

# DISCOVERING A NEW MOON AROUND QUAOAR – WITH AFFORDABLE VIDEO GEAR AND A LOT OF LUCK

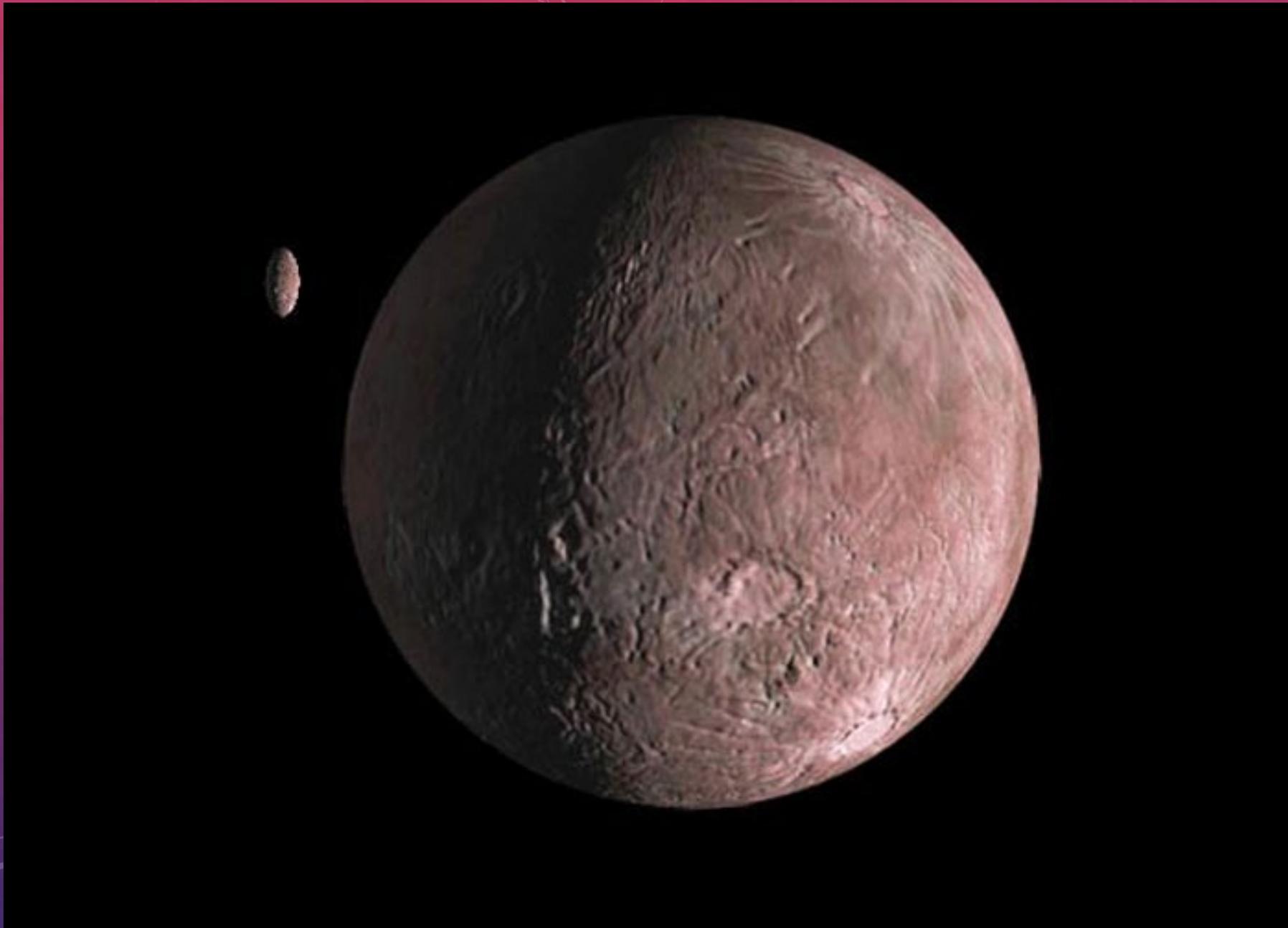
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WITH MAJOR HELP FROM THE MONTEREY INSTITUTE FOR RESEARCH  
IN ASTRONOMY

# ON JUNE 25, 2025 – ONE OF THE FIRST KUIPER BELT OBJECTS DISCOVERED – (50000) QUAOAR – OCCULTED A FAINT STAR FOR FORTUNATE OBSERVERS...

- Faint, but not TOO faint - Magnitude 14.9
- Occultations are a hot technique these days for discovering new moons around small objects in the solar system!
- This Quaoar event, in particular, packed a big surprise against very long odds. Here's the story...



FIRST – WHAT DO  
WE KNOW  
ABOUT THIS  
STRANGE KUIPER  
BELT OBJECT –  
QUAOAR?

(ARTIST'S  
CONCEPTION, NO  
CLOSE UP  
PHOTOS YET. BUT  
SPACE MISSIONS  
ARE PLANNED)

# “KUIPER BELT OBJECTS” – WERE PREDICTED TO EXIST BY 20<sup>TH</sup> CENTURY ASTRONOMY GERARD KUIPER – HE WAS RIGHT.

- Why? Because short period comets, like Halley’s Comet, lose enough mass by solar-caused melting that they should last for only a few million years, he calculated.
- But the solar system is 4.6 BILLION years old!
- Therefore, there must be a continual creation of new comets to replace those melted away!





THINK: THE WIZARD OF OZ.... (“I’M  
*MELTING!*”)

- Kuiper theorized the most likely explanation was a population of hundreds of thousands of icy objects many miles across, orbiting beyond Neptune, and numerous enough to collide frequently enough to make glacier-sized fragments on random orbits from the randomness of their collisional creation. **Comets!**
- But, we didn’t have the telescopes and detectors capable of seeing such dim objects beyond Neptune back in his day. We had to wait for the Keck Telescope and its new friends in the 1990’s, and CCD detectors, to hope to see them.
- One of the first discovered, was Quaoar, in 2002.

# "Quaoar" Compared by Diameter with Other Solar System Bodies



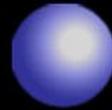
Earth:  
8000  
miles



Earth's  
moon:  
2100  
miles



Pluto:  
1400  
miles



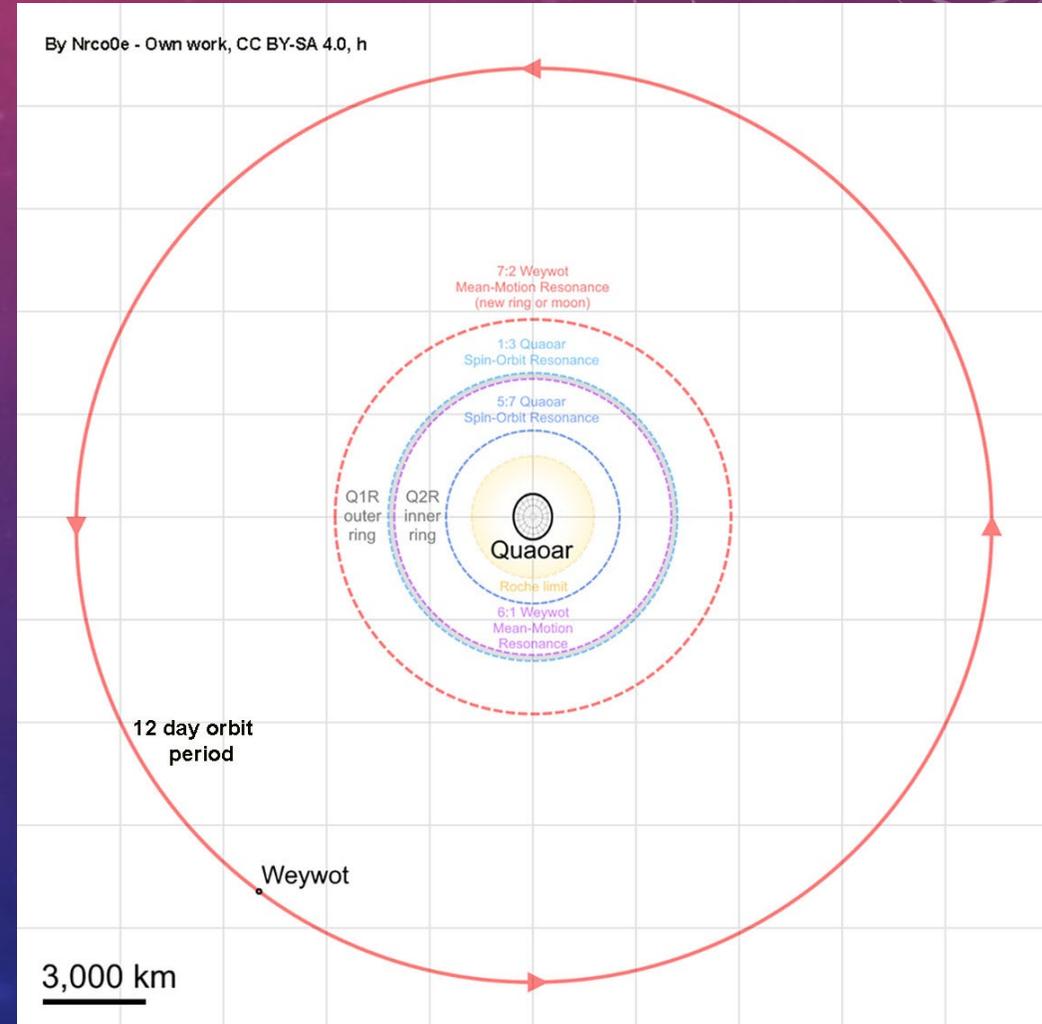
**"Quaoar":  
800  
miles**

QUAOAR –  
SMALL, YET STILL  
AMONG THE  
BIGGER KBO'S

PLUTO IS THE  
BIGGEST, AND  
ERIS IS SECOND,  
(SO FAR)

