Cosmic rays from multi-wavelength observations of the Galactic diffuse emission

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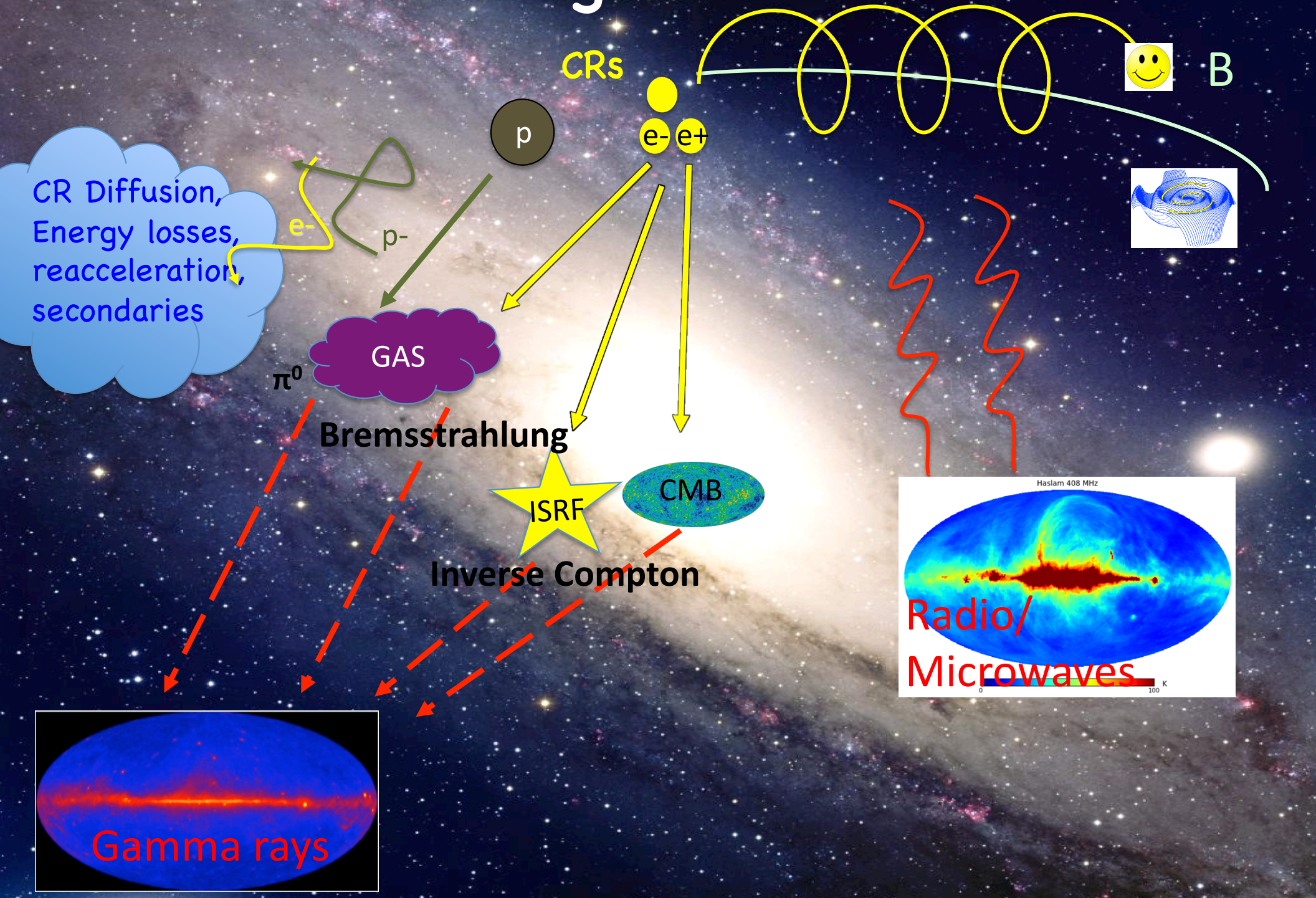
(Stanford University)

TAUP, 6-11 Sep 2015, Torino

The multi-wavelength context



Our method

Extracting information on interstellar CRs, spectral indexes of the injected particles, and propagation parameters by looking simultaneously at the diffuse emission in

- radio
- microwave
- gamma rays

accounting for CR direct measurements and advanced modeling.

Diffuse modeling: GALPROP

THE GALPROP TEAM:
I. Moskalenko and A. Strong (original developers),
S. Digel, G. Johannesson, E. Orlando, T. Porter, A. Vladimirov

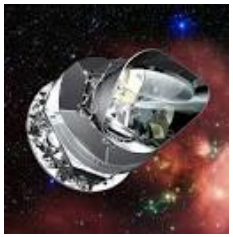
http://*galprop.stanford.edu*

Solve transport equation (energy losses, diffusion, acceleration, convection, fragmentation, radioactive decay) for all CR species

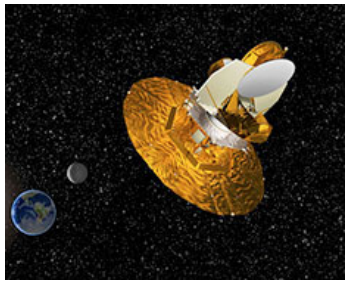
Goal : use all types of data in self-consistent way

Available all-sky data

Fermi-LAT
(now with Pass 8) Talk *by McEnery* on Monday)



