ASTR 310 HW 7

1. Color-magnitude diagram (CMD) for Omega Cen

Download the file "ngc5139.dat" from the course web site. This is a text file containing positions and multi-band fluxes for 32,514 stars in the globular cluster Omega Centauri (NGC 5139) as published in Bellini et al. 2010, AJ, 140, 631. A copy of the paper is also available on the website for your convenience. Using NumPy, Astropy, and Matplotlib, write a program to do the following.

a) Read the data into your program using Astropy's `astropy.io.ascii` routine to produce a `Table` object. [5 pts]

In [98]:
```
import astropy.io.ascii
import astropy.units as u
import numpy as np
import matplotlib.pyplot as plt
```

In [99]:
```
t = astropy.io.ascii.read("ngc5139.dat", guess=False, header_start=12, data_
t
```

Out[99]: *Table length=32514*

Seq	RA	DE	F225W	F275W	F336W	F435W	F606W	F625W
int64	float64	float64	float64	float64	float64	float64	float64	float64
1	201.7162676	-47.5126489	23.421	22.291	21.088	20.971	19.99	19.76
2	201.715687	-47.5123958	20.674	19.843	19.095	19.166	18.436	18.248
3	201.7142821	-47.5123325	21.045	20.156	19.368	19.426	18.65	18.468
4	201.7150112	-47.5122876	24.545	22.899	21.604	21.38	20.289	20.133
5	201.7138235	-47.5122802	23.926	22.485	21.13	21.04	20.033	19.801
6	201.7158384	-47.512243	21.261	20.377	19.555	19.596	18.831	18.625
7	201.7153042	-47.5121646	21.184	20.318	19.513	19.597	18.803	18.633
8	201.7150457	-47.5121237	21.843	20.905	20.033	20.095	19.282	19.092
9	201.7166455	-47.5121043	21.047	20.206	19.413	19.5	18.726	18.548
...	...	...	...	...	...	...	...	...
32505	201.7233675	-47.4992715	22.012	21.058	20.069	20.087	19.286	19.031
32506	201.7241085	-47.500007	20.691	19.887	19.108	19.141	18.457	18.231
32507	201.7240771	-47.4994793	20.645	19.815	19.079	19.113	18.412	18.229
32508	201.7238193	-47.4978461	20.896	20.055	19.254	19.32	18.615	18.396
32509	201.7239828	-47.4972452	22.878	21.711	20.757	20.715	19.803	19.577
32510	201.7244136	-47.4985065	22.478	21.407	20.265	20.126	19.303	19.066
32511	201.7242971	-47.4975919	22.322	21.28	20.321	20.269	19.47	19.235
32512	201.7244195	-47.4970404	25.103	23.414	21.749	21.477	20.367	20.044
32513	201.7244516	-47.4971537	23.732	22.446	21.147	21.047	20.069	19.88
32514	201.7246976	-47.4976861	23.322	22.216	20.972	20.921	19.951	19.721

b) Use the table data to reproduce the lower right panel of Figure 2 in Bellini et al (the one showing the three main sequences). Label the main sequences as shown in the panel (MSa in green, rMS in red, bMS in blue). Use the same axis limits as in that panel, and label the axes as done for the plot as a whole. Note that the plot has an inverted y axis with smaller values toward the top, since smaller magnitude values correspond to higher fluxes. You can achieve that effect with a construction like `plt.ylim(5,3)`.

Your plot will not look exactly like the published version because the published one has gridded the data points into a 2D image whereas you are plotting individual dots.

