THE MASS OF A STELLAR BLACK HOLE

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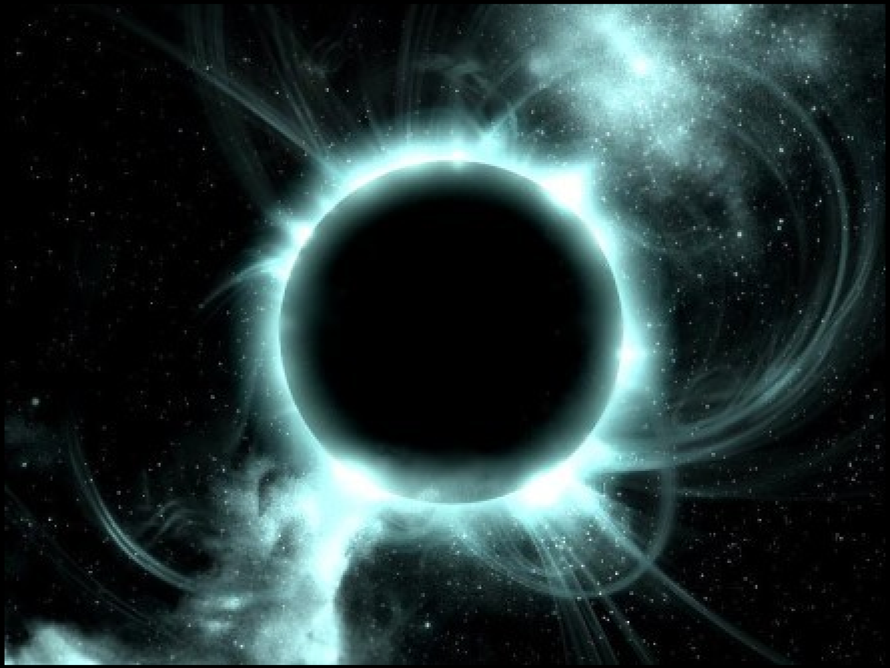
What is a Black Hole?

