Chemical abundance analysis of CP Cyg and HD 33266[☆]

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Abstract

We selected two neglected A-type stars with low rotational velocity ($\mathrm{v}\sin\mathrm{i} < 20$ km s^{-1}) to reveal their chemical composition. Our abundance analysis was based on high resolution spectra of CP Cyg and HD 33266, obtained at the Tubitak National Observatory (TUG). We determined the fundamental parameters of our target stars from traditional methods. We also measured the abundances of 19 elements for CP Cyg and 20 for HD 33266 from the unblended lines emerging in the optical region of our spectra. The results of the analysis show that CP Cyg is a chemically normal A-type star, while HD 33266 is a metallic-line (Am) star. This is the first study in which HD 33266 is classified as a hot Am star. We also plotted the stars on the H-R diagram and calculated the masses from evolutionary tracks and ages from isochrones. We then compared both stars with members of similar ages and atmosphere parameters that belong to Coma Berenices and Hyades clusters. Our study is

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useful to understand the physical processes inside the atmospheres of chemically normal and peculiar A-type stars as well as their origin.
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1. Introduction

The sharp lines that are present in the spectra of slowly-rotating normal A-type stars allow us to derive precise elemental abundances. Detailed abundance analysis of these stars provide information about the chemical structure of their birthplace as well as give an idea of their evolutionary status.

Normal A-type stars generally exhibit nearly solar elemental abundances except those that are heavier. These heavier elements may show over/underabundance within 0.4 dex relative to the Sun (Adelman and Unsuree, 2007). Non-magnetic late-B and A-type stars have chemical diversities such as metallic-line stars (Am) and mercury-manganese stars (HgMn). The typical characteristics of Am stars are a deficiency in Sc abundance (and Ca abundance in some cases), increase in iron-peak element abundances, and remarkably an overabundance of Sr, Y, Zr, and Ba (Fossati et al., 2009). HgMn stars exhibit striking overabundances of Hg and Mn along with an overabundance of various heavy elements such as Cr, Zn, Y, and Ba. These slow rotating stars are also likely to show an underabundance of Co and Ni (Smith and Dworetsky, 1993).

The spectral type of CP Cyg (HD 205939, HR 8272, BD+44 3889) was classified as A7III (Cowley et al., 1969). Burkhart and Coupry (1991) determined the atmosphere parameters of CP Cyg as $T_{\rm eff}$ of 7910 K and log g of 3.4 dex, using the grids of Moon and Dworetsky (1985). The authors derived the logN(Li) of 3.4, logN(Si) of 7.7, and logN(Fe) of 8.0 for the star. Abt and Morrell (1995) calculated the v sin i of CP Cyg, by using Mg II 4481 Å line, as 10 km s^{-1}. Also, the rotational velocity of CP Cyg was found by Royer et al. (2002) as 18 km s^{-1}.

For HD 33266 (HR 1675, BD +61 766), the spectral type was classified as A2III (Cowley et al., 1969). McAlister et al. (1989) noted that this star is a not binary. Abt and Morrell (1995) calculated the v sin i of HD 33266, by using Mg II 4481 Å line, as 10 km s^{-1}. Royer et al. (2002) measured the rotational velocities of some A-type stars and found v sin i of 15 km s^{-1} for HD 33266.

In this paper, our main goal is to derive detailed elemental abundances of the two slowly rotating A-type stars. We will describe the observation and data reduction in Section 2, the determination of atmosphere parameters in Section 3, and the details of abundance analysis in Sections 4. Finally, our results are discussed in Section 5.

2. Observation and Data Reduction

The spectra of CP Cyg and HD 33266 were obtained using the Coudé Echelle Spectrograph attached to the 1.5 m Russian-Turkish Telescope (RTT150) at TUG. The high resolution ($R \sim 40,000$) spectra, covering a wavelength range of 3900 to 7900 Å, were acquired over the course of two nights from December 23-24, 2010. At the beginning of each observation run, we took calibration frames and arc spectra: the halogen lamp for flat fielding and the Th-Ar lamp for wavelength calibration. The observation log and the properties of each target star are listed in Table 1.

Our two consecutive observations of HD 33266 allowed us to co-add the spectra and achieve a higher signal-to-noise ratio (S/N). The poor weather conditions did not permit us to do the same for CP Cyg in the assigned observation time, thus we observed it once.

