We determined astrophysical and dynamical parameters of the open clusters (OCs) NGC 2587, Collinder 268 (Col 268), Melotte 72 (Mel 72), and Pismis 7 from Gaia DR2 photometric/astrometric data and a new technique, fitCMD. fitCMD provides \((Z, \text{Age(Gyr)})\) as \((0.025, 0.45)\) for NGC 2587, \((0.0025, 0.5)\) for Col. 268, \((0.011, 1.25)\) for Mel 72, and \((0.008, 1.00)\) for Pismis 7, respectively. As compared to Gaia DR2 distances, the obtained photometric distances from fitCMD provide somewhat close distances. For NGC 2587 and Mel.72, both distances are in good concordance. Except for NGC 2587, the ages of the remaining OCs are higher than their relaxation times, which suggests that they are dynamically relaxed. NGC 2587 did not undergo dynamical evolution. Mel 72 and Pismis 7 with relatively flat MF slopes indicate signs of a somewhat advanced dynamical evolution, in the sense that they appear to have lost a significant fraction of their low-mass stars to the field. Pismis 7’s negative/flat MFs indicates that its high mass stars slightly outnumber its low mass ones. Given its mild dynamical evolution, the high mass stars move towards the central region, while low-mass stars are continually being lost to the field. Col 268 presents small dimensions which suggest a primordial origin. The outer parts of Mel 72 and Pismis 7 - with large cluster radii expand with time, while Mel 72’s core contracts because of dynamical relaxation (Figs. 10e–f).

**KEYWORDS:** open clusters and associations: individual NGC 2587, open clusters and associations: individual Col 268, open clusters and associations: individual Mel 72, open clusters and associations: individual Pismis 7

**1 | INTRODUCTION**

Astrophysical parameters (reddening, distance, age), structural parameters (core and cluster radii, \(R_{\text{core}}\) and \(R_{\text{RDP}}\)), and overall masses, mass function slopes (\(\mathcal{K}\), MF slopes), relaxation times \(t_{\text{rel}}\) and evolutionary parameters \(t\) of the open clusters (OCs) are needed for the interpretation of the dynamical evolution. The stars inside the OCs undergo internal and external perturbations such as stellar evolution, mass segregation, and encounters with the disk and Giant Molecular Clouds (GMCs) \(\text{(Lamers & Gieles, 2006), (Gieles et al., 2007).}\) All these process produce a varying degree of mass loss that may lead to the cluster dissolution into the field. Mass segregation preferentially drives the low mass stars to the outer parts of the clusters.

Our sample OCs, NGC 2587, Col. 268, Mel. 72, and Pismis 7 were studied in 2MASS \(JHK_s\) by Bukowiecki et al. (2011) hereafter, B11) and Kharchenko et al. (2013) hereafter, K13). Tadross (2011) published the astrophysical parameters of NGC 2587 in 2MASS. The astrophysical parameters of Mel 72 were derived in \(UBVI\) photometry by Hasegawa et al.
2 SEPARATION OF THE CLUSTER MEMBERS

In order to separate the cluster members of NGC 2587, Col 268, Mel 72 and Pismis 7, we have obtained their Gaia DR2 astrometric/photometric data (Brown et al. 2018, Lindegren et al. 2018). To study the issues above, the well-determined cluster parameters (heavy element abundance, colour excess, distance modulus/distance, age and mass) are needed. For this, we employ an approach fitCMD, designed by Bonatto (2019). fitCMD uses the isochrones of Bressan et al. (2012) (hereafter B12) and $G, G_{BP}, G_{RP}$ filters. This paper is organized as follows. The cluster member-ship technique is presented in Section 2. The derivation of reddenings, distance moduli/distances, ages of four OCs from fitCMD algorithm is explained in Section 3. The obtained cluster dimensions, masses/mass function slopes, relaxation times/ evolutionary parameters of four OCs are given in Sections 4–5. A Discussion/Conclusion is presented in Section 6 together with the sub-sections; a comparison with the literature and the dynamical evolution.

### TABLE 1 Equatorial and Galactic coordinates of four OCs.

| Cluster  | $\alpha$ (2000) (h m s) | $\delta$ (2000) (° ′ ″) | $\ell$ | $b$ |
|----------|------------------------|-------------------------|------|-----|
| NGC 2587 | 08 23 22.9             | -29 31 02.1             | 249.46 | 4.46 |
| Col 268  | 13 18 11.4             | -67 05 00.0             | 305.54 | -4.35 |
| Mel 72   | 07 38 31.3             | -10 41 51.4             | 227.84 | 5.38 |
| Pismis 7 | 08 41 08.0             | -38 42 08.6             | 259.05 | 1.99 |

