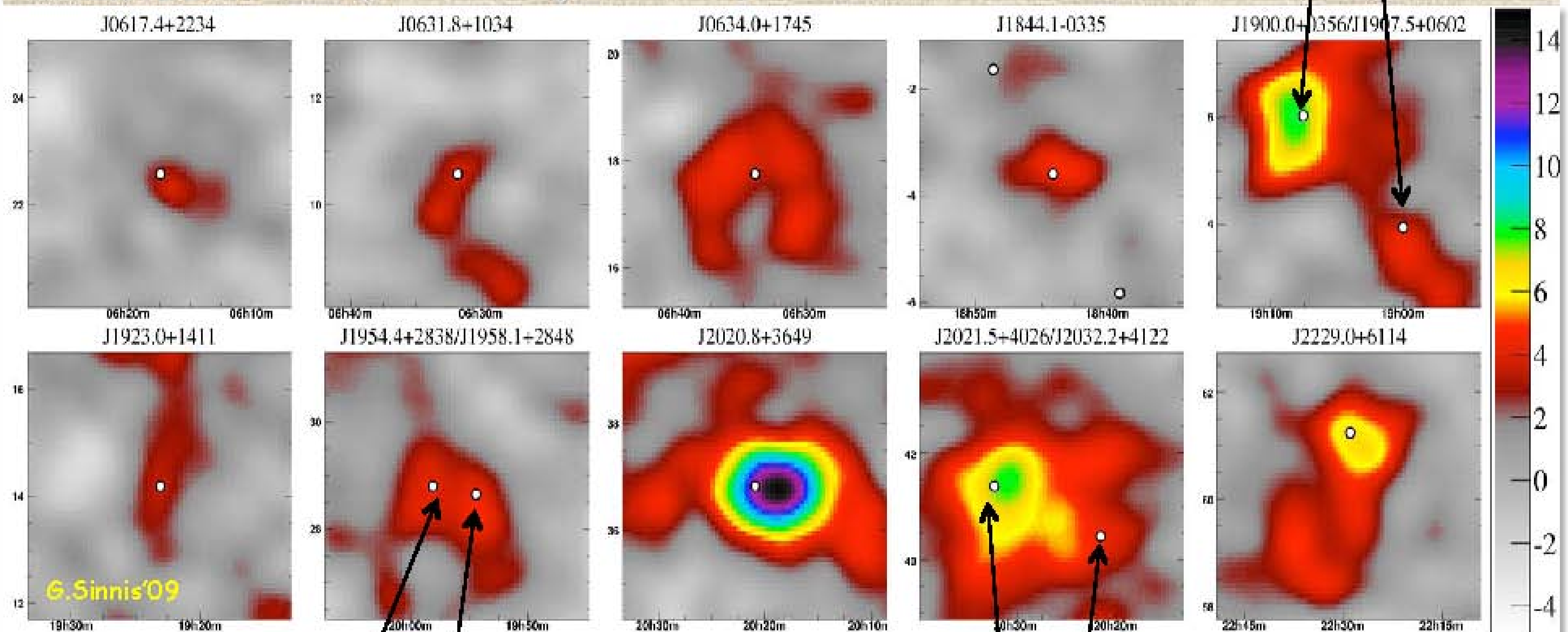
SNR IC433
MAGIC, VERITAS

Radio pulsar
(new TeV source)

Geminga pulsar
Milagro C3

unID
(new TeV source)

unID
(new TeV source)
Fermi Pulsar
MGRO 1908+06
HESS 1908+063



SNR W51
HESS J1923+141

G65.1+0.6 (SNR)
Fermi Pulsar (J1958)
New TeV sources

Pulsar (AGILE /Fermi)
MGRO 2019+37

Fermi Pulsar
SNR γ Cygni
Fermi Pulsar
HESS, Milagro, Magic

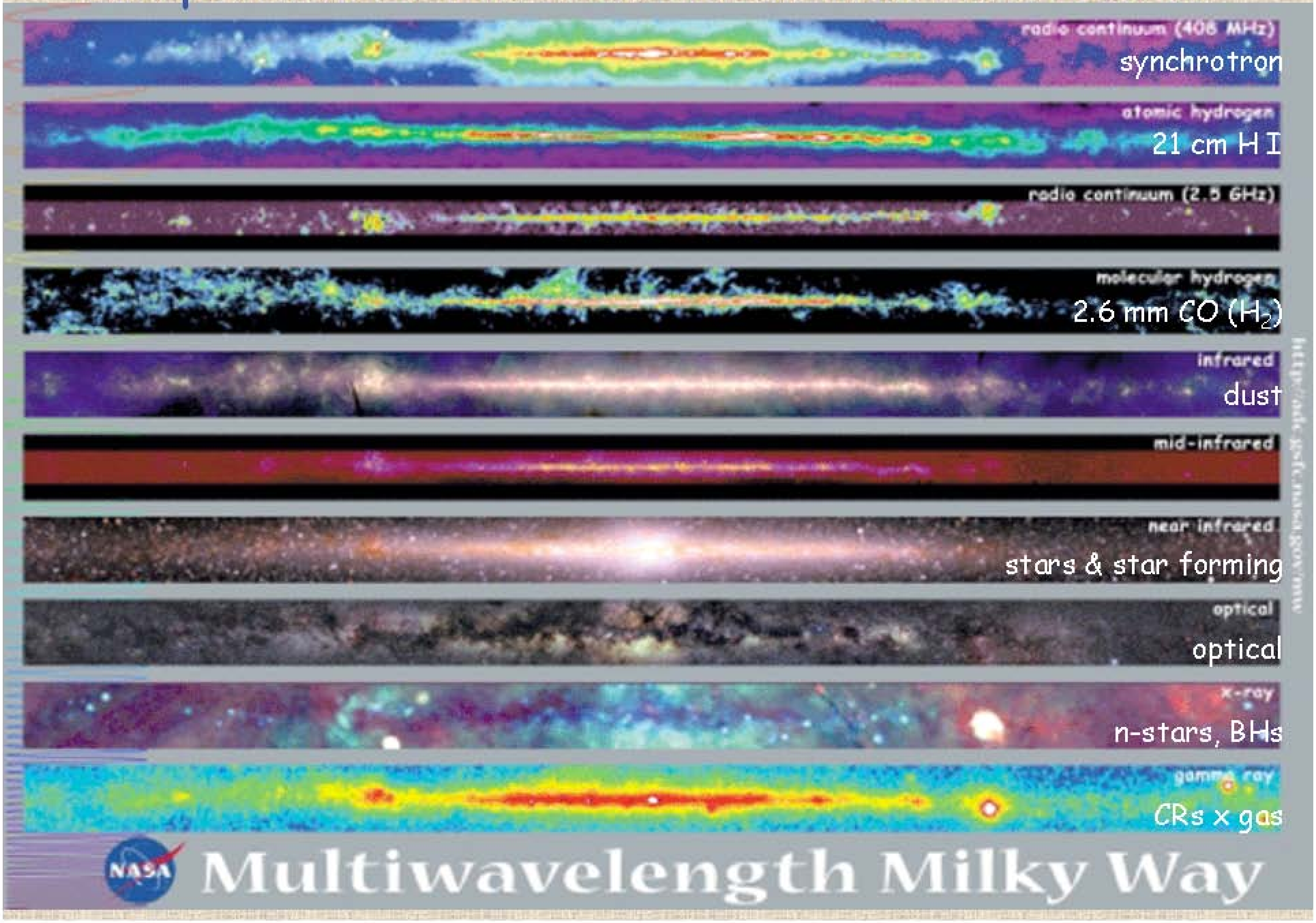
Fermi Pulsar
Milagro (C4)
3EG 2227+6122
Boomerang PWN

GALPROP: A Model of CR Propagation

- Gas distribution (energy losses, π^0, brems)
- Interstellar radiation field (inverse Compton, $e^{\pm}$ energy losses)
- Isotopic & particle production cross sections
- Gamma-ray production: brems, inverse Compton, π^0
- Energy losses: ionization, Coulomb, brems, IC, synch
- Solve transport equations for all CR species
- Fix propagation parameters
- Applications:
  - background for indirect DM searches and other exotics
  - propagation of the DM signal
  - CR fluxes in distant locations
  - Galactic/extragalactic diffuse gamma-ray emission (extragalactic emission may also contain signatures of exotic physics)
  - background for astrophysical gamma-ray sources
  - studies of the origin of CRs and interstellar medium

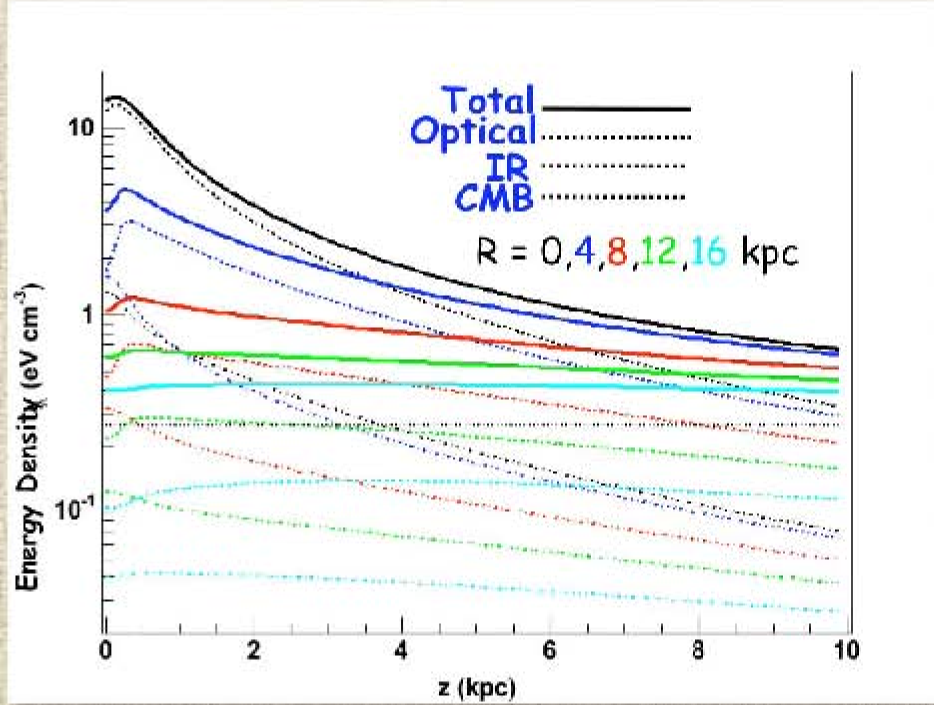
Primary importance for diffuse emission

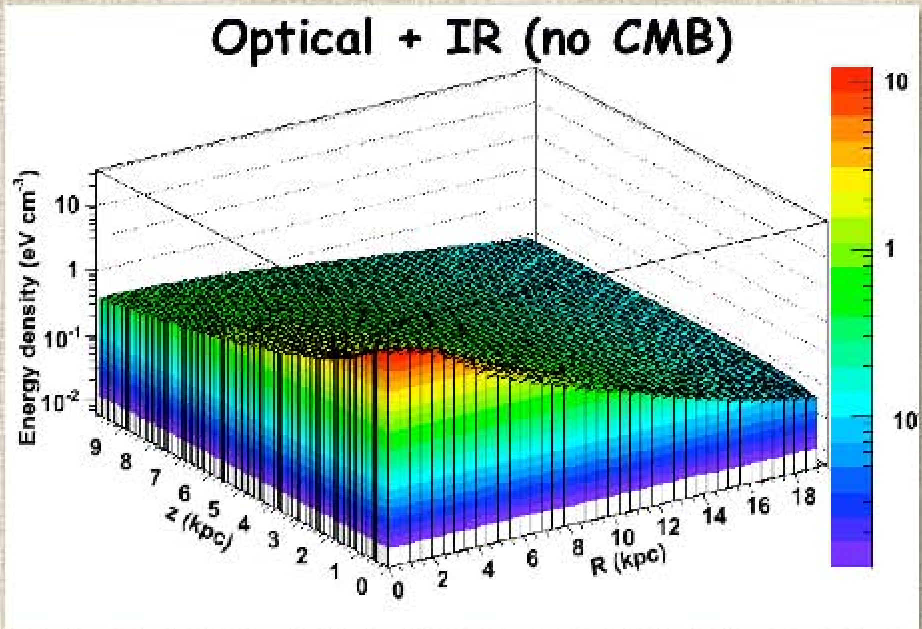
Components of the ISM: Views from the Inside

