iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

**Volume:** 5 **Issue:** XI **Month of publication:** November 2017

**DOI:**

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

# Fundamental Parameters of Early-Type O4 Dwarfs from Galactic O-Stars Spectroscopic Survey

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***Abstract*: We present a synthetic spectral study of three (9 Sgr AB, HDE 229232 AB and HD 5005 A )galactic early-type O4 dwarf stars with high signal-to-noise ratio (S/N) ~ 200-300, medium-resolution R~ 2500 optical spectra of O4 dwarfs stars from Galactic O-Stars Spectroscopic Survey (GOSSS). Stellar Parameters (Teff, surface gravity, rotational velocity) are determined using non-LTE line blanketed photosphere models calculated with TLUSTY204 and SYNSPEC49.**
***Keywords: Stars: early-type;O4 dwarfs; synthetic spectra; model atmosphere; Fundamental Parameters.***

## I. INTRODUCTION

Massive stars of spectral types O play an extremely important role in astrophysics. they possess high effective temperatures (Tiff> 30,000K), intense ionizing radiation fields and often exhibit strong mass-loss through stellar winds, making their description considerably difficult for atmosphere and stellar evolution models. These stars are known to be progenitors of fascinating objects such as red supergiants (RSGs), luminous blue variables (LBVs), Wolf-Rayed stars (W-Rs), and thus also of some of the most energetic phenomena in the Universe type II supernovae and some $\gamma$-ray bursts (Massey 2003[1]; Woolley& Bloom 2006[2]). They also heavily affect their host galaxies by transferring momentum, energy and enriched chemical elements to the interstellar medium (Abbott 1982[3]; Feyeretal.2003[4]).

lthough they have been studied for decades, the properties, origin, and evolution of O stars still present several observational and theoretical challenges. The dependency of their mass loss rates ($\dot{M}$) on the metallicity (Z), for example, as well as their effective temperatures and wind structure (e.g., clumping) have been continually debated in the literature during the last few years (see, e.g., Vink et al.2001[5]; Martins et al. 2002[6]; Borat et al. 2005[7]; Plusetal. 2006[8]).

In order to clarify some of the issues described above, and to get more insight into the problem, we have analyzed in detail optical medium-resolution spectra of five Galactic late type O dwarf stars. Their stellar physical parameters were obtained using the codes TLUSTY and SYNSPEC(Hugely&Lenz 1995[9]).

The remainder of this paper is organized as follows. In Sect.2 we describe the way we have selected our targets and the observational material used. A description of the atmosphere codes and the adopted assumptions are given in Sect.3. The analysis of each object of our sample is presented in Sect.4. The derived stellar parameters are presented later in Sect.5.

## II. OBSERVATIONS

Observations used in this work are retrieved from the Galactic O-Star Spectroscopic Survey (GOSSS). GOSSS is a long-term systematic survey of all Galactic stars ever classified as O. This project is providing moderate resolution ( R~ 2500) spectroscopy in the blue- violet region (approximately 3900-5000A), with high signal-to-noise ratio, typically S/N ~ 200-300. We initially selected a sample of objects belonging to O4 dwarfs class from the Galactic O Star Catalo (Maz-Apellniz et al. 2004[10]). The spectral types are available through the latest version of the Galactic O-Star Catalo (GOSC, Maize Apellaniz et al. 2004[10]). In this paper, we include three early type O4 dwarfs stars from GOSSS.

TABLE 1
OBSERVATIONAL DATA OF THE PROGRAM STARS.

| Star | RA (h:m:s) | dec (d:m:s) | spectral type | V(mag) | B-V(mag) |
|---|---|---|---|---|---|
| 9 Sgr AB | 18:03:52.446 | -24:21:38.64 | O4 V ((f)) | 5.97 | +0.03 |
| HDE 229232 AB | 20:23:59.183 | +39:06:15.27 | O4 V n((f)) | 9.53 | +0.82 |
| HD 5005 A | 00:52:49.206 | +56:37:39.49 | O4 V ((fc)) | 8.38 | +0.06 |

## III. MODEL ATMOSPHERES AND SYNTHETIC SPECTRA

In order to obtain the stellar parameters of the stars of our sample we used the atmosphere code TLUSTY 204 (hugely& Lanz1995)[9], the TLUSTY code assumes a plane-parallel geometry, hydrostatic and radioactive equilibrium, non-LTE, includes line-blanketing, and can only model lines that are formed in the photosphere.