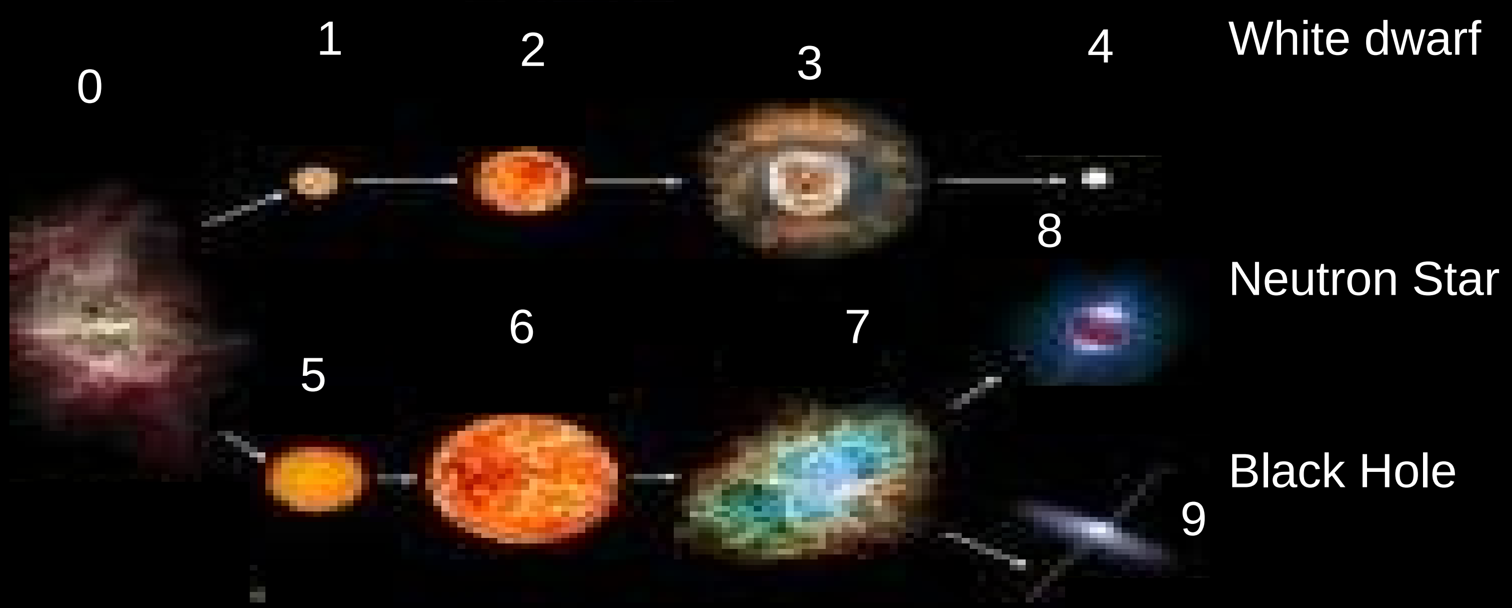


A Black Hole (BH) is the end stage of the evolution of a very massive star.

Its matter is compressed so tightly that its gravitational pull becomes so strong that not even light can escape.

Stellar evolution

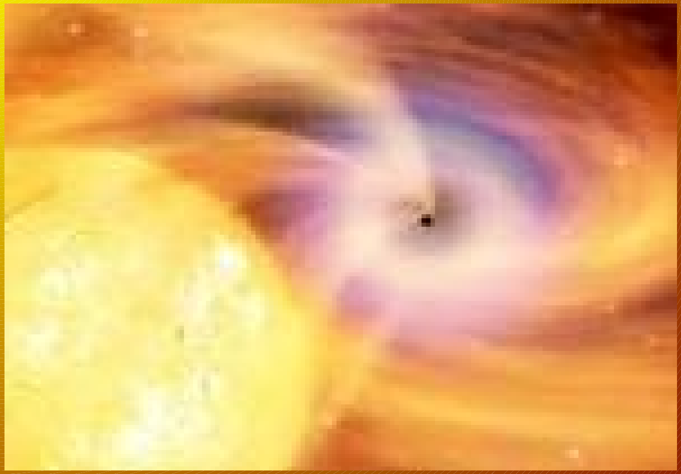
1st case: the evolution from an initial gas cloud to a white dwarf. (0;1;2;3;4)
The cloud (0) becomes a star (1), then evolves in a giant (2) and then ejects matter (planetary nebula) (3)
The interior becomes a white dwarf (4): a compact object with a mass less than 1.4 solar masses (Chandrasekhar limit).



2nd case: the evolution from an initial cloud to a neutron star / black hole (0;5;6;7;8;9)
The cloud (0) becomes a massive star (5), then evolves in a super-giant (6).
The end of this part of evolution is a supernova explosion (7).
The interior becomes a compact object. If it has a mass between 1.4 and 3.2 solar masses it becomes a neutron star (8). <u>Above 3.2 solar mass it becomes a BH</u> (9).

How to calculate the mass of a BH

The light cannot escape a black hole. Therefore, we cannot observe directly this celestial body and at first glance it seems very difficult to calculate its mass.

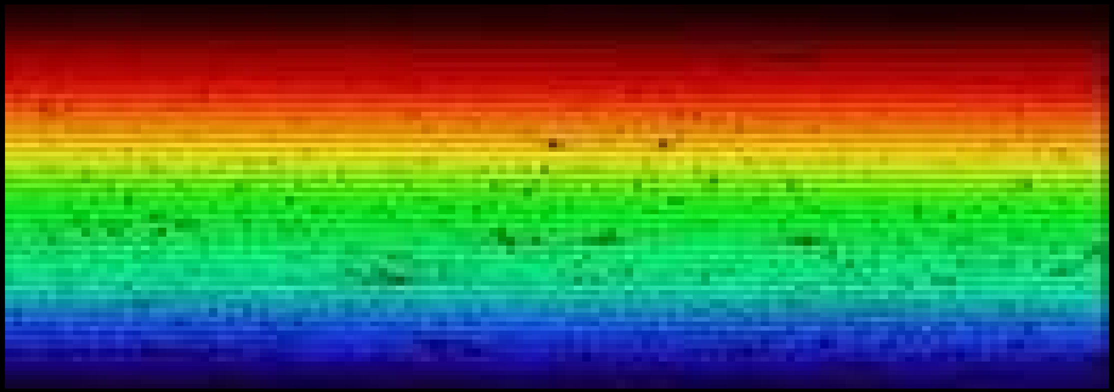


How the astronomers measure the mass of a black hole:

If the black hole belongs to a binary system one analyzes the spectrum of the companion star.

