Celebrating the 400th anniversary of Galileo's telescopic observations

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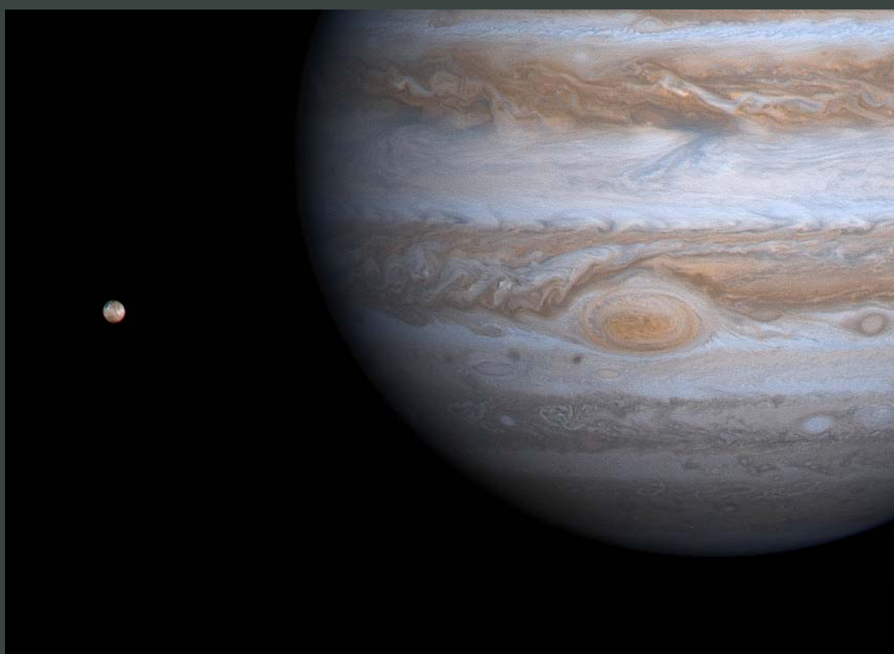
