50 Years of Grazing Occultations

2012 August 25, Pescara, Italy
31st European Symposium on Occultation Projects
David W. Dunham, IOTA
Moscow Institute of Electronics and Mathematics – 50th Anniversary

• I am working at MIEM during 2012 and 2013 with a “megagrant” from the Russian Ministry of Education and Science
• to study optimal trajectories for human space exploration and planetary protection (from hazardous asteroids); that’s another long story
• I was at MIEM in late June when they had their 50th anniversary celebration; I was asked to say a few words
• I thought for a moment, 1962, that was an important year for me, too
• It was the start of my professional career, when I first really did something about grazing occultations,
• making the first computer predictions and mobile expeditions to observe them, and
• reaching out to observers around the world to encourage them to observe these spectacular events
• It was the real start of the International Occultation Timing Association, not yet with that name, but with its intent
The concept of grazing occultations occurred to me earlier, when I was 15 years old. Below is an Occult view of the disappearance of 6.1-mag. $\beta^1$ Capricorni from La Cañada, California, October 29, 1957 at 9:25 pm PST; I observed it there from my backyard with a 60mm refractor.
Appulse of 3.1-mag. $\beta^2$ Capricorni from La Cañada, California, October 29, 1957, min. dist. 5″ at 9:47 pm PST; I was amazed at that sight, I could see the Moon’s motion, the star looked like a spacecraft flying over the Moon. I could see the star’s position change from second to second as it passed over the Leibnitz mountains, a real-time view of celestial motion.
Southern Limit of the $\beta^2$ Capricorni Occultation, 1957 October 29

I was puzzled why I did not have an occultation when one was predicted. Then I realized that the prediction was for a station 300 km nw of me, but no event was given for another station 500 km east of me. I had the idea of a grazing occultation, with multiple events of the star by lunar mountains near the southern limit, which must have been just a few km north of me. I thought it would be neat if someone could compute those lines, but I thought I could never do anything that complicated. At that young age, I underestimated my future ability.
26 years later, I computed the trajectory for flying the 3rd International Sun-Earth Explorer (ISEE-3) spacecraft over the Moon, a gravity assist that resulted in the first comet flyby, of Giacobini-Zinner, in Sept. 1985.
<table>
<thead>
<tr>
<th>GMT</th>
<th>EVENT</th>
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<tbody>
<tr>
<td>17:53</td>
<td>START GEOCENTRIC OCCULTATION</td>
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<tr>
<td>18:19</td>
<td>START SOLAR ECLIPSE</td>
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<tr>
<td>18:39</td>
<td>END GEOCENTRIC OCCULTATION</td>
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<tr>
<td>18:45</td>
<td>PERILUNE - HEIGHT 120km</td>
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<tr>
<td>18:47</td>
<td>END SOLAR ECLIPSE</td>
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My 1957 vision of a spacecraft flying over the Moon was realized, but that’s another long story.
Last Aldebaran Graze of 1959 – 1962 series in California occurred on 1962 March 12

I had completed a course in solid geometry at the Univ. of Calif. At Berkeley shortly before this event, and realized, maybe I could work out the equations and compute it. I started Sat. morning March 10 (event local time was Sun. evening March 11) but the hand calculations using trig function tables and a clunky Marchant calculator were harder than expected; less than 2h before, I had calculated 6 points from Arizona to near Santa Cruz, and convinced a grad student to drive me there. We didn’t make it to the limit; while crossing the Bay on the Dumbarton Bridge, using binoculars, I saw the star had disappeared. At Palo Alto, I quickly set up my 60mm refractor and saw Aldebaran reappear on the bright side, coming out like a drop from a faucet; I realized that was close enough to the limit to see the star’s angular diameter! The chase for grazes was on!
1962 April 10th expedition to Concord, Calif., for a graze of 5.1-mag. 64 Orionis by the 33% sunlit Moon

This promised to be a good event, so I computed the path well in advance, and worked with Jack Borde, leader of the Walnut Creek Moonwatch Team, to time the graze from 4 locations across my predicted limit line (I had no lunar profile predictions then). But the prediction was wrong and we all had an 8-min. occultation, with the R at the n. cusp occurring at my predicted time. I discussed my calculations with Prof. Cunningham and he pointed out that I needed to take into account the motion of the observer. This made the calculations harder (needed to iterate) but now accurate enough to locate in the real graze zone.
Len Kalish’s 1962 Sept. 18\textsuperscript{th} expedition to Castaic Junction, for a bright-limb graze of 4.1-mag. 5 Tauri

This provided the first confirmation of my predictions, and was the first time that multiple events were seen (but not timed) during a mobile effort. My own next 6 attempts, after the April debacle in Walnut Creek, were all clouded out, remarkably bad luck for California. I could not observe the 5 Tauri graze because it was about 700 km from Berkeley, so I asked Carroll Evans of China Lake to try it, and asked Ronald Royer to announce it at the Sept. meeting of the Los Angeles Astronomical Society. Evans couldn’t tell what happened due to desert winds and a low f-number scope, but Kalish responded to Royer’s announcement and drove 60 km nw of his LA home to observe the graze.

