DIRECT DETECTION OF THE SUN'S GALACTOCENTRIC ACCELERATION

U. Bastian

Astronomisches Rechen-Institut, Mönchhofstrasse 12-14, D-69120 Heidelberg, Germany

ABSTRACT

The sun's absolute velocity with respect to a cosmological reference frame was measured photometrically: it shows up as the dipole anisotropy of the cosmic microwave background. The sun's absolute acceleration with respect to a cosmological reference frame can be measured astrometrically: it shows up as proper motions of quasars. The astrometric interferometer satellite GAIA, proposed for ESA's Horizon 2000+ programme, will just be able to detect the effect.

Key words: GAIA; quasars: proper motions; cosmological reference frame; galactic rotation; space astrometry.

1. INTRODUCTION

Recently ESA's Horizon 2000+ Survey Committee in its final report (ESA, 1994) recommended *'that ESA initiate a Cornerstone-level programme in interferometry for use as an observatory open to the wide community. The first aim is to perform astrometric observations at the 10 microarcsec level'.* This recommendation follows a proposal by Lindegren et al. (1994), see also Lindegren & Perryman (1995) for a specific mission under the name of GAIA ('Global Astrometric Interferometer for Astrophysics'), which is designed to measure positions, annual proper motions and parallaxes of about 50 million stars and other pointlike objects to a precision of 10–20 microarcsec. The limiting magnitude of GAIA would be about $V = 16$ mag. In addition to the astrometric data the satellite would also collect high-precision multi-colour photometry of all observed objects.

The present paper demonstrates that such a mission may directly measure the sun's gravitational acceleration towards the galactic centre.

2. THE ASTROMETRIC EFFECT

The solar system's orbital velocity around the galactic centre causes an aberration effect of the order of 2.5 arcmin. All measured star and quasar positions are shifted towards the point on the sky having galactic coordinates $l = 90°$, $b = 0°$. For an arbitrary point on the sky the size of the effect is $2.5 \sin \eta$ arcmin, where η is the angular distance to the point $l = 90°$, $b = 0°$. The acceleration of the solar system towards the galactic centre causes this aberration effect to change slowly. This leads to a slow change of the apparent positions of distant celestial objects, i.e., to an apparent proper motion.

Let us assume a solar velocity of 220 km/s and a distance of 8.5 kpc to the galactic centre. The orbital period of the sun is then 250 million years, and the galactocentric acceleration takes on a value that is both impressive and easy to remember: 2.0 Å/s^2. Expressed in a more useful unit it is 6 mm/s/yr. A change in velocity by 6 mm/s causes a change in aberration of the order of 4 μarcsec. The apparent proper motion of a celestial object caused by this effect always points towards the direction of the galactic centre. Its size is $4 \sin \zeta$ μarcsec/yr, where ζ is now the angular distance between the object and the galactic centre.

The above holds in particular for quasars, for which it can be assumed that the intrinsic proper motions (i.e., those caused by real transverse motions) are negligible. A proper motion of 4 μarcsec/yr corresponds to a transverse velocity of 20 000 km/s at $z = 0.3$ for H_0=100 km/s/Mpc, and to 40 000 km/s for H_0=50 km/s/Mpc. Thus, all quasars will exhibit a distance-independent streaming motion towards the galactic centre. Within the Galaxy, on the other hand, the effect is drowned in the local kinematics: at 10 kpc it corresponds to only 200 m/s.

3. MEASUREMENT OF THE EFFECT BY GAIA

How many quasars must be observed by GAIA to measure the effect? We assume that the random errors of the proper motions of individual objects are 10 μarcsec/yr, and that the systematic errors are significantly smaller than this. Then, in order to measure the effect at a 3σ significance level, about $(10/4)^2 \cdot 3^2 \simeq 60$ objects are needed. However, in Landolt-Börnstein (1982) only a handful of quasars brighter than $V = 16$ mag are listed. So, at first sight the prospects for measuring the effect are looking bleak.

The present GAIA concept is but a preliminary design study based largely on present-day technology. One can expect that an optimized instrument, to be built more than a decade from now, may go fainter by one magnitude. This would give 13 quasars. Adding the 20 Seyfert galaxy nuclei, the 9 BL Lac objects and 6 nuclei of radio galaxies which are brighter than $V = 16$ mag (all according to Landolt-Börnstein), we arrive at 40 objects. This is fairly close to the required number of 60.

In conclusion, it seems quite possible that GAIA can significantly measure the galactocentric acceleration of the solar system.

4. DISCUSSION

Two things should be pointed out. The first concerns the GAIA data reductions. The effect in the quasar proper motions is of interest for the satellite even if it could not be measured significantly. It must be taken into account in the linking of the GAIA observations to a quasi-inertial extragalactic reference frame; else the GAIA system of proper motions would be severely distorted. In order to be able to do so, the size of the effect will then have to be determined from a galactic model. This in turn will have to be derived from GAIA measurements of galactic objects. This is not a logical circle, since the proper motions entering that galactic model are orders of magnitude larger than the quasar proper motions.

The second point concerns the list of usable objects for the measurement of the galactocentric acceleration. Hopefully, a few more bright galactic nuclei will be known 20 years from now. Other types of extragalactic objects will not contribute to the list: The brightest stars (absolute magnitudes around -10) are at the magnitude limit of GAIA at a distance of the order of 1 Mpc already; and all intrinsically brighter objects are not sufficiently pointlike.

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