Spectral Analysis:
of the
Central Stars
in the
Rosette Nebula NGC 2244

Version 1.0

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Content

Cover image: Rosette Nebula NGC 2244, Credit: Wikipedia noirlab creative commons

Image taken with the 4-meter telescope of the Cerro Tololo Observatory, with a line filter for the emissions of excited oxygen (blue), hydrogen and nitrogen (yellow), and sulfur (red).

1 Introduction

The Rosette Nebula, approximately 5'200 light years away, is probably one of the top subjects for astrophotographers. However, few are likely aware of the unusual stellar configuration at the center of NGC 2244 which is responsible for the excitation of this photogenic emission nebula. This publication analyzes the extremely hot central stars of spectral type O. NGC 2244 also offers the opportunity to study a representative cross-section of this extremely rare class of stars, within a single star cluster.

2 Properties and Special Features of the Stellar O Class

Spectral class O comprises the hottest, most massive and shortest-lived stars in the universe [6]. These will all end in a core-collapse supernova of class Ib or Ic, leaving behind a neutron star or, in extreme cases, a black hole as a remnant. Statistically, this class comprises only about 0.00003% of all stars in the wider vicinity of the Sun [6]. The following table shows the impressive range of stellar parameters from the late to the early spectral class O. Mass, radius and luminosity are given here in relation to the corresponding values of the Sun (ʘ).

Mass $M/M_{\odot}$	Lifetime on main sequence (My)	Effective temperature [K]	Radius $R/R_{\odot}$	Luminosity $L/L_{\odot}$
~20 – 60	~10 – 1	~25'000 – 50'000	9 – 15	90'000 – 800'000

The O class is open towards the top, currently with just a single O2 top classification (!). The extremely short lifetime of the O stars shows that NGC 2244 must inevitably be very young and so this luminous spectacle, measured on a cosmic scale, will end very soon.

