BFOSC

Bologna Faint Object Spectrograph & Camera

USER MANUAL

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TECHNICAL REPORT

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1. INTRODUCTION

BFOSC - Bologna Faint Object Spectrograph & Camera - is an instrument buit to allow, with a simple configuration change, the acquisition of both images and spectra. At present, identical instruments are in use at several observatories: Copenhagen Astronomical Observatory, Asiago Astronomical Observatory, Astrophysical Institute of Andalusia and European Southern Observatory.

2. GENERALITIES

The principal instrument characteristics are:

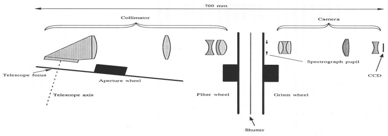
- Collimator-camera optical system acting as a focal reducer;
- Parallel beam area;
- Interchangeable slits;
- Easy interchange of grisms and filters;
- High efficiency.

The instrument is build around a stiff frame holding the collimator, the camera and the detector. On it are also mountes the three wheels for slits, filters and grisms. The last BFOSC optical element is the camera, which last lens is the cryostat window.

The detector is an **EEV LN/1300-EB/1** CCD with 1300 x 1340 pixels, AR Visar coated, back illuminated.

Each wheel has eight positions. Filters and grisms wheels are mounted in the parallel beam area, between the collimator and the camera, while the slits wheel is mounted on the telescope focal plane.
Between the filters and grisms wheels is installed a wheel acting as shutter for the CCD. The optical axis of the instrument is tilted 110° with respect to the telescope optical axis, in order to reduce instrument dimensions and increase its stiffness.

A BFOSC scheme is shown here:



3. INSTRUMENT CHARACTERISTICS

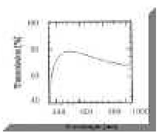
Collimator focal lenght	252.1 mm
Collimator linear field	52.9 x 52.9 mm
Beam diameter	31.5 mm
Camera focal lenght	146.3 mm
Camera linear field	30.7 x 30.7 mm
Reduction ratio	0.58
Spectral range	330 - 1100 nm
Maximum spectral resolution	4200
Projected pixel dimension	0.58 arcsec/pix*
Field dimension	13' x 12.6'*

*using **EEV** CCD.

In case of problems with the **EEV** CCD a backup detector is available. This CCD, a Thomson xxxx, has 1024 x 1024 pixels with a field of 9.6' x 9.6' and a sampling of 0.562 arcsec/pix.

3.1 Optics

Optics have been built using **FK54** and **UBK7** galsses. This in order to give a good transmission (cut-off at 360 nm) in the UV. Optics have been coated with a single layer of $\mathbf{MgF_2}$, centered to 500 nm, to improve anti-reflection characteristics. Reflection losses are ~ 1.5% at central wavelength and increase to ~ 2.5% at the extremes. The following graph shows the optics transmission.



3.2 Slits Wheel

The slit wheel, mounted on the telescope focal plane, can hold seven different slits, beeing one of the apertures intentionally left empty to allow direct image acquisition. At present four different slits are available: **1.5"**, **2"**, **2.5"** and **5"**, a special **2"** slit for echelle spectra and a mask to be used for polarimetry.
The slit length is large as the usable field while the echelle slit is **9"** long.

3.3 Filters Wheel

Like the slits wheel, also the filters wheel has seven available positions. At present can be mounted:

U, **B**, **V**, **R**, **I** **Johnson-Kron-Cousin** filters
G, **R**, **Z**, **I** **Thuan-Gunn** filters.

On the filters wheel can also be mounted the **cross-disperser (#10, #11, #12)** used with the echelle grism **#9** to allow medium dispersion spectroscopy. A differential filter, used as order separator, is mounted on the filter wheel in conjuction with the grism **#13**. Two Hartmann masks can also be mounted to control the camera focusing.

3.4 Grisms Wheel

The available grisms are more than the number of positions on the wheel itself (7 as usual). Let us see in detail their characteristics:

Grism #	L blaze (nm)	L grism (nm)	Dispersion (nm/mm)	D L (nm)	LL EEV (nm)	LL Thom. (nm)	L/pix EEV (nm/pix)
3	390	430	17	0.55	330 ÷ 642	330 ÷ 580	0.27
4	480	580	22	0.83	380 ÷ 470	394 ÷ 786*	0.40*
5	650	700	22	0.75	480 ÷ 980	520 ÷ 905	0.40
6	390	400	11	0.39	330 ÷ 535	330 ÷ 495	0.17
7	530	525	11	0.41	420 ÷ 600	430 ÷ 625	0.10
8	650	700	8.8	0.30	610 ÷ 818	620 ÷ 785	0.10
9 Ech	17 orders		2.6	0.12	350 ÷ 1020	335 ÷ 940	
10 C. D.	380	390	46	1.7		330 ÷ 640	
11 C.D.	520	500	34	1.3		400 ÷ 700	
12 C.D.	730	700	91	3.7		530 ÷ 1020	
13	510	525	3.6	0.12		495 ÷ 560	

*Grism #4 has a "free spectral range" smaller than the value shown in the table. In fact the table shows the first order spectral coverage but the range free from second order overlap ends at 700 nm.

Grisms #10 , #11, and #12 are cross-dispersers to be used mainly with echelle grism #9 and are mounted on the filters wheel. They are optimized with respect to the working band: grism #10 has a peack efficiency in the blue, grism #11 in the visible and grsim #12 in the red. Also the number of orders on the detector varies with the cross-disperser: grism #10 gives 13 orders, grism #11 gives 9 orders and grism # 12 gives 6 orders.
In the following fig A are shown the different grisms spectral range and resolution. The point indicate the blaze wavelenght.

3.5 SHUTTER AND FOCUSING THE CAMERA

BFOSC shutter has been made using a wheel, placed in the parallel beam area, that moves turning 90° each time. On it has been made two apertures allowing the light to reach the detector. The speed of the wheel is electronically controlled in such a way to keep constant the shutter speed rotation during the closing or opening phase. Acceleration and deceleration phases are timed to appen out of the CCD field of view.
For this reason there aren't illumination effect due to shutter movement.

Exposure times have a **0.1 sec resolution** but the **minimum exposure time is 3 seconds**.

The camera is focused using the Hartmann masks mounted on the filters wheel. Since the camera focus change with temperature, a compensation table has been prepared. The camera focus procedure is known and under control of the tecnical personnel.

4 CALIBRATIONS LAMPS

Spectral wavelenght calibration is obtained through exposures of an Fe hollow-cathod lamp filled with He-AR.

Plots of the comparison spectrum in different configurations are shown in the Appendix 4.

5 CCD

The CCD mounted on BFOSC is an EEV LN/1300-EB/1 back illuminated and AR coated (Visar). The detector RON is 3.06 e^-/pix and the gain is 2.22 e^-/ADU. Normally the instrument has the slit oriented in E-W direction but it is possible to rotate the instrument in any direction (physical constrains to be taken into account). Dispersion is always along CCD columns.

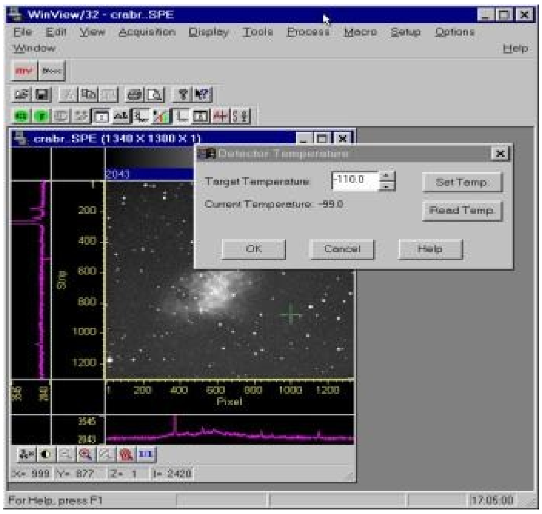
CCD Q. E. curve fig. B

EEV CCD CHARACTERISTICS	
Detector	**EEV LN/1300-EB/1**
Controller	**Photometrics Series ST133B/100 KHz and 1 MHz**
Array	**1300x1340 pixels**
Special Features	**coating AR Visar, back illuminated**
Quantum Efficiency	**80% @ 500 nm, 32% @ 900 nm, >50% @ 300 nm**

Pixel size	**20x20 micron**
Pixel scale	**0.58 arsec/pixel**
Field of view	**13'x12.6'**
Read-out time	**2 sec @ 1 MHz, 18 sec @ 100 KHz (standard work: 100KHz)**
Read-out noise	**3.06 e^-/px @ 100 KHz (standard work: 100 KHz)**
Conversion factor	**2.22 e^-/ADU @ 100 KHz**
Dynamical range	**16 bit**
Full-well capacity	**Sensitivity mode: 117000 elettrons**
Response non-linearity	**< 1% for 16 bit @ 100 Khz**
Response non-uniformity	**< ± 4% over entire ccd area**
Operating temperature	**-100 °C**
Image processing software	**Winview, on line**
Output data format	**Fits**
Image dimension	**3.5 Mbyte**
Typical dark charge	**15.1 e^-/pixel-hour at -97°C**
Liquid nitrogen hold time	**~ 12 hours**

6 OBSERVING PROCEDURES

The observer controls BFOSC using a PC that hosts the CCD controller and the BFOSC controller.



The **WinView** CCD control program allows to control the CCD image acquisition, the real-time image display and the BFOSC control.
In parallel to the **WinView** window is presented on the PC screen the BFOSC status window, that gives to the observer the updated instrument configuration. From the **WinView** window it is possible, using the BFOSC button, to access the BFOSC control window.

6.1 Focusing and Pointing

As previously said, BFOSC focusing is made using Hartmann masks. This is the camera focus with respect to the BFOSC focal plane. To focus the telescope on the BFOSC focal plane the suggestion is to obtain, at the beginning of the night, a set of exposures of a star at different telescope focus values (centered on the last used focus value) and examine the images using the IRAF procedure **starfocus**, on the reduction workstation in the control room. **DO NOT CHANGE THE FOCUS USING THE CAMERA**.
Exposure times should be not less than 15-20 sec. in order to have a good seeing measure.

In order to monitor seasonal seeing variations, observers are requested to measure seeing during the night (possibly using the IRAF **psfmeasure** command).

7 APPENDIX

7.1 Plots for Johnson-Kron-Cousin: U, B, V, R, I filters

7.2 Plots for Gunn: G, R, I, Z filters

7.3 Efficiency curves for grisms: #3, #4, #5, #6, #7, #8, #9E

7.4 Plots for the He-Ar calibration lamp for the different configurations:

#3, #4, #5, #6, #7, #8, #9E

Suggested exposure times for spectral calibration lamp:

#3	30 sec
#4	7 sec
#5	6 sec
#6	50 sec
#7	50 sec
#8	8 sec
#9	8 sec

Fig. A

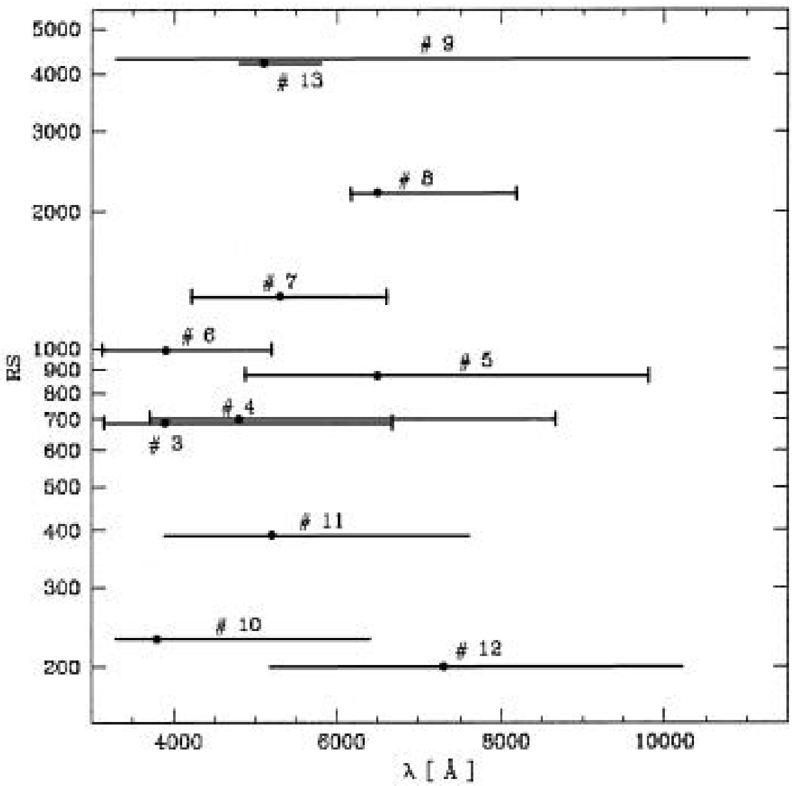
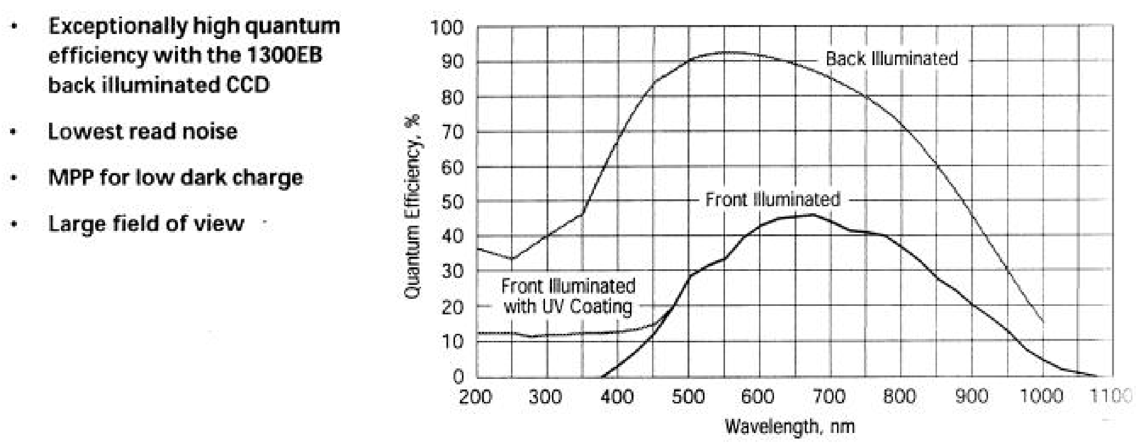
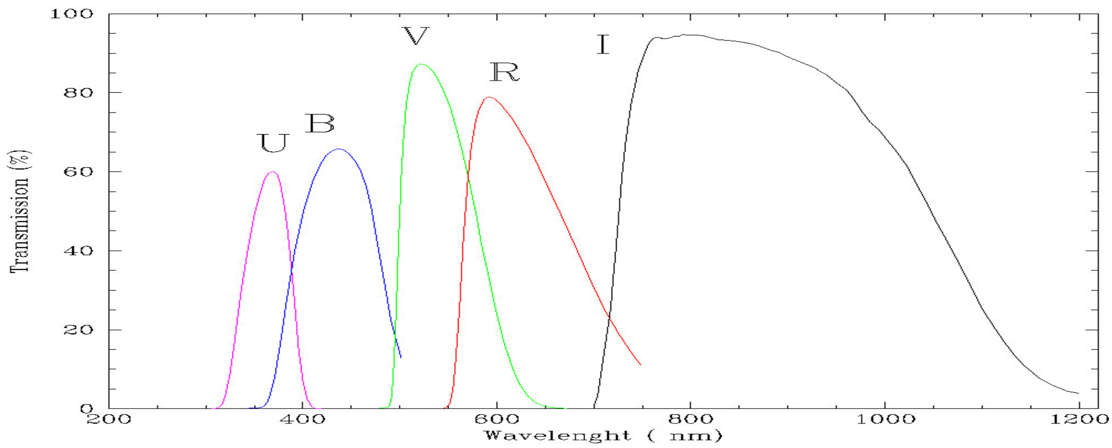


Fig. B

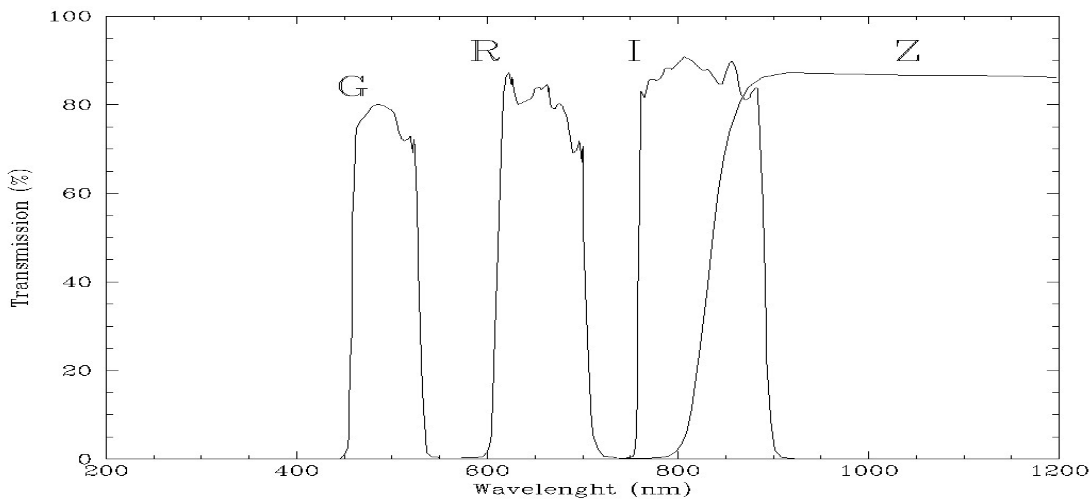


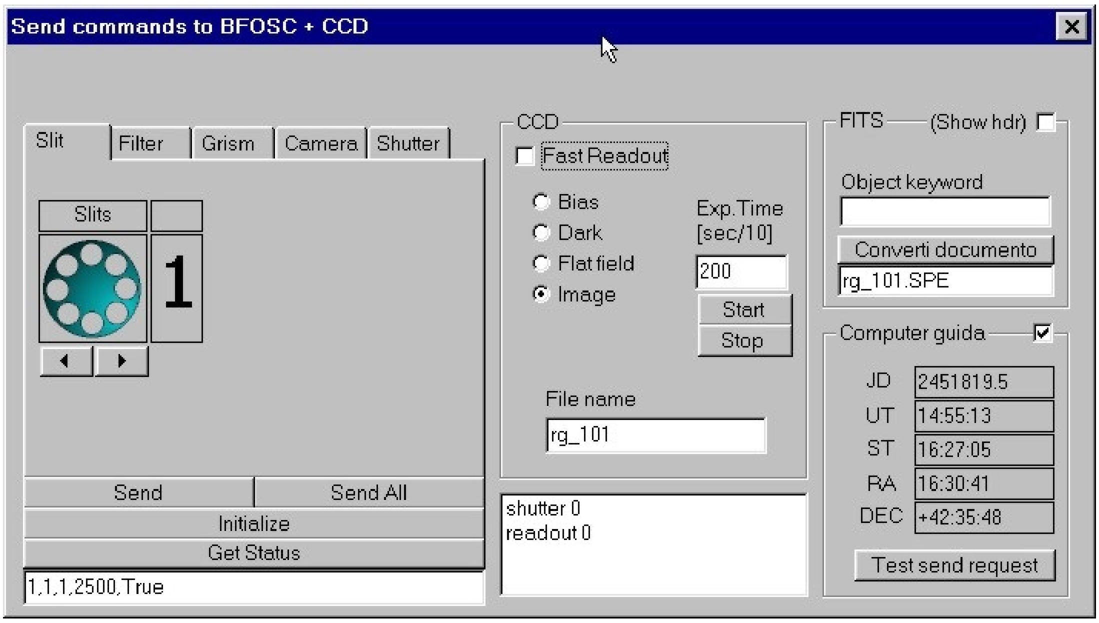
Near each wheel is shown the aperture number (from 1 to 8). During a movement, from one to an other position, the wheel image start to rotate showing that BFOSC is in a non-operative state.
It is not possible to start an exposure if the wheels are moving.
The number on the right of the camera image is the value of the camera focus.
The last symbol on the window shows a rapresentation of what the CCD should "see" in the current instrument configuration (sky, sky behind a slit, spectrum). This in order to help the user to understand the instrument operative state.
The last image shows the shutter status (open or close).

