The Norwegian University of Science and Technology
Department of Physics

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Examination, course TFY4325 and FY2450 Astrophysics
Thursday June 2, 2005
Time: 15.00–19.00

Grades made public: Thursday June 23, 2005

Allowed to use: Calculator, mathematical tables.

A table of physical constants can be found on page 3.
All subproblems count equally for the grading.

Problem 1:

a) What is it that limits the angular resolution of a telescope? Explain briefly why.

b) What is a main sequence star?
Most of the stars we see in the sky are main sequence stars. Why?
Is the Sun a main sequence star?

c) Sketch briefly the "distance ladder", that is, the different methods available for measuring distances, which may be calibrated against each other and which makes it possible to measure distances in the universe, both to the nearest stars and to the farthest galaxies.

d) The first astronomers studying supernovae classified them as type I and type II, depending on their spectra.
What is the main difference between the spectra of supernovae of type I and type II?
Later on it became clear that there were important differences between supernovae of type I, and therefore they were subclassified as types Ia, Ib and Ic.
A supernova of type Ia is, according to theory, a white dwarf star exploding, so violently that there is nothing left apart from an expanding cloud of gas.
What is a white dwarf star, and what causes the explosion?
What is the energy source in such an explosion of a white dwarf?

e) In a supernova of type Ib, Ic or II it is the core of a burnt out massive star (of more than about 8 solar masses) which collapses, and the end result is that most of the mass of the star is thrown out in an explosion.
What is the main energy source in a supernova explosion of this type?
What type of supernova explosion, either type Ia or type II, liberates most energy?
What type shines most brightly in visible light?
(Guessing is allowed, if you do not know the answers!)

Problem 2:

The star Mintaka, also called δ Orionis, is the rightmost of the three stars in the belt of Orion. It is actually a star system consisting of four single stars, but two of the four dominate completely, because they are blue giant stars.
We will consider here the two giant stars. They are classified into nearly the same spectral class, respectively O9 and B0, which means that they both have a surface temperature of about 30 000 K. Each of them has a luminosity 70 000 times the luminositety of the Sun. They orbit each other at distance of only 0.2 AU (astronomical units), with a period of 5.73 days.

a) The two giant stars must have roughly the same radius. Why?
Compute the radius (see formulae on page 3), and compare with the given distance between the stars.

b) Compute the absolute magnitude of each of the two stars (for example comparing with the Sun, see formulae on page 3).
The observed absolute magnitude in visible light is -4.3 for each of them. Does your computation agree with this observation?

c) The two giant stars in Mintaka form a spectroscopic binary star system which is at the same time an eclipsing variable.
Explain how the Doppler effect makes it possible to observe that the spectrum consists of light from two stars, and in addition to measure the distance between the two stars.

d) Compute the mass of each of the stars, assuming that they have equal masses.
Judge your answer, whether it looks reasonable.

e) What is going to happen to the two stars when they burn out? Motivate your answer. (If you have no answer, you may still explain how an answer should be motivated).

Problem 3:

a) The gravitational force between two masses is inversely proportional to the square of the distance between them. Why is the tidal force, e.g. from the Moon here on Earth, inversely proportional to the third power of the distance?

b) Figure 1 (page 4) shows the high and low tides in Trondheimsfjorden over a period of ten weeks.
During this time there were five times spring tide (maximal difference between high and low tide) and five times neap tide (minimal difference between high and low tide).
We get spring tide and neap tide because both the Moon and the Sun contribute to the tides. The Moon has the greatest influence on the tides, as we know because the time between two high tides is 12 hours and 25 minutes.
How long time would there be between two high tides if the Sun had a greater influence than the Moon?
How are the Moon phases at spring tide and neap tide?

c) Use Figure 1 to compute the mass of the Moon, given that the mass of the Sun is 1.989×10^{30} kg, and given the distances (that is, the mean distances) to the Moon, 384 000 km, and to the Sun, 1.496×10^{8} km.
Estimate the uncertainty in your answer.

Some physical constants and formulae

Newton's gravitational constant:	$G = 6.673 \times 10^{-11}\,\mathrm{m^3\,kg^{-1}\,s^{-2}}$
The speed of light in vacuum:	$c = 299\,792\,458\,\mathrm{m/s}$
The permeability of vacuum:	$\mu_0 = 4\pi \times 10^{-7}\,\mathrm{N/A^2}$
The permittivity of vacuum:	$\epsilon_0 = 1/(\mu_0 c^2) = 8.854 \times 10^{-12}\,\mathrm{F/m}$
The reduced Planck's constant:	$\hbar = h/(2\pi) = 1.055 \times 10^{-34}\,\mathrm{J\,s}$
The elementary charge:	$e = 1.602 \times 10^{-19}\,\mathrm{C}$
The fine structure constant:	$\alpha = e^2/(4\pi\epsilon_0\hbar c) = 1/137.036$
Boltzmann's constant:	$k_B = 1.3807 \times 10^{-23}\ \mathrm{J/K}$
Stefan–Boltzmann's constant:	$\sigma = 5.6704 \times 10^{-8}\ \mathrm{W/(m^2\,K^4)}$
The electron mass:	$m_\mathrm{e} = 9.109 \times 10^{-31}\,\mathrm{kg} = 0,511\,\mathrm{MeV}/c^2$
The proton mass:	$m_\mathrm{p} = 1.6726 \times 10^{-27}\,\mathrm{kg} = 938,28\,\mathrm{MeV}/c^2$
The neutron mass:	$m_\mathrm{n} = 1.6749 \times 10^{-27}\,\mathrm{kg} = 939,57\,\mathrm{MeV}/c^2$
The mass of the Earth:	$M_\oplus = 5.974 \times 10^{24}\,\mathrm{kg}$
The radius of the Earth:	$R_\oplus = 6.378 \times 10^{3}\,\mathrm{km}$
The solar mass:	$M_\odot = 1.9891 \times 10^{30}\,\mathrm{kg}$
The solar radius:	$R_\odot = 6.960 \times 10^{5}\,\mathrm{km}$
Distance to the Sun (one astronomical unit):	$1\,\mathrm{AU} = 1.4960 \times 10^{8}\,\mathrm{km}$

