Elliptical galaxies: stellar pumpkins and cucumbers

Domingos Soares

The stars are not isolated in the universe. They are clustered in galaxies. And the galaxies present themselves in the most different shapes. The American astronomer Edwin Hubble (1889-1953) put forward in 1936 a galaxy classification related to the shapes they exhibit on the sky. The most common shapes he observed were the elliptical galaxies and the spiral galaxies. The spiral galaxies are spectacular for the vision due to the presence of the spiral arms. Now, elliptical galaxies represent precisely the opposite. At the first sight they do not call the attention. But they are very important if we want to understand the constitution of the universe and how the galaxies have formed. Which is, without any doubt, of great importance, since we live in galaxy — a spiral — and the questions associated with our origins are fundamental.

To begin with, among the elliptical galaxies are the larger and the smaller galaxies of the universe! Here, we are going to talk about normal elliptical galaxies, that is, we are not going to examine examples neither of the extraordinary large elliptical galaxies nor of the extraordinary small elliptical galaxies — the dwarf elliptical galaxies.

Elliptical galaxies have the form of an ellipsoid, a three-dimensional figure resembling a deformed sphere. The galaxy stars are distributed in this volume. The ellipsoids are present also in our gardens, for example, in the shapes of some pumpkins and of cucumbers. Hence, it is not an overstatement to say that elliptical galaxies are “stellar pumpkins and cucumbers”! But we see the elliptical galaxies, on the sky, as “shadows”, similar to the shadows of a pumpkin or of a cucumber, on a sunny day, projected on the ground.

When classifying the elliptical galaxies, Hubble identified them by the letter “E” followed by a whole number “n”. The number was related to the appearance of the galaxy on the plane of sky. The elliptical galaxies have an elliptical contour. An ellipsis has a major axis "a" and a minor axis "b". Notice that if a=b, we have a circle. Then one can define a quantity called "ellipticity", represented by the letter "e", with e=1–b/a. Hubble measured a and b, for each elliptical galaxy, and defined the whole number n=10×e. In that way, elliptical galaxies were classified from E0 to E7. An E0 galaxy has a circular contour (a=b) and an E7 galaxy has the most flattened elliptical contour possible. Hubble did not find elliptical galaxies above E7. In fact, later it was proved that there were no ellipsoids dynamically stable enough to produce an E8, or higher, elliptical galaxy. In such cases, we enter into the domain of disk galaxies seen edge-on.

Our first illustration is an E0 galaxy. It is the giant elliptical galaxy whose catalog name is M87, or NGC 4486. It is located in the central region of the Virgo cluster of galaxies. M87 is a giant galaxy, much larger than the majority of elliptical galaxies. On the M87 image, note the two luminous speckles located in the lower right quadrant. They are two spiral galaxies seen through the external halo of M87, being much more distant from us than M87, namely, about 20 times more distant. It is a pair of galaxies — a binary galaxy — located outside the galaxy cluster which M87 belongs to. This is yet another example of the usual fact, in observational astronomy, that the proximity on the plane of sky does not necessarily imply spatial, i.e., three-dimensional, proximity. The proximity of two bodies on the celestial sphere is just two-dimensional, not involving the distance to the observer. We must always remember that!

E0 elliptical galaxy, called M87 and NGC 4486, its two names in distinct galaxy catalogs. It has a yellowish color because it is constituted predominantly by cold and old stars (Image: David Malin).

