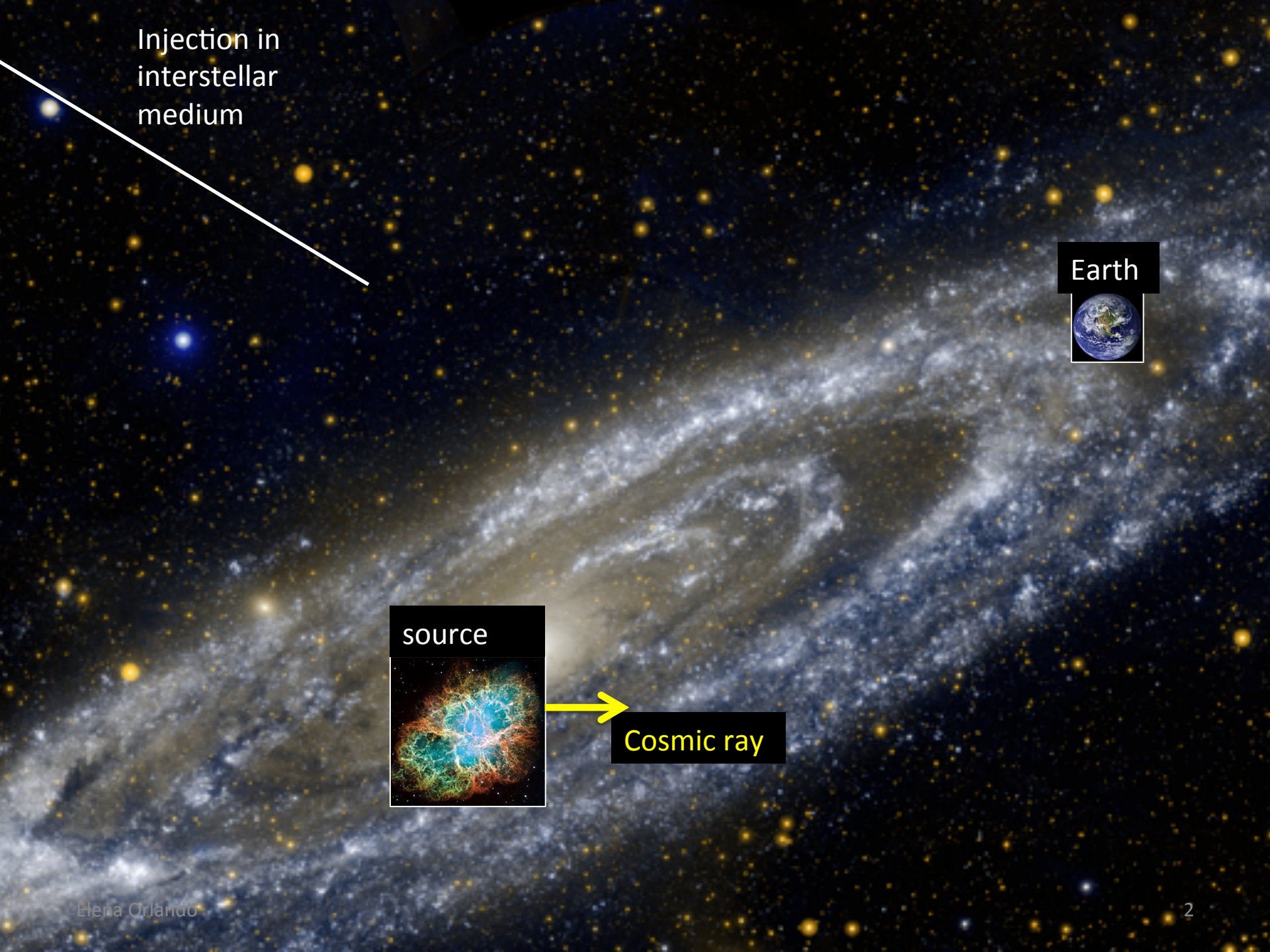
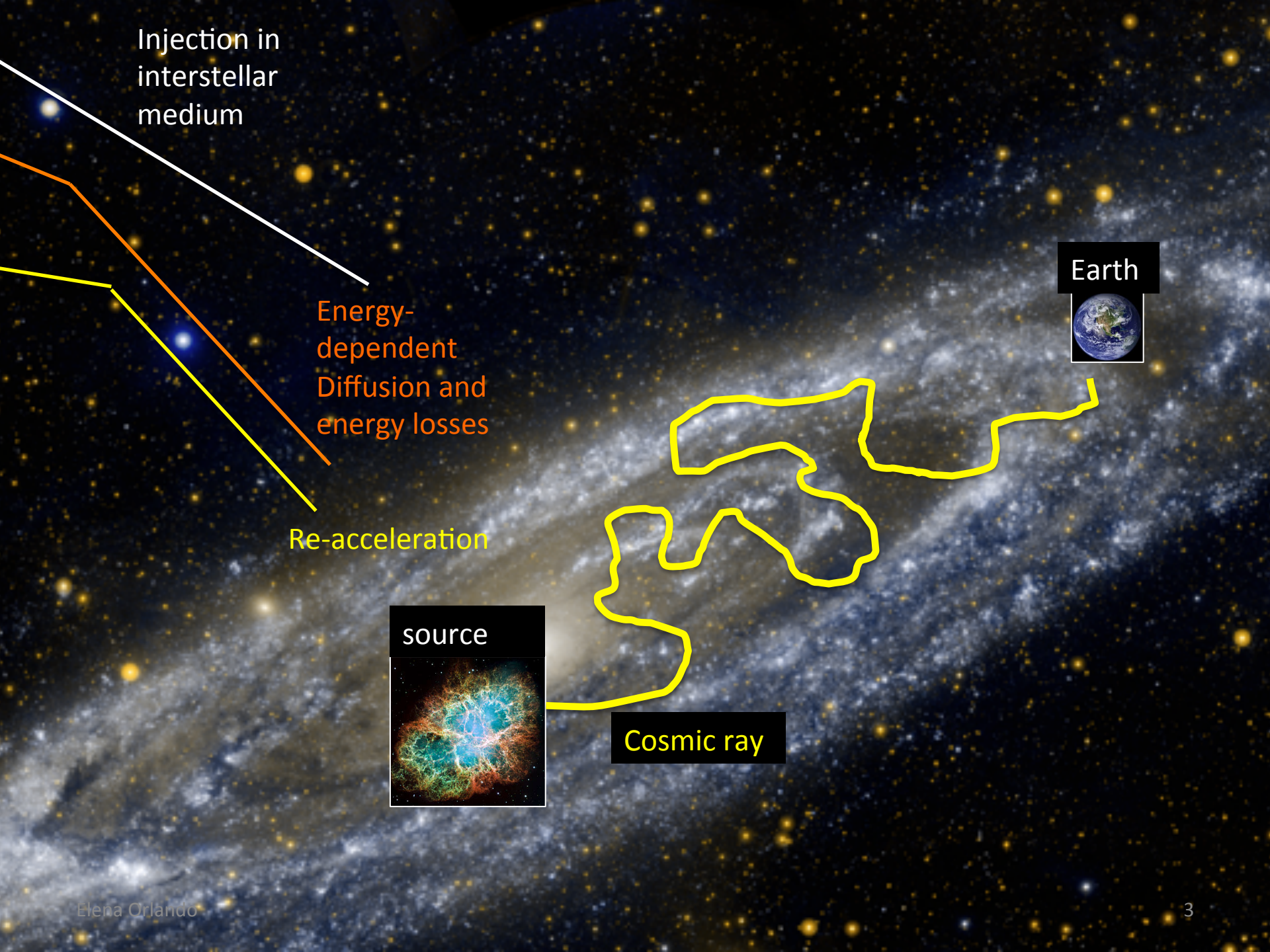
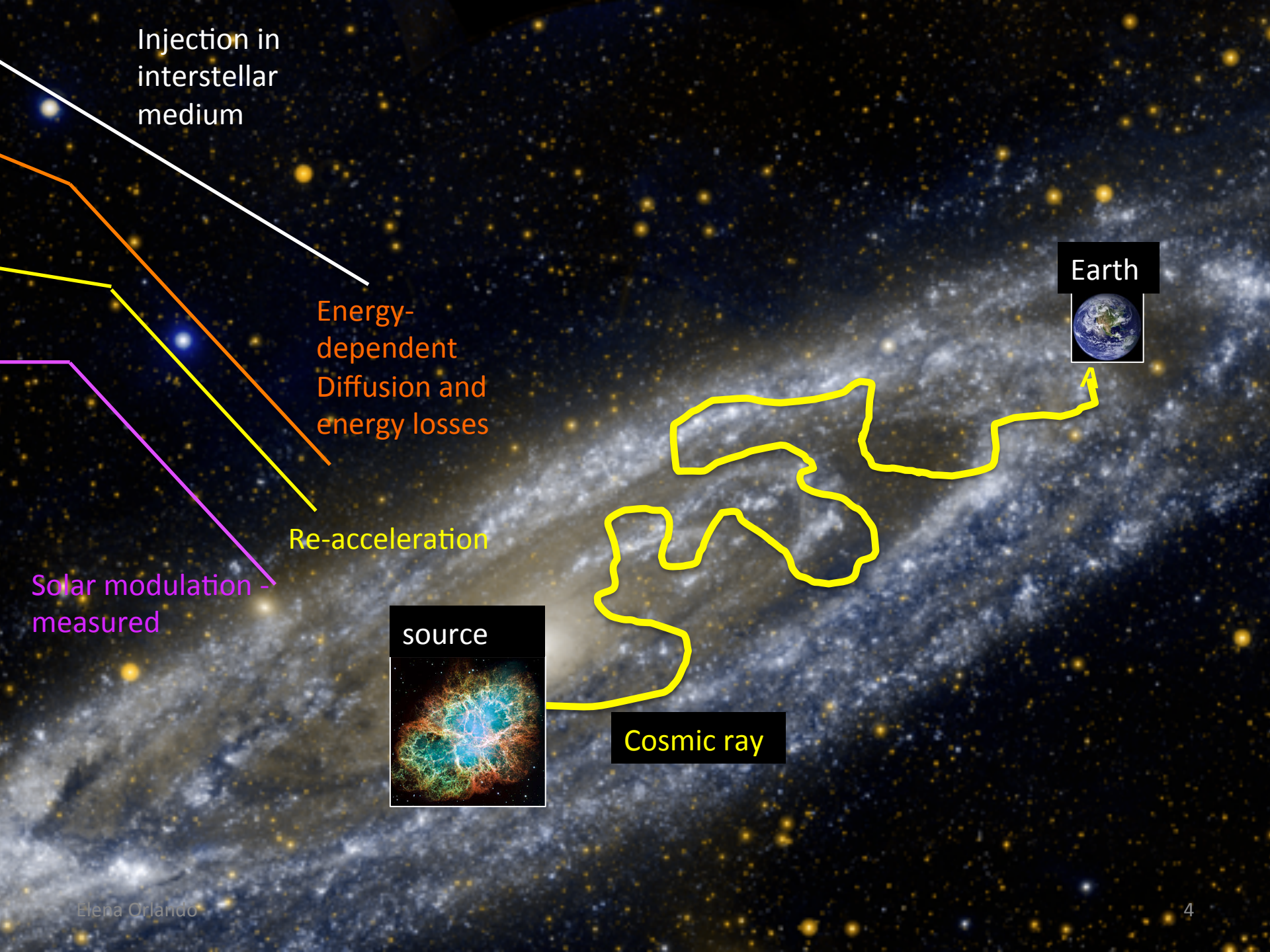
Latest applications and results with the GALPROP cosmic-ray propagation code

