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Comparative Visual Analysis of Observable Stellar Characteristics and Their Relation to Stellar Evolutionary Stage

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ABSTRACT

Stellar evolution influences a star's observable properties, including its color, luminosity, temperature, and radius. This study investigated whether visual observations obtained with amateur astronomical equipment, when interpreted alongside established stellar catalog data, can provide meaningful insight into stellar evolutionary stages. Seven nights of observations were conducted on Vega and Antares, representing distinct stages of stellar evolution. Qualitative observations of apparent color, brightness, and scintillation were compared with published stellar parameters and interpreted using the Hertzsprung–Russell diagram. In addition, this study introduces a preliminary Visual Evolutionary Indicator (VEI), an exploratory heuristic that combines stellar luminosity, radius, and temperature to facilitate comparative analysis of evolutionary characteristics. To assess its consistency, the VEI was applied to a broader selection of stars spanning multiple evolutionary stages using published catalog data. The results demonstrate that both the observational findings and the VEI are generally consistent with established stellar properties and evolutionary trends while also highlighting the influence of atmospheric conditions and light pollution on visual observations. Although the VEI shows promise as an educational and comparative framework, it remains a preliminary heuristic and requires further validation using larger and more diverse stellar datasets before broader scientific application. These findings demonstrate that amateur observations, when combined with established astrophysical data, can provide meaningful educational insight into stellar evolution while illustrating the potential and limitations of visually based observational studies.

INTRODUCTION

Stars are fundamental building blocks of galaxies and play a critical role in shaping the structure, chemistry, and evolution of the universe. Through nuclear fusion, stars generate the heavier elements necessary for planetary formation and, ultimately, life. As stars evolve over time, their physical characteristics including temperature, luminosity, radius, and colour change significantly depending on their mass and stage of evolution.

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The study of stellar evolution is therefore central to astrophysics. Modern classification systems, such as spectral classification and the Hertzsprung-Russell diagram, allow astronomers to categorize stars according to observable and intrinsic properties. These tools help distinguish between main-sequence stars, giants, and super giants, providing insight into stellar life cycles ranging from formation in nebulae to end states such as white dwarfs, neutron stars, or black holes.

Although professional stellar analysis often relies on advanced methods such as spectroscopy, photometry, and computational modelling, amateur astronomy offers opportunities to investigate broader stellar trends through direct visual observation. Bright stars visible to the naked eye display noticeable differences in color, apparent brightness, and atmospheric behaviour, raising an interesting question: can these observable properties provide preliminary clues about stellar evolutionary stage?

This study investigates whether visual observations conducted using a personal 8-inch Schmidt-Cassegrain telescope (Celestron Nexstar 8SE) can reveal patterns corresponding to known stellar classifications and evolutionary stages. Two bright stars, Vega and Antares, were selected due to their visibility, brightness, and diversity in spectral classification and evolutionary status.

Over a seven-day observational period, variables including apparent color, brightness ranking, scintillation intensity, altitude, and image stability will be recorded and compared against catalogued stellar data such as spectral type, luminosity class, temperature, and evolutionary stage. The objective is not to determine precise stellar age or classification through visual observation alone, but rather to evaluate whether amateur observational astronomy can serve as a meaningful preliminary tool for identifying broad astrophysical trends.

The central research question guiding this investigation is: **To what extent can visually observable stellar characteristics provide insight into stellar evolutionary stage?**

It is hypothesized that stars exhibiting redder coloration and characteristics associated with greater luminosity will generally correspond to later evolutionary stages, while blue-white stars will more commonly align with earlier or less evolved stages such as the main sequence.

SECTION II: LITERATURE REVIEW

II.1: Stellar Structure

Stars are massive, self-gravitating spheres of plasma that produce energy through nuclear fusion[1] occurring within their cores. Despite appearing as simple points of light from Earth, stars possess complex internal structures that determine their stability, luminosity, temperature, and long-term evolution[2]. Understanding stellar structure is therefore essential to astrophysics, as a star's internal composition and physical processes directly influence its observable characteristics and eventual fate.

The internal behaviour of a star is primarily governed by the interaction between gravity, pressure, temperature, and energy generation. A stable star is maintained through a balance known as hydrostatic equilibrium[3], in which the inward pull of gravity is balanced by the outward pressure generated by extremely hot gases and radiation within the stellar interior[4]. This equilibrium prevents stars from undergoing immediate gravitational collapse or uncontrolled expansion.

Gravity continuously compresses stellar material toward the core, increasing pressure and temperature to extreme levels[5]. When core temperatures become sufficiently high, nuclear fusion begins, allowing hydrogen nuclei to combine into helium while releasing large amounts of energy[6]. This released energy contributes to the outward thermal and radiation pressure required to maintain stellar stability[7].

The internal structure of a typical star is composed of multiple layers, including the core, radiative zone, convective zone, and photosphere[8]. Each layer plays a distinct role in energy generation or transport, collectively shaping the star's observable properties and evolutionary pathway[9].

