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# Why Early Galaxies Were Pickle-Shaped: A Geometric Explanation

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**Abstract**

The vast majority of currently observed geometric shapes of celestial bodies can be explained by a simple symmetry idea: the initial distribution of matter is invariant with respect to shifts, rotations, and scaling, but this distribution is unstable, so we have spontaneous symmetry breaking. According to statistical physics, among all possible transitions, the most probable are the ones that retain the largest number of symmetries. This explains the currently observed shapes and – on the qualitative level – their relative frequency. According to this idea, the most probable first transition is into a planar (*pancake*) shape, then into a logarithmic spiral, and other shapes like a straight line fragment (*pickle*) are less probable. This is exactly what we have observed until recently, but recent observations have shown that, in contrast to the currently observed galaxies, early galaxies are mostly pickle-shaped. In this paper, we provide a possible geometric explanation for this phenomenon: namely, according to modern physics, the proper space was originally more than 3-dimensional; later, the additional dimensions compactified and thus, became not directly observable. For galaxies formed at the time when the overall spatial dimension was 5 or larger, the pickle shape is indeed more symmetric than the planar shape – and should, therefore, be prevailing – exactly as what we observe.

## 1 Formulation of the Problem

**How observed geometric forms of celestial bodies can be explained.** In the beginning, the Universe was practically uniform and homogeneous, and it was also invariant with respect to homotheties (rescalings) $x \to \lambda \cdot x$. However, such a highly symmetric state is unstable: if a slightly larger concentration of mass appears in one location, this mass starts attracting the neighboring masses, and the concentrations grows even more.

In principle, it is possible that such a spontaneous symmetry violation leads us directly to a state with no symmetries at all. However, according to statistical physics, it is much more probable that the system first goes into a state when some symmetries remain – and the more symmetries remain, the more probable such a transition. For example, usually, if we heat up such a highly symmetric structure as a solid body, we do not immediately get a fully asymmetric state such as a gas state – first we get an intermediate state with some symmetries, such as a liquid state.

So, if we have a disturbance at some spatial location $a$, then the resulting state is invariant with respect to some symmetries $s$. Let us denote the set of all such symmetries by $S$. What can we say about this set $S$?

First, if we do not change anything, then the state, of course, does not change. Thus, the set $S$ contains an identity transformation id.

If the state does not change when we apply a symmetry $s_1$ and does not change when we apply another symmetry $s_2$, then it does not change if we apply these two symmetries one after another – in other words, if we apply a composition $s_2 \circ s_2$ of these two symmetries. Thus, the set $S$ is closed under composition – for which, by the way, $\mathrm{id} \circ s = s \circ \mathrm{id} = s$ for all $s$.

Finally, if the state does not change when we apply a symmetry $s$, it should not change if we apply the inverse transformation $s^{-1}$. These three properties mean that symmetries form a group.

If we have a disturbance at some spatial location $a$, then we have the same disturbance in all the points $s(a)$ corresponding to different symmetries $s \in S$. So, with each point $a$, the disturbance contains all the points $s(a)$ corresponding to all the elements $s \in S$. The set $\{s(a) : s \in S\}$ of all such points is known as the *orbit* of the point $a$. One can easily see that this orbit does not change if we apply any transformation $s \in S$. Thus, each resulting geometric shape consists of orbits – sets which are invariant with respect to an appropriate subgroup $S$ of the original symmetry group $S_0$.

All such orbits are known; see, e.g., [2, 3, 5]. In the beginning, the most highly probable shapes are the ones corresponding to the largest symmetry group – which corresponds to a plane. This orbit has a 4-dimensional symmetry group $S$ generated by shifts in two different directions, rotations in the plane, and homotheties (scalings). Of course, in practice, we only observe the bounded part of this plane, i.e., a disk (which astrophysicists call a *pancake*).

The disk is also not stable, so it undergoes another spontaneous symmetry breaking. The most probable of the resulting shapes is the one corresponding to the largest possible subgroup of the plane's symmetry group. This turns to be a 1-D subgroup, and the corresponding generic shape is a logarithmic spiral – indeed one of the most frequently observed galactic shape.

