[Jump to Today]

Course Syllabus

General Information

Class Times	SL 240, 10:30 - 11:45 AM T Th
Required Texts	*Foundations in Astrophysics* by Ryden and Peterson (ISBN 0321595580)
Instructor	John Armstrong
Office Hours	SL 205, 10:30 AM - 12:30 PM, MW, or by appointment
Email	jcarmstrong@weber.edu (mailto:jcarmstrong@weber.edu)
Web	http://weber.edu/jcarmstrong (http://weber.edu/jcarmstrong)
Phone	801.626.6215

Course Description

ASTR 3160 - Stellar/Planetary Astrophysics uses fundamental physical processes in order to understand the wide variety of phenomena found throughout the universe, focusing on planetary and stellar astrophysics. Consequently, the whole range of ideas studied in the PHYS PS2210-2220 series is applied to planetary and stellar systems. In this course we will investigate the orbital motions of planets, the nature of our Sun, the dust and gas found between the stars, the evolution of extrasolar planets and stars, supernovae, white dwarfs, neutron stars, and black holes. Students will also have the opportunity to build computer models of astrophysical systems using programs that are based on the physical processes discussed in class. ***Prerequisites***: PHYS 2220 and MATH 1200

Course Goals

Astrophysics is the study of physical processes in the Universe. Some of the most immense and powerful natural laboratories (such as black holes, quasars, and the origin of the Universe itself) exist in Nature. This course will focus on the tools and techniques used to probe the Universe for insight into fundamental physics, with particular attention paid to stellar and planetary applications. Modern observational astrophysics employs the most sophisticated technology available in telescopes covering the electromagnetic spectrum. Current research also uses computational models to uncover the details of intricate physical systems. Specifically, the course goals are:

- Examine the field of modern astrophysics, with attention paid to current research topics in stellar and planetary astrophysics.
- Develop your ability to apply basic physics to astrophysical systems.
- Gain some practical experience with astronomical observation, the use of telescopes and imaging equipment, and analyzing large astronomical data sets available on the Internet.

Assignments and Readings

Weekly homework assignments will be due on the indicated day on the schedule. These will be related to problems and assignments from your text and mini-projects involving real astronomical data, including some computational problems in Mathematica. In addition, there are scheduled reading assignments in the text. These are due the day we start discussing the material in class and are associated with graded discussions in Canvas. You are to read the chapter prior to class and post any questions or comments on the discussions. These are credit/no-credit assignments (that is, post a question or comment related to the material and get the points!) but I hope it will encourage you to read the material prior to the start of the class. Also, your discussion questions can help guide the material we cover in class.

Exams

There will be two in-class midterm exams and one comprehensive final exam. Dates for these exams are listed in the schedule.

Grading Policy

Your grade will be compiled from homework, projects, and exams according to the following:

Assignments	50%
Midterms (2 x 15%)	30%
Final	20%

Attendance Policy

While I will not be taking attendance in class, you are encouraged to attend regularly. We will allow time for work on your projects, so attending and being available for your collaborators is important. Also, this is going to be an awesome, exciting class, so why would you want to be anywhere else?

Academic Integrity

Regarding academic integrity, I will enforce policies as laid down in Section IV:D of the Student Responsibilities outlined in the Student Code. Specifically, no cheating or other forms of academic dishonesty will be tolerated. The first instance of cheating will result in a zero on that assignment. The second instance will result in failing the class. You will be working in groups occasionally, however, so you will be required to distinguish the difference between collaboration and cheating. When in doubt, make sure to give credit where credit is due.

Special Accommodations

Any students requiring accommodations or services due to a disability must contact Services for Students with Disabilities (SSD) in room 181 of the Student Service Center. SSD can also arrange to provide course materials (including this syllabus) in alternative formats if necessary.

Date	Details	
Tue Jan 8, 2013	Introductions (https://weber.instructure.com/courses/182386/assignments/927942)	11:59pm
Thu Jan 10, 2013	Assignment 1 (https://weber.instructure.com/courses/182386/assignments/927941)	11:59pm
	Early Astronomy (https://weber.instructure.com/courses/182386/assignments/927962)	11:59pm
Tue Jan 15, 2013	The Emergence of Modern Astronomy (https://weber.instructure.com/courses/182386/assignments/927943)	11:59pm
Thu Jan 17, 2013	Orbital Mechanics (https://weber.instructure.com/courses/182386/assignments/927944)	11:59pm
Tue Jan 22, 2013	Earth-Moon Activity (https://weber.instructure.com/courses/182386/assignments/1008839)	10:30pm
	Assignment 2 (https://weber.instructure.com/courses/182386/assignments/928025)	11:59pm
	The Earth-Moon System (https://weber.instructure.com/courses/182386/assignments/927945)	11:59pm
Tue Jan 29, 2013	Interaction of Radiation and Matter (https://weber.instructure.com/courses/182386/assignments/927946)	11:59pm
Thu Jan 31, 2013	Assignment 3 (https://weber.instructure.com/courses/182386/assignments/928026)	11:59pm
Tue Feb 5, 2013	Astronomical Detection of Light (https://weber.instructure.com/courses/182386/assignments/927947)	11:59pm
Thu Feb 7, 2013	Assignment 4 (https://weber.instructure.com/courses/182386/assignments/928027)	11:59pm
Tue Feb 12, 2013	Exam 1 (https://weber.instructure.com/courses/182386/assignments/927959)	10:30am
	The Sun (https://weber.instructure.com/courses/182386/assignments/927948)	11:59pm
Tue Feb 19, 2013	Overview of the Solar System (https://weber.instructure.com/courses/182386/assignments/927949)	11:59pm
Thu Feb 21, 2013	Assignment 5 (https://weber.instructure.com/courses/182386/assignments/928040)	11:59pm
Tue Feb 26, 2013	Earth and Moon (https://weber.instructure.com/courses/182386/assignments/927964)	11:59pm
Fri Mar 1, 2013	Assignment 6 (https://weber.instructure.com/courses/182386/assignments/928041)	5pm
Tue Mar 12, 2013	The Planets (https://weber.instructure.com/courses/182386/assignments/927950)	11:59pm
Thu Mar 14, 2013	Assignment 7 (https://weber.instructure.com/courses/182386/assignments/928052)	11:59pm
Tue Mar 19, 2013	Exoplanets I (https://weber.instructure.com/courses/182386/assignments/927951)	12am
Thu Mar 21, 2013	Exoplanets II (https://weber.instructure.com/courses/182386/assignments/927952)	12am
	Assignment 8 (https://weber.instructure.com/courses/182386/assignments/928053)	11:59pm
Tue Mar 26, 2013	Exam 2 (https://weber.instructure.com/courses/182386/assignments/927960)	10:30am

	In Class Assignment - Parallax (https://weber.instructure.com/courses/182386/assignments/1047585)	11:45am
	The Properties of Stars (https://weber.instructure.com/courses/182386/assignments/927953)	11:59pm
Thu Mar 28, 2013	Assignment 9 (https://weber.instructure.com/courses/182386/assignments/928054)	11:59pm
Tue Apr 2, 2013	In Class Assignment - Hipparcos (https://weber.instructure.com/courses/182386/assignments/1047597)	11:59pm
Thu Apr 4, 2013	Assignment 10 (https://weber.instructure.com/courses/182386/assignments/928055)	11:59pm
	In Class Assignment - Spectral Classification (https://weber.instructure.com/courses/182386/assignments/1054157)	11:59pm
	Stellar Atmospheres (https://weber.instructure.com/courses/182386/assignments/927954)	11:59pm
Tue Apr 9, 2013	In Class Assignment - Age and Distance to Stellar Clusters (https://weber.instructure.com/courses/182386/assignments/1054211)	11:59pm
Thu Apr 11, 2013	In Class Assignment - Stellar Interiors (https://weber.instructure.com/courses/182386/assignments/928057)	11:59pm
	Stellar Interiors (https://weber.instructure.com/courses/182386/assignments/927955)	11:59pm
Tue Apr 16, 2013	Formation and Evolutions of Stars and Stellar Remnants (https://weber.instructure.com/courses/182386/assignments/927957)	11:59pm
	In Class Assignment - Stellar Evolution (https://weber.instructure.com/courses/182386/assignments/1063514)	11:59pm
Thu Apr 18, 2013	In Class Assignment - The Drake Equation and the Search for Life (https://weber.instructure.com/courses/182386/assignments/928060)	11:59pm
	Who Speaks for Earth? (https://weber.instructure.com/courses/182386/assignments/1054265)	11:59pm
Wed Apr 24, 2013	Final Exam (https://weber.instructure.com/courses/182386/assignments/927961)	4pm

Building a Habitable Planet

In this assignment, you are going to build a model for habitable worlds around other stars using Mathematica. Here is the plan:

1. **Before you open Mathematica:**
   a. **Determine the input parameters for your model.** Your model may depend on planetary properties (mass, radius, etc) and stellar properties.
   b. **Determine what properties of the system you will be computing.** Your model should calculate the planetary surface temperature, total mass of the atmosphere, and other things you might find interesting.
   c. **Determine the algorithm** you will use to compute your planetary model. For this, you will:
      i. Derive, using the energy balance technique we discussed in class, a model for the surface temperature of an airless world orbiting a star.
      ii. You can take the atmosphere into account by modeling the temperature increase caused by the greenhouse effect. Compute the surface temperature by including the planetary atmosphere using the following relationship:

$$T_{surf} = (1+\tau)^{\frac{1}{4}} T_{airless}$$

      where $T_{airless}$ is the temperature derived from your energy balance model, T_{surf} is the surface temperature, and τ represents the atmospheric *optical depth*, a crude estimate of the strength of the greenhouse effect.
      iii. Estimate the total mass of the planetary atmosphere from the derived surface temperature and an input surface pressure.
2. **Build your model in Mathematica.** If you have done your background work from the steps above, this will entail writing up your predetermined algorithm.
3. **Answer the following questions:**

a. Compare the airless body temperature to the actual measured average temperatures for the terrestrial worlds in our solar system. What are the values of τ for Earth, Venus, Mars, and Titan?

b. Can you derive a simple relationship between pressure and τ? If so, what is it?

c. Compute the total mass of the atmosphere for Earth, Venus, Mars, and Titan. Make a plot of planet mass vs. τ.

d. Estimate the mass of each planet's atmosphere, and make a plot of planetary atmosphere vs. planet mass. What conclusions can you draw based on this information?

e. Compute the inner and outer edges of the Habitable Zone for main sequence stars using the data in your text. For this simple model of Earth-like worlds, define the inner edge as where water boils on Earth, and the outer edge as where water freezes on Earth (383 K and 273 K). In general, the habitable zone inner edge is defined by where water boils, and the outer edge is where CO_2 freezes, both of which depend on atmospheric pressure. Make a plot of the luminosity of the star vs. the distance of the inner and outer habitable zones on the same graph.

f. What is the minimum mass necessary to hang on to an Earth-like nitrogen atmosphere in the Habitable Zone? What constraints does this place on the mass of potentially habitable worlds around other stars? ***Hint:*** *As a general rule of thumb, if the RMS velocity of the molecules in the atmosphere is less than 1/6 the planetary escape velocity, the planet will retain its atmosphere.*

g. Where is the best place to be in the solar system when the Sun enters its red giant phase?

h. Your model assumes a rapidly rotating planet (implicit in our energy balance model). How would the environment of a planet change if it rotated very slowly? How would such a world change our habitability requirements? (Note: Planets in the habitable zone of red dwarfs are "tidally locked" so that the same face is towards the star at all times).

Assignment 8 - Due Weds 14 Nov 2007

Unless otherwise noted, all listed problems are in Carroll and Ostlie's Big Orange Book (BOB)

1. Problem 23.1
2. Problem 23.4
3. Problem 23.6
4. Extrasolar Planets (or Exoplanets). For the following questions, use the Extrasolar Planet Encyclopedia (http://exoplanet.eu). You can either use the tools on the website, or download and plot the data yourself in your favorite spreadsheet program.
   a. Every astronomical study, by virtue of the objects selected for study, has intrinsic observational biases. What are the observational biases for the current catalog of extrasolar planets? That is, what are the mass limits, distances, and metalicities of the stars being studied?
   b. Based on your answers above, what limits are placed on our ability to interpret the planetary catalog data?
   c. Based on our discussion of the dominant detection technique (the radial velocity method), what planets should we be most sensitive to in terms of mass and distance from the star?
   d. Using the histogram tool, what is the most common planetary mass in the catalog? How does this relate to the detection limits of the discovery techniques?
   e. Using the histogram tool, what is the most common planetary distance in the catalog? How does this relate to the detection limits of the discovery techniques?
   f. From the mass histogram, estimate the planetary mass function (assuming the mass function has the form $m^{-\alpha}$). In other words, estimate α.
   g. By extrapolating from the mass function, how earth mass planets have yet to be discovered?
   h. Using the correlation tools, identify two planetary quantities that should be correlated, and explain why we see this correlation.

i. Using the correlation tools, identify two planetary quantities that should not be correlated, and explain why this is so. Looking for uncorrelated parameters (that should be uncorrelated) is an excellent test to see if observational biases are skewing our results.

j. Go back to problem 2.6 (in BOB) and do parts a,b, and c for two of the planet-star systems in the catalog.

k. **Extra Credit** (worth one homework grade): Go back and do problem 2.6 parts a, b, and c for all the planet-star systems in the catalog. You can do this with excel, mathematica, or your favorite programming language. Make a histogram of the *ratio* of the planet's angular momentum to the star's angular momentum.

In Class Assignment - Due Today

Parallax

Task 1: Measure the distance to an object of known height (mountain, etc.) *without directly measuring the distance with a meter stick.*

Task 2: Measure the distance to an object in the foreground, again, *without directly measuring with the meter stick*.

Your supplies

Meter stick (or “Freedom Stick”)

Ruler

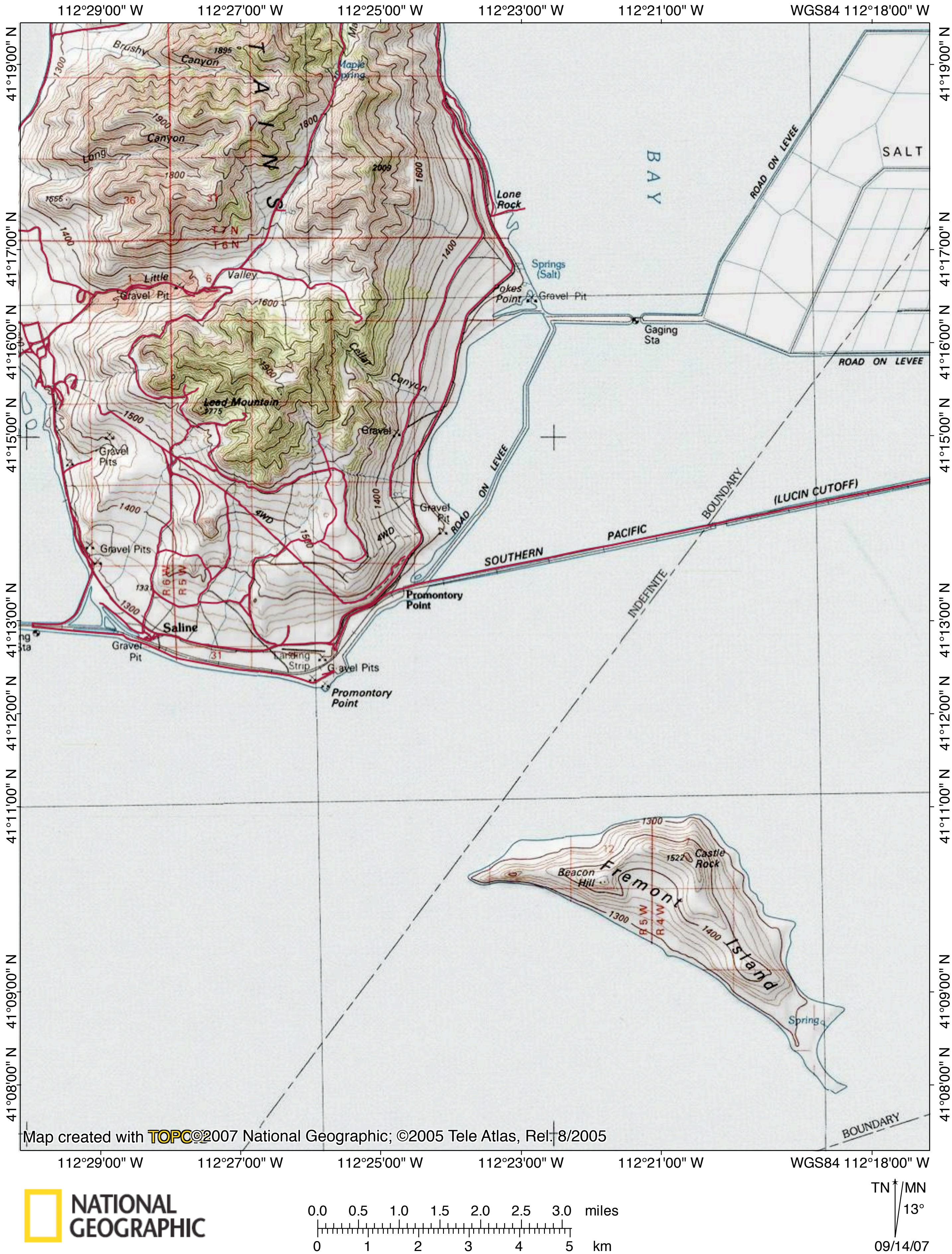
Paper and pencil

Topographical elevations from Dr. Armstrong

To Hand In:

A description of your procedure for each task (with drawings), your calculations and your results.

TOPO! map printed on 09/14/07 from "Untitled.tpo"



NATIONAL GEOGRAPHIC

Stellar Properties and the Hipparcos Data Set

For this assignment, you will use data obtained by the *Hipparcos Space Astrometry Mission*, which pinpointed the positions of more than one hundred thousand stars with high precision, and more than one million stars with lesser precision.

Step 1: Download data and import into Excel

1. Go to http://vizier.u-strasbg.fr/viz-bin/VizieR
2. Search for "Hipparcos" in the Catalog search
3. Click on the "I/239/hip_main" catalog
4. Generate two data sets:
   a. One with the parallax greater than 100 mas (close stars)
   b. One with the V mag less than 4 (bright stars)

   For each dataset, set B-V to greater than -10. This ensures the objects was observed in both filters.
5. On the results page, set "Max Entries" to "unlimited" and select ";-seprated values" for output, and hit "Submit"
6. Save your data file
7. Import data into Excel:
   a. Use the "File -> Open" command to select the file
   b. In the Import Wizard, select "Delimited" and click "Next"
   c. On the next screen, select "Semicolon", then click "Finished"
   d. Check the import and save your files
   e. When you are finished, you should have two Excel files, one called "CloseStars.xls" and one called "BrightStars.xls"

Step 2: Calculate physical parameters from the data

1. For each of your datasets, compute the following:
   a. The distance, in parsecs
   b. The absolute V magnitude, M_V
   c. The luminosity, in units of solar luminosities

d. The effective temperature, T_{eff}, in Kelvin

2. Save your Excel files

Step 3: Analysis of the data and your derived results

Here is where the fun begins! You now have data from two completely different stellar populations: stars closer than 10 pc, and stars brighter than 4^{th} magnitude. You can see all of the bright stars with the naked eye, while most of the close stars you can't see without the aide of a powerful modern telescope.