We use to synthesis the spectra the code SYNSPEC 49 which is a general spectrum synthesis program. The input model atmospheres to SYNSPEC could be taken from TLUSTY or from the literature. Then the program solves the radioactive transfer equation wavelength by wavelength in a specified wavelength range and with a specified wavelength resolution. In the present calculation

To start our analysis, we calculate a small grid of TLUSTY model based on the OSTAR2002 grid (hugely and Lenz, 2003)[11] with an effective temperature range between 40,000 K and 45,000 K, and surface gravity range between 3.80 and 4.20, The new grid uses finer sampling steps in effective temperature (1000 K) and surface gravity (0.1 dex).

We use the helium lines He I λ4471 and He II λ4542 to derive the effective temperatures. Typical errors for $T_{eff}$ range from 1 to 2 K. Our derivation of log g was based on the fit to the Hγ wings but fits other transitions such as Hβ and Hδ were also checked for consistency. For this parameter, the uncertainty varies from 0.1 to0.2 decks, depending on the object. After determining the effective temperatures and surface gravities for the target stars, we turn to determine the rotational velocities. For this purpose, we use the routine rotin3 which is a part of the TLUSTY package. To do that, a small grid of rotated spectra for a given effective temperature and surface gravity is calculated.

## IV. SPECTRAL ANALYSIS

In this section we present the analysis of our sample. A brief introduction about each object is made, followed by the presentation of our TLUSTY model fits to the optical observed spectra. The discrepancies found are discussed and a comparison to previous results in the literature is given when necessary.

### *A. 9 Sgr AB*

9 Sgr (HD 164 794) belongs to the young cluster NGC 6530, and according to the Galactic O-Ster Catalogue (Maiz-Apellaniz et al. 2004) [10], has a classification O4V((f)), exhibiting weak NIII emission and strong Heλ4686. It is a well-known non-thermal radio emitter and according to Van Loo et al (2006)[12] the most likely mechanism is synchrotron emission from colliding winds, implying that all O-star with non-thermal radio emission should be members of binary or multiple systems. Hints of a wind – wind interaction were indeed detected in the X-ray domain ( Rauw et al 2002)[4]. A long term study of its binary nature and spectrum variability has been recently presented by Raw et al (2012)[13] who derived an orbital solution and an orbital period of 8.6 years, the long period of this system explains why it was so difficult to prove the banality.

Our fits to the optical spectrum of 9 Sgr AB are presented in fig. 4.1 the, five different spectral regions were shown contain the diagnostic lines used to drive the photosphere parameters. The effective temperature could be very well constrained. The He I λ4471/He II λ4542 and He I λ4713/Heidi λ4686 ratios are well reproduced with Teff = (43.16±1.0)kK. Hγ has a reasonable fit but the model is somewhat stronger than the observed line. their wings are well matched with a log g of 3.91 ± 0.1. The rotational velocities (v sin i) were estimated from the fitting process 100 ± 10 km s-1. Some of the most intense lines in Fig.1 are He I λ4471, He II λ4542, He II λ4200, Hδ, He, and Hβ. These same transitions are easily identified in the other objects of our sample. He I λ4388 and He I λ4713 Can't count on because they are very weak , also He II λ4686 is affected by wind.

Williams et al.(2011)[14] derived a high effective temperature (46.1±2.8kK), and a very fast rotational velocity vsin i=191±17, their estimated value is far from our result because they used OSTAR2002 Grid with a large steps in effective temperature (2.5kK) and surface gravity (0.25 dex) , also their fitting for the effective temperature don't dependent on the ratio of He I λ4471/He II λ4542, which may lead them to a higher temperature, and for the surface gravity they don't consider Hγ wings for fitting of log g, for the rotational velocity we obtained a reasonable value which agrees with early calculation by Penny (1996)[15] and from the fitting process.

