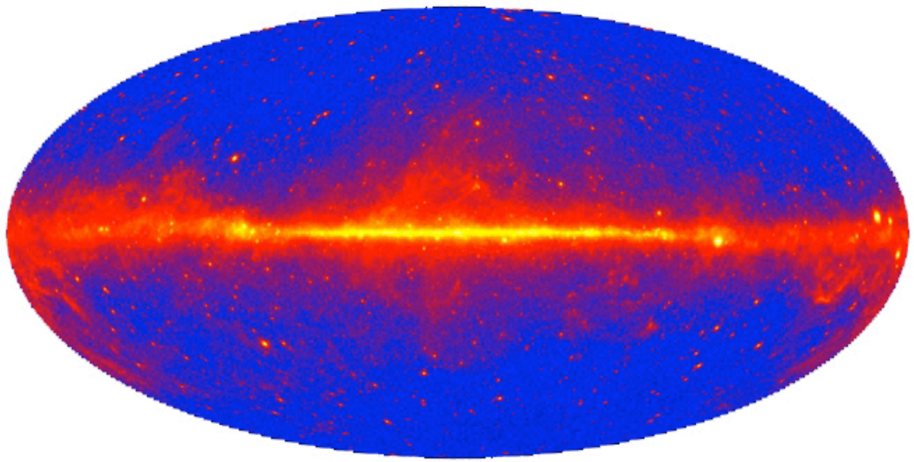
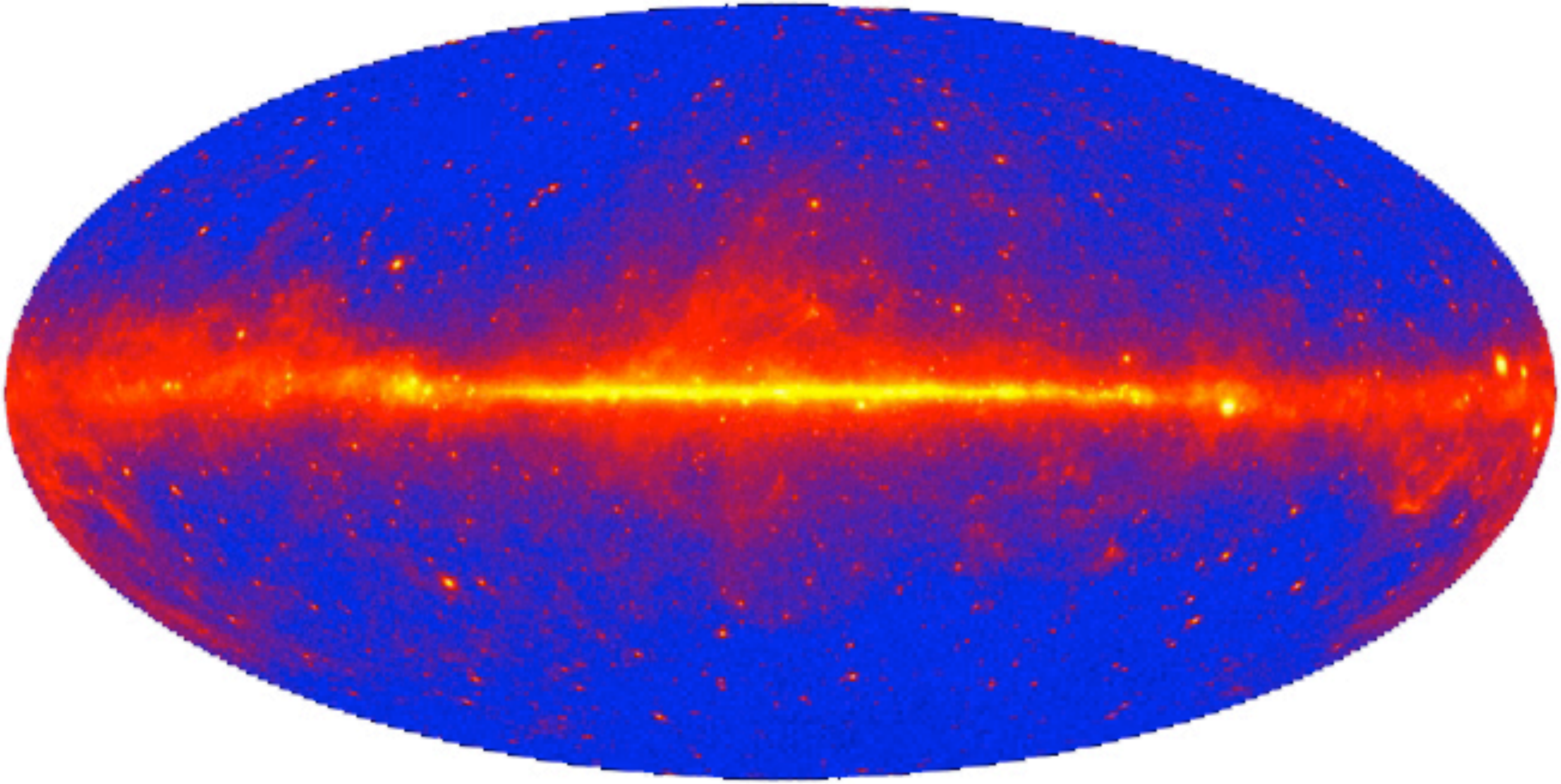


Diffuse Emission & Cosmic Rays

Elena Orlando
(Stanford University)

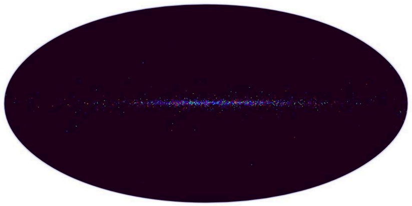
MULTIMESSENGER DATA ANALYSIS IN THE ERA OF CTA
Sesto (BZ) June 27, 2018

Fermi LAT >1 GeV

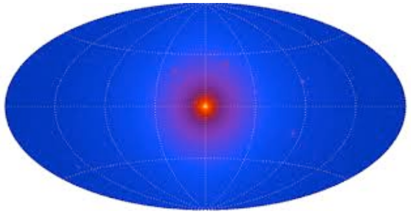


Diffuse Emission Origin

1) unresolved sources

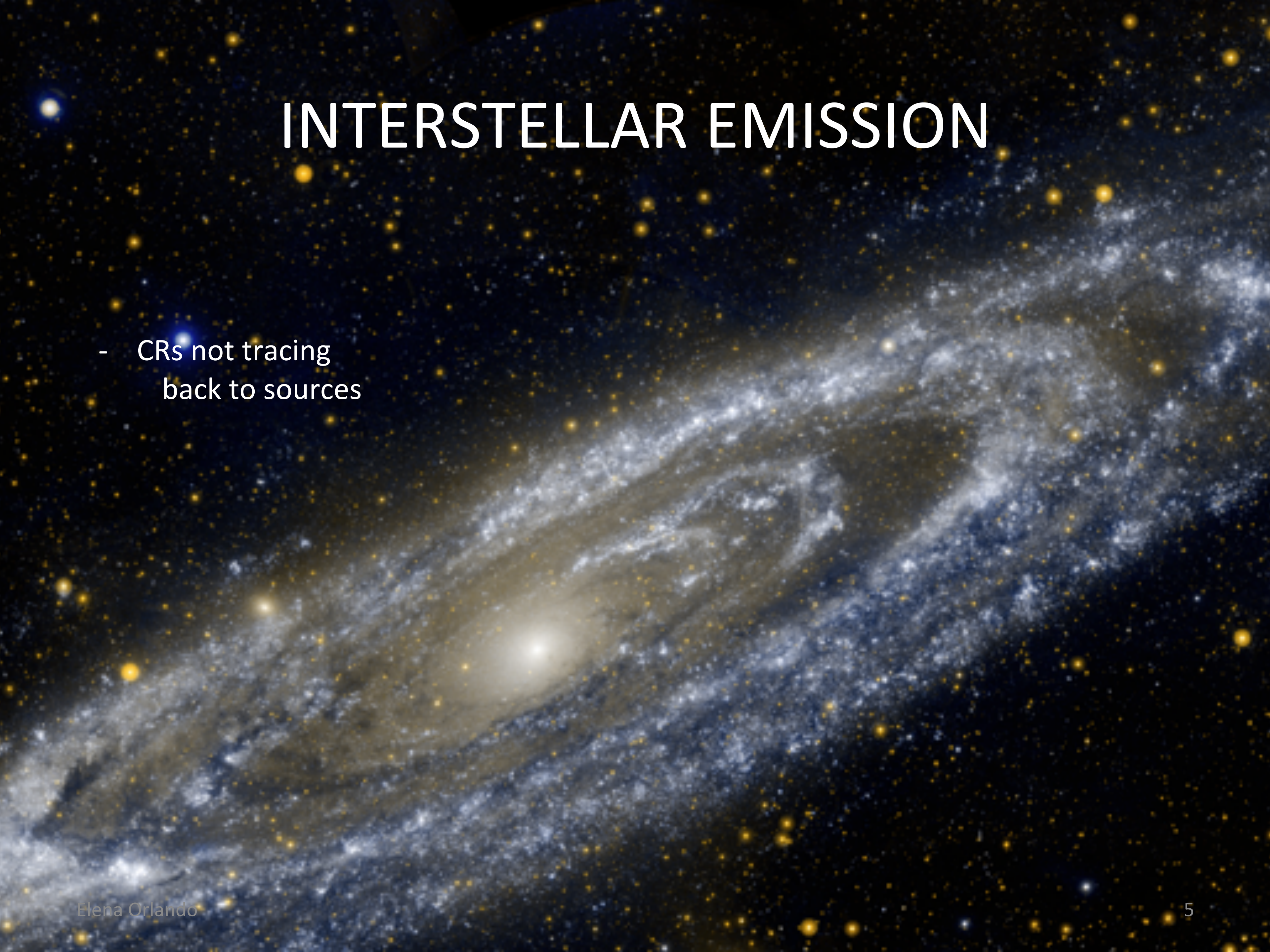
2) annihilation of dark matter



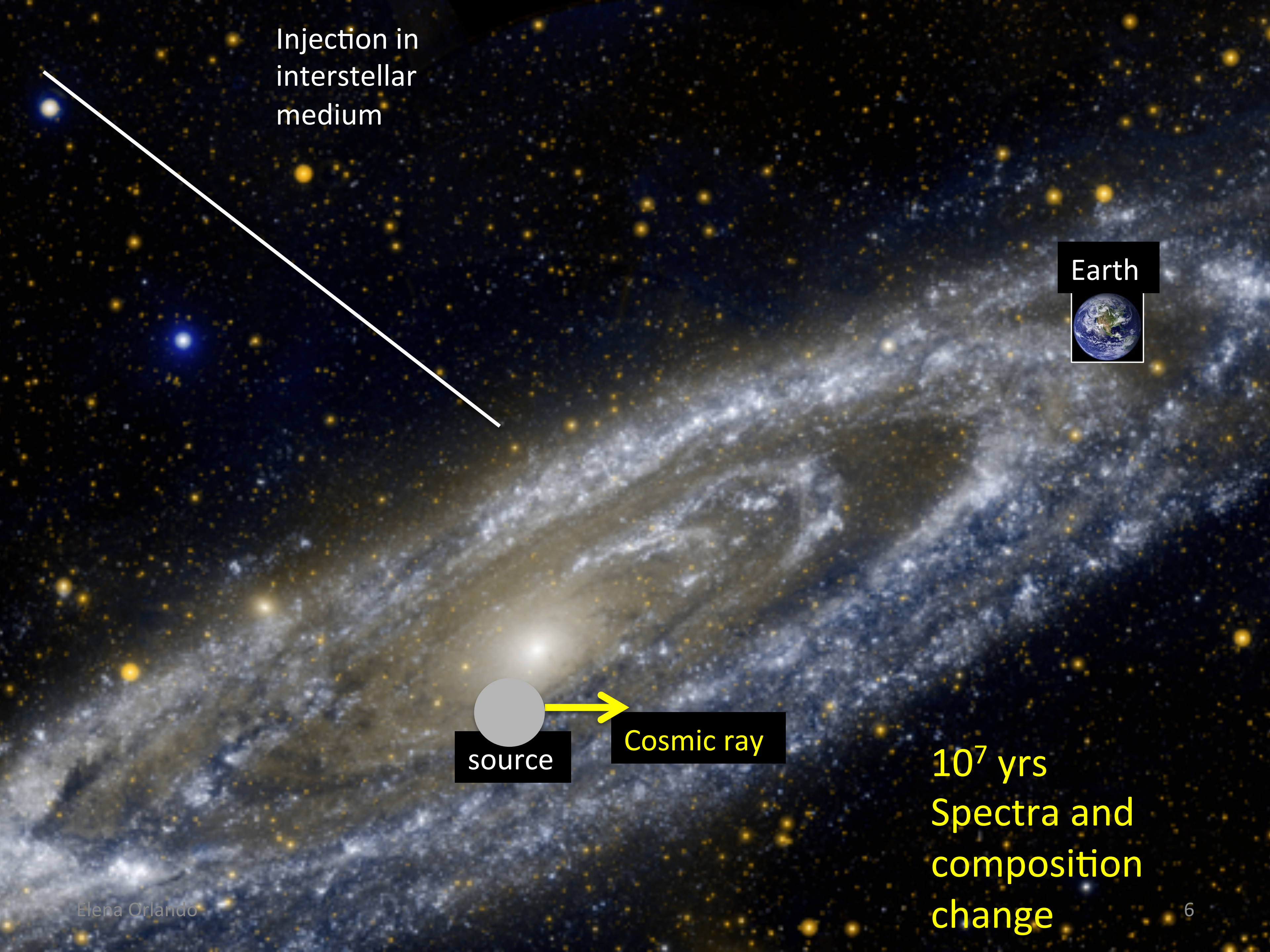
3) Cosmic Rays (CRs) interacting with the interstellar medium -> GAMMA-RAY INTERSTELLAR EMISSION

