SOME ASPECTS OF THE GAIA CONCEPT WITH RESPECT TO PULSATING STARS

M.O. Mennessier, D. Barthès

GRAAL, URA1368 Univ. Montpellier II and CNRS, cc072, F34095 Montpellier Cedex 5, France

ABSTRACT

Pulsating variable stars play an important role in many aspects of astrophysics: stellar and galactic evolution, physics of interstellar and circumstellar media. Moreover Cepheids are prominent in the calibration of the extragalactic distance scale. We try to envisage how the large number of sources that could be observed by GAIA with its precision of measurements can enhance the results that we expect to obtain from Hipparcos. We examine in particular what we can expect from observations of large numbers of pulsating stars observed in 6 or 7 photometric bands over a period of 5 years.

Key words: Hipparcos, GAIA, pulsating stars, distance calibration, stellar physics, galactic evolution.

1. INTRODUCTION

Pulsating stars are important to models of stellar structure and evolution as to studies of galactic dynamics. Cepheids and RR Lyrae are cornerstones for extragalactic distance scale. Miras, due to their very large initial mass and age ranges, are peculiarly good tracers of the history of our Galaxy. As is the case for many stars, very accurate astrometric parameters of pulsating stars will be considerable for these purposes. In this talk we will not insist on this point, we will only consider some specific points related with the possible contribution of GAIA concept to the study of these variable stars.

2. HIPPARCOS AND GAIA

The location of pulsating variables in the HR diagram is indicated in Fig. 1. It can be seen that most of them are luminous and distant stars. So Hipparcos will provide only few accurate parallaxes for such stars: 3 for Cepheids, 3 for RR Lyrae and 9 for Miras (Turon & van Leeuwen 1995).

The schematic comparative diagram by Lindegren & Perryman (1994) shows the respective limits of Hipparcos and GAIA and the lines corresponding to absolute magnitudes of Cepheids and RR Lyrae. So GAIA will measure the 400 presently known Cepheids instead of 60 in the Hipparcos mission and some in the Magellanic Clouds and 6000 presently known RR Lyrae instead of 180. We have added in Fig. 1 the lines for C stars using absolute magnitude from Landolt & Bornstein (1982).

The lines for halo Miras at their minimum luminosity and thick-disk oxygen Miras at both extrema of luminosity are also shown (absolute magnitudes from Mennessier et al. 1995). We can see that according to a limit of $V \sim 15$ mag, GAIA could probably measure all the halo Miras whereas a limit of $V \sim 16$ mag could allow measurement of all oxygen Miras at their maximum light, and all O-Miras within about 1.5 kpc at any phase. As a comparison, Hipparcos can measure O-Miras at any phase only out to about 400 pc for the ones belonging to thick disk, and less than 1 kpc for halo ones. There are 250 O-Miras observed by Hipparcos, and at least 4000 could be observed in the GAIA mission. Very few C stars are included in Hipparcos Input Catalogue, indeed at the time of proposals they were poorly known and did not belong to the main fields of interest—all of them could be among stars measured by GAIA.

3. PERIOD-LUMINOSITY RELATIONS

It is now thought that, for the majority—perhaps all—of types of pulsating stars, the realistic relation is a period-luminosity-metallicity-pulsation mode one. An illustration for Cepheids can be found in Nemec et al. (1994) (Fig. 7, for example), where the authors show observed relations according to pulsation mode and theoretical ones according to metallicities. For a given period, the luminosity can differ up to about one magnitude.

Figure 1. The potential accuracies achievable by GAIA.

Figure 2. Location of the different types of pulsating variables in (period, amplitude, $B-V$) space.

In the GAIA mission, the luminosity will be obtained from the parallax, period, and metallicity from multiband Strömgren photometry. The pulsation mode is not a direct observational product, but could be obtained from the parameters of the light curves by comparison with models.

4. NEW DETECTIONS

The shape of the grid-modulated signal observed by Hipparcos gives the possibility of detecting a large number of as yet unknown binaries. Moreover the accuracy of photometric measurements at different times allows one to detect stars presently unknown as variable (Mignard 1995). Evidently, GAIA will be able to detect a very large number of new double and variable stars including a number of pulsating stars.

It is not obvious to identify the type of variability of newly detected variables using only parameters from the satellite observations. Due to the scanning law a period can generally be estimated. The photometric measurements provide the amplitude of the variation or, at least, a lower limit of it. This is not sufficient to separate the different classes of pulsating variables. Thus the knowledge of one or several colour indices is required. The $B-V$ Johnson index allows one to solve the problem except for long-period variables (Fig. 2), so Strömgren photometry will probably be sufficient for classifying pulsating variables newly detected by GAIA, but not for separating the different types of long-period variables.

However it could be useful to be able to classify these red variables that are so important to models of stellar and galactic evolution: on the one hand they are in an evolutionary key-stage during which the star is deeply transformed up to the ejection of its envelope, and on the other hand they are exceptionally good tracers of the history of our Galaxy owing to their large mass and age ranges. Infrared colour indices are separators for these stars: $(K-L)$ separate oxygen-rich and carbon-rich Miras (Epchtein et al. 1987). Moreover preliminary results using first DENIS observations combined with COSMOS measurements show that $(B-J)$ could separate red giants and supergiants; this colour also seems to have different values for very late dwarfs and to be an indicator of spectral type (Dabrovski 1995).

So to include infrared filters, at least J, could be of great interest for studying red variables. It would be unfortunate if GAIA is unable to provide sufficient photometry for identifying red variables soon to be detected by IR surveys such as DENIS and 2mass, or accurate kinematics to include into models of galactic evolution.

