ALL-SKY SURVEY MISSIONS AND OPTICAL INTERFEROMETERS: COMPLEMENTARY TOOLS IN BUILDING REFERENCE FRAMES

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ABSTRACT. With several space astrometry missions planned for being launched during the next 10 years, celestial reference frames in the optical range should have their accuracy boosted by several orders of magnitude. The potential of all-sky survey missions in building reference frames is compared with that of space interferometers. With their unique capability in quasar imaging, large ground-based interferometers will contribute also to the extension of the International Celestial Reference Frame (ICRF) into the optical/near-IR range.

1. INTRODUCTION

The International Celestial Reference Frame (ICRF) is the primary realization of the International Celestial Reference System (ICRS). It is based on the most accurate positions of compact radio-loud quasars, measured through VLBI observing in the centimeter wavelength range (Arias et al. 1995). In the optical range, the ICRS realization had to be a two-step procedure, firstly with an accurate sphere of stellar objects, the Hipparcos sphere Great Circle solution, and then with the linking of this sphere to the extragalactic frame (Kovalevsky et al. 1997).

The actual frame for astrometric measurements in the optical range is the Hipparcos Stellar Reference Frame (HCRF), with about 100 000 objects. As this name tells us, a frame needs celestial objects and a building tool, i.e. a measuring instrument with accurate methods in its data analysis.

Much denser frames should be materialized for any positioning of celestial objects observed with modern large telescopes (that is with small fields), and large telescopes are needed for positioning extragalactic compact sources (QSOs). Densification and improvement of the optical frame is one of the objectives of future all-sky survey missions. DIVA[1] was supposed to measure the astrometric parameters of all objects up to a magnitude 15 (for a K0 star), that is about 40 millions stars. FAME[2] was supposed to observe the same amount of stars, with improved accuracy mainly due to a longer mission duration (5 years for FAME versus 2 for DIVA). [3]

[1] http://www.ari.uni-heidelberg.de/diva/

[2] http://www.usno.navy.mil/FAME/

[3] This contribution has been prepared while the chances of having a post-Hipparcos astrometry mission launched before GAIA were not meagre. DIVA was then asking for some ESA support. Furthermore a cooperative venture between DIVA and FAME could have been considered. In February 2003, DIVA has been stopped.

Waiting for the next all-sky survey mission, astronomers are left with astrometric catalogs realized with ground-based observations. The most accurate extension catalog with all-sky coverage is supposed to be the USNO CCD Astrograph Catalog (Zacharias et al 2000) with more than 50 millions stars. A preliminary release of UCAC2 has been issued in May 2003. It is covering the all declination range up to about +50 degrees.

An all-sky survey mission is a mass production method providing a systematic census of astrometric parameters for a (large) bulk of celestial objects, whose size is mainly dependent on the aperture size of the telescope. The observing conditions are set at once and cannot be adjusted on purpose. A more versatile instrument for space astrometry is a long baseline steered optical interferometer: (i) fainter objects can be observed with small apertures, the exposure duration being a free parameter, (ii) higher precision in angular measurement can be achieved due to the length of the baseline (as compare to the aperture size of a telescope).

This contribution is mainly an outlook to the intricate relation between optical interferometry and reference frames, with two main questions: what could bring optical interferometers in this field, and conversely, what would be needed as spatial reference frame for optical interferometers to work properly ? Basic principle of measuring tools are first recalled in Sect.2 and Sect.3.

2. ALL-SKY SURVEYS

In the Hipparcos concept, objects from two widely separated fields of view are simultaneously observed with a single telescope. The separation angle between the two fields is along the scan direction of a spinning spacecraft. The DIVA and FAME projects strictly obeyed this concept, with a CCD focal plane assembly and charge transfer along the scan direction (TDI mode). The GAIA mission (see *http://astro.esa.int/gaia/*) partly followed this concept in its 2000 design. Due to the large entrance pupils, two independent telescopes tied on a rigid mount were viewing two widely separated fields. In the 2002 GAIA revised design, the two fields are superposed in an intermediary image plane of a telescope assembly, the two entrance pupils viewing fields at wide angle. The result is a common focal plane for the two superpimposed fields.

A CCD cell in the TDI observing mode is simply modelled as a linear (1-D) detector nearly perpendicular to the scan direction. Furthermore, effects of uncontrolled variations in the spacecraft attitude are strongly reduced for angular measurements between objects in one and the other field. Observing quasi simultaneously different objects in two fields well apart acts precisely as replacing poorly constrained attitude parameters with a fixed basic angle, built in the instrument. The net result is much more accurate measurements in the scan direction, remaining uncertainties in the spin axis direction producing only second order effects.

