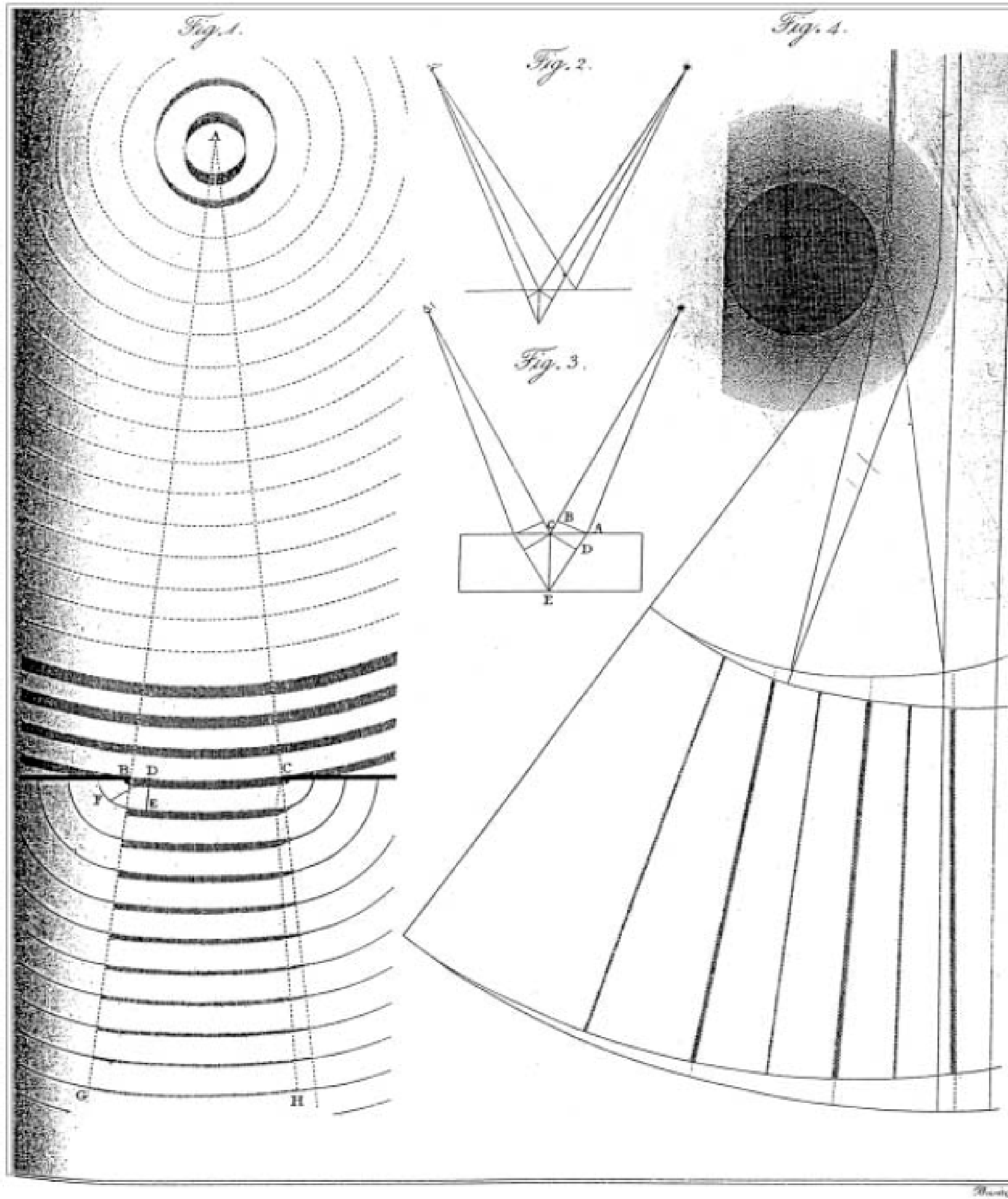
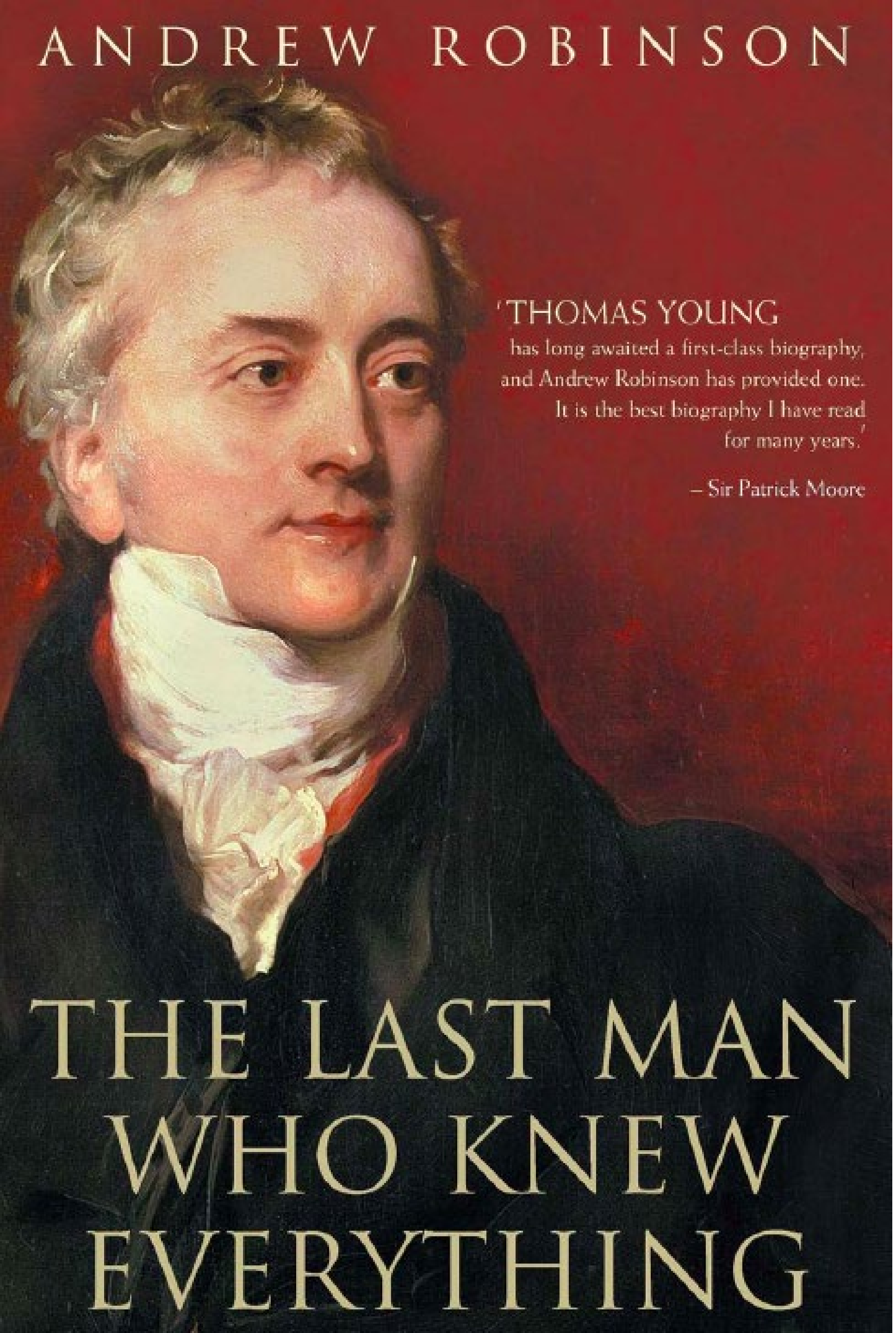
Giuseppe Mezzorani
INFN Sezione di Cagliari

