Galactic Synchrotron Modeling

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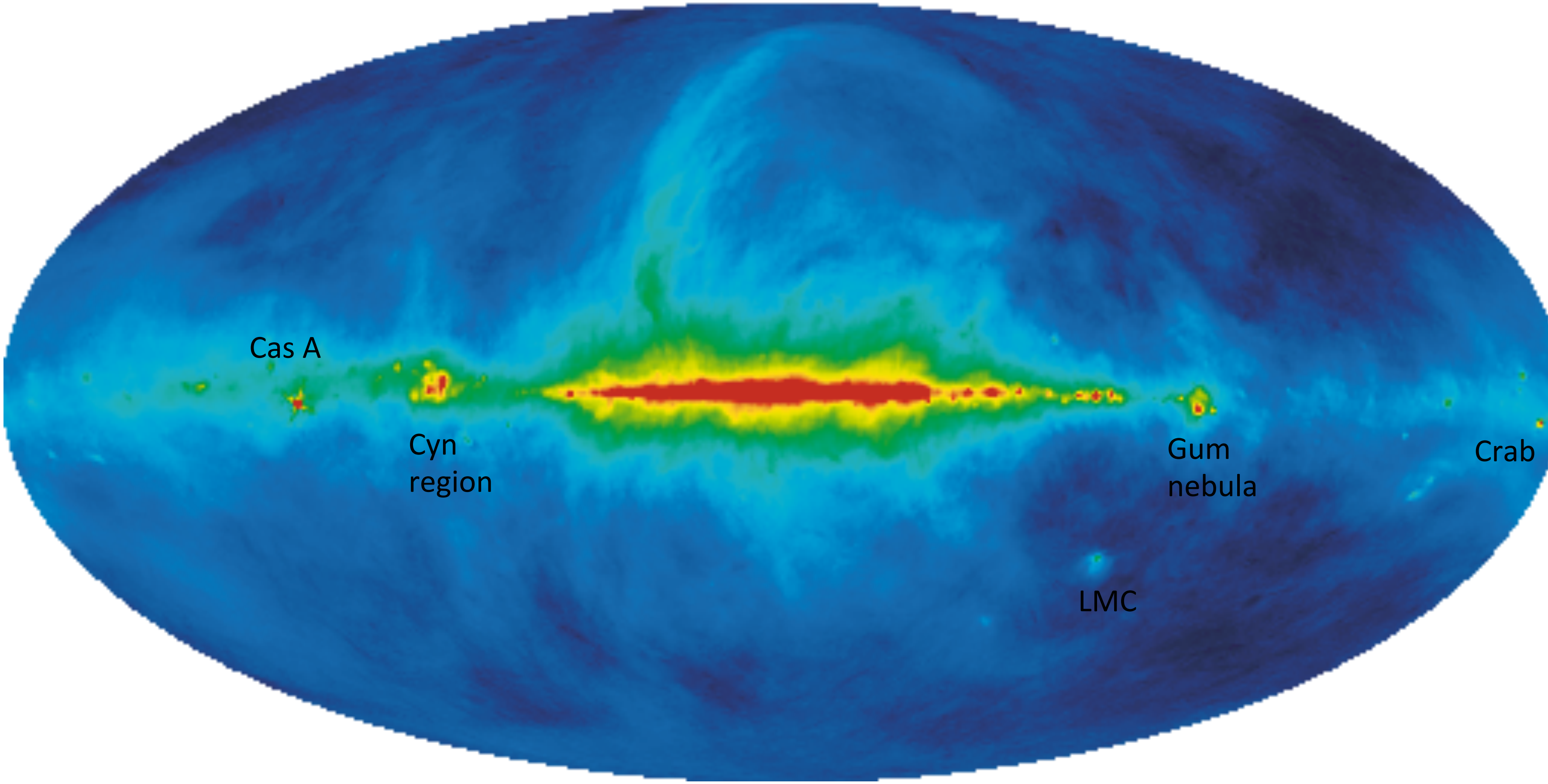
B-modes from Space Workshop
4-6 Dec 2017 – Berkeley