The reduction of the three raw spectra was performed with standard IRAF ([1]) routines. After the bias subtraction, flat fielding, removal of scattered light from the scientific frames, and conduction of wavelength calibration, the heliocentric correction was applied to all spectra. The possible radial velocity shift between the two spectra of HD 33266 was checked before the co-adding process, and no significant shift was found. The heliocentric radial velocities given in Table 1, were measured from unblended and moderately strong metal lines.

All orders of the spectra were normalized by fitting a spline to the carefully selected continuum points. After normalization, v sin i values of each star were measured by comparing the observed spectra with the synthetic ones. They are listed in Table 1.

[1] IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

Table 1: The properties and observations log of CP Cyg and HD 33266.

Star name	RA [h m s]	DEC [° ′ ″]	HJD [day]	Exposure time [s]	v_{helio} [km s^{-1}]	v sin i [km s^{-1}]	S/N [@5000 Å]
CP Cyg	21 37 27.87	+44 41 47.58	2455554.2502	4500	17.7 ± 1.2	19	115
HD 33266	05 13 02.81	+61 51 00.14	2455554.5244	2×4500	4.3 ± 1.4	12	320

3. Atmosphere Parameters

First, the atmosphere parameters were determined photometrically to obtain an initial model atmosphere. We took the Strömgren photometric data from Hauck and Mermilliod (1998) of each star and used the calibrations of Napiwotzki et al. (1993) to determine the surface gravity (log g) and effective temperature ($T_{\rm eff}$), as listed in Table 2. Using these parameters, we calculated the initial model atmospheres for each star with ATLAS9 code (Kurucz, 1993b, 2005; Sbordone et al., 2004).

We refined the photometrically specified atmosphere parameters ($T_{\rm eff}$, log g) as follows: (a)$T_{\rm eff}$ was derived from the excitation equilibrium of Fe I lines, (b) log g was determined from the balance of abundances derived from individual Fe I/II and Cr I/II lines. Hence, the ionization equilibrium is fulfilled on the atmosphere of CP Cyg and HD 33266. To check the final atmosphere parameters, we fitted synthetic H_β profiles computed with SYNTHE code (Kurucz, 1993a, 2005) to the observed ones, as seen in Figure 1.

For each star, we adopted the microturbulent velocity (ξ) which provides the weakest trend of equivalent width (hereafter EQW) with abundances derived from individual Fe I lines. All of the determined parameters are listed in Table 2.

