The multi-purpose astronomical spectrograph ALBIREO

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Contents

Chapter 1

The spectrograph ALBIREO

1.1 Introduction

The multi-purpose spectrograph ALBIREO has been built jointly by the EROES team of the Laboratoire d'Astronomie Extragalactique et de Cosmologie in Meudon Observatory (France) and the Instituto de Astrofísica de Andalucía in Granada, Spain.

This instrument is permanently mounted at one of the 2 Nasmyth foci (F/8, scale: $1'' = 58.72\,\mu$m) of the 1.52-m telescope at the Sierra Nevada Observatory (Spain) and is being used for various stellar and extra-galactic observing programs (see Table 1.1 for a listing of the spectrograph's general parameters). It provides several modes of observation, using either a long slit for classical spectroscopy or optical fiber devices for multi-object (Medusa) as well as integral field (Argus) spectroscopy (Sánchez et al. 2000).

Table 1.1: Optical characteristics and general parameters of *Albireo*

Focal station	Nasmyth West
Effective Focal Ratio	F/2
Image scale:	
at slit	$0.017''\ \mu\mathrm{m}^{-1}$
at detector	$0.056''\ \mu\mathrm{m}^{-1}$
Detector type	based on a EEV8821/T chip
Pixel size	$22.5\ \mu$m
Wavelength range (Å):	3500-10 000
Long slit	
Dispersion (Å/pixel)	$\sim 1 - 5.7$
Resolution	$3500-500$
Field of view	
Argus (IFU)	
Medusa (MOS)	

1.2 General description

The instrumental chain includes a mechanical interface, the spectrograph itself and the detector. The spectrograph consists of three parts: the "bonnette", the spatial stage and the spectrographic stage. Figure 1.1 shows the principles of the spectrograph.

1.2.1 The mechanical interface or "rotator"

The rotator is an interface between the telescope and the spectrograph that ensures a reliable and reproducible position during the rotation of the telescope. This is important for the

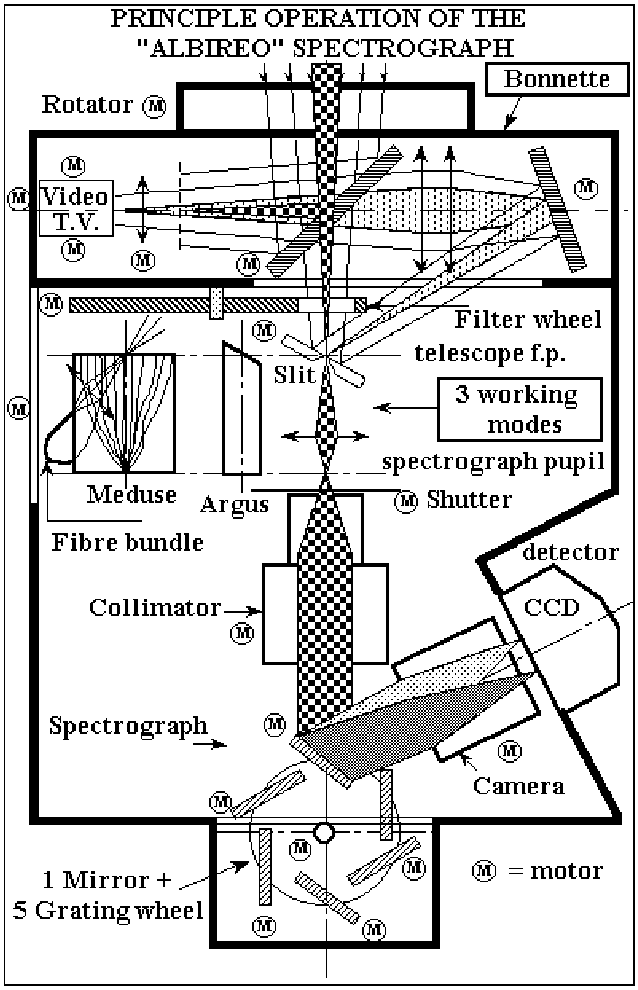

Figure 1.1: The layout of *Albireo*

multi-object mode and may be needed for the long-slit mode when a given orientation is required.

1.2.2 The "bonnette"

It fulfills the functions of field acquisition, guiding and calibration. It contains a high-sensitivity video camera (Herpe et al. 1991) movable on x, y and z axes. When checking the centering in the long-slit and Argus modes, a relay optics views a 18mm (= 5′) field around the slit or the fiber bundle entrance. this configuration may be used for guiding when a suitable (mag 18) star is found. Another configuration allows the scramming of a larger field (a ring of 5′ internal diameter and 20′ external diameter). The bonnette contains also a wavelength calibration unit with for lamps.

1.2.3 The "spatial stage"

Its mission is to select one of the 3 spectrographic modes each with a different spatial coverage: a classical long slit of $6'$ length and adjustable width; a multi-object spectroscopic unit (Medusa) with 40 optical fibers of 200 μm ($= 3.4''$) diameter plugged in an aperture plate covering $20'$; and an integral field spectroscopic unit (Argus) with a bundle of 202 fibers of 88 μm ($= 1.5''$) diameter covering a $15'' \times 30''$ area. A fourth mode is direct imaging. All 4 "spatial" devices are mounted on the same sliding plate and the configuration is rapidly changed (1 min) by the remote control. This part contains also the filter wheel with *U, B, V, R* filters.

A unit for the preparation of aperture plates (Medusa mode) from POSS plates or prints, which is located at the IAA in Granada is also available.

1.2.4 The "spectrograph stage"

It is of classical design, with a dioptric collimator ($F = 336$ mm, $F/D = 5.6$) and camera ($F = 121$ mm, $F/D = 2$) and a 60 mm pupil. The reflection gratings give dispersions between, roughly, 40 and 200 Å mm^{-1}, giving resolved elements of between 2 and 10 Å in Argus mode. The useful wavelength range is from 3500 to 10000 Å.

1.2.5 The detector

It is the CCD detector described in Section 1.4.

1.3 Spectrograph performance

1.3.1 Throughput

A number of flux standards have being observed in photometric conditions to measure the throughput of the complete telescope+spectrograph+detector system. The lowest resolution grating (R300) was used with a wide slit (10 arcsec). Figure 1.2 shows the results.

1.3.2 Exposure times

Atmospheric extinction

Extinction measurements for the sky of Sierra Nevada were made by following a standard star through various airmasses. Figure 1.3 shows the atmospheric extinction curve for the OSN (solid line) and the KPNO and CTIO.

Exposure times

A plot of the flux standard data is available in Fig. 1.2. The y-axis gives the apparent AB magnitude of a star observed at zenith which produces one detected photon per second per Angstrom. In order to calculate the number of detected photons per pixel, the following factors will have to be taken into account:

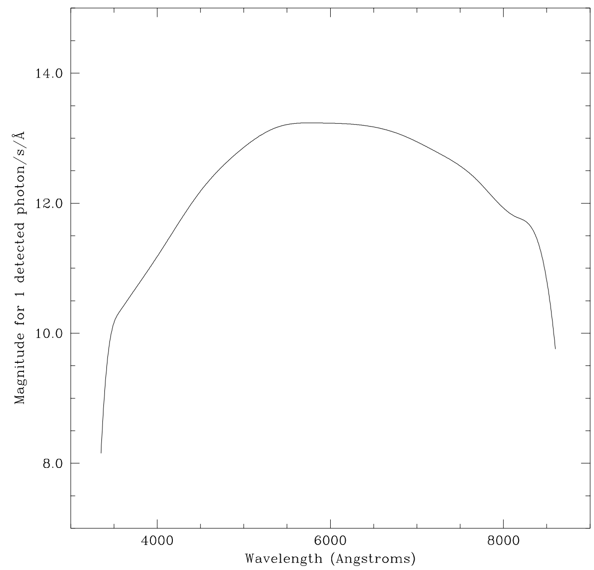

Figure 1.2: Efficiency for the Telescope + Spectrograph + Detector system.

