CHASING SHADOWS OF THE MOST ANCIENT OBJECTS IN THE SOLAR SYSTEM – FOR FUN AND SCIENCE

A Talk for the East Bay Astronomical Society

Saturday Aug 16, 2025

Richard Nolthenius

Dept. Chair – Cabrillo College Astronomy

Through occultations, and with affordable equipment, we can measure the sizes, shapes, and orbits of asteroids and KBO’s, better than can the largest telescopes!

And if you’re lucky, discover new moons around them too.

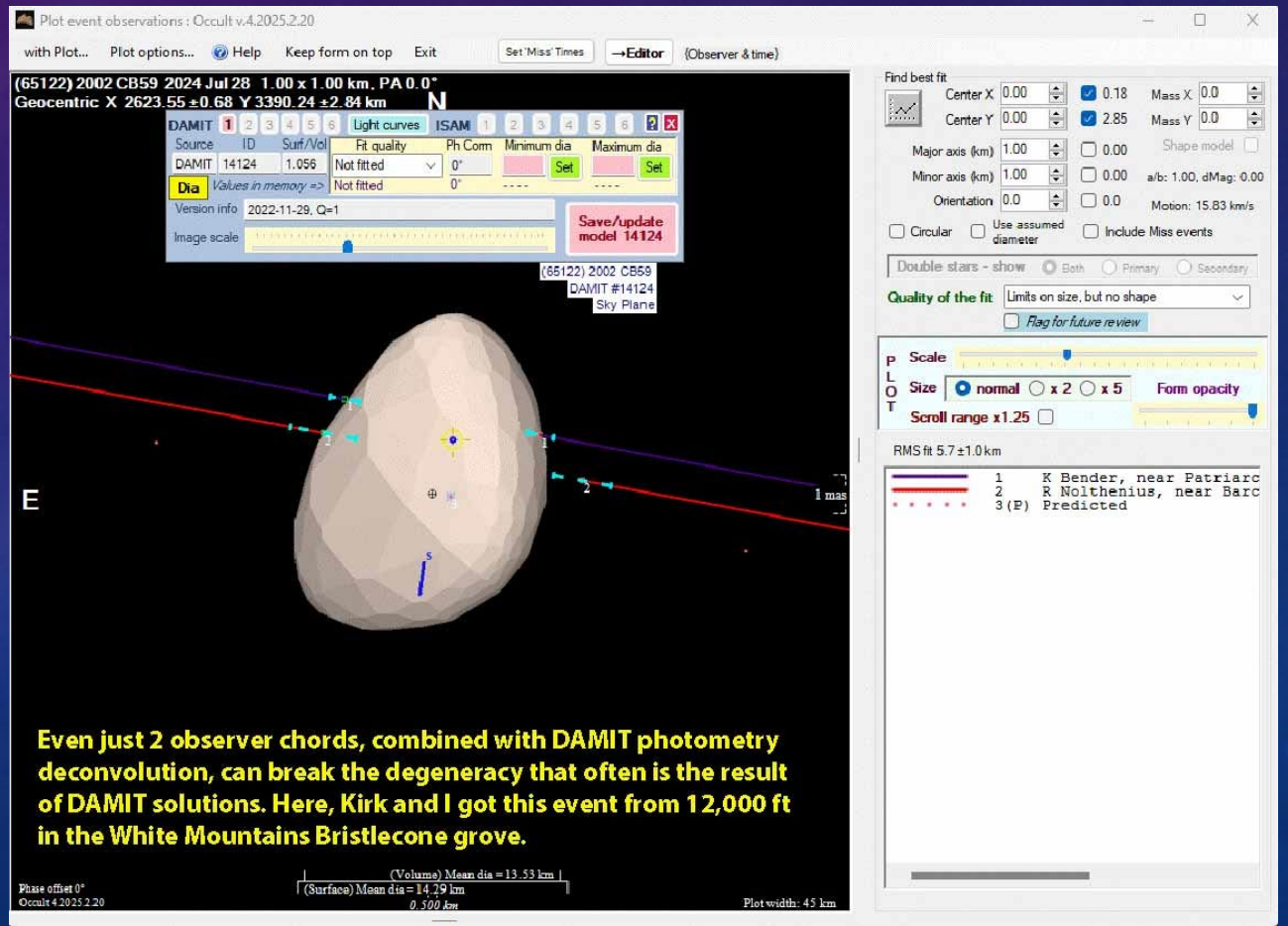
THE KEY IS THIS…

- #1. Asteroids move slowly in their orbits, about 20 km/sec
- #2. And, we can slice time finely and stamp it onto high-speed video frames with GPS gear.
- At right: “F9”: 9 GPS satellites, allowing UT to .0001 sec, stamped onto each 1/60s even/odd field for each interlaced frame, with the IOTA **Video Time Inserter**.

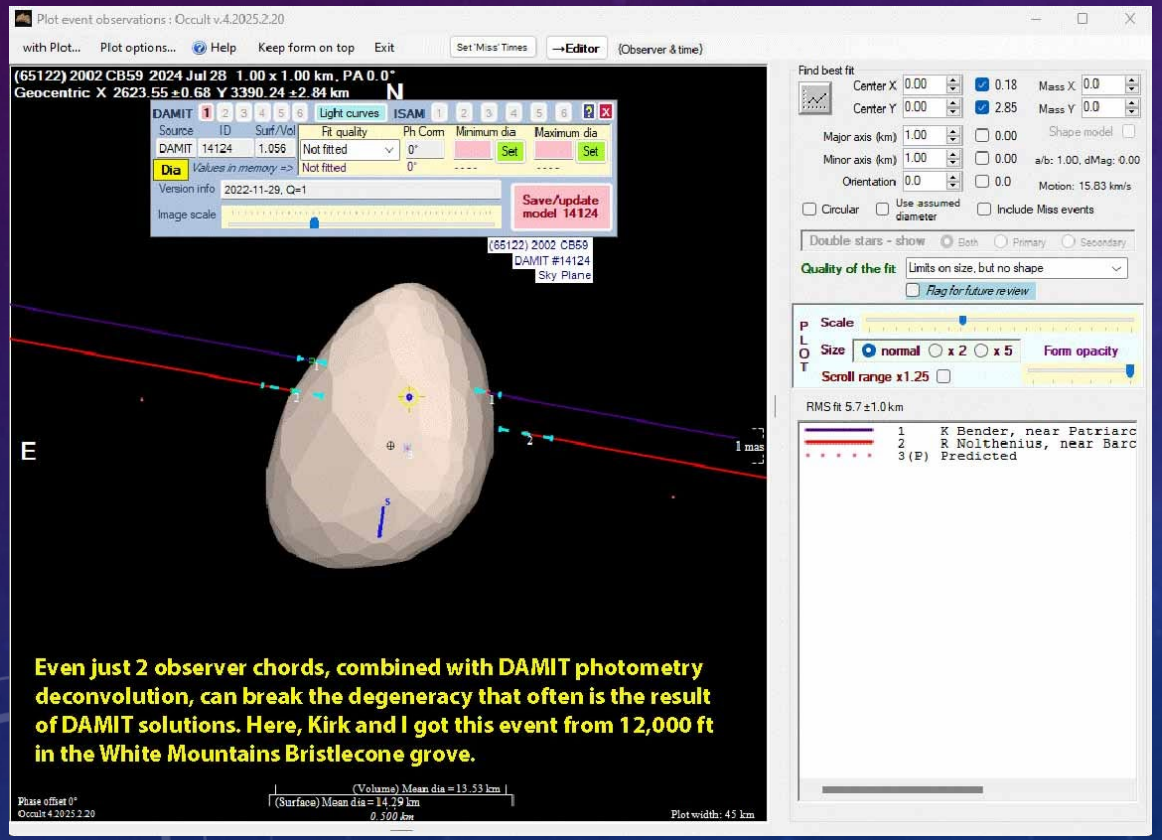
THIS ALLOWS US EXTREMELY HIGH PRECISION MEASUREMENTS…

- …of the asteroid edges at the “D” and the “R” moments, down to a few meters ideally!
- It’s just math, after all, and computers will do that w/o complaint
- Combined with other observers, we can map the outline of the asteroid with better precision than even the largest telescopes could do on their own.
- How so? Because even monster telescopes will still see almost all asteroids as just pin-points of light.

On an expedition to the White Mtns Bristlecone Pines, Kirk Bender and I got this asteroid event…



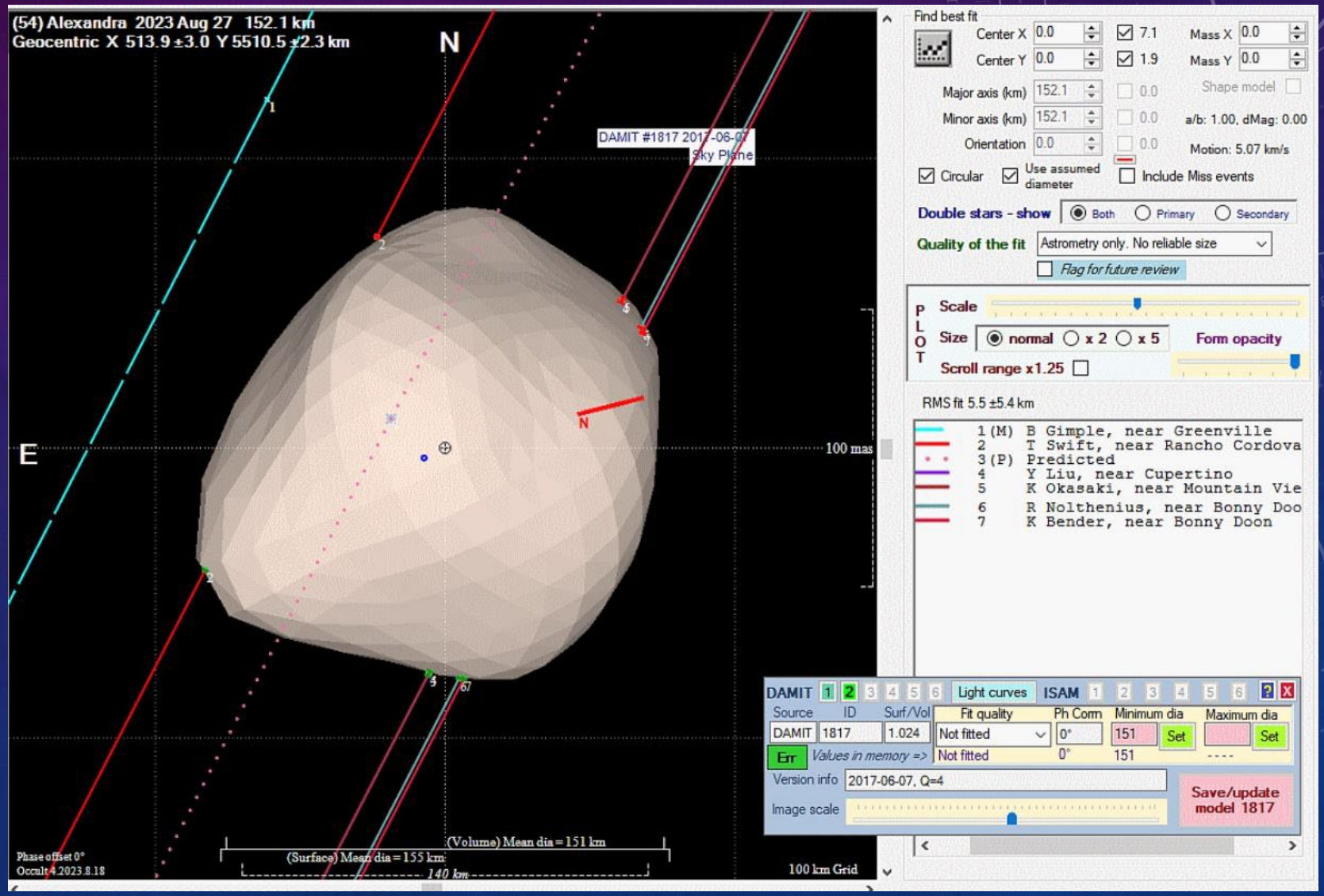
A DIFFERENT WAY TO MEASURE ASTEROID SHAPE DETAILS: **DAMIT**: DATABASE OF ASTEROID MODELS FROM INVERSION TECHNOLOGIES (DURECH *et al*. 2010)



- Long term precision light curves, with lots of math, can be used to infer the shape of the asteroid as it tumbles.
- But these models assume uniform reflectivity over the surface.
- And – often "degeneracy": multiple acceptable fits which are different.
- Occultations from several observers can break that degeneracy and find the right solution, such as at left here.

THANKS TO THE GAIA MISSION AND ITS INCREDIBLE ACCURACY IN MEASURING STAR POSITIONS AND MOTIONS…

- …Volunteer astronomers can now contribute precision measurements of asteroids.
- Combined with photometric DAMIT modelling, can resolve shape, orbit and orientation solutions.



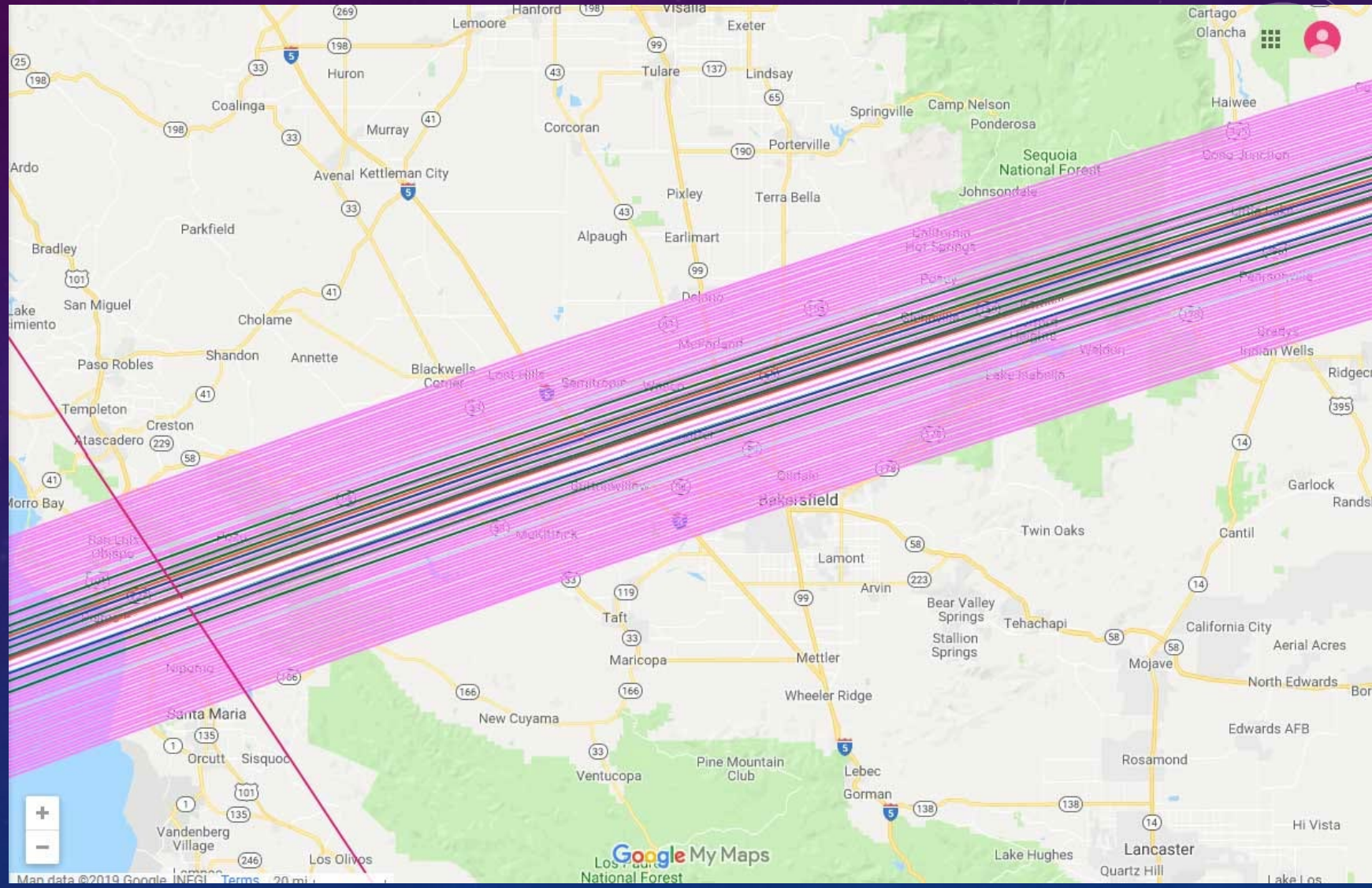
JPL and NASA scientists will beg you, even outfit you (well; sometimes) to get this high precision data so they can better plan their rendezvous space missions

- And the discovery by occultation of a new moon of one of these rendezvous targets would have big implications for the dangers, and the opportunities, for those spacecraft.

Tonight, I'll now show several examples of my team's high adventure / high value occultation successes…

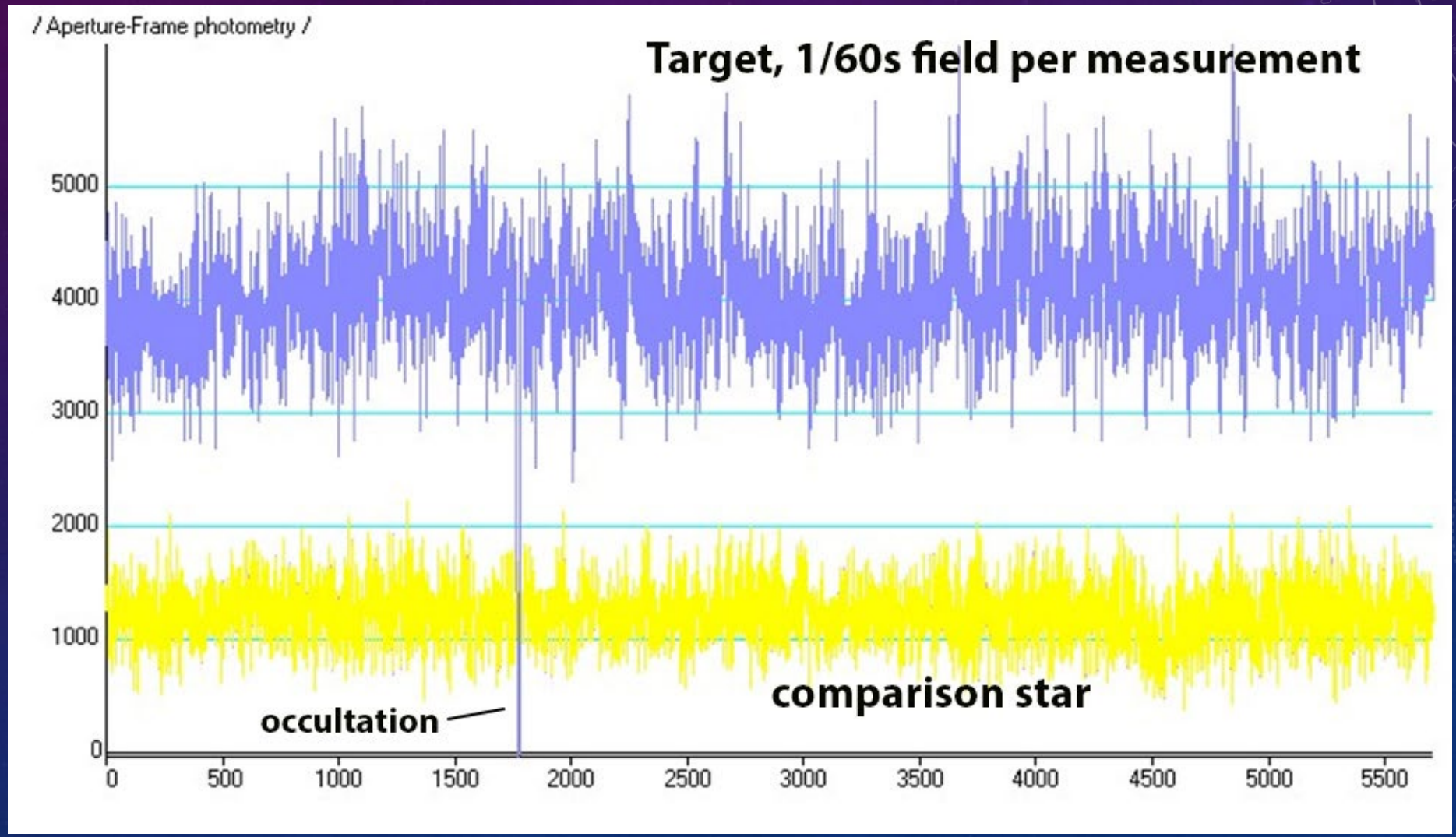
1ST: PHAETHON, PARENT OF THE GEMINID METEOR SHOWER. AND IN THE FUTURE; EARTH-DANGEROUS!

High priority! The Phaethon occultation of a bright star on July 29, 2019. IOTA set out a 60 tracks “net” to snare this 7th mag event. Astronomers from around the country converged on California.

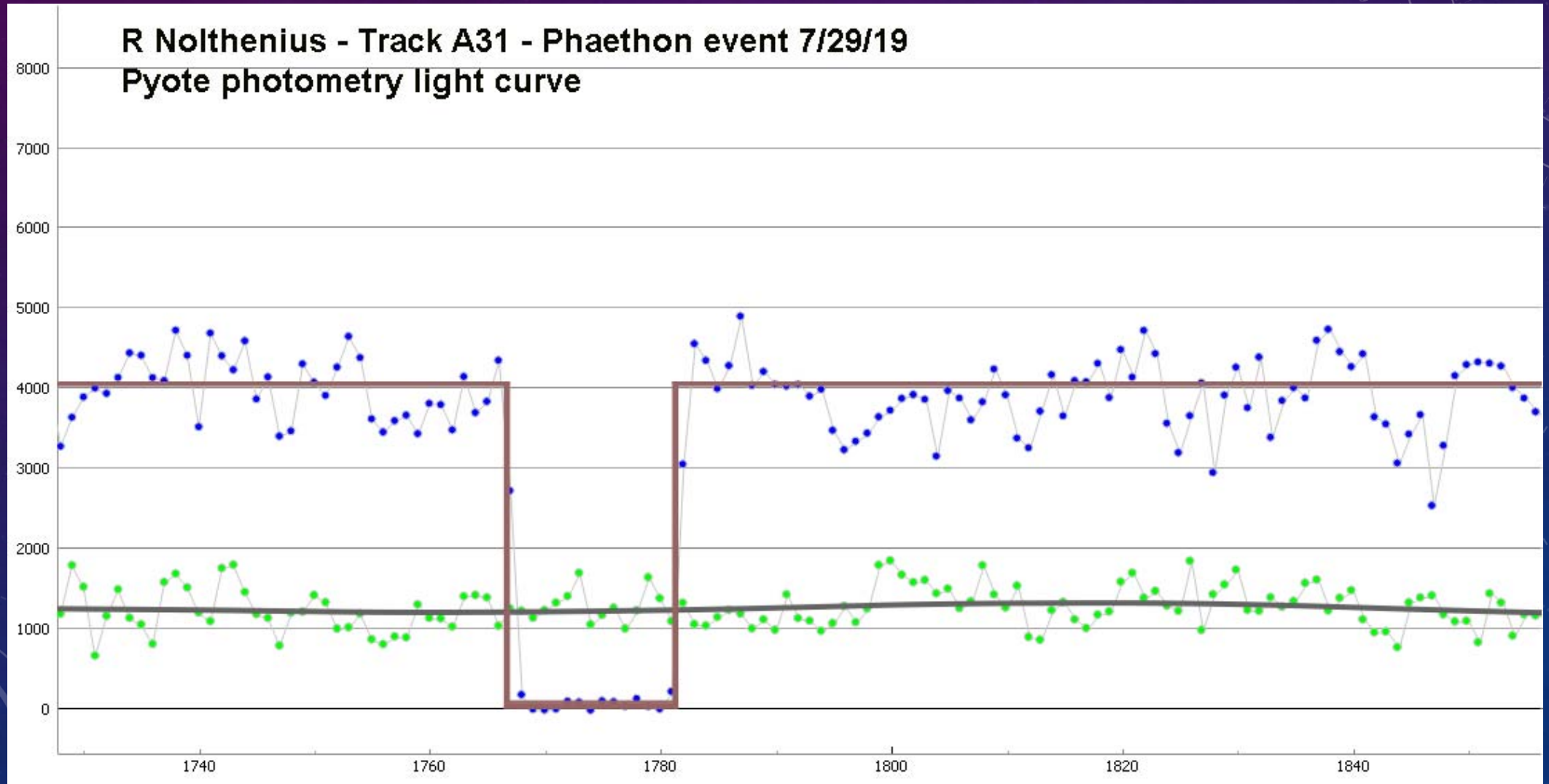


I, and my former student and ace asteroid chaser Kirk Bender joined the effort, setting up on assigned tracks at **Carrizo Plain National Monument.**

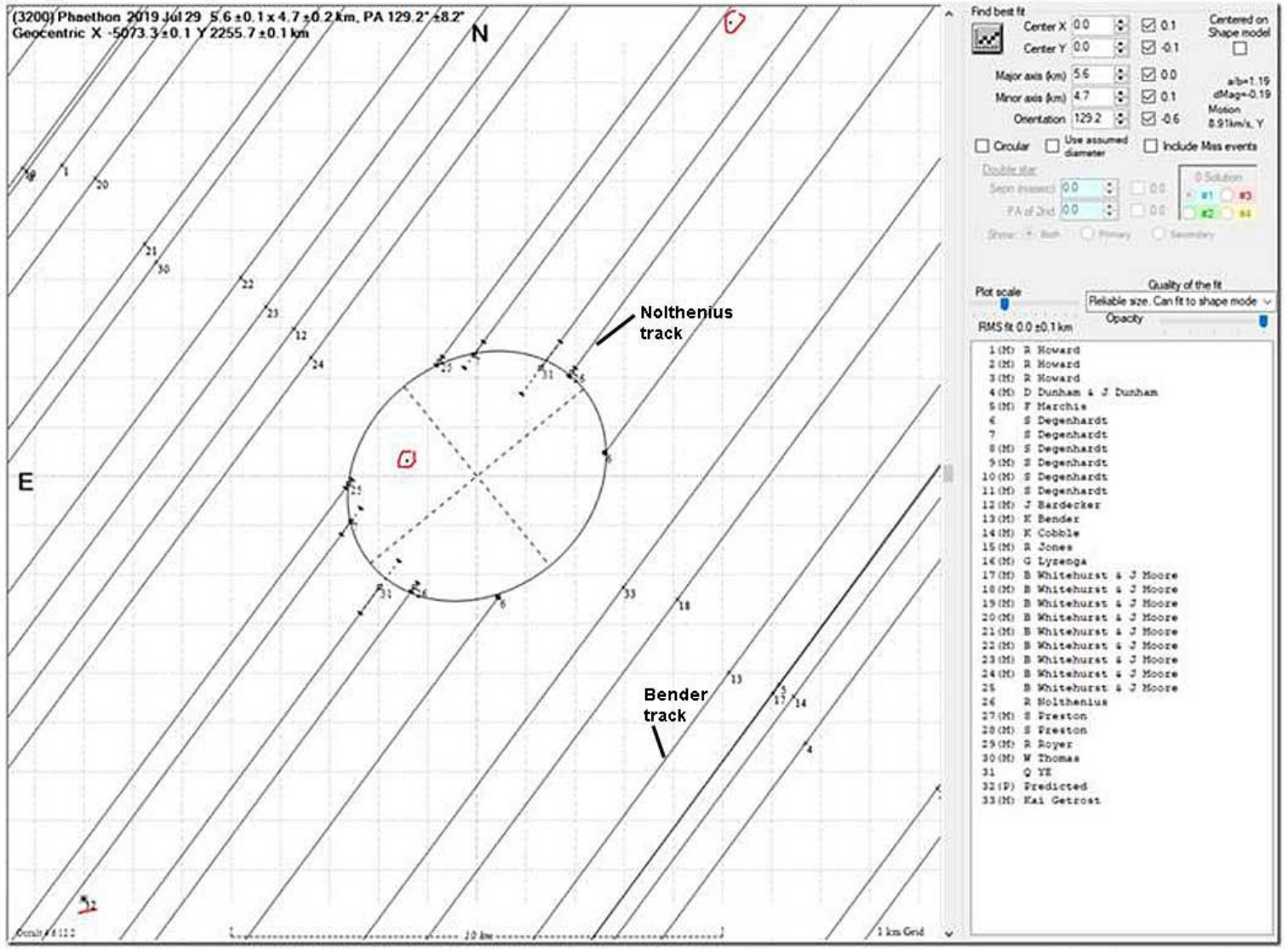
I was assigned a high probability track, and got lucky. The light curve (in blue) of the V=7.1 star and Phaethon: Tiny! Less than ¼ sec long! Success! (24s YouTube video of my occultation)



Zoomed in. A 7.1 magnitude star makes for very high signal-to-noise ratio. Very rare to get such a high value event on such a bright star. 11th -13th magnitude stellar targets are more typical.



2019 July 29 Occ'n of 7.3-mag. HIP 24973 by (3200) Phaethon – Preliminary Sky-plane Plot



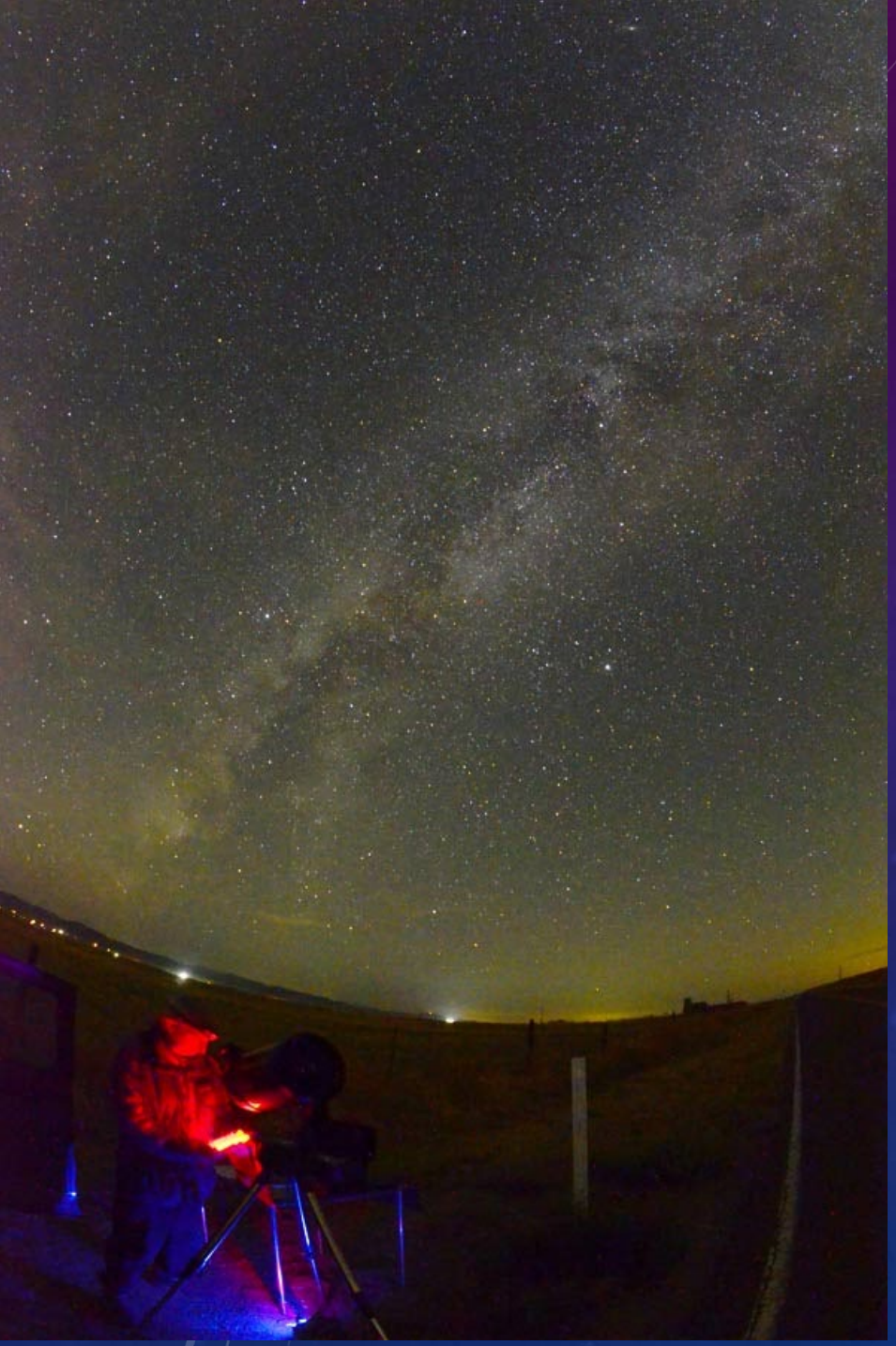
IOTA chords only; SwRI has a bounding negative and 2 more positive chords.

John Moore, Dave Herald, and David Dunham, 2019 August 7

Excellent data.

This asteroid shows significant non-grav forces, and is a threat to Earth. ELE!

Orbit changes for NEO's are vital to monitor. Now, future Phaethon observers can be placed with far better odds of an occultation success



At my Phaethon site…

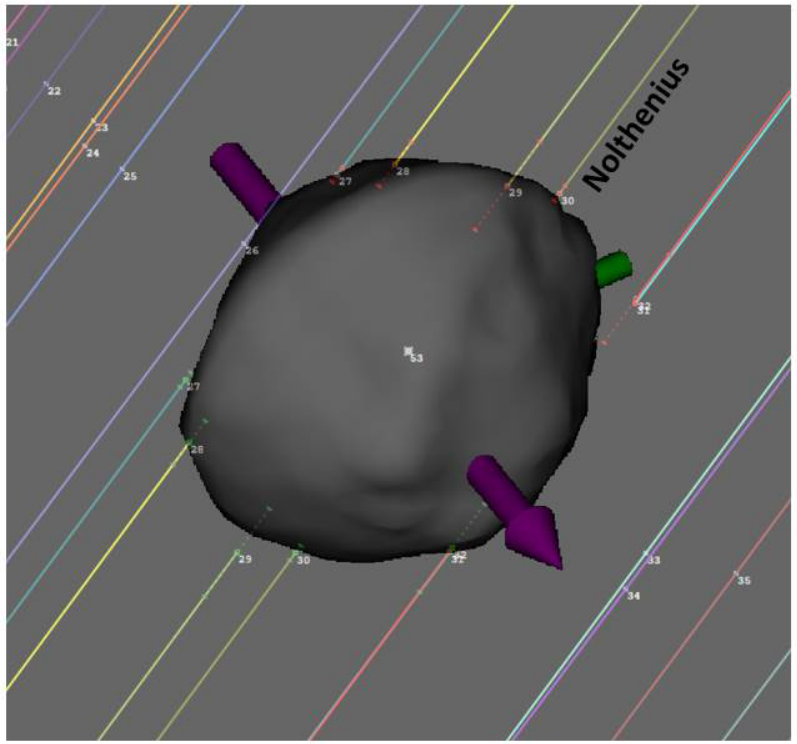
Exciting to be under dark Milky Way skies getting good science.