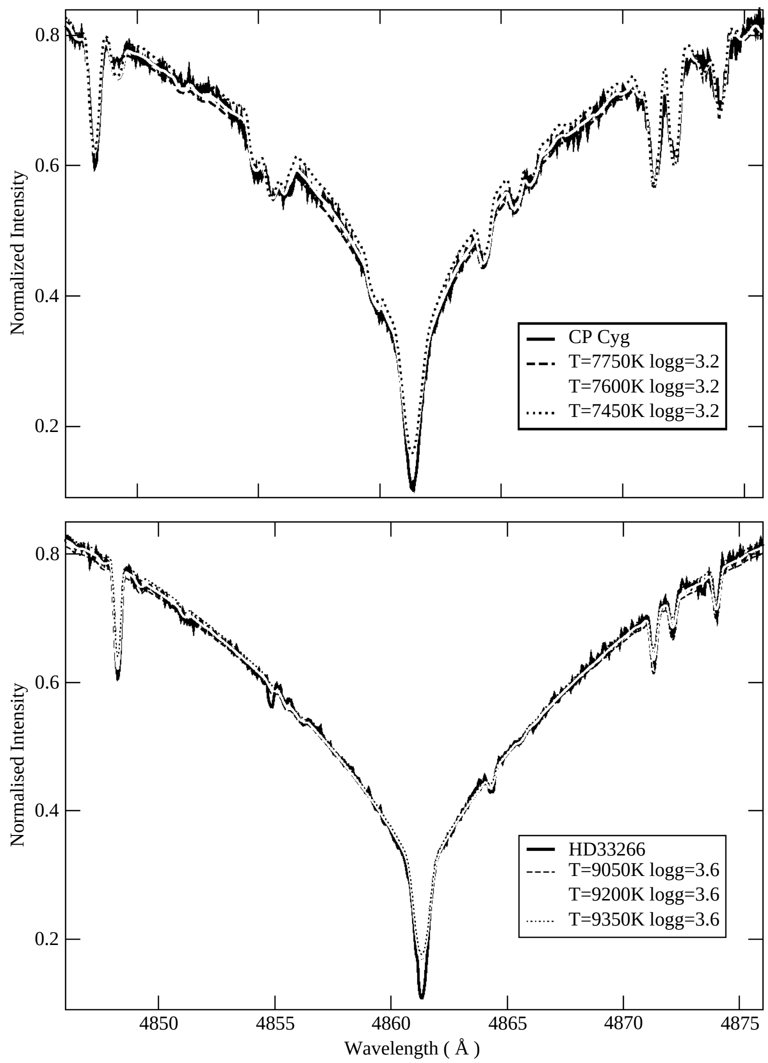

Figure 1: Comparison between the observed and synthetic H_β line profiles of CP Cyg (top fig.) and HD 33266 (bottom fig.). The gray lines show the determined atmosphere parameters from this study, the dotted (+150 K) and dashed (−150 K) lines represent the uncertainties in $T_{\rm eff}$.

Table 2: The atmosphere parameters of the analyzed stars.

	Photometric		Spectroscopic			
Star name	$T_{\rm eff}$ [K]	$\log g$ [dex]	$T_{\rm eff}$ [K]	$\log g$ [dex]	ξ [km s^{-1}]	[Fe/H] [dex]
CP Cyg	7611	3.19	7600	3.20	2.40	0.05
HD 33266	9274	3.43	9200	3.60	2.60	0.21

4. Abundance Analysis

To identify the atomic absorption lines, which emerge on the spectra of the target stars, we use the line lists from Kurucz line database and Vienna Atomic Line Database (VALD, Piskunov et al., 1995; Kupka et al., 1999; Ryabchikova et al., 1999). EQW measurements were done by fitting a Gaussian profile to the normalized spectra. To derive the abundances, based on EQW measurements of individual lines, we used the WIDTH9 code (Kurucz, 2005; Sbordone et al., 2004), which uses ATLAS9 model atmospheres to compute a line formation in LTE. We did not use lines that measured on the EQW more than 190 mÅ for the abundance analysis, since these lines are not sensitive to the abundance calculations. For the line lists of V, Sc, Mn, and Y, we used the hyperfine splitting (HFS) from Robert Kurucz's web page. We produced synthetic spectra with the SYNTHE code (Kurucz, 1993a, 2005) to measure the abundance of these elements. The synthetic spectra included the broadening effects due to the instrumental profile and the macroturbulent velocity. By adjusting the observed and synthetic spectrum, a compatibility between the abundances of the species was reached. All of the derived elemental abundances within their uncertainties for each

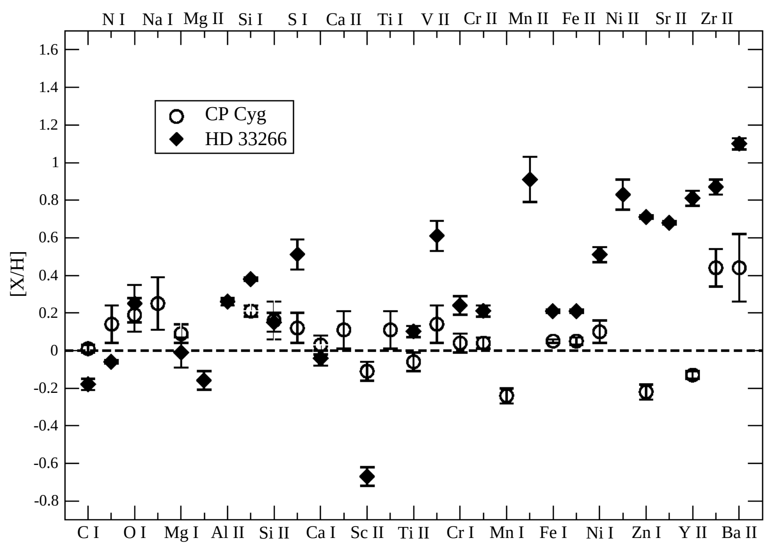

Figure 2: The differences between our derived abundances and the solar abundances of Grevesse and Sauval (1998) for CP Cyg and HD 33266. The error bars shows the standard random errors (gray) and total errors (black).

star are given in Table 3. In this table, the random errors of the elemental abundances were given by the standard deviation of individual measurements over the square root of the number of lines. We adopted an uncertainty of 0.10 dex for species that were measured with spectrum synthesis and also with only one detected line. We also estimated the systematic errors of the uncertainties in the atmosphere parameters for each species, as listed in Table 4. We find that the largest uncertainty in the abundances is due to $T_{\rm eff}$.