Planck



WMAP

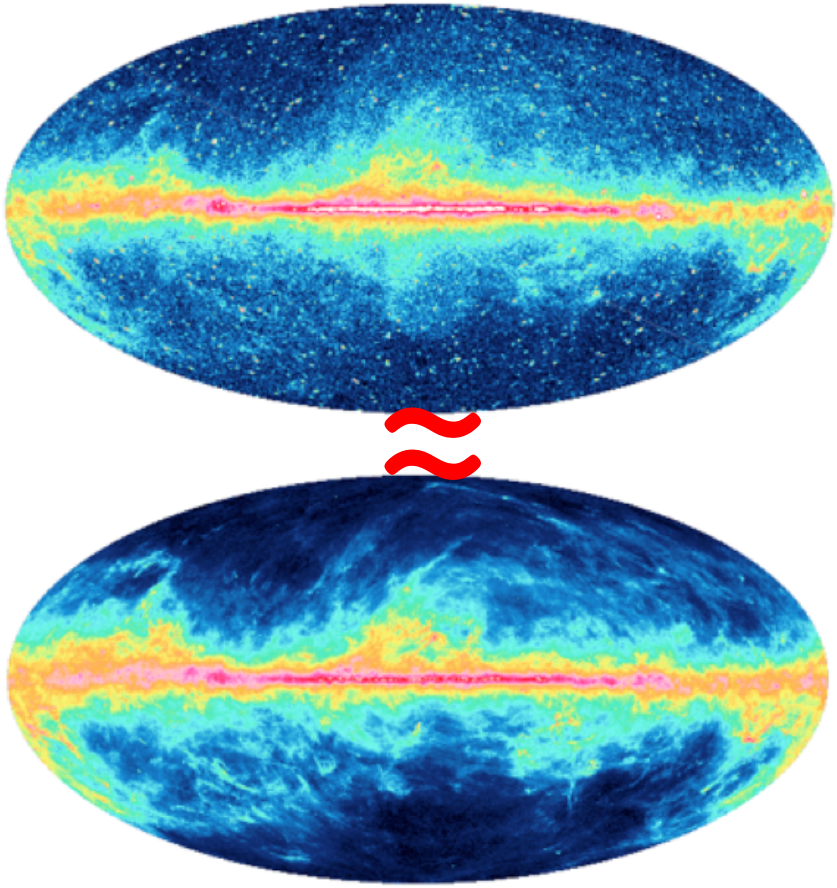
Radio Surveys

Cosmic-ray measurements (talk by *Derome* on Tue and many more this conference)
- AMS02, Pamela, Fermi, Voyager, etc

Diffuse emission

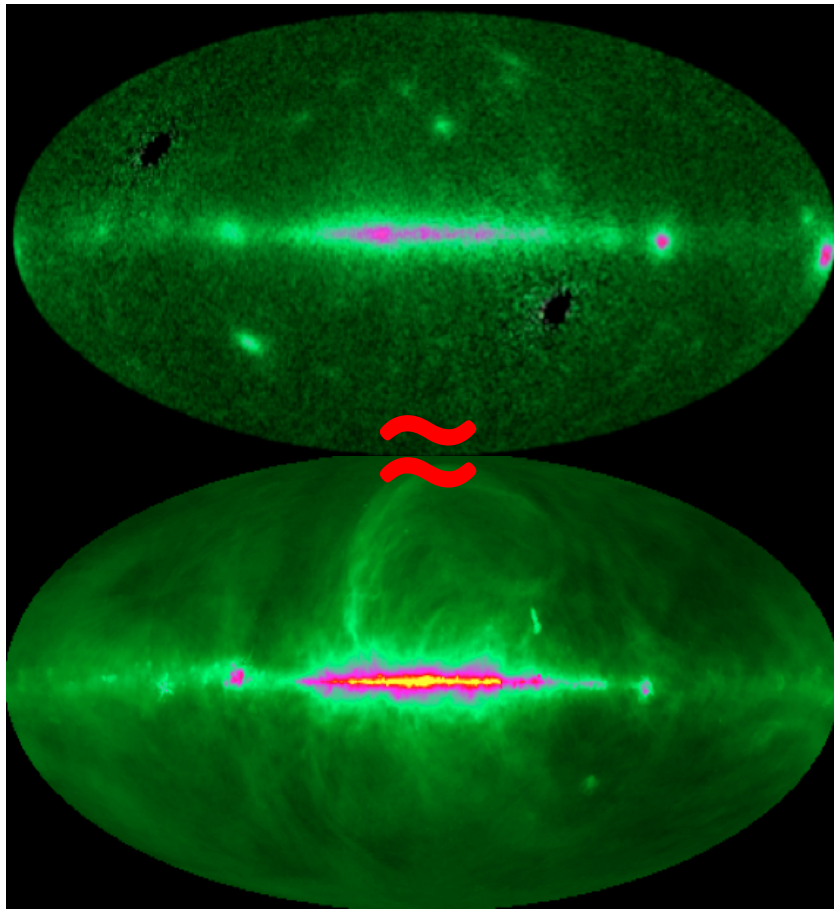
Relation: radio/microwaves – gamma rays

Fermi-LAT > 1 GeV
(Credits: *NASA/DOE/Fermi LAT Coll.* modified by Greiner et al ARAA 2015, 53-199)



Dust optical depth at **353 GHz** from **Planck** and IRAS surveys (Planck Coll. 2014 A&A 564, A45)

Fermi-LAT 30 – 80 MeV
(Orlando et al 2014 Fermi symposium)



408 MHz (Haslam et al 1981)

Our results on CRs so far 1/2

From radio/microwaves *(Strong, Orlando and Jaffe 2011 A&A, 534, 54*)* **:**

- **CR electron spectrum**:

- Break in interstellar and injection spectrum
- Standard reacceleration models are more challenging

From both gamma rays *(Ackerman et al.2012 ApJ 750, 3)* **and radio/ microwaves** *(Orlando & Strong 2013 MNRAS 436, 2127**)* **independently:**

- Flat CR source distribution in the outer Galactic plan preferred
- Halo height larger than 4 kpc preferred
- Residual structures (e.g. Loop and spurs, Fermi Bubbles, WMAP and Planck haze)

