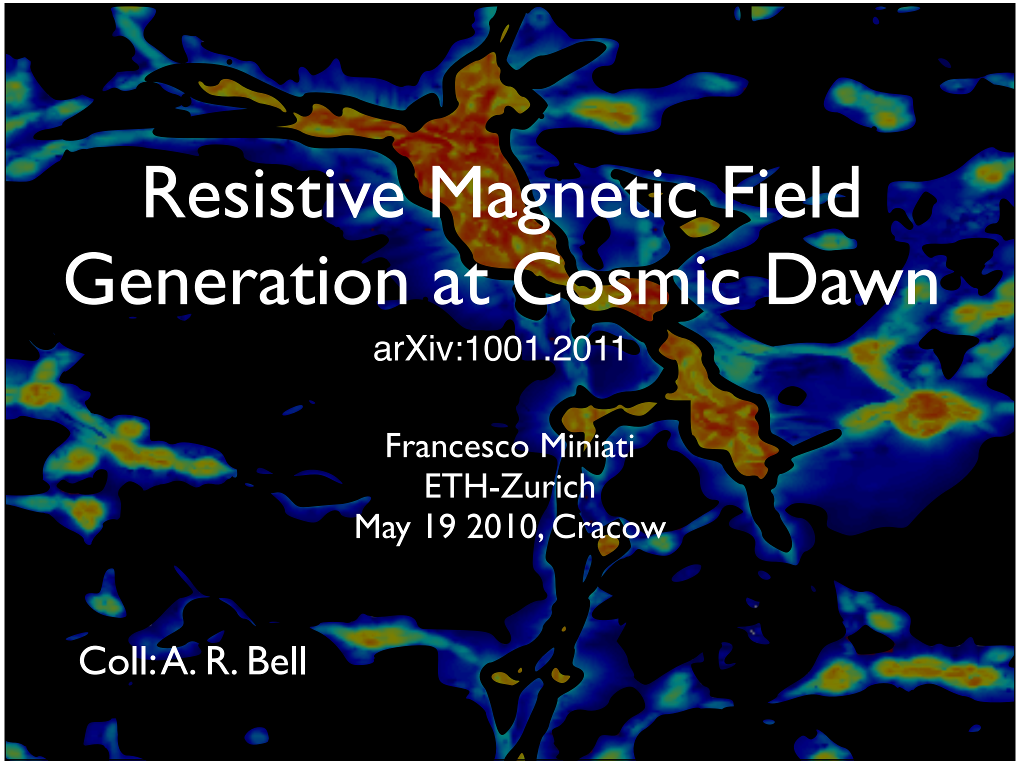

Resistive Magnetic Field Generation at Cosmic Dawn

arXiv:1001.2011

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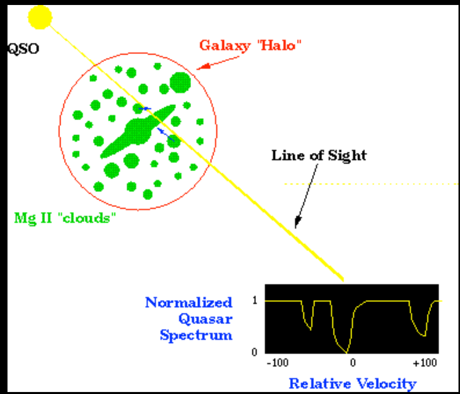
ETH-Zurich
May 19 2010, Cracow

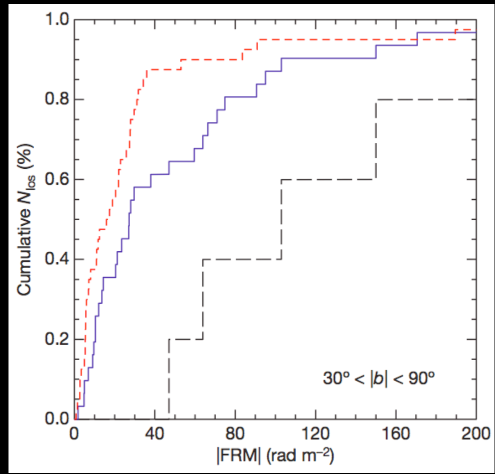
Coll: A. R. Bell

Cosmic Magnetism

- Galaxy
- Nearby galaxies
- Distant, “high-redshift” galaxies
- Clusters of Galaxies
- Filament of Galaxies (?)
- Cosmic Voids

