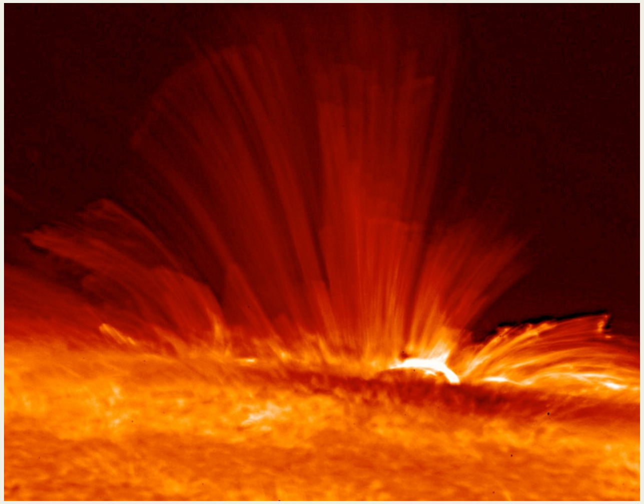
Texas 2015 Symposium on Relativistic Astrophysics

COSMIC MAGNETIC FIELDS

SESSION OVERVIEW

Tina Kahniashvili

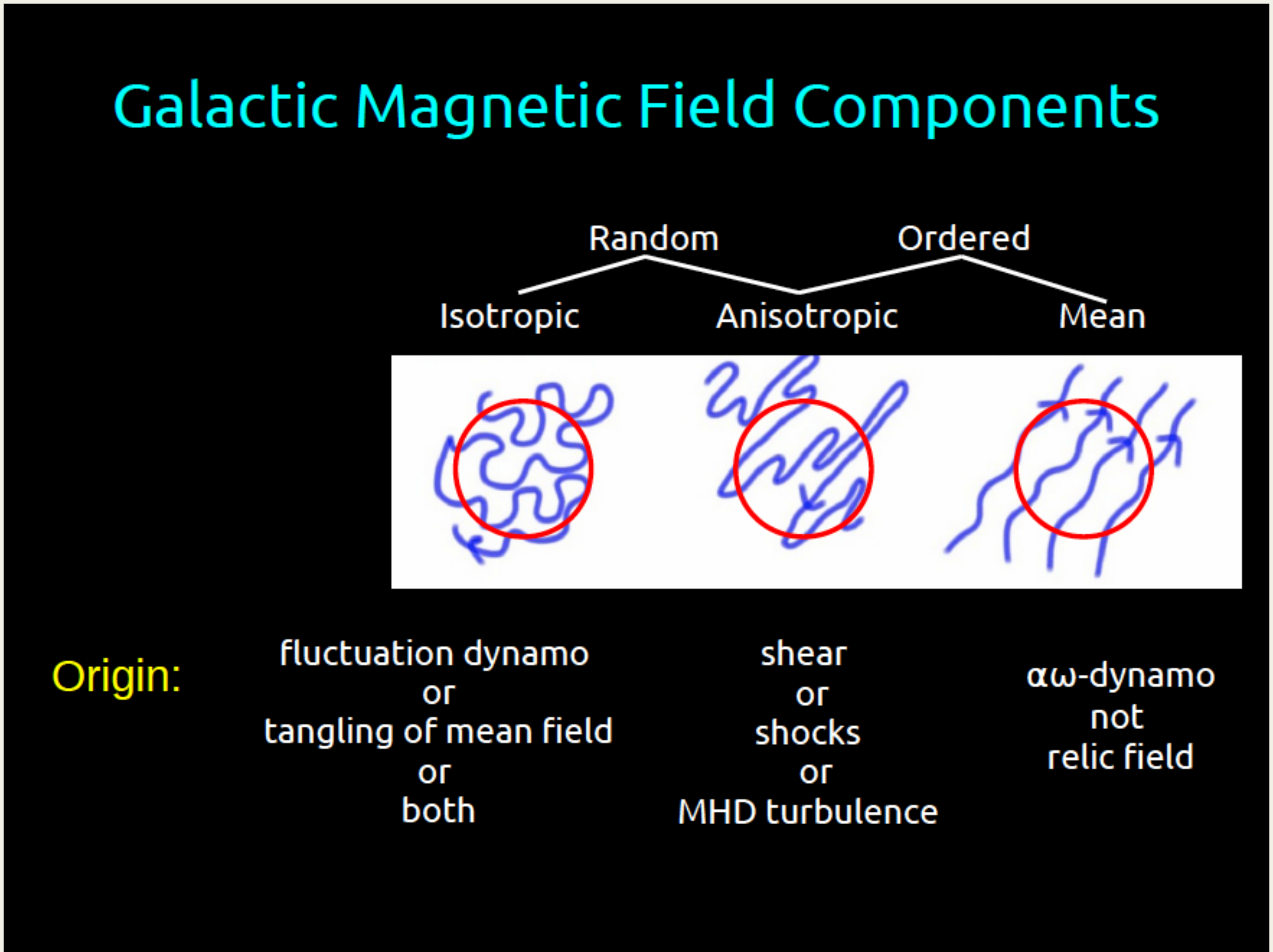
Cosmic Magnetic Fields
Big Questions: Observations & Theory



