How to measure the speed of light (part 3…..using a telescope !)

James Appleton, Martin Cook and Alan Smith

Plan for the evening

History of estimating the speed of light - Alan

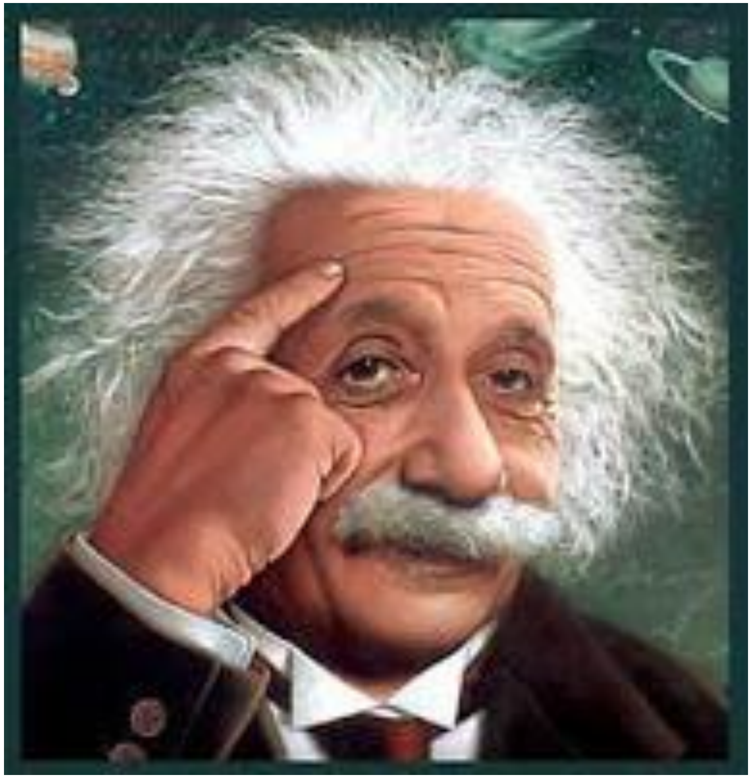
OASI interpretation of Rømer’s method – James

Tea break

Observing Galilean eclipses - Martin

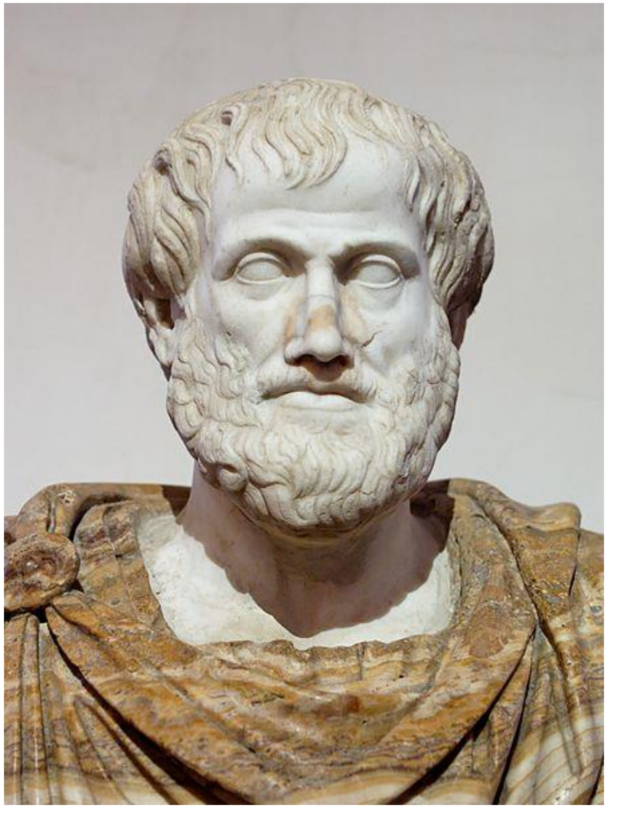
Call to arms: the OASI observing project - Martin

Questions and discussion



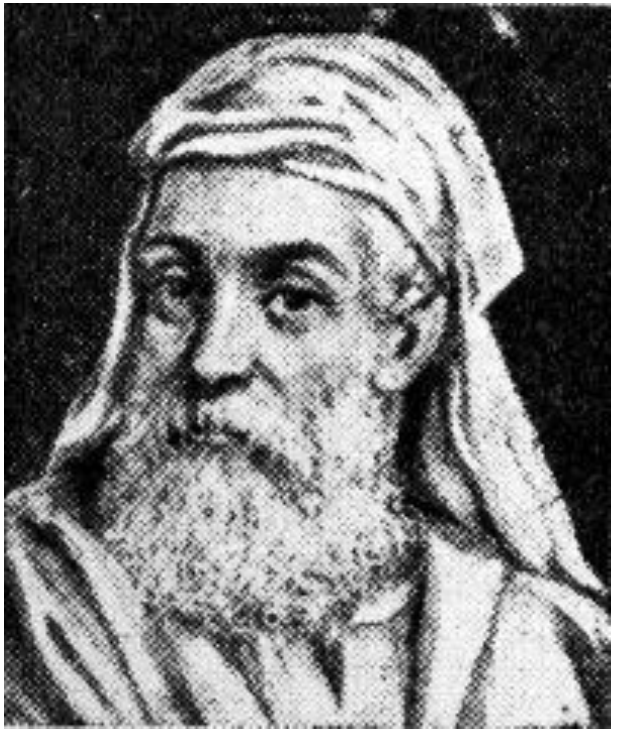
$$E=mc^2$$

Aristotle 384 – 322 BC



- Aristotle argued that "light is due to the presence of something, but it is not a movement”.
- He therefore, argued that light travelled ‘instantaneously’.

Empedocles 490 – 430 BC



- Empedocles maintained that light was something in motion, and therefore must take some time to travel.

Euclid (325 – 265 BC) and Ptolemy (90 – 160 AD)

Euclid and Ptolemy advanced the emission theory of vision, where light is emitted from the eye, thus enabling sight.

Alhazen 965 – 1040 AD

- al-Ḥasan a Muslim scientist, dismissed the emission theory in favour of the now accepted intromission theory of vision, in which light moves from an object into the eye.
- He proposed that light must have a finite speed, and that the speed of light is variable, decreasing in denser bodies.

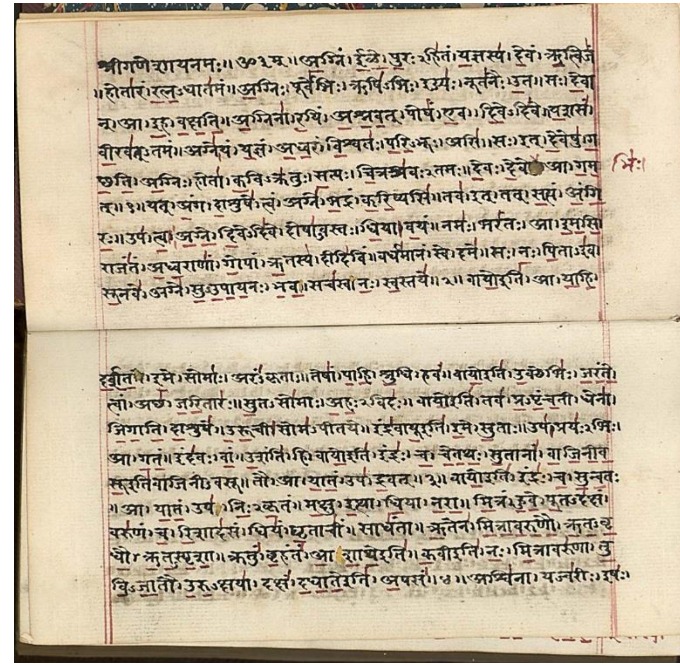
Roger Bacon 1214 –1294

- In the 13th century, The English philosopher Roger Bacon, using philosophical arguments argued that the speed of light in air was not infinite.

Witelo (1230 – 1300 ‘ish’)

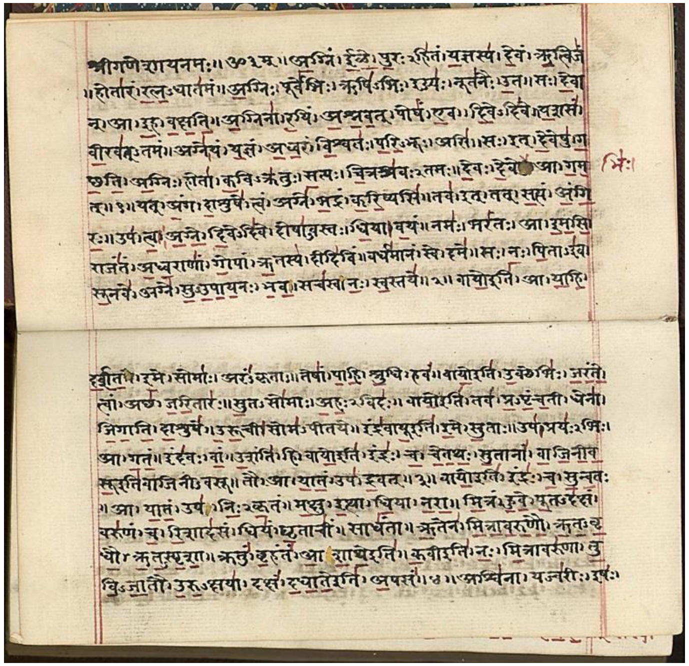
- In the 1270s, Witelo, a Polish philosopher, considered the possibility of light travelling at infinite speed in a vacuum but slowing down in denser bodies.

Sāyaṇa (died 1387)



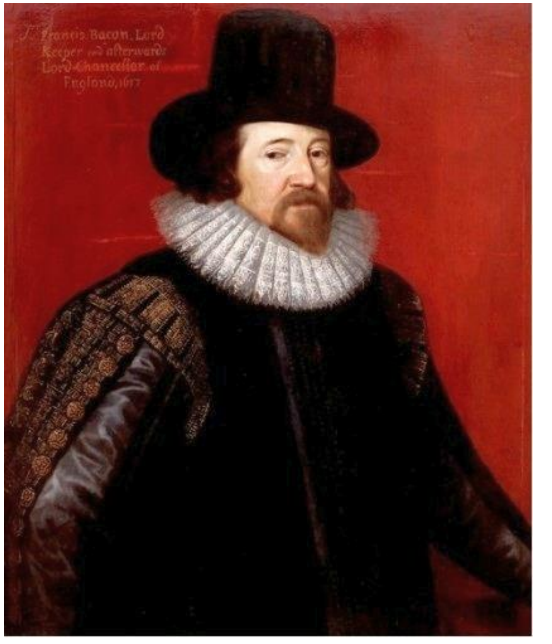
- Sāyaṇa comments on a verse in the Rigveda (a sacred book of Hindu texts) that the speed of the *Sun* was *2,202 yojanas in half a nimesha* .

Sāyaṇa (died 1387)



- Sāyaṇa comments on a verse in the Rigveda (a sacred book of Hindu texts) that the speed of the *Sun* was *2,202 yojanas in half a nimesha* .
- His result: between 267,910 and 300,940 km/sec

Francis Bacon (1561 – 1626)



- Francis Bacon (1600 A.D.) again argued against an infinite speed for light. "Even in sight, whereof the action is most rapid, it appears that there are required certain moments of time for its accomplishment...things which by reason of the velocity of their motion cannot be seen -- as when a ball is discharged from a musket"

Navigation:
(or how not to hit a rock)

- The angle of Latitude of a ship could easily be determined using a sextant and so you would know how far north or south you were. But with no accurate clocks available (let alone ones that would work at sea) there was no way of determining longitude.

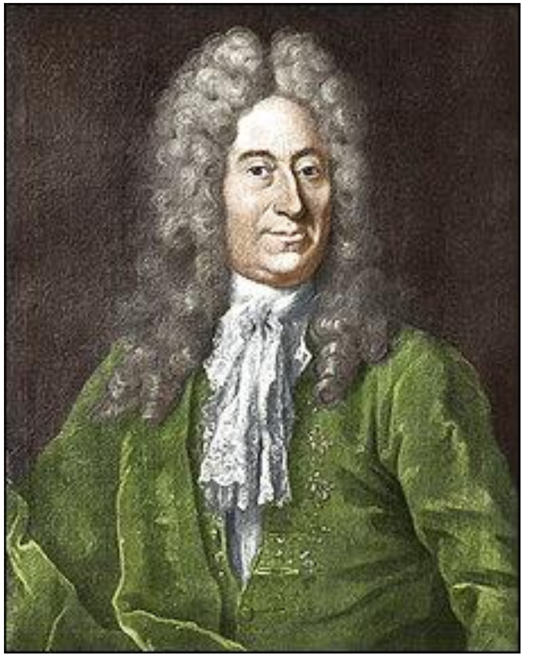
1610

- Moons of Jupiter discovered by Galileo using a telescope with a 35mm lens and a magnification of about 20

Giovanni Domenico Cassini (1625 – 1712)

- Cassini, was one of the people who took up the challenge of longitude by careful timing of Jupiter’s rotation and published the first reliable times for the eclipse timings of Jupiter’s moons.

