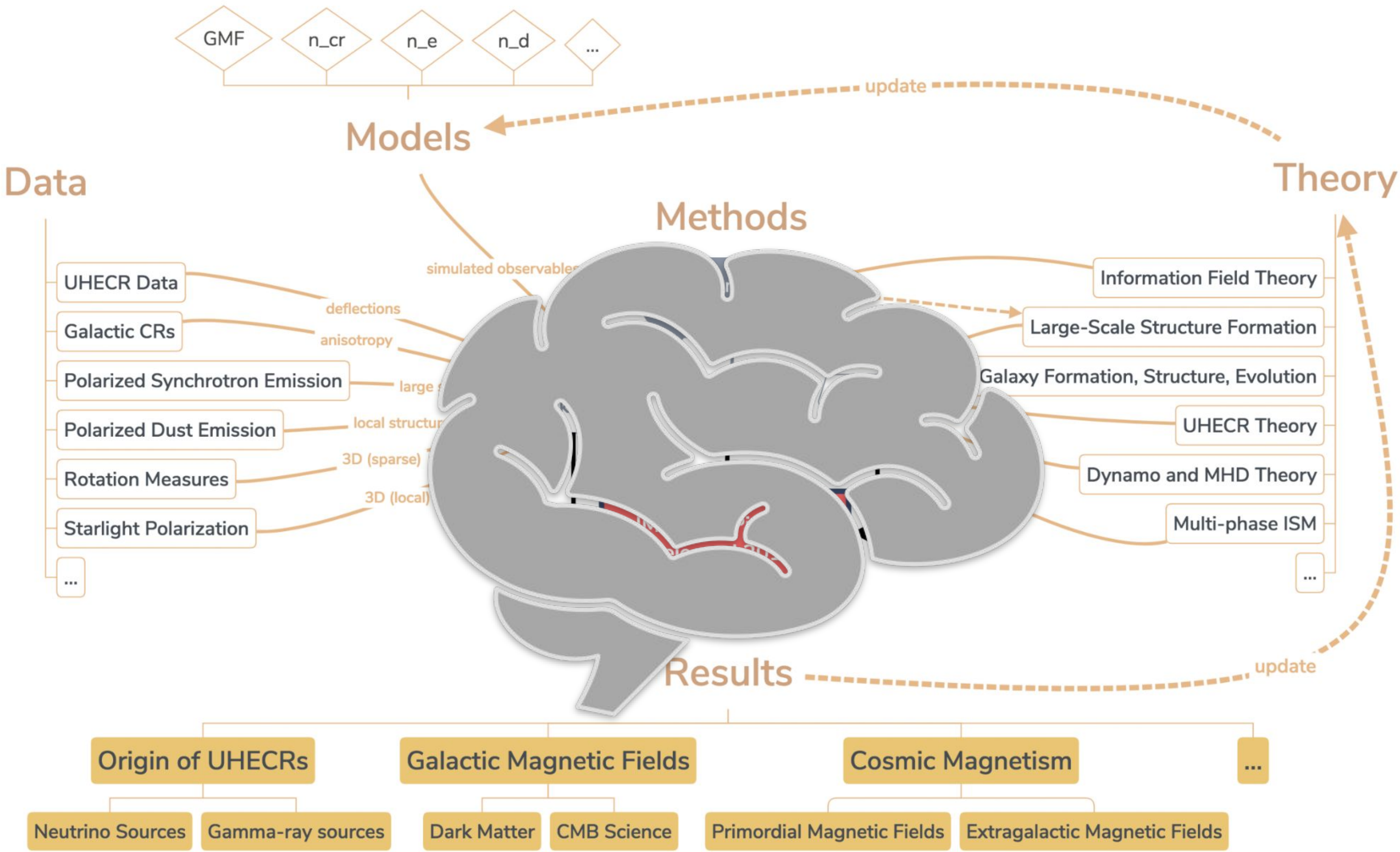
ICRC2021 Discussion session 01: Magnetic fields and CR propagation

Studying magnetic fields and the links to CR propagation looks roughly like this:



Session 01: Magnetic fields and CR propagation

Extragalactic

Arjen Rene van Vliet: Extragalactic magnetic fields and directional correlations of ultra-high-energy cosmic rays with local galaxies and neutrinos

Yutaka Ohira: Magnetic field generation by the first cosmic rays

Rafael Alves Batista: CRPropa 3.2: A framework for high-energy astroparticle propagation

Andrey Saveliev: Multimessenger Constraints on Intergalactic Magnetic Fields from Flaring Objects (**July 16 @ 18h)**

Alexander Korochkin: Sensitivity reach of gamma-ray measurements for cosmological magnetic fields

Lots of talks about UHECR anisotropies, cross-correlations, etc., all of which relate to the magnetic field. 1470, 233, 902, 1230, 1415,

Alex Kääpä: Transition from Galactic to extragalactic cosmic rays. PLENARY SESSION TOMORROW July 13

Galactic scale

Thomas Fitoussi: Faraday rotation constraints on large scale halo model

Ralf-Jürgen Dettmar: Magnetic field structure in halos of star-forming disk galaxies

Stefano Gabici: Giant cosmic ray halos around M31 and the Milky Way **(July 19th @ 18h)**

Elena Orlando: Interstellar cosmic-ray spectra (1) just outside the heliosphere and (2) in the local medium: are they the same? 19 July @ 18h

Ellis Owen: Empirical assessment of cosmic ray propagation in magnetised molecular cloud complexes, 15 July @ 12pm

Tess Jaffe: Constraining magnetic fields at Galactic scales. PLENARY SESSION TOMORROW July 13

Small-scales/Turbulence

Marco Kuhlen: Cosmic Ray Small-Scale Anisotropies in Slab Turbulence

Yoann Génolini: Local turbulence and the dipole anisotropy of galactic cosmic rays

Gwenael Giacinti: Simulations of the cosmic-ray anisotropy down to TeV energies

Ottavio Fornieri: Phenomenology of CR scattering on pre-existing MHD modes

[44] **Nicolò Pinciroli Vago**: On the Use of Convolutional Neural Networks for Turbulent Magnetic Field Helicity Classification

Observations

Theory

Other relevant discussion sessions

- 04 CR Energy Spectrum (14th @ 12pm)
- 06 CR Anisotropies (15th @ 12pm)
  - Chen Ding on interpreting Auger Dipole Anisotropy (affected by GMF)
  - Ryo Higuchi on Effects of GMF on UHECR anisotropies
  - Frank McNally on IceCube anistropies
  - Wei Gao on LHAASO observations of TeV to 100 PeV CRs.
  - Medha Chakraborty on CR anisotropies measured by GRAPES-3
  - (Giacinti, Génolini, Kuhlen cross listed)
- 14 CRs and the ISM (15th @ 12pm)
  - Ellis Owen on CR propagation in Molecular clouds
- 45 Probing the Distribution of CRs in Galaxies (19th @ 6pm)
  - Stefano Gabici on Giant cosmic ray halos around M31 and the Milky Way
  - Isabelle Grenier on Cosmic-ray variations in the solar neighbourhood
  - Elena Orlando on Interstellar cosmic-ray spectra (1) just outside the heliosphere and (2) in the local medium: are they the same?

Extragalactic: Yutaka Ohira

Magnetic field generation by the first cosmic rays

Standard model of magnetic field generation

- Inflation (Quantum fluctuation + New physics)
- QCD phase transition (Quark gluon plasma)
- Cosmic microwave phase (CMB fluctuation + e-)
- Astrophysical processes (Ionization front, Shock front,…)

Our new scenario

Strong collisionless shocks generate small scale magnetic field by the Weibel instability.

