

# Astronomical Techniques 1

(January - February 2015)

## Assignment 1

*Due on 13 Feb 2015; 1700 hrs. Maximum marks: 300, Weightage: 30%*

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### General Instructions

*(1) You should try to obtain solutions to these questions by yourself. The less you talk to others, the more you will learn. (2) Most of the questions test a single concept introduced in class. For such questions, your answer should not be longer than 5-10 lines. (3) The deadline for submission of the answers is fixed. No credit for late submissions (4) I have tried to make the questions unambiguous and correct. But if you suspect that there is any error /ambiguity, feel free to say so in your answers. For a few problems, you may need to look up relevant numbers in the appropriate reference books. Please retain the correct number of significant figures in your answers. (5) Numbers within square brackets are the maximum marks for each question. (6) Hand over your assignments to Kaustubh Vaghmare at IUCAA.*

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- (1) Calculate the length of the sidereal day on Earth. What would be the length of the solar and sidereal days, in the current time measures (our solar hours, minutes and seconds), if the Earth would rotate in the opposite direction, but with the same rotation speed? [10]
- (2) Assume that you are living in the time of Copernicus and do not know anything about Kepler's laws. You might calculate Mars-Sun distance in the same way as he did. After accepting the revolutionary belief that all the planets are orbiting around the Sun, not around the Earth, in circular orbits, you measure that the orbital period of Mars is 687 days, then you observe that 106 days after opposition of Mars, the planet appears in quadrature (Sun-Earth-Mars form a right angled triangle with right angle at Earth). Calculate Mars-Sun distance in astronomical units (au). [20]
- (3) A house located in Pune, India has one of its walls facing due North. Every year, during what date range will this wall be directly illuminated at local noon by the sun? Will these dates change from year to year? (Hint: consult the Astronomical Almanac, available in the library) [10]
- (4) Imagine that on 21 March 2010, you find yourself marooned on a sandy beach of an uninhabited island in the middle of the ocean. The sun is just rising. By sunset,

you need to determine the latitude and longitude of your location. The vegetation on the island indicates that you are at temperate latitudes. All you have with you is a wooden stick (about 2m long), an accurate watch showing Indian Standard time in 24hr format, a measuring tape about 10 m long graduated in centimetres. Explain clearly how you will determine your location. Draw an appropriate figure. [20]

- (5) A selenelion or selenehelion occurs when both the Sun and a fully eclipsed Moon can be observed at the same time from specific locations on the earth. Under what conditions is this possible? Why is it easier seen at sea than on land? [10]
- (6) The pole star Polaris has 2000 AD Epoch equatorial coordinates of RA 02:3:49.08 and Dec. +89:15:50.8. Determine its precessed coordinates for 2100 AD Epoch. [10]
- (7) Explain how timing transits of Venus from two well separated locations on Earth can be used to determine the value of an astronomical unit (AU) in km. [15]
- (8) While photographing a landscape scene with your digital camera under bright sunlight, you find that a 1/30 second exposure is needed for an aperture setting of f/16. If you were to photograph the same scene in the light of a full moon, what would be the exposure with an aperture setting of f/8? What would be the color of a clear sky in such a photograph taken in moonlight and why? [20]
- (9) You have placed a detector with  $10\mu\text{m}$  pixels at the prime focus of a 2m diameter f/10 telescope? What will be the separation in detector pixels of two stars 10 arcsec apart? [10]
- (10) Determine the hour angle of the star Sirius when observed at midnight from the IUCAA Girawali Observatory (IGO) on 10 March 2011. [10]
- (11) What is the airmass of the star Sirius as seen from Pune, on 15 January 2011 at midnight IST? [15]
- (12) The Megacam camera used for CFHT Legacy survey has a field of view of 0.92 sq. deg. It contains 40 identical 2048 x 4612 CCDs. If the focal length of the telescope used is 15 m, compute the pixel size (in microns) of the CCDs used in this camera. [10]
- (13) A drift scanning telescope tracks the sky at the sidereal rate. If the pixel scale of the CCD detector is 0.4 arcsec/pixel and the CCD has  $2048 \times 2048$  pixels, what is the effective exposure time on the sky? Which major sky survey do these parameters correspond to? [10]
- (14) You are making observations of a star in the  $u$  band, with apparent magnitude  $u = 15.0$ . The  $u$  filter is centered at  $3600 \text{ \AA}$ , and has a width of  $800 \text{ \AA}$ . The conversion between magnitudes  $m$  and flux density  $f$  of a star in Janskies ( $1 \text{ Jy} = 10^{-23} \text{ erg/sec/Hz/cm}^2$ ) is:  $f = 3631 \text{ Jy} \times 10^{-0.4m}$ . Calculate approximately how many photons per square centimeter per second from this star hit the top of the atmosphere. Explain where you are making your approximations. [10]