Elena Orlando
(Stanford University)
& the GALPROP team

ECRS 2016 - Torino


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
source
Cosmic ray
Earth

CR Propagation: GALPROP

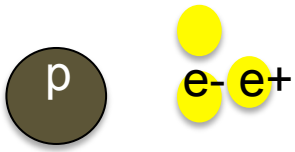
THE GALPROP TEAM:
I. Moskalenko and A. Strong (original developers),
S. Digel, G. Johannesson, E. Orlando, T. Porter, A. Vladimirov

http://*galprop.stanford.edu*

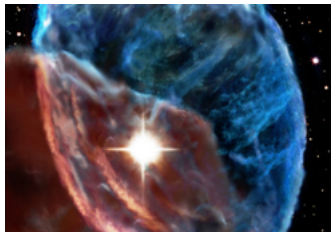
It solves the transport equation (energy losses, diffusion, acceleration, convection, fragmentation, radioactive decay) for all CR species

Ingredients

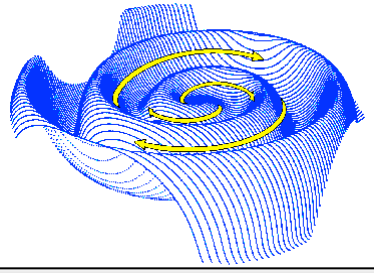
Injected spectra and propagation parameters (adjusted to fit CR measurements)



CR source distribution (see Benyamin's talk)