This shape is, itself, unstable. The largest remaining subgroup is discrete: corresponding to points located in geometric progression around the central body – this description (known as *Bode law*) is a very good first approximation description both of our Solar system and of several planet's satellite systems.

At the end, when all symmetries are gone, we get the stable state of a rotating liquid body – an ellipsoid.

In addition to the most probable transitions corresponding to the largest remaining symmetry subgroup, we can also have less probable transitions directly to less symmetric shapes. For example, instead of a transition of the original highly symmetric state into a plane, with 4-D symmetry group, we can have a transition to a next-large symmetry subgroup for which orbits are straight lines. For a straight line, we have a 3-D symmetry group generated by shifts along the line, rotations around the line, and scalings.

Of course, in practice, we only observe a bounded part of a line – which the astrophysicists call a *pickle*.

The above symmetries idea explains practically all observed shapes and – on the qualitative level – their observed relative frequency [2, 3, 5].

**Early galaxies are different.** The above classification of geometric shapes works well for all the geometric shapes that we have observed until recently. Recently, with the new accurate satellite-based observations, we have been able to also observe early galaxies, galaxies formed close to the beginning of the Universe. Surprisingly, it turned out that their shapes are different: namely, most of them are pickle-shaped; see, e.g., [1, 6, 7]. How can we explain this?

**What we do in this paper.** In this paper, we provide a geometric explanation of this phenomenon.

## 2 Geometric Explanation

**Our space-time is higher-dimensional: a reminder.** According to modern physics, our space-time has spatial dimensions beyond the usual three. The need for such dimensions comes from the fact that in spatial dimension 3 (and even 4, 5, etc.), it is not possible to have a consistent quantum field theory: attempts to design such a theory lead to meaningless infinite values for physical quantities. The smallest spatial dimension for which a consistent theory is possible is dimension 10; see, e.g., [4, 8].

At present, we do not directly observe the additional dimensions, which means that they are *compact*: kind of circular with a very small radius, much smaller that usual macro-distances. So, in the beginning, close to the Big Bang, when the Universe was small in all dimensions, we had more equally observable dimensions – but at some point, additional dimensions grew less and became less visible. So, we gradually move from the original 10-D (or even higher-dimensional) proper space to the currently observed 3-D one.

**Resulting idea.** In view of the above idea, it makes sense to consider the possibility that the early galaxies were formed at the time when the spatial dimension $d$ was still larger than 3.

**This idea indeed provides a possible explanation of why early galaxies were pickle-shaped.** From this viewpoint, let us compare the two most symmetric shapes – plane (disk, pancake) and straight line (pickle) in the $d$-dimensional space.

For a plane, in addition to the usual 4 generators – two shifts, rotations inside the plane, and scalings – we also all possible rotations in the remaining $(d-2)$-dimensional space. In general, in an $n$-dimensional space, the set of possible rotations has dimension $\frac{n \cdot (n-1)}{2}$. Thus, the overall dimension $D_{\text{pancake}}$ of the symmetry group corresponding to a plane in a $d$-dimensional space is

$$D_{\text{pancake}} = 4 + \frac{(d-2) \cdot (d-3)}{2}. \tag{1}$$

On the other hand, for a straight line, in addition to shifts in the direction of the line and scalings, we also have all possible rotations in the remaining $(d-1)$-dimensional space. So, the overall dimension $D_{\text{pickle}}$ of the symmetry group corresponding to a straight line in a $d$-dimensional space is

$$D_{\text{pickle}} = 2 + \frac{(d-1) \cdot (d-2)}{2}. \tag{2}$$

For our usual 3-D space, with $d = 3$, we have $D_{\text{pancake}} > D_{\text{pickle}}$. For $d = 4$, however, we already have equal dimensions, and for larger dimensions, we have

$$D_{\text{pickle}} - D_{\text{pancake}} = 2 + \frac{(d-1) \cdot (d-2)}{2} - 4 - \frac{(d-2) \cdot (d-3)}{2} =$$

$$\frac{d-2}{2} \cdot ((n-1) - (n-3)) - 2 = (d-2) - 2 = d - 4 > 0.$$

Thus indeed, in a space of more than 4 dimensions, pickle shape corresponds to a larger symmetry group – and should therefore be prevalent, exactly as we observe for early galaxies.

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