A quantitative analysis of the observations in the Sidereus Nuncius

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https://www.youtube.com/watch?v=AlmjKkVt0qE

Neutrino Telescopes
29 September 2025

Aula Magna G. Galilei
del Bo' di Padova

https://arxiv.org/abs/2503.12543

Context

I was here

- the name of this conference
- + this evocative location
- + a recent personal interest in the work of Galileo
- + my background (neutrinos)
- + the kind invitation of the organizers

This presentation!

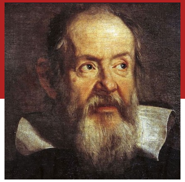
This presentation

I was here

Disclaimer: I am not an historian of Physics.
My focus: try to understand the accuracy & limitations of the observations of Galilei in the Sidereus Nuncius (especially Jupiter). As you will see, this exercise has "automatically" turned into a tribute to the experimental skills of Galileo.

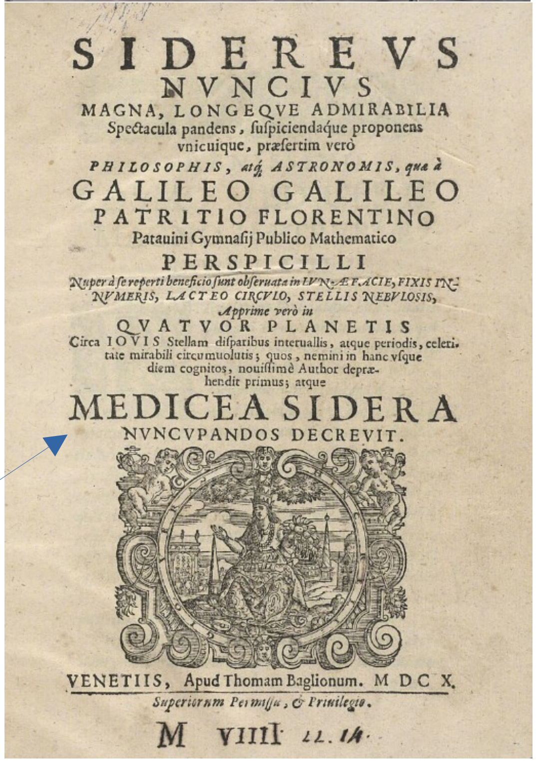
This presentation!

Galileo and Padova



"The best 18 years of my life …"

- Galileo lived in Padova from to 1592-1610 (28-46 years old)
  - from Pisa where he had already started his academic activity
  - he had been hired as professor of "mathematics"
- developed here most of the greatest scientific work of his career
  - Important partnerships
  - Developed instruments with his collaborators
  - Observation of the 1604 SuperNova
  - the groundbreaking astronomical discoveries with his "cannocchiale"
- **March 1610**: the **Sidereus Nuncius** is published in Venice (Starry Messenger)
  - An instant **best seller** throughout Europe
  - The satellites of Jupiter dedicated to Cosimo de Medici ("Medicean satellites")
- Galileo leaves for Florence in 1610 as **a world-level star** after having had the recognition of Kepler at those times the imperial astronomer, in Prague



SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in LVNÆ FACIE, FIXIS IN-
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M D C X.
Superiorum Permissu, & Priuilegio.

Galileo and the telescope

From a toy to a forefront scientific instrument

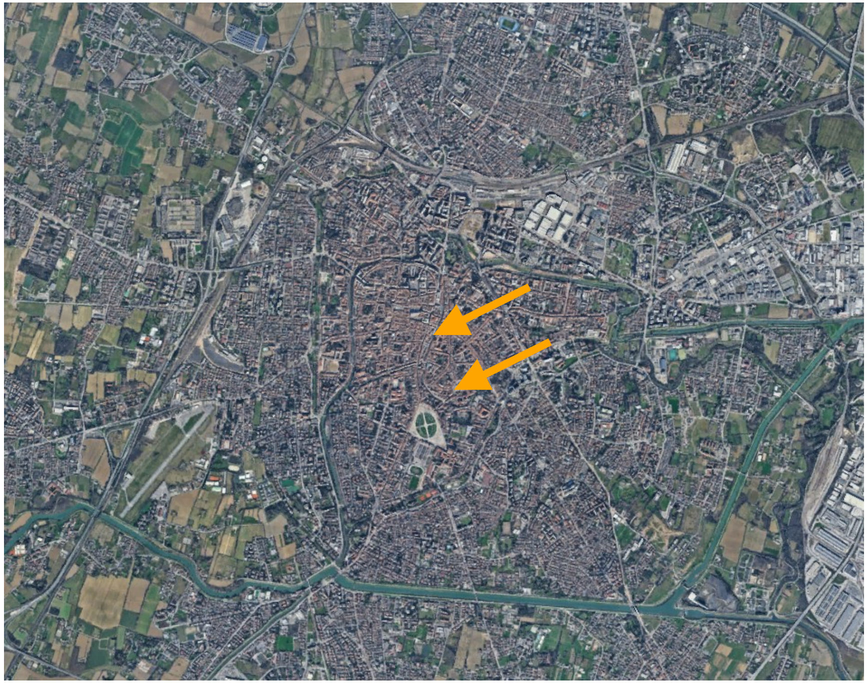
- Starting from ~**1608**, being initially a "military secret", low magnification telescopes based on concave lenses ("Galileian") had begun **spreading widely through Europe**.
- Seen as **"scientific toy/curiosity"** w. moderate magnifications (<10x)
- In **1609** Galileo manages to have one of these instruments in Venice
- He starts grinding lenses with longer focal lengths to increase the magnification. Lenses were a well known technology. Used for glasses and had short focal lengths.
- **August 1609** he manages to make a telescope with **~8x** .
- Demonstration to the "Doge" of Venice. Increase in salary.
- In **late 1609** he manages to reach **20-30x instruments** that open the scene to a "shrine" of groundbreaking discoveries!

August 1609

- In the Sidereus he, fairly, **does not claim the discovery of the telescope**. Still, according to some historians (i.e. Camerota, Giudice, Bucciantini) it seems that he "engineered" it with collaborators (most notably Paolo Sarpi). Not "acknowledged" due to "strategic" reasons … he did not take it well!

Where did Galileo observe from?

- From **his house in Padova** (presently a private residence at via G. Galilei 17)
- It is at ~ 650 m from here on foot, not far from Prato della Valle and the "Basilica del Santo"
- We know from letters that a few observations where done from Venice
  - where he was to prepare the printing of the Sidereus Nuncius (!)



Loggia e
Odeo Cornaro

The “crime scene”

Specola tower

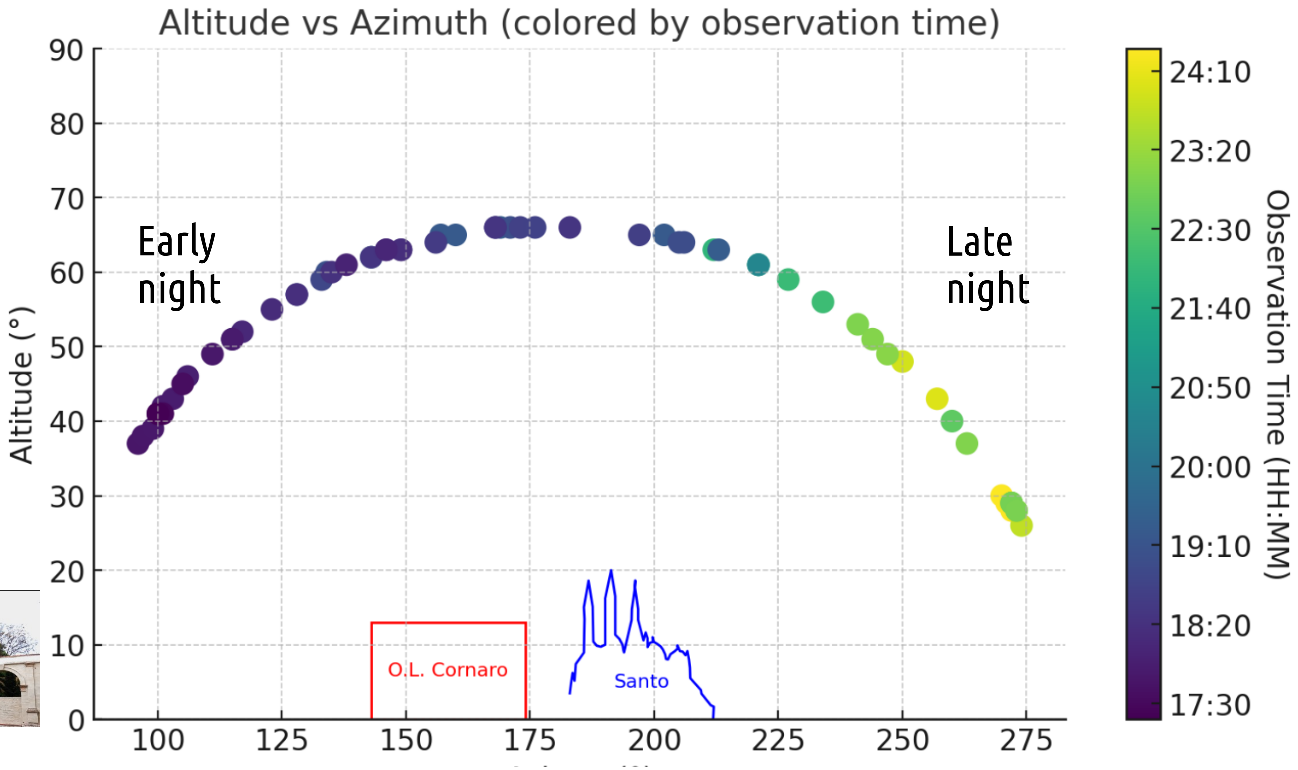
Ponte Molino tower

The skyline to the south with the Basilica del Santo

http://www.galileogalilei.padova.it/FotoGallery.aspx

The “crime scene”: consistency checks

- Position in the sky of Jupiter for the Sidereus Nuncius observations from Galileo’s house (alt., azimuth)
- Color indicates the observation time

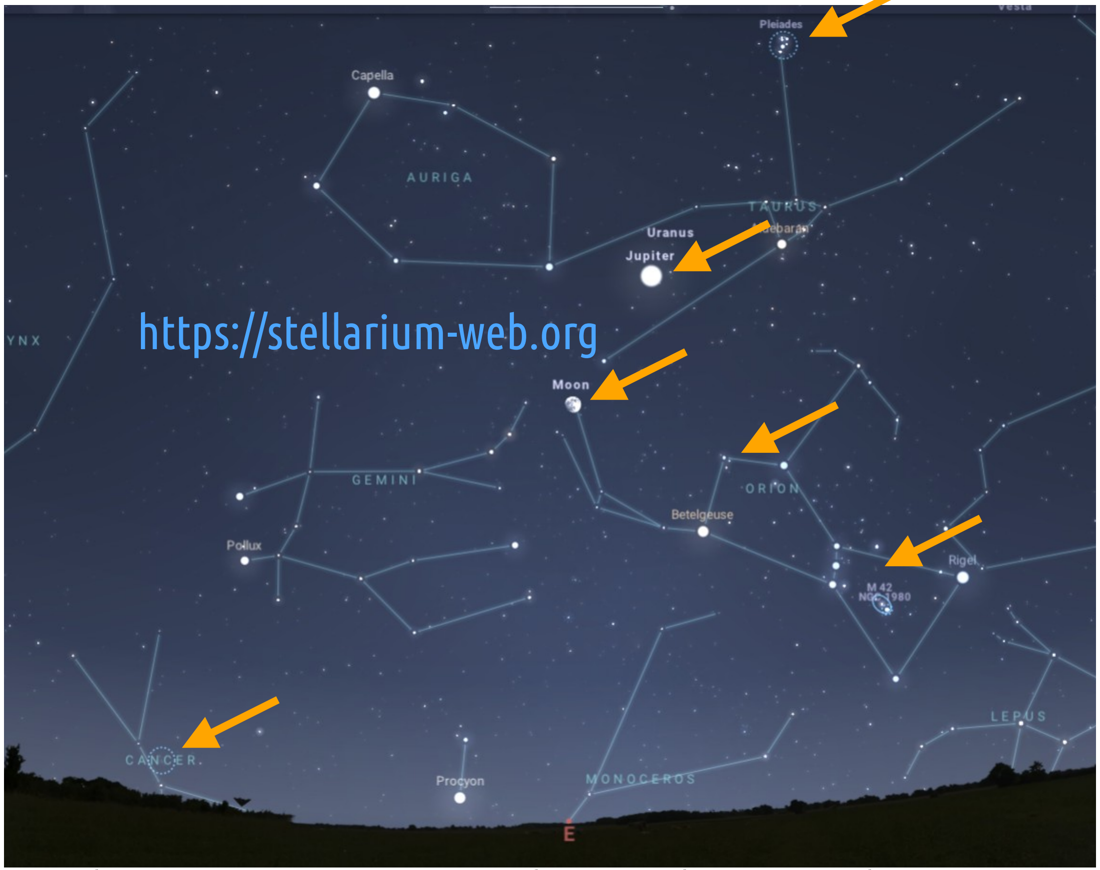


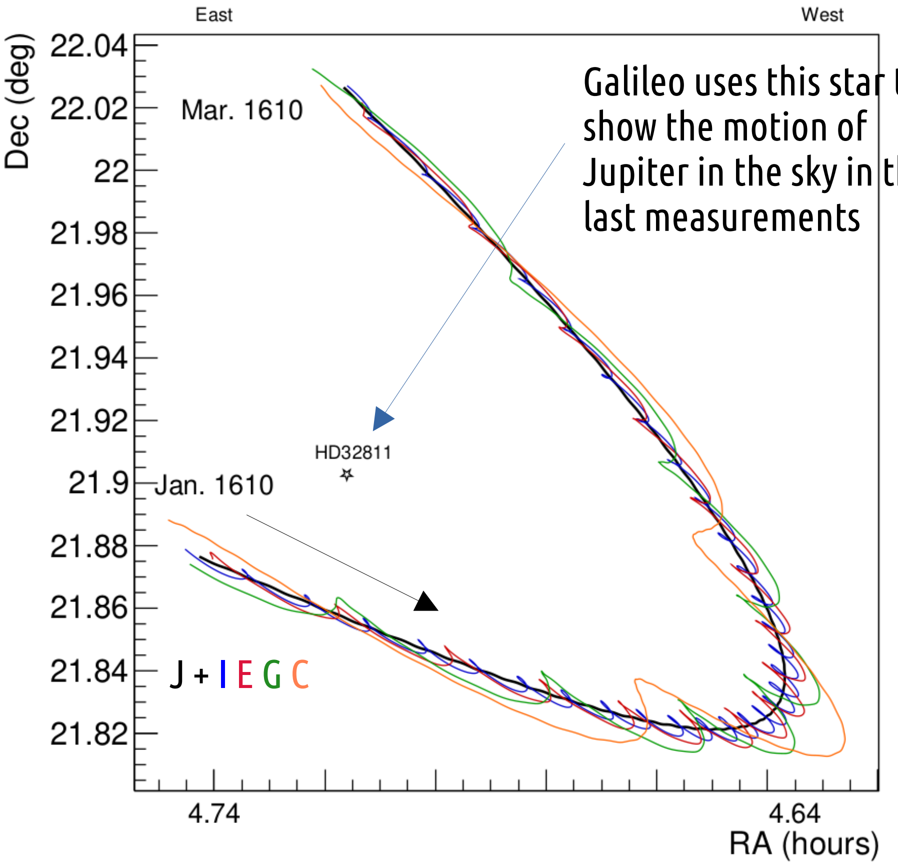
Loggia e Odeo Cornaro

Basilica del Santo

The sky scene on Jan 7th 1610

Jupiter is high in the sky in the constellation of the Bull, towards East in good company: the Pleiades, the Moon, Orion, Cancer (beehive cluster), famous actors in the Sidereus Nuncius





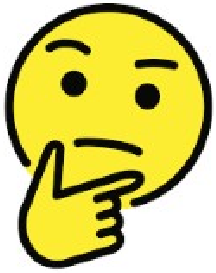
Galileo uses this star to show the motion of Jupiter in the sky in the last measurements

7 January 1610

"Hora prima": 1h after sunset ~17:45

Three bright "fixed" stars appear well aligned to each other and very close to Jupiter

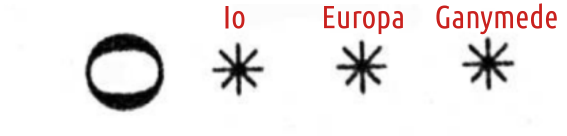
They are: Callisto, (Io+Europa unresolved) and Ganymede



8 January 1610

“guided by some unknown fate”, (“nescio quo fato ducto”) Galileo comes back to Jupiter again the night after …

7 Jan



8 Jan

The 3 stars are all to the left as if Jupiter had moved to the right (=West)

Strange: Jupiter was expected to move in the opposite direction … (slide 9)

Galileo is still a bit “easy going” he doesn’t notice Callisto on the left
(it will never happen again later)

Frustration, nostalgia for Tuscany

E' nugolo
(it is cloudy)

10 January 1610

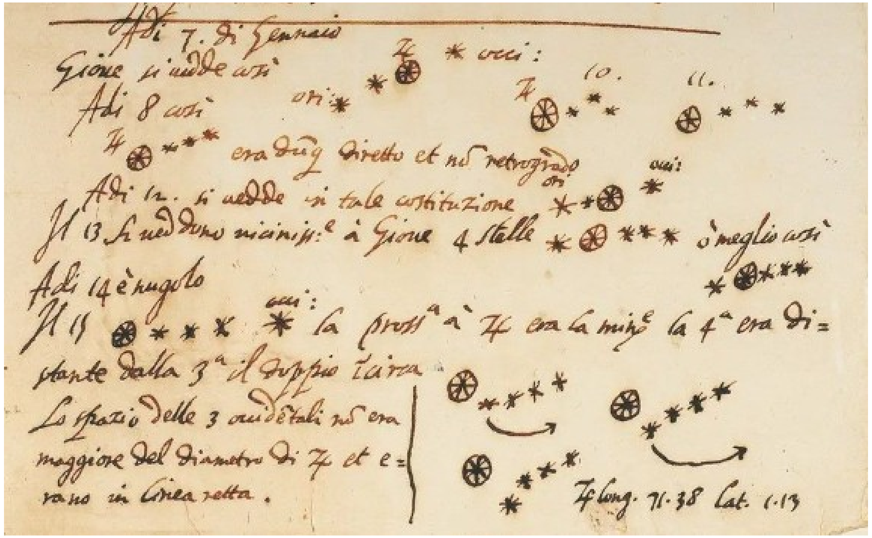
≠

The mundane explanation no longer holds water ...

Hypothetical “fixed” stars

Moreover... why only 2 ? how can one star have disappeared !?

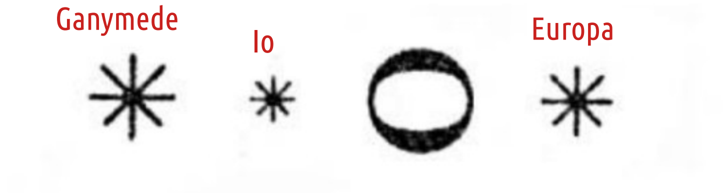
11 January 1610

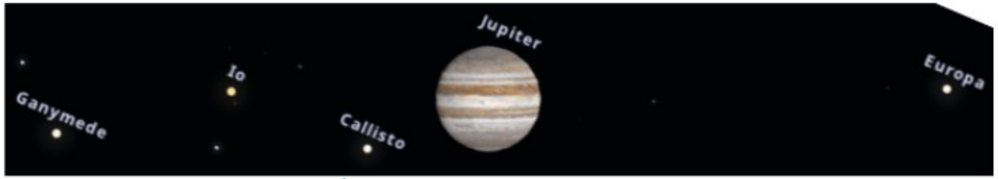


Again a different pattern with two!

Io and Europa are too close to the disk to be seen

12 January 1610





Back to three!
Callisto non seen – too close to the disk

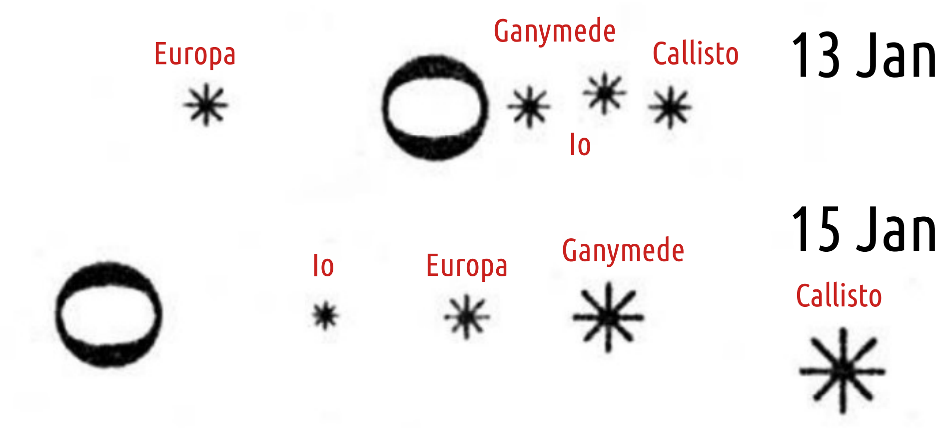
The full story

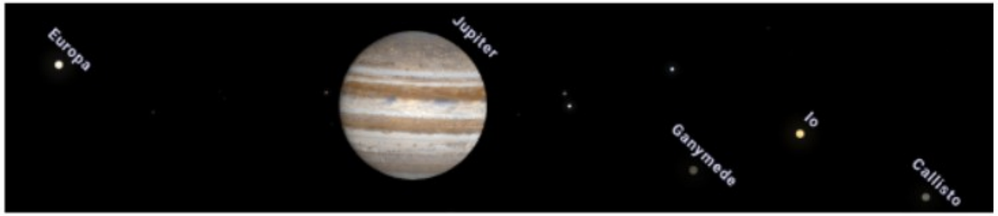
Animation of predicted positions + observations

https://www.youtube.com/watch?v=AlmjKkVt0qE

13-15 January 1610

On the 13th for the first time **all the 4 satellites are seen!**
Galileo starts taking this very seriously: after the 15th notes passes **from Italian to Latin** (in view of a publication), **multiple observations during each night**, reports **angular separations in the text** (not just drawings)





The "**sampling rate**" needs to be high as satellites are fast:
Io orbit takes ~1.8 days, Callisto 16.7 days

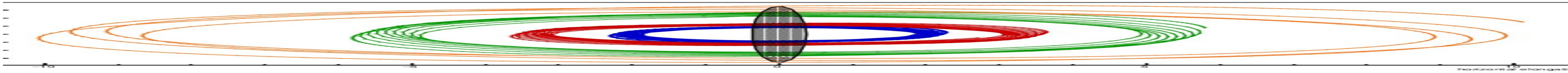
The breakthrough

"It was therefore established by me, and concluded beyond all doubt, that there are in the heavens **three wandering stars revolving around Jupiter, similar to Venus and Mercury around the Sun**; which was finally observed **more clearly than in broad daylight** through many subsequent observations: and not only three, but **four** were found to be the wandering stars performing their revolutions around Jupiter … **And I also measured the intervals between them with the method explained earlier**."

Vertical displacements

Notice the correspondence of the “vertical displacements”

From ephemerides:



The orbits are almost perfectly circular and lying almost exactly at the the Jupiter equatorial plane
The rotation axis of Jupiter forms an angle of 3.1° with respect to the Ecliptic
The inclination of the Jupiter’s orbit forms with the Ecliptic an angle of 1.3°

A multi-σ Copernican evidence!

