HEPL

KIPAC KAVLI INSTITUTE FOR PARTICLE ASTROPHYSICS AND COSMOLOGY

Cosmic rays: interstellar gamma-ray and radio emission from our Galaxy

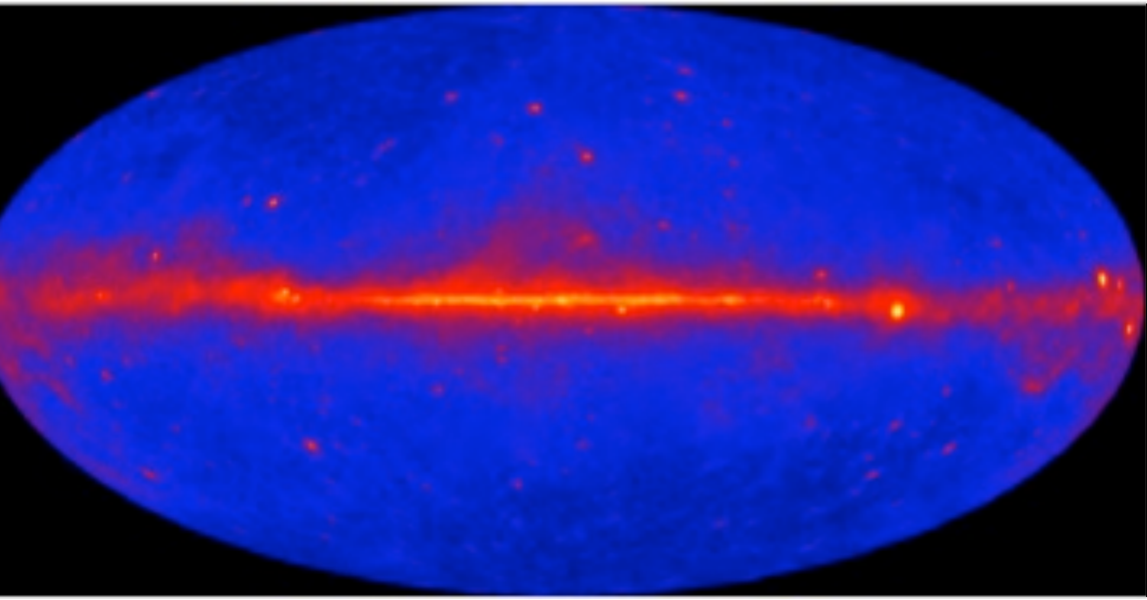
Elena Orlando

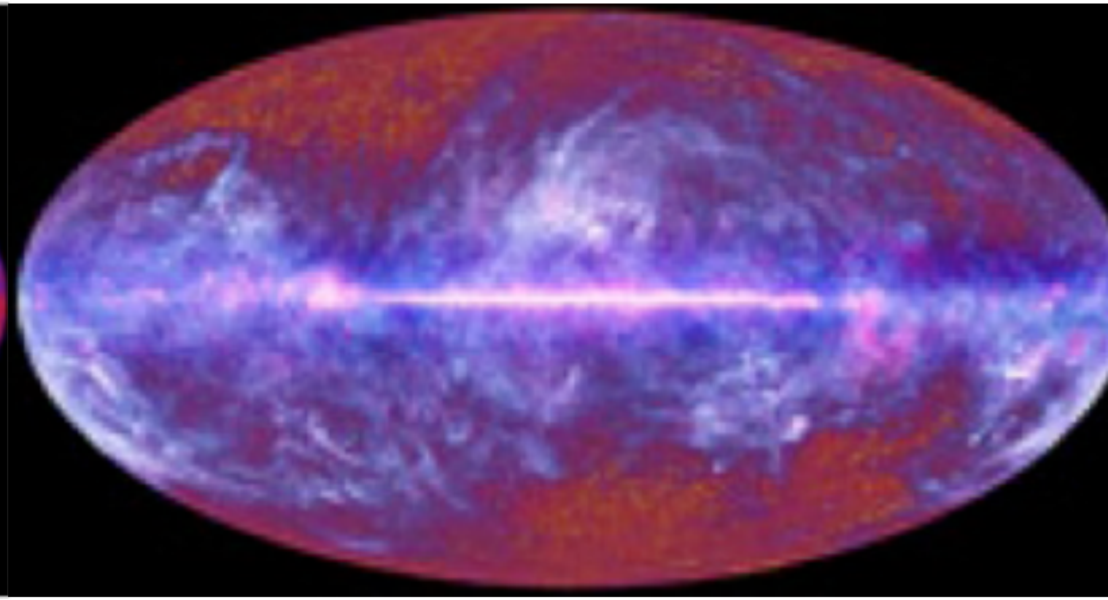
HEPL/KIPAC Stanford University

& Andy Strong for the Fermi-LAT collaboration

SciNeGHE, 22-24 June 2012, Lecce

Cosmic Rays: Indirect measurements

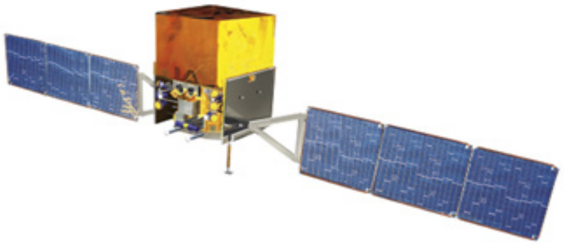




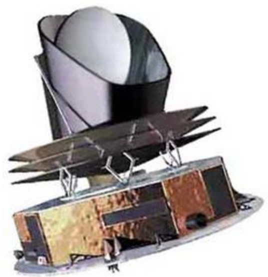
FERMI

PLANCK

CREDIT: Planck collaboration

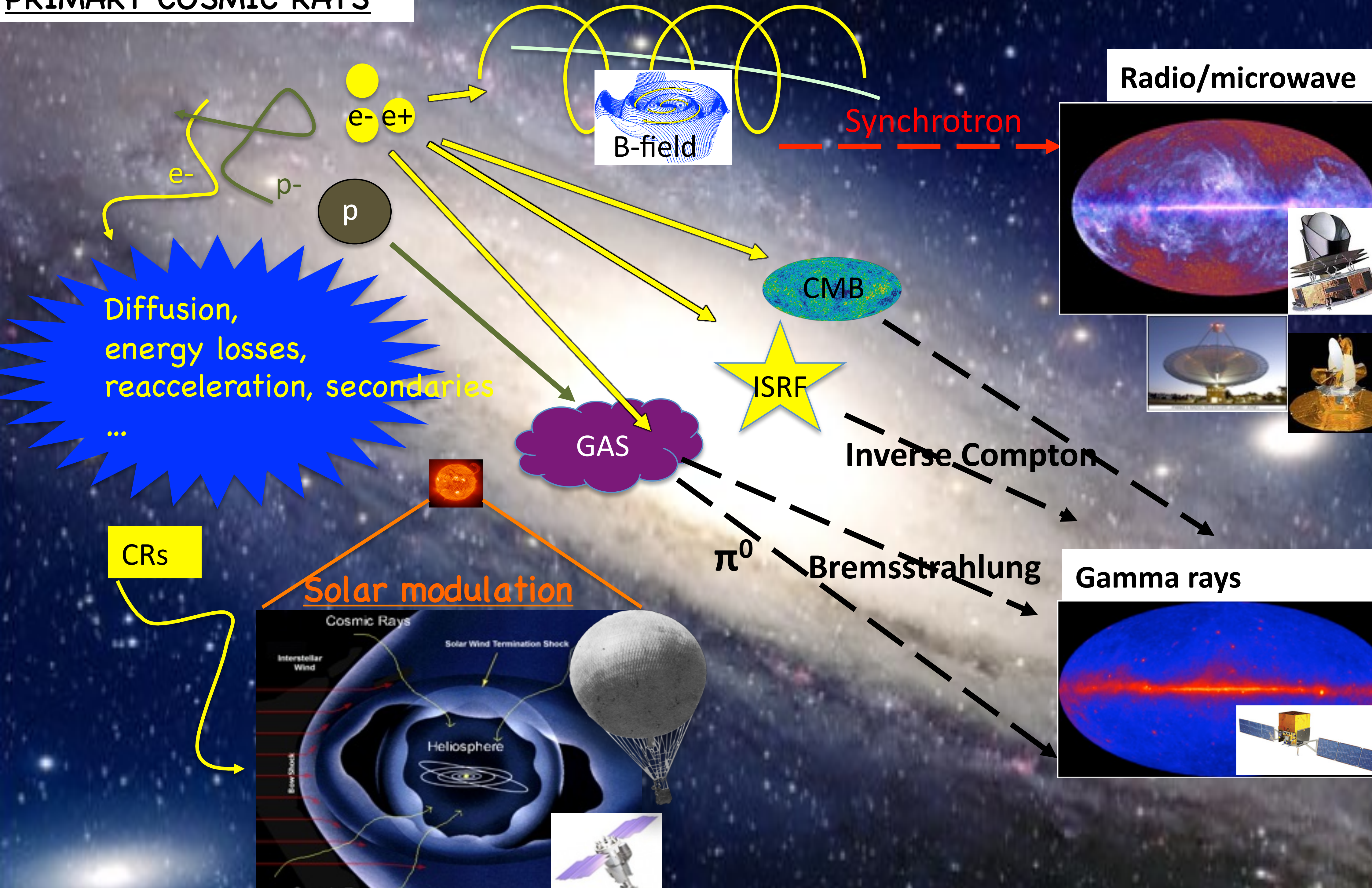


20 MeV - 300 GeV

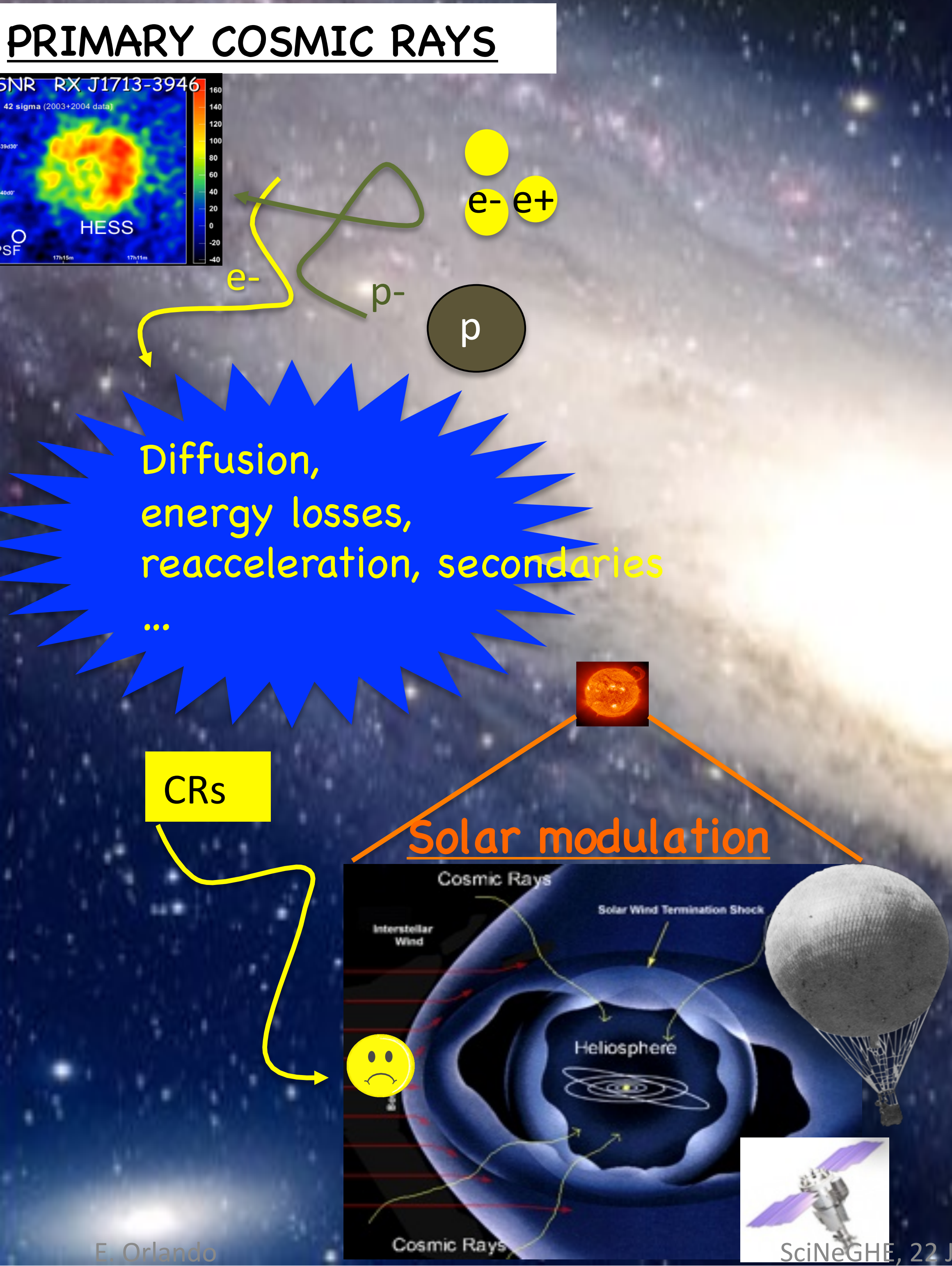


30 GHz – 857 GHz

PRIMARY COSMIC RAYS

