Tycho Brahe

–

High Quality Science Operations in the Epoch of The Armada

Michael Rosa

TYCHONIS
BRAHE DANI,
ASTRONOMIÆ INSTAV-
RATÆ PROGYMNASMATA.
Quorum hæc
PRIMA PARS
DE RESTITVTIONE MOTVVM
Solis & Lunæ, Stellarúmque inerrantium
tractat.
ET PRÆTEREA DE ADMIRANDA
nóua Stella Anno 1572. exorta luculenter agit.
ANNO M. D C X.
Excudi primum cœpta Vraniburgi Daniæ,
ast Pragæ Bohemiæ absoluta.
PROSTANT
Francofurti apud Godefridum Tampachium.
Cum Cæsareâ & Regum quorundam priuilegiis.

TYCHONIS BRAHE

ASTRONOMIAE INSTAURATAE
PROGYMNASMATA

Quorum haec
PRIMA PARS.
DE RESTITUTIONE MOTUUM
SOLIS ET LUNAE
STELLARUMQUE INERRANTIUM
TRACTAT.
ET
Praeterea de admiranda
NOVA STELLA
Anno 1572. *exorta luculenter agit.*

TYPIS INCHOAT A
URANIBURGI DANIAE.
ABSOLUTA
PRAGAE BOHEMIAE.
M. DC. II.

By TYCHO BRAHE

INTRODUCTORY EXERCISES INTO
THE RENOVATED ASTRONOMY

Of which treats the
FIRST PART
ABOUT THE RESTITUTION OF
THE MOTIONS
OF SUN AND MOON
AND THE FIXED STARS,
AND
In addition dealing about the admirable
NEW STAR
Splendidly emerged in the year 1572.

LAYOUT BEGUN AT
URANIBURG, DENMARK.
Finished at
PRAGUE BOHEMIA.
1602

Progress report on Translation Project

- 1 Mar 2011 - Done 340 pages - 1st raw Latin → English
- currently In hands of Ray Wilson (father of the VLT optics) for review of English
- Publ. at Springer expected in April 2012

Epoch of “The Armada”

Epoch of massive political change yet to come

- Spain, Portugal, Denmark – dominating the seas → will go to Britannia
- Spain, also strong on the Continent, is going to loose there as well (NL)
- Central Europe (the Holy Roman Empire) is going to go under …

- …. But not yet. Tycho Brahe has lived the calm years 1546 – 1601.

Some Timing Events

1500 Bosch paints “Garden of Earthly Delights”

1504 Leonardo (**Mona Lisa**), Michelangelo (**David**)

1517 **Luther** nails his 95 Theses

1522 **Magellan** Circumnavigation “Earth is a globe”

1529 1st Siege of Vienna by Turks

1533 **Pizzaro** conquers Inca empire

1541 Santiago de Chile founded

1556 Holy Roman Emperor Charles V abdicates and lives rest of life as monk

1558 **Elizabeth I** Queen of England

1583 Newfoundland claimed as English colony

1584 Oct 15, **Gregorian Calendar** reform

1588 Defeat of the Spanish Armada

1600 **Giordano Bruno** burned on stakes in Rome

1602 **Shakespeare’s “Hamlet, Prince of Denmark”**

1618 Thirty Years War

B 397 – 345 Eudoxos (Knidos)

B 310 – 230 **Aristarchos** (Samos)

B 190 – 120 Hipparchos (Rhodos)

100 – 175 Ptolemaeus (Alexandria)

1029 – 1087 Az-Zarqali (Toledo)

1394 – 1449 Ulugh Beg (Samarkand)

1436 – 1476 Regiomontanus (Vienna/Rome)

1473 – 1543 **Copernicus**

1546 – 1601 Tycho Brahe

1564 – 1642 **Galileo Galilei**

1571 – 1630 **Johannes Kepler**

1642 – 1726 **Isaac Newton**

1543 Copernicus De Revolutionibus

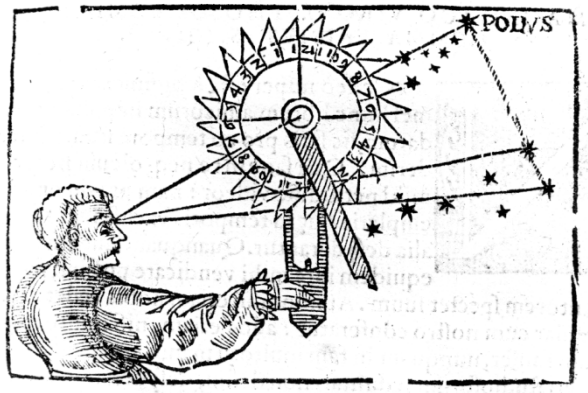
1569 Mercator’s Projection

1572 Tycho Brahe’s Supernova

1573 Galileo’s Thermometer

1601 23 Oct - Tycho from Denmark dead

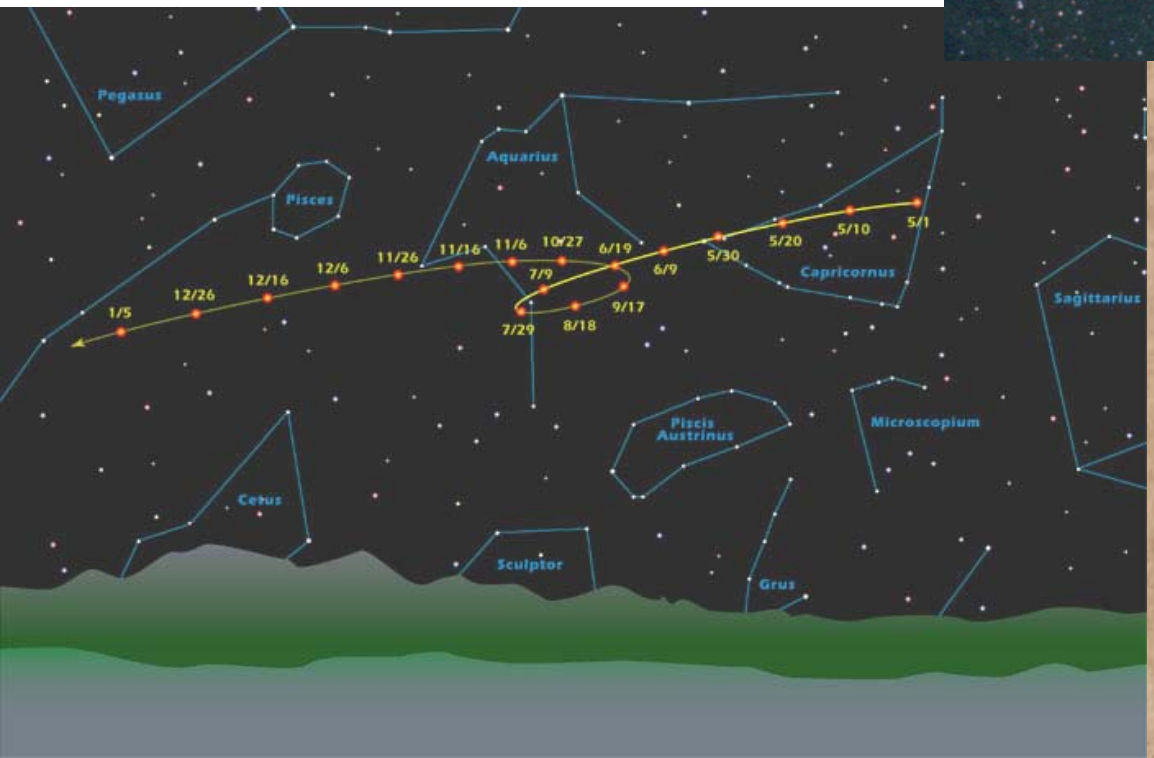
State of Astronomy - by 1563



- 2 main hypotheses "How it might work"
  - **Geocentric** – Ptolemaeus (~ 160)
    - variants with added "improvements"
    - Main update of input parameters – under King Alphonso X of Castillia (1252 to 1270, in Toledo)
  - **Heliocentric** – Aristarchos (BC 200), Copernicus (1543)
    - Can in principle deliver only about same quality of predictions as the geocentric
  - 2 crucial errors in both –
    - No elliptic orbits; No intrinsically varying velocities in orbit

- Very minimalistic set of observational data
  - Ptolemaeus' Almagest – "Made up data" to demonstrate method of calculation
  - Copernicus – 1 man work, only the absolute necessary amount of observations done (1 data point …)
  - Observing was only done sporadically (check all well)

Mars


Pegasus
Aquarius
Pisces
Capricornus
Sagittarius
Piscis Austrinus
Microscopium
Cetus
Sculptor
Grus
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12/16
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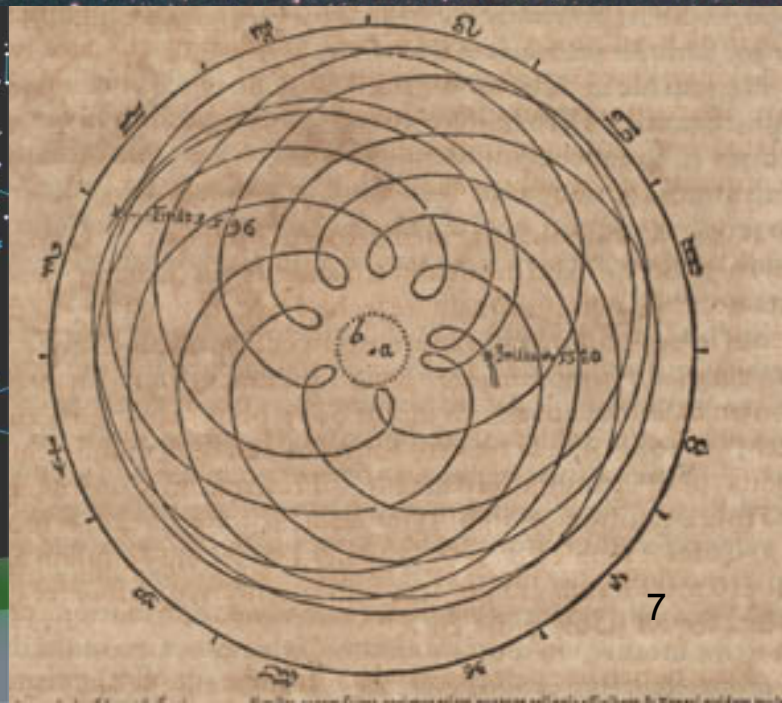
5/1



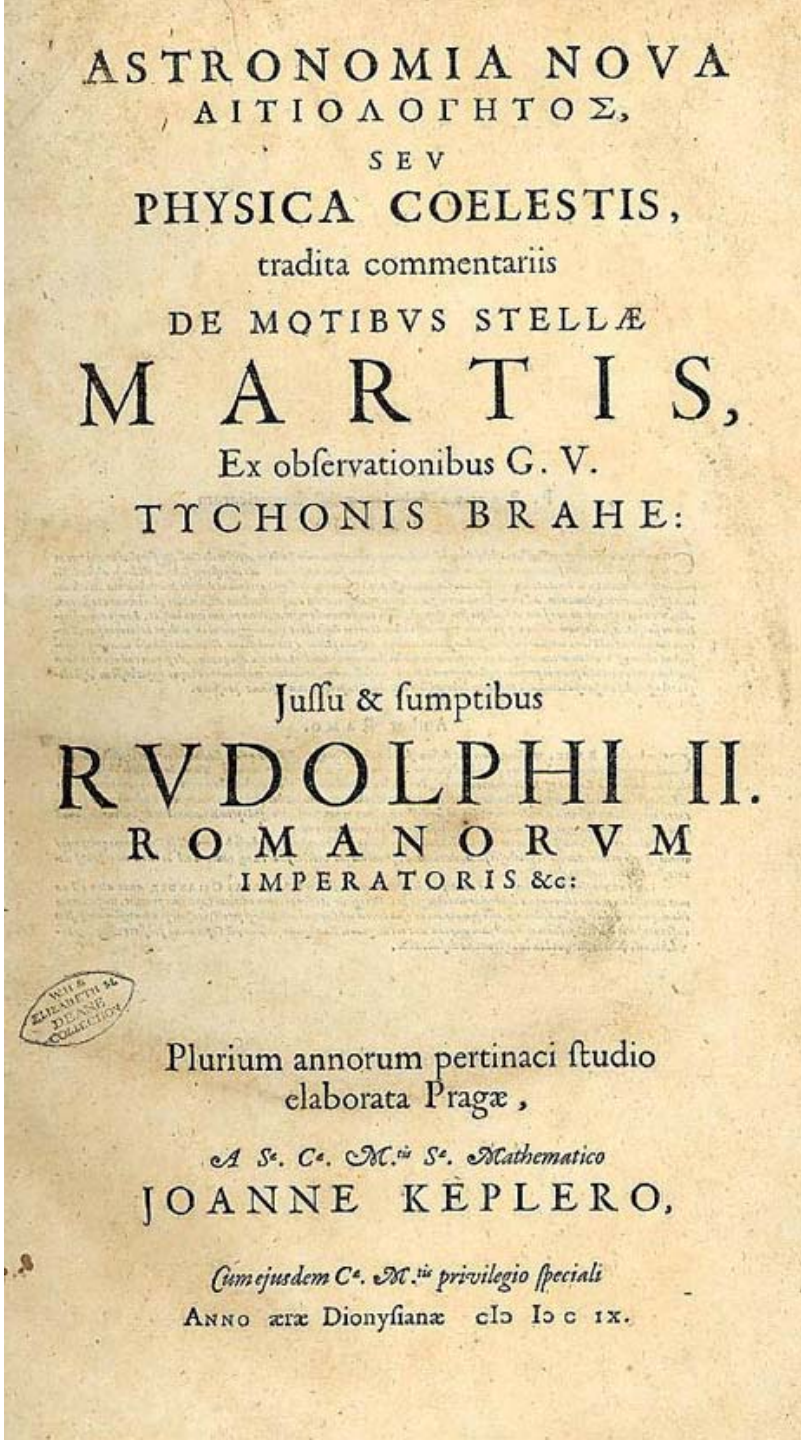
New Astronomy

Founded upon Causes,
or Celestial Physics,

Handed down as Commentaries
on the Motions of the Planet Mars,
according to the Observations
of the splendid man
Tycho Brahe

By order of and at the cost of
Rudolph II.
Roman Emperor etc.

Elaborated during many years of
pertinacious study at Prag
by his majesties Astronomer
Johannes Kepler
1609


ASTRONOMIA NOVA
AITIOΛOΓHTOΣ,
SEV
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBVS STELLÆ
MARTIS,
Ex obſervationibus G. V.
TYCHONIS BRAHE:

Juſſu & ſumptibus
RVDOLPHI II.
ROMANORVM
IMPERATORIS &c:

Plurium annorum pertinaci ſtudio
elaborata Pragæ,

A Sc. Cæ. Mti Sc. Mathematico
JOANNE KEPLERO,

Cum ejusdem Cæ. Mti privilegio ſpeciali
Anno æræ Dionyſianæ clɔ Iɔ c ix.

Kepler will write on Tycho's data quality …

And from this **such small difference** of **8 minutes** of arc it is clear why Ptolemy ,... For **Ptolemy** set out that he actually **did not get below 10** minutes of arc … in making observations.

To us, on whom Divine benevolence has bestowed the most diligent of observers, Tycho Brahe, from whose observations this 8-minute error of Ptolemy's in regard to Mars is deduced, it is fitting that we accept with grateful minds this gift from God, and both acknowledge and build upon it.

Hence, let us work upon it so as to at last **track down the real form of celestial motions .**

For if I thought the 8 minutes in longitude were unimportant, I could make a sufficient correction to the hypothesis found in Chapter 16. (….*the Vicarious Theory*)

Kepler's assessment of Tycho's data quality

- … **these 8 minutes alone** will lead us along a path
  to the **reform of the whole of Astronomy,**
  and **they are the matter for a great part of this work**.

  Astronomia Nova (Heidelberg, 1609) Chapter 19, p 113 -114

- **Why** could Kepler be so sure
  that Tycho Brahe's data are accurate
  to better than a few arc minutes ?

Young Tycho in a Nutshell

- * 14-12-1546 of elevated nobility
- Sent to Leipzig to study Law (→ political career), but instead studies Astronomy from books
- Soon realizes that almost everything one can measure on sky differs from books
- Nov 1572 detects “his” Nova (SN) in Cassiopeia
- No parallax, no p.m. → SN must be in “fixed star sphere” → there are no crystal spheres, universe is earthly (birth and death possible)
- Refuses position as a royal Governor
- Marries outside noble class
- Nevertheless, King Frederik II grants him the means to build a super observatory

Tycho's Starting Point

I have studied all available charts of the planets and stars and none of them match the others.

