The Very Best Limit on Cosmological Magnetic Fields

How Rotation Measures teach us everything about extra-Galactic Magnetic Fields

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STARS2017 / SMFNS2017
Havana/Varadero, Cuba

May 11th, 2017

So

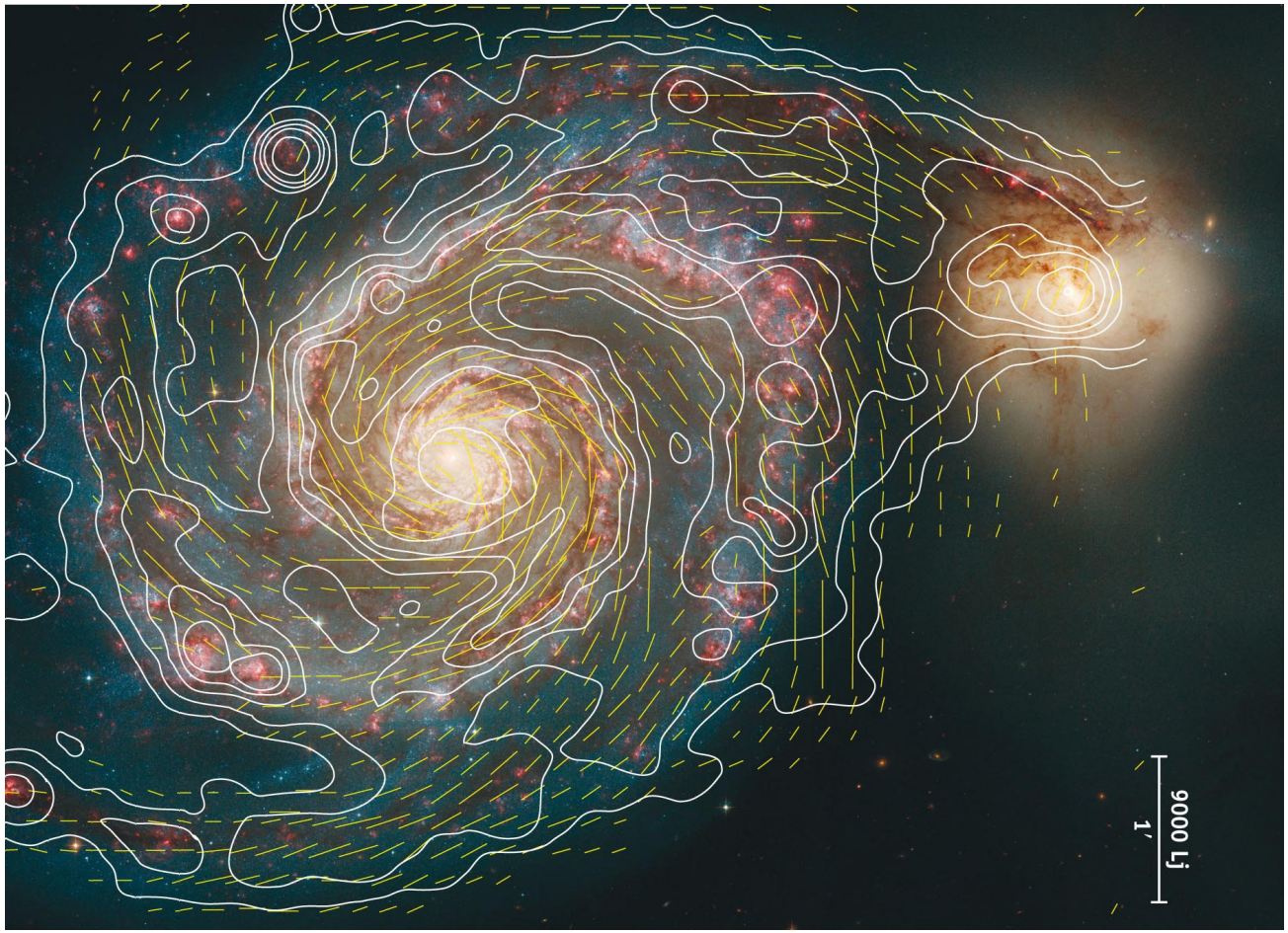
QUESTIONS?

