Quantitative Spectral Classification

Quarknet 2010 Astronomy Group

The Project

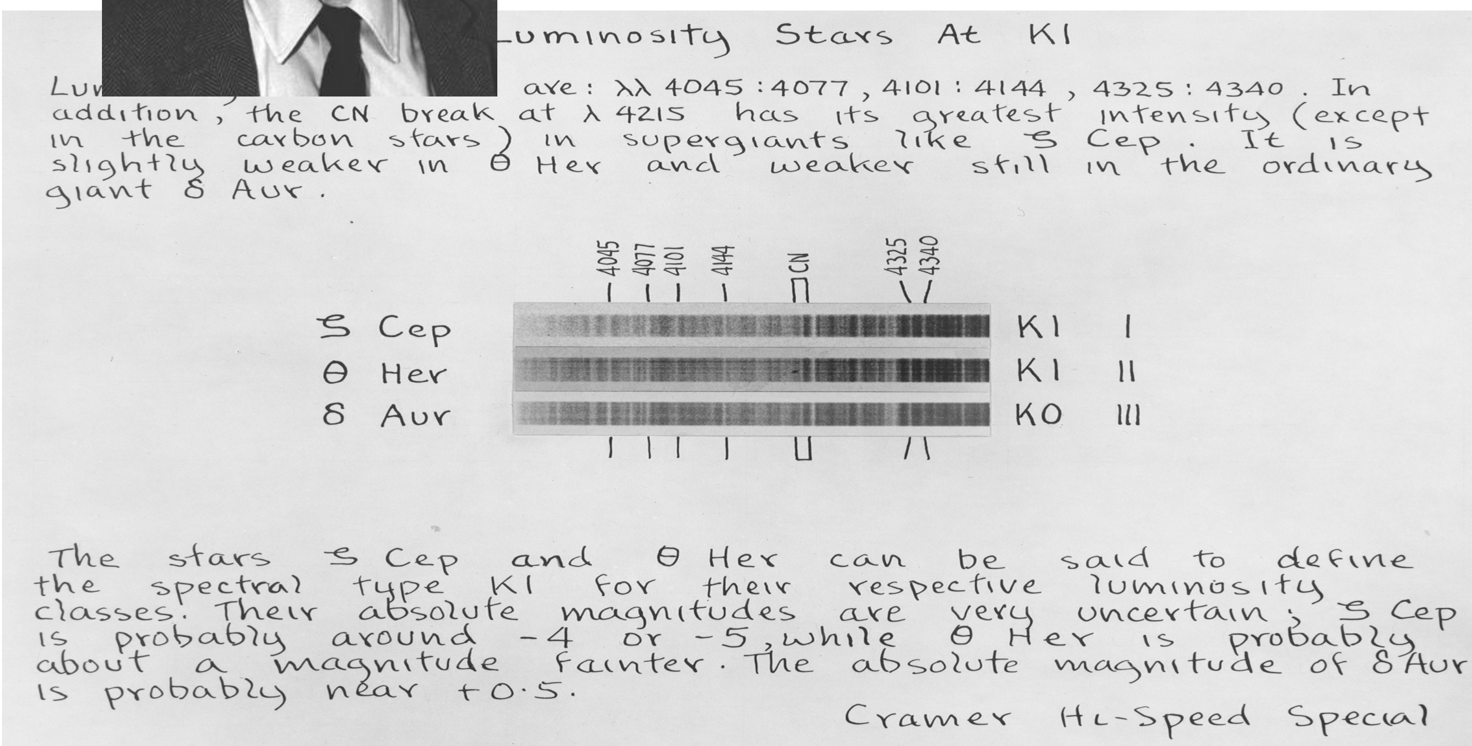
- Develop a quantitative method of stellar classification.
  - Using the MKK system and standard stars as a guide.
  - Apply method to Sloan Digital Sky Survey data

Goals and Implications

- Our goal for the summer:
  - Accurately classify Sloan Stars by hand
- Goals of the project
  - Develop a program that more accurately classifies stars than the current technology
  - Use that program to more accurately determine the distribution of hot and cold stars within galaxies.

William Wilson Morgan

And his System



uminosity Stars At K1

Lum are: λλ 4045 : 4077, 4101 : 4144, 4325 : 4340. In addition, the CN break at λ 4215 has its greatest intensity (except in the carbon stars) in supergiants like ζ Cep. It is slightly weaker in θ Her and weaker still in the ordinary giant δ Aur.

The stars ζ Cep and θ Her can be said to define the spectral type K1 for their respective luminosity classes. Their absolute magnitudes are very uncertain; ζ Cep is probably around −4 or −5, while θ Her is probably about a magnitude fainter. The absolute magnitude of δ Aur is probably near +0.5.

Cramer Hi-Speed Special

From the Book

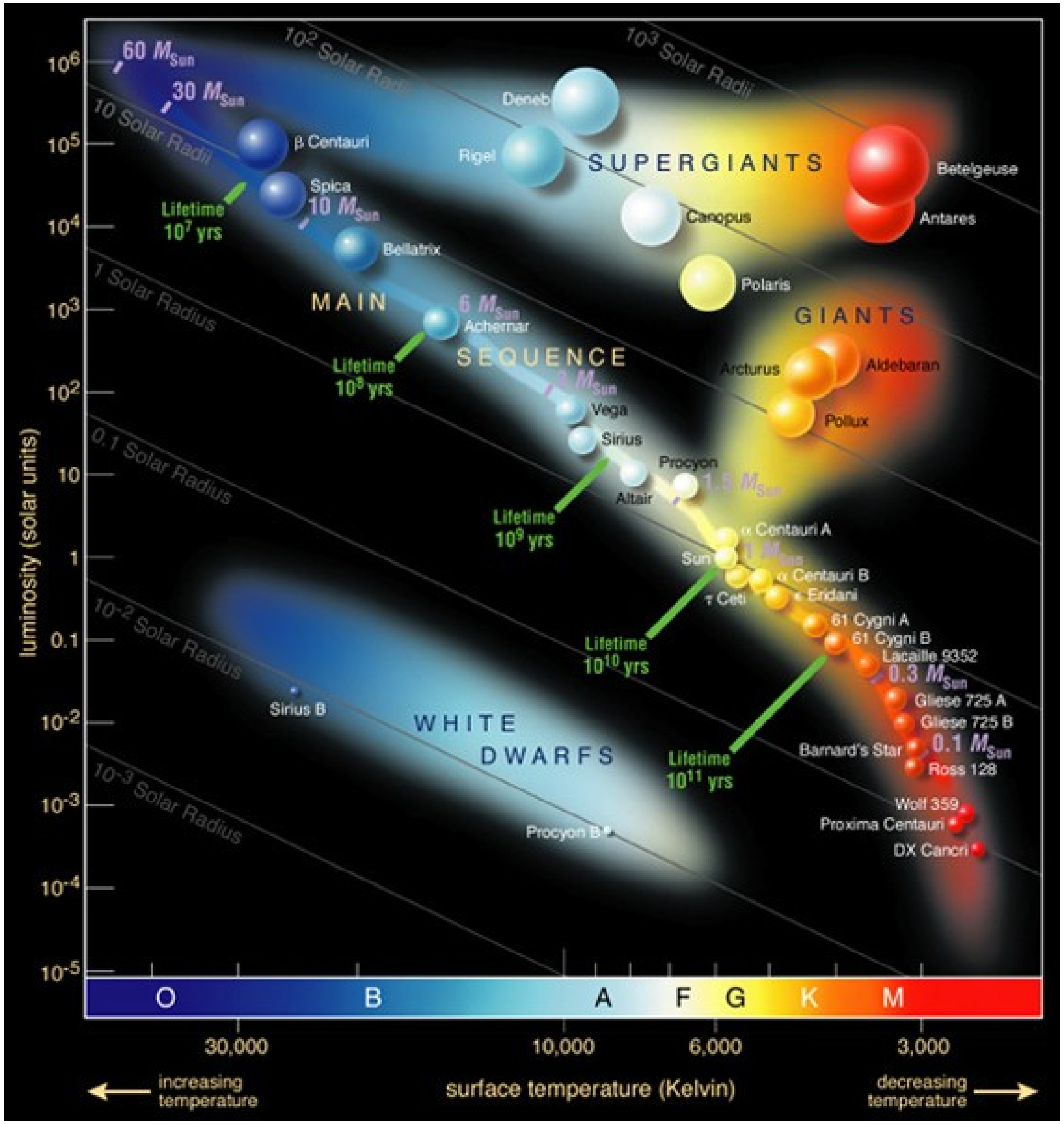
31 K0

Spectral type is determined from the ratios $\lambda\lambda$ 4030–4034:λ 4300, λ 4290:λ 4300, and $H\delta$:λ 4096. Luminosity differences are shown by the ratios λ 4063:λ 4077, λ 4071:λ 4077, λ 4144:λ 4077, and by the intensity difference of the continuous spectrum on each side of λ 4215.

30 G8

The spectral type (except for the supergiants) is determined from the ratios λ 4144:$H\delta$ and λ 4096:$H\delta$ and the ratio of the blend at $\lambda\lambda$ 4030–4034 to the violet side of the G band. On the spectrograms used, $H\delta$ appears to be stronger in dwarfs of this class than in giants and subgiants.

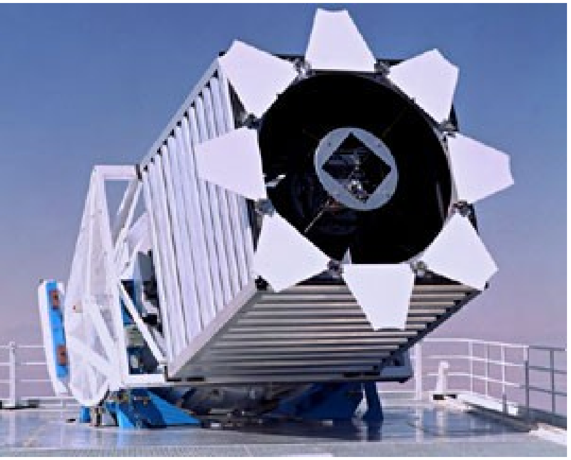
HR Diagram

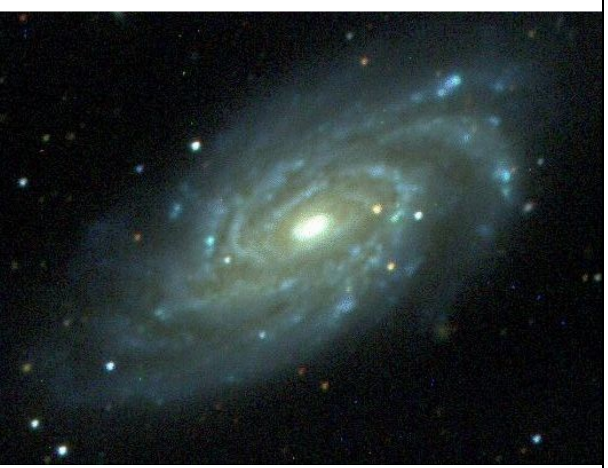


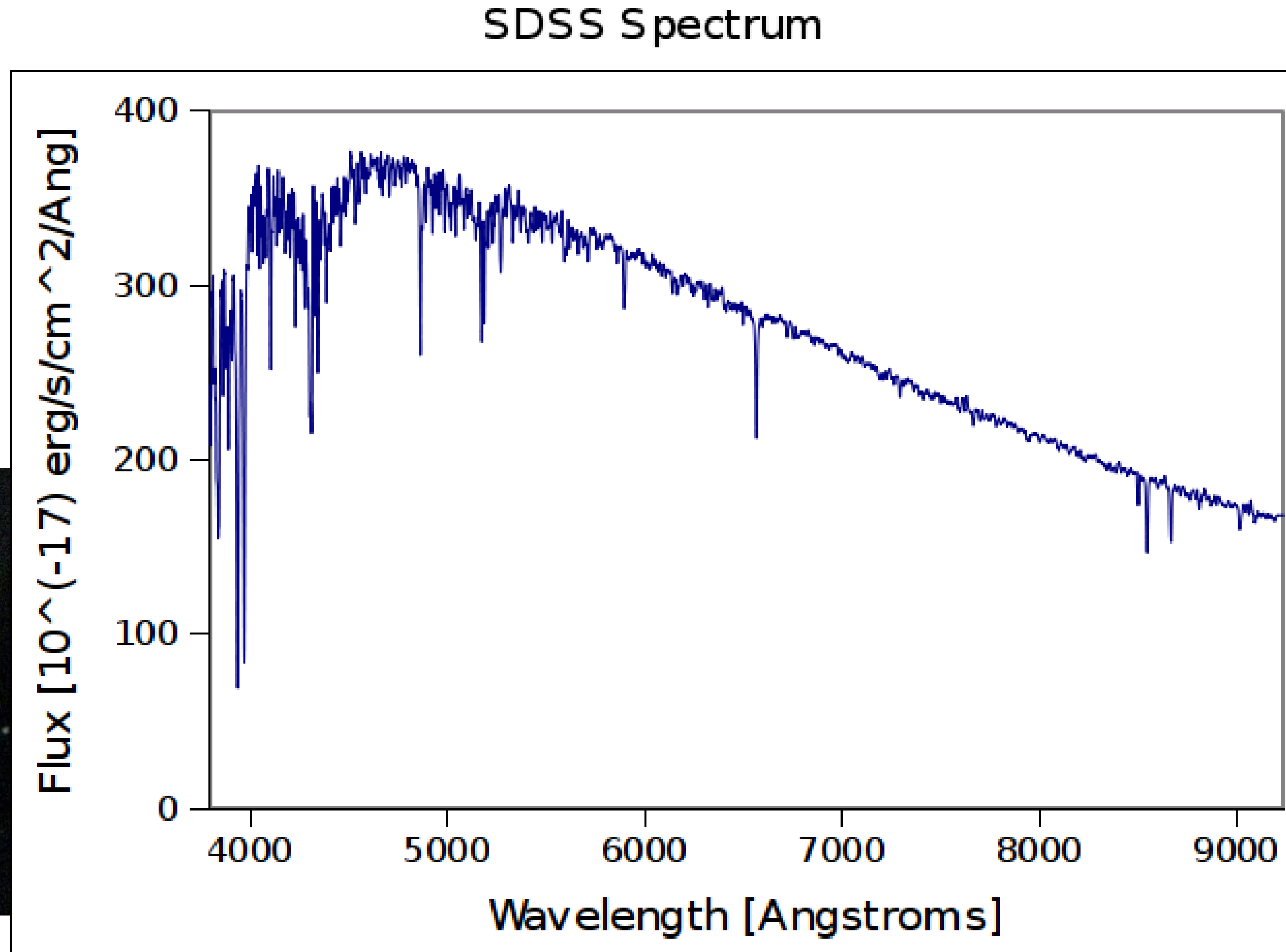
SUPERGIANTS
GIANTS
MAIN
SEQUENCE
WHITE
DWARFS
Deneb
Rigel
Betelgeuse
Antares
Canopus
Polaris
Arcturus
Aldebaran
Pollux
β Centauri
Spica
Bellatrix
Achernar
Vega
Sirius
Procyon
Altair
α Centauri A
Sun
α Centauri B
τ Ceti
ε Eridani
61 Cygni A
61 Cygni B
Lacaille 9352
Gliese 725 A
Gliese 725 B
Barnard's Star
Ross 128
Wolf 359
Proxima Centauri
DX Cancri
Sirius B
Procyon B
60 M_{Sun}
30 M_{Sun}
10 M_{Sun}
6 M_{Sun}
3 M_{Sun}
1.5 M_{Sun}
1 M_{Sun}
0.3 M_{Sun}
0.1 M_{Sun}
Lifetime 10^7 yrs
Lifetime 10^8 yrs
Lifetime 10^9 yrs
Lifetime 10^{10} yrs
Lifetime 10^{11} yrs
10^2 Solar Radii
10^3 Solar Radii
10 Solar Radii
1 Solar Radius
0.1 Solar Radius
10^{-2} Solar Radius
10^{-3} Solar Radius
luminosity (solar units)
10^6
10^5
10^4
10^3
10^2
10
1
0.1
10^{-2}
10^{-3}
10^{-4}
10^{-5}
O
B
A
F
G
K
M
30,000
10,000
6,000
3,000
increasing temperature
surface temperature (Kelvin)
decreasing temperature

