

# Galileo's prediscovery of Neptune

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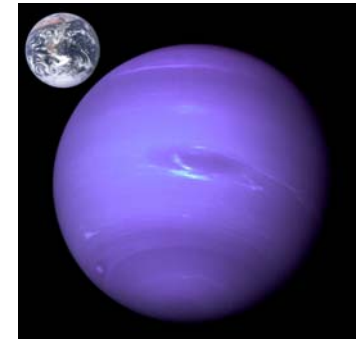
Congresso SAlt Maggio 2009, Pisa



## Neptune' s discovery

Discovered by Johann Gottfried Galle 23 September 1846 (Berlin)

Predicted by John Couch Adams and Urbain Jean Joseph Le Verrier



Lettera di Urbain-Jean-Joseph Le Verrier a Johann Gottfried Galle del 18 settembre 1846] (Morton Grossner, The discovery of Neptune 1979):

"Sarei lieto di trovare un tenace osservatore che volesse dedicare un po' del suo tempo ad esaminare una parte del cielo in cui può trovarsi un pianeta da scoprire. Sono stato portato a questa conclusione dalla teoria di Urano. Un sommario delle mie ricerche sta per essere pubblicato su *Astronomische Nachrichten*. **Vedrete, Signore, che dimostro che è impossibile dar conto delle osservazioni di Urano senza introdurre l'azione di un nuovo pianeta finora sconosciuto;** e, straordinariamente, che c'è una sola posizione nell'eclittica in cui il pianeta può essere localizzato [...] La posizione attuale di questo corpo mostra che adesso siamo, e lo saremo per alcuni mesi, in una condizione favorevole per poter fare la scoperta. Inoltre la massa del pianeta ci permette di concludere che il suo diametro è superiore a 3" d'arco. Questo disco è perfettamente distinguibile, con un buon telescopio, dai diametri stellari spuri causati dalle aberrazioni."

Will complete its first revolution in 2011 (orbital period 165 yr) ...



## Sidereus Nuncius: the Discovery of 4 Jupiter's moons (I)

# S I D E R E V S N V N C I V S

MAGNA, LONGEQVE ADMIRABILIA  
Spectacula pandens, suspiciendaque proponens  
unicuique, præsertim verò

*PHILOSOPHIS, atq; ASTRONOMIS, que à*

## GALILEO GALILEO PATRITIO FLORENTINO

Patauini Gymnasij Publico Mathematico

### PERSPICILLI

*Nuper à se reperti beneficio sunt obseruata in LVN.Æ FACIE, FIXIS IN-  
NUMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,*

*Apprime verò in*

### QVATVOR PLANETIS

*Circa IOVIS Stellam disparibus interuallis, atque periodis, celesti-  
tate mirabili circumuolatis; quos, nemini in hanc vsque  
diem cognitos, nouissimè Author depræ-  
hendit primus; atque*

## MEDICEA SIDERA

NVNCVPANDOS DECREVIT.

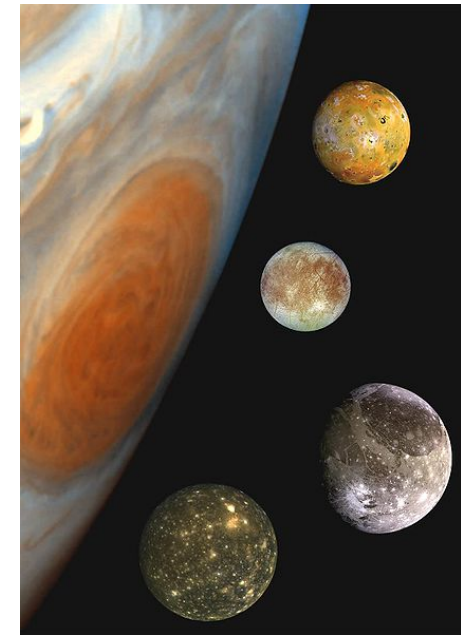


VENETIIS, Apud Thomam Baglionum. M DC X.

