Signatures of a Local Cosmic Ray Source

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Outline of the talk

1. Introduction
   - GMF & calculation of CR trajectories
   - How smooth is the CR sea?

2. A recent nearby SN?
   - Antimatter fluxes
   - Breaks and violation of “universality”
   - Anisotropy: see talk on July, 9.

3. Conclusions
Our approach:

- CR above 0.1–1 TeV: neglect non-linear effects
  \[ \Rightarrow \text{use prescribed model for Galactic magnetic field} \]
- calculate trajectories \( \mathbf{x}(t) \) via \( \mathbf{F}_L = q \mathbf{v} \times \mathbf{B} \).
- turbulent field:
  - Kolmogorov spectrum motivated by AMS-02
  - \( L_{\text{max}} \) from LOFAR: \( L_{\text{max}} \sim 10 \text{ pc in disc} \)
  - determine magnitude of random \( B_{\text{rms}}(x) \) from grammage \( X(E) \)
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$⇒$ CRs escape too slowly
$⇒$ requires anisotropic diffusion
X-field in JF model:

- propagation along $X$ field eases CR escape
How smooth is the CR sea?

- contribution of a single source:

\[ I(E) \simeq \frac{c}{4\pi} \frac{Q(E)}{V(t)} \]

with

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- isotropic diffusion: at \( E_* = 10 \text{ TeV} \) and

\[ D_* \equiv D_\perp = D_\parallel = 5 \times 10^{29} \text{ cm}^2/\text{s} \]

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- anisotropic diffusion in JF model with \( \eta = 0.25 \) \( \Rightarrow D_{\parallel} \sim 5D_* \) and
  \( D_{\perp} \sim D_*/500 \)

  \( \Rightarrow \) volume is reduced by \( 500/\sqrt{5} \approx 200 \)

  \( \Rightarrow \) single source can dominate observed flux at 10 TeV
The $p, \bar{p}, e^+, e^-$ fluxes:

\[ E^{2.7}F(E) \text{ in GeV}^{1.7}/(m^2 \text{ s st}) \]

- protons/5500
- antiprotons
- positrons/2
- electrons/25
Signatures of a young, local single source:

- secondary $\bar{p}$ and $e^+$ flux have same shape as $p$
  - $\bar{p}$ diffuse as $p \Rightarrow$ leads to constant $\bar{p}/p$ ratio
  - $\bar{p}/p$ ratio fixed by source age $\Rightarrow$ $\bar{p}$ flux is predicted
  - $e^+$ flux is fixed, break should be consistent with age
  - relative ratio of $\bar{p}$ and $e^+$ depends only on their $Z$ factors: $R = F_{e^+}/F_{\bar{p}} \simeq 1.8$ for $\alpha = 2.6$
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[MK, Neronov, Semikoz '15]
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- 2-3 Myr SN explains anomalous $^{60}$Fe sediments [Ellis+ '96, ...]
- SNe connected to Local Bubble [Schulreich '17, ...]
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  \[Schulreich '17,\ldots\]
- what about other CR puzzles?
  - breaks? rigidity dependence?
- B/C consistent? Electrons?
- anisotropy
Local source: nuclei fluxes

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- relative **normalisation** of “local source” $F^{(1)}(R)$ and “average” $F^{(2)}(R)$ varies,

\[
F_A(R) = C_A^{(1)} F^{(1)}(R) + C_A^{(2)} F^{(2)}(R)
\]
Local source: nuclei fluxes

⇒ explains breaks and variation of rigidity spectra
Local source: Secondary nuclei and B/C

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Local source: Electrons

\[ E^{2.7} F(E) \text{ in GeV}^{1.7} (\text{m}^2 \text{s}^{-1} \text{st}) \]

AMS-02 average
3 Myr SN prim
3 Myr SN sec
sum

\[ F(E) \] in GeV

[MK, Neronov, Semikoz '17]
Conclusions

1. CRs propagate anisotropically

2. Single source:
   - plateau of $\delta$ points to dominance of single source in anisotropy
   - consistent explanation of secondaries: $\bar{p}$, $e^+$, B/C
   - breaks and variation in rigidity spectra of nuclei
   - $^{60}$Fe, Local Bubble