Even though Galileo seems **genuinely surprised and "conservative"** in the first observations,

at this point he appears fully convinced of having discovered a "**miniature solar system**" in which Jupiter was the center of orbits

A "**smoking gun**" for Copernicanism!

The Earth is surely not the privileged center of revolutions!

Seems so natural to us …
how much more data is then needed ?

The Jupiter dataset

- **64 observations!**

- From Jan 7 to Mar 1

- From about 1h after sunset until about 2 a.m.

- The last observation of March 1st is **only 10 days earlier than the release in press of the Sidereus Nuncius!**

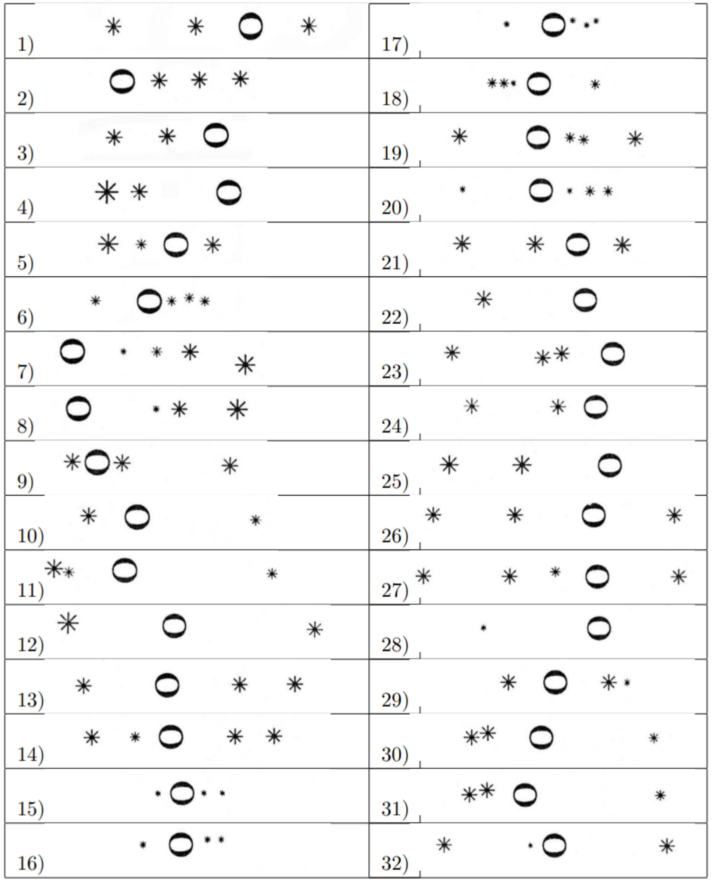


Fig. 1 Sidereus Nuncius sketches A, from January 7 to February 1st.

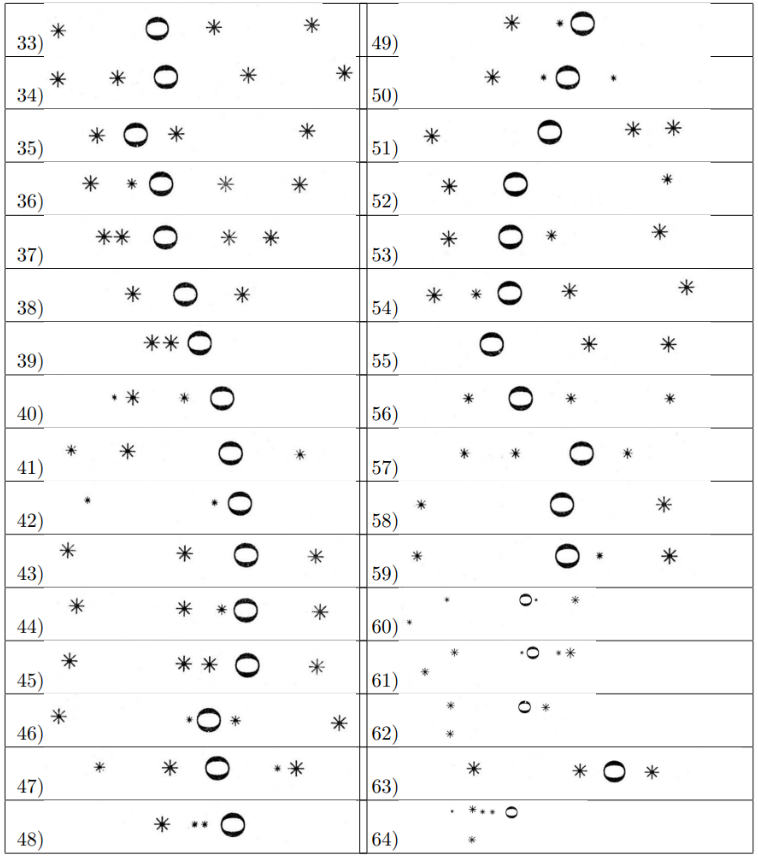


Fig. 2 Sidereus Nuncius sketches B, from February 2 to March 1st.

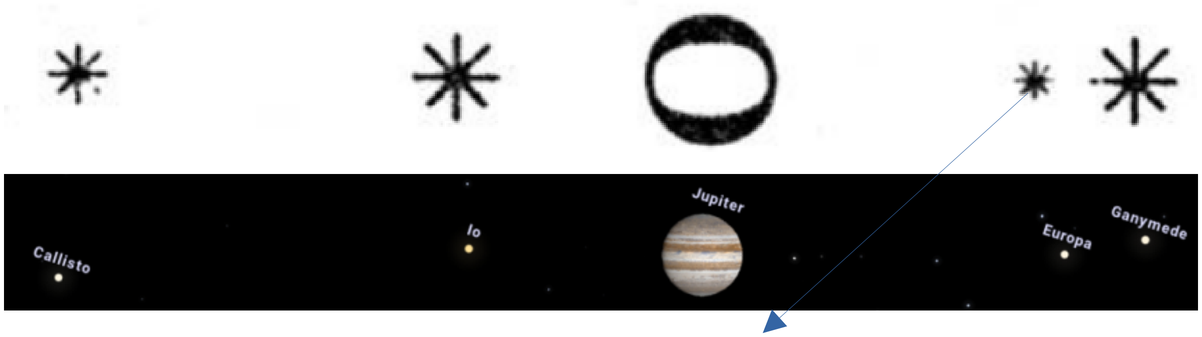
Big discovery needs big evidence

- Still, **collecting "a lot of data" was probably not a bad choice**:
  - the **"prior"** for this evidence was rather **controversial** (in hindsight…)
  - It served as a "protection" against potential **competitors**
    - Simon Mayr, Harriot …
  - Morever, as I will try to show:
    - 1) **convincing the "experts" at the eyepiece was not obvious**: the first demonstration of Galileo to his colleague Magini in Bologna was a "failure". People started to say that the instrument was producing artifacts (Spica, α-Virginis, appeared as double).
    - 2) **these observations did not come absolutely "for free"**!
      - measurements were DIFFICULT and making good telescopes not easy.

Experimental data + powerful instruments

- Whatever the reason… this **stress on "experimental data" is particularly charming for a "modern scientist"** (especially considering how easily claims are put forward nowadays) as well as the **iconic demonstration of the power of new scientific instruments**!

- PS: also the time between the collection of data from a new "frontier" instrument and the (single-author) "publication" induces some envy …

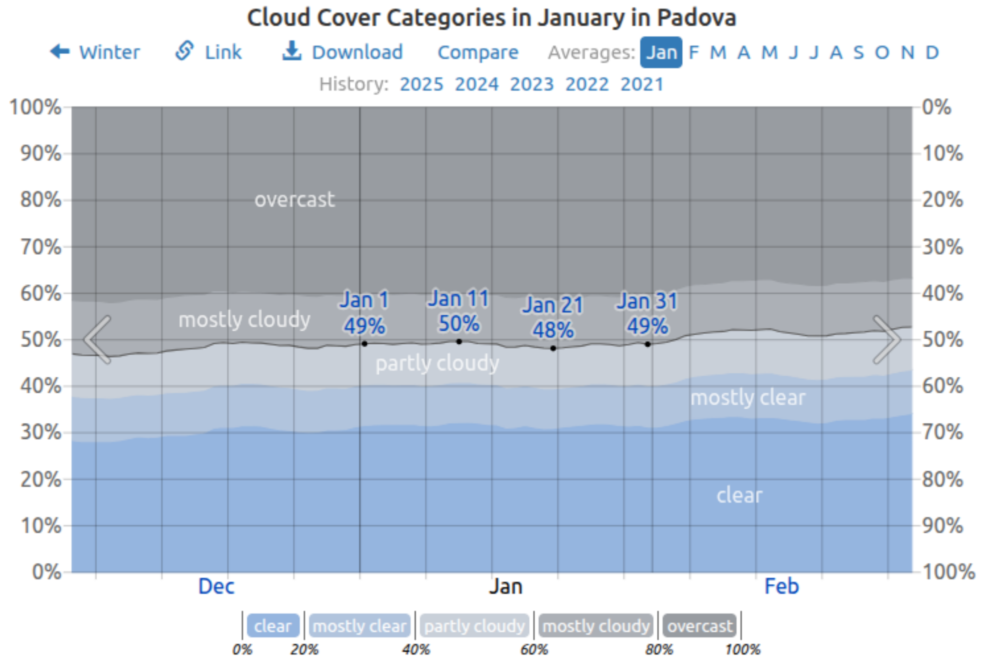


The size of the marker is a proxy for magnitude

Let's have a deeper, systematic look to what this man was capable of in those 54 frantic days →

Collaborative weather

- It is interesting to notice that the weather was very “collaborative” in 1610 in Padova: just **10 cloudy days over 54** against an average of **>50%** nowadays



The percentage of time spent in each cloud cover band, categorized by the percentage of the sky covered by clouds.

https://weatherspark.com/m/69432/1/Average-Weather-in-January-in-Padova-Italy

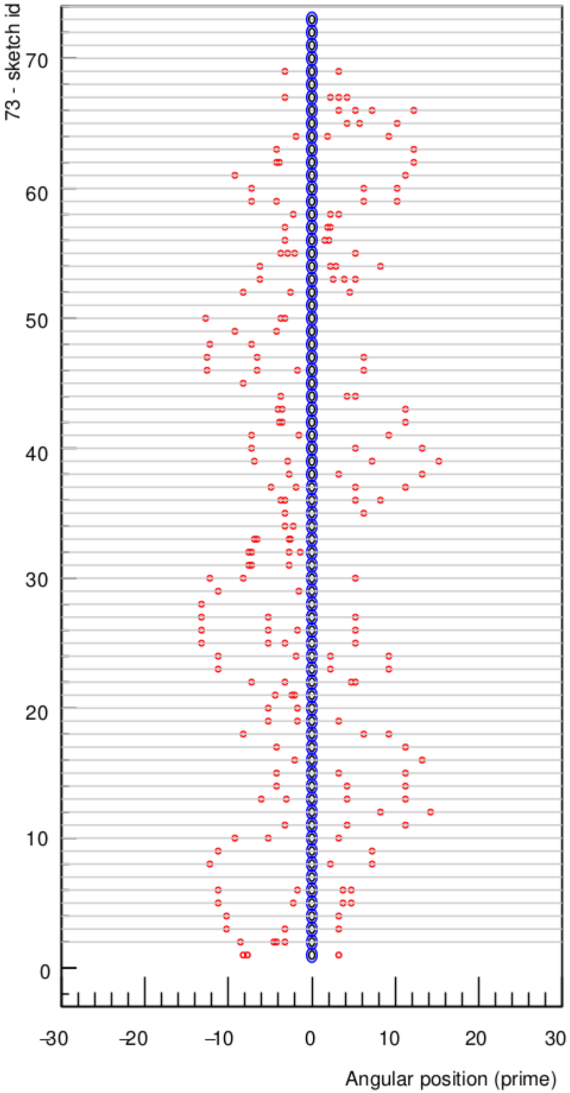
The dataset

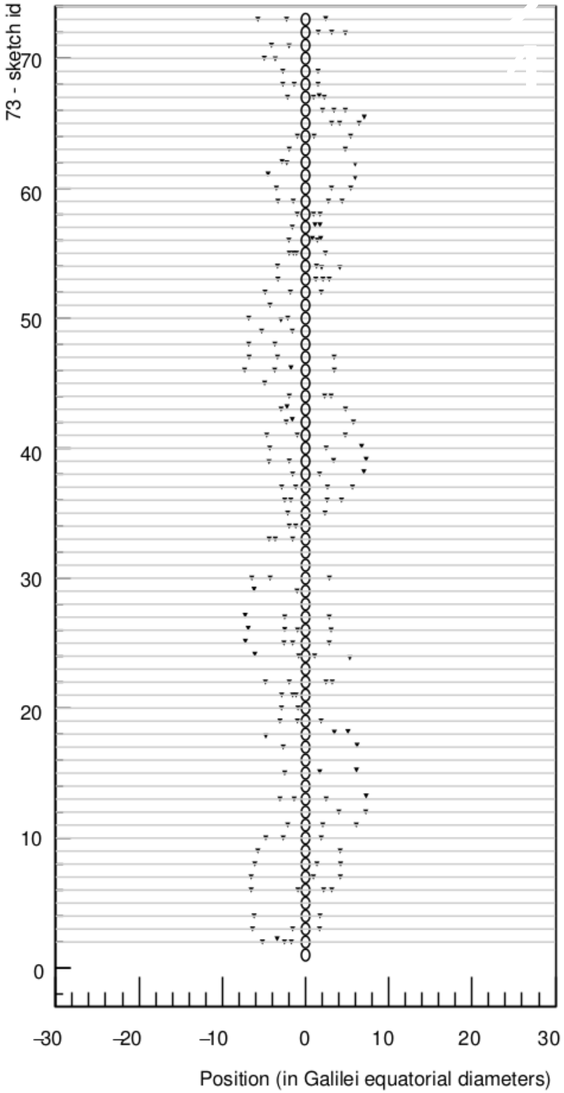
Can exploit two datasets

- 1) the digitized sketches in the Sidereus Nuncius. We express distances in fractions of the Jupiter disk as in the sketches themselves
- 2) the angular measurements reported in words in the text (usually reported as separations between adjacent satellites)

2) are **the real measurements** 1) are passed through the printing process.

We have 64 sketches. Angular measurements appear after some days but sometimes we have the angles but not the sketches.





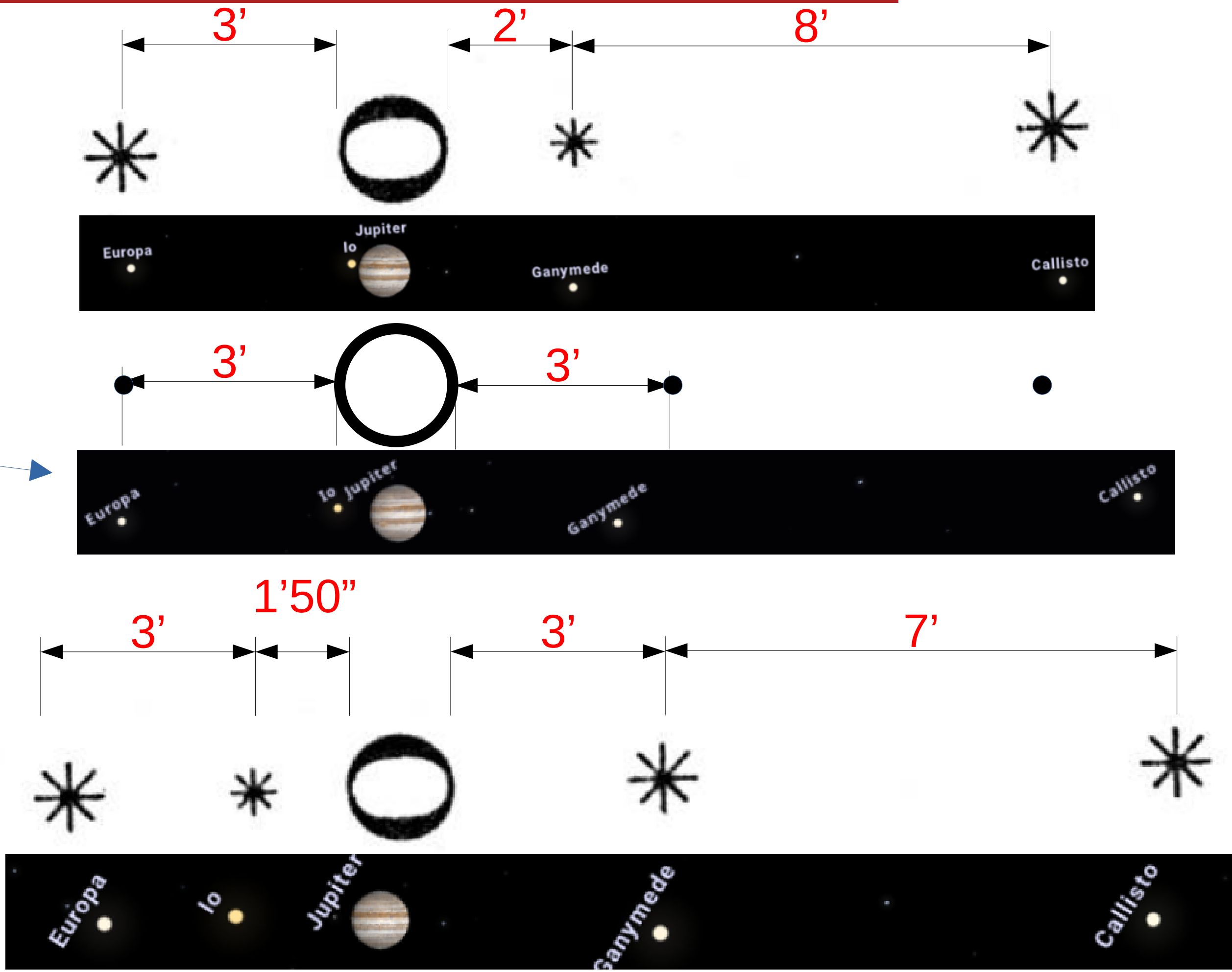
How data are presented: example

… On the 18th day, at the first hour, there were three stars, two to the west and one to the east: the eastern one was 3 minutes from Jupiter; the nearer western one 2 minutes; the other, farther west, was 8 minutes from the middle one. All were exactly on the same straight line, and nearly of equal size.

But at the second hour, the Stars nearest to Jupiter were equally spaced, since the western one was 3 minutes away as well.

No sketch

Then, at the sixth hour, a fourth little star appeared between the eastern one and Jupiter, in the following configuration. The farthest east one was 3 minutes from the next, that one 1 minute and 50 seconds from Jupiter, Jupiter 3 minutes from the next western one, and that one 7 minutes from the farthest western one: they were nearly equal; only the eastern one closest to Jupiter was a little smaller than the others; and they were on the same straight line parallel to the Ecliptic…

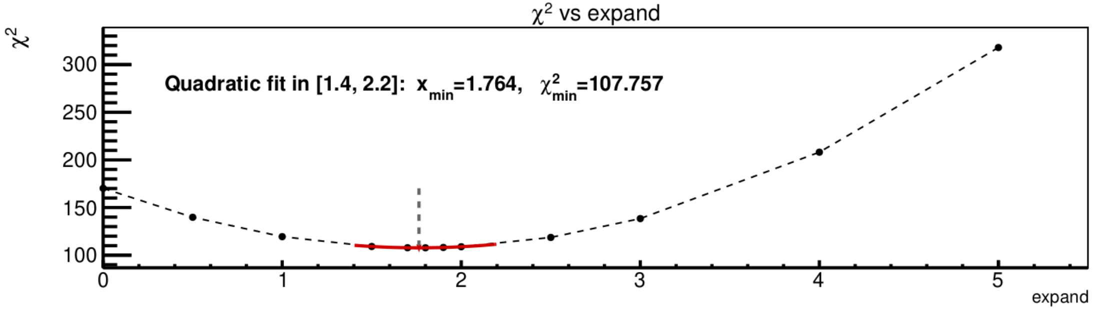


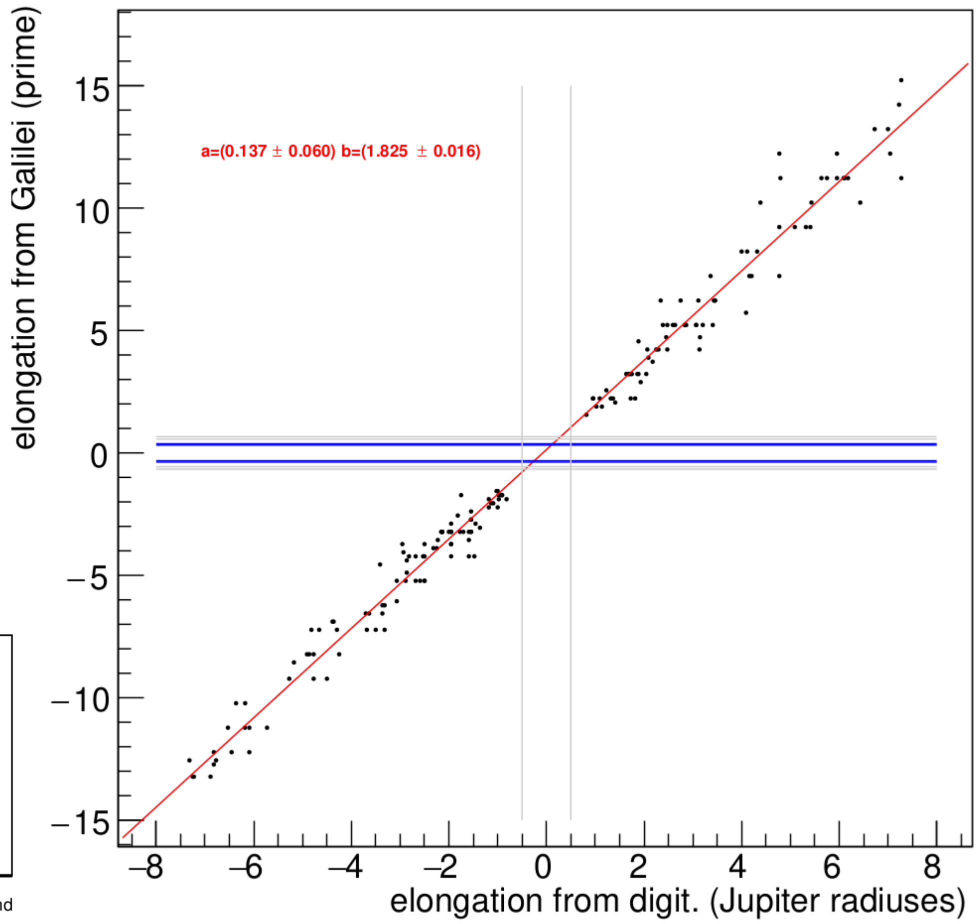
Digitized in J. diameters vs angular measurements

- The two datasets are well correlated provided that measurements are **interpreted from the edge of the disk (otherwise the positive and negative arms have a clear offset)**

- We have fitted the angular dimension of the disk that maximizes the linearity: **ε=1.73 corresponding to 79-67”** (the true size varied from **45” to 38”**)

