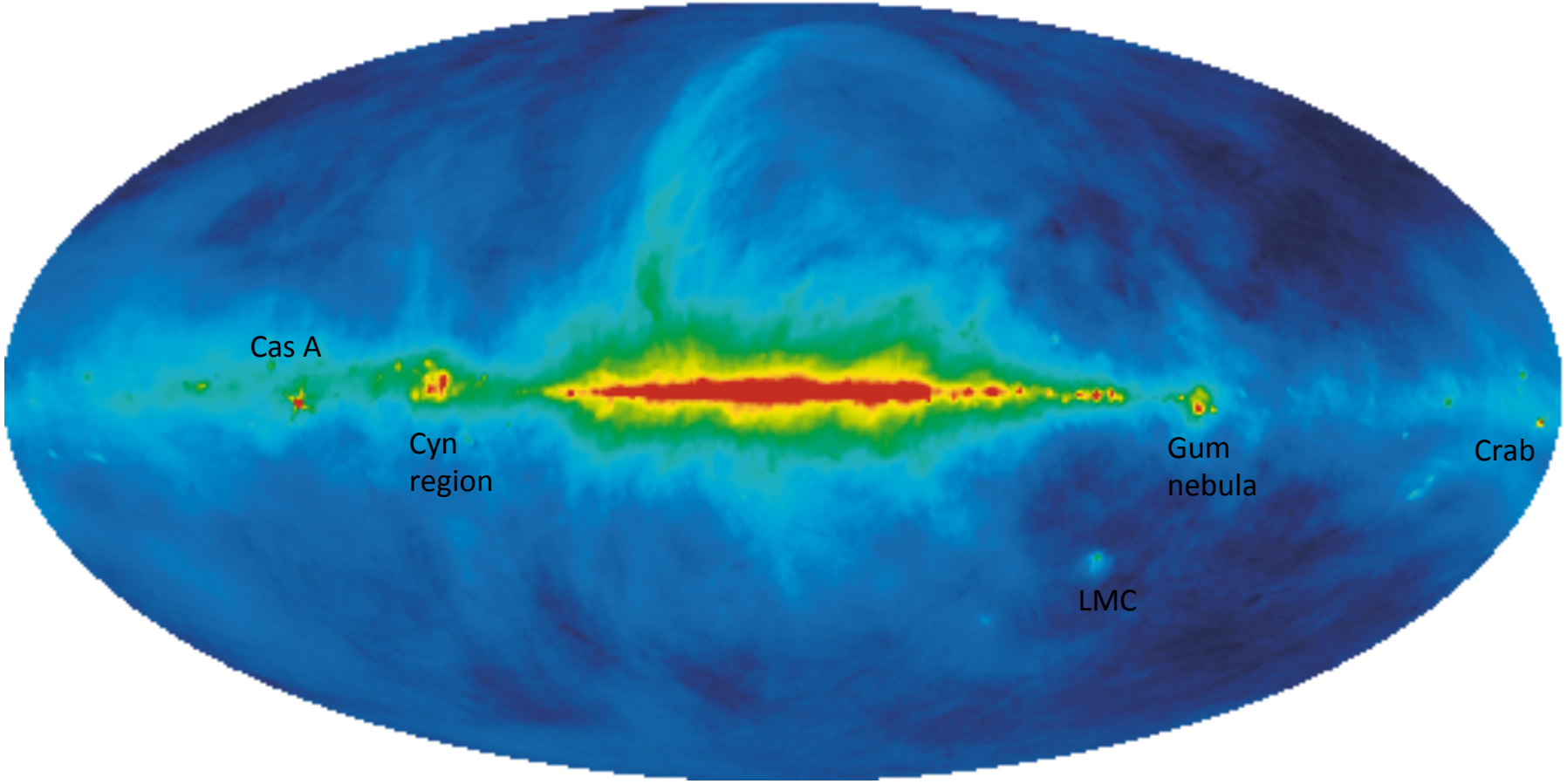
Synchrotron radiation in the context of cosmic-ray propagation models

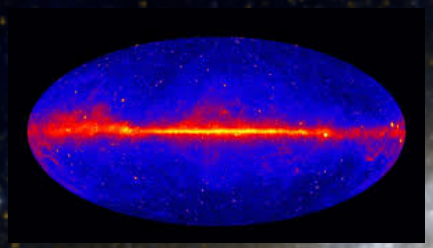
Elena ORLANDO
(Stanford University)

The Radio Synchrotron Background Conference
19-21 July 2017 – Richmond



Reprocessed Haslam 408 MHz map of Remazeilles et al. (2014)
Lambda website

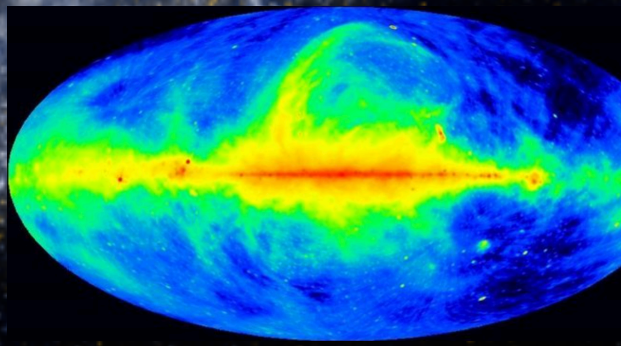
Radio (and microwaves) as a tool to study cosmic rays and magnetic field