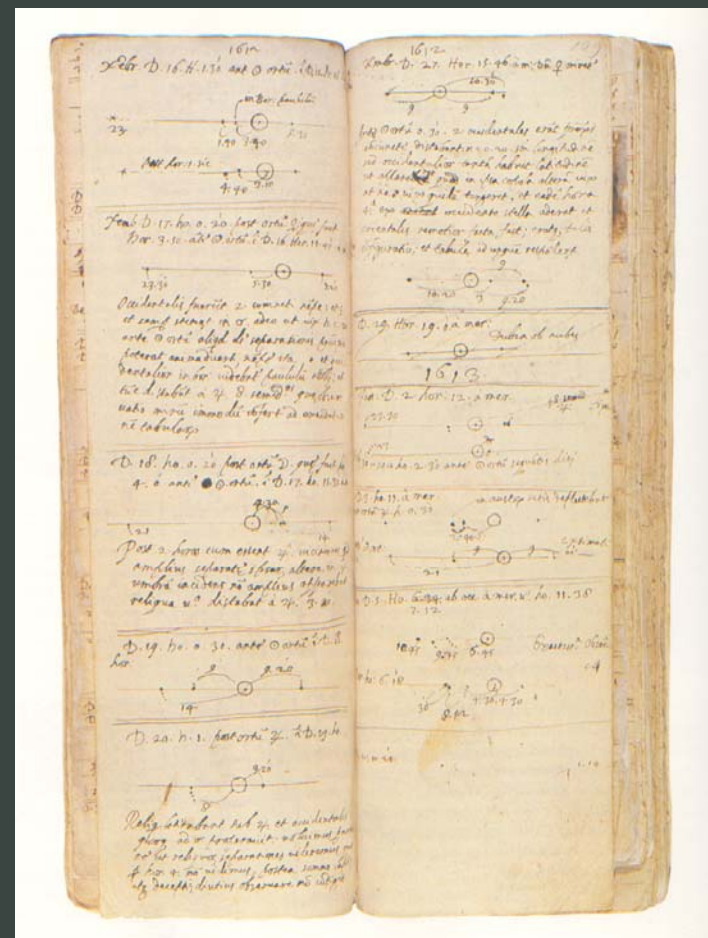
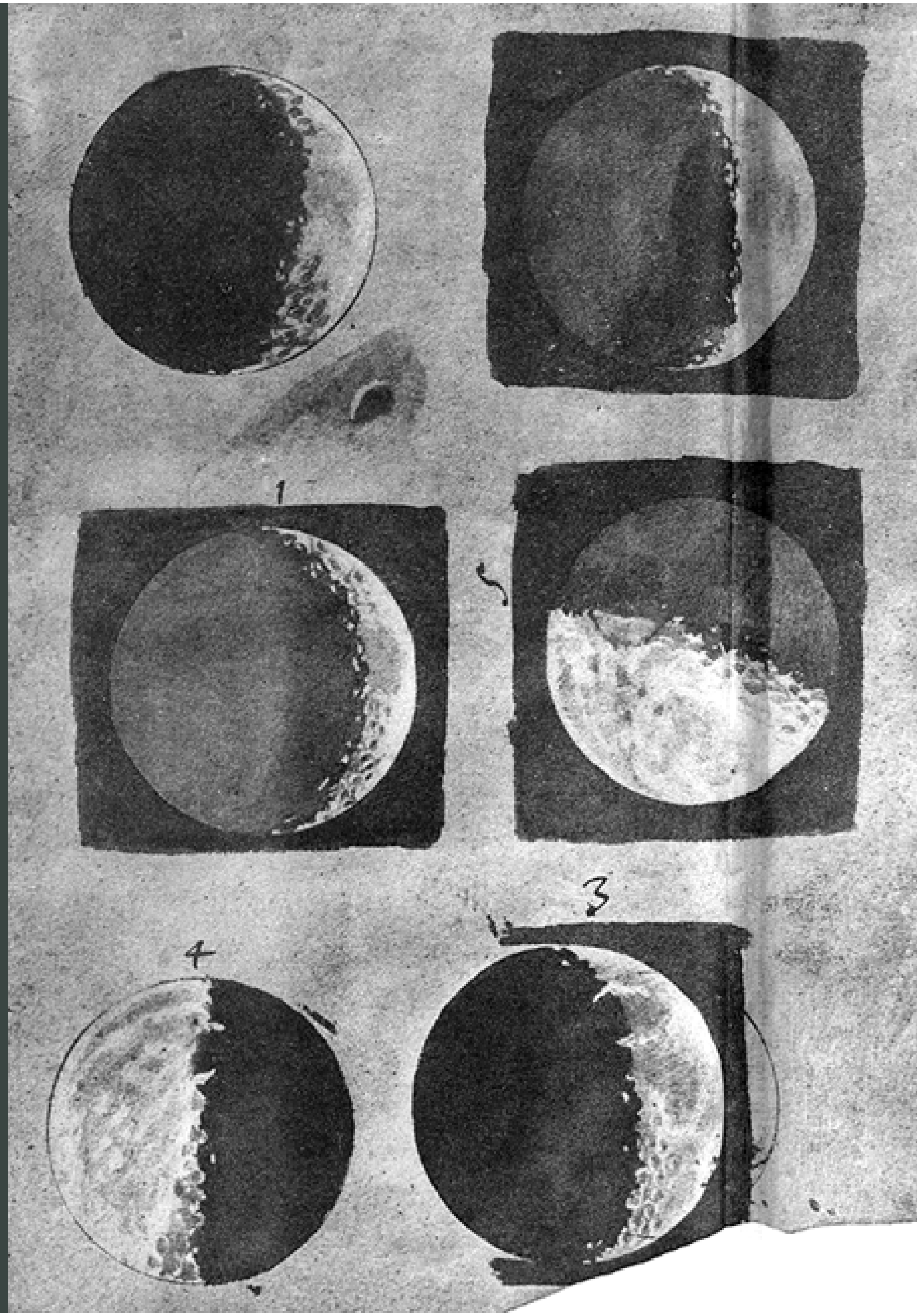
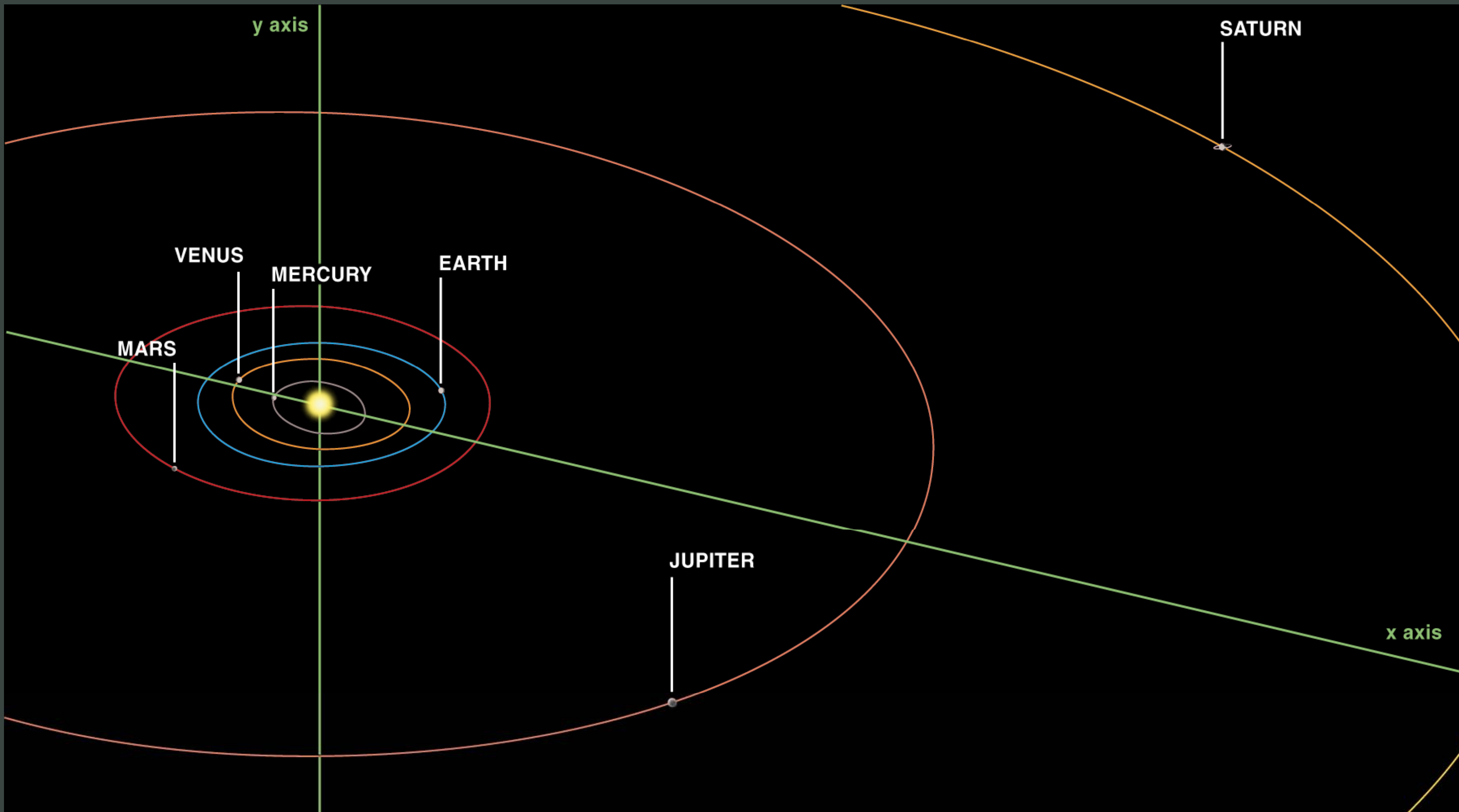