(YouTube; 28min talk on this event in wider context)

Combining our occultation and radar to measure the axis, shape, orientation. Valuable to the JAXA's Destiny+ Space Mission to this unique dead comet and Earth Threat object.

2019 July 29 Phaethon occultation, positive chords

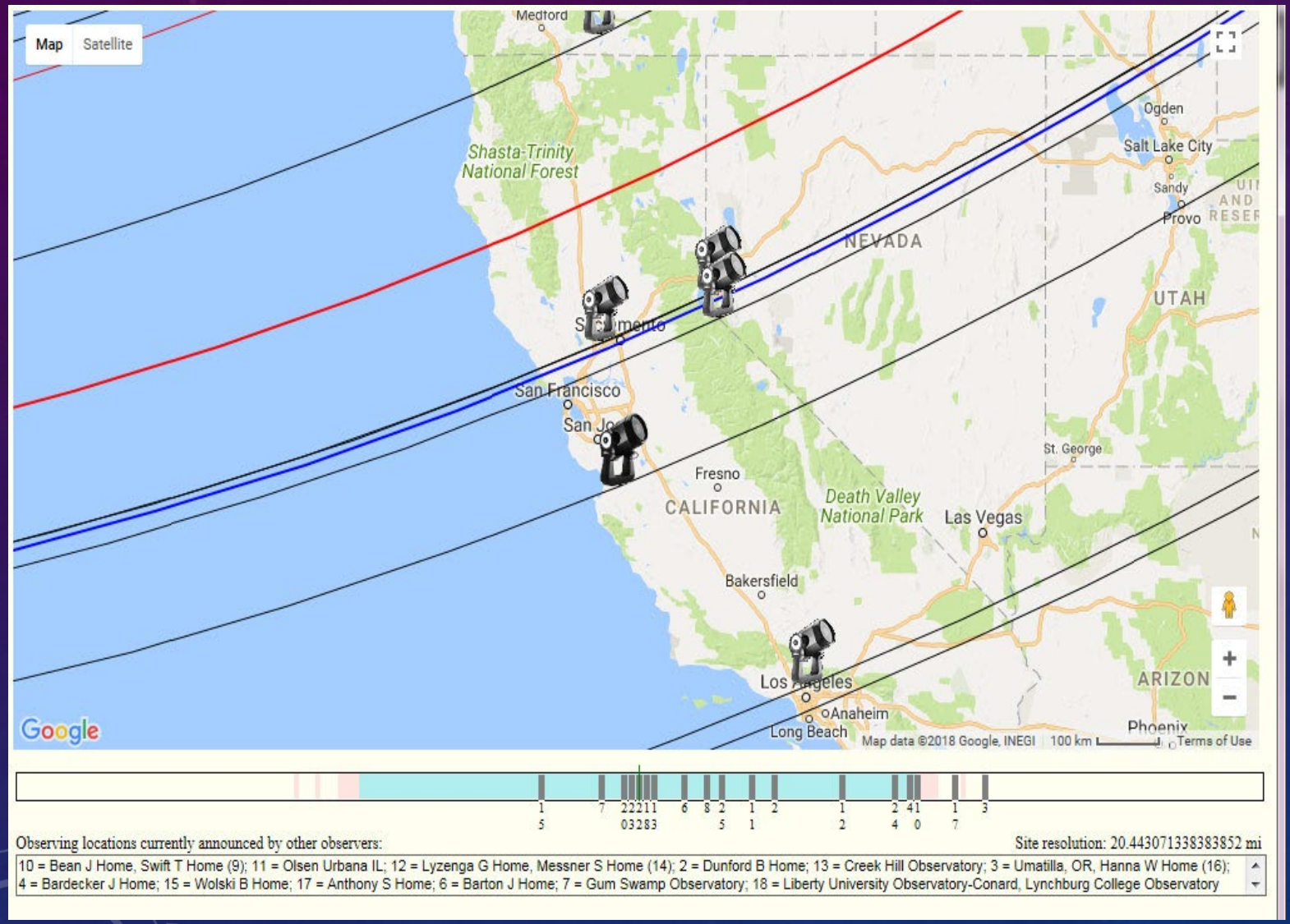
fitted to a shape model determined from 2017 December Arecibo radar observations



by
Dave Herald and
Sean Marshall

The event provided accurate information about Phaethon's size (verifying the radar value), shape, and orbit that will be valuable for DESTINY+'s planning, and will help obtain more data from future occultations that can be better predicted.

Next: The Occultation by Pluto of a V=15.2 Star on Aug 15, 2019



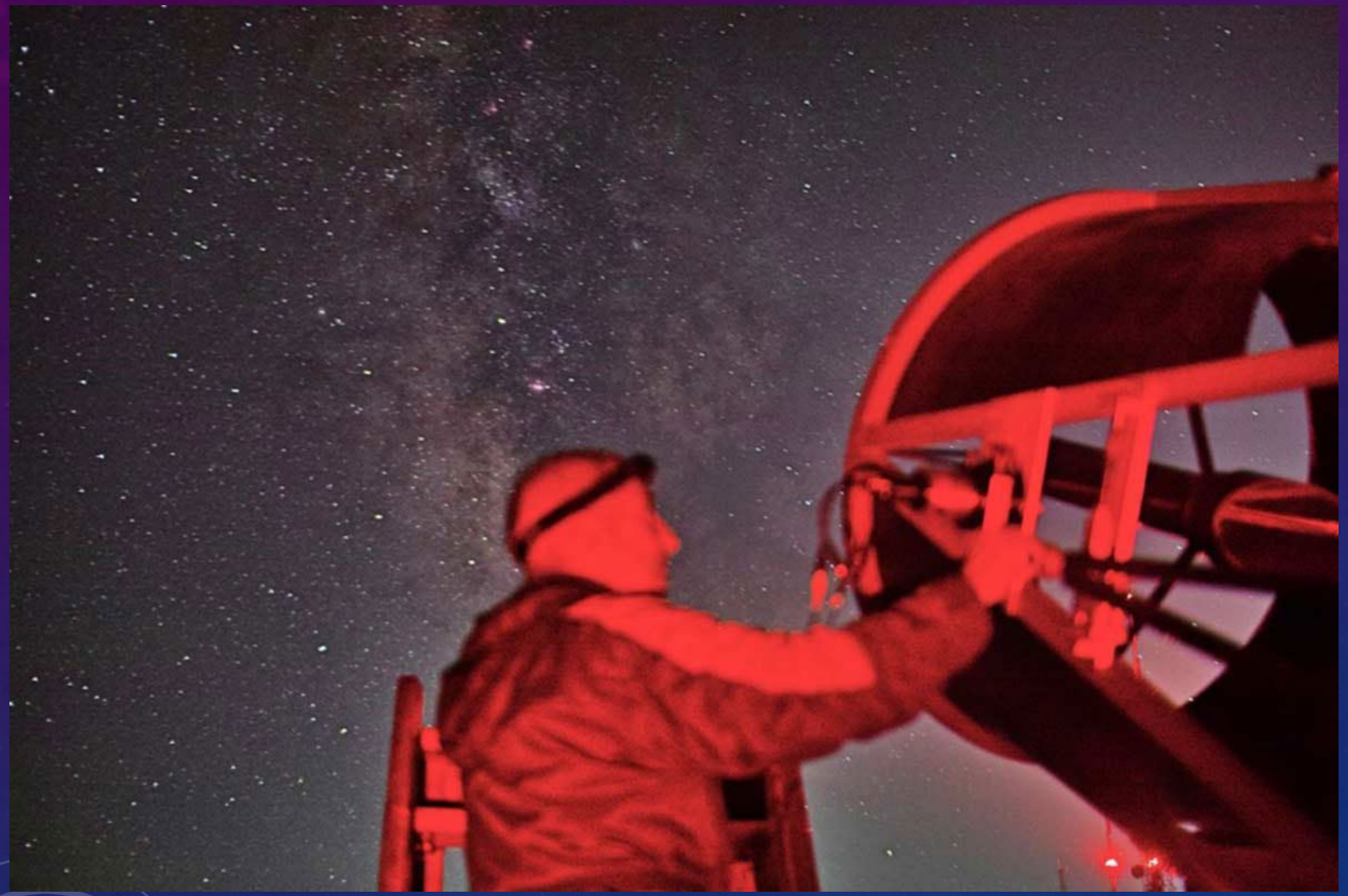
For **Fremont Peak Observatory**, the grazing atmospheric occultation allowed sensitive probing of the temperature and density structure of the now re-freezing nitrogen atmosphere.

15th magnitude?! That's REALLY faint. Our "Mission Impossible" team (left to right) : My former student and FPAO member Chris Angelos, me, and Kirk Bender, at the 30" at Fremont Peak Observatory

Chris controlled the motors on the the 30” Big Reflector.

I did fine-guiding, instrument mounting, data monitoring as it came in.

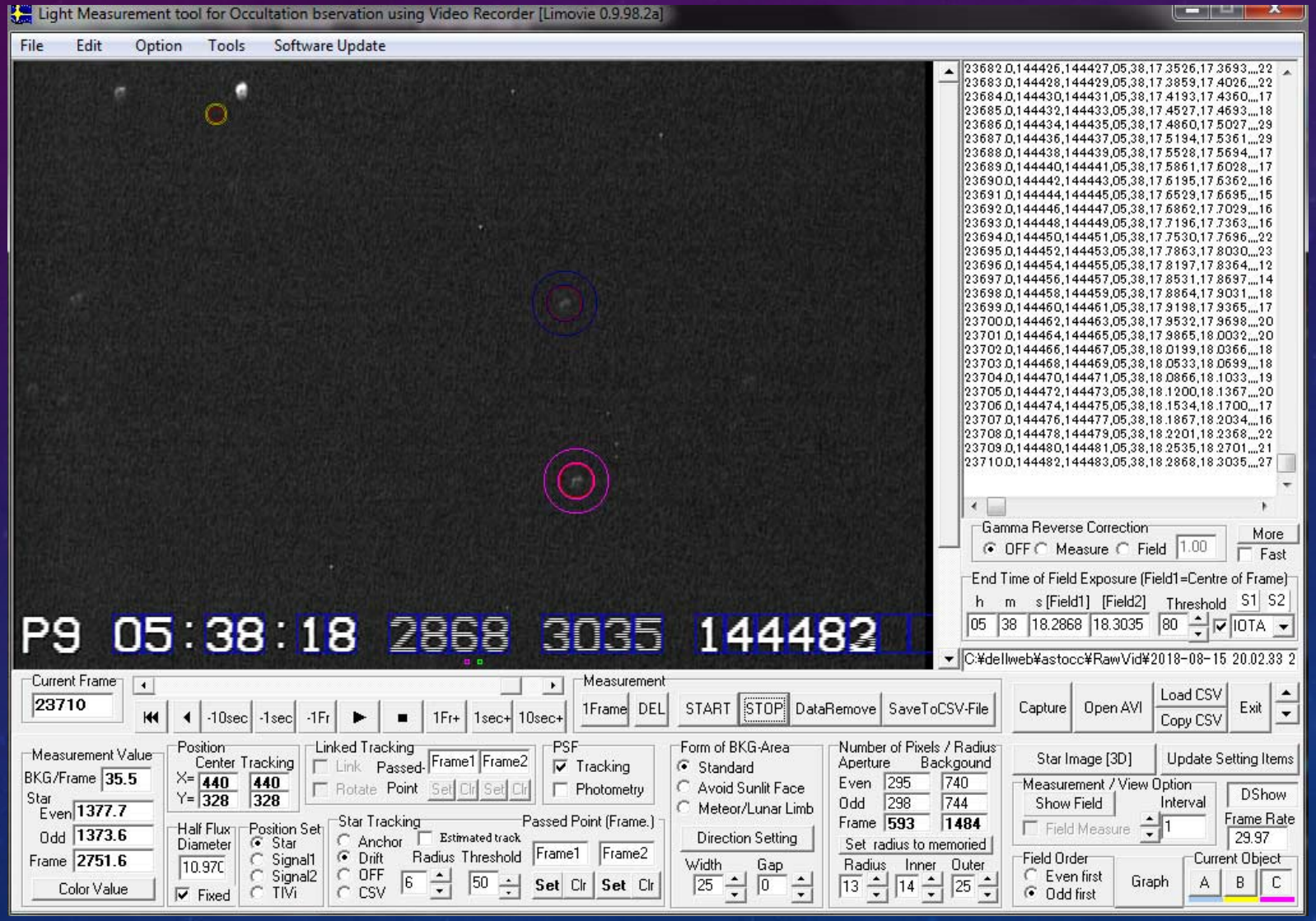
Kirk aided both of us.



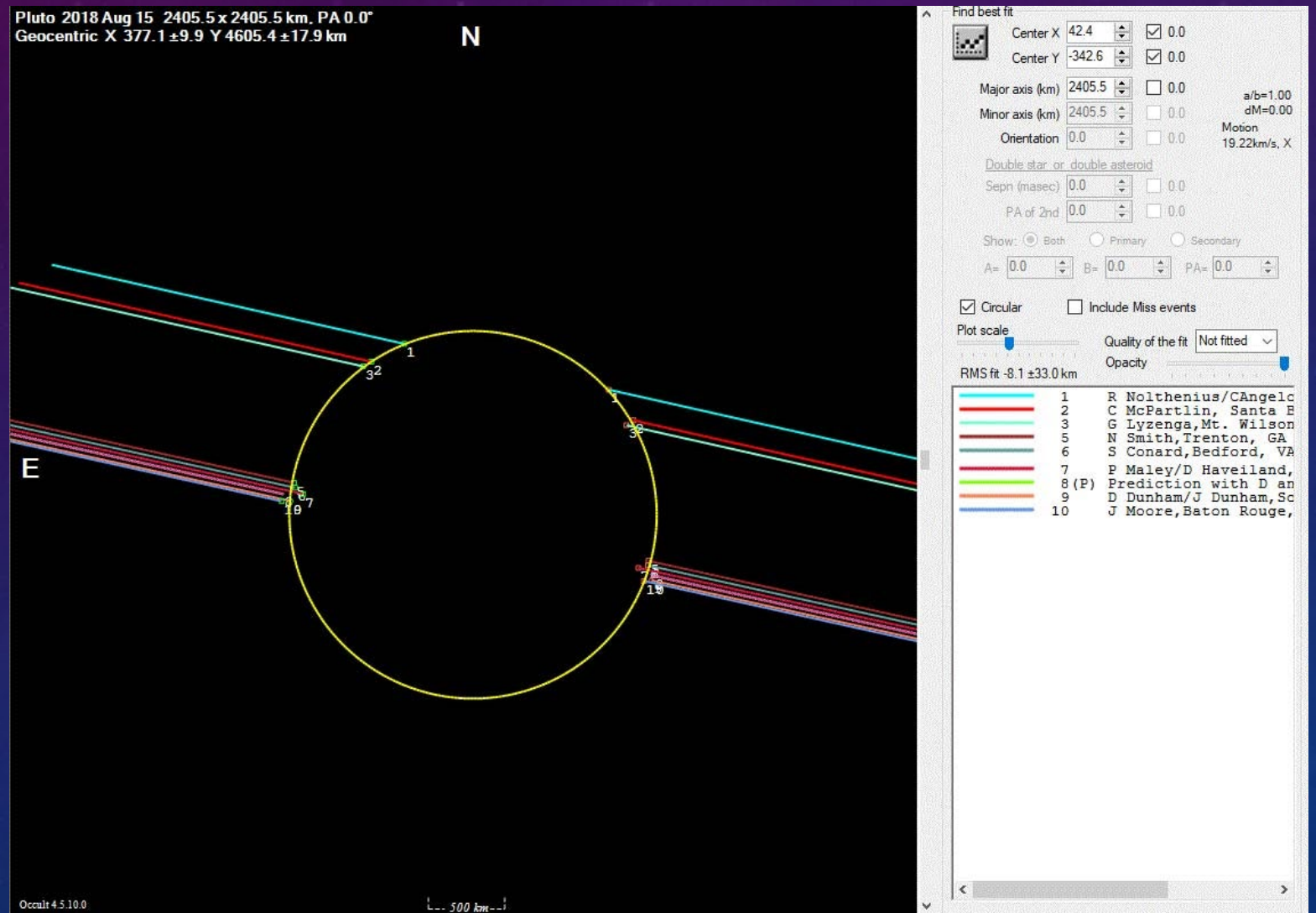
I mounted the sensitive Watec 910hx video camera at the Newtonian focus.

Pluto’s in the Sagittarius Milky Way – good for more occultations in recent years.

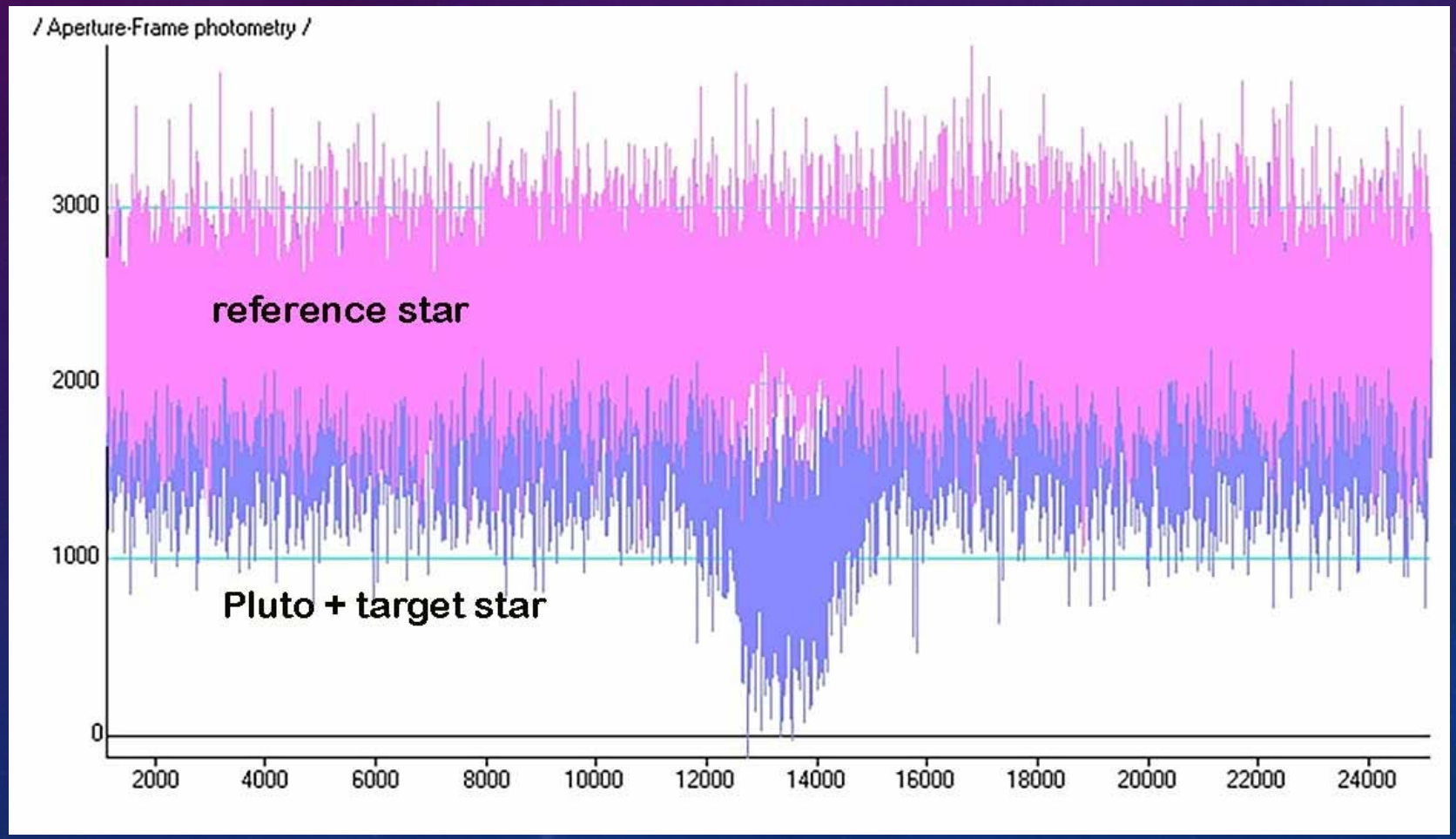
Our 2019 Pluto occultation photometry was done by LiMovie; a software ancestor to modern PyMovie



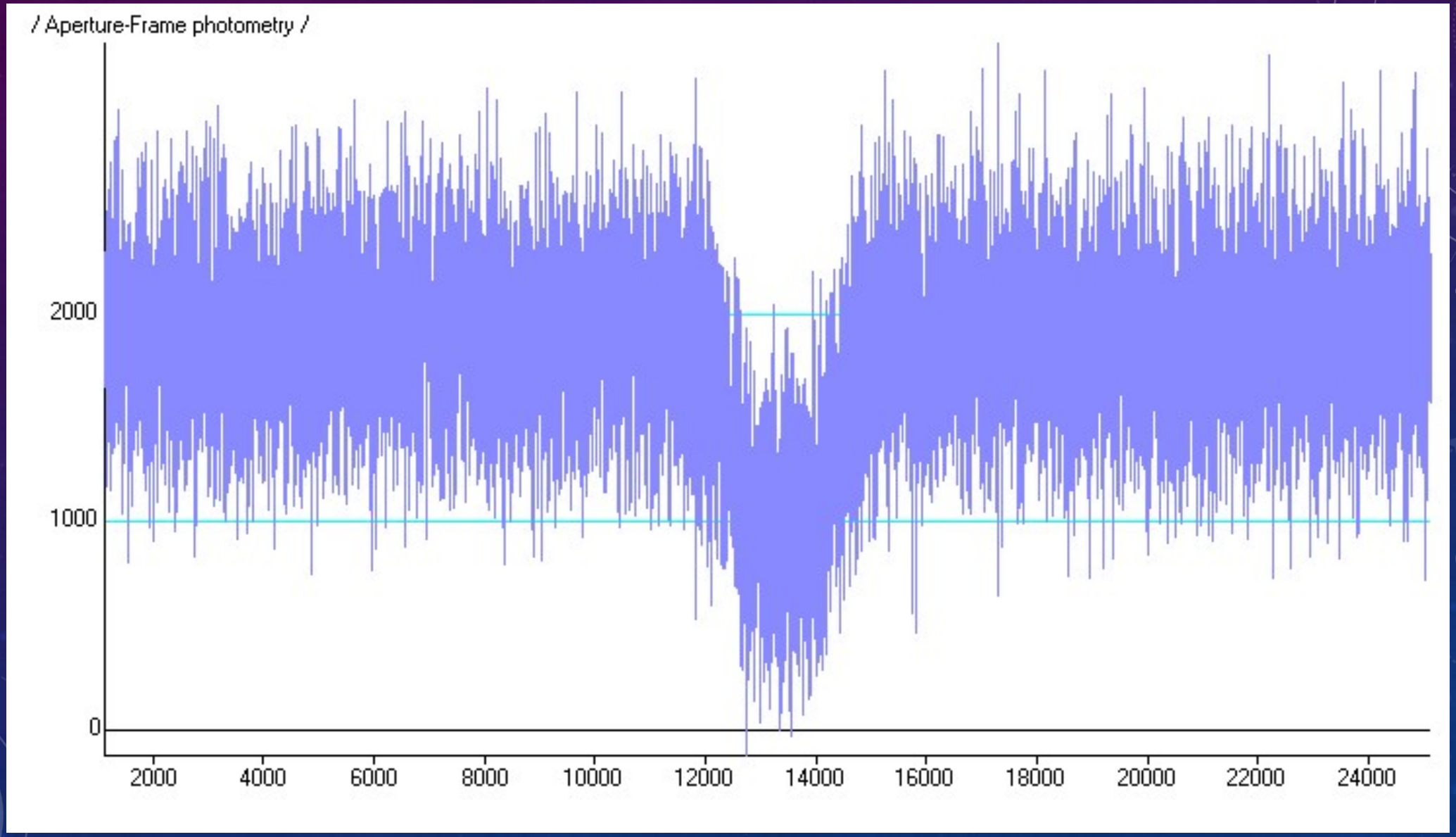
The resulting sky plane plot of the observed timings of the Disappearance and Reappearance; the “D” and “R”, by the planet (but **most** interesting and valuable was the atmospheric occultation…!



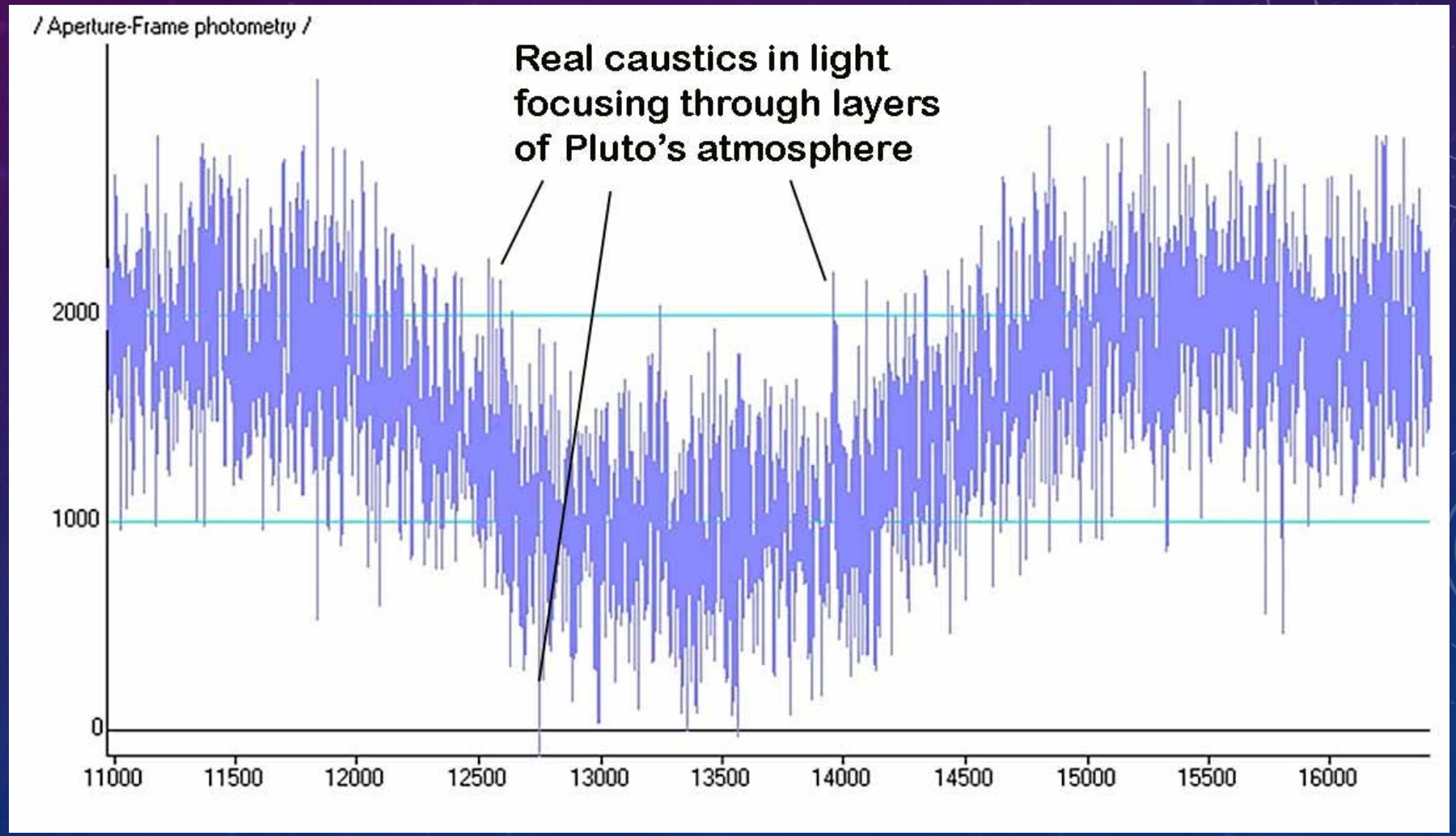
Pluto's atmosphere – is only 13 millionths of Earth's atmospheric density(!), but still gave obvious gradual dimming before/after the D and R of the occultation by Pluto itself.



Light curve of Pluto for entire data set



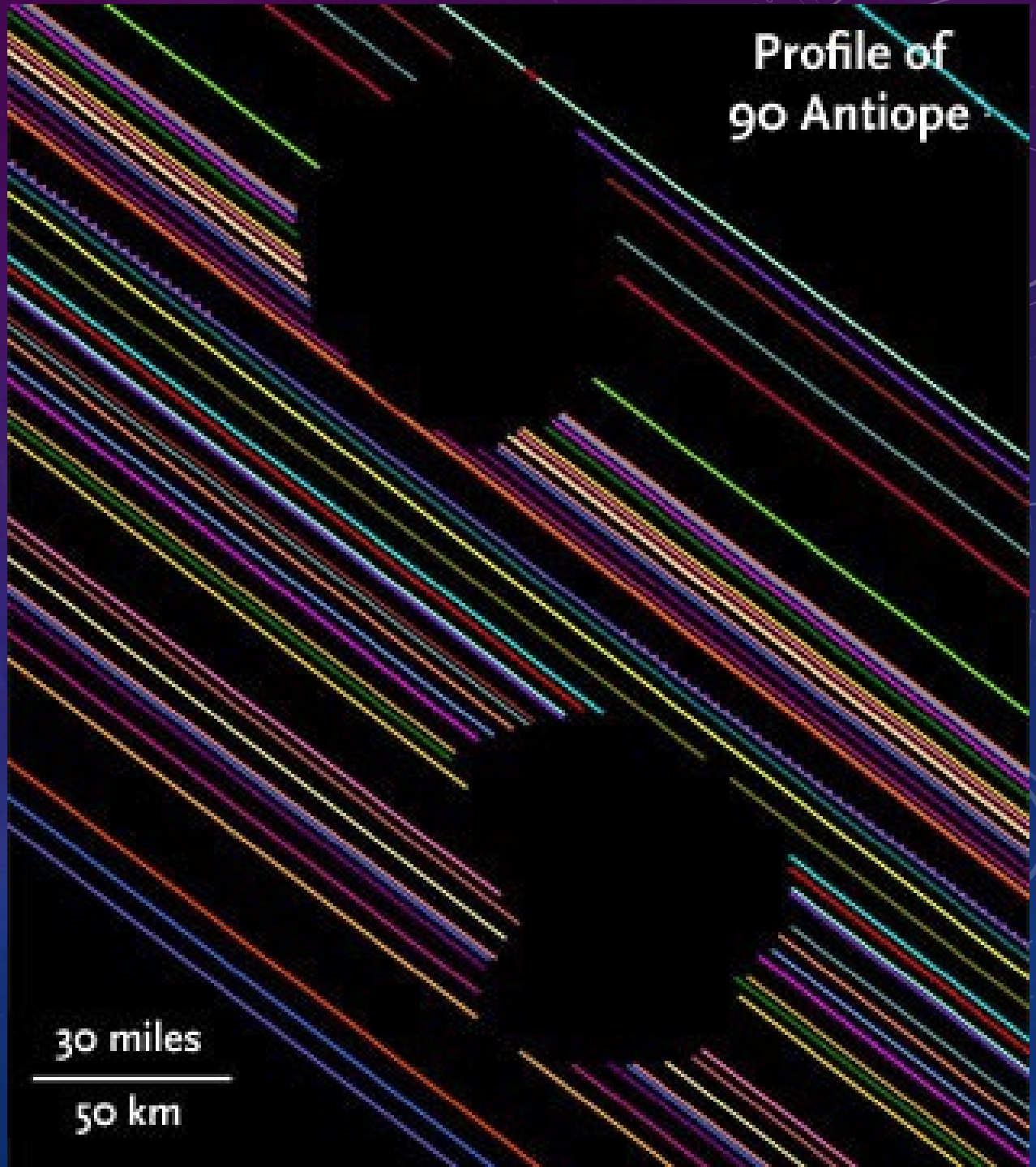
Zoomed in. Point-to-point variance is noise, but the spikes which are wider, stronger than the noise level, are real – caused by the layering of density and temperature in the nitrogen / methane Pluto atmosphere



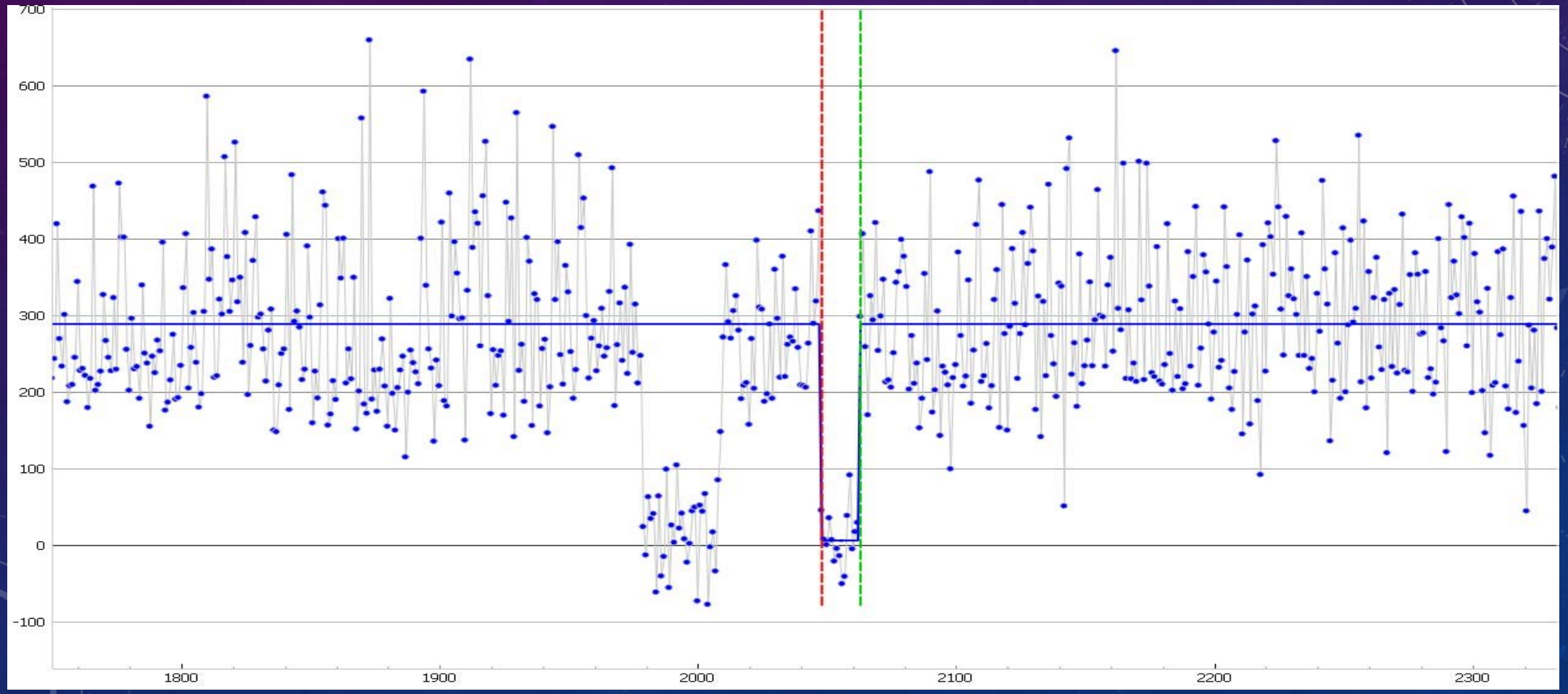
Binary asteroid discoveries…

Kirk Bender and I have tackled several events which involved ~5 different binary asteroids

The most precisely determined orbit for a binary asteroid discovered by occultation, and the first - now is (4337) Arecibo… That brings us to 2021's adventures.