There are just as many measurements and methods as there are astronomers and all of them disagree.

What is needed is a long term project with the aim of mapping the heavens conducted from a single location over a period of several years.

1563 - age 17

How it started

Snippets from the Observing Log page1 and 5

- **Anno 1563**, Aetatis Anno 17, Lipsiae
- **Aug 17**: hora 13 et quadrante, erat Mars in 7 ♉, lat. Mer. 3 Gr. ad fixas.
- **Aug 18**: hora 13. 34. ....
  Ergo … et 40' vel 45 ' distabant.
- **Nov 23 1564**

- **1563**, age 17, at Leipzig
- **Aug 17**: at 13 hours and a quarter, Mars was in 7 deg Tau, southerly latitude of 3 deg relative to fixed stars.
- **Aug 18**: at 13 h 34 … Therefore … they were apart 40‘ or 45‘.

Erat itaque tunc temporis		Ephemerides Stadij habent	Ephemerides Carelli habent
☿ in 25° ♊	com-	☿ in 22 54 ♊	☿ in 24 3 ♊
♂ in 14 ♋	com-	♂ in 12 52 ♋	♂ in 11 20 ♋
♄ in 0 ♌	com-	♄ in 27 36 ♋	♄ in 29 53 ♋
♃ in 3 ♌	pleto	♃ in 1 30 ♌	♃ in 0 50 ♌

Augsburg Quadrans Maximus

- Built 1570 from oak and brass
- 14 m tall, radius 6.4m
- found to be too unwieldy and prone to flexure by moisture
- But accurate SN 1572 positions

Tycho principles

Thus Tycho very early on realized , that progress in astronomy could be achieved

- **NOT** by occasional haphazard observations,

- **BUT only** by systematic and rigorous observation programs,
- (clear) night after night, and day after day (for the Sun)
- by devising and using instruments of the highest accuracy obtainable
- and by continuous development of observational techniques

For that project he secured funding, and gave up the born-into personal security of his social rank

To Do's if you start Astronomy anew

- **You have 20 years (+ funding), and going ….**
- **Canonical Astro-Tasks in order = entirety of Astronomy textbook prior to Astrophysics**

1 - establish latitude of the observatory by 1/3'	without help of fundamental star cat, or GPS etc.
2 - accurate solar orbit	--> THE TIME (to better than 1' corresp. to 4 sec)
3 - construct system of fundamental stars	brilliant ! without good clock !
4 - establish catalogue of 1014 stars	as a grid on sky to map positions of planets
5 - orbits of all planets	the evaluation was Kepler's job description
6 - parallaxes, orbits of comets	quite a number (~11) → break the Crystal Spheres
7 - lunar theory (difficult)	finds inequalities #3 & #4 → Longitude Problem
8 - solar/lunar eclipses	very good account of many → establish zero-points FK
9 - variable stars	SN 1572, o Ceti (Mira)

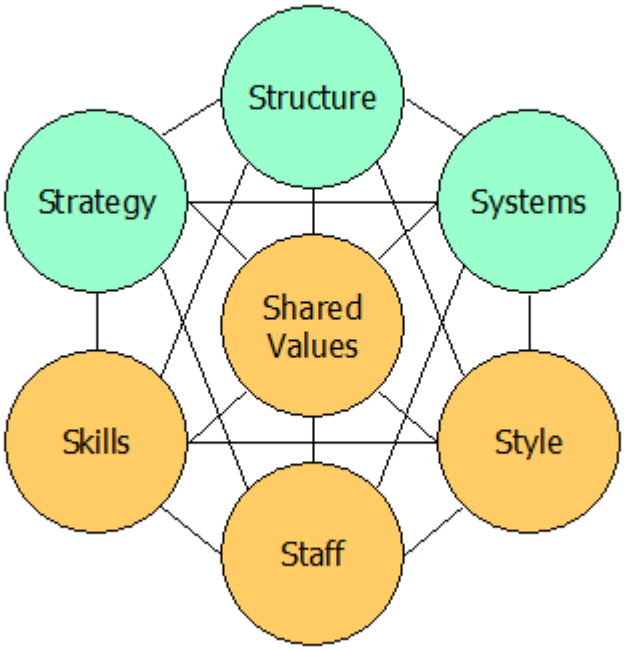
- **Appealing Cosmo-Stuff Tests to decide between Ptolemaean vs Copernican vs Tychonian**

  Parallax measurements for Mars and Venus, Distances and Sizes of Stars

- **Instrumentation / Calibration / Refraction** and other annoyances -- a lot of effort into that / big firsts
- **Write it up → Astronomia Instaurata - Overhaul of Astronomy**

7 S - Principle

Interplay of 7 factors needs to be optimized for success



Hard factors for success

- **Structure –** organization, maps strategy into systems, and allows systems to follow strategy
- **Strategy -** here: “Obtain measurements of the HOW (=from Sky) in order to investigate the WHY”
- **Systems** - hardware, software, processes, frameworks, external conditions

Soft factors for success

- **Shared Values (Super-ordinate Goals)** here: all sign up to a common goal “we renovate Astronomy”
- **Staff** – everyone contributes (can/will ?)
- **Skills** – specific skills making us special
- **Style** – ” … of doing things”, does it need to be tailored/developed ?

How to Reform Astronomy at sub 1' accuracy

Hard factors for success

- **Structure –** organization, maps strategy into systems, and allows systems to follow strategy
- **Strategy -** here: "Obtain measurements of the HOW (=from Sky) in order to investigate the WHY"
- **Systems** - the hardware, software, processes, frameworks, external conditions

Hard factors for success

- **Uraniborg –** a multi person enterprise
  - 100 "specialists" over 20 years
  - Typically 10 at any point in time
  - Inner circle of 3-4 "Assistants" (Dir.)
- **Re-investigation** of all astronomical knowledge from observational data
  - Orbits of Sun (=time), Moon, Planets
  - Grid of Fundamental & Secondary Stars
- **Instruments, Clocks, Calculation Schemes, Printing press**
- **And funding for all that !!**

Tycho's "European" Observatory

- **Total amount spent: ~ 1 ton of gold = $7 * 10^9$ EUR**
  - About 1 % of Denmark's royal budget annually for a period of 20 years
  - Investment on scales similar to ESO, or Keck + Gemini , or HST

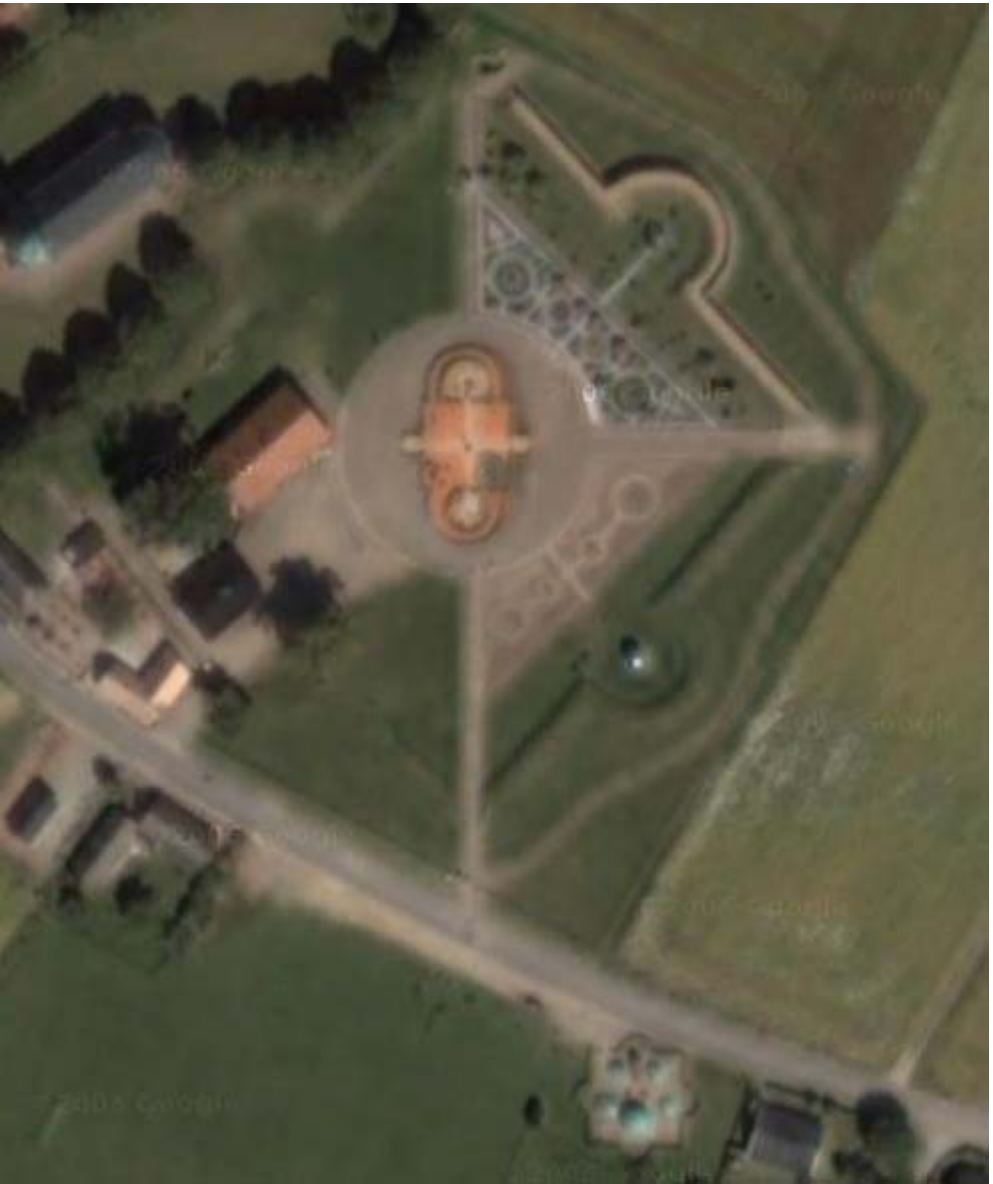
- **Start 1576** – to become a scientific #1 place in Europe
  - In total 100 science support staff in years 82-92, typically 15-20 at a time
  - these later to add to stock of European (natural) scientists

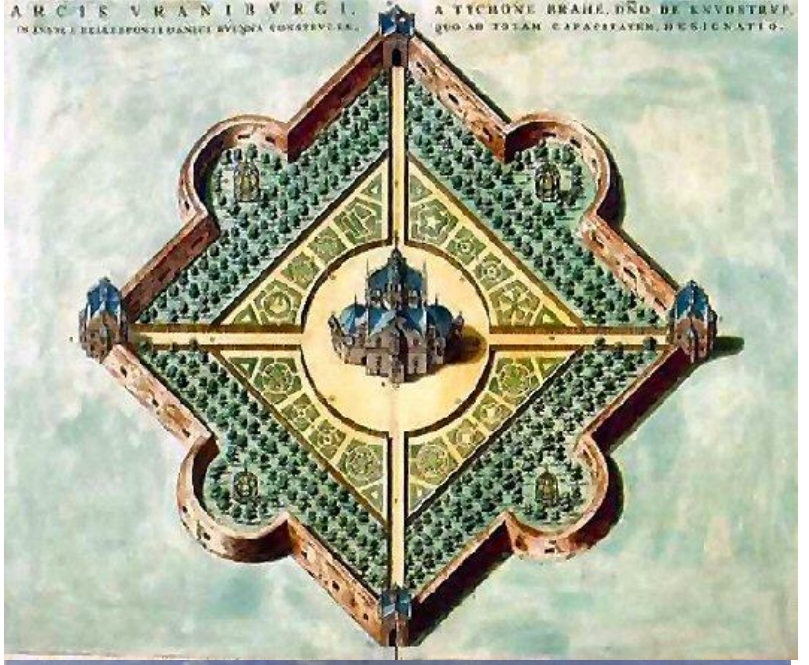
- **Very large library** – almost every book that had ever been out on Astronomy

- Early 1597 funding lost – death of king Frederick II

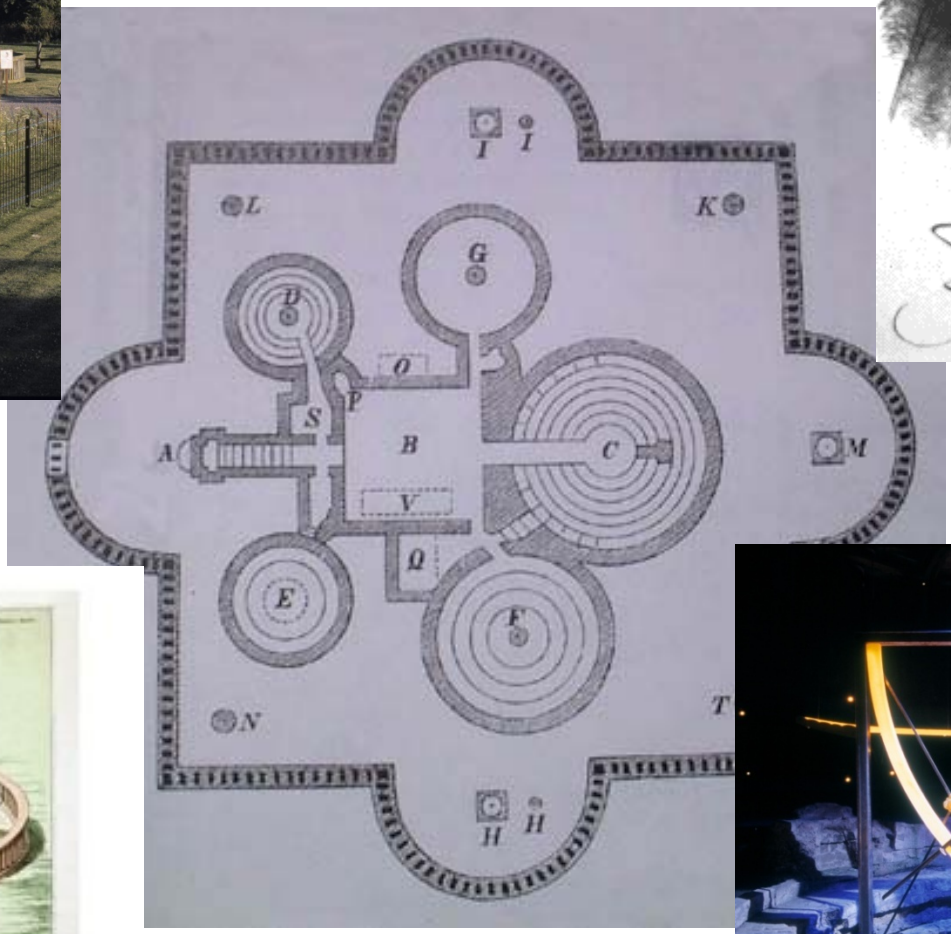
- Uraniborg at Hven abandoned after 20 years – moved Prague

