# Exercises for Nuclear Astrophysics I
# WS 2011/12 - Prof. Shawn Bishop
# Sheet 1

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Problems will be discussed in exercises on 10/27/2011 at 13:00.

## 1  Stellar Distances

(a) **Proxima Centauri**

For near stars, the distance can be measured by observing the change in apparent position due to the earth's movement around the sun (triangulation). The closest star to our sun is the red dwarf Proxima Centauri.

(i) The apparent change of position of Proxima Centauri over half a year has been measured by the Hubble Space Telescope, and thus the parallax determined to be $p = 0.7687''$. Calculate the resulting distance of this star to earth.

(ii) The apparent magnitude of Proxima Centauri is $m = 11.05$ mag. Use the distance obtained in (a) to calculate the absolute magnitude $M$.

(b) **$\delta$-Cephei-Stars**

$\delta$-Cepheides are a class of variable stars. These giants are subject to oscillations in their luminosity due to the Kappa-Mechanism. You can read up on this on your own. The dependence of the average absolute magnitude $M$ on the period of the oscillation $p$ in days can be written as:

$$M = -2.83 \cdot \log_{10}(p) - 1.43$$

In the 1920s, Edwin Hubble observed numerous variable stars in neighboring galaxies. One of them had an oscillation period of $p = 46$ days for an oscillation of magnitude with $m_{min} = 19.25$ and $m_{max} = 18.33$. Calculate the distance to that star. Can you guess what galaxy the star is located in?

(c) **Flux-Magnitude-Relation**

Use the formulas introduced in the lecture to derive the Flux-Magnitude-Relation

$$m = M_\odot - 2.5 \log_{10} \frac{F}{F_{10,\odot}} \qquad (1)$$

where $F_{10,\odot}$ denotes the flux from our sun from a distance of 10 pc.

## 2  Energy considerations in stars

(a) **Supernova 1987A**

On February 24th 1987, the supernova 1987A was discovered. It was visible to the naked eye and faded over roughly 2 weeks. The progenitor star was identified as a blue super giant in the Large Magellanic Cloud at a distance of about 150.000 Ly from earth.

(i) Assume, the energy liberated in this explosion was roughly $5 \cdot 10^{53}$ erg. However, only about 0.01 percent of this energy was radiated away in electromagnetic waves. Where did the rest of this energy go? Can you find something in literature?

(ii) Our sun has an age of about 4 billion years and a luminosity of about $4 \cdot 10^{33} \frac{erg}{s}$. How much luminous energy has it emitted to date? Compare this to the energy output of SN 1987A.

(iii) How many stars similar to our sun would it take to radiate away the same amount of luminous energy as SN 1987A did in 2 weeks? You can look up the number of stars in the Large Magellanic Cloud for a comparison.

(b) **Gravitational energy**

The gravitational energy of a star can be written as

$$\Omega = -\int_0^M \frac{GM_r}{r} dM_r \tag{2}$$

where $M$ is the total mass of the star, and $M_r = \int_0^r 4\pi r^2 \rho dr$. It can be written in the form

$$\Omega = -q\frac{GM^2}{R} \tag{3}$$

Consider a very simple stellar model with constant density profile: $\rho(r) = \rho_c = \text{const}$. Show that in this case, the factor $q$ is equal to $\frac{3}{5}$.

(c) **Variational principle (*)**

The total energy of a star is $W = U + \Omega$, with the internal energy $U = \int E dM_r$, where E [erg/g] is the density of internal energy. Consider an infinitesimal adiabatic variation $\delta W = \delta U + \delta \Omega$ in both terms individually. Transform the variation in energy to one in radial coordinate $r$ to derive the relation

$$\frac{dP}{dM_r} = -\frac{GM_r}{4\pi r^4} \tag{4}$$

Hints: Use $\delta E = -P\delta V_\rho$ with the specific volume $V_\rho = \frac{1}{\rho}$ and show that to first order $\delta V_\rho = \frac{d(4\pi r^2 \delta r)}{dM_r}$. Also use a first order approximation for an expression for $\delta\Omega$ and then put $\delta W = 0$.