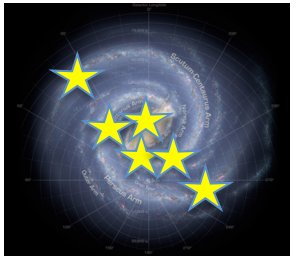


Magnetic field

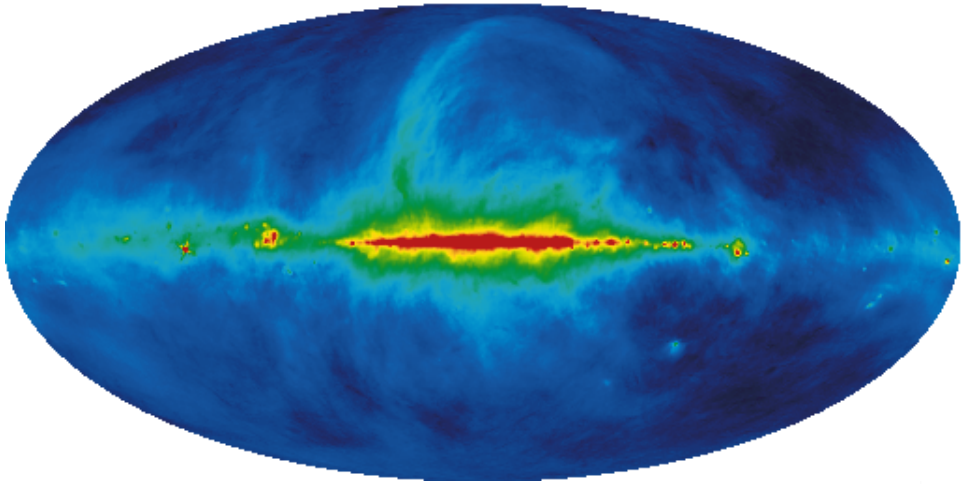


Gas distribution

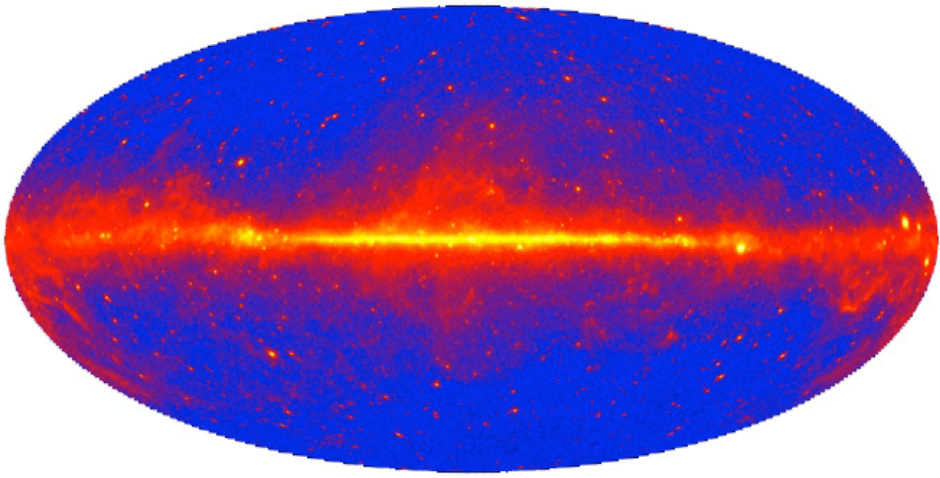
ISRF



Interstellar emission



Haslam 408 MHz



>1 GeV. *Credits: Fermi-LAT*

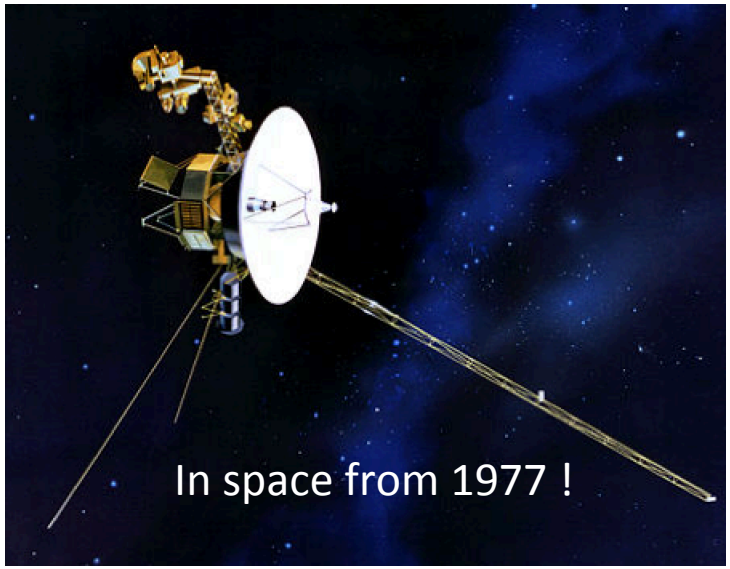
See talk by Neronov and Tibaldo on Mon

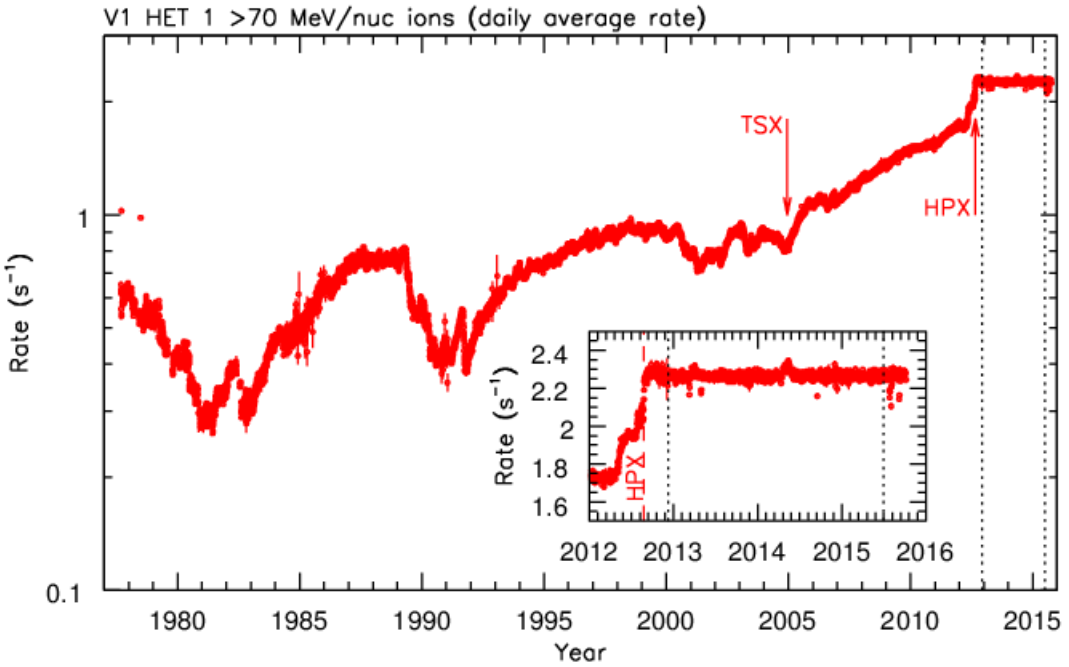
Goal : use all types of data in a self-consistent way

Latest results:
Interpretation of CR measurements

Voyager 1

In the interstellar space!

