Estimating distances to AGB stars using IR data

Rajorshi Bhattacharya[1], Ylva M Pihlström[1], Loránt O Sjouwerman[2]

[1]University of New Mexico, Albuquerque, NM, USA; [2]National Radio Astronomy Observatory, Socorro, NM, USA;

Motivation

The Bulge Asymmetries and Dynamical Evolution (BAaDE) project has delivered line of sight velocities to more than 10,000 AGB stars in the Milky Way, primarily in the bulge region.
To incorporate these velocities into dynamical models and to distinguish between different AGB populations, we want to determine the 3D positions and hence distance estimation becomes crucial. Distances also enables luminosity and mass-loss rates to be evaluated. The vast majority of BAaDE AGB stars lack reliable Gaia parallaxes, hence we are exploring alternative methods to determine distances to AGB stars. The proposed method is advantageous as it builds on utilizing existing infrared catalogs, and can be used for AGB stars throughout the Galaxy.

Methodology

The initial assumption is that stars with similar intrinsic properties produce similar SEDs and are of similar luminosity. To compare whether a template and a source has similar properties, we use three different colors: [J]-[K] (2MASS), [A]-[D] (MSX) and [K]-[A]. After extinction correction, a distance estimate is extracted by comparing the individual target SED with a distance-calibrated template SED:

$$d_{\lambda,\mathrm{AGB}} = d_{\mathrm{Template}}\left(\sqrt{\frac{F_{\lambda,\mathrm{Template}}}{a_\lambda F_{\lambda,\mathrm{AGB}}}} \times 10^{\frac{-Z_\lambda A_K}{2.5}}\right) \tag{1}$$

Z_λ describes the extinction curve, and A_K the K-band extinction. The term a_λ is the ratio of luminosity of the template and target source which is assumed to be unity as we consider them to have similar luminosity. To reduce uncertainty due to source variability, the final distance estimate is an average of the distance estimates calculated at each waveband.

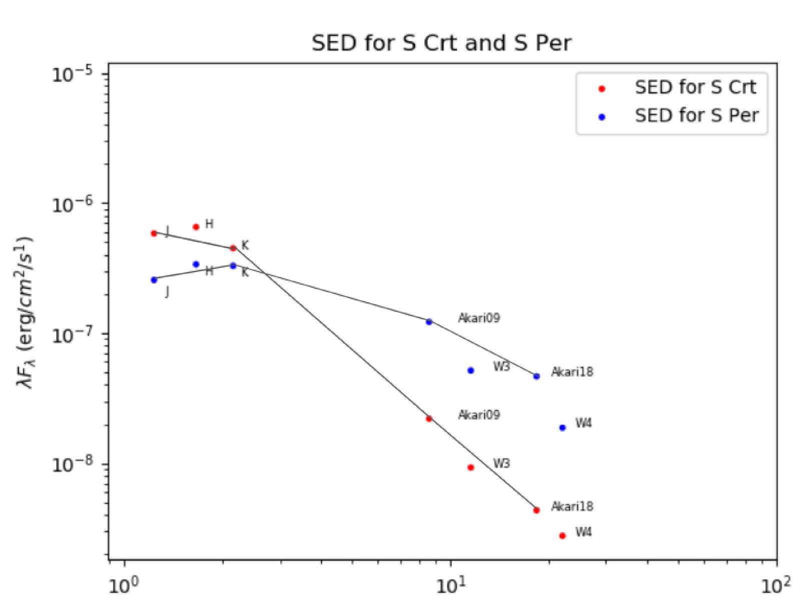

Figure 1: SED for the AGB stars S Crt and S Per using 2MASS, WISE and AKARI bands. This plot shows two completely different SED shapes and how templates can be compared based on the three color cuts.

Comparison to VLBI parallax data

To test the method, we selected sources with known VLBI parallaxes as templates (Xu et. al. 2019). A single VLBI source was used as a template to calculate distances to other VLBI sources. Good agreement was achieved.

