SKA and the Cosmic Radio Dipole

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Abstract. We study the prospects to measure the cosmic radio dipole by means of continuum surveys with the Square Kilometre Array. Such a measurement will allow a critical test of the cosmological principle. It will test whether the cosmic rest frame defined by the cosmic microwave background at photon decoupling agrees with the cosmic rest frame of matter at late times.

Keywords. Cosmology

The Square Kilometer Array (SKA) will enable the observation of extragalactic radio sources up to large cosmological distances. The SKA’s high survey speed offers the unique possibility to survey wide areas and to probe the largest observationally available scales in the Universe. The largest feature on the radio sky is the cosmic radio dipole.

The standard model of cosmology predicts that the radio sky must be isotropic. Deviations from isotropy are expected to arise from the proper motion of the Solar system w.r.t. to the isotropic sky. This kinematic signal is expected to be contaminated by a dipole from the matter distribution in the local large scale structure and from light propagation effects. We show that the SKA will be able to measure the kinematic dipole.

It is expected that this kinematic radio dipole agrees with the cosmic microwave background (CMB) dipole, which is assumed to be caused by the proper motion of the Sun with respect to the cosmic heat bath. The CMB dipole establishes the frame of the comoving observers, a central concept in modern cosmology, i.e. the observers that are at rest with respect to a spatially flat Friedmann-Lemaître space-time.

The CMB dipole has been measured by Planck with high accuracy and allows us to infer a proper motion of the Sun with a speed of $v = (369.82 \pm 0.11) \text{ km/s}$ towards the Galactic coordinates $l = (264.021 \pm 0.011)^\circ$ and $b = (48.253 \pm 0.005)^\circ$ \cite{Akrami2018}. However, the CMB dipole could also contain other contributions, e.g. a primordial temperature dipole or an integrated Sachs-Wolfe effect. Both effects are expected to be sub-dominant, but the cosmic variance of the dipole is large.

The extragalactic radio sky offers an excellent opportunity to perform an independent test of the proper motion hypothesis. It is expected that the radio dipole is dominated by the kinematic dipole, similar to the CMB. This is not the case for galaxy surveys at visible or infrared wavebands, which probe much lower redshifts.

The kinematic dipole in the radio source counts is due to Doppler and aberration effects and leads to a dipole amplitude of\cite{Ellis1984}

$$A = [2 + x(1 + \alpha)]\beta,$$

(0.1) assuming a universal power-spectrum of the flux density $S \propto \nu^{-\alpha}$, a scaling of number counts according to the relation $N(> S) \propto S^{-x}$, and $\beta$ the dimensionless velocity of our
motion relative to the radio sky. We will assume hereafter $\alpha = 0.76$, $x = 1$ and $\beta \equiv v/c$, hence giving a fiducial kinematic dipole amplitude of $A = 0.0046$.

In order to test the ability to measure the cosmic radio dipole, we create mock catalogues on which we test our dipole estimators. The mock catalogues and our analysis is described in detail in Bengaly et al. (2018). Here we present results for a wide area survey with SKA phase 1 by means of the SKA-mid frequency instrument in band 1 (350 MHz to 1050 MHz) and assume a continuum flux density limit of $S > 20 \mu$Jy (see Fig. 1).

The result for the estimated radio dipole from 500 simulations is $l = (260 \pm 20)^\circ$ and $b = (45 \pm 16)^\circ$, when all radio sources are taken into account. The significant scatter is due to the contribution of the local matter dipole, i.e. the inhomogenous distribution of radio objects at small redshifts. This scatter can be reduced when local sources are excluded from the analysis. We assume that we will be able to identify the objects below redshift of 0.5 and exclude them from the analysis. That is likely to be possible by means of redshift measurements based on an SKA HI survey or based on photometric redshifts from surveys in the infrared and visible. Excluding local structures leads to a slight increase of Poisson noise, but the random admixture of the local structure dipole is largely suppressed. The resulting radio dipole points towards $l = (264.9 \pm 5.6)^\circ$ and $b = (46.7 \pm 5.1)^\circ$, in excellent agreement with the CMB dipole direction. Similar improvement is seen in the dipole amplitude, which reduces from $A = 0.0052 \pm 0.0012$ to $A = 0.0048 \pm 0.0005$, when local radio sources are excluded. The estimate is in excellent agreement with the fiducial value, with an uncertainty on the kinematic radio dipole of 10 per cent.

This analysis goes beyond and complements the results presented in Schwarz et al. (2015) where the effects of Poisson noise, survey area, kinematic dipole and declination dependent systematics have been studied. We now included the effects of large scale structure and relativistic light propagation effects.

CB and RM acknowledge support from the South African SKA Project and the National Research Foundation of South Africa (Grant No. 75415). RM was also supported by the UK Science & Technology Facilities Council (Grant No. ST/N000668/1). TMS and DJS acknowledge support from DFG within project RTG 1620 “Models of Gravity”.

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