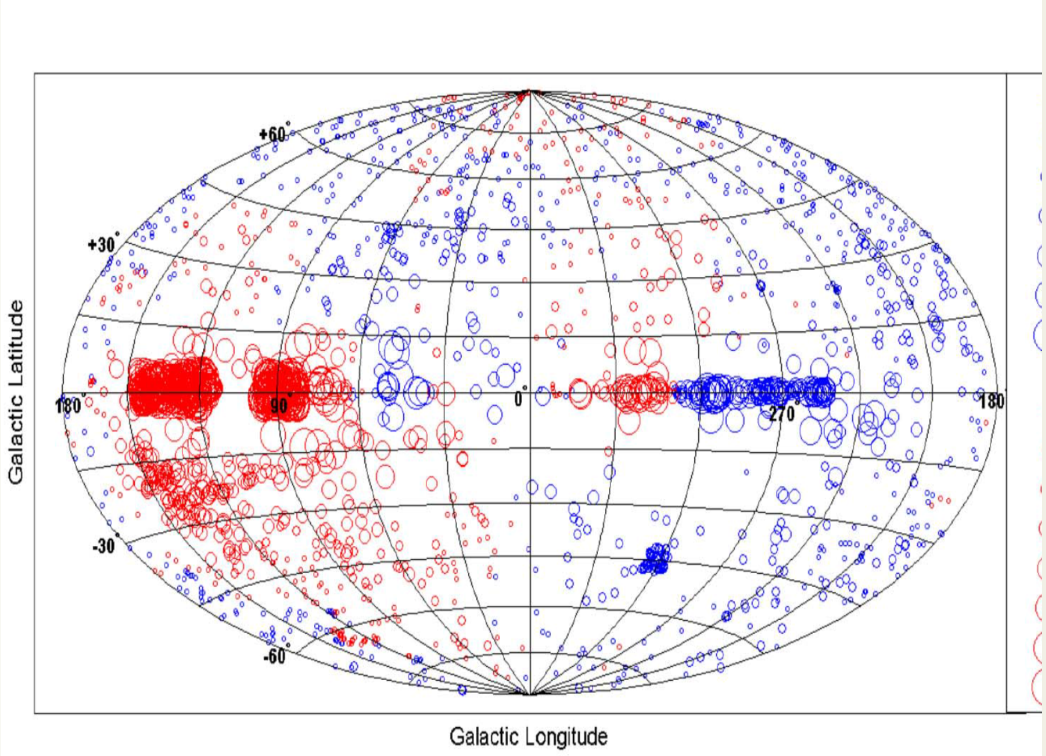
- Origin
- Evolution
- Effects

Probing Magnetic Fields in Galaxies

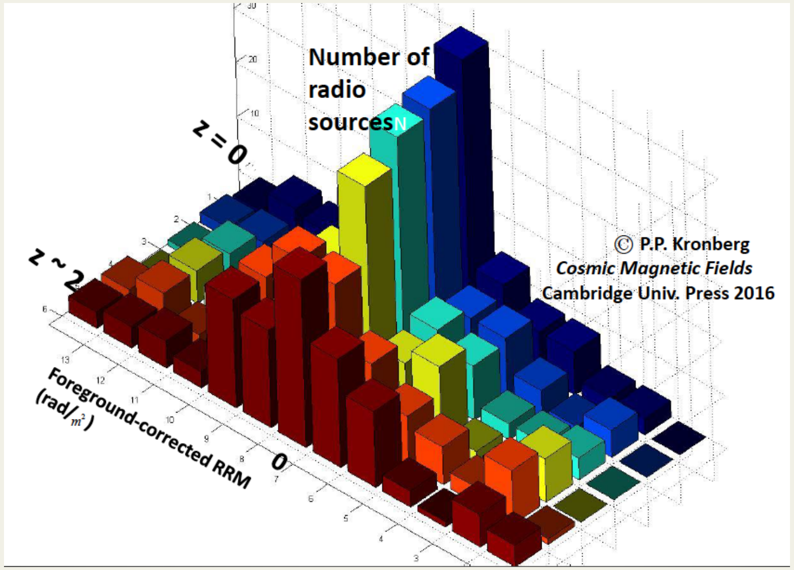
Talk by **Andrew Fletcher**



Probing Magnetic Fields: Faraday Rotation



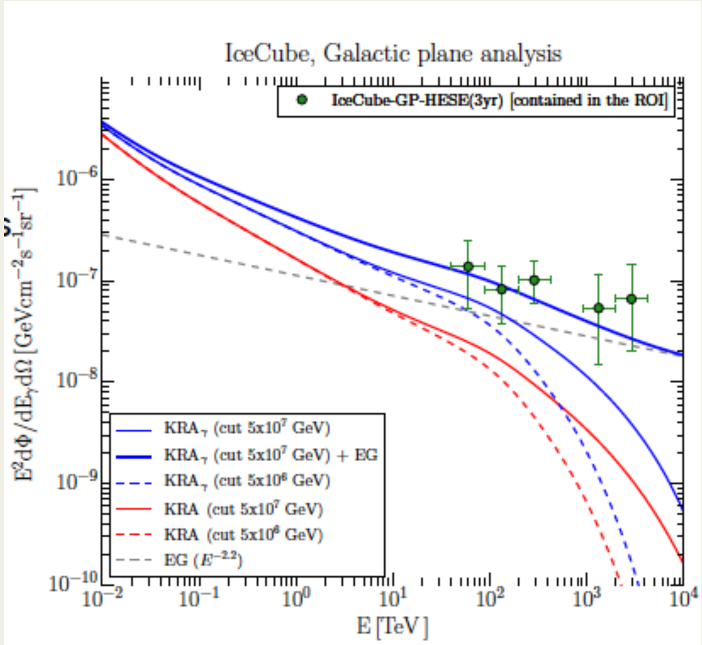
Talk by **Phil Kronberg**



Milky Way RM sky 2256 egrs RM's

Probing Magnetic Fields: Cosmic Rays

Talk by **Dario Grasso**

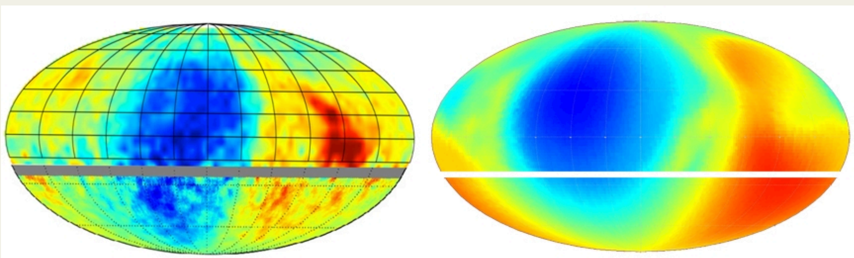


The complex structure of the Galactic MF requires to go beyond the conventional (homogeneous and isotropic) treatment of Galactic cosmic ray (CR) propagation

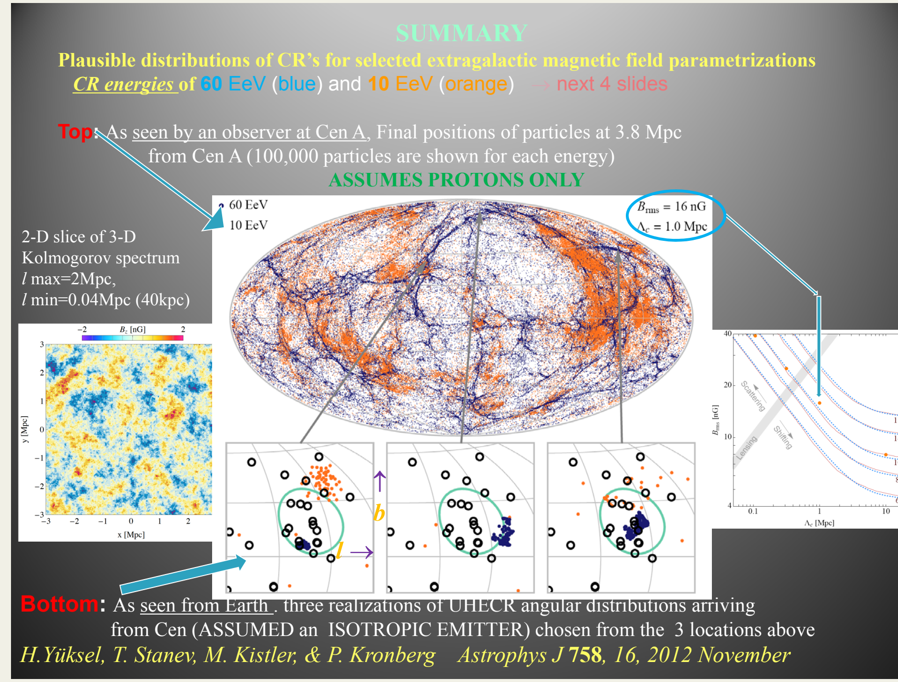
- A more realistic treatment implemented with the DRAGON code can solve several anomalies: γ-ray gradient problem; CR isotropy; γ-ray excess in the inner Galaxy; Milagro excess
- This has also implications for the high energy neutrino emission of the Galaxy. A model with space dependent diffusion such to explain the Fermi and Milagro excess predicts a ν flux along the Galactic plane which is significantly larger than conventional models and reproduces IceCube results (see plot) and arXiv: 1504.00227 (ApJ L.)

Magnetic Fields vs. Cosmic Rays

Talk by **Phil Kronberg**

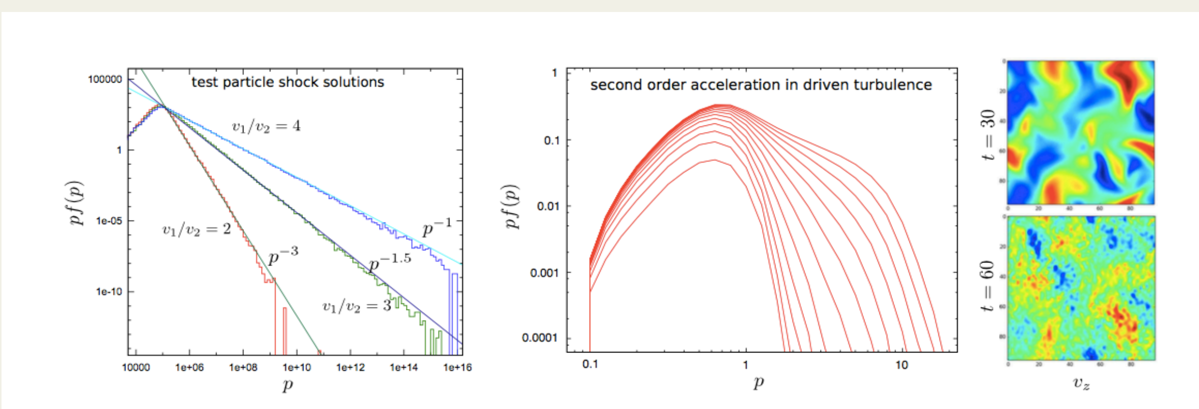


Credit: NASA

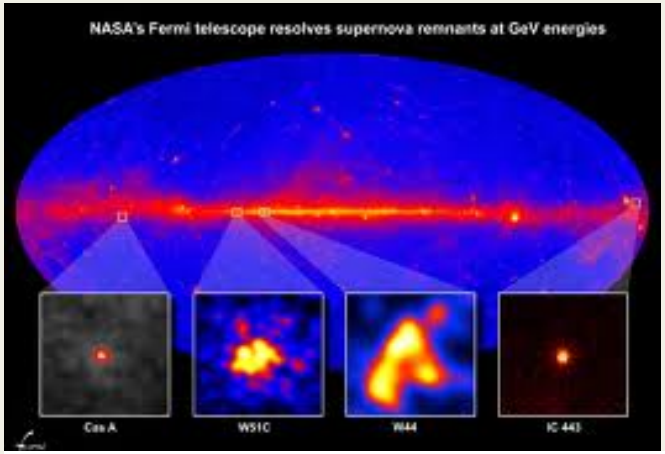


Talk by **Andrey Beresnyak**

Magnetically driven MHD turbulence can accelerate particles



Ultra High Energy Gamma Rays Tests



Neronov and Vovk, Science 2010

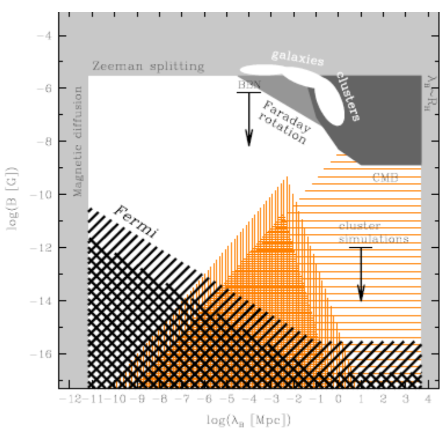


Fig. 2: Light, medium and dark grey: known observational bounds on the strength and correlation length of EGMF, summarized in the Ref. (25). The bound from Big Bang Nucleosynthesis marked "BBN" is from the Ref. (2). The black hatched region shows the lower bound on the EGMF derived in this paper. Orange hatched regions show the allowed ranges of B, λ_B for magnetic fields generated at the epoch of Inflation (horizontal hatching) the electroweak phase transition (dense vertical hatching), QCD phase transition (medium vertical hatching), epoch of recombination (rear vertical hatching) (25). White ellipses show the range of measured magnetic field strengths and correlation lengths in galaxies and galaxy clusters.