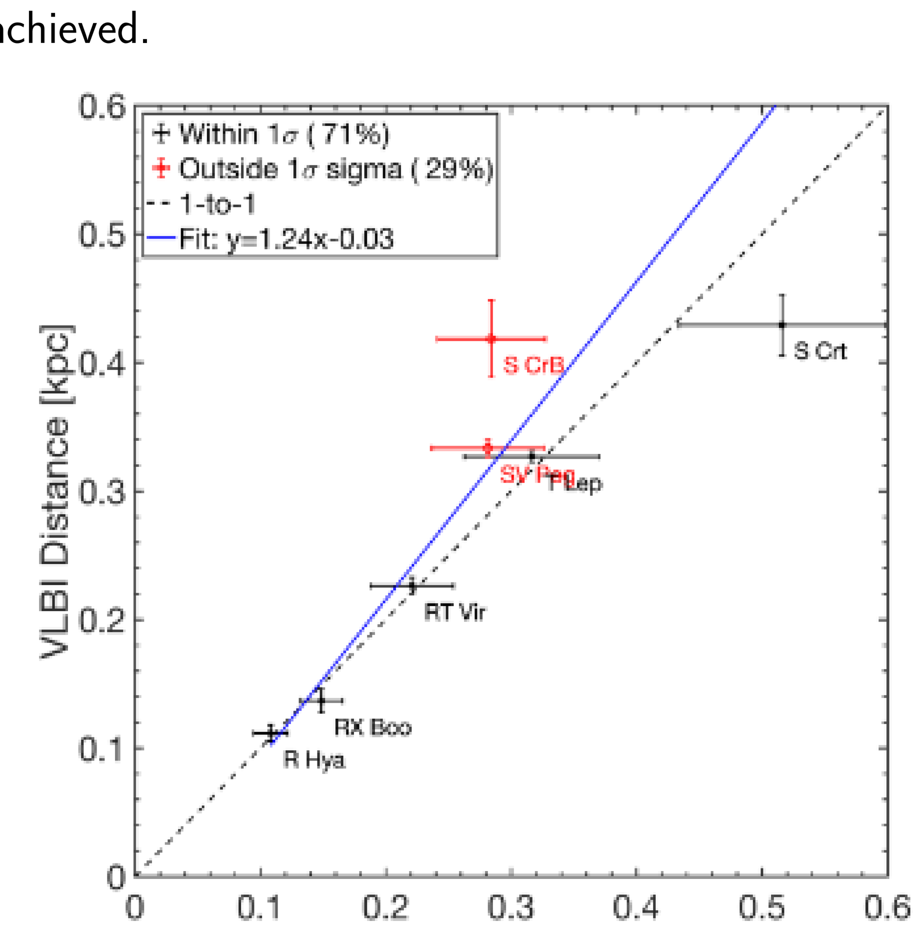

Figure 2: Comparison between the SED distances with the VLBI distances for the VLBI sources using R Cnc as the template (Medina et. al. 2022).

Comparison to Gaia parallax data

As we obtained good agreement with VLBI parallax distances, we continued testing with sources that had Gaia parallaxes available. Figure 3 shows, with grey points, the initial comparison between SED distances and Gaia parallax distance estimates. There is no obvious correlation. However, Andriantsaralaza et al.(2022) points out difficulties for Gaia in providing reliable parallaxes for obscured AGB stars, even if we consider sources with parallax errors $< 20\%$. They also point out that for brighter Gaia sources the errors are underestimated and the relative parallax errors need to be corrected (for a source having $8 <$ G mag < 12 the error gets underestimated by a factor of 2.5 whereas for G mag < 8, the error gets underestimated by a factor of 5). Following their work we find a clear distinction between the fainter and brighter sources. Selecting only those sources for which more reliable parallaxes can be extracted, a correlation is seen (red and blue dots in Fig. 3).