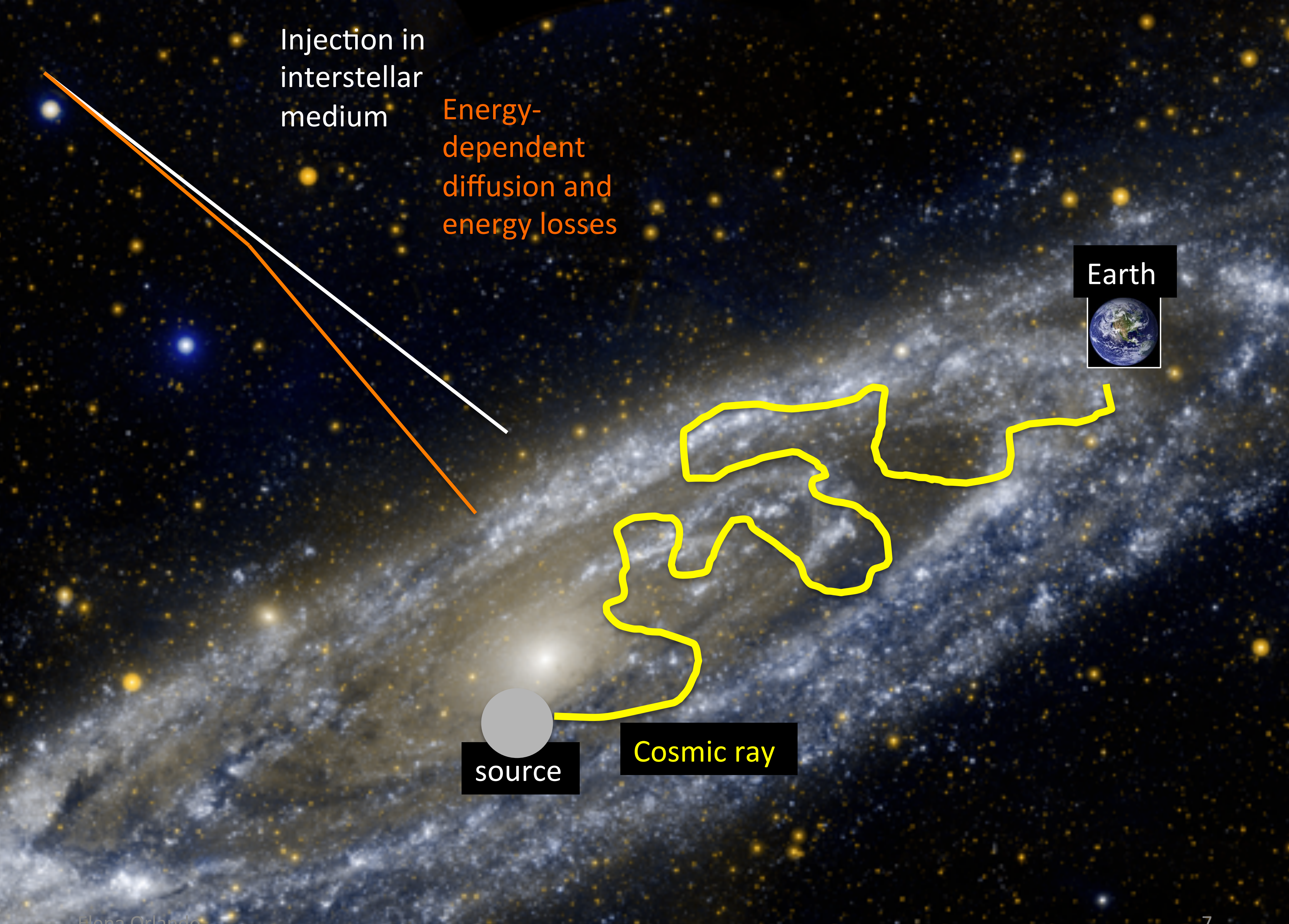
The “two-faced” Interstellar Emission

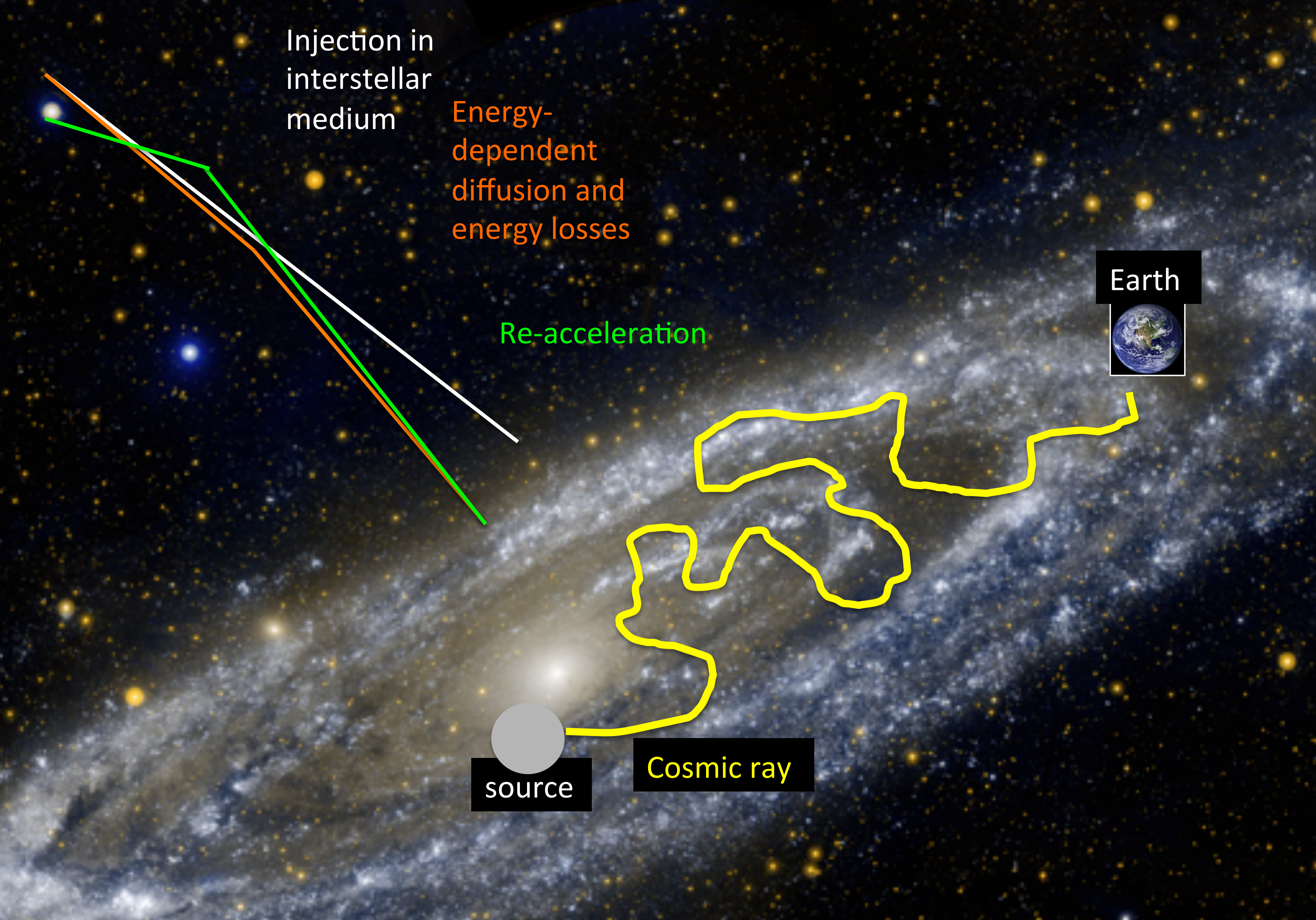
INTERSTELLAR EMISSION



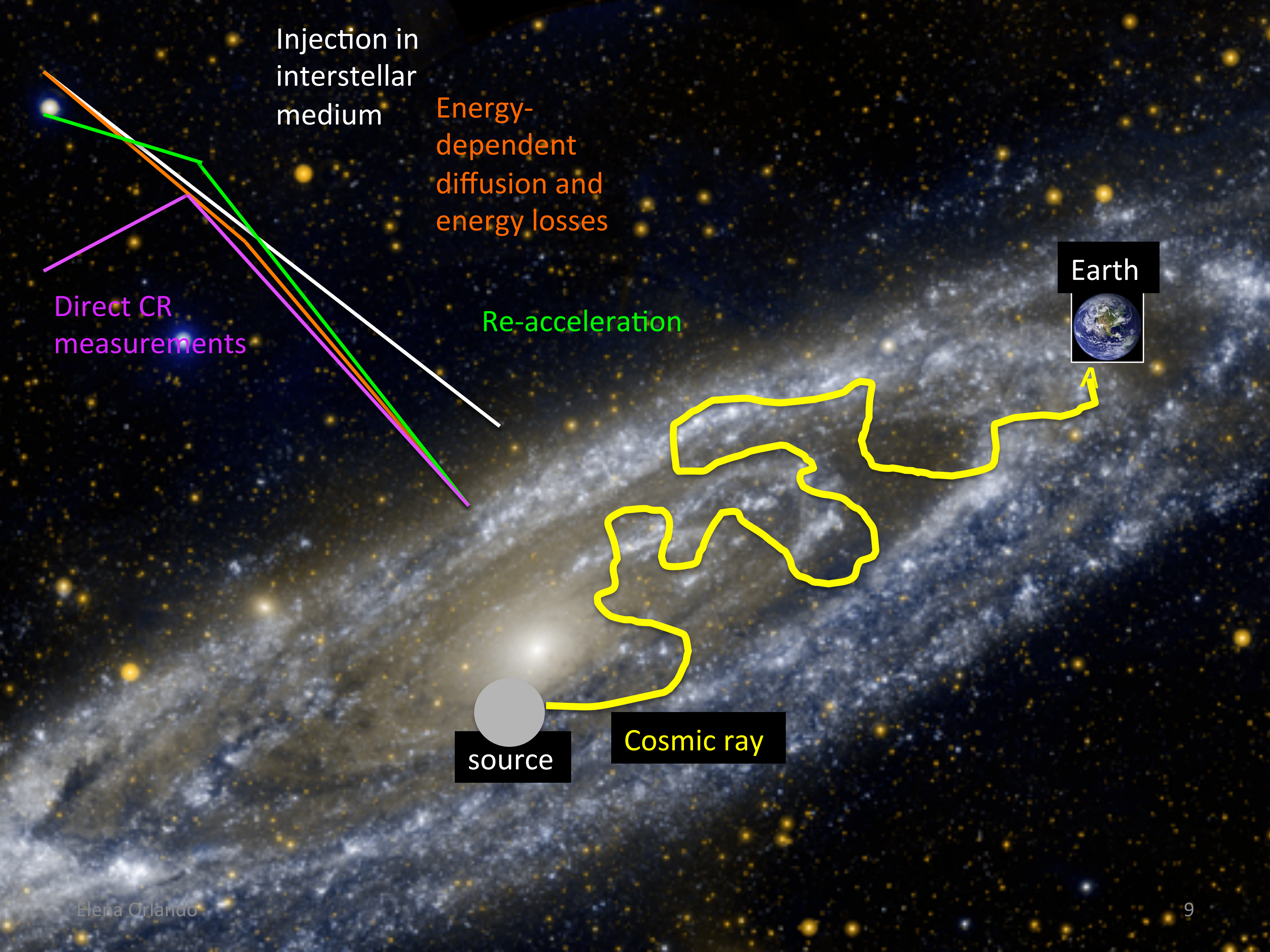
- CRs not tracing
  back to sources


Injection in interstellar medium
Earth
source
Cosmic ray
10^7 yrs
Spectra and composition change

