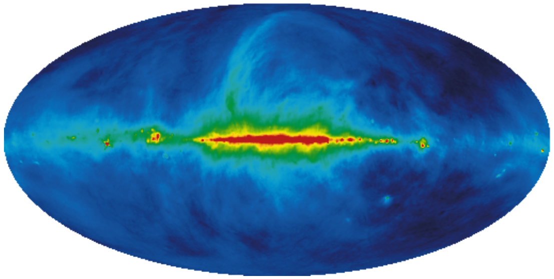
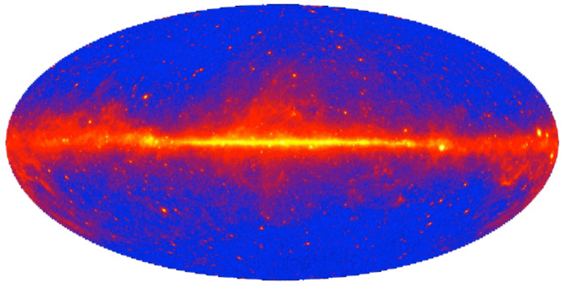




Cosmic rays and interstellar emissions from radio to gamma rays

Elena Orlando
(Stanford University)

Three elephants in the gamma-ray sky
21-24 October 2017
Garmisch-Partenkirchen

Interstellar emissions as a tool to study large-scale CR propagation and interaction in the Galaxy



How do we obtain the background/foreground for the Fermi Bubbles, GC excess, and Loop I?

Spatial templates
Spectral templates
A combination of the above
Data-driven

Issues:
1. Related to Galprop/Dragon
2. Standard CR propagation/interaction models challenged by recent data
3. No more physical info

Usual approach with CR propagation codes (Dragon, Usine, Picard, Galprop)

1. Propagation parameters from B/C and radioactive isotopes, but …
   (Genolini+2015, Jóhannesson+2016, also talk by Ralf)

2. Tuning CR injected spectra to the CR direct measurements

3. Calculating gamma-ray emission assuming models of IRSF, gas distribution, B-field, and a given CR source distribution.

4. Accounting for uncertainties on gas, IRSF, and CR source distributions by fitting and scaling the Galactic emission in rings, and in energy bins

For a general description of these codes see talks by Ralf, Carmelo, Gulli, Andrea

Usual approach with CR propagation codes (Dragon, Usine, Picard, Galprop)

1. Propagation parameters from B/C and radioactive isotopes, but …
   (Genolini+2015, Jóhannesson+2016, also talk by Ralf)

2. Tuning CR injected spectra to the CR direct measurements

3. Calculating gamma-ray emission assuming models of IRSF, gas distribution, B-field, and a given CR source distribution.

4. Accounting for uncertainties on gas, IRSF, and CR source distributions by fitting and scaling the Galactic emission in rings, and in energy bins, BUT: no more info on CRs!

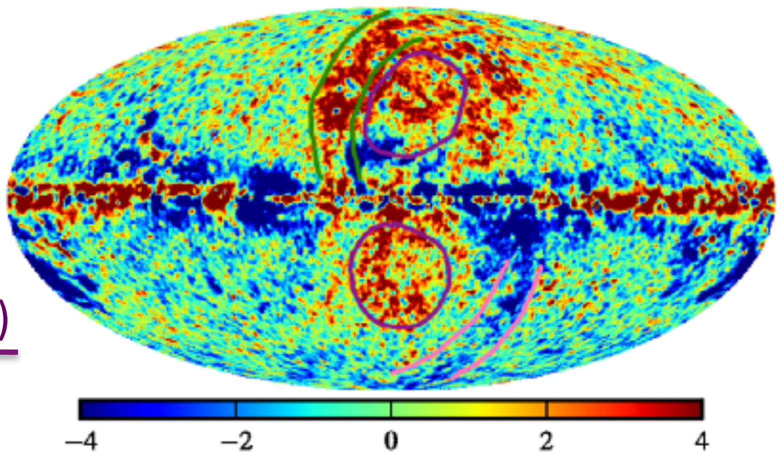
For a general description of these codes see talks by Ralf, Carmelo, Gulli, Andrea

Do we really understand CR propagation/ interaction and distribution?

See also talk by Carmelo, Andrea, Gulli

Challenges 1/3

Ackerman et al.2012 ApJ 750,3
*Also:*Abdo et al. 2010 ApJ 710,133
Ackermann et al. 2011 ApJ 726 81
Ackermann et al. 2012 A&A 538 A71



(model-data) / model

Further excess:
- Outer Galaxy

Hints for:
- Larger halo size*
- Additional gas in the outer Galaxy
- Flat CR source distribution*

Alternative explanation:
- Larger diffusion in the plane (Gaggero et al 2015), anisotropic D

* Also found in the study comparing the synchrotron emission models with radio and microwave data (Orlando & Strong 2013)