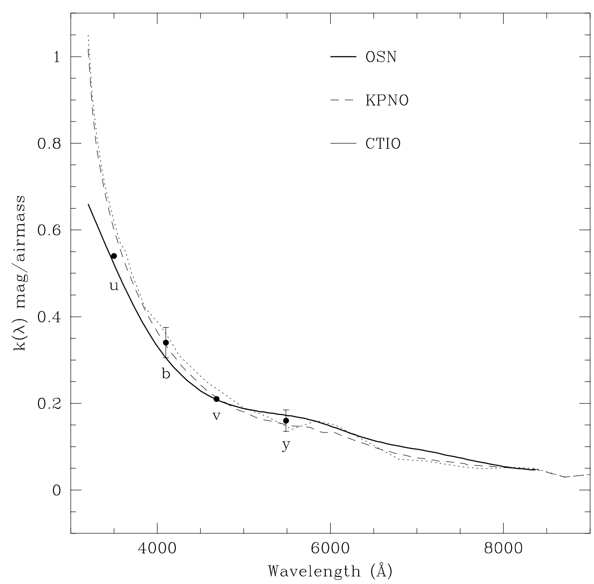

Figure 1.3: Extinction curve for the OSN (solid line). Shown are also the KPNO (dashed) and CTIO (dotted line) curves for comparison. The solid circles represent the values of the extinction coefficients for the u (3500 Å), b (4100 Å), v (4685 Å) and y (5488 Å) bands of the Strömgren system determined from the photometric observations obtained with the 0.90m telescope and the Strömgren photometer.

1. Slit losses: the plot was based on data taken with a wide slit (10"). For a 2" slit in typical 2" seeing, approximately 76% of the star's light will enter the spectrograph.

2. Airmass correction: Fig. 1.2 refers to a star observed at zenith. Corrections for the expected airmass of your object should be made, (see Fig. 1.3 for a plot of extinction versus wavelength). As a guide, at 5500 Å, the extinction is 0.20 Mag per unit Airmass (at 3500 Å it is 0.55; at 4000 Å it is 0.30; at 7000 Å it is 0.10).

3. Grating efficiency: the flux standard data are, by convention, taken with the lowest resolution grating (R300). Scaling to the efficiency of your chosen grating at a particular wavelength will be, therefore, needed. The table of grating options gives the absolute efficiencies at blaze wavelengths.

An example calculation of the expected counts (in detected photons) per pixel in an exposure of 300 seconds of a V=12 star with the R1200B at around 5500 Å. We assume an airmass of 1.15 (correspoding to a zenith distance of 30 degrees), and that we're observing in seeing of 2", with a 2" slit-width.

$$\text{Total Counts} = \frac{t_{\rm exp} \cdot 0.76 \cdot (0.82/0.66) \cdot 10^{-0.4\cdot(12-13.2)} \cdot 1.55}{10^{0.4\cdot(1.15\cdot 0.2)}} \approx 1070$$

where 0.76 represents slit-losses; (0.82/0.66) are the relative grating efficiencies; 1.55 is the dispersion in Å per pixel for the R1200B; $10^{-0.4\cdot(12-13.2)}$ represents the difference in magnitude between target object and the AB standard mag. The bottom line accounts for attenuation due to airmass.

1.3.3 Wavelength range and resolution

Table 1.2 gives the gratings available for use with *Albireo* and their dispersions.

Filters

In Table 1.3, the optical characteristics of the set of Johnson standard filters are given.

1.4 The CCD detector

1.4.1 General description

The current CCD detector for the spectrograph *Albireo* is based on the EEV8821/T chip with 1152 $\times$ 770 pixels of 22.5 μm. The CCD was integrated by staff of the IAA. It is used with its largest side along the dispersion direction. The *three level polysilicon* technology gives a minimum readout noise in the slow reading condition at a temperature of 140 K. It is supplied with a phosphor coating to enhance the blue and UV response. The chip is front illuminated, without anti-blooming channel, with high efficiency transfer charge and equipped with a 16 bits A/D converter. The CCD is read directly by the host via a 10 Mbauds high speed link. A full frame fast readout mode as well as an adjustable sub-raster are available.

The CCD parameters are summarized in Table 1.4

Table 1.2: Parameters of the gratings

Name[1]	Ruling (lines mm^{-1})	Efficiency (%)	Angle (steps)	Central wavelength (Å)	Wavelength range (Å)	Dispersion (Å mm^{-1}) (blue-red)
R300	300	82 at 4500 Å	1 125	5 461	7 000	235-213
R600	600	78 at 4500 Å	480	6 900	2 700	107-94
			1 574	4 300	3 000	112-101
R1200r	1200	62 at 7000 Å	550	7 100	2 000	38-30
			750	6 000	1 600	
			950	4 800	1 600	
			1 150	3 650	1 100	51-44
R1200b	1200	66 at 5800 Å	000	8 400	2 900	38-30
			250	6 650	1 630	
			550	5 150	1 900	
			750	3 800	1 700	51-44
H1800	1800	58 at 5000 Å	300	8 200	1 000	10-4
			500	7 500	1 100	
			800	6 800	1 100	
			1 100	6 000	1 250	
			1 350	5 100	1 150	
			1 600	4 250	1 150	
			1 750	3 700	1 100	30-25

[1]Prefix R for ruled gratings; prefix H for holographic gratings. Suffix *r* for red and *b* for blue.

Table 1.3: Optical characteristics of the filters

Name	Bandpass	Composition
Johnson *U*	2900–4100 Å	1mm UG1+1mm BG14
Johnson *B*	3600–5600 Å	1mm BG28+1mm GG385
Johnson *V*	4700–6700 Å	1mm BG18+1mm GG495
Johnson *R*	5600–7500 Å	1mm OG590+1mm KG5

1.4.2 Performance

Efficiency

Fig 1.4 plots Marconi's measurements of the CCD quantum efficiency (QE) versus wavelength. As can be seen, QE reaches its maximum value of around 45% at 700 nm and decreases steadily towards shorter and longer wavelengths, dropping down to only 7% at 450 and 1000 nm.

Table 1.4: Parameters for the EEV8821/T CCD

Chip	EEV8821/T
Pixel size (μm)	22.5×22.5
Format (pixels)	1152×770
Format (mm)	25.920×17.325
Readout time (seconds)	
Conversion Factor (e^-/ADU)	3.546
Saturation	
R.Q.E. (per cent)	
peak	
400 nm	
800 nm	
Noise:	
Readout noise (e^-)	6.019
Cosmic ray events (events/frame/min) (events/frame/min)	
Dark current (ADUs/pixel/hour)	< 1

Noise level

The readout noise for the *Albireo* CCD chip is given in Table 1.4.

Saturation level and dynamic range

The peak capacity of a CCD pixel is typically 200,000 electrons, and CCDs are demonstrably linear devices up to within a factor of two of this limit. When the limit is exceeded, the arrival of more photons continues to create further photoelectrons, which then spread out along the column of the CCD.

In addition to saturating the chip, it is possible to saturate the analogue-to-digital converter (ADC). Although the maximum digitised count of the 16-bit ADC is 65,535 ($2^{16} - 1$), it is advisable to keep the number of counts below about 35,000 to avoid non-linear effects.

Together with readout noise, the saturation level defines the dynamic range of a CCD, crudely, as (saturation level)/(readout noise).

Detector size and field of view

The total size of the chip is given in Table 1.4. For spectroscopic observations, the detector provides 1152 pixels along the dispersion direction, each 22.5 μm in size. The theoretical pixel scale and field of view are 1.5471 $''$/pixel and $29.7' \times 19.8'$. This is not the case and the actual pixel scale is of 1.26 $''$/pixel, yielding a field of view of $24.2' \times 16.2'$.

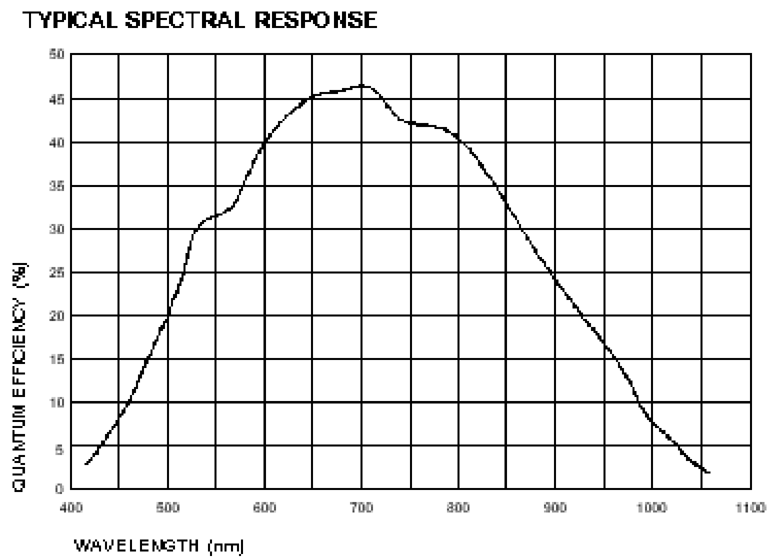

Figure 1.4: Quantum efficiency vs. wavelength (in nm) of the EEV8821/T chip

Cosmic ray events

Cosmic rays are an important source of additional noise on a CCD and they limit the exposure time. A cosmic rays which strikes the detector in a certain pixel produces a huge increase in its charge content shown as a bright and narrow noise spike in the signal. The best way to deal with cosmic rays is to break long exposures into several shorter ones to combine them in the reduction process.

