M37 COLOR MAGNITUDE DIAGRAM ANALYSIS

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Theory

The measurement of flux from the stars in various sources of interest in the specific wavelength band is called photometry. There are mainly two effects that hinder the analysis they are mainly atmospheric effects which we can calibrate by plotting observed magnitude as function of zenith angle via which we can calculate the atmospheric extinction coefficient. That is to be used to find the actual flux from the source. And the second issue is background radiation which can be due to various reason such as man-made sources, airglow lines, zodiacal light, nearby sources in the sky etc. For any telescope, filter and detector systems, the apparent brightness of an object is expressed in apparent magnitudes given by $m = -2.5\log10(f)+m0$ where the constant m0, known as zero-point magnitude is determined by measuring the flux of standard stars which as used for calibration. Hence before using the data for scientific use one need to correct for such effects. That is done via aperture and PSF photometry.

Aperture Photometry: In this method take a circular aperture of diameter larger than the FWHM corresponding to the point spread function(PSF) of the instrument. The sum of all pixel values of pixels lying inside this aperture centered around a star gives us the sum of the source signal corresponding to the star and the background signal over all pixels lying in the aperture. We take an annulus of inner diameter greater aperture diameter and some outer diameter and use it to sample the background. The median of the pixel values of pixels inside the aperture is taken as the background per signal in the vicinity of the star. This background per pixel is multiplied by the number of pixels in the aperture and subtracted from the sum of pixel values for pixels in the aperture to obtain the source signal for the star in ADU. This is generally done for sparse fields.

Procedure

- Pole star alignment was done by setting the telescope stand in the north-direction.
- Two-star alignment was done.
- The Grab feature in CCDOps was used for capturing the images. Since there was an issue of size mismatch and the presence of ring like features while doing flat-fielding, the division of other images with flats is not done.
- Image data reduction for the cluster (M37) and the calibration star (HD65079) is carried out in this analysis.
- Five images each in r,g,b filter of M37 cluster with integration time = 5 seconds is taken.
- Five images each in r,g,b filter of integration time = 10 seconds for calibration star is taken.
- The dark frame is taken by keeping the shutter close and then taking grab of 5 sec and in bias it is set to 0 sec but it automatically set to 0.12 sec (lowest time).
- The subsequent analysis is done in IRAF.

- Using task rename, all files were changed from *.fit to *.fits extension.
- Cosmic ray removal is done using the task "noao-imred-crutil-cosmicrays".
- Master bias and master dark is created using the task "imcombine".
- Master bias is subtracted from all frames including the master dark.
- Then the master dark is subtracted from the filter frames of M37. List is made using "!ls *.fits>list1" and manually removed those that are not required. Similar process is followed wherever we have to do operation on bulk of images.
- To view the image, DS9 is opened using "!ls ds9 &" in IRAF.
- Same process is followed for the standard star too.

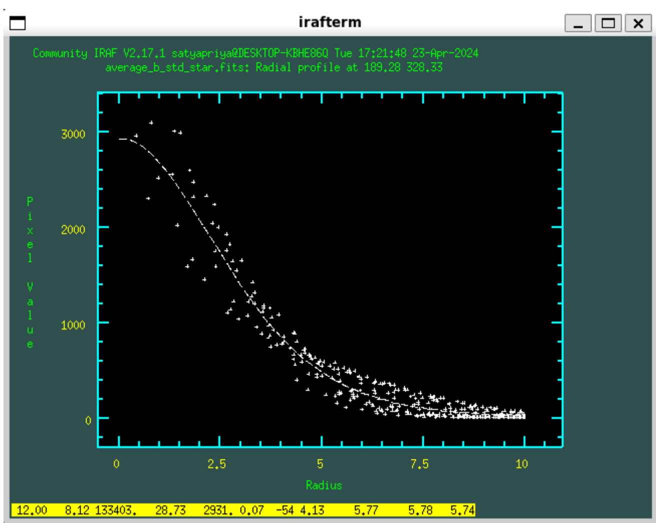
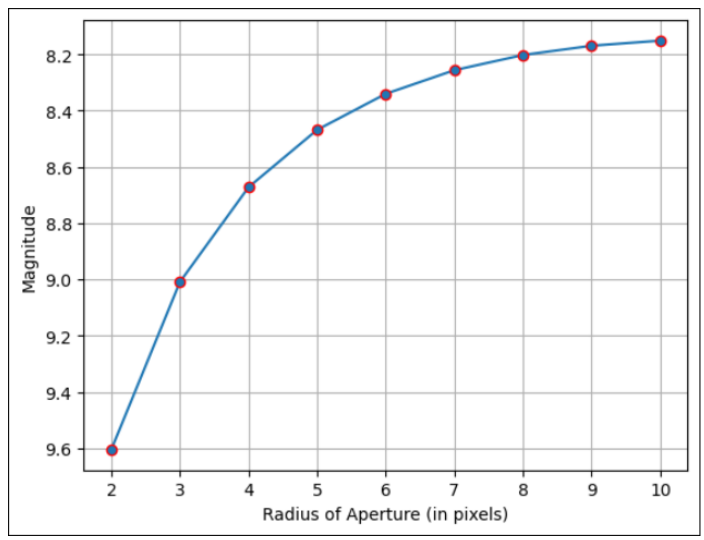


