

# *Gaia* and Clusters

## Draft Report

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## 1 Open Clusters

### 1.1 Data

The data of selected open clusters is taken from the *Gaia* (Gaia Collaboration et al., 2016)’s latest data release, *Gaia* DR3 (Gaia Collaboration et al., 2023).

The following table lists the open clusters selected for analysis in this work.

Table 1: Selected open clusters.

ID
NGC 6834
Messier 18
Berkeley 59
NGC 1502
Messier 50

All the data within 1 degrees from the coordinates of the centers of selected clusters is downloaded using Astroquery (Ginsburg et al., 2019).

### 1.2 Analysis

The following quality cuts have been applied for the data:

- `abs(pmra_error/pmra) < .1`
- `abs(pmdec_error/pmdec) < .1`
- `parallax_over_error > 10`

After applying the quality cuts, the initial membership of clusters is filtered out visually from the inspection of over densities in the distance vs. mean magnitude plots (see figure 1). The distance is estimated from the parallax information provided in the *Gaia* catalog for each sample object in the cluster (see figure 3).

The color magnitude diagrams are plotted along with the distribution of objects by spectral type in figure 4. Also, see table 3).

Table 2: Estimated distances to selected open clusters.

ID	Distance (pc)
NGC 6834	1624
Messier 18	1431
Berkeley 59	999
NGC 1502	1012
Messier 50	1024

## 2 M4 Globular Cluster

This sections describes the analysis performed on M4 cluster using data from *Gaia*. The data is taken from *Gaia* DR3 (Gaia Collaboration et al., 2021). The data consists of sources within 2 degree radius from the coordinates of the center ( $245^{\circ}.89675$ ,  $-26^{\circ}.52575$ ) of M4. The sample size here is 240959.

### 2.1 Cluster membership and subsets

Figure 6 visualizes the selection of samples after and before applying following quality filters:

- `abs(pmra_error/pmra) < .1`
- `abs(pmdec_error/pmdec) < .1`

This brought down the sample size to 121526. Additionally, by analysing the sample distribution in proper motion space, a co-moving cluster is identified. See figure 7. This helps separate stars belonging to cluster from background and foreground. Through following below criteria, a simple selection of cluster is made:

- $-15 < \text{pmra} < -10$
- $-21 < \text{pmdec} < -17$

Among the co-moving cluster, a  $3\sigma$  subset is estimated from the mean of parallax and the sample size reduced to 22451 which is still close to the original co-moving sample. Further, two additional subsets are created based on the assumption that a globular cluster is not larger than 50 and 100 pc (radius). Thus, two subsets of  $3\sigma$  sample where sources are within 100 pc and 50 pc of the distance from mean parallax are extracted.