Ole (Olaus) Christensen Rømer (1644-1710)



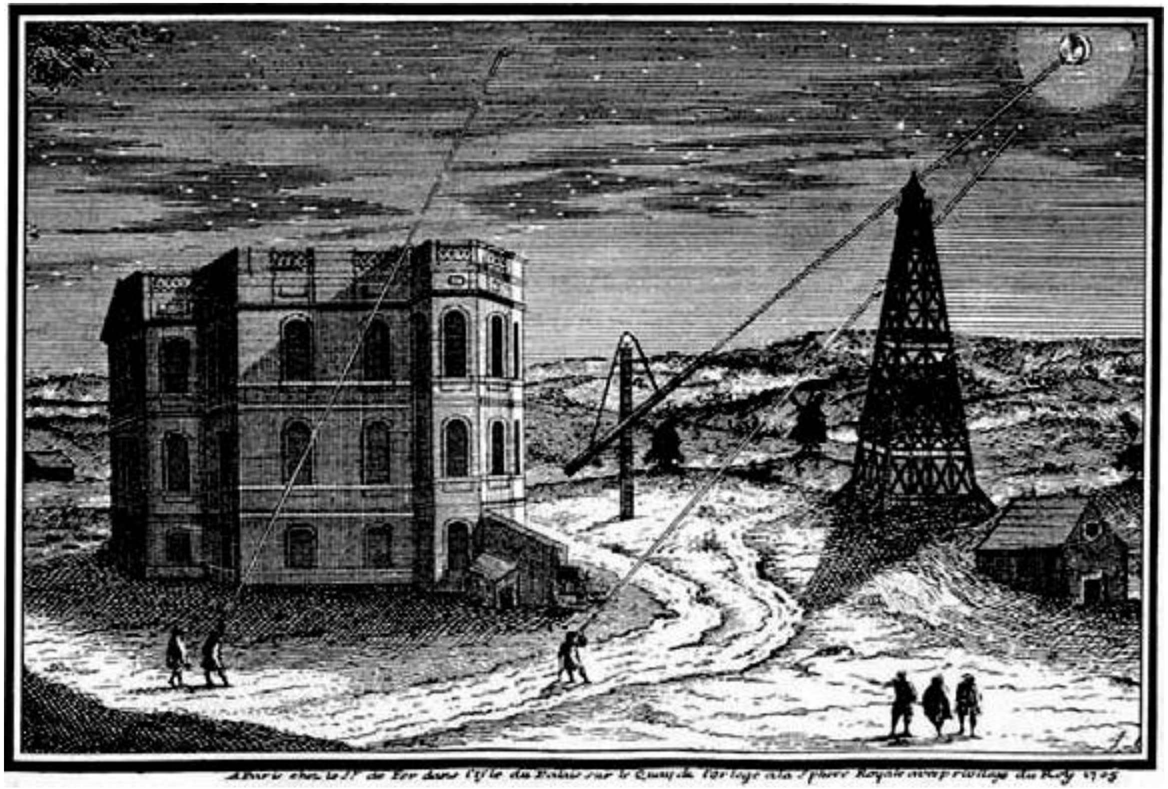
- Ole Rømer, a Danish astronomer, had also made extensive observations of Jupiter and its moons, and in 1672, he went to Paris to observe with Cassini.

Back to the speed of light

- In 1629, Isaac Beeckman (a Dutch philosopher) proposed an experiment in which a person would observe the flash of a cannon reflecting off a large mirror about one mile away.

- In 1638, Galileo repeated the experiment by observing the delay between uncovering a lantern and its perception some distance away.
- His result: Galileo concluded that the speed of light was at least 10 times faster than sound (340m/s).

September 1676
Observatoire Royale Paris



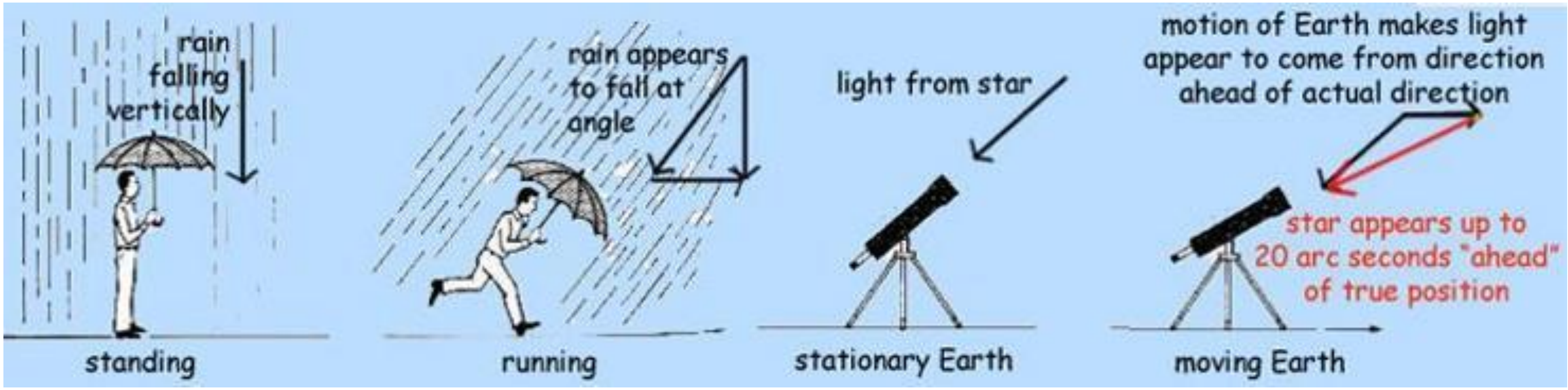
1676 Ole Rømer

- His result: Rømer never actually calculated the speed of light ! He merely ‘proved’ that light had a speed.

- Of course, the establishment largely dismissed his findings.

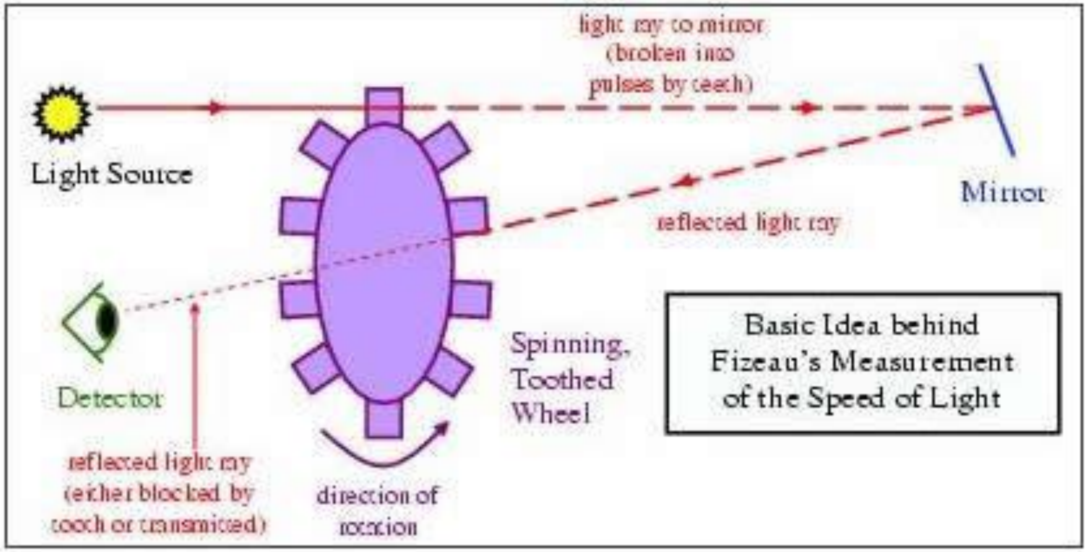
1728 James Bradley

- Used stellar aberration by observing a star in Draco to calculate the speed of light.
- His result: 301,000 Km/s



1849 Hippolyte Louis Fizeau

- Light is shone between the teeth of a rapidly rotating toothed wheel. A mirror 5 miles away reflected the beam back through the same gap between the teeth of the wheel.
- His result: 313,300 Km/s



1862 Leon Foucault

- A light is shone onto a rotating mirror, it bounces back to a remote fixed mirror and then back to the first rotating mirror.
- His result: 299,796 Km/s

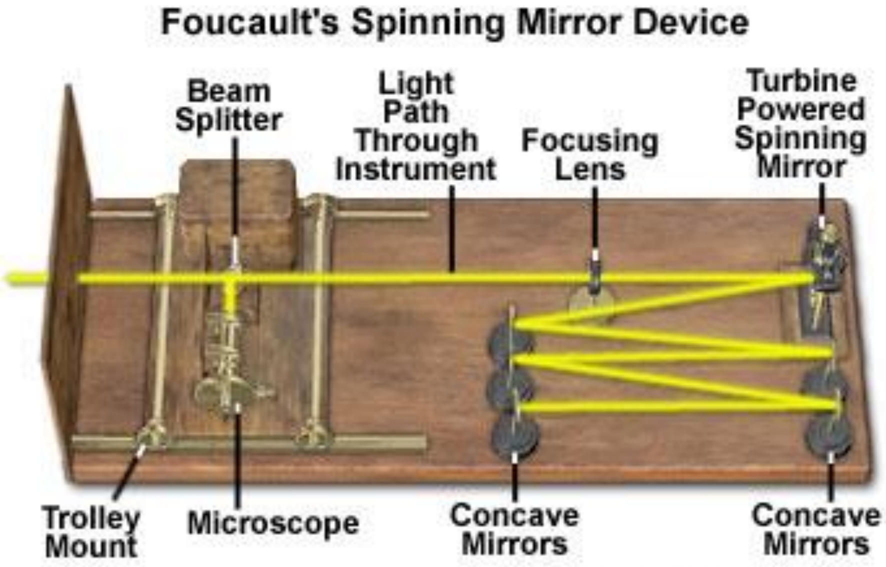
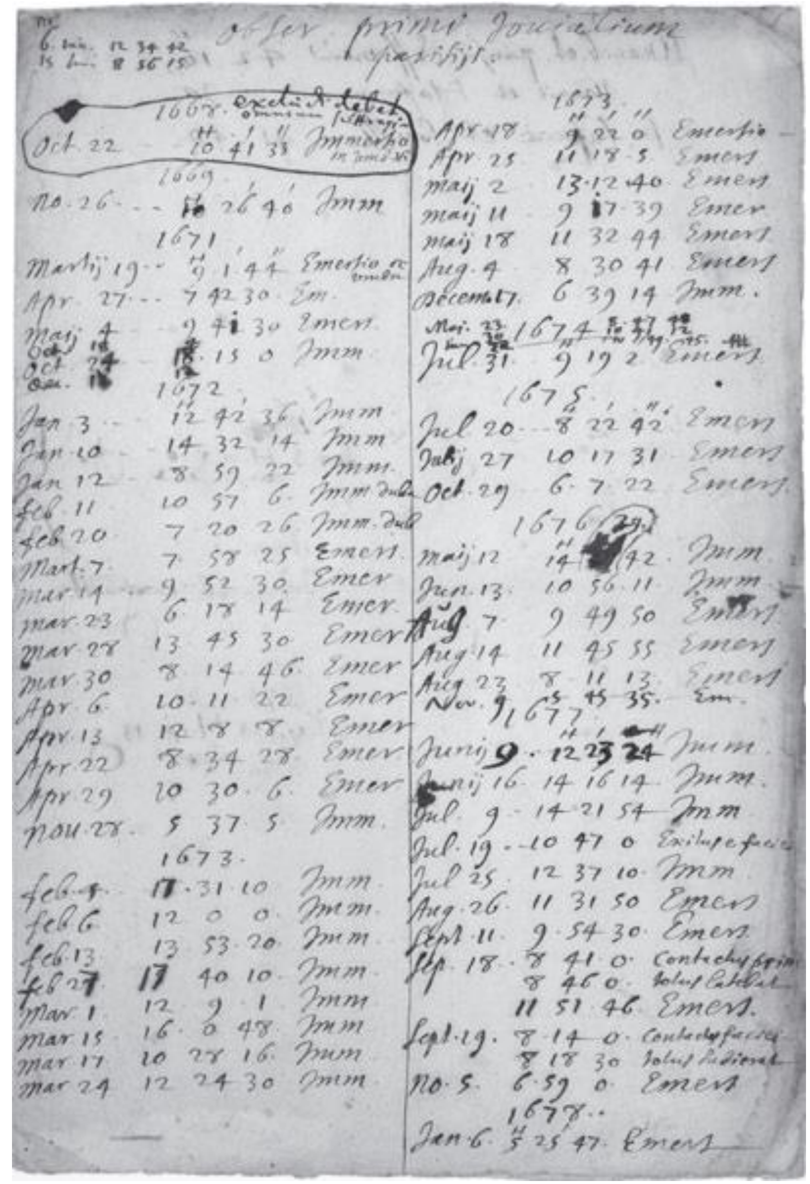


Figure 4

- In 1676 when Ole Rømer published his theory of *mora luminis* (the retardment of light) his main objective was to establish that light is propagated in time and not instantaneously.



- Rømer’s ‘result’: 214,000 km/s (about 30% less than the modern accepted value)

Rømer Revisited

OASI's Measurement of the Speed of Light

James Appleton

Ole Rømer (1644-1710) by Jacob Coning, c. 1700.

