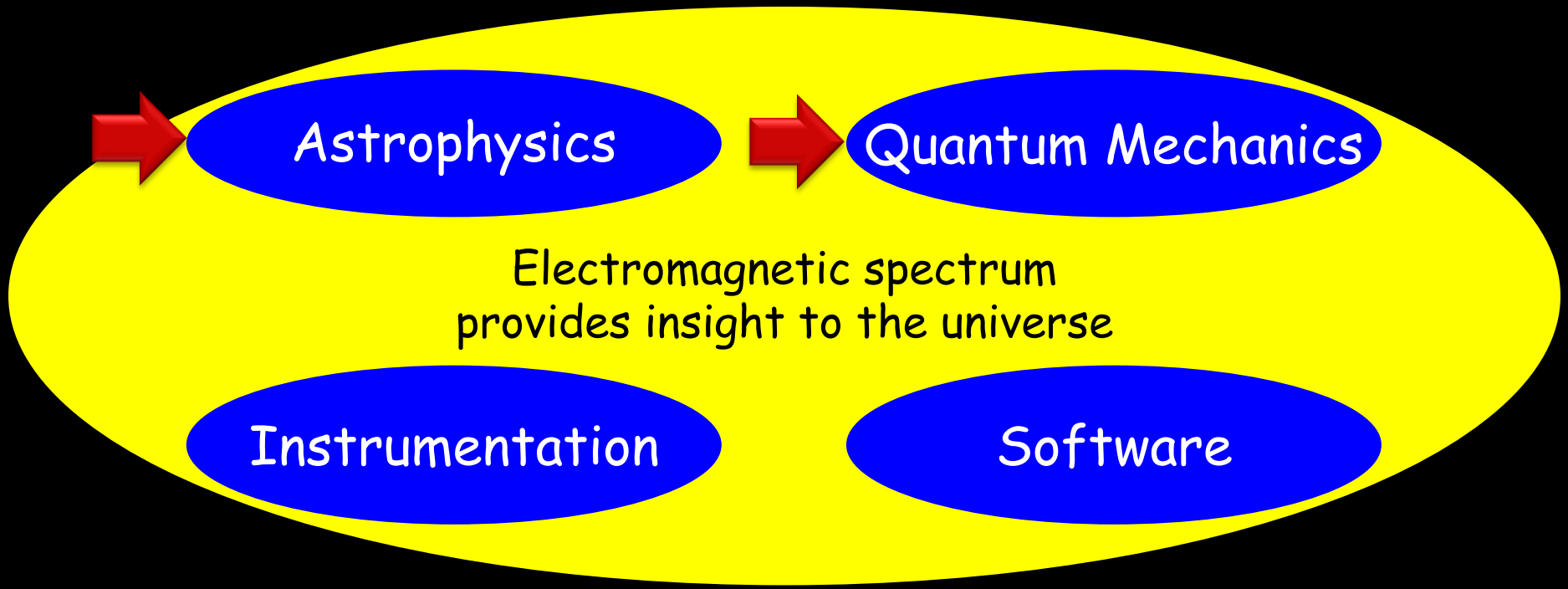
Astronomical Spectroscopy Introduction PMO 2014

David Haworth
www.stargazing.net/david

Astronomical Spectroscopy



Astronomical Spectroscopy

Analyzing Electromagnetic Spectrum

- Composition
  - Spectra line patterns: atoms, ions & modules
- Temperature & density
  - Spectra line patterns: atom states & transitions
  - Stellar classification
- Motions
  - Spectra line Doppler shift

Astronomical Spectroscopy

Analyzing Electromagnetic Spectrum

- Abundance
  - Spectra line strengths
- Pressure
  - Spectra line profile
- Magnetic fields
  - Spectra line splits

Electromagnetic Waves

$$c = \nu\lambda$$

- c: speed of light (~ 3×10^8 meters/sec)
- ν: frequency (Hz)
- λ: wavelength (meters)
- Frequency increases ($\nu\Uparrow$), wavelength decreases ($\lambda\Downarrow$)

Electromagnetic Waves Energy

$$E = h\nu$$

- E: energy of a photon
  - 1 electronvolt (1eV) = 1.602×10^{-19} Joules
- h: Planck's constant (6.626×10^{-34} Joule seconds)
- ν: frequency (Hz)
- Frequency increases ($\nu\Uparrow$), energy increases ($E\Uparrow$)

Electromagnetic Waves Energy

Wavelength increases ($\lambda\Uparrow$), energy decreases ($E\Downarrow$)

UV

IR

λ nm	λ Å	E Joules	eV
300	3000	6.62E-19	4.13
350	3500	5.67E-19	3.54
400	4000	4.97E-19	3.10
450	4500	4.41E-19	2.75
500	5000	3.97E-19	2.48
550	5500	3.61E-19	2.25
600	6000	3.31E-19	2.07
650	6500	3.06E-19	1.91
700	7000	2.84E-19	1.77
750	7500	2.65E-19	1.65

$E = h\nu$

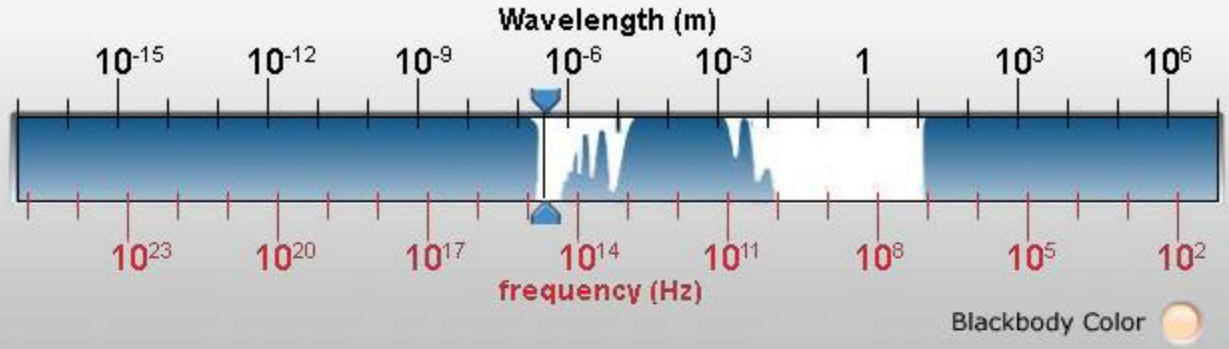
$\nu = c/\lambda$

$E = hc/\lambda$

$1eV = 1.602 \times 10^{-19}$ Joules

Electromagnetic Spectrum

Credit http://astro.unl.edu



Spectrum Screen

Wavelength = 6.600×10^{-7} m — Visible

Frequency = 4.545×10^{14} Hz

E = h * f = 3.000×10^{-19} Joule

Size

Dust

Instrument

Hubble Space Telescope

Astronomy Picture

Visual Image of Spiral Galaxy M51

Wien's Displacement Law

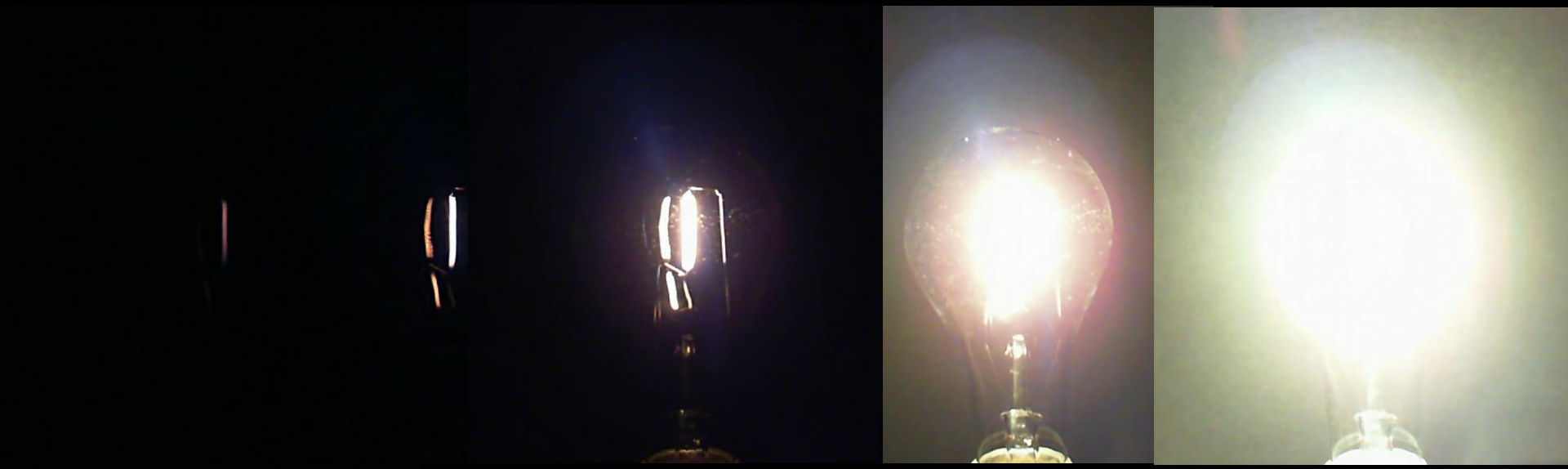
$\lambda_{max} = b/T$

- λ_{max}: Peak emission at wavelength
- b: Wien's displacement constant
  - 2.8977×10^{-3} m·K
- T: temperature in Kelvin
  - Kelvin = C + 273
  - F = (C 9/5) + 32

Kelvin	C	F	Notes
0	-273	-459.4	Absolute Zero
273	0	32.0	Water Freezes
293	20	68.0	
373	100	212.0	Water Boils
798	525	977.0	Draper Point
1000	727	1340.6	Emits Red
6000	5727	10340.6	Emits White

