Theoretical Astrophysics I: Physics of Sun and Stars
Lecture 11: Binary, Variable stars, and Supernovae

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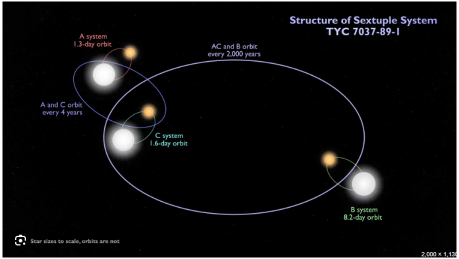
Recap

- We have understood the structure (and a bit of evolution of the stars) though the power of 1-D models.
- There we have assumed that the stars are isolated, and spherically symmetric.
- We have also assumed that the processes in them act extremely slowly.
- We allowed for some, miniscule oscillations that allowed us to perform helio/astroseismology.
- In real life, things are much different...

Departures from ideal approximations

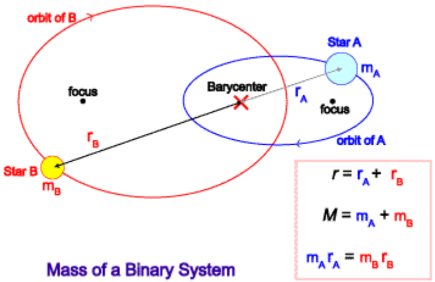
- Stars are not born alone, and they do not evolve alone. 85% of all the stars are in the binary systems.
- Some stars are highly assymetric, either because of fast rotation or strong magnetic fields (or both!)
- Some exhibit strong, periodic changes, and can change their brightness substantially with period of order of hours or days.
- ...explode and completely change their structure (and eject the material in the interstellar space!)



Credits: NASA

Binary stars

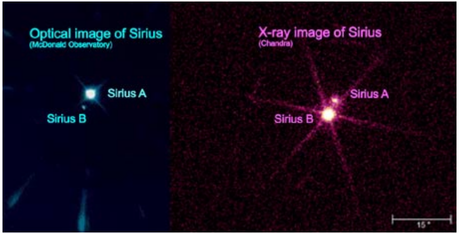
- We will focus on systems of two stars, even though there can be more than one.
- Note: we are **not** talking about stellar clusters now.
- Binary star is a system of two stars that are gravitationally bound to each other.
- They revolve around the center of the mass of the system.



Credits: Australia Telescope National Facility

Visual Binaries

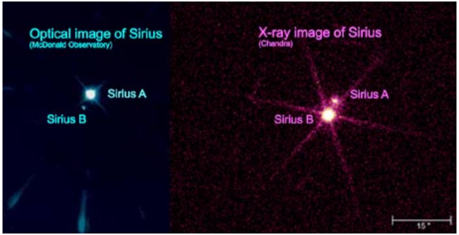
- Binary star is a system of two stars that are gravitationally bound to each other.
- Sometimes their movement can be detected directly - through the change in the apparent position of the stars on the sky - **astrometric methods**
- These stars are often called visual binaries.
- To the right we see Sirius, which is in fact a binary star.



Credits: NASA/SAO/CXC/MacDonald Observatory

Visual Binaries

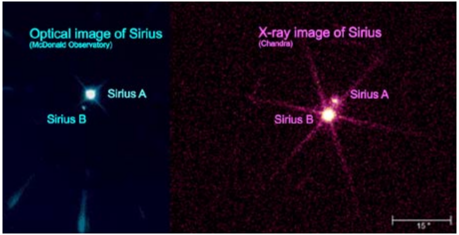
- We did not immediately discover both. In 1844 Bessel detected that Sirius has a companion, through the change in its proper motion.
- In 1915 we observed the spectrum of Sirius B and concluded it is a white dwarf, of the size of the Earth and mass approximately $M_\odot$
- The orbit of the system is very eccentric ($e = 0.6$).
- Sirius A is an A class star (hehe), with temperature around 10 000 K and mass equal to 2 $M_\odot$.



Credits: NASA/SAO/CXC/MacDonald Observatory

Sirius

- Sirius A is an A class star with temperature around 10 000 K and mass equal to 2 $M_\odot$.
- Sirius B and concluded is white dwarf, of the size of the Earth and mass approximately $M_\odot$
- Is there something here that does not fit?



