

Triangles Before Logarithms:



Trigonometry in the Lost Century

Glen Van Brummelen, Quest University

BCCUPMS Meeting, May 17, 2016



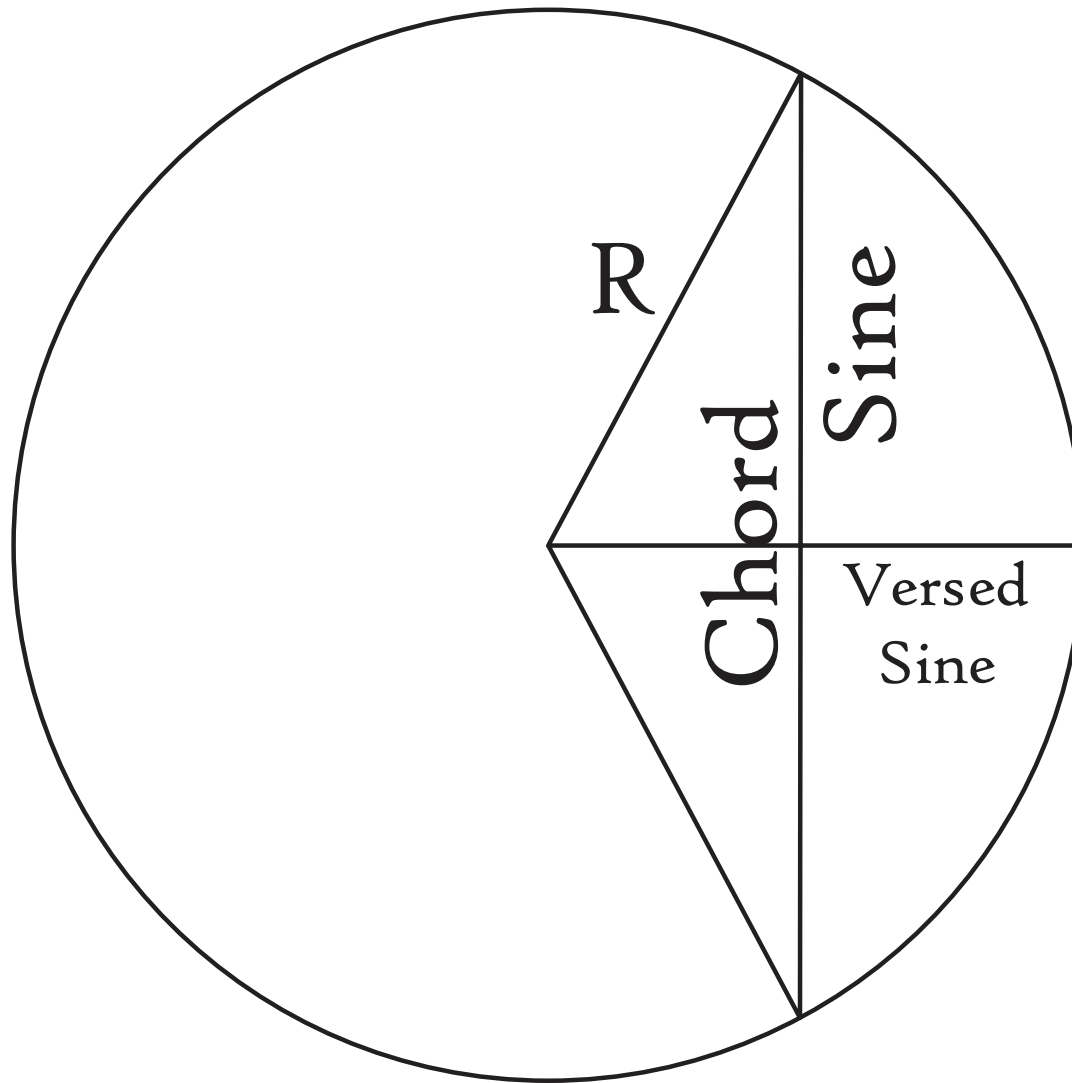
Plato, Aristotle, Euclid, Ptolemy and others

*From Raphael's
School of Athens (1510)*

Hipparchus of Rhodes (ca. 130 BC)

*From William Cunningham's
Cosmographical Glasse (1559)*





Trigonometric functions in ancient Greece,
medieval India, and medieval Europe



Europe, the Middle East, and India in 1500

Johānes vō Königsperg



Johannes Regiomontanus (1436-1476)

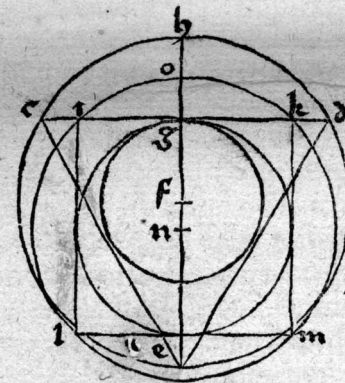
From Hartmann Schedel's
Nuremberg Chronicle (1493)

DOCTISSIMI VIRI ET MATHE-
maticarum disciplinarum eximij professoris
IOANNIS DE RE-

GIO MONTE DE TRIANGVLIS OMNI-
MODIS LIBRI QVINQVE:

Quibus explicantur res necessariae cognitu, uolentibus ad
scientiarum Astronomicarum perfectionem deueni-
re: quæ cum nusquā alibi hoc tempore expositæ
habeantur, frustra sine harum instructione
ad illam quisquam aspirarit.

Accesserunt huc in calce pleraq; D. Nicolai Cusani de Qua-
dratura circuli, Decq; recti ac curui commensuratione:
itemq; Io. de monte Regio eadem de re ελεγκτι-
κα, hæctenus à nemine publicata.



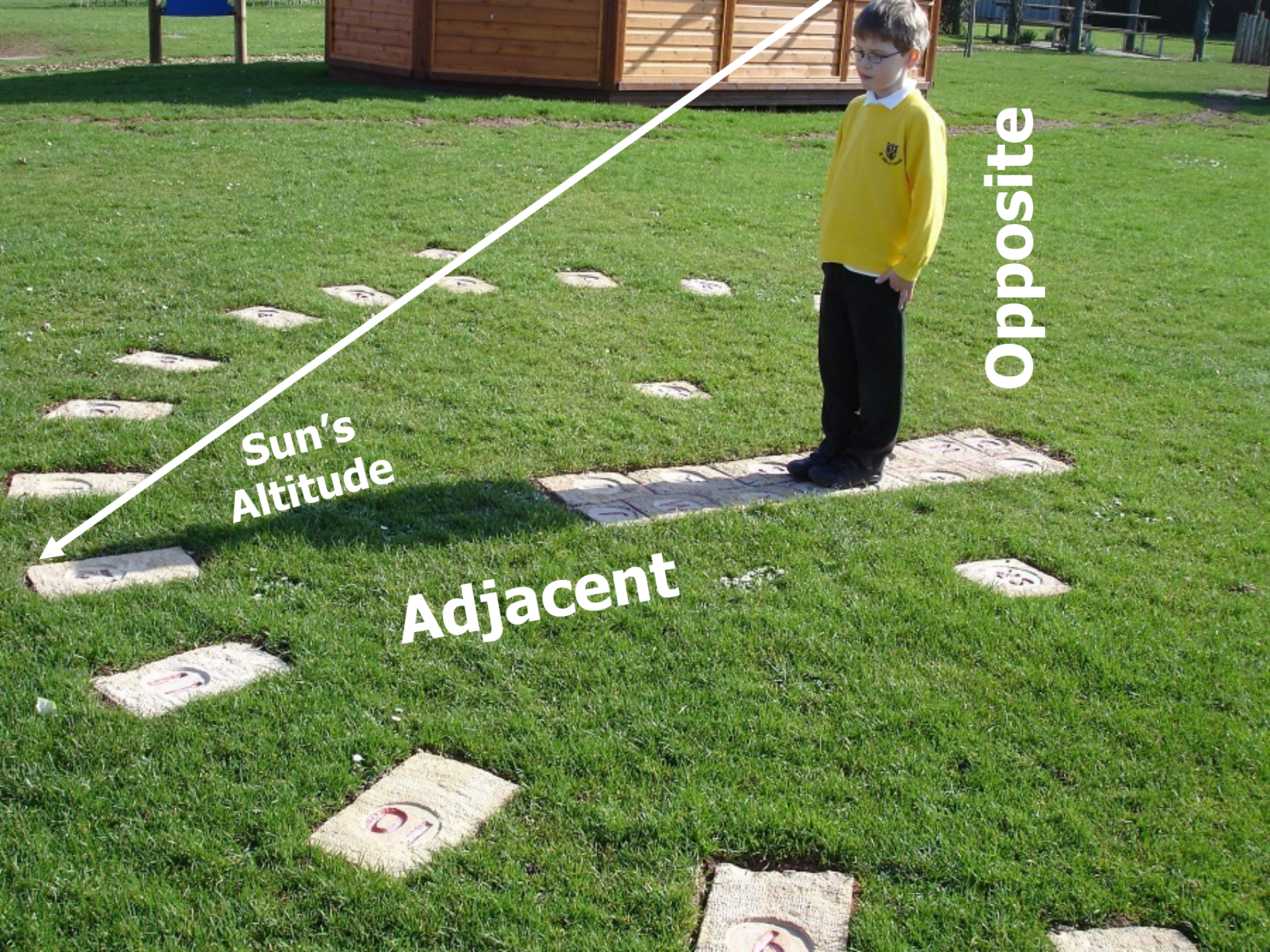
Omnia recens in lucem edita, fide & diligentia
singulari. Norimbergæ in ædibus Io. Petrei,

ANNO CHRISTI
M. D. XXXIII.

