Cosmic rays

Synchrotron

from the Galaxy

Elena Orlando (Stanford University) – TAUP 2011, Munich
Cosmic-ray propagation in the Galaxy

INJECTION SPECTRA

Primary He ... Ni, p, e⁻

Diffusion, Energy losses, reacceleration, secondaries → PROPAGATED SPECTRA (steeper)

Propagated CRs

Secondary

We are here

B field

Synchrotron

Radio

ISRF, CMB

Inverse Compton

π⁰

Bremsstrahlung

γ

Solar modulation

Cosmic-ray propagation in the Galaxy
Overview: Modeling the diffuse emission with GALPROP

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

Dedicated website http://galprop.stanford.edu – webrun and references therein

Recipe:
- cosmic-ray spectra p, He, e-, e+ (including secondaries)
  (NB recently using Fermi-measured electrons)
- cosmic-ray source distribution follows SNR/pulsars
  - Interstellar radiation field
  - HI, CO surveys
- B/C etc for propagation parameters
  - Galactic magnetic field

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

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Review: Diffuse $\gamma$ rays with Fermi/LAT

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

On behalf of the Fermi collaboration
Abdo et al. PhRevLett.103.251101
Review: Diffuse $\gamma$ rays with Fermi/LAT

Gamma-ray emissivity distribution in outer Galaxy

Varying halo size

Varying CR source distribution

Models underpredict gamma rays in outer Galaxy!

Other possibilities:

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

Radio and microwaves parallel study can put more constraints!

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Synergy radio/gamma rays

- B field
- Interstellar radiation field, CMB, gas
- Synchrotron
- Gamma rays
- CR e+e-

PlanCK

PAMELA, FERMI, AMS, HEAT, HESS, ATIC, MAGIC

FERMI

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Synergy radio/gamma rays

Leptons (and not only) are better constrained by radio and microwaves!

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Leptons (and not only) are better constrained by radio and microwaves!

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Diffuse Synchrotron emission

• Synchrotron spectral Index $\rightarrow$ $e^-$ spectral index

• Synchrotron Intensity $\rightarrow$ B intensity and electron flux

• $e^-$ 0.5 – 20 GeV $\rightarrow$ 20 MHz – 100 GHz

TOGETHER WITH GAMMA RAYS PUTS CONSTRAINTS ON:

- Galactic magnetic fields
- CR electron spectrum (local and injected)
- Propagation models
- CR source distribution
- Halo size
- Free-free emission and absorption
- ... separation template for CMB studies, Dark Matter searches, anisotropies ...

(see talk by Taoso yesterday)


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Radio Ground-based Surveys: 22 MHz – 5 GHz
WMAP: 23 – 94 GHz  .... Planck: 30 – 800 GHz
1. Probing Galactic Magnetic fields

**REGULAR COMPONENTS:**

Disc field
(Sun et al. 2008)

Halo field
(Sun et al. 2010)

**RANDOM COMPONENT (from our work):**

Strong et al. A&A accepted
(arXiv:1108.4822)

\[ B(\mu G) = 7.5e^{-(R-R_0)/30kpc}e^{-|z|/3kpc} \]
2a. Probing Interstellar electron spectrum

Probe of interstellar spectrum before modulation

synchrotron

Radio surveys

WMAP

Probing of interstellar spectrum directly measured. Good determination of B field
Synchrotron spectral index measurements ...

\[ \beta = 2 + \frac{p-1}{2} \]  
(p = ambient e- spectrum)

\[ \beta \sim 3.0 \]  
\[ P \sim 3.0 \]

\[ \beta \sim 2.5 \]  
\[ p \sim 2.0 \]


... need of a break in interstellar e-
2b. Probing injection sp. Index

Pure Diffuse model (Strong et al. 2010 ApJ 722L 58) - High latitude

Injection spectral index < 4 GeV ~ 1.3

Injection spectral index above 4 GeV = 2.5

See also Lineros Rodriguez talk
3. Testing models of propagation

Reacceleration model (Strong et al. 2010 ApJ 722L 58)

Primaries

With only primaries reasonable fit

Secondaries


It poses a challenge for the future!

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What synchrotron tells up to now:

1. Break in ambient interstellar e⁻ spectrum from ~2 to ~3 @ few GeV
2. Injection spectrum < few GeV is 1.3–1.6 in pure diffusion models
4. Secondary e⁺ e⁻ important for – and constrained by – radio emission

Coming soon

1. Tests on B fields, both random and regular components using polarized and unpolarized WMAP data – producing galactic profiles
2. Constraints on the halo field
5. A polarized/unpolarized 3D MAP OF SYNCHROTRON EMISSION to be used as a template for foreground studies

Next steps

1. Spatially and spectrally constraining Galactic Cosmic rays and sources distribution.
2. Constrain models of propagation
3. Investigate all-sky anisotropies – local emissions