GENERAL PRINCIPLES FOR SPACE ASTROMETRY

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In order to obtain very precise positions of the stars on a sphere, it seems absolutely necessary to go out the atmosphere.

1) - We avoid atmosphere refraction with always uncertain corrections.

2) - We avoid atmospheric turbulence. So the quality of the images is limited by diffraction and not by the seeing.

3) - We avoid atmospheric absorption and diffusion limiting the possibilities on the faint stars. Moreover if we observe from an artificial satellite we have no bending of the instruments.

In view of very high precision (0".001) on the directions from an artificial satellite, the difficulty is to obtain sufficient stabilisation in attitude. Also, it is necessary to measure the angles between the stars, instead of the directions relative to the satellite.

The mapping of a sphere by angular measurement requires precise measures of large angles. Indeed BACCHUS has shown how that is possible to obtain a precise sphere with relative positions and proper motions, but absolute parallaxes only by precise measures of angles near one value, 90°. Those measures are possible by superposition of two fields in one telescope. A special complex mirror (Fig. I) images the two fields at basic constant angle. We have only to make differential measures to add a small value to the constant.

Because of insufficient stabilisation, we use a photoelectric method for the differential measure. That is, in fact, by counting of photons during the transit of the stars on a grid in the focal plane.

To avoid some errors coming from the irregularity in the motion in attitude, it is necessary to observe the two stars in comparison in the same time, or to mix strictly the measures of the two stars in the time.

These principles are common to all the projects which aim at mapping the sphere. However it is possible to discriminate two different options:

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1) - We can choose all the pairs of stars to be connected. We have then to point the optical device to measure successively all the pairs of stars. This method seems able to give the best precision on the faint stars. We can choose the stars at will and remeasure any star as often as is necessary. But this method demands some facility for pointing. A project to observe from space-lab is being studied.

2) - A cheaper solution is to scan the sphere systematically. We sacrifice our freedom in the choice of the stars, but with homogeneous scanning, we obtain a good distribution of the observations on the sphere, which is very suitable for mapping a coherent reference system.

Thus, two options, option A and option B are presented. They are intentionally very different to explore different feasibilities.

OPTION B - DESCRIPTION

In this option the goal is to obtain good results with the maximum of simplification during the observations in view of security. For this purpose we forego the choice of stars and we accept some more data processing in the reduction.

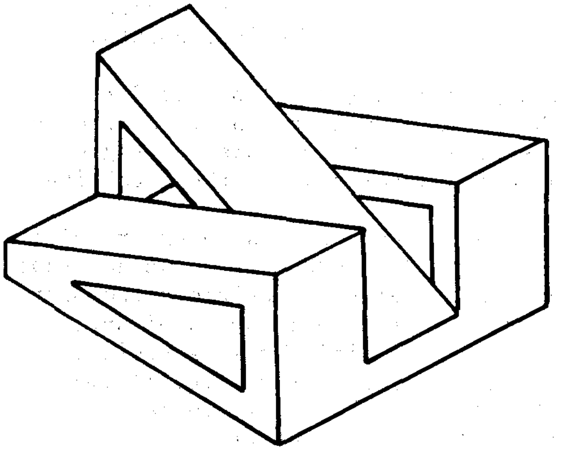

Figure 1.

The orbit of the spacecraft is similar to those experienced with the TD1 A Satellite. But the direction of the observed stars always lies in the orbital plane. Therefore one axis of the spacecraft, the bissectrix of the angle between the two fields of view, will be pointed near the Zenith. The attitude is maintained by differential gravity, and, if necessary, some small corrections around the vertical direction. The angles between the directions of the observed stars and the direction of the sun are always larger than 60°.

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Since we use only one detector to study the transit of the stars on the grids, the measures on different stars are never simultaneous, and we have to mix the measures in time. The attitude of the spacecraft will be very smooth, without jitter. The angles between the stars are deduced from the times of transit on different parts of the grid.

