Change in the mutual orbit of Dimorphos due to the DART impact

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Jet Propulsion Laboratory, California Institute of Technology

Launch

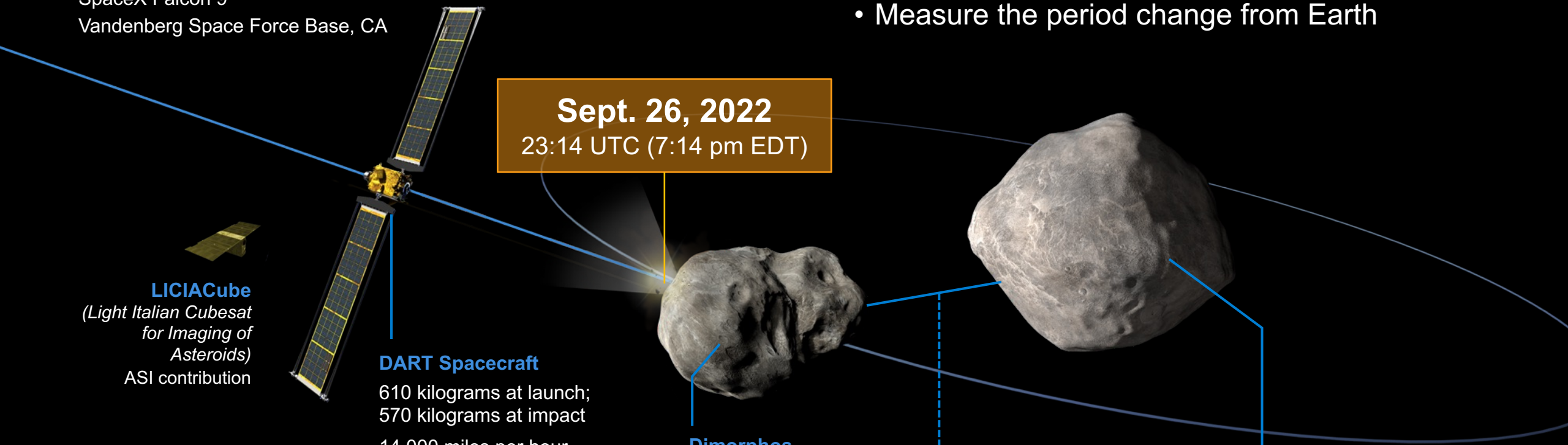
Nov. 24, 2021

SpaceX Falcon 9

Vandenberg Space Force Base, CA

- Planetary defense demonstration
- Target the binary asteroid Didymos system
- Impact Dimorphos and change its orbital period
- Measure the period change from Earth

Sept. 26, 2022
23:14 UTC (7:14 pm EDT)



LICIACube
(Light Italian Cubesat for Imaging of Asteroids)
ASI contribution

DART Spacecraft

610 kilograms at launch;
570 kilograms at impact

14,000 miles per hour
(6.1 kilometers per second)

Dimorphos

150 meters
11.92-hour orbital period

1,200-meter separation between centers

Didymos

760 meters
2.26-hour rotation period

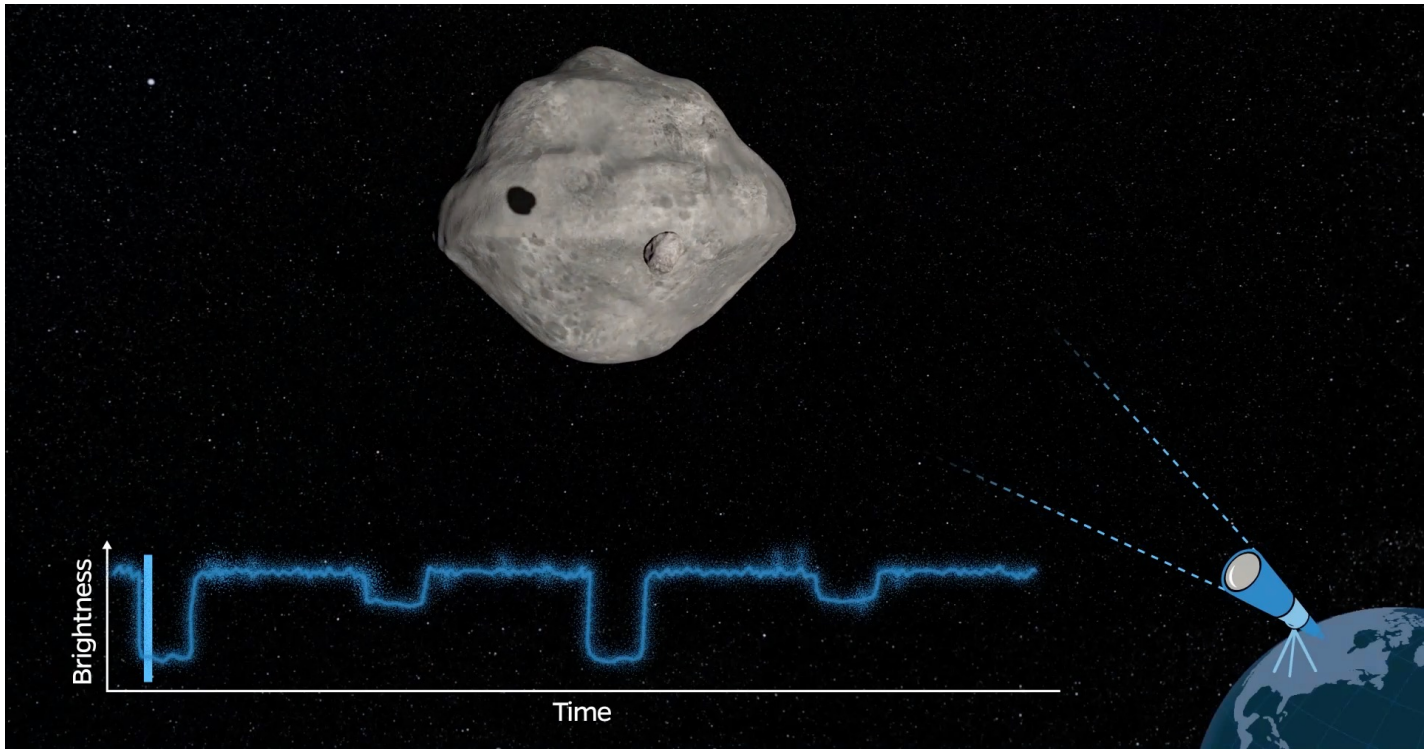
Earth-Based Observations

7 million miles (0.076 AU) from Earth at DART impact

APL JOHNS HOPKINS APPLIED PHYSICS LABORATORY

Dimorphos pre-impact orbit

- Used the times of eclipses and occultations seen in ground-based photometric observations between 2003-2022
- 3σ position uncertainties were ~80 m at the time of impact
- Published in Naidu et al. (2022)



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Anticipating the DART Impact: Orbit Estimation of Dimorphos Using a Simplified Model