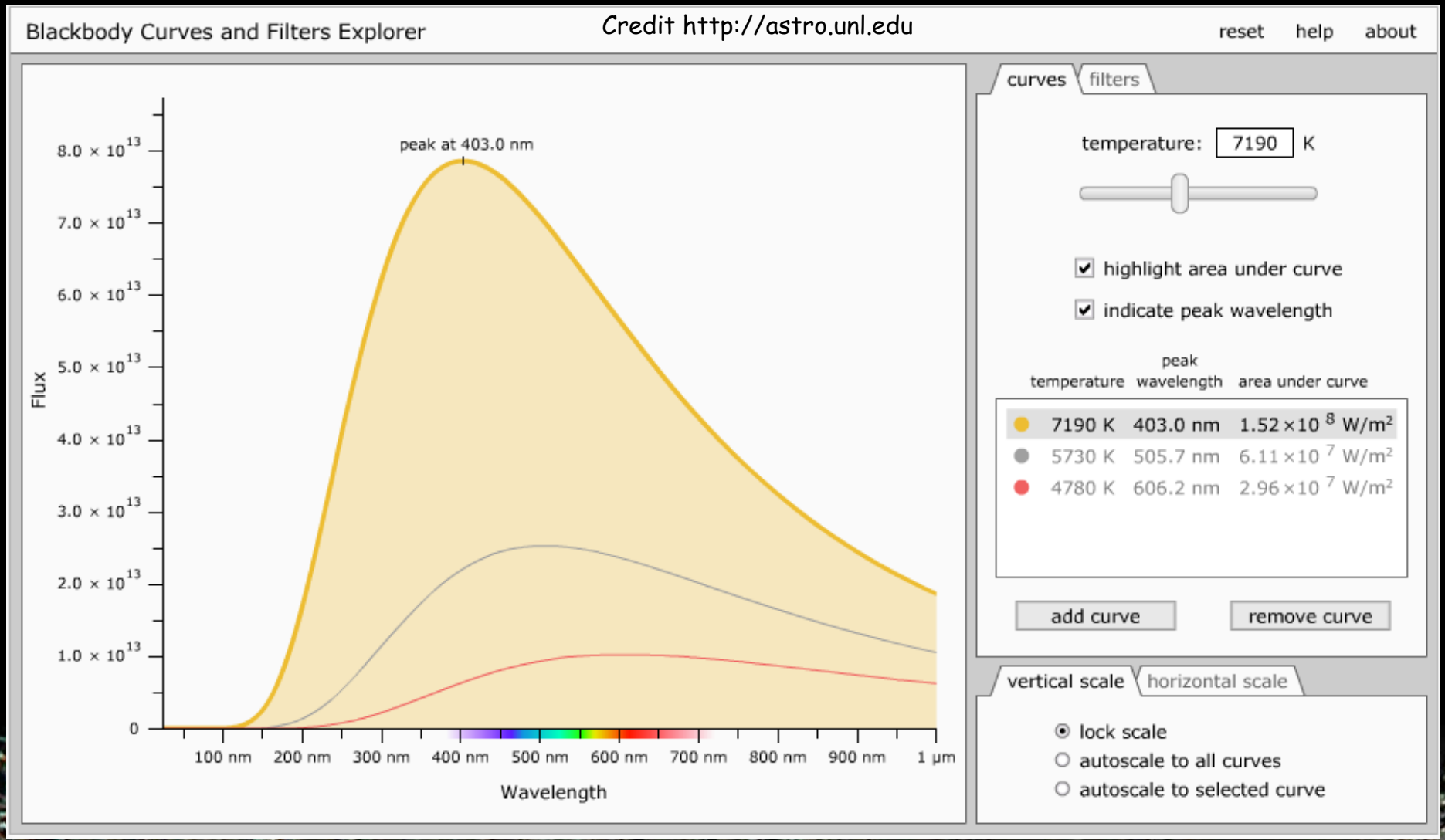
Black Body Radiation

Varying the power to a light bulb



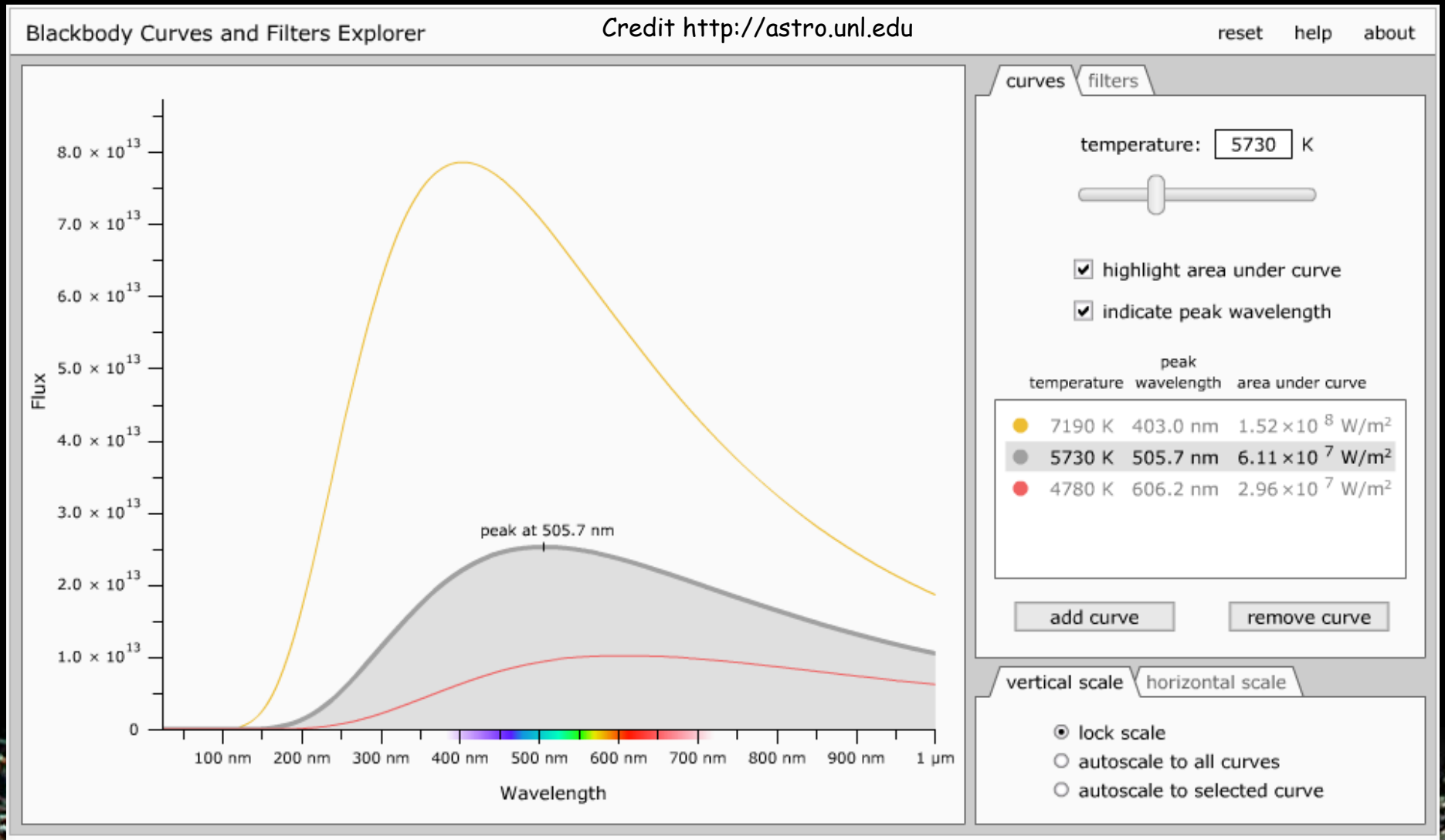
Black-Body Radiation

7190 K & Peak at 403.0 nm



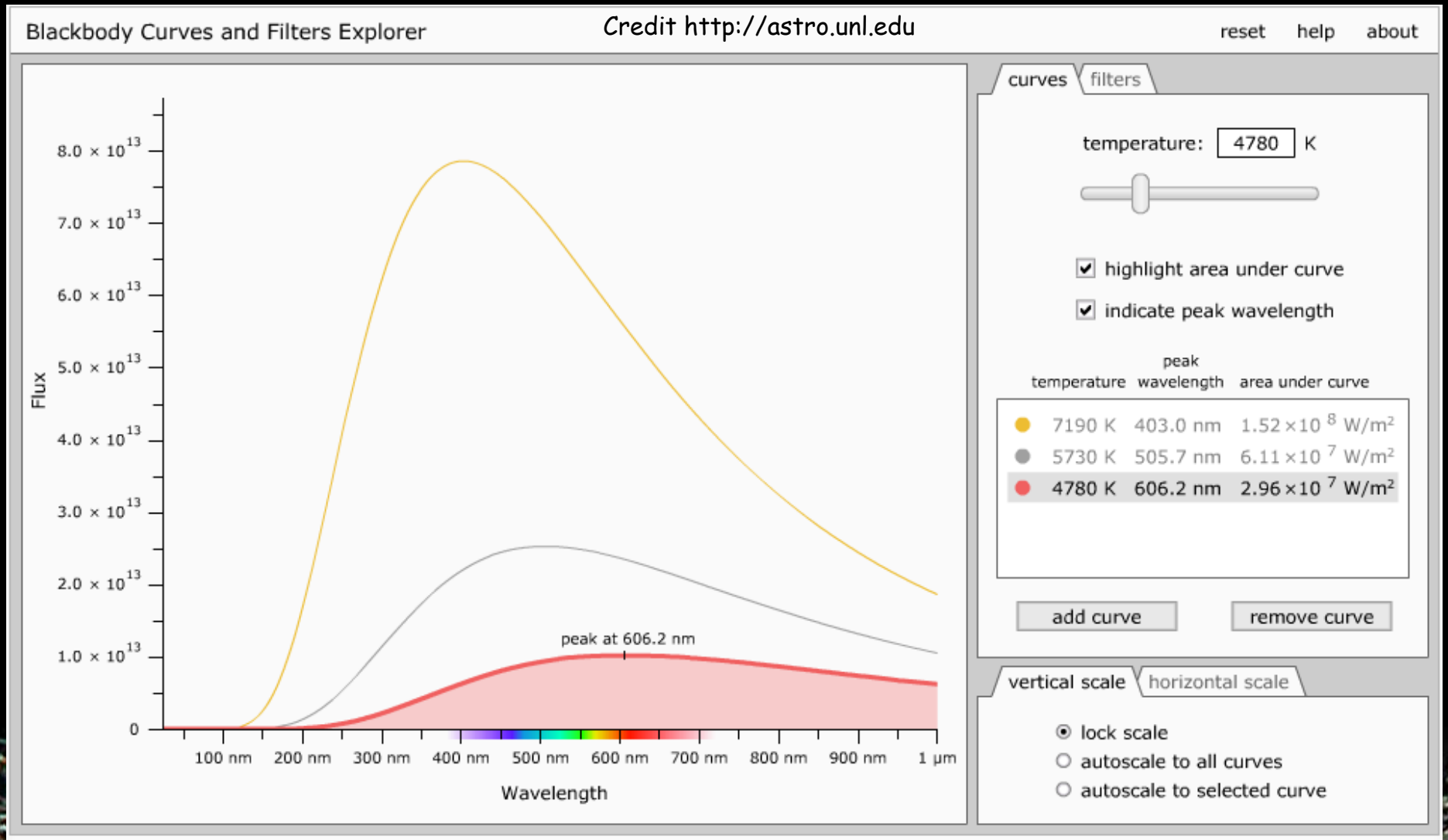
Black-Body Radiation

5730 K & Peak at 505.7 nm



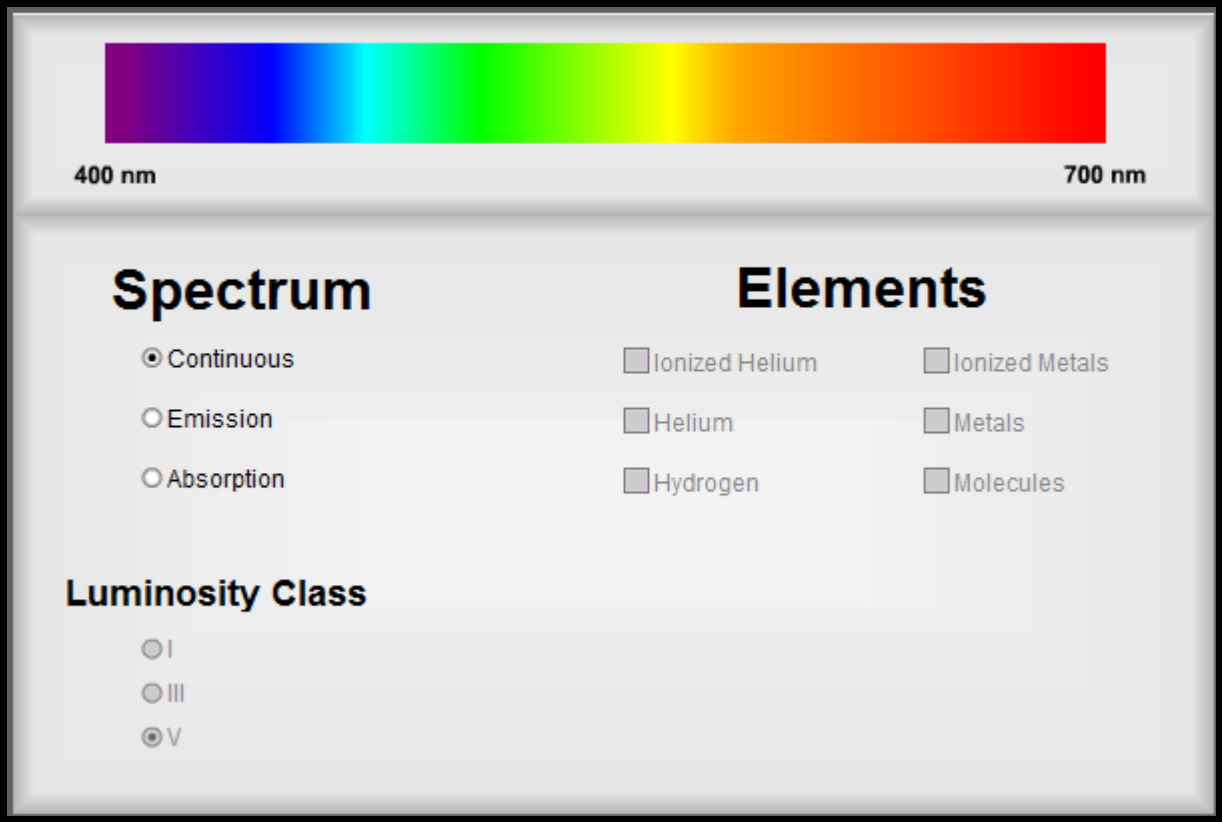
Black-Body Radiation

4780 K & Peak at 606.2 nm



Spectrum of Light

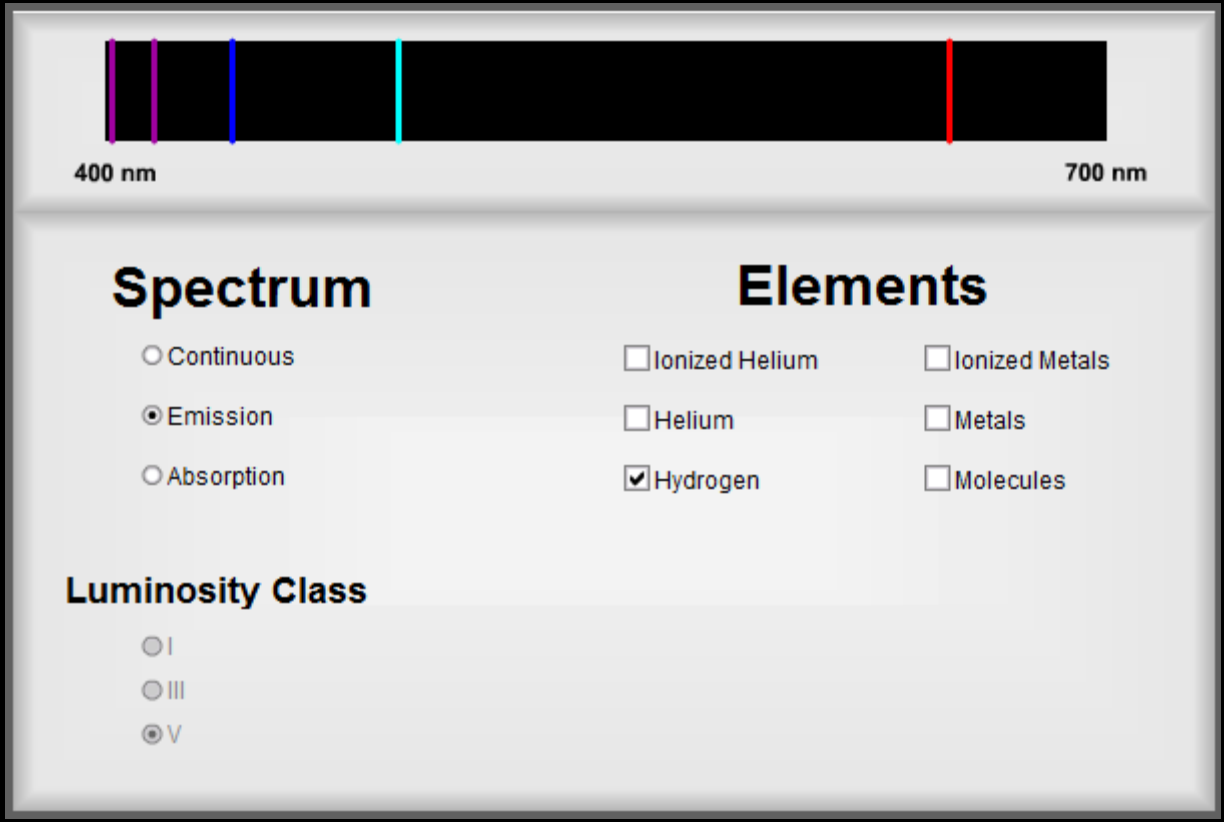
Continuous Spectrum



Credit http:// astro.unl.edu

Spectral Lines of Light

Hydrogen Emission Spectrum



Credit http:// astro.unl.edu

NIST National Institute of Standards and Technology Physics Laboratory

Basic Atomic Spectroscopic Data

Hydrogen (H)

Other Elements | Neutral Atom

Main Page | Finding List | Element Name | Atomic Number | Periodic Table | Atomic Data | Strong Lines | Persistent Lines | Energy Levels | Ref.

Switch to Formatted Version

Strong Lines of Hydrogen (H)

Intensity		Wavelength (Å)	Spectrum	Ref.
		Vacuum		
15		926.2256	H I	MK00a
20		930.7482	H I	MK00a
30		937.8034	H I	MK00a
50	P	949.7430	H I	MK00a
100	P	972.5367	H I	MK00a
300	P	1025.7222	H I	MK00a
1000	P	1215.66824	H I	MK00a
500	P	1215.67364	H I	MK00a
		Air		
5		3835.384	H I	RCWM80
6		3889.049	H I	RCWM80
8		3970.072	H I	RCWM80
15		4101.74	H I	RCWM80
30	P	4340.462	H I	MK00a
30	P	4861.2786	H I	MK00a
10	P	4861.2870	H I	MK00a
60	P	4861.3615	H I	MK00a
90	P	6562.7110	H I	MK00a
30	P	6562.7248	H I	MK00a
180	P	6562.8518	H I	MK00a
5		9545.97	H I	RCWM80

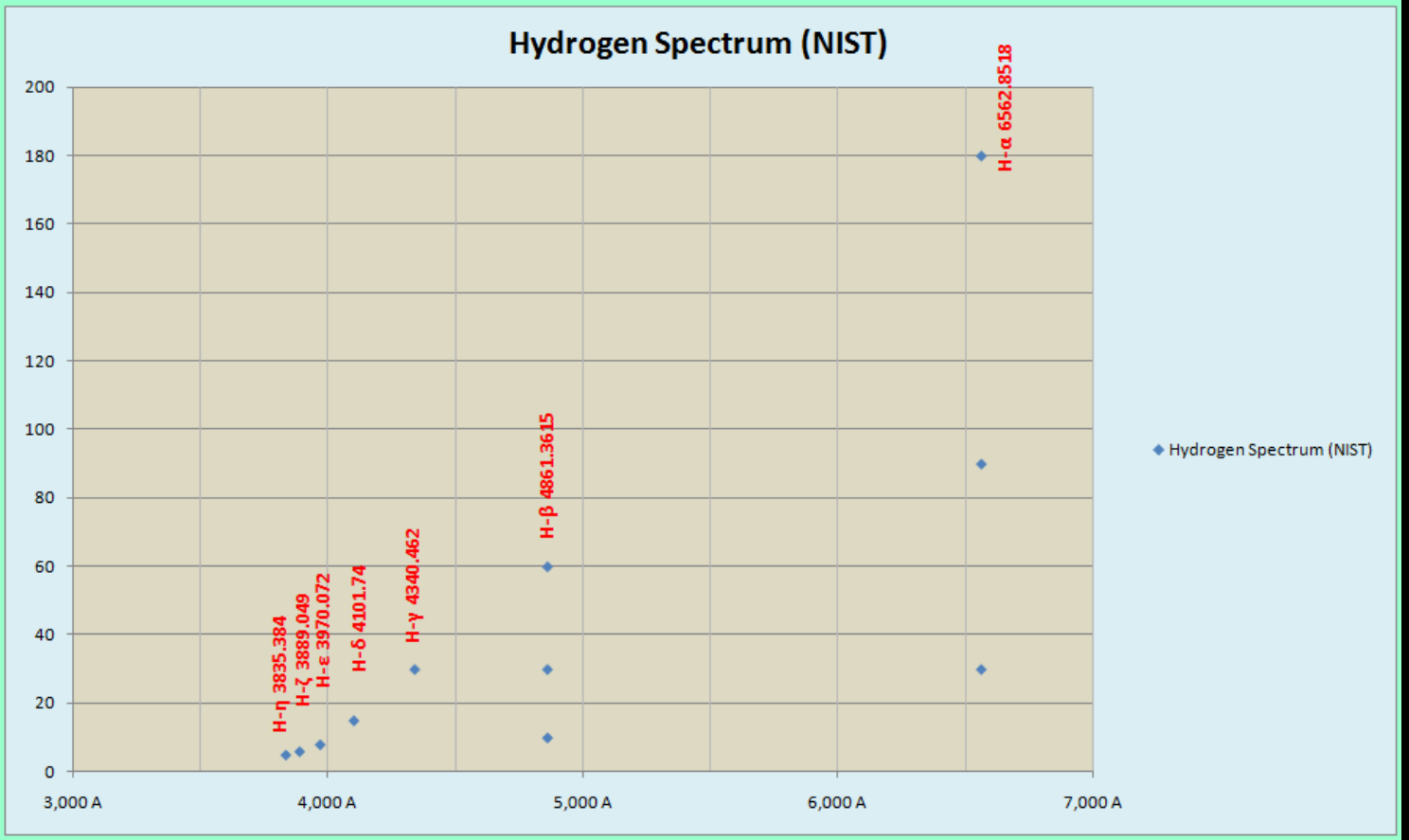
Strong Spectral Lines of Hydrogen

http://physics.nist.gov/PhysRefData/Handbook/Tables/hydrogentable2_a.htm

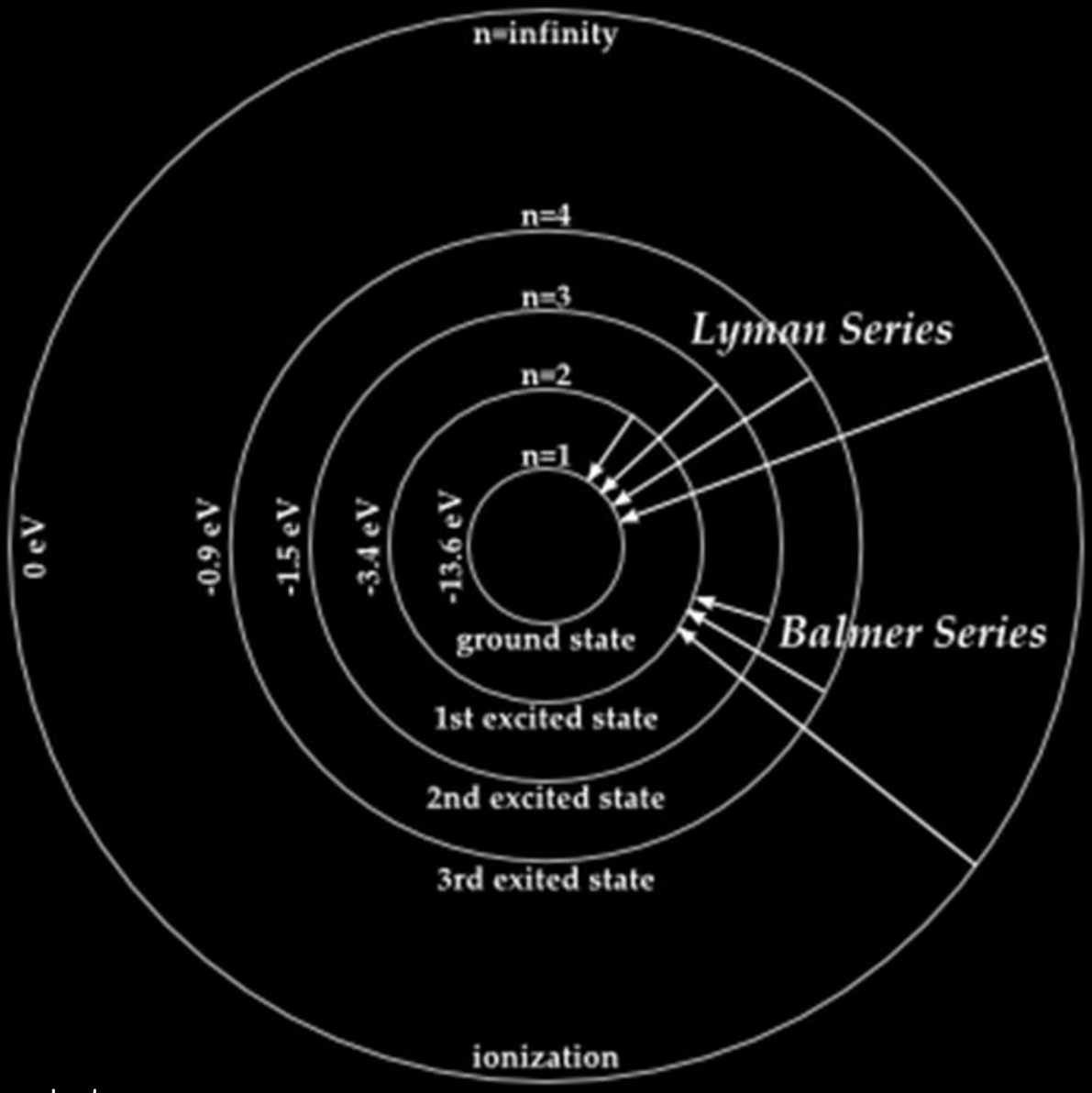
Strong Spectral Lines of Hydrogen

NIST

Angstroms	Intensity	Balmer Series	
3835.384	5	H-eta	η
3889.049	6	H-zeta	ζ
3970.072	8	H-epsilon	ε
4101.74	15	H-delta	δ
4340.462	30	H-gamma	γ
4861.2786	30		
4861.287	10		
4861.3615	60	H-beta	β
6562.711	90		
6562.7248	30		
6562.8518	180	H-alpha	α