Plot for Johnson-Kron-Cousin filters



Plot for Gunn filters





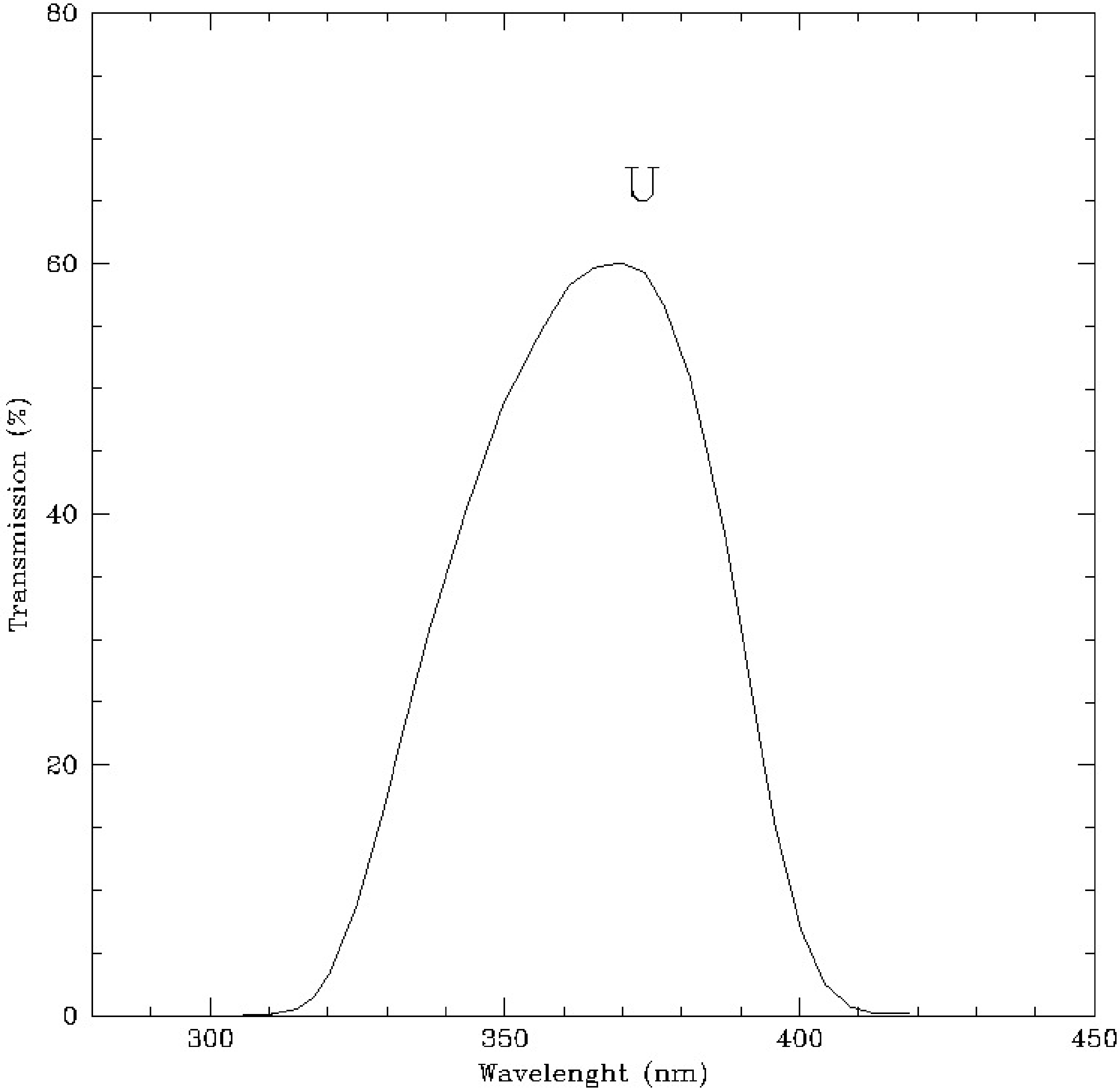
The tags Slit, Filter, Grism are used to move, using the arrows, the wheels in the desired configuration; the Camera tag allows to change the camera focus and the Shutter tag allows to manually control the shutter opening or closing. Pressing the Send switch each command is sent to the instrument.

In the central area of the window are placed the command to control the image acquisition. It is possible to select the image type (bias, dark, ecc.) and, activating the **Fast Readout** option, to increase the CCD readout speed, losing in this case efficiency. This option is usefull only to obtain exposures for checking the telescope pointing.

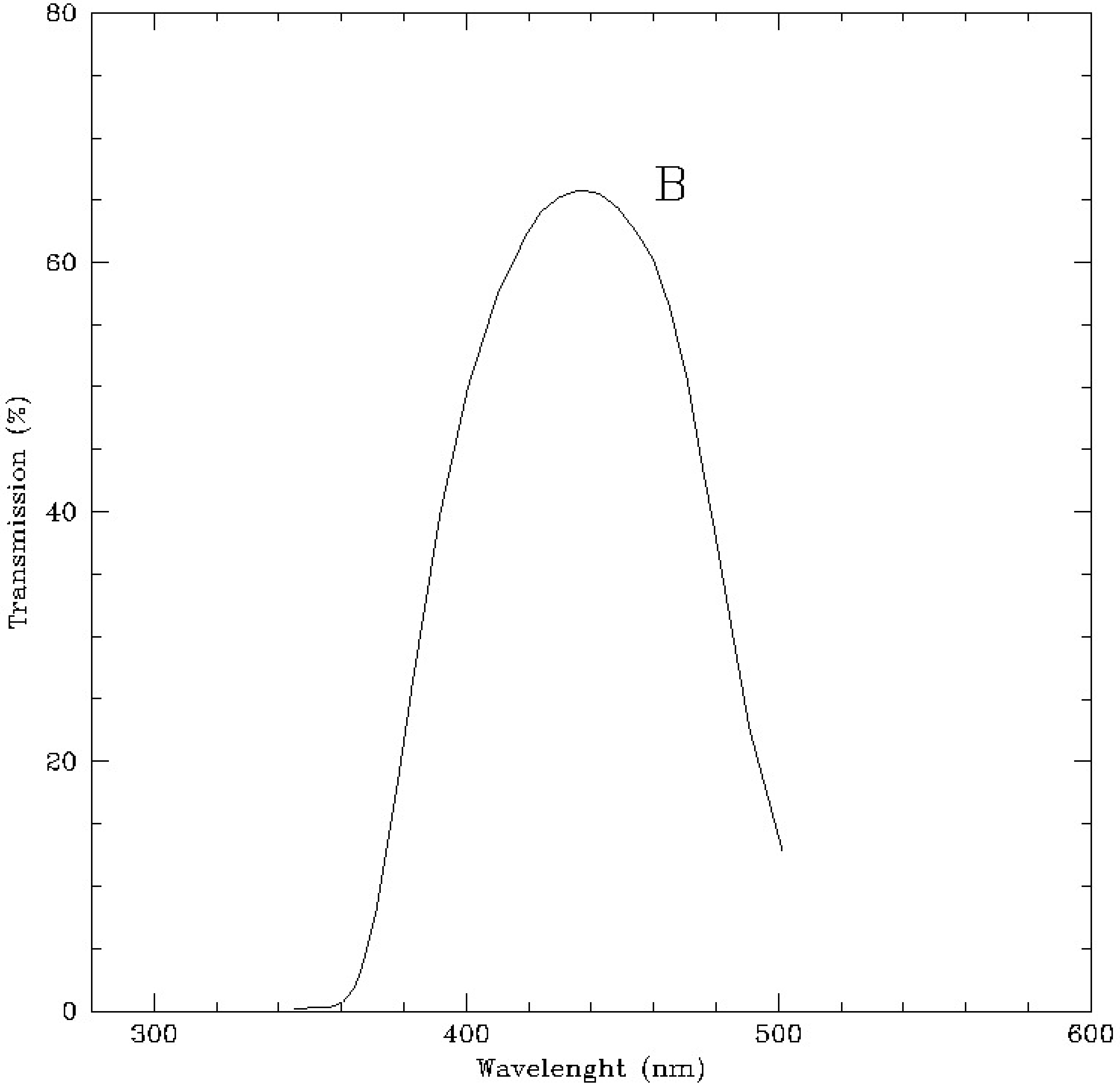
The Start button does what is says, that is starts an exposure which lenght is shown on the window over it (the exposure time is expressed in tenth of sec.). The **Stop** button will terminate an exposure but the image acquired up to that moment will be lost.

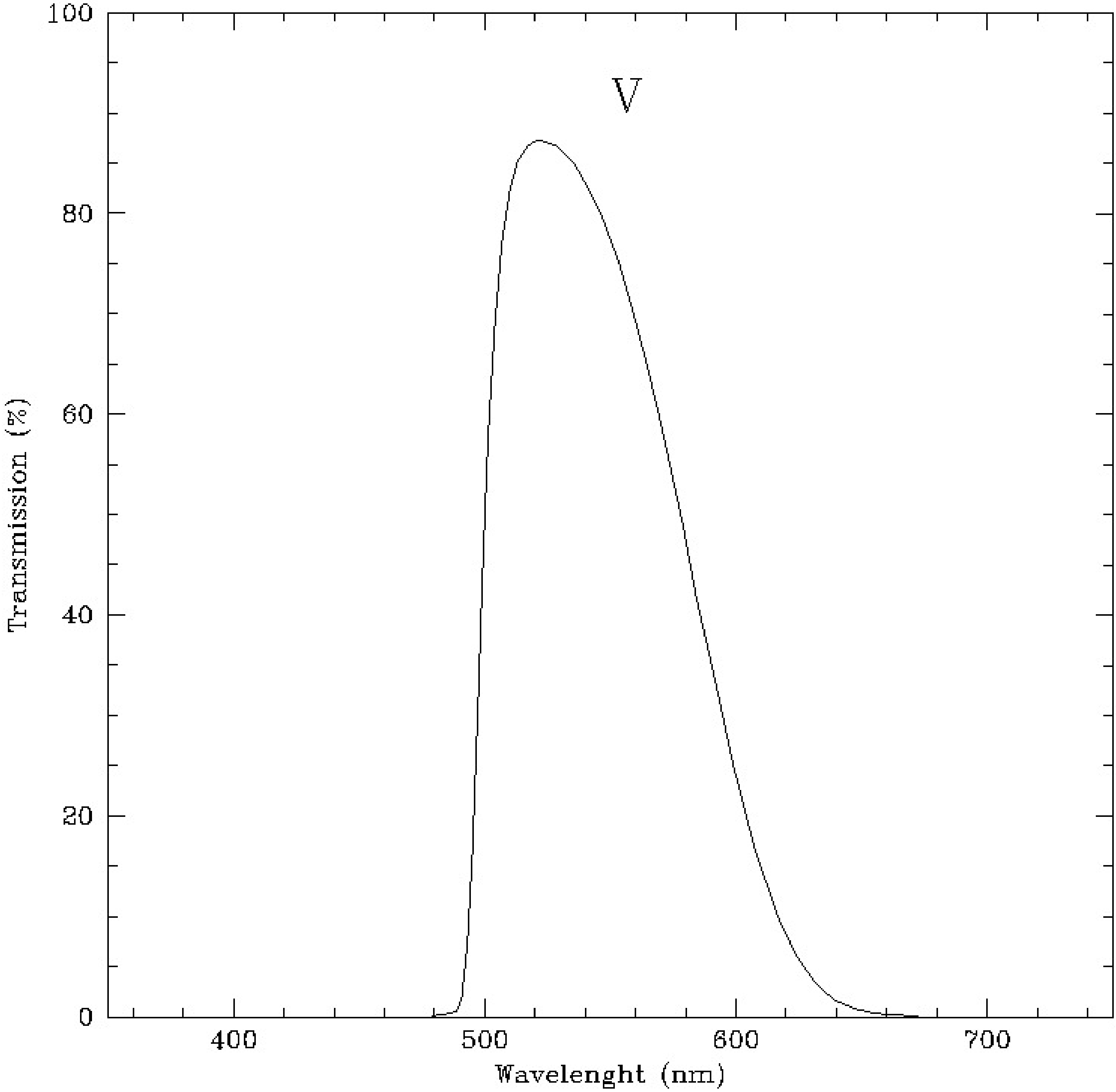
On the right the button **Converti documento** stores on disk the acquired frame in FITS format, allowing the possiblity to enter the object name in the FITS header (**[ObjectKeyword]).**

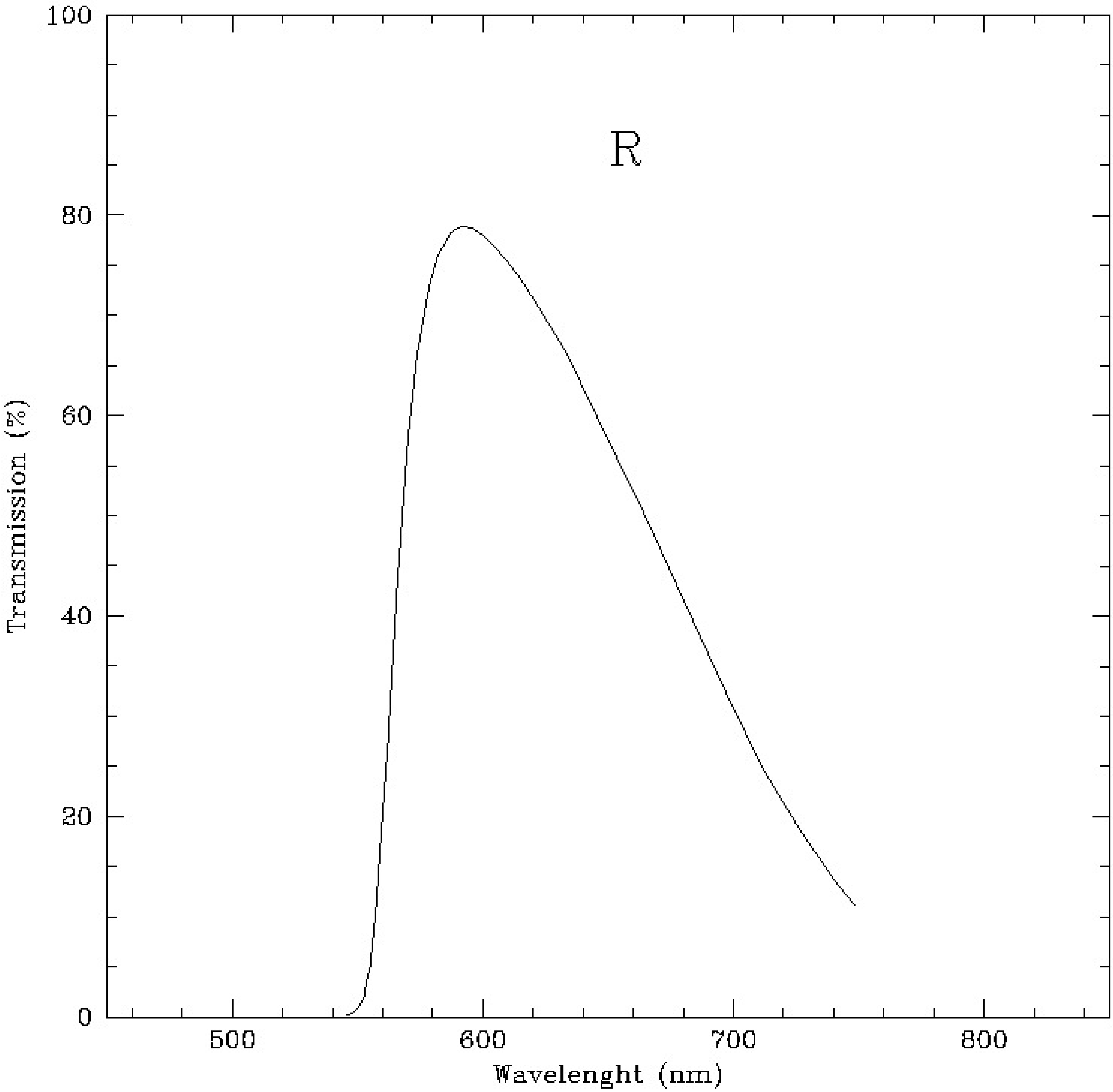
In the FITS header of each image wil be stored the wheels position, the J.D., U.T., S.T, RA and Dec of the object.



