Cosmic rays from multi-wavelength observations of the Galactic diffuse emission

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The multi-wavelength context

- CR Diffusion, Energy losses, reacceleration, secondaries
- GAS
- Bremsstrahlung
- Inverse Compton
- ISRF
- CMB
- Radio/Microwaves
- Gamma rays

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Our method

Extracting information on interstellar CRs, spectral indexes of the injected particles, and propagation parameters by looking simultaneously at the diffuse emission in

- radio
- microwave
- gamma rays

accounting for CR direct measurements and advanced modeling.
Diffuse modeling: 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

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

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

Fermi-LAT
(now with Pass 8) Talk by McEnery on Monday)

Planck

WMAP

Radio Surveys

Cosmic-ray measurements (talk by Derome on Tue
and many more this conference)
- AMS02, Pamela, Fermi, Voyager, etc
Diffuse emission

Relation: radio/microwaves – gamma rays

Fermi-LAT > 1 GeV
(Credits: NASA/DOE/Fermi LAT Coll. modified by Greiner et al ARAA 2015, 53-199)

Fermi-LAT 30 – 80 MeV
(Orlando et al 2014 Fermi symposium)

Dust optical depth at 353 GHz from Planck and IRAS surveys (Planck Coll. 2014 A&A 564, A45)

408 MHz (Haslam et al 1981)
Our results on CRs so far 1/2

From radio/microwaves (Strong, Orlando and Jaffe 2011 A&A, 534, 54*) : 
• CR electron spectrum: 
  - Break in interstellar and injection spectrum 
  - Standard reacceleration models are more challenging 

From both gamma rays (Ackerman et al.2012 ApJ 750, 3) and radio/microwaves (Orlando & Strong 2013 MNRAS 436, 2127**) independently: 
- Flat CR source distribution in the outer Galactic plan preferred 
- Halo height larger than 4 kpc preferred 
- Residual structures (e.g. Loop and spurs, Fermi Bubbles, WMAP and Planck haze)

* Strong, Orlando and Jaffe 2011 best model was used for 9 yr WMAP component separation (Bennet et al 2013 ApJS., 208,20 )
** Orlando & Strong 2013 best model was used for Planck component separation (Planck coll. 2015 arXiv1502.01588)
Our results on CRs so far 2/2

Fermi Bubbles and Loop I (Planck coll. 2015 arXiv: 1506.06660)

Planck polarization map

Updates: focussing here on the spectral study only

DATA

- Reprocessed 408 MHz map by Remazeilles et al. 2015 (better source subtraction)

- WMAP 7-year synchrotron maps $\rightarrow$ WMAP 9-year and Planck 4-year synchrotron maps

- Simultaneous comparison radio and gamma-ray observations

MODELING

- Low-energy Fermi CR electron measurements $\rightarrow$ PAMELA measurements
Cosmic-ray electron spectrum

Injection in interstellar medium
Energy-dependent Diffusion and energy losses

Injection in interstellar medium

Energy-dependent Diffusion and energy losses

Re-acceleration
Cosmic-ray electron spectrum

Injection in interstellar medium

Energy-dependent diffusion and energy losses

Solar modulation - measured

Re-acceleration
Electron LIS with no info from synchrotron

Example of diffusive re-acceleration models that works fine for other CR species and Fermi-LAT gamma-ray data.
Comparison with Fermi-LAT


For the inner Galaxy see also talks by Ando, Cirelli, Calore, etc this conference

Produced synchrotron emission

B-field intensity is fit to the 408 MHz map
Electron LIS with info from synchrotron

Example of plain diffusion propagation models

More details in Orlando, Strong, Moskalenko, Dickinson, Digel, Jaffe, Jóhannesson, Leahy et al. ICRC 2015; arXiv:1507.05958
Produced synchrotron emission

B-field intensity is fit to the 408 MHz map
Produced gamma-ray emission and comparison with Fermi-LAT

Good fit. Especially important at low energy (Pass 8 data), were the models have the biggest difference and the leptonic emission is at its maximum.
Conclusions

We found a propagation model that reproduces CR measurements, and spectral gamma rays and radio/microwave observations simultaneously.

Multi-messenger observations constrain the interstellar spectrum, propagation models, and solar modulation effects.

In turn this is a step forward improving models of the large scale diffuse emission and characterizing structures found at opposite wavelengths.

Important for forthcoming radio telescopes and MeV - GeV energy missions.

Thank you for your attention!