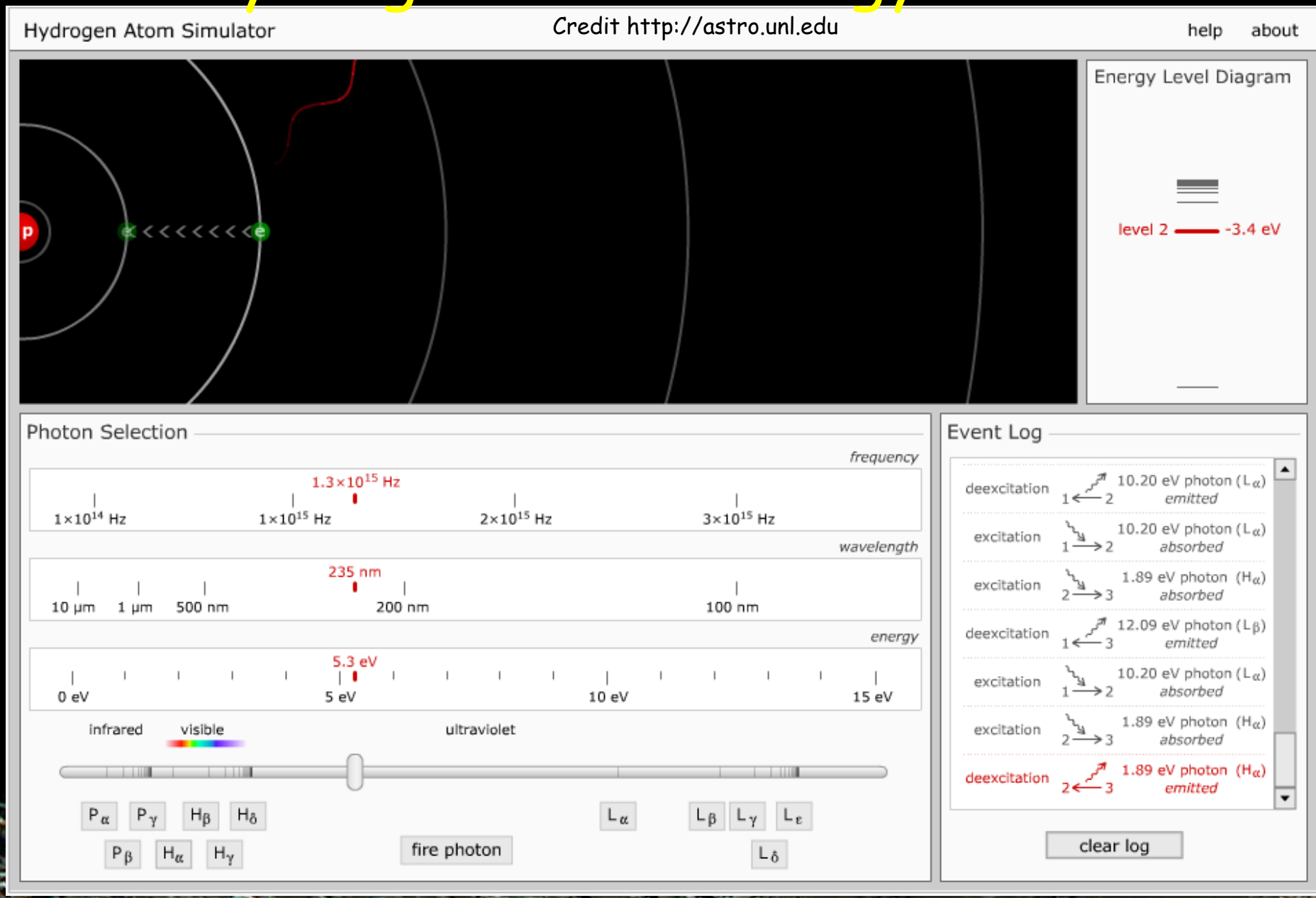


Hydrogen Atom Energy Levels

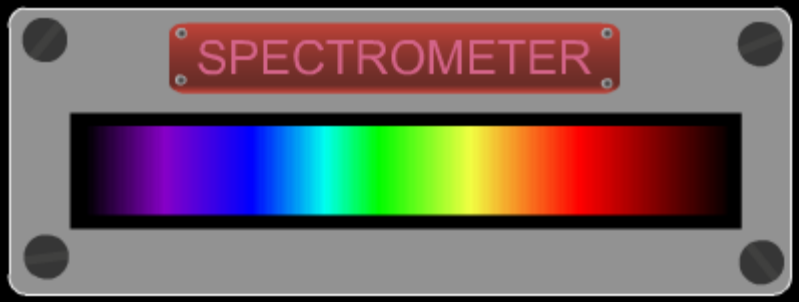


Credit http:// astro.unl.edu

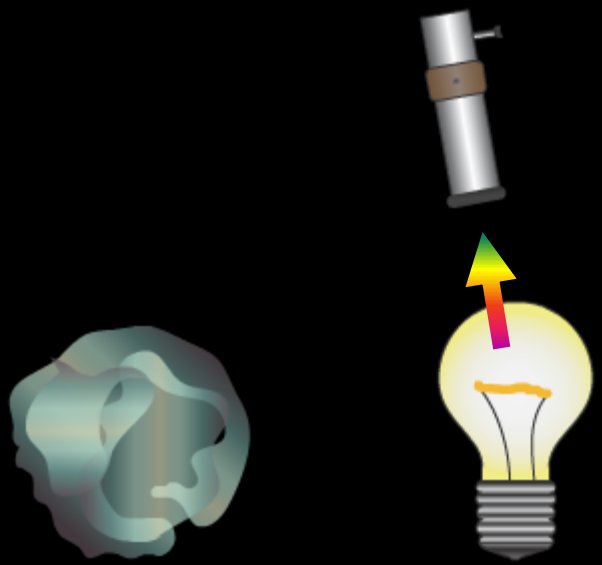
Hydrogen Atom Energy Levels



Continuous Spectrum



Drag the telescope around to see how the three main types of spectra (continuous, absorption, and emission) are obtained from a cold, thin gas cloud and an incandescent lightbulb in space.

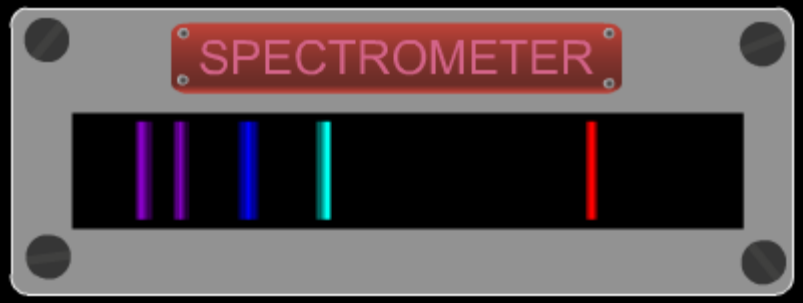


Star atmosphere, Nebula, etc.

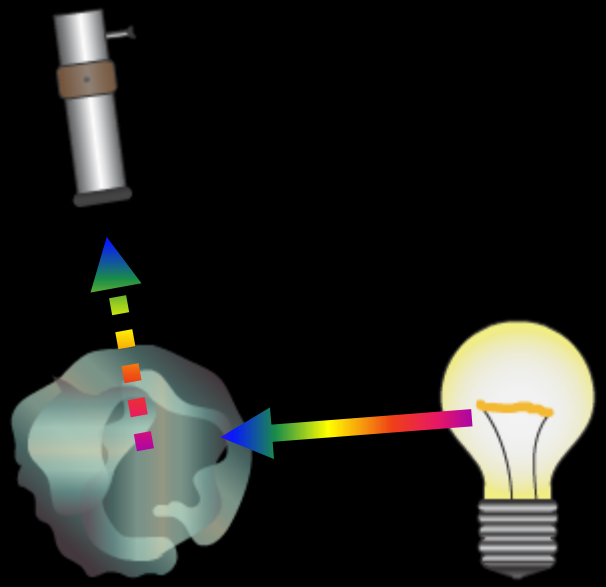
Star

Credit http:// astro.unl.edu

Emission Spectrum



Drag the telescope around to see how the three main types of spectra (continuous, absorption, and emission) are obtained from a cold, thin gas cloud and an incandescent lightbulb in space.

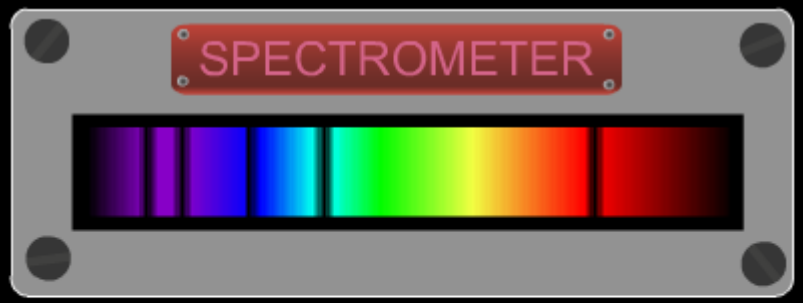


Star atmosphere, Nebula, etc.

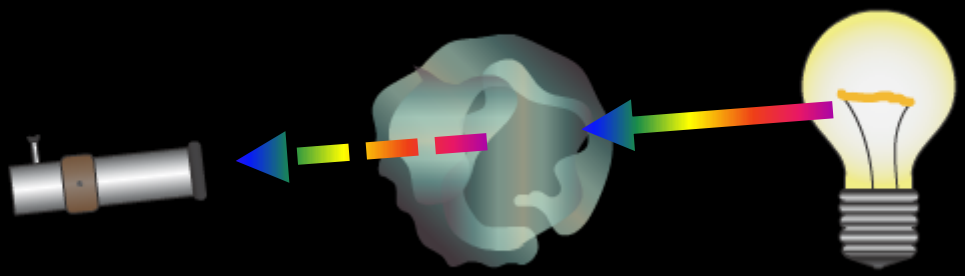
Star

Credit http:// astro.unl.edu

Absorption Spectrum



Drag the telescope around to see how the three main types of spectra (continuous, absorption, and emission) are obtained from a cold, thin gas cloud and an incandescent lightbulb in space.



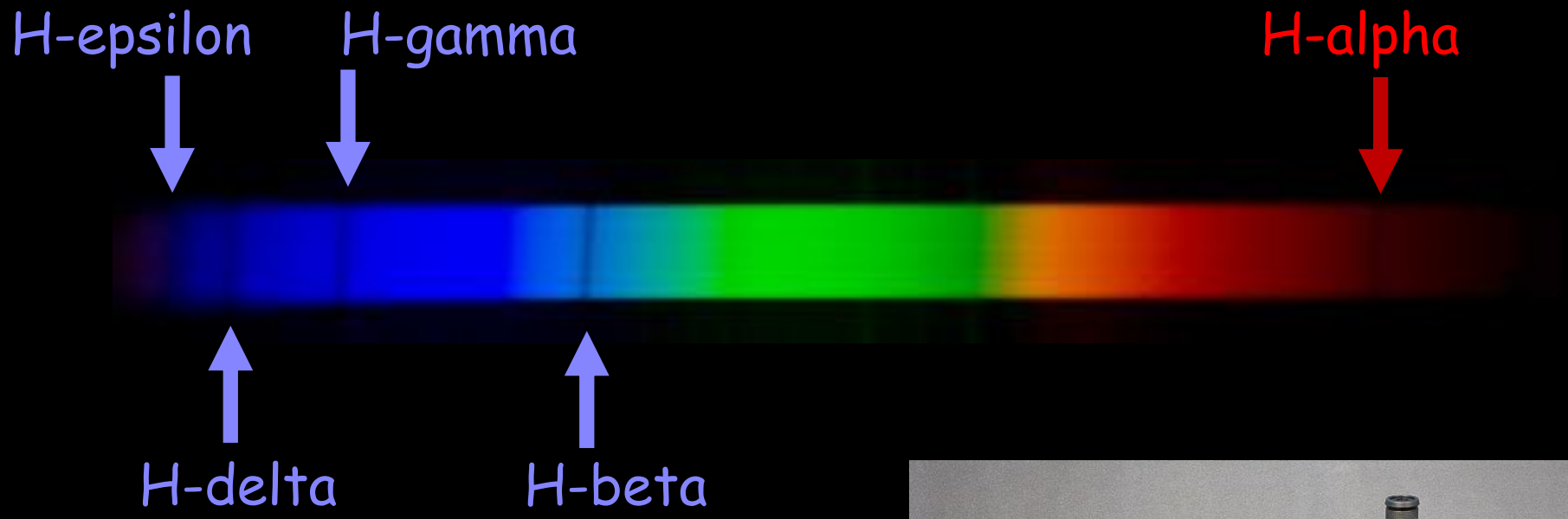
Star atmosphere, Nebula, etc.