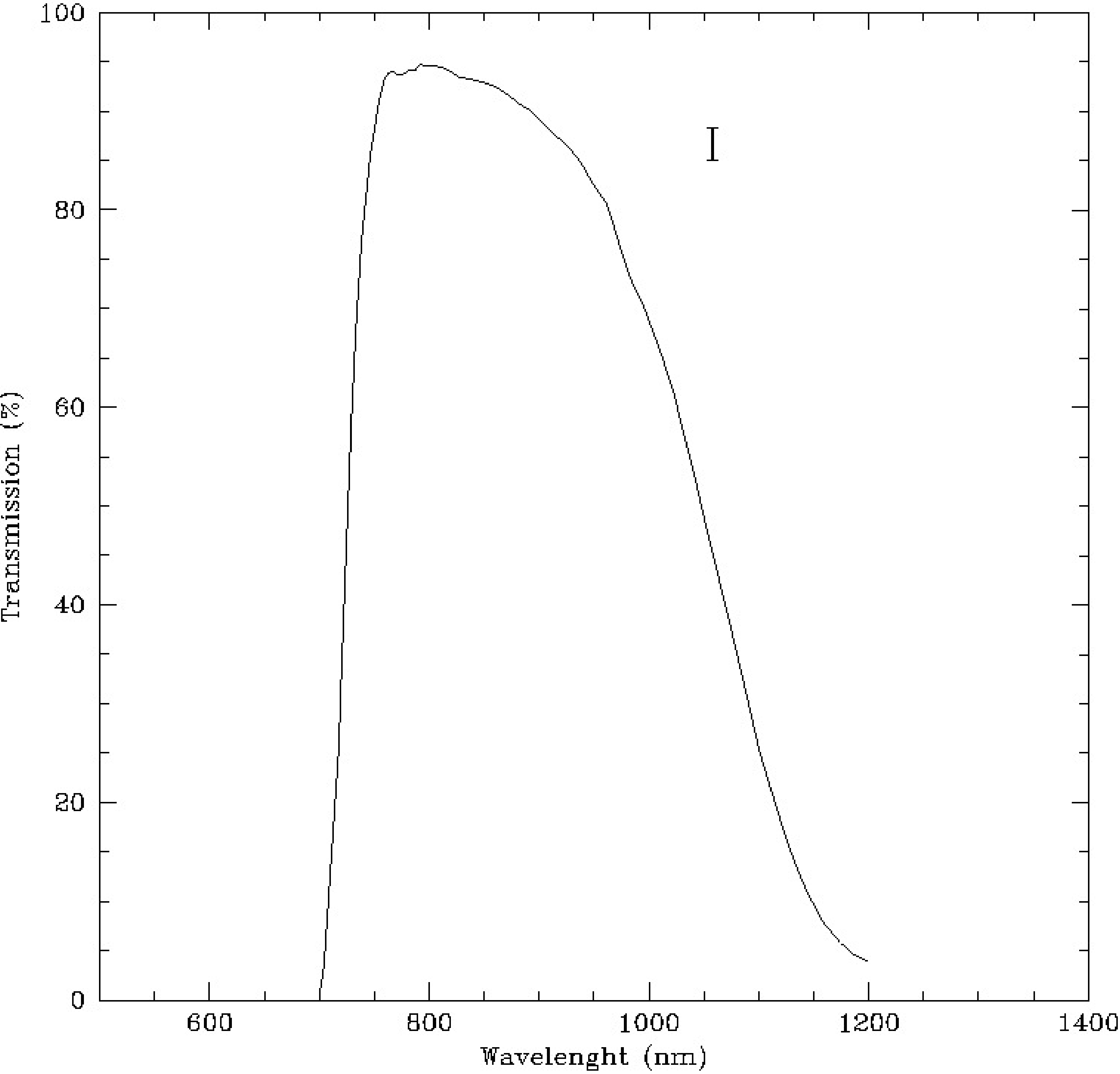
U
Transmission (%)
Wavelenght (nm)
0
20
40
60
80
300
350
400
450

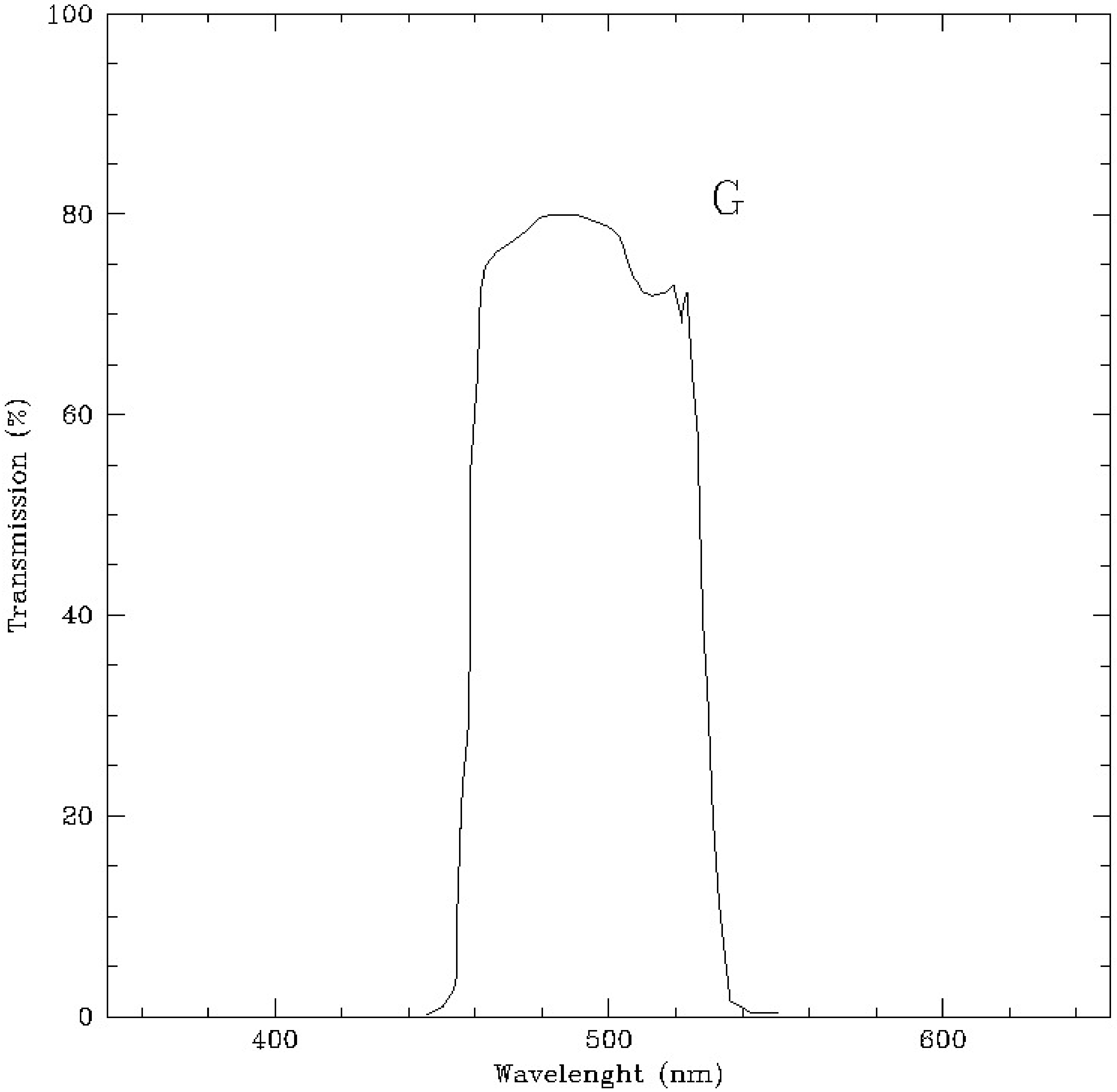

B
Transmission (%)
0
20
40
60
80
300
400
500
600
Wavelenght (nm)

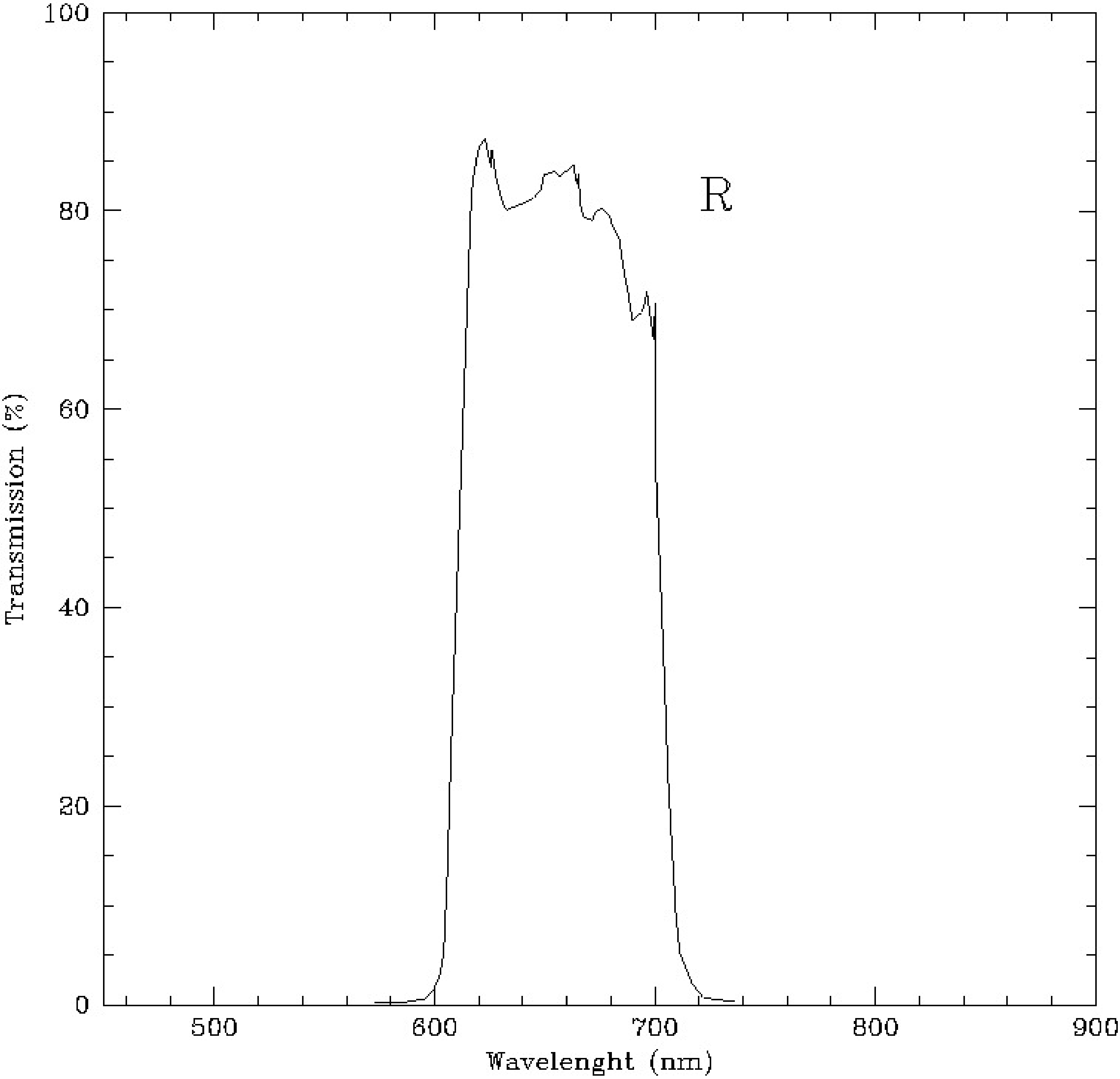

V
Transmission (%)
Wavelenght (nm)
0
20
40
60
80
100
400
500
600
700



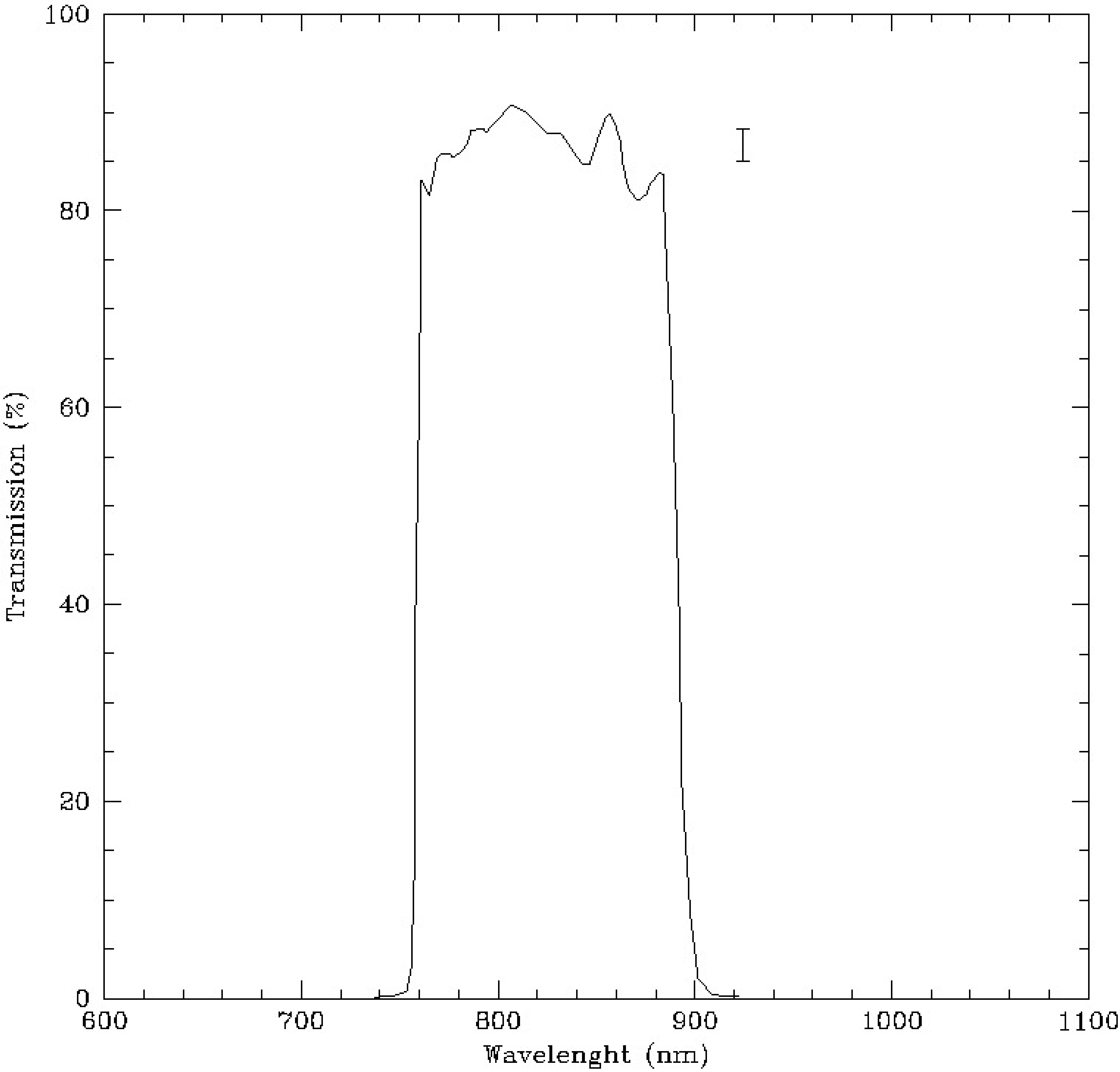
R
Transmission (%)
Wavelenght (nm)
0
20
40
60
80
100
500
600
700
800


100
80
60
40
20
0
Transmission (%)
600
800
1000
1200
1400
Wavelenght (nm)
I

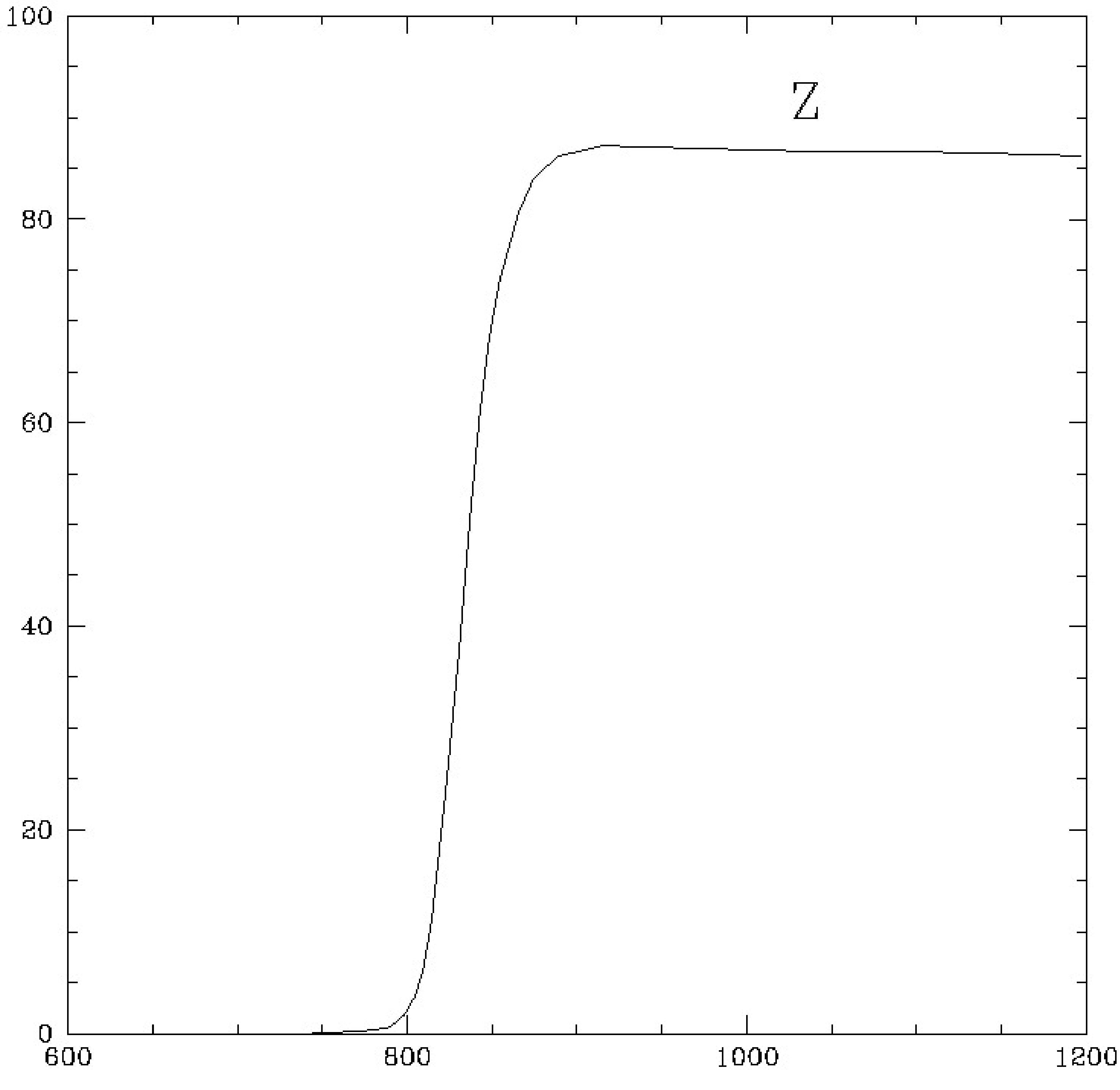

G
Transmission (%)
Wavelenght (nm)
0
20
40
60
80
100
400
500
600



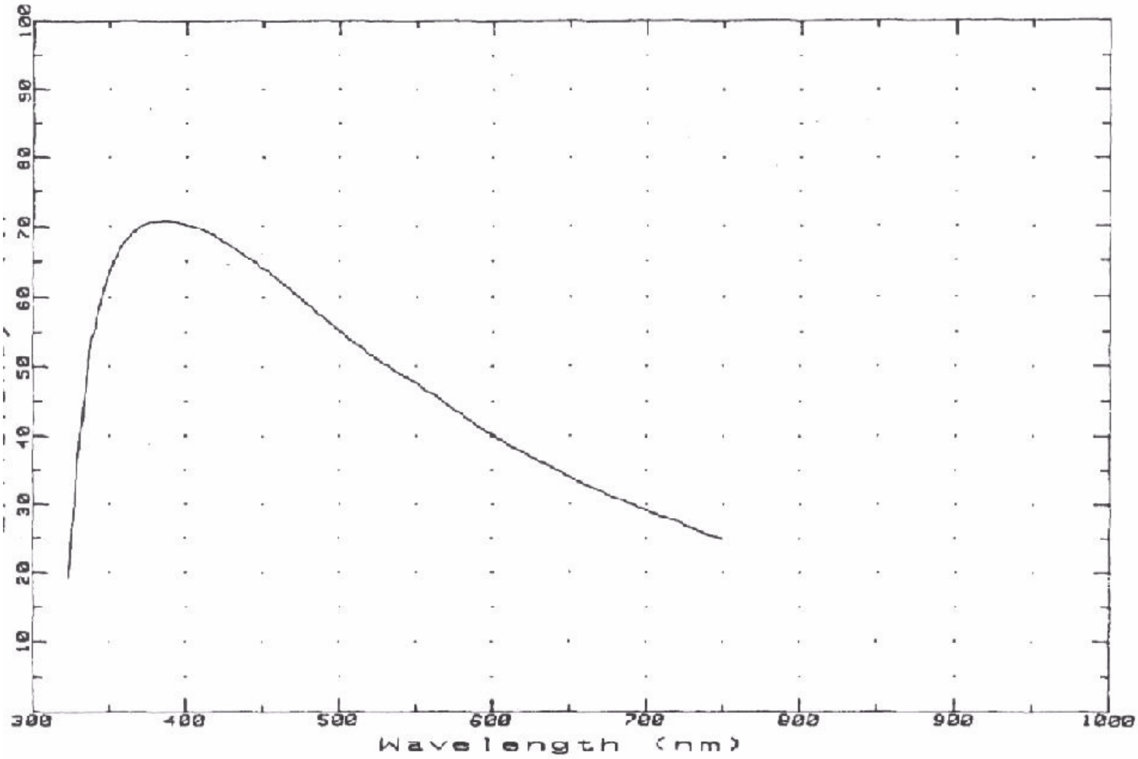
R
Transmission (%)
Wavelenght (nm)
0
20
40
60
80
100
500
600
700
800
900



