Paper summaries

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| Open clusters have long been regarded as important tools for  the studies of stellar evolution, stellar dynamics, and the  Galactic structure. M67 (NGC 2682)  Near distance, low reddening (E(B − V ) ∼ 0.04 mag; Taylor 2007),  high Galactic latitude (l = 215°.70, b = 31°. 90; WEBDA1  ) and rich stellar populations make M67 an ideal laboratory for  studying a wide range of astrophysical problems  High precision astrometric data (positions, parallax, and proper motions) are of great importance to the studies of open clusters, because more accurate cluster members and astrophysical  parameters can be obtained (Perryman et al. 1998). The highprecision astrometric data from the Hipparcos (ESA 1997) and Gaia Mission (Gaia Collaboration et al. 2016) have been used  to investigate several nearby open clusters and deepened our understanding of these clusters (Perryman et al. 1998; van Leeuwen 2009; Gaia Collaboration et al. 2017).  To identify likely cluster members in a deep and wide field, we select sample stars based on the following selection criteria:  (1) the stars must lie within a radius of 2°. 5 from the cluster center  (R.A. = 08h51m18s , decl. = +11°48′00″; WEBDA2)  (2) the stars must have positive parallaxes (π > 0 mas)  (3) the stars must lie within the proper-motion range of ∣μα cos(𝛿)| < 20 mas yr−1 and md ∣μ𝛿∣ < 20 mas yr−1.  (4) the stars must have G-band, BP-band, and RP-band magnitudes.  According to these criteria, we obtain 71117 sample stars with five-parameter astrometric solutions (positions, parallax, and proper motions) and three band magnitudes. These sample stars allow us to identify not only likely cluster members but also likely escaped members, which may lie outside the tidal radius of the cluster.  M67 may only contain 1400–1500 members (Davenport & Sandquist 2010; Gaia Collaboration et al. 2018a)  The RF is a machine-learning method (Breiman 2001), one of its main tasks is to classify a set of unknown objects into different classes according to a given training set. A training set is a set  of objects whose class labels are known, the effectiveness of the RF method strongly depends on the reliability of the training set. The RF usually contains a large number of decision trees, which are built based on a given training set. Each input object will be evaluated by each decision tree in the RF, the best class label for each object will be determined by majority-voting. Assuming that all objects can be divided into classes A and B, if an object is judged to belong to class A by  60% of decision trees in an RF, its probability of belonging to class A is 0.6, and so on  They used an unsupervised clustering technique, Gaussian mixture model (GMM; Lee et al. 2012; Gao 2018a), to perform an effective cluster-field separation.  In this paper, they use a two-component multivariate GMM to assign the sample stars into likely cluster members and field stars, full details about the GMM method can be found in the Appendix. They do this for the 70k+ stars in their sample.  the GMM fails in segregating likely cluster members, because too many field stars are misjudged as likely cluster members. This is because the ratio of the number of field to cluster stars is too large (high-noise environment), and the actual distribution of field stars does not follow a Gaussian distribution (Cabrera-Cano & Alfaro 1990; Gao 2018a). Fortunately, if only the 7312 sample stars lying within 60′ of the cluster center and within a distance range of 500–1600 pc from the Sun are taken into account, reliable cluster members are obtained by making use of the GMM method.  They obtained 1401 likely cluster members with membership probabilities larger than 0.6  They obtained a high value of E = 0.96, indicating a nearly complete cluster-field separation in the normalized five-dimensional parameter space.  They did not take into account the photometric data, which have been confirmed to be  important for membership determination (Gao 2018a).  Furthermore, we do not know whether there might be likely cluster members lying outside this limited region. Therefore, we attempt to use the RF method to segregate likely cluster members from the 71,117 sample stars, which were selected in a deep and wide field.  We construct a reliable training set, which includes 1256 high-probability (PGMM > 0.95) cluster members and 5720 zero-probability (PGMM = 0) field stars.  To identify most likely cluster members, both the  five astrometric (positions, parallax, and proper motions) and  six photometric parameters (G, BP, RP, BP–RP, BP–G, and G–  RP) are taken into account when using the RF method.  color and magnitude parameters cannot be ignored in the RF-based membership determination (Gao 2018a). As a model-dependent clustering technique, the GMM method cannot directly handle the color and magnitude parameters since they do not follow Gaussian distributions.  Fortunately, the RF method does not require any mathematical model, only a reliable training set is needed. This allows us to easily identify most likely cluster members of M67 in the 11- dimensional parameter space, even if the color and magnitude parameters are taken into account.  The 1502 likely cluster members (PRF > 0.6) are listed in Table 3, this table is published in its entirety in the electronic edition. It should be noted that Gaia Collaboration et al. (2018a) have investigated M67 using Gaia-DR2 data and obtained 1520 cluster members, but they did not calculate membership probabilities for these stars. Among the 1520 cluster members in Gaia Collaboration et al. (2018a), 1240 (∼82%) and 1201 (∼79%) stars are determined to be likely (PRF > 0.6) and high-probability (PRF > 0.8) cluster members by the RF method, respectively.  This once again indicates the high effectiveness of the RF method for identifying likely cluster members in high dimensional parameter space.  Data from the paper: <https://iopscience.iop.org/0004-637X/869/1/9/suppdata/apjaae8ddt3_mrt.txt>  <https://iopscience.iop.org/article/10.3847/1538-4357/aae8dd/pdf?fbclid=IwAR1xMX_d6hv70KUM2XzI80bmvKlNmJ-yfe_0e-0yjfZIpF5cZPtZgo640v4> |