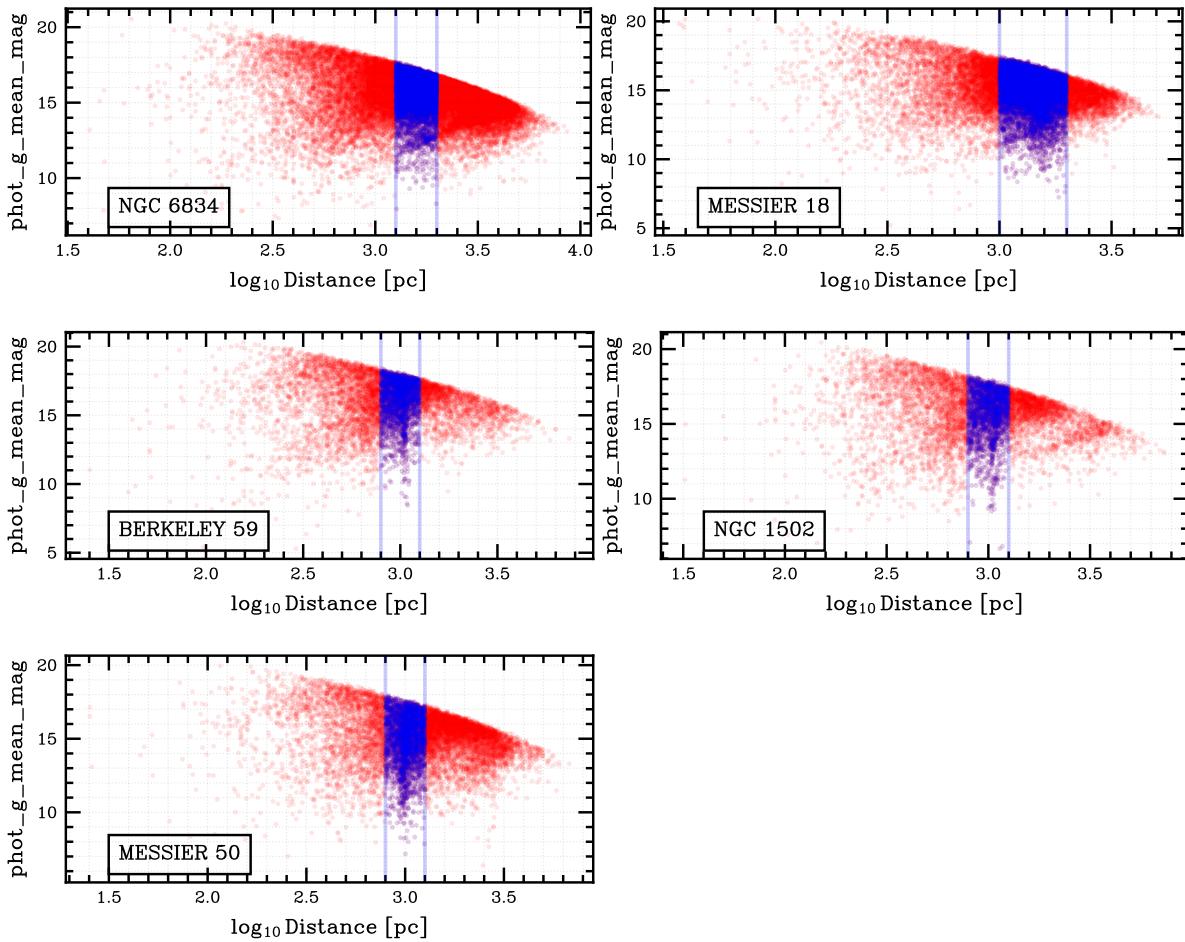


Figure 1: Distance from parallax against G-band magnitude of selected open clusters.