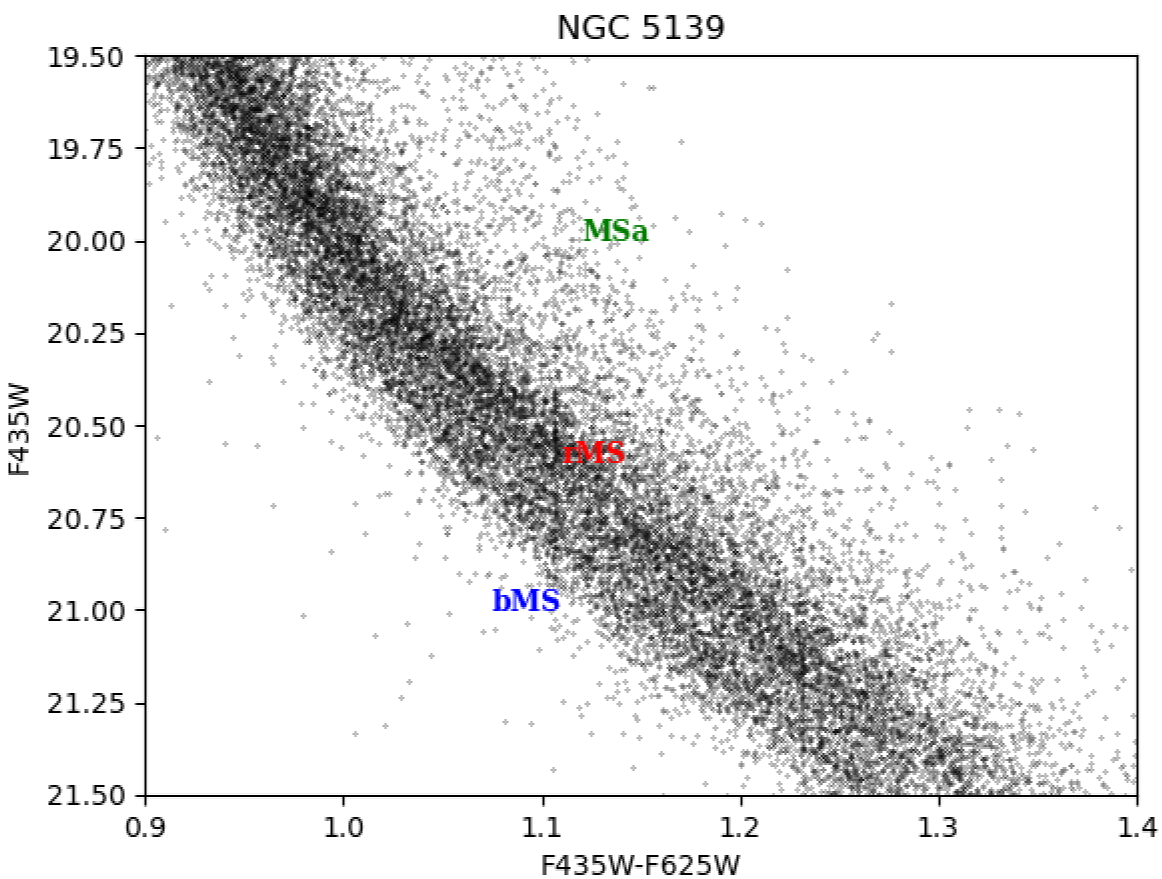
This is a color-magnitude diagram, the observer's analog of a Hertzsprung-Russell diagram. [8 pts]

In [100…

```
plt.scatter(x=t["F435W"]-t["F625W"],y=t["F435W"], s=0.05, c="k")
plt.xlim(0.9, 1.4)
plt.ylim(21.5, 19.5)
plt.text(01.12, 20, "MSa",fontdict={"color":"green", "family": "serif", "wei
plt.text(01.11, 20.6, "rMS",fontdict={"color":"red", "family": "serif", "wei
plt.text(01.075, 21, "bMS",fontdict={"color":"blue", "family": "serif", "wei
plt.xlabel("F435W-F625W")
plt.ylabel("F435W")
plt.title("NGC 5139")
```

Out[100…

```
Text(0.5, 1.0, 'NGC 5139')
```



c) Create two 2D unit vectors: one parallel to the line connecting the points (0.9, 20) and (1.3, 21.7) on the diagram, and the other perpendicular to the line and pointing toward the upper right. We will call them $\hat{\mathbf{n}}_{||}$ and $\hat{\mathbf{n}}_{\perp}$. Check your math by verifying that $\hat{\mathbf{n}}_{||} \cdot \hat{\mathbf{n}}_{\perp} = 0$ and both vectors have length 1.

If you like you can plot the unit vectors on your CMD, but be aware that they will probably not look perpendicular to each other because your plot probably has unequal scales on the x and y axes.

