SCIENTIFIC ASPECTS OF A FUTURE SPACE ASTROMETRY MISSION: SUMMARY OF THE PARALLEL DISCUSSION SESSION

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INTRODUCTION

The discussions concerning the scientific aspects of a future interferometric space mission, aimed at astrometric and photometric measurements of very large numbers of stars, using the GAIA concept as a base-line, focussed on the following range of aspects:

- magnitude range (are there good reasons for pushing the required observation limit beyond magnitudes fainter than 15–16 mag?)
- parallax accuracy (is an accuracy of 10 mas sufficient, not really required, or not accurate enough?)
- mission length (what would be the optimal mission length)
- wavelength coverage (what wavelength bands should observations be made in, from near UV, 380 nm, to near IR, 800–1000 nm?)
- size of subfields (what is the effect of the subfield size on the observational possibilities?)
- time resolution of data (are there specific requirements for high time-resolution in the data handled on-ground?)
- supplementary data needs (is there a specific need for simultaneous radial velocities, spectral data or other information that could possibly be obtained by the satellite?)

These aspects were discussed in presentations during the plenary sessions and/or during the discussion session. The following subjects of possible study were briefly looked into:

1. Solar system objects
2. Unseen companions
3. Stellar evolution
4. Star clusters and associations
5. The galactic distance scale
6. Magellanic Clouds
7. Galactic dynamics
8. Gravitational waves
9. MACHOs
10. AGNs

The basis for the discussions was the papers presented at the meeting, either during the plenary session or during the discussion. In this paper I will summarize the various requirements for a future astrometric mission with respect to the ten subjects and seven aspects mentioned above, supplemented by any additional remarks made during the discussions.

1. SOLAR SYSTEM OBJECTS

It was felt that the observations of objects in the solar system could provide very valuable information concerning the dynamical reference frame to a precision never reached before (see the paper by Hestroffer & Morando). However, the size of the objects possible to be observed, together with their variable shape, albedo and often unknown rotation rates, would make reduction of observations very difficult. Due to the restrictions set by the scanning law any solar system object is only observed at half the average rate of observations (for Hipparcos this gave an average of around 50 observations per object, compared to an average of around 100 for all objects observed).

The observations of solar system objects is insensitive to the parallax accuracy and does not require a fainter limiting magnitude. However, a mission length well beyond 5 years would significantly improve the results as most asteroid orbits get completely covered.

The wavelength coverage and sub-field size are not very important in this subject, but data rates may need to be high because of the peculiar motions of solar system objects during a passage of the field of view.

2. UNSEEN COMPANIONS

This subject covers the detection of any kind of unseen companion: from a low luminosity star to an earth-like planet (see the papers by Casertano et al. and by Bastian & Bernstein). Here a major consideration is the mission length: if the orbital periods of Jupiter and Saturn are typical for large planets, then a mission length of well beyond 5 years would be necessary to disentangle the effects of proper motion, parallax and orbital motion.

Using the Hipparcos data, Bastian & Bernstein have shown that it is in practice possible to solve the orbital information from one dimensional astrometric data. However, the Hipparcos data also showed that around 1% of the stars observed are showing accelerations which can probably be attributed to unseen companions, with orbital motions much longer than 3 years (see also the paper by Wielen).

The subjects for this kind of research are limited to very nearby (within 100 pc) stars for planetary companions, and a few hundred pc for low-luminosity stellar companions. The requirements on limiting magnitude are therefore relaxed, and 15–16 mag would be sufficient. The optimal wavelength coverage would be from visual to near IR, given that most of the stars to be investigated will be late-type stars in the solar neighbourhood.

There are no specific requirements on auxiliary observations and the time resolution of the data. Supplementary radial velocity data can be obtained from the ground. The sub-field size should not be a problem except in some dense cluster areas.

3. STELLAR EVOLUTION

This subject is covered by a wide range of observations, some of which are dealt with in the next section on clusters and other stellar systems. The paper by Mennessier & Barthès showed the impact on the study of pulsating stars of a combined astrometric and photometric mission.

Young stars are mainly concentrated in the galactic plane and this gives two possibly contradictory requirements: as most of those visible at long distances are intrinsically very bright O and B stars, near UV bands would be suitable. However, as these same stars tend to be more and more reddened when further away, near IR bands would be needed. Some aspects of observing the Be stars are described in the paper by Briot et al.