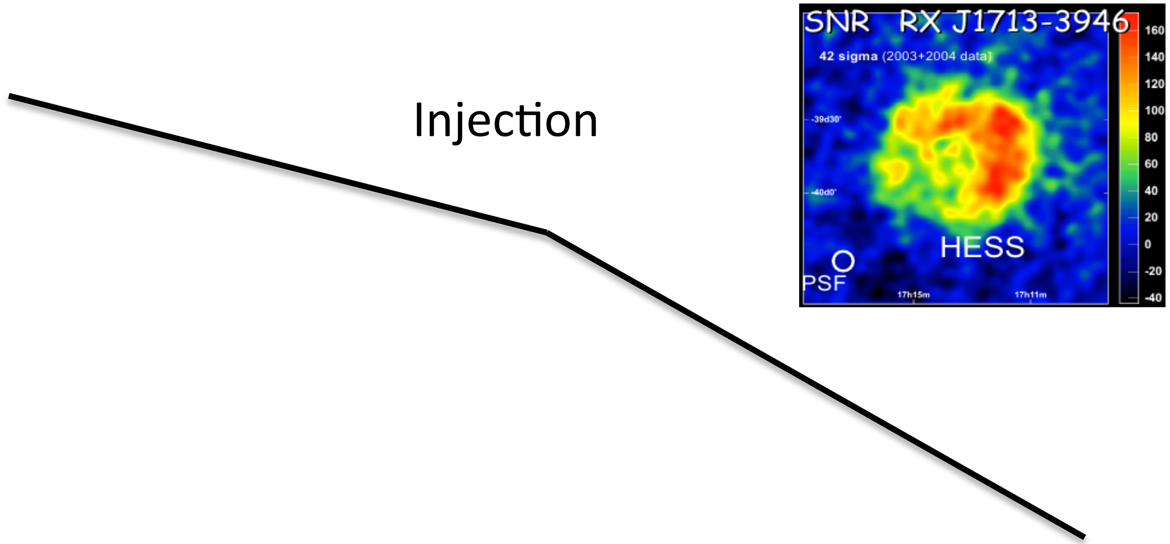


COSMIC RAYS


PRIMARY COSMIC RAYS
SNR RX J1713-3946
42 sigma (2003+2004 data)
HESS
PSF
e-
p-
e- e+
p
Diffusion,
energy losses,
reacceleration, secondaries
...
CRs
Solar modulation
Cosmic Rays
Solar Wind Termination Shock
Interstellar Wind
Heliosphere
Cosmic Rays

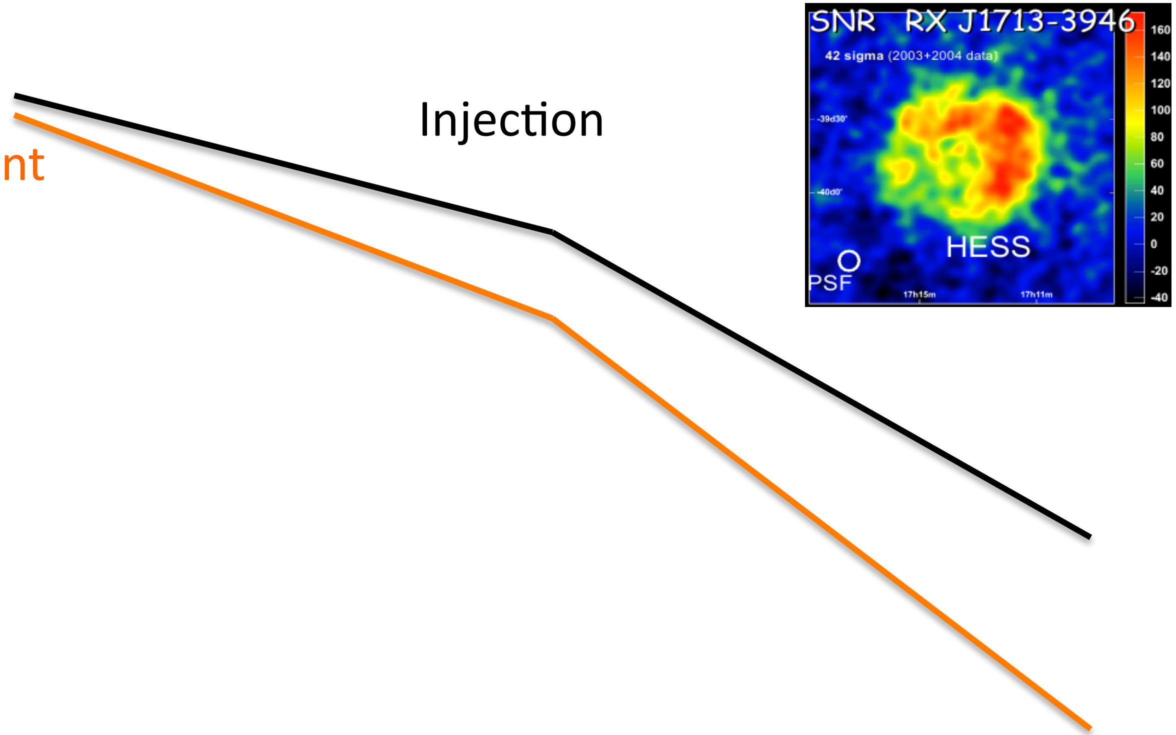
Cosmic-ray spectrum

Injected spectrum (unknown, modeled)



Cosmic-ray spectrum

Injected spectrum (unknown, modeled) -> propagated spectrum, interstellar spectrum (known indirectly)

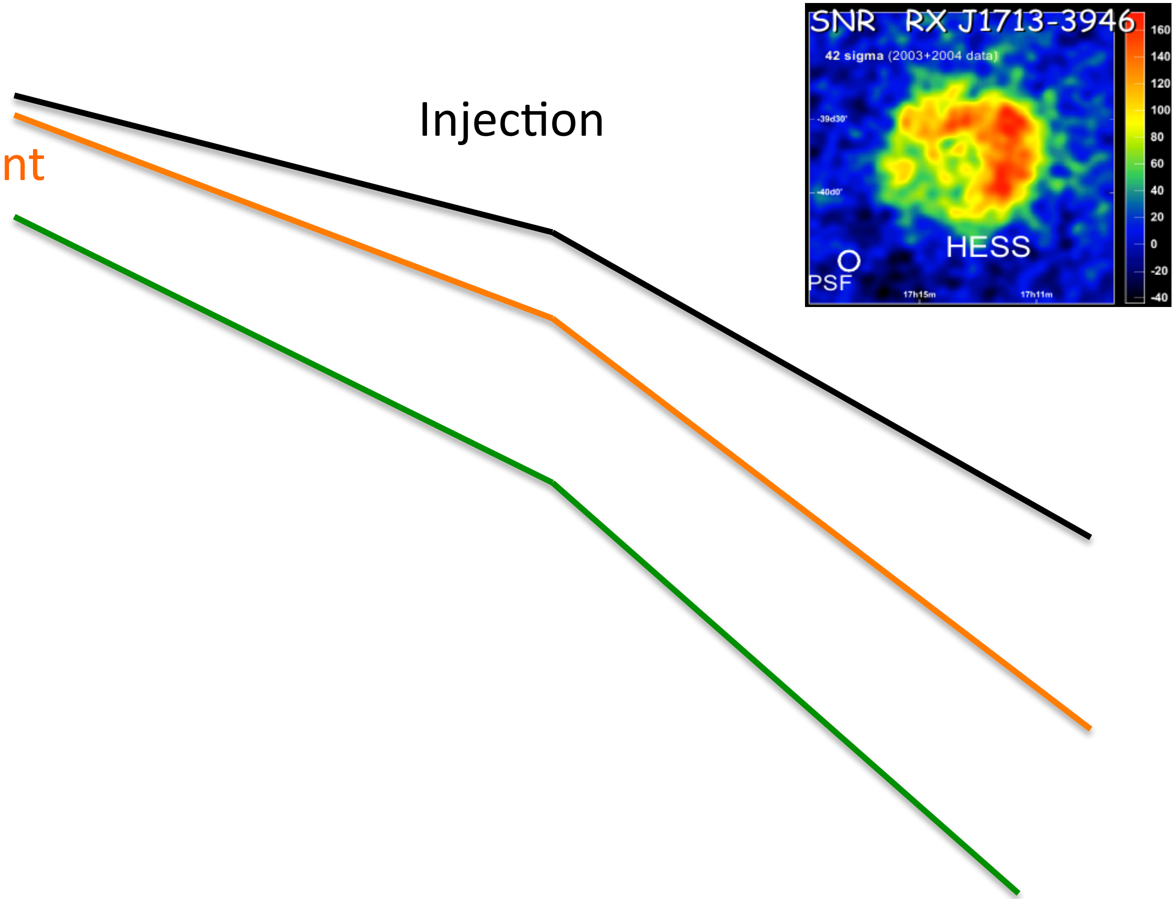


Cosmic-ray spectrum

Injected spectrum (unknown, modeled) -> propagated spectrum, interstellar spectrum (known indirectly)