Magnetism in Distant Galaxies





Bernet, Miniati, Lilly, Kronberg, Dessauges–Zavadsky 2008, Nature, 454, 302

Magnetism in Galaxy Filaments ?!?

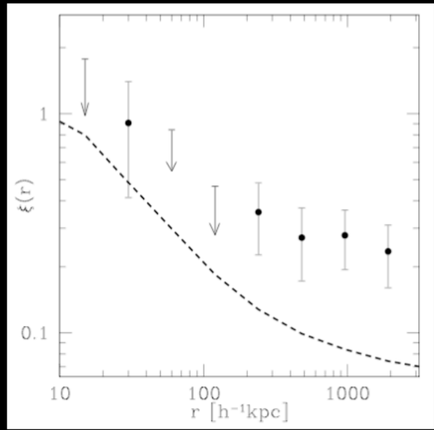
Cross correlation between excess |RM| and galaxies overdensity field (Sloan).

$$\Delta|RM| \text{ vs } \Delta\rho_{gal}$$

$$\Delta|RM| = |RM| - \overline{|RM|}$$

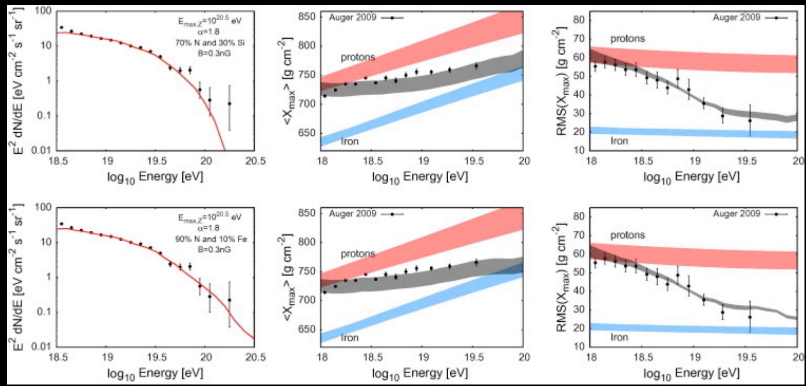
$$\Delta\rho_{gal} = \rho_{gal} - \overline{\rho_{gal}}$$

Authors conclude:
B~30 nG, L~Mpc.



Lee, Pen, Taylor, Stil, Sunstrum (arXiv:0906.1631)

Magnetism in Galaxy Filaments ?!?



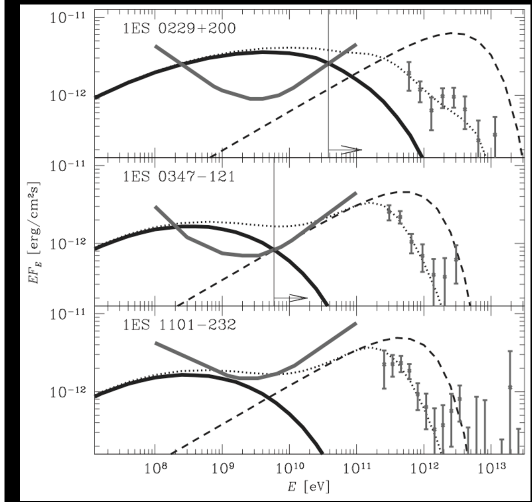
70% nitrogen
and 30% silicon

90% nitrogen
and 10% iron

B~0.3 nG, λ_B~1Mpc

Hooper and Taylor Astropart. Phys 33, 3 (2010,
see also, e.g., Sigl, Miniati, Ensslin (2004), Dolag et al (2005)