Introduction: We all want a good Magnetic Field

- Magnetic fields are just about everywhere in the Universe:
  - Planets and Stars
  - Galaxies and Clusters
  - Filaments
  - Voids?
  - The Entire Universe?
- Astro/Cosmo Physicists love some magnetic fields
  - Propagation of UHECRs
  - Structure formation
  - Very early Universe and beyond the Standard Model physics
  - Astrophysical plasmas, hydrodynamics
  - Radio-astronomy

Kronberg (1994); Grasso and Rubinstein (2001); Han and Wielebinski (2002); Vallée (2004); Govoni and Feretti (2004); Durrer and Neronov (2013); Subramanian (2015)

M51



Lines indicate the orientation of the B field — Beck (2006)

Van Gogh

Lines follow the strokes of the brush — Van Gogh (1889)

Some Theory for the Theorists

Magnetogenesis mechanisms

- Astrophysics

  Works well for small scales, but difficult to stretch/eject fields out across several Mpc

- Phase transitions

  See above: the coherence length for the EWPT is 100 AU, and it's 1 pc for the QCDPT

- Inflation

  Great coherence lengths, but lilliputian field strengths...

Inflationary mechanisms

- EM is conformally invariant, and FLRW is conformally flat $\Rightarrow$ needs BSM physics

$$f^2F^2,\ RA^2,\ aF\tilde{F},\ ((\partial + A)\psi)^2,\ b(t)\mathcal{L}_{\mathrm{EM}}\ \ldots$$

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a. Backreactions: $\rho_{\mathrm{EM}} \ll \epsilon\rho_\phi \Rightarrow H_\phi \ll 10^{-19}$ GeV, that is: $T_\phi \ll 100$ MeV
— Demozzi, Mukhanov and Rubinstein (2009); Green and Kobayashi (2016)

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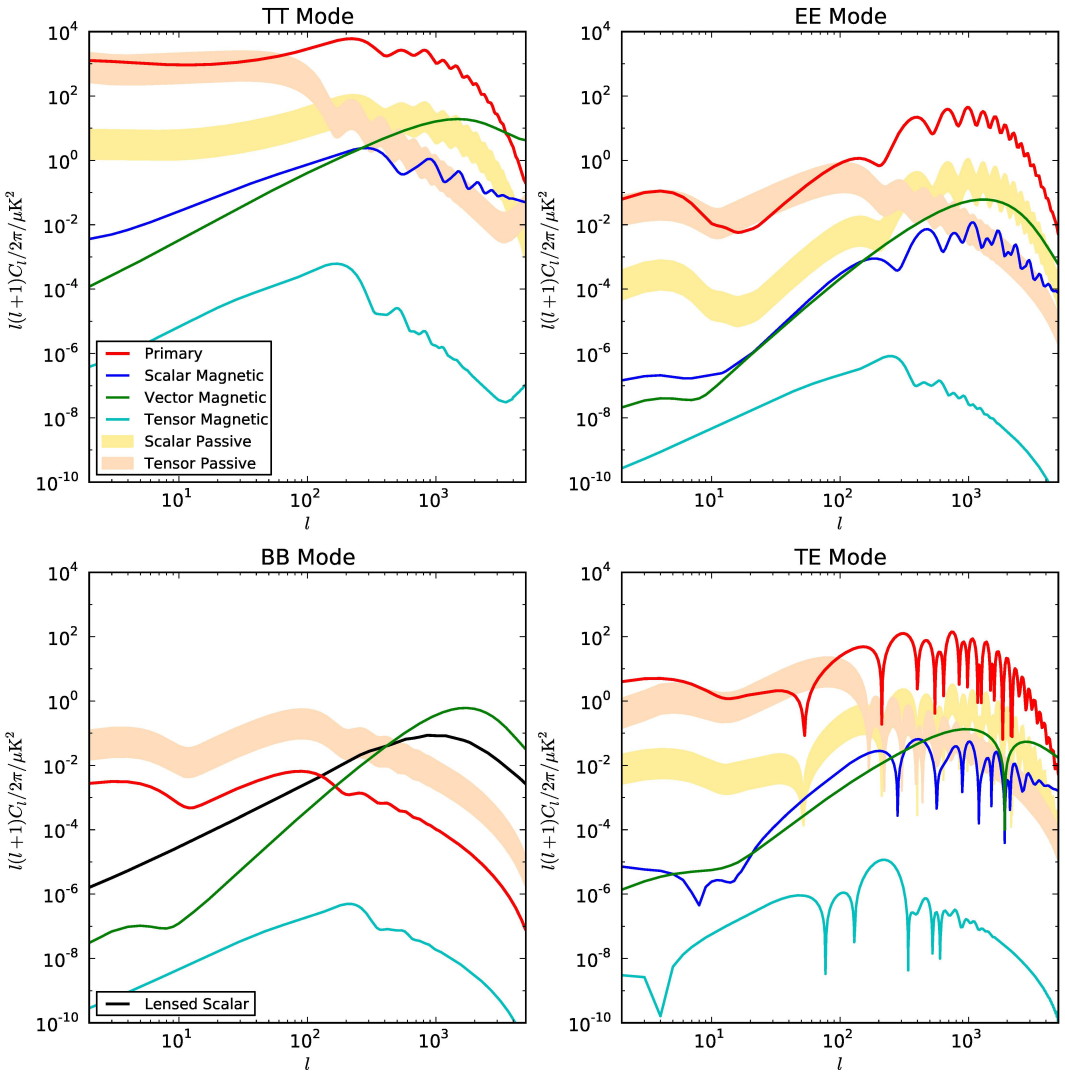
b. Anisotropies: $\langle\zeta_{\mathbf{p}}\zeta_{\mathbf{q}}\rangle \sim P(p)\,[1 + \delta P(\mathbf{p})]$ which severely constrains some models — FU (2013a); (2013b)