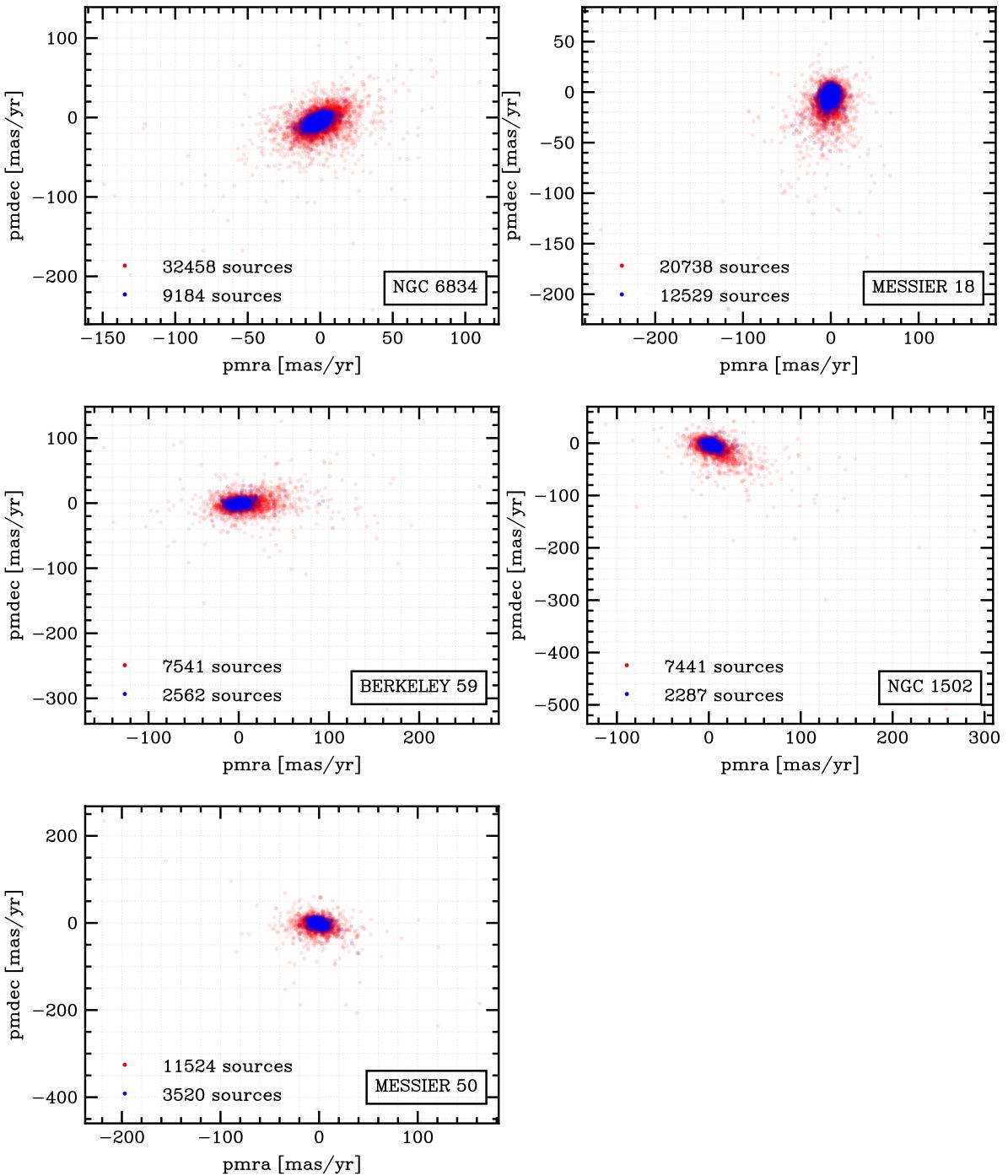


Figure 2: Proper motion diagrams for selected open clusters. The color corresponds to data in figure 1.