Fig.1: - (a) Radial profile of standard star



(b) Curve of growth of the standard star

Aperture of 8 pixels is selected and the inner annulus of 10 and thickness of annulus of 2 is selected. And for the aperture photometry of stars, the annulus of 6 pixels and inner annulus of 7 and thickness 1 is selected to avoid taking photons from other nearby source.

From analysis,
mag_b_std = 8.203 , err_mag_b_std = 0.003, mag_g_std =8.288, err_mag_g_std = 0.003
mag_r_std = 8.307 , err_mag_r_std = 0.004
From the paper (Landolt 1983, AJ, 88, 439):-
mV = 7.832 , B-V = -0.182, V-R = -0.055, mB = mV+(B-V), mR = mV-(V-R)

These relations are used to shift the magnitude of other stars from the filters in our CCD to the jonson filter. The magnitude error in each case is calculated by the IRAF itself and that is used here directly in this analysis.

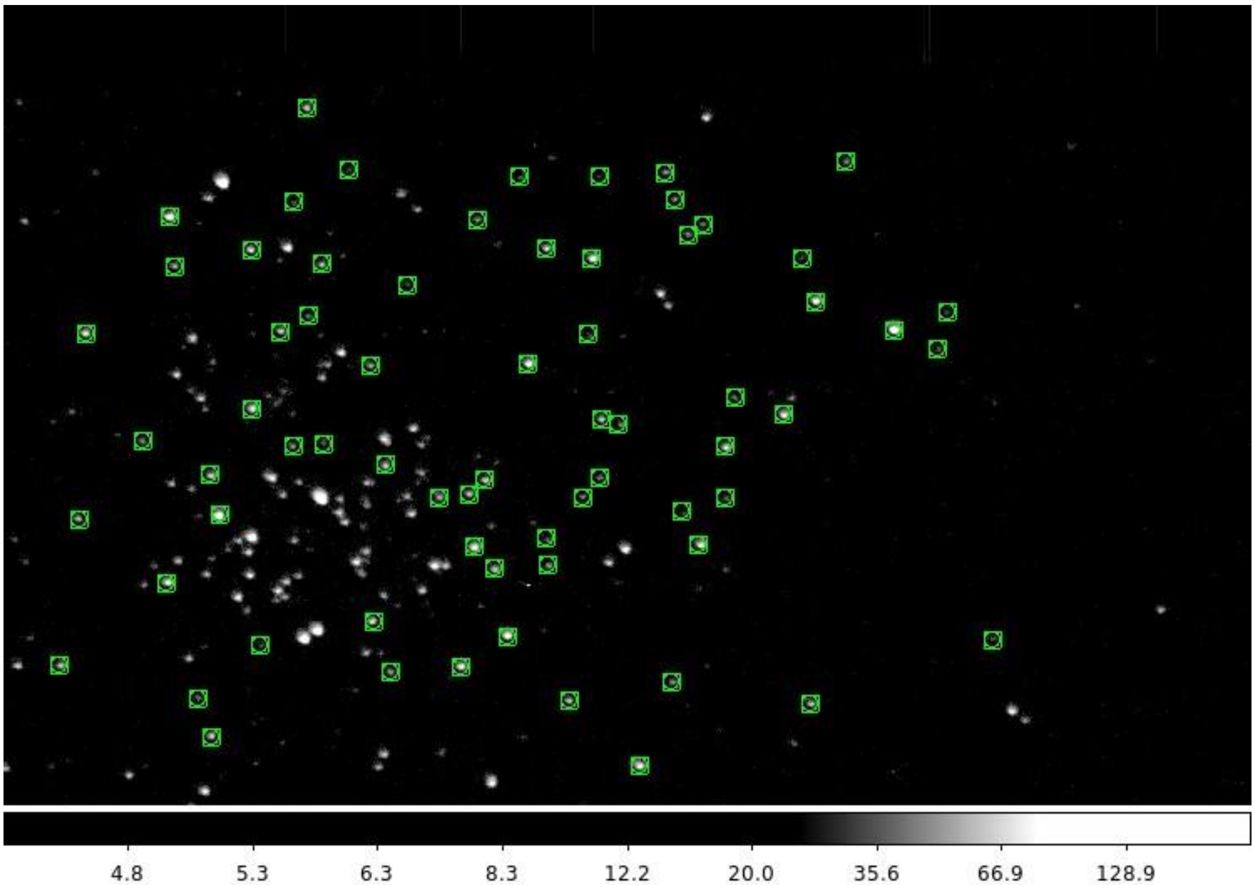


Fig.2: - Selected sources for the analysis using the CMD. Sources are selected such that there are no nearby star in its immediate vicinity for proper aperture photometry.

Table 1: Position of selected sources along with corrected mag and propagated error

X	Y	B	err_B	V	err_V	R	err_R
589	343	11.788	0.035693	11.024	0.031385	10.593	0.019698
437	83	12.105	0.036674	11.989	0.040804	12.028	0.042755
349	73	12.111	0.04653	11.574	0.031385	11.16	0.022472
410	386	12.183	0.058421	12	0.036056	11.938	0.042755
474	215	12.234	0.051478	12.224	0.055317	12.007	0.041773

371	323	12.215	0.051478	11.851	0.050448	11.464	0.032016
182	101	12.777	0.083295	12.715	0.072993	12.689	0.05954
382	392	12.666	0.083295	11.966	0.050448	11.278	0.032985
205	391	12.732	0.077318	12.584	0.062169	12.424	0.056569
358	161	12.059	0.039623	11.135	0.029547	10.512	0.018788
489	273	12.526	0.054452	12.398	0.056294	12.215	0.036878
157	411	12.075	0.051478	11.154	0.033242	10.366	0.017