Effects on the CMB



- MF contribute to curvature perturbations:
  $\langle B_i(\mathbf{p}) B_j^*(\mathbf{q}) \rangle$
  $\sim \{(\delta_{ij} - \hat{p}_i \hat{q}_j) P_B(p)$
  $+ i \epsilon_{ijk} \hat{p}_k P_H(p)\}$
- MF automatically generate non-Gaussianity:
  $T_{\mathrm{MF}} \sim B^2$
- Faraday rotation rotates E-modes into B-modes
- Helical fields generate parity-violating TB and EB correlations

The Very Best Limits on egMF

Pshirkov, Tinyakov and FU

Phys Rev Lett **116**, 191302 (2016)

arXiv:1504.06546 [astro-ph.CO]

The slide with THE formula

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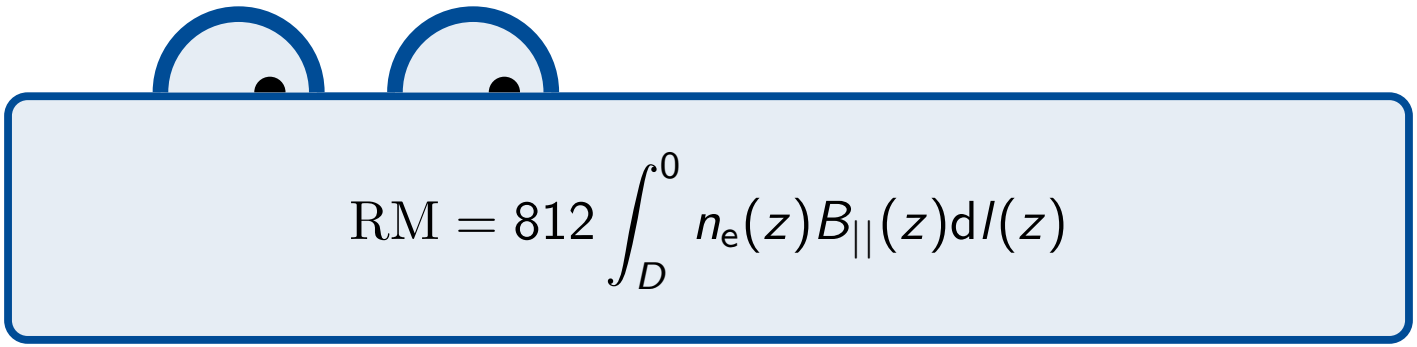
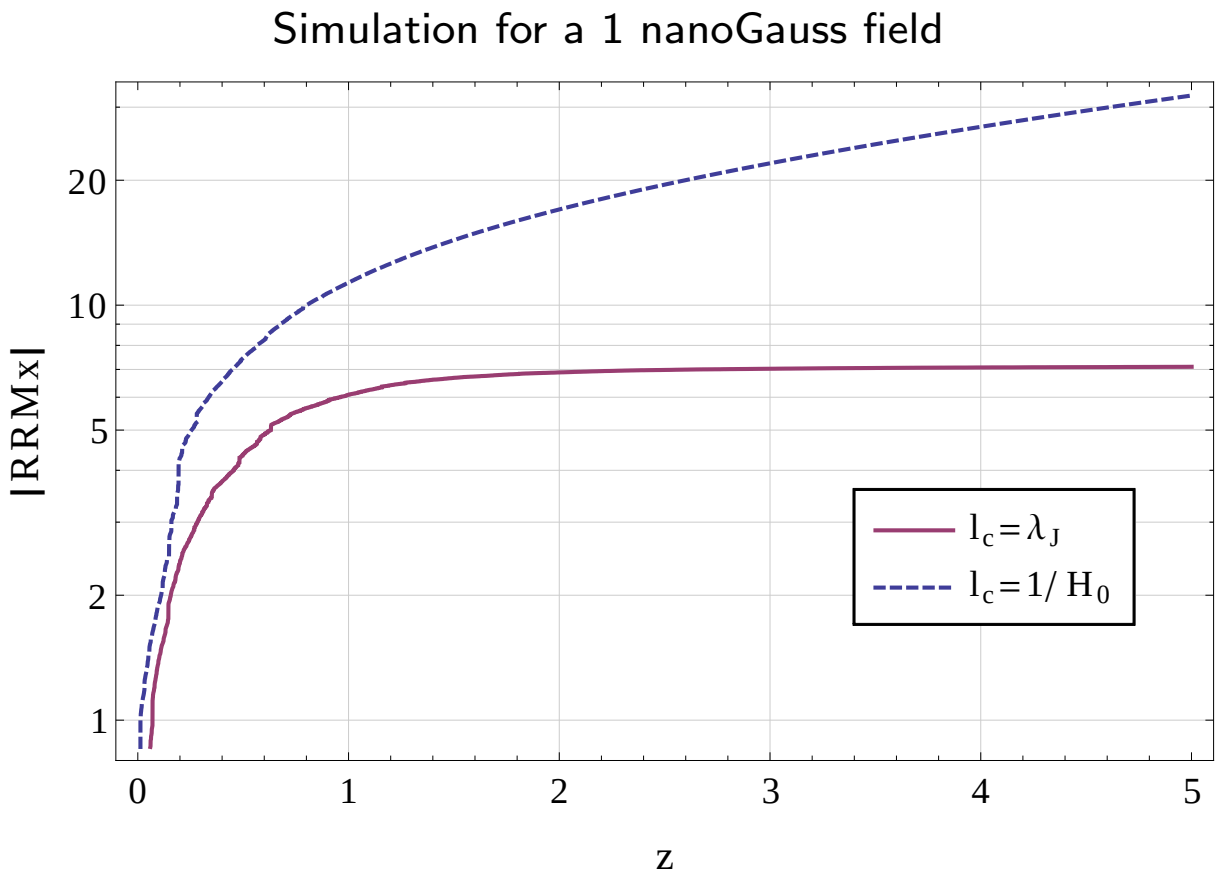


$$\mathrm{RM} = 812 \int_D^0 n_\mathrm{e}(z) B_{||}(z) \mathrm{d}l(z)$$

The polarisation angle of polarised light
ROTATES
when it travels through a magnetised medium