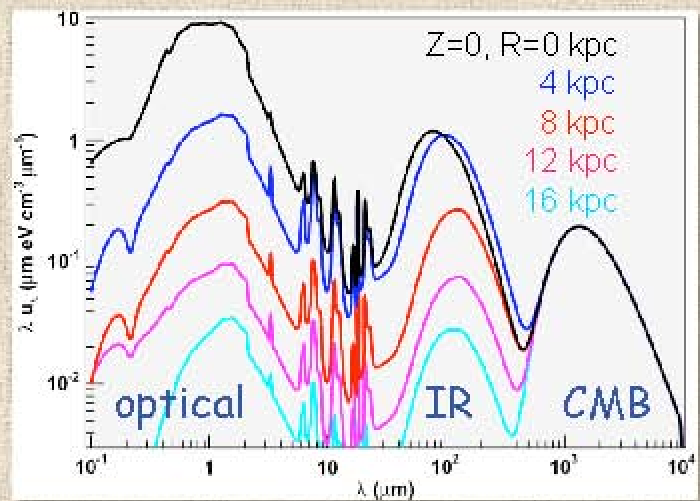


ISRF: Large Scale Distribution

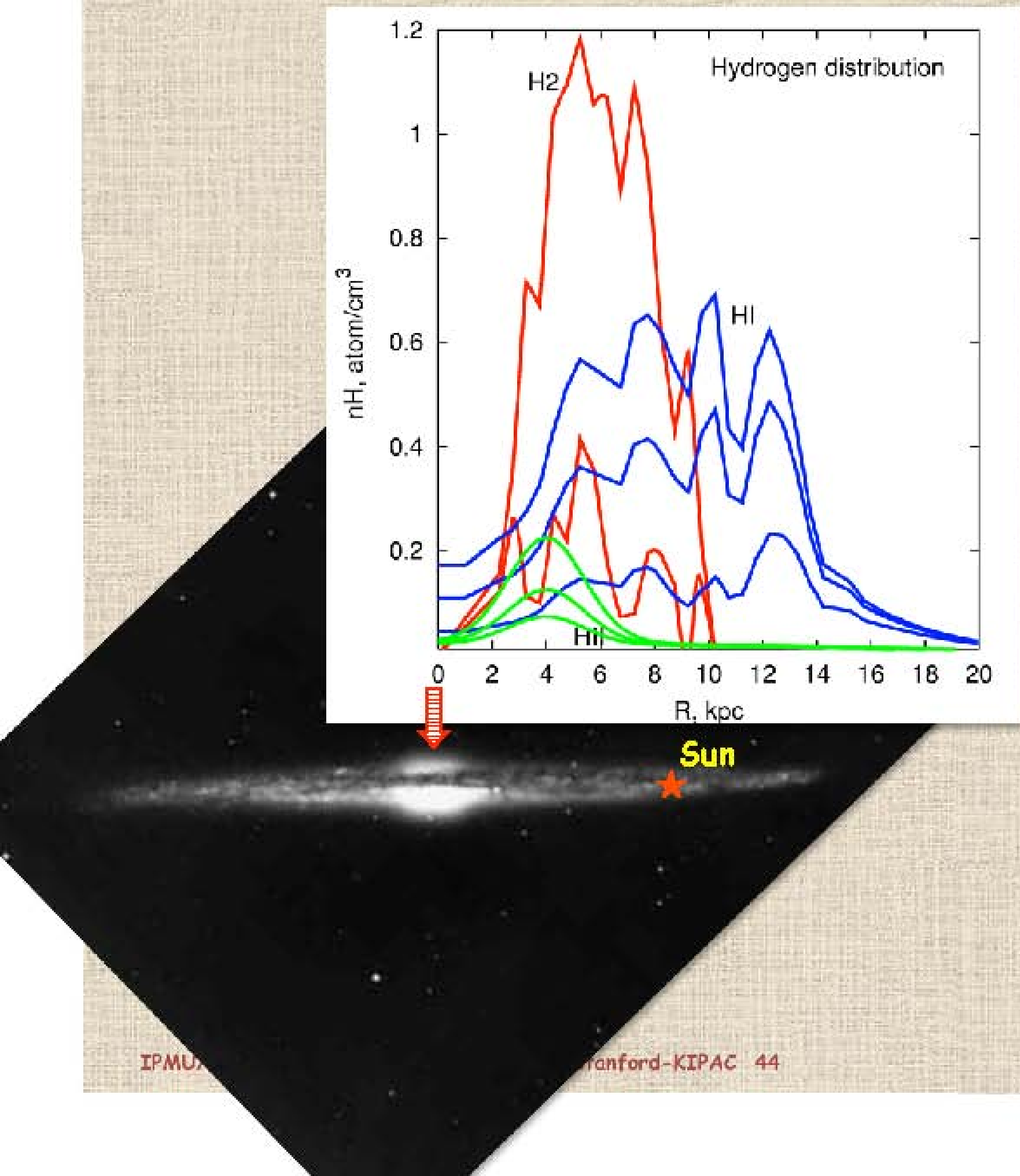
- Requires extensive modelling:
  - Distribution of stars of different stellar classes in the Galaxy
  - Dust emission
  - Radiative transfer
- The z scale height is large, takes 10s of kpc at R = 0 kpc to get to level of CMB







Gas distribution in the Milky Way



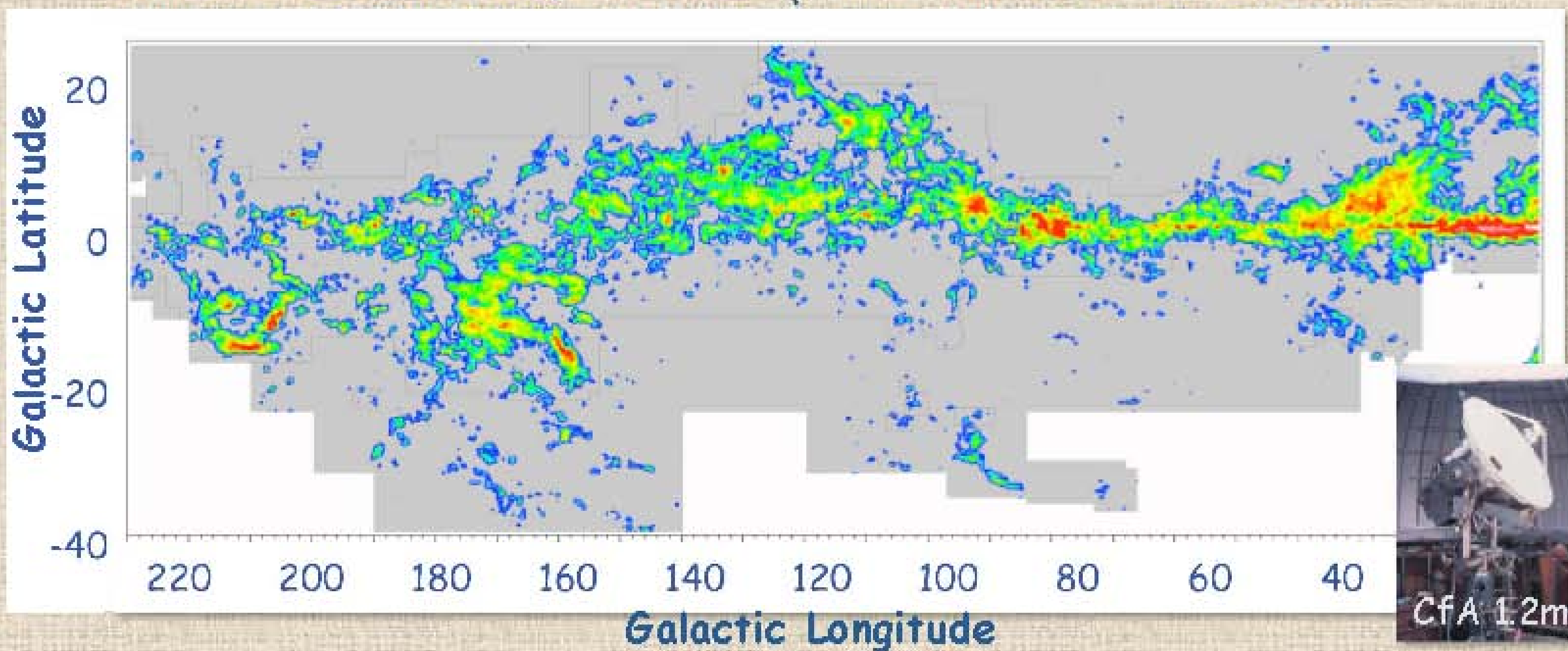
Molecular hydrogen H_2
is traced using J=1-0 transition of ^{12}CO, concentrated mostly in the plane (z~70 pc, R<10 kpc)

Atomic hydrogen H I
(traced by 21 cm emission line) has a wider distribution (z~1 kpc, R~30 kpc)

Ionized hydrogen H II -
small proportion, but exists even in halo (z~1 kpc)

Carbon Monoxide (CO) maps

- **Extend CO surveys to high latitudes**
  - newly-found small molecular clouds will otherwise be interpreted as unidentified sources, and clearly limit dark matter studies

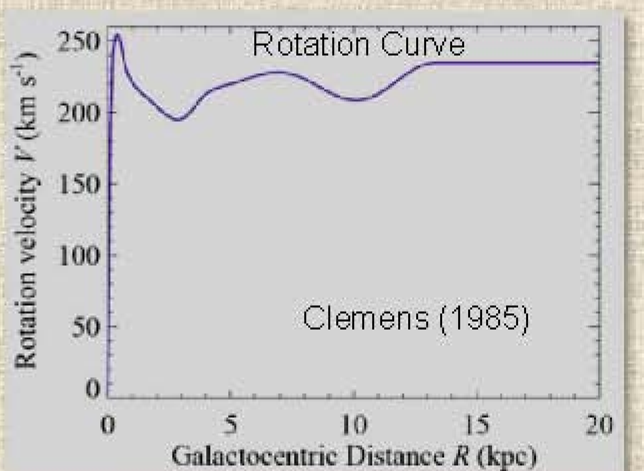


Dame, Hartmann, & Thaddeus (2001)
Dame & Thaddeus (2004)

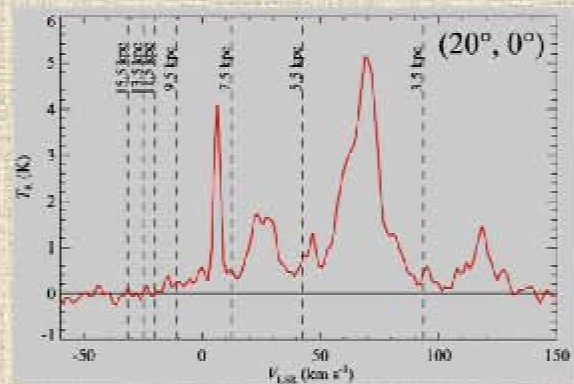
- **$C^{18}O$ observations (optically thin tracer) of special directions (e.g. Galactic center, arm tangents)**
  - assess whether velocity crowding is affecting calculations of molecular column density, and for carefully pinning down the diffuse emission

Calculation of the Gas Distribution

- Neutral interstellar medium – most of the interstellar gas mass
  - 21-cm H I & 2.6-mm CO (surrogate for H_2)
  - Differential rotation of the Milky Way – plus random motions, streaming, and internal velocity dispersions – is largely responsible for the spectrum
  - Rotation curve $V(R) \Rightarrow$ unique line-of-sight velocity-Galactocentric distance relationship