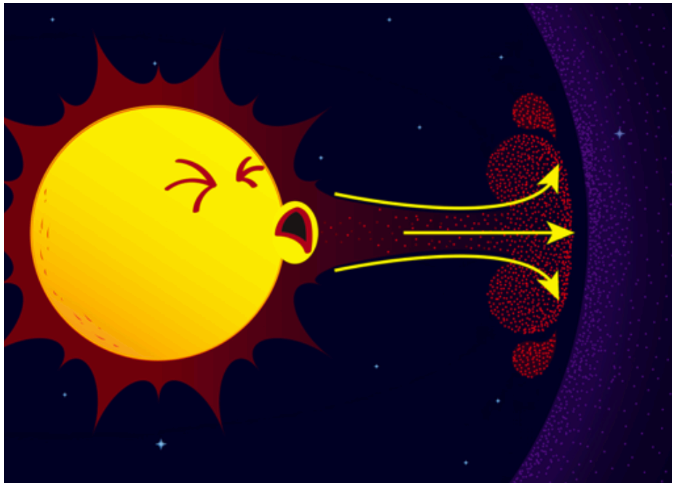

Injection in interstellar medium
Energy-dependent diffusion and energy losses
Earth
source
Cosmic ray

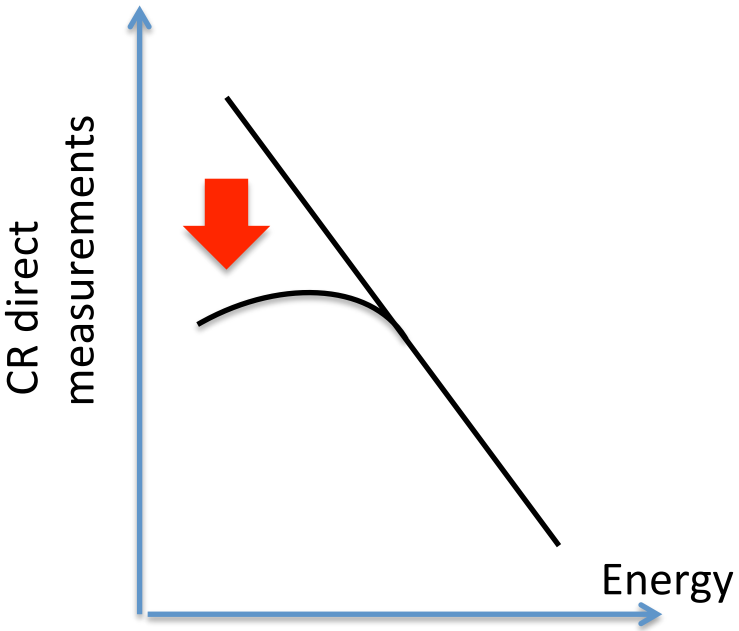


Injection in interstellar medium
Energy-dependent diffusion and energy losses
Re-acceleration
Earth
source
Cosmic ray

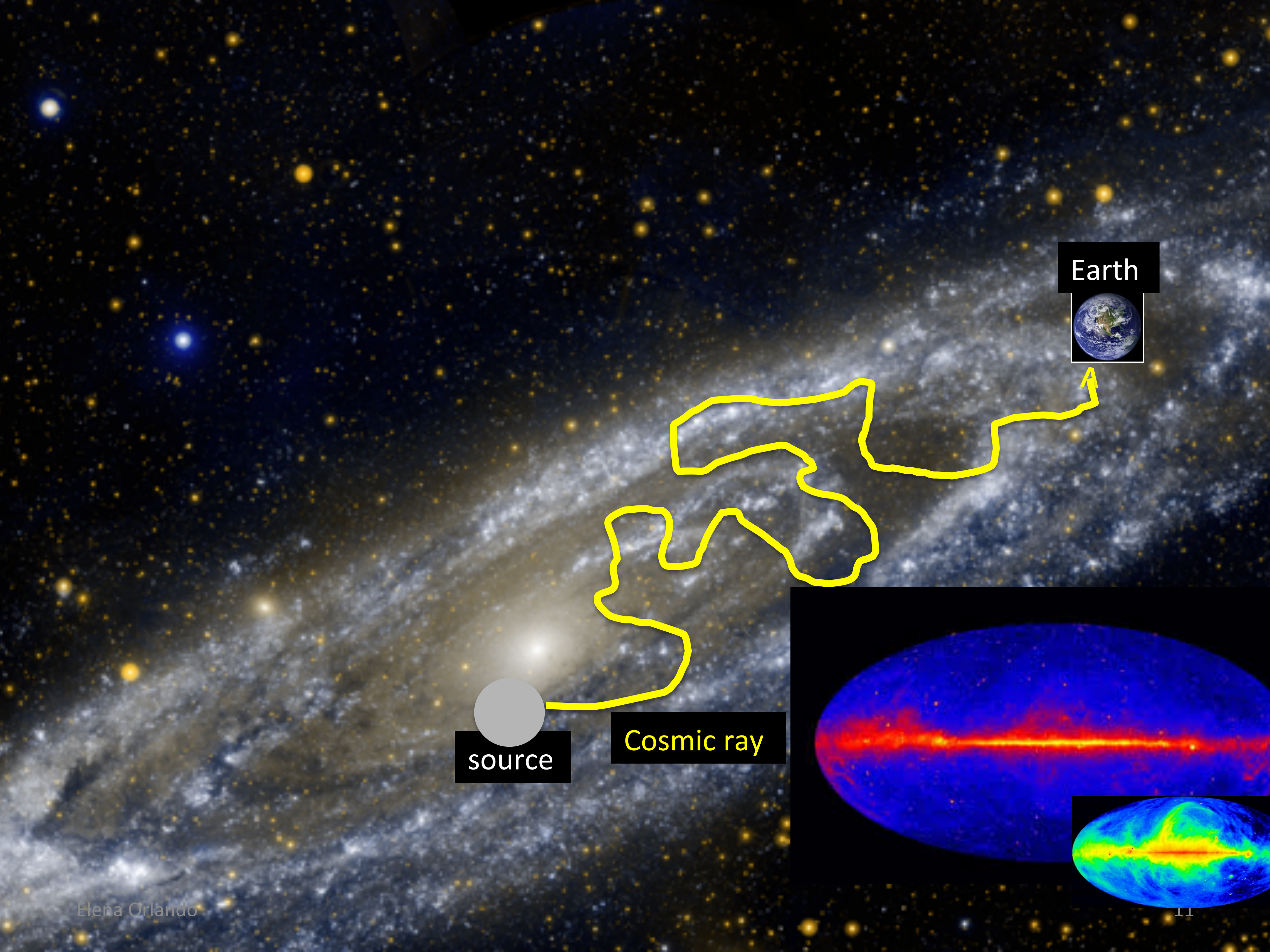

Injection in interstellar medium
Energy-dependent diffusion and energy losses
Direct CR measurements
Re-acceleration
Earth
source
Cosmic ray

Solar modulation of CRs in the Heliosphere

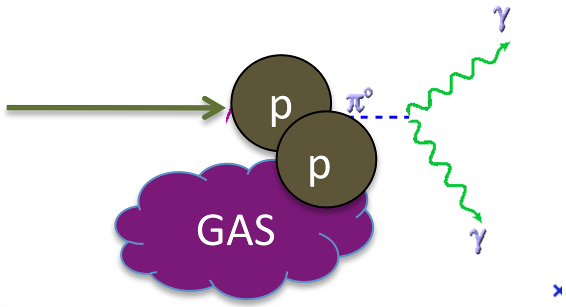




It depends on the solar activity

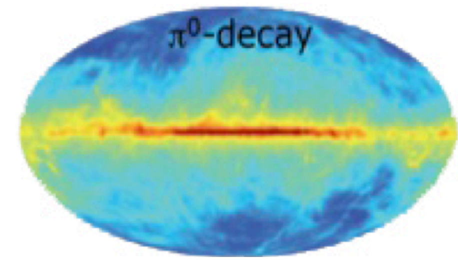

Earth
Cosmic ray
source

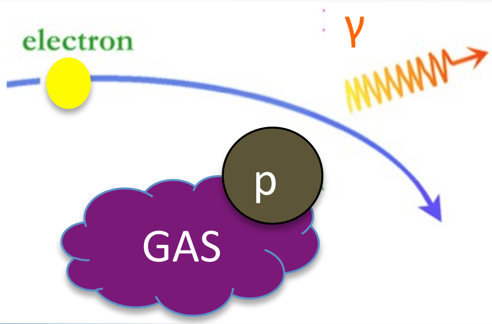
Interstellar Emission Mechanisms



Pion decay

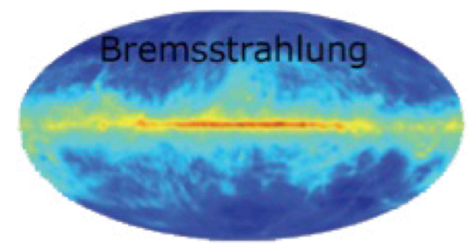
$p + p \rightarrow p + p + \pi^0 \rightarrow 2\gamma$

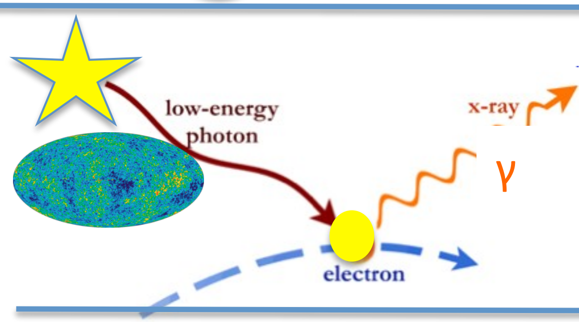




Bremsstrahlung

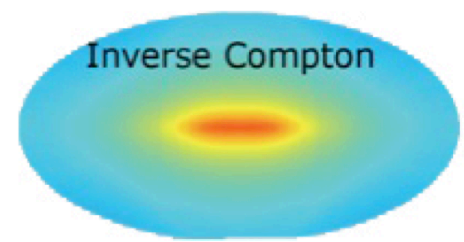
$e^{\pm} \rightarrow e^{\pm} + \gamma$

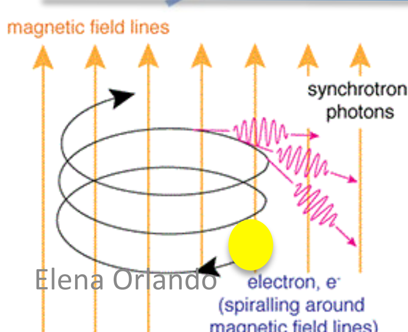




Inverse Compton

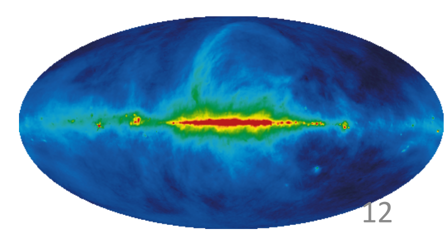
$e^{\pm} + \gamma \rightarrow \gamma + e^{\pm}$



