Why Angles Between Galactic Center Filaments and Galactic Plane Follow a Bimodal Distribution: A Symmetry-Based Explanation

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Abstract Recent observations have shown that the angles between the Galaxy Center filaments and the Galactic plane follow a bimodal distribution: a large number of filaments are approximately orthogonal to the Galactic plane, a large number of filaments are approximately parallel to the Galactic plane, and much fewer filaments have other orientations. In this paper, we show this bimodal distribution can be explained by natural geometric symmetries.

1 Formulation of the problem

What are filaments. Radioastronomy has shown, since the 1980s, that the center of our Galaxy contains a large number of 1-D structures known as *filaments*.

What recent observations showed. Recent observations performed by the state-of-the-art MeerKAT Radio Telescope array provided a detailed image of these filaments. It turnes out that the angles between the filament orientation and the Galactic plane have a clear bimodal distribution:

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- a large number of filaments are (approximately) orthogonal to the Galactic plane, with the angle close to 90°;
- a large number filaments are (approximately) parallel to the Galatic plane, with the angle close to 0°; and
- a relatively small number of filaments have angles different from 0° and 90°.

Problem: how to explain this empirical fact. A natural question is: how can we explain this empirical observation?

What we do in this paper. In this paper, we show that the above empirical observation can be explained by considering natural geometric symmetries/invariances.

2 Our explanation

Symmetries/invariance in cosmology and astrophysics: a brief reminder. In the beginning, the distribution of matter in the Universe was homogenous and isotropic – as we can conclude from the fact that the 3K radiation, the remnant of the Universe's initial state, is almost perfectly homogeneous and isotropic; see, e.g., [1, 5].

With time, small random perturbations often result in breaking the original symmetries. According to statistical physics, changes in which only a few symmetries are broken are more probable than changes in which many symmetries are broken – and in general, the fewer symmetries are broken, the more probable the corresponding change; see, e.g., [1, 5].

The original matter distribution is invariant under:

- all possible shifts,
- all possible rotations, and
- all possible scalings $x \mapsto \lambda \cdot x$.

There is:

- the 3-parametric group of all possible rotations,
- the 3-parametric group of all possible shifts, and
- the 1-dimensional group of all possible scalings.

So overall, we have a 7-parametric family of invariances.

In view of the above fact, the most probable transition is a transition to the state which retains the most invariances. One can check that such a state is a plane: it is invariant with respect to:

- the 2-parametric family of shifts within this plane,
- the 1-parametric family of rotations in this plane, and
- the 1-parametric family of scalings.

So overall we have a 4-parametric family of invariances.

Indeed, the planar ("pancake") shape is supposedly to be the typical initial shape of proto-galaxies – and the vast majority of the galaxies are most planar.

Symmetry ideas explain not only the planar shape, but also all other observed shapes in cosmology and astrophysics – as well as the relative frequency of different shapes; see, e.g., [2, 3, 4]. It therefore makes sense to analyze the position of the filaments from this invariance viewpoint.

What are the symmetries corresponding to different orientation of filaments? Let us consider all possible orientations.

If the filament is parallel to the plane, then, in fact, we have a straight line inside the plane. In this case, out of the original symmetries, only scalings and shifts along the line keep this configuration invariant. Thus, in this case, we have a 2-parametric family of invariances.

If the filament is orthogonal to the plane, then we have a straight line which is orthogonal to the plane. In this case, out of the original symmetries, only scalings and rotations around this line keep this configuration invariant. Thus, in this case too, we have a 2-parametric family of invariances.

If the filament is neither parallel nor orthogonal to the plane, then we have a straight line which is located at an cute angle to the plane. In this case, out of all original symmetries, only scaling keep this configuration invariant. So, in this case, we have only a 1-parametric family of invariances.

As we have mentioned earlier, the transition from 4-parametric family of invariances to a 2-parametric family – when we lose 2 dimensions of symmetries – is more probable than the transition to a 1-parametric family – when we lose 3 dimensions of symmetries. This explains why filaments which are parallel or orthogonal to the galaxy plain are more frequent than filaments at acute angles from the plane.

Acknowledgments

This work was supported in part by the National Science Foundation grants 1623190 (A Model of Change for Preparing a New Generation for Professional Practice in Computer Science), HRD-1834620 and HRD-2034030 (CAHSI Includes), EAR-2225395 (Center for Collective Impact in Earthquake Science C-CIES), and by the AT&T Fellowship in Information Technology.

It was also supported by a grant from the Hungarian National Research, Development and Innovation Office (NRDI).

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