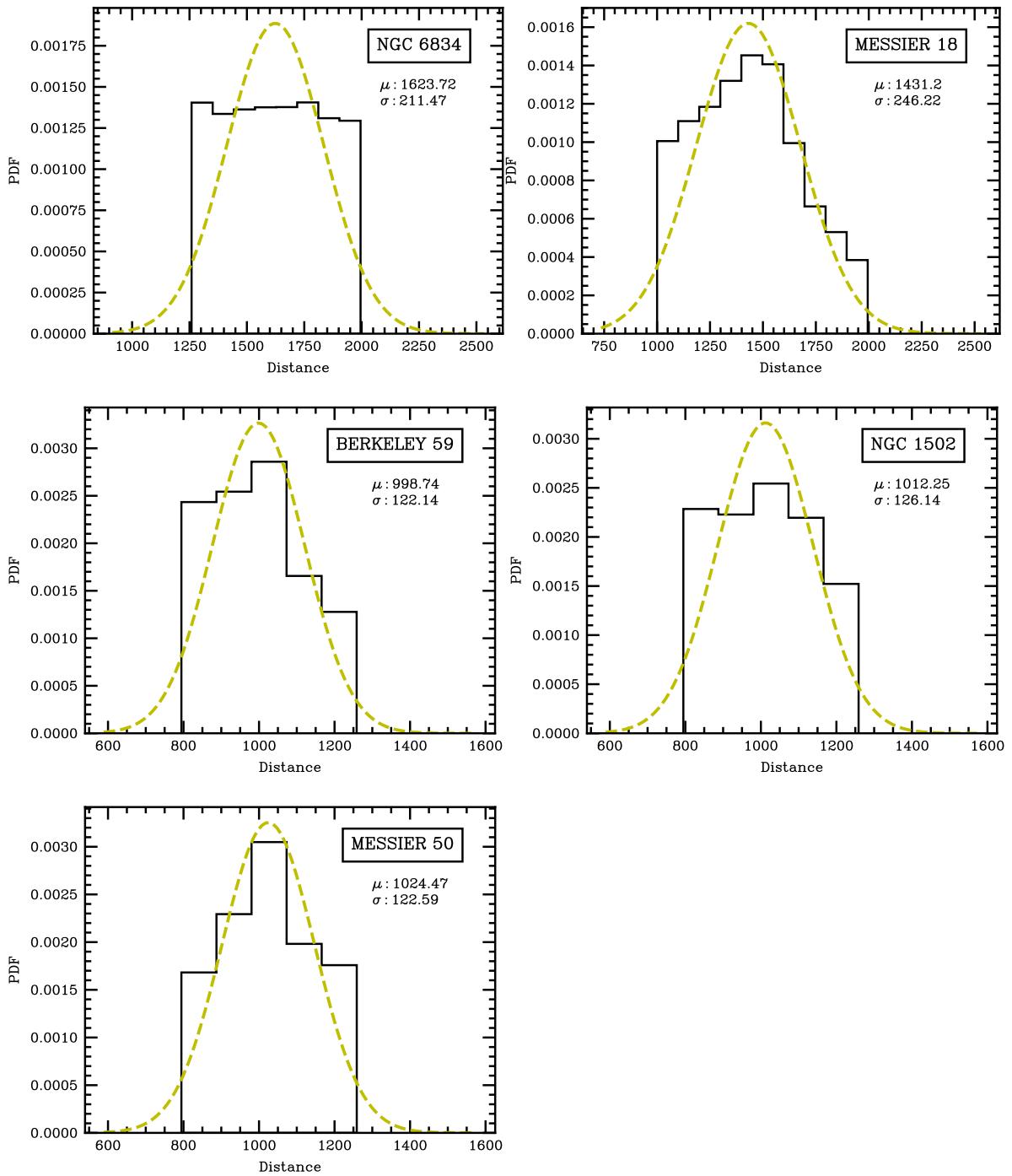


Figure 3: Gaussian best-fits on  $3\sigma$  subsets from the mean of parallax for selected open clusters.