“In every spherical triangle that has been constructed from the arcs of great circles, the ratio of the versed sine of any angle to the difference of two versed sines, of which one is the versed sine of the side subtending this angle, while the other is the versed sine of the difference of the two arcs including this angle, is as the ratio of the square of the whole right sine to the rectangular product of the sines of the arcs placed around the mentioned angle.”

$$\cos c = \cos a \cos b + \sin a \sin b \cos C$$
$$\frac{\text{vers } C}{\text{vers } c - \text{vers}(a - b)} = \frac{1}{\sin a \sin b}$$

Spherical Law of Cosines
Regiomontanus, *De triangulis omnimodis* V.2



Sun's
Altitude

Adjacent

Opposite

Tabula Secunda

Numerus		Numerus		Numerus	
B		B		B	
0	00000	31	60086	61	180402
1	11745	32	62486	62	188075
2	13492	33	64940	63	196263
3	15240	34	67452	64	205034
4	16992	35	70022	65	214450
5	18748	36	72654	66	224607
6	10511	37	75356	67	235583
7	12278	38	78129	68	247513
8	14053	39	80978	69	260511
9	15838	40	83909	70	274753
10	17633	41	86929	71	290422
11	19439	42	93040	72	307767
12	21256	43	90254	73	327088
13	23087	44	96571	74	348748
14	24932	45	100000	75	373211
15	26794	46	103551	76	401089
16	28674	47	107236	77	433148
17	30573	48	111062	78	470453
18	32492	49	115037	79	514438
19	34433	50	119197	80	567118
20	36396	51	123491	81	631377
21	38387	52	127994	82	711569
22	40402	53	132704	83	814456
23	42446	54	137639	84	951387
24	44522	55	142813	85	1143131
25	46631	56	148253	86	1430203
26	48772	57	153987	87	1908217
27	50952	58	160035	88	2863563
28	53170	59	166429	89	5729796
29	55432	60	173207	90	Infinitum
30	57734				

*Tabula fecunda,
In Regiomontanus's
Tabula directionum (1490)*

The first appearance of
the tangent in the West



Europe, the Middle East, and India in 1500



Georg Reticus
(1514-1574)

AD CLARISSIMUM VIRVM
D. IOANNEM SCHONE-
RVM, DE LIBRIS REVOLVTIO-
nis eruditissimi viri, & Mathema-
tici excellentissimi, Reuerendæ
D. Doctoris Nicolai Cos-
pernici Torunnæ, Cas-
nonici Varmien-
sis, per quendam
Iuuenem, Ma-
thematicæ
studio
sum
NARRATIO
PRIMA.

ALCINOVS.

Ἡ δὲ βιβλίον ἔστι τῆς γνώμης τῶν πολλῶν φιλοσόφων

Narratio Prima
(1540)

CANON DOCTRINAE TRIANGVLORVM

NVNC PRIMVM A GEOR-
GIO IOACHIMO RHETICO, IN LVCEM
EDITVS, CVM PRIVILEGIO IMPERIALI,
Ne quis hæc intra decennium, quacunq[ue] forma
ac compositione, edere, neue sibi uendicare
aut operibus suis inserere auit.



LIPSIÆ
EX OFFICINA VVOLPHGAN-
GI GVNTERI.

ANNO
M. D. LI.

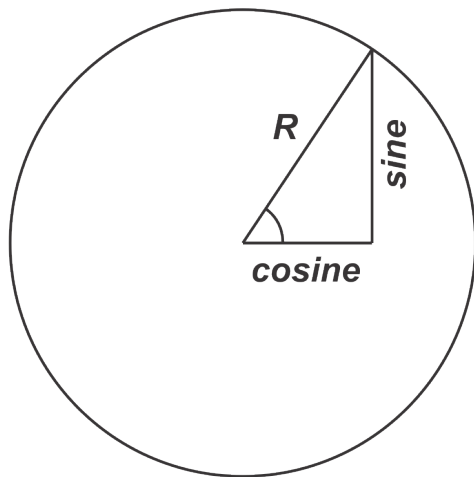
Georg Rheticus,
Canon doctrinae triangulorum
(1551)

CANON DOCTRINAE TRIANGVLORVM IN QVO TRIQVETRI Subtendens angulum rectum

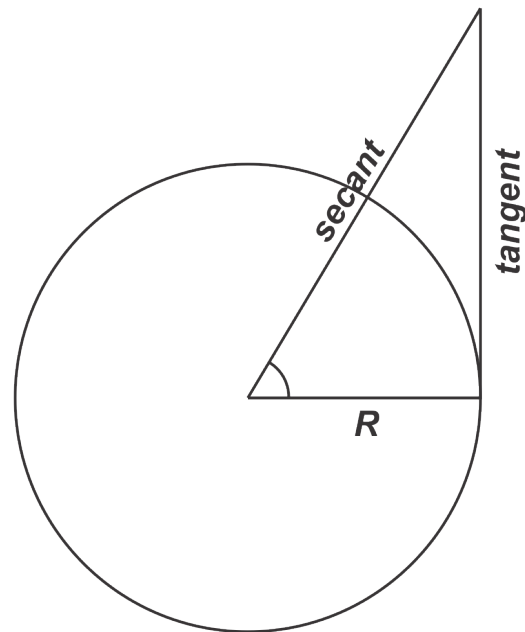
Perpendicu:		Different:	Basis	Differen:	Maius latus includens	Hypotenusa	Differ:
0	0		29088	10000000	43		43
10	29088	29088	9999957	127	10000043	127	
20	58177	29088	9999810	211	10000170	211	
30	87265	29088	9999619	296	10000381	296	
40	116353	29086	9999323	381	10000677	381	
50	145439	29086	9998942	465	10001058	465	
1	0	174525	29083	9998477	550	10001523	550
10	203608	29081	9997927	635	10002074	635	
20	232689	29080	9997292	719	10002709	719	
30	261769	29078	9996573	803	10003428	804	
40	290847	29075	9995770	889	10004232	890	
50	319922	29071	9994881	973	10005122	974	
2	0	348995	29069	9993908	1058	10006096	1059
10	378064	29067	9992850	1143	10007155	1143	
20	407131	29063	9991710	1218	10008298	1229	
30	436194	29059	9990483				

CVM ANGVLVS RECTVS IN PLANITIE PARTIVM 100000000 PONITVR nū angulū rectū:

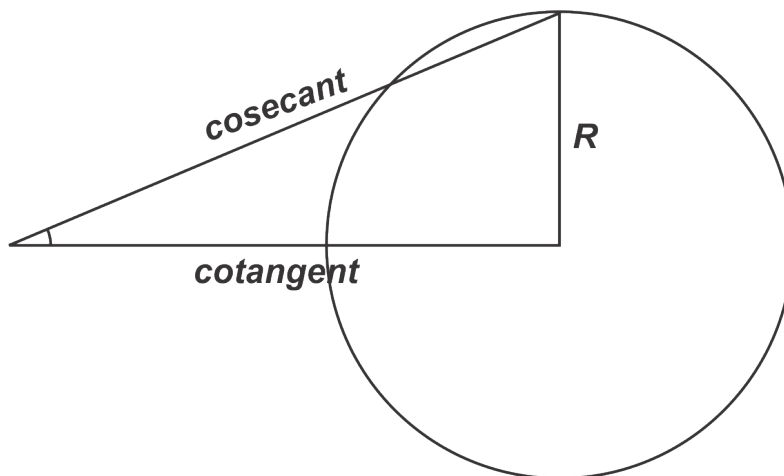
Perpendicu: Dña.		Hypotenusa		Basis		Differencia		
.....		Infinitum	Infinitum	Infinitum	Infinitum	Infinitum	Infinitum	90
29088	29090	3437843784	1618951439	3437829002	3718965894	50		
58178	29090	1718892345	572957549	1718863108	572971972	40		
87268	29092	1145934796	286481237	1145891136	286495762	30		
116361	29093	859453559	171880075	859395374	171894635	20		
145454	29097	687573484	114589671	687500739	114600909	10		
174551	29099	572983813	81843976	572899830	81861806	089		
203650	29102	491139837	61381662	491038024	61396228	50		
232752	29106	429758175	47741970	429641796	47756508	40		
261858	29112	382016205	38192821	381885288	38207341	30		
290970	29115	343823384	31247194	343677947	31261764	20		
320085	29122	312576190	26039134	312416183	26053687	10		
349207	29127	286537056	22031576	286362496	22046137	088		
378314	29134	264505480	18984292	264316359	18998815	50		
407468	29141	245621188	16365399	245417544	16379960	40		



First Species



Second Species



Third Species

OPVS
PALATINVM
DE
TRIANGVLIS

A
GEORGIO IOACHIMO
RHETICO COEPTVM;
L. VALENTINVS OTHO
PRINCIPIS PALATINI
FRIDERICI
IV. ELECTORIS
MATHEMATICVS
CONSVMMAVIT.
Reosladii.
AN. SAL. HVM.
CIC. ID. XCVL

PLIN. LIB. XXXVI. CAP. IX.
RERV. NATVRÆ INTERPRETA-
TIONEM AEGYPTIORVM OPERA PHI-
LOSOPHIA CONTINENT.