*Superiorum Permissu, & Privilegio.*

30 November – December 1609: Moon's face, stars, Milky Way, nebulous stars...

Could be seen by many other people



7 January – March 1610: 4 Jupiter's moons  
Galileo's improvements of spyglass crucial

Published in Venice, March 1610



# Sidereus Nuncius: the Discovery of 4 Jupiter's moons (II)

SIDEREAL MESSENGER  
unfolding great and very wonderful sights  
and displaying to the gaze of everyone,  
but especially philosophers and astronomers,  
the things that were observed by

GALILEO GALILEI,

Florentine patrician<sup>1</sup>

and public mathematician of the University of Padua,  
with the help of a spyglass<sup>2</sup> lately devised<sup>3</sup> by him,  
about the face of the Moon, countless fixed stars,  
the Milky Way, nebulous stars,  
but especially about  
four planets

flying around the star of Jupiter at unequal intervals  
and periods with wonderful swiftness;  
which, unknown by anyone until this day,  
the first author detected recently  
and decided to name

MEDICEAN STARS<sup>4</sup>

1. Galileo came from a Florentine family that can be traced back to the thirteenth century. His ancestors included several members of the governing council of the Florentine Republic and a celebrated physician. His family tree can be found in *Opere*, 19:17. See also Stillman Drake, *Galileo at Work*, 448.

2. The Latin word used here is *perspicillum*. Galileo used the Italian word *occhiale* to describe the instrument. I have translated these terms as *spyglass* throughout. The word *telescope* was unveiled only in 1611. See p. 112, below.

3. Galileo used the Latin word *reperit*, from the verb *reperio*. This word can mean both *invented* and *devised*. Although Galileo was often accused of claiming he actually invented (in our sense) the telescope, this is clearly a calumny, as demonstrated by the passage on pp. 36–37, below. See Edward Rosen, “Did Galileo Claim He Invented the Telescope?” *Proceedings of the American Philosophical Society* 98 (1954): 304–12.

4. Galileo referred to Jupiter's satellites as both “planets” and “stars.” In the old terminology, based on Aristotelian cosmology, both terms were correct. See also note 31, p. 15.

## S I D E R E V S N V N C I V S

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QVATVOR PLANETIS

Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-  
tate mirabili circumuolutis; quos, nemini in hanc vsque  
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NUNCVPANDOS DECREVIT.



VENETIIS, Apud Thomam Baglionum. MDCX.

Superiorum Permissu, & Privilegio.

# Sidereus Nuncius: the Discovery of 4 Jupiter's moons (III)

Switching from Italian to Latin in 1 week!!!

7–15 January 1610:  
notes in Italian...

1610 GENNAIO

Mss. Gal., P. III, T. III, car. 39r.

Adi 7. Di Gennaio 1610 Giove si uideua col Cannone et  
3. stelle fffe costi \* \* \* della quali se hil uisone  
minor si uideua. <sup>oni:</sup> \* a d. 8. apparsa costi \* \* \* era dug  
diretto et no retrogrado come s'hono i calculatori.  
Adi 9. fu rugolo. a d. 10. si uideua costi \* \* \* cio e id.  
giu' s' la piu occidentale di che la uultana <sup>si puo</sup> si puo credere.  
Adi 11. era in questa guisa \* \* \* et la stella piu uicina  
a Giove era la medesima minore dell' altra, et uicinissima all' altra  
come che le altre sere erano le dette stelle apparsite tutte tre  
di equal grandezza et tra di loro equator lontano; dal che  
appare intorno a Giove esser .3. altre stelle essate inuicibile ad  
ogni uno sino a questo tempo.

Adi 12. si uede in tale costituzione <sup>oni:</sup> \* \* \* era la stella  
occidentale poco minor della orientale, et Giove era in mezzo lontano  
tra l'una et dall' altra quinto il suo diametro e iore: et forse era  
una terra fucida et uicinis a \* \* \* verso oriente; anzi piu in era  
uereomp hamedo is is piu diligeta osservato, et uisibile in  
notte.

Adi 13. hauedo benis<sup>o</sup> fermato lo scum. si uedono uicinis a Giove  
4. stelle in questa costituzione \* \* \* e meglio costi \* \* \*  
e tutte apparsione della medesima grandezza, la spazie delle 2. occidentali  
ad era maggiore del diametro di 7. et erano tra di loro notabilmo  
piu uicine che le altre sere; ne erano in linea retta equidistanti come  
se aueto ma la media delle 3. occidentali era u poco eleuata, ouero la  
piu occidentale alquato depresso; sono queste stelle tutte molto lucide et  
fucidiss<sup>e</sup>: et altre si se et apparsione della medesima grandezza non sono  
costi splendidi.

