Measurability of the heliocentric momentum enhancement of the Didymos system from the DART impact

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INTRODUCTION

The Asteroid Impact and Deflection Assessment (AIDA) collaboration was created to demonstrate the viability of the kinetic impactor concept for deflecting potential earth impactors. AIDA consists of two missions, ESA's Hera spacecraft and NASA's Double Asteroid Redirection Test (DART) spacecraft [1,2]. The DART spacecraft impacted Dimorphos, the secondary component of the (65803) Didymos binary asteroid system on 26 September 2022 and reduced its mutual orbital period (Fig. 1). The primary consequence of the DART mission from a planetary defense perspective is the change to the mutual orbital period of Dimorphos around Didymos. However, there is also a change in the heliocentric motion of the system barycenter. Here, we present our latest results on the measurability of this heliocentric orbit change.

Fig. 1: Artist's illustration of DART headed for impact onto Dimorphos.

METHODS & RESULTS

Before the Didymos system is propagated in time, the momentum imparted onto the barycenter by the escaping ejecta needs to be analyzed (Fig. 2). In order to do this, impact scaling laws are used to determine the mass-velocity distributions of ejecta particles as they are kicked off the asteroid's surface. The subset of these particles that cross the system's Hill sphere are escaping particles, and the momentum they carry at the time of crossing the Hill sphere is the momentum that is imparted onto the Didymos system barycenter. The ratio between this cumulative escaping ejecta momentum and the DART spacecraft momentum at impact can be used to calculate the heliocentric momentum enhancement parameter,

$$\beta_{\odot} = 1 + \frac{p_{ejecta}}{p_{DART}}$$

Modeling the impact $\beta_{\odot}$ and propagating it to future Didymos-Earth close approaches can give us the deflection on the B-plane [3]. Therefore, a $\beta_{\odot}$ measurement can be used to directly characterize the heliocentric changes in the system, we take Didymos observations and pass them through a least squares filter to see if this is currently possible. Figures 4 and 5 show the prefit and postfit residuals for this orbit fit.