II.2: Stellar Evolution

Stellar evolution describes the sequence of physical changes that stars undergo throughout their lifetimes[1]. The primary factor governing a star's evolutionary pathway is its initial mass[2]. Stars form through the gravitational collapse of molecular clouds and enter the main sequence once sustained hydrogen fusion begins within their cores. During this stage, which constitutes the majority of a star's lifetime, hydrogen is continuously fused into helium while the star remains in hydrostatic equilibrium[3]. Following the exhaustion of hydrogen in the core, stars evolve along different pathways depending on their mass. Low- and intermediate-mass stars expand into red giants before eventually shedding their outer layers to form planetary nebulae, leaving behind white dwarfs[4]. High-mass stars evolve into supergiants and continue fusing progressively heavier elements until an iron core develops. Since iron fusion does not produce energy, the core becomes unstable and undergoes gravitational collapse, resulting in a core-collapse supernova that leaves behind either a neutron star or a black hole.[5]

Throughout stellar evolution, significant changes occur in stellar luminosity, radius, and effective temperature, causing stars to move across the Hertzsprung–Russell (H–R) diagram[6]. These changing physical properties provide important observational evidence of a star's evolutionary stage.[7]

The relationship between stellar mass and luminosity can be approximated by the mass–luminosity relation:

$L \propto (M)^{3.5}$

where (L) represents stellar luminosity and (M) represents stellar mass. This relationship demonstrates that more massive stars are generally more luminous but consume their nuclear fuel at much faster rates, resulting in shorter lifetimes and distinct evolutionary pathways.[8]

II.3: Spectral Classification

Spectral classification is defined as the classification of stars into classes based on their spectral characteristics. [1] OBAFGKM is the latest system we have, used to classify stars according to their spectral properties, in order of decreasing temperature, where O-type stars are the hottest and M-type being the coolest stars [2]. However, with the revelation of brown dwarfs (do not shine through thermonuclear fusion), the system has been expanded to include L, T, and Y. Stars ranging from O to M spectral classes generally possess similar overall chemical compositions; however, differences in temperature and atmospheric pressure produce distinct spectral features[3].

This naturally raises another question “How are stars classified into these spectral categories?” the answer lies in the analysis of stellar spectra, particularly the absorption lines formed when elements within a star’s atmosphere absorb specific wavelengths of electromagnetic radiation. The strength and arrangement of these absorption lines vary according to stellar temperature and atmospheric pressure, allowing astronomers to distinguish between different spectral classes.[4]

Spectral classifications may be further subdivided using numerical values from 0 to 9. For example, an A0 star is hotter than an A9 star, although both belong to the A spectral class. Additional Roman numerals are used to indicate luminosity classes and evolutionary stages. For instance, Vega is classified as A0V, where "A0" represents its spectral subclass and "V" indicates that it is a main-sequence star.[5]

Another noticeable characteristic of spectral classes is the difference in stellar colour. But why do stars of different spectral classes appear different in colour? This relation is explained by Wien’s law (which will be discussed further in this section), which relates stellar colour to stellar temperature. Hotter stars emit radiation more strongly at shorter wavelengths and therefore are blue, whereas cooler stars emit more strongly at longer wavelengths are seen to be red in appearance. The colour of a star is hence related to its temperature.[6]

To determine the wavelength at which a star emits radiation most strongly, we use Wien’s Displacement Law which is:

$$\lambda max=b/T$$

where b = 2.89777 × (10) ^-3mK, known as Wien’s constant, T represents surface temperature, λmax is the peak wavelength emitted by the star. According to this relationship, hotter stars emit radiation mostly at shorter wavelengths, causing their appearance to be blue or blue white

II.4: Luminosity and Blackbody Radiation

Luminosity is the total amount of energy emitted by a star per unit time and is a fundamental property used to investigate stellar evolution. Unlike apparent brightness, which depends on the observer's distance from a star, luminosity is an intrinsic property determined primarily by a star's radius and effective surface temperature.[1]

Stars closely approximate blackbody radiators, meaning they absorb nearly all incident electromagnetic radiation and emit radiation across a continuous spectrum determined by their surface temperature. According to Wien's Displacement Law, the wavelength at which a star emits the greatest amount of radiation is inversely proportional to its temperature. Consequently, hotter stars emit more strongly at shorter wavelengths and appear blue or blue-white, whereas cooler stars emit more strongly at longer wavelengths and appear orange or red.[2]

The total energy emitted by a blackbody is described by the Stefan–Boltzmann Law,

$$L=4\pi R2\sigma T4$$

where (L) is stellar luminosity, (R) is stellar radius, (T) is effective surface temperature, and σ is the Stefan–Boltzmann constant.[3]

This relationship demonstrates that luminosity depends on both stellar radius and temperature. While hotter stars generally emit more energy per unit surface area, large increases in stellar radius during the giant and supergiant phases can produce extremely luminous stars despite relatively low surface temperatures. This explains why red supergiants such as Antares are significantly more luminous than hotter main-sequence stars such as Vega. Together, blackbody radiation and luminosity provide an important theoretical basis for interpreting stellar colours and relating observable characteristics to stellar evolutionary stage.[4]

Hertzsprung-Russell Diagrams (HR diagrams) are defined as scatter plots used to classify stars by comparing their luminosities or absolute magnitudes against their surface temperatures or spectral classes.[1]

As discussed in II.2: Stellar Evolution, stars evolve in time through different stages, we plot these stages on an HR diagram to trace the evolutionary stage of a star, where they move in regular patterns across.[2]

The Y-axis represents stellar luminosity measured in solar units, while the X-axis represents surface temperatures measured in Kelvin or spectral classification. Interestingly, surface temperature decreases from left to right on the diagram, with O-type stars in the left side to M-type stars in the right side (refer to Section II.3).[3]

As we can clearly see, the stars are not plotted at random, instead they cluster at certain points in the diagram. The majority are running from the upper left to the lower right. This is known as main sequence stars (refer to II.2).[4]

Noticeably, we can say that hotter stars are more luminous than cooler stars. However, you may notice that there are stars in the upper-right region, meaning they are cool stars and have high luminosity. But how is this possible? The only way a star can have low temperatures, yet be high luminosity is that it is a giant or supergiant, meaning that these stars are huge in diameter[5]. Similarly, stars in the lower left corner of the diagram, meaning they have high surface temperature and low luminosity. These stars are known as white dwarfs, these stars have high temperatures but have small surface areas.[6]