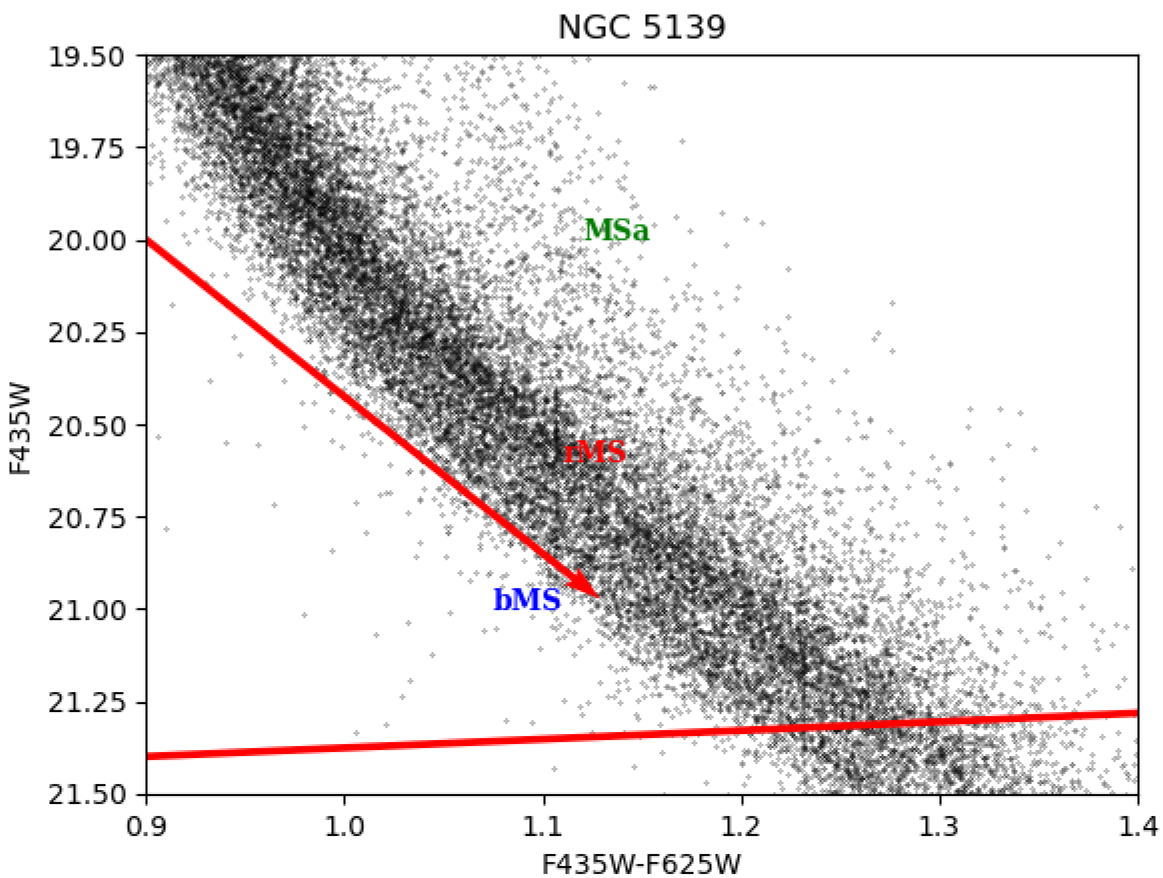
[8 pts]

In [101…

```
plt.scatter(x=t["F435W"]-t["F625W"],y=t["F435W"], s=0.05, c="k")
plt.xlim(0.9, 1.4)
plt.ylim(21.5, 19.5)
plt.text(01.12, 20, "MSa",fontdict={"color":"green", "family": "serif", "wei
plt.text(01.11, 20.6, "rMS",fontdict={"color":"red", "family": "serif", "wei
plt.text(01.075, 21, "bMS",fontdict={"color":"blue", "family": "serif", "wei
plt.xlabel("F435W-F625W")
plt.ylabel("F435W")
plt.title("NGC 5139")

n_par = np.array([0.4, 1.7])
n_par = n_par / np.linalg.norm(n_par)
n_per = np.array([1.7, -0.4])
n_per = n_per / np.linalg.norm(n_per)
plt.quiver(0.9, 20, n_par[0], n_par[1], angles='xy', scale_units='xy', scale
plt.quiver(0.9, 21.4, n_per[0], n_per[1], angles='xy', scale_units='xy', sca
```

