50 Years of Grazing Occultations

2012 August 25, Pescara, Italy 31st European Symposium on Occultation Projects David W. Dunham, IOTA

Grazing Occultation Geometry TO STAR Figure 2-1a MOON'S ORBIT SHADOW OF MOON CAST BY THE STAR M 10 0 N S ~N SUNSET B A Figure 2-1b

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. β^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. β^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 β² 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





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 occuring 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. 18th 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

My 1st prediction published in Sky and Telescope, zeta Geminorum graze of 1963 March 4/5

CELESTIAL CALENDAR

THE RAPIDLY ECCIPSING

H WINTER and spring amateur bservers only wanth the spectacular ing stur Y Leonis, then conveniently d in the evening sky. An 8-inch tele or larger will show its whole light and the charts on this page permit dentification of the field, just out the Sickle of Len. The star's 1950 un is 9° 34° 0, +3%° 29°.

rmally Y is of about visual magni-9.7. Every 1.7 days a rapid fading n, and in only three hours the star to about 13.0. Least brightness fasts ps 20 minares, and is followed by a hour brightening to normal.

rapid is this variation, especially just and just after minimum, that a observer who notes the magnitude at 10-minute intervals will see connode estimates, continued over the addle hours, can furnish the time declipse within a very few minutes. nings of minima are important bethe period of Y Leonix is variable. iding to W. P. Zessewitch, the avermost has been 1.6860705 days sime 1025, hur before that year it was



MINIMA OF ALGOL

M. G. Fracastoro, Catania Observa-Italy, reports the following timing Algol minimum: "Ou December 25 UT, and this determination, with our photoelectric photometer, " This result, after the heliocen- 10:27; 26, 7:16; 29, 4:06.

*	Sec. Sec.
-	Y LEONIE
1	
the second	

attacks sada arguesta This light curve of Y Leonis during primary minimum is based upon \$14 visual brightness estimates made by a Dutch astronumer, A. A. Nijland, with the 10-inch refractor at Utrecht.

from one constant value to another, or whether it is changing continuously.

The following timetable gives approxious jumps. In fact, such a series of mate predictions in Universal time forminima of Y Leonis that will occur during hours of darkness for United States observers. To predict other minima, add sic subtract multiples of 14 162.47. March 5, 62.9; 4, 23*.3; 10, 02,7; 15, 22.1;

20, 3º 5, 25, 4º 9, 90, 6º 3; 31, 22º 8, April 4, 79.7; 5, 19-2, 11, 19-6. Readers who obtain observations of Y

2] seconds longer. It is not clear Leonis are invited to send their estimates ter the period has changed abruptly to SKY AND TELESCOPE for analysis.

> The field of V Leonis. with south at the top and east to the right, as in an inverting telescope. The upper chart, islapted from the "Atlas Eclipticalis," has stars of the 9th magnitude. The lover chart is an enlargement of the small rectangular area. Miss R. Szafraniec's visual magnitudes of comparisom stars are given to tenths (decimal points umitted).

1:49 UT, which is 12 menutes earlier than the prediction on page 58 of the January issue. This timing corresponds to the heliocentric Julian date 2,438,054,577, 862, the mid-minimum occurred at with an uncertainty of about ±0.007 day, or ±10 minutes. March 3, 8:42; 6, 5:31; 9, 2:20; 11, I not be wrong by more than one 25:10; 14, 19:99; 17, 16:49; 20, 13:58; 21,

OF ZETA GEMINORUM N THE NIGHT of March #5, 1978 0 the 4th-magnitude star Zeta Geminorms will be covered by the moon, as seen from the northern port of North America. The Occultation Supplement in the November, 1962, inne of SKY AND TELESCOPE contains predicted times of disappearance for Massachasietts, Montreal, and Edmonton, but notes that there will he no occultation for Tomonto or Washington, D. C. Evidently, there is an inservening line from along which the star will just grave the wanthern edge of the

OCCULTATION

David W. Dunham, Berkeley, California, has calculated in detail the course of the southern limit of this occultation. He writes. "The predicted line follows a southeastward course through Alberta; passing just north of Regina, Saskatcheware: about 50 miles south of Winnipeg. through northern Minnesota and across northern Michigan: 10 to 20 miles north of Toronto; through Rochester, New York, crowing the Hudson River near Poughkerpore: through Wess Haven, Campecticut, and over the cauters end of Long Island."

