Dimorphos orbit solution 523

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Background

- Last delivery was s516 in mid-January
  - Estimated apsidal precession ($\dot{\varpi}$) from s516 differed significantly from the Scheirich & Pravec solution
- We resolved the discrepancy by:
  - Remeasuring the data and adding additional data to the fits
  - Improving the fidelity of dynamical modeling
  - Improving the fidelity of observational modeling
- Thanks to Nick M. for providing primary-subtracted light curves that are vital to this work.

- Dynamical modeling
  - s516 used secular first order perturbation theory
    - $\dot{\varpi}$ and $\dot{M}_0$ (Ignored $(J_2)^2$)
    - But J_2 ~ 0.1, and so it is not a typical small perturbation. The $(J_2)^2$ effect is ~3%. Not ignorable at the level of precision we seek.
    - Additionally, the secular theory neglects periodic variations, which are potentially significant for such a large J_2
  - So, we switched to a numerical integration of the equations of motion
    - Much higher fidelity
    - Less obvious how to obtain derived parameters that are varying periodically
      - E.g., Post-impact period

We have implemented substantially improved dynamical and observational models.

Post-impact dynamical model

- Pre-impact orbit is still characterized by $\boldsymbol{\lambda}$, $\boldsymbol{\beta}$, a, M_0, n_0, and $\dot{n}$.
- Post-impact orbit is now characterized by parameters ΔV_T, $\Delta \mathrm{V_R}$ and $\mathrm{J_2}$.
- **We numerically integrate the post-impact orbit under the influence of J2.**
- ΔV_T and $\Delta \mathrm{V_R}$ are transverse and radial components of the change in the velocity of Dimorphos due to the DART impact.
- $\mathrm{J_2}$ is the oblateness parameter of Didymos.
- Position of Dimorphos remains unchanged at the instant of impact.
- We can estimate all 9 parameters.
- Our approach maintains position continuity across impact
- Estimating ΔV_R allows for an impact point not at apoapsis

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Estimated parameters:

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T0    = 2022 SEP 26 23:14:24.183 UTC
OPlon = 3.086785978791264142 27e+02 +/- 2.06164005919226367425e+00 degrees  (Orbit pole longitude)
OPlat = -7.96323257810634146381e+01 +/- 3.22229972099043582290e-01 degrees  (Orbit pole latitude)
QR    = 1.24234175572866401005e+00 +/- 1.27373540136541674173e-02 km       (Pre-impact pericenter at T0)
M0    = 1.72366127594568808945e+02 +/- 2.05649817713538629604e+00 degrees  (Pre-impact mean anomaly at T0)
Per   = 11.92150364155180142233803 +/- 1.52517772437260350942e-05 h        (Pre-impact period)
N0    = 1.46401771493913916049e-04 +/- 1.87299125517140233697e-10 rad/sec  (Pre-impact mean motion)
Ndot  = 4.44631799068262639257e-18 +/- 6.25772255811340440201e-19 rad/sec^2 (Pre-impact mean motion dot)
DVR   = 4.89752009357022305997e-07 +/- 1.11069792188837526426e-07 km/sec   (post-impact deltaV radial)
DVT   = -2.89258740516820719038e-06 +/- 2.96143083180993143459e-08 km/sec  (post-impact deltaV transverse)
J2    = 4.34977235115179411418e-02 +/- 1.41133089211990868199e-03          (Didymos oblateness)
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Covariance matrix:

OPlon	OPlat	QR	M0	N0	Ndot	DVR	DVT	J2
1.294733615234744e-03	-1.220338658278379e-05	-5.471027308271333e-05	1.256031461949322e-03	-8.822685663173492e-13	-3.047260547652615e-21	-3.563832028587359e-11	1.220706591507204e-10	-4.683974670355508e-06
-1.220338658278379e-05	3.162908312230447e-05	-4.545777117131732e-05	-1.257247144452545e-05	1.029371361840175e-13	3.696297824578258e-22	-2.664446185326407e-11	1.056818150173672e-10	-3.264124340861728e-06
-5.471027308271333e-05	-4.545777117131732e-05	1.622401872691519e-04	-5.884319844796655e-05	-1.931733805110276e-13	-5.994802732325459e-22	2.950610509654820e-11	-3.767265890936202e-10	1.223722969990244e-05
1.256031461949322e-03	-1.257247144452545e-05	-5.884319844796655e-05	1.288283347126472e-03	-2.121052350162281e-13	-1.181708768810879e-21	-4.390122649377296e-11	1.366413691106980e-10	-5.364091747869160e-06
-8.822685663173492e-13	1.029371361840175e-13	-1.931733805110276e-13	-2.121052350162281e-13	3.508096241948545e-20	1.156751296750995e-28	-1.446923660577771e-19	5.082561703843768e-19	-1.728381429492307e-14
-3.047260547652615e-21	3.696297824578258e-22	-5.994802732325459e-22	-1.181708768810879e-21	1.156751296750995e-28	3.915909161432137e-37	-4.537267406683469e-28	1.566830405588065e-27	-5.198291461827366e-23
-3.563832028587359e-11	-2.664446185326407e-11	2.950610509654820e-11	-4.390122649377296e-11	-1.446923660577771e-19	-4.537267406683469e-28	1.233649873687155e-14	-1.548359826264526e-16	-3.702552382608134e-11
1.220706591507204e-10	1.056818150173672e-10	-3.767265890936202e-10	1.366413691106980e-10	5.082561703843768e-19	1.566830405588065e-27	-1.548359826264526e-16	8.770072571594462e-16	-2.716270538043173e-11
-4.683974670355508e-06	-3.264124340861728e-06	1.223722969990244e-05	-5.364091747869160e-06	-1.728381429492307e-14	-5.198291461827366e-23	-3.702552382608134e-11	-2.716270538043173e-11	1.991854887051977e-06

All angles are in radians, distances are in km, and velocities are in km/s

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Derived parameters:
EC+    = 2.4250263910597934299e-02 +/- 2.24105802153305201652e-04       (post-impact osculating ecc. at T0)
P+     = 11.36895524795656164940283 +/- 1.39990115931546907357e-04 h     (post-impact period)
DP     = -3.31529036157143863761e+01 +/- 8.74950089038746894876e-03 min  (change in period due to impact)
LPdot = 6.06043865086504052186e+00 +/- 1.41379467060629621100e-01 deg/day (Longitude of pericenter dot)
GM_sys= 4.07837360374551798516e-08 +/- 1.25394731522866490828e-09 km^3/s^2 (See note on next page)