Adi 14. fu rugolo. Adi 15. era costi \* \* \* <sup>oni:</sup> \* la pross<sup>a</sup> a  
7. era la minore et le altre dimano e meno maggiori: gli interstictij  
tra 2. et la 3. equati erano, quanto il diametro di 7. ma la 4. era di-  
stante dalla 3. il doppio iurea; ad face  
<sup>si uideua</sup>  
7. long: 71. 38. lat: <sup>Mei</sup> 1. 13. <sup>si uideua</sup>  
2. 30 erano interomp linea retta, ma come mostra  
1. 17 l' esempio, erano al solio lucidiss<sup>e</sup>: di che poco  
1. 17 et, et miante scintillauano come au. fl. inax



# Sidereus Nuncius: the Discovery of 4 Jupiter's moons (IV)

During the night of January 15 1610, starting a new page of his notes, Galileo switches to Latin...

428 OSSERVAZIONI.

Mes. Gal. P. III. T. III. car. 301.

*form: Spheris 2 boro ante in u parte, et ceteris bunte itruu nero  
hui n' d'f'ar'na i'p'ari*

fuit precedes d'f'itutio hora noctis 3. sed hora -7. & tres tantu  
aderant stellulz cu 7. i tali aspectu O - \* } minima  
erat inu uiciniu, reliqua 2. maiores \* }  
duplo. et ter se equal. Distantia a 7. ad prop. aucta erat: ipse  
uiciniu erat 2. nefe p' dimidia diametri 7. 3<sup>a</sup> distabat a 2.  
paulo plus q' ipse a 7. Post u' alia hora 2. medie stellulz erant  
ad huc uiciniu adeo ut inter ipse spaciū medietet ipse minima stelle  
minus; sicut circa minuta secunda 40.

Die 16. hora 1<sup>a</sup> noctis talis fuit d'f'itutio \* O \*  
3. n. on cernebat stellulz Que 7. prop. p' 4<sup>a</sup> nefe diametri i'f'it  
parte ab eo utiq' distabat <sup>semp. 7.</sup> 2. u' occidentalis p' quadrupla diam  
tri i'f'it ab illo eberat; prop. q' ad maiorz apparabant remotiori  
sed lucidiores.

Die 17. 1<sup>a</sup> hor. ab Occasu circum. fuit d'f'itutio \* O \*  
stella orientalis a 7. p' 3. distabat occidentalis p' 11. orientalis  
apparebat duplo maior reliqua, nec plures q' iste n. d'f'inebat  
stelly. Sed 4. horis transactis hora noctis 3. tertia stella apparere co:  
pit que antea in orientali; erat iuncta et tali fuit aspectus  
eas \* O erat n. media orientatori qua prop. nefe distat  
ab ea p' minuta secunda no. ferē, et alina recta p' extremos et 7.  
Quia paululu uersus austr. deflectit.

Die 18. hor. o. m. no. ab Occasu talis fuit aspectus \* O \*  
erat stella orientalis maior reliqua; in ternallu iter orientate  
et ceter 7. min: p' 9. inter 7. et occidentate stella .ii. Secundū  
mā existimatio 7. diameter occupat 3. aut 3<sup>o</sup> minus.

