LOW-MASS STARS: A SHARPER VIEW OF THE SOLAR NEIGHBORHOOD

F. Crifo[1], **T. Forveille**[2]

[1]DASGAL, URA CNRS 335, Observatoire de Paris, France
[2]URA 708, Observatoire de Grenoble, France

ABSTRACT

GAIA will see the bulk of the (mostly faint) stars in the solar neighbourhood (listed in the Gliese-Jahreiss Catalogue). Brown dwarf candidates still remain out of direct reach. For a good study of the solar neighborhood, GAIA should have the best possible limiting magnitude, and include a near-infrared channel. Simultaneous measurements of metallicities and radial velocities would greatly enhance the value of GAIA for solar neighbourhood studies.

Key words: nearby stars, lower main sequence, brown dwarfs

1. INTRODUCTION

The well-known series of 'Catalogues of Nearby Stars' (Gliese; Gliese & Jahreiss) summarize our present knowledge of the stars which surround the Sun (closer than 25 pc). Hipparcos will very soon sharpen this picture, but it could only see our brightest neighbours, while GAIA will sample the bulk of the luminosity function. GAIA will also reach the fainter stars which will be discovered or recognized as such by the new infrared photometric surveys (DENIS, now just starting observations; and 2MASS, in construction). These surveys should reach a new class of very cold and faint objects, for which accurate parallaxes will be most desirable.

Here we only discuss some of the benefits to be expected from GAIA; the very important kinematic and dynamical aspects are only mentioned briefly.

2. A BETTER LUMINOSITY FUNCTION

The successive versions of the Catalogue of Nearby Stars (Gliese (1957, 1969) and Gliese & Jahreiss (1979; 1991, hereafter designated as CNS3)), have shown more and more clearly that the Sun is mostly surrounded by red dwarfs, much fainter than the Sun itself.

The solar neighborhood luminosity function, as derived by Wielen et al. 1983 from the Catalogue of Nearby Stars, has its peak at an absolute magnitude $M_V \simeq 13$ mag. With its limiting magnitude of $V \simeq 12$ mag, Hipparcos can therefore only study the dominant stellar population

	Hipparcos $V \leq 12$	GAIA $V \leq 15$	GAIA $V \leq 16$	GAIA $V \leq 17$
$M_V = 13$	6.3 pc	25 pc	40 pc	63 pc
$M_V = 16$	1.6 pc	6.3 pc	10 pc	16 pc
$M_V = 19.5$		1.2 pc	2 pc	3.2 pc

Table 1: Maximum distance for faint stars

of the galaxy up to a distance of about 6pc. The Hipparcos Input Catalogue only contains 36 M dwarfs with $M_V \geq 12$, and 11 with $M_V \geq 13$. Most of the latter are in fact physical companions to brighter stars, and take benefit of its parallax; the faintest one is LP 12-304 (M_V=16.4 mag). The distances reachable with Hipparcos and GAIA are given in Table 1, for $M_V = 13$ mag (maximum of luminosity function, mass of about 0.2 solar mass), 16 mag (star of about 0.1 solar mass), and 19.5 mag (value for the few present brown dwarf candidates).

The spectral energy distribution of these cold objects peaks in the infrared, and the usual V band only contains a tiny fraction of their total luminosity: a $0.2M_\odot$ star has $V - I = 2.8$ mag, and $V - K = 5.2$ mag (Legget 1992). Including an infrared channel (or at least an I channel) would greatly increase the volume in which GAIA can measure intrisically faint stars. The photometry would also be much more useful, as '...optical colours are poor luminosity estimators for very low mass stars (below 0.2 $M_\odot$)...' (Tinney et al. 1993).

On third of the stars in CNS3 have no trigonometric parallax, and many more have poor ones. These are mostly the fainter dwarfs ($V \geq 11$) which haven't been measured by Hipparcos either. An important ground-based effort is being made to measure parallaxes for selected nearby stars (Monet et al. 1992 and reference therein), and the CCD program of the USNO Flagstaff station now routinely measures parallaxes accurate at the milliarcsec level, for stars as faint as $V = 19.5$ mag. These labour-intensive programs, however, remain restricted to small lists of severely selected targets,

The CNS3 is only regarded as complete up to $M_V \simeq 8$ mag (Jahreiss 1995). With a suitable input catalogue, GAIA could complete it up to the peak of the luminosity function at $M_V \simeq 13$ mag (Table 1), or even beyond with an infrared channel. The NLTT Catalogue (Luyten 1979) is the main existing reservoir of those 'missing' nearby stars. This proper motion selected catalogue ($\mu \geq 0.18$ arcsec/y) reaches R= 19.5 mag. Only a satellite program however could obtain parallaxes

	$V \leq 12$	$V \leq 15$	$V \leq 16$	$V \leq 17$	Total
CNS3	2527	3609	3724	3766	3802
NLTT	13000	30000	38000	45000	58000

Table 2: Number of stars in the CNS3 and the NLTT up to various limiting magnitudes

for its 58000 stars. Hipparcos has observed its brighter part, with a fuzzy cutoff between $V = 11$ mag and $V = 12$ mag, and new stars within 25 pc should soon become public. The total number of CNS3 and NLTT stars accessible to GAIA is given in Table 2. The NLTT stars should be given high priority in a GAIA Input Catalogue, despite the large proper motion which complicates their tracking. By its very definition however, the NLTT has an inherent kinematic bias and any sample tracing back to it must be used with some care for dynamical studies. It can however be complemented/replaced by the photometrically selected catalogues which will be produced from the on-going near-infrared surveys (DENIS and 2MASS), and which will not suffer this problem.

