Physical stellar properties of ellipsoidal red giant binaries in Gaia DR3

Image credits: G. Pérez (SMM-IAC)

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Alejandra Recio-Blanco, Patrick de Laverny & Ana Escorza

Binary and Multiple Stars in the Era of Big Surveys – 13 September 2024

Binary stars in the era of Gaia

The Gaia space mission is collecting precise astrometry, photometry and spectroscopy for millions of stars in our Galaxy

Binary stars in the era of Gaia

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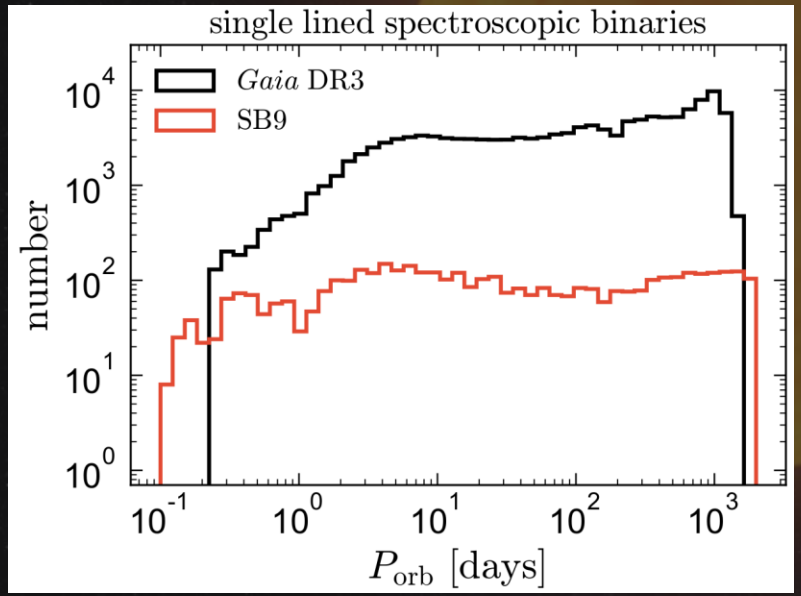
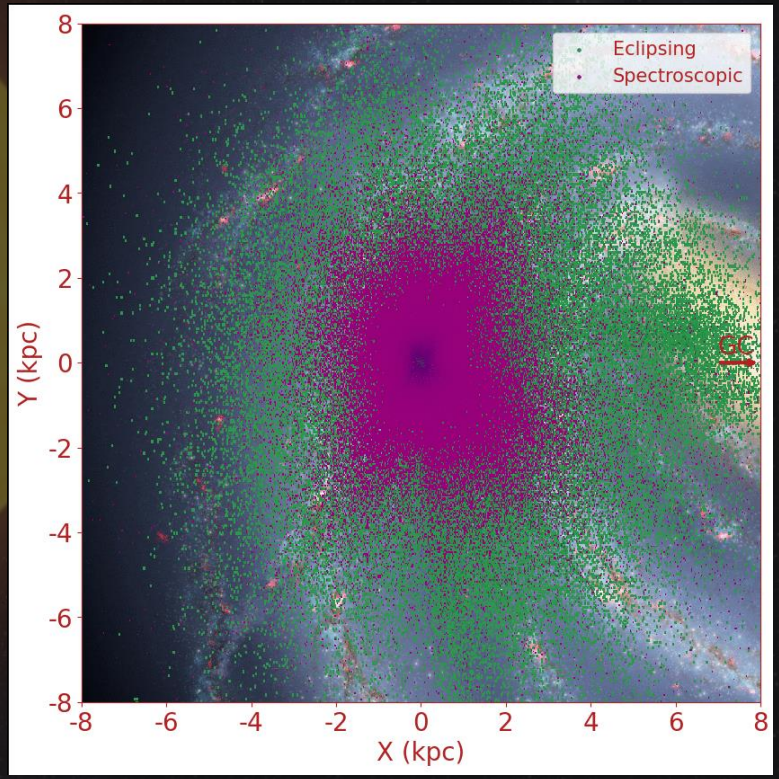
Gaia DR3 Non-single star catalogue:
>800 000 binary systems with orbital solutions

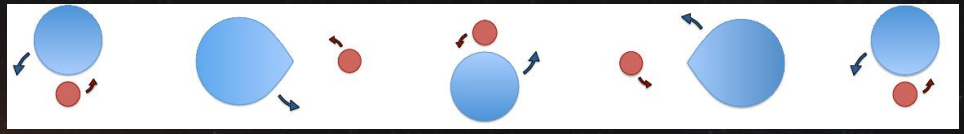




El-Badry (2024)

Credits: ESA/Gaia/DPAC

Ellipsoidal variables



Bell et al. (2018)

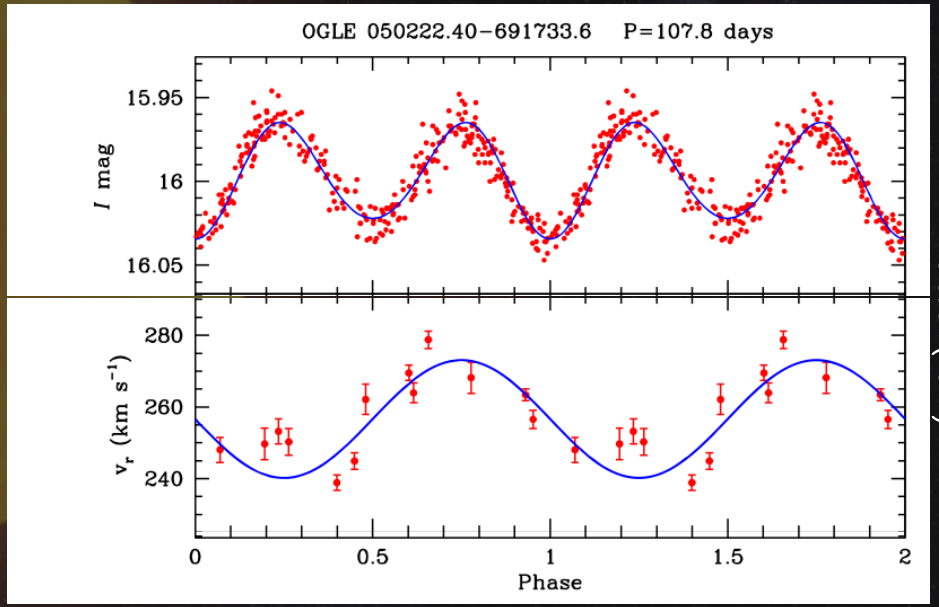
The primary star is tidally distorted due to the influence of its companion

<u>Orbital rotation of the red giant:</u>
two light maxima and two minima
in the light curve variation in each orbital period

Orbital period ~ 2 x Photometric period

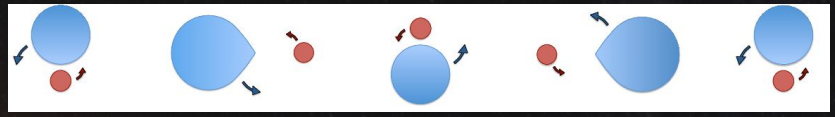
Previous stage before common-envelope phase

Progenitors of close binary PNe?



Nie et al. (2017)

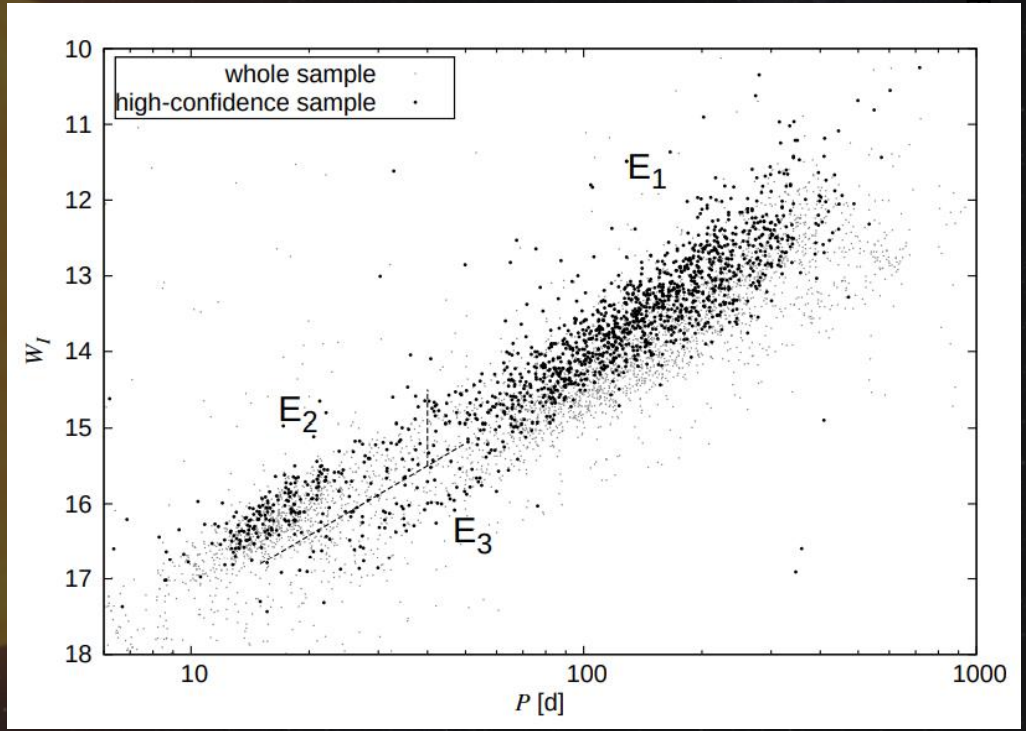
Ellipsoidal red giant binaries



In the Large Magellanic Cloud:

- Define a period-luminosity sequence
E sequence (Soszyński et al. 2004)

- Dependency on the eccentricity of the orbit, mass of the primary, metallicity?
(e.g., Pawlak et al. 2014, Nie et al. 2017)



Pawlak et al. (2014)

This work

The Astrophysical Journal, 835:209 (19pp), 2017 February 1 doi:10.3847/1538-4357/835/2/209

The Orbital Nature of 81 Ellipsoidal Red Giant Binaries in the Large Magellanic Cloud