The mission length most suitable for the observations of pulsating stars would be at 7–8 years, providing sufficient coverage of the long period stars. There are no specific requirements on parallax accuracy: at 0.01 mas even a star at 1 kpc has an error of 0.02 mag only on the absolute magnitude, provided the reddening correction A_V can be determined, which in most cases will not be possible to the same accuracy. At larger distances in the galactic plane this effect becomes worse. Thus, for the study of absolute magnitudes of young stars, the limiting magnitude of 15 and parallax accuracy of 0.01 mas are sufficient.

Outside the galactic plane the situation is different. Here, at larger distances, there is much less confusion by reddening. However, the population of stars is entirely different too: old stars, mainly horizontal giant branch and asymptotic giant branch stars are observed. To find out about the average age of this galactic halo population, it is necessary to reach the main sequence stars of the same population, stars with absolute magnitudes around 5 to 6, equivalent to a distance modulus of 10 (1 kpc) or less when we assume a limiting magnitude of 15–16 mag. This should provide a large sample of these Population II stars, if the numbers of RR Lyrae stars in the same volume (150 to 200) are anything to go by. Stars in this population are easily recognized by their high space motions, as can be seen from the Hipparcos proper motions of the RR Lyrae stars.

4. STAR CLUSTERS AND ASSOCIATIONS

This connects very closely to the preceding subject. The limiting magnitude of 15–16 mag makes it possible to study the HR diagrams for open clusters within 1 kpc (see the paper by Platais et al.). Beyond 1 kpc the calibration of absolute magnitudes becomes more and more hampered by the uncertainty in the reddening. However, if a sufficient number of clusters can be measured for which the reddening is relatively small, it may become possible to calibrate the reddening ratio A_V/A_{B-V}. Extending the magnitude limit beyond 15–16 mag adds lower mass stars to the HR diagrams.

The parallaxes and proper motions will serve as a means of selecting members, and as such help establishing mass and luminosity functions of clusters. Here any extension to fainter magnitudes becomes quite important: the presence of low mass stars in star clusters largely determines the total mass of these systems. At 15 mag, the cut-off in mass for the Pleiades cluster is 0.3 $M_\odot$ approximately. Here it is also important to have a coverage of the wavelengths towards the near IR, although a coverage towards the near UV is needed for the study of the most massive cluster members.

Improvements in the parallax accuracy beyond 0.01 mas will not make significant differences, as most systems worthwhile studying are likely to be well within the range of very accurate distance determinations already.

For the study of internal dynamics the accuracies of proper motions and parallaxes are sufficient to provide data on all clusters within 1 kpc. The limiting factor here is the accuracy of supplementary data: radial velocities which would require accuracies of 10 m/sec at the distance of the Pleiades to become compatible, something not likely to be obtained for most of the early-type cluster members. At a distance of 1–1.5 kpc, the best radial velocities would become compatible with proper motions accuracies of 0.010 mas/year.

There would be a gain from improved parallaxes for the study of the spatial distribution of stars in an open cluster, but this would only be useful if the limiting magnitude was brought down, so that a larger range of masses could be observed and effects of mass segregation studied.

The size of the sub-fields becomes important for the more distant clusters, in particular when projected onto the galactic plane. They become critical for the study of stars in and around globular clusters, and can determine which globulars can still be observed. Mission length is an important aspect for the study of internal dynamics of clusters: the shorter the mission, the more proper motions remain disturbed by not recognized influences of unseen companions (see also the paper by Wielen).

5. THE GALACTIC DISTANCE SCALE

The galactic distance scale calibrations as a function of age, metallicity, stellar rotation and spectral peculiarities is a crucial step towards calibrating the intergalactic distance scale. It requires a wide range of objects (clusters, associations, double and multiple stars, specific types of variables, etc.) to be known in absolute luminosity and fully reddening-corrected colours. It also requires the possibility to distinguish populations of stars on their dynamic characteristics, so that stars of similar background can be treated as more-or-less homogeneous groups.

The GAIA concept allows observing in the galactic plane and within the solar circle over distances of several kpc in some directions. Outside the solar circle distances of 5–10 kpc should be possible to reach. Outside the galactic plane it is almost only the intrinsic brightness of the stars that sets the limit: the brightest Cepheids and super giants can be seen over several tens of kpc.