May 2021 – Dave Gault and Peter Nosworthy in Australia, recorded with high confidence a surprise double occultation by **(4337) Arecibo**. David Dunham of IOTA alerted us of another favorable Arecibo occultation across Central California just 3 weeks later. Bender and I jumped into action. **Successful confirmation** – my light curve below. Kirk's was similar. Peter's 8 min video on their discovery.

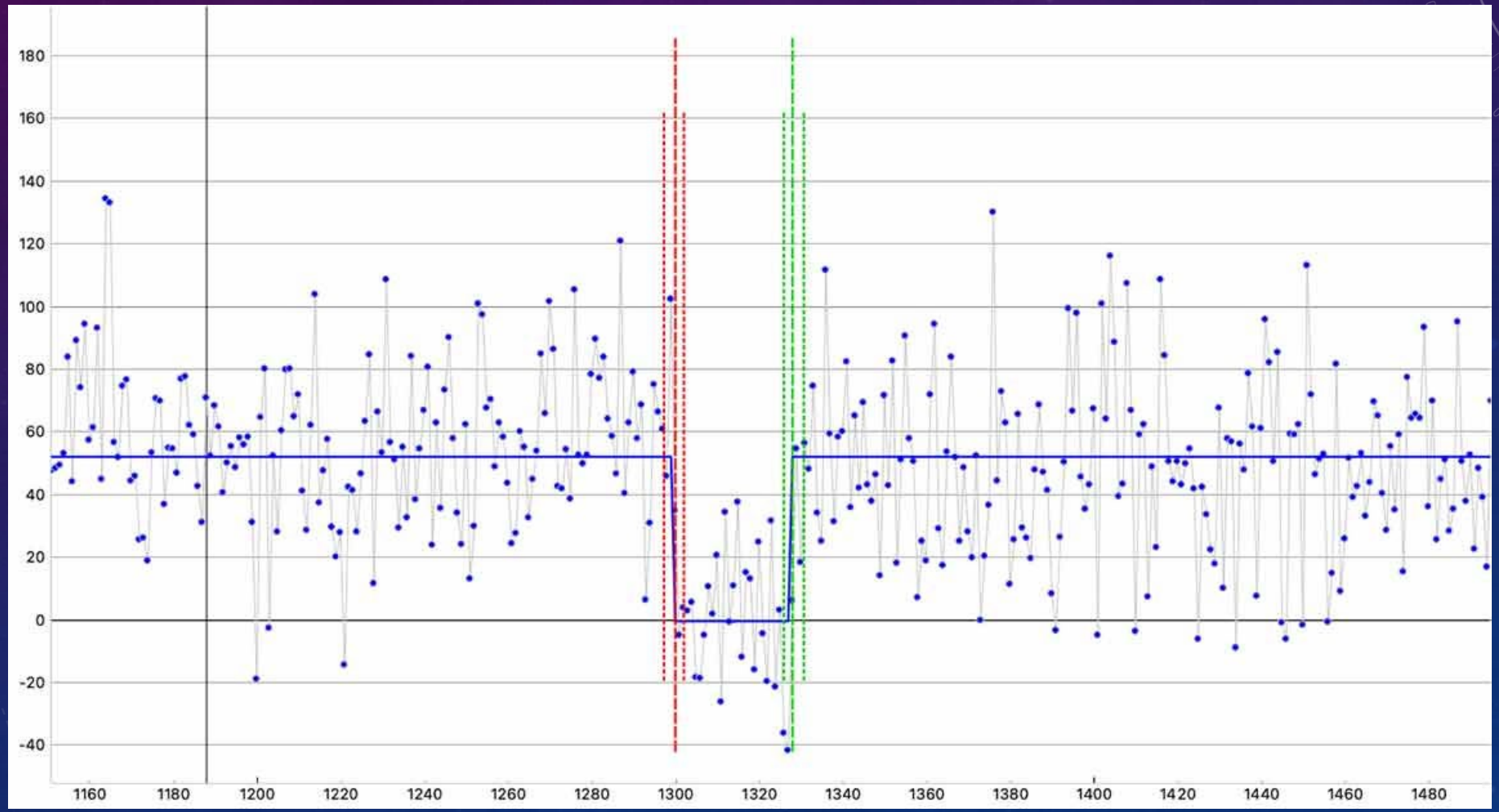


Remarkably; another 3 weeks later: Kirk Bender, CSU Professor Chris Kitting, and I got another Arecibo occultation, from the Sacramento River Delta area on June 30, 2021.

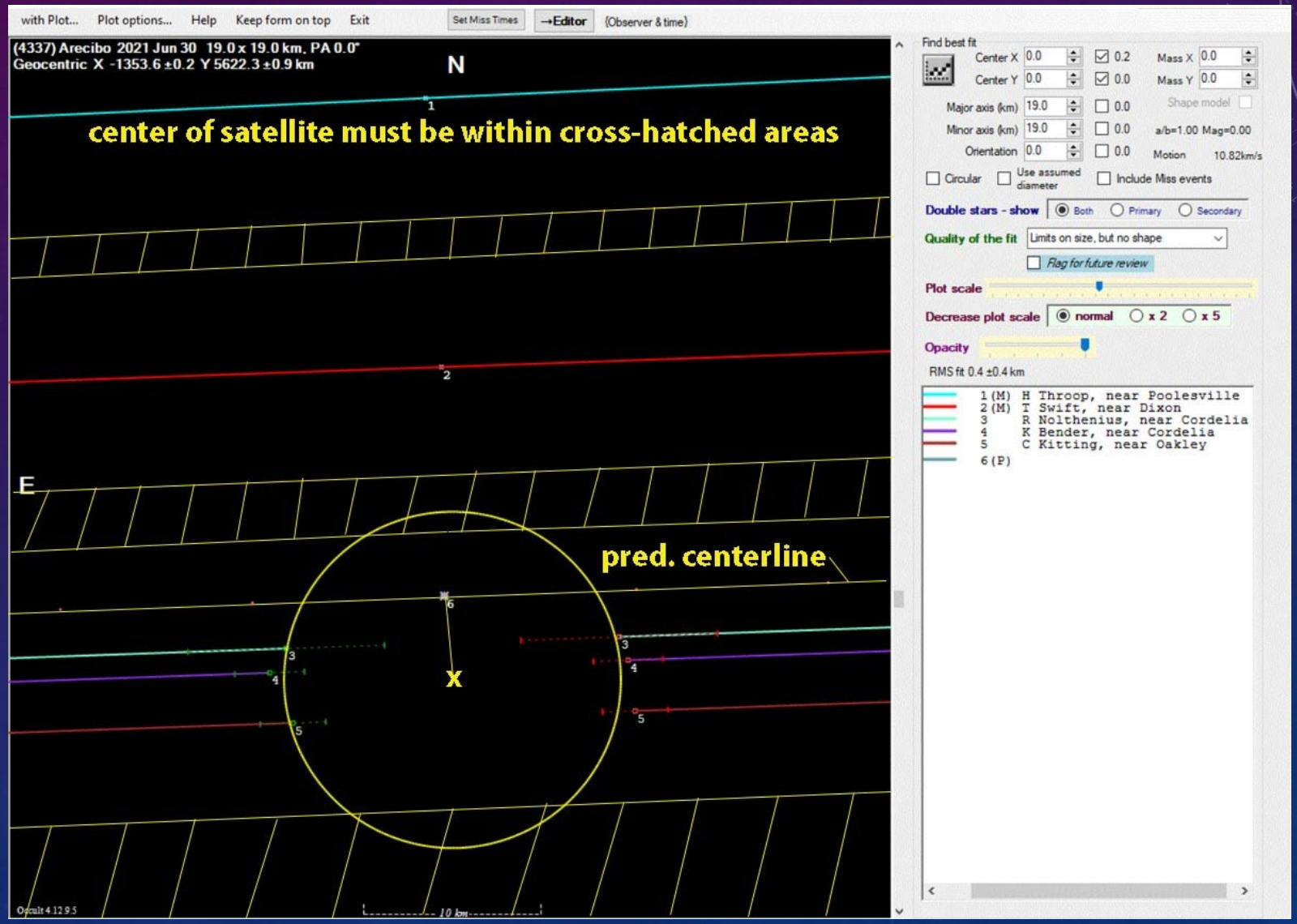
Alas, high winds and unlucky placement of the moonlet gave only single occultations.

This impromptu wind shield (table lashed to my bike rack) blew off, right after the occultation, hitting me and my scope. *Danger to life and limb! Ahwell, Just More adventure!*

Kirk Bender's Arecibo site had Big Trees for wind protection and got the best data. But, still no moonlet occultation seen. Moonlet most likely in conjunction with the main body

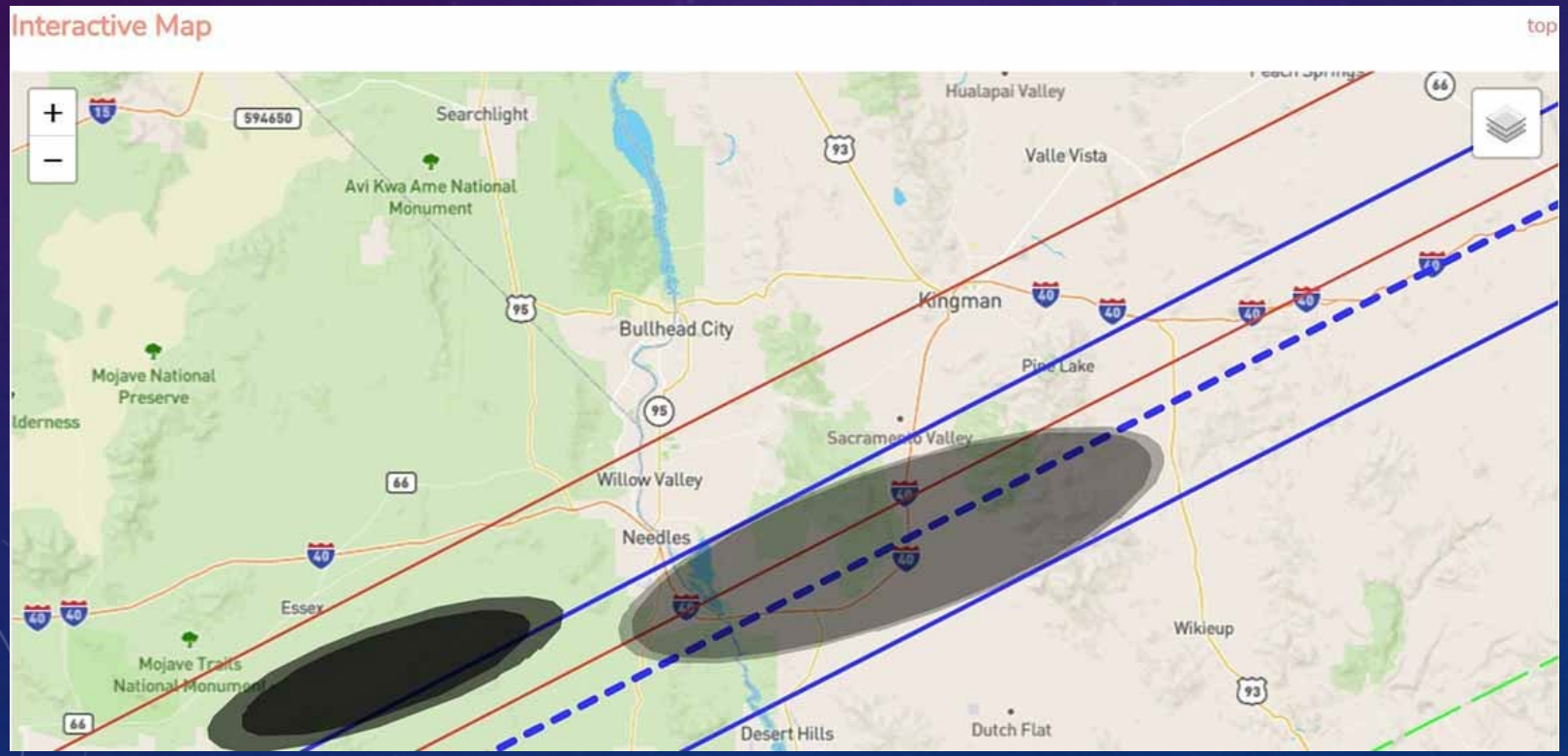


The center of the moonlet, I calculated, must be within the cross-hatched area to have avoided detection, **unless it was in front/behind the primary.**



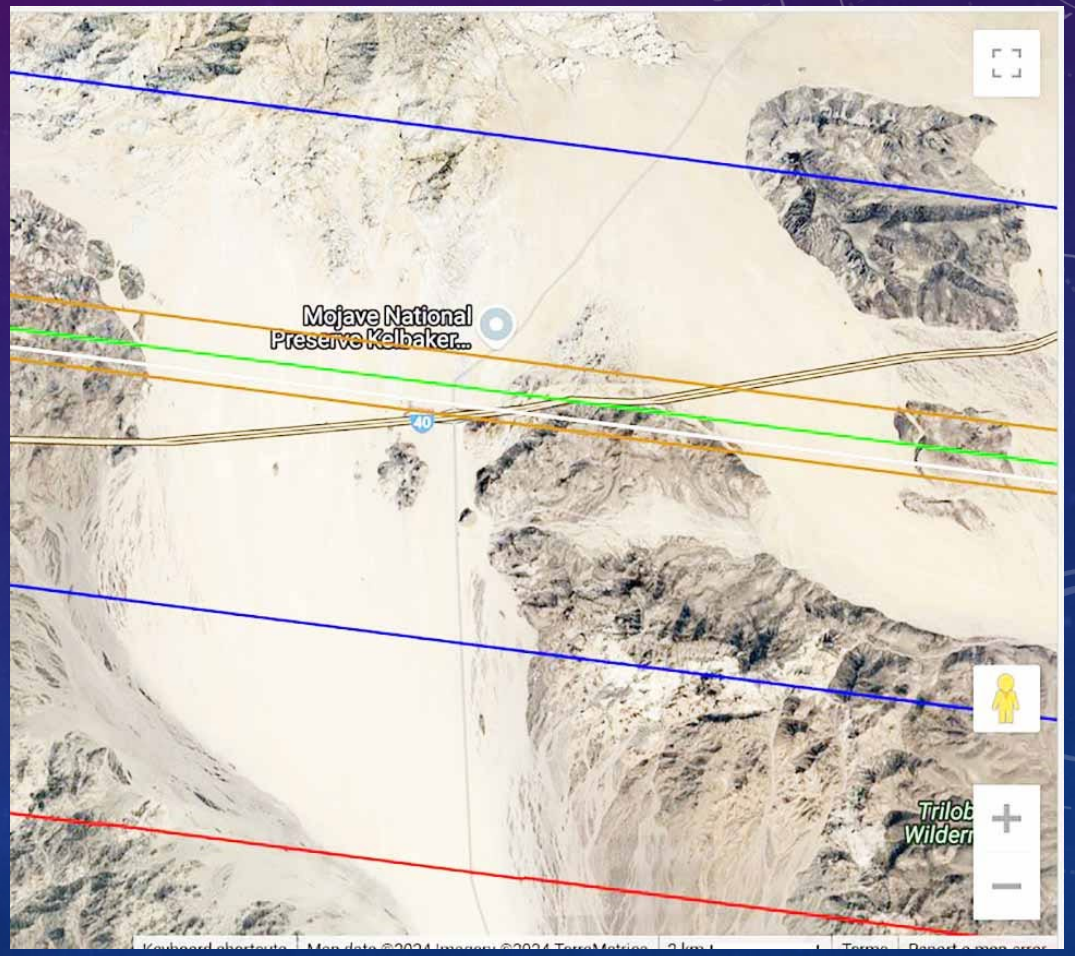
3 years later, we were lucky enough to get another occultation of Arecibo through California; on Saturday Sept 14, 2024

- A success here, with several stations set in CA and Arizona, would allow finally a unique orbit solution.
- With a firm orbit, the masses of the asteroids, their sizes and albedos and hence surface composition hints, and the bulk density of the asteroids, could be determined. So…



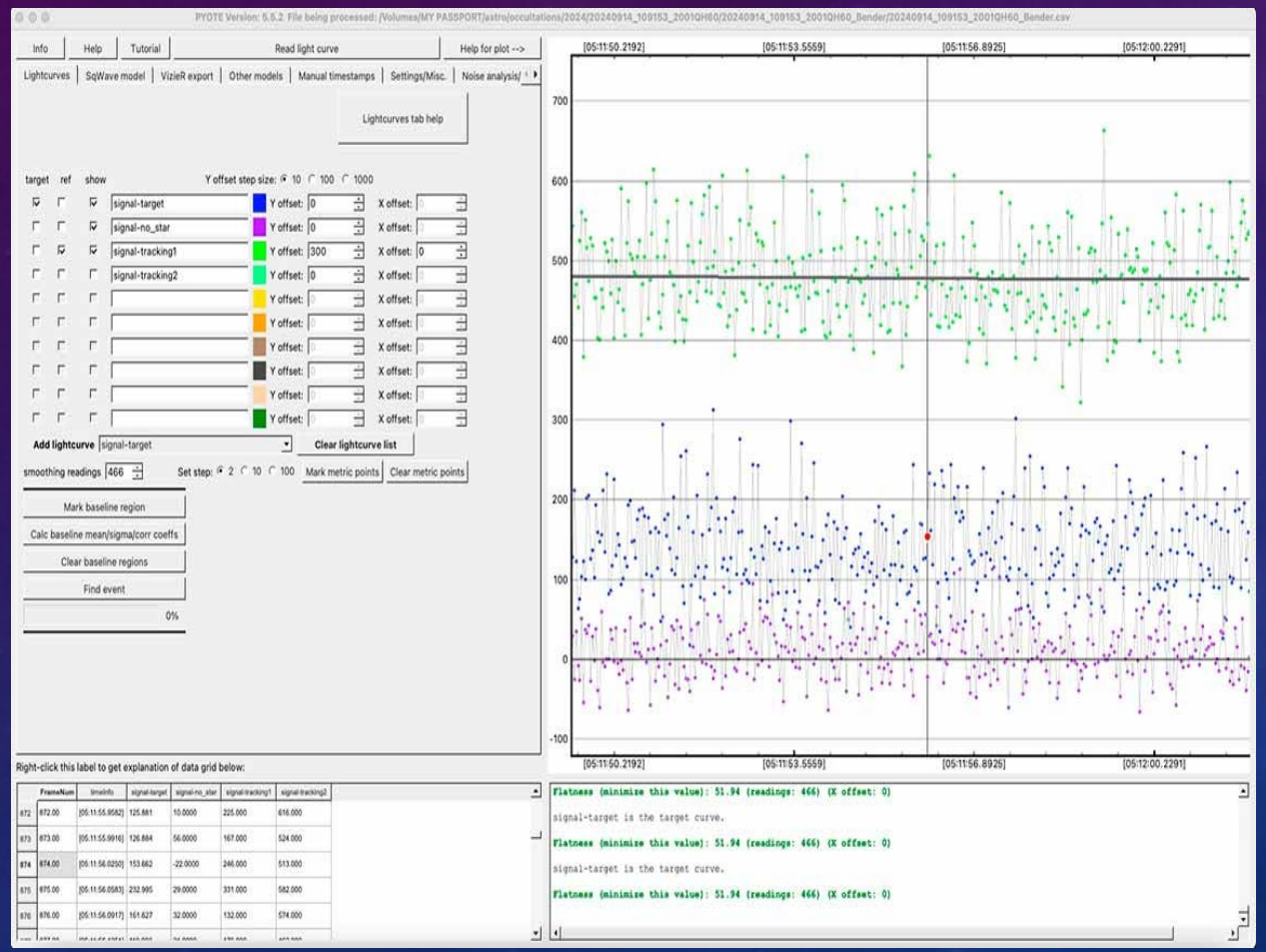
I secured a Cabrillo College van, and with Kirk Bender, set out for Needles, Ca, to get the occultation

- A 1,000 mile adventure!
- On the long drive through the Mojave Desert, we got two more asteroid events which happened to be conveniently path'd and timed to fit with our drive to Needles. The first was by 2000 CT83, a miss for both of us.
- An hour later, 2001 QH60; is a recently discovered asteroid needing occultations to firm up its orbit.
- It crossed I-40 south of the Mojave National Preserve. Remarkable luck: Both events were do-able from the same sites!

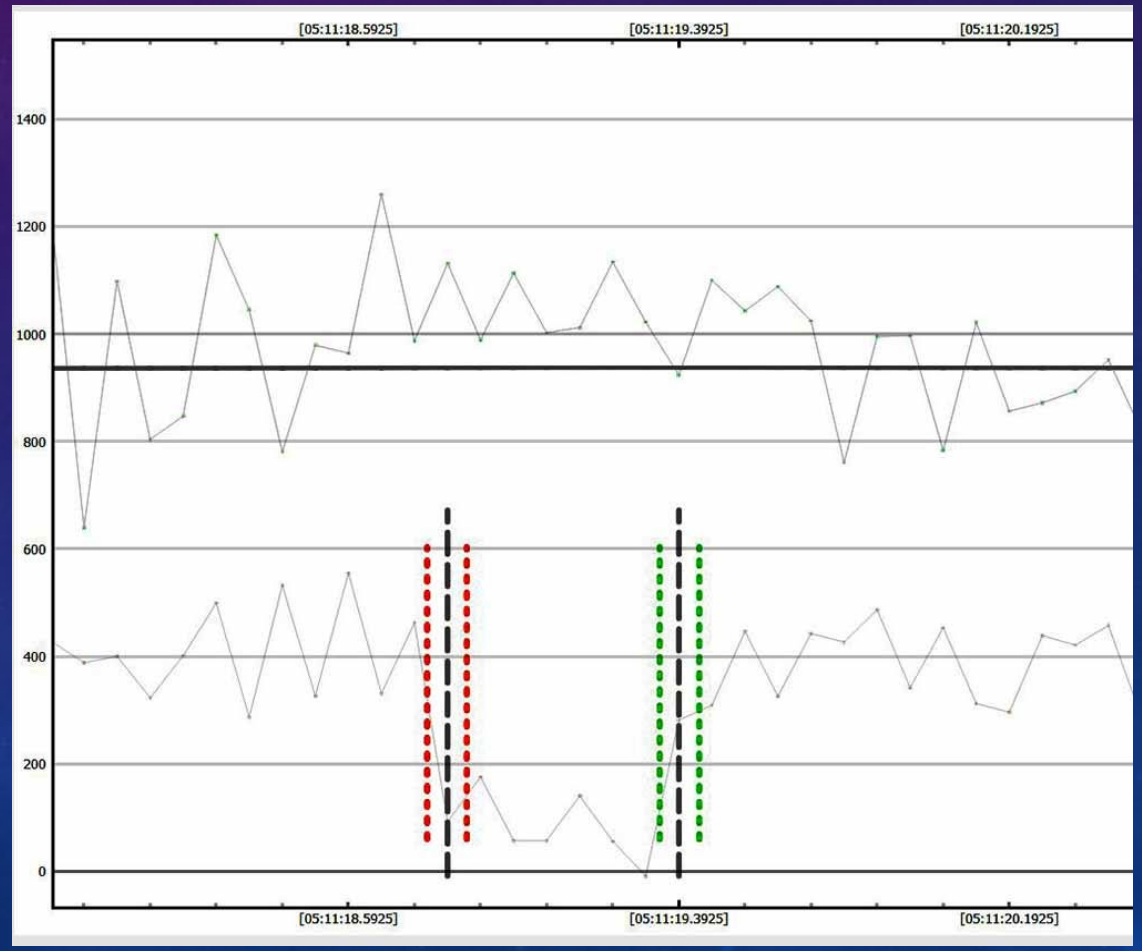


2001 QH60: A south shift; Kirk Bender's site missed the shadow, I was luckier and got a positive occultation.

Kirk's light curve; a miss

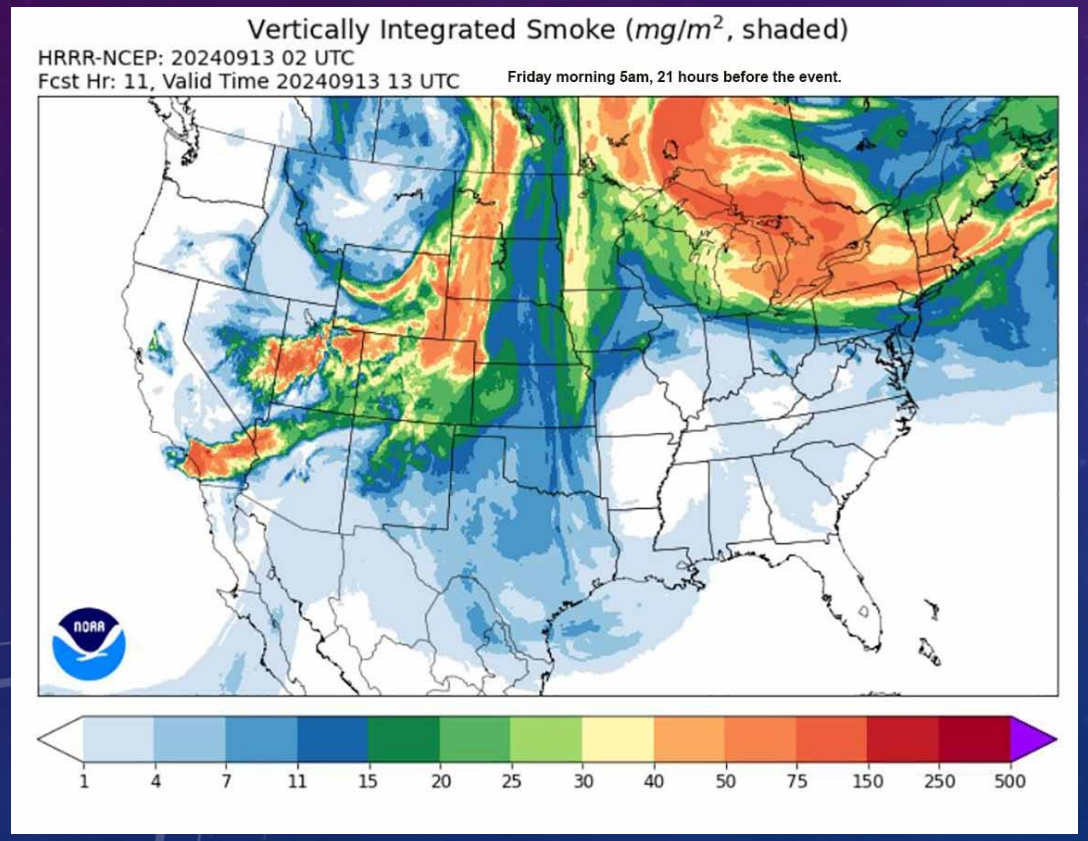


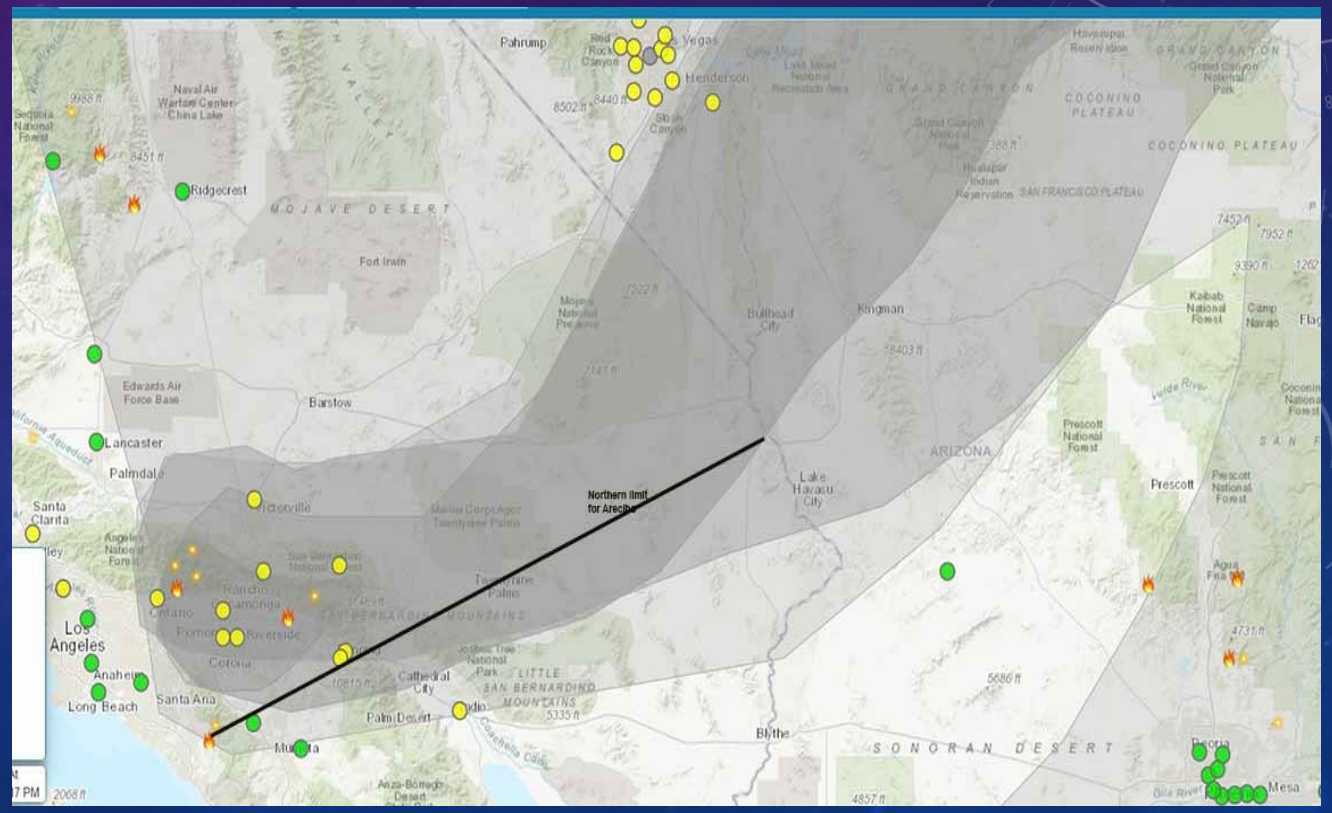
My light curve; a 0.56 sec event



Now the main event: But, a new challenge for Arecibo – smoke from wildfires in So. Calif. My site selection was shifting on the fly, with changing smoke predictions… Idyllwild was abandoned for Needles, in the end.

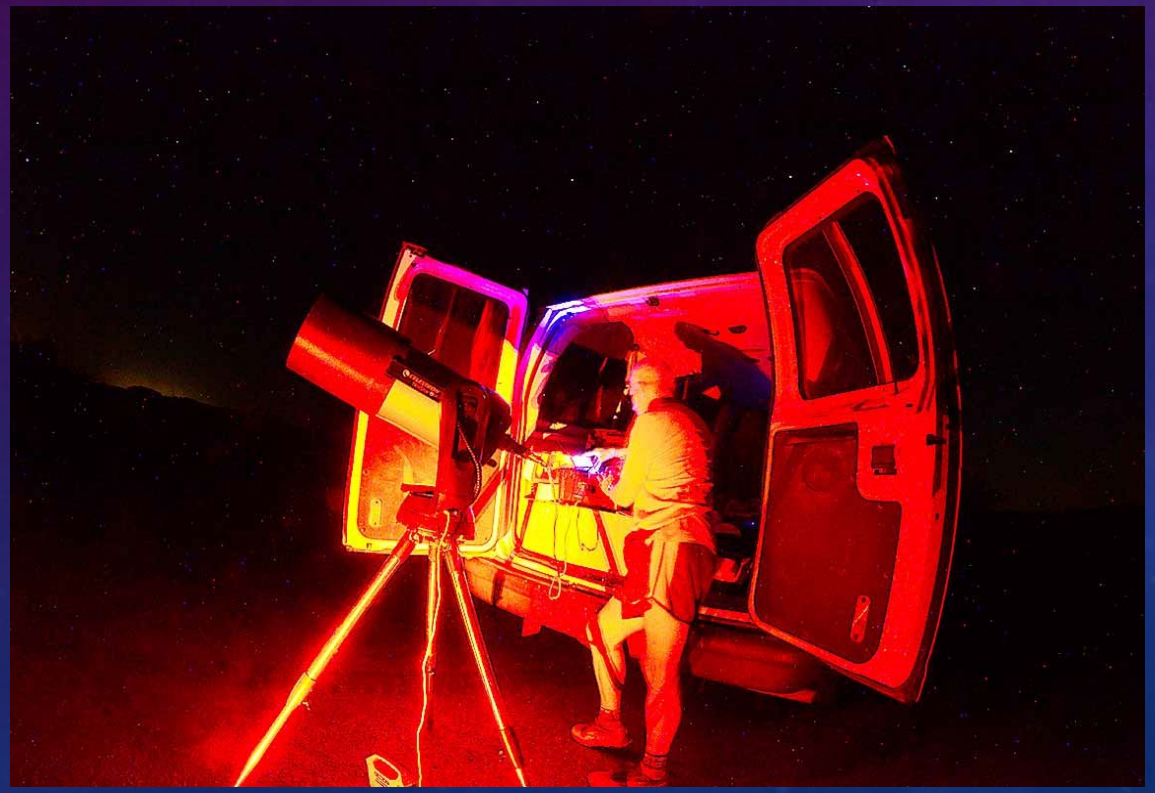
- Smoke predictions! Not good



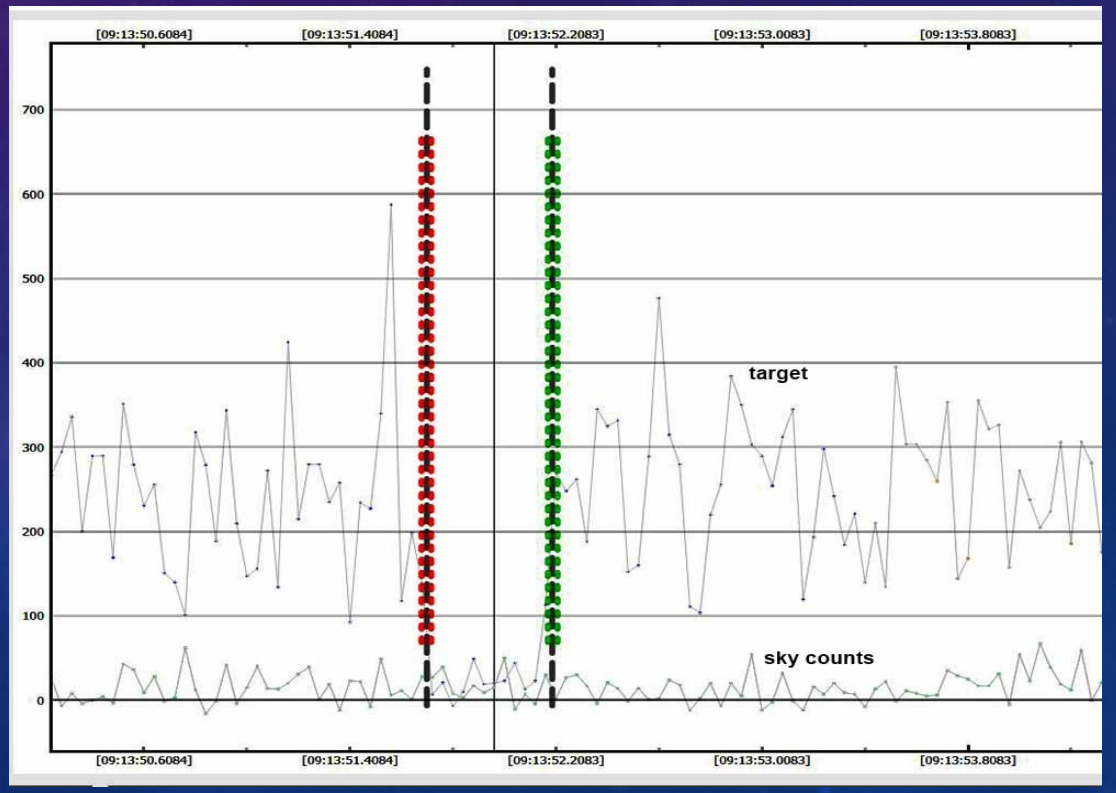


We noted on iPhones while driving, the smoke plume had drifted west, and so we had no trouble in the Eastern Mojave. Kirk and I had a very successful effort.