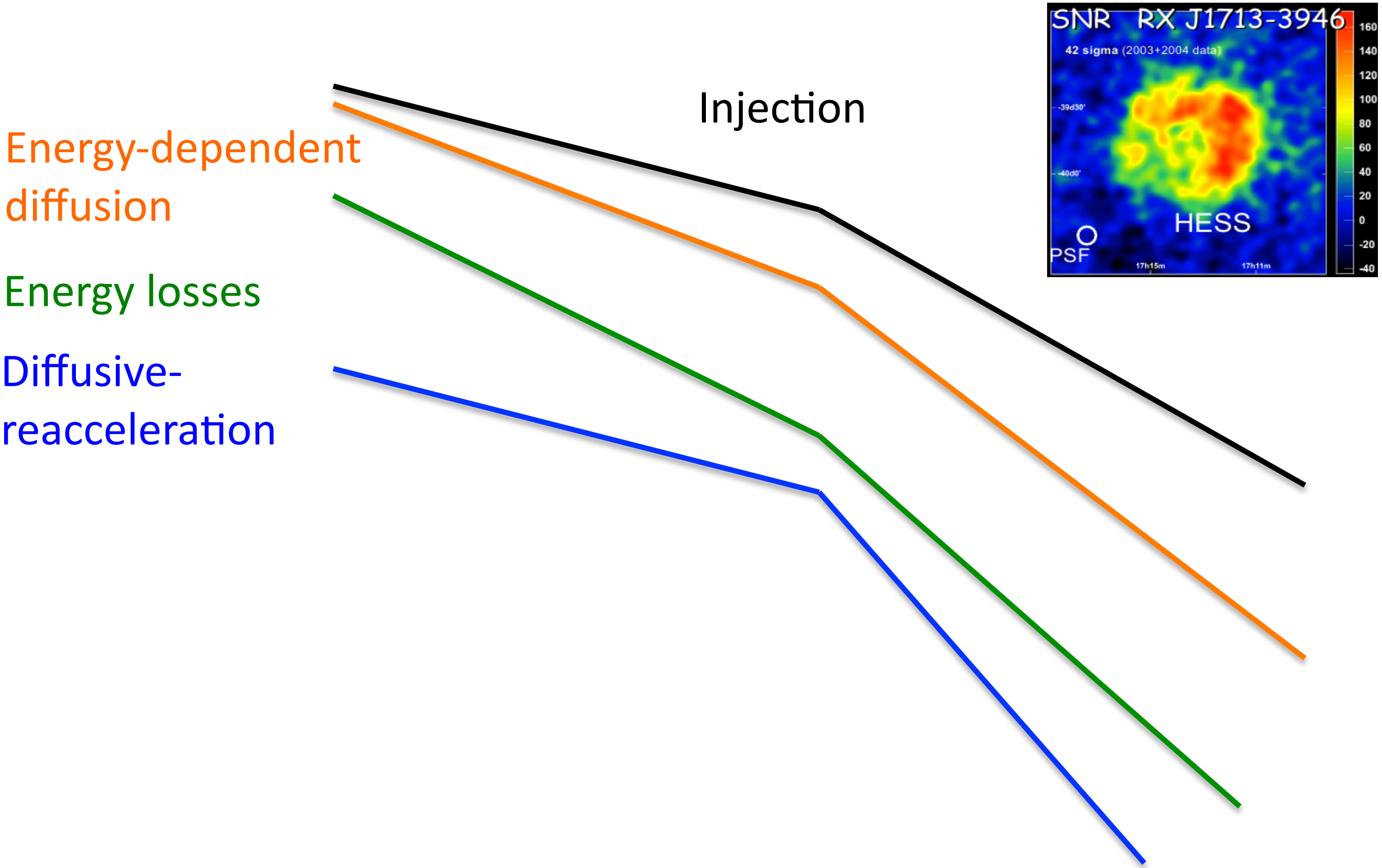
Energy-dependent diffusion

Energy losses



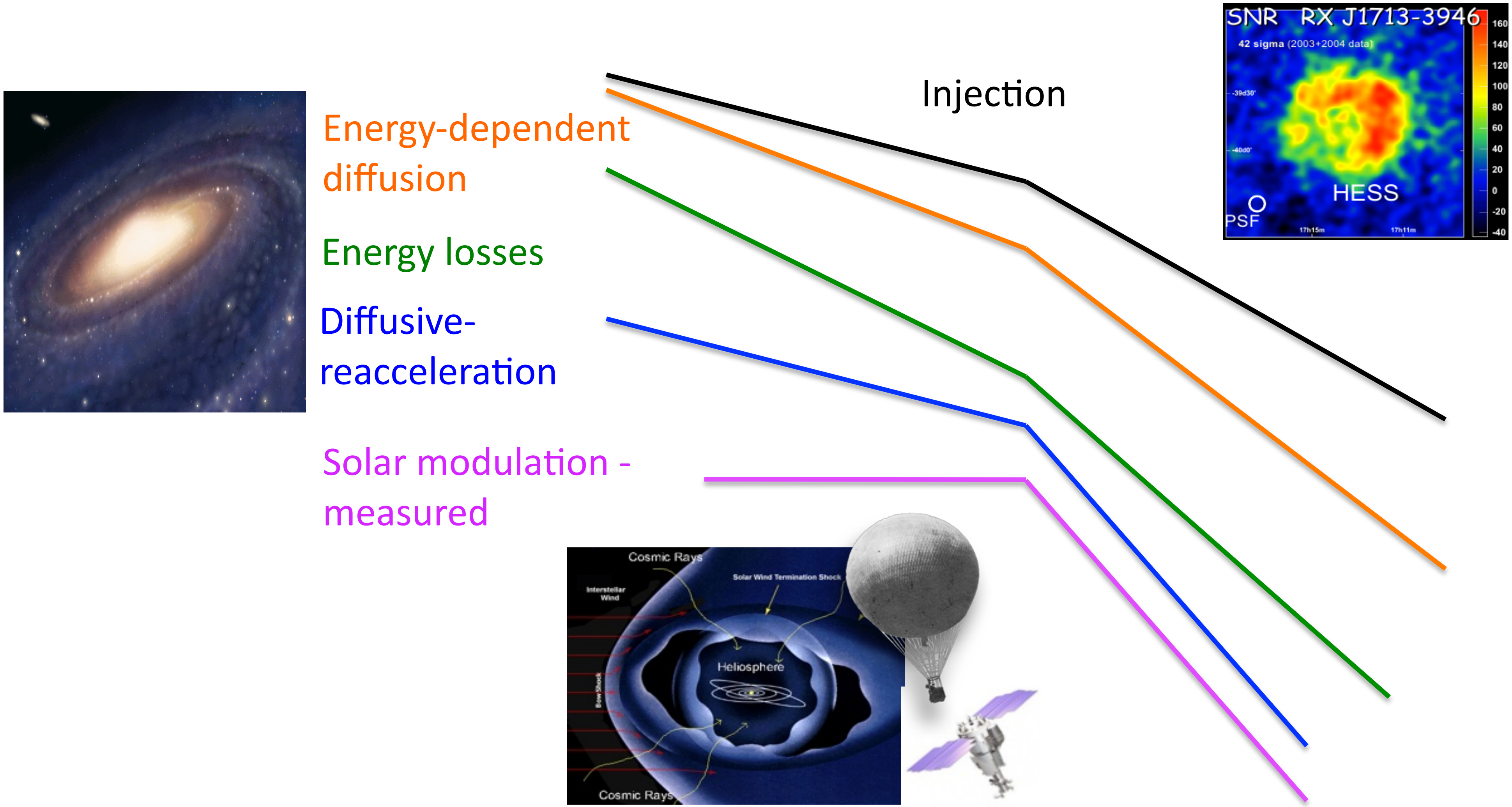
Cosmic-ray spectrum

Injected spectrum (unknown, modeled) -> propagated spectrum, interstellar spectrum (known indirectly)

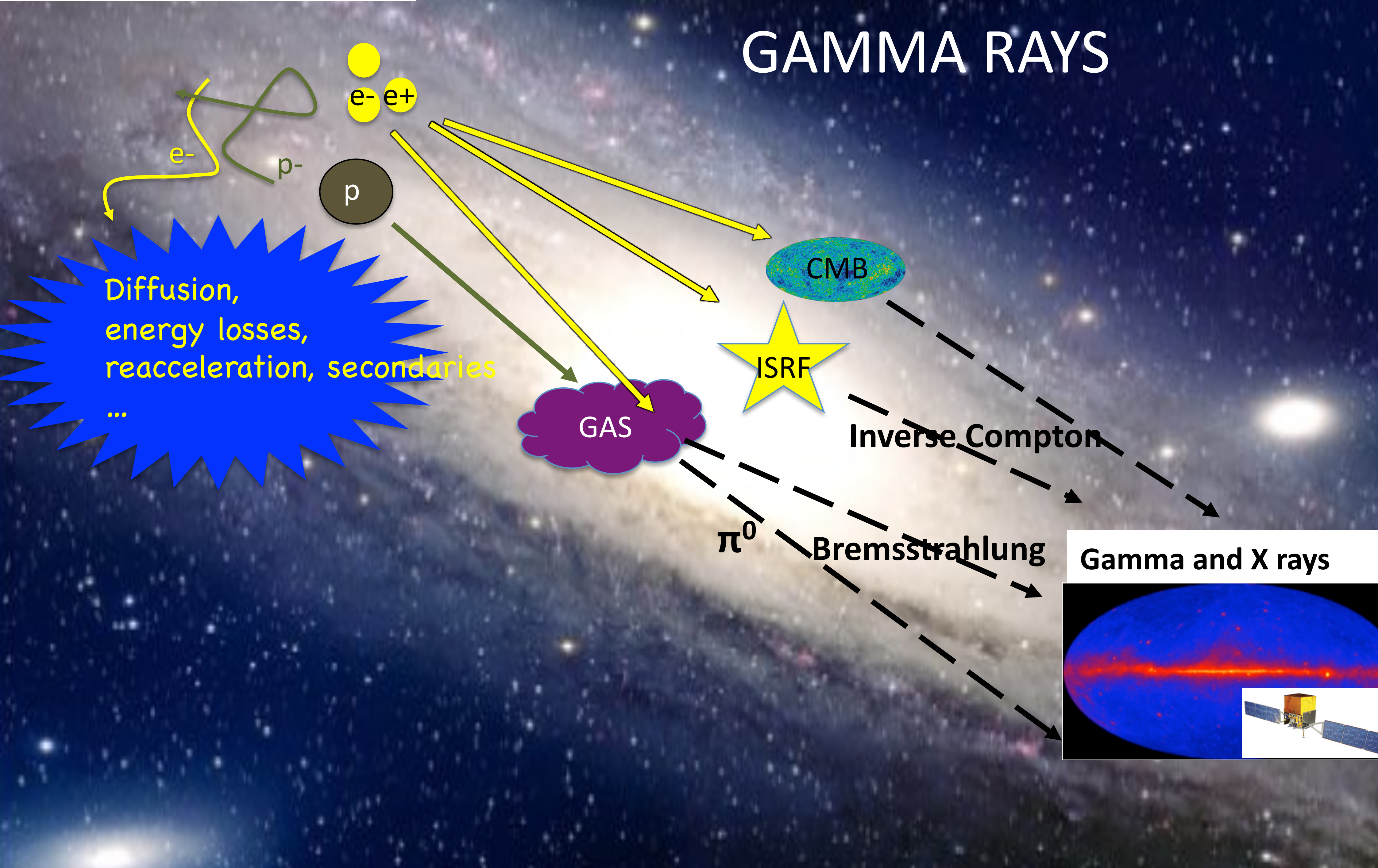


Cosmic-ray spectrum

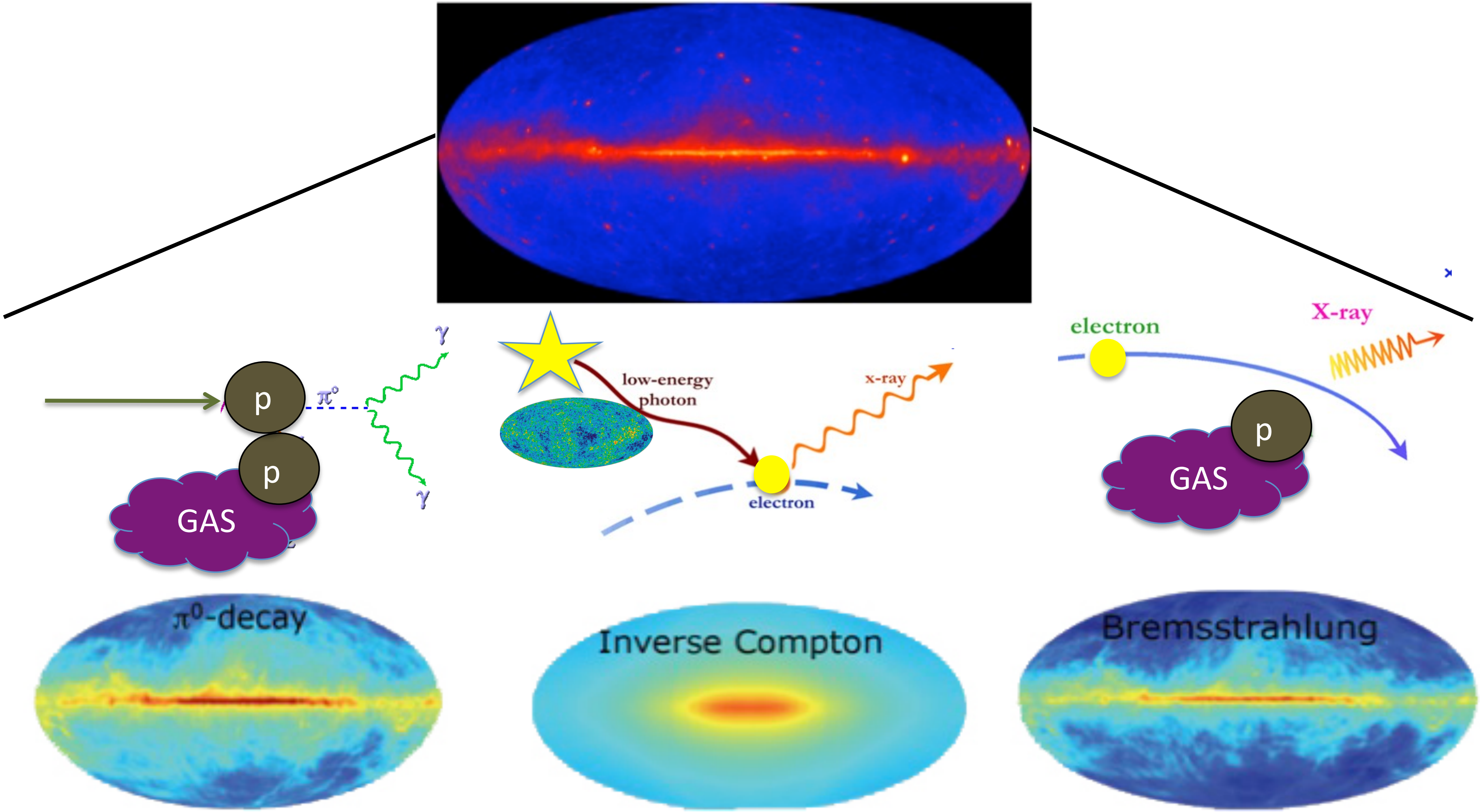
Injected spectrum (unknown, modeled) -> propagated spectrum, interstellar spectrum (known indirectly) -> modulated spectrum (directly measured)



PRIMARY COSMIC RAYS



Gamma-ray interstellar emission



Modeling diffuse emissions with GALPROP

THE TEAM:
I. Moskalenko and A. Strong (original creators),
S. Digel, G. Johannesson, T. Porter, A. Vladimirov and me