↓

The first CRs are accelerated by the shocks with the small scale magnetic fields at z ~20.

↓

The propagating first CRs generate large scale magnetic fields.

+

Amplification

MHD process

- Turbulent dynamo
- Galactic dynamo

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{V} \times \mathbf{B})$$

In our scenario, CRs are accelerated before the generation of large scale magnetic fields. Then, CRs generate large scale magnetic fields. (Ohira & Murase, PRD 2019) 1

Extragalactic: Rafael Alves Batista

CRPropa 3.2: a framework for high-energy astroparticle propagation

Rafael Alves Batista *for the* **CRPropa team**
Rabdoud University Nijmegen

What is this contribution about?

- CRPropa: public framework for the propagation of high-energy particles
- treatment of CRs, neutrinos, gamma rays, electrons
- 1D, 3D, and "4D" simulations possible

Why is it relevant?

- CRPropa enables a self-consistent interpretation of observations with **multiple messengers**
- **modular design** enables easy customisation for various applications in astroparticle physics
- treatment of interactions above TeV (for CRs) and GeV (for gamma rays)

What have we done?

- improved algorithm for Galactic CR propagation
- new Galactic magnetic field models
- targeting algorithm to speed up 3D/4D simulations
- native treatment of electromagnetic interactions
- new channels for photon production
- new interpolation methods

What is the result?

- advanced public code for multimessenger studies at high- and ultra-high energies

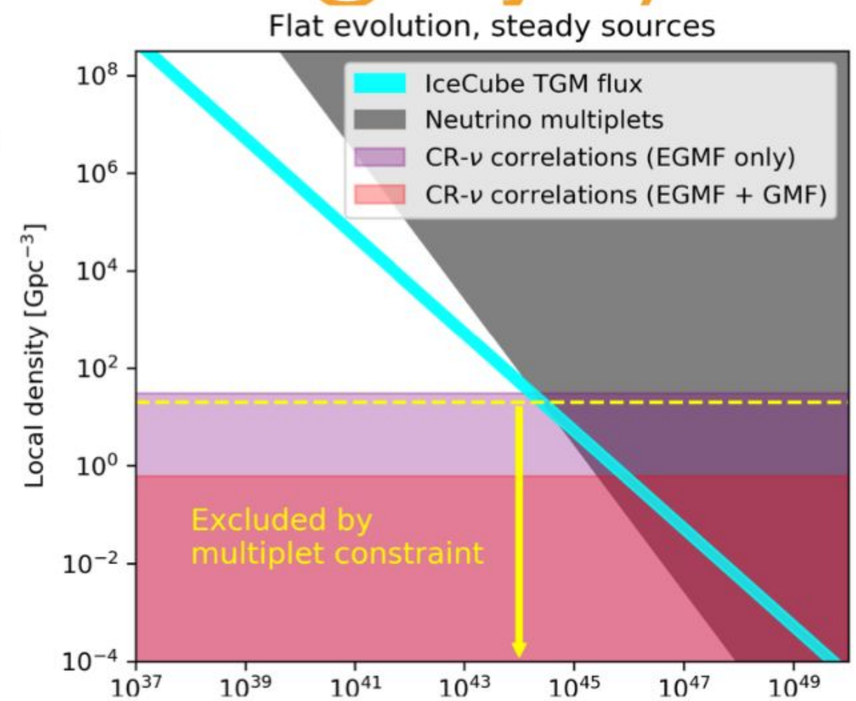
crpropa.desy.de

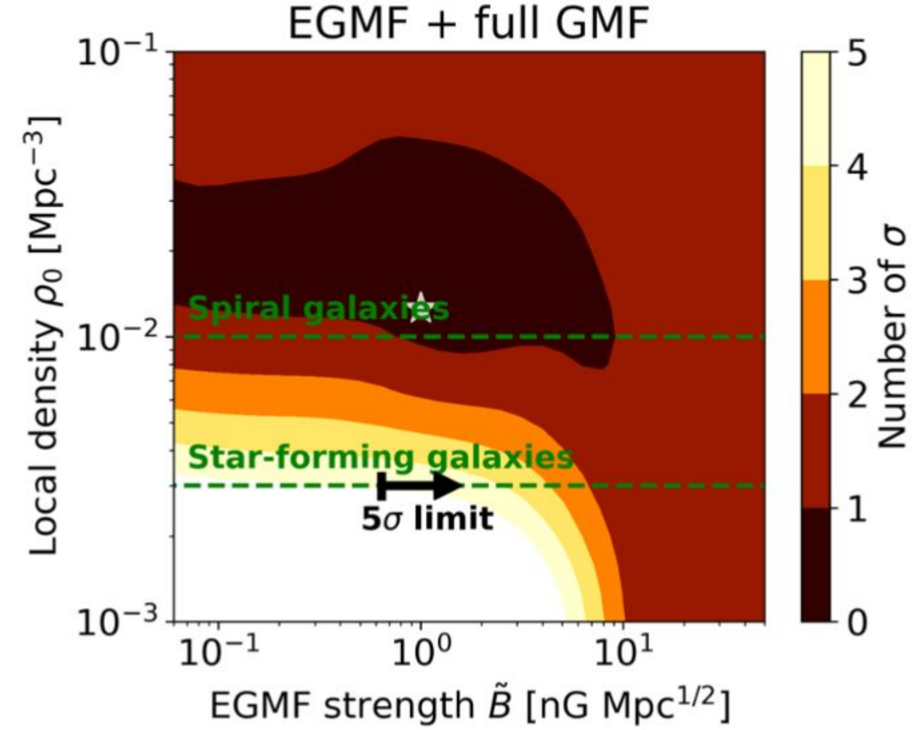
CR Propa

Extragalactic magnetic fields and directional correlations of UHECRs with local galaxies and neutrinos – Arjen van Vliet (arjen.van.vliet@desy.de)

A. Palladino, **AvV**, W. Winter and A. Franckowiak, MNRAS 494 (2020) 4255
AvV, A. Palladino, A. Taylor and W. Winter, arXiv:2104.05732, submitted to MNRAS