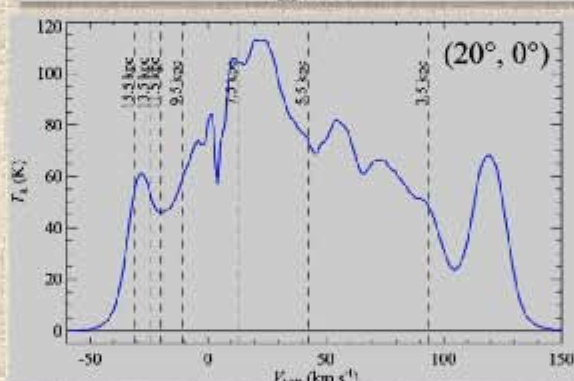


CO



Dame+'01

H I

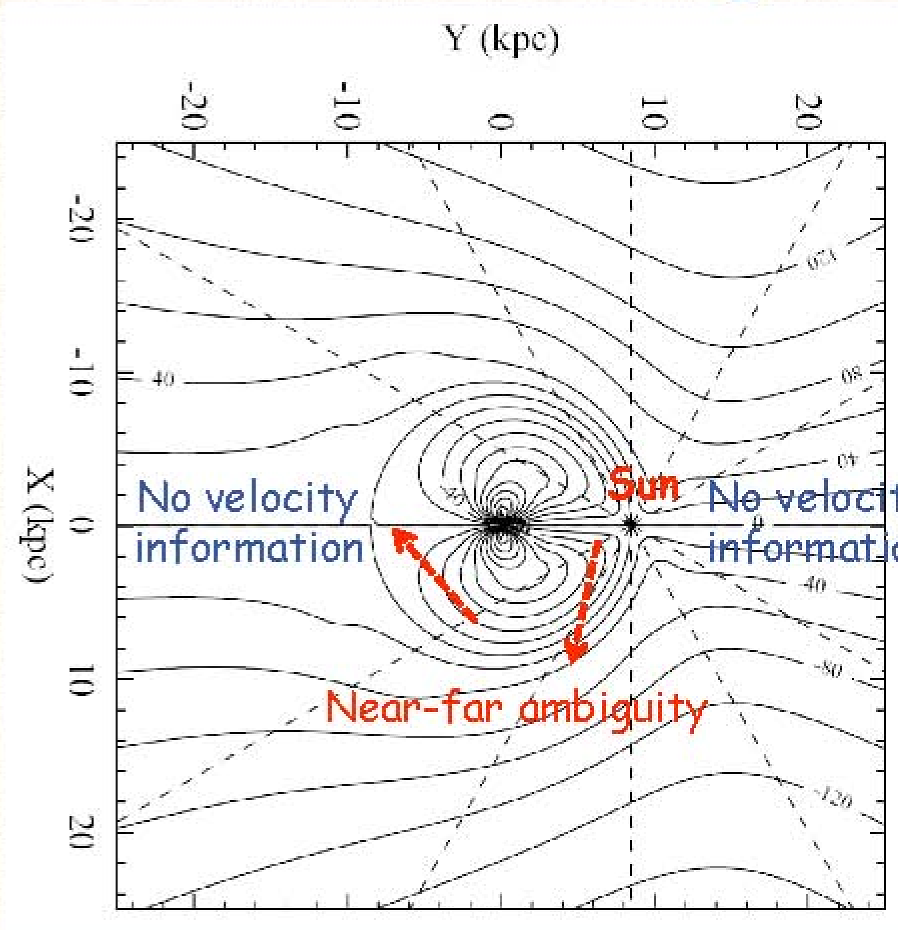


Kalberla+'05

W. Keel

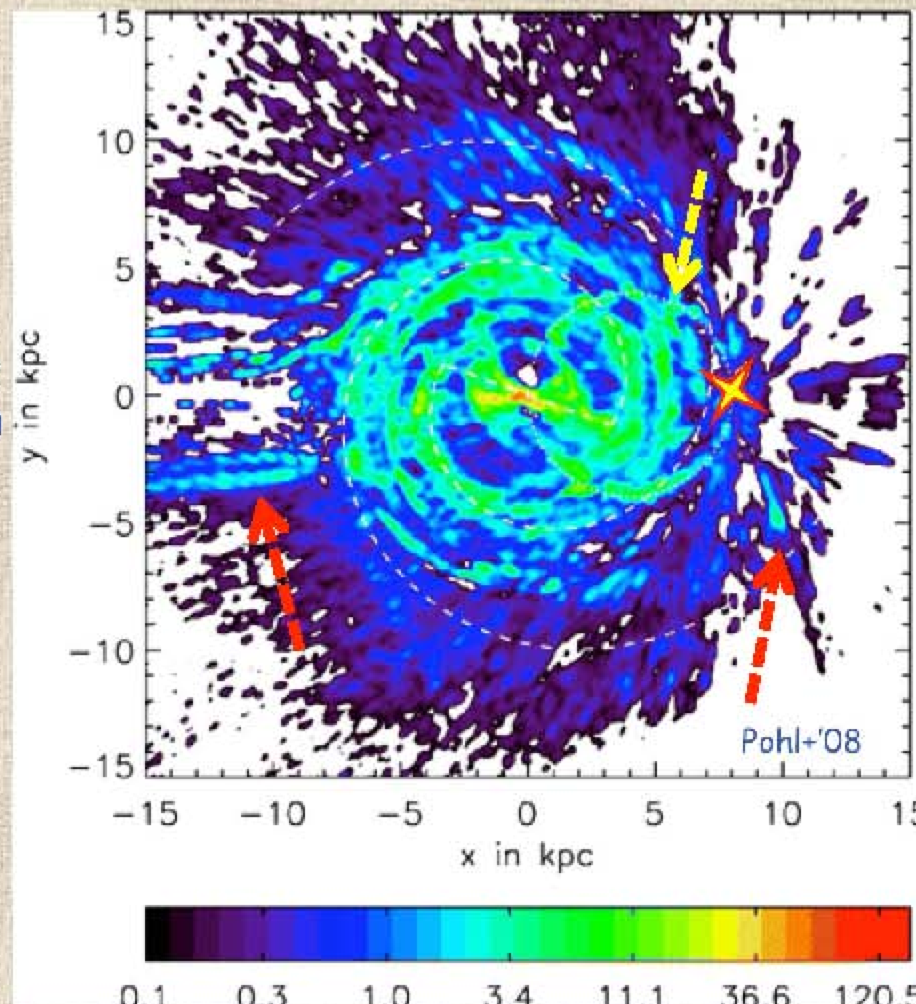
- This is the best – but far from perfect – distance measure available
- Column densities: $N(H_2)/W_{CO}$ ratio assumed; a simple approximate correction for optical depth is made for N(H I); self-absorption of H I remains

More on gas in the Milky Way



Contours of line-of-sight velocities from differential rotation of the Milky Way

Surface mass density of the H_2 in $M_{sun}\ pc^{-2}$



News from the GALPROP Front

New GALPROP model developments to appear in the next release:

- Improved gas maps, which are computed using recent HI and CO (H_2 tracer) surveys
- A new calculation of the Galactic interstellar radiation field using the FRaNKIE code (Fast Radiation transport Numerical Kode for Interstellar Emission, Porter et al. 2008)
- More accurate line-of-sight integration for computing of gamma-ray skymaps
- Considerably increased efficiency of anisotropic IC scattering calculations
- 3D modeling of the Galactic magnetic field, both regular and random components
- The HEALPix output of gamma-ray and synchrotron skymaps. The HEALPix format (Górski et al. 2005) has uniform sky coverage, equal-area pixels and powerful functions (convolution, harmonic analysis), and is a standard for radio-astronomy applications
- The MapCube output for compatibility with Fermi-LAT Science Tools
- Gamma-ray skymaps output in Galactocentric rings to facilitate spatial analysis of the Galactic diffuse gamma-ray emission
- Shared-memory parallel support with OpenMP to take advantage of multi-processor machines
- Implementation of the GNU auto-configuration tools to facilitate installation
- Memory usage optimization
- …

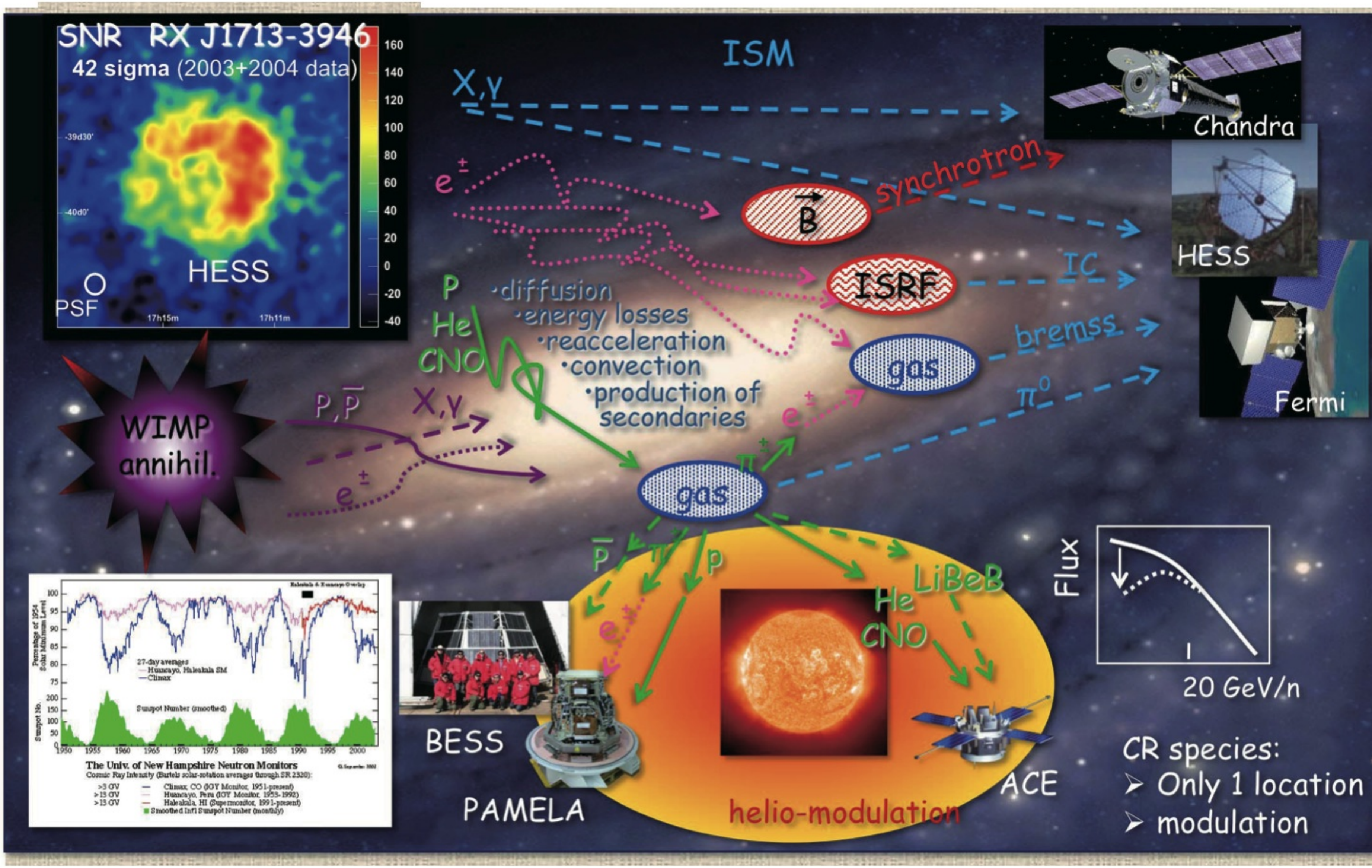
(Some) Important Questions to Answer

- How large is the positron fraction at HE (PAMELA)
  - Identifies the nature of sources of primary positrons
- If SNRs are the sources of primary positrons, this should also affect antiprotons and secondary nuclei @ HE…
  - Measure pbars and secondary nuclei (PAMELA, CREAM…)
- How typical for the local Galactic environment is the observed Fermi/LAT spectrum
  - If this is the typical spectrum then the sources of primary positrons are distributed in the Galaxy (could be pulsars, SNRs, or DM)
  - If this spectrum is peculiar then there is a local source or sources of primary positrons
  - The answer is in the diffuse gamma-ray emission (Fermi/LAT)
- Dark matter vs Astrophysical source
  - Distribution and spectrum of the diffuse γ-ray emission at HE (Fermi)
- <u>To answer these important questions we should consider all relevant astrophysical data (CRs, gamma rays) and particle data (LHC) together</u>


