

ACROSS: The Campaign for occultations by DART target Didymos (and other NEA)

ACROSS
**Asteroid Collaborative Research
via Occultation Systematic Survey**

2022/09/10-11 – ESOP XLI (IAA, Granada)

João Ferreira (Aristotle University of Thessaloniki, AUTh, Greece)

Co-authors: Kleomenis Tsiganis (AUTh), Paolo Tanga (OCA, France), Damya Souami (OCA),
Alex Siakas (AUTh)

What makes Didymos interesting?

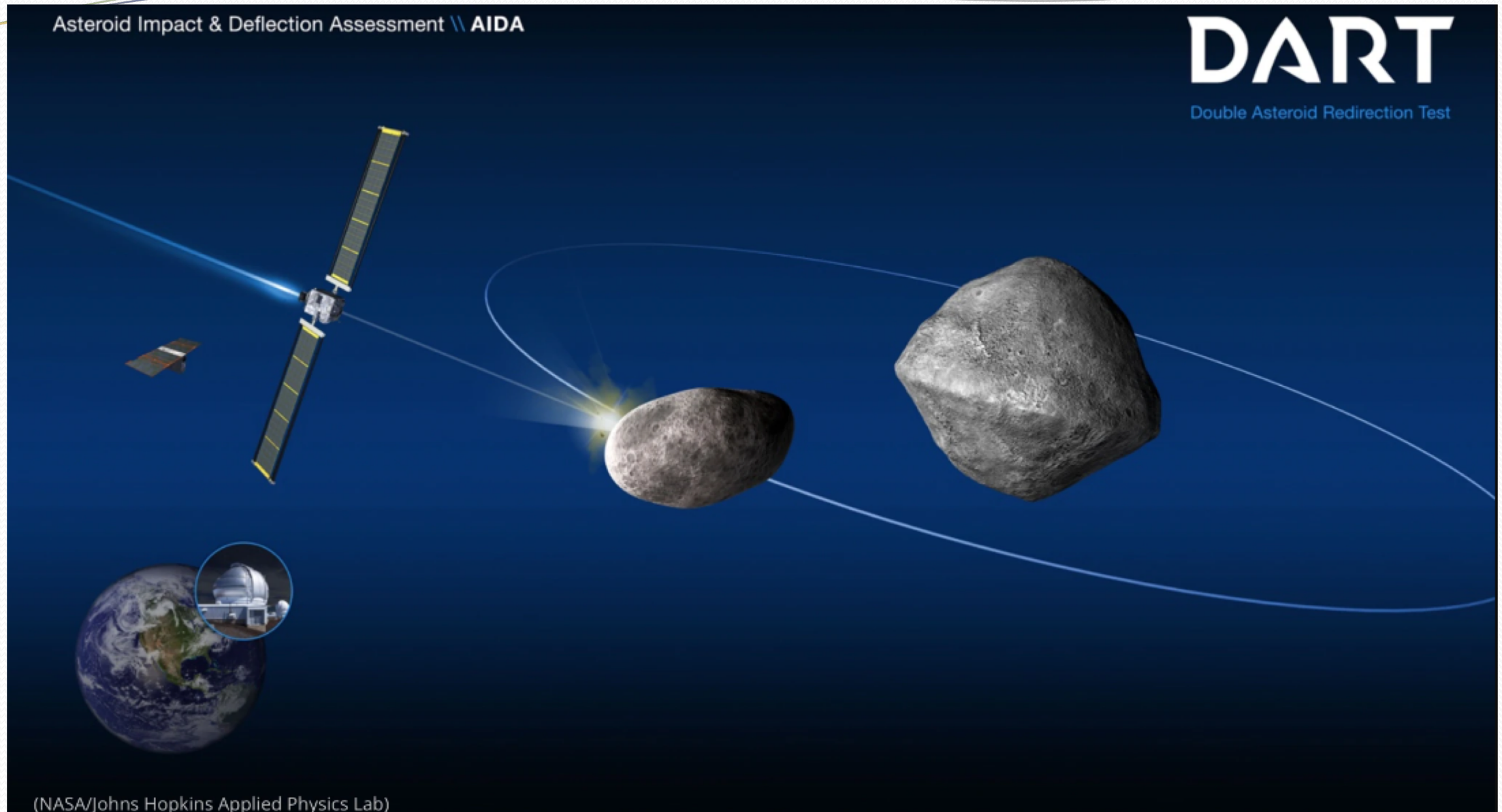


Image
by
NASA

The Didymos binary system

- Binary asteroid system: (65 803) Didymos and its satellite, Dimorphos;
- A NEA system: perihelion of 1.01 au with a Minimum Orbit Intersection Distance of 0.04 au for Earth;
- Didymos is considered a large NEA: 780 m of Diameter. Dimorphos is much smaller, 170 m;
- Ideal target for an Earth defense mission.

The Didymos missions: DART and Hera

- DART mission: deliberate collision of satellite with Dimorphos, to impact the binary System's orbit. Impact date on September 26th;
- Point of interest: studying the impact's effect on the binary system's orbit, to assess the viability of crashing satellites into objects for Earth's defense;
- Hera: ESA mission complementary to DART. Will orbit the Didymos-Dimorphos binary system to confirm the orbital change caused by the satellite impact;
- Launch date in late 2024. Fly-by missions are also a possibility.

Occultations of NEA are notoriously difficult

- NEA are small **and** fast moving in the sky, which makes all stellar occultations by NEA short (< 1 s);
- Close approaches increase positional uncertainties;
- The first occultation by an object is always the most difficult, and we have only observed the NEA (3 200) Phaethon (~ 6 km) and (99 942) Apophis (180 m);
- ACROSS team created for the sole purpose of observing NEA, with a special focus on Didymos.

The ACROSS Team

- Paolo Tanga (coordinator, OCA, Nice, France): Paolo.Tanga@oca.eu;
- Kleomenis Tsiganis (coordinator, AUTh, Greece): tsiganis@auth.gr;
- Damya Souami (OCA): damya.souami@obspm.fr;
- João Ferreira (AUTh): gferreira@auth.gr;
- Other members: Alex Siakas (AUTh), Lyu Abe, Luana Liberato, Pascal Oberti (OCA), Rodrigo Leiva (Univ. Católica, Chile).
- General team contact: across@oca.eu

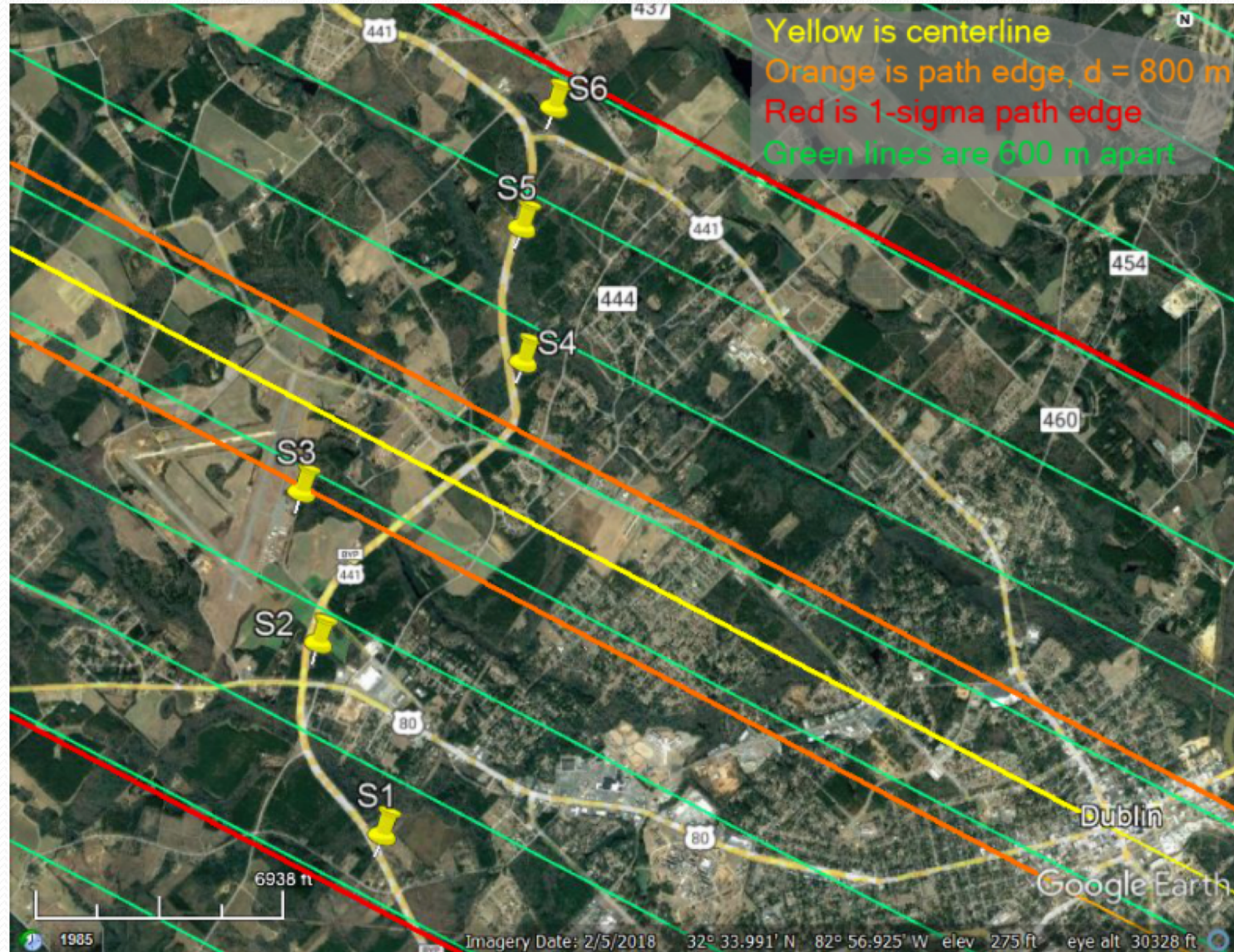
Where are we?

