Impact of Binary Orbits on Astrometric Microlensing Signals

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Background

- When modeling long-duration binary microlensing events, it is important to consider the orbital motion and dynamics of the involved binary system, as the orbital period approaches the duration of the microlensing signal.
- In previous iterations of the Bayesian Analysis of Gravitational Lensing Events (BAGLE), the orbital motion for binaries was not included. Now, we make corrections for the different proper motions of the primary and secondary sources/lenses involved in the binary system by developing new parameterization classes.
- Currently, these parameterization classes account for linear and accelerated orbits in binary source point lens (BSPL) models. Using these additions to BAGLE, we explore the impact of binary orbits on astrometric microlensing signals

Binary Source Geometry With Orbital Motion

- We work in the heliocentric reference frame. The primary source is placed at the origin. The initial separation between the primary and secondary source is defined as the difference between their initial positions:

$$\boldsymbol{s} = \boldsymbol{X}_{\boldsymbol{S_s},\odot} - \boldsymbol{X}_{\boldsymbol{S_p},\odot}$$

- Including binary orbital motion allows for the primary and secondary proper motions to be different. We take in the primary source proper motion as $\mu_{S,\square}$. The secondary source proper motion is taken in as $\blacktriangle\mu_{S,\ sec,\ \square}$. Then, the primary and secondary proper motions relative to the lens are given by:

$$\begin{aligned} \boldsymbol{\mu}_{\mathbf{rel},\odot} &= \boldsymbol{\mu}_{\boldsymbol{S},\odot} - \boldsymbol{\mu}_{\boldsymbol{L},\odot} \\ \boldsymbol{\mu}_{\mathbf{rel},sec,\odot} &= \boldsymbol{\mu}_{\boldsymbol{S},\odot} + \boldsymbol{\Delta\mu}_{\boldsymbol{S},sec,\odot} - \boldsymbol{\mu}_{\boldsymbol{L},\odot} \end{aligned}$$

- We use the sources' proper motions to define their positions. In the linear orbit model, the secondary source moves linearly relative to the primary source. We find that the position of the primary and secondary sources are given by:

$$\begin{aligned} \boldsymbol{X}_{\boldsymbol{S_p},\odot}(t) &= \boldsymbol{X}_{\boldsymbol{S_p},\mathbf{0},\odot} + \boldsymbol{\mu}_{\mathbf{rel},\odot}[t - t_{p,0,\odot}] \\ \boldsymbol{X}_{\boldsymbol{S_s},\odot}(t) &= \boldsymbol{X}_{\boldsymbol{S_s},\mathbf{0},\odot} + \boldsymbol{\mu}_{\mathbf{rel},sec,\odot}[t - t_{s,0,\odot}] \end{aligned}$$

- Similarly, for the accelerated orbit model, the position of the primary and secondary sources are given by:

$$\begin{aligned} \boldsymbol{X}_{\boldsymbol{S_p},\odot}(t) &= \boldsymbol{X}_{\boldsymbol{S_p},\mathbf{0},\odot} + \boldsymbol{\mu}_{\mathbf{rel},\odot}[t - t_{p,0,\odot}] \\ \boldsymbol{X}_{\boldsymbol{S_s},\odot}(t) &= \boldsymbol{X}_{\boldsymbol{S_s},\mathbf{0},\odot} + \boldsymbol{\mu}_{\mathbf{rel},sec,\odot}[t - t_{s,0,\odot}] + 0.5\boldsymbol{a}_{\mathbf{rel},sec,\odot}[t - t_{s,0,\odot}]^2 \end{aligned}$$

