

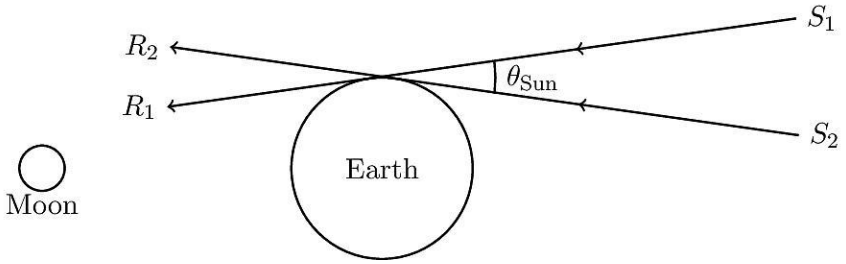
(D2.1) In September 2015, apogee of the lunar orbit is closest to
New Moon / First Quarter / Full Moon / Third Quarter.
Tick the correct answer in the Summary Answersheet. No justification for your answer is necessary. **3**

(D2.2) In September 2015, the ascending node of lunar orbit with respect to the ecliptic is closest to
New Moon / First Quarter / Full Moon / Third Quarter.
Tick the correct answer in the Summary Answersheet. No justification for your answer is necessary. **4**

(D2.3) Estimate the eccentricity, e, of the lunar orbit from the given data. **4**

(D2.4) Estimate the angular size of the umbra, θ_{umbra}, in terms of the angular size of the Moon, θ_{Moon}. Show your working on the image given on the backside of the Summary Answersheet. **8**

(D2.5) The angle subtended by the Sun at Earth on the day of the lunar eclipse is known to be $\theta_{\text{Sun}} = 1915.0''$. In the figure below, S_1R_1 and S_2R_2 are rays coming from diametrically opposite ends of the solar disk. The figure is not to scale. **9**



Calculate the angular size of the penumbra, θ_{penumbra}, in terms of θ_{Moon}. Assume the observer to be at the centre of the Earth.

(D2.6) Let θ_{Earth} be angular size of the Earth as seen from the centre of the Moon. Calculate the angular size of the Moon, θ_{Moon}, as would be seen from the centre of the Earth on the eclipse day in terms of θ_{Earth}. **5**

(D2.7) Estimate the radius of the Moon, R_{Moon}, in km from the results above. **3**

(D2.8) Estimate the shortest distance, r_{perigee}, and the farthest distance, r_{apogee}, to the Moon. **4**

(D2.9) Use appropriate data from September 10 to estimate the distance, d_{Sun}, to the Sun from the Earth. **10**

(D3) **Type IA Supernovae**

Supernovae of type Ia are considered very important for the measurements of large extragalactic distances. The brightening and subsequent dimming of these explosions follow a characteristic light curve, which helps in identifying these as supernovae of type Ia.

Light curves of all type Ia supernovae can be fit to the same model light curve, when they are scaled appropriately. In order to achieve this, we first have to express the light curves in the reference frame of the host galaxy by taking care of the cosmological stretching/dilation of all observed time intervals, Δt_{obs}, by a factor of $(1 + z)$. The time interval in the rest frame of the host galaxy is denoted by Δt_{gal}.

The rest frame light curve of a supernova changes by two magnitudes compared to the peak in a time interval Δt_0 after the peak. If we further scale the time intervals by a factor of s (i.e. $\Delta t_s = s\Delta t_{\rm gal}$) such that the scaled value of Δt_0 is the same for all supernovae, the light curves turn out to have the same shape. It also turns out that s is related linearly to the absolute magnitude, $M_{\rm peak}$, at the peak luminosity for the supernova. That is, we can write

$$s = a + bM_{\rm peak} ,$$

where a and b are constants. Knowing the scaling factor, one can determine absolute magnitudes of supernovae at unknown distances from the above linear equation.

The table below contains data for three supernovae, including their distance moduli, μ (for the first two), their recession speed, cz, and their apparent magnitudes, $m_{\rm obs}$, at different times. The time $\Delta t_{\rm obs} \equiv t - t_{\rm peak}$ shows number of days from the date at which the respective supernova reached peak brightness. The observed magnitudes have already been corrected for interstellar as well as atmospheric extinction.

Name	**SN2006TD**	**SN2006IS**	**SN2005LZ**
μ (mag)	**34.27**	**35.64**	
cz (km s^{-1})	**4515**	**9426**	**12060**
Δt_{obs} (days)	m_{obs} (mag)	m_{obs} (mag)	m_{obs} (mag)
-15.00	19.41	18.35	20.18
-10.00	17.48	17.26	18.79
-5.00	16.12	16.42	17.85
0.00	15.74	16.17	17.58
5.00	16.06	16.41	17.72
10.00	16.72	16.82	18.24
15.00	17.53	17.37	18.98
20.00	18.08	17.91	19.62
25.00	18.43	18.39	20.16
30.00	18.64	18.73	20.48

(D3.1) Compute $\Delta t_{\rm gal}$ values for all three supernovae, and fill them in the given blank boxes in the data tables on the BACK side of the Summary Answersheet. On a graph paper, plot the points and draw the three light curves in the rest frame (mark your graph as "D3.1"). **15**

(D3.2) Take the scaling factor, s_2, for the supernova SN2006IS to be 1.00. Calculate the scaling factors, s_1 and s_3, for the other two supernovae SN2006TD and SN2005LZ, respectively, by calculating Δt_0 for them. **5**

(D3.3) Compute the scaled time differences, $\Delta t_{\rm s}$, for all three supernovae. Write the values for $\Delta t_{\rm s}$ in the same data tables on the Summary Answersheet. On another graph paper, plot the points and draw the 3 light curves to verify that they now have an identical profile (mark your graph as "D3.3"). **14**

(D3.4) Calculate the absolute magnitudes at peak brightness, $M_{\rm peak,1}$, for SN2006TD and $M_{\rm peak,2}$, for SN2006IS. Use these values to calculate a and b. **6**

(D3.5) Calculate the absolute magnitude at peak brightness, $M_{\rm peak,3}$, and distance modulus, μ_3, for SN2005LZ. **4**

(D3.6) Use the distance modulus μ_3 to estimate the value of Hubble's constant, H_0. Further, estimate the characteristic age of the universe, $T_{\rm H}$. **6**