Your task now is to answer the following question: What are the main differences between these two stellar populations? Some ideas on how to proceed:

1. Start graphing stuff. Look for correlations and relationships in the data. Are there any parameters than should be correlated based on your knowledge of physics? Are there any parameters that should not be correlated?
2. Look at averages. What is the average color of each data set? Average apparent magnitude? Average absolute magnitude? Average distance?
3. Probe your knowledge of physics to predict what differences might exist and then go looking for them.

What to Hand In:

For both data sets, hand in:

1. A plot of *log of the Luminosity vs. B-V*
2. A plot of *log of the Luminosity vs.* T_{eff}
3. A plot of one other correlated property of your choice

   Make sure each of your plots has a title and the axes are labeled, including units

Answer the following questions:

1. What are the main differences between these two datasets?
2. Compare your plot of *Luminosity vs. B-V* to your plot of *Luminosity vs.* T_{eff}. Are there any differences or similarities?
3. Compare your plots of *Luminosity vs.* T_{eff} to equation 3.17 in your text.

a. What conclusions can you draw about stars as blackbody radiators?

b. What conclusions can you draw about stellar radius as a function of luminosity? Is it constant? Does it change? Does it change in different ways for each data set?

Note on Calculating the Effective Temperature, T_{eff}:

From study of blackbody radiation, you know there is a relationship between color and temperature - hotter objects are bluer and cooler objects are redder. By extension, there should be a relationship between a star's *B-V color index* and temperature. You can work this out from your knowledge of blackbody radiation and the definition of the magnitude scale (see Section 3.6 on page 75 of your text). However, stars are not perfect blackbodies. For this exercise, you will use an empirical relationship between T_{eff} and color index derived from stellar models. Those relationships, derived from polynomial fits to the data in Appendix G of your book, are[1]:

For objects with *B-V < -0.1:*

$$T_{eff} = 533695(B-V)^2 + 111432(B-V) + 18062$$

For objects with *B-V > -0.1:*

$$T_{eff} = 1850.9(B-V)^2 - 6772.2(B-V) + 9417.9$$

To use these in your excel spreadsheet, you can invoke the IF command:

IF(logical_test,value_if_true,value_if_false)

The logical test, in this case, is checking to see if *B-V* is less than or greater than -0.1. If it is, Excel will use *value_if_true* (in this case, the first equation). If it isn't, Excel will use the *value_if_false* (in this case, the second equation).

For example, if your *B-V* column starts at the cell *M42*, your statement would look like:

*IF(M42 < -0.1,533695*M42^2 + 111432*M42 + 18062,1850.9*M42^2 - 6772.2*M42 + 9417.9)*

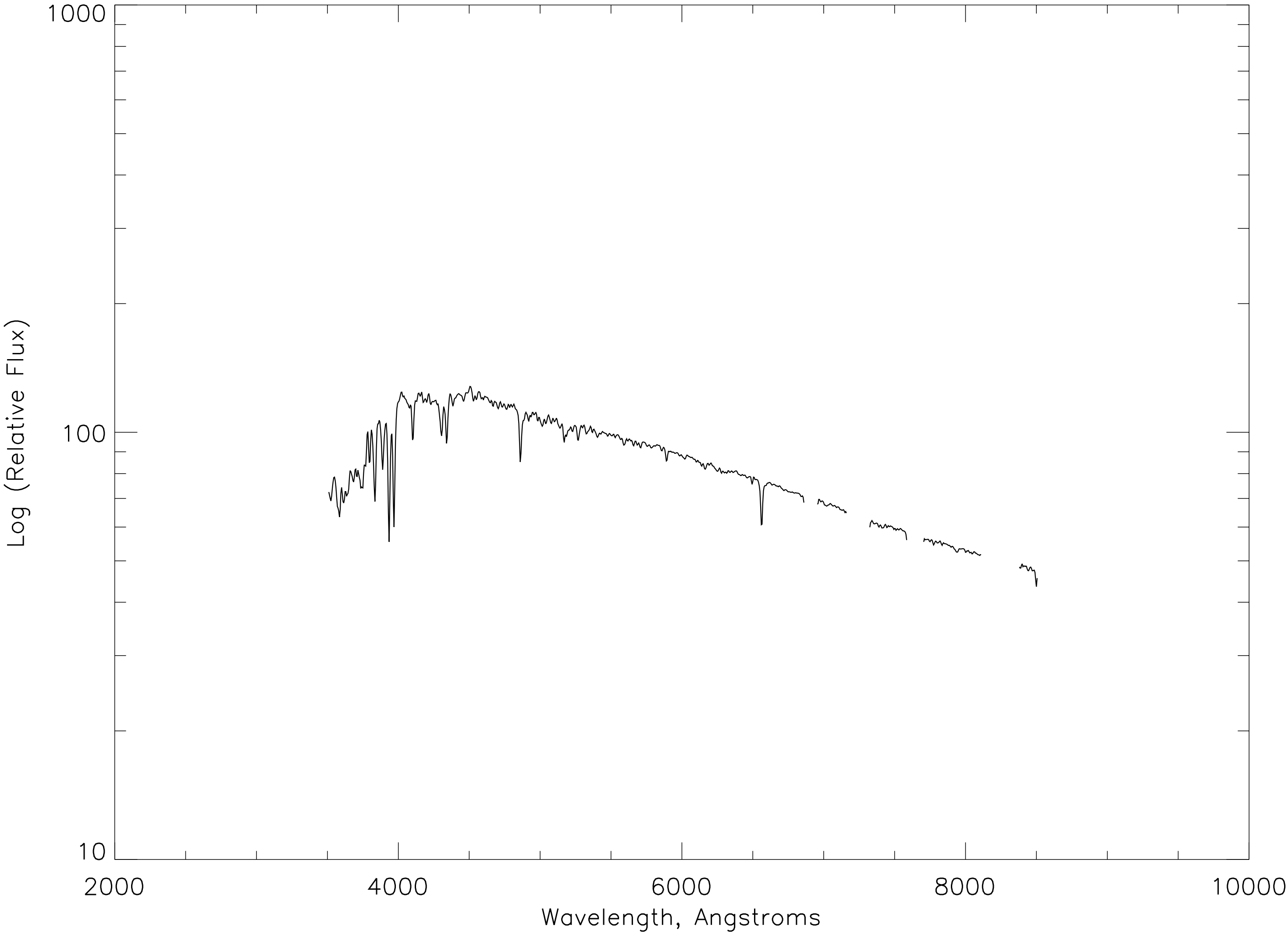
---

[1] These relationships were derived using Excel. Ask me how!

Stellar Classification

Develop a classification scheme for the attached stellar spectra and answer the following questions:

1. Take a moment to identify the hydrogen Balmer lines. Mark these on your spectra.
2. Sort these spectra by the strength of these absorption lines. Mark the spectra with the strongest lines “A”, the next strongest “B” and so forth.
3. Now, using your knowledge of blackbody spectra, determine the peak wavelength and calculate the temperature for each star. Be aware that absorption features, especially at the smaller wavelengths, may skew your results. Try to match each spectrum with a blackbody curve.
4. Re-sort your stars according to their temperature from highest to lowest. What are the order of the letters now?
5. Which classification scheme has the strongest justification from a physics perspective?
6. What temperature has the strongest hydrogen absorption? Given that stars are more or less of similar composition, what is the explanation for why both hot and cool stars show a decrease in hydrogen absorption?



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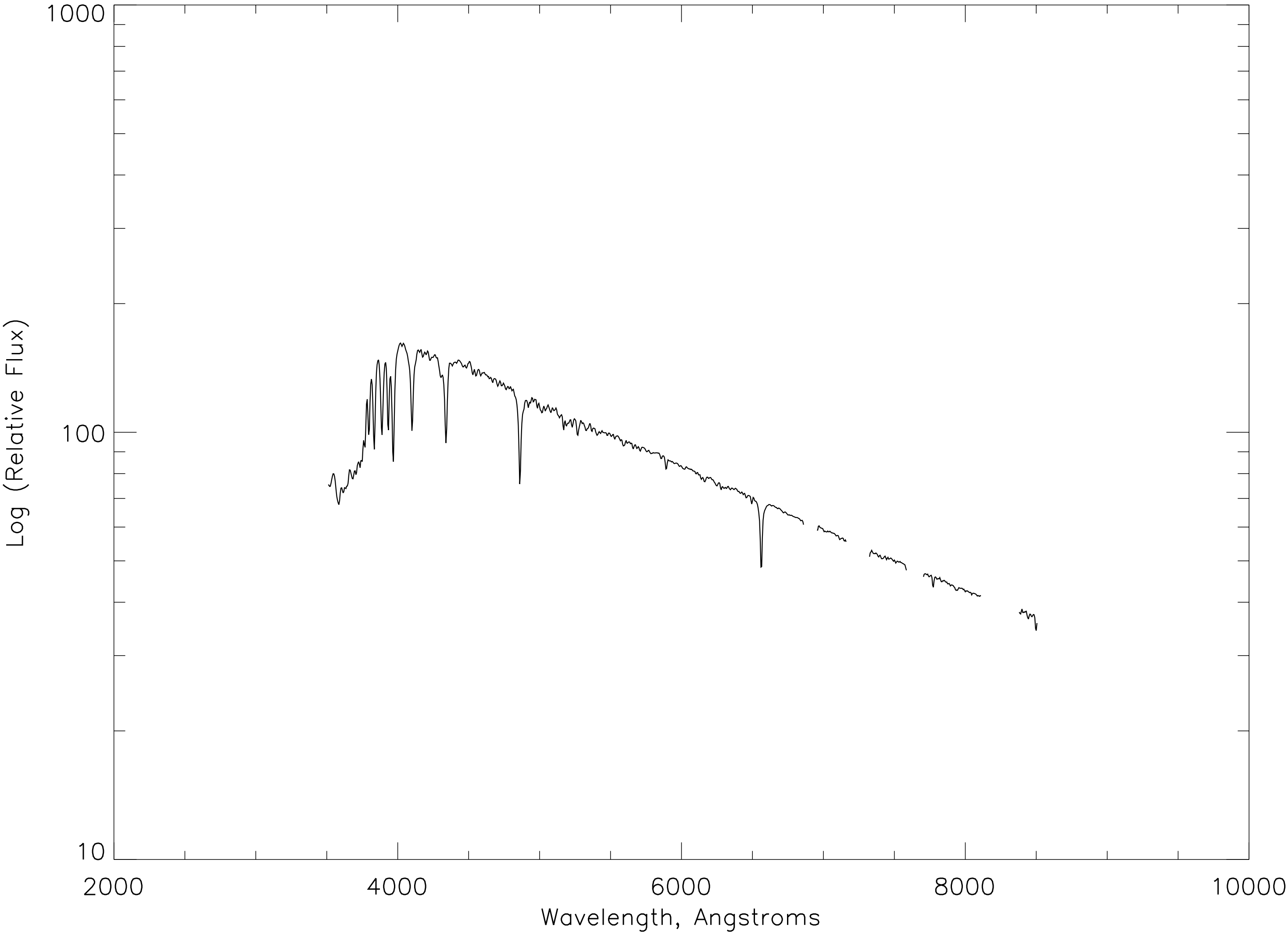
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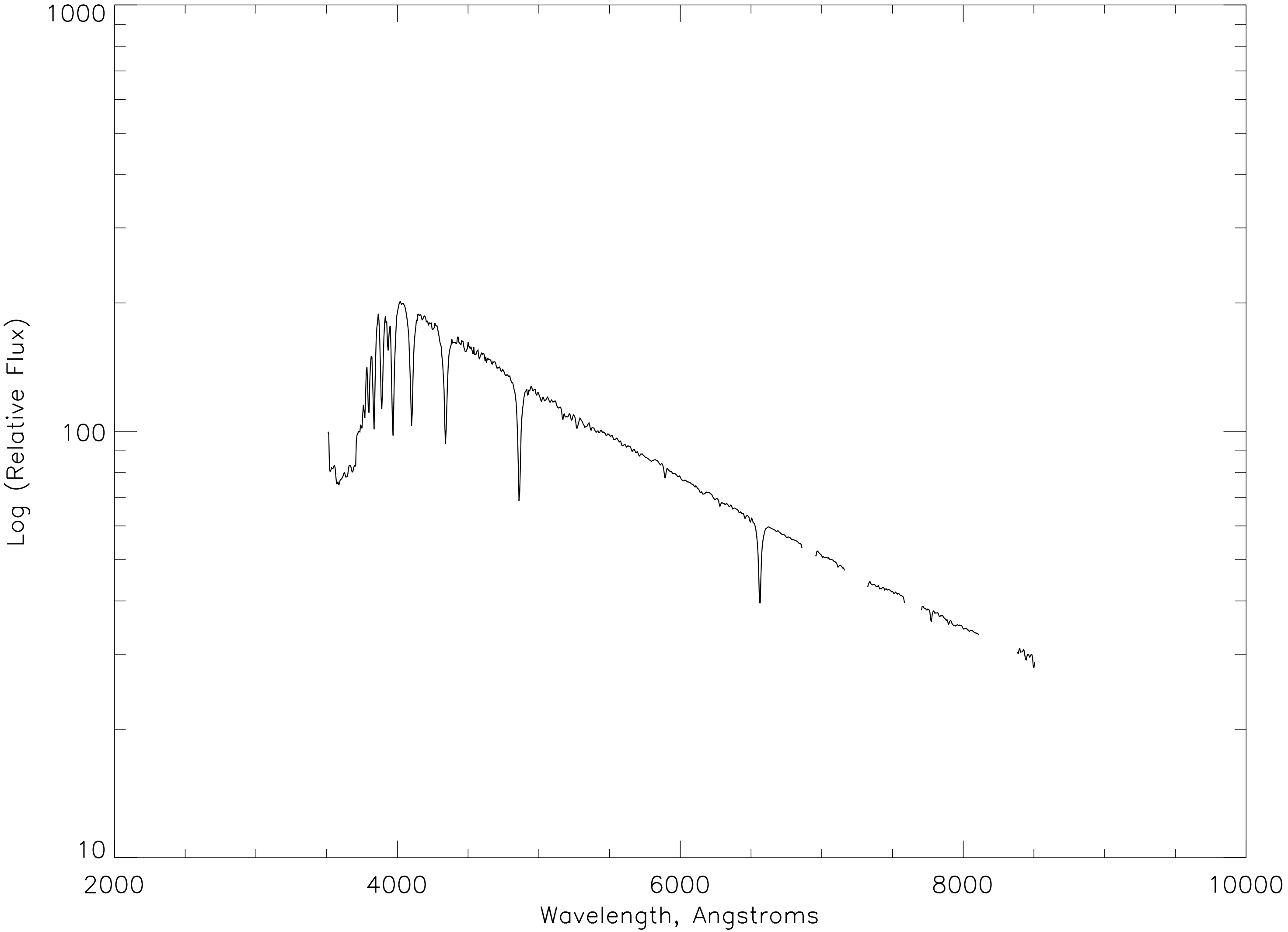
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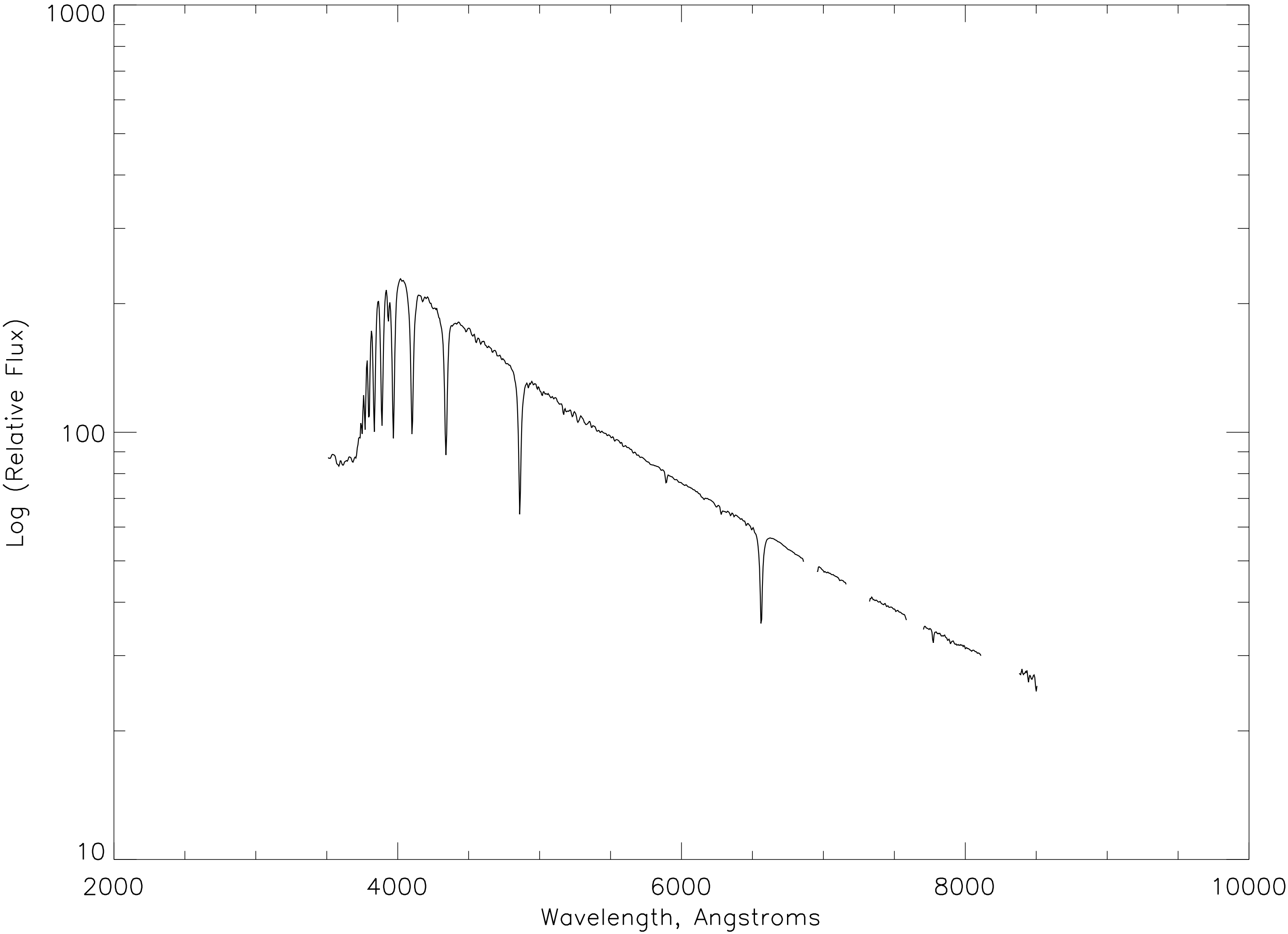
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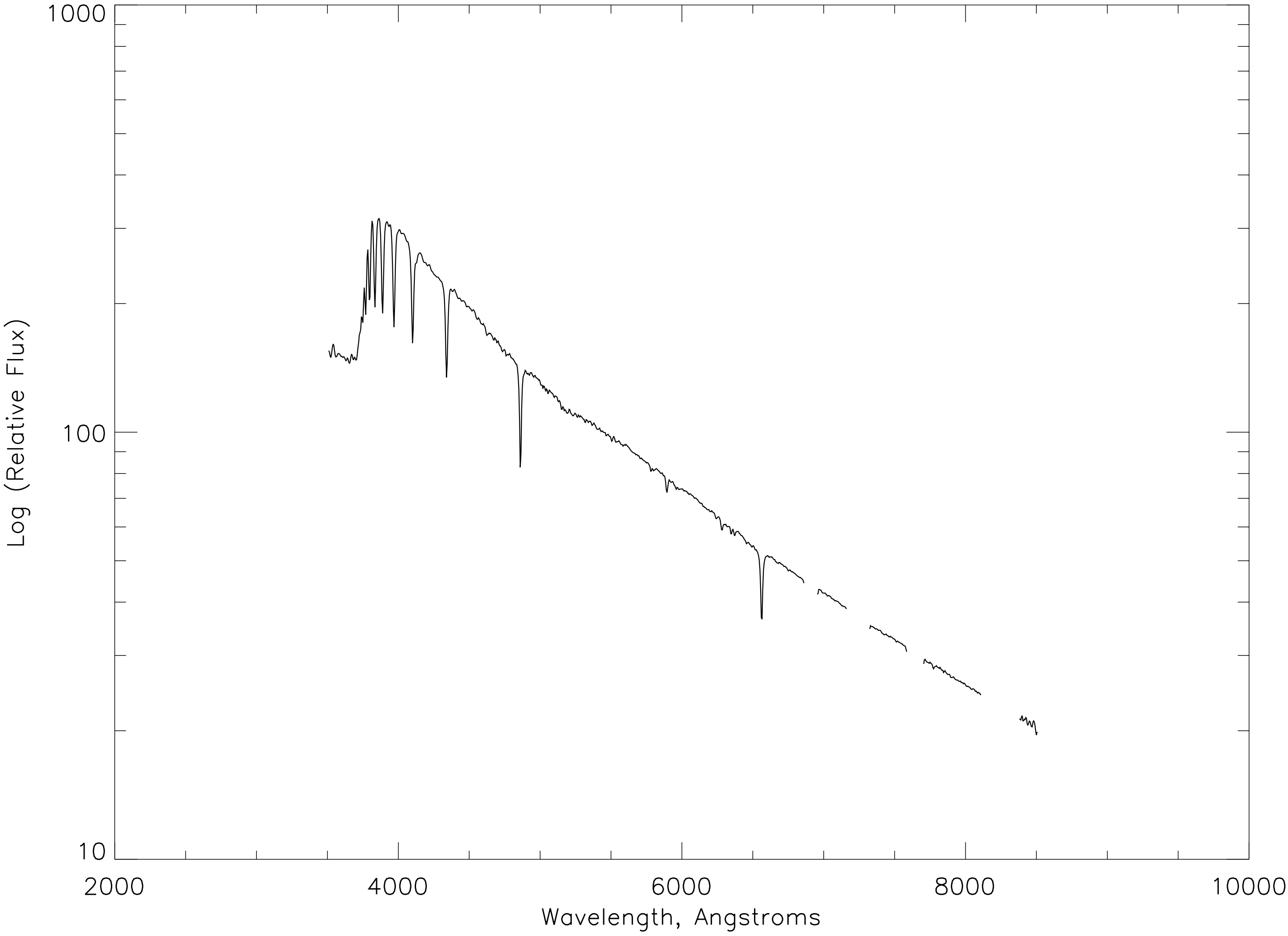

