How Do Galaxies From? A water-Based Approach.

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[Motivation and Objective]

Numerous galaxies exist in the universe, and each is known to possess diverse spiral arm structures. One of the major factors thought to contribute to this diversity is the density wave. Density waves circulate through galaxies and trap interstellar gas within spiral-shaped regions. This compression promotes star formation and forms spiral structures, and differences in the spatial distribution and propagation speed of density waves are believed to influence the variation of spiral arm morphology. However, in real galaxies, direct experimentation and control of physical conditions are extremely difficult, making it challenging to experimentally verify the mechanisms responsible for spiral arm formation.
Therefore, the aim of this study was to understand cosmic phenomena through familiar physical processes. We modeled a galaxy as a rotating fluid and represented density waves as regions of locally increased density using rectangular obstacles that modify the flow of the fluid. Local stagnation and elevation of the fluid around these obstacles were regarded as an analogue of gas compression caused by density waves. Through this simplified model, we aimed to control experimental conditions and investigate factors related to spiral arm formation. By comparing vortex structures generated in a rotating fluid tank with galactic spiral arms, and by varying the positions and numbers of obstacles and the rotation speed, we examined factors that may influence spiral arm formation.

[Methods]

In previous research, Tsuda (2012) conducted an experiment (LEC) using rotating fluid in a tank to reproduce spiral structures and investigate their evolution. In that study, the apparatus itself was fixed. In contrast, our study attempted to generate vortices by rotating the entire apparatus, a method not implemented in the previous work.
A circular container (diameter: 34cm) was fixed on a rotating platform. Rectangular obstacles (1.0cm × 6.5cm ×1.5cm) were placed inside the container at equal intervals in numbers of 0,1,2,3, and 4. The apparatus was rotated manually and recorded from above using a smartphone. After 20 rotations, the rotation was stopped, and images were extracted every 0.5 seconds. Visible streamlines were identified, color-coded according to time, and visualized for analysis.

[Results]

The experiment did not produce clear vortex structures. However, when the streamlines were visualized, characteristic changes depending on the number of obstacles were observed. When no obstacles were present, few streamlines were detected. As the number of obstacles increased, the number of regions with local changes in flow direction and stronger shear increased, resulting in more visible streamlines.
When four obstacles were used, however, fewer streamlines were observed compared with the three-obstacle case. This is likely because the distance between obstacles became smaller, causing interactions among streamlines. As a result, irregular flow and turbulence-like behavior were observed.

[Conclusion and Future Work]

This experiment suggests that simple rotating water alone cannot sufficiently reproduce galactic spiral arms, indicating that factors beyond density waves may be involved in their formation. No clear vortex structures were observed, likely due to insufficient rotation speed and viscous effects that prevented the formation of stable spiral vortices.
Unlike galaxies, this experiment lacked self-gravity and had much smaller density variations, meaning that gas compression by density waves could not be adequately reproduced. Furthermore, galaxies exhibit differential rotation, in which rotation speed varies with radius, whereas our experiment approximated rigid-body rotation. Consequently, the stretching process of spiral arms could not be reproduced, and direct comparison with real galactic spiral structures was not possible.
These results indicate that flow visualization is a major challenge in this study. In future work, we plan to improve visualization by floating aluminum powder on the water surface and to quantitatively measure physical quantities such as the number of vortex arms, symmetry, and rotation conditions. Through these improvements, we aim to more objectively investigate the mechanisms responsible for vortex formation.

[References]

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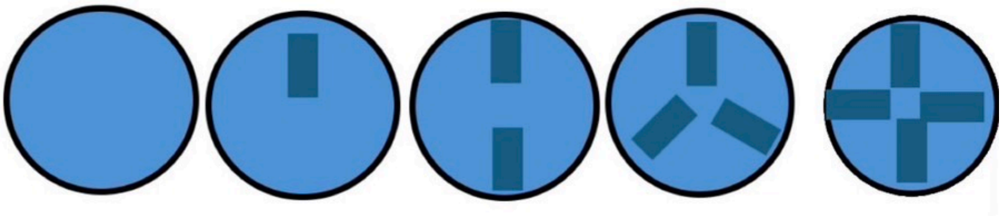

図 1 左から障害物が 0, 1, 2, 3, 4 個のときの配置

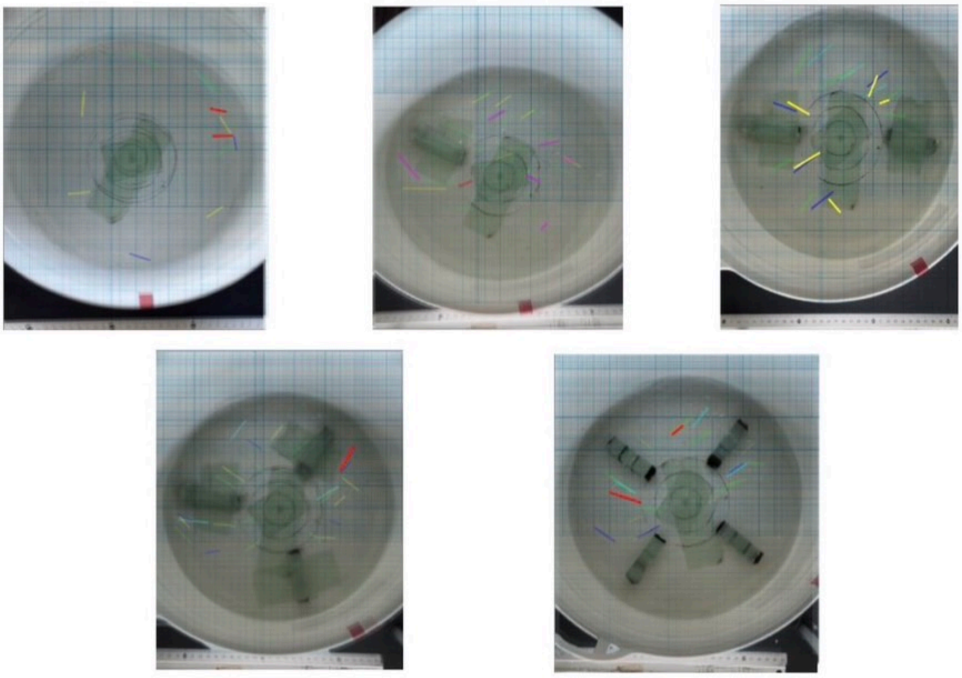

図 2 左上から障害物が 0, 1, 2, 3, 4 個のときの結果

図 3　左は正面から、右は上から装置（改）を見たもの