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

Synchrotron intensity ⟷ B-field intensity and CR density

Synchrotron spectrum ⟷ CR spectrum

See also related talks by of Remazeilles and Baccigalupi

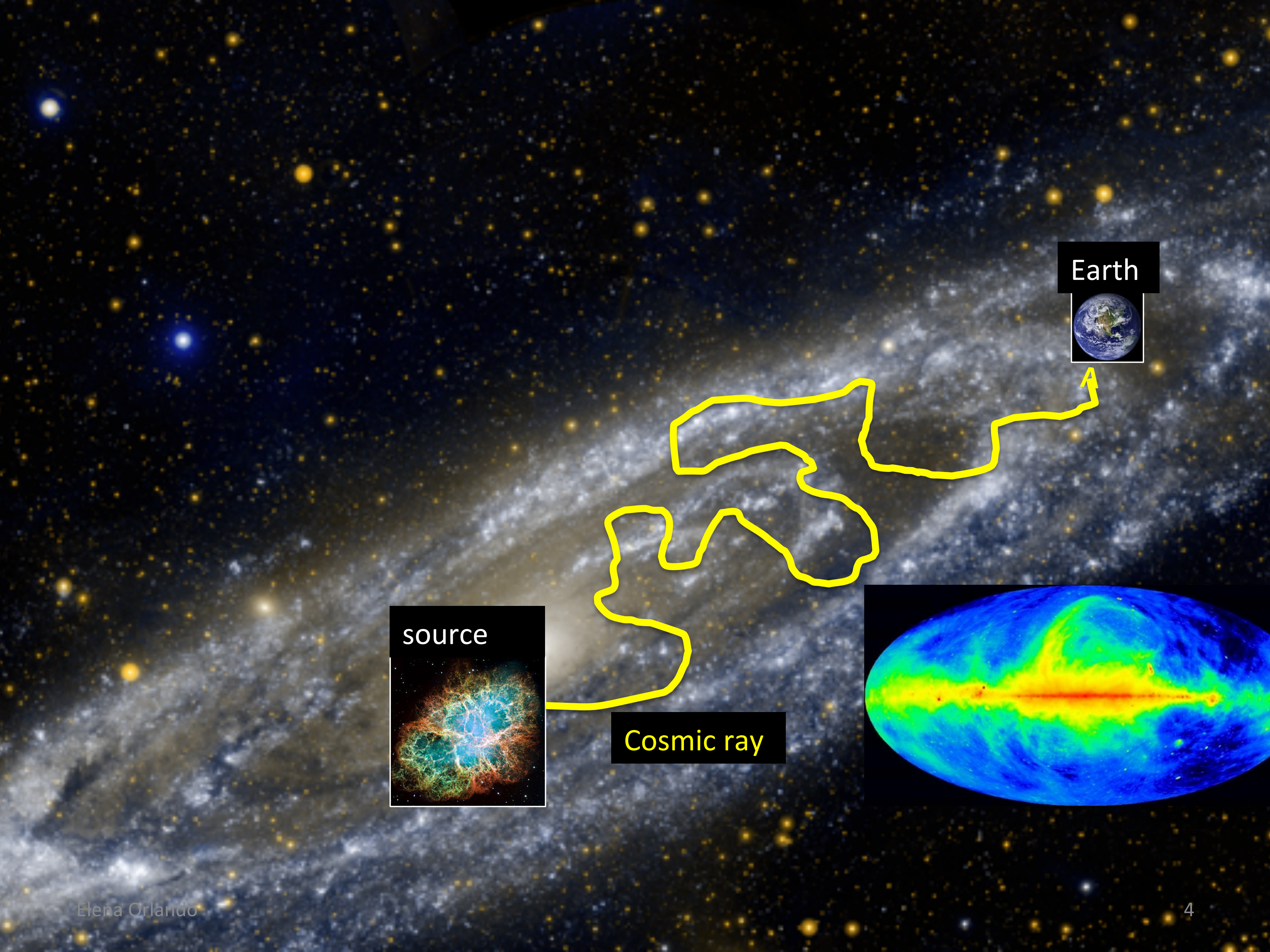
Synchrotron spectral index

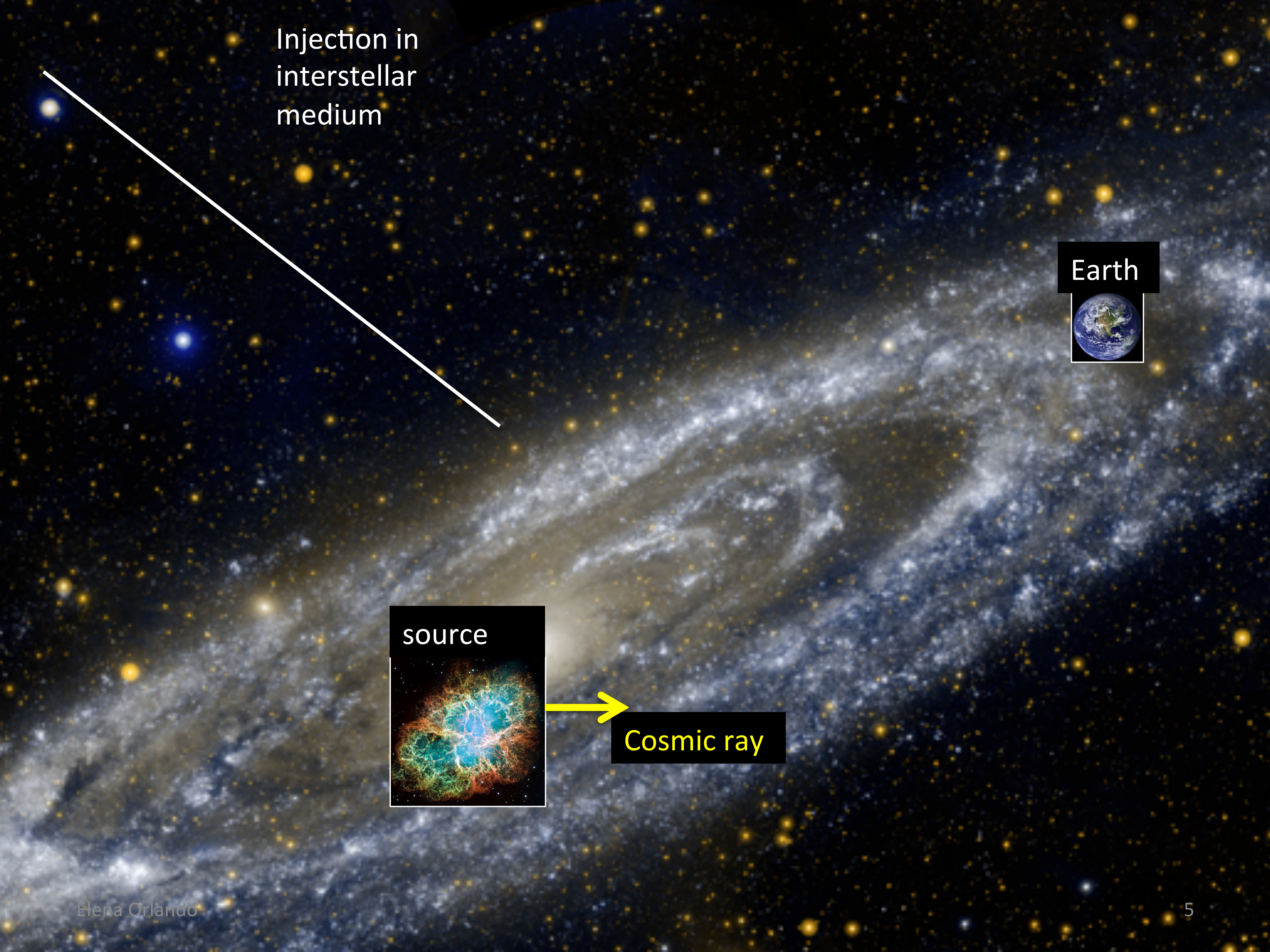
Usually assumed to be -3, BUT

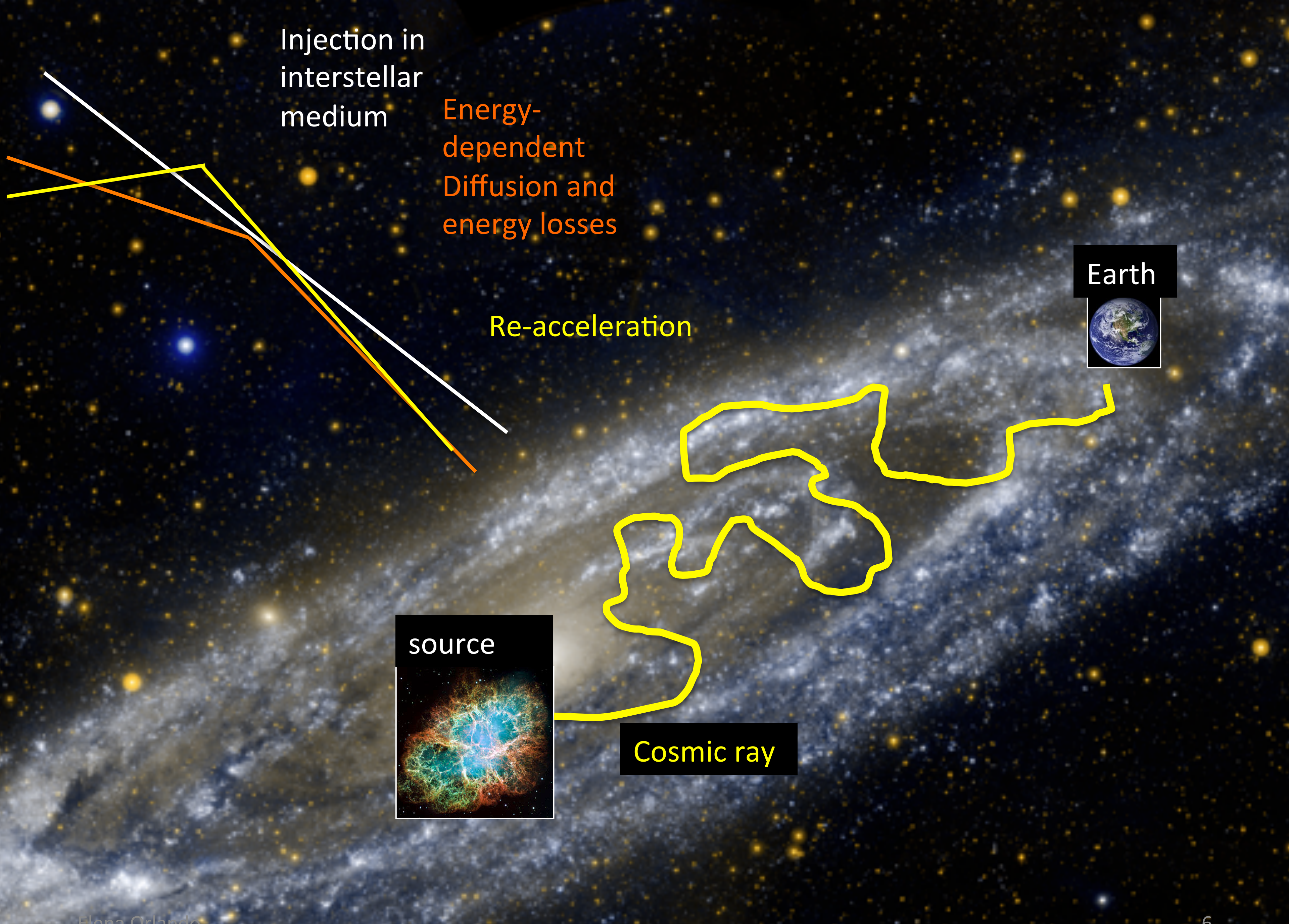
- The observed synchrotron emission is the integration of emission along the line of side