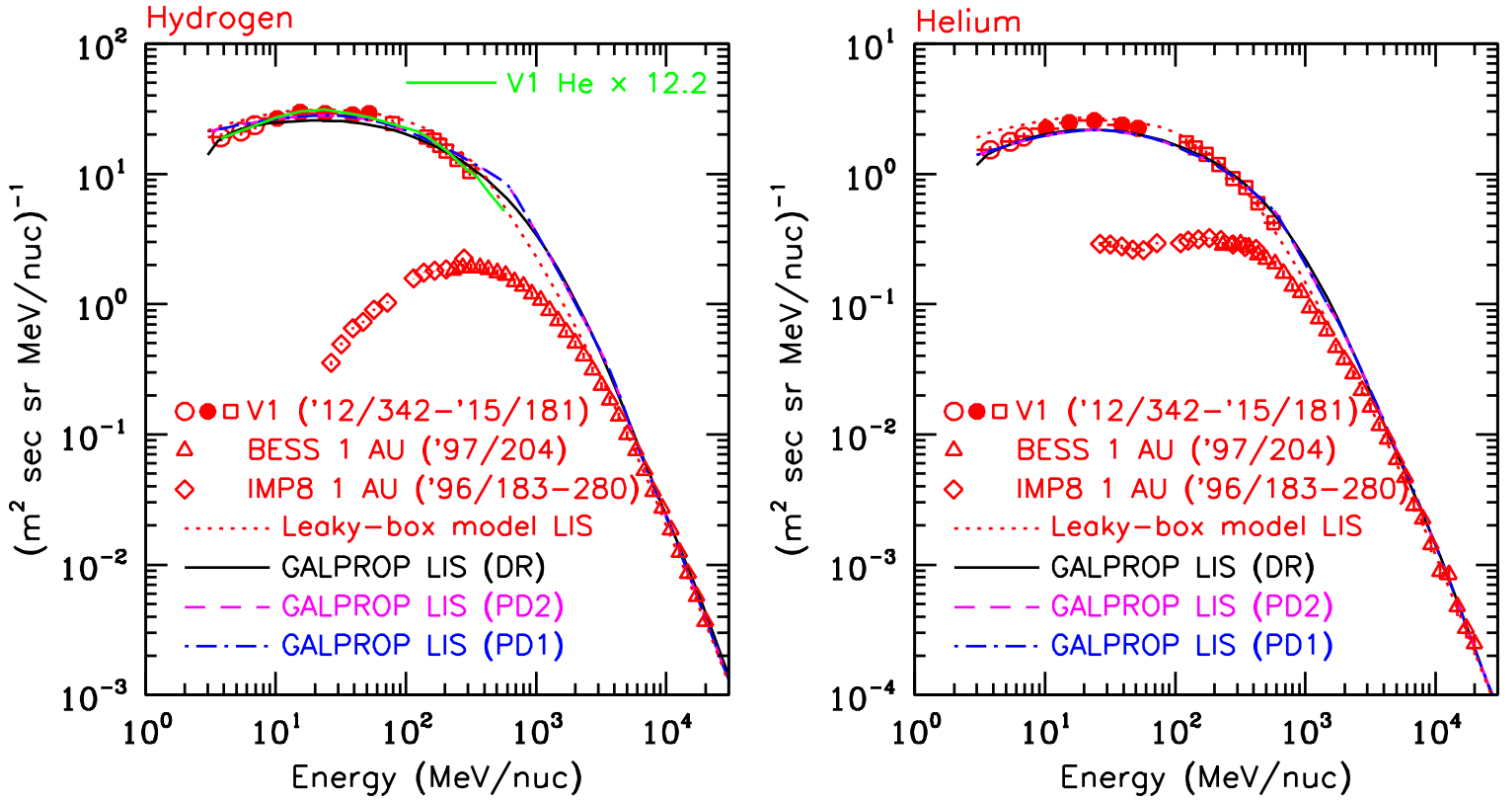




Cummings et al, 2015 Fall AGU

CR measurements from Voyager 1

GALPROP models were fit to data to obtain the energy density (0.83-1.02 eV cm^{-3}) and elemental abundances



Cummings, Stone, Heikkila, Lal, Webber, Jóhannesson, Moskalenko, Orlando, and Porter, ApJ accepted

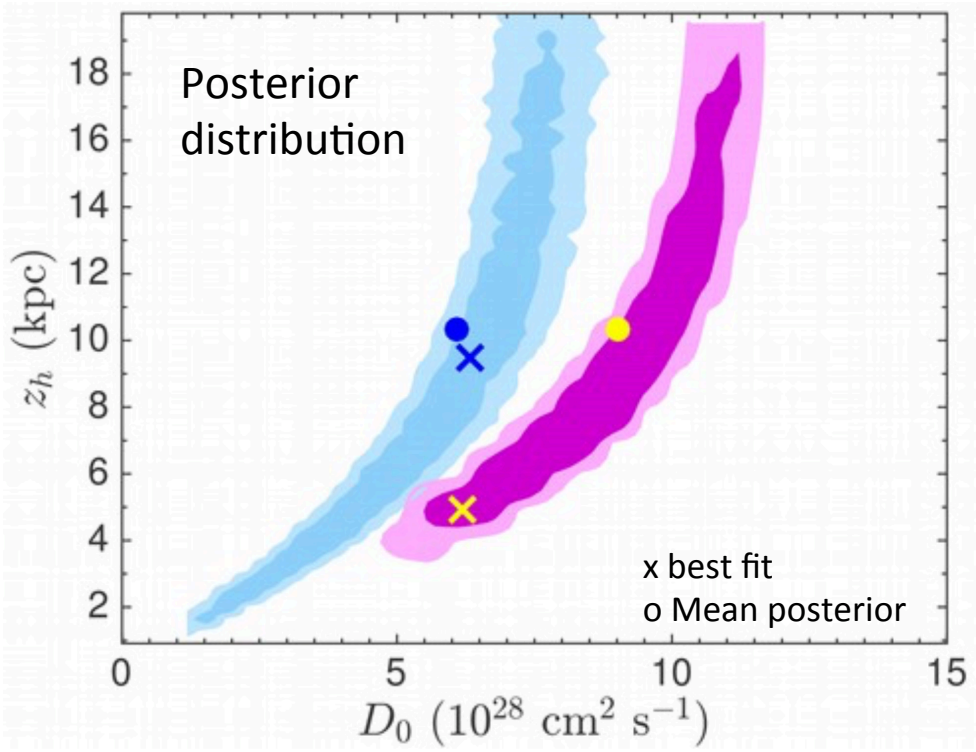
Bayesian analysis of CR propagation

The Galbayes collaboration

No homogeneous diffusion

G. Jóhannesson, R. Ruiz de Austri, A. C. Vincent, I. V. Moskalenko, E. Orlando, T. A. Porter, A. W. Strong, R. Trotta, F. Feroz, P. Graff, M. P., 2016 ApJ 824...16J Hobson, 2016 ApJ 824, 16

Two different scans:
– p, pbar, He
– Light elements



Different propagation parameters !