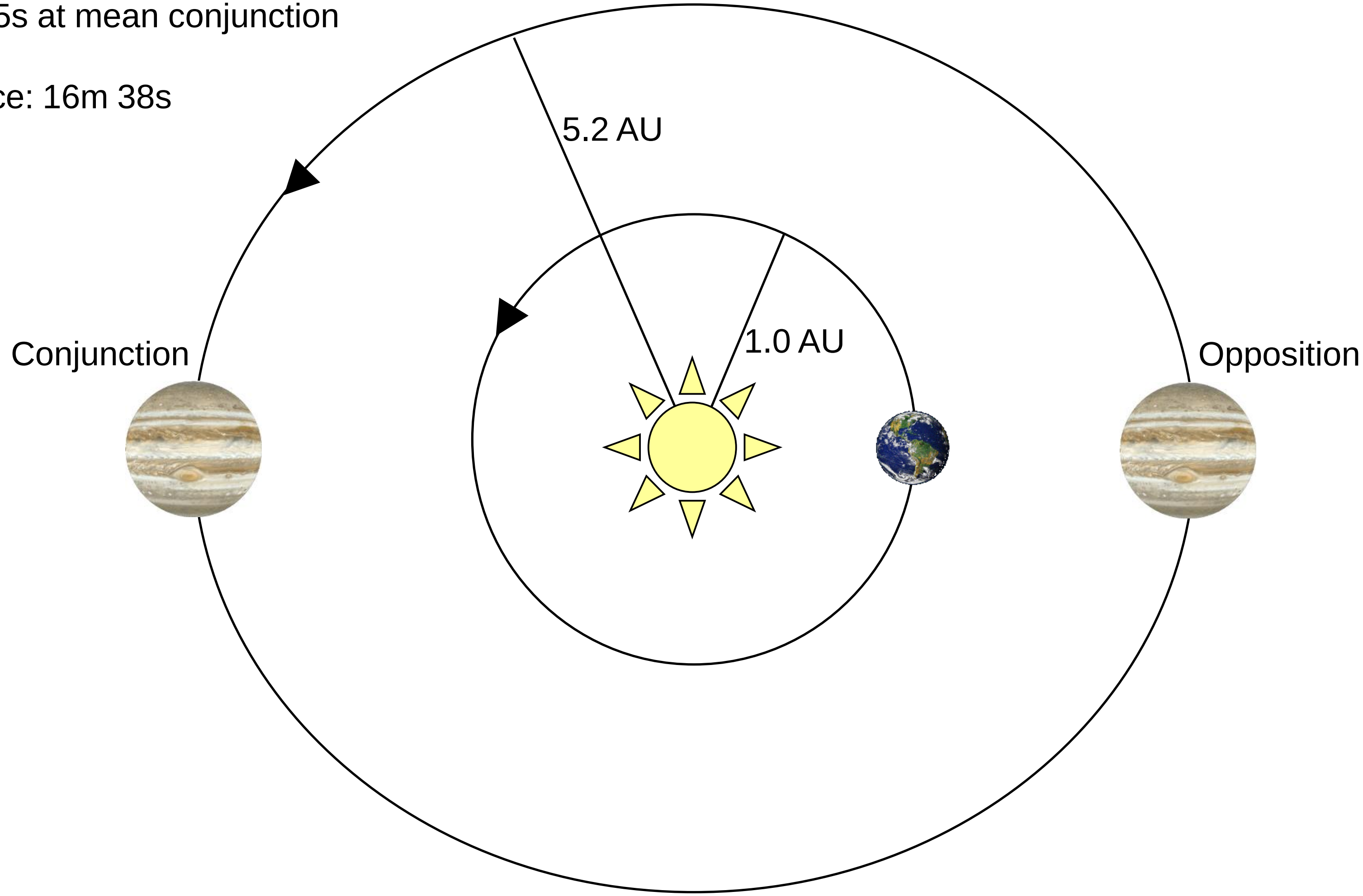
Orbital Dimensions

Light travel time 499 sec per AU

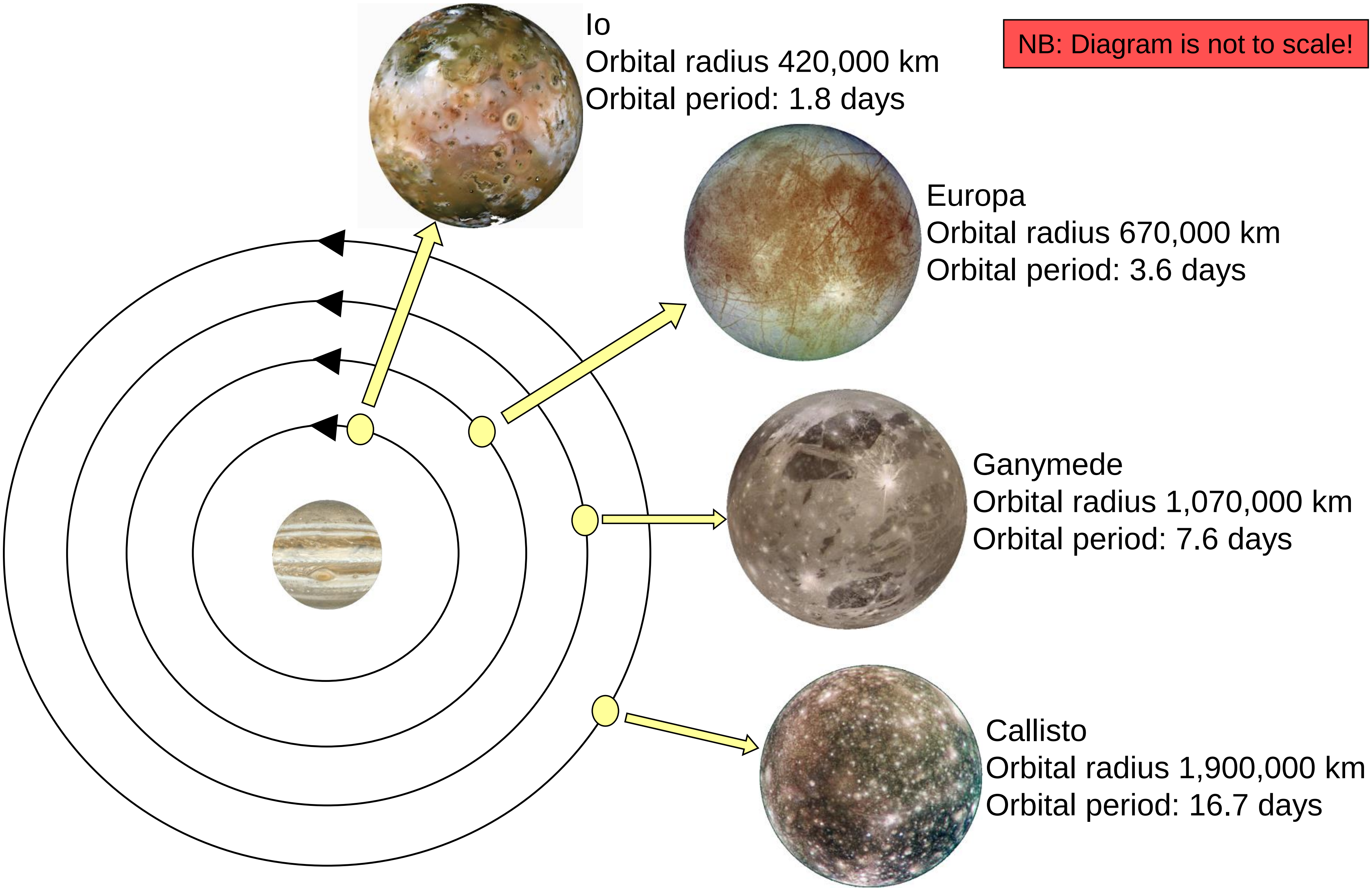
Light travel time Earth – Jupiter:
  34m 57s at mean opposition
  51m 35s at mean conjunction

Difference: 16m 38s

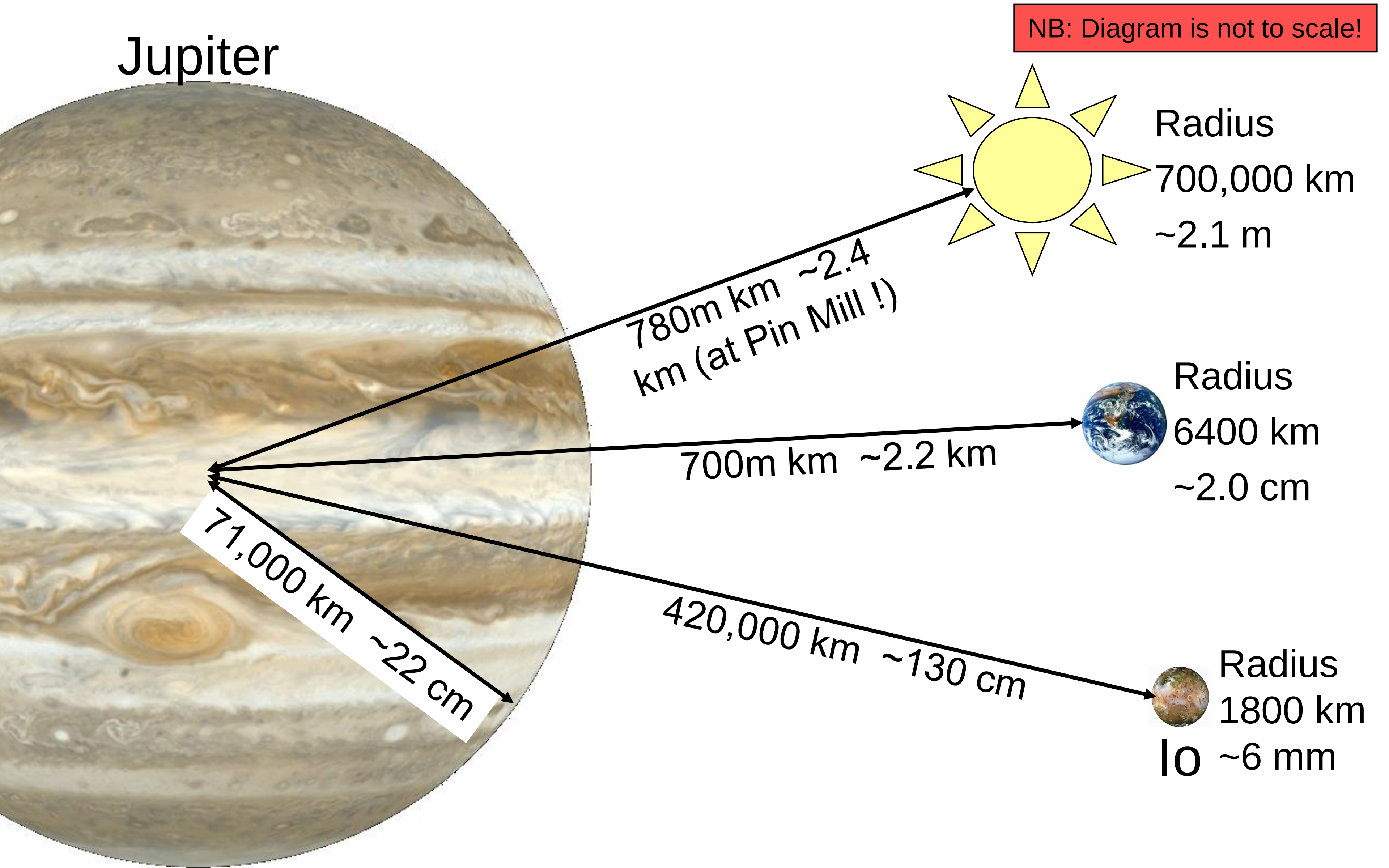
NB: Diagram is not to scale!