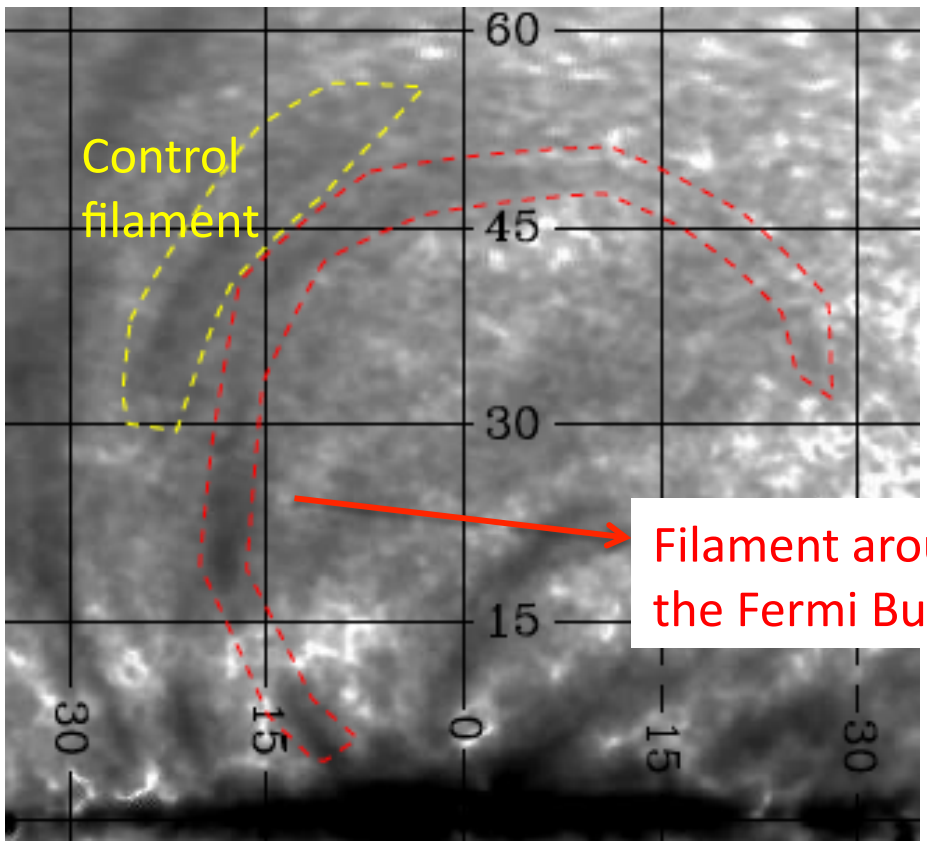
** Strong, Orlando and Jaffe 2011 best model was used for 9 yr WMAP component separation (Bennet et al 2013* ApJS., 208,20 *)*

*** Orlando & Strong 2013 best model was used for Planck component separation (Planck coll. 2015 arXiv1502.01588)*

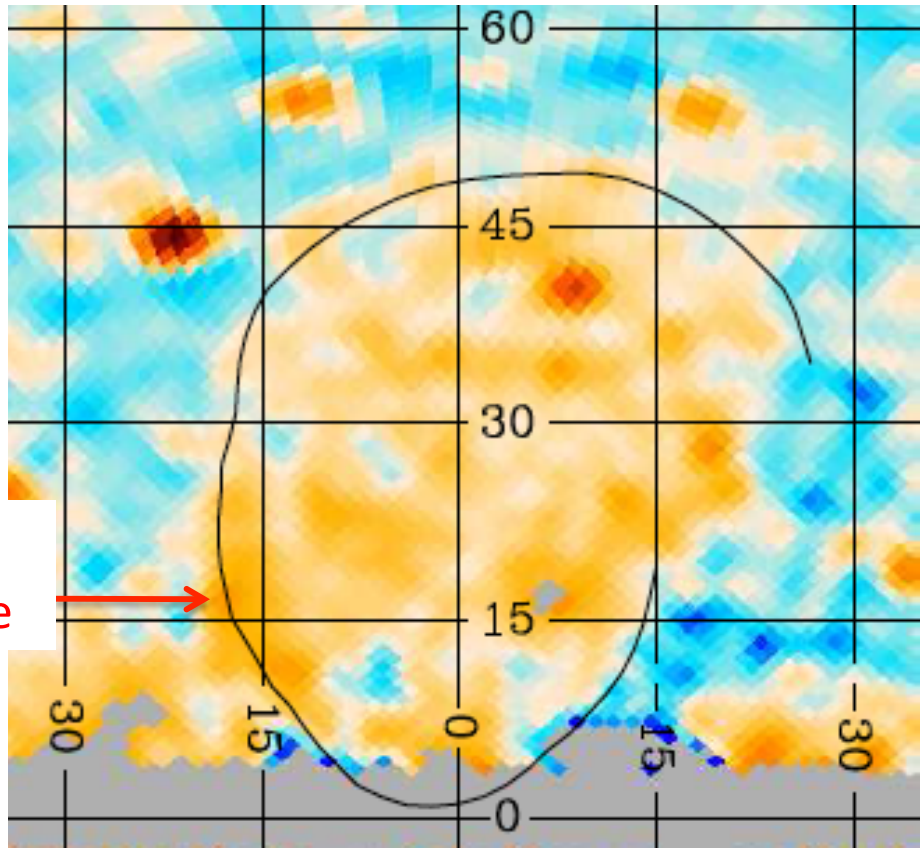
Our results on CRs so far 2/2

Fermi Bubbles and Loop I *(Planck coll. 2015 arXiv: 1506.06660*)

Planck polarization map



Fermi-LAT > 10 GeV from
Ackermann et al 2014 ApJ,793,64 (dust subtracted)



Filament around the Fermi Bubble

Updates: focussing here on the spectral study only

DATA

- Reprocessed 408 MHz map by Remazeilles et al. 2015 (better source subtraction)

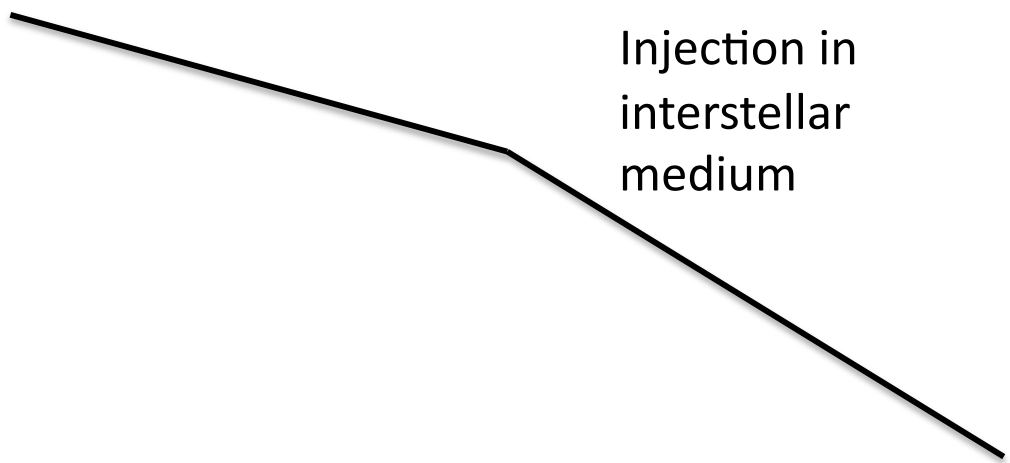
- WMAP 7-year synchrotron maps → WMAP 9-year and Planck 4 -year synchrotron maps