No homogeneous diffusion

G. Jóhannesson, R. Ruiz de Austri, A. C. Vincent, I. V. Moskalenko, E. Orlando, T. A. Porter, A. W. Strong, R. Trotta, F. Feroz, P. Graff, M. P., 2016 ApJ 824...16J Hobson, 2016 ApJ 824, 16

Two different scans:
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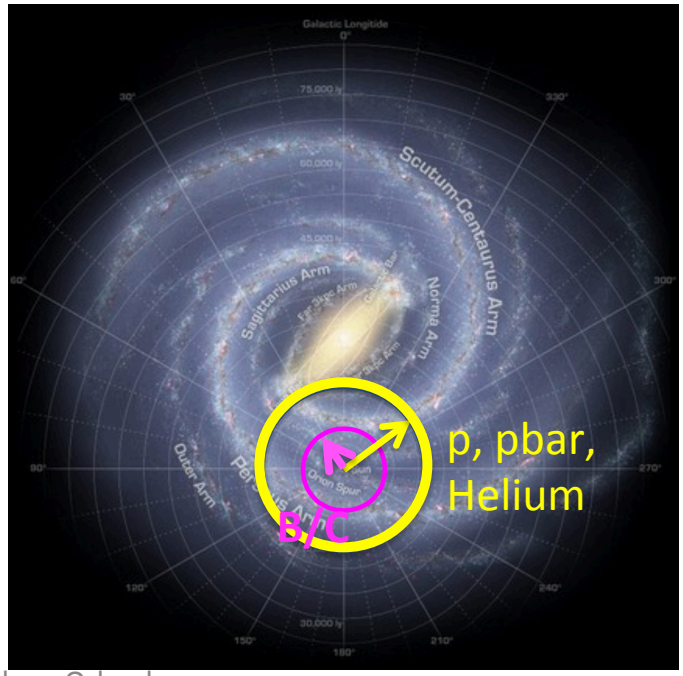
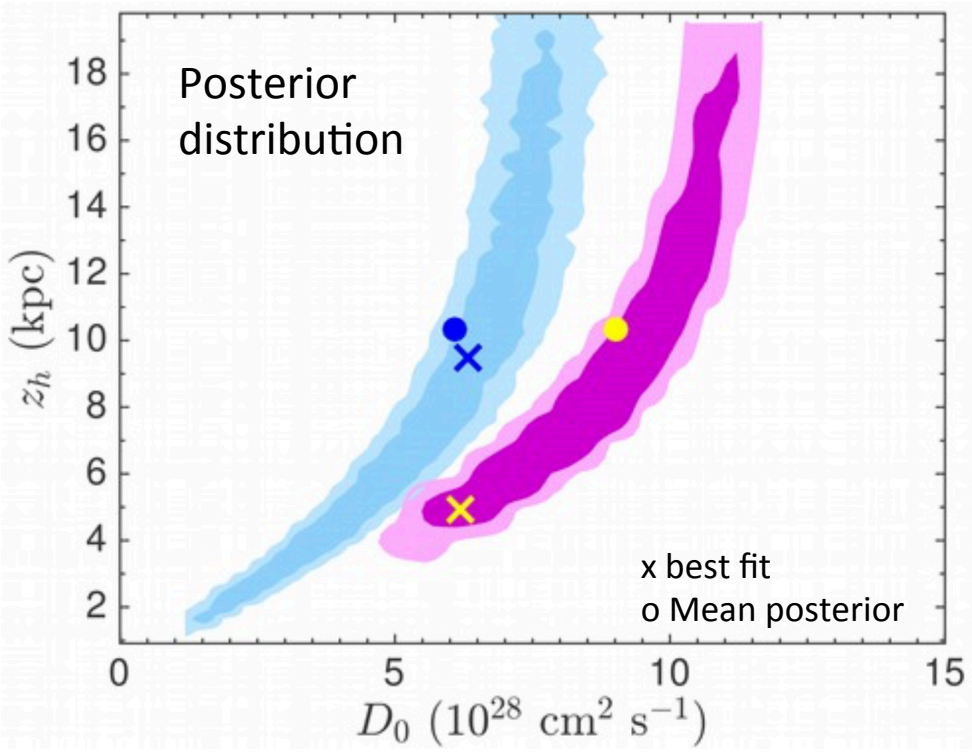


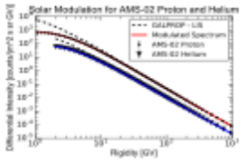


Different propagation parameters !

HelMod applied to GALPROP

http://www.helmod.org

HelMod:
The Modulation Model for Heliosphere
Online Calculator
(version 3.0.0)



Home | Bibliography | News | History and Citation | HelMod 1.5 | Who in HelMod | AMS02 MiB | Login

You are here: Home ▸ Who in HelMod ▸ Calculators Help Pages ▸ Stand-Alone Module for GALPROP

Website Search

Stand-Alone Module for GALPROP

See talk by Davide Grandi on Tue

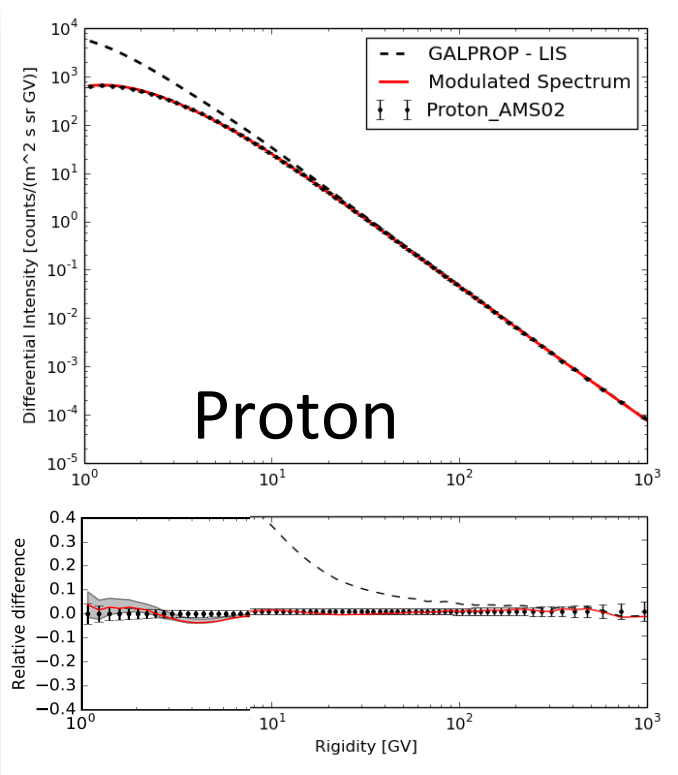
AMS02

1. Solar modulation with HelMod (*See talk by D. Grandi on Tue*)

2. GALPROP framework into the Monte-Carlo-Markov-Chain interface: propagation parameters using AMS-02 data as observational constraints, exploring a very large parameter space (*See talk by Masi*)

Della Torre, Grandi, La Vacca, Gervasi, Johannesson, Masi, Moskalenko, Orlando, Porter, Quadrani, Rancoita, Rozza, in prep. (See talk by Masi)

LIS and solar modulation



- Simultaneous inclusion of diffusion, convection and reacceleration is required
- LIS agrees with data at low- and high- solar activity accounting for modulation