Neronov and Semikoz 2009

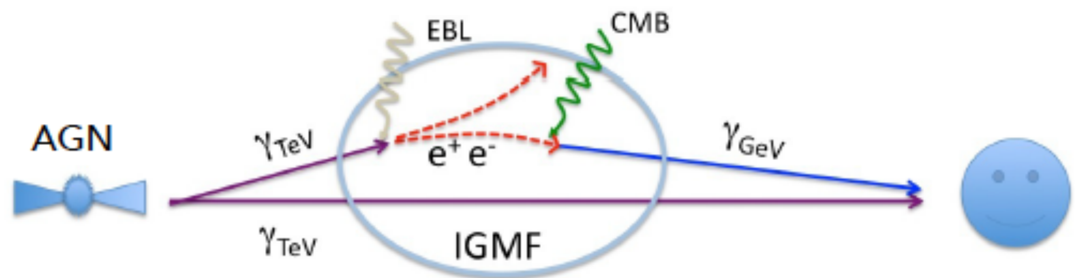
- The ultra high energy photons (gamma rays above 0.1 TeV) interact with the diffuse extragalactic background light

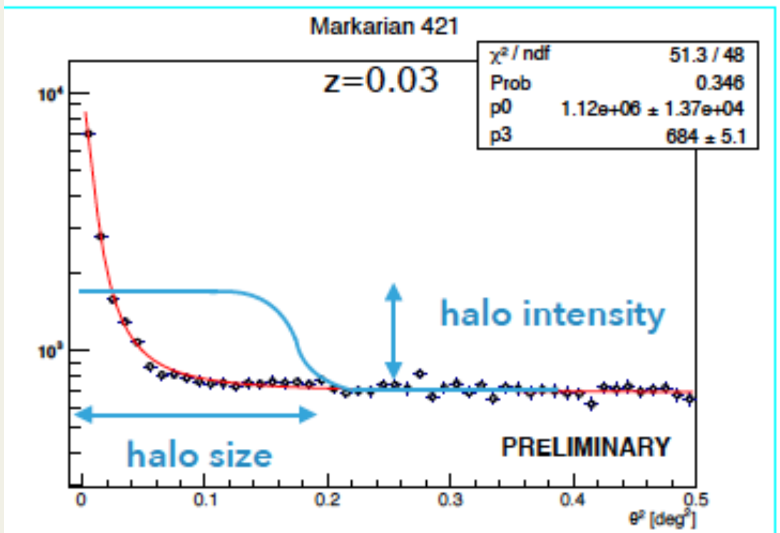
$$\gamma + \gamma \rightarrow e^{+} + e^{-}$$

- If the magnetic field along the path of the cascade production is strong enough to bend the pair trajectories then the cascade emission appears as an extended halo around the initial point source

Probing Magnetic Fields: Gamma Rays

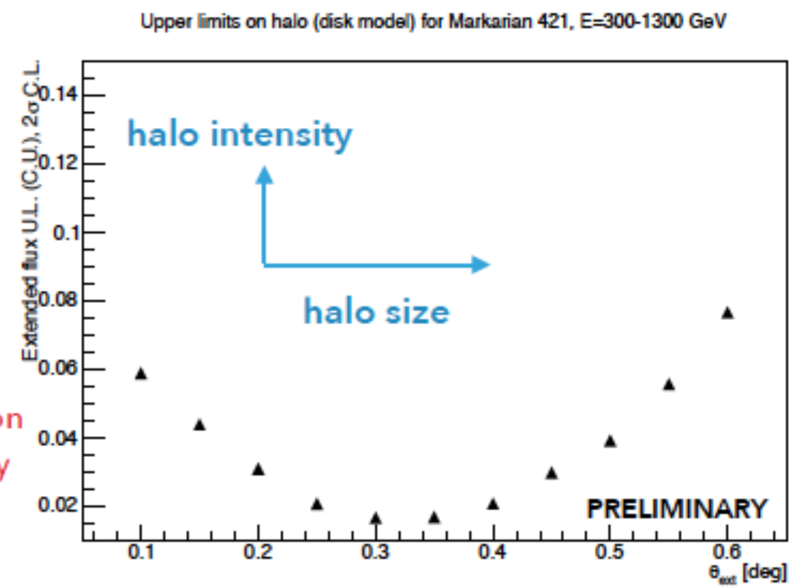
Talk by **Paolo Da Vela**





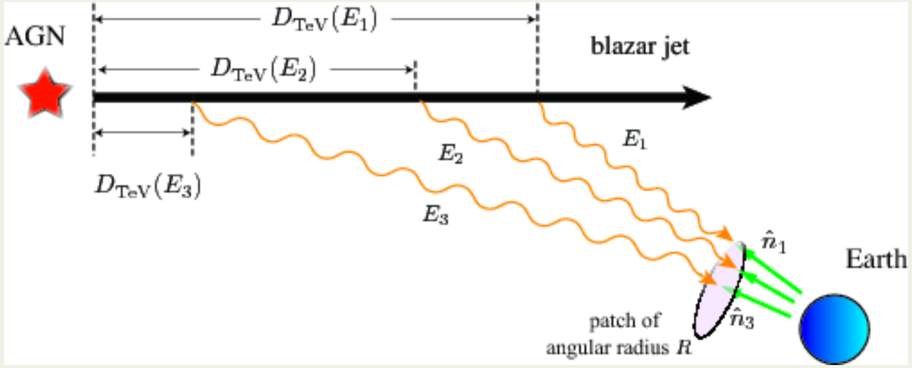
Fit of emission profile of Markarian 421with MAGIC PSF + halo model

upper limits on halo intensity



Most stringent limit limit for θ_{ext}=0.3°. U.L. (C.U.)=1.6%

Probing Magnetic Fields: Gamma Rays



Tashiro and Vachaspati 2015

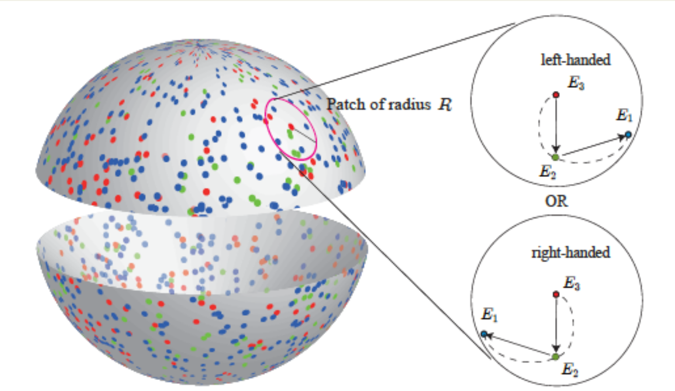
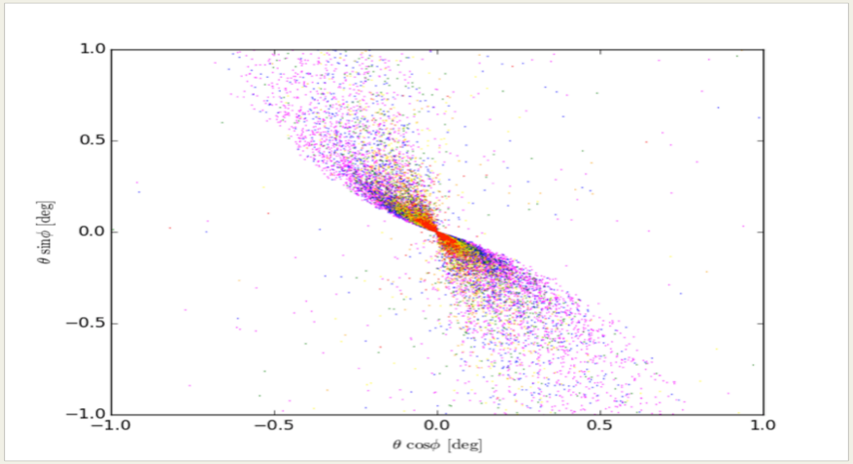


Figure 2. Illustration of the cut-sky with gamma rays distributed on it. Patches of radius R degrees are centered on the highest energy gamma rays. In those patches we test if the lower energy photons are distributed along left- or right-handed spirals.