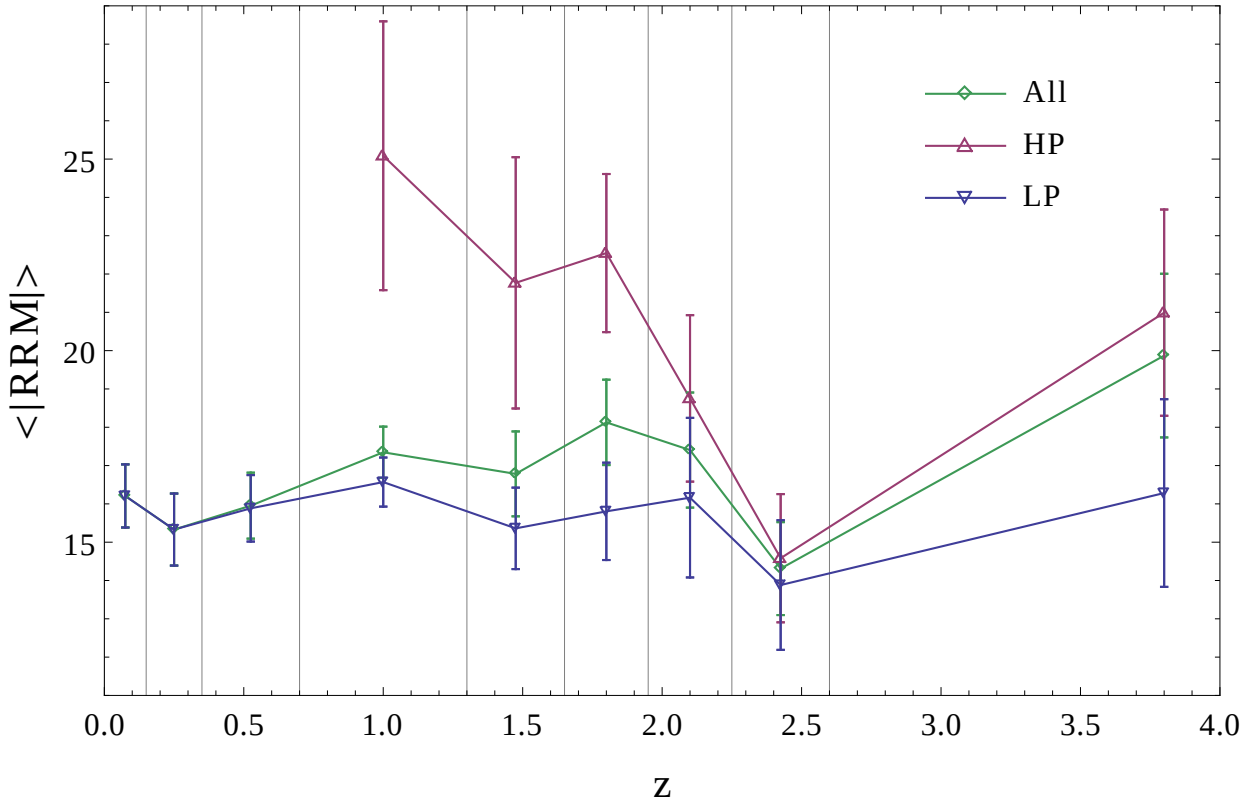
RM in theory



The main ingredient here is the LogN electron density distribution taken from Lyα data — Bi and Davidsen (1997)

RM in practice

We have $\sim$ 4K NVSS sources (of 40K) with known redshift and luminosity



Pshirkov, Tinyakov and FU (2014)

Taylor, Stil and Sunstrum (2009); Hammond, Robishaw and Gaensler (2013)