### TABLE 2 The median proper motion components, proper motion radii and parallaxes/distances of the likely members of four OCs for this paper (top rows) and Cantat-Gaudin et al. (2020) (bottom rows).

| Cluster  | $\mu_\alpha$ (mas yr$^{-1}$) | $\mu_\delta$ (mas yr$^{-1}$) | $\Delta r$ (mas yr$^{-1}$) | $\varpi$ (mas) | $d$ (kpc) |
|----------|-------------------------------|-------------------------------|-----------------------------|---------------|----------|
| NGC 2587 | -4.27±0.08                    | 3.57±0.08                     | 0.21                        | 0.31±0.03     | 3.25±0.08 |
| Col 268  | -5.48±0.08                    | -0.40±0.07                    | 0.19                        | 0.37±0.06     | 2.67±0.13 |
| Mel 72   | -4.18±0.08                    | 3.66±0.07                     | 0.21                        | 0.38±0.05     | 2.61±0.08 |
| Pismis 7 | -3.31±0.09                    | 2.77±0.10                     | 0.15                        | 0.19±0.04     | 4.82±0.35 |
| NGC 2587 | -4.26±0.09                    | 3.59±0.11                     | 0.30±0.05                   | 3.39±0.59     |          |
| Col 268  | -5.48±0.09                    | -0.40±0.08                    | 0.36±0.04                   | 2.80±0.30     |          |
| Mel 72   | -4.16±0.11                    | 3.68±0.09                     | 0.37±0.06                   | 2.71±0.40     |          |
| Pismis 7 | -3.31±0.09                    | 2.79±0.13                     | 0.15±0.04                   | 6.67±2.44     |          |

1 http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=II/246.
2 $P$ is defined $P = \Phi_c - \Phi_f$. Here $\Phi = \Phi_c + \Phi_f$ is the total probability distribution. $c$ and $f$ subscripts for cluster and field parameters, respectively. The used parameters for estimation of $\Phi_c$ and $\Phi_f$ are $\mu_\alpha, \mu_\delta, \varpi, \delta \varpi, \sigma_\mu, \sigma_\delta, \sigma_\varpi$.

3 http://www2.mpia-hd.mpg.de/col/gedr3-distances/main.html
FIGURE 1 The $\mu_\alpha$ versus $\mu_\delta$, parallax histogram plus Gaia CMD for NGC 2587 and Col 268. The red circles indicate the cluster region. The parallax histograms of the potential members inside the red circles are shown in the bottom left. The cluster stars inside $\sigma \pm \sigma_\mu$ mas (the vertical/horizontal lines on the parallax histograms) are our likely members. A single stellar cluster sequence of the probable members (filled dots of bottom right panels) is clearly seen on the $(G, G_{BP} - G_{RP})$ CMDs.

motion components/the proper motion radii and the median parallaxes/distances of four OCs are listed in Table 2. Within the errors, their median values are in compatible with those of Cantat-Gaudin et al. (2013) and Cantat-Gaudin et al. (2020) (bottom panel of Table 2). However, note that both median parallaxes of Pismis 7 are somewhat different.

3 | DERIVATION OF REDDENING, DISTANCE, AGE AND MASS

In order to obtain the astrophysical parameters from Gaia DR2 $(G, G_{BP} - G_{RP})$ for the probable members of four OCs, an approach ($fitCMD$), improved by Bonatto (2019) is utilised. $fitCMD$ is to transpose theoretical initial mass function ($IMF$) properties for the isochrones of given age and metallicity to their observational CMDs. Based on initial mass function ($IMF$) properties of the B12 PARSEC isochrones fitCMD searches for the values of cluster stellar mass $(m_{cl})$, Age, global metallicity $(Z)$, foreground reddening $(E(G_{BP} - G_{RP}))$, distance modulus $(m-M)_G$, and magnitude-dependent photometric completeness that produce the artificial and observational CMDs. The adopted parameter ranges are presented in Table 3. The photometric completeness limits which are estimated from Fermi function are given in row 9 of Table 3.

For the members, a Gaia DR2 CMD with the IMF is built for each isochrone (at $DM = 0$ and no reddening). By CMD cell- containing stars with mass in the range $(m_1, m_2)$, the following parameters are obtained, the number of stars per cluster mass $n_H = N_{1,2}/m_{cl}$ and the average mass $<m>$, which basically involves integrating the mass function $\phi(m) = dN/dm$ between $(m_1, m_2)$: $N_{1,2} = \int_{m_1}^{m_2} \phi(m) \, dm$.

* http://stev.oapd.inaf.it/cgi-bin/cmd.
FIGURE 2 The $\mu_x$ versus $\mu_y$, parallax histogram plus Gaia CMD for Mel 72 and Pismis 7. The symbols and their meanings are the same as Fig.1.