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Dimorphos pre- and post-impact orbit

- We estimated the pre- and post-impact orbit parameters of Dimorphos.
- We used four kinds of observables
  - Optical astrometry from DRACO images
  - Radar Doppler measurements
  - Radar range measurements
  - Eclipse/Occultation times

Data types	Data arc
Mutual event times	2022 Sep 28 – 2023 Feb 21
DRACO astrometry	2 minutes before impact
Doppler	Sep 27 – Oct 13
Range	Oct 04 – Oct 09

Dimorphos orbit model

- Pre-impact orbit:
  - Circular
  - Drift due to binary YORP
- Post-impact orbit:
  - Non-Keplerian
  - Accounts for primary oblateness (J2)
- Estimated Δv of Dimorphos due to the DART impact, J2 of Didymos, other orbit parameters
- Details in Naidu et al. (2022) and Thomas, Naidu et al. (2023)

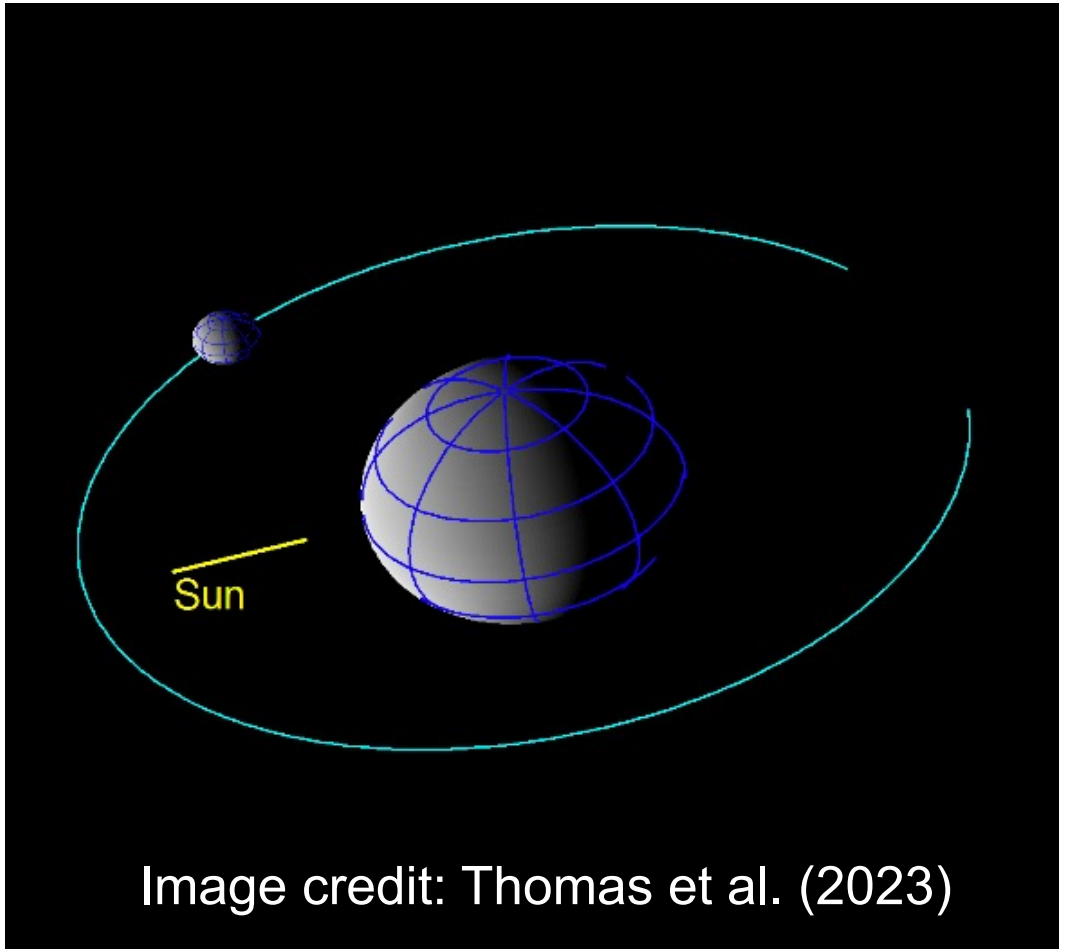
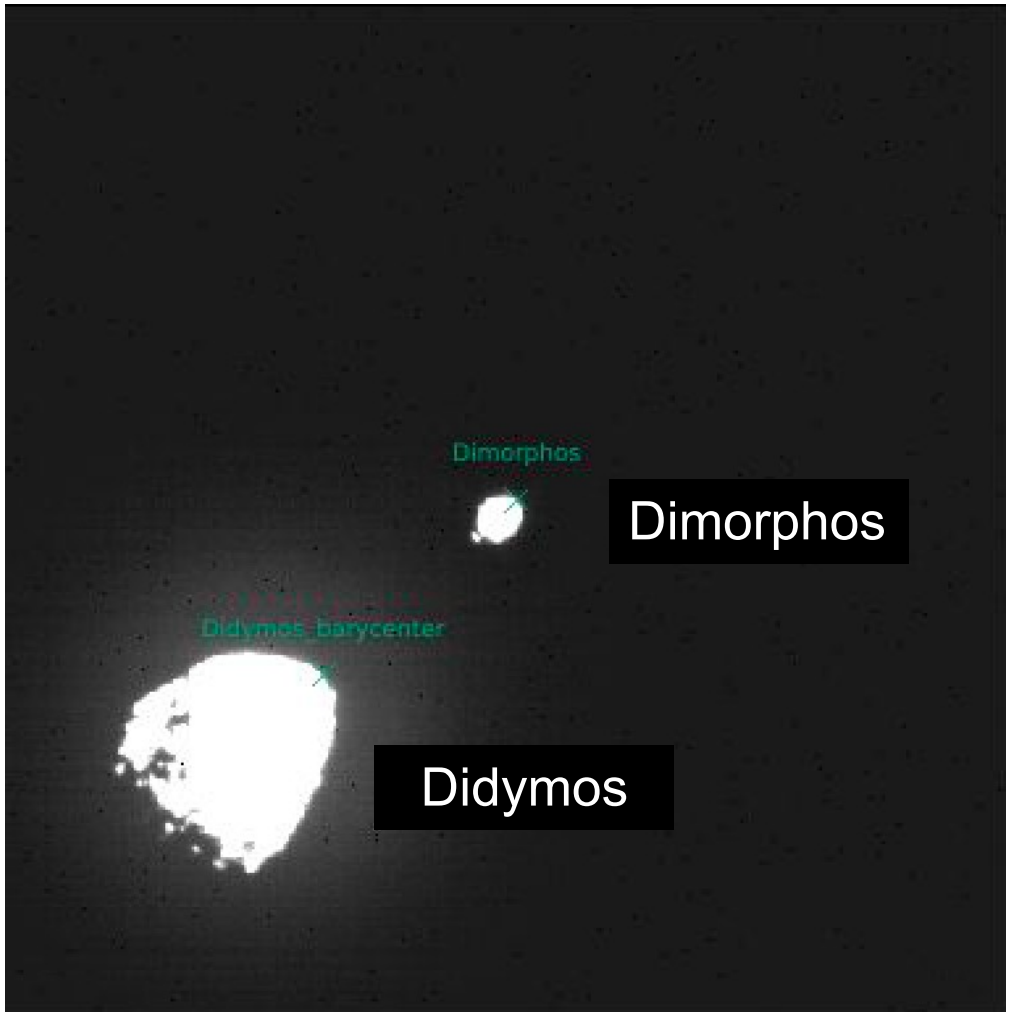