Thomas Young
l'interferenza e le maree

Scuola di Storia della Fisica
Ferrara
Febbraio 2019



Thomas Young
1773 - 1829


ANDREW ROBINSON
'THOMAS YOUNG
has long awaited a first-class biography,
and Andrew Robinson has provided one.
It is the best biography I have read
for many years.'
– Sir Patrick Moore
THE LAST MAN
WHO KNEW
EVERYTHING

The origins of the concept of interference

By J. D. Mollon

Department of Experimental Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB, UK

Published online 28 March 2002

The concept of interference is implicit in Newton's explanation of the anomaly of the tides in the Gulf of Tongkin, but Thomas Young was the first to generalize the principle and to apply it to compound tides, to auditory beats, and to the colours of thin films. In his Bakerian Lecture, delivered on 12 and 19 November 1801, he was able to accurately derive the wavelengths of particular hues from Newton's measurements of the colours of thin plates. The first printed statement of the generalized principle of interference appears in the *Syllabus* for his Royal Institution lectures, which was published early in 1802. His celebrated two-slit experiment is first described in his *Course of Lectures on Natural Philosophy and the Mechanical Arts* of 1807.

Keywords: Thomas Young; thin films; Newton's rings; interference colours; colour vision; wavelength

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THE ROYAL SOCIETY

The origins of the concept of interference

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In the manuscript notes for his Royal Institution lectures, Young makes explicit the analogy with compound tides and the Batsha anomaly (University College London Archives, Ms. Add. 13).
And, to assist the understanding of his fashionable audience, he constructed a mechanical apparatus to illustrate the superposition of two waves
(Young 1802b).

Young, Thomas: Notebooks (MS ADD 13)

20 volumes

Notes for lecture delivered at the Royal Institution in 1802-1803 by **Thomas Young** (1773-1829), Professor of Natural Philosophy, Royal Institution 1801-1803.

Complete microfilm of this collection is available at Special Collections.

Links:

- UCL Archives: Thomas Young Notebooks (MS ADD 13)

there was nothing that *could have* led to it by any author with whom I am acquainted, except some *imperfect hints* in . . . the works of the great. Dr. Robert Hooke, which had never occured to me at the time that I discovered the law; and except the Newtonian explanation of the combinations of tides in the Port of Batsha." [13]

Nahum Kipnis

History of the Principle of Interference of Light

Newton e le maree nel golfo del Tonchino

1687

20° 51' N
106° 41' E

Il golfo del Tonchino è separato dal mare aperto dalla penisola di Luichow e dall'isola di Hainan. Il golfo si addentra per 330 km nella terraferma. La sua larghezza all'ingresso è di 241 km, e la sua profondità è di 40–82 m. A nord, fra Hainan e il continente, il golfo è connesso col mare dallo stretto di Hainan . Le maree sono diurne; l'alta marea raggiunge 5.9 m. Il porto di Haiphong (Repubblica democratica del Vietnam) è il porto principale del golfo.

45.