285	278	12.177	0.050488	11.888	0.04272	11.663	0.032016
540	120	12.853	0.069354	12.895	0.07398	12.817	0.070456
543	360	12.189	0.045541	11.982	0.041761	11.915	0.037855
494	303	13.416	0.108227	13.581	0.125575	13.447	0.107299
340	409	13.37	0.12919	13.082	0.088814	13.132	0.088363
181	256	12.72	0.0614	12.659	0.059228	12.537	0.060531
395	122	13.024	0.092266	12.116	0.043681	11.637	0.033956
367	434	13.697	0.167147	13.559	0.127566	13.434	0.132242
159	381	12.971	0.093263	12.767	0.067082	12.788	0.073437
106	341	12.573	0.06637	12.527	0.063151	12.283	0.05954
230	274	13.389	0.140175	13.154	0.086833	13.024	0.080399
339	213	12.174	0.050488	12.042	0.046573	11.806	0.034928
319	91	13.483	0.146168	13.408	0.136528	13.623	0.129248
102	231	12.965	0.07931	12.769	0.080895	12.734	0.06549
453	438	13.337	0.113217	12.425	0.061188	12.406	0.0536
288	55	13.104	0.076322	12.99	0.089805	12.934	0.080399
489	243	13.556	0.123199	13.769	0.156461	13.367	0.098326
222	343	12.783	0.075326	12.707	0.070036	12.609	0.066483
277	169	12.592	0.0614	12.458	0.064133	12.31	0.0536
231	419	14.016	0.238103	13.662	0.173416	13.642	0.13324
276	322	12.918	0.093263	13.019	0.093771	12.616	0.06549
91	143	12.881	0.084291	11.936	0.043681	11.408	0.027203
561	444	13.289	0.096255	13.517	0.110653	13.511	0.12326
304	415	13.082	0.084291	12.833	0.078918	12.706	0.071449
294	424	12.963	0.086284	12.757	0.080895	12.655	0.070456
259	329	12.542	0.064382	12.452	0.060208	12.356	0.064498
415	290	12.946	0.089275	12.76	0.082873	12.693	0.061522
331	142	12.349	0.04653	12.096	0.041761	12.141	0.045706
429	212	12.19	0.051478	12.016	0.045607	11.952	0.04669
419	204	12.786	0.07433	11.846	0.04272	11.113	0.026249
403	244	13.682	0.138177	13.336	0.134536	13.078	0.09434
414	255	13.275	0.104235	13.166	0.119604	13.286	0.119269
345	254	12.807	0.07433	12.879	0.079906	12.412	0.052612
335	245	12.769	0.065376	12.696	0.072007	12.72	0.064498

