Secular Extragalactic Parallax: Measurement Methods and Predictions for Gaia

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Summary

Secular extragalactic parallax caused by the solar system's velocity with respect to the CMB is observable as a proper motion dipole.

Future Gaia data will enable:

- The **first significant detection** of secular parallax (9 σ)
- Constraints on the **peculiar proper motions induced by large-scale structure**

An extended Gaia mission (or future astrometry mission) may enable an independent constraint on the Hubble constant.

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Paper: arXiv:1912.11935 Poster:

Introduction

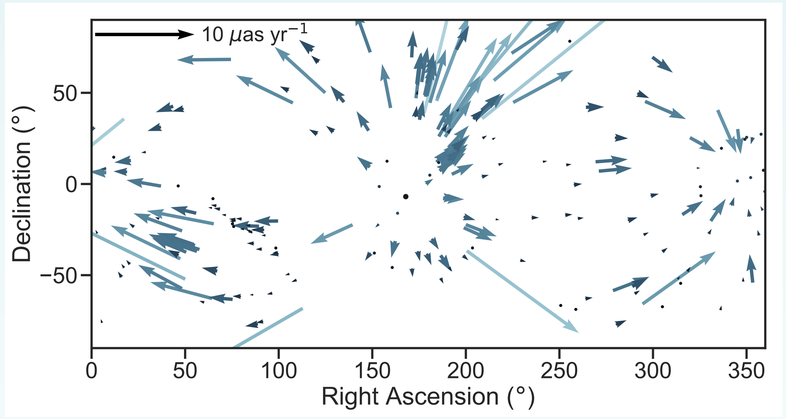

Figure 1. Expected secular parallax proper motions of 232 galaxies observed by Gaia. Color scales with distance to the galaxy and the dot shows the direction of the CMB apex.

Secular parallax is an apparent streaming motion of extragalactic objects, shown in Fig 1, caused by the solar system's 78 AU yr^{-1} velocity with respect to the cosmic microwave background (CMB) frame [1]. It is distinct from annual parallax and is **observable as a curl-free proper motion dipole that diminishes linearly with distance**:

$$|\mu| = (78\ \mu\text{as yr}^{-1}) \left(\frac{1\ \text{Mpc}}{D}\right) |\sin\beta|$$

Detection of secular parallax would enable a new, independent constraint on the Hubble constant:

$$H_0 = \left(\frac{|\mu|}{78\ \mu\text{as yr}^{-1}}\right) \left(\frac{cz}{1\ \text{Mpc}}\right) \frac{1}{|\sin\beta|}$$

Gaia will measure proper motions of ~500,000 extragalactic objects out to high redshift [2,3]. **We demonstrate that Gaia astrometry for a subset of nearby galaxies may be used to probe secular parallax and large-scale structure (LSS).**

A First Secular Parallax Limit

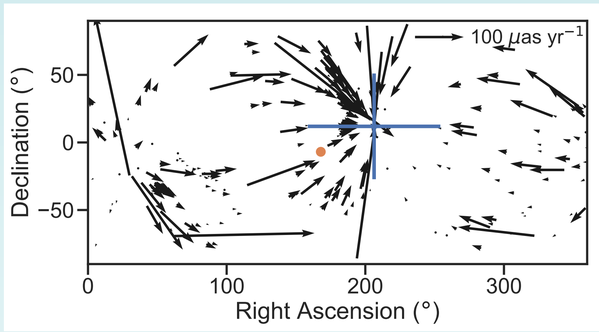

Figure 2. Best-fit dipole for 232 Gaia-CF3 galaxies. The fit is not significant. The blue cross is the fit antapex and the orange dot is the CMB dipole apex.

We find a first secular parallax upper limit of 3500 μas yr^{-1} Mpc using nearby galaxies in Gaia DR2 identified from the Cosmicflows-3 (CF3) catalog [4].

A significant detection will require a larger sample with lower per-object uncertainties, which Gaia will achieve with longer time baselines of future data releases.

Simulated Extragalactic Proper Motions

Simulated proper motions for 9,698 Gaia-CF3 galaxies are based on:

- Expected secular parallax proper motions
- Peculiar proper motions calculated from the CF3 model peculiar velocity field [5]
- Gaia's end-of-mission uncertainties

Impact of peculiar proper motions

Peculiar motions are caused by gravitational interactions with LSS over-densities. As shown in Fig 3, peculiar and secular parallax proper motion amplitudes are roughly correlated due to similar scaling with distance.