Thank you !
You are here
IPMU

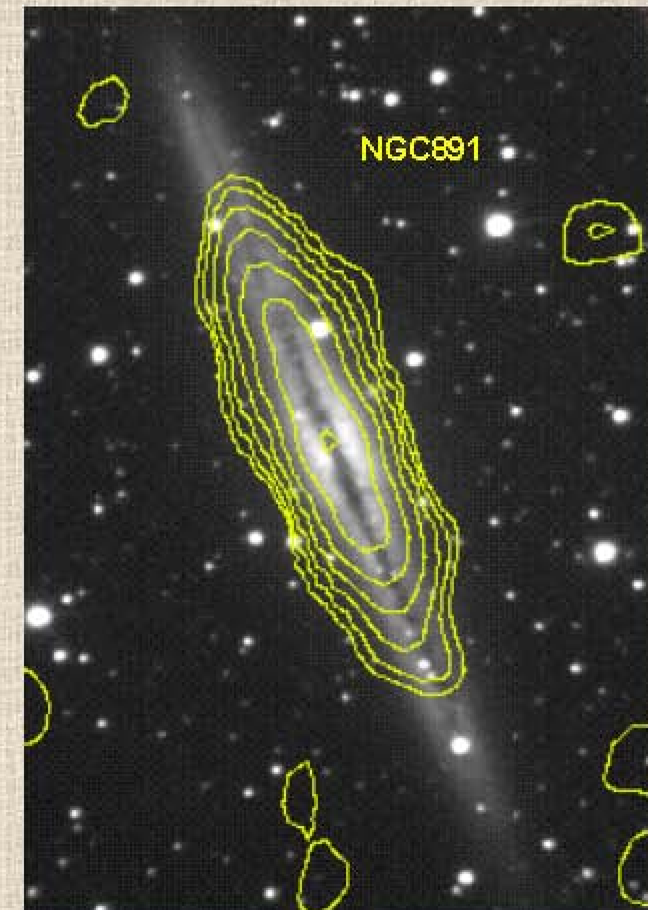
Backup slides

CRs in the Interstellar Medium

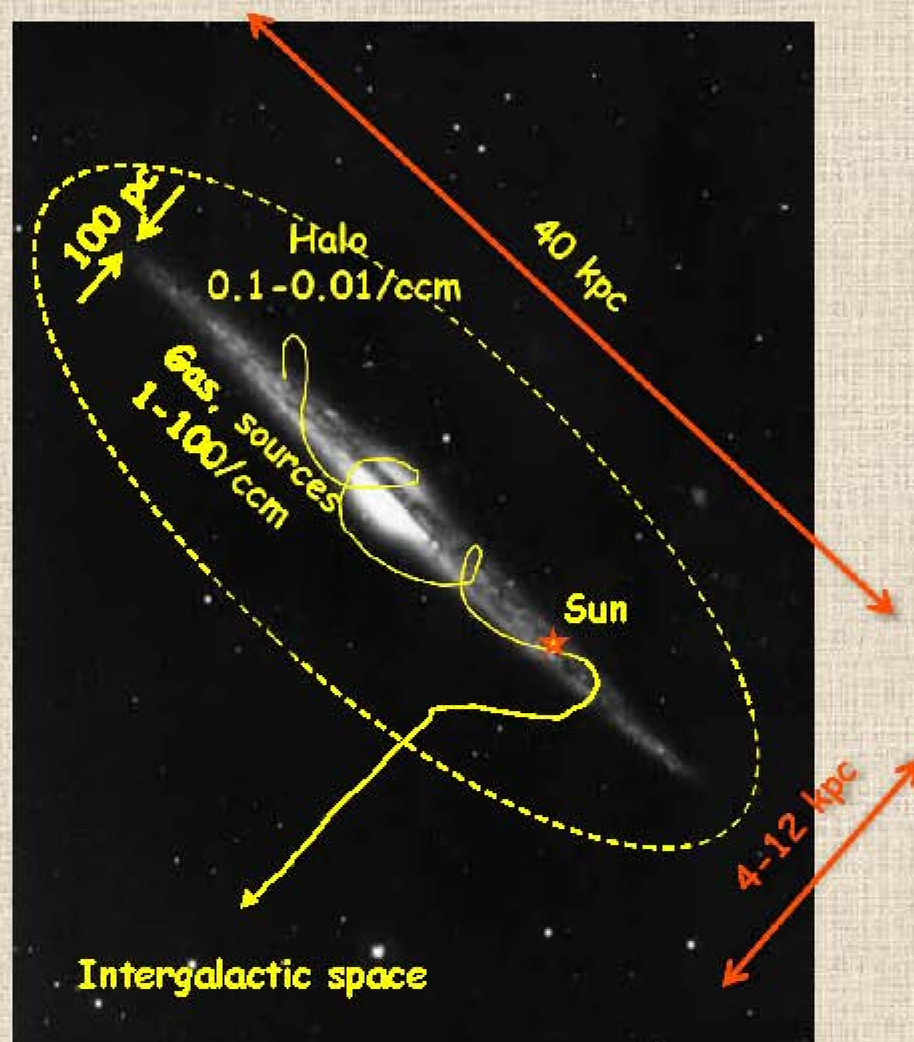


CR Propagation: the Milky Way Galaxy

Optical image: Cheng et al. 1992, Brinkman et al. 1993
Radio contours: Condon et al. 1998 AJ **115**, 1693

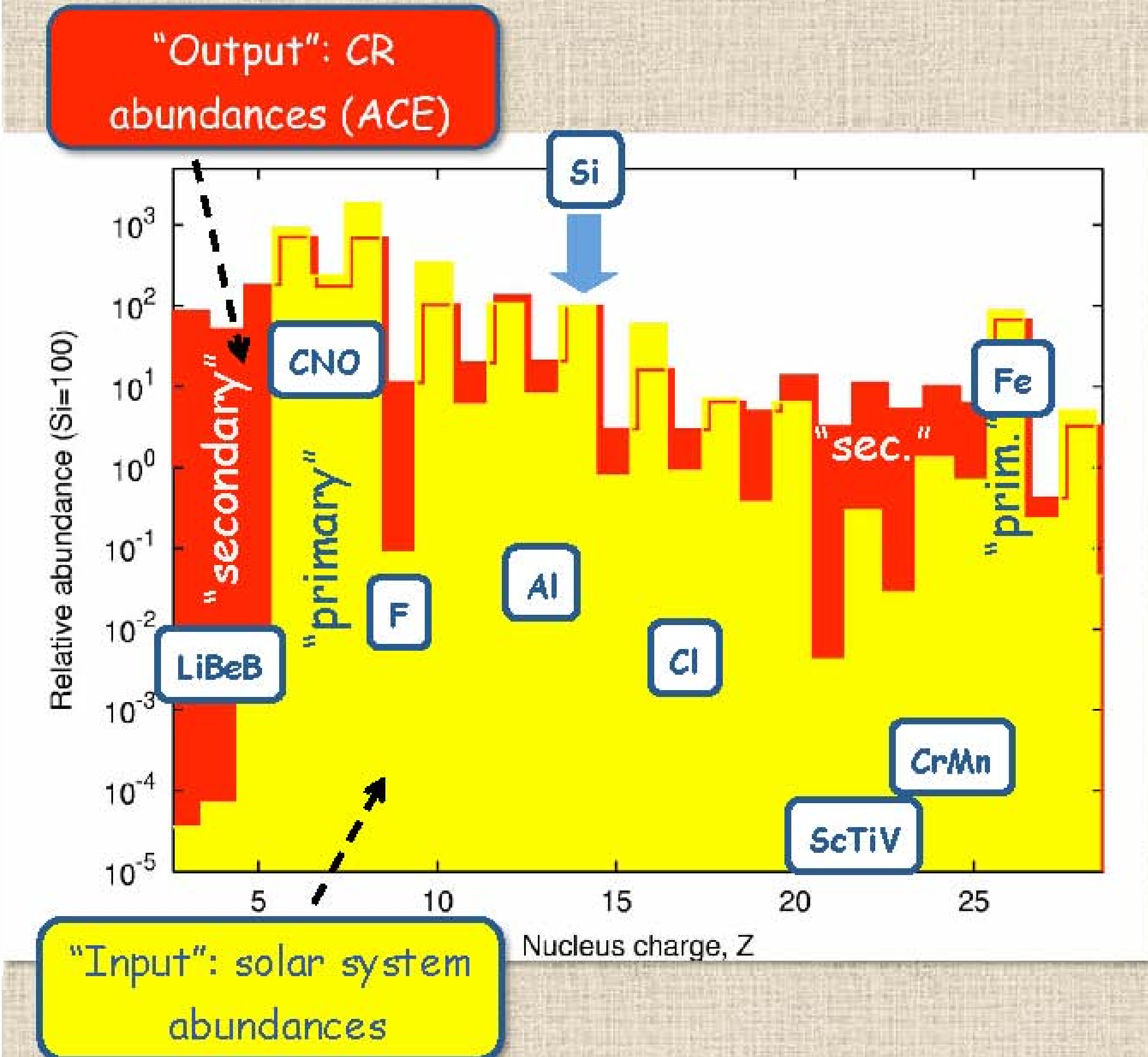


R Band image of NGC891
1.4 GHz continuum (NVSS), 1,2,...64 mJy/ beam



"Flat halo" model (Ginzburg & Ptuskin 1976)

Elemental abundances in CRs and in the Solar System



A lot of information is hidden in elemental and isotopic abundances of CR.

The elements which are rare in the solar system, such as Li, Be, B, Sc, Ti, V, and some others, appear to be abundant in CRs.

They are called "secondaries" because they are produced by spallations of heavier nuclei (so-called "primary", e.g. C, O, Fe) during the CR propagation.

The CR age deduced from the amount of secondaries is ~10 Myr.

Renaissance of Particle Astrophysics

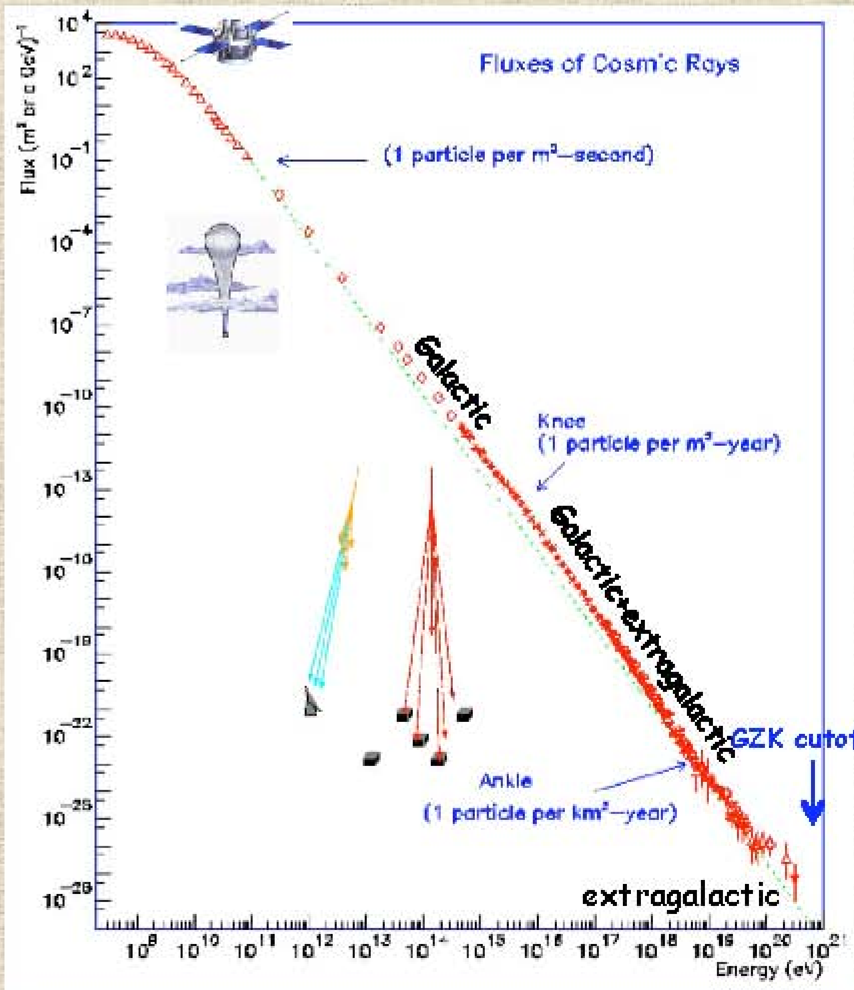
Particle astrophysics, which has recently emerged as an interdisciplinary science, is flourishing nowadays.

It was born in the early days of cosmic-ray physics about a century ago and then reborn twice, first with the launch of the first X-ray telescopes, and second with the discovery that the matter in the universe is dominated by something dark, the dark matter.

The latter rebirth brought an army of particle physicists into astrophysics, while astrophysicists began to realize that supersymmetry can play a role on a macro scale.

Particle astrophysics is now a busy intersection between high -energy astrophysics, particle physics, and cosmology.