3 The Central Area of the Rosette Nebula

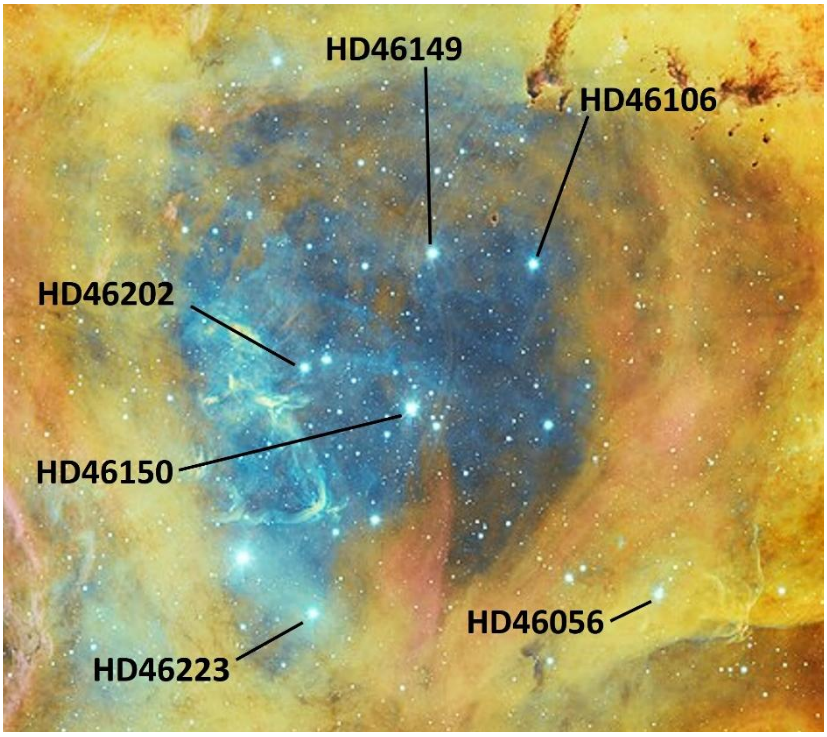


Fig. 1 Central area of the Rosette Nebula with embedded O stars

Numerous scientific publications exist on this central region, e.g., [2] [3] and [4]. Fig. 1 shows the central region, partially "cleaned" of dust and gases by stellar radiation pressure, with a radius of approximately 6.2 pc. The following table shows the parameters of the six embedded O stars according to [1]. The sequence is ordered from top to bottom with decreasing effective temperature. Due to the stellar instabilities, as a typical characteristic of the O class, different classifications may occur between different sources and databases.

The letter ((f)) placed in double brackets after the spectral classification, indicates a "mild" form of the "Of" subclass [6]. This is evident from the faint emission hump of the line He I 4921.93. "Of" stars are currently considered as precursors of LBV and Wolf Rayet stars (WR) [6].

Star	Spectral Class	Vmag
HD 46223	O4 V ((f))	7.28
HD 46150	O5 V ((f))	6.73
HD46056	O8 Vn	8.16
HD 46149	O8.5 V	7.61
HD 46202	O9.2 V	8,27
HD 46106	O9.7 III (n)	7.93

4 The Excitation of the Emission Nebula

To excite the gas of an emission nebula, consisting primarily of hydrogen but also containing nitrogen and oxygen, it must be ionized. This requires at least one star — or preferably several — with an effective temperature [5] of at least 25,000 K. Only stars of the extremely hot spectral class O and the immediately following, hottest subtype B0 produce sufficient energy for this task. The following table shows the required ionization energy in electron volts [eV] for the elements of some typical nebula gases:

H II	He II	N II	O II	O III	C II	C III	C IV	S II	Ne II
13.6	24.6	14.5	13.6	35.1	11.3	24.4	47.9	10.4	21.6

A truly unique feature is that the center is occupied here by six O-stars, representing almost the entire spectrum of the subclasses from O9 to O4, with a temperature range of approximately 25,000−40,000 K. Due to this impressive temperature range, the contribution of the subclass to the excitation energy is crucial, because the total radiated (bolometric) energy F_{Bol} of a star is proportional to the fourth power of its effective temperature T_{eff}! In the following formula, σ is the Boltzmann constant and proportionality factor.

$$F_{Bol} = \sigma T_{eff}^4$$

5 Recording and Processing of the Spectra

Recorded with a DADOS spectrograph, 0.25 µm slit width.

Atik 314L+ camera, 2x2 binning. Exposure times between 400 and 500 seconds, with two stacked images per star (IRIS).

Standard analysis with the IRIS and Visual Spec programs. The pseudo continuum curve has been removed ("rectified spectrum"), allowing direct intensity comparison between the spectral lines.

6 Rough Analysis of the Stellar Spectra

The following graphic shows five superimposed spectral profiles of the six O-type stars at the center of NGC 2244. The order is arranged, from top to bottom, by decreasing effective temperature [5], in a range of approximately 40,000−25,000 K.