318	244	12.817	0.07931	12.618	0.067082	12.436	0.058549
302	284	12.761	0.083295	12.501	0.063151	12.24	0.067476
301	233	12.767	0.088278	11.852	0.038897	11.21	0.026249
168	147	12.961	0.089275	12.744	0.072007	12.741	0.062514
288	139	13.553	0.154159	13.073	0.085843	12.952	0.07642
161	205	12.867	0.067365	12.817	0.066098	12.682	0.060531
457	133	13.213	0.099247	13.077	0.079906	12.957	0.072443
206	296	12.373	0.047518	12.044	0.049477	11.598	0.033956
140	277	13.539	0.117209	13.177	0.105683	12.936	0.08438
407	340	13.588	0.145169	13.576	0.144499	13.261	0.071449
247	382	13.088	0.107229	13.094	0.111647	12.775	0.068469
227	392	12.238	0.056436	11.298	0.035114	10.523	0.020616
188	431	11.26	0.029833	10.903	0.028636	10.382	0.025298
382	218	13.536	0.135181	13.354	0.122589	13.218	0.107299
534	387	14.202	0.251098	13.729	0.184391	13.605	0.121264
352	395	14.094	0.228107	13.8	0.157458	13.767	0.140228
299	370	14.138	0.217113	14.185	0.209344	13.389	0.105304
211	155	14.583	0.335073	13.784	0.172418	13.83	0.175183
477	143	16.386	1.791014	14.164	0.246293	14.283	0.206155
186	232	11.85	0.036674	11.524	0.036056	11.45	0.038833
267	129	14.239	0.265092	13.869	0.13354	13.861	0.16819
530	97	13.381	0.12919	13.394	0.108665	13.388	0.111288
466	401	13.473	0.123199	13.332	0.116619	13.03	0.087367
132	77	12.873	0.085288	12.688	0.069051	12.669	0.067476
177	68	12.407	0.057428	12.291	0.049477	12.19	0.048662
616	332	13.787	0.16315	13.669	0.140513	13.509	0.120266
649	159	13.51	0.106231	12.8	0.072993	12.609	0.057559