The total errors of the elemental abundance were calculated as $\sigma_{\rm tot} = \sqrt{\sigma_{\rm r}^2 + \sigma_{\rm sys}^2}$ for each target star and are listed in Table 3, as $\sigma_{\rm tot} = \sigma_{\rm tot}/\sqrt{\rm N}$ (N is the number of lines).

Table 3: Derived elemental abundances with the standard random (σ_r) and total error (σ_{tot}) estimates of CP Cyg and HD 33266. $\log \epsilon_{\odot}$ values are taken from Grevesse and Sauval (1998).

		CP Cyg					HD 33266				
Species	$\log \epsilon_{\odot}$	$\log \epsilon$	[X/H]	σ_r	σ_{tot}	N	$\log \epsilon$	[X/H]	σ_r	σ_{tot}	N
C I	8.52	8.53	0.01	0.02	0.03	7	8.34	−0.18	0.03	0.07	2
N I	7.92	8.06	0.14	0.10	0.13	1	7.86	−0.06	0.01	0.03	1
O I	8.83	9.02	0.19	0.09	0.10	3	9.08	0.25	0.10	0.10	4
Na I	6.33	6.58	0.25	0.14	0.21	2	...	...	...	...	...
Mg I	7.58	7.67	0.09	0.05	0.12	3	7.57	−0.01	0.08	0.22	3
Mg II	7.58	...	...	...	...	...	7.42	−0.16	0.05	0.07	2
Al II	6.47	...	...	...	...	...	6.73	0.26	0.02	0.04	4
Si I	7.55	7.76	0.21	0.03	0.09	4	7.93	0.38	0.00	0.17	1
Si II	7.55	7.71	0.16	0.10	0.12	4	7.70	0.15	0.05	0.13	4
S I	7.33	7.45	0.12	0.08	0.10	3	7.84	0.51	0.08	0.11	2
Ca I	6.36	6.39	0.03	0.05	0.09	16	6.35	−0.04	0.04	0.07	12
Ca II	6.36	6.47	0.11	0.10	0.11	1	...	...	...	...	...
Sc II^{HFS}	3.17	3.06	−0.11	0.05	0.17	5	2.49	−0.68	0.05	0.11	2
Ti I	5.02	5.13	0.11	0.10	0.29	1	...	...	...	...	...
Ti II	5.02	4.96	−0.06	0.05	0.09	23	5.12	0.10	0.03	0.05	21
V II^{HFS}	4.00	4.14	0.14	0.10	0.16	1	4.57	0.57	0.08	0.11	5
Cr I	5.67	5.71	0.04	0.05	0.12	10	5.91	0.24	0.05	0.10	5
Cr II	5.67	5.71	0.04	0.03	0.07	21	5.88	0.21	0.03	0.04	25
Mn I^{HFS}	5.39	5.15	−0.24	0.04	0.14	4	...	...	...	...	...
Mn II^{HFS}	6.39	...	...	...	...	...	5.85	0.45	0.12	0.38	5
Fe I	7.50	7.55	0.05	0.01	0.03	126	7.71	0.21	0.01	0.02	75
Fe II	7.50	7.55	0.05	0.02	0.05	39	7.71	0.21	0.01	0.02	88
Ni I	6.25	6.35	0.10	0.06	0.11	8	6.76	0.51	0.04	0.06	9
Ni II	7.25	...	...	...	...	...	7.08	0.83	0.08	0.09	4
Zn I	4.60	4.38	−0.22	0.04	0.17	2	5.31	0.71	0.01	0.14	1
Sr II	2.97	...	...	...	...	...	3.65	0.68	0.01	0.83	1
Y II^{HFS}	2.24	2.11	−0.13	0.02	0.18	2	3.01	0.77	0.04	0.11	2
Zr II	2.60	3.04	0.44	0.10	0.28	1	3.47	0.87	0.04	0.08	5
Ba II	2.13	2.57	0.44	0.18	0.43	2	3.23	1.10	0.03	0.26	4

Table 4: Errors analysis for the target stars.