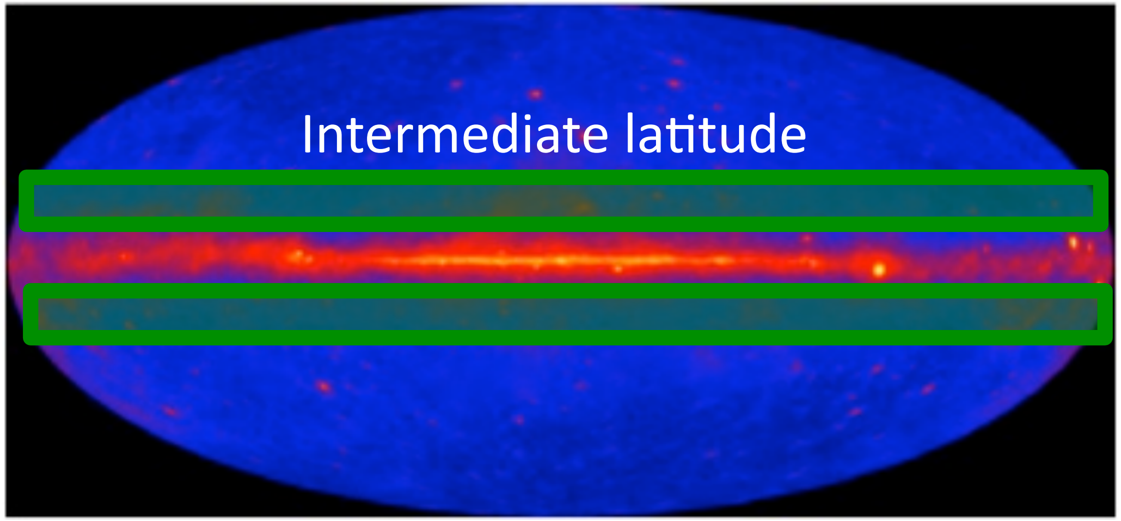
http://galprop.stanford.edu

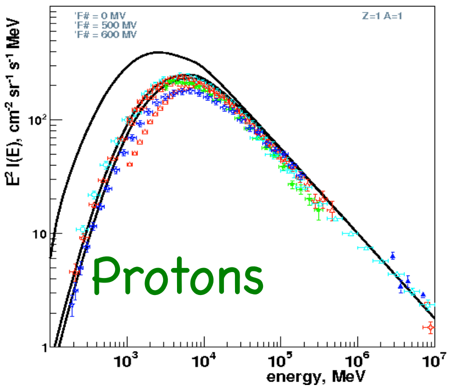
Solve transport equation (energy losses, diffusion, acceleration, convection, fragmentation, radioactive decay) for all CR species

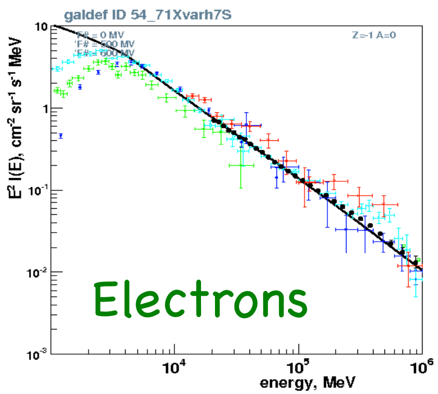
Recipe:

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

Review: Diffuse γ rays with Fermi/LAT

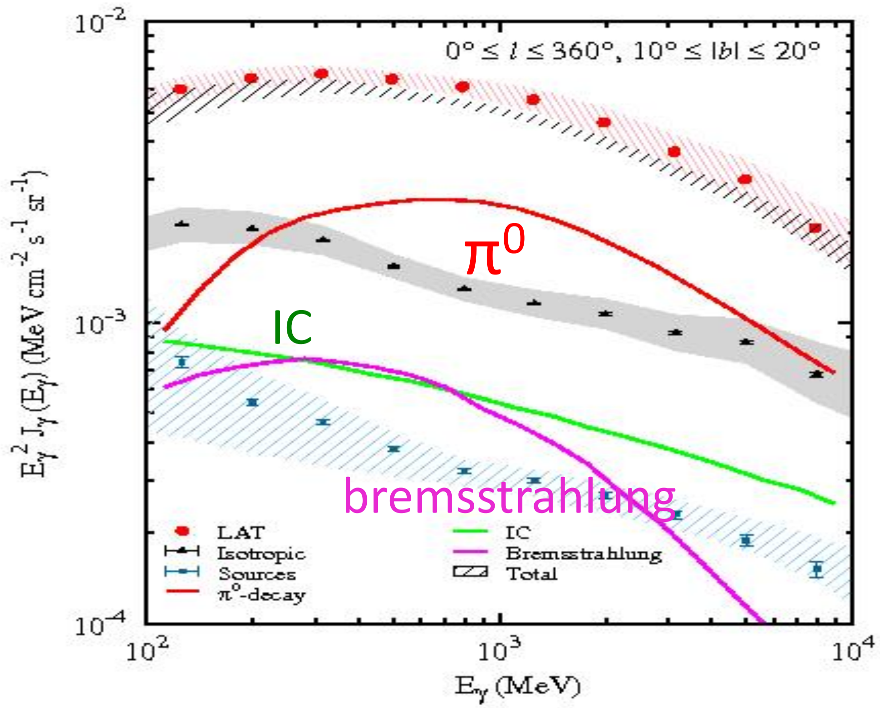






Model based on local cosmic-ray spectra agrees with Fermi !

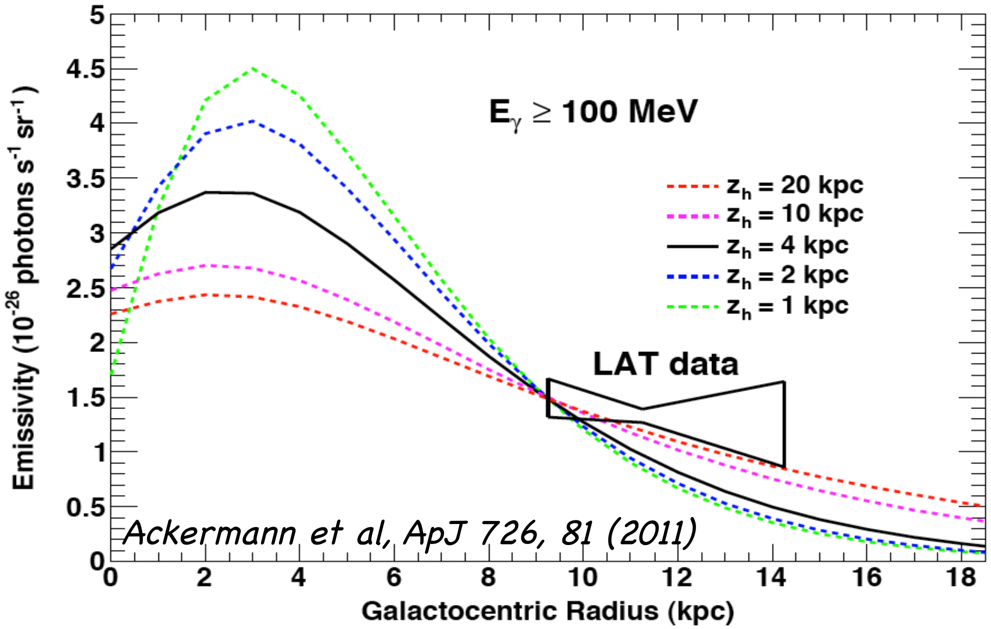
Abdo et al. PhRevLett.103.251101



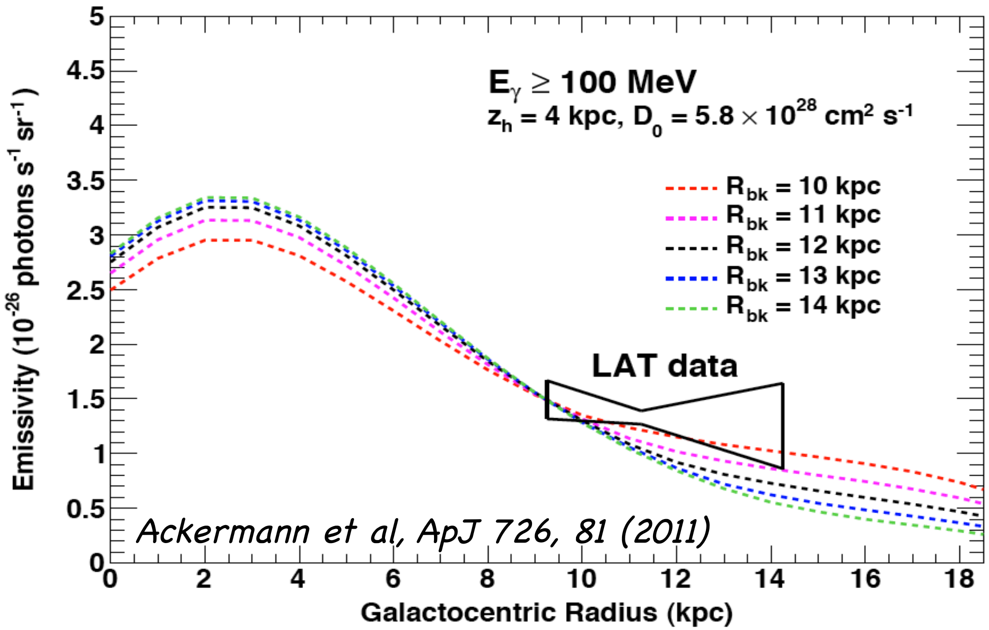
Review: Diffuse γ rays with Fermi/LAT

Emissivity distribution in outer Galaxy

Varying halo size



Varying CR source distribution



Models under-predict gamma rays in outer Galaxy !

Other possibilities:
missing gas, non uniform diffusion coefficient and propagation parameters or sources

See next talk by Luigi Tibaldo

The Astrophysical Journal, 750:3 (35pp), 2012 May 1 doi:10.1088/0004-637X/750/1/3

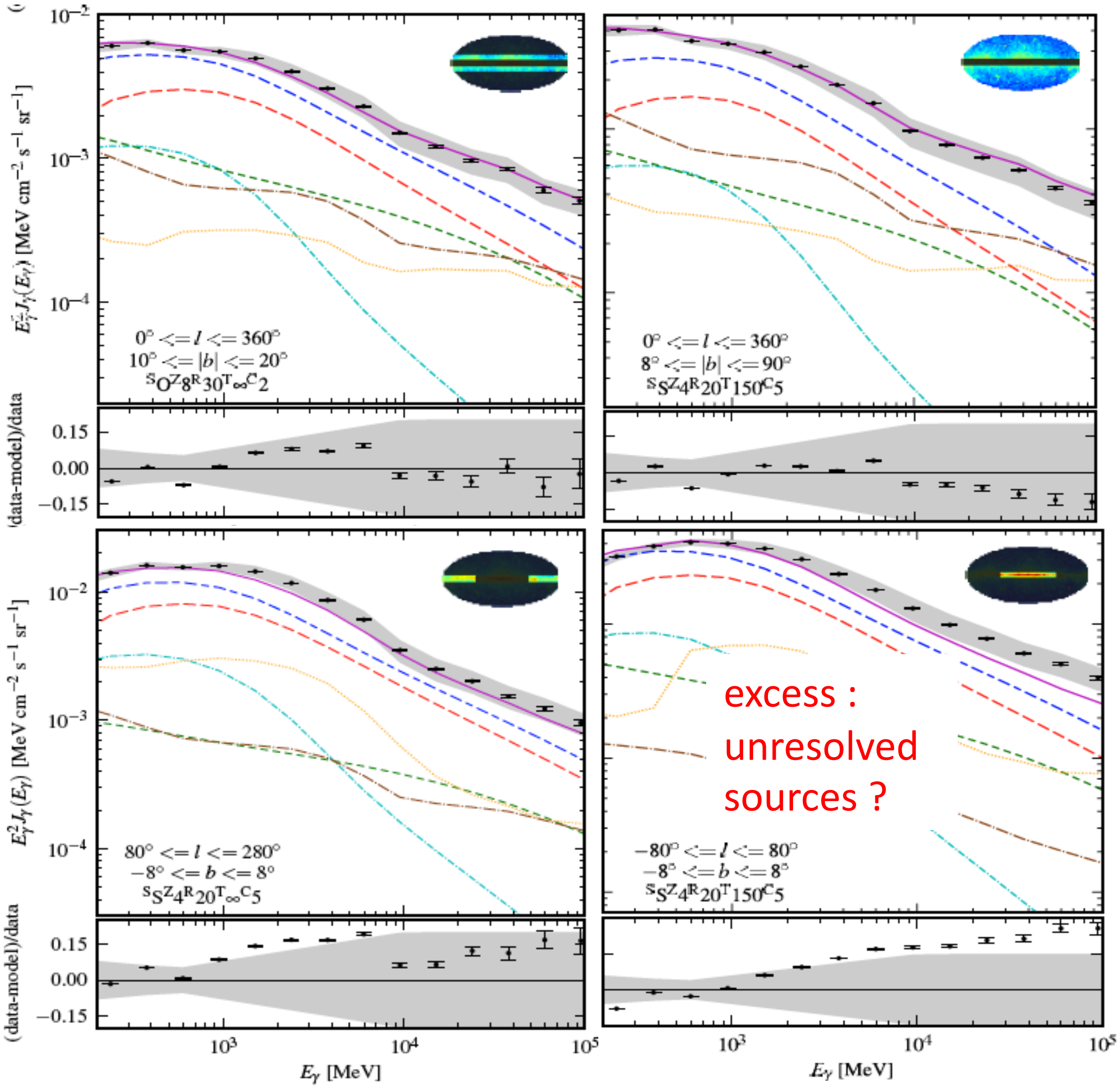
FERMI-LAT OBSERVATIONS OF THE DIFFUSE γ-RAY EMISSION: IMPLICATIONS FOR COSMIC RAYS AND THE INTERSTELLAR MEDIUM

