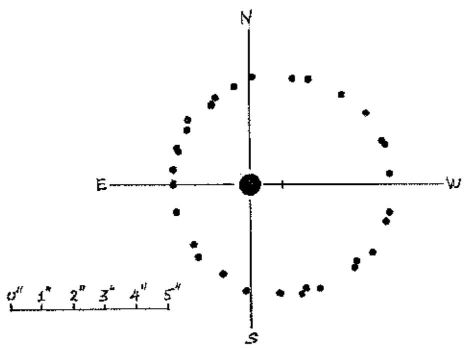
ASTRONOMY 2400. PHYSICS OF STARS

Assignment 1. **Due Date: January 24, 2012.**

1. The newly-discovered Large Magellanic Cloud eclipsing system OGLE-LMC-CEP0227 consists of a Cepheid variable (of pulsation period $3^d.8$) orbiting a bright red giant (luminosity class II) with an orbital period of 310 days and an orbital semi-major axis of 389.4 ±1.2 $R_\odot$ according to radial velocity measures. The radial velocity variations of both stars also indicate that the two stars are of identical mass. Exactly how massive are the stars, in terms of the Sun's mass $M_\odot$? Show your calculations.

2. The visual binary AST 2313 has the orbit depicted below left. All observations are satisfied by a *circle* of radius 3.50 arcseconds, with the centre of the circle displaced exactly 1.0 arcsecond due west of the primary star. The secondary is observed to pass through position angle 90° on the following dates: 1966.041, 1982.261, 1998.481. Use that information to solve for the seven orbital parameters of the system AST 2313: *P, T, a, e, i,* Ω & ω [respectively, the orbital period in years, the epoch of periastron passage (choose the most recent), the semi-major axis (in arcseconds), the orbital eccentricity, the inclination of the orbit to the plane of the sky, the position angle of the nearest node (measured eastwards from north), and the longitude of periastron measured from the point where the orbit crosses the plane of the sky]. The absolute parallax of AST 313 is $\pi_{abs} = 0.297$ arcsecond. What is the corresponding mass of the system?



3. The stars β Aurigae A and β Aurigae B constitute a double-lined spectroscopic binary with an orbital period of $P = 3.96$ days. The radial velocity curves of the two stars have amplitudes of $K_A = 108$ km s^{-1}and $K_B = 111$ km s^{-1}. If the orbital inclination is $i = 90°$, what are the masses of the two stars?

4. According to the mass-luminosity relation, how much more luminous than the Sun is a star of 4 $M_\odot$ corresponding to spectral type B5 V?

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Assignment 2. **Due Date: February 14, 2012.**

1. Demonstrate that the most probable speed for the Maxwell-Boltzmann distribution is given by $v_{mp} = \sqrt{\frac{2kT}{m}}$.

2. Assume that the Sun is composed of pure hydrogen with a central temperature of 15.8×10^6 K and a central electron density of 6.4×10^{25} cm^{-3}. According to the Saha equation, is the material in the centre of the Sun fully ionized? Note: $u(T) = 2$ for H I, $u(T) = 1$ for H II, and the ionization potential for H I is 13.595 eV.

3. Re-examine the result from question (2) by computing the average separation of atoms at the centre of the Sun. The radius of the first Bohr orbital (electron cloud radius) for hydrogen is 0.528 Å. Comment on the validity of the results for question (2) given the results obtained for the present question. Is the material in the centre of the Sun fully ionized?

4. The techniques of spectral classification consist primarily of tricks of visual perception that are difficult to teach except by way of actual hands-on experience. The present exercise involves MK spectral classification, and introduces you to the field by providing the challenge of classifying spectra for five different stars. The spectra for the five stars, taken from Reticon spectra included in the *Project CLEA* software for four stars as well as from a reduced CCD spectrum for the last object, are illustrated on the following pages.