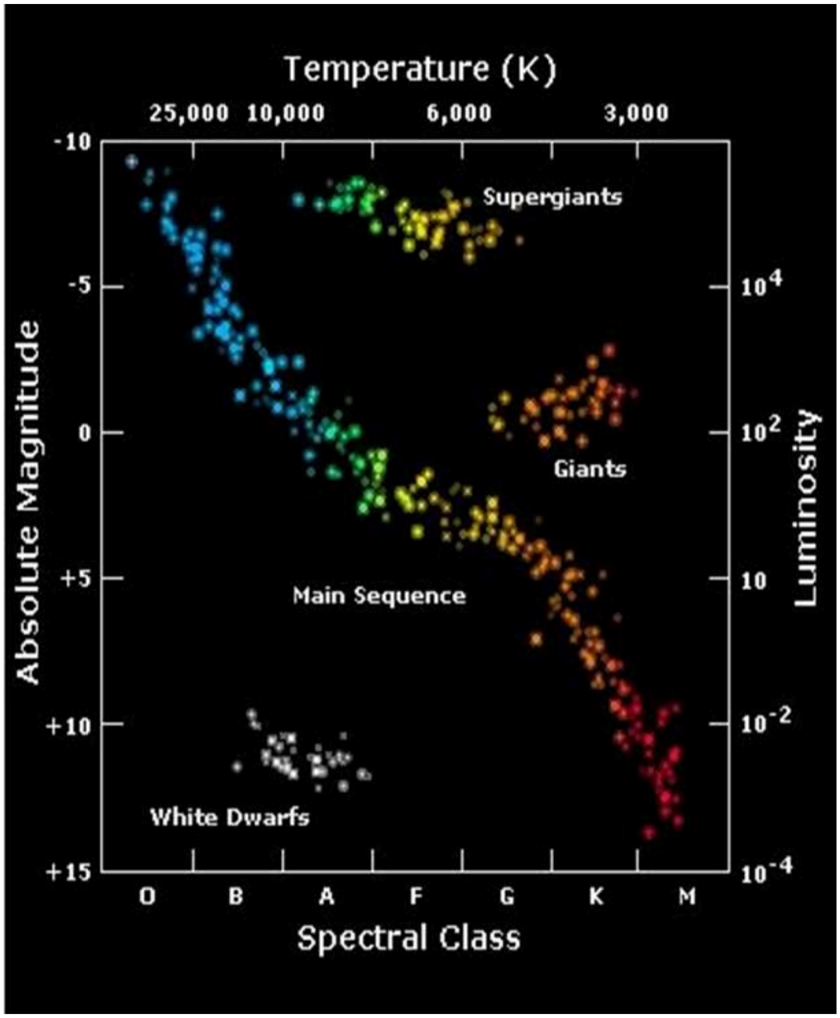

Figure 1: Hertzsprung-Russell diagram. ESA image,
https://www.cosmos.esa.int/web/cesar/the-hertzsprung-russell-diagram#

The placement of stars on the HR diagram also provides insight into their physical properties and evolutionary stages. For example, Vega, a hot blue-white star, is located near the main sequence region, whereas Antares occupies the upper right region associated with red supergiants. The difference in their positions reflects major differences in temperature, luminosity, radius, and evolutionary stage.

II.6: Atmospheric Effects on Observation

Atmospheric conditions affect ground-based astronomical observations greatly, influencing the clarity and accuracy of observed celestial objects. Starlight can also refract irregularly due to atmospheric instability, causing scintillation which decreases image sharpness and make observations less accurate. [1]

Other factors which can disturb stellar observations are humidity, dust particles, clouds, weather conditions, and artificial light pollution. Altering the apparent brightness and colour of observed stars, particularly in urban areas. [2]

Which is why observations will be repeated over the course of multiple nights to reduce inaccura

SECTION III: METHODOLOGY

III.1: Equipment

Observations were conducted using a personal 8-inch Schmidt-Cassegrain telescope, the Celestron Nexstar 8SE scope, primarily with a 25mm eyepiece and occasionally a 10mm eyepiece to compare field visibility and magnification. afocal imaging was performed using a Samsung Galaxy M35. Stellar identification and observational support were carried out using the mobile application Stellarium.[1]

III.2: Observation Site

Observations were conducted from an urban region in Uttar Pradesh, India, located at approximately 28.5°N latitude and 77.5°E longitude. The observing location experiences moderate to high levels of light pollution due to nearby urban development, affecting stellar visibility and image clarity.

III.3: Sample Selection

Vega and Antares were selected due to their strong contrast in stellar evolution, apparent brightness, luminosity, size, and spectral classification. Different spectral types and temperatures allow for easier comparison between observational characteristics such as colour, brightness, and apparent stellar properties. Comparing these distinctions may help reveal how observable characteristics are related to stellar evolutionary stages.

III.4: Observation Procedure

Observations were conducted over the course of a week to ensure accuracy; stellar guidance and identification were done by the mobile application Stellarium.[2]

To ensure that all logs are done with consistent observational comparison, 25mm and 10mm eyepieces were used respectively.

Many observable characteristics were accounted for nightly such as; scintillation, limitations, apparent color and brightness, altitude, atmospheric conditions, and overall seeing conditions. Afocal images were captured for observational reference and comparisons analysis across multiple nights (see section IV).

III.5: Catalog Data Collection

Catalog data for Vega and Antares were collected from astronomical reference sources following the completion of observational data collection. Parameters including spectral type, surface temperature, luminosity, radius, apparent magnitude, distance, and evolutionary stage were recorded. These values were later compared with observational findings to examine relationships between observable stellar characteristics and established physical properties.