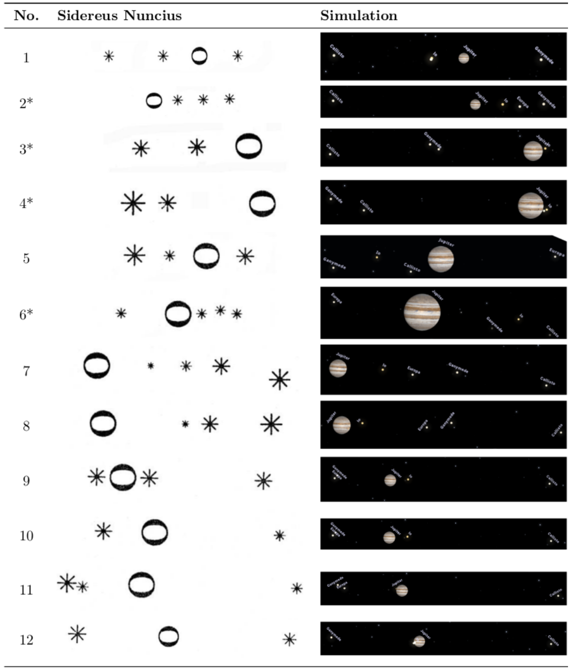
$$\theta_i^{corr} = \theta_i + \text{sign}(\theta_\text{i})\epsilon\frac{\Delta_\text{avg}}{2}$$

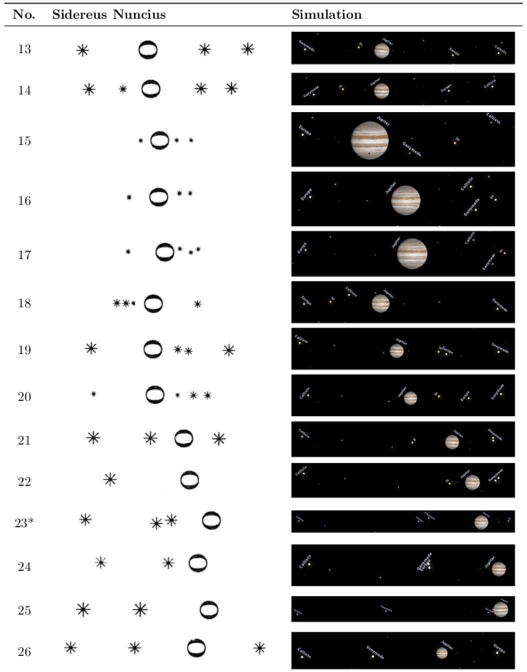


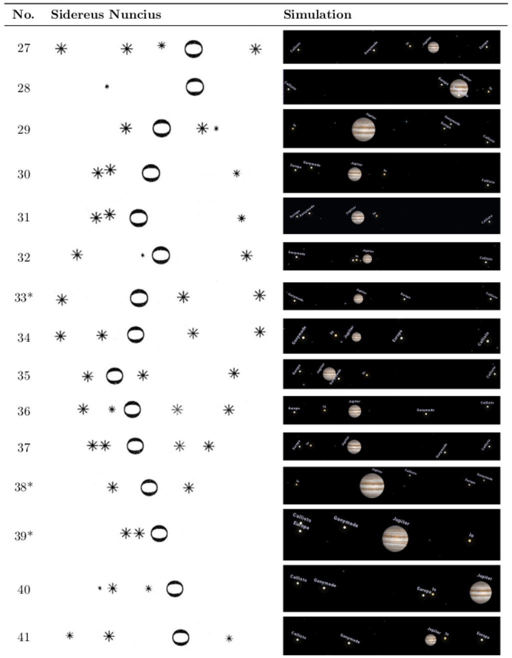


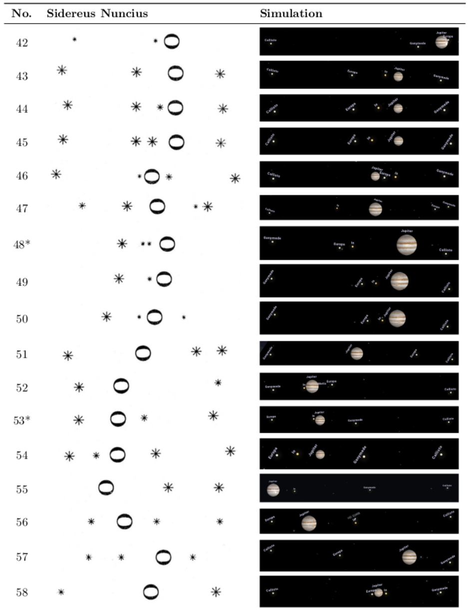
Comparison with the simulation

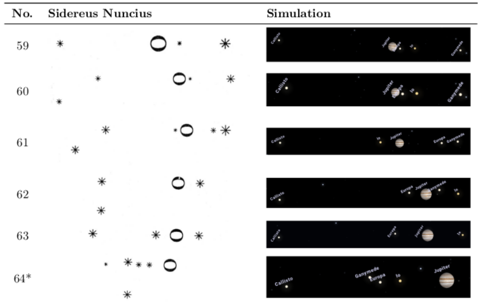
Considering the inefficiencies when satellites are too close to each other or to Jupiter, **all the observations are consistent with be simulation except one**!
n. 46 of 12/2/1610





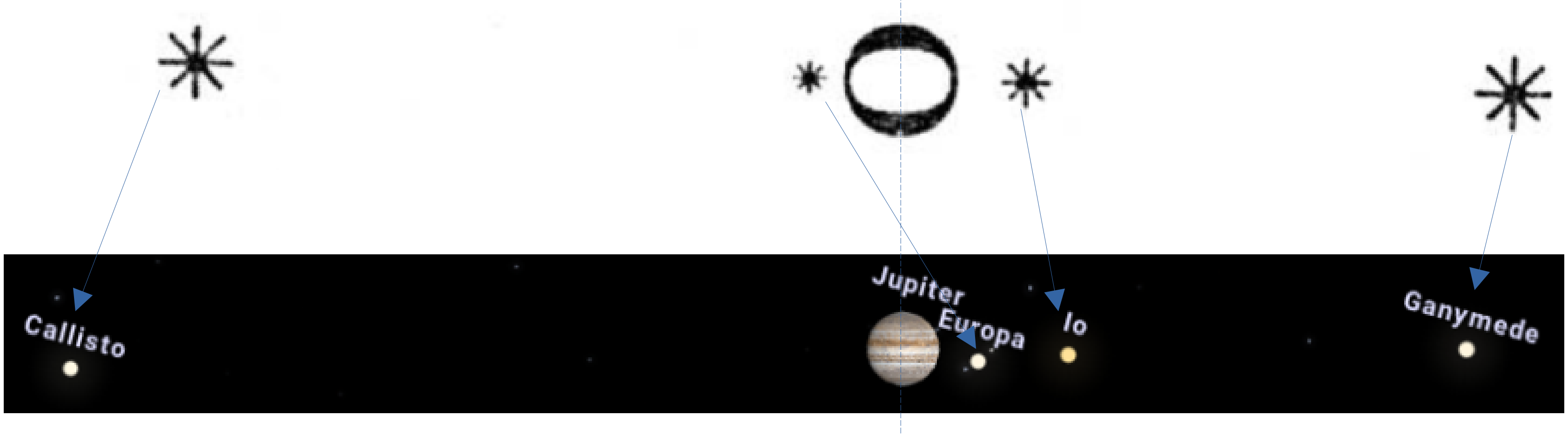






Errare humanum est, traveling diabolicum

Observation n. 46 of 12/2/1610



The Portello fluvial harbour in Padova

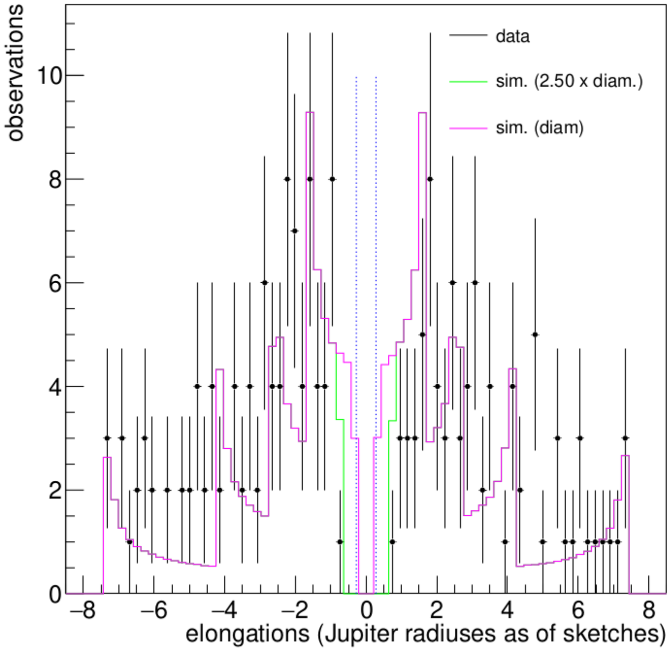
- Considering possible errors on the reported time cannot explain the pattern.
- From a letter we know that Galileo was traveling back from Venice to Padova that day!
  - Maybe he drew the sketch some time later, from memory.
  - Elongation is about correct but the side is wrong.

As is still true today, Galileo had to cope not only with teaching but also with traveling

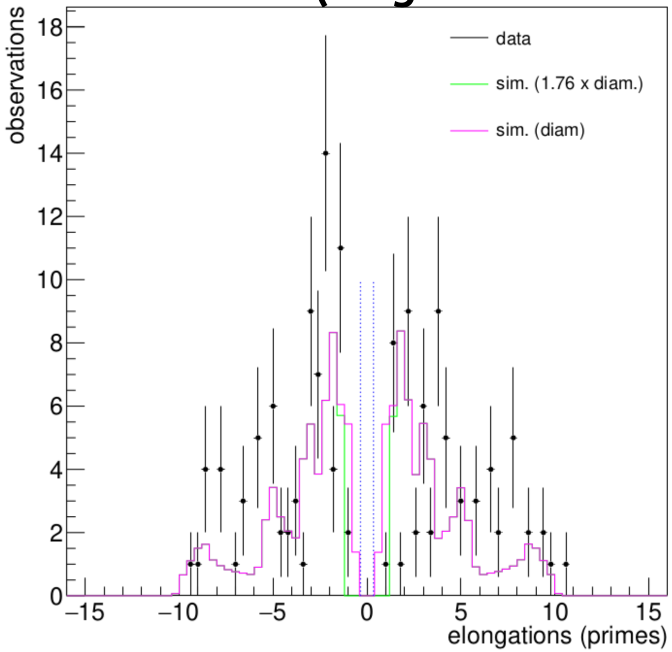
Distribution of the elongations

- This can be seen as an easy, level-0, check that the motions are 4 harmonic motions without disentangling the satellites individually (hard!)
- The prediction is a sum of 4 harmonic motions. For dataset2 it takes into account J. getting further → smearing
- Allows seeing qualitatively the depletion in the proximity of Jupiter (more quantitative later)

Dataset 1 (digitization)



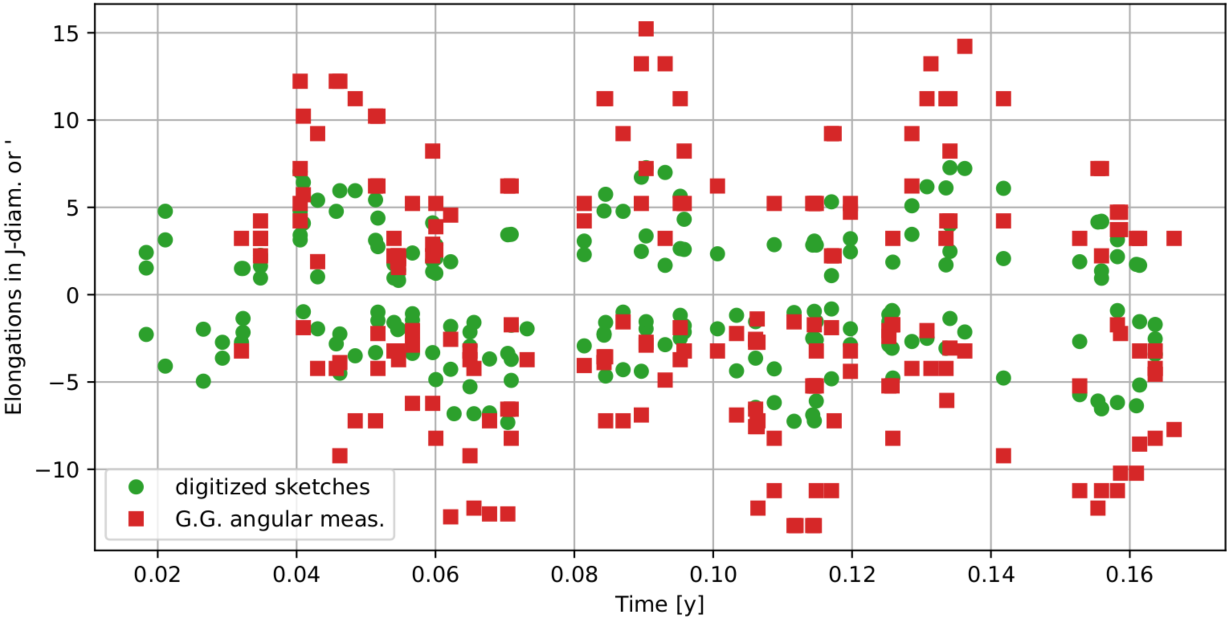
Dataset 2 (angle measurements)



Determining the periods

- Galileo itself in the Sidereus Nuncius solicits astronomers to perform better measurements to determine the periods → **soon recognized as a first class scientific program**

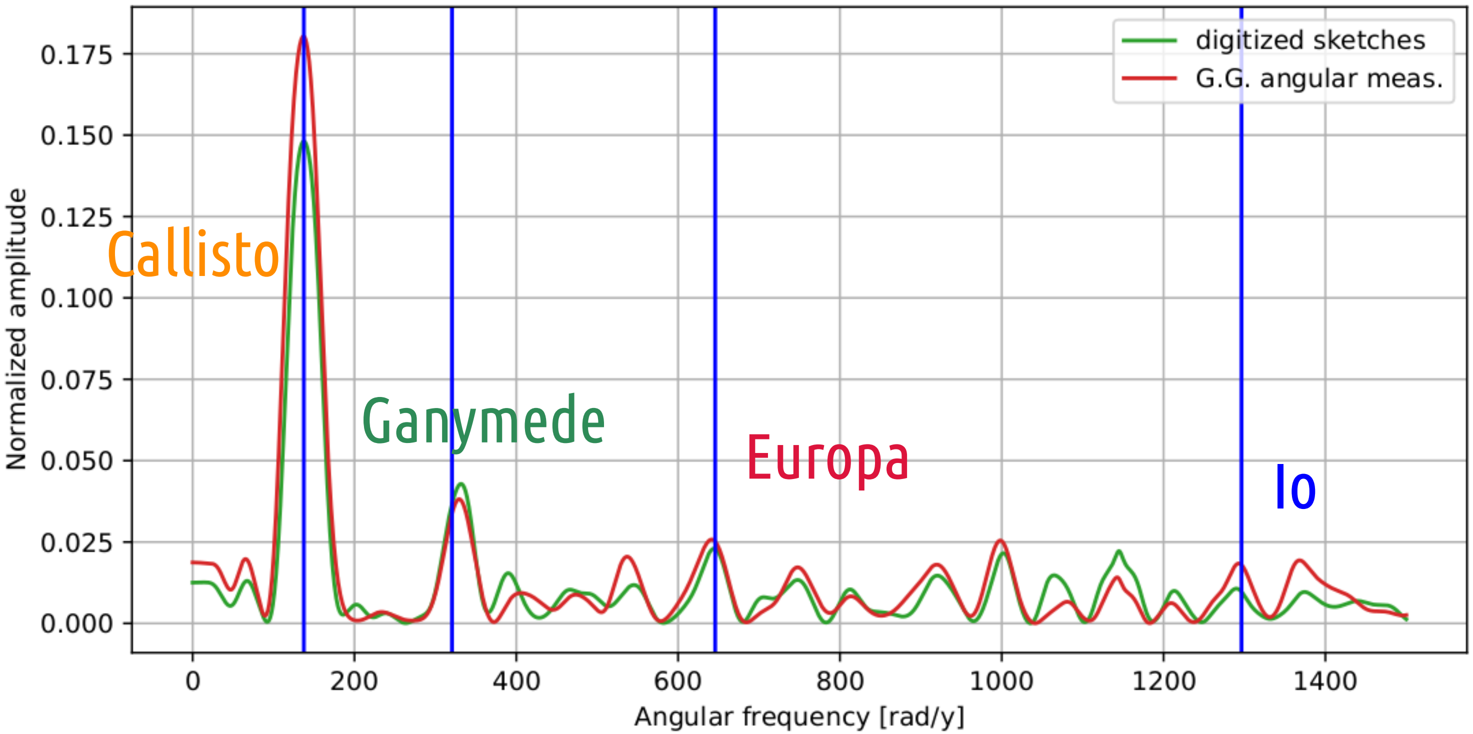
- Were later used to **measure "c"** !
- More practical hope: use as an absolute clock → **determine the longitude** (but telescopes are as unconvenient as pendulums on ships…)



- Galileo focused on this problem until 1617 with better and better measurements
  - in competition with other astronomers (i.e. Peiresc, Harriot, Mayr,…)
- **But can we get the periods from these early data with the help of some modern analysis ?**

Determining the periods

Lomb-Scargle periodograms (frequency analysis for sparsed datasets)



Callisto and Ganymede signals are significant, Europa and Io compatible with background (but small peaks appear at the correct positions)

Satellite-tagging with simulator

We have then used the simulator (stellarium-web) to tag the observations to satellites and produce four separate datasets (~"cheating")

→ new Lomb-Scargle analysis

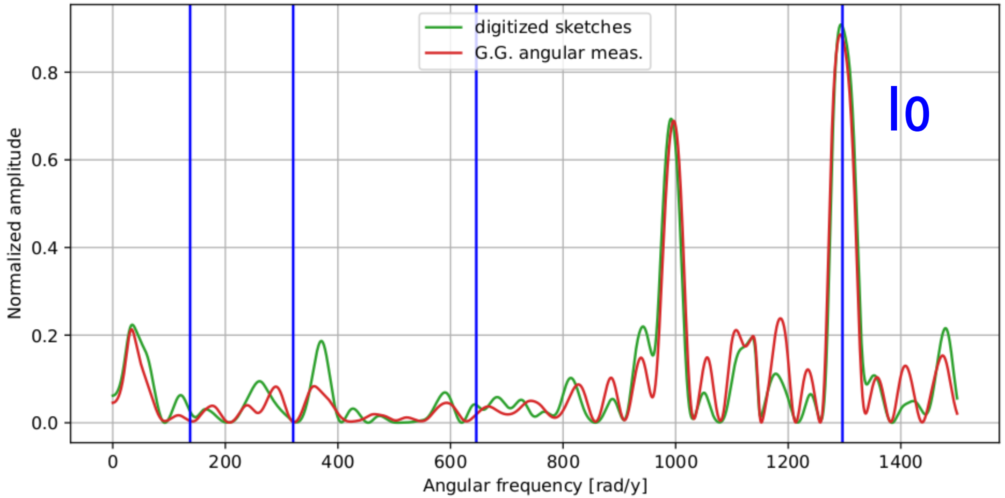
id	comment	pattern	not seen
1		CI ⋆ G	
2	C unseen	⋆ IEG	C
3	G-E unresolved. I too close to J	CE ⋆	I
4	IE too close to J	GC ⋆	
5	I-C unresolved	GC ⋆ E	
6		E ⋆ GIC	
7		⋆ IEGC	
8		EGC	
9	G-E unresolved	I ⋆ EC	
10	G-E unresolved. I too close to J	G ⋆ C	I
11	I behind	GE ⋆ C	
12	I-E close in transit	G ⋆ C	
13	I unresolved too close	G ⋆ EC	I
14		GI ⋆ EC	
15	G unresolved too close at right	E ⋆ IC	G
16	C/G unresolved	E ⋆ CI	
17		E ⋆ CGI	
18		EIC ⋆ G	
19		C ⋆ IEG	
20		C ⋆ IEG	
21	G/E unresolved	CI ⋆ E	
22	IEG too close to J	C ⋆	IEG
23	I too close to J on the right	CEG ⋆	I
24	E-G unresolved, I behind	CG ⋆	
25	IE too close to J (right)	CG ⋆	IE
26	I behind J	CG ⋆ E	
27		CGI ⋆ E	
28	EI too close to J, G in transit	C ⋆	EI
29	G-E unresolved	I ⋆ GC	
30	I (right) too close to J	EG ⋆ C	I
31	?		
32	E-I unresolved	GE ⋆ C	

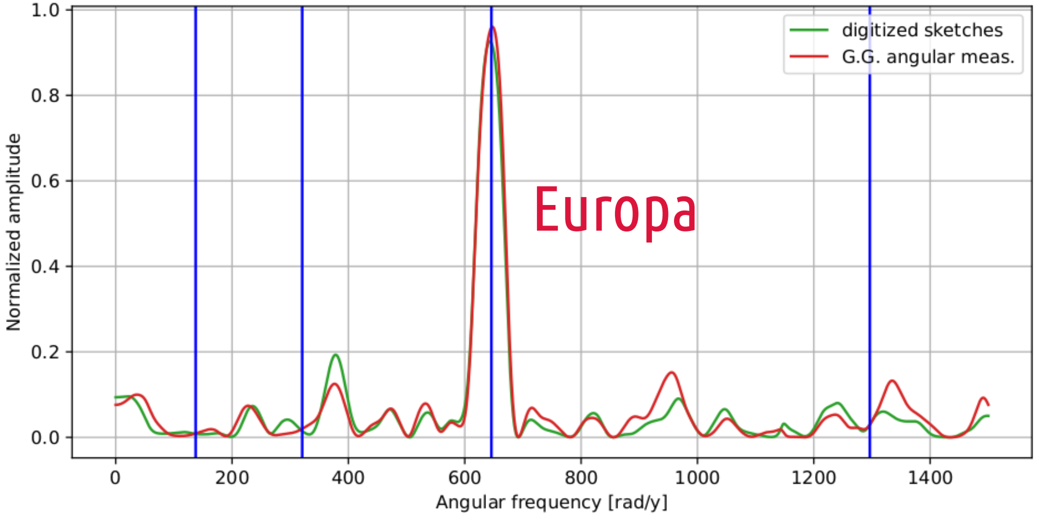
Table 5 Summary of satellites association with comments.