- Official website: <https://lagrange.oca.eu/fr/home-across>;
- Here, you can check near future events, campaign results and tutorial videos for NEA observations;
- We also upload events at OccultWatcher Cloud (OWC): <https://cloud.occultwatcher.net/events/tagged/ACROSS>;
- Events can be updated at a request by observers. Each OWC event has two options: the ACROSS orbit (obtained through the OrbFit tool) and JPL Horizons, the “standard” solution.

Past campaigns (June/July)

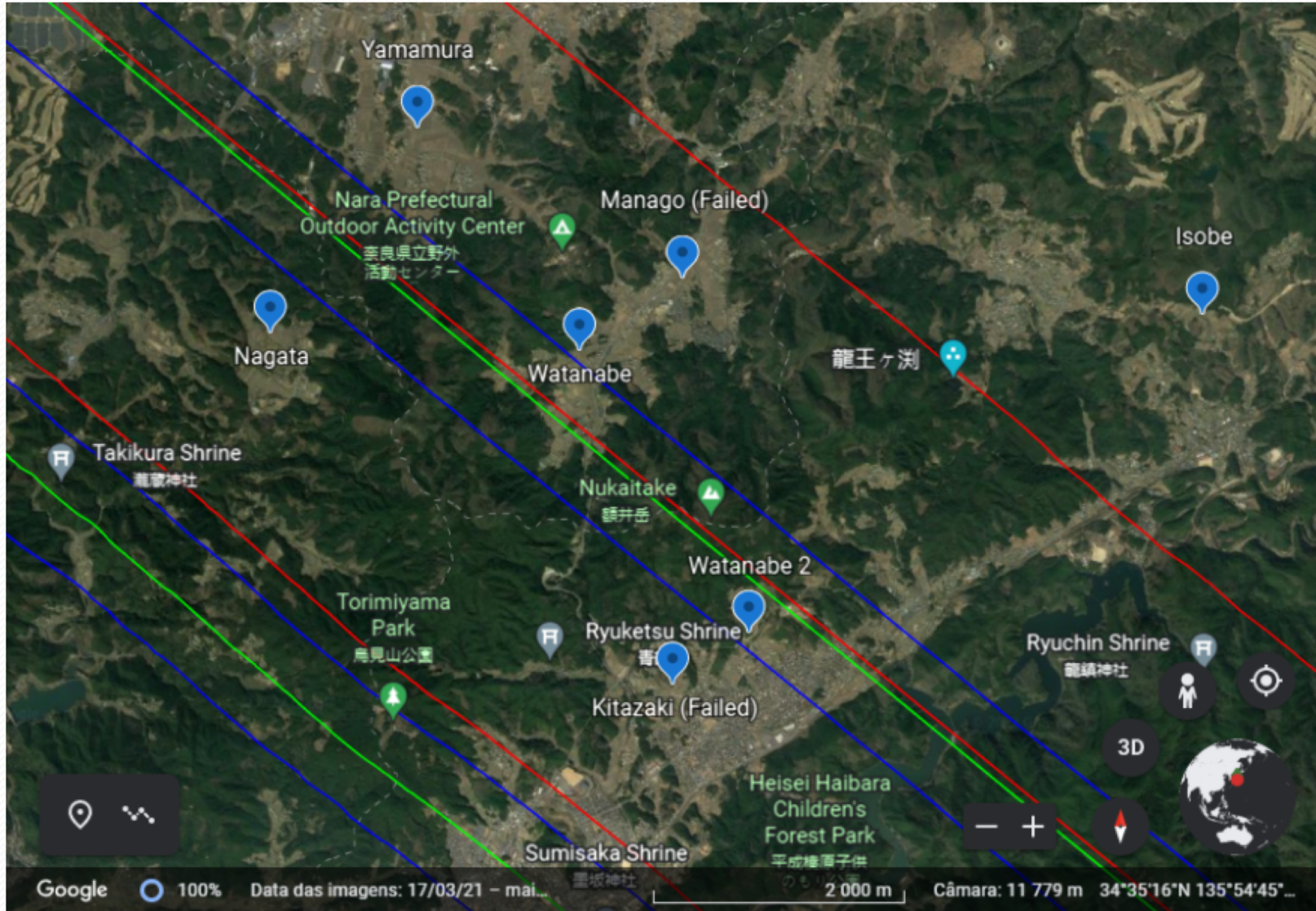
- 2022/07/24 – United States;
- 2022/07/29 – Japan;
- 2022/08/23 – United States;
- 2022/08/25 – Portugal/Spain/Algeria.

Past campaigns (2022/07/24, United States)



ACROSS: The Campaign for occultations by DART target Didymos, João Ferreira

Past campaigns (2022/07/29, Japan)



Green are centre lines.

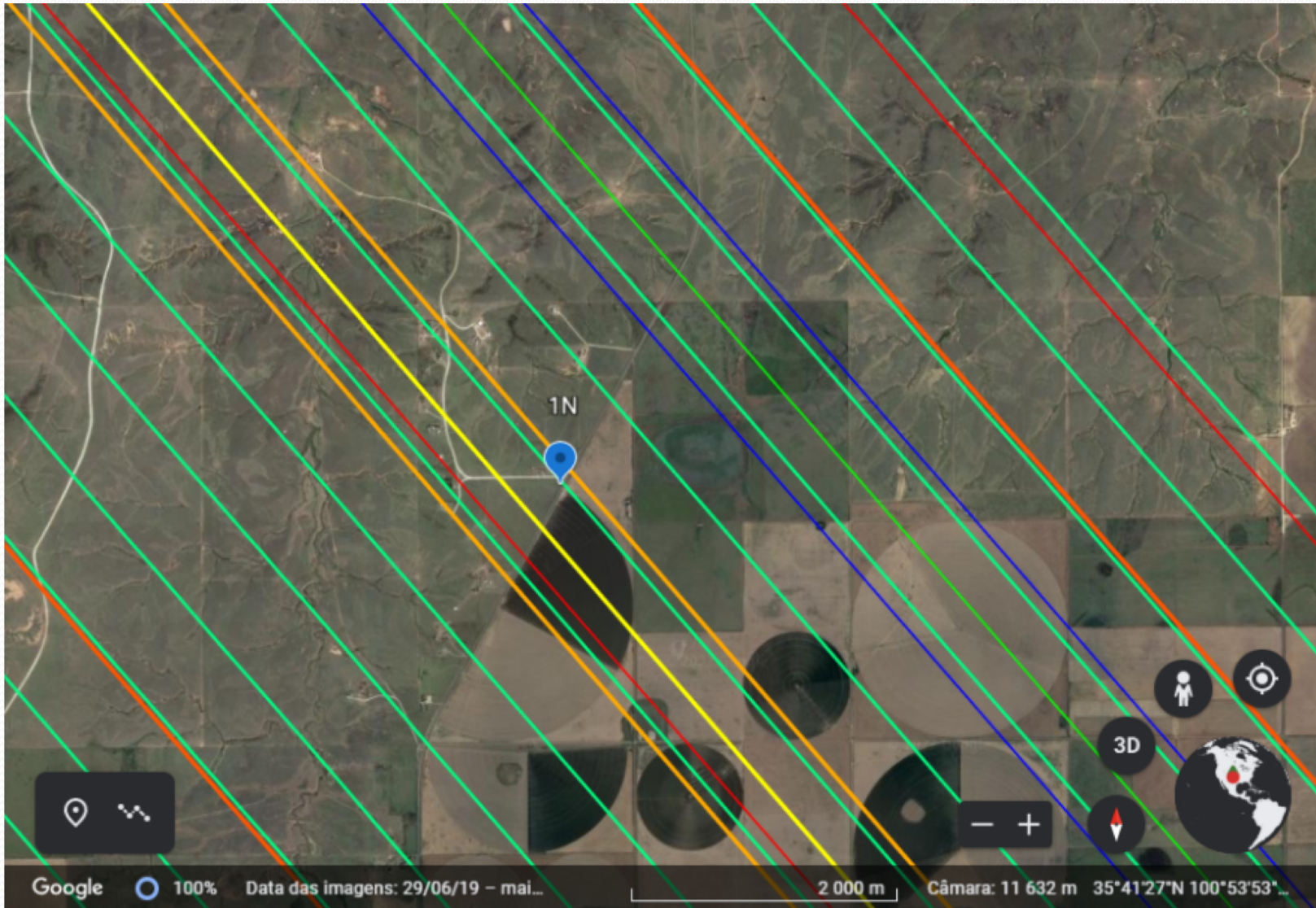
Blue are shadow limits.

Red are 1-sigma intervals.

Lower orbit: Official JPL
Didymos orbit.

Upper orbit: calculated
by the ACROSS team.

Past campaigns (2022/08/23, United States)



Orbits from JPL and ACROSS are closer.

Still all negatives (3).