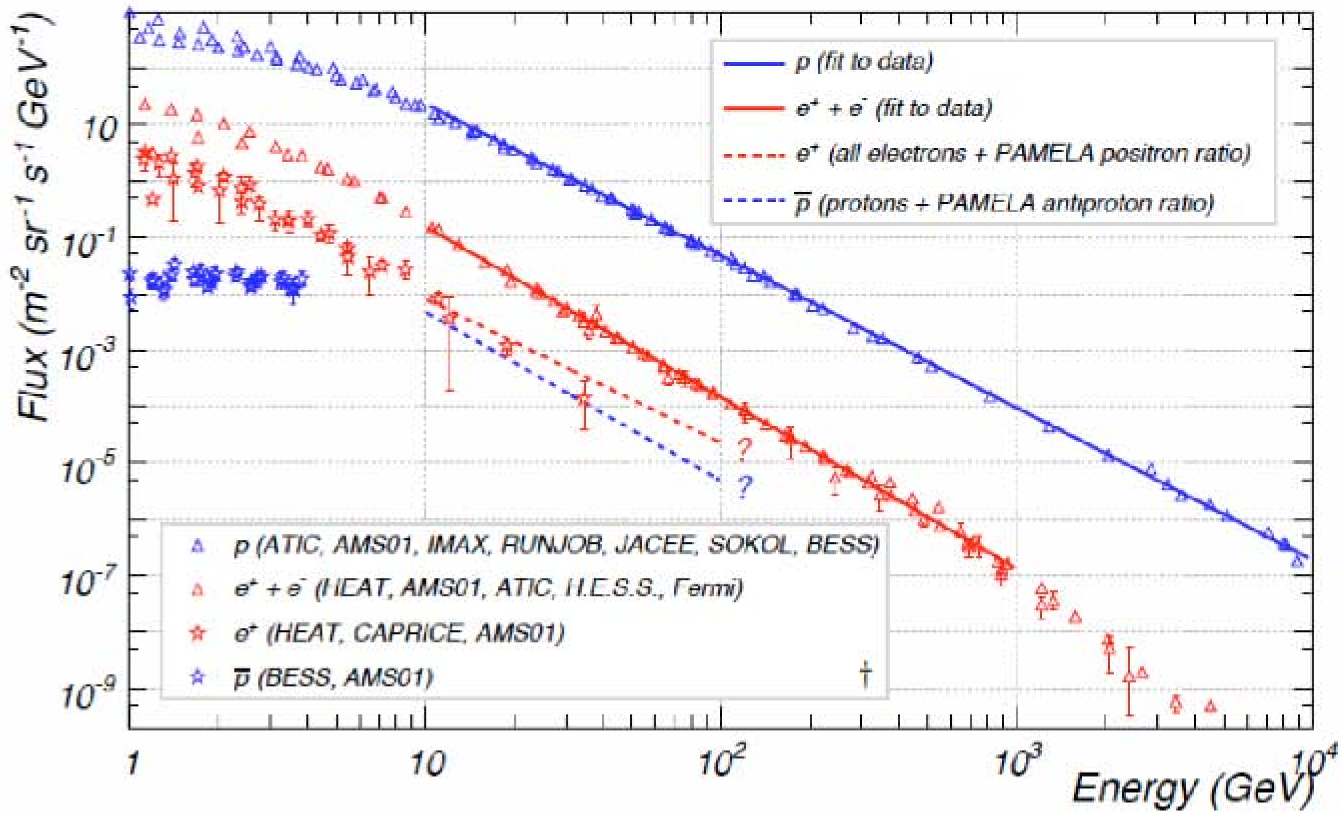
All Particle CR Spectrum



This is an astonishing observation!

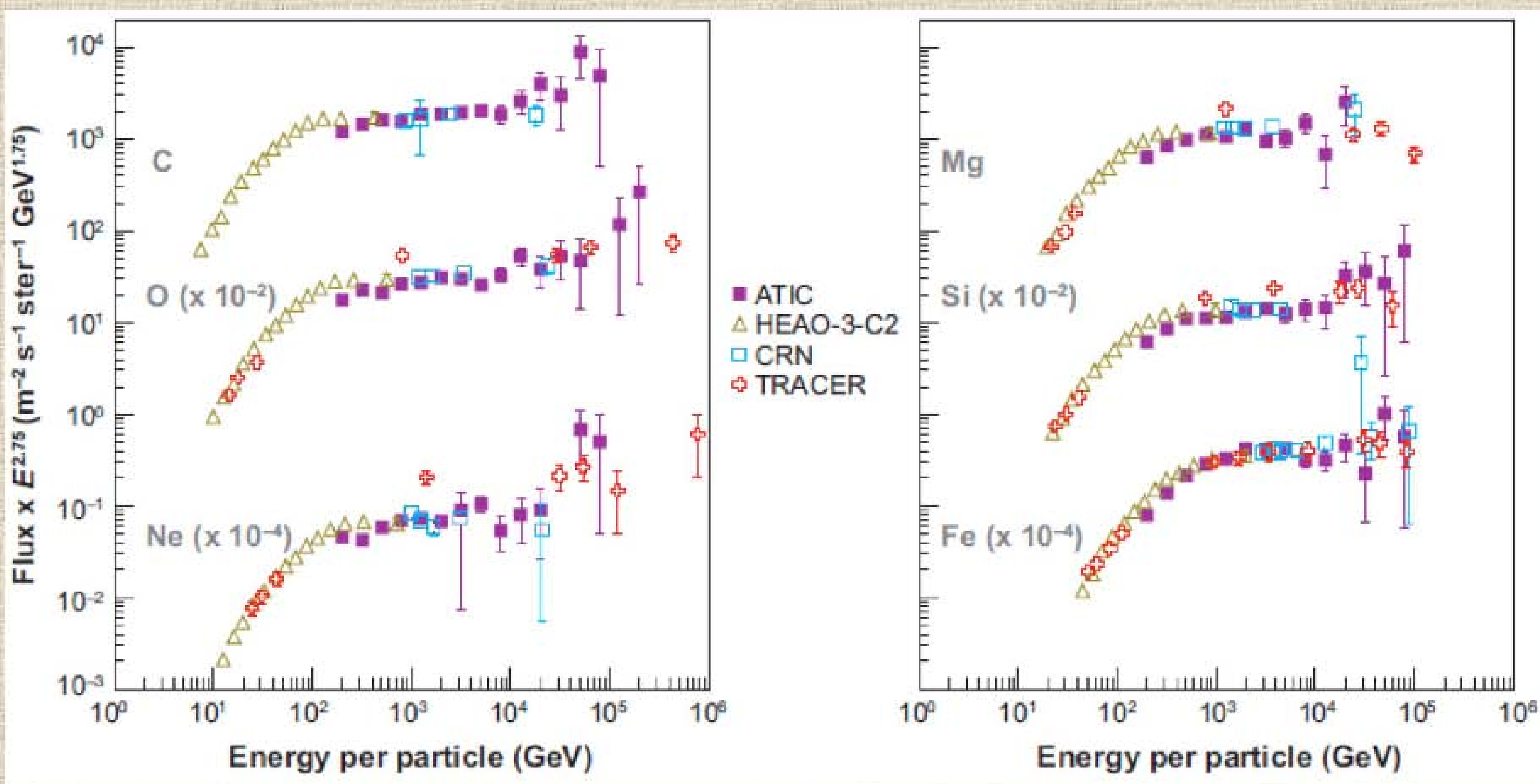
- All particle CR spectrum is almost featureless. It can be described as a single power-law with index -3 in >12 decades in energy and >32 decades in intensity!
- There are only 3 well-established features:
  - the knee
  - the ankle
  - GZK cutoff
- A lot of information is hidden in the spectra and abundances of individual CR species: nuclear isotopes, antiprotons, electrons, positrons (+diffuse gamma rays)
- CRs are the only probes of the interstellar material available to us.
- The whole physics is involved: various branches of Astrophysics, MHD, shock waves, plasma physics, atomic, nuclear, & particle physics, exotic physics – SUSY…

A quick look at the available data



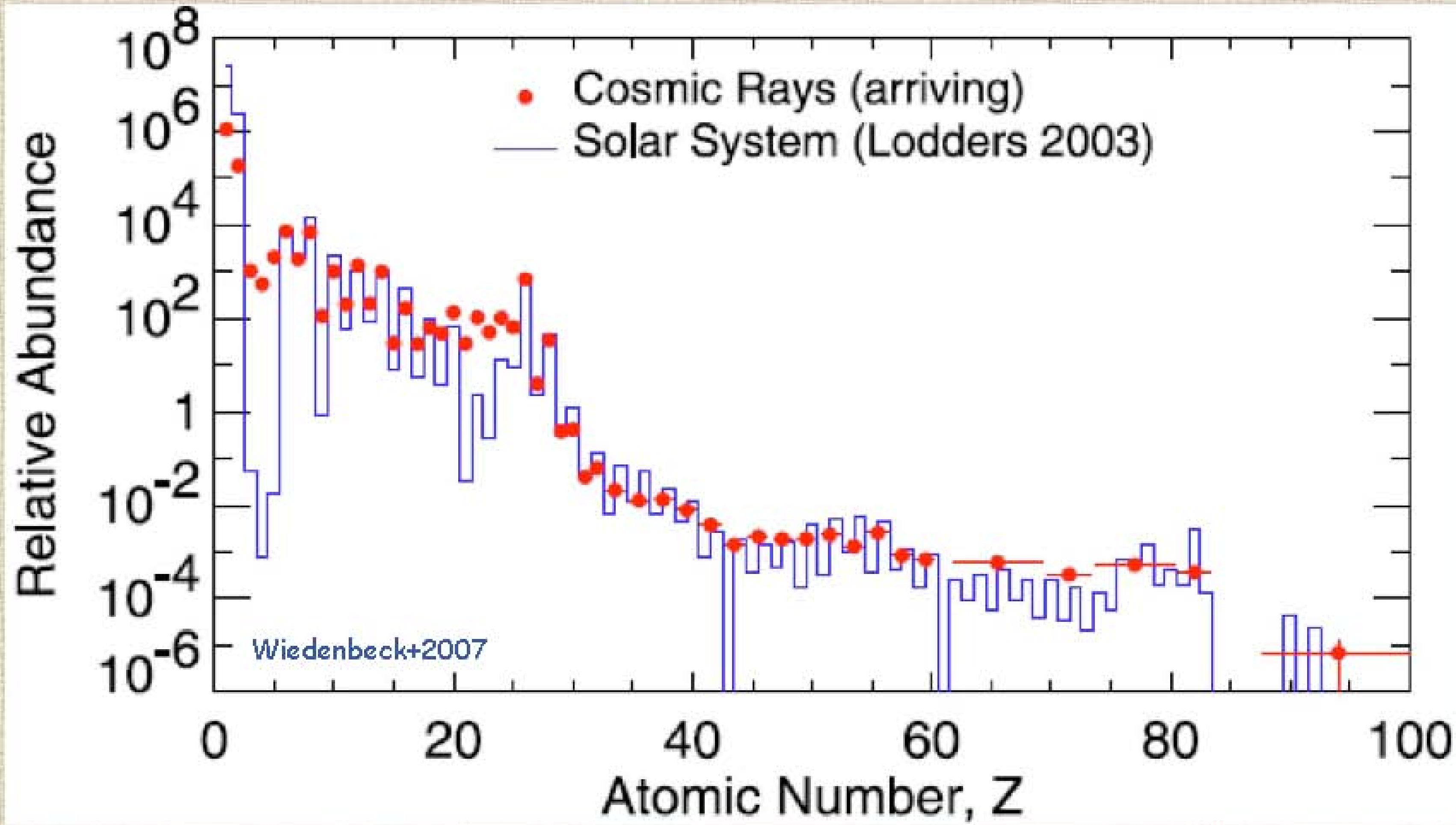
Positrons and antiprotons constitute a tiny fraction of the total CR flux, yet may contain signatures of new physics!