Tashiro, Chen, Francesc, Vachaspati 2014

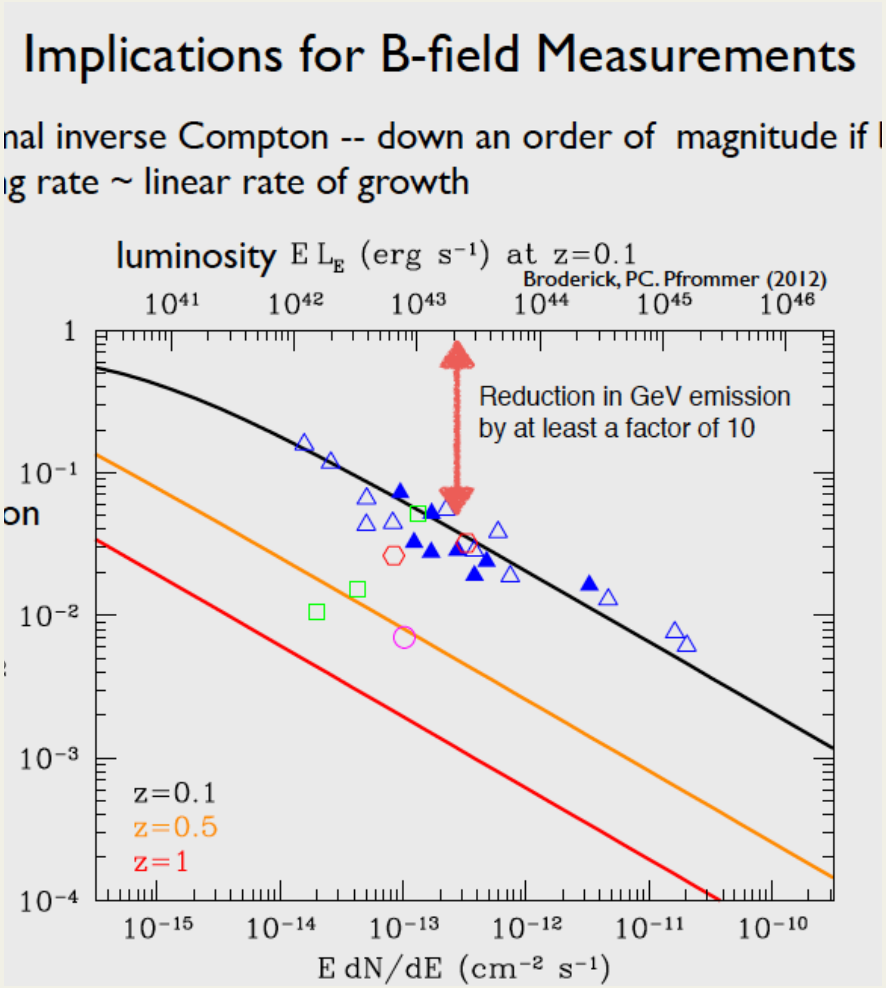
Talk by **Andrey Saveliev**



GRPropa, a new propagation software for electromagnetic cascades including the effects of magnetic fields, is up and running, showing, among others, imprints of magnetic helicity onto the arrival directions of gamma rays

Magnetic Fields vs Plasma Instabilities

Talk by **Phil Chang**



Note: Plasma instabilities vs blazar's observation is debated, see

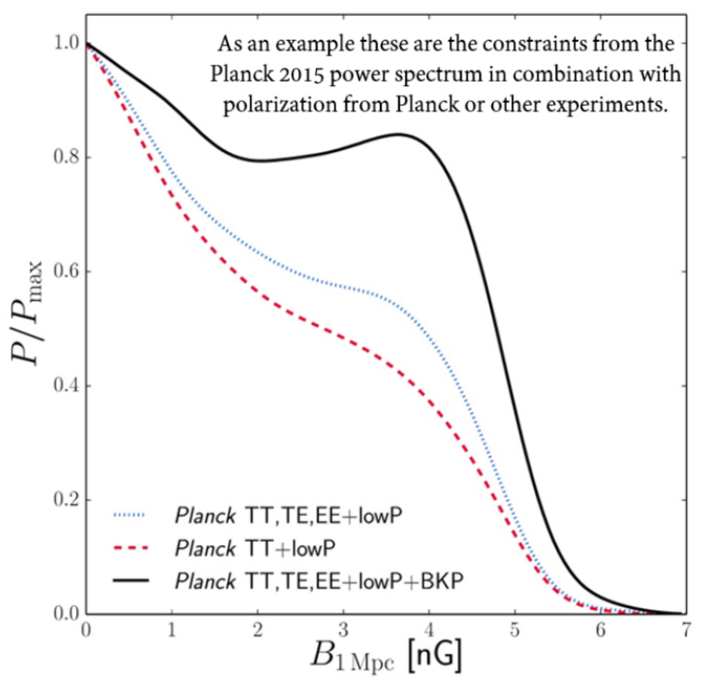
- Miniati, Elyiv, ApJ 770, 54 (2013) (analytic)
- Sironi, Giannos, ApJ, 787, 49 (2014) (simulation)
- Kempf, Kilian, Spanier, arXiv:1512.00662 (2015) (simulation)

More work must be done

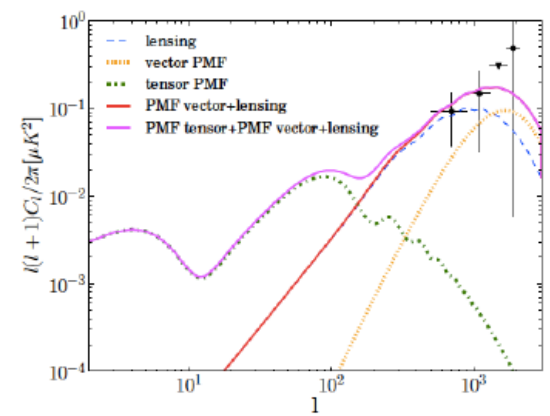
Probing Magnetic Fields: CMB

Talk by **Daniela Paoletti**
(Planck collaboration)

Planck 2015 constraints on PMF amplitude with the three probes –likelihood (with two methods: magnetically induced perturbations and the impact on the ionization history) , non-Gaussianities, Faraday rotation- are mutually consistent and at the level of nG



Talk by **Levon Pogosian**
(POLARBEAR B mode)



Forecasted constraints on PMF from Faraday Rotation

Name - freq (GHz)	f_{sky} (f_{sky}^{opt})	FWHM (arcmin)	Δ_P(μK-arcmin)	B_{eff} (2σ, nG)	+DL (nG)	+DL+DG (nG)
Planck LFI - 30	0.6	33	240	16[b]	same	same
Planck HFI - 100	0.7	9.7	106	23	same	same
Polarbear - 90	0.024[a]	6.7	7.6	3.3	3.0	same
QUIET II - 40	0.04[a]	23	1.7	0.46	0.26	0.25
CMBPOL - 30	0.6	26	19	0.56	0.55	0.51
CMBPOL - 45	0.7	17	8.25	0.38	0.35	0.29
CMBPOL - 70	0.7	11	4.23	0.39	0.32	0.26
CMBPOL - 100	0.7	8	3.22	0.52	0.4	0.34
Suborbital - 30	0.1	1.3	3	0.09	0.07	0.05
Suborbital - 90	0.1	1.3	3	0.63	0.45	same
Space - 30	0.6 (0.2)	4	1.4	0.06	0.04	0.02
Space - 90	0.7 (0.4)	4	1.4	0.26	0.15	0.12

Planck 2015 Results: Constraining Magnetic Fields

Talk by **Daniela Paoletti**

CONSTRAINTS ON PRIMORDIAL MAGNETIC FIELDS WITH PLANCK 2015

Planck data on CMB anisotropies provide three different complementary probes to constrain PMF

Non Gaussianities

A stochastic background of PMF has a fully non-Gaussian contribution to CMB anisotropies

Non-zero bispectrum

Different types of bispectra and different methodologies:

- Passive tensor bispectrum
- Scalar anisotropic bispectrum
- Scalar compensated bispectrum

Constraints at the level of few nG

Planck likelihood

Magnetically induced scalar, vector and tensor perturbations have a direct effect on CMB anisotropies in T & P.

The different combination of Planck likelihood and magnetically induced modes give constraints of the order of few nG.

No evidence of PMF in the Planck+BICEP +KECK analysis

The impact of the dissipation of PMF on the ionization history also leads to tight constraints less than a nG.