CVM PRIVILEGIO
CAES. MATES.

Georg Rheticus,
Valentin Otho

Opus palatinum
(1596)



CANON DOCTRINAE TRIANGVLOR: IN QVO TRIQVETRI CVM
SVBTENDENS ANGLVLM RECTVM MAIVS INCLVDENT.

38	Perpendicular		Basis	Differenc.		Hypotenula	Differenc.	
20	620234913	380188	7844156649	300889	12748343062	483730		
10	620234913	380171	7843831792	300708	12748831792	483797		
0	620234913	380159	784351215	300716	12749320189	483864		
10	620234913	380145	7843194470	300745	12749809455	483931		
0	620234913	380131	7842875797	300765	12750298387	483998		
10	620234913	380116	7842557295	300785	12750787387	484065		
0	620234913	380100	7842238815	300800	12751276454	484134		
10	620234913	380085	7841920315	300818	12751765588	484203		
0	620234913	380071	7841601815	300837	12752254790	484272		
10	620234913	380056	7841283315	300855	12752743960	484341		
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10	620234913	380027	7840646315	300892	12753722802	484479		
0	620234913	380013	7840327815	300911	12754212275	484548		
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10	620234913	380000	7838098315	301039	12757640072	485031		
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10	620234913	380000	7834913315	301224	12762537497	485721		
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0	620234913	380000	7822491815	301946	12781637455	488412		
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10	620234913	380000	7805611315	302926	12807593820	492068		
0	620234913	380000	7805292					

Computing Sine Tables Before 1600

$30^\circ, 36^\circ, 45^\circ, 60^\circ$ easy

$$\sin(a \pm b) = \sin a \cos b \pm \cos a \sin b$$

$$\cos(a \pm b) = \cos a \cos b \mp \sin a \sin b$$

$$\sin \frac{a}{2} = \sqrt{\frac{1 - \cos a}{2}}$$

Solving the $\sin 1^\circ$ problem:

$$\sin 3^\circ = 3 \sin 1^\circ - 4 \sin^3 1^\circ$$

Gerolamo
Cardano

Ars magna
(1545)



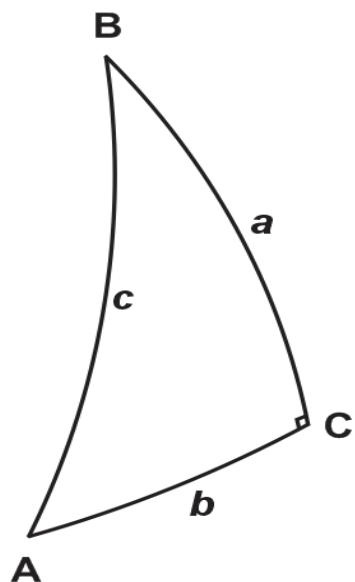


Francois Viète
(1540-1603)

Canon Mathematicus, Trianguli Plani Rectanguli

Circum- commo- PART.		Hypotenusa 100,000 Perpendicularum Basis E CANONE SI- num	Basis 100,000 Perpendicularum Hypotenusa E CANONE FACVENDO Facundilimòque	Perpendicularum 100,000 Basis Hypotenusa E CANONE FACVENDO Facundilimòque	10 ad- daci Basis Basis Basis
I	100,000 0000	I	100,000 0000	I	10,000,000,000 10,000,000,000
II	29 99,999 9958	II	29 99,999 9958	II	343,774,668 343,774,682
III	68 99,999 9831	III	68 99,999 9831	III	171,887,319 171,887,348
III	87 99,999 9631	III	87 99,999 9631	III	114,591,530 114,591,574
V	116 99,999 932	V	116 99,999 932	V	85,943,631 85,943,689
VI	145 99,999 894	VI	145 99,999 894	VI	68,754,887 68,754,960
VII	175 99,999 848	VII	175 99,999 848	VII	57,295,721 57,295,809
VIII	204 99,999 793	VIII	204 99,999 793	VIII	49,110,599 49,110,701
IX	233 99,999 729	IX	233 99,999 729	IX	42,971,757 42,971,873
X	262 99,999 657	X	262 99,999 657	X	38,197,099 38,197,230
XI	291 99,999 577	XI	291 99,999 577	XI	34,377,371 34,377,516
XII	320 99,999 488	XII	320 99,999 488	XII	31,262,117 31,262,279

Canon mathematicus
seu Ad triangula
(1579)



$$\sin b = \tan a \cot A \quad \sin a = \sin A \sin c$$

$$\cos c = \cot A \cot B \quad \cos A = \sin B \cos a$$

$$\sin a = \cot B \tan b \quad \cos B = \cos b \sin A$$

$$\cos A = \tan b \cot c \quad \sin b = \sin c \sin B$$

$$\cos B = \cot c \tan a \quad \cos c = \cos a \cos b$$

XIX.

CANONICÆ DECEM IN SPHÆRICO TRIANGVLO
RECTANGVLO, IAMDIV EXPETITÆ, NECDV M ANTEHAC

EXHIBITÆ, ANALOGIÆ, SEXIES ETIAM PRO

NVmero TERMINORVM REPETITÆ,

QV ARVM ductu, si ex terminis SPHÆRICI TRIANGVLI RECTANGVLI duo quilibet, prater ANGVLVM RECTVM, dentur, vltro quasitus terminus, vel ex vnâ operatione Logistices, siue Multiplicationis, siue Diuisionis, vtra commodior videbitur, viâ, innotescit. *

DECADIS I ^{AE}									
PENTAS. PRIMA				PENTAS. SECUNDA					
Totus	Sinus	Sinus	Sinus	Totus	Fæcundus	Fæcundus	Sinus		
I	C	AB	A	CB	VI	C	AC	B	CB
II	C	AB	B	AC	VII	C	CB	A	AC
III	C	AC	A	B	VIII	C	AB	CB	B
IIII	C	CB	B	A	IX	C	AB	AC	A
V	C	AC	CB	AB	X	C	B	A	AB

SVB DECADIS I ^{AE}									
PENTAS. PRIMA				PENTAS. SECUNDA					
Totus	Hypot. ^a	Hypot. ^a	Hypot. ^a	Totus	Fæcundus	Fæcundus	Hypot. ^a		
I	C	AB	A	CB	VI	C	AC	B	CB
II	C	AB	B	AC	VII	C	CB	A	AC
III	C	AC	A	B	VIII	C	AB	CB	B
IIII	C	CB	B	A	IX	C	AB	AC	A
V	C	AC	CB	AB	X	C	B	A	AB