Spectra of CR nuclei



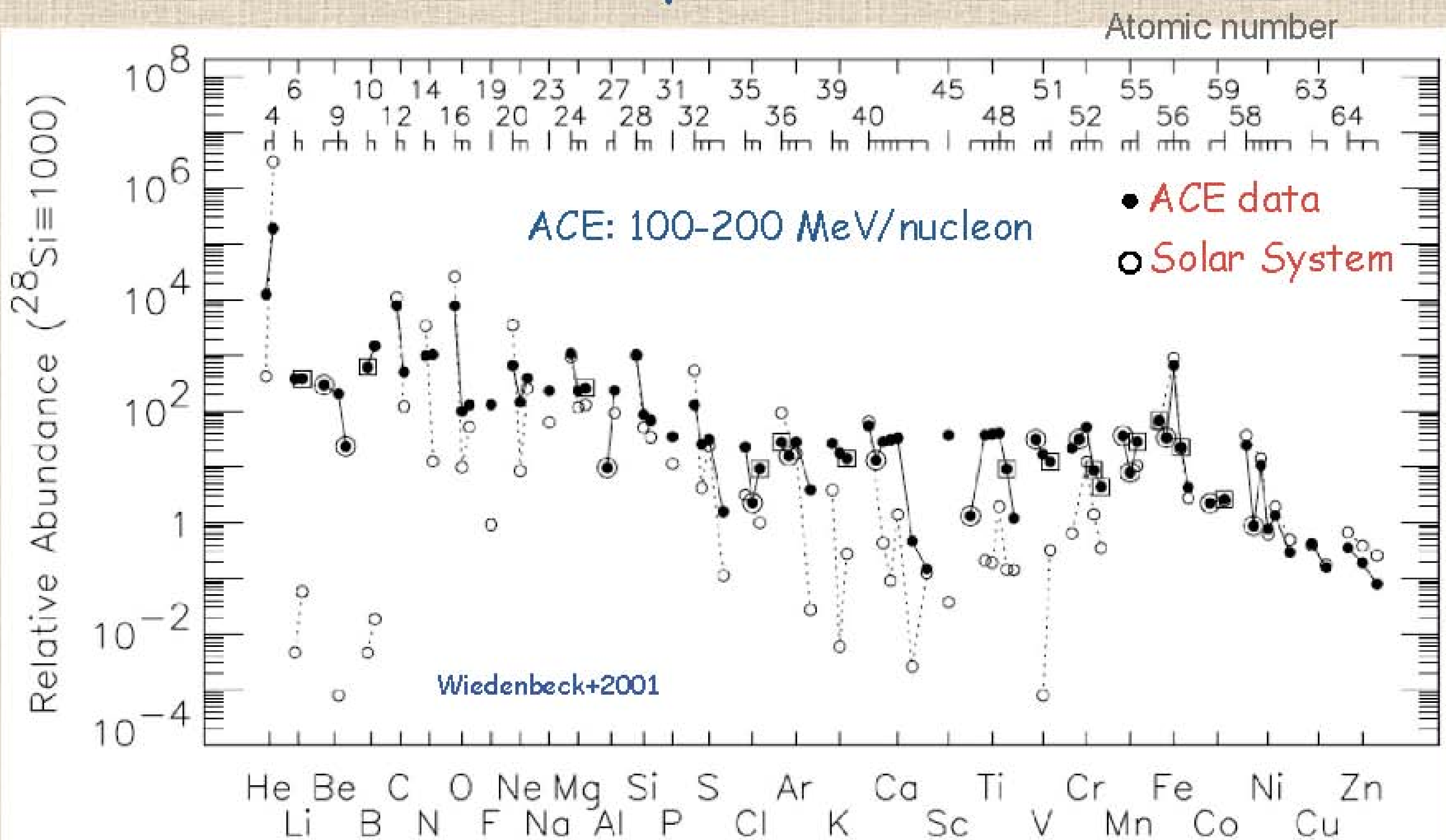
Examples of spectra of individual elements in cosmic rays

Heavy Nuclei in CRs



Heavy nuclei are produced in SN explosions. They can't propagate from large distances because of the very large inelastic cross section.

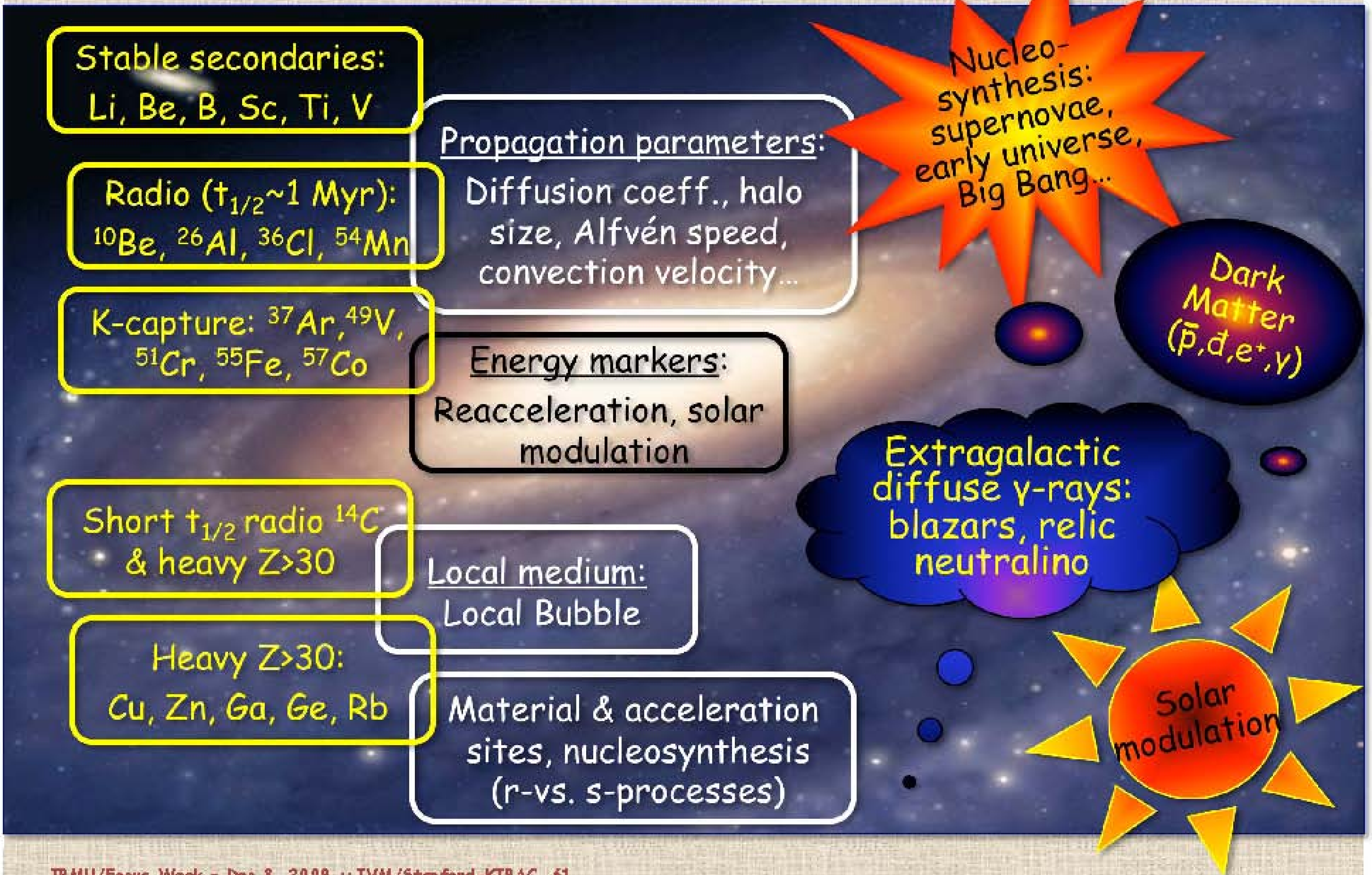
Isotopic Data



Very detailed isotopic data exist at low energies!

(Isotopes of the same element are connected by lines)

Nuclear component in CR: What we can learn?



Transport Equations ~90 (no. of CR species)

$$\frac{\partial \psi(\vec{r},p,t)}{\partial t} = q(\vec{r},p)$$ sources (SNR, nuclear reactions...)

diffusion $$+ \vec{\nabla} \cdot [D_{xx} \vec{\nabla} \psi - \vec{V} \psi]$$

diffusive reacceleration (diffusion in the momentum space) $$+ \frac{\partial}{\partial p} \left[p^2 D_{pp} \frac{\partial}{\partial p} \frac{\psi}{p^2} \right]$$

convection (Galactic wind)

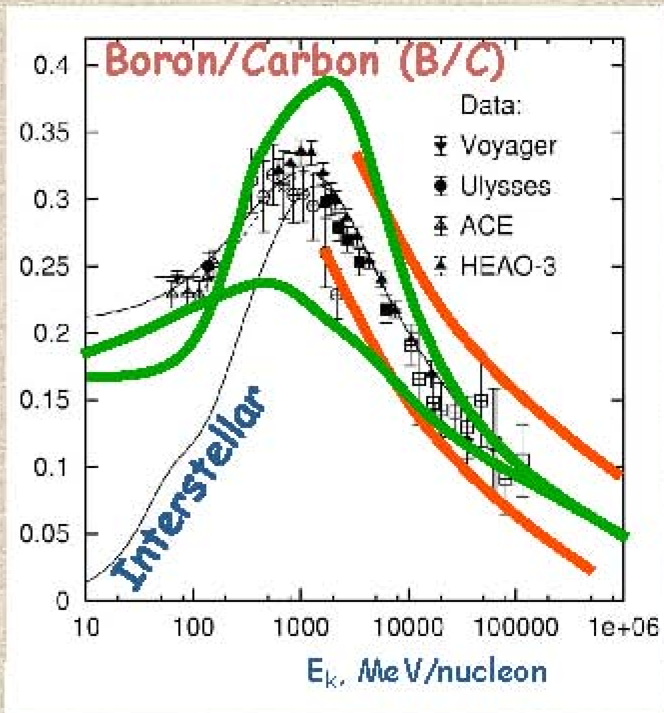
E-loss $$- \frac{\partial}{\partial p} \left[\frac{dp}{dt} \psi - \frac{1}{3} p \vec{\nabla} \cdot \vec{V} \psi \right]$$

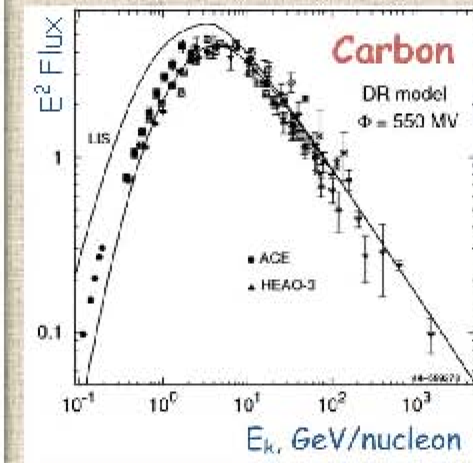
fragmentation $$- \frac{\psi}{\tau_f} - \frac{\psi}{\tau_d}$$ radioactive decay

+ boundary conditions

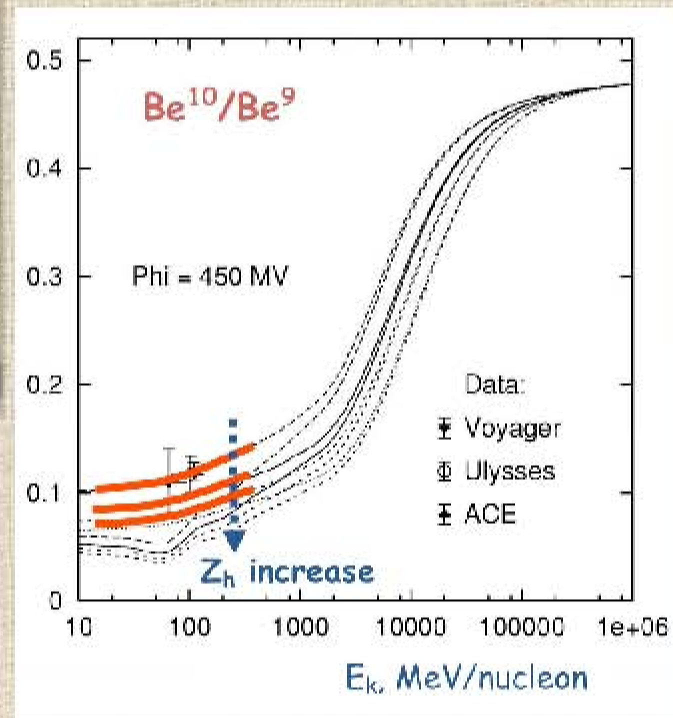
ψ(r,p,t) – density ***per total momentum***