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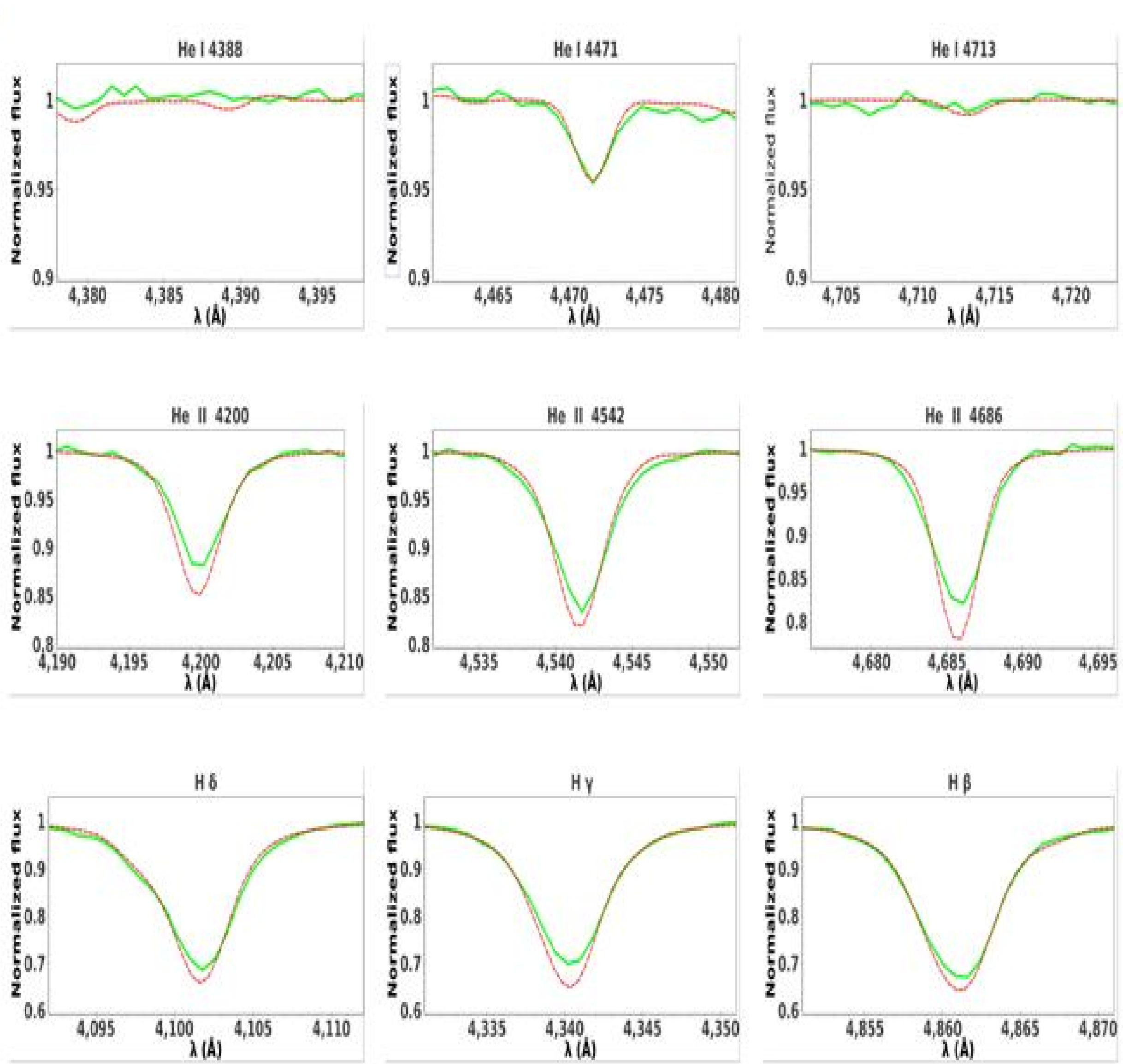


Fig.1 Best fit (red/black dashed line) of the observed He and H lines (green/gray light line) of 9 Sgr AB. The effective temperature is 43160 K, log g = 3.91, and *v sin i* =100 km $s^{-1}$

*B. HDE 229232 AB*

In fig. 2 we show our fit to the optical spectrum, a high rotational velocity convolution is necessary to fit the broad features observed. From the He I and He II lines we have obtained a $T_{eff}$ = (42.80□1) kK, from H □□we estimate the surface gravity log g = 3.98□□□□, and for the rotation velocity (*v sin i=250* km $s^{-1}$)

Williams et al.(2013)[16] derived a low effective temperature (41.1±2.8kK), and a very fast rotational velocity vsin i=191±17, their estimated value is far from our result because they used OSTAR2002 Grid with a large steps in effective temperature (2.5kK) and surface gravity (0.25 dex) , also their fitting for the effective temperature don't dependent on the ratio of He I λ4471/He II λ4542, which may lead them to uncorrected effective temperature.