Each CMD cell contains the respective relative density (number per cluster mass) of occurrence of stars, which is equivalent to the classical Hess diagram, $H_M = H_{M0}(m_{cl}, Age, Z)$. The parameter search consists on finding the absolute minimum of the residual hyper-surface $R_H$ defined as

$$R_H = (H_{obs} - H_{sim})^2,$$

where $H_{obs}$ is the observed Hess diagram and $H_{sim} = H_{sim}(m_{cl}, Age, Z, CE, DM, k_F, m_{TO})$ is the simulated one. Here, $CE$, $DM$, $k_F$, $m_{TO}$ mean the colour excess, distance modulus, the steepness of the descent, and turn-off magnitude, respectively. The adopted thresholds/Hess cell numbers/Hess widths for Gaia colours/magnitudes are listed in rows 7–8 of Table 3. The values for seven parameters at the absolute minimum are assumed to represent those of the star cluster. In practical terms, locating the minima of $R_H$ is equivalent to finding the parameters that minimize the quantity $S_R$. Here,

$$S_R = \sum_{mag,col} W(mag) \times R_H(mag, col)$$

on the colour/magnitude plane. The sum runs over all Hess cells and $W(mag)$ is the statistical weight of each cell. $W(mag)$ corresponds to the inverse of the observed Hess density computed at the respective magnitude of each cell, i.e., $W(mag) = 1/\sum_{col} H_{obs}(mag, col)$.

Residual minimization between observed and synthetic CMDs – by means of the global optimization algorithm $SA$ – then leads to the best-fitting parameters. $SA$ (Simulated Annealing) is an iterative and statistical technique. For any given step $k$, it randomly selects a new set of parameters $(M^k_{cl}, Age^k, Z^k, CE^k, DM^k, k^k_F, m^k_{TO})$ from the respective ranges. Thus, $SA$ concentrates on smaller parameter ranges, centred around the most promising values, and a new step $(k + 1)$ is taken. Iterations stop when $SA$ meets the convergence criterion: five consecutive repetitions of the same value of $S_R$. However, for the statistical nature of $SA$, $fitCMD$ should be repeated a few times to minimize the probability of getting stuck into a deep, but secondary minimum.

The efficiency of $fitCMD$ for input parameters is tested with simulated CMDs, built with pre-defined values of seven parameters. Individual stellar masses are attributed according to Kroupa’s IMF (Kroupa, 2001) – for masses larger than $0.1\, m_\odot$ – until the sum matches $m_{cl}$; the respective magnitudes are taken from the PARSEC isochrone corresponding to $Age$ and $Z$. Typical photometric uncertainties are added for
TABLE 3 The parameters which are used for fitCMD.

| Cluster     | NGC 2587 | Col 268 | Mel 72 | Pismis 7 |
|-------------|----------|---------|--------|----------|
| Cluster (stellar) mass (m⊙) | 100-1000 | 10-10000 | 100-10000 | 10-100000 |
| (m – M)⊙ (mag) | 10.0-15.0 | 10.8-15.1 | 10.0-15.0 | 12.0-17.0 |
| E(B – V) (mag) | 0.00-1.00 | 0.0074-1.76 | 0.00-1.00 | 0.00-2.00 |
| Age (Myr) | 100 - 1000 | 100-1000 | 100-100000 | 120-13500 |
| Z (Z⊙ = +0.0152) | 0.0001 - 0.03 | 0.0001-0.03 | 0.0001-0.03 | 0.0001-0.03 |
| Ay (mag) | 3.1 | 3.1 | 3.1 | 3.1 |
| (G – BP) threshold/Hess Cell/Cell width (mag) | (0.08-1.41)/67/0.020 | (0.37-2.20)/92/0.020 | (0.08-1.41)/67/0.020 | (0.37-2.20)/92/0.020 |
| G threshold/Hess Cell/Cell width (mag) | (11.75-18.06)/64/0.100 | (11.15-17.58)/65/0.100 | (12.31-19.40)/71/0.101 | (12.00-18.83)/69/0.101 |
| Photometric completeness (mag) | G < 17.17 | G < 16.46 | G < 17.02 | G < 18.08 |
| Usable members | 118 | 128 | 273 | 204 |

4 | DIMENSION AND MASS FUNCTION

By utilising the stellar radial density profiles (RDPs), we have derived structural parameters of four OCs. The fitted RDPs of four OCs to the relation of [King 1966] have been displayed in Fig. 6. For this, the three-parameter function, σ(R) = σbg + σ0/R(R/Rcore)^2, given by [King 1966] is considered. For this equation, σbg is the residual background density, σ0 and Rcore are the central density of stars and the core radius, respectively. The meanings of solid line, horizontal bar and the shaded area are mentioned in caption of Fig. 6. We obtained the cluster radii (R_{RDP}) by comparing the RDP level with background and by measuring the distance from the centre. The Rcore, σbg, and σ0 of four OCs have been derived from the fitted King profile to the observational RDPs (Fig. 6). The large uncertainties within R < 1” in the RDPs are due to their low star contents in their central parts. These structural parameters are listed in Cols. 3-10 of Table 7.