Observers slightly north of this line should see an occultation of short duration; those wouth of the line, a near miles There are several previous records of graving occultations at which a star disappeared and reappeared repeatedly, as it passed behind one hunar unsantain after another.

Adding interest to the occultation is the fact that Zeta Geminorum is a double star. Its 86-magnitude companiem, past over 11 minutes of arc north and slightly west, will be occulted when Zera itself is only grazed by the moon's limb.

Condensed from Mr. Dunhais's data is the following table which tells, at fiveminute intervals of Universal time, the geographical fatitudes and longitudes at which graze takes place.

urnal sime	Latitude	Longitude
1225	+ 52.09	+116 02
4:30	+51 50	+113 05
4:35	6.51 32	+110 08
4140	+51.09	+103 11
4.45	+ 50 42	+ 104 14
4-50	+50.10	+101.16
4.35	+49-32	+90.17
5:00	+ 48 49	+95 16
5:05	+ 48 01	+92.12
5-10	+ 87 06	+ 89.04
5:15	+#6 04	+85.50
5:20	+ 64 54	+ 82 28
5:25	+43 35	+78.55
5:30	+ 42 06	+ 15 05

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.



My 1st graze map published in Sky and Telescope, for the 1963 Oct. 8 graze of 3.0-mag. zeta Tauri, CA 13N, Moon 67%-

CAMERA at less than regular price of camera alural

Nis used to be at ex-pers glossogiapher to take percesson 33-mm, camera body, No compli-cated anticaga. No player or limbolders u-read and enloyed. No worker about making Linger, Lange forming screen shows you exactly file viewing field as to moment of showing No accelerated domine exponences. Weathing kands automatically advances from per-laged automatically advances from per-section from per-section from per-section from per-section from per-section from per-formatical from per-section from per-per-section from per-section from per-section from per-section from per-section from per-section from per-formatical from per-persection from per-persection from per-section from per-persection from per-persection from per-persection from per-formatical from per-persection from per-persectio tions martine, which observer, county an

- Dual spirid sering knob controls hoth ing makey montakes impossible.

Taker view experience and also has meeta up to 17300 annual. Guaranteed for 2 pane. Consolets, ready far view. Model CF33 an 15, "experient holder. 197.00 perpend

4.F.36 fm all standard 47 185.00 pestpald

O-SWING CAMERA SUPPORT

Table gamments not of attraptopupitping by provalling presses are printed of carspinion adjustment. Easily entrelied or detached its tube, with right clamp his manimum stability. Special area data you awing carriers owny tools even for variable distances for variable observation. a m costant neture for photographing. Can and with alcount and anothers. Protpaid. Cat. 2005-4 to fe all 4" Desauropes \$17.50 Cat. 2005-47 to fe all 415" O.D. tubes \$18.95

"CS-57 as 61 contain 6" Dynascops d 716" O.D. tubra 319.95 Catalog F. describing other accessories and pione, cherefully seen no remain. International action guaractional, or money informed. All means some postpand. We put all postage toses. No ship

oug, stating, or payking altarget. Send check, the set momey order for emetadiate delivery. Criterian MFg. Co., Dept. STP-54 331 Church Sr., Hertfurd 1, Conn

GRAZING OCCULTATION OF ZETA TAURI

about 11 p.m. Central standard time. a 20-day-old moon will occult the 5tdmagnitude star Zeta Tauri. This event should prove interesting for observers in in custern Canada. Predictions for several American and Ganadian stations are given in the "Occultation Supplement" of SAY AND TELESCOPE last November.

behind the moon's disk. For some it will Rock, Arkansas; southeast of the Missisjust graze the dark limb, for others it sippi and Ohio tiver junction, about will miss the moon altogether. I have eight miles southeast of Evansville, Indicomputed the northern geographical limit of this occultation; its approximate course is plotted on the map. Along this line, Zeta Tauri should appear at the mean limb of the moon; south of the line, the star will be occulted: north of it. Zeta will mus the moon.