Jupiter & The Galilean Satellites



Model at Scale 1:325,000,000



Model Checklist

- Phenomena associated with the Galileans:
  - Transit
  - Shadow transit
  - Occultation
  - Eclipse
- Eclipse most suitable “timing tick” for Rømer’s method
- Effect of tilt of Jupiter’s axis
- Umbral and penumbral shadow
- Determining the beginning and end of an eclipse

Sidereal and Synodic Periods

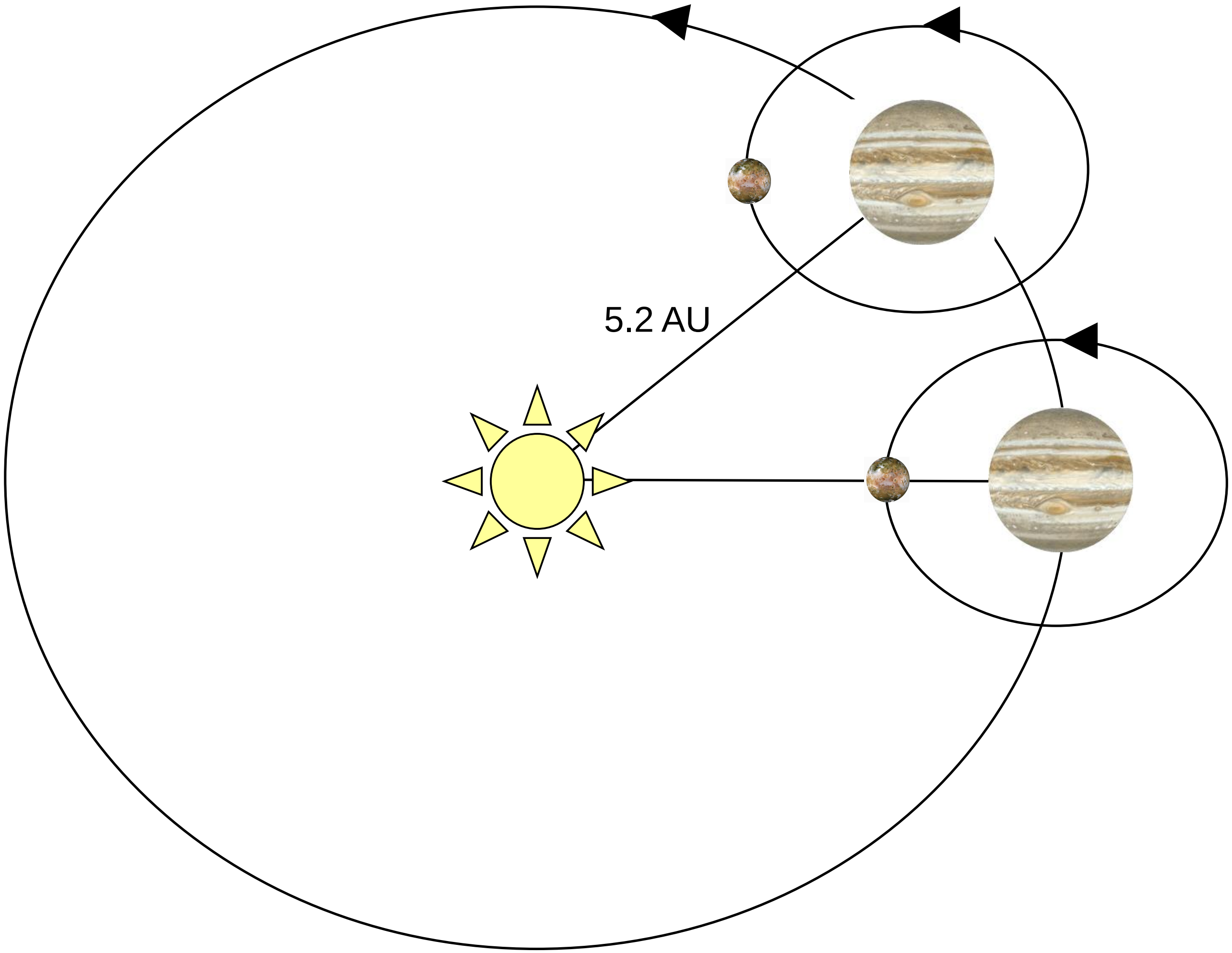
For a Galilean satellite

- *Sidereal period*: average time to complete a revolution of Jupiter, measured with reference to the stars
- *Synodic period*: average time between successive conjunctions with the Sun, as seen from Jupiter

The two differ due to Jupiter’s orbital motion

Synodic Period of a Galilean

NB: Diagram is not to scale!



Observations

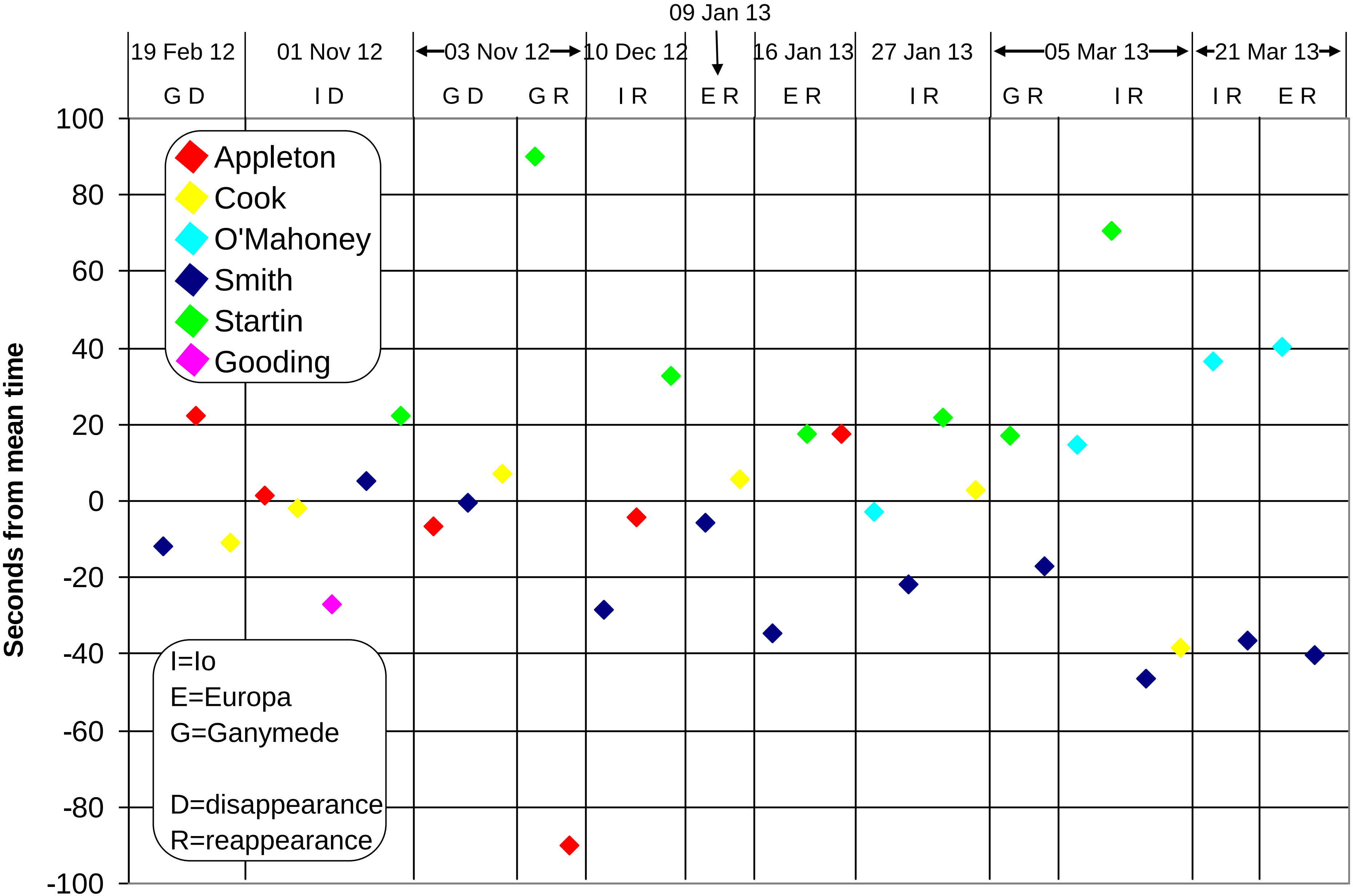
Galilean	Observers	Observations
Io	James Appleton	1D, 2R
	Martin Cook	1D, 5R
	Roy Gooding	1D
	Mike O'Mahoney	3R
	Robin Scagell	1R
	Alan Smith	1D, 6R
	Joe Startin	1D, 4R
Europa	James Appleton	2R
	Martin Cook	2R
	Mike O'Mahoney	1R
	Alan Smith	3R
	Joe Startin	1R
Ganymede	James Appleton	3D, 3R
	Martin Cook	2D
	Alan Smith	3D, 2R
	Joe Startin	2R

Observation period
14 January 2012 –
06 May 2013.

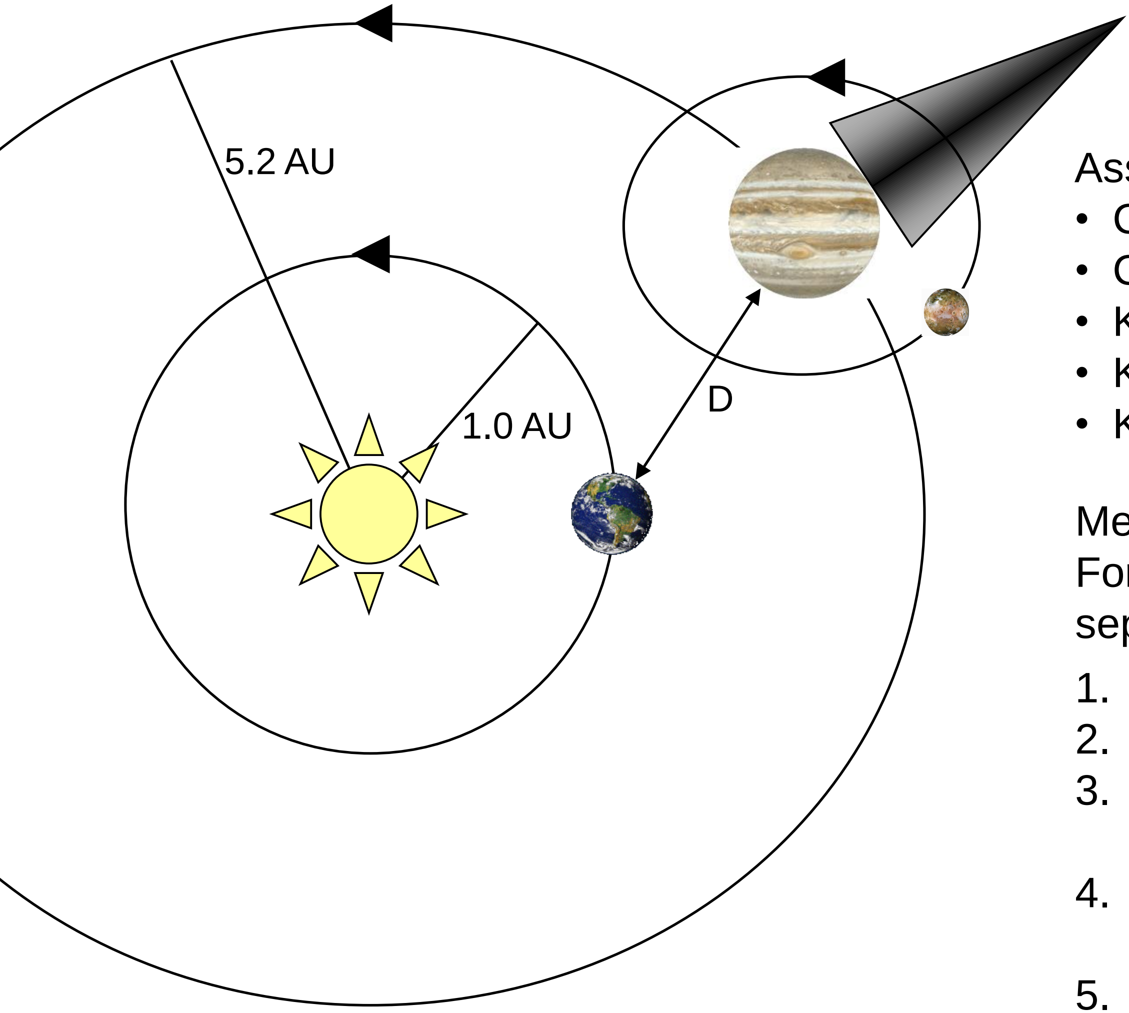
D=disappearance
R=reappearance

Total 13 D, 37 R

Comparison of Observers



Analysis



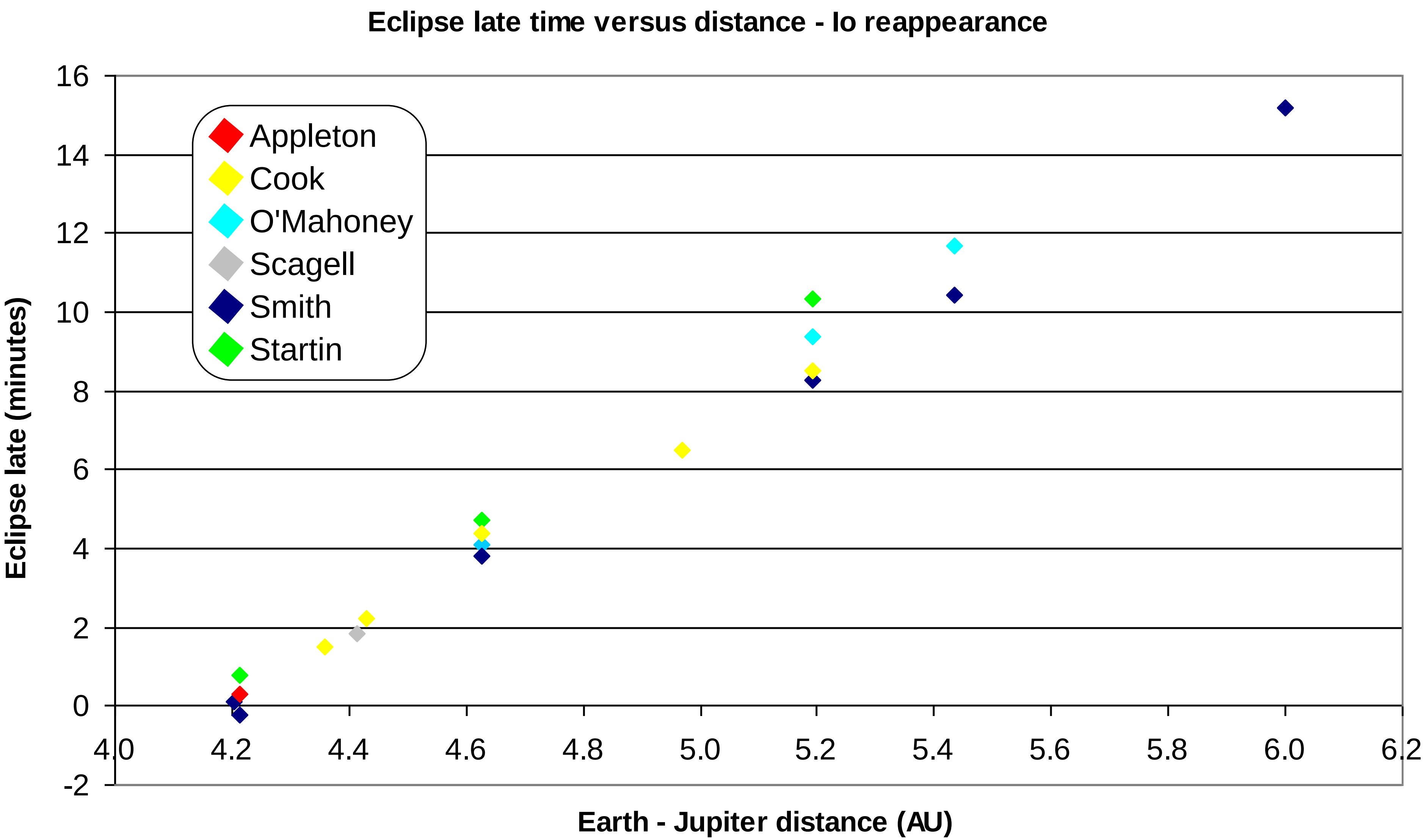
NB: Diagram is not to scale!