1.4.3 Maintenance

Chapter 2

Preparation for the observing run

In this Chapter, the preparation for an observing run is described in detail. Below, the neccessary steps are summarized:

2.1 At your institute

2.1.1 Introduction

2.1.2 Documentation

It will be possible to obtain detailed information about the observatory, and its telescopes and instruments, from the user documentation system given in the "OSN Users' Document Guide" (Not implemented yet). The Documentation should consist of:

1. an "Observer's Guide", which should describe the Observatorio de Sierra Nevada, its telescopes and instruments, explain how to apply for observing time, how to communicate with and travel to the observatory and show what support you can expect before, during and after an observing run;
2. a series of "User Manuals", like the one you are reading right now, providing detailed information on the operation of the telescopes, instruments and detectors;
3. a series of "Technical Notes" with information on a wide range of topics.

In this manual, you will find also copies of the observing log sheet and the closing report form. Copies of all above can be obtain from Pedro Amado (*pja@iaa.es*) at the IAA-CSIC.

All the documentation, including the manual for this instrument, will soon be available to users through the OSN's WWW page.

2.1.3 The selection of spectral regions

2.2 At the telescope

2.2.1 Introduction

2.2.2 Maintainance of the CCD

Pumping of the CCD

Precautions

Preparation steps

When the vacuum in the dewar is good

When there is no vacuum in the dewar

How to mantain a good vacuum

Filling the dewar with liquid nitrogen

Chapter 3

Observations

The first day of your observing run, switch on the CCD and ask the OSN personnel to fill the CCD up with liquid nitrogen. Keep the CCD switched on all along the observing run.

3.1 In the afternoon

- Check that the CCD dewar has been filled up with liquid nitrogen. Refer to Sect 1.4.3 for how to maintain a good vacuum.

3.2 In the evening/twilight

3.2.1 At the control room

- Switch on the oil pump one or two hours prior to the observations.

- Switch on the dome loudspeaker at the box located on the north wall of the control room.

3.2.2 At the dome

- Check that the oil is circulating.

- Switch on the dome control box located at the east wall of the dome, just beside the door.

- Open the dome by first plugging (if it were unplugged) the cable for the dome electric power located up the stairs on the east side of the dome. Downstairs, open the dome by pressing once the red button marked **??** on the dome control box. When the slit is fully open, the motor will automatically stop.

- Open the windbaffle by keeping pressed the orange button just under the red one which opens the dome slit.

- Open manually the diafragm at the west focus of the telescope by turning the handle located at the rotator of the spectrograph. To reach it, one has to use the platform to get to the level of the spectrograph. Handle parallel to the optical axis = open, perpendicular to the optical axis = closed.

- Go upstairs and unplug the cable for the dome electric power. *Important: do not forget to unplug this cable*, since the dome will not move as long as it remains plugged, or, in case of failure of the safety system, it might wreck the socket and break the cable.

- Have a look around and check that the platform is at the floor level and that there are no obstacles in the movement path of the telescope. Switch off all the lights.

3.2.3 Back at the control room

- Power the M1 covers at the main power box.
- Power the Lhesa camera at the main power box.
- Power the spectrograph at the main power box.
- Switch on the SONY TV monitors for the Lhesa and the finder cameras. Change to the video channel.
- Before switching both cameras on, lower their intensities to the minimum. Do not switch them on until the sunlight in the dome is sufficiently low.
- Switch on the telescope control module at the switch at the bottom of the module. Open the M1 covers. The telescope will not move until they are completelly open.

3.3 Before the observations

3.3.1 The OSN observing log

Fill in the observing log with the names of the observers and of the campaign, the date, etc. It is important for the statistics to write at the *weather/seeing* box the dome and outside temperatures. To get the outside one, go to the *TCS* menu *Ver – Meteorología* (see the *TCS* User Manual). For the dome one, check the thermometer hanging from the oil tray of the telescope in the dome.

3.3.2 Running the control system

- Run the telescope control program (by clicking just one once on the *TCS* icon).
- Run the spectrograph control program (by clicking just once on the *Albireo* icon).
- Run the CCD control program (by clicking just one once on the *CCDW* icon).

3.3.3 Initialization of the spectrograph

Initialize *Albireo* and all the motors in the following menus of the spectrograph program:

- *Espectrógrafo – Iniciar – Albireo*, and
- *Espectrógrafo – Iniciar – Motor – Todos los motores.*

Check that all the figures appear in green in the scheme of the spectrograph and that all the motors are set at their origins, i.e., reading *Origen* at the spectrograph control program.

3.3.4 Initialization of the CCD

Initialize the CCD by executing the following menus of the CCD control program:

- *Interfaz – Iniciar*,
- *Interfaz – Reset*, and
- *Cámara – Reset*.

CCD temperature

Check that the CCD temperature reads *OK*. If it reads *Alta*, this means the temperature is still high and you will have to wait some time until it reaches the correct value. From time to time go to the menu *Cámara – Estado* to re-check the status of the chip.

3.3.5 Initialization of the dome

- Initialize the dome in the *dome* menu of the *TCS*
- Set the dome in automatic by clicking on the *Auto* button of the *TCS'* dome box.

3.4 During the night

- Check that the tertiary mirror is looking towards the west focus of the telescope (reading the tertiary green or red leds on the *TCS*.
- Display the *Albireo* menu *Modo – Rendija Larga* y seleccionar los siguientes valores para los distintos parámetros:
  - Select *Espectro de cielo*.
  - Move *Torre de redes* to *Espejo*.
  - Move *Rotador* to 0°.
  - Open *Rendija* to 2".
  - Place *Objetivo de la CCD* to the value of the dome's temperature at that moment.
  - Click on *Mover*.
- Point to a bright star and originate the telescope if necessary.
- Do a focus series.
- Choose a relatively bright star to do the autoguiding. If there was not any within the field of view, move into the light path the field mirror and search for one by moving the motors *Altura de TV.* and *Transversal de TV* at the following menus of *Albireo*:
  - *Espectrógrafo – Mover – Motor –*

  - *Espejo de Campo – Agujero*
  - *Altura TV.*
  - *Transversal TV.*

- Activate the autoguiding if necessary.

- Display the *Modo* menu of *Albireo*, choose the working mode (Long slit, Argus or Medusa), select the values for the various parameters, point the telescope towards your object and take the integration.

3.5 Doing a focus series

To be written

3.6 In the morning

3.6.1 At the control room

- Deactivate the dome's automatic mode by clicking on the *Manual* button (in red) in the dome box of *TCS*.

- Send the dome to the parking position by clicking on *Aparcar cúpula* of the *Cúpula* menu.

- Send the telescope to the parking position by clicking on *Aparcar telescopio a Polar* of the *Telescopio* menu.

- Turn down to the minimum the intensities of the Lhesa and finder cameras.

- Switch off both cameras.

- Switch off the SONY monitors.

- Switch off the telescope control module.

- Log out of the spectrograph, CCD and telescope control programs.

3.6.2 At the dome

- Go upstairs and plug the cable for the dome electric power.

- Go downstairs and close the dome slit and windbaffle.

- Switch off the dome control box.

- Close the diafragm at the west focus of the telescope.

3.6.3 Back at the control room

- Switch off the dome loudspeaker.
- Switch off the oil pump.

Appendix A

Standard stars

A.1 Introduction

A list of spectrophotometric standards from ING Technical Notes 65 (Table A.1) and 100 (Table A.2) is presented here (Sinclair & Wood 1989). This list has been compiled primarily for observers requiring a quickreference list of stars which can be used for flux calibration purposes. It is based on Strom (1977) list of spectrophotometric standards and is intended both for use at the telescope and for reference when planning observations. The original references should be consulted for detailed information regarding instruments used, observational techniques and estimates of precision.