Challenges 2/3

The *Fermi* Galactic Center GeV Excess and Implications for Dark Matter

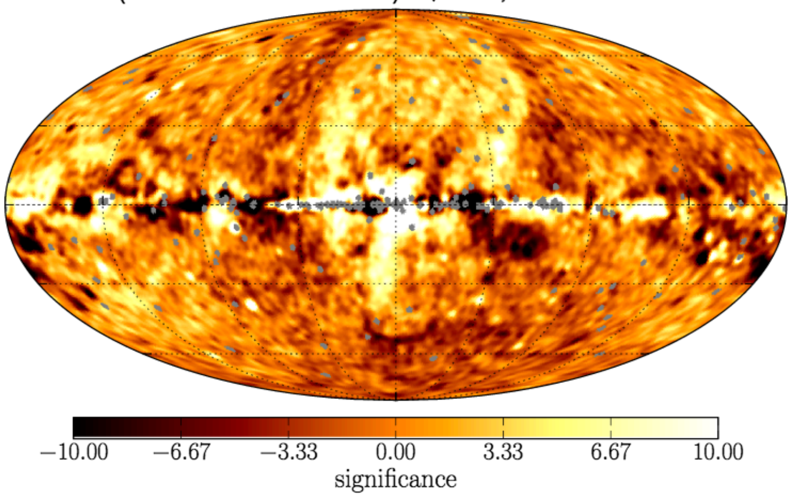
M. Ackermann[1], M. Ajello[2], A. Albert[3], W. B. Atwood[4], L. Baldini[5], J. Ballet[6], G. Barbiellini[7,8], D. Bastieri[9,10], R. Bellazzini[11], E. Bissaldi[12] +Show full author list

Published 2017 May 4 •

The Astrophysical Journal, Volume 840, Number 1

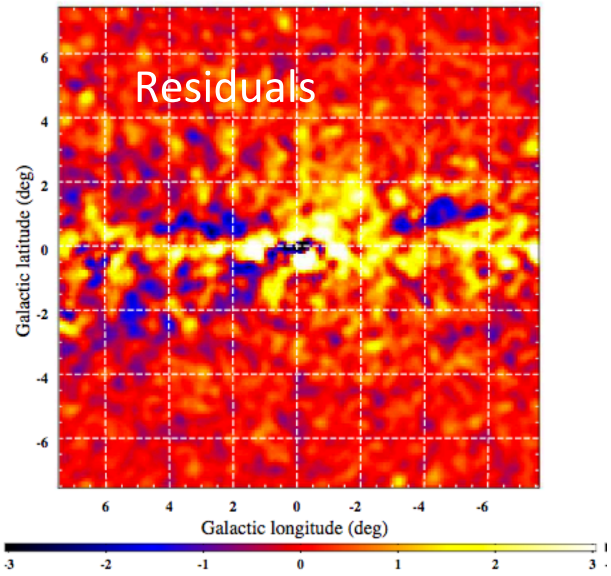
sources of gamma rays. The GC is of particular interest, as it would be expected to have the brightest signal from annihilation of weakly interacting massive dark matter (DM) particles. However, control regions along the Galactic plane, where a DM signal is not expected, show excesses of similar amplitude relative to the local background. Based on the magnitude of the systematic uncertainties,