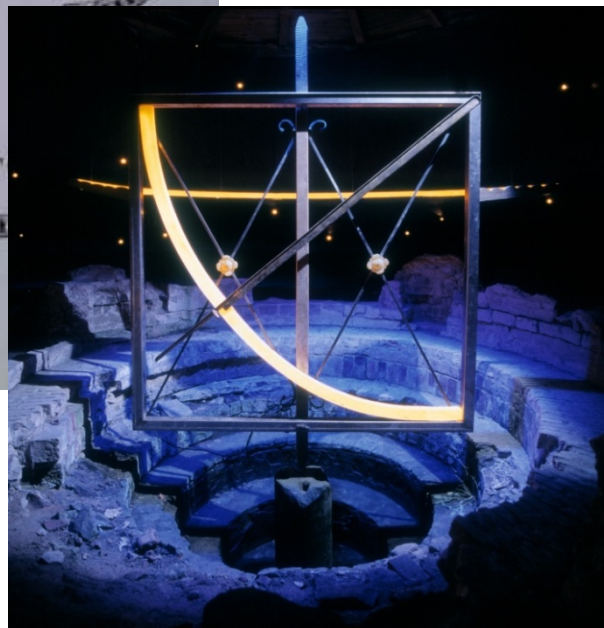
Uraniborg 1576 - 1597





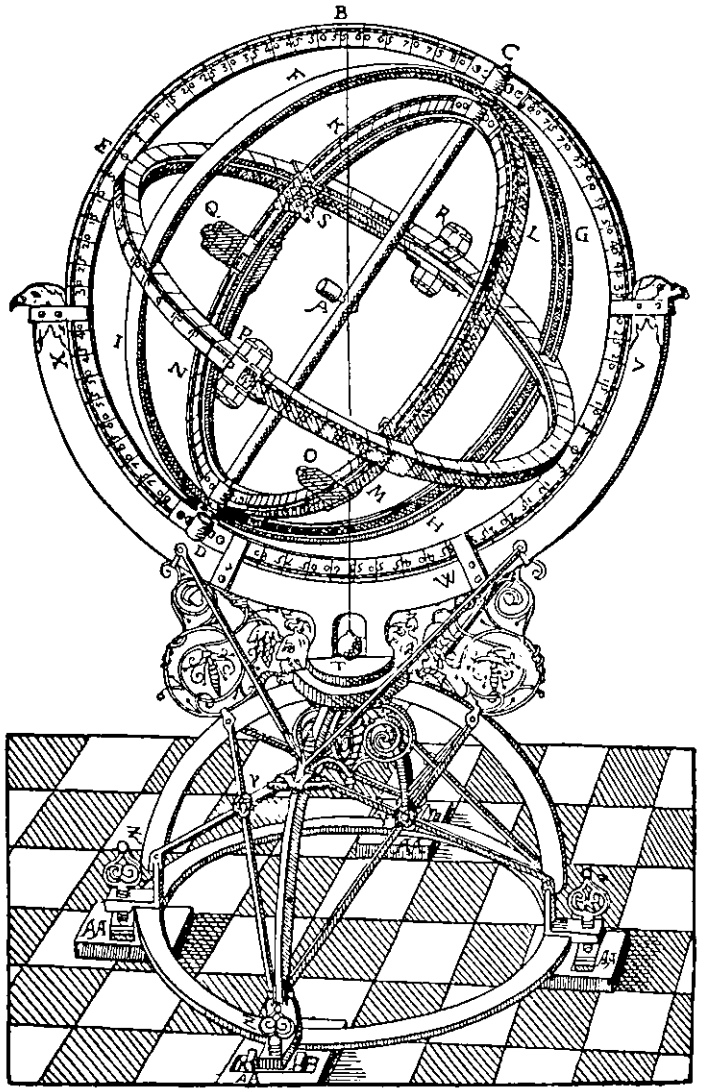
Stjerneborg 1586

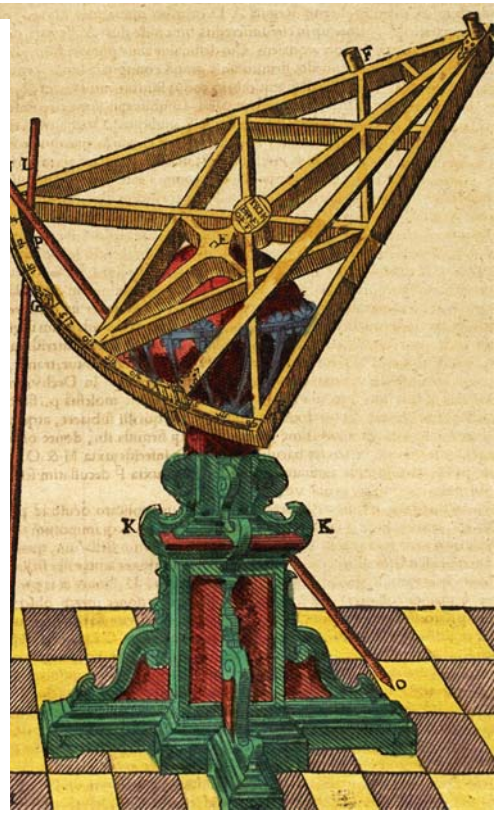


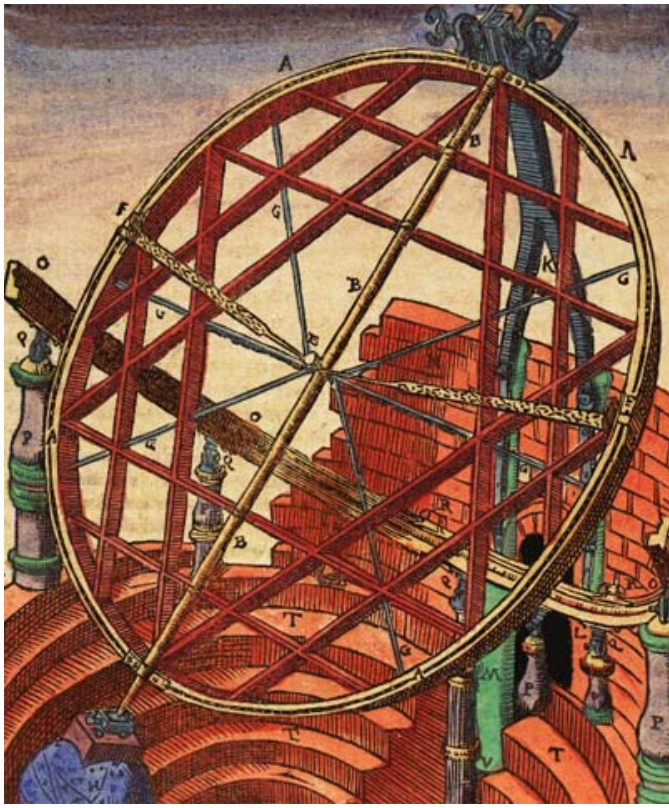


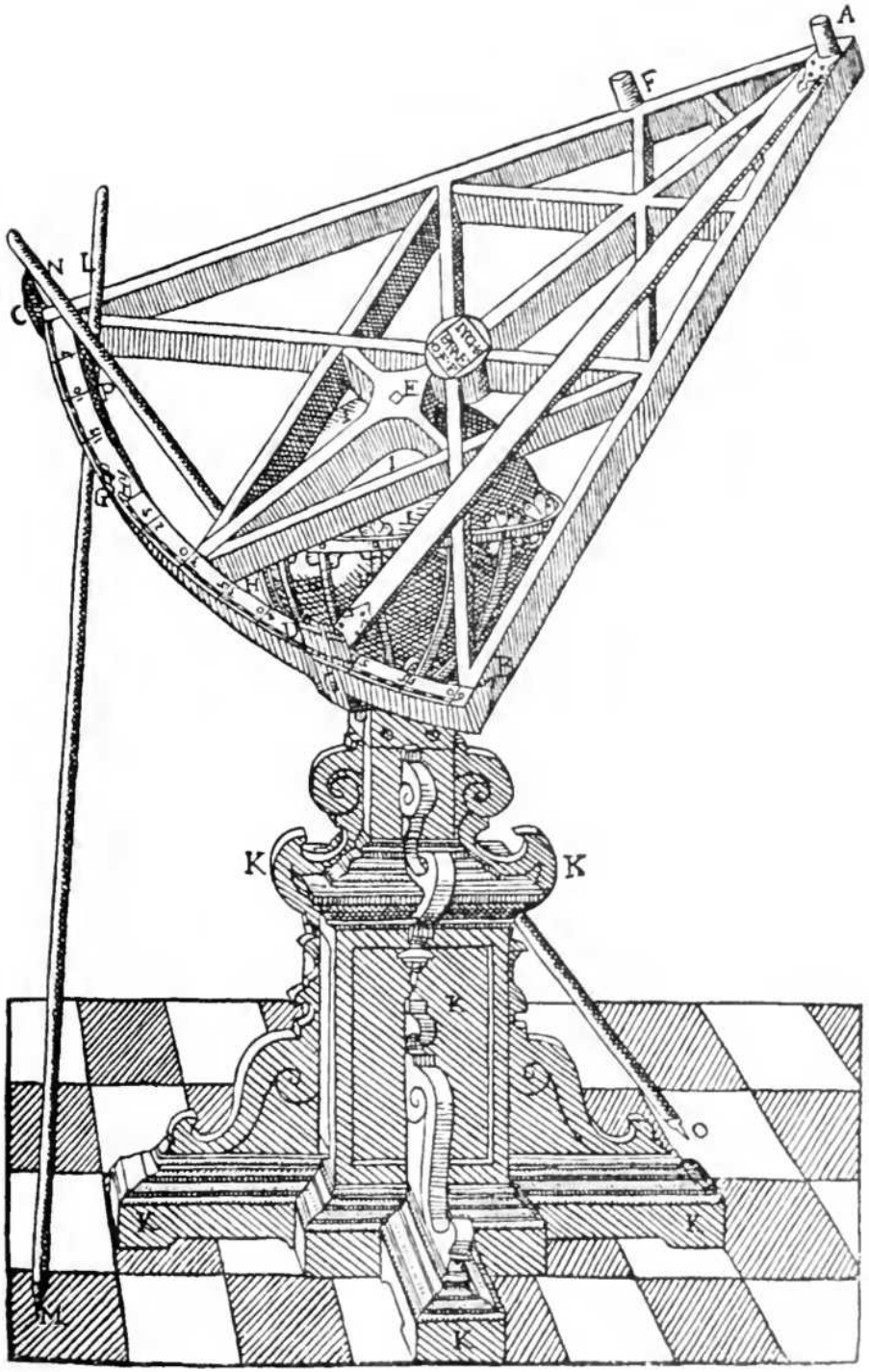
Meridian Line

Key Instruments





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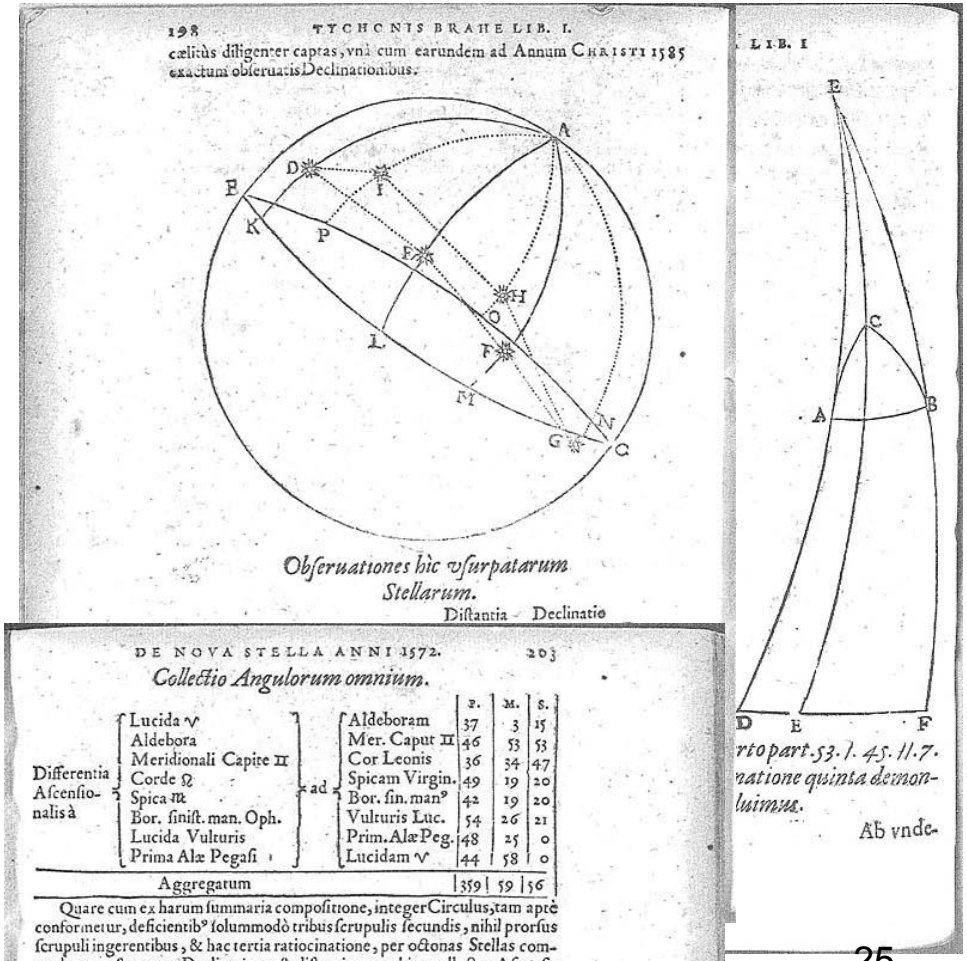
How to secure sub 1’ accuracy

Good is *good*, but *better* carries it

Better is the *enemy* of *good*

- **Observing Program + Data Analysis**
  - Plan observations to minimize evil effects
  - Avoid subtraction of large and almost equal quantities, plan for comparable refraction
  - Plan observations to allow for multiple evaluation by triangular equations



198 TYCHONIS BRAHE LIB. I.

cælitùs diligenter captas, vnà cum earundem ad Annum CHRISTI 1585 exactum obseruatis Declinationibus.

Obseruationes hic vsurpatarum Stellarum.

Distantia Declinatio

LIB. I

rtopart. 53. l. 45. 11. 7.

natione quinta demon-

luimus.

Ab vnde

DE NOVA STELLA ANNI 1572. 203

Collectio Angulorum omnium.

Differentia Ascensionalis à	Lucida ♈	ad	Aldeboram	37	3	15
	Aldebora		Mer. Caput ♊	46	53	53
	Meridionali Capite ♊		Cor Leonis	36	34	47
	Corde ♌		Spicam Virgin.	49	19	20
	Spica ♍		Bor. fin. man^{a}	42	19	20
	Bor. finist. man. Oph.		Vulturis Luc.	54	26	21
	Lucida Vulturis		Prim. Alæ Peg.	48	25	0
	Prima Alæ Pegasi		Lucidam ♈	44	58	0
Aggregatum				359	59	56

Quare cum ex harum summaria compositione, integer Circulus, tam aptè conformetur, deficientib^{a} solummodò tribus scrupulis secundis, nihil prorsus scrupuli ingerentibus, & hac tertia ratiocinatione, per octonas Stellas comprobatum est, earum Declinationes & distantias, atq; hinc collectas Ascensionales differentias omnimodè se rectè habere, nihilque vel in Instrumentis, vel Obseruationis tractatione, aut etiam Calculi subductione latere, dubij. His itaque triplici comprobatione optimè constitutis acquieſcemus. Licet enim plurimis alijs Stellis, variaq; insuper ratione id ipsum attentârim, res

How to secure sub 1’ accuracy

Good is *good*, but *better* carries it

Better is the *enemy* of *good*

- **Instrumentation Program + Observing Strategies**
- Accept new Instruments only after scrutinizing tests (repeatability)
- Accept observations only if identical from several different good instruments
- Repeat observations if possible on diff. dates

292 15

DIE 7 JUNIJ.

Per Q. Tichon.	57	32	10
Per Q. Portat.	57	31½	
Per Q. Maximum	57	32	
Per Regulas 107490, reſp.	57	30	
Per Armillas, Decl.	23	28	
Altitudo 57 32 10 dat declinationem	23	26½	
Reſp. Muralj alt. max.	*57*	*35*	*35*

DIE 8 JUNIJ.

Per Q. Tichon.	57	33½	
Per Q. Portat.	57	33	
Per Q. Max.	57	33	
Decl. per Arm. nouas	23	30	
Reſp. Muralj alt. max.	*57*	*35*	*26*

DIE 9 JUNIJ.

Per Q. Muralem	57	34½	
Decl. per Arm. nouas	23	30	
Reſp. altit. max.	*57*	*35*	*38*

DIE 10 JUNIJ.

Per Q. Tichon.	57	35	10
Per Q. Portat.	57	35	15
Per Q. Max.	57	35	15
Per Reg. 107300, reſp.	57	33	15
Reſp. alt. max.	*57*	*35½*	
Decl. per Arm. nouas	23	31	

Fuit hic ſatis ſerenum.

DIE 23 NOUEMBRIS.

Ad Veſperas.

