GAIA: AGB STARS AS TRACERS OF STAR FORMATION HISTORIES IN THE GALAXY AND BEYOND

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Abstract

We discuss the tracing of star formation histories with ESA’s space astrometry mission GAIA, emphasizing the advantages of AGB stars for this purpose. GAIA’s microarcsecond-level astrometry, multi-band photometry and spectroscopy will provide individual distances, motions, $T_{\text{eff}}$, log $g$ and [M/H] for vast numbers of AGB stars in the Galaxy and beyond. Reliable ages of AGB stars can be determined to distances of $\sim$200 kpc in a wide range of ages and metallicities, allowing star formation histories to be studied in a diversity of astrophysical environments.

1. The GAIA mission, an astrometric and spectrophotometric survey of the Galaxy

The European Space Agency’s GAIA mission, approved for launch in 2010–12, aims at surveying the Galaxy to 20th visual magnitude, using a combination of astrometric measurements (for trigonometric parallaxes and proper motions), multiband photometry (for basic stellar parameters like temperature and metallicity), and radial-velocity measurements. Targeted accuracies versus magnitude allow direct distances and motions to be obtained for large samples of intrinsically bright stars across the Galaxy and in some nearby Local Group galaxies. Expected
Table 1. Predicted accuracies, versus $V$ magnitude, of individual AGB stars observed by GAIA. Standard errors estimated by Lindegren (unpublished, 2002) for parallax ($\pi$) and proper motion ($\mu$), by Katz & Munari (2002) for radial velocity ($v_r$), and by Vansevičius et al. (2002) for photometrically derived $T_{\text{eff}}$, $\log g$ and [M/H]. The last column is the maximum distance of an AGB star ($M_V \simeq -2$) at the given accuracies.

| $V$ mag | $\sigma(\pi)$ | $\sigma(\mu)$ | $\sigma(v_r)$ | $\sigma(\log T_{\text{eff}})$ | $\sigma(\log g)$ | $\sigma([M/H])$ | $d_{\text{max}}$ kpc |
|---------|---------------|---------------|---------------|-------------------------------|------------------|------------------|-------------------|
| 15      | 13            | 8             | 1.1           | 0.007                         | 0.20             | 0.24             | 25                |
| 17      | 32            | 18            | 6.3           | 0.01                          | 0.27             | 0.32             | 60                |
| 19      | 90            | 50            | --            | 0.04                          | 0.60             | 0.63             | 150               |
| 20      | 160           | 90            | --            | 0.13                          | 1.1              | 1.3              | 250               |

Typical accuracies are shown in Table 1. In total more than 1 billion stars will be observed, of which 50–100 million will obtain individual parallax distances to better than 5 per cent. A primary science goal is to study formation, evolution and structure of the Galaxy, for which large-scale mappings of star formation histories are essential. For a full description of the very broad range of science goals see Perryman et al. (2001).

In its present design GAIA comprises two astrometric instruments, with $1.4 \times 0.5$ m$^2$ apertures and a combined 0.5 deg$^2$ field of view, and a separate photometric/spectroscopic instrument with a $0.5 \times 0.5$ m$^2$ aperture. The latter performs photometry in $\sim 11$ bands for astrophysical classification, and $R \sim 10^4$ spectroscopy in the 849–874 nm wavelength range, mainly for radial velocities. During its lifetime of at least 5 years, the satellite will scan the entire sky repeatedly, so that each object is observed at multiple epochs. The above numbers and accuracy predictions refer to the recently (May 2002) completed revised design, aiming at a substantially reduced mission cost compared with the previous baseline (Perryman et al. 2001), while preserving all science goals intact.

2. Tracing stellar populations using AGB stars

The availability of precise photometry is essential for age derivations using isochrone fitting to the main sequence turn-off (MSTO) point. Simulations of GAIA photometry demonstrate that this method may be successfully exploited with GAIA even in such distant stellar systems as the Magellanic Clouds (Kučinskas et al. 2002), but only for populations younger than $\sim 1$ Gyr. In this paper we argue that GAIA observations of AGB stars can be used to determine star formation histories to even greater distances and for much older populations.
GAIA will provide a wealth of astrometric and spectrophotometric data on galactic and extragalactic AGB stars. Their uses are at least twofold: (a) as kinematic tracers, using distances and space motions obtained from the astrometric and radial-velocity data; (b) for age determinations, using basic stellar-atmosphere parameters ($T_{\text{eff}}$, $\log g$ and $[\text{M/}\text{H}]$) derived from the spectrophotometric data, combined with distances and theoretical isochrones.