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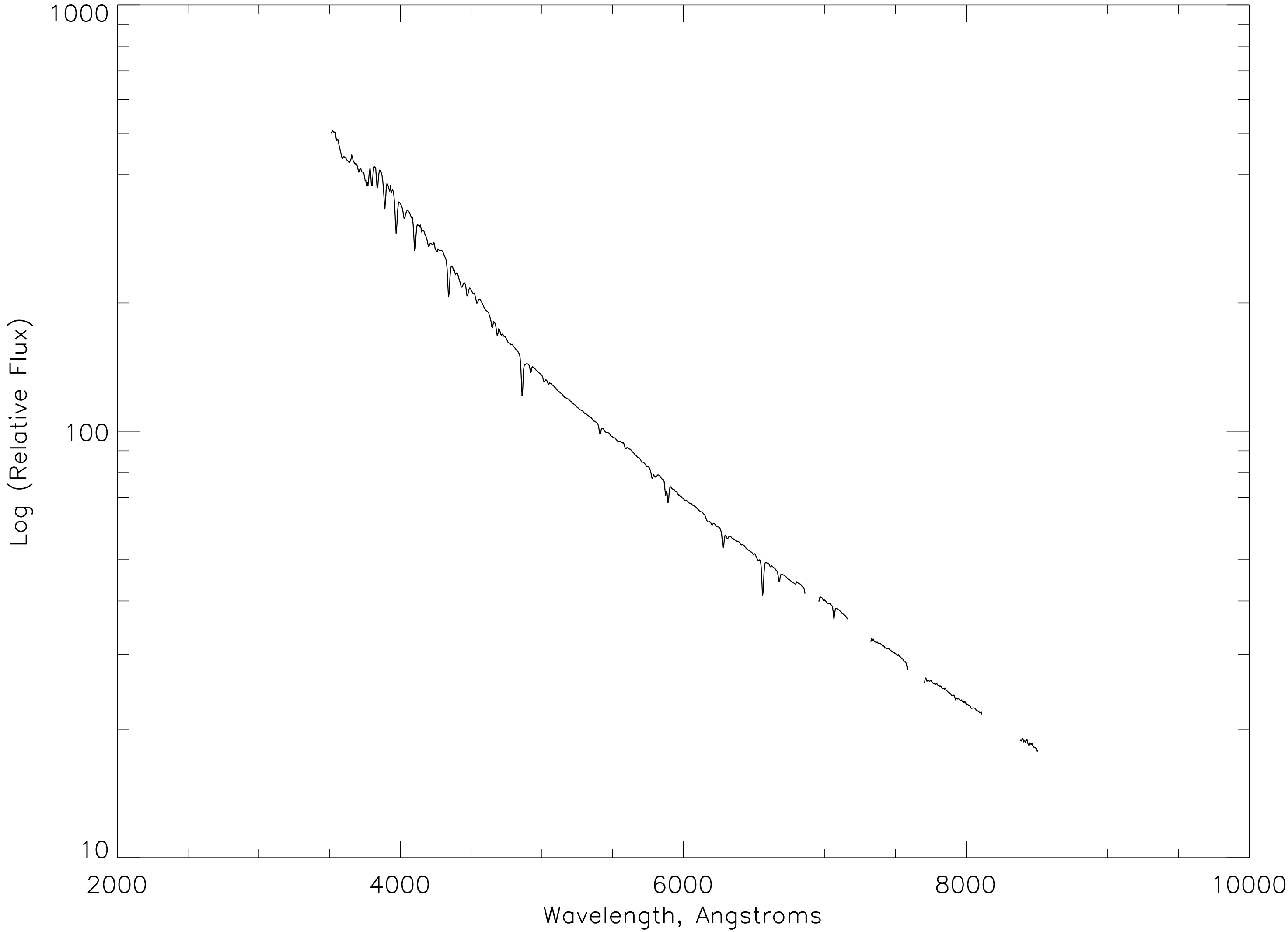

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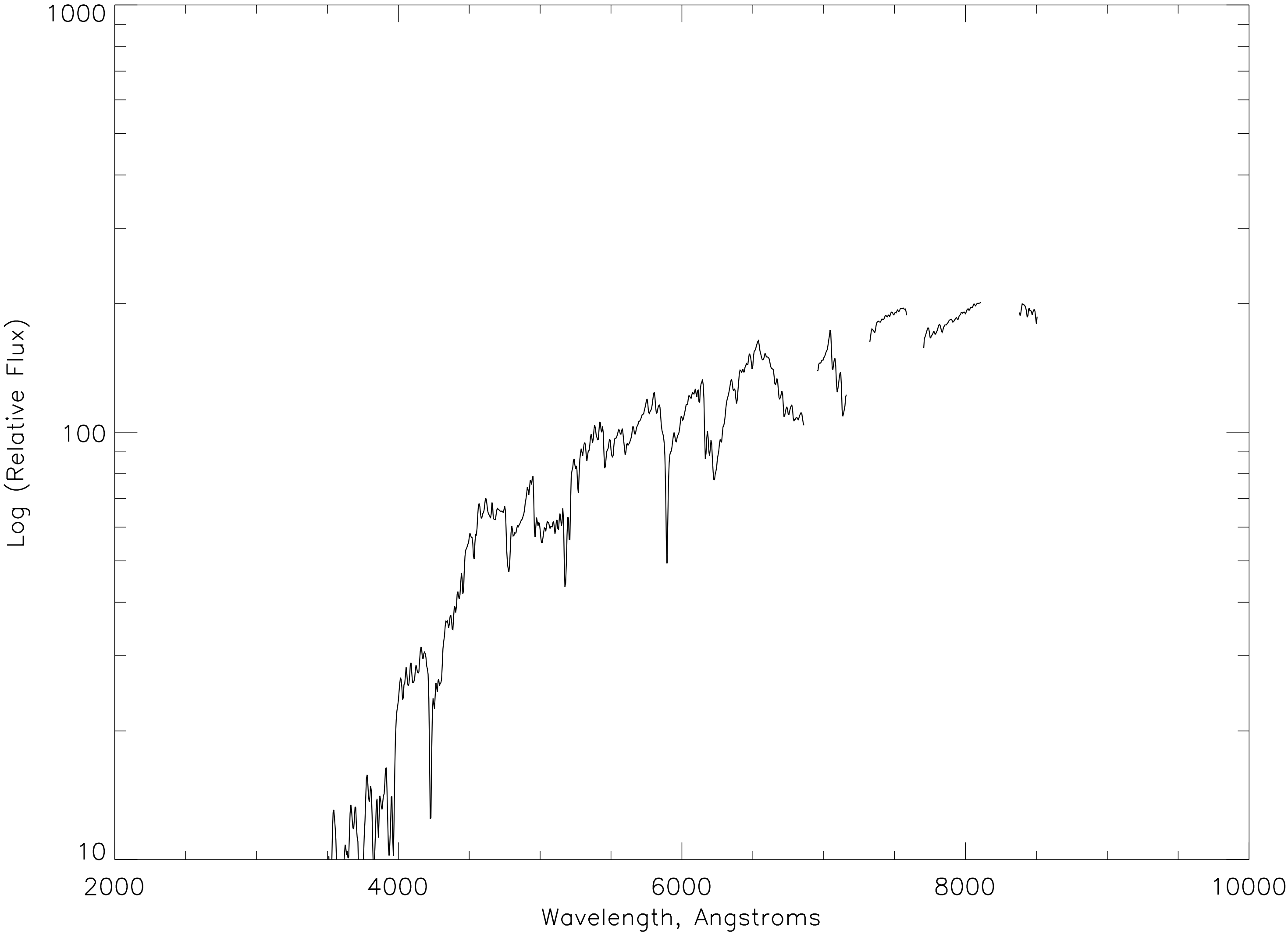
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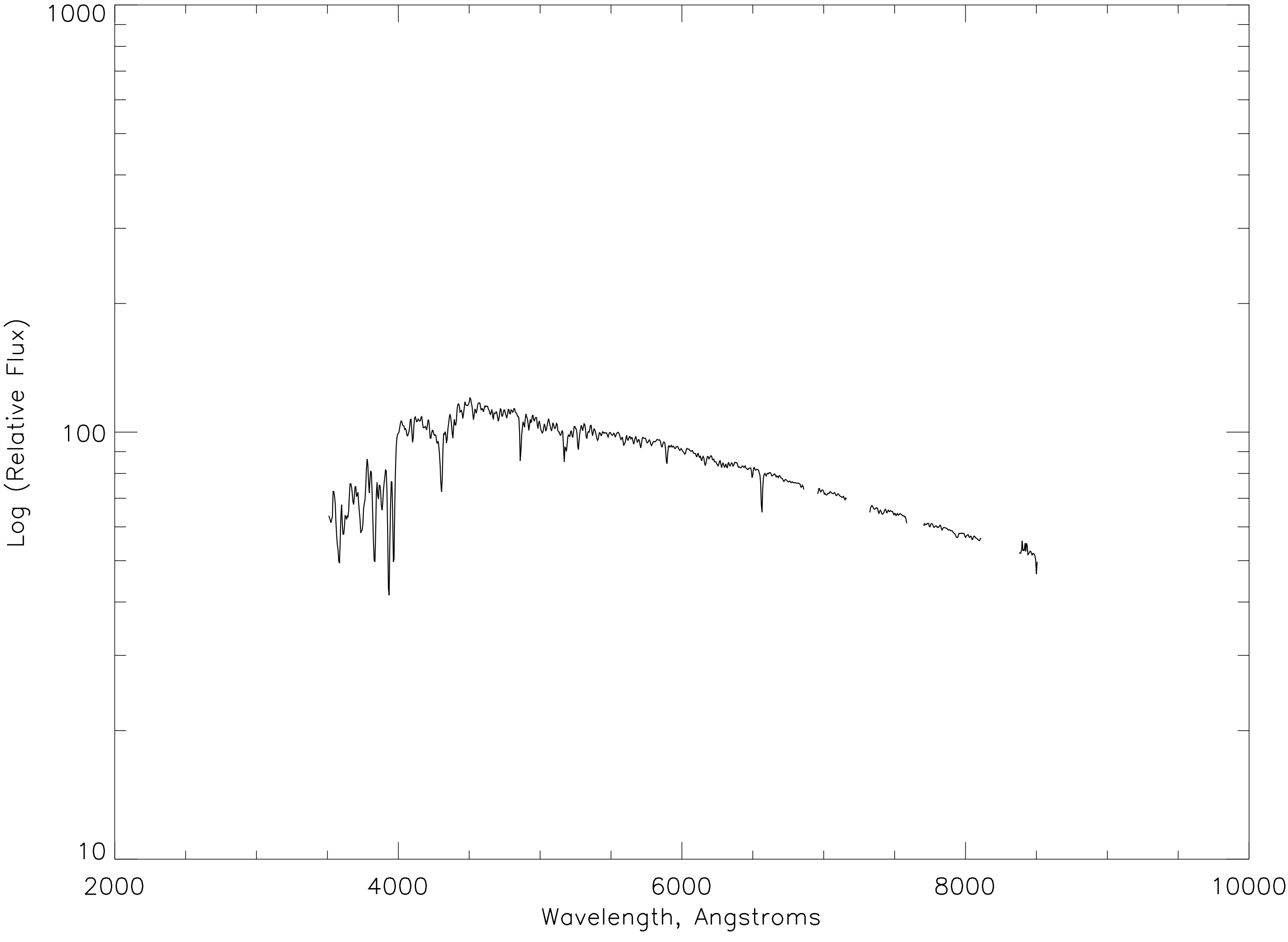
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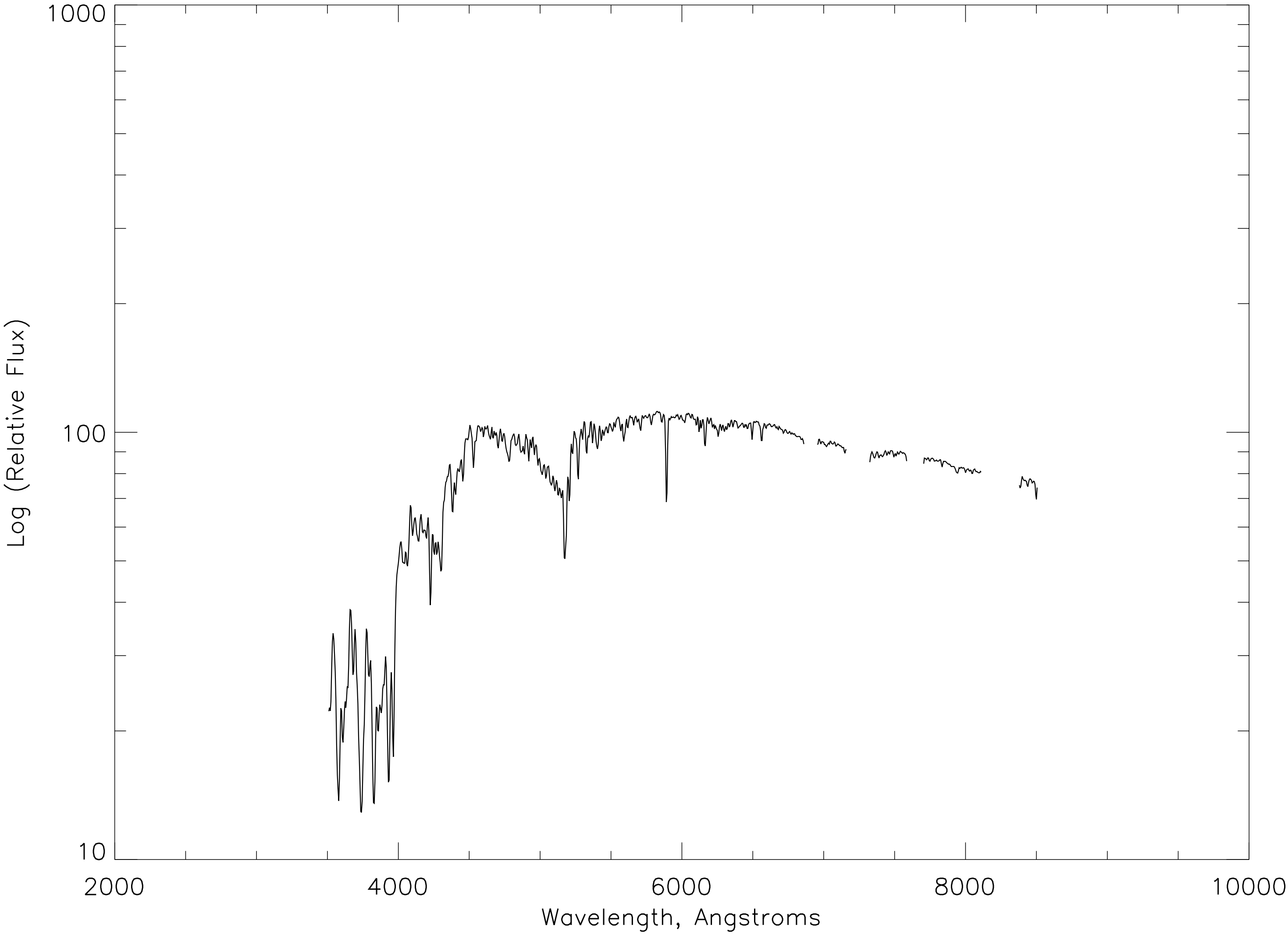
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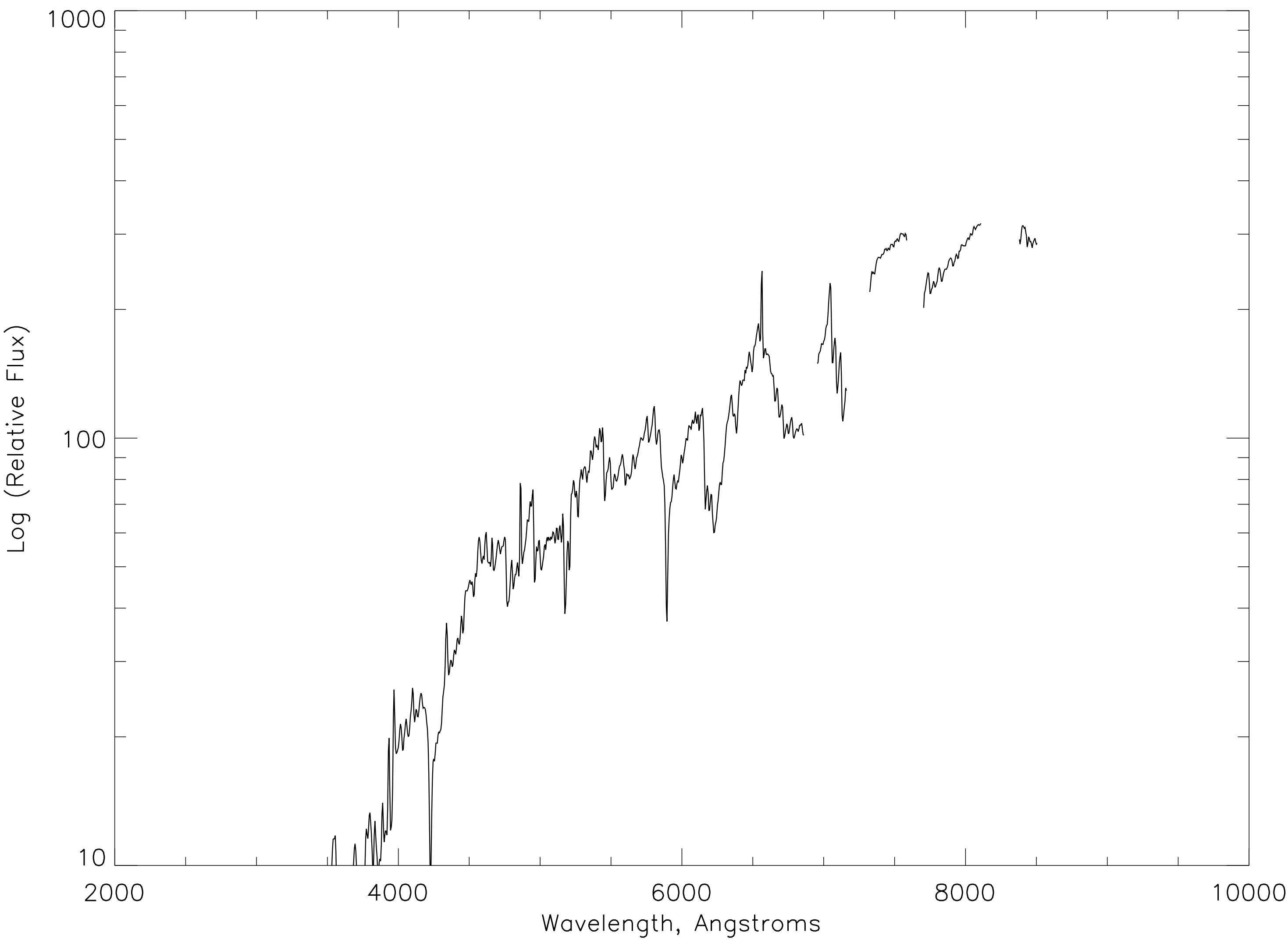