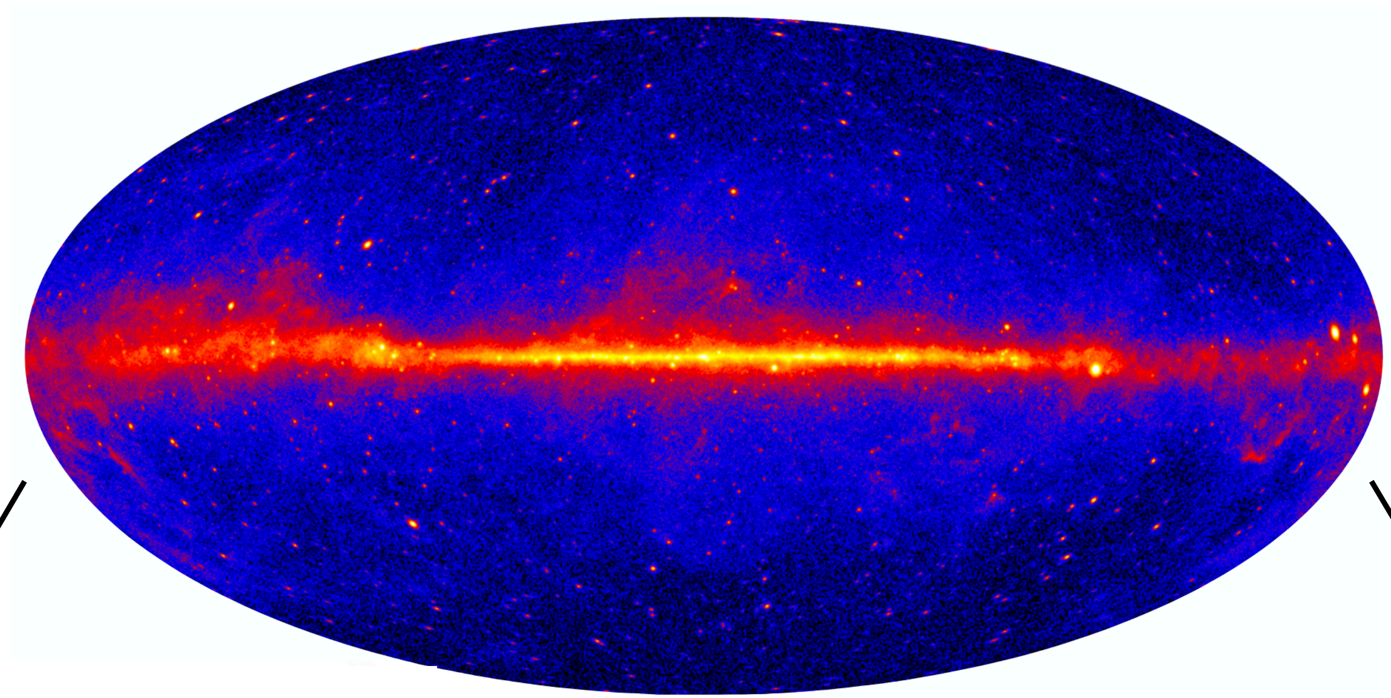


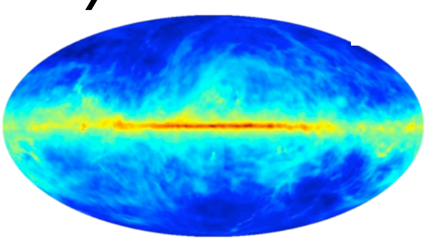
Synchrotron

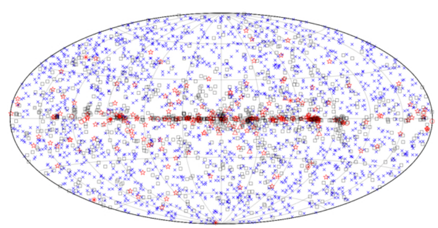
$e^{\pm} \rightarrow e^{\pm} + \gamma$

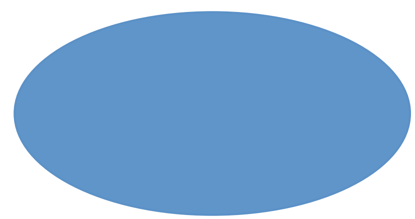


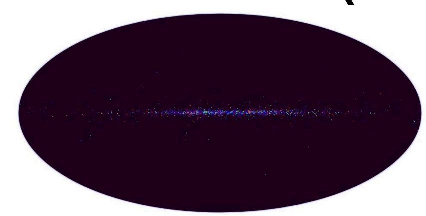
The “two-faced” Interstellar Emission

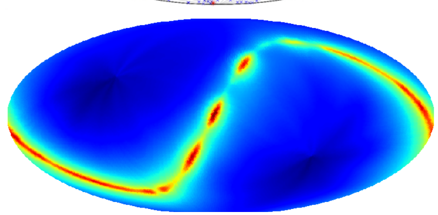


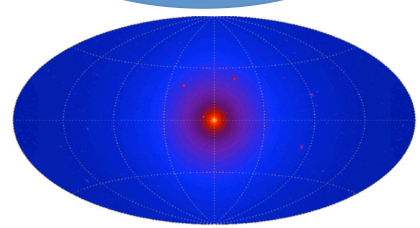




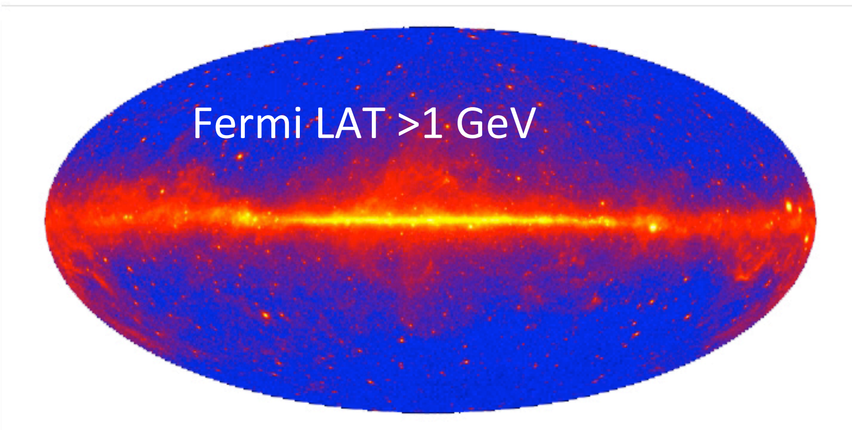


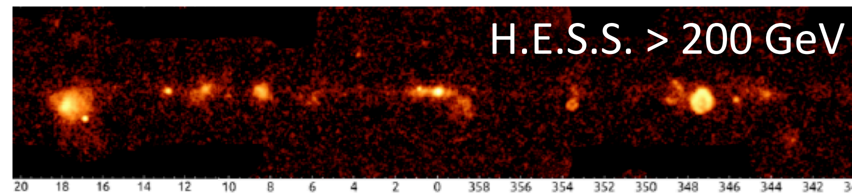


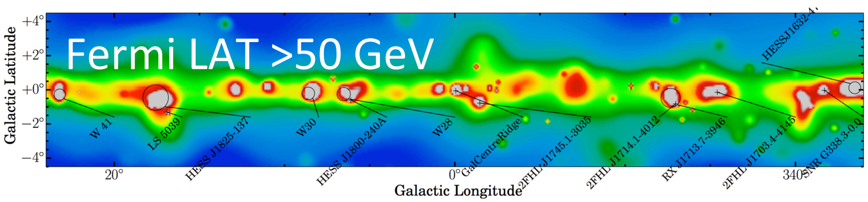


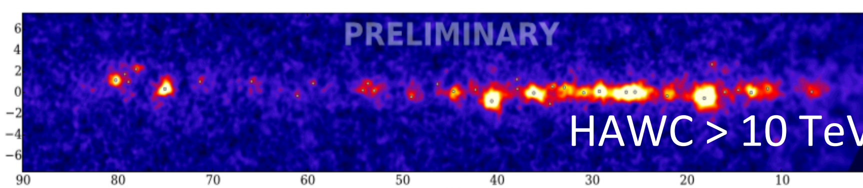


HE vs VHE

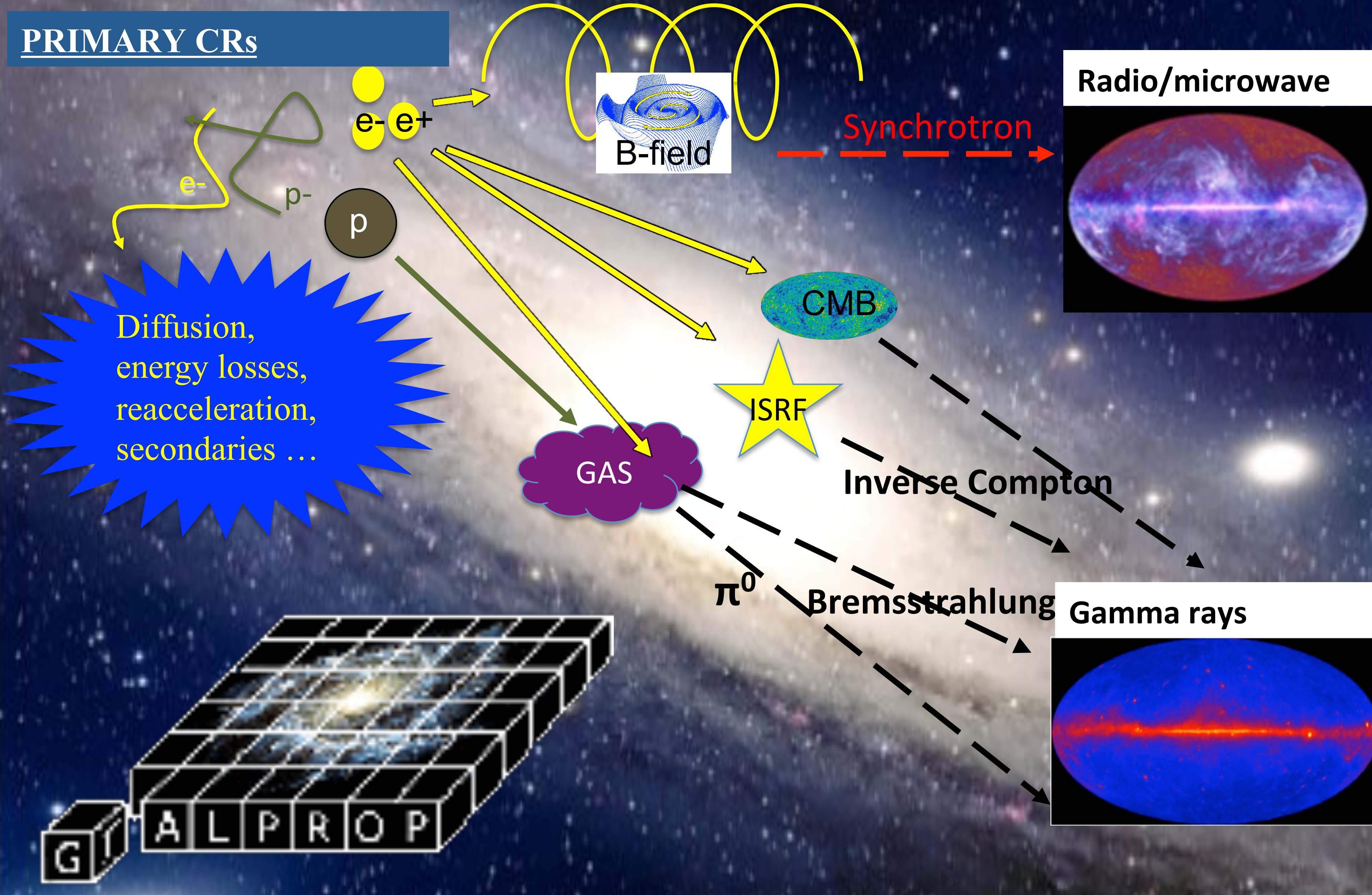

Fermi LAT >1 GeV


H.E.S.S. > 200 GeV
20 18 16 14 12 10 8 6 4 2 0 358 356 354 352 350 348 346 344 342 340


Fermi LAT >50 GeV
Galactic Latitude
Galactic Longitude
W 41
W30
W28

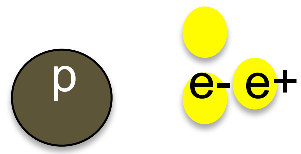

PRELIMINARY
HAWC > 10 TeV
90 80 70 60 50 40 30 20 10 0

CR PROPAGATION CODES

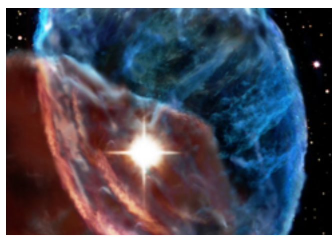


Ingredients for the modeling

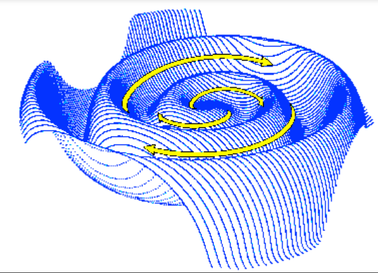
Injected spectra and **propagation parameters**