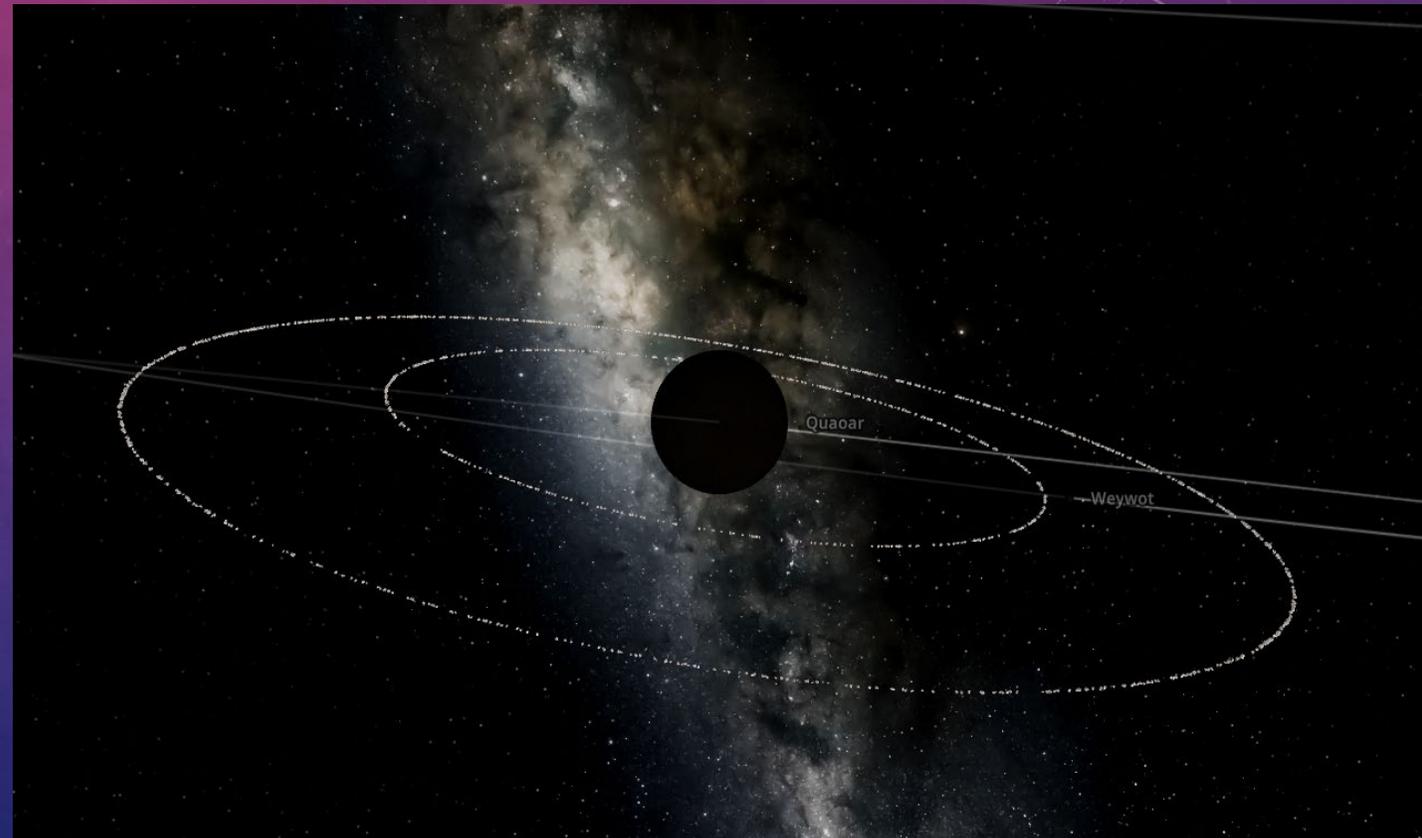
# BUT QUAOAR HAD SOME SURPRISES!

- First, it was discovered by astronomer Mike Brown in 2006 to have a moon – christened “Weywot” (Weywot was the Tongva Sky God, and son of Quaoar)
- Discovering a moon orbiting an asteroid or KBO is a big deal!
- Using Keplers 3<sup>rd</sup> Law from the laws of gravity, it becomes easy to then measure the mass, and (if you have the size) also the density of both objects... a giant step towards understanding what is must be made of.



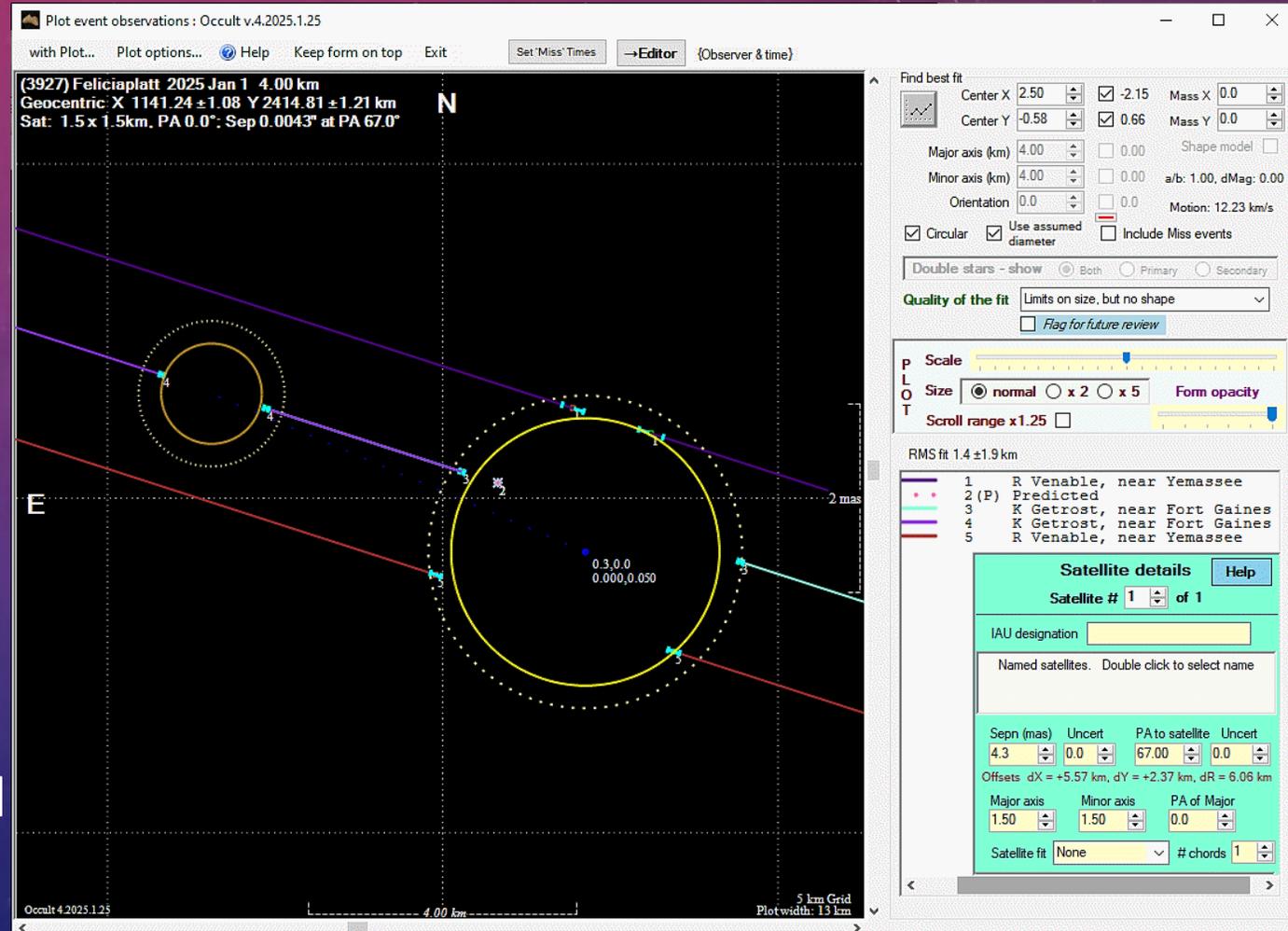
# MORE REMARKABLE, QUAOAR HAS RECENTLY BEEN DISCOVERED TO HAVE NOT ONE, BUT TWO RINGS AROUND IT

- You saw these in the last slide's diagram
- These rings are far too faint to see directly
- Instead, they were discovered by the “Stellar Occultation” technique



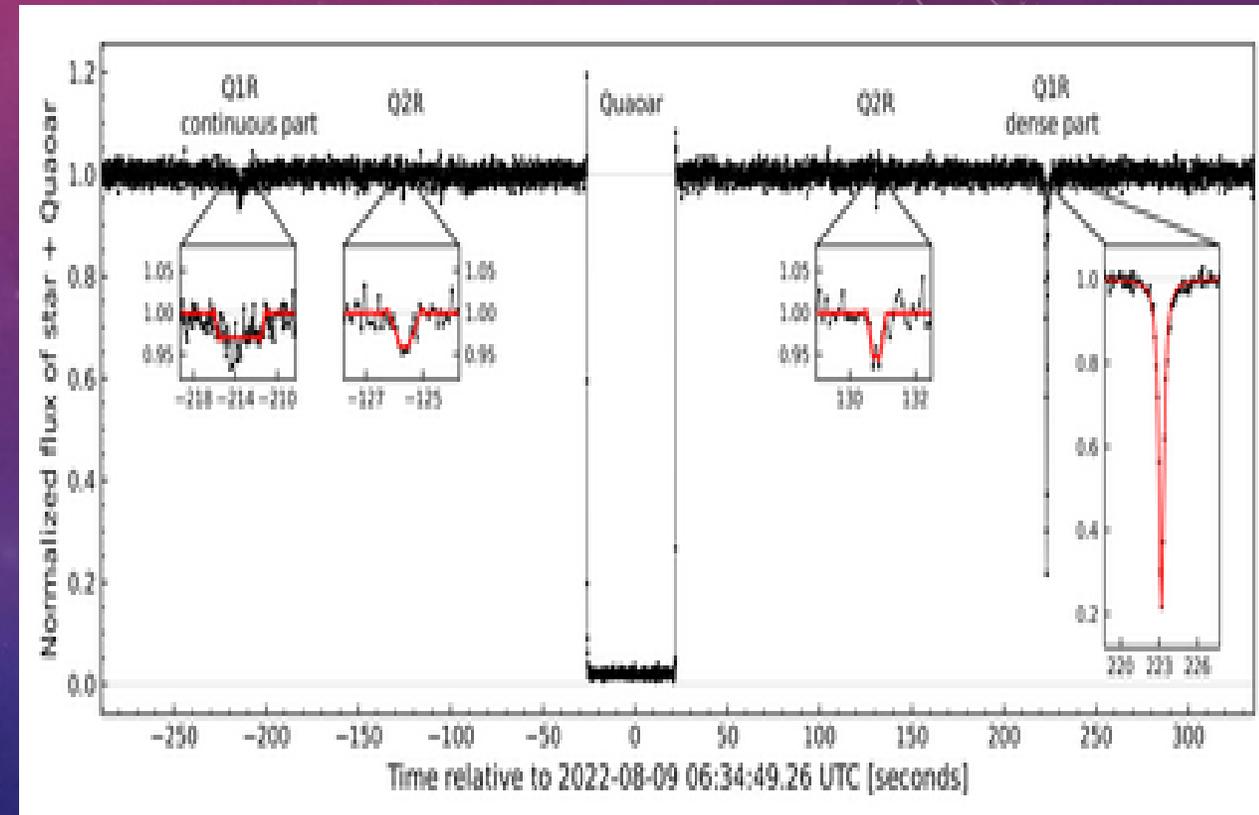
# WHEN A FAINT ASTEROID OR KUIPER BELT OBJECT (KBO) PASSES IN FRONT OF A STAR, THE STAR IS SEEN TO WINK OUT BRIEFLY

- By recording the event in video with accurate 1PPS GPS time stamps on the video frames, it is possible through software to measure the precise moments of the “D” and “R”
- This can then provide a sky-plane view of what is the silhouette, created by the occultation, of the occulting object.
- Very rarely, if the star disappears twice, you have discovered a moonlet orbiting the parent object! Here, around asteroid (3927) Feliciaplatt