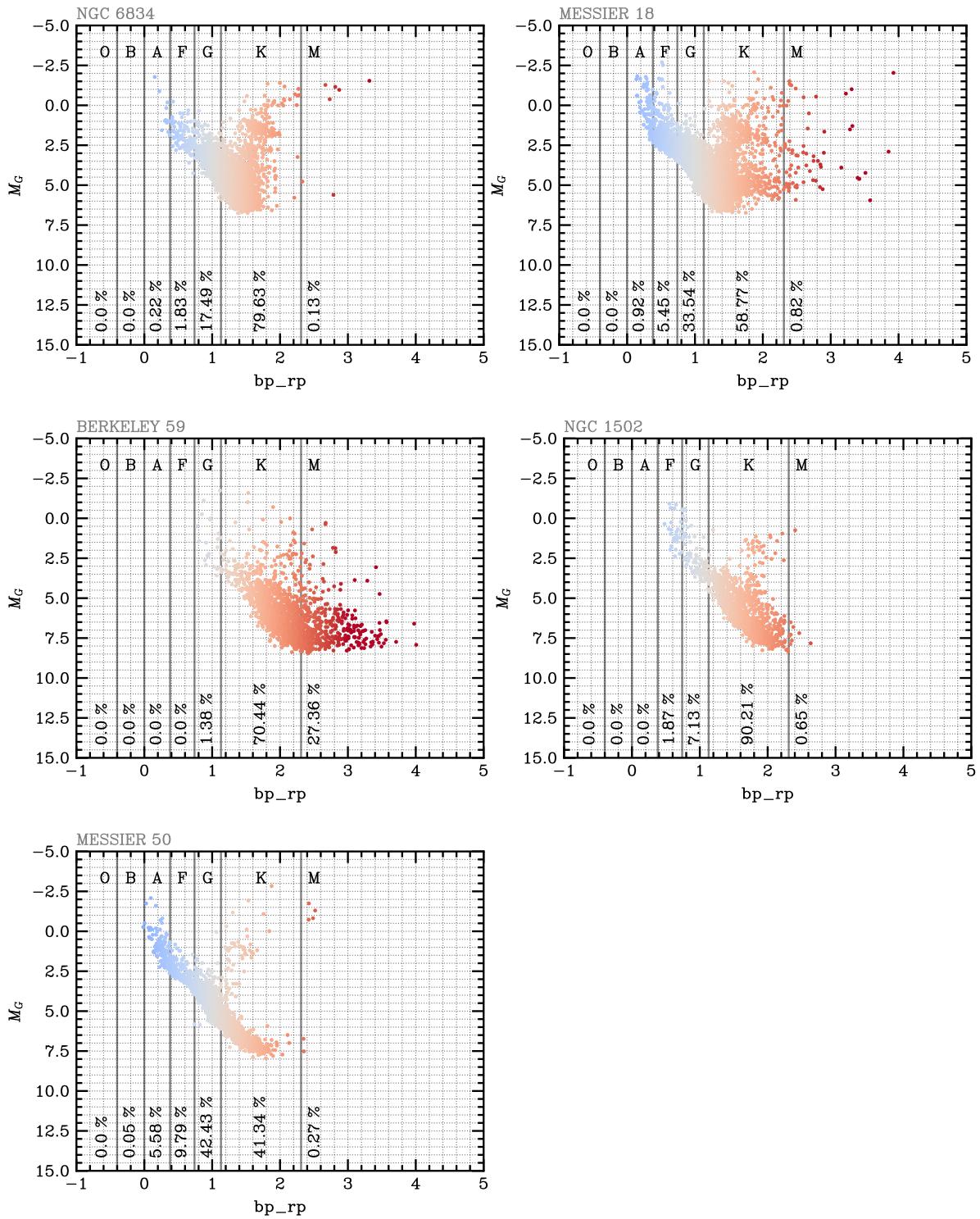


Figure 4: Color-Magnitude diagrams of selected clusters. The spectral classes are separated and their composition estimated and mentioned.

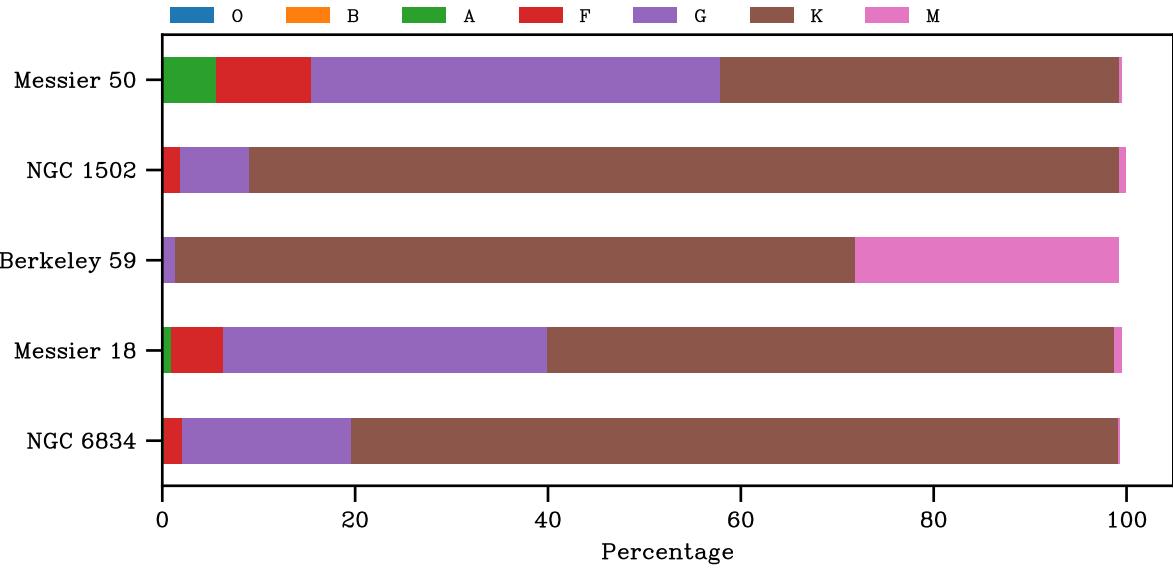


Figure 5: Percentage composition by spectral type for the selected open clusters.

