Gaia EDR3 Data of Post-AGB Stars with Overabundance of *s*-process Elements: Evolutionary Status and Binarity

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Published February 2022 •
Research Notes of the AAS, Volume 6, Number 2

Citation M. Parthasarathy 2022 *Res. Notes AAS* **6** 33

DOI 10.3847/2515-5172/ac54bb

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1. Received February 2022
2. Revised February 2022
3. Accepted February 2022
4. Published February 2022

Stellar evolution; Asymptotic giant branch stars; Stellar distance; Post-asymptotic giant branch stars

Abstract

Kamath et al. analyzed Gaia EDR3 data of 18 post-asymptotic giant branch (AGB) supergiants having overabundance of *s*-process elements, some of which exhibit unusually low luminosities in disagreement with expectations of *s*-process nucleosynthesis. I have examined the Gaia RUWE statistics of these stars, and find that 13 have RUWE ≫ 1.4, suggesting they are most likely unresolved binaries that contain low-mass companions. The remaining five stars have RUWE < 1.4 and I find that their luminosities are in agreement with post-AGB evolutionary tracks.

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1. Introduction

Post-asymptotic giant branch (AGB) supergiants are stars that have recently evolved off the AGB but have not reached high enough temperatures to photoionize their circumstellar dust envelopes. The evolutionary stage of post-AGB supergiants is short-lived depending on the core mass (Schoenberner 1983). The study of post-AGB supergiants began with the discovery of circumstellar dust shells from the IRAS data around the F-supergiant HD 161796 and related stars by Parthasarathy & Pottasch (1986), who concluded that their circumstellar dust shells are the result of severe mass-loss experienced during the AGB stage of evolution. During the transition from the tip of the AGB to the young planetary nebula phase, these stars have spectral types that evolve from M to OB (Parthasarathy 1993), and they mimic the spectra of supergiants because after the termination of the AGB phase of evolution they have a white-dwarf C–O core with a very extended envelope.

During the past 35 yr multi-wavelength studies of these stars have revealed a small subset of F-type post-AGB supergiants that are carbon-rich and have overabundance of *s*-process elements (Kamath et al. 2021 and references therein), indicating that they have gone through a third dredge-up and carbon-star stage on the AGB (Parthasarathy 1999, 2000). These stars are not known to be binaries, and are unlike binary post-AGB stars which show depletion of refractory elements in their photospheric abundances. With the advent of recent Gaia parallaxes, it has become now possible to determine the stars' luminosities and thus to compare them with post-AGB evolutionary tracks in the H-R diagram (Parthasarathy et al. 2019, 2020).

Recently Kamath et al. (2021) have investigated the luminosities and evolutionary status of post-AGB supergiants with overabundance of *s*-process elements based on Gaia EDR3 data. In this paper I report on the accuracy of their distances as well as indicators of possible binarity, which affects their interpretation.

2. Data

Stassun & Torres (2021) have investigated the Gaia EDR3 parallax systematics and photocenter motions of stars. They find that the "RUWE" goodness-of-fit statistic reported in Gaia EDR3 is highly sensitive to unresolved companions through the ability to detect photocenter motions down to ≲0.1 mas. They find that RUWE values greater than 1.4 are highly indicative of companions, and that RUWE values even slightly greater than 1.0 may signify unresolved binaries in Gaia EDR3.

Table 1 lists the Gaia EDR3 parallaxes and RUWE values (Gaia Collaboration et al. 2018; Lindegren et al. 2018) of the 18 post-AGB stars with over-abundance of *s*-process elements discussed by Kamath et al. (2021). The table also lists from Kamath et al. (2021) the 13 normal post-AGB stars which have normal abundances of *s*-process elements, and which are also not known to be binaries, as a comparison set.

Table 1. Gaia EDR3 Parallaxes and RUWE Statistics for Post-AGB Stars from Kamath et al. (2021)

Star	Plx (mas)	Plx Error (mas)	RUWE
Post-AGB stars with overabundance of *s*-process elements			
IRAS 08281−4850	0.33674	0.191672	1.003161
IRAS 22223+4327	0.332528	0.02593	1.684633
IRAS 08143−4406	0.238178	0.017507	1.432755
IRAS 06530−0213	0.2412	0.074206	3.657064
IRAS 14429−4539	−0.1067	0.5072	2.79
IRAS 02229+6208	0.380585	0.060147	2.453611
IRAS 07430+1115	3.057735	0.50083	21.80084
IRAS 14325−6428	0.191554	0.036953	2.180936
IRAS 20000+3239	0.2049	0.0493	2.2458
IRAS 04296+3429	−0.37949	0.173385	5.757889
IRAS 19500−1709	0.39218	0.030765	1.008625
IRAS 05341+0852	0.510187	0.19353	12.96377
IRAS 05113+1347	−0.00923	0.145854	6.662692
IRAS 23304+6147	0.236607	0.027957	1.586183