Fig.2. Best fit (red/black dashed line) of the observed He and H lines(green/gray light line) of HDE 229232 AB.

The effective temperature $T_{eff}$= *42820 K, log g=3.98* and *v sin i=250 km* $s^{-1}$

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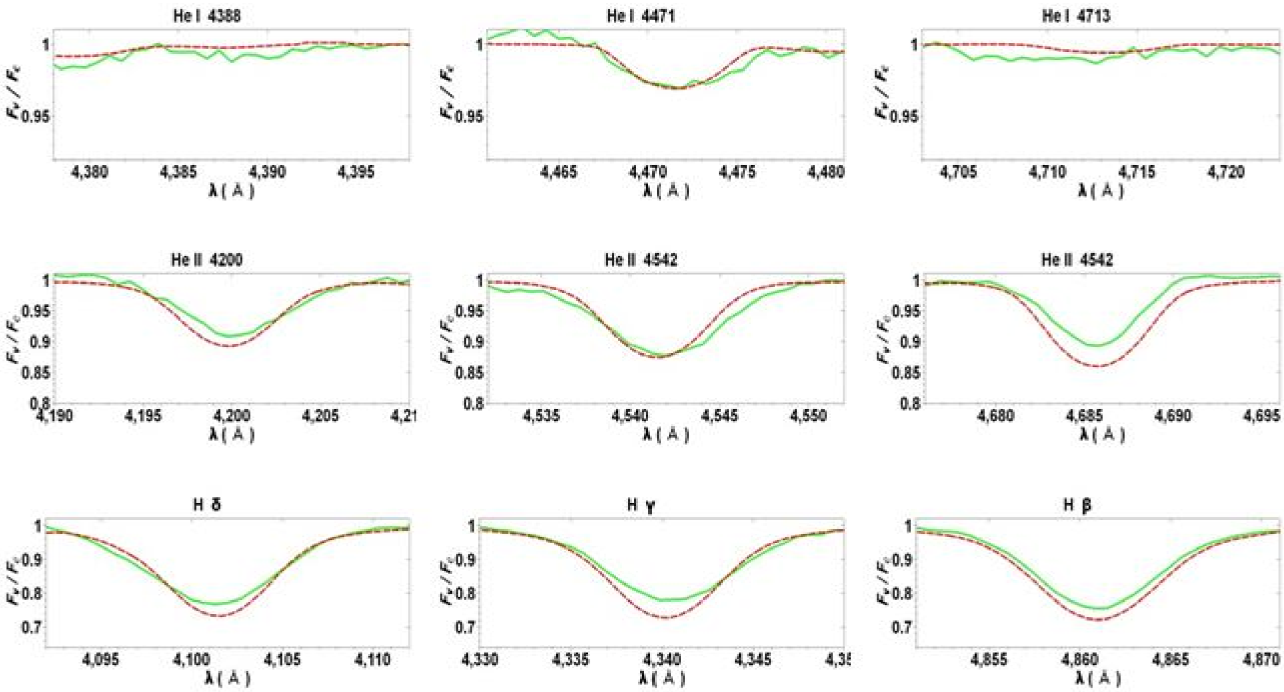


*C. HD 5005A*

The Hippocras DMSA/C catalog lists four components to the multiple system of which HD 5005A is a member, but their membership of the IC 1590 cluster seems unequivocal, unlike the Sp/L of HD 5005A (Bowen et al. 2008)[17]

In Fig. 4.4 we show our fit to the optical spectrum. from our fits to the Hγ we derive a log g = 3.93 ± 0.1, and from the He I λ4471 and He II λ4542 lines we obtain a Teff = (42.96 ± 1) kK, it's rotational velocity are about 160 km s−1

Leitherer et al. (2010)[18] have analyze HD5005a using WM-Basic (Pauldrach et al. 2001) [19] to it's UV spectra from IUE archive, They considered it's spectral type as O6.5V (Walborn 1972.)[20]which make them consider a low effective temperature as 37,688 K, if they considered it as O4Vfrom their table1. (Grid Parameters Related to Stellar Evolutionary Tracks) they will have a closer effective temperature as 42,084 K .

