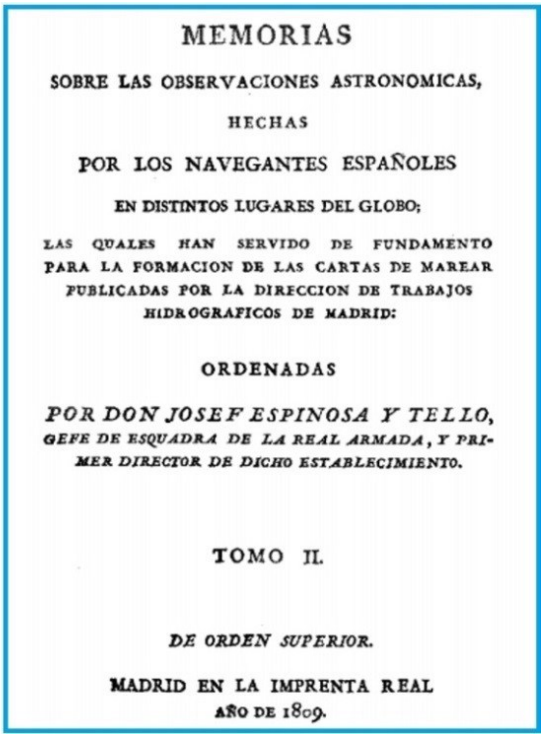
Longitude determination without a clock

“Land in sight!” On November 10, 1799, Capitan Don Miguel Zapiain y Valladares awoke by the call from the mast basket on the Spanish war frigate Nuestra Senora del Pilar. In the middle of the water desert of the North Pacific, halfway between Manila and Acapulco, which is almost 8000 nautical miles away, an island three and a half miles long appears. Don Miguel records the coordinates: 28 ° 09 'North, 184 ° 12' West (Fig. 1a, b).



MEMORIAS

SOBRE LAS OBSERVACIONES ASTRONOMICAS,

HECHAS

POR LOS NAVEGANTES ESPAÑOLES

EN DISTINTOS LUGARES DEL GLOBO;

LAS QUALES HAN SERVIDO DE FUNDAMENTO PARA LA FORMACION DE LAS CARTAS DE MAREAR PUBLICADAS POR LA DIRECCION DE TRABAJOS HIDROGRAFICOS DE MADRID:

ORDENADAS

POR DON JOSEF ESPINOSA Y TELLO,

GEFE DE ESQUADRA DE LA REAL ARMADA, Y PRIMER DIRECTOR DE DICHO ESTABLECIMIENTO.

TOMO II.

DE ORDEN SUPERIOR.

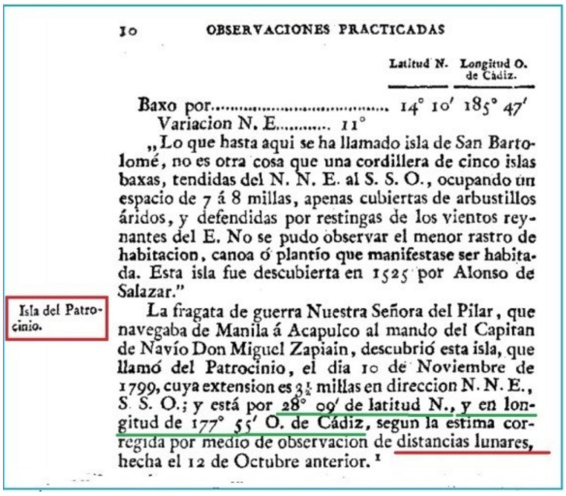
MADRID EN LA IMPRENTA REAL

AÑO DE 1809.

Fig.1a: Astronomical observations

He has determined this position using dead reckoning, i.e. recording the compass direction and ship speed, since October 12, the time of the last determination of the astronomical position back in the Philippines. He used **Moon distances**, for which, apart from a good sextant (Fig. 2), not even a really precise clock is needed.