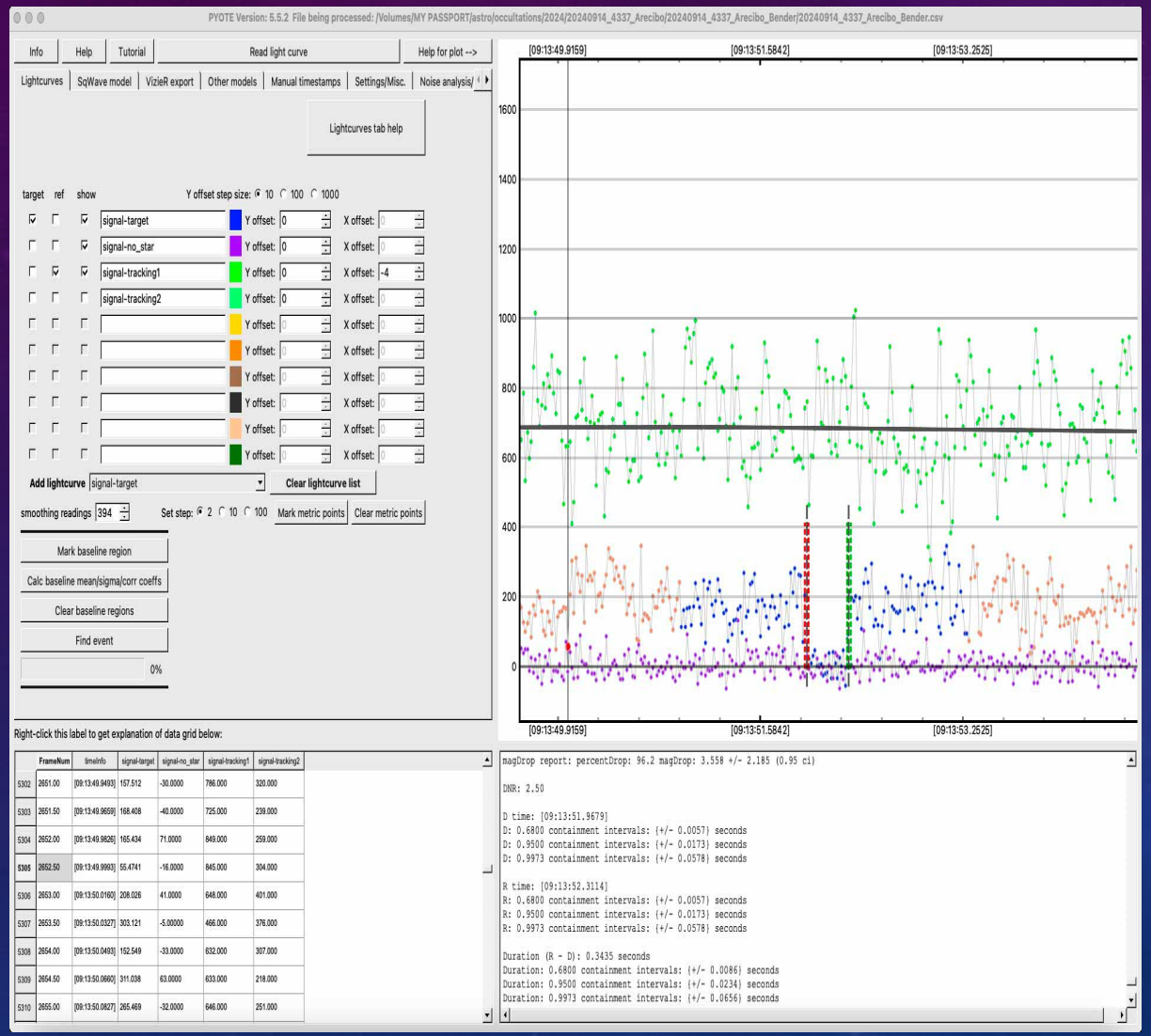
Me, at 2am, still in my running shorts in 80F temperatures

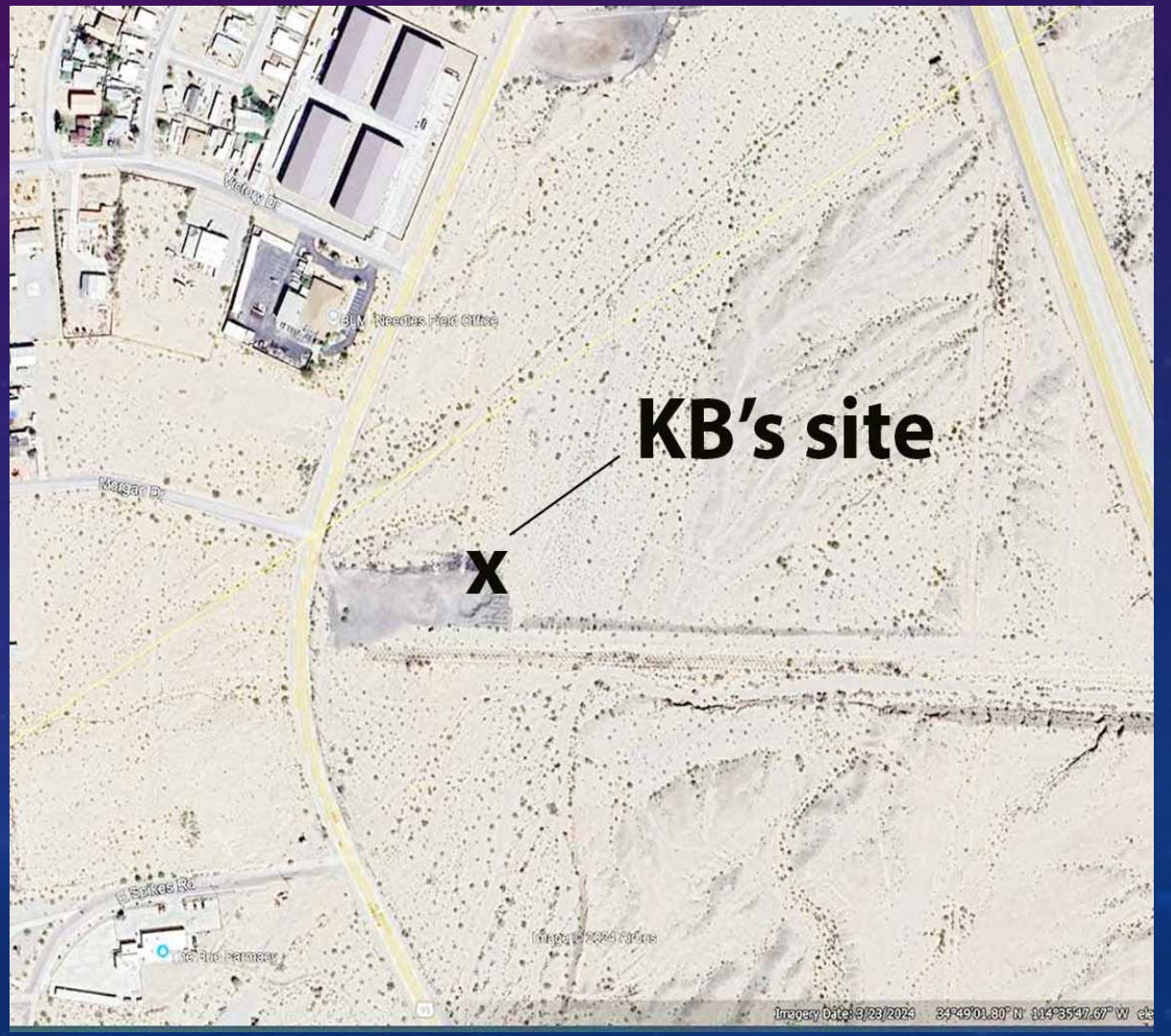


I saw a single occultation



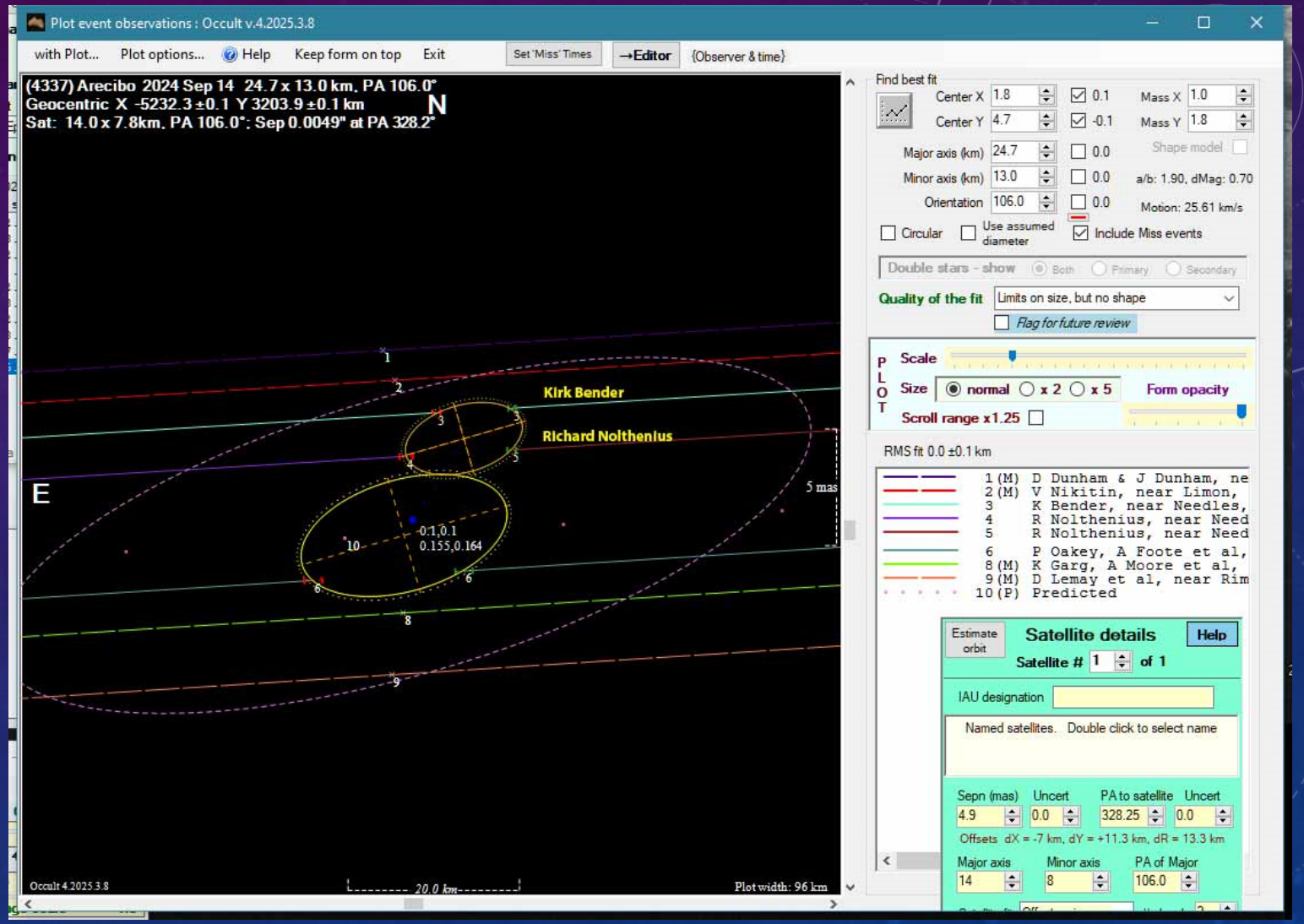
Kirk, too, had a single occultation





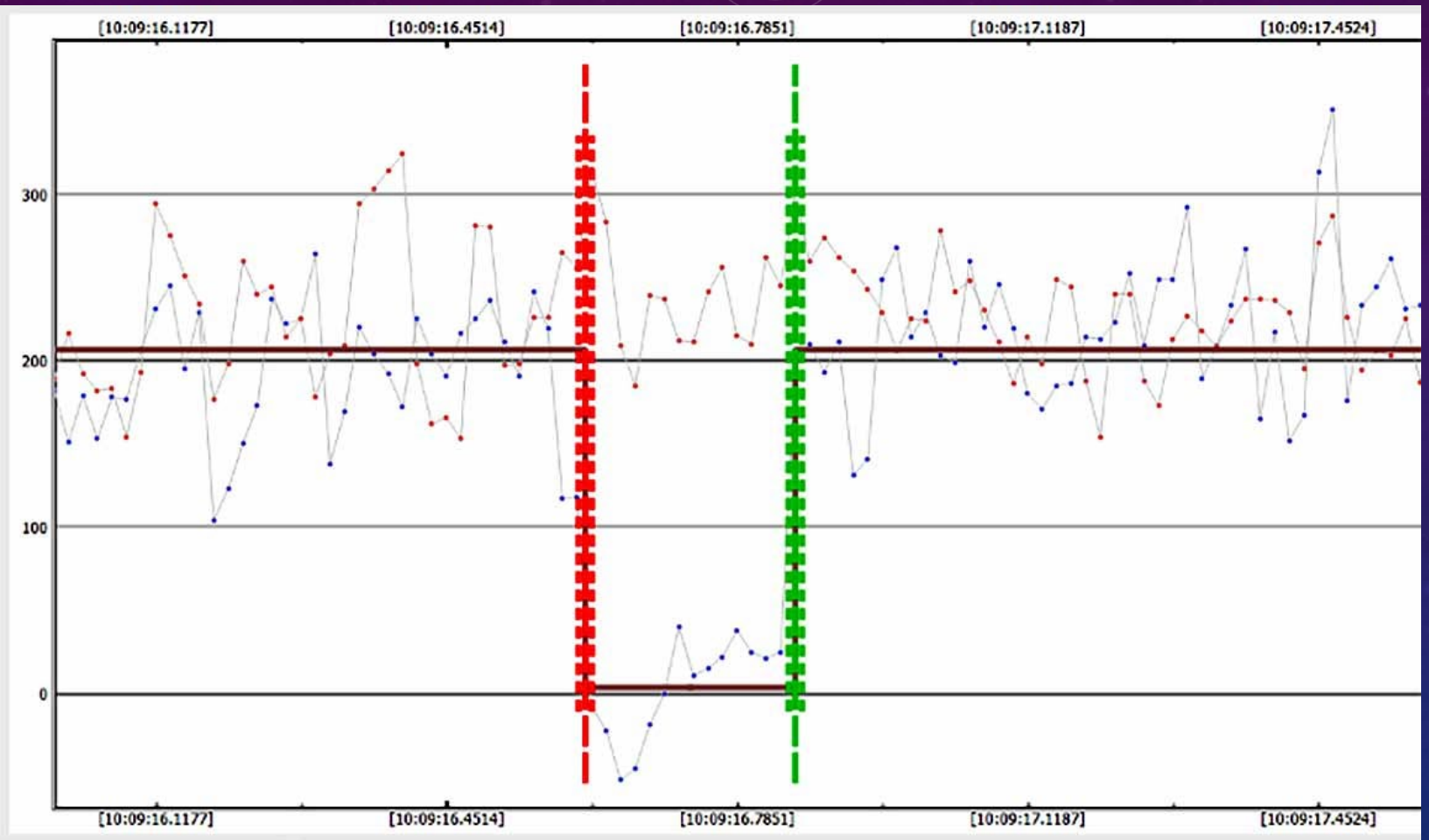
IOTA's Dave Herald and Dave Gault, using their OCCULT4 software, determined the best solution for these objects this night.

For Kirk and I, our 4 events were all on the moonlet. Oakey and Foote got an event on the main Arecibo parent, pinning the positions of this pair!



Next: Nov 12, 2022. The DART mission - NASA tested our asteroid deflection ability by missile-impacting the Didymos / Dimorphos system. After a successful impact, there was high value from NASA on getting precision astrometry of the deflected new orbits; that means: **occultations!**

- An 11th magnitude occultation was predicted to cross SoCal and the Mojave Desert. But Didymos and Dimorphos are only ~1 km or less!
- Required high precision timings and placement. I love the Mojave! Kirk was game to try. We packed the Cabrillo College van and headed out to Mojave National Preserve, to complement other IOTA occult'rs Robert Jones, Paul Maley, and Norm Carlson. 1,000 miles of driving, but great fun.

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magDrop: 4.384 +/- 4.563 (0.95 ci)

snr: 4.74

D time: [10:09:16.6110]
D: 0.6800 containment intervals: (+/- 0.0033) seconds
D: 0.9500 containment intervals: (+/- 0.0078) seconds
D: 0.9973 containment intervals: (+/- 0.0156) seconds

R time: [10:09:16.8518]
R: 0.6800 containment intervals: (+/- 0.0033) seconds
R: 0.9500 containment intervals: (+/- 0.0078) seconds
R: 0.9973 containment intervals: (+/- 0.0156) seconds

Duration (R - D): 0.2408 seconds
Duration: 0.6800 containment intervals: (+/- 0.0048) seconds
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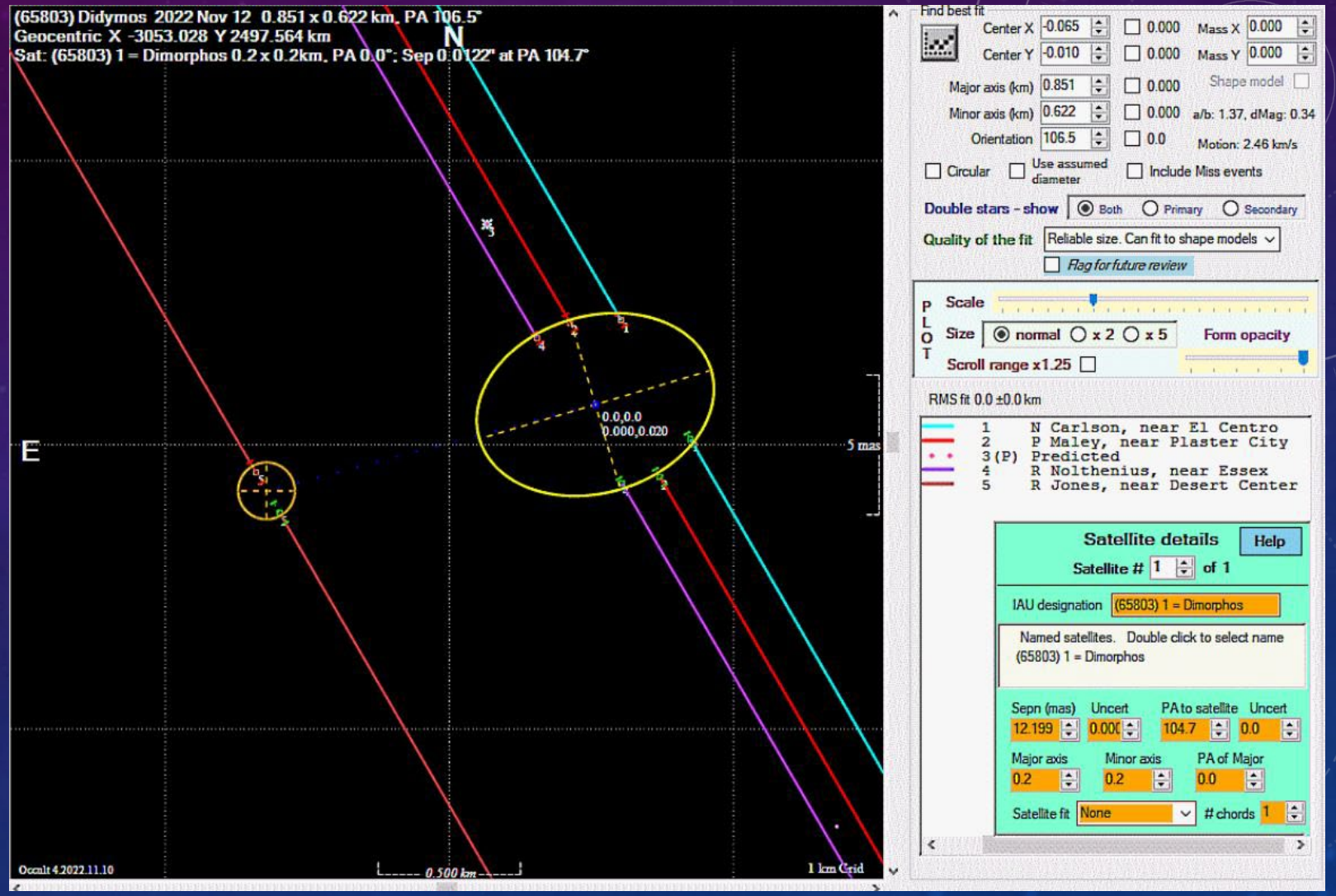
A rock-solid event, at 60 fields per second cadence.

My 0.24 second occultation, with reference star light curve

Together, our CA team got the first high-precision simultaneous astrometry of the post-DART positions of both the primary and moon.

We celebrated with a day of desert photography and cave explorations.



Afterwards; well earned sleep, and then breakfast of eggs and cowboy toast at our quiet desert campsite – which was also my observing site.

Then, to Mitchell Caverns in the Mojave National Preserve, for photography

Asteroid (4337) Arecibo: Two ice-rich bodies forming a binary

Based on *Gaia* astrometric data

Ziyu Liu[1,*], Daniel Hestroffer[1,*], Josselin Desmars[2,1] and Pedro David[1]

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Abstract

Context. Binary asteroids are present in all populations of the Solar System, from near-Earth to trans-Neptunian regions. As is true for the small Solar System bodies (SSSBs), binary asteroids generally offer valuable insights into the formation of the Solar System, as well as its collisions and dynamic evolution. In particular, the binaries provide fundamental quantities and properties of these SSSBs, such as mass, angular momentum, and density, all of which are often hidden. The direct measurement of densities and porosities is of great value in revealing the gravitational aggregates and icy bodies that form the asteroid-comet continuum.

Aims. Several observation techniques from space and ground-based platforms have provided many results in this regard. Here we show the value of the *Gaia* mission and its high-precision astrometry for analysing asteroid binaries and for individually deriving the masses of the components.

Methods. We focus on the binary asteroid (4337) Arecibo, a member of the Themis family. We analysed the astrometry obtained in the *Gaia* FPR catalogue release, and performed orbital fitting for both the heliocentric orbit of the system and the relative orbit of the binary components.

Results. We obtain an estimation of the component masses and their flux ratio, and derive bulk densities $\rho_1 \approx 1.2$ and $\rho_2 \approx 1.6$ for the primary and the secondary, respectively. The results are consistent with an ice-rich body in the outer main belt. They also show a significantly denser secondary or a less closely packed primary. Constraints on these densities and on macroscopic porosities are nevertheless limited by our poor knowledge of the sizes of the components. Observations of future mutual events, and of stellar occultations predicted in 2024–2025, will be essential for improving our knowledge of this system and its formation.

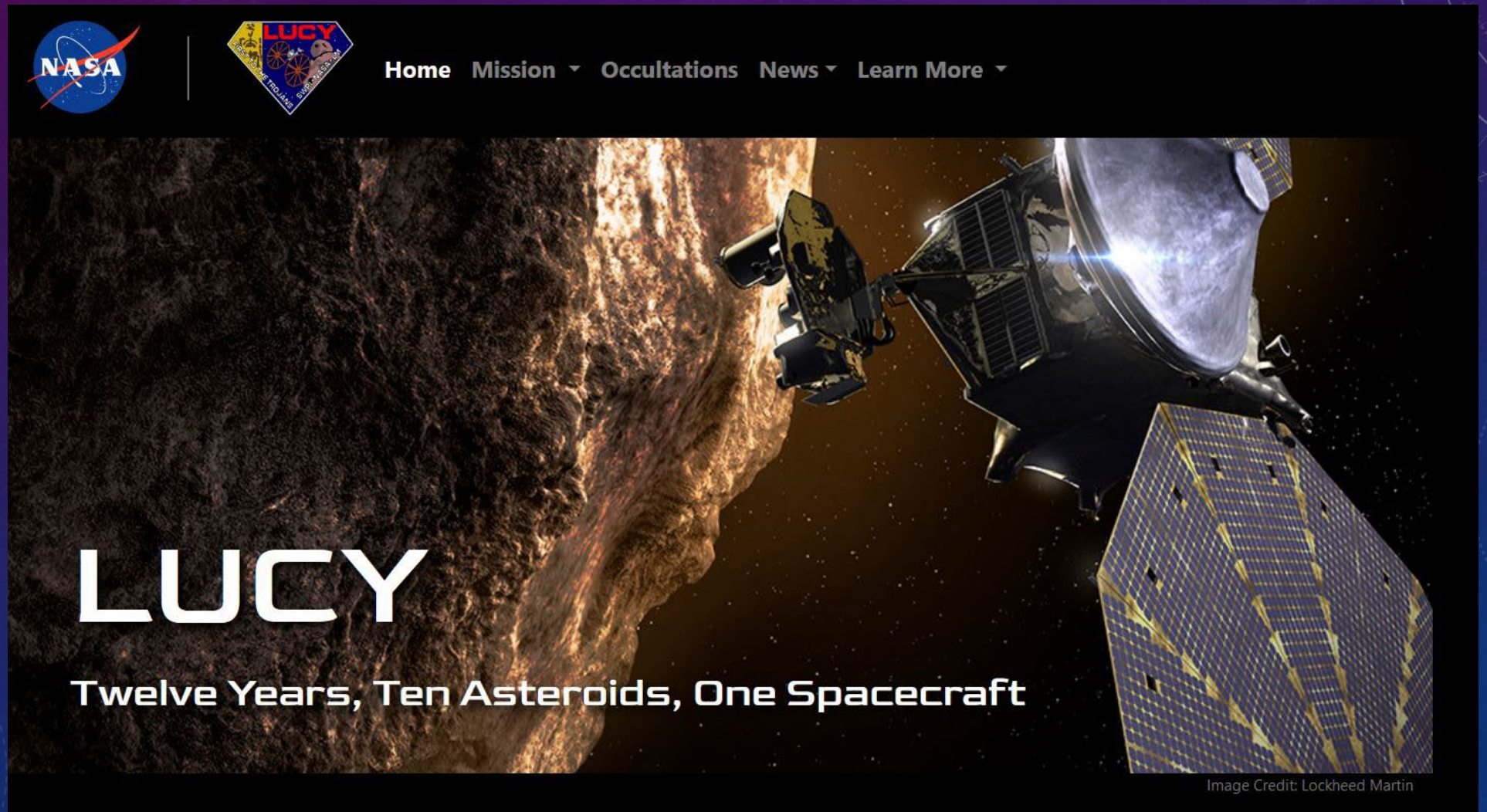
Key words: methods: data analysis / astrometry / minor planets / asteroids: individual: (4337) Arecibo

* Corresponding authors; ziyu.liu@obspm.fr; daniel.hestroffer@obspm.fr.

Science payoff: Liu *et. al.* publishes this paper in Astronomy and Astrophysics in 2024, on our new binary asteroid (4337) Arecibo;

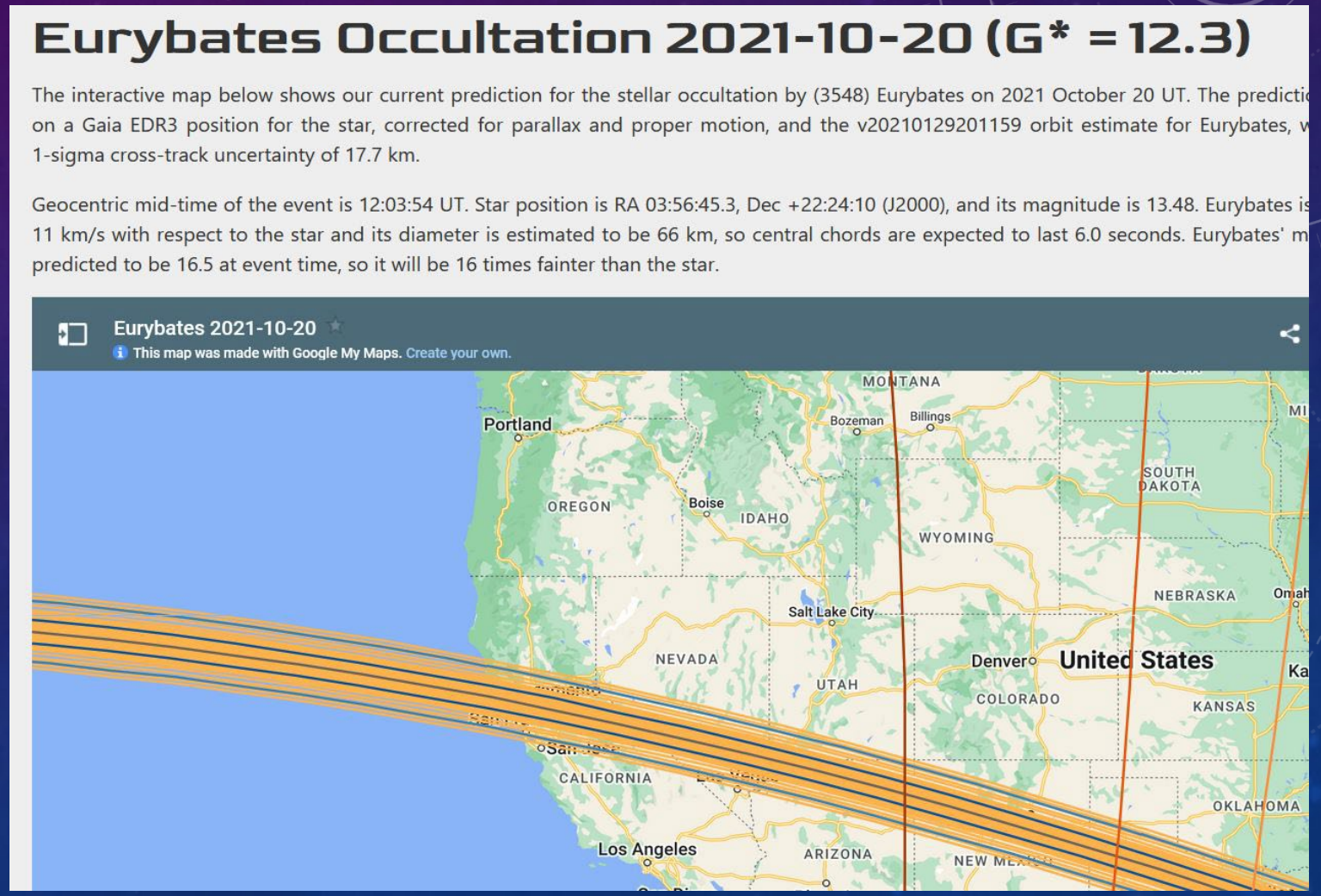
They determined the density of primary and secondary to be 1.6 g/cc and 1.2 g/cc. Hmmm; **Different densities! Interesting!**

NEXT, OCT 20, 2021: EURYBATES - The main target of the LUCY Mission – NASA's first spacecraft visit now on its way to the Trojan Asteroids orbiting at the Lagrange Points in Jupiter's orbit.