Della Torre et al, in prep. (*See talk by Nicolo' Masi, see talk by Stefano Della Torre*)

Recent results:

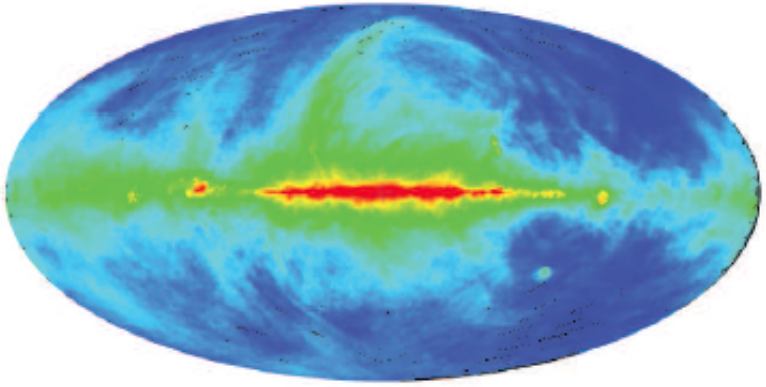
Interpretation of CR-induced interstellar emission

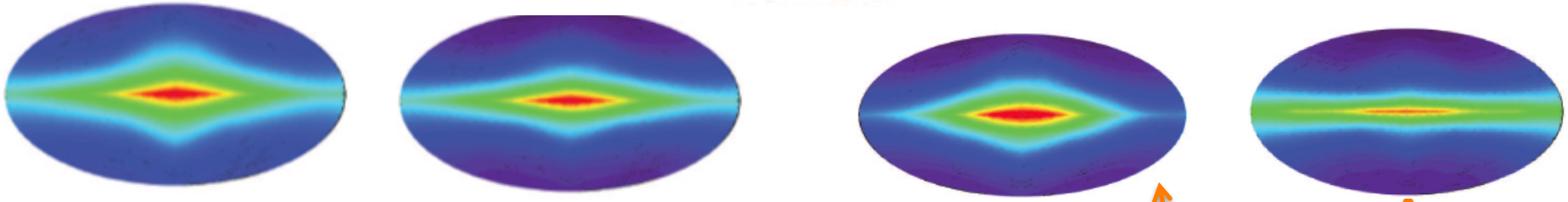
from radio to gamma rays

Radio and microwave modeling

Orlando & Strong 2013 MNRAS 436, 2127

I @ 408 MHz





Z=10 kpc

Z=4 kpc

Different propagation halo size

Different CR electron distribution

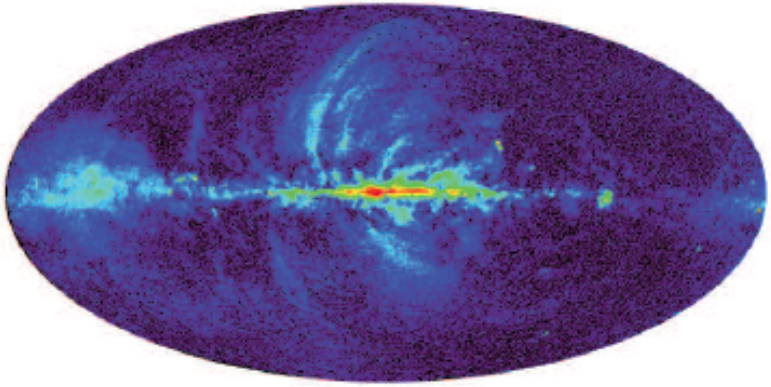
Different CR source distribution

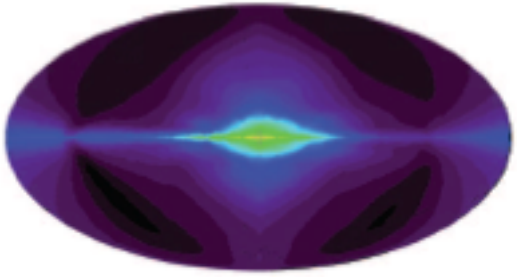
Radio and microwave modeling

Orlando & Strong 2013 MNRAS 436, 2127

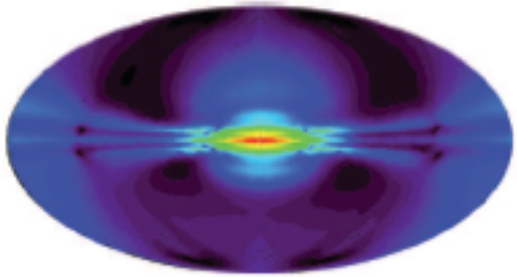
P @ 23 GHz

WMAP

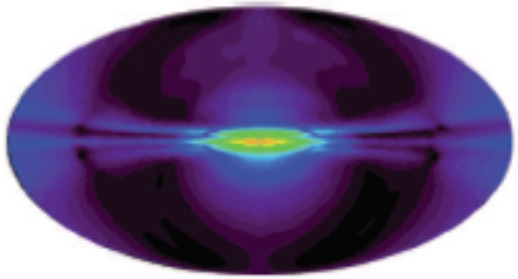




Sun 2008, 2010



Pshirkov, 2011 (ASS)



Pshirkov, 2011 (BSS)

Different B-fields

Main results

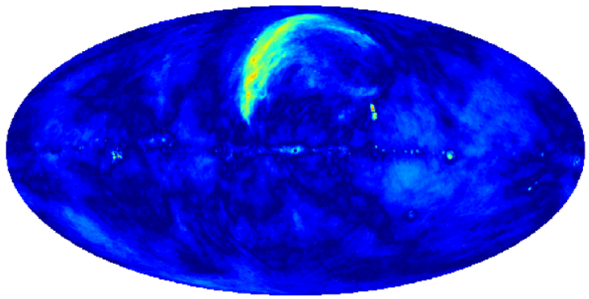
Based on Orlando & Strong 2013 MNRAS 436,2127 and Strong, Orlando and Jaffe 2011 A&A, 534, 54

Electron LIS spectral index needs a break from <2 to ~3 @ few GeV

Best model:

- Pure diffusion
- flat CR source distribution in the outer Galaxy
- Preference of halo height > 4 kpc

Best-fit magnetic field obtained

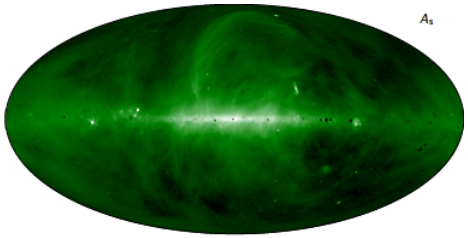


Residual structures (e.g. Loop I)

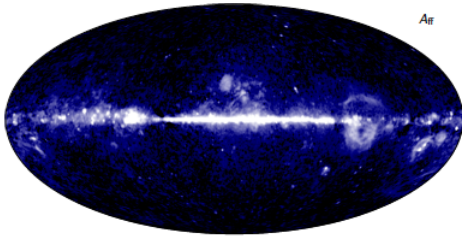
Galprop models & Planck data

- We used the synchrotron model* for Planck low-frequency component separation to generate the maps officially released (Planck 2015 results. XXV & Planck 2015 results. X A&A accepted)