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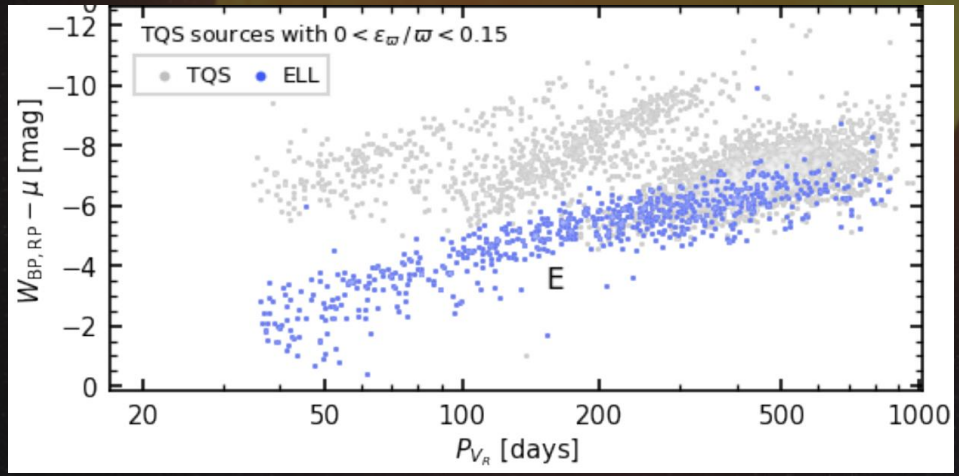
Orbital and physical properties of 81 ellipsoidal red giant binaries in the Large Magellanic Cloud – Nie et al. (2017)



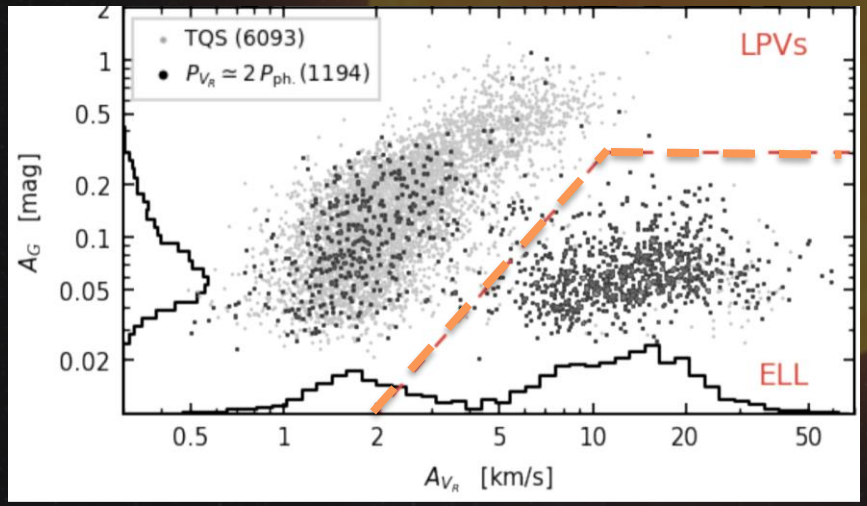
Exploit Gaia astrometry, photometry and spectroscopy for characterizing red giant stars in ellipsoidal binaries in the Milky Way

Gaia Collaboration, Trabucci et al. (2023)

Ellipsoidal red giant binaries in Gaia

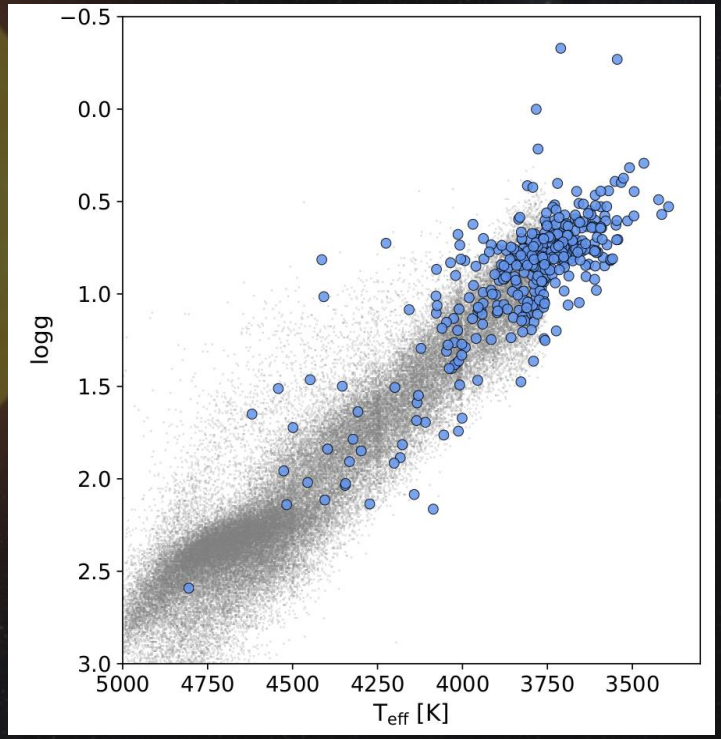
Gaia Focused Product Release:
Radial velocity time series and variability parameters for 6 000+ long-period variables (LPVs)

800+ classified as ellipsoidal red giant binaries



Gaia Collaboration, Trabucchi et al. (2023)

Atmospheric parameters: T_{eff}, logg, [M/H], [α/Fe]
Gaia DR3 RVS spectra (Recio-Blanco et al. 2023)
Gaia BP/RP spectra (Andrae et al. 2023)



Navarrete et al. (2024, in prep.)

Physical parameters

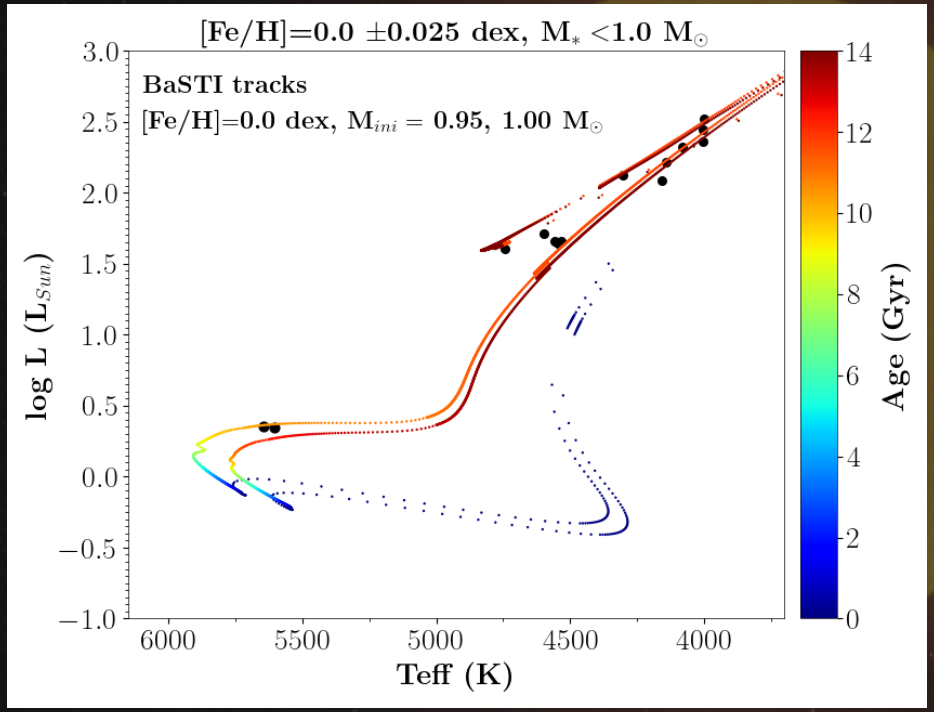
- Extinction A_G: Observed (BP-RP) and intrinsic color from Teff-color relations
- Bolometric corrections (BC) in the Gaia G-band (Casagrange & VandenBerg 2018)

(G mag, distance, BC, A_G)
(Luminosity, T_{eff})
(Radius, logg)

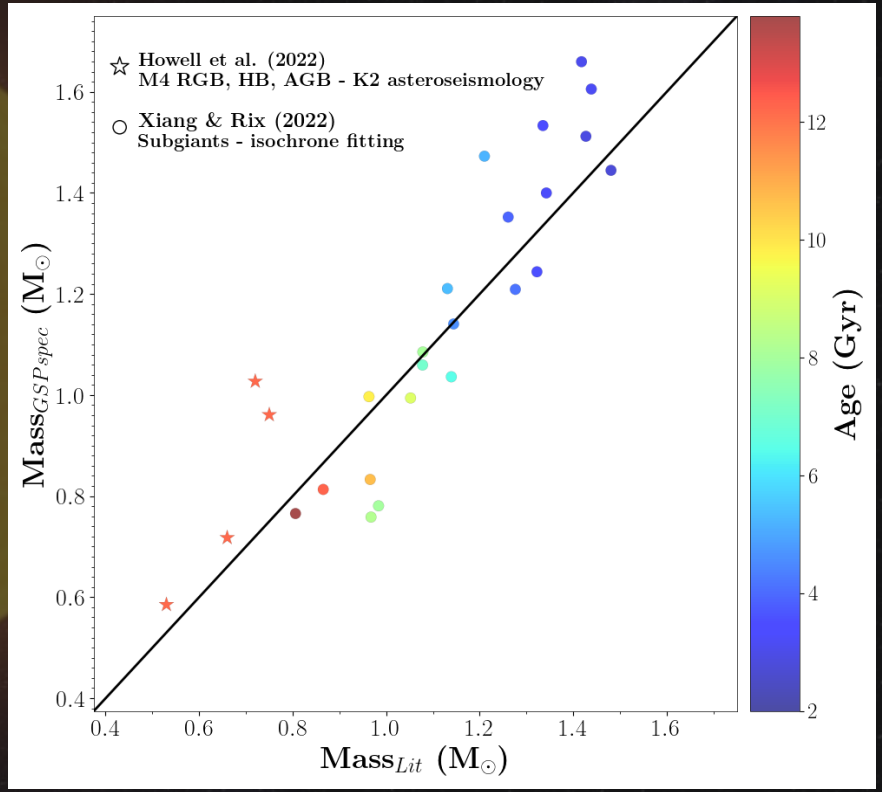
→

Luminosities
Spectroscopic Radii
Spectroscopic Masses

Spectroscopic masses?