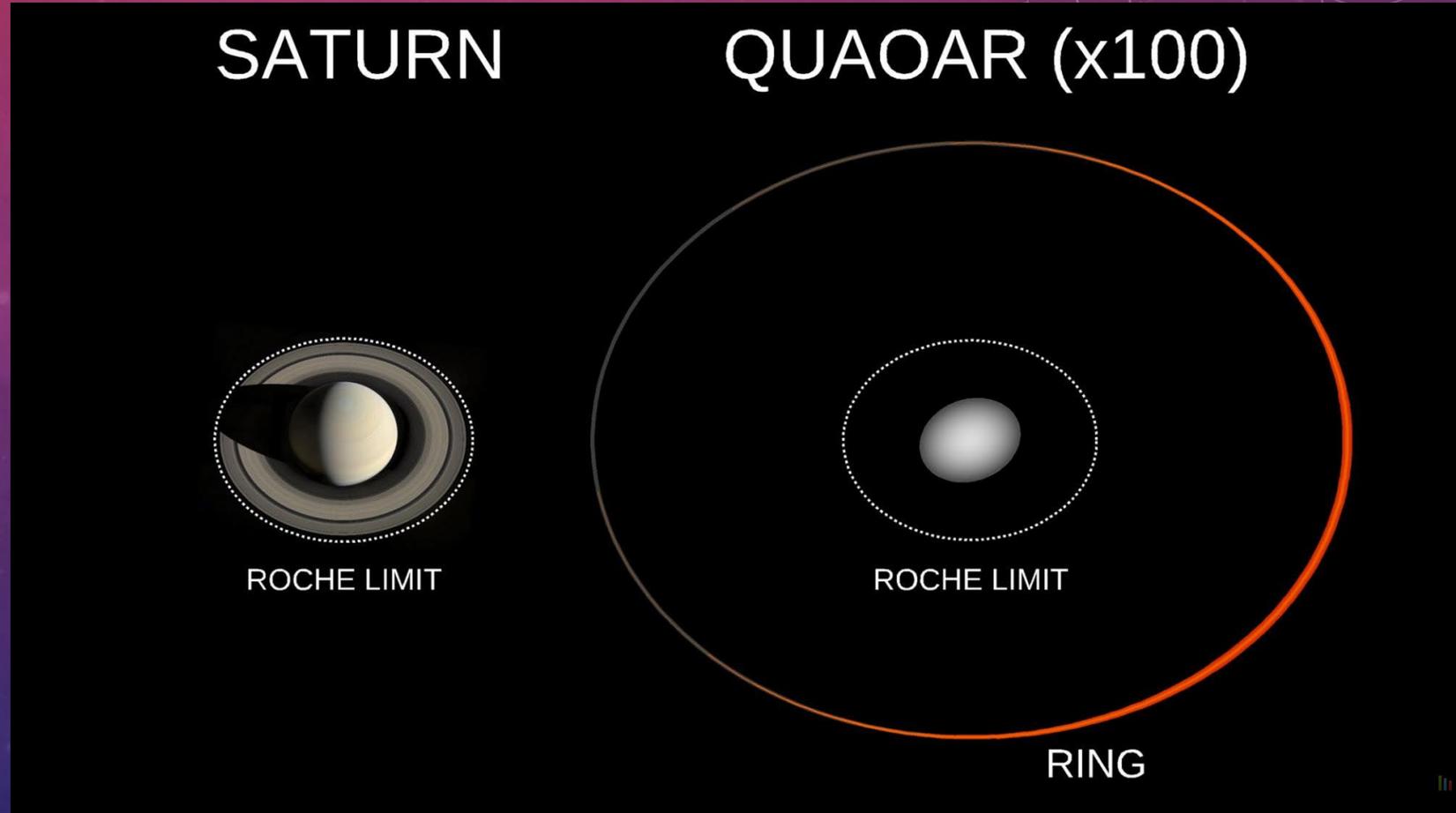
# THE CFHT TELESCOPE ON MAUNA KEA CO-DISCOVERED THE RINGS, THROUGH OCCULTATION, AROUND QUAOAR – RINGS THAT SHOULD NOT BE THERE!

- The light curve at right... By seeing the star fade **twice**, at symmetric places on either side of Quaoar, we discovered the cause must be two rings.
- Ring Q1R has both dense and less dense areas.
- Ring Q2R so far seems only to have very low density, from the contact spots sampled.



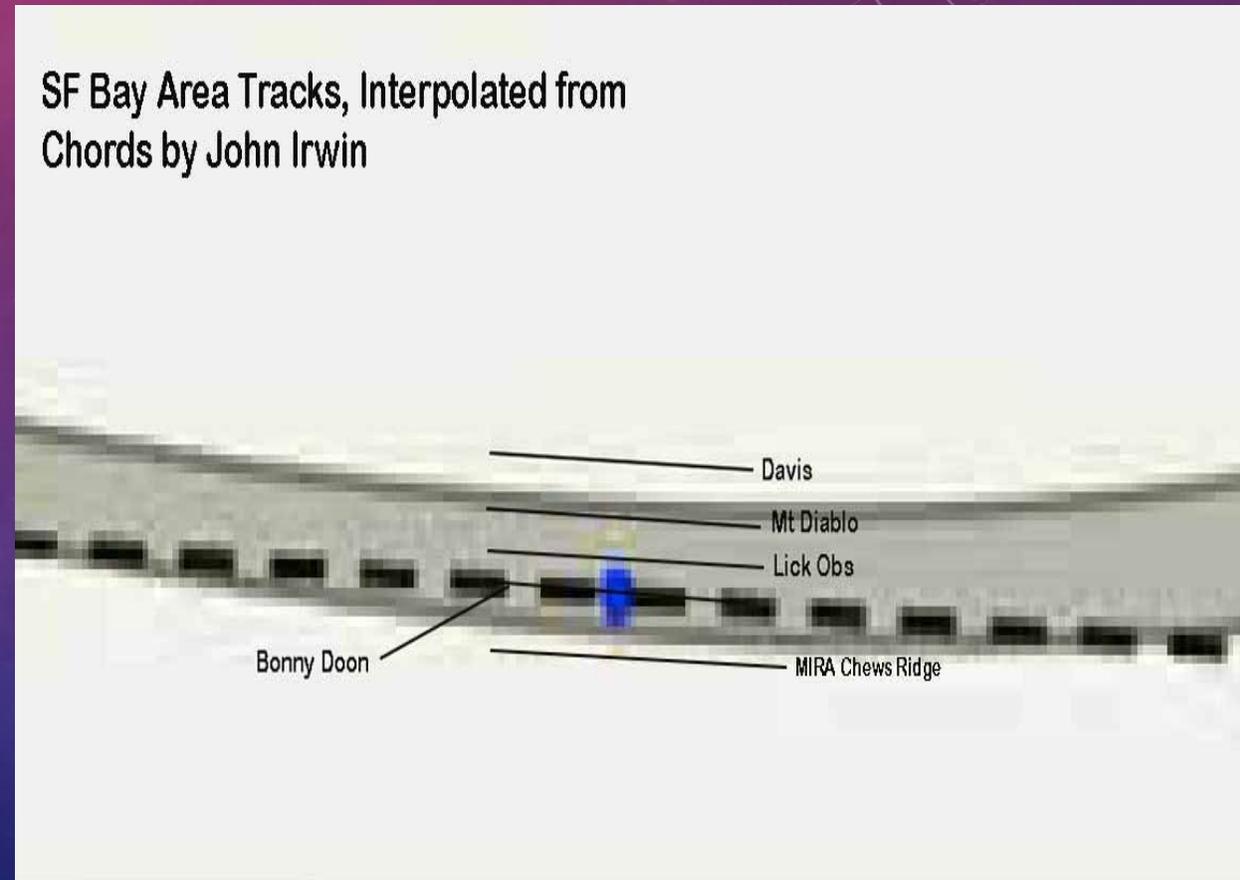
# BUT THESE RINGS SHOULD NOT BE THERE. WHY?

- Unlike Saturn's rings, Quaoar's rings are both beyond the Roche Limit.
- OUTSIDE the Roche Limit, the self-attraction by gravity is stronger than is the tidal force pulling bits of rock and ice apart from each other.
- Rings should therefore quickly collide and self-gravitate in an accelerating way to form moons
- While INSIDE the Roche limit, tidal stretching beats self-gravity, and the rings of all the outer planets obey this – they are all inside the Roche Limit.



# WE'RE NOW SET UP FOR THE NEW WRINKLE – MY, AND KIRK BENDER'S, DISCOVERY OF A NEW MOON OF QUAOAR

- June 25, 2025 – Quaoar was predicted to occult a faint magnitude=14.9 star as seen from a path through the sunlit Arctic Ocean. Unobservable.
- BUT – its denser ring Q1R was predicted to occult this same star from locations in the northern half of the U.S. at midnight
- In particular, through central California we might see a grazing, long duration path of the star behind the denser Ring, Q1R, if predictions were correct.



# I'VE GOT A GOOD SCIENCE RELATIONSHIP WITH MIRA – THE MONTEREY INSTITUTE FOR RESEARCH IN ASTRONOMY

- And they were eager to expand the research of this privately funded observatory when I contacted their chief resident astronomer: Daniel Cotton.
- Their 36” reflector on Chews Ridge, and co-mounted 14” Planewave DK reflector would provide dual data gathering opportunities to map the ring density of Q1R, was my plan