Viète on Computing Sine Tables

$$\sin 3\theta = 3 \sin \theta - 4 \sin^3 \theta$$

$$\sin 5\theta = ?$$

$$\sin 7\theta = ?$$

$$\sin 9\theta = ?$$

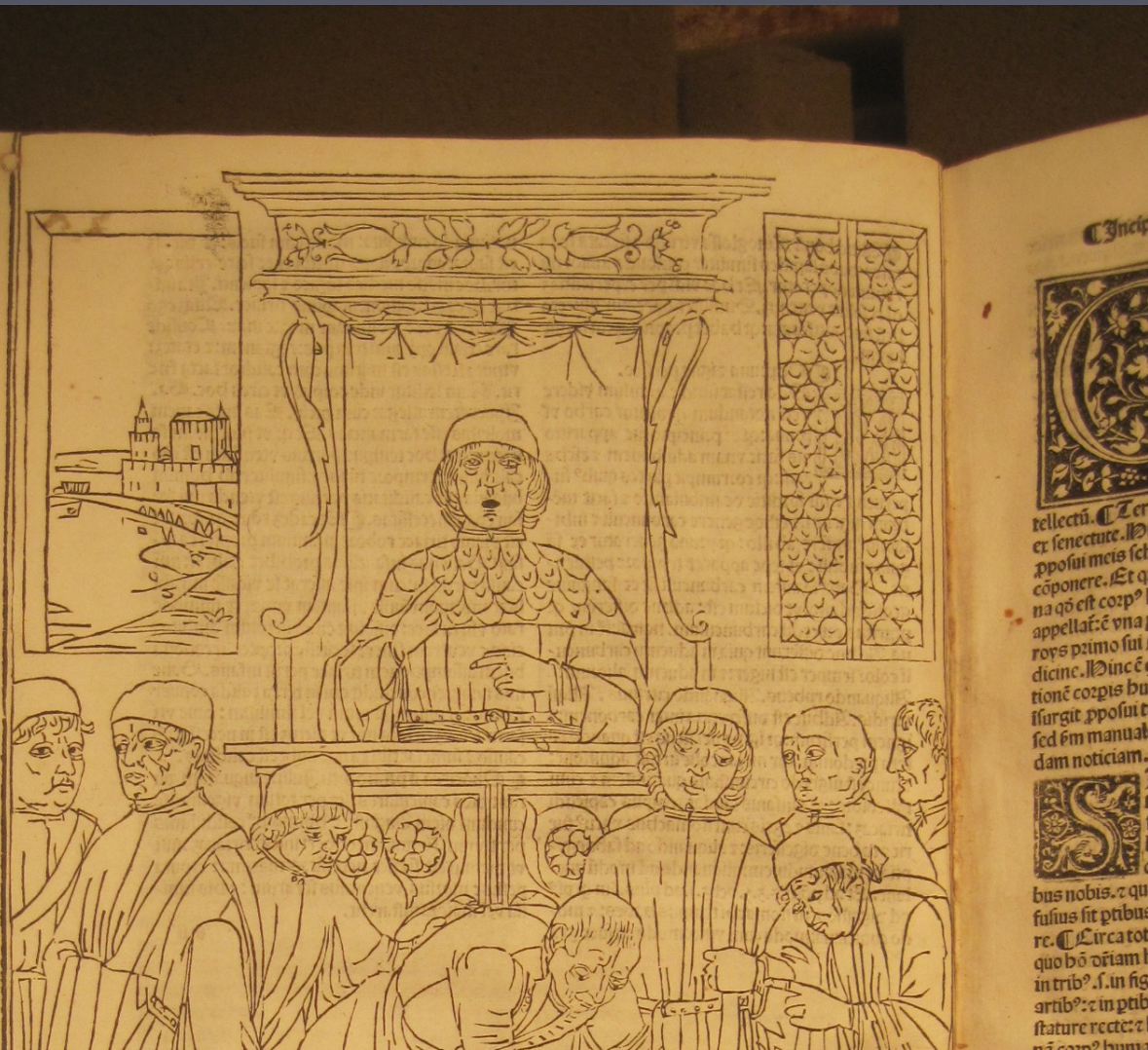
⋮

*Ad angularium
sectionum
analyticen*

(1595)

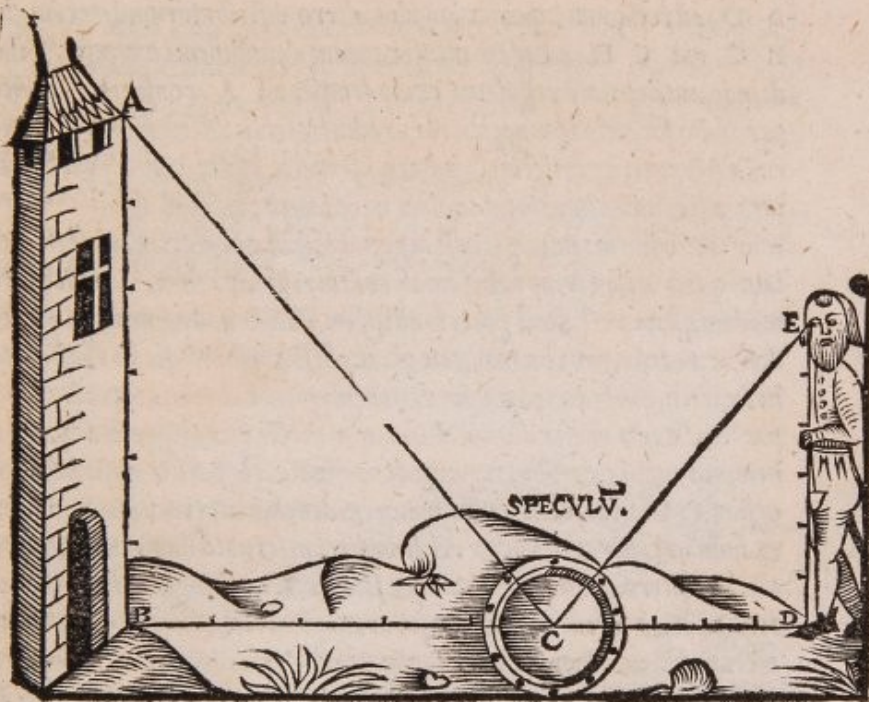
NUMERI MULTIPLICIVM Adfectionis.

Prima negata.											
2	Secunda affirmata										
3											
4	2	Tertia negata.									
5	5										
6	9	2	Quarta affirmata								
7	14	7									
8	20	16	2	Quinta negata.							
9	27	30	9								
10	35	50	25	2	Sexta affirmata						
11	44	77	55	14							
12	54	112	105	36	2	Septima negata.					
13	65	156	182	91	13						
14	77	210	294	196	49	2	Octava affirmata				
15	90	275	450	318	140	15					
16	104	352	660	672	336	64	2	Nona negata.			
17	119	442	935	1122	714	204	17				
18	135	546	1287	1782	1386	540	81	2			
19	152	665	1729	2717	2508	1254	187	19			
20	170	800	2175	4604	4390	1640	815	100			
21	189	952	2940	5733	7007	2148	1079	385			



*Fasciculus
medicine in quo
continentur:
videlicet*

*J. Ketham
(1495)*



DE PRAEDICTARVM, SED
inaccessibilium linearum altitudine mensuranda, per ipsum geometricum quadratum.

CAPVT XI.

SVNT PLAE RV M Q V E R E RV M altitudines, ad quarũ bases minimè conceditur peruenire: idq; uel circumstantibus aquis, uel effossa terra, aut eiusmodi prohibentibus impedimentis. Cum tamen earundem rerum altitudines, è proximo terrestri plano, per quadratum uolueris agnoscere geometricum: in hunc facito modum.

Operandi
Selecto commodiori loco, erige quadrantẽ super latus A B, uel regula, A D ad

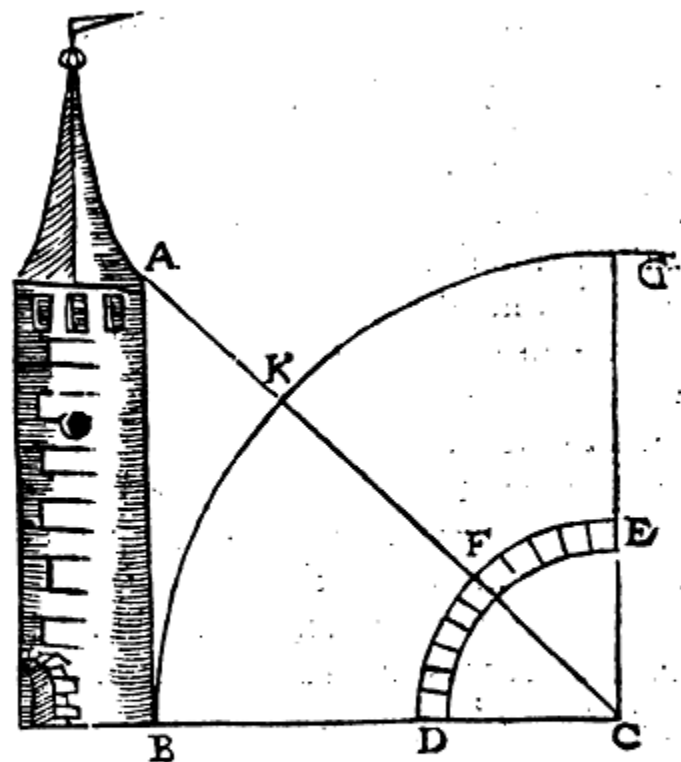
Geometria practica

Oronce Fine
(1494 - 1555)



“[So Gunter] came and brought with him his sector and quadrant, and fell to resolving of triangles and doing a great many fine things. Said the grave knight, ‘Do you call this reading of geometry? This is showing of tricks, man!’ and so dismissed him with scorn, and sent for Briggs from Cambridge.”

