DART

NASA

Dimorphos orbit solution 542

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Solution 527

Superseded by s542

Estimated parameters:

```
T0    = 2022 SEP 26 23:14:24.183 UTC
OPlon = 3.10585033692532306304e+02 ± 2.11414759263359908203e+00 degrees
OPlat =-7.98277271583207266303e+01 ± 3.41157819709318632651e-01 degrees
QR    = 1.24176724240550706568e+00 ± 1.42353191609348311841e-02 km
Per   = 11.92148110205965316765742 ± 1.58020381905648484825e-05 h
Ndot  = 5.19113957839942192495e-18 ± 6.40866206332135824631e-19 rad/sec^2
DVR   = 4.21095196128022329161e-07 ± 3.83167355772550372131e-07 km/sec
DVT   =-2.79987668475977308577e-06 ± 3.46610554054279300490e-08 km/sec
J2    = 9.04600073742499455332e-02 ± 3.32029078319730913682e-03
a     = 9.14133965448308966062e-02 ± 3.01765087953876883289e-03 km          a/b = 1.3 ± 0.06
b     = 7.00368818728321906875e-02 ± 2.30592060467619706585e-03 km          a/c = 1.5 ± 0.1
c     = 6.14642158119826712004e-02 ± 4.27598512035040363016e-03 km          b/c = 1.1 ± 0.1
dragA = 1.73077825888648048118e-14 ± 6.94993478382937423281e-15 rad/s^2
dragT = 1.93098414624002465700e+01 ± 4.59833767420080175015e+00 days
```

Note: A priori values: 1) J2 = 0.09 ± 0.009, 2) DVR = 0.4 ± 0.4 mm/s, 3) a = 89 ± 5 m 4) c = 58 ± 5 m, 5) dragT = 20 ± 5 days

A priori on J2 is from Didymos shape. A priori on a and c are from Daly et al. (2023) but allow for reshaping with the volume constrained to within 10% of the Daly et al. (2023) value of 0.00181 km^3

Solution 527

Superseded by s542

Derived parameters:

```
EC+   = 3.144756843422889108 77e-02 ± 1.671232870201373992 70e-04
P+    = 11.368499734616584362 35666 ± 2.988158281371333224 04e-04 h
DP    =-3.317888204658412831 80e+01 ± 1.816499925642460142 04e-02 min
LPdot = 6.119099999999999539 57e+00 ± 1.675790937588756690 51e-01 deg/day (Longitude of pericenter)
GM    = 4.037722357396054289 90e-08 ± 1.398255823941542136 78e-09 km^3/s^2
Vol2  = 1.648343055408737741 28e-03 ± 1.267423605750551387 96e-04 km^3
```

Notes:

1) Post-impact period is difficult to measure because it has large periodic variations superimposed on the exponential change due to drag. The reported period is an average over ~200 orbits.

2) Post-impact eccentricity is an average over ~200 orbits.

Problem with s527

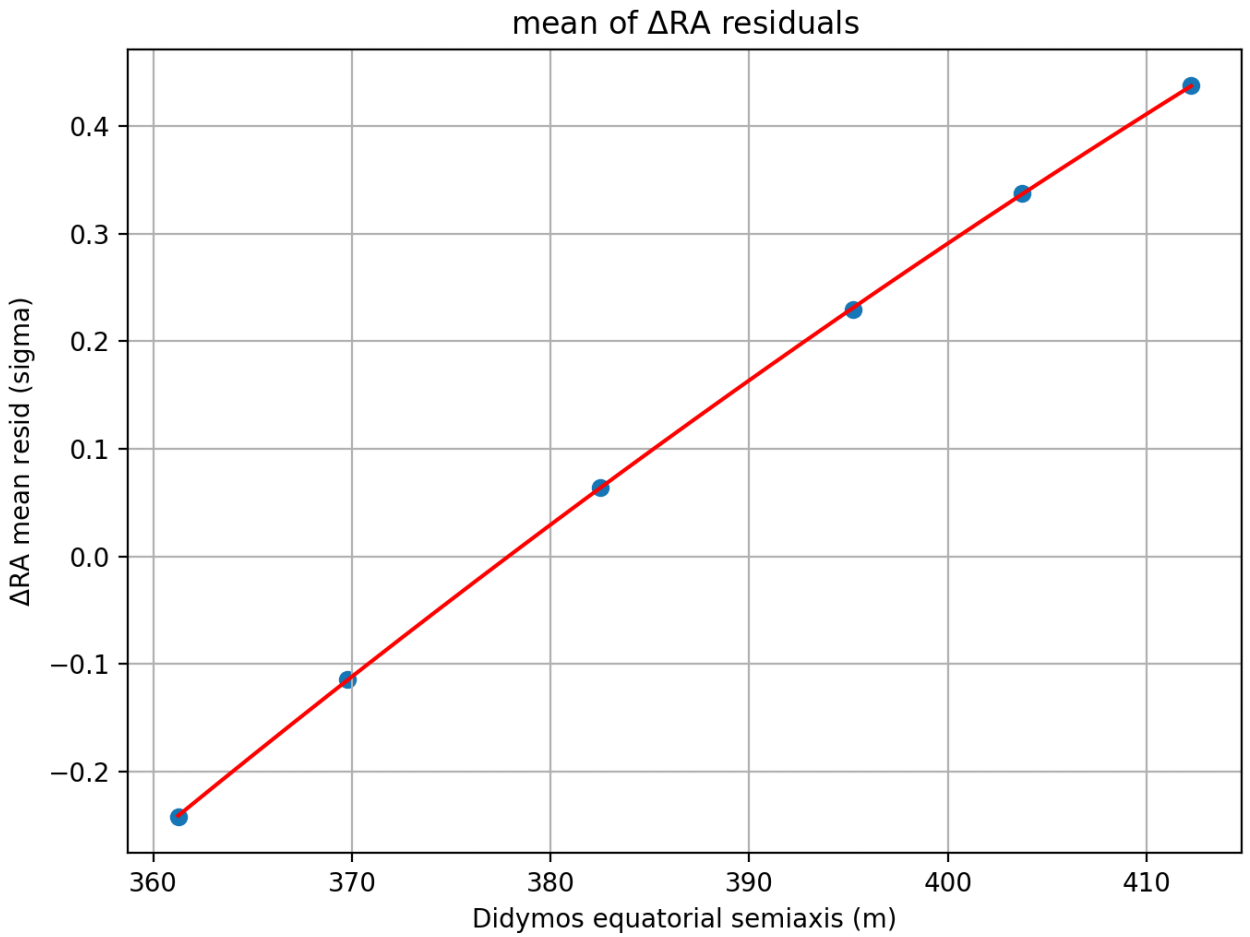
- Mean of RA residuals = 0.55
- Since they were de-weighted by a factor of 4,the OPNAVs are ~2.2 sigma off
- We did not find any problems with the OPNAV measurements, data treatment, or weights.
- OPNAVs were in conflict with secondary lightcurve events.
- We improved our phase correction model for secondary events by using a higher-fidelity photometric model.
- This improved the fit slightly but did not improve the residuals on RA and DEC.