SECTION IV: RESULTS

IV.1: Vega

Vega is the fifth brightest star in the night sky, easily spotted in summer as it is a member of the bright asterism “the summer triangle”. It was earlier believed to be a calm star before astronomer discovered it was rapidly spinning and highly luminous. Vega has been used as the standard for measuring the brightness of other stars and galaxies for over a century. It is 25.3 light years away from earth and has an apparent magnitude of 00.03, its spectral is A0V and is in the constellation of Lyra.[1]

IV.1.1: Observation Data

Table 1. Observations over 7 days on the star, Vega

date	25/5/26	26/5/26	27/5/26	1/6/2026	2/6/2026	3/6/2026	4/6/2026
time (IST)	10:59 PM	10:50PM	10:51PM	10:57PM	10:41PM	11:04PM	11:20 PM
location	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E
weather	slightly cloudy	clear, slightly cloudy	clear, slight haze, wind	clear, slight haze, wind	clear, slight haze	extremely hazy + foggy, polluted and cloudy	windy, extremely cloudy, occasional lightning
eyepiece(s)	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm
seeing conditions	hazy	decent	decent	decent	decent	poor	extremely poor
apparent color	blue - white	blue-white	blue-white	blue-white	blue-white	blue-white	blue-white
apparent brightness	bright	brighter than previouso bvservation	bright	bright	bright	bright	dimmer than usual due to cloud coverage
scintillation	low	high	low	high	medium	low	medium

altitude	high	high	high	high	high	high	high
atmospheric limitations	clouds	N/A	N/A	N/A	N/A	low visibility + cloudy	extreme cloud coverage and wind

As seen in Table 1, throughout the observation period, Vega consistently appeared blue-white in colour and remained brighter than Antares. It was generally easy to locate due to its high position in the sky and strong apparent brightness. Although weather and atmospheric conditions varied from night to night, the overall appearance of Vega remained largely unchanged. The most noticeable variation was in scintillation, which appeared stronger on some nights than others. Interestingly, nights with clearer skies often showed greater scintillation than nights with poorer visibility.

IV.1.2: Images/Figures

Figure 2: Vega observed on 27 May 2026,10:53PM IST

Figures 2 and 3 show Vega under different atmospheric conditions. Although image clarity varied between nights due to weather and seeing conditions, the star's apparent colour and brightness remained largely consistent throughout the observation period. Figure 2 was shot on a clear night while figure 3 was imaged on a cloudy night.

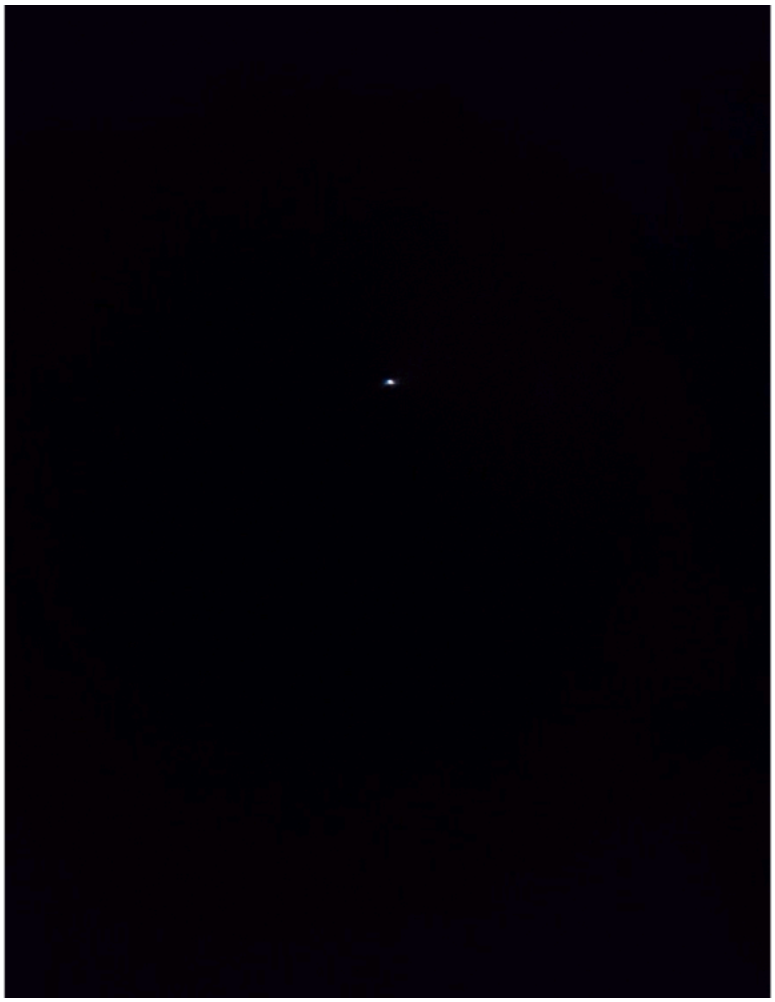

Figure 3: Vega observed on 4 June 2026, 11:22 PM IST

IV.1.3: Catalog Data

To supplement the observational data, catalog information for Vega was collected from astronomical databases and reference sources. These data provide established physical properties that can later be compared with observational findings.

Table 2. Catalog Data for Vega (compiled from SIMBAD Astronomical Database)

parameter	Vega
spectral type	A0V
temperature (K)	9600K
luminosity (L☉)	40L☉
radius (R☉)	2.42 Solar radii (polar radius)
apparent magnitude	0.03
distance (ly)	25.04 lys
evolutionary stage	main-sequence star

The catalog data presented above in table 2 provide a reference for Vega's accepted physical properties and will be used for comparison in subsequent sections.