(Residual + GC excess) / $\sqrt{\text{Data}}$, 1.1 - 6.5 GeV

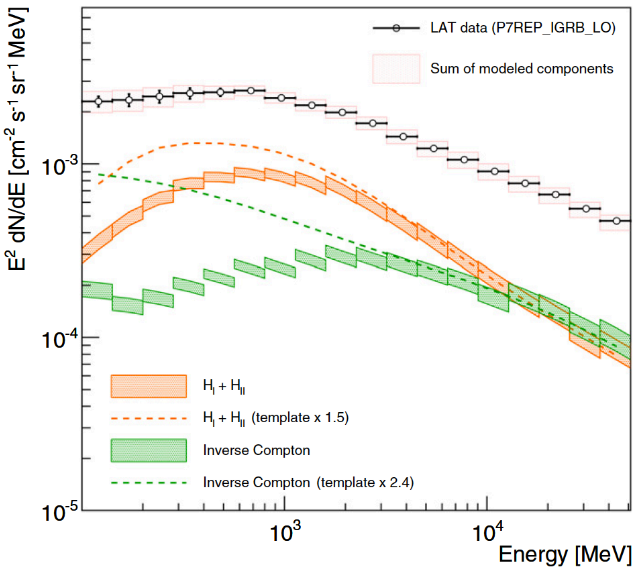


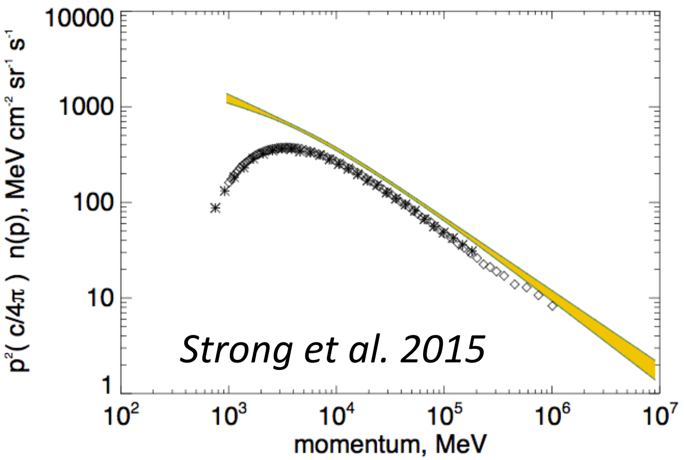
Challenges 3/3

Abdo et al. 2016



Ackermann+ 2015





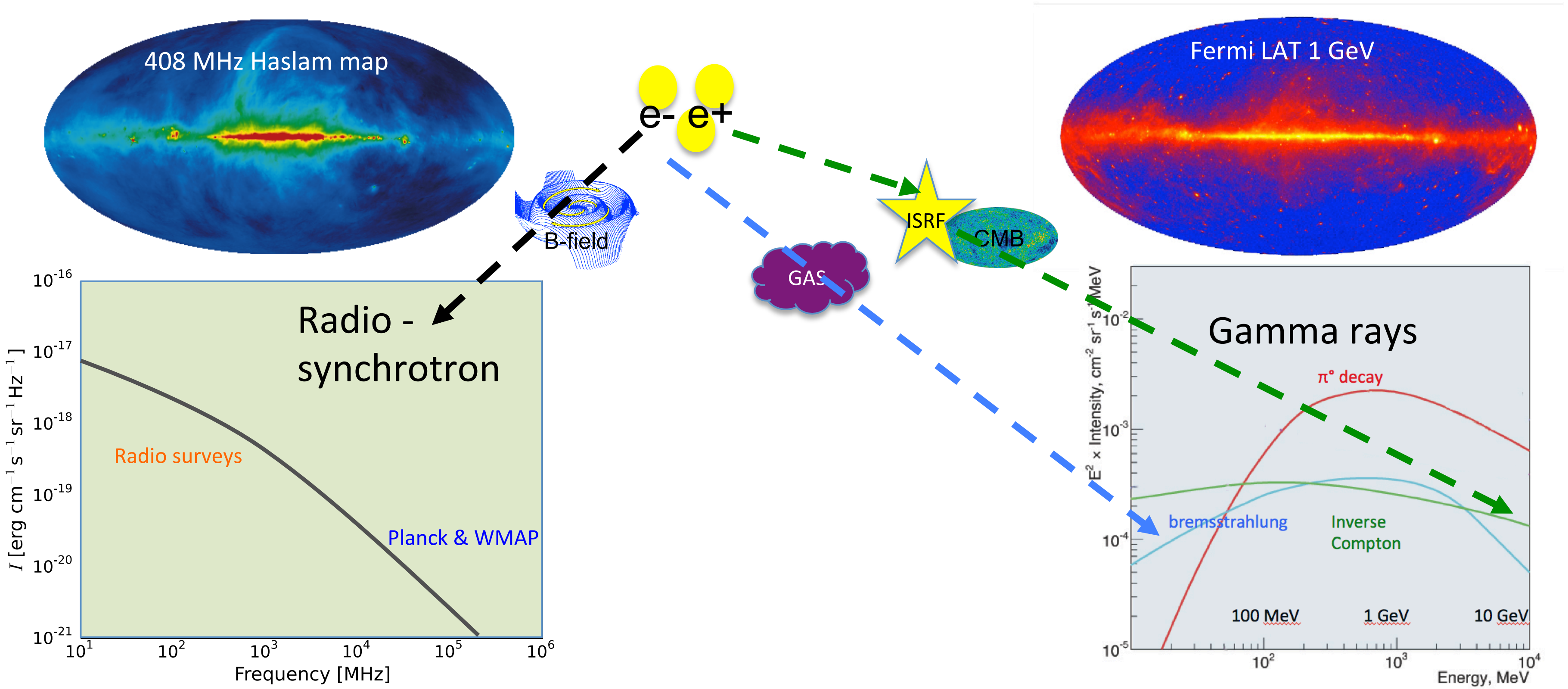
Strong et al. 2015

HELP

by looking for consistency

and from multi-frequency observations

Radio/gamma relation



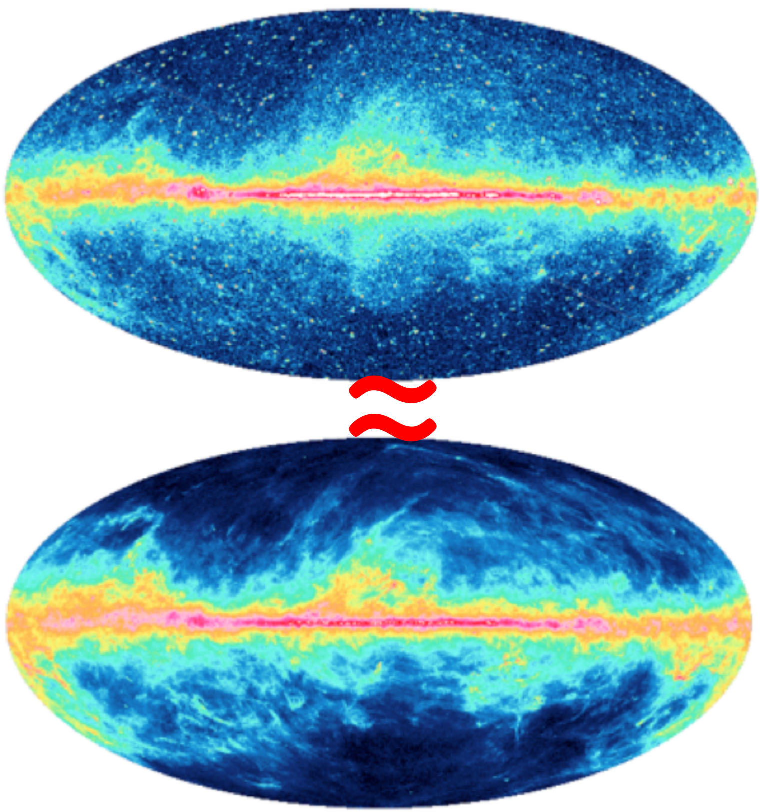
Mitigating degeneracy

Relation radio - microwaves - gamma

Relation: radio/microwaves – gamma rays

Fermi-LAT > 1 GeV

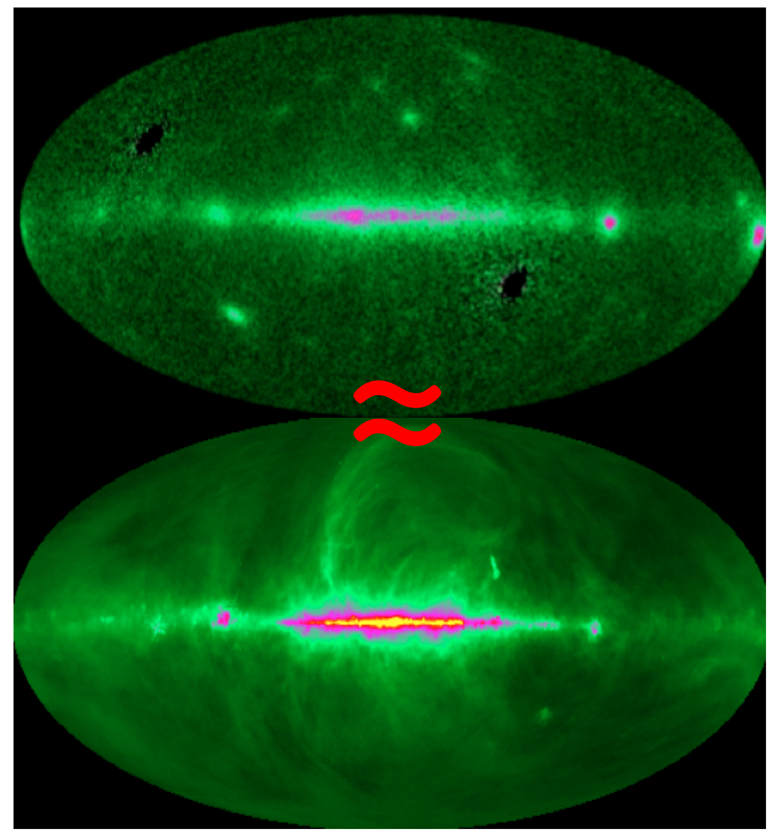
(Credits: *NASA/DOE/Fermi LAT Coll.* modified *by Greiner et al ARAA 2015, 53-199*)



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

Fermi-LAT 30 – 80 MeV

(*Fermi LAT coll. 2014 Fermi symposium, Orlando*)



408 MHz (*Haslam et al 1981*)

Models used for gamma-ray analyses

- Only standard reacceleration models