Because the scanning is on a great circle at an inclination of 98°, we scan almost all the sphere, but the angles between the scans are only about 16° near the equator. Because of this, the mapping of a sphere by only measuring arcs along the scan will not be precise near the equator. We must therefore make accurate measures not only along but also perpendicular to the scan; we use grids with inclinations ± 45° to the path. We thus obtain good angles between the stars, along the scan at distances about the basic angles, and also between the neighbouring stars along the scan and perpendicular to the scan.

For the processing, we use, in auxiliary computation, the precise determination of the attitude of optical device. In this way we check always all the constants, basic angle and field corrections.

The scheme of the work for successive approximation is as follows:

1 - Transit of the stars on the field.
2 - Approximate position of the axis of rotation using the present positions of the stars.
3 - Smoothing on the motion of the axis.
4 - Better positions of the stars.
Return to 2, 3 and 4.
5 - Block of positions on about 20 following orbits at each epoch.
6 - At the end synthesis by small moves of the block, and at the same time positions, proper motions and parallaxes for each star.

Because we connect all the stars together, we do not need a big field: 25 on 25 minute-arc is sufficient. The telescope will be a Ritchey-Chrétien, all in Zerrodur, and the distances between the various optical components will be determined by the same material. All the optical system will be thermally extremely stable.

The analysis of the images behind the grids is made by an image dissector with a field of 25 on 25 second-arc to remove the background light. The selection of the stars and the control of the dissector are deduced from the transits of the stars on some grids at the entrance of the field. If Scout launcher is used the telescope can have an aperture of about 20 cm. With these dimensions we observe only the stars brighter than the magnitude 10.5. In this small field the images are so good that only the first sinusoidal component of the counts need be measured.

This option gives about all the stars to magnitude 10.5, but not fainter stars. The precision on the brighter stars is limited by the accuracy of the frame defined by the connected stars, on about 0$''$.0004. The precision of reference on a square degree is in the mean 0$''$.0007.

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The table gives the number of stars and the expected precision as a function of apparent magnitude.

m	n	Σ 0″001	Σμ 0″001/year	Σπ 0″001
10.5	100 000	3.2	4.5	3.8
10	104 000	2.3	3.2	2.8
9	40 000	1.4	2.0	1.7
8	14 000	0.9	1.3	1.1
7	8 200	0.6	0.8	0.7

SCIENTIFIC SIGNIFICANCE OF THESE RESULTS

The scientific significance of the option A is essentially the same as for option B.

Clearly, the results obtained from Space Astrometry will be useful for a more precise application of astrometric techniques from ground observatories; a large number of very accurate reference stars would permit quite an important improvement in the necessary interpolations, extending the measurements to additional stars, in particular of fainter magnitudes, by means of photography or meridian instruments.

However, this is not the most significant achievement; it is the deep and extended impact on our astronomical knowledge in many diverse fields.

Although all aspects are closely interlinked in astronomy, one may distinguish two principal ways in which the expected results would lead to significant advances:

1) improvement and increase in number for trigonometric parallaxes;
2) establishment of a reference system much more accurate than the present one.

PARALLAXES

At the present time, a large part of our knowledge on stars is derived from the knowledge of some 350 trigonometric parallaxes, which it is hoped are known within 10%, in spite of systematic differences between various observatories. Using this information, absolute magnitudes are calibrated; with the help of clusters, the calibration is extended; then, through the application of methods using apparent magnitudes and measurements of radial velocities and proper motions, we can try to extend the distance scale and to study our Galaxy. The Interstellar absorption is quite a hindrance in this work.

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The proposed project increases by a factor of about 100 the number of trigonometric parallaxes known within 10%, many of them being measured with a much better accuracy.

It will then be possible to obtain much more accurate and refined absolute magnitude calibrations, taking account of all spectral particularities except those of very rare types. Along the same lines, one can cite calibrations as a function of chemical composition, which will be particularly important for checking current theories of stellar atmospheres and evolution.

Of particular interest will be the direct grouping of distances for several open clusters:

4 better than 1%
4 between 1 and 3%
5 " 3 and 10%
9 " 10 and 20%.