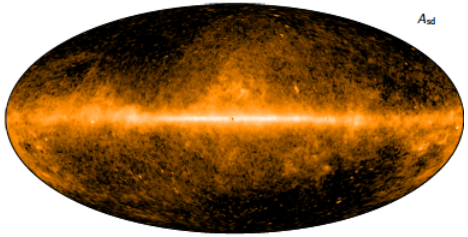
Interstellar synchrotron



free-free



Spinning dust



- Also used for obtaining the Galactic magnetic field (*Planck intermediate results. XLII A&A accepted*)

**Best fit from Orlando & Strong 2013 MNRAS 436,2127*

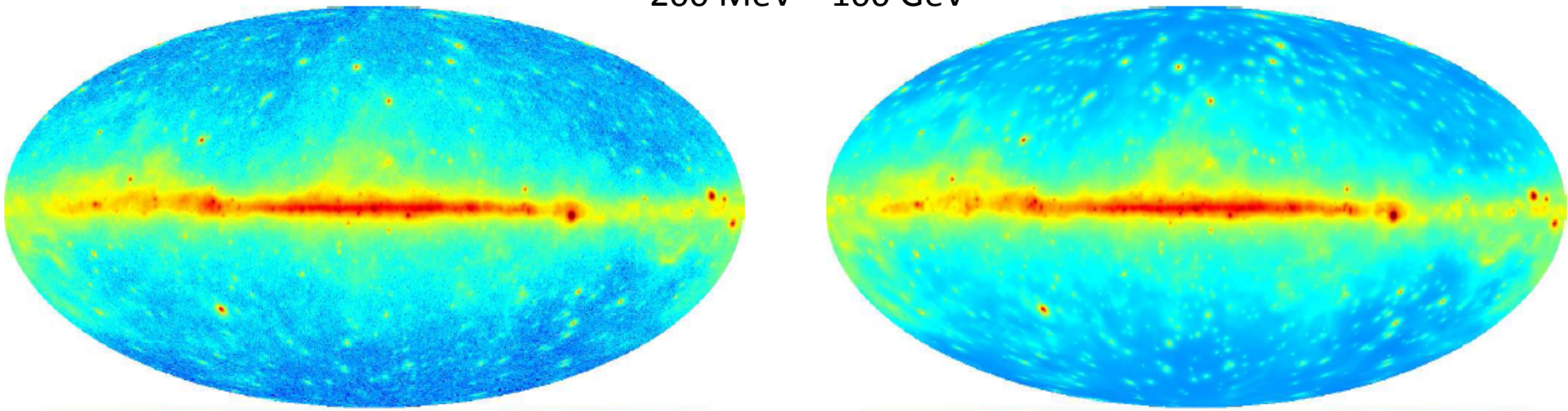
Galprop models & Fermi-LAT data

Officially used to generate foreground models and study CRs in the Galaxy

data

200 MeV – 100 GeV

model

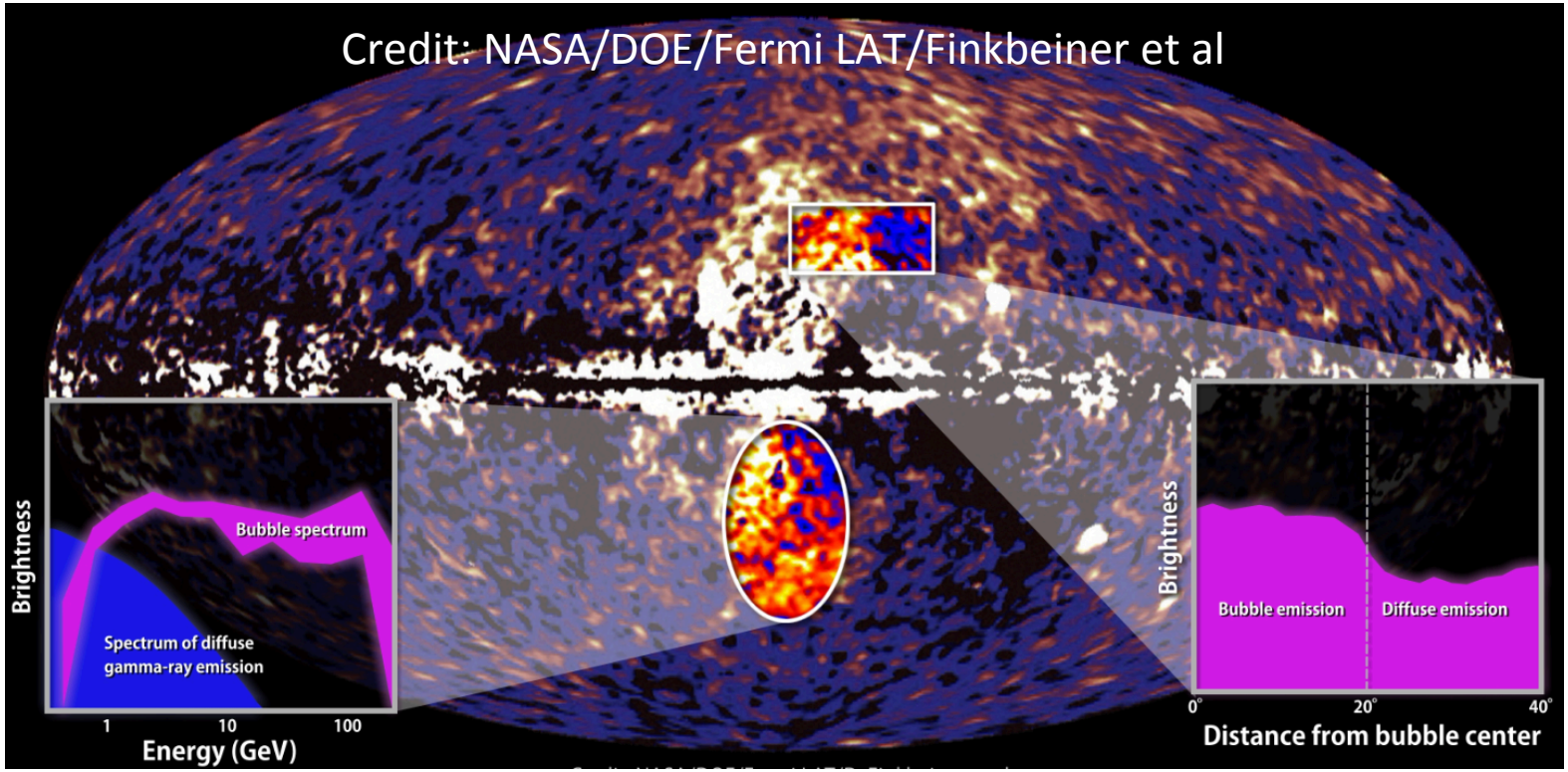


Ackerman et al.2012 ApJ 750,3

The physics of the interstellar gamma emission well understood and described.