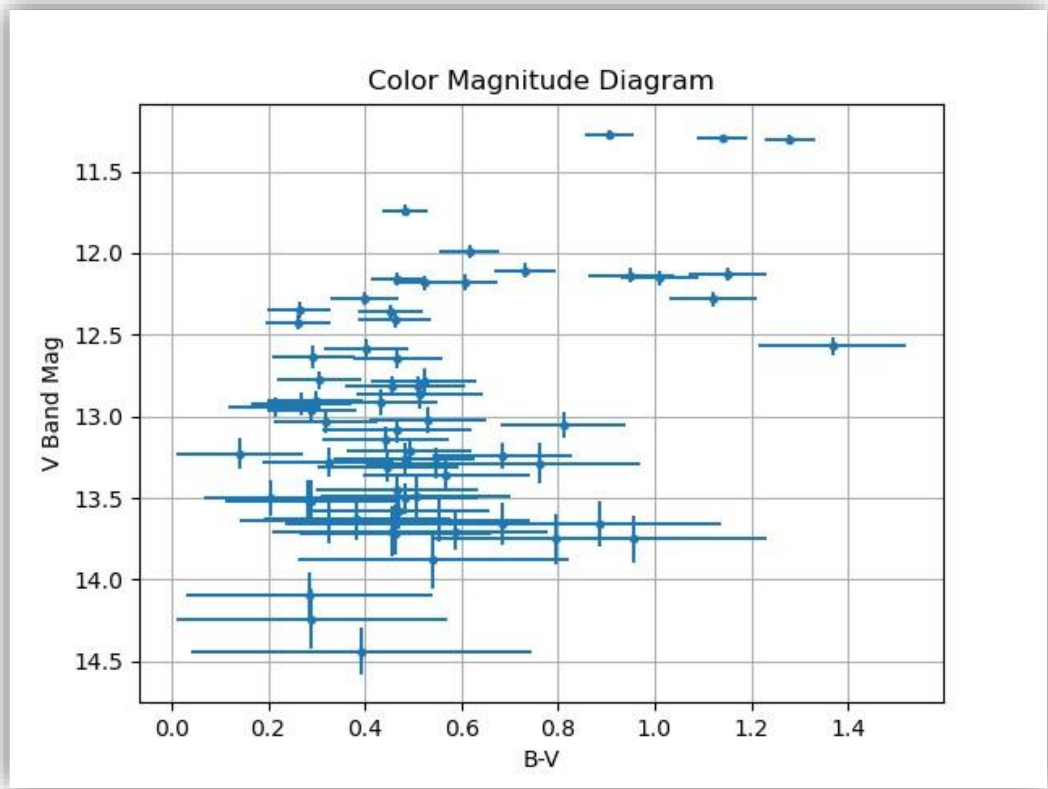


Fig 3: - Plotting the CMD of the selected sources. Galactic extinction correction of 0.26 is applied by adding it to B-V i.e x-axis.