M. Ackermann[1], M. Ajello[2], W. B. Atwood[3], L. Baldini[4], J. Ballet[5], G. Barbiellini[6,7], D. Bastieri[8,9], K. Bechtol[2], R. Bellazzini[4], B. Berenji[2], R. D. Blandford[2], E. D. Bloom[2], E. Bonamente[10,11], A. W. Borgland[2], T. J. Brandt[12,13], J. Bregeon[4], M. Brigida[14,15], P. Bruel[16], R. Buehler[2], S. Buson[8,9], G. A. Caliandro[17], R. A. Cameron[2], P. A. Caraveo[18], E. Cavazzuti[19], C. Cecchi[10,11], E. Charles[2], A. Chekhtman[20,54], J. Chiang[2], S. Ciprini[11,19], R. Claus[2], J. Cohen-Tanugi[21], J. Conrad[22,23,55], S. Cutini[19], A. de Angelis[24], F. de Palma[14,15], C. D. Dermer[25], S. W. Digel[2], E. do Couto e Silva[2], P. S. Drell[2], A. Drlica-Wagner[2], L. Falletti[21], C. Favuzzi[14,15], S. J. Fegan[16], E. C. Ferrara[26], W. B. Focke[2], P. Fortin[16], Y. Fukazawa[27], S. Funk[2], P. Fusco[14,15], D. Gaggero[4], F. Gargano[15], S. Germani[10,11], N. Giglietto[14,15], F. Giordano[14,15], M. Giroletti[28], T. Glanzman[2], G. Godfrey[2], J. E. Grove[25], S. Guiriec[29], M. Gustafsson[8], D. Hadasch[17], Y. Hanabata[27], A. K. Harding[26], M. Hayashida[2,30], E. Hays[26], D. Horan[16], X. Hou[31], R. E. Hughes[32], G. Jóhannesson[33], A. S. Johnson[2], R. P. Johnson[3], T. Kamae[2], H. Katagiri[34], J. Kataoka[35], J. Knödlseder[12,13], M. Kuss[4], J. Lande[2], L. Latronico[36], S.-H. Lee[37], M. Lemoine-Goumard[38,56], F. Longo[6,7], F. Loparco[14,15], B. Lott[38], M. N. Lovellette[25], P. Lubrano[10,11], M. N. Mazziotta[15], J. E. McEnery[26,39], P. F. Michelson[2], W. Mitthumsiri[2], T. Mizuno[27], C. Monte[14,15], M. E. Monzani[2], A. Morselli[40], I. V. Moskalenko[2], S. Murgia[2], M. Naumann-Godo[5], J. P. Norris[41], E. Nuss[21], T. Ohsugi[42], A. Okumura[2,43], N. Omodei[2], E. Orlando[2,44], J. F. Ormes[45], D. Paneque[2,46], J. H. Panetta[2], D. Parent[47,54], M. Pesce-Rollins[4], M. Pierbattista[5], F. Piron[21], G. Pivato[9], T. A. Porter[2], S. Rainò[14,15], R. Rando[8,9], M. Razzano[3,4], S. Razzaque[47,54], A. Reimer[2,48], O. Reimer[2,48], H. F.-W. Sadrozinski[3], C. Sgrò[4], E. J. Siskind[49], G. Spandre[4], P. Spinelli[14,15], A. W. Strong[44], D. J. Suson[50], H. Takahashi[42], T. Tanaka[2], J. G. Thayer[2], J. B. Thayer[2], D. J. Thompson[26], L. Tibaldo[8,9], M. Tinivella[4], D. F. Torres[17,51], G. Tosti[10,11], E. Troja[26,57], T. L. Usher[2], J. Vandenbroucke[2], V. Vasileiou[21], G. Vianello[2,52], V. Vitale[40,53], A. P. Waite[2], P. Wang[2], B. L. Winer[32], K. S. Wood[25], M. Wood[2], Z. Yang[22,23], M. Ziegler[3], and S. Zimmer[22,23]

Studying Systematics Using GALPROP

128 MODELS: in agreement with CR data, varying CR source distribution, CR halo size, gas and compare with Fermi LAT data (21 months, 200 MeV to 100 GeV)

Results: spectra



The physics of the diffuse emissions well understood and described.

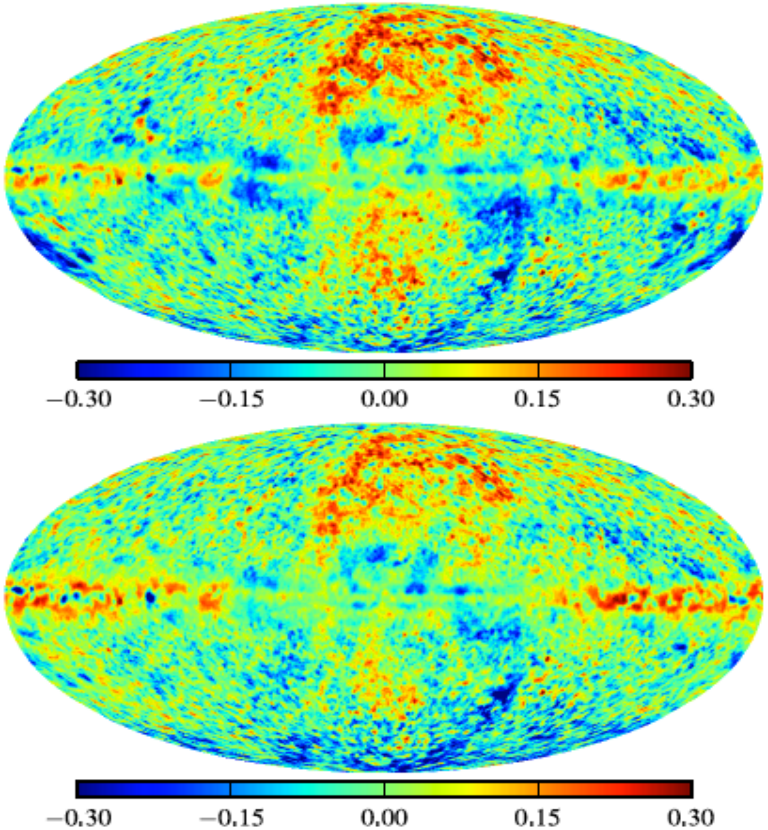
BUT No single model gives best fit over all sky regions

Models under-predict data in the outer Galactic plane

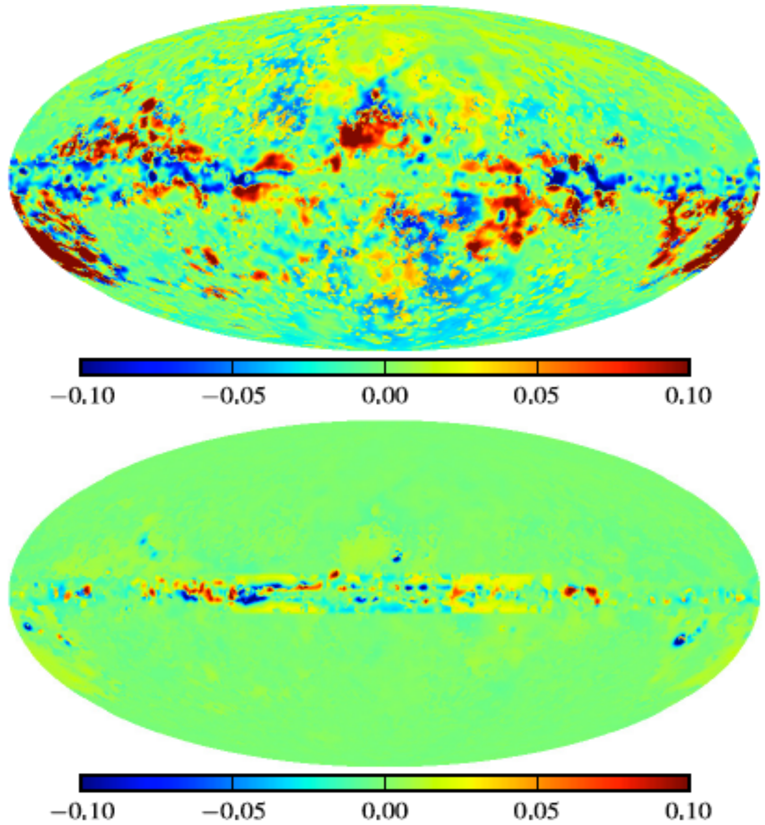
Ackermann et al, ApJ 750, 1,3 (2012)

Results: residual maps

(model-data)/model



Abs(model 1)- Abs(model 2)



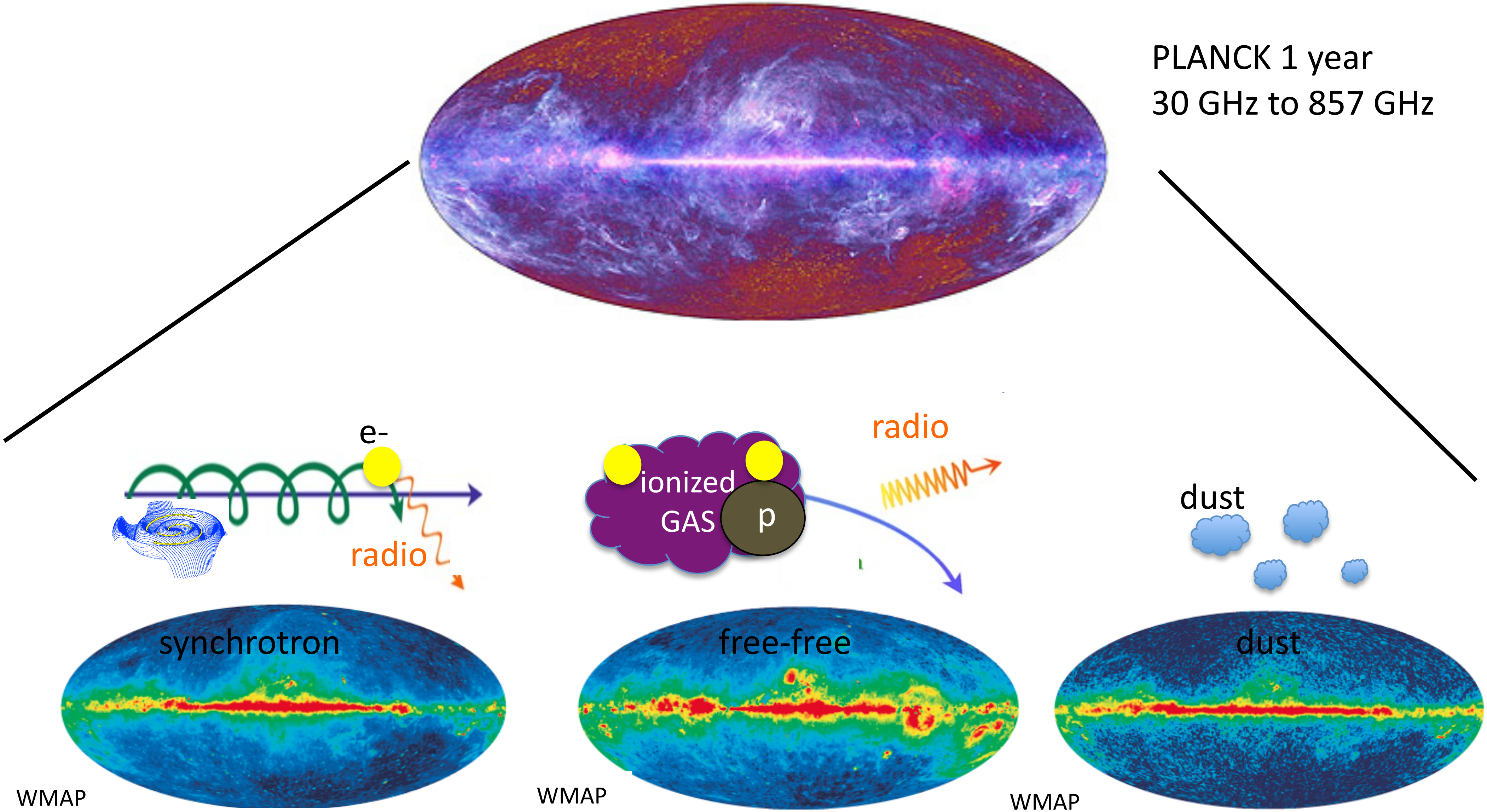
Ackermann et al, ApJ 750, 1,3 (2012)

All models are within 15% of data

Larger Galactic halo size preferred

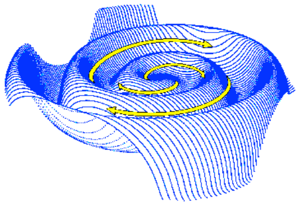
PRIMARY COSMIC RAYS

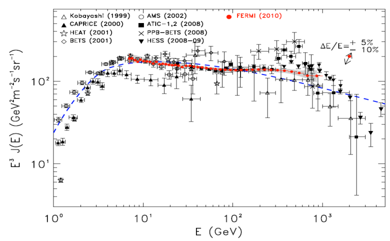
The microwave sky

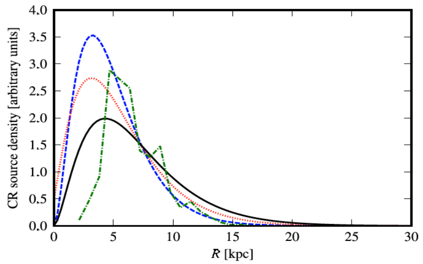


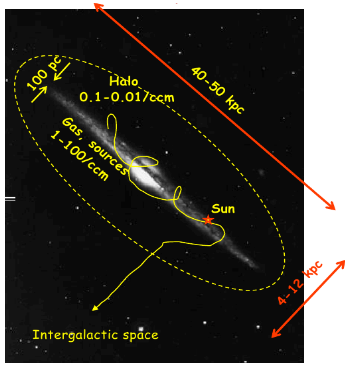
+ Sources + Spinning dust + detector noise + Dark Matter?