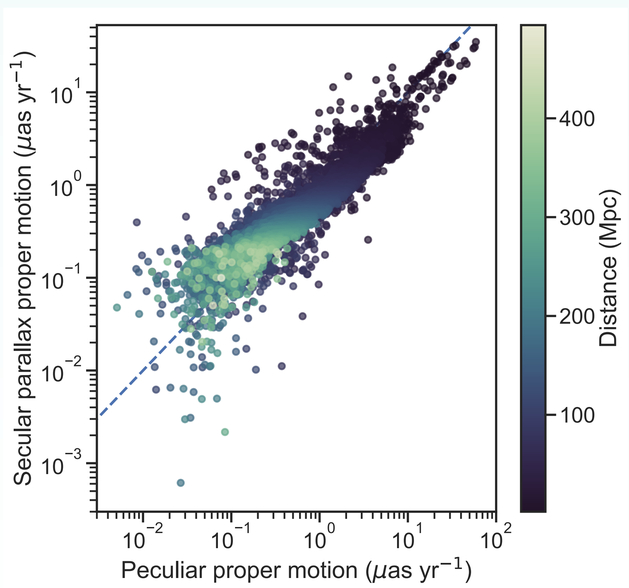

Figure 3. Predicted secular parallax vs. peculiar proper motions of Gaia-CF3 galaxies. The dashed line is one-to-one correspondence.

Predicted Secular Parallax Detection

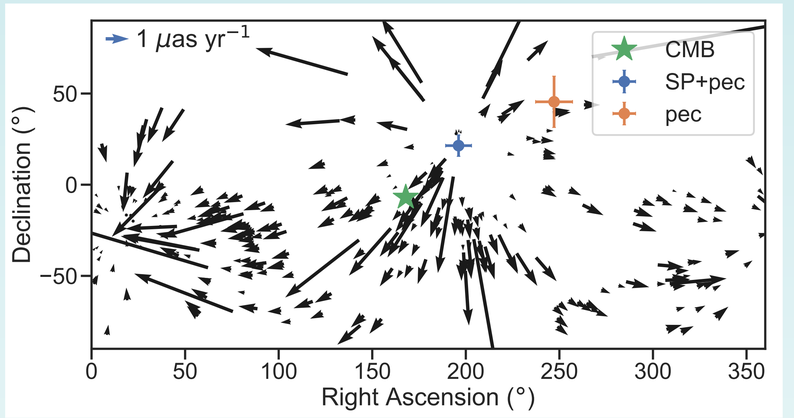

Figure 4. Simulated detected dipole. Arrows are only displayed for a random subset of the catalog. The blue cross shows the apex of the best-fit dipole for the full simulation, whereas the orangs cross is the apex when only noisy peculiar motions are simulated.

Peculiar motions offset the simulated detected dipole, shown in Fig 4. To isolate the secular parallax component of the net dipole, we fix the direction toward the CMB apex.

We predict a 9 σ detection of the secular parallax amplitude when the dipole direction is fixed. The detection is dependent on galaxies:

- Closer than 5 Mpc
- Brighter than G=15 mag

Future constraint on H_0

H_0 will not be measured with Gaia as the secular parallax is not significantly detected at distances > a few Mpc.

A significant H_0 constraint from proper motions will depend on higher precision proper motions of galaxies at moderate distances.

Large-scale Structure Motions

The peculiar proper motion power spectrum, shown in Fig 5, is a probe of the underlying LSS.

Gaia will be sensitive to low-multipole peculiar motions of nearby galaxies (see Fig 4), but will not measure the power spectrum in Fig 5 beyond a few Mpc.

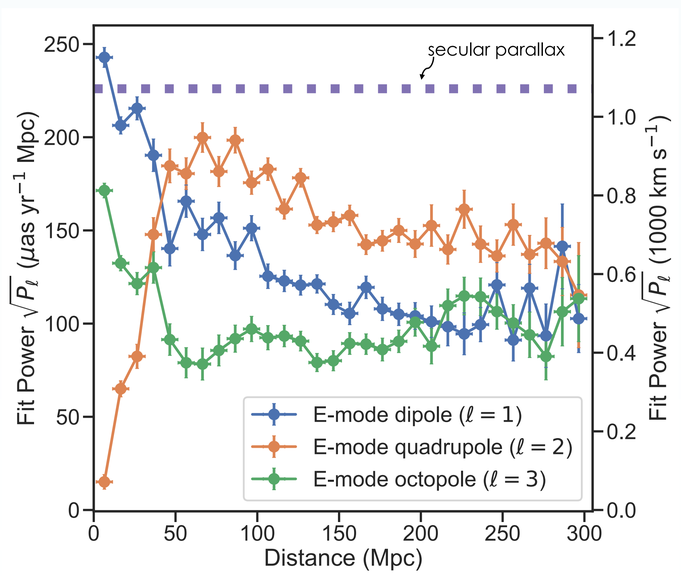

Figure 5. Model predicted peculiar proper motion power spectrum (first 3 modes) as a function of distance, excluding Gaia-like noise. The dashed line indicates the secular parallax power.
The octupole power predicted from CF3 deviates from other LSS simulations [6] for distances <50 Mpc.

References & Acknowledgements

[1] Hinshaw, G., Weiland, J. L., Hill, R. S., et al. 2008, ApJS, 180, 225
[2] Lindegren, L., Hernandez, J., Bombrun, A., et al. 2018, A&A, 616, A2
[3] Paine, J., Darling, J., & Truebenbach, A. 2018, 236, 37
[4] Tully, R.B., Courtois, H.M., & Sorce, J.G. 2016, AJ, 152, 50
[5] Graziani, R., Courtois, H.M., Lavaux, G., et al. 2019, MNRAS, 488, 5438
[6] Hall, A. 2019, MNRAS, 486, 145

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