Physics 160: Stellar Astrophysics (Fall 2013)

Homework #1
Due Friday October 4th at 5pm
Drop off in the box outside of SERF 340

Reading: Carroll & Ostlie sections 1.3-1.4, 3.1-3.6
Problems: [150 points total]

(1) Angular Separations on the Sky [30 pts]

The stars Alkaid (η UMa) and Dubhe (α UMa) comprise the tip of the handle and edge of the cup in the constellation Ursa Majoris (the Big Bear, more commonly referred to as the Big Dipper). Their coordinates are as follows:

- Alkaid: $13^h 47^m 32.43^s +49^\circ 18^\prime 47.76^\prime\prime$
- Dubhe: $11^h 03^m 43.67^s +61^\circ 45^\prime 03.72^\prime\prime$

(a) [10 pts] What is the angular separation of these two stars on the sky, and hence the angular size of the Big Dipper? Note that this is not a small angle, so you have to derive and use the proper spherical angle formula. Give your answer in units of degrees, and show your work.

(b) [10 pts] Alkaid is 31 pc away, Dubhe is 38 pc away. How far apart are these two stars in physical distance in units of pc?

(c) [5 pts] Which of these stars is more luminous? How do you know? (Do not just look this up! Based your answer on the information provided)

(d) [5 pts] The Big Dipper is currently up, so this is a good opportunity to calibrate your angle-measuring instrument – your outstretched hand. On a clear night, figure out the positioning of your outstretched hand (balled fist, fist and spread out thumb, spread out fingers, etc.) that just fits between Alkaid and Dubhe. What is this positioning for you? (We’ll make use of this later in the quarter in our local observing lab)
(2) Parallax Measurement on an Alien World [25 pts]

Ground-based parallax measurements rely on the Earth’s orbit to provide the baseline for angular measurements. Imagine we lived on a different planet (let’s call it Slickle’) orbiting an M-type star of mass $0.3 \, M_\odot$ whose orbital radius was only $0.3 \, \text{AU}$.

(a) [5 pts] What would the parallax angle be in arcseconds for a star $10 \, \text{pc}$ from Slickle?

(b) [5 pts] If the best measurement equipment available can measure an angle of $0.01''$ (= $10$ milliarcsecond, or $10 \, \text{mas}$), what is the maximum parallactic distance we could measure from (i) Earth and (ii) Slickle?

(c) [5 pts] To measure the full parallax angle, we need to make measurements for at least half of an orbit, or $6$ months on Earth. How long would it take to make a parallax measurement from Slickle?

(d) [10 pts] Based on these considerations, how do you think the development of astrometry on Slickle would differ from that on Earth? Draw from the history of astrometry on Earth.

(3) Resolving the Stars [15 pts]

The Hubble Space Telescope (HST) has an angular resolution of $100 \, \text{mas}$. The table below lists the radii of various types of stars and planets. What is the maximum distance (in the units specified) for which each object could be resolved by HST?

<table>
<thead>
<tr>
<th>Object</th>
<th>Radius</th>
<th>Maximum distance object can be resolved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigel (blue supergiant)</td>
<td>$25 , R_\odot$</td>
<td>pc</td>
</tr>
<tr>
<td>Betelgeuse (red supergiant)</td>
<td>$800 , R_\odot$</td>
<td>pc</td>
</tr>
<tr>
<td>Sirius (blue dwarf)</td>
<td>$1.7 , R_\odot$</td>
<td>pc</td>
</tr>
<tr>
<td>61 Cygni (red dwarf)</td>
<td>$0.2 , R_\odot$</td>
<td>pc</td>
</tr>
<tr>
<td>Jupiter (giant planet)</td>
<td>$0.1 , R_\odot$</td>
<td>AU</td>
</tr>
<tr>
<td>Pluto (dwarf planet)</td>
<td>$0.0016 , R_\odot$</td>
<td>AU</td>
</tr>
</tbody>
</table>

(4) Spectrophotometric Distance Estimates of Binary Stars [25 pts]

It is common to estimate the distance of a star based on its spectral type and the average absolute magnitude for that spectral type (determined for similar stars with distance measurements). However, if the star is a binary, this distance will be underestimated.

(a) [5 pts] Assume the star δ Makeyupus has an identical spectral type as the Sun (absolute V magnitude = 4.83) and an apparent visual magnitude of V = 7.22. How far away would we estimate the star to be in pc?

(b) [10 pts] It is discovered that δ Makeyupus is a binary. What are the true apparent magnitudes of both components if
   (i) the two components have the same brightness
   (ii) one component is half as bright?

(Hint: use the definition for apparent magnitude in equation 3.4)

(c) [10 pts] Based on part (b), estimate the true distance to δ Makeyupus for both of the cases above, assuming the brighter component is a Sun-like star.

(5) Properties of a Hot Star [25 pts]

The star PG 1159-035 is located 440 pc away from the Sun, has a surface temperature of 136,000 K and a luminosity of 200 L☉.

(a) [2.5 pts] What is its radius (in units of solar radii)?

(b) [2.5 pts] What is its absolute bolometric magnitude?

(c) [5 pts] At what wavelength is this star brightest? What part of the electromagnetic spectrum is this found?

(d) [10 pts] What is its radiant flux at the surface of the Earth? How does this compare to the Sun’s radiant flux at the surface of the Earth? (in both cases, ignore scattering and absorption from our atmosphere)

(e) [5 pts] What kind of star is PG 1159-035? (justify your answer based on the properties above; do not just look it up!)
(6) Staying Warm [35 pts]

The human body has an average temperature of 310 K (98.6°F) Assume the skin is a perfect radiator and absorber, and that you are standing in a room with a constant temperature of 293 K (68°F).

(a) [5 pts] What is the peak wavelength $\lambda_{\text{max}}$ of your thermal spectrum? In what part of the electromagnetic spectrum is this found?

(b) [10 pts] How much power (in kilowatts kW) do you radiate in the form of blackbody radiation? (Hint: you’ll need to estimate a typical body surface area)

(c) [5 pts] How much power (in kilowatts kW) do you absorb from the environment, and what is your net energy loss per second from just radiation?

(d) [5 pts] How many food Calories does this correspond to in a day? (Note: 1 food Calorie = 4.184 kJ = 1000 “heat” calories)

(e) [5 pts] If we didn’t eat, how long would it take for our body temperature to drop 10°C, at which point you’d likely be comatose? (Assume we are mostly made of water and our body does not generate any additional heat)

(f) [5 pts] What are the flaws in this model? Use this argument to explain how our clothes keep us warm.