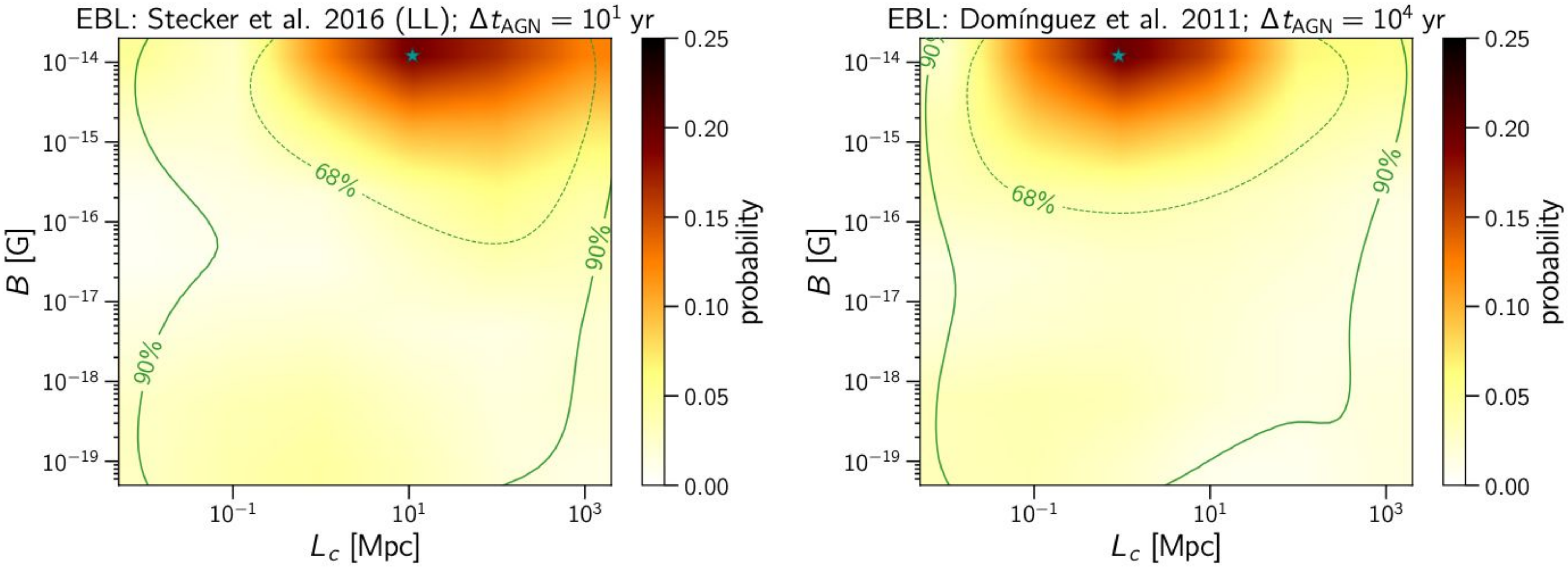
- We investigate the expectations for arrival-direction correlations between UHECRs on the one hand and neutrino arrival-directions or local star-forming galaxies on the other hand.
- We compare the expected UHECR and neutrino arrival directions with neutrino multiplet limits and the UHECR correlations with local star-forming galaxies found by the Pierre Auger Collaboration
- In this way, we determine the **likelihood of finding UHECR-neutrino correlations**, and obtain **lower limits on the local source density** and **lower limits on the strength of the local extragalactic magnetic field**.
- Taking into account:
  - the source density and evolution with redshift
  - UHECR deflections in EGMFs and the GMF
  - UHECR interactions with background photon fields
  - UHECR spectrum and composition measurements by the Pierre Auger Collaboration
- **Arrival-direction correlations between HE neutrinos and UHECRs are not expected**, even in the most optimal scenarios.
- **Arrival-direction correlations of UHECRs with star-forming galaxies suggest the presence of strong local extragalactic magnetic fields ($B > 0.64$ nG Mpc$^{1/2}$) or very numerous UHECR sources ($\rho_0 > 3 \times 10^{-3}$ Mpc^{-3}).**