| 560 stars that give a total membership uncertainty of 1% |
| Gaia has opened a new era in Galactic astronomy and in cluster science, in particular, thanks to the recent second data release (Gaia Collaboration et al. 2018c,a, hereafter GDR2). GDR2 not only provides homogeneous photometric data covering the whole sky, but also unprecedented high precision kinematics and parallax information, that are fundamental to obtain accurate membership and to identify new clusters. This in turn, will allow more precise age determinations.  <https://arxiv.org/pdf/1901.04733.pdf?fbclid=IwAR133KoQRU8bNnG6DDMexXRzT0OX8cJQf3dUVCq1lzvni7PyOWw5HY0BqSo> |
| Measurement of parallaxes  In simplified form, astrometric measurements (source positions, proper motions, and parallaxes) are made by repeatedly determining the direction to a source on the sky and modelling the change of direction to the source as a function of time as a combination of its motion through space (as reflected in its proper motion and radial velocity) and the motion of the observing platform (Earth, Gaia, etc.) around the Sun (as reflected in the parallax of the source). As explained in more detail in Lindegren et al. (2016) and Lindegren et al. (2012), this basic model of the source motion on the sky describes the time-dependent coordinate direction from the observer towards an object outside the solar system as the unit vector  SOME EQUATION FOLLOWS    the observed parallax is an unbiased estimator of the true parallax (under the strong hypothesis that there are no systematic biases associated with the survey and that the errors are normally distributed).  WHICH THEY EXPLAIN FURTHER ABOVE THIS LINE OF THE PAPER  The distance estimator 1∕ϖ is unbiased for vanishingly small values of f, but it rapidly becomes significantly biased for values of f beyond 0.1  Where f is the (error on the parallax/parallax)  <https://www.aanda.org/articles/aa/full_html/2018/08/aa32964-18/aa32964-18.html> |
| M67 distance 857pc  <https://ui.adsabs.harvard.edu/abs/2009A%26A...503..165Y/abstract> |
| Gaia DR2 includes photometry in the GBP, G, and GRP bands for  approximately 1.5 billion sources.  The precision of Gaia photometry is better than that of any other currently available large catalogs of photometric standards; hence its calibration is achieved via an internal, self-calibrating method  (Carrasco et al. 2016). This robust, internal photometric system is then tied to the Vega system by means of an external calibration process that uses a set of well observed spectro-photometric standard stars (Pancino et al. 2012; Altavilla et al. 2015). Observationally, a Gaia magnitude is defined as:    We refer to Paper I and II for a description of the MARCS grid, our interpolation routines, and examples of their use for different input reddenings (in all cases we have adopted the Cardelli et al. 1989 parametrization of the extinction law)  for the Sun:  In the Vega system we have G☉ = −26.90, corresponding to an absolute magnitude of MG,☉ = 4.67, (GBP − G) = 0.33,  (G − GRP)☉ = 0.49  (GBP −GRP)☉ = 0.82  An extinction coefficient of 2.7 is adopted (appropriate for the G band, and in between those for GBP and GRP)        <https://arxiv.org/pdf/1806.01953.pdf> |
| <https://academic-oup-com.ezproxye.bham.ac.uk/mnras/article/475/4/5023/4816746> |
| <https://www-aanda-org.ezproxye.bham.ac.uk/articles/aa/pdf/2019/12/aa36612-19.pdf> |
| <https://www.aanda.org/articles/aa/full_html/2010/15/aa15441-10/aa15441-10.html?fbclid=IwAR2BaXMhv-vjpowGZCeiR7PmJcb24oBGwrkQfBqCzKyeVfmHOR8tldWqKNo> |
| <https://gea.esac.esa.int/archive/documentation/GDR2/Data_analysis/chap_cu8par/sec_cu8par_intro/ssec_cu8par_intro_whatsdone.html#Ch8.E2> |
| The Priam AG estimates are found not be very accurate on a star-to-star basis. This is shown in Figure 8.7 where we compare R with those values taken from external catalogues for main sequence (panel a, Chaplin et al. 2014) and more evolved stars (panel b, Vrard et al. 2016) |
| <http://www.mpia.de/~calj/gdr2_apsis.pdf> |
| It [NGC 2158] is an intermediate-age open cluster, but a rather metal poor one. It is a crucial object in determining the Galactic disk abundance gradient and the abundance spread at a time and place in the disk. The cluster is rather populous, and therefore it is an ideal candidate to be compared with theoretical models of intermediate-low mass stars (Carraro & Chiosi 1994b; Carraro et al. 1999).  <https://iopscience.iop.org/article/10.1088/1674-4527/10/8/006/pdf> |

Kepler field of view: 19h – 21h, 25o-45o.

<https://academic-oup-com.ezproxye.bham.ac.uk/mnras/article/472/4/3979/4094895>

Gaia broad band photometry = <https://www.aanda.org/articles/aa/full_html/2010/15/aa15441-10/aa15441-10.html>

YBC: a stellar bolometric corrections database with variable extinction coefficients: <https://www.aanda.org/articles/aa/abs/2019/12/aa36612-19/aa36612-19.html>

GAIA DATA RELEASE: <https://gea.esac.esa.int/archive/documentation/GDR2/Data_analysis/chap_cu8par/sec_cu8par_process/ssec_cu8par_process_flame.html>