The Spectrum

The visible light from a star can be decomposed in a bundle of colors from red to violet (each color corresponds to a different wavelength).

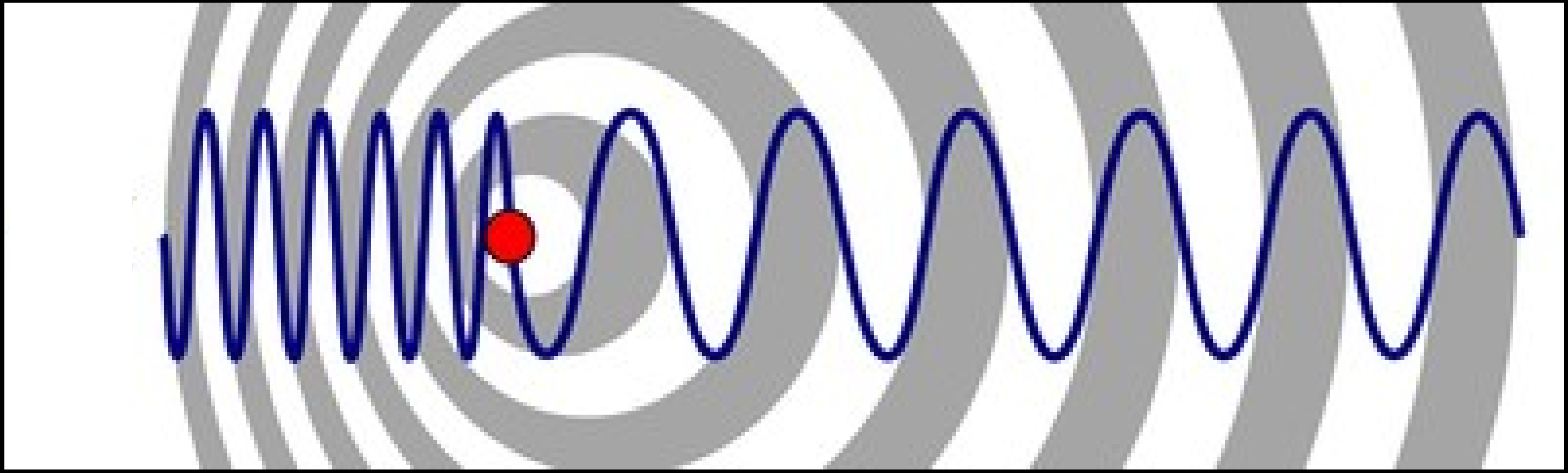


In the stellar spectrum there are many absorption lines (black features in the above spectrum) resulting from gaps of radiation.
Observing these absorption lines we can derive the stellar motion by Doppler shift measurements.

The Doppler effect (Part I)

Doppler discovered that sound waves from a moving source are compressed or expanded, i.e. their frequency changes.

For example the Doppler effect causes a siren to sound higher when it is approaching us and lower when it is receding.



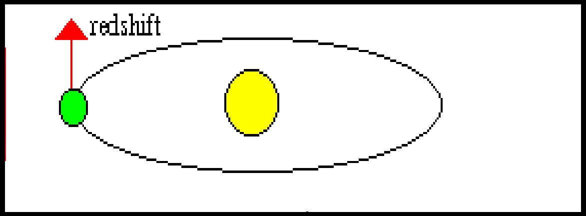
This effect is valid also for the wavelengths of the **light**.