M4 globular cluster



de Laverny et al. in prep. (2024)

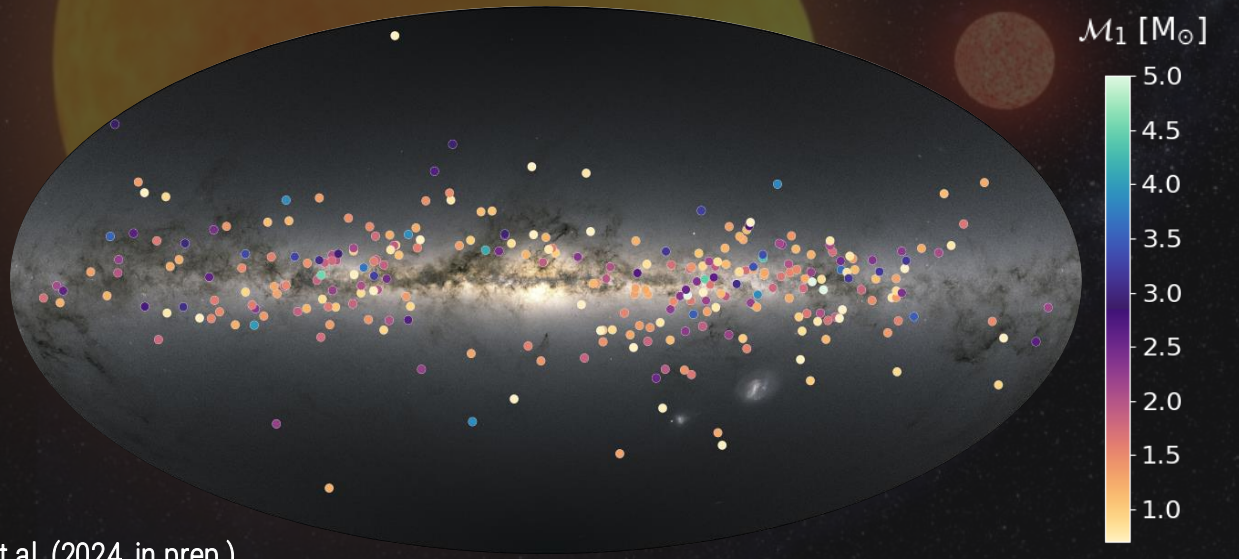
Physical parameters

- Extinction A_G: Observed (BP-RP) and intrinsic color from Teff-color relations
- Bolometric corrections (BC) in the Gaia G-band (Casagrange & VandenBerg 2018)

(G mag, distance, BC, A_G)
(Luminosity, T_{eff})
(Radius, logg)

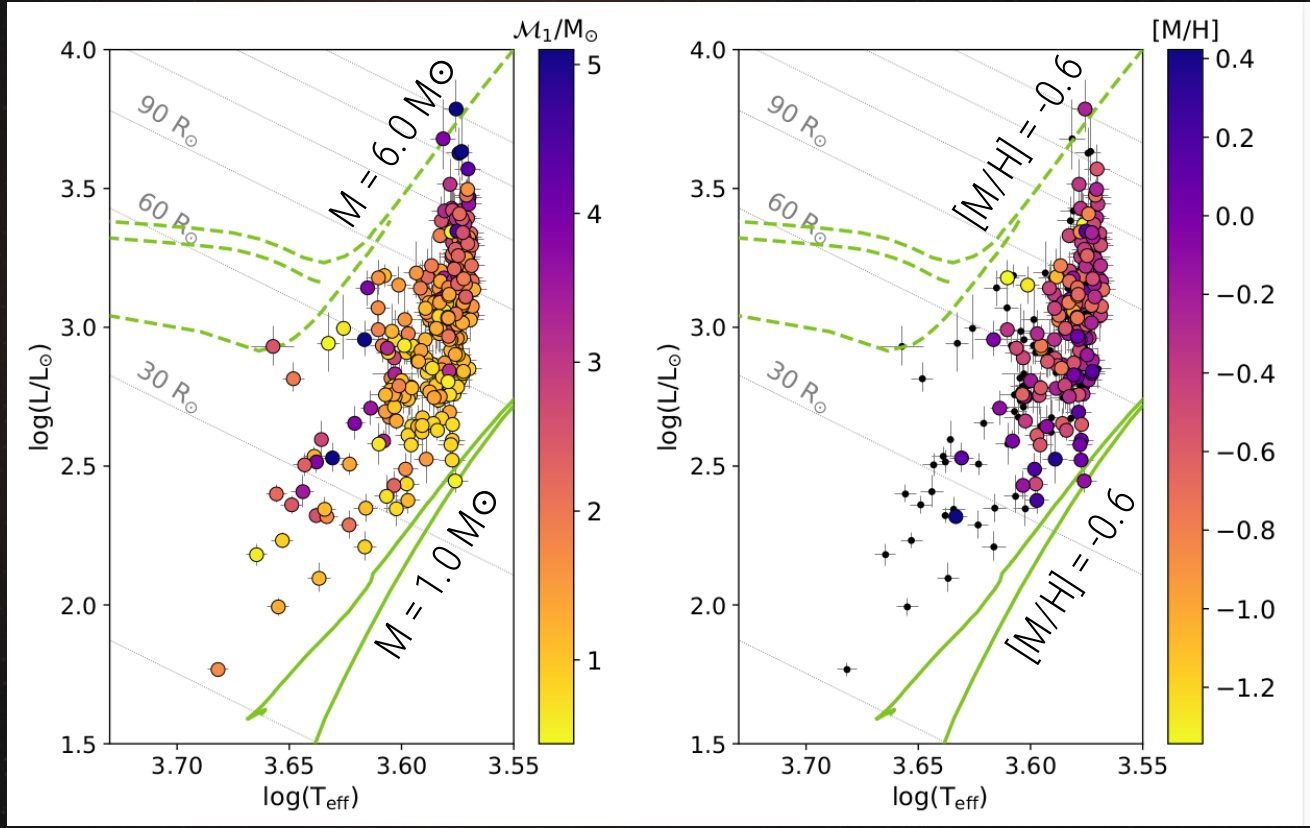
Luminosities, $\sigma_L/L \sim 15\%$
Spectroscopic Radii, $\sigma_R/R \sim 7\%$
Spectroscopic Masses, $\sigma_M/M \sim 25\%$

286 ellipsoidal variables



Navarrete et al. (2024, in prep.)

Physical properties of ellipsoidal red giants

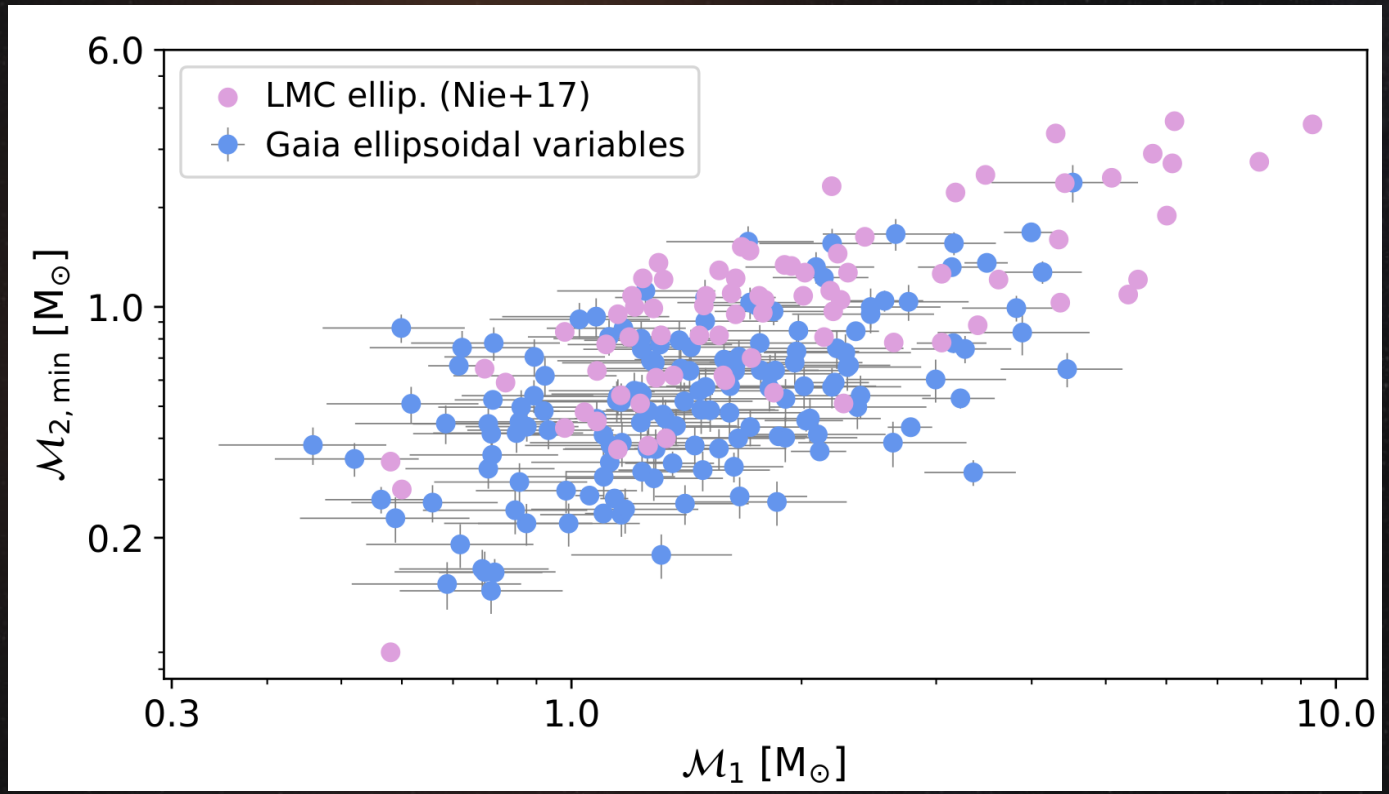


Evolutionary tracks (Lagarde et al. 2012)

Navarrete et al. (2024, in prep.)