This analysis looks very promising in the perspective of new data in polarization

Faraday Rotation

CMB polarization is affected by the induced Faraday rotation by PMF. Strongly dependent on observational frequency.

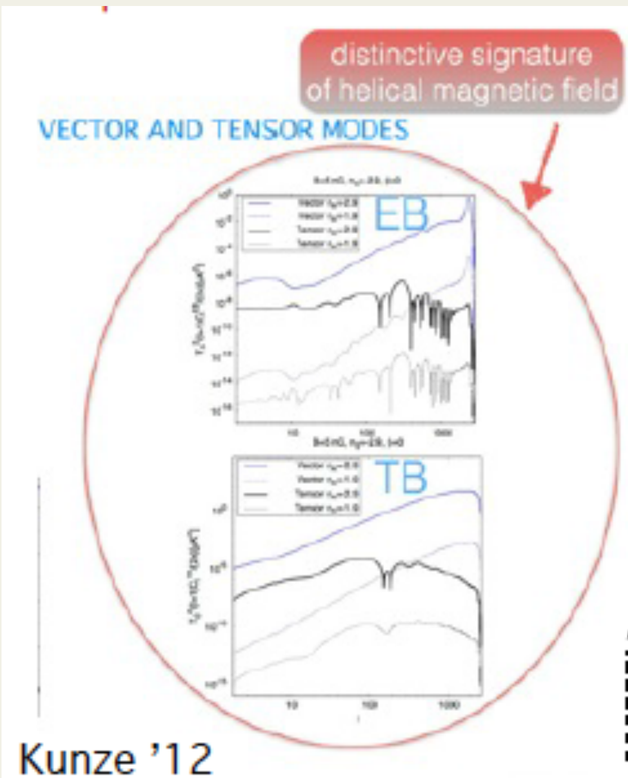
The constraints using only the Planck 70 GHz $2<l<29$ are of the order of the muG due to the limited multipole range allowed for the analysis.

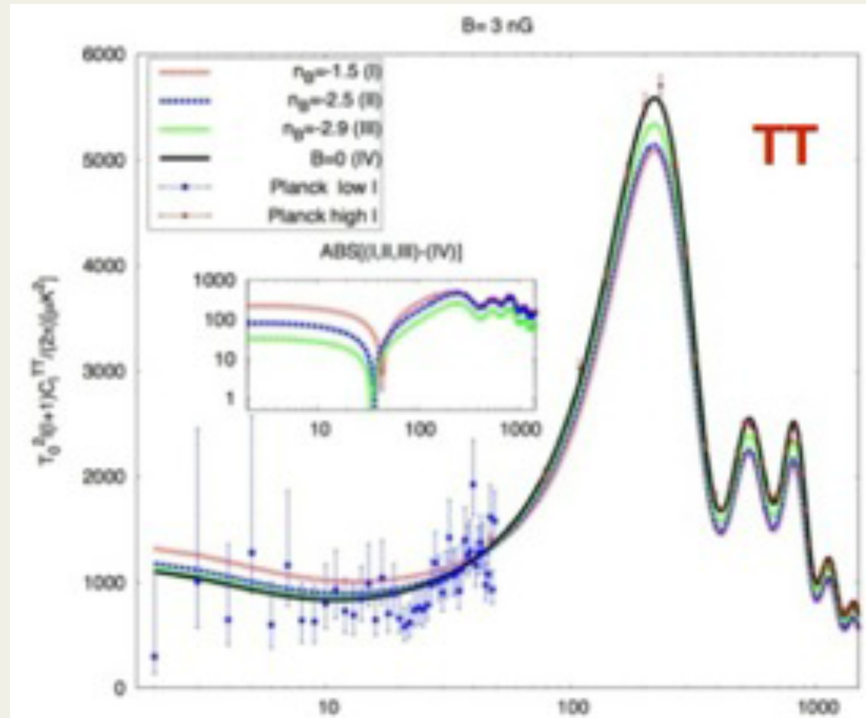
All these results are mutually consistent and lead to constraints at the level of nG

Credit: Daniela Paoletti

Probing Magnetic Fields: CMB

Talk by **Kerstin Kunze**





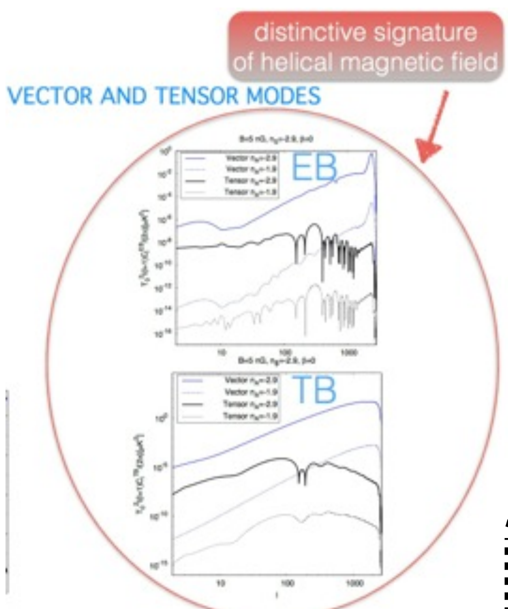
The 95% CL upper bounds are B0 < 0.63, 0.39, and 0.18 nG for nB = −2.9, −2.5, and −1.5, respectively.

See also poster by **Hector Hortua**

Kerstin Kunze. **Prospects of constraining primordial magnetic fields with the CMB**

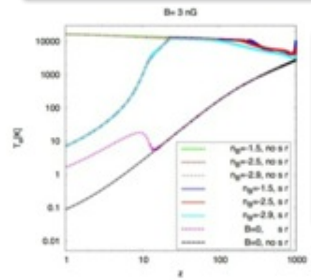
Part of the *magnetic field* which is *not dissipated*: active contribution of magnetic field

- constraints from temperature and polarisation data (Planck, SPT, WMAP,..): few nG field for nearly scale invariant field.
- *More promising*: find distinctive signature of helical magnetic fields with future high precision polarisation observations:

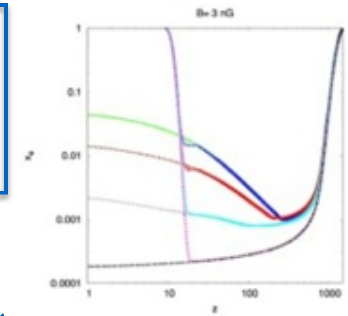


Kunze '12

Part of the *magnetic field* which *is dissipated*: dissipated magnetic energy leads to heating of electrons and energy injection into CMB.



changes thermal and ionisation history



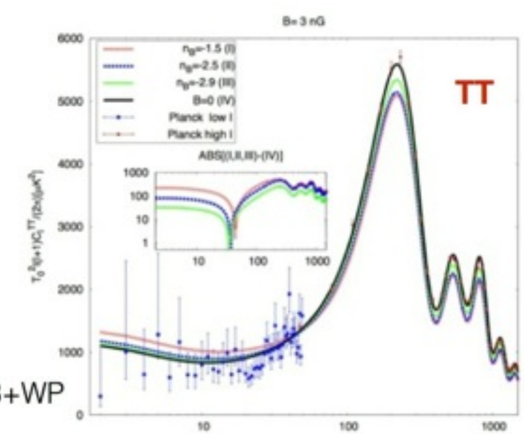
optical depth and visibility function changed

CMB anisotropies

spectral distortions of CMB

Example: *μ-type distortion*

constraints			
COBE/FIRAS		$B_0 < 0.4$ nG	$n_B = -2.2$
$\|\mu\| < 9 \times 10^{-5}$	⇒	$B_0 < 40$ nG	$n_B = -2.9$
$\|\mu\| < 5 \times 10^{-8}$	⇒	$B_0 < 0.9$ nG	$n_B = -2.9$
PIXIE/COrE		$B_0 < 10^{-2}$ nG	$n_B = -2.2$