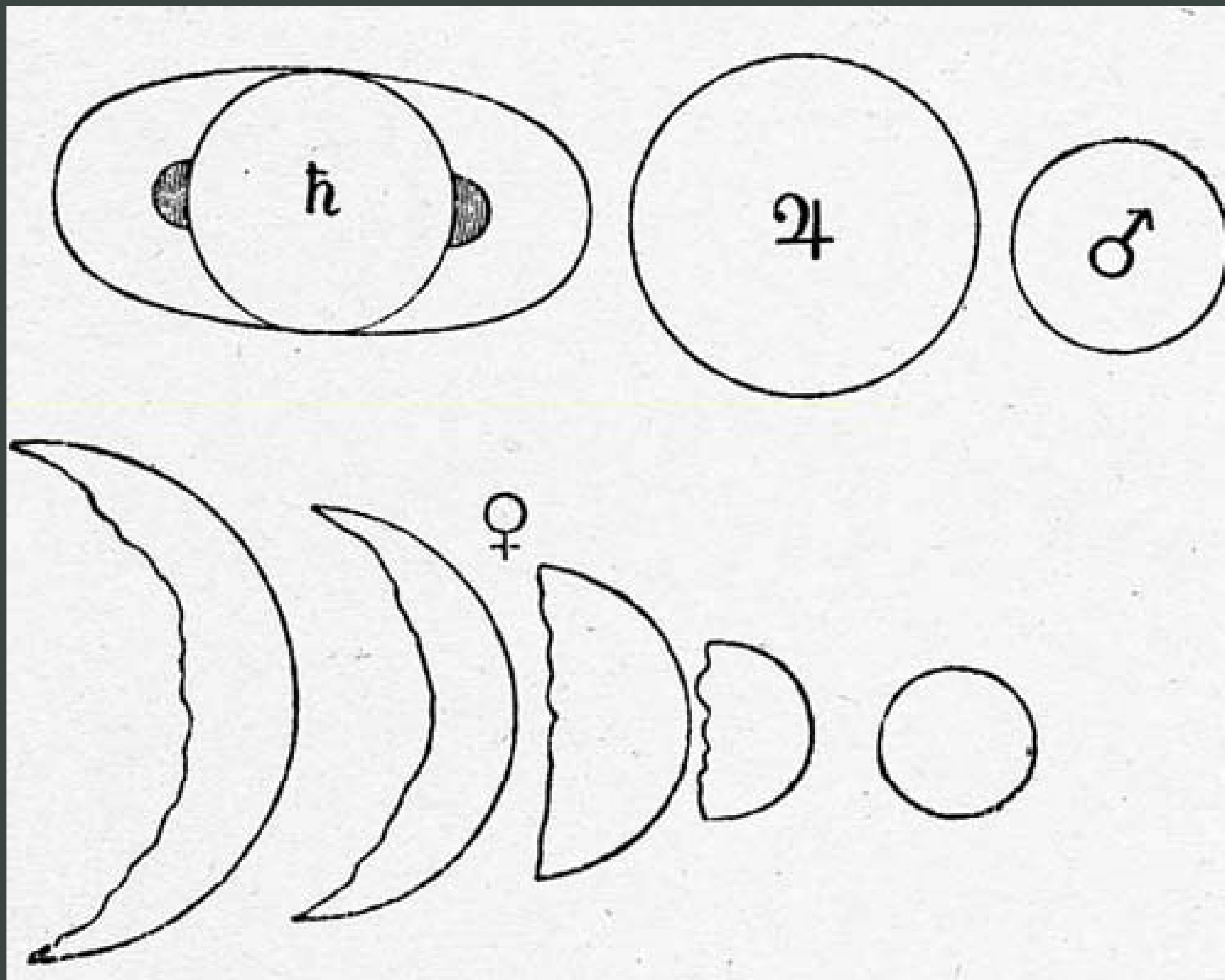
Events every night for the next six weeks; info at astro.swarthmore.edu/iya/