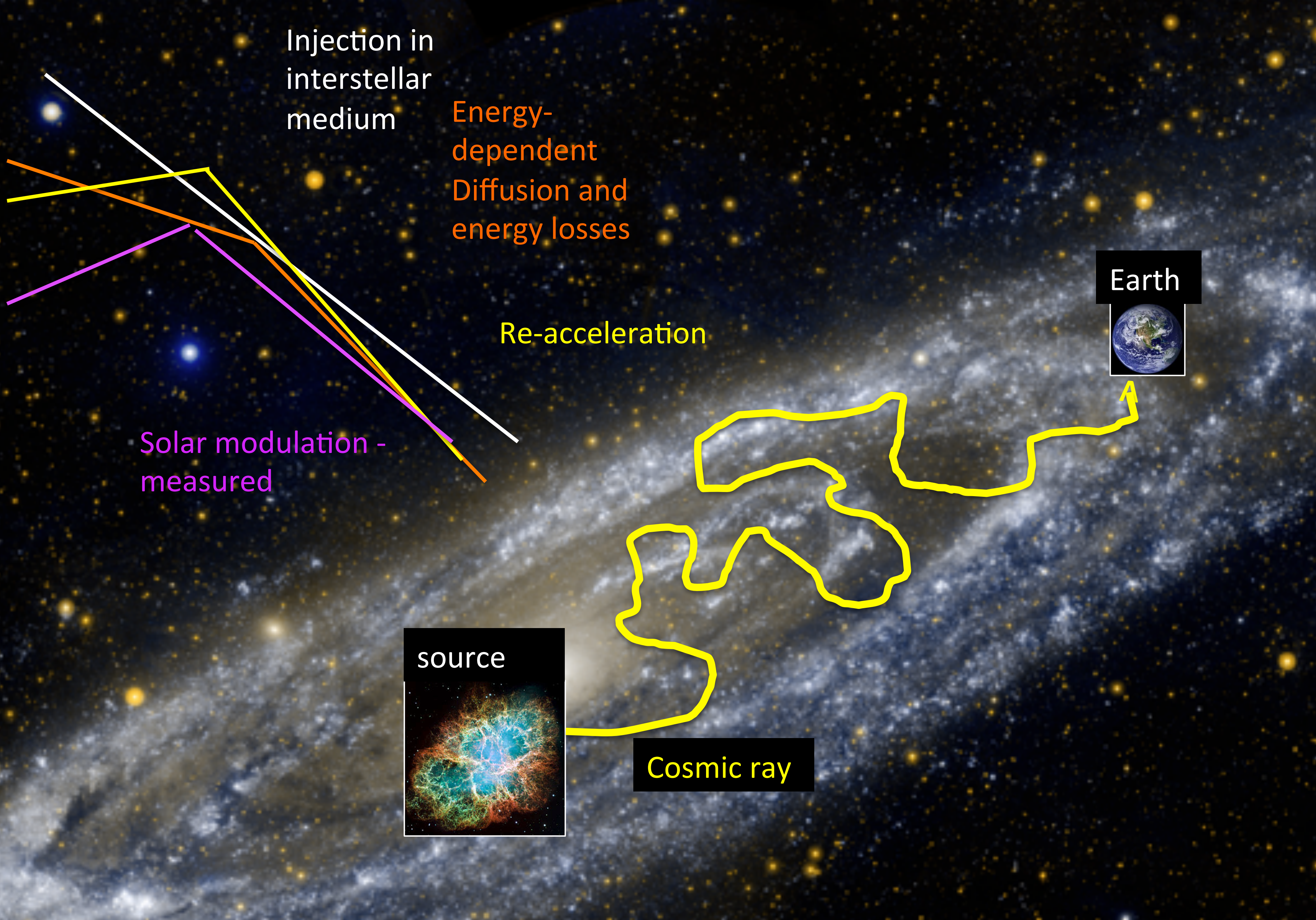
- CR electron spectrum changes in different places of the Galaxy

- CRs we measure at Earth may not resemble the local spectrum

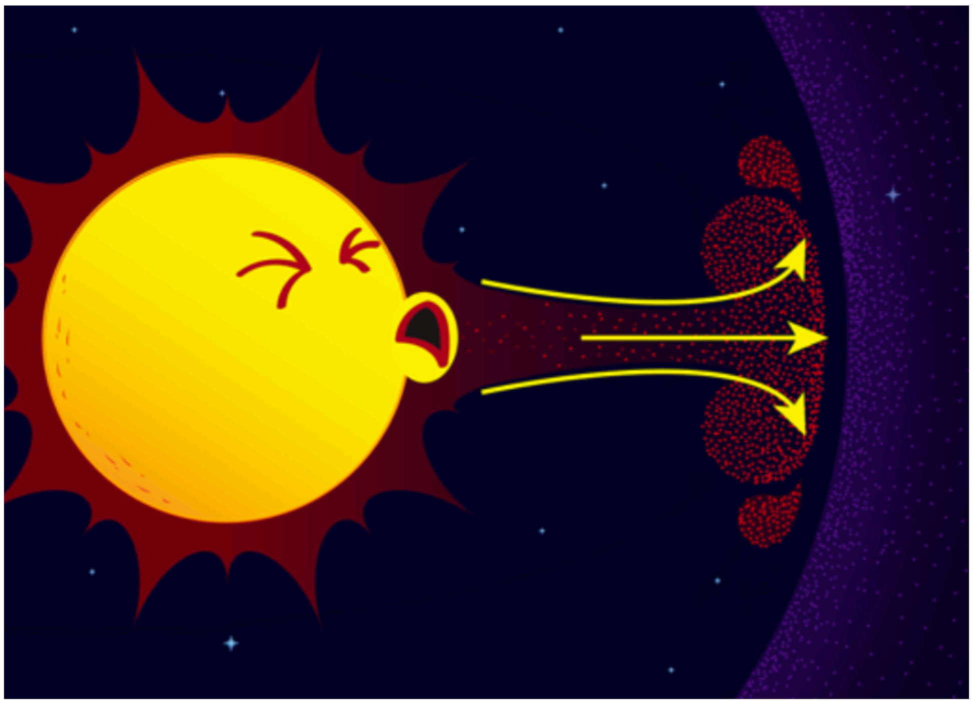

Earth
source
Cosmic ray

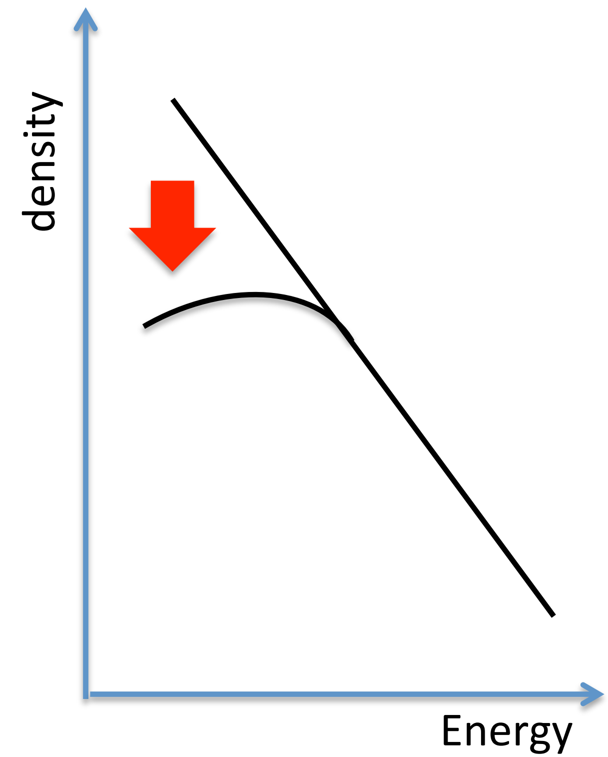

Injection in interstellar medium
Earth
source
Cosmic ray


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



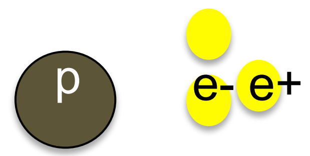


It depends on the solar activity

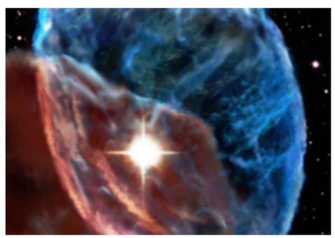
Ingredients (and source of uncertainty) for the modeling with CR propagation codes (e.g. GALPROP)

https://galprop.stanford.edu

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

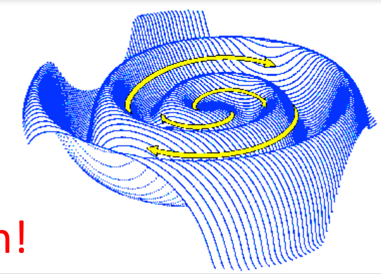


CR source distribution



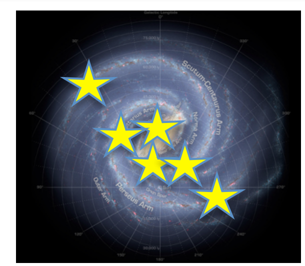
Magnetic field

No assumption of equipartition!



