GAIA: A NEW ERA FOR COSMIC DISTANCE SCALE DETERMINATION

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ABSTRACT

One of the major breakthrough open by the perspective of an astrometric mission such as GAIA is a complete revision of the determination of the distances of the so-called 'primary' distance indicators.

Very accurate direct distance determinations would be obtained for all spectral types and stellar populations within a significant part of our Galaxy, including all galactic open clusters, all galactic Cepheids and RR Lyraes, and at least twenty globular clusters. Moreover, the direct distance determination of the Cepheids of the Magellanic Clouds would be within reach, and this would allow to jump over the first step of distances determination, avoiding any assumption about the supposed universality of the period-luminosity relation for these stars.

Key words: space astrometry; GAIA; distance scale

1. INTRODUCTION

Present day determination of the cosmic distance scale relies on the successive use of so-called 'primary', 'secondary' and 'tertiary' distance indicators. In fact, even the distances of 'primary' indicators, mainly open and globular clusters, Cepheids and RR Lyrae, are presently relying on the calibration of specific relations (main sequence or horizontal branch fitting, period-luminosity or period-luminosity-colour or period-luminosity-metallicity relations) using the best available trigonometric parallaxes for nearby stars of relevant spectral types or metallicities. However, a relative accuracy of 10% or better on trigonometric parallaxes is available for less than 1 000 stars.

Hipparcos will already bring an enormous improvement to the present situation by a considerable enlargement of the number of stars with accurate distance determination (about 15 000 stars with $\sigma_\pi/\pi < 10\%$) and a much larger range of spectral types and metallicities within the observed stars. In addition, good distances will be obtained for about ten open clusters, with various metallicities and ages, and for a few pulsating stars (five Cepheids with periods ranging from two to ten days; three RR Lyrae; etc. See for example Turon & van Leeuwen 1995).

With GAIA, a new era would be open. Such a mission would provide direct distance determinations of unprecedented accuracy and for an unprecedented number of stars of all spectral types and luminosity classes, of all stellar populations, of all ages and metallicities.

A review of the improvements expected from very accurate astrometry (from 10^{-5} to 10^{-7} arcsec) for distance scale determination within disk, intermediate and halo populations is given in Kovalevsky & Turon (1991). The present paper is more precisely dedicated to the improvements expected from the GAIA project, as described in Perryman & Lindegren (1995).

2. OPEN CLUSTERS

Open cluster main sequence fitting is a powerful method, which can be applied up to galaxies of the Local Group. The main difficulties are the following: sampling of cluster stars (membership, depth of the cluster); determination of interstellar extinction and reddening; calibration of the position of the main sequence in the HR diagram versus metal, helium and oxygen content.

The only open cluster within reach of ground-based trigonometric parallaxes is the Hyades, at a distance of 45-50 pc, and the method of the convergent point, making use of proper motions, seems to give more precise results than direct trigonometric measurements (Schwan 1991). Moreover, the metallicity of the Hyades is abnormal with respect to the solar neighbourhood ([Fe/H] of about 1.2 from Cayrel de Strobel 1990).

Mean distances to a relative accuracy better than 10 % will be obtained from Hipparcos trigonometric parallaxes for about 10 clusters, of various ages and metallicities. The spatial structure of the closest clusters (Hyades, Coma Ber, Pleiades) will even be within reach.

GAIA would provide a considerable improvement: direct distance determination to 1% for about 30 open clusters; to 10% for all observable galactic open clusters; spatial structure of these clusters; membership determination for most stars (Platais et al. 1995).

3. GLOBULAR CLUSTERS

The distances of globular clusters are presently mainly determined from the absolute magnitudes of Horizontal Branch stars, themselves obtained by other means (statistical parallaxes or Baade-Wesselink method for RR Lyrae, for example). Globular cluster stars are not accessible to

ground-based or Hipparcos trigonometric parallax measurements. On the contrary, many of them would be within reach of GAIA: distances to 10% for stars within 20 globular clusters, and even more with the 'direct fringe detection option' (Tucholke 1995).

4. CEPHEIDS

Cepheids are essential objects in distance scale determinations for four main reasons: they are intrinsically very bright and therefore individually observable up to huge distances (up to the Virgo and Fornax clusters of galaxies with the Hubble Space Telescope, i.e. to some 10 Mpc); they are common stars and can be found in any type of galaxy; they are easy to identify by their light curves; the correlation between their period and luminosity, possibly with a colour term, is well established. The underlying assumption is the universality of the relation period-(colour-)luminosity, which is presently impossible to prove.