Within a few miles of the line, however, observers may see a grazing occultation in which the star moves almost tangent to the moon's edge, possibly vanishing abruptly behind dark lunar mountains and flashing out again several times. Zeta Tauri will touch the moon's northwest limb at position angle 345° (this angle is counted around the moon's edge from north through east). This is on the dark side of the disk, giving a fine view in small telescopes.

ON THE NIGHT of October 7.8 at Fort Worth, Texas, will be among the about 11 u.m. Central standard time, fort to see the areas. The second dimensional first to see the graze. The moon's altitude above the horizon, however, will be only 11° at the time Zeta is nearest the moon, about 4:39 UT. About 20 miles southeast the central and castern United States and of Montreal. Canada, oscard the opposite end of the track, the grase will occur at about 5:25 UT. There the moon's altitude will be 37".

Other points along the approximate Not everyone will see the star pass line lie some 55 miles northwest of Little ana: about 15 miles northwest of Columhas, Ohio; in Akron, Ohio: a few miles southeast of Eric, Pennsylvania; and some five miles southeast of Rochester, New Nork

DAVID DUNHAM 1519 And St. Berkeley S. Calif.



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 passed near Fort Worth, Texas; mbus, Ohio; and Montreal, Quebec. ctions by David Dunham were publ in SKY AND TELESCOPE for October, page 218.

orably located amateurs saw the 3rditude star wink on and off as elevaon the lunar limb moved through ar's line of sight.

a watcher was well south of the g-occultation path, he saw a normal ation, the star disappearing only North of the line, Zeta passed just of the moon and no occultation ed.

Farland, Texas, the moon was quite he horizon when James E. Smith ta Tauri disappear at 4:58:40 Unitime. The occultation was brief, er, and the star reappeared at), as timed with a 6-inch reflector. mary Pierson, at May, Texas, saw sappear at 4:54 UT. She missed it out, however, while consulting a chart two minutes later.

s a 6-inch reflector, John Brannen hearly 13-minute occultation from lock, Arkansas. He reports, "Zeta entered a small valley located est of a group of craters near ib. It disappeared at 4:55:04.4 UT and reappeared 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 30 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 $1\frac{1}{2}$ miles north of the northern limit.

Observer Freedman probably had one of the most spectacular views. He watched with a 60-power 3-inch reflector at west longitude 84° 12' 08", north latitude 39° 35' 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. At four other stations the star disappeared at least twice, making our program so successful that almost everyone offered to travel a hundred miles to see future grazes. One boy even got his Christmas telescope early for the October event!

DAVID E. LAIRD 99 Virginia Ave. Dayton 59, Ohio

COLUMBUS, OHIO

Members of the Columbus Astronomical Society observed the occultation of Zeta Tauri at the four sites shown on the map. Each was located at roughly $\frac{9}{4}$ -mile intervals along a nearly north-south line about 15 miles northwest of Columbus,

Precision Diagonals
You will get the best possible per- formance from your telescope with one of our clear FUSED QUARTZ diagonals. Accuracy guaranteed 1/20 wars
Ellipse 1.25" x 1.77" \$12.00 Ellipse 1.5" x 2.12" \$15.00
PYREX -brand glass diagonals, 1/8- wave accuracy.
Ellipse 1.25'' x 1.77'' · · \$ 6.00 Ellipse 1.5'' x 2.12'' · · \$ 9.00
Without aluminum coating, deduct \$1.00. Send for our NEW list of supplies, quartz mirrors, blanks, oculars, coatings, and accessories.
E & W OPTICAL CO. 2420 East Hennepin Ave.
Minnespelie 10

This is the 2nd page (page 370) of the 2-page article about the 1963 October 8th zeta Tauri graze in S&T's Dec. 1963 issue



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,



Charles Legg, Larry Ochs, Mike Peugh, Dan Sagstetter, and Steve Yanochek. Allen Austin, Butch Hall, and John Morris of the Worthington High School Astronomy Club, and Dan McGrath of Bishop Watterson High School in Columbus, also joined our group.

We observed with a 6-inch refractor and two 6-inch and one 4-inch reflectors. A two-man team recorded CHU time signals on tape, while the other groups had

OBSERVED CONTACT TIMES

Contact		Univ	ersal	Station
(see chart)		tim	on Map	
1	5^{h}	08 ^m	19°.5	D
2	5	08	57.2	С
3	5	09	04.5	С
4	5	09	05.0	С
5	5	09	31.1	В
6	5	09	45.8	В
7	5	09	52.8	В
8	5	10	03.1	В
9	5	10	29.0	C
10	5	10	38.0	C
11	5	10	44.0	C
12	5	11	21.5	D
10 m 11				

*Italics denote disappearances, all others are reappearances.

a timekeeper, observation recorder observer.