How It Works: Fixing Propagation Parameters





Radioactive isotopes:
Galactic halo size Z_h

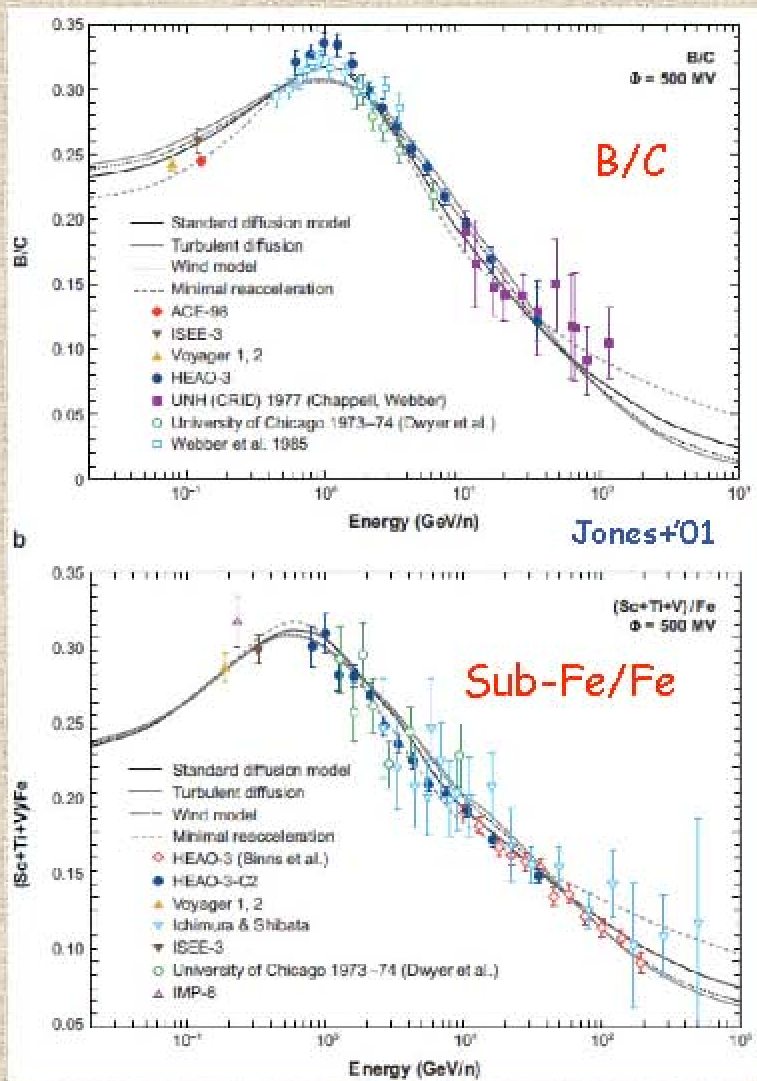


Using secondary/primary nuclei ratio (B/C) & flux:

- Diffusion coefficient and its index
- Propagation mode and its parameters (e.g., reacceleration V_A, convection V_z)
- Propagation parameters are model-dependent
- Make sure that the spectrum is fitted as well

Parameters (model dependent):
D~ 10^{28} $(\rho/1\ GV)^{\alpha}$ cm2/s
$\alpha \approx 0.3$-0.6
Z_h ~ 4-6 kpc
V_A ~ 30 km/s

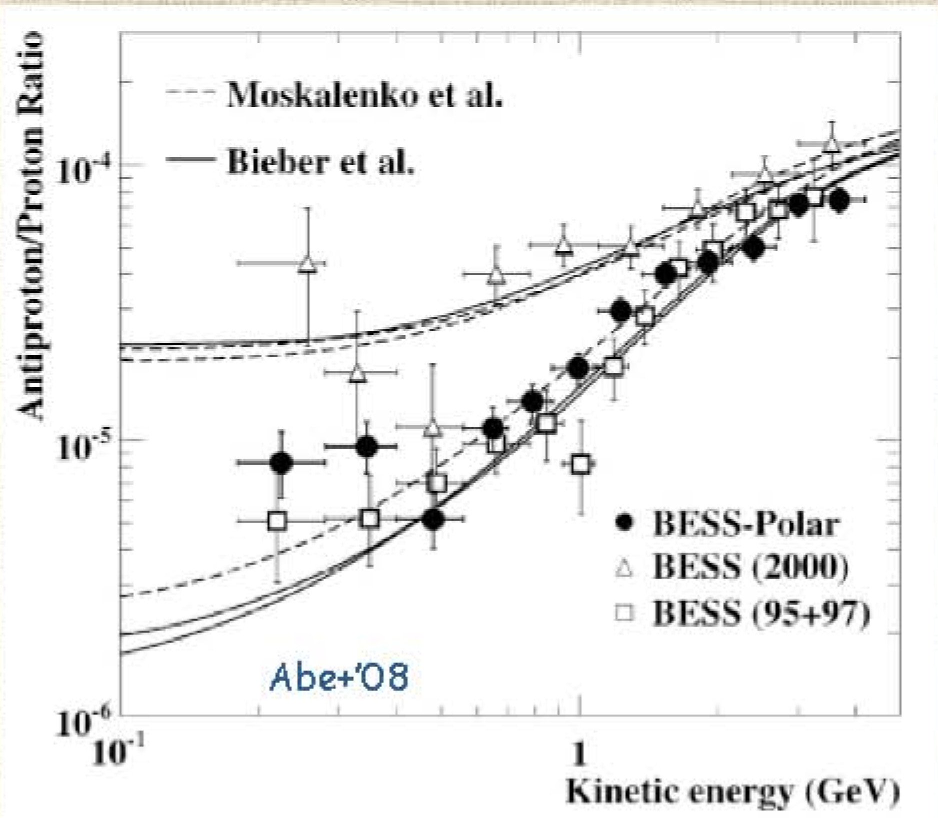
Secondary/Primary Nuclei Ratio



Being tuned to one type of secondary/primary ratio (e.g. B/C ratio) the propagation model should be automatically consistent with all secondary/primary ratios:

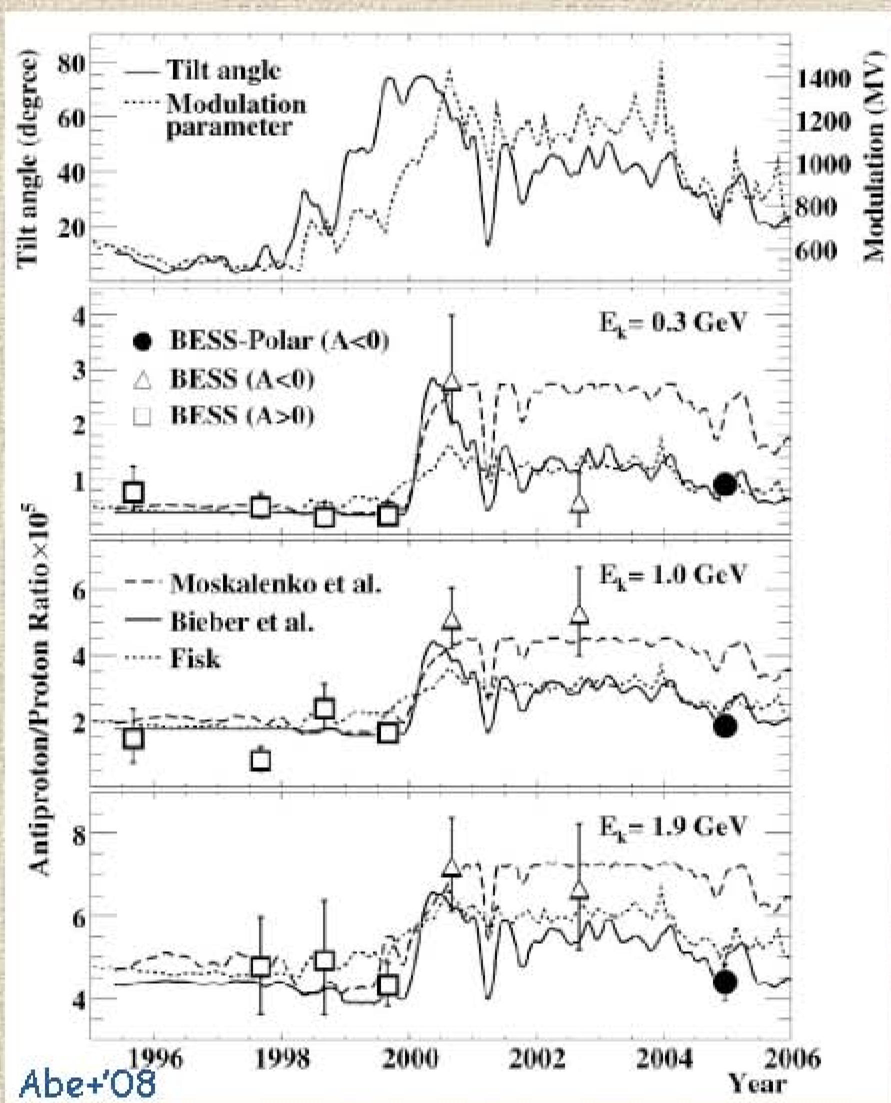
- sub-Fe/Fe
- He^3/He^4
- pbar/p

Importance of the Pbar/P Ratio



- Similarly to other secondary/primary ratios, pbar/p ratio can be used to derive the propagation parameters
- Different ratios probe different volumes in the Galaxy with the pbar/p ratio probing the largest volume since the pbar inelastic cross section is ~40 mb (vs. ~270 mb for Carbon, vs. ~750 mb for Iron)
- The interstellar spectrum of pbars can be calculated because of the production threshold is large vs. the injection spectra of other nucleons which are assumed
- Therefore, it can be used to probe interstellar spectrum of protons, solar modulation, and, of course, to search for signatures of exotic physics

Importance of the Pbar/P Ratio (Cont'ed)

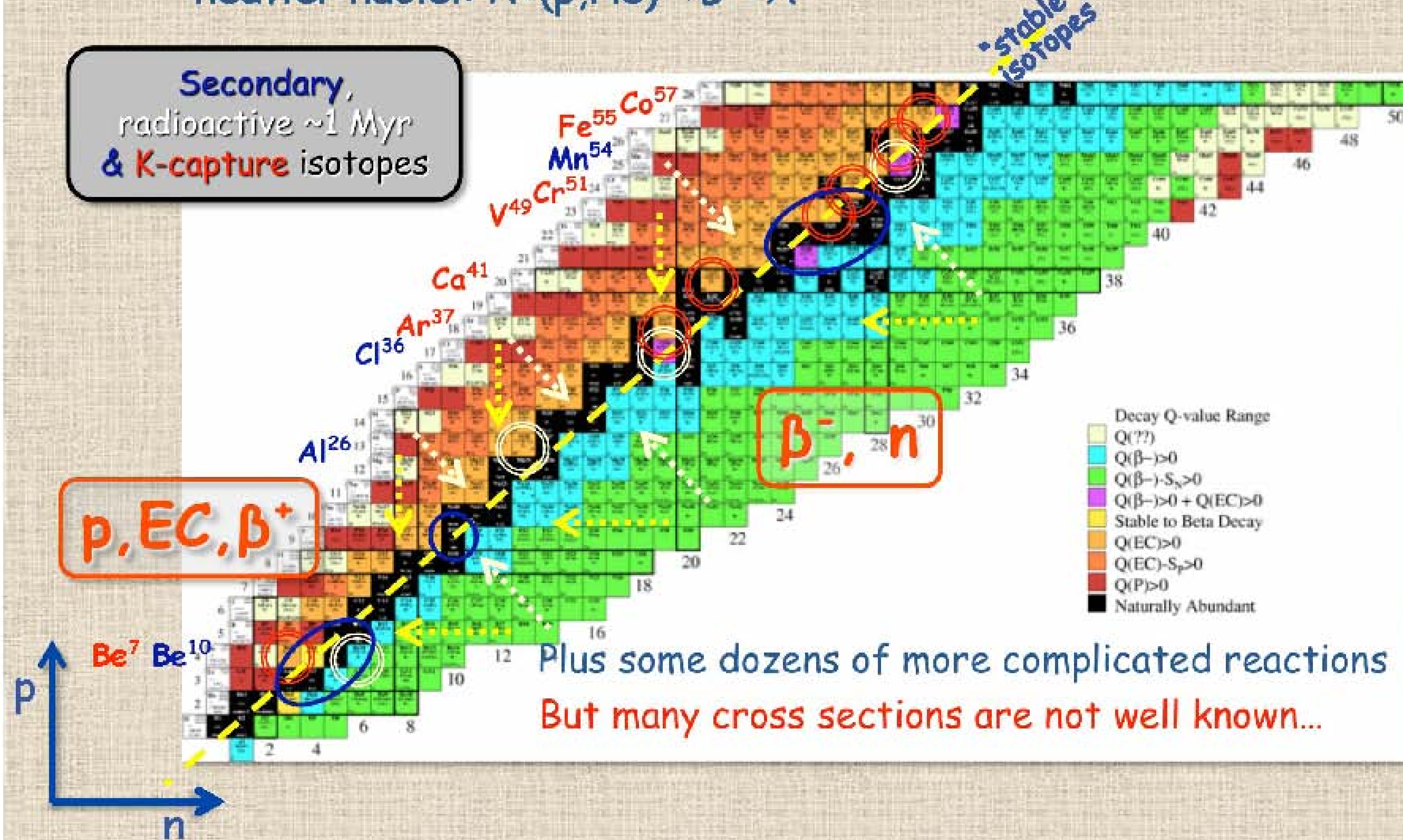


Abe+'08

- Systematic measurements of pbars in CRs (BESS) allow us to study heliospheric modulation and charge-sign effects
- Important also for e^+/e ratio