To Build a Distro

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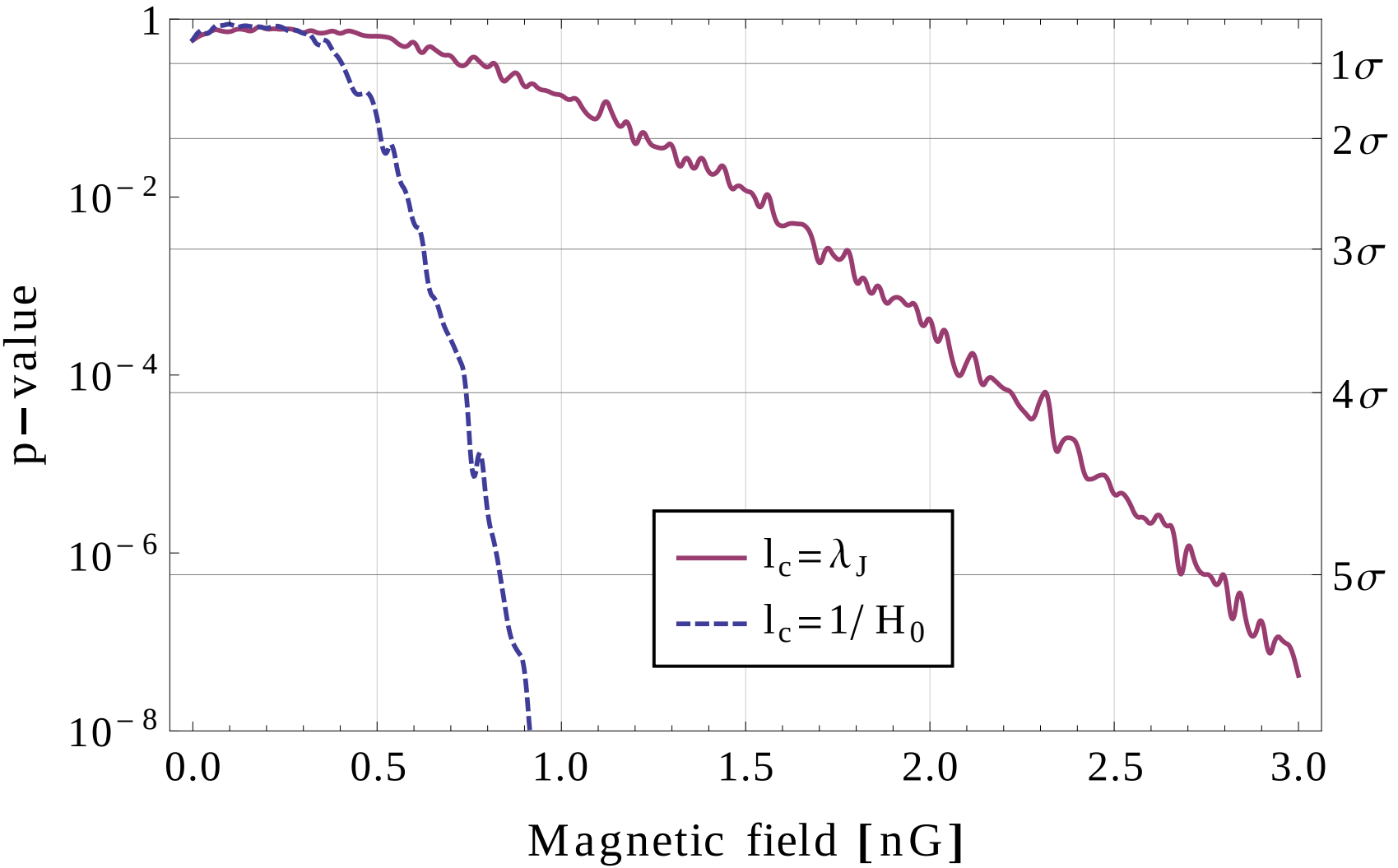
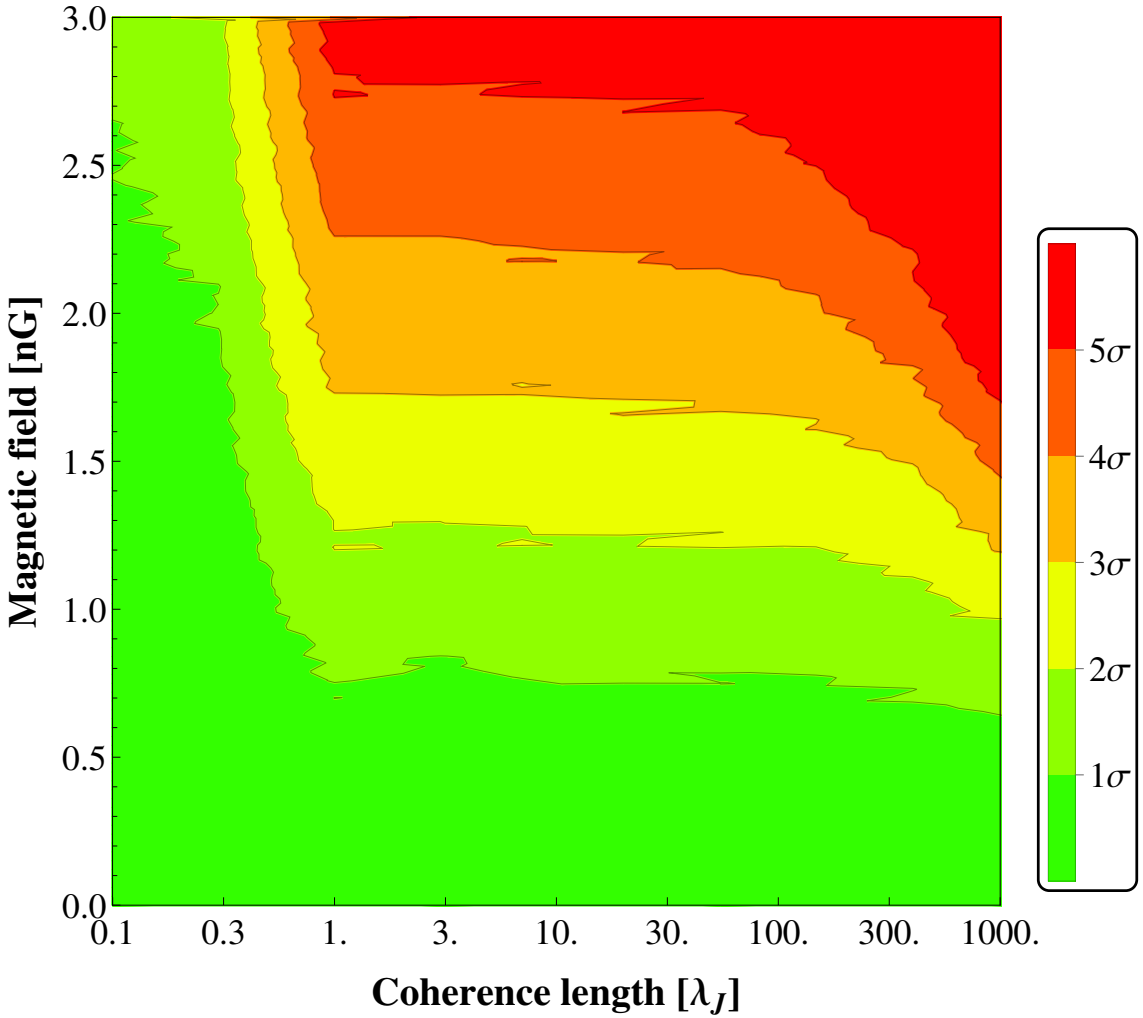
③ We simulate $x\mathrm{RM}$, and put it together with the rest: we have our final distro!

KS p-values


1
10^{-2}
10^{-4}
10^{-6}
10^{-8}
p−value
0.0
0.5
1.0
1.5
2.0
2.5
3.0
Magnetic field [nG]
1σ
2σ
3σ
4σ
5σ
$l_c = \lambda_J$
$l_c = 1/H_0$

KS contours


3.0
2.5
2.0
1.5
1.0
0.5
0.0
Magnetic field [nG]
0.1
0.3
1.
3.
10.
30.
100.
300.
1000.
Coherence length [λ_J]
5σ
4σ
3σ
2σ
1σ

Conclusions

- RMs are a powerful tool to learn about the Universe's Magnetisation
- RMs of distant objects do not show any redshift evolution
- An egMF predicts a rising RM with redshift: compare with data!
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We win :)