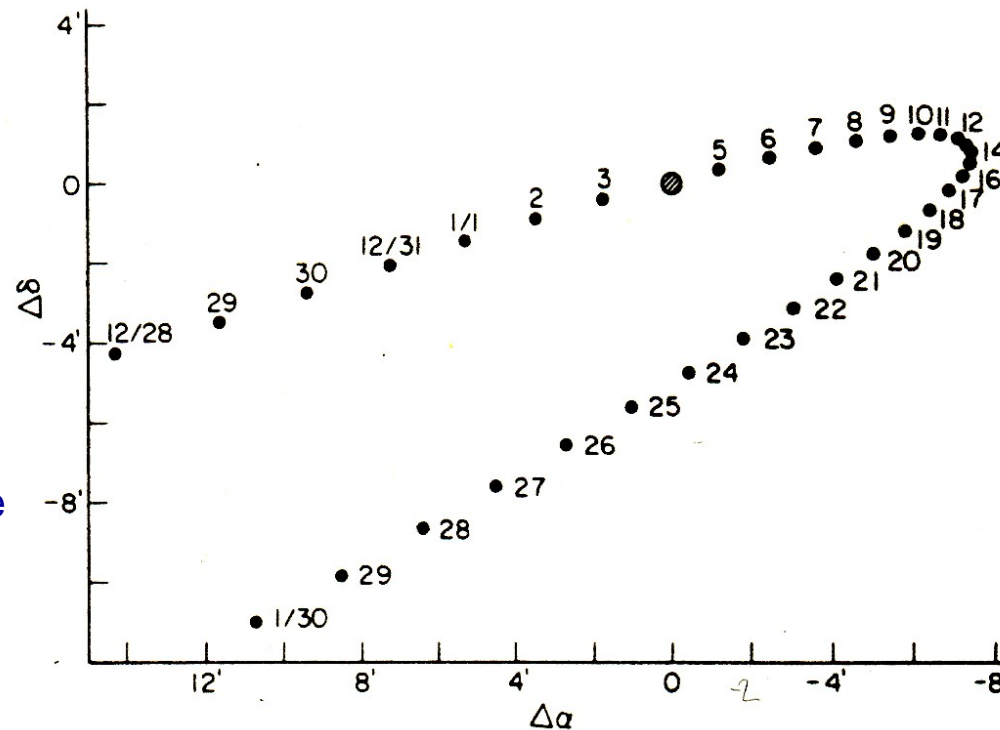
Die 19. H. 2. ita se habebat d'f'itutio; nempe in  
noctis 2. hinc 7. cu 3. stellis. inter orientalem  
et 7. erat iteruallu 6. inter 7. et sequēte 5. inter hūc et occidentalem  
p' orientali erat paululu maior reliq; omnes erā nūq' inter orientate  
et 7. stellula mediores sed 7. prop. q' ut illi fore tēgetat; at hora 5.  
hūc p' manifeste uidi mediū in inter 7. et orientate stellā locū omi  
pante, ita ut talis erat d'f'itutio \* O \* erat aut hūc u' d'f'itutio  
stellula admodū exigua; uox temp' hora 6. reliqua prop. mag' equabat

## Neptune close to Jupiter in 1612-1613

See plot of Neptune-to-Jupiter relative right ascension and declination between 28 December 1612 and 30 January 1613

Neptune's magnitude: 7.9  
Galilean satellites magnitude:  
between 5.5 and 6.0

Observations of Neptune since its discovery in 1846 do not yet cover 1 single revolution of the planet around the Sun: a much older observation by Galileo would be of enormous scientific value to firmly establish its orbit...



**Fig. 1** The positions of Neptune with respect to Jupiter, 28 December 1612 to 30 January 1613. Black dots, Neptune; cross-hatched circle, Jupiter.

Kowal and Drake: "Galileo's observations of Neptune", Nature 1980

# Neptune close to Jupiter at a very special time of Galileo's work....

## Observation technique:

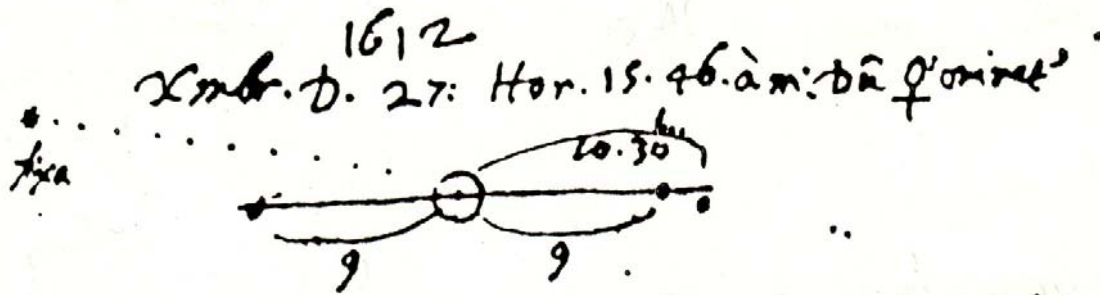
- Starting January 1612 Galileo uses a micrometer (Le Opere Vol III, p. 446) which he states makes his observations accurate to a few arcseconds (from arcminutes before) (Le Opere Vol. III, p 415).