No single model as best fit, but larger halo size and flatter CR source distribution preferred

Some residuals: 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; …)

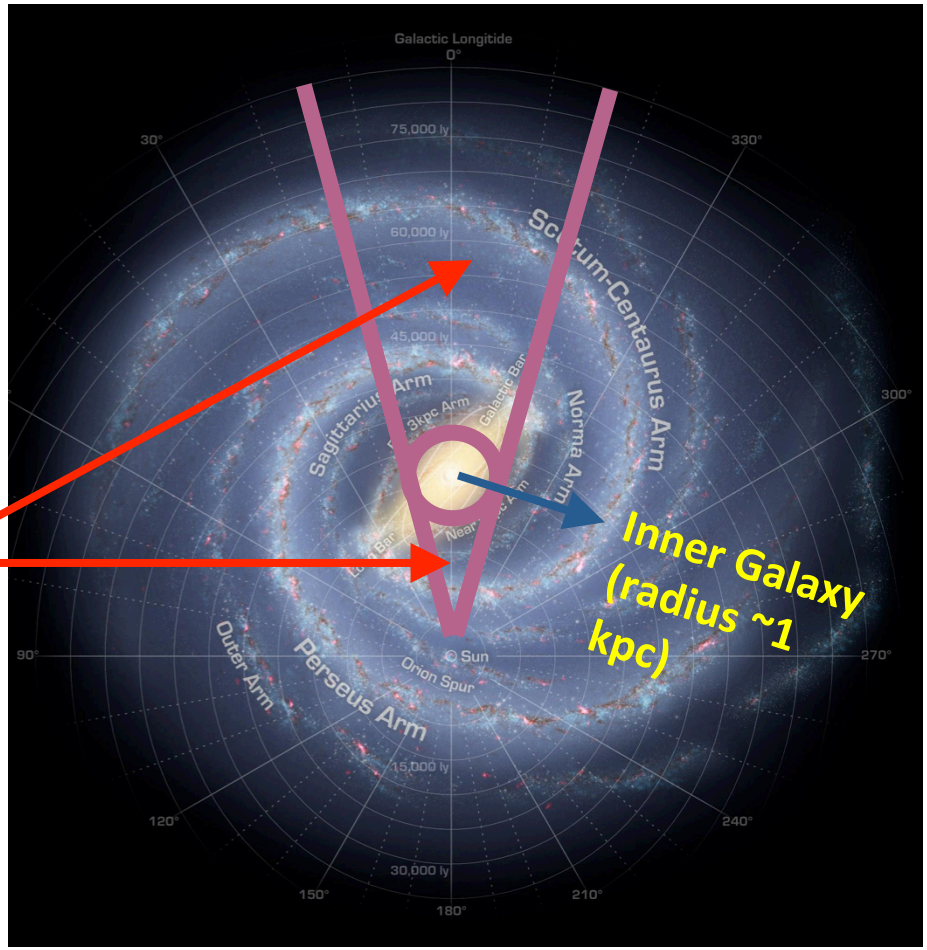
See talk by Tibaldo on Mon

→ Both leptonic and hadronic models represent Fermi spectral data well

(Ackermann et al., 2014)

CRs in the inner Galaxy

- CRs? - Unresoved sources? - Dark Matter?



Fore/background interstellar modeling is critical

Ref:Hooper et all 2010, Goodenough et al. 2011, Abazajian et al. 2012, Hooper et al 2013, Gordon et al. 2013, Daylan eta al. 2014, Calore et al 2015; Mirabal (2013), Petrovic et al (2015), Cholis et al. (2015), Lee et al. 2016, Bartels et al. 2016, Brandt & Kocsis 2015, Carlson et al. 2016 etc

Ajello et al. 2016

- GeV excess with respect to usual interstellar models
- Inverse Comton dominant and enhanced (ISRF or CR electrons?)

What's cooking?

Dxx ≠ Dzz

3D ISRF

Updated 3D B-field

3D CR sources

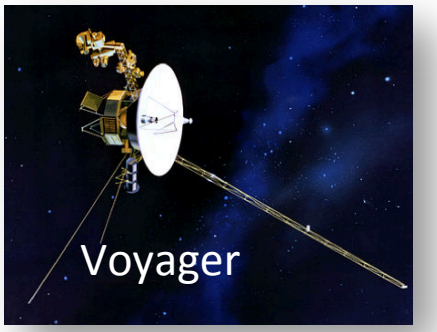
Anisotropic IC

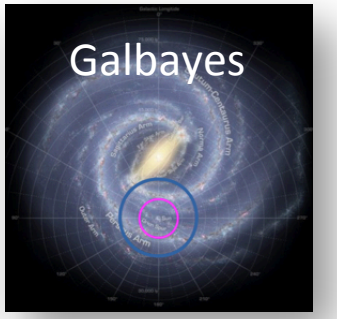
"non-standard" propagation models

Stay tuned !

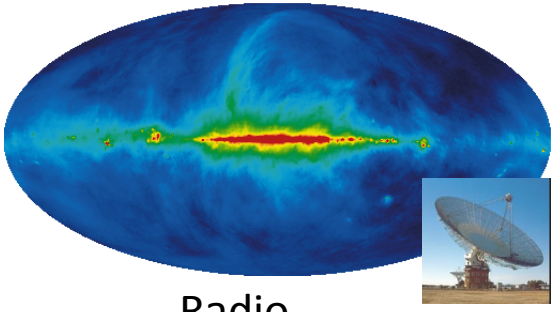
Summary

- CR measurements:

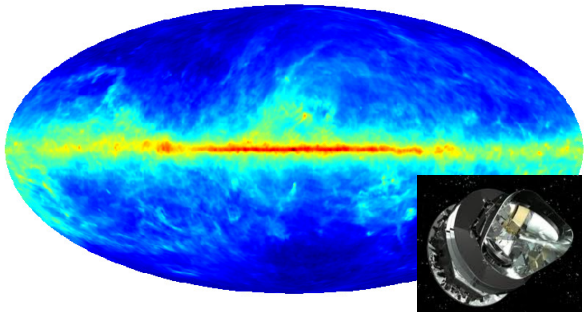




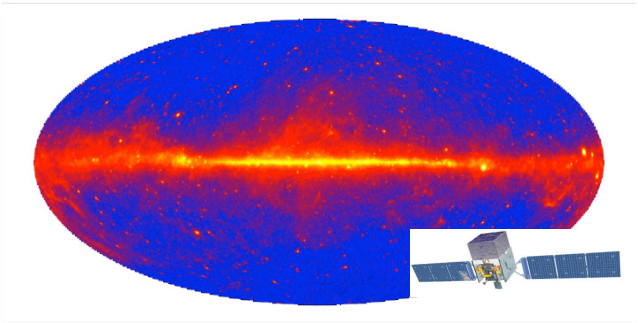
- CR associated emission:



Radio



Microwave



Gamma rays