HIGH RESOLUTION SPECTRAL ATLAS OF TELLURIC LINES

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Abstract. Before reaching our telescopes, stellar radiation passes through Earth's atmosphere. This interaction causes the formation of a number of telluric lines in registered stellar spectra. In this paper an atlas of atmospheric lines is reported. Observations have been carried out at the 91 cm cassegrain telescope of the *M. G. Fracastoro* observing station of the Catania Astrophysical Observatory equipped with a Czerney-Turner echelle spectrograph. The spectral region examined is between 6800 Å and 7800 Å.

The possibility of using this atlas either to recognize telluric lines or as a wavelength calibration source is also discussed.

1. Introduction

The Earth's atmosphere is the major agent of degradation of astronomical images. Its effects on photometric and spectroscopic observations are important.

The natural light of the night sky consists mostly of airglow, zodiacal light and integrated starlight. At a ground-based observatory, there is also an artificial component, which, at the best observing sites, may be only a small fraction of the natural sky brightness or, at urban sites, many times larger. Moreover, particulates and aereosols present in our atmosphere increase both the extinction locally and the scattering of outdoor lighting. All these effects are deleterious for photometric observations.

Many natural gases constitute the Earth's atmosphere, so when light originating from a star passes through it, some spectral lines are formed and these lines will be registered together with those formed in the star's atmosphere. If one does not take into account the presence of telluric lines, the results may be distorted. The adverse effects of atmospheric lines on spectroscopy are the introduction of errors into wavelength and line strength measurements. An error will be introduced into both the measured wavelength and the measured line strength if a contaminating sky line is blended with the feature to be measured.

This atlas has two main goals. First of all, to show the red region of a typical spectrum is very useful for observers to avoid confusion between telluric and stellar lines. In fact, while the spectrum of hot stars has few features in this region,

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TABLE I

Observed stars. Spectral type (Sp) and V magnitudes are from SIMBAD database

Star HD	Sp	T_{eff} K	$\log g$	V	$v_e \sin i$ km s^{-1}
135742	B8V	12100	3.28	2.61	230
144470	B1V	24500	3.99	3.96	140

cool stars show an opposite behaviour. Furthermore, wavelength calibration lamps commonly used do not have enough lines in this spectral region; it is too difficult to calibrate an astronomical spectrum. A possible use of this atlas is as a wavelength calibration data source. In fact, since atmospheric lines are registered on every order of the echelle spectrum and taken automatically in the same exposure, they represent a potential wavelength calibration source.

Some authors have already published similar atlases, but in most cases, their work considered only the night sky emission lines in the spectral region extending out to 10000 Å (see e.g. Oliva and Origlia, 1992; Osterbrock *et al.*, 1997; Osterbrock *et al.*, 1997). For a complete review on the infrared spectrum of the airglow, see Jones (1973). The visual region has been discussed by Louistisserand *et al.*, 1987); in their paper the authors show the emission lines of the sky observed at the Pic du Midi within the range between 381.0 nm and 660.1 nm.

To build this atlas I have used the absorption lines formed from interaction between light coming from hot stars and our atmosphere. This allowed me to get easily recognizable lines in comparison with the ones created in the night sky and therefore more easily usable both as reference for telluric lines identification and as a calibration source.

2. Observations and Data Analysis

The normal stars listed in Table I have been observed to detect atmospheric lines. Spectroscopic observations have been performed in the 6800–7800 Å range at the 91 cm cassegrain telescope of the *M. G. Fracastoro* observing station of the Catania Astrophysical Observatory equipped with a Czerney-Turner echelle spectrograph. The CCD's pixel size was 22×22 μm. The emission lines of the wavelength calibration lamp show that $R = 13000$. The achieved S/N was about 150. Since an echelle order contains about 200 Å, I had to combine orders belonging to different frames to collect the spectral region as large as possible. The region extending from λ6860 Å to λ7350 Å derives from the frame taken in June 1997 when the observed star was HD 144470, while the region extending from λ7600 Å to λ7690 Å derives