Diſtantia inter lucidam Vulturis & caput Ophiuchi 33 32⅛, Alt. Oph. 15½

Eadem repetita	33	31¼	
	33	32	
	33	32	
	33	31¼	14°
	33	31¼	

Oculus ☉ or.	Vultur. occ.	Diſt. æquat.	Alt. Vult.
50 15	80 6	130 21	12
49 52½	80 30	130 22½	

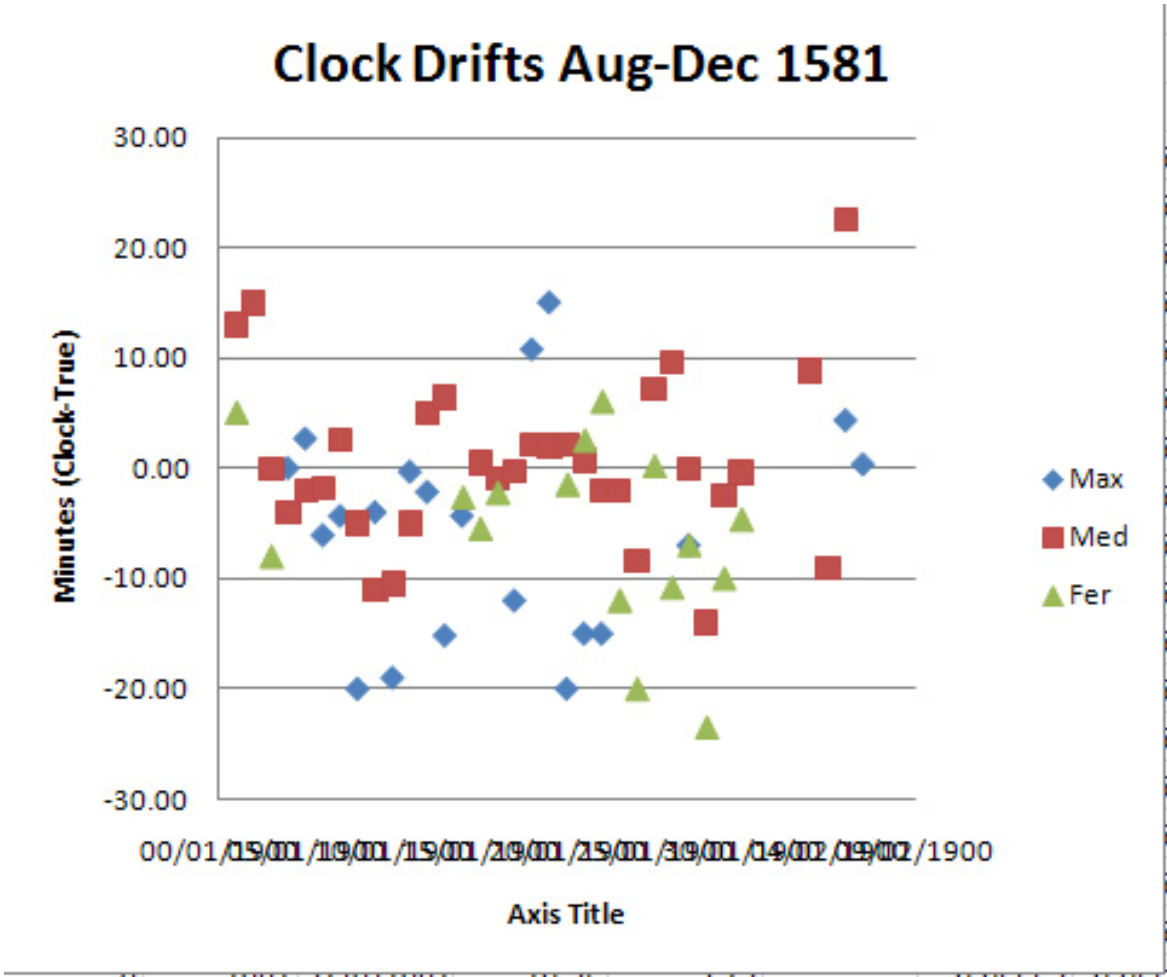
Per Sextantem △.

Diſt. inter Canem minorem & oculum ☉	46	22½	
Eadem repetita	46	23	
Eadem reiterata	46	22½	
Inter oculum ☉ & humerum dextrum Orionis	21	25¼	bis
Eadem reiterata diſt.	21	25¼	
Inter ſiniſtrum humerum Orionis & oculum ☉	15	49	
Eadem repetita diſt.	15	48¼	
Eadem reiterata	15	49	
Inter primam in cingulo Orionis & oculum ☉	21	49	
Eadem reiterata diſt.	21	49	
Eadem	21	50	fere

Zero-Points sub 1’ accuracy ?

Right Ascensions through Hour Angles

- **Using Clocks**
  - 1’ angle = 4 s of time
  - Clocks in 1580^{ies} were good to ~ 5 min/day
- Experimented with
  - Sandclocks (Lead-Oxide)
  - Waterclocks (Mercury)
  - “to weigh the seconds …”
  - 86400 sec * 0.1 g = 8.6 kg
  - ~ 0.5 to 1 liter Hg or Pb

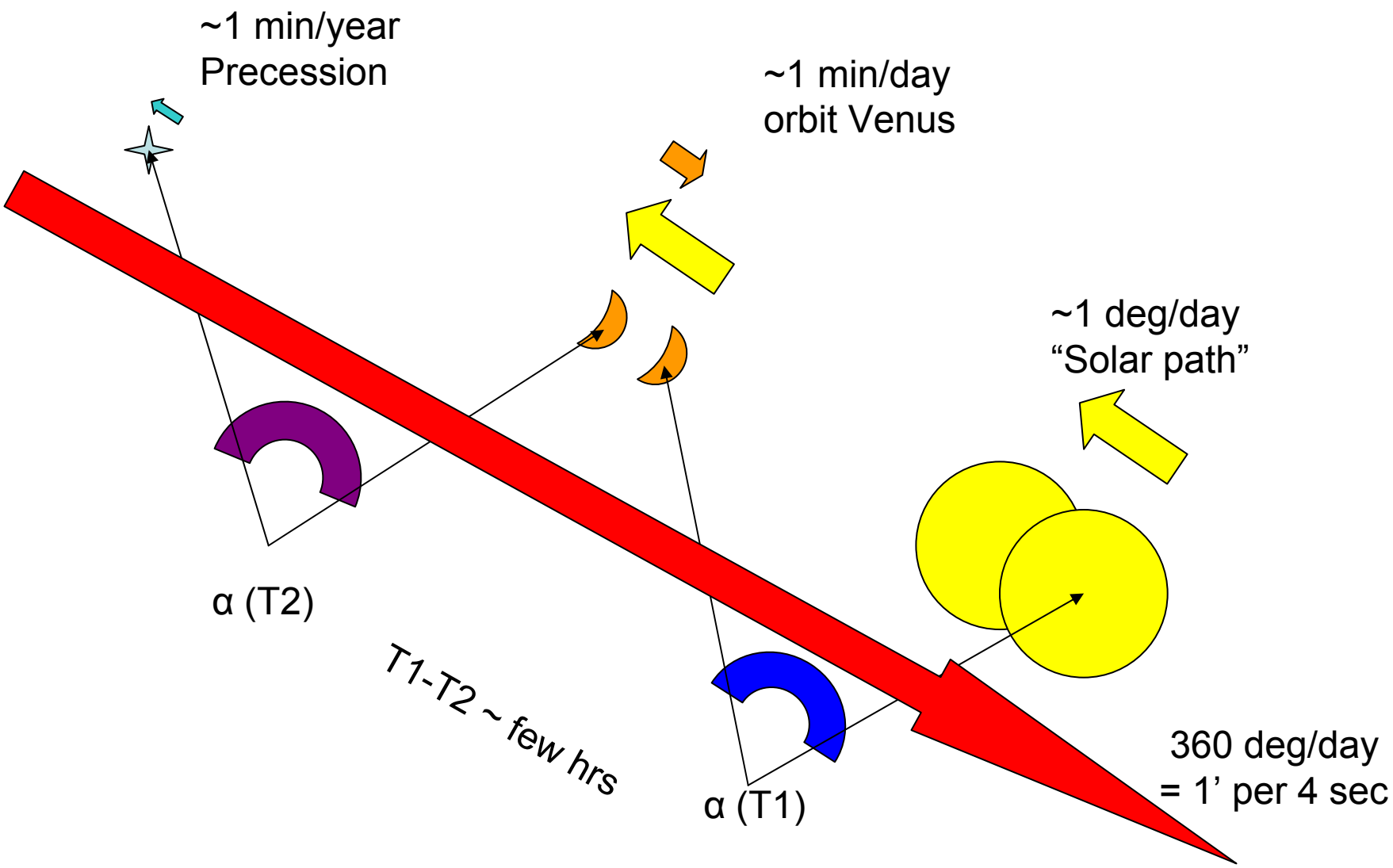


How to Obtain Zero-Points sub 1' accuracy ?

Right Ascensions through Distance to Sun

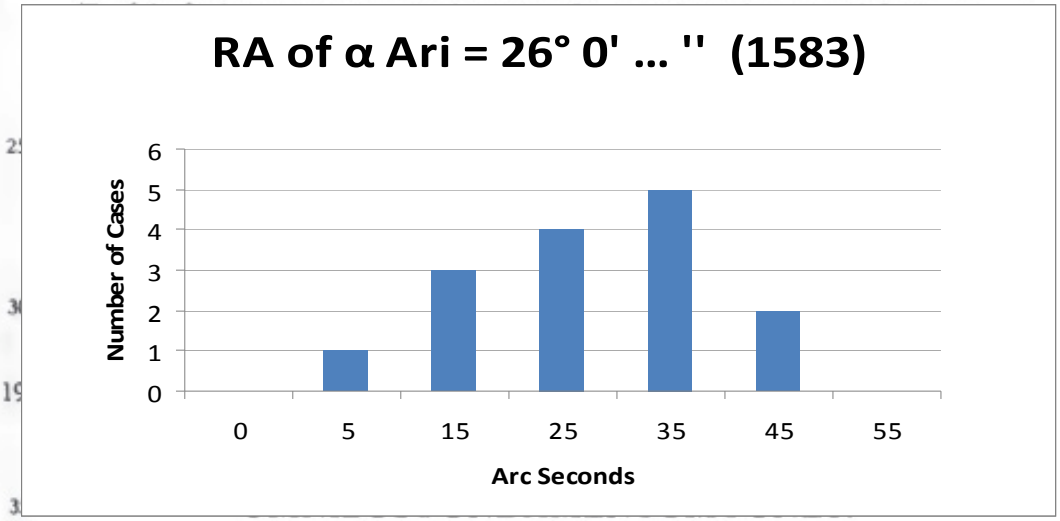
- **Using Venus as "Mediator" between Day and Night**
  - Angle between Venus and Sun at day (around noon) !!!
  - Angle between Fundamental Star and Venus after sunset
  - Correct for daily motion of Venus
- **Do this often for many Fundamental Stars**
  - Morning Venus and Evening Venus (2 years later)
  - So that every Fundamental star gets corrected from Front and Back
- **Achieved - Zero Point accurate to +/- 5"**

Right Ascensions through Distance to Sun



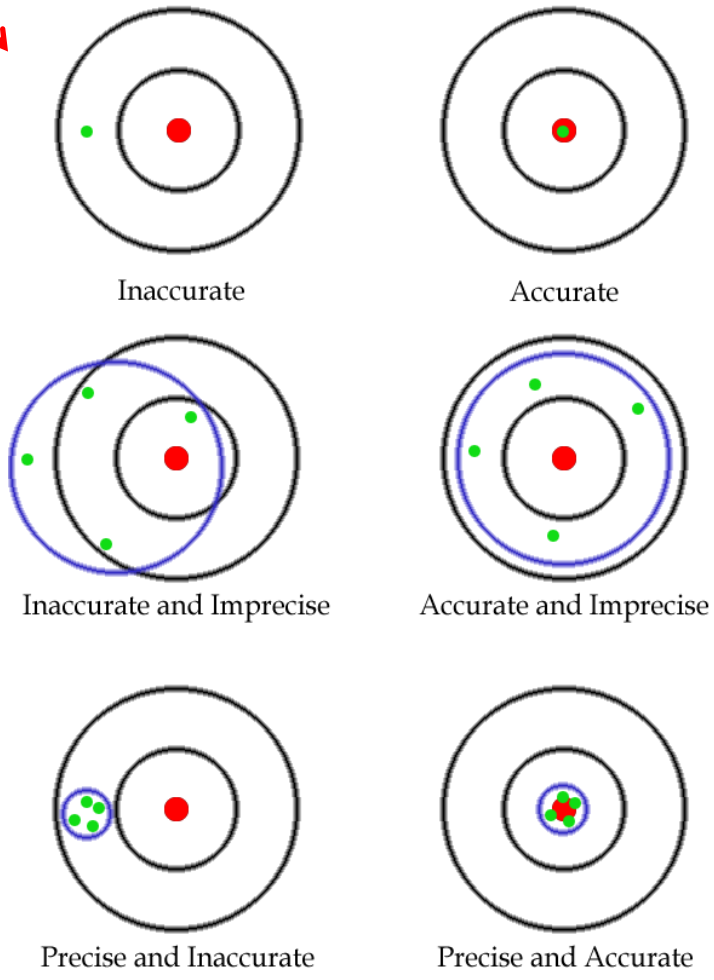
193 # COLLECTIO OMNIUM ASCENSIONUM RECTARUM IN LUCIDA STELLA ♈, PRÆMEMORATIS QUINDECIM CONSIDERATIONIBUS EXPLORATARUM, SINGULIS AD FINEM ANNI 1585 ADAPTATIS.

	ANNI	MENSES	DIES		ANNI	MENSES	DIES	Anno 1585 comp. Aſc. R.	Luc.
I	1582	Februar.	26	In his tribus nulla eſt adhibita				26 0	44
II	1582	Martij	20	viceverſa collatio ſed ſolum oc-				26 0	32
III	1582	Aprilis	3	ciduæ Obſeru. debite verificatæ				26 0	30
IIII	1582	Februar.	27		1585	Septemb.	21	26 0	20
V	1582	Martij	5		1585	Septemb.	14	26 0	38
VI	1582	Martij	5		1585	Septemb.	15	26 0	18
VII	1582	Martij	9		1585	Septemb.	15	26 0	32
VIII	1586	Decemb.	26		1588	Decemb.	15	26 0	42
IX	1586	Decemb.	27		1588	Nouemb.	29	26 0	37
X	1587	Ianuarij	9	ET	1588	Decemb.	6	26 0	27
XI	1587	Ianuarij	24		1588	Octobris	26	26 0	29
XII	1587	Auguſti	17		1588	Aprilis	16	26 0	14
XIII	1587	Auguſti	17		1588	Aprilis	16	26 0	4
XIIII	1587	Auguſti	18		1588	Martij	28	26 0	28
XV	1587	Auguſti	18		1588	Aprilis	16	26 0	39



G. M. S.
26. 0. 30.

Pre-Tycho Style



Accuracy & Precision

Tycho's Style of Observations

Altitude of Pole ~1500 Observations

Eodem 19. DECEMB. Vesperi.

Inter 25. n. in linteo Orionis & Canem min.	40	20	
Inter 32. Orion. & canem minorem	32	29 2/3	
Inter 31. in ense Orion. & canem min.	32	53	
Altit. merid. dextri hum. Orionis	41	20 1/3	
Altit. merid. 38. in genu dextro Orionis	24	14 3/4	

Stellarum circum polarium altitudines meridianæ supra & infra Polum pro elevatione indaganda.

Stellæ Polares.

	Per Chalybæum			Per Volubilem.		
	58	48	55	58	49	0
	58	49	10	58	49	0
Supra Polum	58	49	6	58	49	10
	58	49	0	58	48	50
	53	0	6	53	0	0
	53	0	0	53	0	10

Lucidæ □. Vrsæ minoris.