Sloan Digital Sky Survey

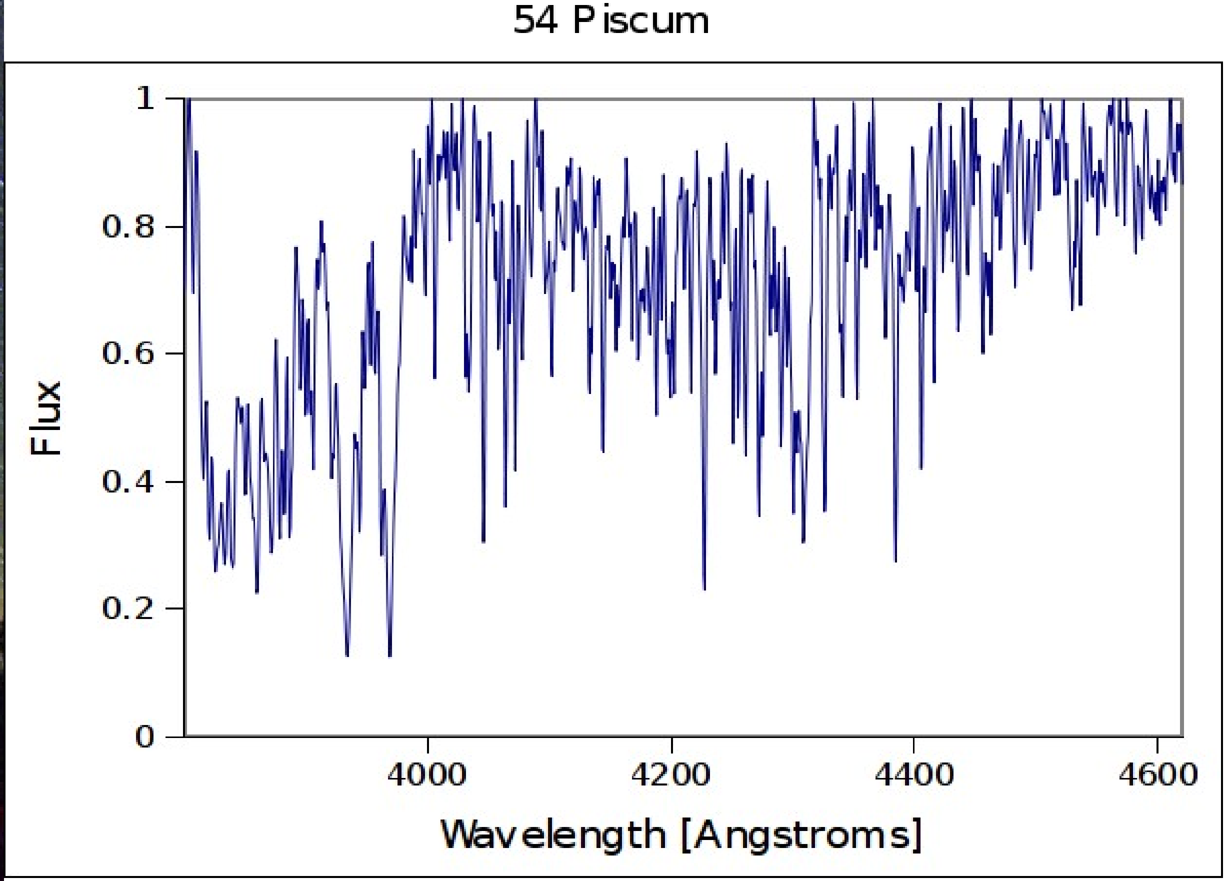
And its System





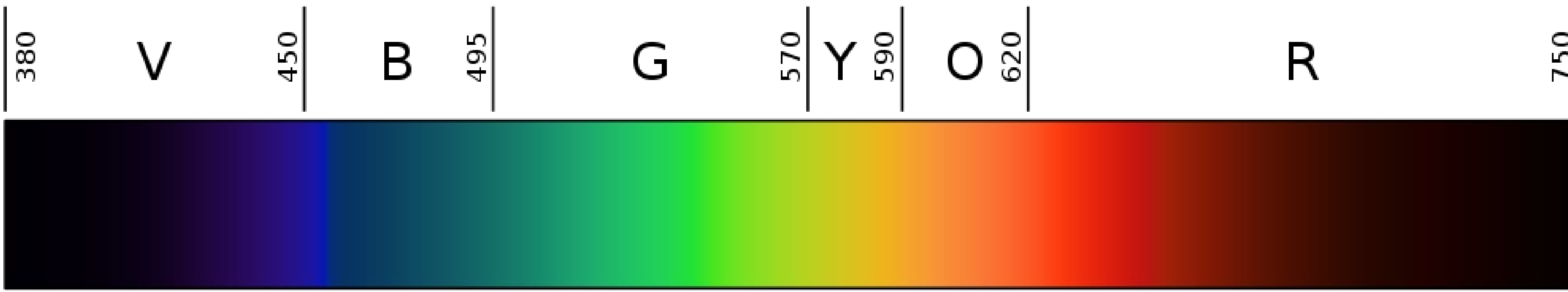


Dark Sky Observatory



Where does this fall?

The sector in blue is the section of the EM spectrum that the Dark Sky Observatory can analyze

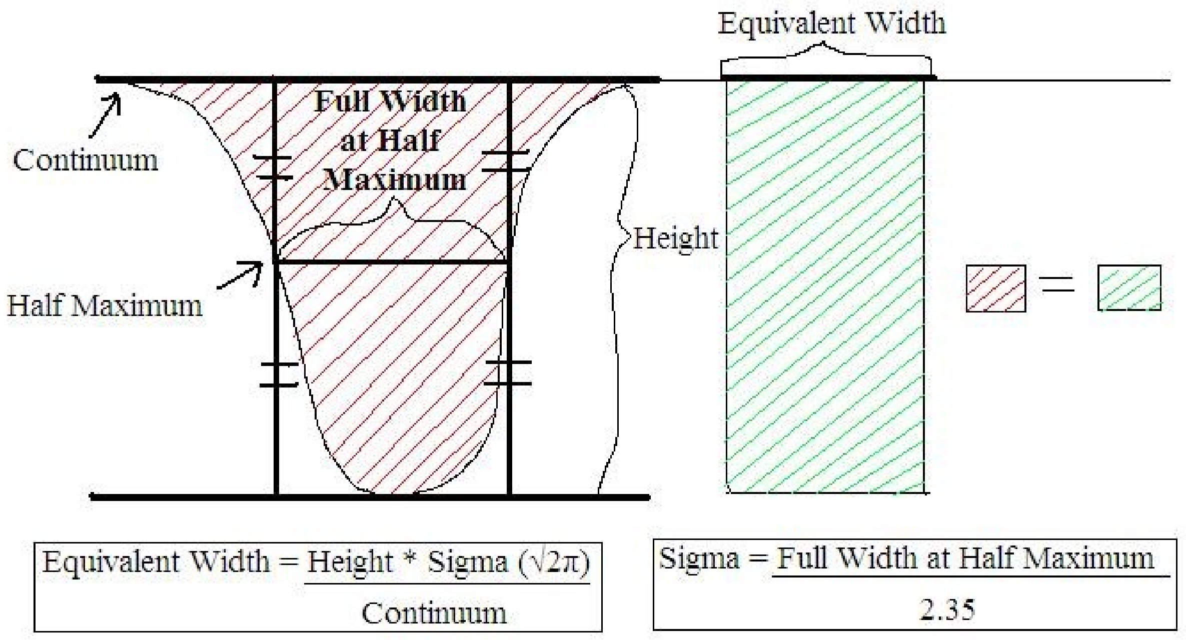


The sector in green is the section of the spectrum Morgan used in his classification

To 900

The SDSS can analyze all of the yellow sector

Equivalent Widths



- Amplitude- distance between vertex and continuum
- FWHM- Full Width at Half Maximum

Methods of Measuring Equivalent Widths

- **Simple Excel Calculation**
- More Complex Excel Template
- IRAF
- All three methods match up with about 10% error margin

Tricks

- If continuum is known and line is near continuum, measuring by hand is fine.
- If line is asymmetrical, measure continuum and amplitude from higher side.
- Line should be symmetrical, so if not measure one side and double FWHM.

Methods of Measuring Equivalent Widths

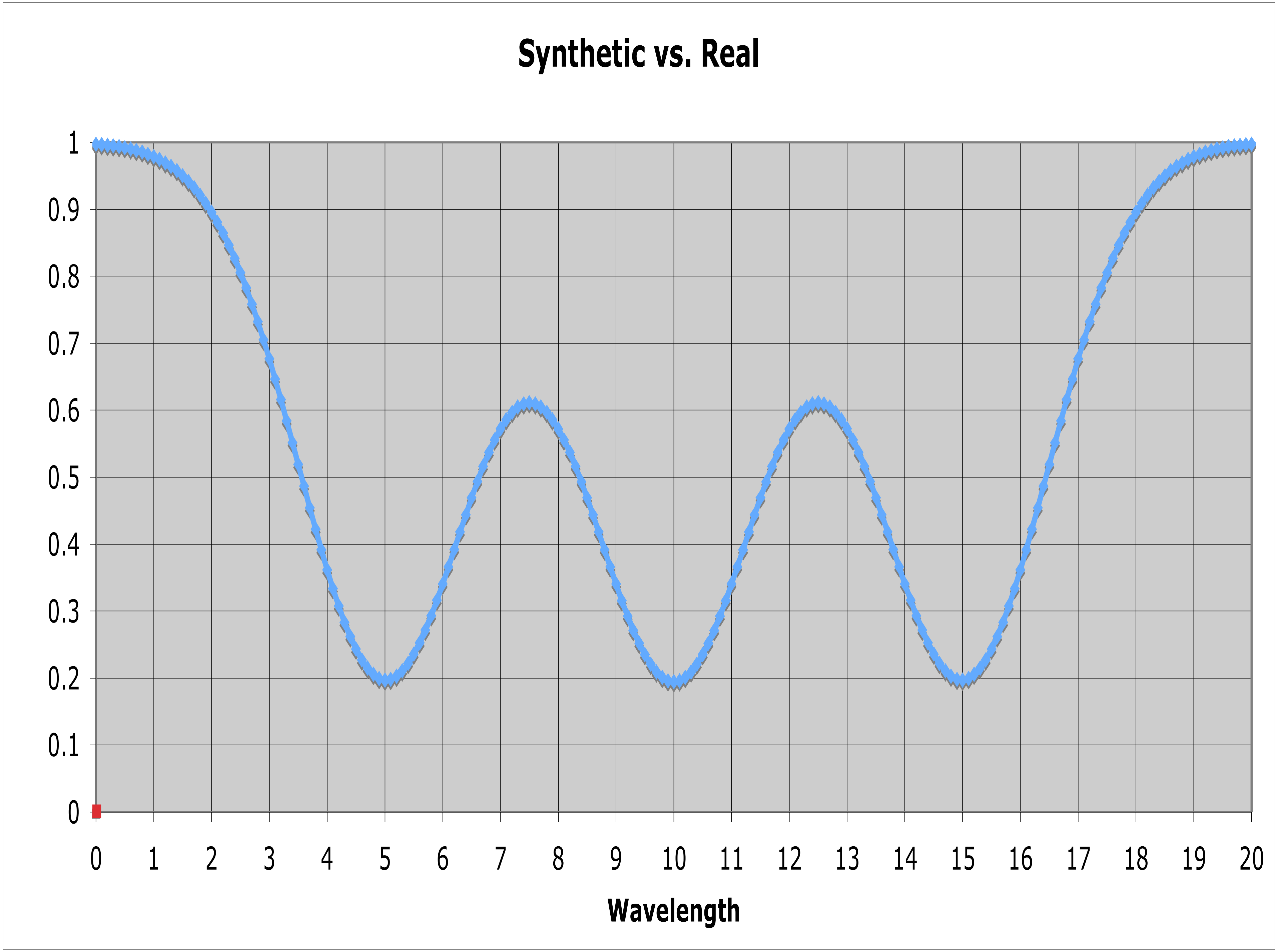
- Simple Excel Calculation
- **More Complex Excel Template**
- IRAF
- All three methods match up with about 10% error margin

What is a template?

- A template is a program I made in excel which helps create a graph that matches the absorption line(s) of a spectrum and calculates the equivalent widths of those lines.
- Templates for matching 1, 2, and 3 absorption lines are available.

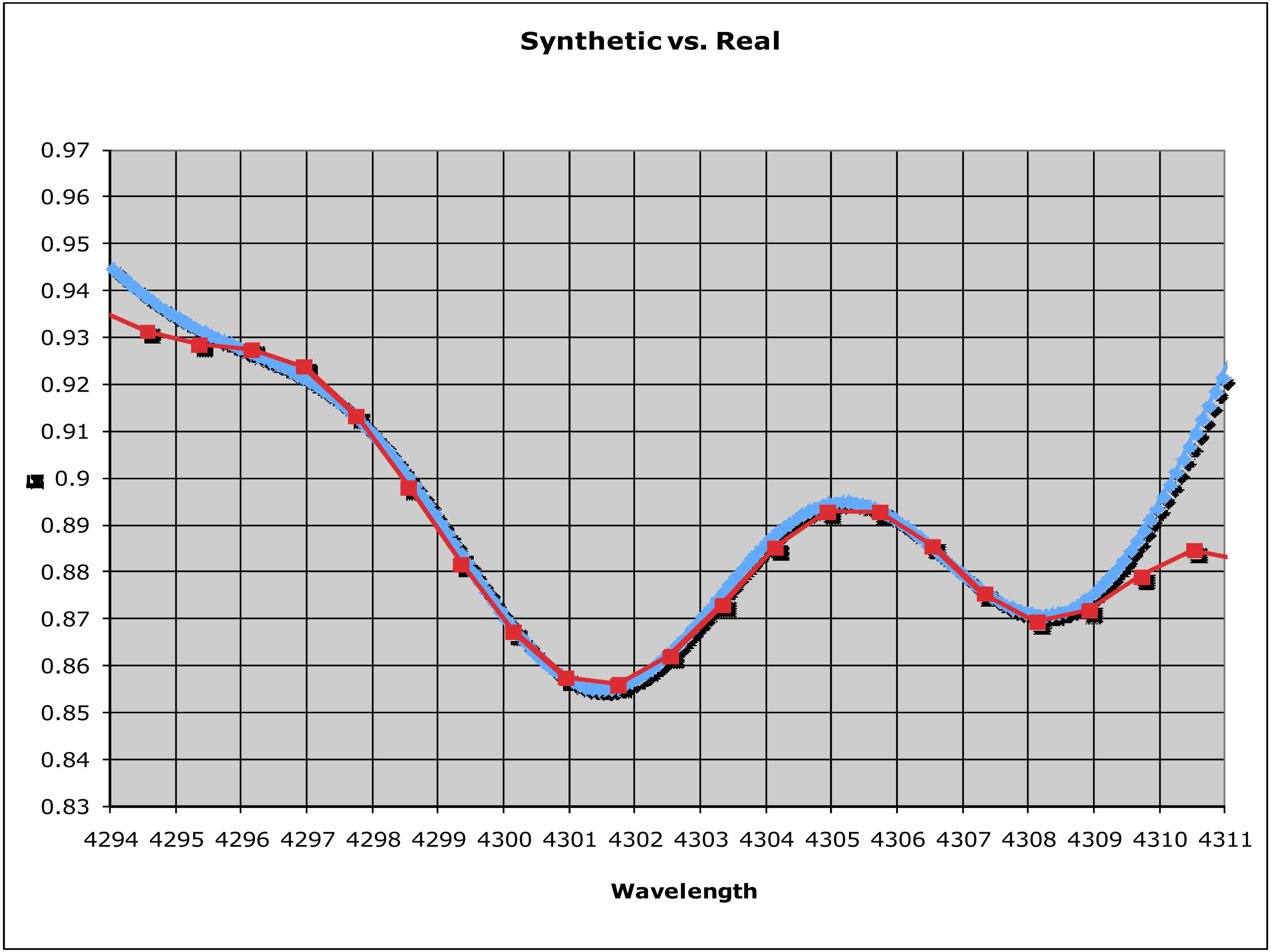
When To Use a Template

- When edges of line are far below continuum
- When there are clear absorption lines on either side of the main line
- Especially when the half-maximum is above the edges


Synthetic vs. Real
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Wavelength

How To Use a Template

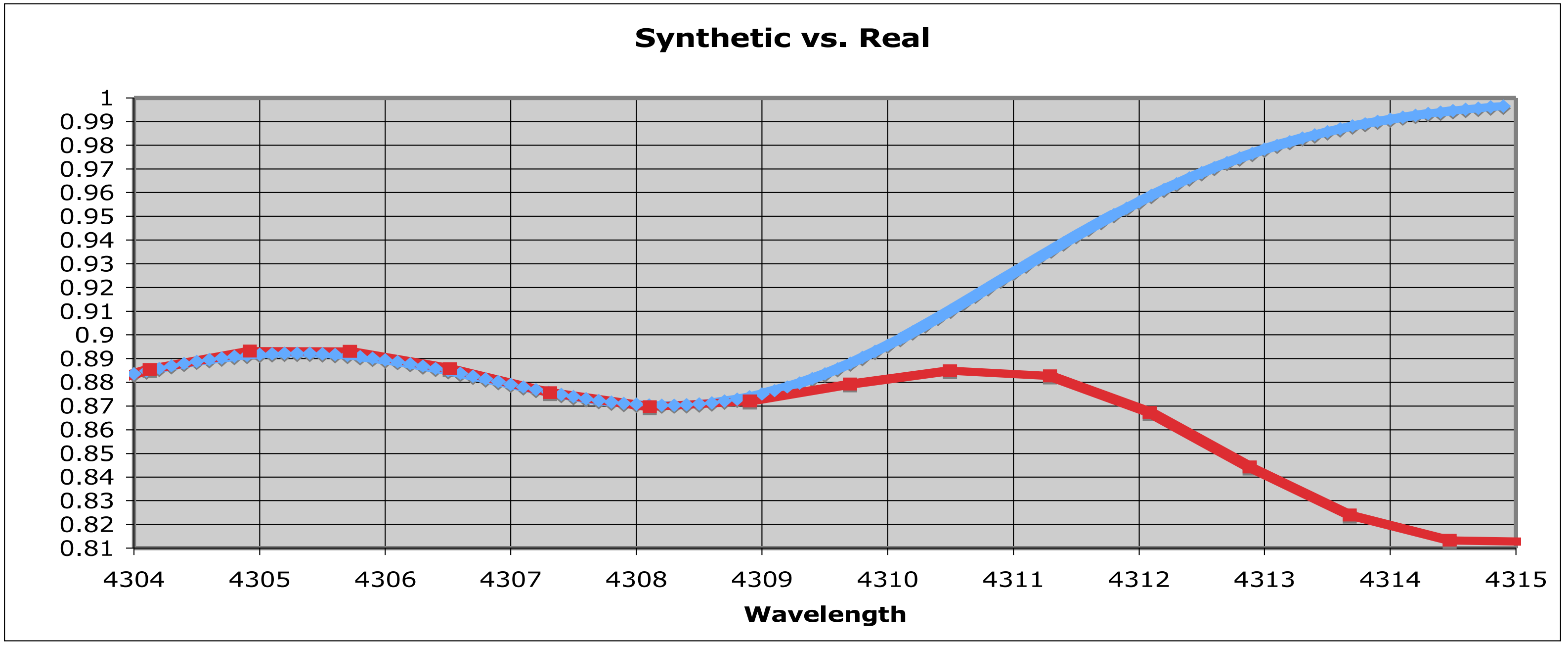
- Copy spectrum data into template file, it will be automatically graphed
- Zoom in on desired line
- Plug in apparent characteristics, it will automatically graph a Gaussian curve with these characteristics in the same plot
- Adjust characteristics to match line(s)
- Record equivalent width of Gaussian curve, which is automatically calculated based on the previously entered characteristics



Synthetic vs. Real
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
0.89
0.88
0.87
0.86
0.85
0.84
0.83
4294 4295 4296 4297 4298 4299 4300 4301 4302 4303 4304 4305 4306 4307 4308 4309 4310 4311
Wavelength

Deviation

- Graph separates at edges.
- Should do this, outside absorption lines not accounted for.