Extragalactic: Andrey Saveliev

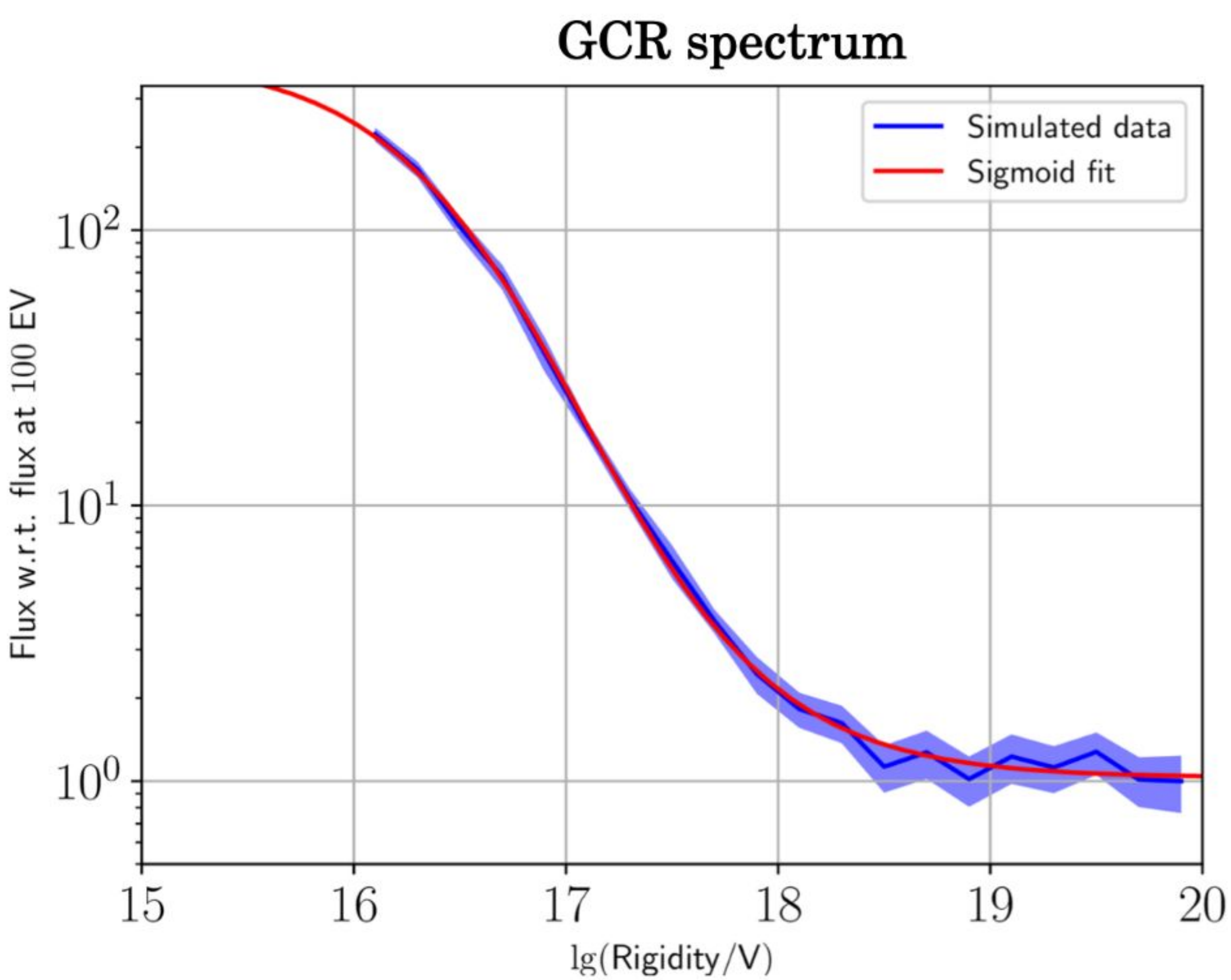
Limits on IGMF using Multimessengers



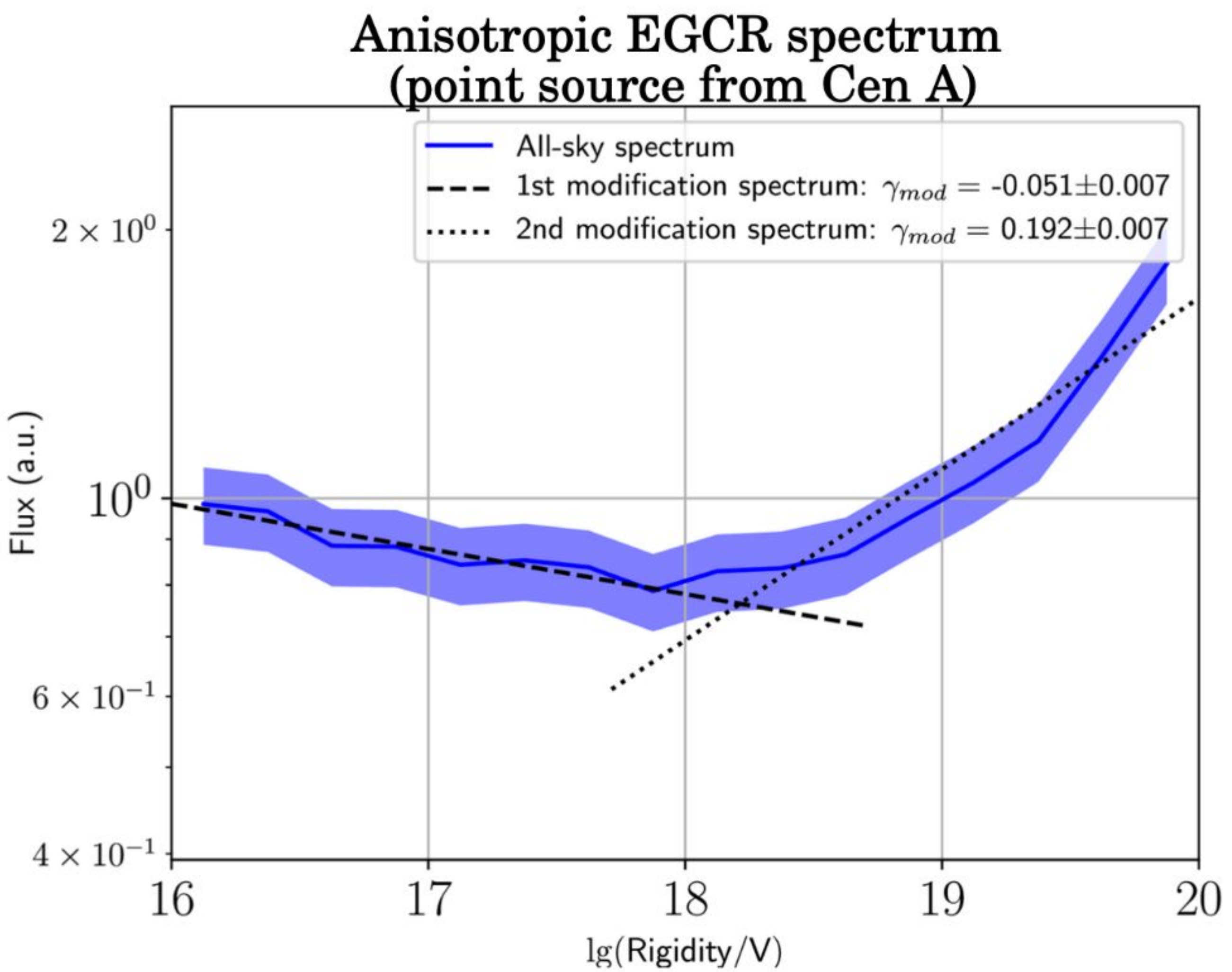
- For two of the EBL models we could reject the $B = 0$ hypothesis
- For these two models it is possible to constrain the magnetic field strength B *and* the correlation length L_c [Alves Batista and Saveliev, 2020]

Extragalactic->Galactic: Alex Kääpä

Transition from GCRs to EGCRs – Propagation in the GMF (Summary)



GCRs: decreasing confinement in Galactic plane (GP) → **flux reduction**



Isotropic EGCRs: shielding from GP counteracts confinement in GP → **flux conservation**

Anisotropic EGCRs: shifting position of magnetic transparency of Galaxy with rigidity → **flux modification**

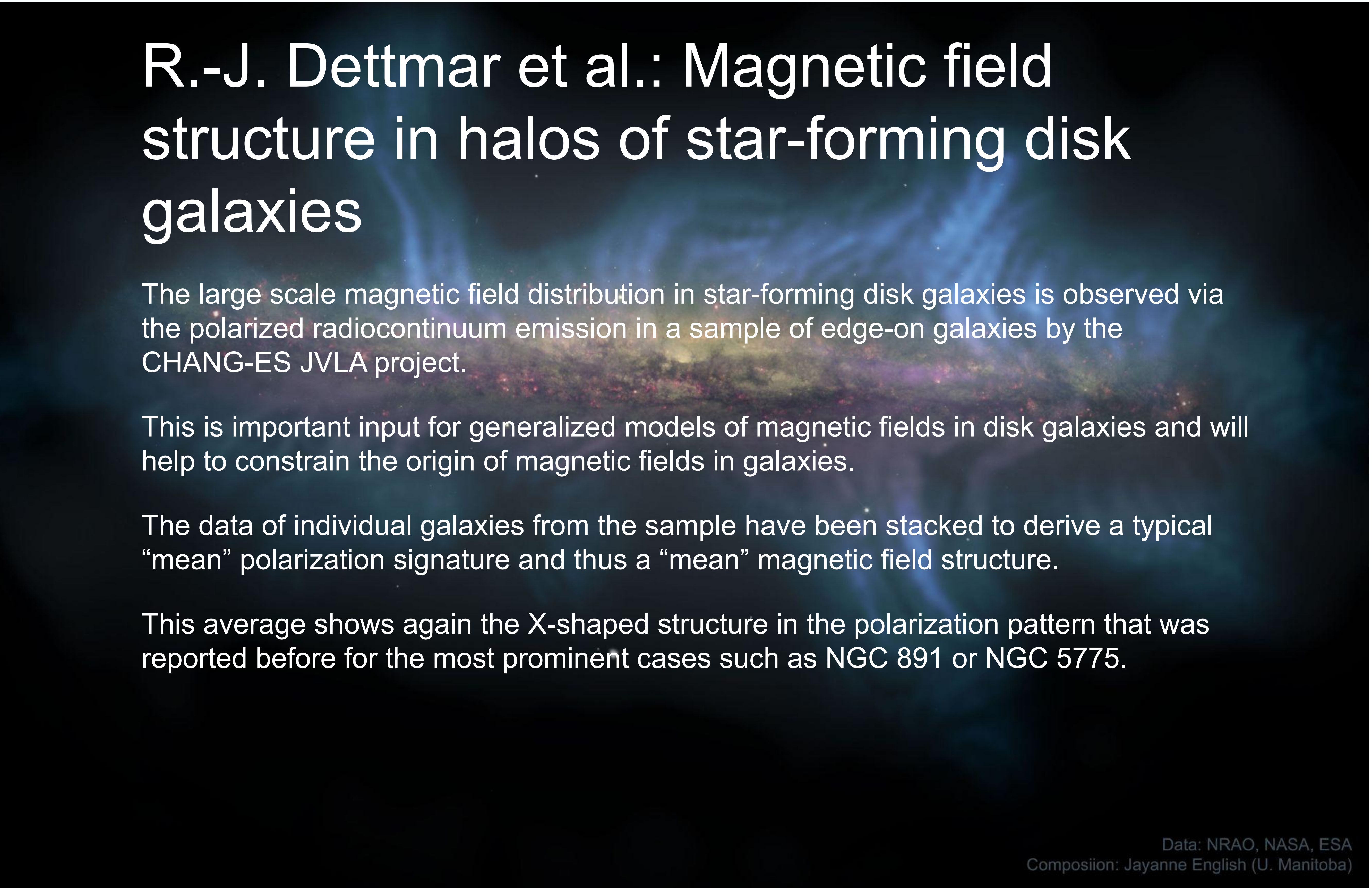
R.-J. Dettmar et al.: Magnetic field structure in halos of star-forming disk galaxies

The large scale magnetic field distribution in star-forming disk galaxies is observed via the polarized radiocontinuum emission in a sample of edge-on galaxies by the CHANG-ES JVLA project.

