Introduction to Astronomy
Exercises week 13

17 January 2020

1. NGC 772 is a barred spiral galaxy that is similar to Andromeda (M31). The angular diameter and apparent magnitudes of NGC 772 are $7'$ and 12.0 respectively, while for Andromeda they are $3°$ and 5.0. Estimate the distance ratio for these two galaxies, assuming a) they have equal physical size; b) they have equal luminosity.

> **Solution:** a) If the galaxies have equal physical size, the ratio of distances can be determined simply by:
>
> $$\frac{D_{\mathrm{NGC772}}}{D_{\mathrm{M31}}} = \frac{r_{\mathrm{M31}}}{r_{\mathrm{NGC772}}} = \frac{3}{7/60} = 25.7,$$
>
> where r is the angular diameter and D the distance.
>
> b) In case the luminosity is equal, their absolute magnitudes must be equal. Ignoring extinction, we get:
>
> $$m_{\mathrm{NGC772}} - 5\log\frac{D_{\mathrm{NGC772}}}{10\,\mathrm{pc}} = m_{\mathrm{M31}} - 5\log\frac{D_{\mathrm{M31}}}{10\,\mathrm{pc}}.$$
>
> We get:
>
> $$\frac{D_{\mathrm{NGC772}}}{D_{\mathrm{M31}}} = 10^{(m_{\mathrm{NGC772}} - m_{\mathrm{M31}})/5} = 10^{7/5} = 25.1.$$
>
> So both measures are quite close, suggesting either assumption is equally valid (or invalid!)
>
> Note: the assumption that extinction can be ignored is justified because extinction is primarily caused by dust and intergalactic space does not have any dust. Therefore any extinction that would affect these observations, would be from the Milky Way itself and would therefore be very limited. (The Galactic latitudes of M31 and NGC 772 are -21 and -41 degrees respectively, so they're well outside the plane of the Milky Way.)

2. Quasar 3C279 shows increases in brightness that last for about a week. If we assume these "bursts" are caused by a single, short-lived event, then the time-scale of the brightness variation is a measure of the light-travel time across the region where the burst originated.

   (a) Use this assumption to estimate the size of the disturbed region (measured in AU). Note this is clearly more an upper limit than an actual physical size!

   > **Solution:** If the light-travel time across the region is one week, then the size can trivially be calculated as:
   >
   > $$S = c \times t = 3 \times 10^8\,\mathrm{m/s} \times 7 \times 24 \times 3600\,\mathrm{s} = 1.81 \times 10^{14}\,\mathrm{m} = 1213\,\mathrm{AU}.$$

   (b) During the outburst, the apparent magnitude of this quasar is 18. Assuming the distance is 2000 Mpc, calculate the absolute magnitude.

   > **Solution:**

We can easily apply the definition of the absolute magnitude:

$$M = m - 5\log\frac{D}{10\,\mathrm{pc}} = 18 - 5\log 2\times 10^8 = -23.5.$$

(c) If the measured magnitude was the magnitude in the V-band, calculate what the total luminosity of the quasar is during the outburst (expressed in Solar luminosities). Then use this value to compute the average luminosity produced per cubic AU.

Solution: We start with the definition of apparent magnitude:

$$m = -2.5\log\frac{F}{F_{\mathrm{ref}}}.$$

subtracting the Solar apparent magnitude from the measured apparent magnitude of the quasar, we can eliminate the (unknown) reference flux:

$$m_{\mathrm{QSO}} - m_{\odot} = -2.5\log\frac{F_{\mathrm{QSO}}}{F_{\odot}} = 18 + 26.74 = 44.74.$$

It follows that the flux of the quasar, expressed in Solar flux, is:

$$F_{\mathrm{QSO}} = F_{\odot}10^{(m_{\mathrm{QSO}}-m_{\odot})/-2.5} = 10^{-44.74/2.5}F_{\odot} = 1.27\times 10^{-18}\,\mathrm{F}_{\odot}.$$

Now remembering that the luminosity is the flux integrated over a sphere, we get:

$$\frac{L_{\mathrm{QSO}}}{L_{\odot}} = \frac{F_{\mathrm{QSO}}\times 4\pi D_{\mathrm{QSO}}^2}{F_{\odot}\times 4\pi D_{\odot}^2} = \frac{F_{\mathrm{QSO}}D_{\mathrm{QSO}}^2}{F_{\odot}D_{\odot}^2}.$$

Hence:

$$L_{\mathrm{QSO}} = 10^{(m_{\mathrm{QSO}}-m_{\odot})/-2.5}\left(\frac{D_{\mathrm{QSO}}}{D_{\odot}}\right)^2 L_{\odot}.$$

This becomes:

$$L_{\mathrm{QSO}} = 10^{(m_{\odot}-m_{\mathrm{QSO}})/2.5}\left(2\times 10^9\times 3.0857\times 10^{16}/1.49597870\times 10^{11}\right)^2 L_{\odot} = 2.16\times 10^{11}L_{\odot}.$$

Given that the size of the emitting region is estimated to be 1213 AU (in diameter), the average luminosity per cubic AU is:

$$\frac{2.16\times 10^{11}L_{\odot}}{4/3\pi(1213/2)^3\,\mathrm{AU}^3} = 237\frac{L_{\odot}}{\mathrm{AU}^3}.$$

So the luminosity density of these bursts is not so incredibly high, which probably means that the size we calculated is a reasonable upper limit; and the luminosity density is a reasonable lower limit.