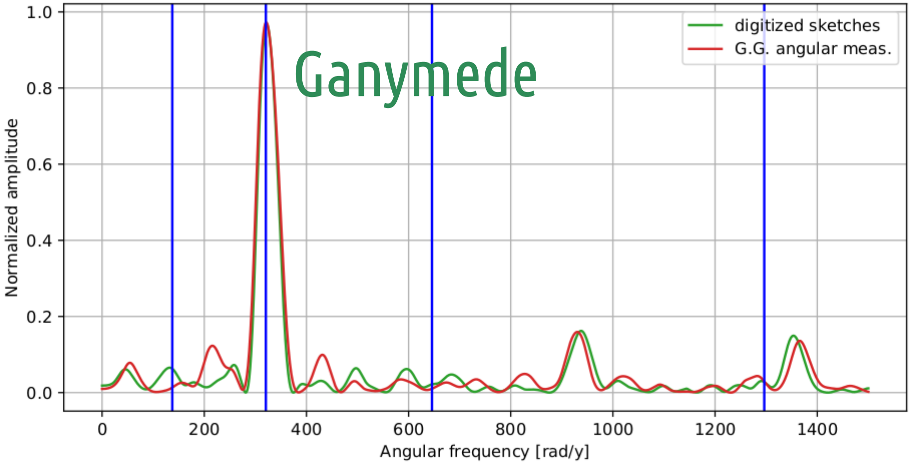
id	comment	pattern	not seen
33		G ⋆ EC	
34		GI ⋆ EC	
35	G too close to J (right)	E ⋆ IC	G
36		EI ⋆ GC	
37		EI ⋆ GC	
38	C too close to J (right), E-G unresolved	I ⋆ G	C
39	C-E unresolved, I too close to J	EG ⋆	I
40	I-E unresolved	CGE ⋆	
41	I too close to J (right)	CG ⋆ E	I
42	I-E on transit	CG ⋆	
43	I too close to J (left)	CE ⋆ G	I
44		CEI ⋆ G	
45		CEI ⋆ G	
46	I seen on the other side than expected (see text)	CI ⋆ EG	
47		CI ⋆ EG	
48	C (right) too close to J	GEI ⋆	C
49	I too close to J (left), C close (right)	GE ⋆	IC
50	I too close (left)	GE ⋆ C	I
51	I behind	G ⋆ EC	
52	I too close (left), E too close (right)	G ⋆ C	IE
53	I too close (left)	E ⋆ GC	I
54		EI ⋆ GC	
55	I too close to J (right), E in transit	⋆ GC	I
56	G behind	E ⋆ IC	
57	I behind	CE ⋆ G	
58	E (left) and I (right) too close to J	C ⋆ G	EI
59	E too close to J (right)	C ⋆ IG	E
60	E too close to J (right)	C ⋆ IG	E
61		CI ⋆ EG	
62	E (left) and G (right) too close to J	C ⋆ I	EG
63	G behind	CE⋆I	
64		CGEI ⋆	

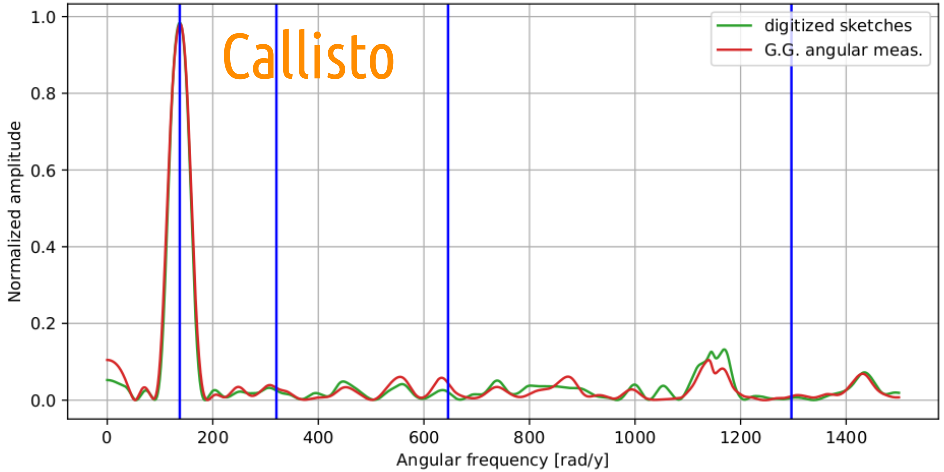
Table 6 Summary of satellites association with comments.

Lomb scargle of tagged samples



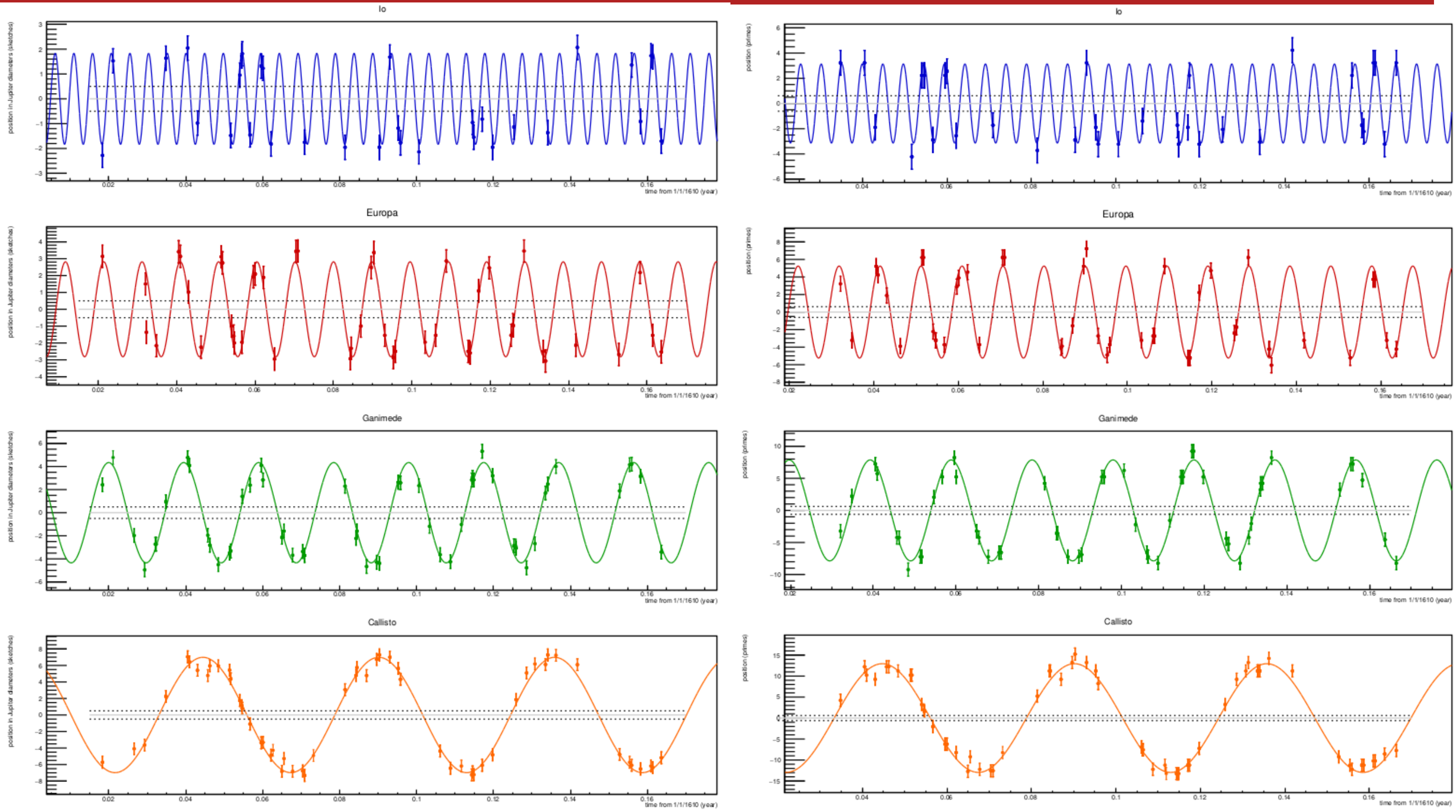


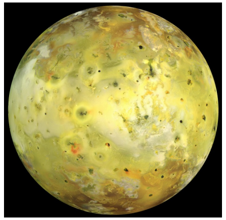


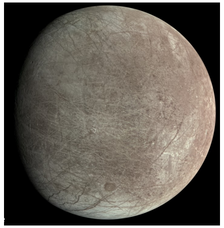


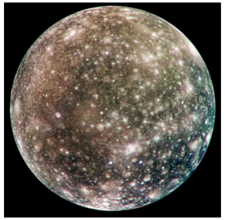
Sinusoidal fits

Amplitude, phase, frequency: free parameters







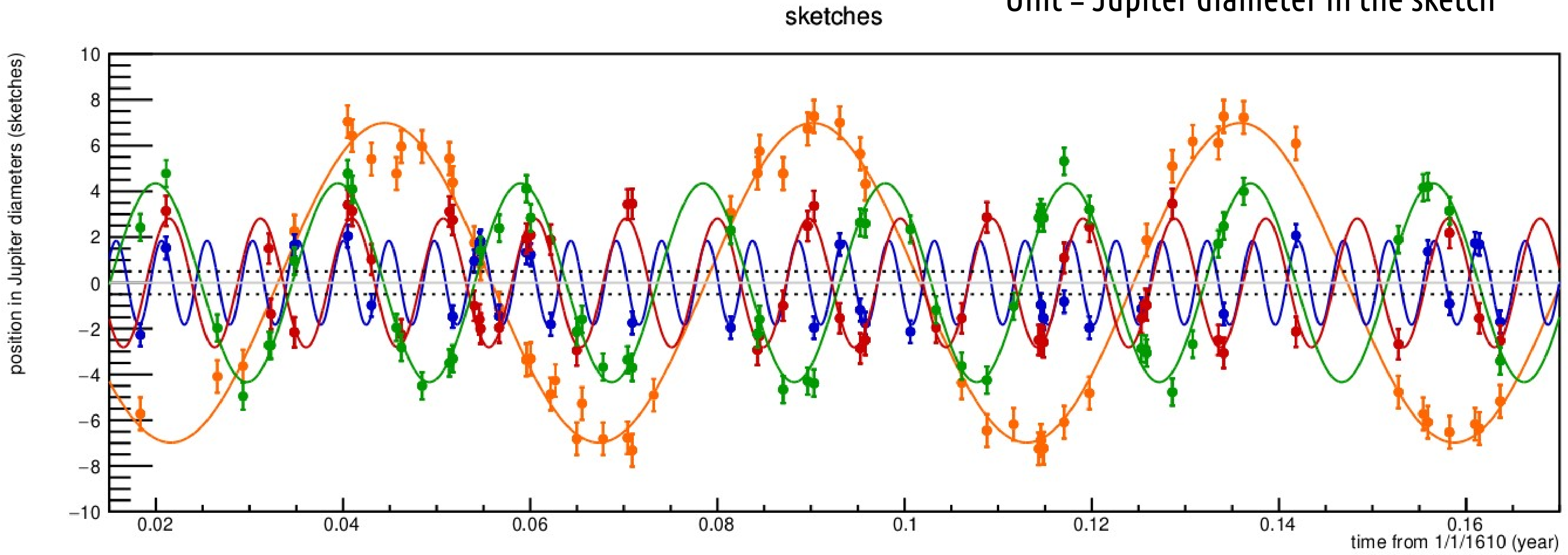


Sinusoidal fits (dataset 1 - digitized)

The error bars are determined as the error "a posteriori" (to make χ^2 /N-3 = 1) they are an estimate of the uncertainties

	σ_I	σ_E	σ_G	σ_C
dataset-1	0.49	0.66	0.59	0.71

Unit = Jupiter diameter in the sketch

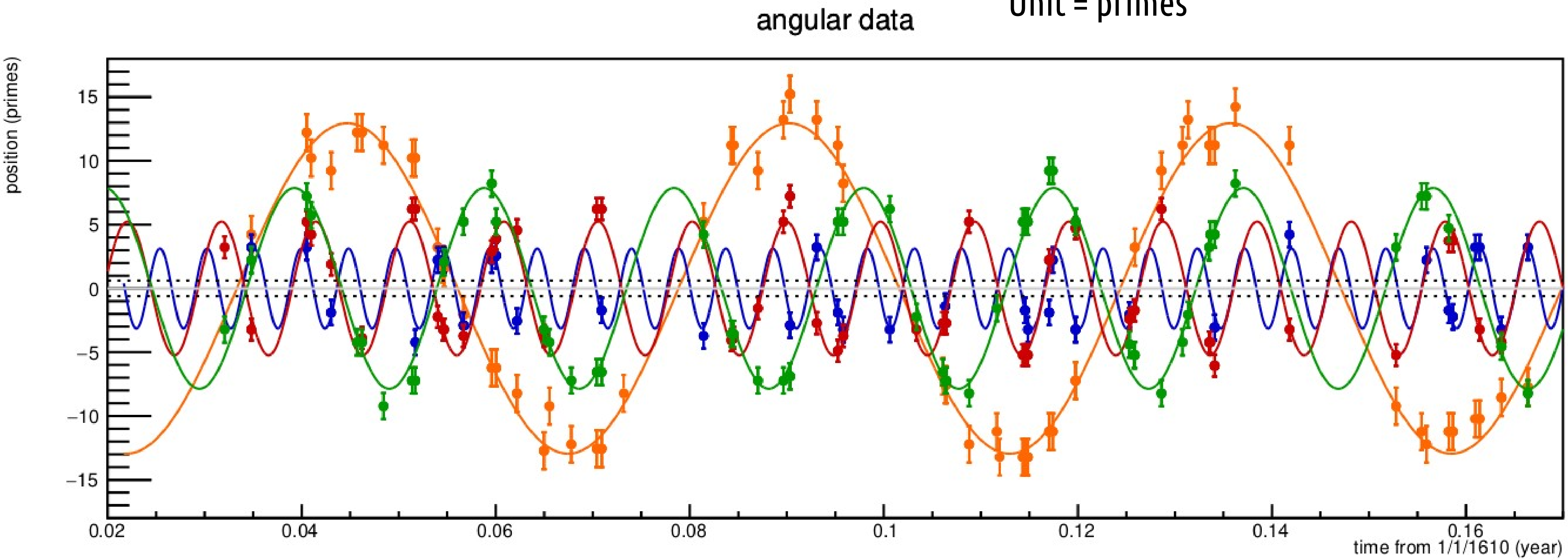


Sinusoidal fits (dataset 2 – meas. angles)

The error bars are determined as the error "a posteriori" (to make χ^2 /N-3 = 1) they are an estimate of the uncertainties

	σ_I	σ_E	σ_G	σ_C
dataset-2	$0.99'$	$0.86'$	$1.02'$	$1.44'$

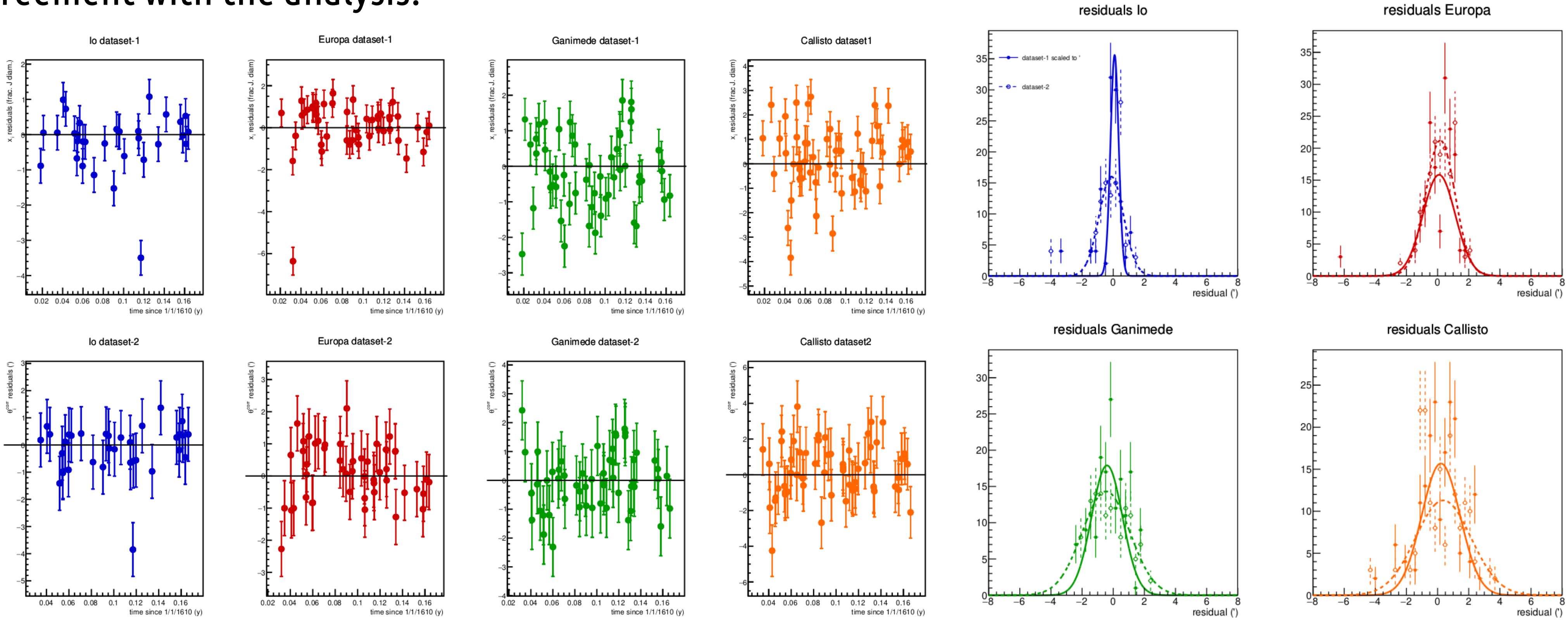
Unit = primes



Residuals

Interesting: the estimation of the uncertainty in the Sidereus is **"just one minute, or two"** in agreement with the analysis!

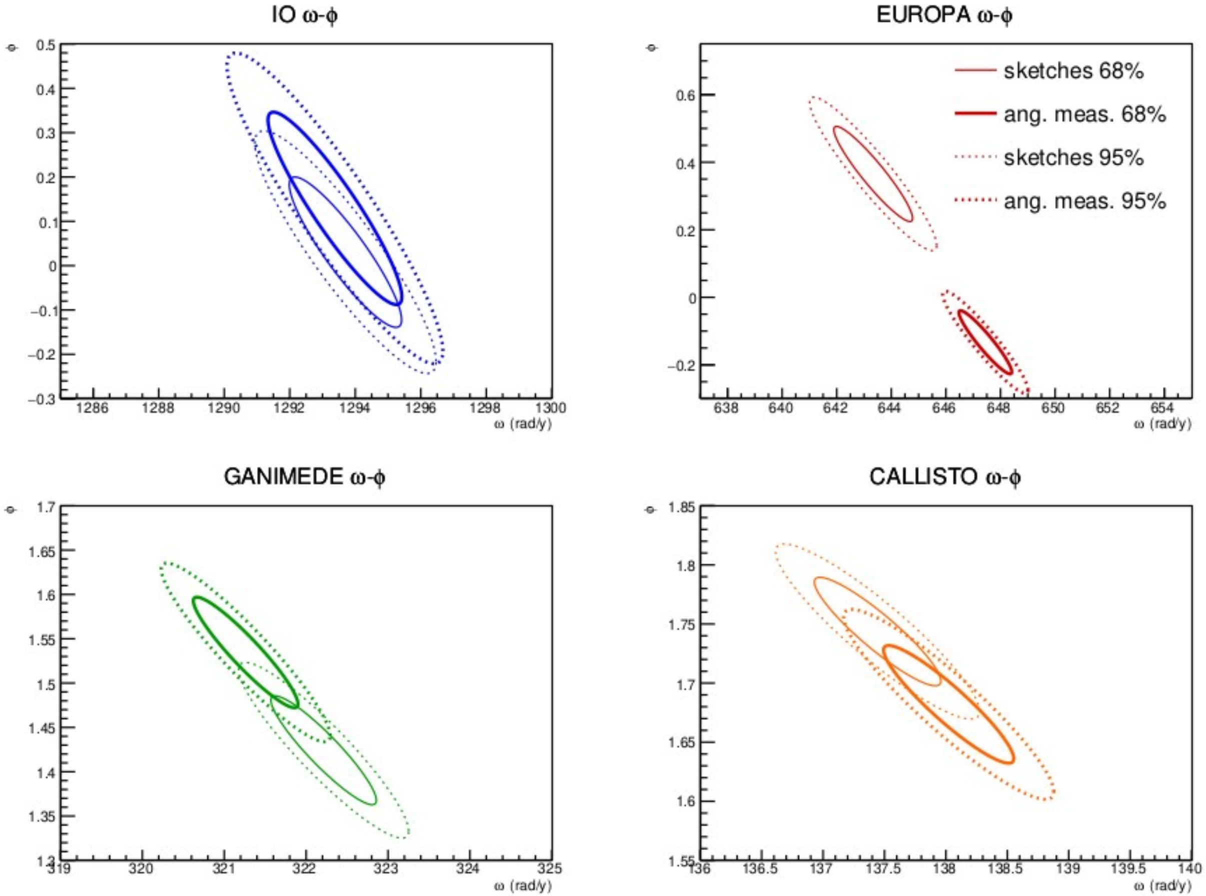
	σ_I	σ_E	σ_G	σ_C
dataset-1	0.49	0.66	0.59	0.71
dataset-2	$0.99'$	$0.86'$	$1.02'$	$1.44'$



Precision on the parameters

- The uncertainties on the **periods are O(0.1-0.2%),** on the **amplitudes O(1-4%)**
- The datasets are **compatible in the ϕ-ω plane** (small tension for Europa)

	Satellite	Value	Uncertainty	e.r. (%)
Dataset-1				
A (/J. drawn diameter)	Io	1.830	0.064	3.5
A (/J. drawn diameter)	Europa	2.884	0.065	2.2
A (/J. drawn diameter)	Ganymede	4.342	0.064	1.5
A (/J. drawn diameter)	Callisto	6.985	0.069	0.98
T [days]	Io	1.7727	0.0015	0.087
T [days]	Europa	3.5551	0.0049	0.14
T [days]	Ganymede	7.1175	0.0094	0.13
T [days]	Callisto	16.6693	0.0395	0.24
Dataset-2				
A ($'$)	Io	3.13	0.12	3.9
A ($'$)	Europa	5.242	0.086	1.6
A ($'$)	Ganymede	7.86	0.11	1.4
A ($'$)	Callisto	12.95	0.13	1.0
T [days]	Io	1.774	0.0018	0.10
T [days]	Europa	3.5415	0.0035	0.10
T [days]	Ganymede	7.1403	0.0095	0.13
T [days]	Callisto	16.613	0.043	0.26



