The color spectrum in stars

Personal project

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Version control

Name	Version	Date	Description	Details
Saamie	0.1	20/10/2023	First setup	Initial setup of document
Saamie	0.2	25/10/2023	Wien's displacement law	Add equations and explanation of Wien's displacement law
Saamie	0.3	26/10/2023	Perception	Add human perception and implementation on phases
Saamie	0.4	01/11/2023	Spectral classification	Describe the Morgan-Keenan spectral classification
Saamie	0.5	03/11/2023	HSL colors	Describe how to implement HSL color scale
Saamie	1.0	07/11/2023	Final touches	Add conclusion and references

Contents

Introduction

This document will describe stellar colors and the characteristics of celestial objects. Using Wien's Displacement Law, it is possible to connect a star's temperature to the color of light it emits. In addition to that, each star can be classified using the Morgan-Keenan spectral classification.

Because it is important to define the relevance of this knowledge in the context of spectral classification, this document will compare and back up the theories of color classification and human interpretation. With a goal of implementing the correct logic for defining color in 3D models in this project, the results of the research will define a HSL color scale.

Wien’s displacement law

The peak wavelength[1] is the specific color of light that an object emits most strongly, determined by the object's temperature. Wien's Displacement Law[2] relates the temperature of a blackbody (like a star) to the peak wavelength of its emission. The formula is as follows:

Equation 1: Wien's displacement law

$$\lambda_{peak} = \frac{b}{T}$$

Where *λpeak* is the peak wavelength of radiation in meters (m), *T* is the surface temperature of the radiating object in kelvin(K), and b is Wien’s displacement constant.

Wien’s displacement constant = 2.897 77 × 10−3 m K

After calculating the wavelength, convert the result to nanometers(nm) since visible light is typically measured in nanometers using:

$$1\ meter(m) = 1^{9}\ nanometers(nm)$$

Wavelengths and human perception

The human eye is sensitive to a limited range of wavelengths, and stars with temperatures within this range are visible to us. This visible range are colors from violet to red[3]. The following explains how the color spectrum of stars correlates with human perception:

- Stars with peak wavelengths around 380-500 nanometers appear violet to blue.
- Stars with peak wavelengths around 500-580 nanometers appear green to yellow.
- Stars with peak wavelengths around 580-750 nanometers appear orange to red.

The visible range of wavelengths is on average between 380nm and 750nm, wavelengths falling outside of this range are not visible to the human eye.

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[1] (Connor, 2019)
[2] (San DIego State University)
[3] (Helmenstine, 2020)

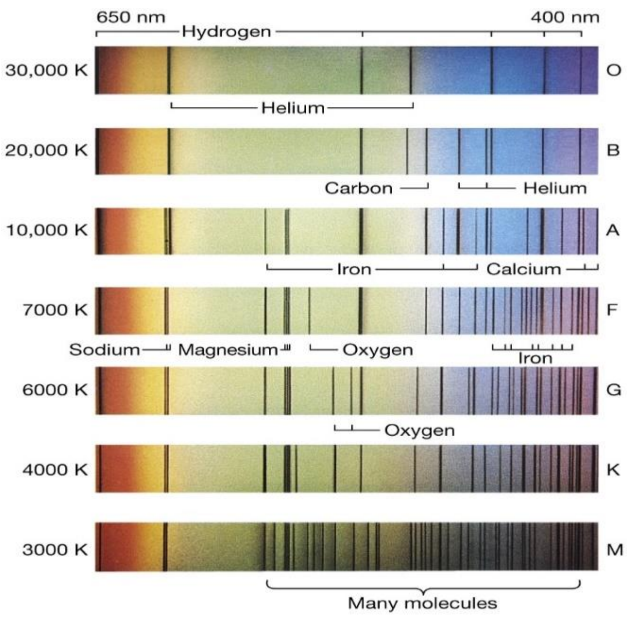
Spectral classification of stars

When the temperature of a star changes, so does its color, and this change is reflected in the star's spectral classification. The spectral classification system categorizes stars based on their color and temperature.

