The distance to the large magellanic cloud

Stefan Völker (Jena)

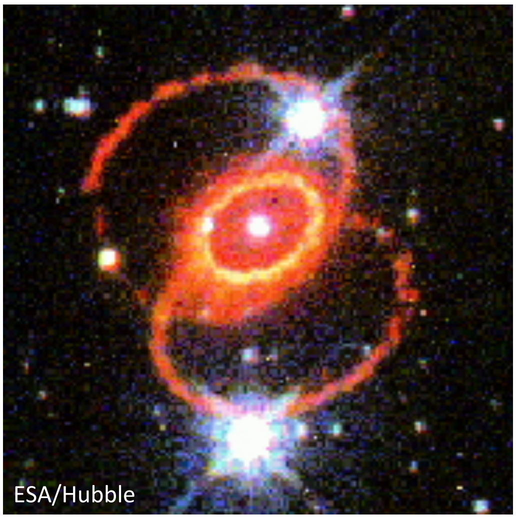
In the era of modern cosmology it is necessary to determine the Hubble constant as precise as possible. Therefore it is important to know the distance to the Large Magellanic Cloud (LMC), because this distance forms the fundament of the cosmological distance ladder. The determination of the LMC's distance is an suitable project for highschool students and will be presented in what follows.

Calculating the distance to the LMC using the supernova SN 1987 A [1, 2]

By combining the angular size α of an object with its absolute size R, one can calculate the distance d (at least for our cosmological neighborhood) using the equation

$$d = \frac{R}{\tan\alpha} \approx \frac{R}{\alpha} \tag{1}$$

and the approximation $d \gg R$. In the case of the SN 1987 A students can measure the angular size of the circumstellar ring on the Hubble Space Telescope (HST) image (Figure 1). The absolute size of the ring can be derived from the delay time due to light-travel effects seen in the emission light curve (also Figure 1). Once the supernova exploded, the UV-flash started



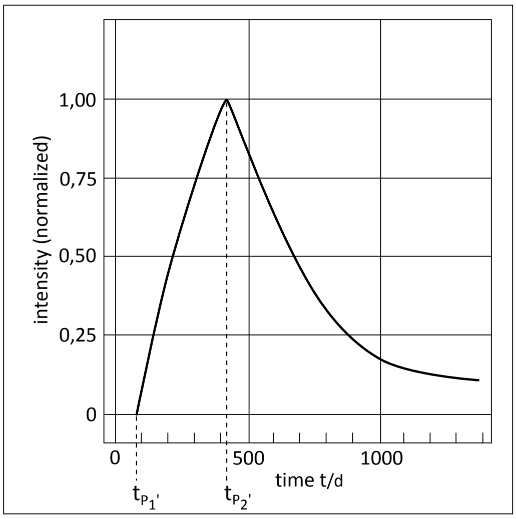


Figure 1: left: HST picture of the SN 1987 A; right: emission light curve of the circumstellar [2, 3]

propagating and reached the whole ring at the same time, which started emitting immediately. The additional distance x is linked to the delay time by the equation $x = c \cdot \Delta t = c \cdot (t_{P_2'} - t_{P_1'})$. The elliptical shape of the ring is a projection effect. The plane of the circumstellar ring is tilted about the angle i against the plane of the sky (Figure 2). With the Pythagorean theorem and the red triangle, shown on the right-hand of Figure 2, one can solve the equation for the radius of the ring ($R = a$)

$$a = \frac{x}{2 \cdot \sqrt{1 - \left(\frac{b}{a}\right)^2}} \,. \tag{2}$$

Measuring b/a and x in figure 1 yield the result

$$d_{SN} = \frac{c \cdot 340\,\mathrm{d}}{2 \cdot \sqrt{1 - (0,72)^2}} = 52\,\mathrm{kpc}\,.$$