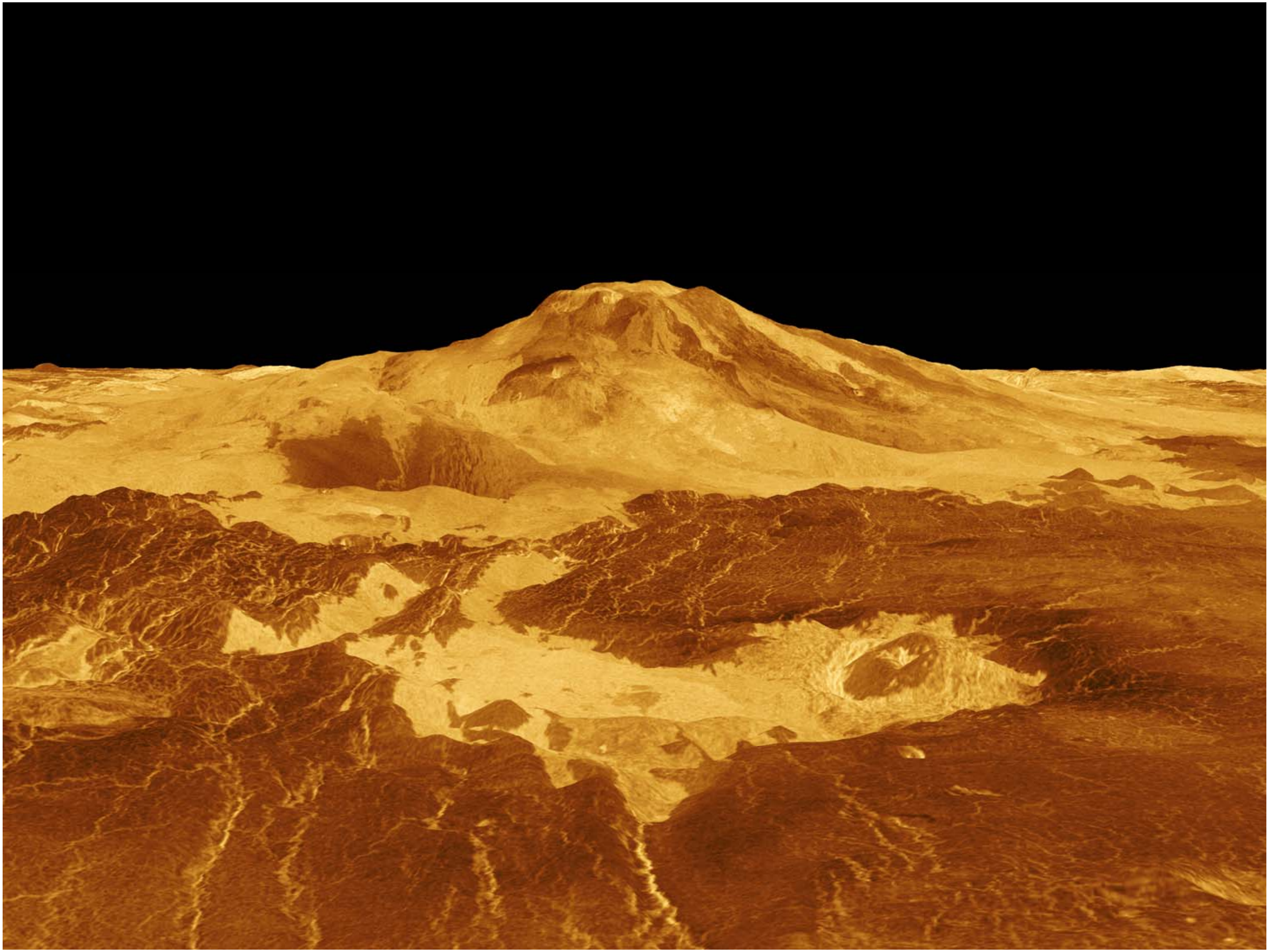

1
3
4

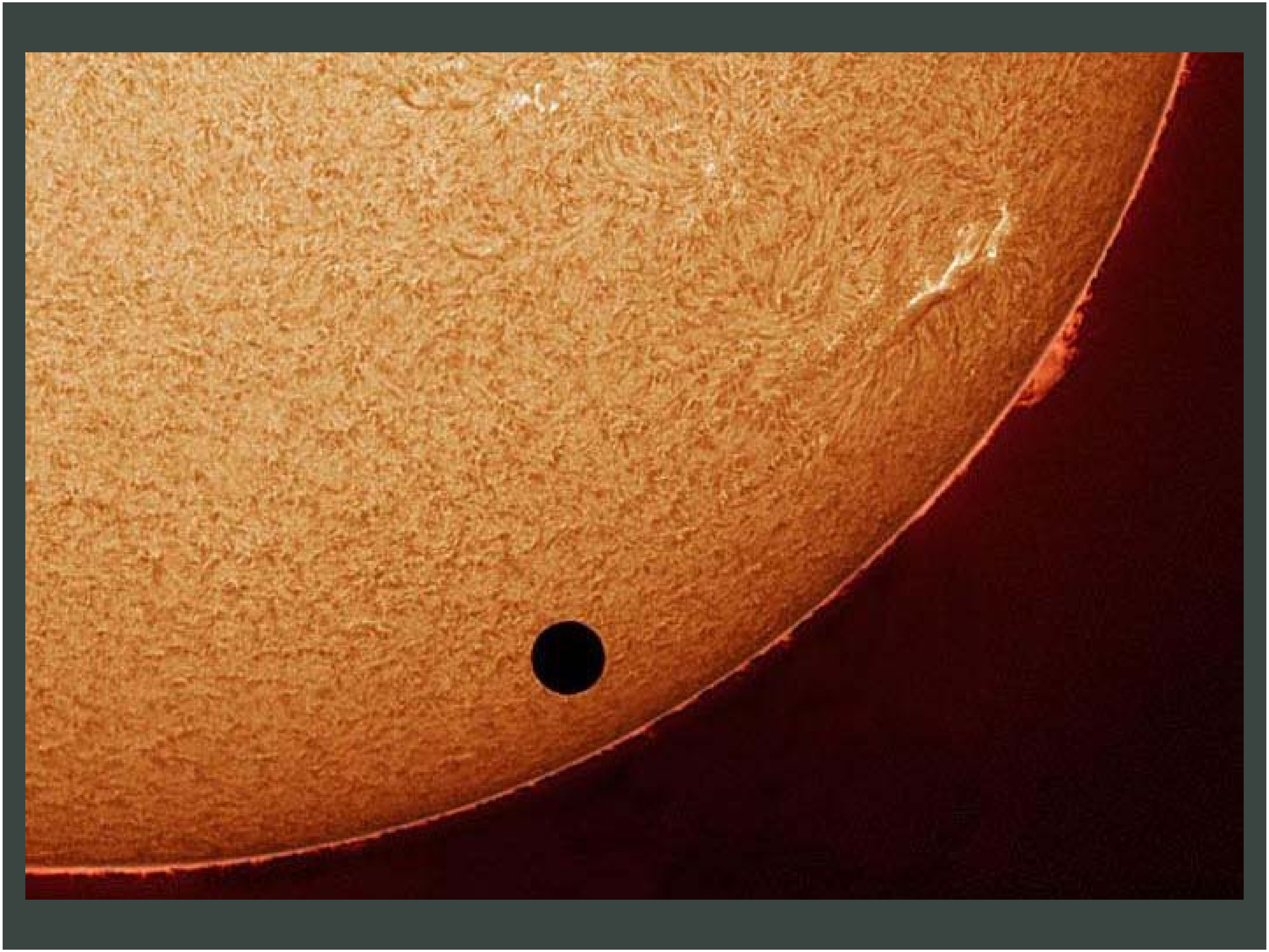

ASTRO
CRUISE

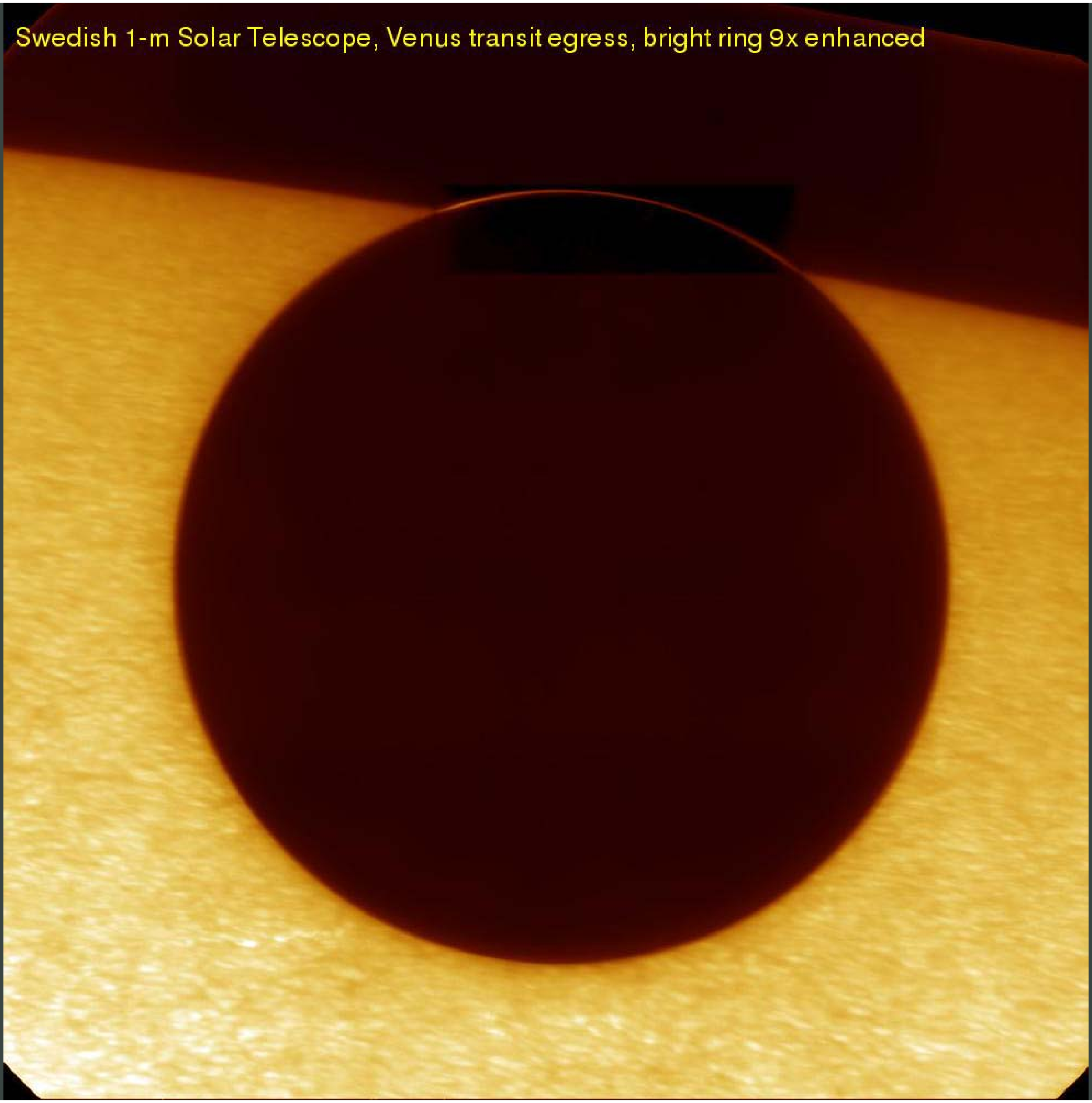

