SOME POSSIBLE MISSION CRITICAL ASPECTS

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INTRODUCTION

GAIA is clearly a most exciting mission astrophysically. I feel that if technical feasibility can be confirmed to be within the cornerstone programme cost, it would certainly fly. It is always difficult when considering a new mission to distinguish the show-stoppers, the real but solvable technical challenges (which will limit performance and drive costs) and the areas where technology will have advanced sufficiently to allow a straightforward implementation.

Rather than pass what must always be a biased judgment, let me instead mention some areas where more work probably needs to be done before a review committee can confirm that a concept similar to GAIA falls into the category of technically feasible for reasonable cost. Several other potential problems such as system stability and the difficulty of pico-metre level metrology, fringe ambiguity, the need for high time resolution, high QE and low noise detectors, and data rate, were extensively discussed at the meeting, so I will not discuss them further here, except to note that it is hard to see insurmountable problems in these areas, even though they may turn out to be major cost drivers.

1. GRAVITATIONAL LENSING PERTURBATIONS

One goal of the mission is to produce a catalogue of positions and proper motions over the entire Galaxy. Similar studies are also envisaged in dense stellar systems such as globular clusters. There is an interesting limit in principle to what can be done with a magnitude limited survey such as GAIA when the majority of stars in the Galaxy are below the instrument's sensitivity limit. A faint star anywhere close to the line of sight to a programme star will bend the light and hence the apparent position by the general relativistic gravitational effect.

The position error is time dependent because of the relative motion of the stars hence leads to apparent proper motion. When the impact parameter (grazing distance) is D, the amount of bending is given by the expression $4GM/c^2d$ for a perturbing star of mass M. If we define a significant perturbation as 7 microarcsec, then this occurs if the light from a target star passes at 800 AU from a $0.7\mathrm{M}_\odot$ perturber. Using the local stellar density of about $0.1/\mathrm{pc}^3$, we get a path length of 147 kpc for a 50 per cent chance of a significant perturbation, a distance comparable to the Galaxy size. Assuming a perturber velocity of 200 km/sec across the line of sight to the target, due to its peculiar velocity and differential galactic rotation, we get a time scale for the perturbation to change of 19 years, which is not long compared to the planned mission lifetime of 5 years.

Clearly this calculation is very rough, but it does indicate that a more careful study of this noise source is necessary in the context of the expected scientific returns from proper motion studies. This astrophysical noise source will affect proper motion studies particularly in crowded stellar environments, such as globular clusters, and in the disk of the galaxy. It can also significantly affect parallax determinations in a minority of cases.

2. VEILING GLARE

Veiling glare is an intrinsic noise source for any astrometric mission. Hipparcos suffered somewhat from light from bright stars which was predominantly masked by the image dissector's instantaneous field of view leaking through and perturbing the measurement of a fainter star. However, because the instantaneous field of view was small and cut off rapidly, and the astrometric accuracy of a few milliarcseconds was not very small compared to the diffraction limit of the telescope, the effect was not too severe.

In the case of GAIA, at least in the baseline configuration of Lindegren & Perryman, the problem is evidently worse. They consider a baseline of 2.45 m, which for an eventual astrometric accuracy of 5 microarcsec requires measuring fringe phase to a precision of much better than 1 part in 8000. This suggest that no star brighter than $V = 24.8$ mag can be present in the field of view for a target star with $V = 15$ mag, although the effect is randomised with the scanning motion, as it was with Hipparcos. The baseline instantaneous field of view of 27×13.5 arcsec^2 will on average contain a star with $V = 20$ mag. Even at high galactic latitude, there is often a problem. In addition, object number counts are starting to be dominated by galaxies at these brightness levels which will also introduce a phase shift.

Veiling glare proper from bright objects outside the instantaneous field of view but within the telescope field of view may also present a problem. In general, a star of 8 mag will be present in the field of view. It must be attenuated into the instantaneous field of view to 25 mag, a suppression of 17 mag, or 6×10^7. Using the HST experience (where great efforts were made to keep the optics clean), dust particles on the mirrors will typically have a covering factor of about 3 per cent after launch, and sizes in the range 10–200 microns, with a steep power law distribution in radius.

As well as scattering some light to large angles, they will diffract visible light into a cone with a characteristic size of a few degrees. Thus each bright star will be surrounded by a halo that in principle may be modulated by the interferometer, and contribute an apparent phase shift to the target. A rough calculation indicates that with the proposed instantaneous field of view the halo is bright enough to cause problems.

The solution to both of these problems (faint spoilers in the instantaneous field of view and bright stars in the field of view) is to reduce the size of the instantaneous field of view, and perhaps to increase the baseline. Both of these changes require larger format detectors than are presently available, but there has been rapid progress in this area.

3. CHROMATIC ABERRATIONS

It may seem strange to talk of chromatic aberrations in an all-reflective system, however although the system is close to diffraction-limited over its field, it does suffer from aberrations at the level of $1/20\lambda$. One effect of these aberrations is to decrease the fringe modulation, which does not concern us much as the system is well corrected. On the other hand, the fringe harmonic content, and the phases of these harmonics, will be affected and affected differently for different wavelengths, and this will directly affect the astrometry.

If all stars were of identical colour, the resulting position shifts would be exactly removed by low-order polynomial geometric distortion calibrations that could be solved for in the data reduction. This calibratable fringe phase error will be of the same order as the aberration expressed in waves. It is hard to assess the size of the stellar colour-dependent part of the effect, and detailed numerical work must be done in order to assess the amount of colour information about the targets that must be known (or deduced from the data) in order to calibrate the effect. For a 10 per cent bandpass in the visible, a range of spectral types may shift the effective central wavelength by perhaps 2 per cent. Thus the fringes may be relatively shifted by perhaps 2 per cent of the overall fringe shift due to the aberrations. If the aberration is $1/20\lambda$, the relative shift would be 1/1000 fringe which is large compared to the needed fringe centroid precision of order 1/10000 fringe.