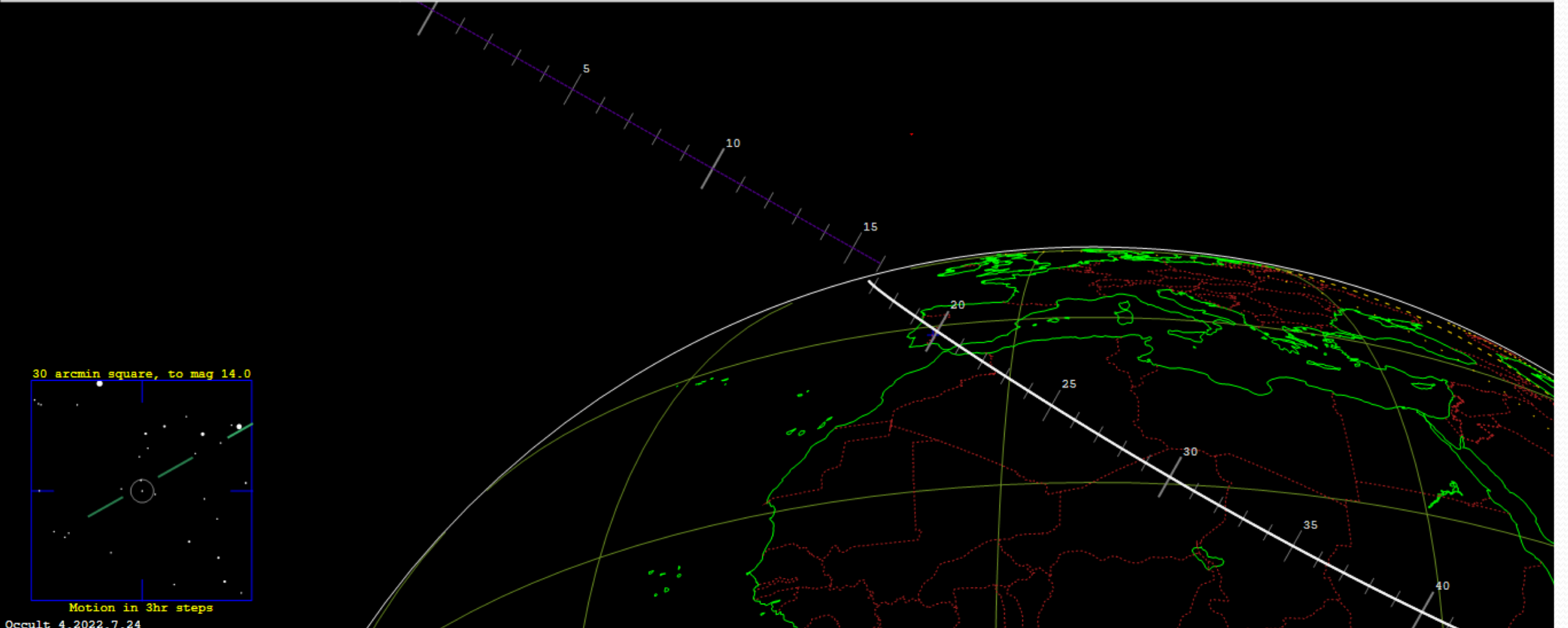
The Iberia/Algeria campaign - What?

65803 Didymos occults UCAC4 314-251595 on 2022 Aug 25 from 1h 16m to 1h 54m UT

Star: (Dia < 0.1 mas)
Mv 13.0; Mb 13.5; Mr 12.4
RA = 23 38 56.8190 (astrometric)
Dec = -27 23 58.904
[of Date: 23 40 9, -27 16 22]
Prediction of 2022 Aug 9.7
Reliable 1.4 (good),

Durations: Max = 0.20 secs
1km = 0.25 secs, 1mas = 0.032 secs
Mag Drop: 2.9 [93%]v, 3.0 [94%]r
Sun : Dist = 154°
Moon: Dist = 139°, illum = 5%
Error 23.0 x 9.0 mas in PA 84°

Asteroid:
Mag = 15.8
Dia = 0.80 ± 0.10km, 6.3 mas
Parallax = 49.938"
Hourly dRA = 7.118s
dDec = -53.58"
OrbFit2022Aug26, Known errors



The Iberia/Algeria campaign – Where?



Orbits even closer!

The Iberia/Algeria campaign – Who?

- Total of 40 observing stations prepared, each with at least 2 observers => **More than 80 people were part of this campaign!**
- Coordination with another occultation in the same area by the Lucy mission (NASA) target (15 094) Polymele;
- People involved from Portugal, France, Greece, United States, Spain and Algeria => international collaboration!
- Enough telescopes to cover 3-sigma uncertainty on ground for orbits of JPL and ACROSS.

What could go wrong?

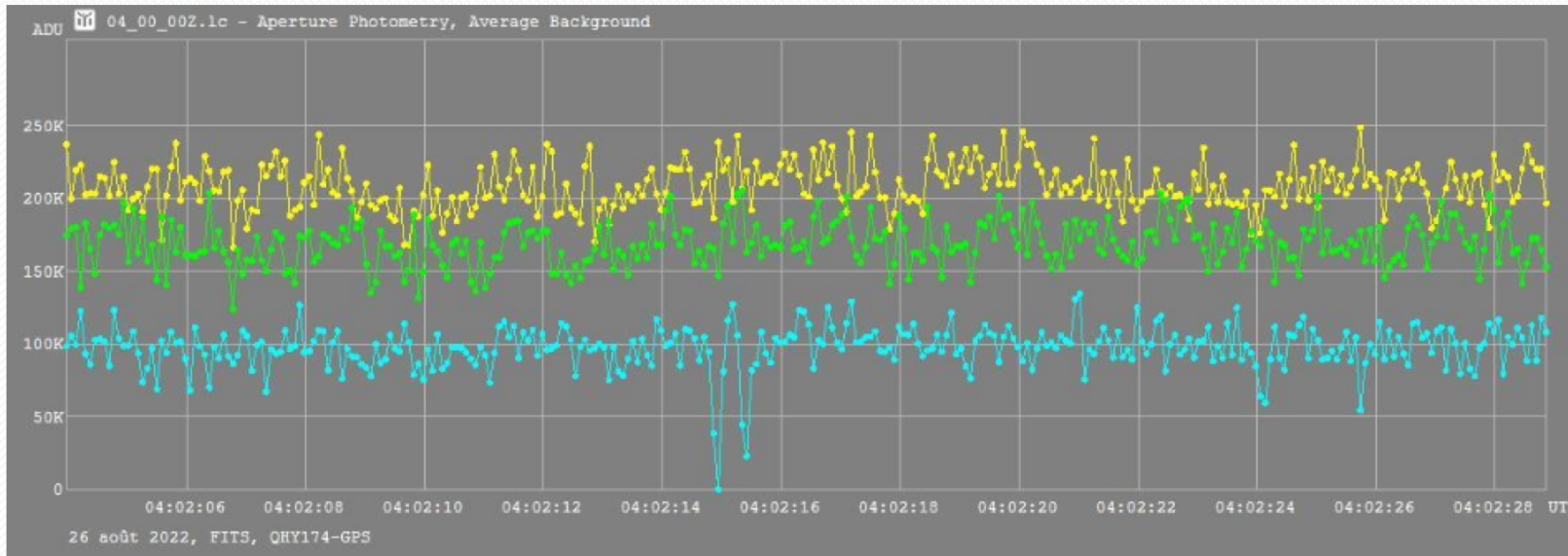


Clouds and humidity...
Even in August.

Sandstorm in Algeria.

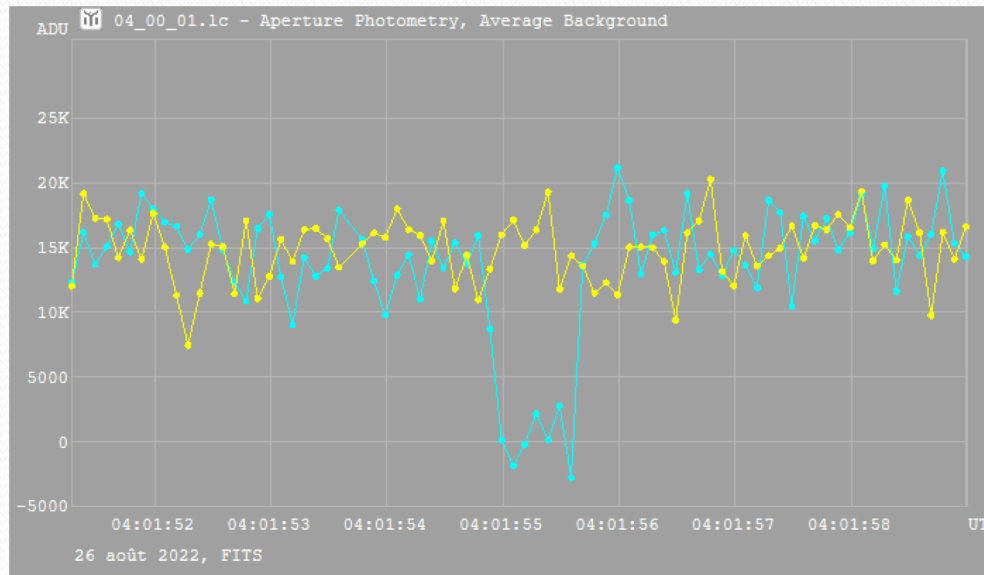
Potential results from
Spain only (tbd).

Polymele was a success, at least



Examples of the (at least 8) positive chords for Polymele.

These chords were obtained by Pierre Le Cam and Arnaud Leroy (France).



What now?

- Only a couple of weeks for the DART impact. Chances for occultation are dwindling;
- September events in Australia might be observable. Campaigns are being attempted. Event in the Arabian Peninsula 6 days before event is also being tracked;
- Depending on conditions, the observation of Dimorphos, as well as Didymos, might be possible.

