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Matsuno, Tadafumi; Koppelman, Helmer H.; Helmi, Amina

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Bright stars from the ancient merger Gaia-Enceladus visible with binoculars

Tadafumi Matsuno,[1] Helmer H. Koppelman,[2] and Amina Helmi[1]

[1]*Kapteyn Astronomical Institute, University of Groningen, Landleven 12, 9747 AD Groningen, The Netherlands*
[2]*School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540, USA*

ABSTRACT

We present here a list of 25 bright stars ($G < 8$) that are possible members of Gaia-Enceladus, a system that merged with the Milky Way approximately 10 Gyr ago, and whose debris dominates the halo near the Sun. These stars were therefore born beyond the edges of the Milky Way and are visible with binoculars. We expect the list to be of interest for public outreach and amateur astronomers. These bright stars are also useful as standard stars for calibration and validation of analysis since very high-quality spectra can be obtained with reasonable amount of telescope time.

Observations of stars with the naked eye have played a very important role in human lives since ancient times. Nowadays bright stars are largely of interest to amateur astronomers, but they are also of use for validation and calibration of analysis carried out by professional astronomers (e.g., Heiter et al. 2015). It has recently been shown that the Milky Way experienced a very prominent merger approximately 10 Gyr ago, with a system known as Gaia-Enceladus (Helmi et al. 2018). As it turns out, several relatively bright stars are likely members of this object. These stars born beyond the edges of the Milky Way, are visible with binoculars.

In this Research Note, we present a list of bright stars that are likely members of Gaia Enceladus. These stars have been identified using their peculiar kinematics and chemical abundances. The left panel of Figure 1 shows the velocity distribution of bright stars (down to $G = 8.0$) in the Gaia DR2 radial velocity sample with Gaia EDR3 astrometry (Gaia Collaboration et al. 2018, 2020), where Gaia Enceladus member candidates are shown with red circles. We conservatively select Gaia Enceladus members using the following criteria: -800 kpc km s^{-1} $< L_z <$ 300 kpc km s^{-1} and $E_n > -1.7 \times 10^5$ km^2 s^{-2}, where L_z is the z-component of the angular momentum in galactocentric polar coordinates and E_n is the total orbital energy calculated in the McMillan (2017) potential using `AGAMA` (Vasiliev 2019). These criteria, especially the cut in E_n, are chosen to obtain an as pure sample as possible (e.g., Feuillet et al. 2020). We obtain 25 stars from this selection.

The right panel of Figure 1 shows relative Mg and Fe abundances for a subset of the stars (in red) taken from the literature (Fulbright 2000; Ishigaki et al. 2012; Siqueira-Mello et al. 2015; Niedzielski et al. 2016). For reference we also plot data from APOGEE DR16 (Jönsson et al. 2020; Ahumada et al. 2020). These abundances serve to select high confidence Gaia-Enceladus members since they have lower [Mg/Fe] ratios at [Fe/H]> -1.5 than stars formed in the Milky Way (see e.g., Nissen & Schuster 2010; Helmi et al. 2018). The blue circles in the figure have been selected from APOGEE using the Gaia-Enceladus selection criterion in $L_z - E_n$. As the figure shows there is only object with low [Mg/Fe] abundance at [Fe/H]> -1.5 ([Mg/Fe]$= 0.12$ at [Fe/H]$= -1.17$). This star is HD 97560 and a member of Gaia-Enceladus with high-confidence. Note that the few stars with apparently high [Mg/Fe] ratios at $-1.5 <$ [Fe/H] < -1.0 are not inconsistent with the low-Mg abundance of Gaia Enceladus due to the large measurement uncertainties. We expect that spectroscopic observations of the remaining candidate bright stars would reveal other true members.