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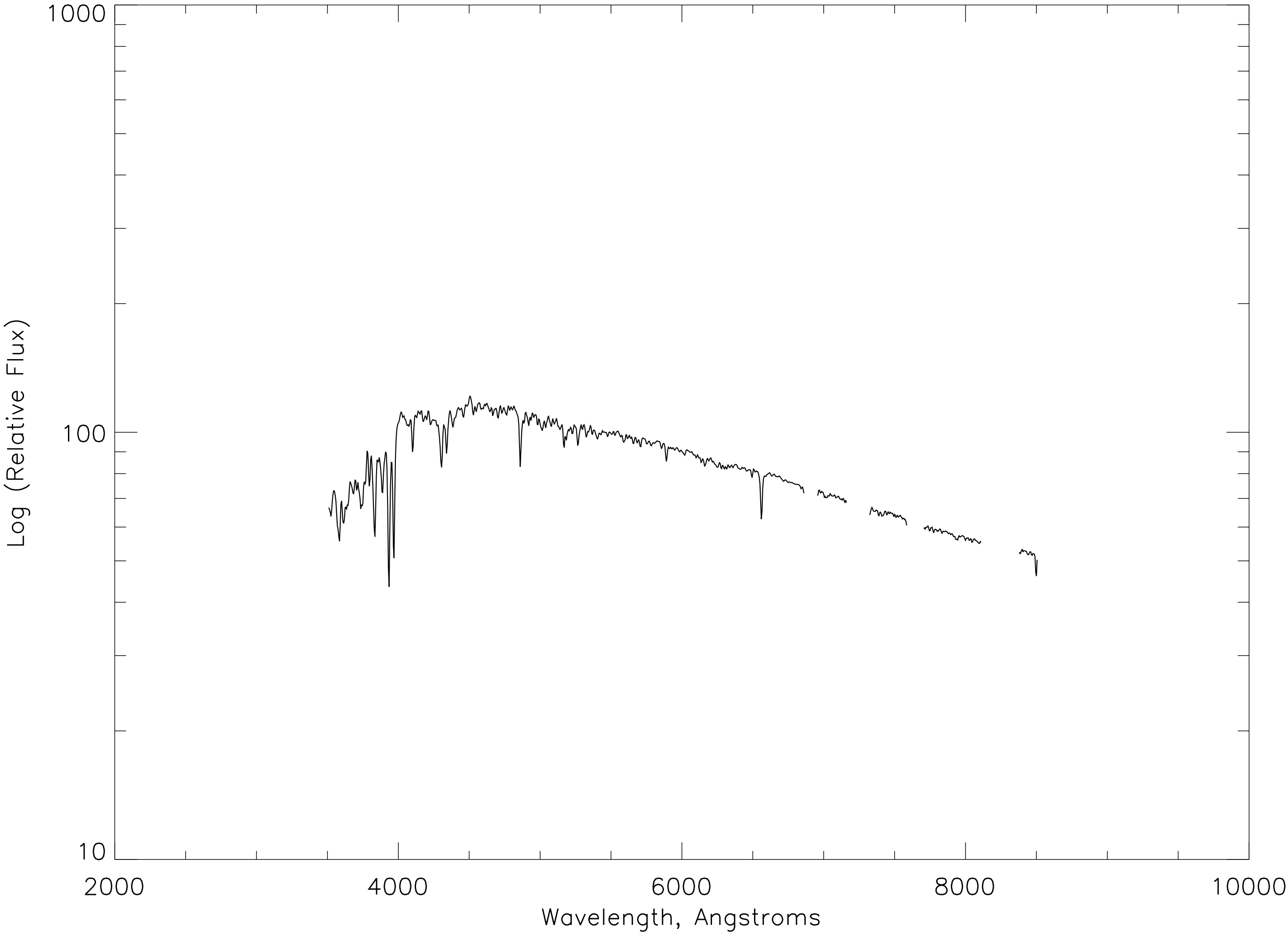

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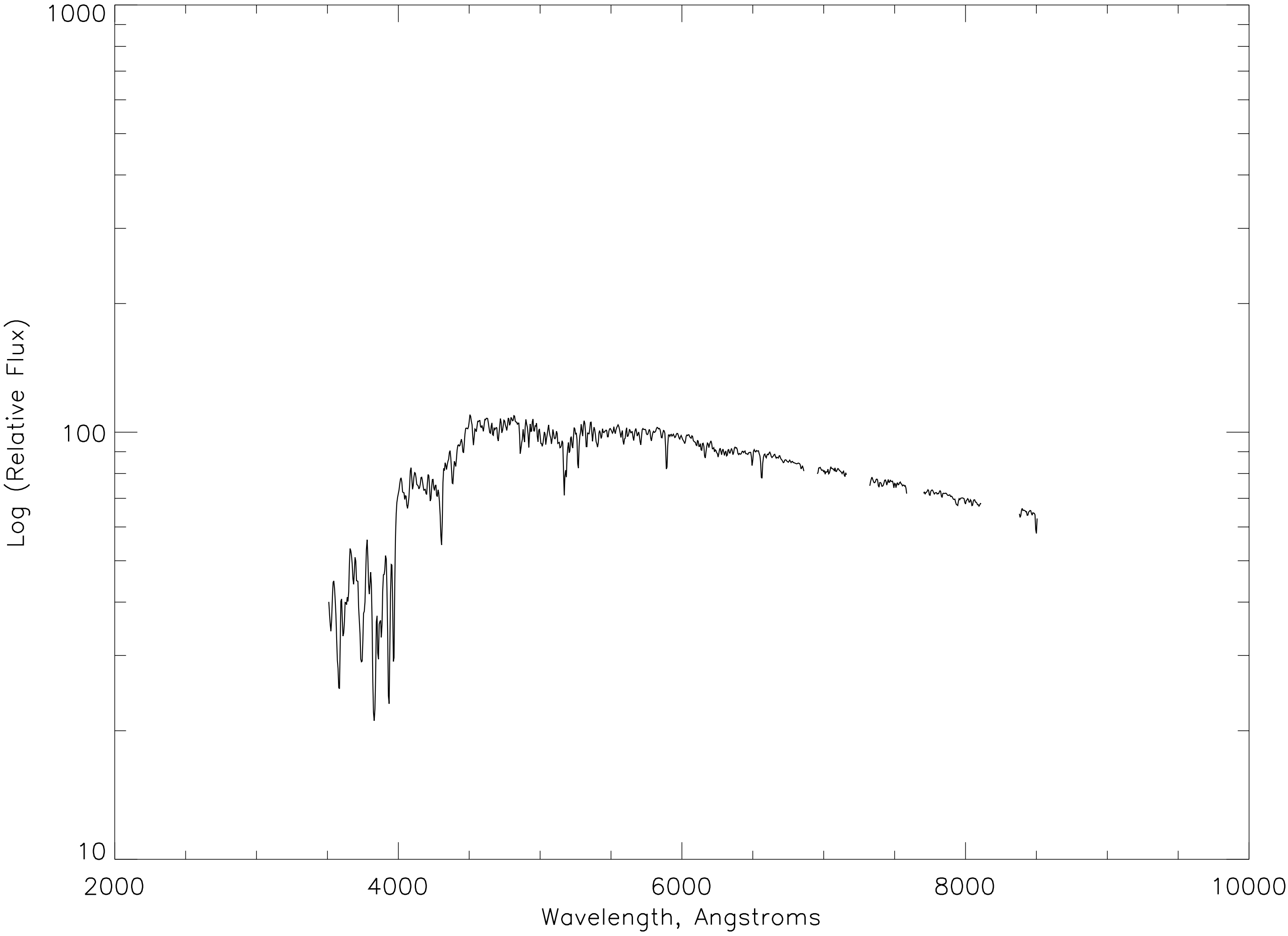
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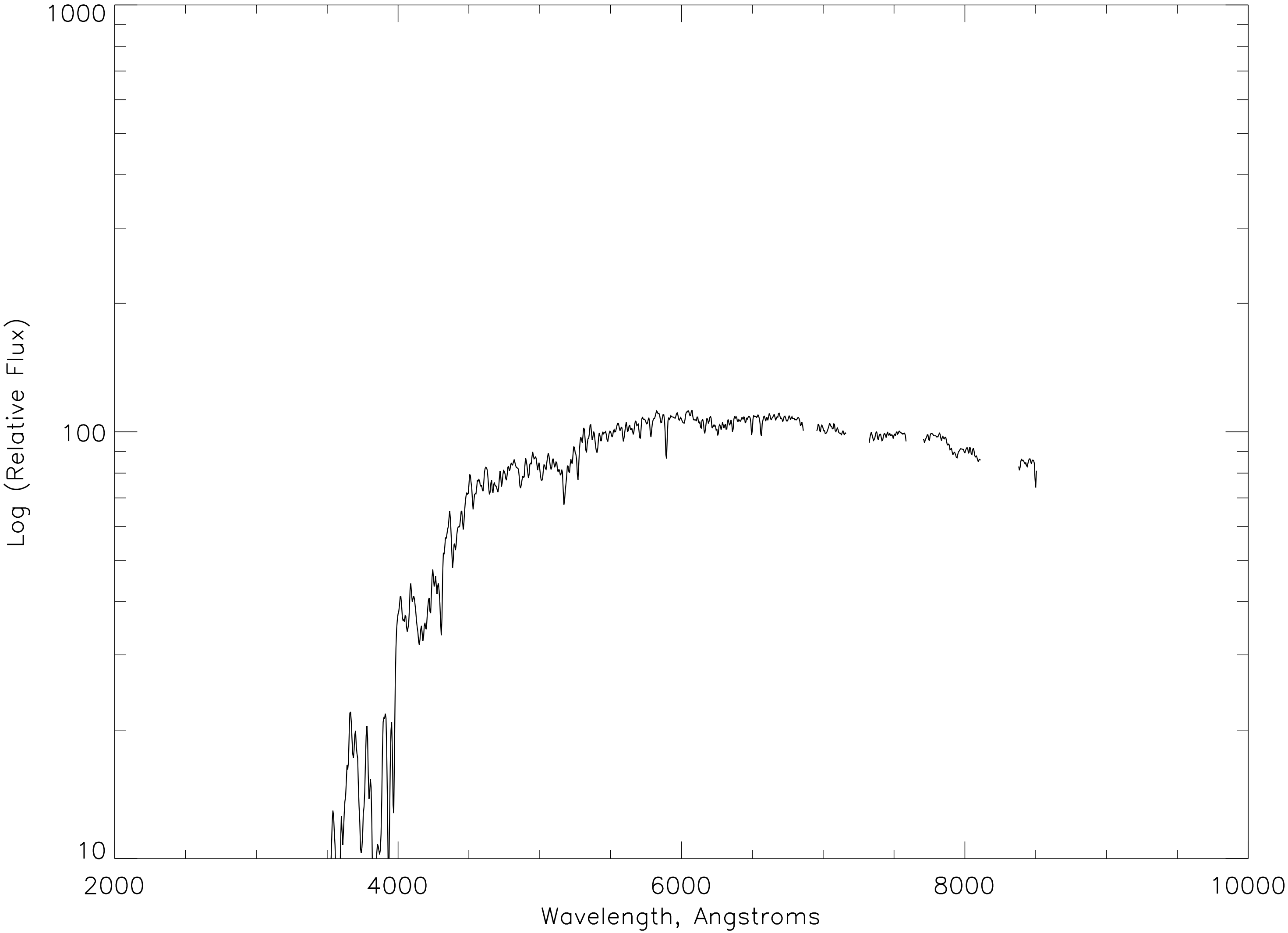
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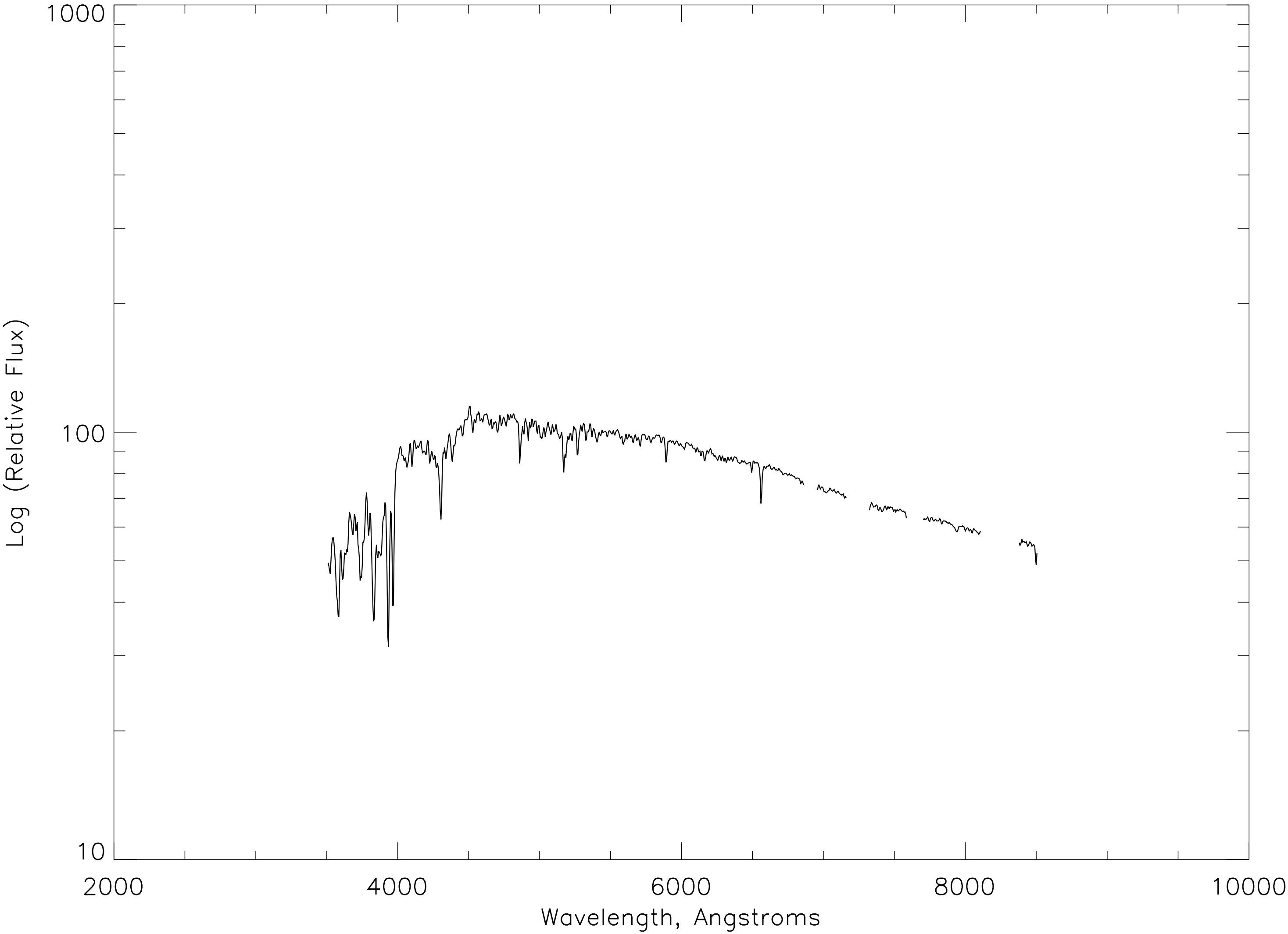
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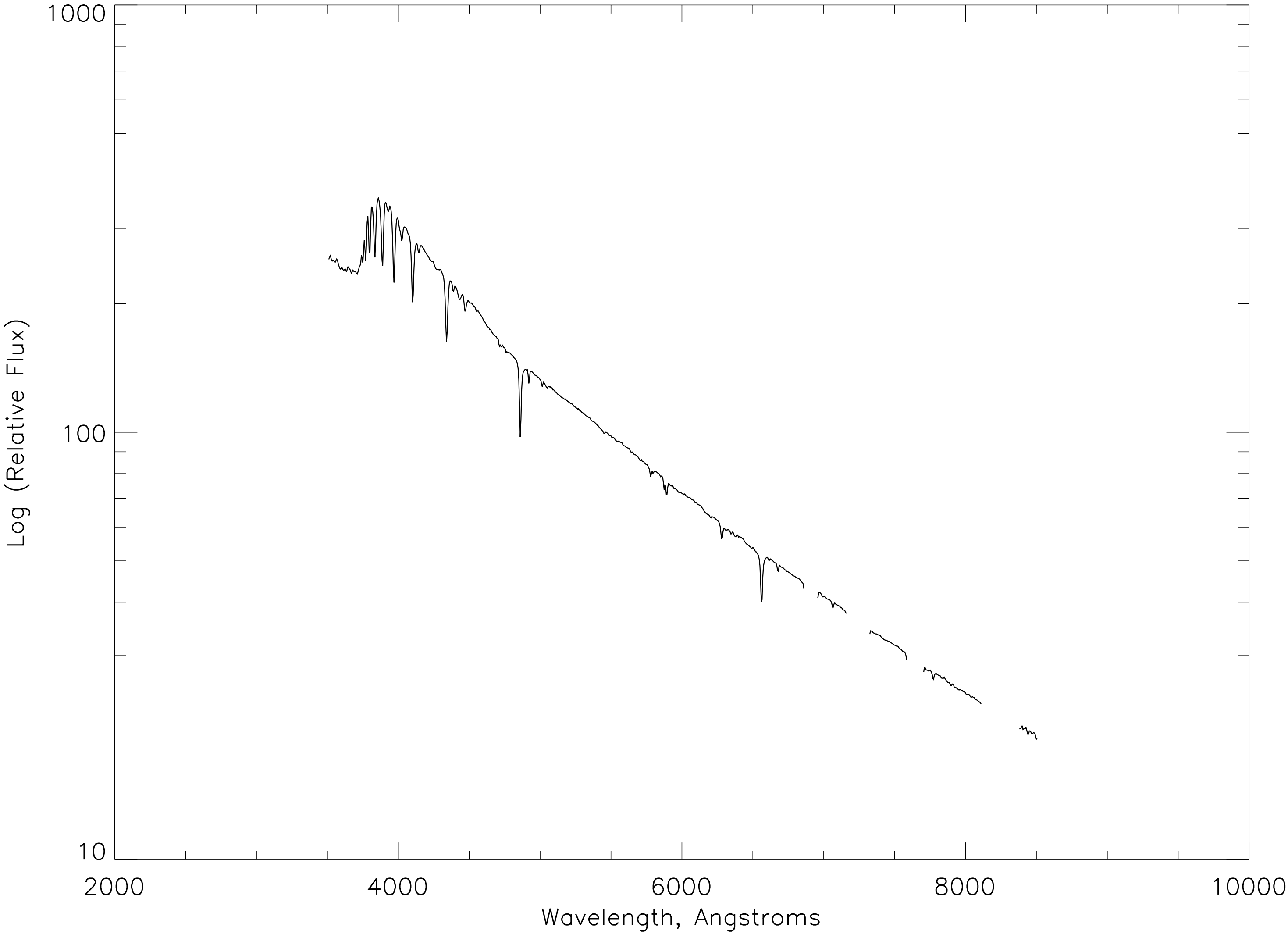
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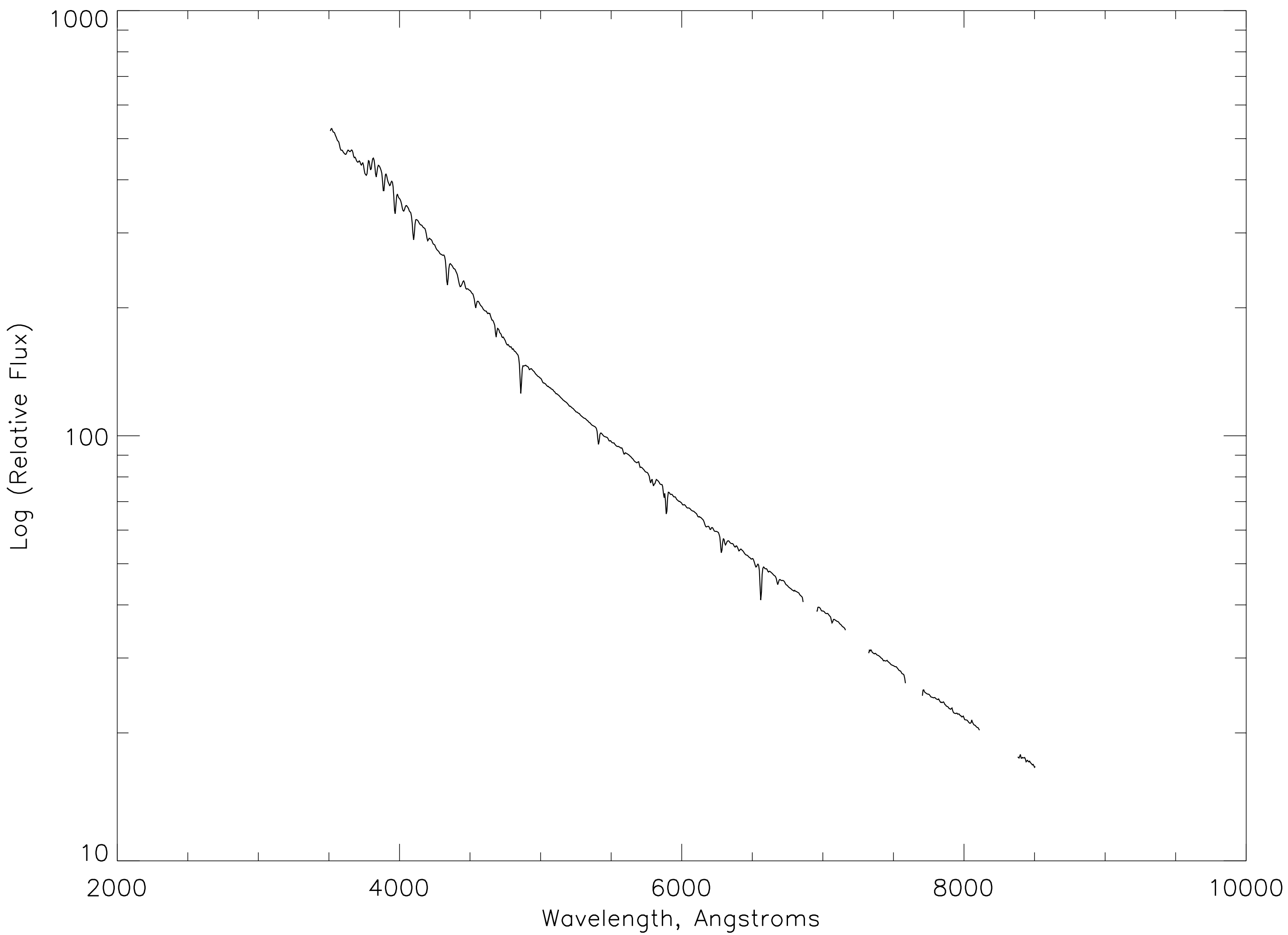