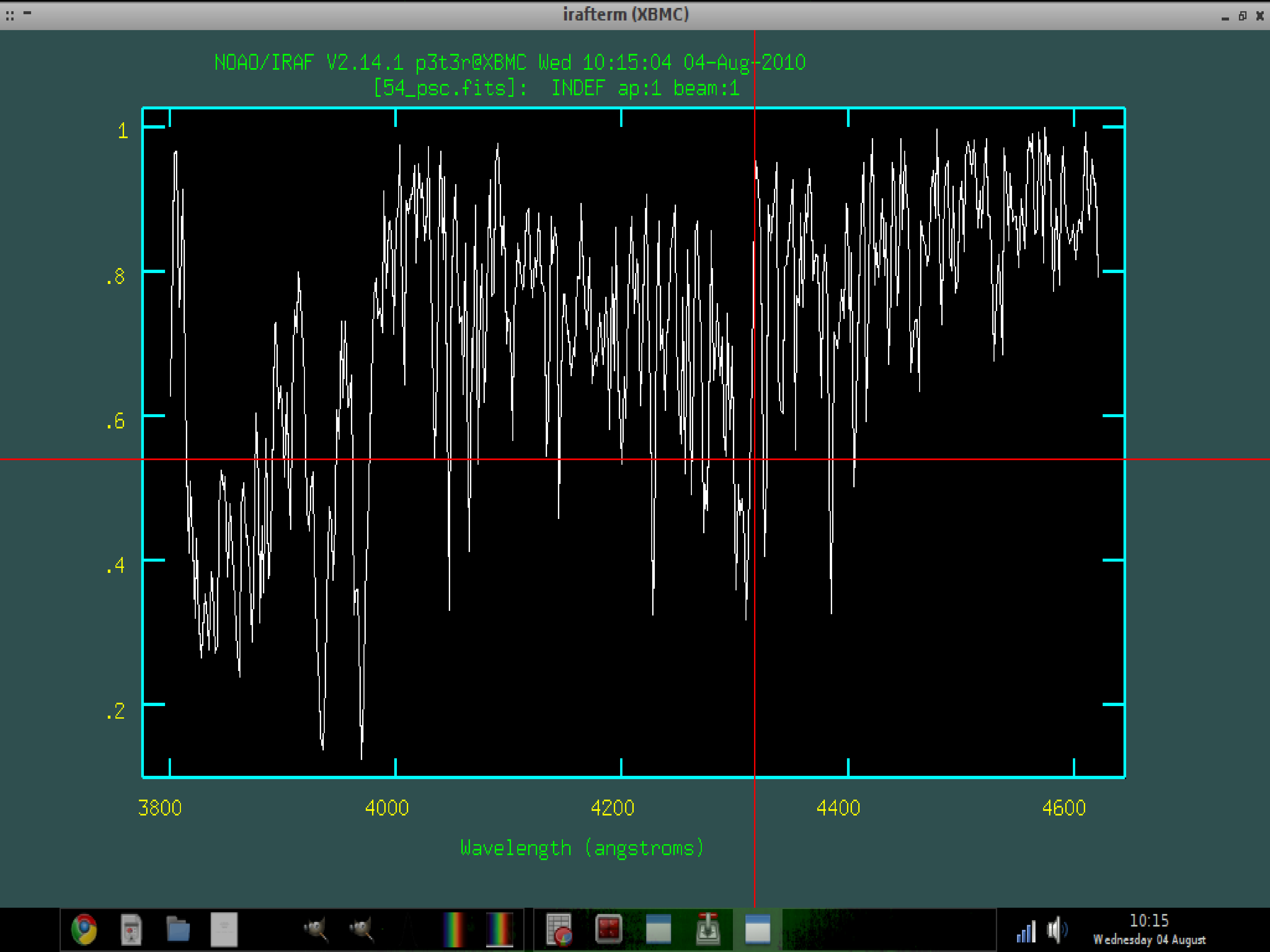


Degrees of Freedom

- What they are: ways to alter graph
- Too many leads to less accuracy
- Solutions:
  - Give all Gaussians same continuum
  - Give all Gaussians same FWHM
- Reduces from 12 to 8 parameters

Methods of Measuring Equivalent Widths

- Simple Excel Calculation
- More Complex Excel Template
- **IRAF**
- All three methods match up with about 10% error margin

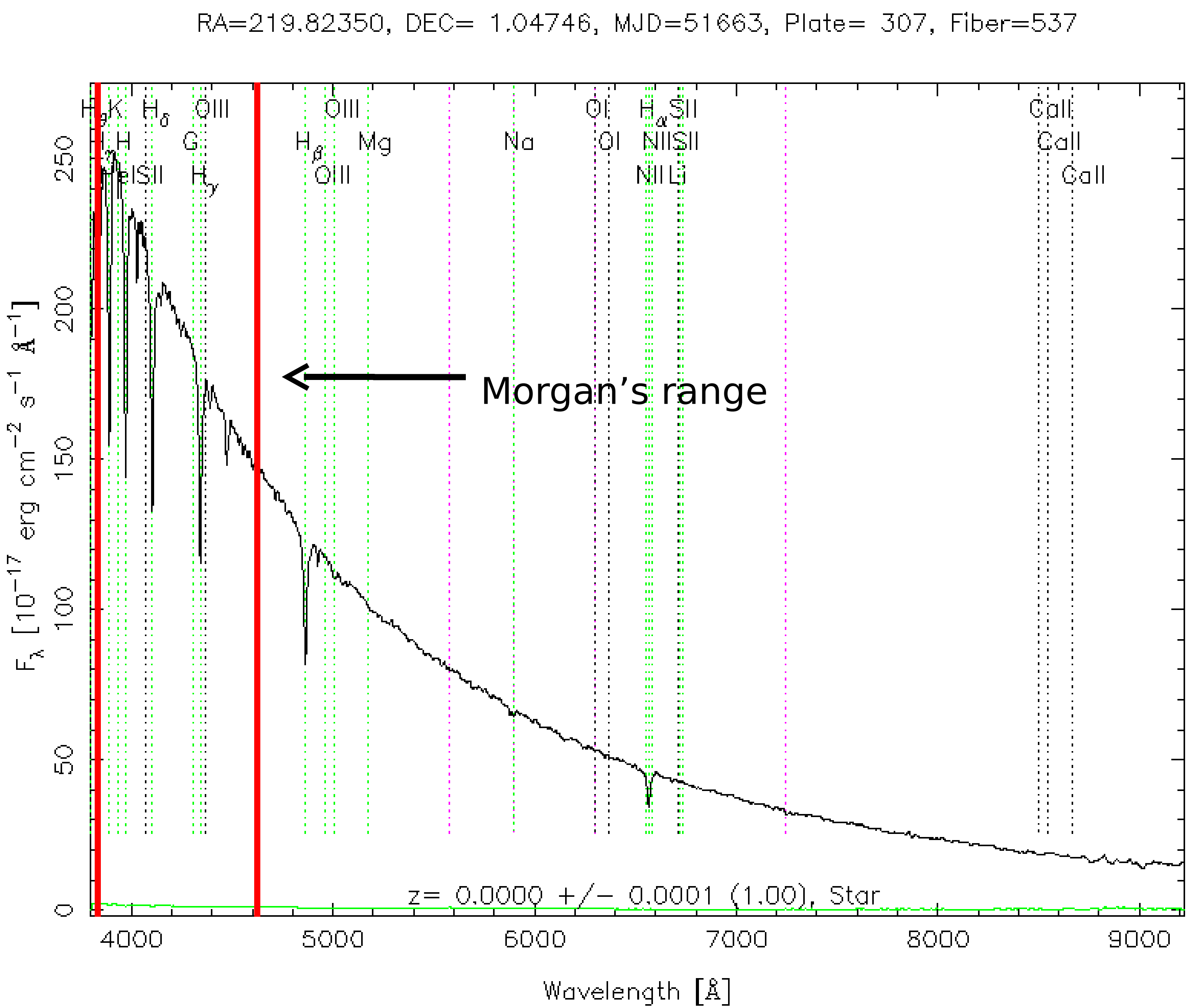

irafterm (XBMC)
NOAO/IRAF V2.14.1 p3t3r@XBMC Wed 10:15:04 04-Aug-2010
[54_psc.fits]: INDEF ap:1 beam:1
1
.8
.6
.4
.2
3800
4000
4200
4400
4600
Wavelength (angstroms)
10:15
Wednesday 04 August

SDSS’s System

- System gives equivalent width of line and error.
- Error correlates with signal-noise ratio
- Enormous amount of data
  - Not every line can be measured
- Much of data has low signal-noise, resulting in inaccurate measurements
  - Can be solved by ignoring spectra with high error

O and B stars

- Hottest Stars
  - O: > 30,000 K
  - B: 10,000 K to 30,000K
- Extremely Luminous
  - O: > 30,000 L
  - B: 25 to



RA=219.82350, DEC= 1.04746, MJD=51663, Plate= 307, Fiber=537
Morgan's range
z= 0.0000 +/- 0.0001 (1.00), Star
Wavelength [Å]
F_λ [10^-17 erg cm^-2 s^-1 Å^-1]
K
H
G
OIII
Mg
Na
OI
SII
NII
Li
CaII
4000
5000
6000
7000
8000
9000
0
50
100
150
200
250

Spectral Classification of O stars

“If the spectral types of the O stars are determined from the single ratio of the absorption lines He i 4471: He ii 4541, results accurate to a tenth of a class between O5 and O9 can be obtained”

Spectral Classification of B Stars

- Two ratios
  - He I : K
  - K : Ti I + C II
- He I: K is generally more useful.
  - MKK: “The line He i 4026 is weaker relative to K than in class B8.”
- K: Ti I + CII is more useful for cooler subclasses.

He I : K

K : Ti I + C II

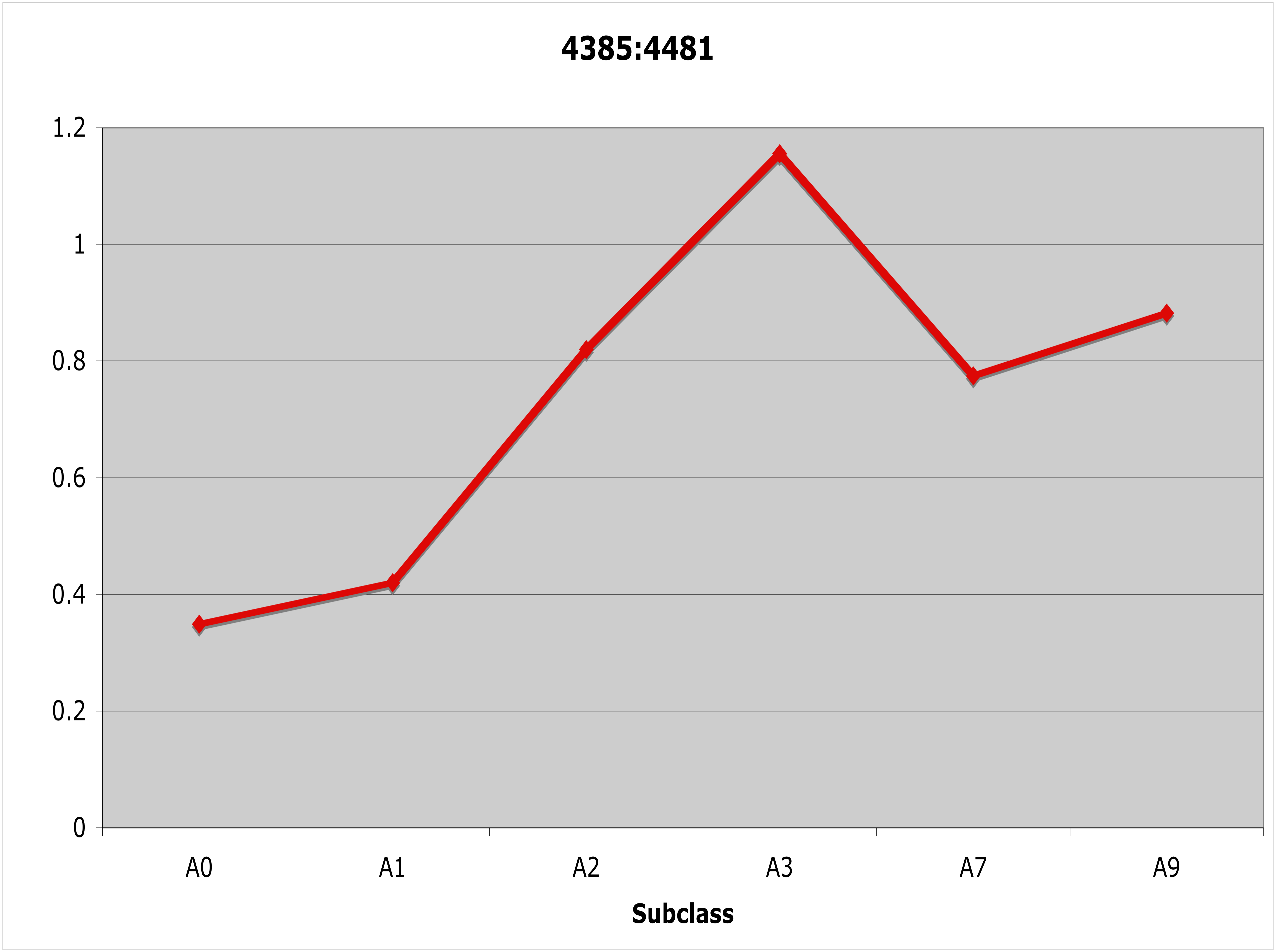

10
9
8
7
6
5
4
3
2
1
0

Comparison of Ratios

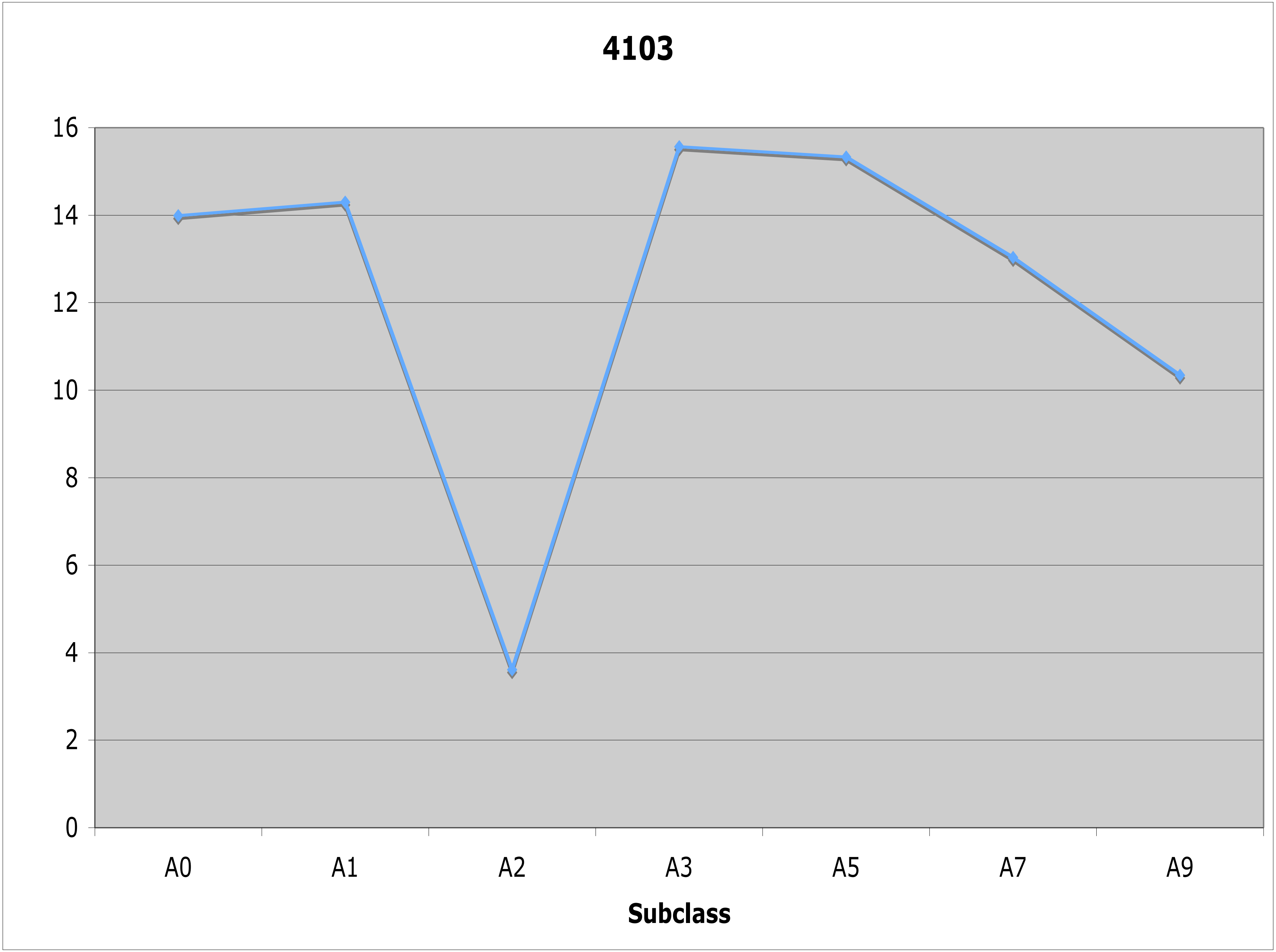
‘A’ Stars

- 1.4 to 2.1 solar masses
- 7,600˚ to 10,000˚ Kelvin surface temperature
- Sirius is an A1V
- True color white, apparent color changes with red-shift