Assumptions:
- Circular orbits
- Coplanar
- Known orbital periods of planets
- Known synodic periods of Galileans
- Known orbital radius of Earth

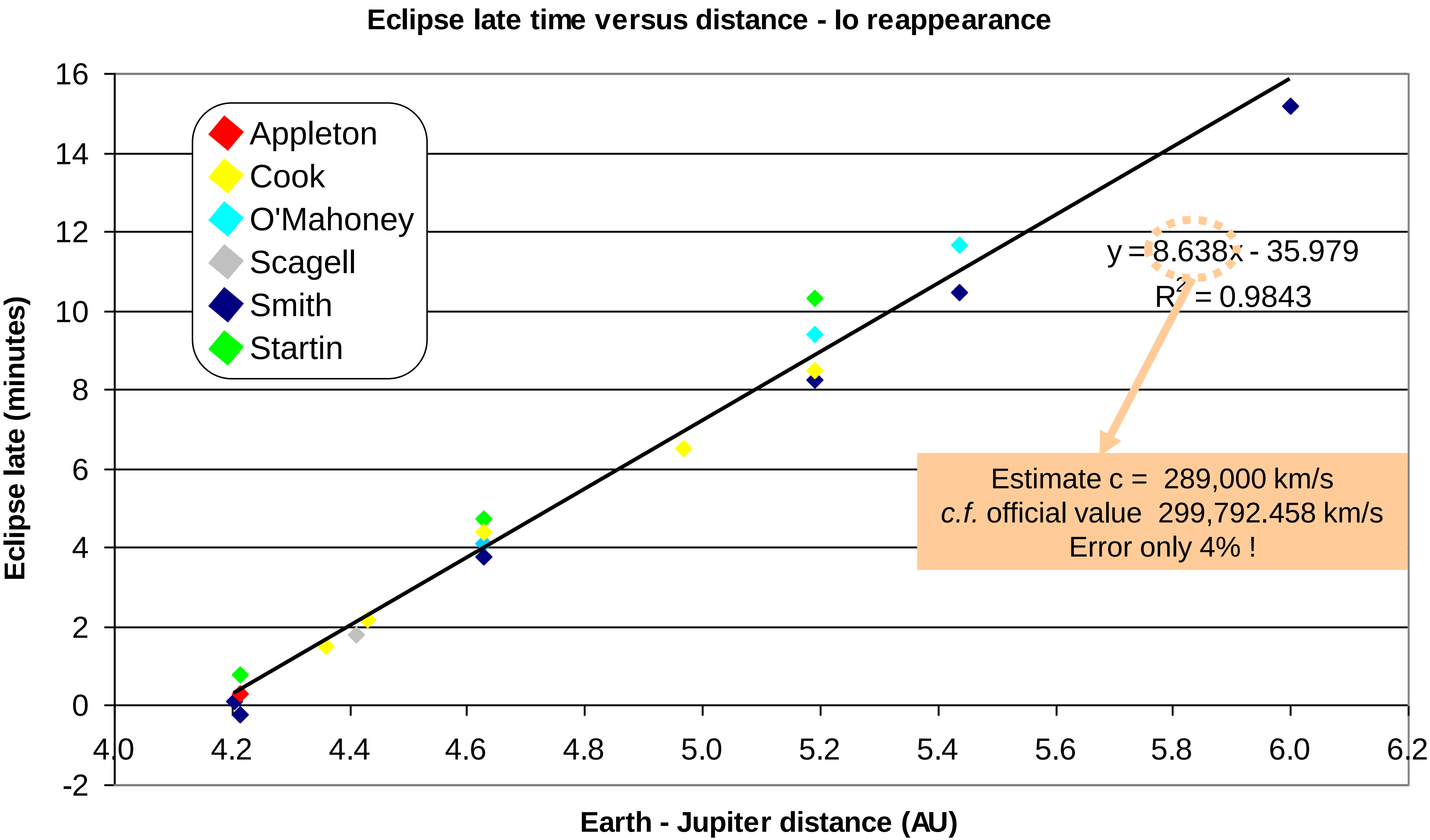
Method:
For each Galilean in turn, considering separately D and R events -

1. Exclude uncertain timings.
2. Note time of first reported observation.
3. Assume subsequent events happen at integral multiples of synodic period later.
4. For each subsequent event, calculate how much later/earlier it is than above.
5. Plot early/late time versus Earth-Jupiter distance, D.
6. Read off speed of light from slope of graph.