Inoltre può accadere che la marea si propaghi dall'oceano a un medesimo porto attraverso diversi canali, passando piú rapidamente attraverso alcuni che non attraverso altri: nel qual caso la medesima marea, divisa in due o piú maree, che sopraggiungono successivamente, può dar luogo a nuovi movimenti di diverso genere. Supponiamo che la marea sia divisa in due maree uguali, la prima delle quali preceda l'altra di sei ore, e cada nell'ora terza, o nella ventisettesima, dopo il passaggio della Luna al meridiano del porto. Se la Luna, quando perviene al meridiano, si trova all'equatore, si avranno alte maree uguali ogni sei ore, che, ricadendo sulle rispettive basse maree, verranno a contrabbilanciarle, in modo che l'acqua ristagnerà tranquilla per tutto quel giorno. Se invece la Luna declina dall'equatore, si avranno nell'oceano maree alternativamente maggiori e minori, come è stato detto, e dall'oceano si diffonderanno in questo porto due alte maree maggiori e due alte maree minori, alternativamente. Peraltro le due alte maree maggiori solleveranno l'acqua ad una grandissima altezza nel periodo intermedio fra l'una e l'altra; la seconda alta marea maggiore e la prima minore faranno salire l'acqua ad una media altezza nel periodo intermedio fra l'una e l'altra; nel periodo invece compreso fra le due alte maree minori, l'acqua si solleverà ad una minima altezza. Nello spazio di ventiquattro ore l'acqua non raggiungerà quindi per due volte la massima altezza, come in genere avviene, ma soltanto una volta, cosí come raggiungerà una sola volta la minima altezza; se la Luna declina al polo sopra l'orizzonte del luogo, la massima altezza dell'acqua cadrà nell'ora sesta o trentesima dopo il passaggio della Luna al meridiano, e quando la Luna cambia declinazione, prenderà inizio la bassa marea. Di tutto ciò abbiamo un esempio in un porto del regno del Tonchino, presso Batsham, alla latitudine boreale di 20° 50′. Qui, nel giorno che segue il passaggio della Luna all'equatore, l'acqua ristagna; declinando poi la Luna verso settentrione, l'alta e la bassa marea cominciano a farsi sentire, ma non si presentano due volte come negli altri porti, bensí una sola volta al giorno. L'alta marea coincide con il tramonto della Luna, e la marea piú bassa con il suo sorgere: il flusso aumenta secondo la declinazione della Luna fino al settimo o all'ottavo giorno; nei sette giorni seguenti esso decresce gradualmente, cosí come era aumentato, e quando la Luna muta la declinazione, si arresta e si trasforma tosto in riflusso. Infatti subito dopo la bassa marea coincide col tramonto della Luna, l'alta col suo sorgere, finché la Luna non muti di nuovo declinazione. Due sono gli ingressi dall'oceano in questo porto: uno piú diretto e piú breve si trova fra l'isola di Hainan e le coste del Cuangtung, provincia della Cina; l'altro si apre, con un lungo giro, fra la stessa isola e le coste della Cocincina. È attraverso

il passaggio piú breve che la marea si propaga piú rapidamente fino a Bathsam.


The Royal Society of London

PHILOSOPHICAL TRANSACTIONS

Phil. Trans. 1 January 1684 vol. 14 no. 155-166 677-688

An account of the courſe of the Tides *at* Tonqueen *in a Letter from Mr.* Francis Davenport *July* 15. 1678. *with the* Theory *of them, at the* Barr *of* Tonqueen, *by the learned* Edmund Halley *Fellow of the* Royal Society.

WHen the reported irregularity, of the *Ebbing* and *Flowing* of the *Sea* came firſt under my conſideration at a diſtance, I was content to fancy that I had gueſſed aright in aſcribing the occaſion of it principally to the *Indraughts* and *outlets* of this *bay*, which as I Imagined might give (the different times of the year in reſpect of the *Monſoon's*, and the currents accordingly ſhifting with ſeveral other conceited coadjutant circumſtances,) the moſt conſiderable ſhare in the unuſual courſe of the *Tides*, and that conſequently it would ſcarſe be poſſible to diſcover any conſtancy in them, if their regiment depended ſo much upon accidents and uncertainty's.

But during my continuance at *Batsha* I have observed such an order and constancy in the course of the *tides*, that notwithstanding I must needs confess it different from all that ever I observ'd in any other Port, yet not only from the coincidents of simular alterations on peculiar dayes of some particular *Moone's*, in different *monsoons* in respect of their increase and decrease, as well as from their keeping equal pace with the *Moon's* rising and setting in this *Horizon*, in respect of the duration of their *influx* and *reflux*, but also from that which seems to render them most irregular, *viz*. the constant falling back of the *flood* nearest 13 hours on every second day of the waters age and increase, so that at the end of 15 dayes there is an inversion of their motion in respect of their begining to Flow and Ebb.

It is evident that they are regularly influenced though not reconcileable with a dependance on the *lunar* motion

An Account of the Course of the Tides at Tonquin; in a Letter from Mr. Francis Davenport. N° 162, p. 677.

The peculiar circumstances of the tides at Tonquin are sufficiently stated in the following paper by Dr. Halley, which renders the reprinting of this tedious description of them quite unnecessary.

THE

PHILOSOPHICAL TRANSACTIONS

OF THE

ROYAL SOCIETY OF LONDON,

FROM THEIR COMMENCEMENT, IN 1665, *TO THE YEAR* 1800;

Abridged,

WITH NOTES AND BIOGRAPHIC ILLUSTRATIONS,

BY

CHARLES HUTTON, LL.D. F.R.S.
GEORGE SHAW, M.D. F.R.S. F.L.S.
RICHARD PEARSON, M.D. F.S.A.

VOL. III.

FROM 1683 to 1694.

A Theory of the Tides at the Bar of Tonquin. By Mr. Edm. Halley, F.R.S.
N° 162, p. 681.

The effect of the moon on the waters in the production of the tides in the port of Tonquin is the more surprising, as it seems different in all its circumstances from the general rule, whereby the motion of the sea is regulated in all other parts of the world that I have yet heard of. For first, each flux is of about 12 hours duration, and its correspondent reflux as long; so that there is but one high water in 24 hours. Then there are in each month two intermissions of the tides, about 14 days asunder, when there is no sensible flood or rising of the waters to be observed, but the sea is in a manner stagnant. Thirdly, that the increase of the water has its 14 days period between the aforesaid intermissions; and at 7 days end makes the highest tides; from which time the water again gradually abates, and the flood is weaker till it comes to a stagnation, both increase and decrease observing the same rule in being exceedingly slow in their beginning and end, and swift in the middle. Lastly, and which is most strange, the rising moon in the one half of each month makes high water, and the setting moon in the other half.