The Morgan-Keenan spectral classification

The Morgan-Keenan spectral classification system[4] is a system for classifying stars based on their spectral characteristics. In ***Figure 1*** an overview of the classification system is shown[5].

Figure 1: Morgan-Keenan Spectral Classification



The system classifies stars using the letters O, B, A, F, G, K, and M, a sequence from the hottest (O type) to the coolest (M type). Each line indicates a particular chemical element or molecule, with the line strength indicating the abundance of that element.

The hottest classes in the system appear blue color, while the coolest appear red in color. For values and more detailed information for each class, refer to the overview of stellar classification types.

Table 1 serves as a guideline for easy classification based on temperature and luminosity ranges. For the colors in the table, the ***Visual color spectrum*** is used to represent each class.

Table 1: Spectral classification details

Class	Color	Temperature range (K)	Luminosity range (L⊙)
O		> 30.000	10,000 to 1,000,000
B		10.000 to 30.000	25 to 30,000
A		7.500 to 10.000	5 to 80
F		6.000 to 7.500	1.5 to 6
G		5.000 to 6.000	0.6 to 1.5
K		3.500 to 5.000	0.08 to 0.6
M		< 3.500	< 0.08

[4] (University of Cambridge & Institute of astronomy)
[5] (University of Oregon)

Luminosity class

In the Morgan-Keenan classification, each star can also be categorized in different luminosity subclasses which serve as a relation between the luminosity and size. The luminosity class is displayed using Roman numerals and ranges from I (supergiant star) to D (white dwarfs).[6]

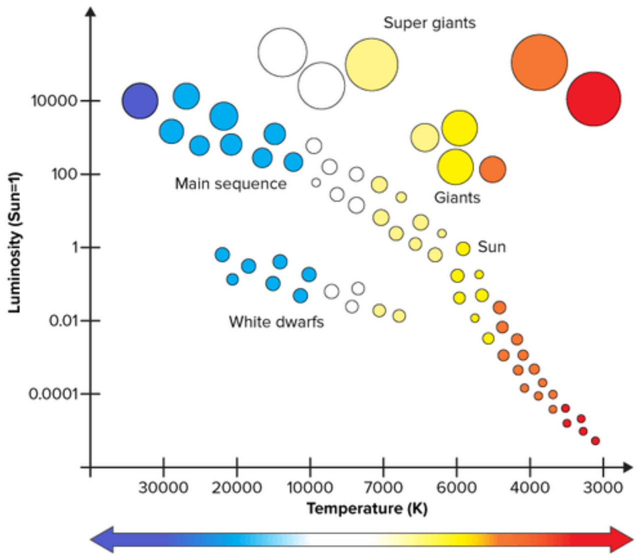


Figure 2: Hertzsprung Russell diagram

The Hertzsprung Russell diagram[7] displays each luminosity classification based on its temperature and luminosity values.

Using these values the spectral and luminosity classes can be defined. Specifically for the luminosity classification, the value of luminosity in solar Luminosity (L⊙) is needed.

Table 2: Luminosity class overview

Class	Luminosity (L⊙)	Spectral Type	Description
Ia-O	> 100,000	O, B	Extremely luminous supergiants
Ia	10,000 to 100,000	A, F, G, K, M	Luminous supergiants
Ib	25 to 30,000	B, A, F, G, K, M	Less luminous supergiants
II	25 to 80	A, F, G, K, M	Bright giants
III	5 to 25	G, K, M	Normal giants
IV	1.5 to 6	G, K	Subgiants
V	0.6 to 1.5	O, B, A, F, G, K, M	Main sequence dwarf stars
VI	0.1 to 0.6	K, M	Subdwarfs
D	< 0.1	Not specified using Hertzsprung Russell diagram	White dwarfs

To form an example of these values, our sun has a luminosity of 1 L⊙ and a temperature of about 5800 Kelvin. This would classify it as a G-type (G) main-sequence (V) dwarf star with a relatively low brightness and size.

