Cosmology

Summer Term 2020, Lecture 06

Rainer Verch

Inst. f. Theoretische Physik
Universität Leipzig
27 April 2020

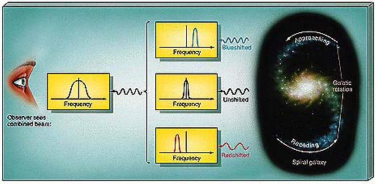
[Continued: Examples for distance indicators]

Globular stellar clusters (GSCs)

GSCs are aggregations of stars in or near a galaxy (mostly, in galaxy halos, i.e. not in the galaxy bulk or the spiral plane) with a much higher density of stars than in most other parts of the galaxy, in a ball-like arrangement. There are around 150 GSCs known for our Milky Way. Larger galaxies contain far more GSCs in their halos. GSCs are typically very old stellar populations. There are indications for intermediate size black holes (of a few thousend solar masses) in the core regions of GSCs.

The luminosity of GSCs is very high and empirically there is a correlation between their absolute luminosity and their spectral characteristics, similarly as in a HRD. The absolute luminosity of nearby GSCs can be calibrated using Cepheids contained in the GSCs; then assuming the relation between their absolute luminosity and spectral characteristics is also valid for more remote GSCs, their apparent luminosity can be used to conclude their distance. Due to their brightness, GSCs are distinguishable in other galaxies and are good distance indicators.

Tully-Fisher relation If a spiral-type galaxy is observed "edge-on", i.e. with the line of sight in the spiral plane of the galaxy, the rotation of the galaxy leads to a Doppler shift of the spectral lines. On the side of the spiral arm of the galaxy rotating away from the observer, the light is red-shifted; on the side of the spiral arm moving towards the observer, the light is blue-shifted.



In total, there results a broading of the spectral lines which increases with the rotation velocity of the spiral arms. There is an empirical relation which relates the broadening of the spectral lines of edge-on viewed spiral galaxies and their absolute luminosity, called **Tully-Fisher relation**. Following a similar idea as before, one calibrates the relation using nearby galaxies whose distances can be determined by Cepheids or GSCs. Then assuming the Tully-Fisher relation is valid for more distant spiral galaxies, one can conclude their distance from their broadening of the spectral lines.

Faber-Jackson relation

Also elliptical galaxies show a broadening of the spectral lines they emit. This is caused by the velocity distribution of the stars in the galaxy – some are moving towards the observer, some away from the observer, similarly as in a cloud of gas – and the incurring red-shift effect results in a total broadening of spectral lines. There is also an empirical relation between the absolute luminosity of an elliptical galaxy (usually related to its size, i.e. the amount of luminous matter it contains) and its broadening of spectral lines, known as **Faber-Jackson relation**.

Similarly as for the Tully-Fisher relation, the Faber-Jackson relation is calibrated for elliptical galaxies whose distance can be determined by Cepheids or GSCs, and then used as a distance indicator for elliptical galaxies that are more distant, observing their broadening of spectral lines.

Elliptical galaxies are often very old and very large, assumed to have resulted from galaxy mergers. They are therefore very bright among the very distant objects.

Supernovae of Type Ia (SNIa)

Supernovae appear when a star can't counterbalance the gravitational pressure caused by its mass by thermal pressure through nuclear fusion of its material.

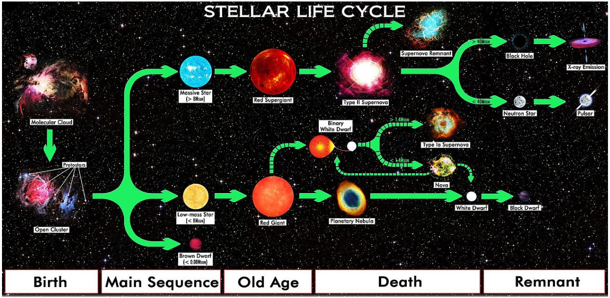
We take this opportunity to mention the **stable remnant stats of stars**. Which of the case occurs depends strongly on the initial mass of the star, resp. on the mass of the remnant core left after a Nova or Supernova explosion.

- **white/black dwarf** The star is kept from gravitational collapse due to the Fermi degeneracy pressure of the electrons in the atoms forming the star. This is possible if the star (remnant) has a mass not exceeding ≈ 1.4 solar masses (the "Chandrasekhar limit"). When white dwarfs form, the material is still very hot and therefore they are luminous. With time, they get colder and less luminous, ending up in non-luminous black dwarfs.
- **neutron stars** In this case, the star (remnant) is too massive for the Fermi degeneracy pressure to resist gravitational collapse. The electrons are gravitationally pressed into the atomic cores, fusing with the protons to form neutrons. The star is thus a compact ball of neutrons. Since the neutrons are Fermions, the Fermi degeneracy pressure can halt further gravitational collapse if the mass of the neutron star doesn't exceed ≈ 2.1 solar masses (Tolman-Oppenheimer-Volkhoff limit).

- **black hole** If the mass concentration of a star (remnant) is larger than the Tolman-Oppenheimer-Volkhoff limit, it undergoes complete gravitational collapse, leaving behind a black hole (in the sense of general relativity).

Particularly neutron stars and black holes are remnants of Supernova explosions of massive stars at the end of their thermonuclear life cycle: With no more thermal energy to gain from nuclear fusion in the core, the star cools down, and the outer layers are contracting rapidly onto the denser, inner layers (core) of the star material. They thereby heat up dratically and start new fusion processes. The outer layers of the star heat up immensely, leading to a thermal explosion, ripping the outer layers away. There is an increase of brightness of the star by many orders in magnitude in a very short time (hours...days), after which the nebula-like exploded outer layers of the star become visible. The core of the star typically undergoes gravitational collapse to a neutron star of black hole, depending on the mass of the remnant.

The following viewgraph illustrates the typical life cycle of stars and the possible stable final states (from R.N. Bailey/Wikipedia)



The mechanism for SNIa is different. They are thought to be formed by a binary star system consisting of a white dwarf and a large (giant) star orbiting each other in close proximity. The white dwarf graviationally accretes mass from the companion star until it passes the Chandrasekhar limit and starts a Supernova process. The resulting Supernova is extremely luminous and has a very specific signature in terms of its luminosity increase/decrease pattern in time. Since the SNIa are thereby all formed by the same process with narrow bounds set by the Chandrasekhar limit, one can assume that they all have the same absolute luminosity. This, together with their immense brightness, makes them the most important distance indicators for the largest distances that can so far be observed on stellar objects (they are therefore also called “standard candles”).

Again, the absolute luminosity of SNIa is calibrated by observing such objects in nearby galaxies whose distances have been determined by the previously indicated methods.