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Project #1: “The Colors of Stars”
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Introduction

We can learn much about a star simply by the colors that it emits. To take advantage of this, astronomers have devised a simple system to both classify and quantify what the human eye sees. Each star we observe in the sky is given a magnitude, a quantity which is based on parameters such as temperature, distance from observer, and size. Because the temperature of a star is associated with its color, it follows that magnitude will reflect star color as well. In an effort to demonstrate the connection between star color and magnitude at different wavelengths, I gathered data on stars catalogued by the Sloan Digital Sky Survey (SDSS). A massive archive of star data in a wide range of filters is available through the SDSS, all recorded on a dedicated 3.5-m telescope, making it the perfect source for demonstrating the fundamentals of astronomy. It is vital that any practicing astronomer understands which parameters of a star lead to others, so that accurate predictions can be made about their nature and evolution. This project will help clarify one of these connections.

Procedure/Data

Using the SDSS SkyServer Navigational tool[1], I was able to locate stars by their color and apparent magnitudes on a map of the sky. This interactive map comes with multiple functionalities, allowing one to highlight an object and have multiple parameters associated with the object displayed. The tool allowed this data to be bunched together and exported to programs such as Microsoft Excel. To ensure that I collected broad enough data to see patterns, I handpicked 22 stars within the tool, each based on their color, so I had a good mix of blue, white, yellow, and red stars. Each star’s designation, position (right-ascension and declination), and magnitudes in filters u, g, r, i, and z were recorded on Table 1.

Analysis

With enough data on hand, I proceeded to search for any relationship between star color and magnitude by first organizing stars by magnitude value in each filter separately. Table 2 demonstrates this process done for filter u, where brighter stars (smaller magnitude value) appear near the top of the list. Then, in order to further investigate relationships, I calculated several color indices for the stars and ordered them by these values. For each sorted list, I visually inspected if there were any groupings of colors, and what this entails. First, I will address my findings for the sorting by magnitudes. Then, I will discuss the results of sorting by color indices.

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[1] http://skyserver.sdss.org/dr7/en/tools/chart/navi.asp

Analysis 1

Before organizing the stars by magnitudes in each filter, I expected that bluer stars would be near the top of the list for filters closer to the ultraviolet range, and red stars near the top for infrared filters. To my surprise, my results did not reflect my predictions very well. For the u (ultraviolet) filter, our highest magnitude star is indeed a blue star. However, the rest of the bluer stars are spread out in the list, from top to bottom, and many red/yellow stars show up near the top. Table 2 showcases these results; notice that it is unreasonable to propose a meaningful pattern due to how mixed the colors are. We have very similar results for the g (green) filter, where no strong pattern is found. I only found a slight pattern when moving all the way to the z (infrared) filter, where most blue stars show up at the bottom. If one is observant, it can be seen that the pattern first starts forming in the r filter, and finally shows itself properly in the z filter.

A possible explanation for this behavior is that magnitude does not only depend on the color of a star. And indeed, as stated in the intro, a star's magnitude depends also upon its size and distance from viewer. Besides size, distance is a factor in the brightness we see in this data since the magnitudes are apparent, not absolute. With this in mind, I reason that many of our blue stars are either smaller or more distant than the red stars in the data that I gathered. This would explain why we see no pattern in the u filter, where we would expect blue stars to peak, but we do see a pattern in the z filter, closer to where red stars peak. Many of the red stars are generally brighter than the blue stars, which is enough to spoil any observable pattern on the end of the spectrum where blue should dominate.

Analysis 2

Sorting my stars by color index rather than magnitudes was much more enlightening. I proceeded with similar assumptions about what the results would be as with *Analysis 1*. This time, my assumptions proved correct, but with caveats. Starting with the color index u-g, almost all of the blue stars come before any of the red stars in the list, with straight red/yellow stars lining the bottom of the list. The pattern is very similar with the g-r and r-i indices, but a close examination shows that the blues are slowly becoming less dominant. The i-z index sees the bluer stars fall down the list towards the middle, with mostly white stars at the top. Finally, the u-i color index, the largest spanning index, gave an overwhelming preference to the bluer stars, more than any of the other indices. Table 3 shows the results of the u-i index, a demonstration of the strongest pattern I found. I note that, in the end, we never do see the red stars become dominant the way that the blue stars do.