- No constraints from radio synchrotron

BUT

- Magnetic field is important for energy losses and diffusion

- Synchrotron spectrum informs on e-e+ spectrum

All very important especially for the Inverse Compton emission!

Radio and microwave modeling

A&A 534, A54 (2011)

The interstellar cosmic-ray electron spectrum from synchrotron radiation and direct measurements*

A. W. Strong[1], E. Orlando[2,1] and T. R. Jaffe[3,4]

Hardening in local interstellar electron spectrum due to Injection < GeV

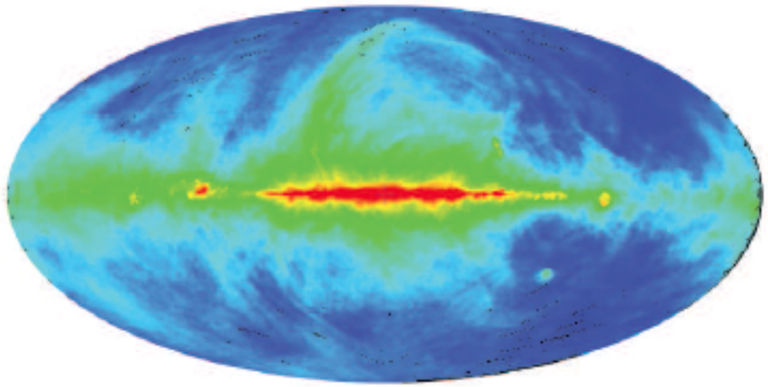
Standard reacceleration models challenging to reconcile with radio data (too many secondaries)

Also confirmed by Jaffe 2011 and Gaggero et al. 2013

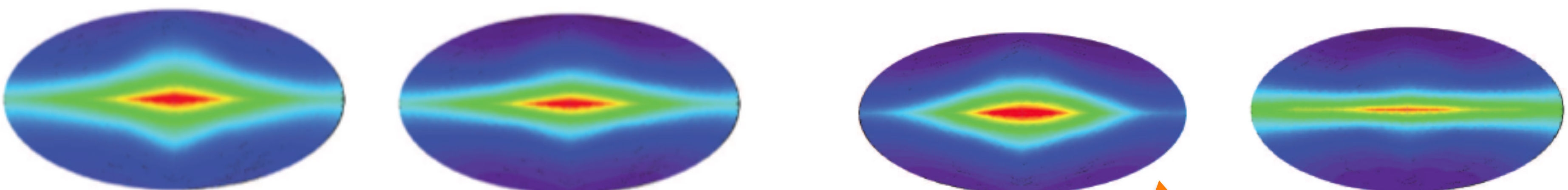
Radio and microwave modeling

Orlando & Strong 2013 MNRAS 436, 2127

I @ 408 MHz



3D models of
B-fields and
polarization
Implemented
in GALPROP!