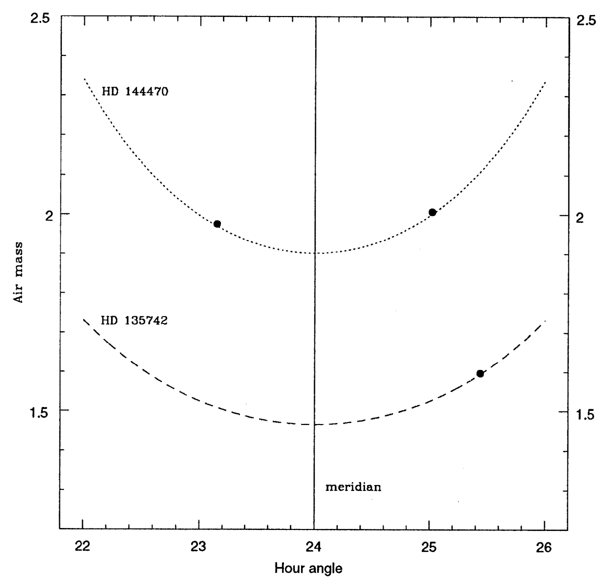

Figure 1. Behaviour of air mass vs hour angle for the observed stars. Dotted line refers to HD 144470, dashed line to HD 135742, points represent the instants of each observations. Hour angles greater than 24:00 refer to observations after meridian, while hour angles less than 24:00 refer to observations before meridian.

from the frame taken in February 1997 when the observed star was HD 135742. The resulting spectrum extends from λ6860 Å to λ7690 Å. It should be noted that missing parts of the spectral region are due to no overlap between orders.

Each star was observed at several hour angles to investigate the influence of air mass on spectral features. For the program stars, the trend of the air mass versus hour angle is reported in Figure 1. The points represent the instants of each observations.

Data have been reduced and analysed using IRAF package. The reduction procedure consisted of subtracking a dark from each frame and dividing it by a flat field obtained in the same region. Then I normalized the resulting spectrum by fitting the continuum with a spline function.

As the program stars have a high value of $v_e \sin i$, spectral features belonging to them differ from those belonging to the Earth's atmosphere in their width: the former are wider than the latter. Besides, the observed stars are early-type stars with few features in the red region. In any case, to avoid confusion, I have calculated the synthetic spectrum using the parameters listed in Table I. This has been done in three steps:

- first of all, I determined the effective temperature and gravity from Strömgren photometry according to the grid of Moon and Dworetsky (1985), as coded by Moon (1985). The photometric colours have been de-reddened with Moon's algorithm (1985). The source of the Strömgren data was SIMBAD database;

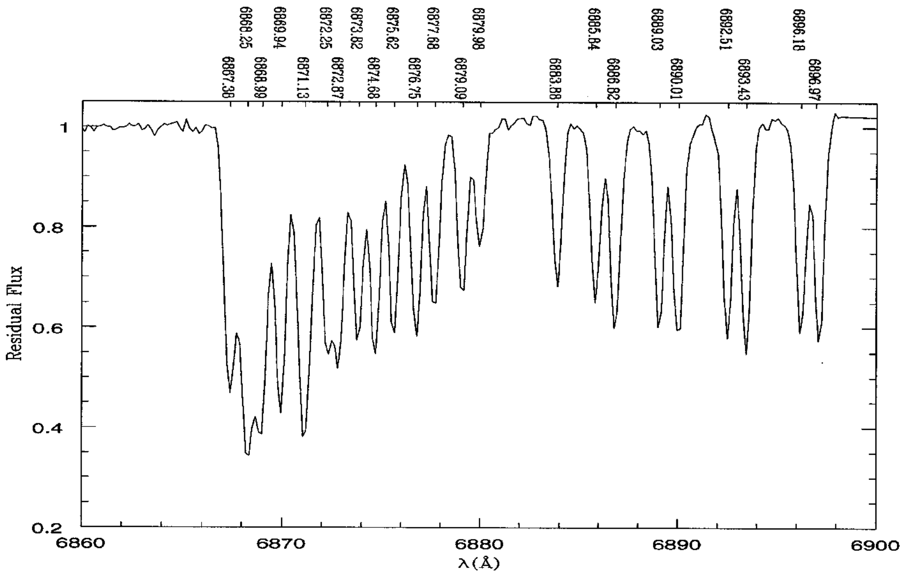

Figure 2. Stellar spectrum taken at Catania Astrophysical Observatory when the observed star was HD 144470. Units are residual flux vs wavelength.