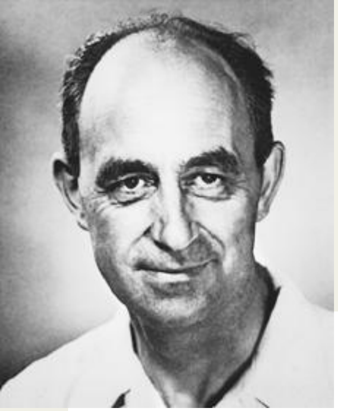


Planck13+WP

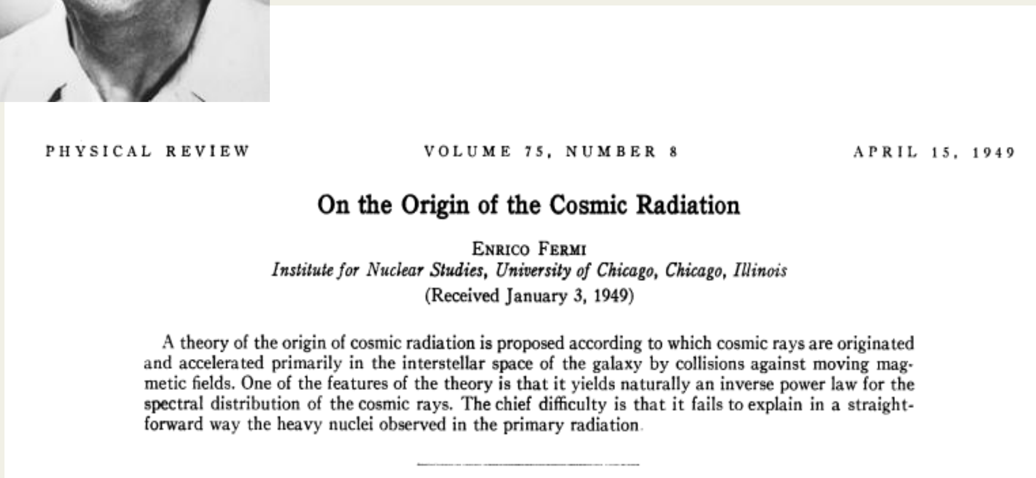
Kunze, Komatsu '14,'15

The 95% CL upper bounds are B0 < 0.63, 0.39, and 0.18 nG for nB = −2.9, −2.5, and −1.5, respectively.

Stronger limits from dissipation of magnetic field



Origin of Cosmic Magnetic Fields



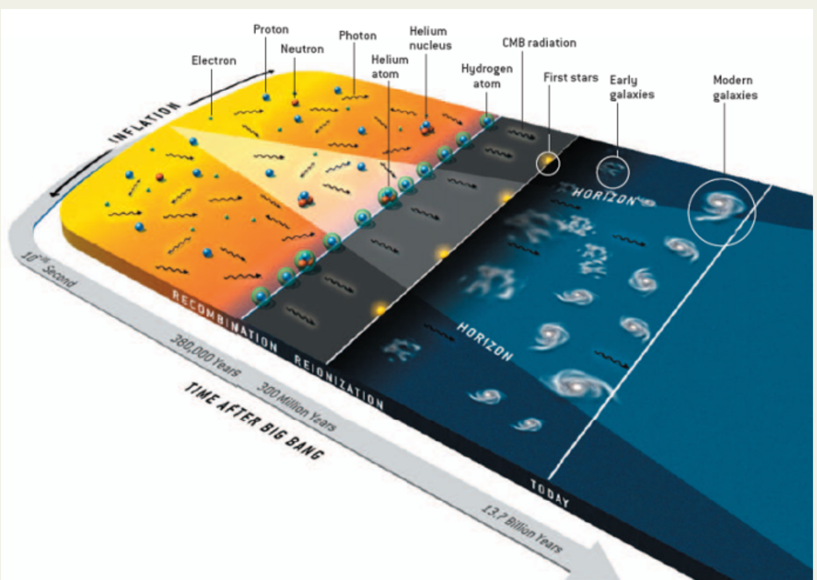
PHYSICAL REVIEW VOLUME 75, NUMBER 8 APRIL 15, 1949

On the Origin of the Cosmic Radiation

ENRICO FERMI
Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
(Received January 3, 1949)

A theory of the origin of cosmic radiation is proposed according to which cosmic rays are originated and accelerated primarily in the interstellar space of the galaxy by collisions against moving magnetic fields. One of the features of the theory is that it yields naturally an inverse power law for the spectral distribution of the cosmic rays. The chief difficulty is that it fails to explain in a straightforward way the heavy nuclei observed in the primary radiation.

- Astrophysical
- Cosmological

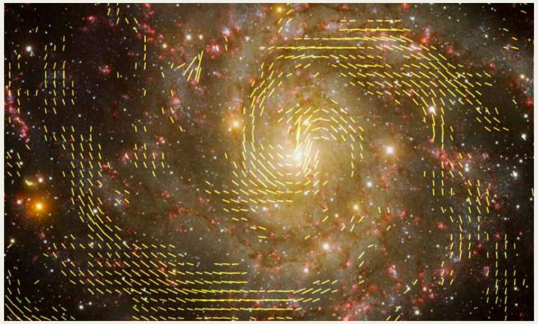


F. Hoyle in Proc. *"La structure et l'evolution de l'Universe"* (1958)

Magnetic Field Generation

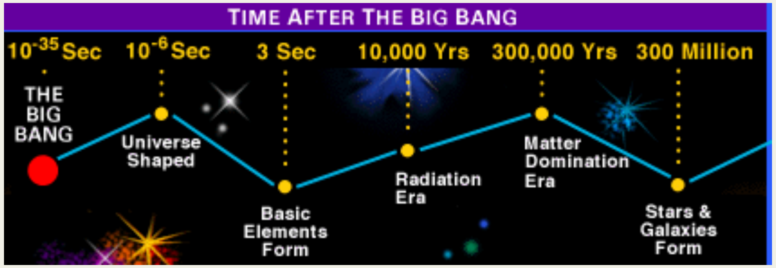
- Plasma physics driven mechanisms

Talk by **Reinhard Schlickeiser**



- Inflation-generated magnetic fields:

Talk by **Christos Tsagas**

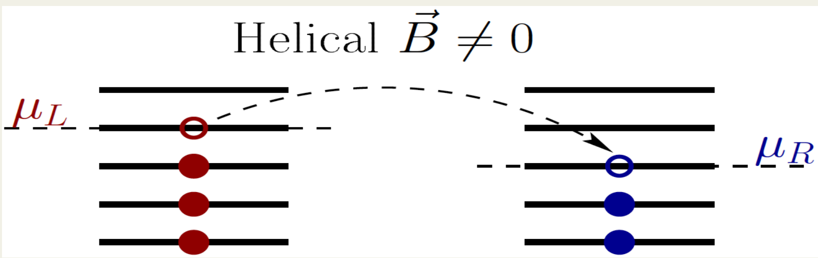


- Appealing to causality and the inferred absence of electric currents with super-horizon correlations, it might be possible to slow down the adiabatic magnetic decay on super-Hubble scales after inflation. This should make it much easier for inflation to produce magnetic fields of astrophysical relevance today

Chiral Magnetic Fields:

Generation Theory:

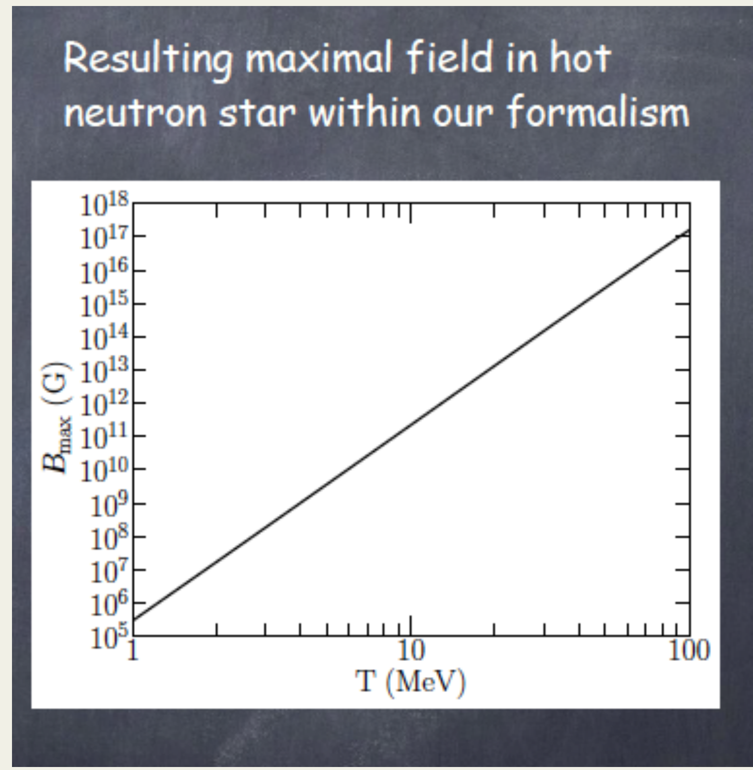
Talk by **Oleg Ruchayskiy**



- Relativistic plasmas should be described by chiral MHD (rather than ordinary MHD with relativistic equation of state) and that the Chiral Magnetic Effect can play an important role in generation and evolution of cosmic magnetic fields in the early epochs

Applications:

