Jupiter's Acceleration of the Sun Imprints a Time-Dependent Large-Scale Pattern on the CMB Sky

Abraham Loeb
Astronomy Department, Harvard University, 60 Garden St., Cambridge, MA 02138, USA
(Dated: July 28, 2010)

The reflex acceleration of the Sun by Jupiter adds a periodic 11.86 yr time component with a variable orientation to the dipole anisotropy of the Cosmic Microwave Background (CMB). Although this contaminating signature is an order of magnitude below the sensitivity of WMAP, it might be detectable with future CMB experiments. The time-dependent large-scale anisotropy pattern must be corrected for, in order to realize the full sensitivity of future CMB experiments in constraining cosmological parameters.

PACS numbers: 95.30Dr, 95.55Jz, 98.80-k

Jupiter accelerates the Sun in its direction by an amplitude,

$$a_\odot = \frac{GM_{\rm J}}{r_{\rm J}^2} = 6.9 \times 10^{-3} \frac{\rm km\ s^{-1}}{\rm yr}, \qquad (1)$$

which varies periodically over its orbital time of 11.86 yr. Here $M_{\rm J} = 1.9 \times 10^{30}$ g and $r_{\rm J} = 7.8 \times 10^{13}$ cm are the mass and semi-major axis of Jupiter. The motion of the Earth and its human-made satellites around the Sun follows adiabatically this acceleration, because the orbital period of the Earth is an order of magnitude shorter than that of Jupiter.

Jupiter's acceleration represents the biggest change to the peculiar velocity of the Sun over the timescale of a decade, which is characteristic for the lifetime of cosmological experiments. Because the variability timescale is long, the effect is not washed out. The steady gravitational acceleration towards the Galactic center, for example, is smaller by 4 orders of magnitude.

Over its first seven years, the WMAP satellite measured the dipole anisotropy of the Cosmic Microwave Background (CMB) in terms of a Doppler peculiar velocity $\mathbf{v}$ with a precision of

$$\mathbf{v} \pm \Delta\mathbf{v} = (-25.65, -244.6, 275.7) \pm (0.55, 0.44, 0.33) {\rm km\ s^{-1}} \qquad (2)$$

in Galactic (x, y, z) coordinates (based on Table 6 in Jarosik et al. [1] for a present-day CMB temperature of 2.725K [2]). The 1–σ uncertainty in the WMAP7 data to the acceleration of the Sun is therefore,

$$\Delta\mathbf{a} = \left(\frac{\mathbf{\Delta v}}{7\ \rm yr}\right) = (7.9, 6.3, 4.7) \times 10^{-2}\ \frac{\rm km\ s^{-1}}{\rm yr}, \qquad (3)$$

only an order of magnitude above the amplitude of $a_\odot$ owing to the acceleration of the Sun by Jupiter. The microwave emission from Jupiter (and other planets) is masked out by CMB experiments like WMAP, but the dipole pattern we consider here is not removed since it stretches across the entire sky.

In difference from the cosmological dipole, the Jupiter-induced dipole changes its orientation in Galactic coordinates periodically over a time of 11.86 years, because it is always aligned with the Sun-Jupiter axis. Only the barycenter velocity of the solar system should be assumed constant in time in the CMB analysis pipeline [3]. If the Jupiter-induced dipole is not subtracted off properly in a time-dependent fashion, the CMB would acquire a residual large-scale anisotropy pattern which depends on the specific time-ordered scan path of each experiment across the sky. Any uncorrected large-scale pattern on the sky could compromise the determination of cosmological parameters from the CMB anisotropies.

Since the projected sensitivity of the Planck satellite to the CMB dipole is expected to be better than that of WMAP [4], the above time-dependent signature should be included in its data analysis pipeline.

Acknowledgements. This work was supported in part by NSF grant AST-0907890 and NASA grants NNX08AL43G and NNA09DB30A.

[1] N. Jarosik, et al., Astrophys. J. Suppl., submitted, arXiv:1001.4744 (2010).
[2] J. C. Mather, D. J. Fixsen, R. A. Shafer, C. Mosier, & D. T. Wilkinson, Astrophys. J. **512**, 511 (1999).
[3] G. Hinshaw, et al., Astrophys. J. Suppl. **180**, 225 (2009).
[4] M. Piat, G. Lagache, J. P. Bernard, M. Giard, & J. L. Puget, Astron. & Astrophys. **393**, 359 (2002).