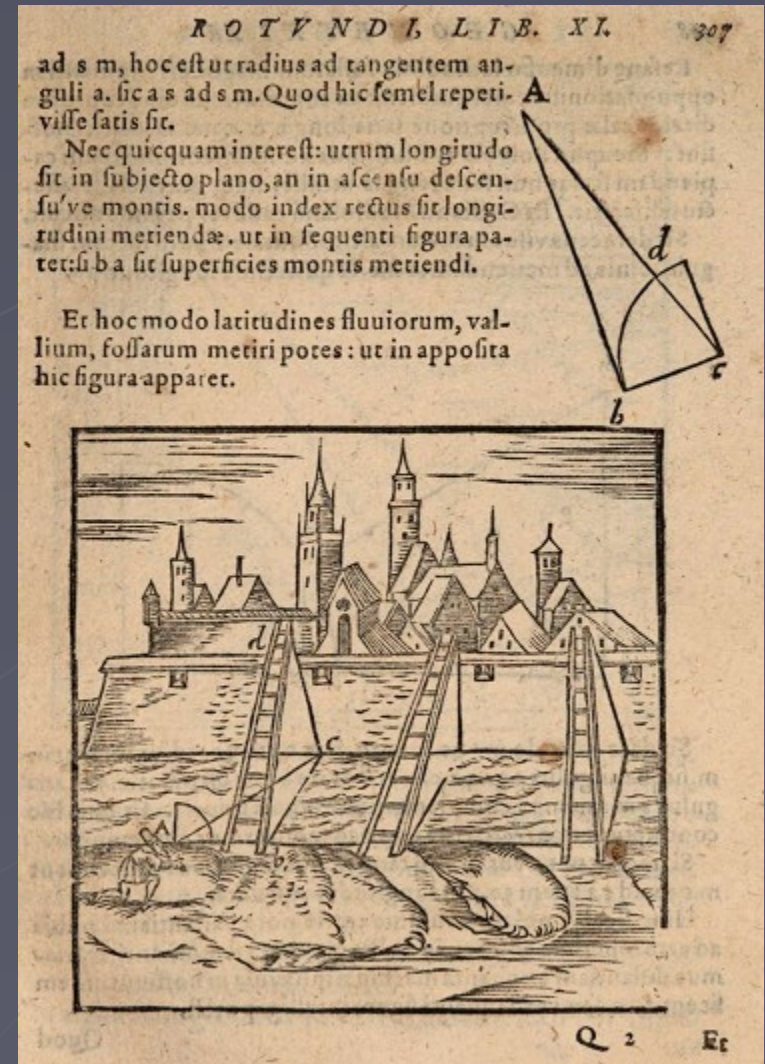
Non ingratum fore lectori sperauimus, si ὁδὸς γεωδαιτικῆς, geodæticam περιθνήσκῃ ex fontibus doctrinæ planorum triquetrorum deriuatam, hic inferemus. Etenim ex secunda propositione huius, corporum altitudines, profunditates & longitudines venari licet. Est enim exploranda altitudo turris AB. Quadrantem circuli DFE in 90 partes diuido, & rursus earum quaque in scrupula 60. Centroque ipsius c volubilem dioptram affigo. Eius ita concinnati latus c normale datæ altitudini AB in puncto B statuo. Productum igitur donec concurrat cum AB, faciet angulum ABC rectum. Deinde posito ad c oculo, voluo dioptram circa cētrum c, donec per opposita foramina fastigiū propositæ altitudinis conspiciam, radio cFA secante quadrantem DFE in F. & quadrantem BKG centro eodem & interuallo CB descriptum, in puncto K. Quoniam igitur datus est arcus DF, dabitur & ei similis BK, eiusque adscripta AB, earum partium, quarum radi⁹ CB est 1 sex. I. Quarum ergo partium CB, distantia à mensore ad propositam altitudinem datur, earundem & altitudo quoque AB dabitur:



Sit DF, hoc est arcus BK 60.30 m. interuallum BC 50 passuum adscripta AB erit 1 sex. I. 46 g.3 m. qualium CB 1 sex. I. ergo qualium CB interuallum 50 est passuum, exempli gratia talium altitudo AB erit 1 sex. I. 28 g.23 m. 30 z. passuum. Quod inueniendum fuit.



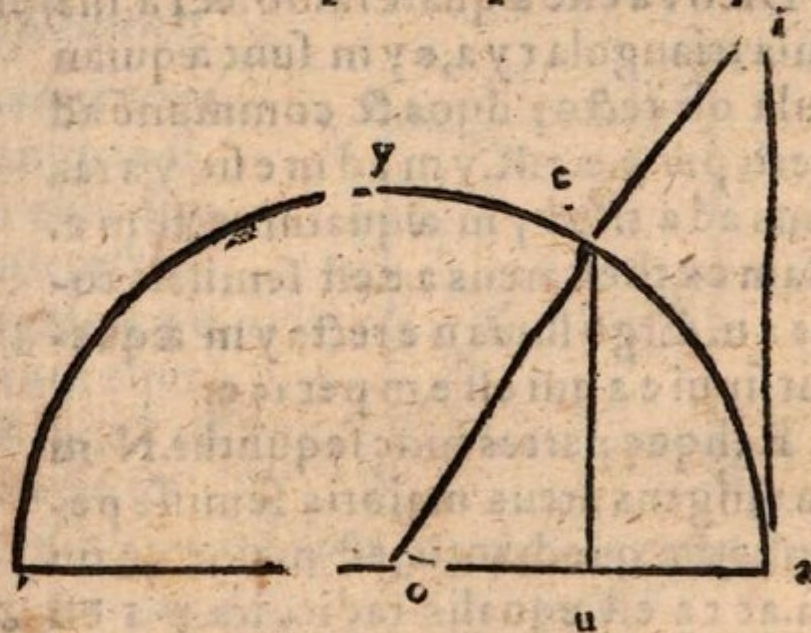
Thomas Fincke
(1561-1656)



Geometria rotundi
(1583)

22. *Tangens est à termino peripheria altero perpendicularis in radium extra per reliquum terminum continuatum.*

Esto peripheria a c. sitq; ab ejus termino a perpendicularis a i terminata in radio o e continuato in i. per reliquum datae peripheriae terminum. erit a i tangens datae peripheriae. Sic vocare placuit quia sit perpendicularis extremæ diametro. hoc dato per 1. e. 2 erit tangens: itaq; Geometria ipsa commodum suppeditavit nomen: nec aliunde adferri comodius poterit. Nam quod quidam numerum fœcundum rectam a i vocant. id ii videant quomodo defendant: mihi non probabunt. Damus aliquid peritissimo illi artifice Regiomontano homini Germano: qui primus



First appearance of the word “tangent” (*Geometria rotundi*, 1583)

Canon Triangulorum
Siue
**TABVLAE SIN-
VVM TANGENTIVM
ET SECANTIVM**

Ad partes radij 100000. & ad scrupula prima
Quadrantis.

R. D. TABVLÆ

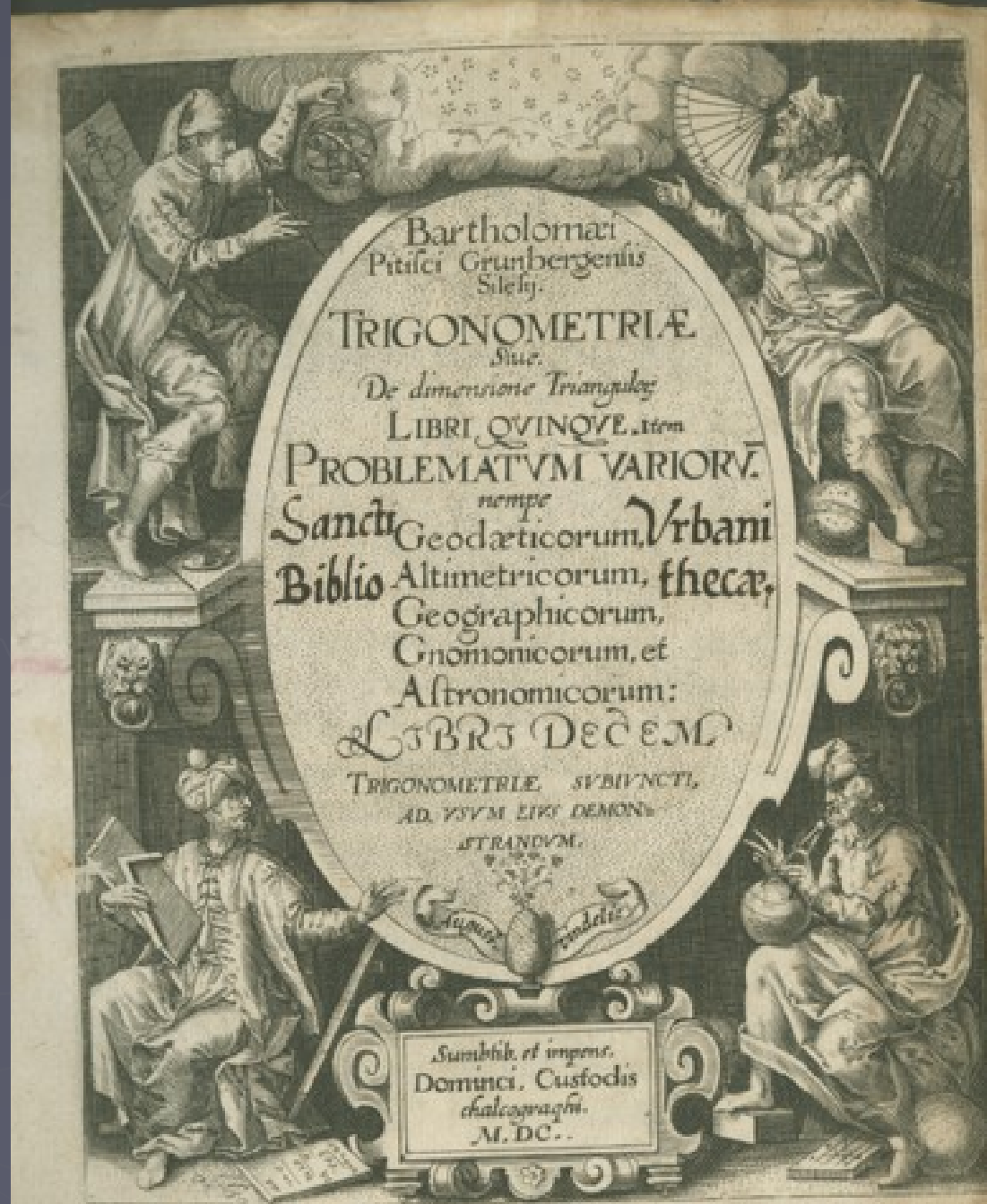
Bartholomew Pitiscus
Trigonometria
(1600)