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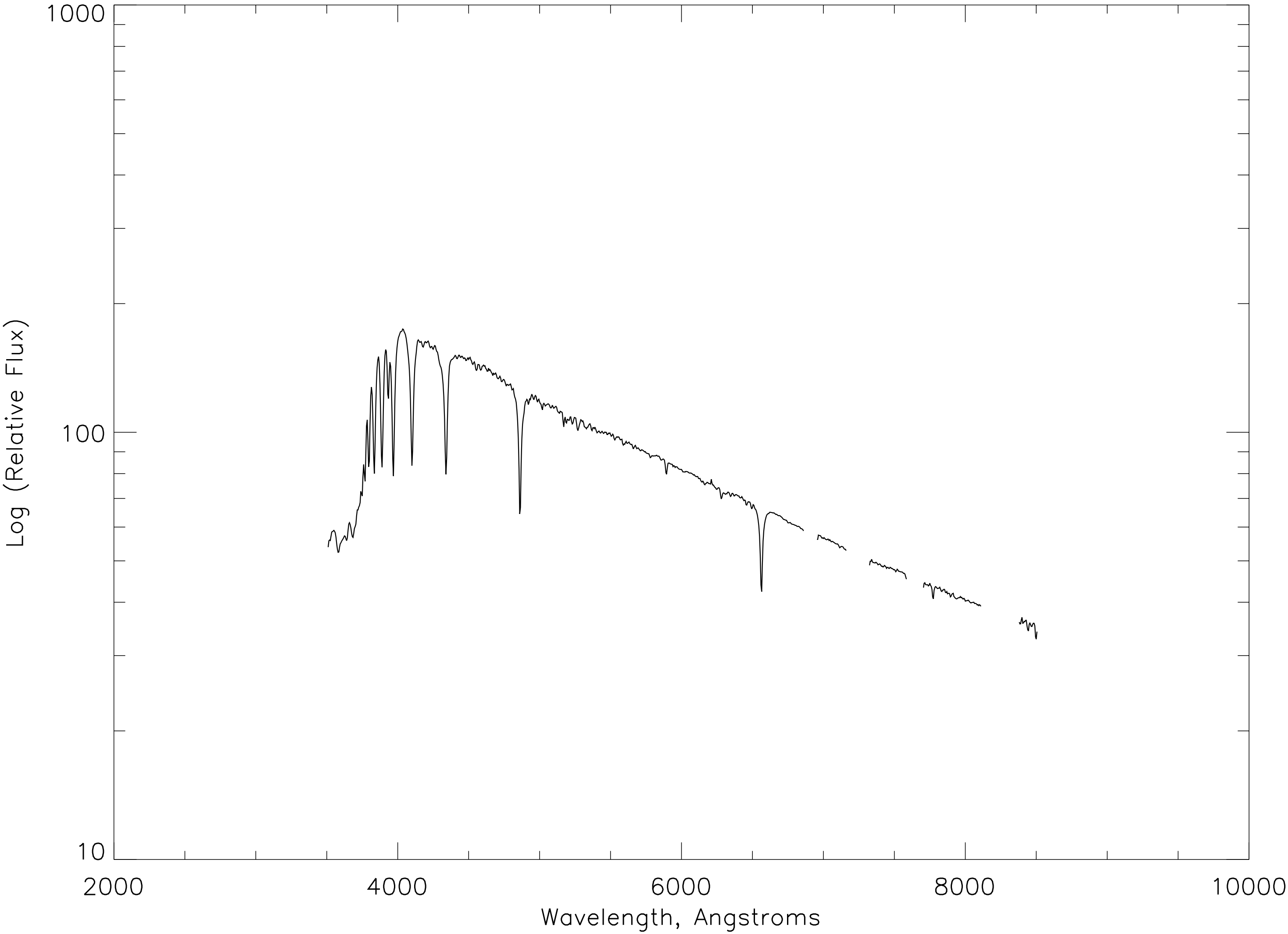


1000
100
10
Log (Relative Flux)
2000
4000
6000
8000
10000
Wavelength, Angstroms

Age and Distance to Stellar Clusters

Examine the cluster color-magnitude diagrams handed out with this assignment and answer the following questions:

1. For each cluster:
    a. Identify the main sequence.
    b. Sketch in a line that follows the main sequence from its brightest point to the bottom of the diagram. For some clusters, you will need to extrapolate the main sequence to magnitudes fainter than have been plotted. Sometimes astronomical photographs don't reach faint enough stars to detect the bottom portion of the main sequence.
2. Which cluster contains stars with the brightest apparent magnitude?
3. Which cluster contains the stars with the brightest absolute magnitude?
4. Which cluster has the most red giants?
5. In which cluster have white dwarf stars been detected?
6. What is the difference in magnitude between white dwarf stars and main sequences stars of the same color?

7. Estimate the distance to each of the clusters (you can assume a sun-like star has a B-V color of 0.6)

Cluster ID	Distance (in pc)	Age (in Gyrs)
NGC 752		
M 67		
Hyades		
Pleiades		
M 34		
Jewelbox		

