

Spiral Arms as Fossil Tracers of Cosmic Expansion: Inferring Galaxy Formation Epochs from Pitch Angle Morphology

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We propose that the pitch angle of spiral arms in disk galaxies encodes the cosmological expansion rate at the epoch of galaxy formation. By modeling spiral structure as a geodesic inflow determined by the balance of gravitational binding and cosmic expansion, we derive a direct mapping between spiral pitch angle and the Hubble parameter $H(z)$. Applying this framework to a sample of nearby galaxies with known pitch angles, we infer consistent formation redshifts of $z \approx 10$, corresponding to $t \approx 150$ Myr after the Big Bang. These results suggest that spiral arms serve as fossil records of early-universe conditions, offering a novel chronometric tool for galaxy formation and a new observational window into the expansion history of the universe.

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I. INTRODUCTION

Spiral galaxies are among the most iconic and well-studied structures in the universe, yet the origin and evolution of their morphology remain open questions. In particular, the pitch angle of spiral arms (α) varies systematically across galaxies and has been linked to mass distribution, angular momentum, and star formation. Here, we present a cosmological interpretation of α , treating spiral arms as geodesics in a metric inflow model shaped by both local gravity and the Hubble expansion, further elaborating the velocity of space approach of (1, 2).

II. THEORETICAL FRAMEWORK

We model the total inflow velocity vector \vec{v}_L as the sum of a tangential orbital component \vec{v}_{orb} and a radial component $\vec{v}_{\text{rad}} = (v_{\text{esc}}(r) - H(z)r)\hat{r}$. Assuming a constant magnitude for \vec{v}_L based on the Lagrangian $v_L = \sqrt{3GM/R}$, the pitch angle becomes:

$$\tan \alpha(r) = \frac{v_{\text{rad}}(r)}{\sqrt{v_L^2 - v_{\text{rad}}^2}} \quad (1)$$

This relation allows inversion to estimate $H(z)$ from observed $\alpha(r)$.

III. APPLICATION TO GALAXY SAMPLE

Using observed pitch angles for galaxies such as M81, M51, NGC 628, and others, and assuming standard bulge and disk mass models, we recover consistent values of $H(z) \approx 10,000\text{--}15,000$ km/s/Mpc. This corresponds to redshifts $z \approx 10$ under Λ CDM cosmology. The time since the Big Bang at this epoch is approximately 0.15 Gyr.

IV. IMPLICATIONS

These results suggest that spiral arms may preserve the cosmic flow conditions from the time of galaxy disk formation. If pitch angles are indeed “frozen” early and remain dynamically stable, they can serve as fossil chronometers encoding the expansion rate at formation. This challenges purely secular or density-wave models of spiral structure and introduces a new cosmological observable.

V. DISCUSSION AND FUTURE WORK

Further work is needed to test the preservation of pitch angle over cosmic time, validate the geodesic model via N-body simulations, and extend the method to high-redshift spirals (e.g., from JWST). A full survey-based analysis could reconstruct a fossil $H(z)$ history and constrain cosmic expansion independent of standard candles or rulers.

VI. CONCLUSION

Spiral pitch angle may provide a direct, fossil imprint of the Hubble parameter at the time of disk formation. This bridges galactic morphology with cosmology and opens new directions for understanding both the origin of spiral structure and the early universe.

REFERENCES

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