Image credit: Thomas et al. (2023)

DRACO measurements



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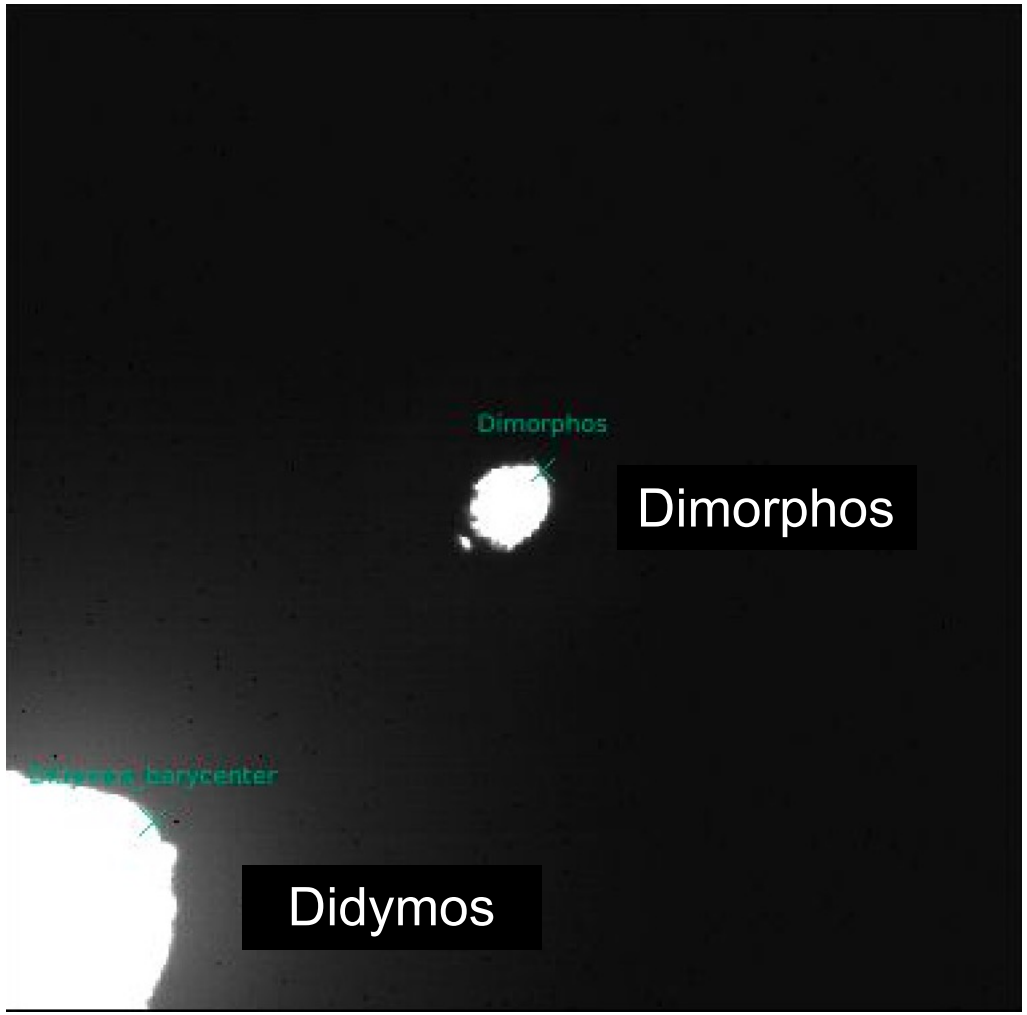

