Synchrotron radiation, magnetic fields and cosmic rays

Elena Orlando (Stanford University) & Andy Strong (MPE Garching)
Synchrotron

Connection

Gamma rays

Cosmic rays

100 years of discovery

100 years of discovery

100 years of discovery
Cosmic-ray propagation in the Galaxy

Sources
Primary CRs

Synchrotron

Inverse Compton

Bremsstrahlung

Gamma

Radio microwave

Diffusion, Energy losses, reacceleration, secondaries

GAS

CMB

π^0

Inverse Compton

IRSF

Gamma

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Overview: 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

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
- Galactic magnetic field

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

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Review: Diffuse γ 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

See also talk by L.TIBALDO on Fermi-LAT
Synergy radio/gamma rays

See also talk by L. Tibaldo on Fermi-LAT

B field

Synchrotron

\( e^- e^+ \)

Gamma rays

GAS

CMB

ISRF

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

FERMI

PLANCK

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Synergy radio/gamma rays

Interstellar electrons and positrons are better constrained by radio than gamma rays!

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Synchrotron emission from the Galaxy

Primary CRs
INJECTION SPECTRA

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

Radio/ Microwaves

We are here

Solar modulation

B
Synchrotron emission from the Galaxy

- Synchrotron spectral Index $\rightarrow$ electron spectral index
- Synchrotron Intensity $\rightarrow$ B-field intensity and electron flux
- $e^{-} 0.5 - 20$ GeV $\rightarrow$ 20 MHz – 100 GHz

SYNCHROTRON PROBES:
- Galactic magnetic field
- CR electron spectrum (local and injected)
- CR source distribution
  - Galactic Halo size

IMPORTANT FOR:
- Separation template for CMB studies
- Gamma ray studies with Fermi/LAT (see also talk by L. Tibaldo this morning)
- Dark Matter searches
Synchrotron emission from the Galaxy

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- $e^{-} \ 0.5 - 20 \ GeV \rightarrow 20 \ MHz - 100 \ GHz$

SYNCHROTRON PROBES:

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

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Radio surveys & WMAP

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

(Using Cosmic rays and total synchrotron)

REGULAR COMPONENTS:

Disc field
(Sun et al. 2008)

Halo field
(Sun et al. 2010)

RANDOM COMPONENT (from our work):

\[ B(R,z) = 7.5 e^{-\frac{(R-R_0)}{30 \text{kpc}}} e^{-\frac{|z|}{3 \text{kpc}}} \mu G \]

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

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2a. Probing Interstellar electron spectrum

Probe of interstellar spectrum before modulation

Radio surveys

Synchrotron

WMAP

Probe of interstellar spectrum directly measured. Good determination of total B field

Abdo, et al. 2009; Ackermann et al. 2010
Synchrotron spectral index measurements …

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

\( \beta \approx 3.0 \)  \( \beta \approx 2.5 \)  \( P \approx 3.0 \)  \( p \approx 2.0 \)

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

… need of a break in interstellar electron spectrum independent of propagation models!

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2b. Probing electron injection spectrum


**ELECTRONS**

- NO BREAK
- But high solar modulation

**SYNC. SPECTRA**

- Injection spectral index < 4GeV ~1.3
- Synchrotron with GALPROP

**Strong, Orlando & Jaffe**

A&A 534, 54 (2011)

**WMAP**

Miville-Deschenes et al.

*Injection spectral index above break at 4 GeV = 2.5*
Synchrotron spectral index model (408MHz-23GHz)

Small variations but systematic, reality is more complicated but good start, since physical model of electron propagation.

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First attempt including all components

Synchrotron total
Radio surveys
Free-free
Synchrotron
Dust + Spinning dust

Also with absorption

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Now also synchrotron polarized

Preliminary result: regular B-field component few times higher than usually assumed

Paper in preparation!
In short

With our approach we can do detailed modeling of:

• Large scale Galactic synchrotron emission
• Both regular and random magnetic fields
• Synchrotron spectral index variations over the sky in Planck range

...and the key future goal is

Exploiting Planck, Fermi-LAT & cosmic rays data simultaneously