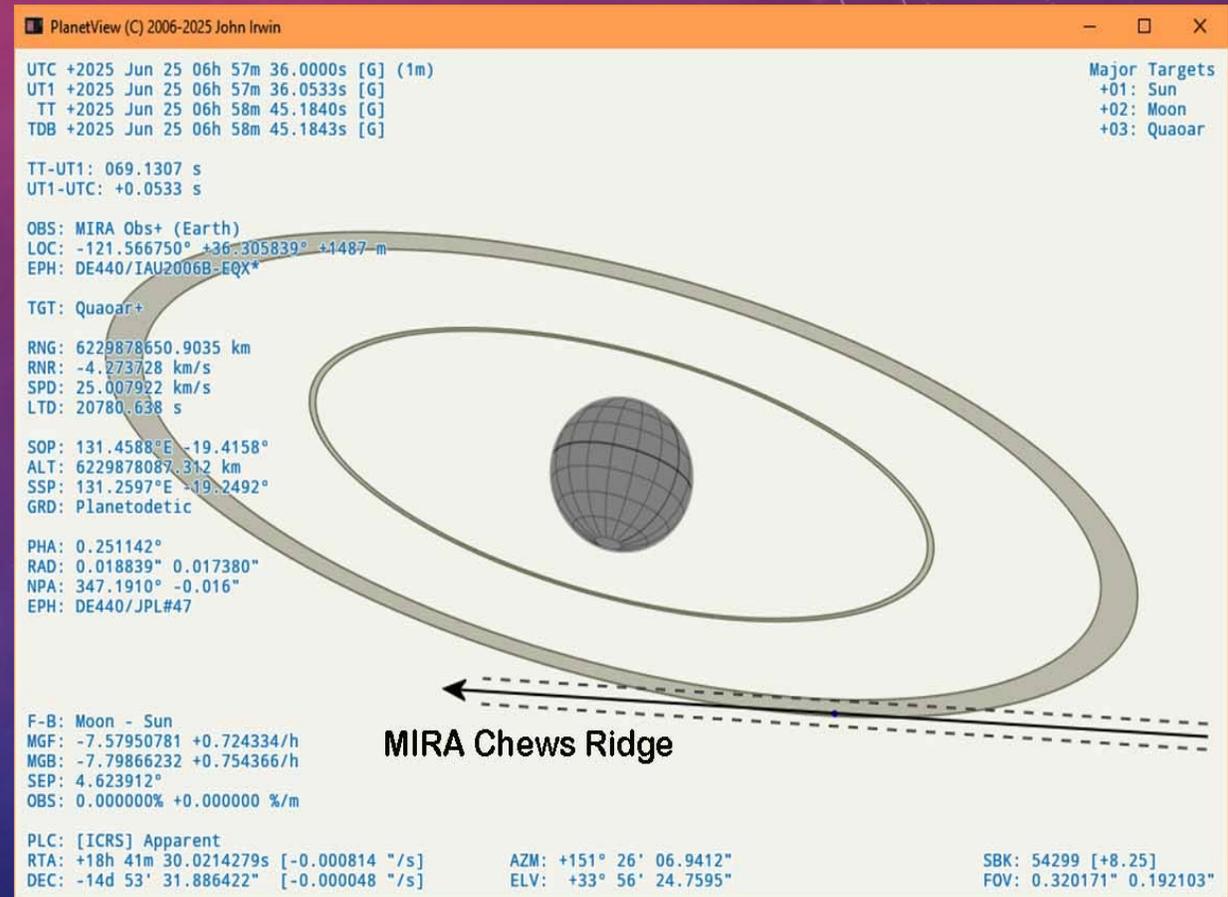
MIRA IS A MAGICAL MOUNTAINTOP PLACE...



# “CHANCE FAVOURS THE PREPARED MIND”

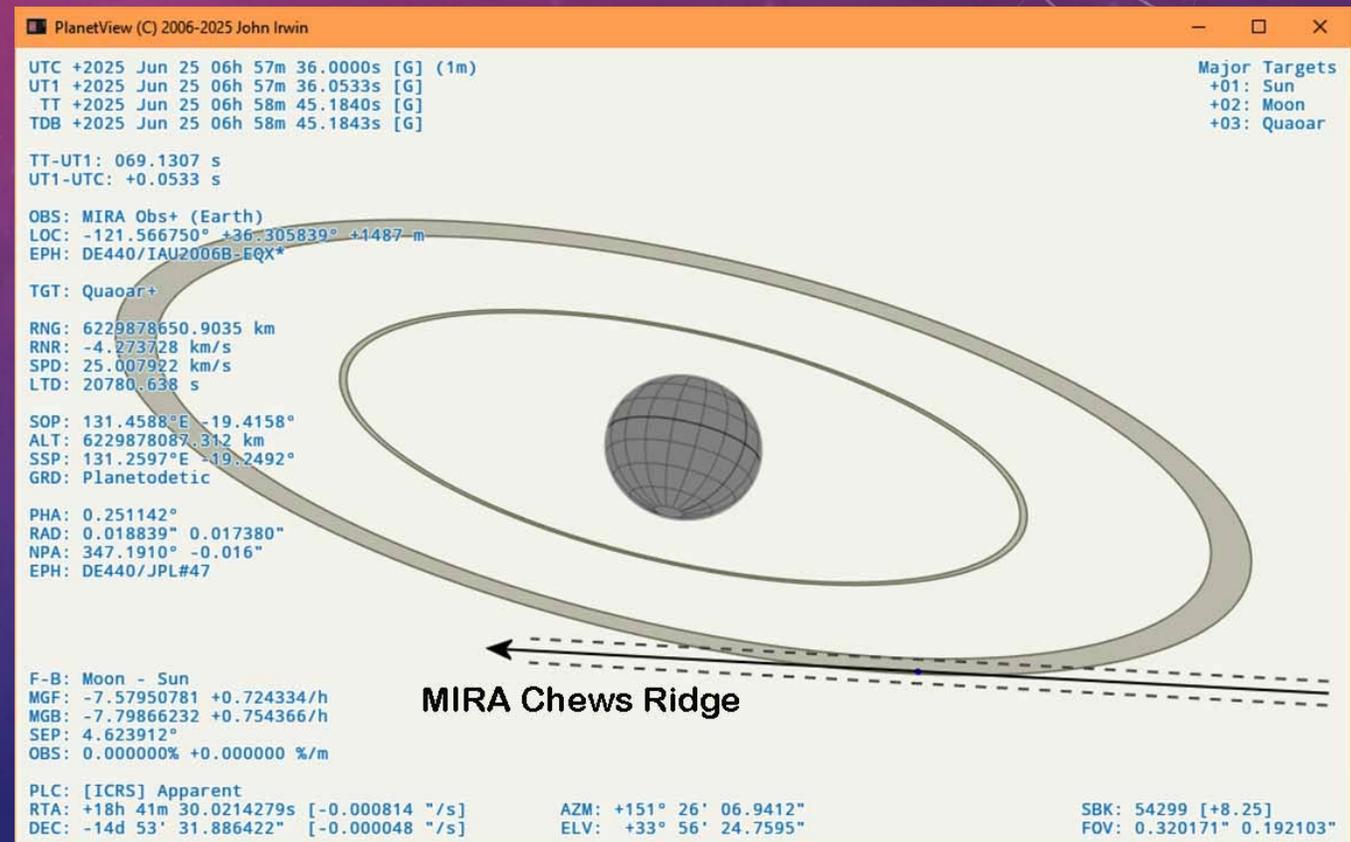
— LOUIS PASTEUR — DEC 7, 1854

- I figured – after all the hours of preparation and travel – let’s plan to do an extended occultation recording. Who knows if there might be a 3<sup>rd</sup> ring? Or an undiscovered moon?... beyond ring Q1R. The marginal added cost is trivial, to spend a few extra minutes accumulating a few more gigabytes, in hopes of something new.
- Indeed our primary plan, to detect occulting material from ring Q1R, did not show any fading of the target star.



# INSTEAD, 2.4 MINUTES BEFORE THE PREDICTED GRAZE OF RING Q1R...

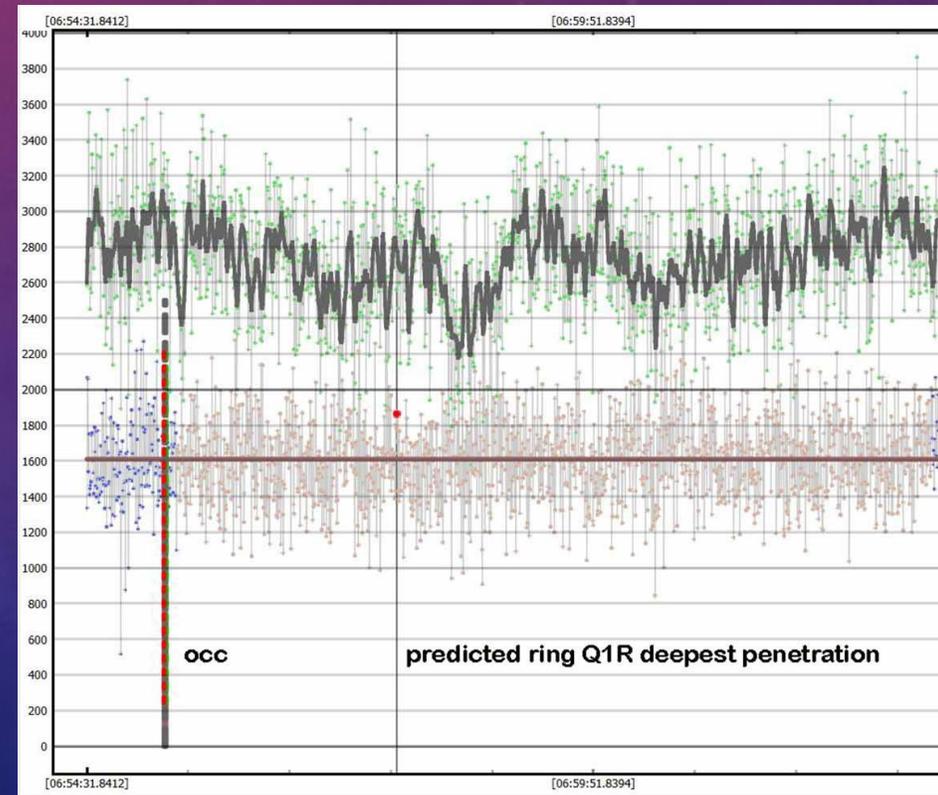
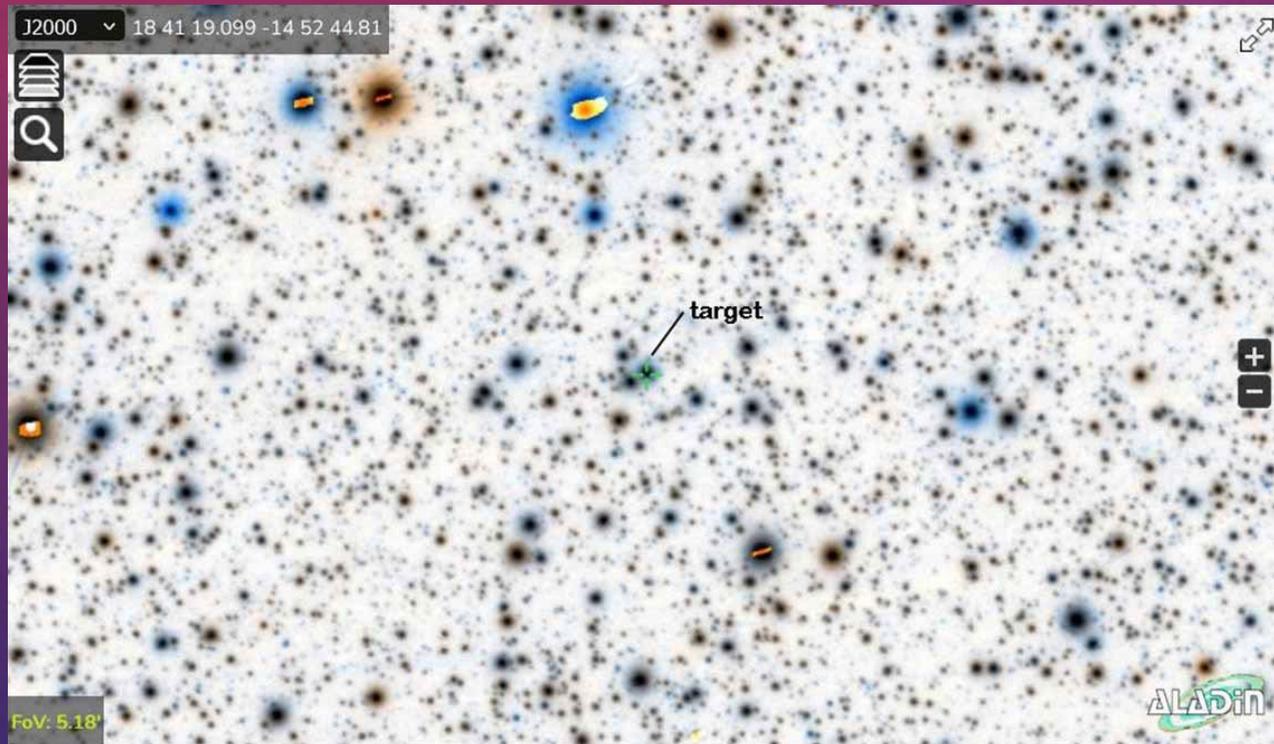
- ...while monitoring the image mirrored on my laptop output from my Watec 910hx low-light video camera...
- ...I saw the target star disappear, exclaiming –
- *“OH! Did you see that? The star just winked out for about 1 second!”*
- *My former student and now fellow occultationist – Kirk Bender – on the 14” scope, had not. He was busy attending to his recording. So; was it real?*



AFTERWARDS, WE EAGERLY RE-ENTERED THE “WARM ROOM” TO PLAY BACK OUR VIDEO RECORDING....