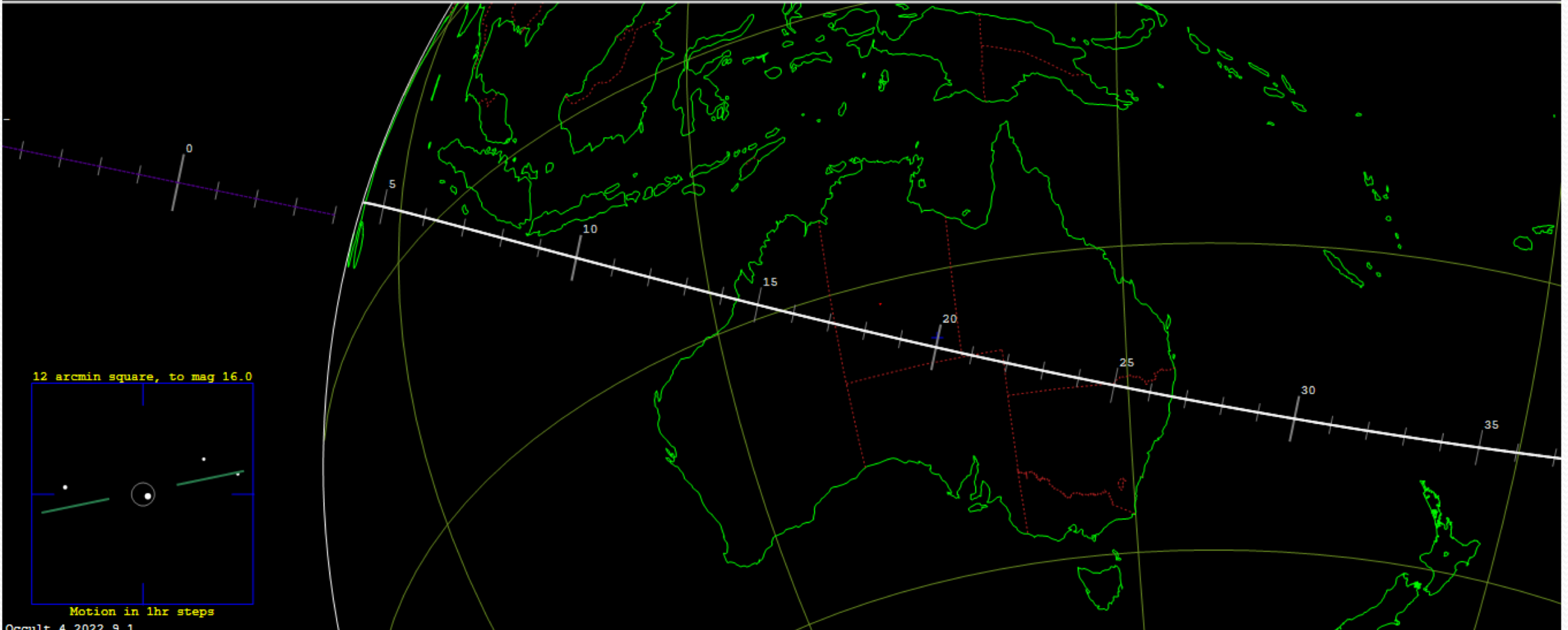
Pre-impact campaigns – Australia

65803 Didymos occults UCAC4 279-001139 on 2022 Sep 12 from 15h 5m to 15h 49m UT

Star: (Dia < 0.1 mas)
Mv 15.8; Mb 16.1; Mr 15.2
RA = 1 3 14.5405 (astrometric)
Dec = -34 17 11.755
[of Date: 1 4 20, -34 9 46]
Prediction of 2022 Sep 1.6
Reliable 1.0 (good),

Durations: Max = 0.16 secs
1km = 0.20 secs, 1mas = 0.015 secs
Mag Drop: 0.40 [31%]v, 0.43 [33%]r
Sun : Dist = 142°
Moon : Dist = 39°, illum = 94%
Error 28.0 x 11.0 mas in PA 73°

Asteroid:
Mag = 14.9
Dia = 0.80 ± 0.10km, 10.4 mas
Parallax = 82.807"
Hourly dRA = -17.608s
dDec = -45.07"
OrbFit2022Sep01, Known errors



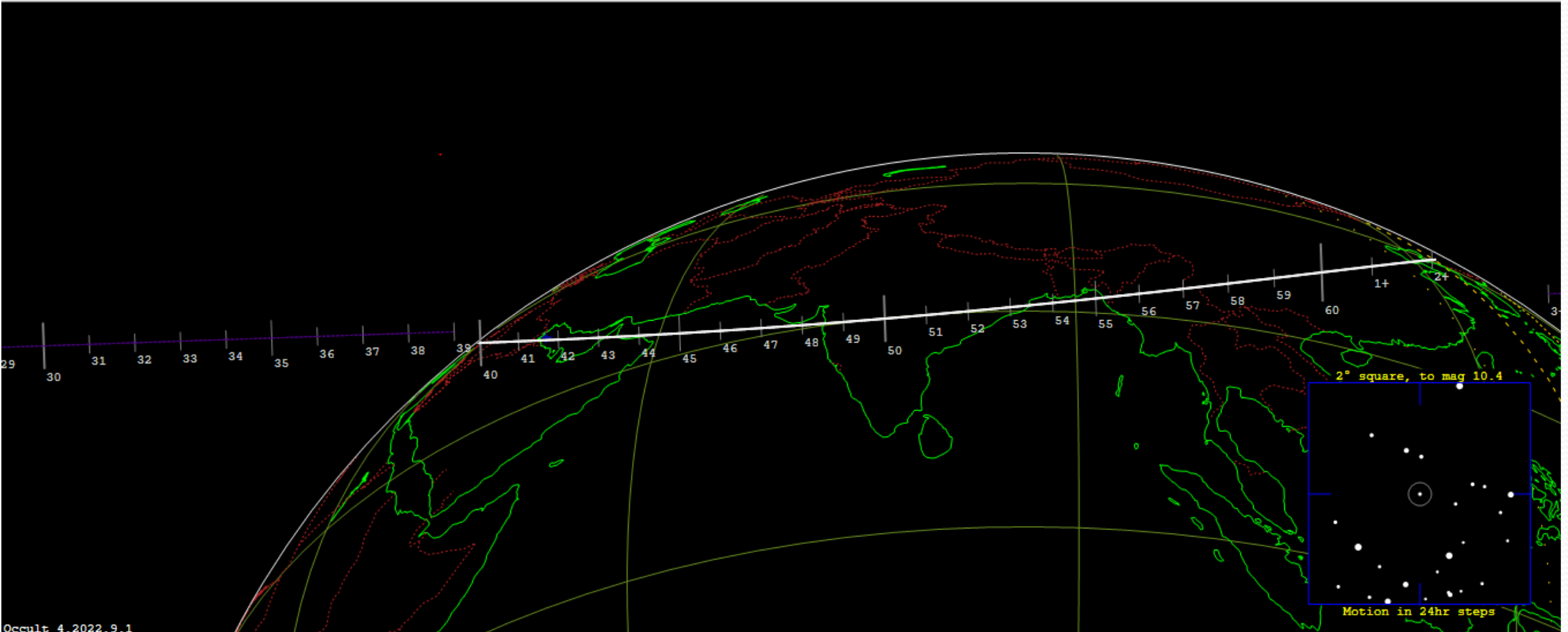
Pre-impact campaigns – UAE

65803 Didymos occults TYC 7009-01233-1 on 2022 Sep 20 from 20h 40m to 21h 2m UT

Star: (Dia = 0.1 mas)
Mv 9.4; Mb 9.6; Mr 9.0
RA = 2 14 35.7655 (astrometric)
Dec = -35 30 32.811
[of Date: 2 15 35, -35 24 2]
Prediction of 2022 Sep 1.7
Reliable 1.0 (good),

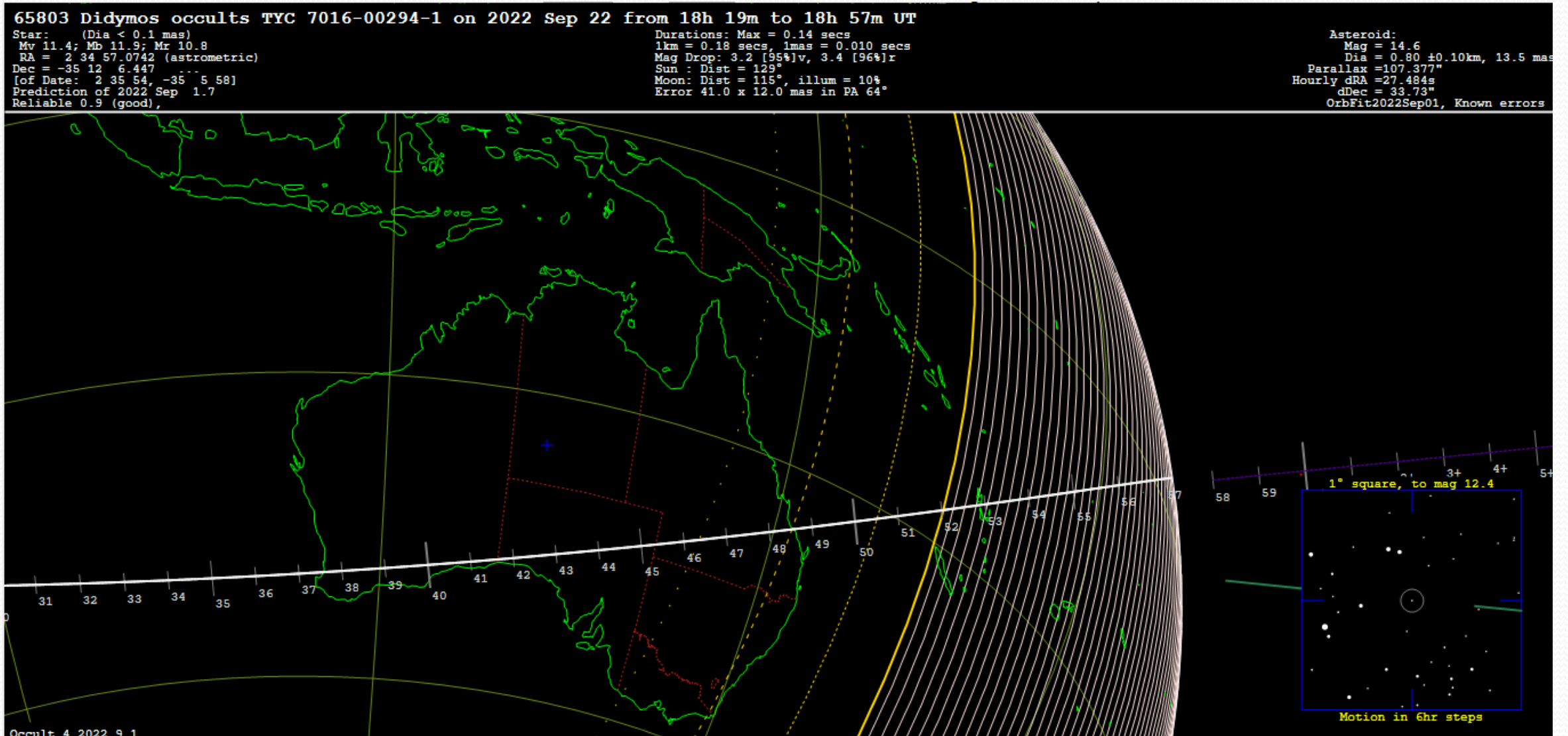
Durations: Max = 0.14 secs
1km = 0.18 secs, 1mas = 0.011 secs
Mag Drop: 5.2 [99%]v, 5.2 [99%]r
Sun : Dist = 132°
Moon: Dist = 104°, illum = 23%
Error 39.0 x 12.0 mas in PA 66°