- (15) When the moon is not up, the sky at a dark site has a surface brightness of 22 magnitudes in a patch of area of one square arcsecond. Moreover, the atmosphere also absorbs about half the light of the star in the  $u$  band when observed at airmass 1.4. What is the ratio of number of photons received per second from the star with  $u = 15$  to that received from the sky, when measured over a circular aperture of diameter 2 arcsec. You may assume that the seeing is good, and therefore none of the light of the star falls outside the aperture. Now redo this calculation when the moon is up; the sky surface brightness is now 17 magnitudes in one square arcsecond. [20]
- (16) You observe the star in the above problem with a telescope which has a primary mirror diameter of 2.5 meters. In practice, only about 20% of the  $u$  band photons that hit the primary mirror are detected; the remainder are lost due to the imperfect reflectivity of various optical surfaces, and the fact that the detectors are not perfect. How many photons are detected from the star per second? [10]
- (17) The refractive index  $\eta$  of air at sea level at 15 degrees C is given by:

$$(\eta - 1) \times 10^8 = 8342 + \frac{2.4 \times 10^6}{130 - \lambda^{-2}} + \frac{1.6 \times 10^4}{40 - \lambda^{-2}}$$

where  $\lambda$  is the wavelength measured in microns. Calculate the angle by which the position of a star appears to shift, as measured at 0.5 microns, as a function of airmass. You may assume that the atmosphere is a single slab of constant density. Note  $\eta$  is very close to unity, so an expansion in the quantity  $\eta - 1$  to first order will make the algebra much easier. [15]

- (18) Suppose you are observing with the Sloan Digital Sky Survey imaging camera, whose field of view has a diameter of 3 degrees. If the camera is observing the sky at an airmass of 1.4, what is the differential atmospheric refraction from one side of the camera to the other, at 5000Å ? [10]
- (19) There is also chromatic atmospheric refraction, caused by the wavelength dependence of  $\eta$ . Expand the expression above to first order in  $\lambda^{-2}$ . Compute the difference in the position of a star observed at an airmass of 2.0, at wavelengths of 4000Å (blue light) and 7000Å (red light). Is the effect large enough to be measureable? [10]
- (20) If the optics of a telescope are diffraction limited, then its angular resolution is given by the diameter of the Airy disc  $A = 1.22\lambda/D$  where  $\lambda$  is the wavelength of observation and  $D$  is the diameter of the objective in the same units. At  $\lambda = 5000\text{Å}$  the resolution of the human eye is about 4 arcminutes. If a telescope of diameter  $D$  meters is to be used visually, what magnification should be used to place it at the diffraction limit? [10]
- (21) A digital camera is used with a aperture setting of  $f/16$  at visual wavelengths. What pixel size (in microns) would result in the highest possible resolution? [10]

- (22) The surface brightness of an extended source like a galaxy or nebula does not change when viewed with the naked eye instead of through a telescope. Nevertheless, real experience shows that extended objects like the Andromeda galaxy or the Orion nebula are brighter when viewed with a telescope as compared the naked eye. Can you explain how this is possible? [5]
- (23) On a visit to the southern hemisphere, you contemplate the rise of the south ecliptic pole and wonders how fun it would be if the sky started spinning around the ecliptic pole, instead of the usual celestial pole. Sketch your displacement over the Earth's surface, to observe the stars revolving around the south ecliptic pole in the same direction and with the same period that they usually revolve around the south celestial pole. Sketch your trajectory for one entire day. Determine your velocity (direction and speed) when crossing the Equator for the first time. [30]