Luminosity: 0,00249x Sun
Class: DA2
Apparent diameter: 1° 25' 54,8"
Surface temp: 25.200 K
Radius: 0,00 Rsun
Rotation period: 30,000 minutes
Speed: 0,00000 m/s
Follow Sirius B
FOV: 6° 27' 38,5" (5,79×)



4385:4481
1.2
1
0.8
0.6
0.4
0.2
0
A0
A1
A2
A3
A7
A9
Subclass


4103
16
14
12
10
8
6
4
2
0
A0
A1
A2
A3
A5
A7
A9
Subclass

Trends Confirmed

- 4385:4481 increases with subclass number to an extent
- 4103 decreases from A0 to A9

Problems

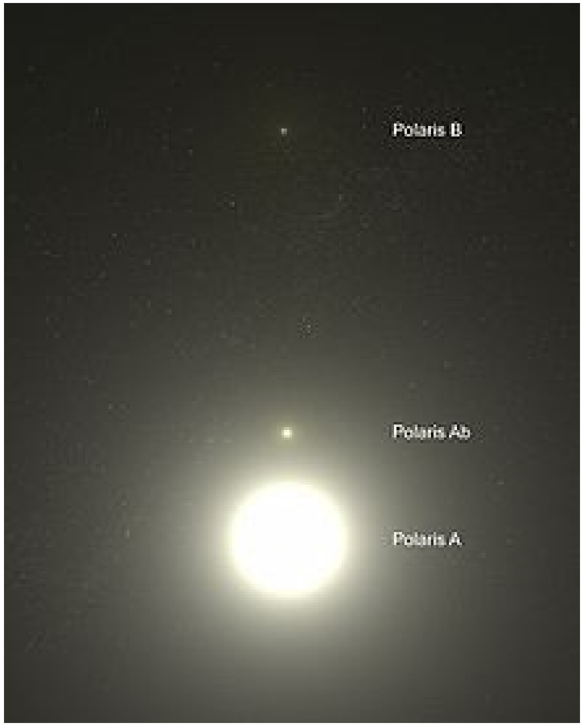
- No trend beyond A3 for 4385:4481
- Barely any trend for 4103
- Only line measured by SDSS related to A stars is 4103

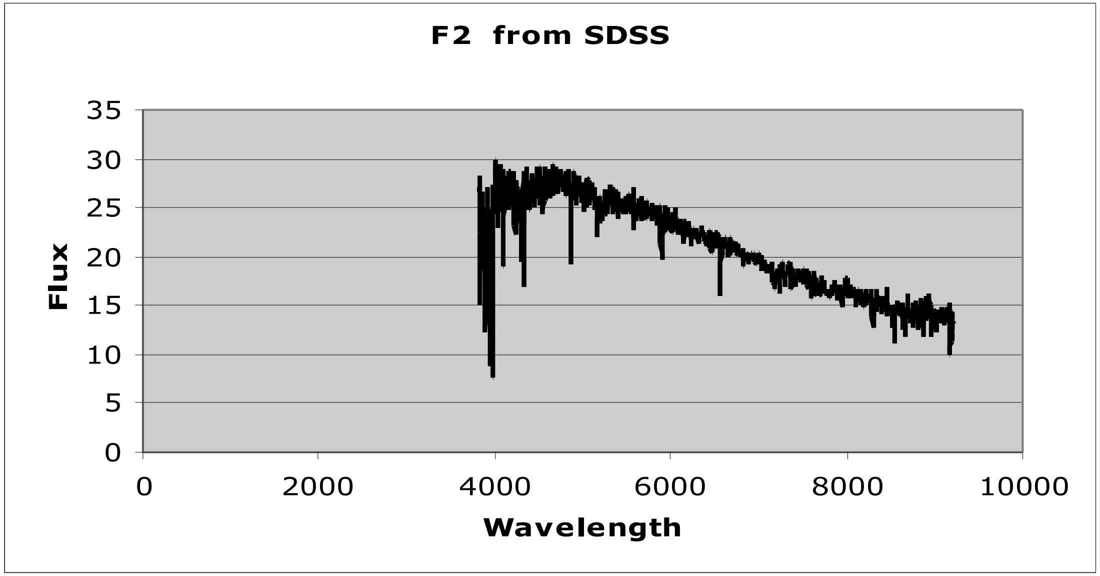
Findings

- Ratios of absorption lines can be used to create an automated spectral classification system, but accuracy will be a problem, and some human supervision will be necessary.

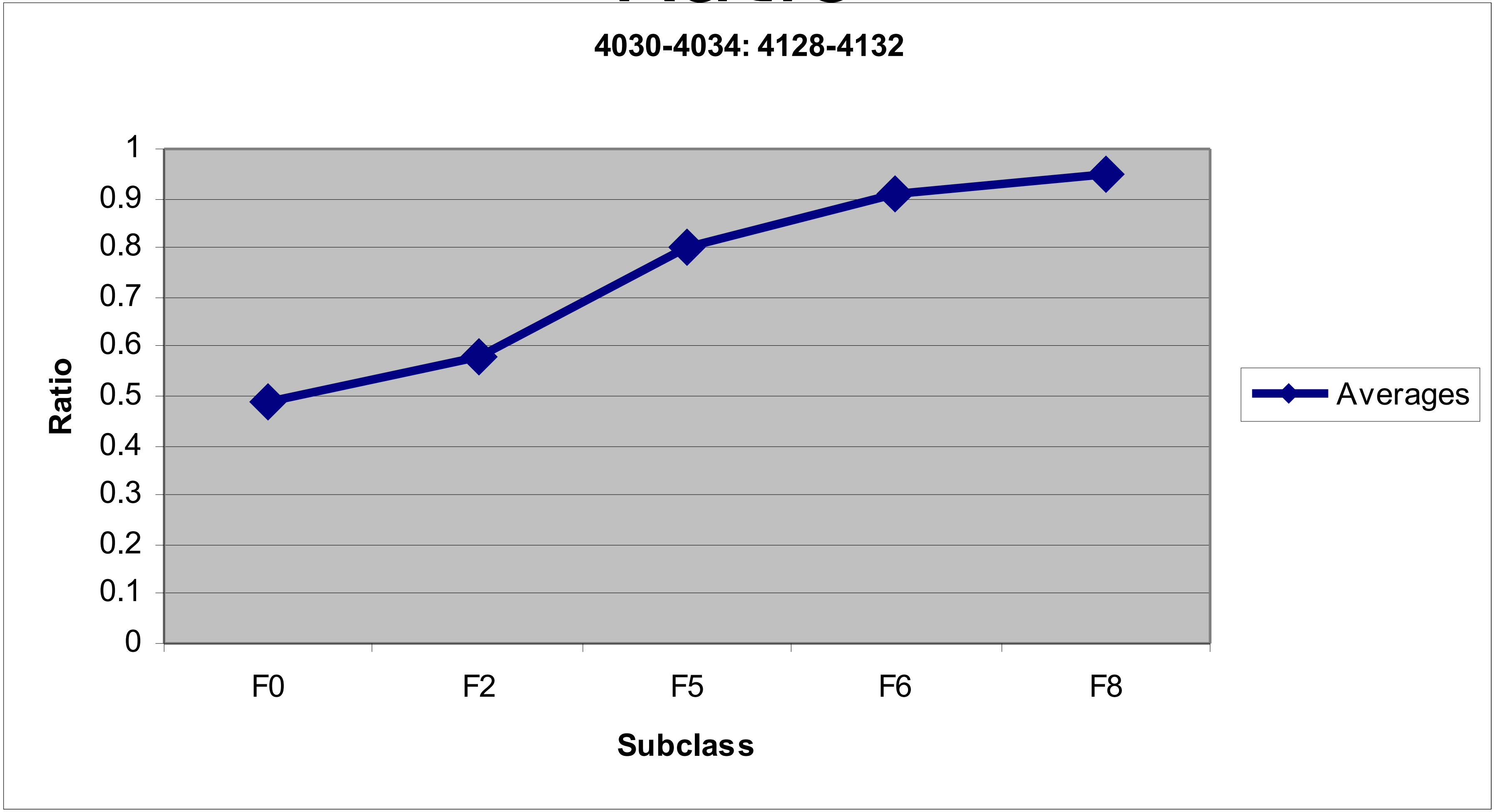
F stars

- OBAFGKM – middle temperature
- 6000 – 7500 Kelvin
- Yellowish White
- 1 in 33 in neighborhood





Classifying Spectral Type: Ratio



Standards

Classifying Spectral Type: Ratio

F9 Stars

- Not in MKK Standards
- Ratios
  - 4328: 4385 Ratio (average) 1.24
  - 4033: Hydrogen Delta Ratio 0.54
  - 4436: 4370 Ratio 1.92
- Tested with SDSS
  - F9: Ratios *did* match
  - F5: Ratios *did* match
  - F2: Ratios *did not* match

Classifying Spectral Type: Other Factors

24 F5

The G band is observed as a broad absorption with the violet part of the band somewhat stronger than the red edge. *Fe* I 4045 and λ 4226 are very much weaker than Hγ and Hδ.

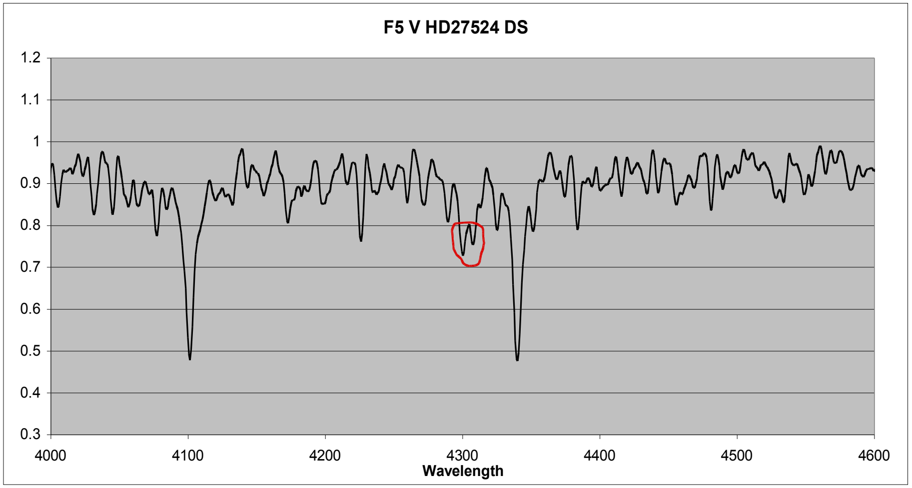
Iron I Calcium I

Classifying Spectral Type: Other Factors

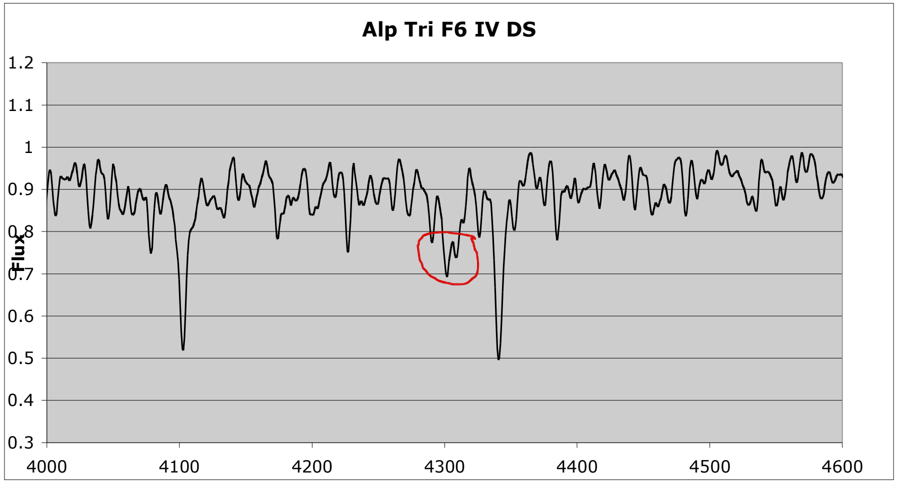
25 F6

The G band is slightly stronger than at class F5.

