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Catalog of variable stars in open clusters using the *Gaia* mission data

Bianca Ramielly Bonfim de Jesus[1], Leandro de O. Kerber[1], Marildo G. Pereira[2], Paulo César da Rocha Poppe[2]

[1] Universidade Estadual de Santa Cruz – UESC. e-mail: biancaramielly@hotmail.com, lokerber@uesc.br
[2] Universidade Estadual de Feira de Santana – UEFS. e-mail: mgpereira@uefs.br, paulopoppe@uefs.br

Abstract. In its third data release (DR3), the *Gaia* mission provided 34 months of multi-epoch observations, allowing a comprehensive analysis of stellar variability across the entire sky. This work aims to compile a catalog of variable stars in the Milky Way open clusters, using the cluster catalog of Cantat-Gaudin et al. (2020) and the catalog of variable stars from DR3. We identified 28771 variable stars in 1663 clusters, with 26853 of them classified into 15 variability types or subtypes. We selected a sample of 50 open clusters, choosing those with at least 100 variable stars, aiming to ensure better statistical sampling. Among the clusters with VRM-type stars, we selected a sample of 20 objects, for which we constructed color-magnitude diagrams and performed isochrone fits. Using the mass-luminosity relation obtained by these fits, we determined the stellar masses and analyzed the time evolution of the rotational period for masses close to the solar mass.

Resumo. Na sua terceira liberação de dados (DR3), a missão *Gaia* forneceu 34 meses de observações multi-época, permitindo uma análise abrangente da variabilidade estelar em todo o céu. Este trabalho tem como objetivo compilar um catálogo de estrelas variáveis em aglomerados abertos da Via Láctea, utilizando os catálogos de aglomerados de Cantat-Gaudin et al. (2020) e de estrelas variáveis do DR3. Identificamos 28771 estrelas variáveis em 1663 aglomerados, com 26853 delas classificadas em 15 tipos ou subtipos de variabilidade. Selecionamos uma amostra de 50 aglomerados abertos, escolhendo aqueles com pelo menos 100 estrelas variáveis, visando garantir uma melhor amostragem estatística. Dentre os aglomerados com estrelas do tipo VRM, selecionamos uma amostra de 20 objetos, para os quais construimos diagramas cor-magnitude e realizamos ajustes de isócrona. Por meio da relação massa-luminosidade obtida por estes ajustes, determinamos as massas estelares e analisamos a evolução temporal do período rotacional para massas próximas à solar.

Keywords. (Galaxy:) open clusters and associations: general – Stars: variables: general – (Stars:) Hertzsprung-Russell and C-M diagrams

1. Introduction

The study of variable stars stands out as one of the most dynamic and popular fields in modern astronomy. Variability, a characteristic present in most stars, provides additional parameters—such as time scales and amplitudes—that are inaccessible in non-variable stars. Observing variable stars allows us to directly track stellar changes, ranging from dramatic phenomena associated with stellar birth and death to subtle variations that reveal evolutionary processes over time (Percy 2007).

The *Gaia* mission represents a groundbreaking effort to map the three-dimensional structure of our Galaxy, shedding light on its composition, formation, and evolution (Brown et al. 2018). Since its launch in 2013, *Gaia* has delivered three data releases, offering unprecedented astrometric precision for a vast number of stars. Its near-simultaneous photometric measurements in the G, GBP, and GRP bands have been transformative for multi-epoch photometric surveys. Additionally, *Gaia*'s BP and RP spectroscopic capabilities represent a unique and valuable feature (Eyer et al. 2023).

Previous studies have made significant strides in cataloging variable stars within globular clusters, leading to comprehensive datasets for these environments in the Milky Way (Clement et al. 2001). However, open clusters offer equally compelling opportunities for exploring stellar variability. These clusters are ideal laboratories for determining stellar ages, as their constituent stars were formed in the same molecular cloud and approximately in a single burst of star formation. Consequently, due to the wide range of ages and other physical parameters, open clusters provide an excellent framework for enhancing our understanding of the evolutionary processes of variable stars.

The primary aim of this study is to compile a catalog of variable stars in open clusters by combining two key *Gaia* datasets: the open cluster catalog from Cantat-Gaudin et al. (2020) and the DR3 variable star catalog from Eyer et al. (2023). This approach leverages the strengths of *Gaia*'s data to provide new insights into the variability and evolution of stars within these fascinating environments.

2. Method

Our study begins by cross-matching two datasets: the variable star catalog from the third *Gaia* data release (DR3) and the open cluster catalog from Cantat-Gaudin et al. (2020), which in turn is based on the *Gaia* DR2. The *Gaia* DR3 catalog includes 10.5 million sources identified as variable stars, categorized into 35 types and subtypes of variability, with classifications and characterizations achieved using statistical and machine learning models (Eyer et al. 2023). Meanwhile, the open cluster catalog contains 2105 clusters with physical parameters derived through isochrone fitting, encompassing ages from 1.5 million to 7.9 billion years and distances ranging from 47 pc to 12.6 kpc (Cantat-Gaudin et al. 2020). Both datasets were accessed via the Vizier catalog database, and their cross-matching was performed using TopCat alongside custom Python scripts. After that, color-magnitude diagrams were generated and visual isochrone fits were performed using PARSEC-COLIBRI stellar evolutionary models (Chen et al. 2015) incorporating distance, metallicity and reddening values from Cantat-Gaudin et al. (2020) and Dias et al. (2021). Additional fine-tuning was conducted visually by the authors to improve the fit. This allows the determination of the stellar masses of the variable stars