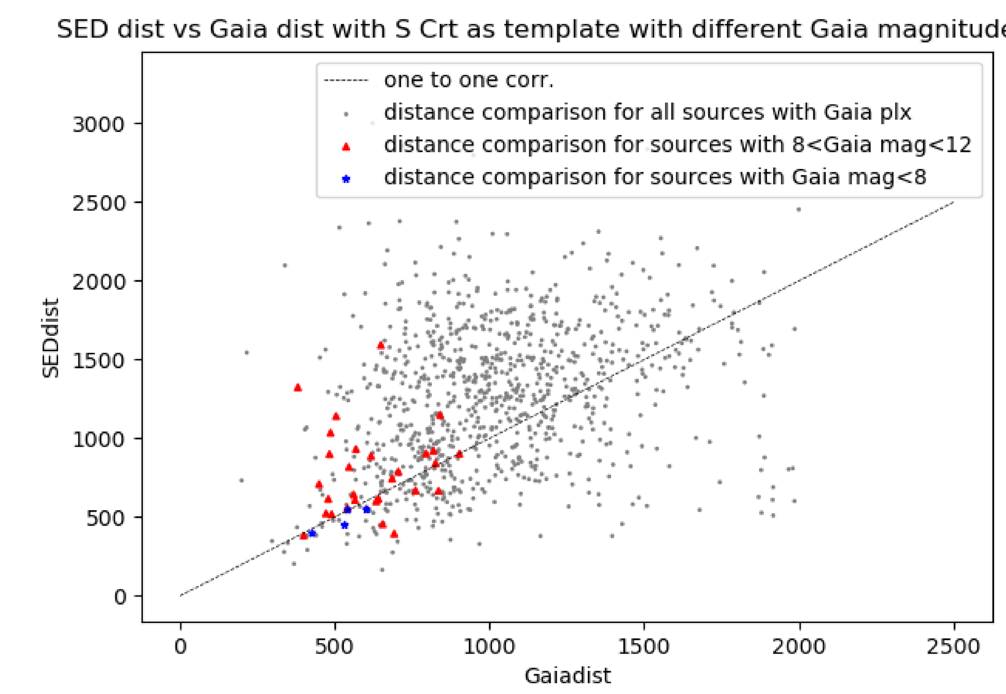

Figure 3: Comparison between estimated SED distances for BAaDE sources with their Gaia counterparts. Grey dots are all BAaDE sources with Gaia parallax errors $< 20\%$, while blue and red dots are the sources selected to have reliable parallax estimates based on the work by Andriantsaralaza et al. (2022).

Expanding template set with Galactic Center sources

As there are only a small set of AGBs with VLBI parallaxes, a larger set of templates must be defined to cover the full property range of the BAaDE sample. Sources with Galactic longitude and latitude < 1 degree, and with absolute line-of-sight velocities $> 100\mathrm{Km/s}$ were selected to form a sample most likely to be located close to the Galactic Center. We adopted a distance of 8.178 kpc [GRAVITY collaboration et. al. (2019)] for this source sample. Using one of the GC sources as a template we obtained distances to the other GC sources which were in good agreement with our assumption of the sources being close to GC.

