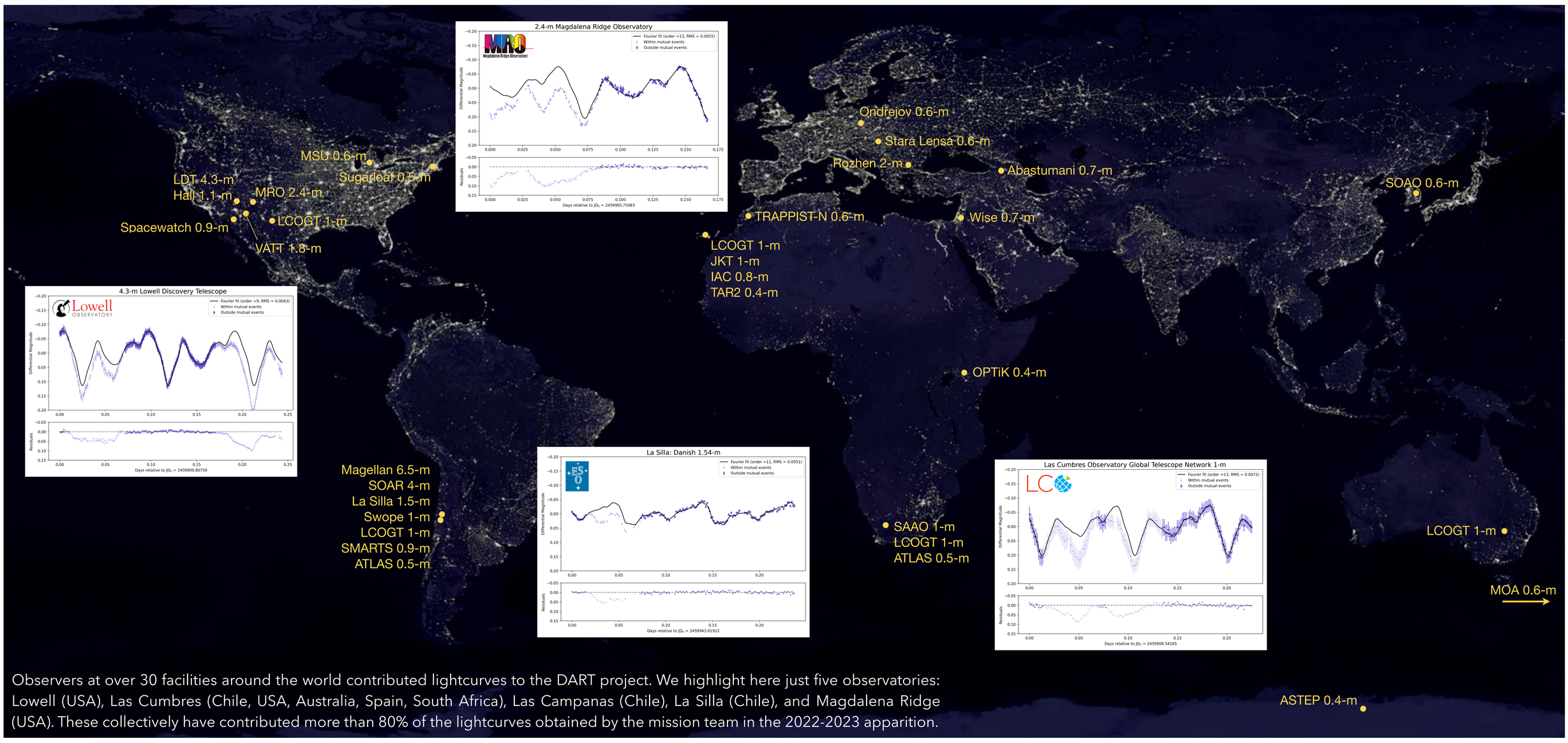
Photometry of Didymos in Support of NASA's DART Mission

Nicholas Moskovitz[1], Cristina Thomas[2], Petr Pravec[3], Shantanu Naidu[4], Steven Chesley[4], Petr Scheirich[3], Tim Lister[5], David Osip[6], Tom Polakis[1], Brian Skiff[1], Teddy Kareta[1], Matthew Knight[7], Tony Farnham[8], Carrie Holt[8], William Ryan[9], Eileen Ryan[9], Carlos Contreras[6], Peter Kušnirák[3], Kamil Hornoch[3], Agata Rożek[10], Colin Snodgrass[10], and the DART investigation team.