Z=10 kpc

Z=4 kpc

Different propagation
halo size

Different CR
electron
distribution

Different CR source
distributions

Also Different B-fields
(regular, random, anisotropic)

Main results

Best model:

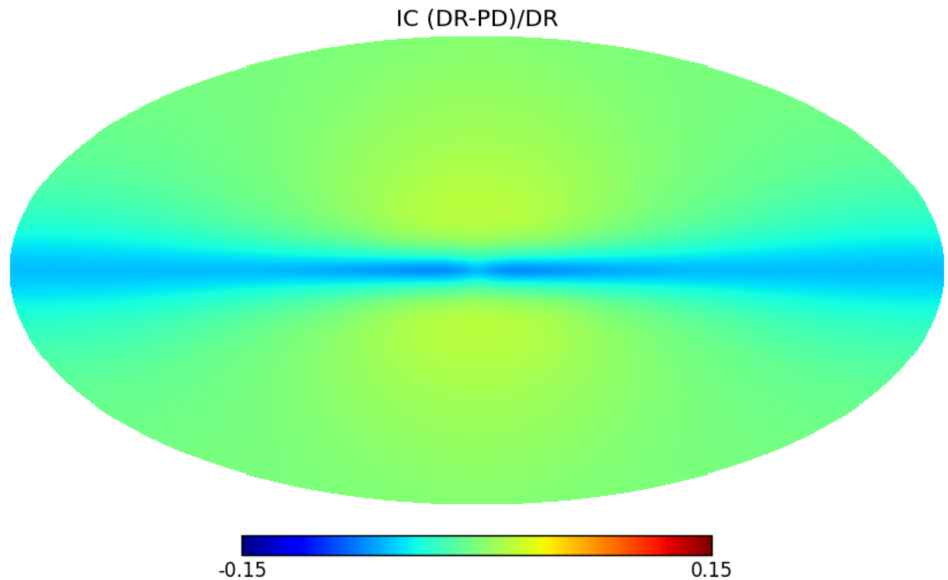
- Flat CR source distribution in the outer Galaxy
- Preference of halo height > 4 kpc

Magnetic field intensity obtained

Plain diffusion fits best also spatially

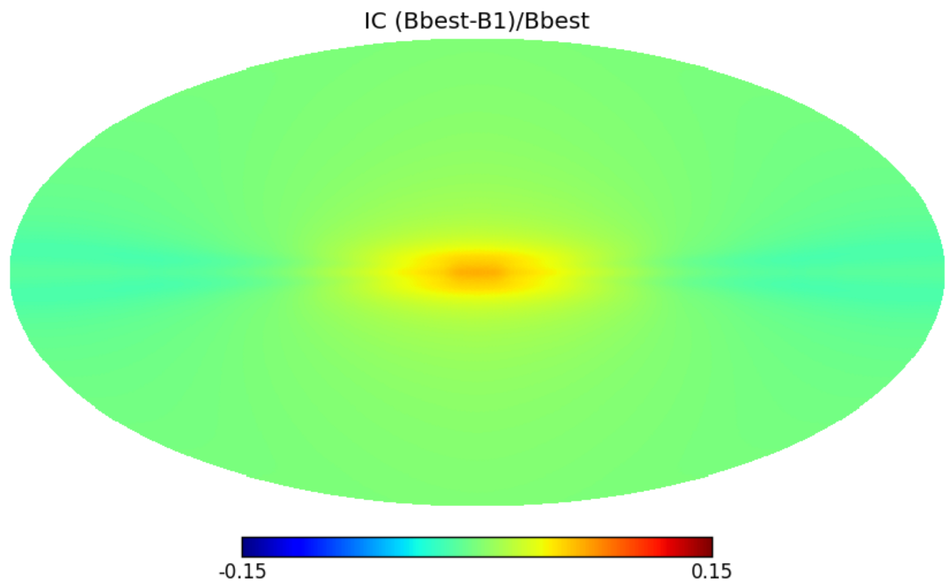
Orlando & Strong 2013 MNRAS 436,2127

Examples for illustration: effect of reacceleration



(See also Gulli's talk on the effect of 3D CR source distribution)