These particulars considered, together with the tables showing the days of the water's stagnation in each month, gave me a light into the secret of this strange appearance, so as to be able to bring the hitherto unaccountable irregularity of these tides to a certain rule. And first it appears that the intermissions of the tides happen nearly on those days that the moon enters the signs of Aries and Libra, or passes the equinoctial, which divides the moon's course nearly into two equal parts, as well as the sun's; and from hence it follows, that the tropical moons in ♋ and ♑, are those which occasion the greatest flux and reflux. It also appears that the moon in northern signs brings in the flood, whilst she is above the horizon, so as to make high water at her setting, and on the contrary, that whilst she is in southern signs, it flows all the time the moon is below the horizon, and so makes high water at her rising. But it is to be observed, that though the moon pass swiftly from south to north when she is in or near ♈, and from north to south when in or near ♎, yet the motion of the sea, which is the cause of this tide, is scarcely discernible for 3 or 4 days, when the moon passes the said equinoctial points; whence it appears, that though the declination of the moon be that whereby these tides are regulated, yet the increase and decrease of the water is by no means proportionate to that of her declination, that changing swiftly, where the increase of the water is observed to be most slow. It seems therefore, and I propose it as a probable conjecture, that the increase of the waters should be always proportionate to the versed sines of the doubled distances of the moon from the equinoctial points; upon which hypothesis, fig. 8, pl. 2, will give an elegant synopsis of the whole matter. Let AB be the bottom of the bar of Tonquin, CD a perpendicular thereto, whereon to measure the several depths of the water; C♈ C♎ the mean depth, which is that whereat the water is stagnant on the moon's being on the equinoctial points, which is commonly about 15 feet; C♋ occid, the high water mark when the moon is in ♋ or ♑ being about 24 feet; C♑ occid the height of the low water mark when the moon is in ♋ or ♑, being about 6 feet; so that the greatest rise of the water on the tropical moons will be about 18 feet; then dividing ♈ ♋ and ♎ ♑ into two equal parts in E, F, on those two points, as centres, describe the two circles, each of whose radii are $4\frac{1}{2}$ feet, which being kept between the compasses, naturally divide the said circles in the points ♉ ♊ ♋ ♌, &c. through which points if we draw lines parallel to the base AB, they shall cut the perpendicular CD, in the heights of the high and low water marks, which will be at the entrance of the moon into the said signs. So the greatest depth of the high water when the moon enters ♉, ♍, ♌, ♓, is but $17\frac{1}{4}$ feet, and the least at low water $12\frac{3}{4}$ feet; but when she enters ♊, ♌, ♐, ♒, the high water depth is $21\frac{3}{4}$ feet, the low water but $8\frac{1}{4}$ feet, as appears by the figure. And this hypothesis not only agrees with all that Mr. Davenport has observed himself or collected from the natives, but has been found to hold true since, in the year 1682, by the ingenious Captain Knox, in his voyage to this port, so that there is no room to doubt of the truth thereof. By this method port, so that there is no room to doubt of the truth thereof. By this method then may the time and height of the tides be with sufficient certainty computed; but to philosophize thereon, and to attempt to assign a reason, why the moon should in so particular a manner influence the waters in this one place, is a task too hard for my undertaking, especially when I consider how little we have been able to establish a genuine and satisfactory theory of the tides, found upon our own coasts, of which we have had so long experience. It would be however a very acceptable thing if some curious navigators would inform us, what tides or currents are found at Macao, Quemoy, and other places on the coast of China, and on Formosa; it being most probable that this flood comes out of the north east, along the coast of China, for the northerly monsoon is found to occasion the highest spring tides. There is yet another thing well worth inquiry, viz. seeing that this motion of the sea is more or less, as the moon is farther from or nearer to the equinoctial, it is not unlikely that some years may have much higher spring tides than others, according to the various obliquity of the moon's orbit to the equinoctial; for when the ascending node is in ♈, as it was anno 1671, and will be anno 1690, the moon in ♋ and ♑ deviates from the equator full $28\frac{1}{2}^{\circ}$, and but $18\frac{1}{4}^{\circ}$ when the same node is in ♎, as it was anno 1680.

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Keywords: Thomas Young; thin films; Newton's rings; interference colours; colour vision; wavelength

1. 'The Tides at the Bar of Tunkin'

In the 17th century, trade with Tongkin, now Hanoi, was hampered by a treacherous sand bar at the mouth of the river that gave access from the sea, and the danger to British merchantmen was complicated by the curious behaviour of the tides on this coast. The pattern of the tides was set out in a letter published in the *Philosophical Transactions* for 1684 by an English traveller, Francis Davenport, who had resided at a place called Batsha (Davenport 1684). In this region, near the modern Haiphong, there is never more than one flood tide a day, and twice each lunar month, at intervals of 14 days, there is no tide at all. For the next seven days the height of the solitary tide increases and it is maximal when the moon is at its maximum declination. Thereafter it declines again (Cohen 1940; Naval Intelligence Division 1943).

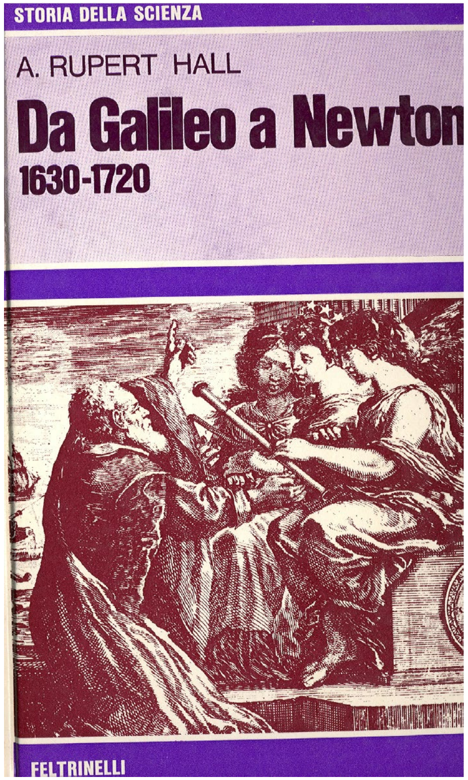
This curiosity had attracted the attention of Edmund Halley, and it was natural that Newton should discuss it in his *Principia* of 1688. Newton attributed the pattern of the tides of Tongkin to the superposition of component tides arriving from different directions. One tide, he suggested, came from 'the sea of China', with a delay of 6 h, and one from 'the Indian sea', with a delay of 12 h. When they were of equal magnitude, their effects cancelled at the port of Batsha (Newton 1688).