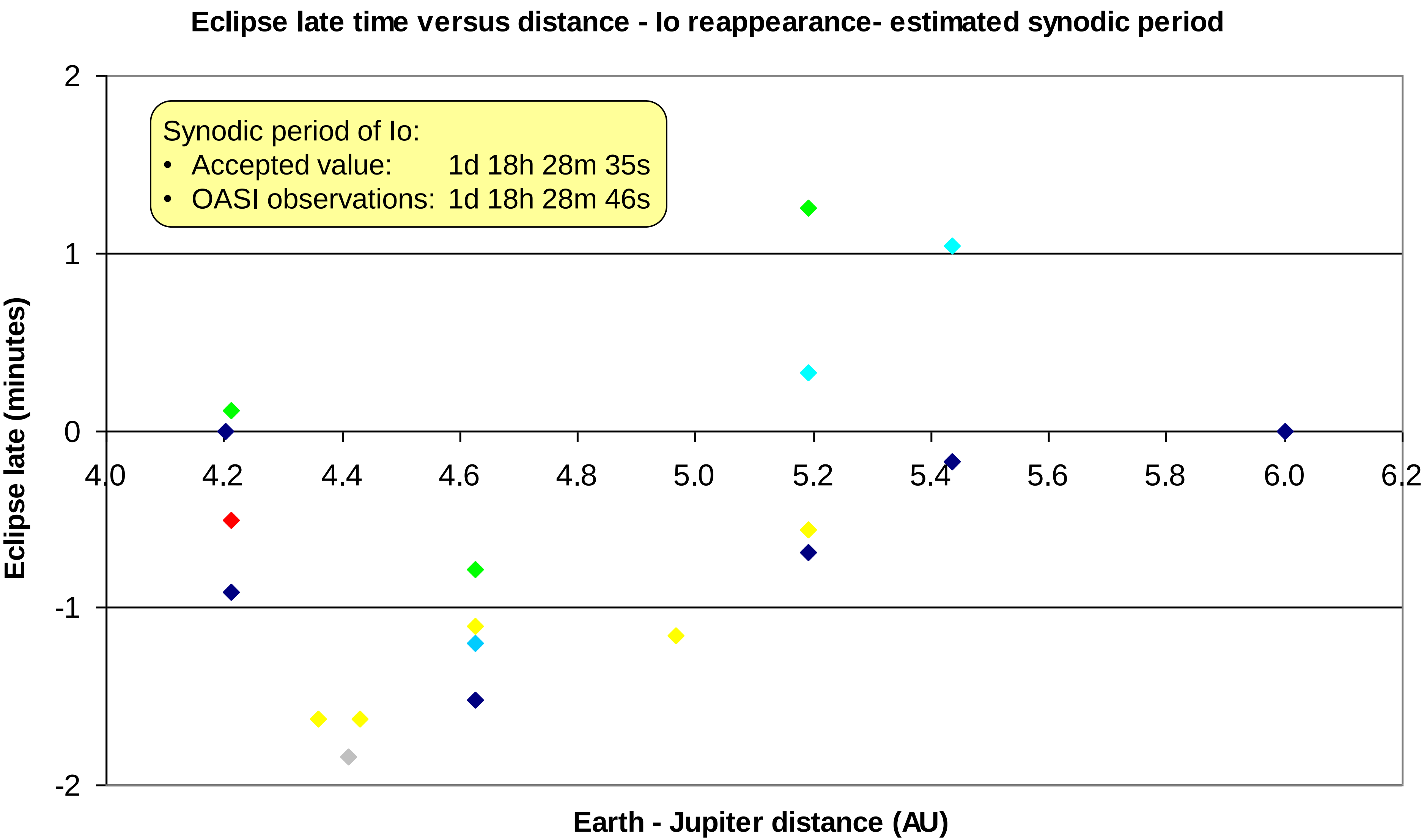
Io Eclipse Reappearances



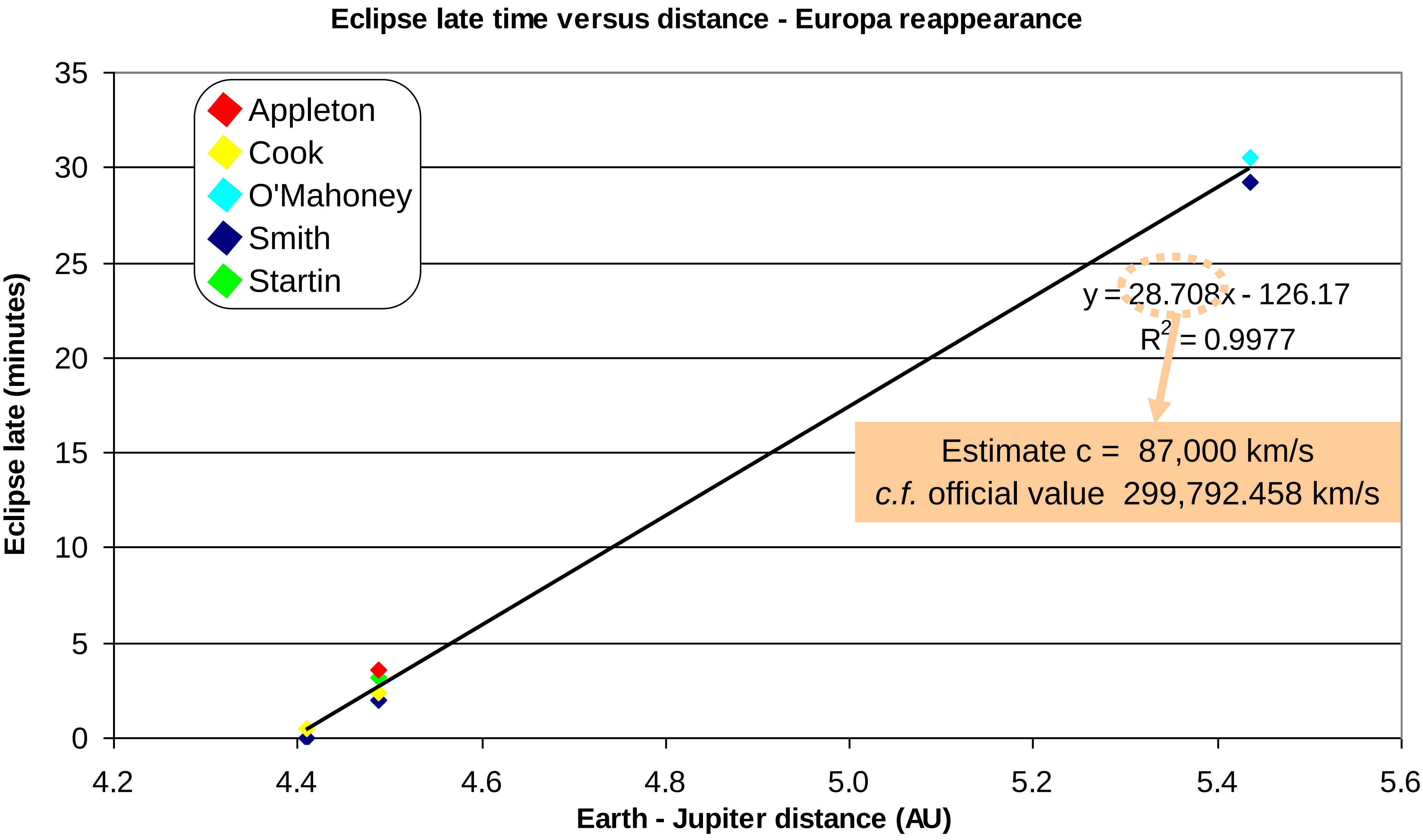
Io Eclipse Reappearances



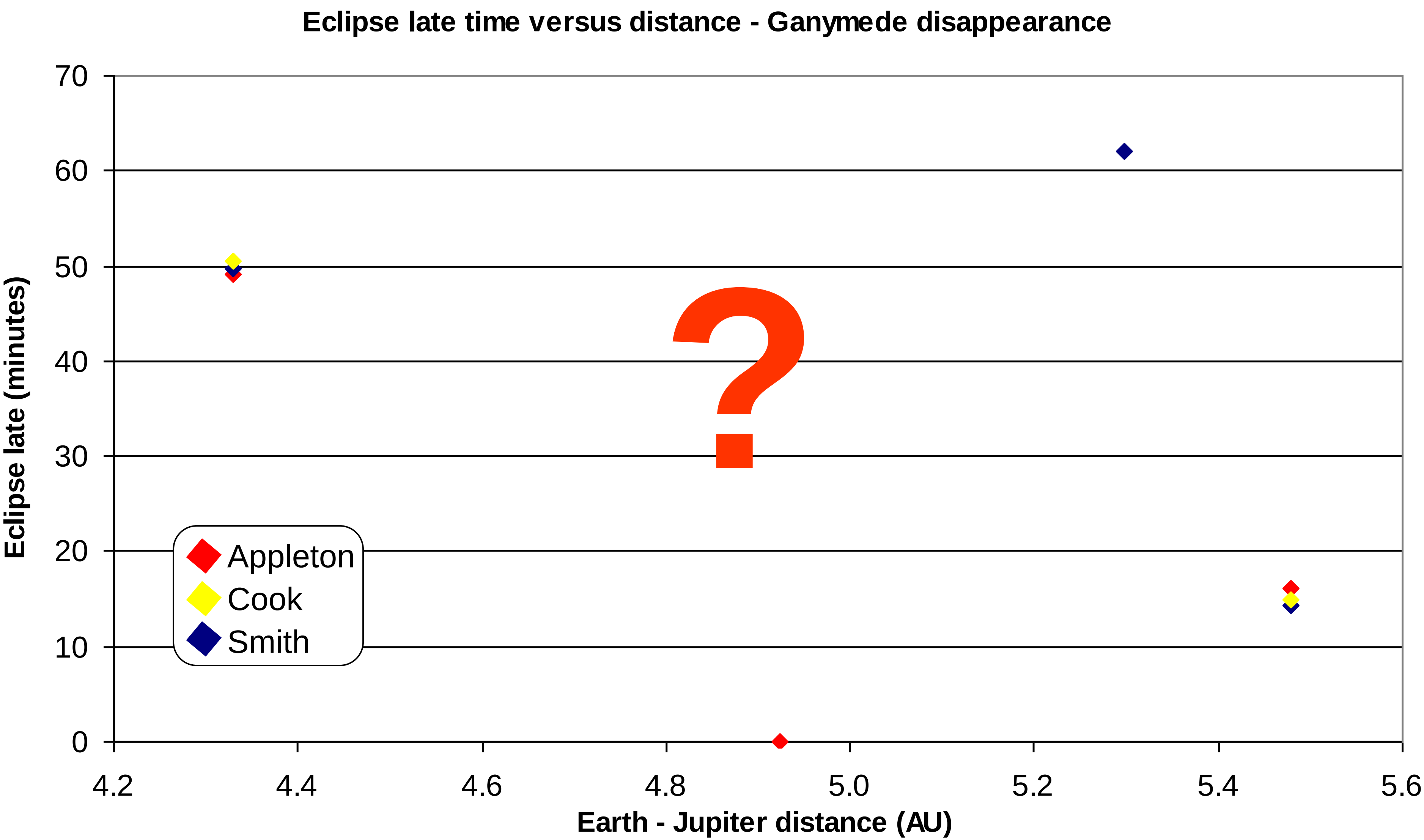
Estimating Io's Synodic Period



Europa Reappearance



Ganymede Disappearance



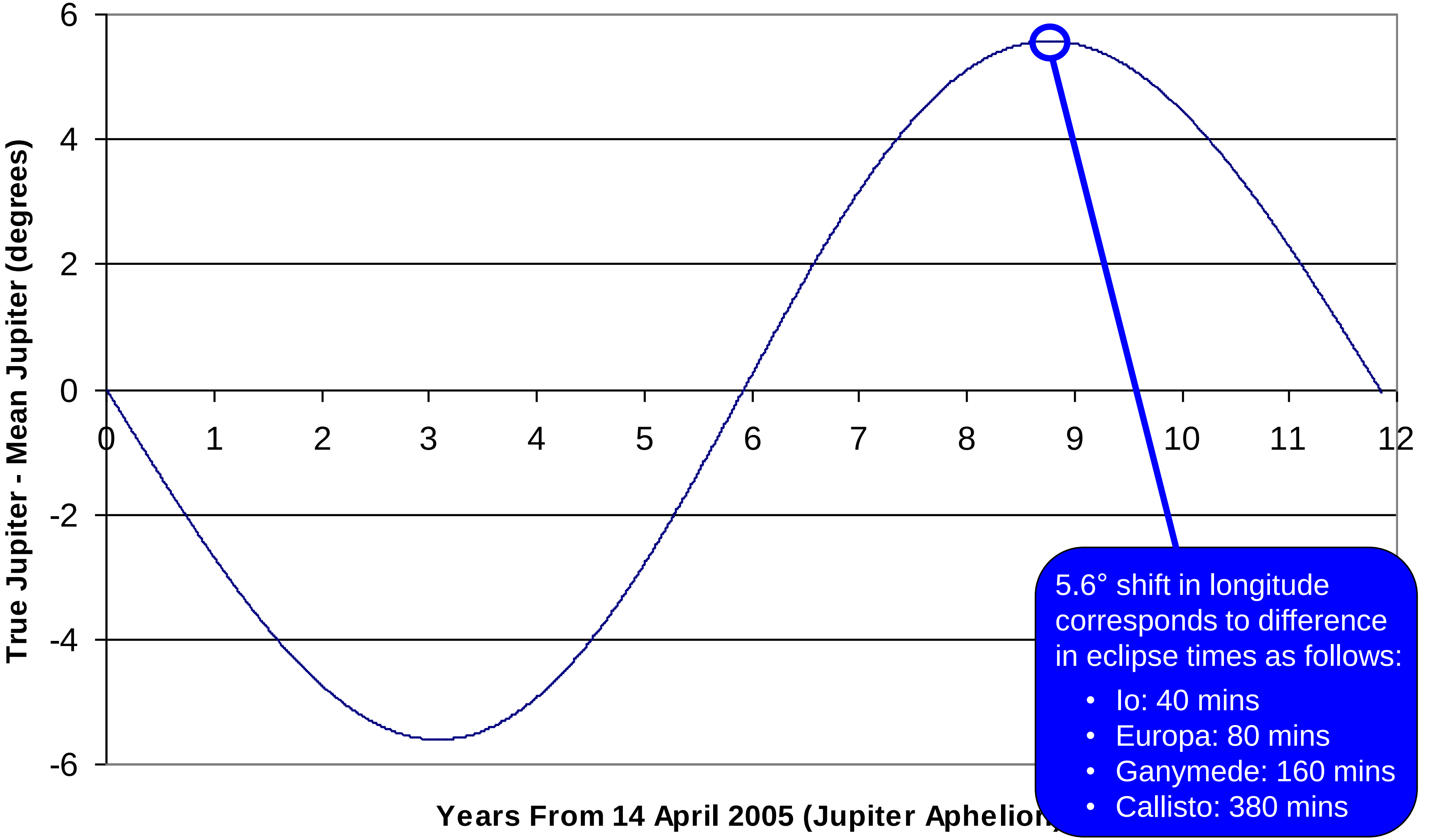
Accuracy of the Galileans as Timekeepers

Maximum times fast/slow compared to mean sidereal period. Evaluated during period 1990-2014.

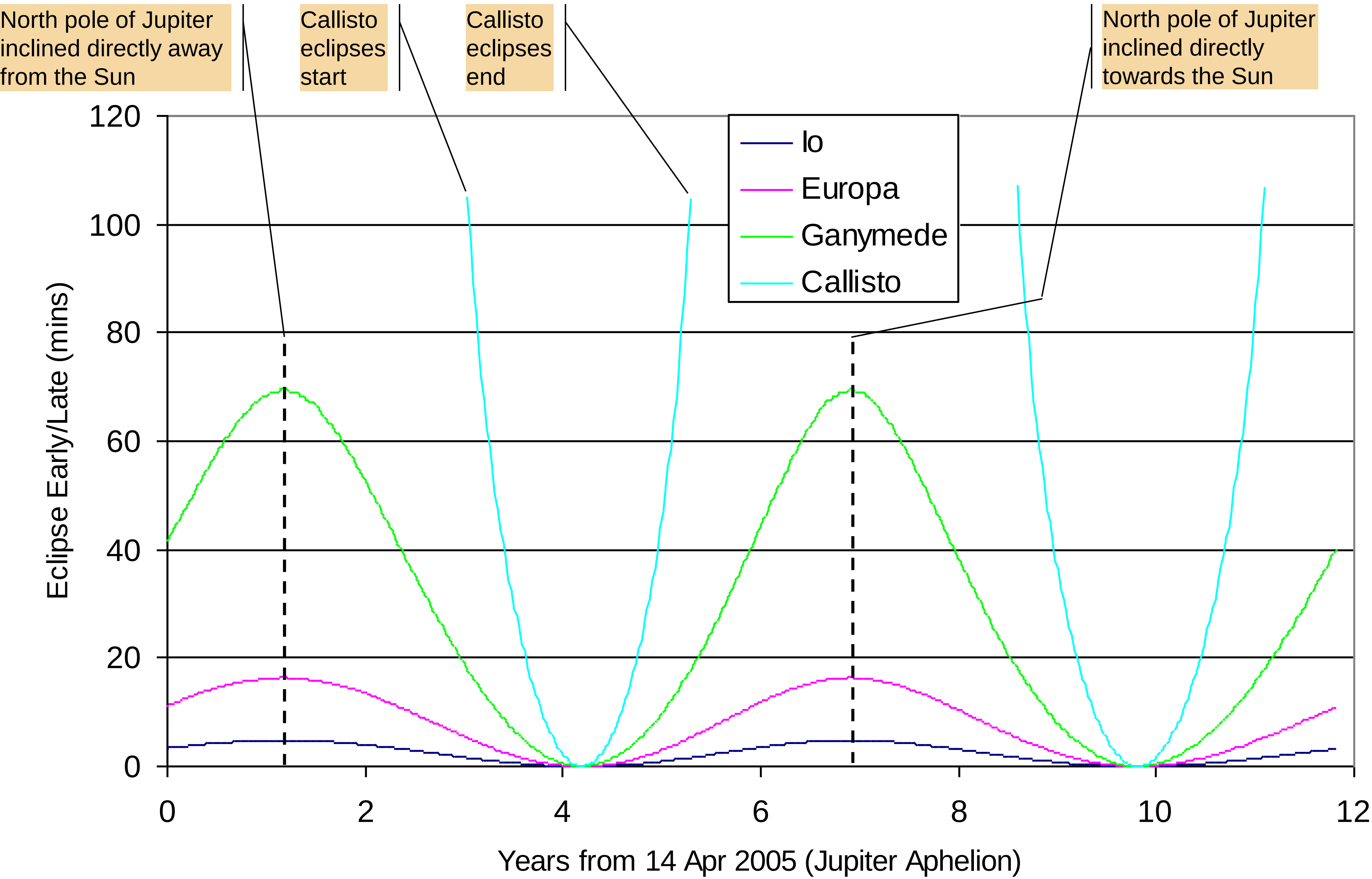
Satellite	Fast/Slow (minutes)
Io	±3.5
Europa	±16
Ganymede	±4.3
Callisto	±7*

(*Up to one hour on a timescale of centuries)

Heliocentric Longitude of Jupiter



Axial Tilt of Jupiter



Main Factors Influencing Eclipse Times

(in addition to Jupiter → Earth light-travel time)

	Influence on Eclipse Time (± mins)		
Galilean	Synodic Variability	Jovian Axial Tilt	Inherent Variability
Io	40	5	3.5
Europa	80	16	16
Ganymede	160	70	4.3
Callisto	380	110	7*

(*Up to one hour on a timescale of centuries.)

c.f. 16m 38s, the difference in Jupiter → Earth light-travel time exploited by Rømer's method.

Applicability of Rømer's Method

Galilean	Applicability of Rømer's Method	
Io	√	Observations limited to at most several months' duration
Europa	X	
Ganymede	X	
Callisto	X	

Application of the method outside the above constraints requires use of compensation factors based on a sophisticated understanding of orbital dynamics.

Tea Break…

Followed by Martin…

Timing tips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This Lorus Stopwatch is the ideal companion for anyone wishing to do exercise inside or outside. Time yourself with the easy to use buttons, and the clear digital display screen makes for easy reading. Use in hand or wear around your neck with the nylon neck strap creating a very safe and comfortable fit.