Nuclear Reaction Network + Cross Sections

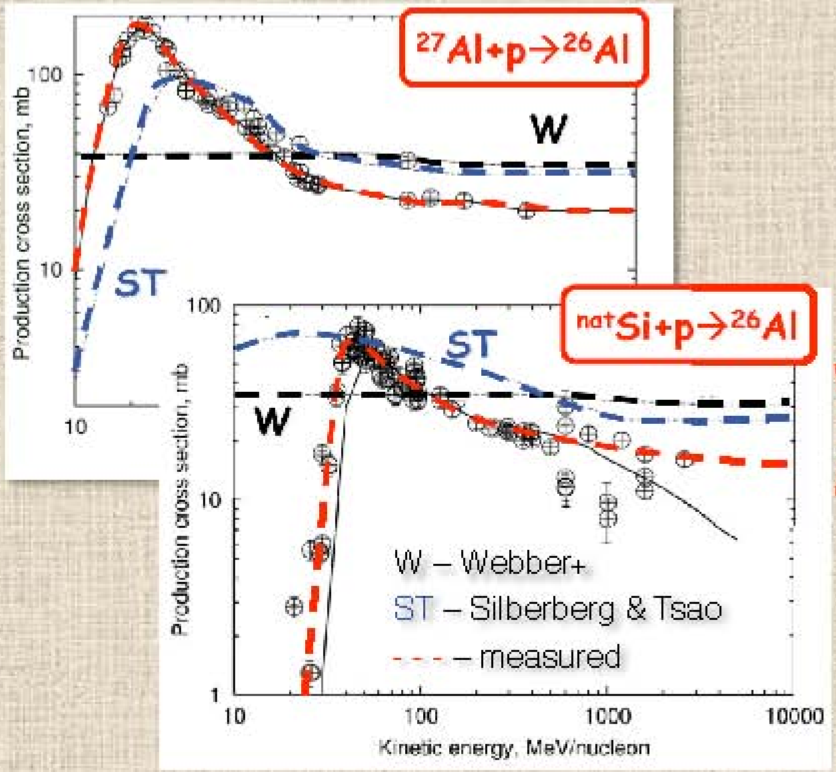
Many different isotopes in CRs are produced via spallations of heavier nuclei: A+(p,He)→B*+X



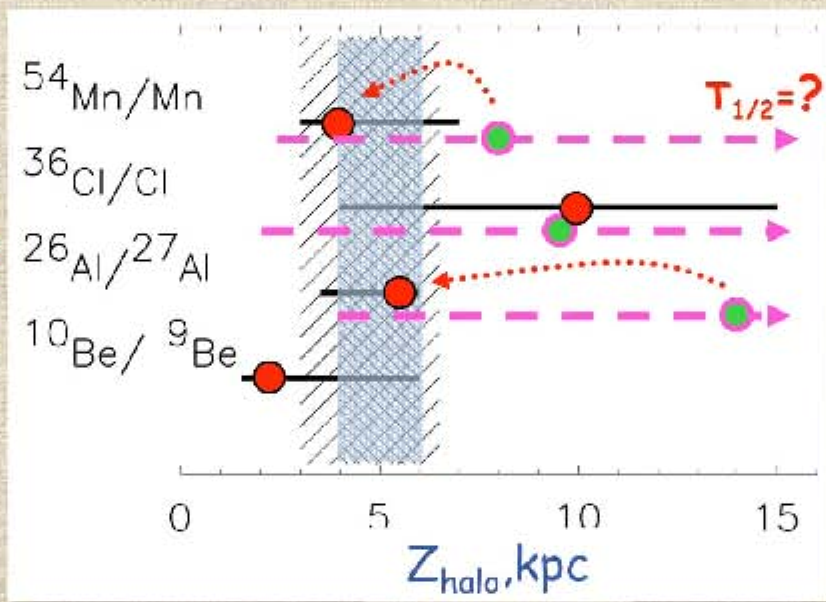
Plus some dozens of more complicated reactions

But many cross sections are not well known…

Effect of Cross Sections: Radioactive Secondaries



Different size from different ratios…

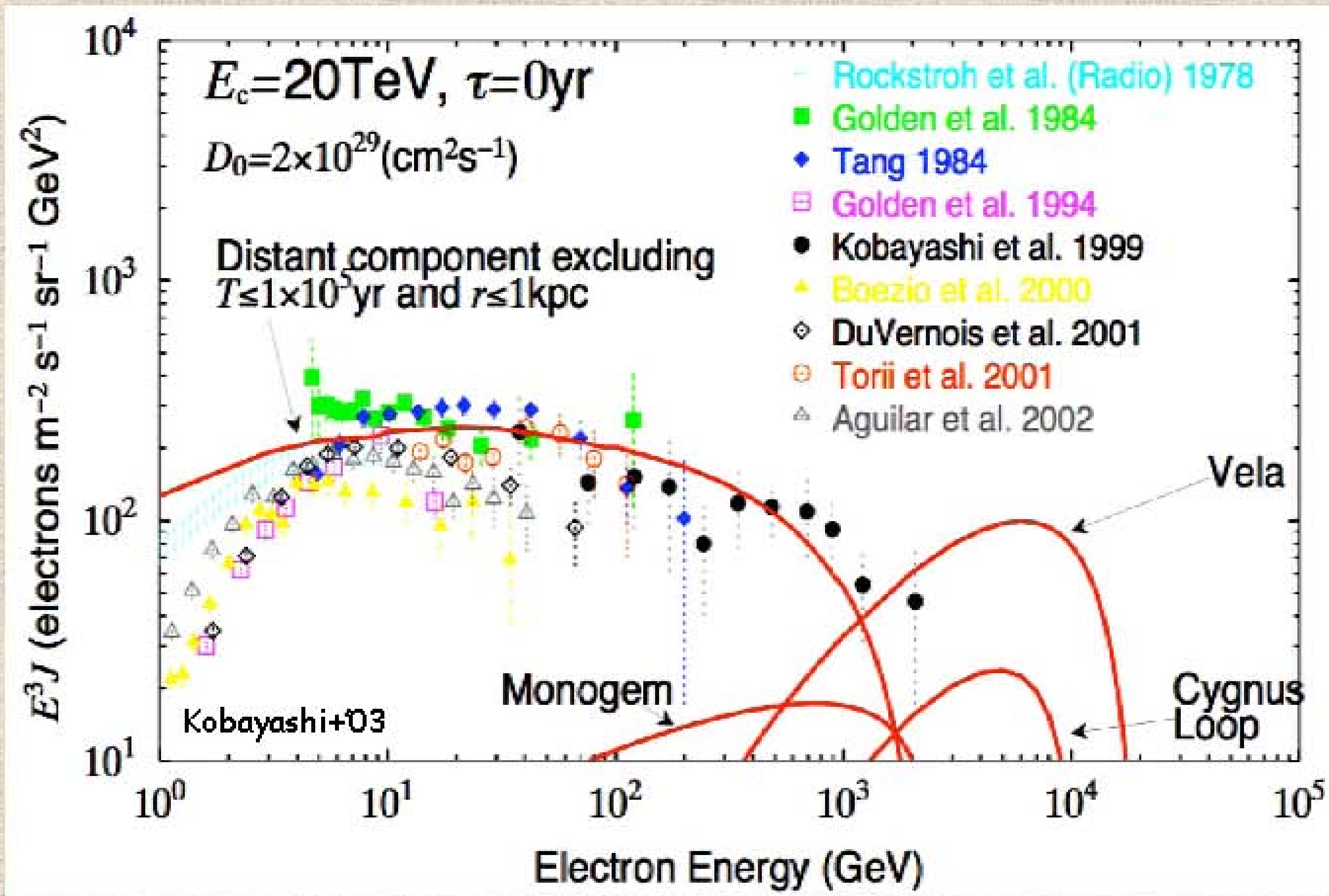


In determination of the propagation parameters one has to take into account:

- Errors in CR measurements (@ HE & LE)
- Errors in production cross sections
- Errors in the lifetime estimates

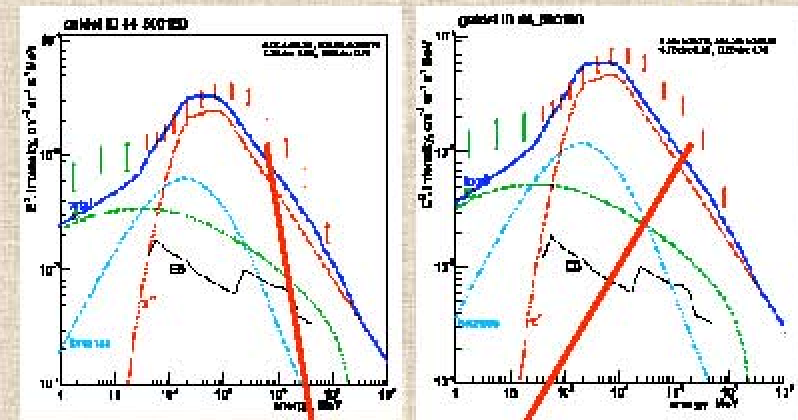
- The error bars can be significantly reduced if more accurate cross sections are used
- Different ratios provide consistent parameters

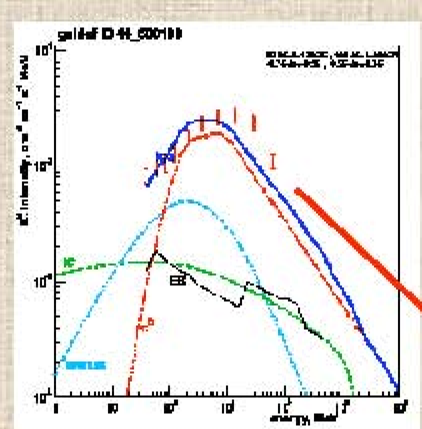
Early Measurements of CR Electrons

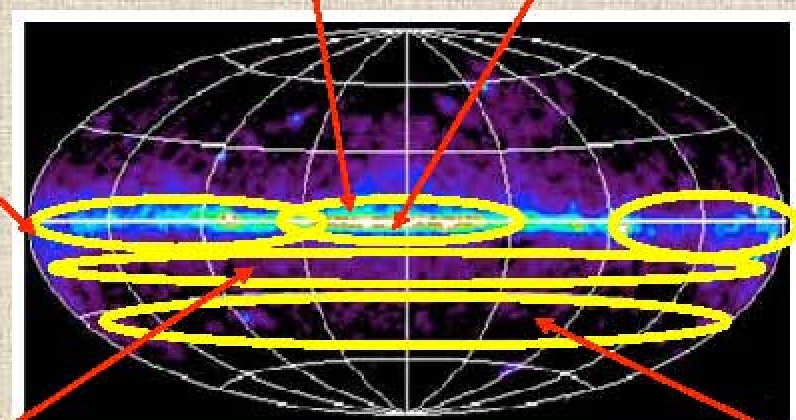


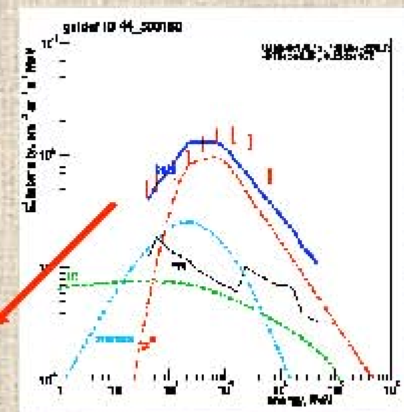
- Early measurements have shown that the spectrum of CR electrons is steeper than that of protons
- Predictions of possible spectral features @ HE associated with local SNR

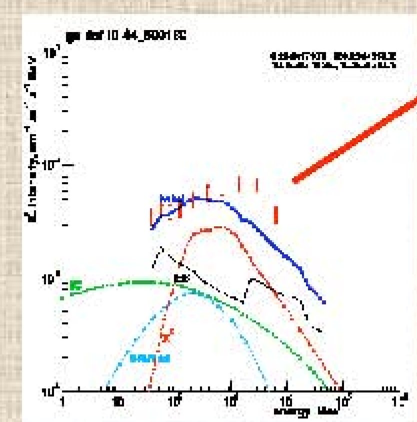
EGRET: The famous GeV γ-ray excess

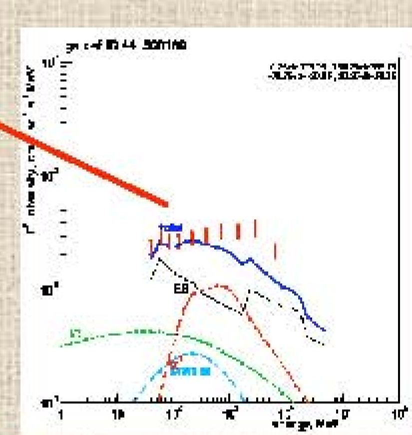












- Physical phenomena?
- Dark Matter?
- Instrumental artifact?

Strong+'00,'04