A.2 Contents

Summary data for all the stars in the list are gathered in Tables A.1 and A.2. In addition to the star name the table contains: accurate equatorial coordinates and proper motions, an indication of visual magnitude and spectral type. All these data, together with flux files, flux plots and finding charts are held at the ING WWW pages:

http://www.ing.iac.es/Astronomy/observing/manuals/html_manuals/tech_notes/tn065-100/workflux.html

A.3 Star names

The names given are those following the IAU convention for astronomical sources.

A.4 Positions

Since modern telescopes have the capability of setting very accurately, accurate positions should be provided to make efficient use of telescope time. Any star in this list has a measured position accurate to 1 arcsec or better.

Where the proper motions of the spectophotometric standards of Table A.1 are known, the positions are given for epoch and equinox B1950.0; otherwise, the epoch is that of the Palomar Observatory Sky Survey (POSS) plate on which the position was measured. Similarly, the positions of all the standars in Table A.2 are given to equinox J2000.0. Where proper motions are known, positions are given for epoch J2000.0; otherwise, the epoch is that of the POSS plate on which the position was measured.

A.5 Proper motions

Some of the standards appear in lists published by Giclas in various Lowell Observatory Bulletins (Giclas 1963), or the proper motion catalogues of Luyten, published by the University of Minnesota (Luyten 1944; Luyten 1961). Their proper motions have been adopted here except where given in the Carlsberg Meridian Catalogues (CMC) (Carlsberg Meridian Catalogue 1984 1993).

A.6 Magnitudes and spectral types

The magnitudes and spectral types given in the table are all taken from the papers in which the relevant spectrophotometry appear. The magnitude given is intended to give an approximate 'visual magnitude for identification and planning purposes. The magnitude for stars from the Massey et al. (1988) publication are M_{5556}, and those from Oke (1990) are M_{5460}. The spectral types are intended to give a broad idea of the overall light distribution, so that a suitable object can be selected for the required purpose.

Table A.1: Spectrophotometric Standards referred to equinox B1950.0

Name	α h m s	δ ° ' "	μ_α (s/yr)	μ_δ ("/yr)	m	Sp. T.	Note
Hiltner 102	01 05 53.7	+62 31 31			10.35	B0III	2
L870−2	01 35 26.2	−05 14 42	+0.037	−0.34	12.82	DA	1,6
Feige 15	01 46 28.4	+13 18 18	+0.003	+0.03	10.41	A1V	2,35
Feige 24	02 32 31.0	+03 30 52	+0.003	−0.03	12.42	DA+M1V	1,35
Feige 25	02 36 00.0	+05 15 17			12.01	B6V	2
HD 19445	03 05 28.6	+26 09 06	−0.016	−0.83	7.98	sdF	4,7
LB 1240	04 01 32.6	+25 00 53	+0.011	−0.23	13.94	DA	1,8
LB 227	04 06 36.7	+17 00 05	+0.008	−0.02	15.29	DA	1,9
HZ 2	04 09 57.2	+11 44 16	+0.003	−0.09	14.07	DA	1
40 Eri B	04 13 03.6	−07 44 06	−0.146	−3.44	9.55	DA	1,10
HZ 7	04 30 57.0	+12 36 27	+0.01	0.0	14.29	DA	1
HZ 15	04 37 56.0	+08 35 00			12.59	B5	2
G99−37	05 48 45.6	−00 11 16	+0.007	+0.20	14.51	DGp	1
He 3	06 44 14.8	+37 35 03	−0.018	−0.91	12.05	DA	1,12
L745−46A	07 38 02.1	−17 17 22	+0.078	−0.57	12.91	DF	1,13
BD+080 2015	08 13 01.1	+07 46 29	−0.012	−0.17	10.39	G2V	2
LDS 235	08 45 13.3	−18 48 46	−0.008	−0.05	15.66	DB	1
G47−18	08 56 11.2	+33 08 54	−0.027	0.0	15.18		1
SA29 130	09 43 29.5	+44 08 31	0.000	+0.29	13.22	DA	1,14
HD 84937	09 46 12.0	+13 59 17	+0.027	−0.79	8.27	sdF	4,15
L970−30	11 05 27.8	−04 52 51	−0.002	−0.43	12.97	DA	1,16
Ton 573	11 07 18.5	+26 35 12	+0.007	−0.11	15.83	DB	1,17
Ross 627	11 21 38.7	+21 38 05	−0.072	+0.02	14.12	DA,F	1,18
Feige 56	12 04 13.8	+11 56 54	0.000	+0.03	11.11	B5p	2,35
HZ 29	12 32 28.5	+37 54 15	+0.002	+0.02	14.16	DBp	1,19
HZ 43	13 14 00.6	+29 21 49	−0.010	−0.08	13.03	DAwk	1,20
Wolf 485A	13 27 39.8	−08 18 38	−0.074	−0.42	12.22	DA	1,21
Feige 92	14 09 41.5	+50 21 07	−0.003	0.00	11.62	Bp	2,35
Feige 98	14 36 03.9	+27 42 30	+0.007	−0.03	11.84	B7	2,35

Table A.1: (Continued)

Name	α h m s	δ ° ' "	μ_α (s/yr)	μ_δ ("/yr)	m	Sp. T.	Note
BD+26 2606	14 46 50.2	+25 54 53	+0.000	−0.35	9.66	sdF	4,22
GD 190−193	15 42 03.8	+18 16 13	+0.003	−0.10	14.66	DB	1
Ross 640	16 26 39.3	+36 52 12	−0.042	+0.74	13.82	DFp	1,23
Kopff 27	17 41 28.4	+05 26 04			10.31	A3V	2
Grw+70 8247	19 00 39.0	+70 35 05	+0.019	+0.52	13.12		1,24
BD+25 3941	19 42 21.9	+26 06 01	0.000	−0.03	10.36	B1.5V	2,35
BD+40 4032	20 06 40.0	+41 06 15			10.45	B2III	2
Grw+73 8031	21 26 43.4	+73 25 52	+0.010	−0.32	12.75	DA	1,27
LDS 749 B	21 29 41.2	+00 01 56	+0.022	+0.05	14.70	DB	1,28
L1363−3	21 40 22.5	+20 46 46	−0.019	−0.68	13.28	DC	1,29
L930−80	21 44 57.5	−07 58 02	+0.024	−0.16	14.88	DB	1,30
BD+17 4708	22 09 05.8	+17 50 42	+0.036	+0.05	9.41	sdF	4,31
G157−34	23 11 50.9	−06 49 02	−0.023	−0.16	15.35	DQ6	3,32
L1512−34	23 41 21.0	+32 16 10	−0.018	−0.06	12.92	DA	1,34

Table A.2: Spectrophotometric Standards referred to equinox J2000.0

Name	α h m s	δ ° ' "	μ_α (s/yr)	μ_δ ("/yr)	m	Sp. T.	Note
G158 − 100	00 33 54.5	−12 07 58	+0.011	−0.17	14.82	sdG	2,3
PG 0205+134	02 08 03.4	+13 36 25			14.87	sdOB	1
PG 0216+032	02 19 18.8	+03 26 54			14.79	sdOC	1
PG 0310+149	03 13 37.2	+15 06 22			15.63	sdO	1
GD 50	03 48 50.0	−00 58 32	+0.002	−0.15	14.06	DA2	2
SA95 − 42	03 53 43.7	−00 04 29			15.60		2
HZ 4	03 55 22.0	+09 47 19	+0.012	0.0	14.47	DA	2,3
HZ 14	04 41 01.8	+10 59 41	+0.007	+0.01	14.01	DA	1,3
G191−B2B	05 05 30.6	+52 49 56	+0.004	−0.09	11.85	DA0	1,2,3
Hiltner 600	06 45 13.4	+02 08 15			10.42	B1V	1,3
G193 − 74	07 53 27.2	+52 29 31	−0.008	−0.26	15.58	DC	2
BD +75° 0325	08 10 49.2	+74 57 57	−0.002	−0.01	9.52	O5p	2
PG 0823+546	08 26 49.4	+54 28 01			14.36	sdOC	1
PG 0846+249	08 49 05.9	+24 45 08			16.94	DA1	1
PG 0934+554	09 38 20.4	+55 05 54	+0.002	−0.04	12.16	sdO	1,4,5
PG 0939+262	09 42 50.8	+26 01 01			14.89	DA1	1

Table A.2: (Continued)