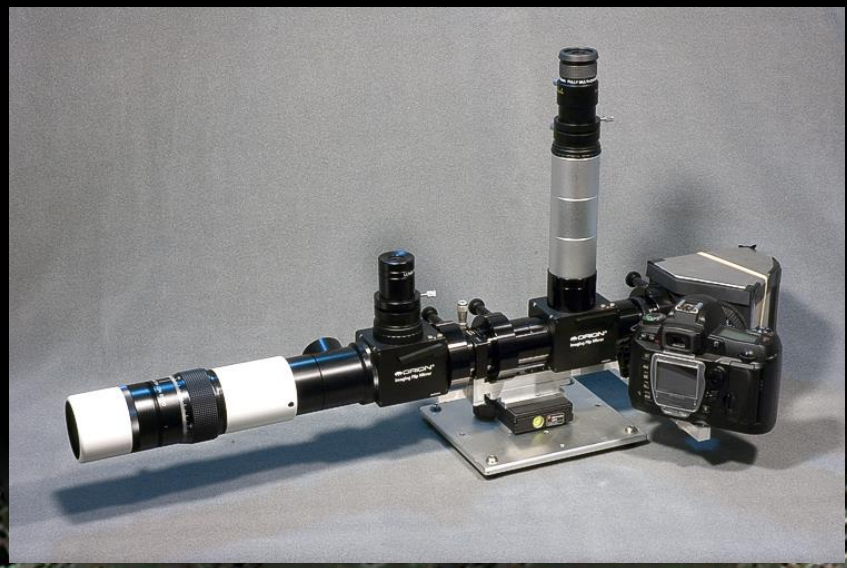
Star

Credit http:// astro.unl.edu

Hydrogen Absorption Spectrum

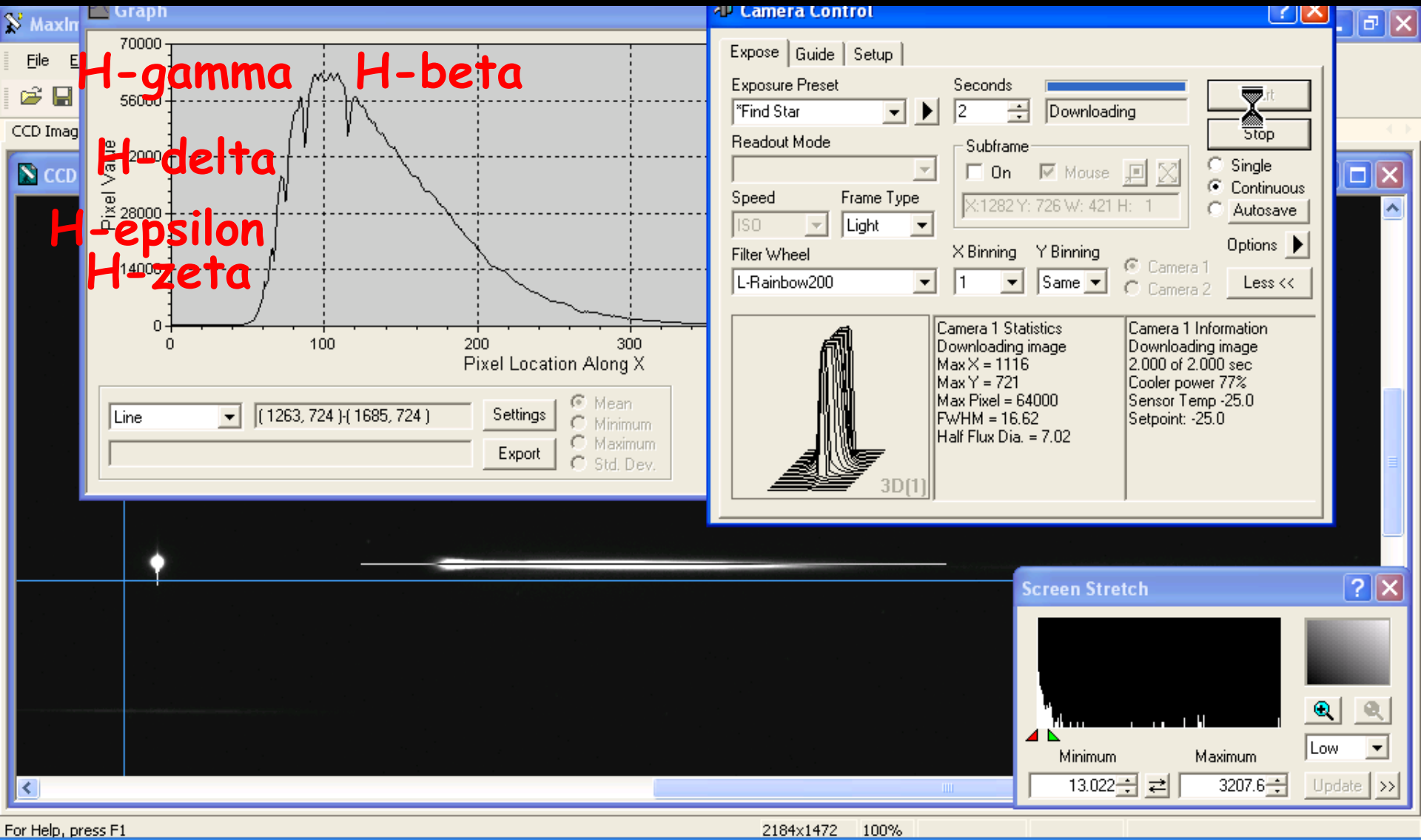
Vega





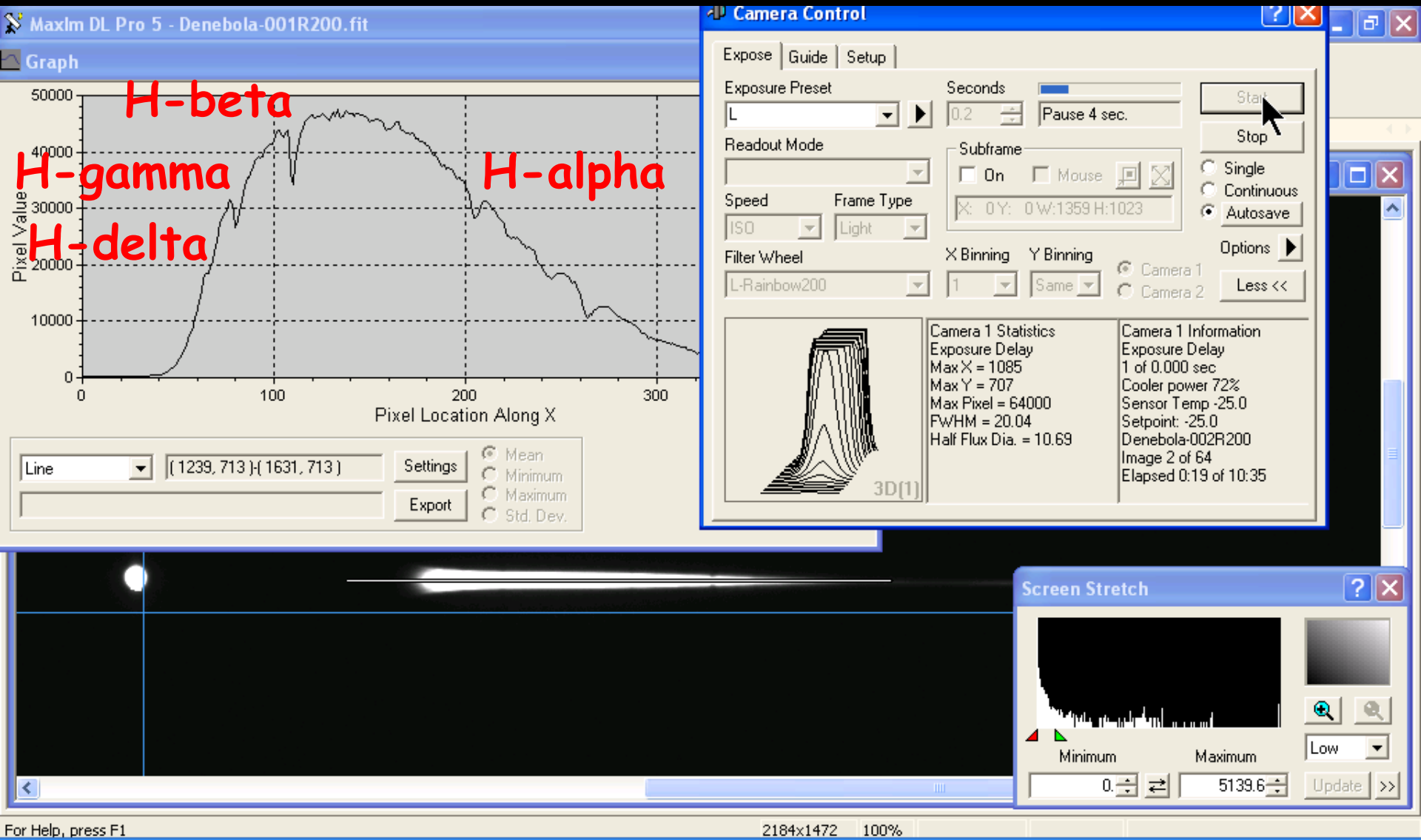
Hydrogen Absorption Spectrum

Denebola Spectrum



Hydrogen Absorption Spectrum

Denebola Spectrum

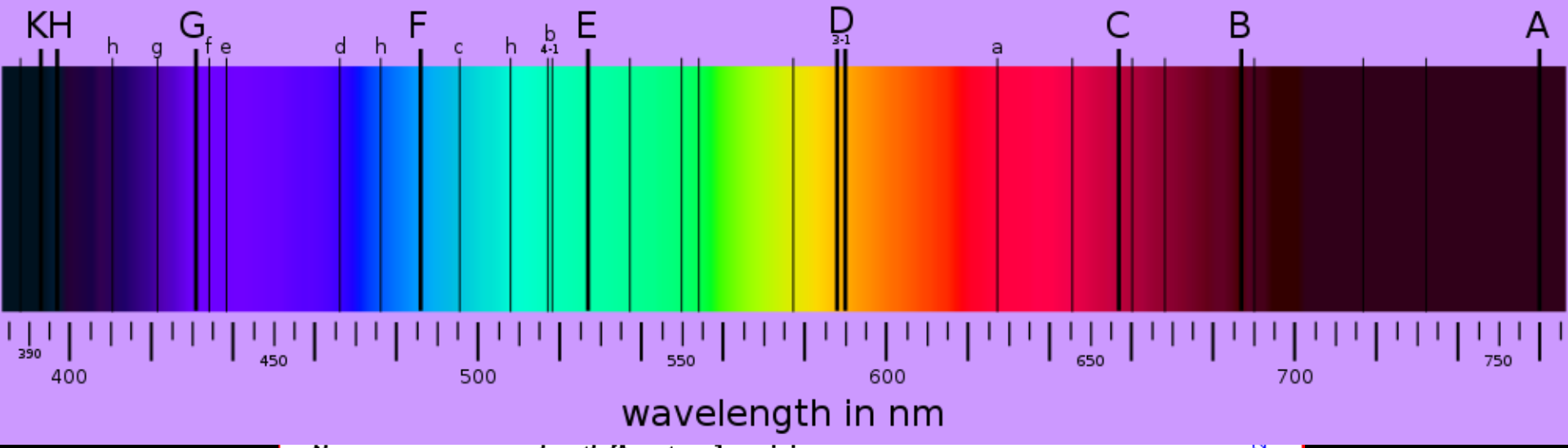


Fraunhofer Solar Spectrum Lines

Joseph von Fraunhofer (1787–1826)

Credit http://en.wikipedia.org/wiki/File:Fraunhofer_spectroscope.JPG

Fraunhofer Solar Spectrum Lines



Name	wavelength [Angstrom]	origin
A	7594 [red]	terrestrial oxygen**
a	7165	terrestrial water vapour**
B	6867	terrestrial oxygen**
C	6563	H-alpha
D	5890, 5896	neutral sodium (NaI)
E	5270	neutral iron (FeI)
b	5167, 5173, 5184	neutral magnesium (MgI)
F	4861	H-beta
d*	4384	neutral iron (FeI)
G	4300	CH band
g*	4227	neutral calcium (CaI)
h	4102	H-gamma
H	3968	ionized calcium (CaII)
K*	3934 [violet]	ionized calcium (CaII)

M.Gavin

Note: Fraunhofer labeled lines from red to blue - the reverse of modern convention ordered by wavelength.

 Credit http://en.wikipedia.org/wiki/File:Fraunhofer_lines.svg
http://www.astroman.fsnet.co.uk/fraunhofer.gif

Fraunhofer Solar Lines

DVD Spectrograph

G: Ca, Fe, H_γ

F: H_β

b: Mg

E: Fe

D: Na

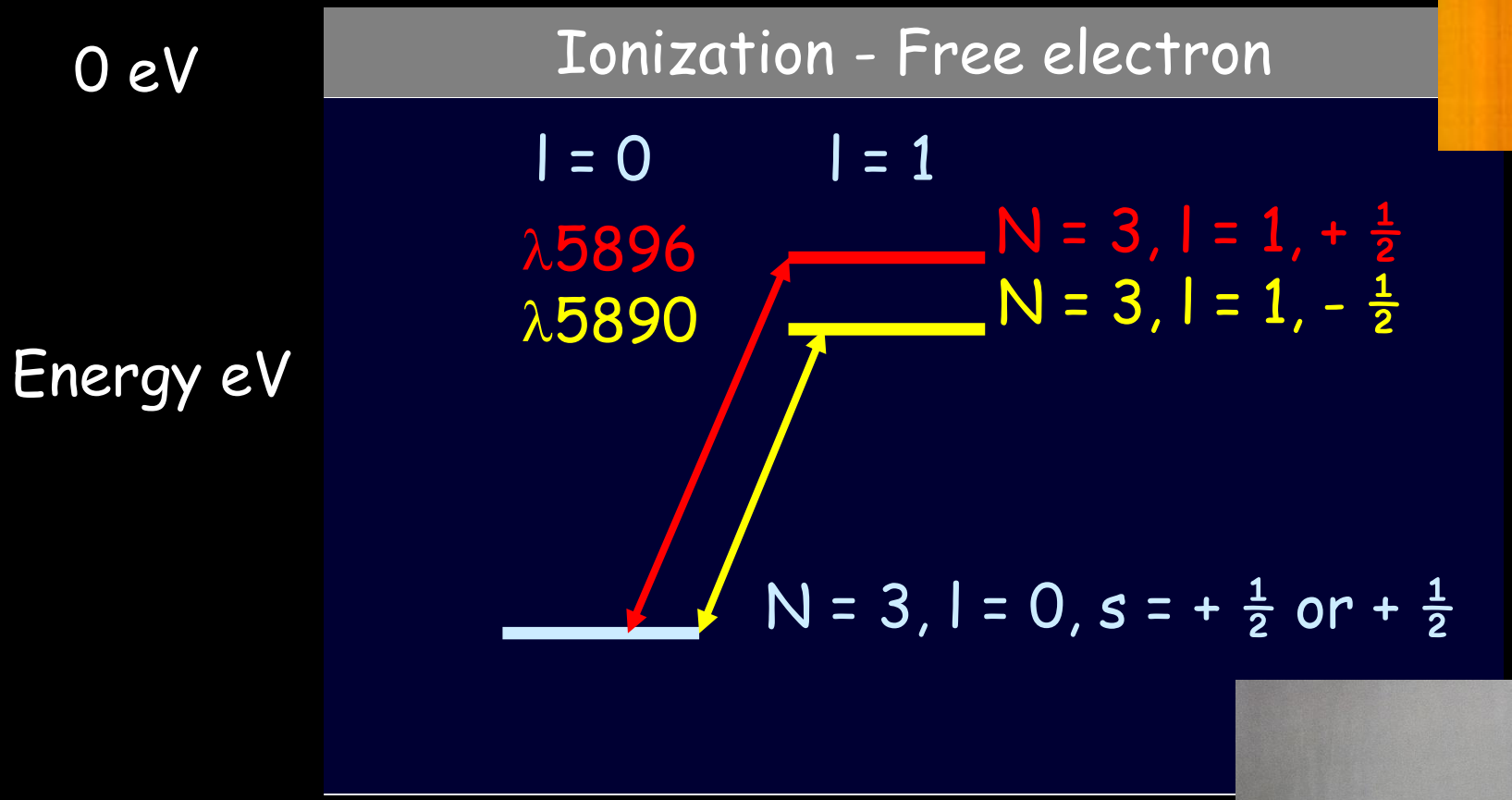
Quantum Mechanics

Lines Energy Levels

- Principal quantum number: n
- Angular momentum quantum number: l
  - (sharp 0, principal 1, diffuse 2 or fundamental 3)
- Magnetic quantum number: m
  - Same energy levels except in external magnetic fields.
- Spin quantum number: s
  - Spin up (+ $\frac{1}{2}$) or spin down (- $\frac{1}{2}$)

Na Double Lines – Betelgeuse

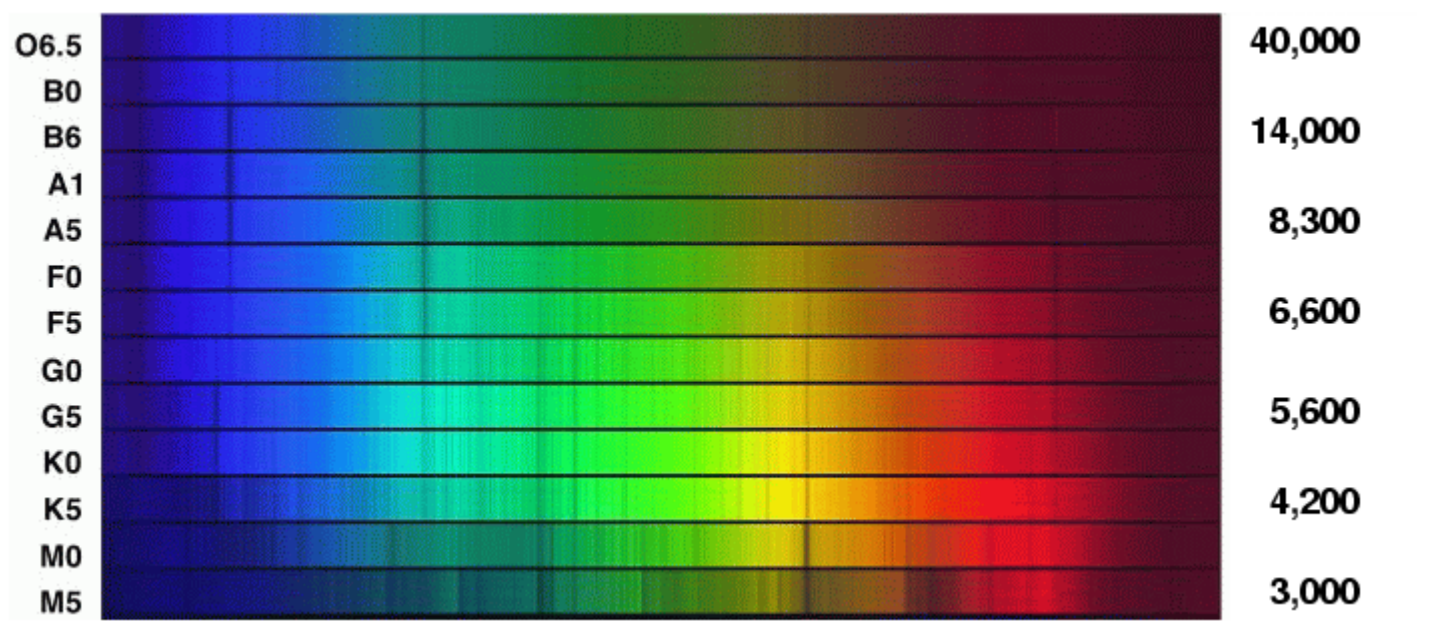
Lines Energy Levels



Early Astronomical Spectroscopy

1890: Harvard College Observatory

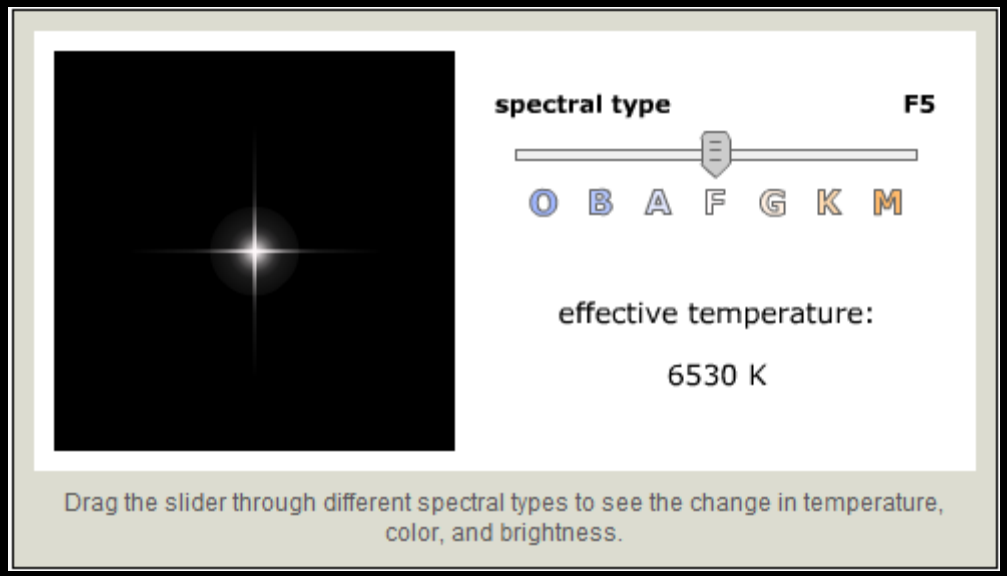
- 1890: 1st Draper Memorial Catalogue 10,351 stars
- 1912: Last of the 4 Draper Memorial Catalogues
- 1922 IAU formal adoption of Draper system
- By temperature: OBAFGKM with decimal types