Table 4. Didymos-relative optical astrometry of Dimorphos observed by the DART spacecraft. Times are in Barycentric Dynamical Time (TDB). ΔRA are ΔDEC are the RA and DEC of Dimorphos relative to Didymos. Unc. RA and Unc. DEC are the 1σ uncertainties of the RA and DEC measurements. Res. RA and Res. DEC are the residuals (observed - computed) for solution 527, which is described in Sec. 6

Time (TDB)	ΔRA (deg.)	Unc. RA (deg.)	Res. RA (sigma)	ΔDEC (deg.)	Unc. DEC (deg.)	Res. DEC (sigma)
2022 SEP 26 23:12:07.417	-0.0514196	0.0038304	0.627	-0.0125218	0.0034673	0.055
2022 SEP 26 23:12:14.157	-0.0534928	0.0039585	0.545	-0.0117131	0.0034132	0.423
2022 SEP 26 23:12:20.897	-0.0558010	0.0040724	0.444	-0.0125985	0.0034639	0.297
2022 SEP 26 23:12:27.637	-0.0576213	0.0041940	0.498	-0.0134683	0.0035253	0.189
2022 SEP 26 23:12:33.415	-0.0593477	0.0043055	0.532	-0.0143021	0.0035859	0.083
2022 SEP 26 23:12:40.155	-0.0615916	0.0044643	0.550	-0.0140441	0.0035711	0.319
2022 SEP 26 23:12:46.895	-0.0641259	0.0046184	0.547	-0.0150902	0.0036472	0.198
2022 SEP 26 23:12:53.635	-0.0667637	0.0047804	0.567	-0.0165720	0.0037620	-0.021
2022 SEP 26 23:13:00.375	-0.0699190	0.0049938	0.527	-0.0157601	0.0036996	0.399
2022 SEP 26 23:13:07.115	-0.0732115	0.0051960	0.519	-0.0170424	0.0038000	0.264
2022 SEP 26 23:13:13.855	-0.0766707	0.0054239	0.538	-0.0180365	0.0038846	0.231
2022 SEP 26 23:13:20.595	-0.0803118	0.0056719	0.588	-0.0193630	0.0040040	0.138
2022 SEP 26 23:13:27.335	-0.0849044	0.0059557	0.543	-0.0204015	0.0040924	0.146
2022 SEP 26 23:13:34.075	-0.0893027	0.0062723	0.611	-0.0214126	0.0041959	0.189
2022 SEP 26 23:13:40.815	-0.0948127	0.0066306	0.591	-0.0225141	0.0042994	0.243
2022 SEP 26 23:13:48.518	-0.1020540	0.0070766	0.560	-0.0253911	0.0045736	-0.016