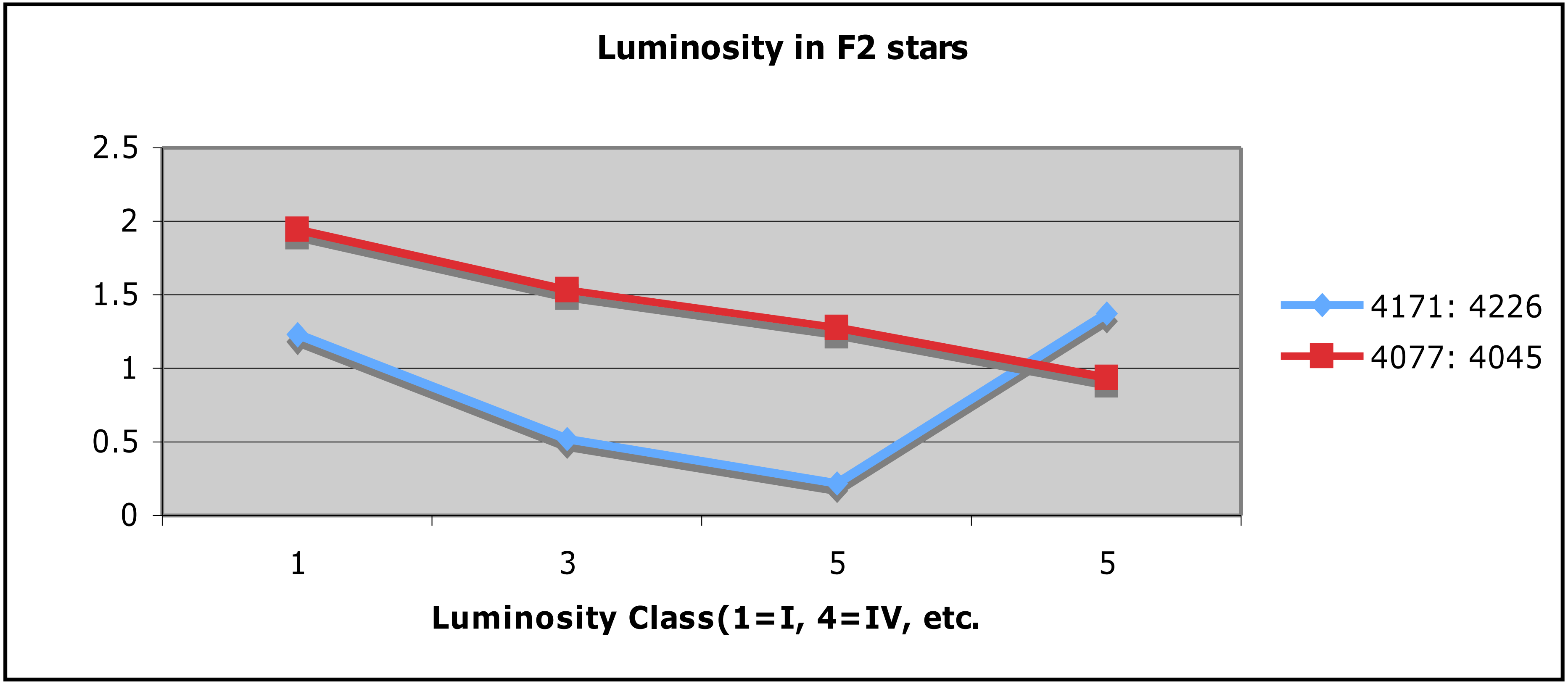
F5



F6

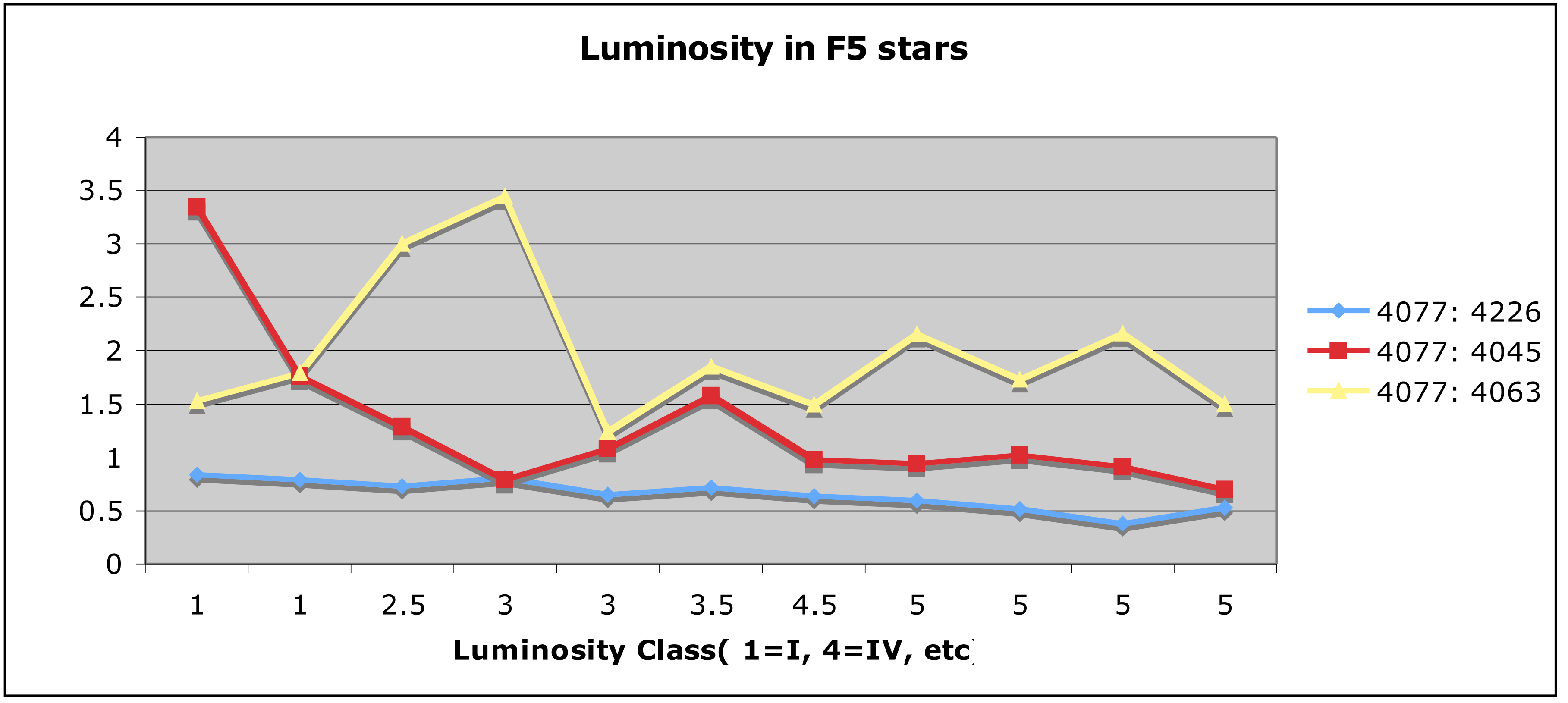


Luminosity



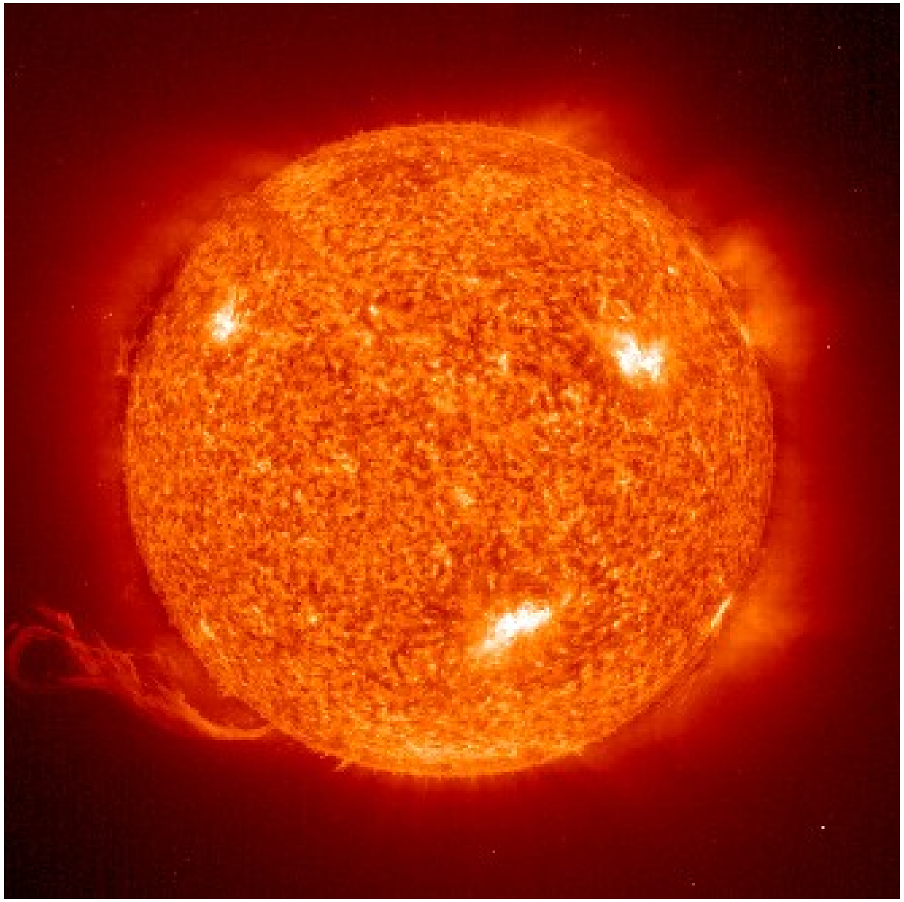
At Strontium II: Iron I as the luminosity class increases, the equivalent width ratio decreases.

Luminosity



At Strontium II: Iron I, as the luminosity class increases, the equivalent width ratio generally decreases

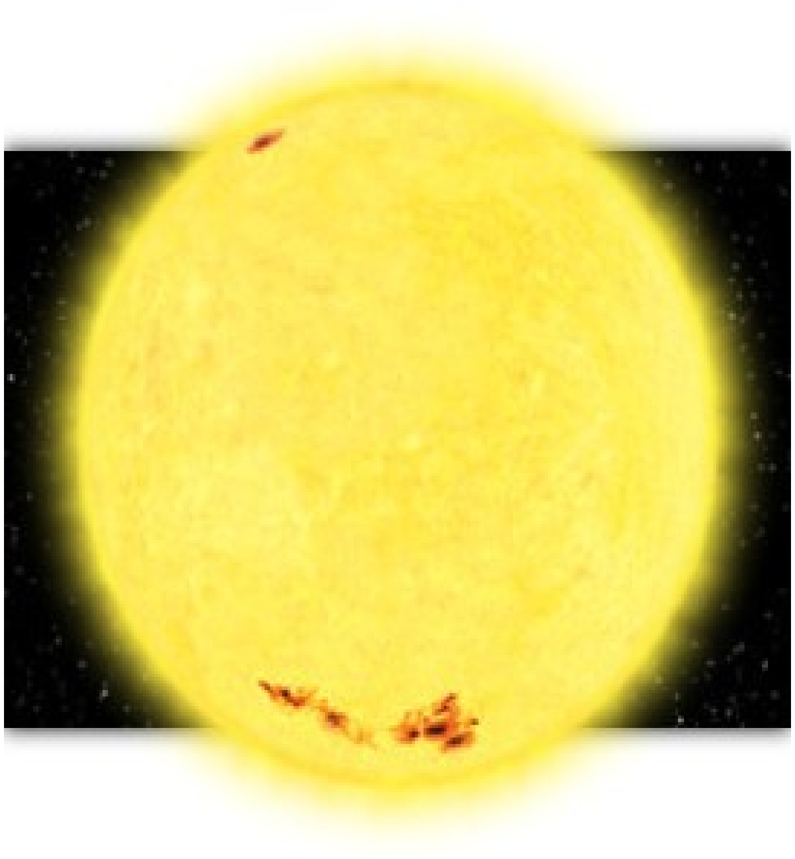
G Stars



Emily Setchell

Background Information

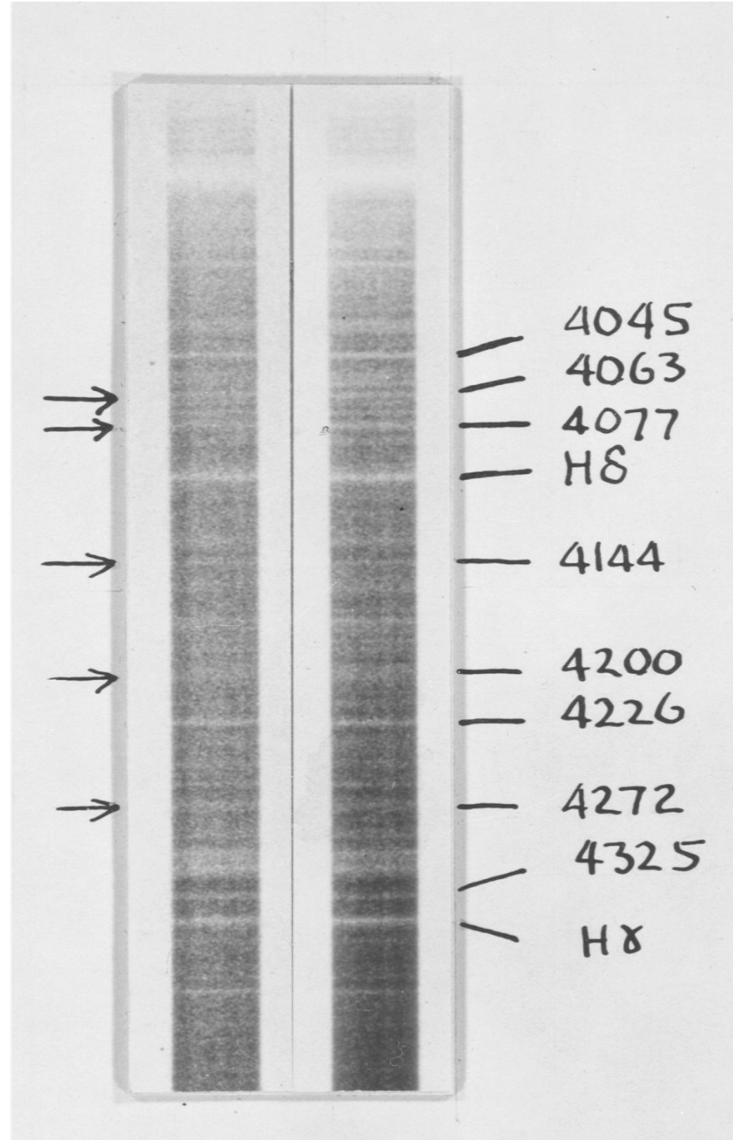
- Yellow stars
- 5000 to 6000 K
- Make up 7.7% of stars
- 10 billion years
- Neutral and ionized metals, especially calcium
- Our SUN!



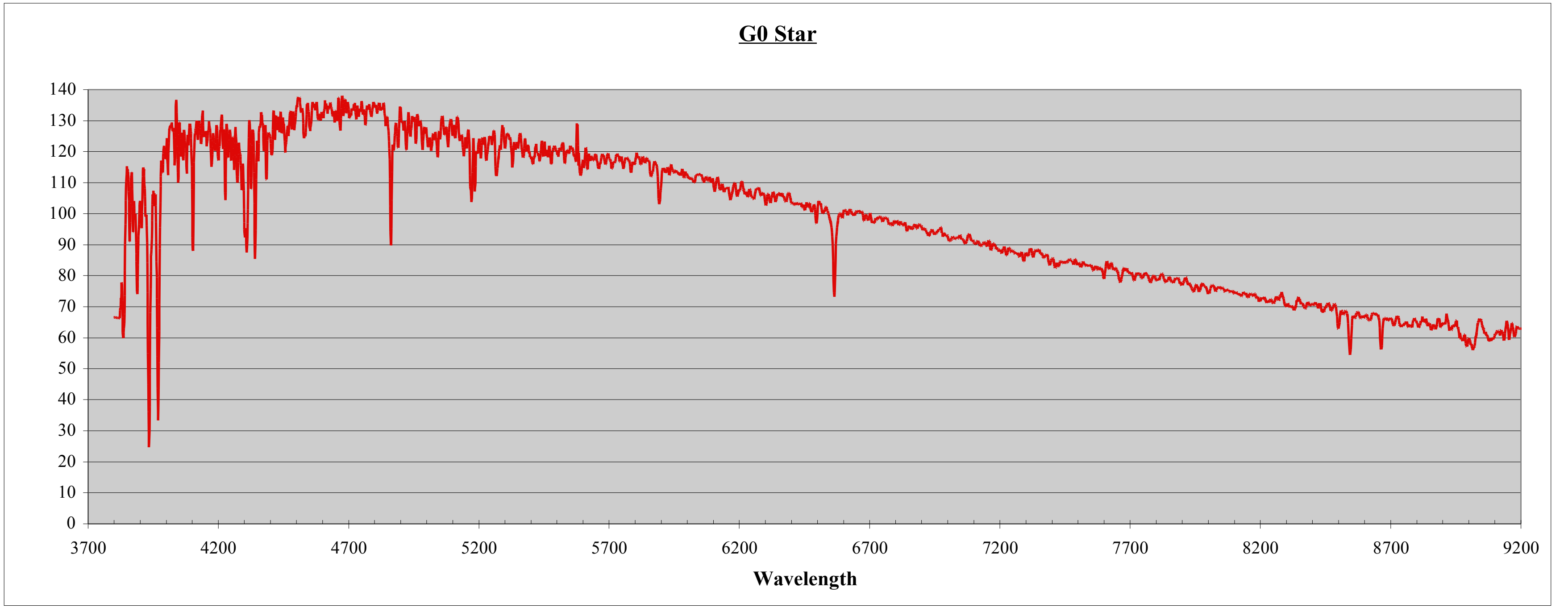
The Mkk Book

Important Lines for G Stars

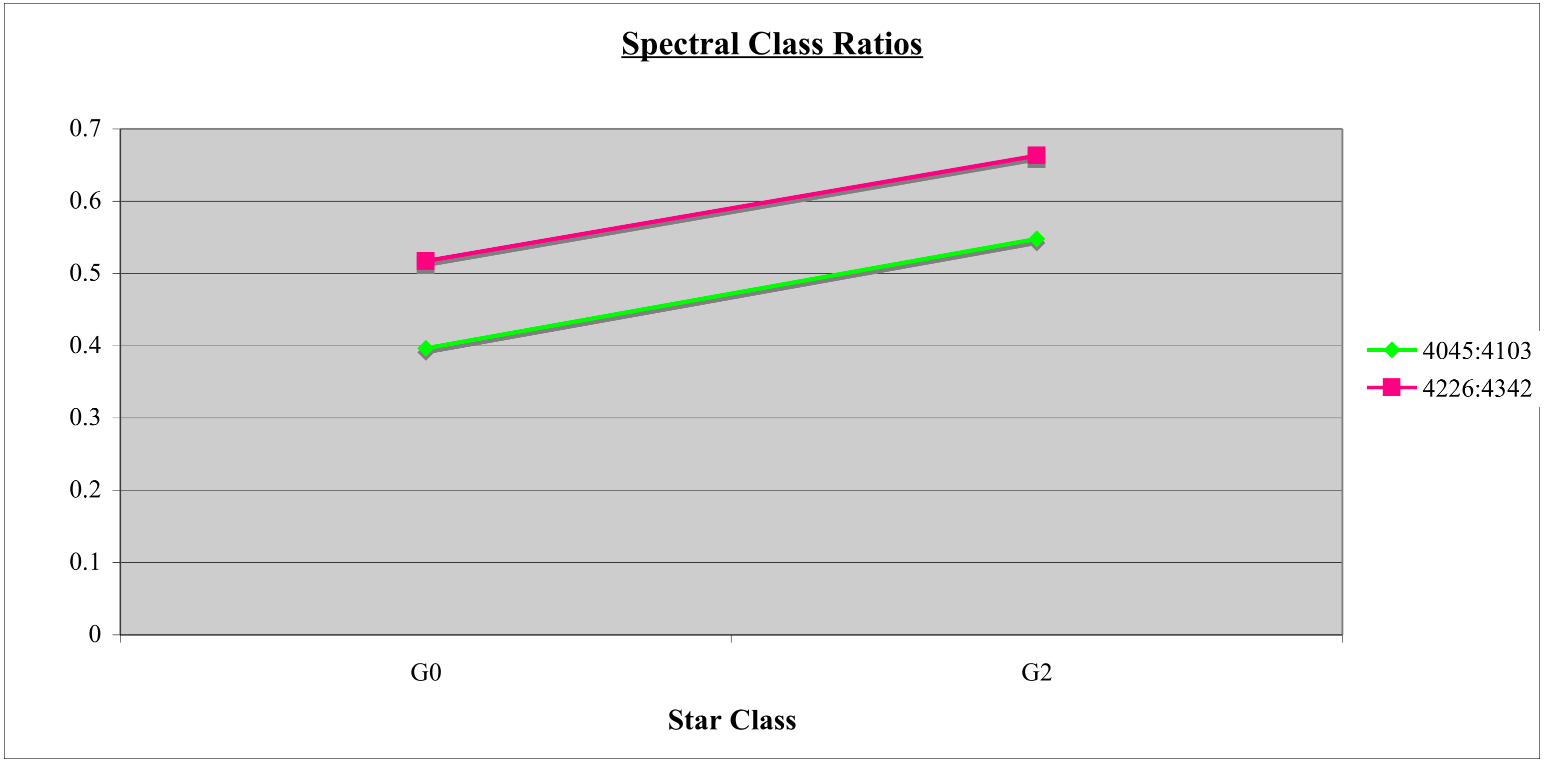
- Hδ = 4103
- Hγ = 4342
- 4226 = Ca I
- 4045 = Fe I
- 4077 = Sr II
- 4144 = He I
- 4063
- 4096