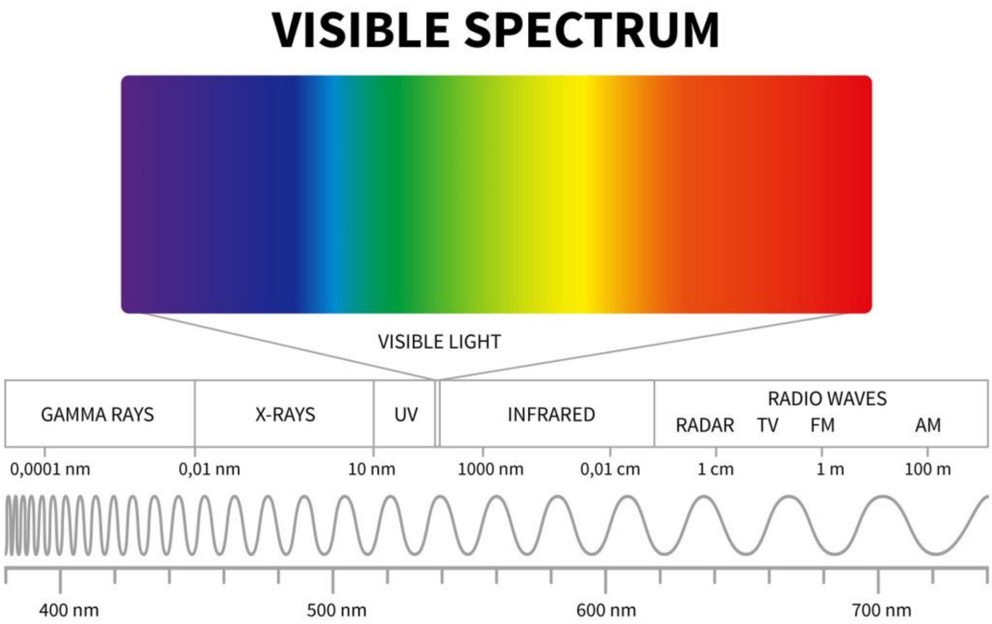
[6] (Swinburne University of Technology)
[7] (V., 2016)

Defining a color

To create accurate visual representations for each star, a HSL scale is used to translate the visible color spectrum to a HSL scale. An HSL (Hue, Saturation, Lightness) scale is a color model that represents colors by specifying their hue (the type of color), saturation (vividness or intensity), and lightness (brightness or darkness).

Figure 3[8] displays the visible color spectrum defined by the intensity of a wavelength. Figure 4 is used to compare the difference between the visible spectrum and a hue color scale.

Figure 3: Visual color spectrum



HSL color scale

In *Figure 4* a HSL (Hue, Saturation, and Lightness) is represented as a circle to visualize the full spectrum of colors and their relationships, with hue as the angular dimension and saturation as the radial dimension

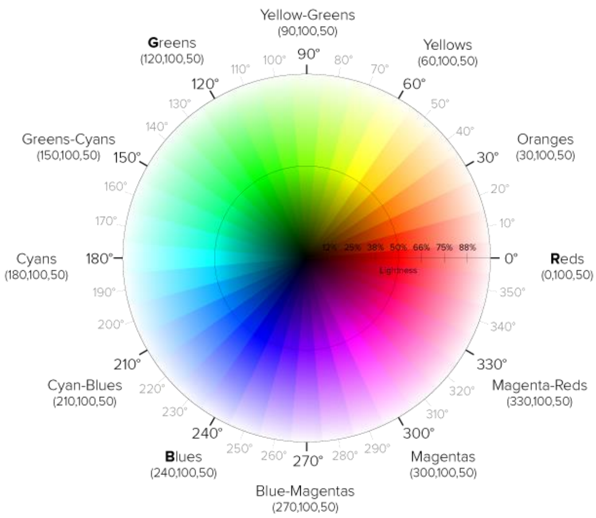


Figure 4: HSL color scale

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[8] (ASML, n.d.)

