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New Models of the Coherent Galactic Magnetic Field

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We present a major revision of the widely used Jannson-Farrar 2012 model of the coherent magnetic field of the Galaxy. We fit to new full-sky data of extragalactic rotation measures and the final polarized intensity maps from WMAP and Planck. Our analysis employs the latest models for the thermal electron density tuned to the dispersion measures of Galactic pulsars and a suite of state-of-the-art cosmic-ray electrons models, needed to predict the rotation measures and synchrotron emission from the Galaxy, respectively. We have developed new divergence-free parametric models of the global structure of the magnetic field, with parameters tuned to the data. We will give a brief overview over the features of the new models and discuss the effect of our new suite of models on the deflection of ultrahigh-energy cosmic rays.

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1. Introduction

Spiral galaxies are known to be permeated by large-scale magnetic fields with energy densities comparable to the turbulent and thermal energy densities of the interstellar mediums, see e.g. Beck (2016) for a recent review. A good knowledge of the global structure of these fields is important to understand their origin, to infer their effect on galactic dynamics, to estimate the properties of diffuse motion of low-energy charged particles and to study the impact of magnetic deflections on the arrival directions of extragalactic ultrahigh-energy cosmic rays.

The determination of the large scale structure of the magnetic field of our Galaxy is particularly challenging since one must infer it from from the vantage point of Earth located inside the field. Previous attempts to model the Galactic magnetic field (GMF) are summarized by Jaffe (2019). In this paper we focus on the coherent magnetic field of the Galaxy, leaving study of its turbulent component to the near future. Following Jansson & Farrar (2012), we derive the GMF by fitting suitable parametric models of its structure to the two astrophysical data sets which are the most constraining of the coherent magnetic fields: the *rotation measures* (RMs) of extragalactic polarized radio sources and the *polarized intensity* (PI) of the synchrotron emission of cosmic-ray electrons in the Galaxy.

The interpretation of this data relies on knowledge of the three-dimensional density of thermal electrons and cosmic-ray electrons in the Galaxy. We will discuss these *auxiliary models* and introduce the details of the parametric models of the GMF investigated in Unger & Farrar (2023).

The combination of different data sets, auxiliary models and parametric functions yields an ensemble of GMF models that reflect the uncertainties and degeneracies inherent in the inference of the global field structure from the limited information provided by the RM and PI data. We have narrowed down these model variants to a few benchmark models that encompass the largest differences within the ensemble. Comparing the properties of these models, we address the question: What is known and not known about the coherent magnetic field of the Galaxy?

2. GMF Models and UHECR Deflections

Our ensemble models of the GMF can be summarized as follows

base: Our baseline model was tuned to the data using the YMW16 thermal electron model (Yao et al., 2017) and a cosmic-ray electron model generated with DRAGON (Evoli et al., 2008) for a diffusion volume with a half-height of 6 kpc. The parametric description of the GMF is composed of a the smooth spiral disk field introduced in Unger & Farrar (2019), a simple toroidal halo and an improved version of the 'model C' poloidal field of Ferrière & Terral (2014).

xr: The radial dependence of the magnetic field strength of the poloidal component of the baseline model is varied from a logistic to an exponential.

spur: Instead of a full grand magnetic spiral, the disk field includes only the local spur (Orion arm).

ne: Here we use the NE2001 thermal electron model of Cordes & Lazio (2002) instead of YMW16 to interpret RM.

twist: The 'twisted X-field' model introduced in Unger & Farrar (2019) is used to model the magnetic halo.

κ: An anti-correlation between the thermal electron density and the magnetic field pressure is introduced following Beck et al. (2003), resulting in a larger estimate of the magnetic field strength of the Galaxy.

cre: The half-height of the cosmic-ray electron halo is increased to 10 kpc.

syn: The polarized synchrotron emission inferred by the Cosmoglobe analysis (Watts et al., 2023) is used instead of the average of WMAP and Planck measurements.

The resulting deflection of ultrahigh-energy cosmic rays with a rigidity of 20 EV propagating through these different fields is shown in Fig. 1. For reference, the deflections with JF12 are shown at the top. As can be seen, although the models were derived under very different assumptions, they predict qualitatively similar deflection patterns. However, the over strength and the exact direction of the deflection depends on the model assumptions. Further discussion of these differences as well as a detailed description of the models can be found in Unger & Farrar (2023), the full reference will be available at the time of the conference.