The Isla del Patrocinio discovered on this November day was almost forgotten when N. C. Middlebrooks rediscovered it as Midway Island in 1859, 28 ° 13'N, 177 ° 22'W, although the island had still been noticed rather carefully by Nathaniel Bowditch in: "The New American Practical Navigator “, Sixth Edition“, New York 1826 (Fig. 3).



10 OBSERVACIONES PRACTICADAS

	Latitud N.	Longitud O. de Cádiz.
Baxo por	14° 10′	185° 47′
Variacion N. E.	11°	

„Lo que hasta aqui se ha llamado isla de San Bartolomé, no es otra cosa que una cordillera de cinco islas baxas, tendidas del N. N. E. al S. S. O., ocupando un espacio de 7 á 8 millas, apenas cubiertas de arbustillos áridos, y defendidas por restingas de los vientos reynantes del E. No se pudo observar el menor rastro de habitacion, canoa ó plantío que manifestase ser habitada. Esta isla fue descubierta en 1525 por Alonso de Salazar.”

Isla del Patrocinio.

La fragata de guerra Nuestra Señora del Pilar, que navegaba de Manila á Acapulco al mando del Capitan de Navío Don Miguel Zapiain, descubrió esta isla, que llamó del Patrocinio, el dia 10 de Noviembre de 1799, cuya extension es 3½ millas en direccion N. N. E., S. S. O.; y está por 28° 09′ de latitud N., y en longitud de 177° 55′ O. de Cádiz, segun la estima corregida por medio de observacion de distancias lunares, hecha el 12 de Octubre anterior. [1]

Fig.1b: Isla del Patrocinio (to 1a)

The islands latitude could be determined quite precisely already in 1799, but the large deviation in longitude by 360 nautical miles in this gigantic ocean was entirely within the scope of the usual inaccuracies at that time.

Fig. 2: Sextant 19th century.

First attempt, Atlantic Ocean, Oct. 8, 2015

A 44-foot sailing yacht with a crew of 6 leaves Lisbon on October 6, 2015 for the Canary Islands. Two days later, skipper Michael Zahlten woke me up to let me know that he had already prepared the sextant and had already tested the first Moon distance to Venus on a trial basis. This morning the planet Jupiter stands at 5 a.m. UTC in the clear east sky a fist wide above the horizon, Venus above it and a little higher the narrow crescent Moon.

An almost forgotten method of longitude determination is now to be tried: time determination over Moon distances, the angular distance between the Moon and planets or stars near the ecliptic. The Moon runs around the earth once in a month, and thus represents a kind of additional, absolute, clock compared to the daily earth rotation.

288 TABLE XLVI. Latitudes and Longitudes.

New South Wales.	Lat. D. M.	Long. D. M.
Cape Hawke	32 13S.	152 30E.
Smoky Cape	30 51	153 7
Solitary Islands	30 9	153 21
	29 56	
Cape Byron	28 7	153 30
Point Danger	28 7	153 30
Shoals off ditto	28 7	153 39
Cape Morton	27 1	153 23
Shoal	26 58	153 28
Sandy Point	24 42	153 17
Cape Capricorn	23 29	151 00
Keppel Bay	23 18	150 36
Barrier Reef, S. P.	22 50	152 36
Cape Townsend	22 12	150 11
Cape Palmerston	21 27	149 00
Cape Hillsborough	21 00	148 33
Cape Conway	20 32	148 30
Cape Gloucester	19 58	148 6
Cape Cleveland	19 10	146 40
Cape Sandwich	18 16	146 8
Cape Grafton	16 51	145 54
Cape Flattery	14 52	145 18
Cape York	10 38	142 33
New Year's Island	10 48	133 18
Vandieman's Cape	11 12	129 54
Red Island, off P. Vulcan	15 9	124 22
Minstrel's Shoal	17 14	118 57
Greyhound Shoal	19 58	114 40
Clarke's Reef N. of Rosemary I.	20 17	
Eastern Rosemary I. N. E. P.	20 26	
Western ditto N. P.	20 35	115 40
Doubtful Shoal	21 37	112 25
Piddington's Islands	21 36	114 56
Shoal (land of N. Holland in sight from the mast head)	20 15	
North West Cape	21 50	114 25
Dirk Hartog's Road, ent. to Shark's Bay	25 6	113 15
Houtman's or Abrohlos Shoals	28 30	113 35
Rottenest Island	31 58	114 24
Cape Leuwen or S. W. Cape	34 22	115 6
Cape Chatham	35 3	116 22
Cape Howe	35 9	117 38
K. George III. Harbour	35 6	118 1
Point Hood	34 23	119 36
Termination Island	34 30	121 58
Endeavour, small Isl.	36 27	127 2
Port Lincoln	34 48	135 45
Nepean Bay	35 44	137 56
Endeavour Shoal, off Cape Jaffa	36 58	139 31