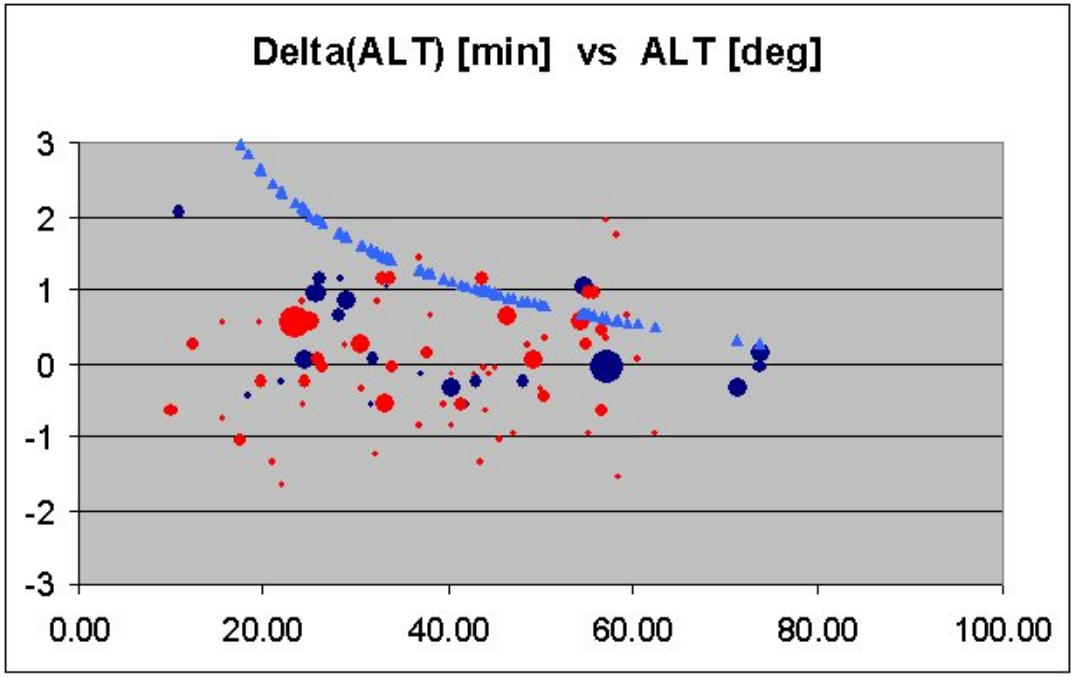
Per Chalybæum			Per Volubilem		
70	4	40	70	4	40
70	5	10	70	4	45
70	5	20	70	5	0
70	5	15	70	3	50
41	44	20	41	43	45
41	44	20	41	44	30
41	44	20	41	44	0
41	44	15	41	44	30
41	44	30	41	44	20

Minus lucidæ □ Vrsæ minoris.

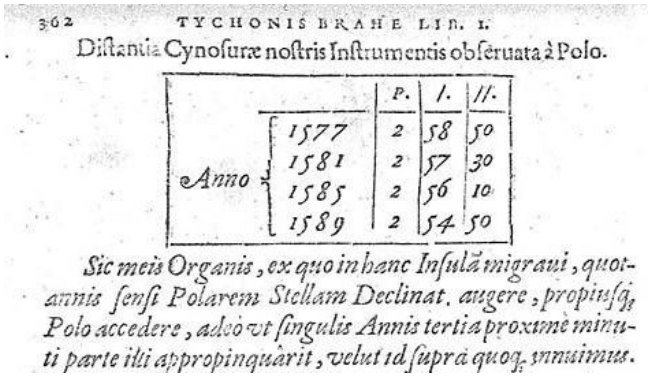
Per Chalybæum			Per Volubilem		
72	36	50	72	36	40
72	36	30	72	36	50
72	37	0	72	36	50
72	36	50	72	36	30
72	36	50	72	36	50
72	37	0	72	36	40
39	12	20	39	12	30
39	12	15.	39	12	30
39	12	0	39	11	50
39	12	20	39	12	0

- "Latitude" of Uraniborg

Tycho (A.I.M. 29)	55°	54′	30″
Today (ellipsoid)	55°	54′	28".7
Tycho is off by only			1".3
At Uraniborg 1" correspond to	31 m		
Scale of Uraniborg gardens is	100 m		
But …. Refraction for pole 55°.9			40″



α UMi - Polaris – Distance to Pole

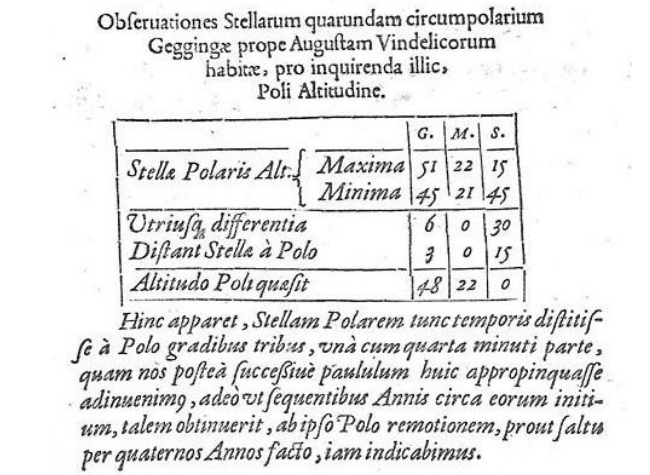


362 TYCHONIS BRAHE LIB. I.

Distantia Cynosuræ nostris Instrumentis obseruata à Polo.

		P.	I.	II.
Anno	1577	2	58	50
	1581	2	57	30
	1585	2	56	10
	1589	2	54	50

Sic meis Organis, ex quo in hanc Insulã migraui, quotannis sensi Polarem Stellam Declinat. augere, propiusq; Polo accedere, adeò vt singulis Annis tertia proximè minuti parte illi appropinquârit, velut id supra quoq; innuimus.

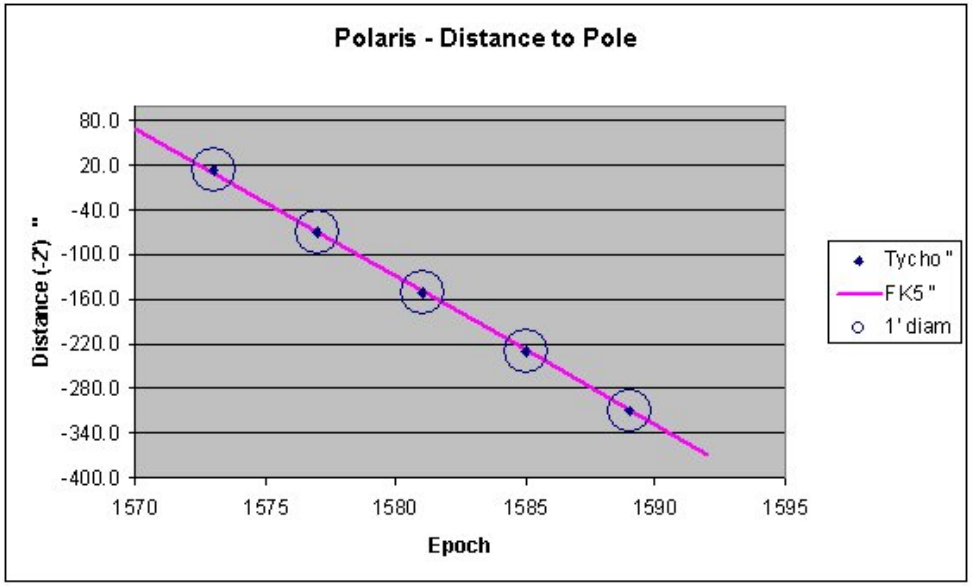


Obseruationes Stellarum quarundam circumpolarium Geggingæ prope Augustam Vindelicorum habitæ, pro inquirenda illic, Poli Altitudine.

		G.	M.	S.
Stellæ Polaris Alt.	Maxima	51	22	15
	Minima	45	21	45
Vtriusq; differentia		6	0	30
Distant Stellæ à Polo		3	0	15
Altitudo Poli quæsit		48	22	0

Hinc apparet, Stellam Polarem tunc temporis distitisse à Polo gradibus tribus, vnà cum quarta minuti parte, quam nos posteà successiuè paululum huic appropinquasse adinuenimus, adeò vt sequentibus Annis circa eorum initium, talem obtinuerit, ab ipso Polo remotionem, prout saltu per quaternos Annos facto, iam indicabimus.

Epoch	Location	Tycho	FK5	T-FK5 "
1573	Augsburg	3 0 15	3 0 10.2	4 . 8
1577	Uraniborg	2 58 50	2 58 50.4	-0 . 4
1581	Uraniborg	2 57 30	2 57 30.5	-0 . 5
1585	Uraniborg	2 56 10	2 56 10.7	-0 . 7
1589	Uraniborg	2 54 50	2 54 50.9	-0 . 9
2000			0 44 9.2	

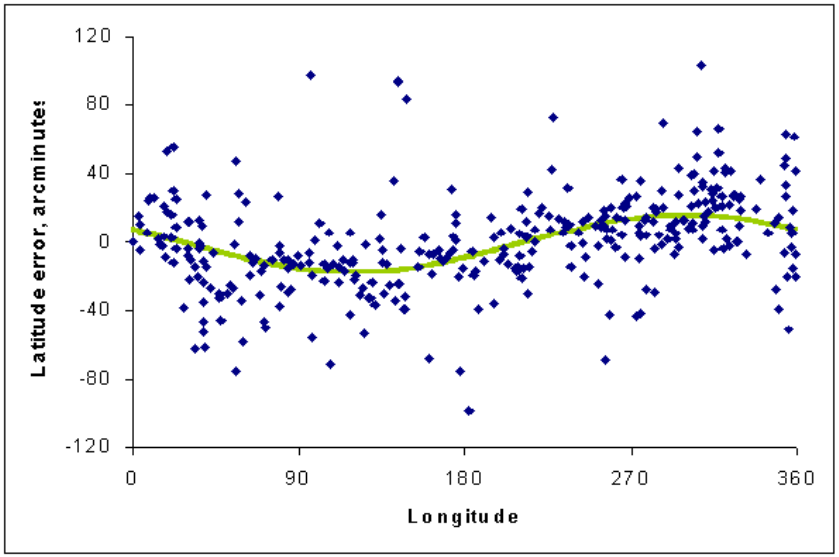


Tycho's Catalogue vs the Almagest

Almagest (Ptolemy)

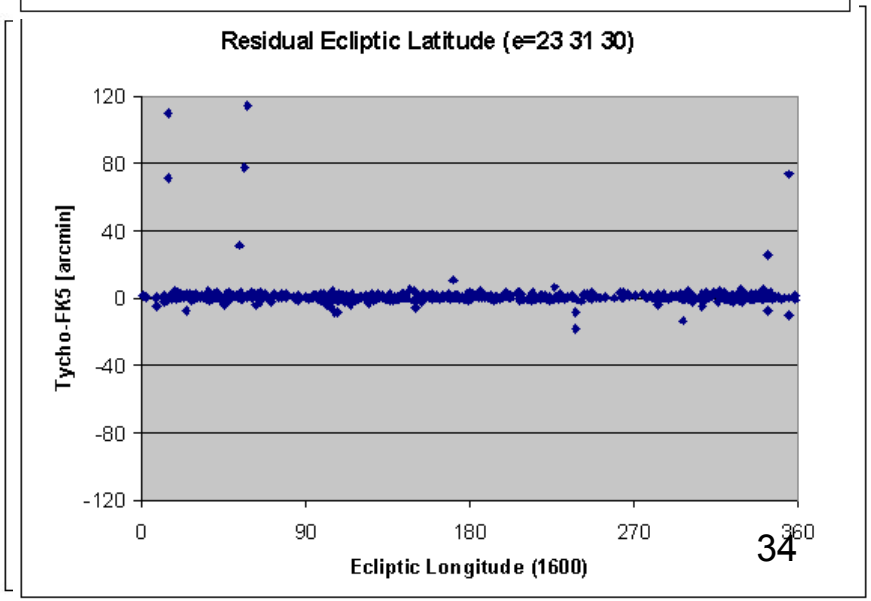
Sinosoidal longitudinal error - Tycho was first to accuse Ptolemy of having copied the data from Hipparchos and precessed wrongly to his epoch

- coordinates show a spread of +/- 30' about the positions that "should have been" observed

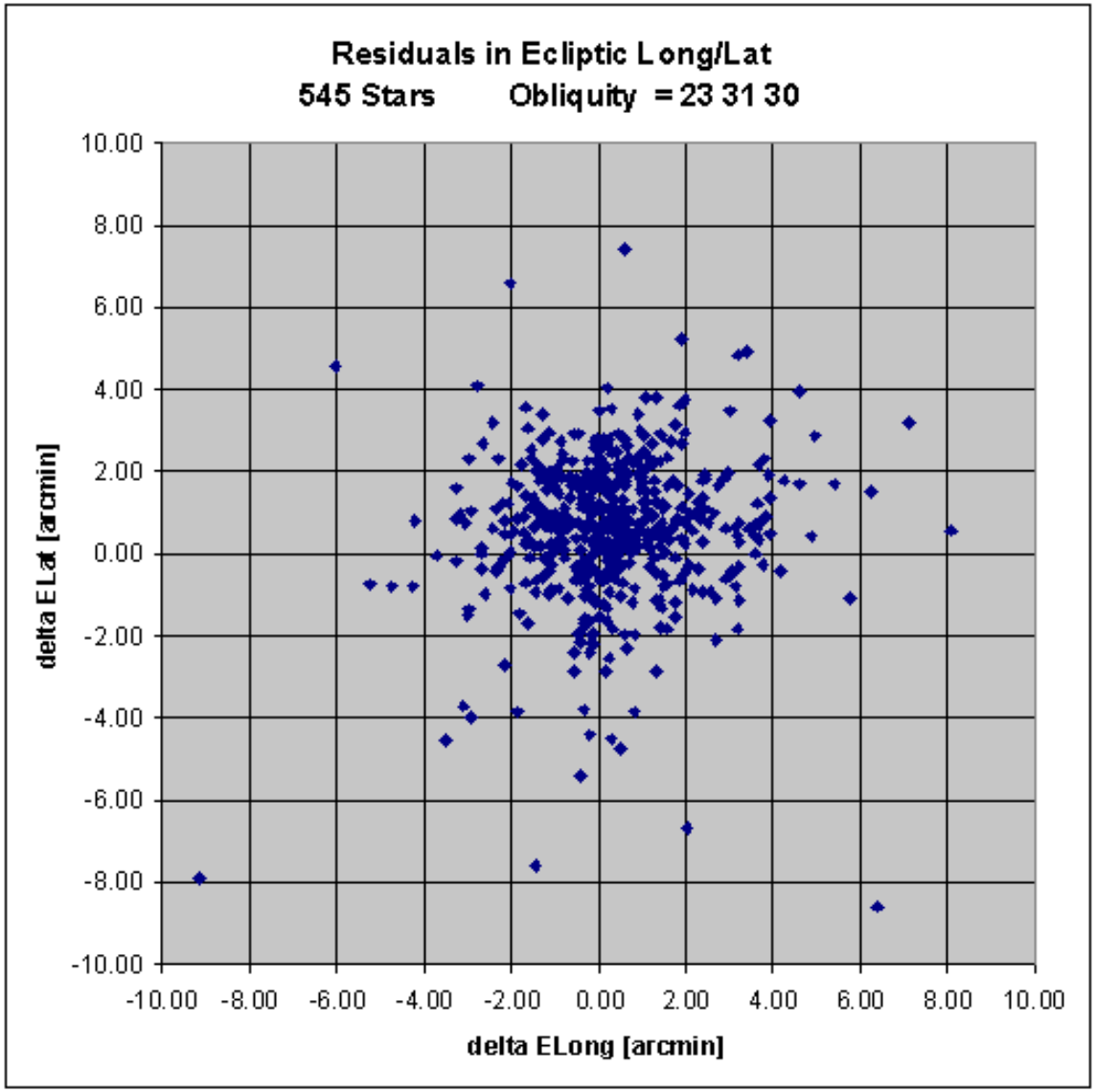


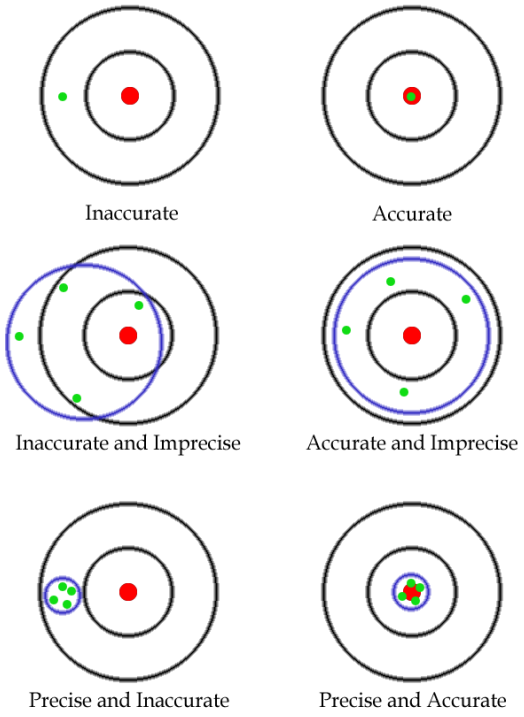
Tycho Catalogue

- spread of +/-3' about 0
- Slightly inclined & offset 0-line
  (due to 2' error in incl. of ecliptic)