Gas distribution for production of secondary e+e-

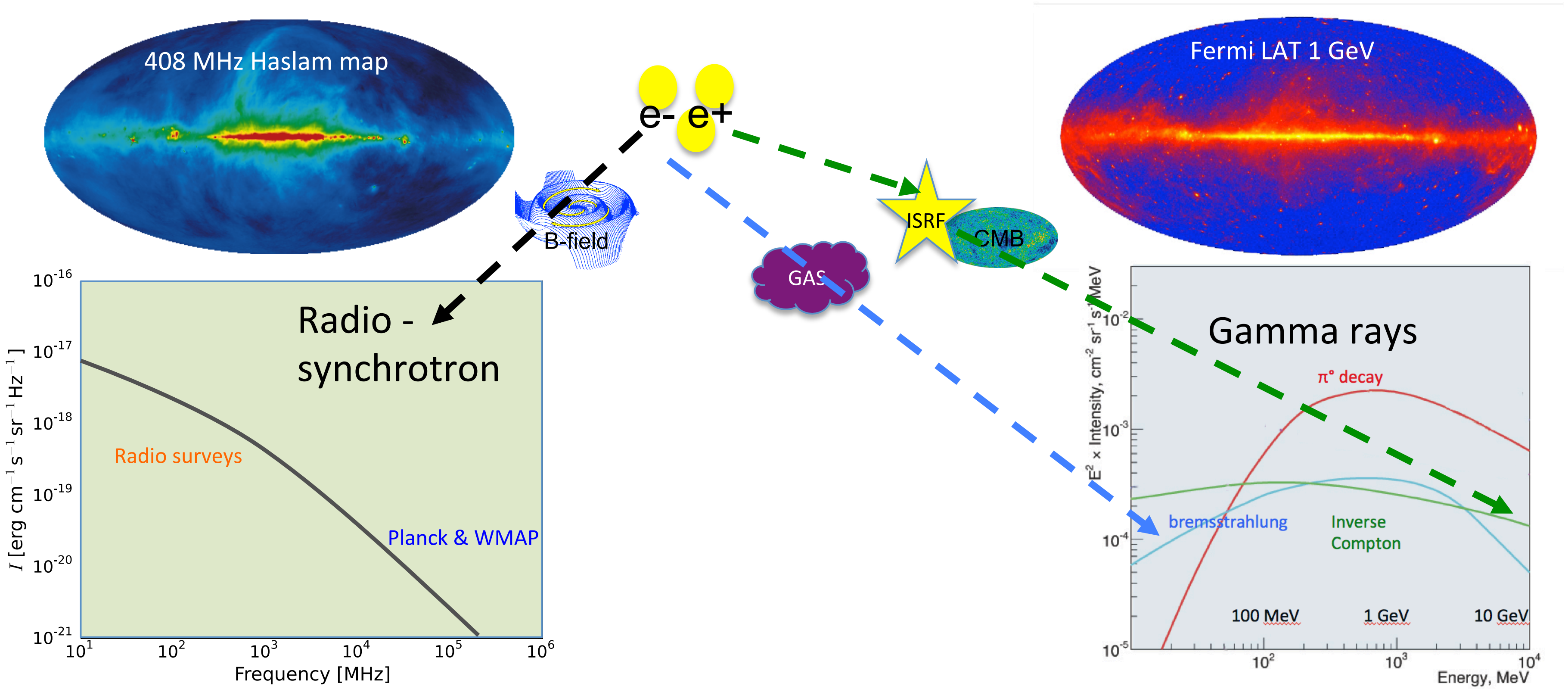
ISRF (for energy losses)



Solving the transport equation for all the CR species

Multi-frequency observations help in mitigating uncertainties

Radio/gamma relation

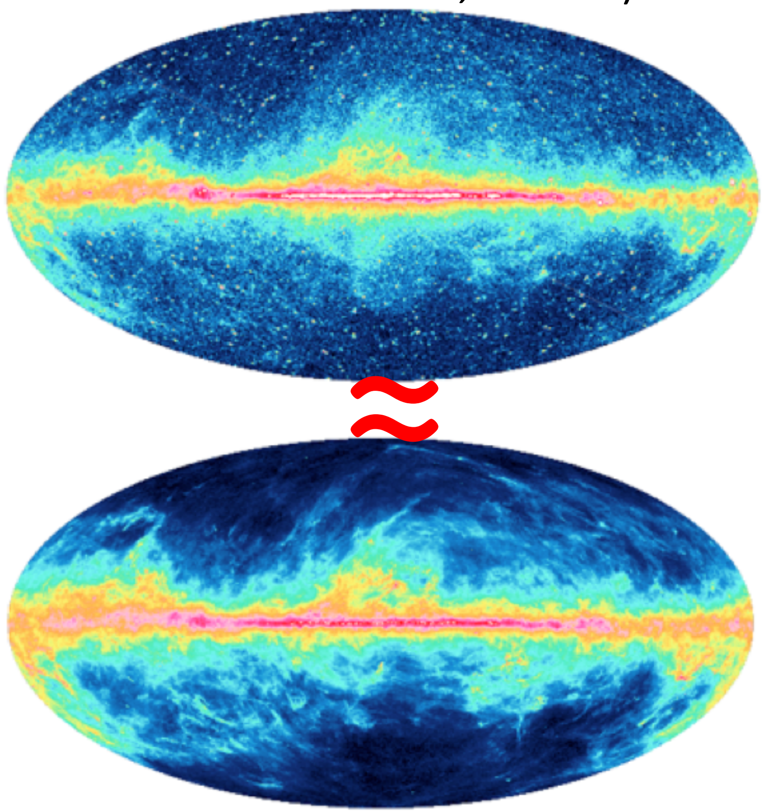


Mitigating model degeneracy and uncertainties

Relation radio - microwaves - gamma

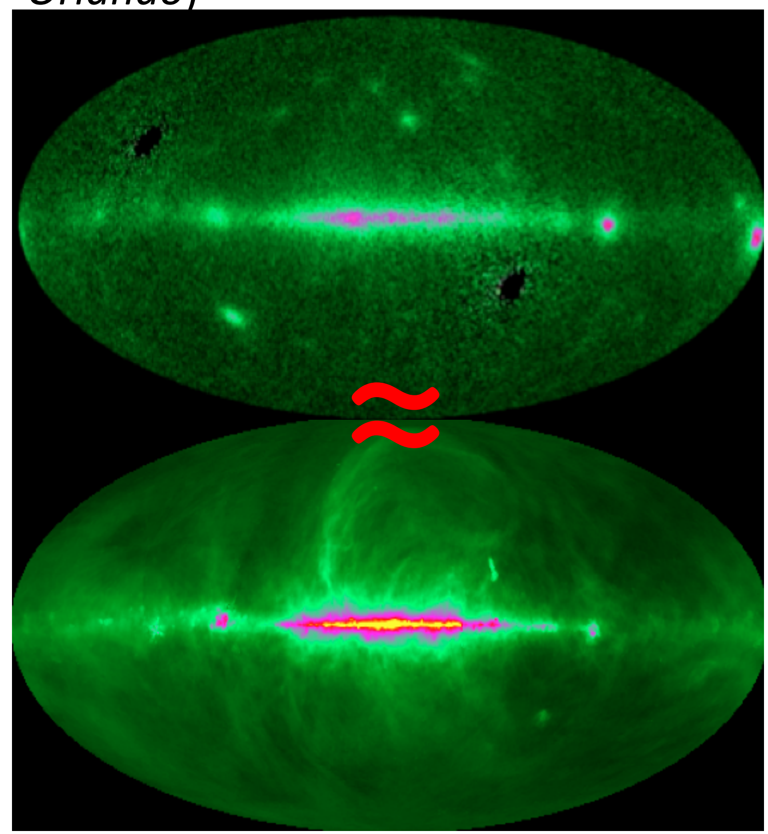
Relation: radio/microwaves – gamma rays

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*)