Magnetism in Voids



$$B_G \geq \begin{cases} 6\times10^{-17}\,\tau\left(\dfrac{E_{\gamma,\min}}{10\mathrm{TeV}}\right) & \lambda_B > D_e, \\ 8\times10^{-16}\,\tau\left(\dfrac{E_{\gamma,\min}}{10\mathrm{TeV}}\right)^{3/4}\left(\dfrac{\lambda_B}{kpc}\right)^{-1/2} & \lambda_B < D_e \end{cases}$$

Neronov and Vovk, Science 328 73 (2010), see also Tavecchio et al (2010) and Ando & Kusenko 2010 (**arXiv:1005.1924**)

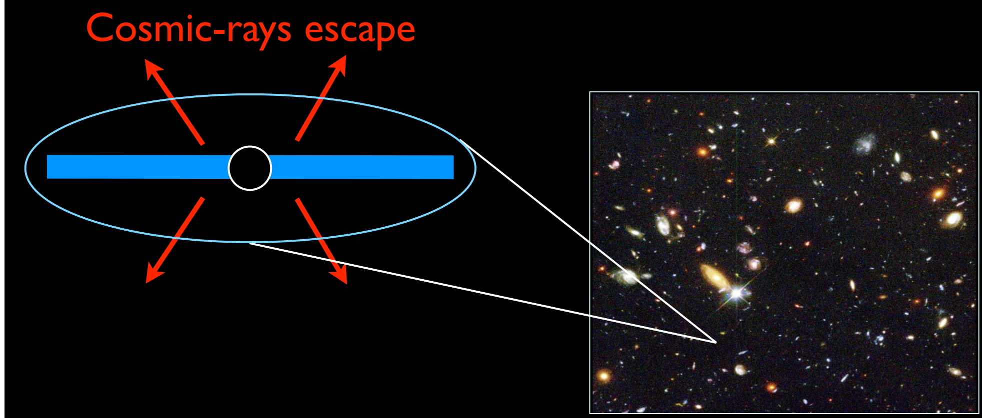
Mechanisms

$$\frac{\partial \vec{B}}{\partial t} = -c\vec{\nabla} \times \vec{E} = \vec{\nabla} \times \vec{u} \times \vec{B} + \frac{c^2}{4\pi\sigma}\nabla^2 \vec{B}$$

- Plasma processes: Biermann's battery (Kulsrud et al. 1997), Weibel's instability (Schlickeiser & Shukla 2003), Return currents.
- Galactic outflows (Bertone et al. 2006, Donnert et al.2009, Dubuois & Teyssier 2010)
- Early Universe (Ichiki et al. 2006)
- Jets from radiogalaxies (e.g., Furlanetto & Loeb 2001)
- Inflationary processes (see Durrer and coll.)

Resistive Mechanism

High-redshift (z>6) star forming galaxies produce copious amount of cosmic-rays which escape into the intergalactic medium.



Basics

- the CR current, j_{cr}, drives a return current in the plasma, j_{th}, that tends to cancel j_{cr} itself.
- The return current is associated with an electric field,

$$\vec{E}' = \frac{\vec{j}_{th}}{\sigma}, \quad \text{where (Spitzer) } \sigma \simeq 10^{7}\left(\frac{T}{K}\right)^{3/2} s^{-1}$$

Just prior to cosmic reionization the temperature of the IGM was at its lowest point (~1K), providing favorable conditions for the resistive mechanism.

Governing Equations

Ampere: $$\vec{\nabla} \times \vec{B} = \frac{c}{4\pi}\left(\vec{j}_{cr} + \vec{j}_{th}\right)$$

Ohm: $$\vec{E} + \frac{\vec{u}}{c} \times \vec{B} = \frac{c}{4\pi\sigma}\vec{\nabla} \times \vec{B} - \frac{\vec{j}_{cr}}{\sigma}$$

Faraday: $$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times \vec{u} \times \vec{B} - \frac{c^2}{4\pi\sigma}\vec{\nabla} \times \vec{\nabla} \times \vec{B} + c\vec{\nabla} \times \frac{\vec{j}_{cr}}{\sigma}$$