During the last months of 1962, at Prof. Cunningham’s suggestion and support, I took a course in the then new Fortran computer programming language, and avidly learned it, applying it immediately to the task of computing grazing occultation paths. This allowed me to compute many more paths and expand my predictions to areas beyond California. I contacted Sky and Telescope about publishing my predictions. They first wanted to be sure my work was legitimate so I documented my procedures. Satisfied, they published a first prediction in March 1963. That graze was not observed, as far as I know. There was still some tedium limiting what could be done as 50 numbers had to be specified to high precision for each event.
My First Observed Graze, north of Roseville, California, 1963 Mar. 31, 6.3-mag. ZC 881, Moon 39%+, CA -3N

I observed this with my 60mm refractor north of Roseville with Bruce Bowman from the Sacramento Moonwatch Team. Most of the Interstate highways weren’t built yet and the town of Rocklin was much smaller then. Although the graze was on the bright limb, I could see the star well enough to know that it grazed among the mountains at the northern cusp, but not well enough to make any definite timings. At least, I saw for myself that my predictions were good.
Two nights later (1963 April 2), Fremont, Calif., I saw a graze of 5.4-mag. 85 Geminorum, Moon 63%+, CA -2S

Remarkably, two nights later, Jack Borde, a few other members of the Walnut Creek Moonwatch Team, and I observed another graze from Fremont. Again it was on the sunlit limb near the southern cusp, but we were able to make crude timings of a few of this brighter star’s graze events.
The first successful dark limb graze where the observers travelled to their sites - 1963 Sept. 8 Graze of 6.1-mag. ZC 464, Davis, Calif.

Finally, good timings were made of this graze with CA 15N and Moon 72%- sunlit. This is adopted from Dave Gault’s presentation on the current graze archive given at the 2010 IOTA meeting.

This map helped generate interest among new observers across the eastern USA.
Observations of the 1963 October 8th graze of zeta Tauri were the first published in Sky and Telescope, in the Dec. 1963 issue.

A WELL-OBSERVED GRAZING OCCULTATION

N THE evening of October 7-8, 1963, Zeta Tauri grazed the moon’s dark for observers along a narrow strip near Fort Worth, Texas; Columbus, Ohio; and Montreal, Quebec. Conclusions by David Dunham were published in Sky and Telescope for October, page 218.

Several amateurs saw the 3rd magnitude star winkle on and off as elevation the lunar limb moved through arc’s line of site.

A watcher was 100 south of the 3rd magnitude star winkle on and off as elevation the lunar limb moved through arc’s line of sight.

Zeta Tauri disappeared at 5:08:02.3. My latitude is 34° 43’ 55” north, and longitude 92° 13’ 58” west.

The following reports are from amateur groups with more extensive programs:

DAYTON, OHIO

My physics students at the Washington Township High School in Dayton responded enthusiastically to news of the predicted grazing occultation of Zeta Tauri. On the night of October 7th, about 50 of them reported, with all the telescopes and binoculars they could find.

We separated into eight groups along the predicted graze path. Timing the event was made easy by the local radio station WONE, which broadcast voice time signals every 15 seconds. The time and observations were tape recorded at each station. All observers reported seeing the occultation, except two who remained at our school, about 1½ miles north of the northern limit.

Observer Fried and probably had one of the most spectacular views. He watched with a 60-power 5-inch refractor at west longitude 84° 12° 08”, north latitude 39° 53’ 13”, altitude above sea level 975 feet. Zeta disappeared and reappeared at the following Universal times: D, 5:07:35; R, 5:07:52; D, 5:07:57; R, 5:08:05; D, 5:08:15; R, 5:08:55; D, 5:09:00; R, 5:09:05; D, 5:09:15; R, 5:09:30.

COLUMBUS, OHIO

Members of the Columbus Astronomical Society observed the occultation of Zeta Tauri at four sites shown on the map. Each was located at roughly ½-mile intervals along a nearly north-south line about 1½ miles northeast of Columbus.