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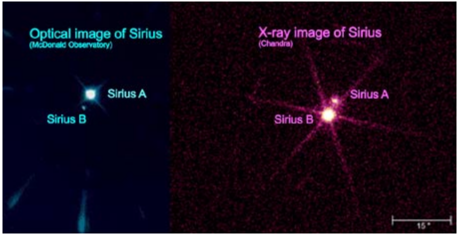
- Is there something here that does not fit? - How is less masive star a white dwarf and the more massive one still on the main sequence?



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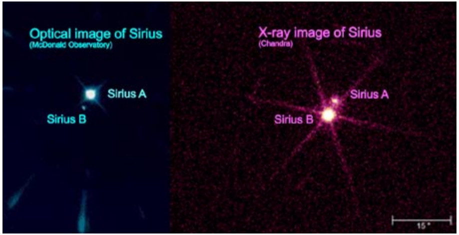
- Is there something here that does not fit? - How is less masive star a white dwarf and the more massive one still on the main sequence?
- Sirius B must have lost a big part of its mass through the evolution.
- How do we know these stellar masses?



Credits: NASA/SAO/CXC/MacDonald Observatory

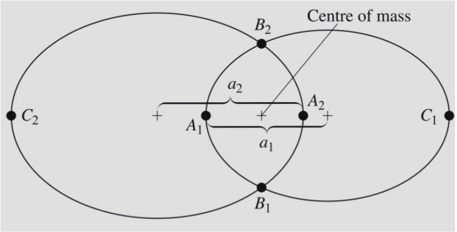
Visual binaries - mass determination

- Observing systems like this one is crucial for measuring stellar masses.
- **First** we measure the period of the system.
- **Then** we can use Kepler's third law:

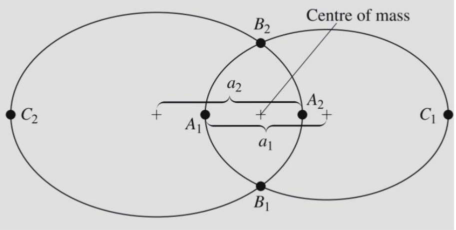
$$\frac{(a1 + a2)^3}{T^2} = \frac{G(M_1 + M_2)}{4\pi^2} \qquad (1)$$

- To find the mass of the system. Then, we can find individual masses from:

$$M_1 a_1 = M_2 a_2 \qquad (2)$$

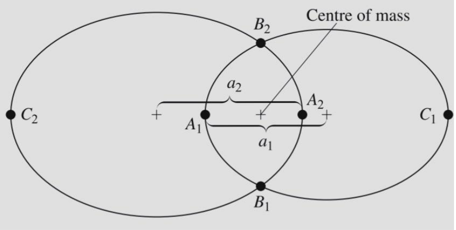


- What did we have to measure to perform this?



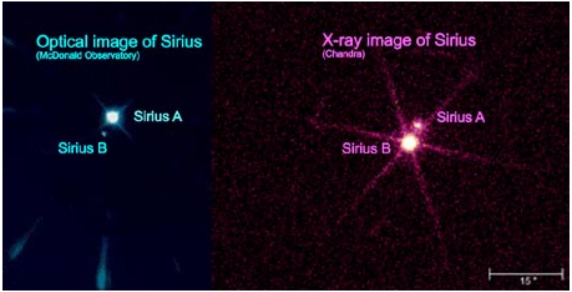
Visual binaries - mass determination

- What did we have to measure to perform this?
- Period of the system
- Orbits of both of the stars.
- We also needed the orbit to be in the plane of the sky.
- We need to be a bit fortunate for this to happen!
- **But, it allows us to directly measure stellar masses and test our models!**



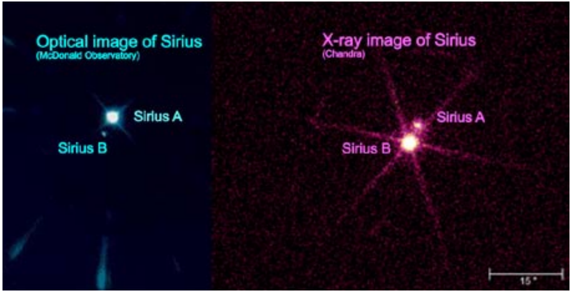
One more question on Sirius

- How come that Sirius A is brighter in optical wavelengths and Sirius B is brigther in X ray?