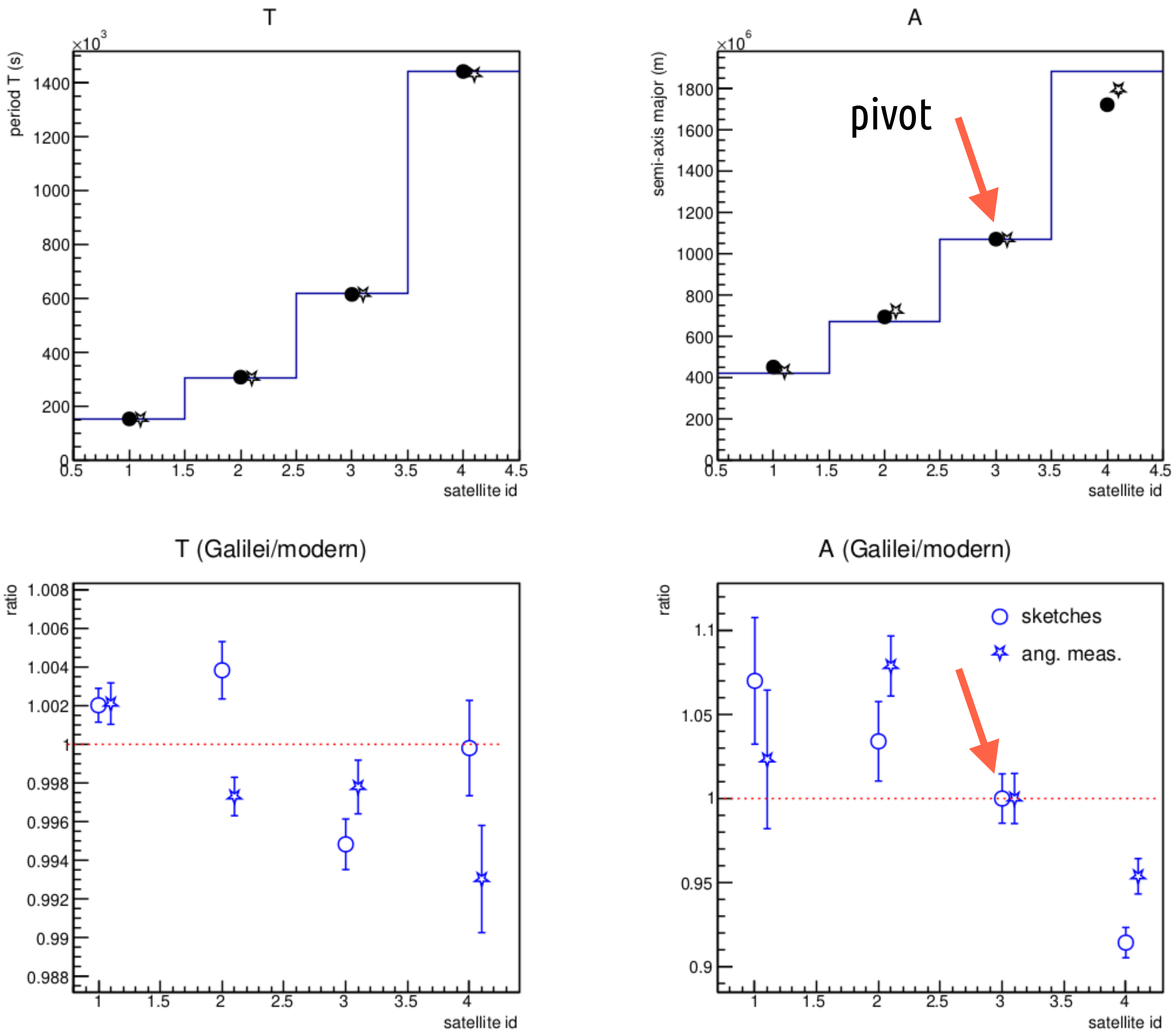
Accuracy

Bullets: Galileo fits (•,*)
Histogram: modern data

Periods: largest deviation 0.7%, typical 0.2-0.3%

Amplitudes ("shape")
In this case we have rescaled the fitted elongations to the true semi-axis of Ganymede and compared the others:

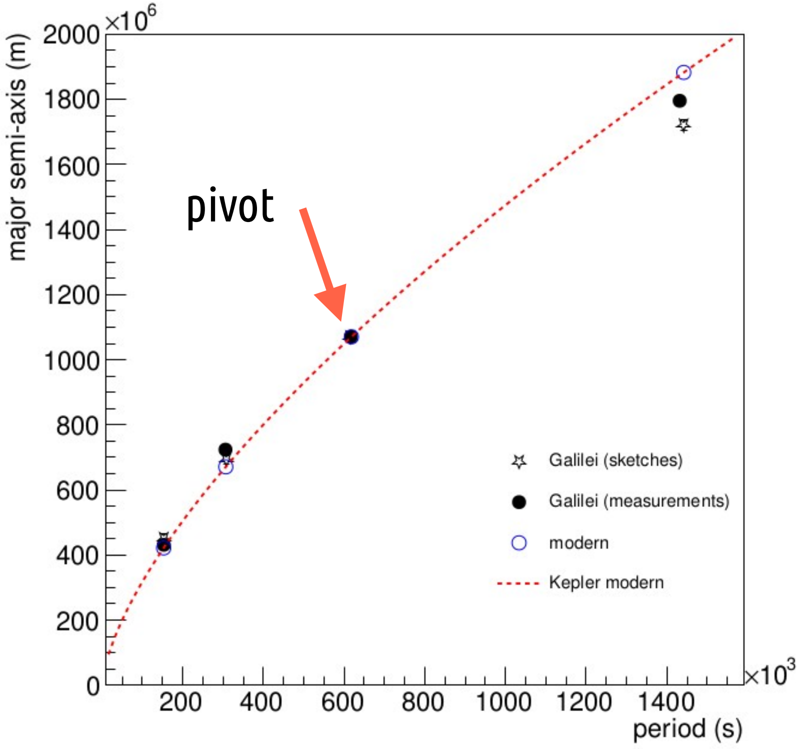
largest deviation 9%
(Callisto, dataset 1), typical ~5%

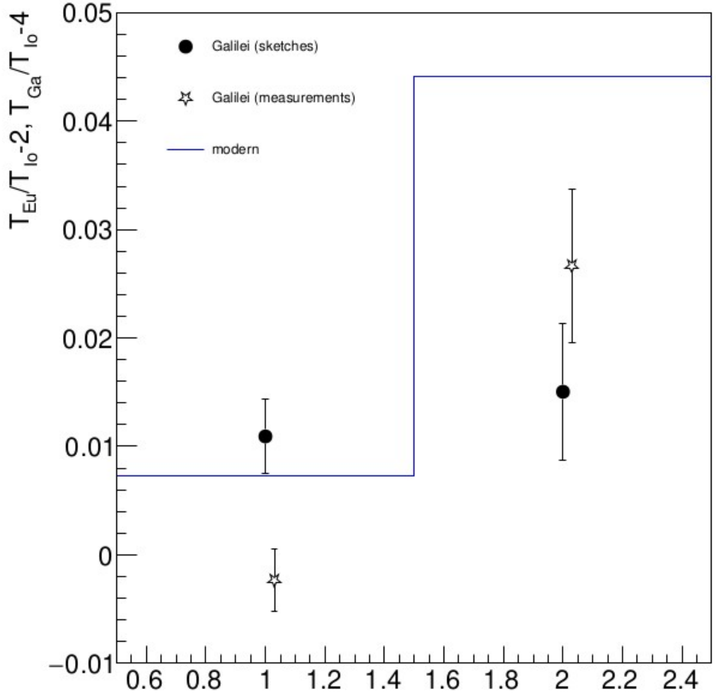


Kepler III law + 1:2:4 resonance

- The data clearly show that $\mathbf{T^2 \propto A^3}$
  - (but remember Galileo could not disentangle the individual T in 1610 – we used the simulator!)
  - Kepler law was formulated in 1619 (Harmonices Mundi) when the periods had been determined
- The ratio 1:2:4 of the periods of the inner satellites (resonance) is compatible with modern data

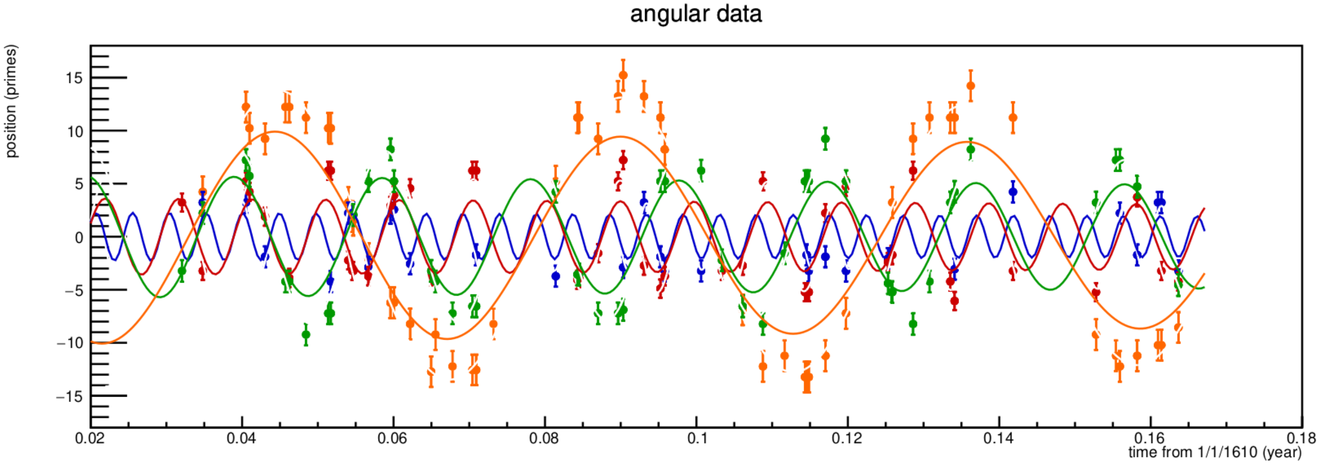
As before, we have rescaled the fitted elongations to the true semi-axis of Ganymede and compared the others



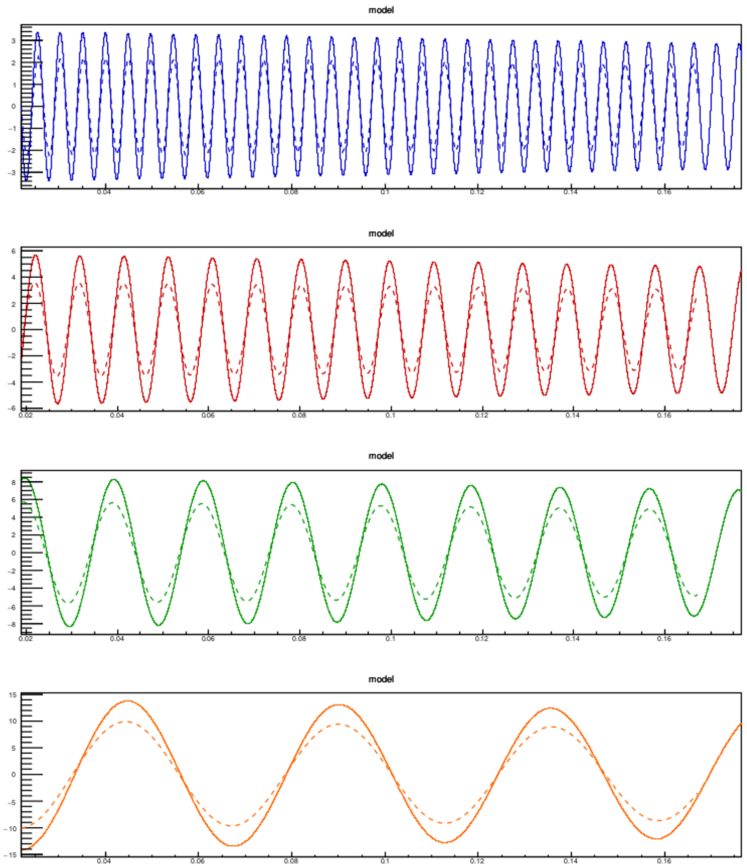


Accuracy of the angular amplitudes (dataset-2)

But what happens if we do not normalize to Ganymede but attempt an **absolute comparison: measured angular elongations vs those expected from the ephemerides** (not the fit with free amplitudes) →



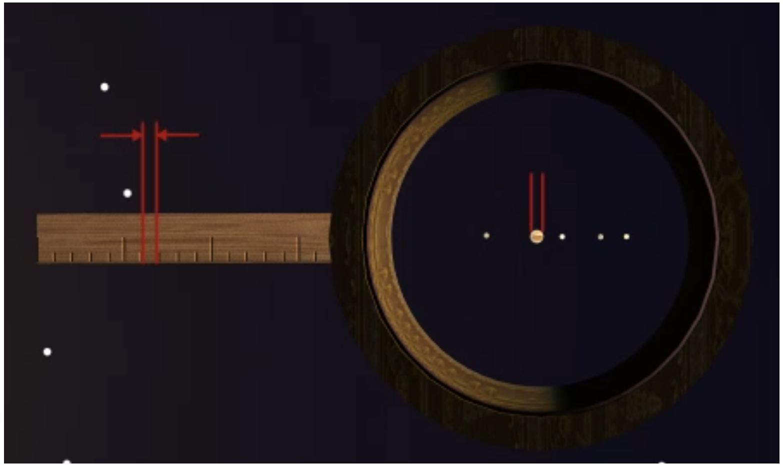
Dash = ephemerides, solid = fit



Accuracy gets worse: the **data are overestimated systematically** w.r.t. to predictions by a factor (1.47, 1.53, 1.45, 1.37) for Io, Europa, Ganymede and Callisto.

Angular measurements: “micrometer”

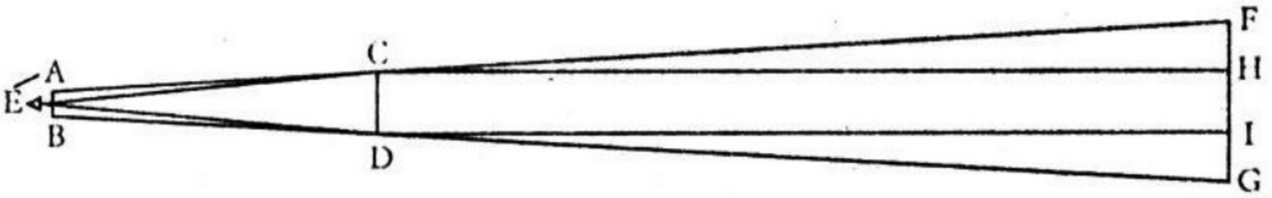
https://vitruvio.imss.fi.it/movies/isd/e500176.mp4



- Device described by G. A. Borelli, not in the Sidereus Nuncius:
  - a sliding ruler with 20 divisions.
  - distance is tuned until disk of J. corresponds to a division
  - a candle illuminates the scale
  - one eye sees Jupiter and the other sees the scale

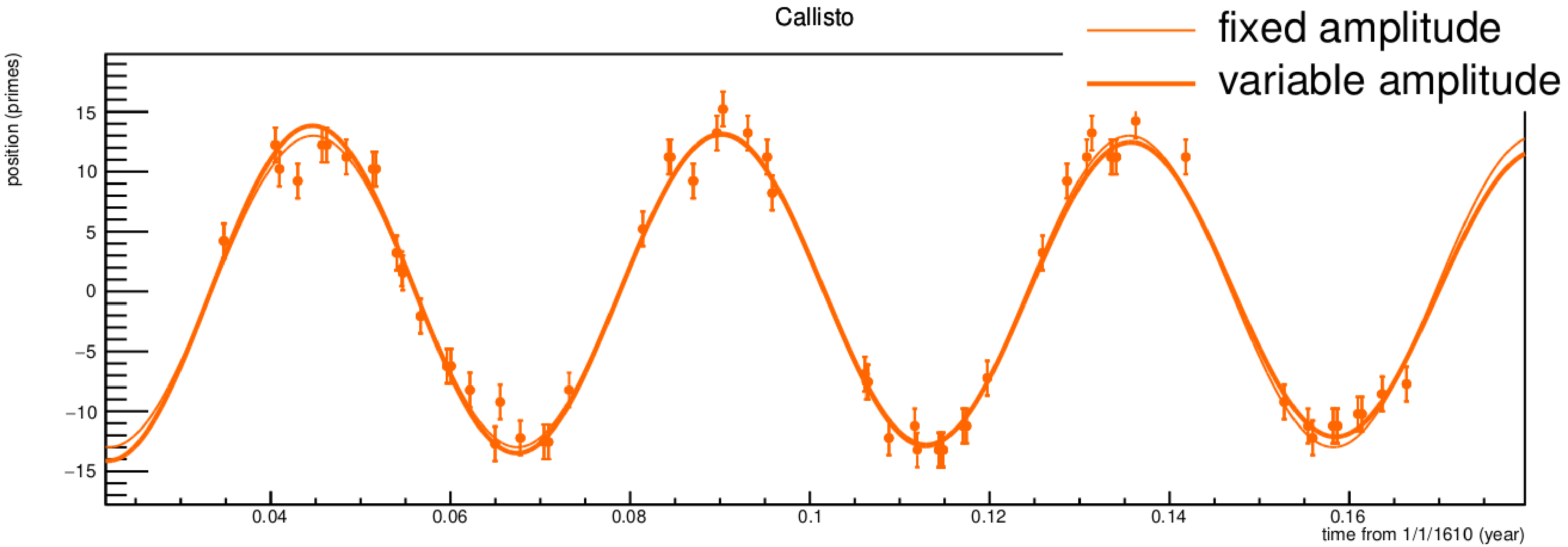
In this way the angular measurements are indeed **not a real absolute angle measurement but rather a relative one**!

Sidereus: Galileo explains how to calibrate: draw two shapes with a fixed dimension ratio, find the distance at which they look the same size with the open eye or through the telescope



Test on the angular measurements with data

- From Jan 7 to Mar 1 the distance of Jupiter changed significantly (16%) the disk passing **from 45” to 38”**
- Alternative model: variable amplitude according to expectations: $\Delta(') = 46.2842 - 0.100186t - 0.00103484t^2 + 9.86778\times10^{-6}t^3$
- The fixed amplitude fit yields a slightly better χ^2 → **angular measurements are indeed relative to the disk**



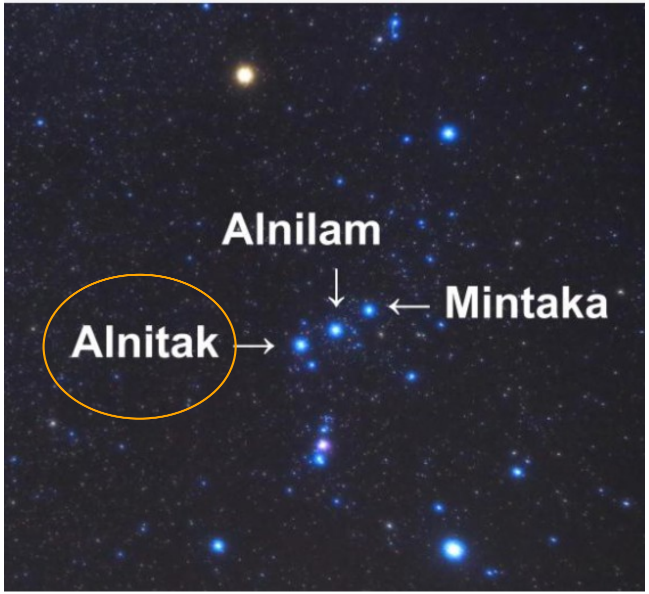
Why such a large discrepancy ?

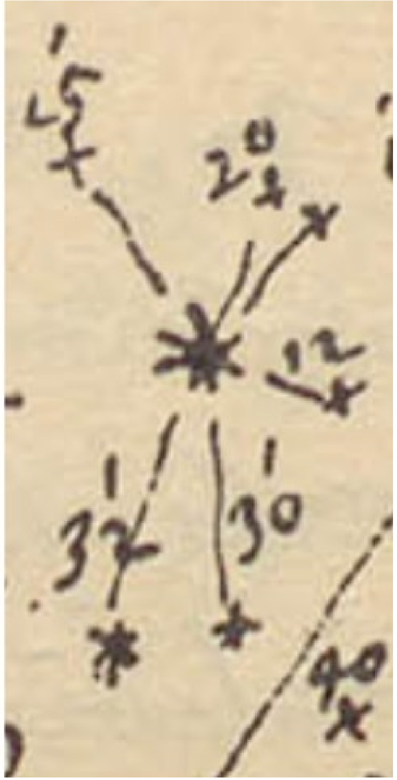
- After all the calibration is described in the Sidereus Nuncius
- Seems measurable at better than 40-50% systematic
- Interestingly John Roche (1982): the data of Harriot, Mayr show a similar overestimation!
- His hypothesis: the angular field of view was used as ruler
- BUT… the variation of the eye-pupil with luminosity, would alter the dimensions of the field of view passing from daylight, Moon, Jupiter …
- I showed that to reconcile the two datasets we need a disk slightly larger that 1'
- If Galileo had assumed that the disk was 1' instead of the real 38-45" this would explain why the elongations are overestimated by 40-50%

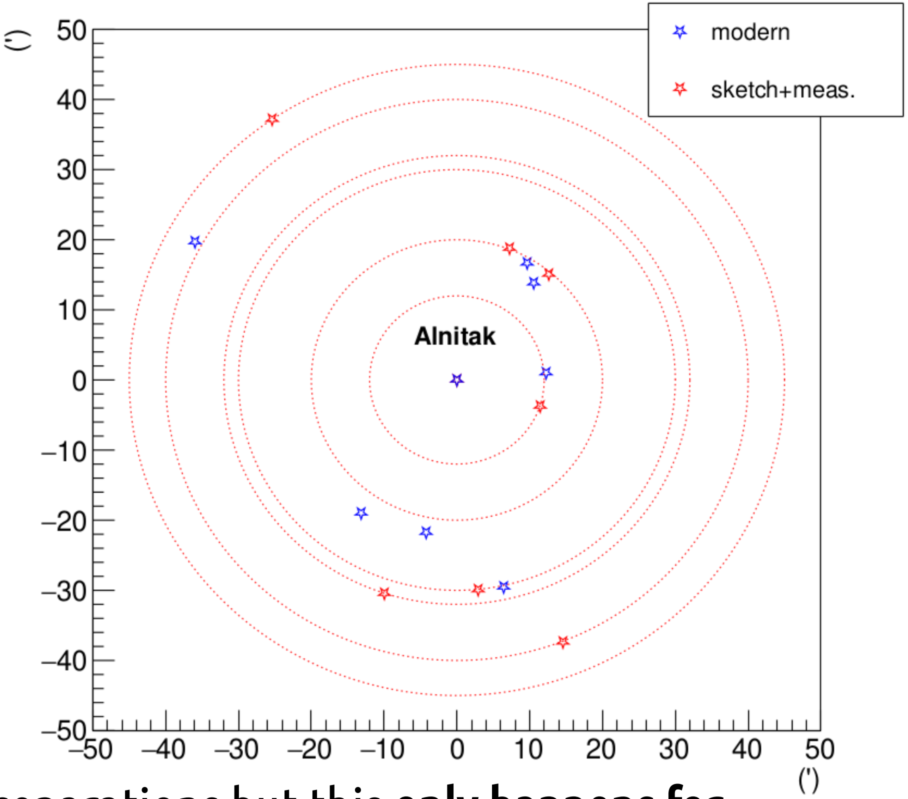
- But … another, cleaner, check on the accuracy of angular measurements could be done **using a sketch that did not make into the Sidereus Nuncius →**

The “Alnitak ruler”

- Alnitak (left star of the Orion Belt)





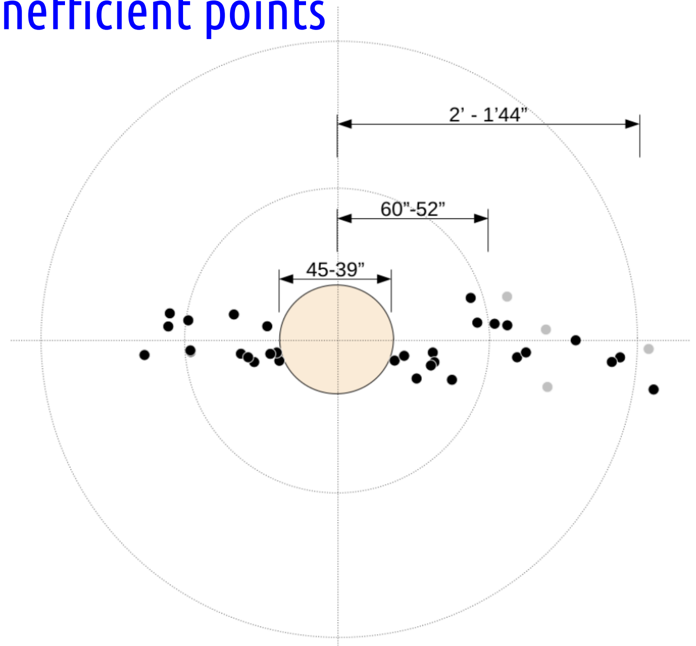


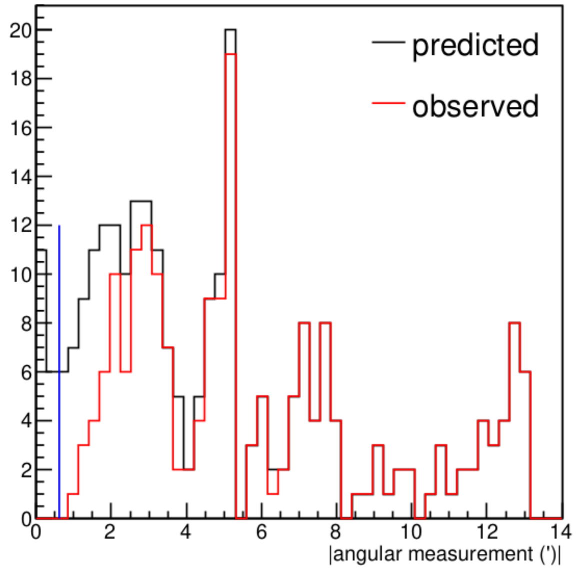
- In this case again there is an overestimation of angular separations but this **only happens for separations >30’ while those at about 10’ (similar to Jupiter) are pretty accurate!**
- Might have been a different telescope? **The case remains somewhat open**