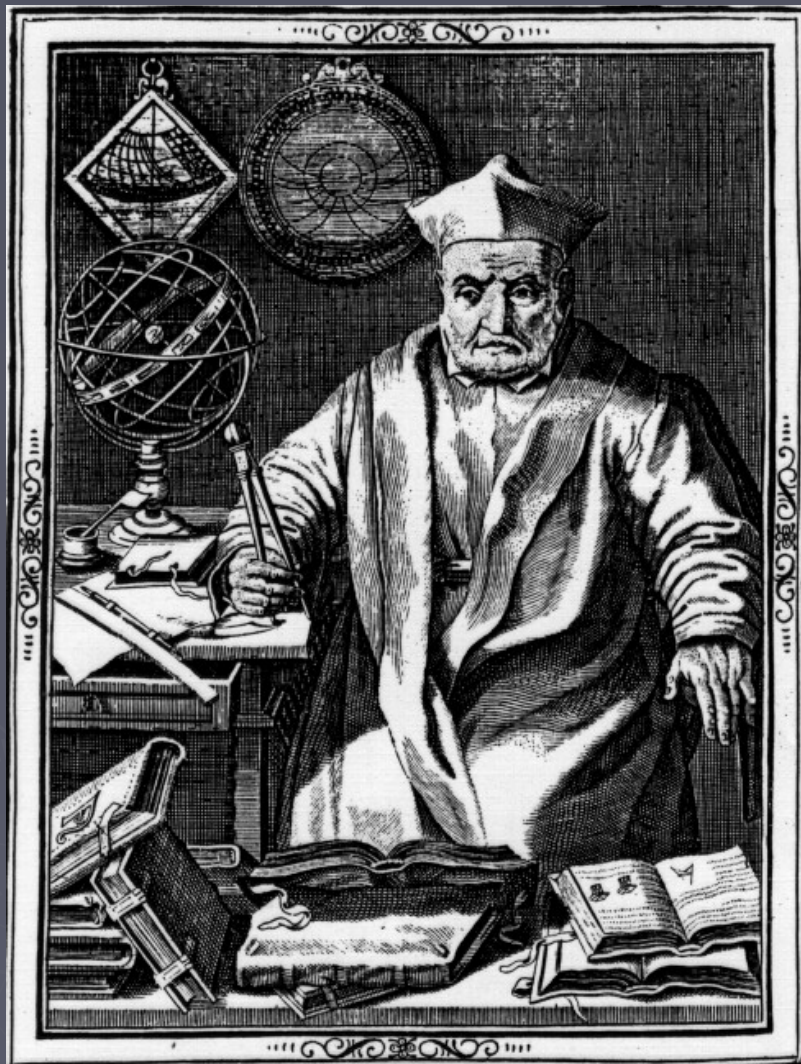
		TABVLÆ							
		Sinuum		Tangentium		Secantium			
1	29	100000	29	343760708	100000	343760723	59		
2	58	99999	58	171880337	100000	171880366	58		
3	87	99999	87	114586868	100000	114586912	57		
4	116	99999	116	85940125	100000	85940184	56		
5	145	99999	145	68756800	100000	68756873	55		
6	175	99999	175	57296338	100000	57296426	54		
7	204	99999	204	49112455	100000	49112556	53		
8	233	99999	233	42971819	100000	42971935	52		
9	262	99999	262	38196963	100000	38197094	51		
10	291	99999	291	34378299	100000	34378435	50		
11	320	99999	320	31252767	100000	31252827	49		
12	349	99999	349	28648192	100000	28648317	48		
13	378	99999	378	26444340	100000	26444509	47		
14	407	99999	407	24555338	100000	24555542	46		
15	436	99999	436	22918739	100000	22918957	45		
16	465	99999	465	21486199	100000	21486430	44		
17	494	99999	494	20222198	100000	20222345	43		
18	524	99999	524	19098650	100000	19098911	42		
19	553	99999	553	18093374	100000	18093650	41		
20	582	99999	582	17188631	100000	17188922	40		
21	611	99999	611	16370057	100000	16370362	39		
22	640	99998	640	15625900	100000	15626220	38		
23	669	99998	669	14946455	100000	14946789	37		
24	698	99998	698	14323630	100000	14323797	36		
25	727	99997	727	13750822	100000	13751185	35		
26	756	99997	756	13221887	100000	13222265	34		
27	785	99997	785	12732134	100000	12732537	33		
28	814	99997	814	12277365	100000	12277772	32		
29	844	99996	844	11853959	100000	11854381	31		
30	873	99996	873	11458911	100000	11459348	30		



Bartholomew Pitiscus
(maybe), (1561-1613)

Trigonometriae (1600)





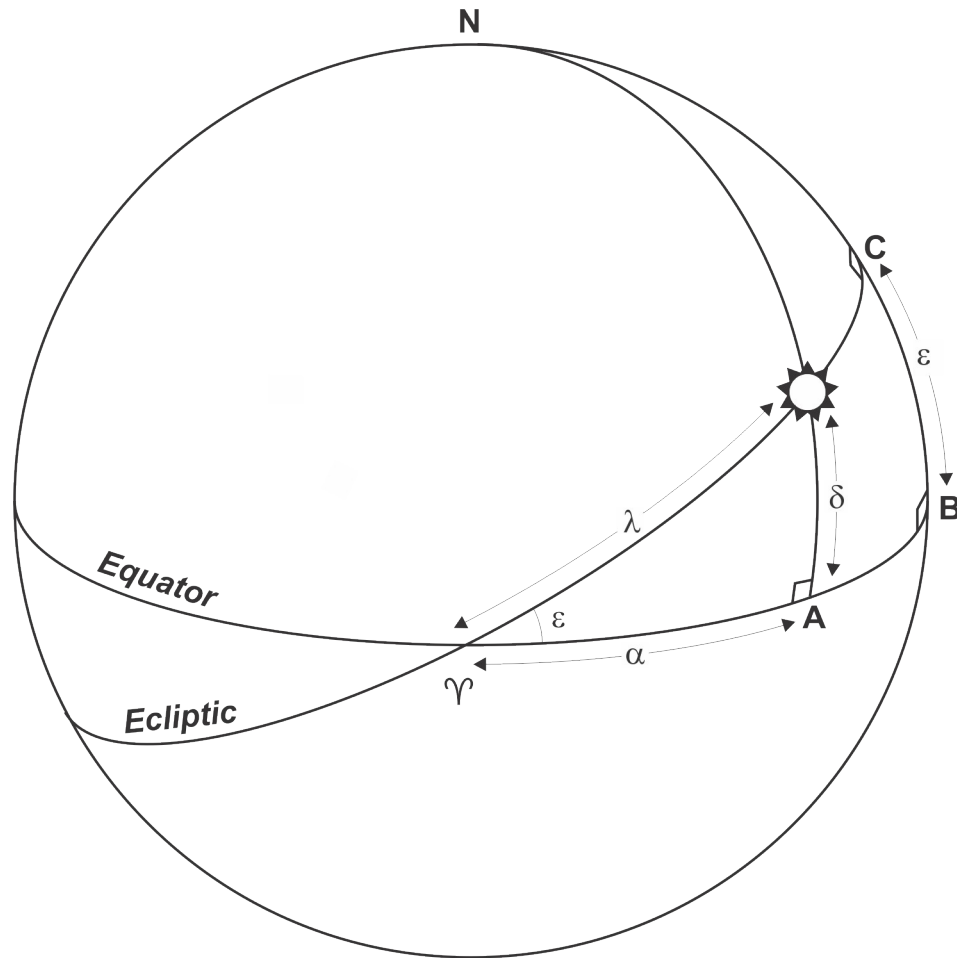
Christoph Clavius
(1538-1612)

Geometria practica (1604)

CHRISTOPHORI
CLAVII BAMBERGENSIS
E SOCIETATE IESV,
GEOMETRIA
PRACTICA.



