LETGS observations of Delta Orionis: Variability by eclipsing?

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Introduction

We report on the temperature structure and its distance relative to the stellar surface as well as variability in the stellar wind of the O−supergiant Delta Orionis. The X−ray spectra were obtained by LETGS on board CHANDRA, covering a range from 0.07−2 keV i.e., 6−175 A.
The dominating temperatures are in the range from 0.1 to 0.6 keV, corresponding with 1−7 MK. In this temperature regime many lines of H− and He−like ions appear, such as CVI, NVI, NVII, OVII, OVIII, Ne IX, Ne X, together with several ions of highly ionized iron such as Fe XVII and Fe XVIII (see Fig.1).
Delta Ori is a complex and eclipsing system.
Most X−ray radiation is produced in an area close to the stellar surface (< 10R*). Especially the higher stages of ionization of the ions, i.e., the hotter ions such as Ne IX and Mg XI are formed closest to the stellar surface.

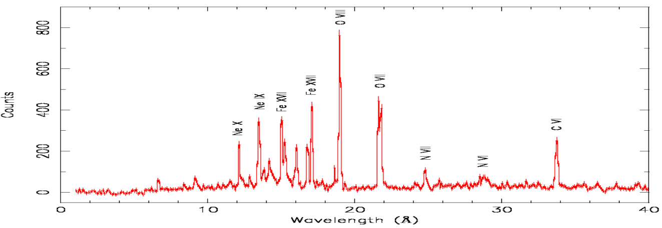

Fig 1. Part of the LETGS spectrum of Delta Ori.

In Fig.2 we show a fit of the spectrum applying the SPEX code (Kaastra et al. 1996a) in combination with MEKAL (Mewe et al. 1995; Kaastra et al. 1996b).
The fit model is a Collisional Ionization Equilibrium (CIE) model for optically thin plasmas, based on ionization equilibrium calculations by Arnaud and Rothenflug (1985).

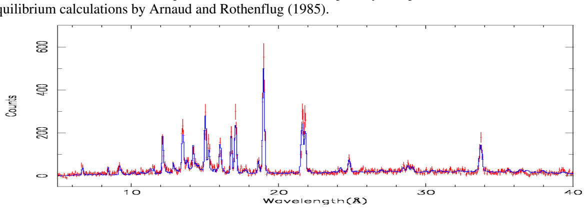

Fig. 2. Part of the spectrum of Delta Ori modeled with a CIE−model in combination with SPEX.

The He−like ions N VI, O VII, Ne IX, Mg XI and Si XIII are strong diagnostic tools.
The He−like line triplet, consisting of the resonance (r), the intercombination (i), and the forbidden (f) line, is sensitive to density as well as to the radiative UV field. The latter is especially true for hot, UV luminiscent O−stars. Here we use the line ratio f/i in the ions N VI, O VII, Ne IX, and Mg XI to locate the emission zone of the ions relative to the stellar surface.
In Fig.3 the relative formation distance of the ions N VI, O VII. Ne IX and Mg XI is given relative to the sellar surface.

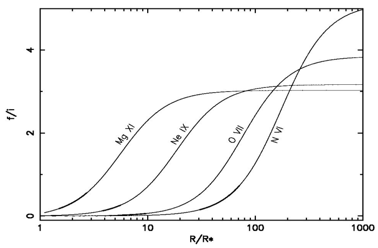

Fig. 3. The curves show the calculated f/i line ratio as a function of the formation distance for the labelled He−like ions. Thickened parts indicate the actually measured f/i value with error bars for each ion.

Delta Ori is a complex systems, containing several stars. Dominant components are the O9.5II and B0.5III stars. They are separated by 4R*. The period is 5.74 days.
Fig. 4 shows the lightcurve. During the beginning of the observation the B0.5III star was partly in front of the O−star. If the minimum in the lightcurve is due to this eclips, part of the X−ray emission originates within 4R*.
To Prove this statement we have modeled the spectrum divided over three time intervals of 33000 seconds each.
The results of these CIE model fits are given in table 1.
The calculations concern temperature, emission measures and abundances. Abundances are given relative to solar photospheric values (Anders and Grevesse 1989, Grevesse and Sauval 1999).

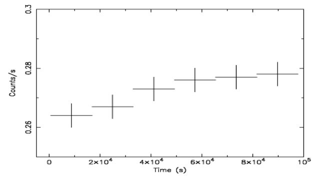

Fig. 4 The lightcurve of Delta Ori.