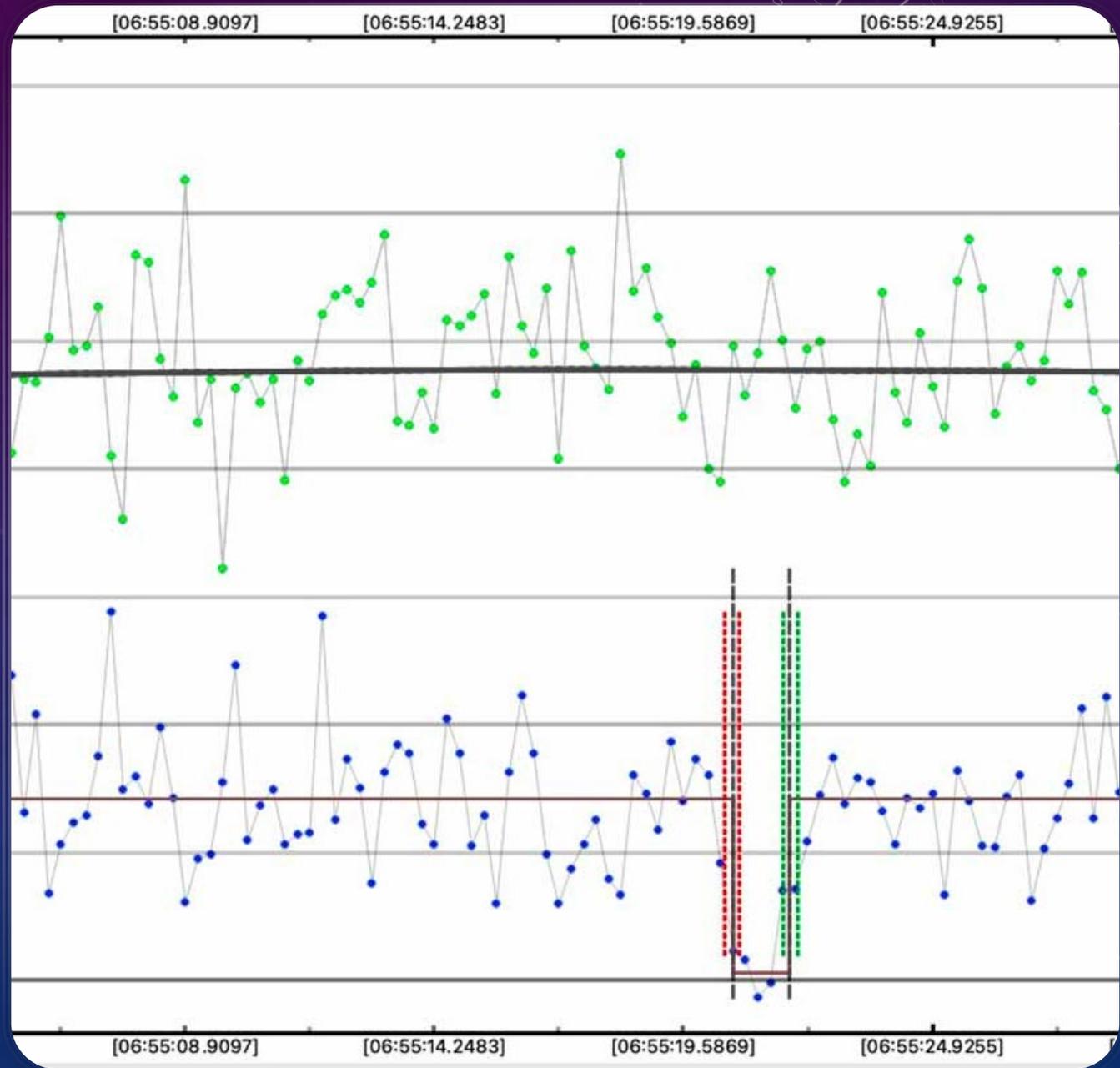
Target star: buried in the dense Scutum Star Cloud of the Milky Way

Light Curve, with reference star smoothed optimally as black curve.

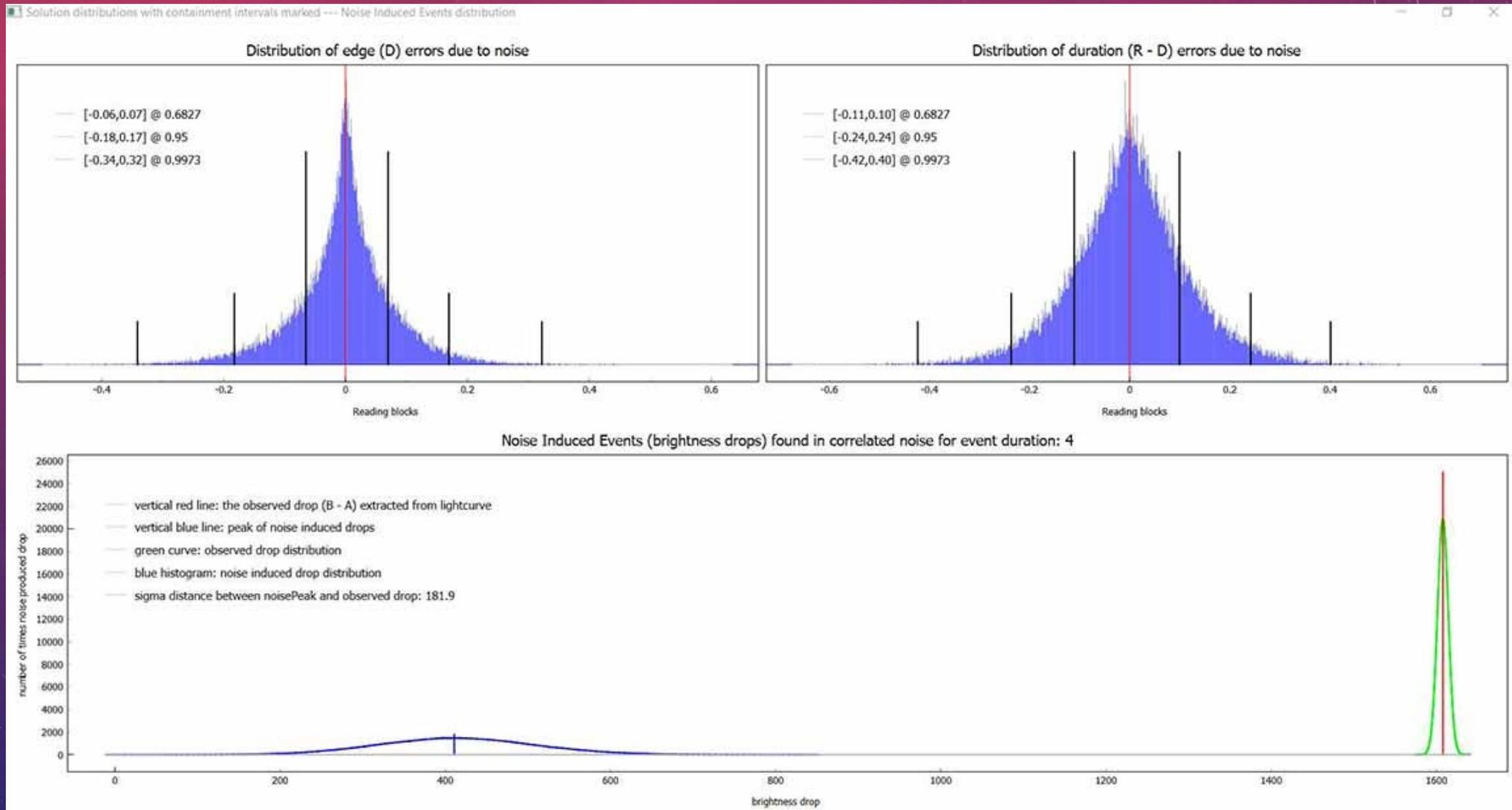


HERE IS MY LIGHT CURVE,  
ZOOMED IN TO THE 1.2  
SECOND OCCULTATION  
(BOTTOM CURVE)

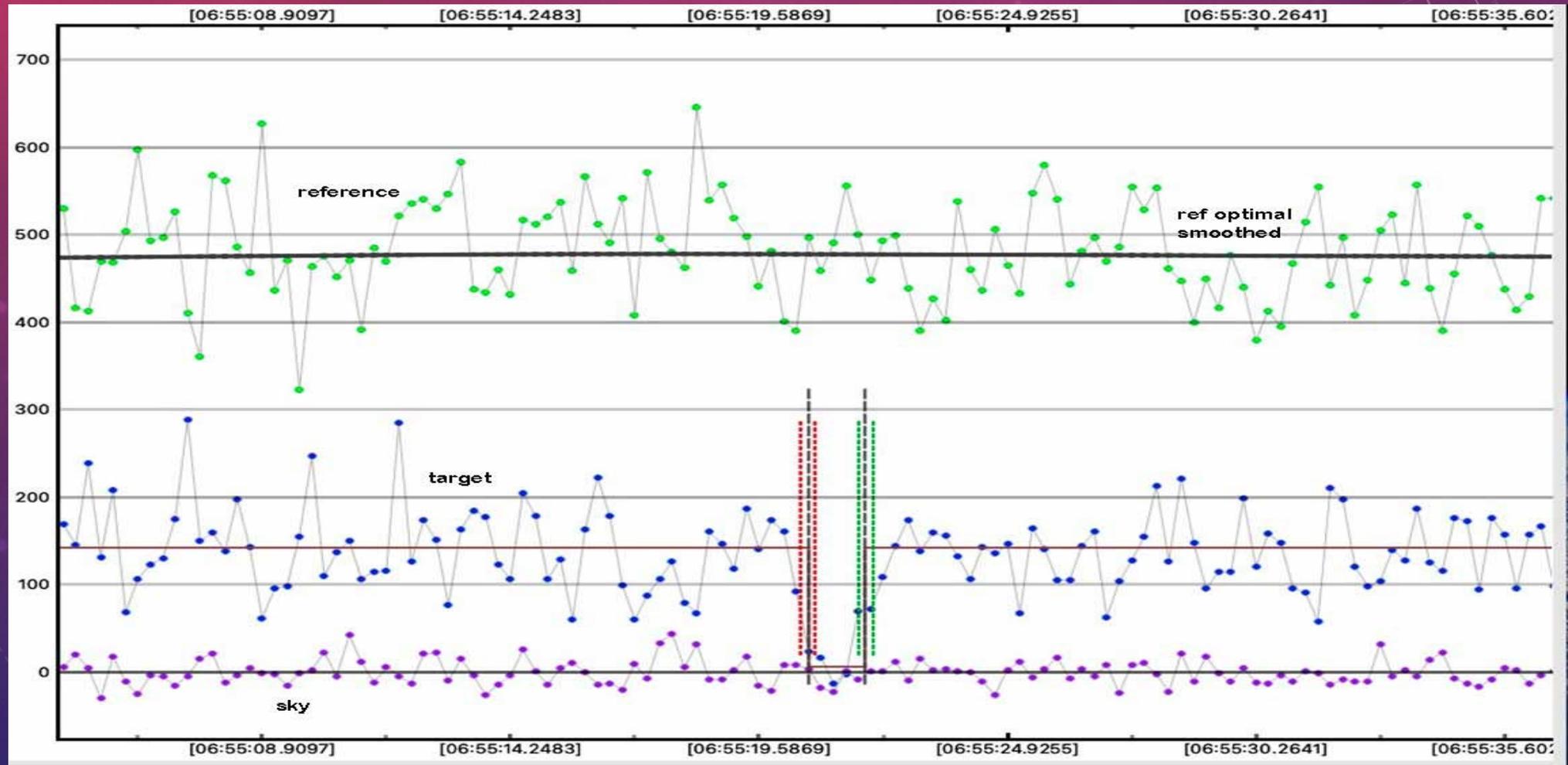
- But could it be just noise...?
- noise...a chance collection of brightnesses measured to be near zero?