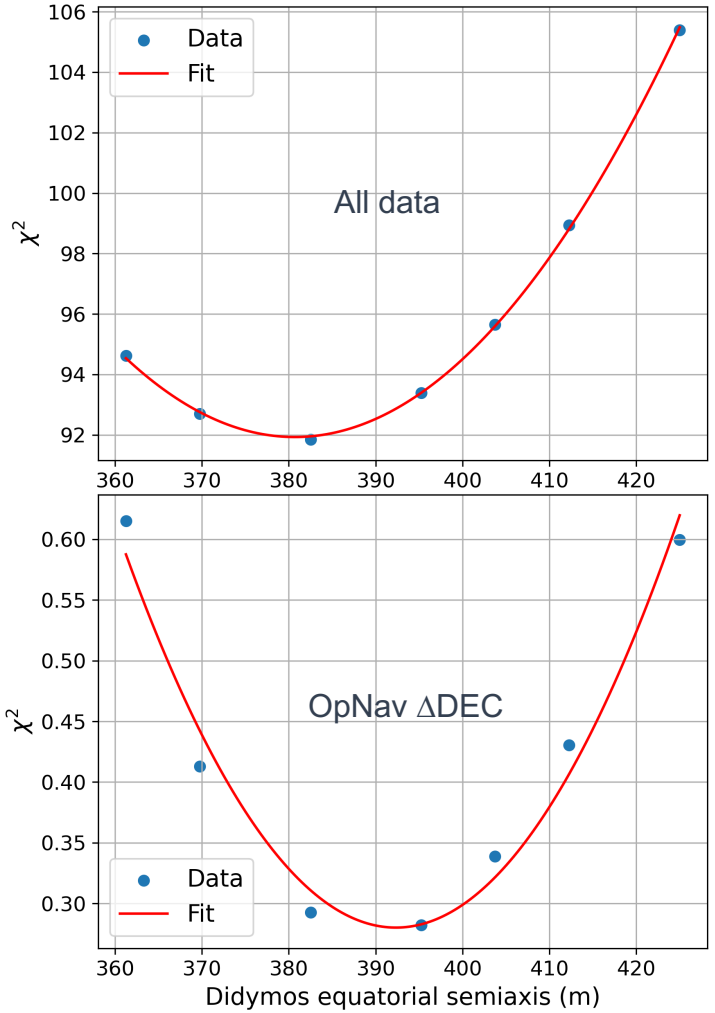
We found that scaling down the primary size not only improved the overall chi-squares of the fit, but also the OPNAV residuals and mutual event residuals.

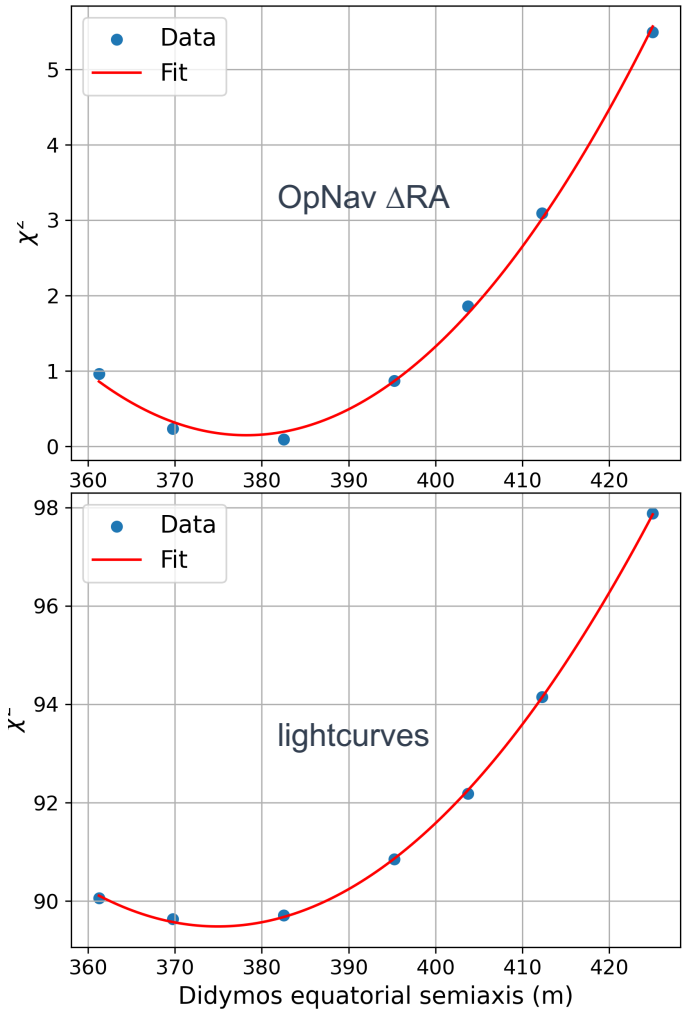
OpNav bias depends on Didymos size



Best-fit primary size

Scaling the primary down by ~10% from Daly et al. (2023) provided the best fit to OPNAV, LC, and all data





OPNAV residuals for solution 542

Spacecraft residuals:

#Time(TDB)	deltaRA(deg)	sigmaRA(deg)	resRA(sig)	deltaDEC(deg)	sigmaDEC(deg)	resDEC(sig)	SCID
2022 SEP 26 23:12:07.417	-0.0365846	0.0038338	0.296	-0.0089092	0.0034682	-0.027	-135
2022 SEP 26 23:12:14.157	-0.0380726	0.0039622	0.236	-0.0083366	0.0034140	0.230	-135
2022 SEP 26 23:12:20.897	-0.0398633	0.0040763	0.128	-0.0090002	0.0034649	0.130	-135
2022 SEP 26 23:12:27.637	-0.0411334	0.0041982	0.174	-0.0096145	0.0035264	0.053	-135
2022 SEP 26 23:12:33.415	-0.0423576	0.0043100	0.200	-0.0102077	0.0035872	-0.023	-135
2022 SEP 26 23:12:40.155	-0.0438889	0.0044692	0.230	-0.0100075	0.0035724	0.146	-135
2022 SEP 26 23:12:46.895	-0.0457352	0.0046237	0.219	-0.0107625	0.0036487	0.056	-135
2022 SEP 26 23:12:53.635	-0.0476527	0.0047862	0.227	-0.0118283	0.0037638	-0.103	-135
2022 SEP 26 23:13:00.375	-0.0498628	0.0050002	0.208	-0.0112393	0.0037013	0.194	-135
2022 SEP 26 23:13:07.115	-0.0522636	0.0052030	0.193	-0.0121661	0.0038021	0.093	-135
2022 SEP 26 23:13:13.855	-0.0547216	0.0054316	0.209	-0.0128730	0.0038870	0.069	-135
2022 SEP 26 23:13:20.595	-0.0572774	0.0056804	0.253	-0.0138094	0.0040068	0.003	-135
2022 SEP 26 23:13:27.335	-0.0606322	0.0059652	0.209	-0.0145692	0.0040956	0.002	-135
2022 SEP 26 23:13:34.075	-0.0636542	0.0062829	0.278	-0.0152627	0.0041996	0.036	-135
2022 SEP 26 23:13:40.815	-0.0676117	0.0066426	0.261	-0.0160550	0.0043035	0.070	-135
2022 SEP 26 23:13:48.518	-0.0729274	0.0070904	0.218	-0.0181444	0.0045789	-0.123	-135
			Mean=0.22			**Mean= 0.05**	

Solution 542

Estimated parameters:

Estimated parameters:

```
Lambda  = 3.100061591142521137 95e+02 +/- 2.825851655841300047 46e+00 degrees (Pole Lon.)
Beta    = -8.061424418232451216 68e+01 +/- 4.696061725706628942 06e-01 degrees (Pole Lat.)
QR      = 1.183500536057438434 77e+00 +/- 1.610743486133507651 47e-02 km
Per     = 11.921492881148498810 26203 +/- 1.593293878759712153 22e-05 h
Ndot    = 4.802655667393600140 49e-18 +/- 6.440228588551389181 14e-19 rad/s^2
DVR     = 3.501469060143060639 94e-07 +/- 3.850374565022038708 56e-07 km/s
DVT     = -2.648995434585680213 88e-06 +/- 4.484541841176998924 88e-08 km/s
J2      = 1.068240225094667095 18e-01 +/- 4.160007735515121318 76e-03
a       = 9.078357180334006848 45e-02 +/- 3.138285739880818710 91e-03 km (Dimorphos)
b       = 6.931993295241058172 80e-02 +/- 2.373639020995064064 65e-03 km (Dimorphos)
c       = 6.130909543518109350 30e-02 +/- 4.337830375589595000 02e-03 km (Dimorphos)
dragA   = 3.581250366161772157 34e-14 +/- 3.636168187979527726 90e-14 rad/s^2
dragTau = 1.252210364367273598 42e+01 +/- 7.209241011811408306 19e+00 days
primx   = 3.916747844014476509 50e-01 +/- 1.122183170564853942 06e-02 km (Didymos equ. radius)
primz   = 2.919484827380627312 01e-01 +/- 1.287471121756925303 28e-02 km (Didymos polar radius)
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A priori constraints:
1) J2 = 0.094 ± 0.009,
2) DVR = 0.4 ± 0.4 mm/s,
3) a = 89 ± 5 m