Name	α h m s	δ ° ′ ″	μ_α (s/yr)	μ_δ (″/yr)	m	Sp. T.	Note
GD 108	10 00 47.2	−07 33 31	−0.003	0.00	13.57	sdB?	2,5
Feige 34	10 39 36.7	+43 06 10			11.25	sdO	1,2,3, 5
HD 93521	10 48 23.5	+37 34 13	0.000	+0.01	6.96	O9Vp	2,5
PG 1121+145	11 24 15.1	+14 13 46			16.97	DA1	1
GD 140	11 37 05.1	+29 47 58	−0.012	−0.01	12.50	DAn	1,3,5
EG 81	11 37 26.4	+14 10 15	−0.006	−0.05	13.30	sdO	1
HZ 21	12 13 56.6	+32 56 30			14.67	D02	2
Feige 66	12 37 23.6	+25 03 5	0.000	−0.03	10.54	sdO	1,2
Feige 67	12 41 51.8	+17 31 21			11.89	sdO	1,2
G60 − 54	13 00 09.0	+03 28 38	−0.026	−0.92	15.73	DC	2
HZ 44	13 23 35.3	+36 08 01	−0.004	+0.03	11.74	sdO	1,2,3
Grw+70° 5824	13 38 52.8	+70 17 08	−0.027	−0.02	12.72	DA	2,3
PG 1545+035	15 48 24.2	+03 22 51			14.34	sdOB	1
BD 33° 2642	15 51 59.9	+32 56 53			10.74	B2IVp	2,3
G138-31	16 27 53.4	+09 12 16	−0.007	−0.46	16.07	DA7	2,3
PG 1708+602	17 09 15.9	+60 10 10			13.92	sdOC	1
HD 192281	20 12 33.2	+40 16 06	−0.001	+0.02	7.44	O5f	1
G24 − 9	20 13 55.7	+06 42 45	−0.017	−0.58	15.77	DQ7	2,3
Cyg Ob2 − 9	20 33 10.8	+41 15 09			10.70	O51f	1
Wolf 1346	20 34 21.9	+25 03 51	−0.030	−0.55	11.59	DA	1,3
BD +28° 4211	21 51 11.1	+28 51 53			10.56	sdOp	1,2,3
BD +25° 4655	21 59 41.9	+26 25 57	−0.002	−0.05	9.65		2
NGC 7293	22 29 38.4	−20 50 14			13.48		2
HD 217086	22 56 47.1	+62 43 38	+0.000	−0.01	7.49	05	1
LTT 9491	23 19 34.6	−17 05 29	+0.018	+0.04	14.06	DC	2
Feige 110	23 19 58.4	−05 09 57			11.88	DOp	1,2,3,5
GD 248	23 26 06.5	+16 00 21	−0.003	−0.09	15.08	DQ5?	2,3

Notes to Table 1. Massey, P., Strobel, K., Barnes J.V. & Anderson, E., 1988, Ap. J., 328, 315. 2. Oke, J.B., 1990, Astron. J. 99, 1621. 3. Sinclair, J.E. & Wood, R., 1989. ING Technical Note, No. 65. 4. Alias GD 299. Magnitude given is m, 5. Positions and proper motions from CMC

Appendix B

Calibration arcs

In the following, we give a spectral atlas of the calibration lamps in use with ALBIREO. Maps for the HgCdZn-Cs, Ne and Ar lamps are given at each dispersion provided by the various gratings.

The main features of each lamp are described also here, so that users can decide which lamps are more adequate for their observations.

B.1 Comparison lamps

Several lamps are available for wavelength calibration. These lamps are listed below.

B.1.1 HgCdZn-Ne lamps

The HgCdZn lamp shows the following features:

B.1.2 Ar lamp

B.1.3 Cs lamp

Table B.1: HgCdZn-Ne line list of the lamps in use with *Albireo*. Wavelengths are from MIT Wavelength Tables

λ (Å)	Ident	λ (Å)	Ident
3403.653	CdI	6304.790	NeI
3466.201	CdI	6334.430	NeI(1)
3467.656	CdI	6362.347	ZnI
3610.510	CdI	6382.990	NeI(3)
3611.690	Blend CdI 3610.510 and CdI 3612.875	6402.250	NeI(1)
3612.875	CdI	6438.470	CdI
3613.607	Hg	6506.530	NeI(3)
3650.146	HgI	6532.880	NeI
3654.833	HgI	6598.950	NeI(6)
3663.276	HgI	6678.280	NeI
4046.561	HgI	6716.170	HgI
4077.811	HgI	6717.040	NeI
4339.235	HgI	6907.160	HgI
4347.496	HgI	6929.470	NeI(6)
4358.350	HgI	7024.050	Ne
4679.148	Blend CdI 4678.156 and ZnI 4680.138	7032.410	NeI(1)
4680.138	ZnI	7081.880	HgI
4722.159	ZnI	7091.990	HgI
4799.917	CdI	7173.940	NeI(6)
4810.534	ZnI	7245.170	NeI(3)
4916.036	HgI	7438.900	NeI
5085.824	CdI	7488.870	NeI
5460.740	Hg	7535.780	NeI
5769.590	HgI	7544.050	NeI
5790.650	HgI (also 5789.66 HgI at 1/2 intensity of 5790.650 HgI)	7728.490	HgI
5852.490	NeI(6)	7732.500	ZnII
5881.900	Ne	8300.330	NeI(12)
5944.830	NeI(1)	8377.610	NeI(12)
5975.530	Ne	8418.430	Ne
6030.000	NeI(3)	8495.360	NeI(18)
6074.340	NeI(3)	8591.260	Ne
6096.160	NeI	8634.650	NeI(23)
6143.060	NeI(1)	8654.380	NeI(33)
6163.590	NeI(5)	8853.870	NeI(27)
6217.280	NeI(1)	8865.540	Ne
6266.500	NeI(5)		

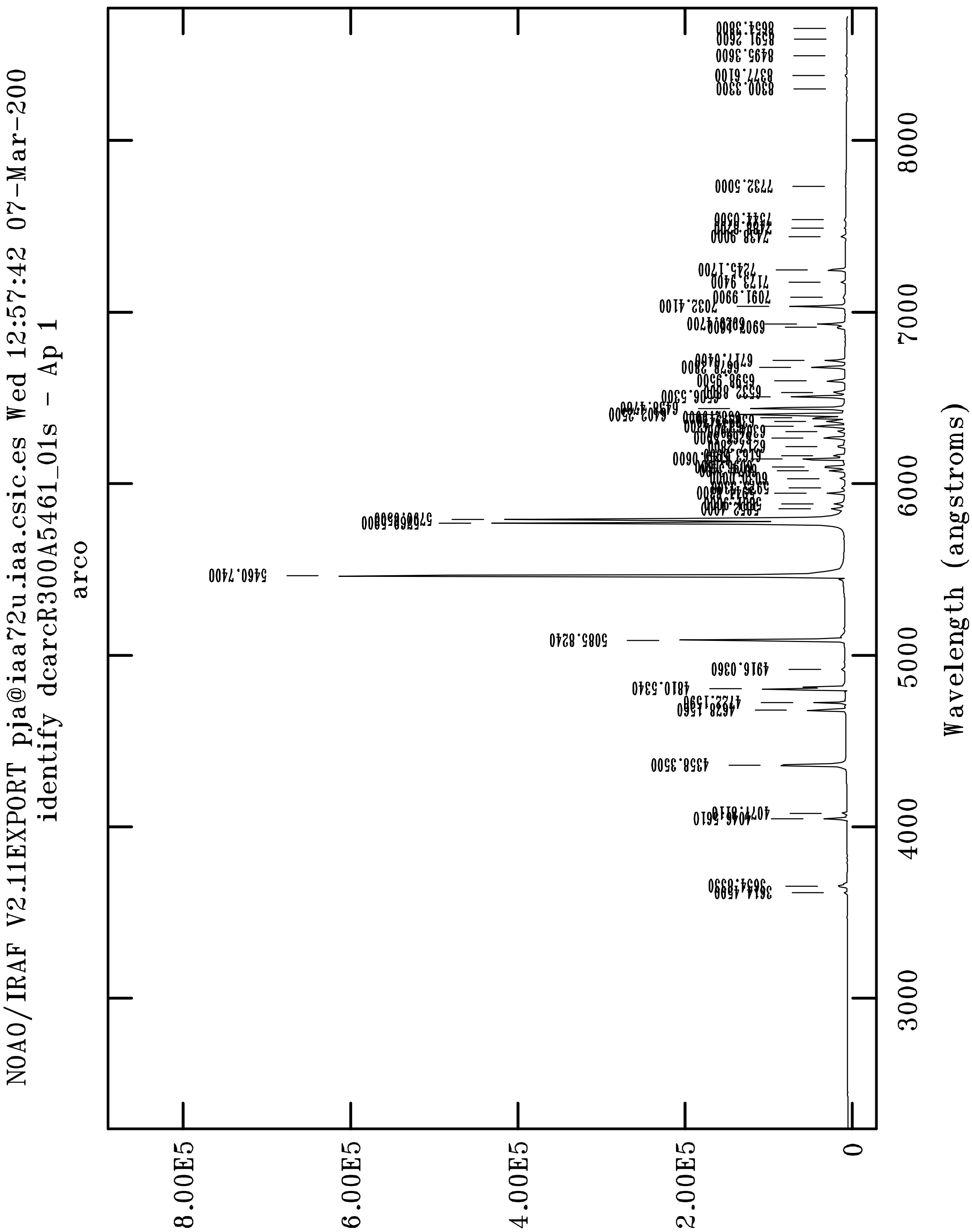

Figure B.1: A 1 second HgCdZn-Ne spectrum with 2" slit width and grating R300. Wavelength calibrated on the basis of the line list in Table B.1