[1]Lowell Observatory, [2]Northern Arizona University, [3]Astronomical Institute AS CR, [4]JPL, [5]Las Cumbres Observatory Global Telescope Network, [6] Las Campanas Observatory, [7]US Naval Academy, [8]University of Maryland, [9]New Mexico Institute of Mining & Technology, [10]University of Edinburgh.

DART
Double Asteroid Redirection Test



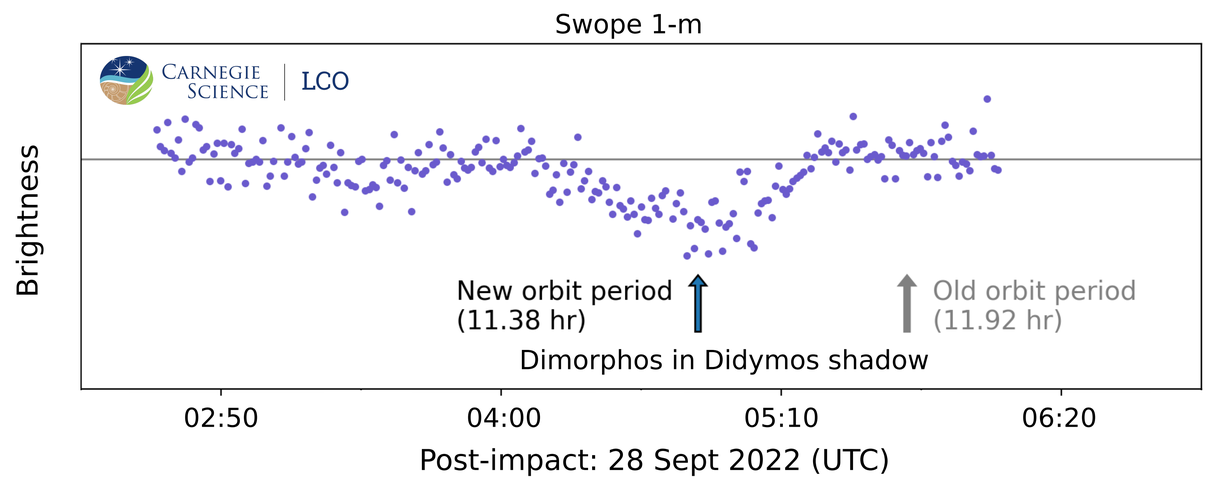
Observers at over 30 facilities around the world contributed lightcurves to the DART project. We highlight here just five observatories: Lowell (USA), Las Cumbres (Chile, USA, Australia, Spain, South Africa), Las Campanas (Chile), La Silla (Chile), and Magdalena Ridge (USA). These collectively have contributed more than 80% of the lightcurves obtained by the mission team in the 2022-2023 apparition.

ABSTRACT On 26 September 2022, NASA's DART (Double Asteroid Redirection Test) spacecraft intentionally impacted the ~170-m asteroid moon Dimorphos. We present results from a coordinated campaign of photometric observations during the 2022-2023 apparition. Analysis of observations from this and prior apparitions resulted in high precision orbital parameters for the Dimorphs-Didymos system. For example, the pre-impact orbit period of Dimorphos = 11.92147 hr was constrained to a precision of about 70 milliseconds [2,3]. This is more than two orders of magnitude better than typical constraints for binary asteroids (e.g. [4]). Following the DART impact, observations of mutual events determined a new orbit period for Dimorphos =11.371 +/- 0.003 hr, representing a 33-minute change in the period [1]. Highlights of the observational campaign are presented here, along with implications for planetary defense considerations.