Ohmic Heating: $$\frac{3}{2} n k_B \frac{dT}{dt} = \frac{1}{\sigma} j_{cr}^2$$

Growth rate around bright galaxies

$$\dot{B} \approx c\vec{j}_{cr} \times \vec{\nabla}\frac{1}{\sigma} \approx \frac{cj_{cr}}{\sigma \ell_T}$$

$$\approx 10^{-15}\left(\frac{\ell_T}{\mathrm{kpc}}\right)^{-1}\left(\frac{T}{\mathrm{K}}\right)^{-3/2}\left(\frac{L}{L_*}\right)\left(\frac{d}{\mathrm{Mpc}}\right)^{-2}\frac{\mathrm{Gauss}}{\mathrm{Gyr}}$$

CR-current density

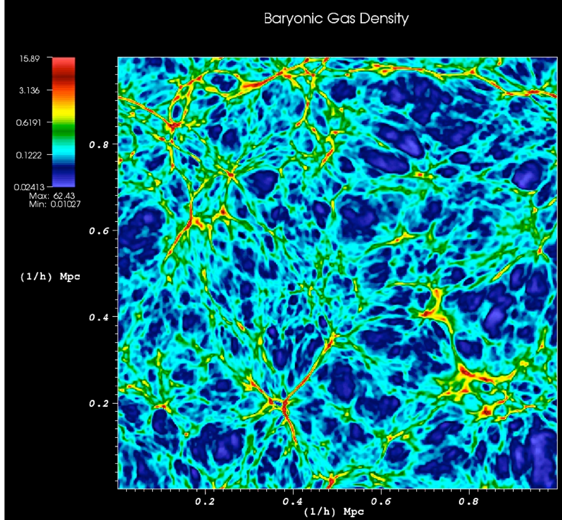
$$j_{cr} \simeq \frac{e\varepsilon_{cr}L}{2\pi R^2 p_{\min} c \Lambda_{cr}}\left(\frac{\theta d}{R}\right)^{-2}$$

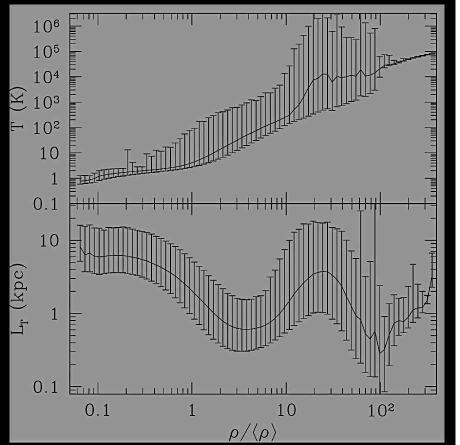
Temperature scale-length

$$\ell_T \equiv \frac{T}{|\nabla T|}$$

Ohmic heating increases the temperature, i.e. conductivity, so after one Gyr B~10^{-16} Gauss.

IGM at z≈6





Miniati & Colella (2007)

Growth rate in the IGM

Luminosity Function

$$\Phi(L) = \Phi_* \left(\frac{L}{L_*}\right)^{-\alpha} e^{-L/L_*} \quad : \quad dn(L) = \Phi(L)\frac{dL}{L_*}$$

Mean distance between L-galaxies

$$\langle d_L \rangle = \left[\frac{L}{L_*}\Phi(L)\right]^{-1/3} \propto L^{(\alpha-1)/3}$$

Magnetization around L-galaxies

$$\dot{B} \propto L \langle d_L \rangle^{-2} \propto L^{1/2}$$

Prior to reionization the universe is magnetized with fields B~10^{-16}-10^{-17} G

Conclusions

- Magnetic fields are ubiquitous and various mechanisms likely responsible for their origin.
- Interesting recent developments to measure magnetic fields in filaments and voids !
- Resistive mechanism provides suitable seeds for effects observed in filaments and voids, with fields $B \sim 10^{-16}$-10^{-17} G at $z \sim 6$.