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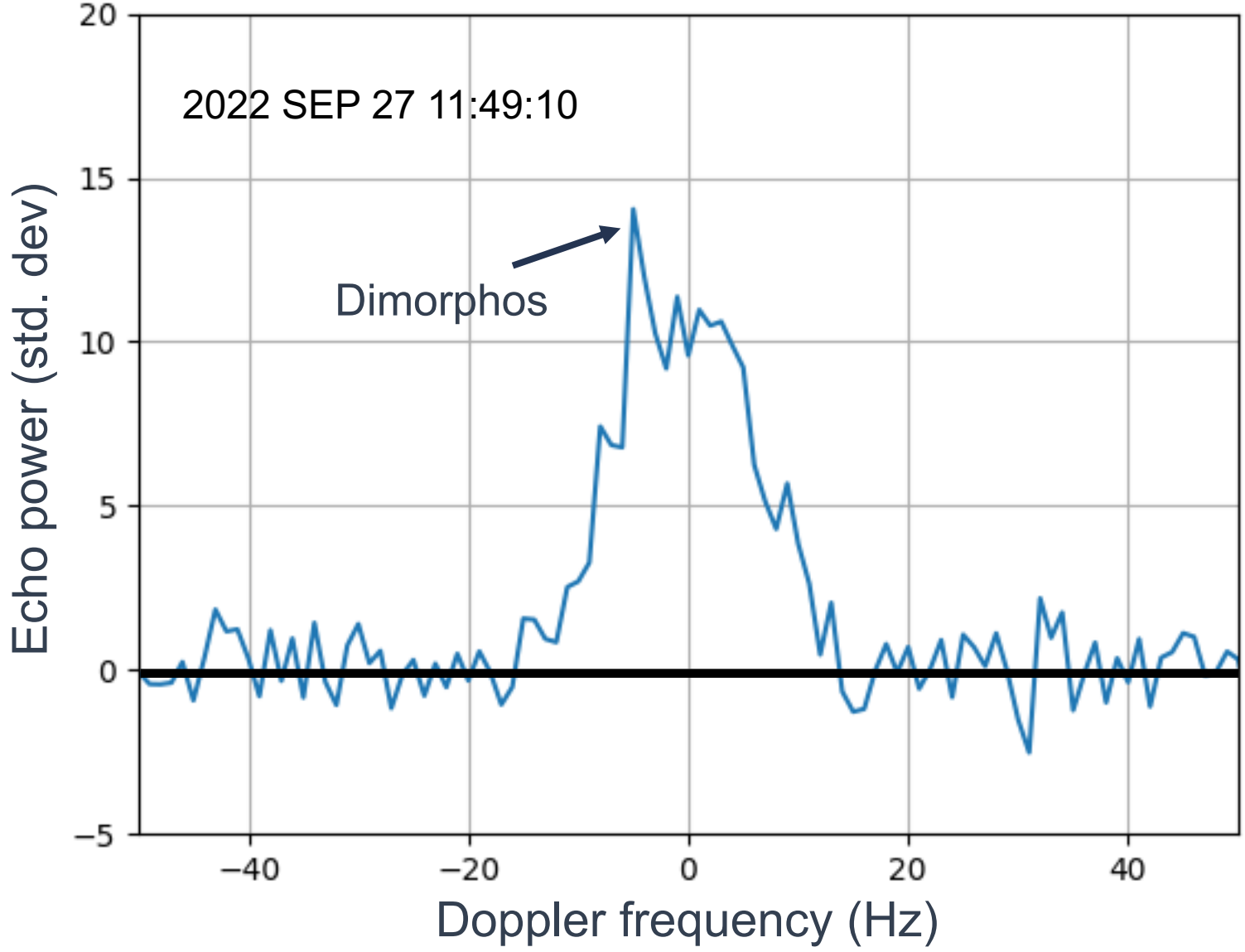
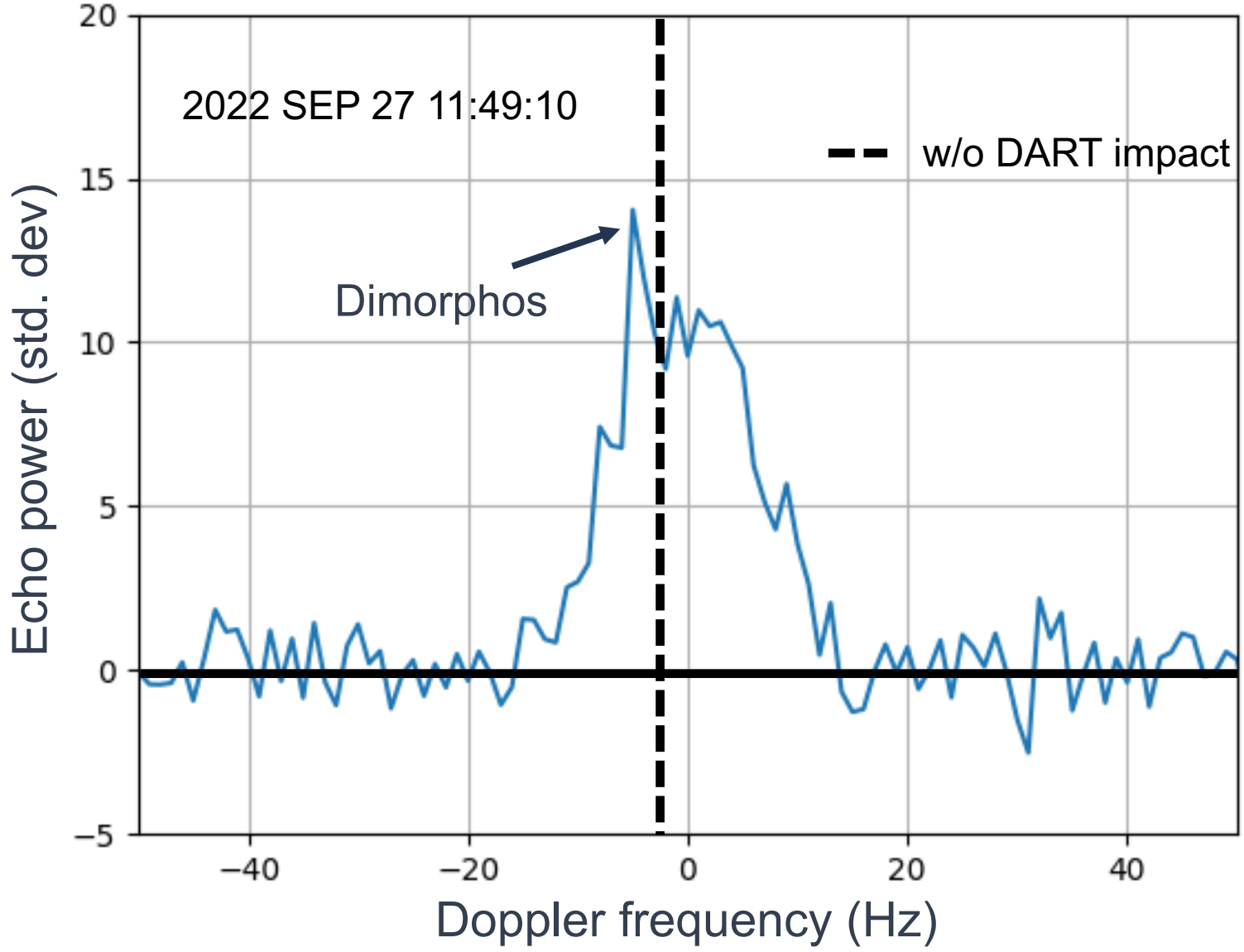
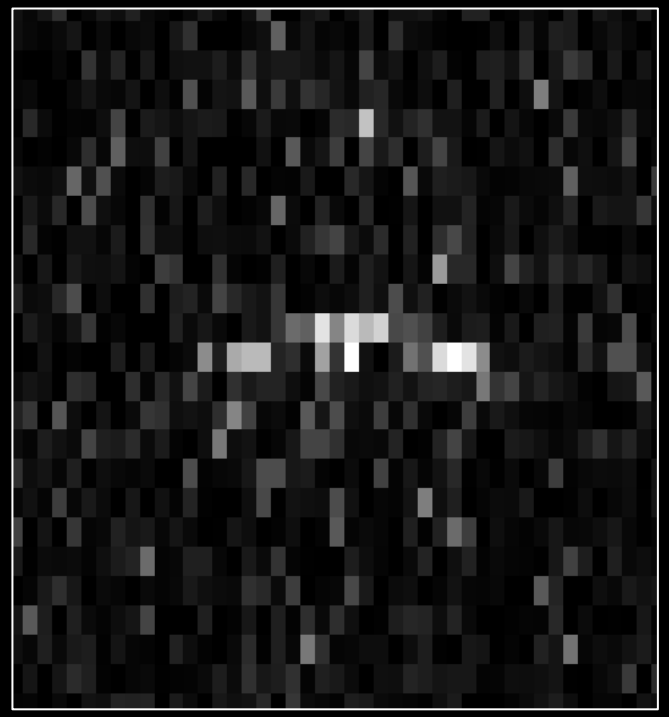
First Goldstone radar detection