XLVIII. *Islands, Rocks and Shoals, in the NORTH PACIFIC OCEAN.*

	Lat. D. M.	Long. D. M.
Alcootskia I.		
— Westermost	52 46N	170 42E.
— Oonalaska	53 54	166 22W
Bank (64 fathoms)	34 22	178 30E.
Rica de Plata	33 50N.	160 39E.
Reef	32 00	147 00
Island	31 30	140 00
Week's Reef 36′ N. E. and S. W.	31 15	153 9
Island	31 00	147 6
Ganges Island	30 45	154 25
Bank of Soundings	30 30	177 30
Island	30 00	137 00
Island	30 00	139 00
Island	30 00	141 30
Island	30 00	143 00
Island	30 00	144 24
Rica de Oro	29 54	157 3
Island	29 40	143 00
Island	29 33	137 00
Island	29 30	143 00
Island	29 00	176 45
Calunas I.	28 55	158 00
ditto (another account)	28 53	162 00
~~Island~~	~~28 30~~	~~176 50~~
Patrocinio Island	27 58	175 44
~~Disappointment Island~~	~~27 19~~	~~139 25~~
St. Juan	27 30	142 48
Bassiosos I.	26 6	173 27
Island	26 6	154 36
Reef	26 6	160 00
Copper Island	26 00	131 48
Tree Island	26 00	145 44
Lasker's Island	26 00	173 24
Island	25 53	131 17
Island	25 42	131 13
Reef	25 30	152 50
Bishop's Rock	25 22	132 00
North Island	25 14	141 14
Island	25 12	131 36
Grampus Island	25 10	146 00
Sulphur Island	24 48	141 20
Kendrick's Rock	24 30	133 36
Marcus Island	24 18	153 42
Weeks Island	24 00	154 00
Dexter's Island	23 24	163 5
Island	23 3	162 57
Reef	22 6	142 28
Jardines	21 35	151 30
Parel or Peru I.	21 10	141 40
Abregoes Shoal	21 1	136 43
Reef	20 42	153 00
Douglas Reef	20 32	136 12
Lamira I.	20 30	166 42
Island	20 30	152 50
Bishop's Rock	20 16	136 53
Week's or Wilson's I.	19 21	166 55
Reef	19 10	165 42
Halcyon I.	19 6	163 33
Folger's I.	18 22	155 15
Reef	17 9	156 13
Tarquin I.	17 00	160 00
Reef	16 36	169 42
Island	16 00	171 42
Pajaros Islet, northern.	20 34	145 48
Urrucas, about	20 20	146 15
Assumption Island	19 45	145 35
Almagan Island	18 5	146 21

Fig.3: N. Bowditch, sixth edition 1826

The ordinary sextant measurement, such as the height of the sun above the horizon, already is a challenge for the inexperienced. When the sun is brought down to the horizon with the rotating alidade mirror in the sextant, the horizon still runs as a line through the image, even if the sextant is held slightly wrong.