The best method for classifying spectra is to follow the following procedure:

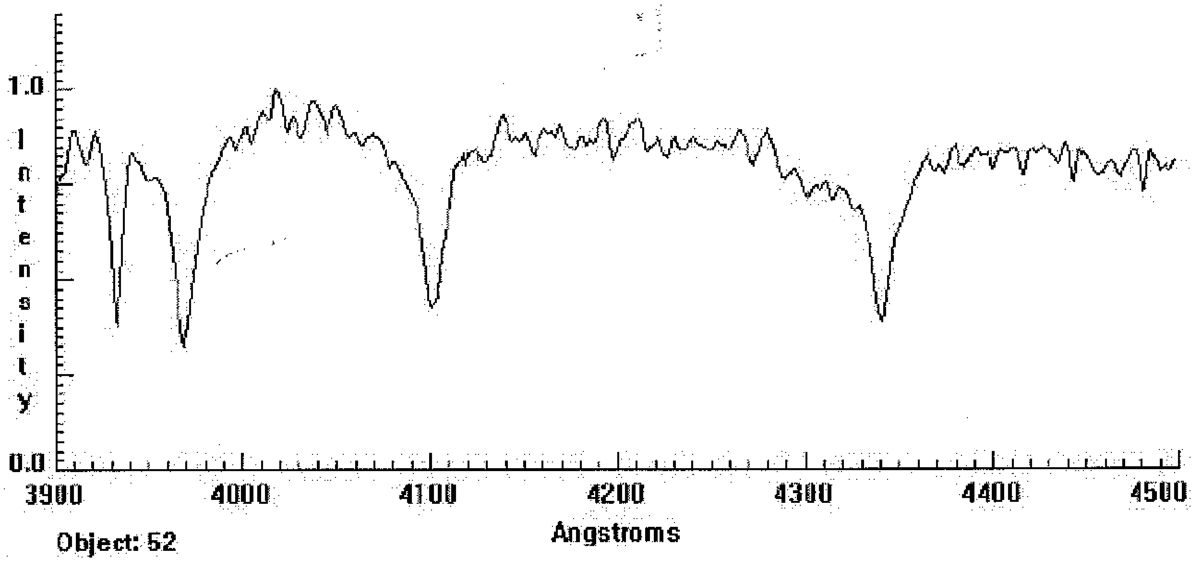
a. Make an initial guess at the spectral type from the dominant spectral lines visible, then isolate the specific spectral class of the star further using a Spectral Atlas or by reference to the spectra of standard stars.

b. Identify specific spectral lines in the program star spectra with reference to the standard star spectra, then use the observable temperature-sensitive line ratios to isolate the spectral type further. Good spectral atlases and the class handout identify the ratios for you.

c. Once the spectral class has been fixed to your satisfaction, use luminosity-sensitive line ratios to determine the specific luminosity class (Ia, Iab, Ib, II, III, IV, or V) for the star. Since luminosity-sensitive line ratios are also temperature-dependent, it will probably be necessary to iterate the procedure through step b again. There is always some trade-off between luminosity and temperature class that is necessary to obtain the best overall match of all line ratios to a specific standard. In some cases it may be necessary to interpolate within the standards themselves (*e.g.* B2.5 IV–V as a best fit to B2 and B3 standards in temperature class, and class IV and V standards in luminosity class).

Write down a description of the steps you followed to obtain a spectral classification for each star, indicating the path used to reach the final classifications. Your descriptions should include estimates of specific line ratios pertinent to the classifications — the more detail the better. Since proper classification is done using line ratios rather than the overall appearance of spectra, the MK techniques work well even for overexposed or underexposed spectra (although that should not be a problem here). Not everyone is blessed with the visual acuity necessary for spectral classification, so there is no reason to be concerned if your results do not match those of your classmates. However, you may find that discussing the spectra of specific stars among classmates provides insights into the proper classification of the stars.