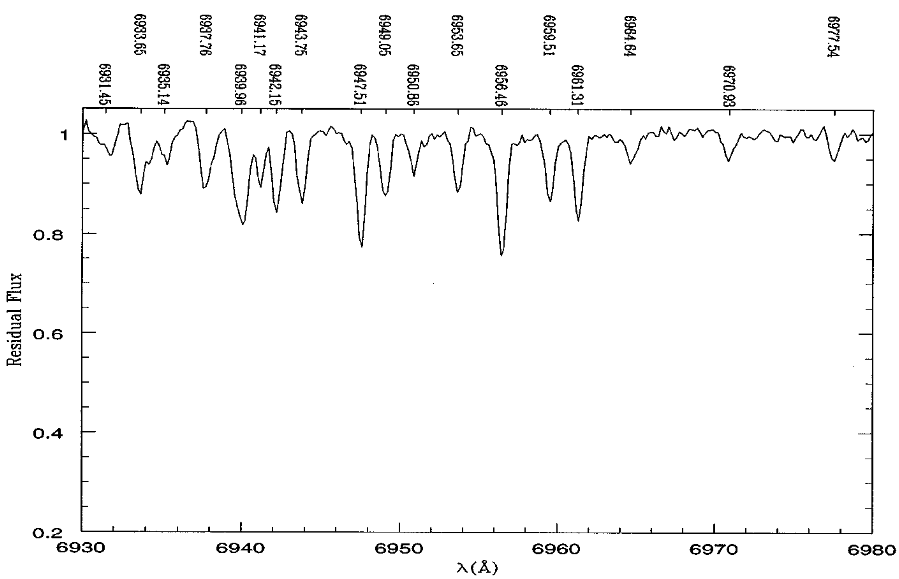

Figure 3. Stellar spectrum taken at Catania Astrophysical Observatory when the observed star was HD 144470. Units as in Figure 2.

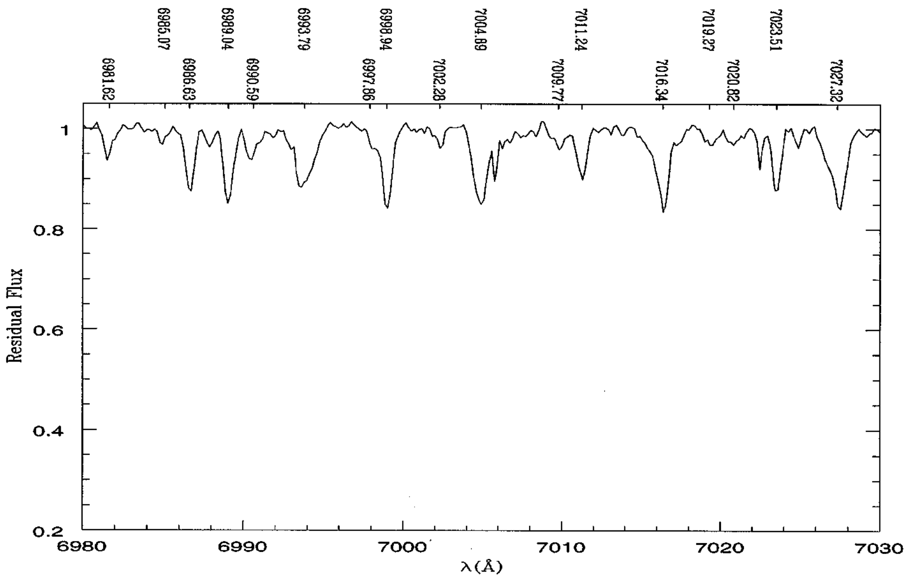

Figure 4. Stellar spectrum taken at Catania Astrophysical Observatory when the observed star was HD 144470. Units as in Figure 2.