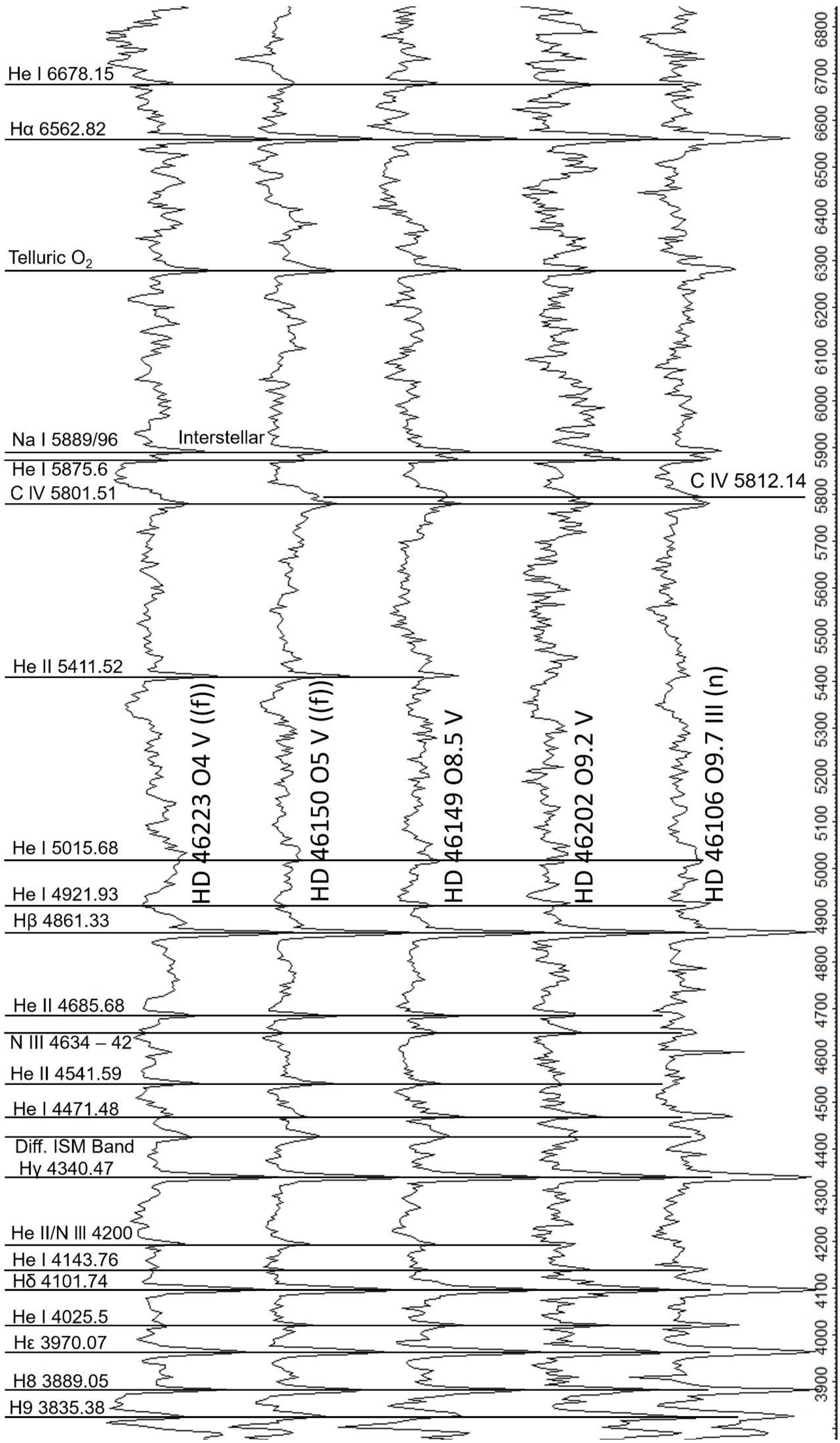
Historically, the boundary between the B- and the hottest O-class was defined by the appearance of ionized helium, He II. Therefore, it becomes immediately clear that this spectral class is O. With current technology, however, this ion can also be detected in class B0.

At first glance, there are hardly any differences between the individual profiles. However, a closer look reveals that the absorption intensity of neutral helium, He I, decreases with increasing temperature. Conversely, it increases for singly ionized helium, He II, which is also consistent with theory. This is clearly visible for He I at the lines λ4025.5 and λ4471.48. For He II, the lines λ5411.52, λ4686.68 and λ4541.59 are exemplary.

The intensity of the H-Balmer series from Hα to H9 appears to be barely affected by the temperature difference. However, theoretically a decrease in H intensity with increasing temperature would be expected.