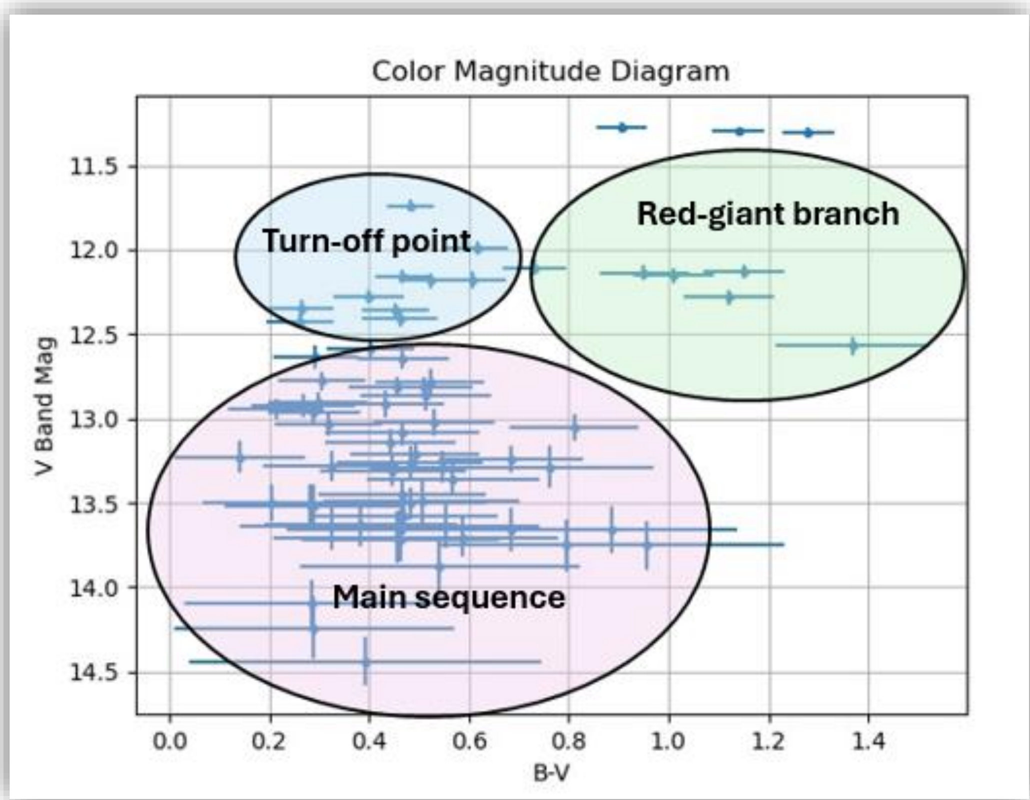


Fig 4: - Various regions of the Color Magnitude Diagram

Comparing CMD with Literature

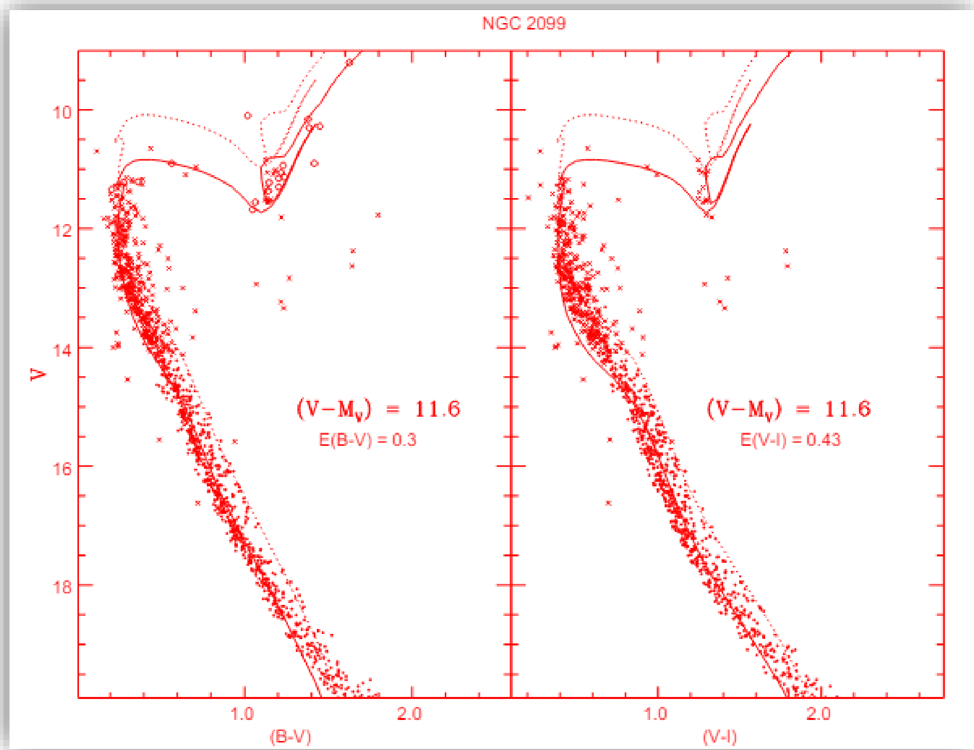


Fig 5: - CMD of M37 from Nilakshi, & Sagar, R. 2002, A&A, 381, 65.

The left figure in figure 5 shows that the turning point is at around 11 magnitude. For me it is around 12 magnitude. One reason I can think is due to the atmospheric extinction.

For a better understanding and comparison I took the data from GAIA DR3 from VOTable in TOPCAT around M37. Then I applied constraints (free hand selection of subset) from proper motion plot. And then plotted the Bmag-Gmag vs Gmag. Along with the color coding for various temperature given in the GAIA data itself for better understanding which matches with the literature. I also checked the statistics of this data and found the basic properties as follows: -