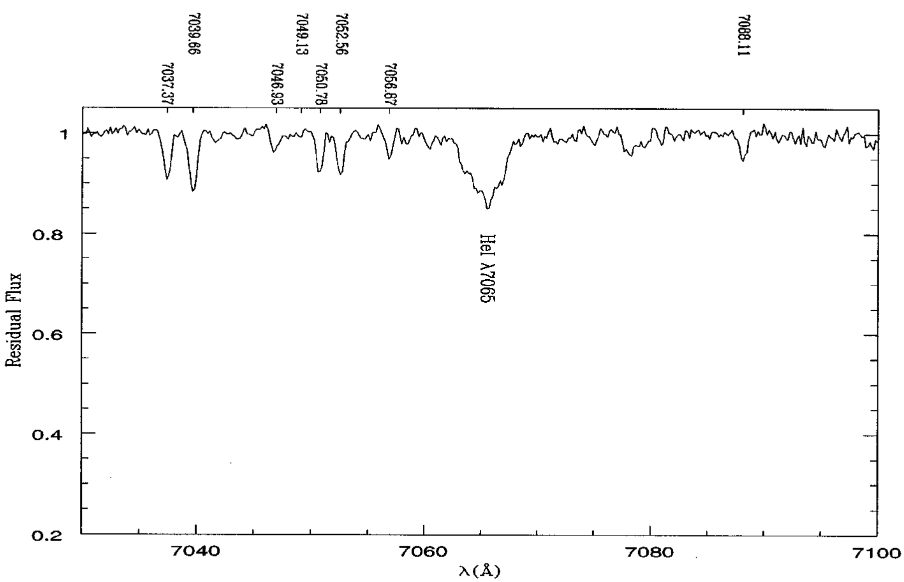

Figure 5. Stellar spectrum taken at Catania Astrophysical Observatory when the observed star was HD 144470. Units as in Figure 2. The HeI λ7065 Å is the only feature belonging ot the star's atmosphere.

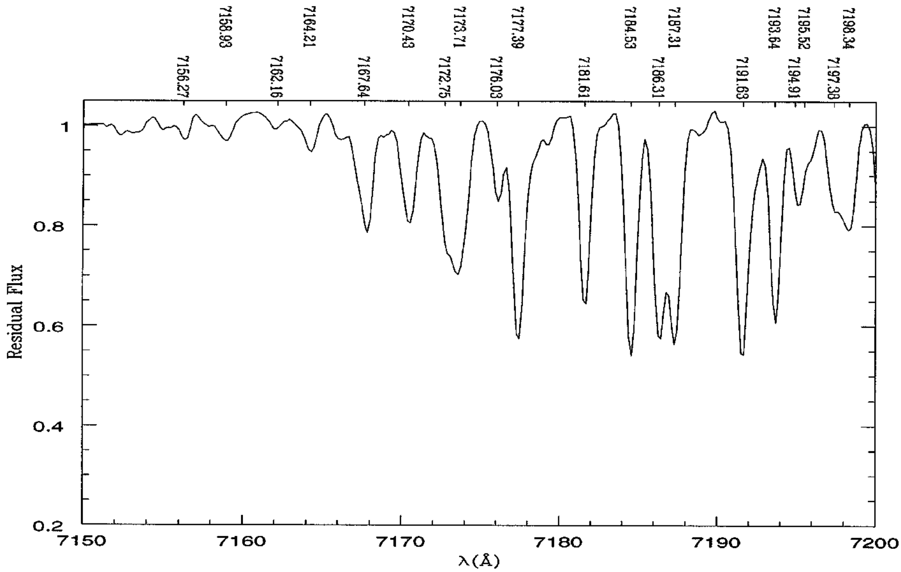

Figure 6. Stellar spectrum taken at Catania Astrophysical Observatory when the observed star was HD 144470. Units as in Figure 2.