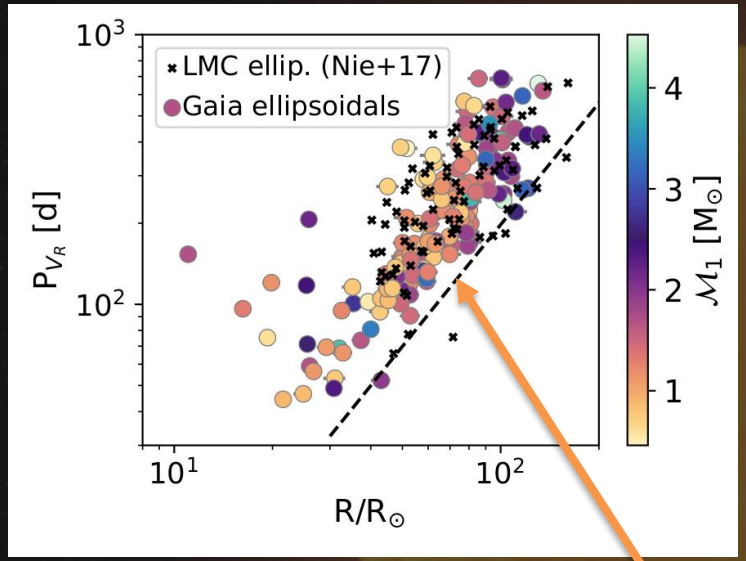
Minimum companion mass

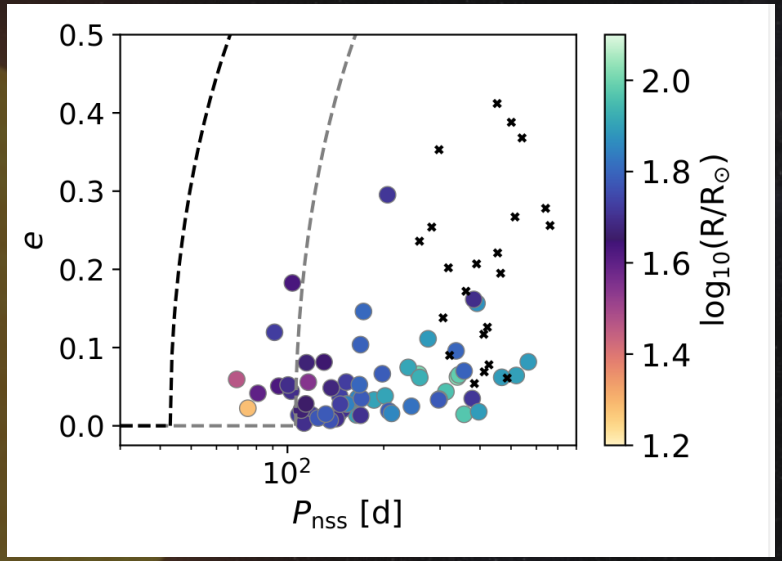
$$f(M) = \frac{PK^3\left(1-e^2\right)^{\frac{3}{2}}}{2\pi G} = \frac{M_2^3 \sin^3 i}{\left(M_1+M_2\right)^2}$$



Navarrete et al. (2024, in prep.)

Orbital and physical properties





Navarrete et al. (2024, in prep.)

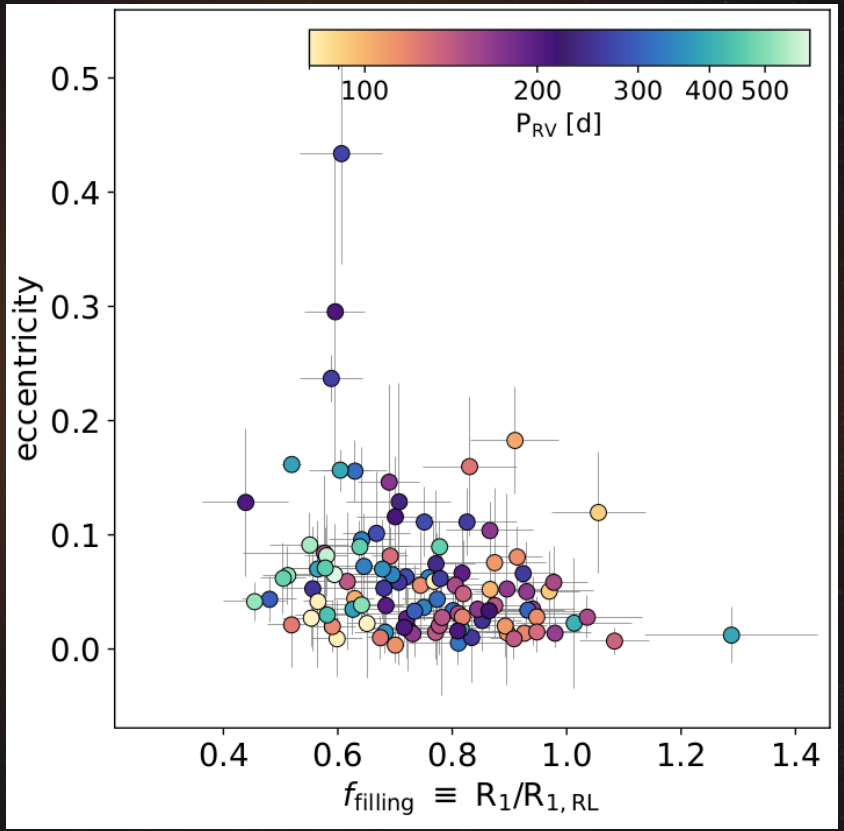
$$\log\left(\frac{P_{threshold}}{365.25\ d}\right) = \frac{3}{2}\log\left(\frac{R_1}{216\ R_\odot}\right) - \frac{1}{2}\log(M_1 + M_2)$$

Circularization threshold period
(Gaia Collaboration, Arenaou et al. 2023)

Tidal circularization:
At longer periods, the tidal circularization of the orbit occurs at larger radii.

Lower eccentricities than LMC ellipsoidal red giants (Nie+2017).

Orbital and physical properties

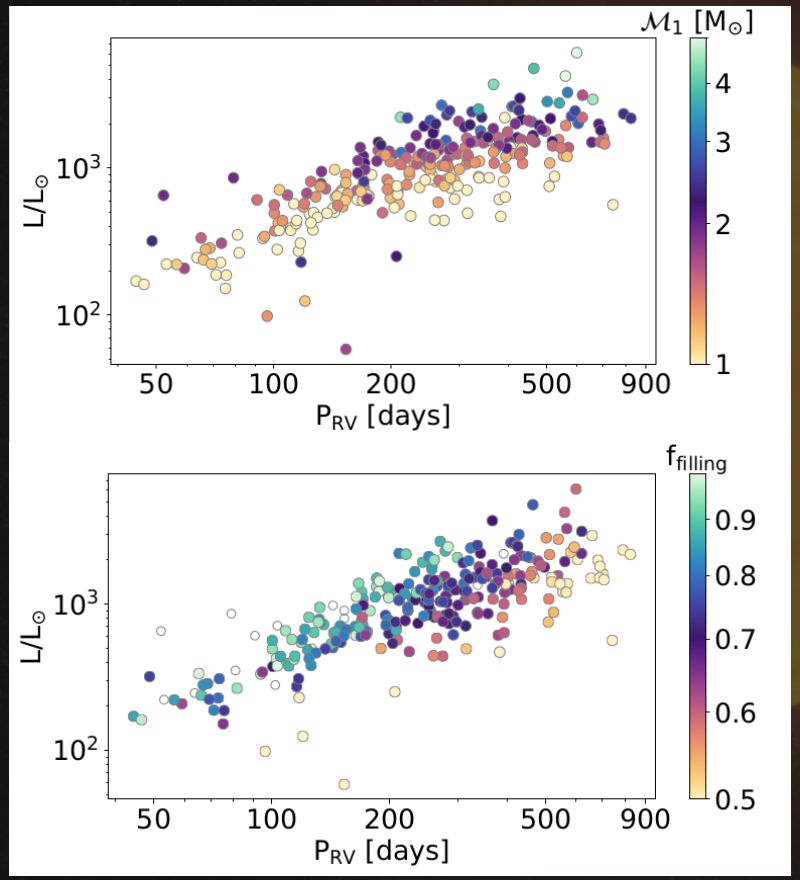


Navarrete et al. (2024, in prep.)

Filling factor:

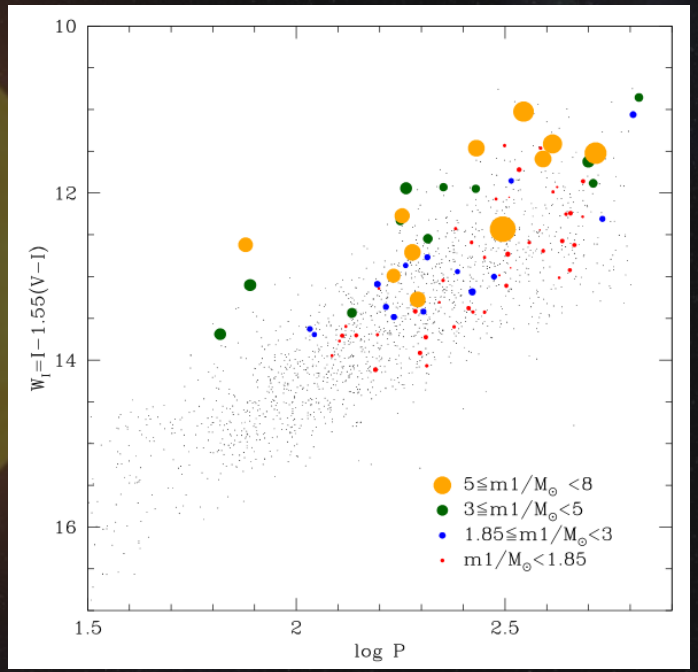
More circular orbits are found in ellipsoidal red giants in which the radius of the primary star is comparable with the Roche lobe radius.

Period-Luminosity sequence



Navarrete et al. (2024, in prep.)

LMC ellipsoidal variables, N = 81



Nie et al. (2017)

Summary

Gaia DR3 photometry, spectroscopic and orbital properties:
Luminosities, Masses, Radii for more than 250 ellipsoidal red giant binaries!

Statistically large sample to perform population studies of red giant binaries.

Spectroscopic radii – period – eccentricity in agreement with detached, circularized binaries.

Minimum masses for the companions: white dwarfs and/or main-sequence stars.

Chemically peculiar primary stars? Overabundance of [Ce/Fe] could hint of pollution from the secondary while it was in the AGB phase.

Period-Luminosity relation (PL) for ellipsoidal binaries in the Milky Way:
its intrinsic dispersion depends significantly on the mass of the primary and the filling factor!

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Thank you for your attention!