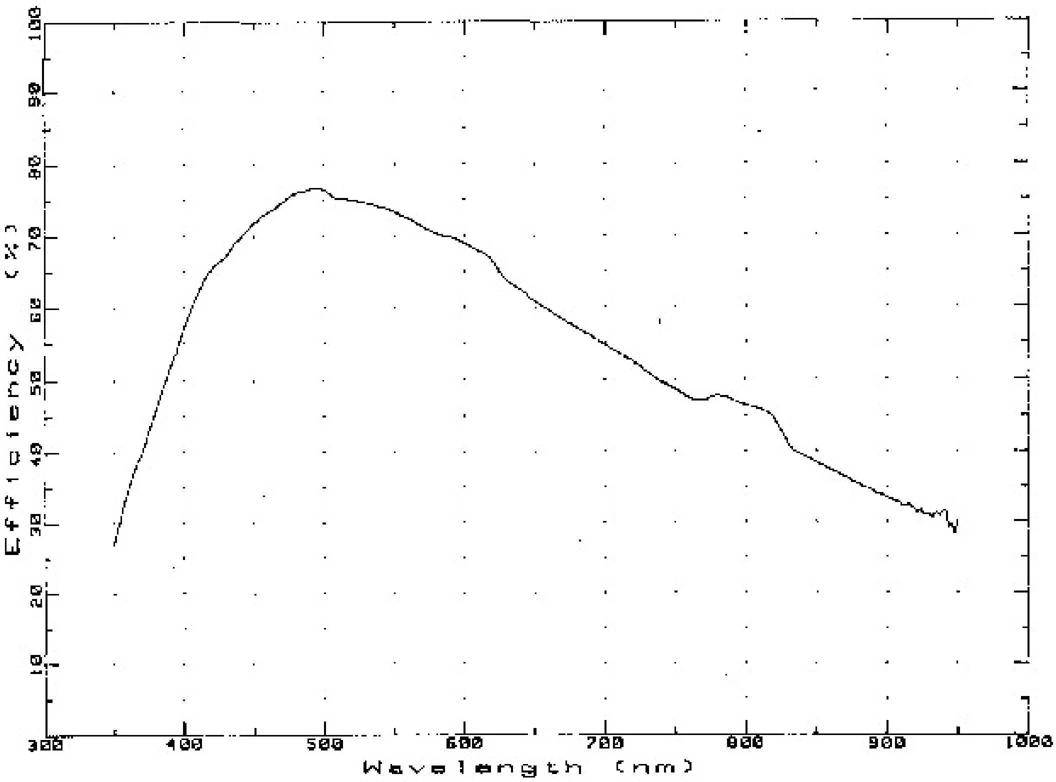
100
80
60
40
20
0
Transmission (%)
I
600
700
800
900
1000
1100
Wavelenght (nm)