5. LIGHT CURVES

Light curves are very difficult to obtain from ground-based observations: either the period is short (of the order of one day) so that it is necessary to have an observational network all around the different longitudes, or the period is long and annual motion of the earth induces observing interruptions for a large phase range. A scanning satellite is very good for obtaining light curves. However the degree of extracted informations depends on: (a) the number of observations per cycle; (b) the mission length; (c) the regularity of the observations.

The first and third points are clearly related to the scanning law of the satellite. Obviously the typical period of each type of variable stars induces very different kinds of results. In the following, the scanning law of GAIA was assumed to be close to the Hipparcos one, i.e., two observations at an interval of about 20 minutes repeated 2 hours after (eventually few successive times at every 2 hours), and the same scheme about every 2 months.

5.1. MAIN PERIOD OF RR LYRAE AND CEPHEIDS

The relevant period range is 0.2–1 day for RR Lyrae and 10–50 days for Cepheids. Hipparcos gives light curves with an estimation of the main period for both these types (Turon & van Leeuwen 1995, Mignard 1995). However the scanning law induces a nearly random cover with respect to RR Lyrae curves, allowing to detect period changes during the mission time.

Obviously not only GAIA could give light curves of these stars but moreover they will be multicolour ones. The longer time duration of the mission will allow a more precise analysis of RR Lyrae period changes.

5.2. MODES AND HARMONICS

Pulsating stars are in general multimode pulsators with non-linear phenomena resulting in coupling, resonances, and harmonics, etc., the study of which is fundamental for stellar physics and stellar evolution.

It is well known that some Cepheids are double-mode. Unfortunately the Hipparcos (temporal) coverage is not optimum, and possible double-mode objects cannot be routinely detected. It is likely that this determination will remain difficult with GAIA.

However one way may be accessible to the GAIA mission. It concerns the estimation of the ratio of the amplitudes of the main frequency (ν_p) and of its first harmonics:

$$r_{21} = a(2\nu_p)/a(\nu_p)$$

that was studied in detail for RR Lyrae and Cepheids (Buchler & Kovacs 1982).

This could essentially concern Miras for which the scanning law induces relatively regular observations. These ratios determined from 20-year AAVSO data of oxygen-rich Miras in Hipparcos Input Catalogue are shown in Fig. 3. It seems that its value could be related to the thickness of the envelope. So we have done one simulation for exploring such a possibility.

Figure 3. Ratio of the amplitudes of the main frequency and of its first harmonics of light curves of Miras with an indication of error bar.

5.3. SIMULATIONS FOR MIRAS

We have proceeded as follows: (1) we have chosen an 'average' Mira, i.e., with a period around 300 days and in an ecliptic position such that the number of observations induced by the scanning law is an average. (2) We have built a simulated light curve from the Fourier spectrum of its real AAVSO 20-year curve (Fig. 4). (3) We have used the Hipparcos scanning law to select the date and magnitude to be considered in the analysis (Fig. 5). (4) We have performed a Fourier analysis of the resulting simulated observing points as a function of several assumed mission lengths.

The results are as follows:

- 5-years simulated data: $r_{21} = 0.11 \pm 0.06$
- 6-years simulated data: $r_{21} = 0.35 \pm 0.07$
- 8-years simulated data: $r_{21} = 0.18 \pm 0.06$
- 10-years simulated data: $r_{21} = 0.22 \pm 0.05$
- 15-years simulated data: $r_{21} = 0.22 \pm 0.04$

to be compared with that obtained from 20 years of AAVSO data, $r_{21} = 0.25 \pm 0.03$. We can see that the ratio is estimated with a sufficient accuracy in an 8-year mission, and is not greatly improved in the case of a longer mission.

Figure 4. Fourier spectrum of the test 20-year light curve.

Figure 5. Dates and magnitudes used in the simulation.

This first simulation shows that r_{21} should eventually be determined, but more simulations are necessary to make a refined estimate of the required minimum mission duration for results to be obtained for a sufficient number of Miras.

6. CONCLUSIONS

As is the case for the other stars, the actual GAIA concept (Lindegren & Perryman 1994) can enhance our knowledge of galactic dynamics from a large quantity of very accurate astrometric data.

Two characteristics can be of great interest in the field of pulsating stars: the mission length and the multi-colour photometry. If the mission is sufficiently long, important indications as period changes of RR Lyrae or properties of harmonics could be extracted from light curves. More simulations are necessary to adjust the necessary minimum time length but the first rough estimate of this limit seems to indicate that it should not be more than 8 years.

It is highly suitable for red variables to include infrared filters in the 1–3 μm wavelength range, at least a J-filter. This is necessary for classifying the newly-detected variable stars. Moreover light curves in both the visible and infrared ranges allow separation of variability due to internal pulsations and the effects of the envelope. Lastly, I and J filters are essential to observe the numerous objects that will have been found in the infrared deep surveys and that are not so luminous in the visible range, such as the red variables with a thick envelope. The importance of these stars, variable or not, is well known for models of galactic evolution.

REFERENCES

Buchler, J.R., Kovacs, G., 1986, ApJ, 303, 749

Dabrovski, Y., 1995 *DEA, Univ. Paris VII-XI*

Epchtein, N. et al, 1987, AASS, 71, 39

Landolt-Bornstein, 1982, *Numerical Data and Functional Relationships*, 2, 351

Lindegren, L. Perryman, M.A.C., 1994, *GAIA, Horizon 200+*, ESA

Mennessier, M.O., Luri, X., Figueras, F., Torra, J., 1995, IAU Coll. 155, ASP Conf., in press

Mignard, F., 1995, ESA SP–379, this volume

Nemec, J., Nemec, A., Lutz, T., 1994, AJ, 108, 222

Turon, C., Van Leeuwen, F., 1995, IAU Coll. 155, ASP Conf., in press