PROSPECTS OF SPACE ASTROMETRY

P. BACCHUS and P. LACROUTE
Observatoire de Strasbourg, France

Abstract. The advantages of making astrometric observations from space are reviewed, and a project for measuring angular separations between stars along great circle arcs of the order of 90°, by means of a telescope mounted on a TD 1 satellite is described. Positions with accuracy of the order of $\pm 0\overset{''}{.}01$, parallaxes to $\pm 0\overset{''}{.}007$ and proper motions to $\pm 0\overset{''}{.}005$ yr^{-1} for some 40000 stars brighter than $9\overset{m}{.}5$ would be obtainable in a two year programme.

1. Introduction

The problems in astrometry which may benefit from the specific character of space observations are those related to relative positions of stars, either at small angular separations (double stars) or distributed on the whole sky (reference sphere). The problems of proper motions and of trigonometric parallaxes are of the same nature.

On the other hand, problems dealing with the position of the Earth with respect to the stars (precession, etc.) can benefit only indirectly from space observations.

The advantages of space astrometry over ground based observations are the following:

(1) No atmospheric refraction, and hence no uncertainty affecting its value, and no rapid changes of the refraction

(2) No atmospheric absorption, which renders astrometry in the UV and X-ray wave lengths feasible

(3) No atmospheric diffusion, semi-permanent observations being therefore possible

(4) No gravity, hence no flexure

(5) Better images; stars at smaller angular distances, and fainter stars are within reach.

In Section 3 of this paper, a project submitted to ESRO, implying the launching of a new TD 1 satellite, is described. The order of magnitude of the cost would be of 10^7 F.F., a comparatively small figure, with regard to the results hoped for.

2. Consequences for Astrometry

We assume that relative positions, parallaxes and proper motions of at least 40000 stars, brighter than $m = 9.5$, with accuracies of $0\overset{''}{.}01$, $0\overset{''}{.}007$ and $0\overset{''}{.}005$ yr^{-1} respectively will be secured within two years.

This sphere, because of the way it is established, will be 'fitted' to the present fundamental system FK4; although 'fitted' is somewhat ambiguous, because the fit depends on the weight attached to the stars' present position. The weighting system, which should take into account the random errors and the systematic errors, is not easy to set up.

Gliese, Murray, and Tucker, 'New Problems in Astrometry', 277–282. *All Rights Reserved.*
Copyright © 1974 *by the IAU.*

https://doi.org/10.1017/S0074180900069977 Published online by Cambridge University Press

We shall examine some of the possible uses of this sphere.

(1) The positions and proper motions of the stars observed define a frame of reference. It can be rendered absolute in different ways:

(a) One may use the information on precession constants that are now available

(b) One may use observations of extragalactic objects

(c) One may use celestial mechanics

In any case, the fact that the system is rigidly defined enables us to use simultaneously observations obtained for any region of the sphere, and will yield far more accurate results than those now being used.

(2) The number of stars included in the system will be such that systematic errors in all our catalogues of present positions and of proper motions will easily be removed.

Furthermore, the absolute parallaxes observed without any systematic error for a much larger number of stars than is now available, will enable us to make statistical estimates of luminosities and to study systematic errors in the presently available material.

(3) The reference system obtained will be very well suited for problems of celestial mechanics and for all calculations of plate constants. It is even unnecessarily accurate for this purpose. Its main advantage in this case is that it will be free of systematic errors.

Of course, such a system does not solve all our problems. It will have to be extended to the fainter stars. The bright stars which will not be included in the system because of the presence of neighbouring disturbing stars, will require special observations. This is the case for double stars, which are of interest in themselves. Ground based observations would do, but it would be possible to make space observations, with slightly modified devices, and also a good deal more computing work.

It seems that the availability of such a sphere, which users of our results would find very convenient indeed, demands that we should reconsider all our ground based programs, considering the results obtained by space techniques.

3. A Project for Space Astrometric Observations

3.1. Short description

A project had been submitted in 1967 to the IAU. It has evolved since and was tested by CNES, which could not carry it out, because it could not be modified so as to be launched by a 'Diamant' Rocket.

It appears now that a rather different project based on the use of a TD 1 satellite, could achieve much more easily far better results.