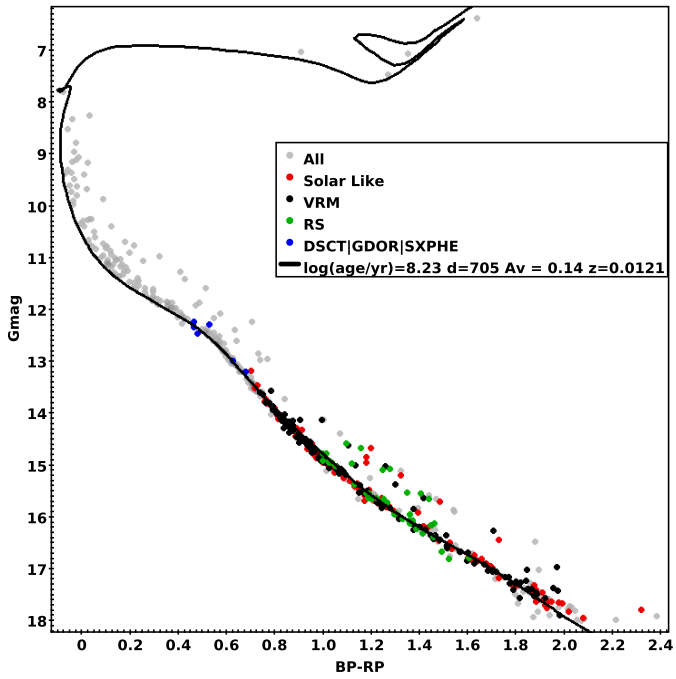

Figure 1. Isochrone fit of the cluster NGC2287, highlightning the different types os variability present in this cluster

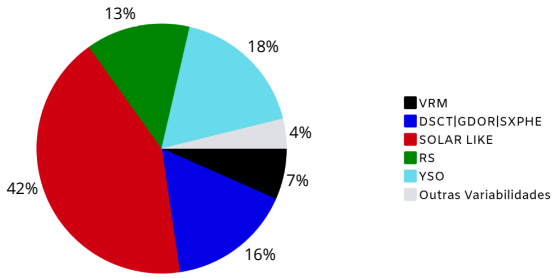

Figure 2. Distribution of variability types in our sample.

through the mass-luminosity relation (MLR) from the isochrone fits. In Fig.1 we can see the CMD of the NGC2287 cluster, the isochrone fit, and the variable stars present in this cluster.

3. Results and Discussion

We found 28771 sources identified as variables distributed in 1663 clusters, of which 26853 obtained a defined classification in 15 types or subtypes of variability. In order to obtain a better statistical sample, we made an initial cut in our sample by selecting 50 clusters with at least 100 variable sources. In Fig.2 we can see the main types of variability in our sample.

Among the analyzed types of variable stars, solar-like stars with rotational modulation (VRM) stood out, as their periods were already defined by Distefano et al (2023). To focus on clusters with significant VRM population and very well defined Main Sequence (MS), we applied additional selection criteria that included only clusters with at least 15 member stars of this type of variability and apparent absence of differential reddening, resulting in a final sample of 20 clusters. By combining the stellar mass information obtained from the MLR with their periods, we examined the time evolution of the rotational period for specific mass intervals. Figure 3 illustrates the rotational evolution with stellar age for stars with masses close to 1 solar mass. As expected, the data reveal an almost linear trend, reflecting the predictable relationship between stellar rotation period and age within this mass range.

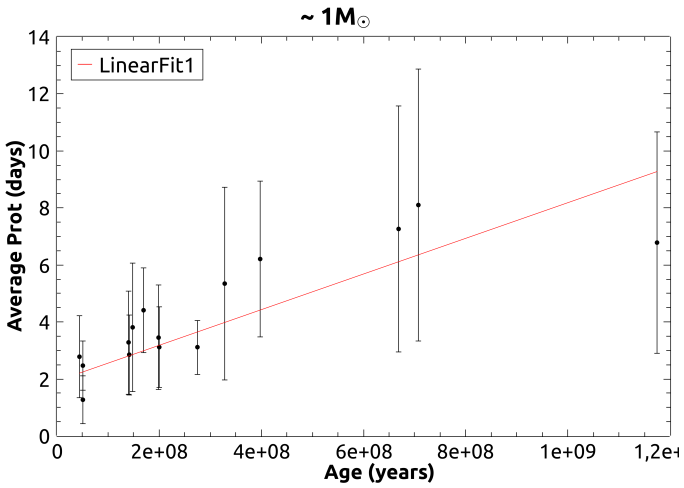

Figure 3. Evolution of the average period of MRV stars with mass close to $1M_{\odot}$

Another intriguing class of variable stars that drew our attention includes pulsating stars such as δ Scuti, γ Doradus, and SX Phoenicis. These MS stars are relatively bright ($-2 < M_G < 4$) and exhibit short variability periods of a few hours; their characterization can be significantly enhanced using photometric data obtained with small telescopes. In this sense, our next step is to build photometric time series using telescopes at the Observatório Astronômico Antares (OAA) and Observatório do Pico dos dias (OPD), both located in Brazil. We also intend to analyze Eclipsing Binary sources (VEBs), determine the fraction of binaries in each cluster, and define the completeness of the data based on the most complete clusters in the sample.

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