Notes: EC+ is post-impact osculating eccentricity at T0
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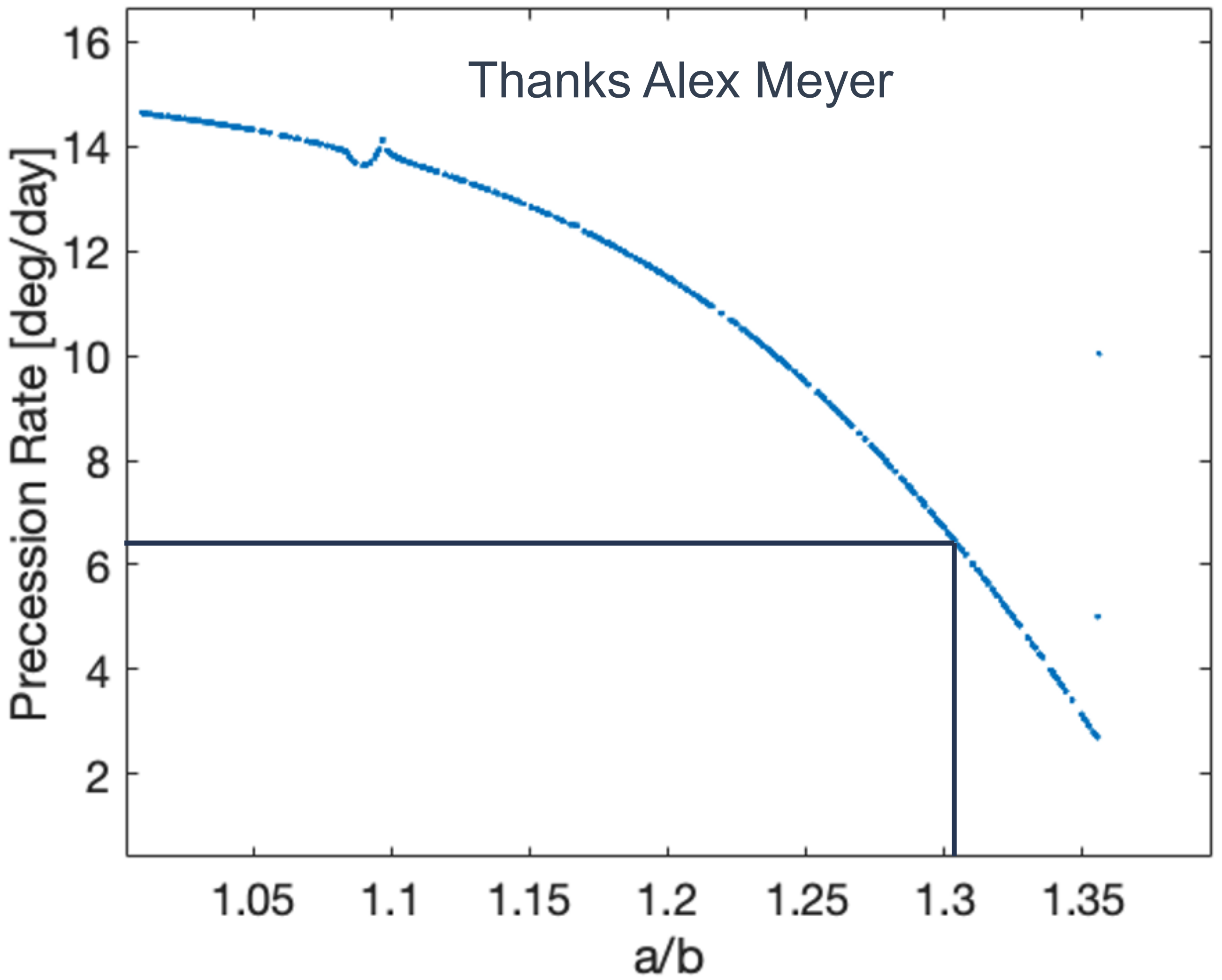
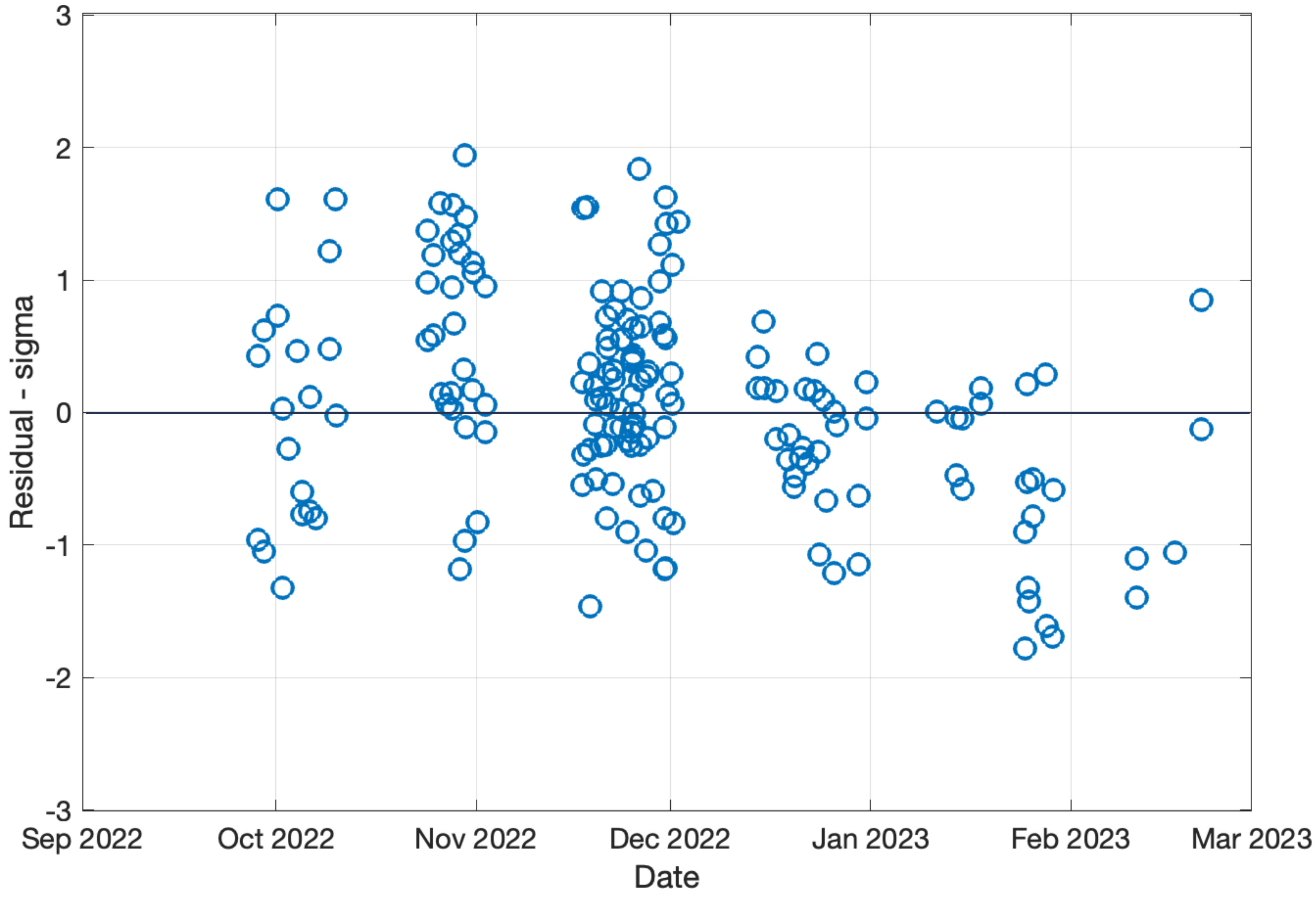
Effect of secondary elongation

