

DOI: <http://dx.doi.org/10.18524/1810-4215.2018.31.144691>

## MOLYBDENUM ABUNDANCE IN SOME OPEN CLUSTERS

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**ABSTRACT.** This paper presents the results of determination of the molybdenum abundances in 13 G, K type stars in the open clusters NGC 2477 and NGC 2506. The abundances of molybdenum were determined using stellar atmosphere models by Castelli & Kurucz (2004), as well as a modified STARSP LTE spectral synthesis code (Tsymbal, 1996). For the used Mo I lines 5506 and 5533 Å the oscillator strengths  $\log g_f$  were adopted from the latest version of the VALD database dated 2016 (Kupka *et al.*, 1999). The high resolution spectra were obtained with a VLT telescope at the European Southern observatory (ESO, Chile).

We used atmospheric parameters of the investigated stars which we had obtained earlier. We have found out that the molybdenum abundances depend on metallicity [Fe/H] in giants of NGC 2506 and NGC 2477. For the stars in NGC 2506, molybdenum is slightly overabundant as compared to the solar abundance; such an overabundance is slightly higher in the stars of the second investigated cluster NGC 2477. Further investigation of the Mo abundance in larger number of open clusters is required to draw reliable conclusions.

**Keywords:** stars: abundances – stars: late-type – Galaxy: disc – Galaxy: evolution.

**АБСТРАКТ.** Наведено результати визначення вмісту молібдену в 13 зорях спектральних класів G, K, розсіяних скупчень NGC 2477 та NGC 2506. Вміст молібдену визначається за моделями атмосфери Кастеллі і Куруц (2004) та модифікованим кодом спектрального синтезу STARSP LTE. Для використовуваних ліній Мо I 5506 та 5533 Å сили осциляторів  $\log g_f$  були взяті з останньої версії (2016) бази даних VALD (Купка *та ін.*, 1999). Спектри високої роздільної здатності були отримані за використання телескопу VLT Європейської південної обсерваторії (ESO, Чилі).

Атмосферні параметри досліджуваних зір були отримані нами раніше. Ми виявили залежність величини вмісту молібдену від металичності [Fe/H] у гігантів скупчень NGC 2506 та NGC 2477. Для зір скупчення NGC 2506 ми отримали малі надлишки вмісту молібдену від сонячного значення і дещо більші для другого досліджуваного скупчення - NGC 2477. Необхідно додатково досліджувати вміст Мо в багатьох РС для отримання більш надійних висновків.

### 1. Introduction

Stellar clusters are groups of loosely gravitationally bound stars which were formed from one and the same gas-and-dust cloud and have similar kinematics and chemical composition.

Open clusters (OC) belong to the plane of the Galactic disc. The age of OCs vary from few Myr to several Gyr. The stellar density in OCs is lower than in globular clusters (GCs) and is decreasing towards the cluster centre. The metallicity [Fe/H] of the OC stars is close to that of the Sun and may differ by a factor of 5. For older clusters, [Fe/H] decreases with increasing distance from the centre of the Galaxy, and on average, it is lower than metallicities of the clusters formed later.

This paper presents the molybdenum abundances estimated for two open clusters, namely NGC 2477 and NGC 2506. The target stars in this study are the G and K type red giants.

It is known that molybdenum is produced in several different processes, such as slow neutron-capture (s-process), rapid neutron-capture (r-process) and proton-capture (p-process) processes.

Mo is a highly convolved element that receives contributions from both the s-process and the p-process and less from the main and weak r-processes (see, e.g. Hansen *et al.*, 2014).

The study of molybdenum is of interest for several reasons: there is limited number of determinations of the molybdenum abundance in the open cluster stars; and virtually, there have been no observations of the field stars with the solar metallicities. At the same time, an important feature of molybdenum is that current model calculations of nucleosynthesis do not describe its contribution to the relevant solar abundance. The data which we obtained make it possible to investigate the ways of production of molybdenum and its enrichment in both individual components of the Galaxy and the entire Galaxy itself.

### 2. Observation data. Basic parameters of the investigated clusters and constituent stars

The spectra used in this study had been obtained earlier by G. Carraro with the multi-object fibre-fed FLAMES facility mounted at the VLT/UT2 telescope at the Paranal Observatory operated by the European Southern Observatory (ESO) in Chile. Either two or three exposures (depending on the cluster; Table 1) were taken with the red arm of

the UVES high-resolution cross-dispersed echelle spectrograph. The UVES spectrograph was set up at the central wavelength 5800 Å thereby covering the 4760–6840 Å wavelength range and providing a resolution  $R=47000$ .

The following basic parameters of the investigated clusters are listed in Table 1: Galactic coordinates (for J2000.0); Galactocentric distance  $R_{GC}$  and age. More detailed information on the data sources can be found in (Mishenina *et al.*, 2015).