The Doppler effect (Part II)

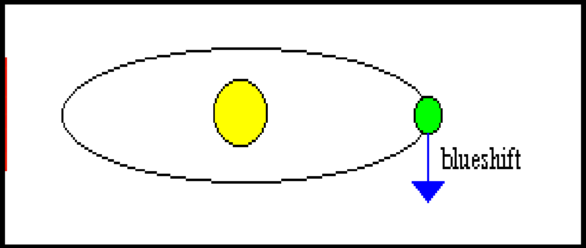
If the star is moving towards or away from us with some radial velocity, we see small shifts in the location of the spectral lines:

The star moves towards us → shift to shorter wavelengths (blue)

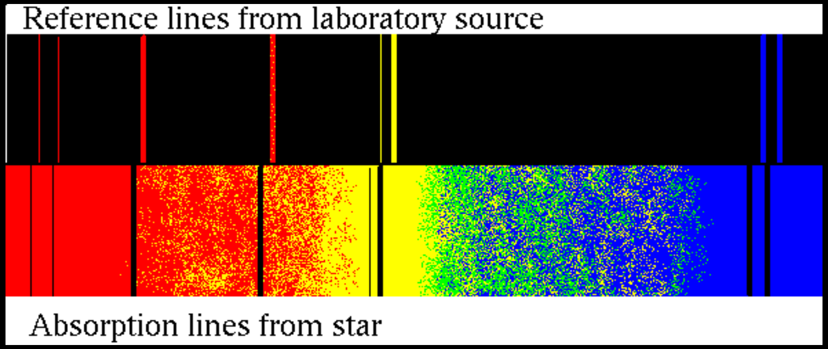
The star moves away from us → shift to longer wavelengths (red)

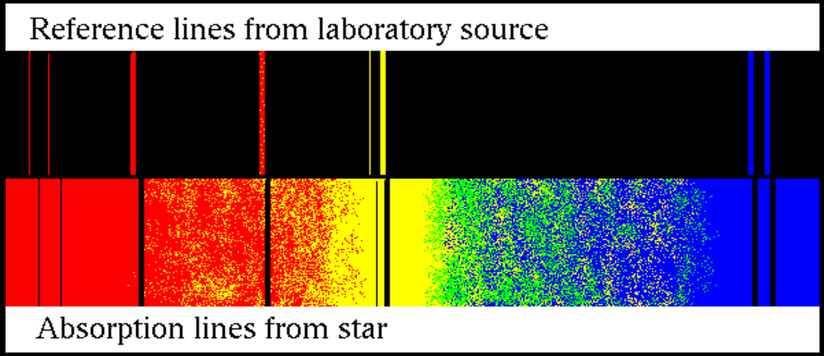


The star moves away



The star moves towards us





A Black Hole in a Binary System

A binary system is formed by two celestial bodies gravitationally bound orbiting a common center of mass.

In our case the system is composed by a black hole and a star.

The star moves around their common center of mass and we can analyze its movement using the Doppler Effect :

$$\frac{\Delta\lambda}{\lambda} . c = K$$

K.star speed

c : light speed

λ : wavelength of the spectral line

$\Delta\lambda$ represents the wavelength difference if the source is moving

The Mass Function

With the velocity (K) and the orbital period (P) we can calculate the mass function f(M)

Stellar mass (M_1)

Black hole mass (M_2)

mass M_1 and M_2 with orbital period P

(semi major axis a_1 and a_2 with $a_1 M_1 = a_2 M_2$)

seen under an inclination angle ***I***

radial velocity of component 1 is seen to with amplitude K_1

for a circular orbit

$$K_1 = 2\pi a_1 \sin i / P_b.$$

using Kepler's laws

expressed in observed quantities we can calculated the mass function

$$f(M_2) \equiv \frac{M_2^3 \sin^3 i}{(M_1 + M_2)^2} = \boxed{\frac{K_1^3 \; P}{2 \; \pi \; G}}$$

G: gravitational constant

for known sin I and $M_1 > 0$ this will be a lower limit on the compact star mass;

For a complete solution one needs the inclination and the mass of the companion star.

References

http://en.wikipedia.org/wiki/Doppler_effect

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http://www.astro.washington.edu/users/ben/a510/NSTARS.new.html
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Images:

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