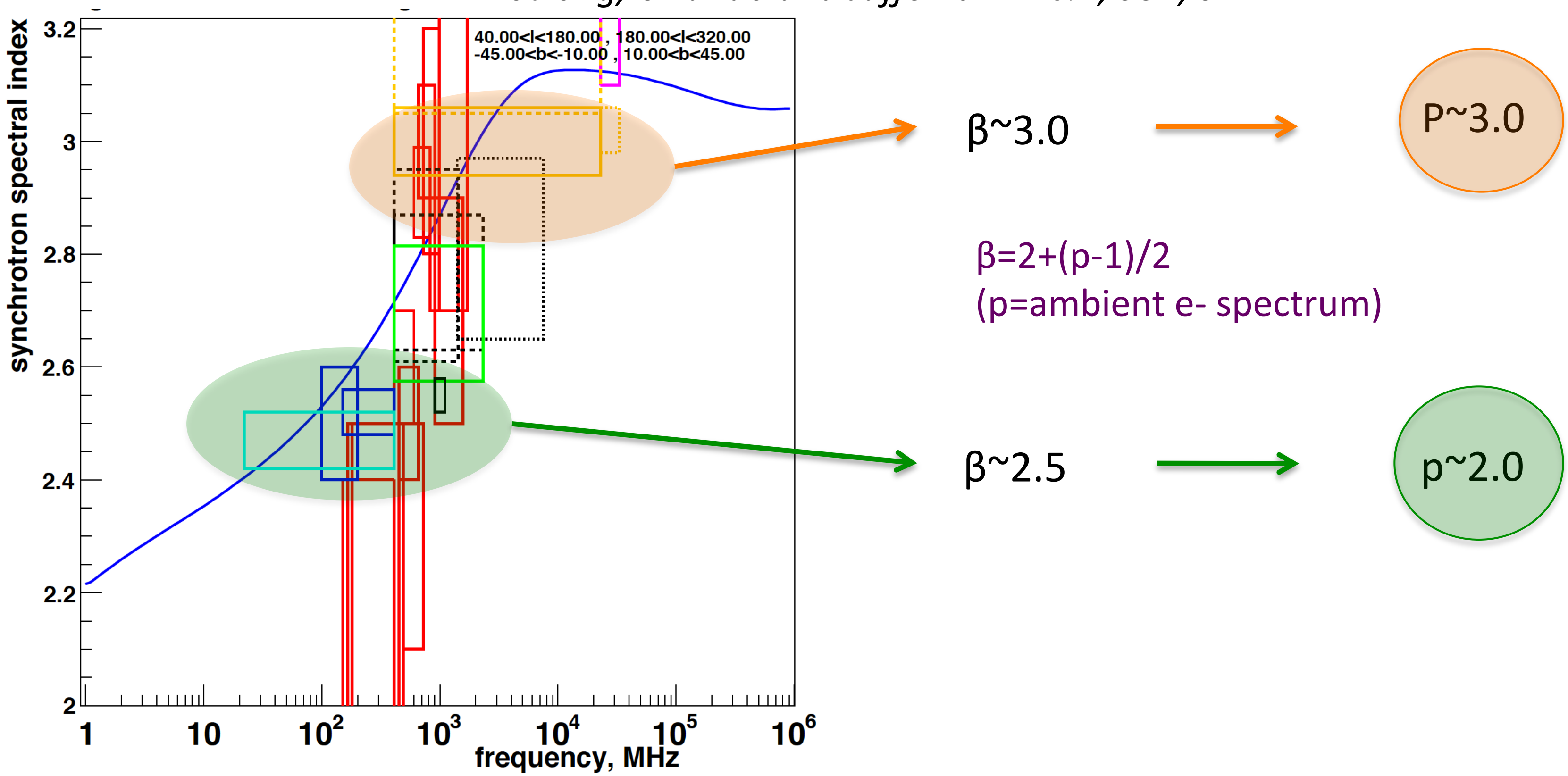
Fermi-LAT 30 – 80 MeV
(*Fermi LAT coll. 2014 Fermi symposium, Orlando*)



408 MHz (*Haslam et al 1981*)

Synchrotron spectral index

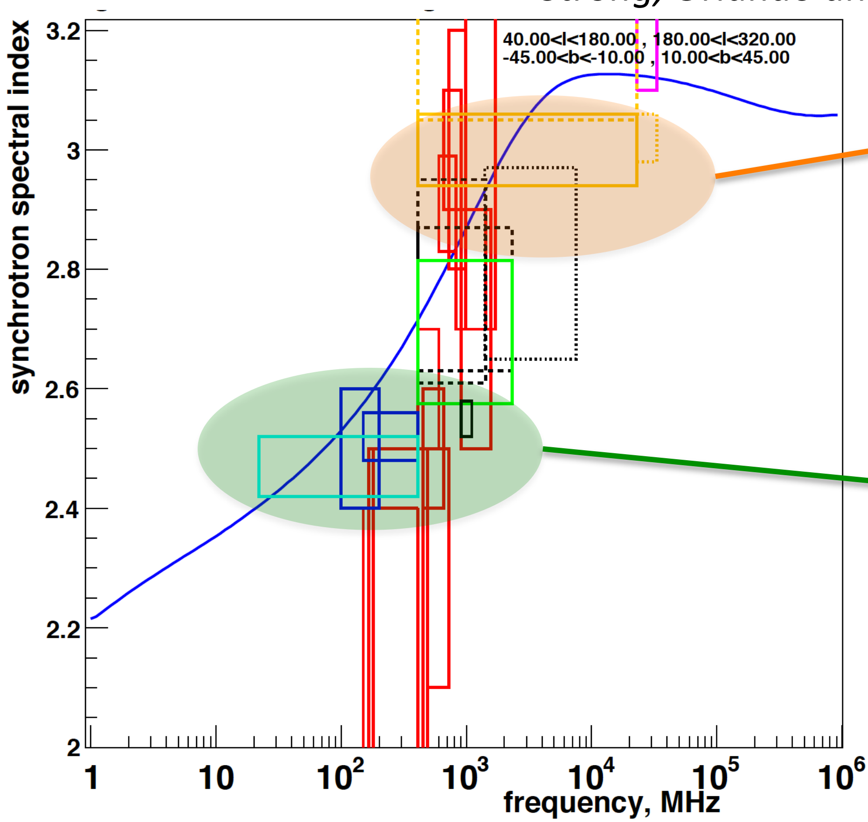
Strong, Orlando and Jaffe 2011 A&A, 534, 54



Intermediate latitudes

Synchrotron spectral index

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

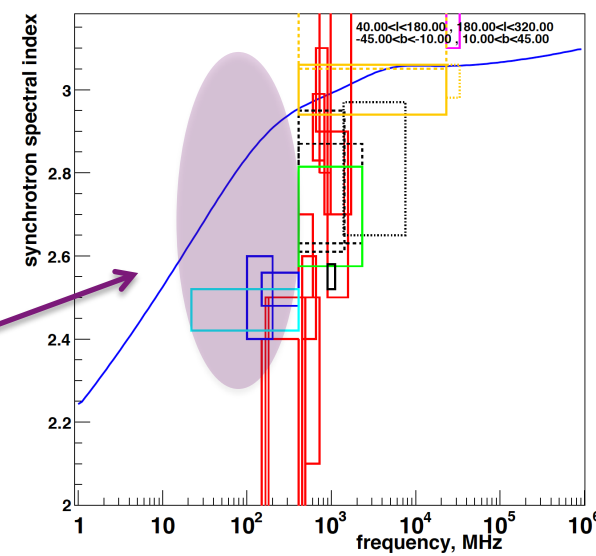


β~3.0 → P~3.0

β=2+(p-1)/2
(p=ambient e- spectrum)

β~2.5 → p~2.0

Intermediate latitudes



Standard reacceleration models challenged
(too many secondary CRs)

Improvements in modeling

Orlando & Strong 2013 MNRAS 436, 2127

- polarization (Stokes I, U, Q)

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

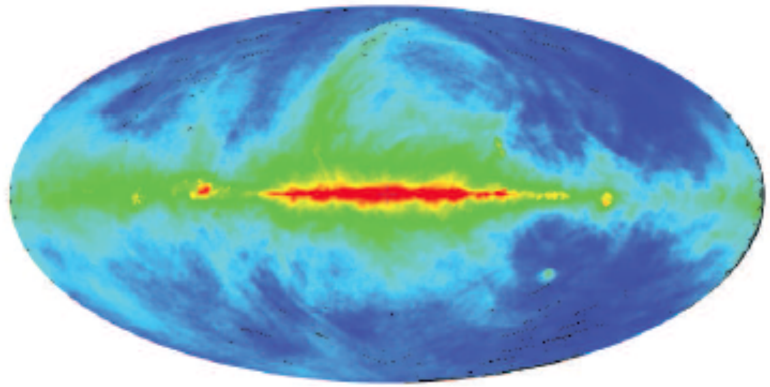
- absorption

First time models of total and polarized synchrotron emission in the context of CR propagation -> physical distribution of electrons and secondary positrons!