Credit http://spiff.rit.edu/classes/phys301/lectures/comp/comp.html

Star Classification

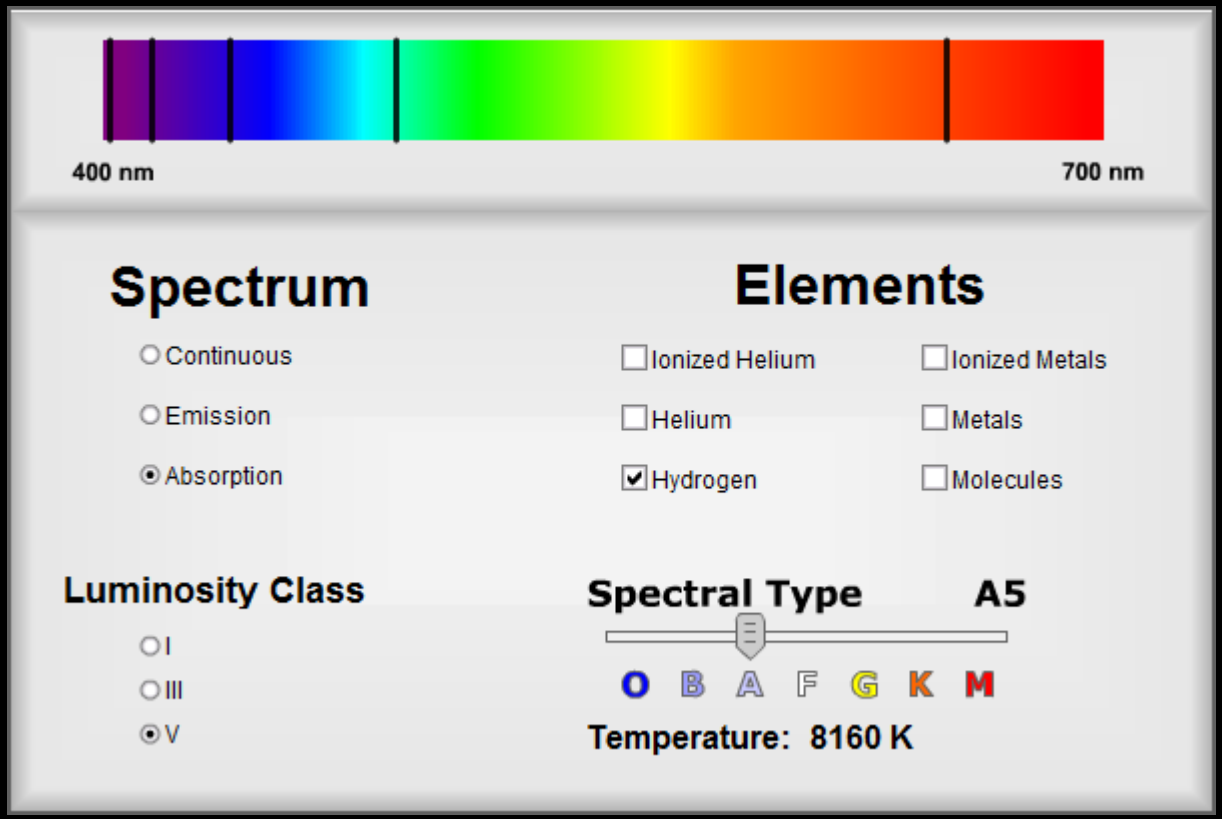
Spectral Type = Star Temperature



Credit http:// astro.unl.edu

Spectral Lines of Light

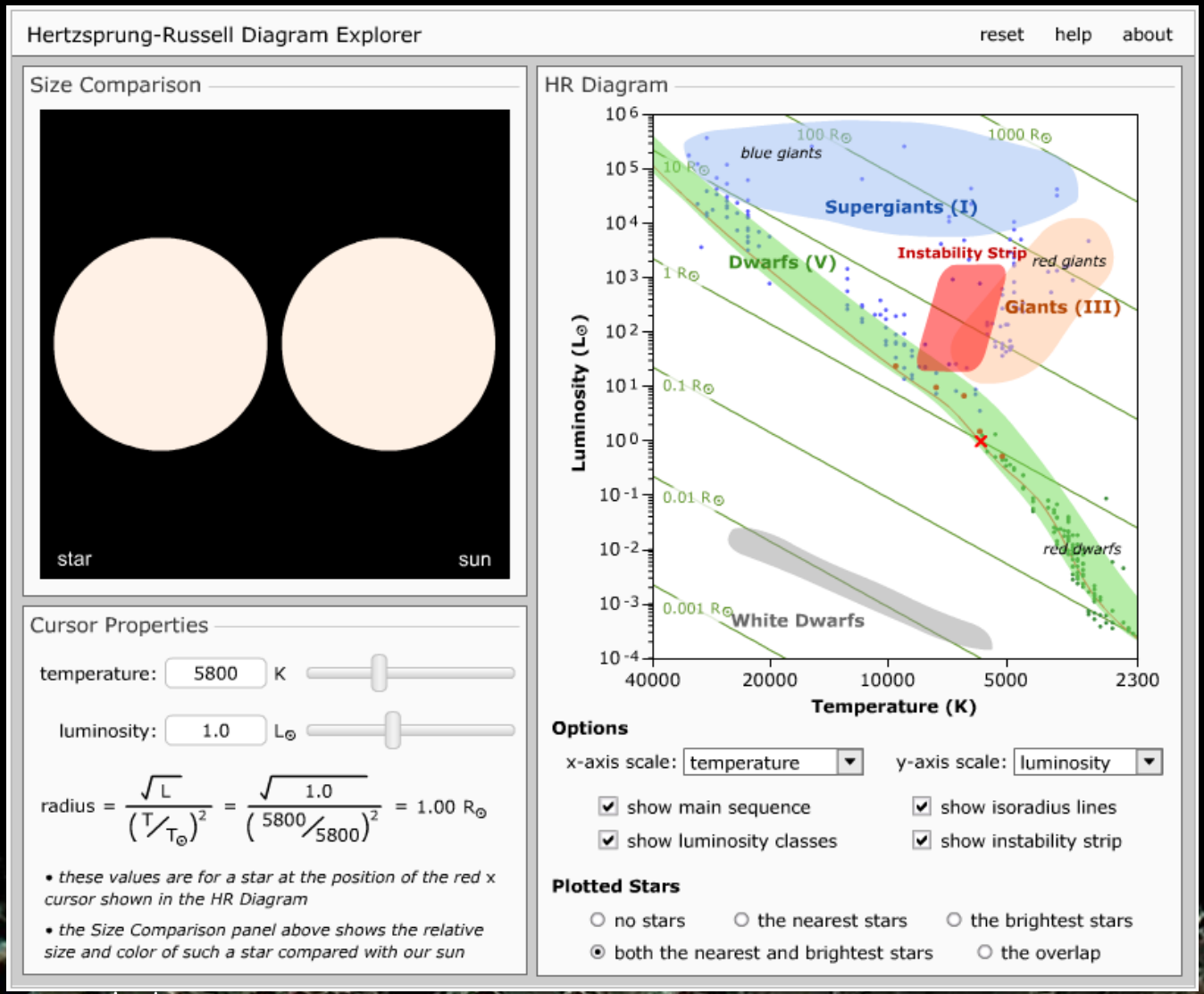
Hydrogen Absorption Spectrum



Credit http:// astro.unl.edu

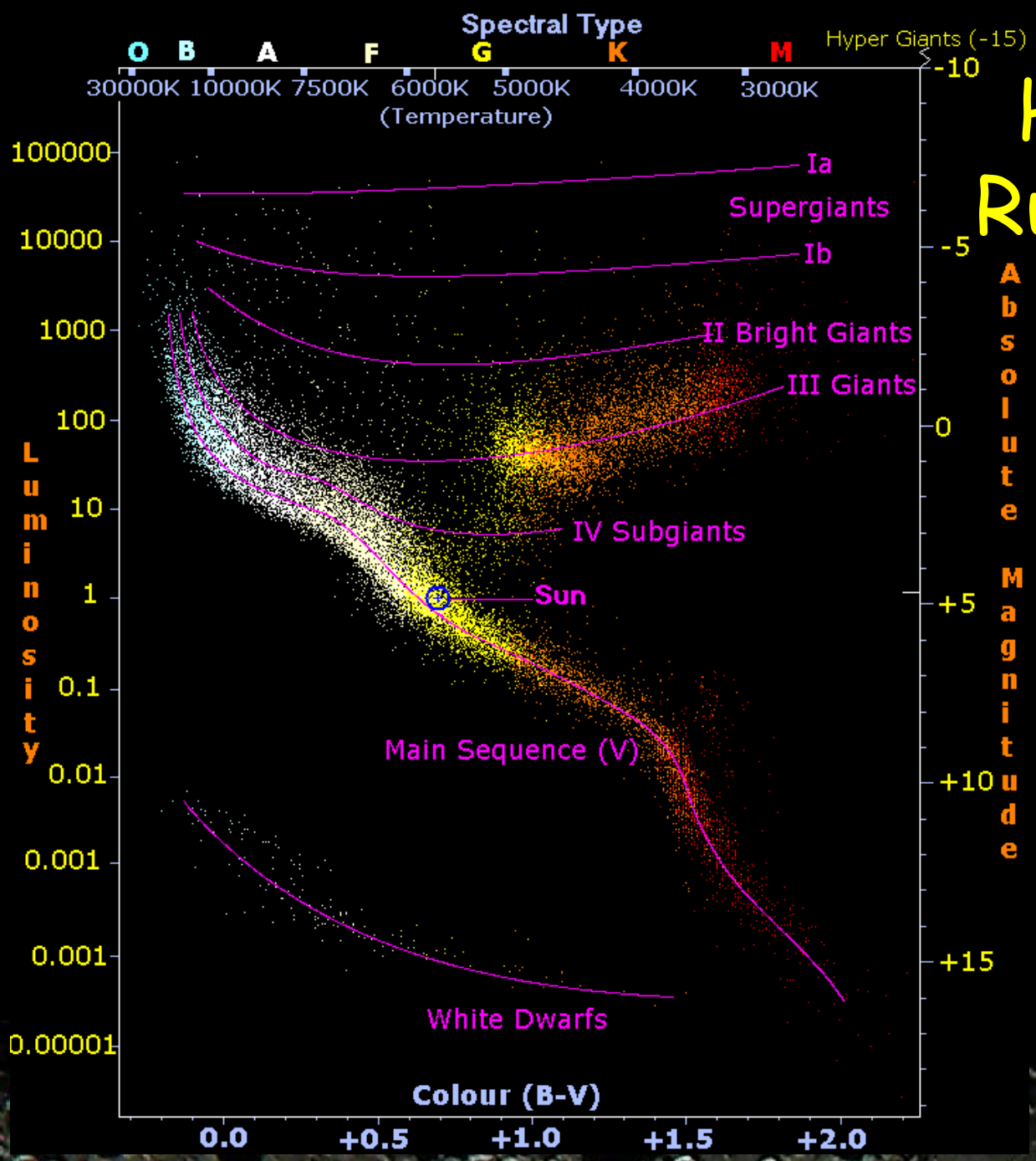
Hertzsprung-Russell Diagram

Luminosity vs. Temperature



Credit http:// astro.unl.edu

Hertzsprung-Russell Diagram



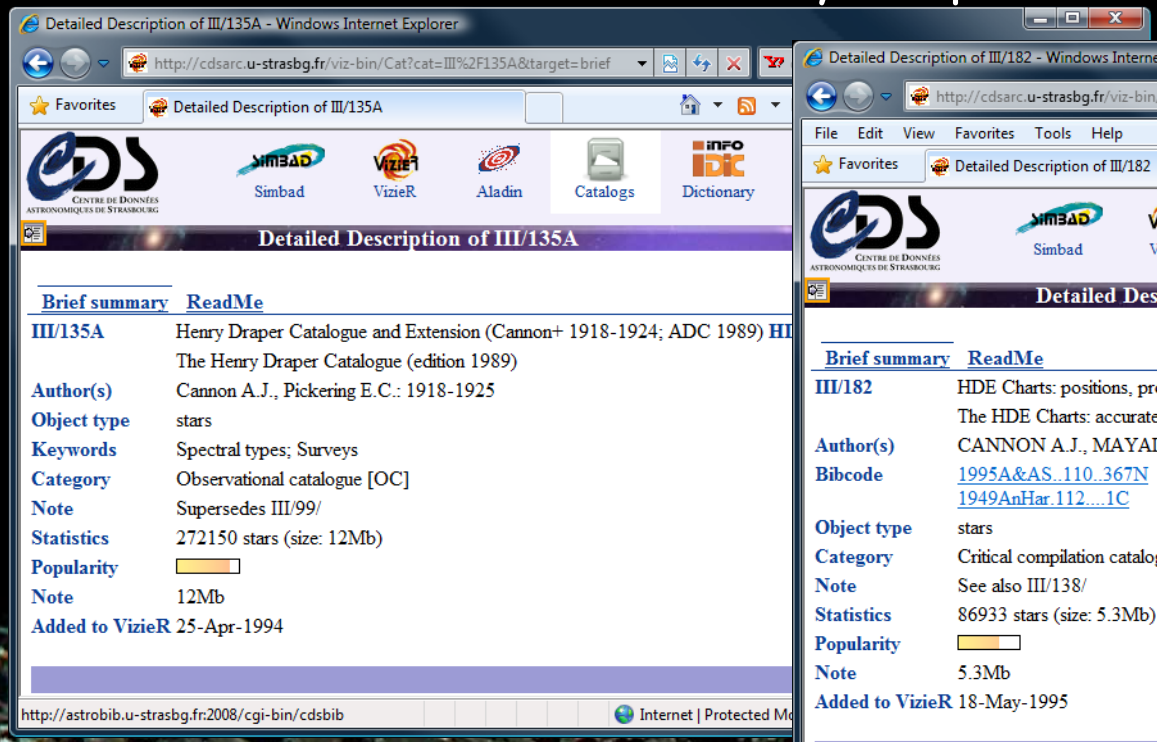
22,000 stars from the Hipparcos Catalogue + 1,000 Low-lum.

Credit http://commons.wikimedia.org/wiki/File:H-R_diagram_-edited-3.gif

Henry Draper Catalgues

Astronomical Spectroscopy

- 1912-49: Harvard College Observatory
  - 225,300 stars Henry Draper (HD) Catalogue
  - 46,850 stars Henry Draper Extension (HDE)
  - 86,933 stars Henry Draper Extension Chart (HDEC)



Microsoft WorldWide Telescope

Vega, Lyra

SIMBAD

Vega A0V

Web Window - Maximize window for full browser

SIMBAD query result

28-Dec-2009: Hierachical links are now available for several objects. See details here.

---

other query modes : Identifier query | Coordinate query | Criteria query | Bibliography query | Basic query | Script submission | Output options | Help

Object query : Vega

C.D.S. - SIMBAD4 rel 1.136 - 2009.12.31CET03:26:11

Available data Basic data | Identifiers | Plot & images | Bibliography | Measurements | External archives | Notes

---

Basic data :

V* alf Lyr -- Variable Star

query around with radius 2 arcmin

Other object types:	* (*,AG,ASCC,BD,CSI,FK5,GC,GCRV,GEN#,GJ,HD,HGAM,HIC,HIP,HR,JP11,N30,8pc,PLX,PMC,PPM,ROT,SAO,SKY# [HFE83]) ,IR (IRAS,IRC,2MASS,RAFGL) ,** (ADS,CCDM,IDS) ,PM* (LSPM,LTT,NLTT) ,V* (V*,CSV,NSV) , (1E)
ICRS coord. (ep=2000) :	18 36 56.3364 +38 47 01.291 (~) [5.65 4.88 144] A 1997A&A...323L..49P
FK5 coord. (ep=2000 eq=2000) :	18 36 56.336 +38 47 01.29 (~) [5.65 4.88 144] A 1997A&A...323L..49P
	067.4482 +19.2373 (~) [5.65 4.88 144] A 1997A&A...323L..49P
Proper motions *mas/yr* [error ellipse]:	201.03 287.47 [0.63 0.54 144] A 1997A&A...323L..49P
Radial velocity / Redshift / cz :	V(km/s) -13.9 [0.9] / z(~) -0.000046 [0.000003] / cz -13.90 [0.90] (~) A 1979IAUS...30...57I
Parallaxes *mas*:	128.93 [0.55] A 1997A&A...323L..49P
Spectral type:	A0V C ~

Spectral Type

Vega A0V

Spectral Type	Surface Temperature	Distinguishing Features
O	> 25,000K	H; HeI; HeII
B	10,000-25,000K	H; HeI; HeII absent
A	7,500-10,000K	H; CaII; HeI and HeII absent
F	6,000-7,500K	H; metals (CaII, Fe, etc)
G	5,000-6,000K	H; metals; some molecular species
K	3,500-5,000K	metals; some molecular species
M	< 3,500K	metals; molecular species (TiO!)
C	< 3,500K	metals; molecular species (C2!)

Credit www.cfa.harvard.edu/~pberlind/atlas/atframes.html

Luminosity Class

Vega A0V

Luminosity Class	Description	Comments
0	Hypergiants	extreme
Ia	Supergiants!	large and luminous
Ib	Supergiants!	less luminous than Ia
II	Bright Giants	
III	Giants	
IV	Sub-Giants	
V	Dwarfs	Main Sequence
sd	Sub-Dwarfs	
D	White Dwarfs	

Credit www.cfa.harvard.edu/~pberlind/atlas/atframes.html

SIMBAD

Vega, HD172167

Web Window - Maximize window for full browser

from: 1983 to: 2010

Measurements (20 types) :

☐ CEL : 1 ☐ Fe_H : 21 ☐ GEN : 1 ☐ GJ : 1 ☐ Hbet1 : 3 ☐ IRAS : 1 ☐ IRC : 1 ☐ ISO : 99 ☐ IUE : 65 ☐ JP11 : 5 ☐ MK : 33 ☐ oRV : 17
☐ PLX : 4 ☐ PM : 3 ☐ pos : 2 ☐ ROT : 6 ☐ SAO : 1 ☐ TD1 : 1 ☐ UBV : 13 ☐ uvby1 : 7

display selected measurements | display all measurements | clear

External archives :

Archive data at HEASARC - High-Energy Astrophysics Science Archive Research Center

Catalogue information from VizieR

V* alf Lyr	AG+38 1711	BD+38 3238	CCDM J18369+3847A	EUVE J1836+38.7
FK5 699	GJ 721	HD 172167	HIC 91262	HIP 91262
HR 7001	IRAS 18352+3844	IRC +40322	LSPM J1836+3847	2MASS J18365633+3847012
NLTT 46746	NSV 11128	PPM 81558	RAFGL 2208	SAO 67174
USNO-B1.0 1287-00305764				

To bookmark this query, right click on this link: simbad:Vega and select 'bookmark this link' or equivalent in the popup menu