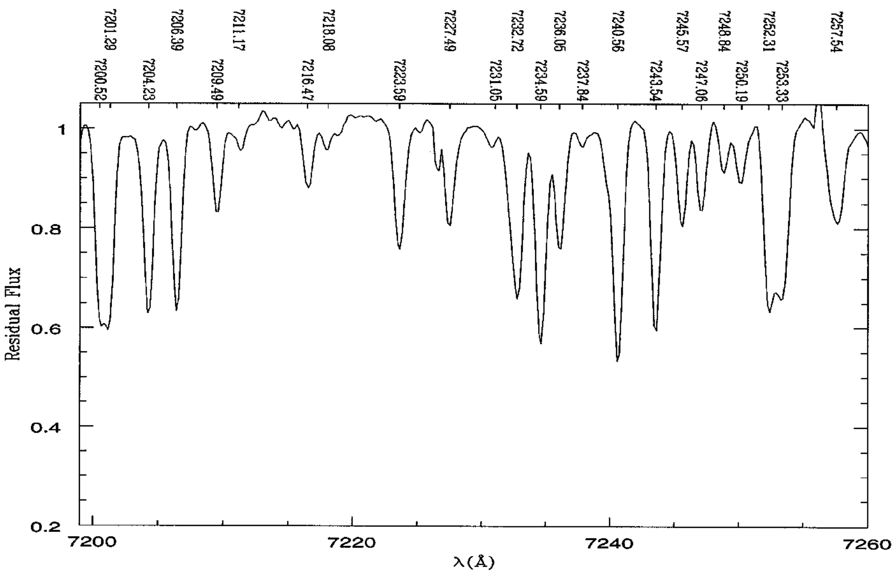

Figure 7. Stellar spectrum taken at Catania Astrophysical Observatory when the observed star was HD 144470. Units as in Figure 2.

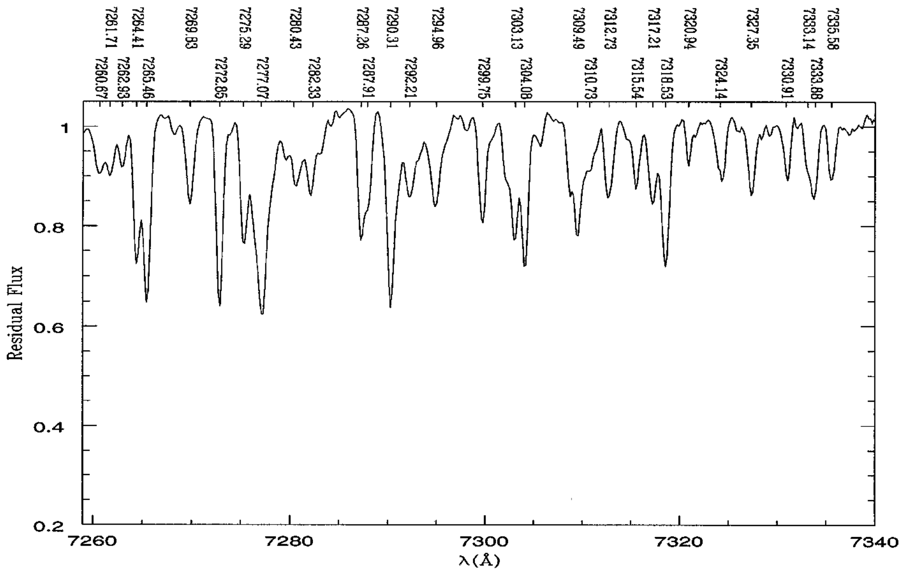

Figure 8. Stellar spectrum taken at Catania Astrophysical Observatory when the observed star was HD 144470. Units as in Figure 2.