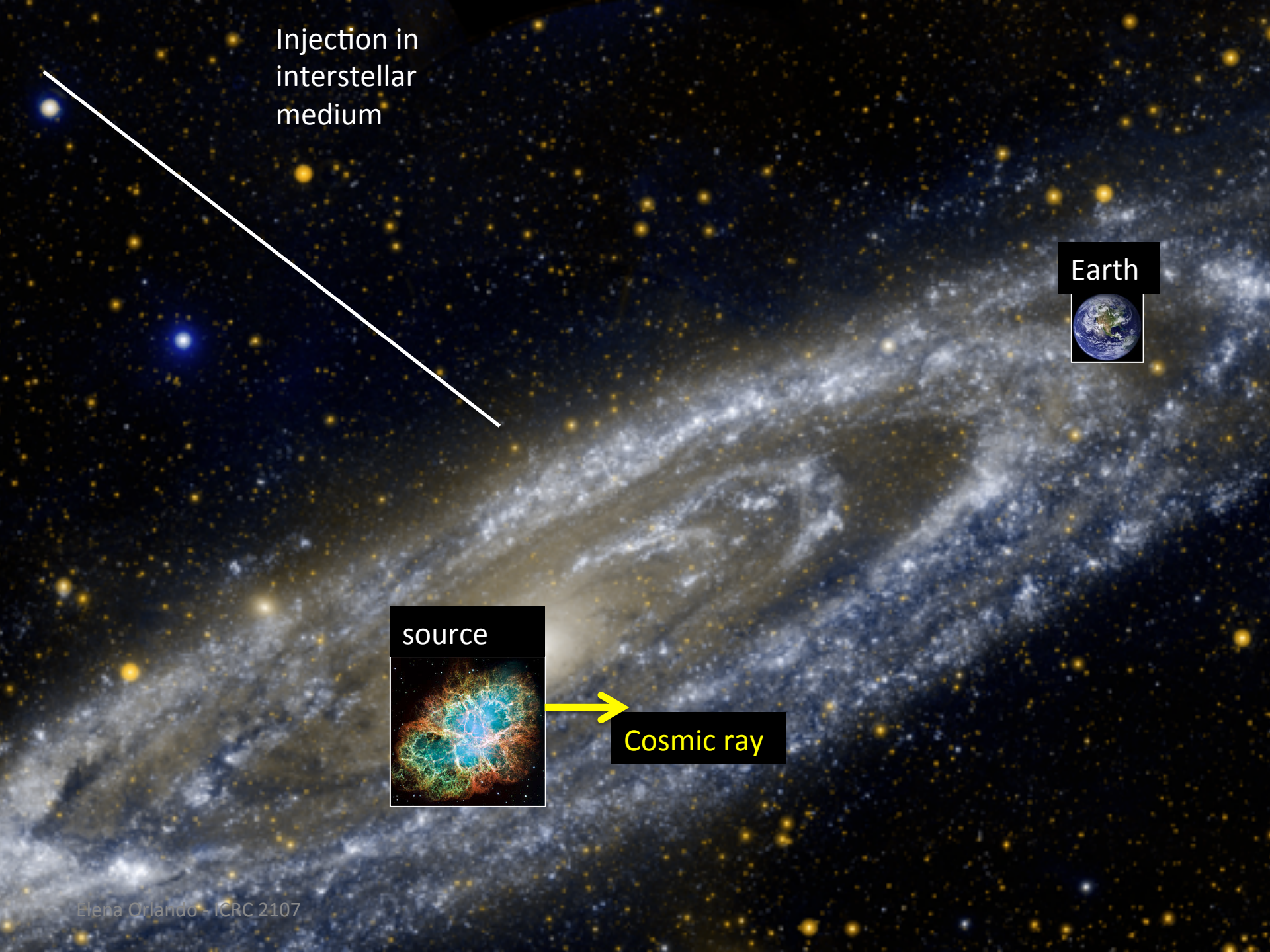


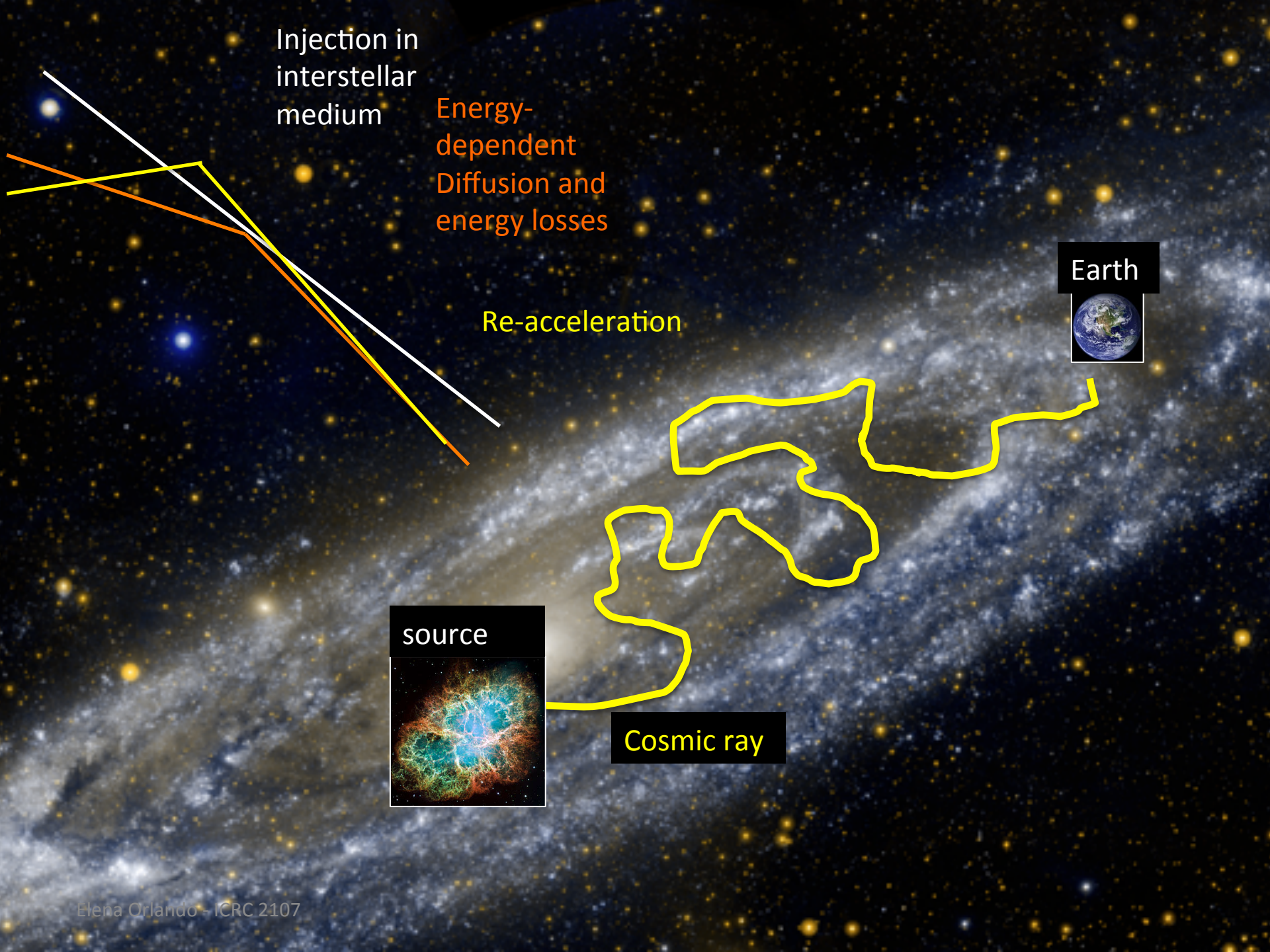
Earth

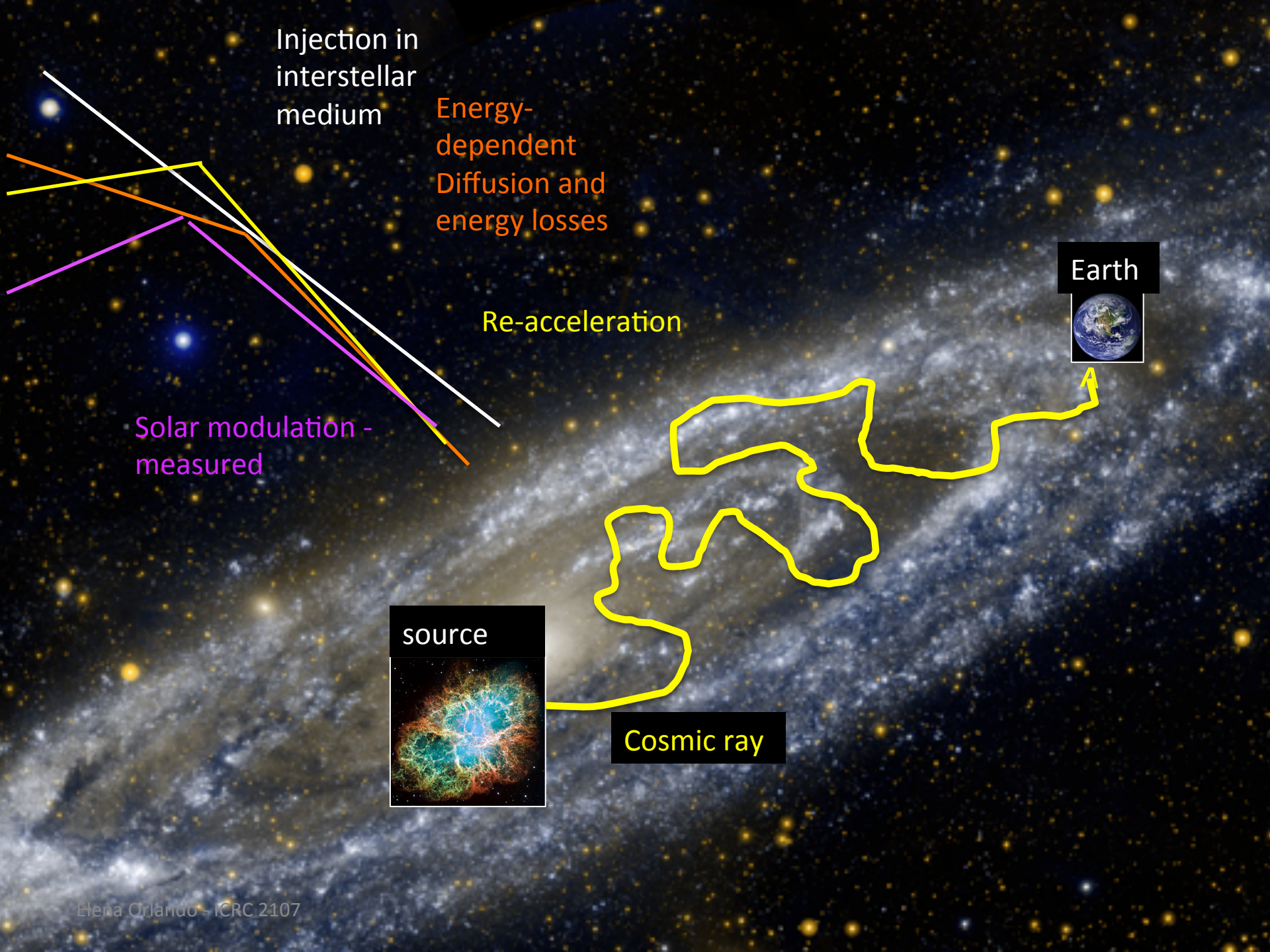
source

Cosmic ray

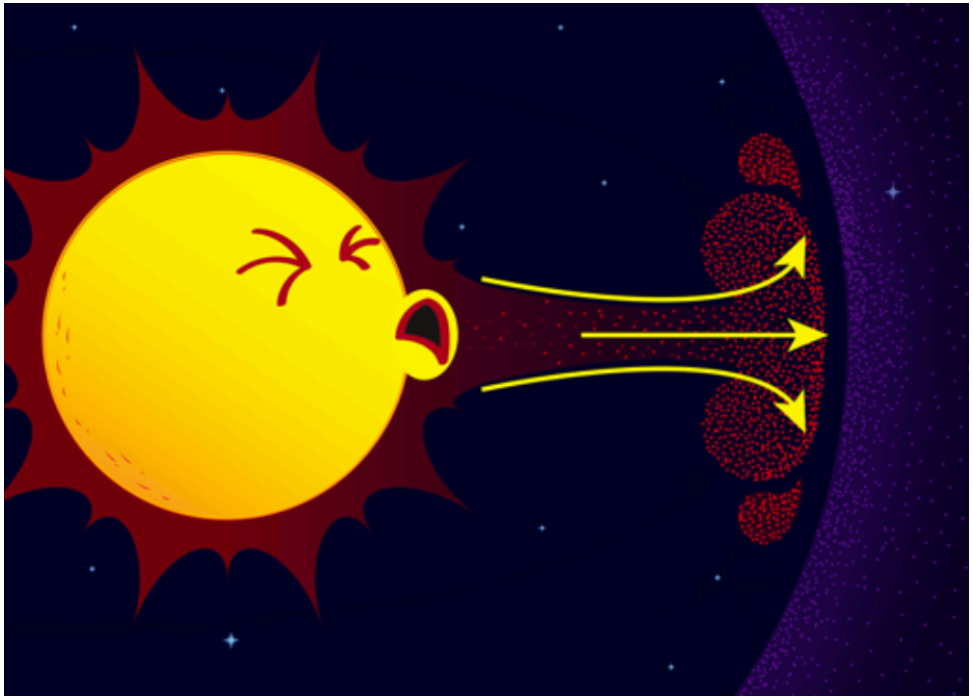


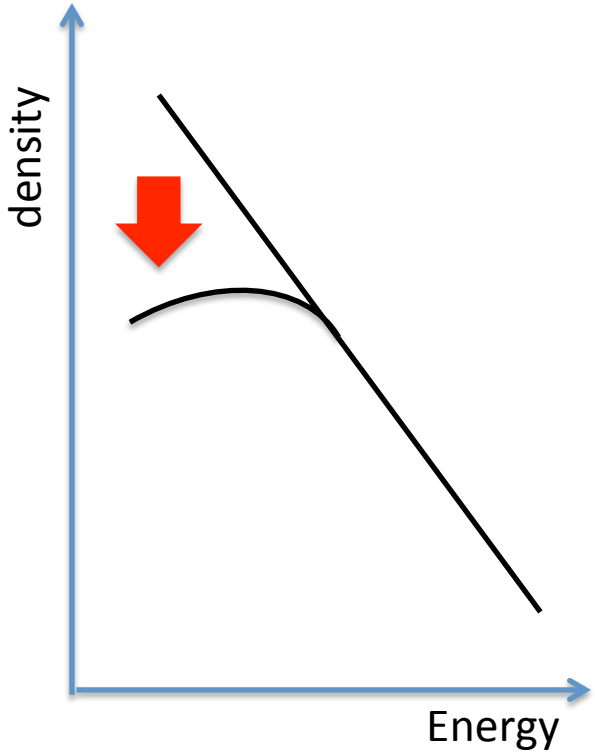

Injection in interstellar medium
Earth
source
Cosmic ray


Injection in interstellar medium
Energy-dependent Diffusion and energy losses
Re-acceleration
Earth
source
Cosmic ray

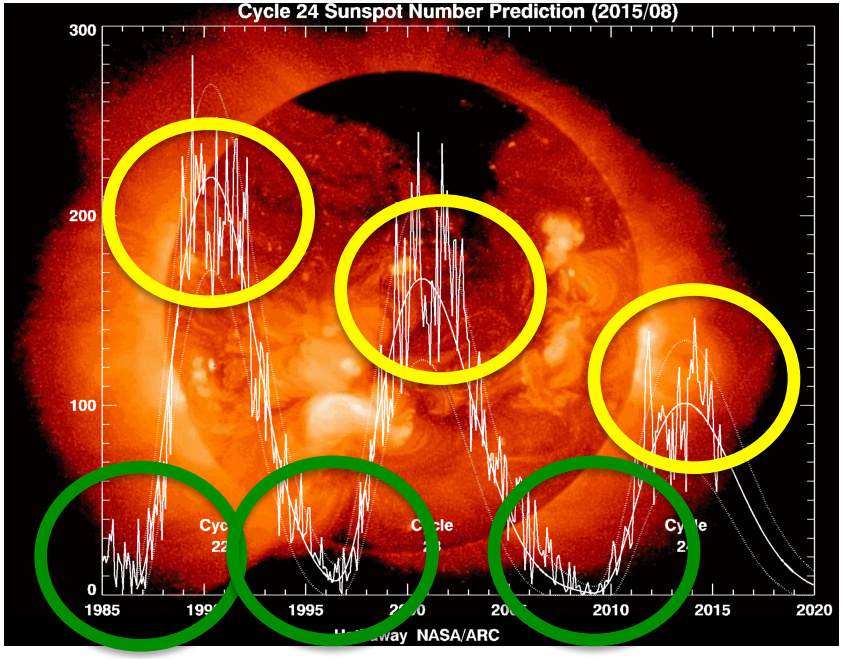

Injection in interstellar medium
Energy-dependent Diffusion and energy losses
Re-acceleration
Solar modulation - measured
Earth
source
Cosmic ray

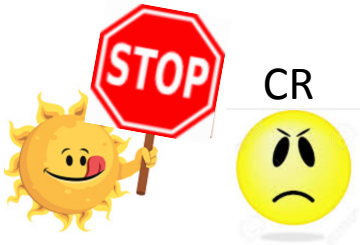
Solar modulation of CRs





Dependency with solar activity





CR Propagation: GALPROP

AROUND SINCE '98

http://*galprop.stanford.edu*

Officially used for COMPTEL, EGRET,
Fermi LAT, Planck, Voyager, AMS-02

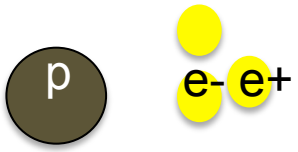
THE TEAM:

I. Moskalenko and A. Strong (original developers),
G. Johannesson, E. Orlando, T. Porter, (A. Vladimirov)

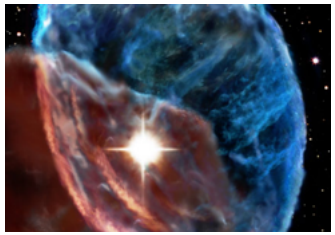
It solves the transport equation for all the CR species

Ingredients (and source of uncertainty)

Injected spectra and **propagation parameters** (adjusted to fit CR measurements)

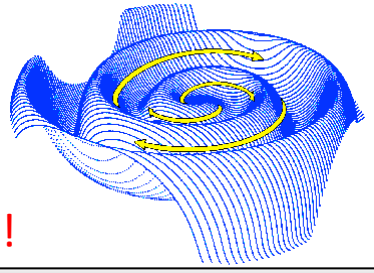


CR source distribution



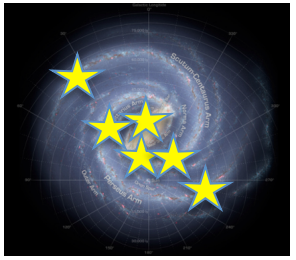
Magnetic field

No assumption of equipartition!