Asteroid:
Mag = 14.6
Dia = 0.79 ±0.10km, 12.8 mas
Parallax = 102.735"
Hourly dRA = 25.802s
dDec = 11.21"
OrbFit2022Sep01, Known errors



Occult_4_2022_9_1

Pre-impact campaigns – Australia again



Post-impact campaigns

- Some September events post-impact are available on OWC;
- October events in France are interesting => Possible other synergy with Lucy target? Event for (3 548) Eurybates on October 23rd, and events for Didymos on October 21st and 25th in North of France.
- Post-impact observations are still essential! Ideal is to get events pre and post impact, to try to observe the shift in the orbit.

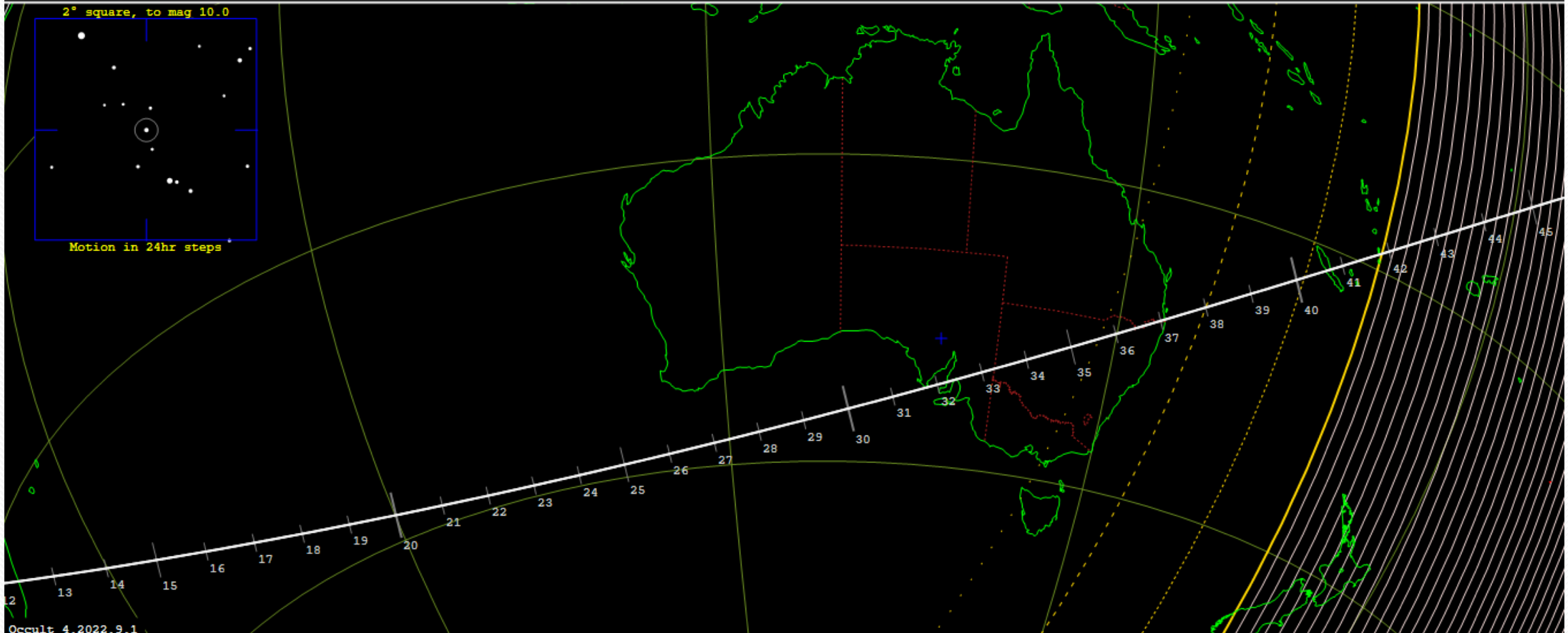
Post-impact campaigns – Australia

65803 Didymos occults HIP 15606 on 2022 Sep 26 from 18h 12m to 18h 48m UT

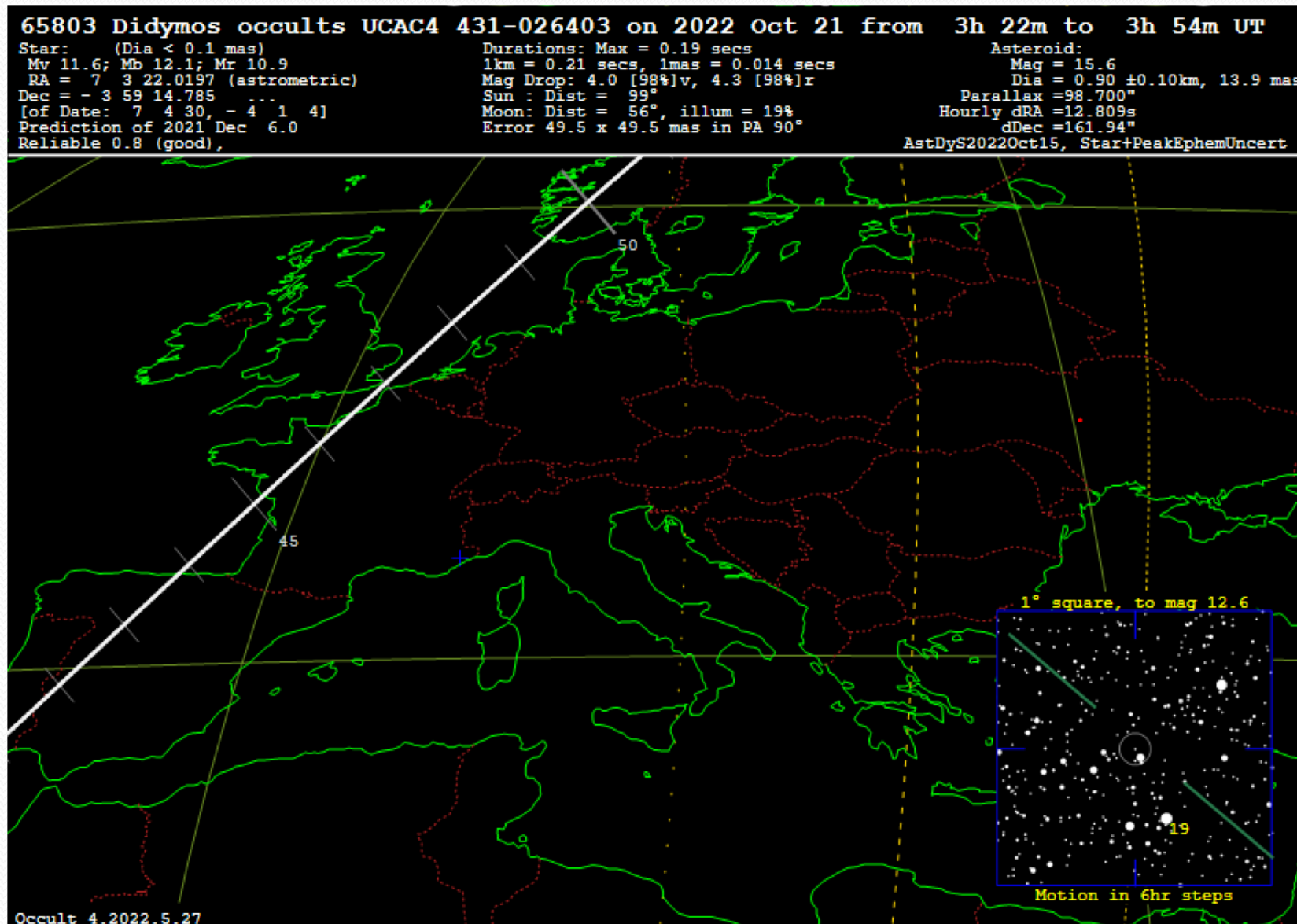
Star: (Dia = 0.1 mas)
Mv 8.3; Mb 8.6; Mr 7.9
RA = 3 20 58.2515 (astrometric)
Dec = -33 33 24.147
[of Date: 3 21 53, -33 28 17]
Prediction of 2022 Sep 7.6
Reliable 1.1 (good),

Durations: Max = 0.13 secs
1km = 0.16 secs, 1mas = 0.009 secs
Mag Drop: 6.3 [100%]v, 6.3 [100%]r
Sun : Dist = 124°
Moon: Dist = 130°, illum = 1%
Error 46.0 x 12.0 mas in PA 59°

Asteroid:
Mag = 14.6
Dia = 0.79 ± 0.10km, 14.4 mas
Parallax = 115.865"
Hourly dRA = 29.763s
dDec = 90.62"
OrbFit2022Sep07, Known errors