From the obtained masses from fitCMD (Sect. 3), the mass function relation of φ(m(stars m⊙⁻¹)) versus m(m⊙) is displayed in Fig. 7 for the overall parts of four OCs. Table 4 provides the mass information. The observed number of stars and the corresponding total mass (obviously, the mass is computed by the simulation) are listed in Cols. 4-5. The mass range (Col 3) refers to the mass which is actually present in the observed CMDs, while m_{total} (m⊙) and star number (Cols. 6-7) refer to fitCMD’s full simulation (including stars with > 0.08 m⊙). Ideally, the simulated number of stars should be exactly the same as the observed, but sometimes there are residual field stars. The full simulation corresponds to the whole mass range assumed to be present in the cluster. For instance, in the case of NGC 2587, the observed CMD contains 118 stars with m_{total} = 180 m⊙ in the mass range: 0.96–3.09 m⊙; if we had access to the full range, the stars would have masses between 0.08 m⊙ to 3.09 m⊙. Therefore, fitCMD computes the values for this full range as 1621 stars storing 681 m⊙.

The MF slopes shown in the plots are the observed ones, i.e., those computed directly from the observed CMDs. The
FIGURE 4 \((G, G_{BP} - G_{RP})\) CMDs (Hess diagram) for NGC 2587 and Col 268. The blue dots represent the probable members (the bottom rows of Table 3). Solid black lines denote the B12 isochrones. The coloured shaded regions show the relative stellar densities (number per cluster mass) within CMD cells.

FIGURE 5 \((G, G_{BP} - G_{RP})\) CMDs (Hess diagram) for Mel 72 and Pismis 7. The symbols and their meanings are the same as Fig. 4.

Theoretical IMF is used only for the purpose of estimating the completeness-corrected mass (by estimating the difference in the number of stars actually detected at a given magnitude with respect to the expected one). Therefore, all the other parameters are unaffected by this procedure.

The MFs of NGC 2587 (Fig. 7) presents a break followed by slope flattening for masses in the range \(0.96 \leq m \lesssim 3.09\), which is noticeable particularly in the overall region. Up to \(m \sim 1.5m_\odot\), its overall MFs is very steep negative \((\chi = -2.60 \pm 0.46)\). After \(m > 1.5m_\odot\), this MFs becomes very steep positive.
FIGURE 6 Stellar RDPs (filled dots) of four OCs. Solid line shows the best-fit King profile. Horizontal bar: stellar background level measured in the comparison field. Shaded region: 1σ King fit uncertainty.

FIGURE 7 $\phi(m)$ versus $m$ ($m_\odot$) for the overall regions of four OCs. Here $\phi(m) = dN/dm$ (stars $m^{-1}$).

$(\chi = +1.98 \pm 0.63)$. Since the break occurs at $m \sim 1.5m_\odot$, it is not the same as that implied by Kroupa’s mass function ($m \sim 0.5m_\odot$). This break is due to completeness affecting masses lower than $m \sim 1.5m_\odot$. We use the MFs for $m > 1.5m_\odot$ as representative of the overall cluster. This mass range does not seem to be critically affected by completeness. The overall MF slopes of Col 268 and Mel 72 are quite positive/flat ($\chi = +0.61 \pm 0.23$) and ($\chi = +0.54 \pm 0.23$), respectively. Pismis 7’s overall MFs is negative/flat ($\chi = -0.76 \pm 0.25$).

TABLE 4 Mass information for the overall regions of four OCs. Their meanings are explained in Sect.4.

| Cluster    | r (pc) | mass range-m($m_\odot$) | N  | $m_m$($m_\odot$) | N  | $m_m$($m_\odot$) |
|------------|--------|--------------------------|----|-----------------|----|-----------------|
| NGC 2587   | 0.0–13.7 | 0.96-3.09                | 118| 180             | 1621| 681             |
| Col. 268   | 0.0–5.0   | 0.84-2.52                | 128| 170             | 1901| 748             |
| Mel. 72    | 0.0–14.9  | 0.66-2.06                | 273| 310             | 2546| 950             |
| Pismis. 7  | 0.0–13.7  | 1.06-2.18                | 204| 230             | 2575| 973             |

5 RELAXATION TIME AND EVOLUTIONARY PARAMETER

The relaxation times, $t_{rlx}$ (Myr) of four OCs are obtained from a relation, $t_{rlx} \approx 0.04 \left( \frac{N}{lnN} \right) \left( \frac{R}{1pc} \right)$. Here N is the number of stars located inside the cluster radius, $R_{RDP}$. As an indicator of dynamical evolution, the evolutionary parameters are estimated from the relation of $\tau = Age/t_{rlx}$. The relations of these timescales can be found in the works of Bonatto et al. (2005), Bonatto & Bica (2006) and Bonatto & Bica (2007). By adopting $\sigma_v \approx 1kms^{-1}$ as an upper value explicitly (Bonatto & Bica [2011], instead of $\sigma_v \approx 3kms^{-1}$ of Binney et al. [1998], these time scales are estimated and listed in Table 5.