Out[101… <matplotlib.quiver.Quiver at 0x15e88c3e0>



In [102…

```
np.dot(n_par, n_per)
```

Out[102… -3.661148649106795e-18

In [103…

```
np.linalg.norm(n_par)
```

Out[103… 1.0

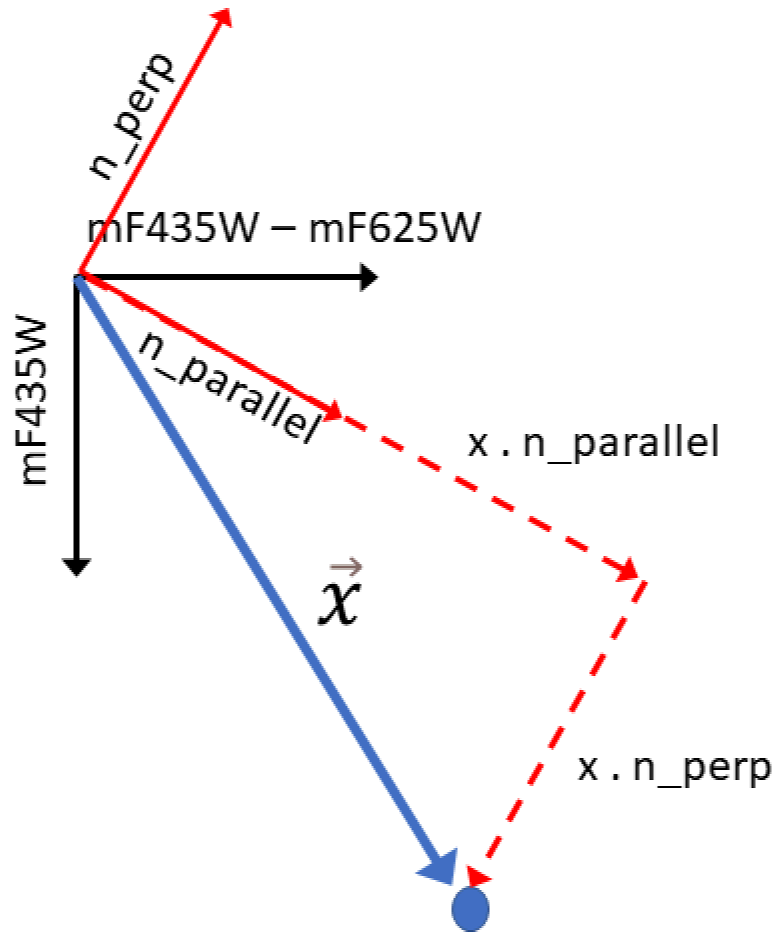
In [104…
```
np.linalg.norm(n_per)
```

Out[104…
```
1.0
```

In the next part you will calculate the dot product of each star's position vector with each of the two unit vectors. This effectively rotates the whole figure so that the line defined by the two points at the beginning becomes the new x axis. The different main sequences will lie roughly parallel to it, ie. horizontally or vertically, and we will be able to create a histogram of the main sequences by binning in the new x or y coordinate.

What's the point of this analysis? It's to show how you might distinguish stars in the different main sequences in an automated fashion. A common analysis task in working with color-magnitude diagrams of different types of objects is to identify physically distinct groupings. There are different ways to approach this problem --- you could do it graphically by hand, use geometrical criteria, and/or perform some kind of clustering analysis. It's best to do the classification in a reproducible way, and this assignment shows one way you might approach the task.

d) Select from the table the F435W magnitudes and F435W-F625W colors of just those stars that fall within the ranges 20.5 to 21.7 in magnitude and 0.9 to 1.4 in color. For each star, project its position vector onto the two unit vectors computed in (c). Specifically: if a star's position on the plot is given by $\mathbf{x} = (m_{F435W} - m_{F625W},\ m_{F435W})$, compute $\mathbf{x} \cdot \hat{\mathbf{n}}_{||}$ and $\mathbf{x} \cdot \hat{\mathbf{n}}_{\perp}$. These are the new coordinates of the star. The figure below illustrates the relationship of the three vectors for a given star (the blue dot). [8 pts]