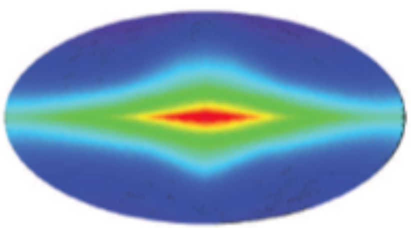
Example of Radio and microwave modeling

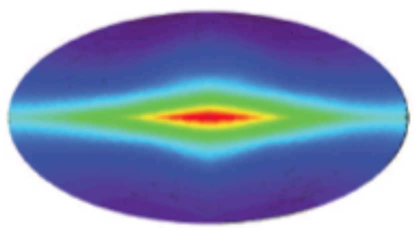
Orlando & Strong 2013 MNRAS 436, 2127

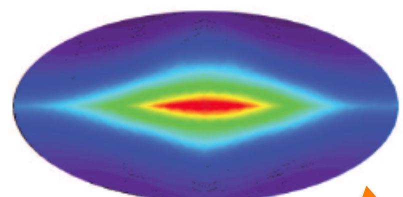
I @ 408 MHz

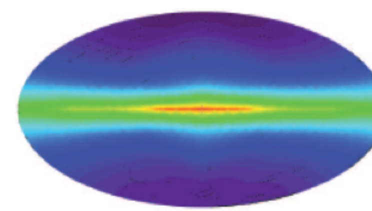


Best model used for Planck component separation









Z=10 kpc

Z=4 kpc

Different propagation halo size

Different CR electron distribution

Different CR source distributions

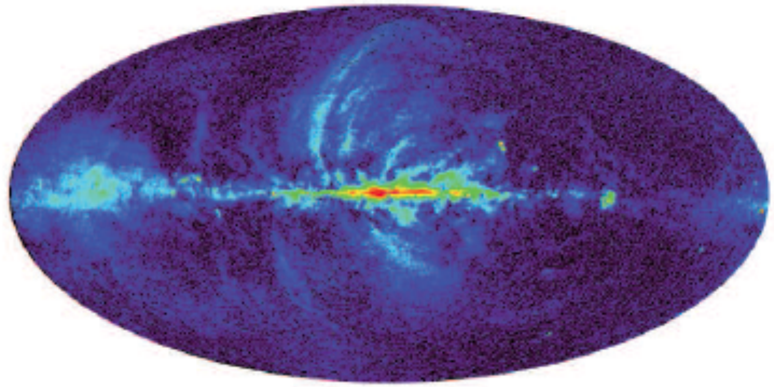
Also Different B-fields (regular, random, anisotropic)

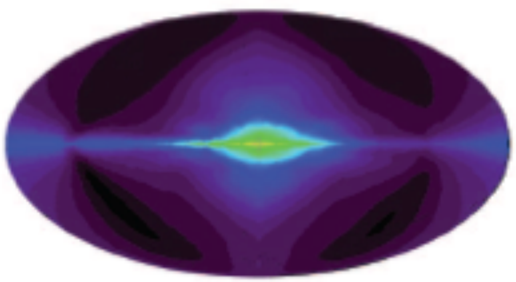
Synchrotron spatial modeling

Orlando & Strong 2013 MNRAS 436, 2127

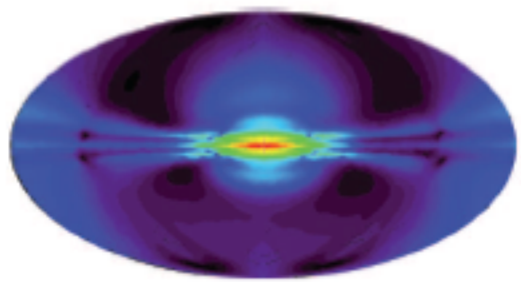
P @ 23 GHz

WMAP

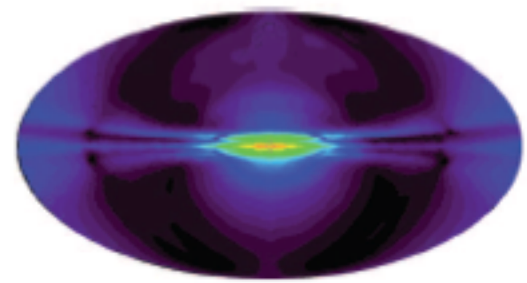




Sun 2008, 2010



Pshirkov, 2011 (ASS)

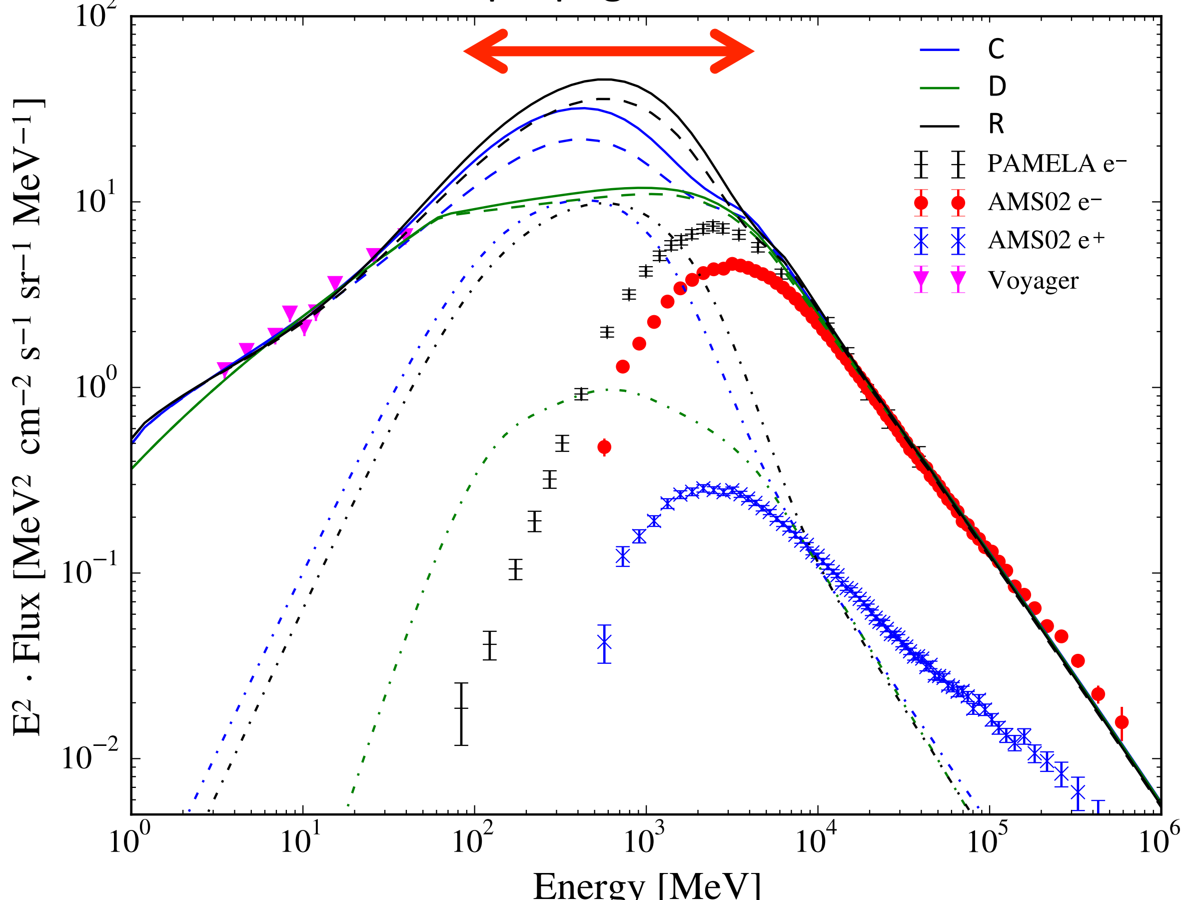


Pshirkov, 2011 (BSS)