Classifying Each Spectral Type

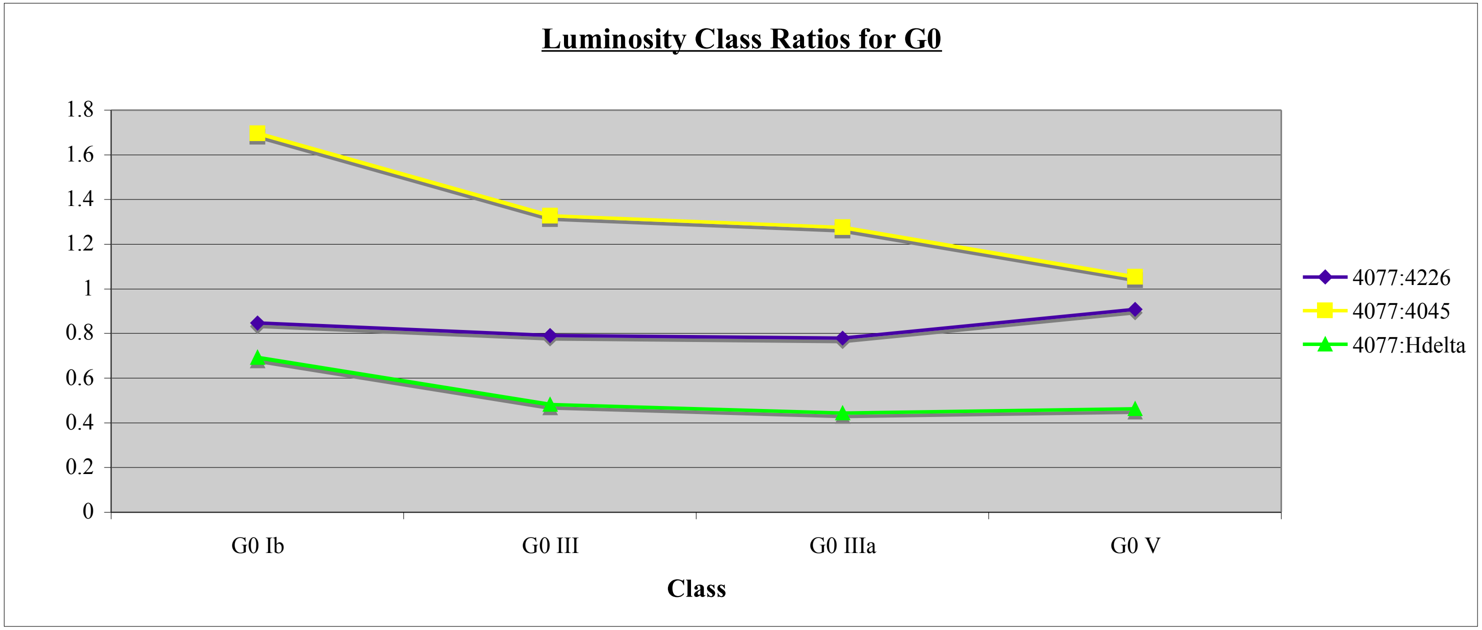


G0 and G2



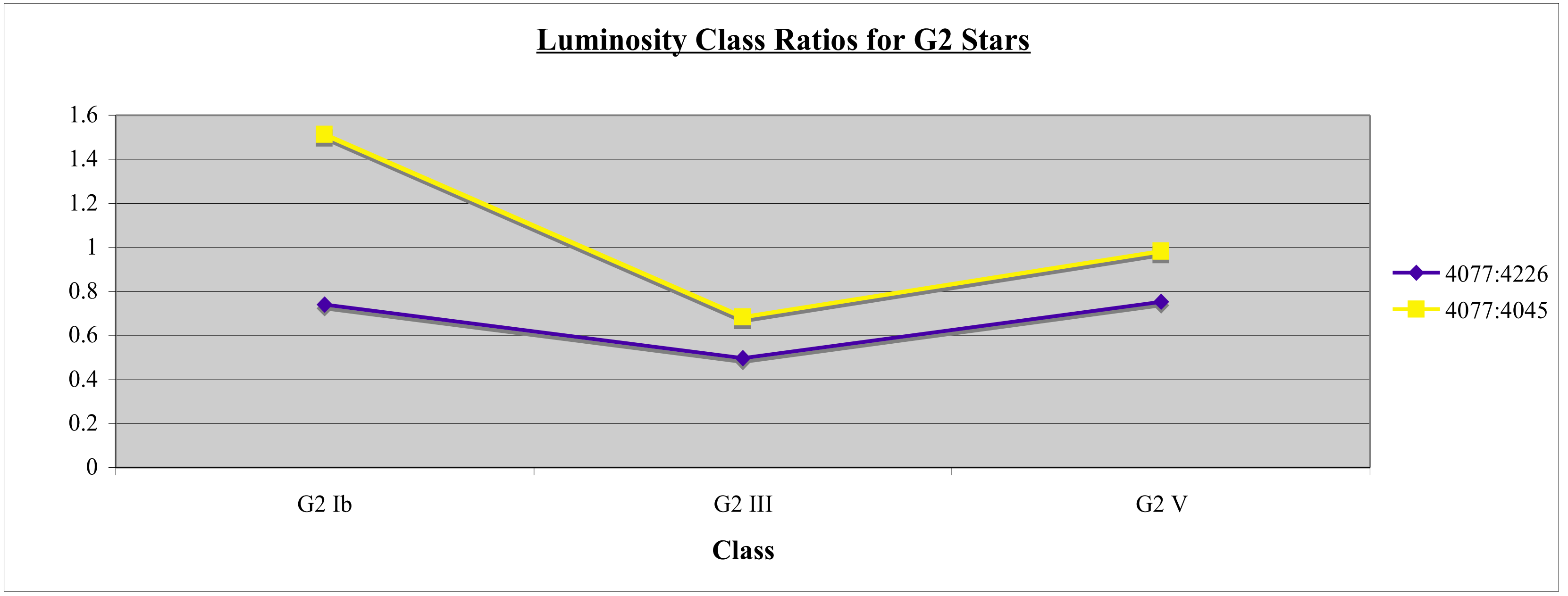
	G0	G2
4045:H□	0.39621 ± 0.07198	0.54770 ± 0.09292
4226:H□	0.51749 ± 0.06090	0.66351 ± 0.08834

G0



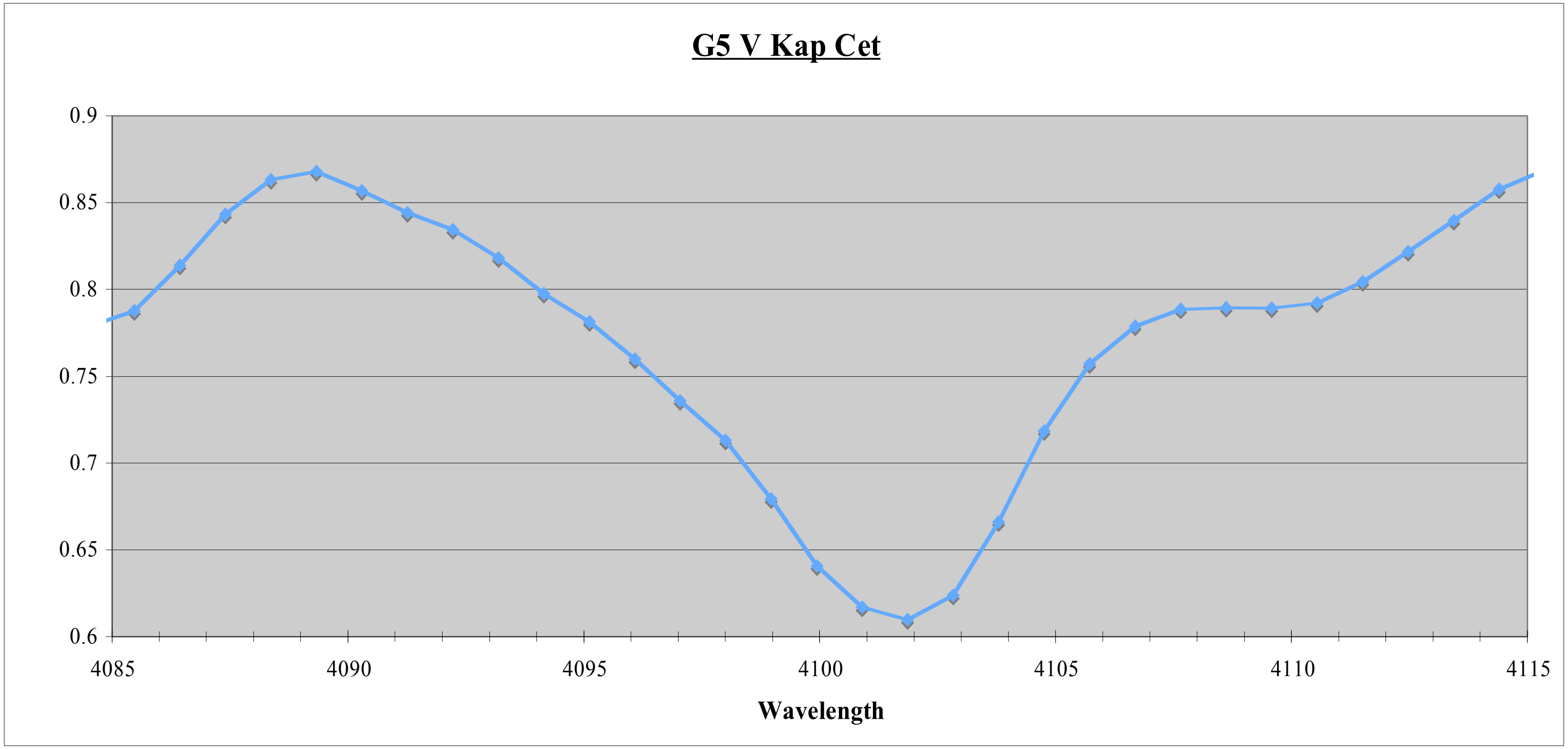
	4077:4226	4077:4045	4077:H*
Ib	0.84647	1.69581	0.69204
III	0.79132	1.30447	0.48165
IIIa	0.77880	1.27613	0.44281
V	0.90826	1.05421	0.46260

G2



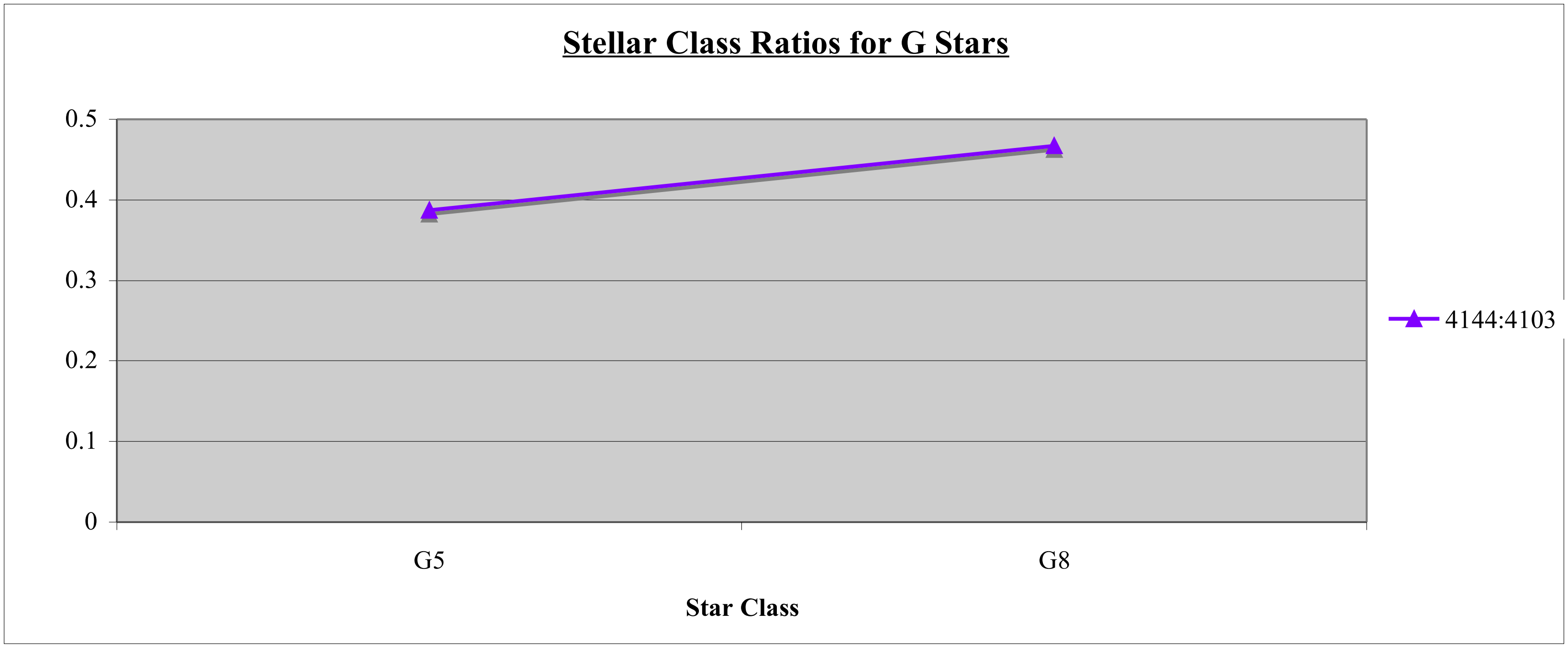
	4077:4226	4077:4045
Ib	0.74033	1.51287
III	0.62918	0.68286
V	0.75266	0.98220