In [105…
```
x0 = t["F435W"] - t["F625W"]
y0 = t["F435W"]

mask = (x0 > 0.9) & (x0 < 1.4) & (y0 > 20.5) & (y0 < 21.7)
x = x0[mask]
y = y0[mask]

# Calculate new vectors
vectors = np.array(list(zip(x,y)))

new_x = np.dot(vectors, n_par)
new_y = np.dot(vectors, n_per)
```

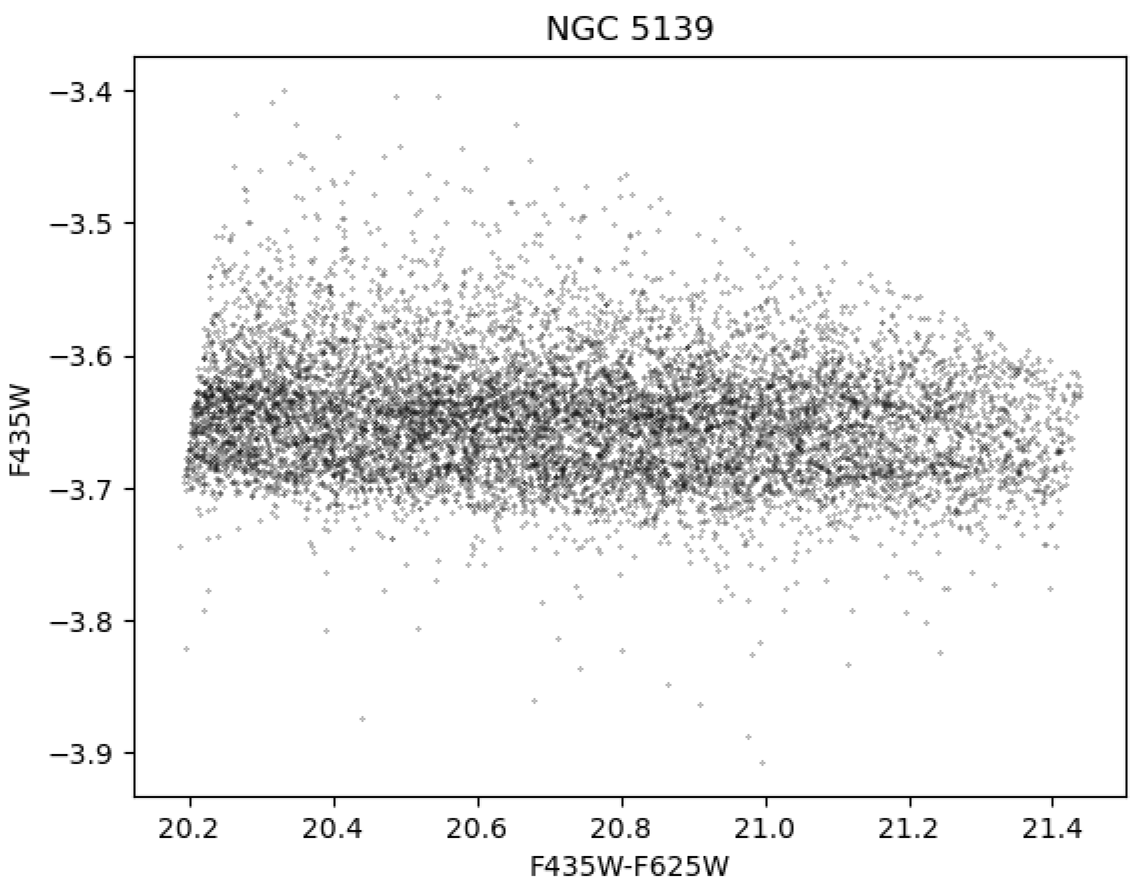
e) Plot the projected positions. You should see a figure similar to the one you created above, but rotated to match the orientation of the vectors computed in part (c). [5 pts]

In [106…
```
plt.scatter(x=new_x,y=new_y, s=0.05, c="k")
# plt.xlim(0.9, 1.4)
# plt.ylim(-5, 0)
# plt.text(01.12, 20, "MSa",fontdict={"color":"green", "family": "serif", "w
# plt.text(01.11, 20.6, "rMS",fontdict={"color":"red", "family": "serif", "w
```

```
# plt.text(01.075, 21, "bMS",fontdict={"color":"blue", "family": "serif", "w
plt.xlabel("F435W-F625W")
plt.ylabel("F435W")
plt.title("NGC 5139")
```