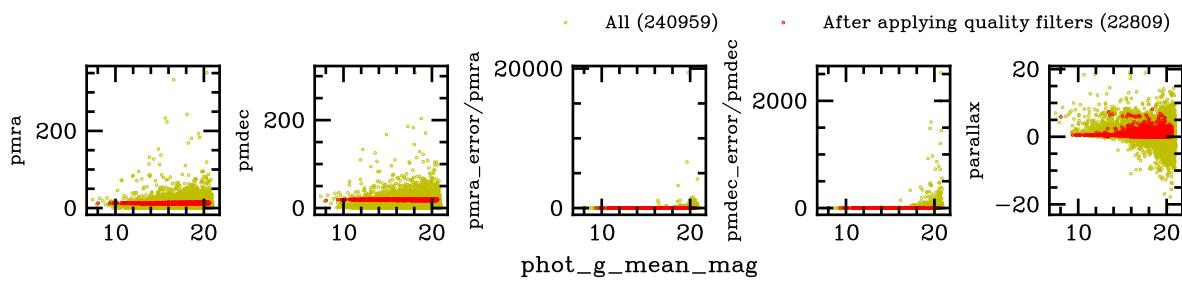


Figure 6: Error viz.

Table 3: Percentage composition by spectral type.

Object ID	O-type	B-type	A-type	F-type	G-type	K-type	M-type
NGC 6834	0.0	0.0	0.22	1.83	17.49	79.63	0.13
Messier 18	0.0	0.0	0.92	5.45	33.54	58.77	0.82
Berkeley 59	0.0	0.0	0.0	0.0	1.38	70.44	27.36
NGC 1502	0.0	0.0	0.0	1.87	7.13	90.21	0.65
Messier 50	0.0	0.05	5.58	9.79	42.43	41.34	0.27

Table 4: Estimated distances to selected open clusters.

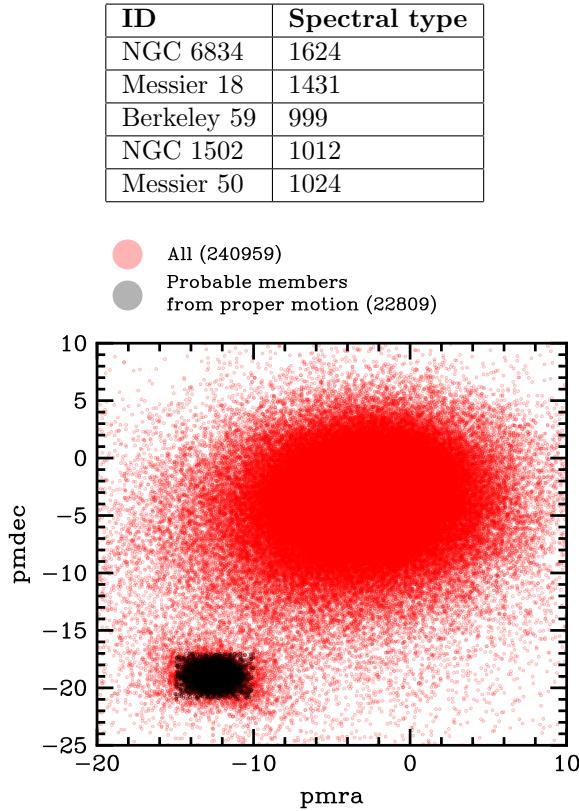


Figure 7: Co-moving cluster highlighted.