Tycho Star Cat - Accuracy

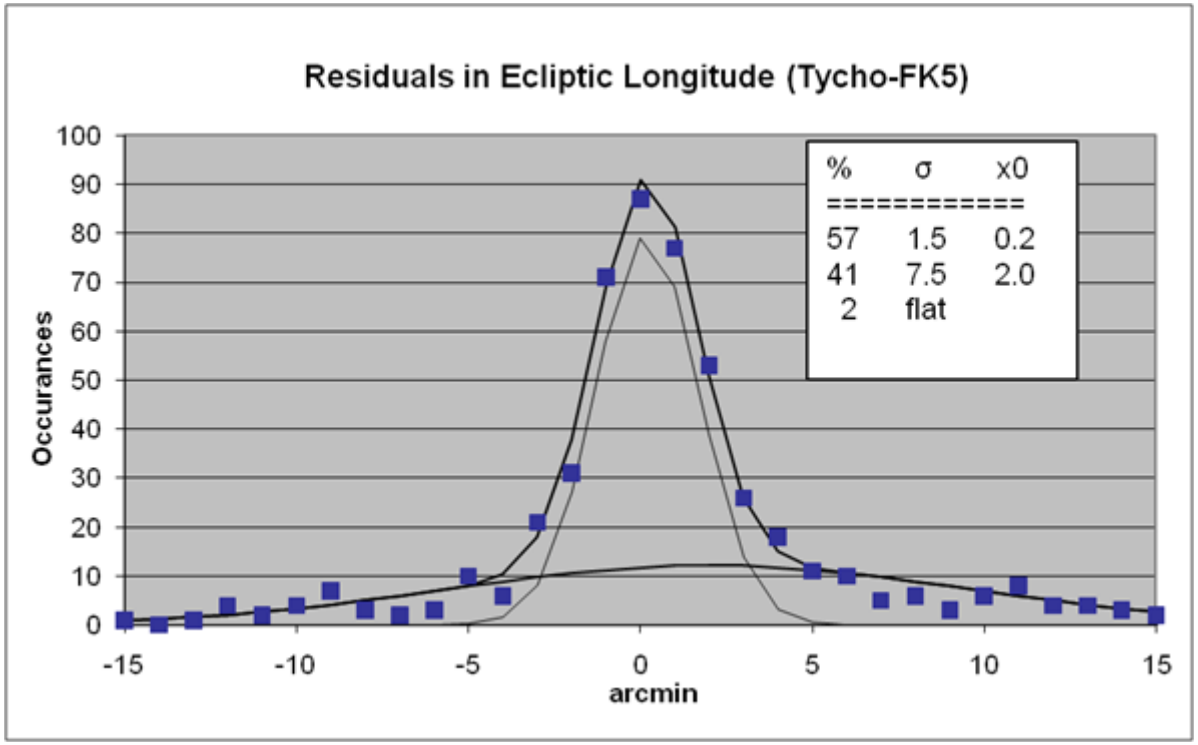




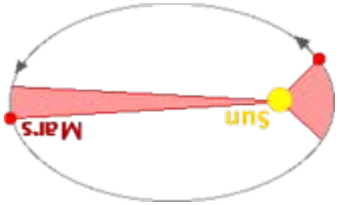
Kepler's Assessment correct

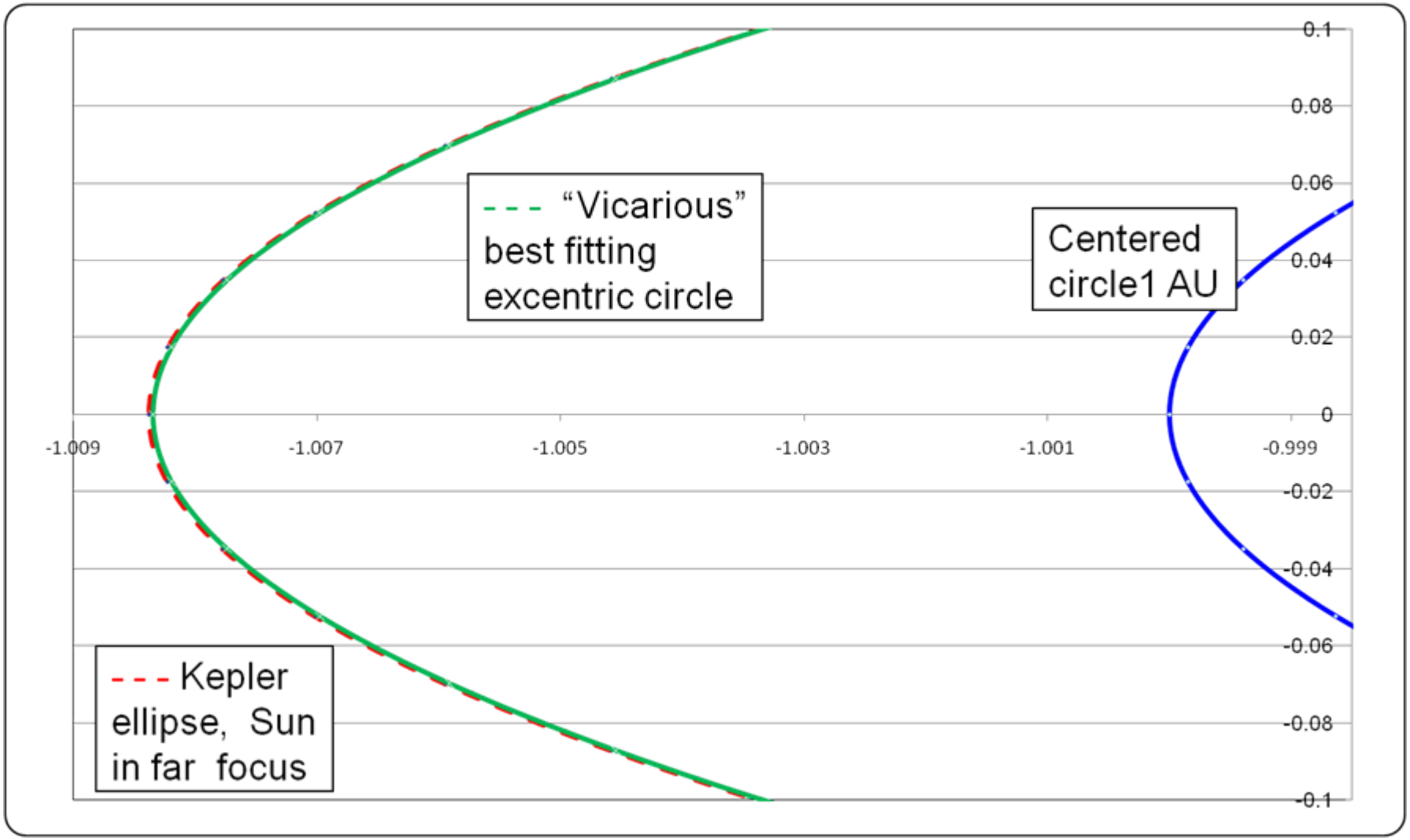
" Now, because they could not be disregarded, **these 8 minutes alone** will lead us along a path to the **reform of the whole of Astronomy, "**

since 8′ are ≅ 5 * σ [1′.5] and more than 4 * Δx0 [1′.8], as follows from scrutiny of the TB Catalogue

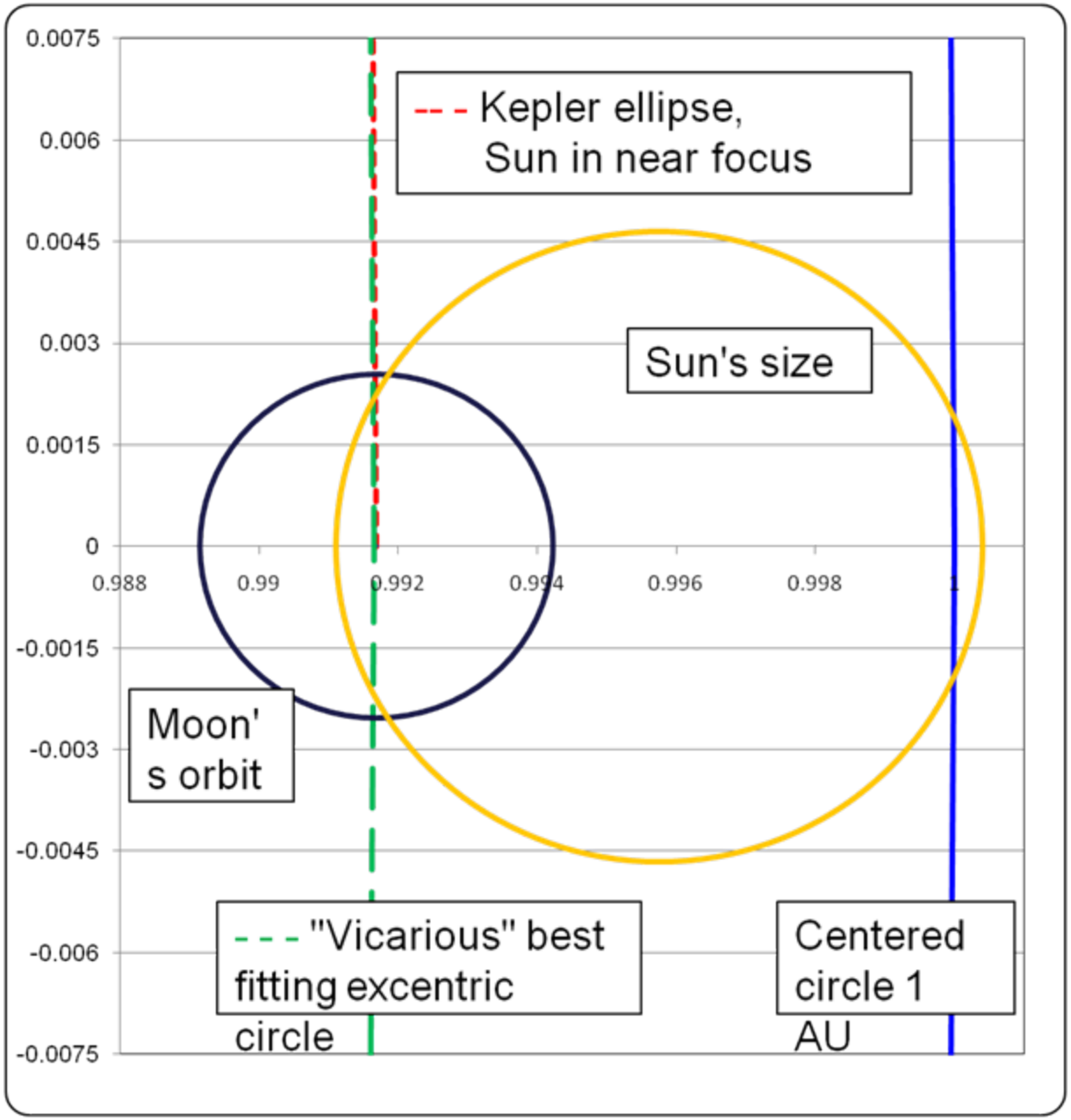


Ellipse and Circle at Aphel

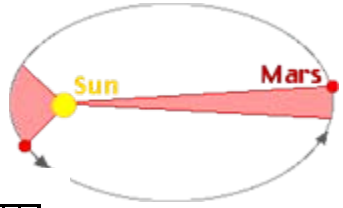


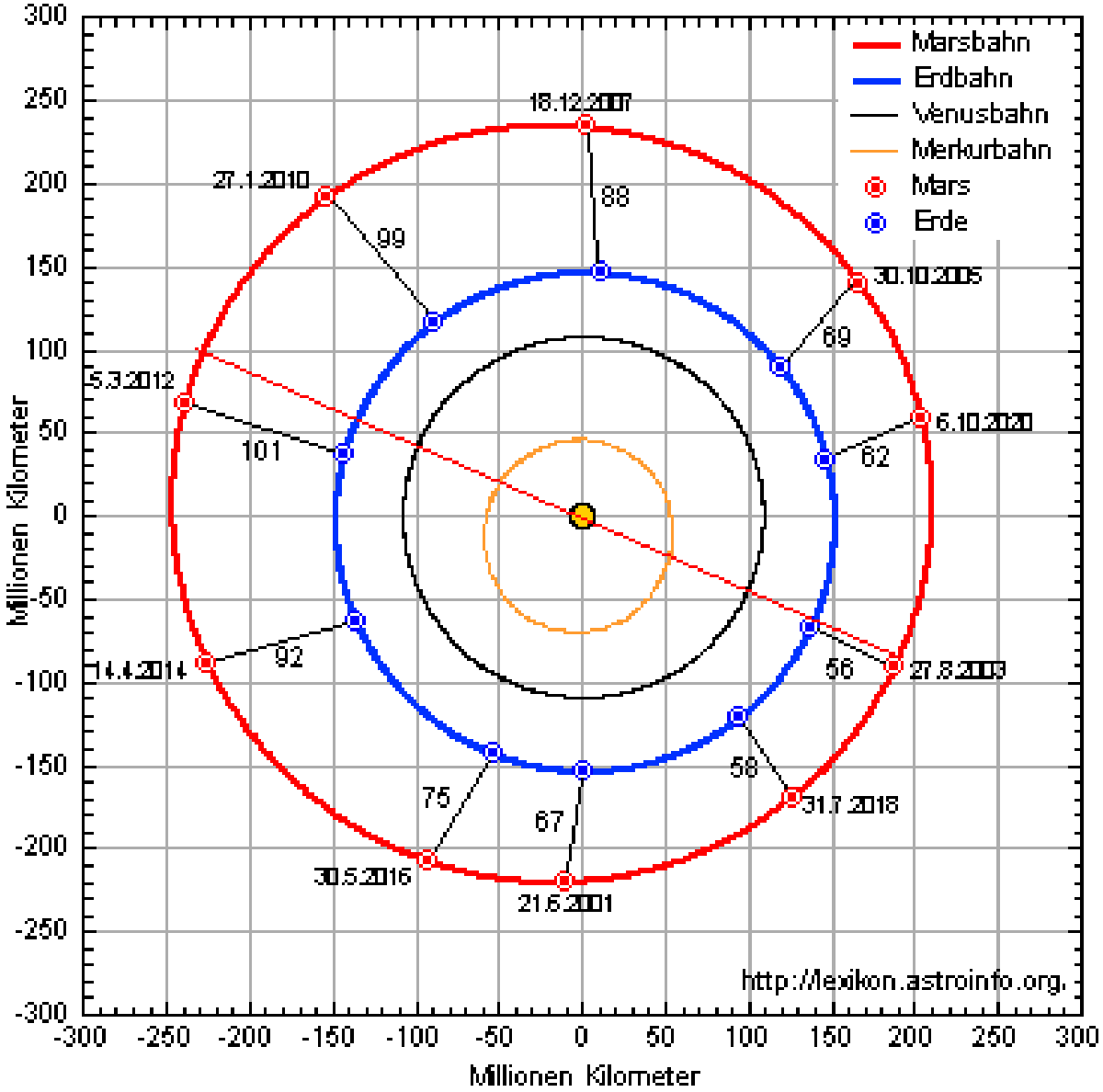


Scale of problem at Perihel



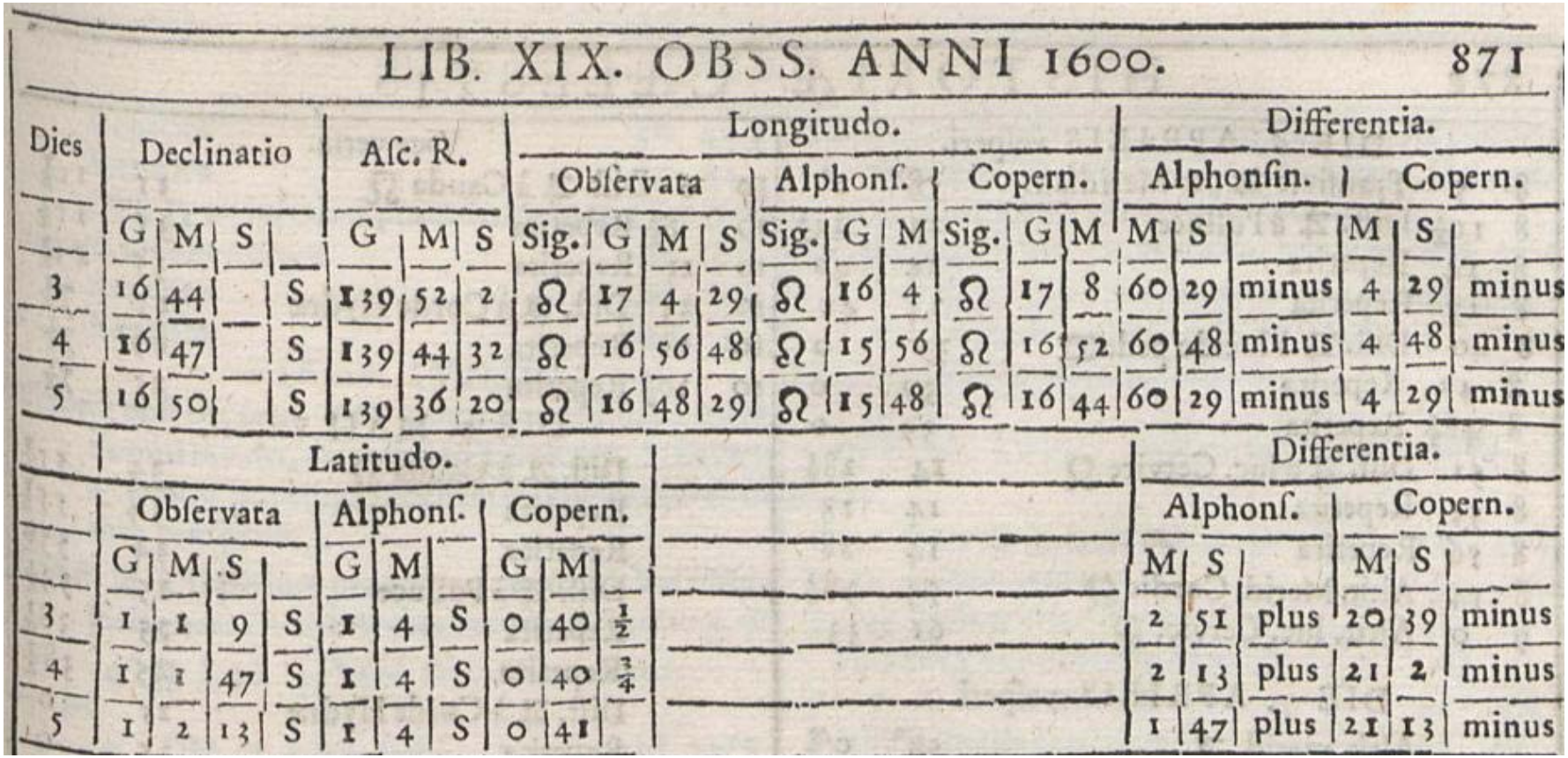
Inner Solar System to scale





Can one decide on positions alone ?

