IWAA 2018 - Zánka, Hungary
The Cosmic Distance Ladder - Problem Sheet

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Problem 1 - Life of an ancient astronomer

What is the relative distance and the relative size of the Moon and the Sun? You measure, that the angular separation of these two celestial bodies at a lunar dichotomy is 87°. Based on our current knowledge, what angle should you have measured?

Problem 2 - Moon radar

Zoltán Bay received radio signals reflected back from the surface of the Moon.

a) How much time did the signals need for the route back and forth?

b) Bay and his colleagues had only a weak radio source. How could they increase the amplitude of the received signal just by sending a sequence of short signals?

Problem 3 - Exoplanet

What is the distance of the terrestrial exoplanet candidate Gliese 581d from its parent star, if its orbital period is 67 days? Its parent star is an M dwarf having a mass of 0.31 $M_\odot$.

Problem 4 - Stellar positions

We have measured the position of a star on 5 May and 5 November. The difference between the two positions was $7.436 \cdot 10^{-6}$ radians. How far is the star from us? Which star could it be?

Problem 5 - Cepheids

Figure 1 shows the period-luminosity relation of classical cepheids. Figure 2 shows the lightcurve of a Cepheid observed in a galaxy of the Local Group.

a) Estimate the distance of the Cepheid.

b) Do another estimation taking the interstellar extinction into consideration. In the direction of this particular source, the extinction is $A = 0.25^m$

c) The period-luminosity relation has the following form: $M = \beta \log P + C$. Estimate the values of the two constants, β and C.