Talk by **Guenter Sigl**

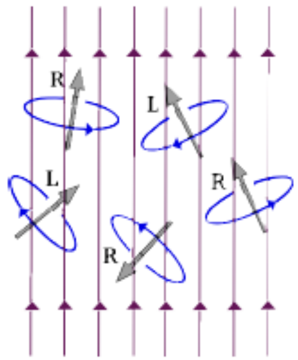


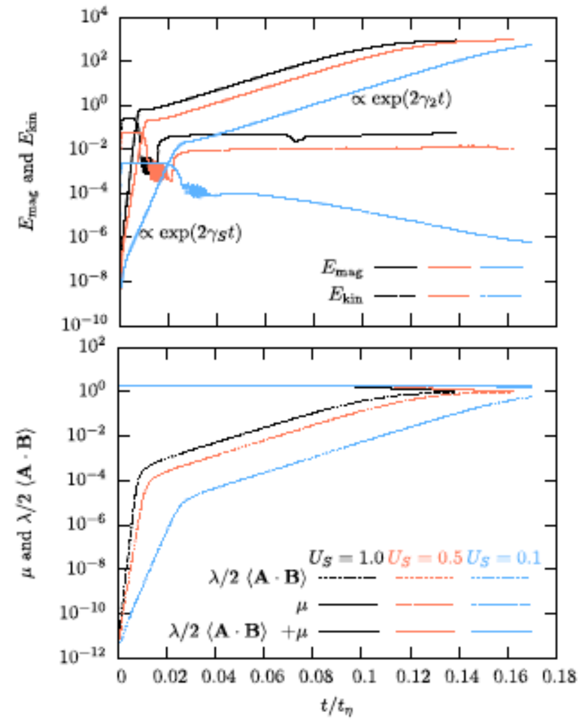
Chiral Magnetic fields: Simulations

Talk by **Jennifer Schober**

- At high energies, the MHD equations are modified due to the chiral chemical potential μ with

$$\frac{\mathrm{d}\mu}{\mathrm{d}t} \propto \vec{E} \cdot \vec{B}$$





- Numerical simulations of laminar dynamos with the *Pencil Code*:
  - α^2 dynamo
  - α - shear dynamo

  → Confirmation of analytical predictions for growth rates and dynamo waves.

- Strong magnetic fields can be generated in the early Universe with various implications for its subsequent evolution.

- Open question: How is the magnetic field amplification affected by turbulence?

Chiral Magnetic Fields: Evolution

Talk by **Guenter Sigl**

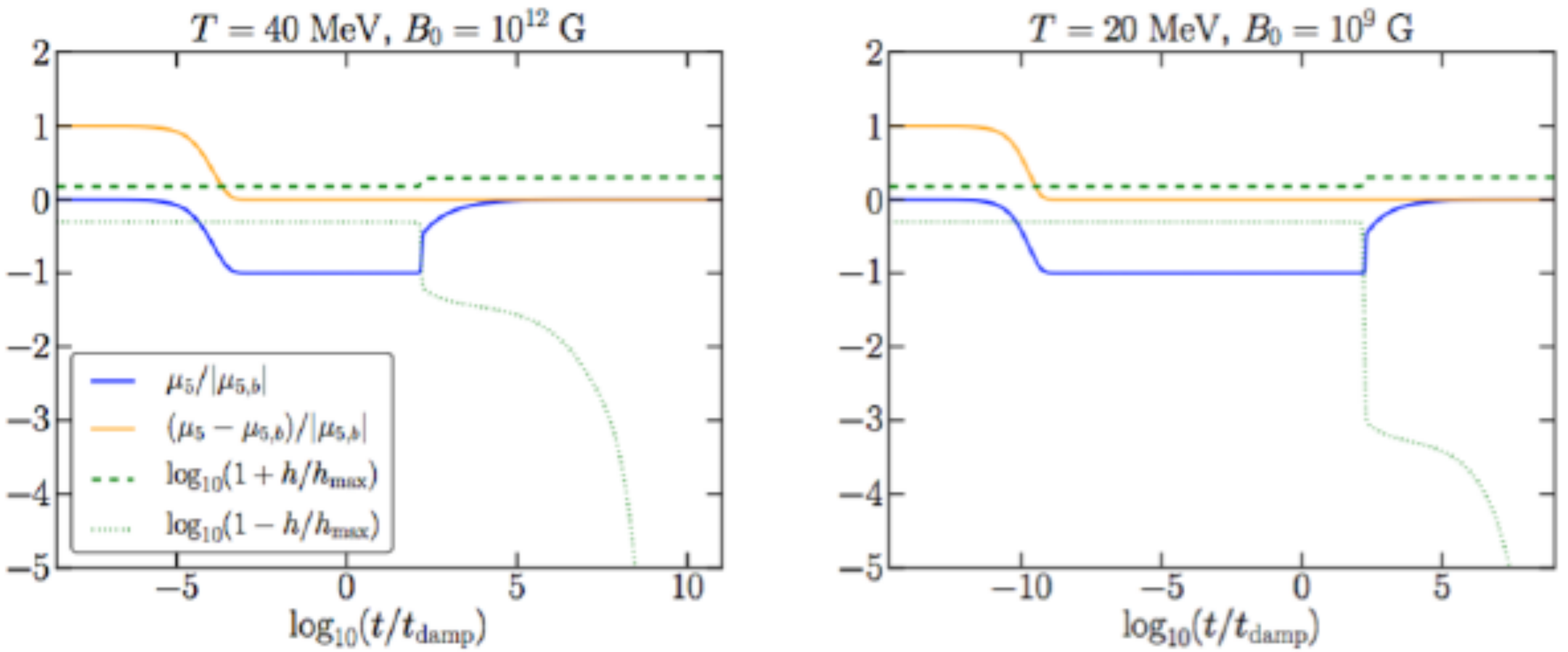


Figure 2. Time evolution of the chiral chemical potential normalized to the equilibrium value, $\mu_5/|\mu_{5,b}|$, relative difference of the chiral chemical potential to the equilibrium value, $(\mu_5 - \mu_{5,b})/|\mu_{5,b}|$ and, in logarithmic units, relative deviation of the helicity density from its maximal and minimal value, $1 \pm h/h_{max}$. The left panel is for a temperature of $T = 40$ MeV and seed field $B_0 = 10^{12}$ G, and the right panel is for $T = 20$ MeV and a seed field of $B_0 = 10^9$ G.

Primordial Magnetic Field Evolution

Talk by **Axel Brandenburg**

$$E(k,t) = \xi^{-\beta}\phi(k\xi)$$

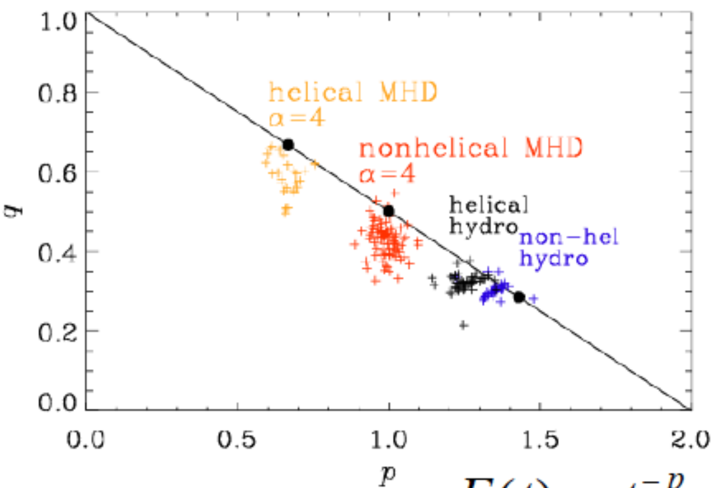
with integral scale ξ

$$\xi = \xi(t) \propto t^{q}$$

and q determined by physics

$$\beta = -3 + 2/q$$

from dimensional arguments



$$E(t) \propto t^{-p}$$

β p q physics

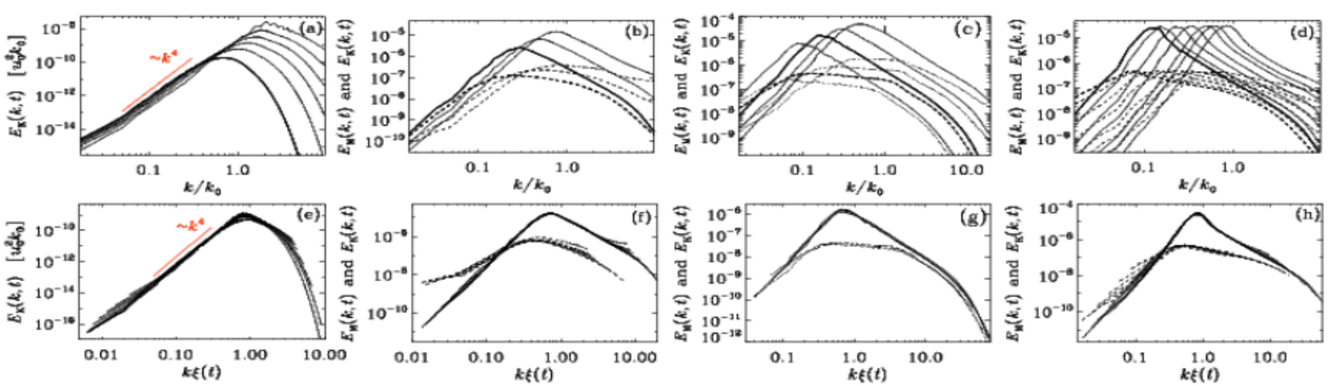


FIG. 1: Kinetic energy spectra in a hydrodynamic simulation (a), compared with magnetic (solid) and kinetic (dashed) energy spectra in a hydromagnetic simulation without helicity (b) and (c), and with (d). Panels (e)–(h) show the corresponding collapsed spectra obtained by using $\beta_{\rm M} = 3$ (e), $\beta_{\rm M} = 2$ (f), $\beta = 1$ (g), and $\beta = 0$ (h). In (f) we used $\beta_{\rm K} = 1 \neq \beta_{\rm M}$.