- **Which model is right - Ptolemaic or Copernian ?**
  - TB saw that both not good – only Kepler found out why from TBs data
  - here Jupiter's positions in February 1600 AD (Benatky)



LIB. XIX. OBSS. ANNI 1600. 871

Dies	Declinatio				Asc. R.			Longitudo. Observata				Alphonſ.			Copern.			Differentia. Alphonſin.			Copern.		
	G	M	S		G	M	S	Sig.	G	M	S	Sig.	G	M	Sig.	G	M	M	S		M	S	
3	16	44		S	139	52	2	☊	17	4	29	☊	16	4	☊	17	8	60	29	minus	4	29	minus
4	16	47		S	139	44	32	☊	16	56	48	☊	15	56	☊	16	52	60	48	minus	4	48	minus
5	16	50		S	139	36	20	☊	16	48	29	☊	15	48	☊	16	44	60	29	minus	4	29	minus

	Latitudo. Observata				Alphonſ.			Copern.			Differentia. Alphonſ.			Copern.		
	G	M	S		G	M		G	M		M	S		M	S	
3	1	1	9	S	1	4	S	0	40	½	2	51	plus	20	39	minus
4	1	1	47	S	1	4	S	0	40	¾	2	13	plus	21	2	minus
5	1	2	13	S	1	4	S	0	41		1	47	plus	21	13	minus

Can I do a decisive experiment ?

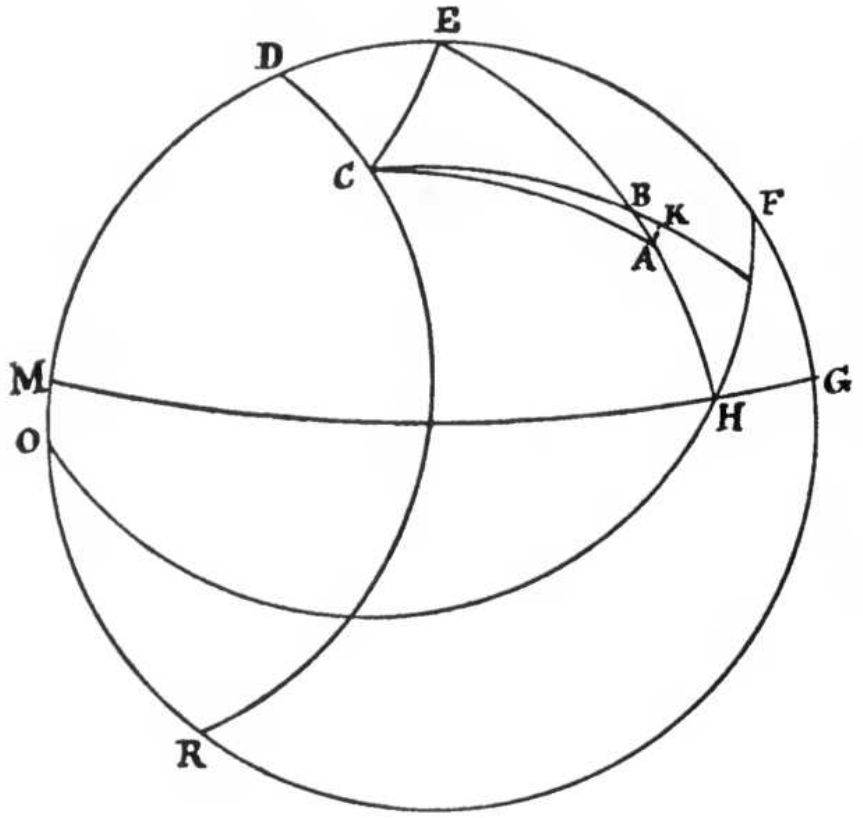
- **We all deep down desire to be once given this opportunity**
  - Just once do a decisive set of observations – and then go to Stockholm

- **Chance to decide between Ptolemy, Copernicus & TB**
  - "Simply" find distance between Earth and Mars at Opposition
  - Required: Morning/Evening (diurnal) parallax of Mars
  - Estimated at: 4' Cop., 2' Ptolemy, 5' TB
  - Measurable for Tycho **IF** the Solar System is **SMALL**
  - Else, the value is un-measurable for Tycho – ~ 23" as we know today

- **Pit Fall**
  - Not finding what was anticipated can be due to …
  - an unfit experiment, or wrong assumptions, or (most likely) both

Principle of Observation

Determine very small angle by reference across large sections of sky



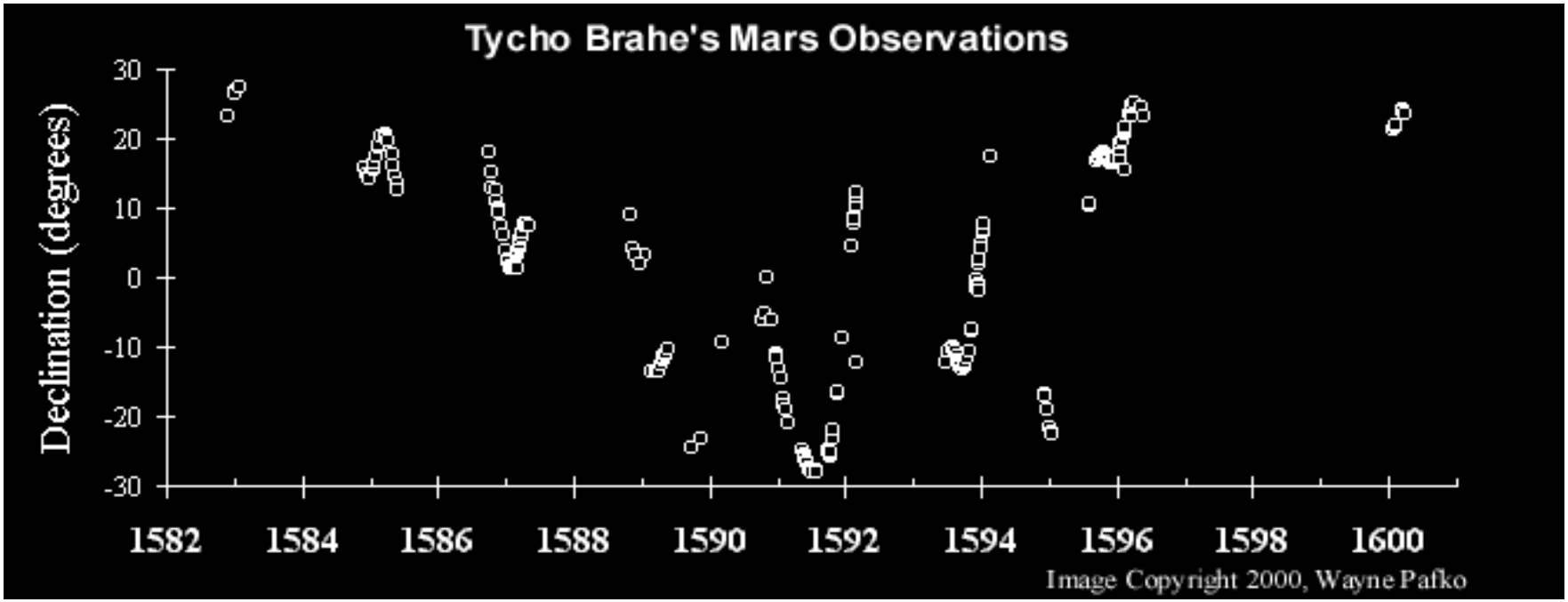
Expected

AK ~ 3’

BK ~ 2’

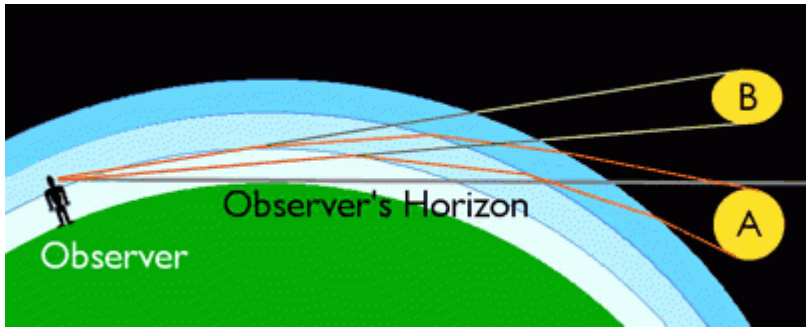
HA ~ 20 deg

AC ~ 60 deg

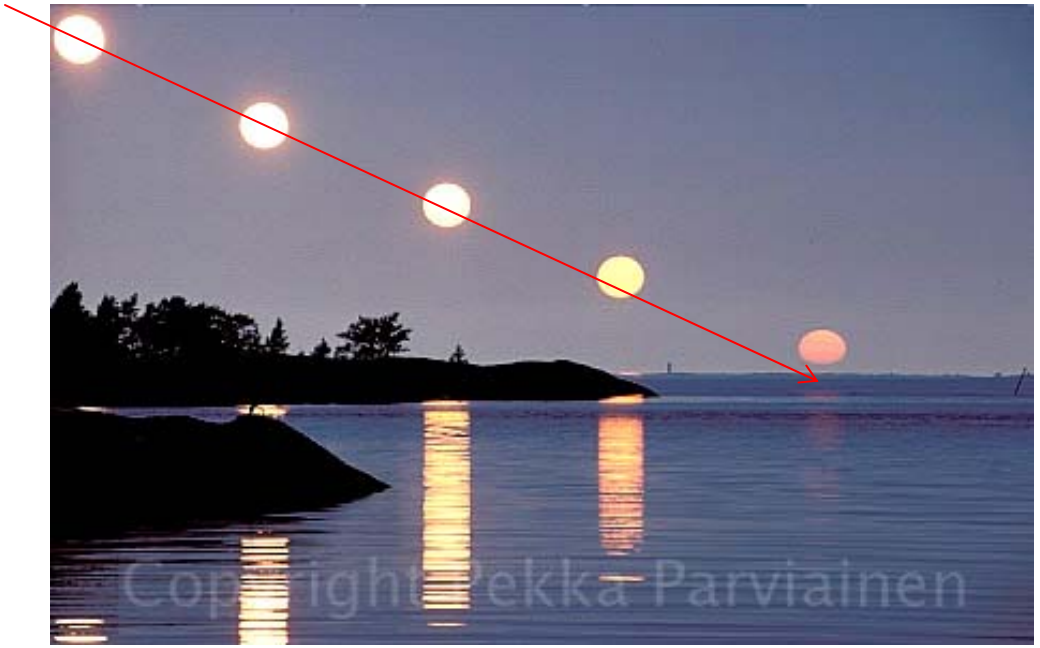


http://www.pafko.com/tycho/index.html

Refraction

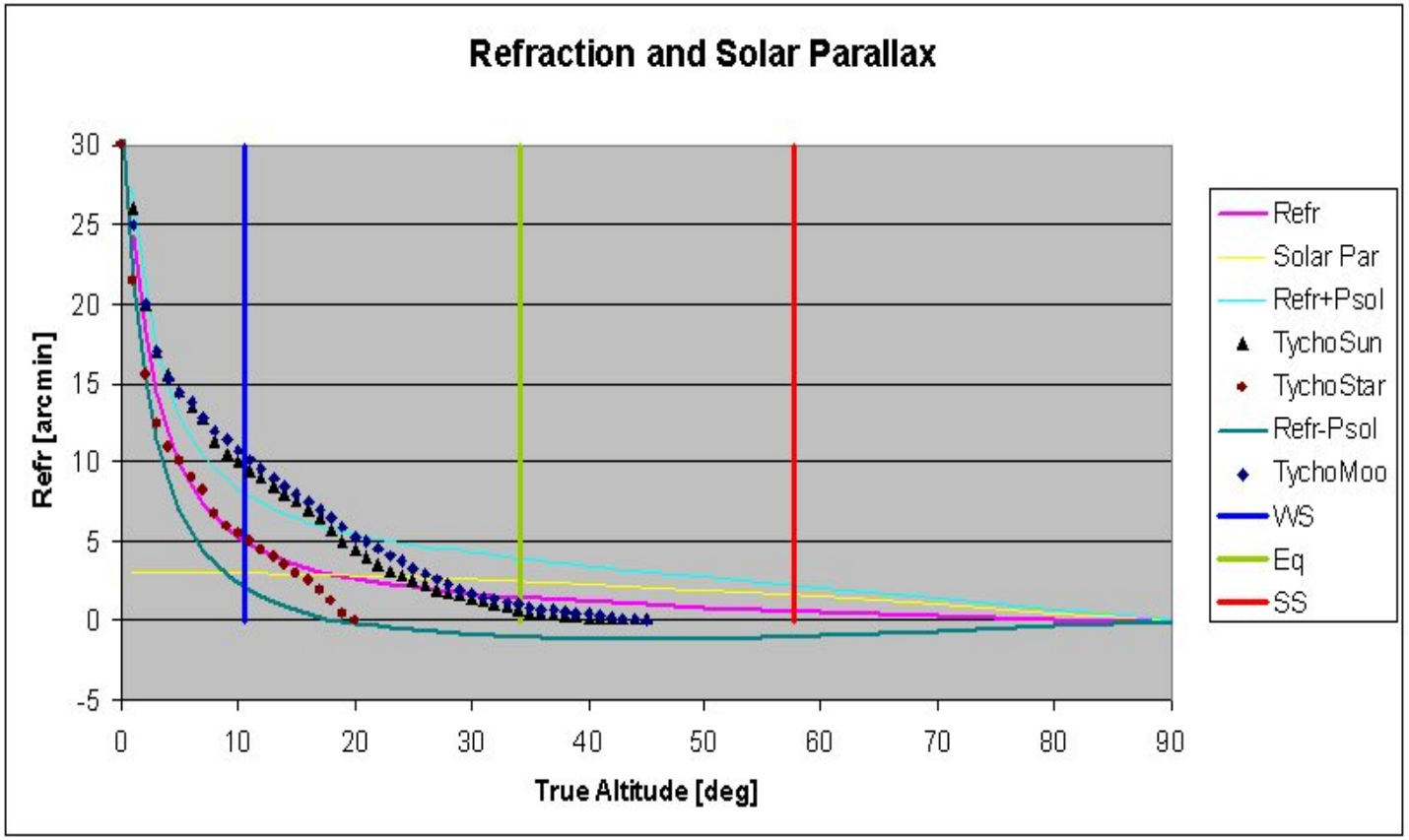


- At Winter Solstice 1583 Tycho discovers that “somehow” the Sun seems higher in sky than just
- In summer 84 the portable armillary used to measure 1-30 deg horizontal distances
- Separate refraction tables for Sun, Moon, Stars
- Refraction table for Stars = modern values
- Refraction Table for Sun / Moon distorted by a wrongly assumed parallax (distance)