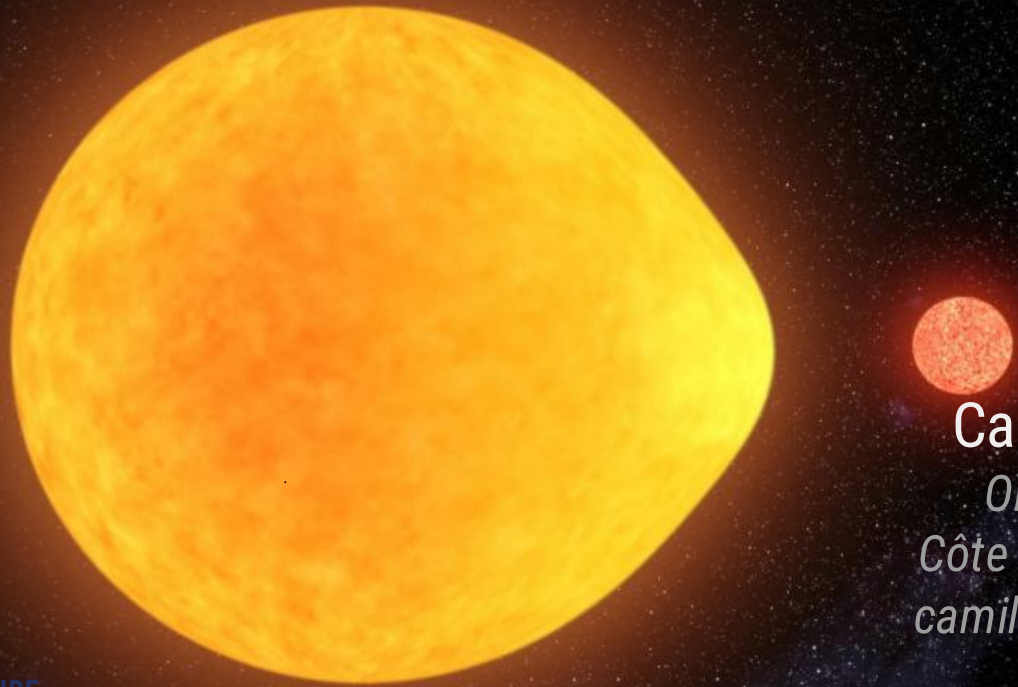

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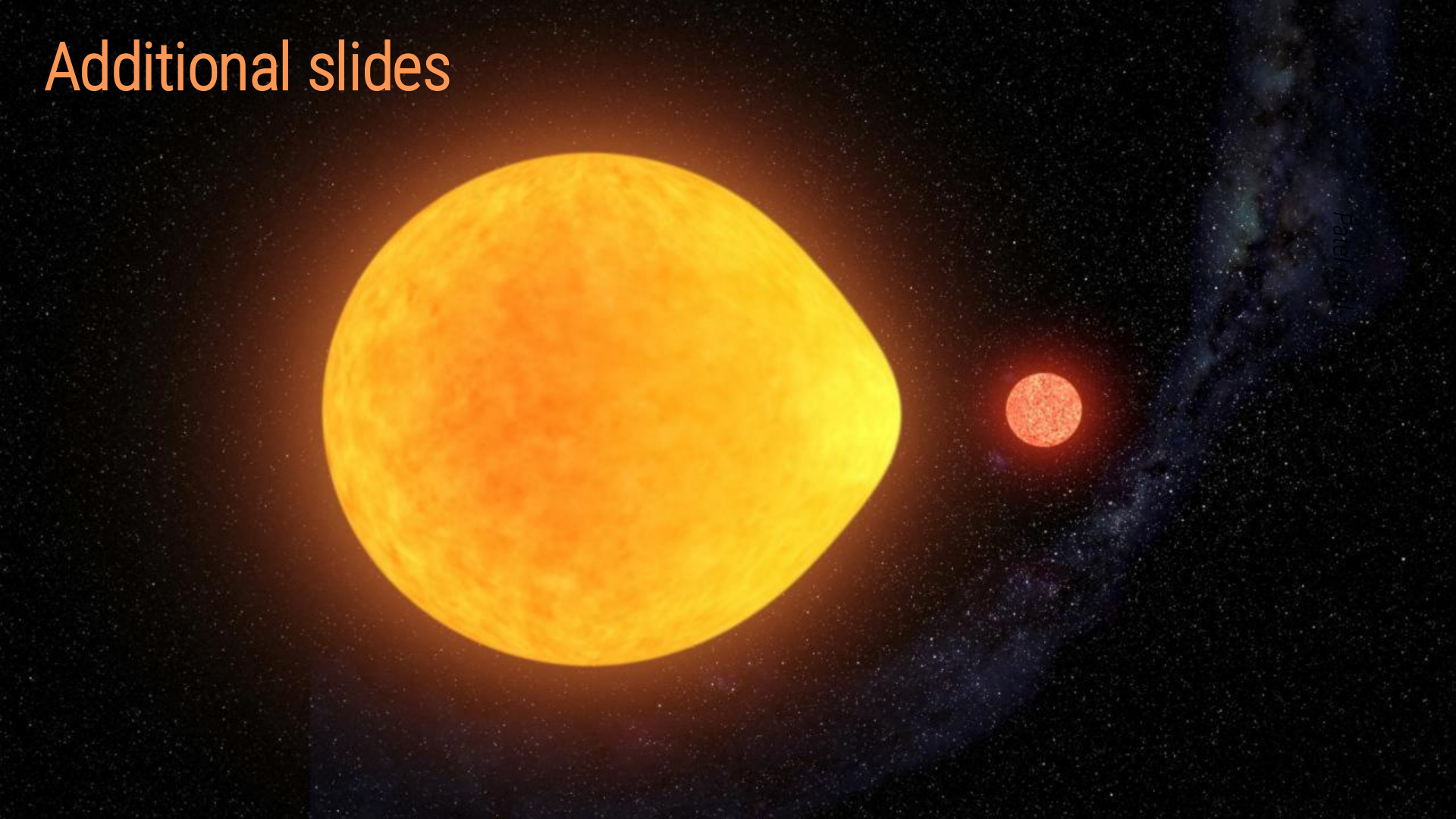
Image credits: G. Pérez (SMM-IAC)

Binary and Multiple Stars in the Era of Big Surveys – 13 September 2024

Additional slides



Mass function and minimum companion mass

Gaia FPR: Orbital period (P),
Radial velocity Semi-amplitude (K)

Gaia DR3, NSS (Gaia Collaboration, Arenaou et al. 2023)
Subsample of sources has eccentricity

$$f(M) = \frac{PK^3\left(1-e^2\right)^{\frac{3}{2}}}{2\pi G} = \frac{M_2^3 \sin^3 i}{\left(M_1+M_2\right)^2}$$

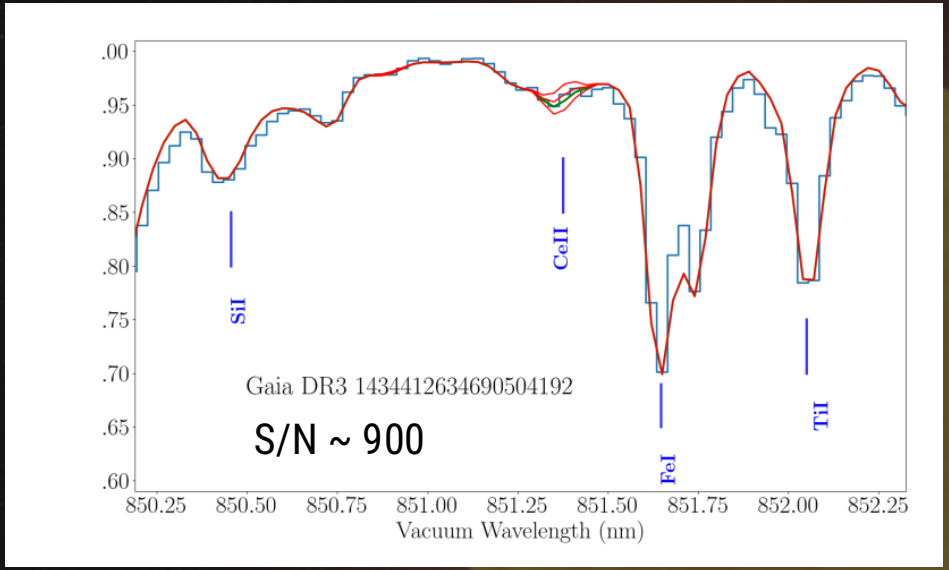
Orbital inclination: unknown

Spectroscopic mass of the primary M_1

In the limit of sin(i) = 1:
Minimum mass of the companion, $M_{2,min}$

White dwarf / main-sequence companions?

[Ce/Fe] enhancement

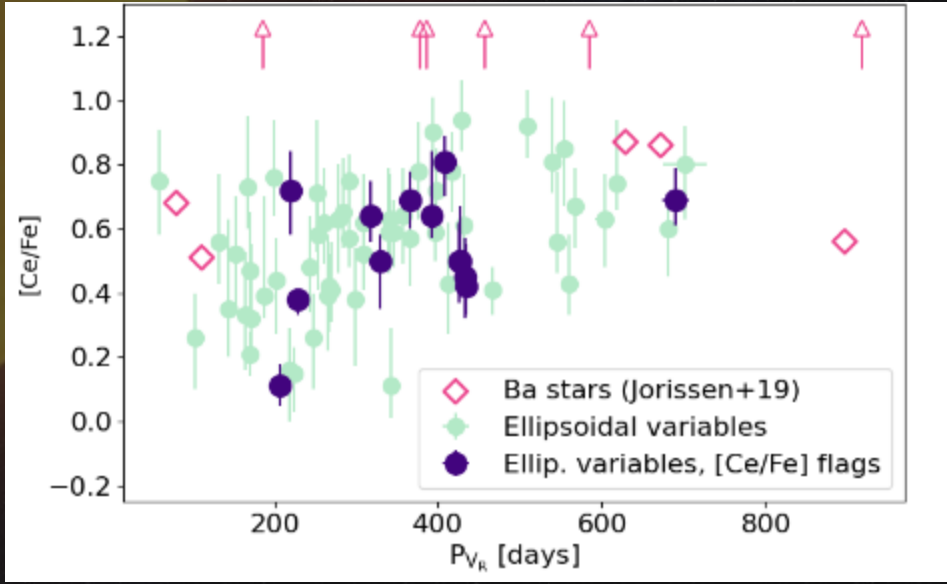


Recio-Blanco et al. (2023)