ROMAE,
Ex Typographia Aloisij Zannetti. MDCIII.
Superiorum Permissu.



$$\frac{1}{\sin \lambda} = \frac{\sin \epsilon}{\sin \delta}$$

Tycho Brahe's Group and the “Prosthaphairesis” Formulas



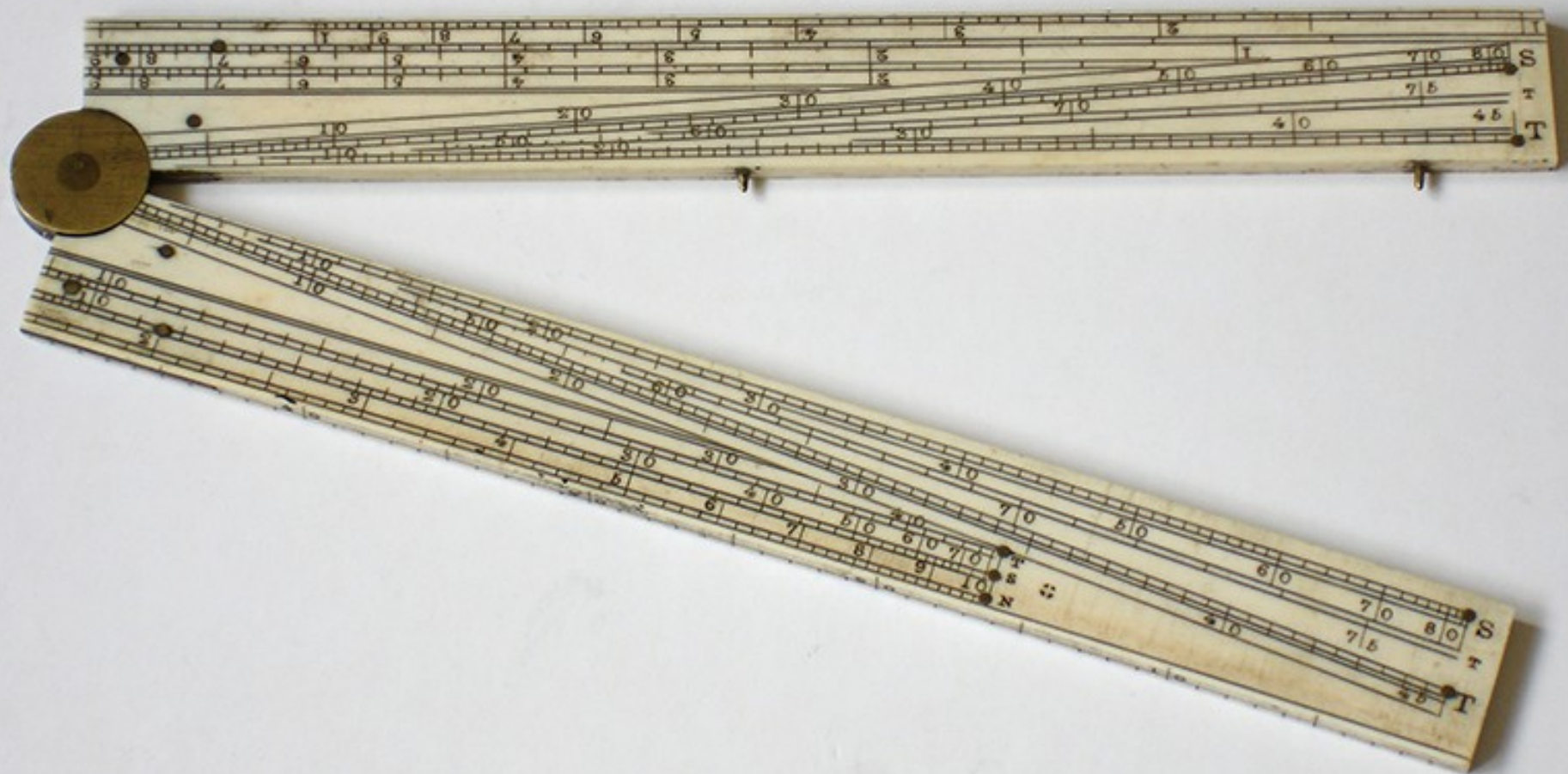
Tycho Brahe
(1546-1601)

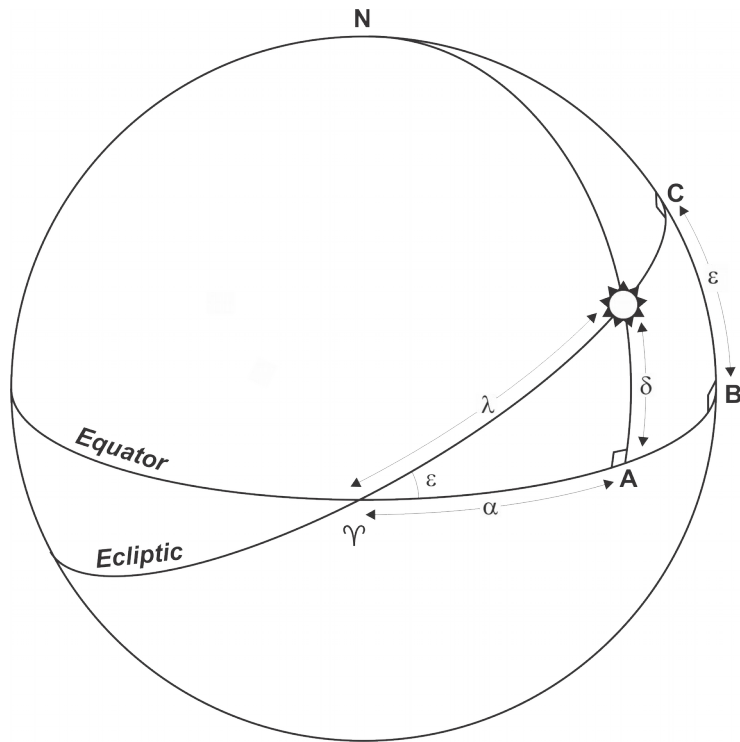
$$\sin a \sin b = \frac{\cos(a - b) - \cos(a + b)}{2}$$



*The Description and Use
of the Sector, the Cross-
Staff and Other
Instruments*

Edmund Gunter (1620)