$t_{rlx}$ gives the time required for the stars in the core/halo to travel from one end of these regions to the other (Stars move at $\sigma_v \approx 1kms^{-1}$). Mass segregation (known as migrating from the cores to halo) is directly related to $t_{rlx}$ and $\tau$. $\tau$ also depends on both age and $t_{rlx}$. There is a negative relationship between $t_{rlx}$ and $\tau$. Large $\tau$ and small $t_{rlx}$ correspond to advanced mass
segregation, accordingly, small $\tau$ and large $t_{relax}$ mean small scale mass segregation.

From the propagating the errors in Age (Col. 5 of Table 6), radii and N (Col.6 of Table 4) into $t_{relax}$ and $\tau$, the uncertainties of the evolutionary parameters ($\tau$) are estimated. The errors in ages and radii are at a similar ($\sim 3\% - 13\%$) level. If the uncertainties in the number of stars (N) become to be larger, this is responsible for a large uncertainty in $t_{relax}$ (Table 5) and, consequently, a large uncertainty in the evolutionary parameter. Here, $t_{relax}$ and $\tau$ are considered simply as an order of magnitude estimate.

**TABLE 5** Relaxation times and evolutionary parameters of overall regions of four OCs.

| Cluster     | $t_{relax}$ (Myr) | $\tau$ |
|-------------|------------------|--------|
| NGC 2587    | 1120.7±814.0     | 0.4±0.3 |
| Col 268     | 250.0±142.5      | 2.0±1.2 |
| Mel 72      | 592.7±341.0      | 2.1±1.2 |
| Pismis 7    | 148.8±105.0      | 6.7±4.8 |

6 | DISCUSSION AND CONCLUSION

6.1 Comparison with the literature

The astrophysical parameters of four OCs have been determined from fitCMD algorithm. A comparison of $E(B-V)$, $E(G_{BP}-G_{RP})$, $Z$, $(V-M_V)_0$, $d$ (pc) and Age (Gyr) values of four OCs with the literature is presented in Table 6/Fig. 8. The reddening comparison has been given in $E(B-V)$, which is converted from Gaia/2MASS. The small/large differences between our values and the literature can be seen from Table 6/Fig. 8. We leave the detail comparison to the reader.

Reddenings and the photometric distances which are found from fitCMD for NGC 2587 and Mel 72 are in good agreement with the ones of Cantat-Gaudin et al. (2020). Differences of the redenning and distances for Col 268 and Pismis 7 are up to 0.16–0.18 mag and ~1.0 kpc, respectively. This stems from the usage of $Z$ values of fitCMD, instead of solar abundance. For Mel 72, our redenning/distances/ages are in good agreement with Hendey & Tadross (2021). The obtained photometric distances from fitCMD provide somewhat close distances, as compared to Gaia DR2 distances (Col.6 of Table 2). For NGC 2587 and Mel 72, both distances are in good concordance. The differences of both distances are at a level of ~1.0 kpc for Col 268 and Pismis 7.

**FIGURE 8** The differences between this paper and literature for $E(B-V)$, $d$ (kpc), and Age (Gyr) in Table 6.

The results for Pismis 7 are necessarily rather tentative. It is the most distant and the most heavily reddened cluster and clearly shows that its stars are differentially reddened.

As emphasized by Paunzen & Netopil (2006) and Motinhó (2010), the small/large discrepancies in ages and distance moduli/distances (Table 6) result from the adopted isochrones and the reddening values, which are found from CMDs. Although the B12 Padova isochrones are used for this paper and the papers of B11 and K13, large/small differences in ages can be explained by the derived redenning.