Different B-fields

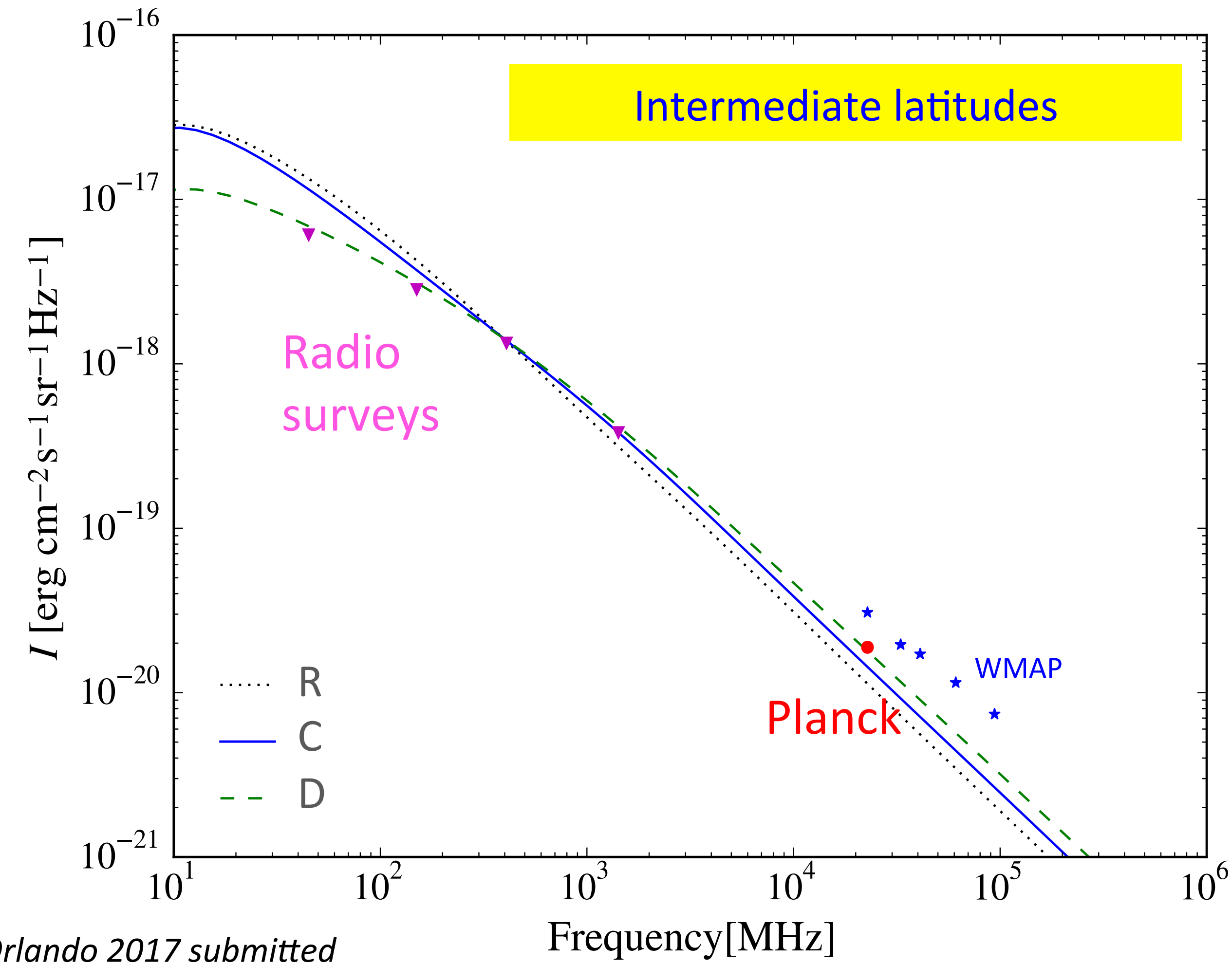
Electron (& positron) local interstellar spectrum

Energy range important for:
LIS and propagation models



Orlando 2017 submitted

Produced synchrotron emission



Orlando 2017 submitted

Electron (& positron) local interstellar spectrum

Energy range important for:
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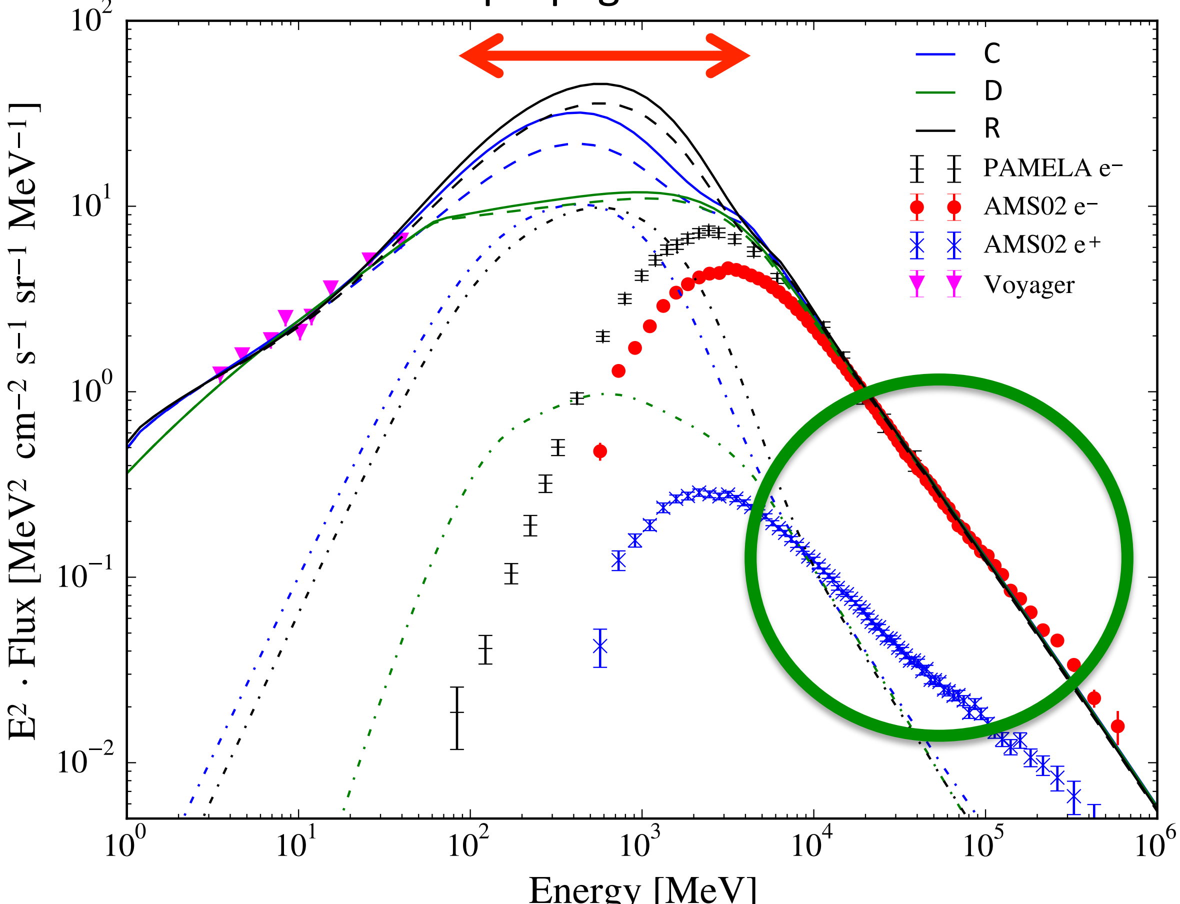
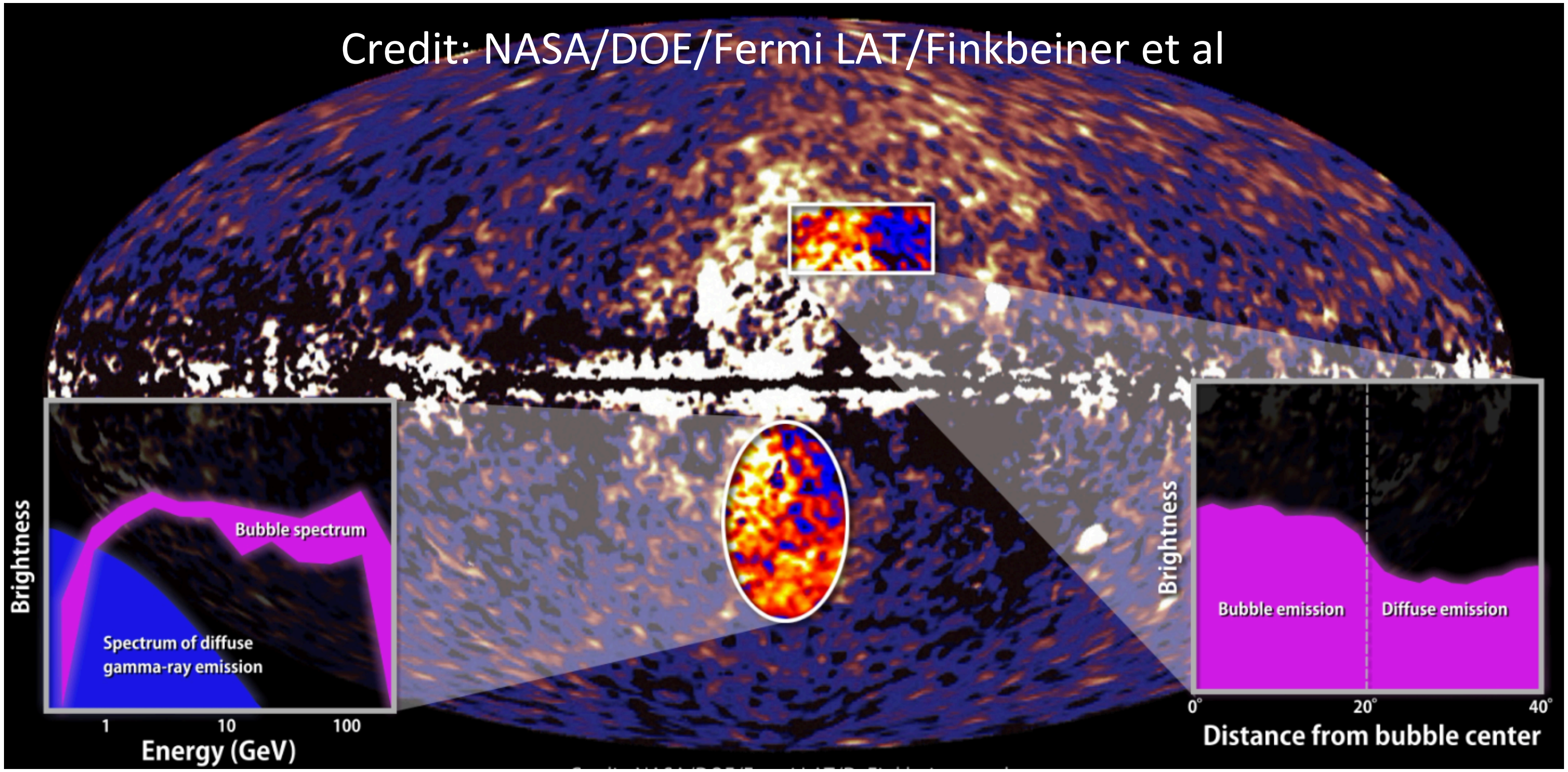