This is important input for generalized models of magnetic fields in disk galaxies and will help to constrain the origin of magnetic fields in galaxies.

The data of individual galaxies from the sample have been stacked to derive a typical “mean” polarization signature and thus a “mean” magnetic field structure.

This average shows again the X-shaped structure in the polarization pattern that was reported before for the most prominent cases such as NGC 891 or NGC 5775.

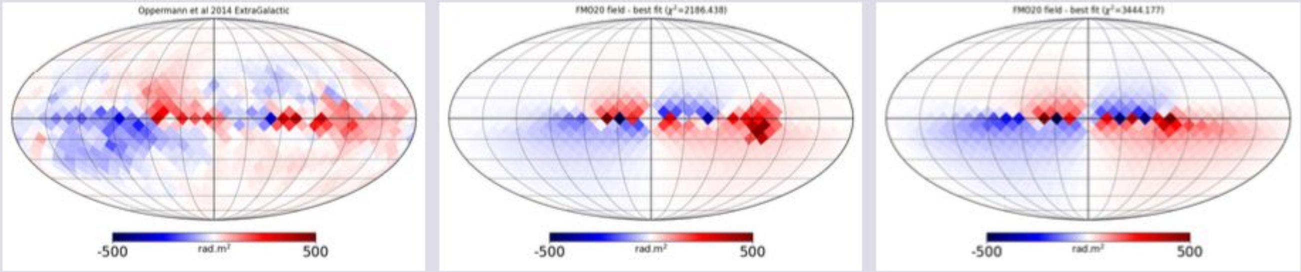


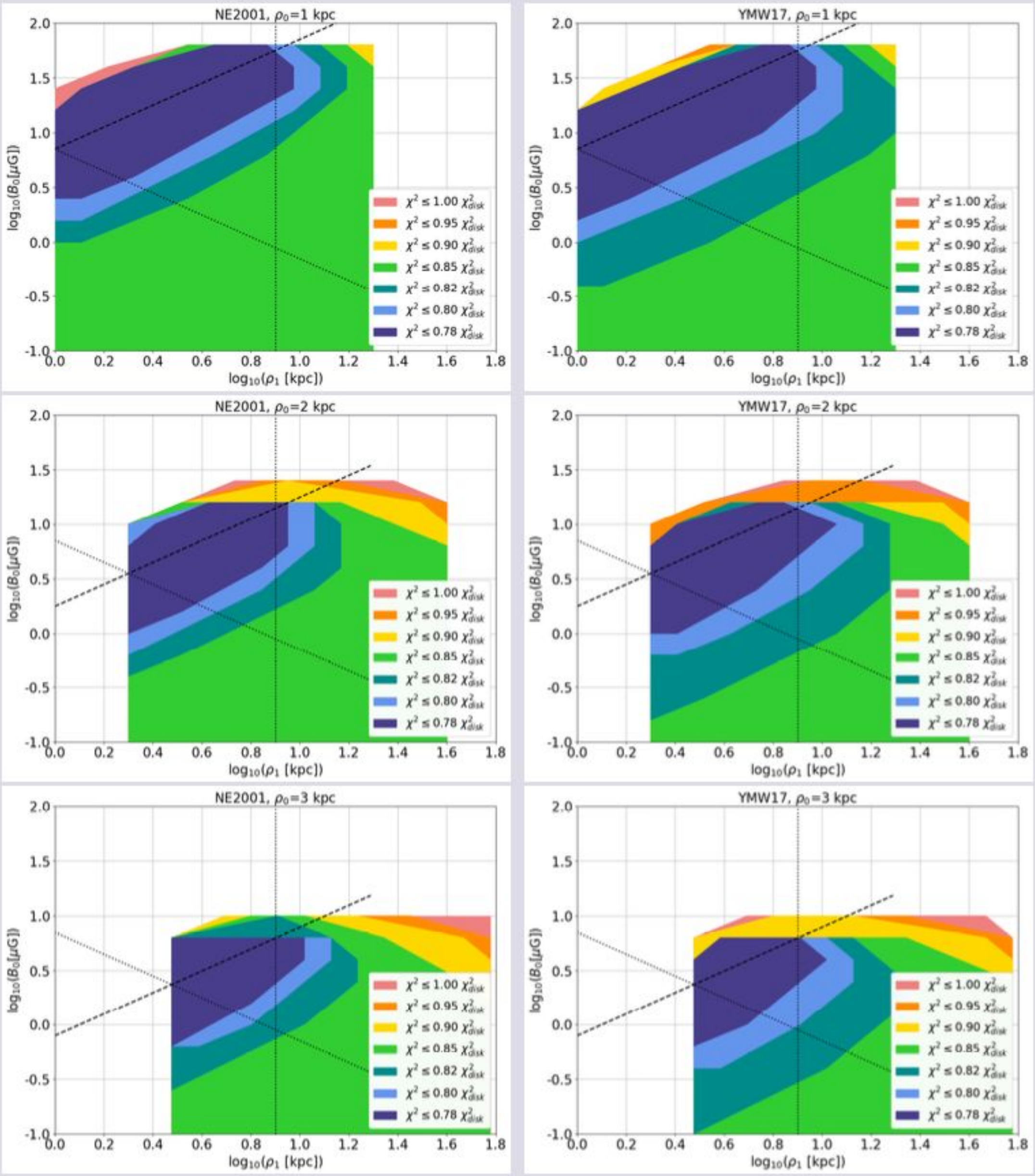
Data: NRAO, NASA, ESA
Composiion: Jayanne English (U. Manitoba)

Galactic scale: Thomas Fitoussi

Parameter	Values tested	best fits	
		NE2001	YMW17
χ^2 (χ^2_{red})		2186 (2.88)	3445 (4.53)
disk			
B_0^{D} [μG]	1.5	1.5	1.5
R_c [kpc]	5	5	5
d [kpc]	-1, 0, 1	-1	-1
p [deg.]	-6, -8, -10	-6 (-8)	-6
z_0 [kpc]	0.5, 1, 1.5	0.5	0.5 (1)
halo			
B_0^{H} [μG]	[0.1, 60] (log step 0.1)	10 (8 $\rightarrow$ 15)	10 (7 $\rightarrow$ 15)
ρ_0 [kpc]	[1, 5] (step 1)	1 (2)	1 (2)
ρ_1 [$\times\rho_0$]	[1, 20] (log step 0.1)	1 (1 $\rightarrow$ 5)	1 (1 $\rightarrow$ 5)

On the figure below are represented the Faraday rotation sky maps predicted by the best fitted models for both free electron density models (center and right). We can see that they reproduce well the main features visible on the Oppermann et al sky map (left).