	CP Cyg						HD 33266					
Species	$\Delta T_{\rm eff}$ [K]		$\Delta \log g$ [dex]		$\Delta\xi$ [km s^{-1}]		$\Delta T_{\rm eff}$ [K]		$\Delta \log g$ [dex]		$\Delta\xi$ [km s^{-1}]	
	+150	−150	+0.1	−0.1	+1.0	−1.0	+150	−150	+0.1	−0.1	+1.0	−1.0
C I	0.04	−0.02	0.01	−0.01	−0.02	0.01	0.08	−0.09	0.02	−0.03	0.00	0.00
N I	−0.07	0.04	0.02	−0.02	−0.04	0.04	0.08	−0.02	0.00	0.01	0.00	0.02
O I	−0.08	0.05	0.02	−0.01	−0.02	0.02	0.01	0.00	−0.01	0.00	0.01	−0.02
Na I	0.16	−0.08	−0.01	0.01	−0.09	0.15	...	...	...	...	...	...
Mg I	0.16	−0.08	−0.02	0.03	−0.15	0.15	0.11	−0.14	0.12	0.05	0.35	−0.25
Mg II	...	...	...	...	...	...	0.00	0.00	0.00	0.01	0.07	−0.07
Al II	...	...	...	...	...	...	−0.04	0.06	−0.03	0.03	0.02	−0.02
Si I	0.16	−0.09	−0.02	0.01	−0.06	0.08	0.08	−0.12	0.03	−0.03	0.11	0.01
Si II	−0.07	0.05	0.02	−0.02	−0.14	0.13	0.00	0.00	−0.01	0.01	0.13	−0.25
S I	0.09	−0.05	−0.01	0.00	−0.05	0.06	0.09	−0.10	0.03	−0.03	0.00	−0.01
Ca I	0.22	−0.12	−0.02	0.01	−0.18	0.24	0.15	−0.18	0.05	−0.06	0.03	−0.07
Ca II	0.01	0.00	0.02	−0.01	−0.02	0.04	...	...	...	...	...	...
Sc II	0.13	0.00	0.09	0.04	−0.11	0.40	0.10	−0.09	−0.02	0.00	0.04	−0.10
Ti I	0.25	−0.14	−0.01	0.01	−0.06	0.12	...	...	...	...	...	...
Ti II	0.12	−0.06	0.03	−0.03	−0.20	0.34	0.07	−0.09	−0.01	0.02	0.09	−0.17
V II	0.11	−0.06	0.03	−0.03	−0.03	0.04	0.10	−0.03	−0.06	−0.03	0.01	−0.15
Cr I	0.24	−0.13	−0.01	0.00	−0.13	0.24	0.12	−0.16	0.03	−0.03	0.06	−0.11
Cr II	0.07	−0.03	0.03	−0.02	−0.15	0.28	0.04	−0.05	−0.02	0.02	0.06	−0.12
Mn I	0.22	−0.12	−0.01	0.01	−0.07	0.15	...	...	...	...	...	...
Mn II	...	...	...	...	...	...	0.47	0.42	−0.46	−0.43	−0.43	−0.48
Fe I	0.20	−0.11	−0.01	0.01	−0.14	0.27	0.10	−0.14	0.03	−0.02	0.04	−0.06
Fe II	0.07	−0.04	0.02	−0.03	−0.19	0.27	0.02	−0.02	−0.03	0.02	0.09	−0.15
Ni I	0.21	−0.12	−0.01	0.01	−0.07	0.15	0.10	−0.12	0.03	−0.03	0.02	−0.03
Ni II	...	...	...	...	...	...	0.01	−0.01	−0.03	0.03	0.05	−0.09
Zn I	0.22	−0.12	−0.01	0.01	−0.04	0.07	0.10	−0.14	0.03	−0.03	0.02	−0.02
Sr II	...	...	...	...	...	...	0.16	−0.17	0.01	−0.02	0.60	−0.81
Y II	0.15	−0.07	0.03	−0.02	−0.09	0.27	0.14	−0.08	−0.04	−0.04	−0.03	−0.05
Zr II	0.16	−0.09	0.02	0.03	−0.09	0.21	0.09	−0.10	−0.02	0.01	0.05	−0.12
Ba II	0.27	−0.13	0.01	0.00	−0.44	0.48	0.15	−0.17	0.02	−0.02	0.20	−0.48