2022-2023 data used to determine period change [1]

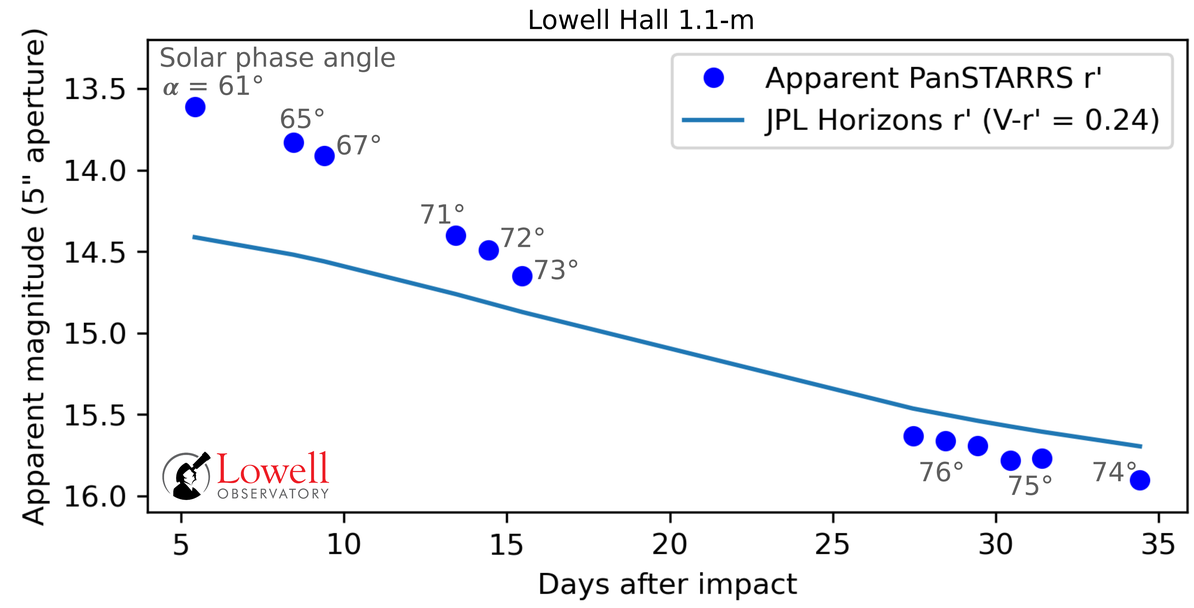
Number of lightcurves	147
Number of mutual events detections	244
Number of individual exposures	28,405
Total time on sky	29.51 days

First post-impact mutual event – only ~29 hr after impact!



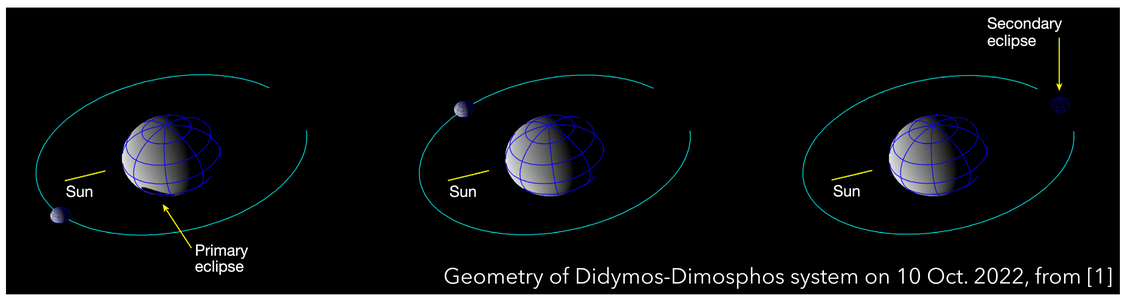
Models [5] suggested ejecta would obscure mutual events for 4-6 days after impact. These data show the ejecta cloud became optically thin in about 1 day.