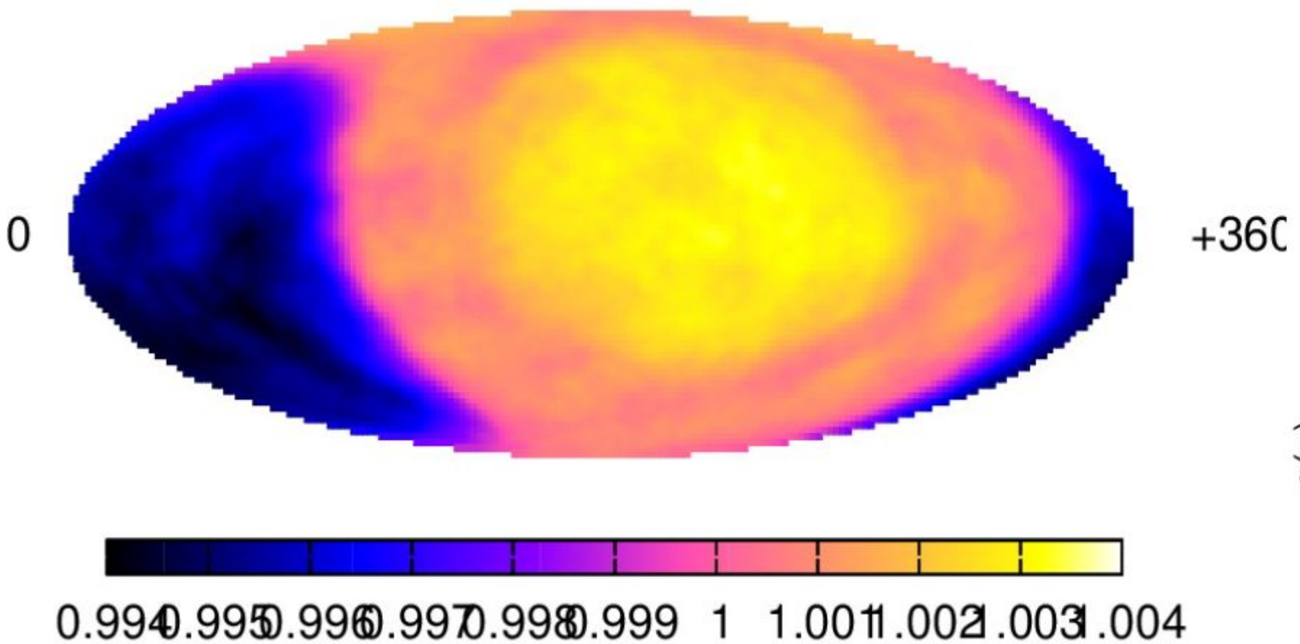
Small-scale/Turbulence: Gwenael Giacinti

Simulations down to 3 TeV

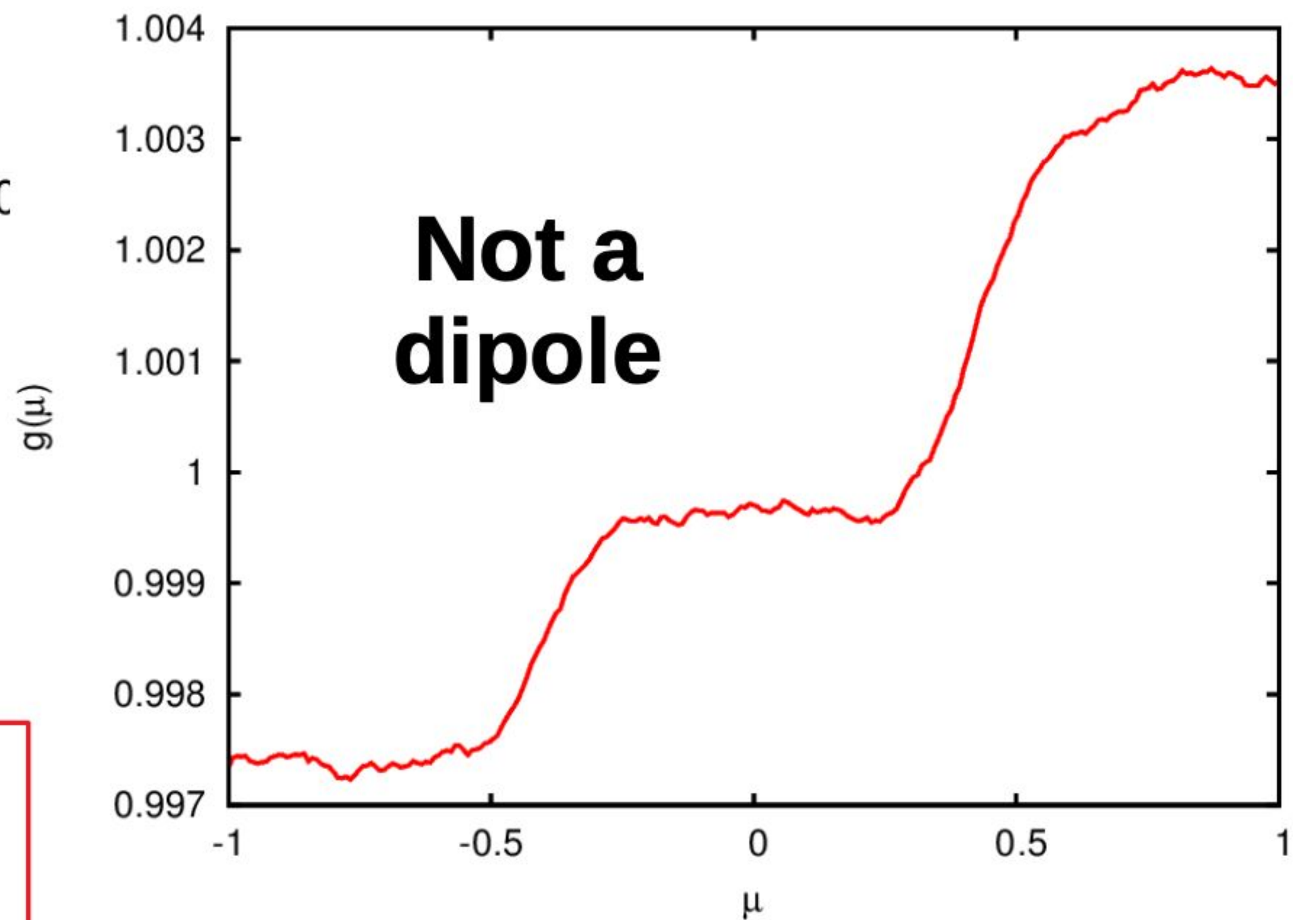
Giacinti & Reville, In prep. (2021)

First simulations that reach TeV energies with L_{max} = 150 pc

Kolmogorov, B_{rms} = 4 μG



Shape of the large-scale anisotropy:



→ LSA aligns with the direction of local magnetic field lines,

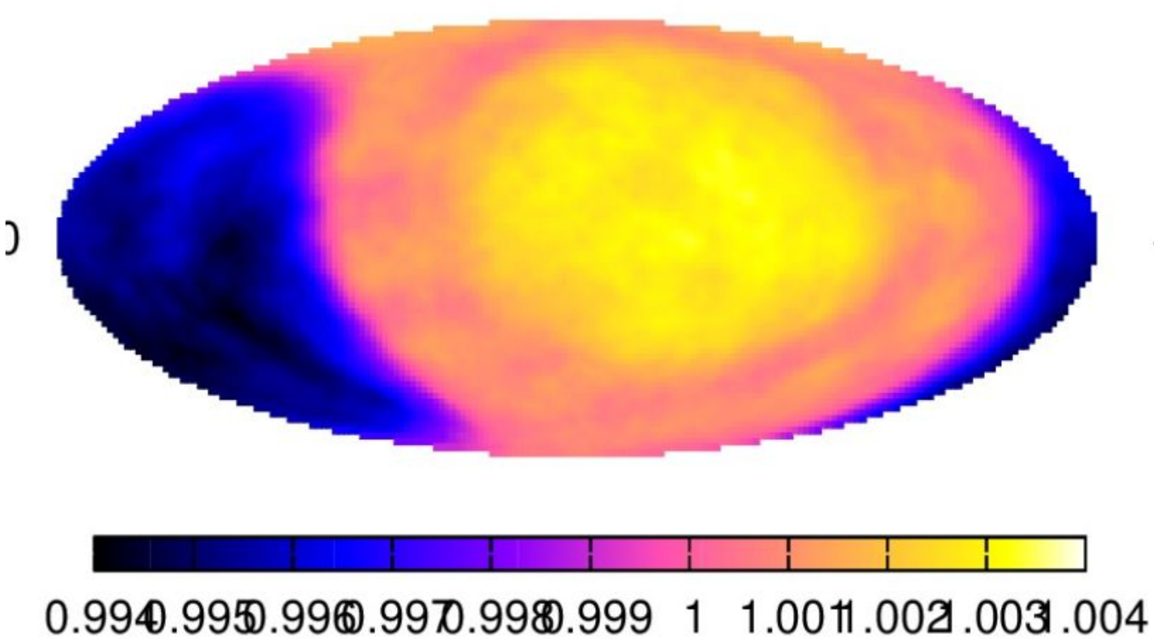
→ LSA **not a dipole.**

Simulations down to 3 TeV

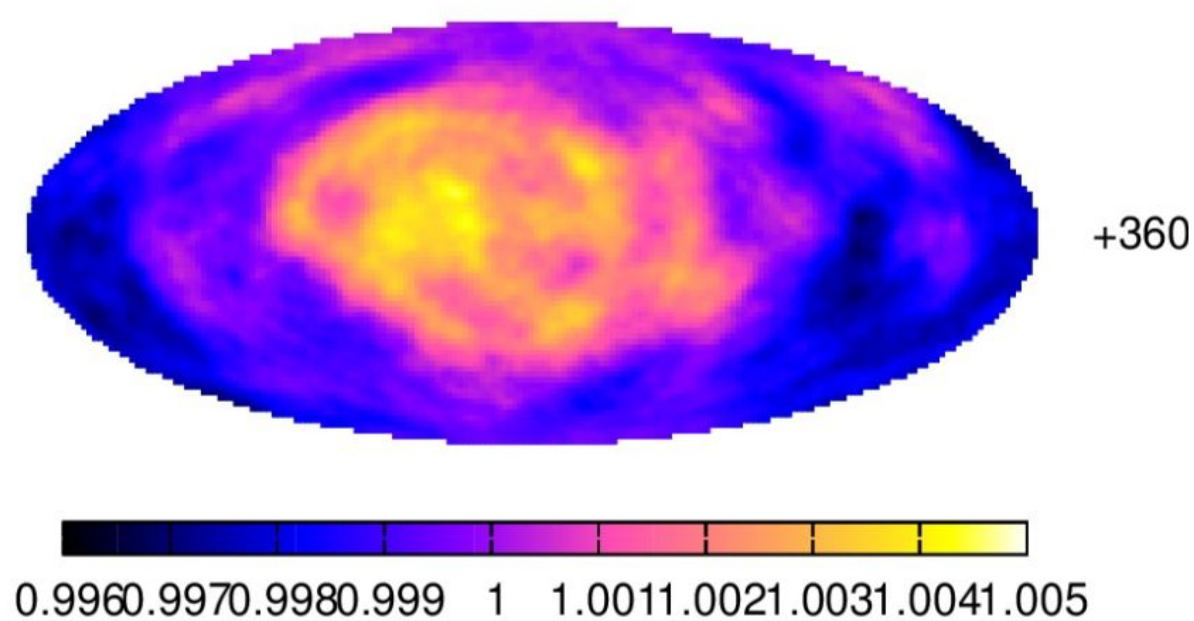
Giacinti & Reville, In prep. (2021)

First simulations that reach TeV energies with L_{max} = 150 pc

Observer 1 (Low δB/B):



Observer 2 (High δB/B):



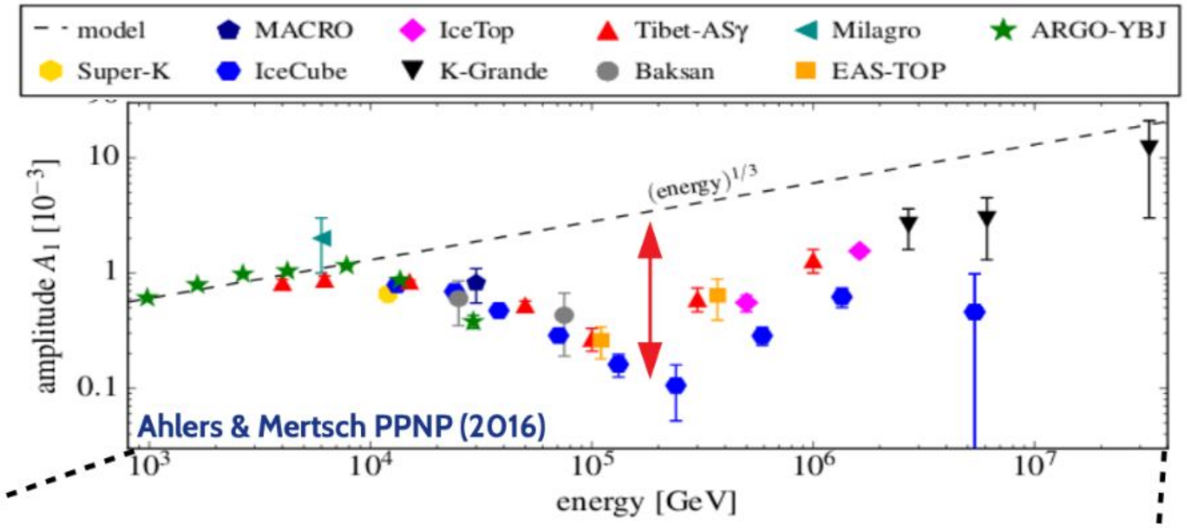
→ "Non-gyrotropic", smaller-scale anisotropies appear too,

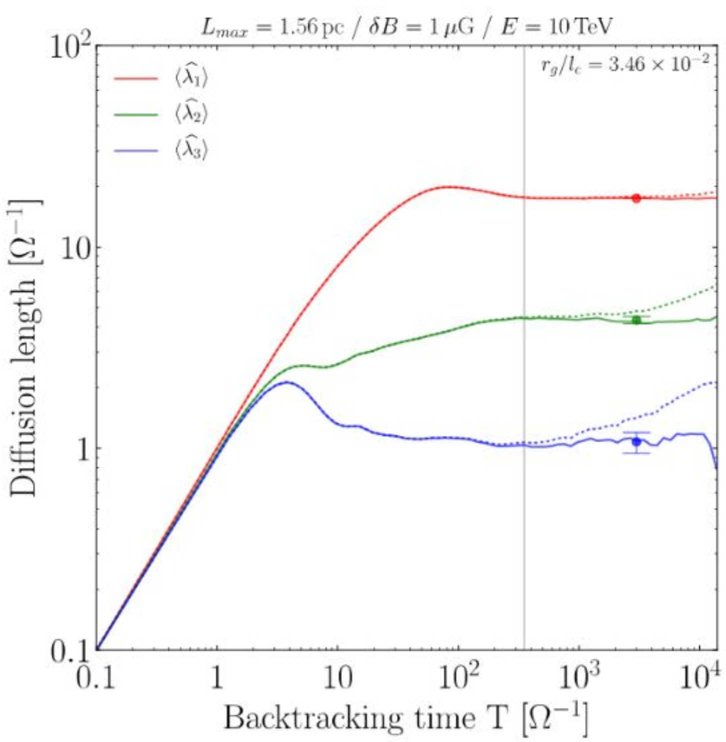
→ Ampl. SSA/LSA related to local δB/B on gyroresonant scales.