y axis
SATURN
VENUS
MERCURY
EARTH
MARS
JUPITER
x axis

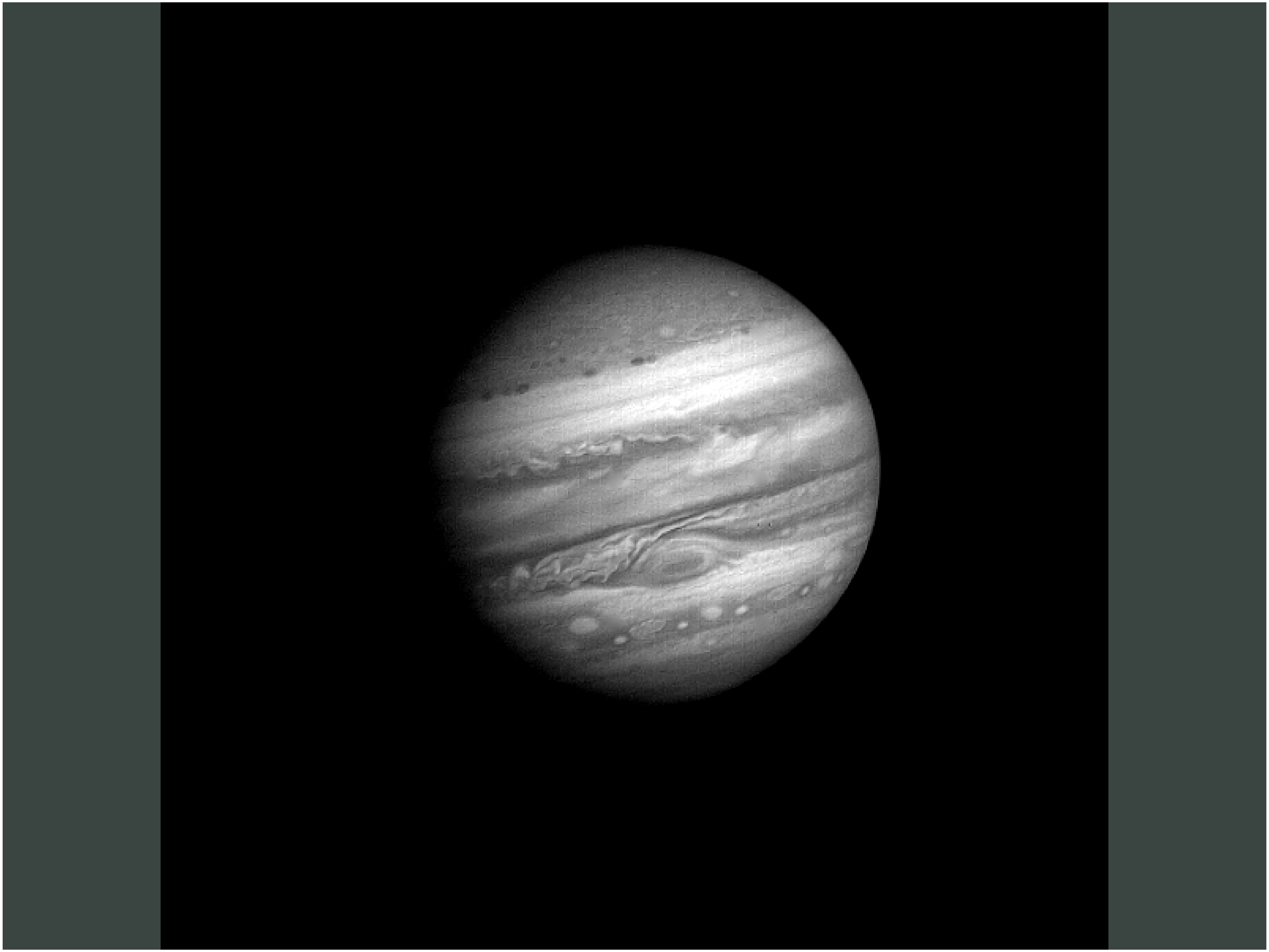

April 1
May 1
April 10
May 9
April 19
April 25