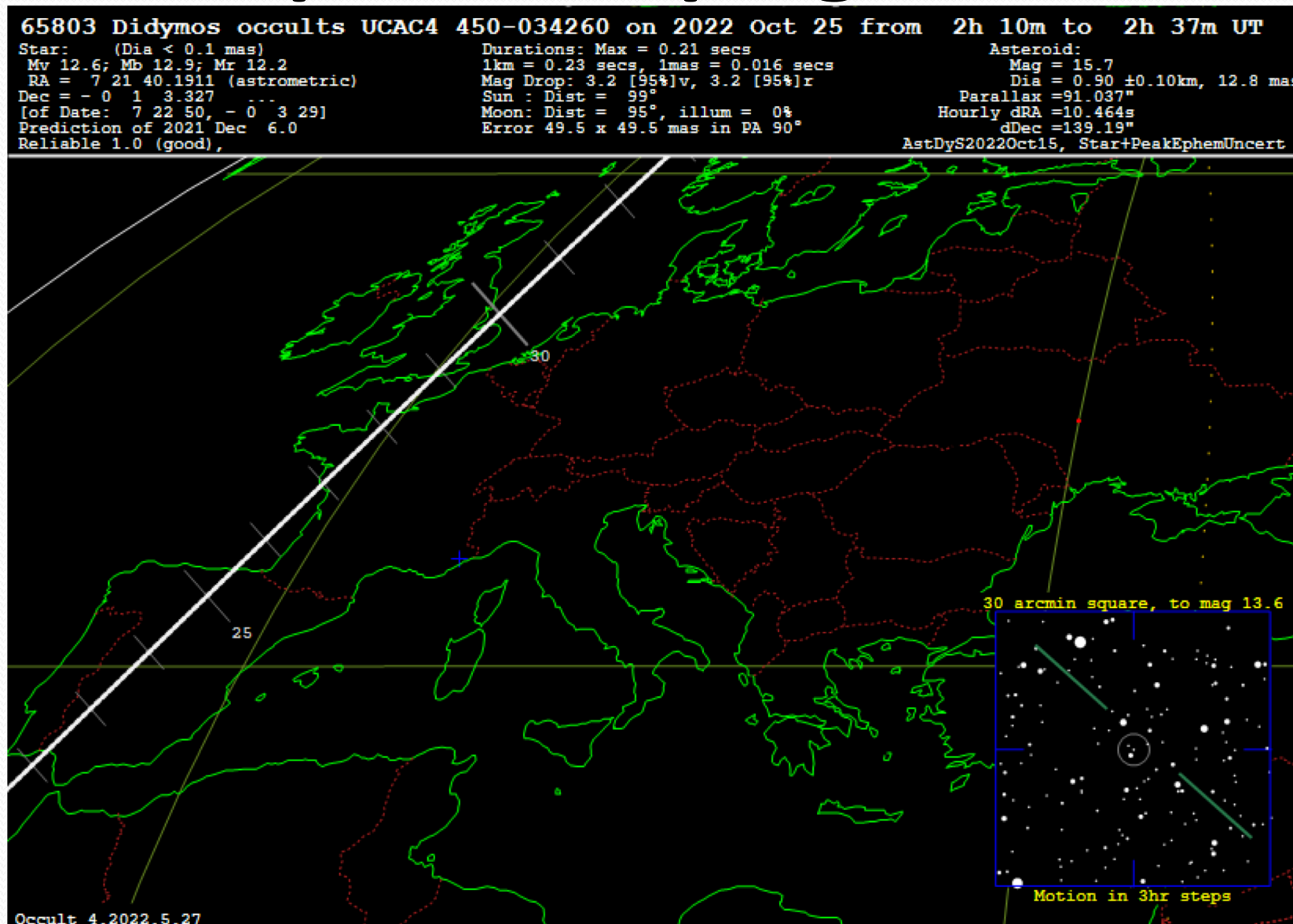


Post-impact campaigns – France



ACROSS: The Campaign for occultations by DART target Didymos, João Ferreira

Post-impact campaigns – France



Other NEA: Potential Hera targets

- 9 potential targets for a fly-by of ESA's Hera mission:
 - (29 886) Randytung;
 - (42 532) 1995 OR;
 - (54 212) 2000 HJ89;
 - (88 992) 2001 TJ72;
 - (95 802) Francismuir;
 - (122 764) 2000 SX69;
 - (169 549) 2002 EG105;
 - (188 708) 2005 TR99;
 - (477 416) 2009 WW1.

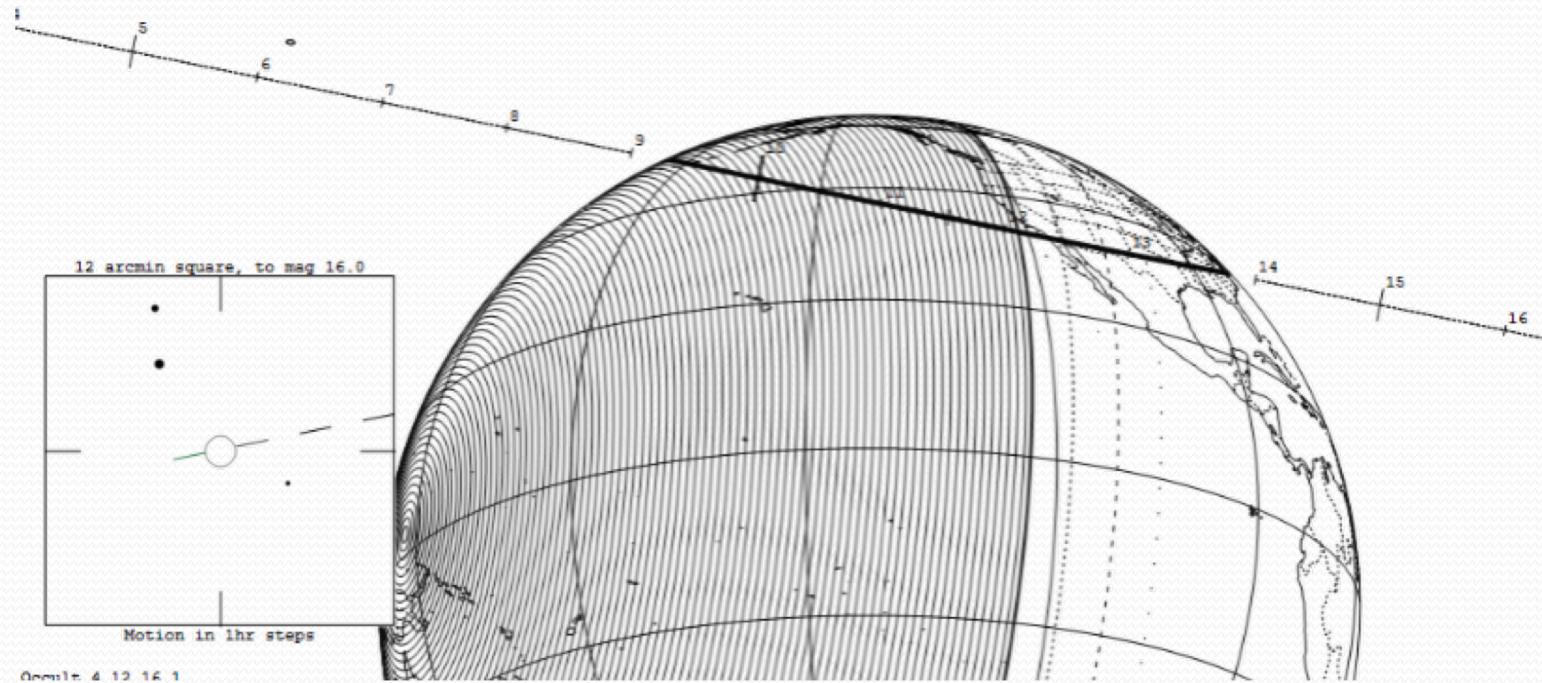
Other NEA: Potential Hera targets

- Some focus on events by these objects on the ACROSS feed as well;
- Special focus on (95 802) Francismuir, with the addition of recent imaging and Gaia DR3 data;
- Hera mission launches in late 2024 => more time for campaigns.