VizieR Detail Page

Vega, HD172167

VizieR Detail Page

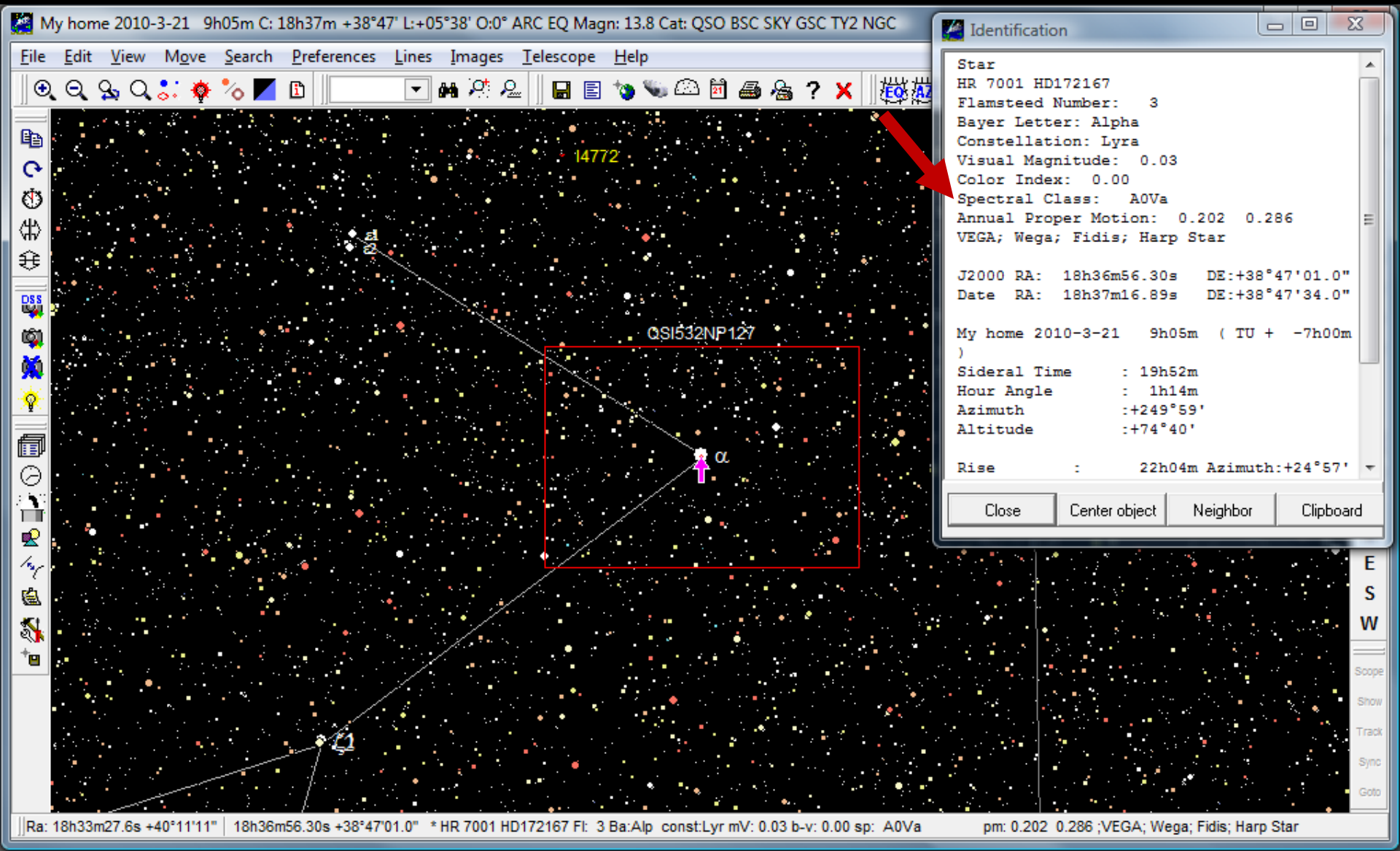
Vega, HD172167

Web Window - Maximize window for full browser

_DEB1950	**+38 44** "d:m:s"	*Declination (FK4) Equinox=B1950.0 Epoch=J1900. (computed by VizieR, not part of the original data)* (pos.eq.dec;meta.main) (POS_EQ_DEC_MAIN)
_Glon	**067.43** deg	*Galactic longitude Epoch=J1900. (computed by VizieR, not part of the original data)* (pos.galactic.lon) (POS_GAL_LON)
_Glat	**+19.23** deg	*Galactic latitude Epoch=J1900. (computed by VizieR, not part of the original data)* (pos.galactic.lat) (POS_GAL_LAT)
HD	**172167**	[1/272150] Henry Draper Catalog (HD) number (meta.id;meta.main) (ID_MAIN)
DM	**BD+38 3238**	Durchmusterung identification (Note 1) (meta.id) (ID_ALTERNATIVE)
RAB1900	**18 33.6** "h:m:s"	Hours RA, equinox B1900, epoch 1900.0 (pos.eq.ra;meta.main) (POS_EQ_RA_MAIN)
DEB1900	**+38 41** "d:m:s"	Degrees Dec, equinox B1900, epoch 1900.0 (pos.eq.dec;meta.main) (POS_EQ_DEC_MAIN)
q_Ptm	**0**	[0/1] Code for Ptm: 0 = measured, 1 = value inferred from Ptg and spectral type (meta.code.qual) (CODE_QUALITY)
Ptm	**0.14** mag	Photovisual magnitude (Note 2) (phot.mag;em.opt.V) (PHOT_PHG_V)
n_Ptm		[C] 'C' if Ptm is combined value with Ptg (meta.note) (NOTE)
q_Ptg	**1**	[0/1] Code for Ptg: 0 = measured, 1 = value inferred from Ptm and spectral type (meta.code.qual) (CODE_QUALITY)
Ptg	**0.14** mag	Photographic magnitude (Note 2) (phot.mag;em.opt) (PHOT_PHG_MAG)
n_Ptg		[C] 'C' if Ptg is combined value for this entry and the following or preceding entry (meta.note) (NOTE)
SpT	**A0**	Spectral type *(spectral types **P** are generally nebulae)* (src.spType) (SPECT_TYPE_GENERAL)
Int		[0-9B] Photographic intensity of spectrum (Note 3) (phot.count;em.opt) (PHOT_INTENSITY_ESTIMATED)
Rem	**R**	[DEGMR*] Remarks, see note (Note 4) (meta.note) (REMARKS)
Simbad	Simbad	*ask the **Simbad** data-base about this object* (DATA_LINK)
Tycho	Tycho	*Cross-identification with Tycho-2 (Cat. IV/25)* (meta.ref.url) (DATA_LINK)

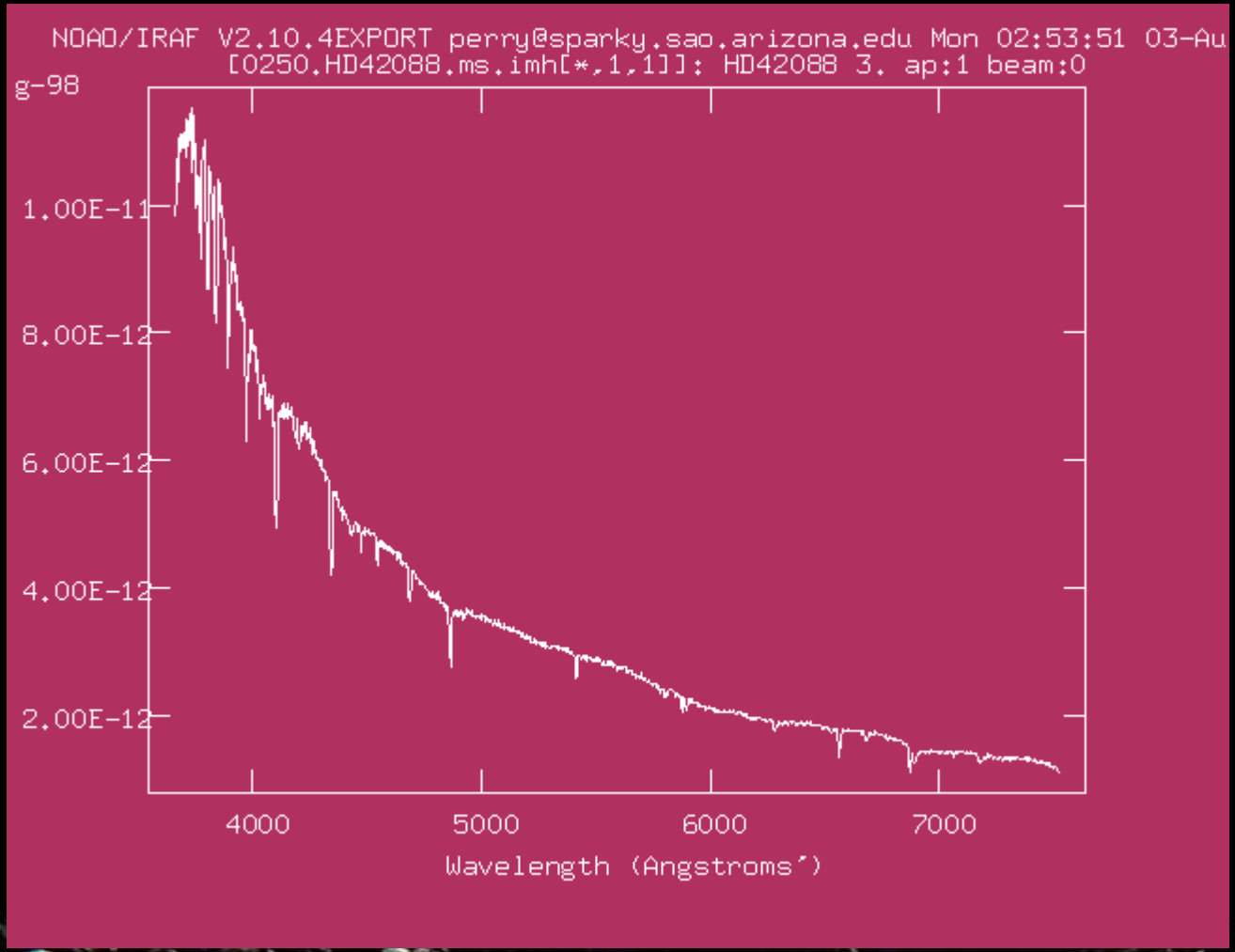
Vega HD172167

Sky Charts V2.76c



HD42088

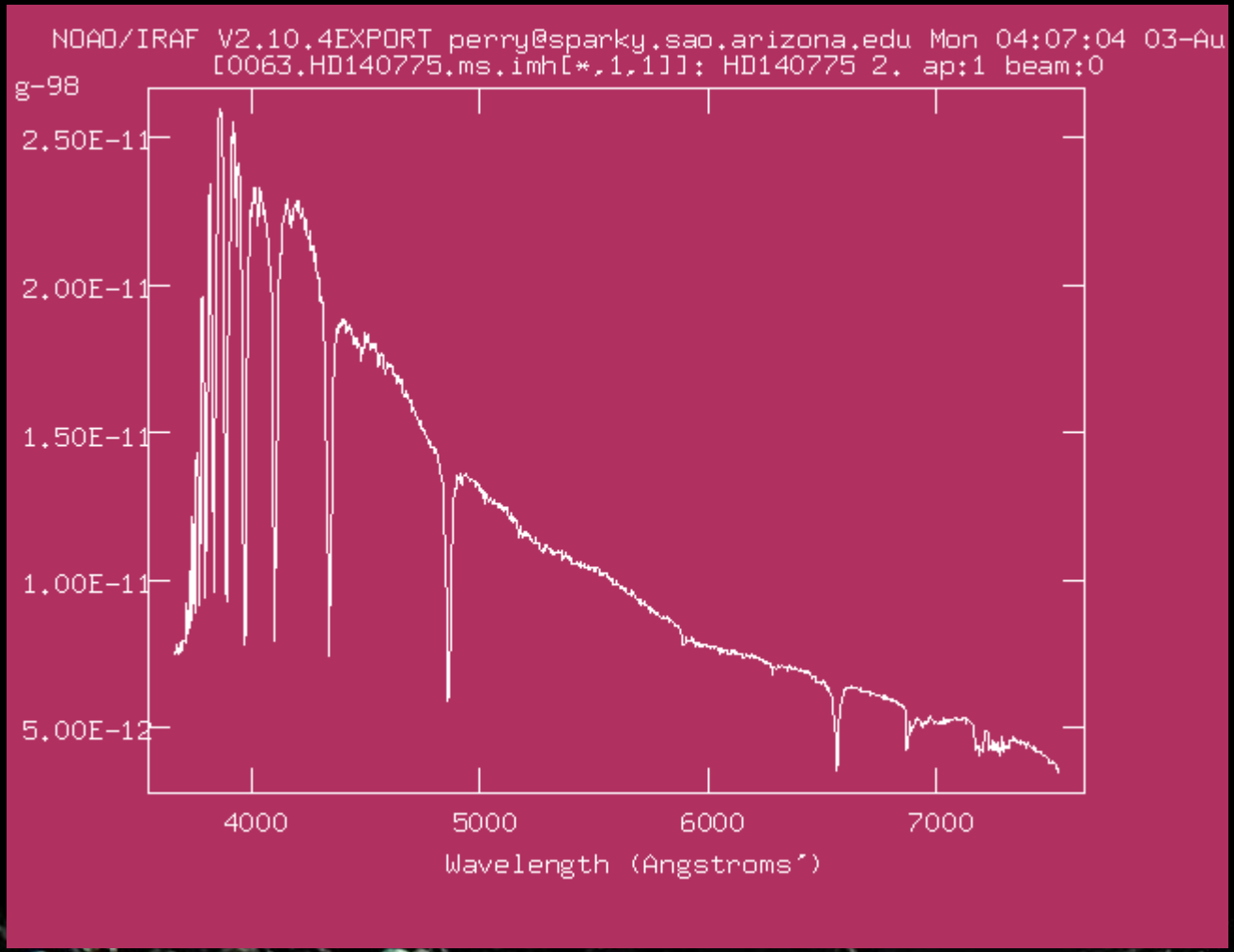
O6V



Credit http://www.cfa.harvard.edu/~pberlind/atlas/atframes.html

HD140775

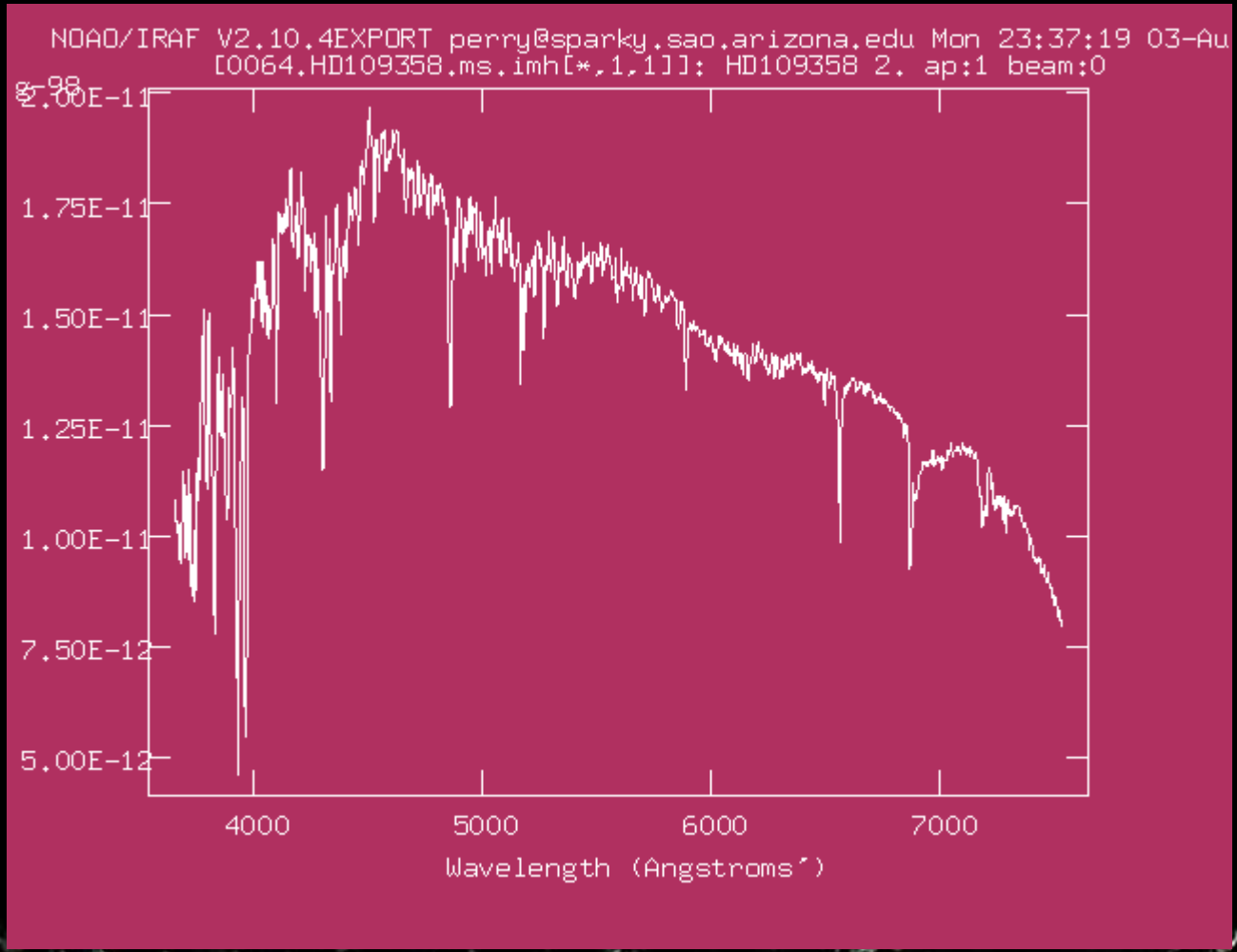
A0V



Credit http://www.cfa.harvard.edu/~pberlind/atlas/atframes.html

HD109358

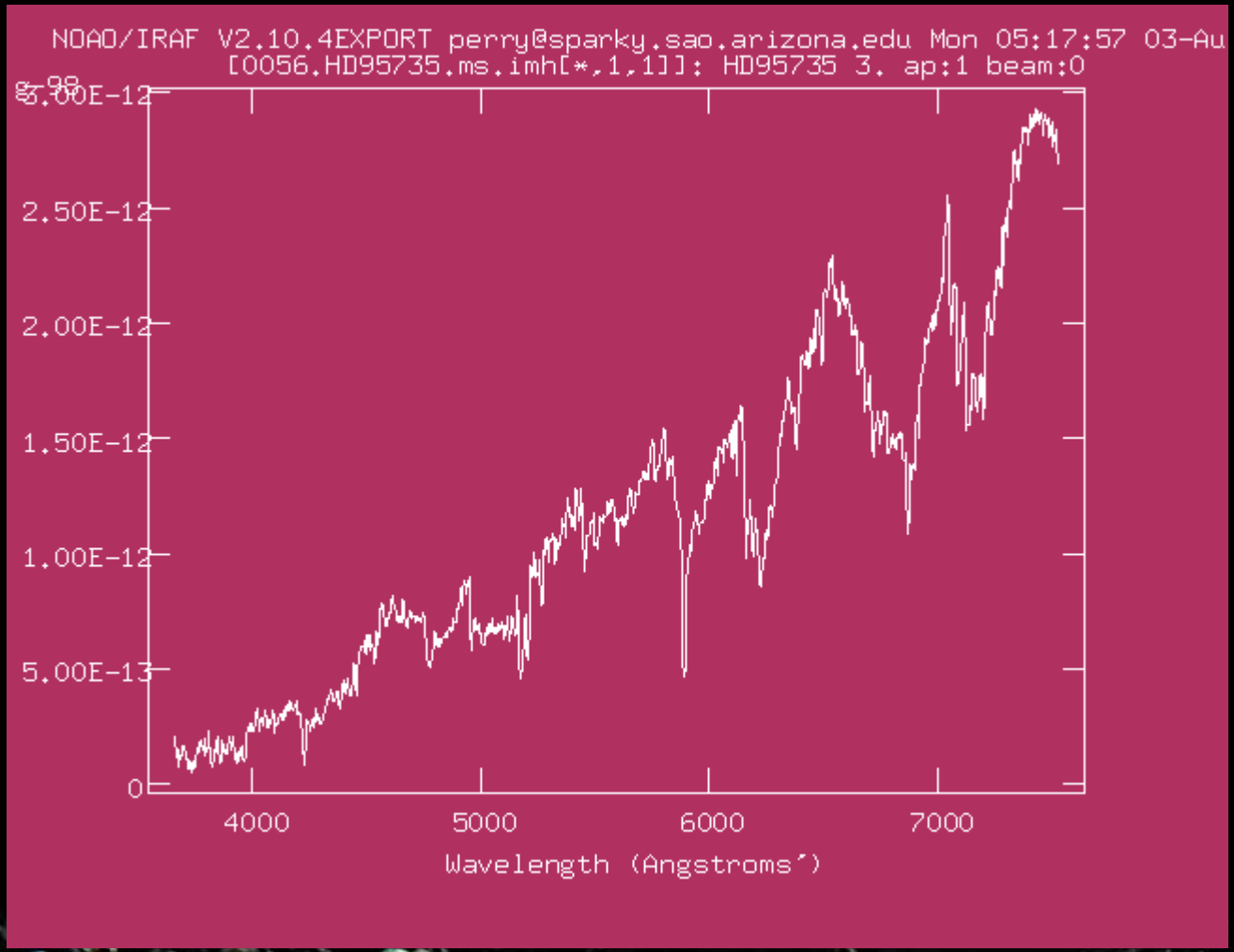
G0V



Credit http://www.cfa.harvard.edu/~pberlind/atlas/atframes.html

HD95735

M2V



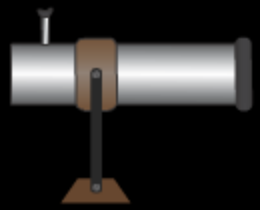
Credit http://www.cfa.harvard.edu/~pberlind/atlas/atframes.html