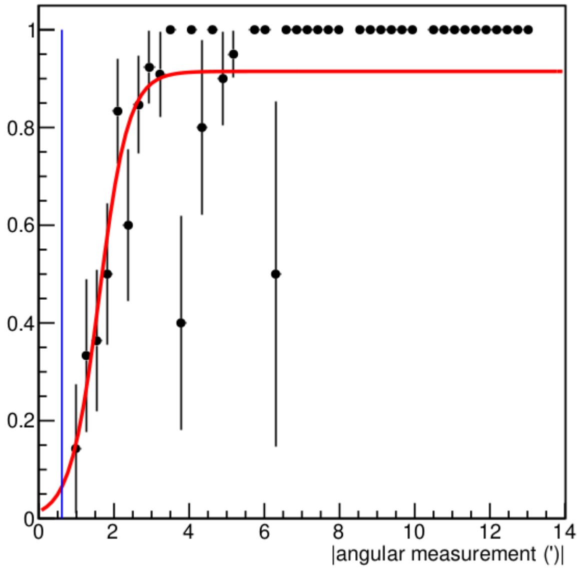
Closeness to the disk: blinding effect

- We have systematically estimated the **efficiency loss as a function of the distance from the disk**

Inefficient points



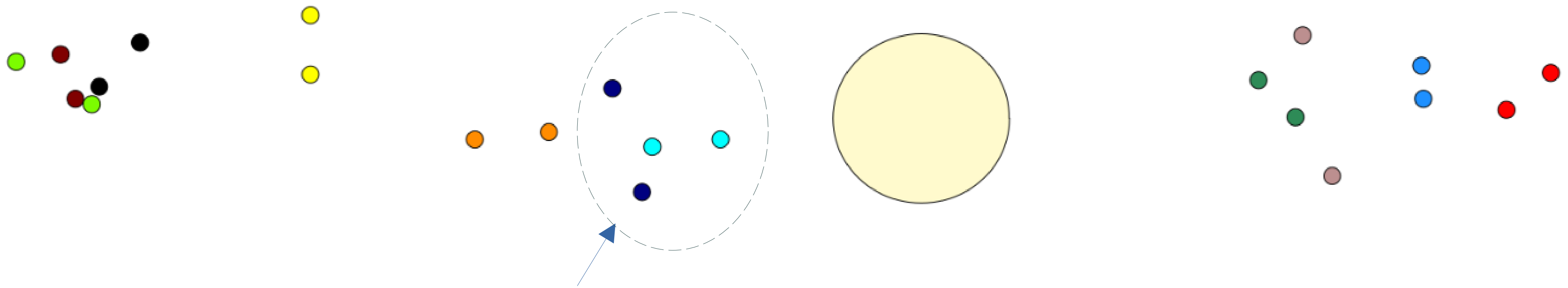




Likely more related to the **glare of the planet** rather than aberrations (limited using collimators).
In 1992 Greco et al. measured the objectives of the telescopes at "Museo Galileo" in Florence and found they were **nearly diffraction limited with errors below λ/4**. Eyepieces were worse, but less critical.

2-satellite resolution

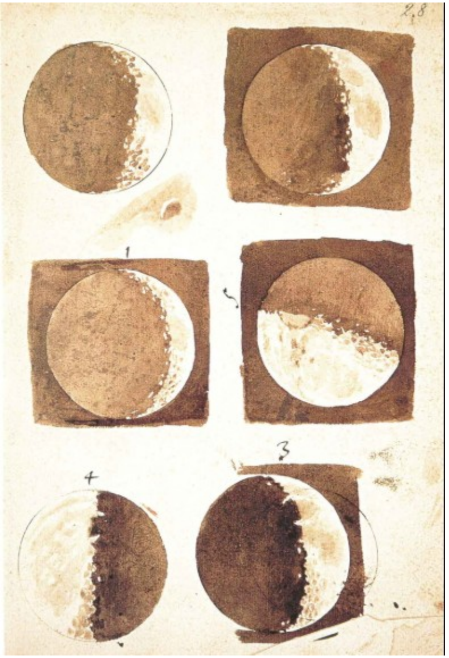
- The largest unresolved case has an angular separation of 31-37´´ but other typical cases are in the order of **15-17´´** (true values from simulation).
- This estimate is somewhat affected by the uncertainty in the exact time of the observation, especially when Io was involved or in the proximity of Jupiter where the velocity is higher.



- Interestingly the pairs in cyan color and dark blue, were observed as a single object even if they fall in the region where efficiency was low (glare compensated by doubled luminosity).

Other observations in the Sidereus Nuncius

- Appetite comes with eating:
  - after having exploited in depth the Jupiter dataset and profiting of Stellarium-web we have done some additional **“fact-checking”** on the observations of
  - the Pleiades, the Orion belt, the Orion Head, the beehive cluster and the Moon
- Moon: comparison with the 6 inkwashes thata are the basis for the illustrations in the Sidereus (more rough/imprecise)



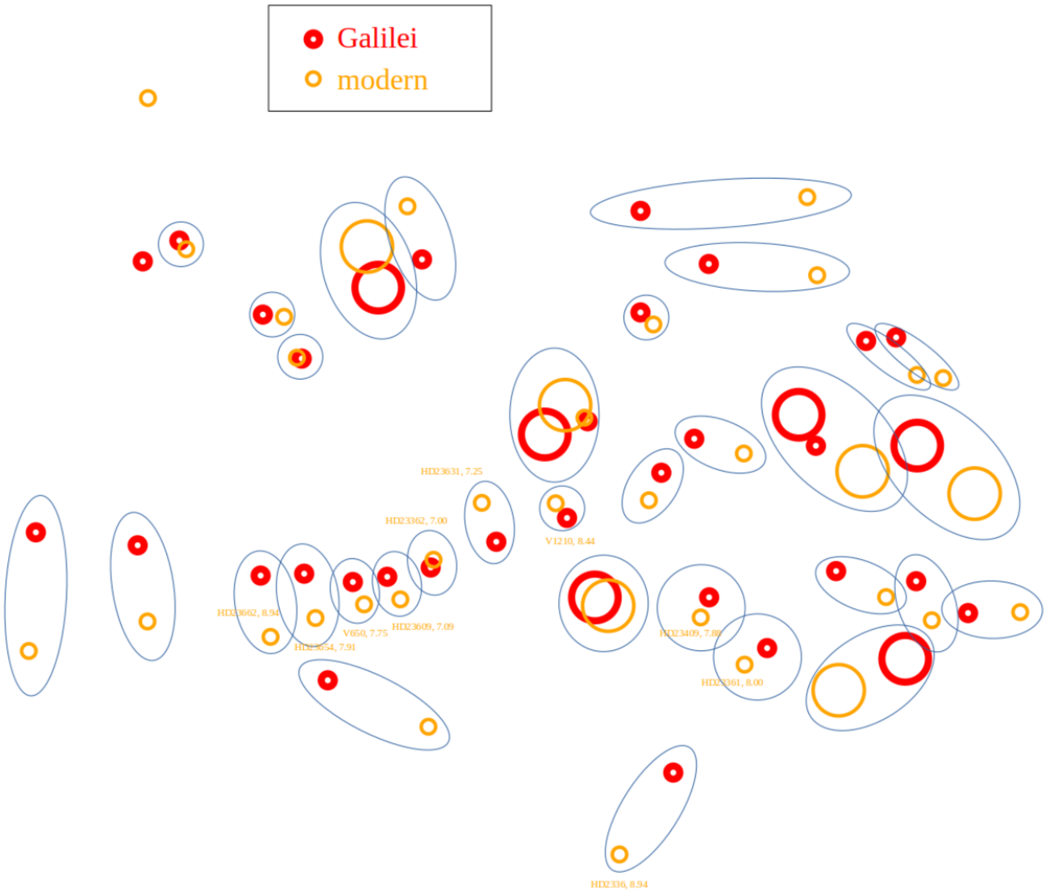
The Pleiades

The Pleiades

This is **the most accurate representation**: the pattern is extremely well reproduced despite some “deformations”: **the F.O.V. is ~15’, the cluster ~90’**

Galileo could see stars **up to magnitude almost 9 (i.e. 8.94 for HD2336)**. Quite **remarkable** considering the small aperture of the telescope. Helped by the **total absence of light pollution in Padua, unlike nowadays…**

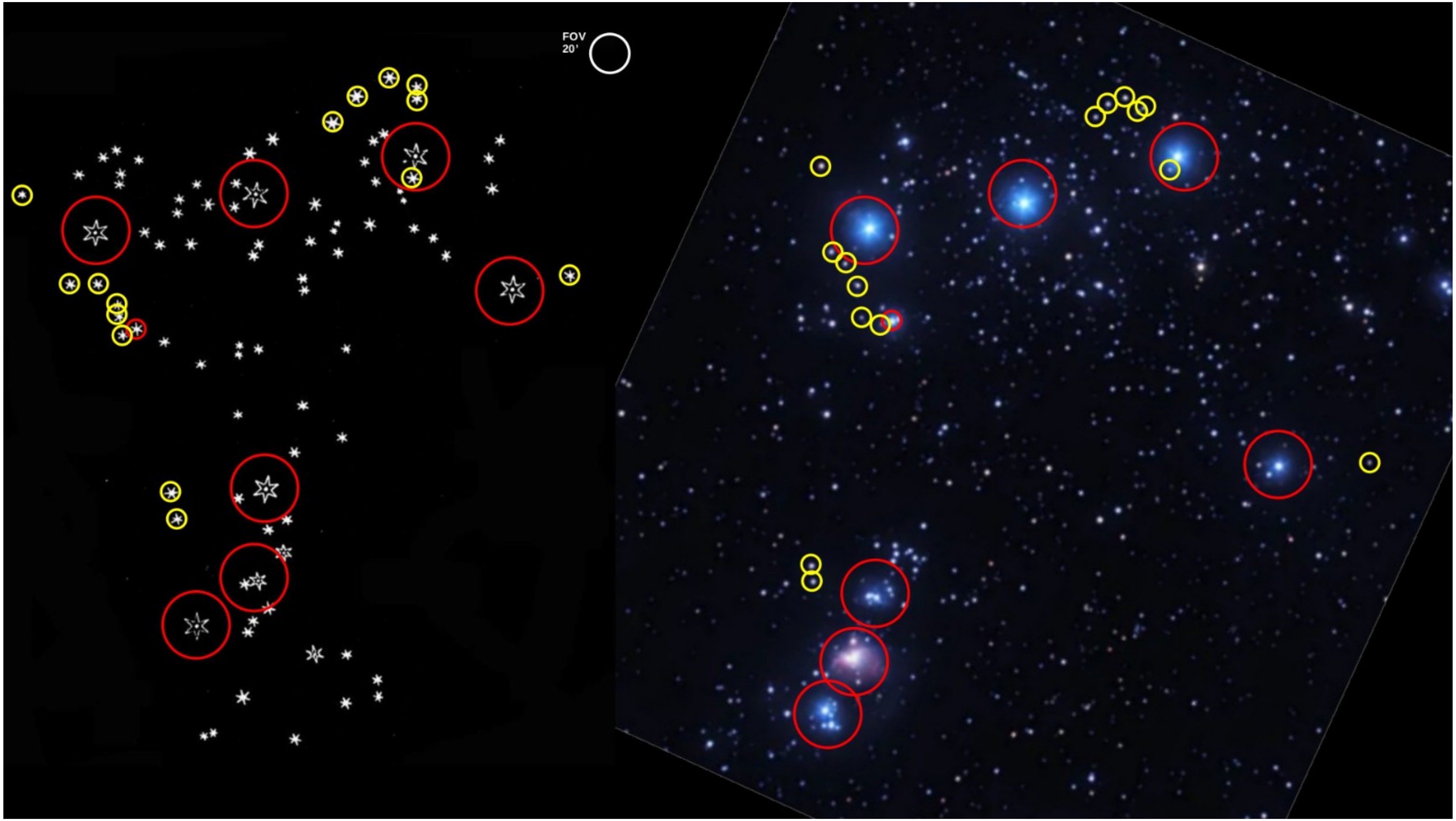
Proper motions: could the positions of some of the stars might really have changed in **415 years** ?
60 mas/year → **0.5’** corresponding to about half the size of the Jupiter disk. → **sub-leading** on a field of view of ~ 90’



The Orion belt

The area is huge wrt to the FOV of the telescope (might have used a lower magnification one?)

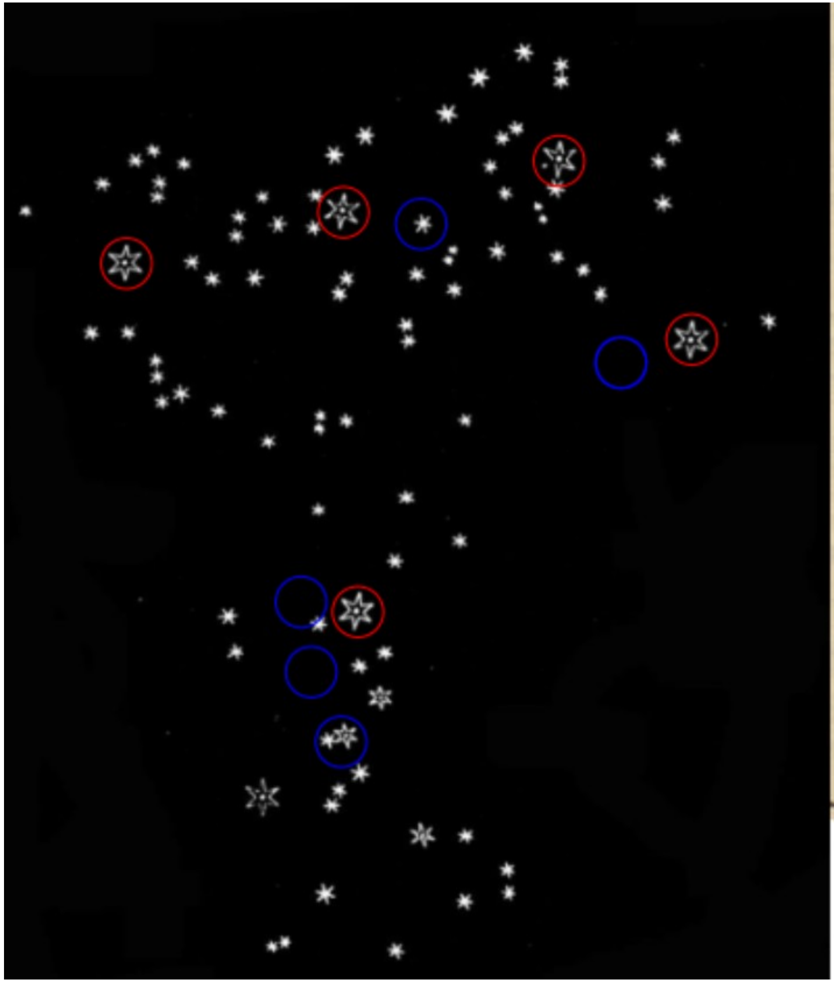
Not so accurate … BUT →

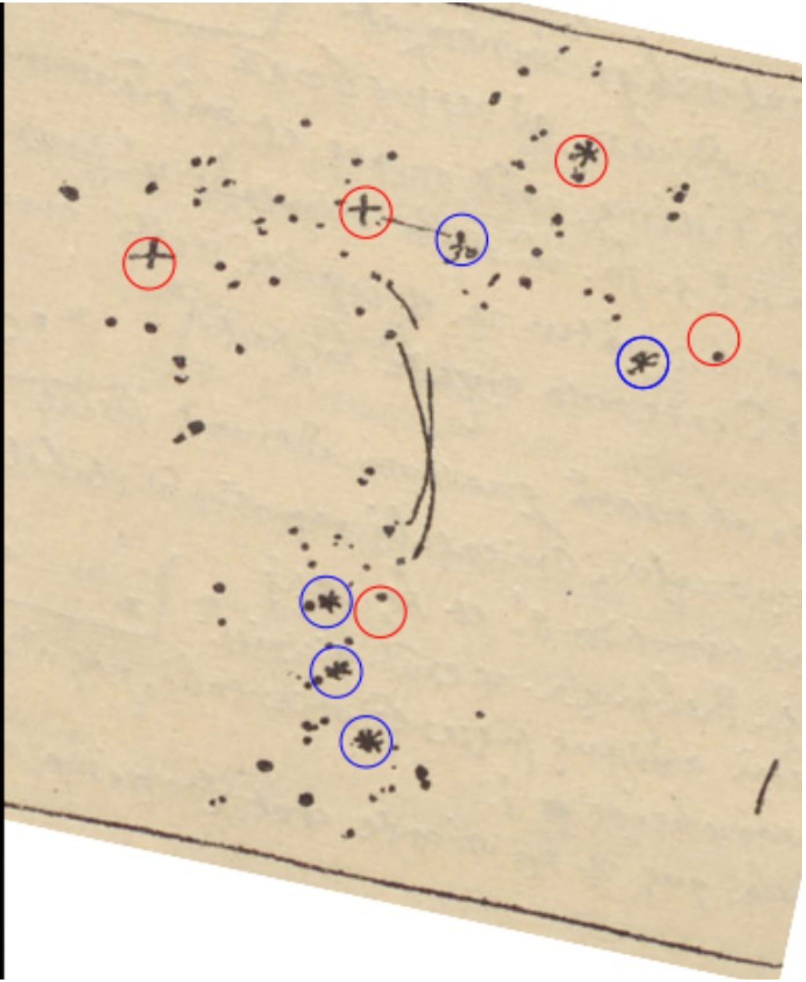


The Orion belt: notes vs printed

Passing from sketches to the printed version there were some errors

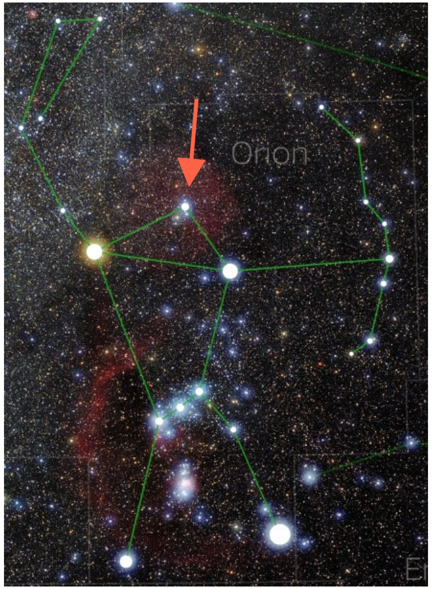
Sketches are more accurate!

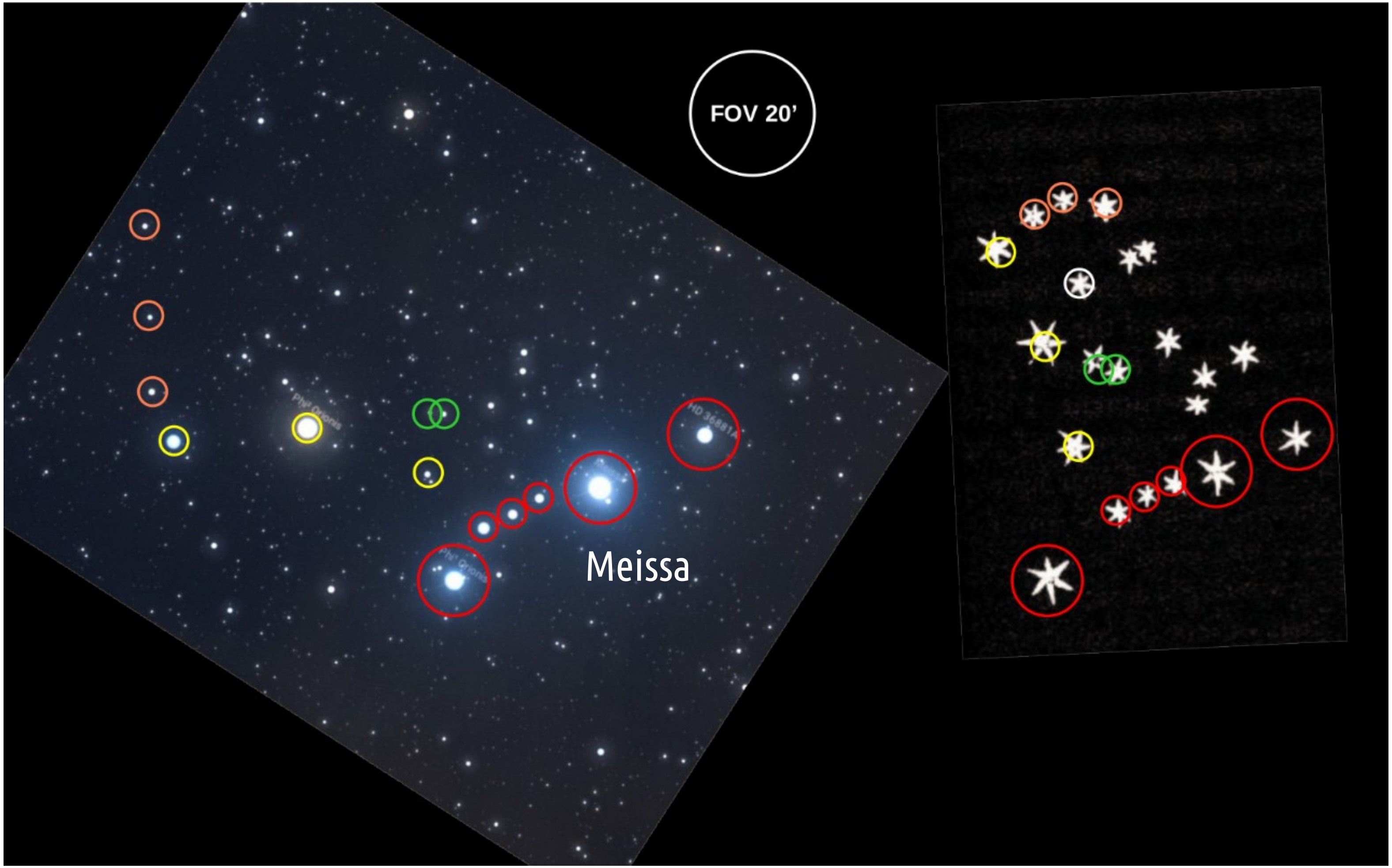




The Orion head

Red stars pattern is quite convincing. The rest requires assuming large distorsions ...