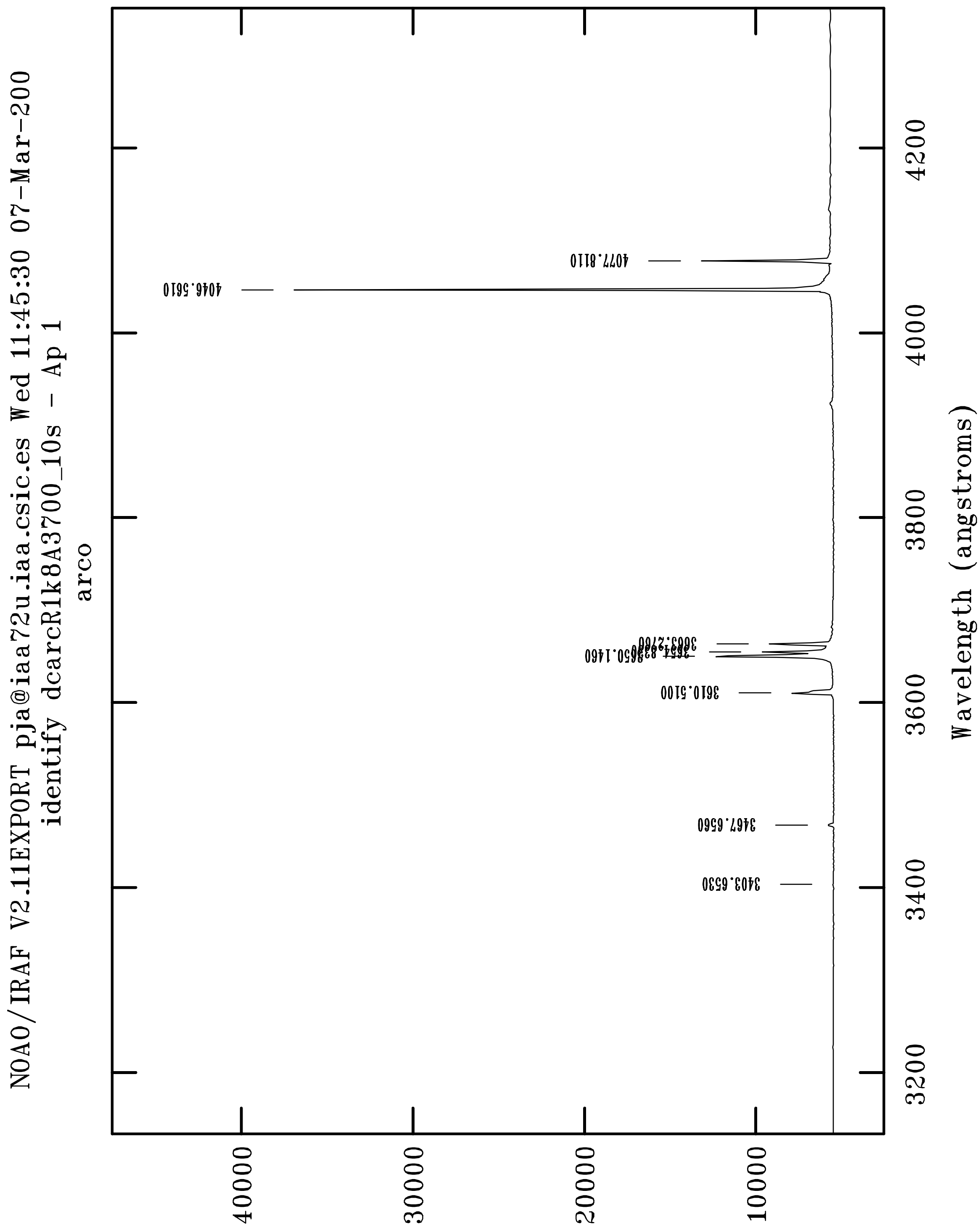

Figure B.2: A 10 second HgCdZn-Ne spectrum with 2" slit width and grating R1800 centered at a wavelength of 3700 Å. Wavelength calibrated on the basis of the line list in Table B.1

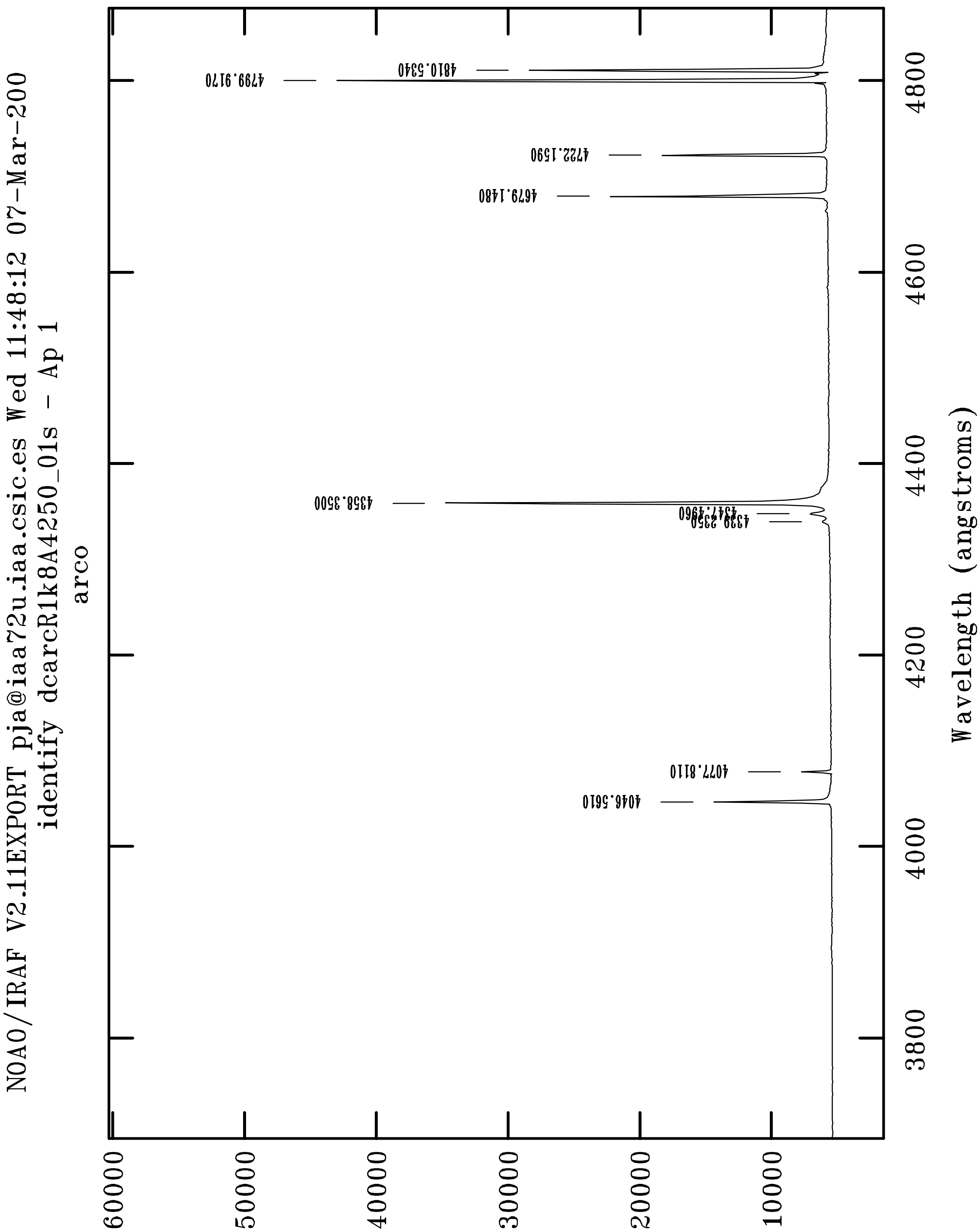

Figure B.3: A 1 second HgCdZn-Ne spectrum with 2" slit width and grating R1800 centered at a wavelength of 4250 Å. Wavelength calibrated on the basis of the line list in Table B.1