Z
100
80
60
40
20
0
600
800
1000
1200

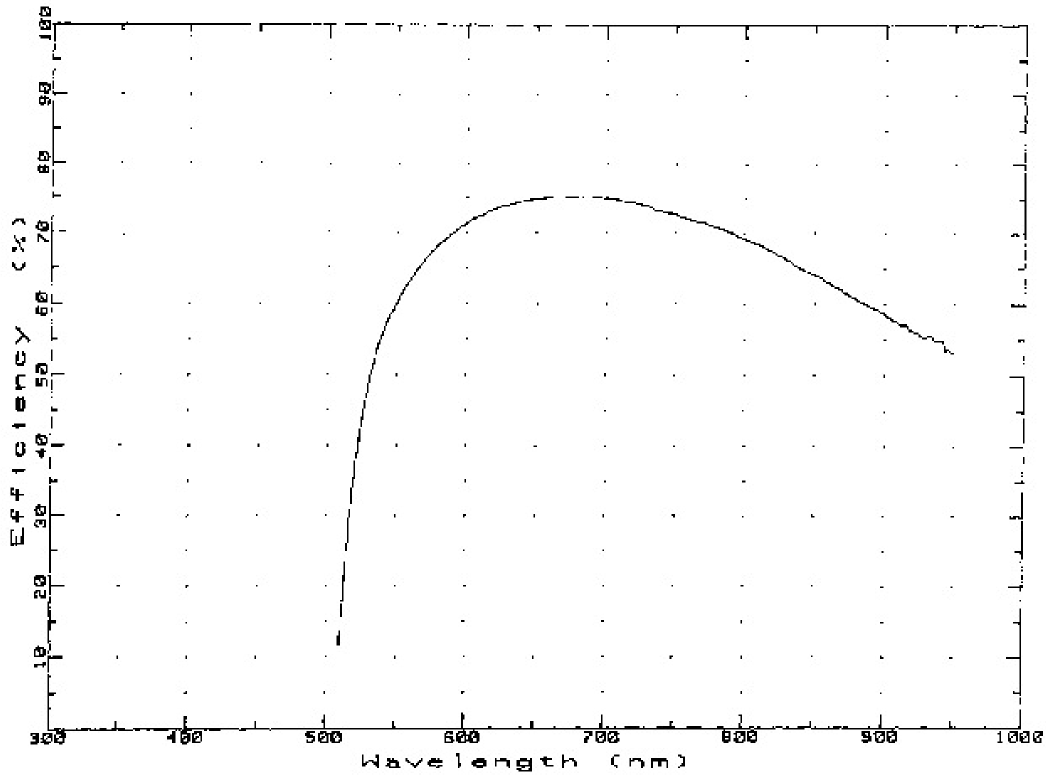
GRISM # 3 - 400 Gr/mm



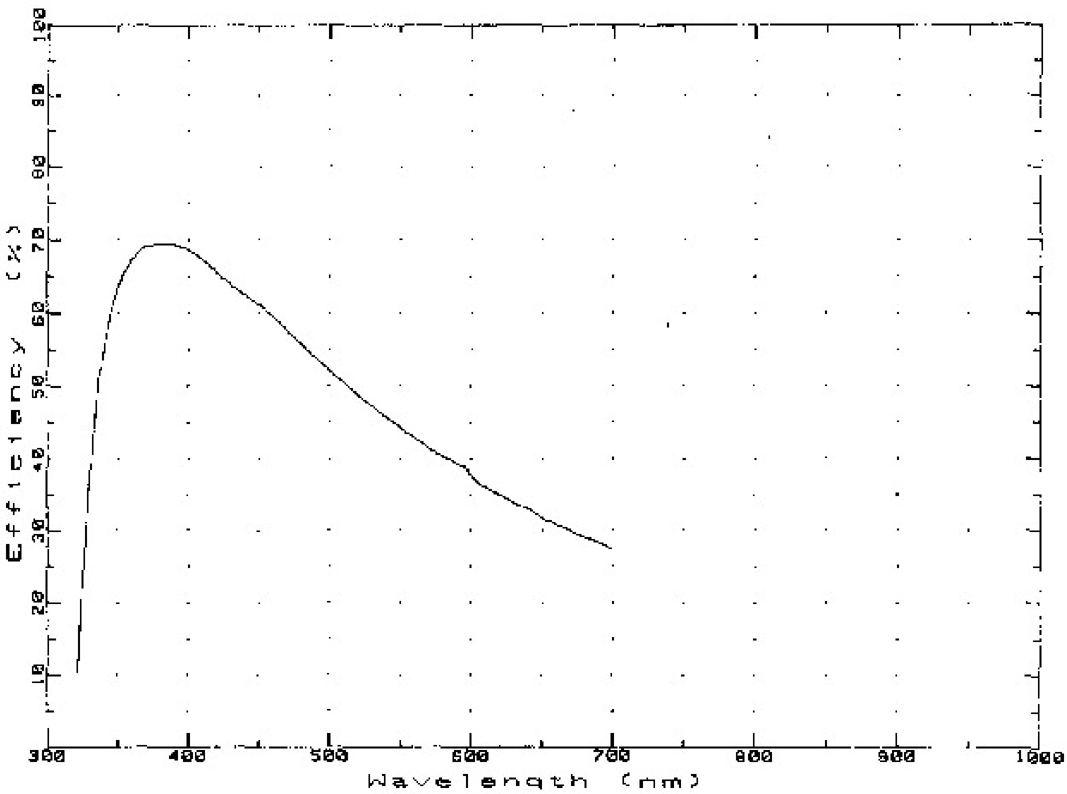
GRISM # 4 - 300 Gr/mm

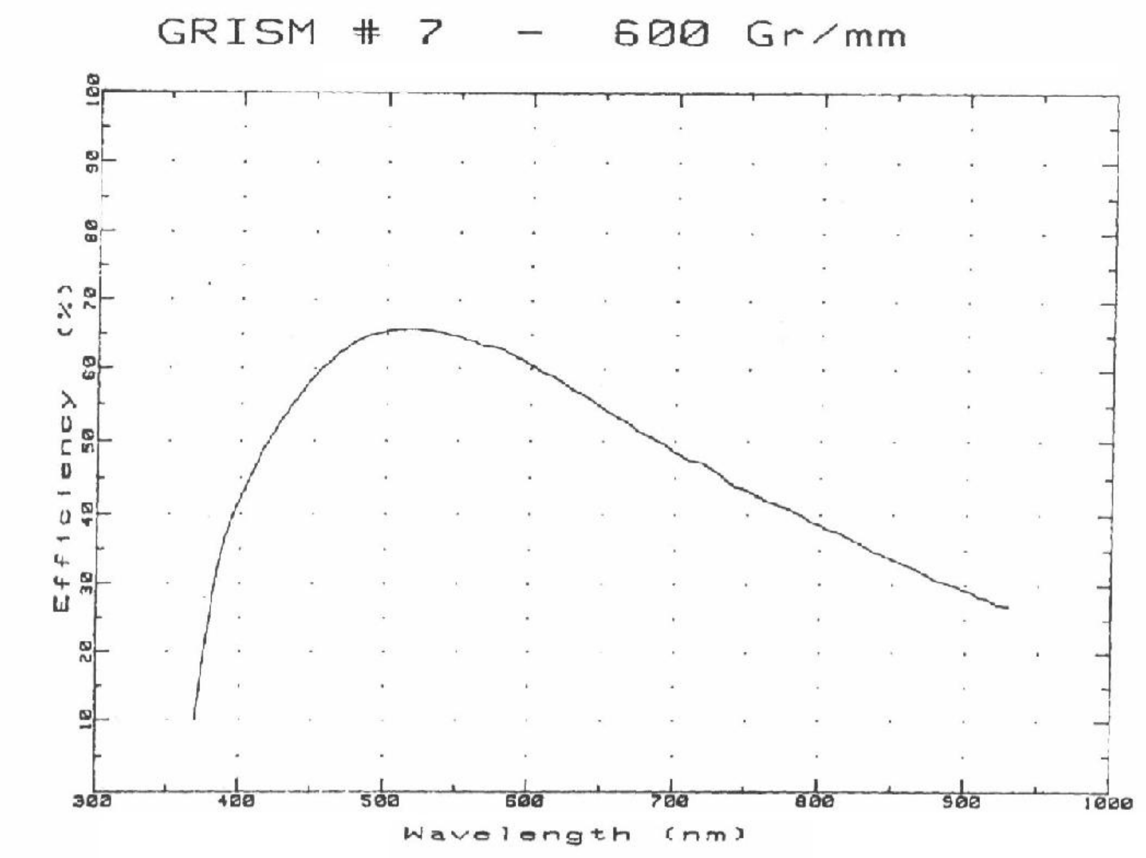


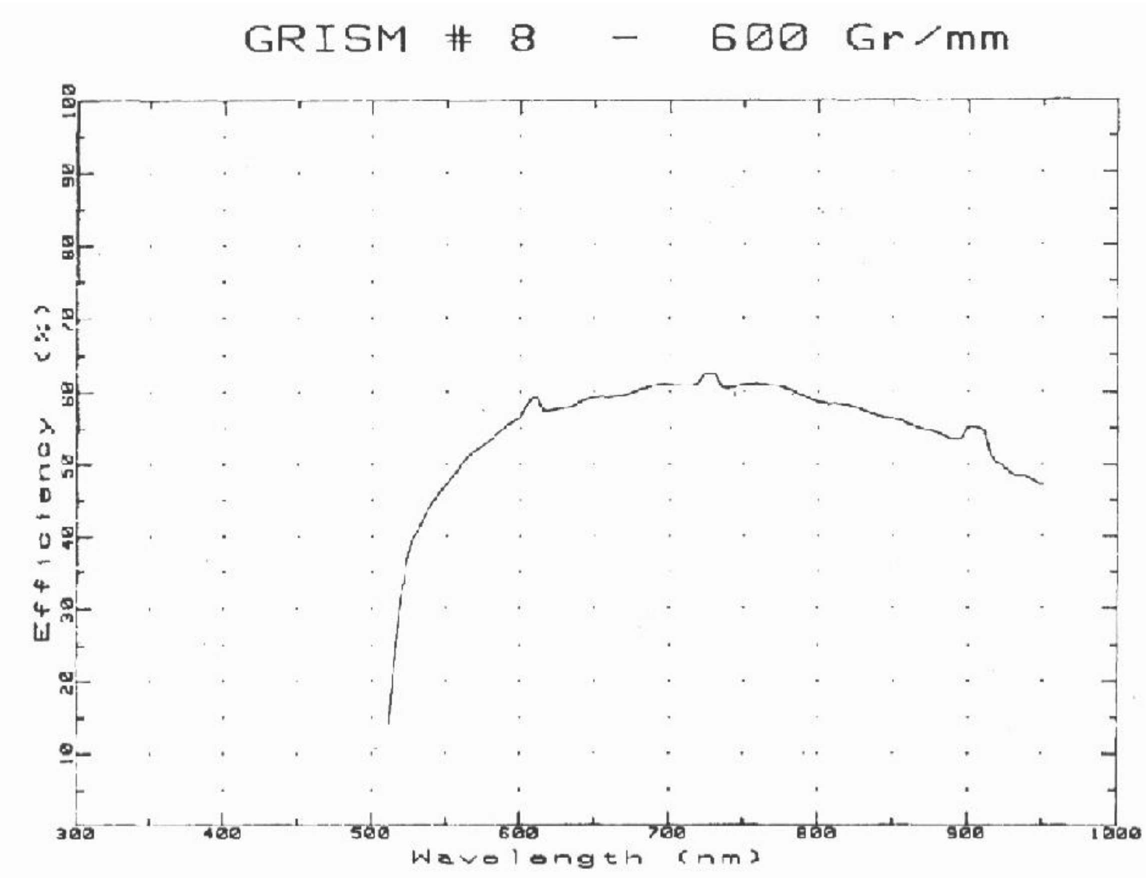
GRISM # 5 - 300 Gr/mm



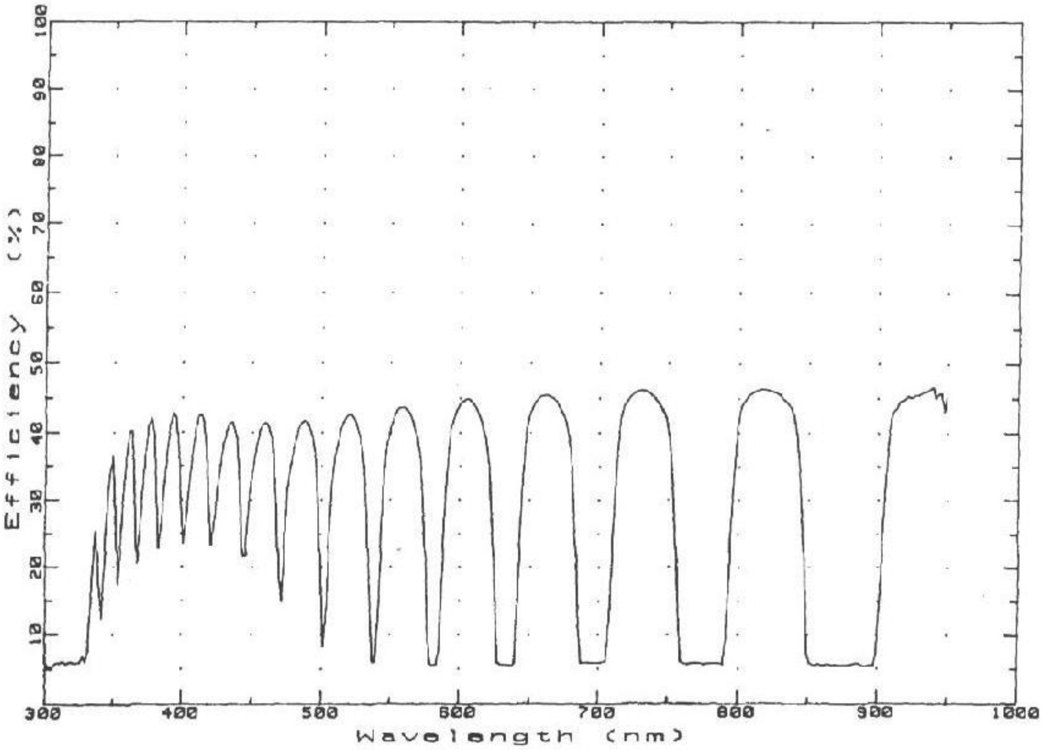
GRISM # 6 - 600 Gr/mm

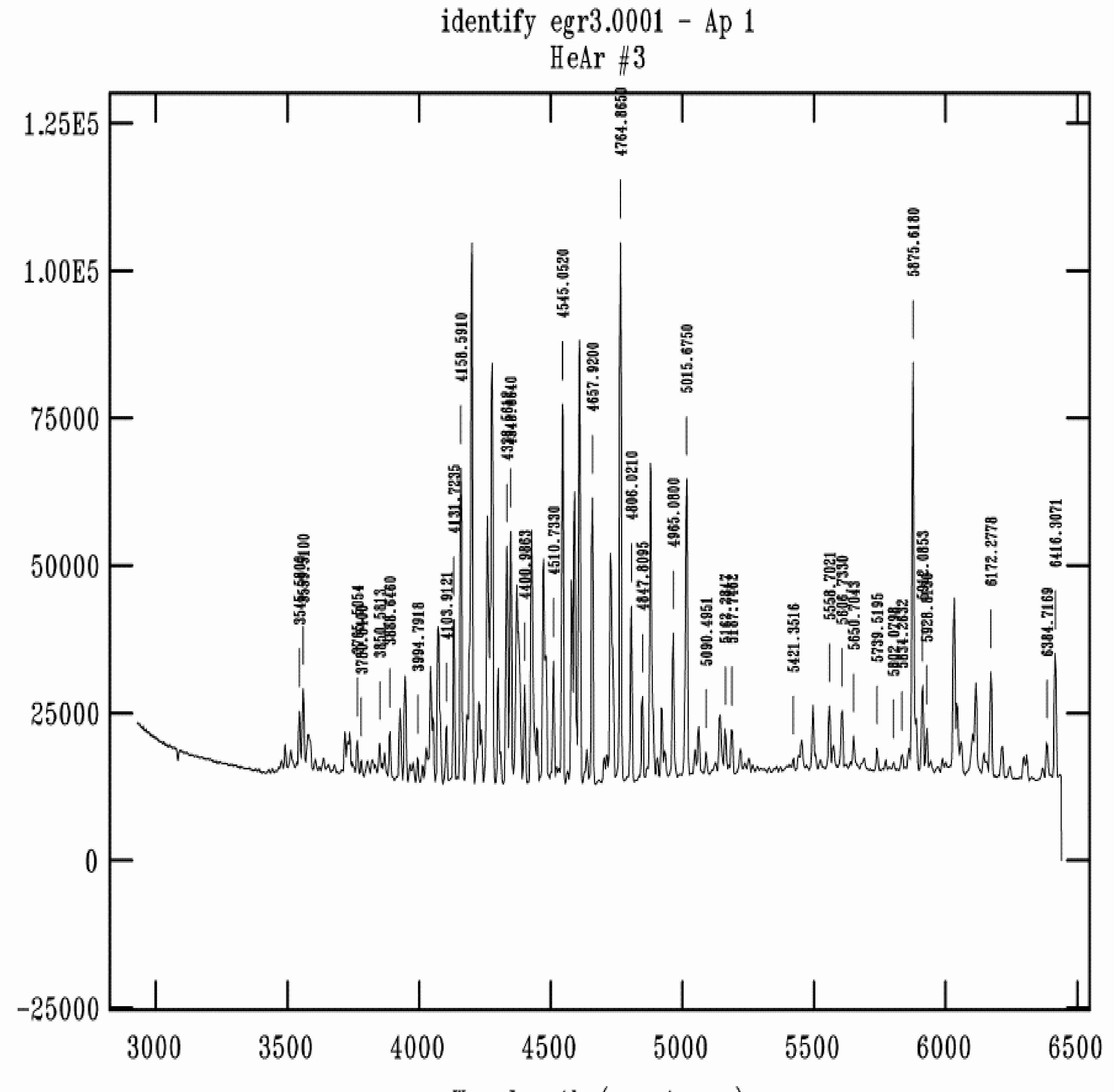


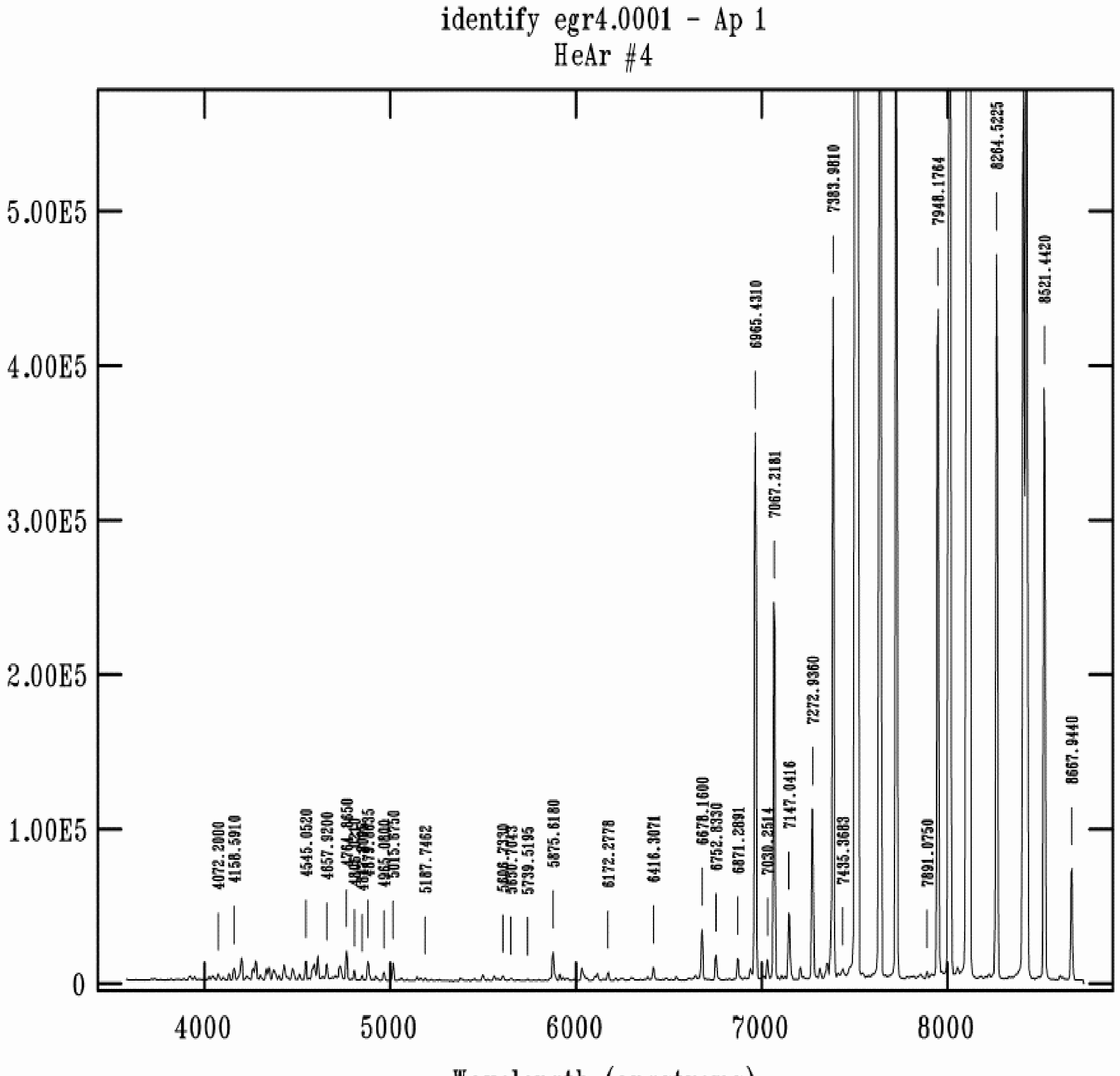

GRISM # 7 - 600 Gr/mm
Efficiency (%)
Wavelength (nm)
10
20
30
40
50
60
70
80
90
100
300
400
500
600
700
800
900
1000


GRISM # 8 - 600 Gr/mm
Efficiency (%)
Wavelength (nm)
10
20
30
40
50
60
70
80
90
100
300
400
500
600
700
800
900
1000

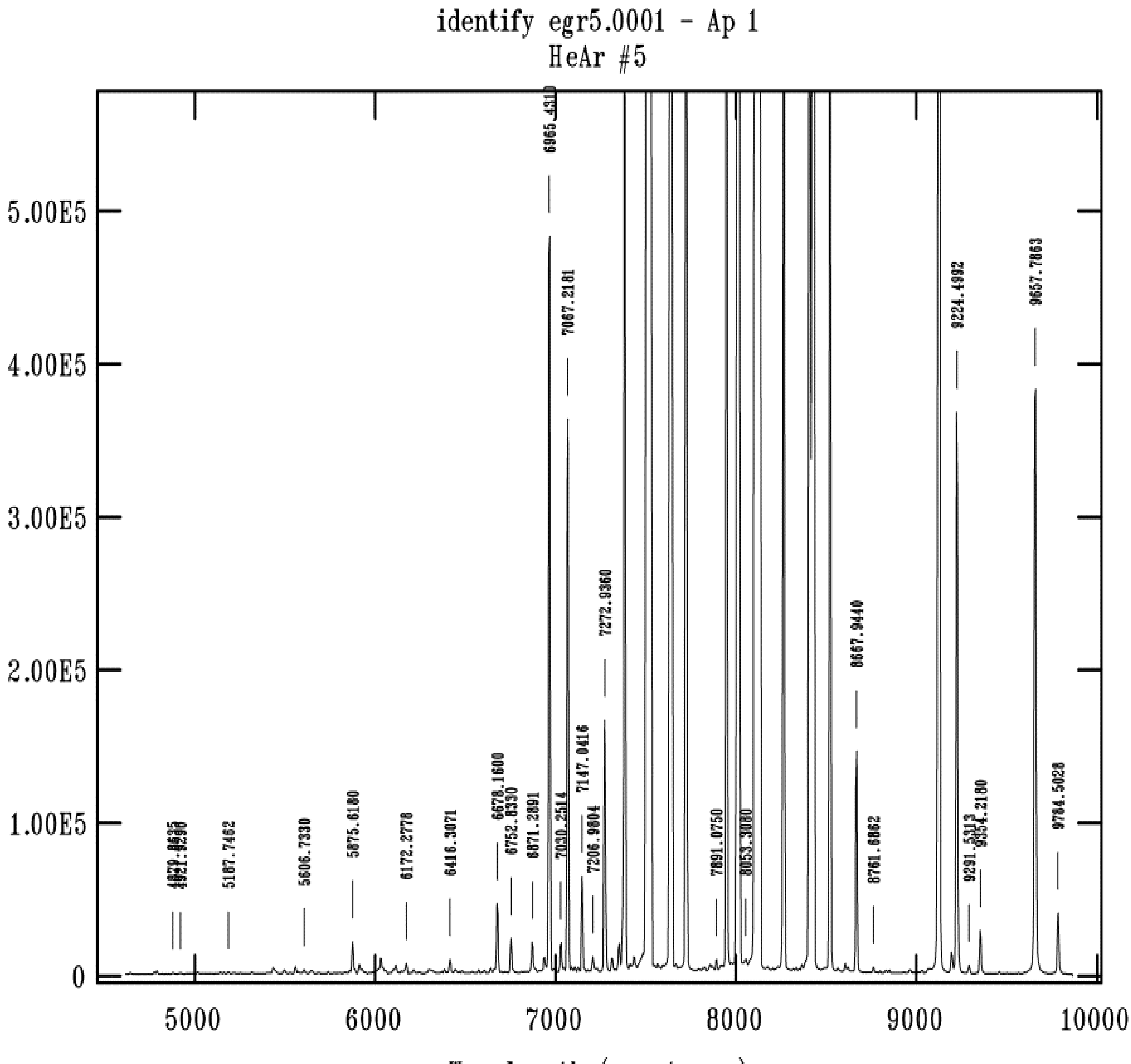
GRISM # 9 - ECHELLE 79Gr

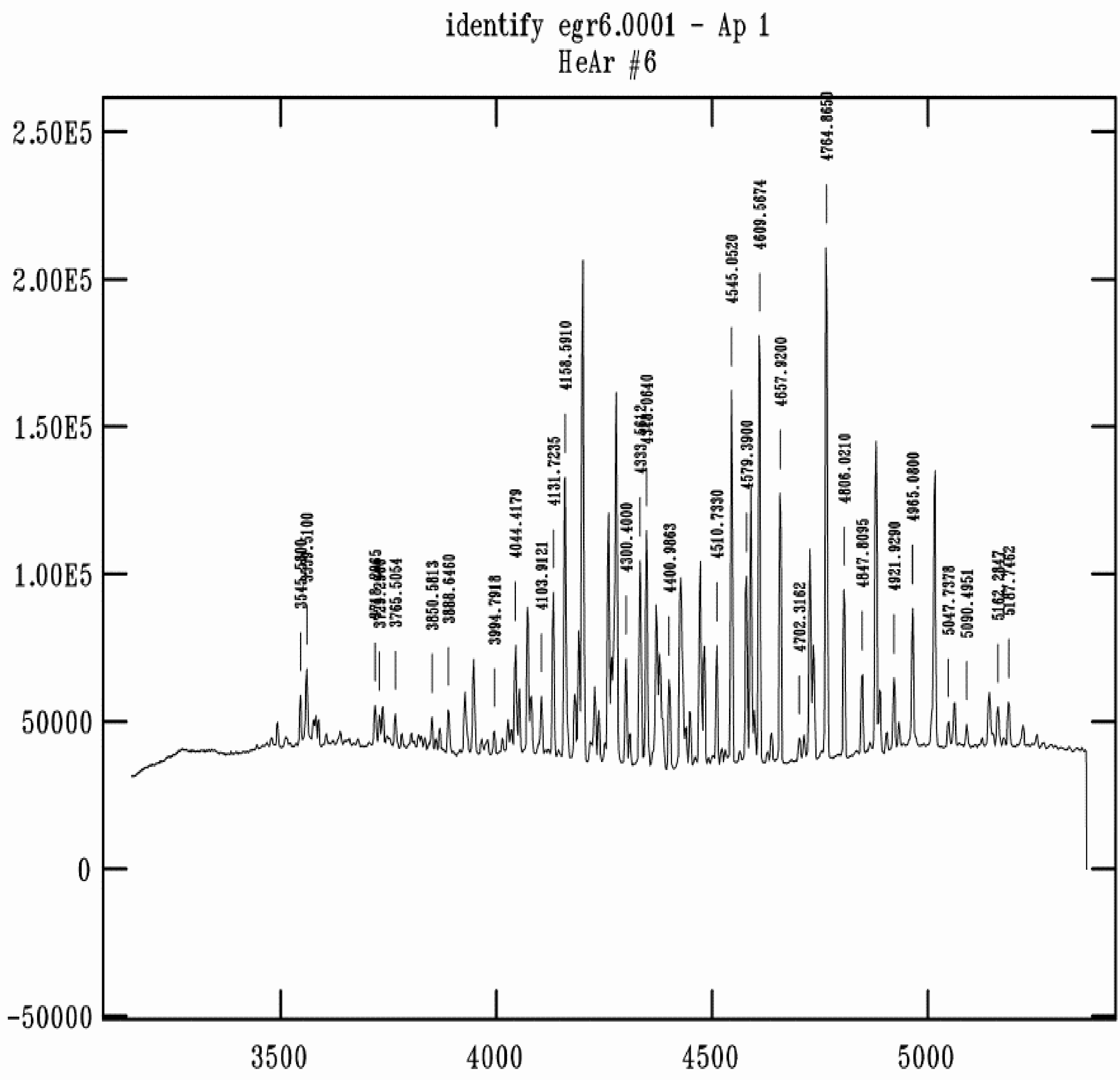



identify egr3.0001 - Ap 1
HeAr #3
1.25E5
1.00E5
75000
50000
25000
0
-25000
3000
3500
4000
4500
5000
5500
6000
6500
3994.7918
4103.9121
4131.7235
4158.5910
4400.9863
4510.7330
4545.0520
4657.9200
4764.8650
4806.0210
4847.8095
4965.0800
5015.6750
5090.4951
5421.3516
5558.7021
5650.7043
5739.5195
5875.6180
6172.2778
6384.7169
6416.3071



identify egr4.0001 - Ap 1
HeAr #4
4072.2000
4158.5910
4545.0520
4657.9200
4764.8650
4879.8635
4965.0800
5015.6750
5187.7462
5739.5195
5875.6180
6172.2778
6416.3071
6678.1600
6752.8330
6871.2891
6965.4310
7030.2514
7067.2181
7147.0416
7272.9360
7383.9810
7435.3683
7891.0750
7948.1764
8264.5225
8521.4420
8667.9440
0
1.00E5
2.00E5
3.00E5
4.00E5
5.00E5
4000
5000
6000
7000
8000


identify egr5.0001 - Ap 1
HeAr #5
0
1.00E5
2.00E5
3.00E5
4.00E5
5.00E5
5000
6000
7000
8000
9000
10000
5187.7462
5606.7330
5875.6180
6172.2778
6416.3071
6678.1600
6752.8330
6871.2891
6965.4310
7030.2514
7067.2181
7147.0416
7206.9804
7272.9360
7891.0750
8053.3080
8667.9440
8761.6862
9224.4992
9291.5313
9354.2180
9657.7863
9784.5028


identify egr6.0001 - Ap 1
HeAr #6
2.50E5
2.00E5
1.50E5
1.00E5
50000
0
-50000
3500
4000
4500
5000
3545.5800
3765.5054
3850.5813
3888.6460
3994.7918
4044.4179
4103.9121
4131.7235
4158.5910
4300.4000
4400.9863
4510.7330
4545.0520
4579.3900
4609.5674
4657.9200
4702.3162
4764.8650
4806.0210
4847.8095
4921.9290
4965.0800
5047.7378
5090.4951
5162.2847
5187.7462

