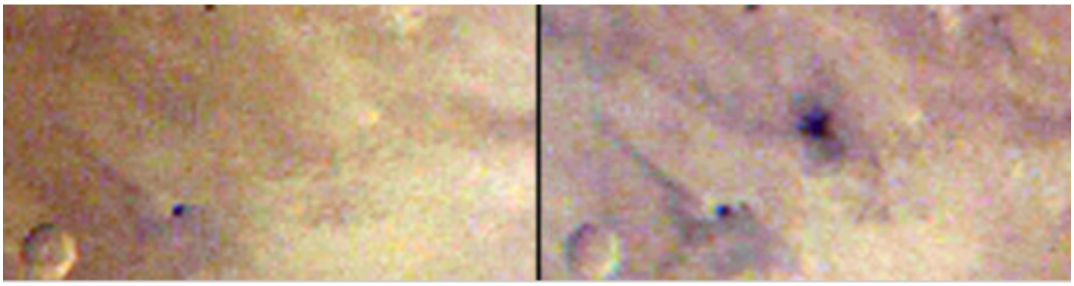
Problem Set #5

PHY 300 Observational Astronomy
Throop / Booth

ASSIGNED: WEDNESDAY 22-APR-2015
DUE: WEDNESDAY 6-MAY-2015, BEGINNING OF CLASS

1. Martian Crater Mining [30 points]

You are searching through data from a Mars mission. You find a pair of images, seen below. In it you see where a new crater has just been made on Mars. You measure it to be 50 meters in diameter.



The left image was taken during Martian afternoon on March 27, 2012; the right one on the afternoon of March 28, 2012 by the Mars Color Imager (MARCI) weather camera on NASA's Mars Reconnaissance Orbiter.

Pin it

a. What is the impactor velocity? How much energy (in kJ) is dissipated in this making this crater? You can assume that the impactor comes in to Mars from infinity. You can use the following assumptions:

- (Crater depth)/(crater diameter) = 0.1
- (Impactor diameter)/(crater diameter) = 0.1
- Impactor has a density equal to that of Mars (ρ = 4 g/cm^3)
- Ejecta has a uniform velocity of 1 km/sec.

b. About how many tons of dynamite (TNT) equivalent is this? 1 ton of TNT gives off roughly 4 x 10^9 J.

c. Roughly how often do you expect such a crater to be formed on Mars? Assume that Mars gets roughly double the impactor flux that we have on Earth (due to its closer proximity to the asteroid belt), and use the chart for impactor frequency presented in class.

d. On the field trip, Danie mentioned that heavy metals in South Africa are typically found at the bottom of the Transvaal supergroup, to a depth of roughly 3 km. You decide on a brilliant new way to mine for gold: simply wait for an impact crater to excavate down to this depth, and then sweep up the debris. How large an impactor would it take to excavate a crater to this depth? How long would you have to wait for such an impactor? (You can use the same general assumptions as in the first

2. Precise Exoplanet Photometry [30 points]

You are observing stars with a photometer on your 1-meter telescope. You are watching the star gamma Ori, which you know from previous work gives you about 1000 photons/second at your focal plane.

You are monitoring your star once per second. You notice that the star starts to dip in brightness, to 0.9 of its original brightness.

a. What is your SNR for the transit itself? Assume that all of your noise is from Poisson statistics — that is, you can remove any noise from dark current, flat-fielding, sky brightness, etc. very accurately.

b. You'd like to adjust your integration time (exposure time), so that you can measure its light curve very accurately. What integration time should you choose to get an SNR of 20 during the occultation?

c. The star that you are monitoring continues to be interesting, so you acquire a larger telescope and detector. This telescope is a 2-meter diameter. This new CCD has a dark-current of 10 e- sec, a bias of 200 e-, a QE of 0.5, and a gain of 10 e- per DN. What is the count rate in your detector in DN per second?

d. You would like to calculate the SNR to the same level of 20 with this new telescope. How does your exposure time here compare to that calculated in part b. (i.e., shorter or longer, and by how much?) Consider only Poisson noise.

e. After much work, you measure the transit depth to be 9%, and have a period of 50 days. You know (from the star's spectrum) that it has a mass of 3 M_{sol} and a radius of 0.7 r_{sol}. What is the planet's orbital distance? Its radius? What measurements would you need to determine its mass?

3. Photometric Bands [40 points]

Astronomers typically use filters to do stellar photometry. Here, you will calculate the ratio of energy in different bands.

a. Assume you have two stars. One has a temperature of 3000 K (a very cool star that will burn for a long time), and the other has a temperature of 10,000 K (which makes it a very hot star that will burn out within a few Myr).

b. The blackbody flux is given by B(λ,T). Make a plot of the flux vs. wavelength for each star. Make sure to scale the plots appropriately — that is, choose a reasonable range for B and λ so that the curves can be clearly plotted.

   You can assume the stars to be perfect black bodies. B(λ,T) has units of W m^{-2} m^{-1}. k is the Boltzman constant (1.4 10^{-23} J K^{-1}), and h is Planck's constant (6.6 10^{-34} J sec).

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

c. What is each star's total integrated flux emitted in the red 'R' filter (i.e., between 550-700 nm)? Similarly, what are their fluxes in the ultraviolet ('U') filter (300-400 nm)? What is the ratio between these: F_U/F_R for each star? To be clear, you are essentially calculating the integral

$$\int_{\lambda_1}^{\lambda_2} B(\lambda, T) d\lambda$$

Hint: In theory you could do this problem analytically, by integrating B(λ,T). But that is quite difficult for an equation of this form. Instead, I suggest doing it numerically. You might consider approaching it this way:

i. Set up a matrix of values, something like the one below. You could do this in a spreadsheet (like Excel or Google Docs), or write a short program in something like python or MATLAB. Either one is fine.

ii. Break up the spectrum into a number of different wavelength bins (perhaps 100 or 1000). For each bin, calculate both B and the flux. Note that the units of B are in flux per wavelength, so in order to get the total flux within one of your bins, you need to multiply by the bin width. (Just like you'd multiply by dλ in an analytic integral.)

iii. To calculate the flux seen through a given filter, sum the flux emitted across the wavelengths covered by that filter (e.g., the total flux from 550 to 700 nm). You are numerically integrating the blackbody equation here. This is common to do for such heinous equations which are difficult to manually integrate.

T = 5000 K

λ1	λ2	dλ	B(λ,T)	Flux in bin
100 nm	110 nm	10 nm		
110	120	10		
120	130	10		
130	140	10		