## Theory:

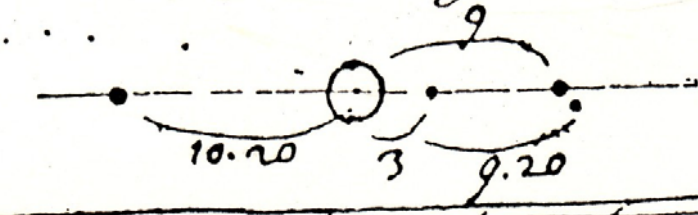
- Galileo has distinguished the satellites and determined their orbital periods already in April 1611 (Le Opere Vol. III 406). By 1612 he sends around his predictions to other people routinely (Le Opere Vol. XI p. 129). On June 16 1612 Sagredo complains that they arrive not enough time in advance.. (Le Opere Vol. XI, p. 330)
- On June 23, 1612 Galileo writes that he can make predictions accurate to 1 arcsec (Le Opere Vol. XI p. 335) with a new jovilab (Le Opere Vol. III, pp 486-487)
- A fit of computed satellites positions (Lieske, A&A, 1980 to Galileo's observations (from the beginning of 1612) as measured with a ruler clearly shows a change of scale factor at the end of January 1612 shows that
- By the beginning of 1612 Galileo is able to compute the effect of the relative motion between Jupiter and the Earth and thus to improve his ephemerides



...and indeed he saw Neptune!



Ante ortu 0.30. 2 occidentales erat prope  
 coniuncti; distabant. n. 0.20. in longitudine  
 sed occidentalis tantam habuit latitudinem  
 ut apparetur quod in ista copula altera vis  
 at ne vis quidem tangeret, et eade hora  
 4.ª ex oriente occidente stella aderat et  
 orientalis remotior facta fuit; eoque talis  
 configuratio; et tabule ad unguem responderet.



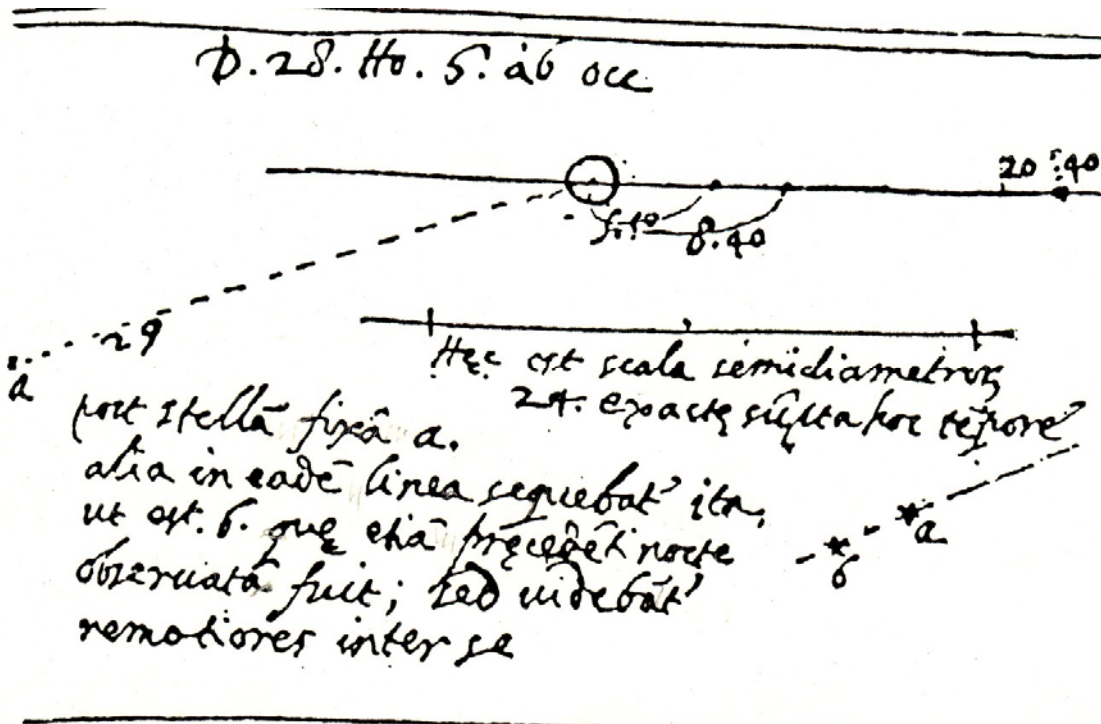
“ 1612

December 27: hour 15.46 after  
 noon: while Venus was rising”

“Before sunrise 0.30. The two  
 westerly ones were very closely  
 joined; they were distant 0.20  
 according to their longitude, but the  
 more easterly one had such latitude  
 that it appeared that in this  
 conjunction it almost touched the  
 other and at the same hour a fourth  
 star was present and the easterly  
 one became more remote; and the  
 configuration was so; and the tables  
 agreed at a nicety”

The “fixa” (fixed star) was indeed  
 not a star but Neptune!