Gas distribution (atomic HI; molecular H2; ionized HII)

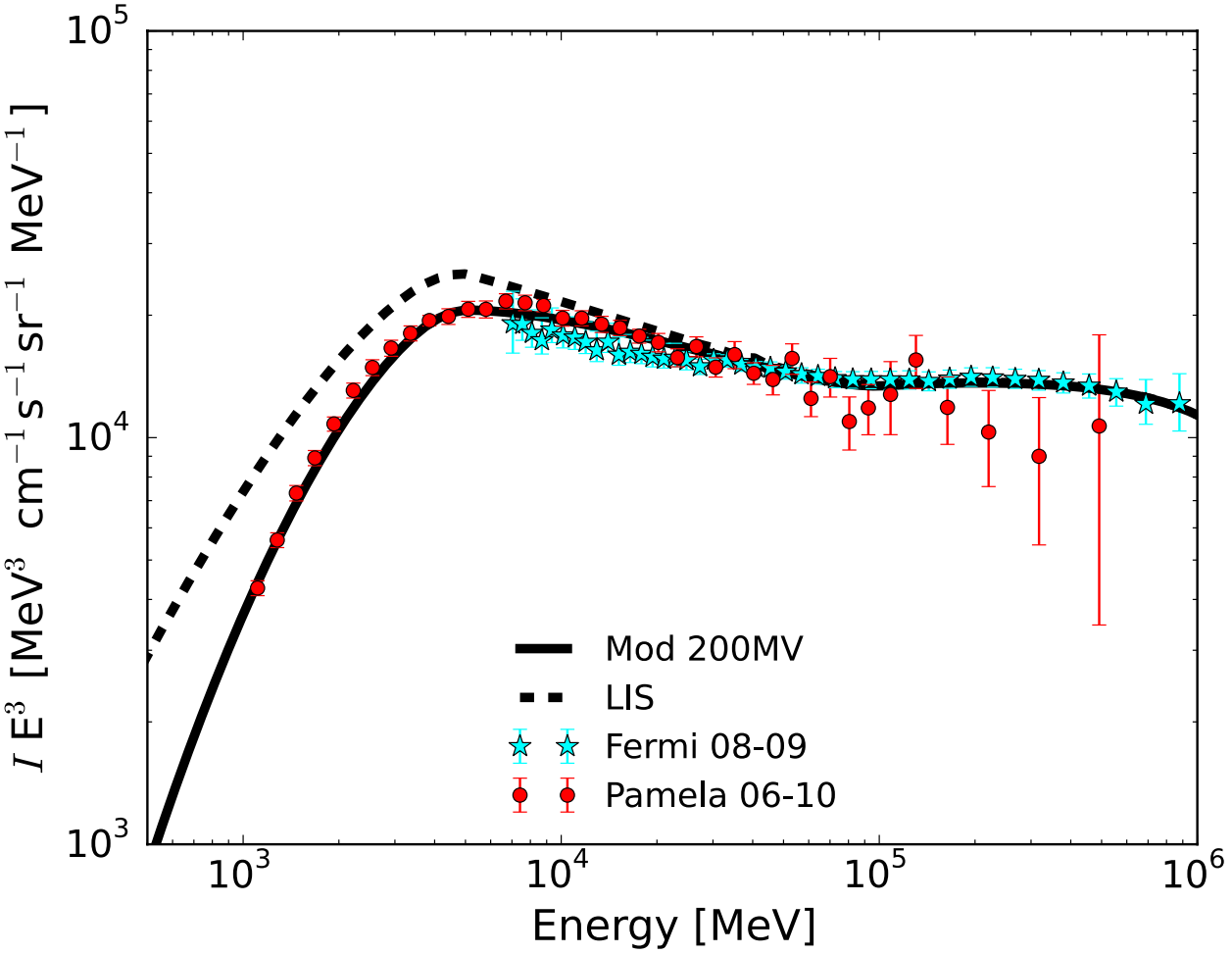
ISRF (for energy losses)



Probing interstellar CR spectrum and B-field

- Synchrotron spectral Index -> e^- spectral index
- Synchrotron Intensity -> B intensity and electron density
- e^- 0.5 - 20 GeV -> 20 MHz - 100 GHz

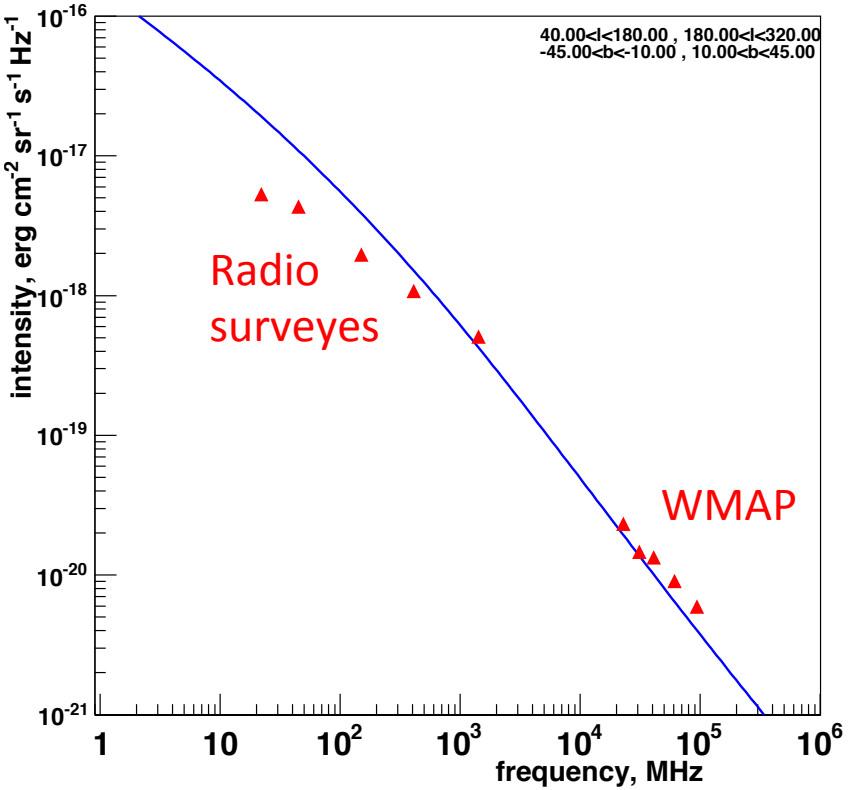
Electron spectrum



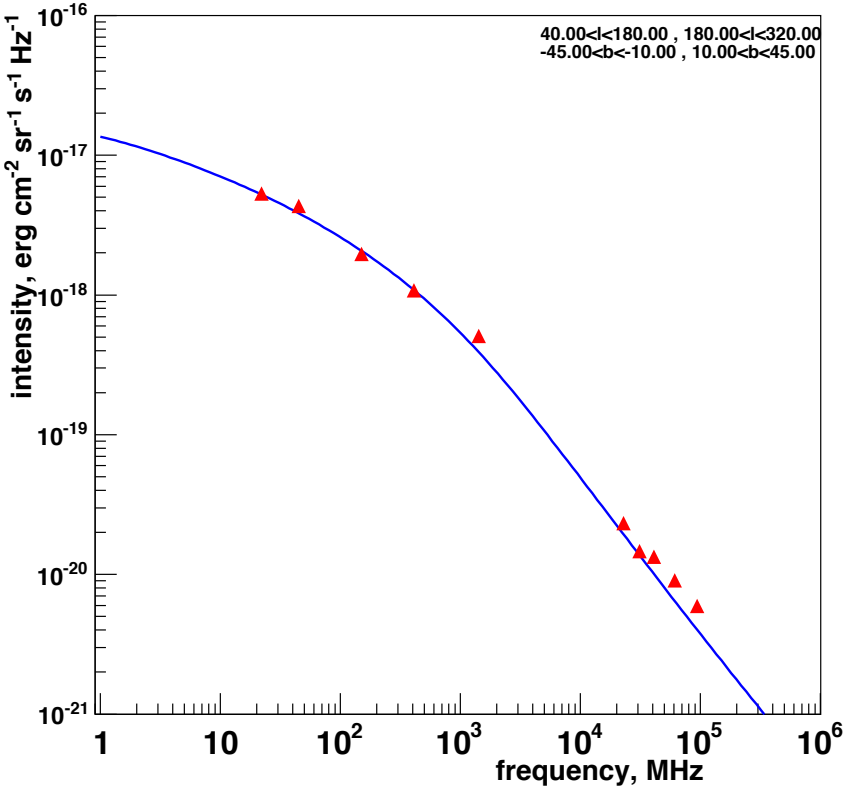
Synchrotron spectum

Strong, Orlando and Jaffe 2011 A&A, 534, 54

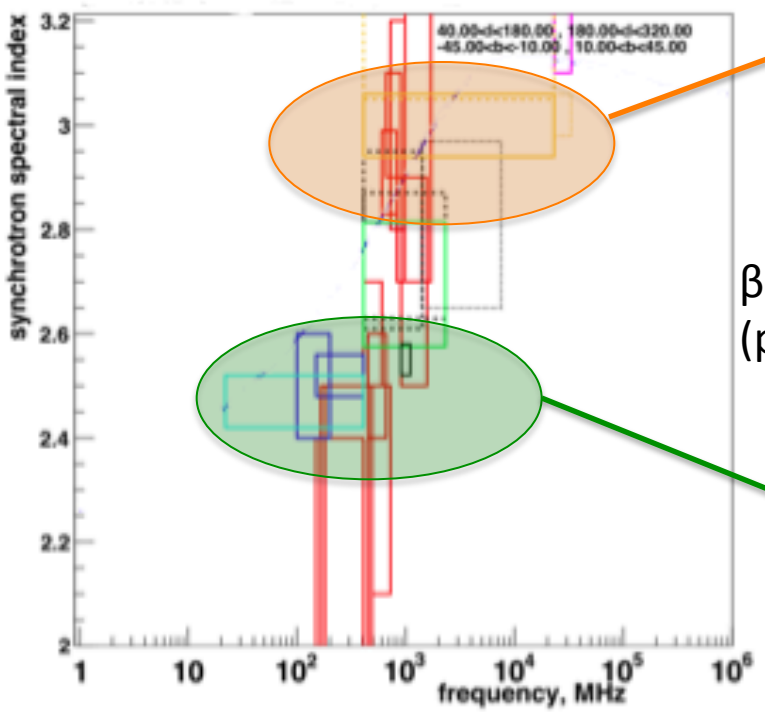
No break



With break



Synchrotron spectral index measurements …



β~3.0 → P~3.0

β=2+(p-1)/2
(p=ambient e- spectrum)

β~2.5 → p~2.0

… need of a break in interstellar e-

Radio and microwave modeling

Strong, Orlando and Jaffe 2011 A&A, 534, 54

→ Break in local interstellar electron spectrum from <2 to ~3 @ few GeV

→ Injection spectrum < few GeV is harder than 1.6

→ Standard reacceleration models hard to reconcile with synchrotron.