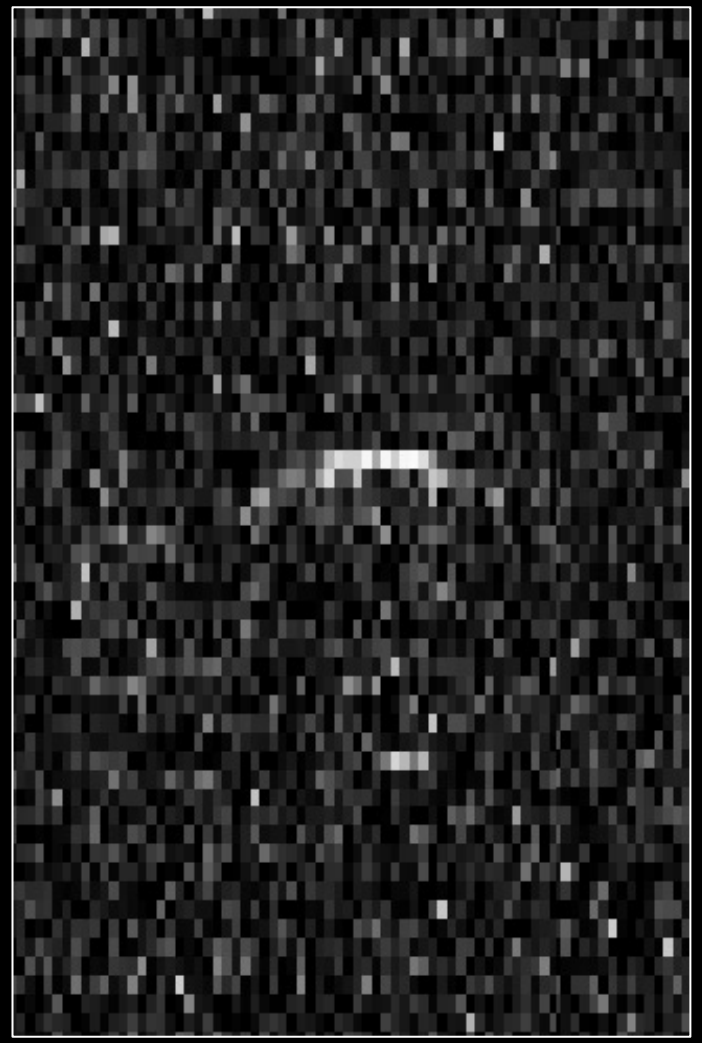
First Goldstone radar detection



Radar imaging of Didymos Of Dimorphos



2022 Oct 04 11:55:39 UTC



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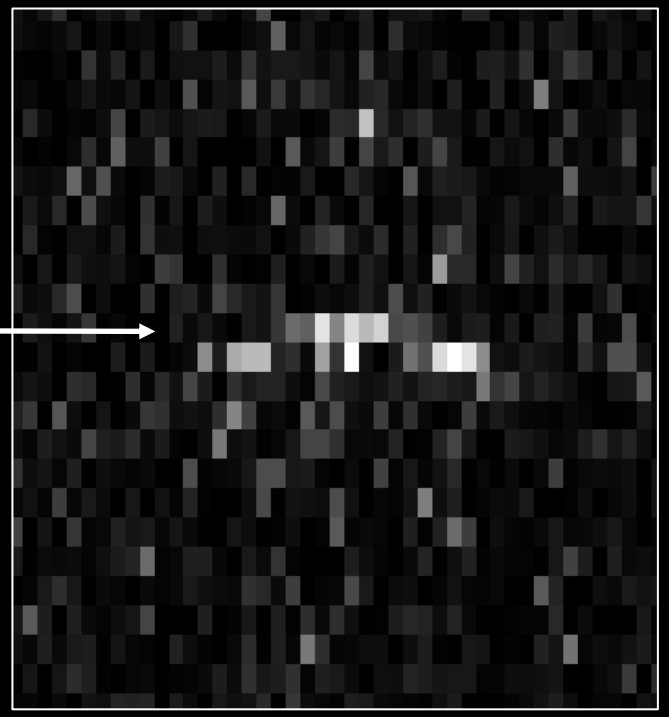
Radar imaging of Didymos Of Dimorphos



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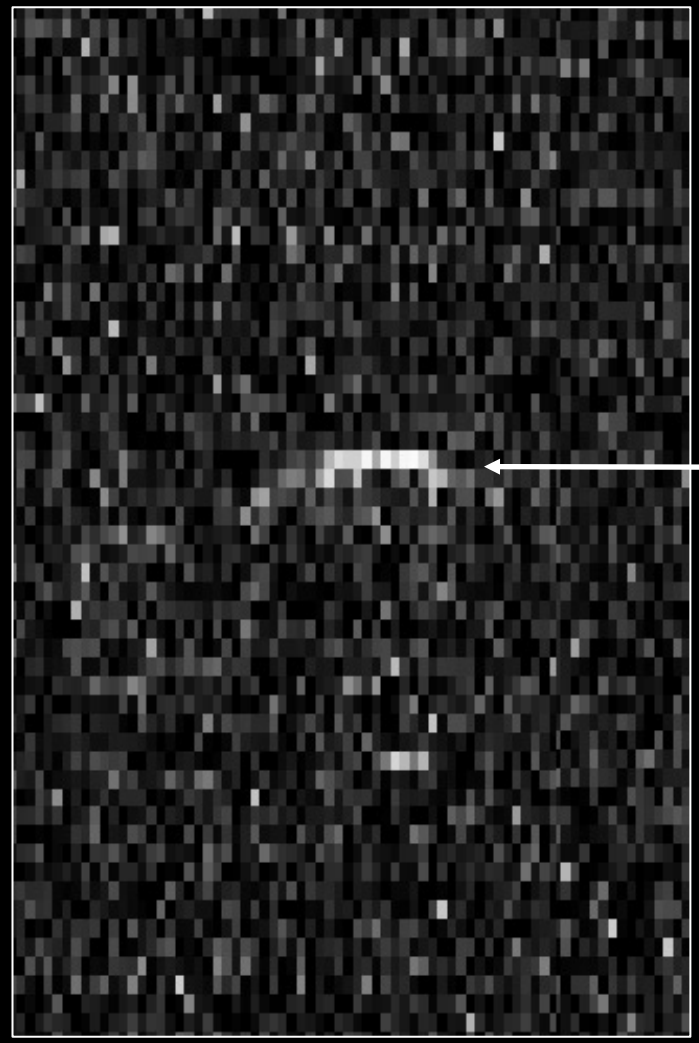

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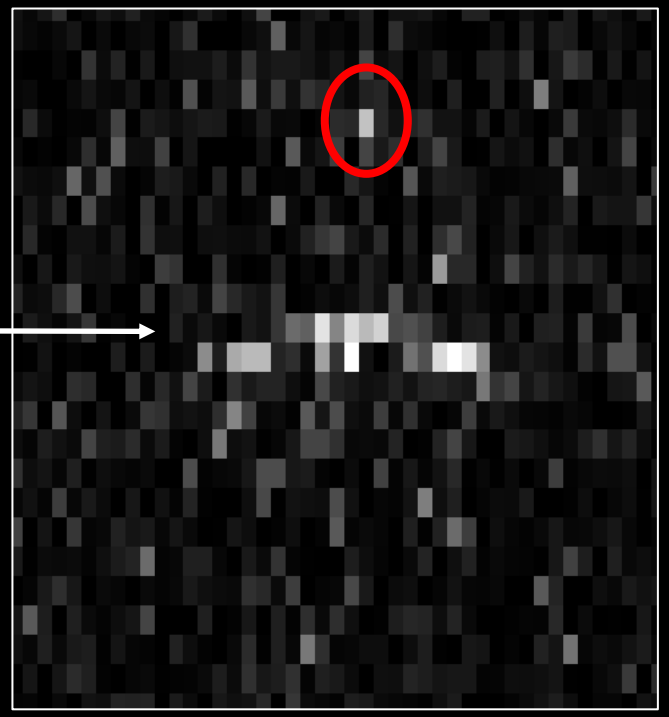
Radar imaging of Didymos Of Dimorphos