As the predicted time of contact seat one observer thought the moon we miss Zeta, for the illuminated portion its disk had already passed the star ing the illusion that the dark part we also miss. However, the star had reached the predicted contact possiangle, and his location eventually reveal to be a proper one.

The southernmost station. D. had a simple occultation lasting 3^m (C^m) a shown in the accompanying diagram and table. There was a deep graze at C. when Zeta Tauri was hidden three times in 1^m 47^s. The observer at **B**, near the **band** ern limit, saw two disappearances in S seconds. Zeta was not occulted at A. num of the predicted limit.

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

> BARNETT GOLDINE 111 Richards M Columbus. Chin

High school students open the eyes of USNO

- **D**X

19631008_ZC847-DunhamComments.txt - Notepad

<u>File Edit Format View Help</u>

The 1963 Oct. graze is important since it was the <u>first one for which details of observation expeditions were published.</u> <u>Tom Van Flandern</u> was just starting work at the US Naval Observatory at the time; when he <u>saw the article in Sky and Telescope</u>, he got the US topographic map that showed the sites north of Columbus, scaled the positions, and analyzed the timings that he was able to measure from the time diagram. <u>Tom found a mismatch (shift) of 0.4</u>" or so; at the time, it was assumed that the FK3 star positions and Watts data were more accurate than that, so <u>Raynor Duncombe</u>, director of the <u>Nautical Almanac Office</u>, was incredulous when Tom showed him the results. This sparked USNO's interest in grazes at the time. David

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



Microsoft Excel	l - GrazeLi	ist.xls										
10 2 8 31	4017	ALL X RA	2 · · · · · · · · · · · · · ·	😧 🚆 Courier 💽 1	10 · B	IU	FT	11 - SA	1 5 9		12 -28 E	 (本) (二) · (□
(S) Ele Edit Ve	ew Insert	Format Look	Data Window Help								Type a qu	estion for help 8
A1031 -	f.	19810510										
A	8	CD	E	F	G	н	1	J	ĸ	1. L	M	N
1 YYYYMMDD	Star	He	Iocation	Organizer	#St	#Tn	CA	N.N.	×Sn1	SCE	In	Reviewed
2	ZC	SAO									Occult	
1020 19810314	995	4	1 Lion's Head, Ont	Doug Cunningham	2	7	2N	0	61+	TIM	6	Y
1021 19810315	1138	2	1 Applegarth, NJ	David Dunham	3	3	4N	1	72+	TIM		Y
1022 19810315	1138	7	1 Ingersoll, Ont.	Bob Radko	1	2	4N	1	72+	TIM		Y
1023 19810315	1138	7	1 St. Joseph. Ont.	Doug Cunningham	1	1	4N	1	72+	TIM		Y
1024 19810316	1275	5	6 Edgar Springs, MO	Joseph Senne	1	3	4N	1	82+	TIM		Y
1025 19810325	2247	5	6 Austin, TX	Rick Binzel	3	8	155	193	-80	TIM		Y
1026 19810328	2591	6	5 Harrisburg, RSA	H. D. Overbeek	3	8			-57	TIM		Y
1027 19810329	2797		3 Vebster, MD	David Dunham	0	55	-7N	9	-44	TIM		Y
1028 19810407	453	7	3 Five Mi. Fork, VA	Villian Stein	6	24	75	182	7+	TIM	N	
1029 19810410	930	8	1 Ottawa, Ontario	Brian Burke	2	2	-05	180	35+	TIM		Y
1030 19810508	1129	5	3 Warabad, RSAfrica	J. Barsby	3	37			27+	TIM		Y
1031 19810510	1310	4	2 Conovingo Dam. MD	David Dunham	18	111	4N	2	41+	TIM	N	30
1032 19810510	1310	4	2 Spry, PA	Steve McLaughlin	1	3	4N		41+	TIM	N	
1033 19810510	1310	4	2 Evert, MI	Paul Assus	1	11	4N	1	41+	TIM	N	
1034 19810511	1504	5	7 Babsfontein, RSA	J. Barsby	9	75			58+	TIM		Y missing nmes
1035 19810514	1773	5	1 Blenheim, N. Zeald	Brian Loader	1	3	SN		82+	TIM		Y
1036 19810525	3113	5	4 Flora, MS	Benny Roberts	2	6	25	185	-65	TIM		7
1037 19910522	2292	2	1 Mine ME	Banner Bohante	1		-16	190	-11	TTM		v