Out[106…

```
Text(0.5, 1.0, 'NGC 5139')
```



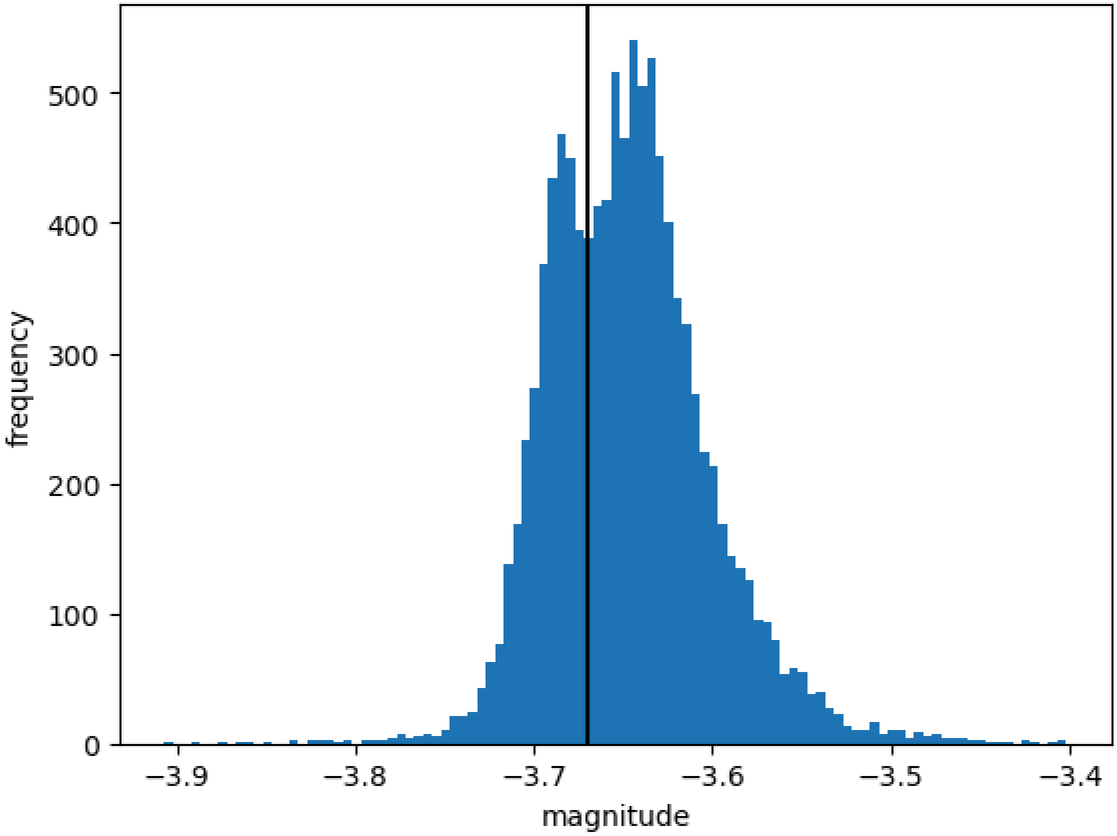
f) Create a histogram plot of $\mathbf{x} \cdot \hat{\mathbf{n}}_\perp$ for the stars in the sample of part (d). Use a bin spacing of 0.005 magnitude. Label the plot appropriately. You should see two local maxima in your histogram, each corresponding to one of the main sequences in the cluster. [8 pts]

In [107…

```
plt.hist(new_y, bins=np.arange(min(new_y), max(new_y), 0.005))
plt.xlabel("magnitude")
plt.ylabel("frequency")
plt.axvline(-3.67, c='k')
```

Out[107…

```
<matplotlib.lines.Line2D at 0x15e97c530>
```



g) Estimate and report the distance in magnitudes between the peaks of the distribution. There are many sophisticated algorithms for doing that task, but here we can do a simple version by slicing the histogram into two parts and finding the maximum of each part. [8 pts]

In [108…
```
abs(max(new_y[new_y < -3.67]) - max(new_y[new_y > -3.67]))
```

Out[108…
```
0.2703809334630085
```