7 The Nebula Spectrum of NGC 2244

The original idea was to obtain the nebula's emission spectrum as a secondary objective, as a "bycatch" to the numerous stellar spectra. Despite exposure times of up to 500 s in 2x2 binning mode, no usable nebula spectrum could be obtained next to any of the five stars. In contrast for M42, this is feasible within about 60 s with the same equipment [6].


He I 6678.15
Hα 6562.82
Telluric O2
Na I 5889/96
Interstellar
He I 5875.6
C IV 5801.51
C IV 5812.14
He II 5411.52
He I 5015.68
He I 4921.93
Hβ 4861.33
He II 4685.68
N III 4634 – 42
He II 4541.59
He I 4471.48
Diff. ISM Band
Hγ 4340.47
He II/N III 4200
He I 4143.76
Hδ 4101.74
He I 4025.5
Hε 3970.07
H8 3889.05
H9 3835.38
HD 46223 O4 V ((f))
HD 46150 O5 V ((f))
HD 46149 O8.5 V
HD 46202 O9.2 V
HD 46106 O9.7 III (n)
3900
4000
4100
4200
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4500
4600
4700
4800
4900
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8 Comparison Rosette Nebula NGC2244 vs Orion Nebula M42

NGC2244, at 5200 ly, is about four times as distant as M42 at 1300 ly. The Rosette Nebula is excited by six O-type stars loosely distributed throughout the central bubble. In the Orion Nebula, it is the highly compact central cluster of the Trapezium stars [6], consisting of just one single O-type star (O7V) and three others that just miss the O class: B1V, B1.5V, and B0.5V. This leads to the sole O-type component, HD 37022, being responsible for >50% of M42's luminosity!