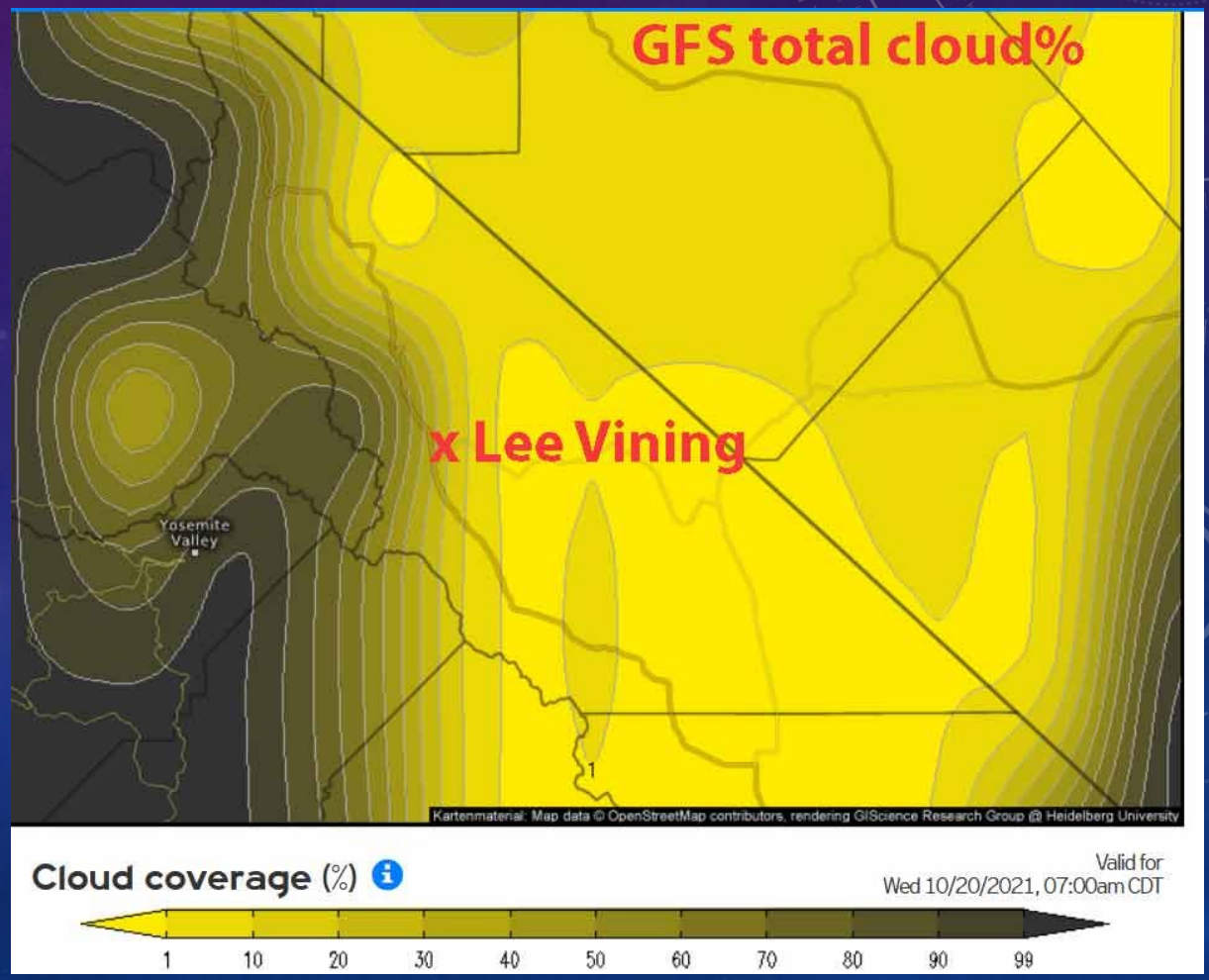
Eurybates: A Very High Value Target, on Oct. 20, 2021

- A faint 13.5 magnitude star in Taurus, shadow path predicted to cross California's Eastern Sierra.
- Tough conditions: faint star, storm system would cloud out everything west of the Sierra, and low altitude and dawn would worsen things farther east.

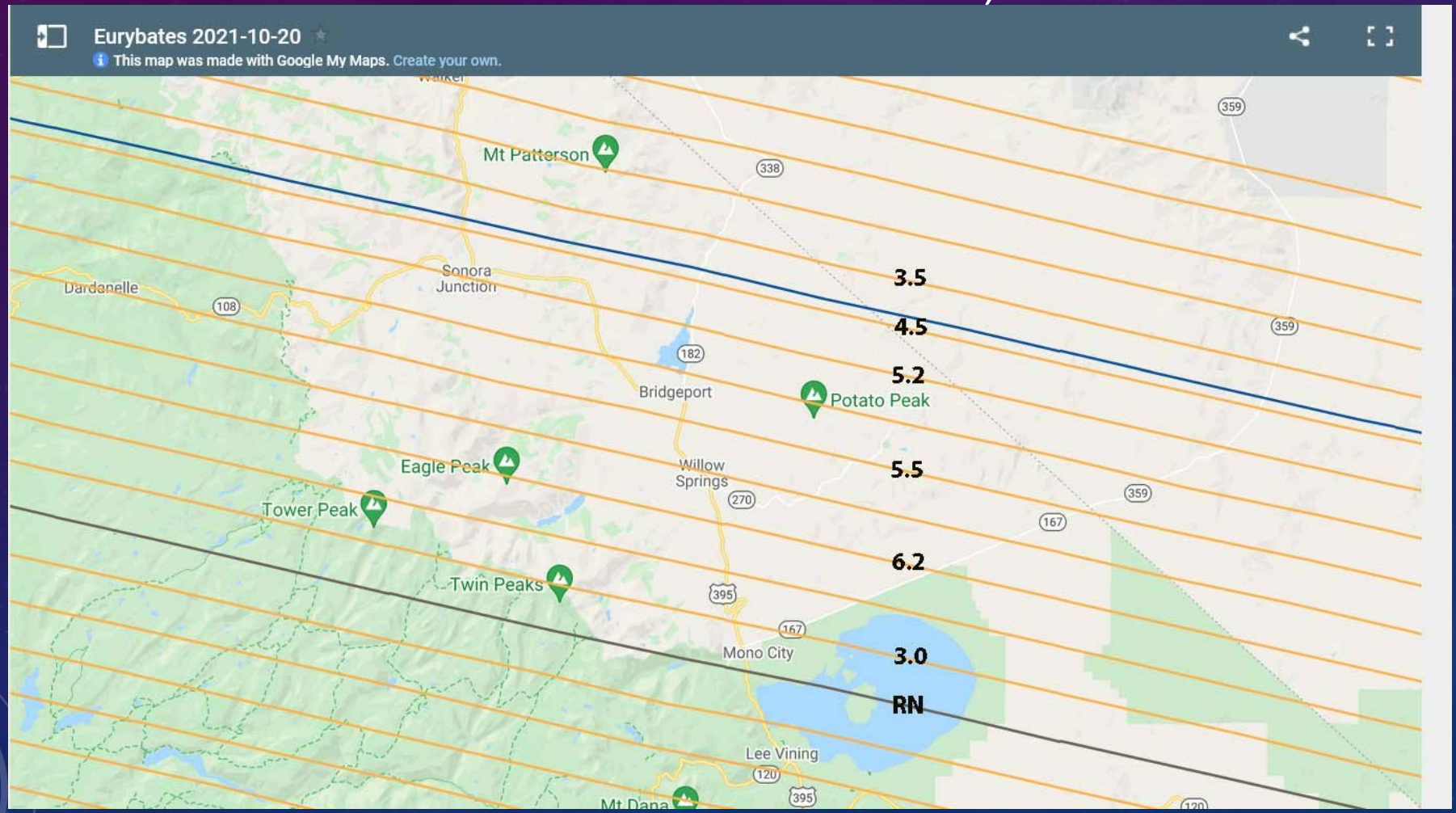


Weather was a challenge! We had the first storm of the season, west of the Sierras

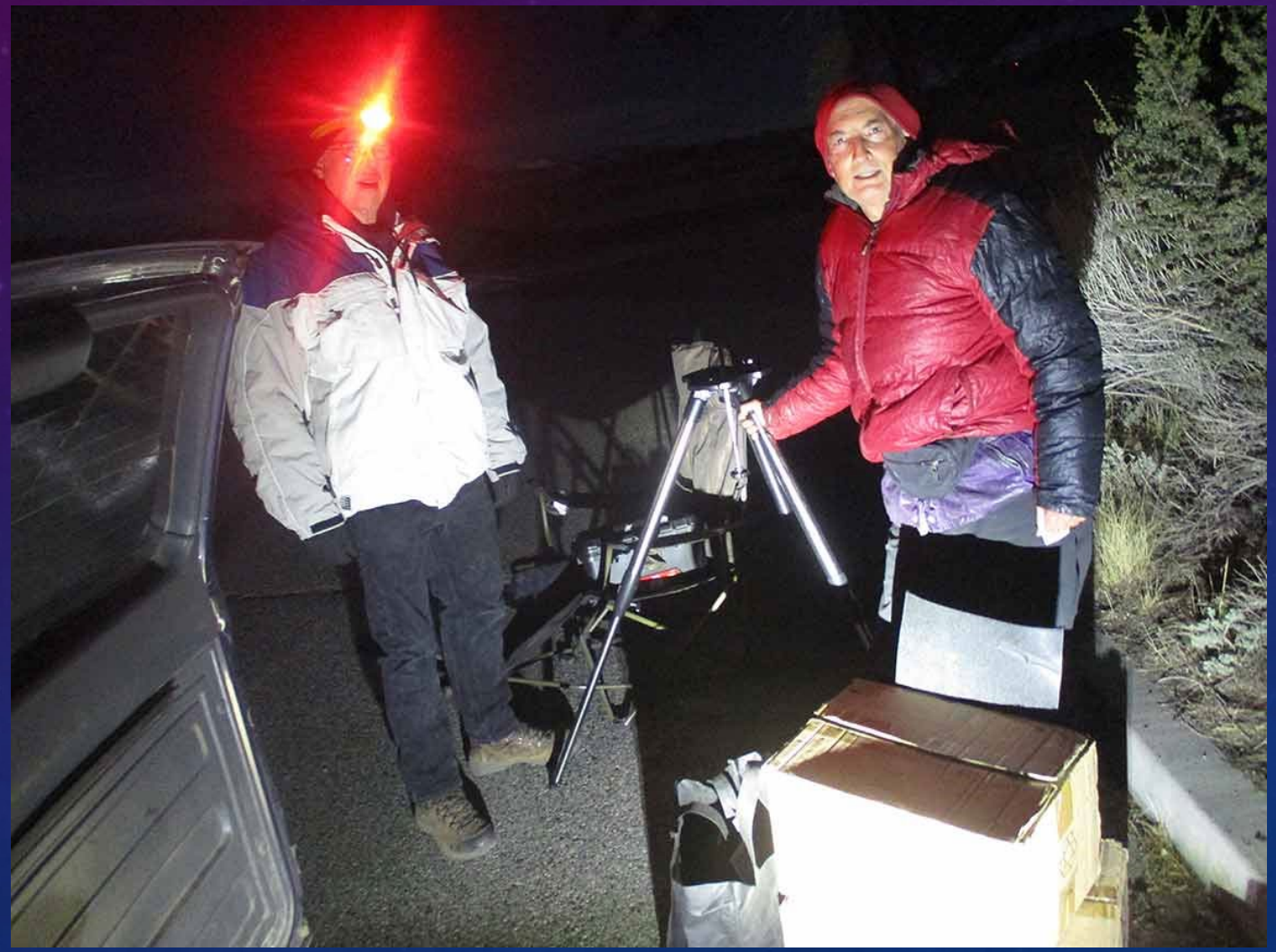
- Should I commandeer my Astro 8A class time? Much nail-biting watching latest cloud forecasts come in on my Cabrillo College office computer… before I threw caution to winds, called Kirk Bender, told him to meet me at my place ASAP, and I'd drive us in my RAV4 to Mono Lake to get clear of the clouds (we hoped).
- Astro Adventure!



SwRI - The Southwest Research Institute, was organizer for this campaign. Regularly spaced tracks were assigned to the "RECON" equipped observers, and Kirk and I ("RN") were to cover what we could. I set Kirk at the Mono Lake Visitor Center, on the track south of mine.



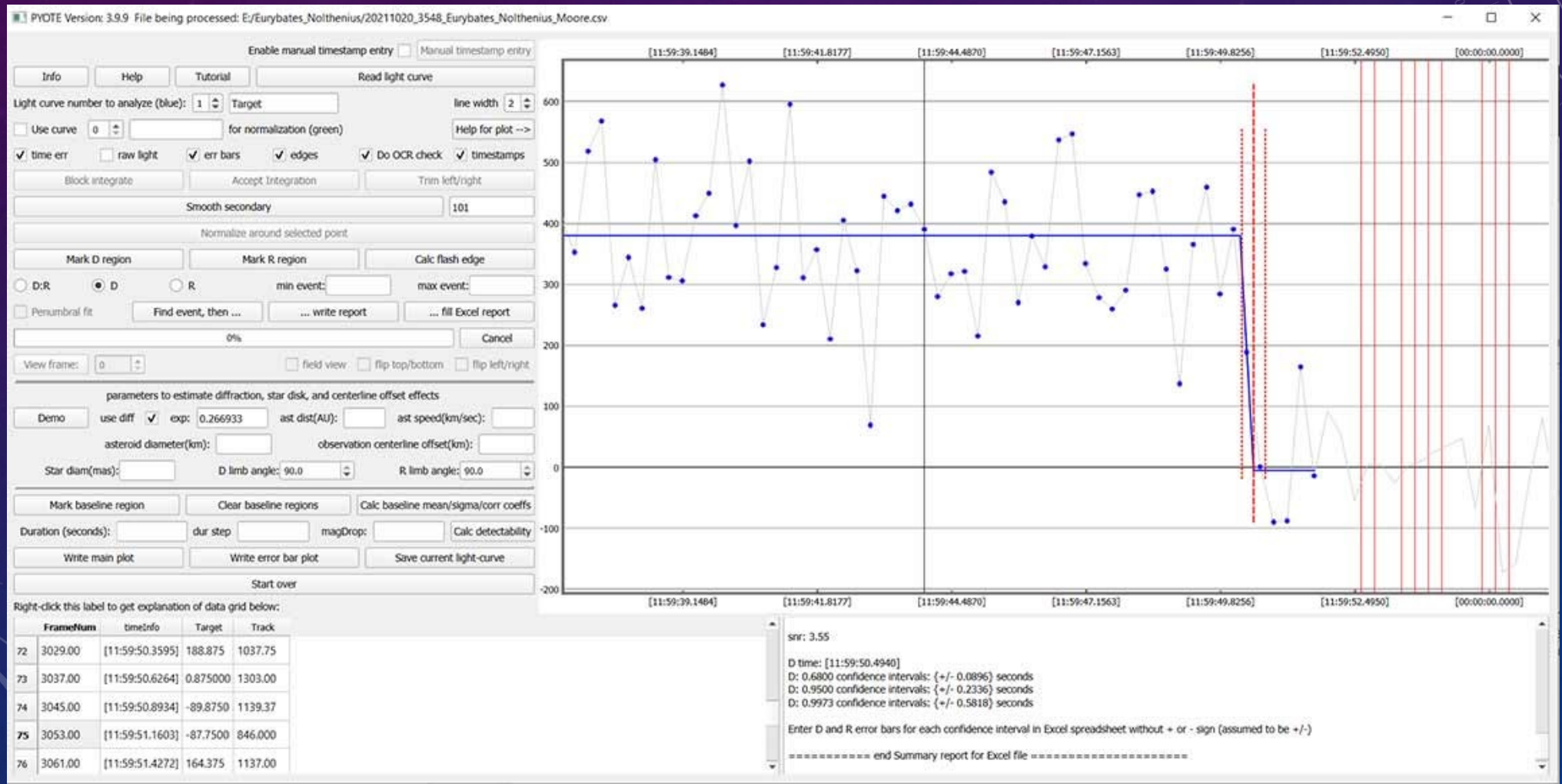
Tioga Pass conquered, we descended to Lee Vining, scouting a site for Kirk. Here I'm helping set up Kirk Bender at the Mono Lake Visitor Center, at 2 am.



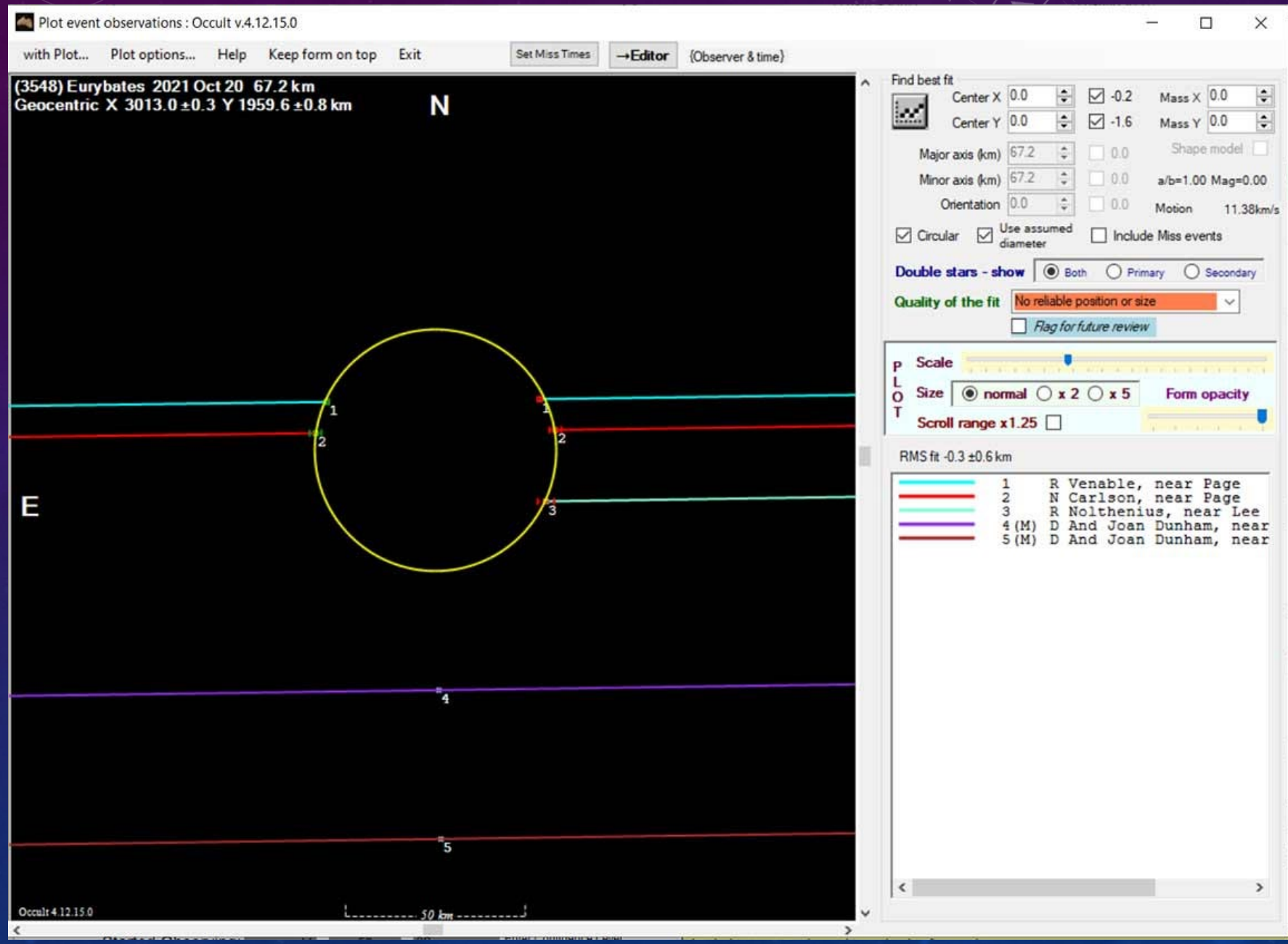
My site, on the central track, at a cemetery dating back to the Old West (I hoped this wasn't a sign).

Fast-moving clouds made prospects dicey. Would we get data?

MY EURYBATES DATA. AT EVENT MOMENT: Eurybates and a big cloud, raced each other to see who would cover the target star first. Fortunately – Eurybates won, by a nose! (<1 second!)



CLOUDS FOILED MOST, OBSERVERS, ALAS. But a few did get the valuable data needed to pinpoint the orbit of Eurybates and first indications of its shape. My “D” was the only data for IOTA which was south of the center of the star, crucial for accurate centroid and diameter astrometry

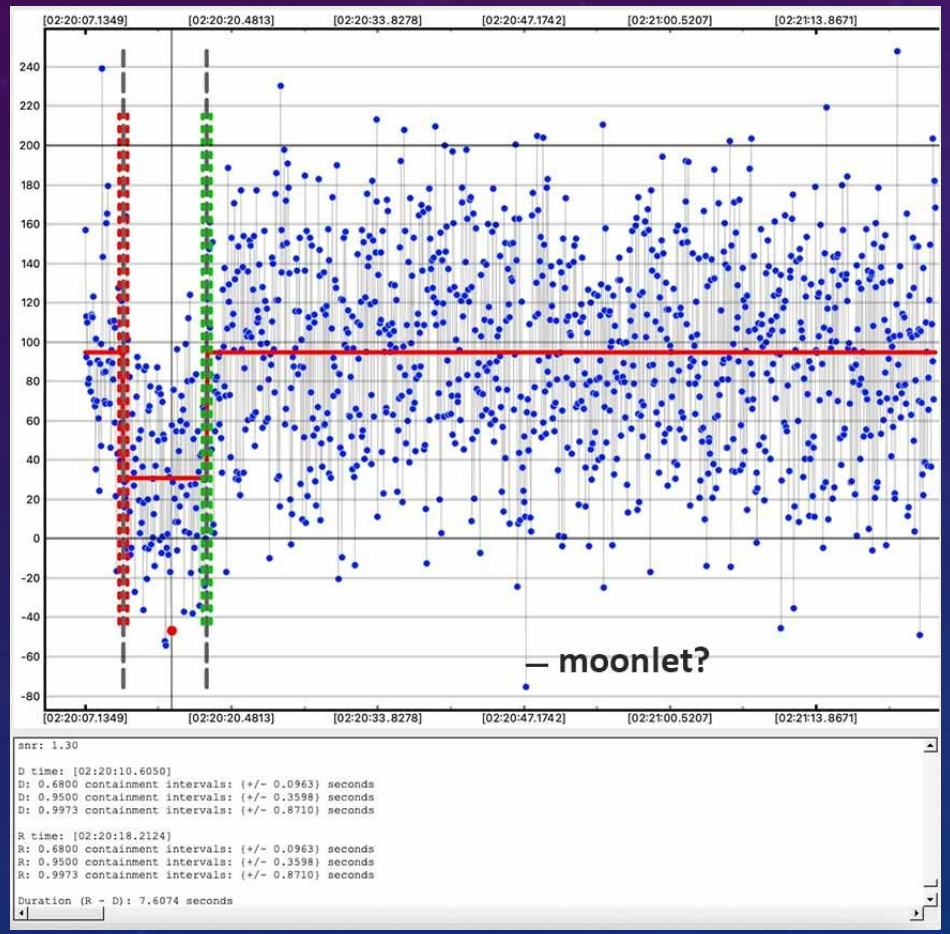


Kirk was clouded out, but we celebrated our team success with some Fall aspen photography, and a beer at a June Lake pub down the road, as we texted the other team members.

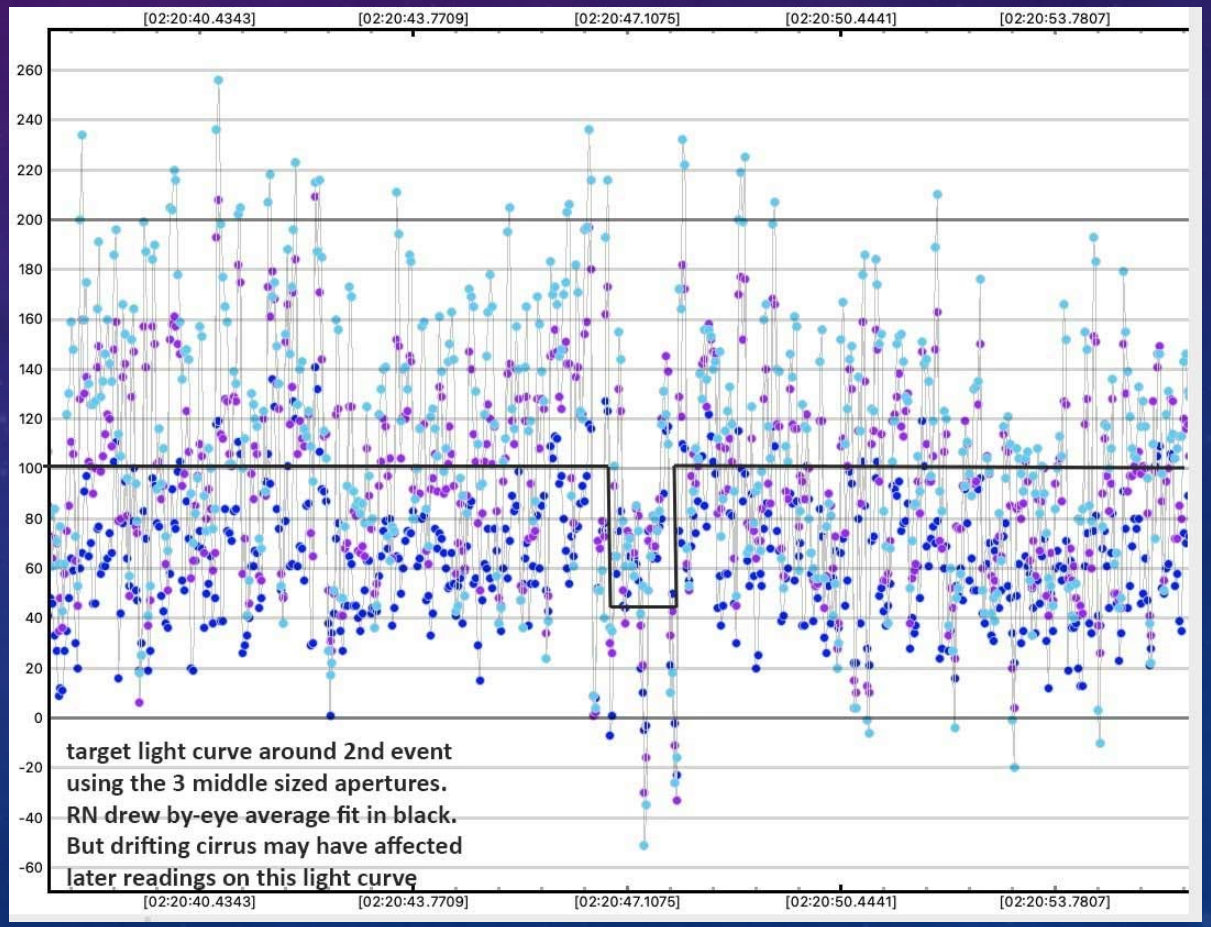
Getting home was more dicey; new snow over Tioga Pass. But, we made it over, lived to tell the adventure!

More: Kirk Bender recorded a possible secondary event during the Jan 26, ‘23 occultation by (906) Repsolda. Unconfirmed as yet – but we’re on the lookout for more occultations by this asteroid.

The primary occultation



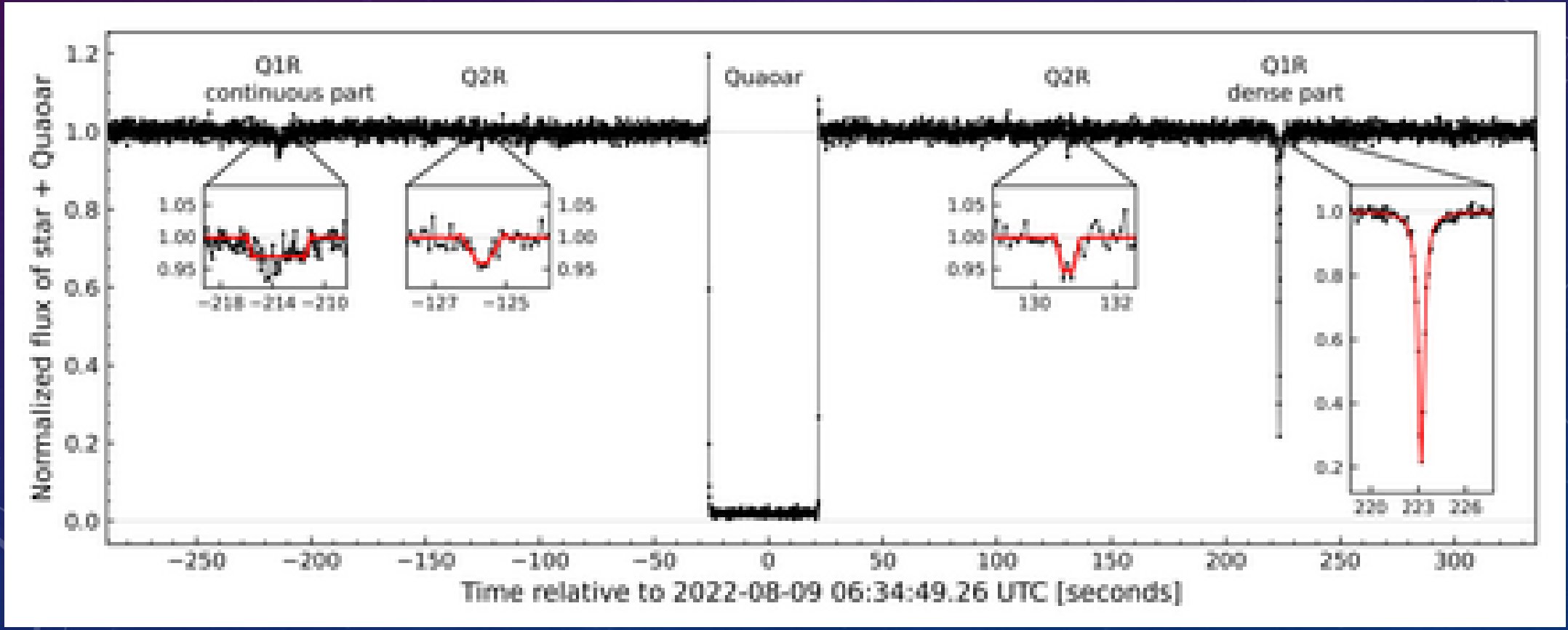
Secondary event? New moonlet?



NEXT: THE FIRST KBO DISCOVERED SINCE PLUTO: QUAOAR

- Through occultations, is now discovered to have two rings around it. And amazingly, both rings are beyond the Roche Limit, the first such rings known.
- So how did they form?
- How can they be stable, or are they perhaps extremely young and not stable?
- What is their structure? Are they azimuthally uniform in density? Or patchy, like Neptune's rings?
- Quaoar is going through the Scutum Star Cloud now, offering more occultation opportunities…

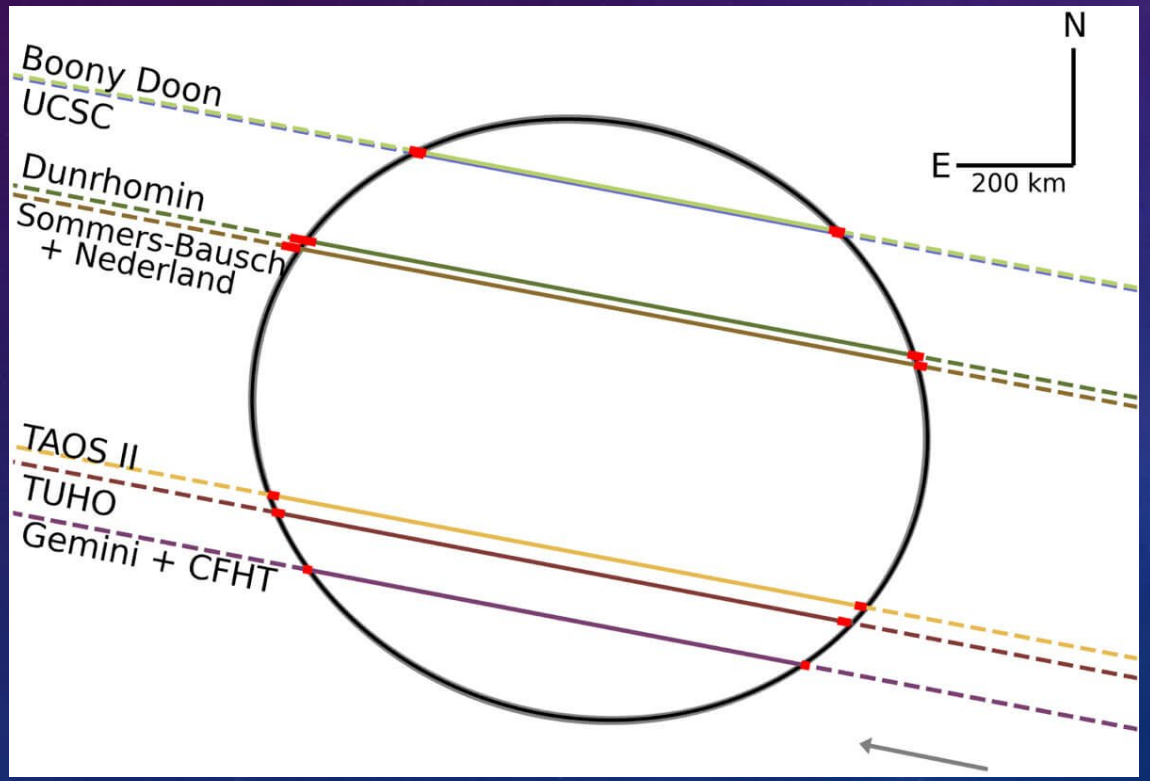
Earlier: The Aug 8, 2022 Event. The CFHT big scope on Mauna Kea discovered the 2nd ring, and the first ring was the denser. Discovery by occultation! Ring?? Two occultations on opposite sides of the main body, at perfectly the same radial distance from that body: odds are 99.999% you're looking at a ring, not *e.g.* two luckily placed moons. Note density asymmetry!

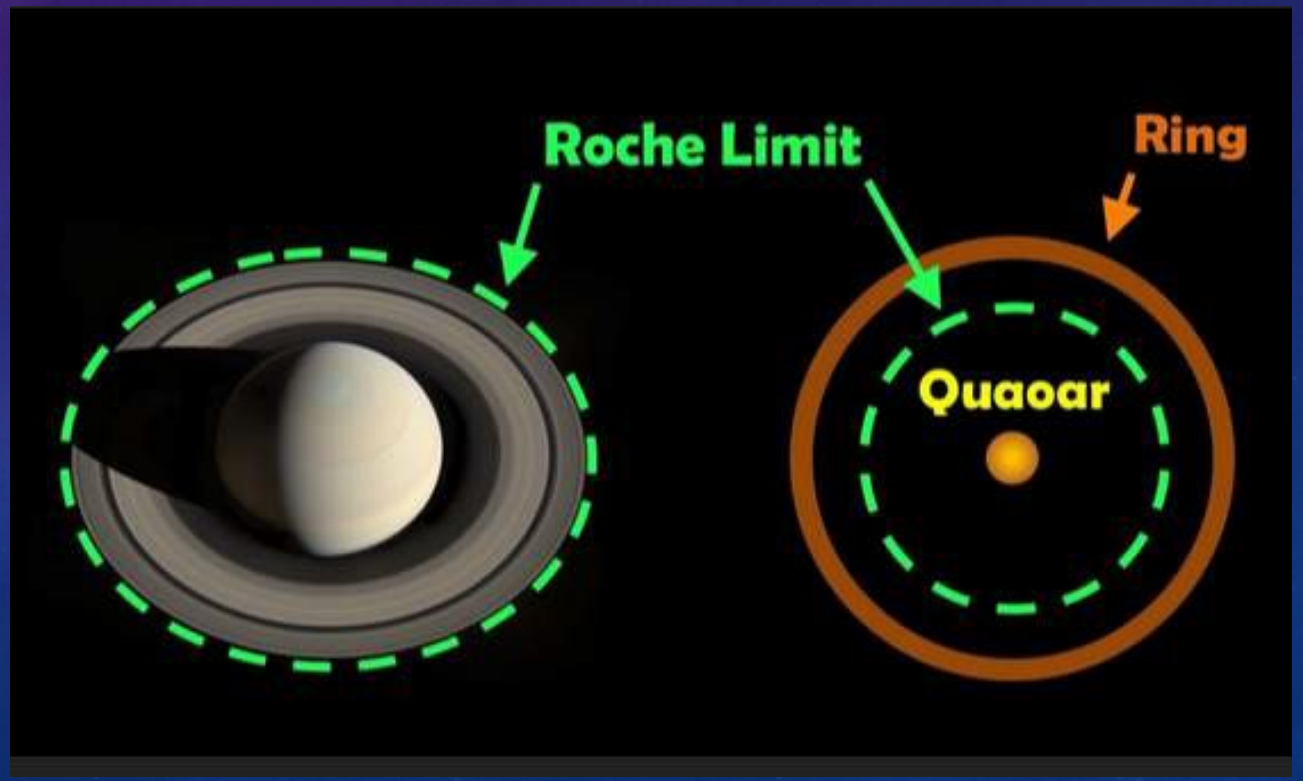


Kirk and I are now co-authors on a paper describing the advances in our knowledge of Quaoar from this event. So, excitement was high for the next Quaoar event, in 2023…

Our timings (Bonny Doon and UCSC) +
Gemini/CFHT, defined “ellipticity” for Quaoar!
Oblong, not spherical.