3.2. Optics

A complex mirror reflects on a telescope, two fields at right angles. It is most essential that this mirror be rigid, so that the angle between the two fields remains rigorously constant. (The mirror should be made out of a single block.)

The two fields are 40 cm × 15 cm in size. The Cassegrain telescope has a focal length

https://doi.org/10.1017/S0074180900069977 Published online by Cambridge University Press

equivalent to 3 m. The constraints of TD 1 impose that the beam be reflected once.

A grid in the focal plane, as shown in Figure 1, enables the measurement of the transit times of the stars.

The grid has a step of 1″; each segment of the figure represents 20 stripes at a

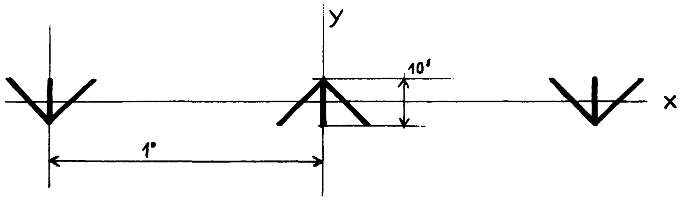

Fig. 1.

distance of 1″. The telescope and the reticule must be rigidly linked together so that the magnification remains as constant as possible (mirrors, reticule and shims would be made of cervit).

3.3. Electronics

3 photon counters each examine one of the three parts of the grid. The different transit times (one for each part) are used to derive, at the time the star crosses the y axis, the value of y and of the successive derivatives of $x(t)$ and $y(t)$.

The plane containing the two directions observed will be perpendicular to the direction pointing, usually towards the Sun.

The mean crossing time for each part of the grid should be computed on board the satellite. In the course of this work a large proportion of the perturbed data (perturbed by the presence of neighbouring stars) would be eliminated.

Computations show that the crossing times are affected by random errors due to these background stars.

One can also show that the frequency and accuracy of stars at different magnitudes is such that, during each orbital revolution, data would be collected for:

16	stars of	$m<6.5$	$<0''.0010$
35		$m\sim 7.5$	$0''.0016$
57		$m\sim 8.5$	$0''.0029$
33		$m\sim 9.5$	$0''.0052$.
141			

3.4. The computation of angular distances

If two transits occuring at a short time interval correspond to star in the two different fields, then the rotation angle of about 90° defined by the mirror comes in as an unknown experimental constant. In any case, we can observe only separations of stars having transits at small time intervals, and the motion of the satellite must be

https://doi.org/10.1017/S0074180900069977 Published online by Cambridge University Press

taken into account in order to derive the x's and y's of the two stars at some given time between the two crossings. Computations show that we can thus evaluate angles between 0° and 4°, and between 86° and 94° without losing accuracy, by taking into account the data collected and the equations of motion of the satellite. The range of angles can be increased somewhat, but in consequence the accuracy diminishes.

It must be understood that these determinations can only be made if the satellite's orientation has not been changed while information was collected. This is an incentive not to change the satellite's orientation too often, but valuable results can already be obtained if this occurs only at intervals of several minutes.

Thus the data collected during one revolution of the satellite will yield with very high accuracy, approximately 6 angular distances per star, or, in other words, 420 arcs on the sphere, half of which between stars at about 90 deg distance.

The great circle arcs connecting two stars belonging to different fields are always determined to an accuracy of better than 0″.01 if the mirror angle is well defined.

Arcs connecting two stars of the same field yield precise information on the value of the arc and on its orientation with respect to the arc that connects one of the two stars to a star in another field, transiting at approximately the same time.

3.5. The Setting up of a Sphere

Observations at right angles in a plane perpendicular to the direction of the Sun are most easy and straight forward with the TD 1 satellite, but they cannot suffice to determine completely the reference sphere, since clearly arcs are all measured along a meridian in the ecliptic system of coordinates. Such arcs give information on the latitudes of the stars, but none on their longitudes.

In order to determine its two coordinates, the star must be at the end of at least two arcs intersecting at an angle markedly different from zero or 180°.

We can obtain and measure new series of arcs not on meridians in three different ways:

(1) By changing the orientation of the satellite so that its axis of rotation lies at say 10° from the Sun's direction. These changes could occur at the rate of one every two days.