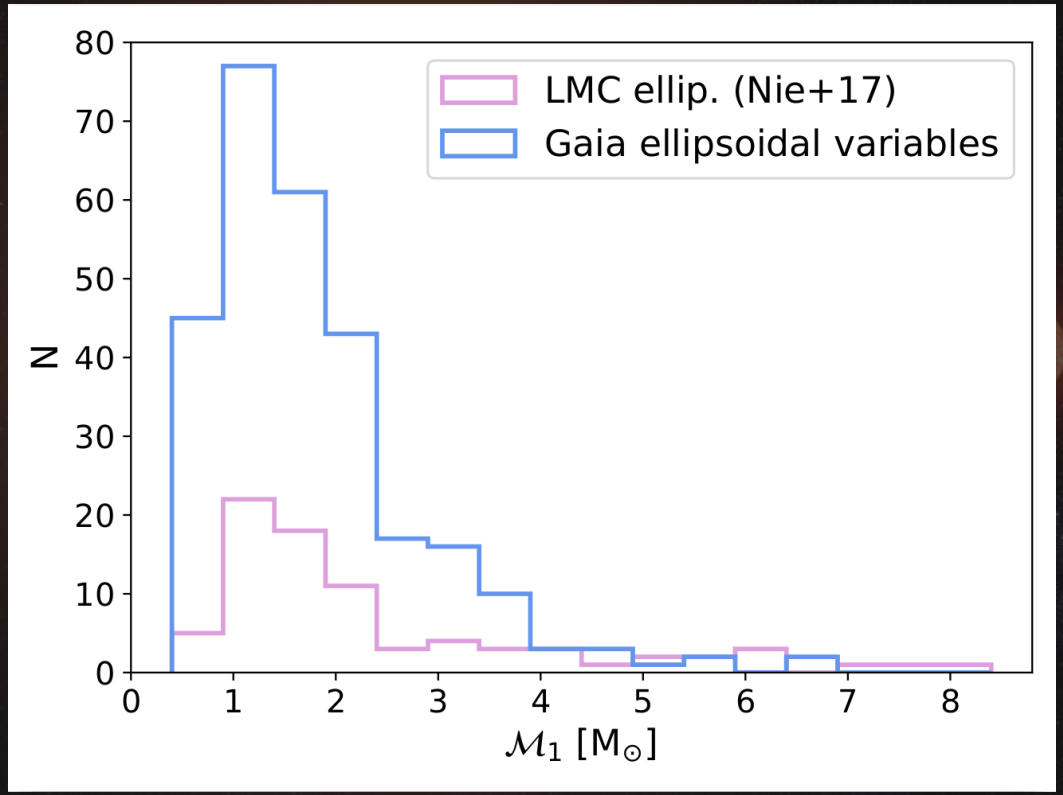
Chemically-peculiar RGB stars?

s-process enhancement due to AGB evolution?

Navarrete et al. (2024, in prep.)



Physical properties of ellipsoidal red giants

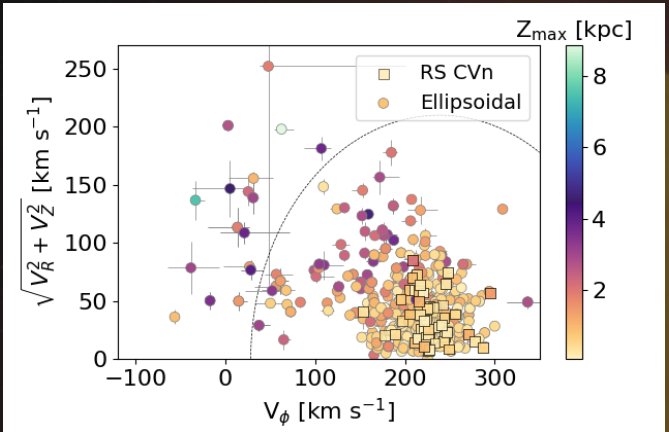


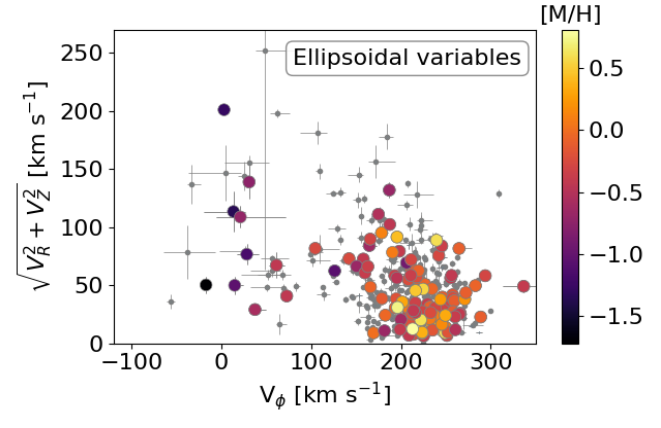
Navarrete et al. (2024, in prep.)

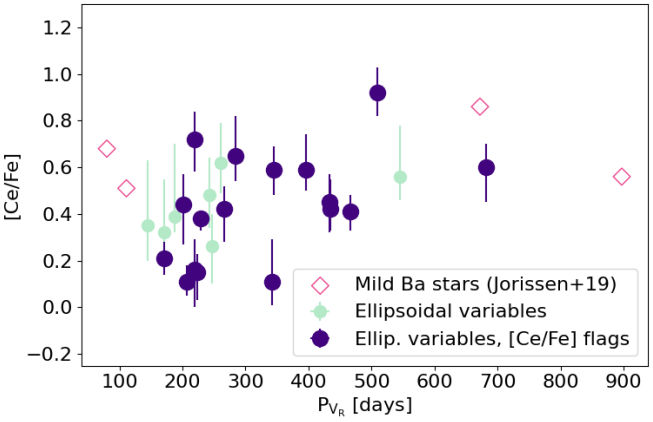
Galactic populations, [M/H], [Ce/Fe] abundance

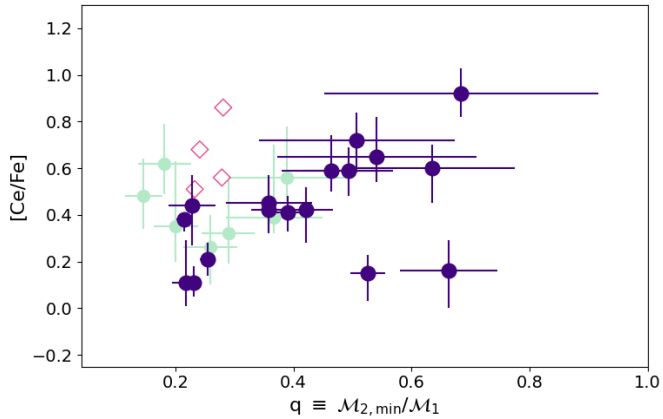
Galactic populations: halo/disk stars

Metallicity distribution







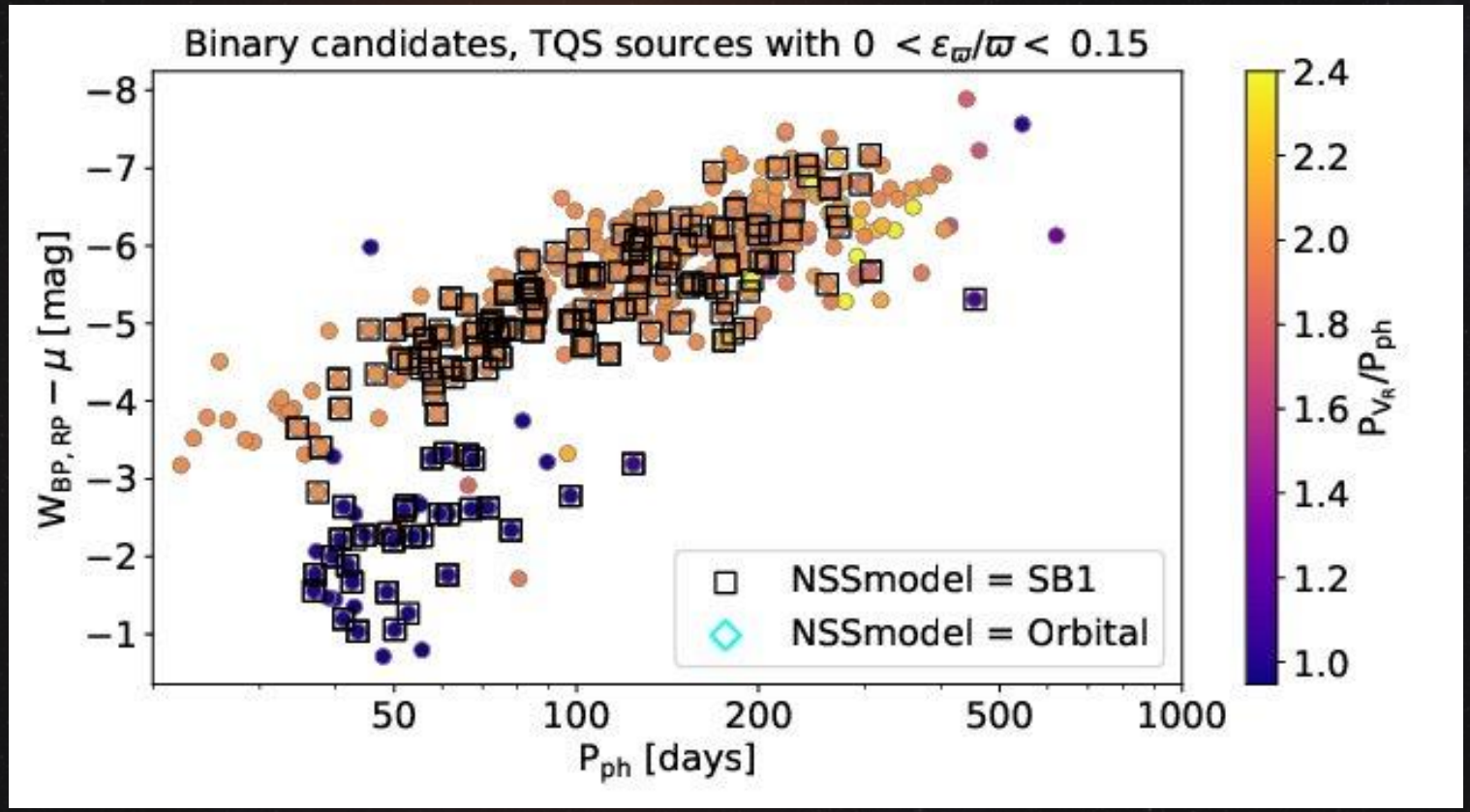


Chemically peculiar stars?

s-process enhancement: evolutionary status of the secondary

Navarrete et al. (2024, in prep.)