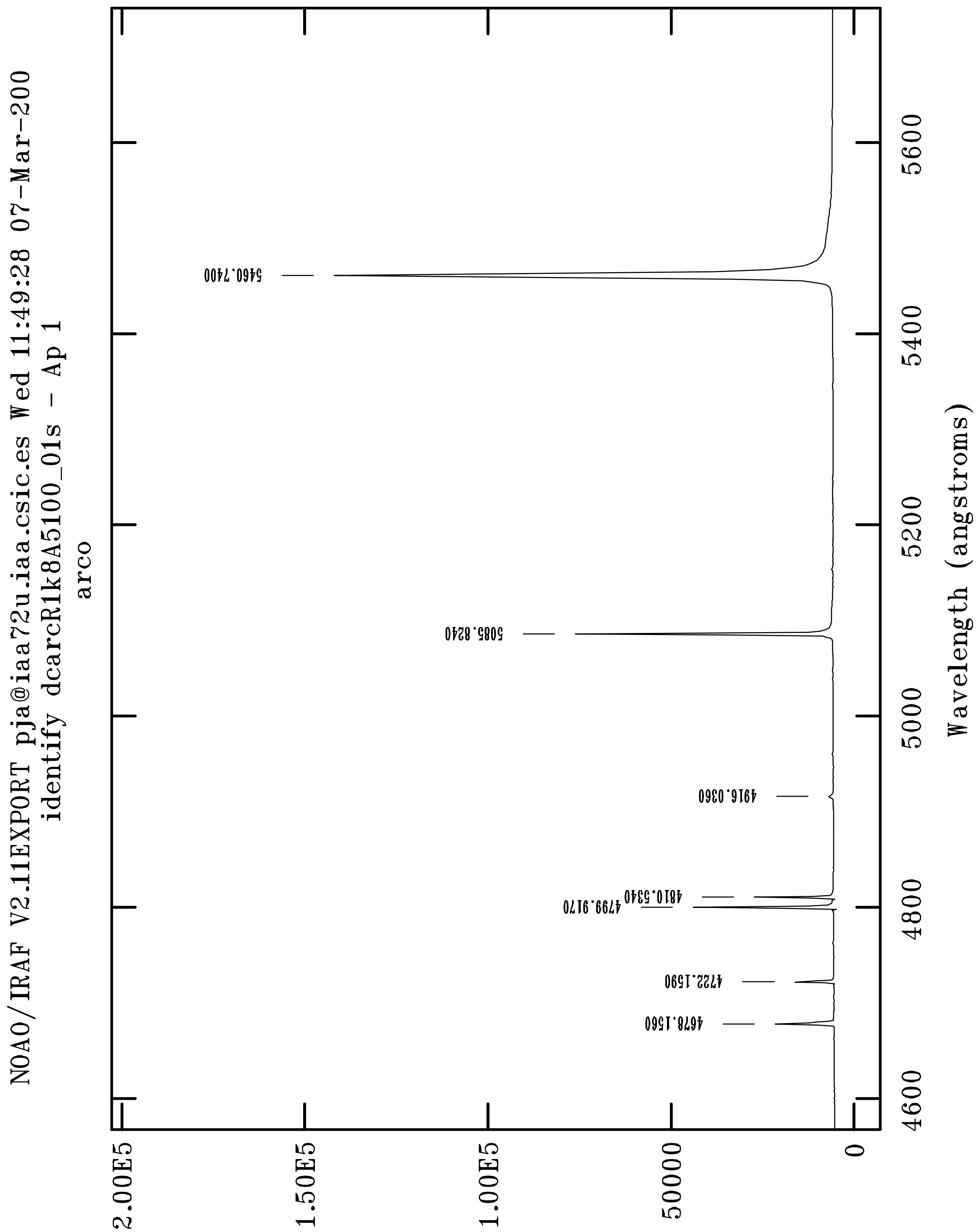

Figure B.4: A 1 second HgCdZn-Ne spectrum with 2" slit width and grating R1800 centered at a wavelength of 5100 Å. Wavelength calibrated on the basis of the line list in Table B.1

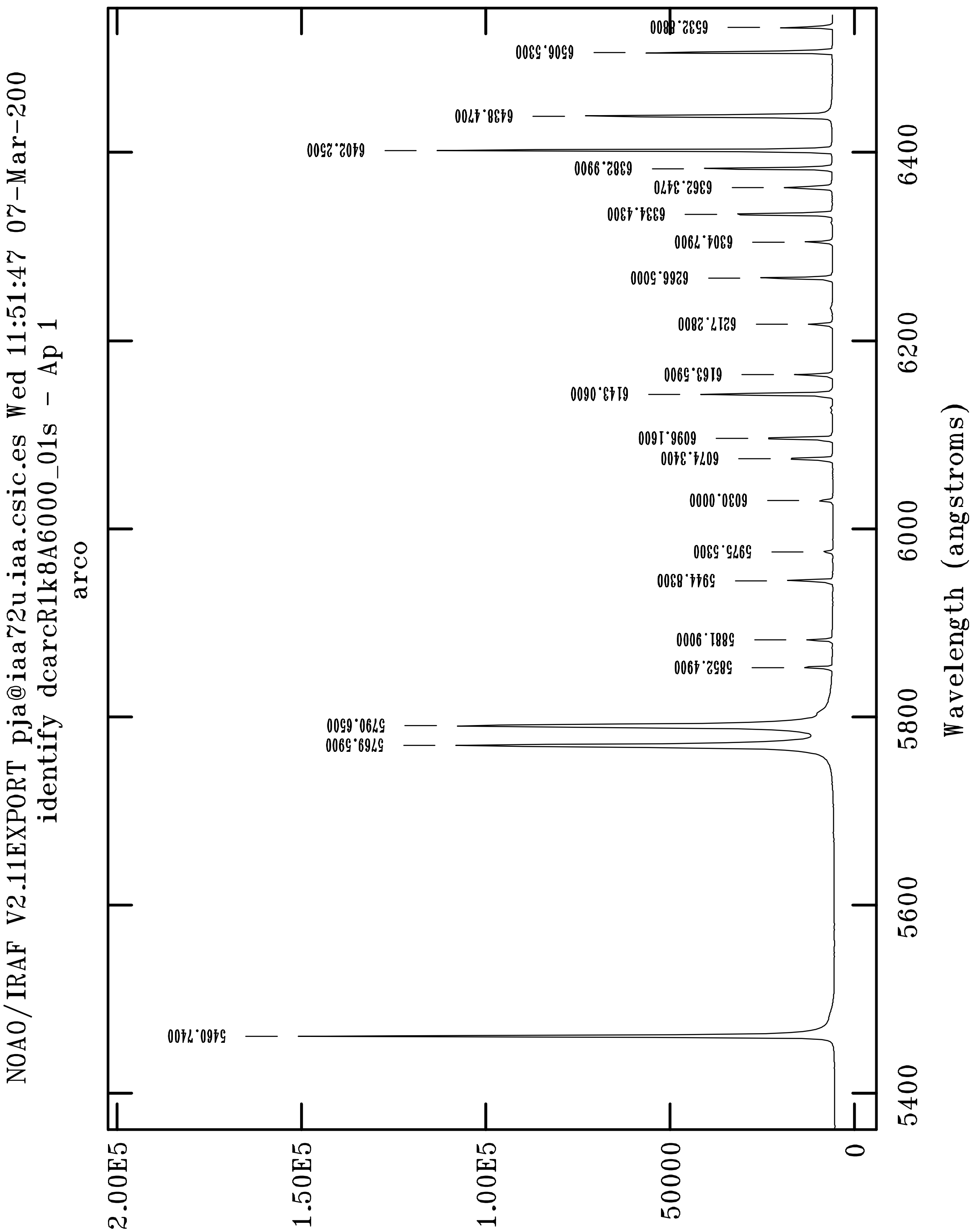

Figure B.5: A 1 second HgCdZn-Ne spectrum with 2" slit width and grating R1800 centered at a wavelength of 6000 Å. Wavelength calibrated on the basis of the line list in Table B.1