The rings; now an intense subject of head-scratching pondering… Stable rings beyond the Roche Limit???





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Astronomy & Astrophysics

LETTER TO THE EDITOR

The two rings of (50000) Quaoar

C. L. Pereira[1,2], B. Sicardy[3], B. E. Morgado[4,1,2], F. Braga-Ribas[5,1,2], E. Fernández-Valenzuela[6,7], D. Souami[3,8,9,10,⋆], B. J. Holler[11], R. C. Boufleur[1,2], G. Margoti[5], M. Assafin[4,2], J. L. Ortiz[7], P. Santos-Sanz[7], B. Epinat[12,13], P. Kervella[3], J. Desmars[14,15], R. Vieira-Martins[1,2], Y. Kilic[16,17], A. R. Gomes Júnior[18,19,2], J. I. B. Camargo[1,2], M. Emilio[20,1,5], M. Vara-Lubiano[7], M. Kretlow[7,21,22], L. Albert[23,24], C. Alcock[25], J. G. Ball[26], K. Bender[27], M. W. Buie[28], K. Butterfield[29], M. Camarca[30], J. H. Castro-Chacón[31], R. Dunford[29], R. S. Fisher[32], D. Gamble[29,33], J. C. Geary[25], C. L. Gnilka[34], K. D. Green[35], Z. D. Hartman[26], C.-K. Huang[36], H. Januszewski[13], J. Johnston[37], M. Kagitani[38], R. Kamin[29], J. J. Kavelaars[39], J. M. Keller[37], K. R. de Kleer[30], M. J. Lehner[36], A. Luken[32], F. Marchis[40,41], T. Marlin[30], K. McGregor[42], V. Nikitin[29,43], R. Nolthenius[27], C. Patrick[29], S. Redfield[42], A. W. Rengstorf[44], M. Reyes-Ruiz[31], T. Seccull[26], M. F. Skrutskie[45], A. B. Smith[26], M. Sproul[46], A. W. Stephens[26], A. Szentgyorgyi[25], S. Sánchez-Sanjuán[31], E. Tatsumi[47,48], A. Verbiscer[45], S.-Y. Wang[36], F. Yoshida[49,50], R. Young[51], and Z.-W. Zhang[36]

(Affiliations can be found after the references)

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ABSTRACT

Context. Quaoar is a classical trans-Neptunian object (TNO) with an area-equivalent diameter of 1100 km and an orbital semi-major axis of 43.3 astronomical units. Based on stellar occultations observed between 2018 and 2021, an inhomogeneous ring (Q1R, i.e., Quaoar's first ring) has been detected around this body.

Aims. A new stellar occultation by Quaoar was observed on August 9, 2022, with the aim of improving Quaoar's shape models and the physical parameters of Q1R, while searching for additional material around the body.

Methods. The occultation provided nine effective chords across Quaoar, pinning down its size, shape, and astrometric position. Large facilities, such as Gemini North and the Canada-France-Hawaii Telescope (CFHT), were used to obtain high acquisition rates and signal-to-noise ratios. The light curves were also used to characterize the Q1R ring (radial profiles and orbital elements).

Results. Quaoar's elliptical fit to the occultation chords yields the limb with an apparent semi-major axis of 579.5 ± 4.0 km, apparent oblateness of 0.12 ± 0.01, and area-equivalent radius of 543 ± 2 km. Quaoar's limb orientation is consistent with Q1R and Weywot orbiting in Quaoar's equatorial plane. The orbital radius of Q1R is refined to a value of 4057 ± 6 km. The radial opacity profile of the more opaque ring profile follows a Lorentzian shape that extends over 60 km, with a full width at half maximum (FWHM) of ~5 km and a peak normal optical depth of 0.4. Besides the secondary events related to the already reported rings, new secondary events detected during the August 2022 occultation in three different data sets are consistent with another ring around Quaoar with a radius of 2520 ± 20 km, assuming the ring is circular and co-planar with Q1R. This new ring has a typical width of 10 km and a normal optical depth of ~0.004. Just as Q1R, it also lies outside Quaoar's classical Roche limit.

Key words. methods: data analysis – methods: observational – techniques: photometric – Kuiper belt objects: individual: Quaoar – planets and satellites: rings

1. Introduction

In the last decade, three ring systems have been discovered around minor bodies in the outer Solar System: the Centaur Chariklo (Braga-Ribas et al. 2014), the dwarf planet Haumea (Ortiz et al. 2017), and the trans-Neptunian object (TNO) (50000) Quaoar (Morgado et al. 2023). Dense material has also been detected around the Centaur Chiron (Ruprecht et al. 2015; Ortiz et al. 2015; Sickafoose et al. 2020). However, the nature of this material, namely, whether it is a permanent or transient ring or a dust shell, is still a matter of debate.

Quaoar's ring, referred to as Q1R hereafter, was detected during several stellar occultations observed between 2018 and 2021 (Morgado et al. 2023). Q1R has a radius of about 4100 km with significant azimuthal variations in the optical depth, ranging between 0.004 and 0.1–0.7, and in width, ranging from 5 km to 300 km. Like Chariklo's and Haumea's rings, Quaoar's Q1R ring orbits close to the 1/3 spin-orbit resonance (SOR) with the central body, suggesting a link between this resonance and the ring (Salo et al. 2021; Sicardy et al. 2021; Morgado et al. 2023). Meanwhile, a unique property of Q1R is its location, which is far outside Quaoar's classical Roche limit. This limit is estimated to be at 1780 km from the body center, assuming particles with a bulk density of $\rho = 0.4\,\mathrm{g\,cm^{-3}}$. Outside the Roche limit, rings should accrete into satellites over timescales of less than 100 years (Kokubo et al. 2000; Takeda & Ida 2001). However, collisions more elastic than previously considered for Saturn's ring may maintain a ring unaccreted at distances greater than the Roche limit (Morgado et al. 2023). The 6/1

⋆ Fulbright Visiting Scholar (2022–2023) at University of California, Berkeley.

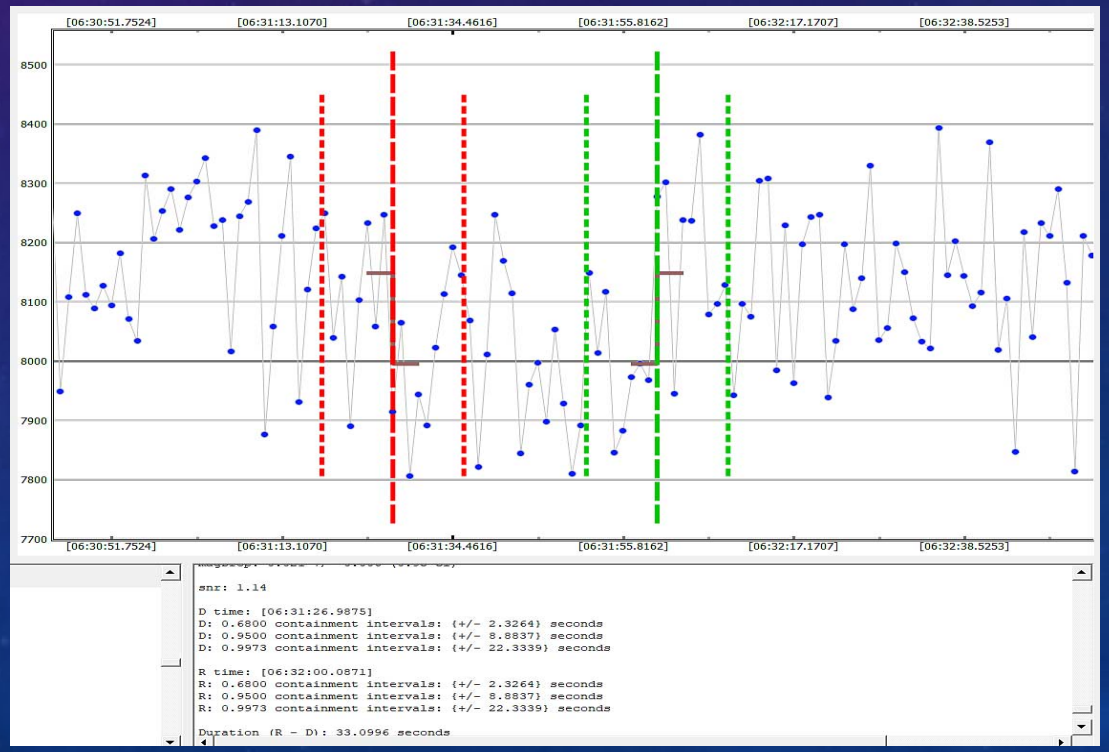
Co-authors Nolthenius & Bender, with our Celestron 8SE scopes got data from Bonny Doon and UCSC; crucial in defining the shape of Quaoar itself and its positioning in the system.

And, at the very similar 2022 Quaoar occultation: Mauna Kea scopes discovered the 2nd ring. Published paper in A&A at left.

Insanely difficult on paper: V=15.2 star, only 12 degrees above a gibbous moon in Sagittarius. Could our Cabrillo College heroes Rick and Kirk have any hope of success using only 8” Celestrons??

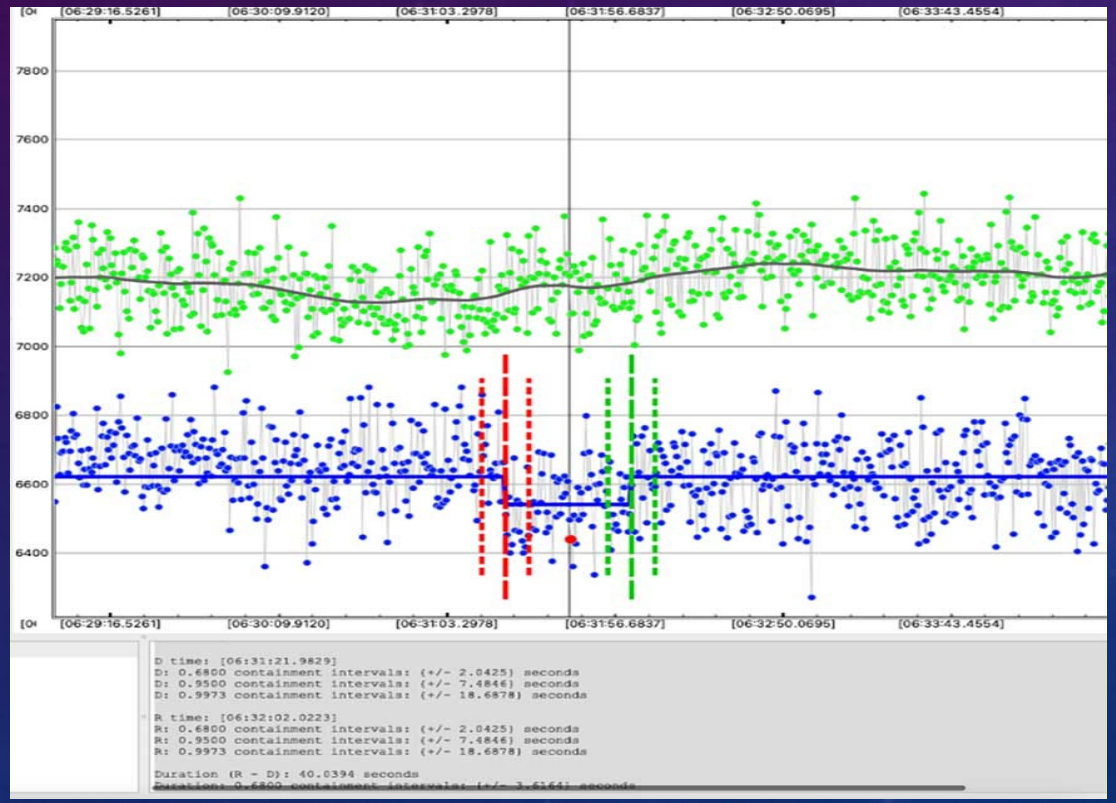
Kirk and I set up separate sites; Bonny Doon, UCSC

Noisy for sure, but PyOTE dug out timings which beautifully fit with those of bigger scopes in CA and Hawaii. No rings data, but we helped define the ellipsoidal shape of Quaoar.

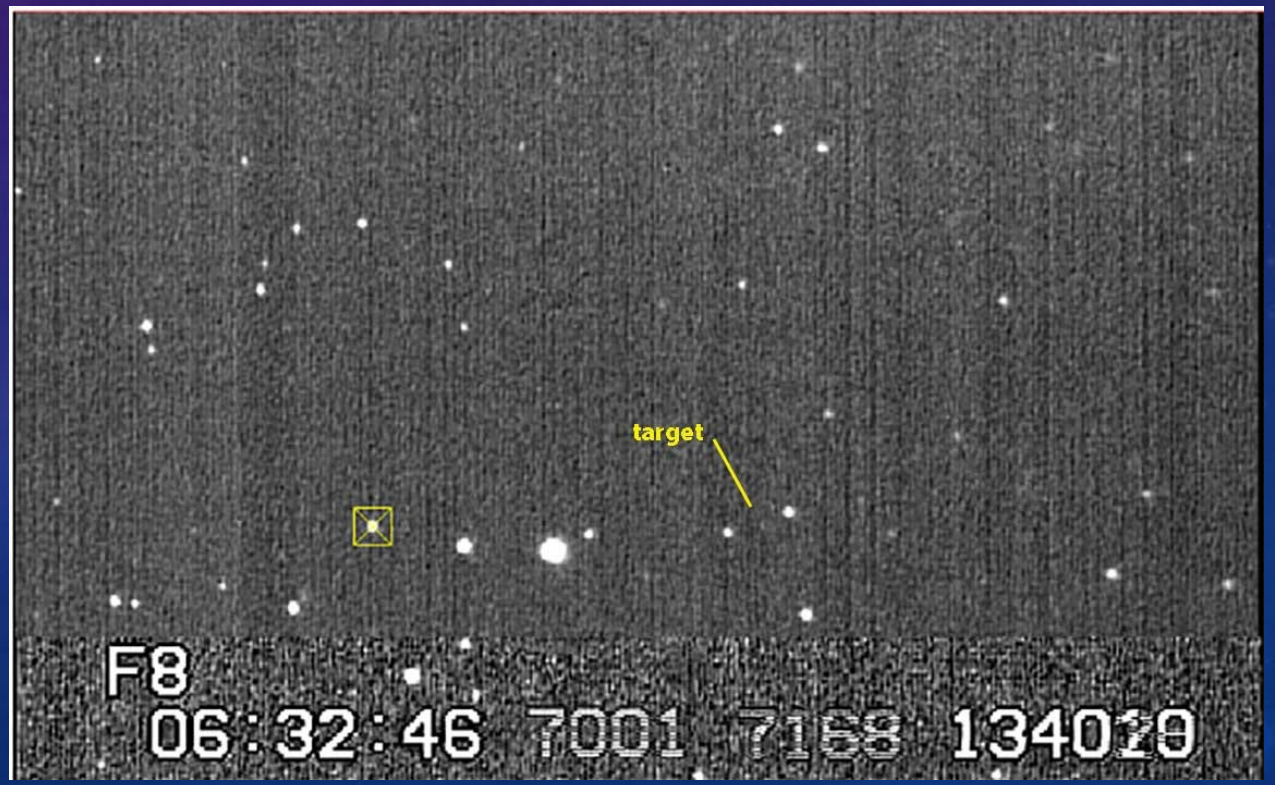


We used in-camera integration of 32 fields per readout, and removed the f/3.3 reducer to lower sky brightness. Can also adjust the camera gamma to help with very faint targets. Finally, I did not do sky subtraction, in order to remove uncorrelated subtraction noise too. The result did just “clear the bar” for the signal-to-noise (S/N) reality of the event. This is by far the toughest event I’ve ever tried.

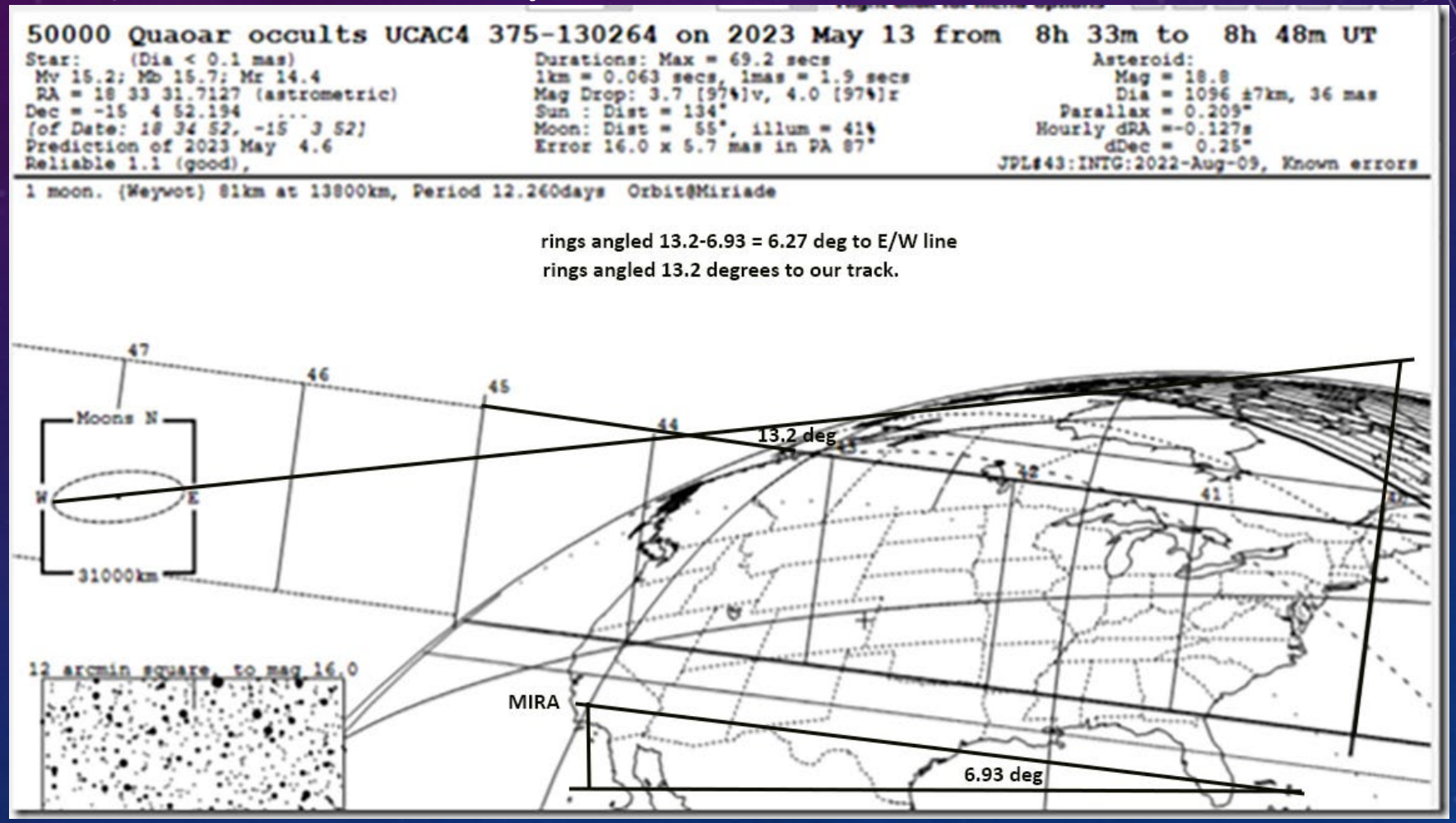
Kirk’s data a bit better than mine, I gave him a very good camera. Timings were consistent.



PyMovie “finder” stack of frames, allows better positioning of your tight aperture masks to improve S/N. Target still just barely above “sky”.

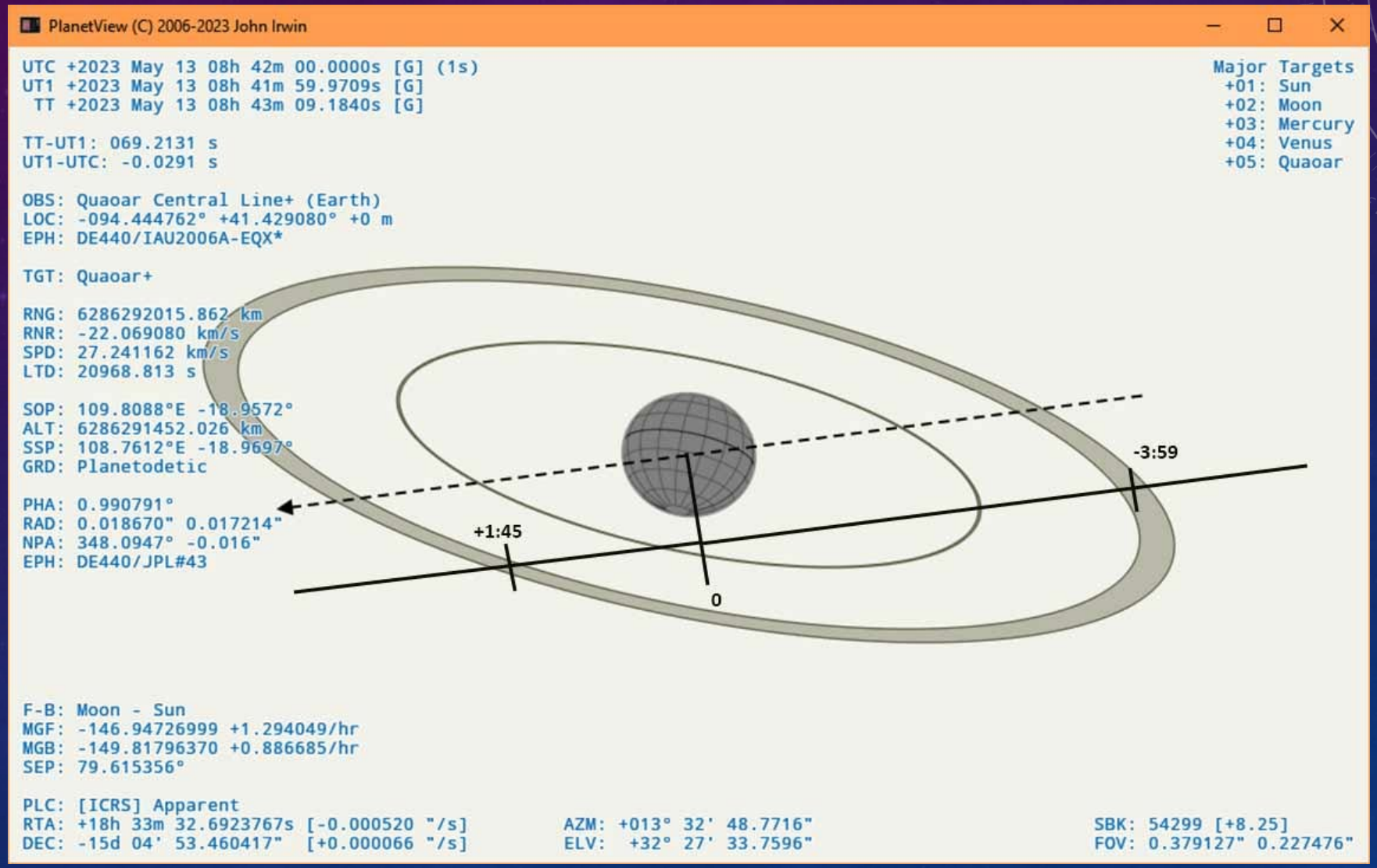


May 13 ‘23, Quaoar occulted a 15.2 mag star. While the main body misses here, Quaoar’s rings would cover the star. But! ***“We need more power, Scotty!”.*** I called up the Monterey Institute for Research in Astronomy: **MIRA, who operate their 36” reflector on Chews Ridge.**

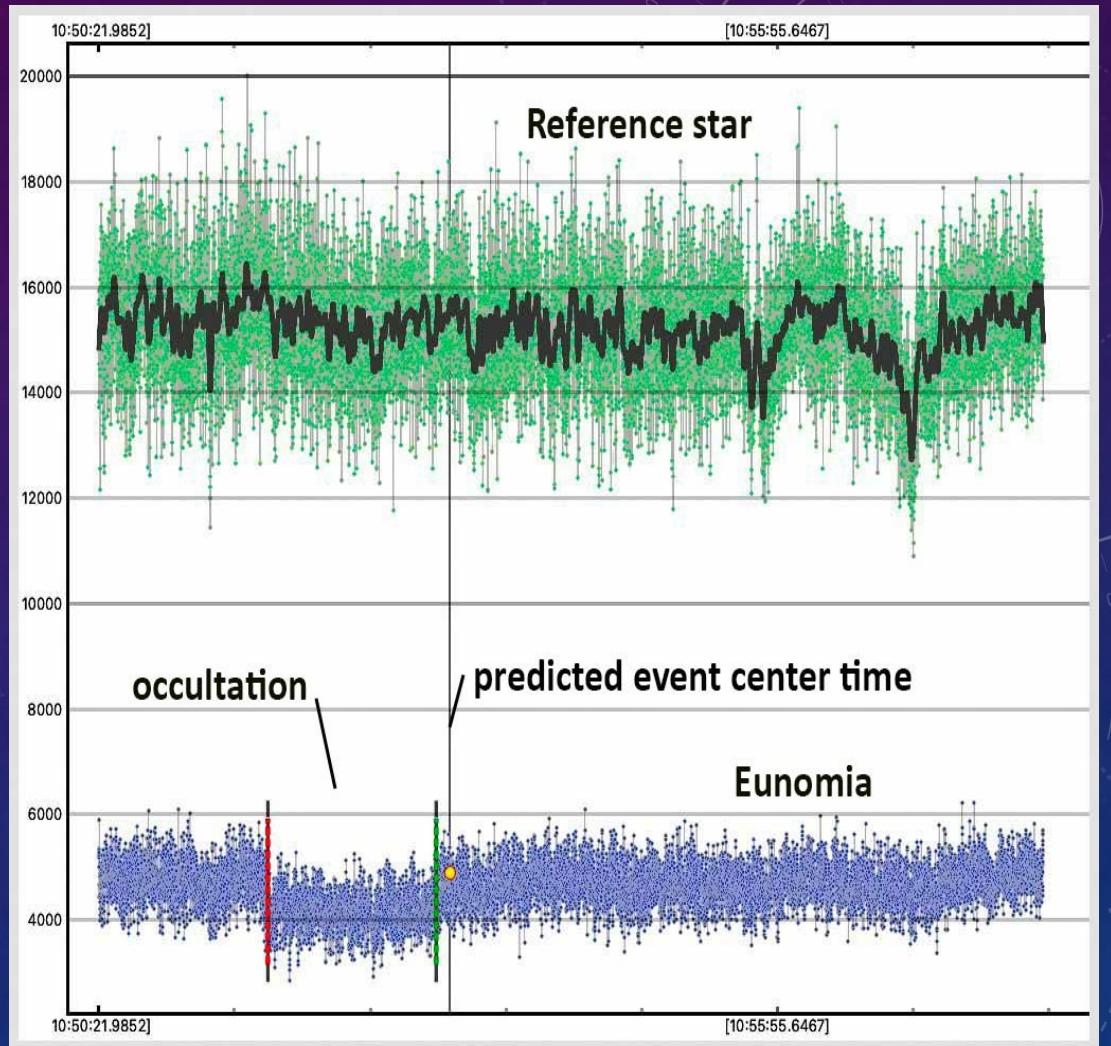


MIRA'S Oliver Observatory Station. A 36" highly instrumented Cass in a giant roll-off structure. They loved the idea of expanding their science opportunities into this new area with us. We were given two nights on the telescope.

Predictions for the sky track as seen at MIRA's Chews Ridge Observatory. Would we detect the faint rings?



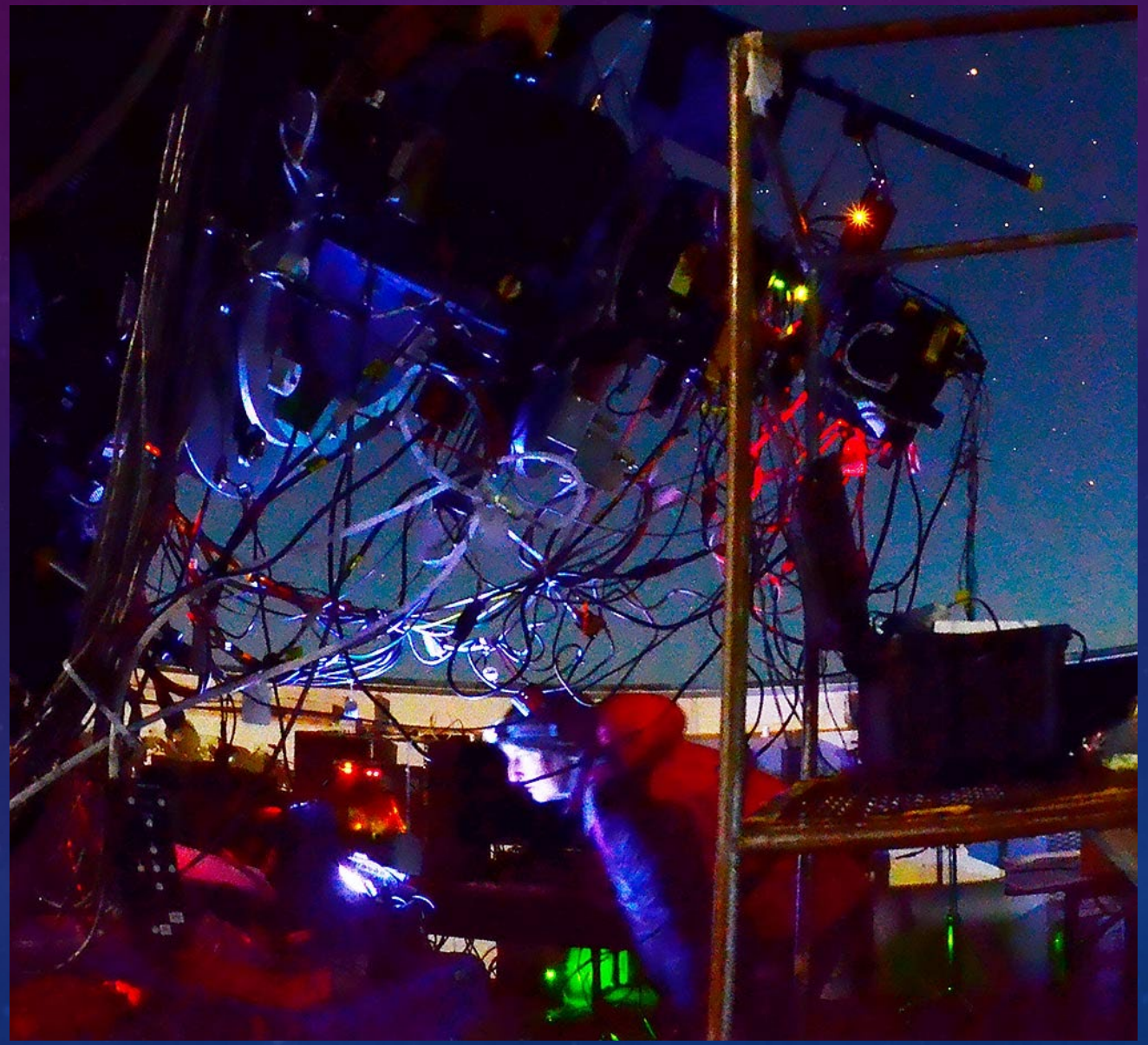
LUCK AT MIRA – We had another occultation, by Eunomia, on the shake-down night before the main Quaoar 2023 event. Only a 0.09 magnitude predicted drop, but yet great data on this big scope. Having 36” helps! My data was very clean on the smaller 14” Planewave Cass-Dall-Kirkham as well. Note; event was early… interesting, for such a low-number asteroid.