G5 and G8



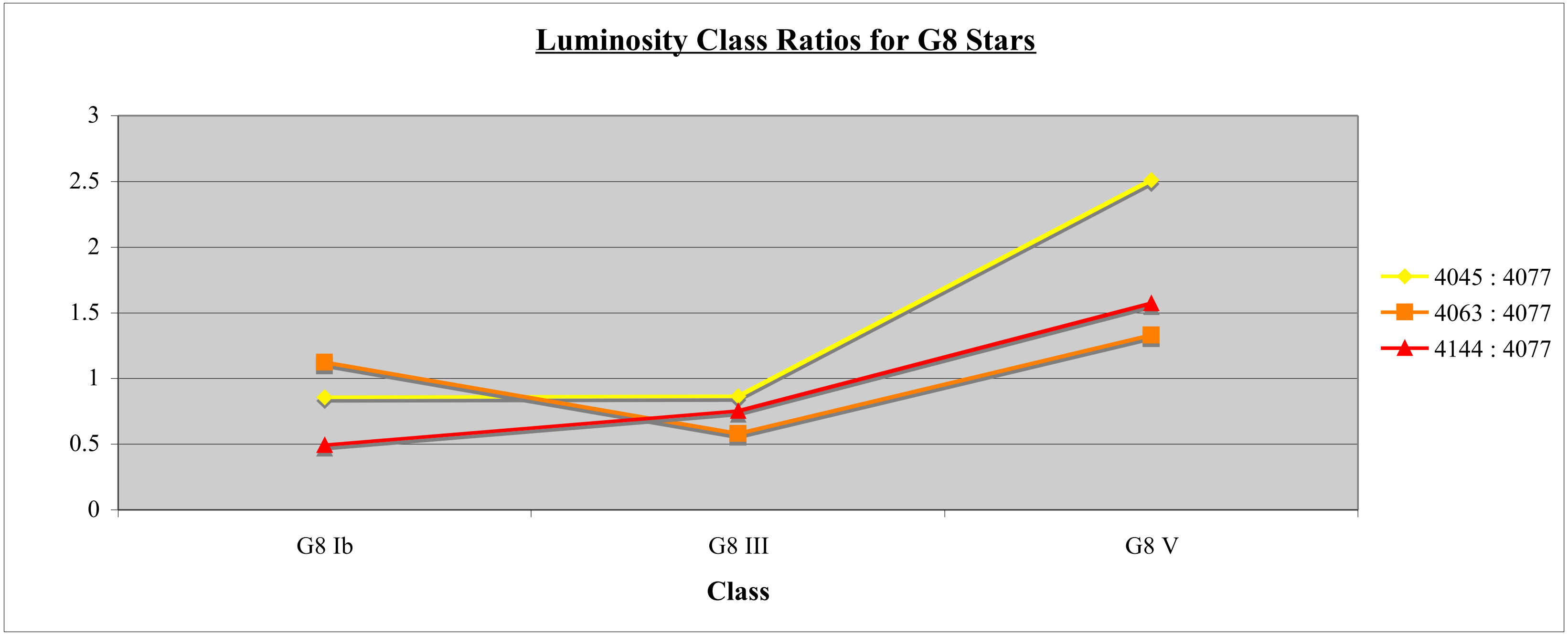
4096:H

G5 and G8

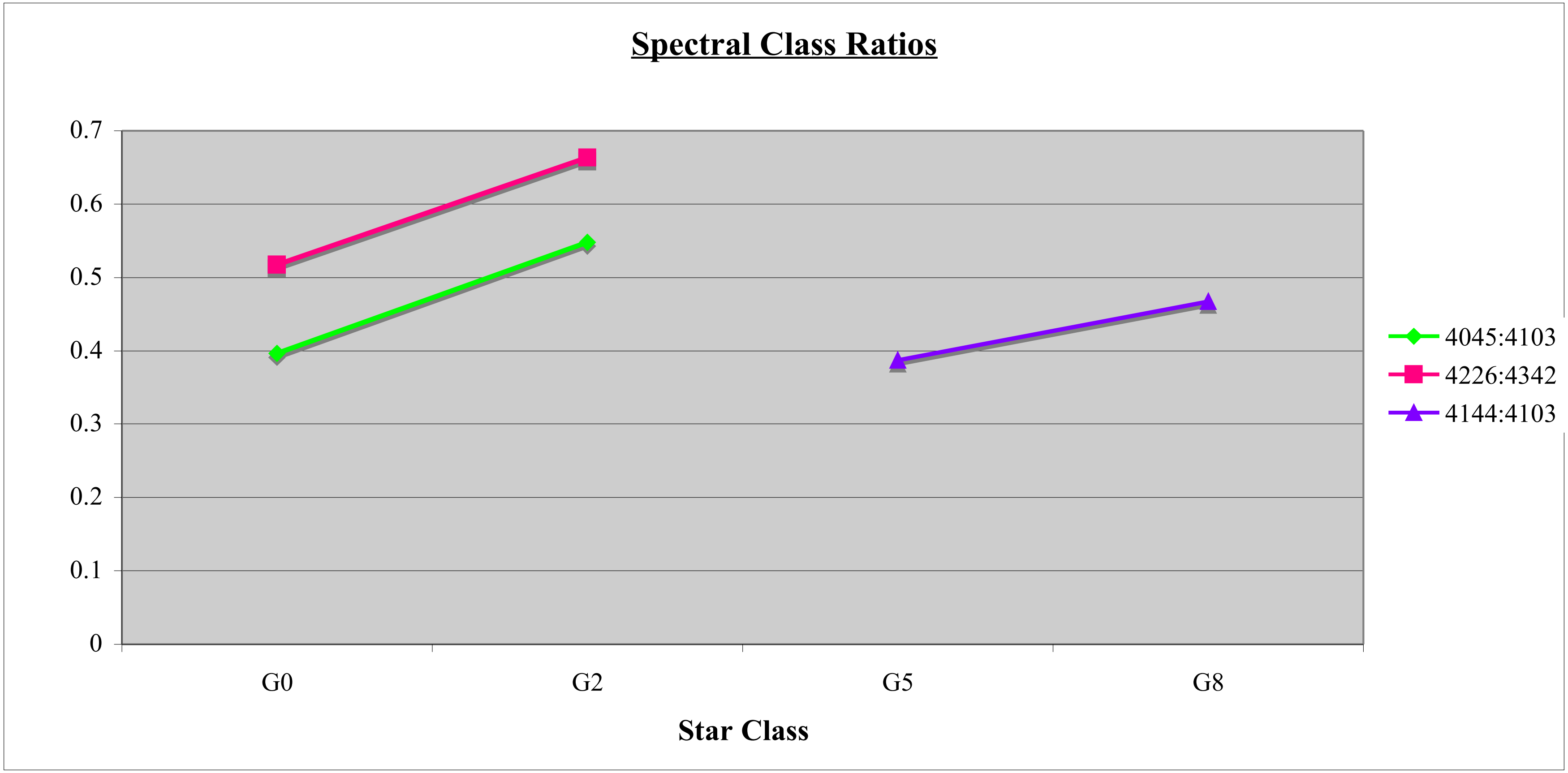


	G5	G8
4144:H	0.38713 ± .11565	0.46733 ± 0.09137

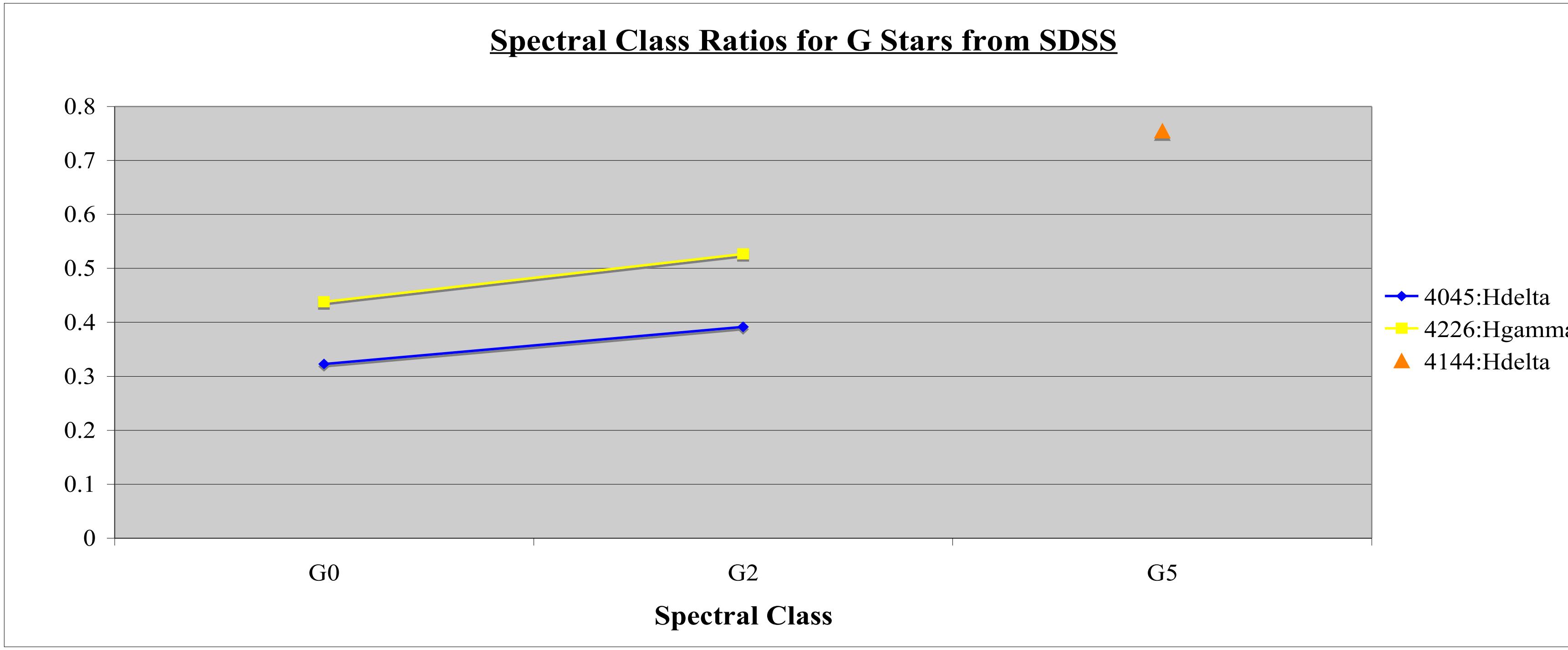
G8



	4045:4077	4063:4077	4144:4077
Ib	0.85870	1.12322	0.49186
III	0.86368	0.58018	0.75122
V	2.50934	1.33102	1.57130


Spectral Class Ratios
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
G0
G2
G5
G8
Star Class
4045:4103
4226:4342
4144:4103

SDSS Data

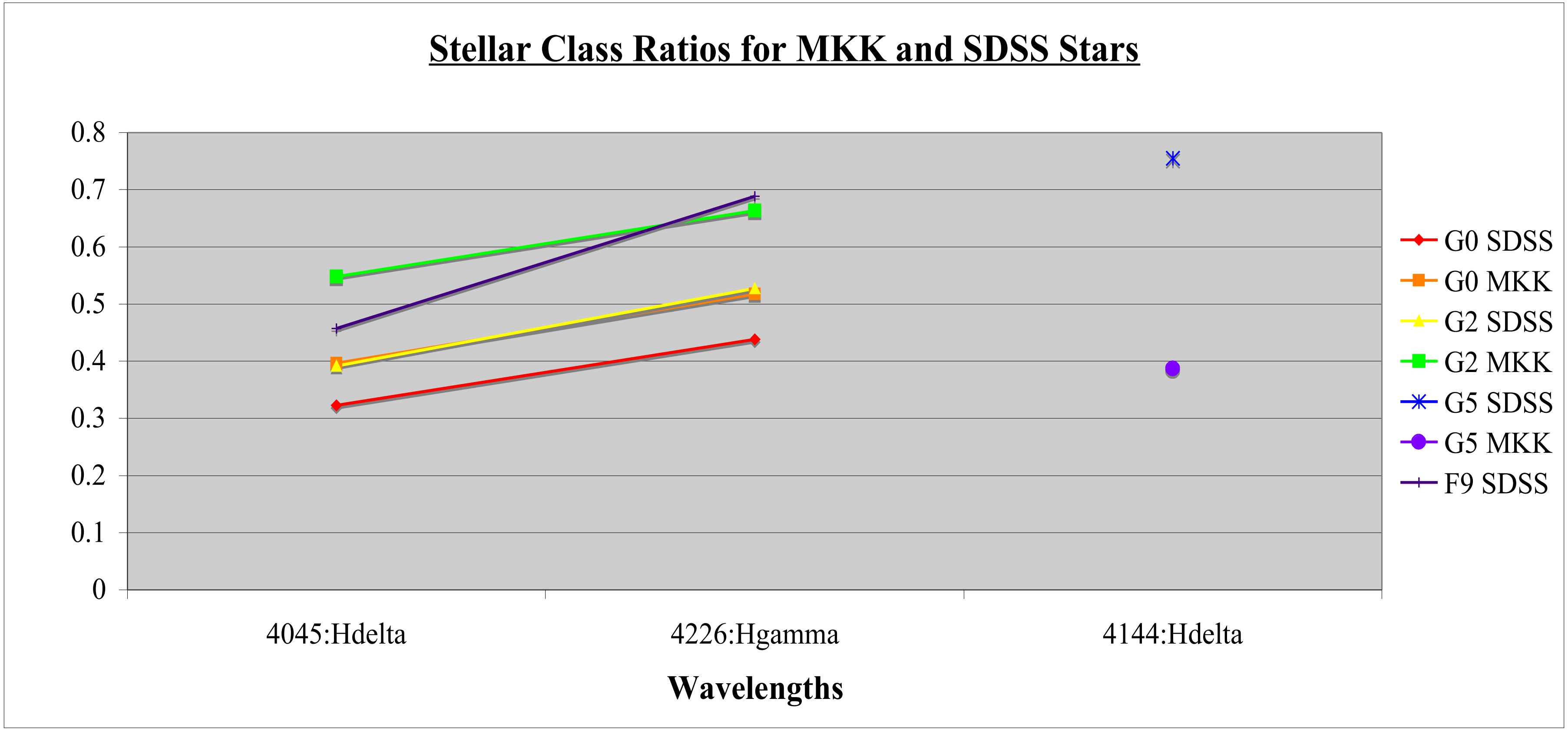


G0 G2 G5

4045:H□ 0.32277 □ 0.17096 0.39159 □ 0.14826

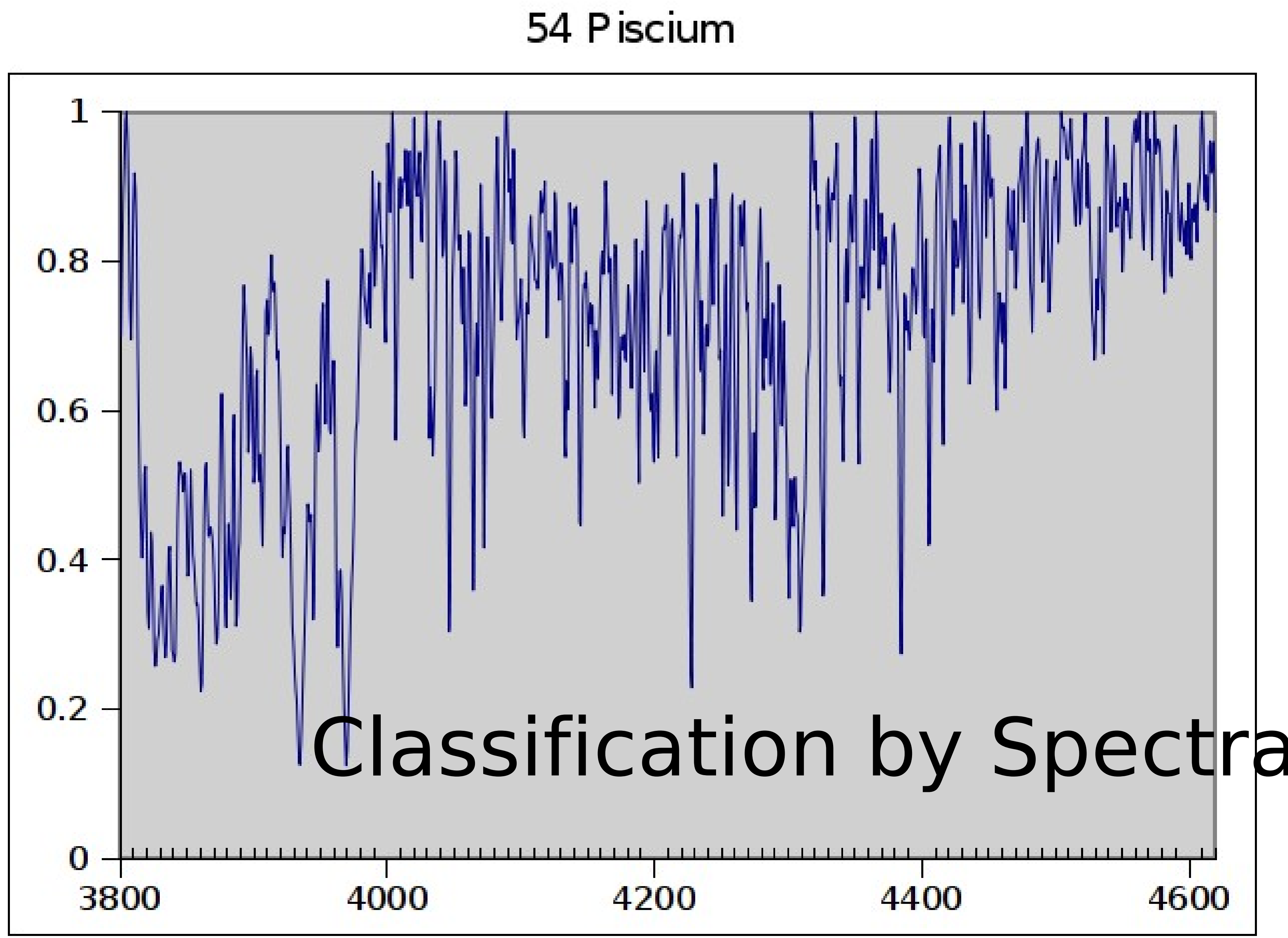
4226:H□ 0.43798 □ 0.124797 0.52698 □ 0.08962

4144:H□ 0.75460 □ 0.38826



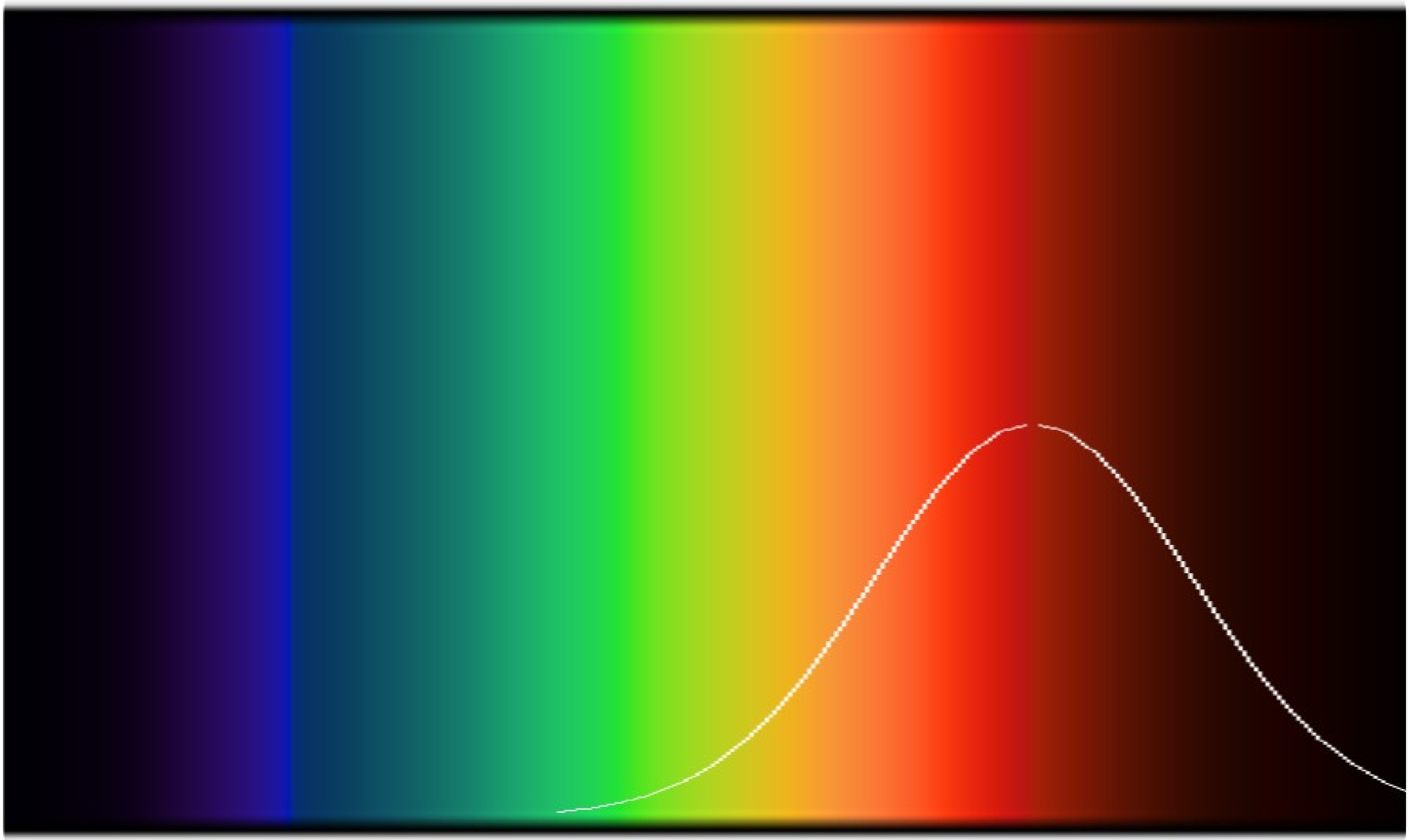
Stellar Class Ratios for MKK and SDSS Stars
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
4045:Hdelta
4226:Hgamma
4144:Hdelta
Wavelengths
G0 SDSS
G0 MKK
G2 SDSS
G2 MKK
G5 SDSS
G5 MKK
F9 SDSS