Independent calibrations of groups of stars of different ages and chemical composition will thus be obtained, which will be highly instructive.

The famous problem of Hyades distance, an essential basis for all large-scale extrapolations, will actually become pointless, as the cluster depth will be detected. Other clusters will also be used. Moreover, there will be a sufficient number of giant stars with well measured parallaxes for calibrating absolute magnitudes as a function of spectral details, which will have to be carefully identified in order to establish the galactic scale.

RR Lyrae and Cepheids, so important for our distance scale, are unfortunately too sparse, so that not enough are close and bright enough to obtain individually significant trigonometric parallaxes. However, an uncertainty on the average as low as 0.20 m in absolute magnitude can be expected, using these parallaxes, which should be free of systematic errors, in a statistical way.

The improvement resulting from new knowledge will make the present indirect methods much more accurate.

When carrying out these investigations, one is confronted with interstellar absorption. However, the possibility of directly placing a great number of stars along the distance scale will make the study of interstellar absorption much more accurate by establishing its relationship with the reddening.

The distance scale will be considerably improved and consolidated. This may have cosmological implications.

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MASSES

For at least half of the visual double stars with close orbits, very accurate parallaxes of the light centre will be obtained, thus leading to an important improvement in mass determination.

PROPER MOTIONS

Proper motions, which are provisionally assumed as absolute, will be measured within 2 to 3 years on a very large number of stars with an accuracy slightly better than those presently known. However, these motions will not contain any systematic error. Therefore, an immediate improvement and an increased confidence will result for all indirect methods using proper motions for the extension of the distance scale.

An immediate interesting application is a more accurate kinematic study of nearby stars, with all information that can be derived on the age and galactic distribution of the various star types.

However, for many investigations, in particular the study of motions at large distance in the Galaxy, it will be necessary to wait for a second observation period. Uncertainties would be reduced by a factor of 5 after 10 years.

New data will be obtained for studying in better condition the outstanding problem of the missing mass and more generally, for all studies on the Galaxy, its structure and motions. In order to exploit fully the revolutionary astrometric advances, more spectroscopic and photometric observations will be needed.

REFERENCE SYSTEM

The reference system obtained will be very coherent, free from local systematic errors, but will depart from an absolute system by an unknown rotation velocity. Comparison with FK5 will give a first estimate within $0\overset{''}{.}15$/century. Comparison with absolute proper motions obtained for nebulae by photographic techniques will allow a check on the individual determinations; consideration of the whole set will immediately give a probable accuracy of $0\overset{''}{.}01$/century.

To improve and prepare future studies, it will be necessary to link the system as precisely as possible to quasars. Radio astronomy could be used, but only a few stars are accessible to both optical and radio astronomy. Various devices can be thought of, but the most accurate and direct method would doubtless be the Spacelab instrumentation which could link accurately the reference system to quasars. For that purpose only and in order to reduce Spacelab costs, a few hours of observations on a minimum of 3 flights widely separated in time would be sufficient.

The absolute reference system, with its proper motions, will then be accurate enough to give increased value to all relative measurements carried out over a century on the solar system objects, with consequently a large improvement in the study of planetary motions. For present and future investigations, this system will be essential for exploiting the full accuracy of new techniques such as lunar laser ranging and radar echoes. Comparisons will allow a much more accurate check on celestial mechanics than presently achievable, which is essential for assessing the validity of various assumptions on relativity, variation of g, etc.

With regard to the Earth-Moon system, it will be possible to determine the tidal acceleration. Improvement on the stellar catalogue will be very useful for study of the Earth's rotation using PZT and astrolabs, and also for geodesy. Past observations could be rediscussed to study plate movements.

It would take too long to mention all the applications likely to be made using the expected results. It appears to me, however, that the most specific characteristic of the project, apart from the directly obtained scientific results (which could not be reached without space observation), is the enormous mass of investigations in all fields which will have to be re-examined for the benefit of our general knowledge in astronomy.

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