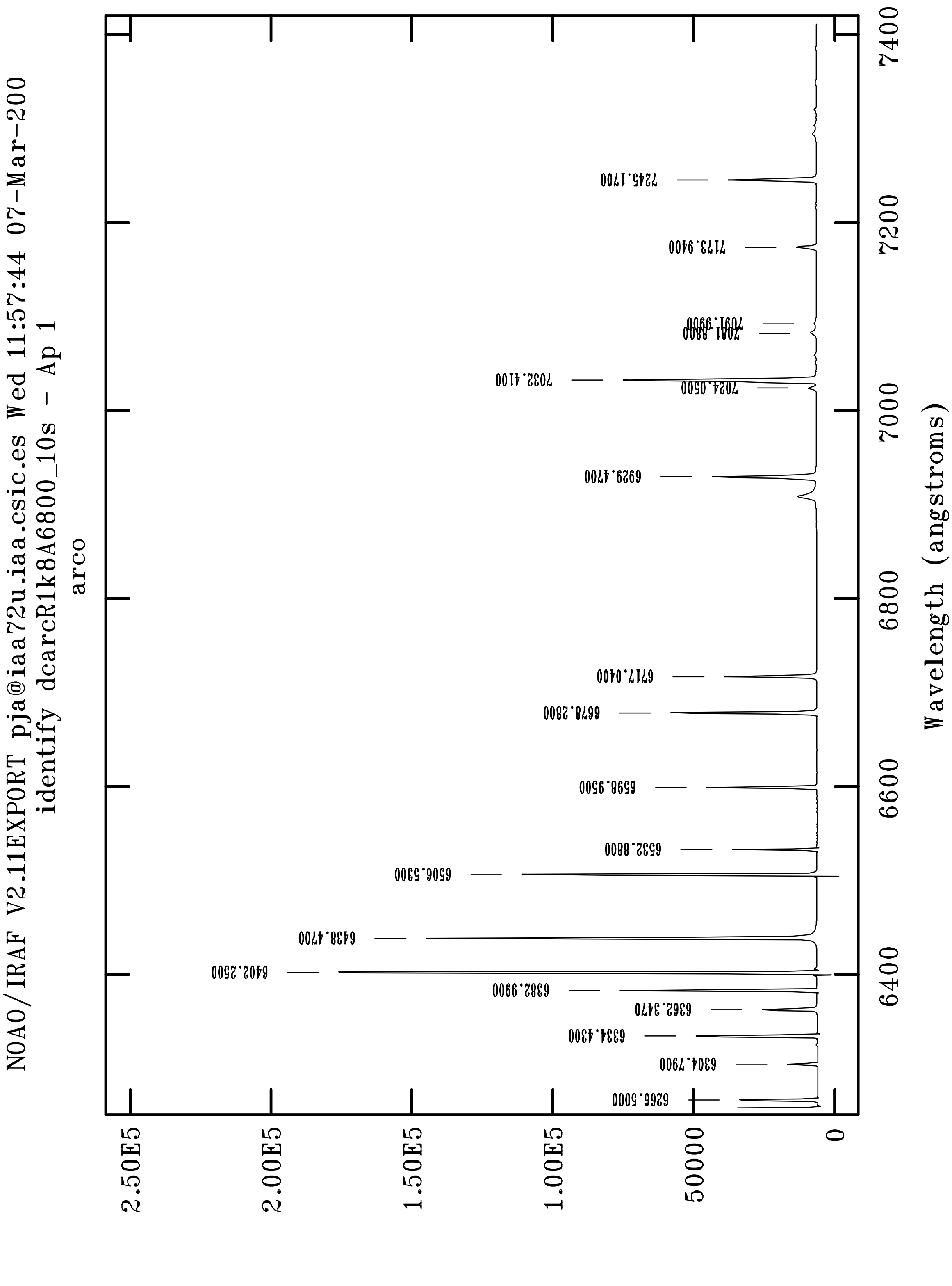

Figure B.6: A 10 second HgCdZn-Ne spectrum with 2" slit width and grating R1800 centered at a wavelength of 6800 Å. Wavelength calibrated on the basis of the line list in Table B.1

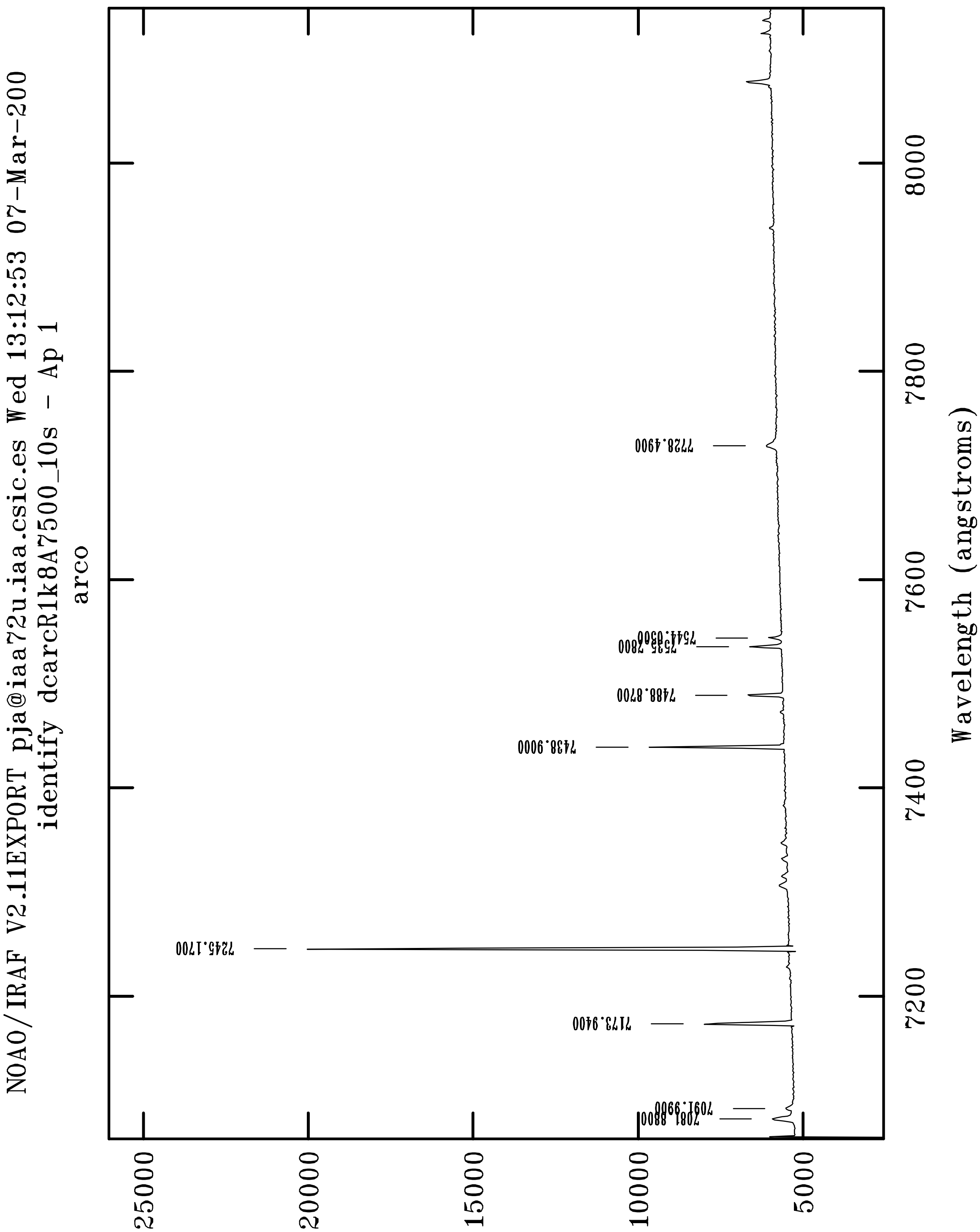

Figure B.7: A 10 second HgCdZn-Ne spectrum with 2” slit width and grating R1800 centered at a wavelength of 7500 Å. Wavelength calibrated on the basis of the line list in Table B.1

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