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Gaps in the Main-Sequence of Star Cluster Hertzsprung–Russell Diagrams

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Abstract

The presence of gaps or regions of small numbers of stars in the main sequence of the Hertzsprung–Russell Diagram (HRD) of star clusters has been reported in literature. This is interesting and significant as it could be related to star formation and/or rapid evolution or instabilities. In this paper, using Gaia DR3 photometry and confirmed membership data, we explore the HRD of nine open clusters with reported gaps, identify them and assess their importance and spectral types.

Keywords: HRD, star clusters, Gaia DR3, stellar evolution

1. Introduction

The Hertzsprung–Russell Diagram (HRD) of star clusters is the holy grail to understanding stellar evolution and populations. It is a snapshot of stellar lives as a plot of color (temperature) versus magnitude (luminosity). The precise position of a star can be used to find various parameters of a star including its size, metallicity, and evolutionary state. The HRD traces stars at various phases of evolution along the main sequence and as they turn off to the giant branch and beyond. The HRD has been used to find the distances, ages and reddening of star clusters.

The European Space Agency Gaia mission has provided unprecedented sub-milliarcsecond parallax precision for over a billion stars (Gaia Collaboration, 2016, 2021) that can be utilized to study the precise locations of individual stars on the HRD as well as populations of stars. The accurate, all-sky data produces an HRD that shows previously unknown features.

Gaps or regions of low density of stars in the HRD have been reported by various authors (Hawarden, 1971; Bohm-Vitense and Canterna, 1974; Kjeldsen and Frandsen, 1991; Rachford and Canterna, 2000) and could be important milestones of stellar evolution. In this paper, we present a detailed study of main sequence gaps in the HRD of a sample of nine clusters of ages ranging from $\log t = 7.09$–9.63 and at distances 889–2773 pc using Gaia DR3 data. We use membership data and parameters from Cantat-Gaudin et al. (2020). We identify the gaps, assess their statistical significance using the χ^2 test and identify their spectral types.

Table 1: Main Sequence Gaps (Kjeldsen and Frandsen, 1991).

Structure	M_V (mag)	$(B-V)_0$ (mag)	ΔM_V (mag)	$\Delta(B-V)_0$ (mag)	Sp Type	Temp (K)
Mermilloid	0.0	−0.12	0.25		B8V	12300
Canterna Gap	1.0	−0.05	0.20		A1V	9330
A-bend	1.3	−0.02	0.7	0.05	A2V	9040
A-group	1.5	0.00	0.7	0.05	A3V	8750
M11 gap	1.7	0.05	0.5	0.5	A4V	8480
Bohm-Vitense Gap	2.8	0.25	0.3	0.05	F0V	7350
NGC 6134-IC4651 Gap	4.5	0.5	1.0	0.15	G2V	5800

Table 2: Cluster parameters (Cantat-Gaudin et al., 2020).

Cluster	RA (deg)	Dec (deg)	$r50$ (deg)	$\log t$	A_V (mag)	DM (mag)	Distance (pc)
NGC 2169	92.13	13.95	0.076	7.09	0.85	10.15	1072
NGC 2360	109.44	−15.63	0.154	9.01	0.39	10.25	1122
NGC 1778	77.03	37.02	0.112	8.25	0.87	11.11	1663
NGC 6939	307.9	60.65	0.123	9.23	0.85	11.3	1815
NGC 3680	171.39	−43.24	0.149	9.34	0.1	10.15	1072
NGC 2682	132.85	11.81	0.167	9.63	0.07	9.75	889
Trumpler 1	23.92	61.28	0.031	7.46	1.63	12.22	2773
NGC 2420	114.6	21.58	0.053	9.24	0.04	12.06	2587
NGC 6134	246.95	−49.16	0.156	8.99	0.87	10.36	1182

2. Reported Gaps in Literature

Main sequence gaps in HRD were reported in literature (Kjeldsen and Frandsen, 1991; Sagar and Joshi, 1978; Bohm-Vitense and Canterna, 1974; Rachford and Canterna, 2000) and are listed in Table 1. A gap was also found by Jao et al. (2018) in Gaia DR2 data at $G \approx 10$. The gap is very narrow (≈ 0.05 mag) and is near the region in the HRD where M dwarf stars transition from partially to fully convective, near spectral type M3.0V.

3. Cluster Sample

We selected a sample of nine clusters as clusters with confirmed gaps from literature. These are NGC 2169, NGC 2360, NGC 1778, NGC 6939, NGC 3680, NGC 2682, Trumpler 1, NGC 2420 and NGC 6134. We used the following cluster parameters Cantat-Gaudin et al. (2020) shown in Table 2 to convert magnitudes to absolute scale. The table shows the coordinates of these clusters (RA and Dec), the angular diameter ($r50$) which is the radius that contains half the number of members from the same reference, the logarithm of age $\log t$, the extinction A_V, distance modulus DM and the distance to the cluster in parsecs.