Parameters				
model	total	0-33400s	33400-66700s	66700-98500s
$\log N_H$[cm^{-2}]	20.12	20.12	20.12	20.12
z (Redshift)	-4.2e-4-+4.3e-6	-2.0e-4-+3.9e-5	-3.2e-4-+2.0e-5	-9.4e-4-+7.3e-6
v_{mic}	1012(18)	1106(36)	998(34)	1000(35)
T_1[keV]	0.113(.004)	0.102(.006)	0.113(.005)	0.129(.006)
T_2[keV]	0.220(.004)	0.217(.006)	0.213(.007)	0.246(.014)
T_3[keV]	0.574(.009)	0.582(.018)	0.574(.015)	0.576(.017)
EM_1[10^{54}cm^{-3}]	8.73(.72)	8.63(1.22)	8.84(1.20)	11.1(1.44)
EM_2[10^{54}cm^{-3}]	11.9(.68)	12.8(1.08)	11.2(1.15)	11.4(1.36)
EM_3[10^{54}cm^{-3}]	7.98(.39)	7.27(0.67)	8.59(0.69)	7.91(0.72)

Table 1 Temperatures and emission measures from CIE−model fits.

C	0.250(.016)	0.253(.031)	0.269(.030)	0.227(.026)
N	0.233(.020)	0.257(.039)	0.197(.033)	0.231(.032)
O	0.201(.009)	0.200(.015)	0.207(.015)	0.188(.015)
Ne	0.260(.016)	0.254(.028)	0.251(.027)	0.248(.024)
Mg	0.164(.021)	0.163(.037)	0.164(.036)	0.164(.036)
Si	0.139(.012)	0.143(.022)	0.161(.021)	0.087(.036)
Fe	0.146(.007)	0.153(.013)	0.144(.012)	0.134(.010)

Table 1 Abundances from a CIE−model fit relative to solar photospheric values. The columns show fits to the total spectrum, the first 33ks, the middle 33ks, and the last 32ks.

Apart from the CIE−model fits the fluxes, wavelengths and Full Width at Half Maximum of individual line features have been measured to search for differences between the three chosen time intervals.
The results are collected in Table 2. It concerns stronger lines because the weaker ones have to few counts in time limited intervals.

ion	λ_0 [Å]	0-33.4ks λ_{obs} [Å]	33.4-66.7ks λ_{obs} [Å]	66.7-98.5ks λ_{obs} [Å]	0-33.4ks $FWHM/\lambda$	33.4-66.7ks $FWHM/\lambda$	66.7-98.5ks $FWHM/\lambda$	0-33.4ks $Flux_{obs}$	33.4-66.7ks $Flux_{obs}$	66.7-98.5ks $Flux_{obs}$
Si XIII	6.688	6.623(.012)	6.650(.012)	6.648(.030)	.0131(.0131)	.0000(—-)	.0000(fix)	0.181(0.052)	0.276(0.062)	0.119(0.045)
Mg XI	9.250	9.189(.038)	9.192(.023)	9.206(.035)	not appl.	not appl.	not appl.	0.609(0.135)	0.578(0.119)	0.645(0.149)
Ne X	12.134	12.132(.011)	12.123(.007)	12.128(.005)	.0045(.0031)	.0044(.0021)	.0015(.0015)	0.735(0.245)	1.080(0.264)	0.942(0.194)
Fe XVII	15.013	15.012(.005)	15.006(.006)	15.016(.006)	.0050(.0009)	.0049(.0009)	.0055(.0011)	2.237(0.266)	2.012(0.253)	2.177(0.276)
Fe XVII	16.775	16.780(.008)	16.772(.008)	16.767(.008)	.0044(.0013)	.0049(.0013)	.0052(.0013)	1.311(0.224)	1.227(0.213)	1.318(0.224)
O VIII	18.969	18.973(.004)	18.972(.004)	18.962(.003)	.0064(.0005)	.0055(.0005)	.0050(.0005)	6.997(0.447)	6.246(0.427)	6.523(0.434)
C VI	33.736	33.721(.012)	33.725(.011)	33.736(.015)	.0055(.0009)	.0056(.0007)	.0067(.0011)	4.748(0.652)	5.633(0.660)	5.098(0.654)

Table 2. Measured wavelengths, FWHM over lambda and line fluxes (10 photons cm s).

The idea is that during the eclips phase especially hot plasma produced near the stellar surface (see Fig. 3) will be hidden behind the compagnion at 4R*.
This idea to notice some lower line fluxes for the hotter ions in the first selected period is not confirmed by the measurements, although Ne X might give a hint. Mg XI and Si XIII suffer by bad statistics.

Conclusions

The line rich spectrum of the early type star Delta Ori (O9.5 II) was analyzed by means of a collisional ionization equilibrium model for optically thin plasma, resulting in temperatures from 0.1 to 0.6 keV.
The abundances derived from these fits are given relative to solar photospheric values and are subsolar.
Based on the He−like f/i ratio the average emission areas have been located as < 44 R* for N VI and from 3 to 15 R* for Mg XI, Ne IX and O VII. No convincing additional prove by means of the eclipsing nearby compagnion has been obtained.

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