Your grade will be based upon the general accuracy of your classifications and your descriptions of the qualitative and quantitative estimates of specific line ratios or line visibilities pertinent to the temperature and luminosity classifications of the stars. Remember that the final classifications *should be your own.*



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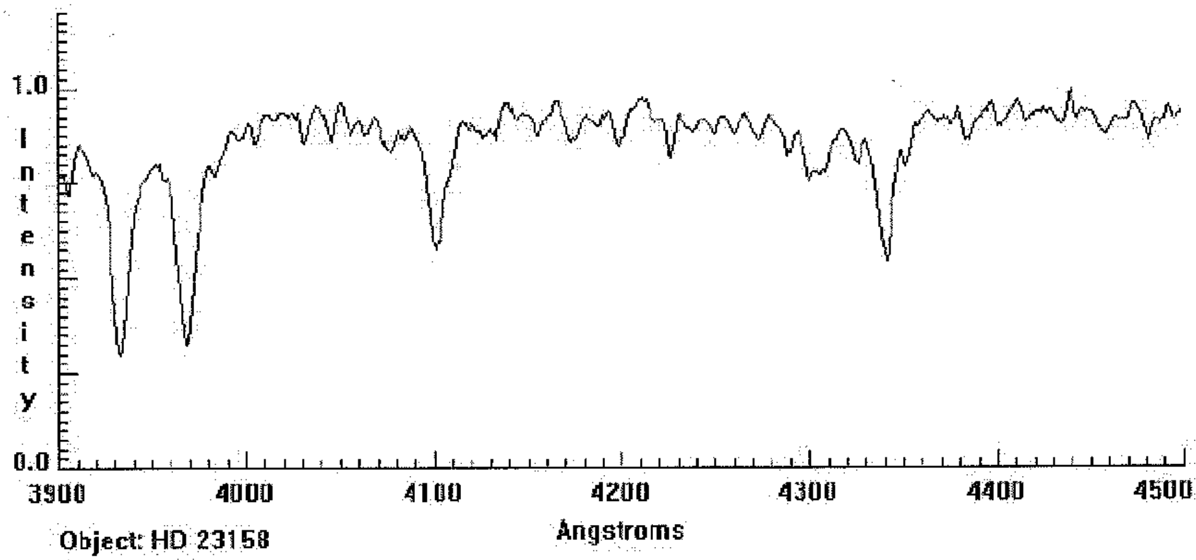

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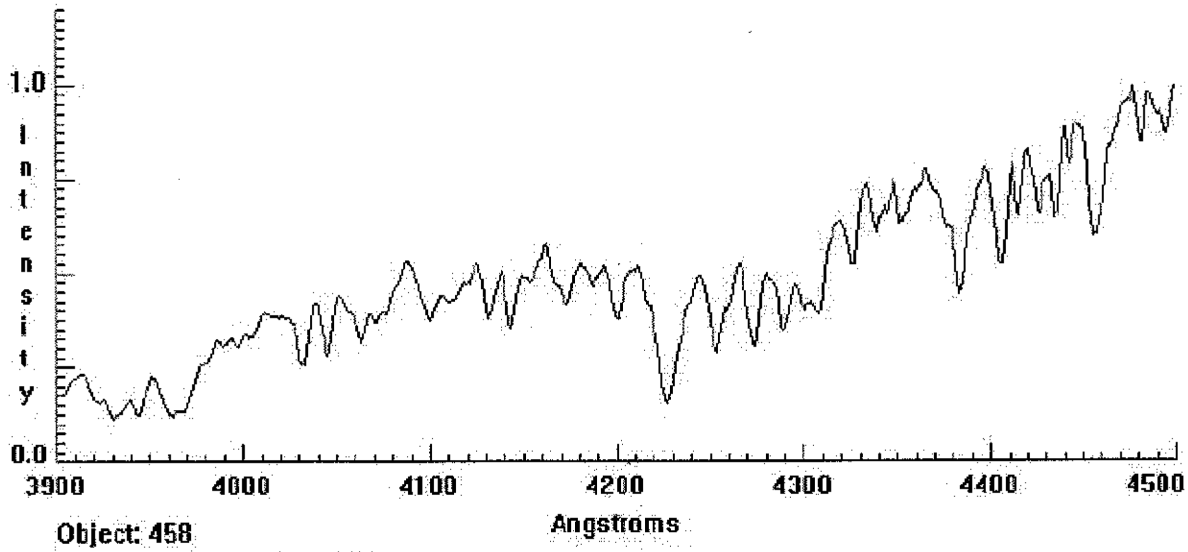