...and even noticed something unusual! (II)



“Day 28 (Januray 1613). Hour 5 from sunset

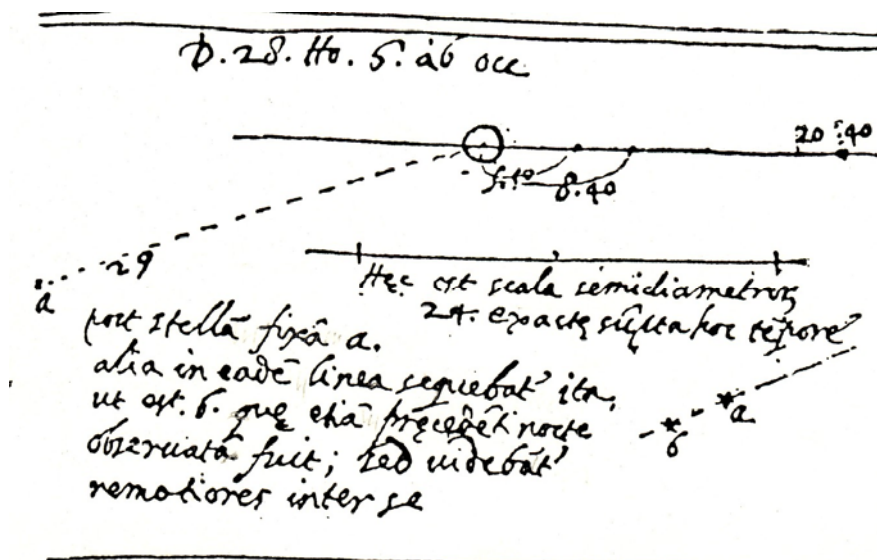
“This is the semidiameter scale 24 exactly taken at this time”

“after fixed star “a” another followed in the same line, thus that is “b” which was also observed in the preceding night; but they seemed more remote from each other”

There are: Jupiter, 3 satellites. SAO star # 119234 (“a”) and Neptune (“b”)

Kowal and Drake: “Galileo’s observations of Neptune”, Nature 1980

## Did Galileo draw the position of star/Neptune to scale?



“Day 28 (January 1613). Hour 5  
from sunset

According to modern ephemerides the distance separating Neptune from the star should be  $7.1 R_J$ .

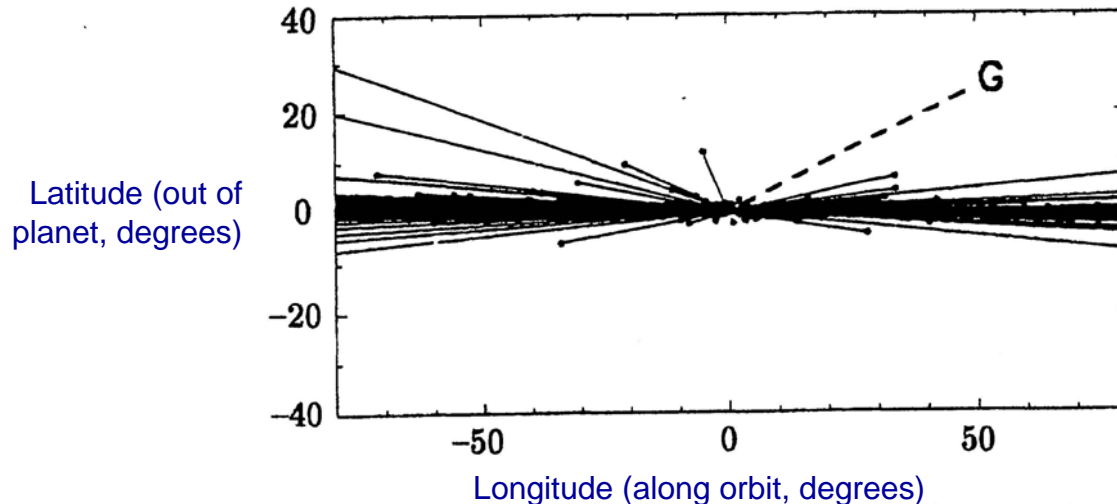
In Galileo's drawing (after applying for his consistent 10% scale factor..) the separation is only  $4 R_J$ .