- Simultaneous comparison radio and gamma-ray observations

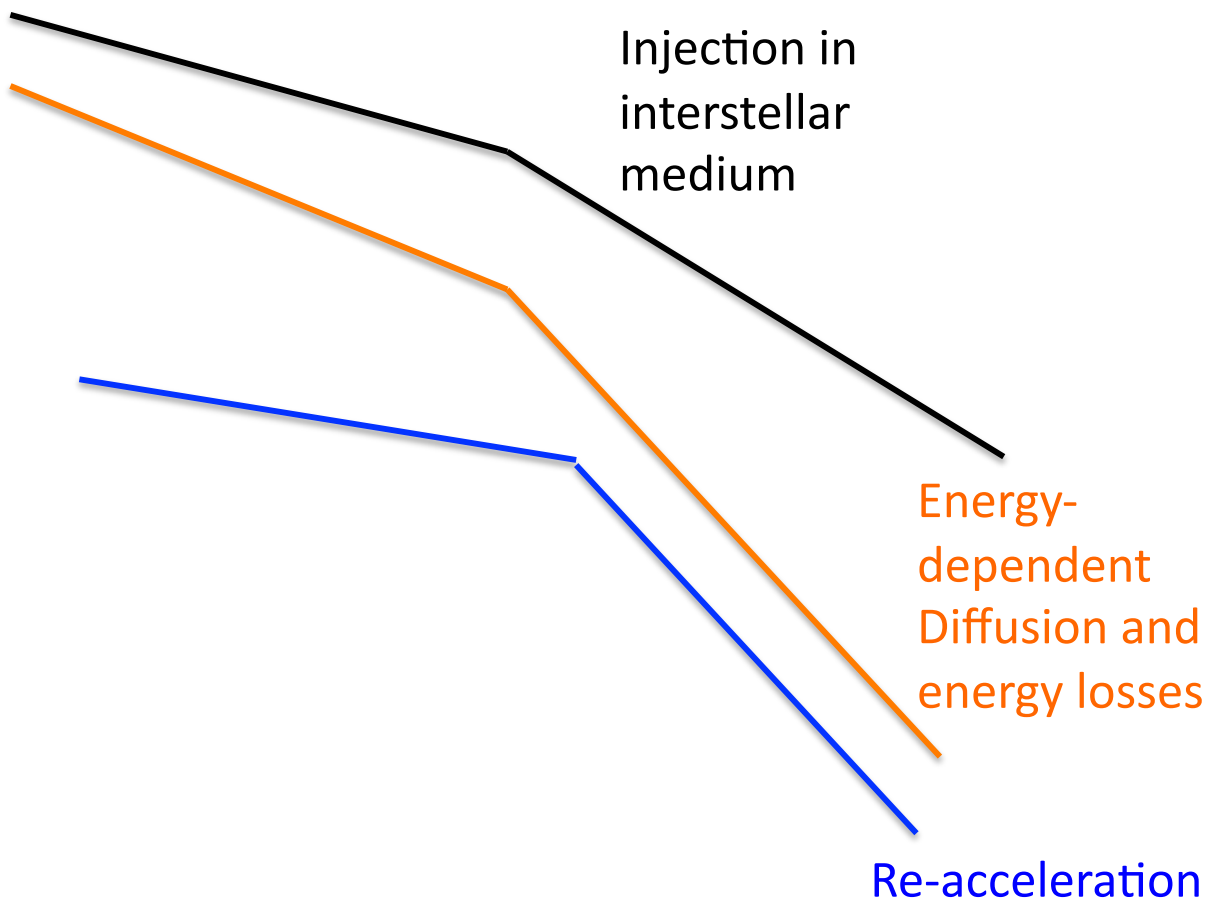
MODELING

- Low-energy Fermi CR electron measurements → PAMELA measurements

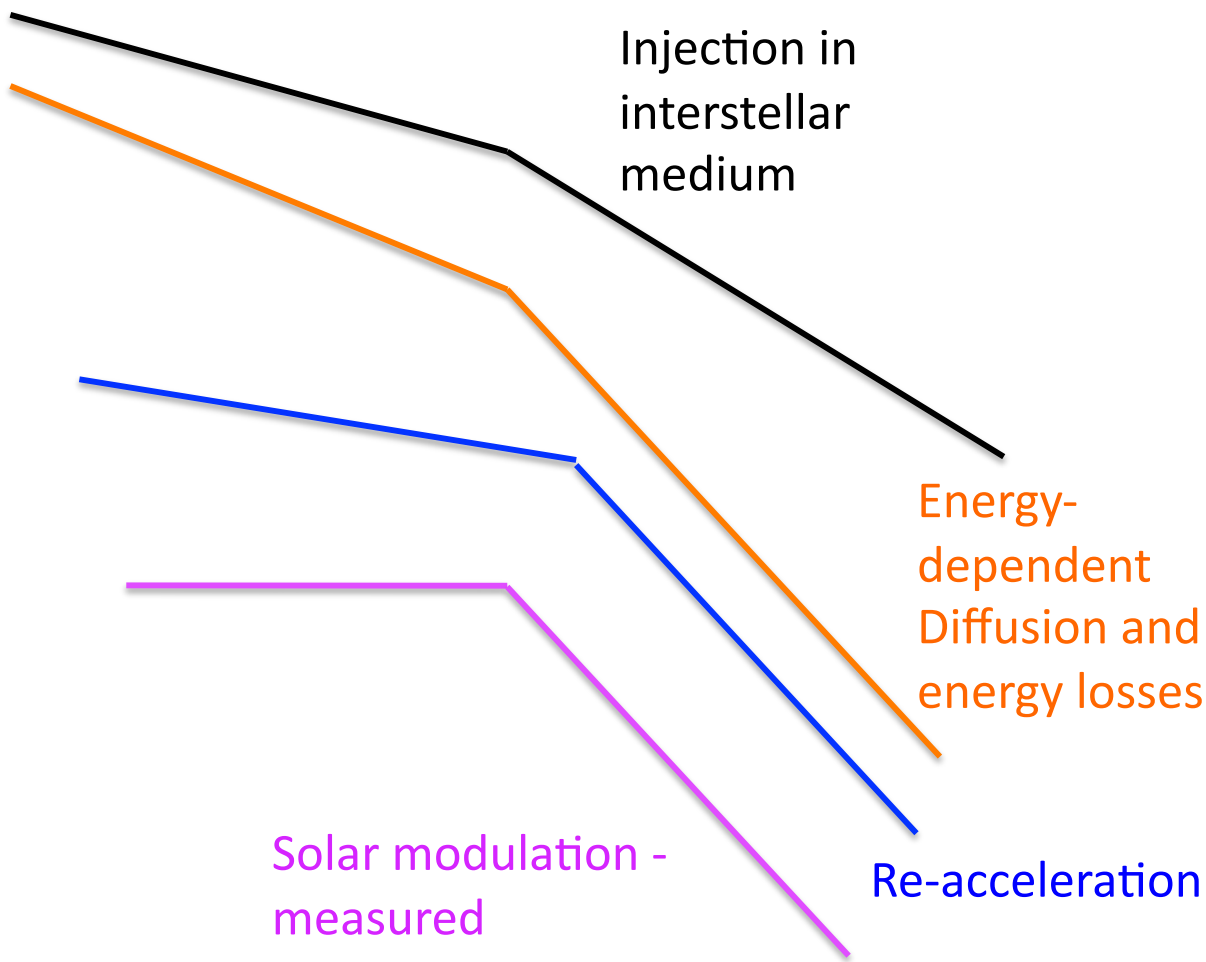
Cosmic-ray electron spectrum