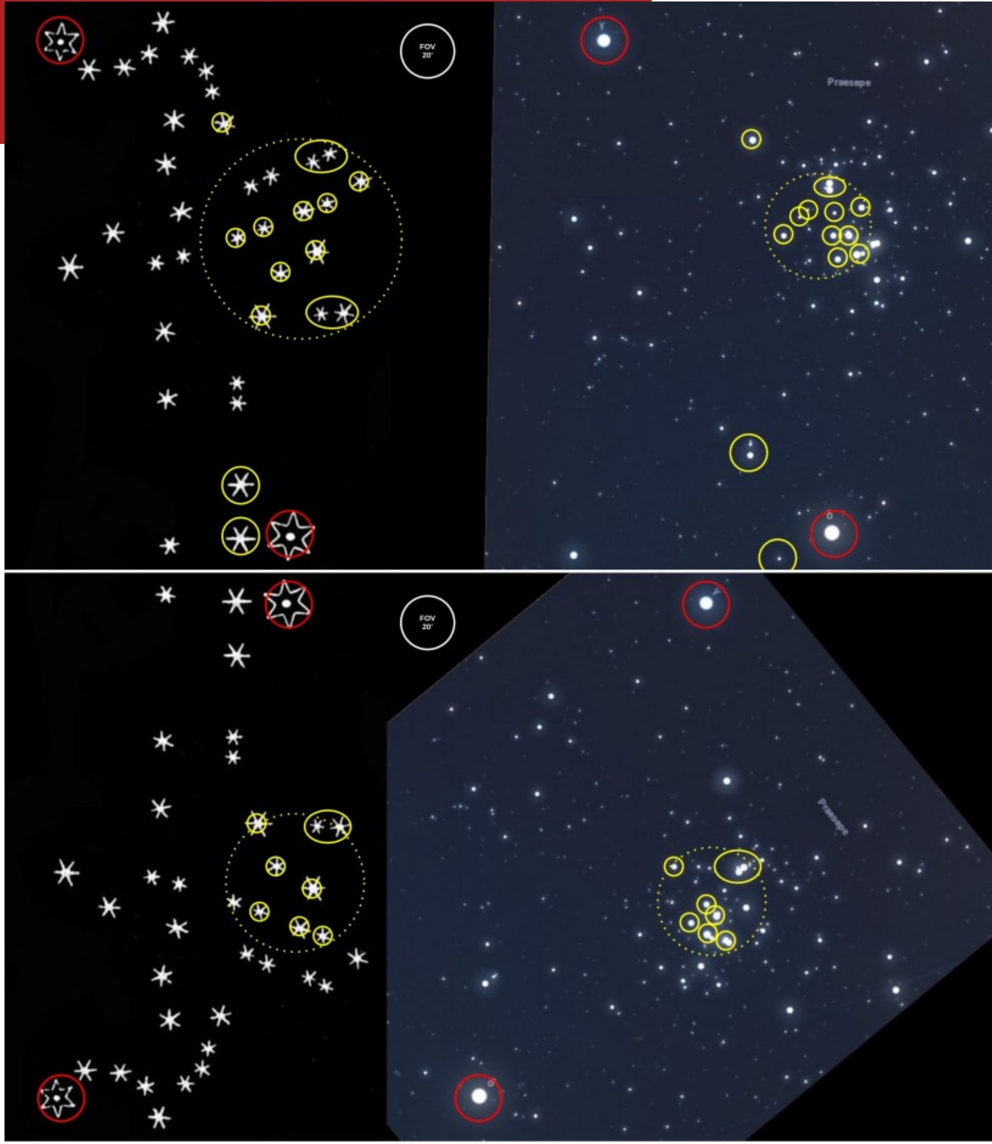


The beehive cluster

M44 open cluster in Cancer (Praesepe).

Larger stars are the ones visible by naked eye (Galileo' convention): the "little donkeys" (γ and δ Cancri)

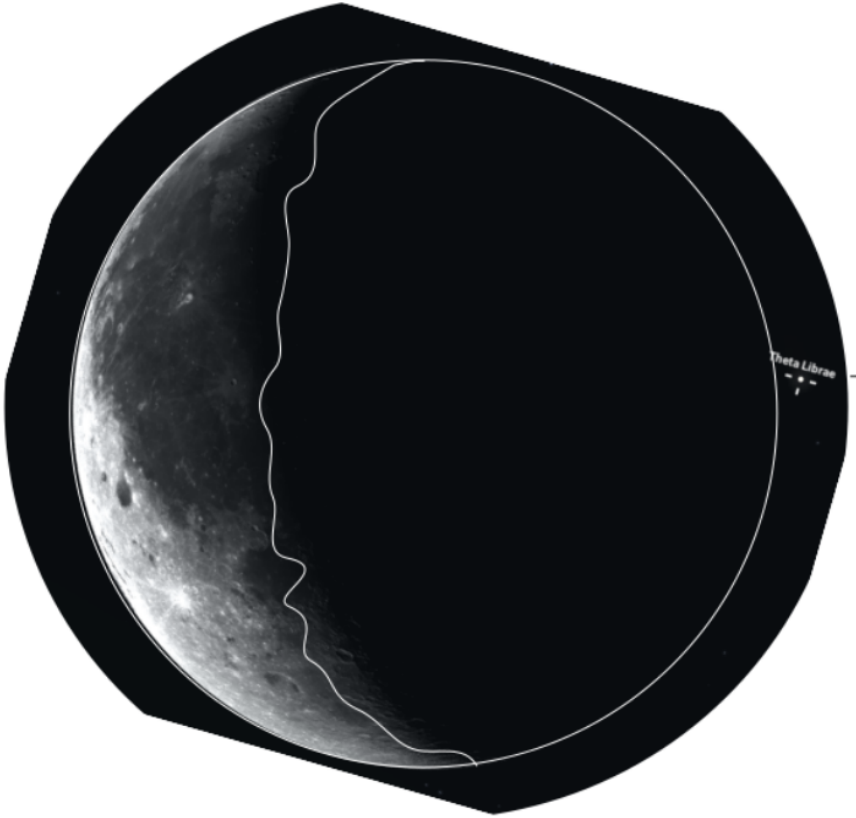
The rest is much less faithful than the Pleiades (tried also assuming flipping of the printing). Tentative matching. The real cluster is much more compact. Also here the cluster is much larger than FOV

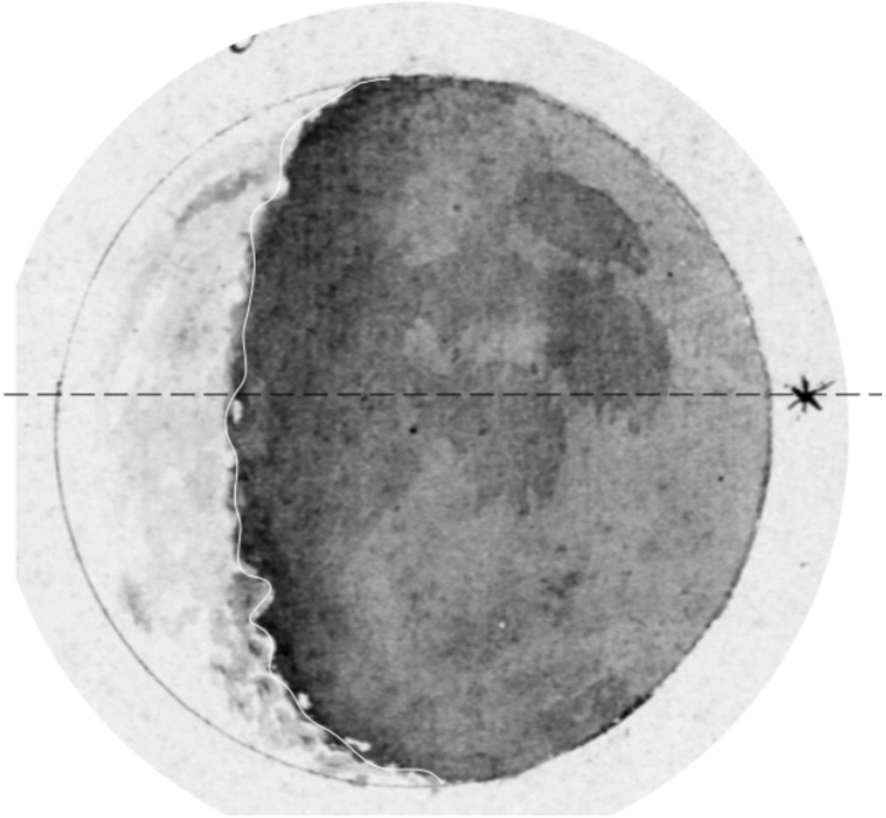


Inkwashes of the Moon

19/1/1610, 6.36

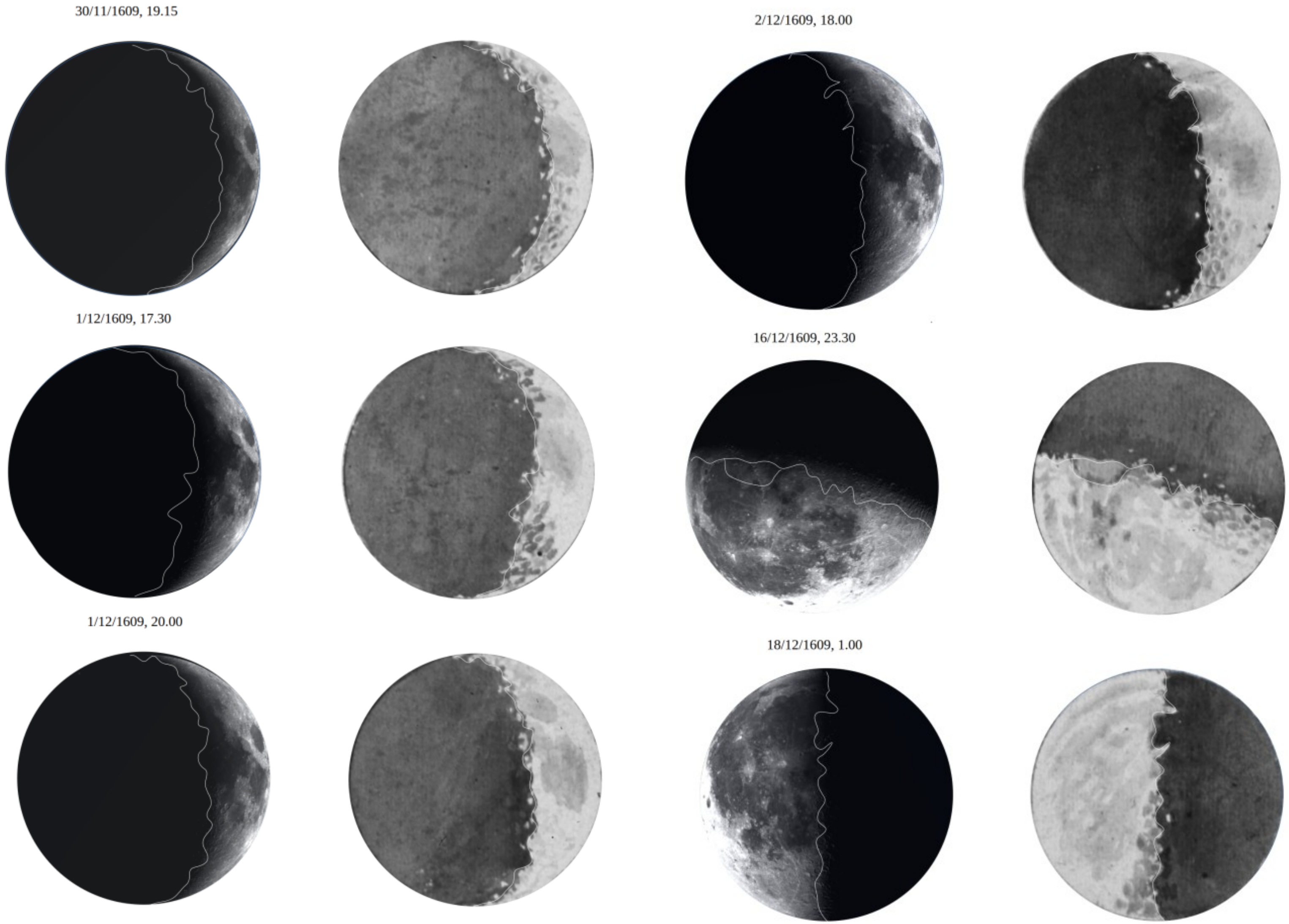
We know with a precision O(min)! when this observation was made thanks to the occultation of θ-Librae





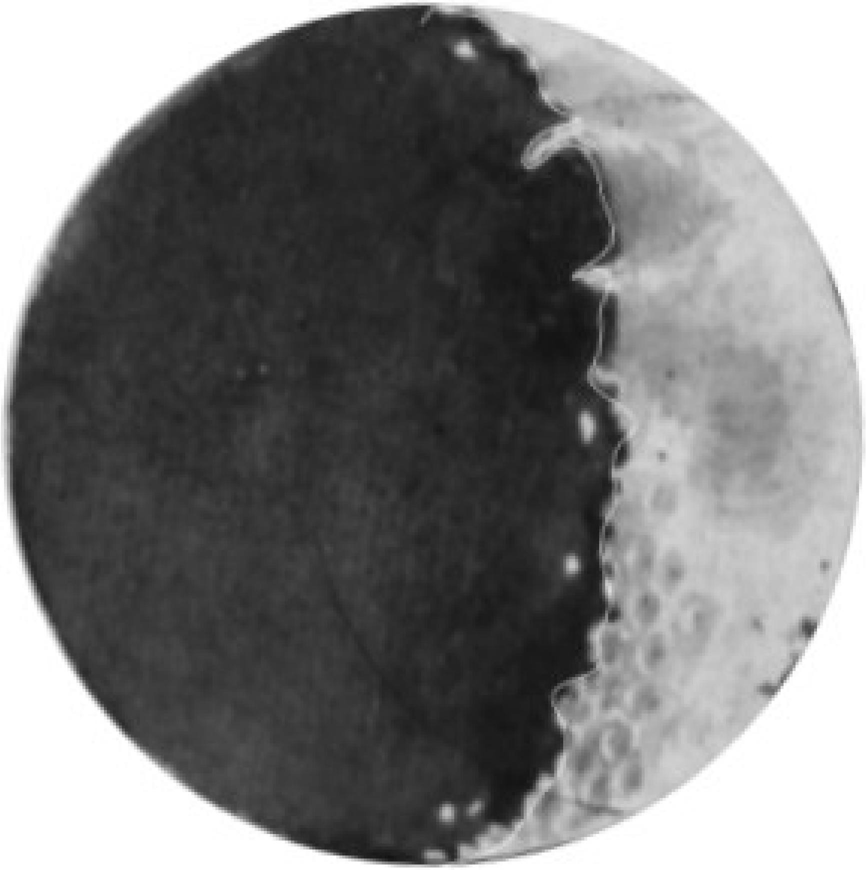
Moon

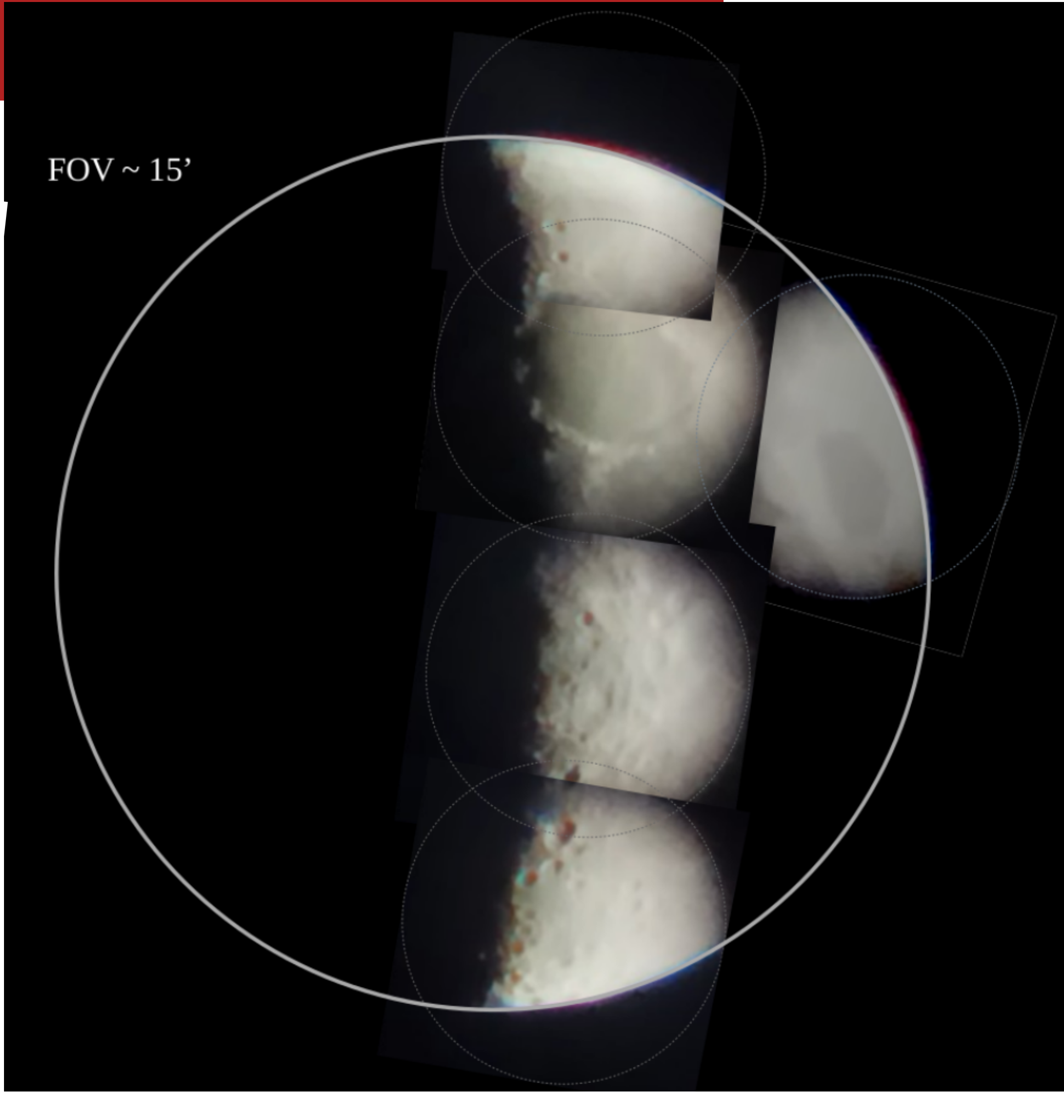
- Galileo had been working systematically on the Moon phases in **Nov-Dec 1609 before J. satellites in Jan 1610 became “top priority”**
- The dates of the sketches have been **debated**. We considered the dates that are generally accepted.
- The white line is the terminator from the inkwash.



Replica of one of the telescopes of Galileo

Galileo vs replica2025



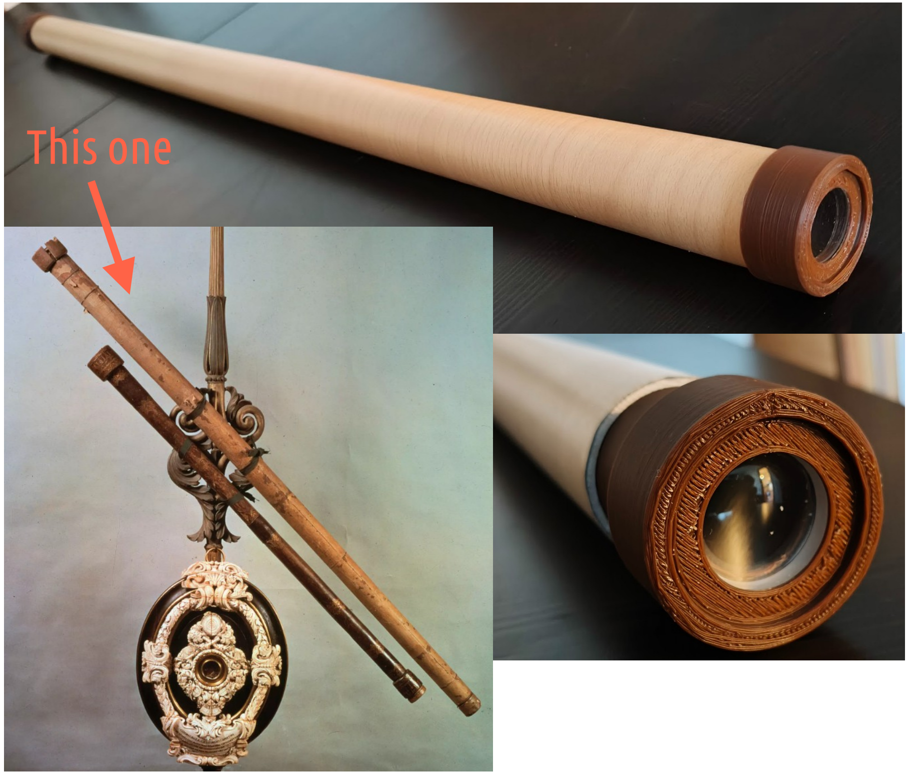


And finally: the neutrino telescope!

The **prize for the best poster** will be a faithful reproduction of the Galileian telescope (which perfectly fits in a poster tube!)

I hope I convinced you how amazing the early observations of Galileo were...

...but after checking **how difficult the measurements are (pointing, following the drift, glare...)** they will become jaw-droppingly amazing !



