The turbulent galactic magnetic field

Correlation lengths from RM maps

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MESSAGE

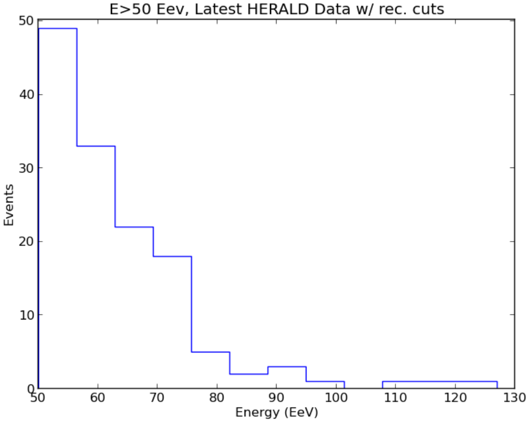
Ultimate science question: "what is the origin of high/ultra high energy cosmic rays?".

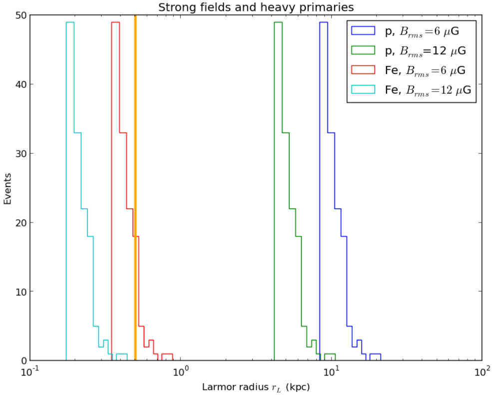
Perhaps the more important question is: "*if* high energy cosmic rays are accelerated astrophysically, *is it possible* to know where they came from?"

If one hopes to do cosmic ray astronomy or back track cosmic rays to their sources it is imperative to constrain the impact of the GMF.

Motivation

- Intermediate scale magnetic field parameters aren't well known
- Correlation length can have serious consequences for deflection
- Addresses the feasibility of cosmic ray astronomy


E>50 Eev, Latest HERALD Data w/ rec. cuts
Events
Energy (EeV)
0
10
20
30
40
50
60
70
80
90
100
110
120
130



$$r_L = \frac{E\ [\mathrm{EeV}]}{ZB\ [\mu\mathrm{G}]}\ \mathrm{kpc}$$

THE GALACTIC MAGNETIC FIELD (GMF)

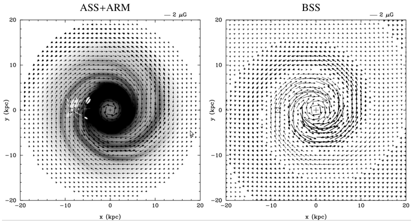
It's helpful to break up the GMF into three length scales/regimes.

- Large scale or coherent or regular field. $L > 1$ kpc.
- Intermediate scale field. $1 < L < 1000(?)$ pc.
- Small/very small scale field. $L \ll 1$ pc.

Regular GMF, $L > 1$ kpc

First point: field structure depends on galaxy morphology: i.e. disk like or elliptical?

Current wisdom is that MW is a barred spiral. Given this, the simplest models for fields in the disk are axisymmetric or bisymmetric or a combination, resulting from a dynamo.



Taken from Sun et al. A&A 477, 573. 2008

More sophisticated regular GMF models

The limit of our knowledge is underscored by the abundance of plausible models:

- Concentric circular ring (Rand and Kulkarni, 1989)
- Logarithmic spiral arms (Page et al., 2007)
- Bi-Toroidal or halo model (Sun et al., 2008, Prouza & Smida 2003)

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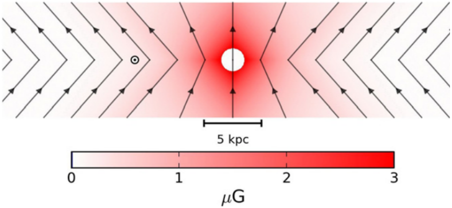
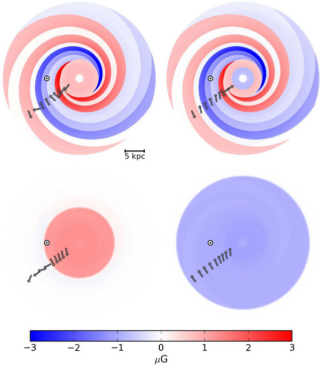
- JF12 model (Jannson & Farrar, 2012)