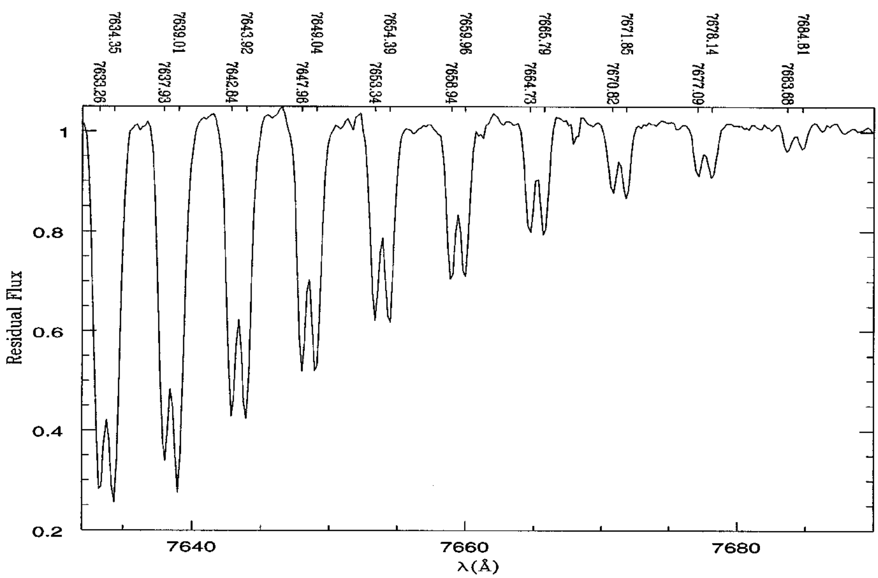

Figure 9. Stellar spectrum taken at Catania Astrophysical Observatory when the observed star was HD 135742. Units as in Figure 2.

TABLE II

List of observed atmospheric lines with their equivalent width

λ (Å)	W (Å)	λ (Å)	W (Å)	λ (Å)	W (Å)	λ (Å)	W (Å)	λ (Å)	W (Å)	λ (Å)	W (Å)
6867.38	0.31	6939.96	0.26	7019.27	0.04	7193.64	0.42	7253.33	0.48	7320.94	0.10
6868.25	0.44	6941.17	0.07	7020.82	0.05	7194.91	0.07	7257.54	0.37	7324.14	0.12
6868.99	0.37	6942.15	0.14	7023.51	0.11	7195.52	0.16	7260.67	0.12	7327.35	0.15
6869.94	0.33	6943.75	0.11	7027.32	0.24	7197.38	0.22	7261.71	0.09	7330.91	0.10
6871.13	0.48	6947.51	0.19	7037.37	0.09	7198.34	0.26	7262.93	0.09	7333.14	0.09
6872.25	0.23	6949.05	0.12	7039.66	0.12	7200.52	0.33	7264.41	0.24	7333.88	0.11
6872.87	0.27	6950.86	0.08	7046.93	0.04	7201.29	0.30	7265.46	0.33	7335.58	0.10
6873.82	0.25	6953.65	0.11	7049.13	0.04	7204.23	0.44	7269.83	0.23	7633.26	0.72
6874.68	0.26	6956.46	0.21	7050.78	0.09	7206.39	0.38	7272.85	0.31	7634.34	0.74
6875.62	0.24	6959.51	0.12	7052.56	0.10	7209.49	0.18	7275.29	0.18	7637.93	0.59
6876.75	0.24	6961.31	0.14	7056.87	0.04	7211.17	0.10	7277.07	0.68	7639.01	0.74
6877.68	0.21	6964.64	0.06	7088.11	0.05	7216.47	0.15	7280.43	0.30	7642.84	0.53
6879.09	0.19	6970.93	0.06	7156.27	0.07	7218.08	0.11	7282.33	0.24	7643.92	0.58
6879.98	0.13	6977.54	0.04	7158.93	0.08	7223.59	0.28	7287.26	0.21	7647.96	0.43
6883.88	0.17	6981.62	0.05	7162.16	0.06	7227.49	0.25	7287.91	0.19	7649.04	0.49
6885.84	0.20	6985.07	0.04	7164.21	0.12	7231.05	0.14	7290.31	0.43	7653.34	0.31
6886.82	0.23	6986.63	0.11	7167.64	0.36	7232.72	0.47	7292.21	0.40	7654.39	0.33
6889.03	0.23	6989.04	0.13	7170.43	0.35	7234.59	0.51	7294.96	0.30	7658.94	0.26
6890.01	0.26	6990.59	0.06	7172.75	0.29	7236.05	0.25	7299.75	0.21	7659.96	0.25
6892.51	0.24	6993.79	0.19	7173.71	0.38	7237.84	0.13	7303.13	0.14	7664.73	0.19
6893.43	0.25	6997.86	0.02	7176.03	0.18	7240.56	0.57	7304.08	0.28	7665.79	0.19
6896.18	0.22	6998.94	0.15	7177.39	0.53	7243.54	0.43	7309.49	0.22	7670.82	0.13
6896.97	0.17	7002.28	0.03	7181.61	0.38	7245.57	0.22	7310.73	0.21	7671.85	0.12
6931.45	0.10	7004.89	0.21	7184.53	0.48	7247.06	0.18	7312.73	0.21	7677.09	0.09
6933.65	0.13	7009.77	0.05	7186.31	0.46	7248.84	0.11	7315.54	0.15	7678.14	0.11
6935.14	0.10	7011.24	0.09	7187.31	0.44	7250.19	0.16	7317.21	0.20	7683.68	0.06
6937.76	0.12	7016.34	0.22	7191.63	0.59	7252.31	0.37	7318.53	0.34	7684.81	0.05