References + acknowledgements

Soon will be updated:
https://arxiv.org/abs/2503.12543

Thanks to: Alessandro Bettini, Carlo Broggini, Giulio Peruzzi, Enrico Maria Corsini and Mauro Mezzetto

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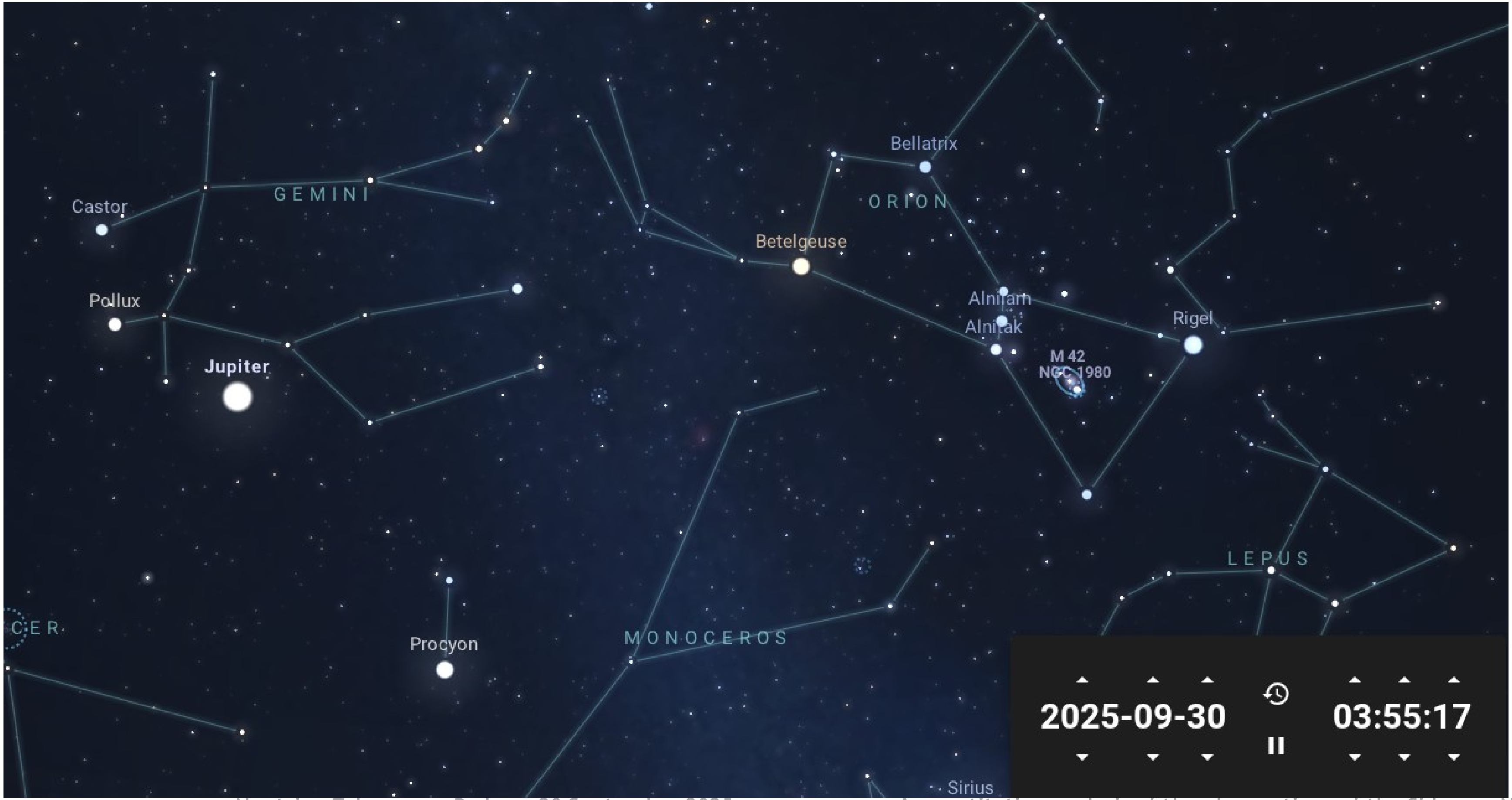
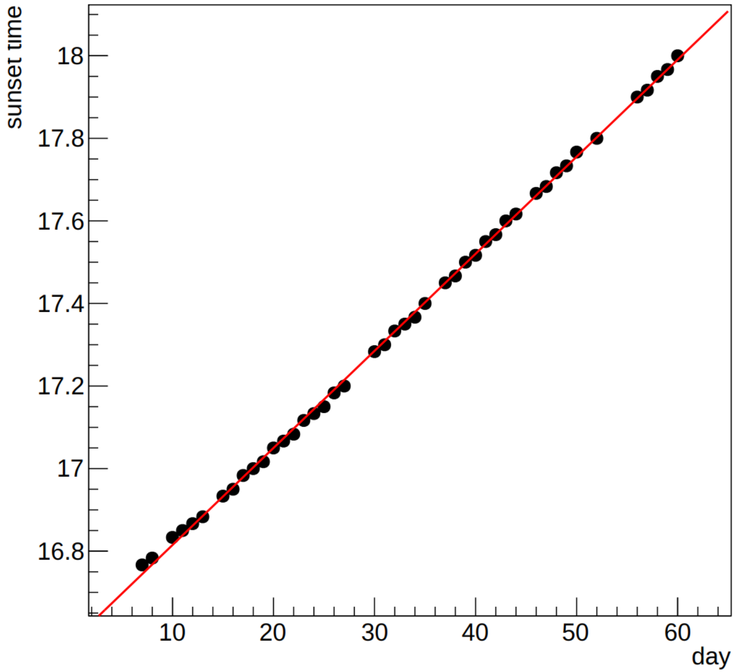
Jupiter September 2025

Padova. Jupiter is visible in Gemini early in the morning



Observation times

- Galileo reported the observation time in “italian hours” counted from sunset.
- In the analysis I converted them to modern hours considering the time of sunset.
- On Jan 7 in Padova “hora prima” becomes 17:44
- Some observations do not report the time → assumed they were done at “hora prima” (most frequent)
- Assuming the observations to be taken at the same hour worsens the significantly the χ^2



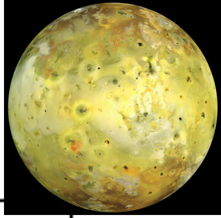
id	month	day	after sunset (h)	sunset	modern time (h:min)
1	1	7	1:00	16.74	17:44
2	1	8	1:00	16.77	17:46
3	1	10	1:00	16.81	17:48
4	1	11	1:00	16.84	17:50
5	1	12	1:00	16.86	17:51
6	1	13	1:00	16.89	17:53
7	1	15	3:00	16.93	19:55
8	1	15	7:00	16.93	23:55
9	1	16	1:00	16.96	17:57
10	1	17	0:30	16.98	17:28
11	1	17	5:00	16.98	21:58
12	1	18	0:20	17.00	17:20
13	1	19	2:00	17.03	19:01
14	1	19	5:00	17.03	22:01
15	1	20	1:15	17.05	18:17
16	1	20	6:00	17.05	23:02
17	1	20	7:00	17.05	24:02
18	1	21	0:30	17.07	17:34
19	1	22	2:00	17.10	19:05
20	1	22	6:00	17.10	23:05
21	1	23	0:40	17.12	17:47
22	1	23	5:00	17.12	22:07
23	1	24	1:00	17.14	18:08
24	1	24	6:00	17.14	23:08
25	1	25	1:40	17.17	18:50
26	1	26	0:40	17.19	17:51
27	1	26	5:00	17.19	22:11
28	1	27	1:00	17.21	18:12
29	1	30	1:00	17.29	18:17
30	1	31	2:00	17.31	19:18
31	1	31	4:00	17.31	21:18

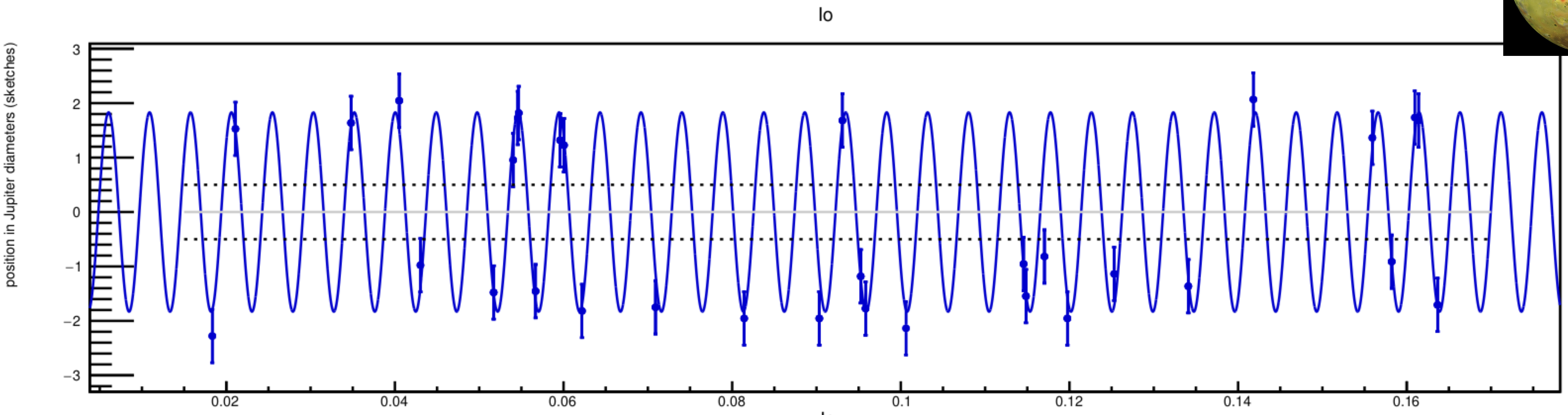
Table 3 Conversion from Italic to modern hours (January 1610).

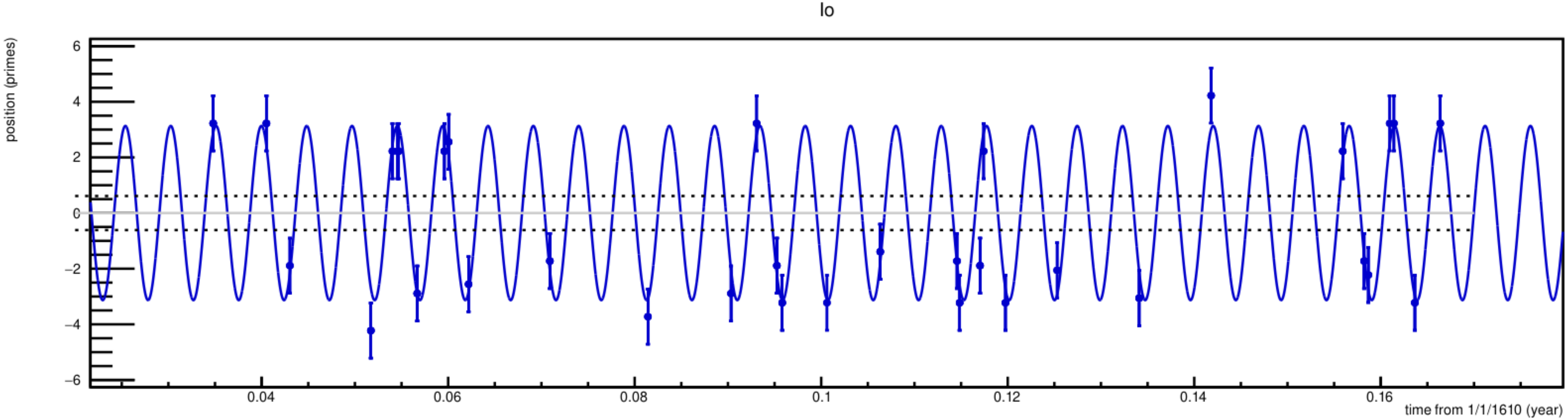
id	month	day	after sunset (h)	sunset	modern time (h:min)
32	2	1	2:00	17.33	19:19
33	2	2	1:00	17.36	18:21
34	2	2	7:00	17.36	24:21
35	2	3	7:00	17.38	24:22
36	2	4	2:00	17.40	19:24
37	2	4	7:00	17.40	24:24
38	2	6	1:00	17.45	18:26
39	2	7	1:00	17.47	18:28
40	2	8	1:00	17.50	18:29
41	2	9	0:30	17.52	18:01
42	2	10	1:30	17.54	19:02
43	2	11	1:00	17.57	18:34
44	2	11	3:00	17.57	20:34
45	2	11	5:30	17.57	23:04
46	2	12	0:40	17.59	18:15
47	2	13	0:30	17.61	18:06
48	2	15	1:00	17.66	18:39
49	2	15	5:00	17.66	22:39
50	2	15	6:00	17.66	23:39
51	2	16	6:00	17.68	23:41
52	2	17	1:00	17.71	18:42
53	2	18	1:00	17.73	18:43
54	2	18	6:00	17.73	23:43
55	2	19	0:40	17.76	18:25
56	2	21	1:30	17.80	19:18
57	2	25	1:30	17.90	19:23
58	2	26	0:30	17.92	18:25
59	2	26	5:00	17.92	22:55
60	2	26	5:00	17.92	22:55
61	2	27	1:04	17.94	19:00
62	2	28	1:00	17.97	18:58
63	2	28	5:00	17.97	22:58
64	3	1	0:40	17.99	18:39

Table 4 Conversion from Italic to modern hours (February, March 1610).

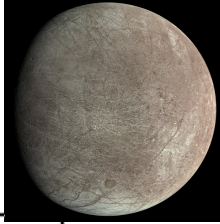
Tagged dataset: Io

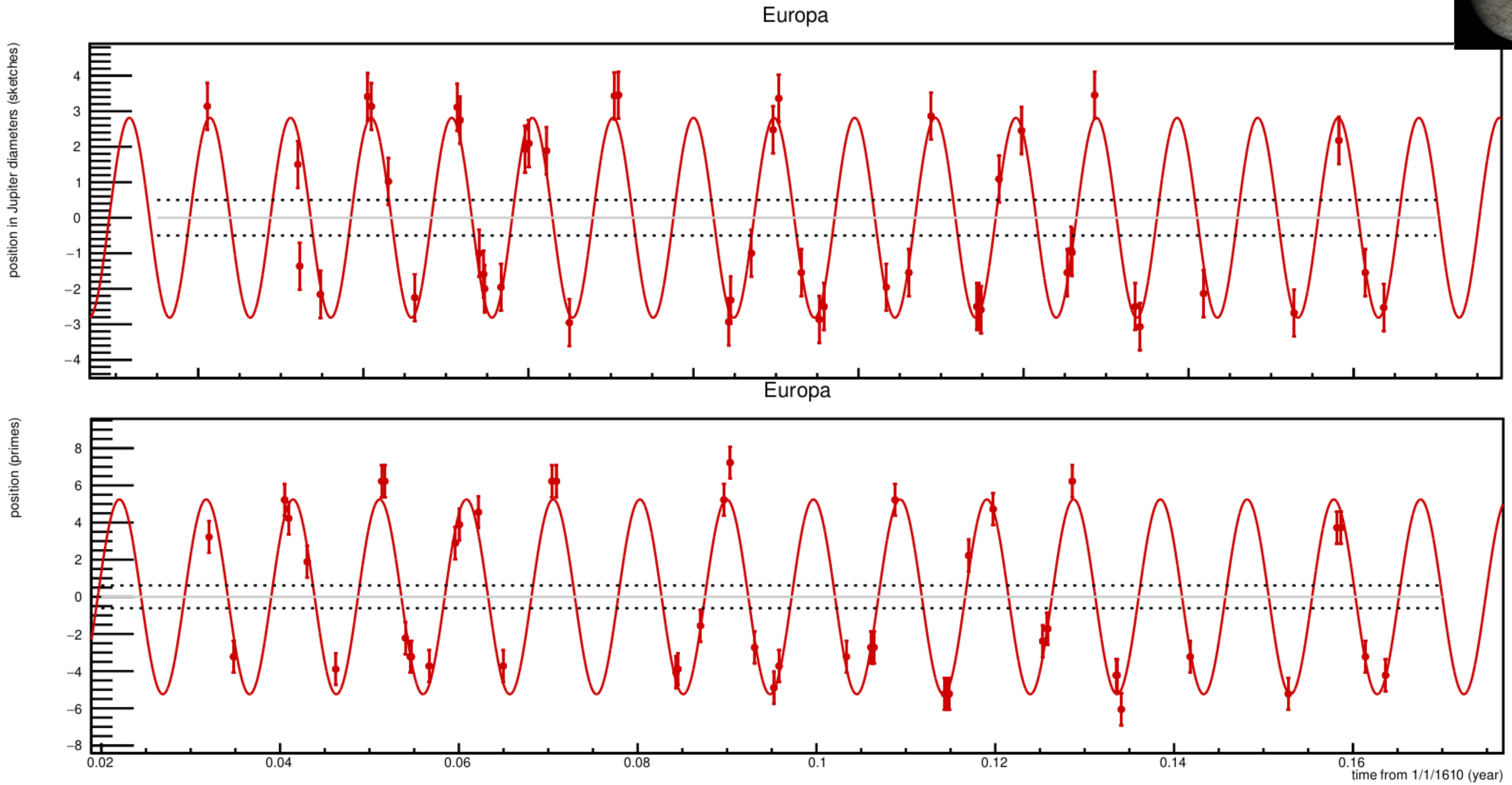




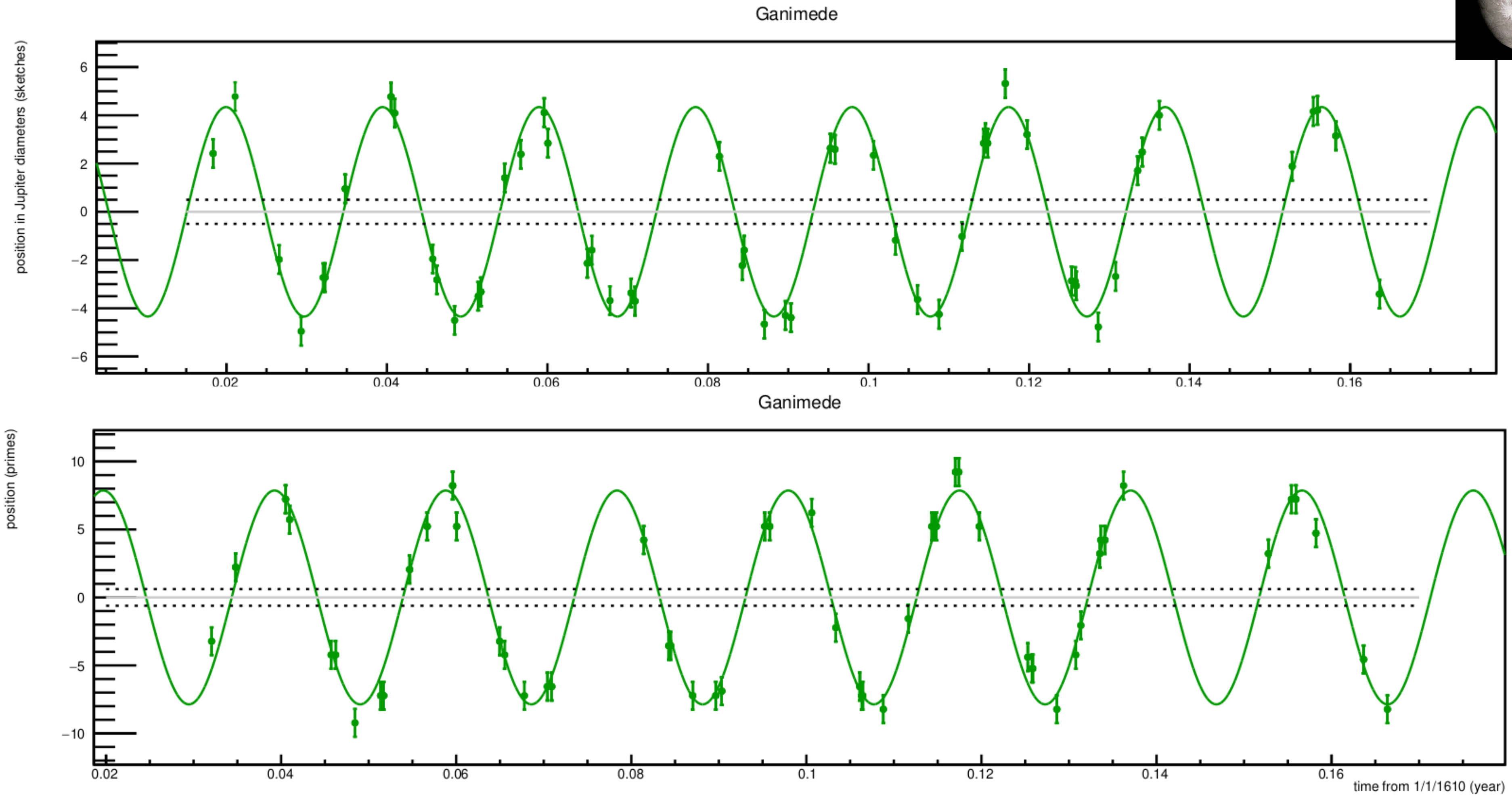


Tagged dataset: Europa

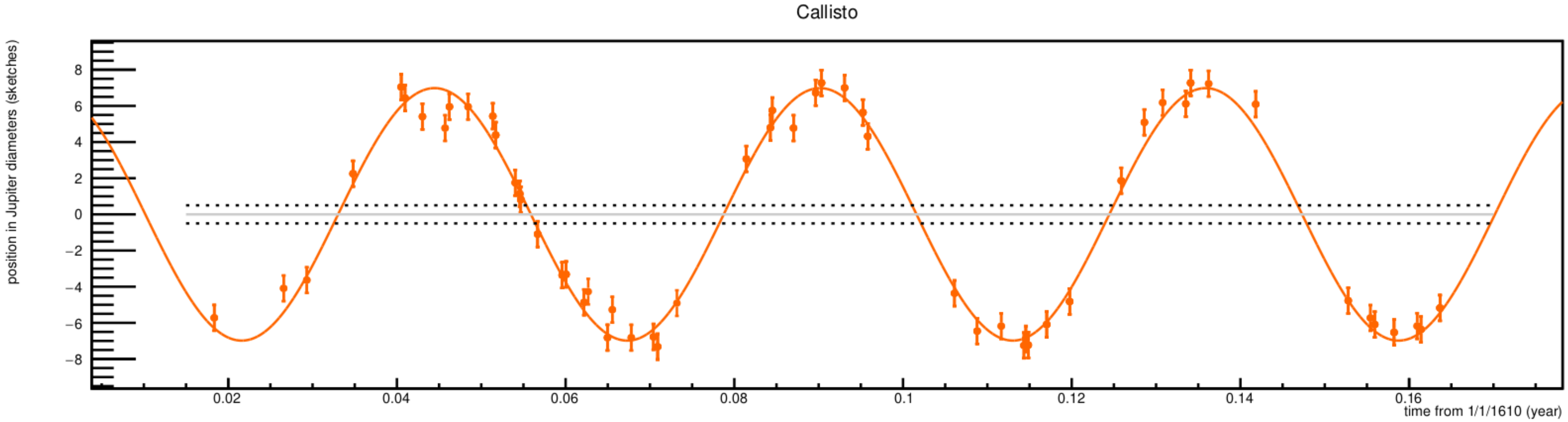


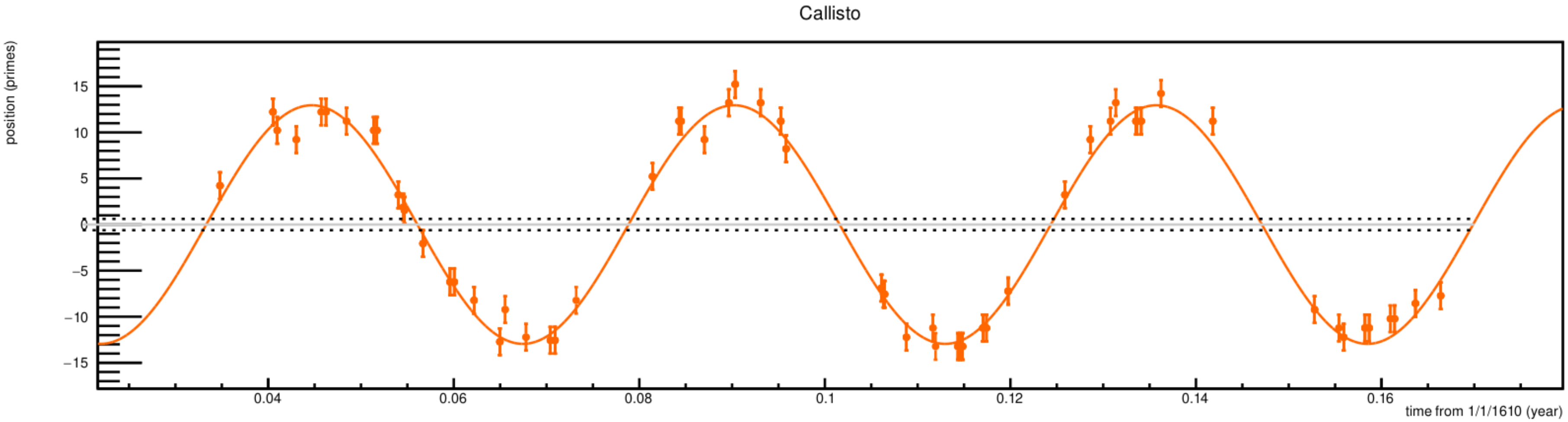


Tagged dataset: Ganymede



Tagged dataset: Callisto





Replica