Improvements in modeling

- polarization (Stokes I, U, Q)

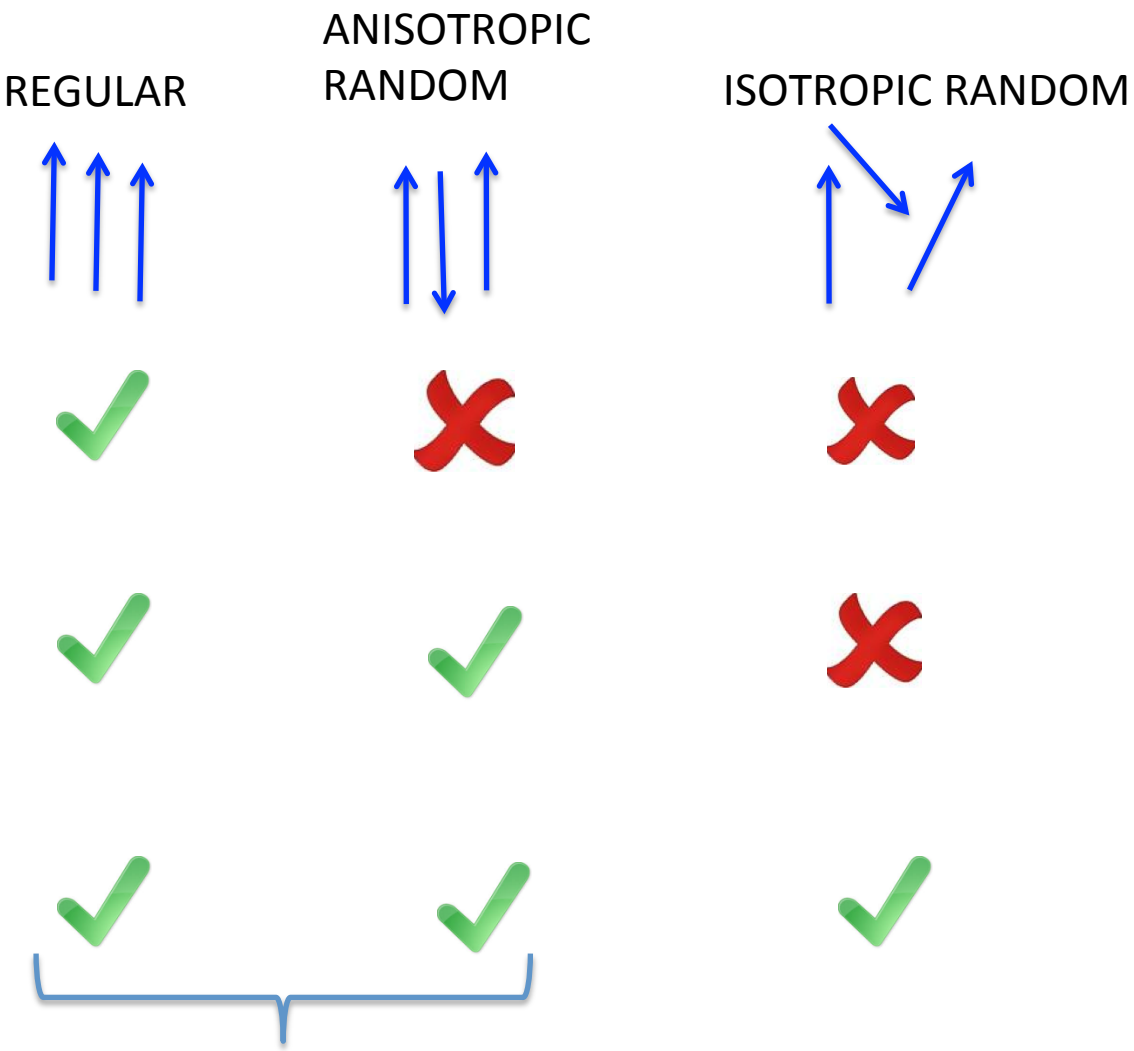
- 3D B-field configuration: random + regular + anisotropic random components

- basic free-free emission model (based on NE2001)

- absorption

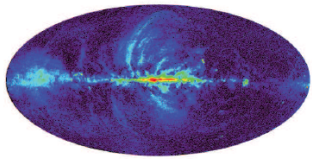
More info in:
Orlando & Strong 2013 MNRAS 436, 2127. Upcoming results from this paper

Observations and B-fields

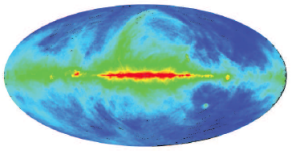


Rotation Measures

polarized synchrotron



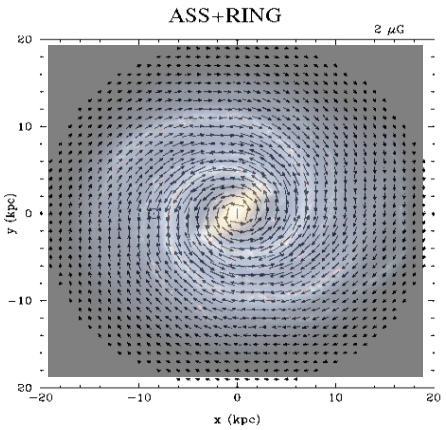
Unpolarized synchrotron



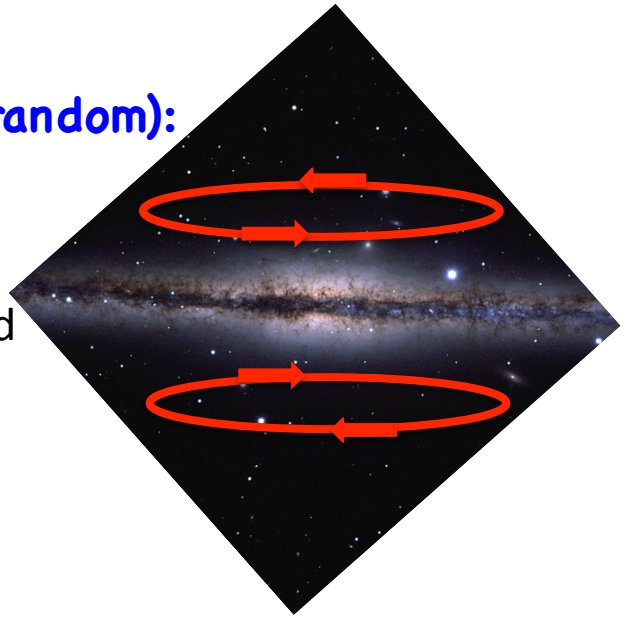
B-field model

ORDERED COMPONENTS (regular & anisotropic random):

Local disc field



Halo field

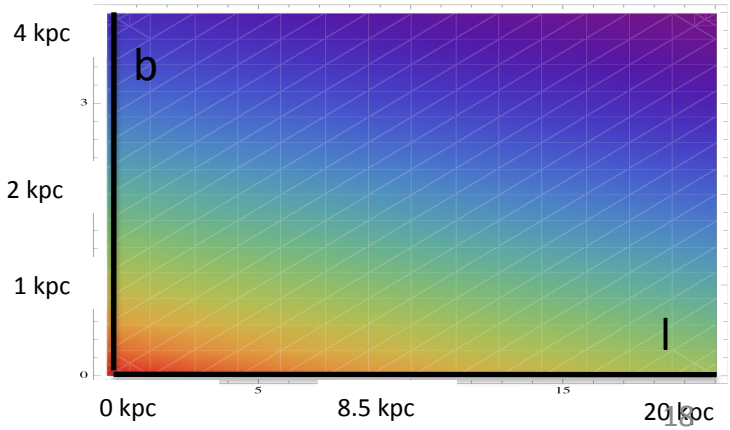


RANDOM COMPONENT:

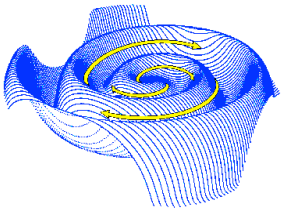
μG

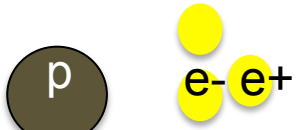
$$B(\mu G) \approx e^{-(R-R_*)/30\,kpc}\; e^{-|z|/4\,kpc}$$