The dimensions, total masses, MF slopes and star numbers of four OCs are presented in Table 7 together with the literature values. The inconsistency of these parameters with the literature may be partly explained by the detected star numbers (Col. 13 of Table 7).
TABLE 6 Comparison of the astrophysical parameters to the literature. Cols. 1-4 represent the cluster name, reddenings, the metal/heavy element abundances, true distance moduli \((V - M_V)_0\), and their corresponding heliocentric distances, respectively. Col. 5 gives the ages \((\log(A)/A \text{ (Gyr)})\). The isochrones, photometry and the references are listed in Cols. 6-8, respectively.

| Cluster    | \(E(B - V) \) & \(E(G_{BP} - G_{RP})\) | [M/H] & Z | \((V - M_V)_0\) & d (pc) | \(\log(A)/A \) & A (Gyr) | Isochrone | Phot. | Reference          |
|------------|-------------------------------|--------|--------------------|-----------------|----------------|----------------|----------|-------|-------------------|
| NGC 2587   | 0.11 / 0.13                   | 0.22 / 0.025 | 12.48 / 3128 | 8.65 / 0.45 | Bressan et al. (2012) | Gaia DR2 | This paper |
|            | 0.23 / -                      | -      | 11.20 / 1740 | 8.00 / 0.10 | Bonatto et al. (2004) | 2MASS | 5        |
|            | 0.10 / -                      | 0.02 / 0.02 | 12.18 / 2700 | 8.70 / 0.50 | Lejeune & Schaerer (2001) | UBV | 6        |
|            | 0.09 / -                      | solar | 12.55 / 3250 | 8.60 / 0.40 | Girardi et al. (2002) | 2MASS | 3        |
|            | 0.10 / -                      | solar | 12.19 / 2700 | 8.70 / 0.50 | Marigo et al. (2008) | 2MASS | 4        |
|            | 0.15 (\(A_V = 0.45\)) / -    | solar | 12.53 / 3210 | 8.50 / 0.32 | Bressan et al. (2012) | Gaia DR2 | 10       |
| Col 268    | 0.53 / 0.66                   | -0.78 / 0.0025 | 10.97 / 1564 | 8.70 / 0.50 | Bressan et al. (2012) | Gaia DR2 | This paper |
|            | 0.36 / -                      | -      | 11.23 / 1740 | -              | -              | -              | -        | -     | -                 |
|            | 0.23 / -                      | solar | - / 1900 | 8.95 / 0.60 | Girardi et al. (2002) | 2MASS | 9        |
|            | 0.24 / -                      | solar | 11.10 / 1680 | 8.85 / 0.71 | Girardi et al. (2002) | 2MASS | 3        |
|            | 0.34 / -                      | solar | 11.40 / 1810 | 8.79 / 0.62 | Marigo et al. (2008) | 2MASS | 4        |
|            | 0.37 (\(A_V = 1.16\)) / -    | solar | 12.10 / 2630 | 8.38 / 0.24 | Bressan et al. (2012) | Gaia DR2 | 10       |
| Mel 72     | 0.16 / 0.19                   | -0.14 / 0.011 | 11.79 / 2277 | 9.10 / 1.25 | Bressan et al. (2012) | Gaia DR2 | This paper |
|            | 0.20 / -                      | solar | 12.38 / 3000 | 8.80 / 0.60 | MAI | \(UBV_I_{Kc}\) | 1        |
|            | 0.08 / -                      | solar | 12.31 / 3180 | 9.20 / 1.60 | Bertelli et al. (2004) | BVI | 2        |
|            | 0.07 / -                      | solar | 12.03 / 2550 | 8.95 / 0.89 | Girardi et al. (2002) | 2MASS | 3        |
|            | 0.23 / -                      | solar | 13.06 / 3960 | 8.86 / 0.72 | Marigo et al. (2008) | 2MASS | 4        |
|            | 0.14 / 0.18                   | solar | 12.22 / 2340 | 9.00 / 1.00 | Marigo et al. (2017) | Gaia DR2 | 11       |
|            | 0.13 (\(A_V = 0.41\)) / -    | solar | 12.14 / 2680 | 8.99 / 0.98 | Bressan et al. (2012) | Gaia DR2 | 10       |
| Pismis 7   | 0.70 / 0.86                   | -0.28 / 0.008 | 12.79 / 3614 | 9.00 / 1.00 | Bressan et al. (2012) | Gaia DR2 | This paper |
|            | 0.69 / -                      | solar | 13.46 / 4920 | 8.70 / 0.50 | Girardi et al. (2000) | BVRI | 7        |
|            | 0.36 / -                      | solar | 14.07 / 6690 | 8.90 / 0.79 | Girardi et al. (2002) | 2MASS | 3        |
|            | 0.94 / -                      | solar | 13.70 / 4780 | 8.70 / 0.50 | Marigo et al. (2008) | 2MASS | 4        |
|            | 0.52 (\(A_V = 1.60\)) / -    | solar | 13.32 / 4610 | 8.89 / 0.78 | Bressan et al. (2012) | Gaia DR2 | 10       |

Table Notes. (1): Piatti et al. (2010), (2): Hasegawa et al. (2008); (3): Bukowiecki et al. (2011); (4): Kharchenko et al. (2013); (5): Tadross (2011); (6): Piatti et al. (2009); (7): Ahumada (2005); (8): Moffat et al. (1975), (9): Bica et al. (2008), (10): Cantat-Gaudin et al. (2020), (11): Hendy and Tadross (2021). MAI (Col. 6) means the morphologic age index.