IV.2: Antares

Antares is the brightest star in the constellation of Scorpius. It is located 554 light years from the sun; it is a red giant and the 15th brightest star in the night sky. It has a reddish orange colour which is due to its cool value. It appears in the north during summer months, and its spectral type is M1.5lab-lb. M1.5 tells us its place on the temperature scale, while 'lab' is given to intermediate-size luminous supergiants and 'lb' is being a less luminous supergiant, Antares lies between those places. [2]

IV.2.1: Observation Data

Table 3: Observations over 7 days on the star, Antares

date	25/5/26	26/5/26	27/5/26	1/6/2026	2/6/2026	3/6/2026	4/6/2026

time (IST)	11:07PM	10:51PM	10:55PM	11:04PM	10:44PM	11:06PM	11:33PM
location	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E
weather	slightly cloudy	clear, slightly cloudy	clear, slight haze, wind	clear, slight haze, wind	clear, slight haze	extremely hazy + foggy, polluted and cloudy	windy, extremely cloudy, occasional lightning
eyepiece(s)	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm
seeing conditions	hazy	decent	decent	decent	decent	poor	extremely poor
apparent color	reddish orange	redder than previous observation	reddish orange	reddish orange	reddish orange	reddish orange	reddish orange
apparent brightness	dimmer than vega	brighter than previous observation	dimmer than vega	dimmer than vega	dimmer than vega	dimmer than vega	dimmer than usual due to cloud coverage
scintillation	medium	lower than previous observation	low	low	high	low	medium

altitude	medium	medium	medium	medium	medium	medium	medium
atmospheric limitations	near city lights	near city lights	near city lights	N/A	N/A	low visibility + cloudy	extreme cloud coverage and wind

Throughout the observation period as shown in table 3, Antares consistently appeared reddish-orange in colour and remained dimmer than Vega. Unlike Vega, observations of Antares were more frequently affected by atmospheric conditions, nearby buildings, and artificial light pollution due to its lower position in the sky. Despite these limitations, its distinctive colour remained visible throughout successful observation sessions. While weather conditions varied between nights, the overall appearance of Antares remained largely consistent.

IV.2.2: Images/Figures

Figure 4: Vega imaged on 1 June 2026, 11:04PM IST

Figure 4 shows Antares as observed during the observation period. Despite occasional interference from clouds, city lights, and its lower altitude, the star's distinctive reddish-orange colour remained visible in successful observations.

IV.2.3: Catalog Data

To supplement the observational data, catalog information for Antares was collected from astronomical databases and reference sources. These data provide established physical properties that can later be compared with observational findings.

parameter	Antares
spectral type	M1.5lab-lb
temperature (K)	3500K
luminosity (L☉)	75900L☉

radius (R☉)	680 solar radii
apparent magnitude	0.6 to 1.6
distance (ly)	550 lys
evolutionary stage	red supergiant

Table 4: . Catalog Data for Antares (compiled from SIMBAD Astronomical Database)

The catalog data presented above in table 4 provide a reference for the accepted physical properties of Antares. These values will be used in the following section to compare Antares with Vega and examine how differences in stellar properties are reflected in observational characteristics.

IV.3: Comparative Summary

date	25/5/26	26/5/26	27/5/26	1/6/2026	2/6/2026	3/6/2026	4/6/2026
time (IST)	10:59 PM + 11:07PM	10:50PM + 10:51PM	10:51PM + 10:55PM	10:57PM + 11:04PM	10:41PM + 10:44PM	11:04PM + 11:06PM	11:20 PM + 11:33PM
location	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E	28.5°N, 77.5°E
weather	slightly cloudy	clear, slightly cloudy	clear, slight haze, wind	clear, slight haze, wind	clear, slight haze	extremely hazy + foggy, polluted and cloudy	windy, extremely cloudy, occasional lightning
eyepiece(s)	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm	25mm + 10mm

seeing conditions	hazy	decent	decent	decent	decent	poor	extremely poor
apparent color	blue - white + reddish orange	blue-white + redder than previous obv.	blue-white + reddish orange	blue-white + reddish orange	blue-white + reddish orange	blue-white + reddish orange	blue-white + reddish orange
apparent brightness	bright + dimmer than vega	brighter than yesterday (both)	bright + dimmer than vega	bright + dimmer than vega	bright + dimmer than vega	bright + dimmer than vega	dimmer than usual due to cloud coverage (both)
scintillation	low + medium	high + lower than yesterday	low + low	high + low	medium + high	low + low	
altitude	high + medium	high + medium	high + medium	high + medium	high + medium	high + medium	high + medium
atmospheric limitations	clouds + near city lights	N/A + near city lights	N/A + near city lights	N/A (both)	N/A (both)	low visibility + cloudy	extreme cloud coverage and wind

Table 5: Observations over 7 days on the star, Antares and Vega

parameter	Vega	Antares
spectral type	A0V	M1.5lab-lb
temperature (K)	9600K	3500K
luminosity ($L_\odot$)	40$L_\odot$	75900$L_\odot$
radius ($R_\odot$)	2.42 Solar radii (polar radius)	680 solar radii
apparent magnitude	0.03	0.6 to 1.6
distance (ly)	25.04 lys	550 lys
evolutionary stage	main-sequence star	red supergiant

Table 6: . Catalog Data for Antares and Vega (compiled from SIMBAD Astronomical Database)

The observational and catalog data reveal substantial differences between Vega and Antares. Vega consistently appeared blue white and brighter, while Antares appeared reddish-orange and dimmer. Catalog data further show significant differences in temperature, luminosity, radius, and evolutionary stage. These findings suggest a relationship between observable stellar characteristics and underlying physical properties.

SECTION V: ANALYSIS AND DISCUSSION

V.1: Visual Evolutionary Indicator (VEI)

The observational comparison of Vega and Antares demonstrated that stars at different evolutionary stages exhibit substantial differences in their observable and physical characteristics, including colour, luminosity, radius, and effective temperature. This prompted the question of whether these fundamental stellar properties could be combined into a simple comparative metric that broadly reflects evolutionary trends while remaining accessible for educational and observational studies.

To explore this concept, a **Visual Evolutionary Indicator (VEI)** was developed. The VEI is a preliminary heuristic designed to combine three fundamental stellar parameters, luminosity, radius, and effective temperature, into a single comparative value. It is intended as an exploratory metric to illustrate broad evolutionary differences between stars and should not be regarded as a replacement for established stellar classification methods or evolutionary models.