R =8.5 kpc

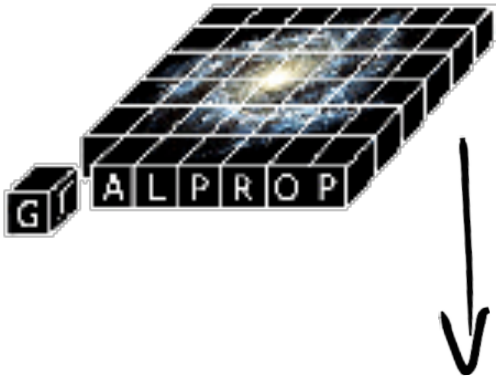


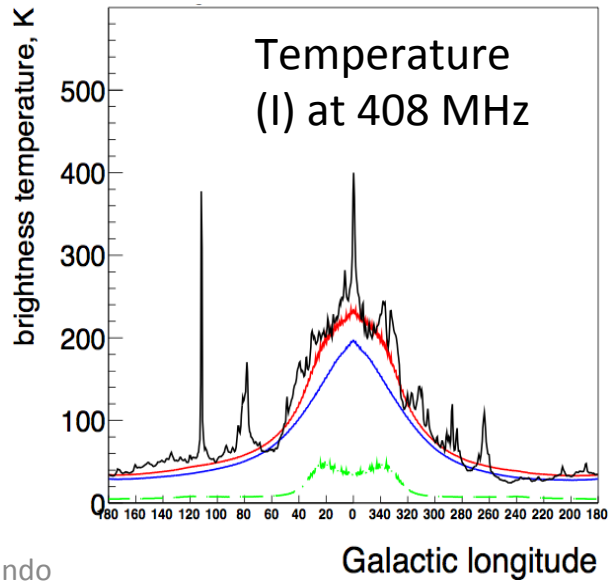
Procedure

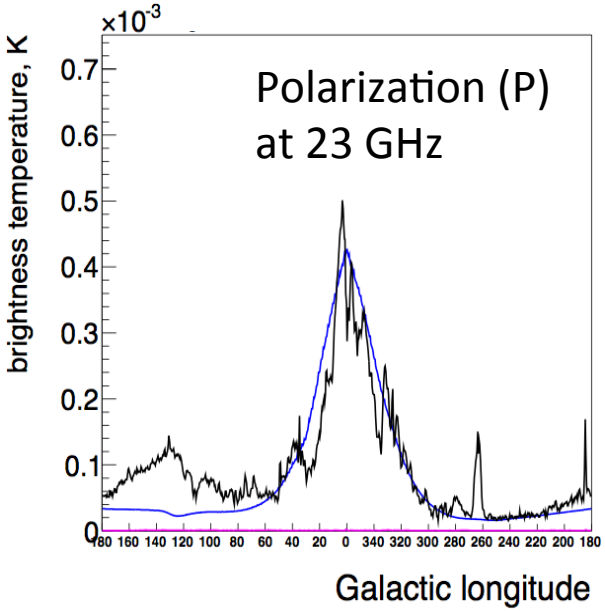




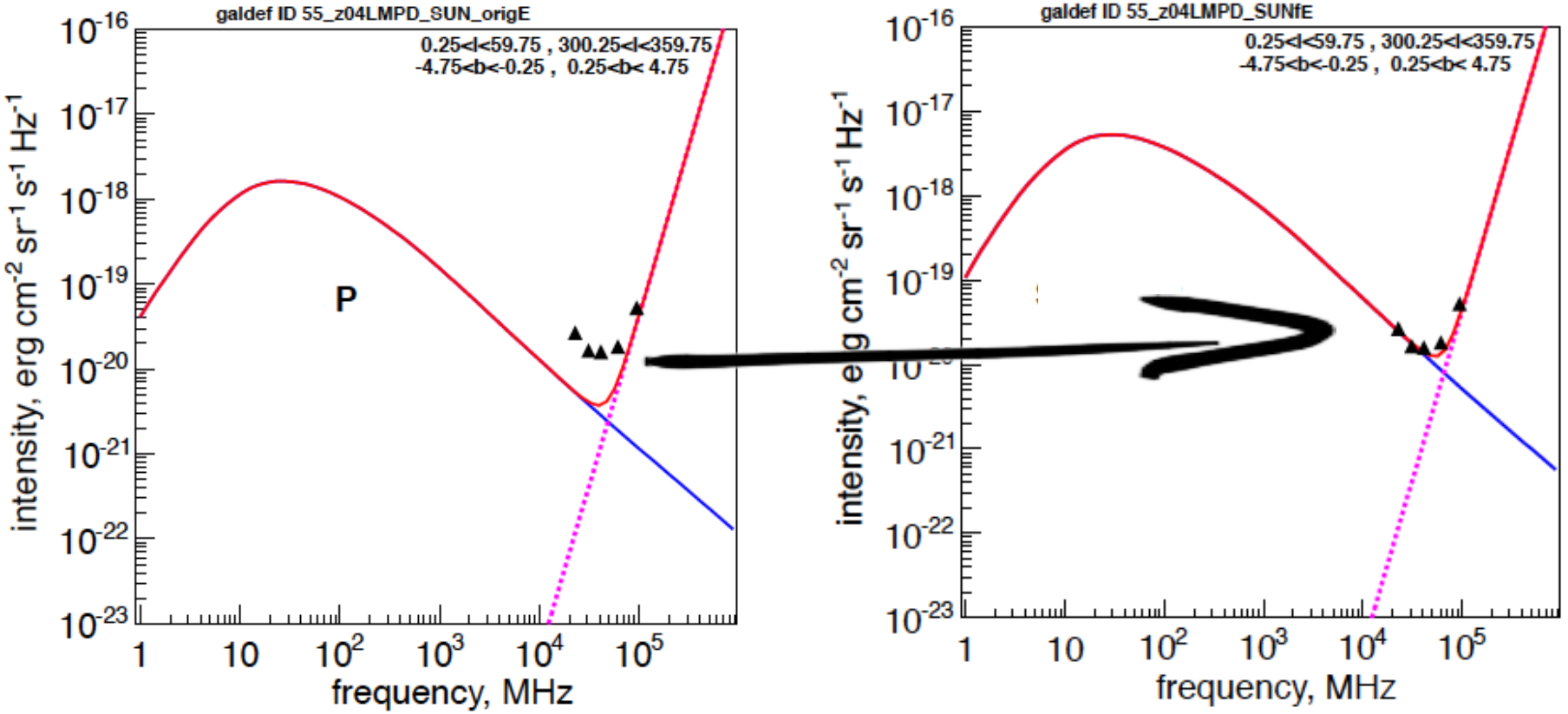
INPUT







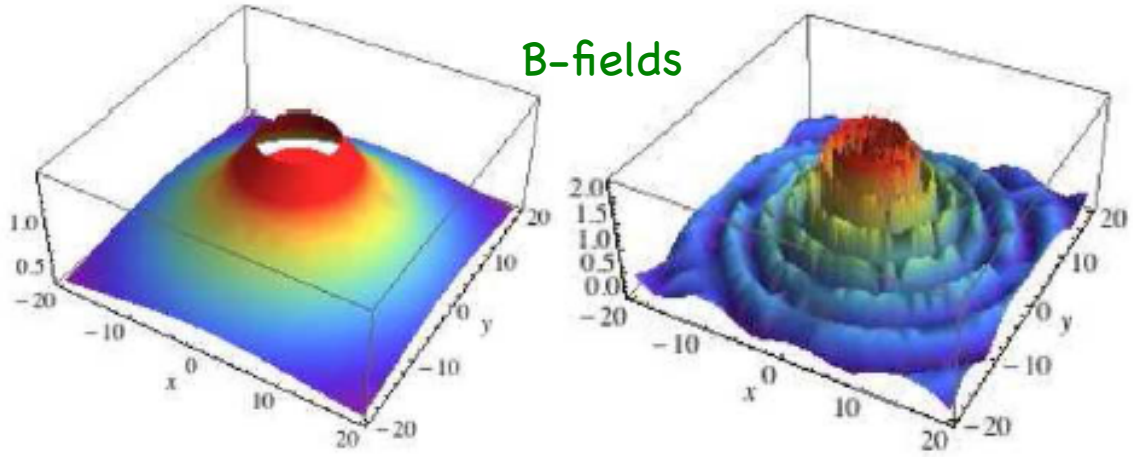
Additional component



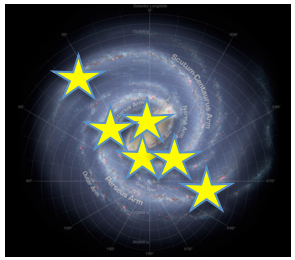
Anisotropic random component
~ regular B

Sensitivity to different parameters

B-fields

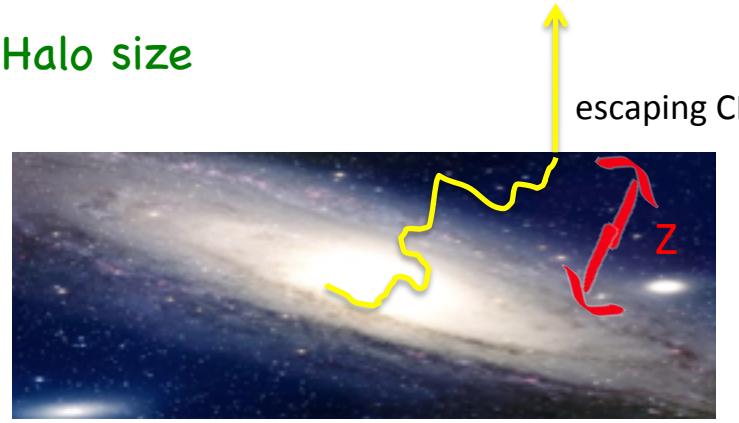


CR source distribution



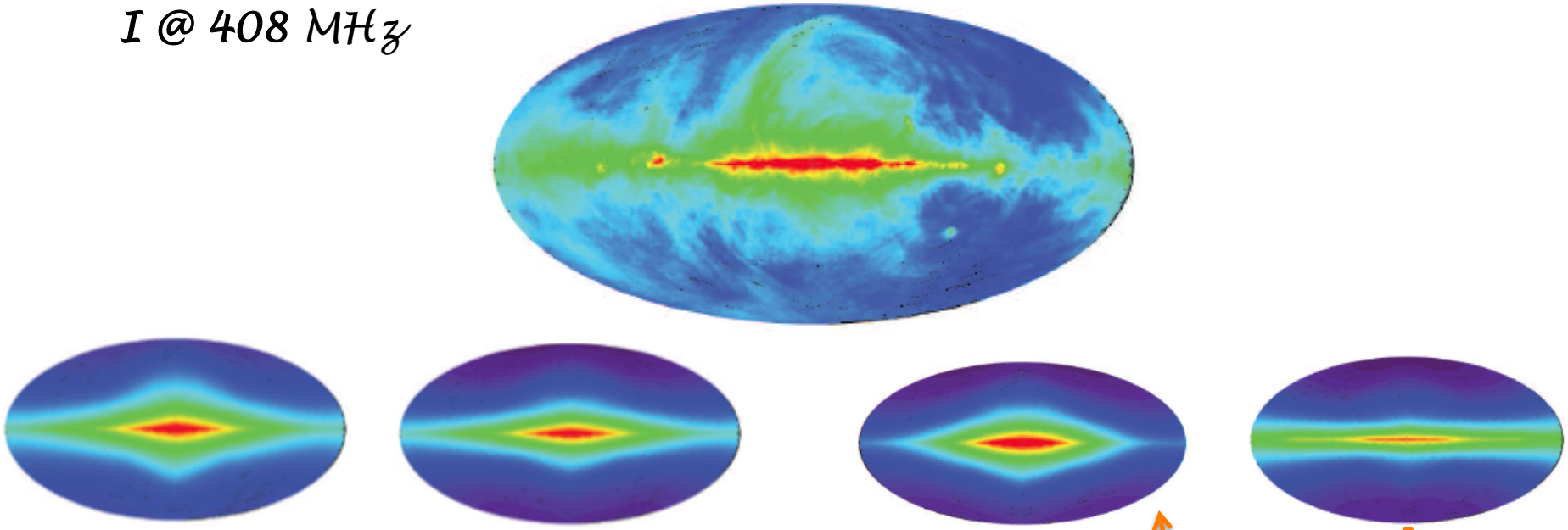
From pulsars, SNRs, OB stars, checked against gamma rays

Halo size



Synchrotron spatial modeling

Orlando & Strong 2013 MNRAS 436, 2127

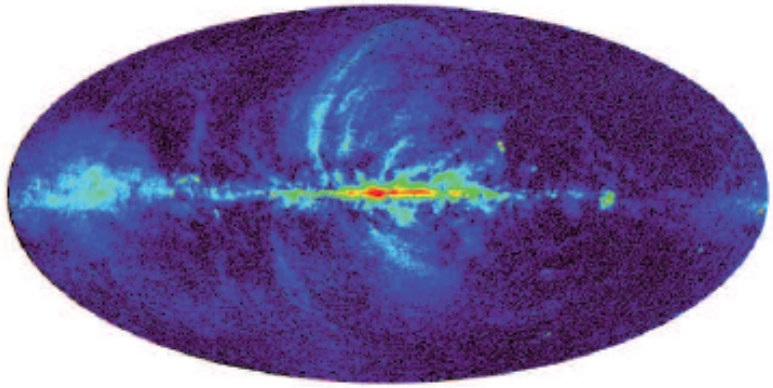


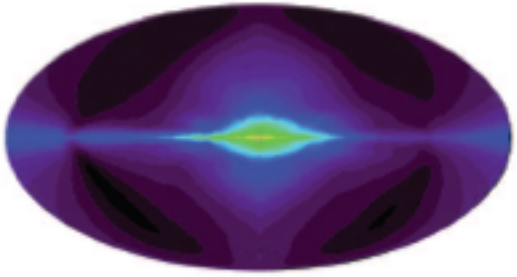
Synchrotron spatial modeling

Orlando & Strong 2013 MNRAS 436, 2127

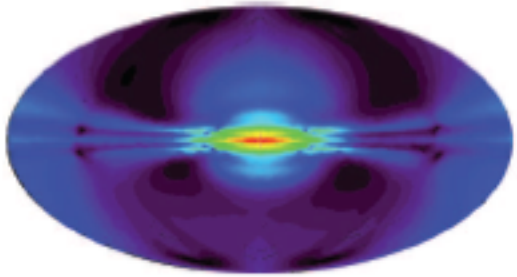
P @ 23 GHz

WMAP

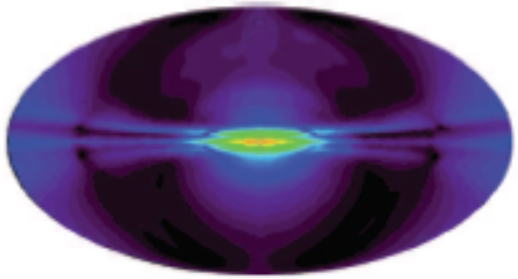




Sun 2008, 2010



Pshirkov, 2011 (ASS)