Orlando 2017 submitted

Fermi Bubbles



References: Dobler et al. 2010; Su et al 2010, 2012; ..; since then many studies including different wavelength (e.g. Carretti 2013, S-PASS; Dobler 2012, WMAP; Snowden 1997, Su 2012 ROSAT; Kataoka 2013, Tahara 2015, Suzaku, Planck coll 2013; …)

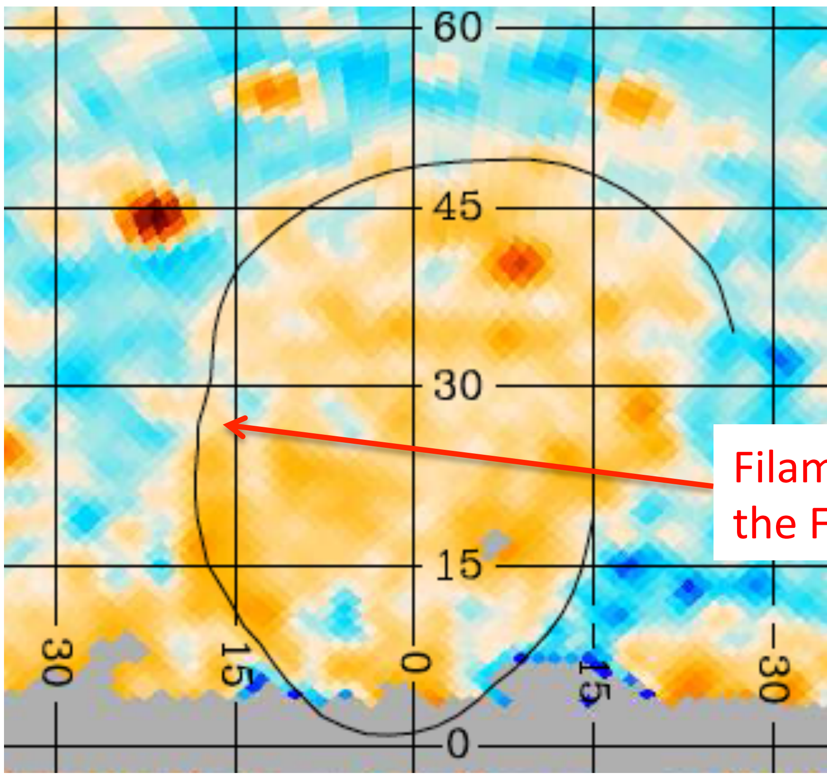
→ Both leptonic and hadronic models represent Fermi spectral data well

(Ackermann et al., 2014)

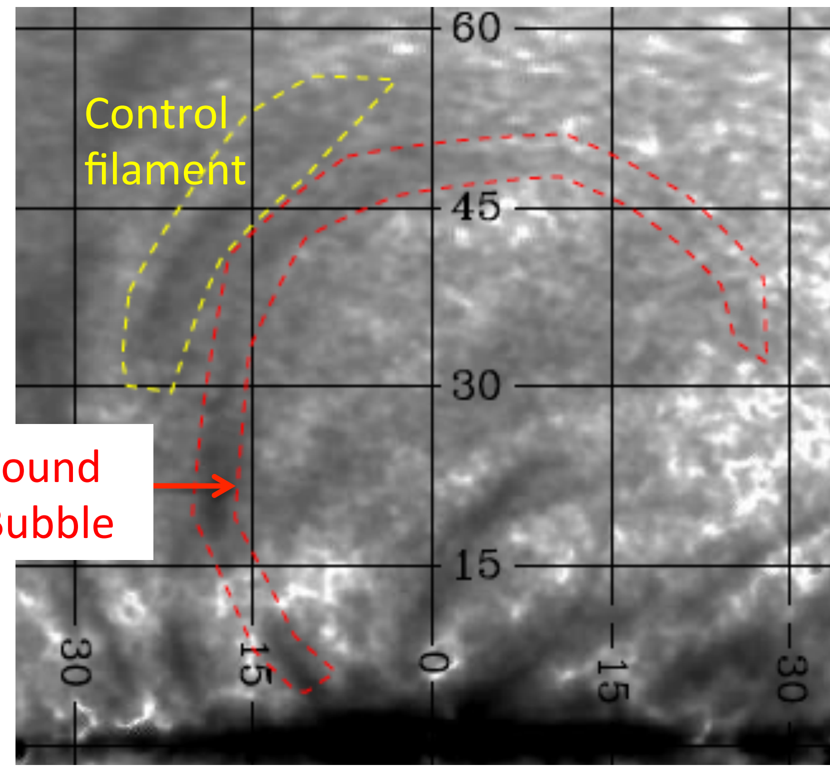
Planck polarization and Fermi Bubbles

Planck 2015 results. XXV

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



Planck polarization map



Conclusions

- The approximation of spatially constant spectral index is not rigorous, however the CR propagation modeling is affected by large uncertainties

- Additional constraints from CR propagation models and gamma rays help in understanding the interstellar foregrounds, and together may mitigate some degeneracies and uncertainties