The following explains the hierarchy of the subsets:

- $3\sigma$  of parallax  $\subset$  Proper motion co-moving  $\subset$  Quality filtered  $\subset$  Initial full
- Mean parallax distance  $\pm 50$  pc  $\subset$  Mean parallax distance  $\pm 100$  pc  $\subset$  Quality filtered  $\subset$   $3\sigma$  of parallax

## 2.2 Color-Magnitude Diagrams and Isochrones

Figures 8 and 9 shows Color-Magnitude Diagram (CMD) for different subsets.

A distance-modulus of 11.17 estimated from the

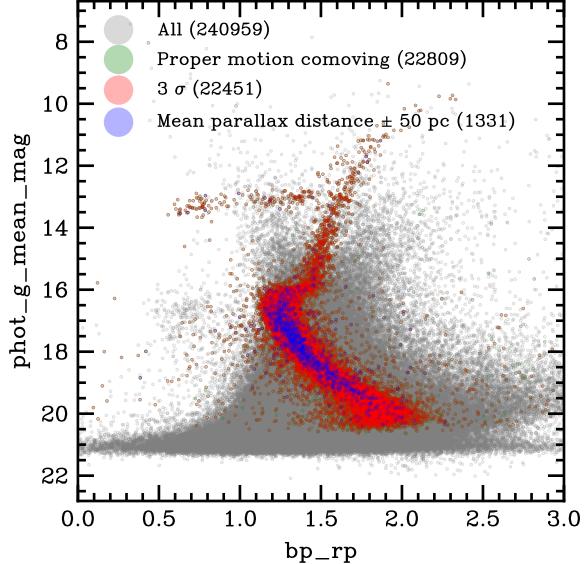


Figure 8: Color-Magnitude diagram of M4 cluster.

mean parallax of the  $3\sigma$  sample set is offset on the `phot_g_mean_mag`. [Missing references for extinction and other offset corrections]. Figure 10 shows an isochrone at 12 Gyr over the  $3\sigma$  sample set.

## 2.3 Radii

King (1962) describes an empirical formula for density distribution in globular clusters.

$$f = k \left( \frac{1}{[1 + (r/r_c)^2]^{1/2}} - \frac{1}{[1 + (r_t/r_c)^2]^{1/2}} \right)^2$$

This equation (hereafter, King's profile) describes an individual cluster by means of three parameters: a number factor  $k$ , a core radius  $r_c$  and a limiting radius  $r_t$ .

Firstly, the density of the cluster is estimated for annuli around the center and then, the King's profile is fitted to this density curve. Figure 11 shows the fitting of the King's profile for different subsets. It can be seen that the fit is best for the subsets of  $3\sigma$  sample than for the  $3\sigma$  sample itself. The non-differential minima represents the limiting radius of the cluster.

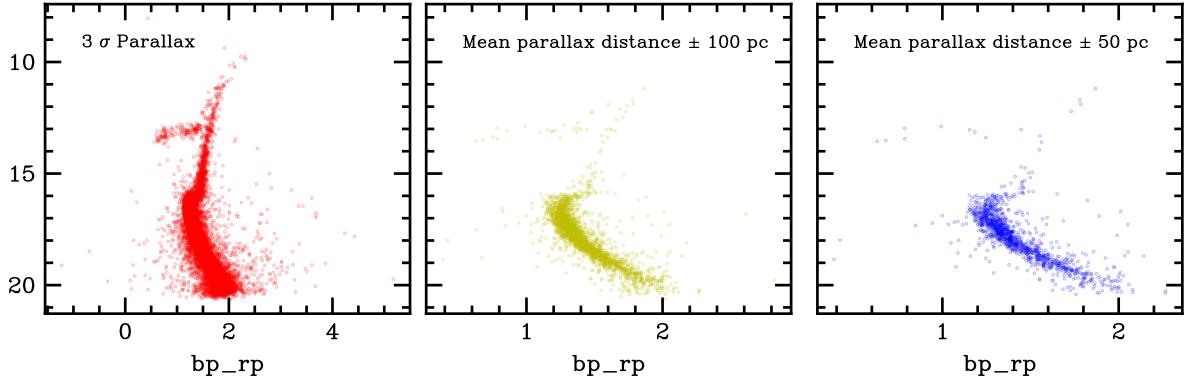


Figure 9: Color-Magnitude diagrams for subsets of the dataset of M4 cluster.