8. Determine the turn-off color for each cluster and estimate its age using Figure 1.

9. Why has a cluster with a turnoff color of B-V = 0.9 never been discovered?

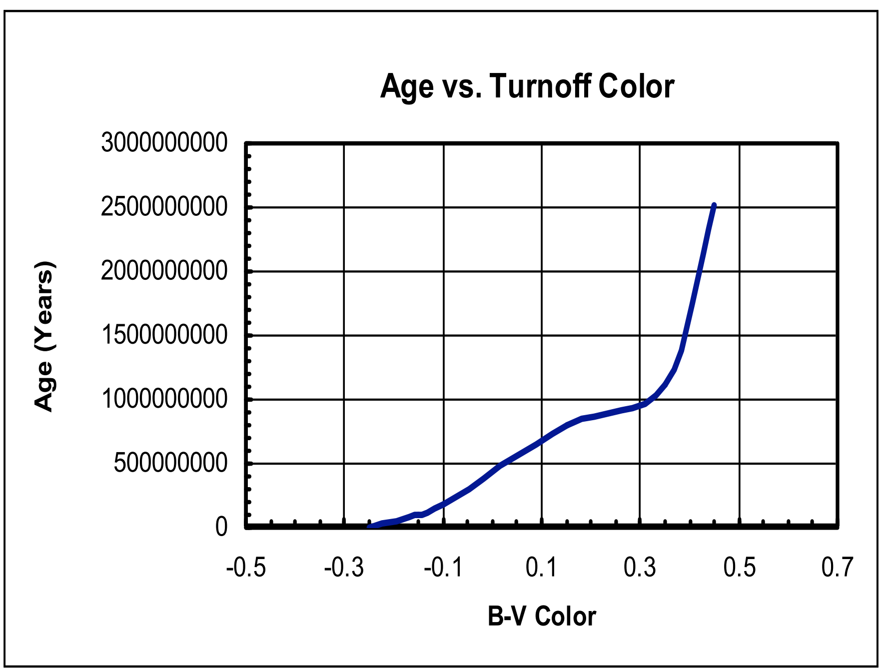
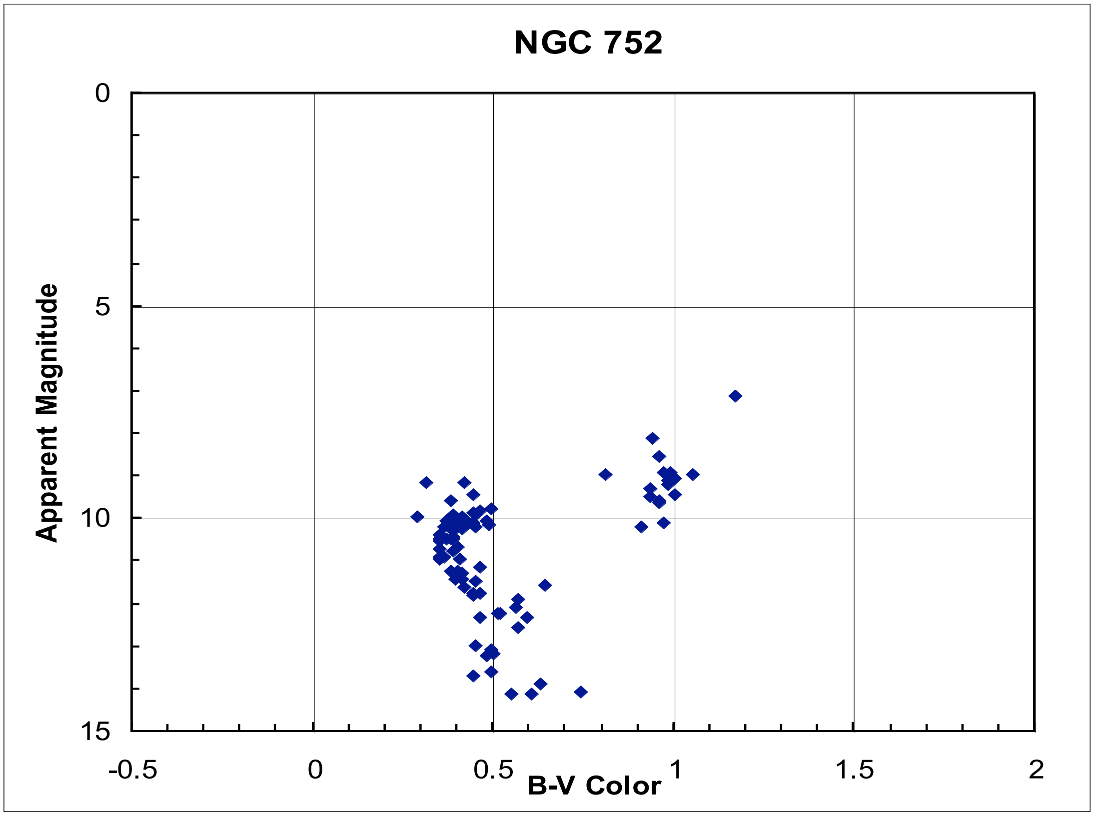
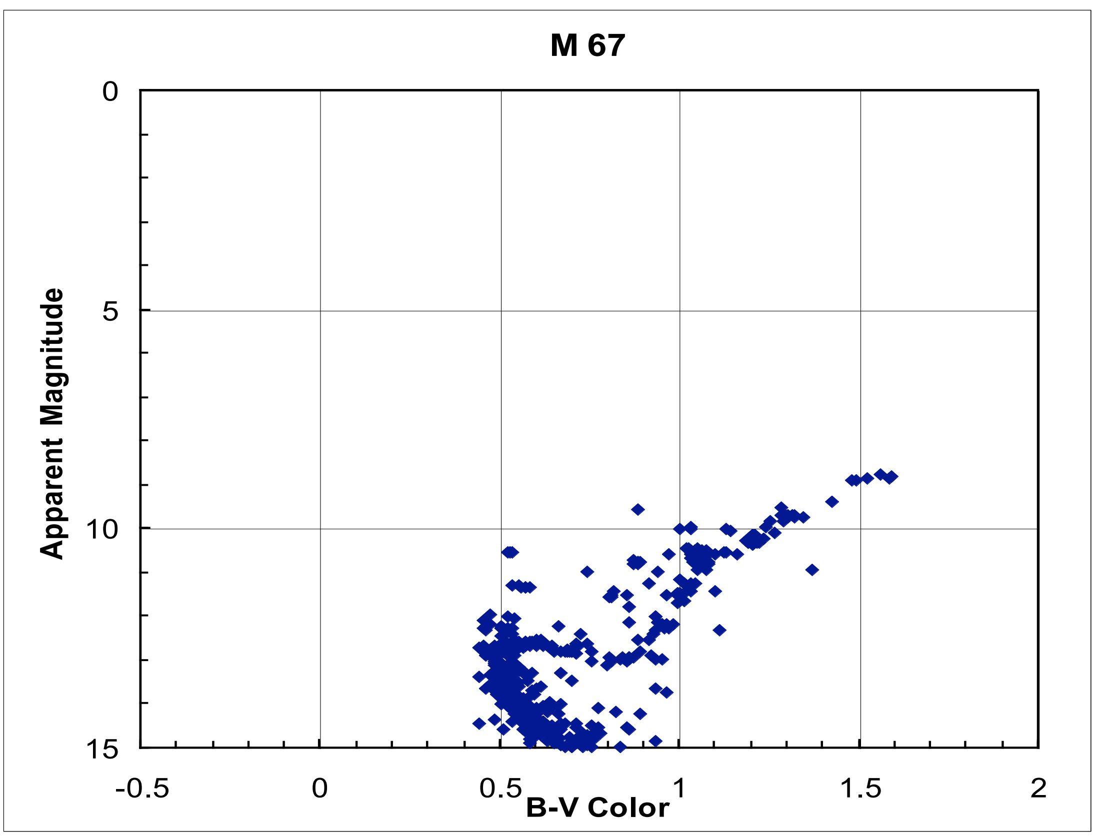
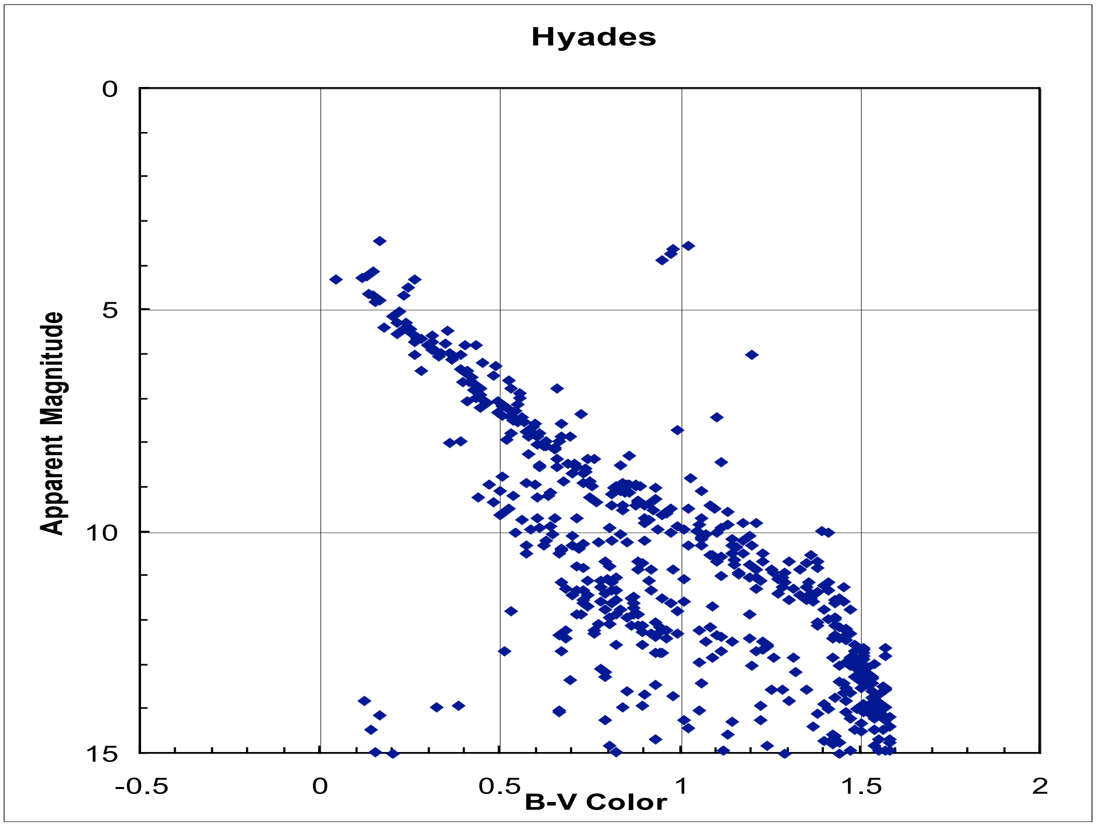
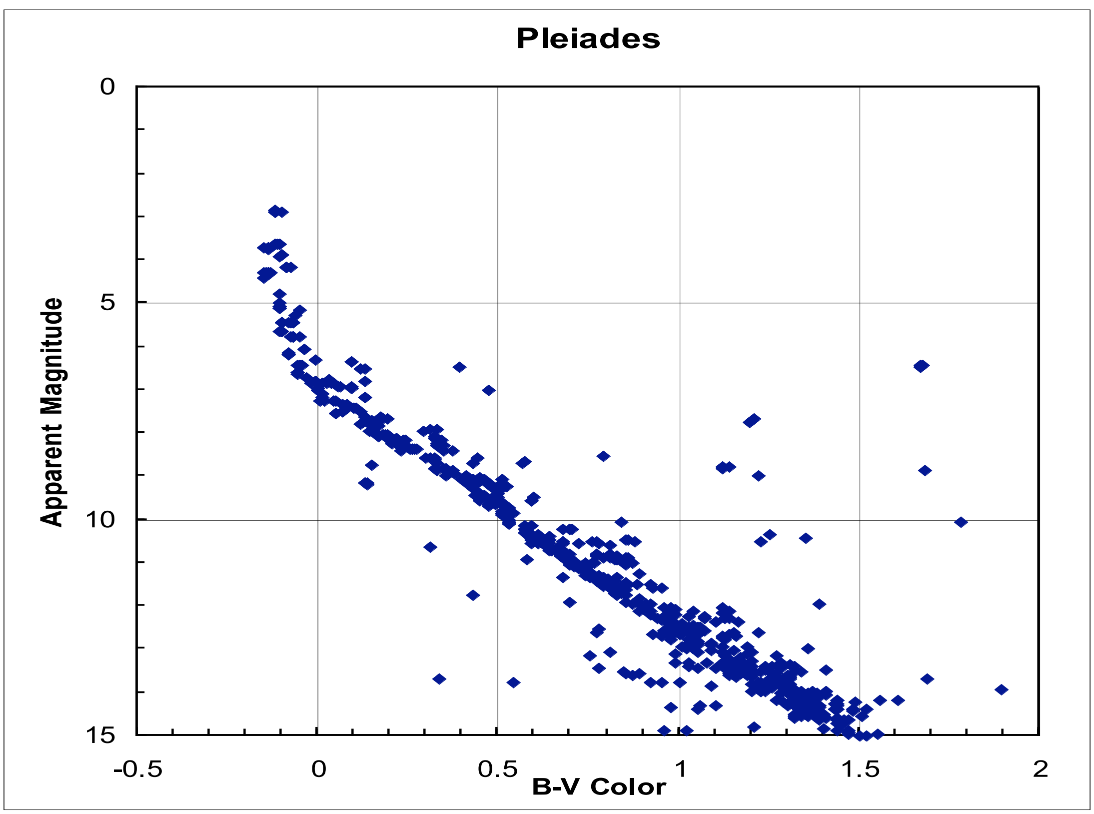


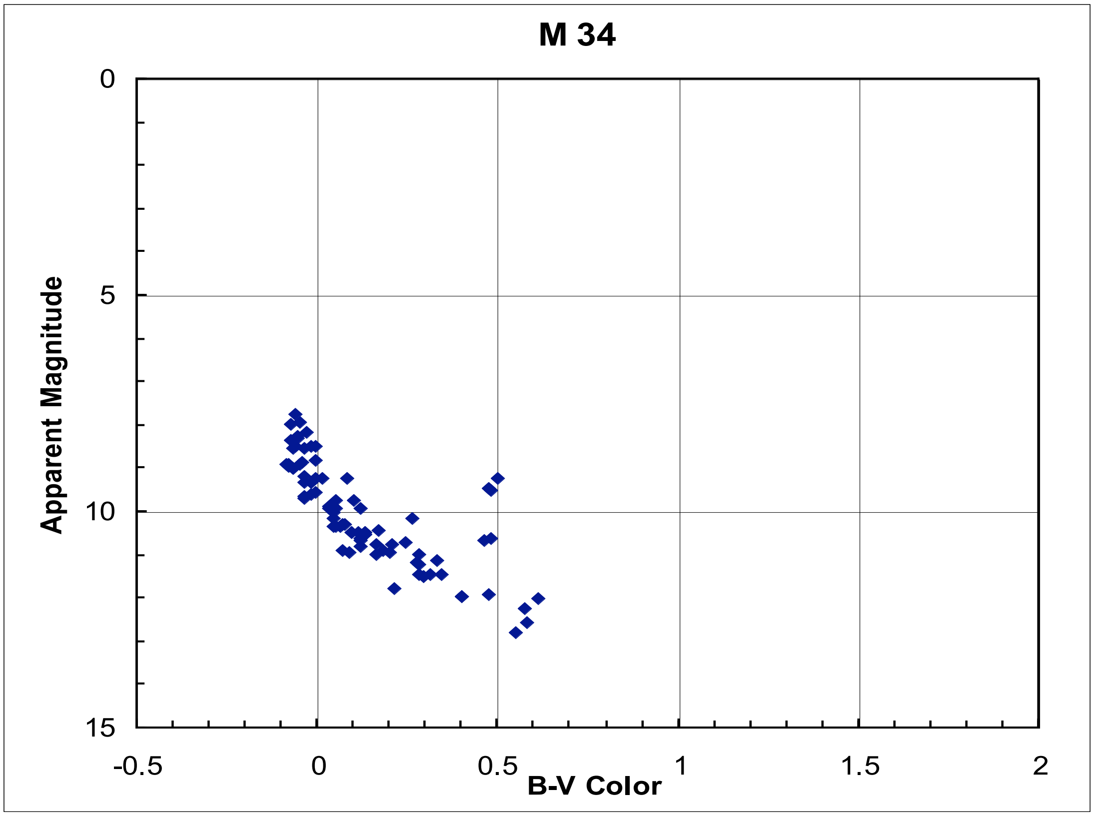
Figure 1: Age vs. turnoff color

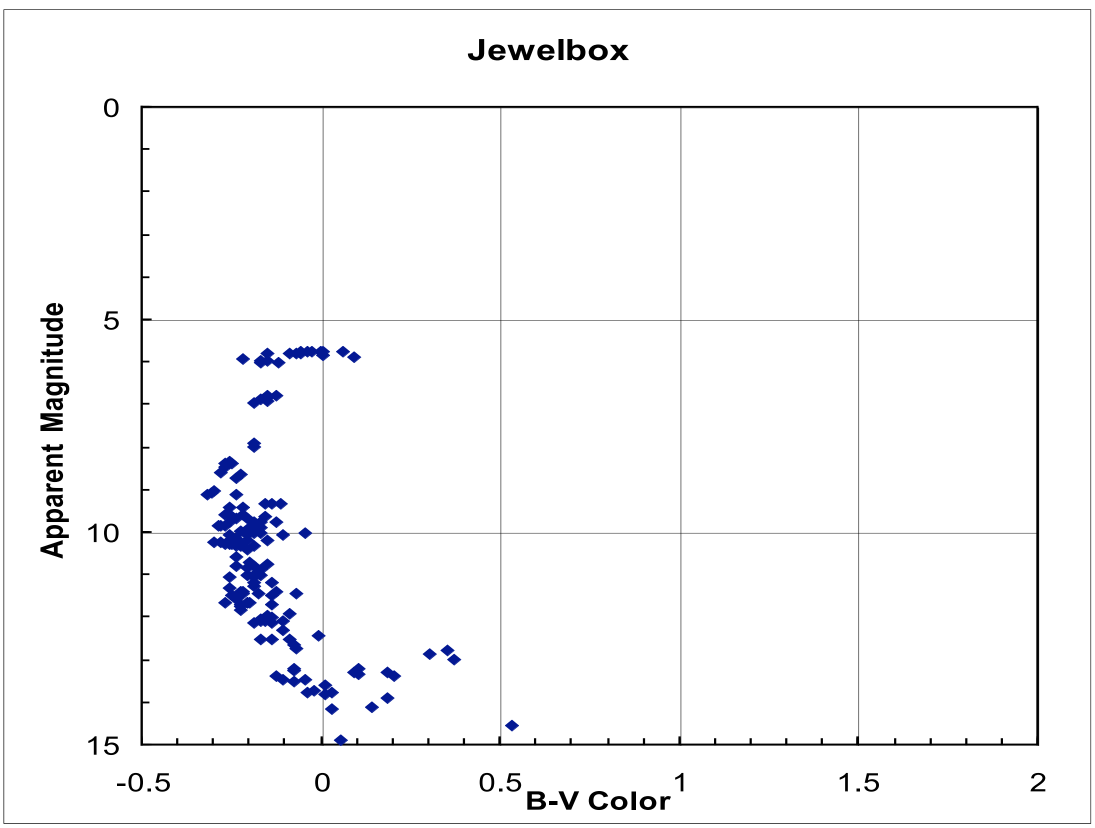

NGC 752
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2

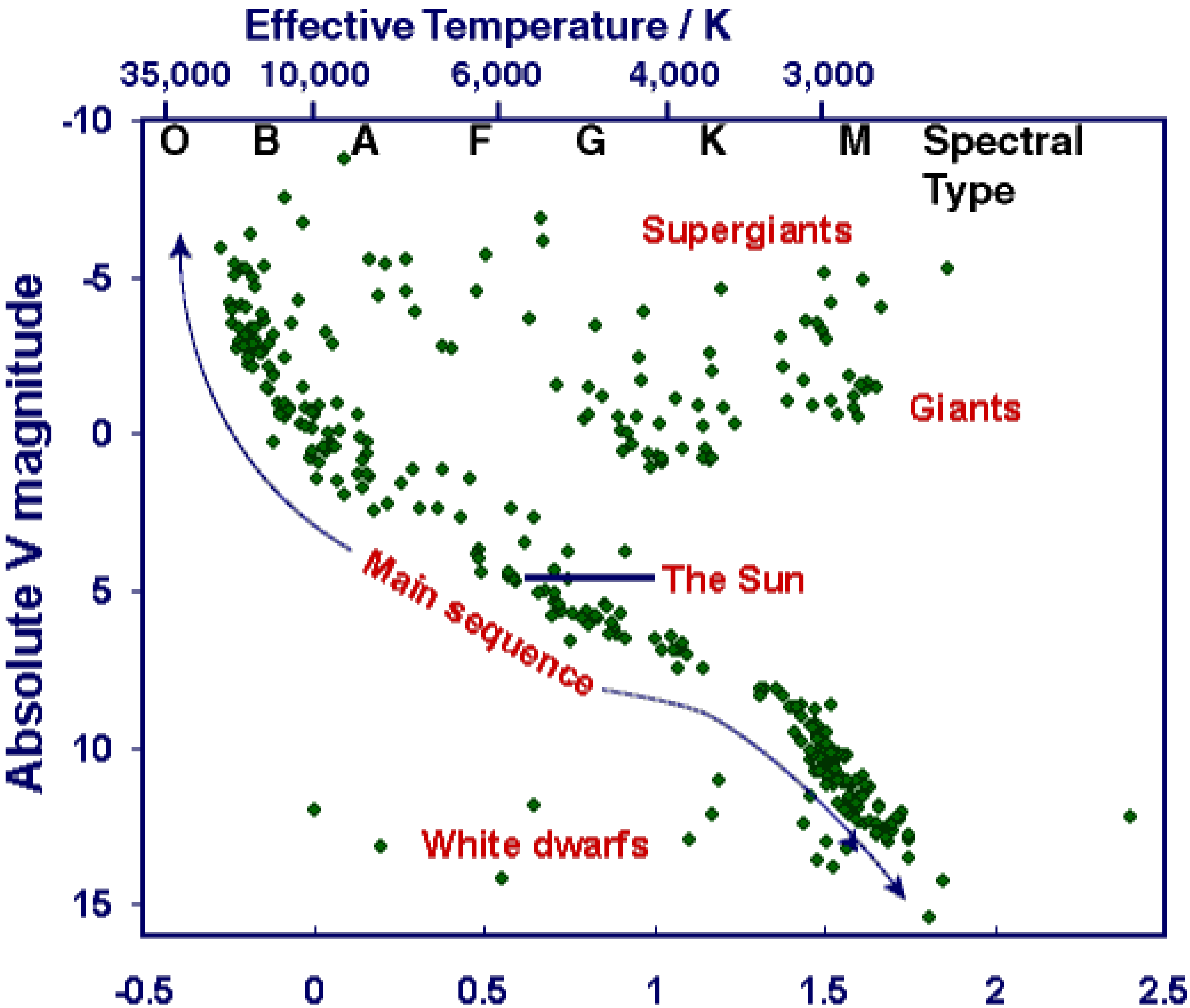

M 67
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2


Hyades
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2


Pleiades
Apparent Magnitude
B-V Color
0
5
10
15
-0.5
0
0.5
1
1.5
2


M 34
Apparent Magnitude
0
5
10
15
-0.5
0
0.5
1
1.5
2
B-V Color


Jewelbox
Apparent Magnitude
0
5
10
15
-0.5
0
0.5
1
1.5
2
B-V Color



Effective Temperature / K
35,000
10,000
6,000
4,000
3,000
-10
O
B
A
F
G
K
M
Spectral Type
Supergiants
-5
Giants
0
The Sun
Main sequence
5
10
White dwarfs
15
-0.5
0
0.5
1
1.5
2
2.5
B-V colour index
Absolute V magnitude

Stellar Modeling

For this assignment, you will need the program *StatStar*, which can downloaded from your text's companion website *www.aw-bc.com/astrophysics*.

1. Download the code for this assignment. You will need a computer running Windows XP or use the computers in SL 220 (open a Terminal and type "*statstar*"). Linux users: Compile from the code! C++ and Fortran95 available!

2. Use *StatStar* to create valid zero-age main sequence (*ZAMS*) models for the following stars. You can use the masses and temperatures below, and Figure 1 can help you determine the luminosity, but these will just be starting points. You will need to try a few values of the luminosity to find a valid model. A valid model means no negative values for pressure, density and temperature, as well as realistic values for luminosity and radius. Doing this in a systematic way will save you a lot of time (I'll demonstrate how to do this in class). For each model, use X = 0.7 for the mass fraction of hydrogen, Y = 0.292 for the mass fraction of helium, and 0.008 for the mass fraction of metals.

Mass (Solar Masses)	T_{eff} (K)
0.50	2287.70
0.75	3788.50
1.00	5402.00
2.00	10,952.60
10.00	27,933.00
15.00	32,873.30

3. For each star, use your models to determine
   a. The central temperature
   b. The central pressure
   c. The central density
   d. The radius

4. For **two** of your models (the highest mass and the lowest mass), generate a plot of temperature vs. radius and a plot of pressure vs. radius.
5. Using the output from *StatStar* for each model (the data saved in *ZAMSmodel.txt*), determine the region of the star undergoing nuclear fusion. For example, you can assume that the inner 10% of the 1.0 solar mass star is undergoing fusion. Find the percent of each star that has that same or higher temperature and pressure.
6. Using the luminosities and masses from your models, estimate the lifetime of each star, assuming that 0.7% of the region where nuclear fusion occurs is converted from mass into energy.