Uncertainties









Using synchrotron radiation for constraints and for foreground studies

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

Recent Improvements in Galprop

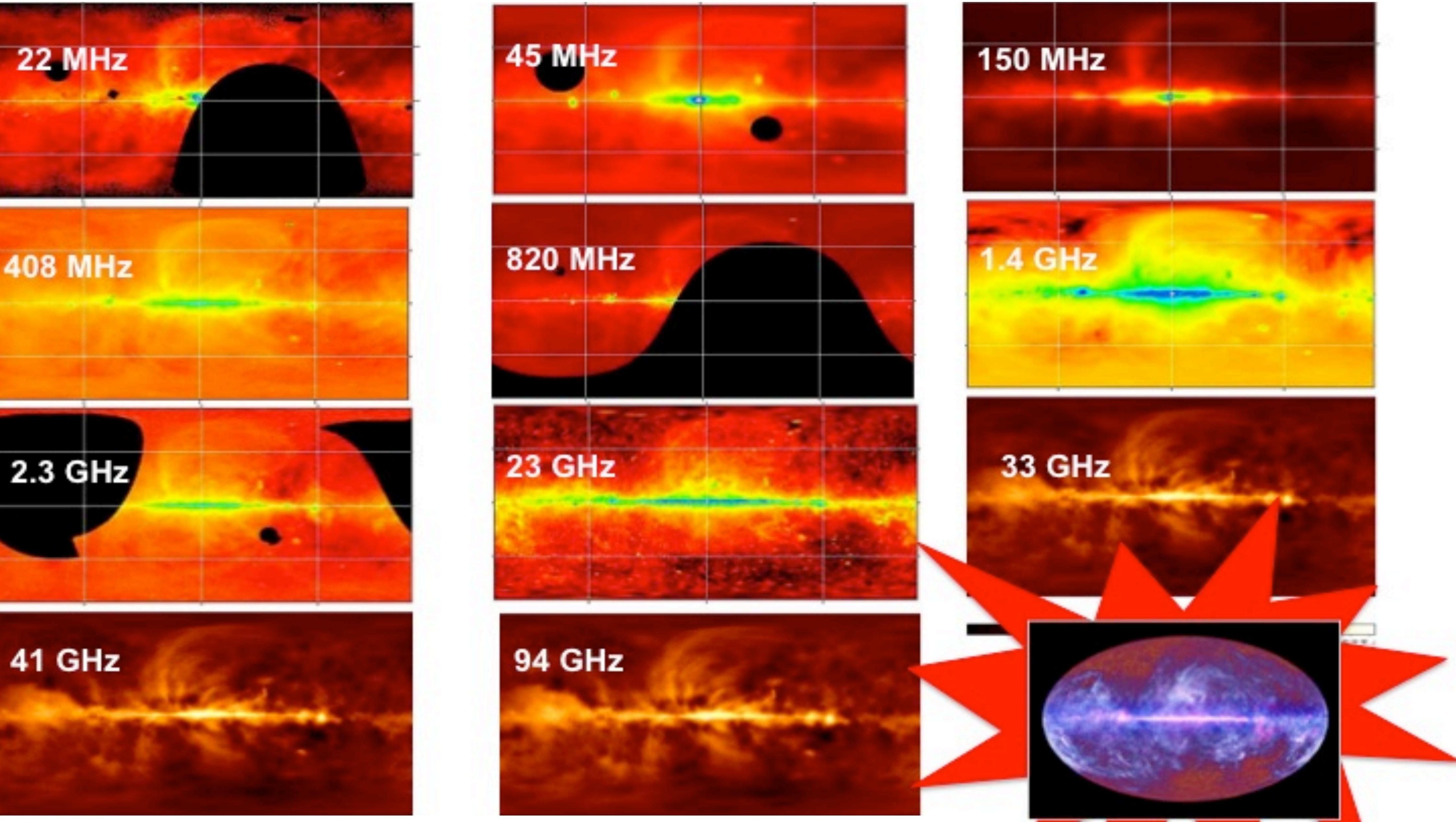
- 3D model of the magnetic field
- Regular and random components

Strong, Orlando, Jaffe A&A 2011

- Polarized synchrotron
- Free-free emission model

Orlando, Strong et al in prep

Radio surveys & WMAP



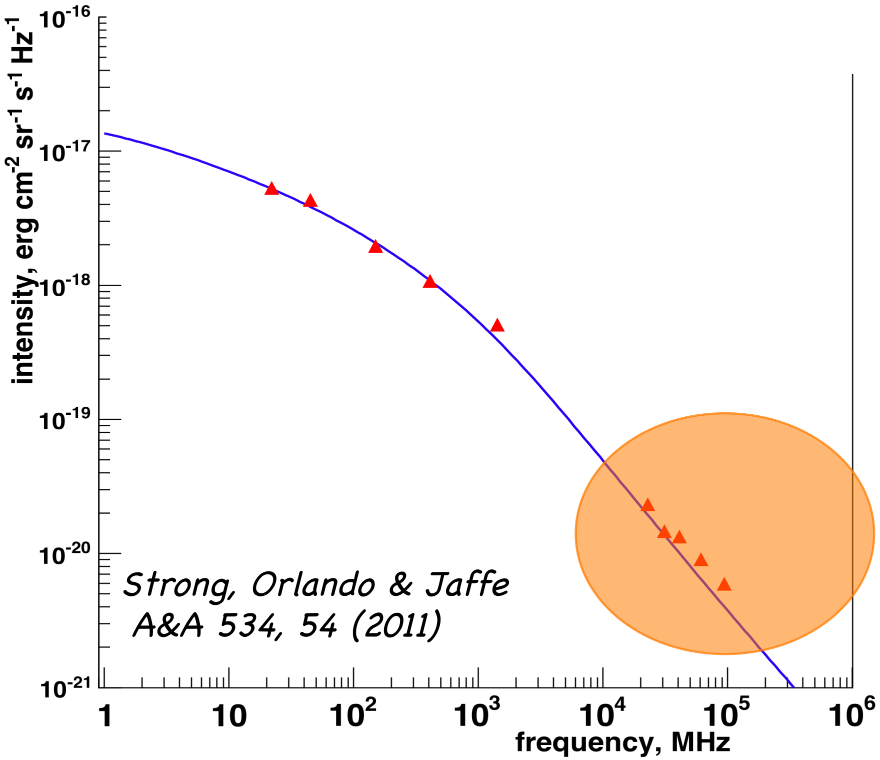
Radio Ground-based Surveys: 22 MHz – 5 GHz
WMAP: 23 – 94 GHz …. Planck: 30 - 800 GHz