(2) By displacing the measuring telescope with respect to the satellite so that its axis would make an angle of say 80° (instead of 90°) with the axis of rotation. These changes could be done also at the rate of one in two days; they would require relatively little energy.

(3) By carrying two unorientable measuring telescopes, one at 90°, the other one at 80° from the axis. No displacement would then be necessary, and more information would be collected.

With any of these methods, the majority of the stars observed will be at the intersection of several arcs, carried by two or three great circles.

All these methods can work and yield accurate results; the choice between them will depend, to a large extent, on space technological factors.

Since these arcs are not generally measured at the same epochs; they can be fitted

https://doi.org/10.1017/S0074180900069977 Published online by Cambridge University Press

together only by taking into account proper motions and parallaxes. The elimination (or derivation) of these new unknown necessitates three sets of observations, each at intervals of six months. The minimum length of time for the measuring campaign is therefore eighteen months. In fact, a campaign of two years would avoid losing observations due to moonlight.

3.6. Reductions

The computation of the arcs will be done 'off line'. Stars will be identified, and approximate positions, at a precision of about 0".2 will be obtained from the Stellar Data Center in Strasbourg.

The corrections for aberration must be carried out. If an accuracy of 0".001 is required, then the satellite's velocity must be known to 1.5 m s^{-1}.

The instrumental constants must be determined. A crude estimate of the angle between the mirrors can be obtained after each revolution by comparing the 420 arcs that are close to 90° and the arcs deduced from the currently known positions. The constants will be thus obtained to about 0".015.

The position of each star will be improved by using the arcs that link it to other stars and weighting the observations according to the uncertainties of the arcs and of these other stars' positions. For example, if a star has been observed on two orbits, and is thus connected to 12 different stars, its position can be secured to about 0".08.

At this stage, the scaling factor and the constant of the optical system can be solved for at the same time by comparing the measured arcs with the arcs deduced from the positions mentioned above. With the information deduced from a single revolution, that is 420 arcs, the uncertainty due to the scaling factor can be cut down to 0".004 for an angular distance of 2°, and the uncertainty of the angular constant to 0".002. Thus the stability of the scaling factor and of the angular constant can be constantly kept under control, and their values improved.

We will iterate the computation of the positions and of the constants several times, always taking into account the estimated accuracy of the positions estimated at the step before.

The stars linked to many others by accurately measured angles will have more accurate positions. If the links are less abundant, the accuracy will be poorer; but even for a star observed only once, and linked to another star in the same field, the position will still be obtained to 0".01.

In fact, our computations indicate an accuracy of 0".003 for the majority of positions, which would give 0".0015 yr^{-1} for the proper motions, and 0".002 for the parallaxes, but we must reckon with time instabilities in the constants, scaling factor and angle between the mirrors; they will have to be known permanently to 0".005, if the above stated precision is to be achieved. They are perhaps not constant to this accuracy, but they can be measured to better than this, every ten minutes, during the final reduction.

It will be seen that we cannot observe all the stars in this way; double stars and all those perturbed by a star at less than 20" separation and $\Delta m < 5$ will be eliminated.

https://doi.org/10.1017/S0074180900069977 Published online by Cambridge University Press

3.7. Advantages of TD 1 for the astrometric project

The limits in the accuracy are set mostly by the stability of the constants and the latter is obviously related to the thermal stability of the optical system. Great care should be taken to avoid the existence of steep thermal gradients, the value of the temperature itself being far less important. TD 1, which retains approximately the same orientation with respect to the perturbating sources, i.e. the Sun and the Earth, is in this respect perfectly well suited to our purpose.

3.8. Accurate locations of X-ray sources

The position of the optical system with respect to the sphere it measures is known at every instant to an accuracy of about $0\overset{''}{.}01$. If a device to observe X-ray sources is coupled to the optical system, the location of the X-ray sources will be determined with an accuracy limited only by that of the X-ray device. Accuracy of the order of $1''$ will be easily obtained, which is quite sufficient to identify the optical counterparts beyond doubt.

https://doi.org/10.1017/S0074180900069977 Published online by Cambridge University Press