To measure the angle between the crescent Moon and a planet, however, two approximately punctiform objects on the yawing and rolling boat in the sextant must be brought to overlay by hand. Four degrees of freedom are to be controlled.

Because of these difficulties, Don Miguel apparently had only relied on dead reckoning navigation in 1799

After a first successful measurement of the angular distance between Venus and the Moon, move on - still a little sleepy - to Jupiter, which is further away from the Moon. The distance Moon-Jupiter is measured at 18 ° 57.4 '(time 05h20m20s UTC, but only recorded for control purposes!).

At the same time, the heights of the Moon and Jupiter above the horizon have to be measured in order to compensate for refraction and horizon parallax. In the 18th century, three to four men were entrusted with sextant measurements at the same time.

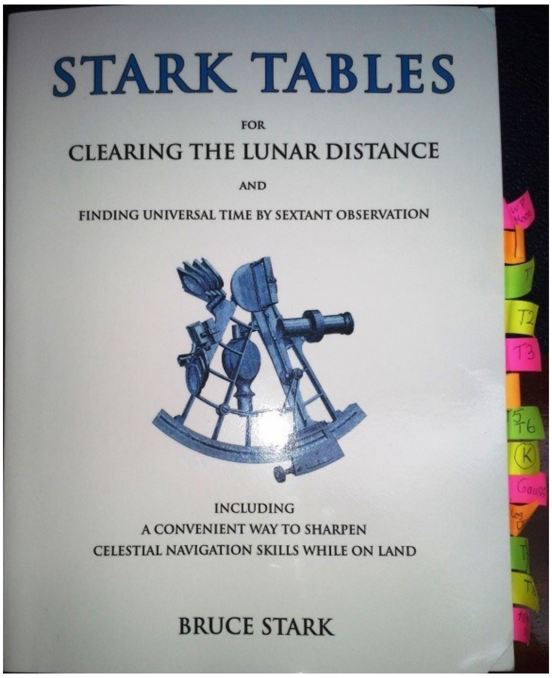


Fig.4: Bruce Stark's tables

These clearing calculations ("clearing the lunar distance") without a computer is now to be made using logarithmic tables, their official publications ended shortly after 1900. We owe Bruce Stark to recalculate these tables (Fig. 4). After diligent calculation and leafing through these tables, the "cleared" lunar distance to Jupiter is 19 ° 54.3 '(Fig. 5).

Further table calculations give the target values 20 ° 08.0 'and 19 ° 38.7' for the angular distance between Jupiter and Moon for the times 05h and 06h UTC, from which the determined time 05h28m03s UTC follows from linear interpolation.

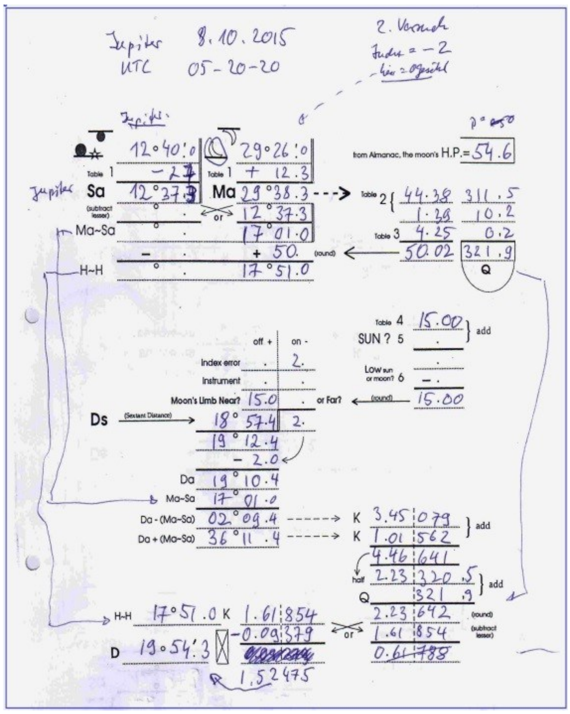


Fig.5: Lunar Distance to Jupiter

This approximation for time means that the height of the stars measured with the sextant would have been taken 7 minutes 43 seconds later than the actual chronometer-time mentioned above. In turn, this results in an apparent shift of the ship's position in longitude by 1 ° 56 ' or 94 nautical miles to the west, i.e. instead of GPS position 36 ° 07'N 012 ° 43'W to a position at length 014 ° 39'W (Fig. 6).