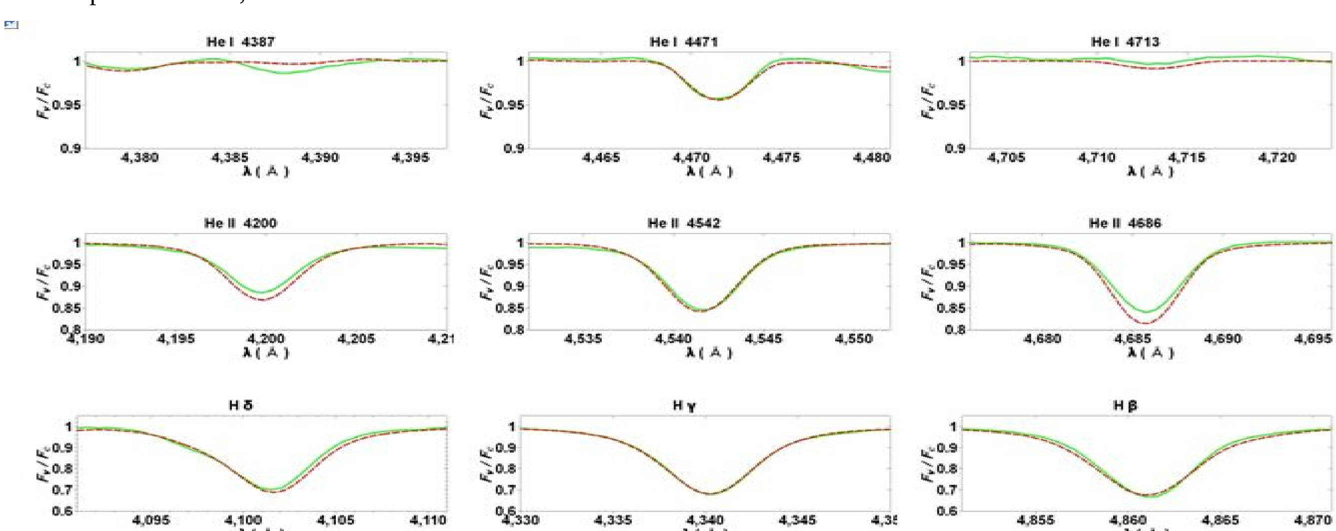


Fig.3 Best fit (red/black dashed line) of the observed He and H (green/gray light line) of HD 5005A.
The effective temperature Teff = *42960 K*, *log g=3.93* and *v sin i=160 km* $s^{-1}$

## V. RESULTS AND DISCUSSION

In this section we summarize the results of our spectral analysis; The stellar parameters obtained are presented in Table 3. The stellar properties of our sample are quite homogeneous. The effective temperatures range around ~ 43,000 K. The lowest surface gravity is for 9 Sgr AB. The derived physical properties show a fair agreement with the latest calibration of Galactic O star parameters for the O4V spectral type (see Martins et al. 2005)[21].

TABLE 2
STELLAR PARAMETERS

| Star | Spec. type | Teff (kK) | Log g | *v sin i* ($km\ s^{-1}$) |
|---|---|---|---|---|
| 9Sgr AB | O4 V ((f)) | 4316±1.0 | 3.91±0.1 | 100 |
| HDE 229232 AB | O4 V n((f)) | 42.82±1.0 | 3.98±0.1 | 250 |
| HD 5005 A | O4 V ((fc)) | 42.96±1.0 | 3.93±0.1 | 160 |

## VI. ACKNOWLEDGMENT

This research is supported by Kottamia Centre of Scientific Excellence for Astronomy and Space Science (Kosice) and the Science and Technology Development Fund (STDF N5217).

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