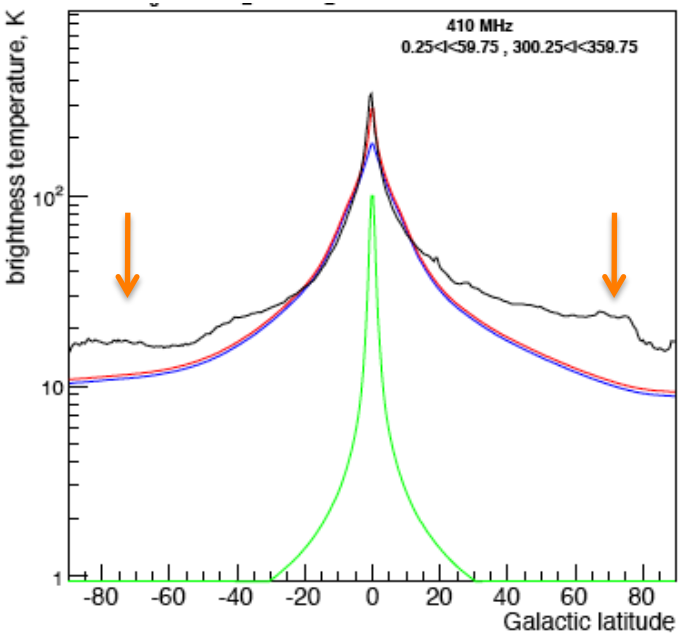


Pshirkov, 2011 (BSS)

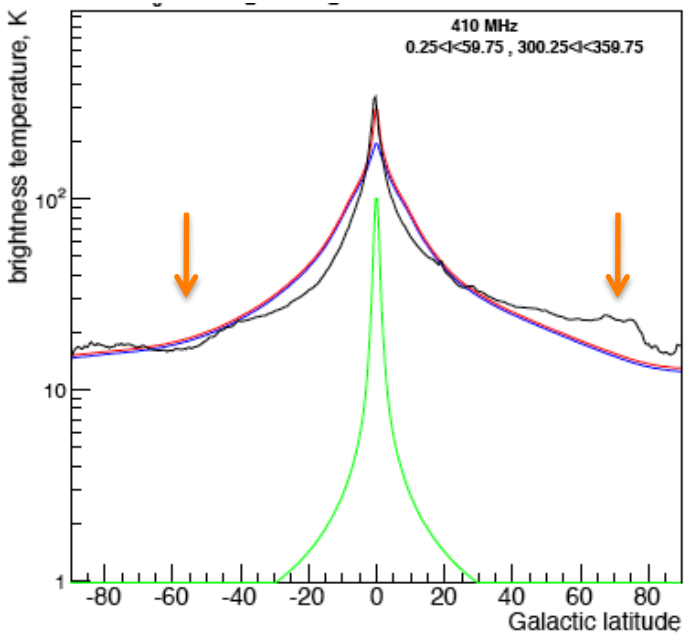
Different B-fields

Sensitivity to halo size

z = 4 kpc



z = 10 kpc



	4 kpc	**10 kpc**	
Lower frequencies $I(408\,\mathrm{MHz})$			
B_{ran0} (μG)	5.16	5.03	
offset (K)	4.71	0.98	(+3.7 K)

See also Sun et al 2010 and Fornengo et al 2014 for different interpretations

Main results

High degeneracy among model parameters

Preference of:

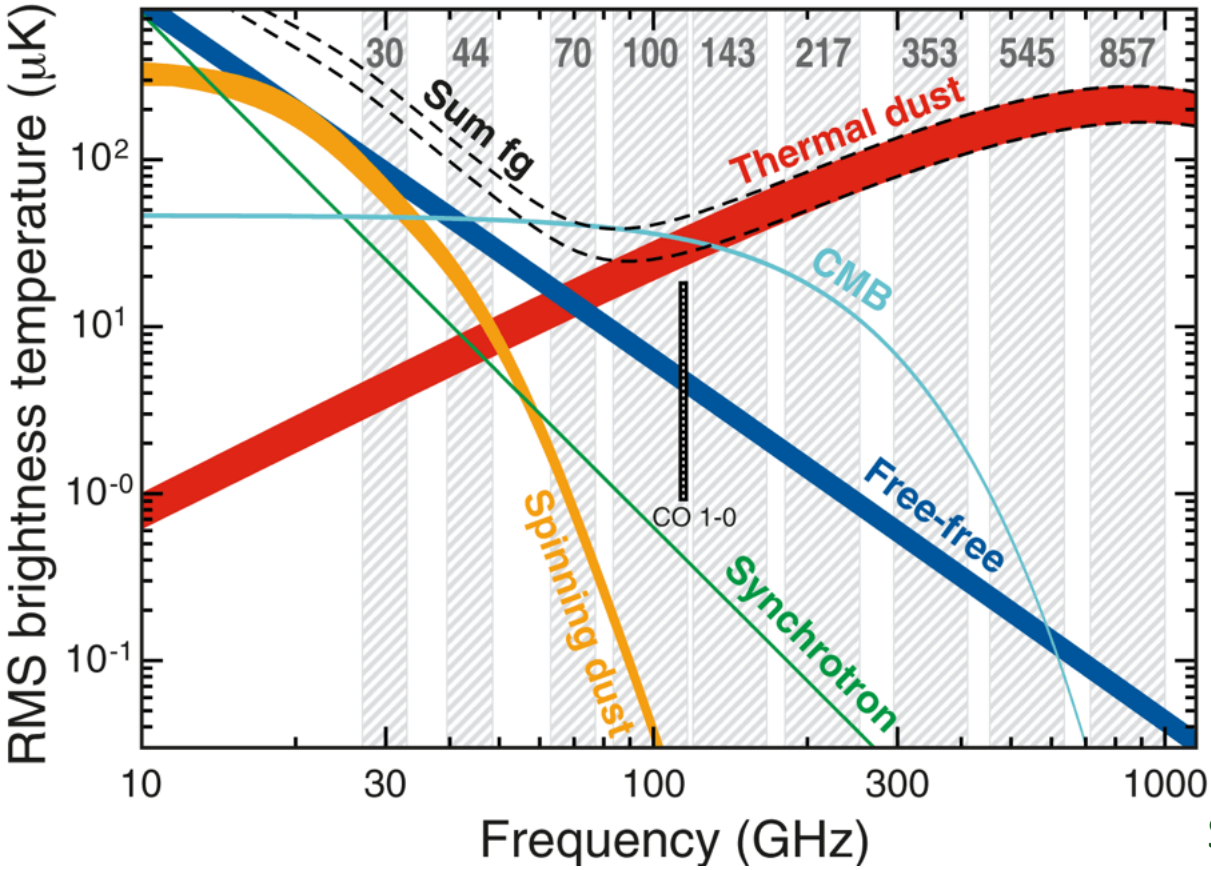
- Flat CR source distribution in the outer Galaxy
- Halo height > 4 kpc

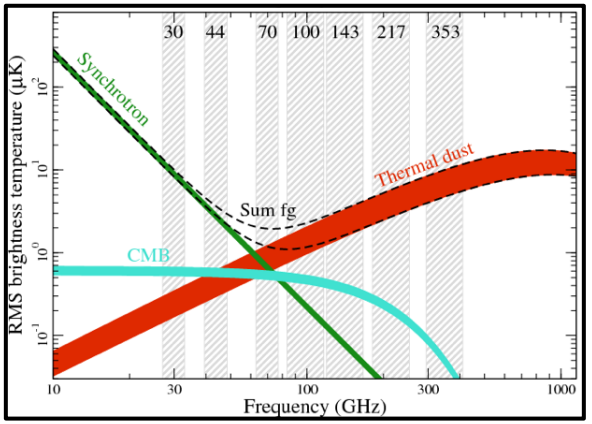
Anisotropic component of the magnetic field

Best model used separating Planck components.