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

ASTRONOMICAL SCRAPBOOK

C. H. WATTS AND THE MARCHAEL ZONE OF THE MOON

names are correctly unknown to the wider public that gets in astronomy from the incorpapers. Reporters gather around the man who has just armentment to a wrenits reasting that the unserve is blowing up or collepsing. They are less likely as incovers automnion engaged in large Insighterns projects of great voltar to further elevitists, but not bradline material noday. Elimiter R. Warts is an automotory man. When he recent from the \$1. 5. March Observators in September, 1858. Its Just been in charge of its formly



Above: Chemer Buy heigh Warm is equally well known ormany the world's same mere as a leader in and a skillful instru ment designat.

Right In Dr. Water apparatus for tracing hazar profile. light from a source. at the horizon manage apward through an institut system and the photographic negative of the moon. As the horiunial plate carriage notates, the phins tells at the up state the linear line, Of the three sens at upper right, nue micro the profile, a second straws a seraight have line, and the third records the dressity of the segment.

"EXTAIN ASTRONOMERS do work around clide for a quarter contain. This and the fest importants, set that is our of the very free altier excelling instruments in the woold, set the fundaverntal stor positions determined with them are vital to the study of siellar sections and of Milke Way aracture. Dr. Watts' estimates references of the 6-ited motair cinit, increasing its securicy and speed of operation have, disreface, a quotial spridenant. He went on to design a new 3-tech inscrepants embedding the cause improvements, new in sense, me. After his menimal retirement. Dr. Watts our sound in work at the Naval Observitory on an enormous proper he had be the same than a decade believe and which he has recommin formanits on a same crudul conclusion. This is his envery of the marginal soor of the mars, just pals Index or the 17 of the Astronomical

Patent of the American Ephemeric II. is worth considering why this 951 page tome, practically all of it disgrams, is moting to be a presented attandant to air The most's orbital matters is the store

dard to which proving timekooping is inschornel, over since it was oscablished that small arrelan furnations in the largehof the dow make the earth's evision macontable except at a secondary standard three associates are contribuilly als service; the susser's positions with manual circles, Muchaelts common, and he trained occulturions of stars, in order to find whether the earth's estation is sterning hart or alma. Of course the monious of the create is committeen. has the according





The machine pictured on page 34 does their profiles from two most photographs taken a few minutes apart with the Yale-Calumbia 27-inch refractor. The mares have been dightly rarneri about deir midpoint to make comparison oniest note the dight differences. All illustrations are courses: U. S. Naval Observatory,

formities are predictable with high percitizen from E. W. Browte's Junar theory. All this would be fine if the moon's

other were a convert sincle. Actually, commutation, valleys, and consens seen in urofile produce a jagged limb that introduirs sublic errors direquently one secand of sec5 in susparements of the most's position. To make matters worse, this tanged edge is continually charging as libration silt the lanar plobe.

Consider, for example, an observed time of secultation of a stay by the ensure, To make full our of this observation, it, is necessary in know the length of the lamar radius no-the point where the star was covered, this length usually expected as a small correction to the overage radius of the disk.

It is this problem that Dr. Watts has salord, far more completely than any of his predecessors. About 700 photographs. of the muon were used, taken with longknus reltation at the Nasal Observatory. the towner Vale-Colorabia station in South Africa, and at Lowell Observatory. These pictures from the years 1927 to 1955 were sciecced to over all possible conducations of Mirations in Impitudeand hadrande. Since as any one time the illuminated kinh of the moon in general extends only through a semicircle, double the manher of photography you reeded.