Distance = 1045 pc

Proper motion = 6 mas/yr

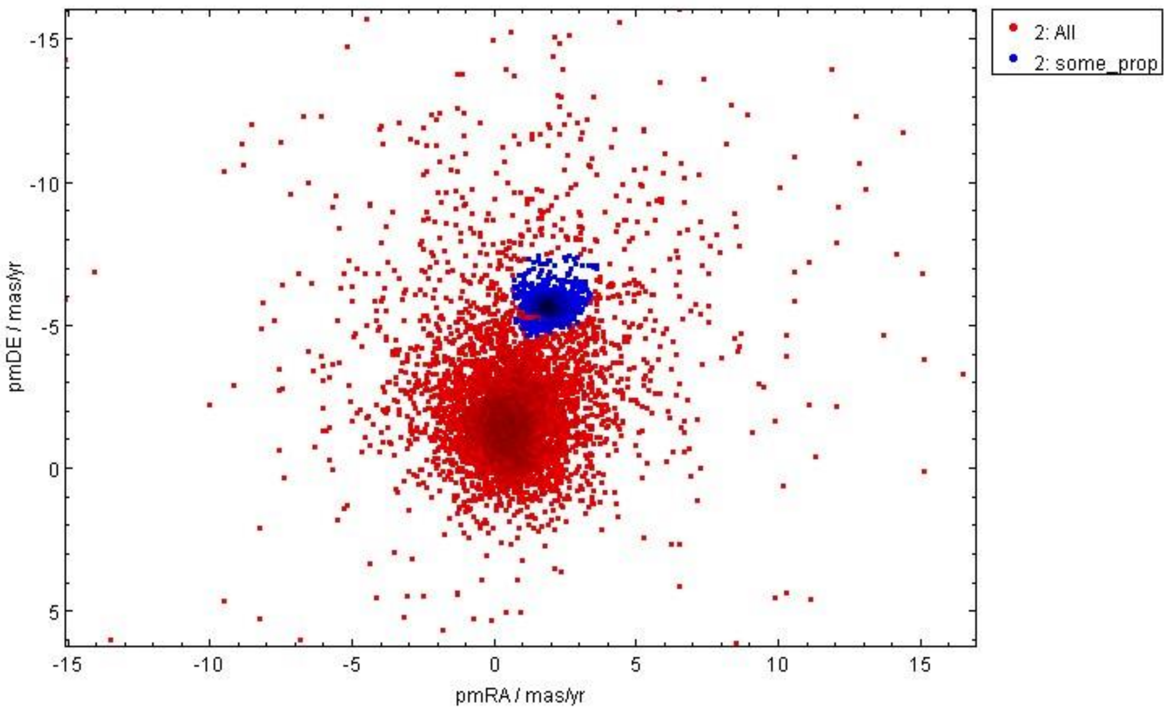


Fig 6: - Proper motion plot of GAIA. Manual selection of subset of the cluster.

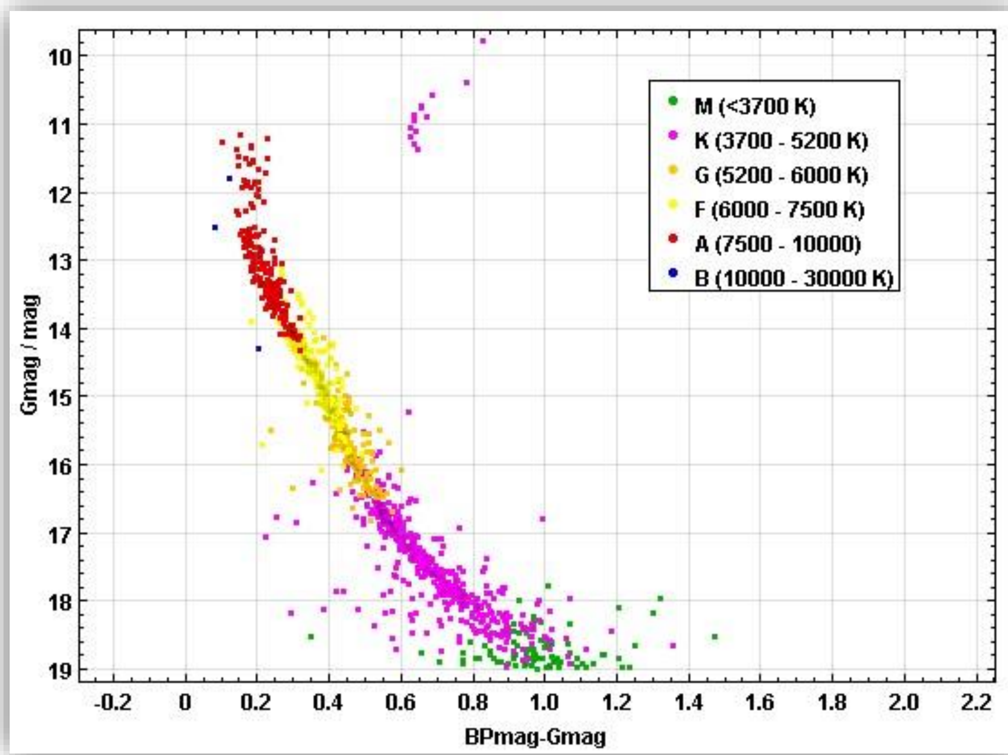


Fig 7: CMD plot of GAIA

Summary: -

- From this analysis we were able to study various populations of stars.
- We learn how to handle telescopes, do two-star alignment, get the data, and teamwork.
- It revised the aperture photometry we learned in the last semester and made me more thorough with it.
- Plotting the CMD, analysis by comparing with the existing literature, and exploration of M37 using GAIA data for better understanding.