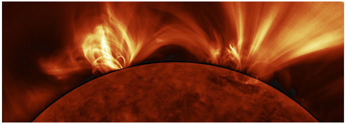


(Jannson & Farrar, 2012)

SOLAR SCALE FIELD, $L \ll 1$ PC

Turbulence of conducting material (plasmas/free e^-) is "well understood" on these scales: described by a power law consistent with Kolmogorov turbulence (Armstrong et al., 1995), although other indices also fit the data (Lomer et al. 2001 & Shisov et al. 2003).

- Stellar winds
- Protostellar jets
- SN shock fronts/ejecta

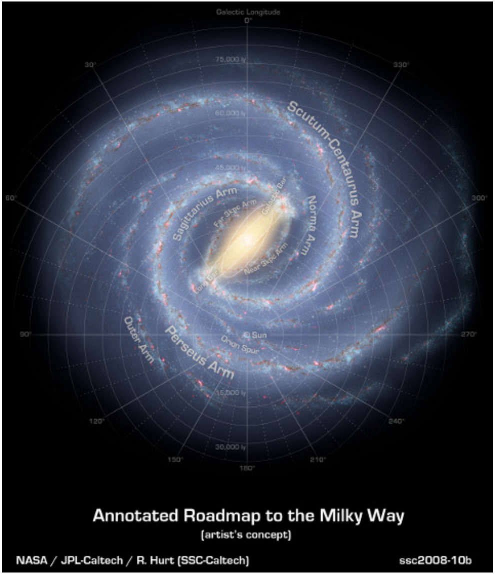


Interstellar scale field, $1 < L < 1000$ pc

This is an interesting length regime that demands more study. Not clear where the outer scale of turbulence is (80pc, 150pc, 300pc?).

Historical studies (e.g. Minter & Spangler, 1996) found 2-D turbulence between 4 and 80 pc with $\sqrt{< B^2 >} \sim 1\ \mu$G.

All these studies are based on sparse RM measurements for a particular direction in the galaxy.

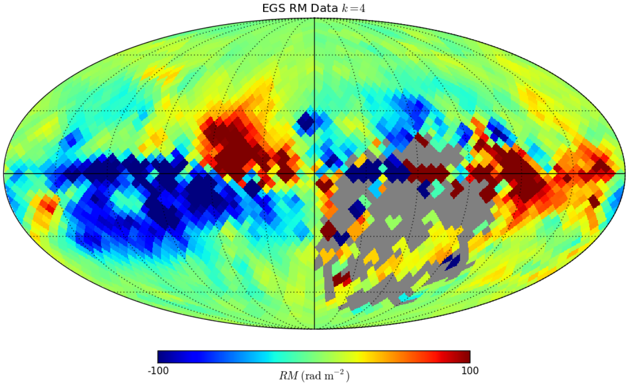

Galactic Longitude
0°
30°
330°
60°
300°
90°
270°
120°
240°
150°
210°
180°
75,000 ly
60,000 ly
45,000 ly
15,000 ly
30,000 ly
Scutum-Centaurus Arm
Sagittarius Arm
Norma Arm
Perseus Arm
Outer Arm
Sun
Orion Spur
Annotated Roadmap to the Milky Way
(artist's concept)
NASA / JPL-Caltech / R. Hurt (SSC-Caltech)
ssc2008-10b

Because cosmic ray sources are unknown, other observables must be used to study the GMF.

$$RM = 0.81 \int_{\text{here}}^{\text{there}} n_e \vec{B} \cdot \vec{dl} \qquad \text{rad m}^{-2}$$

n_e is a complex function, but one can use intricate and peer reviewed models.

Ronnie was kind enough to share his RM data, which will be very useful when we're confident in our methodology


EGS RM Data $k = 4$
-100
RM (rad m^{-2})
100

Goal is to somehow relate the angular features of the RM sky map to a physical length of the turbulent field "cell size" or correlation length.