4) c = 58 ± 5 m
5) prim_xy = 404 ± 20 m
6) prim_z = 295 ± 20 m

Note: A priori values: A priori on J2 is from Didymos shape. A priori on a and c are from Daly et al. (2023) but allow for reshaping with the volume constrained to within 10% of the Daly et al. (2023) value of 0.00181 km^3.

Solution 542

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Derived parameters:
P+(t= ∞) = 11.36755203319325069344359 +/- 3.281719309802387410 21e-04 h
DP(t= ∞) = -3.323645087731488700 91e+01 +/- 1.960859098944136430 51e-02 min
LPdot    = 6.626700000000127488 42e+00 +/- 2.415056151823012364 77e-01 deg/day (Apsidal precession)
GM       = 3.489612098756402683 54e-08 +/- 1.436808198083959949 74e-09 km^3/s^2
Vol_sat  = 1.616139769911544834 74e-03 +/- 1.265544122976440999 30e-04 km^3
RHO      = 2.763122512275878307 26e+03 +/- 1.302286496689614523 35e+02 kg/m^3
ATau     = 3.874589705579211330 36e-08 +/- 1.779502393052360736 10e-08 rad/s
a/b      = 1.309631558150303964 89e+00 +/- 2.078217770846415603 24e-03
a/c      = 1.480752099813979594 24e+00 +/- 1.324543417261305477 96e-01
b/c      = 1.130663117117735483 32e+00 +/- 1.010210074102762256 58e-01
QR/primx = 3.021640869391295503 02e+00 +/- 8.020750407090307398 94e-02
```
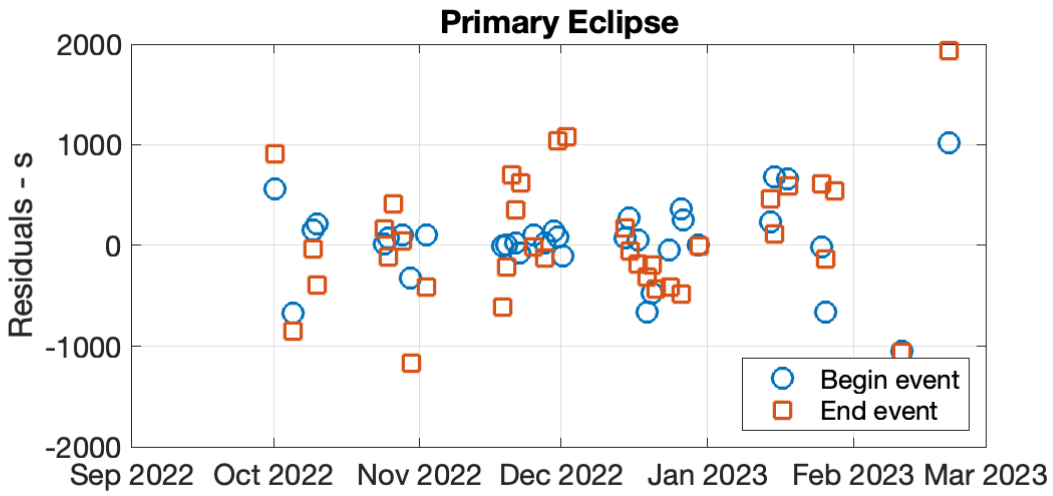
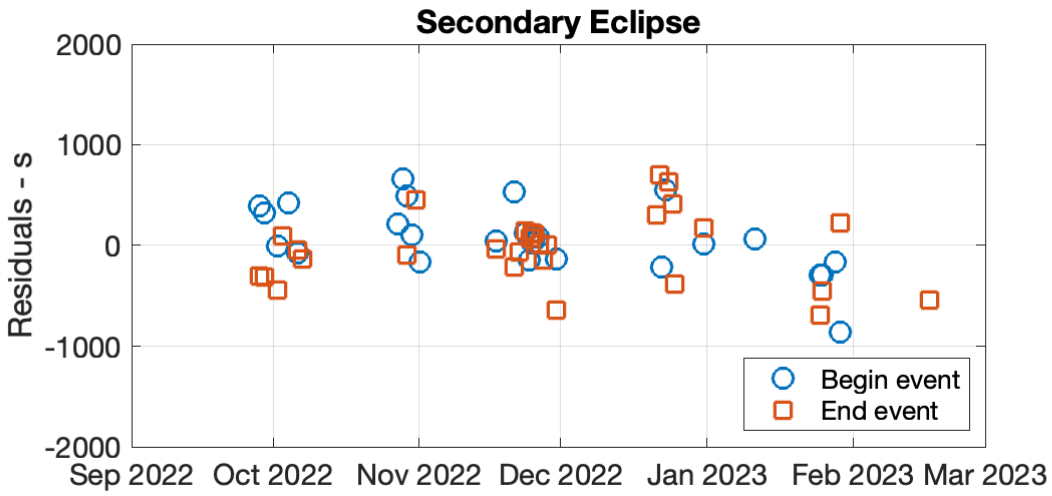
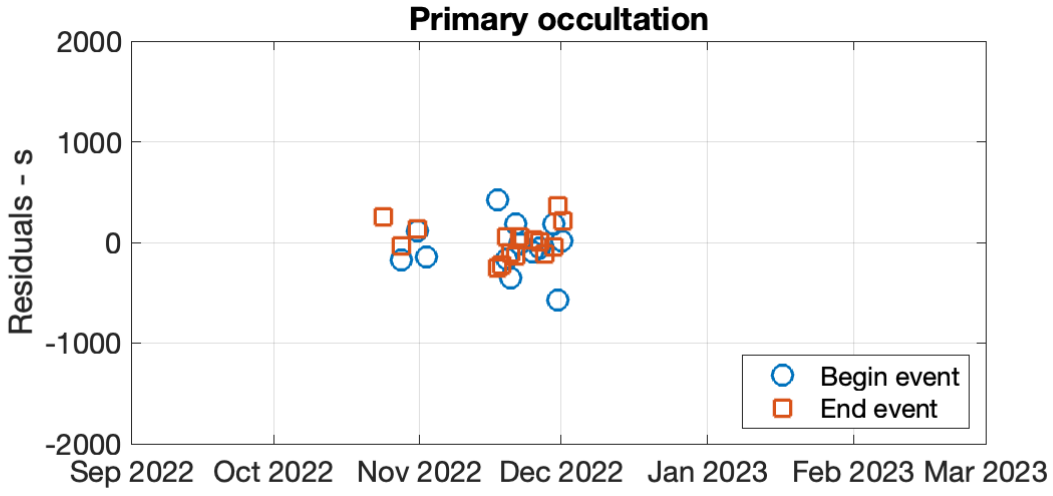
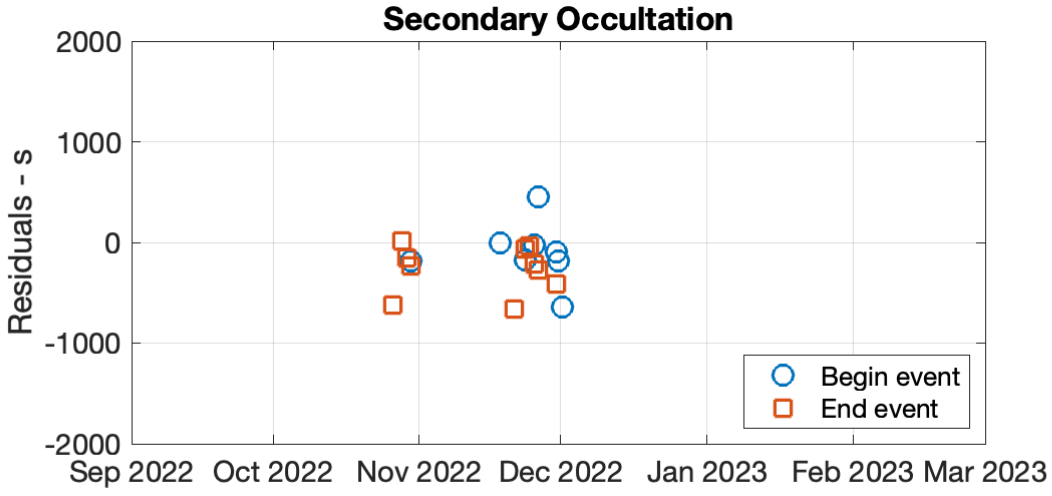