May 15

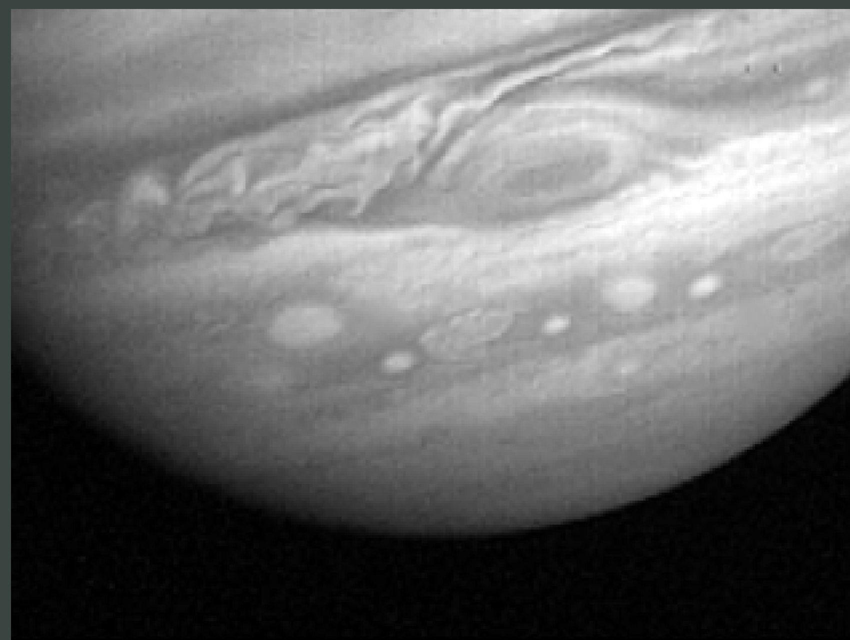


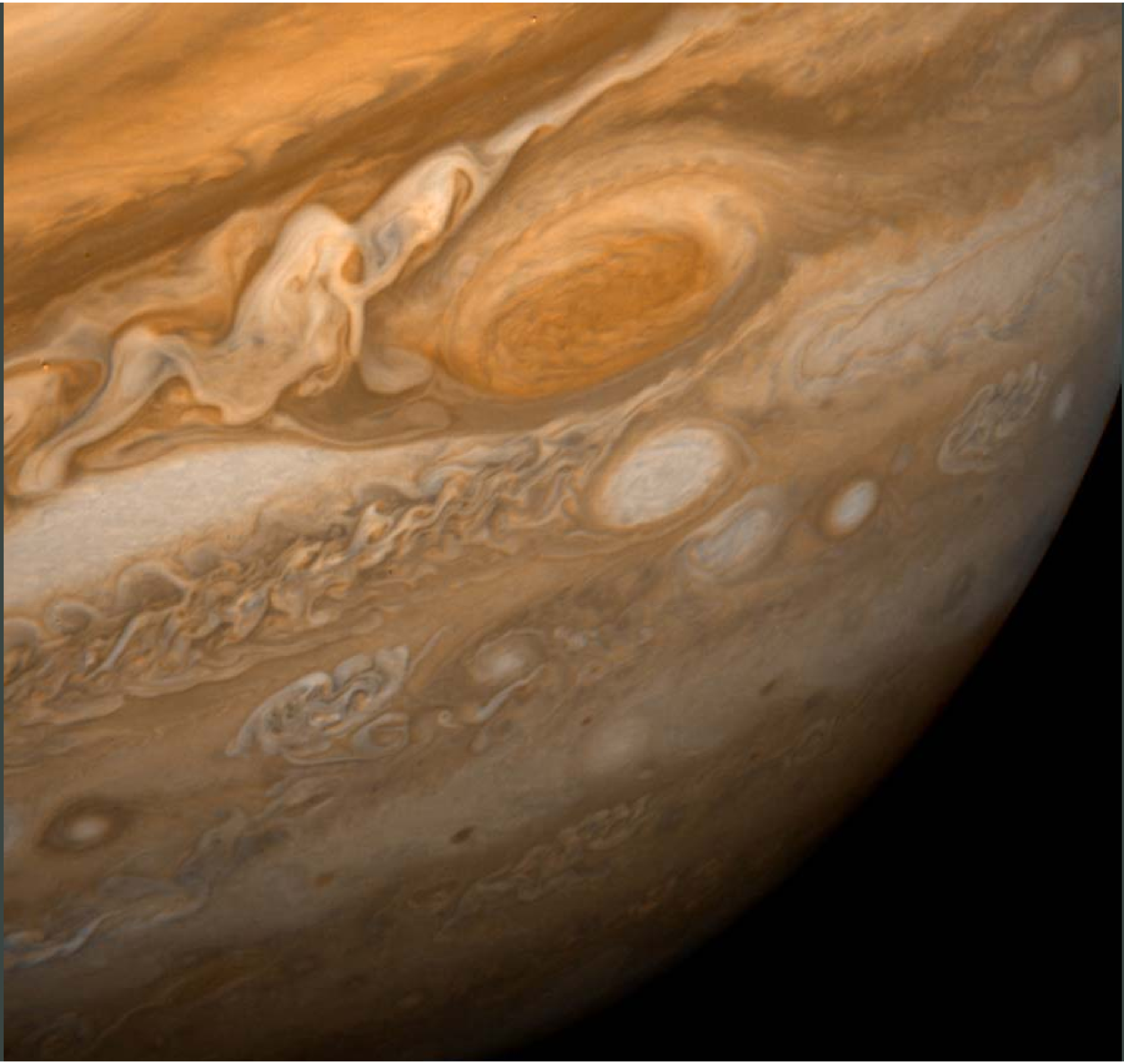


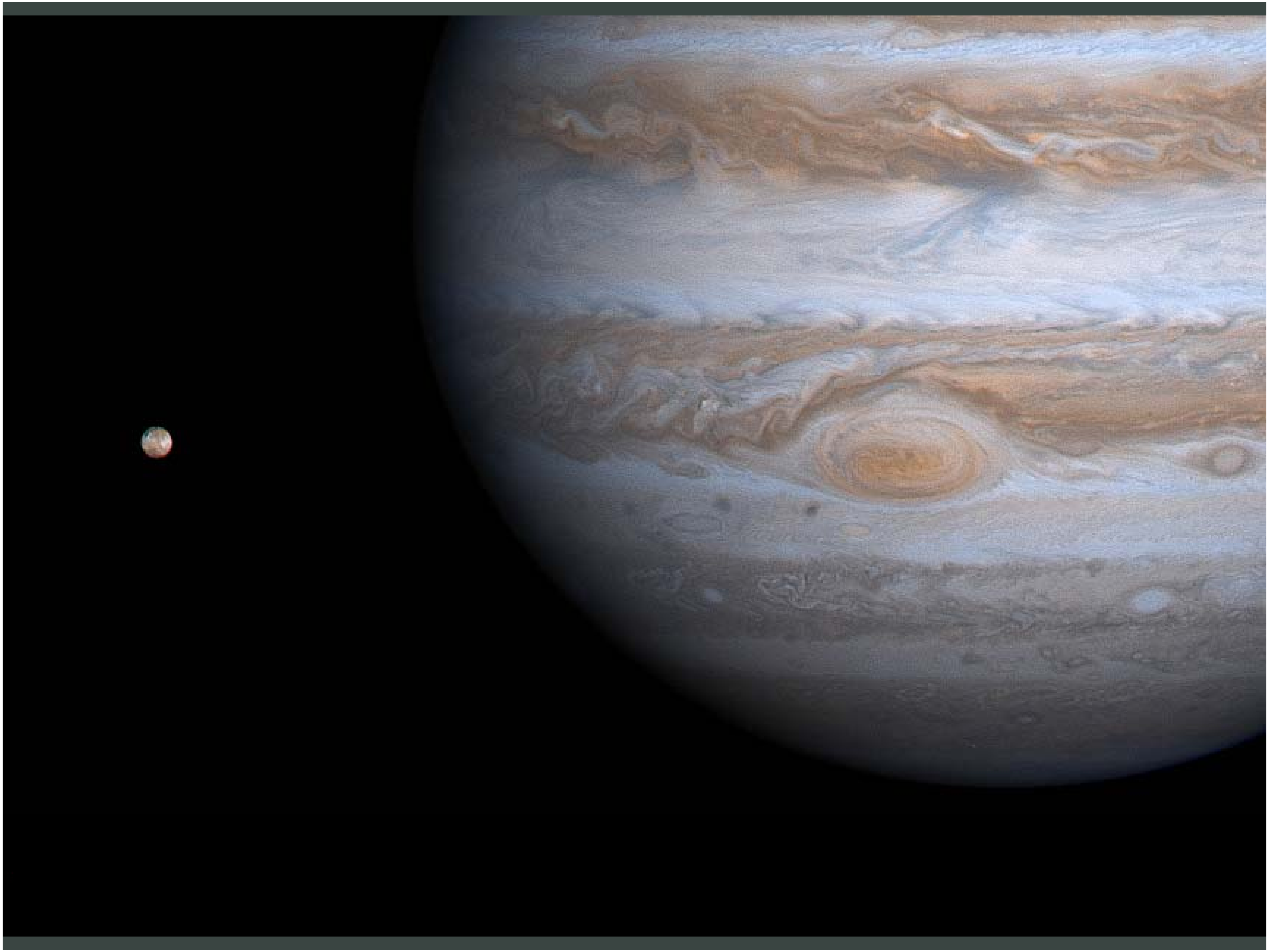