Origin of the dipole anisotropy ?

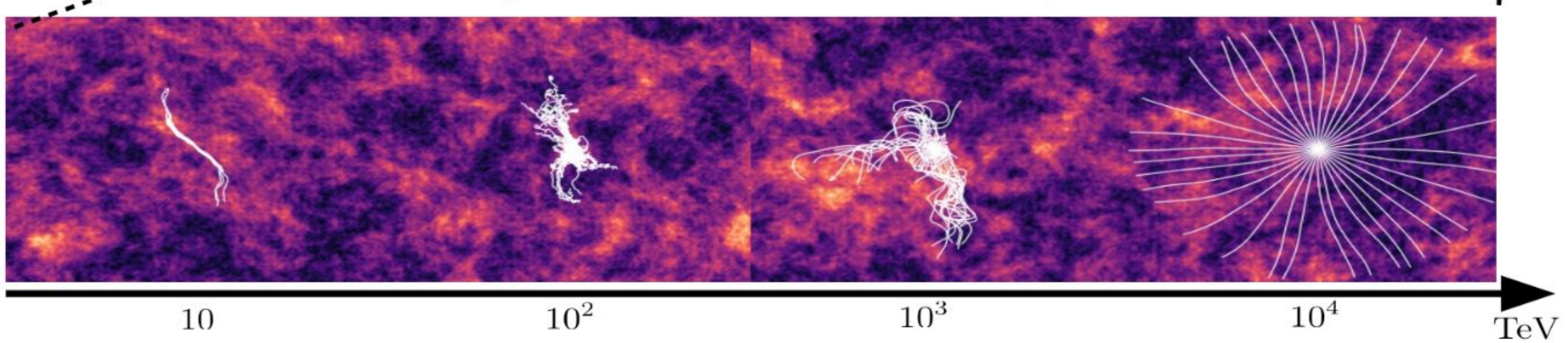
Local CR current: $\boldsymbol{j}_{\mathrm{CR}} = -\boldsymbol{K} \cdot \nabla\Psi$

→ Distribution of sources and halo geometry halo?
→ Structure of local magnetic field?





→ Test-particle simulations in **isotropic 3D turbulence**

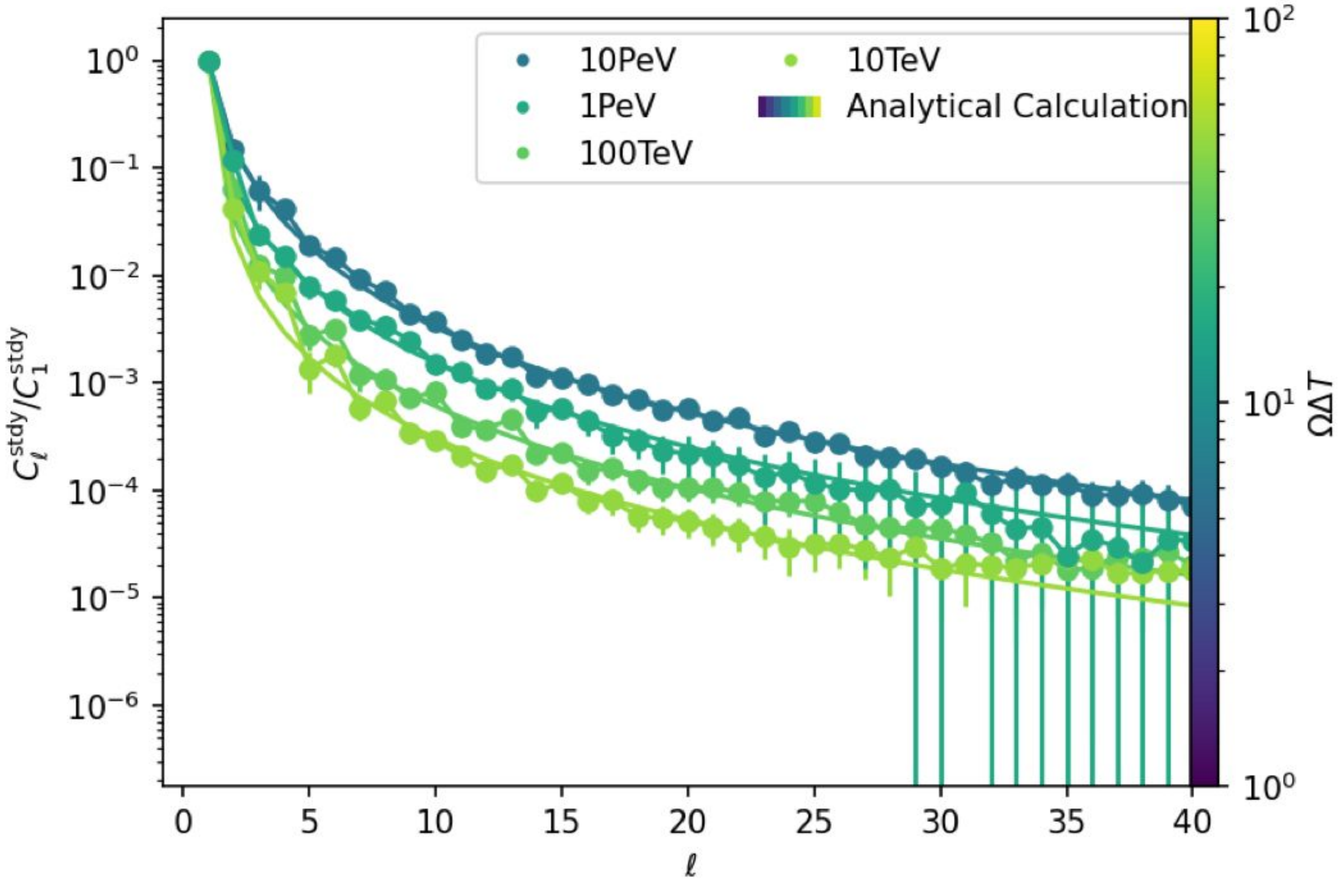


$$K_{local} = \begin{bmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{bmatrix} \longrightarrow \begin{bmatrix} \lambda & 0 & 0 \\ 0 & \lambda & 0 \\ 0 & 0 & \lambda \end{bmatrix}$$

Y.G. et Ahlers (to appear)

1- Anisotropic local diffusion tensor
2- Energy dependence of the anisotropy

Small Scale Anisotropies in Slab Turbulence



- Magnetic field turbulence leads to small scale anisotropies.
- Small scale anisotropies contain information on the turbulent magnetic field.
- We predict the angular power spectrum both analytically and numerically.

⇒ The numerical and analytical results agree well. The next step is the application to observational data.

Phenomenology of CR-scattering on pre-existing MHD modes

Our result for $D(E)$

Inefficiency of the Alfvén modes