To measure the profile of the mous aneach negative, Dr. Worn levented an ingenius photoelectsis scatter-

Altogether, 457,000 points were meamost, and were and to complie 1.600 flagrom, of which an example is reptoduced below. Three is one such chart for every 0.2 degree around the moon's limit; this one is for a place 176.4 degrees from the nurth cail of the myon's axis. somed cosward around he rin. The accimutal and vertical stabs are degrees of liberation in longitude and lationle, respectively. Corved lines are labeled with finals corrections or intervals of 0.7 sec. and of an

This particular disgram concerns a part of the lunar south solar regions. near the center Cabeus. It wills as that under librations of +25 degrees in longsunder, +44 in latitude, the moon's limbwill protride 22 accesss of our at this prim. If the libration in animals grows to +7 degrees, the limb balge will shrink to 1.5 second.

These are not mostow stops of the antimer and. Obviously, + high mountain in the mann's material more will dummant the profile over a considerable range in liberation, desays hiding the ergion bubined in. It is not possible to obtain true slope angles of the latter sortare is a direction transferre to the linds.



The limb-correction chart described in the next releas to an many's wash pole. The authors ligh is arrer illuminated at times when the unsen has a large southerly libeation in latitude. For this mason, the vertical scale of this chair is largely limited to south (4) libertions. The large usi of compling the 1.800 churts from nearly half a million measures was aided by the Air Force Acconducted Chart and Information Center

The principal limitation to the or curry of positional observations of the more has for more years been the linds interrulation, higherty impossible in our rect for satisfactorily. What Dr. Watts tim done is approximately to double the weight of all the many thousands of existing meridian, occultation, and estn era observations of the moon. With modern computers, the re-reduction of these chargestions is a large but possible task. The prospects therefore, are for a substantial improvement in our knowledge of the variation of the sky both for the furner and the past.

We can also anticipate some major aleaners in understanding the moon's orbital perities. By 1900 standards, the deunited gravitational theory of the mean's mution was an intricage chan its development to practi and paper methods was a libreark for a skilltst applied mathematician. To keep the various detailed parts of the problem in mind required a contal effort that Brown compared to playing three-dimensional chess blindtokted. Nowadays, composite car do must of the courses munipedations of trigonometric erries, for example, that und in vort inconstinue labor. Perhaps. then, we can look forward so hunge theory being pushed to still greater completeness than Brown amained. This would be the theoretical counterpart of the obtance that Dr. Wars has made possible on the discretional side. Moreover, the impresent throny would require the more precise orbital parameters that the refined duestations would supply

JOSEPH ASHBROOK

RADAR CONTACT WITH JUPITER Sovier scientists have succeeded in observing radio echoes from the planet Jupiter die Monow urospaper Prandu announced an December 20th. The say, assist experiments were conducted in September and October, 1965, when the planet was about \$70 million miles from carth. The use-way instel time for the signals was about 66 menuors.

The 700-megacyale pulses were minamatted from a 52-best dish amounta. According to the New York Times, the work was probably done at a radie installation erected in the Crimes in 1960 for track hig investigation performance

This was published in the 1964 Feb. issue of Sky and Telescope. The figure at the bottom for WA 176.4° 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

OBSERVER'S PAGE

Universal time (UT) is used unless otherwise noted.

CALIFORNIA OBSERVATIONS OF A GRAZING OCCULTATION.

in from of the 6.7 magnitude star-Z.C. 308 on the running of February 18, 1964. the disappearance was visible from the nurthwestern United States. But for southers California and Arimna, the mount write well muth of the star.

Productions by David W. Dunthum of Berkeiter, California, showed that the southern limit of the occulturion was to fall near the town of Davis in the Sacramento Valley. Watchers within a mile or two of the line could anticipate a spectacular view as the star drifted among the mountains along the moon's southern.