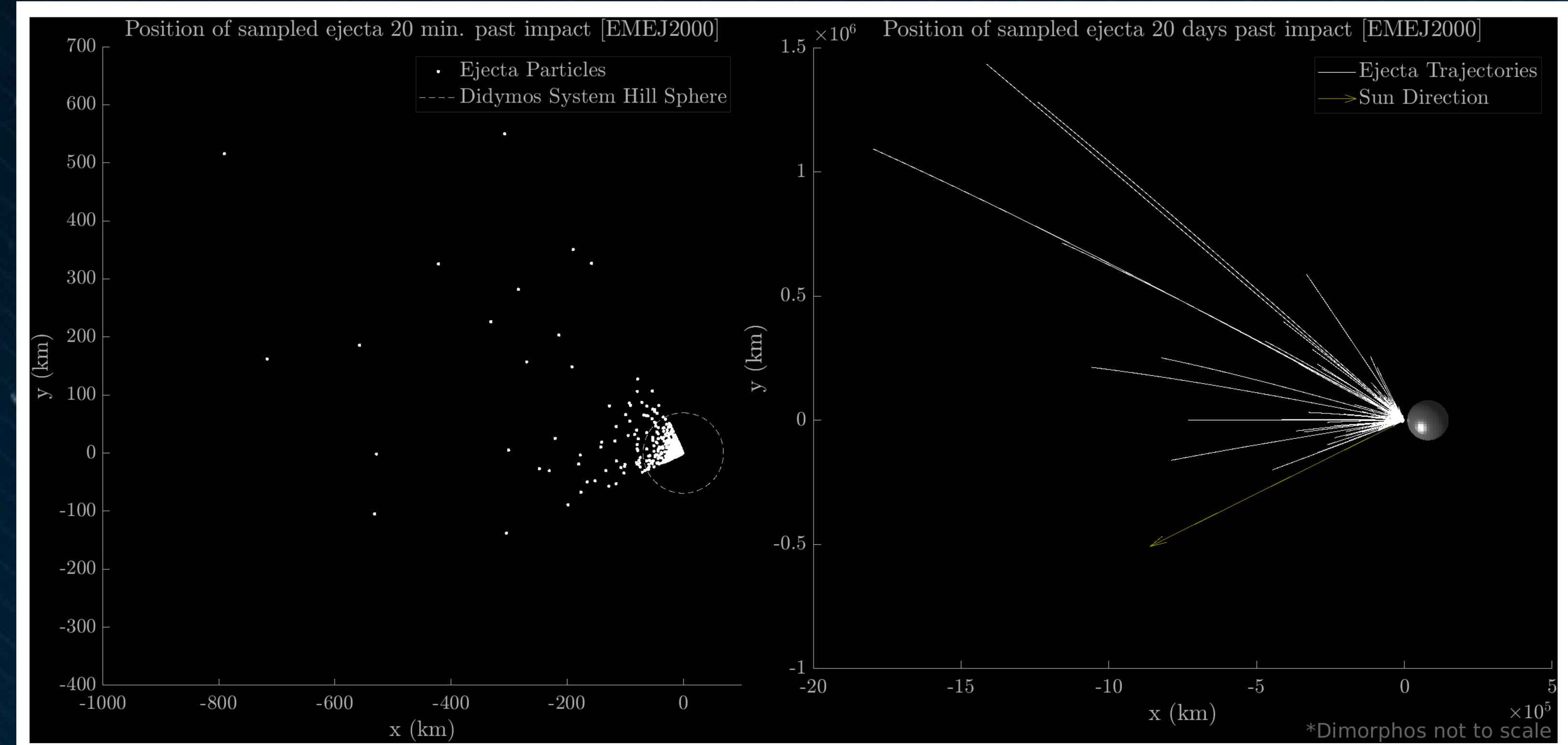

Fig. 2: Simulated ejecta particle positions after 20 min (left) and 20 days (right).