CR source distribution

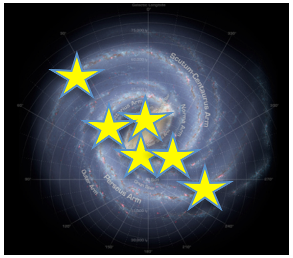


Magnetic field



Gas distribution

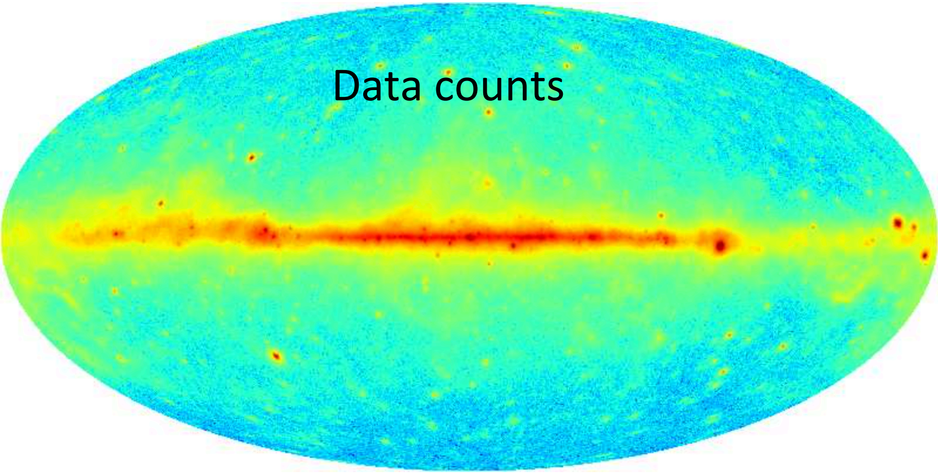
Interstellar photons

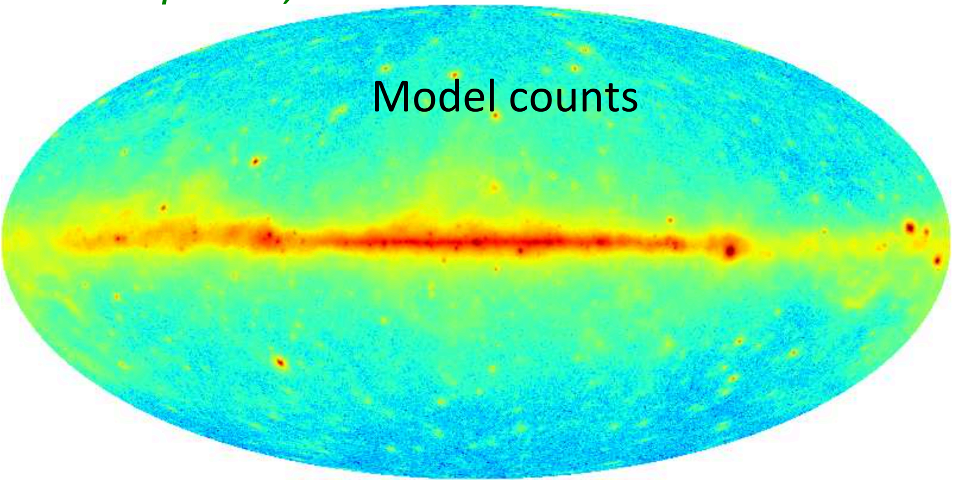


Gamma-Ray data:
Some Challenges

All-sky Fermi Analysis of the Interstellar Emission

Ackerman et al. 2012 ApJ 750, 3





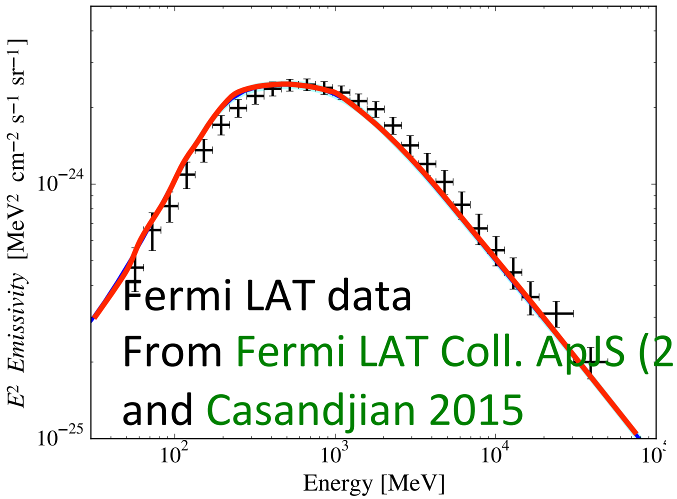
No best model found; hints for:

- Large propagation halo size
- More CRs in the outer Galaxy
- Additional gas in the outer Galaxy
- Spectral hardening in the inner Galaxy

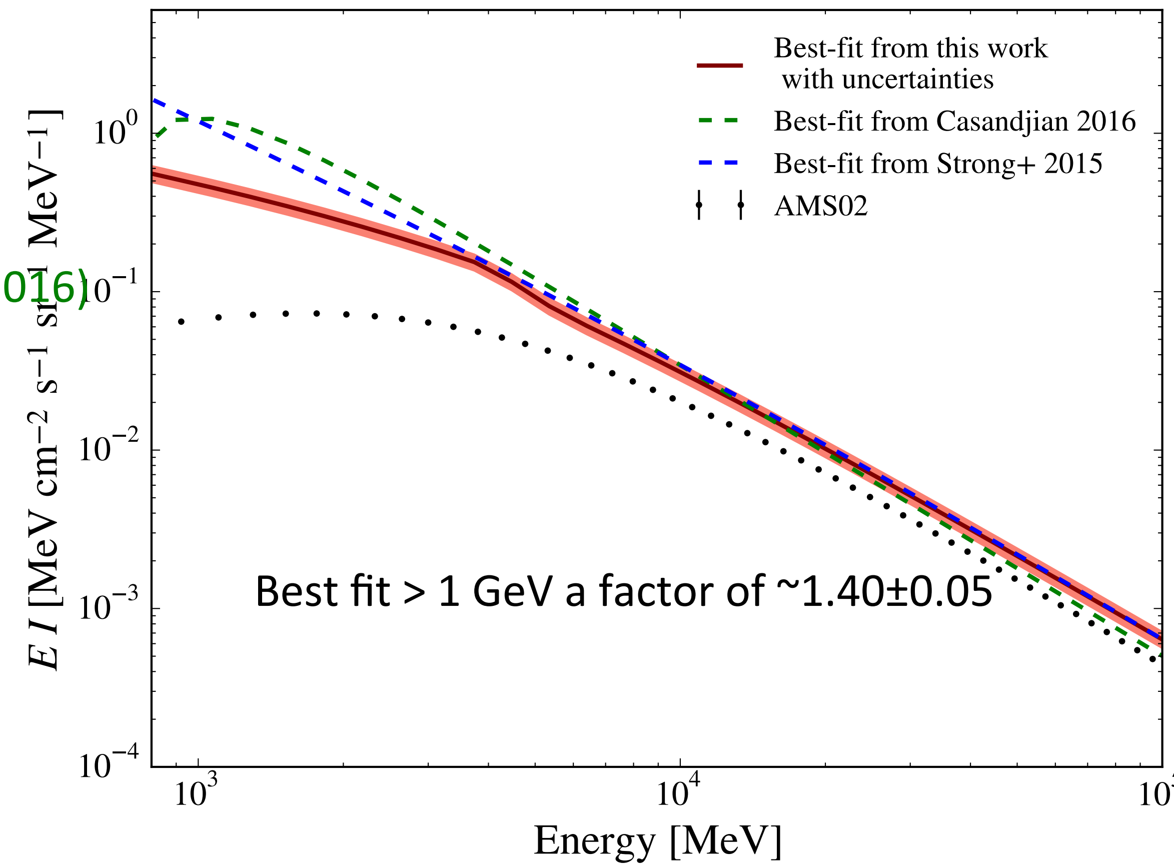
→ models based on CR local measurements consistent with Fermi LAT data

Updated Fermi LAT Gamma-Ray & Derived Proton Spectrum

Orlando (2018) MNRAS 475, 2724



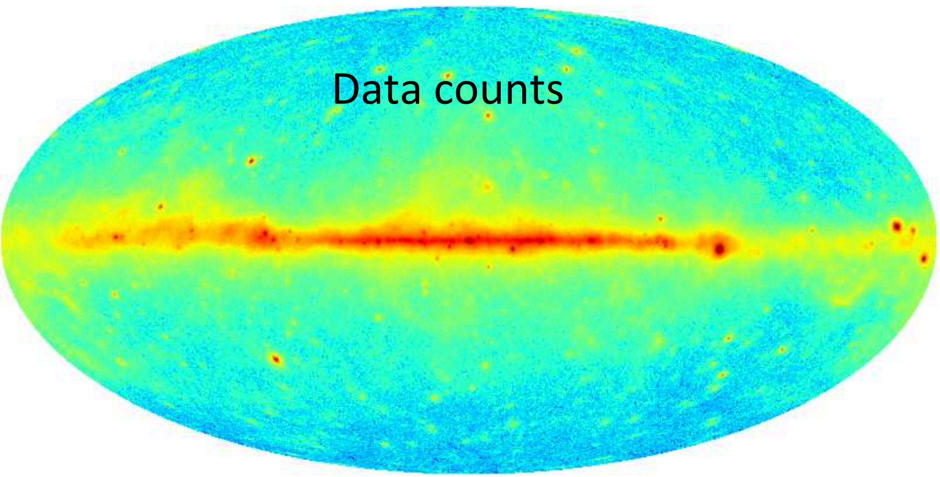
Fermi LAT data
From Fermi LAT Coll. ApJS (2016)
and Casandjian 2015