This would mean a difference wrt the position given by modern ephemerides by 53 arcsec in longitude and 26 arcsec in latitude. This disagreement, especially the one in latitude, would be unacceptable for a modern ephemeris of Neptune!!!

Standish and Nobili: “Galileo's observations of Neptune”, *Baltic Astronomy*, 1997  
(available on NASA's ADS)



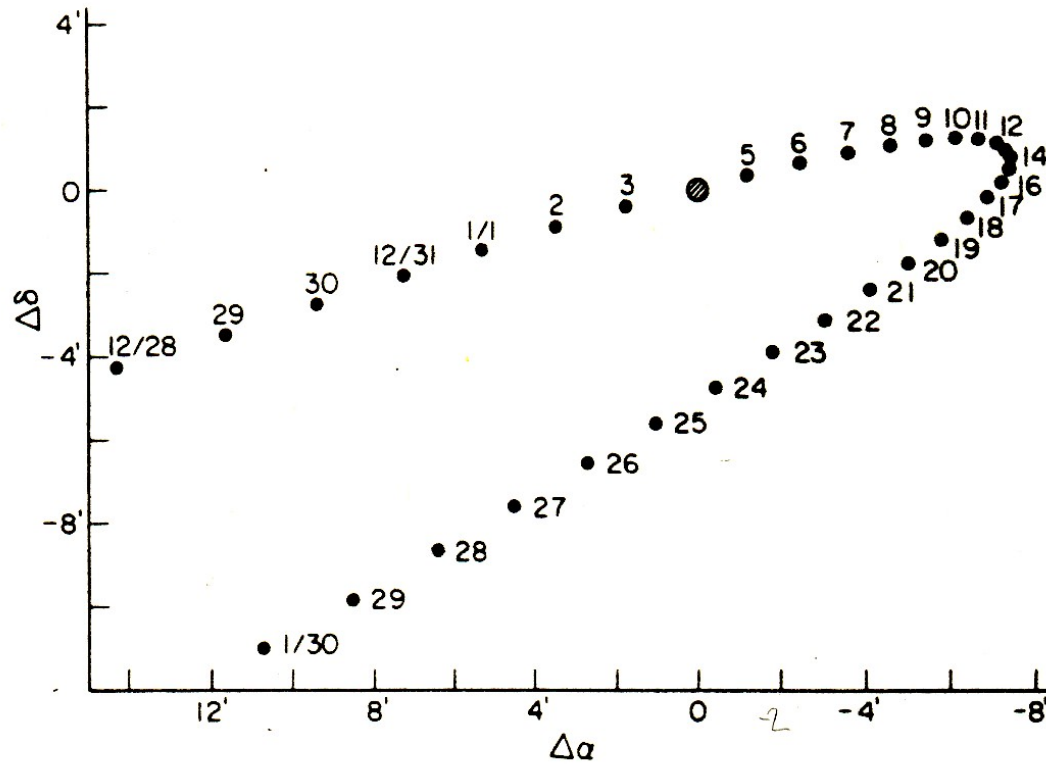
## Planet X's perturbations of Neptune on January 28, 1613



**Fig. 3.** Perturbations of Neptune on January 28, 1613, caused by randomly chosen Planet X's of one earth mass. Most of the cases show Neptune perturbed in the direction along the orbit (longitude). For virtually all of the out-of-plane cases, the perturbation is small, indicating that a perturbation large enough to agree with Galileo's measurement (denoted by the letter "G") would require tens of earth masses - a Planet X as large as Neptune itself!

Conclusion: If Galileo's drawing of the star/Neptune was to scale like the satellites, and Neptune was perturbed to where he drew it, the perturbation was a rare, pathological one

# But Neptune passed much closer by to Jupiter... (I)



Why did Galileo not record Neptune when it was much closer to Jupiter than in the observations of December 27 1612 and January 28 1613?

Or did he?