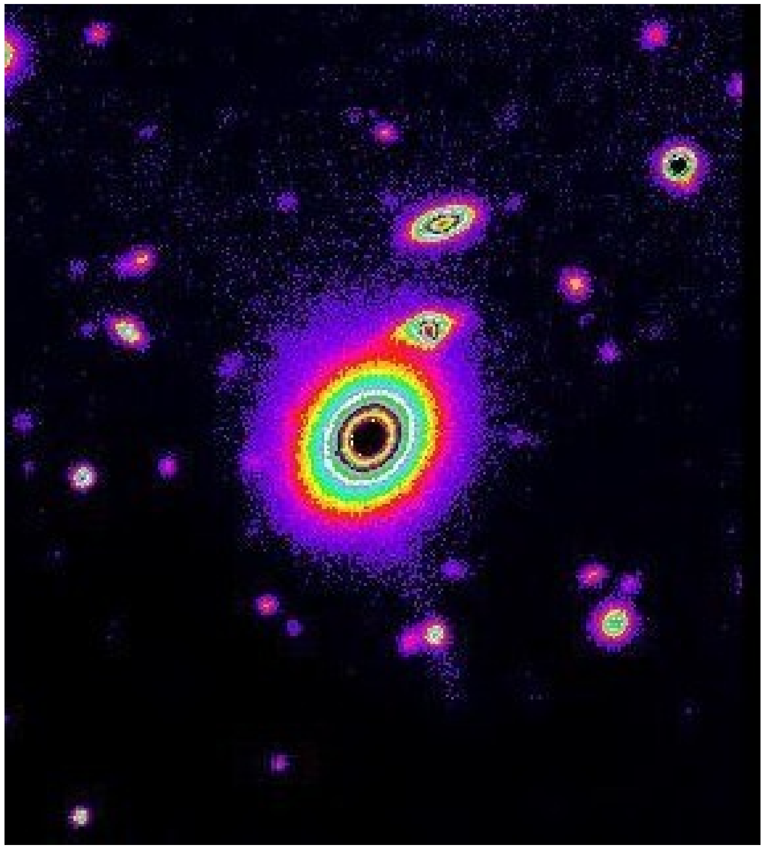
Elliptical galaxies have little interstellar dust or gas and, therefore, there is no star formation anymore. The stars that constituted them are old and cold. This is one of the main contrasts between them and spiral galaxies, which have intense star formation, in the spiral arms, that result in high mass and high temperature stars, leading to the characteristic blueish color of the spirals.

Our second example is the galaxy M59 (NGC 4621), an E5. Its major axis is approximately the double of its minor axis. It is located in the Virgo cluster of galaxies as well.

Elliptical galaxy M59, classified as E5. Notice the smooth light distribution without features, which could call someone's attention. This a general characteristic of elliptical galaxies (Image: NOAO, National Optical Astronomy Observatories, United States).

To finish, we show the elliptical NGC 3819, an E2. The image was obtained by me at the Pico dos Dias Observatory, located in the city of Brazópolis, MG, Brazil. The observatory is a facility for astronomical research, linked to National Astrophysics Laboratory, whose headquarters is located in Itajubá, MG, close to the observatory.

In the case of NGC 3819 there is a similar case to the one we saw in M87. There are two small galaxies close to NGC 3819. Look at the image, up and slightly to the right. But here, the two galaxies are really small, because they are located at the same distance of NGC 3819. Thus, they are dwarf galaxies and satellites, that is, bound to NGC 3819 by the gravitational force. That was not the case, as we saw, of the two small galaxies close to M87. In that case, they are small just because they are very far away.



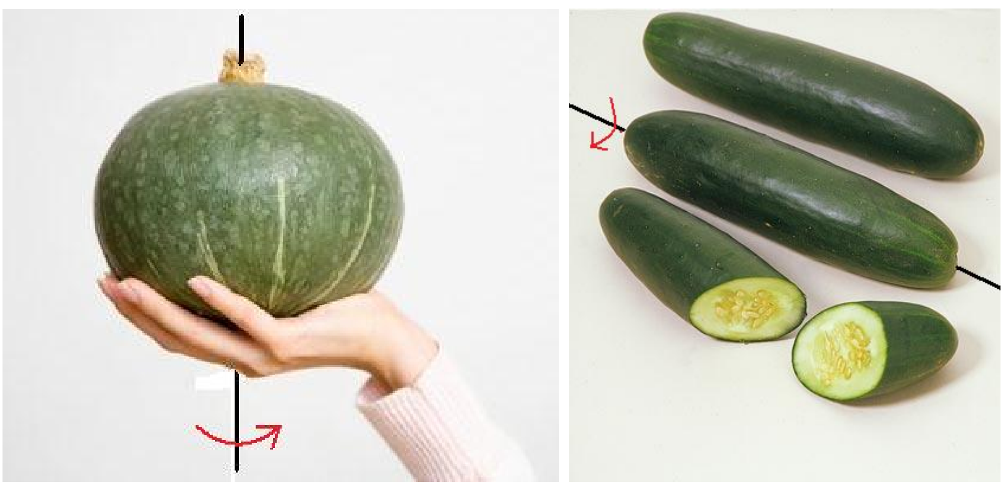
E2 elliptical galaxy, NGC 3819. The galaxy colors are artificial and represent the running of luminous intensity along the galaxy. Notice the two galaxies above and slightly to right of NGC 3819. They are in fact dwarf galaxies, because they are at the same distance of NGC 3819. These galaxies are NGC 3819 satellites (Image: Domingos Soares, Pico dos Dias Observatory, National Astrophysics Laboratory, Brazil).