Many of the M dwarfs belong to the dMe class and have chromospheric activity, which is strongly related with age, mass and rotation rate (see Liebert 1995; Stauffer 1995). GAIA's 5-years accurate photometric survey will detect the often irregular photometric variability associated with this activity.

The study of these objects would also enormously benefit of the simultaneous availability of multi-colour photometry, for ages, metallicities, and future calibration of photometric parallaxes of the many objects that will remain too faint for GAIA.

3. SUBDWARFS

If the NLTT contains most of the missing stars in the CNS3, however most of its stars are beyond 25 pc, with an important fraction of halo subdwarfs.

GAIA represents a unique opportunity for studies of halo stars. Observationnaly these objects are mostly characterized by their high velocity with respect to the LSR (and thus to disk stars), and by their low metallicity. Some of them are found in the CNS3, while most of the nearby ones, recognized or not, are in the NLTT. Recently Monet et al. 1992 and Dahn et al. 1995 used new accurate parallaxes, measured at the USNO Flagstaff station for very faint stars, to determine the local density of halo stars and the Population II luminosity function. It seems to have a maximum near $M_V = 12.5$ mag, followed by a rapid fall-off. The well-defined sample of Dahn et al. 1995, however only contains 114 stars, so this conclusion is subject to considerable sampling noise. It would be extremely desirable to extend this sample, to ascertain whether disk and halo stars have or or do not have the same luminosity function, mass function and IMF (D'Antona 1995). GAIA will settle these points.

As most of the stars involved have M_V between 10 and 18, the best possible sensitivity for GAIA will again be most desirable. The addition of tools for measuring at the same time the metallicity and the radial velocity would be extremely desirable to characterize the objects, and to study their individual and collective kinematic behavior as a function of metallicity.

4. BROWN DWARFS

Brown dwarfs have long been predicted by theory, but no such object has yet been firmly identified, though a few good candidates do exist. With a firm lower limit to their absolute magnitude M_V of at least 18 (Henry and McCarthy 1993), and more probably 19.5 (Ianna and Frederick 1995), these objects are beyond direct reach for GAIA (Table 1) and could only be found as companions to more massive stars. With its maximum magnitude difference for a companion of about 3, GAIA will rarely (if ever) be able to detect the secondary light. An infrared channel would have a more favourable contrast, but could probably still not directly compete with on-going programs using ground-based speckle imaging (Henry and McCarthy 1992) or coronographic adaptive optics (Beuzit et al., private communication).

Companions will thus mostly be detected through the reflex motion of the primary, and the systems as astrometric binaries. GAIA could detect Jupiter (0.001 $M_\odot$) orbiting the Sun up to distances of the order of 30 pc (Lindegren and Perryman 1994 page 14), and the much heavier brown dwarfs ($0.08 M_\odot$) will be detectable to much larger distances around their generally lighter primaries, provided that the mission covers half an orbital period. GAIA will thus detect many astrometric binaries, hopefully including some brown dwarfs. It will provide much needed (Reid 1995) information on stellar multiplicity in the solar neighbourhood, complementary to on-going radial velocity work Duquennoy and Mayor 1991, and Marcy and Butler 1995). Follow-up radial-velocity work (and/or a ground-based determination of the relative orbit) will be needed to determine masses and ascertain the brown dwarf status of the companions. All stellar parameters will then be available, providing strong constraints on theoretical models of internal structure and atmospheres (Baraffe et al. 1995).

5. CONCLUSION

GAIA's expected accuracy will allow for the first time direct distance measurements *outside* our own Galaxy. Only the brightest objects however will be accessible there, and we will somehow be in the position of seeing only the kings of far-away countries. Due to unavoidable sensitivity limitations, the fainter stars which make up the bulk of the stellar population will still have to be studied in a small sphere around the Sun, and the the faintest ones will still be missed even with GAIA's improved sensitivity.

M dwarfs dominate the solar neighbourhood by numbers, but our inventory of these faint red stars is incomplete. Hipparcos parallaxes have sufficient accuracy for those stars at their maximum detectable distance, but will only be available for the brightest and closest ones. Ground-based measurements can now be as accurate, but only for very small samples. GAIA will for the first time produce parallaxes to large numbers of M dwarfs, and reach at least to the peak of the luminosity function. The number of parallaxes, and more importantly the faintest accessible luminosity, strongly depend on the limiting magnitude of the instrument, and on available the photometric channels. A near-infrared channel, or at least an I band channel, is highly desirable.