NO. IT PASSES THE “NOISE INDUCED EVENT” TEST AT THE LEVEL OF 181 STANDARD DEVIATIONS (!). BENDER’S DATA IS ALSO QUITE SOLID, AND ENTIRELY ON INDEPENDENT GEAR AND POWER.

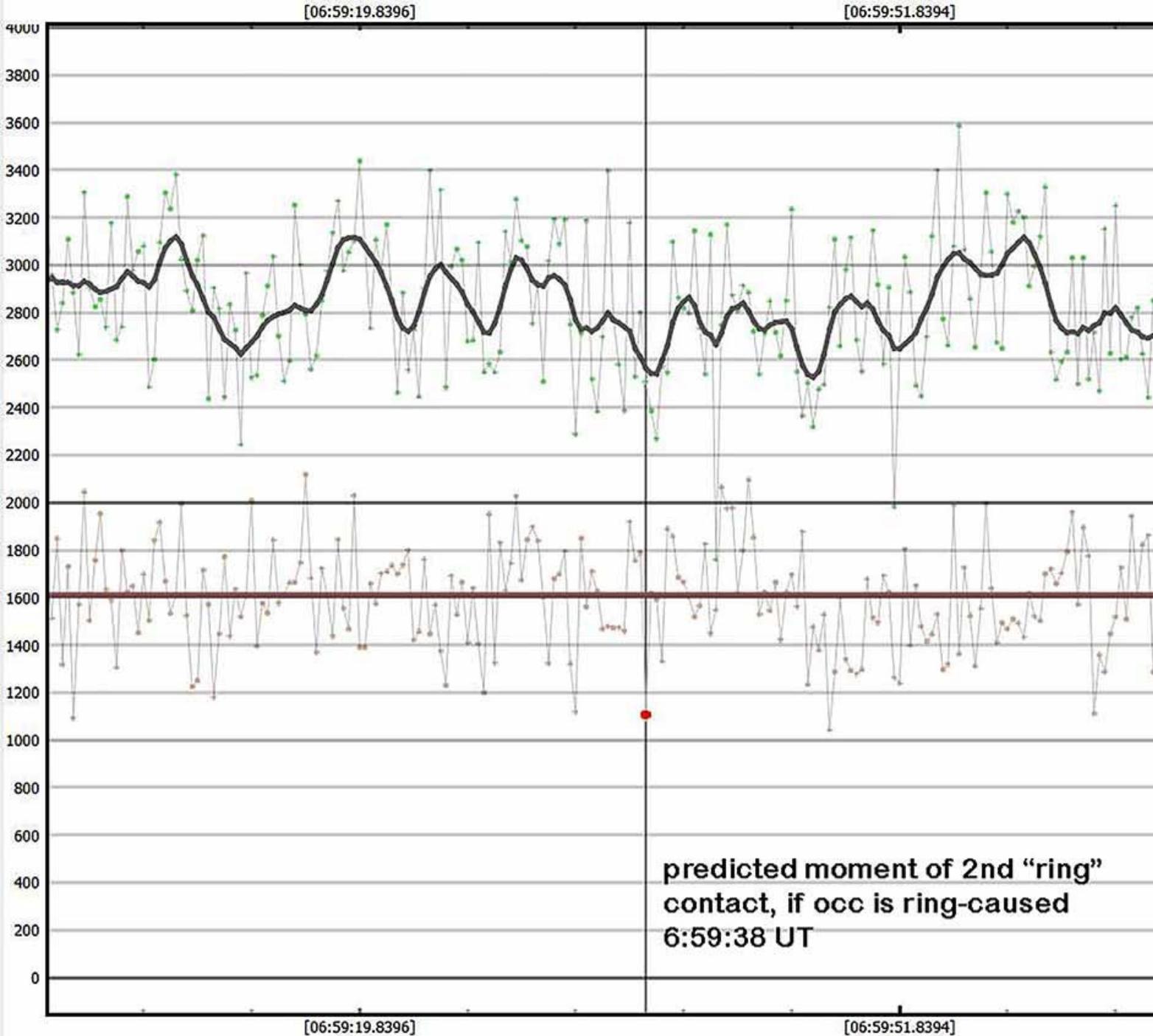


# KIRK BENDER'S DATA – GOT PRECISELY THE SAME D AND R TIMES AS MY DATA, ON THE SMALLER 14" TELESCOPE



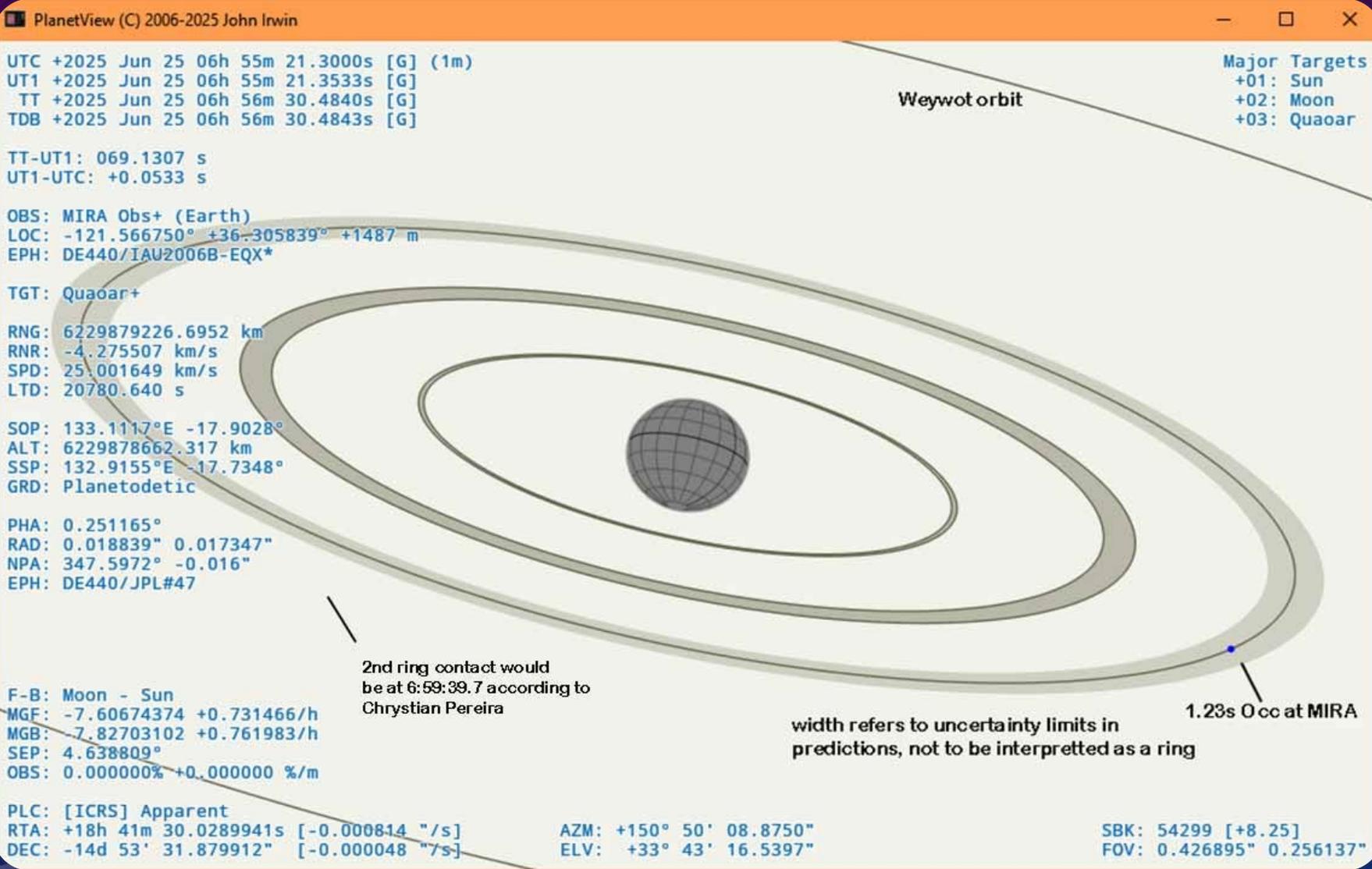
OK, SO IT WAS A REAL DISAPPEARANCE. BUT COULD IT HAVE BEEN CAUSED BY A BIRD? A SPY DRONE? AN INTERLOPER ASTEROID? AN AIRPLANE? A POWER GLITCH? NO.

- A bird would have to hover for a full 1.23 seconds – the only possible bird big enough to occult BOTH telescopes, barely, at the same instant, is the Mother of all Condors – and condors don't hover, and they don't fly at midnight!
- A mutant monster hummingbird?? Yikes. There's not enough flowers big enough to energize such a scary creature!
- A large enough Main Belt asteroid would be bright enough to easily detect.
- Airplanes would occult for a maximum of 0.02 seconds, and staff monitored for planes and saw none. Our gear was independently powered, with no glitches.
- Drones? The nearest habitation is over 5 rough road miles away – at Tassajara Zen monastery. Not a likely source. And a humongous drone big enough to occult both scopes would be loud, and its moving blades would not cause the 100% drop in light such as my gear on the 36" telescope saw.