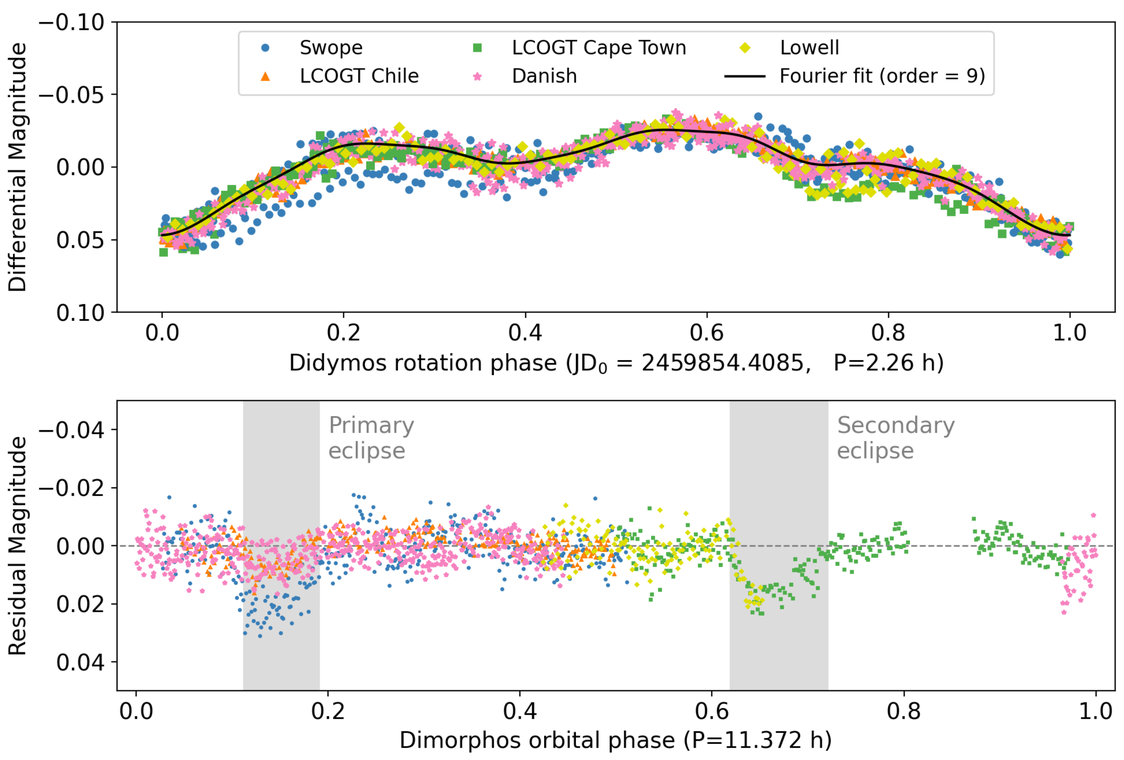
Ejecta faded from 0.06 down to 0.01 mag / day in the month after impact



The Didymos system was fainter than ephemeris predictions in late October. The high solar phase angle ($\alpha > 70°$) on these dates may have been a contributing factor.

Mutual events detected via lightcurve decomposition





Lightcurve decomposition process

1. Geometry correct (phase angle, geocentric range) and normalize apparent magnitudes
2. Fit primary lightcurve, phase folded to 2.26 hr rotation period, outside of mutual events
3. Subtract off fit to primary lightcurve
4. Mutual event times measured (e.g. [2]) to determine Dimorphos orbit period

Implications for planetary defense

- **Effective coordinated response to high priority targets:** the collective response of the DART observing community produced one of the most extensive planetary data sets in existence
- **Size estimates can be off by 10's of percent:** uncertainties in absolute magnitude H and phase angle behavior can lead to errors in size and inferred mass
- **Uncontrolled systematics influence estimates of physical properties:** even for well understood objects and carefully controlled observations, photometric calibration of ground-based data at the 1%-level or better is difficult
- **Importance of redundancy:** repeat and/or simultaneous observations are essential to derive physical properties from remote observations
- **Validation of asteroid deflection with ground-based telescopes:** the DART experiment highlights the important synergy between spacecraft operations and ground-based telescopic support

REFERENCES [1] Thomas et al. 2023, *"Orbital Period Change of Dimorphos Due to the DART Kinetic Impact"*, Nature, in press. [2] Naidu et al. 2022, *"Anticipating the DART Impact: Orbit Estimation of Dimorphos Using a Simplified Model"*, PSJ 3, 234. [3] Scheirich & Pravec 2022, *"Preimpact Mutual Orbit of the DART Target Binary Asteroid (65803) Didymos Derived from Observations of Mutual Events in 2003-2021"*, PSJ 3, 163. [4] Pravec et al. 2006, *"Photometric survey of binary near-Earth asteroids"*, Icarus 181, 63. [5] Fahnestock et al. 2022, *"Pre-encounter Predictions of DART Impact Ejecta Behavior and Observability"*, PSJ 3, 9.