Yet Newton, despite his active interest in the colours of thin films and despite his awareness of their periodic nature, did not make the leap from the tides of Tongkin to the fleeting hues of a soap bubble. That leap was made by Thomas Young, and it was only in 1801 that the concept of interference emerged as an explanatory principle applicable equally to the interaction of tides, to the beats of sounds of nearly the same frequency, and to the colours of thin films. This principle—he himself called it a general law (Young 1802*c*)—has proved to be the most powerful of Young's several legacies to science and scholarship.

Thomas Young
Bakerian lecture
1803

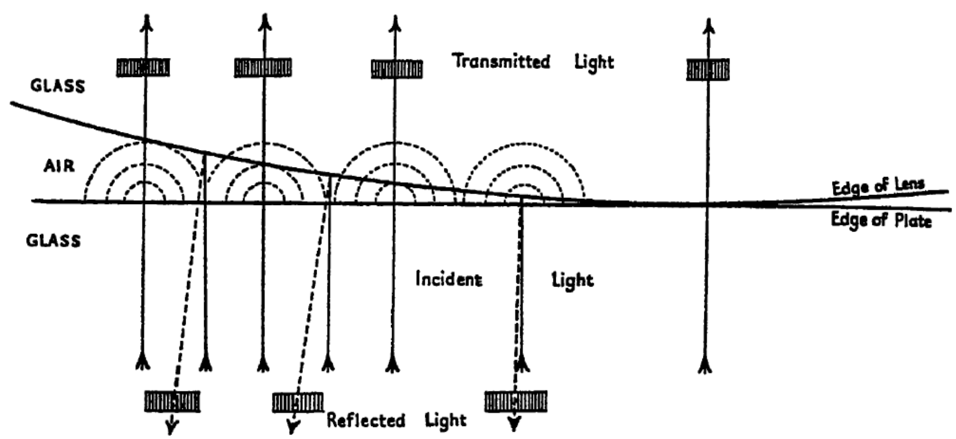
The absolute length and frequency of each vibration is expressed in the table; supposing light to travel in $8\frac{1}{8}$ minutes 500,000,000000 feet.

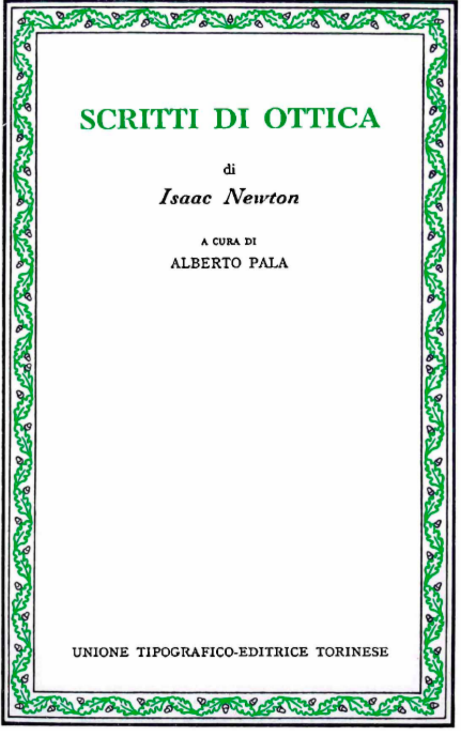
Colours.	Length of an Undulation in parts of an Inch, in Air.	Number of Undulations in an Inch.	Number of Undulations in a Second.	Wavelength (nm)
Extreme -	.0000266	37640	463 millions of millions	
Red - -	.0000256	39180	482	650
Intermediate	.0000246	40720	501	
Orange - -	.0000240	41610	512	609
Intermediate	.0000235	42510	523	
Yellow -	.0000227	44000	542	576
Intermediate	.0000219	45600	561 (= 2^{48} nearly)	
Green - -	.0000211	47460	584	536
Intermediate	.0000203	49320	607	
Blue - -	.0000196	51110	629	497
Intermediate	.0000189	52910	652	
Indigo - -	.0000185	54070	665	469
Intermediate	.0000181	55240	680	
Violet - -	.0000174	57490	707	444
Extreme - -	.0000167	59750	735	



Newton poteva ora abbandonare la sua ipotesi dell'etere; bastava infatti postulare solo, com'egli fece nell'*Opticks*, che i raggi fossero disposti in "sbalzi" regolari, di facile trasmissione e di facile riflessione, senza ricercarne una spiegazione fisica. Partendo da questo postulato, tutto il resto della teoria poteva essere sviluppato per via esclusivamente matematica. Il successo maggiore che Newton ottenne mediante questa teoria fu di riuscire a calcolare, sulla base delle dimensioni della sua apparecchiatura la misura degli spazi d'aria corrispondenti ai vari anelli; essi erano pari a 5,5 milionesimi di pollice (14 milionesimi di centimetro, moltiplicati per la serie dei numeri pari: 14 milionesimi di centimetro corrispondono a circa un quarto della lunghezza d'onda della luce gialla). Ora, poiché la teoria di Newton richiedeva che i raggi venissero riflessi quando lo spessore della lastra sottile (o dello spazio d'aria) era uguale a un multiplo pari di una semi-lunghezza d'onda degli "sbalzi," ne conseguiva che questa lunghezza era uguale a circa 11 milionesimi di pollice per la luce gialla — valore pari a circa la metà di quello reale.[23]

$$2t = m\lambda$$





LIBRO SECONDO DELL'OTTICA

$$\frac{r_m^{\,2}}{R} = m\lambda$$

PARTE II.

Osservazione 16. I quadrati dei diametri di questi anelli formati da un qualsiasi colore prismatico erano in progressione aritmetica, come nella quinta osservazione. E il diametro del sesto cerchio, quando veniva formato un giallo limone e quando veniva osservato quasi perpendicolarmente, era circa $^{58}/_{100}$ di pollice, o un po' meno, in accordo con la sesta osservazione.