To hand in:

1. A table listing your model parameters (Mass, T_{eff}, and Luminosity) as well as the results of your models (core pressure, core temperature, core density, and radius). It should look something like this:

Mass (solar masses)	T_{eff} (K)	L (solar units)	Core Pressure (Pa)	Core Temp (K)	Core Density (kg/m^3)	Radius (solar units)
0.5	2287.7	0.02	...	...	...	...
0.75	3788.5	...	...	...	...	...
...	...	...	...	...	...	...

2. Plots of temperature vs. radius and pressure vs. radius for **two** of your models. (**EC: do all of your models, +10 points if well presented!)**
3. An estimate of the region undergoing fusion and each star's estimated lifetime (for all stars).
4. A discussion of your results. In particular, how do your results compare to your understanding of the H-R diagram and the main sequence? What are the main differences between low mass and high mass stars?

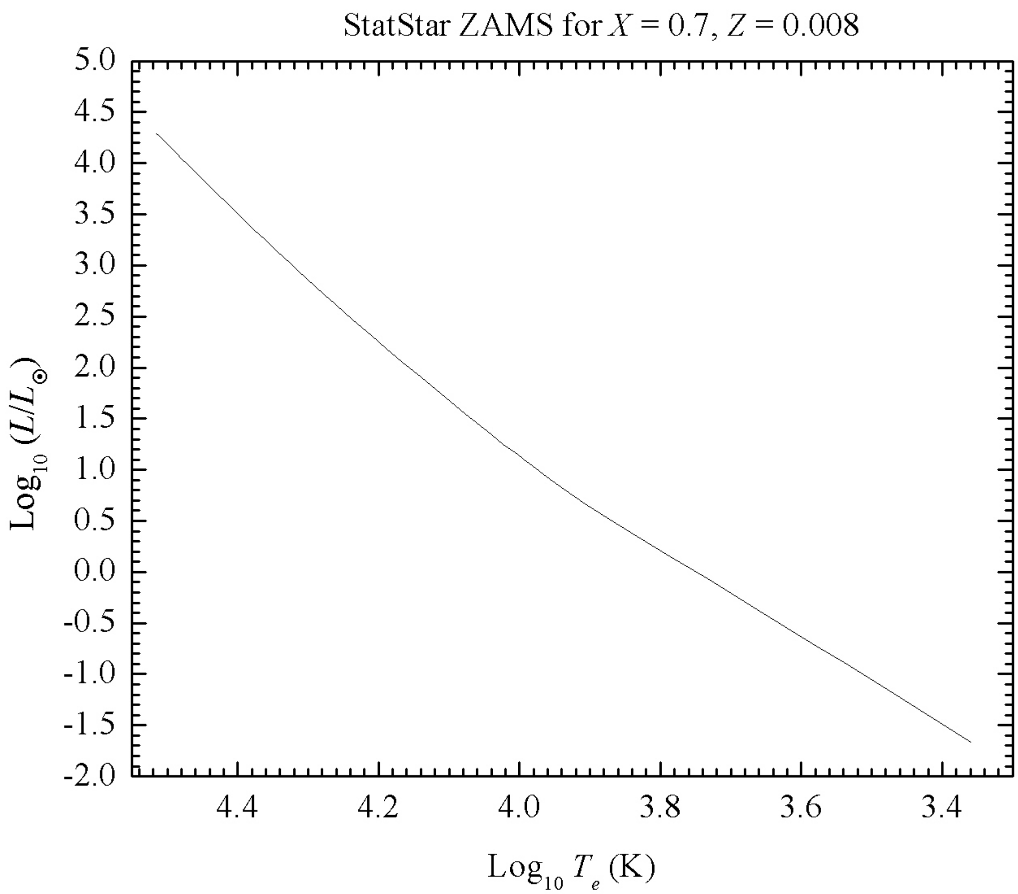


Figure 1: ZAMS Luminosity Estimates.

SETI - The Search for Extra-terrestrial Intelligence

The purpose of this assignment is to determine the number of alien civilizations in our galaxy, compose a message, and discuss some of the implications for humanity if we do (or do not!) find life in the galaxy.

Finding and communicating

1. Using the Drake Equation (http://en.wikipedia.org/wiki/Drake_equation) estimate the number of civilizations in our galaxy. In addition to reporting the total number of civilizations, make sure you specifically indicate all of your values, and briefly discuss why you made these estimates.
2. Compose an image to send to a communicating civilization. Since you are on a tight budget, you can only send 143 bits of information, corresponding to an 11x13 pixel image. Hand in your completed image and a description of what governed your decision to choose this particular image?
3. Assuming you sent your image 100 times over the span of 10 hours, compare the duration of your transmission to the distance between us and the nearest star (α Centauri, about 4 light years away). Discuss the likelihood of any α Centaurians detecting your message.

Where are they?

4. What is the Fermi Paradox? That is, what are its main assumptions and what is the “paradox”?
5. One solution to the Fermi Paradox suggests that we are the most advanced civilization in the galaxy. How does that conflict with the Copernican Principle?
6. What are some other possible solutions to the Fermi Paradox?

Who speaks for Earth?

7. Imagine a signal from a communicating civilization is received on Earth, detected simultaneously by many astronomers in many nations. Describe the effect this would have world events, both globally, regionally, and in your personal life.
8. Go on Canvas and post to the graded discussion “Who Speaks for Earth”: If you could ask only one yes or no question of an extraterrestrial civilization, what would it be? What are the implications of the “yes” answer and what are the implications of the “no” answer?

Assignment 10 Solutions

Problems: 14.1, 14.2, 14.3, 14.5, 14.6, 14.7

14.1: 9 Sagittarii is a main sequence star type O5. Find the distance if:

In[1]:=
```
apparentMagnitude = 6.0;
absoluteMagnitude = -5.7 ;
distanceModulus = apparentMagnitude - absoluteMagnitude;
distance = 10^((distanceModulus + 5)/5) pc;
"Distance to 9 Sag"
SetPrecision[distance, 2]
```

Out[5]=
```
Distance to 9 Sag
```

Out[6]= 2.2×10^3 pc

14.2: What is the mean free path at the center of the Sun?

In[7]:=
```
massDensity = 1.52 × 10^5 kg m^-3;
opacity = 0.12 m^2 kg^-1;
"Mean free path:"
SetPrecision[1/(massDensity opacity), 2]
```

Out[9]=
```
Mean free path:
```

Out[10]= 0.000055 m

14.3: What is the approximate central pressures of the following stars?

In[59]:=

```
"Start with hydrostatic EQ:"
G = 6.67 × 10^-11;
Msun = 1.989 × 10^30;
Rsun = 6.955 × 10^8;
ρ[M_, R_] = M / (4/3 π R^3);
"Central Pressure (integrate HSEQ
  assuming constant density (but not constant g!)"
centralPressure[M_, R_] = 2/3 π (ρ[M, R])^2 R
"a) K0 V star:"
SetPrecision[centralPressure[0.8 Msun, 0.85 Rsun] , 2]
"b) K0 III star"
SetPrecision[centralPressure[4 Msun, 16 Rsun] , 2]
"c) K0 I star"
SetPrecision[centralPressure[13 Msun, 200 Rsun] , 2]
```

Out[59]= Start with hydrostatic EQ:

Out[64]= Central Pressure (integrate HSEQ
  assuming constant density (but not constant g!)

Out[65]= $\frac{3 M^2}{8 \pi R^5}$

Out[66]= a) K0 V star:

Out[67]= 4.2×10^{15}

Out[68]= b) K0 III star

Out[69]= 4.4×10^{10}

Out[70]= c) K0 I star

Out[71]= 1.5×10^{6}

14.4: Neutral gas

In[135]:=
```
X = 0.734
Y = 0.25
Z = 0.016
A = 10
"So A doesn't really matter"
muNeutral = (X + Y / 4 + Z / A)^-1
```

Out[135]= 0.734

Out[136]= 0.25

Out[137]= 0.016

Out[138]= 10

Out[139]= So A doesn't really matter

Out[140]= 1.25298

14.5: effect of distance errors on H-R diagram:

In[179]:=
```
"From our distance modulus equation, you can show that"
distanceModError[error_] = 5 Log10[1 + error]
SetPrecision[distanceModError[-.1], 2]
SetPrecision[distanceModError[.1], 2]
"So we get a range of -.23 mag brighter for
  90% or 0.21 mags fainter for 110% of nominal distance"
```

Out[179]= From our distance modulus equation, you can show that

Out[180]= $\frac{5\,\text{Log}[1+\text{error}]}{\text{Log}[10]}$

Out[181]= -0.23

Out[182]= 0.21

Out[183]= So we get a range of -.23 mag brighter for 90% or 0.21 mags fainter for 110% of nominal distance

14.6: How does surface gravity vary along the main sequence with luminosity?

In[234]:=
```
"deploy mass - radius and luminosity-mass relationships in g = GM/r^2"
```

Out[234]= deploy mass - radius and luminosity-mass relationships in g = GM/r^2

In[321]:=

```
RstarSmall[Mstar_] = 1.06 (Mstar)^0.945;
RstarBig[Mstar_] = 1.33 (Mstar)^0.555;
"Since more massive stars are more luminous,
  we can use this to estimate the surface gravity"
gravity[Mstar_, Rstar_] = G Mstar/Rstar^2 m/s^2;
"For a low mass star (< 1.66 Msun)"
SetPrecision[gravity[1.0 Msun, RstarSmall[1.0] * Rsun], 2]
"For a high mass star (>> 1.66 Msun)"
SetPrecision[gravity[10 Msun, RstarBig[10] * Rsun], 2]
"So, note, that more massive and more
  luminous stars can have **lower** surface gravity!"
```

Out[323]= Since more massive stars are more luminous, we can use this to estimate the surface gravity

Out[325]= For a low mass star (< 1.66 Msun)

Out[326]= $\frac{2.4 \times 10^2\ \text{m}}{\text{s}^2}$

Out[327]= For a high mass star (>> 1.66 Msun)

Out[328]= $\frac{1.2 \times 10^2\ \text{m}}{\text{s}^2}$

Out[329]= So, note, that more massive and more luminous stars can have **lower** surface gravity!

14.7: How much larger is Betelgeuse than GL 887?

In[225]:=

```
Mbol[BC_, Mv_] = BC + Mv;
Lsun = 3.839 × 10^26;
σ = 5.67 × 10^-8;
luminosity[BC_, Mv_] = 10^(0.4 (4.74 - Mbol[BC,Mv])) Lsun;
radius[T_, BC_, Mv_] = (luminosity[BC, Mv] / (4 π σ T^4))^(1/2);
radiusOfBetel = radius[3370, -1.62, -0.60];
radiusOfGL887 = radius[3520, -1.89, 9.76];
"Betelguese relative to GL 887:"
SetPrecision[radiusOfBetel / radiusOfGL887, 2]
```

Out[232]= Betelguese relative to GL 887:

Out[233]= 1.1×10^2

Take Home Exam I - Due Tuesday, Feb 12 at 10:30 AM

NO LATE EXAMS WILL BE ACCEPTED

This is the first take home exam for ASTR 3160. The guidelines:

1. You must work alone.
2. You may use any resources at your disposal (internet, book, calculator, abacus, tea leaves, fortune cookies, lucky charms, etc.) provided you follow guideline #1 (i.e. no Facebook crowd sourcing!)
3. Provide your answers on your own paper (don’t write on this exam!).
4. When necessary, provide professional-quality drawings of the problem (that is, use a compass, ruler, etc.).
5. Describe your procedures and answers to all of the questions.
6. Annotate your mathematical solutions with descriptions of all variables and show all work.
7. Since many of these problems require you to develop a full solution from your own resources, describe all of your variables (with units), discuss why you selected them (with sources, if necessary), and state all assumptions.
8. The exam will be out of 100 points, broken down as follows:
   a. 20 points reserved for the quality and completeness of the presentation.
   b. 20 points for the clarity of the procedures and computations.
   c. 60 points for the correctness or feasibility of the solutions, in accordance with your assumptions. Note there are five questions, worth a variable number of points. Answer enough of them to reach 60 points.
   d. There is one extra credit question embedded in the exam that is worth an additional 5 points if you complete it.
   e. To aid in grading, on the front of your exam, please note which problems you completed. You may answer as many as you like, but your total score cannot exceed 105 points (I will evaluate all you submit, however, and give you the best possible score).

Good luck and have fun. If you have any questions, feel free to send me (and me alone) an email or message on Canvas.

Problem 1 - Lost! (15 Points)

The Setup - You were stargazing on the winter solstice, enjoying the clear, dark skies, when you were suddenly abducted by aliens! (You know this for certain because you can't remember anything). You awake, dazed and confused, surrounded by the tattered shreds of your star charts and observing notebook, to the following observations:

Observation 1: Just before dawn, you notice the north star is located 37.2350 degrees off the horizon (yes, you always carry a sextant with you, especially when you are observing).

Observation 2: Later, exactly at solar noon (the sun at its highest point) you note that the time on your watch, set to GMT (of course), is 19:43:15.

Question 1: How did you determine solar noon?

Question 2: Where are you? Show your calculations, check your location on a map and include a copy of it. Can you identify this location by name?

Problem 2 - Orbital Mechanics I: Fate of the Moon (15 - 20 Points)

The Setup: As discussed in class, eventually the Moon will recede from Earth as the Earth slows its rotational speed due to tidal friction. Based on this scenario:

Question 1: Right now we experience perfect solar eclipses. How long will it be before the Moon only covers 99% of the surface of the sun during a solar eclipse?

Question 2: When will the Moon reach the edge of Earth's Hill Radius?

Question 3: How much of the Sun will the Moon cover during an eclipse at this point?

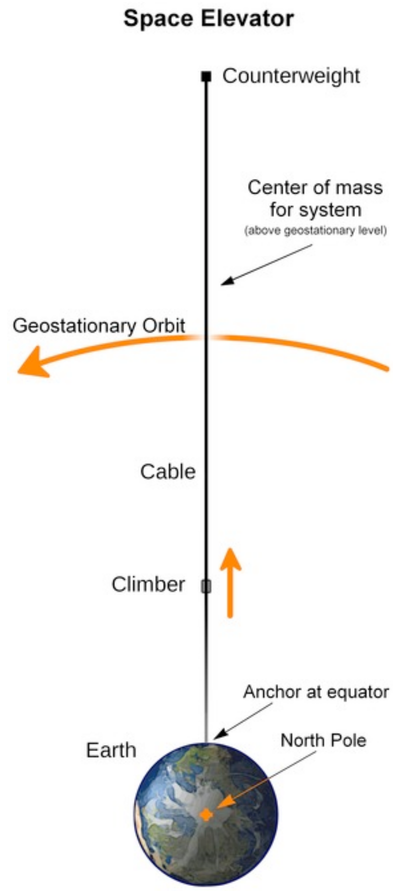
Question 4: How does this compare to Question 2?

Question 5: Describe the fate of the Moon after it passes the Earth's hill radius?

Extra Credit Question: Can you estimate when Earth will become tidally locked to the Moon (that is, the same face of Earth will always face the moon)? Hit: derive an expression for the period of Earth as a function of time, and derive an expression for the period of the Moon as a function of time. Set the two equal and find the time. You may have to do this iteratively. Will this happen before the moon reaches the Hill radius?

Problem 3 - Orbital Mechanics II: The Space Elevator (30 Points)

The Setup: Imagine if we could hang a thin ribbon from a geosynchronous satellite straight down to the surface of the Earth. Such a contraption would have a stable position relative to Earth's surface that we could use to send electric-powered elevators up and down into orbit (see figure). You get to design one!



Question 1: Where will the center of mass of the space elevator be located relative to the surface of the Earth?

Question 2: To offset the mass of the cable, you need a counterweight. Where will you locate the counterweight? You'll need to solve this iteratively (with Step 3) and you have some latitude about how you do this.

Question 3: What is the total mass of your space elevator (including the counterweight)? Also, what is the mass of the portion of the cable from geosynchronous orbit to Earth?

Question 4: What is the tension on the cable due to centripetal acceleration?

Question 5: What is the tension on the cable due to the gravity from the force of its own weight? *Hint: You need to take into account the change of* g *with height.*

Question 6: Can the total tension (Steps 4 and 5) be supported by a material such as carbon nanotubes? Compare your answer.

Question 7: Let's say you wanted to deploy a cable on the other side of the counter weight to fling you to Mars. How long would this cable have to be to give you the right velocity to reach Mars' orbit (consider your Hohman Transfer Orbit to determine a proper velocity)? Would this addition affect the design of your cable and counter weight to Earth?

Question 8: How much energy is required to lift a 1 ton payload to orbit?

Question 9: Provide an estimate of the cost of your system to power a payload to orbit (using current utility rate of 10 cents per kWh).

Some information on carbon nanotubes:

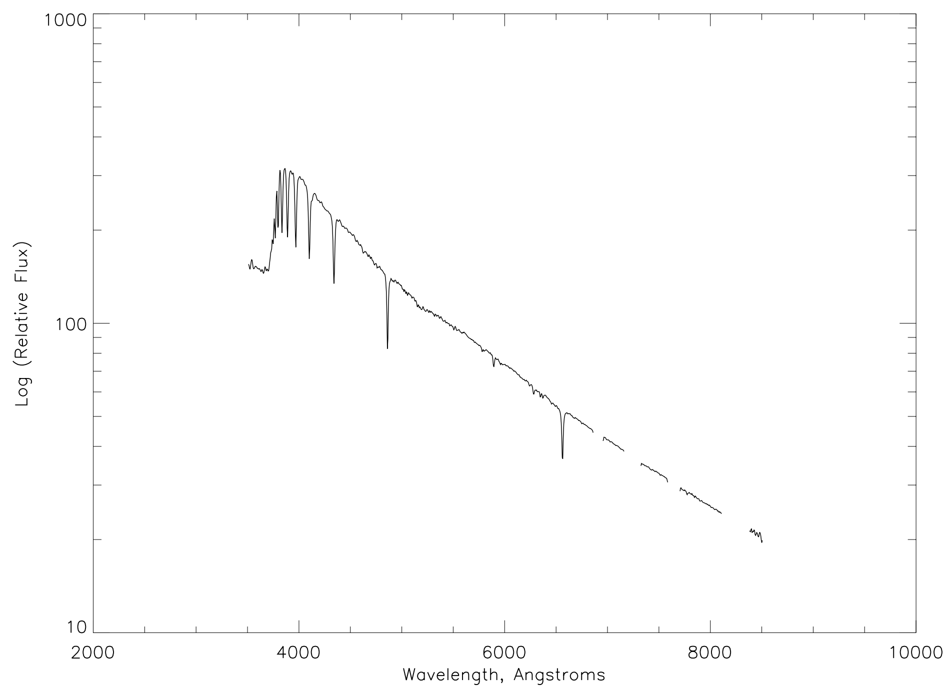
Typical carbon nanotube strength: 140 - 177 GPa

Typical densities: 1000 - 5000 kg/m^3

Typical costs: $375 - $2000/gram for single wall nanotubes, contact http://www.cnanotech.com

Problem 4 - Analyzing Spectra (15 Points)

The Setup: Below you will find the spectrum of the star Regulus. Using this graph, answer the following questions:



Question 1: Identify all of the major spectral features (i.e. absorption lines) for this star. What element(s) are evident? What are their electron transition states?