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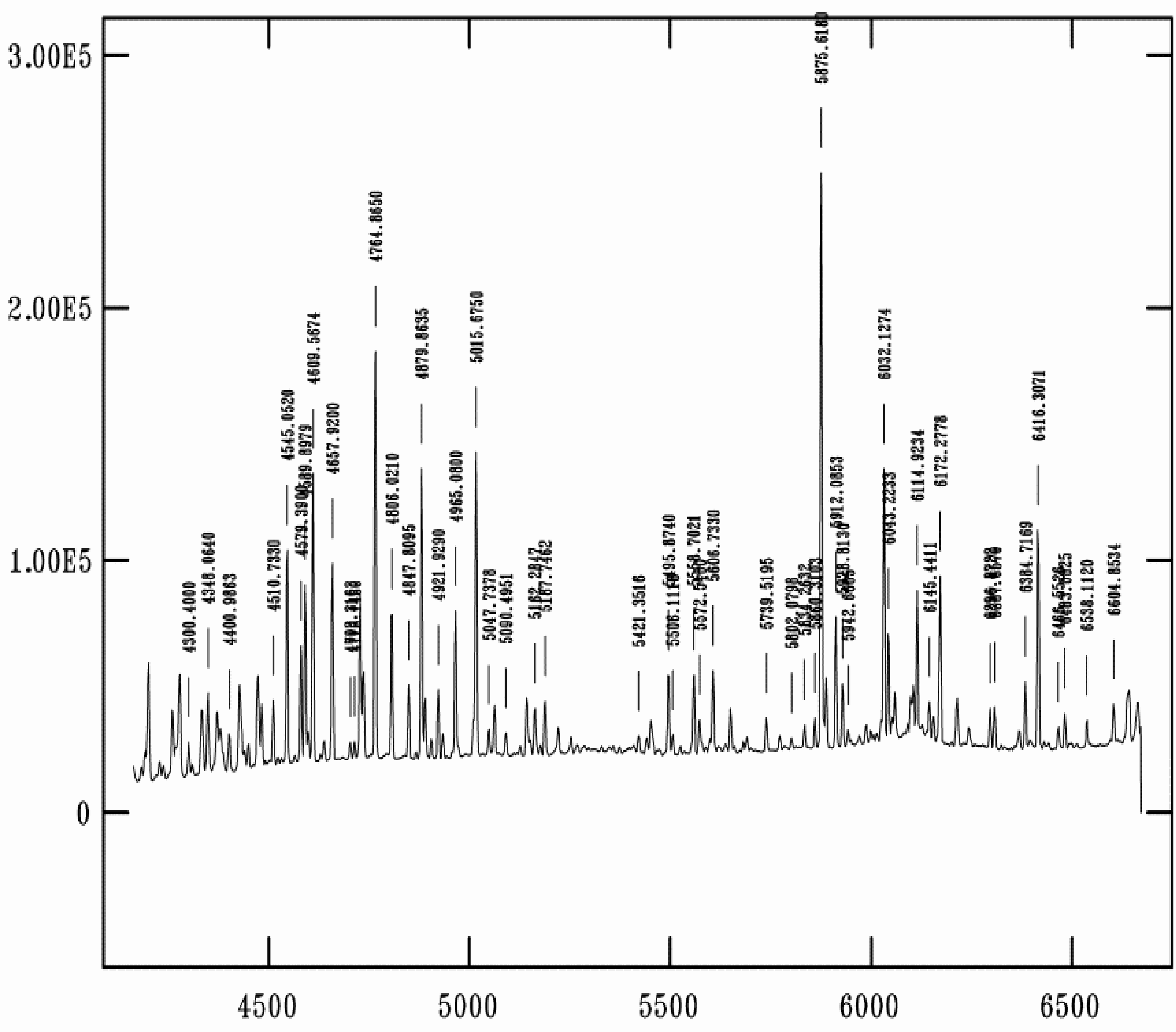
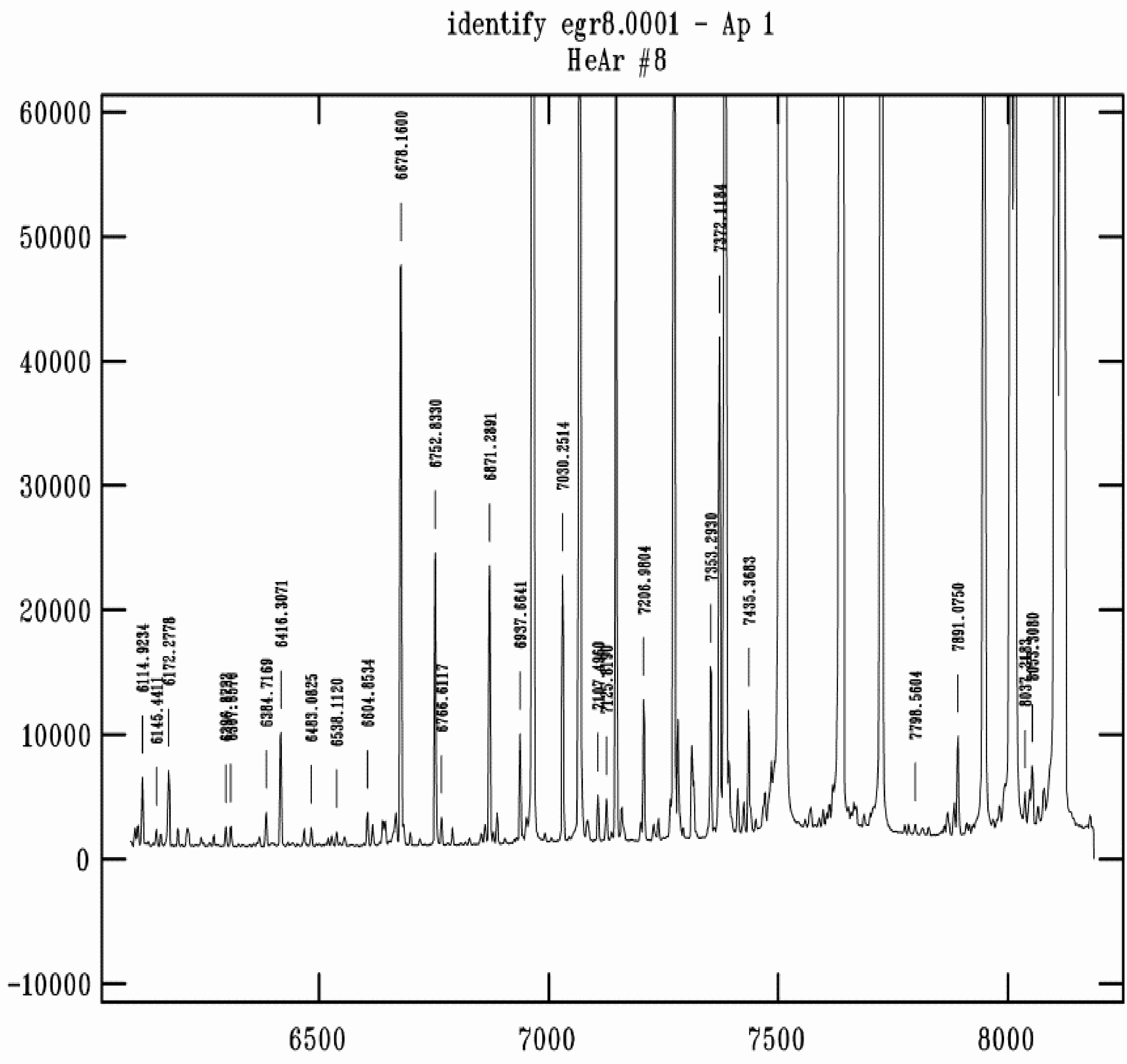
HeAr #7

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HeAr #8
6114.9234
6145.4411
6172.2778
6384.7169
6416.3071
6483.0825
6538.1120
6604.8534
6678.1600
6752.8330
6766.6117
6871.2891
6937.6641
7030.2514
7206.9804
7353.2930
7372.1184
7435.3683
7798.5604
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20000
30000
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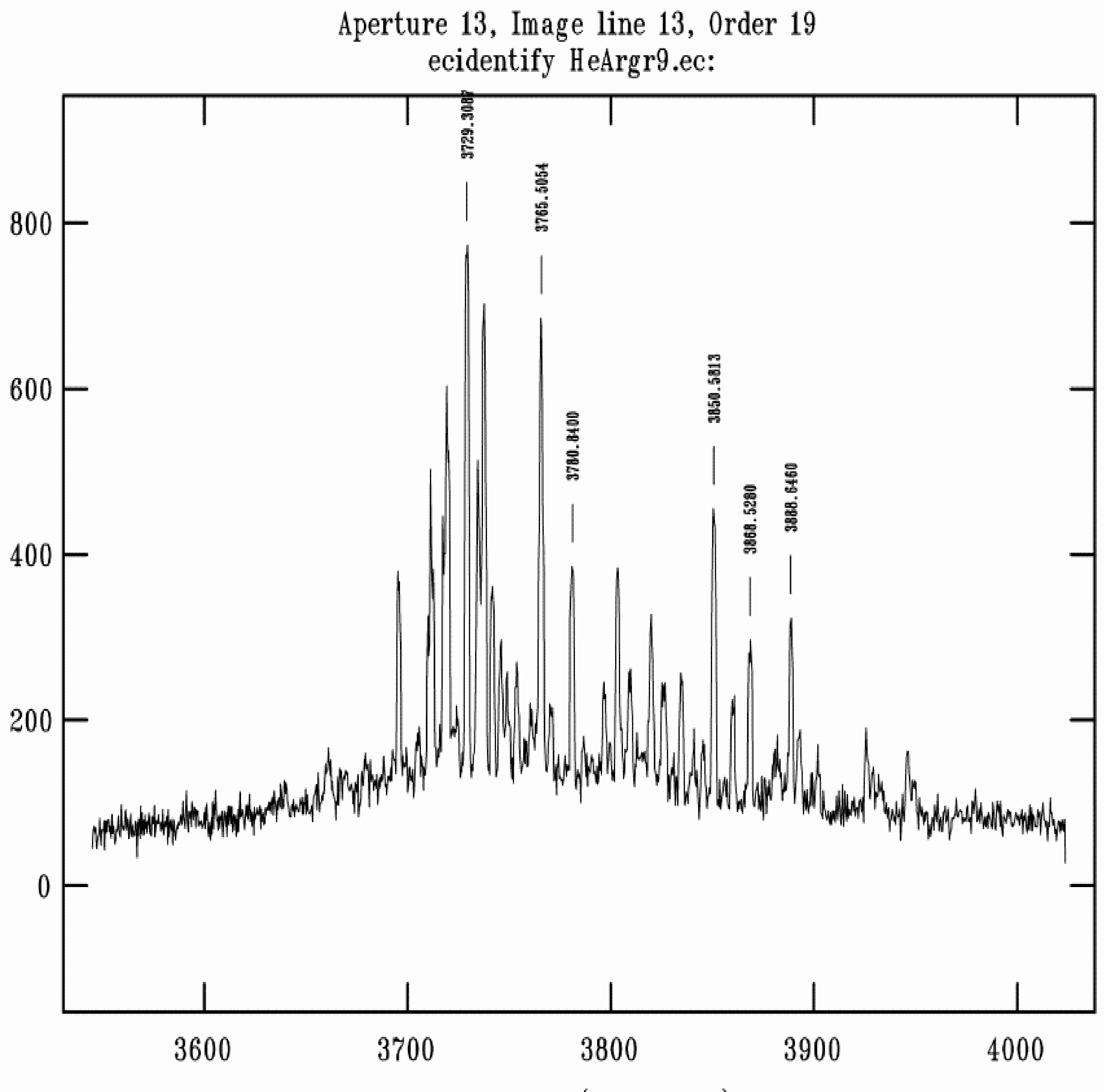
8000


Aperture 13, Image line 13, Order 19
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600
400
200
0
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3900
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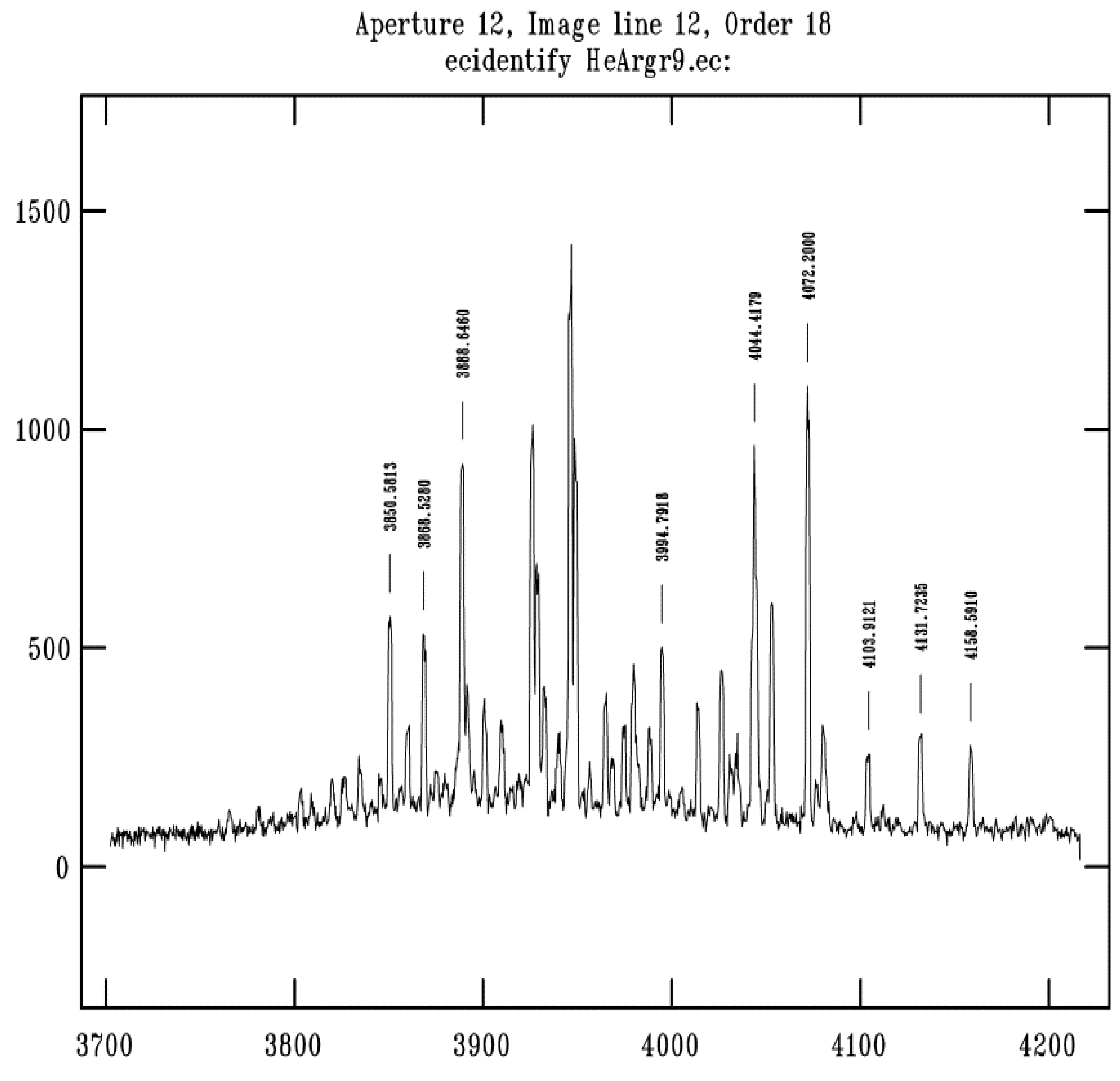

Aperture 12, Image line 12, Order 18
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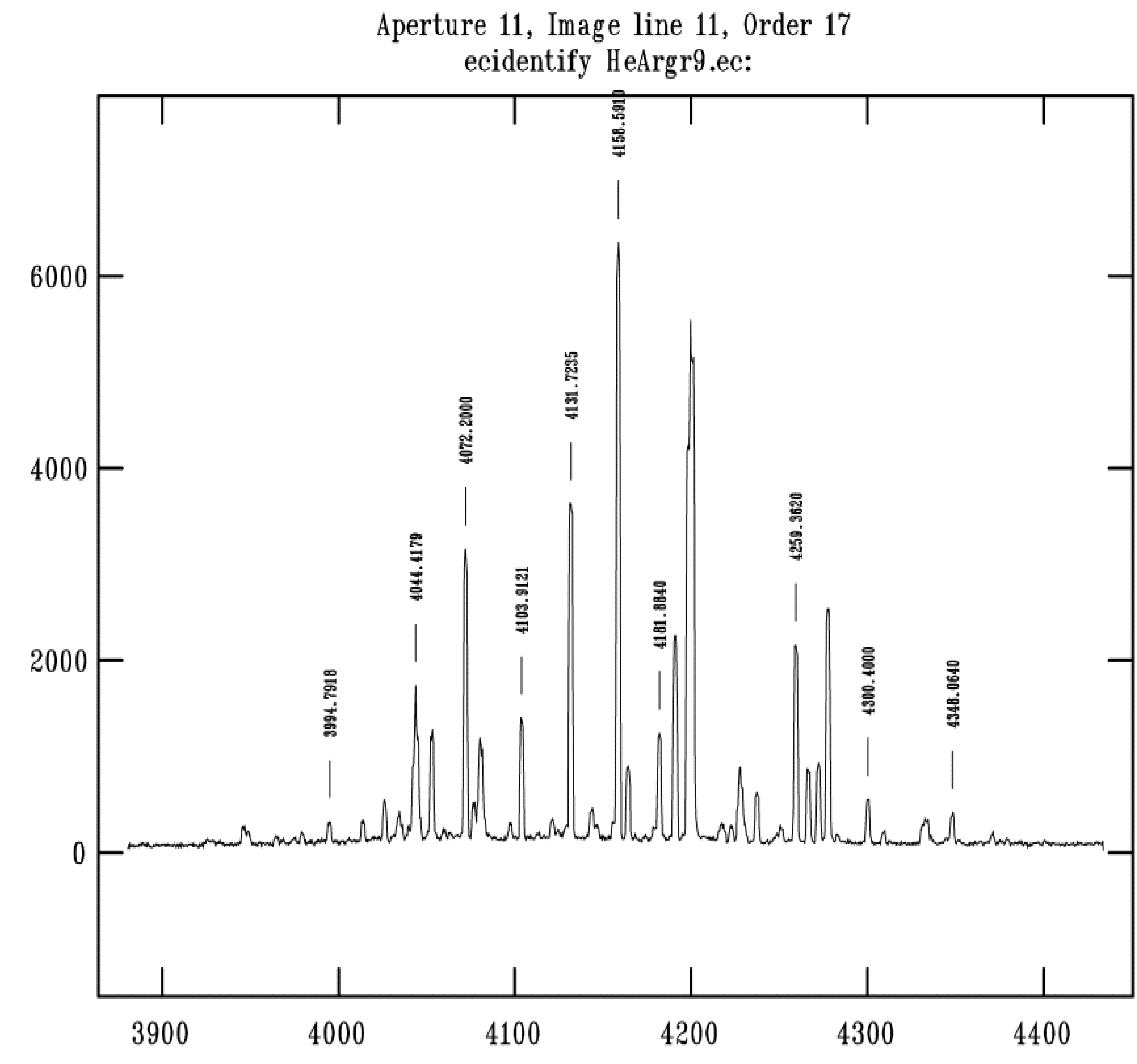