MHD Turbulence: Spectra

Talk by **Axel Brandenburg**

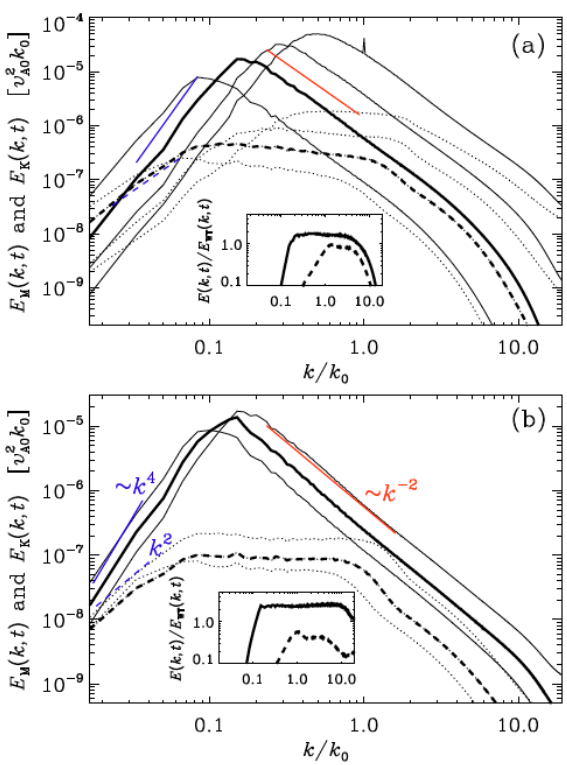
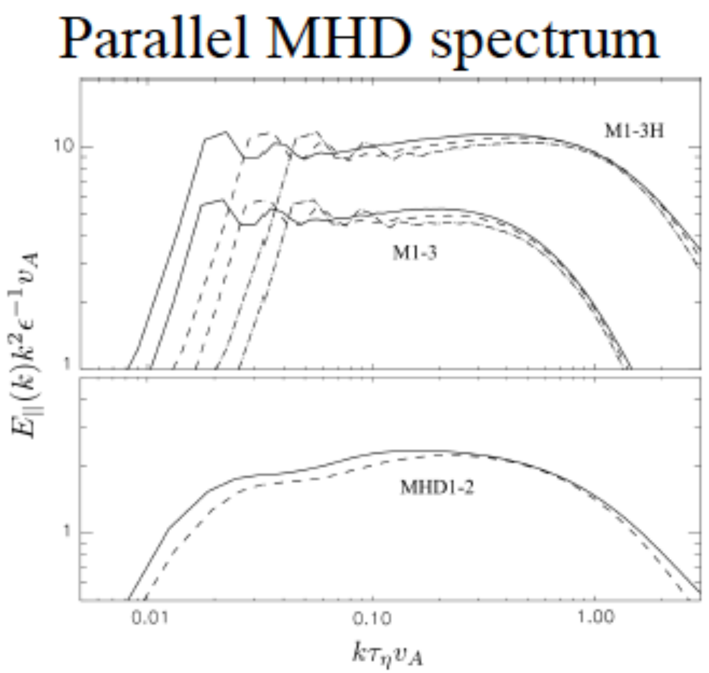


FIG. 1: (Color online) (a) Magnetic (solid lines) and kinetic (dashed lines) energy spectra for Run A at times $t/\tau_A = 18$, 130, 450, and 1800; the time $t/\tau_A = 450$ is shown as bold lines. The straight lines indicate the slopes k^4 (solid, blue), k^2 (dashed, blue), and k^{-2} (red, solid). (b) Same for Run B, at $t/\tau_A = 540$, 1300, and 1800, with $t/\tau_A = 1300$ shown as bold lines. The insets show E_M and E_K compensated by E_{WT}.

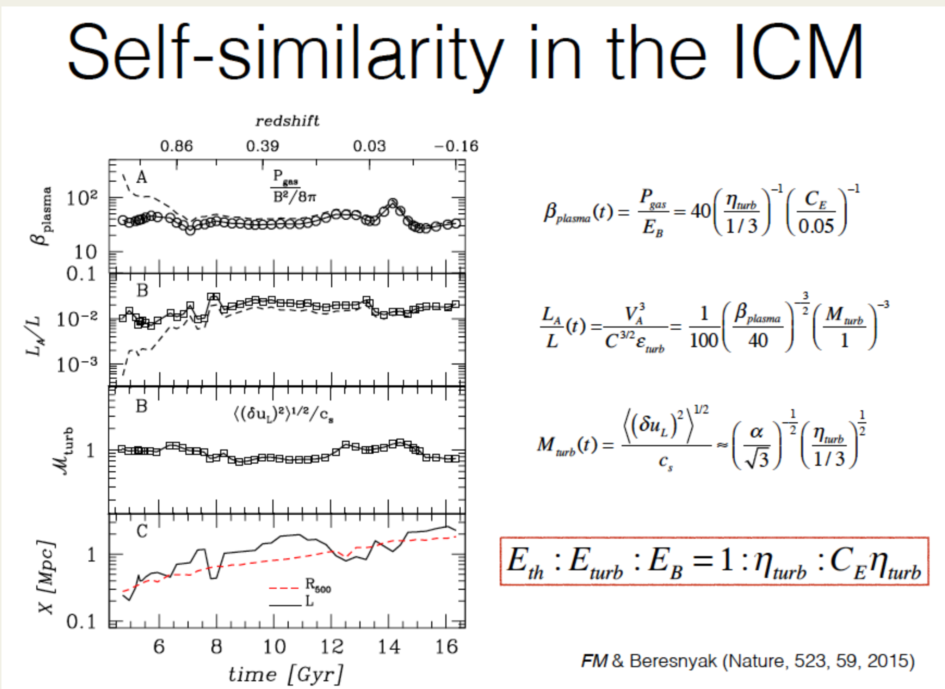
Talk by **Andrey Beresnyak**



$$E(k_\parallel) = C_\parallel \epsilon v_A^{-1} k_\parallel^{-2}$$

MHD Turbulence

Talk by **Francesco Miniati**



Results from a recent numerical model of structure formation that resolves the ICM turbulent cascade for the first time

Coupled with numerical studies of MHD turbulence our model reproduces remarkably well the observed properties of ICM magnetic field without any free parameter and independent of initial conditions

This calculation also shows that the evolution of ICM thermal, turbulent and magnetic field strength and structure are self-similar, with the turbulent dynamo far away from saturation as always

Non-Helical Inverse Transfer?

Talk by **Axel Brandenburg**

- High resolution direct numerical simulations

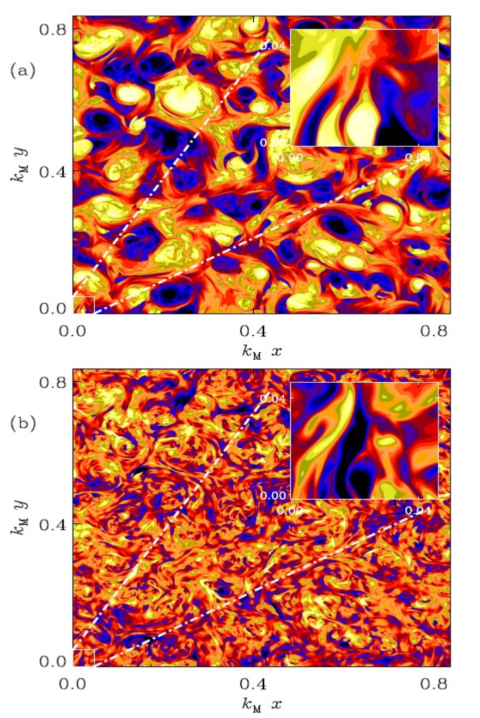


FIG. 2: (Color online) Contours of (a) $B_z(x, y)$ and (b) $u_z(x, y)$ for Run A. The insets show a zoom into the small square in the lower left corner.

Talk by **Andrey Saveliev**

- A semianalytic approach allows to determine the time evolution of the magnetic energy spectra including helicity directly, thus giving an alternative to much slower numerical simulations

Thank you!