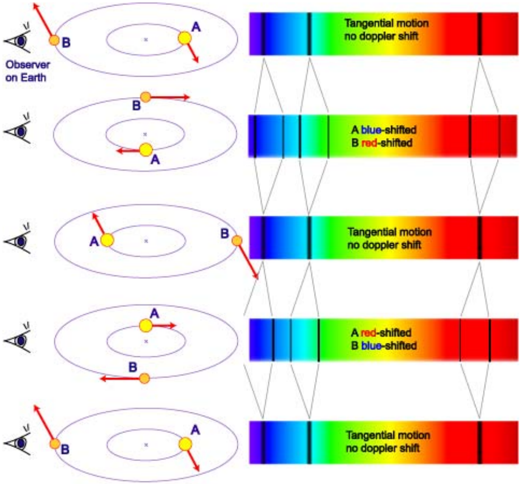
One more question on Sirius

- How come that Sirius A is brighter in optical wavelengths and Sirius B is brigther in X ray?
- $L_\nu \approx B_\nu 4\pi R^2$
- Sirius B is smaller but **much hotter**.
- Because of non-linearity of Planck function. It can still be brighter in X domain but not in the optical.

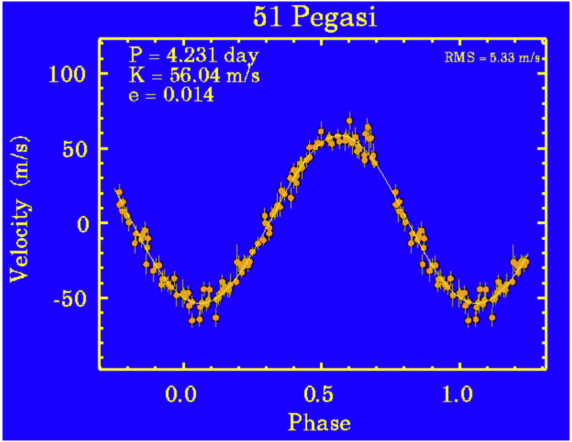


Spectroscopic binaries

- If we take the spectrum of the binary star, we will see spectral lines shifting to red and blue.
- This allows us to infer the line-of-sight velocity of these stars:
- $v_{los} = \frac{\lambda - \lambda_0}{\lambda_0} c$
- Today we can measure these velocities down to **one meter per second**. (E.g. famous HARPS spectrograph).

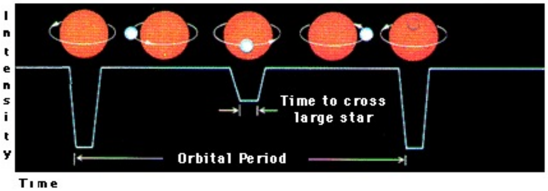


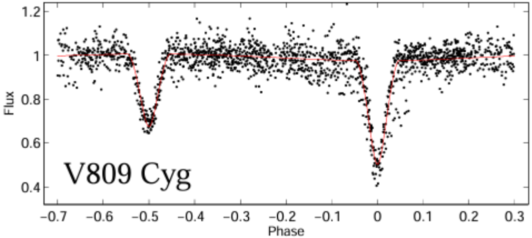
- Sometimes we can only see the spectrum of one component, but we can still detect the shifts.
- That still gives us some information about the other component.
- The problem is always the inclination of the system w.r.t us.
- Similar technique is used to detect exoplanets.
- What is the relative velocity of the Sun due to influence of the Earth?



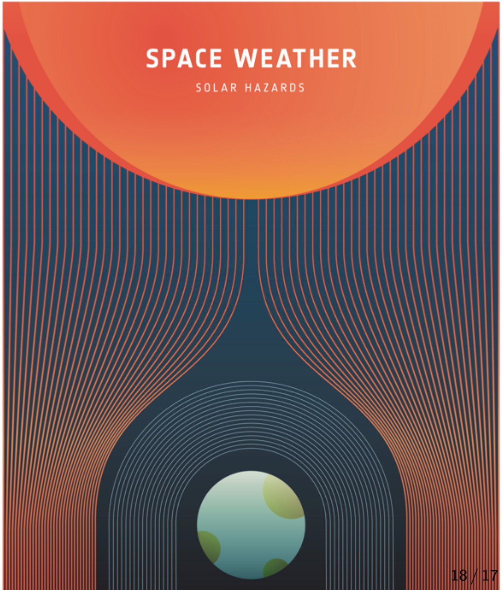
Eclipsing binaries

- If it happens that the orbit of the system coincides with line of sight, we can see the stars eclipse each other.
- Here we can learn something even if we cannot directly see them separately.





How come we not in a binary star system?



- If 85% of the stars are in the binary systems, how come we are living along the single star?