WELL – OK – SO THE OBJECT WAS ASSOCIATED WITH THE QUAOAR SYSTEM. COULD IT HAVE BEEN A NEW RING? IF THERE ARE ALREADY 2 RINGS BEYOND ROCHE – WHY NOT 3?

- Good point. And so we examined that idea.
- First – no occultation was seen on the other side of Quaoar, as a ring would do.

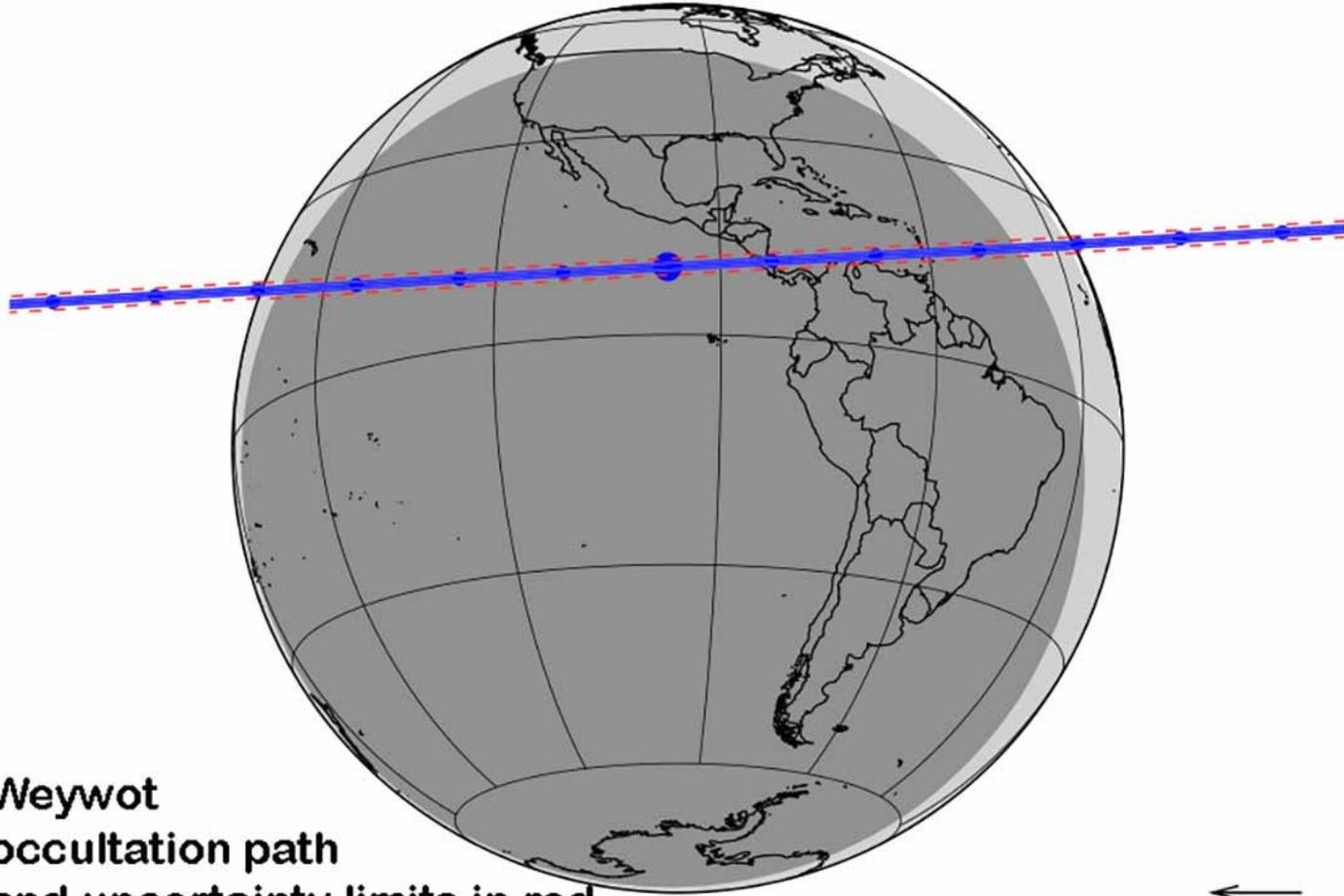


JOHN IRWIN  
 CONSTRUCTED THIS  
 DIAGRAM IF OUR  
 OCCULTATION WERE  
 DUE TO A 3<sup>RD</sup> RING  
 CO-PLANAR WITH THE  
 OTHER TWO RINGS.

WELL, COULD IT HAVE  
 BEEN DUE TO  
 WEYWOT? NO.  
 WEYWOT ORBITS TOO  
 FAR AWAY TO FIT FOR  
 OUR EVENT.

Weywot, GaiaDR3+pmGaiaDR3, NIMAv19+GENOID  
updated: 2025-04-14 by Lucky Star

Offset: 0.0mas 0.0mas



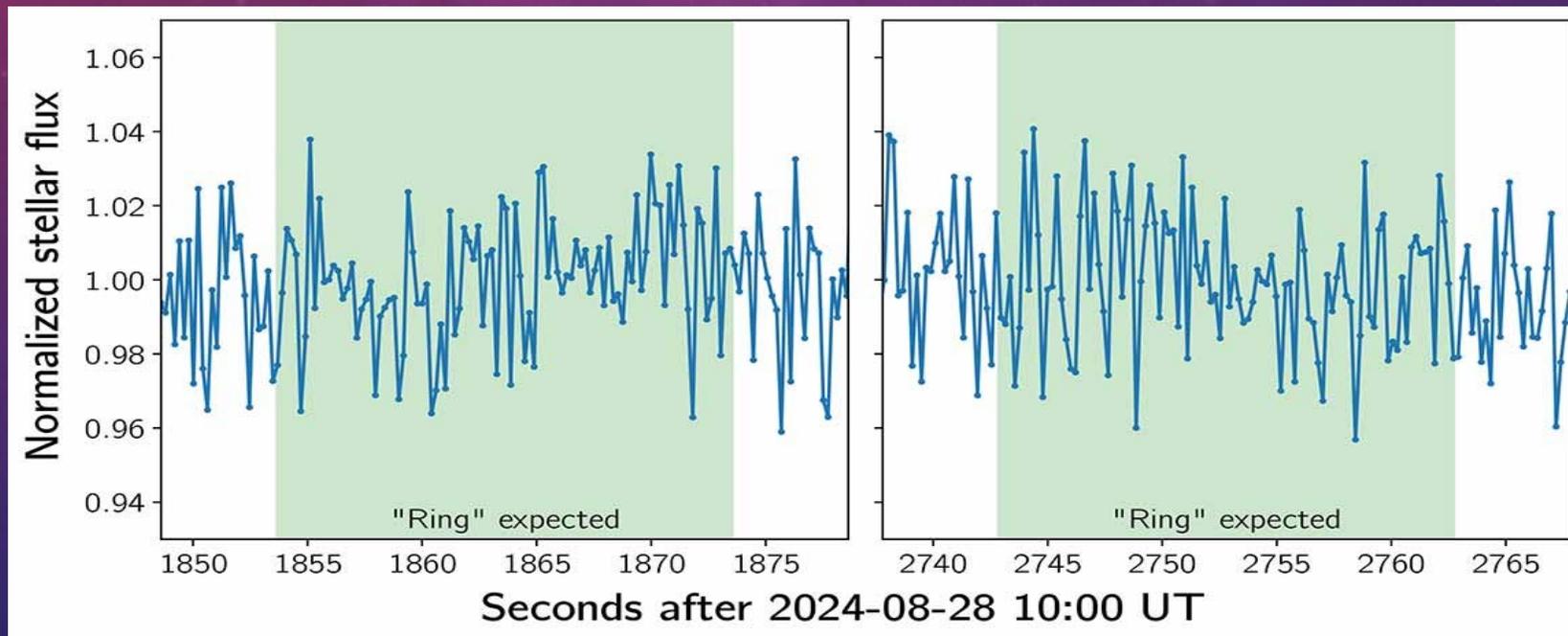
**Weywot  
occultation path  
and uncertainty limits in red**

yyyy mm dd hh:mm:ss.s	RA_star_J2000	DE_star_J2000	C/A	P/A	vel	Delta	G*	RP*	H*
2025-06-25 06:50:25.6	18 41 28.6208	-14 53 33.084	0.086	356.77	-24.49	41.6438	15.1	14.1	11.6

INDEED, THERE WAS A  
PREDICTED  
OCCULTATION OF THIS  
STAR BY WEYWOT – BUT  
WITH HIGH CERTAINTY,  
IT CROSSED COSTA RICA  
– NOT CALIFORNIA.

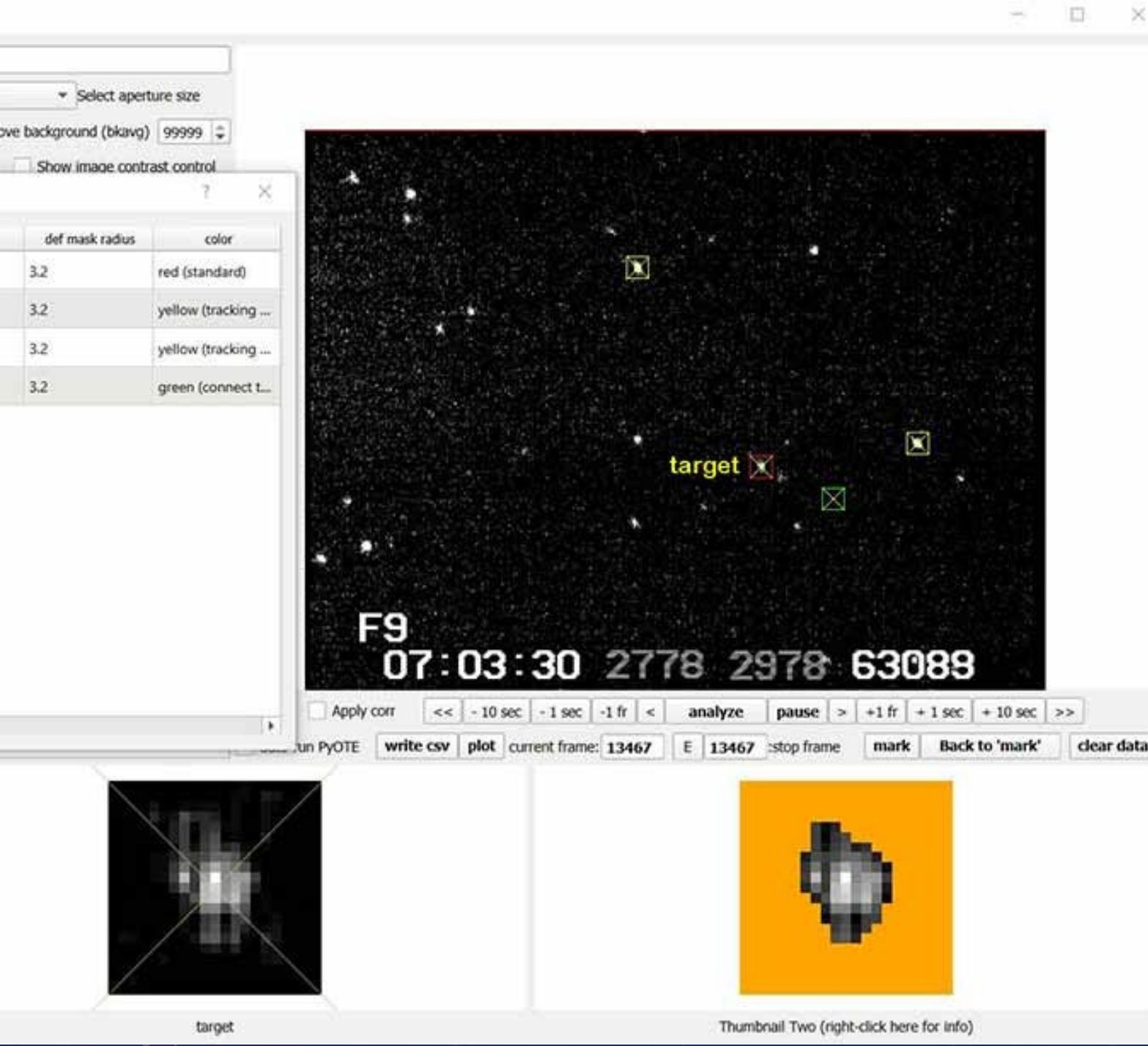
BUT MORE CONVINCING – THE AMAZING JAMES WEBB TELESCOPE TOOK DATA ON A DIFFERENT STELLAR OCCULTATION A YEAR EARLIER. SO, DID IT SEE EVIDENCE OF ANY ADDITIONAL RINGS? NO.