Residuals by event types

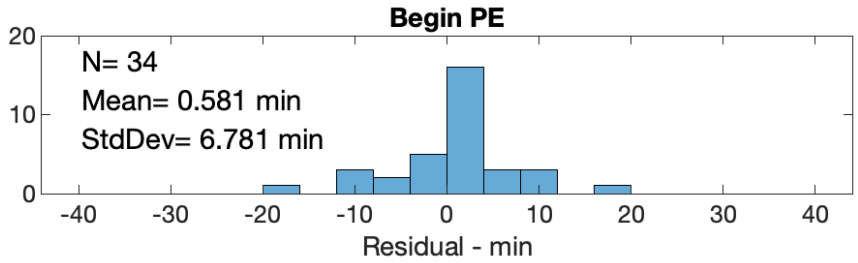


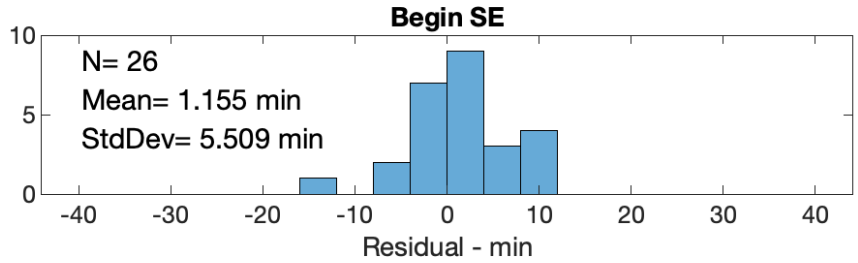


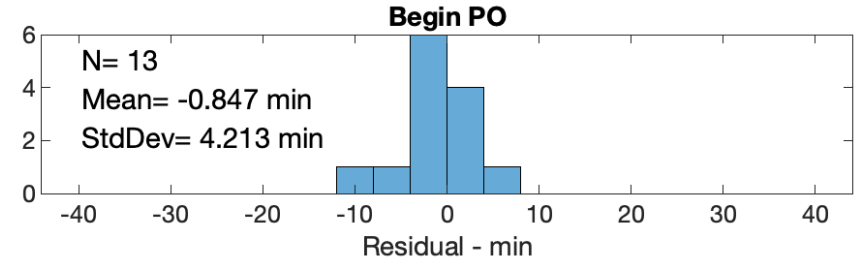


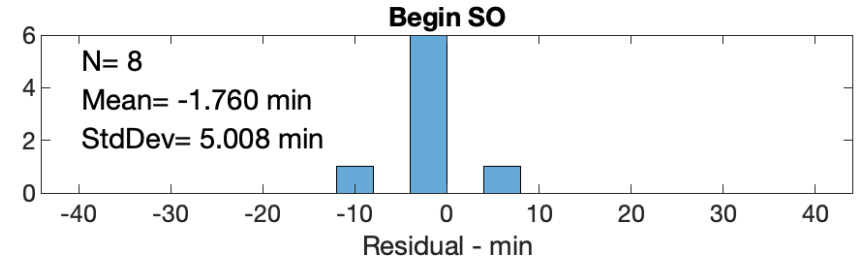


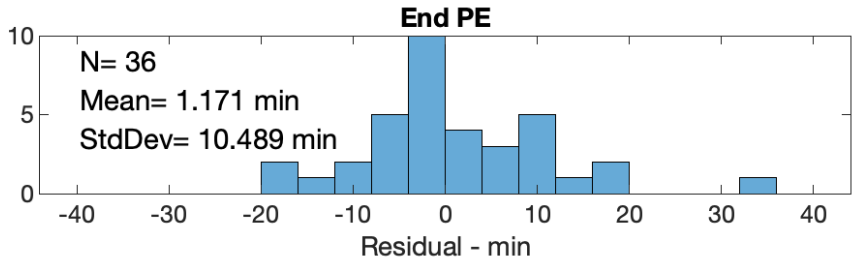
Residuals histograms by event type

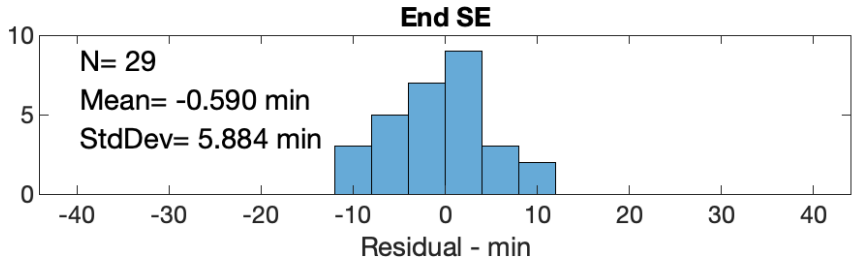


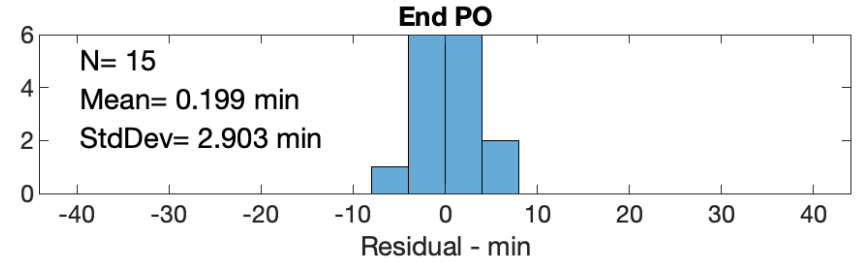


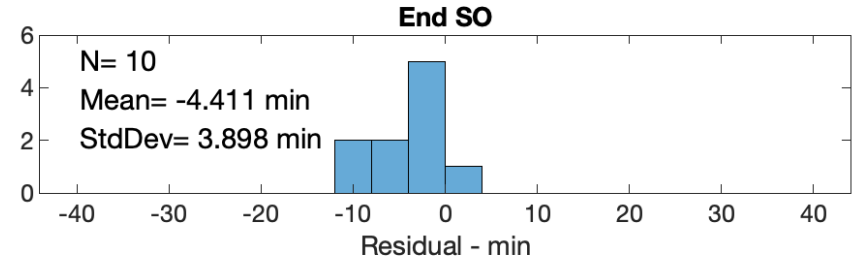






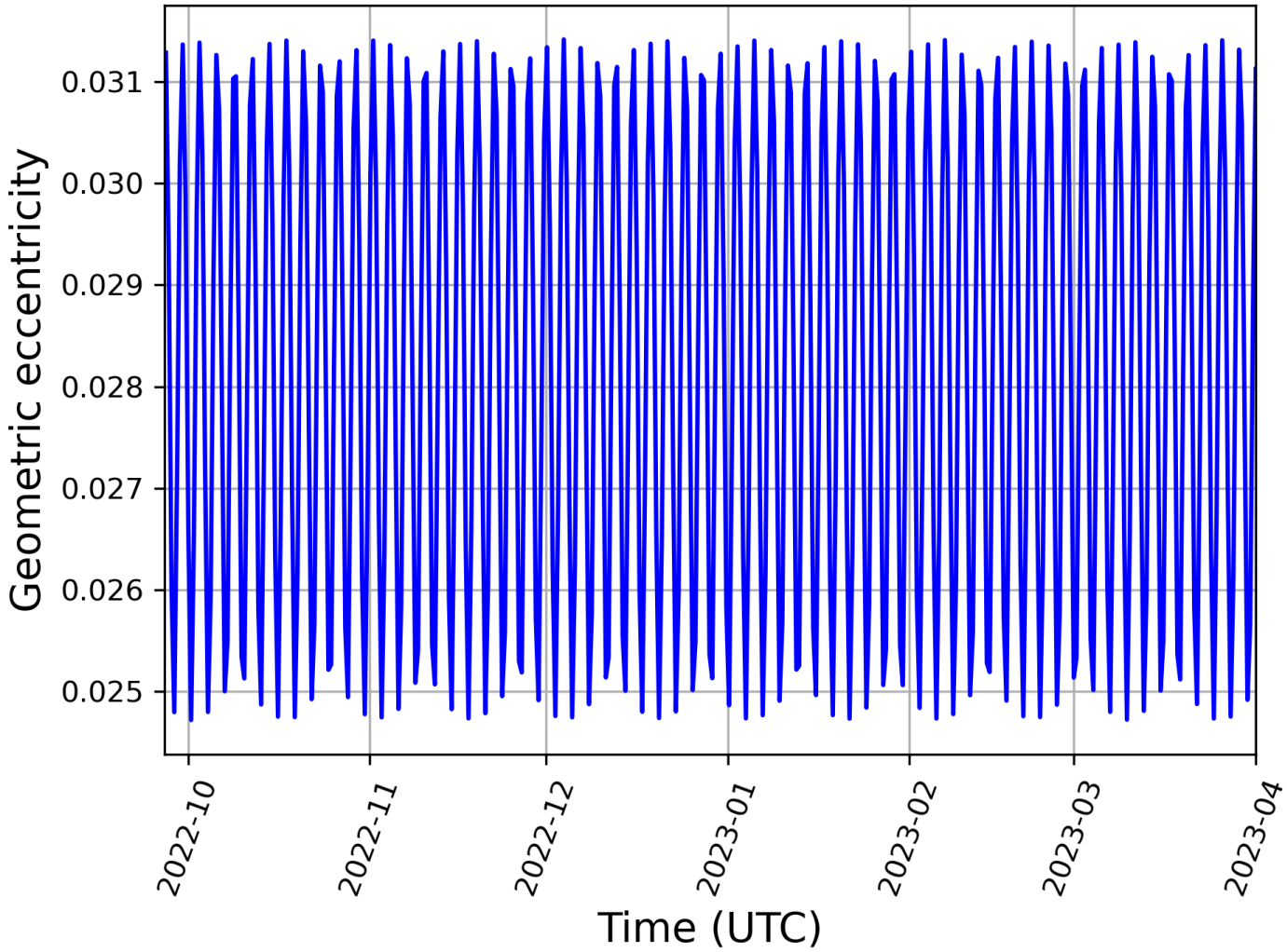






Geometric eccentricity

- Mean ~ 0.028
- Doesn’t change with time



Discussion (Didymos size estimates)

- The primary dimensions (425×425×310 m) from Daly et al. (2023) are not compatible with the OpNav and mutual event data.
- The dimensions presented by Palmer (at the May team meeting?) of 405×388×293 m m (*equatorial mean 397 m*) are more consistent with our estimates, but still seem too large.
  - Sept. 18 email from Barnouin reports slightly larger 409×398×295 m (*equatorial mean 404 m*), ~95% of Daly dimensions
- Naidu et al. (2020) radar shape modeling estimates give a mean equatorial extents of 396 ± 12 m. This is consistent with Palmer/Barnouin within 1 sigma.
- Our (unconstrained) best fit has Didymos at 380×380×292 m, about 90% of Daly's equatorial values
  - Note perfect match to Palmer and Barnouin in polar radius.