Computational approach:

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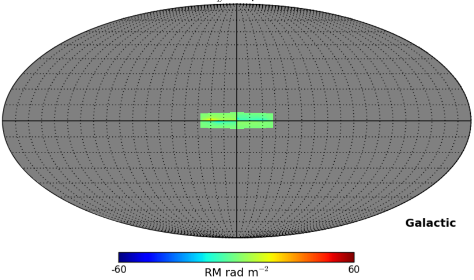
- Derive a connection between the power spectrum peak and the input parameters

Investigating different correlation lengths



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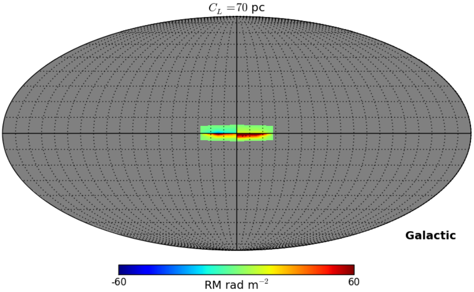

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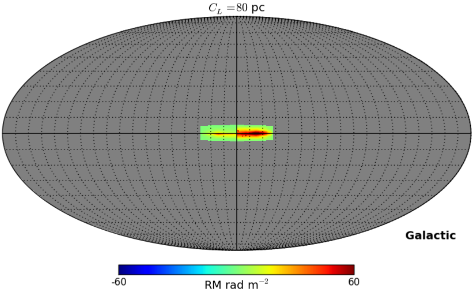

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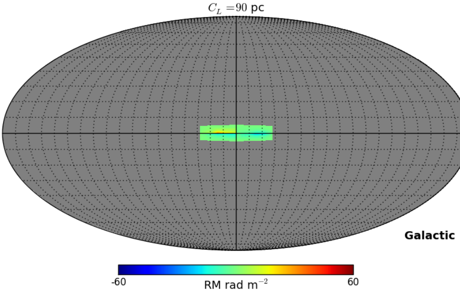

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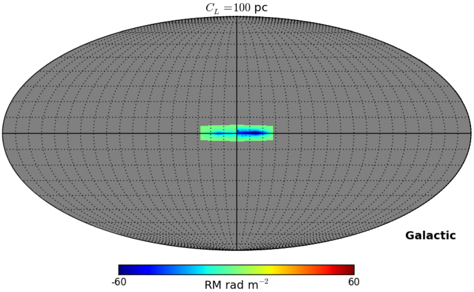

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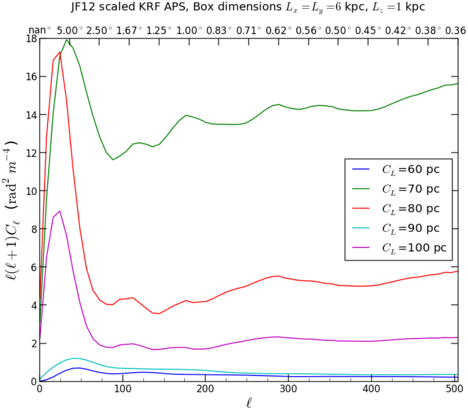
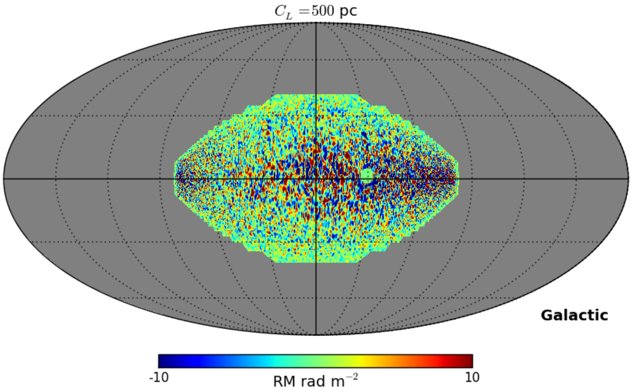


Current stage: determining the robustness of power spectrum peaks



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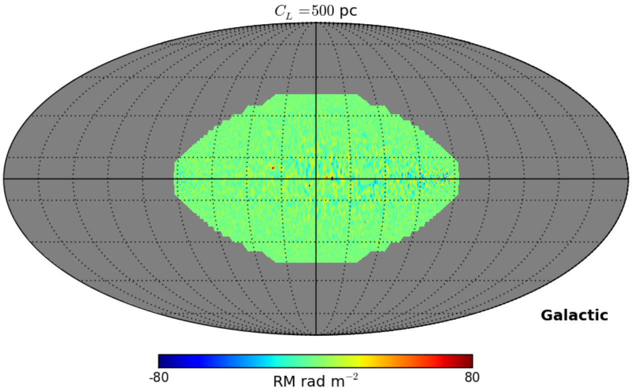