Luminosity, radius, and effective temperature were selected because they are among the principal physical parameters that change throughout stellar evolution and collectively determine a star's position on the Hertzsprung–Russell diagram. As stars evolve beyond the main sequence, they commonly experience substantial increases in radius and luminosity as their outer layers expand. Effective temperature provides complementary information by distinguishing stars that may possess similar luminosities but occupy different regions of the Hertzsprung–Russell diagram owing to differences in their surface temperatures. Together, these parameters provide a physically meaningful basis for comparing stars at different stages of evolution.

The VEI was therefore defined as:

$$VEI = \frac{\log_{10}\left(\frac{L}{L_{\odot}}\right) + \log_{10}\left(\frac{R}{R_{\odot}}\right) - \log_{10}\left(\frac{T}{T_{\odot}}\right)}{3}$$

where (L) is stellar luminosity, (R) is stellar radius, (T) is effective surface temperature, and the corresponding solar values ⊙ are used for normalisation.

Base-10 logarithms were employed because stellar luminosities and radii span several orders of magnitude across different stellar types. Logarithmic scaling compresses these wide numerical ranges, allowing the three parameters to contribute more comparably to the index rather than permitting a single parameter to dominate because of its magnitude. The temperature term was subtracted to reflect the general observational trend that many evolved giant and supergiant stars possess lower effective temperatures despite exhibiting substantially larger radii and higher luminosities than compact main-sequence stars. This formulation is intended to capture this broad trend and should not be interpreted as a universal physical relationship.

Accordingly, the VEI should be regarded as a preliminary exploratory metric rather than a validated classification tool. Its purpose is to investigate whether a simple combination of fundamental stellar parameters can broadly reflect evolutionary characteristics while providing an intuitive framework for comparative analysis

V.2: Comparison with Known Data

To evaluate the consistency of the proposed Visual Evolutionary Indicator beyond the primary observational targets, the VEI was calculated for an expanded sample of stars representing a broad range of spectral classes and evolutionary stages. In addition to the Sun, Vega, and Antares, the validation sample included Sirius A, Altair, Procyon A, Polaris, Arcturus, Aldebaran, Capella Aa, Rigel, Deneb, Spica, Betelgeuse, Canopus, Regulus, Barnard's Star, Proxima Centauri, and Fomalhaut. The stellar luminosities, radii, and effective temperatures were obtained from published catalog data, and the VEI for each star was calculated using Equation (1).

Star	**Spectral Type**	**Luminosity (L⊙)**	**Radius (R⊙)**	**Temperature (K)**	**VEI**
Sun	G2V	1	1	5772K	0
Vega	A0Va	40	2.42	9600K	0.58
Sirius A	A1V	25.4	1.711	9940K	0.47
Altair	A7V	10.6	2.01	7377K	0.41
Procyon A	F5 IV-V	7.05	2.1	6530K	0.37
Polaris	F7lb	2500	46	6015K	1.68
Arcturus	K1.5III	170	25.4	4286K	1.25
Aldebaran	K5+ III	439	45.1	3900K	1.49
Capella Aa	K0 II	79	12	4940K	1.01
Rigel	B8 la	120,000	79	12100K	2.22
Deneb	A2 la	196,000	203	8525K	2.48

Spica	B1 III-IV	12,100	7.4	22400K	1.45
Betelgeuse	M1-M2 la-ab	60,000 - 140,000	764	3600K	2.7
Antares	M1.5 lab-lb	75,900	680	3500K	2.33
Canopus	F0 lb	10,700	71	7350K	1.93
Regulus	B7 V	288	3.8	12,460K	0.93
Barnard's Star	M4.0 V	0	0.187	3195K	-0.6
Proxima Centauri	M5.5 Ve	0	0.154	3042K	-0.75
Fomalhaut	A3 V	17	1.84	8590K	0.34

Table 7: Stellar Parameters and Calculated VEI Values for the Validation Sample (Compiled from SIMBAD Astronomical Database)

The expanded dataset spans low-mass red dwarfs, main-sequence stars, subgiants, giants, bright giants, and supergiants, enabling the proposed metric to be examined across a substantially wider range of stellar properties than the original observational sample alone. The calculated VEI values generally followed expected evolutionary trends. Red dwarf stars such as Proxima Centauri and Barnard's Star produced the lowest VEI values, reflecting their low luminosities and small radii. Main-sequence stars, including Vega, Sirius A, Altair, Procyon A, and Fomalhaut, produced relatively low positive values, while giant and supergiant stars generally exhibited progressively higher VEI values owing to their substantially larger radii and luminosities.

Although the expanded validation demonstrates that the VEI broadly follows expected astrophysical trends across a diverse sample of stars, the metric remains exploratory. Certain stars may not conform perfectly to the overall progression because stellar evolution depends on additional physical factors, including stellar mass, chemical composition, rotation, multiplicity, and evolutionary history, which are not explicitly incorporated into the present formulation. Consequently, the VEI should be interpreted as a heuristic comparative indicator rather than a definitive evolutionary classification system.

Overall, the expanded validation provides preliminary support for the consistency of the VEI while demonstrating its potential as an educational and comparative framework for relating fundamental stellar properties to broad evolutionary characteristics. Future work incorporating substantially larger stellar samples, formal statistical analyses, and additional physical parameters would be required to further evaluate and refine the proposed metric.