6.2 Dynamical Evolution of Four OCs

The relations between dynamical evolution parameters are presented in Figs. 10(a)-(f). The relations, the horizontal lines, the labels \(R1-R4\), "C" and filled grey points of panels (a), (e), (f) are from Güneş et al. (2017) (their figs. 11, 14, and 17). From panel (a), NGC 2587, Mel 72 and Pismis 7 do not follow the relation of Güneş et al. (2017). These OCs can be partly attributed to clusters with large radii retaining their masses. Whereas Col 268 with the small dimensions is quite close to the relation (dashed diagonal).

The relaxation times/evolutionary parameters of four OCs exhibit similarity because they are all within one sigma of one another (Table 5 and panel b). Except NGC 2587, the ages of the remaining OCs are higher than their relaxation times. So, they are dynamically relaxed. From panel c, they seem to be less massive OCs than \(m_{tot} = 1000m_\odot\). Mass function gives the distribution of the stars in the cluster. In this context, NGC 2587’s steep MFs (\(\chi = +1.98\)) means that its low-mass stars outnumber its massive ones (panel d). This OC

FIGURE 9 Spatial distribution of our sample OCs (filled circles). The schematic projection of the Galaxy is seen from the North pole. \((X_{GC}, Y_{GC})\) kpc show the Galactocentric cartesian coordinates.
TABLE 7 Structural parameters and literature comparison of four OCs. Col. 2: arcmin to parsec scale. The symbol $r^{-2}$ in Cols. 7-8 mean stars arcmin$^{-2}$. Comparison field ring and the correlation coefficient (CC) are listed in Cols. 9-10. Total mass, mass function slope (MFs), total star number, references, respectively are given in Cols. 11-14.

| Cluster | $R_{\text{core}}$ | $R_{\text{RDP}}$ | $R_{\text{core}}$ | $R_{\text{RDP}}$ | $\sigma_{K}$ | $\sigma_{\text{v}}$ | $\Delta R$ | CC | $m_{\text{tot}}$ | MFs | N |
|---------|-----------------|-----------------|-----------------|-----------------|-------------|-------------|---------|----|--------------|-----|---|
| NGC 2587 | 1.40±0.60 | 13.70±0.50 | 1.5±0.7 | 15.10±0.60 | 3.9±2.1 | 6.63±0.05 | 16-25 | 0.69 | 681 | 1.98±0.63 | 1621 | This paper |
| Col 268 | 0.90±0.2 | 5.62±0.72 | – | – | – | – | 12-31 | 0.95 | 748 | 0.61±0.23 | 1901 | This paper |
| Mel 72 | 1.10±0.2 | 15.00±0.90 | 1.7±0.3 | 22.6±1.4 | 9.5±1.3 | 5.63±0.05 | 23-31 | 0.99 | 950 | 0.54±0.23 | 2546 | This paper |
| Pismis 7 | 0.90±0.2 | 17.00±0.60 | 0.9±0.2 | 13.0±0.6 | 16.7±4.6 | 8.27±0.06 | 14-21 | 0.99 | 973 | -0.76±0.25 | 2575 | This paper |
| 2.10±0.95 | – | – | – | – | – | – | – | – | – | – | 2 |

Table Notes. (1): Bukowiecki et al. (2011); (2): Kharchenko et al. (2013); (3): Bica et al. (2008); (4): Hendey and Tadross (2021).

TABLE 7

| Cluster | $R_{\text{core}}$ | $R_{\text{RDP}}$ | $R_{\text{core}}$ | $R_{\text{RDP}}$ | $\sigma_{K}$ | $\sigma_{\text{v}}$ | $\Delta R$ | CC | $m_{\text{tot}}$ | MFs | N |
|---------|-----------------|-----------------|-----------------|-----------------|-------------|-------------|---------|----|--------------|-----|---|
| NGC 2587 | 1.40±0.60 | 13.70±0.50 | 1.5±0.7 | 15.10±0.60 | 3.9±2.1 | 6.63±0.05 | 16-25 | 0.69 | 681 | 1.98±0.63 | 1621 | This paper |
| Col 268 | 0.90±0.2 | 5.62±0.72 | – | – | – | – | 12-31 | 0.95 | 748 | 0.61±0.23 | 1901 | This paper |
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| Pismis 7 | 0.90±0.2 | 17.00±0.60 | 0.9±0.2 | 13.0±0.6 | 16.7±4.6 | 8.27±0.06 | 14-21 | 0.99 | 973 | -0.76±0.25 | 2575 | This paper |
| 2.10±0.95 | – | – | – | – | – | – | – | – | – | – | 2 |