The microwave sky

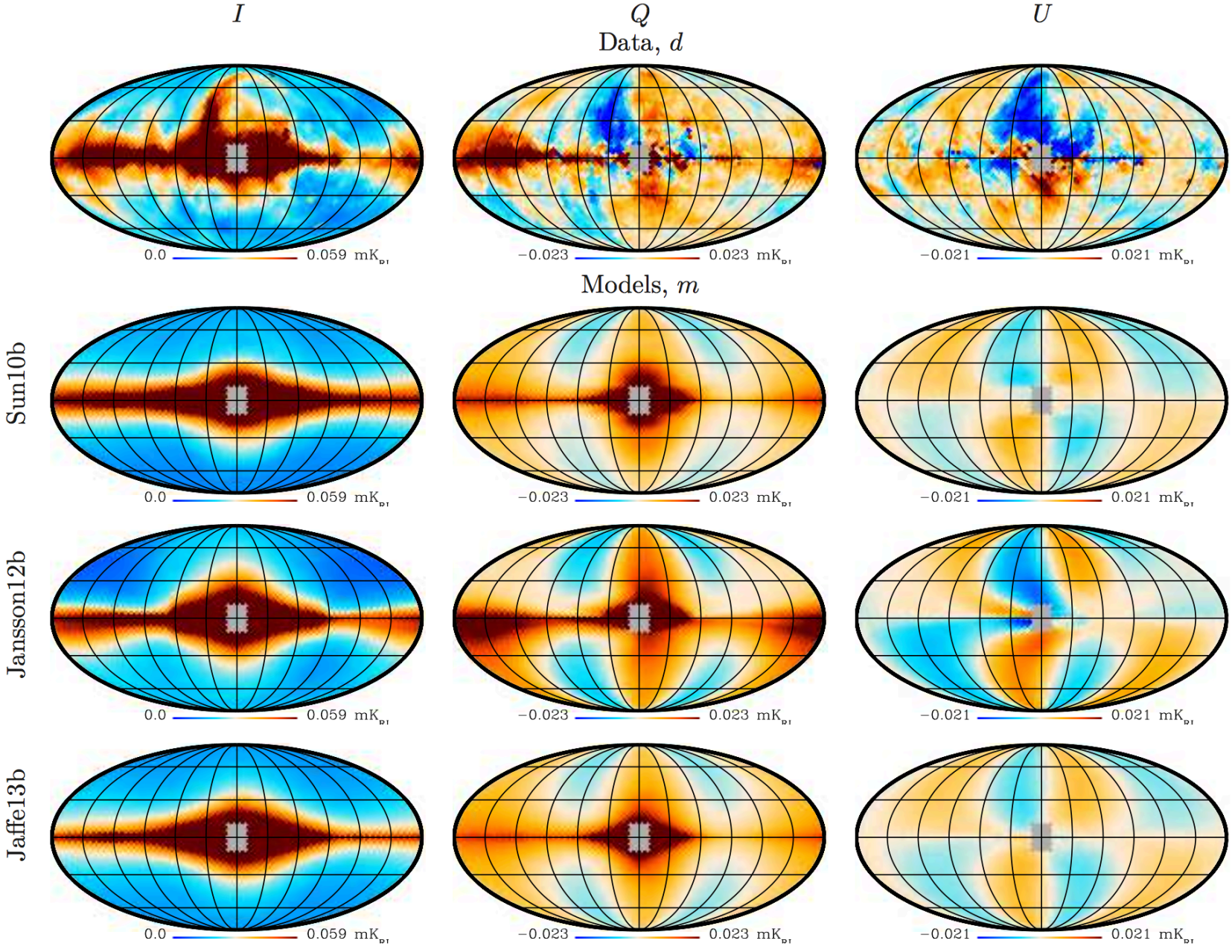
Planck 2015 results. X



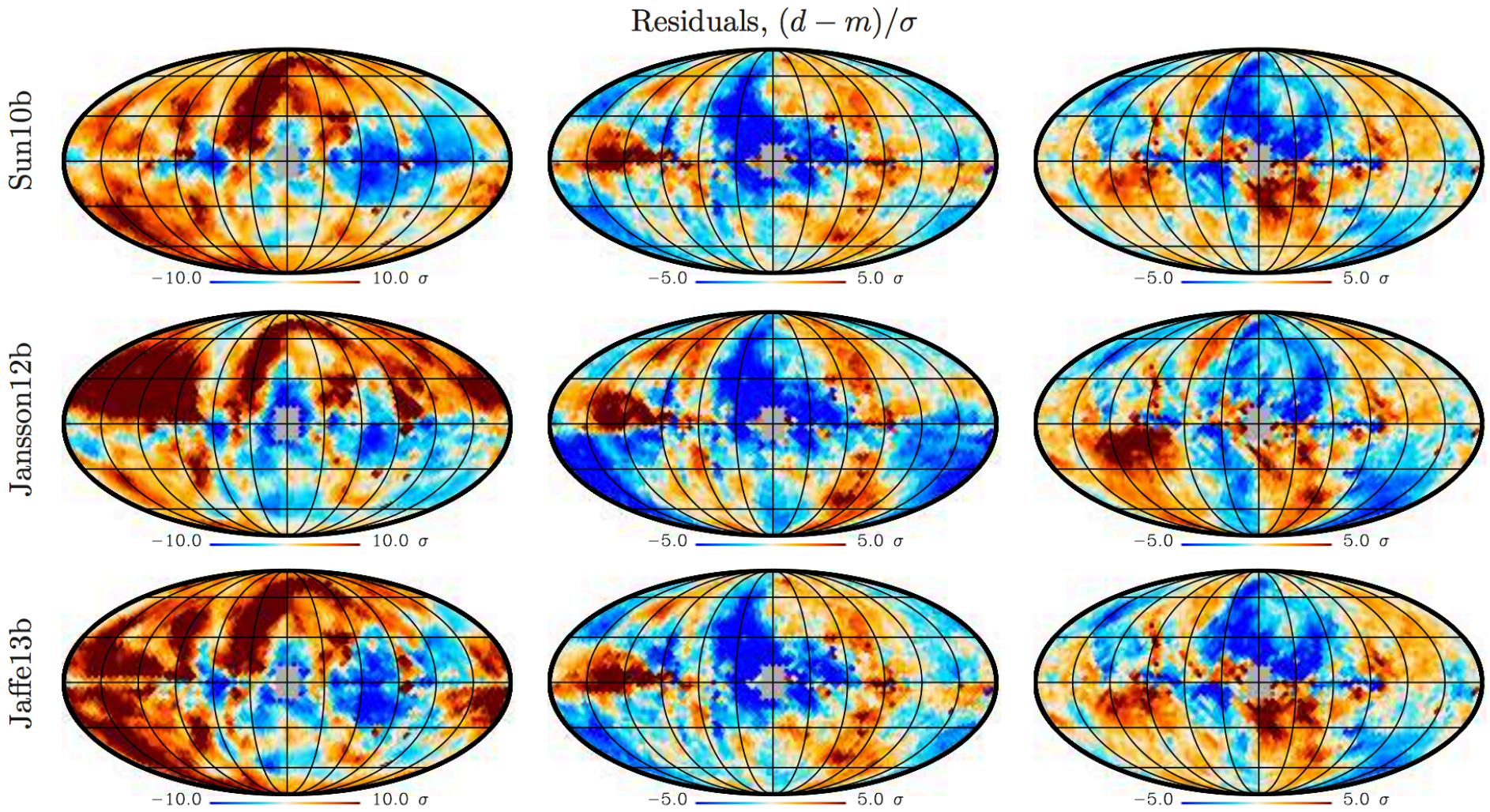


Synchrotron spectrum depends on CRe spectrum !

Planck intermediate results. XLII



Planck intermediate results. XLII



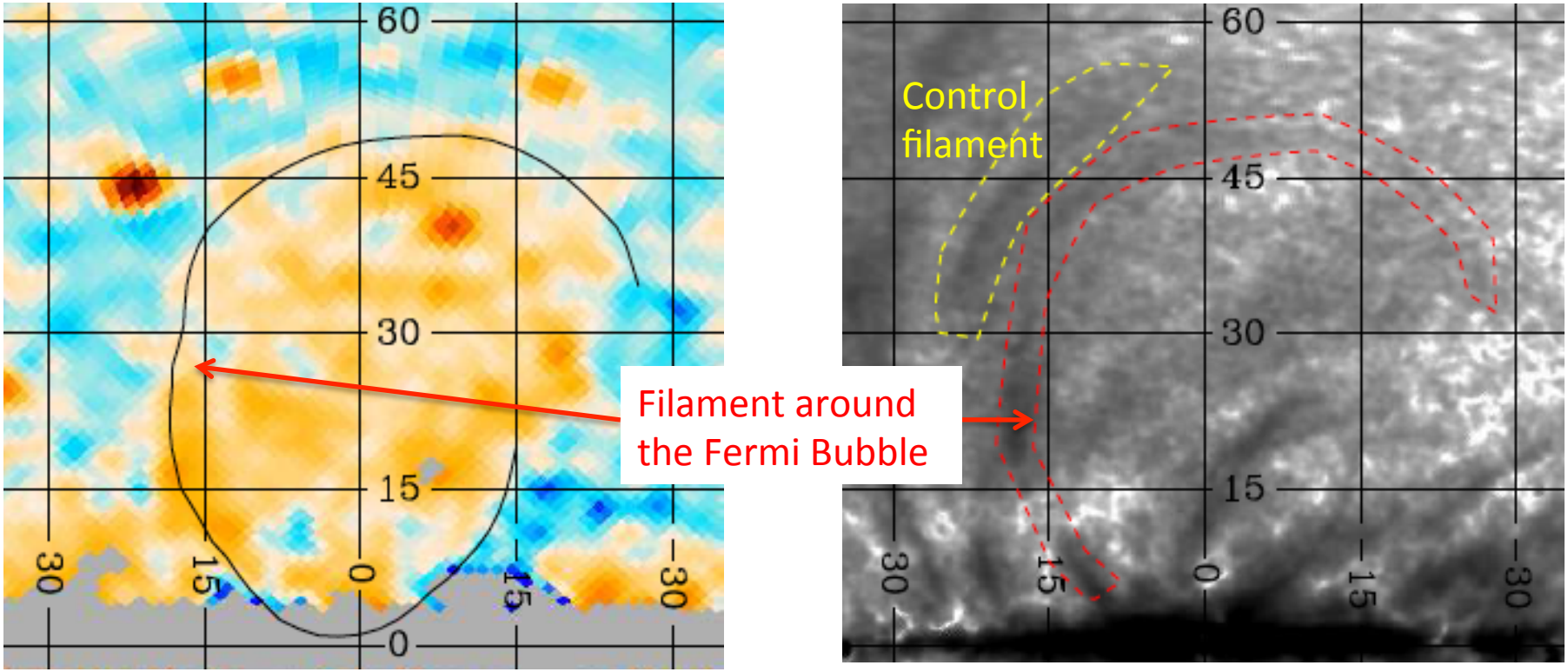
Under-prediction of polarization away from the plane for all the models

Planck polarization and Fermi Bubbles

Planck 2015 results. XXV

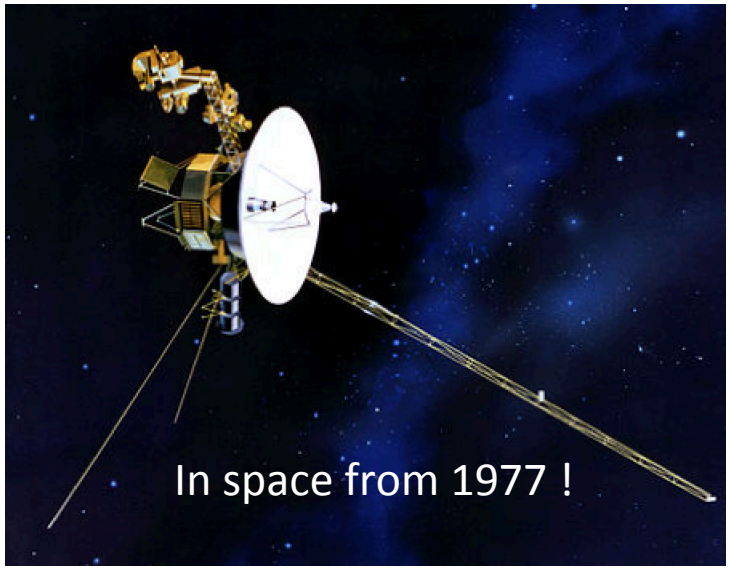
Fermi-LAT > 10 GeV from
Ackermann et al 2014 ApJ,793,64 (dust subtracted)