Other NEA: 2000 SX69 Event

122764 2000 SX69 occults UCAC4 357-076880 on 2022 Sep 16 from 2h 9m to 2h 14m UT

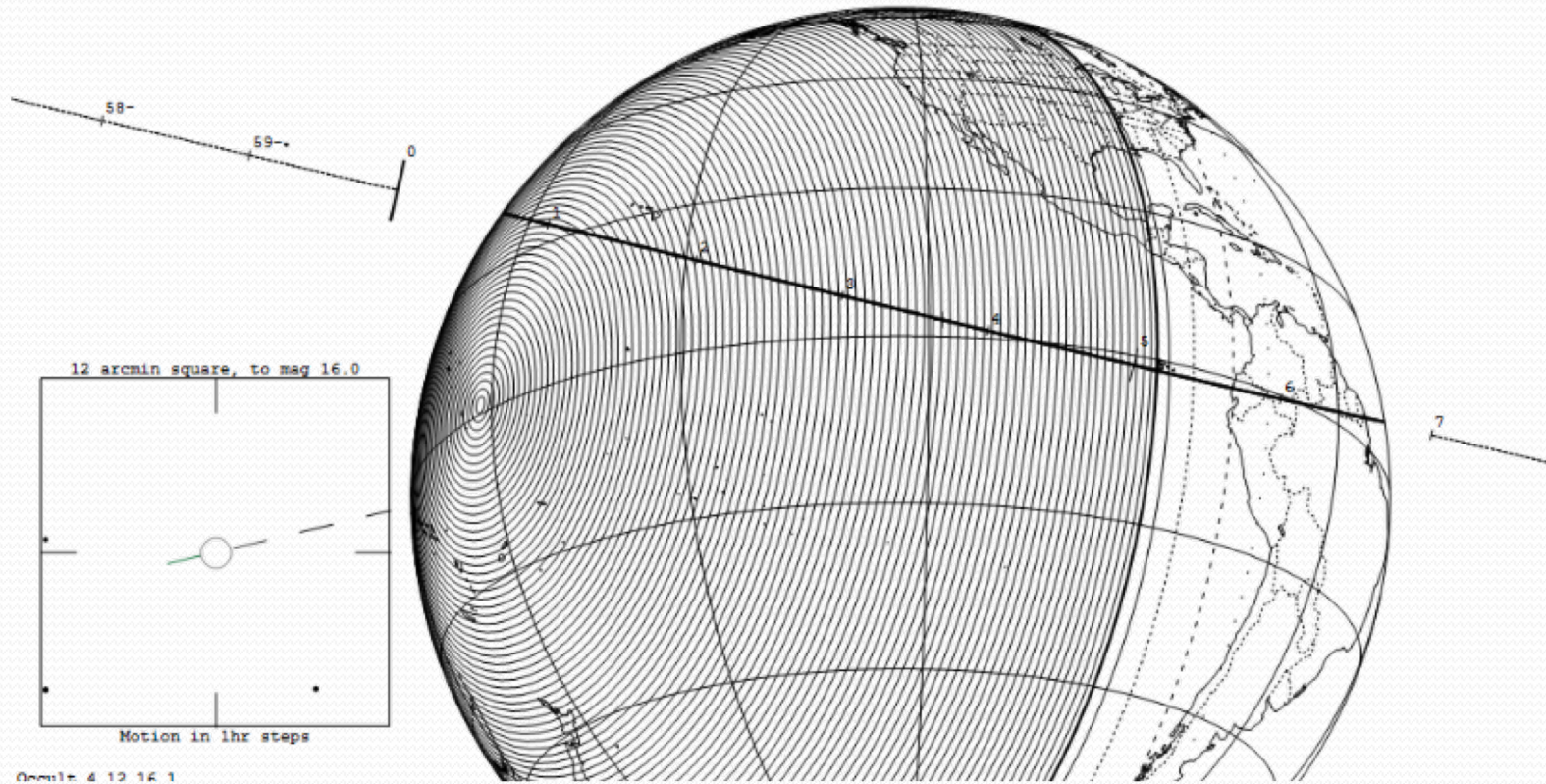
Star: (Dia < 0.1 mas)	Max Duration = 0.07 secs	Asteroid:
Mv 15.1; Mb 15.2; Mr 14.8	Mag Drop = 5.7 (5.5r)	Mag = 20.8
RA = 16 20 20.5323 (astrometric)	Sun : Dist = 74°	Dia = 1.80 ± 0.20km, 1.2 mas
Dec = -18 44 24.692	Moon: Dist = 174°	Parallax = 4.259"
[of Date: 16 21 38, -18 47 38]	: illum = 67 %	Hourly dRA = 4.579s
Prediction of 2022 Jun 27.5	Error 34.0x20.0 mas in RA 98°	dDec = -13.18"
Reliable 1.0 (good),		AstDyS2022Jul28, Star+PeakEphemUncert



Other NEA: Francismuir Event

95802 Francismuir occults UCAC4 354-073760 on 2022 Sep 20 from 0h 1m to 0h 7m UT

Star: (Dia < 0.1 mas)	Max Duration = 0.07 secs	Asteroid:
Mv 15.5; Mb 15.9; Mr 14.9	Mag Drop = 7.2 (7.3x)	Mag = 22.7
RA = 15 44 42.0604 (astrometric)	Sun : Dist = 62°	Dia = 2.40 ±0.20km, 1.4 mas
Dec = -19 12 23.912	Moon: Dist = 125°	Parallax = 3.780"
[of Date: 15 45 59, -19 16 37]	: illum = 31 %	Hourly dRA = 4.834s
Prediction of 2022 Sep 1.7	Error 11.0x6.0 mas in PA 97°	dDec = -16.19"
Reliable 1.0 (good),		OrbFit2022Sep01, Known errors



Other NEA: “Good” objects

- Short-list of NEA with orbits that allow for good occultation predictions under favourable circumstances:
 - $\sigma_a < 1e-9$ au;
 - $D > 0.5$ km (but smaller than 10 km);
 - Uncertainty on ground < 50 mas;
 - Uncertainty/Diameter ratio < 5 .
- Special focus on (2 100) Ra-Shalom, due to large amount of viable events and recent imaging/Gaia DR3 data.

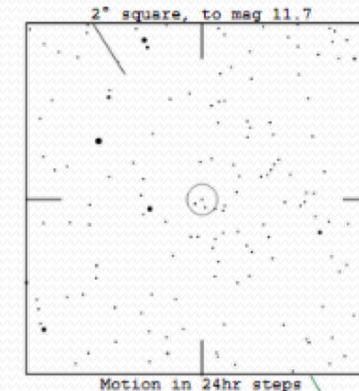
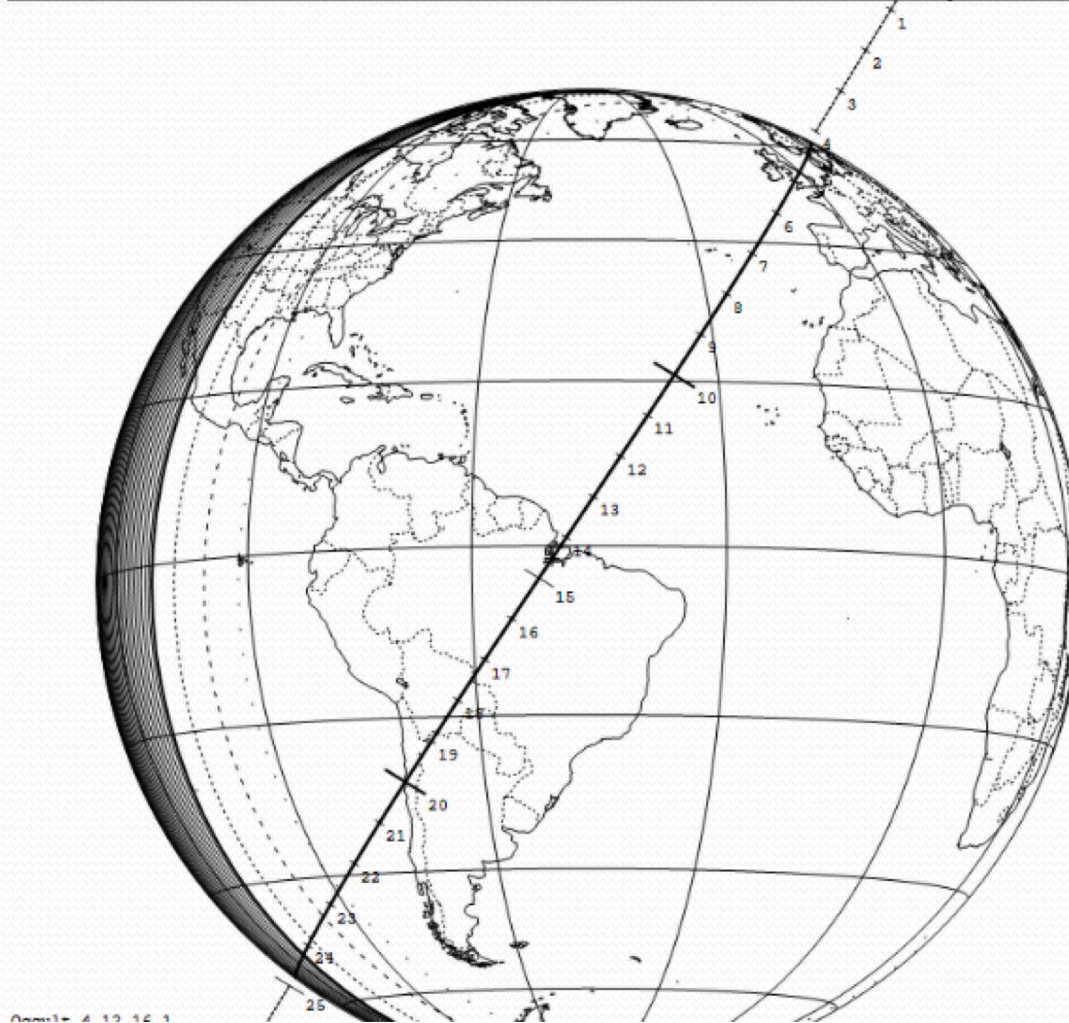
Other NEA: Ra-Shalom event

2100 Ra-Shalom occults UCAC4 429-115317 on 2022 Sep 12 from 1h 4m to 1h 25m UT

Star: (Dia < 0.1 mas)
Mv 10.7; Mb 10.9; Mr 10.2
RA = 21 32 56.0193 (astrometric)
Dec = - 4 18 55.372
[of Date: 21 34 8, - 4 12 51]
Prediction of 2022 Sep 1.7
Reliable 1.1 (good),

Max Duration = 0.19 secs
Mag Drop = 5.5 (5.5r)
Sun : Dist = 153°
Moon: Dist = 48°
: illum = 96 %
Error 16.0x9.0 mas in PA 53°

Asteroid: (in DAMIT, ISAM)
Mag = 16.1
Dia = 2.00 ± 0.20km, 13.4 ma:
Parallax = 42.649"
Hourly dRA = -8.684s
dDec = -210.75"
OrbFit2022Sep01, Known errors