Kepler's third law for masses m_1 and m_2 in an elliptical orbit of semimajor axis a and period P:

$$P^2 = \frac{4\pi^2 a^3}{G(m_1 + m_2)}\ .$$

Stefan–Boltzmann's law (flux F of black body radiation of temperature T): $F = \sigma T^4$.

Relation between apparent magnitude m and absolute magnitude M for a star at a distance d:

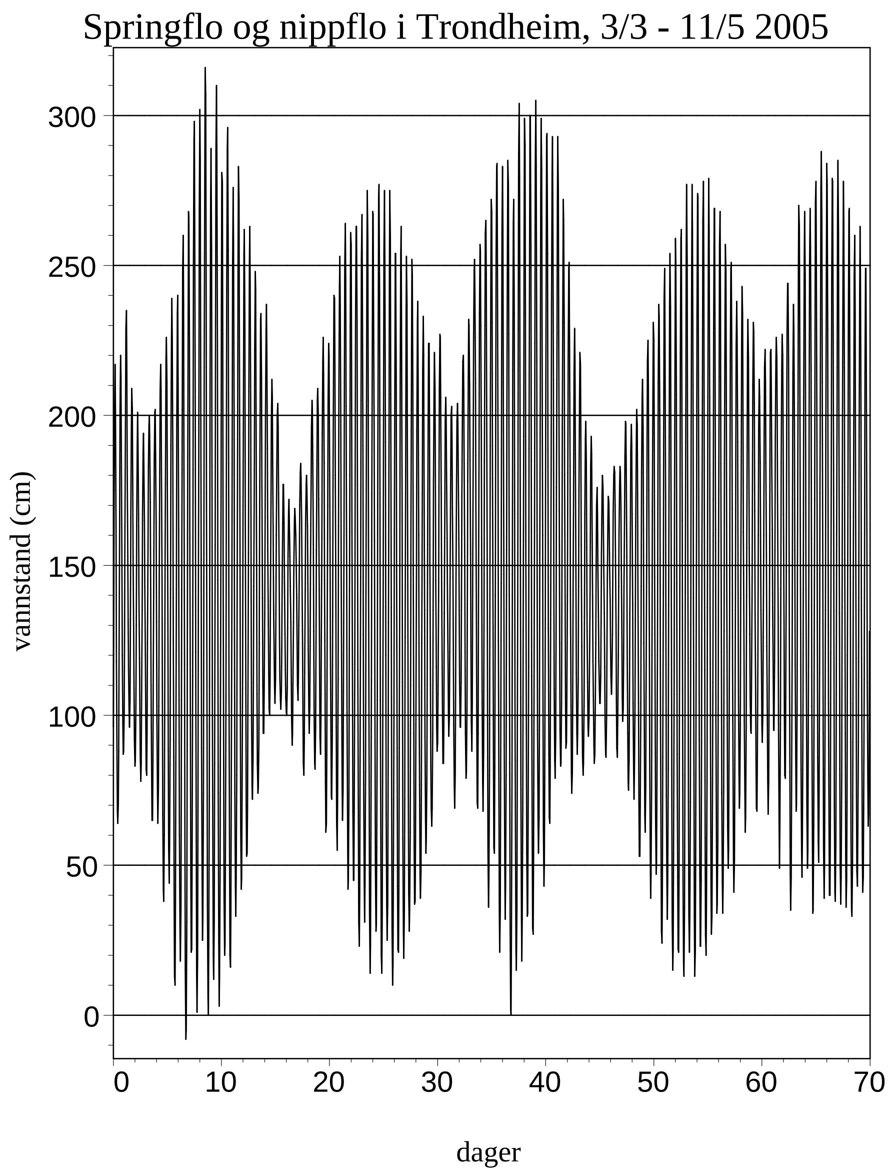
$$m - M = 5\ \log_{10}\left(\frac{d}{10\ \mathrm{parsec}}\right).$$

For two stars 1 and 2 the following relations hold:

$$\begin{aligned} m_2 - m_1 &= 2.5\ \log_{10}\left(\frac{b_1}{b_2}\right), \\ M_2 - M_1 &= 2.5\ \log_{10}\left(\frac{L_1}{L_2}\right). \end{aligned}$$

Where b is the apparent brightness and L is the luminosity (absolute brightness).

The Sun has absolute magnitude $M = 4.8$ and luminosity $L = 3.86 \times 10^{26}$ W.



Figur 1: Water level in Trondheimsfjorden, measured every hour, from March 3 to May 11, 2005. The zero level is roughly the lowest low tide. Data from Statens kartverk.