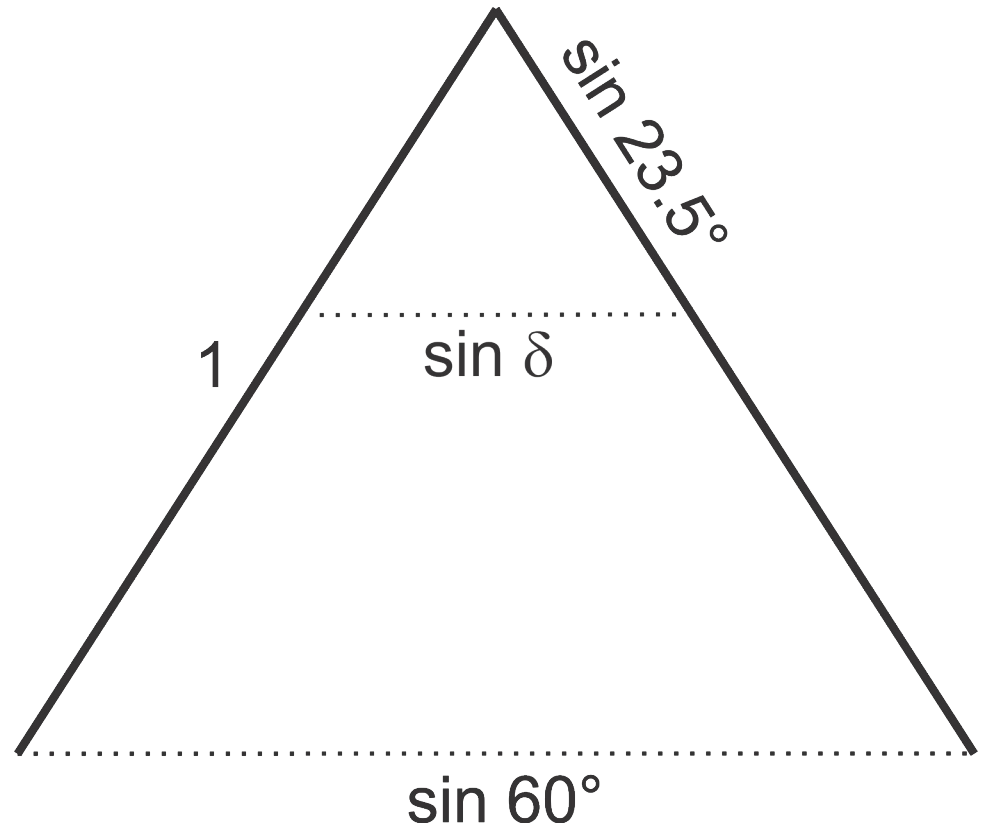




$$\frac{1}{\sin \lambda} = \frac{\sin \epsilon}{\sin \delta}$$

$$\epsilon = 23.5^\circ$$

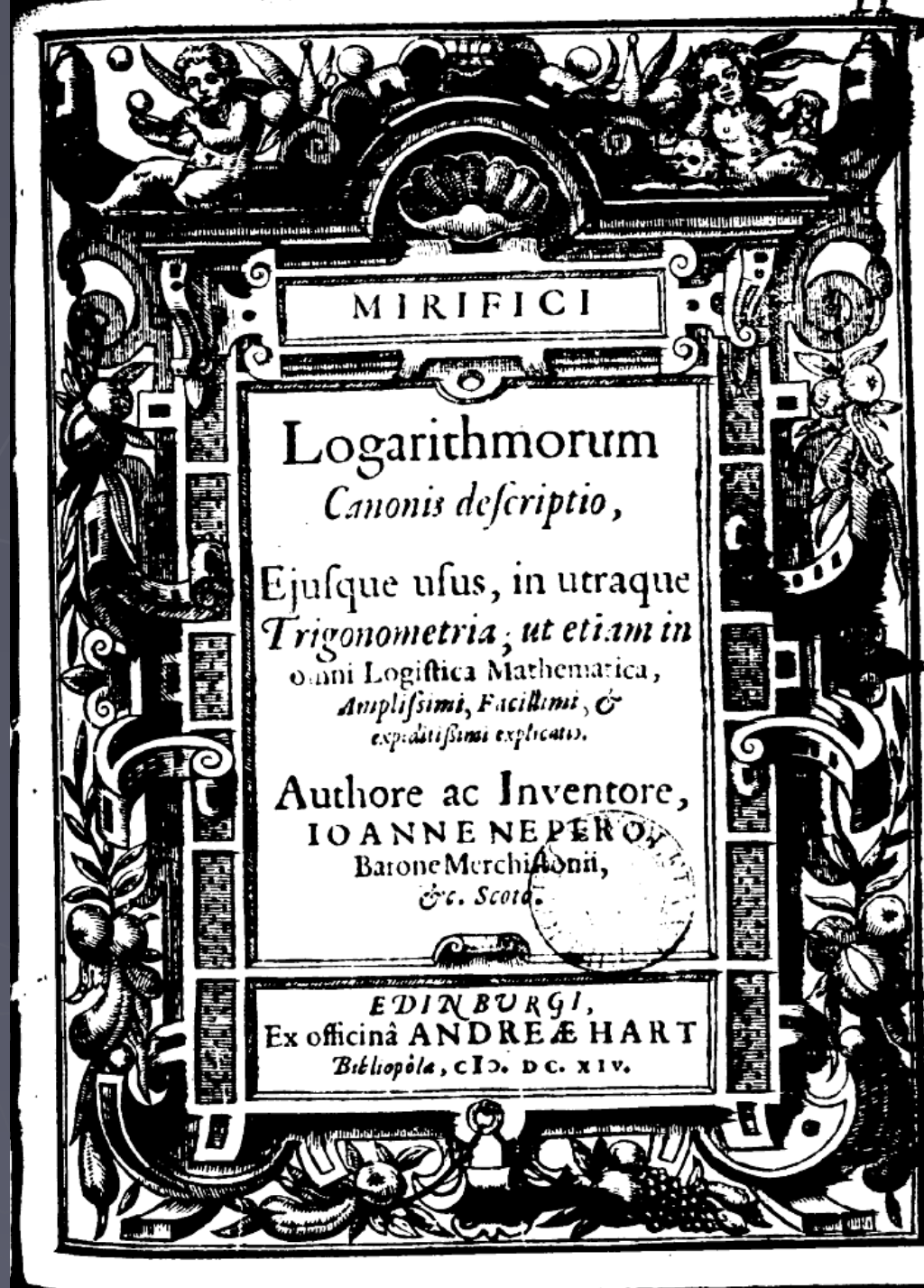
$$\lambda = 60^\circ$$

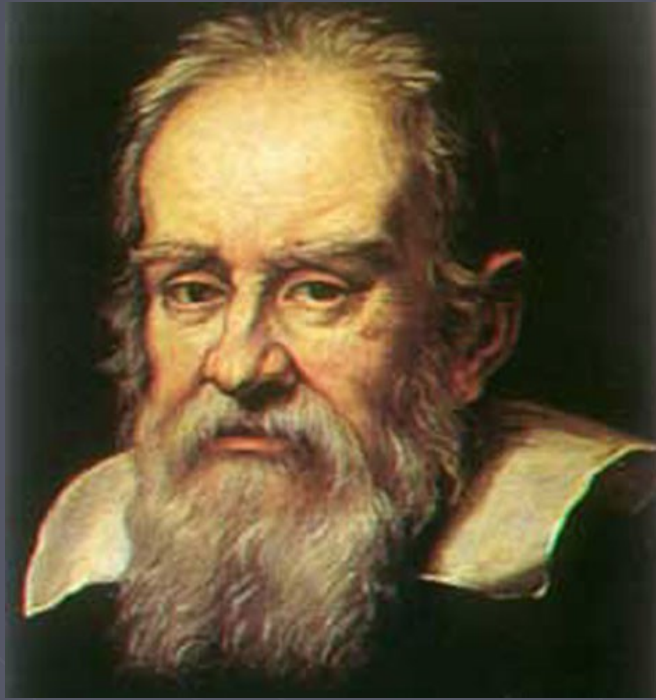




John Napier
(1550-1617)

*Mirifici logarithmorum
canonis descriptio*
(1614)





Galileo Galilei
(1564-1642)

*"Mathematic[s] is the language in
which God has written the
universe."*

The Assayer (1623)

*Diclides
coelometricae
(1602)*

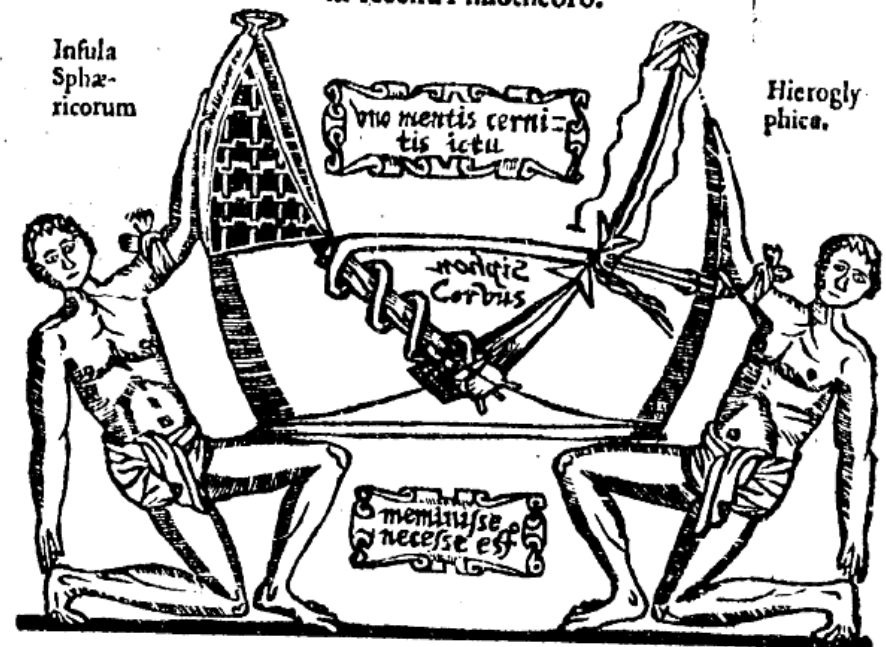
Nathaniel
Torporley

7.3.
DICLIDES COELOMETRICÆ
feu
VALVÆ ASTRONOMICÆ
VNIVERSALES

*Omnia artis totius munera Psephophoretica in sat modicis
finibus duarum Tabularum Methodo noua, generali,
& facilima continentes.*

*Praeunte Directionis accurata consumata Doctrina, Astrologis
hactenus plurimum desiderata.*

Authore NATHAL^E TORPORLÆO Salopiensi
in secessu Philotheoro.



*Fragilis & laboriosa mortalitas in partes ista digessit, ut portionibus quisque
coleret, quo maxime indigeret; PLIN.
Sed quæ carptim singula constant
Eadem nos hic missa iugamus. BOET.*

LONDINI
Excudebat FELIX KINGSTON. 1602.



HONORATIS- SIMO DOMINO

Dn. Iohanni Egerton, Comiti

de Bridgewater, Vicecomiti de
Brackley, Baroni de Ellesmere

Hunc suum Canonem
Triangulorum

D D

EDM. GUNTER.



Descriptio Canonis.

Canon noster sex habet columnas, duabus lineis a se invicem distinctas. Quartū prima est arcuū ab 0, in 45 Gra. sexta arcuum a 45 Gra. in quadrantem, reliquæ quatuor intermediae continent *Sinus* & *Tangentes* horum arcuum. Sunt autem *Sinus* nostri non semisses subtensarum, et *Tangentes* non perpendiculares ab extremitate diametri: sed numeri proprii eorū loco substituti, quos propterea cum primo inventore DOMINO MARC HARTONIJ artificiales dicimus. Arq; ita secunda colūna et quarta continent *Sinus* & *Tangentes* arcuū primæ colūnae, tertia colūna & quinta *Sinus* & *Tangentes* arcuū sextæ colūnae.

Vt si queratur sinus artificialis nostræ latitudinis quæ Londini est Gra. 51 M 32. Invenies *sinū* 51. in ima parte paginæ, & minuta 32. in sexta colūna, cōmunis angulus dat 9893. 7452, pro *sinu* quæsito, cui in eadem linea respondet sinus cōplementi 9793. 8317, quem brevitatis causa *cosinū* dicimus. Similiter *tangens* Gra. 51. M. 32. est 10099. 9134, & *cotangens* 9900. 0865. *Secantes* quoties vsus postulat suppleri auferendo *cosinum* ē duplo radij.

Vt cum duplum radij sit	20000	0000
Hinc aufer <i>cosinū</i> Gra. 51. M. 32.	9793	8317
Fiet secans Gra. 51. M. 32.	10206	1682