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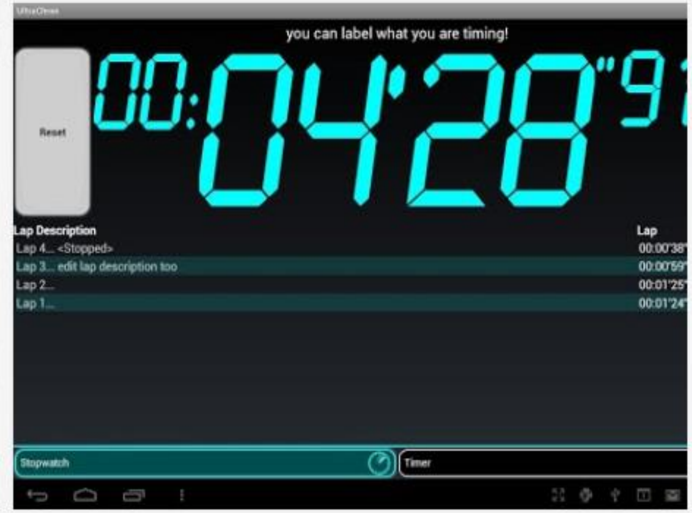

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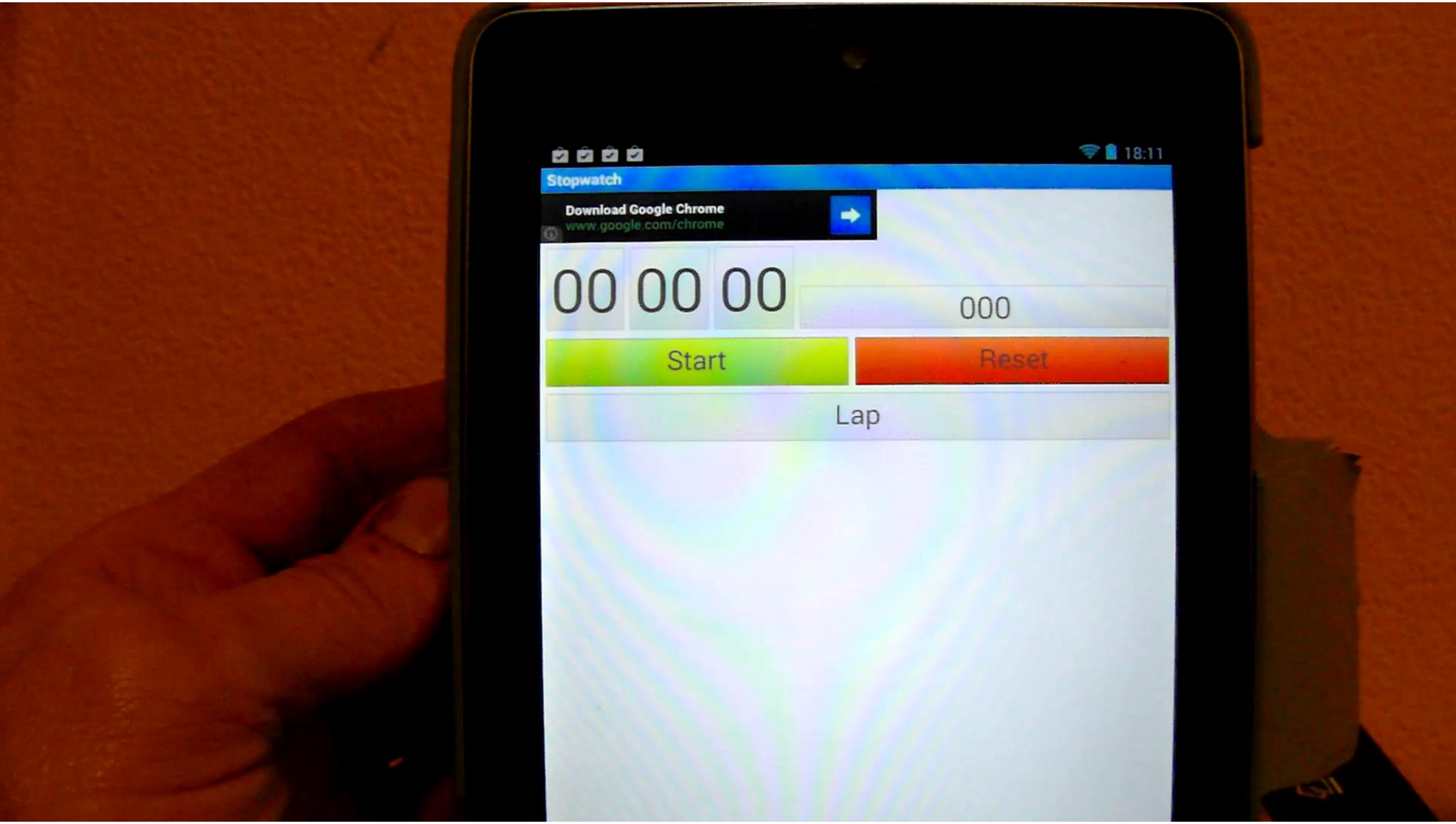
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25m:19s

21h:20m:00s

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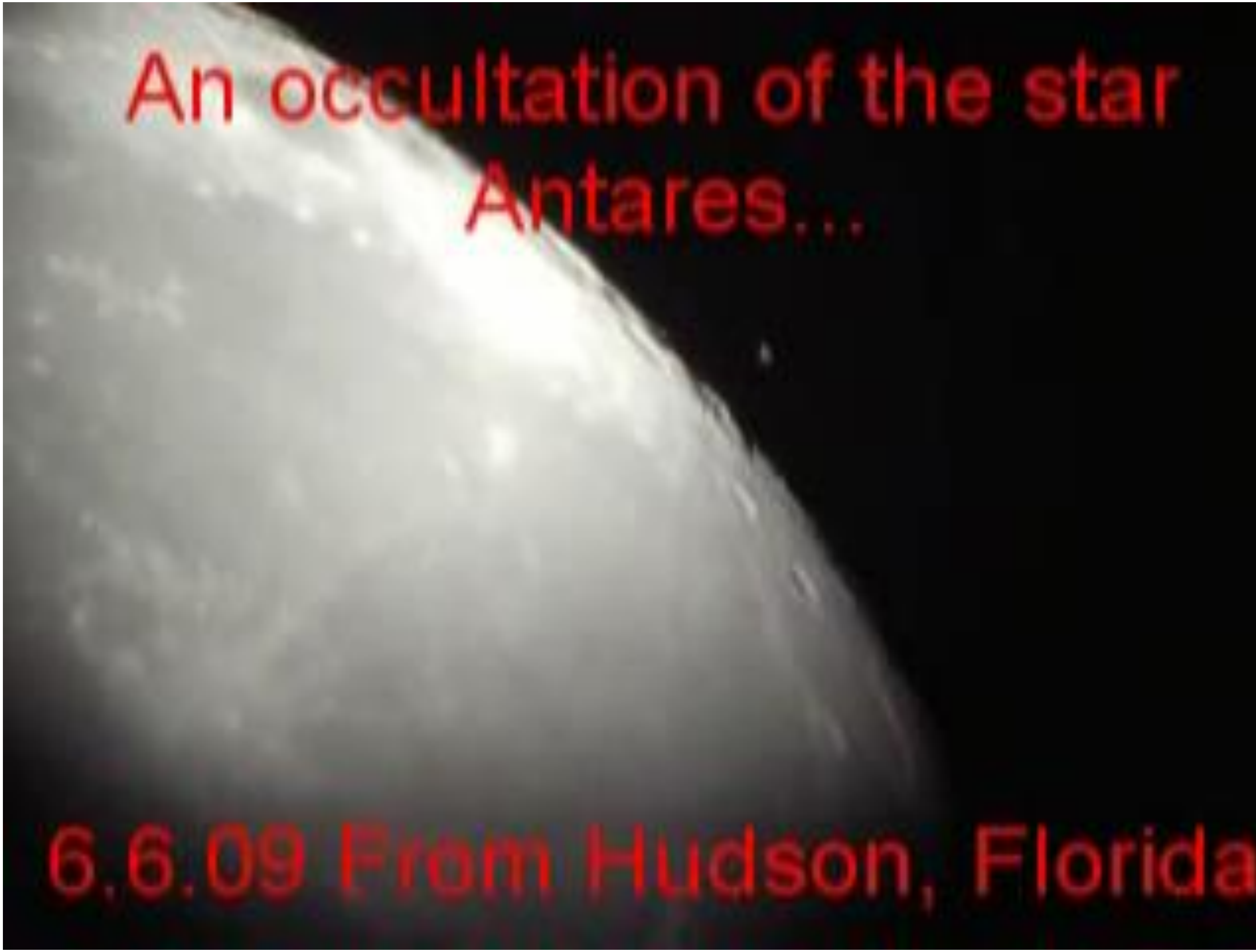
RADIO CONTROLLED
REPEAT
AL 1
AL 2
ON / OFF
6:53 34
SU 6 10 40


Tropby
PM
9:10:54
AL 1
°C


An occultation of the star
Antares...
6.6.09 From Hudson, Florida

Public Access Events

09 November 2013, 17:30 onwards, Observing Group open evening at Newbourne Village Hall. Booking not necessary.

22 & 23 November 2013, 19:30-22:00, Orwell Park Observatory open days. Booking not necessary.

01-08 March 2014, events TBA to mark National Astronomy Week.

Full events list.

Taster Evenings

Taster evenings provide an opportunity for people considering joining OASI to visit Orwell Park Observatory and find out more about the Society. Dates are as follows:

- Tuesday 12 November 2013
- Tuesday 03 December 2013
- January 2014 onwards TBC

Taster evenings and joining OASI.

Search the website

OASI is a society for anyone w scopes, space travel and related matters. We are basec age of Nacton, near Ipswich, Suffolk, UK, and mos Suffolk or north-east Essex. Current membership numbers over 160.

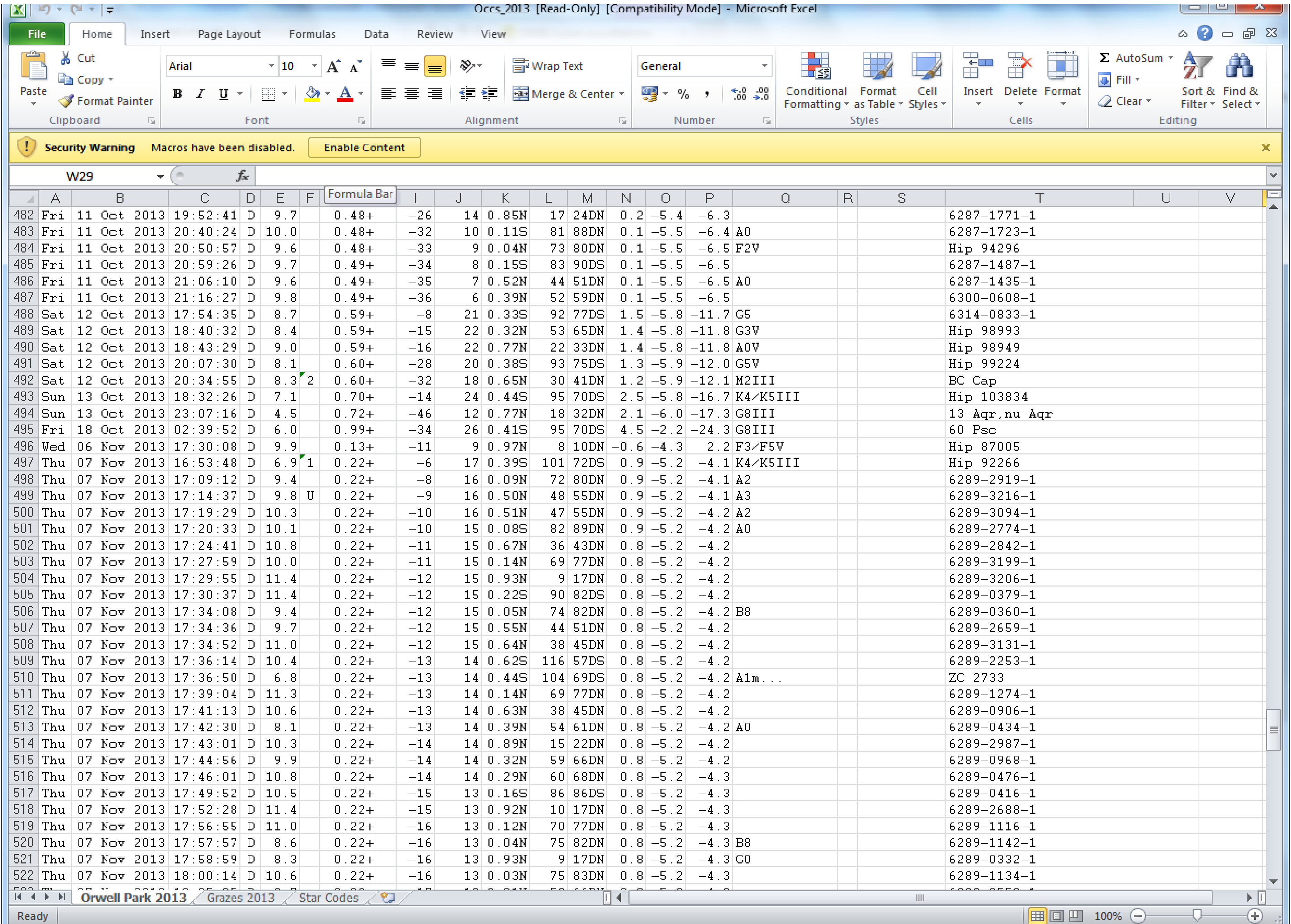
Our members span a wide range of interests and abilities in astronomy, from those with a general interest through to those with specialist interests in topics such as visual and photographic observing, constructing telescopes and other instrumentation, and the history of astronomy. OASI encourages and supports the astronomical activities of all our members, whatever their level of knowledge and expertise. Our events and activities currently include:

- observing at Orwell Park Observatory, Newbourne Village Hall and occasional field trips to other locations;
- winter-season lectures;
- winter-season astronomy workshops;
- visits to places of astronomical interest;
- social events;
- production of a monthly newsletter distributed to all members.