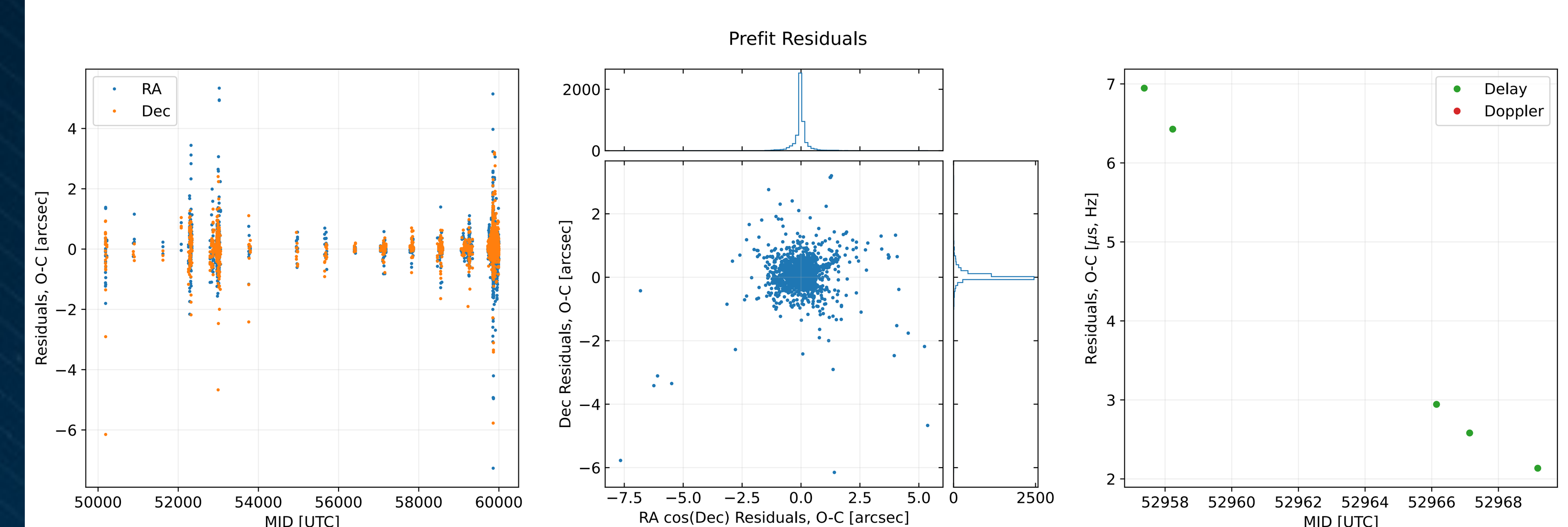

Fig. 4: Prefit residuals for (65803) Didymos observations until 15-Mar-2023

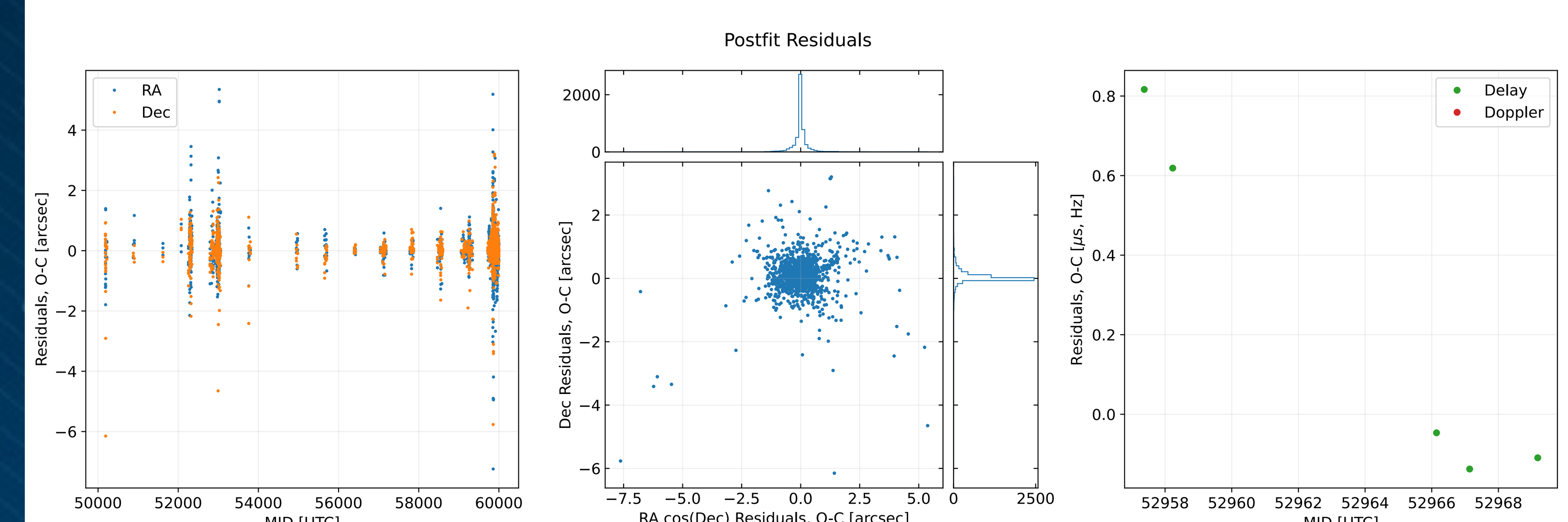

Fig. 5: Postfit residuals for (65803) Didymos observations until 15-Mar-2023

Trying to extract information about $\beta_{\odot}$ from presently available observations is not possible because of the relatively short post-DART impact arc. Therefore, we generate synthetic observations for the system barycenter with Gaussian noise and an assumed $\beta_{\odot}=3$ in the anti-DART direction.

The filter is then able to fit $\beta_{\odot}$ in addition to the state of the barycenter and the A_2 transverse nongravitational acceleration parameter representing the contributions from the Yarkovsky effect. This A_2 parameter is currently estimated to be -1.06e-14 from from JPL Solution 203 [4]. The different scenarios use observations from the Minor Planet Center (MPC) until 15 March 2023 along with a combination of stellar occultations, ground-based radar, and Hera pseudo-range measurements as described in Table 1.

Table 1: $\beta_{\odot}$ estimation results ("true" $\beta_{\odot}$ = 3, "true" A_2 = -1.06e-14)

Observation Scenario	$\beta_{\odot}$ estimate	$\beta_{\odot}$ uncertainty (1σ)	A_2 estimate	A_2 uncertainty (1σ)
All MPC observations until 15-Mar-2023 + 4 post-impact delay observations (Sep-22/Oct-22) [Current Obs.]	-	-	-	-
Above + 4 occultations (Oct-22/Nov-22/Dec-22/Jan-23)	-	-	-	-
Above + 2 Hera pseudo-range (Feb-27/Jun-27)	2.96	0.53	-1.07e-14	1.51e-15
Current Obs. + 7 occultations (Oct-22/ Nov-22/Dec-22/Jan-23/Jul-23/Jan-24/Jul-24)	4.28	0.99	-0.97e-14	3.09e-15
Above + 2 occultations (Feb-27/Jun-27)	3.31	0.95	-1.10e-14	3.03e-15

CONCLUSIONS & FUTURE WORK

The heliocentric changes to the (65803) Didymos system can be characterized using a momentum enhancement parameter, $\beta_{\odot}$. The measurability of $\beta_{\odot}$ is explored in this work. Results from current observations of the system indicate that the post-impact observation arc is currently too short. However, stellar occultations and spacecraft pseudo-range observables are highly accurate measurements that provide significant information about the observed body. Using these two types of synthetic observations, we find that $\beta_{\odot}$ can be estimated within 1.5σ before the launch of the Hera spacecraft using biannual stellar occultations in 2023 and 2024. Additional occultations can bring this estimate to about 0.3σ but pseudo-range measurements using the Hera spacecraft bring the estimate down to 0.1σ. Future work will combine real pre-impact observations with synthetic post-impact observations to refine the epoch, number and type of measurements needed to measure $\beta_{\odot}$.

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