The most well-studied object among the selected stars is HD 140283, although its metallicity is too low ([Fe/H]$\sim$ -2.5) to conclude from the [Mg/Fe] ratio if the star was once part of Gaia Enceladus. We note that it is estimated to be as almost old as the Universe from a detailed investigation of its age (14.27 ± 0.38 Gyr), which is the reason why it is called Methuselah star (VandenBerg et al. 2014). This star is the closest object in our list with a distance of 61 pc. Wolf 1106 is the closest ($d = 24$ pc) Gaia Enceladus member in the entire Gaia radial velocity sample, although it is

matsuno@astro.rug.nl

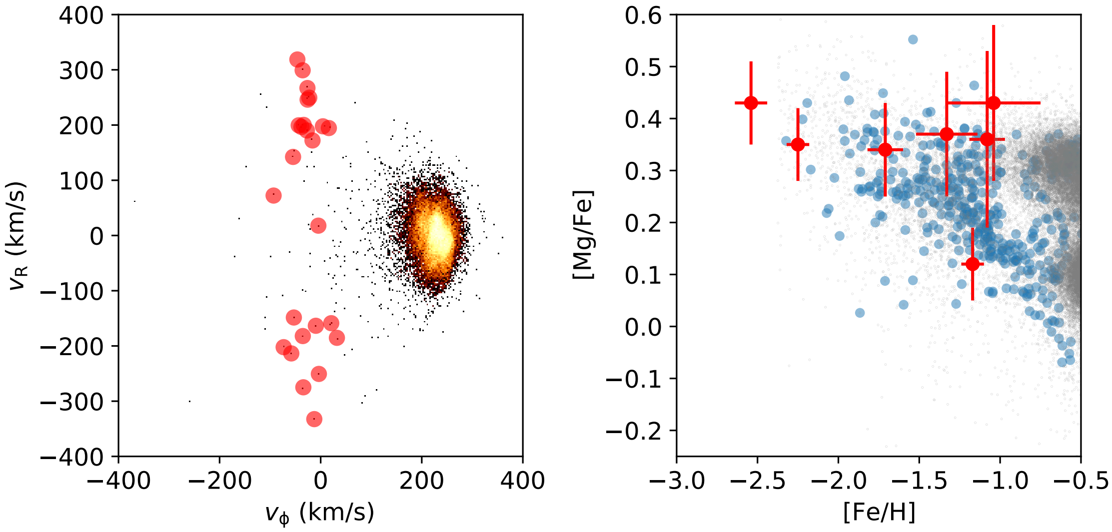

Figure 1. *Left*: Velocity distribution of bright ($G < 8$) stars in the Gaia DR2 radial velocity sample. The v_ϕ and v_R respectively show the stars' azimuthal and radial velocity components in galactocentric polar coordinates. The candidate members of Gaia Enceladus are shown with large red circles. *Right*: Mg and Fe abundances of stars from APOGEE DR16 (Jönsson et al. 2020; Ahumada et al. 2020) and those of the bright Gaia Enceladus candidates. The data from APOGEE are shown with grey points and the subset of Enceladus candidates, selected using the same $L_z - E_n$ criterion, are highlighted with blue circles. The bright Enceladus candidates are again shown with large red circles, for which the data are collected from Leep & Wallerstein (1981); Fulbright (2000); Ishigaki et al. (2012); Siqueira-Mello et al. (2015); Niedzielski et al. (2016); Steinmetz et al. (2020).

much fainter than the stars we consider in the present study ($G = 12.4$). This means that there could be even closer members but having fainter magnitudes.

We expect our list[1] of bright Enceladus members to be beneficial in public outreach providing an opportunity to see stars with extragalactic origin. All the selected stars will easily be visible with the use of binoculars or small telescopes. With the brightest being $G = 6.60$ mag, it will be difficult to see them with the naked eye. However, it does not seem to be entirely impossible since naked-eye catalogs sometimes record stars down to ~ 7 mag, fainter than the commonly quoted value of 6 mag (e.g. Weaver 1947).

[1] The table with the tentative members can be found here: https://www.astro.rug.nl/~ahelmi/brightGE.dat

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