5. Results and Discussion

We obtained high resolution spectra of the relatively bright neglected stars CP Cyg and HD 33266. Our results are the first detailed abundance analysis of these stars. Most of the element abundances in CP Cyg are nearly ± 0.2 dex except for Zr and Ba which are overabundant of 0.44 dex relative to the Sun. HD 33266 shows an absence in C (-0.18 dex) and N (-0.06 dex) abundances, while its [O/H] is 0.25 dex. The [Al/H] abundance is 0.26 dex. The Si, S, and Ti abundances are overabundant by 0.26, 0.51, and 0.10 dex relative to the Sun, respectively. The Mg and Ca abundances are nearly at solar value by -0.08 and -0.04 dex, respectively, while the Sc abundance is very low at -0.68 dex. The V, Cr, Mn, and Ni abundances are overabundant by 0.57, 0.22, 0.45, and 0.67 dex relative to the Sun, respectively. In contrast, the abundances of Zn, Sr, Y, Zr, and Ba are higher than 0.65 dex. The abundances of both stars are listed in Table 3 and their differences in terms of solar values are shown in Figure 2.

We checked if the target stars exhibit possible complications due to chemical peculiarity in their surface distributions. For CP Cyg, we did not find any trace of peculiarity, such as a considerable underabundance of Ca and Sc as seen in Am stars. Thus, the abundance pattern of CP Cyg reveals that this star is a chemically normal A-type star.

On the other hand, almost all ions of HD 33266 show notable overabundance in iron peak (V, Cr, Mn, Ni) and heavy elements (Zn, Y, Zr, Sr, Ba). The Sc abundance of -0.68 ± 0.07, Ca abundance of -0.04 ± 0.15, and effective temperature of 9200 K is similar to o Peg ([Sc/H] $= -0.37$, [Ca/H] $= 0.14$, $T_{\rm eff} = 9600$ K), which is classified as a hot Am star by (Adelman, 1988).

Table 5: The apparent magnitude in the V band, m_{v} (Oja, 1991; Perryman and ESA, 1997), parallax, π, (van Leeuwen, 2007), absolute magnitude, M_{v} (this study), bolometric correction, BC (Balona, 1994), luminosity, $\log(L/L_{\odot})$ (this study), and logarithmic effective temperature, $\log T_{\mathrm{eff}}$ (this study).

Star name	m_{v} [mag]	π [mas]	M_{v} [mag]	BC	$\log(L/L_{\odot})$	$\log T_{\mathrm{eff}}$ [K]
CP Cyg	6.20 ± 0.009	5.92 ± 0.34	-0.044 ± 0.016	0.043	1.889 ± 0.070	3.881 ± 0.006
HD 33266	6.17 ± 0.003	7.59 ± 0.52	0.988 ± 0.017	-0.145	1.551 ± 0.062	3.964 ± 0.005

Another characteristic indicator of Am stars is their low rotational velocities ($<$ 120 km s^{-1}, Abt and Morrell, 1995). HD 33266 has a low $\mathrm{v}\sin\mathrm{i}$ value as similar as o Peg, which is 6 km s^{-1}. As a result, the abundance pattern and $\mathrm{v}\sin\mathrm{i}$ of HD 33266 allow us to assign it as an Am star.

The luminosity of each star was calculated from the apparent magnitude and parallax given in Table 5. In Figure 3, we placed both stars on the H-R diagram using the calculated luminosities and the derived effective temperatures from Section 3. We took the evolutionary tracks with solar metallicity from (Salasnich et al., 2000) and plotted them on the H-R diagram as black lines for masses of 2.20 M$_{\odot}$ (dash-dot) and 2.50 M$_{\odot}$ (solid). By taking into account these evolutionary tracks, we note that HD 33266 is a main sequence star with a mass of 2.30 ± 0.06 M$_{\odot}$ and CP Cyg is most likely a sub-giant star with a mass of 2.48 ± 0.09 M$_{\odot}$.