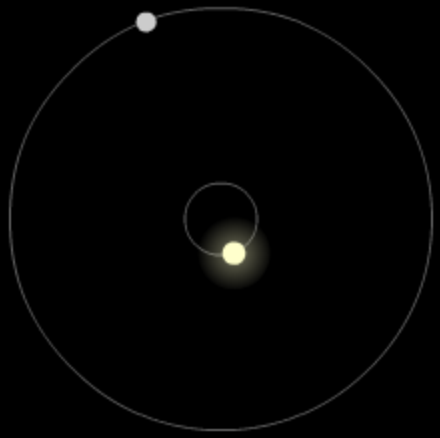
Astronomical Spectroscopy

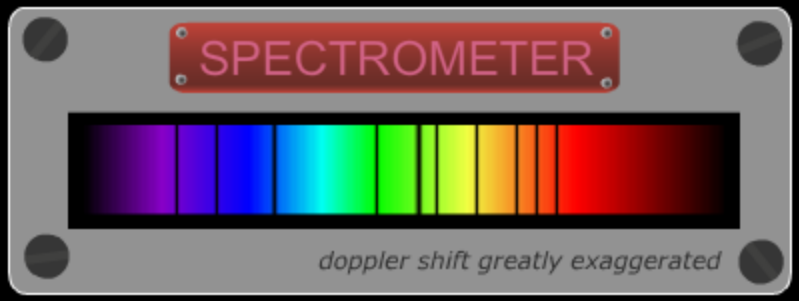
Analyzing Electromagnetic Spectrum

- Composition
  - Spectra line patterns: atoms, ions & modules
- Temperature & density
  - Spectra line patterns: atom states & transitions
  - Stellar classification
- Motions
  - Spectra line Doppler shift

Radial Velocity Spectra







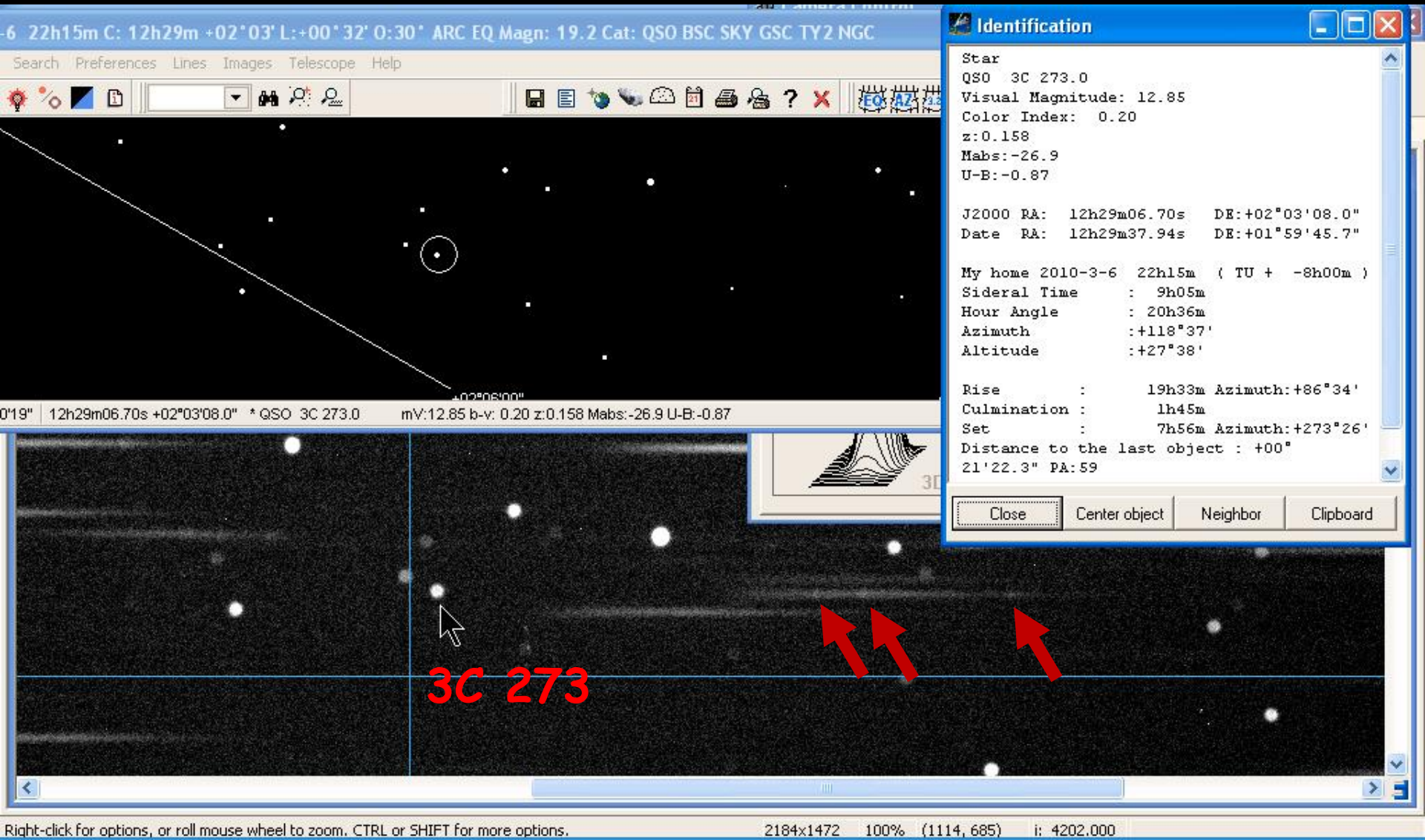
Credit http:// astro.unl.edu

Radial Velocity Spectra

Quasar 3C 273 Redshift Measurement

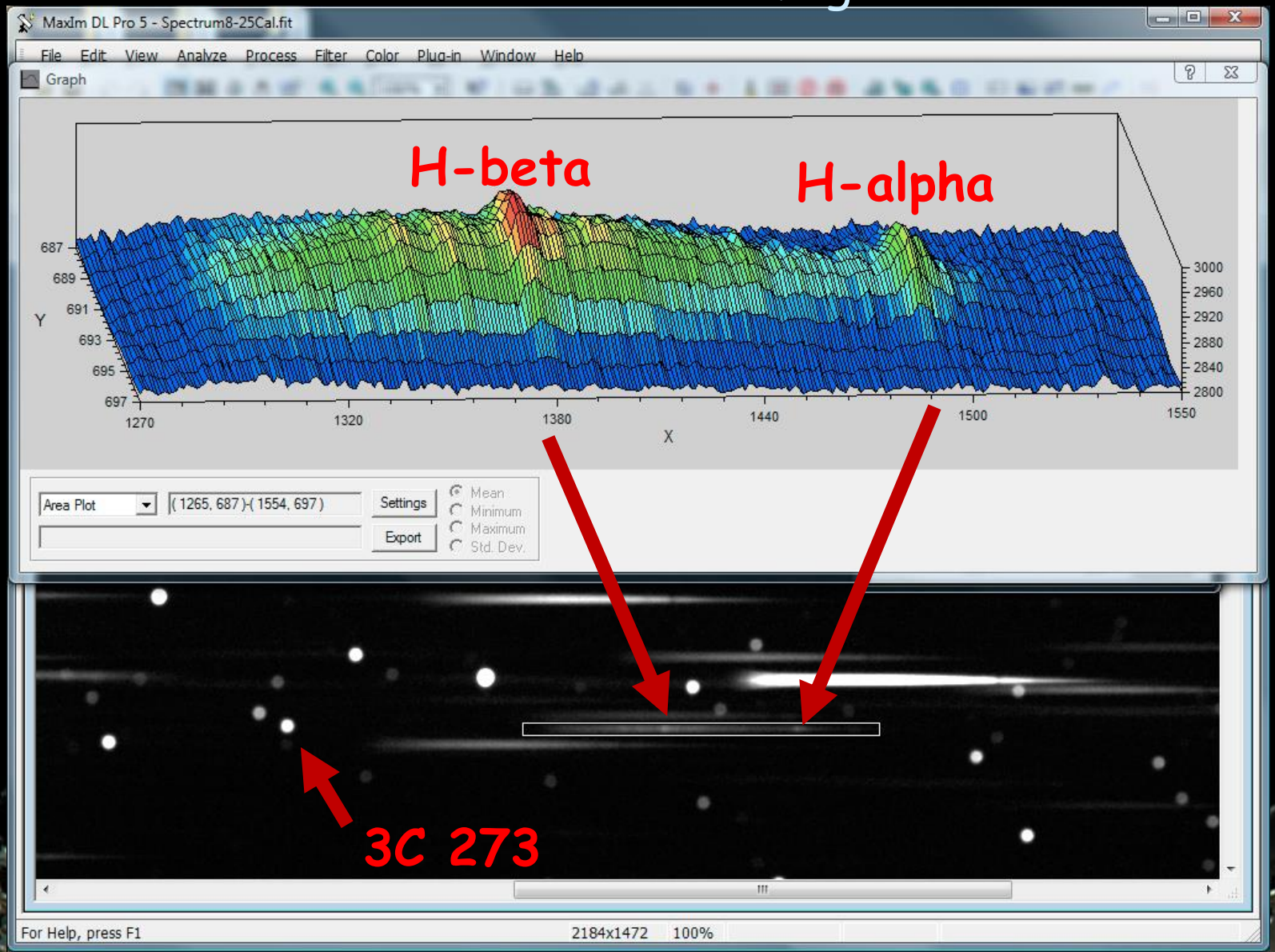
Quasar 3C 273 Redshift

One 300 second image



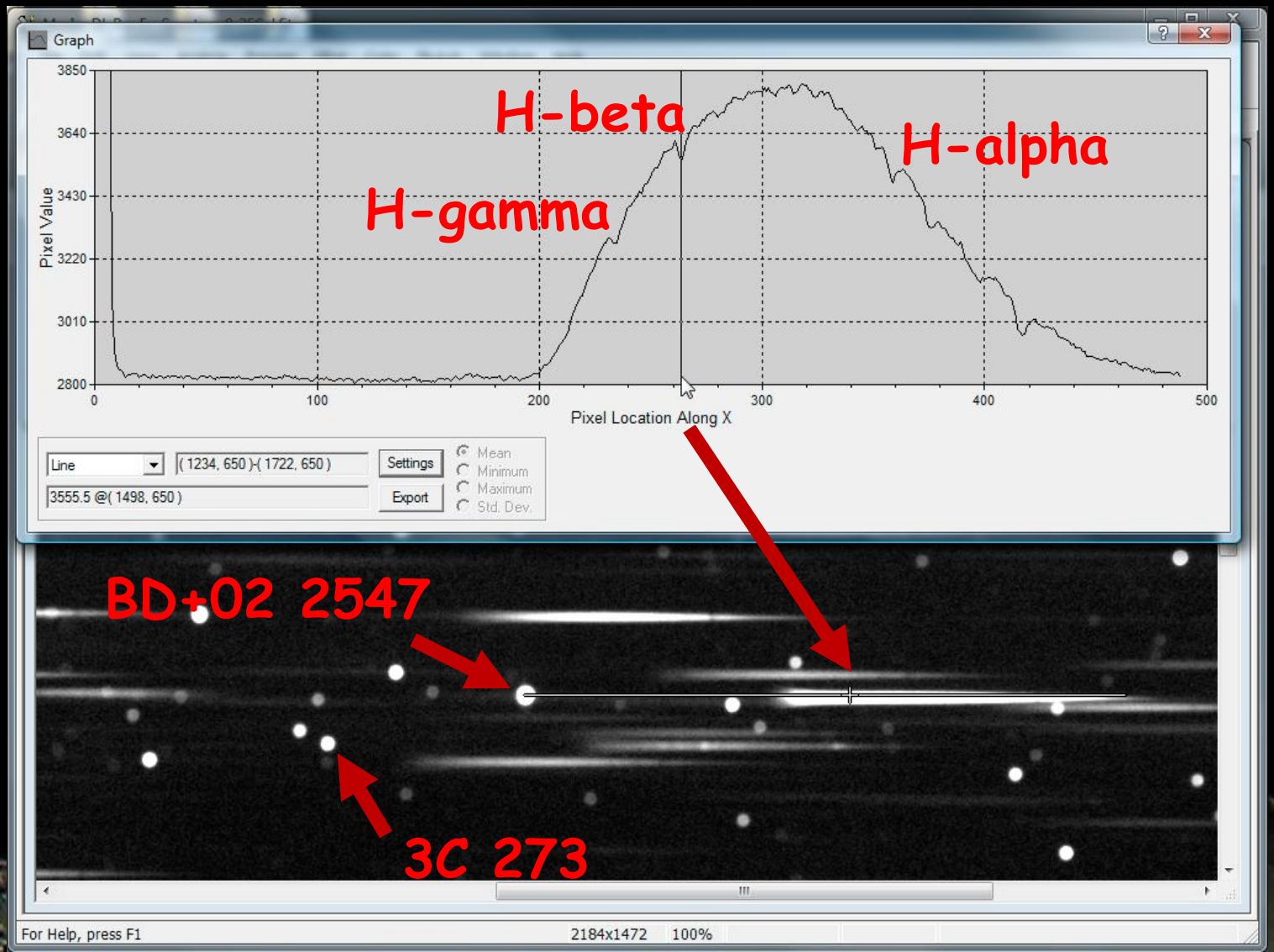
Quasar 3C 273 Redshift

16 x 300 second images



Quasar 3C 273 Redshift

Star BD+02 2547, F5 used for calibration



Quasar 3C 273 Redshift

Redshift z = 0.158339

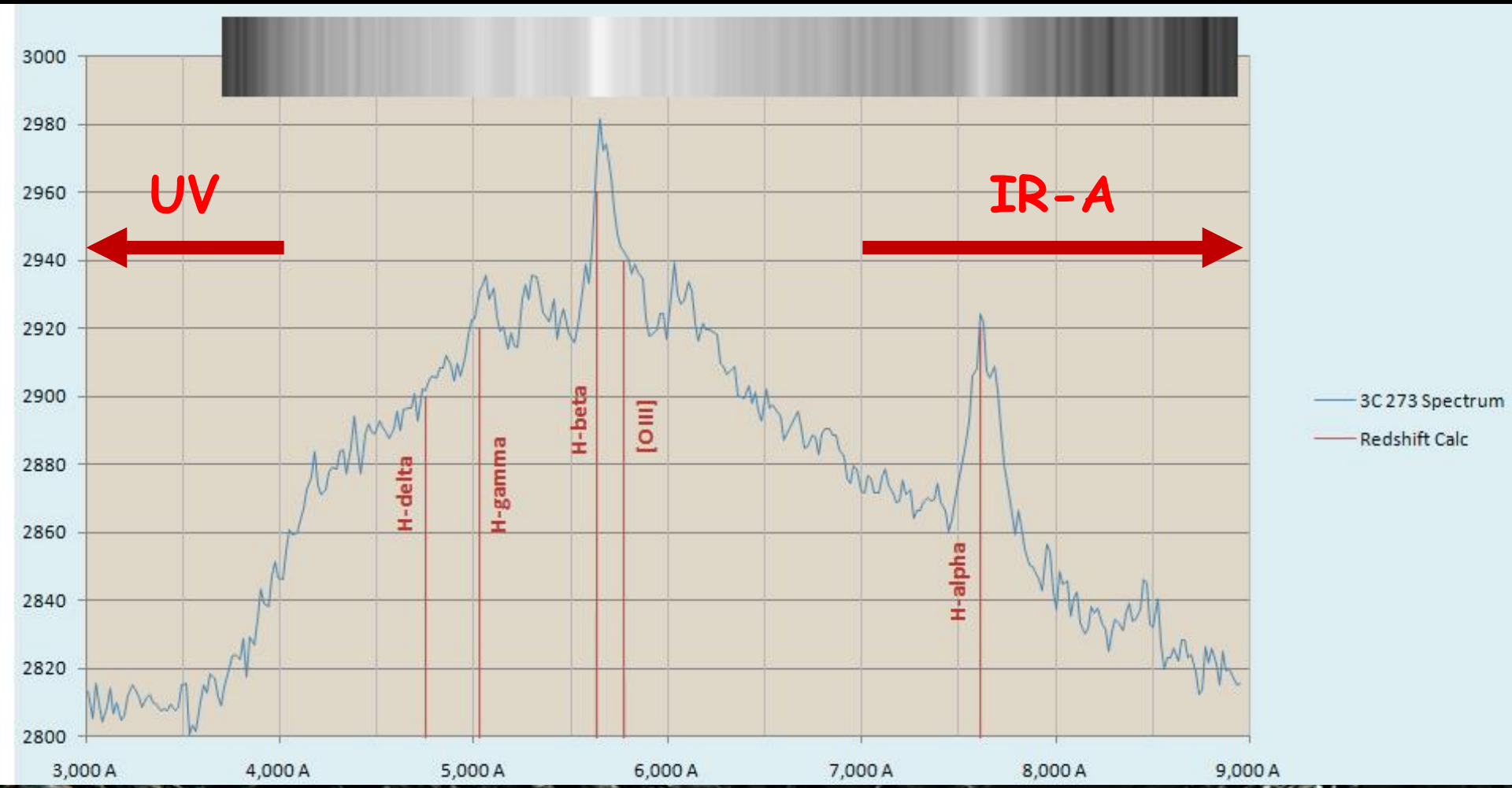
3C 273 Redshift z=0.158339

$$z = \frac{\lambda_{obsv} - \lambda_{emit}}{\lambda_{emit}}$$

Elements	Emit Wavelength	Redshift Change in Wavelength	Observed Wavelength
H-alpha	6563 Å	1039 Å	7602 Å
[O III]	5007 Å	793 Å	5800 Å
H-beta	4861 Å	770 Å	5631 Å
H-gamma	4340 Å	687 Å	5027 Å
H-delta	4102 Å	650 Å	4752 Å