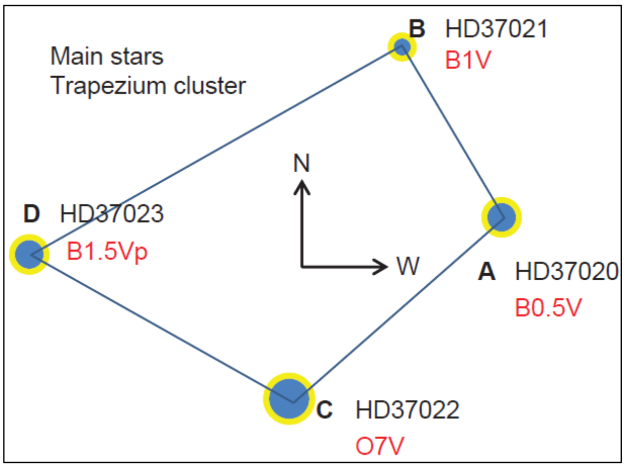
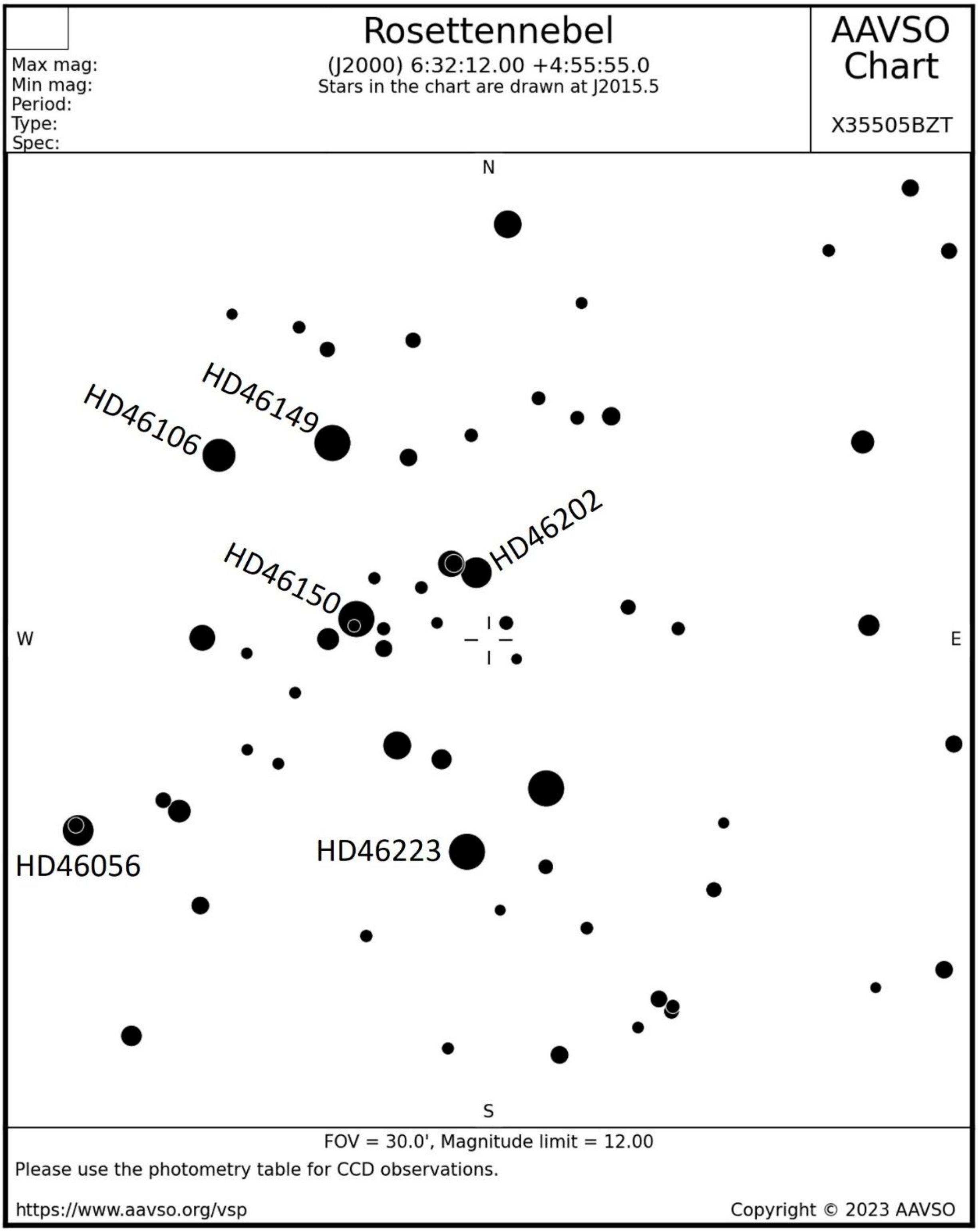


Abb. 2 Trapezium stars of M42 [6]

9 AAVSO Finder Chart

The following finder chart is configured for a C8, the mirror effect of a zenith prism, and a 25mm eyepiece. The FOV was set to 30' and the magnitude limit to 12.0.



10 Literature

[1] SIMBAD *Astronomical Database, CDS (Strasbourg)*

[2] L. Mahy et al. *Early-type stars in the young open cluster NGC 2244 and in the Monoceros OB2 association*, 2009 Astronomy & Astrophysics.

[3] L. Mahy et al. *The multiplicity of O-type stars in NGC2244*, 2011

[4] F. C. Bruhweiler et al. *The Young Interstellar Bubble within the Rosette Nebula,* 2010

Author:

[5] M. F. M. Trypsteen, R. Walker: *Spectroscopy for Amateur Astronomers -Recording, Processing, Analysis and Interpretation*, 2017 Cambridge University Press, ISBN: 9781107166189

[6] R. Walker: *Spectral Atlas for Amateur Astronomers -A Guide to the Spectra of Astronomical Objects and Terrestrial Light Sources*, 2017 Cambridge University Press, ISBN: 9781107165908

Internet documents by the Author

https://www.ursusmajor.ch/astrospektroskopie/richard-walkers-page/index.html