Star	Plx (mas)	Plx Error (mas)	RUWE
IRAS 22272+5435	0.685988	0.028201	1.183704
IRAS 07134+1005	0.453771	0.023979	0.921502
IRAS 12360−5740	0.091152	0.014437	1.070371
IRAS 13245−5036	0.011639	0.022074	1.605342
Post-AGB stars with normal *s*-process abundances			
IRAS 01259+6823	0.6155	0.1410	1.309
IRAS 08187−1905	0.2879	0.0334	1.695
SAO 239853	−0.0085	0.0659	3.651
HD 107369	0.3669	0.0212	1.120
HD 112374	0.5670	0.0229	0.971
HD 133656	0.5629	0.0262	0.888
HR 6144	0.2808	0.0252	1.156
HD 161796	0.5022	0.0235	1.216
IRAS 18025−3906	0.5360	0.1942	8.582
HD 335675	0.0328	0.1840	13.740
IRAS 19386+0155	0.3238	0.1616	11.587
IRAS 19475+3119	0.3159	0.0209	1.429
HR 7671	1.3355	0.0271	0.809

3. Results

Only five of the 18 post-AGB stars with overabundance of *s*-process elements exhibit "good" RUWE values less then 1.4; they also have accurate Gaia EDR3 parallaxes. These stars can be inferred to be single and I find their luminosities (Kamath et al. 2021) are consistent with expectations from post-AGB evolutionary tracks. These five stars are IRAS 07134+1005, IRAS 08143−4406, IRAS 12360−5740, IRAS 19500−1709, and IRAS 22272+5435.

All the remaining 13 stars have RUWE values much greater than 1.4. Kamath et al. (2021) derive the luminosities of IRAS 05341+0852 (highly overabundant in *s*-process elements, see Reddy et al. 1997 and Kamath et al. 2021) and IRAS 07430+1115 to be 324 $L_{\odot}$ and 20 $L_{\odot}$, respectively.

However, their RUWE values are 12.96 and 21.80, respectively. The large RUWE values of these stars and other stars (Table 1) indicate that these stars may be binaries and may have unresolved companions.

Second, the Gaia EDR3 parallax of IRAS 05341+0852 is less than three times the error in the parallax (i.e., less than 3σ significance). Another four stars have parallaxes comparable to three times their errors in addition to large RUWE values, and yet another four stars have negative parallaxes (Kamath et al. 2021 use Bayesian based distances from Bailer-Jones et al. 2021 for these stars). For stars with negative parallaxes and parallaxes with less than 3σ significance, the distances and therefore the derived luminosities may not be accurate.

I have also examined the Gaia EDR3 RUWE values of the comparison stars (Table 1) and find that IRAS 08187−1905, SAO 239853, IRAS 18025−3906, HD 335675, IRAS 19386+0155, IRAS 19475+3119 have RUWE values greater than 1.4 indicating that they may have unresolved companions. Second, SAO 239853 has a negative parallax, the parallax of IRAS 18025−3906 is less than three times the error in parallax, the parallax of HD 335675 is six times smaller than the error in the parallax, and IRAS 19386+0155 has a parallax that is about two times the error in its parallax. Hence their distances and luminosities are not reliable.

Recently, Aoki et al. (2021) have also analyzed Gaia EDR3 parallaxes of 20 high radial-velocity post-AGB stars. They found large RUWE values for some of the stars, and some of them are already known and well studied post-AGB binary stars. For *s*-process rich high-velocity post-AGB star HD 56126 (Parthasarathy et al. 1992; Kamath et al. 2021), and for high galactic-latitude normal post-AGB star HD 161796 (Parthasarathy & Pottasch 1986), the luminosities derived by Aoki et al. (2021) are in agreement with the values derived by Kamath et al. (2021). Thus they also found that some of the *s*-process rich post-AGB stars and post-AGB stars with no overabundance of *s*-process elements have similar luminosities and similar initial main-sequence masses. The above mentioned two stars have accurate parallaxes and RUWE values less than 1.4 and they are not known to be binaries.

4. Conclusions

The Gaia EDR3 RUWE values of eighteen post-AGB stars with overabundance of *s*-process elements from Kamath et al. (2021) reveals that most of them likely have unresolved companions, which results in poor determination of true luminosities. Only five stars have RUWE values less than 1.4 and these also have accurate Gaia EDR3 parallaxes resulting in reliable luminosities

(Kamath et al. 2021) which are in agreement with post-AGB evolutionary tracks. These five stars are IRAS 07134+1005, IRAS 08143−4406, IRAS 12360−5740, IRAS 19500−1709, and IRAS 22272+5435.