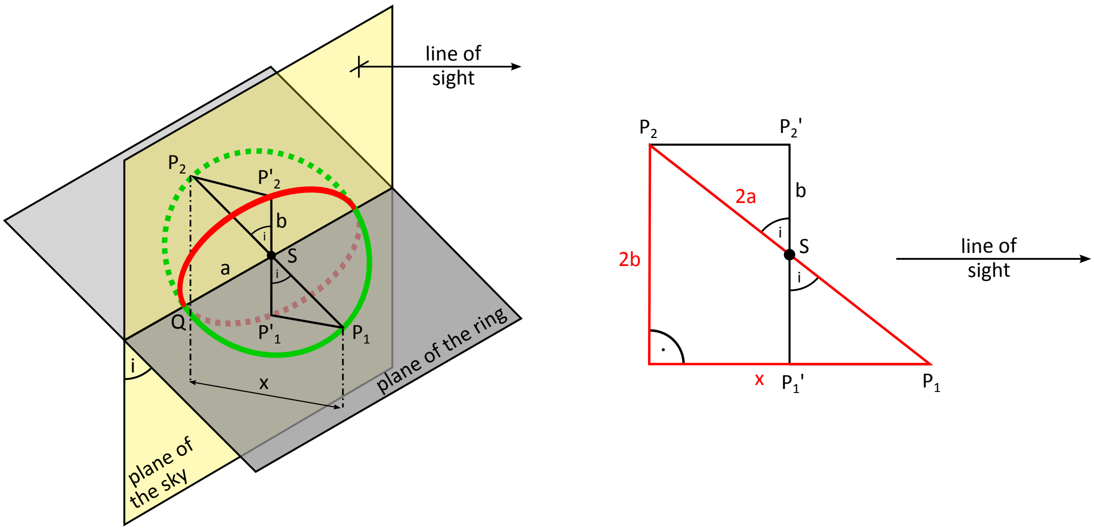


Figure 2: geometry of the SN; left: 3-dimensional; right: view on the line of intersection

With the assumption that the dimension of the LMC is small against their distance one can set the distance of the SN equal to the distance to the LMC

$$d_{LMC} \approx d_{SN} \approx 52\,\mathrm{kpc}\,.$$

Calculating the distance to the LMC using eclipsing binaries

Combining photometric with radial velocity measurements one can calculate the geometrical radii of the two components of an eclipsing binary. The knowledge of the angular diameters of the binary stars yields the distance of the system by the use of equation 1. Figure 3 shows an

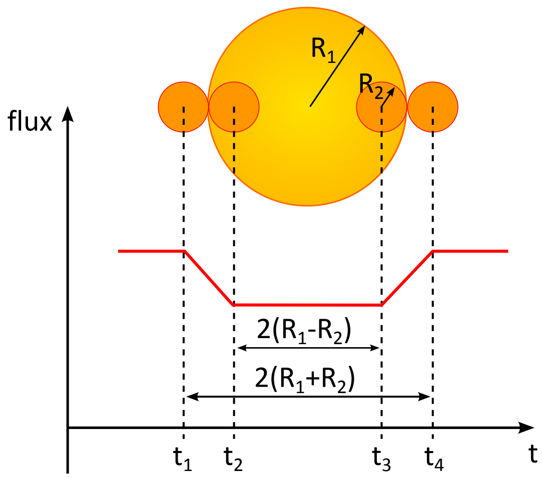


Figure 3: light curve of an eclipsing binary

occultation and one can derive the two equations

$$2 \cdot (R_1 + R_2) = v \cdot (t_4 - t_1) \quad (3)$$

$$2 \cdot (R_1 - R_2) = v \cdot (t_3 - t_2) \quad (4)$$

with the speed v beeing the relative speed of the stars in the center-of-momentum frame. The speed v is a result of the radial velocity measurements, while the time differences can be inferred from the photometric light curve. The angular size of the stars follows from the empirical surface brightness color relation (SBCR). Pietrzynski et al. [4] performed this kind of calculation for eight long-period eclipsing binary systems, consisting of late-type giants in an quiet evolutionary phase of the helium-burning loop. The systematic error of their result $d_{LMC} = (49,97 \pm 1,11)$ kpc is only about 2%. Their calculations can be reproduced, at least in principle, with students in highschool.

References

[1] Lotze, K.-H.: *Die Entfernung der Supernova SN 1987 A – Praktische Schülerübung mit Originaldaten des Hubble-Weltraumteleskops*; for example at http://www.lehrer-online.de/sn1987a.php (access on 26.08.13)

[2] Panagia N. , Gilmozzi R., Macchetto F. et al.: P*roperties of the SN 1987A circumstellar ring and the distance to the large magellanic cloud*; ApJ 380(1991) L23-L29

[3] ESA/Hubble: http://www.spacetelescope.org/images/opo9719b/ (access on 26.08.13)

[4] Pietrzynski G., Graczyk D., Gieren W. et al.: *An eclipsing-binary distance to the Large Magellanic Cloud accurate to two per cent*; Nature 495(2013)(7439)76-79