- In both the models, the primary source's separation with respect to the lens is given by:

$$\begin{aligned} \boldsymbol{u}_{p,\odot} &= \frac{\boldsymbol{X}_{\boldsymbol{S_p},\odot}(t) - \boldsymbol{X}_{\boldsymbol{L},\odot}(t)}{\theta_E} \\ &= \boldsymbol{u}_{p,\mathbf{0},\odot} + \frac{t - t_{p,0,\odot}}{t_{E,\odot}}\hat{\boldsymbol{\mu}}_{\mathbf{rel},\odot} \\ &= u_{p,0,\odot}\hat{\boldsymbol{u}}_{\mathbf{0},\odot} + \frac{t - t_{p,0,\odot}}{t_{E,\odot}}\hat{\boldsymbol{\mu}}_{\mathbf{rel},\odot} \end{aligned}$$

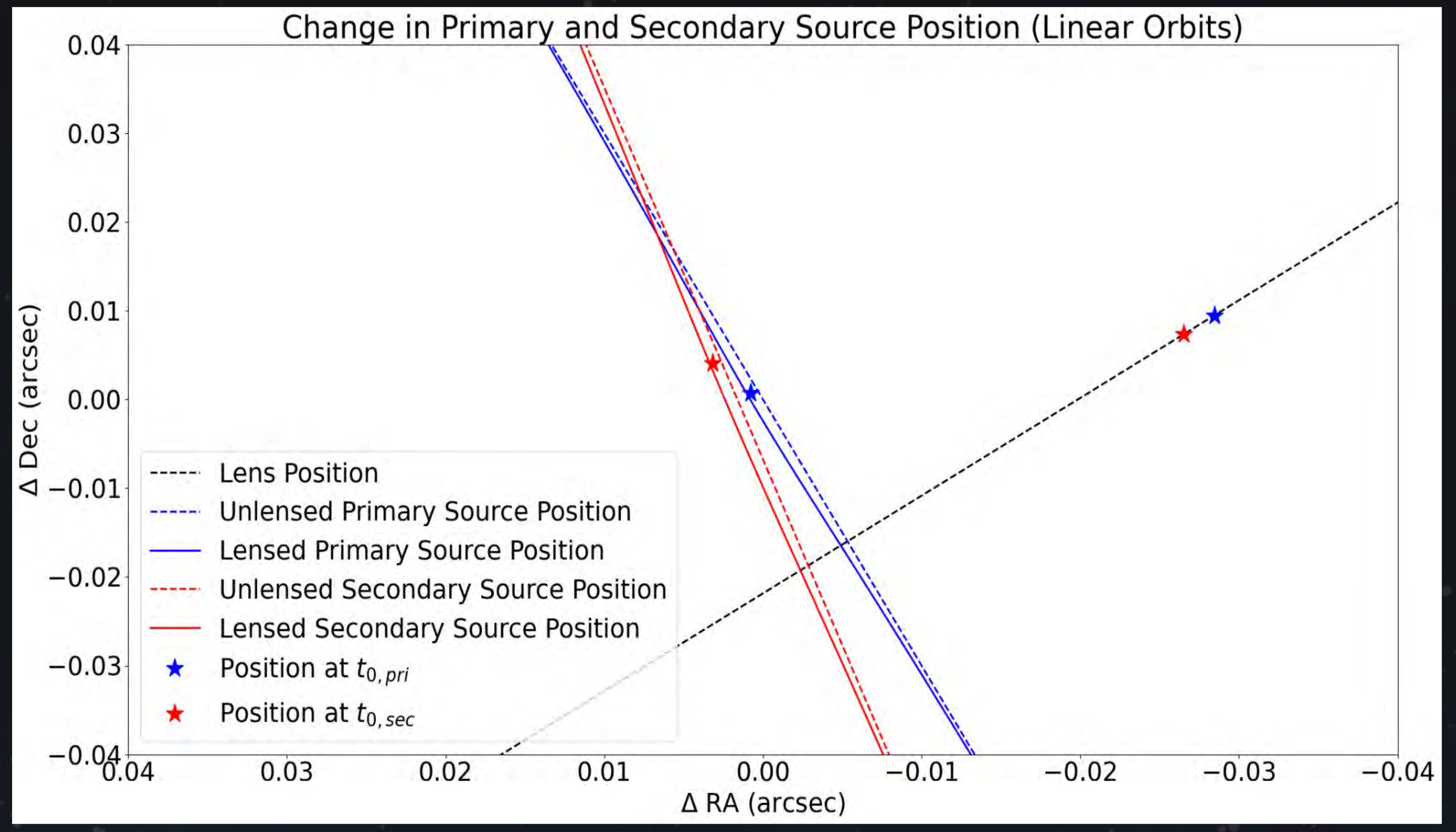
- In linear binary orbital motion, the secondary source's separation with respect to the lens is given by:

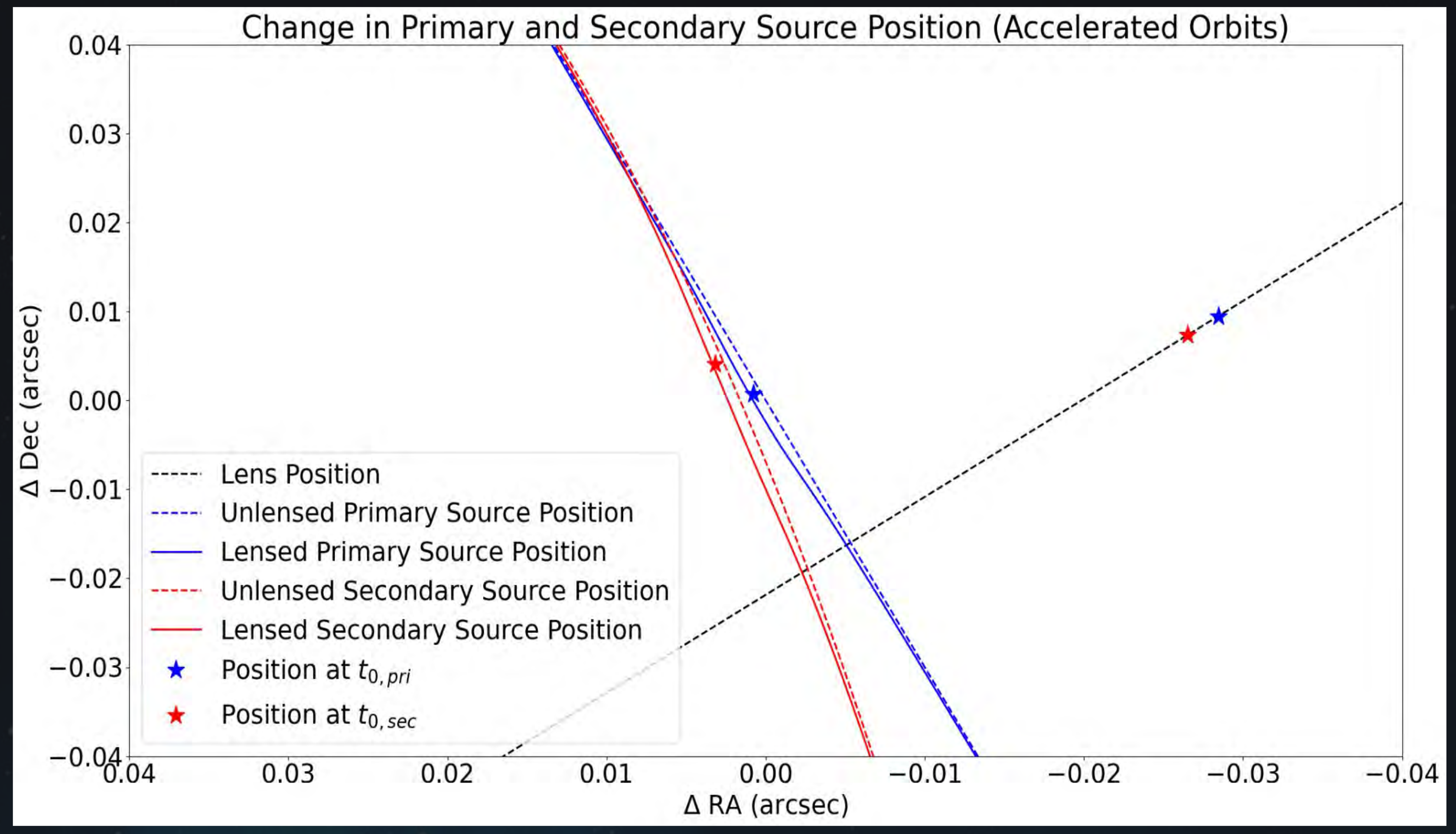
$$\begin{aligned} \boldsymbol{u}_{s,\odot} &= \frac{\boldsymbol{X}_{\boldsymbol{S_s},\odot}(t) - \boldsymbol{X}_{\boldsymbol{L},\odot}(t)}{\theta_E} \\ &= \boldsymbol{u}_{s,\mathbf{0},\odot} + \frac{t - t_{s,0,\odot}}{t_{E,sec,\odot}}\hat{\boldsymbol{\mu}}_{\mathbf{rel},sec,\odot} \\ &= u_{p,0,\odot}\hat{\boldsymbol{u}}_{\mathbf{0},\odot} + \frac{\boldsymbol{s}}{\theta_E} + \frac{t - t_{s,0,\odot}}{t_{E,sec,\odot}}\hat{\boldsymbol{\mu}}_{\mathbf{rel},sec,\odot} \end{aligned}$$