OASI was founded in 1967 and is a UK registered charity, no 271313. We are affiliated to the following organisations:

- British Astronomical Association (BAA),
- Federation of Astronomical Societies (FAS),
- Society for Popular Astronomy (SPA),
- Society for the History of Astronomy (SHA).

Orwell Park Observatory is equipped with several astronomical telescopes, of which the most notable is the 26 cm Tomline Refractor dating from 1874. The Society encourages use of the

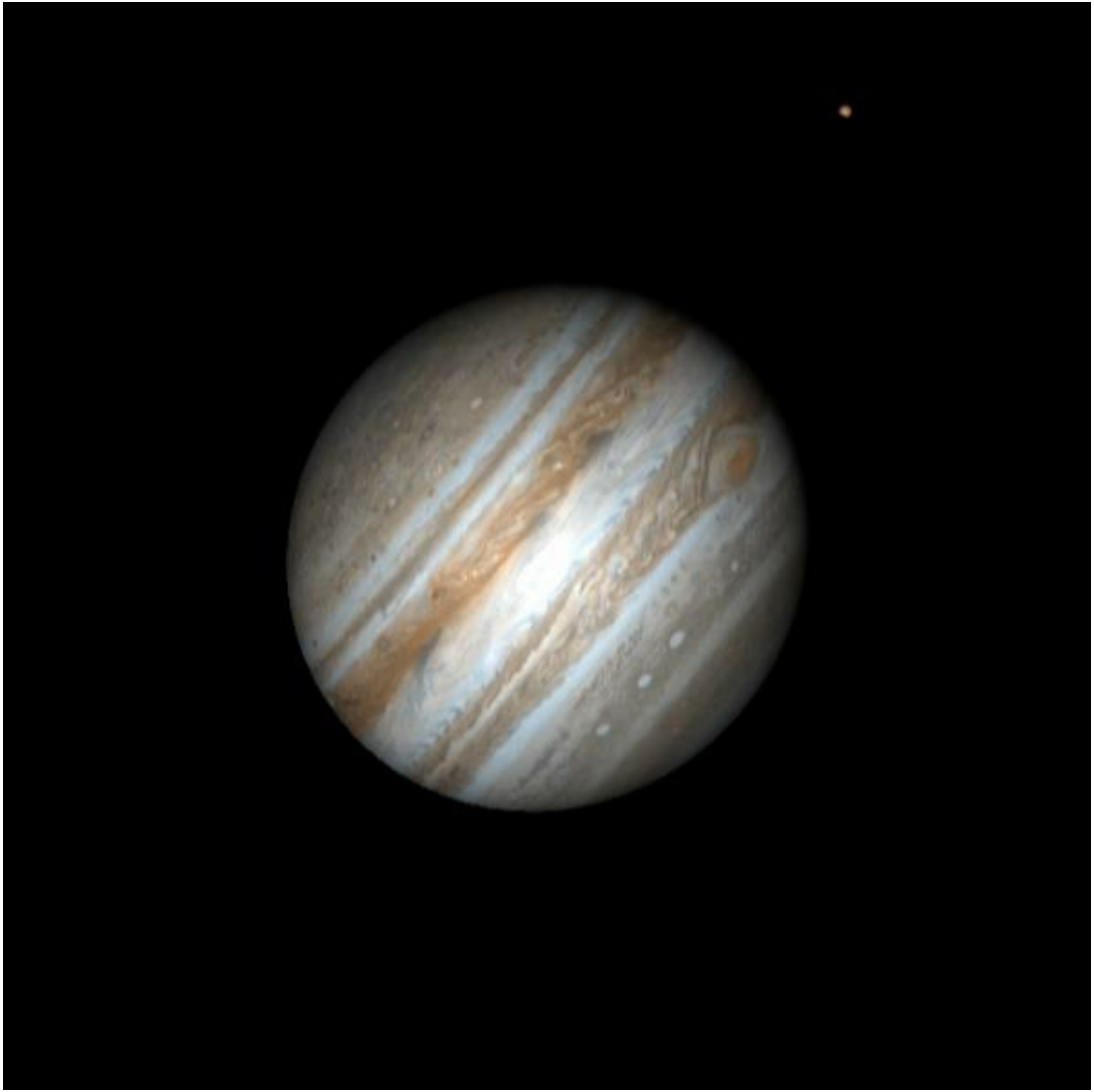


	A	B	C	D	E	F		I	J	K	L	M	N	O	P	Q	R	S	T	U	V
482	Fri	11 Oct 2013	19:52:41	D	9.7		0.48+	-26	14	0.85N	17	24DN	0.2	-5.4	-6.3				6287-1771-1		
483	Fri	11 Oct 2013	20:40:24	D	10.0		0.48+	-32	10	0.11S	81	88DN	0.1	-5.5	-6.4	A0			6287-1723-1		
484	Fri	11 Oct 2013	20:50:57	D	9.6		0.48+	-33	9	0.04N	73	80DN	0.1	-5.5	-6.5	F2V			Hip 94296		
485	Fri	11 Oct 2013	20:59:26	D	9.7		0.49+	-34	8	0.15S	83	90DS	0.1	-5.5	-6.5				6287-1487-1		
486	Fri	11 Oct 2013	21:06:10	D	9.6		0.49+	-35	7	0.52N	44	51DN	0.1	-5.5	-6.5	A0			6287-1435-1		
487	Fri	11 Oct 2013	21:16:27	D	9.8		0.49+	-36	6	0.39N	52	59DN	0.1	-5.5	-6.5				6300-0608-1		
488	Sat	12 Oct 2013	17:54:35	D	8.7		0.59+	-8	21	0.33S	92	77DS	1.5	-5.8	-11.7	G5			6314-0833-1		
489	Sat	12 Oct 2013	18:40:32	D	8.4		0.59+	-15	22	0.32N	53	65DN	1.4	-5.8	-11.8	G3V			Hip 98993		
490	Sat	12 Oct 2013	18:43:29	D	9.0		0.59+	-16	22	0.77N	22	33DN	1.4	-5.8	-11.8	A0V			Hip 98949		
491	Sat	12 Oct 2013	20:07:30	D	8.1		0.60+	-28	20	0.38S	93	75DS	1.3	-5.9	-12.0	G5V			Hip 99224		
492	Sat	12 Oct 2013	20:34:55	D	8.3	2	0.60+	-32	18	0.65N	30	41DN	1.2	-5.9	-12.1	M2III			BC Cap		
493	Sun	13 Oct 2013	18:32:26	D	7.1		0.70+	-14	24	0.44S	95	70DS	2.5	-5.8	-16.7	K4/K5III			Hip 103834		
494	Sun	13 Oct 2013	23:07:16	D	4.5		0.72+	-46	12	0.77N	18	32DN	2.1	-6.0	-17.3	G8III			13 Aqr,nu Aqr		
495	Fri	18 Oct 2013	02:39:52	D	6.0		0.99+	-34	26	0.41S	95	70DS	4.5	-2.2	-24.3	G8III			60 Psc		
496	Wed	06 Nov 2013	17:30:08	D	9.9		0.13+	-11	9	0.97N	8	10DN	-0.6	-4.3	2.2	F3/F5V			Hip 87005		
497	Thu	07 Nov 2013	16:53:48	D	6.9	1	0.22+	-6	17	0.39S	101	72DS	0.9	-5.2	-4.1	K4/K5III			Hip 92266		
498	Thu	07 Nov 2013	17:09:12	D	9.4		0.22+	-8	16	0.09N	72	80DN	0.9	-5.2	-4.1	A2			6289-2919-1		
499	Thu	07 Nov 2013	17:14:37	D	9.8	U	0.22+	-9	16	0.50N	48	55DN	0.9	-5.2	-4.1	A3			6289-3216-1		
500	Thu	07 Nov 2013	17:19:29	D	10.3		0.22+	-10	16	0.51N	47	55DN	0.9	-5.2	-4.2	A2			6289-3094-1		
501	Thu	07 Nov 2013	17:20:33	D	10.1		0.22+	-10	15	0.08S	82	89DN	0.9	-5.2	-4.2	A0			6289-2774-1		
502	Thu	07 Nov 2013	17:24:41	D	10.8		0.22+	-11	15	0.67N	36	43DN	0.8	-5.2	-4.2				6289-2842-1		
503	Thu	07 Nov 2013	17:27:59	D	10.0		0.22+	-11	15	0.14N	69	77DN	0.8	-5.2	-4.2				6289-3199-1		
504	Thu	07 Nov 2013	17:29:55	D	11.4		0.22+	-12	15	0.93N	9	17DN	0.8	-5.2	-4.2				6289-3206-1		
505	Thu	07 Nov 2013	17:30:37	D	11.4		0.22+	-12	15	0.22S	90	82DS	0.8	-5.2	-4.2				6289-0379-1		
506	Thu	07 Nov 2013	17:34:08	D	9.4		0.22+	-12	15	0.05N	74	82DN	0.8	-5.2	-4.2	B8			6289-0360-1		
507	Thu	07 Nov 2013	17:34:36	D	9.7		0.22+	-12	15	0.55N	44	51DN	0.8	-5.2	-4.2				6289-2659-1		
508	Thu	07 Nov 2013	17:34:52	D	11.0		0.22+	-12	15	0.64N	38	45DN	0.8	-5.2	-4.2				6289-3131-1		
509	Thu	07 Nov 2013	17:36:14	D	10.4		0.22+	-13	14	0.62S	116	57DS	0.8	-5.2	-4.2				6289-2253-1		
510	Thu	07 Nov 2013	17:36:50	D	6.8		0.22+	-13	14	0.44S	104	69DS	0.8	-5.2	-4.2	A1m...			ZC 2733		
511	Thu	07 Nov 2013	17:39:04	D	11.3		0.22+	-13	14	0.14N	69	77DN	0.8	-5.2	-4.2				6289-1274-1		
512	Thu	07 Nov 2013	17:41:13	D	10.6		0.22+	-13	14	0.63N	38	45DN	0.8	-5.2	-4.2				6289-0906-1		
513	Thu	07 Nov 2013	17:42:30	D	8.1		0.22+	-13	14	0.39N	54	61DN	0.8	-5.2	-4.2	A0			6289-0434-1		
514	Thu	07 Nov 2013	17:43:01	D	10.3		0.22+	-14	14	0.89N	15	22DN	0.8	-5.2	-4.2				6289-2987-1		
515	Thu	07 Nov 2013	17:44:56	D	9.9		0.22+	-14	14	0.32N	59	66DN	0.8	-5.2	-4.2				6289-0968-1		
516	Thu	07 Nov 2013	17:46:01	D	10.8		0.22+	-14	14	0.29N	60	68DN	0.8	-5.2	-4.3				6289-0476-1		
517	Thu	07 Nov 2013	17:49:52	D	10.5		0.22+	-15	13	0.16S	86	86DS	0.8	-5.2	-4.3				6289-0416-1		
518	Thu	07 Nov 2013	17:52:28	D	11.4		0.22+	-15	13	0.92N	10	17DN	0.8	-5.2	-4.3				6289-2688-1		
519	Thu	07 Nov 2013	17:56:55	D	11.0		0.22+	-16	13	0.12N	70	77DN	0.8	-5.2	-4.3				6289-1116-1		
520	Thu	07 Nov 2013	17:57:57	D	8.6		0.22+	-16	13	0.04N	75	82DN	0.8	-5.2	-4.3	B8			6289-1142-1		
521	Thu	07 Nov 2013	17:58:59	D	8.3		0.22+	-16	13	0.93N	9	17DN	0.8	-5.2	-4.3	G0			6289-0332-1		
522	Thu	07 Nov 2013	18:00:14	D	10.6		0.22+	-16	13	0.03N	75	83DN	0.8	-5.2	-4.3				6289-1134-1		


WE NEED
YOU

A Selection Of Eclipses During The Next Month

Date	Satellite	Ec D	Ec R	Oc D	Oc R
06 Nov	Io	20:22	**On the horizon**		23:49
12 Nov	Io	03:37			07:11
13/14 Nov	Io	22:16			01:39
14/15 Nov	Europa	21:35			02:24
19 Nov	Io	05:41			09:00
21 Nov	Io	00:09			03:27
22 Nov	Europa	00:08			04:46
22/23 Nov	Callisto	22:15	01:14	07:15	11:24
25/26 Nov	Ganymede	20:15	23:21	23:59	03:11
28 Nov	Io	02:04			05:13
29 Nov	Europa	02:42			07:05
29 Nov	Io	20:32			23:40
03 Dec	Ganymede	00:14	03:21	03:26	06:38
05 Dec	Io	03:58			06:59
06/07 Dec	Io	22:26			01:26



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Report An Eclipse Observation

Observer

Name

Location

Email address

Equipment details

Telescope

Type ◉ Reflector ○ Refractor

Aperture

Magnification

Timing method: e.g. stopwatch synchronised to speaking clock

Observation

Galilean: Io

Phenomenon ◉ Disappearance ○ Reappearance

Date

Time

Additional comments

Reset | Submit

James Appleton

Updated: 08 October 2013


ANY QUESTIONS
?

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