Objects are observed many times, with different scanning directions. For simple objects, estimating the astrometric parameters is an over-determined problem. The first reduction step of along scan strips, in so-called Great Circle provisionary frames, could take their initial solution from Hipparcos (HCRF) in case of a DIVA/FAME type of mission, and eventually from such a mission with sub-mas accuracy in case of GAIA.

All-sky surveys, and particularly a series of all-sky survey missions, are powerful tools for building celestial reference frames, as long as they are realizations of the ICRS. GAIA will observe and measure the position of several millions extragalactic objects, QSOs and galaxies, for a new realization of the ICRS in the optical range. With a smaller mission, like DIVA, only a few extragalactic objects might be observed, but a link with sub-mas accuracy per each quasar is still possible with ground-based technics such as large optical interferometers in the near-IR, as discussed in the last Section.

3. OPTICAL INTERFEROMETERS

In long-baseline optical interferometry with dilute apertures, the measured quantity is an optical path difference, given by the scalar product $\vec{B} \cdot \vec{\Theta}$, where $\vec{B}$ is the baseline vector and $\vec{\Theta}$ the source direction. Astrometry with a single baseline interferometer appears to be an under-determined problem with a single measurements and three unknown if the baseline length is measured independently. The problem can only be solved with the observation of several sources and a set of baseline directions. For ground-based observations, Earth rotation makes the baseline to change, as seen from the direction of the sources. With enough sources, their relative direction together with baseline orientations can be determined in the same reference system.

In space, baseline orientation or precise attitude control of a spacecraft is much more of a problem. The Space Interferometry Mission (SIM) (see *http://planetquest.jpl.nasa.gov/SIM/*) brings an answer with two auxiliary (or guide) interferometers and a main (or science) one sharing the same baseline. The guide interferometers will observe two different sources well apart the main target for attitude control of the interferometer baseline.

High precisions can be reached in small angle measurements, even with not so accurate positioning of the guide stars in a celestial reference frame. They need only to be fixed during a whole observing sequence of several stars with a set of baseline orientations. A local solution will be found for the relative directions of sources. This mode of observation has been labelled the Gridless Narrow Angle Astrometry mode. It will be used by SIM for the detection of exoplanetary system through the displacement of their central star, which is the driving scientific program for SIM. 'Basic' requirements for narrow-angle astrometry (less than 1 degree) are 3 μas per measurement.

Although not really design for, SIM will be able to build a whole celestial frame, step by step, with measurement of angular distances up to 15 degrees. Such a frame, the 'astrometric grid', will be further used during the 5 years mission for accurate baseline calibration. It will be materialized with the position (and astrometric parameters) of about 3000 stars in the V magnitude range 11-12. With a baseline orientation under control, objects as faint as V=18-19 can also be observed with the science interferometer, and the 'astrometric grid' can be positioned in the inertial system (ICRS). 'Basic' requirements for global astrometry are 30 μas in each object position uncertainty.

By analogy with the basic angle setup of all-sky survey missions, an astrometric space interferometer will greatly benefit from a dual-field system, with simultaneous observation of two sources at a certain angle. The measured quantity will be the projection of the separation angle between the two sources ($\vec{\Delta}\Theta$) onto the interferometer baseline. Attitude control is still needed, but becomes much less stringent when the two vectors, $\vec{B}$ and $\vec{\Delta}\Theta$ are nearly aligned. Such a setup has been proposed in the OSIRIS project which should be mounted on the Russian segment of the International Space Station (ISS) (Tokovinin et al. 1999). This dual-field optical interferometer had been designed for wide-angle measurements and a precision of 20-30 μas per measurement.

Optical space-based interferometry will probably reach very high precision in angular measurements, all the more these are small angles. But, in trying to build a celestial reference frame by its own, it may suffer from the lack of closure relations and of the lack of redondancies. Space interferometry appears to be a complementary tool in astrometry, and not so much a primary one. The effect of baseline uncertainty is proportional to the measured angle, and the benefit of an all-sky mission being launched before SIM may have to be reconsidered for not too small angular measurements with the space interferometer.

4. DISCUSSION

Much denser frames than HCRF have to be considered for ground-based observations with large telescopes, and much more accurate frames have to be considered for space interferometry. With both needs, the most useful magnitude range for a celestial reference frame is probably V=11-16. On the faint edge, the mean on-sky density is about a thousand stars per square degree. On the bright edge, optical interferometry and fringe tracking is possible with small apertures.

Such a magnitude extension of HCRF requires a post-Hipparcos survey mission. With detailed imaging of the near-IR counterpart of quasars (Daigne et al. 2003), large ground-based interferometers will greatly contribute to building an optical/near-IR reference frame with about the same accuracy as that of the ICRF.

5. REFERENCES

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