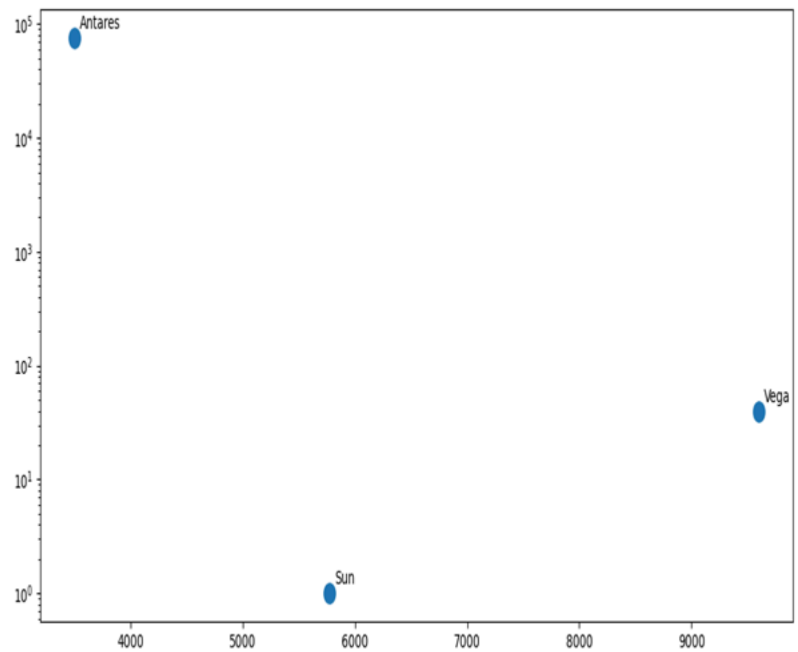

Figure 5: Hertzsprung-Russell diagram showing the positions of the Sun, Vega, and Antares based on catalog temperature and luminosity values

As shown in Figure 5, Vega occupies the main-sequence region of the Hertzsprung-Russell diagram, while Antares is located within the red supergiant region.

V.3: Discussion

The results of this investigation showed a clear relationship between observable stellar properties and evolutionary stage. Although Vega and Antares are both bright stars that can be observed with relatively simple equipment, the differences between them became increasingly apparent throughout the investigation. These differences were not limited to their appearance in the night sky but were also reflected in their catalog data and positions on the Hertzsprung-Russell diagram.

Colour proved to be one of the most useful observational indicators. Vega consistently appeared blue white, while Antares appeared red orange. These observations closely matched the known temperatures of the two stars and demonstrated how colour can reveal important information about a star's physical properties.

Another interesting finding was the difference between apparent brightness and luminosity. During most observing sessions, Vega appeared brighter than Antares. However, catalog data showed that Antares is far more luminous. This difference can be explained by distance; Vega is much closer to Earth, causing it to appear brighter despite producing significantly less energy overall. This highlighted the importance of combining observational data with catalog data rather than relying on visual observations alone.

The VEI and Hertzsprung-Russell diagram supported these findings. Both placed Vega and Antares in positions consistent with their accepted evolutionary stages. While the VEI was developed specifically for this investigation and was only tested on a small sample, it successfully distinguished the main-sequence stars from the red supergiant. This suggests that physical properties such as luminosity, radius, and temperature can be useful indicators of stellar evolution when considered together.

V.4: Sources of Error and Atmospheric Influence

Several factors may have influenced the accuracy and consistency of the observations carried out during this investigation. Since all observations were conducted from the ground using amateur astronomical equipment, atmospheric conditions played a significant role in the quality of the collected data.

The most significant limitation was weather. Throughout the observation period, multiple nights were affected by cloud cover and rainfall, reducing the number of opportunities available for observation. In some cases, stars were only visible for short periods between passing clouds, limiting the amount of data that could be collected during a session.

Atmospheric turbulence also influenced the observations. Variations in seeing conditions caused noticeable changes in scintillation between nights, affecting the apparent steadiness of the stars. This was particularly evident during clearer nights, when fluctuations in brightness became more noticeable.

Light pollution introduced an additional source of uncertainty. Antares was often observed at a lower altitude and in a region of the sky affected by nearby buildings and urban lighting. As a result, estimates of its apparent brightness and colour may have been influenced by local observing conditions.

Another limitation was the subjective nature of visual observations. Characteristics such as apparent colour and relative brightness were estimated by eye rather than measured using photometric instruments. While efforts were made to maintain consistency throughout the investigation, small observational differences between sessions were unavoidable.

Despite these limitations, the overall trends remained consistent across the observation period. Vega was repeatedly observed as a bright blue white star, while Antares consistently appeared red orange and less bright. These recurring observations suggest that the main findings of the investigation remain reliable despite the presence of observational uncertainties.

VI: LIMITATIONS

Like all observational investigations, this study was subject to several limitations that may have influenced the accuracy and consistency of the collected data. The most significant limitation was weather. During the observation period, several planned observing sessions were affected by cloud cover and rainfall, reducing the number of nights available for data collection. In some cases, observations could only be conducted during brief periods of clear sky between passing clouds, limiting the amount of information that could be gathered.

Atmospheric conditions also varied between observing sessions. Changes in seeing conditions and atmospheric turbulence affected the apparent steadiness of the stars, resulting in noticeable variations in scintillation. Since observations were conducted from ground level, atmospheric effects such as turbulence and extinction could not be eliminated and may have influenced visual estimates of brightness and colour.

Light pollution represented another source of uncertainty. Observations were conducted in an urban environment, and Antares was often observed at a lower altitude than Vega. Nearby buildings, artificial lighting, and reduced contrast against the night sky may have affected the visibility of Antares and influenced estimates of its apparent brightness.

The investigation also relied primarily on visual observations. Characteristics such as colour, brightness, and scintillation were estimated by eye rather than measured using specialised photometric equipment. Although observations were recorded consistently and compared across multiple nights, some degree of observational bias is unavoidable when relying on visual estimates.

A further limitation was the relatively small sample size. Only two stars, Vega and Antares, were observed directly during the investigation. While these stars were deliberately selected because they represent different stages of stellar evolution, a larger sample would provide a more comprehensive basis for comparison and strengthen the conclusions drawn from the study.