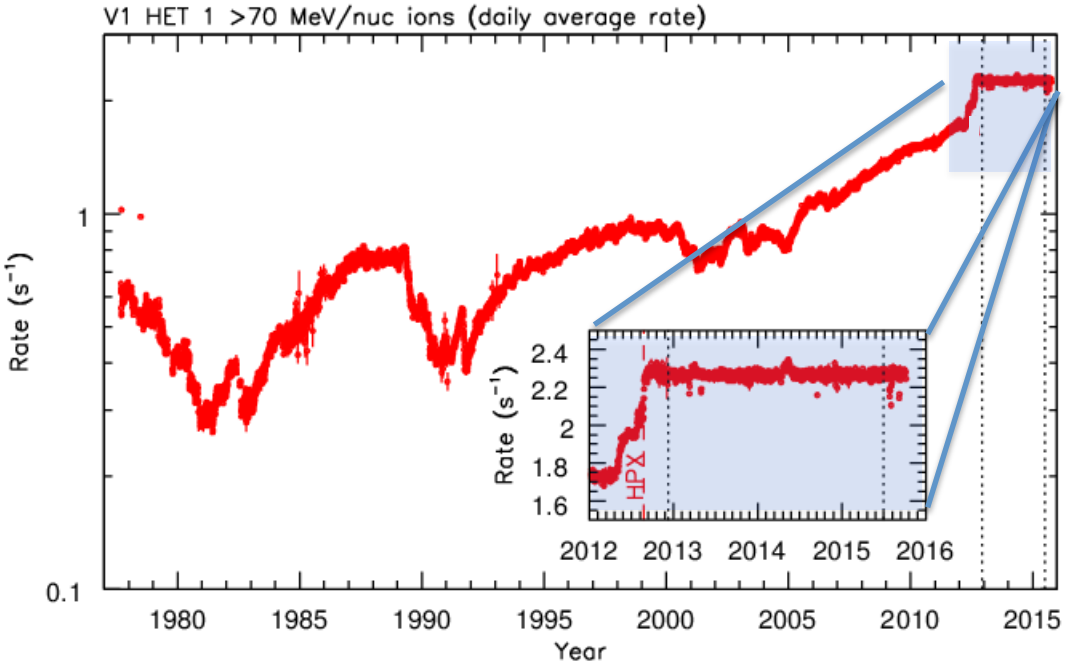
Planck polarization map



Voyager 1

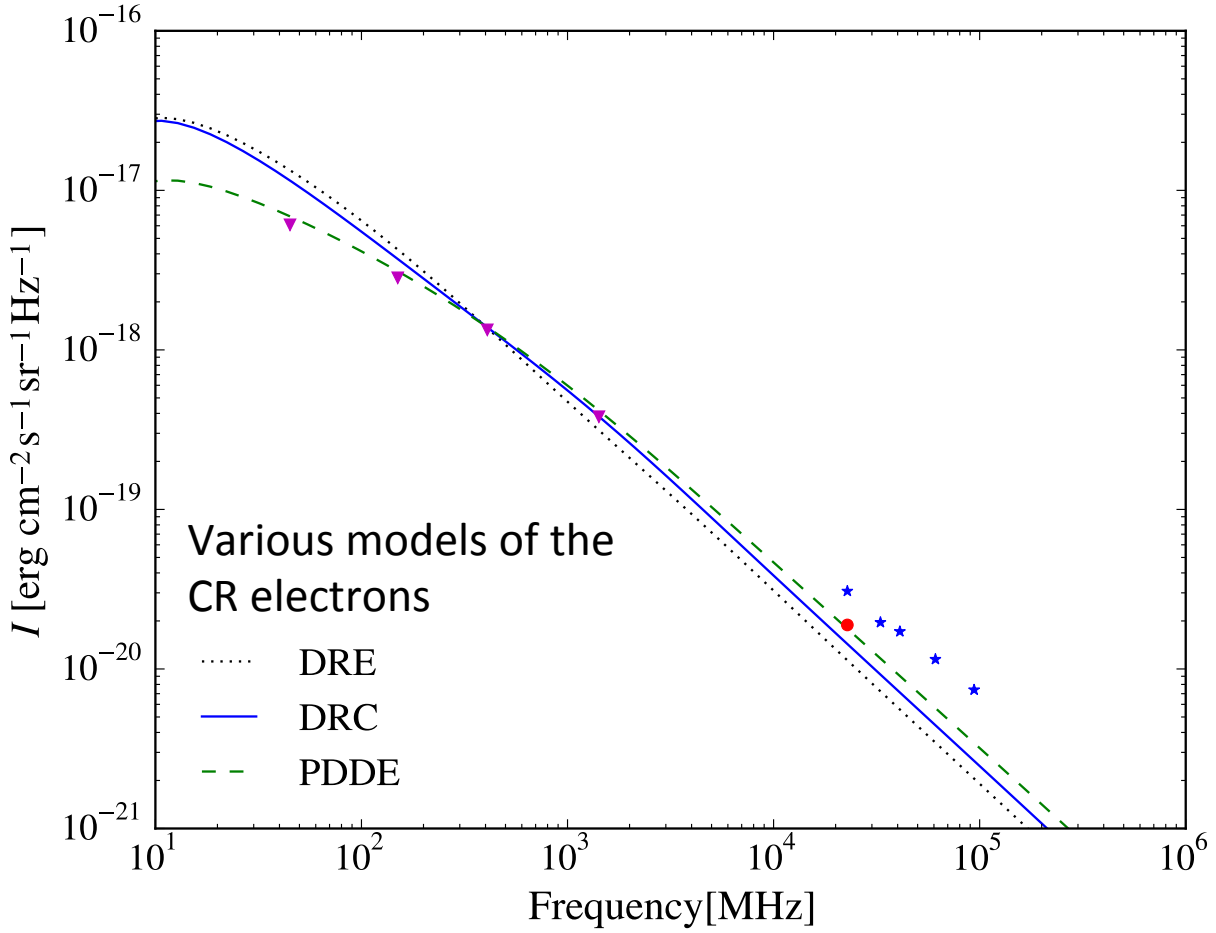
In the interstellar space!





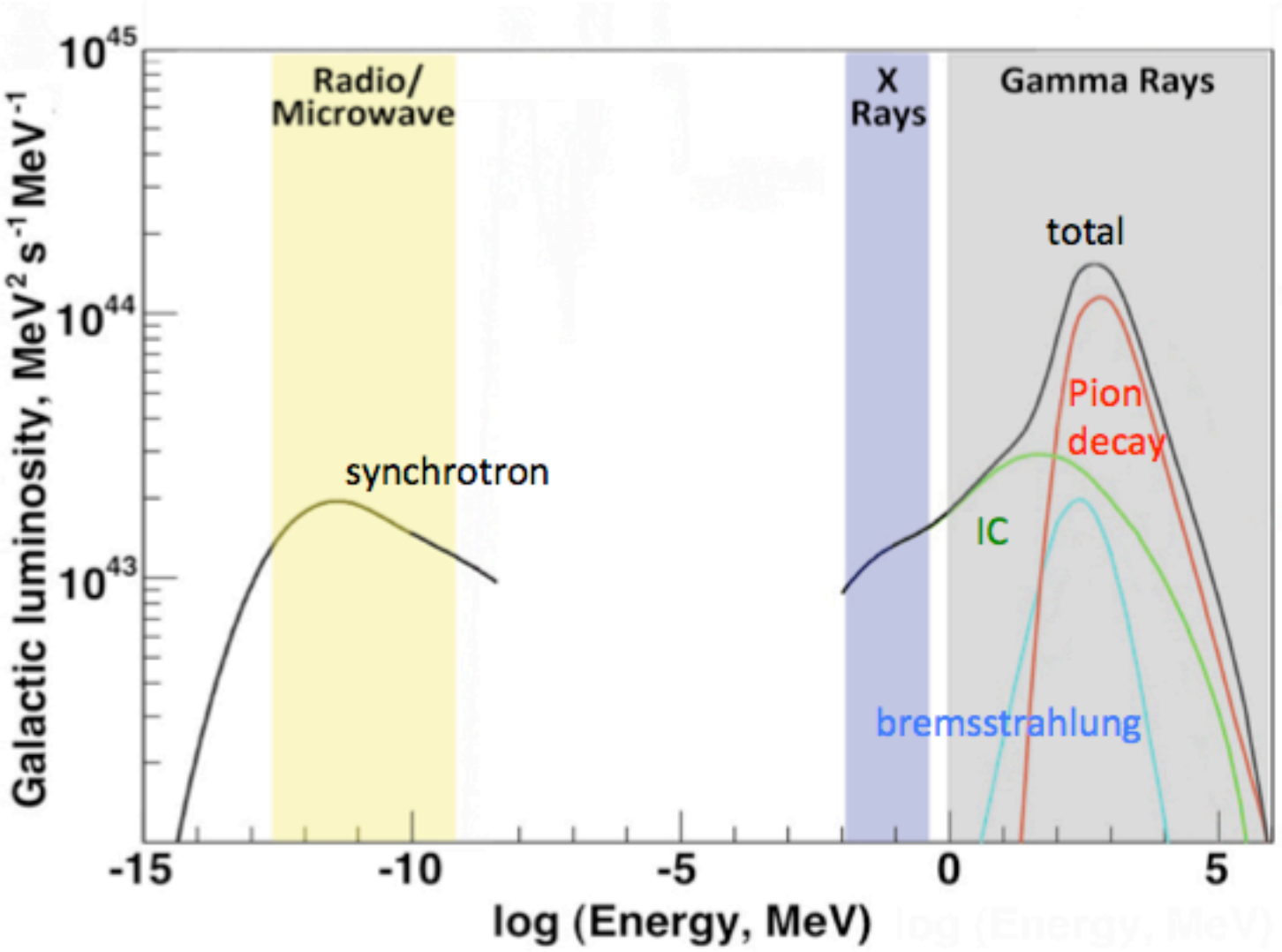
Cummings, Stone, Heikkila, Lal, Webber, Johannesson, Moskalenko, Orlando, and Porter, 2016 ApJ 831, 18

Produced synchrotron emission



CONSTRAINTS AT SYNCHRTRON CAN HELP ALSO IN MODELLING THE GAMMA-RAY SKY and VICEVERSA!

CR-induced diffuse emission of the Milky Way

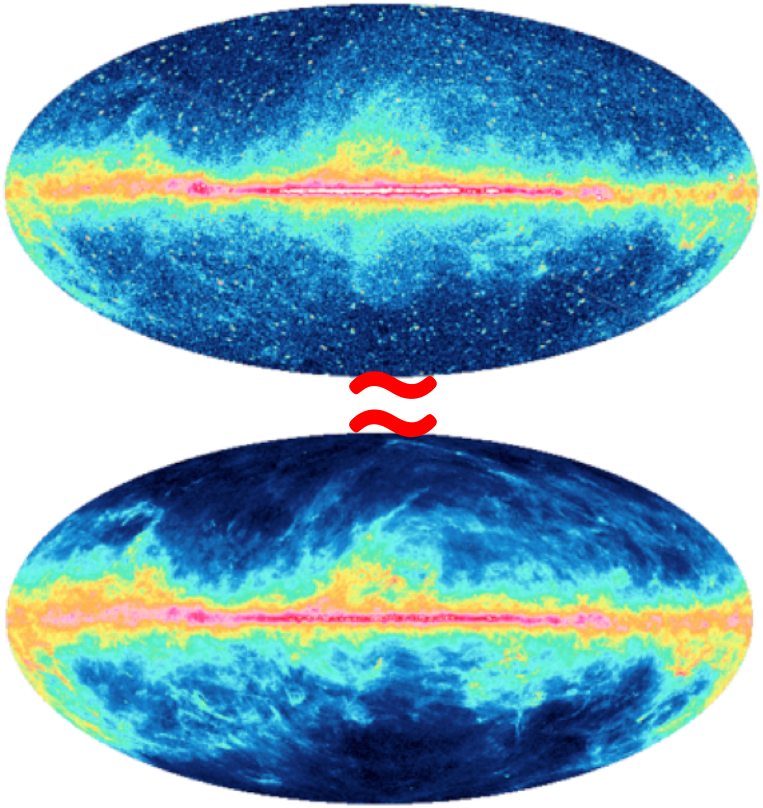


Relation radio - microwaves - gamma

Relation: radio/microwaves – gamma rays

Fermi-LAT > 1 GeV

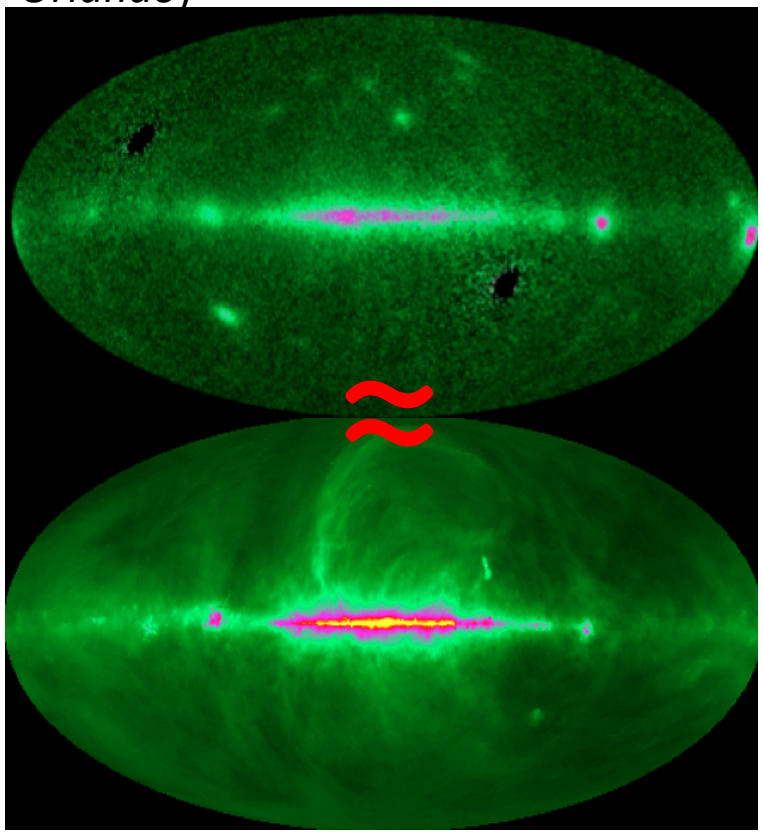
(Credits: *NASA/DOE/Fermi LAT Coll.* modified *by Greiner et al ARAA 2015, 53-199*)



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*)

Where are we now?

- More and more accurate propagation models - we have taken the first steps – (reality is much more complicated; also some residual structures need to be understood).

- Synergy with multi-frequency observations - we have taken the first steps - (Fermi, and next generation of MeV instruments will help)

- Increasing knowledge of the magnetic field models - we have taken the first steps – (more rotation measurements? Magneto-hydrodynamic simulations? SKA?)

- Need of all-sky surveys both in temperature and polarization covering the entire frequency band of the synchrotron emission up to 30 GHz (what do we have? Arcade, S-PASS, C-BASS, SKA, LWA1, what else?)