- Our model assumes that the apsidal precession is due to the J2 of Didymos alone.
- However secondary elongation can cause apsidal regression, which would partly offset the apsidal precession due to J2.
- We can compute the precession rate as a function of Dimorphos' elongation assuming the shape-based J2.
- Conclude that elongation (a/b) is ~1.3.
- As a result, the estimated J2 is an underestimate: It is a factor of ~2 smaller than the J2 computed from a uniform density Didymos.
- The estimated J2 is used in the computation of GM_sys, causing the computed GM_sys to be an overestimate.
- We recommend scaling GM_sys down by ~1% to 4.04166824e-8 km^3/s^2 to account for this.

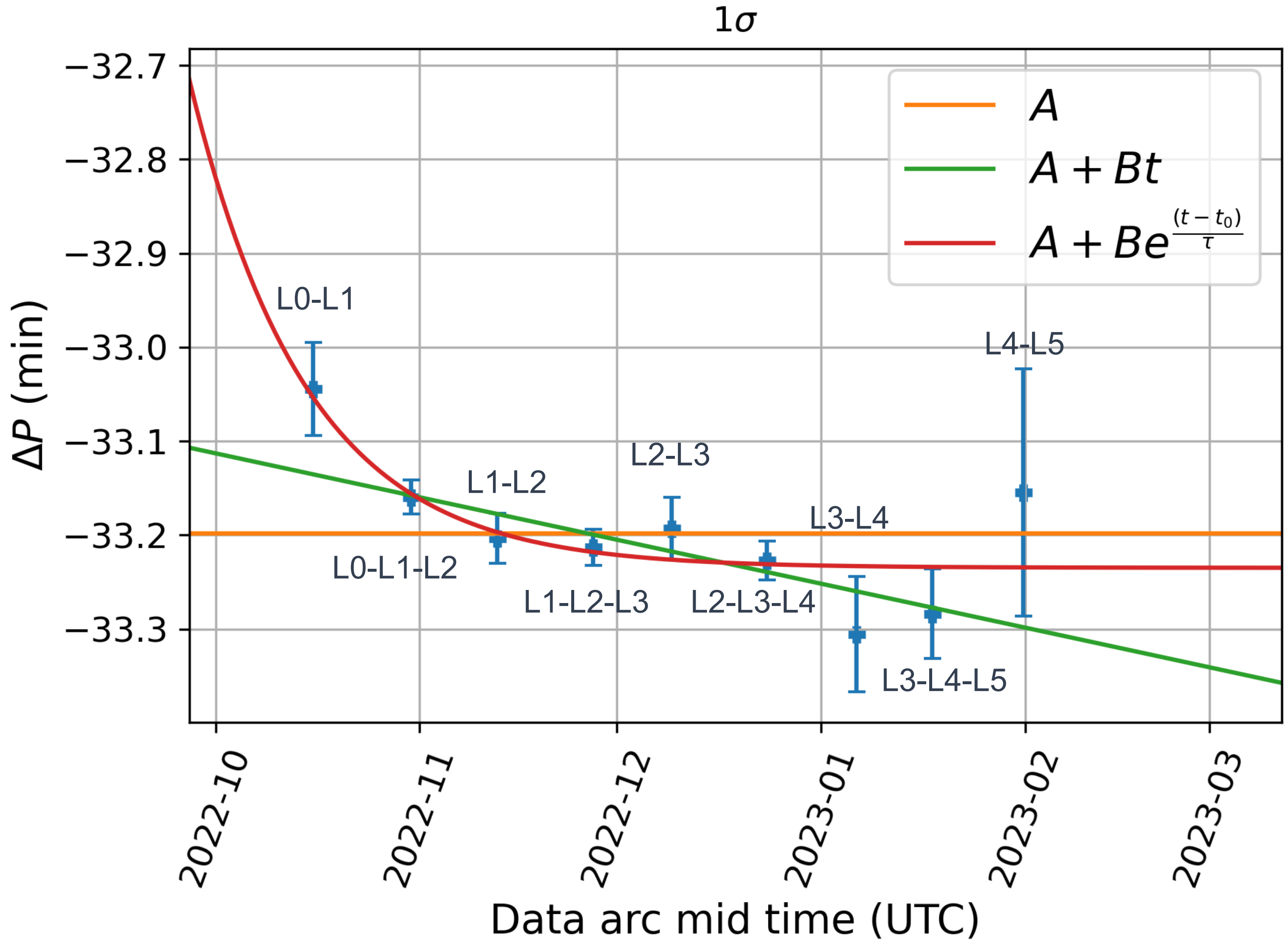


Residuals

- L2 is the largest dataset (second half of November)
- Apparent run off starting in December (L3) probably due to model deficiencies.



Is the orbit constant with time?



- Fits to sub-arcs suggest changing period?
    - Exponential?

Delivery

- https://ssd.jpl.nasa.gov/ftp/eph/small_bodies/dart/dimorphos/
- SPK file: ‘dimorphos_s523.bsp’
  - Contains pre-impact as well as post-impact trajectories.
  - This SPK file avoids discontinuity between the pre- and post-impact orbits by computing post-impact elements based on the DART impact velocity vector and the estimated period change.
- There are two PCK files that describe the orientation of Dimorphos:
  - ‘dimorphos_s523-preimpact.tpc’: Valid for times prior to the DART impact at 2022 SEP 26 23:14:24.183 UTC
  - ‘dimorphos_s523-postimpact.tpc’: Valid for times after the DART impact at 2022 SEP 26 23:14:24.183 UTC