

# Astrophysics II - Exercise Sheet 7

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## 1 Measuring the abundances of heavy elements in a distant galaxy

When the line of sight to a high-redshift quasar crosses the disk of a galaxy, we observe in the spectrum of this quasar a strong Ly $\alpha$  absorption line. Analyzing this line allows the determination of the column density of neutral hydrogen (HI), as well as the lines of heavy metals like zinc (Zn) or chrome (Cr), which then give information about these elements. In the spectrum of the quasar PHL 957 ( $z_{\text{em}} = 2.681$ ), Pettini et al. have detected such a system of absorption lines at the redshift  $z_{\text{abs}} = 2.3091$ , with a column density  $N_{\text{HI}} = 2.5 \cdot 10^{21} \text{ cm}^{-2}$ . Among the detected lines, we mention four in particular, with the following characteristics:

$n$	Id	$\lambda_0$ [Å]	$f$	$W_\lambda$ [Å]
1	ZnII	2025.48	0.515	$0.051 \pm 0.006$
2	CrII	2055.60	0.140	$0.080 \pm 0.006$
3	CrII	2061.57	0.105	$0.097 \pm 0.008$
3	ZnII	2062.00	0.253	$0.097 \pm 0.008$
4	CrII	2065.50	0.070	$0.042 \pm 0.006$

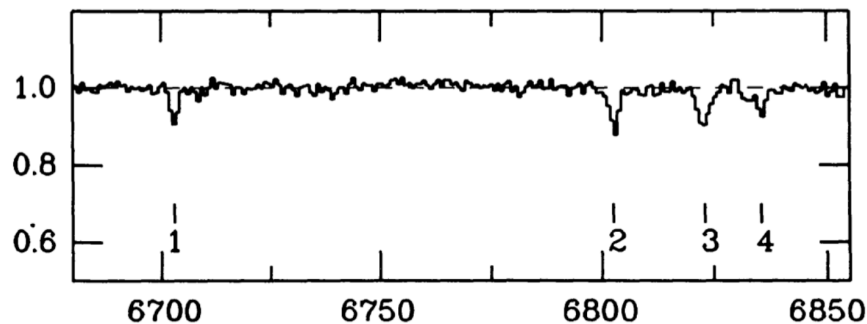


Figure 1: Observed spectrum of the quasar PHL957. The  $x$ -axis is in Å.

It is important to note that the third line is composed of the superposition of two very close lines. The equivalent width that is given is of course that of this superposition. The wavelength  $\lambda_0$  is that of the line in a laboratory, and  $f$  is the oscillator force. We recall that for an optically thin line, we have, with  $W_\lambda$  and  $\lambda_0$  given in Å,

$$N [\text{cm}^{-2}] = 1.13 \cdot 10^{20} \frac{W_\lambda}{f \lambda_0^2} \quad (1)$$

Let's also recall that due to the spectral shifting, the observed equivalent widths are also multiplied by  $1 + z_{\text{abs}}$ . However, this effect has already been corrected in the data given above.

1. Explain why it is reasonable to suppose that lines 2 and 4 are optically thin. What would we have observed if this wasn't the case ?
2. Deduce from this an estimate of  $N_{\text{CrII}}$ .

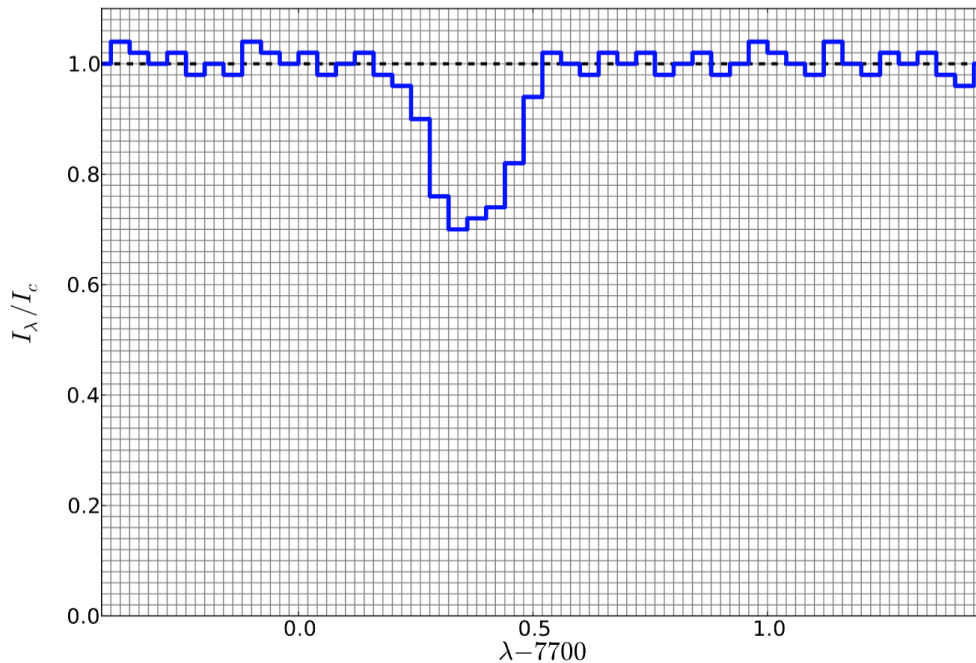
3. Assuming that line 1 is optically thin (justify this in a few words by making use of question 2), estimate  $N_{\text{ZnII}}$ .
4. We will assume that when two optically thin lines overlap (as is the case for line 3), their equivalent widths add up. By using the value of  $N_{\text{CrII}}$  obtained in question 2, derive a second estimate of  $N_{\text{ZnII}}$  and comment. In what follows, adopt the mean of those two values.
5. We can suppose that  $N_{\text{HI}} = N(\text{H})$ ,  $N_{\text{ZnII}} = N(\text{Zn})$  and  $N_{\text{CrII}} = N(\text{Cr})$ , in other words, HI, ZnII and CrII are the main ionization states of the elements hydrogen, zinc and chrome, respectively. Derive the relative abundances of zinc and chrome in this distant galaxy, in units of their solar abundance,