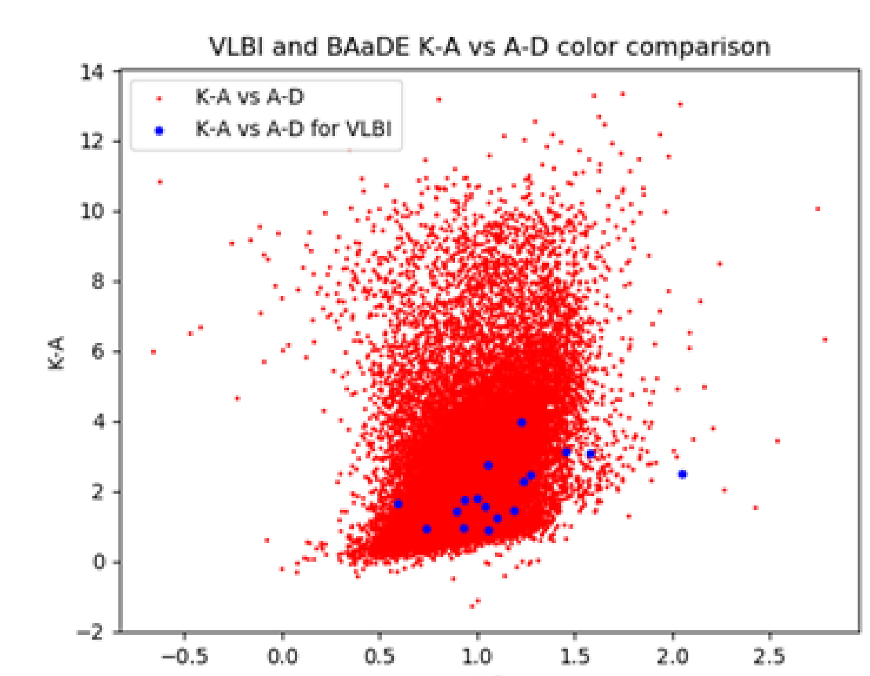

Figure 4: Color-color diagram showing a limited color coverage of VLBI sources with respect to the BAaDE sources.

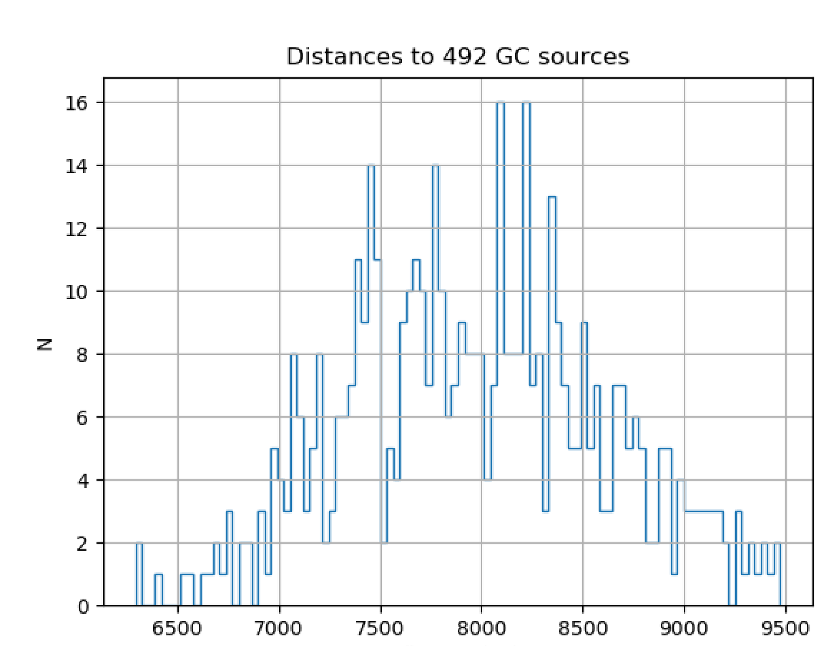

Figure 5: Histogram of obtained distances for the BAaDE GC sources.

Conclusion

Our method works well when comparing to reliable distance estimates from parallax measurements including both VLBI and Gaia. The work on expanding the template set so the full sample can be covered is promising, although with more fine tuning needed.

Bibliography

[1] Xu, Shuangjing, Bo Zhang, Mark J. Reid, Xingwu Zheng, and Guangli Wang. "Comparison of Gaia DR2 parallaxes of stars with VLBI astrometry." The Astrophysical Journal 875, no. 2 (2019): 114.

[2] Andriantsaralaza, Miora, Sofia Ramstedt, WH T. Vlemmings, and E. De Beck. "Distance estimates for AGB stars from parallax measurements." arXiv preprint arXiv:2209.03906 (2022).

[3] Abuter, Roberto, A. Amorim, M. Bauböck, J. P. Berger, H. Bonnet, W. Brandner, Y. Clénet et al. "A geometric distance measurement to the Galactic center black hole with 0.3% uncertainty." Astronomy and Astrophysics 625 (2019): L10.