Aperture 11, Image line 11, Order 17
ecidentify HeArgr9.ec:
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4300.4000
4348.0640
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4200
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Aperture 10, Image line 10, Order 16
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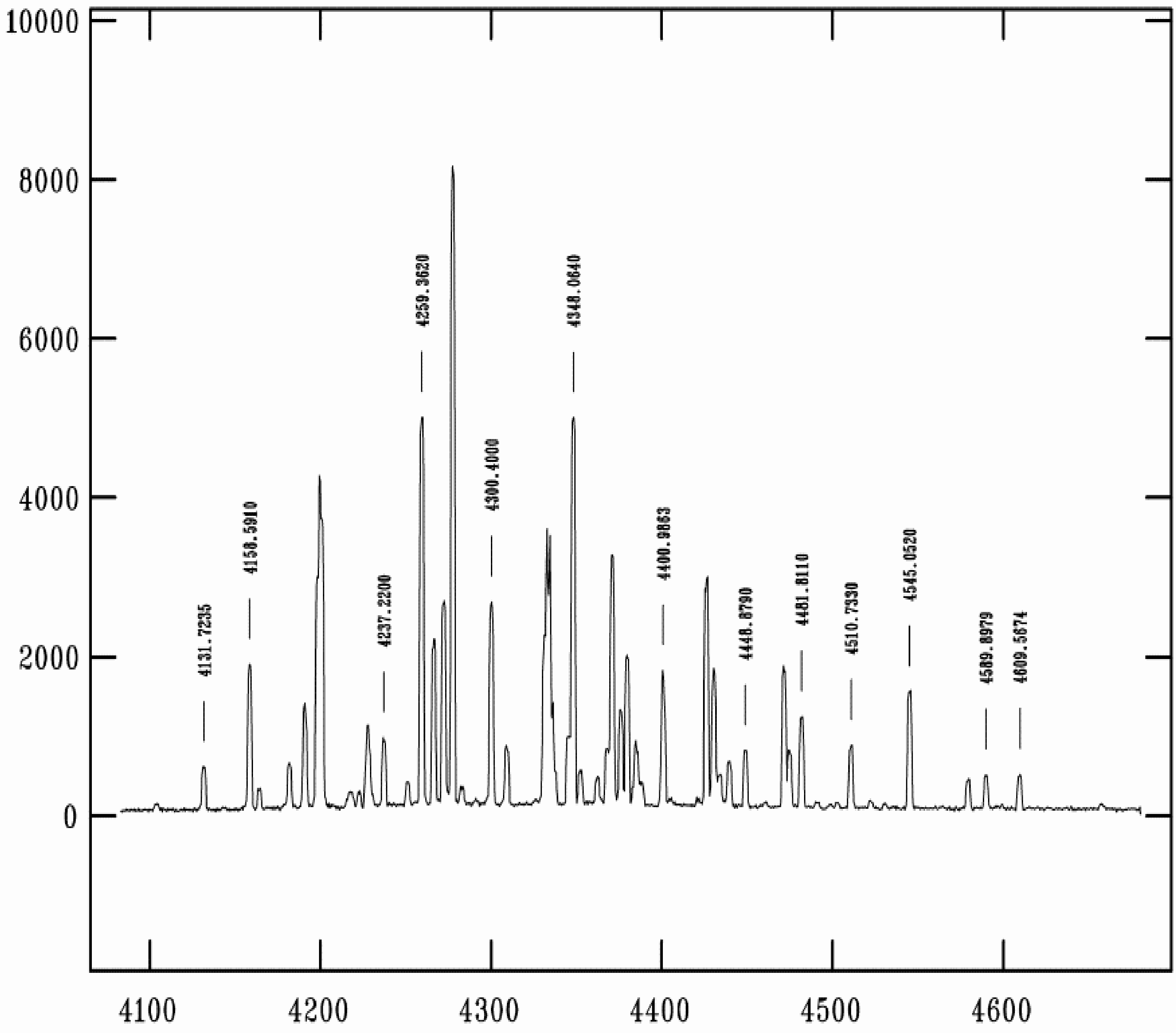

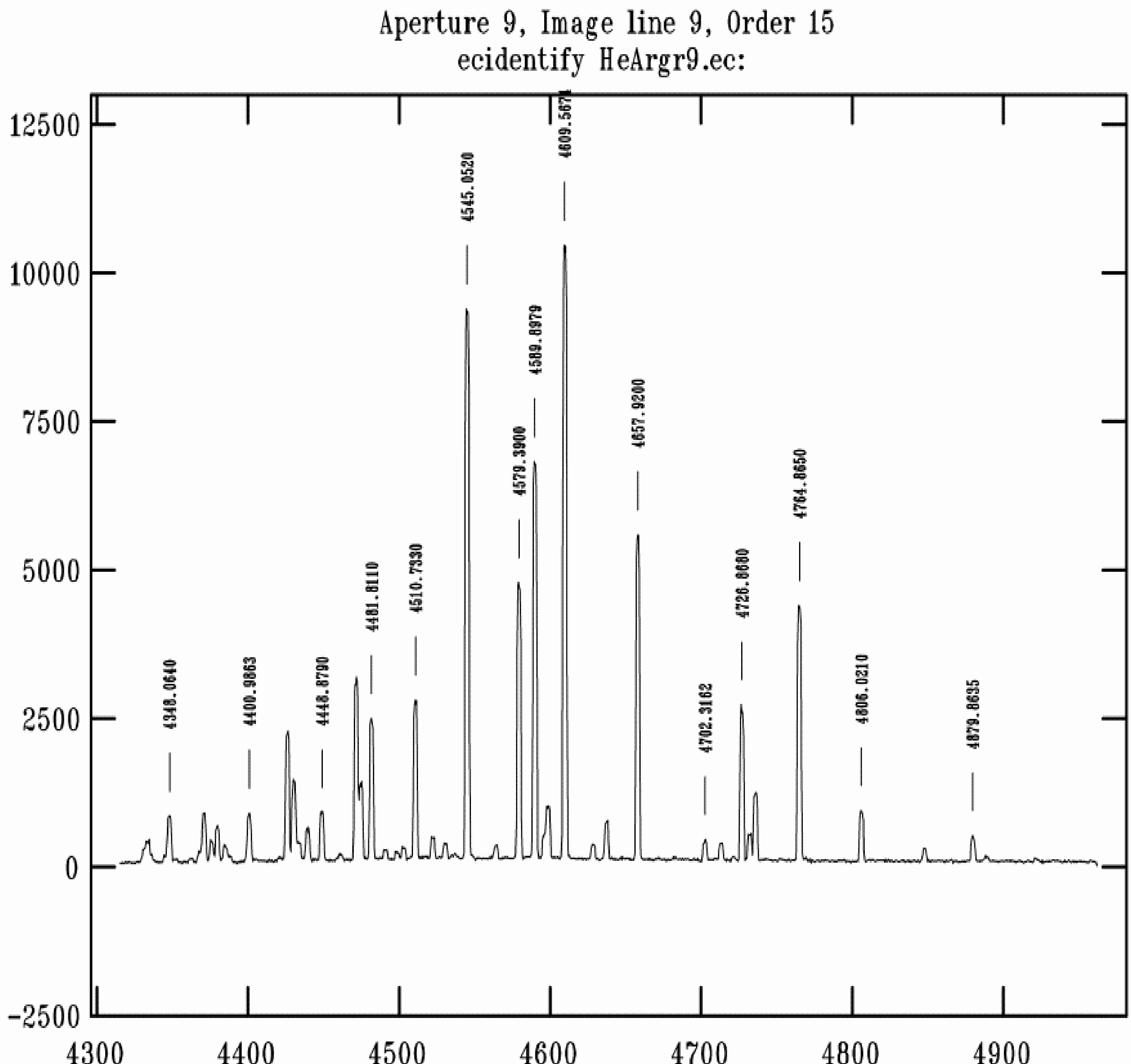

Aperture 9, Image line 9, Order 15
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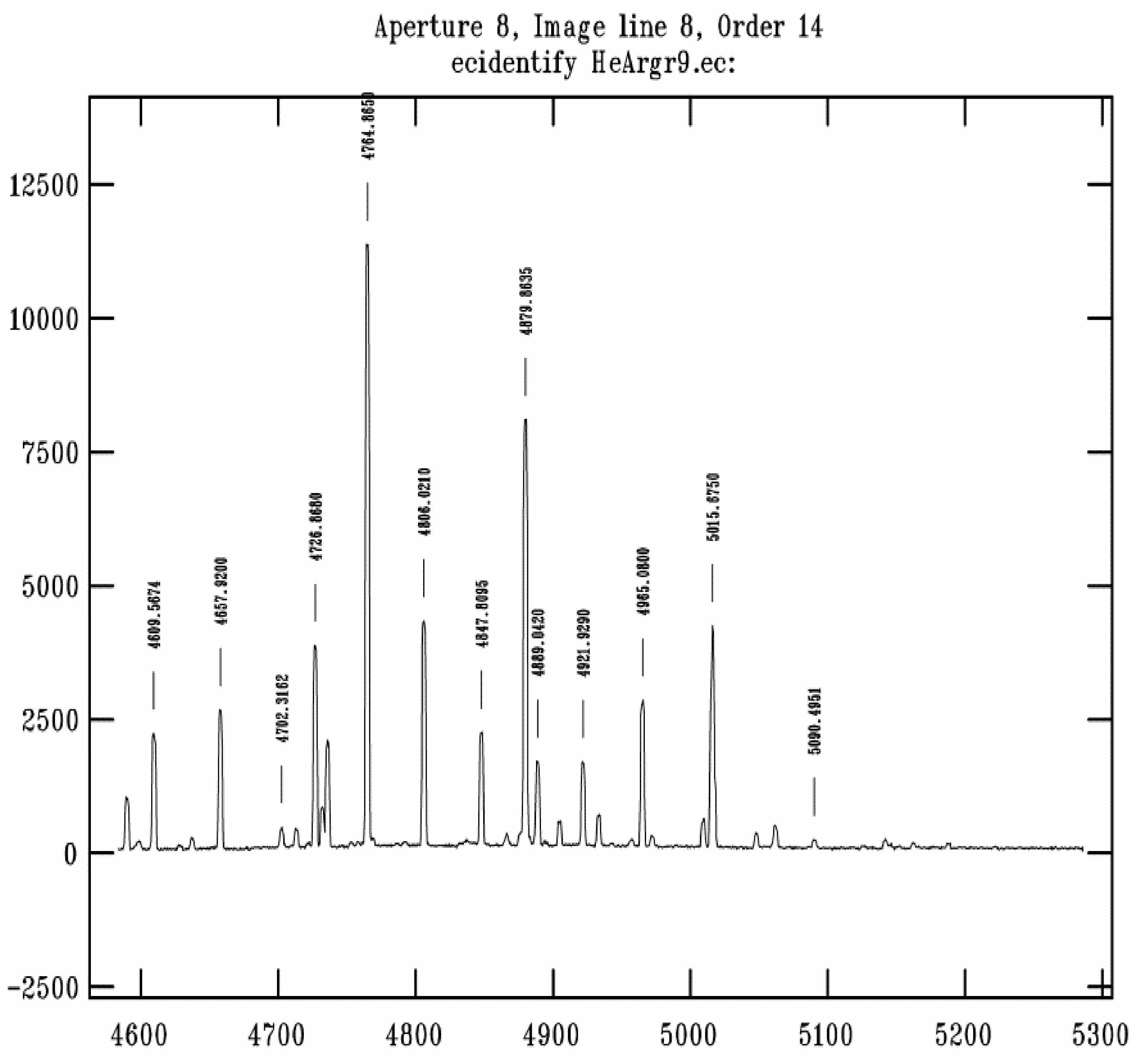
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5090.4951
12500
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7500
5000
2500
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4800
4900
5000
5100
5200
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Aperture 7, Image line 7, Order 13
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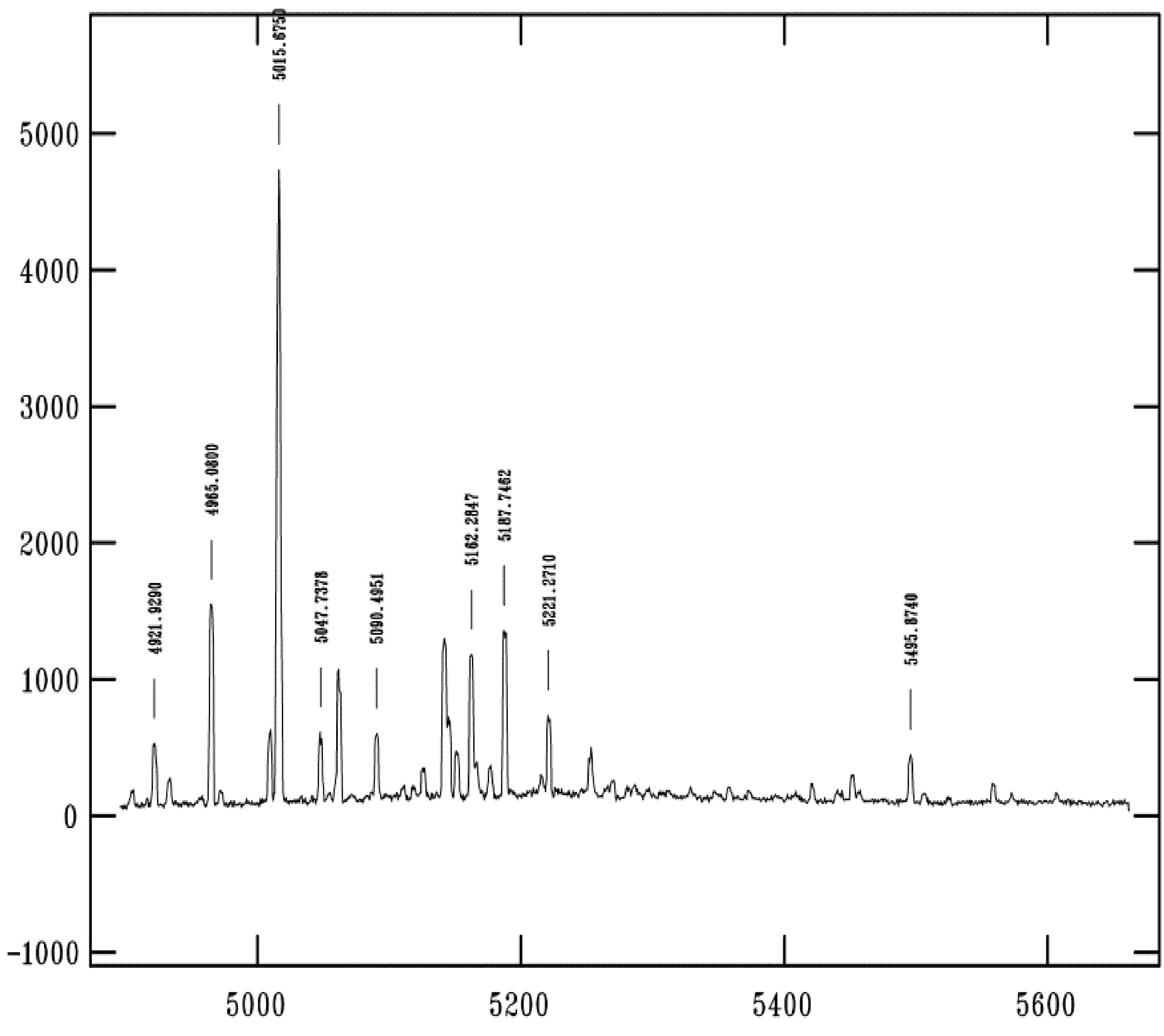

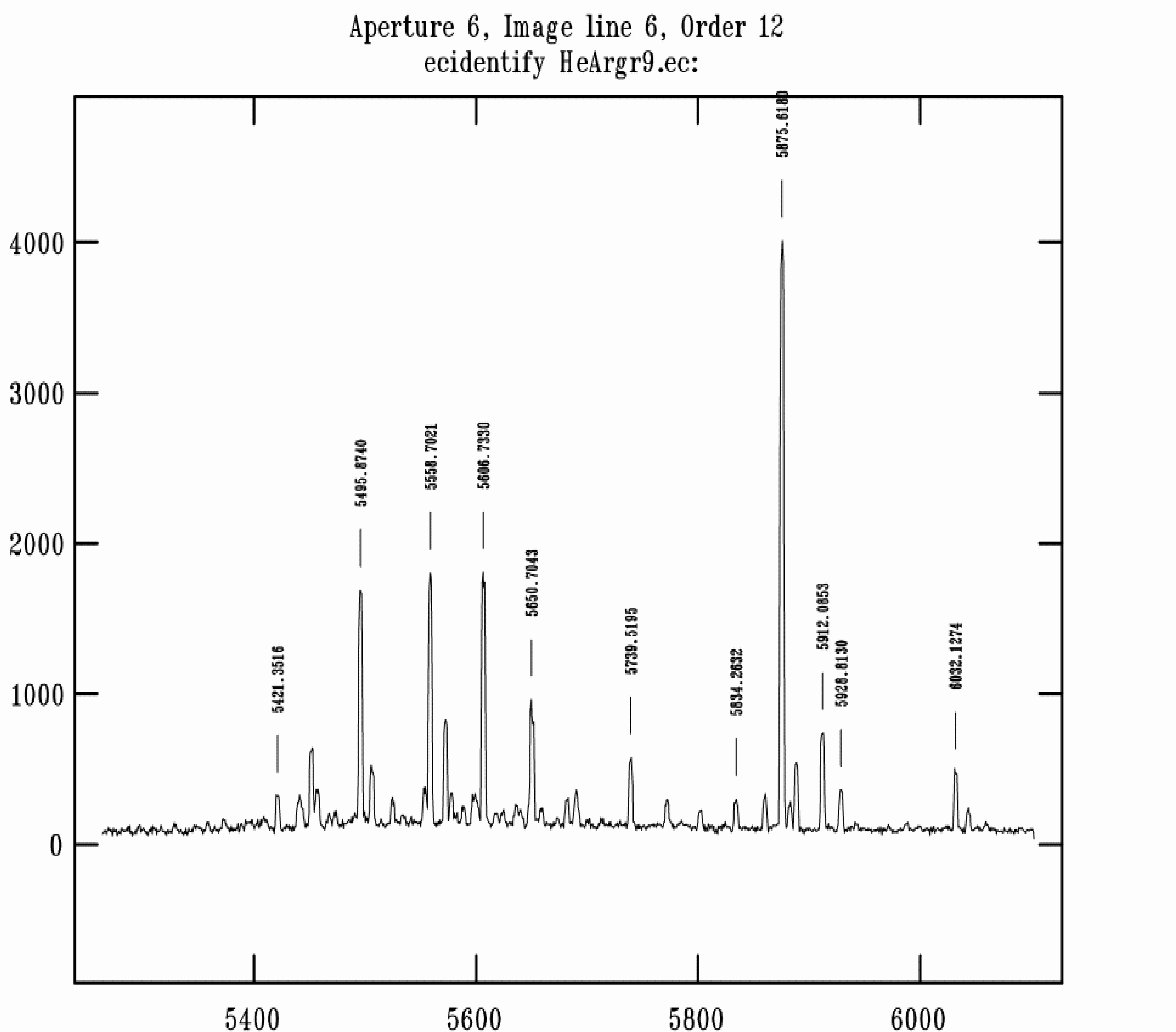
Aperture 6, Image line 6, Order 12
ecidentify HeArgr9.ec:
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5800
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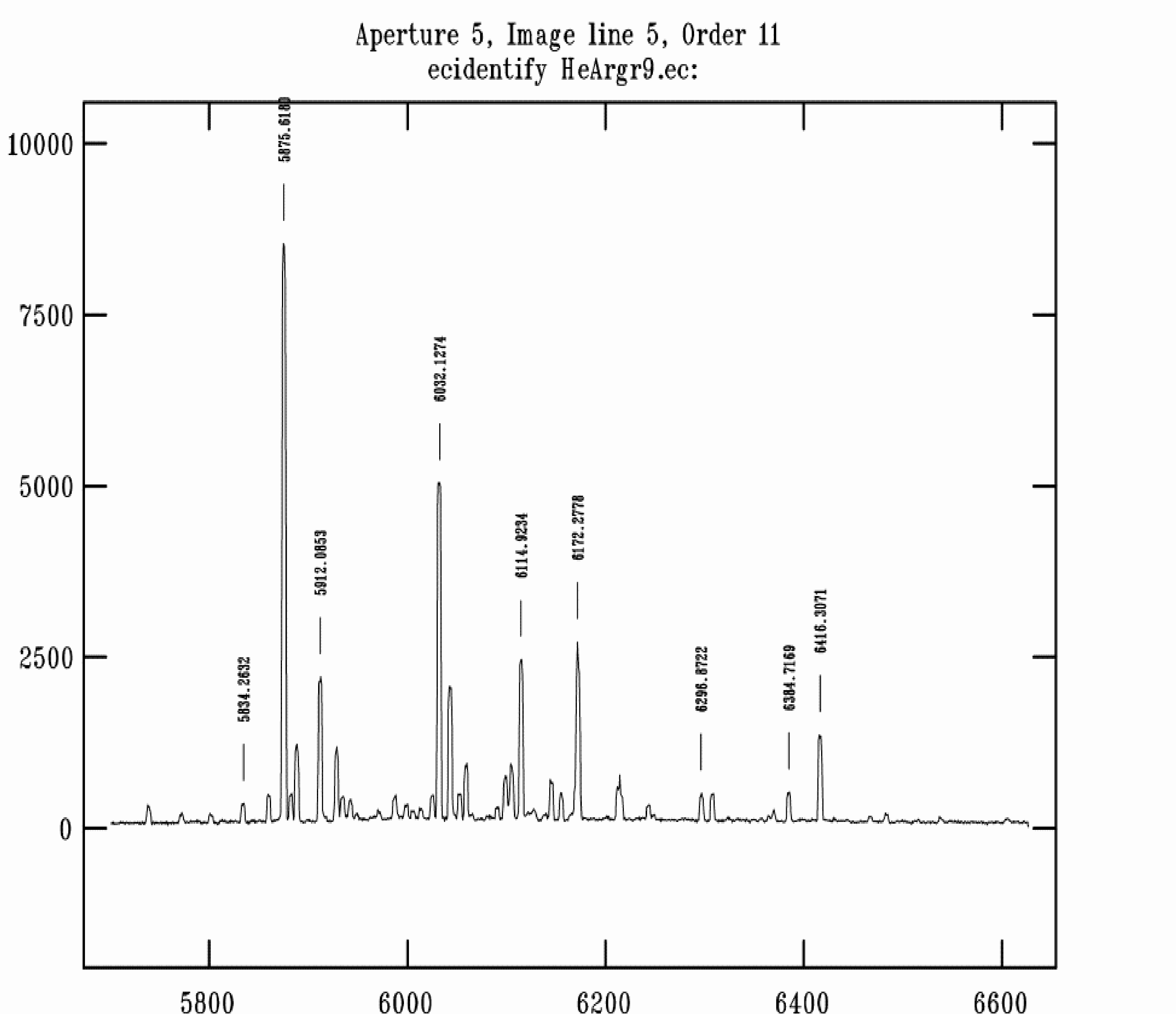
Aperture 5, Image line 5, Order 11
ecidentify HeArgr9.ec:
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2500
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6000
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6600
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5875.6180
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6032.1274
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6384.7169
6416.3071