- In accelerated binary orbital motion, the secondary source's separation with respect to the lens is given by:

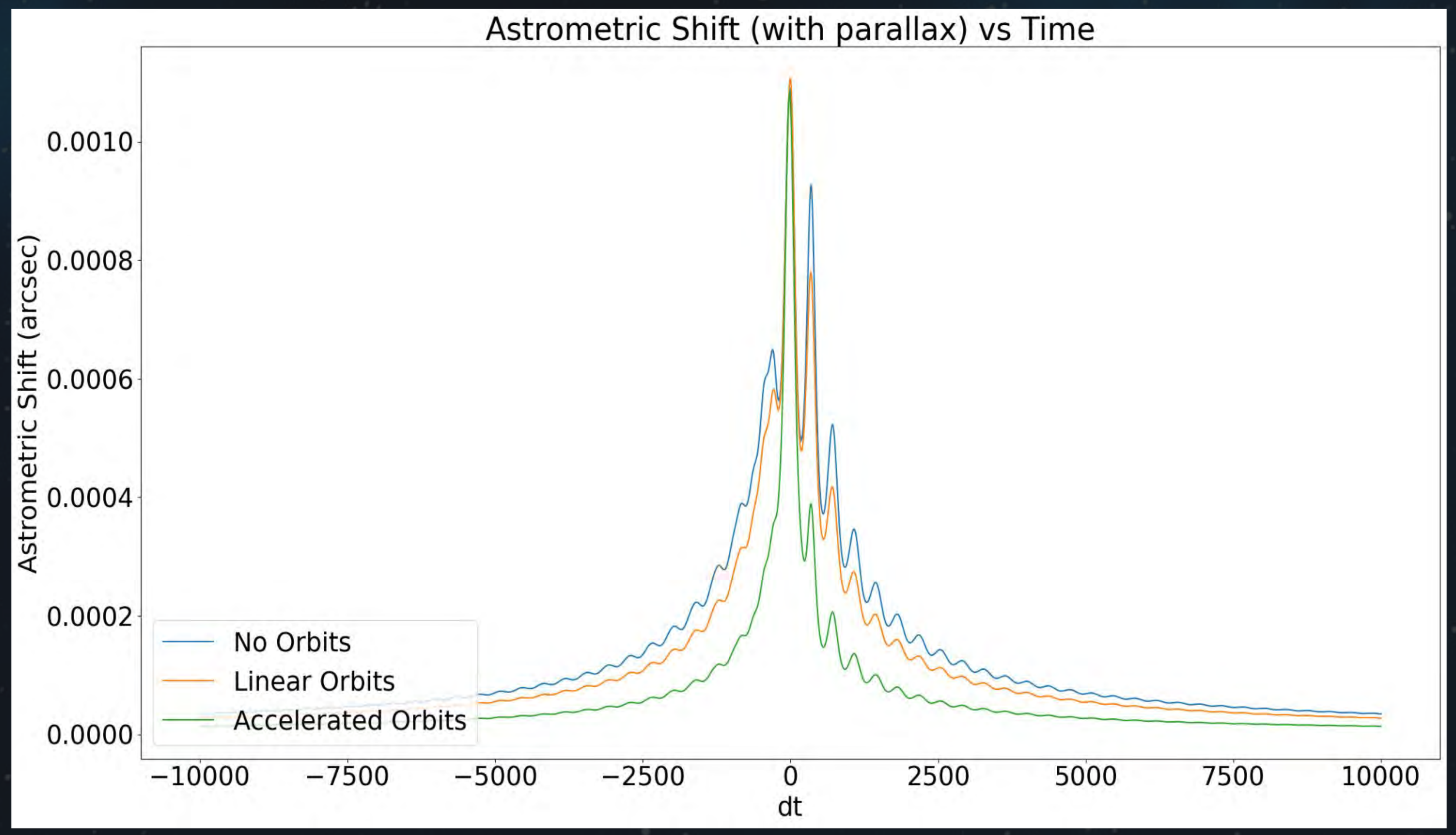
$$\begin{aligned} \boldsymbol{u}_{s,\odot} &= \frac{\boldsymbol{X}_{\boldsymbol{S_s},\odot}(t) - \boldsymbol{X}_{\boldsymbol{L},\odot}(t)}{\theta_E} \\ &= u_{p,0,\odot}\hat{\boldsymbol{u}}_{\mathbf{0},\odot} + \frac{\boldsymbol{s}}{\theta_E} + \frac{t - t_{s,0,\odot}}{t_{E,sec,\odot}}\hat{\boldsymbol{\mu}}_{\mathbf{rel},sec,\odot} + 0.5\frac{a_{sec,\odot}(t - t_{s,0,\odot})^2}{\theta_E}\hat{\boldsymbol{a}}_{sec,\odot} \end{aligned}$$