Table 5: Radii of M4

Sample set	$r_c$	$r_t$
$3\sigma$	2.44'	143'
Mean parallax distance $\pm 100$ pc	2.9'	39'
Mean parallax distance $\pm 50$ pc	3.1'	32'

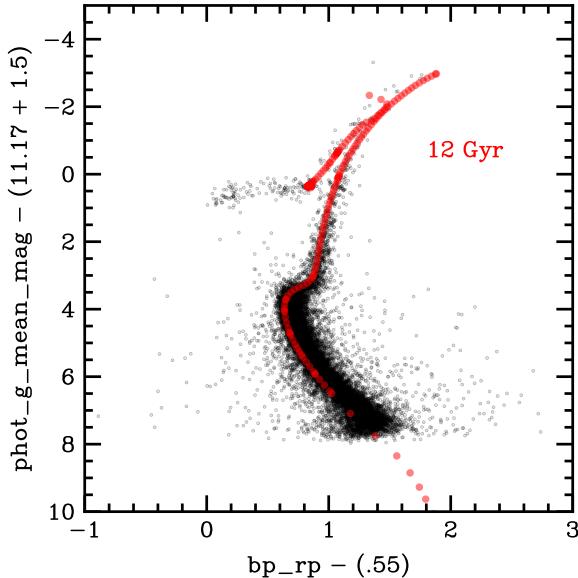
### 3 Acknowledgements

This work has made use of data from the European Space Agency (ESA) mission *Gaia* (<https://www.cosmos.esa.int/gaia>), processed by the *Gaia* Data Processing and Analysis Consortium (DPAC, <https://www.cosmos.esa.int/web/gaia/dpac/consortium>). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the *Gaia* Multilateral Agreement.

### References

- Gaia Collaboration et al., 2016, , 595, A1
- Gaia Collaboration et al., 2021, , 649, A1
- Gaia Collaboration et al., 2023, , 674, A1
- Ginsburg A., et al., 2019, , 157, 98
- King I., 1962, , 67, 471

Figure 10: Isochrone fitted to corrected color-magnitude diagram of M4.



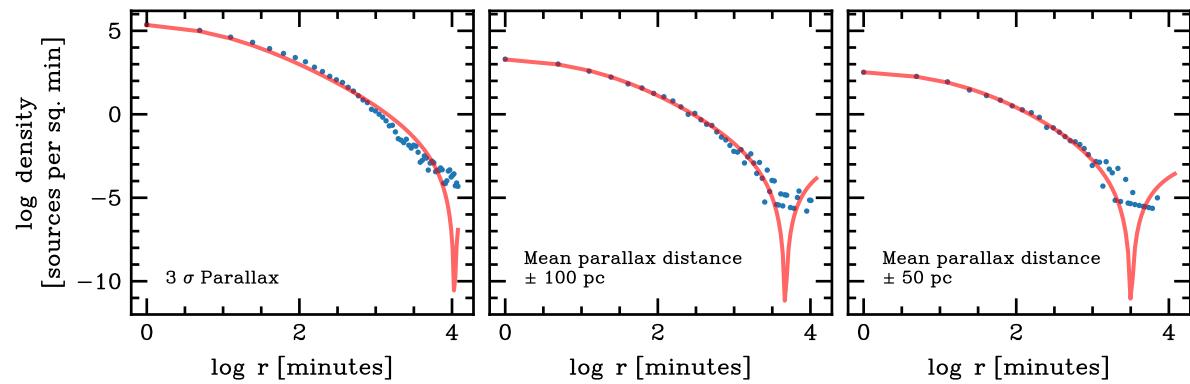


Figure 11: King profile best-fits to different subsets of the dataset of M4 cluster.