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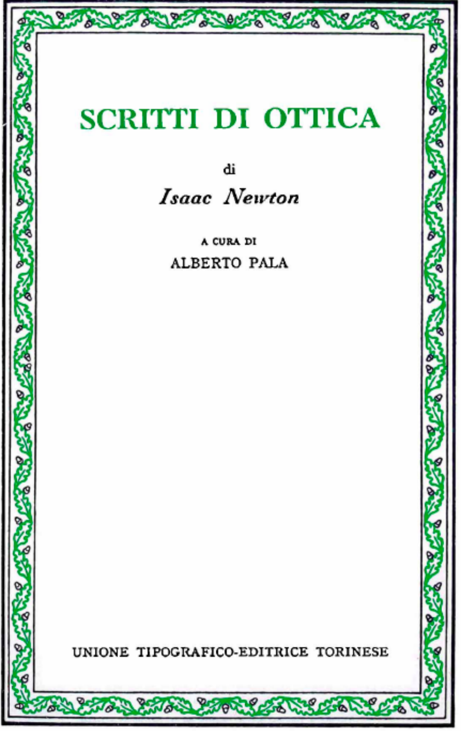
Se viene richiesto in parti di pollice non soltanto l'ordine e le specie di questi colori, ma anche il preciso spessore della lamina, o corpo sottile, in cui i colori sono presentati, ciò può essere ottenuto con l'aiuto delle osservazioni sesta e sedicesima. Infatti, secondo queste osservazioni, gli spessori dell'aria assottigliata, che tra due lenti presenta le parti massimamente luminose dei primi sei anelli, sono $^{1}/_{178000}$, $^{3}/_{178000}$, $^{5}/_{178000}$, $^{7}/_{178000}$, $^{9}/_{178000}$, $^{11}/_{178000}$ parti di un pollice.

$$t = \frac{r_m^{\,2}}{2R}$$



Su queste basi ho composto la seguente tabella, nella quale lo spessore dell'aria, dell'acqua e del vetro, in cui ciascun colore ha la massima intensità e specificità, è espressa in parti di pollice, diviso in un milione di parti uguali.

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Spessore delle lamine colorate e particelle di

		Aria	Acqua	Vetro
Colori del primo ordine	Molto nero	$^{1}/_{2}$	$^{3}/_{8}$	$^{10}/_{31}$
	Nero	1	$^{3}/_{4}$	$^{20}/_{31}$
	Inizio del nero	2	$1\,^{1}/_{2}$	$1\,^{2}/_{7}$
	Azzurro	$2\,^{2}/_{5}$	$1\,^{4}/_{5}$	$1\,^{11}/_{22}$
	Bianco	$5\,^{1}/_{4}$	$3\,^{7}/_{8}$	$3\,^{2}/_{5}$
	Giallo	$7\,^{1}/_{9}$	$5\,^{1}/_{3}$	$4\,^{3}/_{5}$
	Arancione	8	6	$5\,^{1}/_{6}$
	Rosso	9	$6\,^{3}/_{4}$	$5\,^{4}/_{5}$
Del secondo ordine	Violetto	$11\,^{1}/_{6}$	$8\,^{3}/_{8}$	$7\,^{1}/_{5}$
	Indaco	$12\,^{5}/_{6}$	$9\,^{5}/_{8}$	$8\,^{2}/_{11}$
	Azzurro	14	$10\,^{1}/_{2}$	9
	Verde	$15\,^{1}/_{8}$	$11\,^{2}/_{3}$	$9\,^{5}/_{7}$
	Giallo	$16\,^{2}/_{7}$	$12\,^{1}/_{5}$	$10\,^{2}/_{5}$
	Arancione	$17\,^{2}/_{9}$	13	$11\,^{1}/_{9}$
	Rosso acceso	$18\,^{1}/_{3}$	$13\,^{3}/_{4}$	$11\,^{5}/_{6}$
	Scarlatto	$19\,^{2}/_{3}$	$14\,^{3}/_{4}$	$12\,^{2}/_{3}$