Now that we examined some elliptical galaxies, we are going to see how pumpkins and cucumbers can help us to understand their structure.

The first theoretical models put forward by the astrophysicists for the elliptical galaxies considered that they were spheroids, which are special ellipsoids called "revolution ellipsoids". The spheroids are more or less like flattened spheres. Take a sphere and from its center draw three axes perpendicular to each other. You will verify that these axes will intercept the surface of the sphere at equal distances from its center. We say that the sphere has three equal axes. The spheroids are a bit more complicated than a sphere, because they have only two equal axes. The third axis is the symmetry axis of the spheroid.

And it is here that the pumpkins and cucumbers come into play again. Pumpkins represent a kind of spheroid called "oblate", in which the two equal axes are larger than the third axis. Try to identify, in your daily life, other bodies that are, even approximately, oblate spheroids. You will be surprised with the amount of them you will find. Cucumbers represent another kind of spheroids, the "prolates", those in which the two equal axes are smaller than the third axis. Again, do the previous exercise and try to identify other prolate spheroids present in your everyday life. Are not they many? Make a list for each of the cases and compare them with your friends lists.

Look next at the figure, where a pumpkin and some cucumbers are shown, in order to illustrate the concepts of oblate and prolate spheroids.



The pumpkin is approximately an oblate spheroid. The axis of revolution is represented by the black line. The cucumber is, also approximately, a prolate spheroid. Its revolution axis is also represented by the black line. The spheroids are generated by the rotation of an ellipsis around its axis of symmetry, or of revolution. Because of that, they are also called "ellipsoids of revolution".

Now, the appearance of an elliptical galaxy on the sky does not allow us to decide, immediately, whether we are watching the projection of an oblate or a prolate spheroid onto the plane of sky. For example, take an E0. It presents a circular contour to our sight. But this circular contour may come from the projected view of either an oblate or a prolate spheroid, if they are being seen along their symmetry axes. Check the pumpkin and cucumber illustrations. If you look at both, along the axes shown on the figures, you will see a circular contour, corresponding to the two equal axes. Another example: look at the cut cucumber on the the figure. Each cucumber piece is at a different position and they correspond to different angles of sight. One of the sections is seen more flattened than the other, due to the perspective under which it is seen. It corresponds to an E4 elliptical galaxy, as one can verify, simply measuring the major and minor axes of that section, on the figure, and making the appropriate mathematical operations to obtain the number "n" of Hubble's classification. The other piece clearly corresponds to an E0, because the major and minor axes are equal. In this case, then, we have an E4 and an E0, which we know to be the projections of a prolate spheroid. With respect to the elliptical galaxies the situation is much more complicated, because we only have access to their projections on the plane of sky. We have to find out the means of, from a "shadow", to discover which three-dimensional body projects it. That is the task which astronomers propose to themselves.

Therefore, it is necessary a very detailed study of the light distribution on elliptical galaxies in order to decide whether we are in the presence of an oblate or a prolate galaxy. Besides the galaxy light, astronomers also measure the velocities of the galaxy stars. The distribution of these velocities, that is, their values in different parts of the galaxies, will be one, if the stars are distributed in an oblate model, and another one, for a prolate model.

But the situation can be yet more complicated. Astronomers have verified that the majority of elliptical galaxies are neither oblate nor prolate. They have, in general, three different axes! They are called "triaxial ellipsoids". The models of spheroids of revolution imply in that the galaxies have a small rotation, around the axis of symmetry of the spheroids. Whereas in triaxial models there is no rotation, the stars move in the galaxy in a completely disordered manner. The astronomers relate the three-dimensional shape of the galaxy with the way it was formed. This is why it is so important the investigation of the shapes of galaxies. But, how were elliptical galaxies formed? There is not a definitive answer, as we shall see next.

The elliptical galaxies are found in the more densely populated regions of clusters of galaxies. While spiral galaxies show up preferentially in less dense regions. As we said, there is not yet a definitive and general explanation for the way elliptical galaxies were formed. They may be formed from a single initial gas cloud, or they may be formed from the "assemblage", by gravitational attraction, of stars formed in the cluster of galaxies where they are. Or still, some elliptical galaxies may be formed from the merging of two spiral galaxies. All of these possibilities are investigated by astronomers.