This large sample of stars with extremely accurate parallaxes would allow for the first time:

(a) the study of the luminosity function, mass function and IMF, separately for disk and halo stars;

(b) a much improved knowledge of stellar structure and evolution at the bottom of the main sequence, and the fine details in this part of the HR diagram. Age effects in particular become important for very low mass stars, whose pre-main-sequence time becomes a significant fraction of the Hubble time, and they have up to now been largely ignored, for lack of available data.

(c) many new studies and general galactic modeling taking into account the various kinematic aspects, provided metallicities and radial velocities are known.

GAIA will also detect many nearby multiple systems as astrometric binaries and produce much needed mass determinations of low mass stars. For the best progress in the field of low-mass stars, the following instrumental requests should be fulfilled: (a) as high a limiting magnitude as possible; (b) a near-infrared (or at least I-band) channel; (c) complementary measurements of metallicities and radial velocities.

REFERENCES

Baraffe, I., Chabrier, G., Allard, F., Hauschildt, P.H., 1995, Astrophys. J. 446, L35.

D'Antona, F., 1995, in: *The Bottom of Main Sequence and beyond*, C. Tinney ed., Proceedings of the ESO Workshop, 10-12 Aug 1994, Springer, p.13.

Dahn, C.C., Liebert, J., Harris, H.C., Guetter, H.H., 1995, in: *The Bottom of Main Sequence and beyond*, C. Tinney ed., Proceedings of the ESO Workshop, 10-12 Aug 1994, Springer, p. 239.

Duquennoy, A., Mayor, M., 1991, A&A 248,485.

Gliese, W. 1957, *Katalog der Sterne näher als 20 Parsek für 1950.0*, Mitt. Astr. Rechen-Inst. Heidelberg Serie A, Nr 8

Gliese, W. 1969, *Catalogue of Nearby Stars. Edition 1969*, Veröff. Astron. Rechen-Inst. Heidelberg Nr 22.

Gliese, W., Jahreiss, H. 1979, Astron. Astrophys. Suppl. Ser. 38, 423

Gliese, W. & Jahreiss, H. 1991, *Preliminary version of the Third Catalogue of Nearby Stars* in : The Astronomical Data Center CD-ROM: selected Astronomical Catalogs, vol.1, eds L. E. Brotzmann and S.E. Gesser, NASA/ADC, Greenbelt, Md or: available by ftp at the CDS (Centre de Données de Strasbourg)

Henry, T.J., McCarthy, D.W.Jr., 1992, in: *Complementary Approaches to Double and Multiple Star Research*, Mc Allister and Hartkopf eds., Astronomical Society of the Pacific, San Fransisco, Page 10.

Henry, T.J., McCarthy, D.W.Jr., 1993, Astron.J. 106,773.

Ianna, P.A., Frederick, L.W., 1995, Astrophys. J. 441, L47.

Jahreiss, H., 1995, in: *The Bottom of Main Sequence and beyond*, C. Tinney ed., Proceedings of the ESO Workshop, 10-12 Aug 1994, Springer, p. 71.

Legget, S.K., 1992, Astrophys.J. Suppl. 82, 351

Liebert, J., 1995, in: *The Bottom of Main Sequence and beyond*, C. Tinney ed., Proceedings of the ESO Workshop, 10-12 Aug 1994, Springer, p. 217.

Lindegren, L., Perryman, M.A.C., 1994: *GAIA: a concept for an ESA Cornerstone Mission*, supplementary information submitted to the Horizon 2000+ Survey Committee, september 1994.

Luyten, W., 1979, *NLTT Catalogue*, University of Minnesota, Minneapolis.

Marcy, G.W., Butler, R.P., 1995, 1995, in: *The Bottom of Main Sequence and beyond*, C. Tinney ed., Proceedings of the ESO Workshop, 10-12 Aug 1994, Springer, p. 98.

Monet, D.G., Dahn, C.C., Vrba, F.J., Harris, H.C., Pier, J.R., Luginbuhl, C.B., Ables, H.D., 1992, Astron. J. 103, 638

Reid, N., 1995, in: *The Bottom of Main Sequence and beyond*, C. Tinney ed., Proceedings of the ESO Workshop, 10-12 Aug 1994, Springer, p. 53.

Stauffer, J.R., 1995,in: *The Bottom of Main Sequence and beyond*, C. Tinney ed., Proceedings of the ESO Workshop, 10-12 Aug 1994, Springer, p.233.

Tinney, C.G., Reid, I.N., Mould, J.R., 1993, Astrophys. J. 414, 254.

Wielen, R., Jahreiss,H., Krüger, R. 1983, in IAU Coll. 76, 163, *The Nearby Stars and the Luminosity Function*, eds A.G. Philips, A.R. Upgren, L. Davis Press, Schenectady, N.Y.