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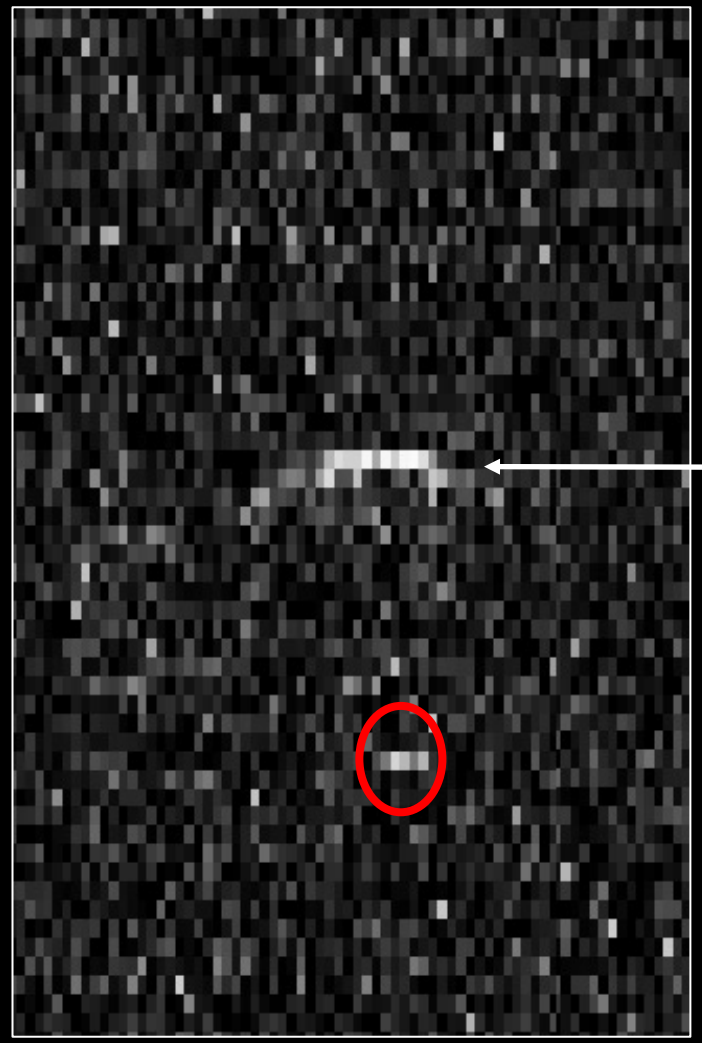

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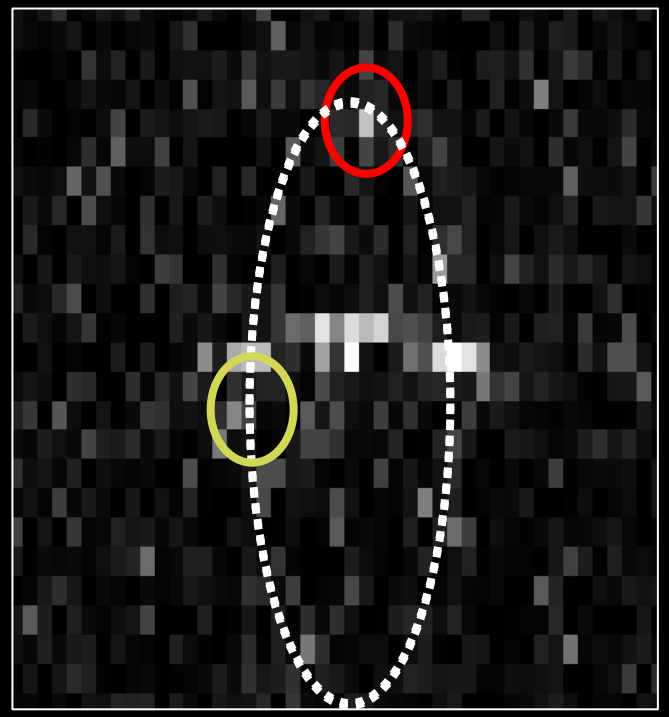
Radar imaging of Didymos Of Dimorphos



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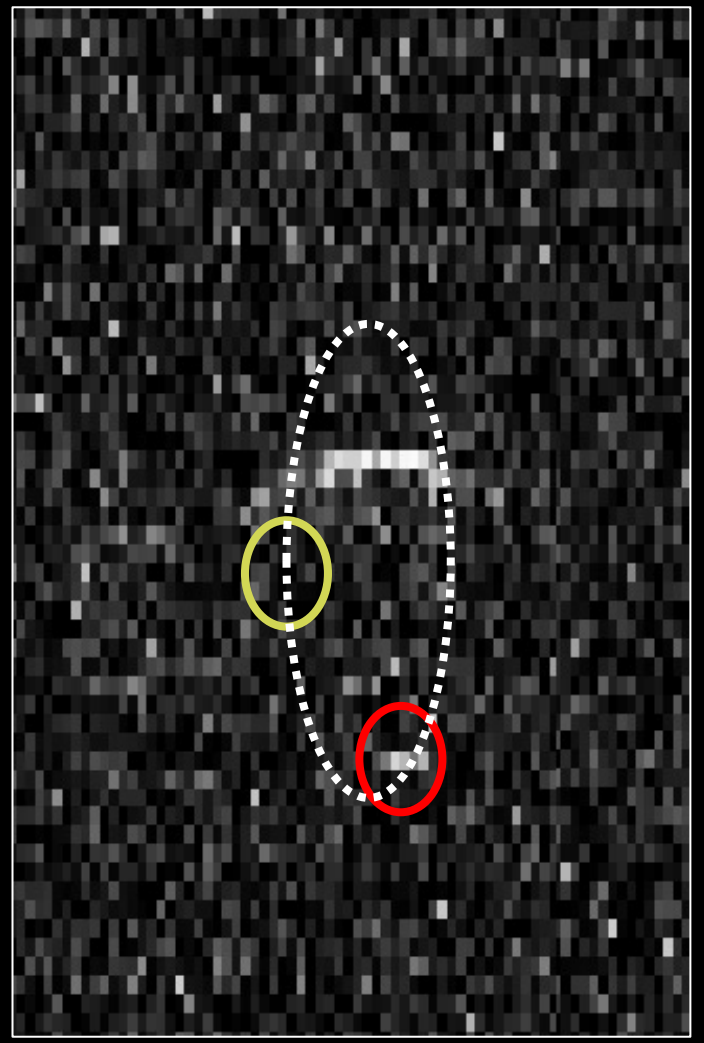


