Stellar Astronomy and Astrophysics (SS12)

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Exercise 10 for July 3, 2012

Rotation and mass loss

10.1 Rotation and magnetic field

Suppose that the Sun were to collapse down to the size of a neutron star of $\sim 10\,\mathrm{km}$.

a) Assuming that no mass is lost in the collapse, find the rotation period of the neutron star.

b) Find the magnetic field strength of the neutron star.

Even though our Sun will not end its life as a neutron star, this shows that conservation of angular momentum and magnetic flux can easily produce pulsar-like rotation speeds and magnetic fields.

10.2 Future of the Earth

There are several processes by which the Sun loses mass. Here, we estimate the influence of the solar mass loss on the orbit of the Earth.

a) The present-day luminosity of the Sun is $L_\odot \approx 4 \times 10^{33}\ \mathrm{erg\,s^{-1}}$. Assume that the Sun had the same luminosity since it was formed 4.6 billion years ago. What is the total mass loss that the Sun has experienced since its birth due to nuclear fusion, where mass is converted into energy? By what amount did the semi-major axis of the Earth's orbit change due to this effect?

b) The is also the solar wind. At the distance of the Earth the mean velocity of the solar wind is $v = 500\,\mathrm{km\,s^{-1}}$ and the mean density amounts to $\rho = 5$ protons per cm^3. Assume that the solar wind is expelled isotropically and had the same value since 4.6 billion years. Note, the actual mass loss was much higher during the T Tauri phase at the beginning of the life of the Sun. What is the total mass loss due to the solar wind since the birth of the Sun and what did this mean for the orbit of the Earth?

c) During the red giant phase, particularly at the end of the AGB phase, the Sun will lose a significant part of its mass. Before the Sun arrives at its largest radius of about $180\,R_\odot$, it loses about one third of its current mass. By what amount does the Earth's radius change due to this effect, and does this help the Earth to survive?

10.3 AGB mass loss

Various researchers have proposed parametrizations of the AGB mass loss rate that are based on fitting observed rates for a specific set of stars with some general equation that includes measurable quantities associated with the stars in the sample. One of the most popular, developed by Reimers (1977, A&A, 61, 217), is given by

$$\dot{M} \approx -1.4 \times 10^{-13} \eta \frac{L}{gR} \, M_\odot \, \mathrm{yr}^{-1} \tag{1}$$

where L, g, and R are the luminosity, surface gravity, and radius of the star, respectively (all in solar units; $g_\odot = 274 \, \mathrm{m \, s^{-2}}$). η is a free parameter whose value is expected to be near unity.

a: Explain qualitatively why L, g, and R enter the equation in the way they do.

b: Estimate the mass loss rate of a $1 \, M_\odot$ AGB star that has a luminosity of $7000 \, L_\odot$ and a temperature of $3000 \, \mathrm{K}$.

c: Show that the Reimers mass loss rate can also be written in the form

$$\dot{M} = -1.4 \times 10^{-13} \eta \frac{LR}{M} \, M_\odot \, \mathrm{yr}^{-1} \tag{2}$$

where L, R, and M are all in solar units.

d: Assume (incorrectly) that L, R, and η do not change with time and derive an expression for the mass of the star as a function of time. Let $M = M_0$ when the mass loss phase begins.

e: Using $M_0 = 1 \, M_\odot$, $L = 7000 \, L_\odot$, and $\eta = 1$, make a graph of the star's mass as a function of time.

f: How long would it take for a star with an initial mass of $1 \, M_\odot$ to be reduced to the mass of the degenerate carbon-oxygen core of $\sim 0.6 \, M_\odot$?