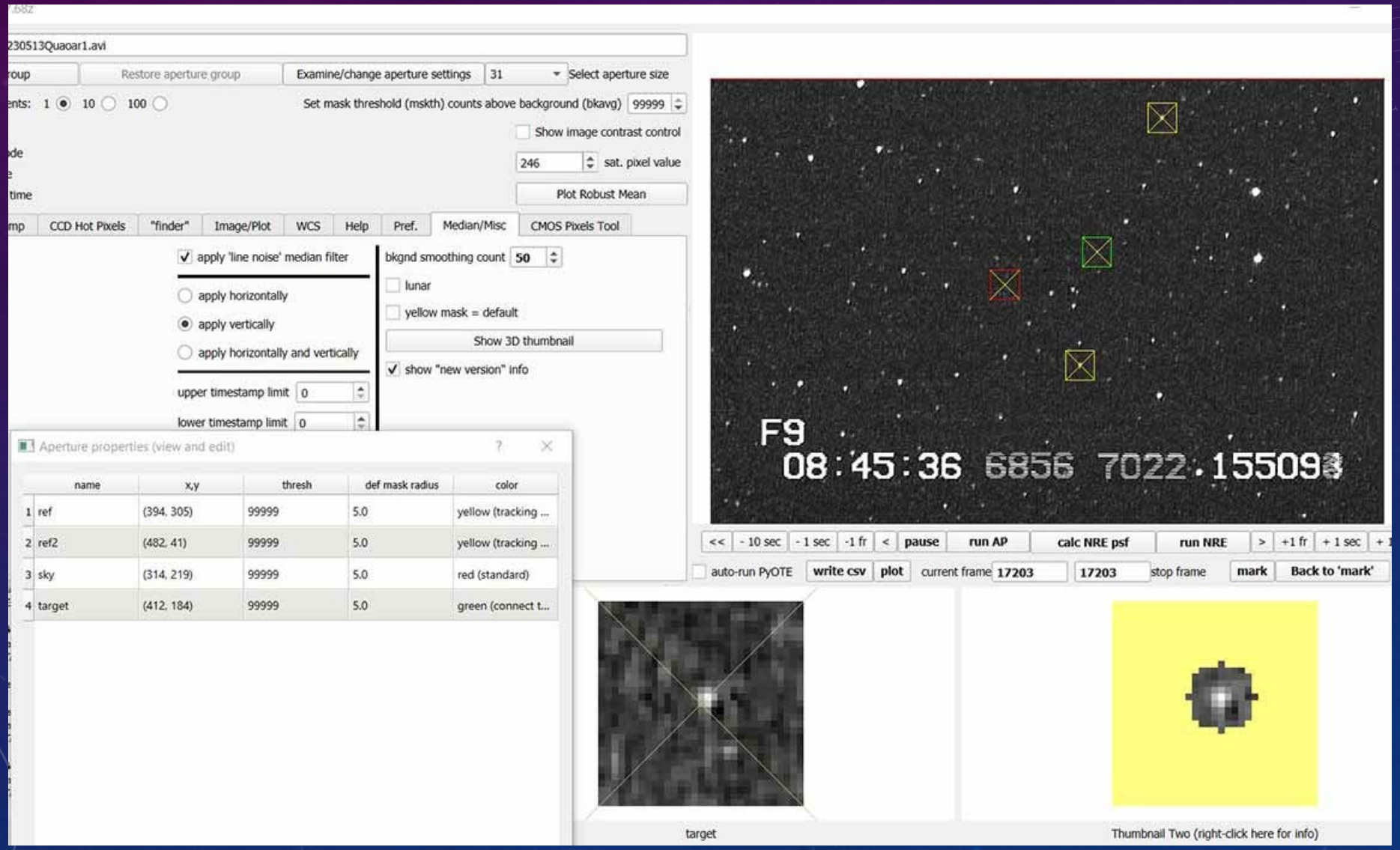

```
snr: 2.19

D time: [10:51:45.1003]
D: 0.6800 containment intervals: (+/- 0.0270) seconds
D: 0.9500 containment intervals: (+/- 0.2380) seconds
D: 0.9973 containment intervals: (+/- 0.6456) seconds

R time: [10:53:07.9151]
R: 0.6800 containment intervals: (+/- 0.0270) seconds
R: 0.9500 containment intervals: (+/- 0.2380) seconds
R: 0.9973 containment intervals: (+/- 0.6456) seconds

Duration (R - D): 82.8148 seconds
```

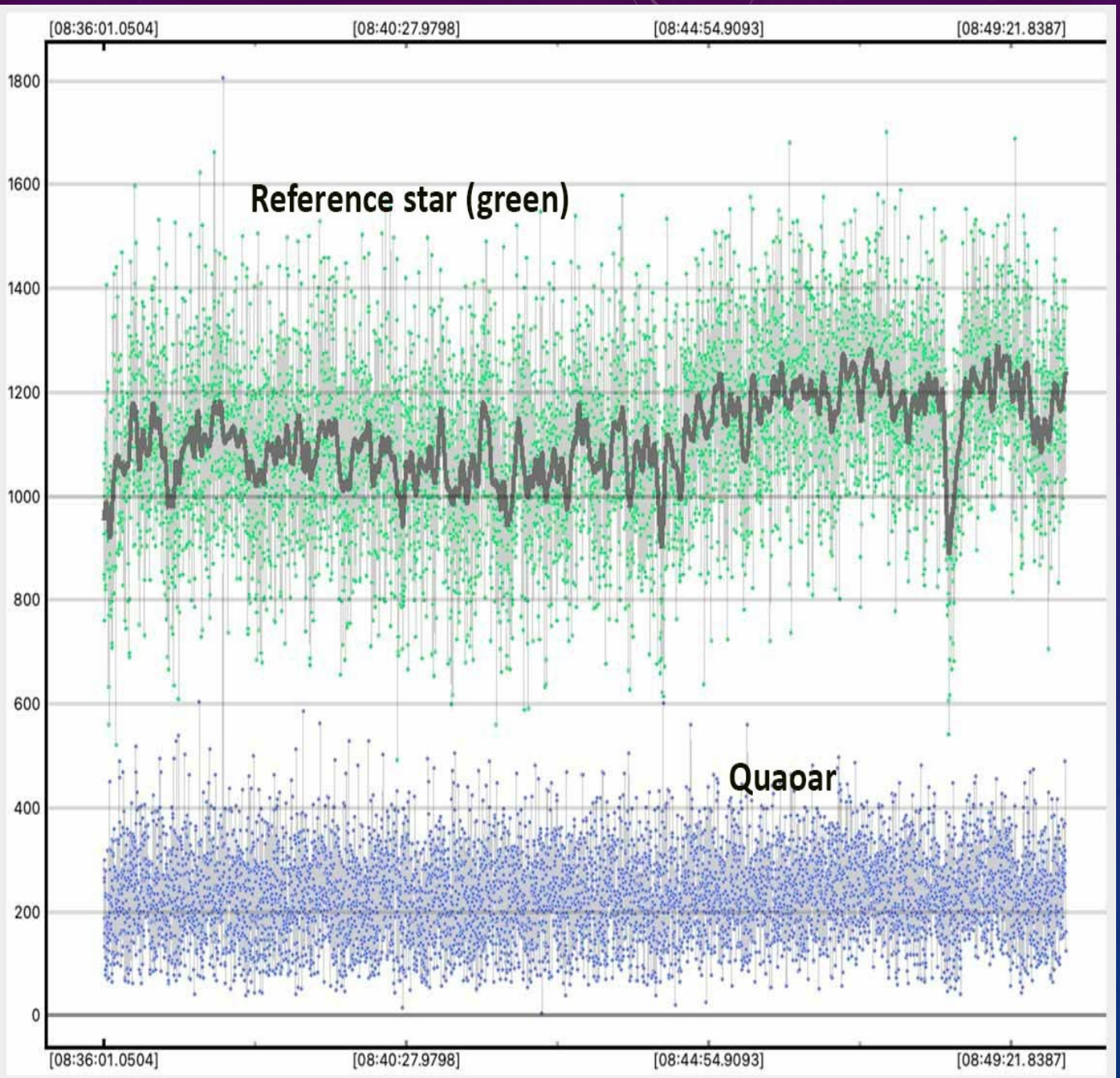
Quaoar Night: Kirk's gear was selected to be on the big scope. The Watec 910hx I loaned him, turns out to be higher S/N than the one I use. I set up on the new 14" Planewave CDK for parallel data taking.

That’s me in purple jacket… hidden under all the data and power cables



First we run the video through PyMovie – Free Win10 software (by IOTA's crack programmer Bob Anderson) for photometric reduction – (=measuring the brightness of targets) on raw video data





At the contact points for star and rings, the rings were not dense enough to cause detectable drops, alas. But, valuable upper limits obtained.

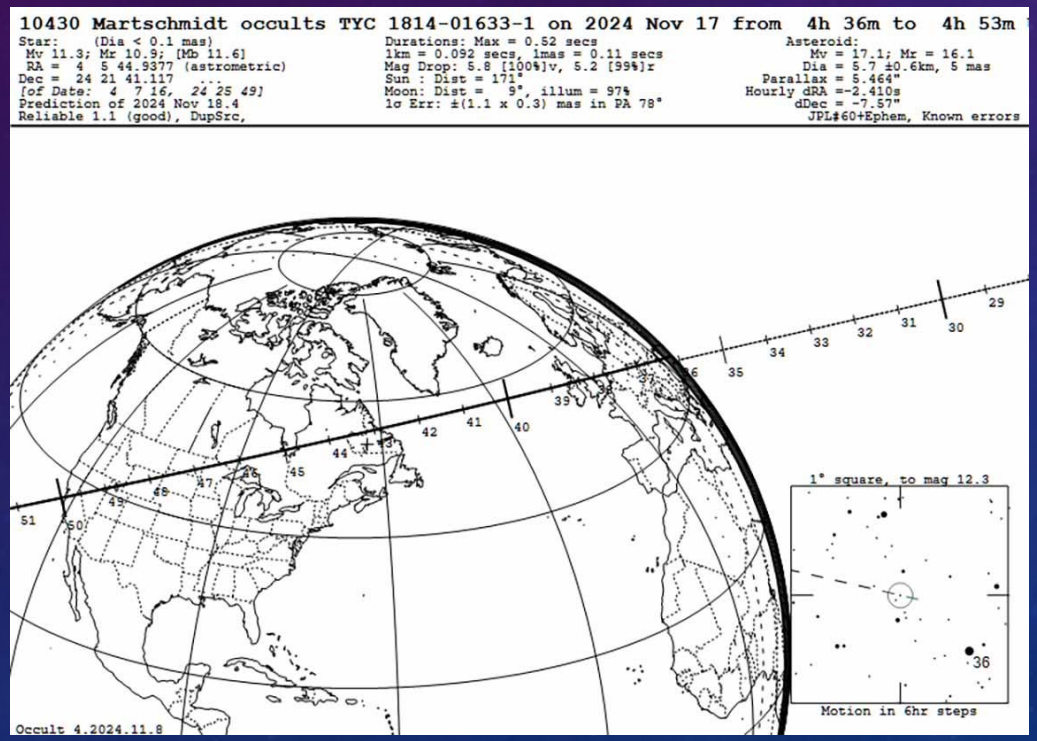
Software? **PyOTE**: Companion Win10 software for analyzing PyMovie photometry to determine best-fit occultation timings.

Kirk and I also got a night at MIRA for the occultation of a star by Jupiter Trojan asteroid (3451) Mentor on October 25, 2024.

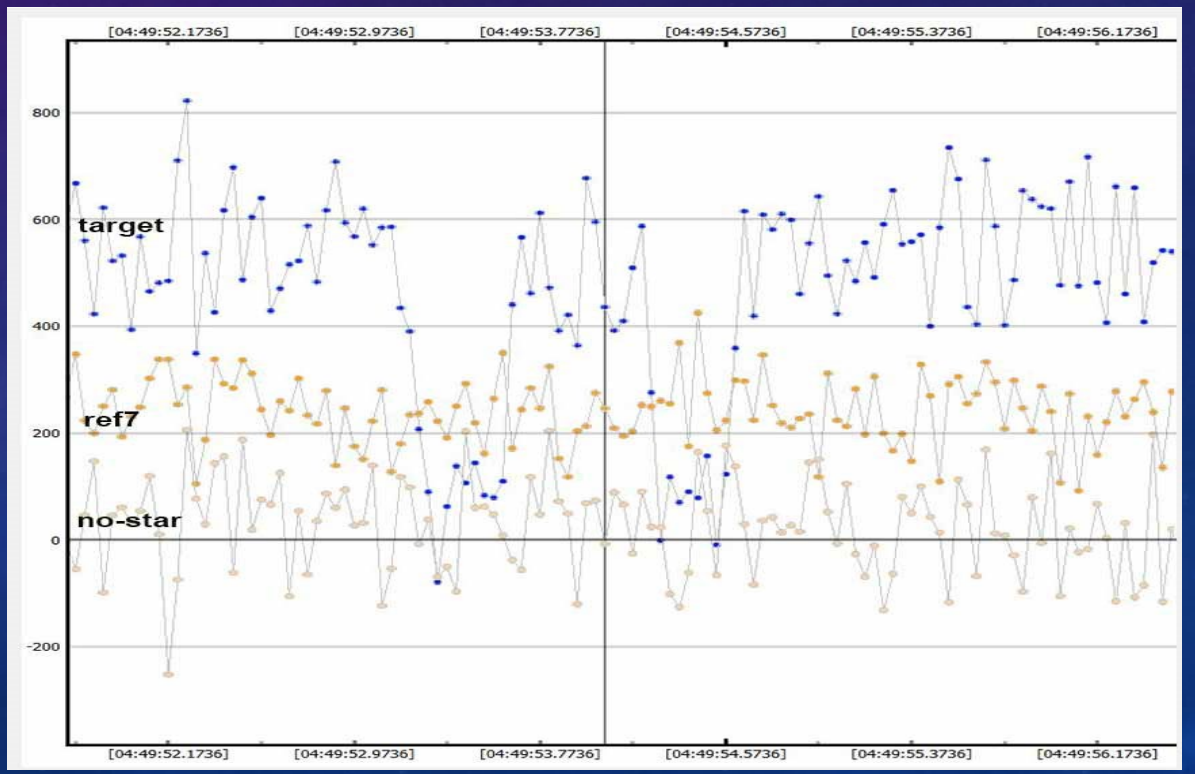
Mentor missed the star, but Kirk got this wonderful image of the **Great Comet of ’24,** with me and the Big Scope

Next: the discovery of (10430) Martschmidt as a new binary asteroid; Nov 16, 2024 and Feb 23, 2025. How to tell a binary asteroid from a binary star?

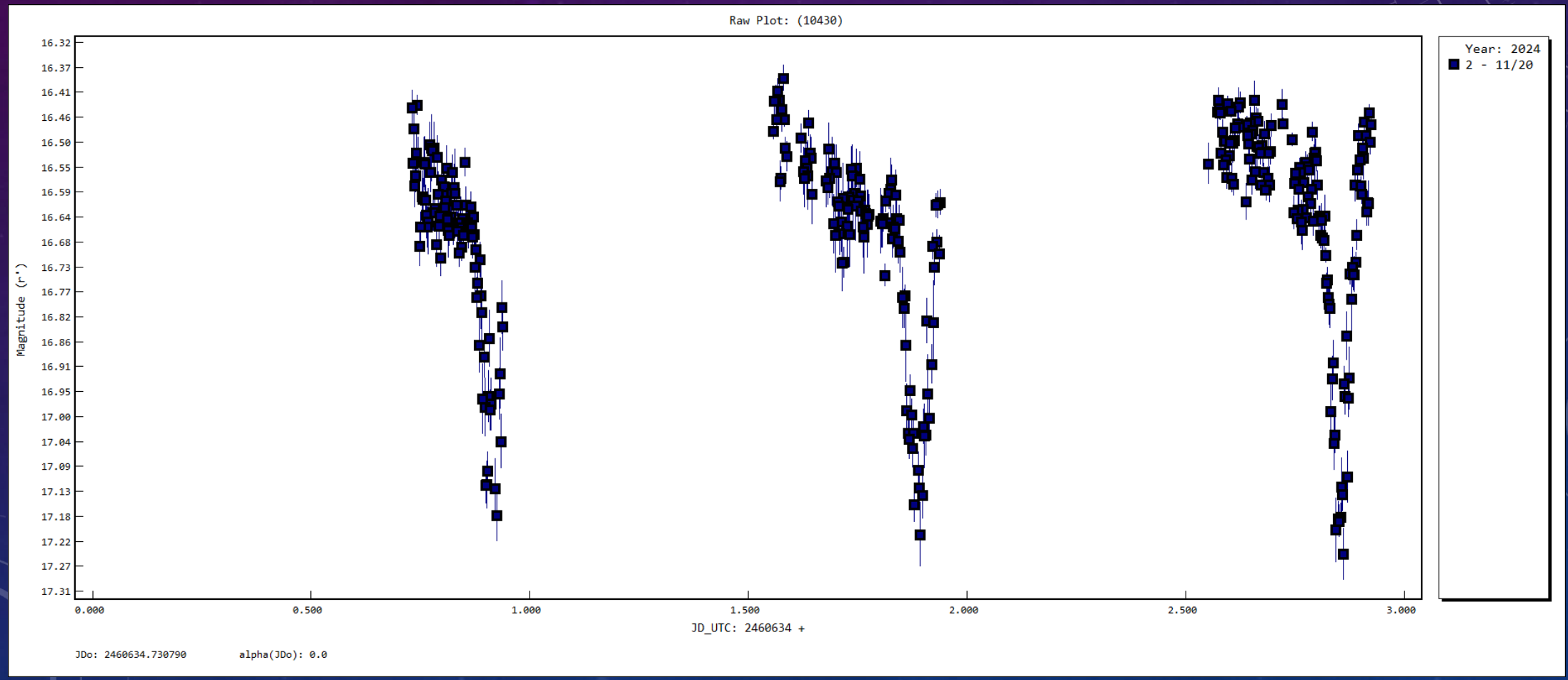
The narrow track crossed Cabrillo College Observatory. I was ready, and got a big surprise: a double occultation!



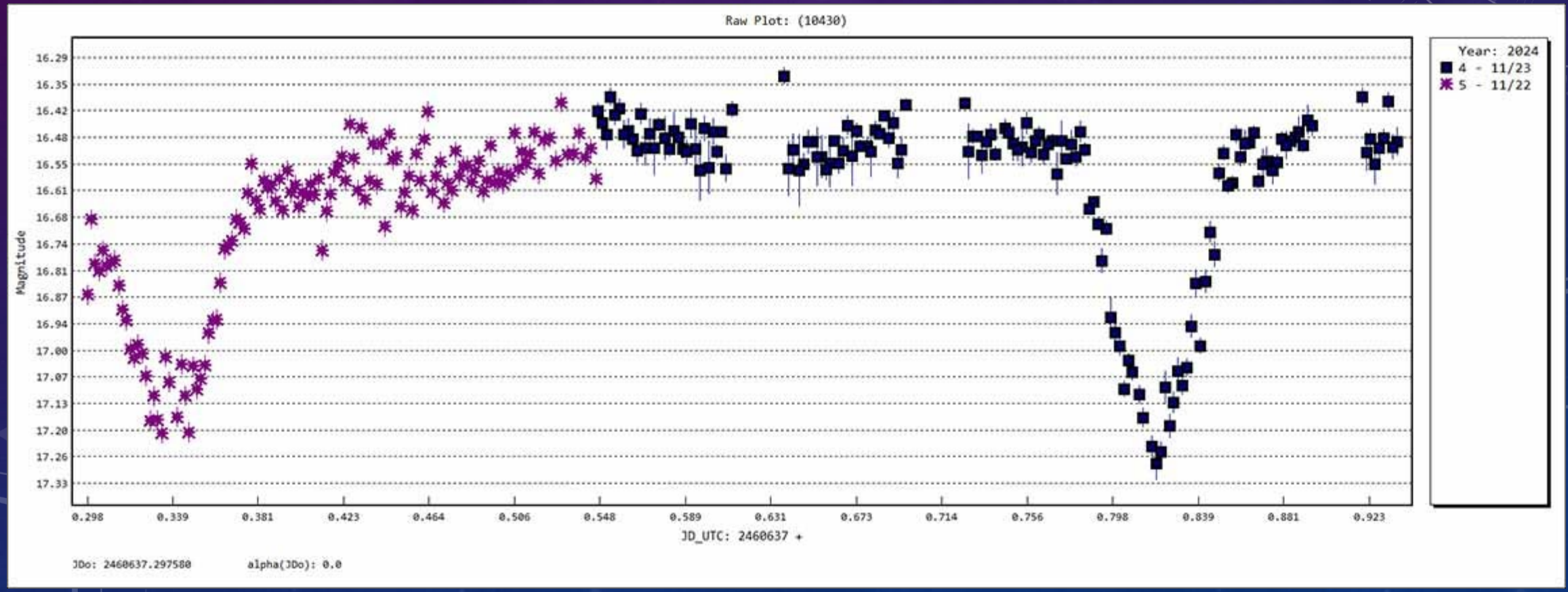
Star “Ref7” is less than half the brightness of the target star, yet both occultations dim below it. Proof it was a binary asteroid, not a binary star.



More proof: Jean-Francois Gout and M. Conjat in France, on hearing of my discovery, got on it and did photometry of the faint 17th mag asteroid itself – and wow! Mutual eclipses of the two components!



M. Conjat, at a different longitude, in France, was able to see the secondary eclipse (purple) 11.7 hr before Gout got a primary eclipse! Results confirmed a 23.17 hr orbit period.

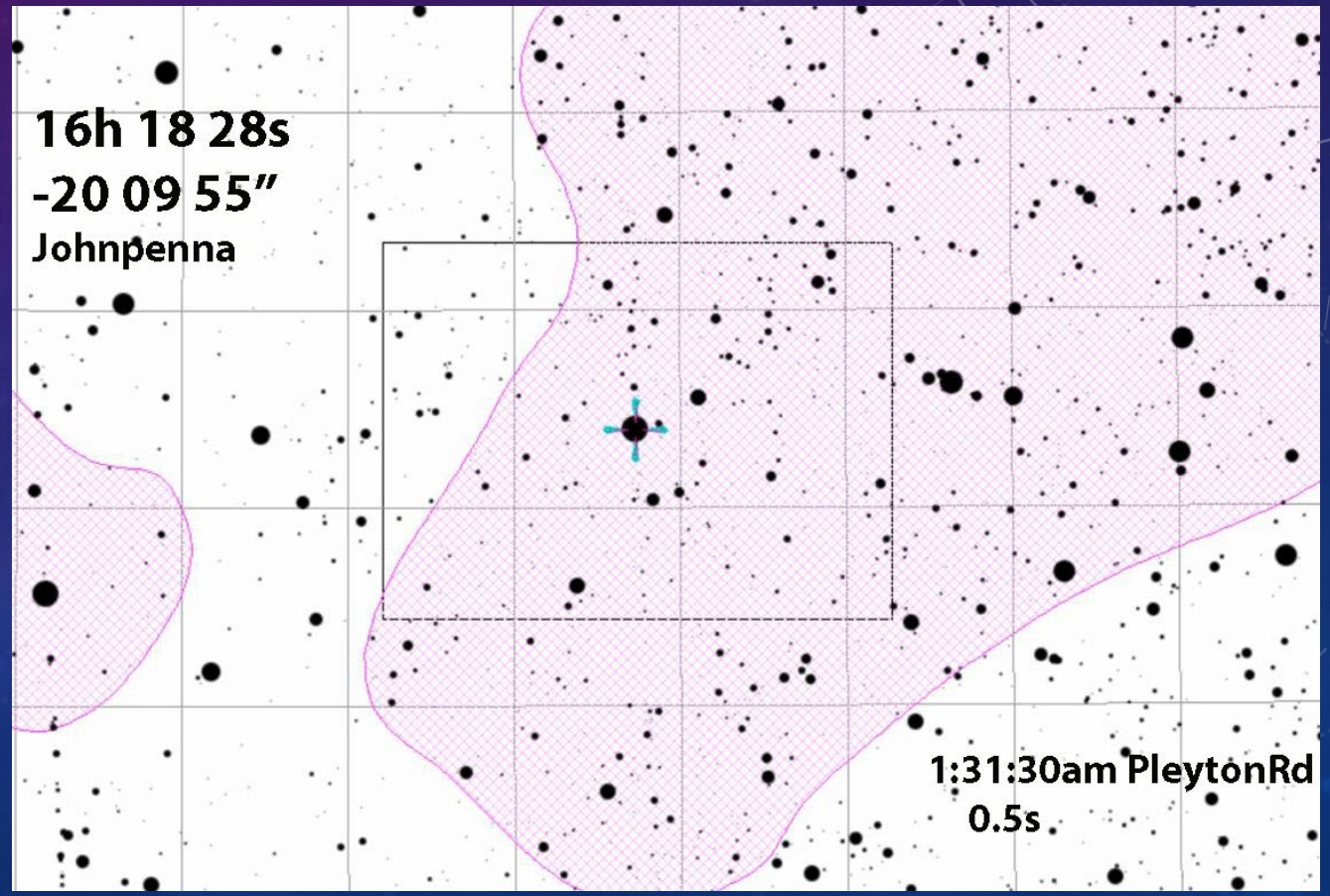


Against astronomical odds, this same asteroid had another occultation just 3 months later, and whose narrow 4 km wide path went right over Cabrillo College Observatory… A**gain**! Alas, clouds chased us all the way out to the Central Valley. where my student Bernard nailed a double occultation, and Kirk a single occ

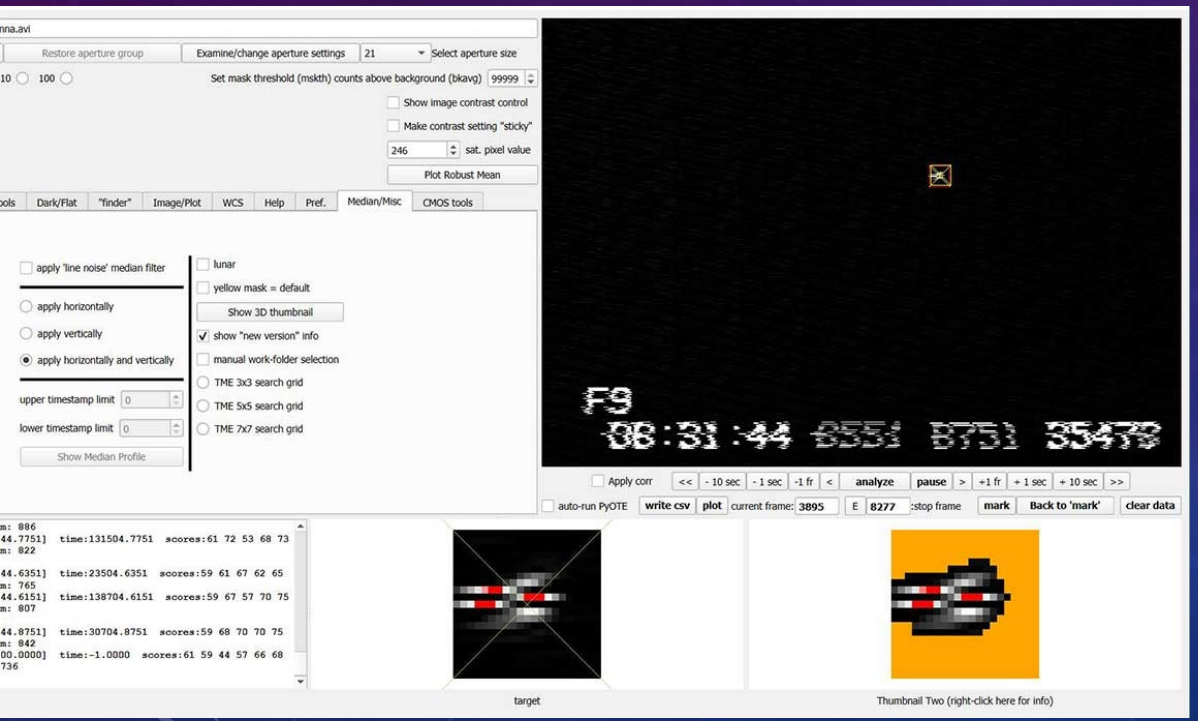
Afterwards - our team at a Subway sandwich place in the Central Valley. Success and smiles, in our “Rock ‘n Roll album cover” pose.

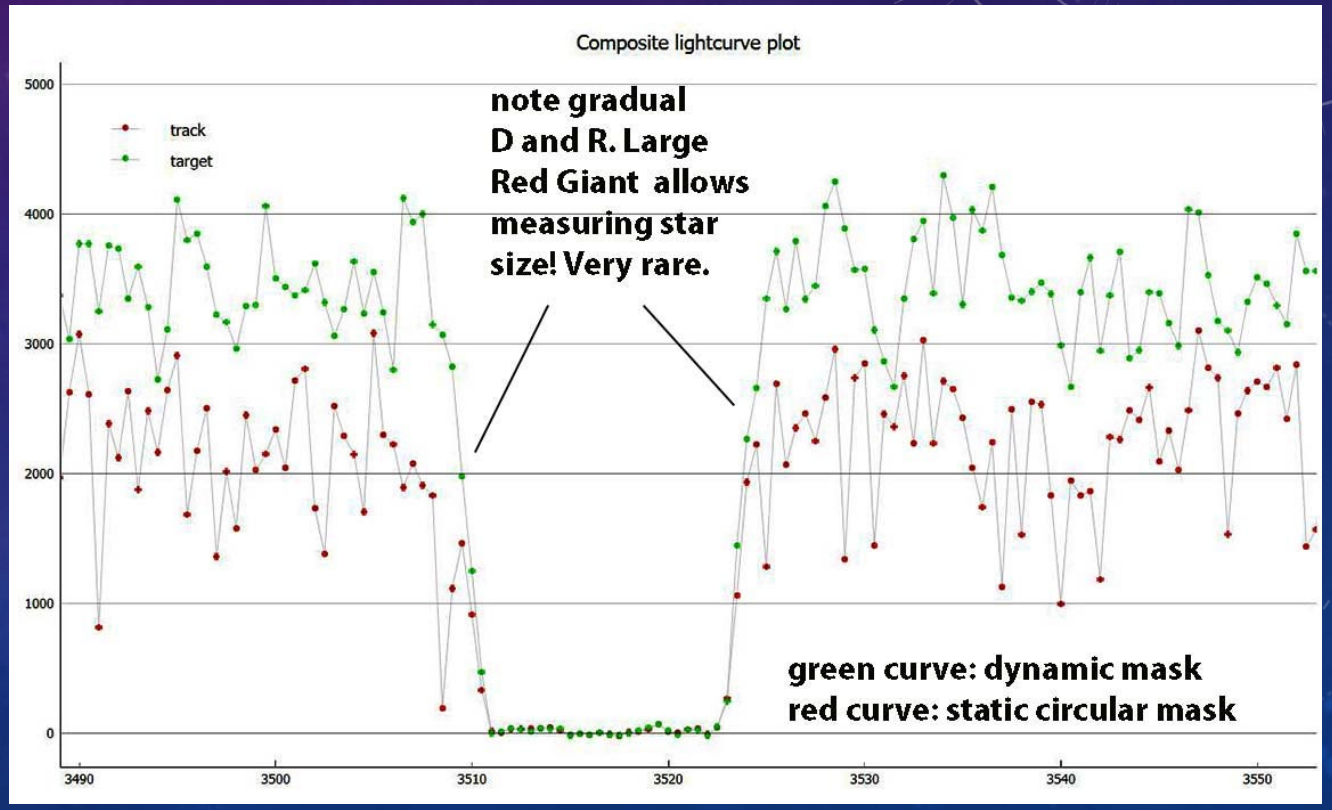
More Science – Stellar diameter measuring too, is sometimes possible if the star is big enough:

- Just 5 months ago, our team of myself, Kirk Bender, Sandy Astone, and Bernard Huynh journeyed all night for the occultation of a brilliant 5th magnitude red giant star occulted by the asteroid Johnpenna, from Lake San Antonio. (brightest asteroid occ of my 40 yr career!)



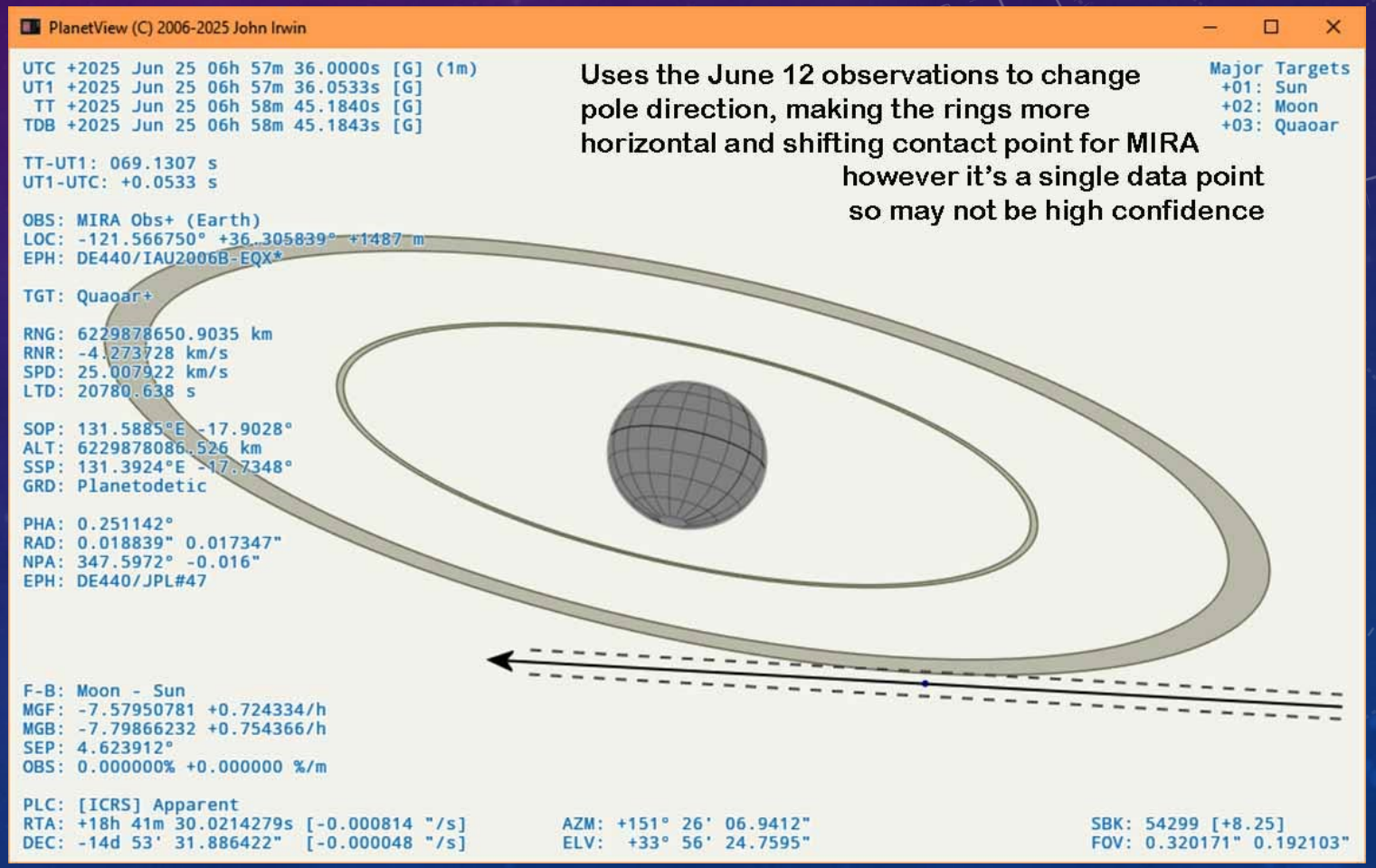
This Red Giant is large enough and bright enough to allow 1/50th sec video imaging, with signal capable of determining the gradual occultation of the star and hence the angular diameter! This is rare. First-look data at right. Challenges remain…



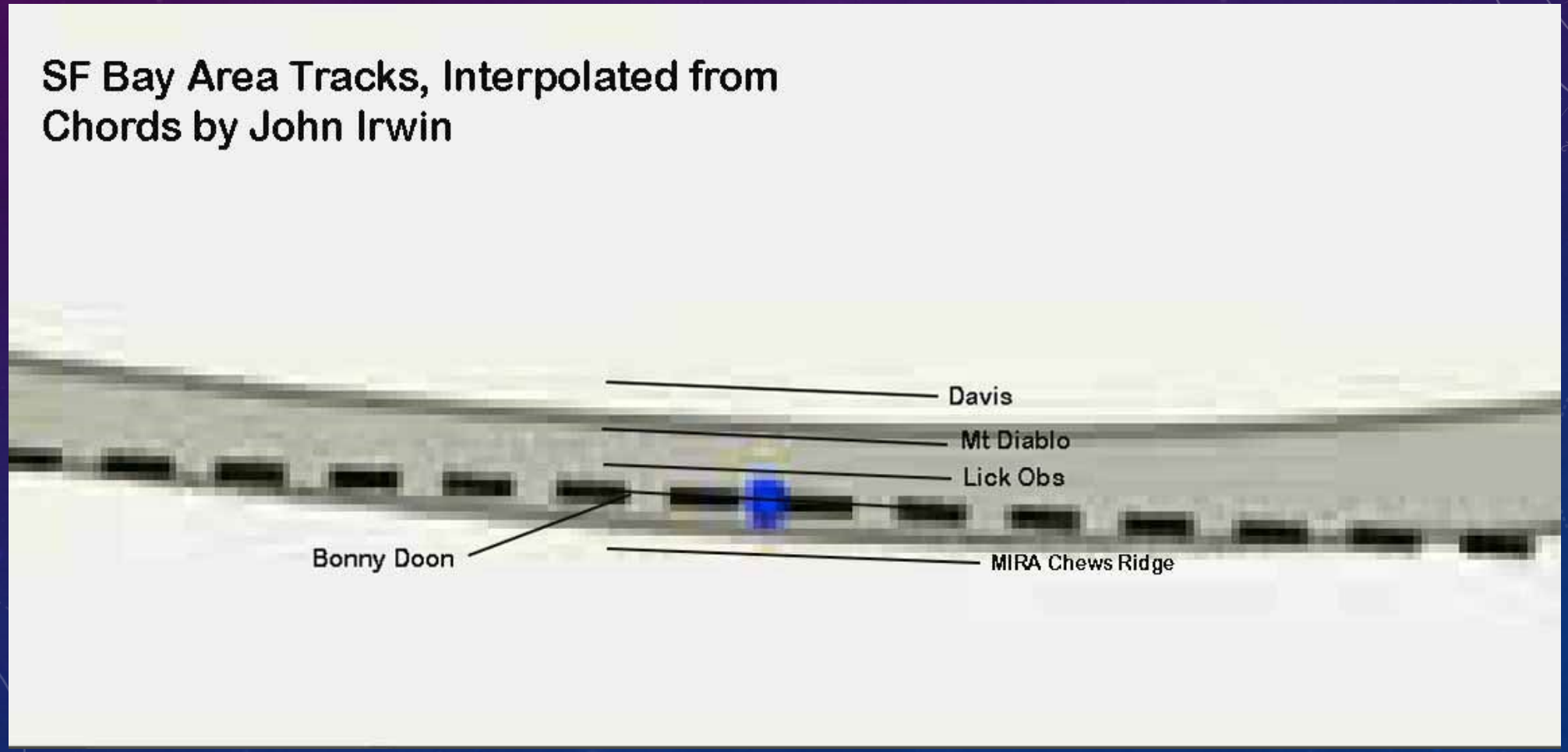


And – Last: Newest, and most exciting – We discovered a new moon (or less likely, a 3rd ring) around Quaoar this summer

- On June 25, Quaoar occulted a “bright” star under moonless skies. Magnitude 14.5 (OK, not really that bright – but, bright enough if you can get time on the MIRA 36” Reflector at Chews Ridge.
- This time, the shadow of Quaoar was firmly known to only cross the Arctic in daylight.
- But in the northern US, we could hope to see occultations by the denser outer ring Q1R



I tried to get time at Lick Observatory, and Fremont Peak Observatory – but no-go. They would have had tracks deeper into the Q1R ring than at MIRA.



