Modeling the Evolving Cosmological Magnetic Fields

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Abstract We try to use the change of variance of residual rotation measures (RRMs) of 43 extragalactic radio sources at Galactic latitudes $|b| > 70$ deg with their redshift to explore the evolution of cosmological magnetic fields. Three models have been considered to fit our data: the evolving Friedmann (EF) model, the steady state (SS) model and the ionized cloud (IC) model. We find that the EF+IC model can fit our data best, which means cosmological magnetic fields probably evolve with time and evolve more in the intercloud medium, though we can not exclude the other models.

Rotation measures (RMs) of extragalactic radio sources contain information of large-scale cosmological magnetic fields. The observed rotation measures contain two contributions: Galactic rotation measure (GRM) and residual rotation measure (RRM). In other directions of our Galaxy, the Galactic contribution is very uncertain, while near the two Galactic poles, the GRM is very small, about ± 3 rad m^{-2} (Han, Manchester & Qiao 1999) .

We select all objects of Galactic latitudes $|b| > 70$ deg and use the change of variance of RRMs with redshift to explore the evolution of cosmological magnetic fields. In this sky area, some sources have RM values but do not have redshift measured, which had to be discarded in our analysis. We exclude a few objects with redshift $z > 2.5$. These objects with rotation measure $|RM| > 100$ rad m^{-2} are ruled out too, because the large rotation measure is most probably intrinsic to the source. Finally, we have 43 objects with observed rotation measures and redshift values.

We now consider three models of intergalactic Faraday rotation.

Nelson (1973) has presented the evolving Friedmann (EF) model. In this model, both the cloud and the medium between the clouds evolve with redshift. The distribution of RMs have a variance of

$$V_{EF} = \gamma_{_{EF}} \int_0^{z_s} \frac{(1+z)^3}{(1+\Omega z)^{1/2}} dz \qquad , \qquad \gamma_{_{EF}} = (0.81 n_0 B_{\|0})^2 \frac{l_0 c}{H_0}$$

where z_s is the source redshift, Ω the density parameter of the universe, n the electron density (cm^{-3}), $B_{||}$ the line-of-sight field component (μG), l the size of the cell (pc) and H the Hubble parameter. The subscript 0 denotes the present epoch. c is the light speed.

Burman (1974) derived an expression for the variance of RMs in the steady state (SS) model. In this case, neither the cloud nor the medium between the clouds evolves with redshift. The electron density n_e, the field component along line-of-sight $B_{||}$ and cell size l do not vary with epoch. The variance becomes

$$V_{SS} = \frac{\gamma_{SS}}{4} \left[1 - (1+z_s)^{-4}\right] \qquad , \qquad \gamma_{SS} = (0.81 n_e B_{\|})^2 \frac{lc}{H}$$

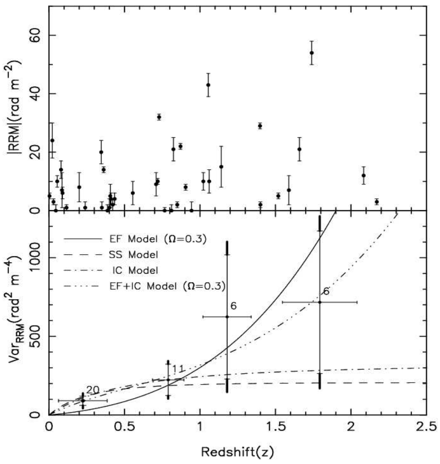

Fig. 1 Estimated variance of residual rotation measure V_{RRM} versus redshift z for objects near two Galactic poles

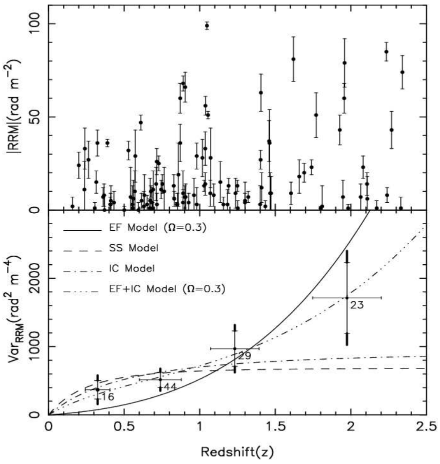

Fig. 2 The relation between variance of residual rotation measure V_{RRM} and redshift z in WPK's data

In the ionized cloud (IC) model (Thomson & Nelson 1982), the cloud does not evolve with redshift, but the medium between the clouds does, then the variance is

$$V_{IC} = \frac{\gamma_{IC}}{2}\left[1-(1+z_s)^{-2}\right] \qquad , \qquad \gamma_{IC} = (0.81 n_e B_{\|c})^2 \frac{l_c c f_0}{H_0}$$

where f_0 is the fraction of space in present epoch. The subscript c means the cloud.

We can use these three models to fit our RRM data. The results are shown in figure 1. It is clear that the dispersion of $|RRM|$ increases with redshift (upper panel). It is also obvious that none of the three models can fit our data well, but the combination of the EF model and IC model (see model parameters in table 1) can fit our data better (lower panel).

Table 1 Best fit model parameter γ as estimated from RRM data

	EF	SS	IC	EF+IC	
				γ_{EF}	γ_{IC}
γ (rad^2 m^{-4})	88	828	650	44	442

We also use the same method to fit the WPK's RRM data (Welter, Perry & Kronberg, 1984). The sources are distributed randomly in sky, so the GRM is more uncertain, hence error bar of their data is larger than ours. But the number of their sample is greater than ours. In figure 2, we can see that the best fitting to their data is almost the same as ours.

We conclude that the EF+IC model can best fit our and WPK's RRM data, which indicates that cosmological magnetic fields probably evolve with time and evolve more in the intercloud medium. But no model can be excluded from our results because of small sample and large error bar. We need observe more rotation measures of high polarized quasars and AGNs to increase sample size and decrease the error bar, which can improve our results.

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