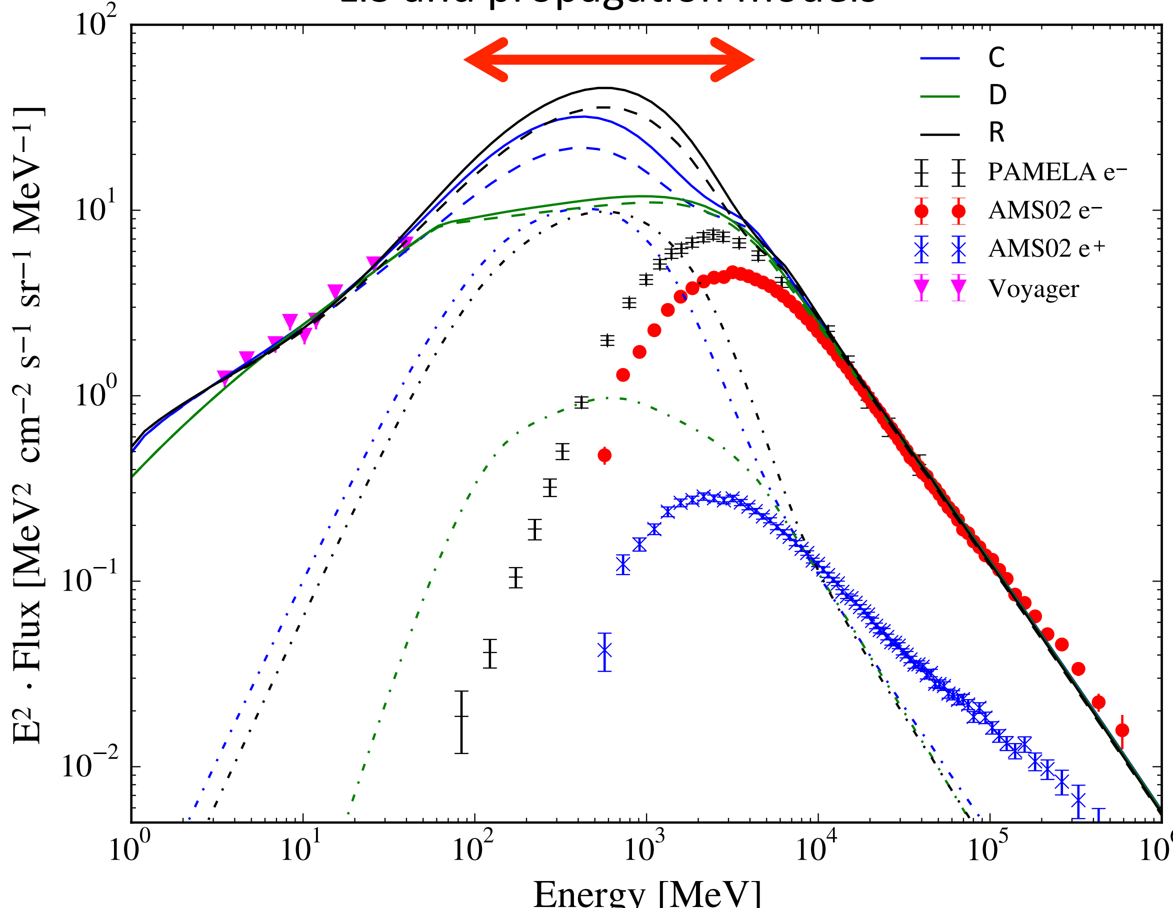
Examples for illustration:
Effect of different B-field models on the Inverse Compton emission



(See also Gulli's talk on the effect of 3D CR source distribution)

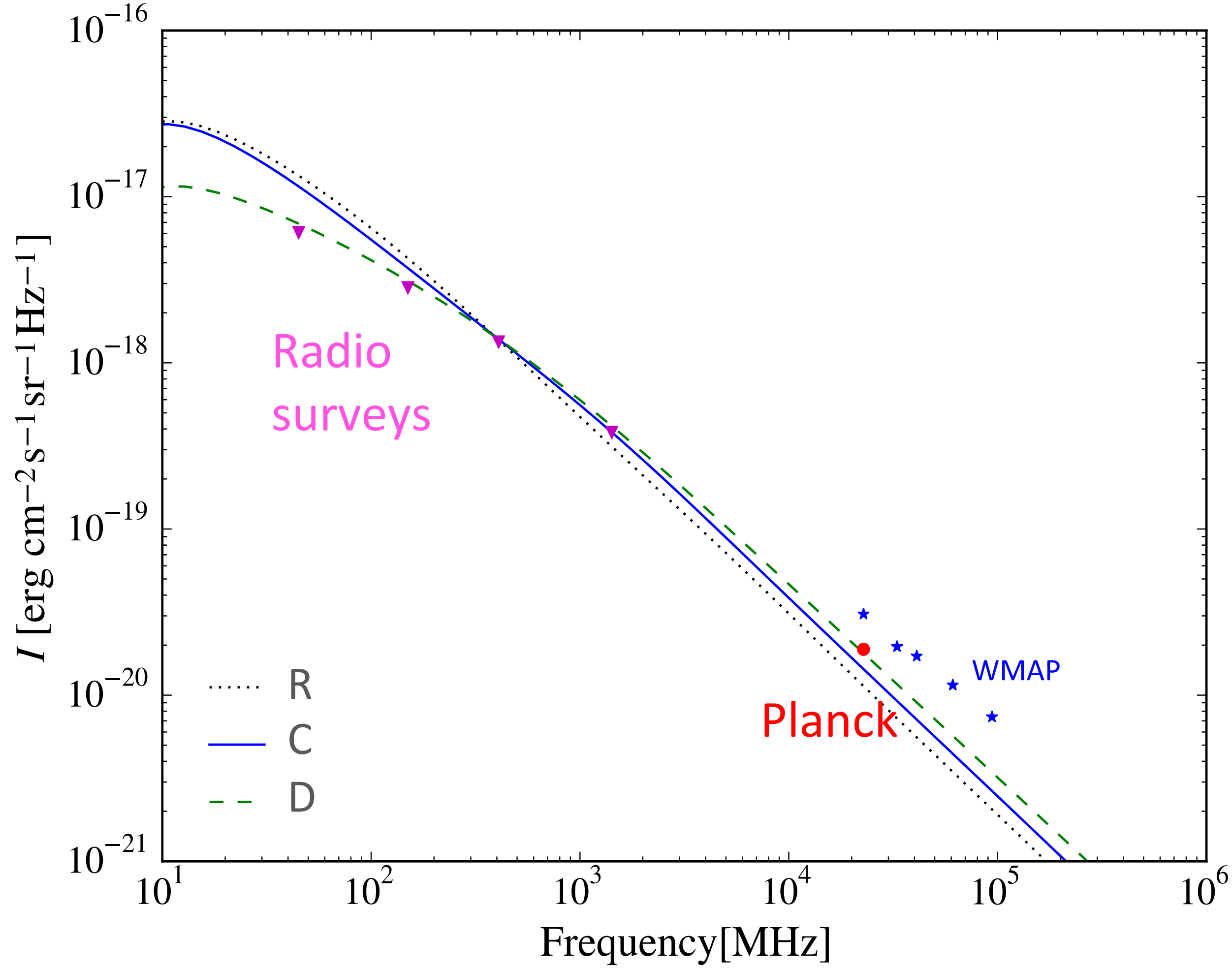
Electron (& positron) local interstellar spectrum