– moreover, I computed the atmosphere models, using ATLAS9 (Kuruck, 1993);
– and finally, using SYNTHE (Kurucz and Avrett, 1981) I identified spectral lines belonging to the star's atmosphere.

From comparison between observed and synthetic spectra I have excluded the presence of stellar lines in this region, except for the HeI λ7065 Å.

3. Lines Identification

Lines identification has been done using the table of solar spectrum published by Moore *et al.* (1966). A complete list of the observed telluric lines, with their equivalent width, is reported in Table II.

3.1. Water vapour

One of the most common and important constituents of our atmosphere is water vapour. Its importance is due not only to its determining effects on weather development within the troposphere, but also to the role as an important partner in the photochemical reactions and important agent of the heat exchange and of atmospheric motions. Due to the bent structure of its molecule, water vapour exhibits a very large number of absorption lines.

The features present in the spectral region extending from 7150 Å to 7340 Å (Figures 5 and 6) are due to the water vapour (Panchuk *et al.*, 1996). Using these lines the troposphere humidity profile can be reconstructed. Study of the correlation between water vapour and temperature is most important to understand the greenhouse effect.

3.2. Oxygen

Oxygen is supplied to the atmosphere from formation of sedimentary rocks and as a result of photodisintegration of water vapour in the upper atmosphere layers. Two oxygen bands have been observed in this spectral region: the band λ6884 Å, transition (0,1) and the band λ7621 Å, transition (0,0). These lines due to rotational tranasition of molecular oxygen of the Earth's atmosphere can be observed in detail so that they offer an excellent opportunity to determine the temperature of the layers where they are effectively formed (Meinel, 1950).

4. Conclusions

When light coming from a star passes through the Earth's atmosphere, a lot of spectral lines are formed. These lines have been collected to provide a high resolution spectral atlas. Observations were carried out at the *M. G. Fracastoro* observing station of the Catania Astrophysical Observatory using the 91 cm cassegrain telescope equipped with a Czerny-Turner spectrograph.

This paper discusses the possibility of using this atlas as a data calibration source to calibrate spectra of astronomical objects and to avoid the errors due to the presence of telluric lines blended with features observed. It also stresses the importance of using a star as a light source to obtain deeper lines instead of only night sky emission lines.

To make an accurate identification I used hot stars with high rotational velocity in such a way to avoid confusion between lines originating in the star's atmosphere and those originating in the Earth's atmosphere. The results are presented in Figure 2 to 9.

Acknowledgements

This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

This paper is based on observations collected at the *M. G. Fracastoro* observing station of the Catania Astrophysical Observatory.

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