The galactic distance scale calibration for metal poor objects (galactic halo, globular clusters, Magellanic Clouds) is therefore well within the observational possibilities of the GAIA concept, but for younger, more metal-rich objects the quality of reddening corrections will be the main limiting factor. Here, the width of the photometric system is very important: due to reddening, objects will be observed all across the spectrum, from the blue end for un-reddened objects, to the near IR for highly reddened objects. Both types need to be observed in order to obtain a reliable sample.

6. THE MAGELLANIC CLOUDS

The main importance here is obtaining a distance calibration using stars with abundancies different from those in our Galaxy. Parallax accuracy is essential. An accuracy of 0.01 mas is only just smaller than the parallax of individual members of the LMC and SMC. The parallax of each would therefore rely on a statistical determination.

The possibility to do so depends on the size of the sub-fields, where the basic requirement would be to keep the number of stars visible within such sub-field limited to three. Increasing the sensitivity of the instrument to fainter magnitudes can in this case be detrimental: more stars become visible and the chances of finding sufficiently separated stars rapidly decreases.

Another important aspect for the Magellanic Clouds is the possibility to study their kinematics from the distribution of proper motions, and the determination of the proper motions of the Clouds themselves to a accuracies of better than 1 km/sec.

7. GALACTIC DYNAMICS

A very major contribution towards the study of galactic dynamics can be made in the region outside the solar circle. With densities not as high as inside this circle, reddening plays a much less important role. Inside the solar circle the requirements for detectors very soon move beyond the near IR in order to be able to see far enough, and a whole new mission concept is needed. Mission length is important (see the paper by Wielen) for the reduction of the orbital effects introduced by unseen companions.

With a limiting magnitude of 15–16 mag, and a wavelength coverage from the near UV to the near IR, it should be possible to investigate the Galaxy for several kpc within the solar circle, and up to at least 10 kpc outside the solar circle, although there the numbers of tracers available will drop significantly beyond 6–7 kpc, at which distance the horizontal giant branch stars become invisible.

In its present configuration, the GAIA concept could make very significant contributions to the investigation of the galactic halo. The distribution up to several kpc from the sun can be studied in conjunction with high accuracy proper motions and photometric information. This should give an insight into distributions of stellar populations, their related ages and metallicities, as well as the presence of more extreme objects such as blue stragglers and OB disc runaways.

8. GRAVITATIONAL WAVES

Papers presented by Fakir and Makarov showed the exiting prospects of indirect gravitational wave detection. Given the right circumstances, a detection may be possible. This requires, however, either the pre-selection of target objects, or a very high volume of data to be send from the satellite to the ground.

9. MACHOs

Similarly, the paper presented by Miyamoto showed the possible impact of a combined astrometric and photometric detection of a micro-lensing events. Here too, the requirement on the time resolution of the data is high, but no pre-selection of objects is possible.

10. AGNS

Terlevich showed that it may well be possible that AGNs do not radiate from exactly the same position at different epochs. This may give some problems for the creation of an inertial reference frame using extragalactic sources.

CONCLUSIONS

Within the current specifications of the GAIA concept a very large amount of extremely high quality data on fundamental astronomy can be obtained. In almost all cases the magnitude limit of 15–16 mag does not cause severe limitations (also considering that in incoherent mode stars down to 19–20 mag can be measured). The parallax accuracy is in most cases sufficient. Only for the study of the Magellanic Clouds, and for the detection of gravitational waves, an improvement would help. The preferred mission length for most subjects is longer that the five years suggested in the GAIA concept, with 7–8 years appearing to be a good compromise.

In wavelength coverage, the entire range of the spectrum from near UV (350–380 nm) up to near IR (800–1000 nm) should preferably be covered, in order to deal with problems like interstellar reddening and calibrations of metallicity, effective temperature and surface gravity. The size of the sub-fields can be a problem, in particular in star clusters and the Magellanic Clouds, where the size will limit the number of stars available for measurements. This problem rapidly gets worse when the detectors become sensitive to fainter objects.

High time resolution of data is required only by the gravitational wave detection and to a lesser extent by the solar system observations. As high time resolution will create a demand for a very high data rate and thus on high power requirements, which could damage the astrometric aim of the mission due to increased difficulties in controlling satellite temperature and torques, it is probably only reasonable to preserve high time resolution data for a very small number of pre-selected objects, or to pre-process the data on-board.

Supplementary radial velocity data would in many cases be very beneficial: from the study of cluster and galactic dynamics to the study of pulsating stars, where in particular the simultaneous radial velocities are very valuable.