The results of the color indices compared to the magnitudes can be explained by the normalizing nature of color indices. When we subtract two magnitudes from different filters for the star in question, we are effectively factoring out the parameters which gave us the results we see for *Analysis 1*. Thus, we can easily see how bluer stars have higher magnitudes than redder stars towards the ultraviolet side of the spectrum. However, this does not quite answer why the redder stars never became dominant in the part of the spectrum that they peak in. This result is explained simply by temperature. A bluer star peaks at higher frequencies than a redder star because it is hotter, and due to Planck's law, also emits more light at *all* frequencies. Thus, even towards where red stars peak, the blue stars still compete with their color indices because they emit more light than same size red stars in general. Table 4 demonstrates this fact with the i-z color index.

Conclusion

The advantages of using color index to determine color was well established by my results in this project. I found that even though the color of a star is connected to its temperature, and thus its emittance, this alone is not enough to determine which stars will be brighter than others. Thus, we cannot know for sure if a brighter star is also a blue star. However, brightness can be normalized through the use of color indices, a powerful way to determine which stars emit the most at certain filters compared to the rest of their spectrum. I conclude that magnitudes of stars quantify the amount of light we receive from a star in general, while color indices quantify how much more of one color a star emits compared to another color. In the end, stars have different colors to our eyes not just because some stars are brighter than others, but because of the fundamentals of radiation described by Planck where only the peak wavelength emitted within our visible spectrum is the color we see. This is the type of phenomenon which color indices attempt to describe. I sought to find a relationship between star color and magnitude, and while I did find correlation, it turns out to not be a direct relationship like I initially thought it would be. Instead, we can only learn of a star's temperature, and thus peak wavelength, by a star's color, and not a definitive magnitude.

TABLE 1 (Raw Data)

objId	ra	dec	u	g	r	i	z	
5.8773E+17	18.9671311	-0.9070213	19.938526	17.121716	15.750569	15.198534	14.891254	Red
5.8773E+17	18.6767189	-0.6008536	14.742484	13.381237	12.809788	12.69844	13.495191	White
5.8773E+17	18.6949413	-0.6048778	17.428656	15.013547	13.837328	13.532888	13.44785	Red
5.8773E+17	18.6554838	-0.1572488	14.914968	12.895764	12.439948	12.332634	13.42136	White
5.8773E+17	18.7671717	-0.1903083	15.97309	14.809129	14.436152	14.297379	14.279492	White
5.8773E+17	19.312763	-0.2094017	15.180963	13.639534	13.07127	12.878784	13.431687	Blue/white
5.8773E+17	19.3391259	-0.0759881	16.632294	15.867721	15.498884	15.57653	15.654007	Blue
5.8773E+17	19.477601	-0.1167203	15.114457	15.234186	15.050097	11.689728	13.429601	White
5.8773E+17	19.6239276	-0.124059	17.560072	15.270185	13.890049	13.524414	13.151349	Orange/Red
5.8773E+17	19.6268225	-0.0564779	16.078825	14.903651	12.977633	12.688709	13.249923	Yellow
5.8773E+17	19.7381751	-0.1492939	19.327969	16.633284	15.230467	14.537353	13.402305	Red
5.8773E+17	19.7943596	-0.1741817	15.229355	14.435374	14.00077	14.057848	14.081721	Blue
5.8802E+17	18.572401	-0.6922481	16.513803	14.685555	14.060603	13.817564	13.713374	Yellow
5.8802E+17	18.5775473	-0.8204504	14.266938	14.609695	15.031694	15.379022	15.693101	Blue
5.8802E+17	18.666451	-0.7329923	16.985334	15.813018	15.417446	15.25949	15.22938	White
5.8802E+17	18.8430625	-0.7689474	14.821564	11.388192	10.53291	10.289508	10.461241	Red
5.8802E+17	18.9035022	-0.6862368	16.469687	15.014927	14.45531	14.279514	14.187049	Red/Yellow
5.8802E+17	19.0632604	-0.7030761	16.216717	14.505032	13.827558	13.32939	13.459525	Orange/Yellow
5.8802E+17	18.4426349	-0.3611173	18.746588	17.822479	16.594393	17.507275	15.206824	Orange/Yellow
5.8802E+17	18.5464646	-0.4006484	15.094057	15.141891	14.783654	11.455692	13.378473	Orange/Yellow
5.8802E+17	18.9523109	-0.2414797	16.445736	14.672665	13.888217	13.676832	13.487049	Yellow
5.8802E+17	19.4418377	-0.2550652	14.877278	12.362012	11.837667	11.683492	13.230782	Yellow/Red