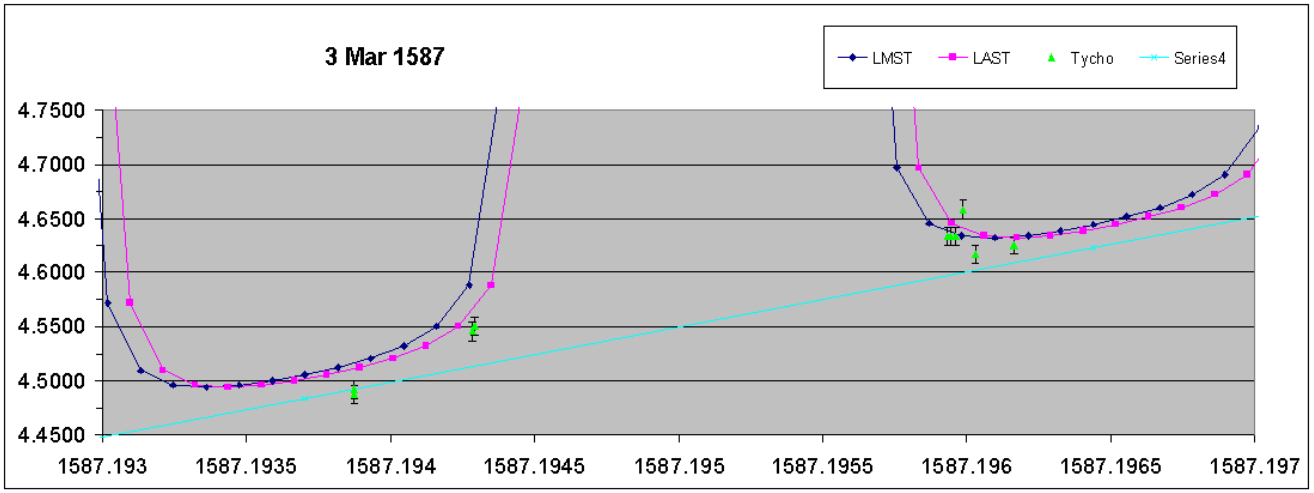


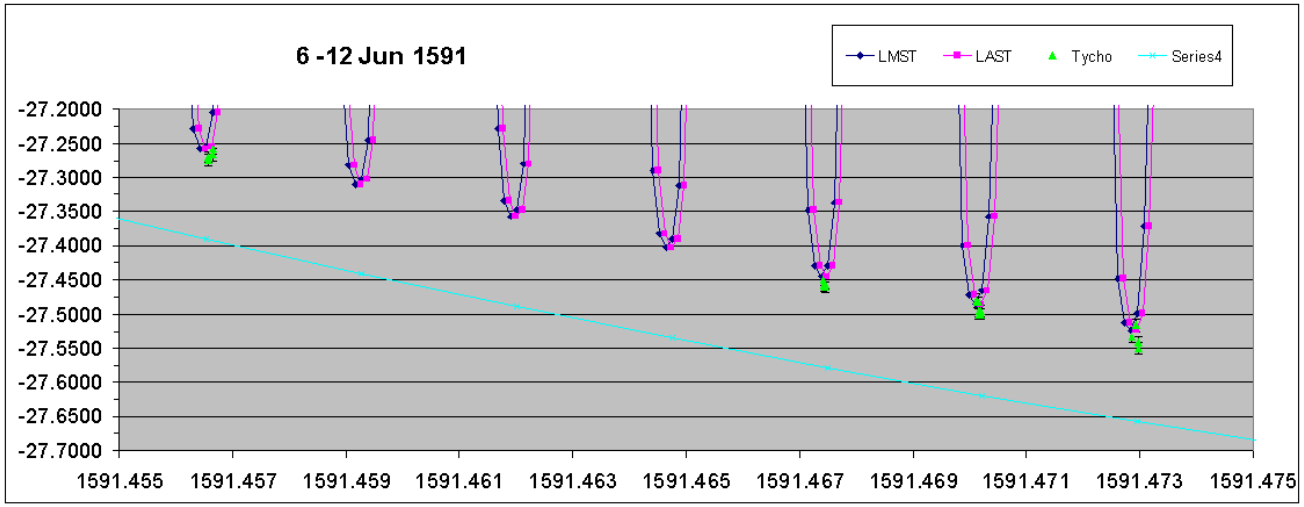
Refraction

Tycho first to systematically study refraction



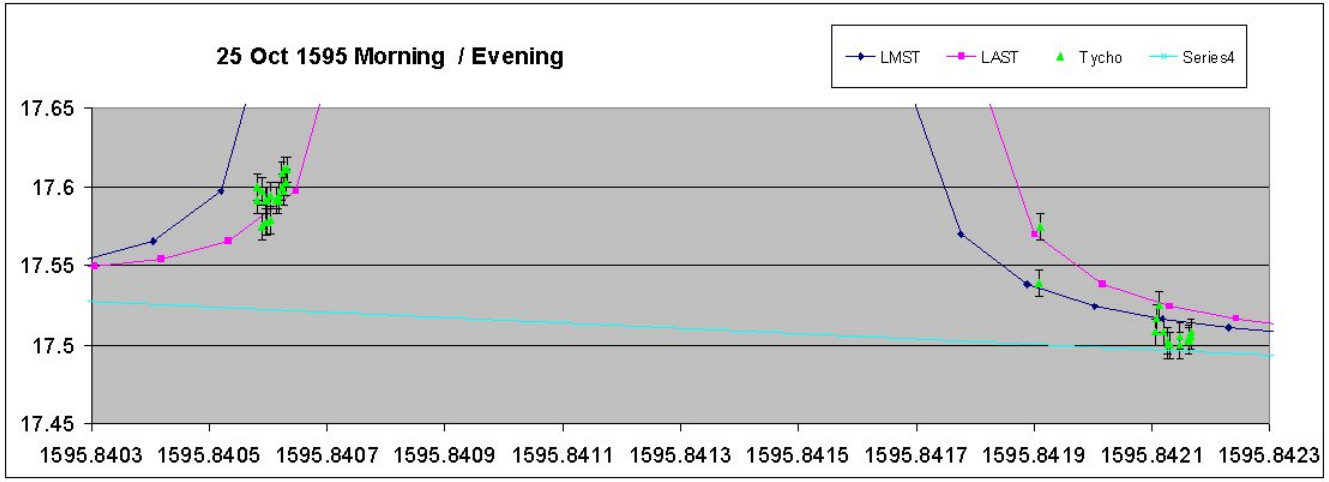
1587 Mar 3 - the Trial

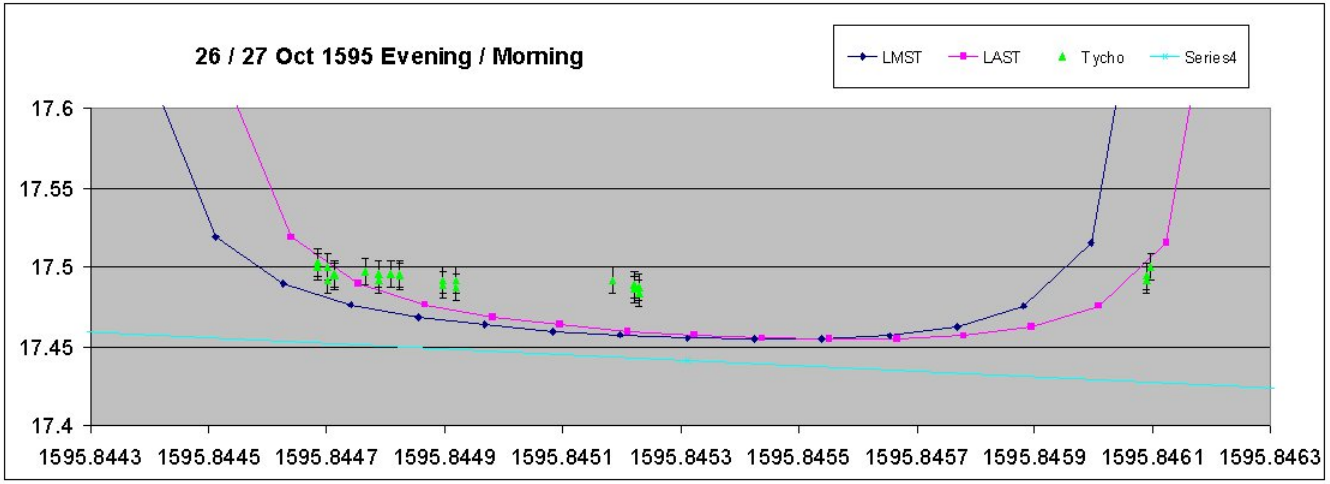




Some of the last Hven observations on Mars, 1595 Oct 25-27

- One of the best oppositions
- Yet - only one useful set
- Tycho not present.
- No special remarks that these are for parallax
- Clearly enthusiasm for Mars campaign had waned





Mars Parallax Anti-Copernican Result 1582-83

- Start Uraniborg build 1576, 1581 Quadrans Mayor+ Zodiacal armillary go on line. Oct 81 bifurcated sextant, replaced 3 month later by trigonal sextant (one of the most used inst.) 24-12-81 Quadrans maximus (steel quandrant). June 82 mural quadrant.
- Task 1: Fundamental stars (d < 45 from mural quad, longitudes using venus to link to sun) – long series in west elongation in Feb/March 82.
- 26/27 12 82 and 17 1 83 attempt to diurnal p of M
- Involves obs Mars near e\East in eve and near West in morning
- 26 12 at 20 30 M to Aldebaran = 44 41 (40 deg above Horiz)
- 27 12 at 7 15 Mars to Regulus = 36 43 (13 deg above Horizon)

Aldebaran-Mars	Eve 26 Jan	43 40.75
Mars-Regulus	Mor 27 Jan	36 34
Sum Longitude		80 14.75
Aldebaran-Regulus		80 4.5
Mars moved	in 10h 45m	10.25
Average motion M in 4 days 26/30 from Meridian obs	1 deg 40’ = 1’ 2.5” per hour	Expected motion alone 11.25
Copernican Parallax should give	2’ 1” eve 2’ 36” mo 4’ 37” total	Expected incl Parallax 15.75
Result		-1’ (negative Par)

How to test Keplerian Theory in mid 17th century

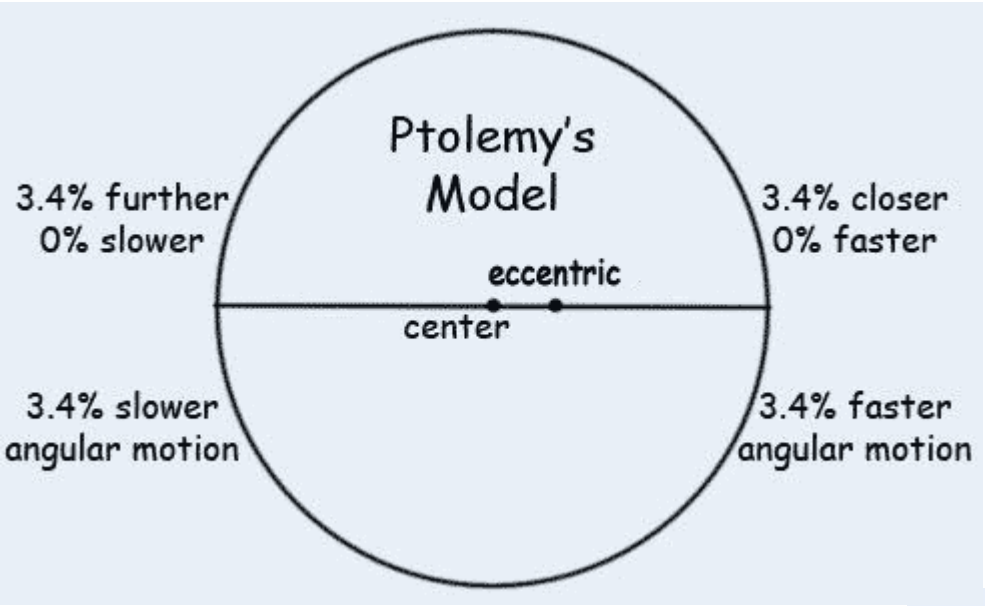
- **Subtle truth – not really possible**
  - for another 2 centuries, no other classical observational data available, simultaneously as homogenous, accurate and precise as T Brahe's.
  - testing "Kepler-from-TB-data" against "TB-data" is not decisive

- **So what to do ?**

How to test Keplerian Theory 3

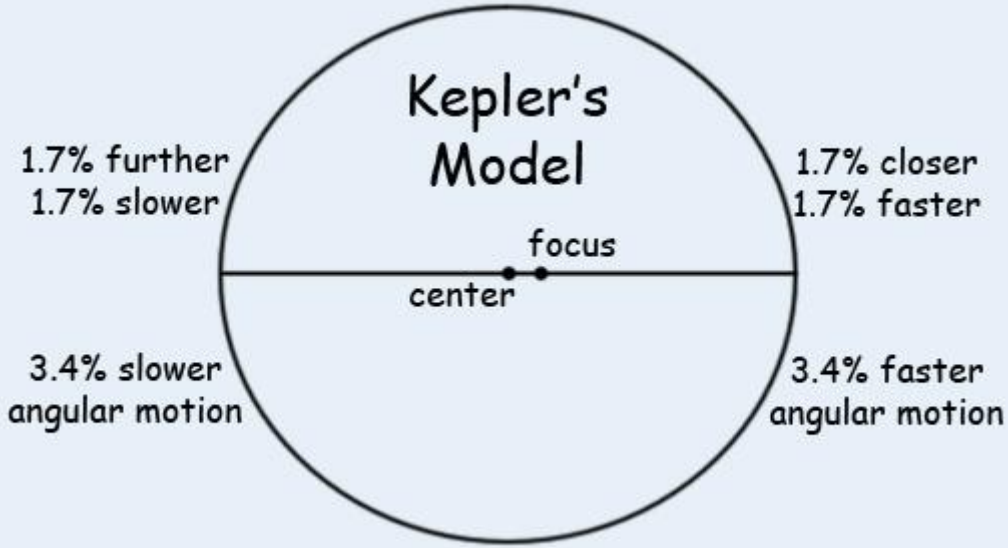
- **Roman Church & Jesuits come to help**
  - using the Meridiana in Bologna (Basilica of San Petronio)
    - 4500 observations of solar timings, diameters
    - -- compiled in Manfredi's (1735) register

How to test Keplerian Theory 2



Solar image 3.4% or only 1.7% larger/smaller in the two apsides depending on model (Ptolemy/Kepler)

Cassini (1695) shows from these data that Kepler's theory of planetary motion was most likely to be correct



The End

- Driven from Denmark - tries to find a place to “finalize” the WORKS
- Namely: Complete underpinning of Tychonic World Model with scale
- Requires staff with math capabilities – here comes Kepler
- Meanwhile is approaching paranoia w.r.t. fraud and steeling of data (case Ursus)
- Hands out only very selected parts of Mars data -- does not want to have the scale issue go public
- Has Kepler swear that he will use the data only to produce the Tychonic Solution
- Meets Emperor with Kepler – Kepler designated as successor
- On 24 Oct 1601 dies from/with urological congestion
- 1990ies analysis of beard hair finds enormously large Mercury dose
- Old Myth: Drank to much and did not go out
- New Myth: Poissoned by (eg Kepler) to get onto his data (that is largely refutable)
- My prop.: Had enough, saw that things went 180 degrees astray, knew Alchemy

✞ 13 Oct 1601 Prag

Ex »De Vita Et Morte DN. Tychonis Brahei etc. - Oratio Funebris a D. Iohani Iessenii.»

Nihil fictum, nihil simulatum in ipso,
sed scapham scapham appellabat:
unde omne, quod sustinuit, odium.

From « Life and Death of Sir Tycho Brahe - Funeral Oration by Sir Johann Jessenius[+] »

[[+)] Rector of the University at Prague]

Nothing pretended, nothing feigned with himself,
but he called a tiny boat a tiny boat [*]:
From where all is the hatred, that he had to put up with.

[*)] "called a spade a spade" == was very outspoken