2022 Oct 09 10:56:47 UTC

Observed Dimorphos

Expected Dimorphos from 11 hr 55 min orbit

Dimorphos orbit

Radar imaging of Didymos Of Dimorphos

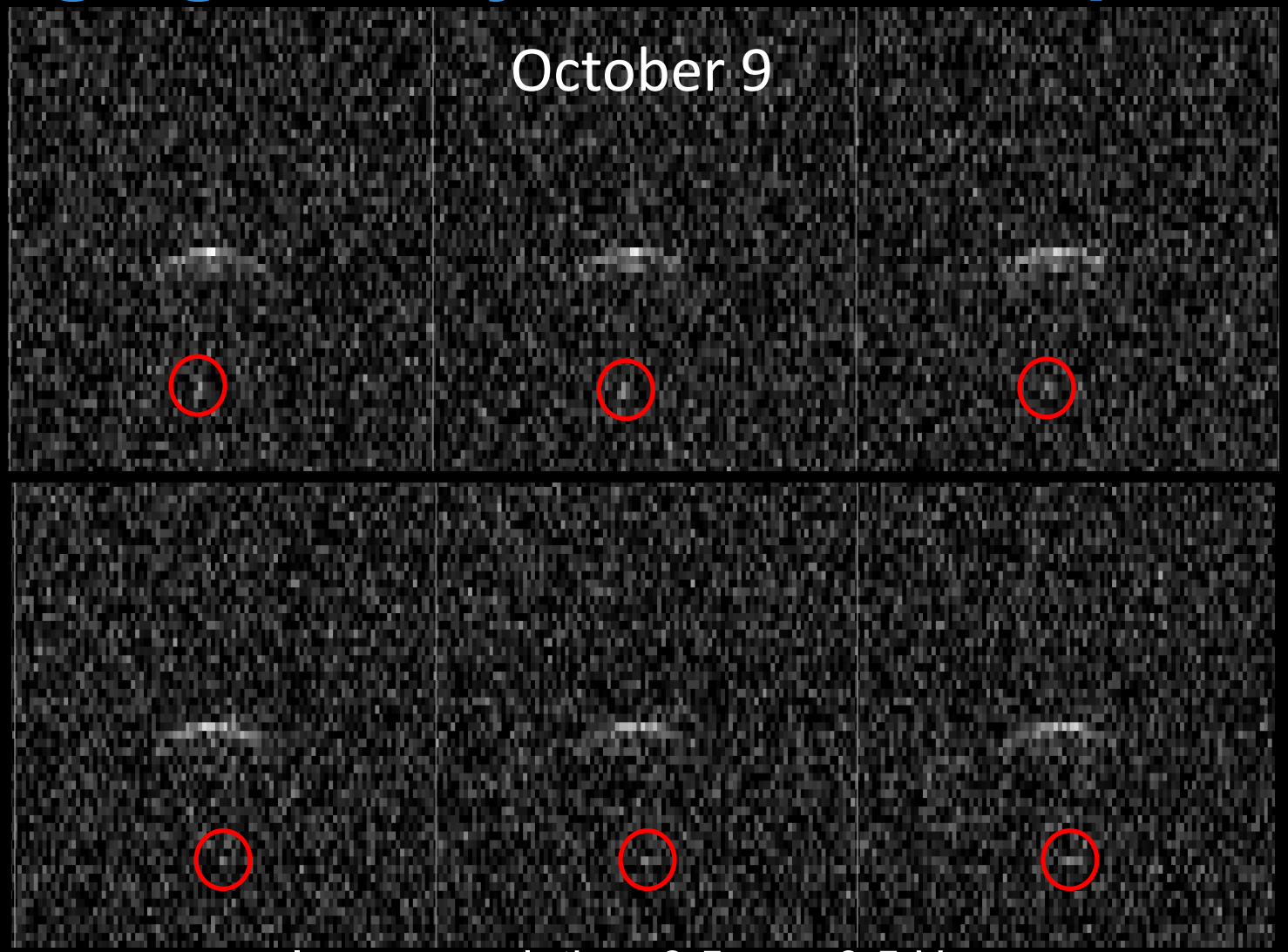
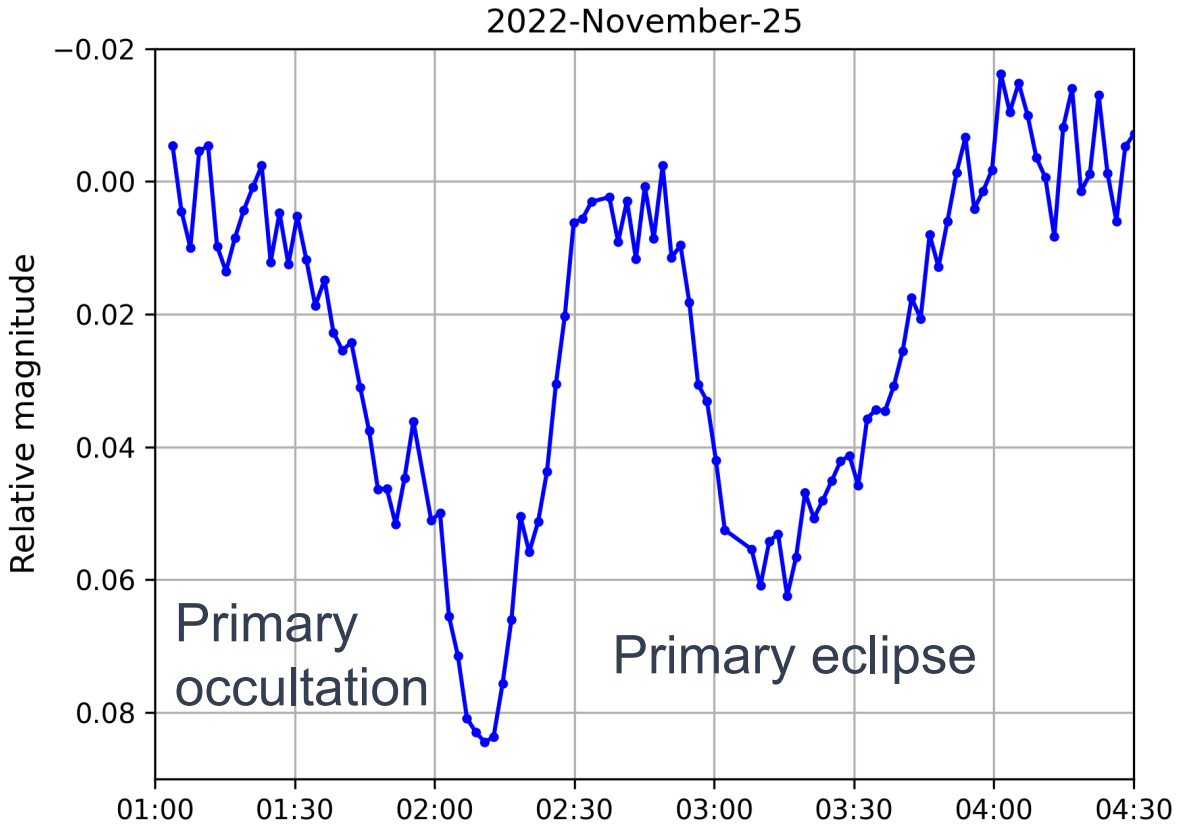