This error sounds huge, but it is less than a third of the error from lunar distance and dead reckoning by Don Miguel 1799. We would still have reached the Canary Islands without GPS and chronometer by measuring the lunar distances.

Of course, determining the position at sea with GPS is easier, but it is also easier to get to the Canary Islands by plane than by sailboat.

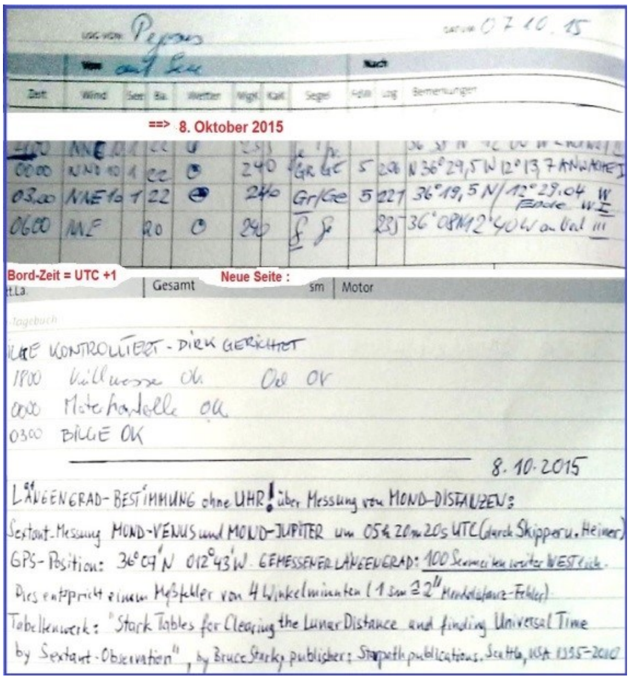


Fig.6: Logbook excerpt October 7th-8th, 2015

Second attempt, Atlantic Ocean June 17, 2017

The Azores high pressure system lives up to its name. It continues to expand towards England, with the 53-foot sailing yacht Magic Star in the middle of the return journey from the Caribbean.
For two days I have been trying - so far unsuccessfully - to measure the distance between Moon and Venus in the sky, about 50 ° apart. There was always some part of the ship superstructure in between, mostly the large boom, but sometimes the sunroof linkage. I had just mixed up Venus and Saturn on paper, both of which can be seen about 20 degrees above the horizon. Skipper Robert Winzen had already offered to bring the ship into hove-to position for reduced movements. But this is the night of the nights now.

With my back solidly ajar, I use the perfectly corrected ships sextant to pull the crescent Moon across the sky until Venus appears in the telescope as a shining point. Every now and then the Moon had escaped from the telescope-sight. But it was easier to find the Moon again rather than the planet, from which I had started in the preliminary experiments. Slightly rotating the sextant to capture the precise touch of the planet just at the edge of the Moon in fact turned out to be easier compared to normal sun-on-horizon positioning.

Fig.7: Schiff sextant by *Cassens & Plath*

Immediately writing down the time for comparison was necessary, then measuring the horizon heights of Moon and Venus in the approaching twilight, which however was not ideal for precise results. These latter data were therefore not used in the later evaluation.
On this trip I had left the "Stark Tables" Fig.4 at home. Evaluation therefore done only after returning home, for convenience with the computer program from Frank Reed.

Instead of the measured star heights, one can also enter the calculated heights. This is even useful for the purpose intended here, since one then only checks the accuracy of the Moon distance measurement instead of the entire combined measurements.