Cosmic-ray electron spectrum

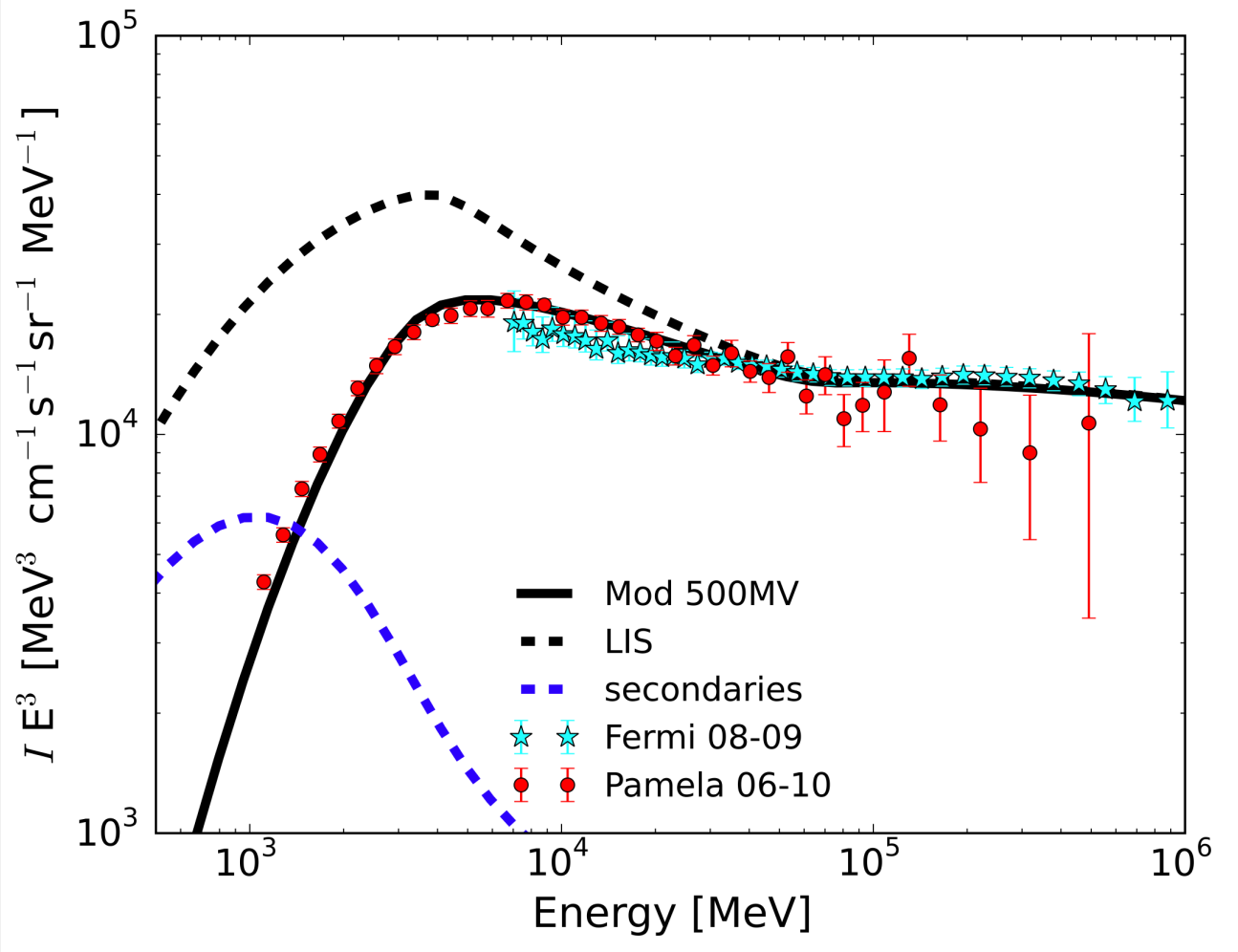


Cosmic-ray electron spectrum

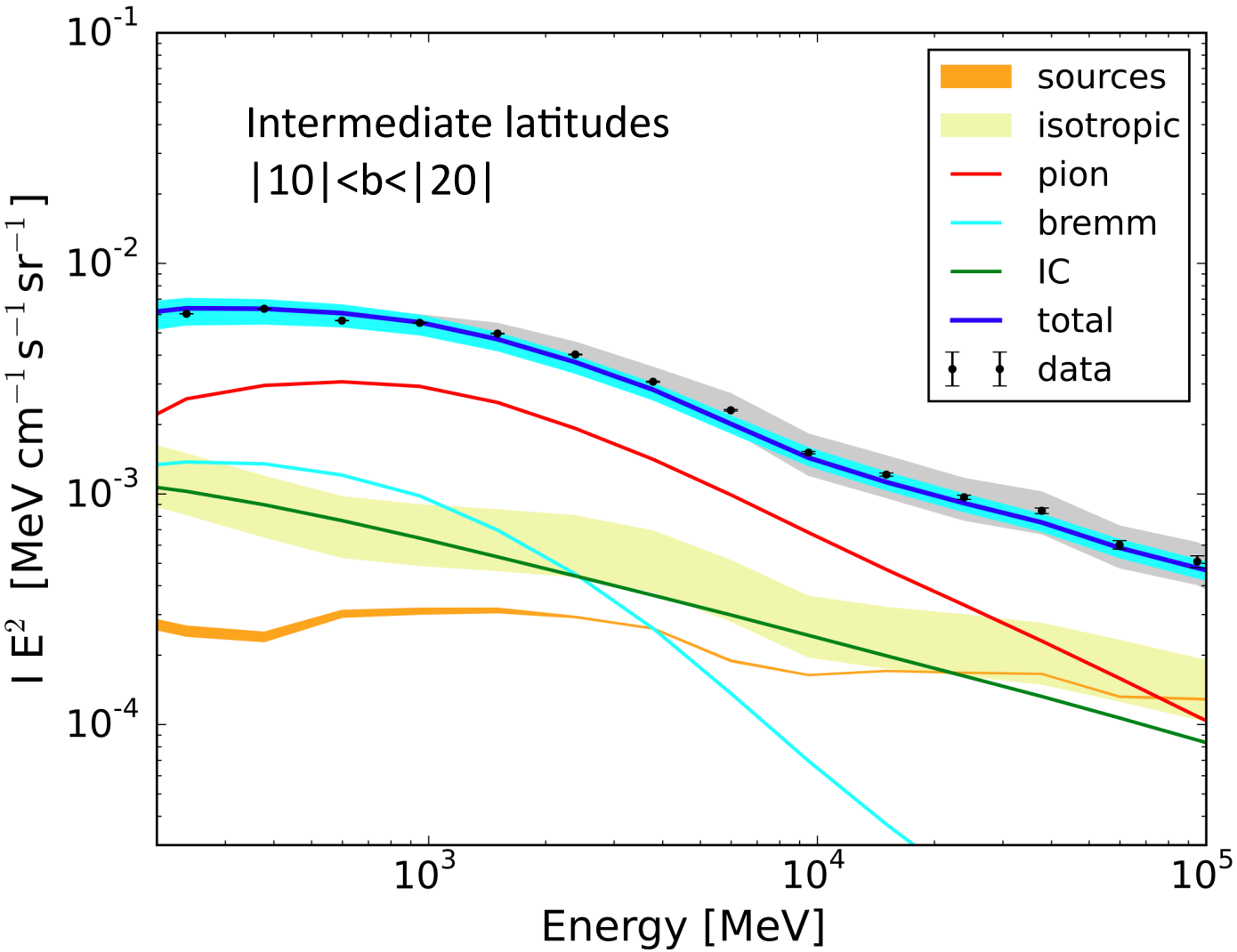


Electron LIS with no info from synchrotron

Example of diffusive re-acceleration models that works fine for other