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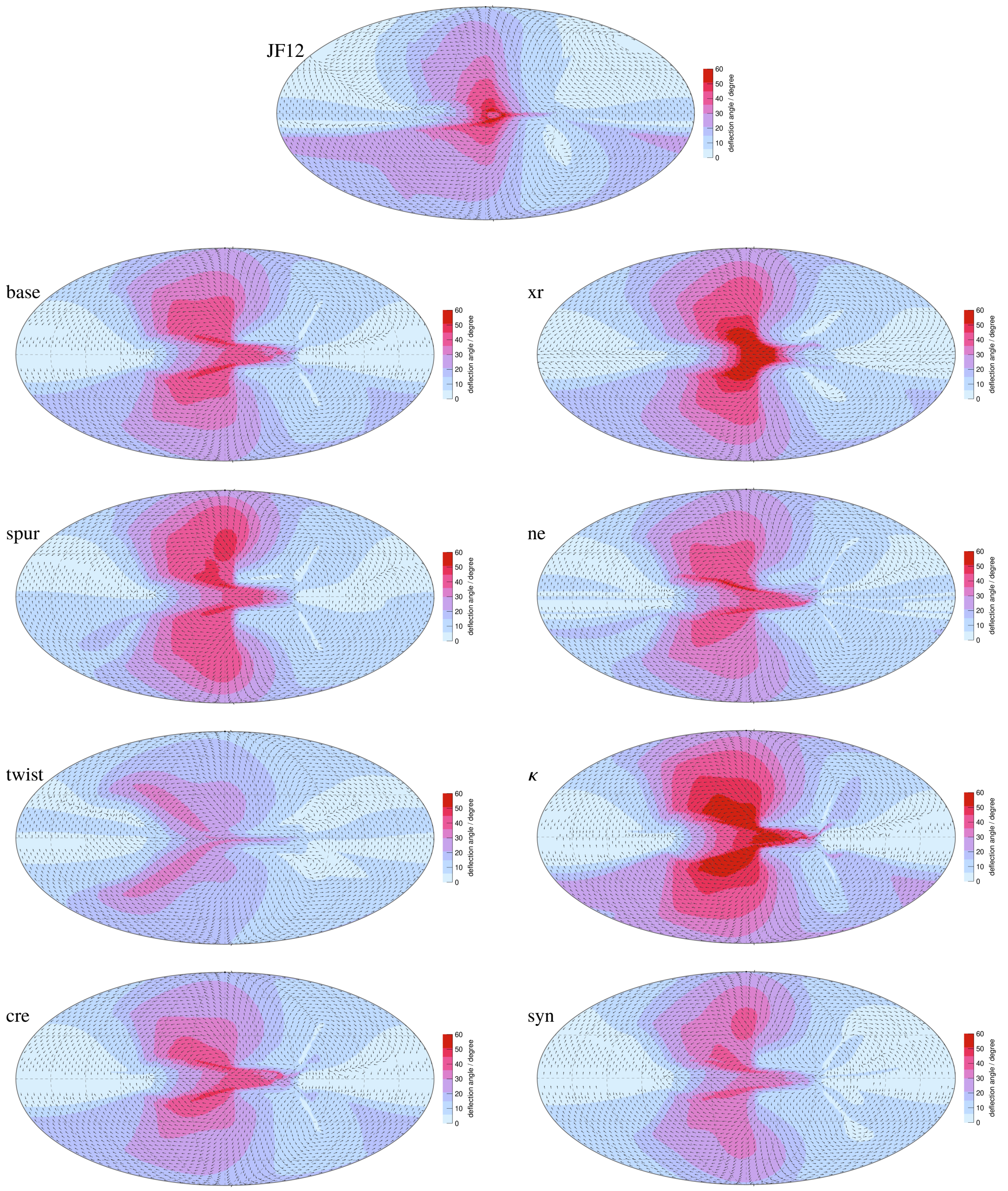

Figure 1: Angular deflections of ultrahigh-energy cosmic rays in JF12 model (top) and the eight model variations derived in this paper. Arrows and colors illustrate the size and direction of the deflection in the GMF following the particles from Earth to the edge of the Galaxy. Positions denote on the skymap denote arrival directions at Earth. The rigidity is 20 EV.