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2420 East Hennepin Ave.
Minneapolis 14, Minn.
near the predicted geographical limit.

Early on the evening of October 7th, the following members of the Columbus society gathered with telescopes and other equipment: Barnett Golding, John Kissel, a timekeeper, observation record observer.

As the predicted time of contact was one observer thought the moon would miss Zeta, for the illuminated portion of its disk had already passed the star, giving the illusion that the dark part was also missed. However, the star had reached the predicted contact point angle, and his location eventually to be a proper one.

The southernmost station, D, was the simplest occultation of the night, lasting 3 minutes shown in the accompanying diagram table. There was a deep graze at C, and Zeta Tauri was hidden three times in 1 minute 47 seconds. The observer at B, near the eastern limit, saw two disappearances in one second. Zeta was not occulted at A, outside of the predicted limit.

Our society has additional information available to interested persons. We also like to hear from other successful observers of this occultation.

BARNETT GOLDING
111 Richards
Columbus, Ohio
High school students open the eyes of USNO

From Dave Gault’s 2010 IOTA meeting presentation
Dave Gault declared, the illegitimate delta Cancri graze now legitimate!

Lunar Profile from Graze of delta Cancri – 1981 May 9-10

Circled dots are Watts' predicted limb corrections
The 1964 publication of Watts’ charts gave us the possibility to predict the lunar profile for grazing occultations.

This was published in the 1964 Feb. issue of Sky and Telescope. The figure at the bottom for WA 176.4º was in the range for a graze we observed that month, so I knew from it that a high mountain would dominate our profile.
Graze of 6.4-mag. ZC 398 observed 1964 February 19, again near Davis, Calif., Moon 34%+ sunlit, Cusp Angle 6S

I led this expedition (I believe some sites from 1963 Sept. 8th were reused) with members of the Walnut Creek and Sacramento Moonwatch Teams, and from as far away as San Jose. Most observers had one occultation by the high mountain since I didn’t know then about the rest of the profile. Others and I obtained Watts’ charts and started plotting (by hand!) profiles for future grazes.
Starting in 1965, cable systems were developed for observing grazing occultations, first at USNO, then by 3 clubs in California (Riverside, Santa Barbara, and Mount Diablo Astronomical Society), and Milwaukee, Wisconsin.

This is a Riverside A.S. expedition to the desert in 1966; I’m wearing a white jacket. Observations were visual, with audio tones recorded at the central station.
1970 July 11, standing on the Milwaukee cable trailer at our wedding in Highland Park, Illinois

From left to right, Tom Van Flandern, Ronald Abileah, Homer DaBoll, Edward Halbach, David Dunham, and Joan Dunham
Finally, I observed a graze of $\beta^2$ Capricorni with 12 others near Ruther Glen, VA on 1977 June 5, Moon 83%-, CA 3N, Sun alt. -2°.

In spite of the conditions, the events were easily seen with the star’s 3.1-mag. brilliance. In the meantime, the International Occultation Timing Association (IOTA) had been formally established as a dues-paying organization in July 1975, primarily to promote the observation and analysis of lunar grazing occultations.
Lunar Profile from Graze of delta Cancri – 1981 May 9-10

Alan Fiala, USNO, obtained the first video recording of multiple events during this graze, with 7 D’s and 7 R’s.

Circled dots are Watts’ predicted limb corrections.
Video of 1990 April Aldebaran Grazing Occultation from Poland
The First Multiple Stations were Deployed for Grazing Occultations

• In the 1990’s, I often thought, the equipment is doing all the work, maybe I should be somewhere else making another observation.

• For a graze of omicron Leonis the morning of 1998 November 12, I set up a 5-in. clock-driven SCT at Delta, Pennsylvania, near York

• I left a student there after showing him how to make adjustments to keep the star in the field of view, and set up another telescope about 0.5 km away to record the event

• When I came back, he was excited to see the multiple occultations of the star. “Did you make any adjustments?” “No”. “At least, you were there to protect the equipment”.

• “Actually, it was the other way around. Whenever a car drove by, I hid behind the telescope box.”
Remote Stations Successfully Run Two Weeks Later

- On 1998 Nov. 26, after Thanksgiving dinner, I drove about 10 miles south and set up a 20-cm SCT with video to record a marginal grazing occultation.

- Then I set up another telescope 200 m north and observed the graze visually there. The video station recorded three events, the first unattended mobile video occultation observation, as far as I know.