Energy range important for:
LIS and propagation models



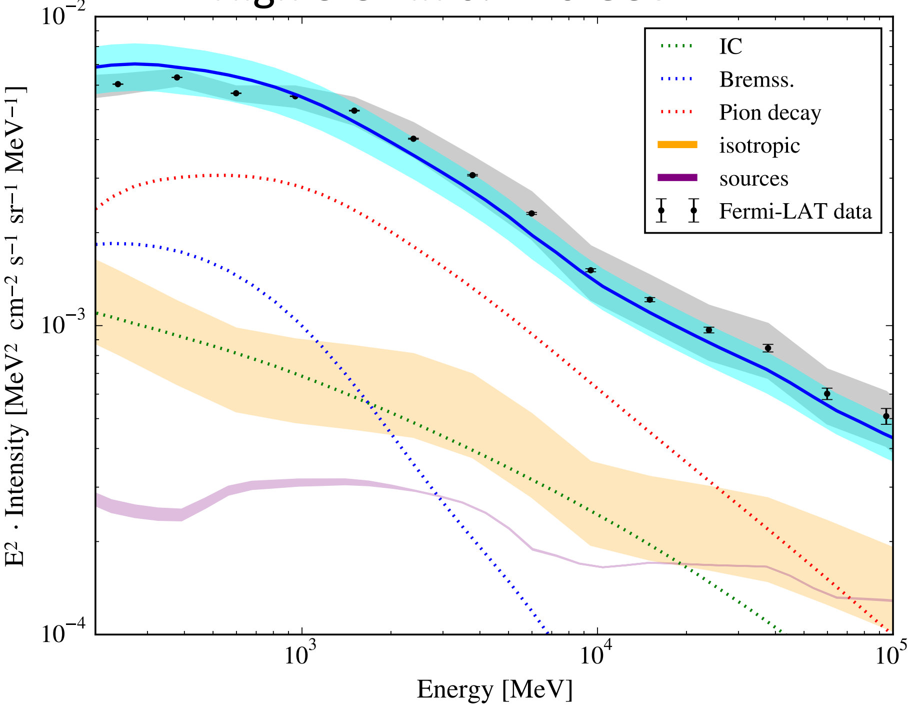
Orlando 2017 submitted (and following)