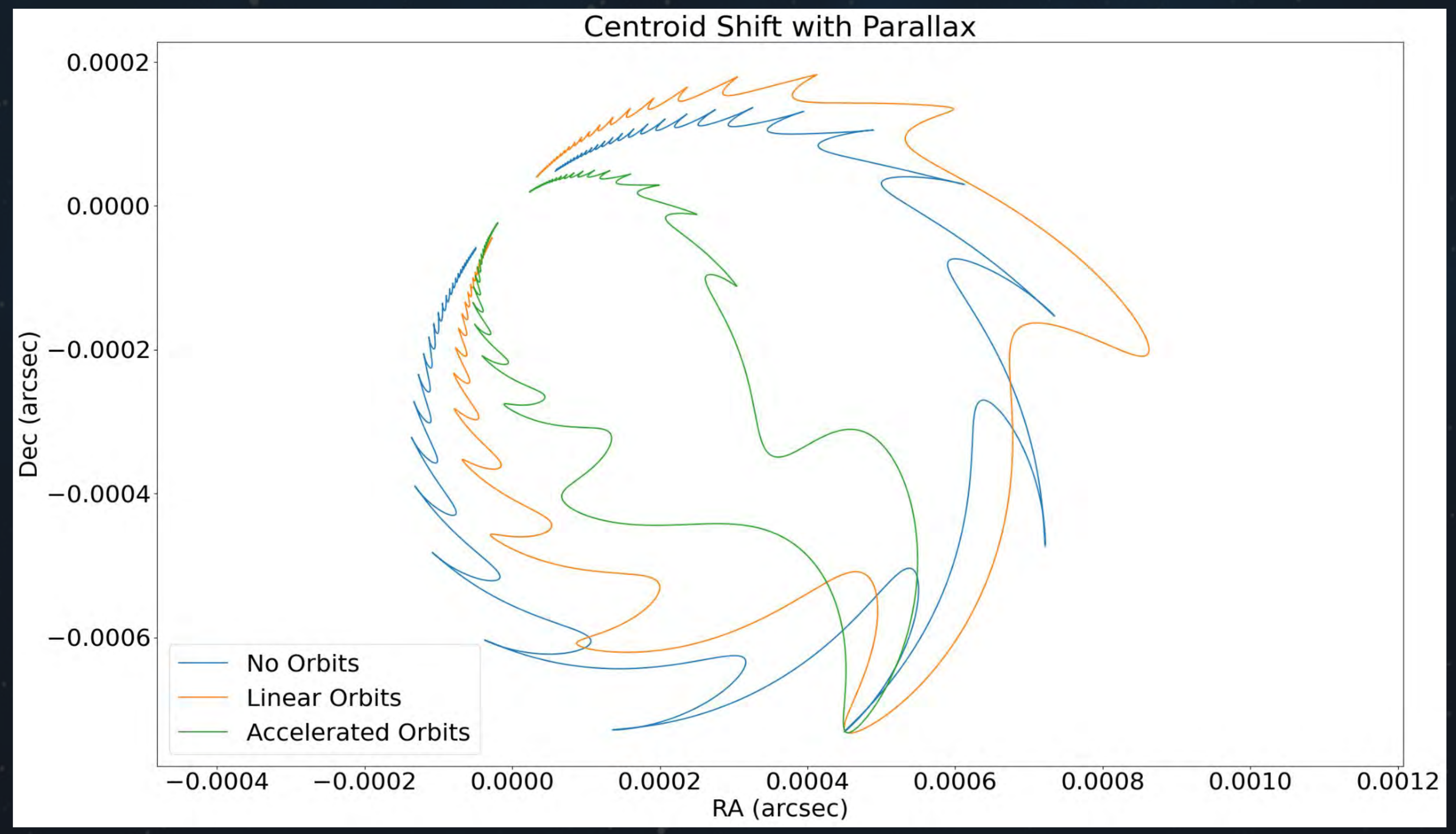
Result: Binary Source, Point Lens with Orbital Motion