Many California amateurs took part in a carefully planned campaign to observe the event. They included members of the maneur societies at Socramento, San Jooe, San Marro, and Walnur Creek. Favored. to excellent weather, the amaneurs manned a closely spared chain of a dozenobserving sites, as shown on the map,

Each station had a edmoupt, tanging in sin from a 16-mell reflictor to a 2,4incle retractor. Timing tess done with atoprotoches and tape seconders, and some days south of Pattah Cerck had shortwave receivers for WWV callo time signals. At the mothermony site, J, no lower

DU REALLY E MILKY WAY?

re explored the length of our own Millig Way me of these specialized instruments, you have of the most striking telensupic views imaginable

ipead for one spearts purpose Big sumber of story at one time for a pivet spectors. ope right-performing power and methed scapilingtion of the choice and front, extended periodicities that This determines is a particul instrument second a star obtained



WHEN the first-sparter mean panel than four disappearance followed by reappearances were seen in 31 minutes, as the star threaded its way behind hanar hards anountains. The first time the star canished was for only 2.6 seconds, fathing a lunar emissence so small that no correquantized interval of invisibility was moved from station II, only 45 yards from 47

> KEY TO STATIONS. 1. 1.20 miles north of predicted limit. Observers: H. Simmons, J. Borde. Al: 1.17 miles north. J. Felker, C. 0.74 mile north. A. and N. Leonard. D. 0.6 mile north. W. Kcomm. R. Smith. 6. 0.25 mile morth, K. Wells, 0.2 mile north. J. Marr. J. Kirby.

G. 6399 mile south R. Wasland, J. Dono-

12. B.14 mile south, W. Seens, R. Buchmur, dur.

0.32 mile south. D. Donham. 1.12 miles south. W. Fisher, E. Beowne, & 1.17 miles muth. B. Bowman.

1.15 miles south R. Smith, W. Leonard,



Labeled here are the 12 statisms for observing the grazing accultation of the star Z.C. 398. The mapped area is about two miles west and slightly of Davis, California



David Dunham's chart shows by horizontal hars the intervals when the star was hidden by hour limb mountains during the grazing occultation of February 18, 1964. Three additional stretches of invisibility were noted from station A, but are not placted because their durations are unknown.



In the diagrams are six lines marking periods when the star could not be seen from C: shorter durations of invisibility occurred at other sites. As seen froms E. the star's track was slightly farther from the moon's center, and hence was blocked for a shorter time by each hill, or not at all. About #:53 p.m. Pacific standard sime,

a particularly prominent elevation blocked the star from view for all 12 sites. At seven of them, the duration of invisibility was mensured: K, 24.5 seconds; J, 27.2; I, 39.0; H, 40.5; G, 41.0; E, 45.5, followed after 10 seconds by a 0.7-second blackout; and C, 68.0 seconds, but interrupted just after the beginning by a brief flash. Another observer 2.4 miles south of the predicted limit reported that the moon missed the star entirely.

It is clear how, in principle, a precise profile of the mountain might be drawn to scale from such observations. The final heief invisibility front # reveals a little spor on the mountain flank, too low to have produced a noticeable effect for observers at G. On the opposite slope of the mountain, the flash seen from C indicates a match.

Mr. Dunham also writes: "Some of the ulucryers who wanched this occultation came from points over a hundred miles away. We gathered at the house of Are and Natalie Leonard in Davis, From their backyard five of us timed an occulration of Z.C. 393 at about 6:50 p.m., twohours before the graze. About five minuses before the occultation of Z.C. 308 was to occur, many of us timed the disappearance of the 6.3-magnitude star 85

CORRECTIONS

On page 182 of the June, 1964, issue, the caption under the finder charm for 3C-273 gives the wrong orientation; north, not south, is downward.

The schematic diagram of the transiano oscillator-amplifier on page 279 last month has a nonfunctional wire. The vertical line showing +12 volus coming to the right side of transformer T1 should stop at the center doe

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 β^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^{th} -mag. χ Piscium at Assateague Island, Maryland

2001 Dec. 21 Grazing Occultation of 4.0-mag. τ^2 Aqr

- Moon 32%+, Cusp Angle 12S
- 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



My Telescopes for Remote Observation



Station "A", C-5 & PC23C, & f/6.4 focal reducing lens from Orion



Station "B", Sony Digital Camcorder



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.





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)



Eta Geminorum - Graze

RISE OF THE MACHINES



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



Stations on N. 387th Ave.



(Map center is at (WGS84 datum) Lat = 33.520538, Lon = -112.884222, which is 0.335 Km from path center.)

Graze of 4.9-mag. ω^2 Tauri (ZC 628) over Minneapolis, Minn. on 2012 Aug. 11, Moon 35%-, CA 2N



Station 4's single R indicates a south shift of about 200m; we can still determine corrections to stellar proper motions from graze observations

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.

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!