- Our current best solution constrains the Didymos size to the Barnouin numbers ±10m
  - **Final size from lightcurves and OpNavs 392×392×292 m with uncertainties 11×11×13 m**
  - This essentially splits the difference between the OpNav-based and Palmer/Barnouin equatorial sizes

Discussion (Other parameters)

- Precession rate estimate of 6.6 ± 0.2 deg/day is consistent with the estimate of Scheirich et al. (2023, in prep.) of 7.3 ± 0.7 deg/day.
- Density estimate of 2760 ± 130 kg/m^3 is consistent with the latest DRA value of 2950 ± 300 kg/m^3.
  - This value uses both the estimated GM and the estimated volume (of both bodies), and so is internally consistent.
- New pre-impact semimajor axis estimate of 1.184 +/- 0.016 km is consistent with the Thomas et al. (2023) value of 1.206 ± 0.035 m within 1.1 sigma.
  - Also with the Naidu et al 2020 value of 1190 ± 30 m.
- Current ratio of semimajor axis to Didymos diameter of 1.51 ± 0.04 is consistent with the value of Scheirich et al. (2023, in prep.) of 1.46 ± 0.04 within 1 sigma.

Delivery

- https://ssd.jpl.nasa.gov/ftp/eph/small_bodies/dart/dimorphos/
- SPK file: ‘dimorphos_s542.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.
- PCK file: ‘dimorphos_s542-preimpact.tpc’
  - Describes the orientation of Dimorphos.
  - Valid for times prior to the DART impact at 2022 SEP 26 23:14:24.183 UTC