Produced synchrotron emission

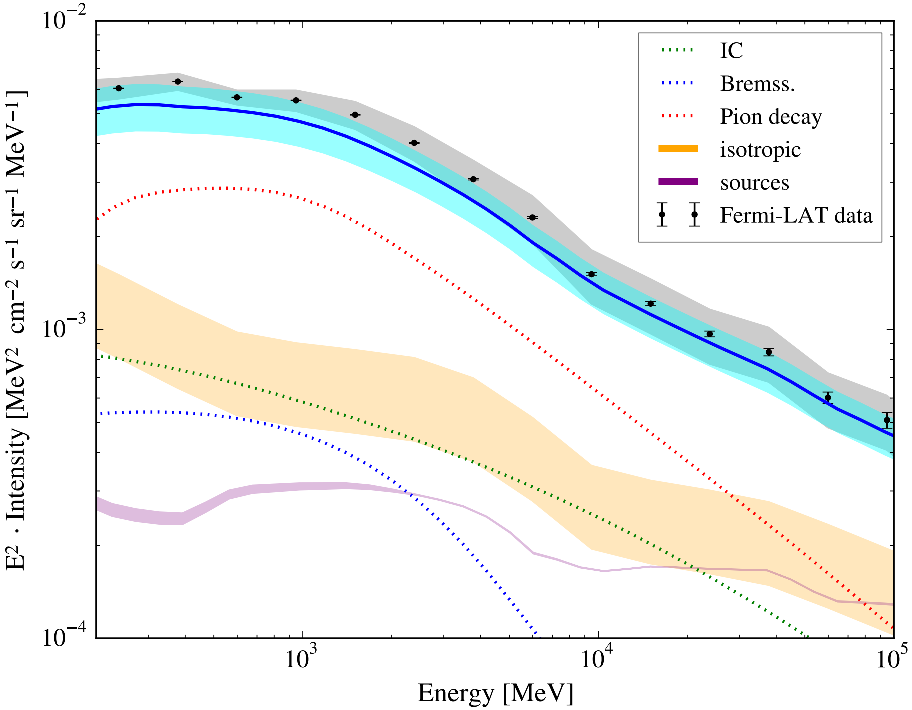


Constraints to Gamma-ray emission

High e-e+ in 0.1-10 GeV

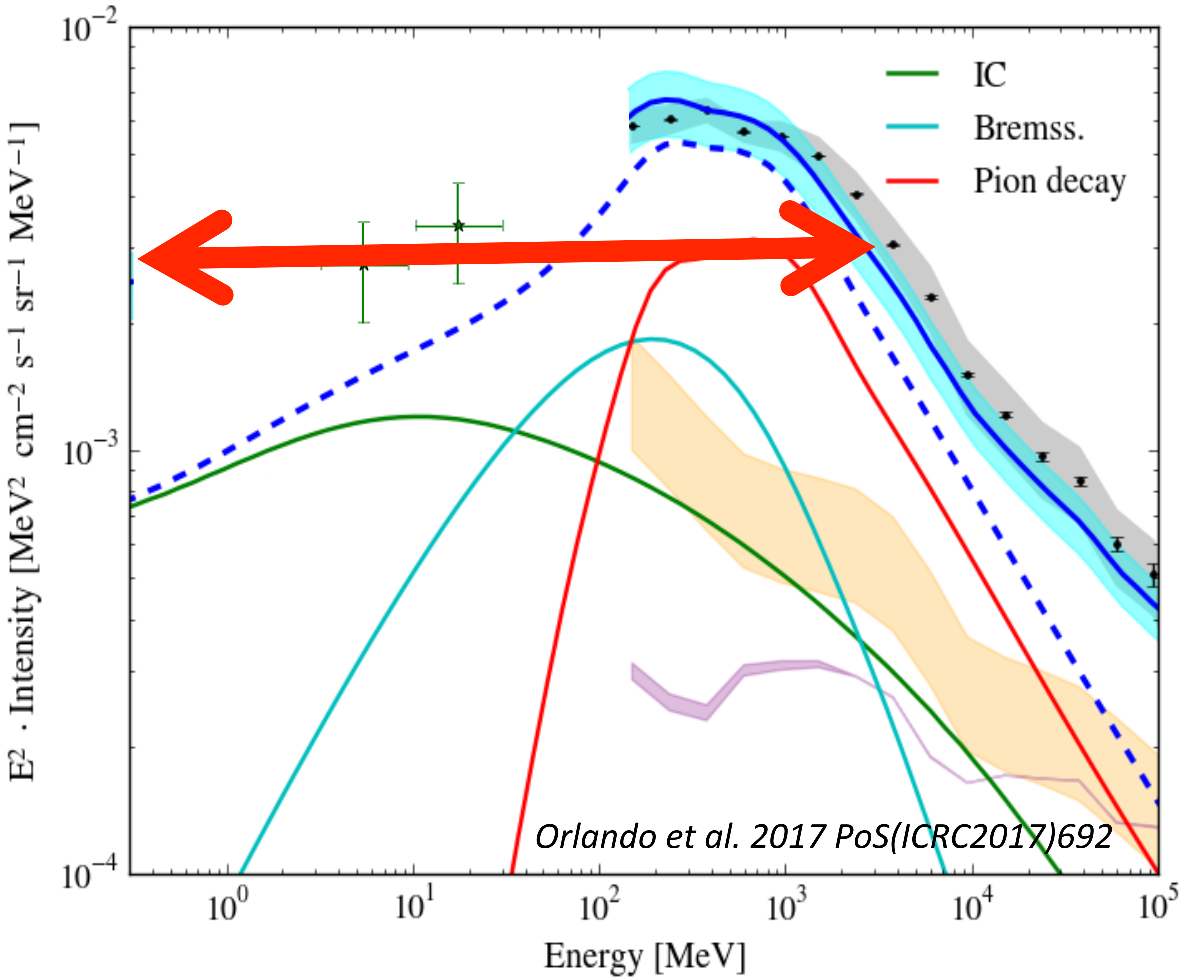


Low e-e+ in 0.1-10 GeV



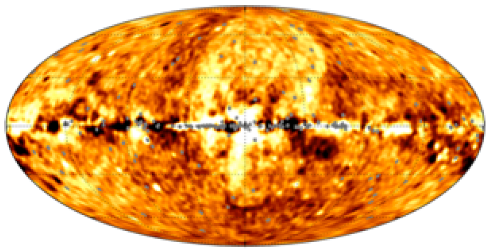
Fermi data are from
Ackermann et al.2012, ApJ,750,3

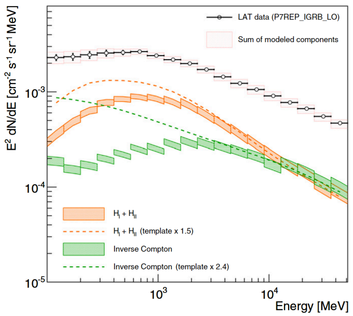
MeV energy ranges



Summary

- There are many challenges to the basic interstellar models. Even the story outside the elephants is not understood





- Additional constraints from radio/microwave emission help in understanding not only the elephants, but also the basic IEM and CR propagation, and together can mitigate some degeneracy