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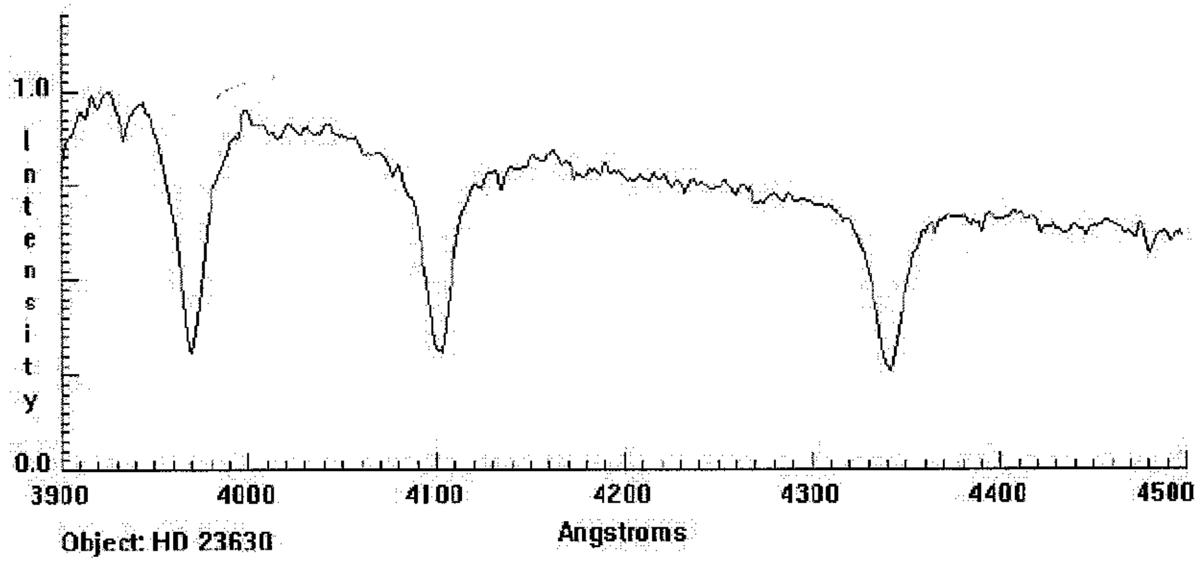

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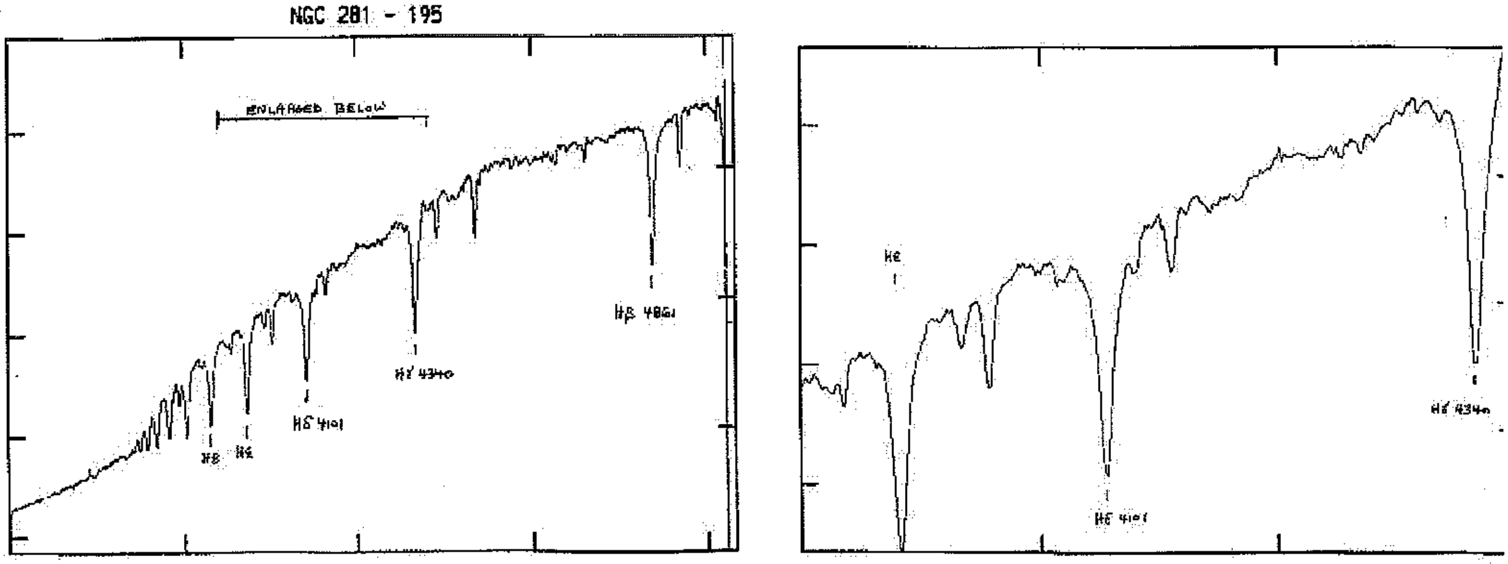
NGC 281 - 195