CR species and Fermi-LAT gamma-ray data.



Comparison with Fermi-LAT

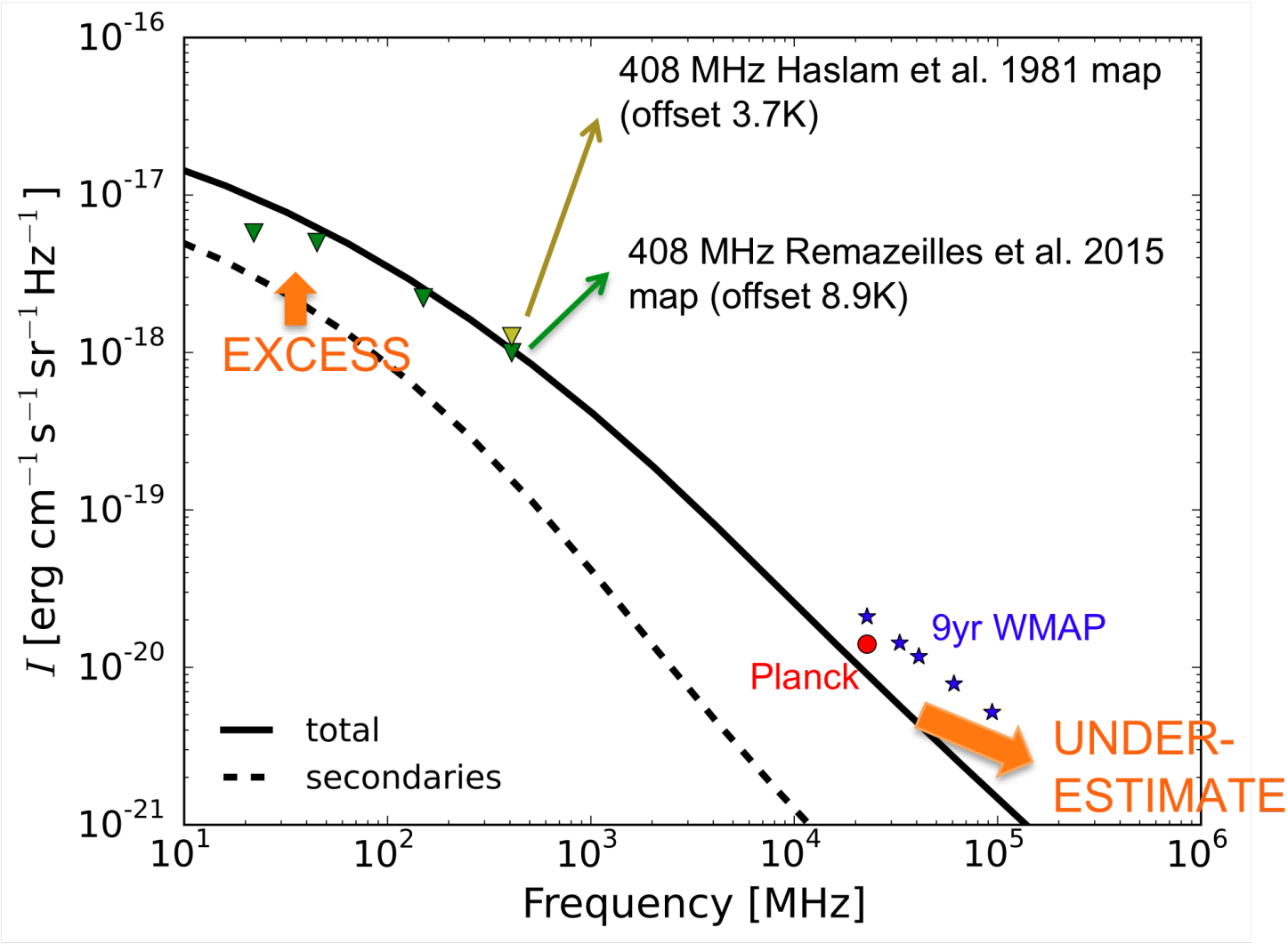


Fermi data are from Ackermann et al.2012, ApJ, 750,3

For the inner Galaxy see also talks by *Ando, Cirelli, Calore*, etc this conference