To estimate the ages of each star, four isochrones (260, 390, 630, and 760 Myr) with solar metallicity were taken from Marigo et al. (2008) and plotted on the H-R diagram as gray lines. With the help of these isochrones, the age of CP Cyg and HD 33266 are estimated as 690 ± 65 Myr and 340 ± 65 Myr, respectively.

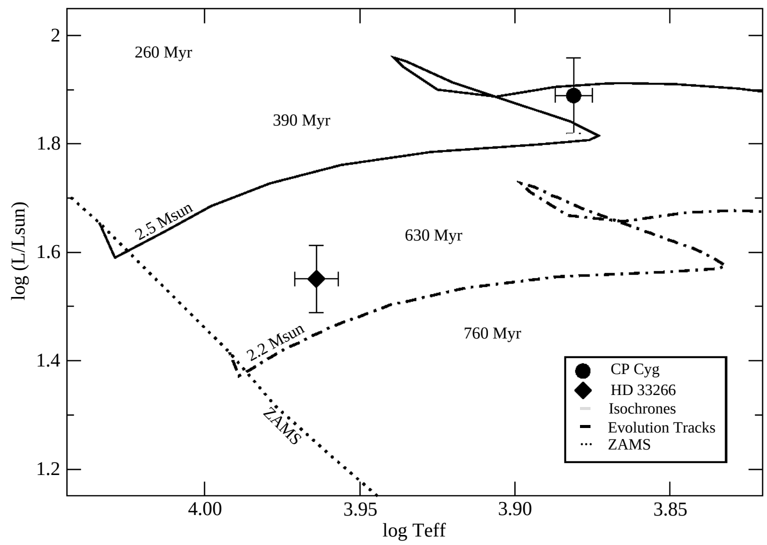

Figure 3: The position of CP Cyg and HD 33266 on the H-R diagram. Evolutionary tracks are from Salasnich et al. (2000) and isochrones from Marigo et al. (2008).

It is difficult to estimate the initial chemical composition of field stars, as the birthplace of these stars is hard to specify. Detailed elemental abundance analysis of many open clusters, which were performed in the last few decades, provide the chemical composition of stars with various spectral types for different age groups. This let us to compare the abundance pattern of our target stars with those of cluster members having similar ages: Hyades (age $\sim$ 625 Myr) and Coma Berenices (age $\sim$ 450 Myr).

We compared HD 33266 (A2m, age $\sim$ 340 Myr) with HD 106887 (A4m, $T_{\rm eff}$ = 8291 K, log g = 4.20, age $\sim$ 450 Myr) in Coma Berenices cluster analyzed by Gebran et al. (2008). Although these two stars do not have any common origin, the abundance pattern of HD 33266 surprisingly resembles HD 106887 with few exceptions. Among the light elements, only O is slightly overabundant for HD 33266, while it is slightly underabundant for

HD 106887. The Ti, Cr, Fe, and Ni abundances of both stars are consistent within ±0.1 dex. For HD 33266, Sc is underabundant and Mn is overabundant while the abundance of both elements are solar for HD 106887. The Sr, Y, Zr and Ba are overabundant which have a difference of about 0.1 dex (except for Zr which is 0.25 dex) for both stars. We thus concluded that the initial chemical composition of HD 33266 should not be much different than the stars in Coma Berenices cluster.

We also chose HD 28319 ($T_{\rm eff}$ = 7950 K, log g = 3.70, age of $\sim$ 625 Myr) in the Hyades cluster, which was analyzed by Gebran et al. (2010), to compare the abundances of CP Cyg (age of $\sim$ 690 Myr). The trend of O, Na, and Mg abundances in CP Cyg is higher than that of HD 28319, while Sc, Ti, Mn, and Y abundances are lower. Both stars have similar elemental abundances, which are about [X/H] = ±0.2 dex, except for Zr which is 0.4 dex. These diversities indicate that the origin of CP Cyg could be different from the Hyades member HD 28319.

Our detailed abundance analysis of CP Cyg and HD 33266 gave a chance to compare their abundances with the cluster members of similar age and spectral type. Chemical elemental abundances of HD 33266 is similar to those of Coma Berenices cluster, and the abundance pattern of CP Cyg shows that its origin is likely different from Hyades. As a result, more spectral studies with additional samples are needed for the normal and chemically peculiar stars to understand their abundance behavior as well as their origin.

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