$$\left[ \frac{N(\text{Zn})}{N(\text{H})} \right]_{\odot} = 4.6 \cdot 10^{-8} \quad \text{and} \quad \left[ \frac{N(\text{Cr})}{N(\text{H})} \right]_{\odot} = 4.8 \cdot 10^{-7} \quad (2)$$

6. Comment on the previous values, knowing that in the interstellar medium of our galaxy, almost no zinc is condensed in grains, while chrome is.
7. Establish the assumption made at the beginning of question 4.

## 2 Analysis of an interstellar neutral potassium absorption line

The figure below represents a spectrum in which the line of neutral potassium KI, of rest-frame wavelength  $\lambda_0 = 7698.96 \text{ \AA}$  and oscillator strength  $f = 0.339$  is detected. The instrumental resolution is  $\mathcal{R}_{\lambda} = 10^5$ .



1. Estimate, for this spectrum, the value of the signal-to-noise ratio (SNR) per pixel and per resolution element.
2. Estimate the width at half-height of the line. Is it resolved ?
3. What constraint can one derive on the temperature of the gas or on its turbulent velocity dispersion ?

4. What is the redshift  $z$  of the absorbing gas ? What is its relative velocity compared to the observer ? If we repeat the observation a few months later, would we obtain the same result ? On which parameters do potential changes depend ?
5. Estimate the equivalent width of this line. Can this be used to robustly derive the column density  $N(\text{KI})$  ?

### 3 Identification of absorption lines in a quasar spectrum

We consider a series of lines (numbered 1 to 17) whose wavelengths observed in the spectrum of a distant quasar are as follows:

$n$	$\lambda_{\text{obs}} [\text{\AA}]$
1	4047.9
2	4054.8
3	4149.3
4	4332.4
5	4360.0
6	4385.2
7	4745.7
8	4760.4
9	4785.3
10	4802.8
11	4812.0
12	4819.7
13	5147.1
14	5160.1
15	5193.4
16	5764.6
17	5790.2

Identify these lines using the table given below. For each of the 17 lines observed, indicate the relevant transition and the redshift of the absorbing element. We suggest to start with the doublets (4,5), (11,12) and (13,14).

Transition	$\lambda_0 [\text{\AA}]$	Transition	$\lambda_0 [\text{\AA}]$	Transition	$\lambda_0 [\text{\AA}]$
HI $\lambda 1215$	1215.6701	AlII $\lambda 1670$	1670.7874	FeII $\lambda 2260$	2260.7805
OI $\lambda 1302$	1302.1685	PbII $\lambda 1682$	1682.1500	FeII $\lambda 2344$	2344.2140
SiII $\lambda 1304$	1304.3702	NIII $\lambda 1703$	1703.4050	FeII $\lambda 2374$	2374.4612
CII $\lambda 1334$	1334.5323	NIII $\lambda 1709$	1709.6000	FeII $\lambda 2382$	2382.7650
CuII $\lambda 1358$	1358.7730	NIII $\lambda 1741$	1741.5490	MnII $\lambda 2576$	2576.8770
NIII $\lambda 1370$	1370.1310	NIII $\lambda 1751$	1751.9100	FeII $\lambda 2586$	2586.6500
SiIV $\lambda 1393$	1393.7550	SiII $\lambda 1808$	1808.0126	MnII $\lambda 2594$	2594.4990
SII $\lambda 1400$	1400.4000	AlIII $\lambda 1854$	1854.7160	FeII $\lambda 2600$	2600.1729
SiIV $\lambda 1402$	1402.7700	AlIII $\lambda 1862$	1862.7900	MnII $\lambda 2606$	2606.4620
GaII $\lambda 1414$	1414.4020	TiIII $\lambda 1910a$	1910.6000	MgII $\lambda 2796$	2796.3520
SiII $\lambda 1526$	1526.7070	TiIII $\lambda 1910b$	1910.9700	MgII $\lambda 2803$	2803.5310
CIV $\lambda 1548$	1548.1950	ZnII $\lambda 2026$	2026.1360	MgI $\lambda 2852$	2852.9642
CIV $\lambda 1550$	1550.7700	CrII $\lambda 2056$	2056.2540	TiII $\lambda 3073$	3073.8770
GeII $\lambda 1602$	1602.4863	CrII $\lambda 2062$	2062.2340	TiII $\lambda 3230$	3230.1310
FeII $\lambda 1608$	1608.4511	ZnII $\lambda 2062$	2062.6640	TiII $\lambda 3242$	3242.9290
FeII $\lambda 1611$	1611.2005	CrII $\lambda 2066$	2066.1610	TiII $\lambda 3384$	3384.7400