Quasar 3C 273 Redshift

Observed Quasar 3C 273 Spectrum



Quasar 3C 273

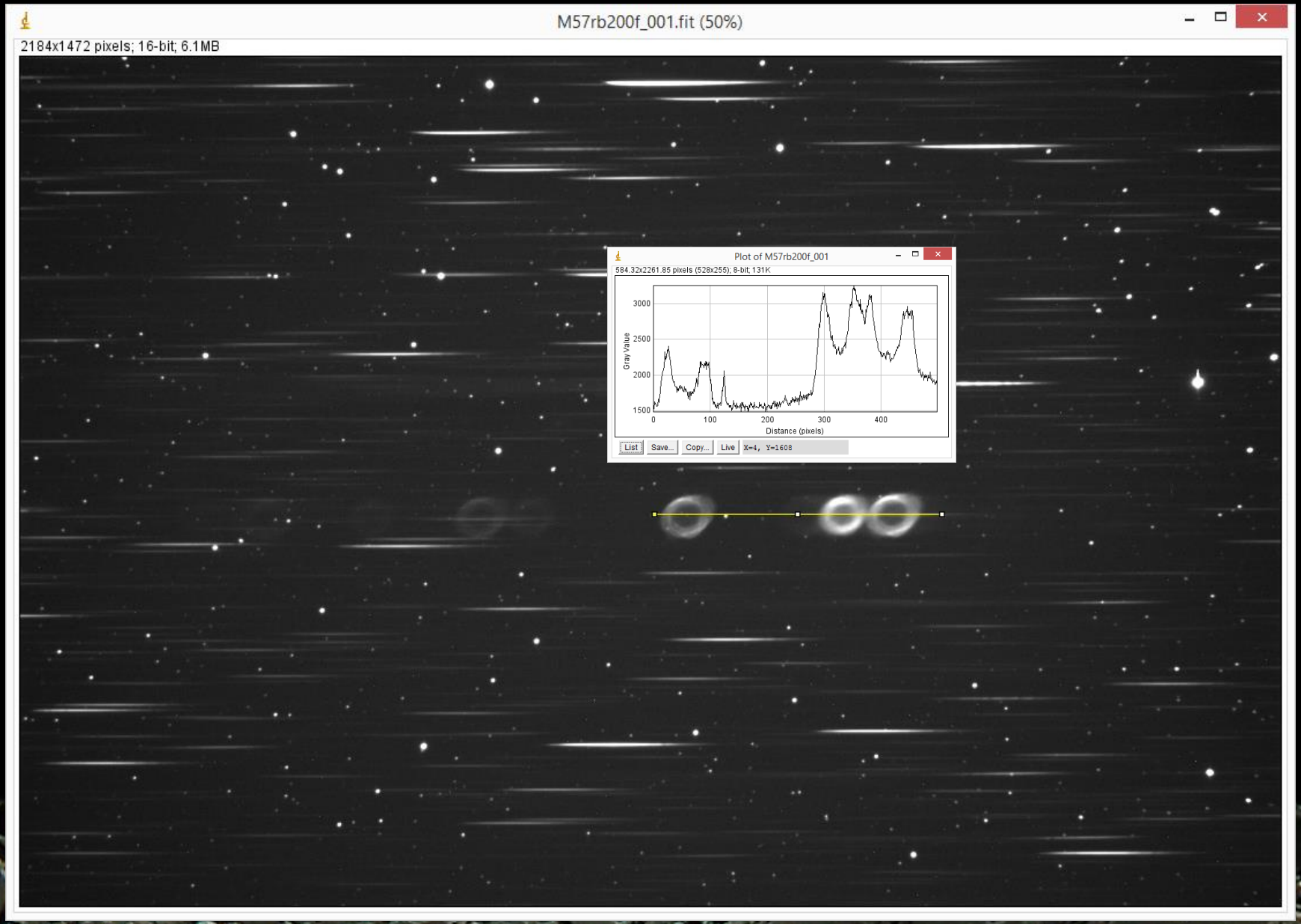
Observed Spectrum Redshift 0.1608

Elements	Emit Wavelength	Observed Wavelength at Peak	Observed Redshift z	Redshift Error z=0.158339	Signal/Noise Ratio at Peak
H-alpha	6563 Å	7609 Å	0.1594	0.6909%	26.28
H-beta	4861 Å	5649 Å	0.1622	2.421%	39.14
The average of the measured H-alpha and H-beta redshifts is z=.1608 which is 1.5%: higher than z=0.158339 in the NASA/IPAC Extragalactic database.					

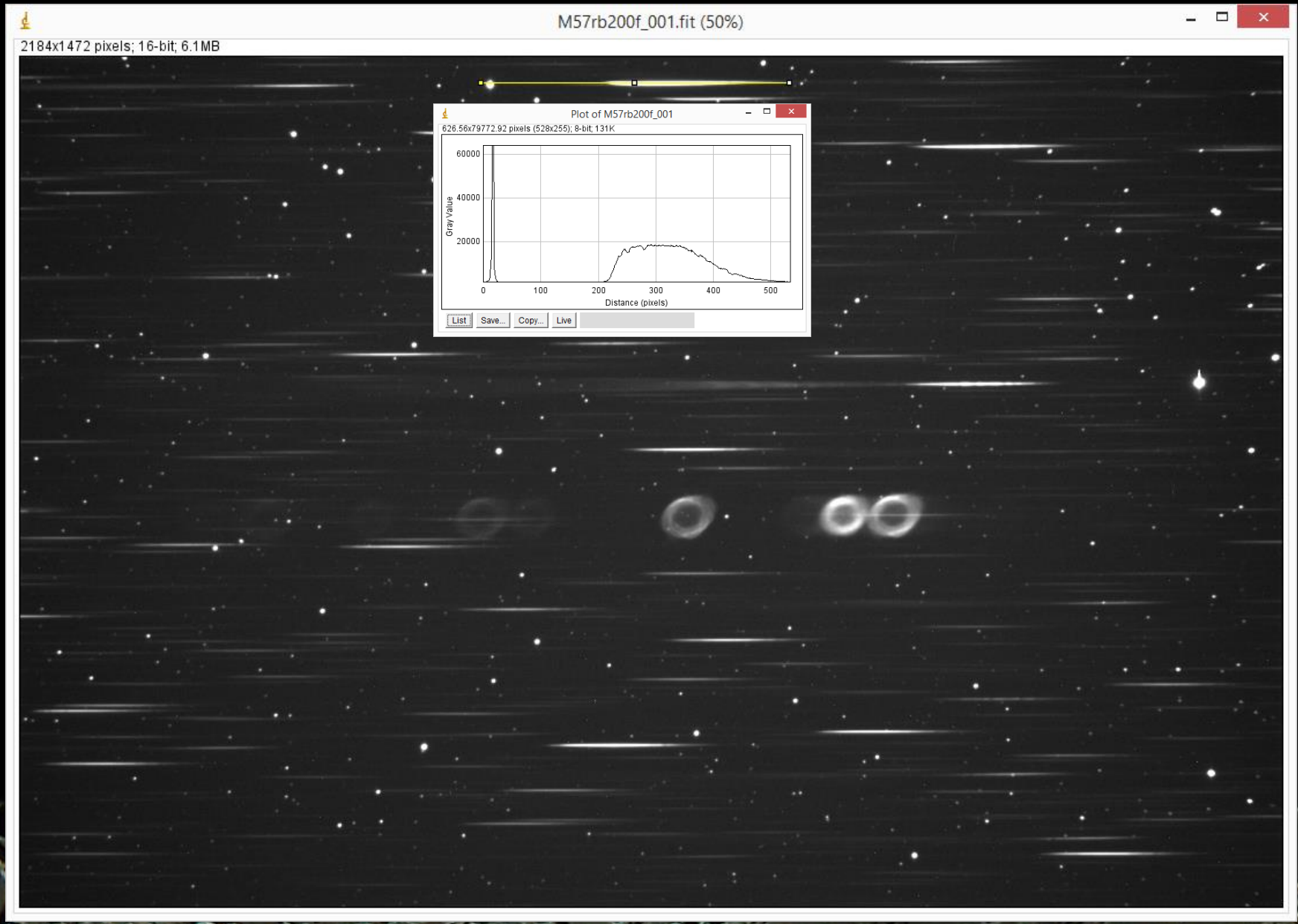
Note: Signal/Noise Ratio at Peak = (Peak-Background Ave)/(Background Std Dev)
H-beta Signal/Noise Ratio at Peak = (2981.76-2806.47)/(4.478) = 39.14 S/N

M57 PMO 2014 Sunday Night

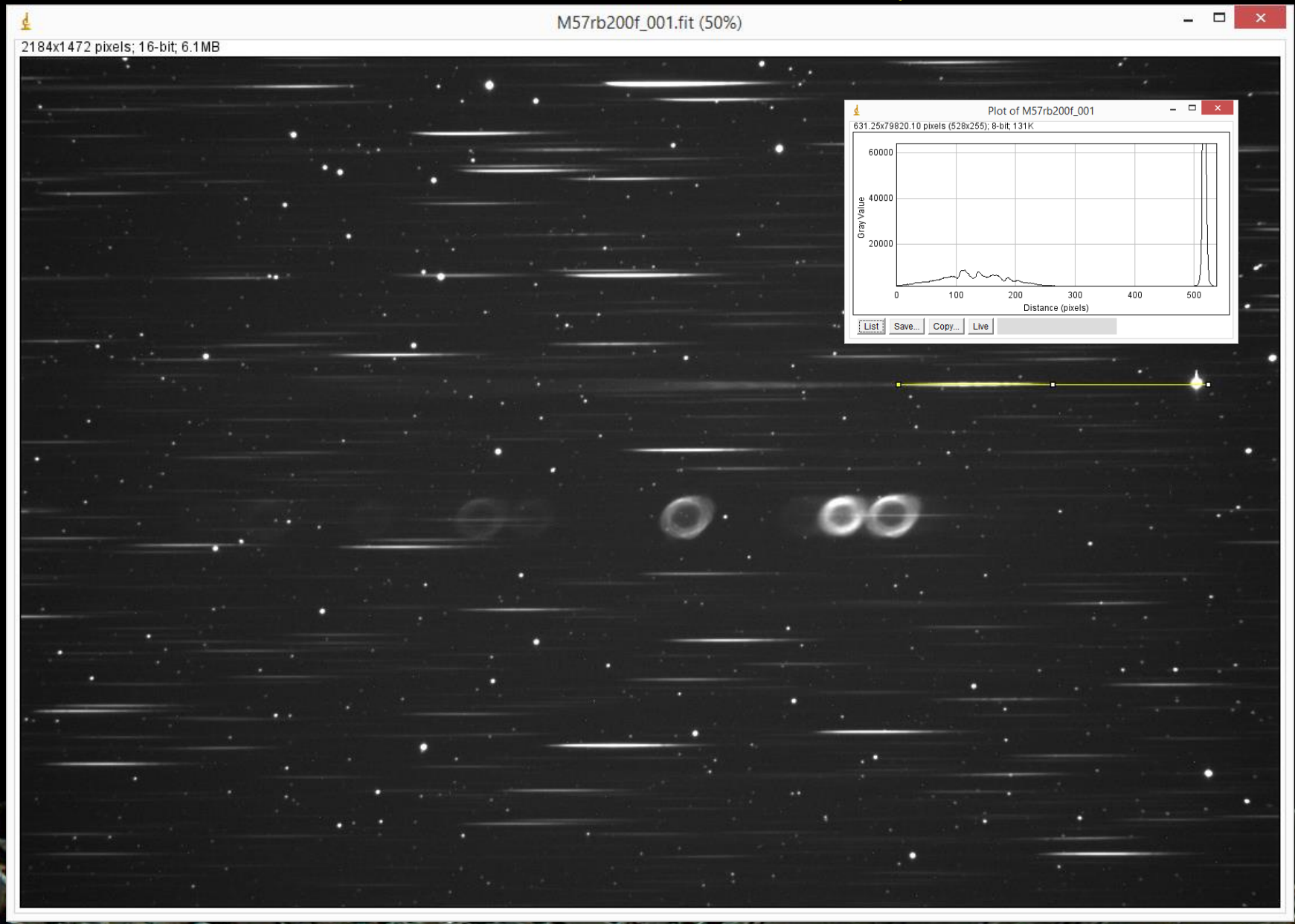
M57 PMO 2014 Sunday Night



M57 PMO 2014 Sunday Night



M57 PMO 2014 Sunday Night



Astronomical Spectroscopy Summary

Analyzing Electromagnetic Spectrum

- Composition
  - Spectra line patterns: atoms
- Temperature & density
  - Spectra line patterns: atom states & transitions
  - Stellar classification
- Motions
  - Spectra line Doppler shift

Credits: http://astro.unl.edu/

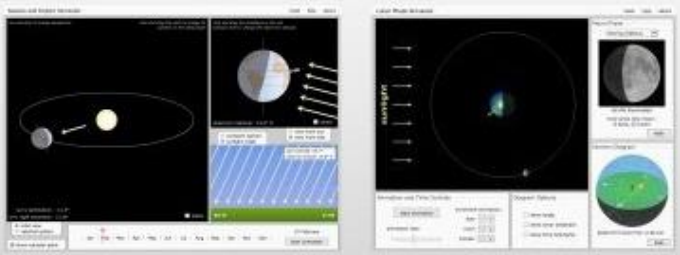
Astronomy Education at the University of Nebraska-Lincoln

mirror

Home | ClassAction | NAAP Labs | Interactives | Contact

The Nebraska Astronomy Applet Project

interactive, simulator-based online laboratories for introductory astronomy



ClassAction

dynamic think-pair-share questions to engage students in the astronomy classroom

About close

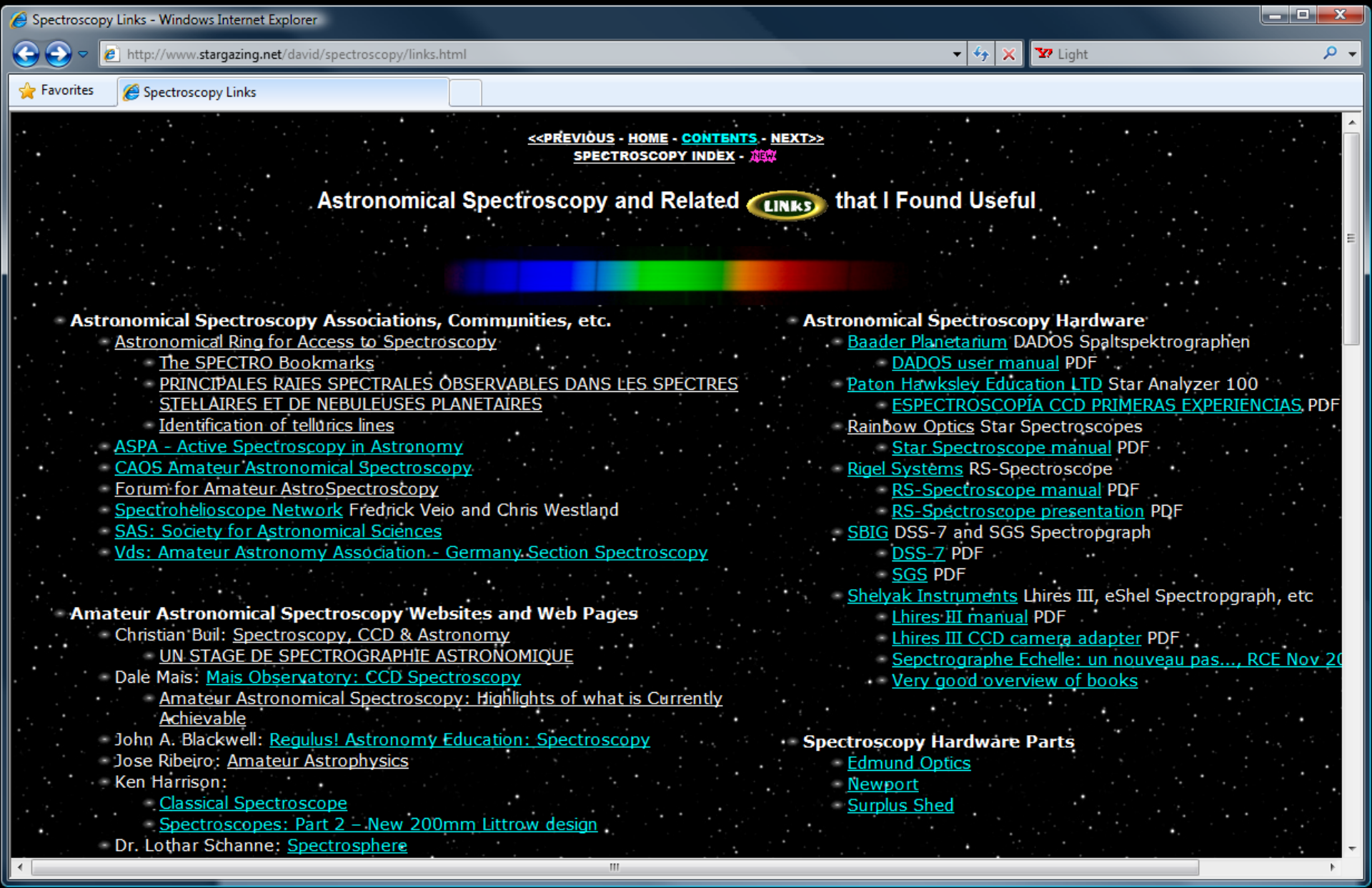
This simulator is part of the Blackbody Curves & UBV Filters Module of the Nebraska Astronomy Applet Project. Supporting materials and additional astronomy education resources can be found at

http://astro.unl.edu

Funding for this work was provided by NSF grants #0231270 and/or #0404988.

bbExplorer025, 18 July 2007
your player version: WIN 10,0,45,2

http://www.stargazing.net/david/spectroscopy/links.html



www.stargazing.net/david