TABLE 2 (u Filter Sorted)

objId	ra	dec	u	g	r	i	z	
5.8802E+17	18.5775473	-0.8204504	14.266938	14.609695	15.031694	15.379022	15.693101	Blue
5.8773E+17	18.6767189	-0.6008536	14.742484	13.381237	12.809788	12.69844	13.495191	White
5.8802E+17	18.8430625	-0.7689474	14.821564	11.388192	10.53291	10.289508	10.461241	Red
5.8802E+17	19.4418377	-0.2550652	14.877278	12.362012	11.837667	11.683492	13.230782	Yellow/Red
5.8773E+17	18.6554838	-0.1572488	14.914968	12.895764	12.439948	12.332634	13.42136	White
5.8802E+17	18.5464646	-0.4006484	15.094057	15.141891	14.783654	11.455692	13.378473	Orange/Yellow
5.8773E+17	19.477601	-0.1167203	15.114457	15.234186	15.050097	11.689728	13.429601	White
5.8773E+17	19.312763	-0.2094017	15.180963	13.639534	13.07127	12.878784	13.431687	Blue/white
5.8773E+17	19.7943596	-0.1741817	15.229355	14.435374	14.00077	14.057848	14.081721	Blue
5.8773E+17	18.7671717	-0.1903083	15.97309	14.809129	14.436152	14.297379	14.279492	White
5.8773E+17	19.6268225	-0.0564779	16.078825	14.903651	12.977633	12.688709	13.249923	Yellow
5.8802E+17	19.0632604	-0.7030761	16.216717	14.505032	13.827558	13.32939	13.459525	Orange/Yellow
5.8802E+17	18.9523109	-0.2414797	16.445736	14.672665	13.888217	13.676832	13.487049	Yellow
5.8802E+17	18.9035022	-0.6862368	16.469687	15.014927	14.45531	14.279514	14.187049	Red/Yellow
5.8802E+17	18.572401	-0.6922481	16.513803	14.685555	14.060603	13.817564	13.713374	Yellow
5.8773E+17	19.3391259	-0.0759881	16.632294	15.867721	15.498884	15.57653	15.654007	Blue
5.8802E+17	18.666451	-0.7329923	16.985334	15.813018	15.417446	15.25949	15.22938	White
5.8773E+17	18.6949413	-0.6048778	17.428656	15.013547	13.837328	13.532888	13.44785	Red
5.8773E+17	19.6239276	-0.124059	17.560072	15.270185	13.890049	13.524414	13.151349	Orange/Red
5.8802E+17	18.4426349	-0.3611173	18.746588	17.822479	16.594393	17.507275	15.206824	Orange/Yellow
5.8773E+17	19.7381751	-0.1492939	19.327969	16.633284	15.230467	14.537353	13.402305	Red
5.8773E+17	18.9671311	-0.9070213	19.938526	17.121716	15.750569	15.198534	14.891254	Red

TABLE 3 (u-i Color Index Sorted)

objId	ra	dec	u	g	r	i	z	u-i	
5.8802E+17	18.5775473	-0.8204504	14.266938	14.609695	15.031694	15.379022	15.693101	-1.11208	B
5.8773E+17	19.3391259	-0.0759881	16.632294	15.867721	15.498884	15.57653	15.654007	1.055764	B
5.8773E+17	19.7943596	-0.1741817	15.229355	14.435374	14.00077	14.057848	14.081721	1.171507	B
5.8802E+17	18.4426349	-0.3611173	18.746588	17.822479	16.594393	17.507275	15.206824	1.239313	O/Y
5.8773E+17	18.7671717	-0.1903083	15.97309	14.809129	14.436152	14.297379	14.279492	1.675711	W
5.8802E+17	18.666451	-0.7329923	16.985334	15.813018	15.417446	15.25949	15.22938	1.725844	W
5.8773E+17	18.6767189	-0.6008536	14.742484	13.381237	12.809788	12.69844	13.495191	2.044044	W
5.8802E+17	18.9035022	-0.6862368	16.469687	15.014927	14.45531	14.279514	14.187049	2.190173	R/Y
5.8773E+17	19.312763	-0.2094017	15.180963	13.639534	13.07127	12.878784	13.431687	2.302179	B/W
5.8773E+17	18.6554838	-0.1572488	14.914968	12.895764	12.439948	12.332634	13.42136	2.582334	W
5.8802E+17	18.572401	-0.6922481	16.513803	14.685555	14.060603	13.817564	13.713374	2.696239	Y
5.8802E+17	18.9523109	-0.2414797	16.445736	14.672665	13.888217	13.676832	13.487049	2.768904	Y
5.8802E+17	19.0632604	-0.7030761	16.216717	14.505032	13.827558	13.32939	13.459525	2.887327	O/Y
5.8802E+17	19.4418377	-0.2550652	14.877278	12.362012	11.837667	11.683492	13.230782	3.193786	Y/R
5.8773E+17	19.6268225	-0.0564779	16.078825	14.903651	12.977633	12.688709	13.249923	3.390116	Y
5.8773E+17	19.477601	-0.1167203	15.114457	15.234186	15.050097	11.689728	13.429601	3.424729	W
5.8802E+17	18.5464646	-0.4006484	15.094057	15.141891	14.783654	11.455692	13.378473	3.638365	O/Y
5.8773E+17	18.6949413	-0.6048778	17.428656	15.013547	13.837328	13.532888	13.44785	3.895768	R
5.8773E+17	19.6239276	-0.124059	17.560072	15.270185	13.890049	13.524414	13.151349	4.035658	O/R
5.8802E+17	18.8430625	-0.7689474	14.821564	11.388192	10.53291	10.289508	10.461241	4.532056	R
5.8773E+17	18.9671311	-0.9070213	19.938526	17.121716	15.750569	15.198534	14.891254	4.739992	R
5.8773E+17	19.7381751	-0.1492939	19.327969	16.633284	15.230467	14.537353	13.402305	4.790616	R