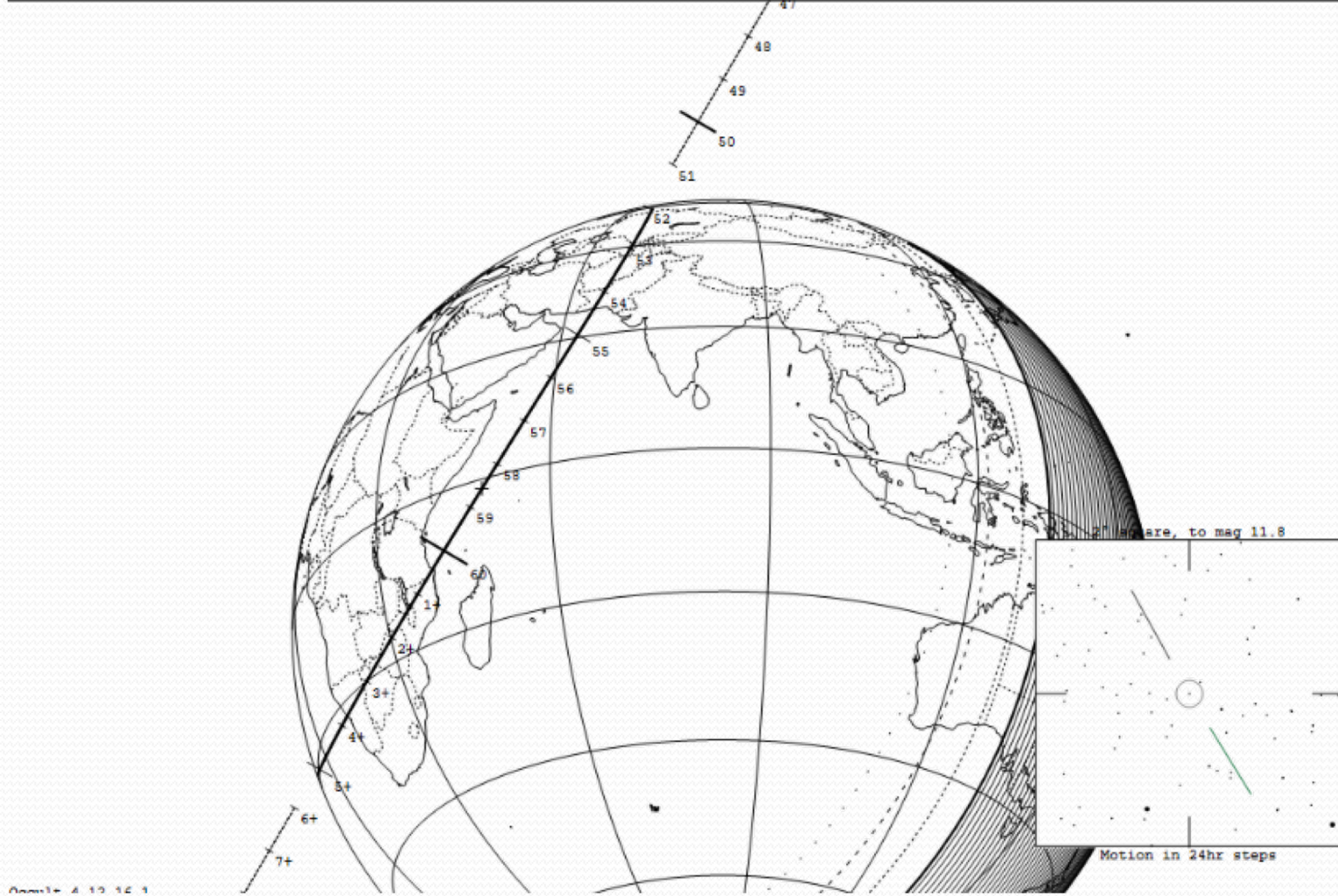
Other NEA: 1999 CV3 event

11405 1999CV3 occults TYC 6433-00968-1 on 2022 Sep 18 from 20h 52m to 21h 5m UT

Star: (Dia < 0.1 mas)
Mv 10.8; Mb 11.2; Mr 10.2
RA = 2 23 6.5777 (astrometric)
Dec = -25 5 54.909
[of Date: 2 24 9, -24 59 34]
Prediction of 2022 Jun 27.5
Reliable 1.0 (good),

Max Duration = 0.12 secs
Mag Drop = 6.2 (6.4r)
Sun : Dist = 135°
Moon : Dist = 79°
: illum = 41 %
Error 26.0x26.0 mas in PA 63°

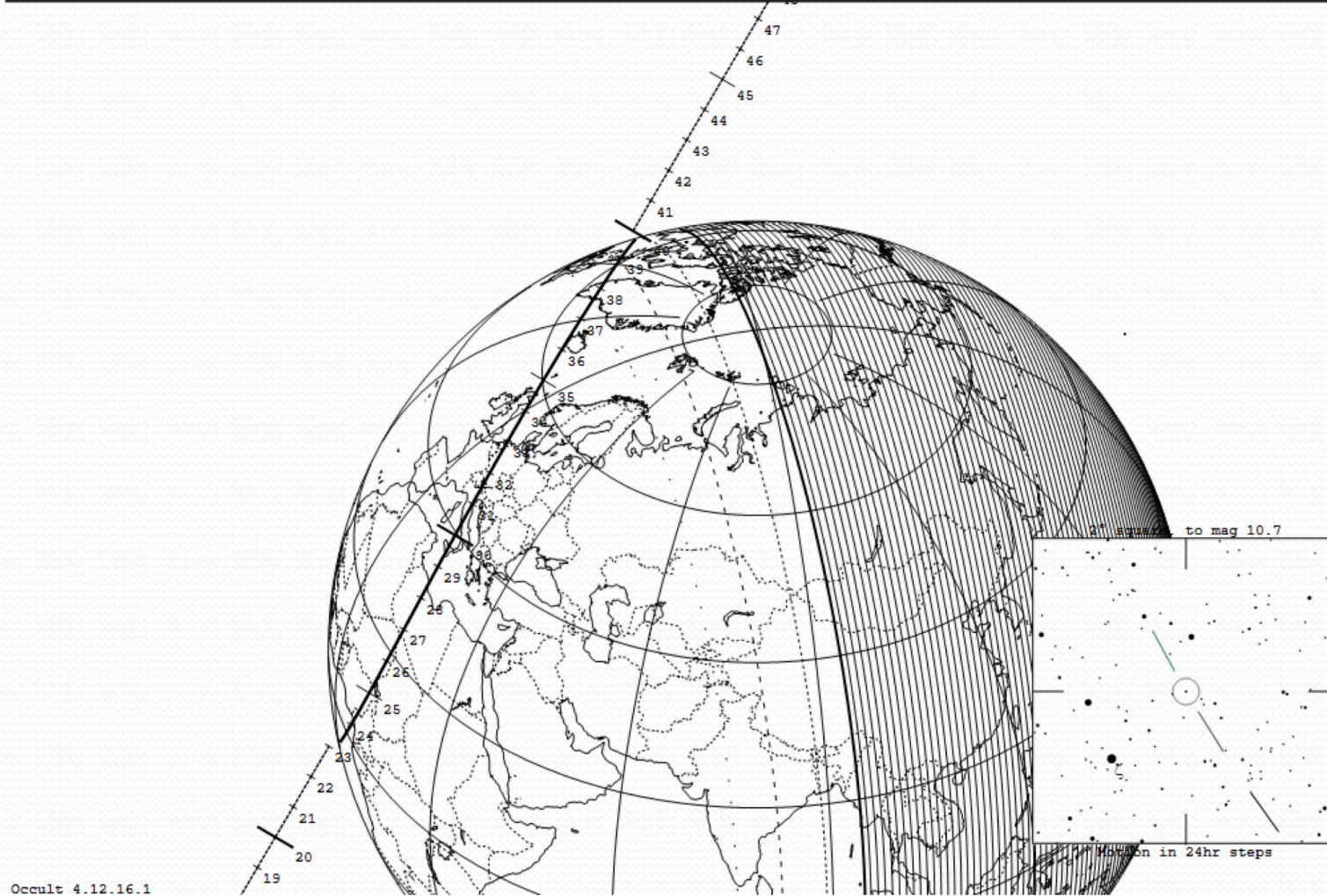
Asteroid:
Mag = 17.0
Dia = 1.50 ±0.20km, 2.6 mas
Parallax = 11.101"
Hourly dRA = -2.863s
dDec = -66.27"
AstDyS2022Jul28, Star+PeakEphemUncert



Other NEA: Geographos event

1620 Geographos occults TYC 2902-02875-1 on 2022 Sep 23 from 23h 23m to 23h 40m UT

Star: (Dia < 0.1 mas)	Max Duration = 0.30 secs	Asteroid: (in DAMIT, ISAM)
Mv 9.7; Mb 9.7; Mr 9.5	Mag Drop = 10.8 (10.6r)	Mag = 20.5
RA = 4 59 54.1338 (astrometric)	Sun : Dist = 102°	Dia = 2.60 ±0.20km, 3.8 mas
Dec = 41 30 59.332	Moon: Dist = 79°	Parallax = 9.302"
[of Date: 5 1 29, 41 32 56]	: illum = 4 %	Hourly dRA = 2.072s
Prediction of 2022 Aug 16.5	Error 6.0x4.0 mas in PA 155°	dDec = 39.46"
Reliable 1.0 (good),		OrbFit2022Aug16, Known errors



Other NEA: Validating Gaia's DR3 data

- Gaia's DR2 (2018) gave the first set of data for Solar System Objects, with ~14 000 objects and 22 months of data. "Our DR1";
- Gaia's DR3 (2022) has ~120 000 objects and 34 months of data => Paradigm shift for occultations?
- Most objects that are tracked for occultations should now have usable Gaia data, and OrbFit is now compatible with Gaia;
- ~450 NEA, in particular, are present, and they are good objects to validate Gaia.

Conclusions for Didymos

- There was some tension between our calculated orbit and that of JPL, but the differences were shortened with the addition of July and August observation data for Didymos. Orbits get closer in end of September/October;
- Campaign organization for Iberia/Algeria was effective, with prior scouting of the possible locations for all observers. Weather couldn't permit the observations;
- Convergence between orbits leaves hope for an observation prior to the impact, still. Objective of reducing orbital uncertainty to the levels of the impact's effect may still be within reach.

Future Prospects

- Some campaigns pre and post impact are still being planned for Didymos;
- Other NEA are a secondary focus for ACROSS, and Francismuir and Ra-Shalom are interesting targets for observation;
- In the near-future, the way we choose our targets will change, thanks to the very accurate Gaia data. NEA can be a good source to validate their sets of Gaia observations;
- Our work doesn't end with DART! Hera is waiting for us, too.

Thank you!



ACROSS: The Campaign for occultations by DART target Didymos, João Ferreira