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.
Luminosity Stars At K1

Lum: S_Cep, θ_Her, 8_Aur

axe: 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 S_Cep. It is slightly weaker in θ_Her and weaker still in the ordinary giant 8_Aur.

The stars S_Cep and θ_Her can be said to define the spectral type K1 for their respective luminosity classes. Their absolute magnitudes are very uncertain; S_Cep is probably around -4 or -5, while θ_Her is probably about a magnitude fainter. The absolute magnitude of 8_Aur is probably near +0.5.
31  K0

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

30  G8

The spectral type (except for the supergiants) is determined from the ratios $\lambda 4144: H\delta$ and $\lambda 4096: H\delta$ 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.
Sloan Digital Sky Survey

And its System

SDSS Spectrum

Flux $[10^{-17}\text{ ergs/cm}^2/\text{Ang}]$

Wavelength [Angstroms]
Dark Sky Observatory

54 Piscum

![Graph showing flux vs. wavelength for 54 Piscum](image)
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.

The SDSS can analyze all of the yellow sector.
Equivalent Widths

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

**Equation:**

\[ \text{Equivalent Width} = \text{Height} \times \frac{\text{Sigma} (\sqrt{2\pi})}{\text{Continuum}} \]

\[ \text{Sigma} = \frac{\text{Full Width at Half Maximum}}{2.35} \]

**Diagram:**

- Continuum
- Half Maximum
- Full Width at Half Maximum
- Equivalent Width
- Height
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
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

Flux vs. 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
Procedure

- Different than everybody else
- IRAF
- Quicker to use, harder to set up
- Not recommended for non-technical students
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 30,000 K

- **Extremely Luminous**
  - O: > 30,000 L
  - B: 25 to

- **Extremely Massive**
  - O: > 16 M
  - B: 2 to 16 M

- Short life span

- **OB associations**
  - Pleiades Cluster
RA=219.82350, DEC= 1.04746, MJD=51663, Plate= 307, Fiber=537

Morgan’s range

$z = 0.0000 \pm 0.0001 (1.00), \text{Star}$
“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 + C II is more useful for cooler subclasses.
He I : K

4026:3935 in Standard B stars
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
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

4030-4034: 4128-4132

Subclass

F0 F2 F5 F6 F8
Classifying Spectral Type: F9 Stars

- Not in MKK
- 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. \( Fe \, ^{1} \, 4045 \) and \( \lambda \, 4226 \) are very much weaker than \( H\gamma \) and \( H\delta \).

Iron I  Calcium I
Classifying Spectral Type: Other Factors

25 F6

The G band is slightly stronger than at class F5.
Luminosity in F2 stars

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

- $\text{H}$ = 4103
- $\text{H}$ = 4342
- 4226 = Ca I
- 4045 = Fe I
- 4077 = Sr II
- 4144 = He I
- 4063
- 4096
Classifying Each Spectral Type

G0 Star

Wavelength

F

l

u

x
G0 and G2

**Spectral Class Ratios**

<table>
<thead>
<tr>
<th></th>
<th>G0</th>
<th>G2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4045:HO</td>
<td>0.39621 ± 0.07198</td>
<td>0.54770 ± 0.09292</td>
</tr>
<tr>
<td>4226:HO</td>
<td>0.51749 ± 0.06090</td>
<td>0.66351 ± 0.08834</td>
</tr>
</tbody>
</table>
Luminosity Class Ratios for G0

G0

4077:4226  4077:4045  4077:Hδ*

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

Luminosity Class Ratios for G2 Stars

<table>
<thead>
<tr>
<th>Class</th>
<th>4077:4226</th>
<th>4077:4045</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ib</td>
<td>0.74033</td>
<td>1.51287</td>
</tr>
<tr>
<td>III</td>
<td>0.62918</td>
<td>0.68286</td>
</tr>
<tr>
<td>V</td>
<td>0.75266</td>
<td>0.98220</td>
</tr>
</tbody>
</table>
G5 and G8

G5 V Kap Cet

Wavelength

4096: Hα
G5 and G8

Stellar Class Ratios for G Stars

<table>
<thead>
<tr>
<th>Star Class</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G5</td>
<td>4144:H 0.38713 ± 0.11565</td>
</tr>
<tr>
<td>G8</td>
<td>4144:H 0.46733 ± 0.09137</td>
</tr>
<tr>
<td>Class</td>
<td>4045:4077</td>
</tr>
<tr>
<td>-------</td>
<td>-----------</td>
</tr>
<tr>
<td>Ib</td>
<td>0.85870</td>
</tr>
<tr>
<td>III</td>
<td>0.86368</td>
</tr>
<tr>
<td>V</td>
<td>2.50934</td>
</tr>
</tbody>
</table>
### SDSS Data

#### Spectral Class Ratios for G Stars from SDSS

<table>
<thead>
<tr>
<th>Spectral Class</th>
<th>4045:Hδ</th>
<th>4226:Hγ</th>
<th>4144:Hλ</th>
</tr>
</thead>
<tbody>
<tr>
<td>G0</td>
<td>0.32277</td>
<td>0.17096</td>
<td>0.39159</td>
</tr>
<tr>
<td>G2</td>
<td>0.43798</td>
<td>0.124797</td>
<td>0.52698</td>
</tr>
<tr>
<td>G5</td>
<td></td>
<td></td>
<td>0.75460</td>
</tr>
</tbody>
</table>

#### Diagram

- **4045:Hδ**
- **4226:Hγ**
- **4144:Hλ**
Stellar Class Ratios for MKK and SDSS Stars

Wavelengths

4045: H\delta
4226: H\gamma
4144: H\delta

G0 SDSS
G0 MKK
G2 SDSS
G2 MKK
G5 SDSS
G5 MKK
F9 SDSS

Wavelengths
K Stellar Classification
Classification by Spectra
Problems with light
Results

<table>
<thead>
<tr>
<th>Star</th>
<th>K0 Stars</th>
<th>K2 Stars</th>
<th>K3 Stars</th>
<th>K5 Stars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dwarf</td>
<td>Giant</td>
<td>Dwarf</td>
<td>Dwarf</td>
</tr>
<tr>
<td>54 Psc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \lambda 4030-4034: \lambda 4300 )</td>
<td>2.19</td>
<td>( \lambda 4290: \lambda 4300 )</td>
<td>6.57</td>
</tr>
<tr>
<td></td>
<td>( \lambda 4290: \lambda 4300 )</td>
<td>3.06</td>
<td>( \lambda 4226: \lambda 4325 )</td>
<td>2.78</td>
</tr>
<tr>
<td></td>
<td>H( \delta ): \lambda 4096</td>
<td>2.53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eta Cyg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \lambda 4030-4034: \lambda 4300 )</td>
<td>5.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \lambda 4290: \lambda 4300 )</td>
<td>6.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H( \delta ): \lambda 4096</td>
<td>1.92</td>
<td></td>
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<tr>
<td>Alp Tau</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>( \lambda 4030-4034: \lambda 4300 )</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>( \lambda 4290: \lambda 4300 )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>H( \delta ): \lambda 4096</td>
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</tr>
</tbody>
</table>
M Type Stars

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

M dwarfs cannot become giants
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

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