1. Probing Interstellar electron spectrum

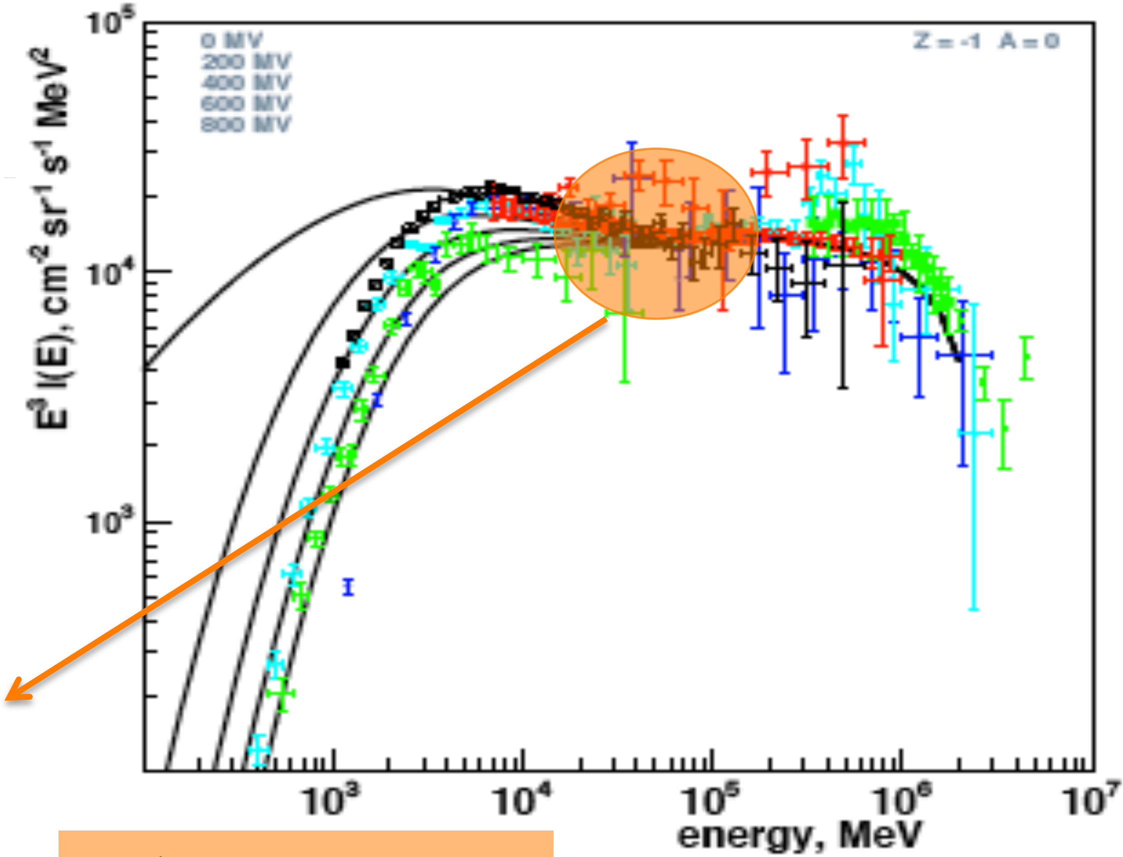
e- e+

…

Synchrotron



Direct measurements



… directly measured

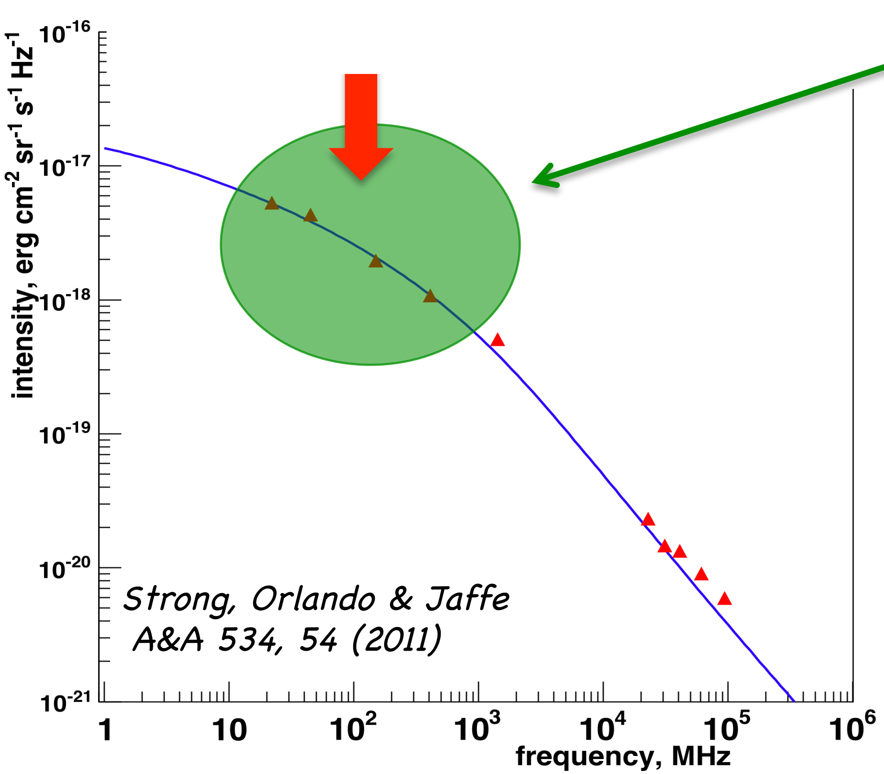
Obtaining info on B-field intensity

1. Probing Interstellar electron spectrum …

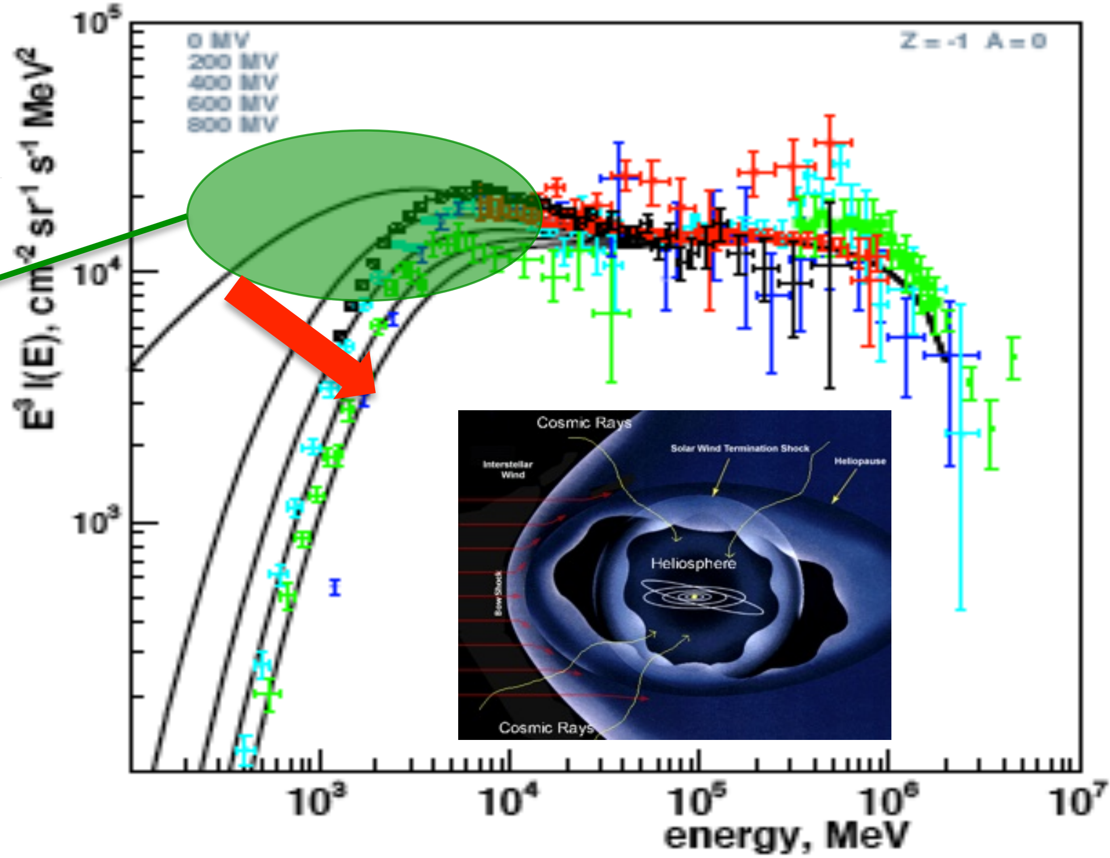
e- e+

… before modulation

Synchrotron



Direct measurements



Change in the spectral index

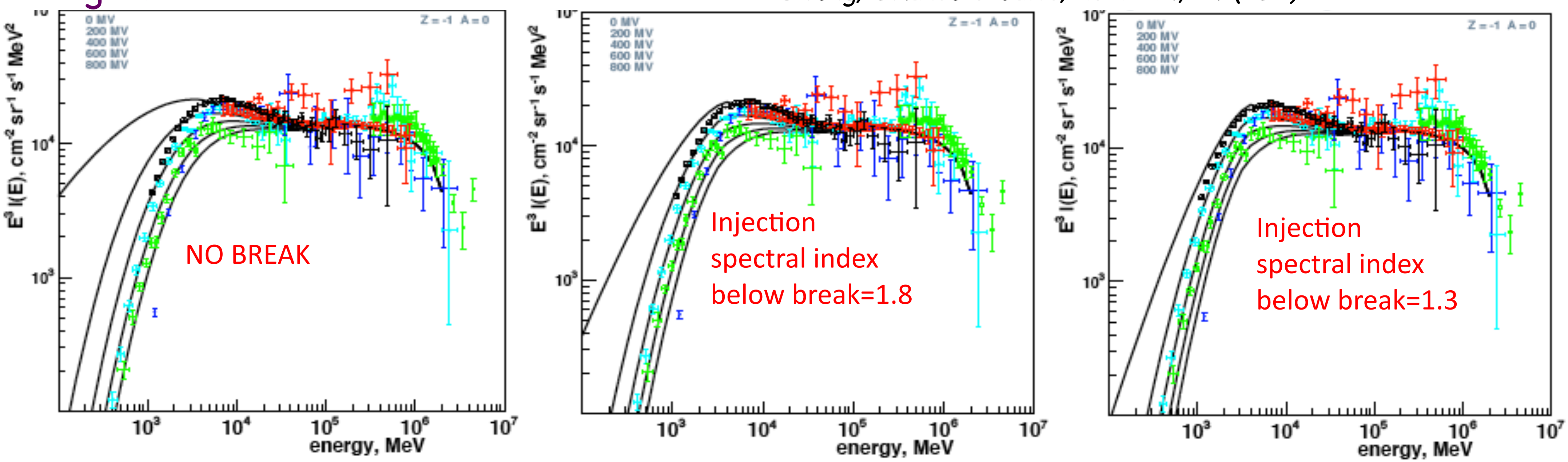
2. Probing electron injection spectrum

e- e+

High latitudes

Strong, Orlando & Jaffe, A&A 534, 54 (2011)

ELECTRONS



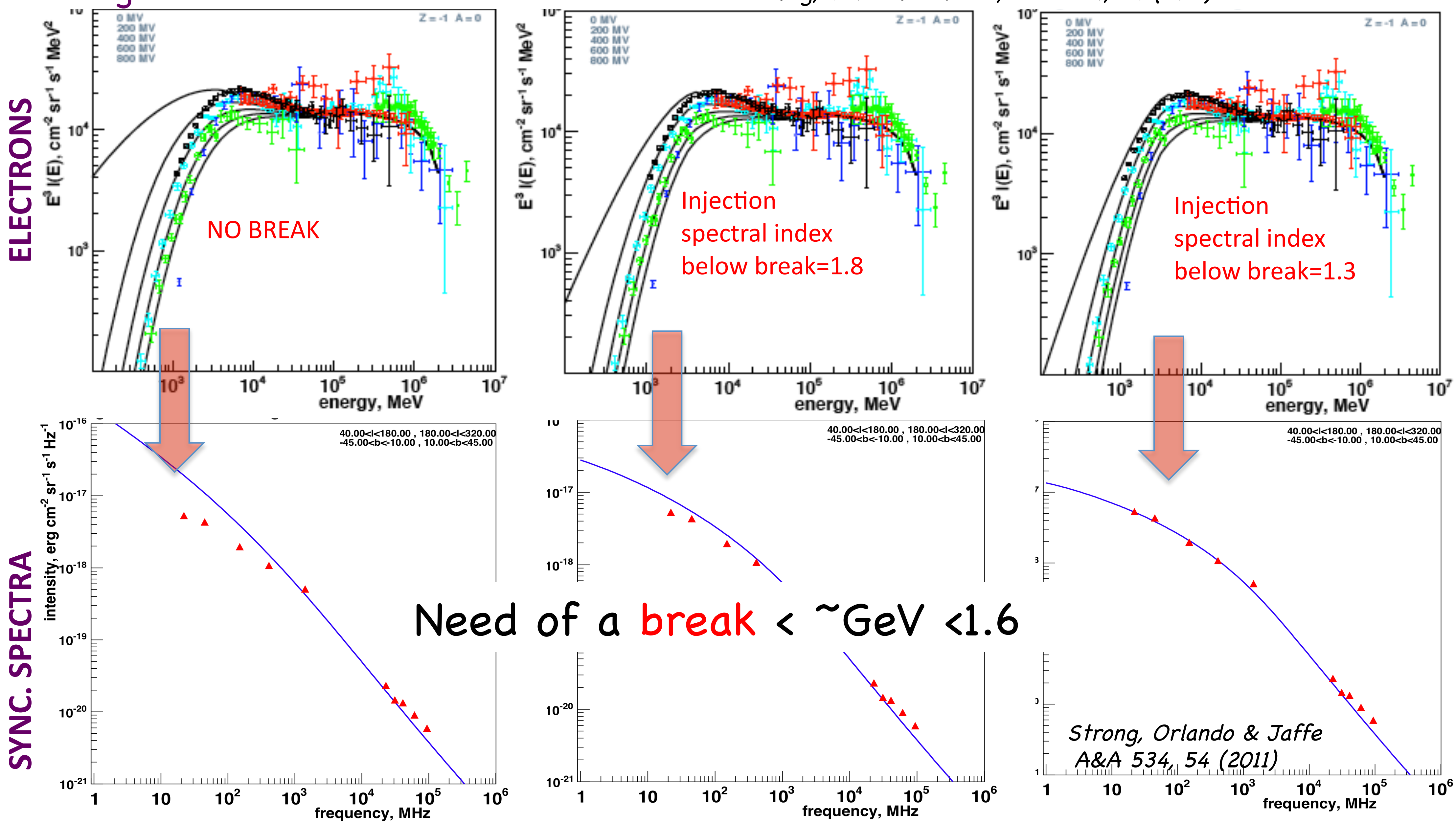
*injection spectral index above break at 4 GeV = 2.5

2. Probing electron injection spectrum

e- e+

High latitudes

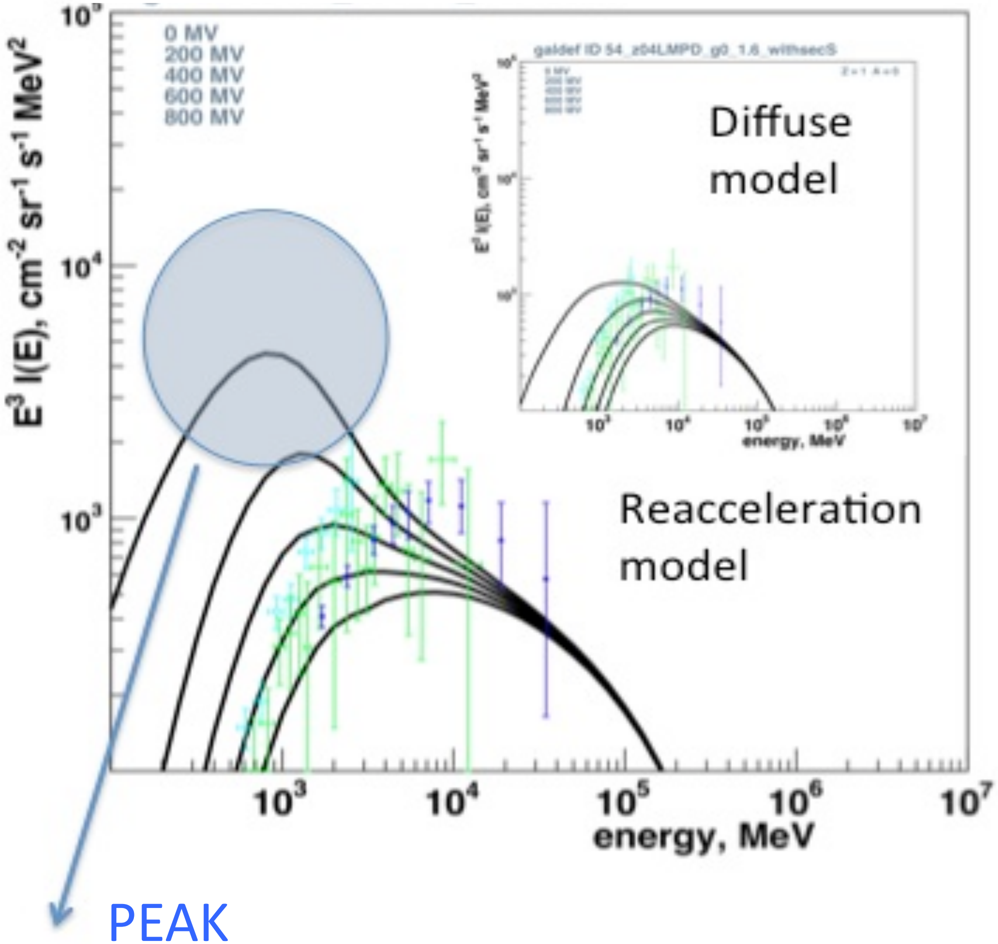
Strong, Orlando & Jaffe, A&A 534, 54 (2011)



*injection spectral index above break at 4 GeV = 2.5

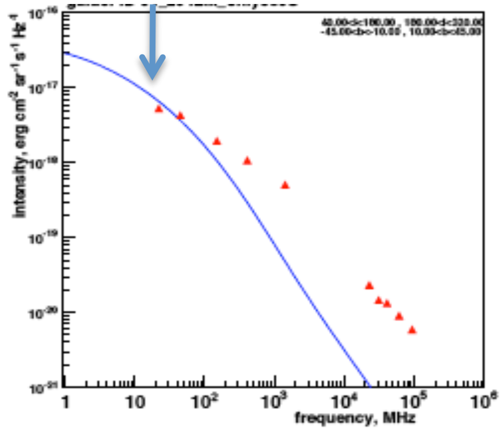
3. Testing models of propagation

POSITRONS (secondaries)