B=Blue W=White Y=Yellow O=Orange R=Red

TABLE 4 (i-z Color Index Sorted)

objId	ra	dec	u	g	r	i	z	i-z	
5.8802E+17	18.5464646	-0.4006484	15.094057	15.141891	14.783654	11.455692	13.378473	-1.92278	O/Y
5.8773E+17	19.477601	-0.1167203	15.114457	15.234186	15.050097	11.689728	13.429601	-1.73987	W
5.8802E+17	19.4418377	-0.2550652	14.877278	12.362012	11.837667	11.683492	13.230782	-1.54729	Y/R
5.8773E+17	18.6554838	-0.1572488	14.914968	12.895764	12.439948	12.332634	13.42136	-1.08873	W
5.8773E+17	18.6767189	-0.6008536	14.742484	13.381237	12.809788	12.69844	13.495191	-0.79675	W
5.8773E+17	19.6268225	-0.0564779	16.078825	14.903651	12.977633	12.688709	13.249923	-0.56121	Y
5.8773E+17	19.312763	-0.2094017	15.180963	13.639534	13.07127	12.878784	13.431687	-0.5529	B/W
5.8802E+17	18.5775473	-0.8204504	14.266938	14.609695	15.031694	15.379022	15.693101	-0.31408	B
5.8802E+17	18.8430625	-0.7689474	14.821564	11.388192	10.53291	10.289508	10.461241	-0.17173	R
5.8802E+17	19.0632604	-0.7030761	16.216717	14.505032	13.827558	13.32939	13.459525	-0.13013	O/Y
5.8773E+17	19.3391259	-0.0759881	16.632294	15.867721	15.498884	15.57653	15.654007	-0.07748	B
5.8773E+17	19.7943596	-0.1741817	15.229355	14.435374	14.00077	14.057848	14.081721	-0.02387	B
5.8773E+17	18.7671717	-0.1903083	15.97309	14.809129	14.436152	14.297379	14.279492	0.017887	W
5.8802E+17	18.666451	-0.7329923	16.985334	15.813018	15.417446	15.25949	15.22938	0.03011	W
5.8773E+17	18.6949413	-0.6048778	17.428656	15.013547	13.837328	13.532888	13.44785	0.085038	R
5.8802E+17	18.9035022	-0.6862368	16.469687	15.014927	14.45531	14.279514	14.187049	0.092465	R/Y
5.8802E+17	18.572401	-0.6922481	16.513803	14.685555	14.060603	13.817564	13.713374	0.10419	Y
5.8802E+17	18.9523109	-0.2414797	16.445736	14.672665	13.888217	13.676832	13.487049	0.189783	Y
5.8773E+17	18.9671311	-0.9070213	19.938526	17.121716	15.750569	15.198534	14.891254	0.30728	R
5.8773E+17	19.6239276	-0.124059	17.560072	15.270185	13.890049	13.524414	13.151349	0.373065	O/R
5.8773E+17	19.7381751	-0.1492939	19.327969	16.633284	15.230467	14.537353	13.402305	1.135048	R
5.8802E+17	18.4426349	-0.3611173	18.746588	17.822479	16.594393	17.507275	15.206824	2.300451	O/Y

B=Blue W=White Y=Yellow O=Orange R=Red