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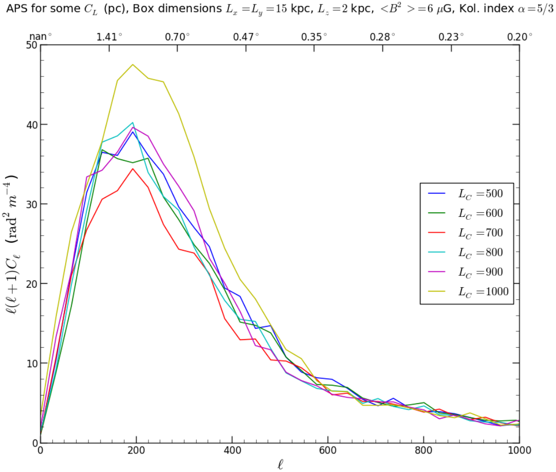

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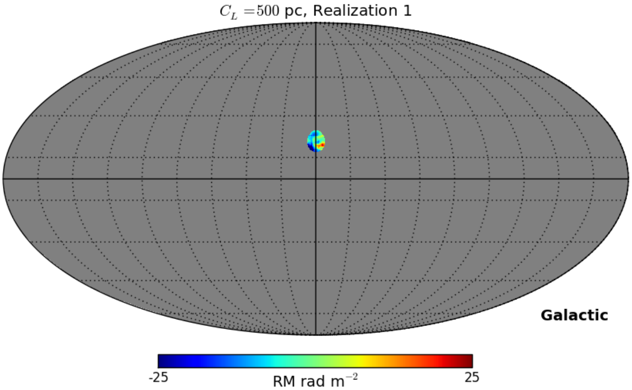

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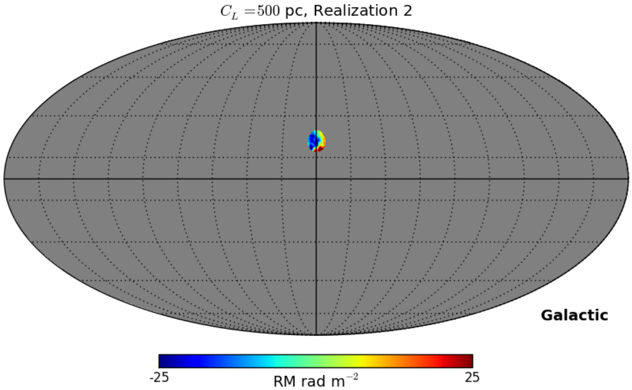

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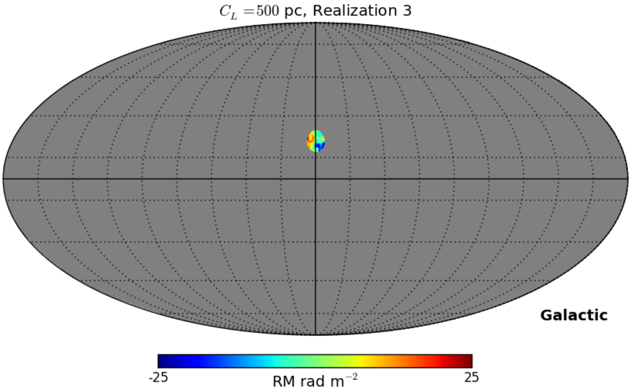