Image resolution: 0.5 μs x 0.5 Hz

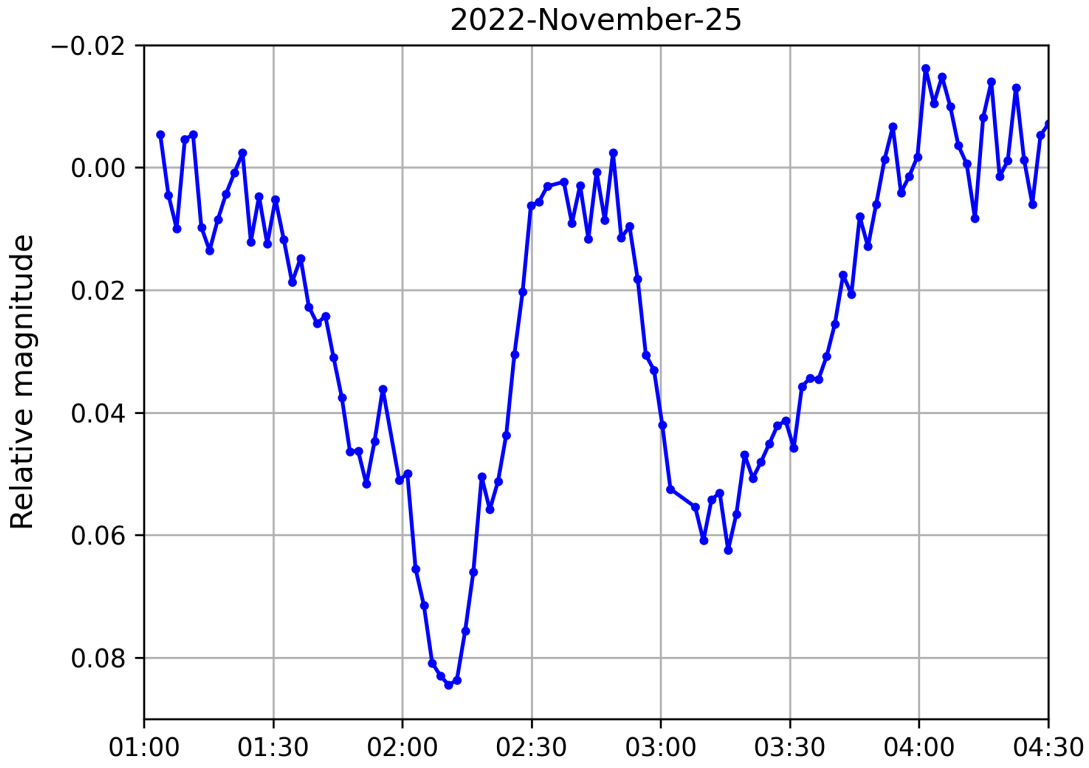
Light curve mutual event times

Four types of events:

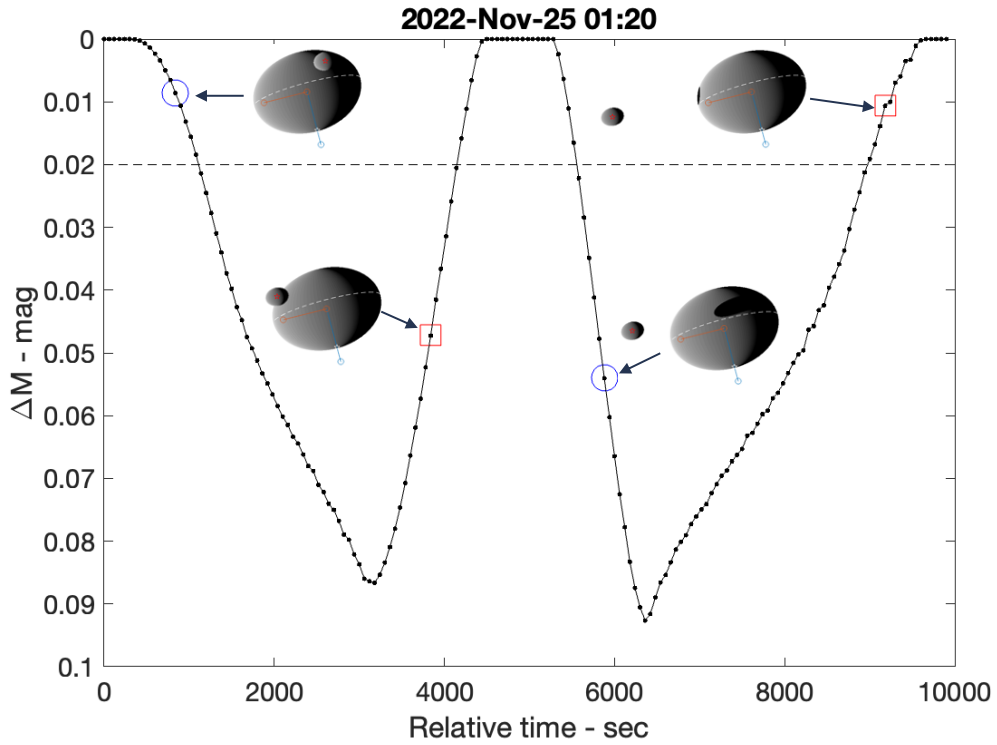
- Primary eclipse
- Secondary eclipse
- Primary occultation
- Secondary occultation



Lightcurve modeling



Observed



Modeled

Best-fit parameters

Parameter	Estimate +/- 1σ uncertainties
Pre-impact semimajor axis (a, km)	1.24 ± 0.02
Pre-impact period (h)	11.92151 ± 0.00002
Rate of change of mean motion ($\dot{n}$, rad/sec^2)	(3.7 ± 0.7) x 10^{-18}
Tangential Δv (mm/s)	-2.9 ± 0.04
Post-impact period (h)	11.369 ± 0.0002
Period change (min)	-33.15 ± 0.02 (0.8 s)
Post-impact eccentricity	0.0247 ± 0.0002
Post-impact apsidal precession (deg/day)	5.8 ± 0.1
Solution epoch (UTC)	2022 Sep 26 23:14:24.183

Summary

- We fit the pre- and post-impact mutual orbit of Dimorphos to DRACO astrometry, lightcurve mutual events, and radar measurements.
- The estimated period change due to the DART impact is -33.15 min +/- 0.8 seconds (formal 1-sigma uncertainties).
- The fit is consistent across all four data types.
- Data obtained until March 2023 will be incorporated into the orbit estimate.