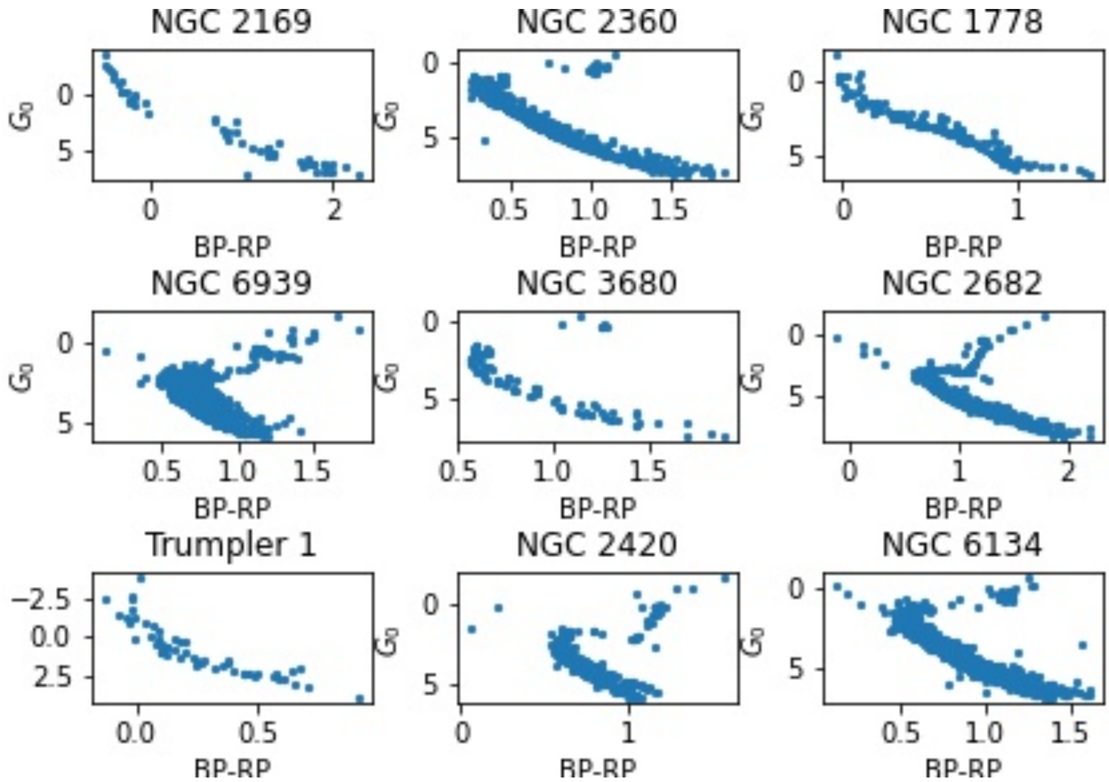

Figure 1: HRD of the sample of nine clusters.

4. Analysis

We use membership data from Cantat-Gaudin et al. (2020) for our sample of nine clusters. As described in Donada et al. (2023), we find the absolute magnitude and color:

$$G_0 = G - \mu - 0.89 * A_V$$

$$(BP - RP)_0 = (BP - RP) - 0.89/1.85 * A_V.$$

We plot the color magnitude diagrams (Fig. 1) and the luminosity functions (Fig. 2) to identify possible gaps in the HRD listed in Table 3.

The likelihood that the observed gap represents a chance variation can be estimated as follows. For the identified gaps, we calculate $\chi^2 = \frac{(N-N_o)^2}{N}$, where N is the expected number of stars and N_0 is the observed number of stars as described in Hawarden (1971). We find the expected number as the average of the numbers before and after the gap. χ^2 is related to p that is the probability that the gap is an chance event. For a $\chi^2 = 4.0$, with one degree of freedom, the p value is 0.05. This means that the probability of the gap being significant is $1 - 0.05 = 0.95$, that is 95%. This implies that a smaller value implies a higher chance of the gap being significant. Table 3 lists the gaps found in our sample with their spectral Types and significance. We notice the gaps we found are of similar spectral types as described in Table 1.

Table 3: Details of gaps found.

Cluster	G_{median} (mag)	$G_{\text{BP-RP,mean}}$ (mag)	N	N_0	χ^2	p	Temp (K)	Sp Type
NGC 2169	2.2	0.3	4	0	4.0	0.05	6852	F8V
	5.6	1.45	7.5	3	2.7	0.1	3631	K1V
NGC 2360	0.8	0.12	17.4	12	1.67	0.196	8550	A3V
	1.7	0.3	21.6	17.8	0.67	0.41	7500	A8V
	2.8	0.45	24.3	18.5	1.38	0.24	7030	F1V
NGC 1778	−1.11	−0.03	3	0	3	0.08	9700	A0V
	1.5	0.14	14	7	7	0.008	8550	A3V
NGC 6939	3.0	0.5	80	70	1.25	0.26	6720	F3V
NGC 3680	5	0.95	8.5	4	2.38	0.1229	5280	K0V
NGC 2682	3.07	0.7	67.5	54.5	2.5	0.1138	6040	F9V
	4.2	0.77	80	55.6	7.44	0.0064	5880	G1V
Trumpler 1	−2.0	−0.08	2.5	1	0.9	0.34	10400	B9.5V
	−0.25	0.018	5	2	1.8	0.18	9200	A1V
	1	0.121	6	5	0.16	0.69	8550	A3V
	1.75	0.25	4.7	3	0.617	0.43	7800	A7V
NGC 2420	3.25	0.55	54	44	1.85	0.17	6640	F4V
	4.25	0.8	59	53	0.61	0.43	5770	G2V
NGC 6134	2.5	0.5	30.6	27	0.42	0.62	6720	F2V
	3.15	0.6	37.4	31	1.09	0.29	6400	F5V
	3.6	0.675	39	34.4	1.09	0.29	6150	F8V
	4.09	0.748	39.5	33.5	0.91	0.34	5920	G0V
	4.62	0.83	44.6	28	6.17	0.012	5660	G5V