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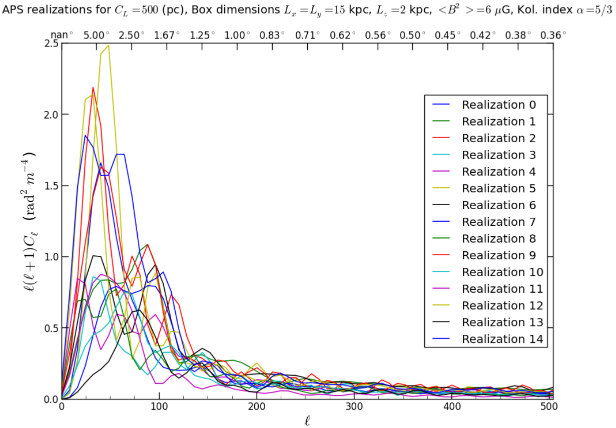
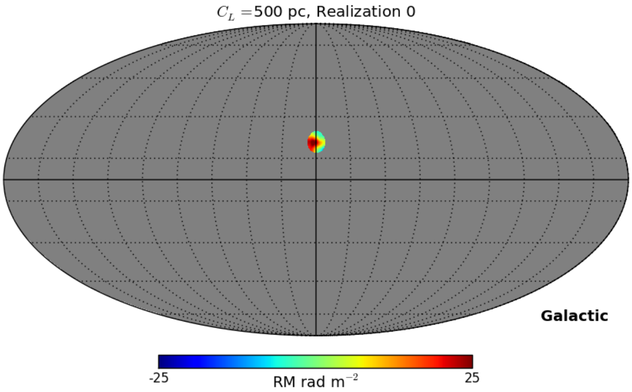


Investigating different integration lengths



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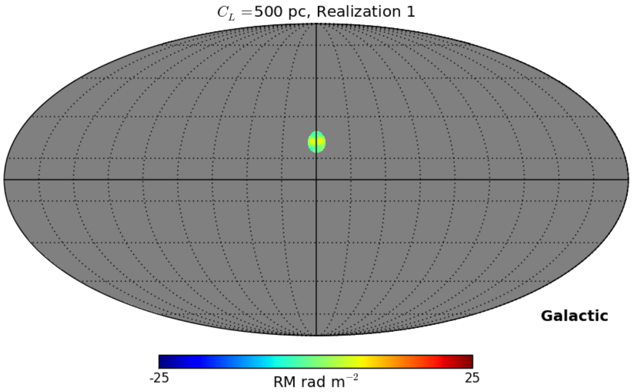

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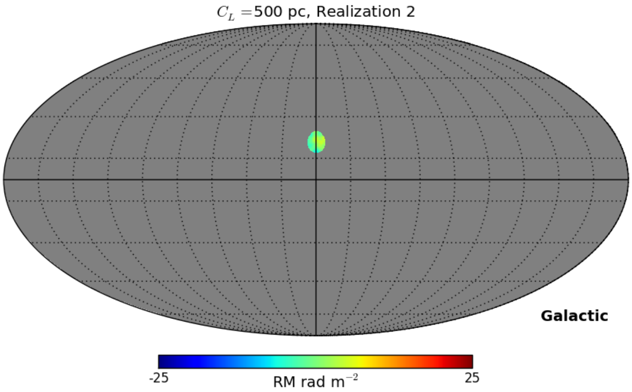

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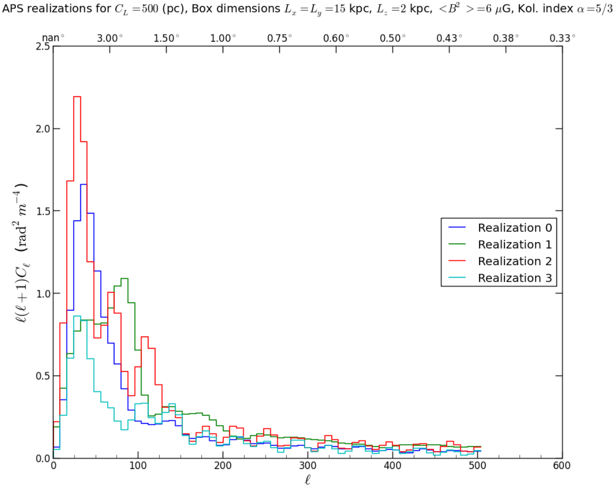

Preliminary results

- There is an obvious peak
- Not clear how this peak varies with C_L
- Situation is further complicated by seeming dependence on random field configuration
- Moreover, it seems the RM contribution from different line of sight integration lengths varies

Future work

- Compute 2pt function
- Compute structure function, compare inferred C_L to actual C_L
- Implement a JF12 scaled Kolmogorov random field using CRT (Sutherland et al., 2010), repeat analysis ☑
- Parametrize APS peak and relate it to C_L
- Get better computational resources to explore higher resolution field grids ($L \sim 8$ pc)

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Thanks for Michael Sutherland and Azadeh Keivani for providing a version of CRT that can produce KRF.

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