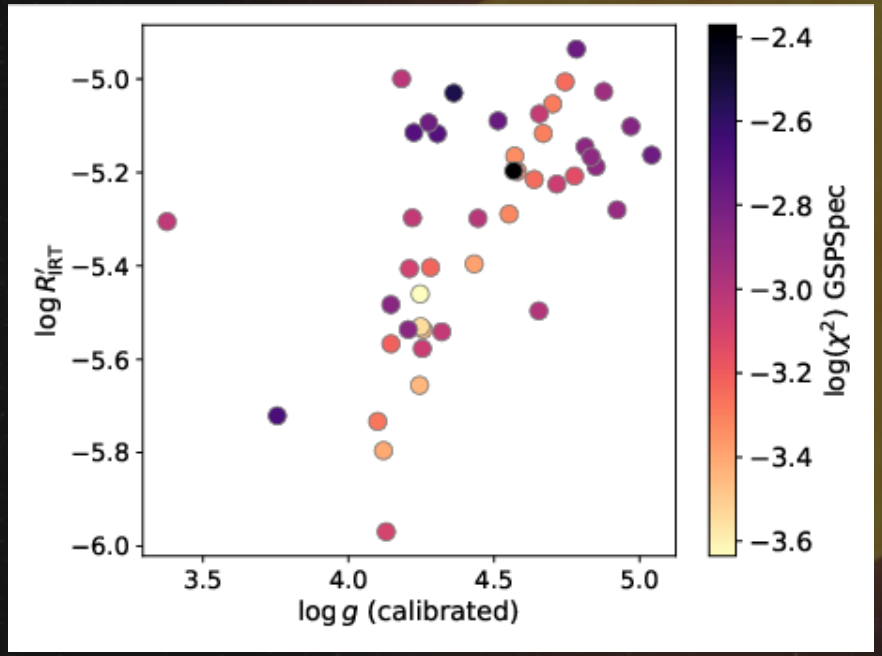
Period-luminosity diagram

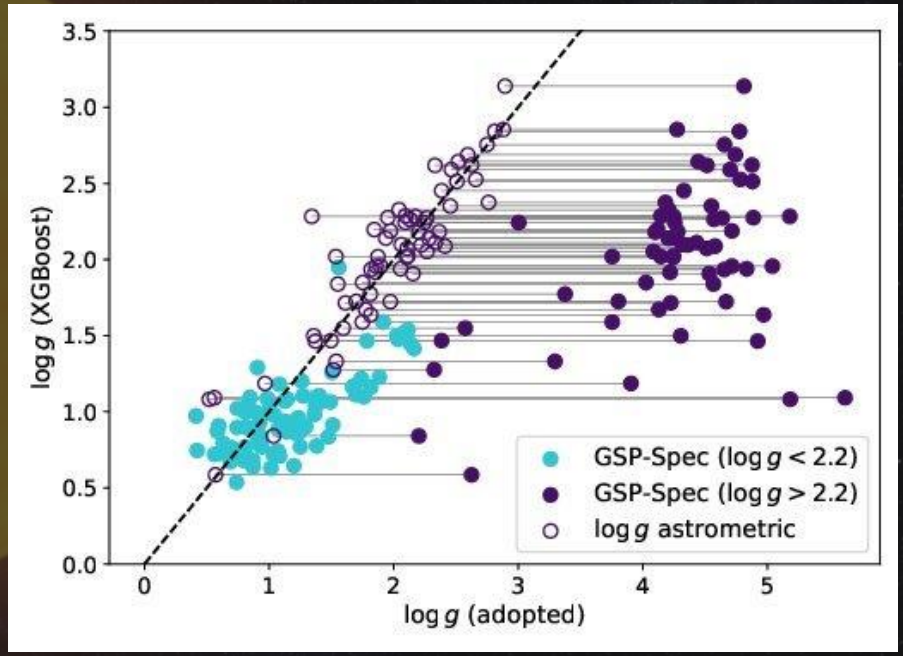


Patel et a. (2020)

Navarrete et al. (2024, in prep.)

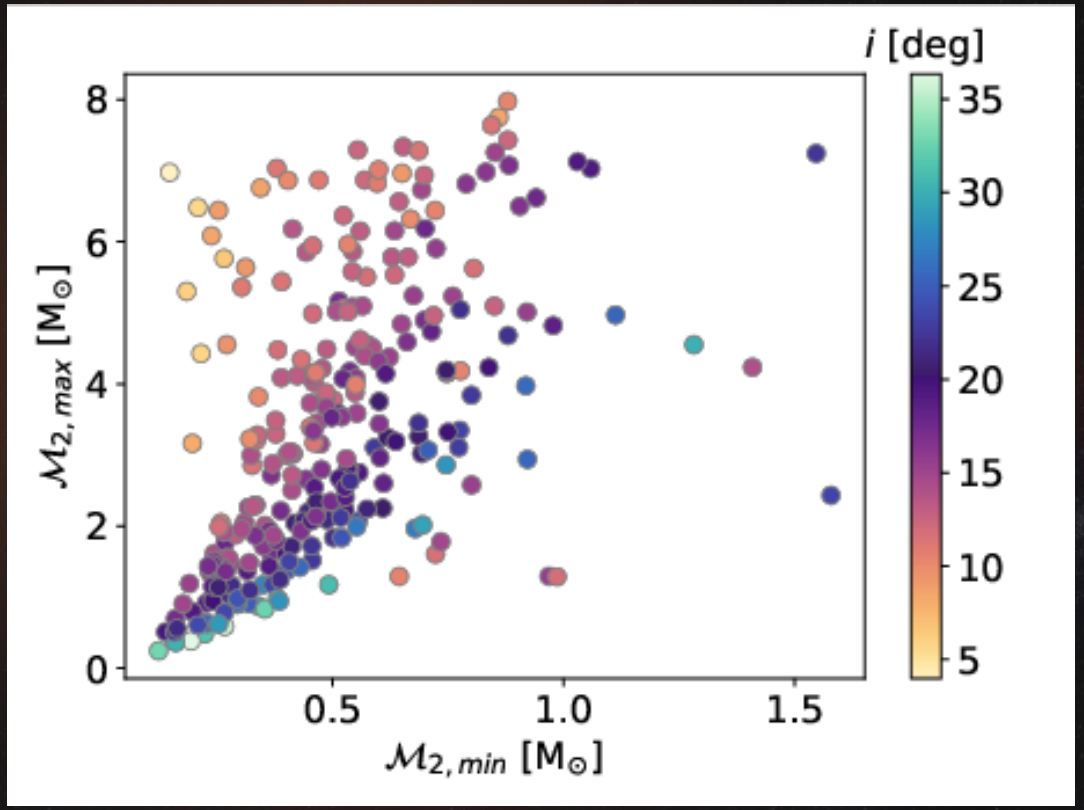
Activity and spectroscopic logg





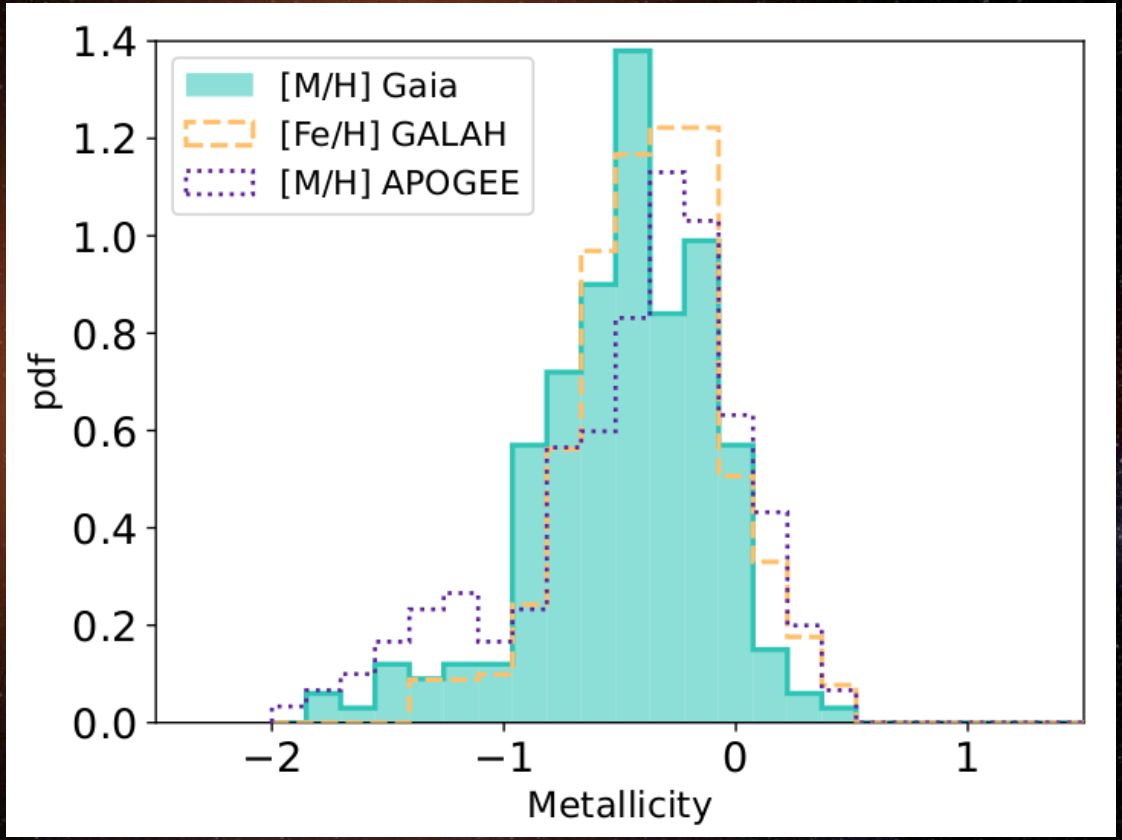
Navarrete et al. (2024, in prep.)

Masses of the companions: maximum mass?



Navarrete et al. (2024, in prep.)