Table Notes. (1): Bukowiecki et al. (2011); (2): Kharchenko et al. (2013); (3): Bica et al. (2008); (4): Hendey and Tadross (2021).

did not undergo dynamical evolution due to its small evolutionary time. This explains the reason that this OC lies in R1/R3 with large cluster/small core radii (panels e and f). The relatively flat (as compared to $\chi = +1.35$ of Salpeter (1955) or $\chi = 1.30$ of Kroupa (2001)) MF slopes of Col 268 and especially Mel 72 (panel d) suggest that both OCs present signs of a somewhat advanced dynamical evolution, in the sense that they appear to have lost a significant fraction of their low-mass stars to the field.

Col 268 with the small dimensions ($R_{\text{core}}$, $R_{\text{RDP}}$) = (0.9, 5.0) pc is intrinsically small. Instead of shrinking in size and mass with time, it may have a primordial origin which may be related to high molecular gas density in Galactic directions (Camargo et al., 2010; van den Berg et al., 1991). Note that Col 268 (0.5 Gyr) falls in the range "C" (panels e–f).

Pismis 7’s negative/flat MFs (panel d) implies that its high-mass stars slightly outnumber its low-mass stars. Due to its age $= 6.7$ Gyr, Pismis 7 shows a sign of mild dynamical evolution. In this context, its high mass stars move towards the central region, while its low mass stars are continually being lost to the field. Regarding Pismis 7, it is the most distant OC, so completeness may affect the detection of its low-mass content. However, since its age is about 1 Gyr, mass segregation also may played some role in depleting its low-mass stars. The combination of these two factors may explain its MFs.

In panels e–f, the cluster dimension versus cluster age is given. As discussed by Camargo et al. (2010), this kind of relationship provides some information for cluster survival/dissociation rates. From this perspective, some clusters expand with time, while some seem to shrink. According to Mackey & Gilmore (2003), the dynamical evolution of the core/cluster radii of the clusters started at 500-600 Myr (the label "C", panels e–f), and continued to 1 Gyr. A bifurcation occurs at an age $\sim 1$ Gyr. Pismis 7 locates at the bifurcation. Mel 72 locates in R2 region. Therefore, the outer parts of Mel 72 and Pismis 7 expand with time. However, Mel 72’s core contracts because of dynamical relaxation, depending on its R4 location. However, Pismis 7’s core may expand with the time because its massive stars move towards its central parts, given its mild dynamical evolution.

Considering the locations of four OCs in the Galaxy (Table 1/Fig. 9), NGC 2587, Mel 72 and Pismis 7 locate at third quadrant (outside solar circle), which is a region with low density of GMCs. So, except for Pismis 7, they do not seem to expose to the external dynamical effects much, such as tidal stripping due to disk and bulge crossings plus encounters with GMCs. Col 268 did not seem to lost its star content much because of the presence of massive GMCs, and tidal effects from disk and Bulge crossings as external process, taking care its direction (e = 305.54, $R_{\text{GC}} = 7.6$ kpc)?

We adopt the value $R_{\text{GC}} = 8.2 \pm 0.1$ kpc of Bland-Hawthorn & Gerhard (2016) for their $R_{\text{GC}}$ distances.
FIGURE 10 For four OCs, $R_{RDP}$ versus $R_{core}$ (panel a), $\tau$ versus $t_{rlx}$ (panel b), $m_{tot}(m_\odot)$ versus $t_{rlx}$ (panel c), $\chi$ versus $t_{rlx}$ (panel d), ($R_{core}$, $R_{RDP}$) versus Age (panels e–f). The meanings of the symbols in panels (a), (e), (f) are explained in the text.

Star clusters usually present crowding, especially towards the central region. This means that, near the center, some fraction of the faintest stars will not be detected because of crowding. At the outer parts where crowding is less important, one can get more faint stars observed. However, two factors should be considered on our results. A large uncertainty in $t_{rlx}$ and $\tau$ reduces the reliability of the interpretation of the dynamic evolution of these OCs. In this respect, for the interpretations we consider their mean values as a simple approach. Binaries widen the main sequence of the OCs by 0.75 mag, so the theoretical isochrones are fitted to the mid-points of CMDs of the OCs, rather than the faint or blue sides (Carney et al., 2001). Due to a consequence of the dynamical evolution in OCs, multiple systems tend to concentrate in central regions (Takahasi & Portegies Zwart, 2000). Because of a significant fraction of binaries in the central parts of OCs, the number of low-mass stars is underestimated with respect to the high mass stars (Bonatto et al., 2005).

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