Wavelength to Hue

To define the hue value of the HSL scale, the wavelength of the star is used. The wavelength can be calculated using

Wien's displacement law. The colors used in stellar color classification are only a part of the hue 360-degree color scale.

Magenta

When comparing both ***Figure 3*** and ***Figure 4*** we can see that the color Magenta is missing in the visible spectrum. This is something that has to be considered when calculating the hue value of the HSL color.
The color Magenta on the hue scale is not visible because it has no wavelength and so the color does not exist. The human brain creates it by mixing signals from the red and blue colors.

Green

The color green is visible based on the visible light spectrum. However, when a star emits green light, we cannot directly see it. Any star emitting mostly green is also putting out red and blue light, making the star look white. This has to be considered when defining the hue value, as the green color would not look like an accurate representation. Therefore in the 3D models when the hue value is green, the hue is adjusted to white using a high lightness.

Temperature to saturation

To define the saturation value of the HSL scale, the temperature of the star is used. The temperature is directly related to the intensity of a color. The saturation is a percentage value which is defined using temperature thresholds as shown in ***Table 1***.

Luminosity class to lightness

To define the lightness value of the HSL scale, the luminosity class is used. As described in ***Table 2*** the luminosity ranges serve as thresholds for the lightness percentage. With the lowest values (> 0%) appearing very dark and the highest value appearing very bright (< 100%).

Conclusion

This document covered the stellar colors and classifications. Wien's Displacement Law is used for relating a star's temperature to the color of its emitted light, providing a scientific foundation for understanding a star's colors.

The Morgan-Keenan spectral classification system is used as a practical tool for categorizing stars based on their temperature and color. This system offers a structured approach to star classification.

The inclusion of luminosity classes within this system adds extra definition to the classification, helping define stars based on their brightness in relation to their size.

For the 3D modelling of stars in this project, the HSL color scale represent stars accurately and visually, aligning scientific data with visualization.

In conclusion, the exploration of stellar colors and spectral classification serves as a valuable resource for improving the information and visual representation of each star.

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Overview stellar classification types

The following values for each type are defined using the Morgan-Keenan classification as seen in the above table.

O-type Stars

O types are very rare and short-lived, but they play a crucial role in the formation of massive star clusters.
Temperature Range: Larger than 30,000 Kelvin
Luminosity range: 10.000 to 1.000.000 L⊙
Color: Blue or white

B-type Stars

B-type stars are known for their strong stellar winds and are often found in associations with other massive stars.
Temperature Range: 10,000 to 30,000 Kelvin
Luminosity range: 25 to 30.000 L⊙
Color: Blue

A-type Stars

A-type stars have stable atmospheres, making them valuable for the study of exoplanets.
Temperature Range: 7,500 to 10,000 Kelvin
Luminosity range: 5 to 80 L⊙
Color: White or light blue

F-type Stars

F-type stars are famous for their spectral lines used as references in the spectral classification system.
Temperature Range: 6,000 to 7,500 Kelvin
Luminosity range: 1.5 to 6 L⊙
Color: White

G-type Stars

G-type stars, like the Sun, are capable of sustaining life and are often the focus of exoplanet searches.
Temperature Range: 5,000 to 6,000 Kelvin
Luminosity range: 0.6 to 1.5 L⊙
Color: Yellow

K-type Stars

K-type stars are common hosts for potentially habitable exoplanets and are known for their lower surface temperatures.
Temperature Range: 3,500 to 5,000 Kelvin
Luminosity range: 0.08 to 0.6 L⊙
Color: Orange

M-type Stars

M-type stars are the most abundant stars in the galaxy, and some have Earth-sized exoplanets in their habitable zones.
Temperature Range: Less than 3,500 Kelvin
Luminosity range: $<$ 0.08 L⊙
Color: Red