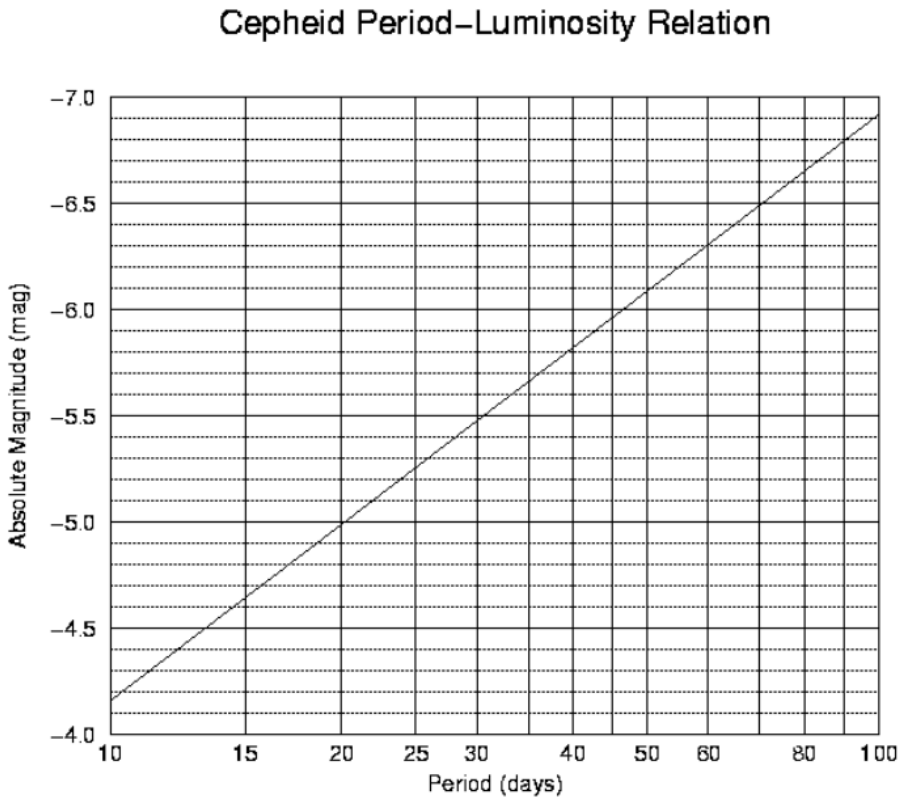

Figure 1: Period-luminosity relation of classical Cepheids

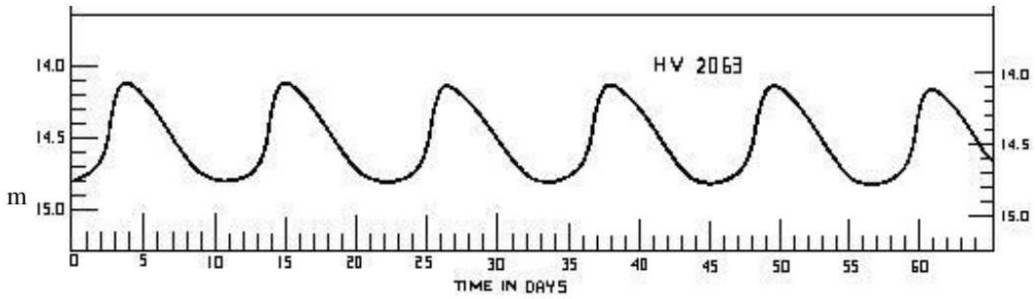

Figure 2: Lightcurve of the Cepheid

Problem 6 - Supernovae

Estimate how far is the farthest Ia-type supernova which could be seen by the naked eye. Estimate, what could be the maximal mass of a super-Chandrasekhar mass supernova.

Problem 7 - PNLF

The main point of the Planetary Nebula Luminosity Function is the following. Observations indicate that the number distribution of planetary nebulae based on their absolute magnitudes in a galaxy is described by the following formula:

$$N(M) \sim e^{0.307M}(1 - e^{3(M^* - M)}),$$

where M is the absolute magnitude and $M^* = -4.48$ is the maximal brightness of a planetary nebula. The formula works with apparent magnitudes as well, since the planetary nebulae are located in the same galaxy hence have nearly the same distance. However, then we can not use M^*, but we have to find out what m^* could be (the maximal apparent brightness of a planetary nebula, which will be different for each galaxy).

A sky survey observed 3 planetary nebula in the NGC 55 with $m_1 = 22.90^m$ and 5 with $m_2 = 23.38^m$. How far is the galaxy if these two values fit exactly to the PNLF of the galaxy?

Suggestion: According to the aforementioned facts, the number of nebulae and the function are proportional. The exact multiplier between them is not known, but if we calculate the fraction of two such functions, the multiplier constant will cancel out. Also, m^* will be the same in the two functions.

Problem 8 - Spiral galaxy populations

A sky survey sensitive near the 21 cm line of Hydrogen measured the values in Table 1 for a handful of spiral galaxies, where $\lambda_{\max}$ denotes the maximally redshifted value of the 21 cm line and M_{B} means the B-band absolute magnitude of the galaxy.

Assume that we observe all galaxies edge-on, they are all spirals and the Tully-Fisher relation has the following form:

$$M_{\mathrm{B}} = A \cdot \log_{10} V_{\max} + B,$$

where A and B are constants and $V_{\max}$ is the maximal rotational velocity of the galaxy measured in km/s.

Could you find different populations in the data which obey the Tully-Fisher relation with different constants? If so, how many and what could be the physical difference between them? Estimate the constants A and B for all the found populations.

Problem 9 - Expanding Universe

From a galaxy named G (located 3 Gpc away from us) the aliens measured the distance and the position of another galaxy named F. Based on their calculations, F is 2.5 Gpc away from the Milky Way, and from F, the apparent angular separation of G and the Milky Way is 65.38°. If the aliens of G get the spectrum of F, where will they see the α line of Hydrogen? *Hint: The Hα line's wavelength in 656.28 nm in the laboratory.*

$\lambda_{\max}$ [cm]	M_{B}
21.009762	-19.47
21.011980	-20.07
21.014383	-20.88
21.014692	-21.28
21.015375	-20.15
21.017113	-21.65
21.017429	-20.33
21.019075	-21.88
21.019227	-21.42
21.021013	-21.50
21.021888	-22.74
21.023263	-23.01
21.025345	-22.31
21.030602	-22.87
21.030289	-23.08

Table 1: Data for spiral galaxies from the sky survey.