Below: JWST occultation light curve from 2024. If our MIRA occultation were due to a co-planar ring like the other rings, it should have created opacity in the green zones. It didn't; not even for a drop of just a few percent.



# CONCLUSION: BY FAR, THE MOST LIKELY CAUSE IS A NEW MOON AROUND QUAOAR

- What are the prospects for new observations of this object?
- Grim! That is the conclusion of a follow up paper, this one led by one of my co-authors – a post-doctoral fellow at Florida Institute of Technology - Ben Proudfoot - a strong focus in his work is Quaoar. He also data-mined the JWST for us.
- This new moon is too small and hence faint for direct imaging by even JWST – 28<sup>th</sup> magnitude. We will have to await a new generation of even larger telescopes for direct imaging.
- For occultations? It would take an army of volunteer observers scattered perpendicular to the path of a bright-star occultation to have a reasonable chance of having the luck that my MIRA team had. We're working on prospects for that now.
- Quaoar is in the dense **Scutum Star Cloud** only for another 10 years. After that, it will be slim pickings for occultations, most likely for another century.

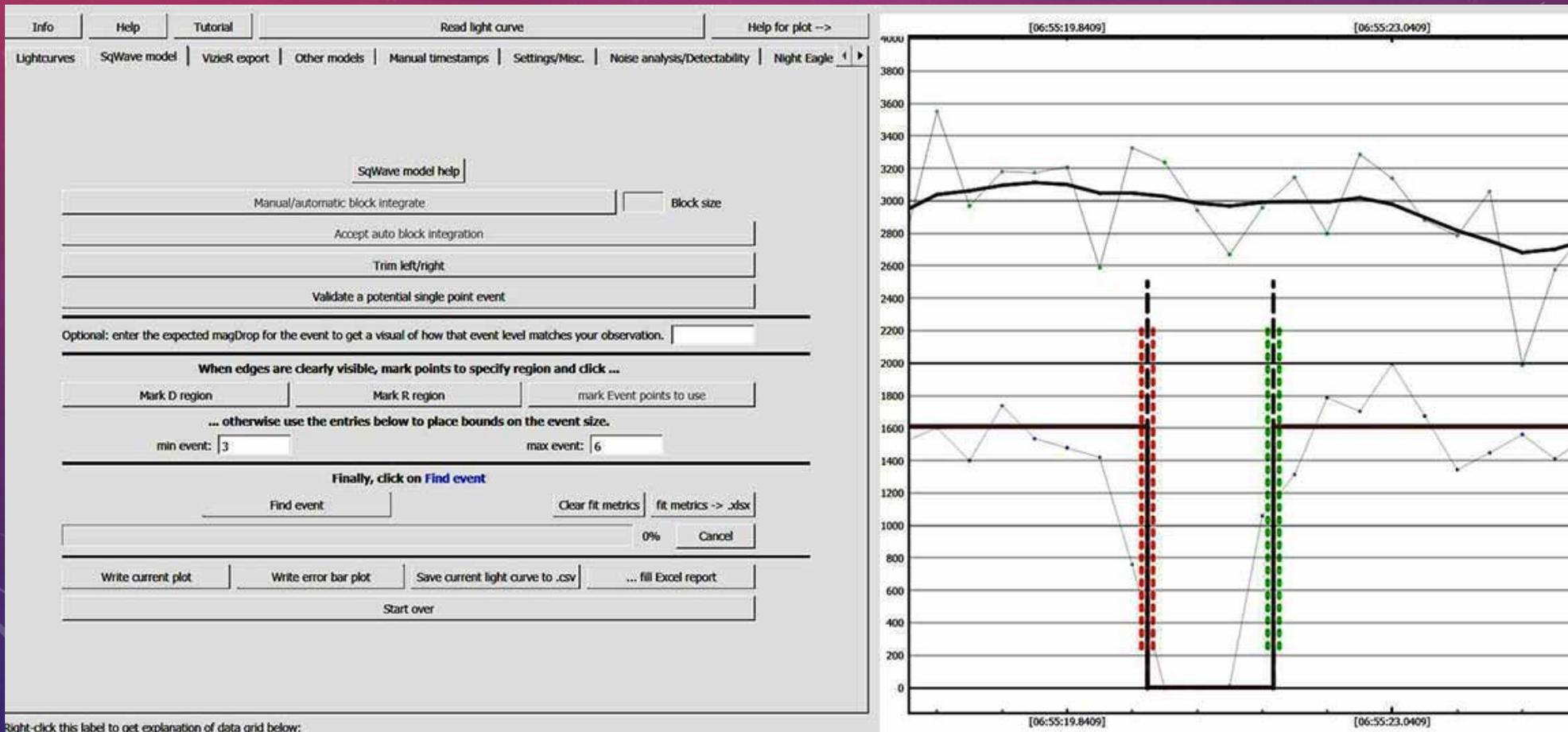


## NUT'S 'N BOLTS:

HOW DID WE GET AND REDUCE THIS DATA? HERE'S A SCREEN SHOT OF THE FREE OCCULTATION SOFTWARE "PyMOVIE" – A PYTHON PROGRAM FOR REDUCING VIDEOS OF OCCULTATIONS, WRITTEN BY BOB ANDERSON

IT ALLOWS YOU TO SET DOWN APERTURES FOR COUNTING PIXEL LIGHT AROUND ANY AREA ON YOUR CHIP, AND DOES SKY-LIGHT SUBTRACTION AS WELL.

BOB ANDERSON ALSO WROTE THE FREE SOFTWARE “PyOTE” A COMPANION PYTHON PROGRAM WHICH DETERMINES THE OPTIMAL TIMINGS OF THE “D” AND “R” AND ASSOCIATED STATISTICS. MY QUAOAR EVENT IS THE EXAMPLE HERE



Right-click this label to get explanation of data grid below:

# GEAR: AMATEUR ASTRONOMERS “IOTA: INTERNATIONAL OCCULTATION TIMING ASSOCIATION” ARE USING OCCULTATIONS TO HELP NASA REFINE THE ORBITS OF ASTEROIDS AND KBO’S. WHAT DO THEY USE?

- Classic system I use: A Watec 910hx PAL video camera (~ \$600) and Startech analog-to-digital cable (\$35).
- Various data, power connectors and battery, about \$100.
- An IOTA Video Time Inserter; time-stamps each video frame with 1pps GPS time; about \$250.
- **Or: An Astrid system goes for about \$800, does plate solving and is pretty complete**
- A Win11 laptop and free software will allow you to record and then reduce your own data ready for submission to IOTA
- A Celestron 8SE telescope, is our favorite for most events of magnitude 13<sup>th</sup> and brighter.
- Free predictions service from IOTA and software (OccultWatcher) will show you many asteroid shadow events per week near your location.

# I MUST THANK ALL MY CO-AUTHORS FOR CONTRIBUTING TO THIS WORK!

- Kirk Bender – for his tireless help in all asteroid occultations over the past few years, and his success on the 14” MIRA scope for confirming this discovery.
- Dan Cotton at MIRA for graciously helping us use the MIRA big scopes on the mountain, and in all observatory background operations.
- Ben Proudfoot, for his work on assembling the JWST data and interpretations.
- John Irwin, for his construction of the sky plane geometry of our observations and hypothetical structures and known rings of Quaoar.

# SOME LINKS TO THE PUBLICATIONS ASSOCIATED WITH THIS DISCOVERY...

- <https://ui.adsabs.harvard.edu/abs/2025RNAAS...9..226N/abstract>
- and also Google Scholar, e.g.:
- [https://scholar.google.com.au/scholar?q=related:IJv3b6YLBdcJ:scholar.google.com/&scioq=quaoar+author:Nolthenius&hl=en&as\\_sdt=0,5](https://scholar.google.com.au/scholar?q=related:IJv3b6YLBdcJ:scholar.google.com/&scioq=quaoar+author:Nolthenius&hl=en&as_sdt=0,5)
- And popular-level articles are now appearing...
- **IFL Science**  
*"Distant Dwarf Planet Quaoar Might Have More Moons Than We Thought – Or Yet Another 'Impossible' Ring"* by Dr. Alfredo Carpineti – 1 September 2025  
<https://www.iflscience.com/distant-dwarf-planet-quaoar-might-have-more-moons-than-we-thought-or-yet-another-impossible-ring-80626>
- **Orbital Today**  
*"Astronomers Saw a Star Blink – Did They Just Find a New Moon at Quaoar?"* By Matthew Gover – 12 September 2025  
<https://orbitaltoday.com/2025/09/12/occultation-points-to-possible-moon-around-quaoar/>
- **Phys.Org**  
*Discovery of New Moon or Ring System Orbiting Mysterious Distant Planet Quaoar"* by Paul Arnold – 11 September 2025  
<https://phys.org/news/2025-09-discovery-moon-orbiting-mysterious-distant.html>
- **Space.com**  
*"The Weird Ringed Dwarf Planet Quaoar May Have an Extra Moon, Astronomers Discover"* by Nola Taylor Tillman – 9 September 2025  
<https://www.space.com/astronomy/dwarf-planets/the-weird-ringed-dwarf-planet-quaoar-may-have-an-extra-moon-astronomers-discover>
- **Universe Magazine (Space Tech)**  
*"Scientists Have Discovered a New Moon or Ring System Orbiting the Dwarf Planet Quaoar"* by Oleksandr Burlaka – 12 September 2025  
<https://universemagazine.com/en/scientists-have-discovered-a-new-moon-or-ring-system-orbiting-the-dwarf-planet-quaoar/>