$$2t = m\lambda$$

Thomas Young
Bakerian lecture
1803

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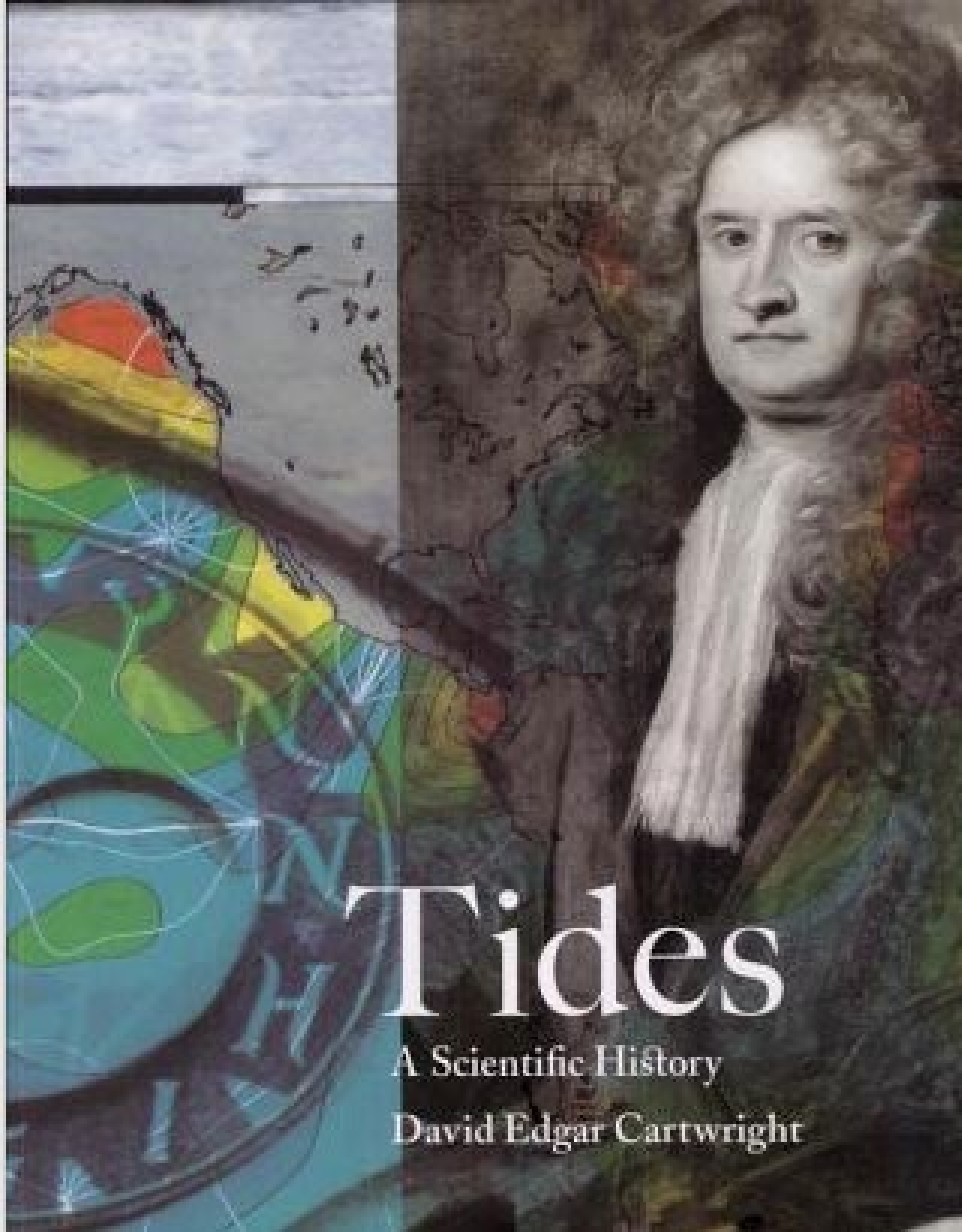
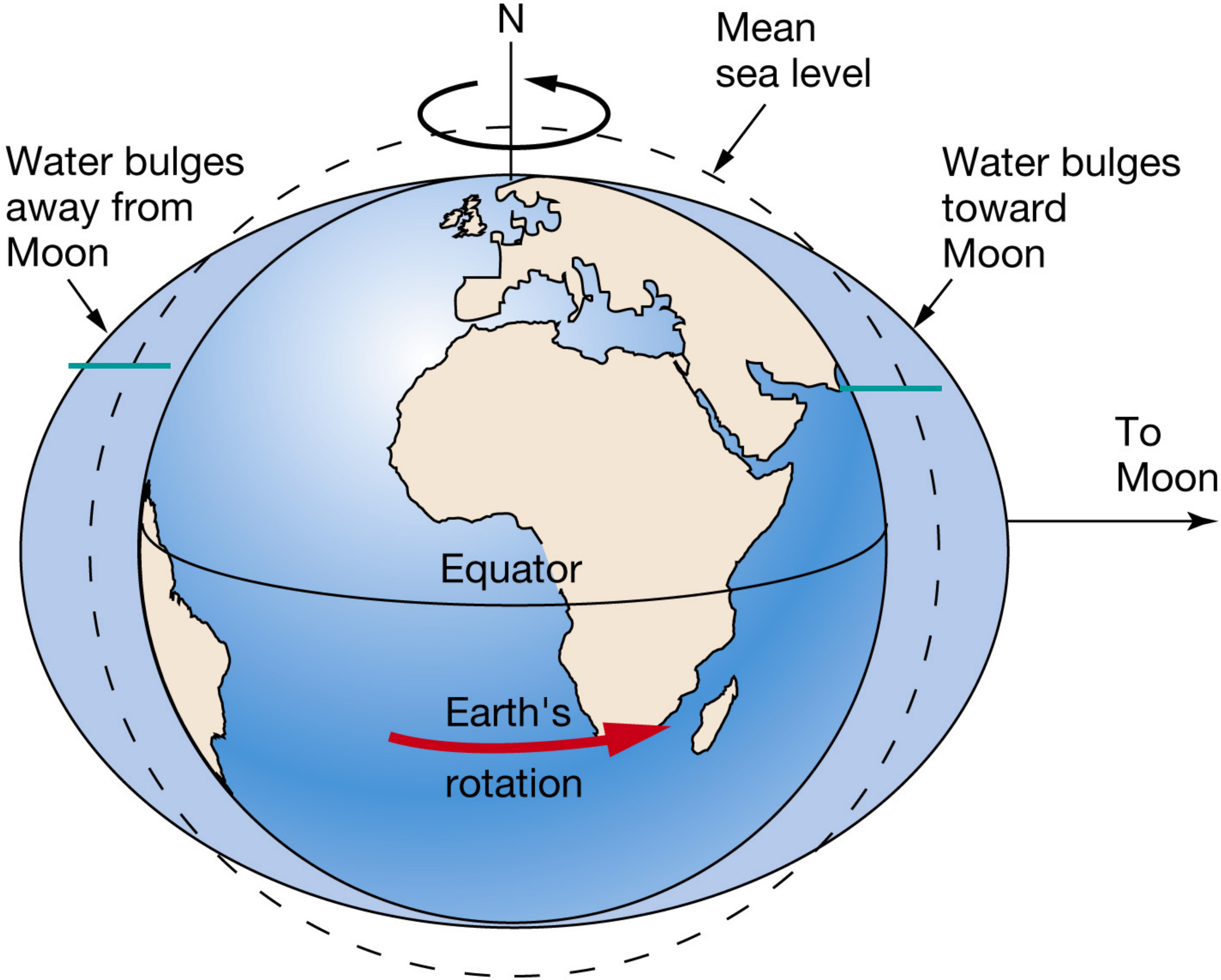