The main difficulty is the calibration of this relation and, more specifically, the determination of its zero-point. Other problems may come from sampling effects due to the stars used as calibrators (spread in period, in colour, in luminosity) or from the correction of interstellar extinction and reddening.

The determination of the zero-point is presently very difficult. No Cepheids are within reach of ground-based trigonometric parallaxes. Cepheids in nearby and dense open clusters are very few (9 Cepheids in 7 open clusters within about 3 000 pc). Moreover, these clusters lie at low galactic latitudes, and the correction of interstellar extinction and reddening is delicate. Cepheids are often in the coronae of the clusters, and their membership may be questionable. The effects due to metal and helium contents are small for the period-luminosity relation but much higher for the period-luminosity-colour relation (Walker, 1988).

Hipparcos will slightly improve the situation: good trigonometric parallaxes will be obtained for five Cepheids, with periods ranging from two to ten days; the membership of a few other Cepheids to open clusters within 2 kpc will be improved by the use of the proper motions; the distance of these clusters by main-sequence fitting will be improved; and a few new Cepheids may be discovered.

GAIA would drastically improve our knowledge about Cepheids. The distance and absolute magnitude of all galactic Cepheids will be known to a very high accuracy: to 1% up to 5 000 pc for the baseline option, up to 10 000 pc for the direct fringe detection option. Stars up to distances of 30 000 pc for the baseline option, to 50 000 pc for the direct fringe detection option will be within reach with a relative accuracy of 10%. As a result, distances of Cepheids in the Magellanic Clouds (at least, in the Large Magellanic Cloud) would be obtained directly, and period-luminosity relations established independently for stars in different regions of our Galaxy and in the Large Magellanic Cloud, providing a direct test of the unicity (or non-unicity) of these relations, in regions where the mean metallicities are very different.

GAIA would thus offer the first possibility of direct distance and absolute luminosity measurements outside our Galaxy.

5. RR LYRAE STARS

RR Lyrae stars are also very essential distance indicators. Fainter than Cepheids, they will not be observable up to such large distances, but they provide elements for the determination of the distance scale of Population II when Cepheids are typical objects of Population I. Their light curves are also very characteristic and easy to identify.

RR Lyrae stars are completely out of the range of application of ground-based trigonometric observations, and only very few of them will be measured satisfactorily with Hipparcos.

Five methods are mainly used to estimate their absolute luminosities: statistical parallaxes for field RR Lyrae; sequence fitting for RR Lyrae in globular clusters; Baade-Wesselink method for stars for which photometric and radial velocity measurements are available for part of the cycle; pulsation theories; observation of RR Lyrae in the Magellanic Clouds and independent estimation of the distance of the Clouds. The results obtained (Smith 1995, Table 2.1) are quite discordant: unique magnitude (from 0.44 to 0.86) or magnitudes varying with [Fe/H], with different slopes (from 0.15 to 0.51).

Hipparcos will provide a reliable basis for the calibration of sequences of stars with low metallicities, and this will improve the determination of the distances of globular clusters. In addition, Hipparcos will very likely provide the discovery of a number of new RR Lyrae.

GAIA would again for this type type of pulsating stars provide a drastic improvement. Stars up to distances of 2 500 pc for the baseline option, to 5 000 pc for the direct fringe detection option would be within reach with a relative accuracy of 1%. These distances are increasing up to 8 000 and 18 000 pc respectively for a relative accuracy of 10%. As a result, absolute magnitudes of most galactic RR Lyrae would be determined with an excellent accuracy. These results would provide direct elements to the strong controversy related to the variation of the RR Lyrae absolute magnitudes with [Fe/H]: the metallicity of RR Lyrae stars is significantly variable with galactocentric distances within 10 kpc from the galactic centre (Smith 1995), and all such stars would be observable with GAIA.

In addition, GAIA photometry could provide the discovery of many new RR Lyrae. Suntzeff et al. (1991) estimate the total number of RR Lyrae stars in our Galaxy to be of the order of 85 000, to be compared with about 8 000 presently known (Smith 1995).

6. CONCLUSION

A GAIA-type mission would provide an astonishing improvement of distance scale determinations. Distances and absolute luminosities would be available with a very high accuracy, not only for the main primary indicators described above, but also for many other powerful indicators such as novae, central stars of planetary nebulae, other pulsating stars such as Mirae, supergiants, etc. All relations such as period-luminosity, luminosity at maximum, most probable luminosity for a given type of star, position of the main sequences and/or horizontal branches of clusters, will be calibrated in thorough detail.

The use of these relations, first directly in the Local Group, but also up to groups of galaxies such as Virgo or Fornax, and the further calibration of 'secondary' and 'tertiary' distance indicators, would allow to determine much more safely the Hubble constant and the age of the Universe.

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