Table 1: Basic parameters of the investigated clusters

Name of cluster	$l$ , (deg)	$b$ , (deg)	$R_{GC}$ , (kpc)	age, (Gyr)	$V_r$ , (mag)
NGC 2477	253.563	−05.838	8.9	0.6	+5.8
NGC 2506	230.564	9.935	10.9	1.9	+7,6

As can be seen in Table 1, the cluster NGC 2506 is older and more distant from the Galactic centre than the NGC 2477 cluster.

Earlier, we have determined the atmospheric parameters and chemical abundances of the stars in the clusters NGC 2477 and NGC 2506 (Mishenina *et al.*, 2015).

The following basic and atmospheric parameters are given in Table 2: the ICRS coordinates; photometric data ( $V$ ,  $B-V$ ); effective temperatures  $T_{eff}$ ; gravity factor  $\log g$ ; microturbulent velocity  $V_t$ ; metallicity  $[Fe/H]$  and radial velocity  $V_r$ .

Table 2: Basic data and atmospheric parameters of the investigated stars

Star number	RA(2000.0), (deg)	Dec(2000.0), (deg)	$V$ , (mag)	$B-V$ , (mag)	$T_{eff}$ , (K)	$\log g$	$V_t$ , (km/s)	$[Fe/H]$	$V_r$ , (km/s)
NGC 2477									
4027	118.087 917	−38.577 194	12.153	1.198	4966	2.7	1.4	0.1	$7.03 \pm 0.13$
4221	118.152 083	−38.631 750	12.27	1.171	4975	2.8	1.2	0.19	$8.80 \pm 0.23$
5043	118.040 417	−38.598 306	12.165	1.17	5001	2.8	1.2	0.08	$13.22 \pm 0.27$
5076	118.061 667	−38.629 194	12.41	1.22	4954	2.7	1.2	0.18	$9.22 \pm 0.33$
7266	117.955 000	−38.535 694	12.252	1.193	4966	2.8	1.2	0.19	$9.30 \pm 0.14$
7273	117.947 917	−38.543 389	12.39	1.174	4985	2.8	1.2	0.2	$8.77 \pm 0.51$
8216	118.064 583	−38.457 306	12.334	1.272	4945	2.7	1.2	0.14	$3.99 \pm 0.50$
NGC 2506									
1112	120.013 750	−10.762 250	12.961	0.958	4969	2.6	1.2	−0.22	$83.99 \pm 0.27$
1229	120.030 833	−10.740 722	13.118	1.011	4728	2.4	1	−0.22	$82.54 \pm 0.58$
2109	120.029 583	−10.779 000	13.146	0.89	5040	2.6	0.9	−0.22	$89.31 \pm 0.05$
2380	120.038 750	−10.818 806	13.187	0.927	4992	2.6	1	−0.19	$83.64 \pm 0.53$
3231	119.982 917	−10.805 944	13.105	0.952	4974	2.6	1.2	−0.22	$84.36 \pm 0.51$
5271	120.028 750	−10.752 000	13.204	0.923	4993	2.6	1.1	−0.24	$83.52 \pm 0.15$

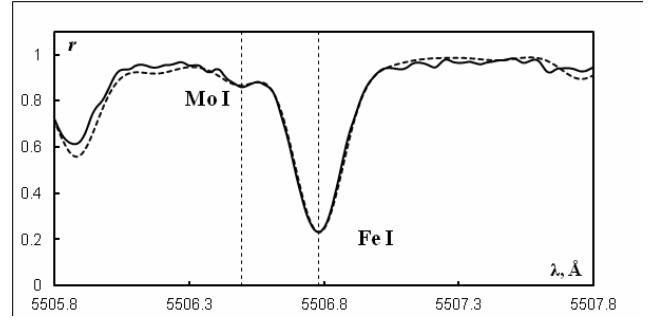


Figure 1: An example of the observed and synthetic spectra in the region near the Mo I 5506.493 Å line for the star 5271 in the NGC 2506 cluster.

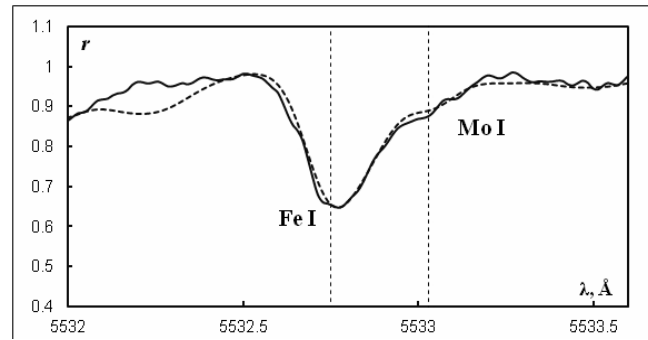


Figure 2: An example of the observed and synthetic spectra in the region near the Mo I 5533.031 Å line for the star 5271 in the NGC 2506 cluster.