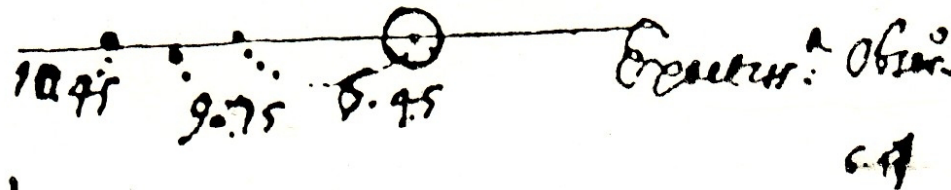
**Fig. 1** The positions of Neptune with respect to Jupiter, 28 December 1612 to 30 January 1613. Black dots, Neptune; cross-hatched circle, Jupiter.

# But Neptune passed much closer by to Jupiter... (II)

“Jan day 5. (1613) hour 7.12 from sunset from noon hour 11.38”

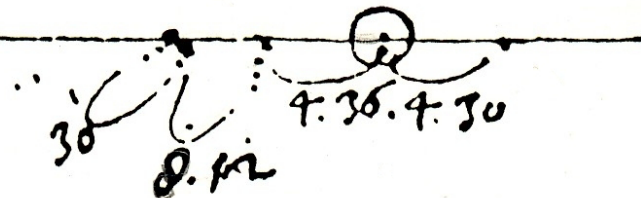
Jan: D. 5. Ho. ~~6.39~~ ab occ. à mer. u. ho. 11.38  
7.12

“Most exact observation”



“Pae. ho: 6.18”

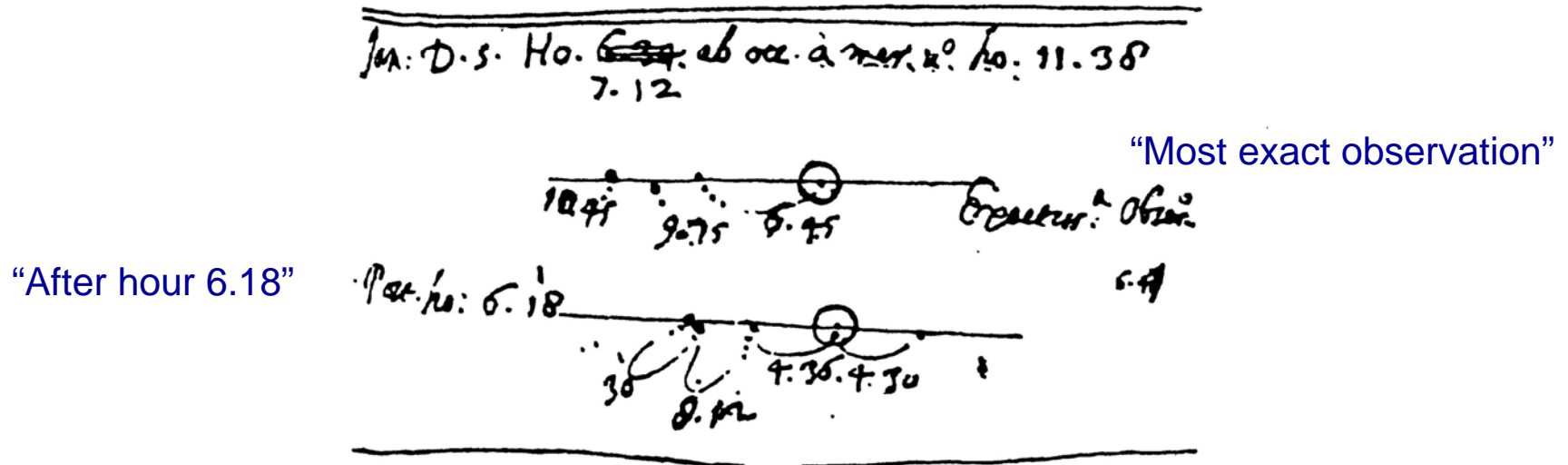
“After hour 6.18”





## Did Galileo mark it?

“Jan day 5. (1613) hour 7.12 from sunset from noon hour 11.38”



**Fig. 4.** Galileo’s drawings of January 5 - 6, 1613. In the second, the spot to the lower right is just where Neptune was at that time. Magnification of the spot shows that it was an intentional mark, made with ink.

- It is ink, it is intentional: microscope + back light; UV lamp .. suitable for the ink used at the time of Galileo
- It is where modern ephemerides would put Neptune....

Standish and Nobili: “Galileo’s observations of Neptune”, *Baltic Astronomy*, 1997  
(available on NASA’s ADS)

# The actual notebook of Galileo "La vacchetta...."