Metallicity distribution function

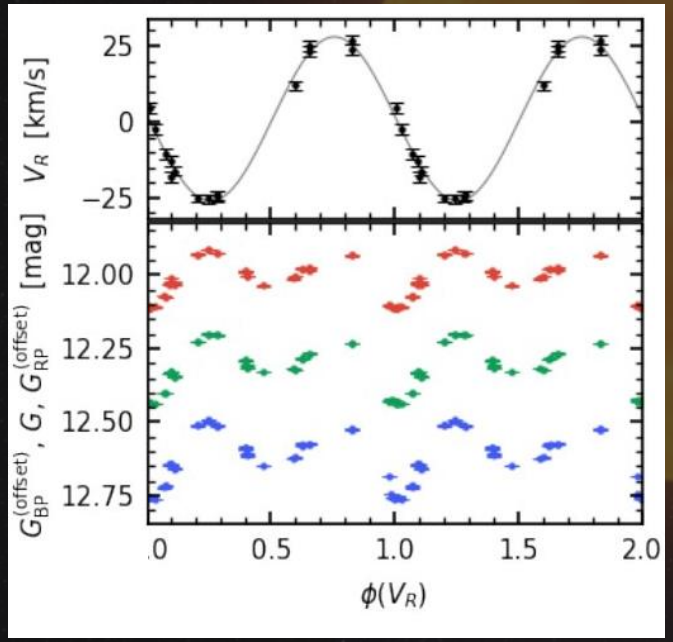


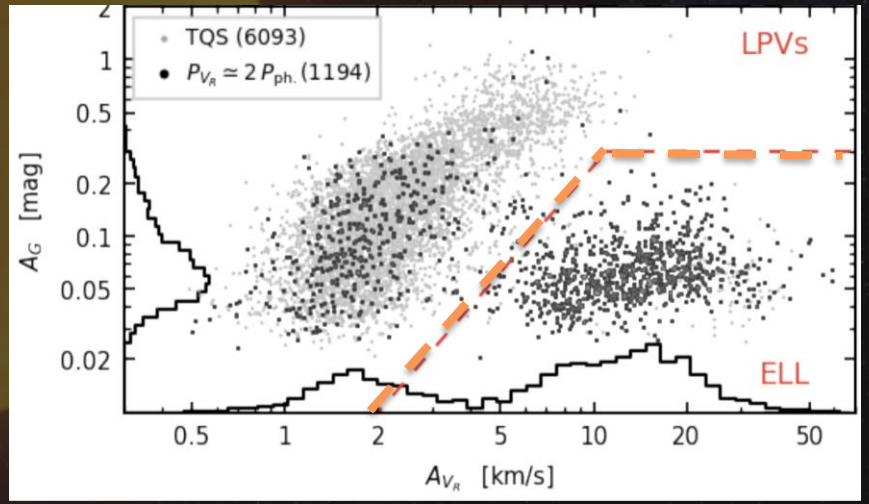
Navarrete et al. (2024, in prep.)

Gaia FPR: Radial velocity time series of LPVs

More than 6 000 LPVs with radial velocity time series and variability parameters

800+ classified as ellipsoidal red giant binaries

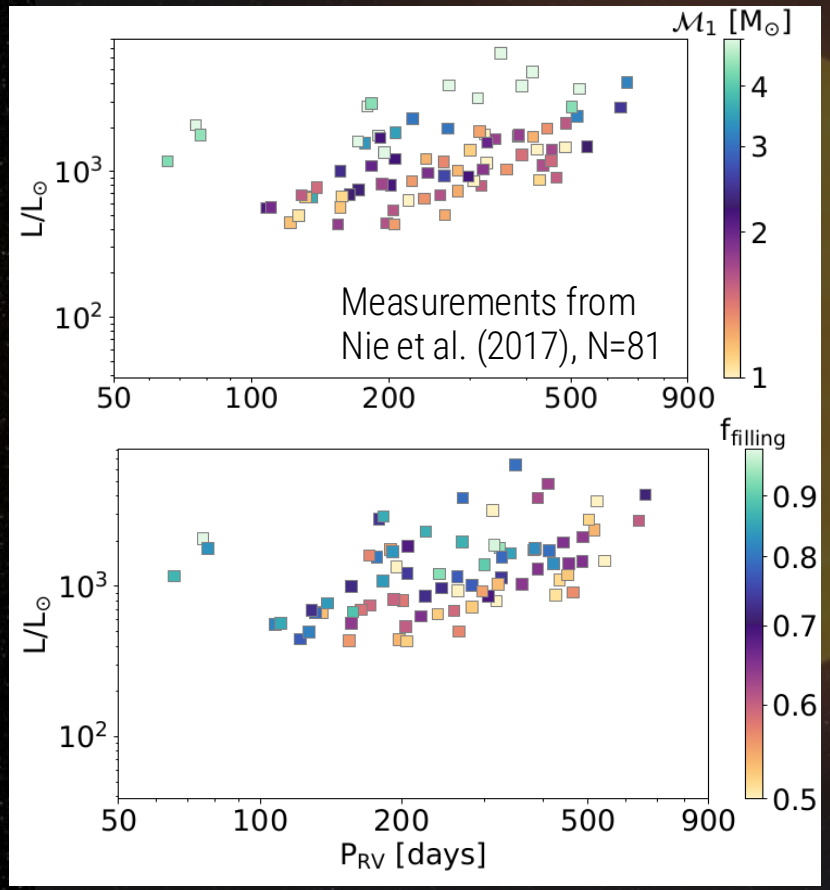




Gaia Collaboration, Trabucchi et al. (2023)

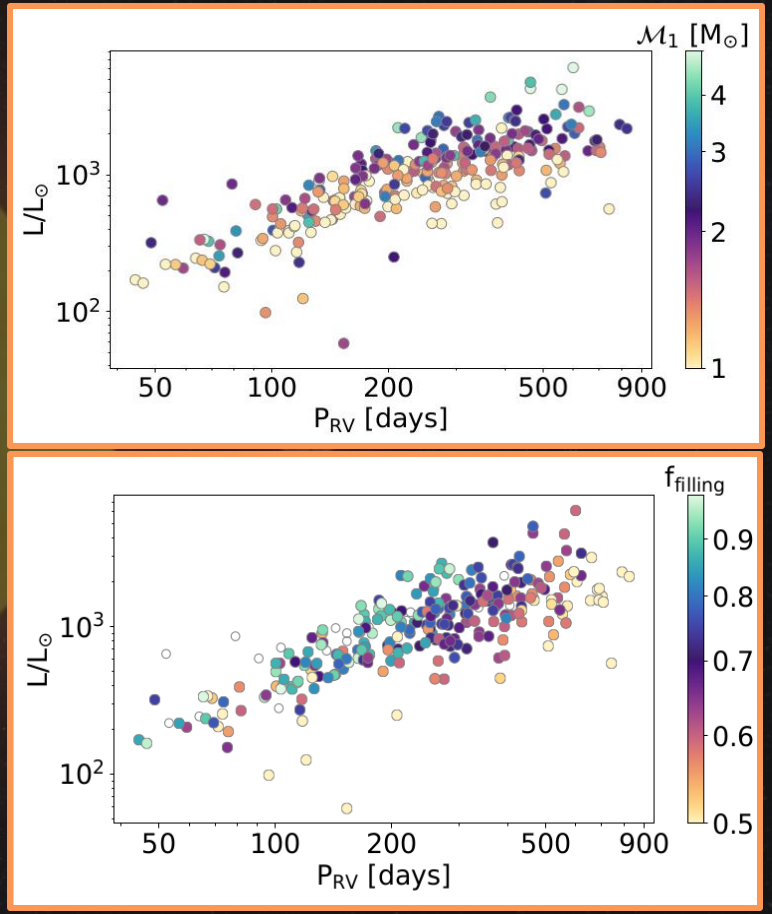
Period-Luminosity sequence

LMC ellipsoidal red giant binaries



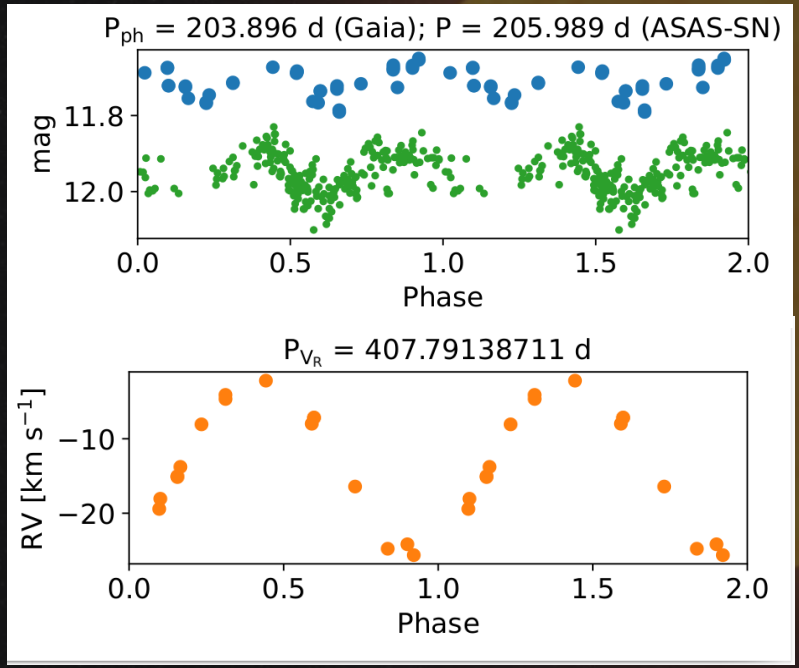
Galactic ellipsoidal red giant variables, N = 283

Navarrete et al. (2024, in prep.)



[Ce/Fe] enhanced star?

Gaia DR3 4508653330719192960
ASASSN-V J183232.37+140803.8



Navarrete et al. (2024, in prep.)

Atmospheric parameters (Recio-Blanco et al. 2023)
Teff = 3700 K; logg = 0.8 dex
[M/H] = -0.64; [alpha/Fe] = 0.25

Physical parameters:
L_1 = 1189 ± 125 $L_\odot$
M_1 = 1.58 ± 0.2 $M_\odot$
R_1 = 83.94 ± 3.8 $R_\odot$

Orbital parameters:
P_{orb} = 407.7913 days
Minimum M_2 = 0.72 ± 0.12 $M_\odot$
filling factor f (R_1/R_{RL}) = 0.61 ± 0.06

[Ce/Fe] = 0.81 ± 0.1 dex
Chemically-peculiar star?