To my amazement, the target star completely disappeared for over a second, but yet a full 2.4 minutes before any predicted ring contact. Kirk Bender, on the 14” CDK telescope with independent gear, got exactly the same occultation.

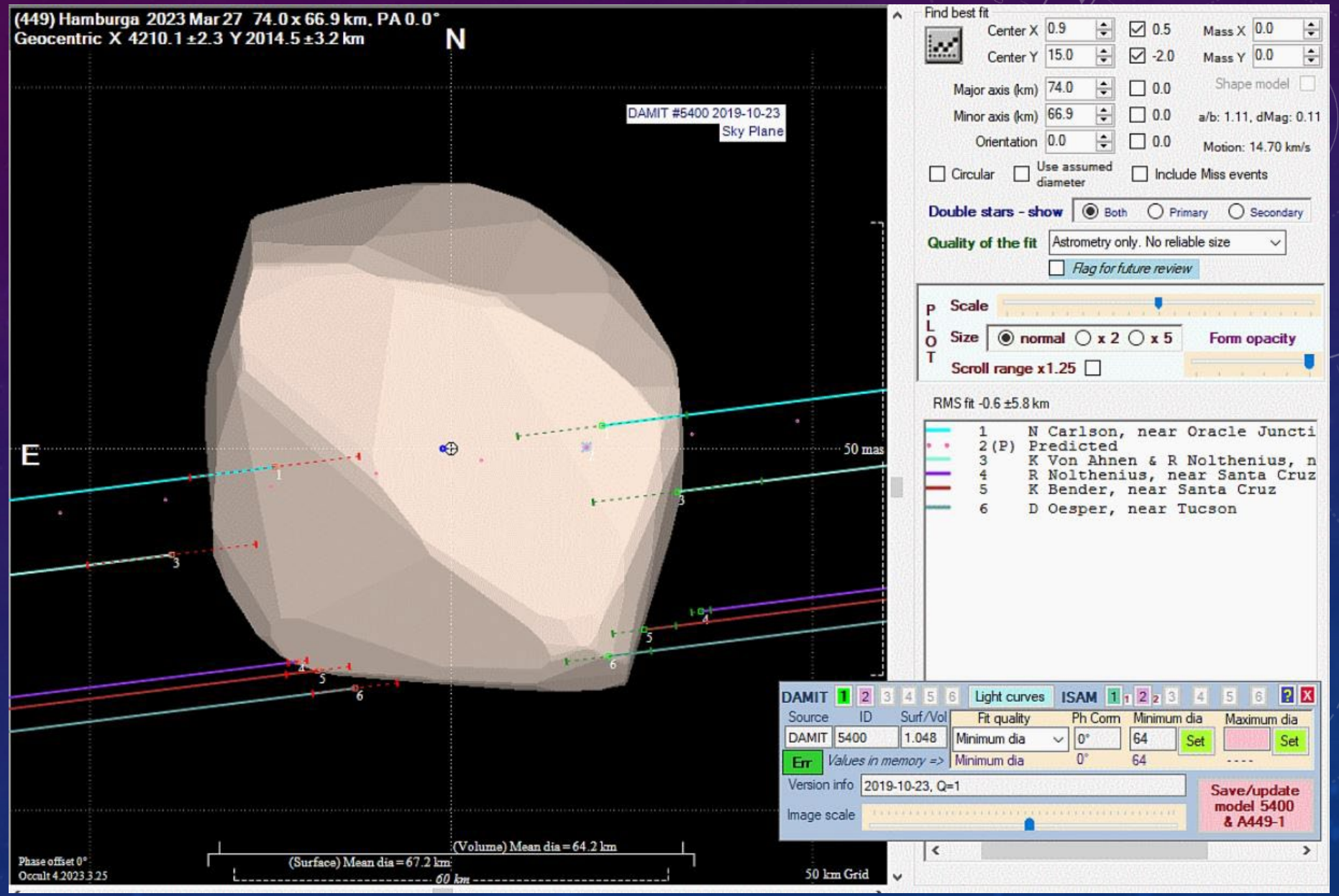
- Because our AAS paper submission hasn’t been given the green light yet, I can’t show you the data.
- But, this is very very cool! Rings beyond the Roche Limit are amazing and poorly understood.
- Quaoar will be a subject of intense interest for astronomers for a long time, especially by occultation methods.

Occultations: They're exciting, and they're important real science.

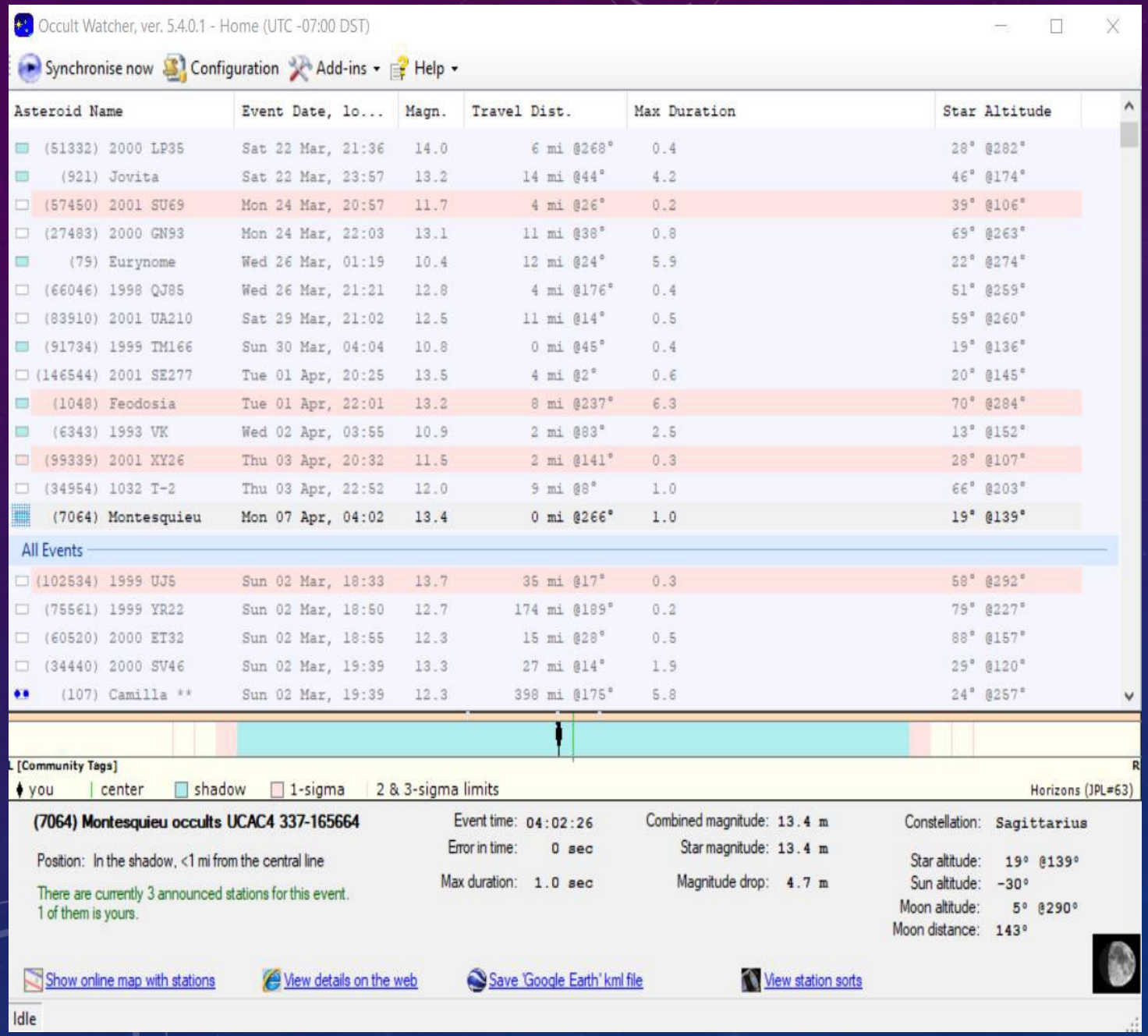
It's an astro adventure, all compressed into a single expedition and a few seconds of climactic data-taking.

A million things can go wrong, but you learn, and the memories of the successes stay with you!

We can briefly go over gear, software (12 slides). Or… Maybe you have some questions?

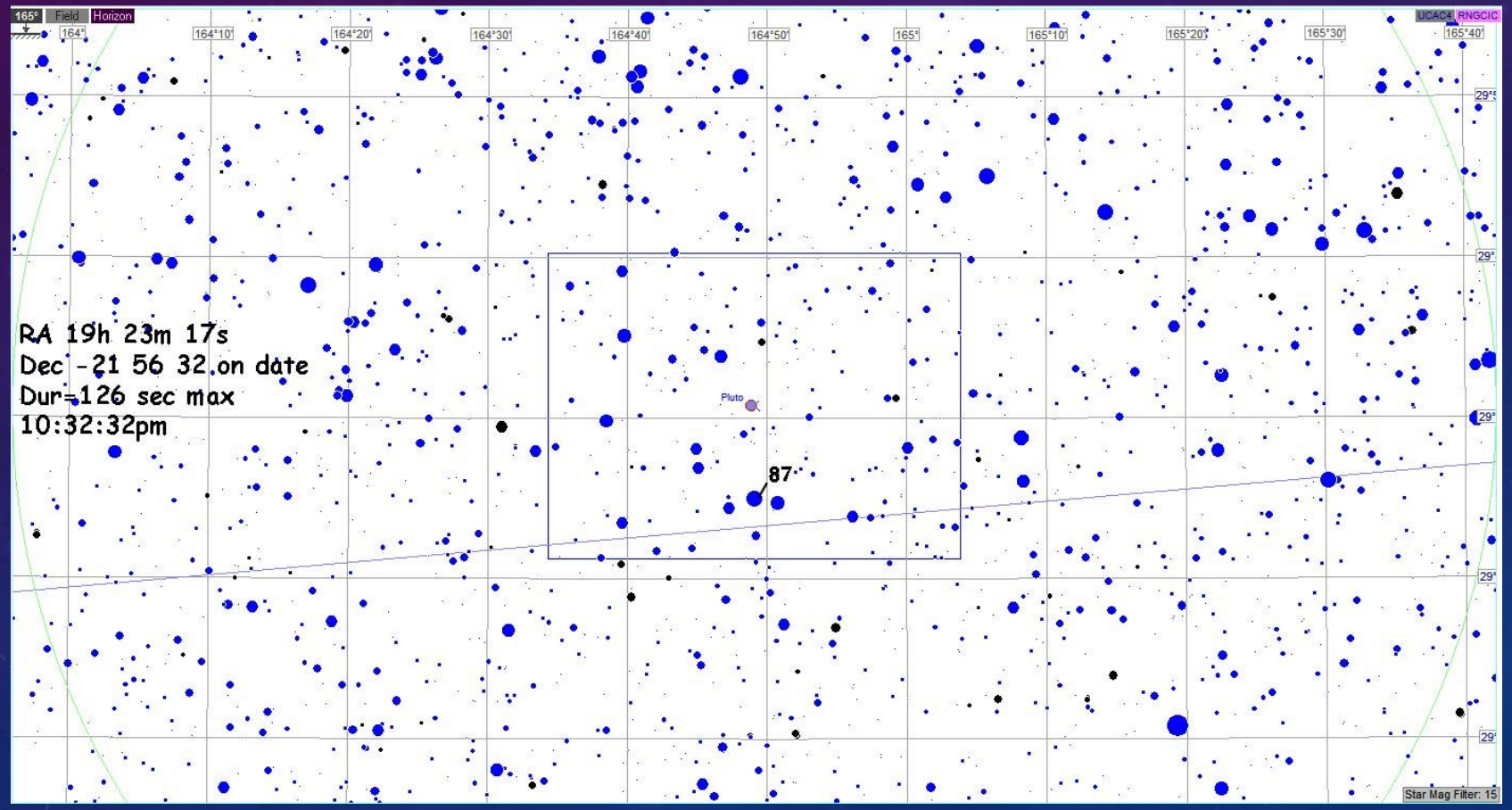


So, how do we get such data as these? What's the process and the gear needed?



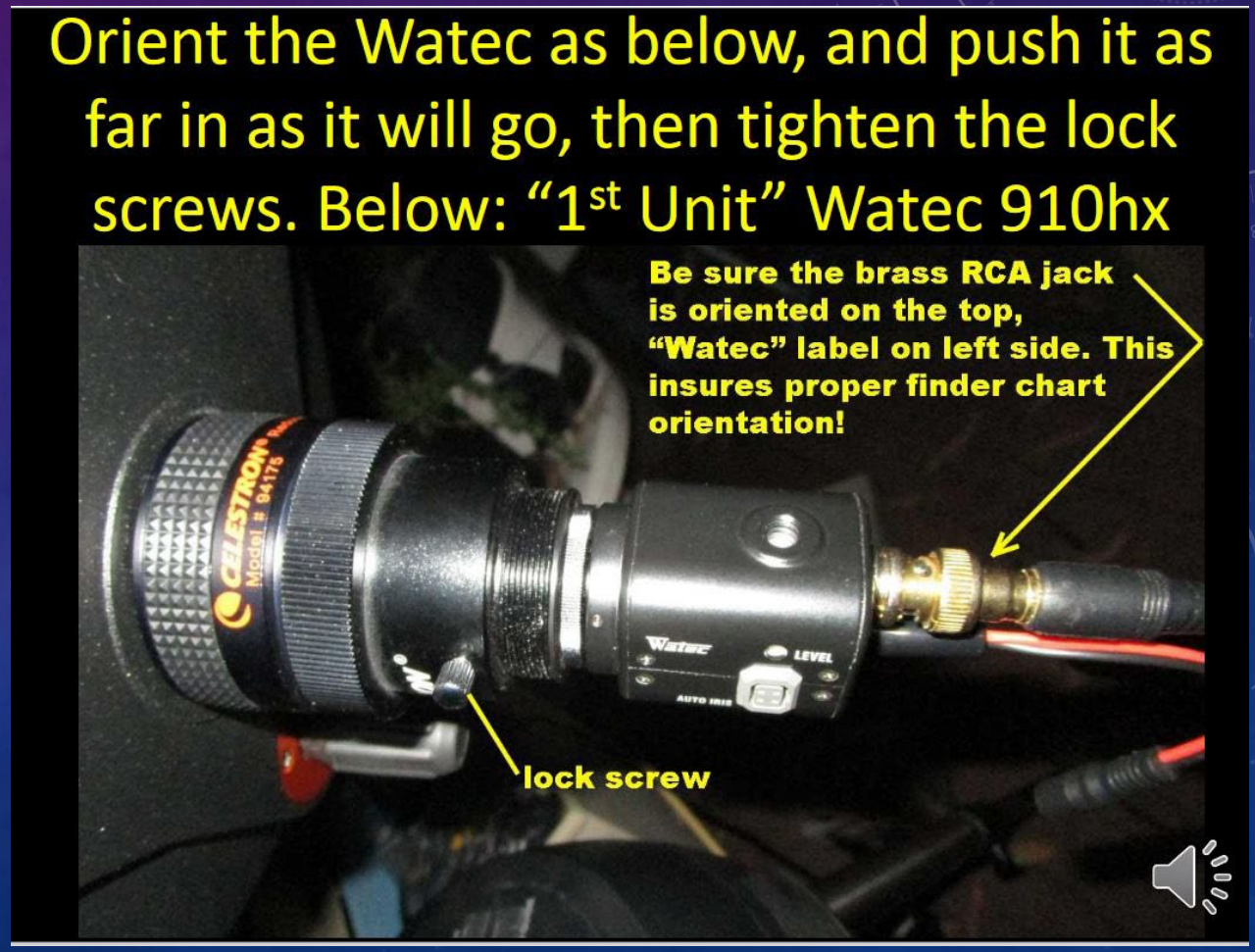
Predictions: Install freeware: OccultWatcher Desktop (OWd) will comb through the master database of global occultations in OccultWatcher Cloud (OWc) and generate a list of all events upcoming that satisfy your filters

If I see one that looks promising and weather is a “go”, I prepare finder charts showing the 32mm Q70 eyepiece view, and Watec’s chip view. OccultWatcher helps make this process fairly easy, by auto-startup of C2A planetarium software at the time and long/lat chosen by you, with eyepiece and camera apertures you set.



EQUIPMENT? I LOVE OUR CELESTRON 8SE SCOPES, AND WATEC 910HX LOW-LIGHT VIDEO CAMERAS

- My gear sets up quickly. From arrival to on-target recording, 20 min if things go smoothly. 8SE's do 2-star align fast and reliably. Has robust electronics (our old Meade scopes? not!), and they're light weight and pack compactly for our many expeditions.
- We use a Celestron f/3.3 reducer to concentrate starlight onto fewer pixels for better S/N. Only the f/6.3 reducer is still made.



I like deploying out of the back of my RAV4. My home made “Occ Box” houses the DV camcorder, IOTA VTI video time inserter, microphone, battery, data lines to connect to the video camera at the back end of the Celestron 8SE scope

We have used mini-DV camcorders to record the time-stamped video out of the IOTA-VTIs. Now, I and most IOTA occult’rs use laptops and direct-to-disk recording.

<u>91 successes in 2024. 2025 looks to be similar</u>

The IOTA website – Has links to all the software and instructions you need, as well as publishing sky plane solutions for your occultations submitted to IOTA.

The IOTA message board is excellent to post questions, get answers, and get notifications on new events needing observers.

- Celestron NextStar 8SE SCT telescope..... $1199.00
- Orion Q70 eyepiece..... $ 100.00
- Celestron 2” diagonal..... $ 124.00
- Watec 910hx-RC camera..... $ 700.00
- Canon ZR45mc camcorder (ebay)..... $ 150?
- Meade or Celestron f/3.3 reducer..... $ 100? Will have to find on eBay, not made any longer
- Highpoint 0.5x focal reducer..... $ 26.95
- Astromania 1.25” c-adapter..... $ 16.00
- Short-nose 1.25” c thread for use w/ 0.5x..... $ 12.00
- IOTA VTI video time inserter..... $ 249.00
- 2 Tool boxes (Ace Hardware)..... $ 26.00
- 8ah 12VDC battery ..... $ 35.00
- 2 “LED Innovations” triple sockets..... $ 30.00
- RCA cord, 2 male 2.1mm “N” barrel plugs.....~$ 30.00
- Various fuses, connectors..... $ 38.00
- Total..... ~$2836

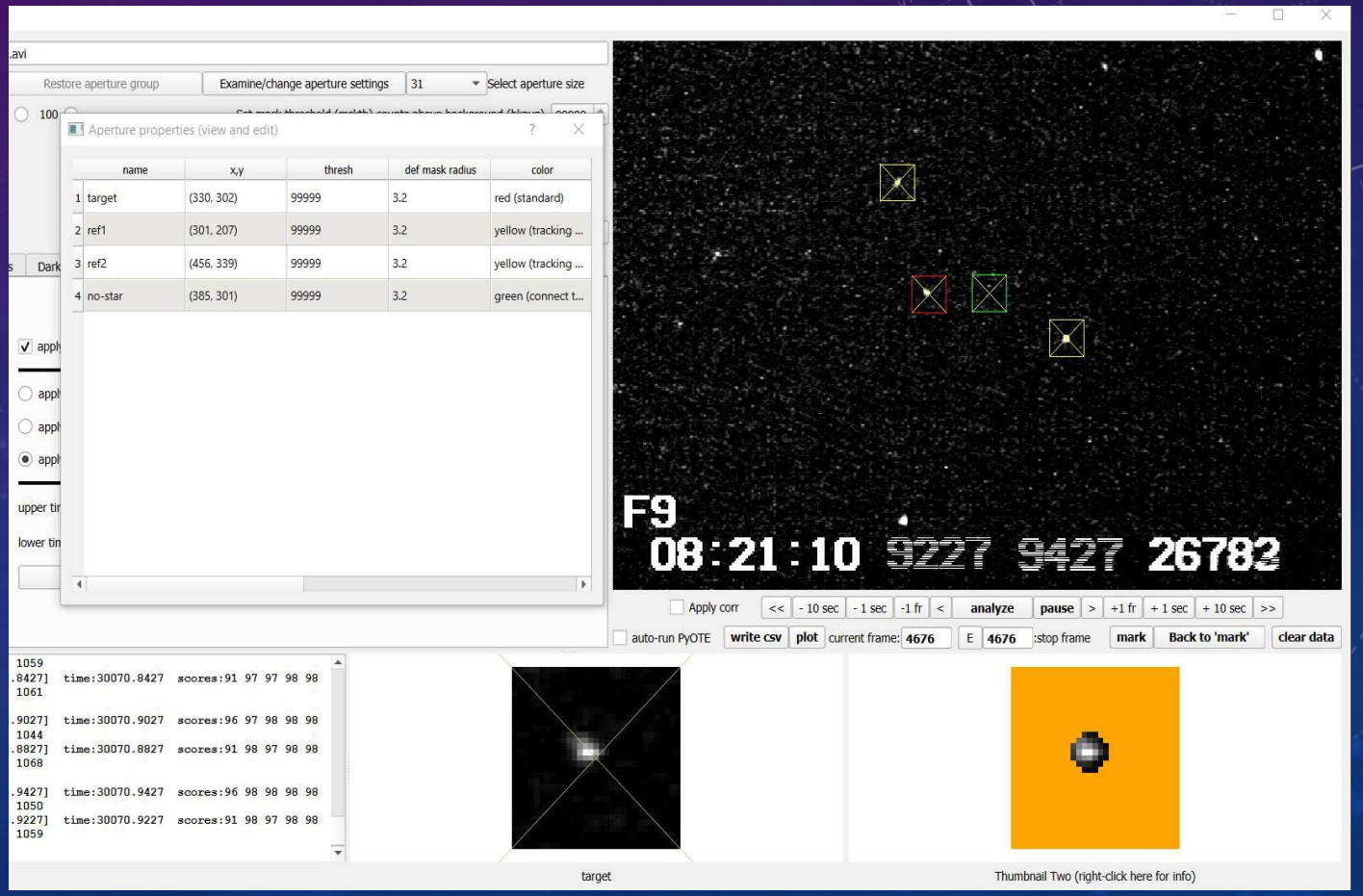
Our classic gear will get 14th magnitude occultations under good conditions. all for under $3k ‘23 prices, alas. Now, more… but given today’s chaotic pricing, I left this slide as is)

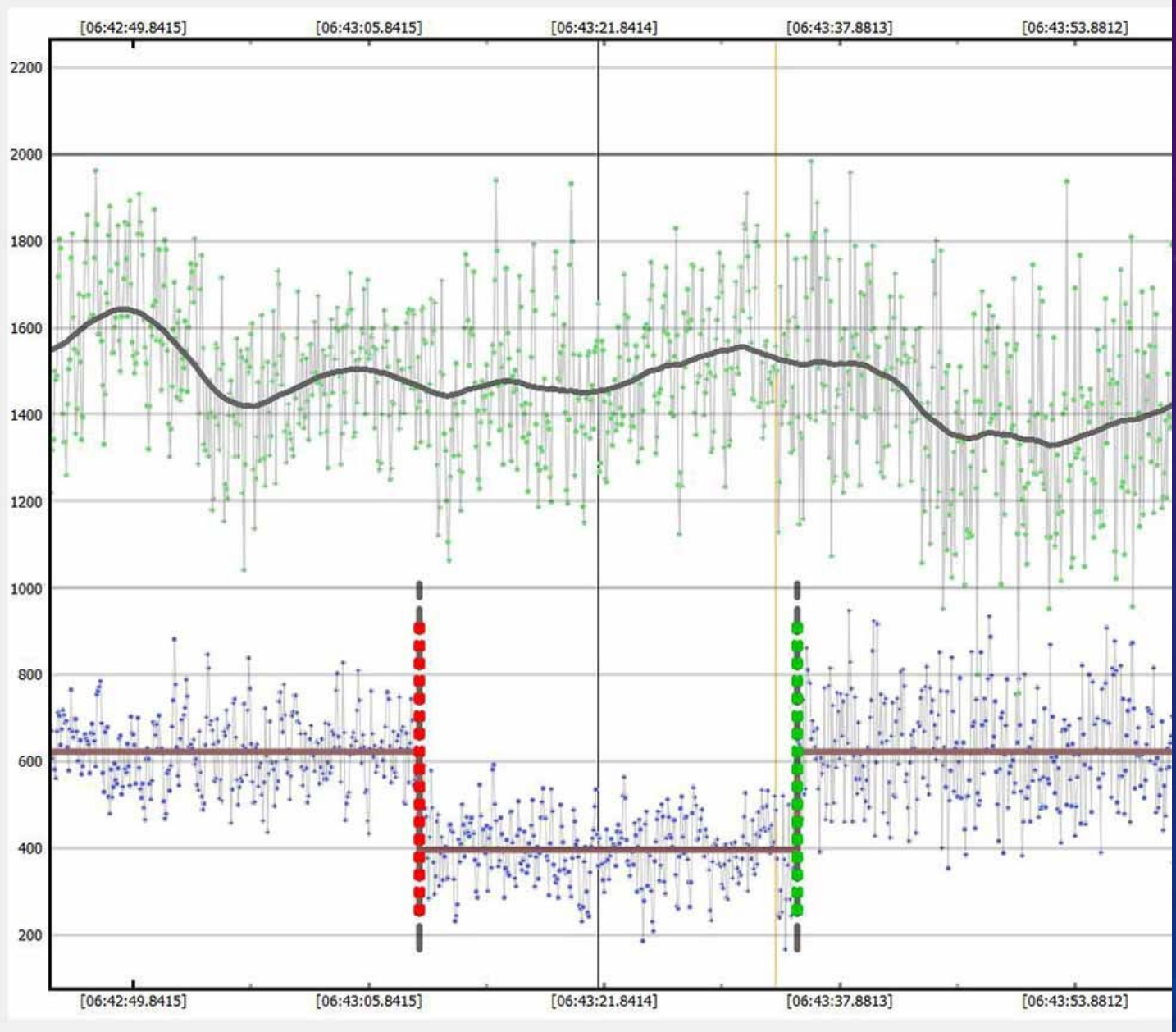
IOTA's Mark Simpson has designed a new self contained occultation system: Astrid. ~$750

"Astrid is a Raspberry Pi-based, self-contained GPS-equipped astronomy imaging device with features that make it a complete, all-in-one device for recording and accurately timing occultation events. Using a tablet or laptop to connect to Astrid (via its wifi hotspot) the user can plate-solve, pre-point a telescope, control a computerized mount (if desired), schedule a recording, confirm in advance that the exposure and gain chosen are sufficient to record the target star, automatically record an event, and play back the recording (with a helpful identification of the target star)".

Reducing your data (brief summary). PDF for more detail. PyMovie does your photometry (star brightnesses!)

- Your video needs to be raw, no compression. AVI format is what is downloaded off the miniDV camcorders into my Win10 laptop.
- Install the Python (free) language onto your Windows machine
- Then install PyMovie. PyMovie lets you place apertures on your target, reference stars, and blank sky.
- Then click “analyze” and in a few minutes you’ll have a .csv file with the photometric values for all selected objects for each frame of your video.



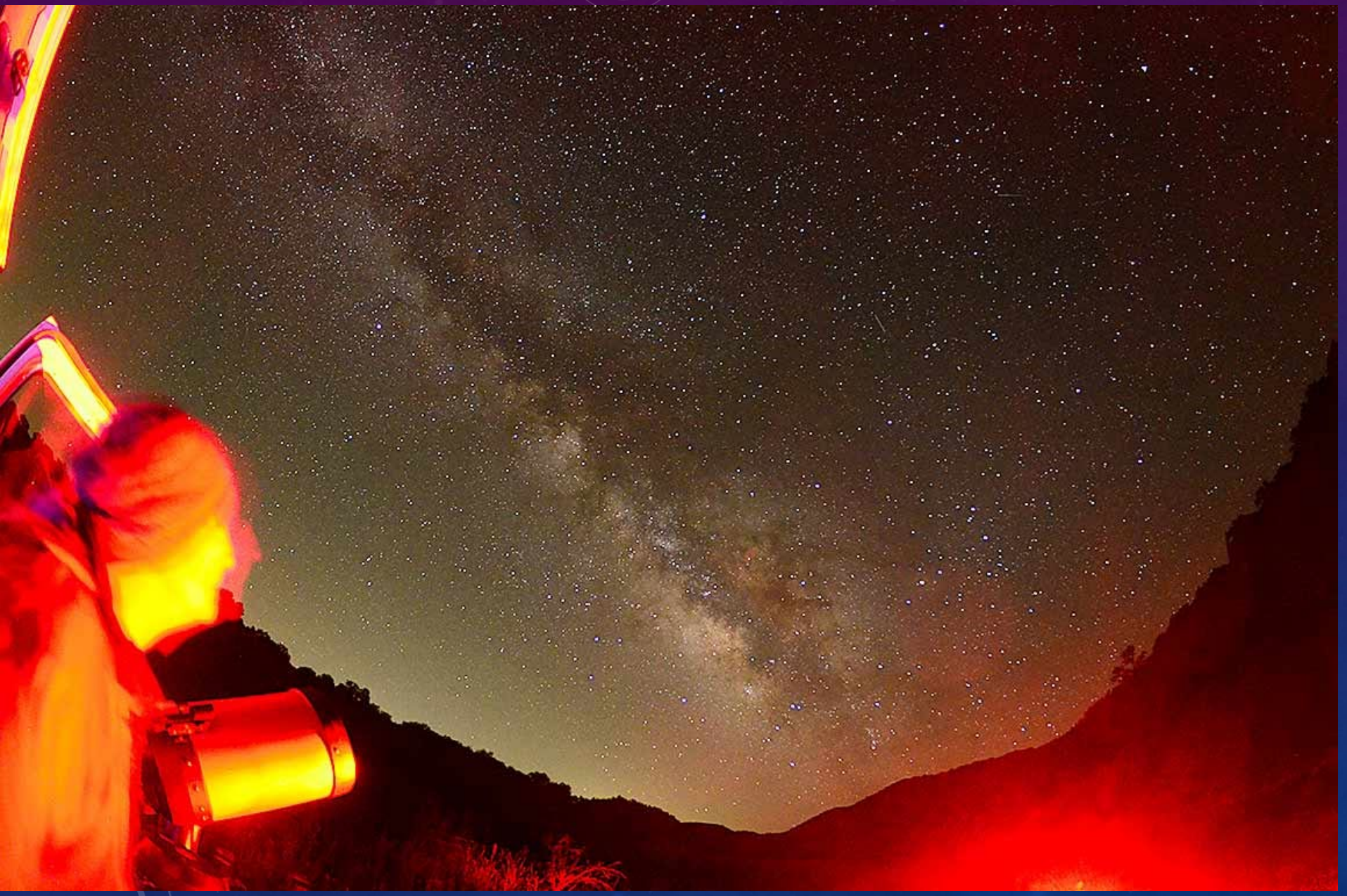


PyOTE – then lets you calibrate your target by smoothing a reference star you know stayed constant.

This calibrated light curve it then analyzes to determine the best “D” and “R” moments

I require my team members to do all this themselves. They then send me images of the relevant light curves and their timings

- I then assemble a web page with the narrative and images of each occultation we try.
- Here's an example; an occultation by Lilaea Jan 30 this year
- It's gotten to be rather time consuming! I'm going to further require my team to send me files that are already properly in my naming convention and size, and a narrative of anything relevant that the IOTA auditors data/checkers may ask as they filter through the data to give it a thumbs up / thumbs down for inclusion into the larger astronomical databases.



Thanks for your interest!

There’s always a need for more asteroid occultation observers. Every location gives a unique record of value.