From the astrometric and radial-velocity accuracies in Table 1 it is obvious that GAIA will yield accurate distances ($< 10\%$) and full space velocities ($< 1 \text{ km s}^{-1}$) for individual AGB stars up to distances of $10–15$ kpc, if no interstellar extinction is present.

Extensive simulations by the Vilnius GAIA group (Vansevičius et al. 2002; Kučinskas et al. 2002) show that GAIA will also provide precise metallicities ($\sigma([\text{M/}\text{H}]) \leq 0.3$) and gravities ($\sigma(\log g) \leq 0.3$) for AGB stars brighter than $V \sim 17$ (Table 1). Precise effective temperatures ($\sigma(\log T_{\text{eff}}) \leq 0.04$) are derived down to $V \sim 19$. This holds within a broad range of metallicities ($[\text{M/}\text{H}] > -2$) and ages ($0.05–15$ Gyr).

Metallicity estimates of intermediate age and old stellar populations can also be obtained from the slope of the red giant branch (e.g. Ferraro et al. 2000). Our simulations show that the method could provide an independent estimate of $[\text{M/}\text{H}]$ with GAIA, effective up to distances of $\sim 200$ kpc, if no interstellar extinction is present (Kučinskas et al. 2002).

We have recently shown (Kučinskas et al. 2000) that reliable ages can be derived using isochrone fits to the AGB sequences on the observed HR diagram. It is essential for this procedure to have precise effective temperatures of the AGB stars, which can be derived by fitting synthetic spectral energy distributions to observed photometric fluxes (e.g., $BVRIJHK$). The method was successfully tested and compared with the MSTO method on a sample of populous star clusters in the Magellanic Clouds spanning a wide range of ages (Table 2 and Fig. 1). For galactic AGB stars, it is clear that the distance information needed to construct the observational HR diagrams will be available through GAIA. It thus appears that precise age estimates ($\sigma(\log t) < 0.3$) can be obtained for a wide range of ages ($0.05–10$ Gyr) and metallicities ($[\text{M/}\text{H}] > -2$).

3. Conclusions

GAIA will provide unique astrometric and photometric data for studying individual and collective properties of stars in the Galaxy and its surroundings. AGB stars, being intrinsically bright, will provide precise individual distances, kinematics, $T_{\text{eff}}$, $\log g$ and $[\text{M/}\text{H}]$ up to distances of $10–15$ kpc. Using isochrone fitting to the AGB stars will give reliable
Table 2. MSTO and AGB ages for a sample of LMC and SMC clusters. AGB ages (Kučinskas et al., in preparation) were derived using the same cluster metallicities (Col. 2) as for the MSTO estimates.

| Cluster | [Fe/H] | MSTO | AGB |
|---------|-------|------|-----|
| LMC:    |       |      |     |
| NGC 1783| −0.4  | 0.9 ± 0.4 | 0.8 ± 0.2 |
| NGC 1846| −0.7  | 2.0 ± 0.2 | 1.5 ± 0.5 |
| NGC 1978| −0.7  | 3.2 ± 0.5 | 3.5 ± 0.5 |
| NGC 2121| −0.7  | 1.3 ± 0.3 | 9 ± 3   |
| SMC:    |       |      |     |
| Kron 3  | −1.3  | 0.8 ± 0.8 | 1.2    |
| NGC 152 | −1.0  |       |      |
| NGC 419 | −0.7  | 1.2 ± 0.5 | 1.4 ± 0.2 |

Figure 1. AGB sequences in NGC 1783 and Kron 3. Isochrones are from Bertelli et al. (1994).

For a wide range of ages and metallicities. If distances are known by other means (e.g. in distant clusters), the method can be used up to ~ 200 kpc. Thus, AGB stars will allow the formation histories and kinematics of stellar populations to be probed in a diversity of astrophysical environments both in the Milky Way and in neighbouring galaxies.

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