Tides
A Scientific History
David Edgar Cartwright

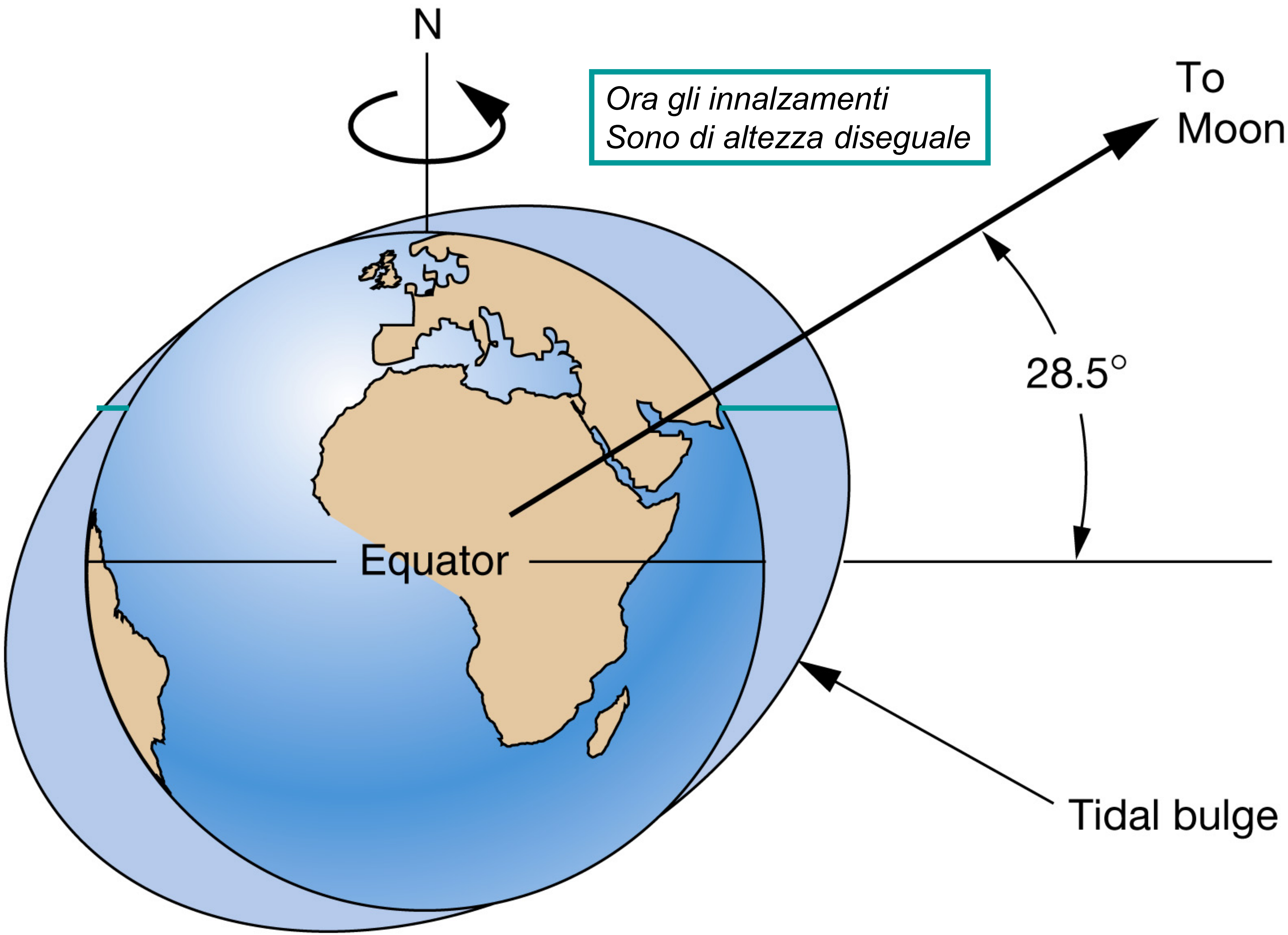
Disuguaglianza diurna

150 A.C.

[Posidonio] riferisce dunque che Seleuco, quello del mare Eritreo, parla di una diseguaglianza o eguaglianza in questi [fenomeni] secondo le variazioni dei segni dello zodiaco; dice infatti che quando la Luna si trova nei segni equinoziali le mutazioni [cioè le due maree giornaliere] sono eguali, in quelli solstiziali vi è una diseguaglianza, sia in quantità che in velocità, mentre in ciascuno degli altri segni [l'andamento] è in proporzione alla vicinanza [tra la Luna ed i segni suddetti].[43]

[43] Φησὶ δ'οὖν Σέλευκον τὸν ἀπὸ τῆς Ἐρυθρᾶ' θαλάττης καὶ ἀνωμαλίαν τινὰ ἐν τούτοις καὶ ὁμαλότητα λέγειν κατὰ τὰς τῶν ζῳδίων διαφοράς· ἐν μὲν γὰρ τοῖς ἰσημερινοῖς ζῳδίοις τῆς σελήνης οὔσης ὁμαλίζειν τὰ πάθη, ἐν δὲ τοῖς τροπικοὶς ἀνωμαλίαν εἶναι, καὶ πλήθει καὶ τάχει, τῶν δ'ἄλλων ἑκάστῳ κατὰ τοὺς συνεγγισμοὺς εἶναι τὴν ἀναλογίαν. αὐτὸς δὲ κατὰ τὰς θερινας τροπὰς περὶ τὴν πανσέληνόν φησιν ἐν τῷ Ἡρακλείῳ γενόμενος τῷ ἐν Γαδείροις πλείους ἡμέρας μὴ δύνασθαι συνεῖναι τὰς ἐνιαυσίους διαφοράς (Strabone, *Geographia*, III, v, 9).


N
Mean
sea level
Water bulges
away from
Moon
Water bulges
toward
Moon
To
Moon
Equator
Earth's
rotation


N
Ora gli innalzamenti
Sono di altezza diseguale
To
Moon
28.5°
Equator
Tidal bulge