Exercises Stellar Transients

Useful numbers

These numbers may be useful when solving the exercises.

Solar mass	$\mathrm{M}_\odot$	$1.99 \cdot 10^{33}\,\mathrm{g}$
Solar luminosity	$\mathrm{L}_\odot$	$3.85 \cdot 10^{33}\,\mathrm{erg\,s^{-1}}$
Parsec	pc	$3.086 \cdot 10^{18}\,\mathrm{cm}$
Speed of light	c	$2.998 \cdot 10^{10}\,\mathrm{cm\,s^{-1}}$
Gravitational constant	G	$6.673 \cdot 10^{-8}\,\mathrm{erg\,cm\,g^{-2}}$
Mass of proton	$\mathrm{m_p}$	$1.66 \cdot 10^{-24}\,\mathrm{g}$
Energy	1 eV	$1.602 \cdot 10^{-12}\,\mathrm{erg}$
	1 erg	10^{-7} Joule

Introduction to 4, 5 and 6

In the lecture we have seen that:

- electron-degenerate stars are white dwarfs
- white dwarfs cool to $T = 0$, and
- there is an upper limit to the mass of white dwarfs.

Here, we will investigate what happens if a white dwarf accretes mass such that it exceeds the upper mass limit (the Chandrasekhar mass). Note that this is not an academic question, but we know that this happens in the universe. Most white dwarfs are composed of a mixture of carbon and oxygen (roughly 50% each), and if one of them has a close binary companion, mass overflow onto the white dwarf may lead to a catastrophe...

Exercise 4

If we take a model of the sun and disturb it a little bit, i.e., we increase the central energy generation rate in the sun by a small amount, the following sequence of events happens in the model.

1. The increased nuclear energy generation will lead to a higher temperature in the center of the solar model.
2. The increased temperature will lead to an increased central pressure.
3. The force balance is disturbed, and the overpressure makes the core of the sun expand.
4. The expansion makes the temperature decrease.
5. As the nuclear fusion rate is a strongly increasing function of the temperature, the drop in temperature leads to a decrease of the nuclear energy generation rate.

The sun is stable against the applied disturbance.
Now, make the same gedankenexperiment with a white dwarf...

Exercise 5

The more massive a white dwarf is, the smaller it becomes. Higher masses in an ever decreasing volume lead to higher and higher gravitational forces. When a white dwarf reaches the Chandrasekhar mass (about $1.4\,M_\odot$, the electron pressure can not compensate the gravitational force any longer: the white dwarf starts to collapse. During the collapse, density and temperature rise, and nuclear fusion will start under degenerate conditions. Once started, the nuclear fusion will practically incinerate the whole white dwarf: most of the carbon and oxygen is fused to ^{56}Ni, the most stable isotope with equal number of protons and neutrons, thereby producing an energy of roughly 10^{18} erg per gramme.

a. Assuming that most of this energy is converted into kinetic energy of the exploding white dwarf: with which velocity does it fly apart?

b. Correct the result obtained in **a**, by subtracting the potential energy of the white dwarf: which is the smallest radius which the white dwarf may obtain when it collapses in order for the thermonuclear energy being sufficient to reverse the collapse into an explosion?

Exercise 6

A successful explosion of a white dwarf transforms it, as mentioned above, into ^{56}Ni. This is a radioactive isotope, which decays with a half life of about 6 days. Each decay yields an energy of 1.7 MeV.

a. Assume that this energy is immediately transformed into light: how bright does the supernova shine initially?

b. Knowing that with the most modern telescopes we can just about see a star like the sun at a distance of 10^6 light years, up to which distances can we observe exploding white dwarfs (assuming that all the light is always at visual wavelengths)? Compare this to the size of the universe (which may have an age of $1.5 \cdot 10^{10}$ years).