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Assignment 3. **Due Date: April 3, 2012.**

1. Calculate the mean free path for λ = 5000 Å photons in Earth's atmosphere if it has the opacity of the solar photosphere, which was assumed to be $\kappa_{5000} = 0.264$ cm^2 g^{-1} in a textbook example. Assume that the average density of Earth's atmosphere is 1.2×10^{-3} g cm^{-3}.

2. Suppose that the Sun was 100% carbon (coal, for instance) and that burning it can extract 3 eV per carbon nucleus. Given an inexhaustible supply of oxygen from outside for burning the coal, how long could burning carbon maintain the Sun's current luminosity?

3. Calculate the amount of energy released or absorbed (in MeV) in the following reactions:

(a) $^{12}\mathrm{C} + {}^{12}\mathrm{C} \rightarrow {}^{24}\mathrm{Mg} + \gamma$

(b) $^{12}\mathrm{C} + {}^{12}\mathrm{C} \rightarrow {}^{16}\mathrm{O} + 2\,{}^{4}\mathrm{He}$

(c) $^{19}\mathrm{F} + {}^{1}\mathrm{H} \rightarrow {}^{16}\mathrm{O} + {}^{4}\mathrm{He}$

The mass of ^{12}C is 12.000000 u by definition, and the masses of ^{16}O, ^{19}F, and ^{24}Mg are 15.994915 u, 18.99840 u, and 23.98504 u, respectively. Identify each of the reactions as being exothermic or endothermic.

4. Complete the reaction sequences given below. For each reaction justify the choice of nucleons and leptons involved, according to arguments of conservation of electric charge, number of nucleons, and number of leptons.

(a) $^{27}\mathrm{Si} \rightarrow {}^{?}\mathrm{Al} + e^{+} + ?$

(b) $^{?}\mathrm{Al} + {}^{1}\mathrm{H} \rightarrow {}^{24}\mathrm{Mg} + {}^{4}?$

(c) $^{35}\mathrm{Cl} + {}^{1}\mathrm{H} \rightarrow {}^{36}\mathrm{Ar} + ?$

5. (a) At what rate is the mass of the Sun decreasing as a consequence of nuclear reactions in its core? Express the result as a rate of mass loss in solar masses per year.

(b) What is the rate of mass loss for the Sun arising from the solar wind, in units of solar masses per year? Is the value obtained in part (a) larger or smaller than the rate of mass loss arising from the solar wind?

(c) Assume that the rates calculated in parts (a) and (b) remain constant over the main-sequence lifetime of ~10^{10} years for the Sun. Calculate the total loss of mass from the Sun during its main-sequence lifetime arising from nuclear reactions and the solar wind. What proportion of the total mass of the Sun is expected to be lost over that time period as a result of both processes?