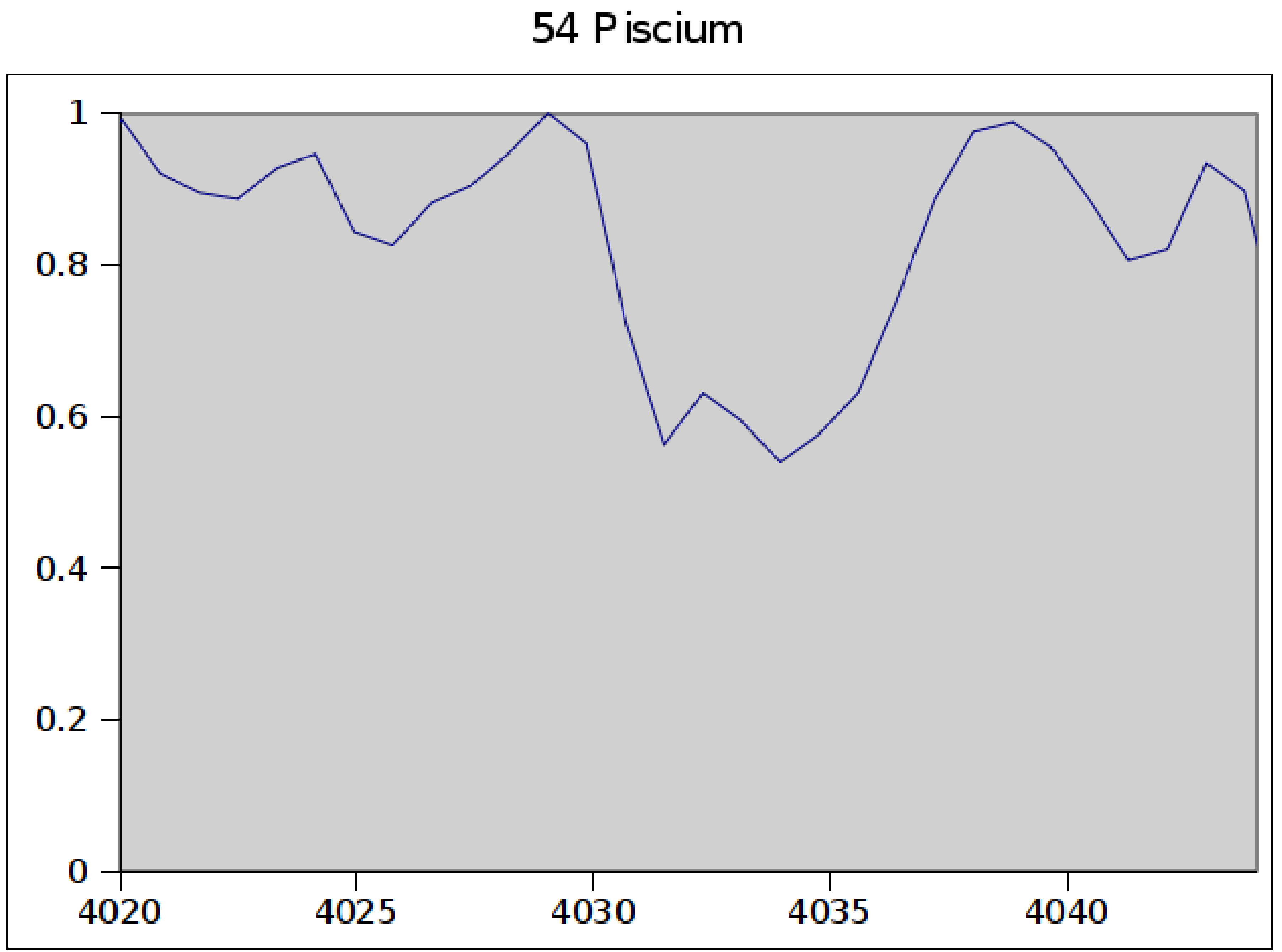

K Stellar Classification

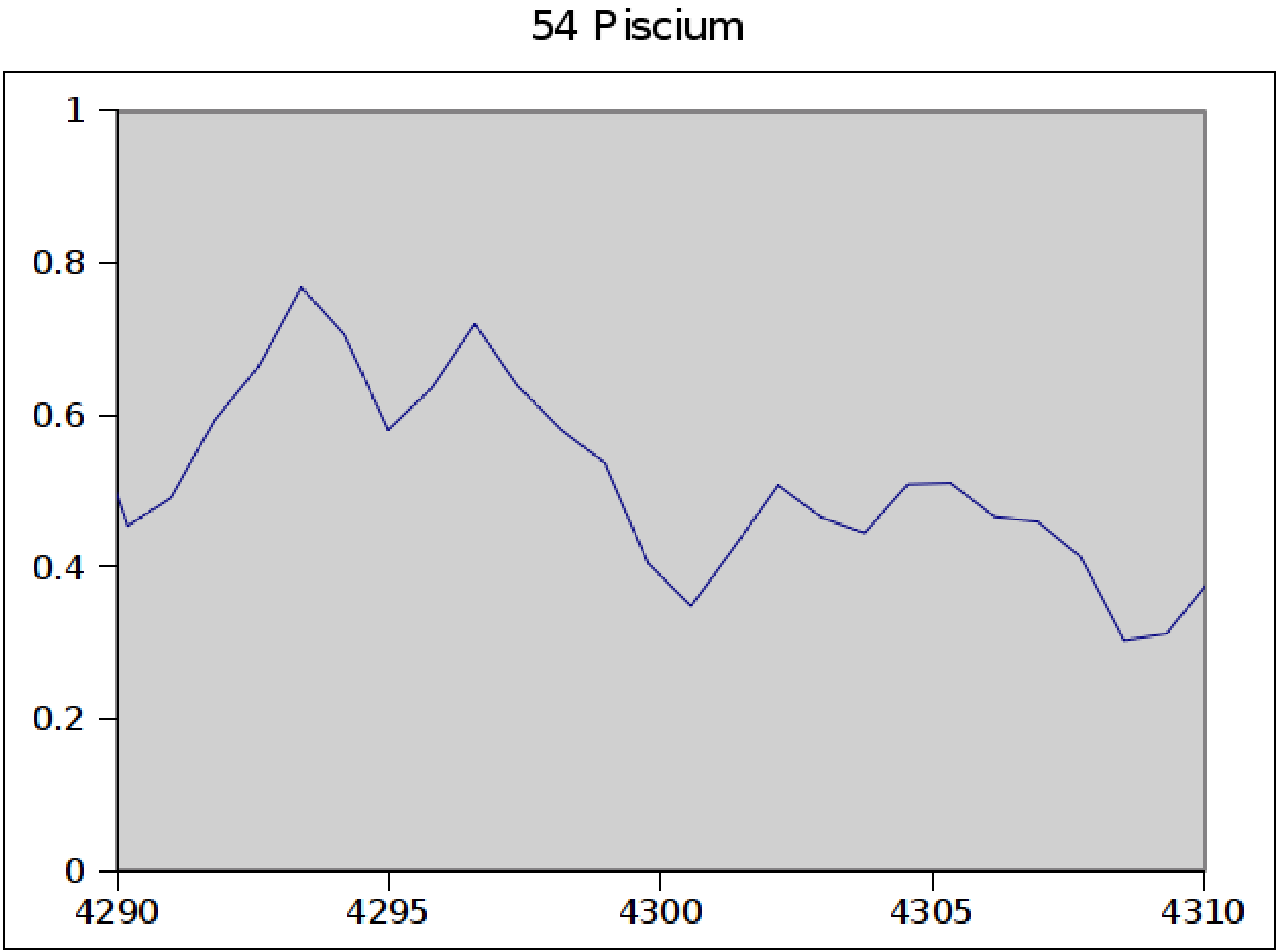


54 Piscium
1
0.8
0.6
0.4
0.2
0
3800
4000
4200
4400
4600
Classification by Spectra

Problems with light




54 Piscium
1
0.8
0.6
0.4
0.2
0
4020
4025
4030
4035
4040

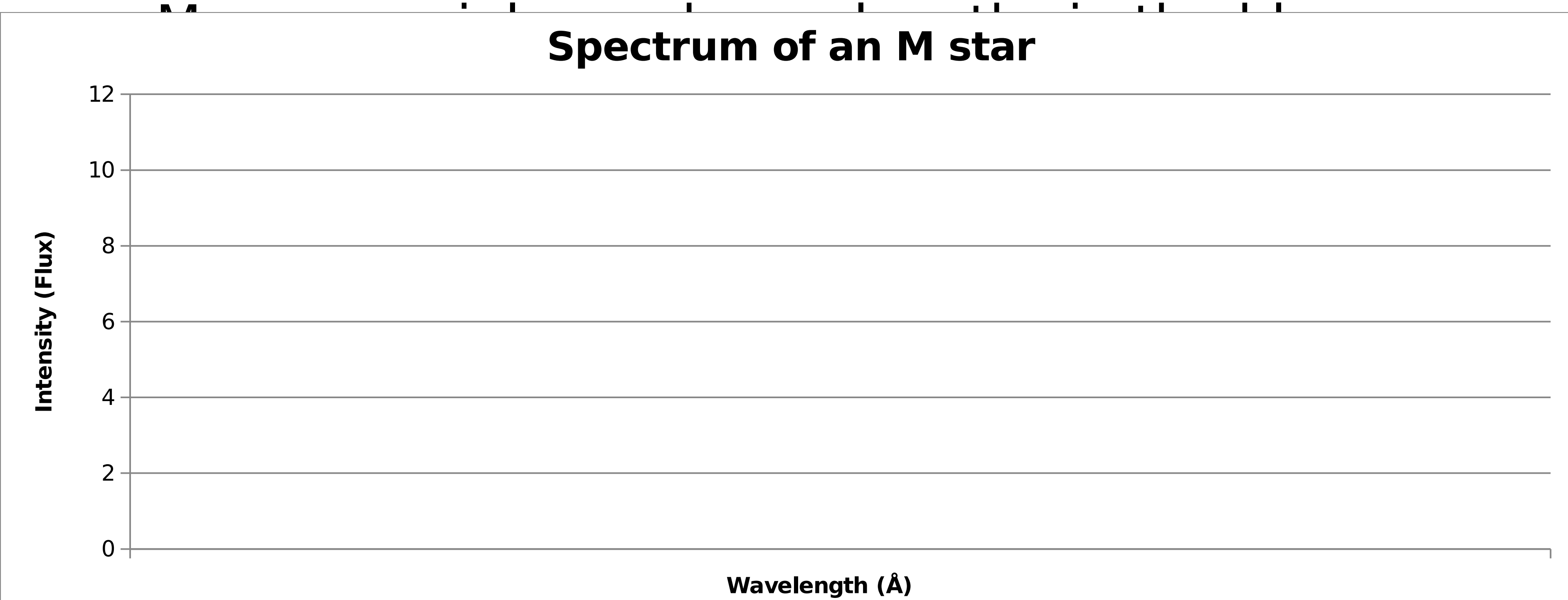

54 Piscium
1
0.8
0.6
0.4
0.2
0
4290
4295
4300
4305
4310

Results

K0 Stars		K2 Stars		K3 Stars		K5 Stars	
54 Psc		*Kap Oph*		*hr753*		*61 Cyga*	
Dwarf		**Giant**		**Dwarf**		**Dwarf**	
λλ 4030–4034:λ 4300	2.19	λ 4290:λ 4300	6.57	λ 4226:λ 4325	3.19	λ 4226:λ 4325	4.52
λ 4290:λ 4300	3.06	λ 4226:λ 4325	2.78	λ 4290:λ 4299	6.75	λ 4290:λ4299	4.78
Hδ:λ 4096	2.53					λ 4383:λ 4406	2.89
Eta Cyg						*Alp Tau*	
Giant						**Giant**	
λλ 4030–4034:λ 4300	5.03					λ 4226:λ 4325	4.49
λ 4290:λ 4300	6.75					λ 4290:λ4299	3.6
Hδ:λ 4096	1.92					λ 4383:λ 4406	3.12

M Type Stars

- Coldest stars
- The black body curve is prominent in the near-infrared range



Spectral Type

- Determined by titanium oxide band intensity
- TiO band 4900-5200 was used for this classification
- Measurement area was from the prominences around 4950 and 5160
- OIII lines slightly disturb the left part of the band

Spectral Type Results

- Results have a 5% error
- High noise in many cases
- Concentrated on M2 stars
- Two sets of data seem reliable, however, they are both around 37 Å

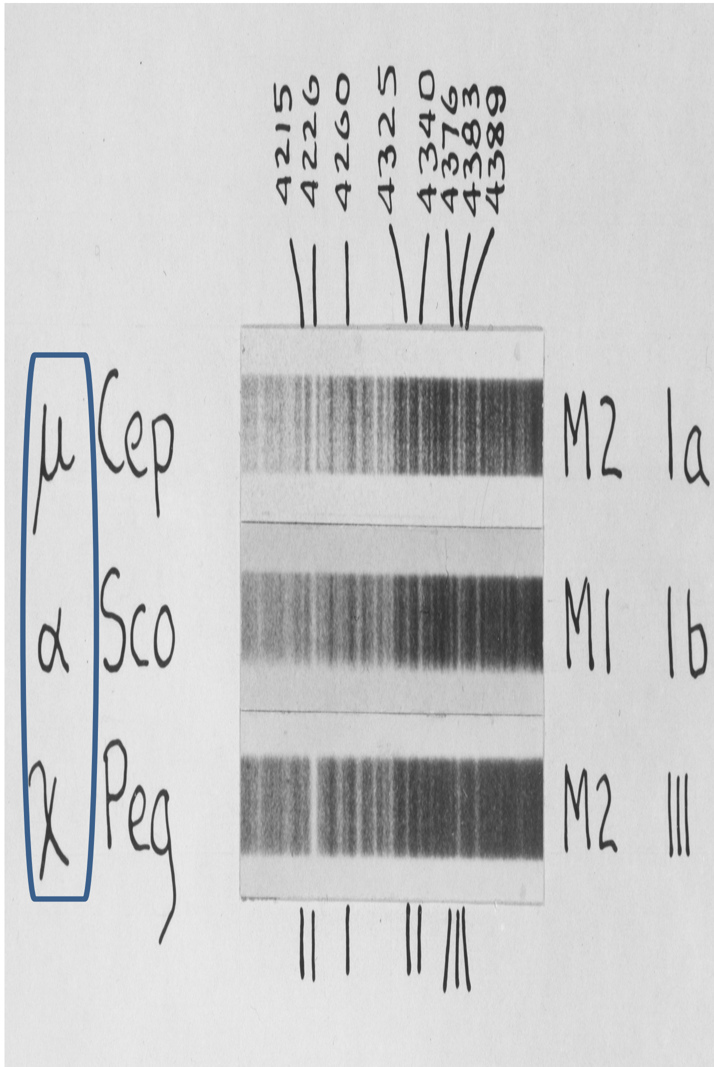
Luminosity Type

- Differentiates between giants and dwarfs
- Not very good at specifically classifying giants

Luminosity Type Results

- Obvious difference between giants and dwarfs
- Line 4045 (FeI) also changes with spectral type

Luminosity Type



- Photographic plates Morgan used
- 4376:4383:4390 used to classify giants
- The lighter the line, the greater the absorption
- Digital data gives similar results

Luminosity Type – A Deductive Process

- Luminosity lines often interact with each other
- Hard to get good data in digital spectra
- M-stars cannot be classes VII or IV
- Use ratio 4045:4077 to distinguish between giants/dwarfs
- Use ratios 4376:4383:4390 to distinguish between giants

Findings

More data in the red wavelengths is needed
An easier, efficient tool to calculate equivalent widths is needed
Morgans' system needs broadening to included analysis of a wider wavelength band

More Data, More Time

- National Optical Astronomy Observatory http://www.noao.edu/cflib/
- Standard Objects for Astronomy http://sofa.astro.utoledo.edu/SOFA/spectroscopy.html
- STELIB spectrum
- http://www.ast/obs-mip.fr/users/leborgne/stelib/list_index
- UVES spectrum

Where do we go from here?

- We have made valuable progress.
- More Standard Star Data
  - Working on a proposal for observing time to take spectra of more of Morgan’s standards.
- Next summer at Quarknet
- Start developing software

Acknowledgements

- Chris Stoughton
- Richard Kron
- Brian Yanny
- Jim Volk
- Jim Brown
- Drew Sobczak
- Fermilab education office and the Quarknet program