Furthermore temperature and air pressure are also included, in addition to taking the flattening of the earth into account for refractive corrections. Nevertheless, there are of course small uncertainties regarding the local conditions.

Now enter the measured Moon distance to Venus into the computer, 48 ° 07.0 ', the UTC time with 03h57m20s, and the GPS position. As a result, we get the surprising value of just 0.1 angular minutes of measurement error, corresponding to only a 2.4 'longitude-minute deviation from the GPS position, so hardly 2 nautical miles!

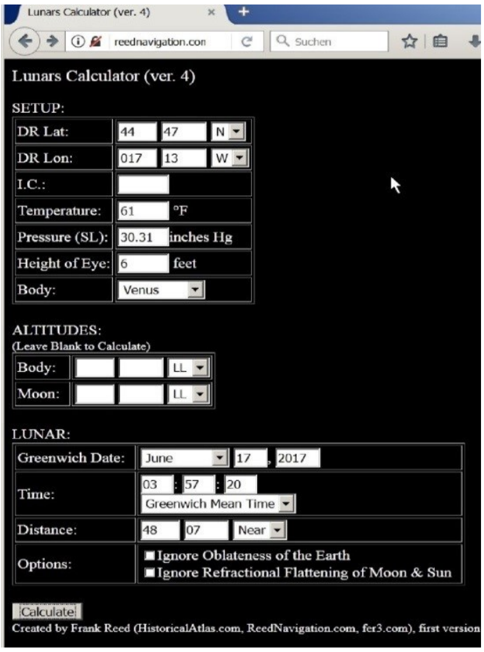


Fig.8: LUNARS calculator, input mask

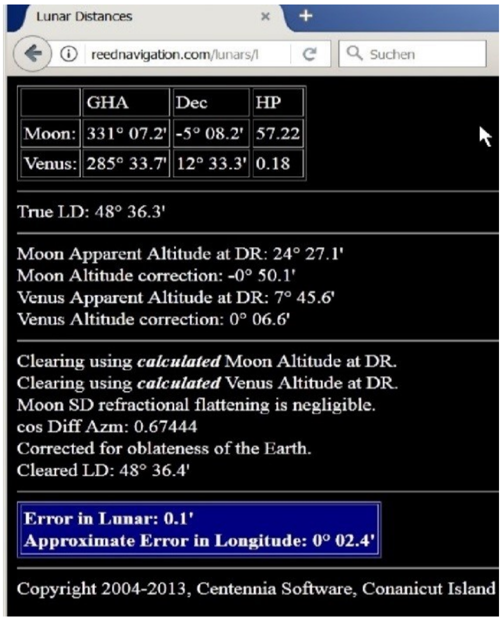


Fig.9: LUNARS calculator, result

An error of just one angular minute in a lunar distance gives an error of 30 nautical miles, which is thirty times more than the chronometer method. On the other hand: chronometers stop more often than the Moon!

This also explains Sir Nevil Maskelyne's negative attitude towards John Harrison's first precision chronometers around 1760. Maskelyne benefited from the exact tables by Tobias Mayer from Göttingen in 1755.

And already in 1514, Johannes Werner from Nuremberg had proposed the Moon distances for the lomgitude problem for the first time.

Georg Forster also considers the Moon distance method to be the only reliable method on Easter Island with James Cook on March 13, 1774.

In June 1896, after weeks of sailing in the Pacific Passat, circumnavigator Joshua Slocum was a little surprised at his lunar distance deviation of only 5 miles compared to the dead reckoning estimate. Of course, our minimal sextant measurement error in the second attempt was probably a coincidence. In practice a measurement error of at least one angular minute would probably be expected.

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Literature: Charles H. Cotter: A History of Nautical Astronomy, Hollis & Carter, London 1968.

H.M.-K. on the Magic Star Yacht (2017).

S.Y. Magic Star, Berlin