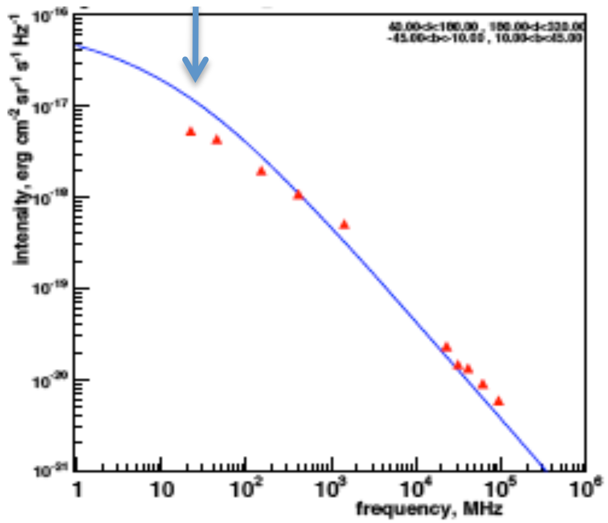


PEAK

PEAK (only secondaries)



Primaries+secondaries

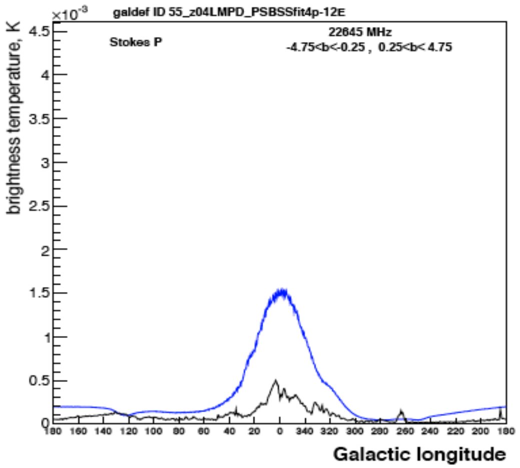


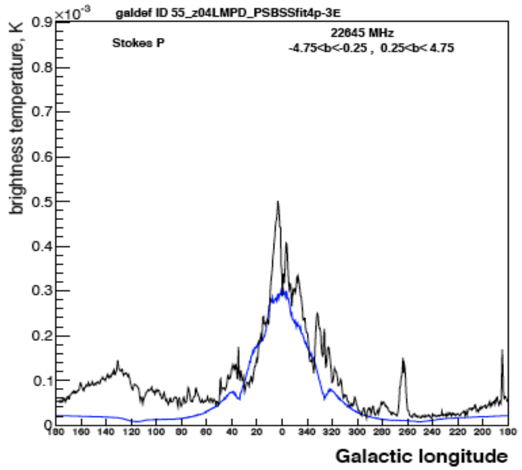
Synchrotron helps in constraining models used to described gamma-ray data!

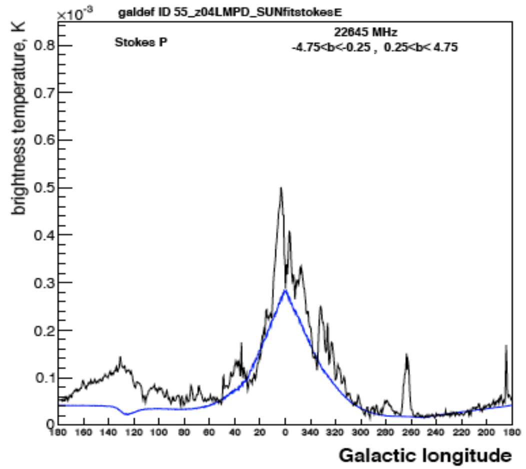
3. Probing Galactic Magnetic fields

Model 1 | Model 2 | Model 3

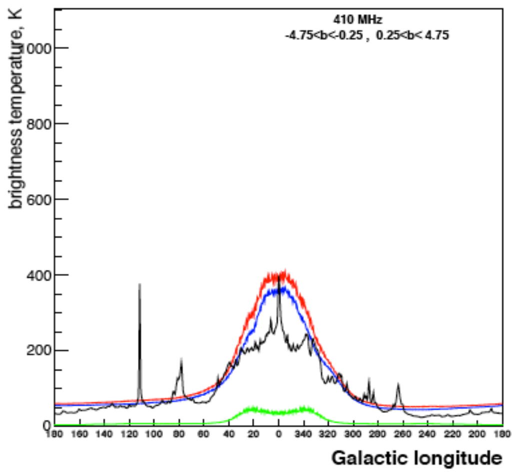
P
@ 23 GHz

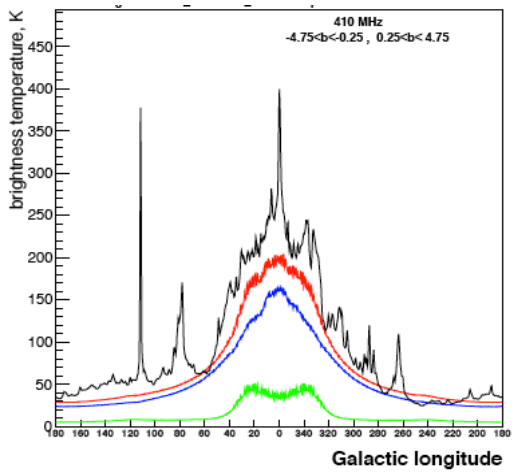


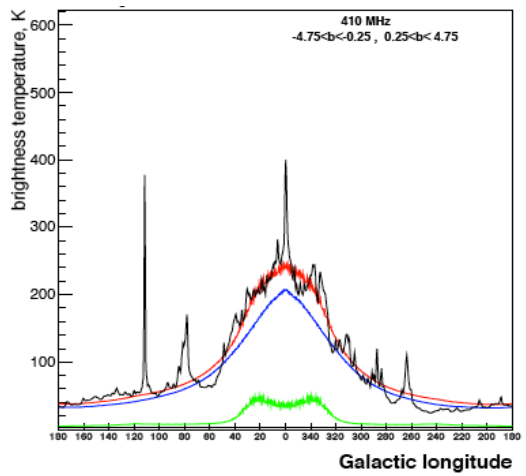




TOT
@ 408 MHz





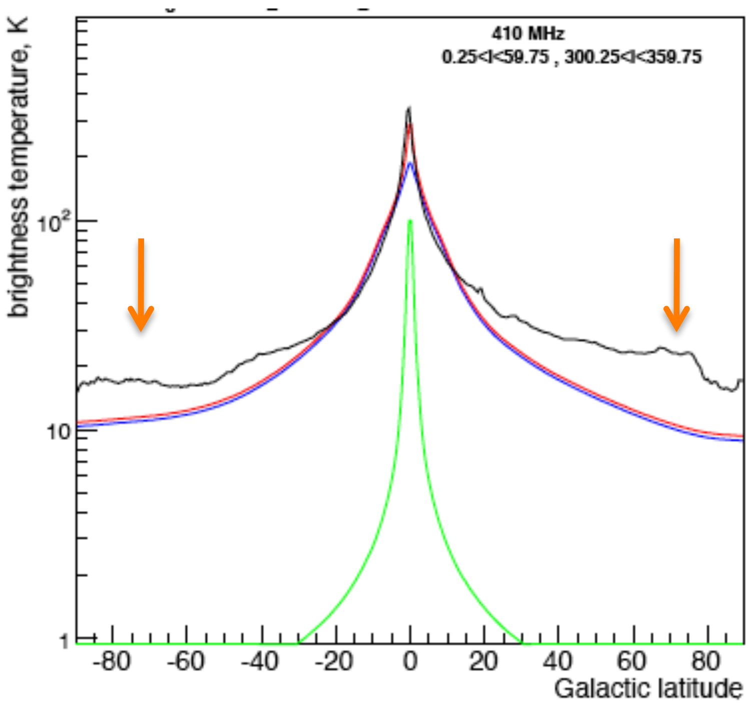


B-field 2-3 times higher than previous models !

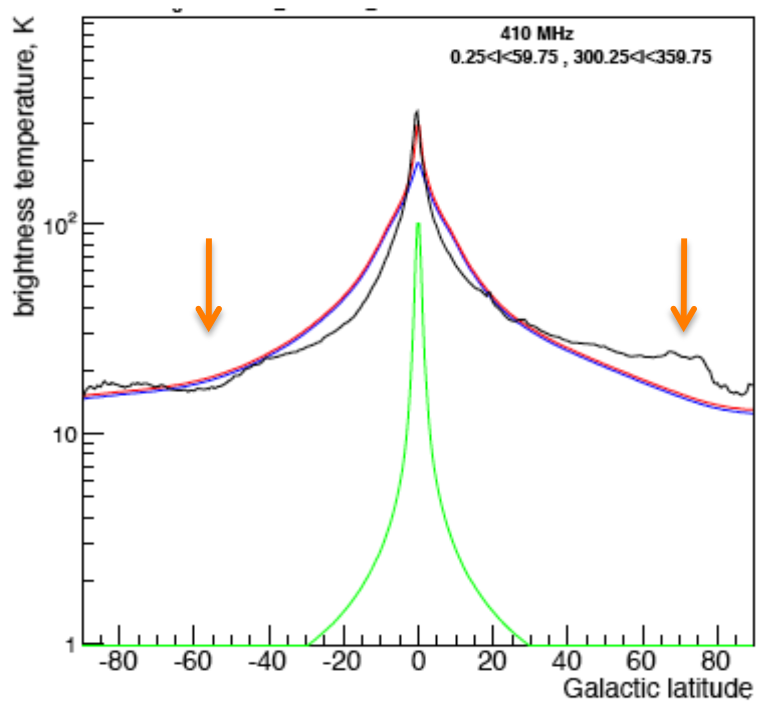
paper in prep

3. Sensitivity to halo size z

z = 4 kpc



z = 10 kpc

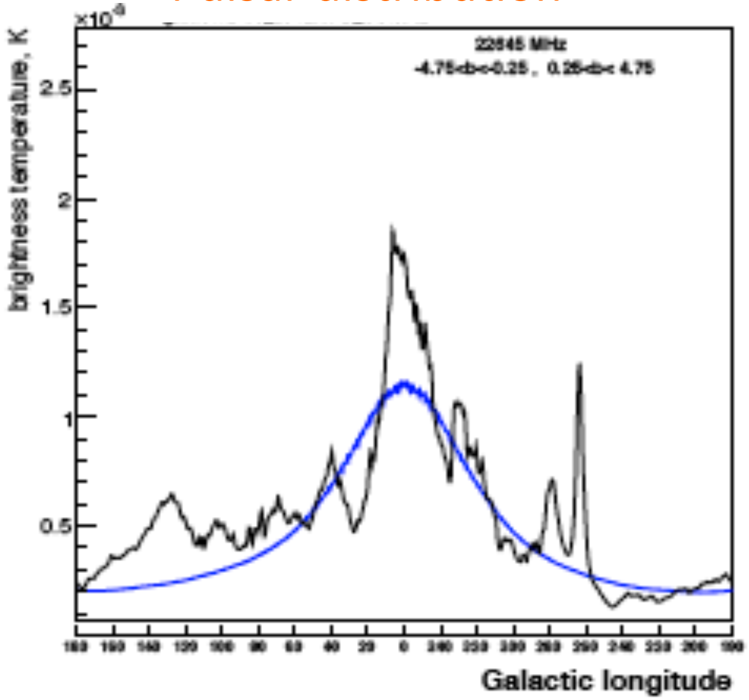


Larger halo size preferred !

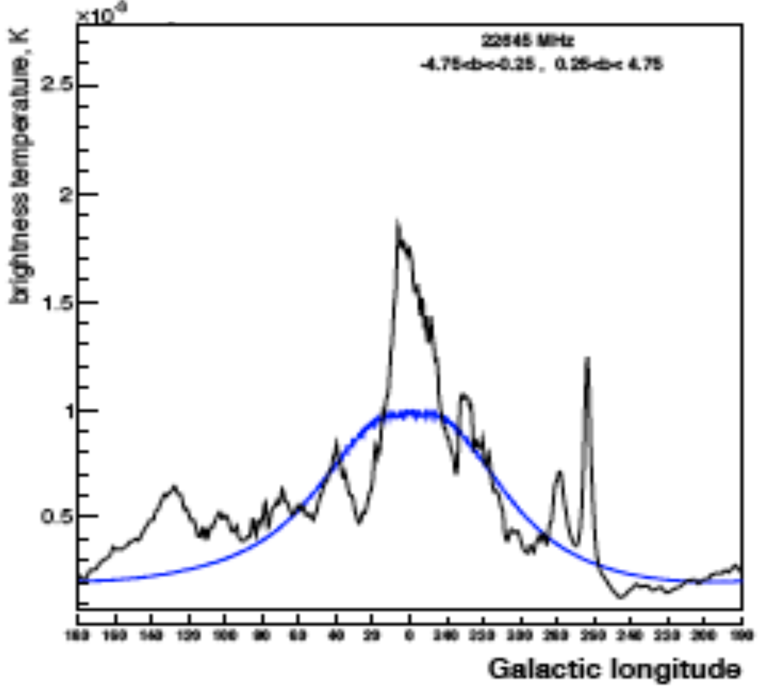
paper in prep

4. Sensitivity to CR source distribution

Pulsar distribution



SNR distribution



paper in prep

Conclusions

The physics of the diffuse emissions is well understood

Cosmic rays bring info on the interstellar medium

With a multi-wavelength approach we can put better constraints

Galactic foreground studies need a global approach consistent with different observations