Question 2: Draw an estimate of the blackbody contribution to this star's spectrum (overlaying the curve on the graph).

Question 3: What color would Regulus appear to be viewed with the naked eye?

Question 4: What is the temperature of this star?

Question 5: Regulus has a luminosity approximately 290 times that of the Sun. What is its size?

Problem 5 - Building a telescope (15 Points)

The Setup: Using sensitive measuring techniques, astronomers have determined that the star Betelgeuse in the constellation Orion is 660 times larger than the sun, with an apparent angular diameter of 0.044 arcseconds.

Question 1: How far away is Betelgeuse?

Question 2: How large of an optical telescope would you need to measure an angular size this small? State your assumptions.

Question 2: How large of a radio telescope would you need to measure an angular size this small? State your assumptions.

Question 3: Discuss the feasibility of these two options. If such an instrument doesn't exit, how do you think astronomers made the measurement?

Take Home Exam 2 - Due Tuesday, Mar 26 at 10:30 AM

NO LATE EXAMS WILL BE ACCEPTED

This is the second take home exam for ASTR 3160. The guidelines:

1. You must work alone.
2. You may use any resources at your disposal (internet, book, calculator, abacus, tea leaves, fortune cookies, lucky charms, etc.) provided you follow guideline #1 (i.e. no Facebook crowd sourcing!)
3. Provide your answers on your own paper (don't write on this exam!).
4. When necessary, provide professional-quality drawings of the problem (that is, use a compass, ruler, etc.).
5. Describe your procedures and answers to all of the questions.
6. Annotate your mathematical solutions with descriptions of all variables and show all work.
7. Since many of these problems require you to develop a full solution from your own resources, describe all of your variables (with units), discuss why you selected them (with sources, if necessary), and state all assumptions.
8. The exam will be out of 100 points, broken down as follows:
    a. 20 points reserved for the quality and completeness of the presentation.
    b. 20 points for the clarity of the procedures and computations.
    c. 60 points for the correctness or feasibility of the solutions, in accordance with your assumptions. Note there are five questions, worth a variable number of points. Please answer all questions.

Good luck and have fun. If you have any questions, feel free to send me (and me alone) an email or message on Canvas.

The Setup: The planetary system, Gliese 581.

Gliese 581 is a red dwarf star located approximately 20 ly from Earth. The properties of the star are indicated in the table to the right. (source: Wikipedia).

In 2009, observers determined the star is surrounded by four planets with the following properties (source: Wikipedia):

The Gliese 581 system[28]

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (days)	Eccentricity	Radius
e	1.95 – <3.1 $M_\oplus$	0.028	3.14945 ± 0.00017	0.32 ± 0.09	—
b	15.86 – <30.4 $M_\oplus$	0.041	5.36865 ± 0.00009	0.031 ± 0.014	—
c	5.34 – <10.4 $M_\oplus$	0.073	12.9182 ± 0.0022	0.07 ± 0.06	—
d[11] (unconfirmed)	6.06 – <13.8 $M_\oplus$	0.22	66.64 ± 0.08	0.25 ± 0.09	—
Comet belt[22]	25 ± 12 AU–>60 AU				

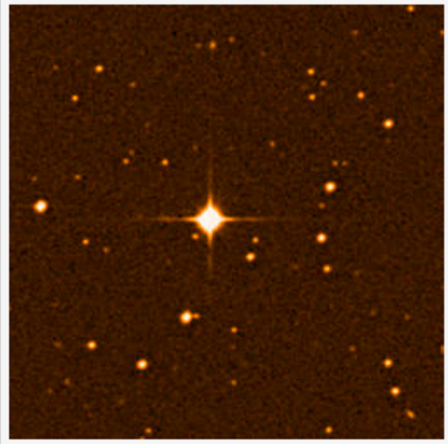
However, in 2010, further analysis of the system indicated several other, yet to be confirmed, planets:

The Gliese 581 system[13]

Companion (in order from star)	Mass	Semimajor axis (AU)	Orbital period (days)	Eccentricity	Radius
e	≥1.7 $M_\oplus$	0.0284533 ± 0.0000023	3.14867 ± 0.00039	0	—
b	≥15.6 $M_\oplus$	0.0406163 ± 0.0000013	5.36841 ± 0.00026	0	—
c	≥5.6 $M_\oplus$	0.072993 ± 0.000022	12.9191 ± 0.0058	0	—
g (unconfirmed)	≥3.1 $M_\oplus$	0.14601 ± 0.00014	36.562 ± 0.052	0	—
d (unconfirmed)	≥5.6 $M_\oplus$	0.21847 ± 0.00028	66.87 ± 0.13	0	—
f (unconfirmed)	≥7.0 $M_\oplus$	0.758 ± 0.015	433 ± 13	0	—
Comet belt[22]	25 ± 12 AU–>60 AU				

There is still strong debate over the existence of the unconfirmed planets, especially planet g. However, a study conducted by a Weber State University undergraduate (Zollinger and Armstrong, 2009, http://bit.ly/WRB1R7) indicates that the orbital location of planet g is one of the most stable in the planetary system, suggesting that even if g is unconfirmed, there is a strong likelihood such a planet could exist and be detected with future observations. Using the information provided, please answer the following questions:

Gliese 581



The star Gliese 581.
Digitized Sky Survey photo.

Observation data	
Epoch J2000.0	Equinox J2000.0 (ICRS)
Constellation	Libra
Right ascension	$15^h\ 19^m\ 26.8250^s$[1]
Declination	−07° 43′ 20.209″[1]
Apparent magnitude (V)	10.56 to 10.58[a]
Characteristics	
Spectral type	M3V[2]
B−V color index	1.61[1]
Variable type	BY[b]
Astrometry	
Radial velocity (R_v)	−9.5 ± 0.5[1] km/s
Proper motion (μ)	RA: −1233.51[3] mas/yr Dec.: −94.52[3] mas/yr
Parallax (π)	160.91 ± 2.62[3] mas
Distance	20.3 ± 0.3 ly (6.2 ± 0.1 pc)
Absolute magnitude (M_V)	11.6[4]
Details	
Mass	0.31[5] $M_\odot$
Radius	0.29[2] $R_\odot$
Luminosity (bolometric)	0.013[2] $L_\odot$
Surface gravity (log g)	4.92 ±0.10[6]
Temperature	3,480 ± 48[6] K
Metallicity [Fe/H]	−0.33 ± 0.12[6] dex
Age	7 to 11[5][7] Gyr
Other designations	
HO Librae, HO Lib, BD−07°4003, GJ 581, HIP 74995, LFT 1195, LHS 394, LPM 564, LTT 6112, NLTT 39886, TYC 5594-1093-1, Wolf 562.[1][8]	
Database references	
SIMBAD	data

1. (5 points) Based on the stellar properties of Gliese 581, what are reasonable limits on the habitable zone? Perform these calculations for an Earth-like planet assuming an Earth-like atmosphere. Are there any planets that fall within these limits?
2. (5 points) What is the orbital period of a planet inside the habitable zone of this system?
3. (5 points) What is the angular size of the star seen from the middle of the habitable zone?
4. (5 points) What color is the star? That is, what is its peak wavelength.
5. (5 points) Due to the proximity of the planet to the star, any planet in the habitable zone is likely under strong tidal influence of the star resulting in some form of tidal locking (either complete locking, like the Moon is to Earth, or something like Mercury, which is in a 3-2 resonance). Redo the calculation of the inner edge of habitable zone assuming a slowly rotating planet. How does this change your estimate from above?
6. (5 points) What is the magnitude of tidal force on Gliese 581 g? Assume an Earth-like density and compare your results to the tidal force of the Moon on Earth.
7. (30 points total) Let's assume Gliese 581 g exists and is tidally locked. On tidally locked worlds, the strong thermal gradient can produce massive winds, up to 35 m/s. In the absence of other ways of moving the atmosphere around, this would mean the atmosphere would flow from the hot side to the cold side rapidly. Assuming an Earth-like atmosphere:
    a. (5 points) How hot would the front side of the planet need to get for there to be a risk of losing the atmosphere to space? Compare this to your slow-rotator temperature from 5.
    b. (5 points) What is the total mass of the atmosphere? That is, assume a 1 bar atmosphere and determine how much mass you need given the surface gravity to get that pressure. Hint: Use hydrostatic equilibrium.
    c. (5 points) Next, imagine that parcels of material are moving from the hot side to the cold side at a rate of 35 m/s. How long does it take for all the mass on the hot side to move to the cold side?
    d. (10 points) If you assume the back side of the planet is cold enough to freeze nitrogen (60 K), how long would it take for the atmosphere on the cold side to freeze out on the surface? Hint: You can get a rough estimate for this by imagining how long it would take to cool a parcel of nitrogen gas from the front side temperature to the back side temperature via the radiative cooling rate using

$$E = \sigma T^4$$

where T is the temperature difference between the gas and the surface. You will need to know how much heat you need to lose to turn nitrogen into ice.

e. (5 points) Finally, based on this analysis, comment on the type of environment you would expect on the surface of Gliese 581 g. Would you classify this planet as habitable in the standard sense of the word?

Take Home Exam 3 - Due Wednesday, Apr 24 at 4:00 PM

NO LATE EXAMS WILL BE ACCEPTED

This is the second take home exam for ASTR 3160. The guidelines:

1. You must work alone.
2. You may use any resources at your disposal (internet, book, calculator, abacus, tea leaves, fortune cookies, lucky charms, etc.) provided you follow guideline #1 (i.e. no Facebook crowd sourcing!)
3. Provide your answers on your own paper (don't write on this exam!).
4. When necessary, provide professional-quality drawings of the problem (that is, use a compass, ruler, etc.).
5. Describe your procedures and answers to all of the questions.
6. Annotate your mathematical solutions with descriptions of all variables and show all work.
7. Since many of these problems require you to develop a full solution from your own resources, describe all of your variables (with units), discuss why you selected them (with sources, if necessary), and state all assumptions.
8. The exam will be out of 100 points, broken down as follows:
    a. 20 points reserved for the quality and completeness of the presentation.
    b. 20 points for the clarity of the procedures and computations.
    c. 60 points for the correctness or feasibility of the solutions, in accordance with your assumptions. Note there are five questions, worth a variable number of points. Please answer all questions.

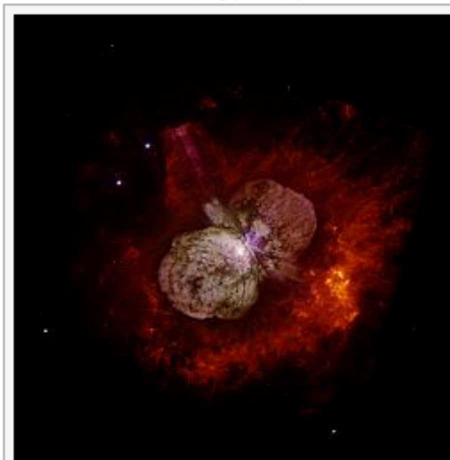
Good luck and have fun. If you have any questions, feel free to send me (and me alone) an email or message on Canvas.

η Carina (20 points)

This object is one of the most massive stars in the Universe, weighing in with over 150 M⊙. Because it is so massive, it is also highly unstable, as evidenced by the lobes of material surrounding the star. In fact, η Carina periodically goes into outburst due to this instability, but stubbornly remains gravitationally bound. During outburst, at its brightest, it has an apparent magnitude of -0.8, and, at its dimmest, an apparent magnitude of 7.9. It is located at a distance of roughly 3,000 parsecs from the Earth. During the 1841 outburst, η Carina was losing mass at a prodigious rate of roughly 0.1 M⊙/yr. Using this information, answer the following questions:

1. Compute the minimum and maximum luminosity for this object using the data provided. Express in terms of solar luminosity.
2. During the outburst of 1841, how much mass did η Carina lose per minute as a fraction of the star's total mass? How much in terms of Earth masses? *Rate your reaction to this, on a scale of 1 - 10 (with 1 = bored to 10 = blowing your mind).*
3. If the temperature of the original cloud that formed η Carina was 100 K, what was the original density of the cloud provided it collapsed due to the Jean's criteria? What would the free-fall time be for such a cloud? (Assume 100% hydrogen.)
4. Assuming η Carina derives its energy from hydrogen fusion in the inner 10% of its mass while on the main sequence (converting 0.7% of that mass directly to energy), estimate the minimum main sequence lifetime of the star, assuming the maximum luminosity as calculated from Part 1 (about 1×10^7 L⊙). How does that compare to the free-fall time of the cloud that formed the star?

Eta Carinae



Hubble Space Telescope image showing Eta Carinae and the bipolar Homunculus Nebula which surrounds the star. The Homunculus was partly created in an eruption of Eta Carinae, the light from which reached Earth in 1843. Eta Carinae itself appears as the white patch near the center of the image, where the two lobes of the Homunculus touch.

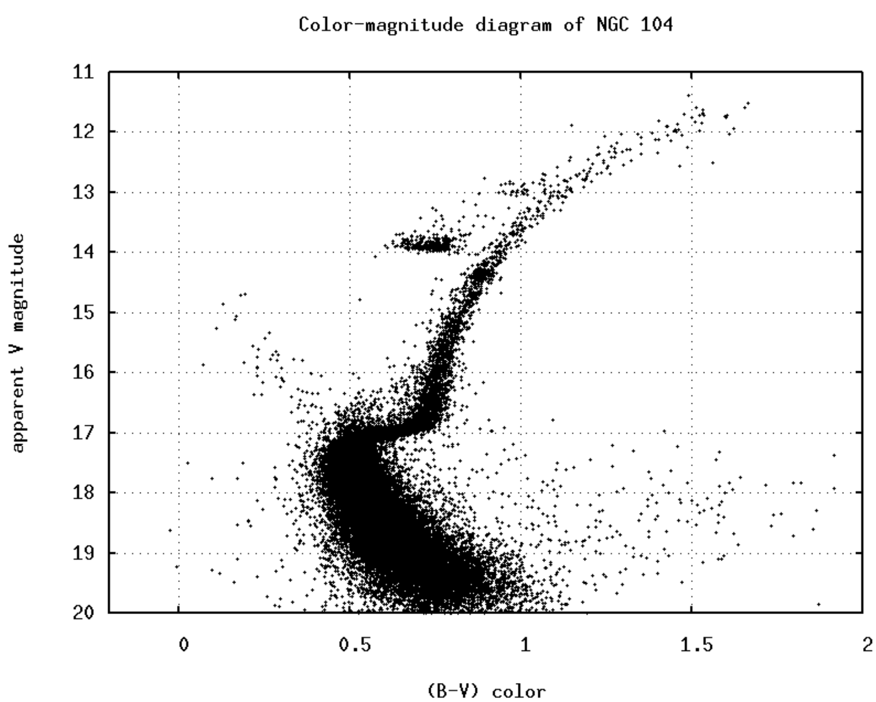
Observation data	
Epoch J2000	Equinox J2000
Constellation	Carina
Right ascension	$10^h\ 45^m\ 03.591^s$[1]
Declination	–59° 41′ 04.26″[1]
Apparent magnitude (V)	–0.8 to 7.9[2] (4.6 February 2012)[3]
Characteristics	
Spectral type	Blae-0 / OI[4]
U–B color index	-0.45
B–V color index	0.61
Variable type	LBV[2] & binary
Astrometry	
Radial velocity (R_v)	–25.0[1] km/s
Proper motion (μ)	RA: –7.6[1] mas/yr Dec.: 1.0[1] mas/yr
Absolute magnitude (M_V)	-7 (current)
Details	
Mass	120 / 30[5] $M_\odot$
Radius	~240[6][n 1] / 24[4] $R_\odot$
Luminosity	5,000,000 / 1,000,000[4] $L_\odot$
Temperature	~15,000[7] / 37,200[4] K
Age	~ <3 × 10^6 years
Other designations	

Foramen, Tseen She, 231 G. Carinae,[8] HR 4210, CD–59°2620, HD 93308, SAO 238429, WDS 10451-5941, IRAS 10431-5925, GC 14799, CCDM J10451-5941

NGC 104 (47 Tucanae) - Globular Cluster (20 points)

NGC 104 is a globular cluster located in the constellation Tucana (visible only from the southern hemisphere, with a declination of about -72 degrees). Based on the available data:

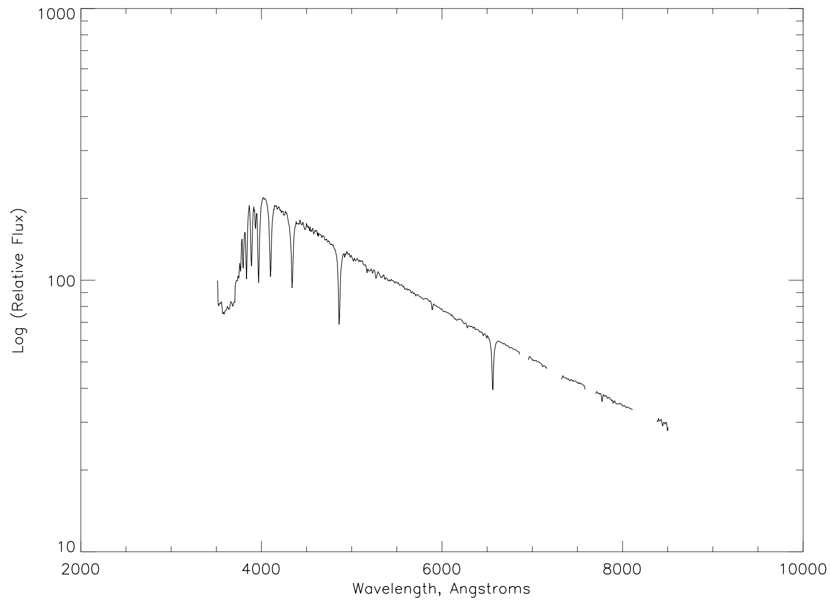
1. Label the features of the HR diagram, including:
   a) A temperature scale
   b) The spectral sequence (OBAFGKM)
   c) The main sequence
   d) Red giant branch



2. Determine the distance to this globular cluster. Show your calculations and method, including an estimate of your uncertainty.
3. Determine the age of this globular cluster. Show your calculations and method, including an estimate of your uncertainty.
4. What is the luminosity of the brightest stars in this cluster, in units of solar luminosity?

Stellar Spectrum (20 points)

Based on this normalized stellar spectrum:



1. Find the peak wavelength and temperature of this star.
2. What is the B-V color index of this star?
3. Identify the major absorption signatures, including the element and transition.
4. What type of star is this (OBAFGK or M)?
5. Estimate the star's intrinsic luminosity.
6. The apparent magnitude of this star is 6.01. How far away is it?
7. How big is this star?