- The plots above (**top-left and top-right**) show ▲RA and ▲Dec of the primary source (lensed and unlensed), secondary source (lensed and unlensed), and the lens.
- The primary proper source motion is [$\mu_E = 28$ mas/yr, $\mu_N = 3$ mas/yr]; the secondary proper source motion relative to the primary source is [$\mu_{E,\ sec} = 1$ mas/yr, $\mu_{N,sec} = 14$ mas/yr] for all plots. The acceleration of the second source is [$acc_E = 1$ mas/yr^2, $acc_N = -7$ mas/yr^2] in the models for accelerated orbits. For all models, the t_E=154 days and u_0=6 θ_E.
- Below, we observe the lens-induced astrometric shift from the combined centroid motion of the primary and secondary source (**bottom-left).** We observe that linear and accelerated orbits can significantly affect the astrometric shift over time.
- Both plots below (**bottom-left and bottom-right)** account for parallax effects. The centroid shift (**bottom-right)** is plotted in RA and Dec with source proper motion subtracted.





Conclusion

- Our simulated results for linear and accelerated orbital motion in BSPL models confirm changes in astrometric shift and centroid shift due to the different primary and secondary proper source motion.
- Our next steps involve:
  - Adding circular and elliptical orbits to BSPL models.
  - Adding binary orbital motion to point source binary lens (PSBL) and binary source binary lens (BSBL) models.

References and Acknowledgments

https://github.com/MovingUniverseLab/BAGLE_Microlensing

https://bagle.readthedocs.io/en/latest/

Lam, C. Y., Lu, J. R., Hosek, Jr., Dawson, W. A., & Golovich, N. R. (2019, December 10). *PopSyCLE: A new population synthesis code for compact object microlensing events*. arXiv.org. https://arxiv.org/abs/1912.04510

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