Table 3: The resulting Mo abundance determinations, rms deviations  $\sigma$  and metallicities  $[\text{Fe}/\text{H}]$  (Mishenina *et al.*, 2015) for 13 giants in NGC 2477 and NGC 2506.

NGC 2477				
Star number	$[\text{Fe}/\text{H}]$	$\pm\sigma$	$[\text{Mo}/\text{H}]$	$\pm\sigma$
4027	0.1	0.12	-0.12	0.14
4221	0.19	0.09	-0.19	0.06
5043	0.08	0.12	-0.23	0.14
5076	0.18	0.12	-0.14	0.12
7266	0.19	0.12	-0.08	0.08
7273	0.2	0.1	-0.11	0.07
8216	0.14	0.12	-0.24	0.06
NGC 2506				
Star number	$[\text{Fe}/\text{H}]$	$\pm\sigma$	$[\text{Mo}/\text{H}]$	$\pm\sigma$
1112	-0.22	0.1	-0.12	0.19
1229	-0.22	0.11	-0.4	0.12
2109	-0.21	0.17	-0.09	0.07
2380	-0.19	0.13	-0.23	0.35
5271	-0.22	0.13	-0.22	0.09
3231	-0.24	0.12	-0.11	0.11

### 3. Analysis of the abundance determinations and the results obtained

The molybdenum abundances were determined for 13 giants in two OCs using stellar atmosphere models by Castelli & Kurucz (2004), as well as a modified STARSP LTE spectral synthesis code (Tsymbal, 1996). For the used Mo I lines 5506 and 5533 Å the oscillator strengths  $\log g_f$  were adopted from the latest version of the VALD database dated 2016 (Kupka *et al.*, 1999).

The processing of observed spectra (continuum definition, smoothing at three points etc.) was carried out using the DECH20 software package (Galazutdinov, 1992).

The examples of fitting the calculated spectra to the observed spectra of the star 5271 in the NGC 2506 cluster are shown in Figs. 1 and 2.

As can be seen from Figs. 1 and 2, the molybdenum line is in the wing of the iron line at 5506.493 Å and 5533.031 Å lines, respectively, i.e. it is blended by the iron line. This means that correct determination of the molybdenum abundance requires fitting the synthetic spectrum to the observed spectrum at the regions near the Fe lines 5506.440 Å and 5532.870 Å, respectively; hence, we carried out such a fitting in this study.

Table 3 summarizes the resulting determinations of the molybdenum abundance, the root-mean-square (rms) deviations  $\sigma$  and metallicities  $[\text{Fe}/\text{H}]$  (Mishenina *et al.*, 2015) for 13 giants in NGC 2477 and NGC 2506.

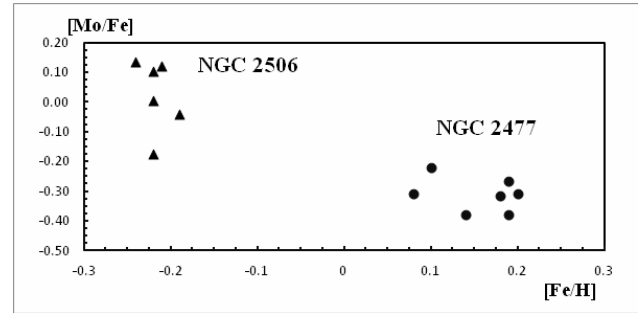


Figure 3: The dependence of the molybdenum abundance on the metallicity  $[\text{Fe}/\text{H}]$  for all stars in the OCs NGC 2506 and NGC 2477.

The dependence of the molybdenum abundance on the metallicity  $[\text{Fe}/\text{H}]$  in the investigated stars in NGC 2506 and NGC 2477 is shown in Fig. 3.

To determine the ratio between the Mo abundance and the solar  $[\text{Mo}/\text{Fe}]$ , the following data of the Fe and Mo abundances in the solar atmosphere were adopted from the study (Asplund *et al.*, 2009): Mo = 1.88, Fe = 7.50.

### 4. Conclusions

The molybdenum abundances in NGC 2477 and NGC 2506 are close to the solar ones.

For the stars in NGC 2506, molybdenum is slightly overabundant as compared to its solar abundance; such an overabundance is slightly higher in the stars of the second investigated cluster NGC 2477.

In future in order to provide a detailed picture of the enrichment of open clusters in molybdenum, we are to determine the molybdenum abundances for a larger number of clusters and compare these data with those reported in the literature.

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