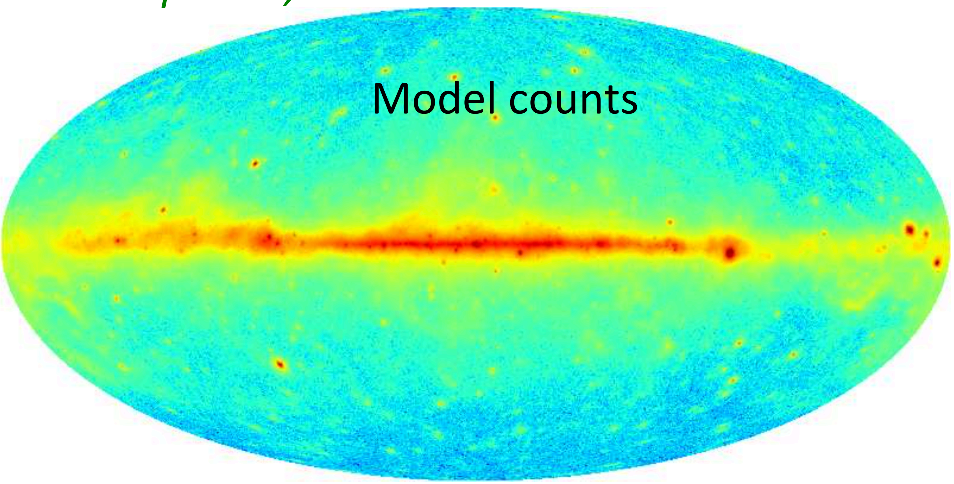


Best fit > 1 GeV a factor of ~1.40±0.05

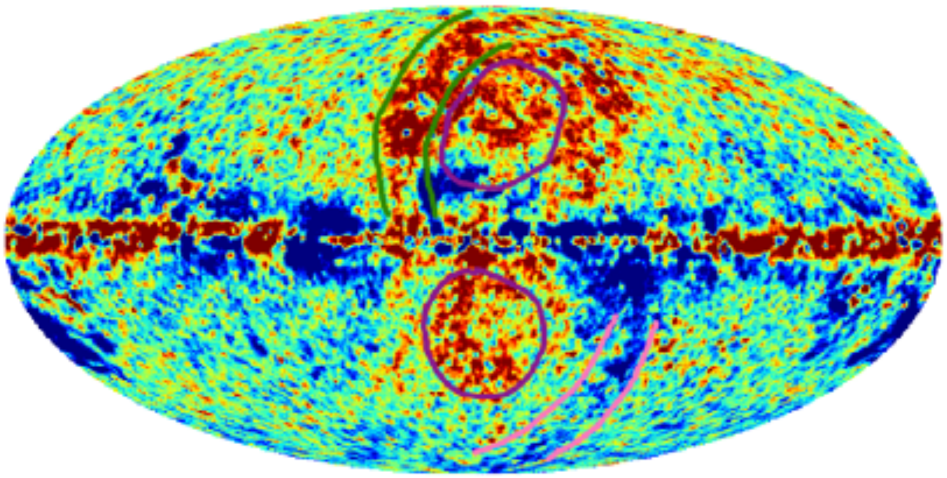
All-sky Fermi Analysis of the Interstellar Emission

Ackerman et al. 2012 ApJ 750, 3





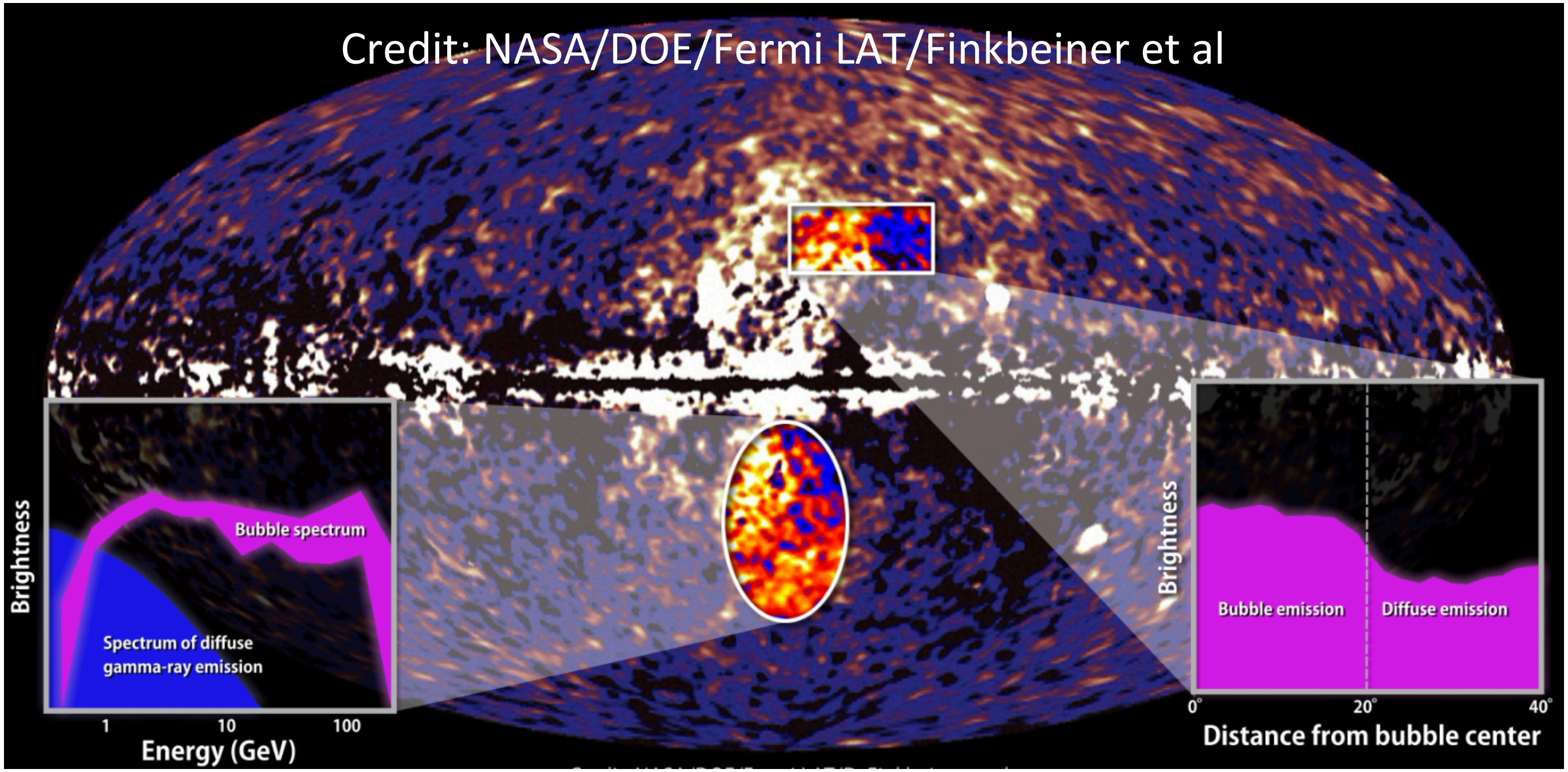
$\frac{\text{(data-model)}}{\text{model}}$



Excess

Standard models

CRs and the Fermi Bubbles



Su et al 2010

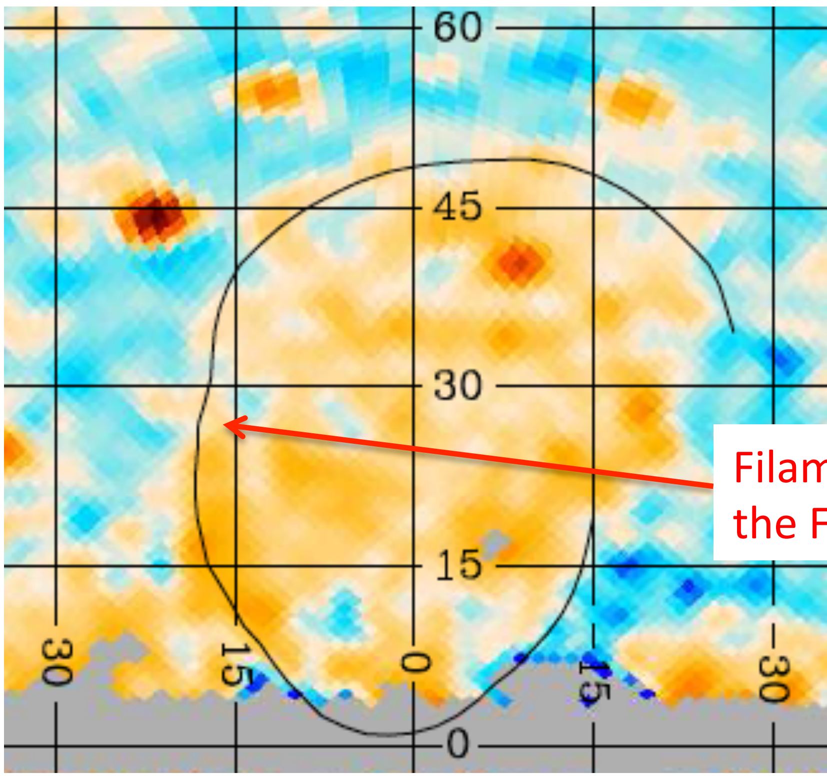
→ Both leptonic and hadronic models represent Fermi spectral data well

(e.g. Ackermann et al. 2014)