Aperture 4, Image line 4, Order 10
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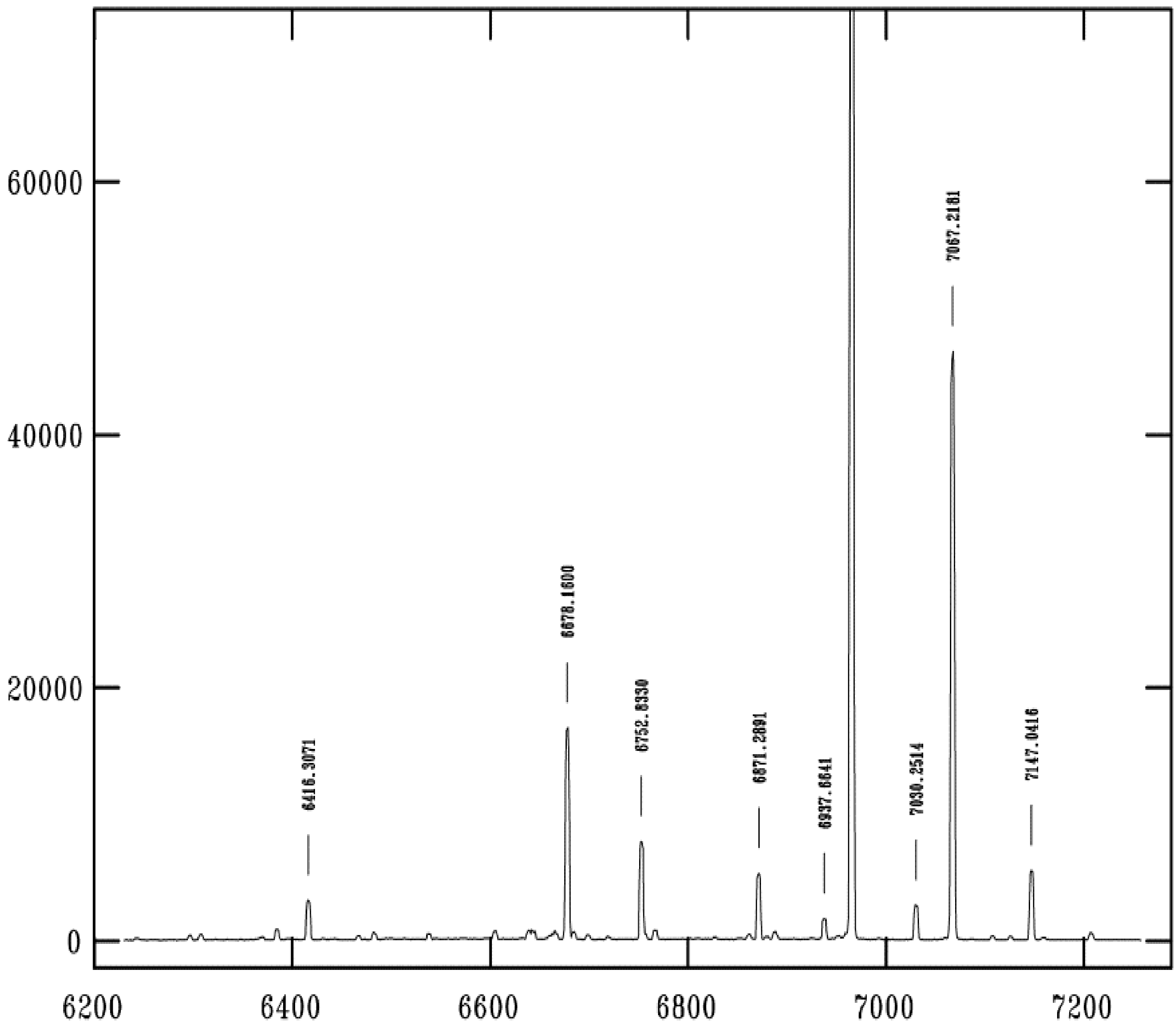

Aperture 3, Image line 3, Order 9
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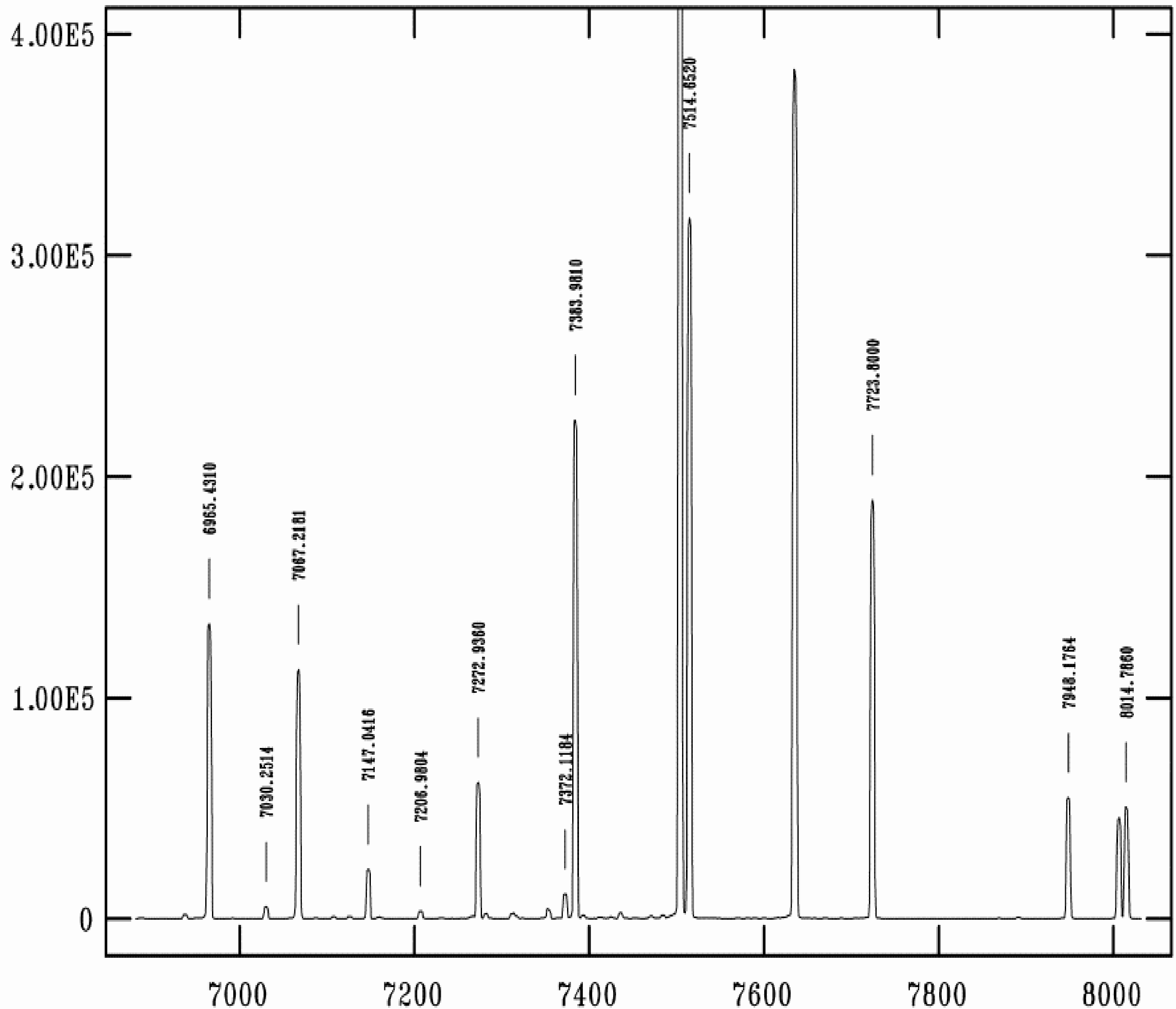

Aperture 2, Image line 2, Order 8
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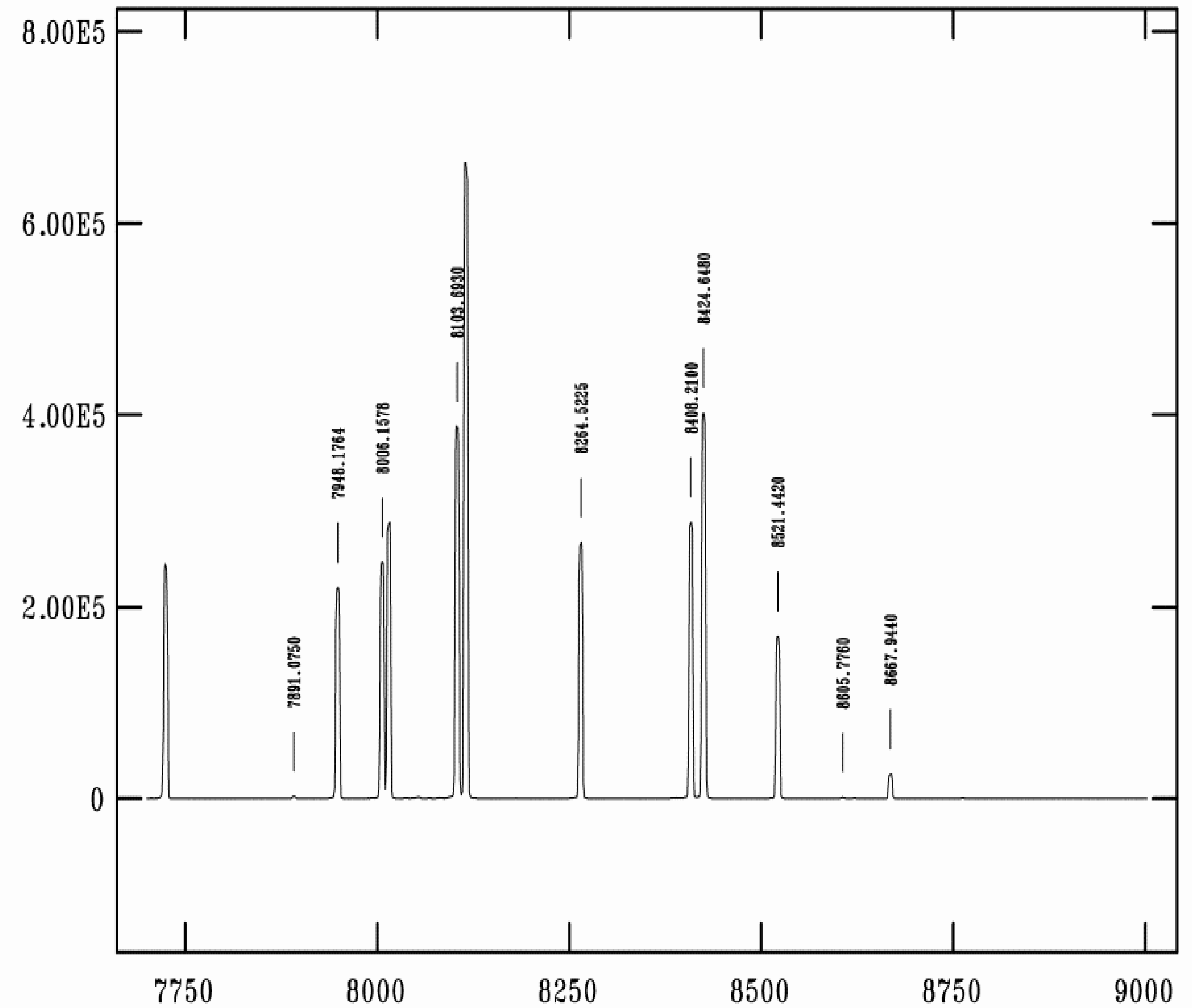

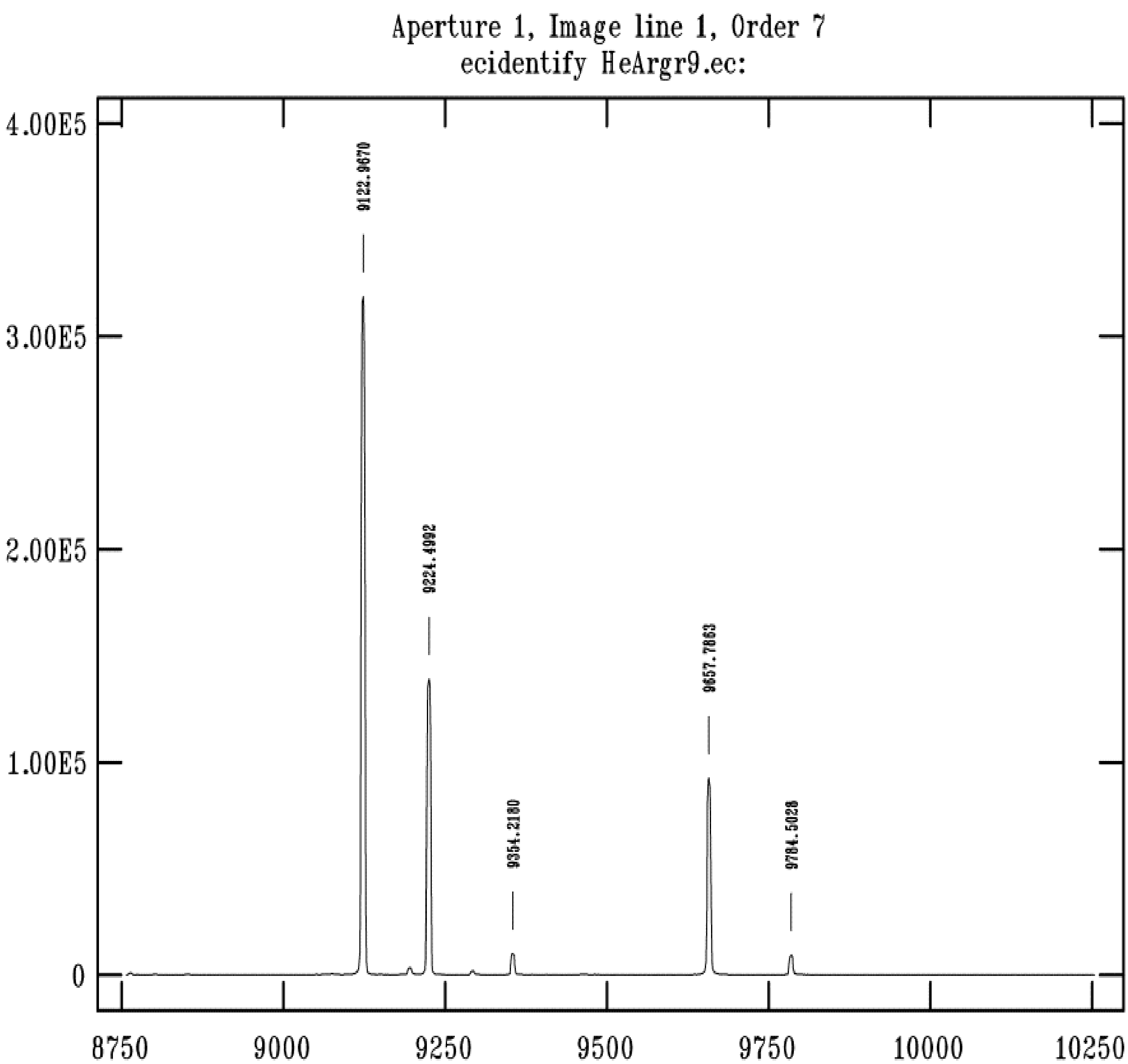
Aperture 1, Image line 1, Order 7
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9784.5028
8750
9000
9250
9500
9750
10000
10250