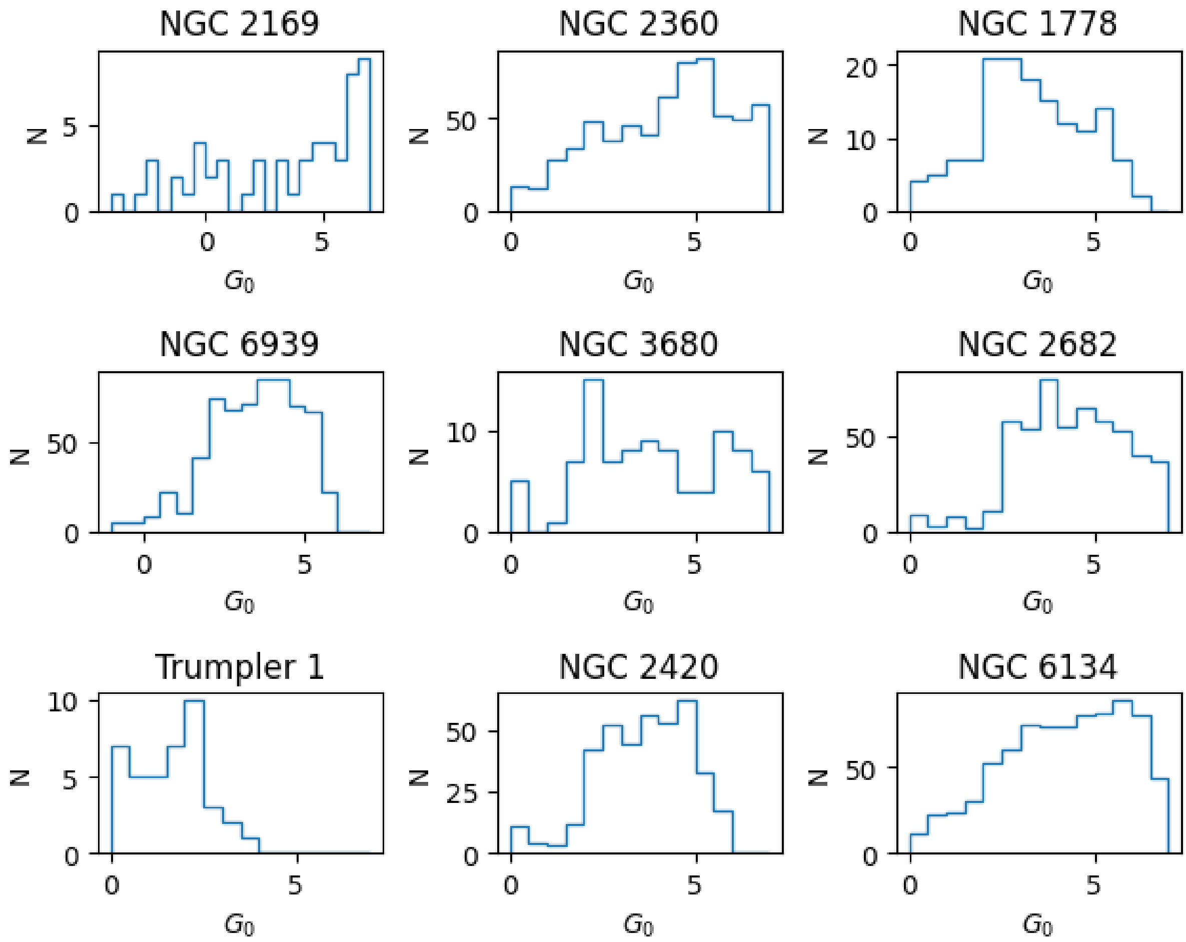

Figure 2: Luminosity functions of the sample of nine clusters.

5. Conclusions

In this paper, we use Gaia DR3 data and membership data of Cantat-Gaudin et al. (2020) to study gaps in the main sequence of the HRD of star clusters. We use the χ^2 test to find the significance of the gaps. We compare the spectral types of earlier detections and find that they agree with our present results. Gaps were reported by Jao et al. (2018) in Gaia DR2 data for M dwarfs. In our sample, the membership data used is available only till apparent G magnitude 18 and does not include M dwarfs, we go to a spectral type of upto G, therefore we don't find that in our data. A more detailed study of HRD of star clusters is necessary to characterise these gaps and study them in more detail.

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Further Information

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Conflicts of interest

The author declares that there is no conflict of interest.

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