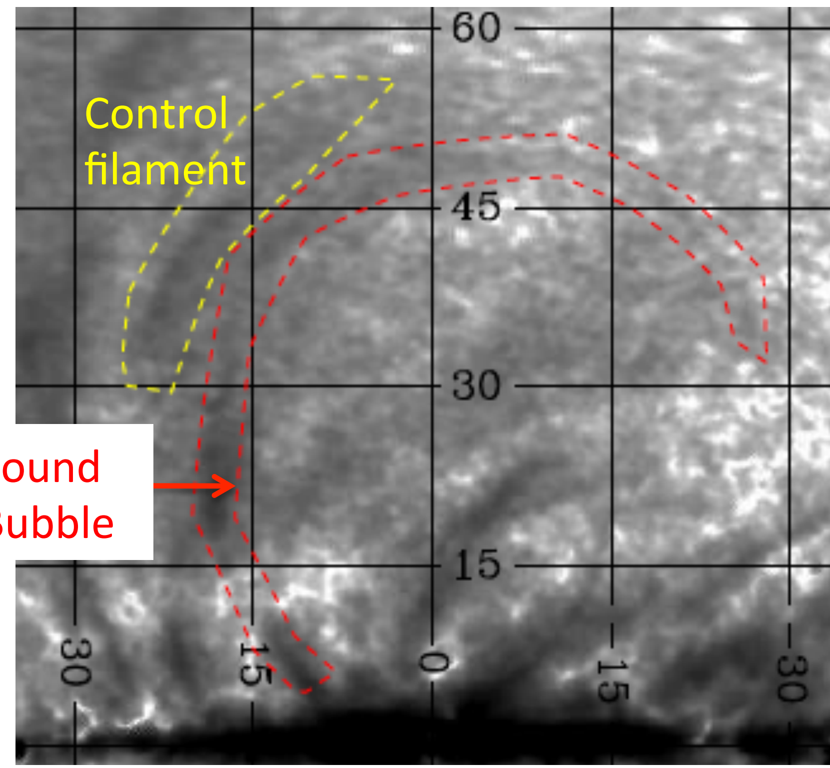
Planck polarization and Fermi Bubbles

Planck 2015 results. XXV

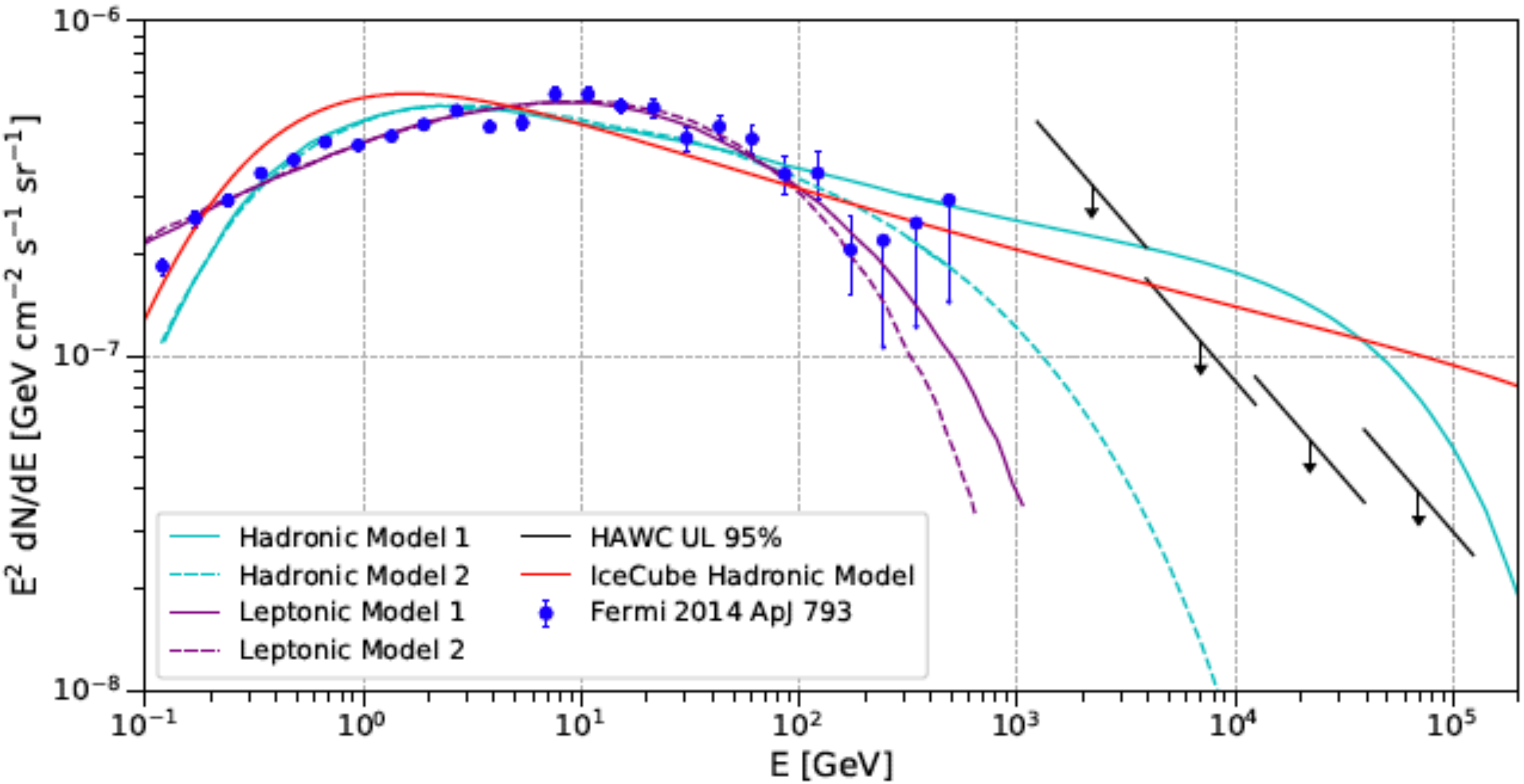
Fermi-LAT > 10 GeV from
Ackermann et al 2014 (dust subtracted)



Planck polarization map



HAWC & Fermi Bubbles, b>10 deg



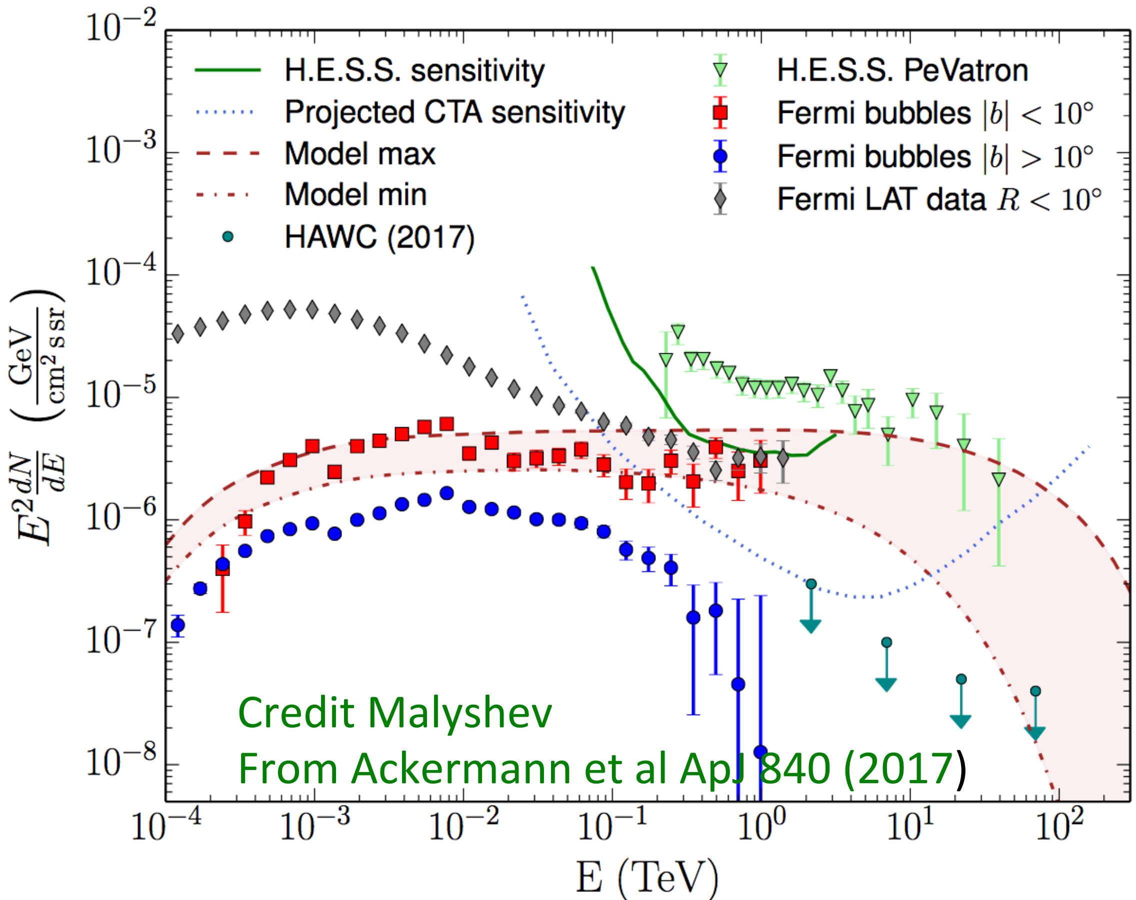
HAWC Collaboration: Abeysekara et al. ApJ 842 (2017), 85

Fermi Bubbles, also b<10 deg

Herold & Malyshev A&A 625 (2019)

No cutoff up to ~ 1 TeV for low latitude bubbles emission

Hints of Bubbles harder and brighter at the base

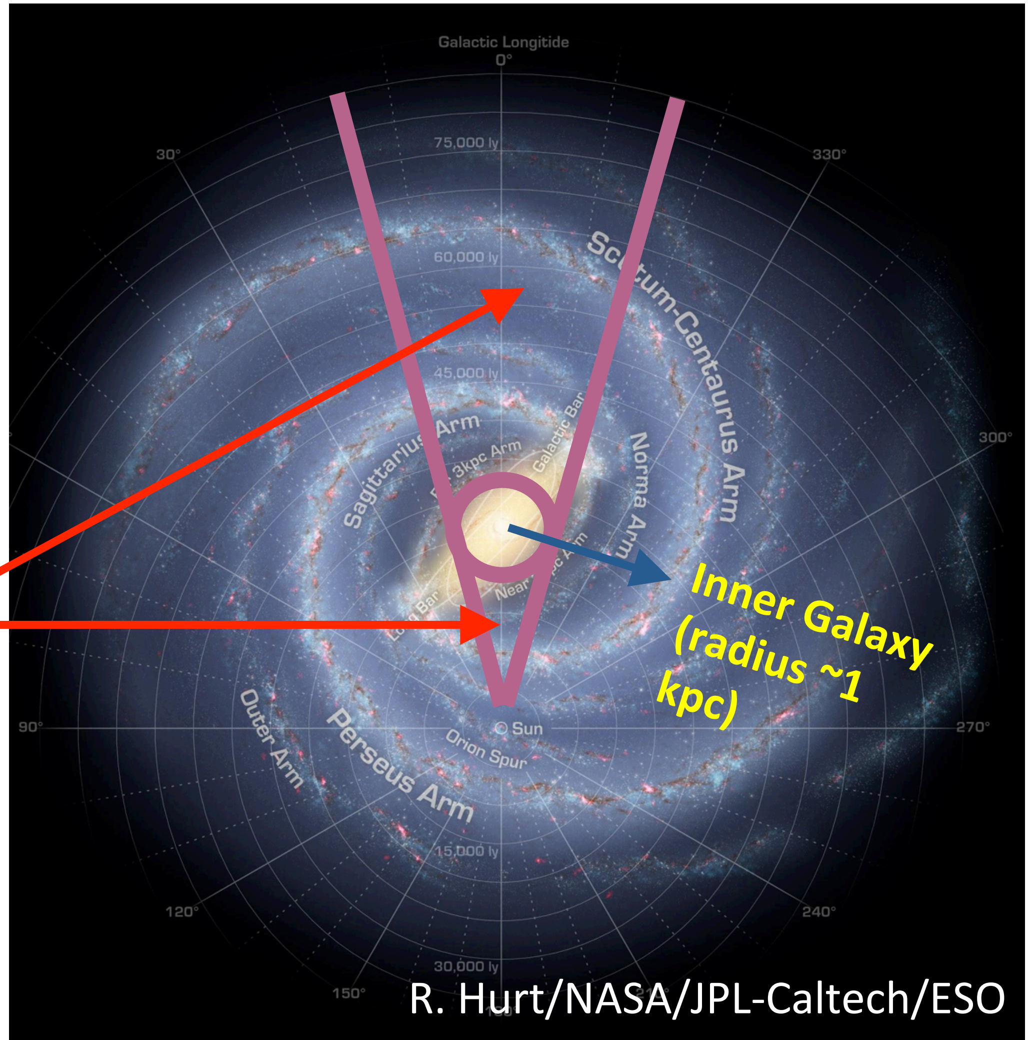


CRs in the inner Galaxy

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

- CRs? - Unresoved sources? - Dark Matter?

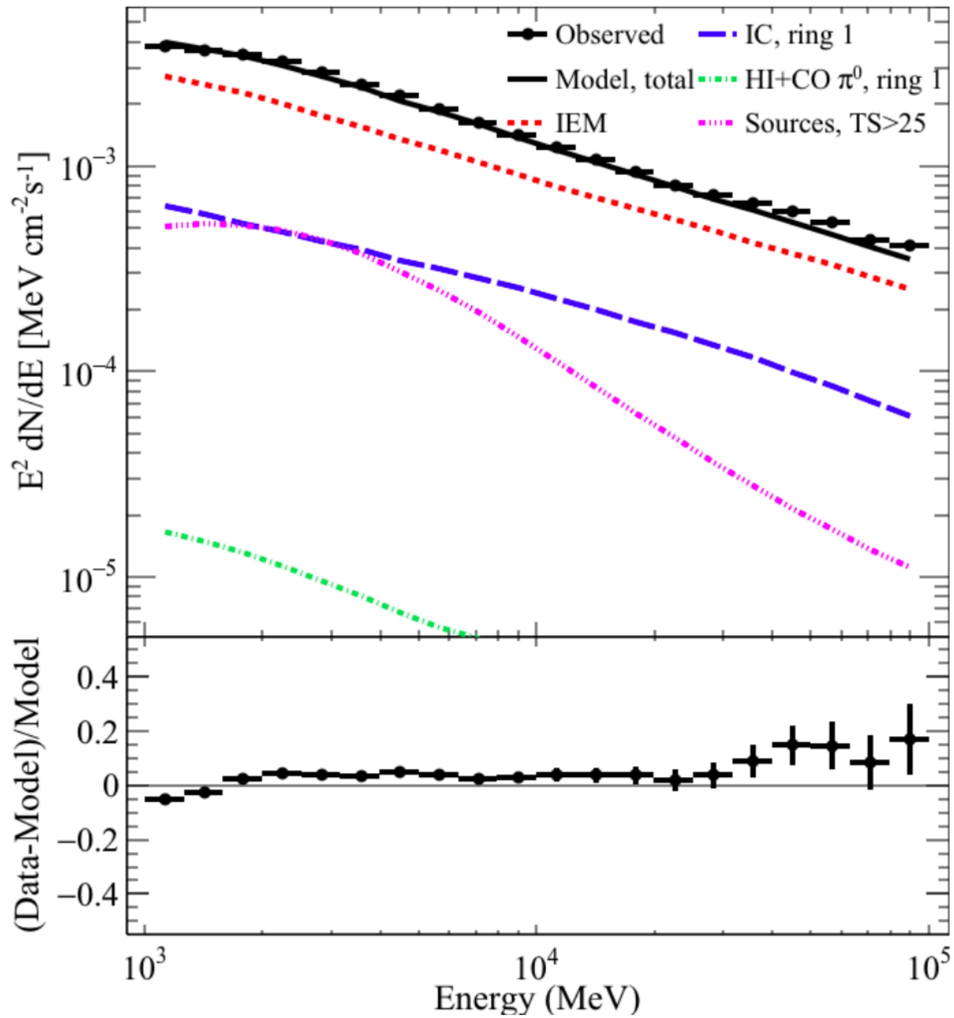
Fore/background interstellar modeling is critical