The Visual Evolutionary Indicator (VEI) developed during this investigation also has limitations. The index was designed specifically for this study and was tested using a limited number of stars. Although the resulting values were consistent with accepted stellar classifications, additional testing across a wider range of stellar types would be required to determine the broader reliability and applicability of the indicator.

Despite these limitations, the overall trends observed throughout the investigation remained consistent. The observational data, catalog values, Hertzsprung-Russell diagram, and VEI calculations all supported similar conclusions regarding the relationship between observable stellar properties and evolutionary stage. As a result, while the limitations should be considered when interpreting the findings, they do not significantly affect the overall conclusions of the investigation.

VII: CONCLUSION

The aim of this investigation was to explore the relationship between observable stellar properties and stellar evolution through a comparative study of Vega and Antares. By combining direct observations with catalog data, it was possible to examine how characteristics such as colour, luminosity, temperature, and position on the Hertzsprung-Russell diagram relate to a star's evolutionary stage.

Throughout the investigation, clear differences were observed between Vega and Antares. Vega consistently appeared as a bright blue-white star, while Antares appeared red-orange and comparatively dimmer. These observations were supported by catalog data, which showed significant differences in temperature, luminosity, radius, and evolutionary classification. The Hertzsprung-Russell diagram further demonstrated the contrast between the two stars, placing Vega within the main sequence and Antares within the red supergiant region.

To further investigate these differences, the Visual Evolutionary Indicator (VEI) was developed using stellar luminosity, radius, and temperature. When applied to the Sun, Vega, and Antares, the resulting values followed the expected progression of stellar evolution, with the Sun producing the lowest value, Vega a moderately higher value, and Antares the highest value. Although the VEI was only tested on a limited sample, the results suggest that it may serve as a useful comparative tool for exploring evolutionary differences between stars.

Overall, the findings of this investigation support the conclusion that observable stellar properties can provide valuable insight into stellar evolution. While more advanced observations and a larger sample of stars would strengthen the study, the results demonstrate that even relatively simple observations, when combined with catalog data and analytical tools, can reveal meaningful patterns in the life cycles of stars.

VIII: FUTURE RESEARCH

This investigation focused on two stars representing different stages of stellar evolution. While the results provided useful insights into the relationship between observable stellar properties and evolutionary stage, several opportunities exist for further study.

One possible extension would be to increase the number of observed stars. Including a wider range of stellar types, such as red giants, white dwarfs, blue giants, and supergiants, would provide a broader basis for comparison and allow evolutionary trends to be examined in greater detail.

Future investigations could also extend the observation period. Collecting data over several months rather than a single week would reduce the influence of short-term atmospheric variations and provide a larger observational dataset. Additional observations under different seasonal conditions may also improve the reliability of the results.

The Visual Evolutionary Indicator (VEI) developed during this investigation could be further refined and tested using a larger sample of stars. Applying the indicator to stars with well-established classifications would help evaluate its reliability and determine whether it can consistently distinguish between different evolutionary stages.

Future studies may also benefit from the use of more advanced equipment. Photometric instruments, CCD cameras, and spectroscopic observations could provide more precise measurements of brightness, colour, and stellar properties than visual observations alone.

Overall, this investigation provides a foundation for further exploration of stellar evolution and demonstrates several directions through which the study could be expanded and improved.

IX: REFERENCES

[1] NASA, "Stars," NASA Science, https://science.nasa.gov/universe/stars/

[2] Encyclopaedia Britannica, "Star – Stellar Interiors," https://www.britannica.com/science/star-astronomy/Stellar-interiors

[3] Encyclopaedia Britannica, "Star – Stellar Structure," https://www.britannica.com/science/star-astronomy/Stellar-structure

[4] OpenStax Astronomy 2e, https://openstax.org/details/books/astronomy-2e

[5] Cosmos – "Stellar Evolution," https://astronomy.swin.edu.au/cosmos/s/Stellar+Evolution

[6] CESAR – "Stellar Evolution," https://cesar.esa.int/upload/201801/stellarevolution_booklet_v2.pdf

[7] Cornell University – "Spectral Classification," https://arxiv.org/abs/2410.07301

[8] Las Cumbres Observatory – "Types of Stars," https://lco.global/spacebook/stars/types-stars/

[9] Center for Astrophysics (Harvard & Smithsonian), "Spectral Atlas and Classification," https://lweb.cfa.harvard.edu/~pberlind/atlas/htmls/note.html

[10] Lumen Learning, "Colors of Stars," https://courses.lumenlearning.com/suny-astronomy/chapter/colors-of-stars/

[11] Penn State, "Luminosity and Apparent Brightness," https://courses.ems.psu.edu/astro801/content/l4_p4.html

[12] ESA, "Blackbody Radiation," https://sci.esa.int/web/education/-/48986-blackbody-radiation

[13] OpenStax Astronomy 2e (PDF), https://peachf.org/images/Science/AstronomyTextOpenStax.pdf

[14] Encyclopaedia Britannica, "Hertzsprung–Russell diagram," https://www.britannica.com/science/Hertzsprung-Russell-diagram

[15] ESA/CESAR, "The Hertzsprung–Russell Diagram," https://www.cosmos.esa.int/web/cesar/the-hertzsprung-russell-diagram#

[16] OpenStax Astronomy 2e, "The H–R Diagram," https://openstax.org/books/astronomy-2e/pages/18-4-the-h-r-diagram

[17] Harvard University, "Atmospheric Turbulence and Telescopic Observations," https://ui.adsabs.harvard.edu/abs/1982BGeod..56..341B/abstract

[18] Stellarium, https://stellarium.org/

[19] Encyclopaedia Britannica, "Vega," https://www.britannica.com/place/Vega-star

[20] Encyclopaedia Britannica, "Antares," https://www.britannica.com/place/Antares-star

[21] SIMBAD Astronomical Database (used for catalog tables in this study)