- Two nights later, I had another success with a better graze, of 4\textsuperscript{th}-mag. $\chi$ Piscium at Assateague Island, Maryland.
2001 Dec. 21 Grazing Occultation of 4.0-mag. \(\tau^2\) Aqr

- Moon 32\%, Cusp Angle 12\S
- Observed from 8 stations at Kitty Hawk, North Carolina, by only 4 observers. Kitty Hawk has many summer homes, unoccupied on a December weekday, so we had many safe places to set up telescopes 1 to 2 hours before the graze.
- 4 of the video stations were unattended
- Also observed from 6 stations in Georgia
Map of Kitty Hawk, North Carolina showing observing sites for the Graze of $\tau^2$ Aquarii, 2001 December 21

by Wayne H. Warren, Jr.
My Telescopes for Remote Observation
Station “A”, C-5 & PC23C, & f/6.4 focal reducing lens from Orion
No Telescope, just an undriven good camcorder! I set the Moon just outside the field, above and left, 8 min. before the graze. This station had 5 D’s and 5 R’s, more than any other; although it had less than 1000th the aperture of the 1m telescope on Hokkaido, it was more successful!
Station “C”, C-8 & Watec 902H and Meade f/3.3 focal reducing lens ($150 from Focus Camera). A cat jiggled the video a little after the graze.
My Visual Observation

I only had a couple of minutes before the graze when I arrived here. I discovered that I had left the last eyepiece holder (visual back) at another station, so I watched the graze with the 50mm finder scope.
Alin Tolea’s Remote Setup

He also observed about 100m away visually with binoculars held steady against a trash dumpster. Alin is a grad student at Johns Hopkins U. in Baltimore; he’s from Romania, where he has organized graze expeditions by e-mail and telephone.
Graze of 4.0-mag. $\tau^2$ Aquarii by the dark southern limb of the 32% sunlit waxing crescent Moon

2001 December 21, Kitty Hawk, NC and Georgia

Also, Robert Hays' timings the same night of a graze in the same area of 5.7-mag. 69 Aquarii, and another graze of $\tau^2$ Aqr recorded in 2002 Jan. with a 1-m observatory scope on Hokkaido (H. Tsuda)

by Marshall Stapko, Mitsuru Sôma, and David Dunham
Multi-Station Occultation Observing with Galileo Sized Optical Systems

Scott Degenhardt, IOTA

Galileo’s Legacy 2009 Waianae, Hawaii
Mighty Mini

Can record occultations of stars to mag. 9.5, even mag. 10.0 under good conditions. These are fine for asteroidal occultations, but how about lunar grazes? Glare from the Moon and their low power cause problems.
Mighty Midi – Orion 80mm short tube

Can record occultations of stars to mag. 11.0, even mag. 11.3 under good conditions; these work better for grazes.

I use visual finder scope and $60 Quantanray tripod while scotty uses a mighty mini video as the finder and MX-350 tripod (not as sturdy as the Quantanray).
Grazing
Occultation of
3.5-mag. eta
Geminorum in
Arizona,
2011 April 10,
my first success
with remote
stations (a
humiliating
defeat, it was
machines, 3;
humans, 0)
Moon 36%+
Cusp Angle 15N
Graze path in central Arizona
2011 April 10 (UT; April 9 MST)

Map center is at (WGS84 datum) Lat = 33.335117, Lon = -112.483521, which is 3.327 Km from path center.
Graze path in Tonopah, AZ area
Graze of 4.9-mag. ω² Tauri (ZC 628) over Minneapolis, Minn. on 2012 Aug. 11, Moon 35%-+, CA 2N

I attended an astrodynamics conference in Minneapolis, Minnesota Aug. 12-16. I went there early because I noticed that this graze occurred 2 days before; I made plans to observe it from near Grant. With the small cusp angle, I thought that there would be too much glare to record with midi systems, but I took 2 of them, to try, and 2 4-inch SCT’s for attended stations that Joan and I ran. But like in Arizona, the machines triumphed; it was machines, 2, humans, 0. Station 3 recorded 6 D’s and 6 R’s; I’ll play the video.

Station 4’s single R indicates a south shift of about 200m; we can still determine corrections to stellar proper motions from graze observations.
Comparison of Kaguya & LRO profiles

Here is a recent reduction of observations of the 2011 April 10th eta Geminorum graze by Dr. Mitsuru Sôma at the Japanese National Observatory. The profiles are close, but LRO’s, with more orbits and points than Kaguya, is more accurate near Axis Angles 14.3 and 15.4.

With multiple stations and LRO data, there are still new things that can be done with grazing occultations!