See Morselli's talk

CRs toward the Galactic center

Ajello et al. 2016



1) IC dominant and brighter than predicted by standard models
2) Hardening in the inner Galaxy with respect to standard models

- CRs? – ISRF? - Unresolved sources? - Dark Matter? -

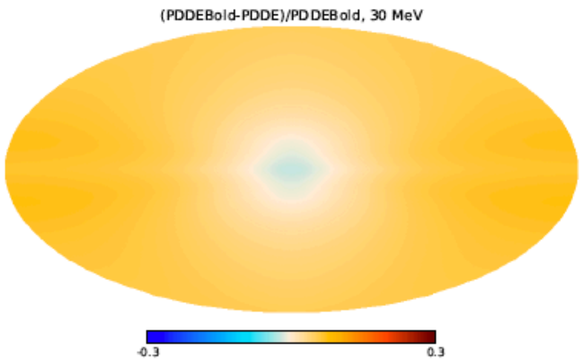
All the standard models still used in most Fermi LAT analyses are from Abdo et al. 2012

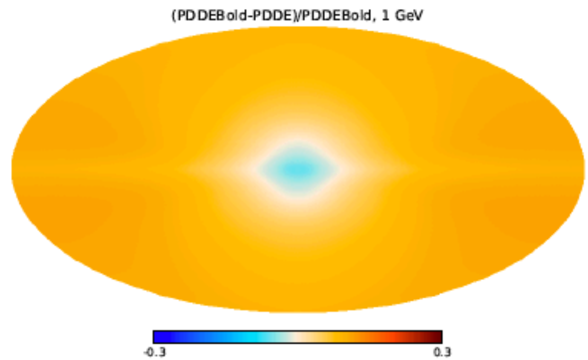
- Only standard set of models
- Models that are not consistent with from radio and microwave data
- Never updated to recent CR measurements

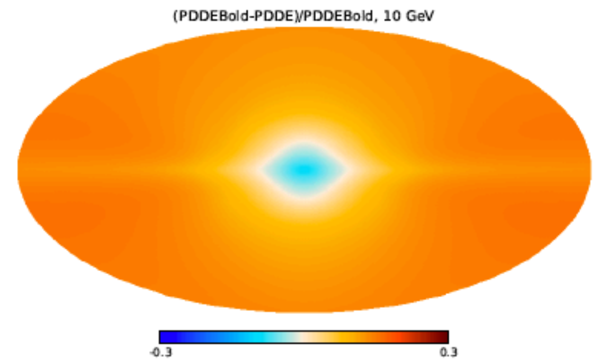
Alternative Possibilities to test with data

1) Updating B-fields and CRs produces brighter IC than predicted previous models

Orlando (2019) Phys.Rev.D 99, 043007

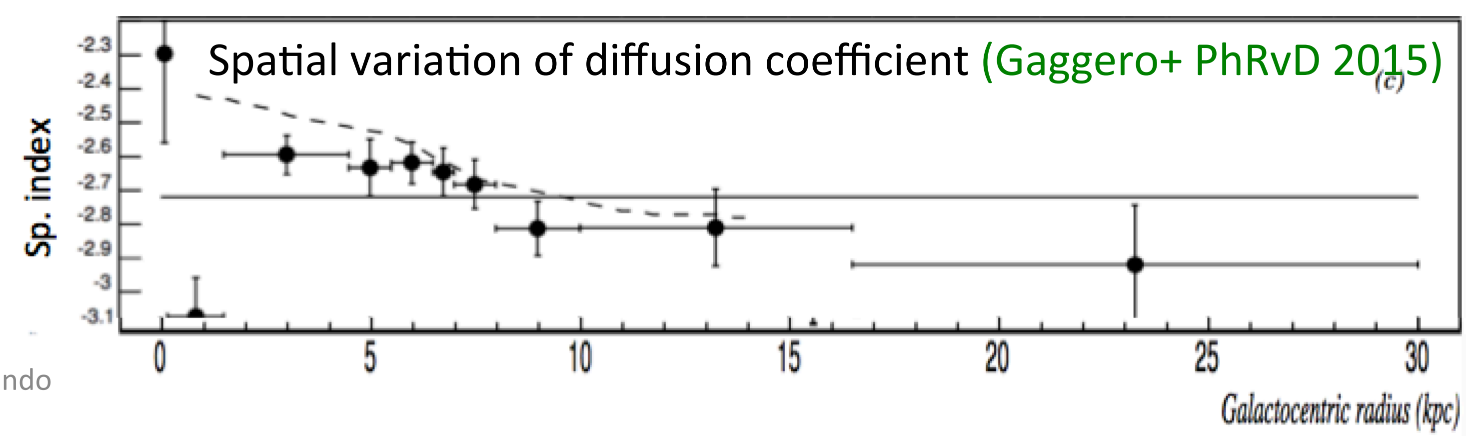




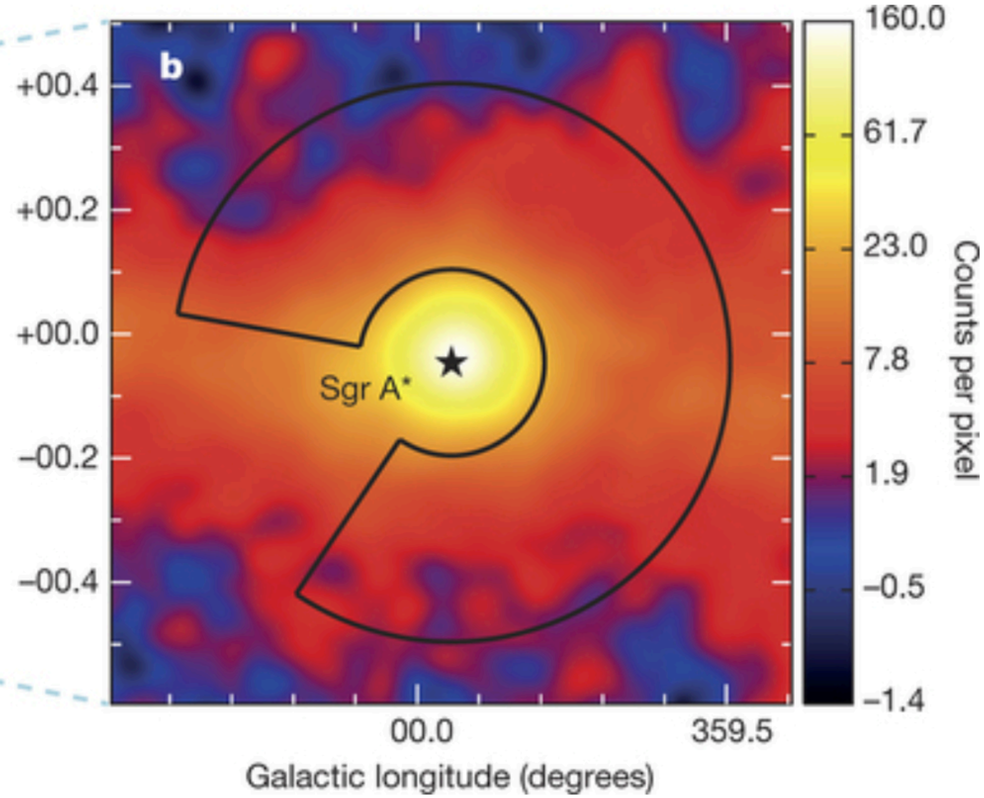


2) Hardening towards the inner Galaxy

Fermi LAT Coll. ApJS (2016)

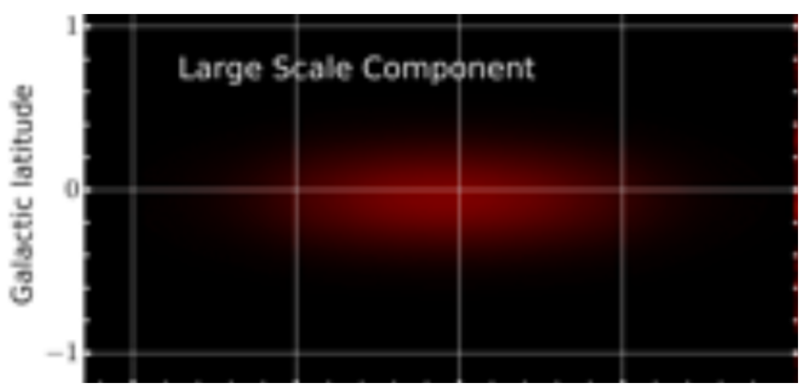


Discovery of PeVatron protons



- Location of a CR source in the inner ~10 pc
- - Diffuse emission possibly associated to activity in the last 10^6-10^7 yrs

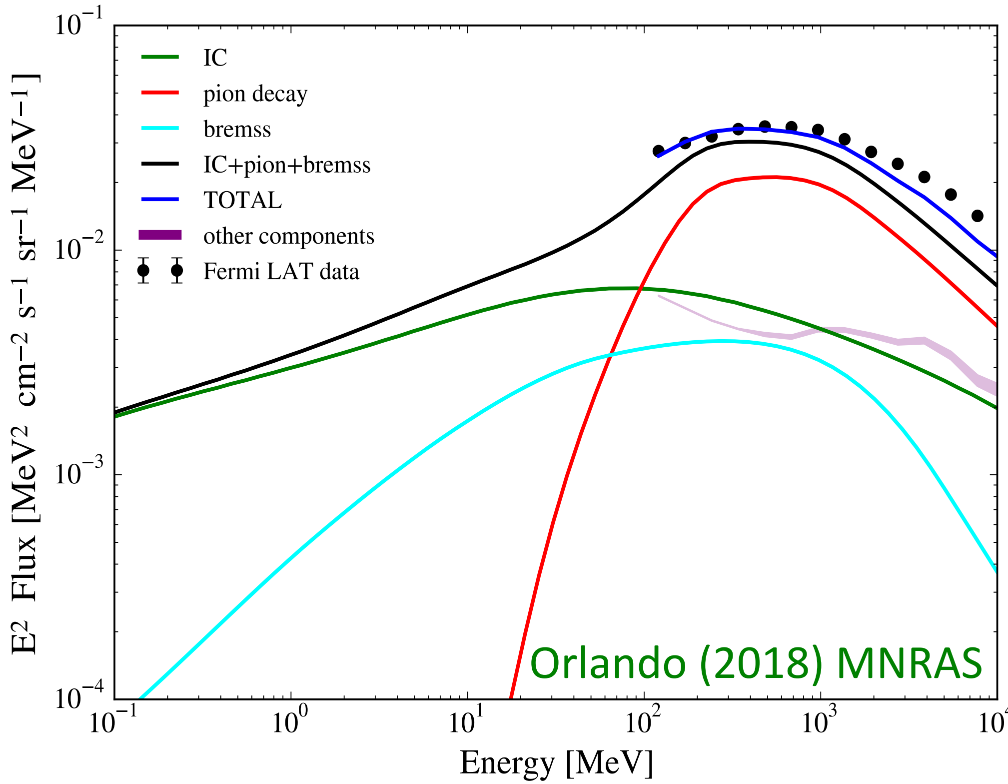
H.E.S.S. Coll. Nature (2016) 531, 476



HESS Coll. A&A 612, A9 (2018)

Further Perspectives – MeV Gammas

AMEGO &
E-ASTROGAM



See also Orlando et al 2019 "*Cosmic Rays and Interstellar Medium with Gamma-Ray Observations at MeV Energies*" ASTRO2020 Decadal Survey on Astronomy and Astrophysics, Science white paper 151

Importance for CTA

Gaining info on CRs from interstellar emission

- in different places of the Galaxy
  - E.g. Fermi Bubbles origin
  - E.g. Galactic center excess origin
  - (E.g. star-forming regions or stellar clusters)
- in external galaxies
  - E.g. LMC, M82, M87, Cen A, M31

Thank You

For Your Attention