Good fit. For details see Ackermann et al.2012, ApJ,750,3

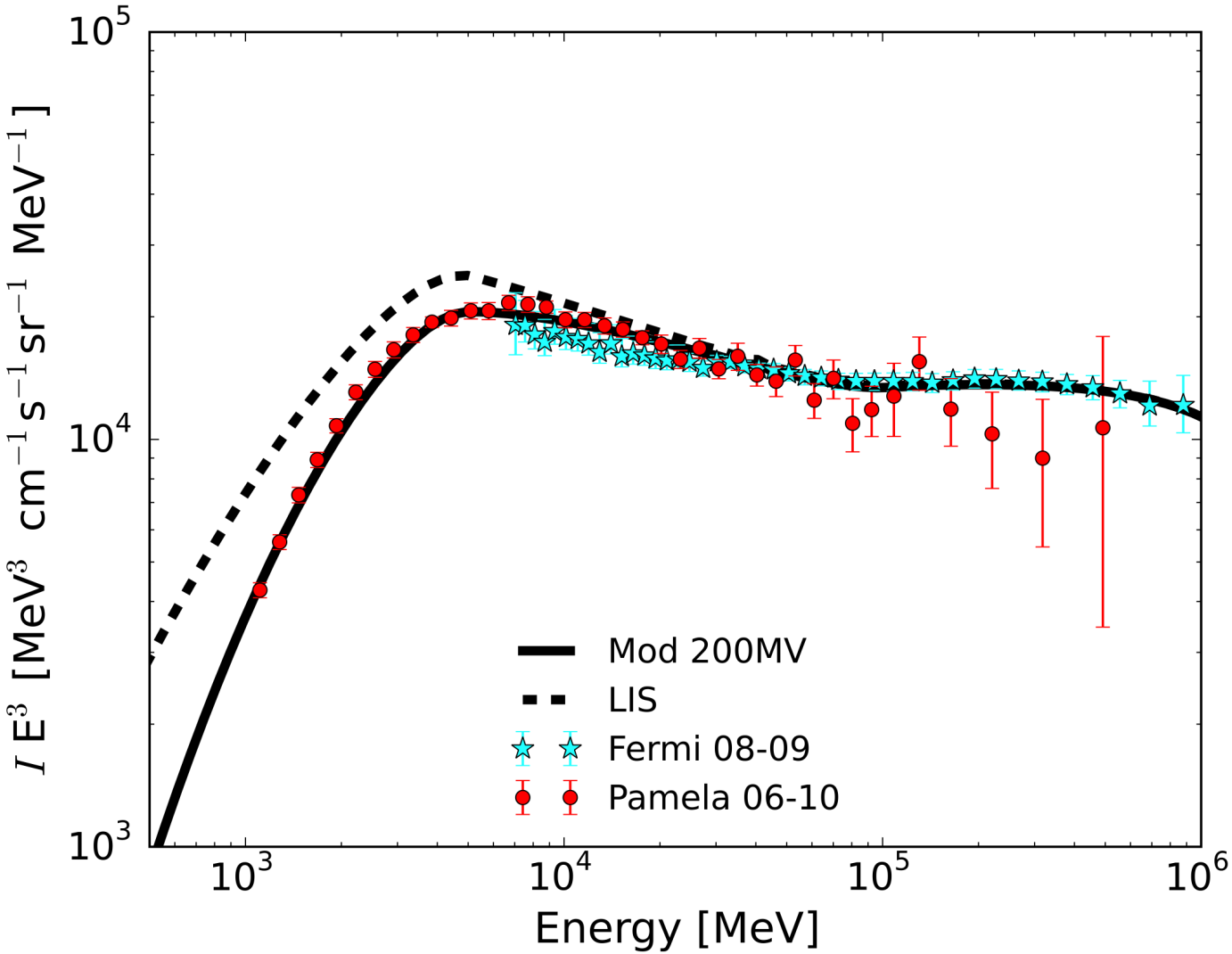
Produced synchrotron emission



B-field intensity is fit to the 408 MHz map

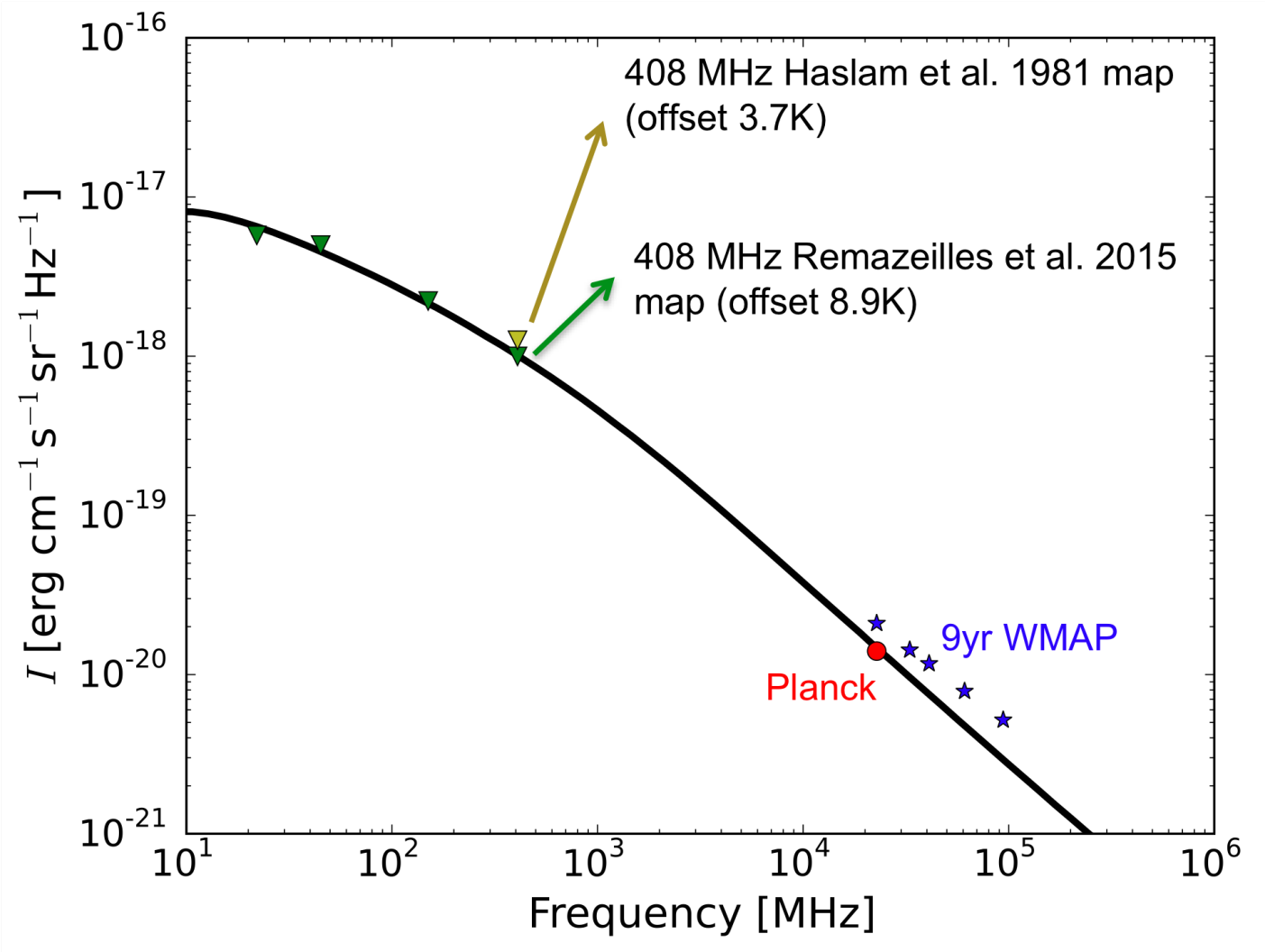
Electron LIS with info from synchrotron

Example of plain diffusion propagation models



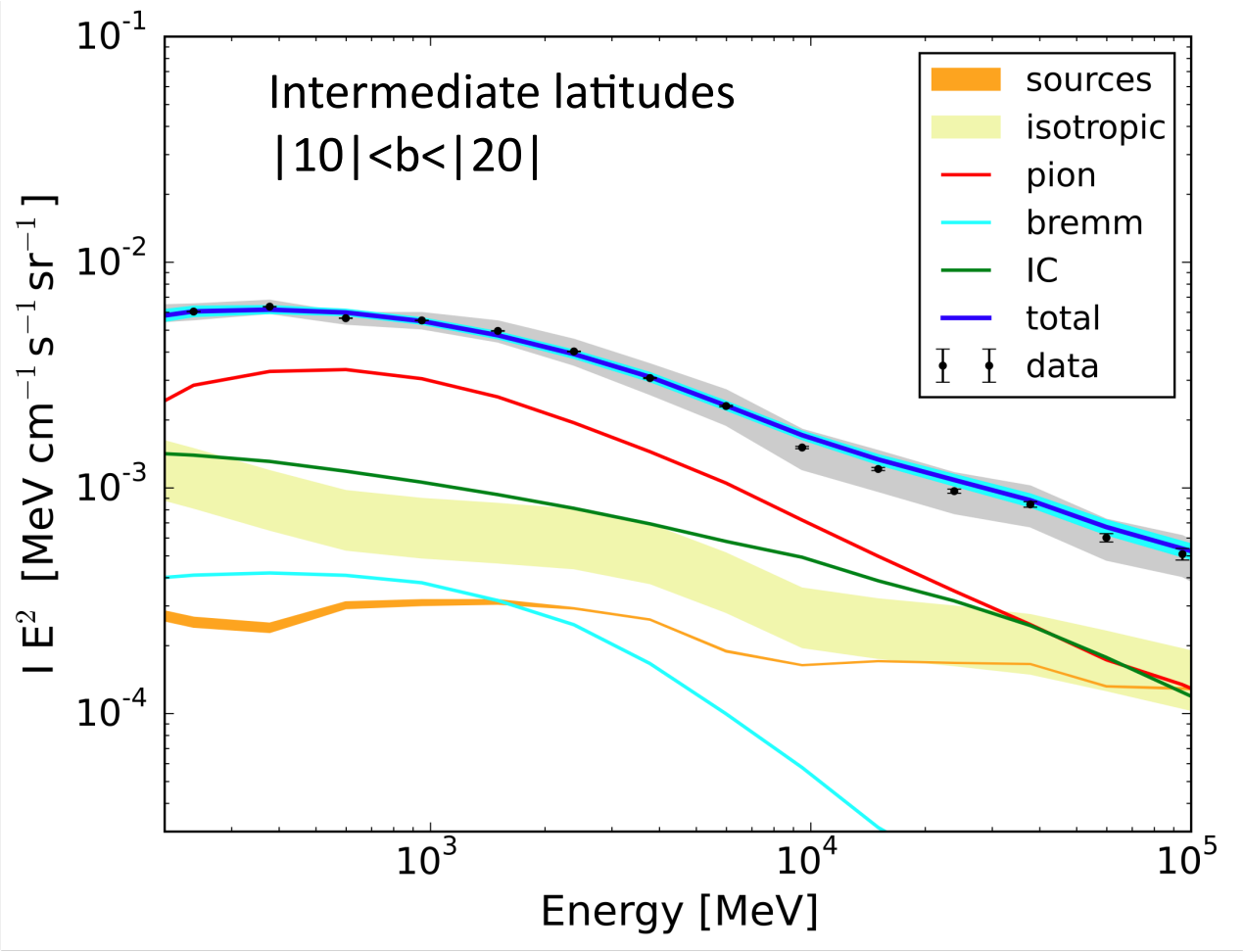
More details in Orlando, Strong, Moskalenko, Dickinson, Digel, Jaffe, Jóhannesson, Leahy et al. ICRC 2015; arXiv:1507.05958

Produced synchrotron emission



B-field intensity is fit to the 408 MHz map

Produced gamma-ray emission and comparison with Fermi-LAT



Fermi data are from Ackermann et al.2012, ApJ,750,3.

Good fit. Especially important at low energy (Pass 8 data), were the models have the biggest difference and the leptonic emission is at its maximum

Conclusions

We found a propagation model that reproduces CR measurements, and spectral gamma rays and radio/microwave observations simultaneously.

Multi-messenger observations constrain the interstellar spectrum, propagation models, and solar modulation effects.

In turn this is a step forward improving models of the large scale diffuse emission and characterizing structures found at opposite wavelengths.

Important for forthcoming radio telescopes and MeV - GeV energy missions.

Thank you for your attention!