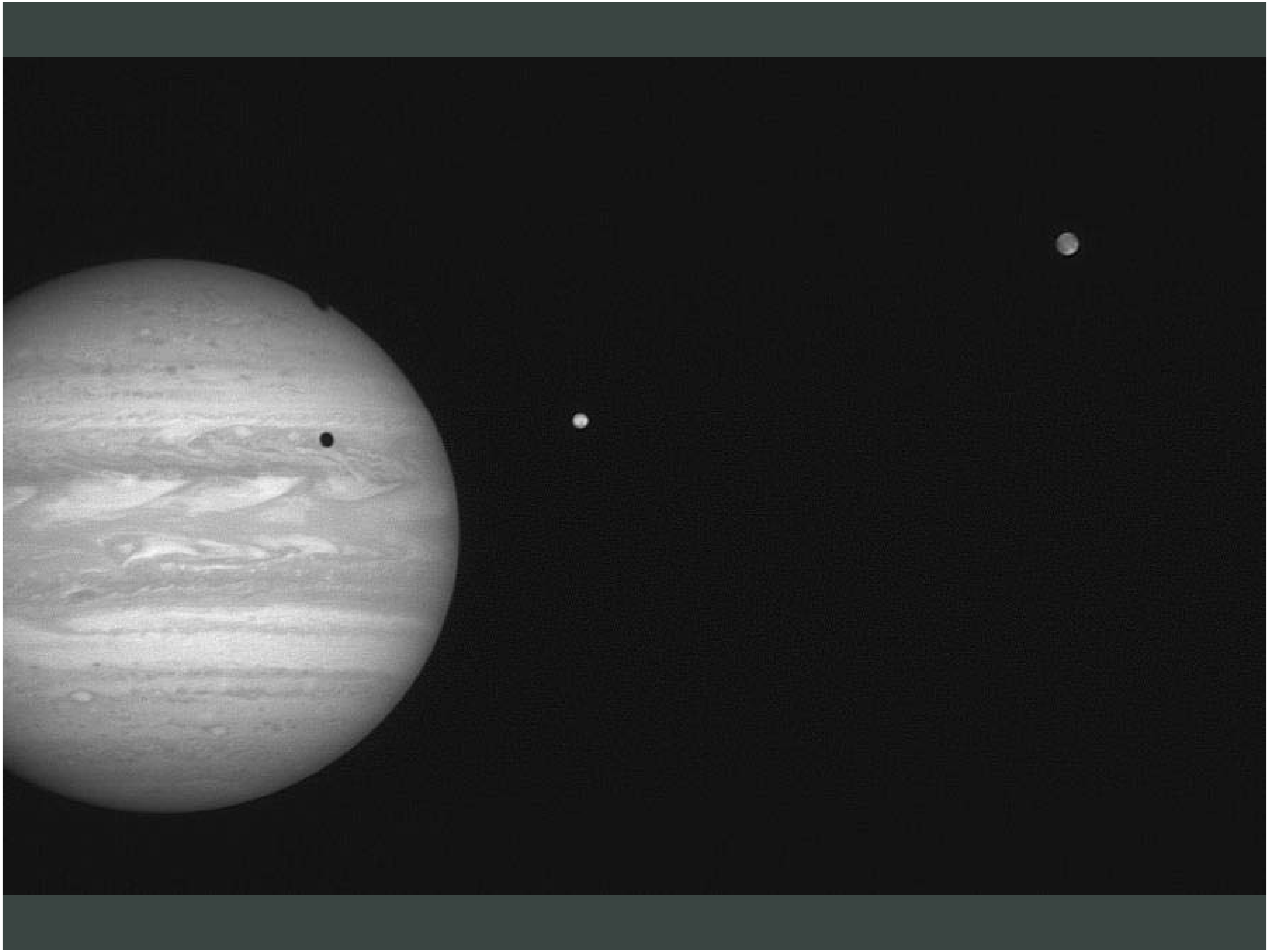

Swedish 1-m Solar Telescope, Venus transit egress, bright ring 9x enhanced

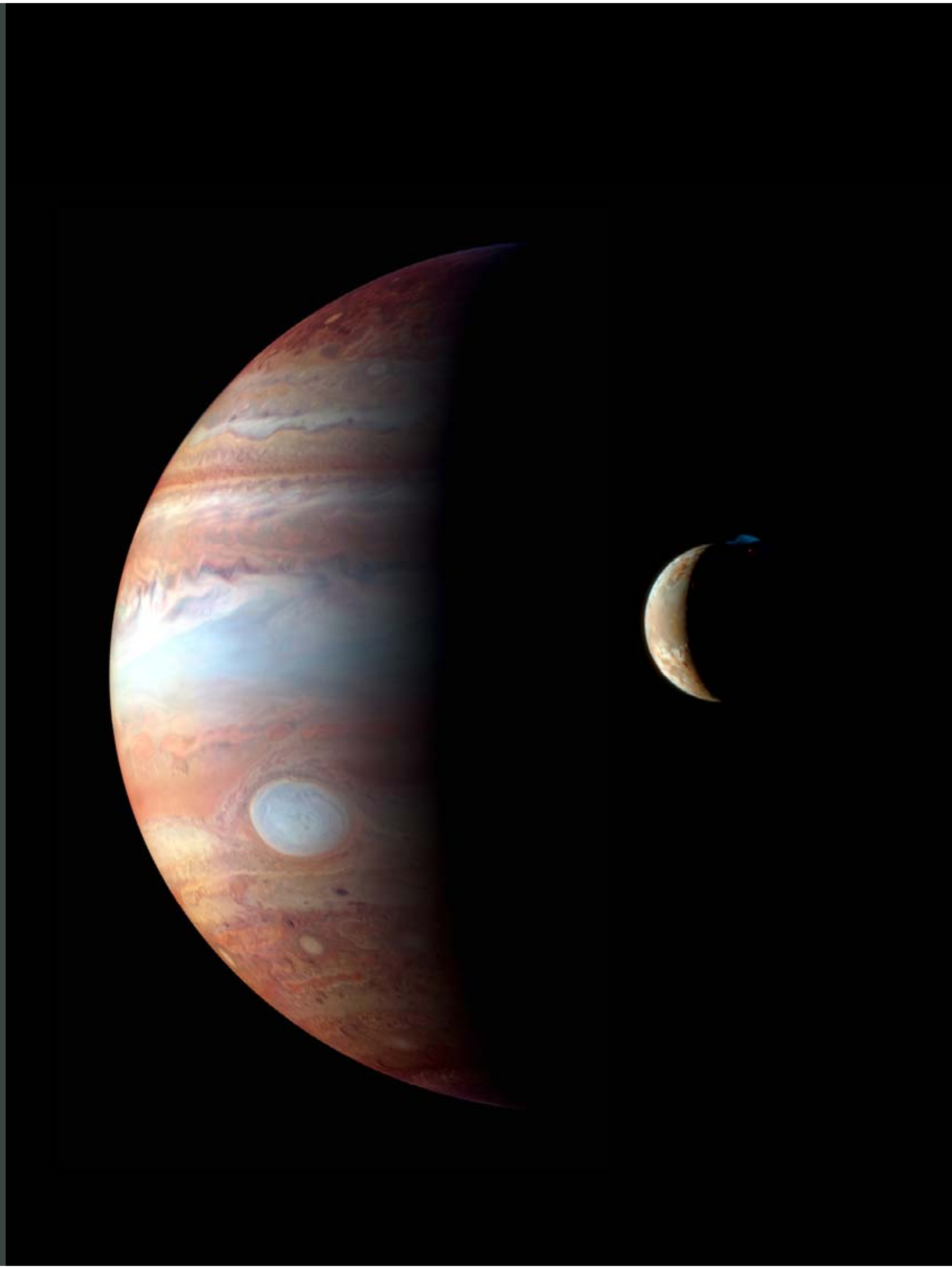












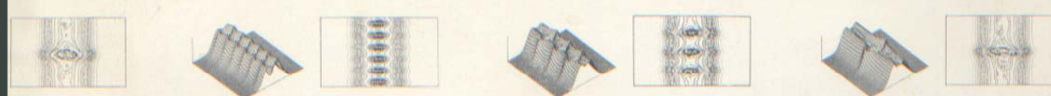
Edward R. Tufte

Envisioning Information

ESCAPING FLATLAND

MICRO / MACRO READINGS

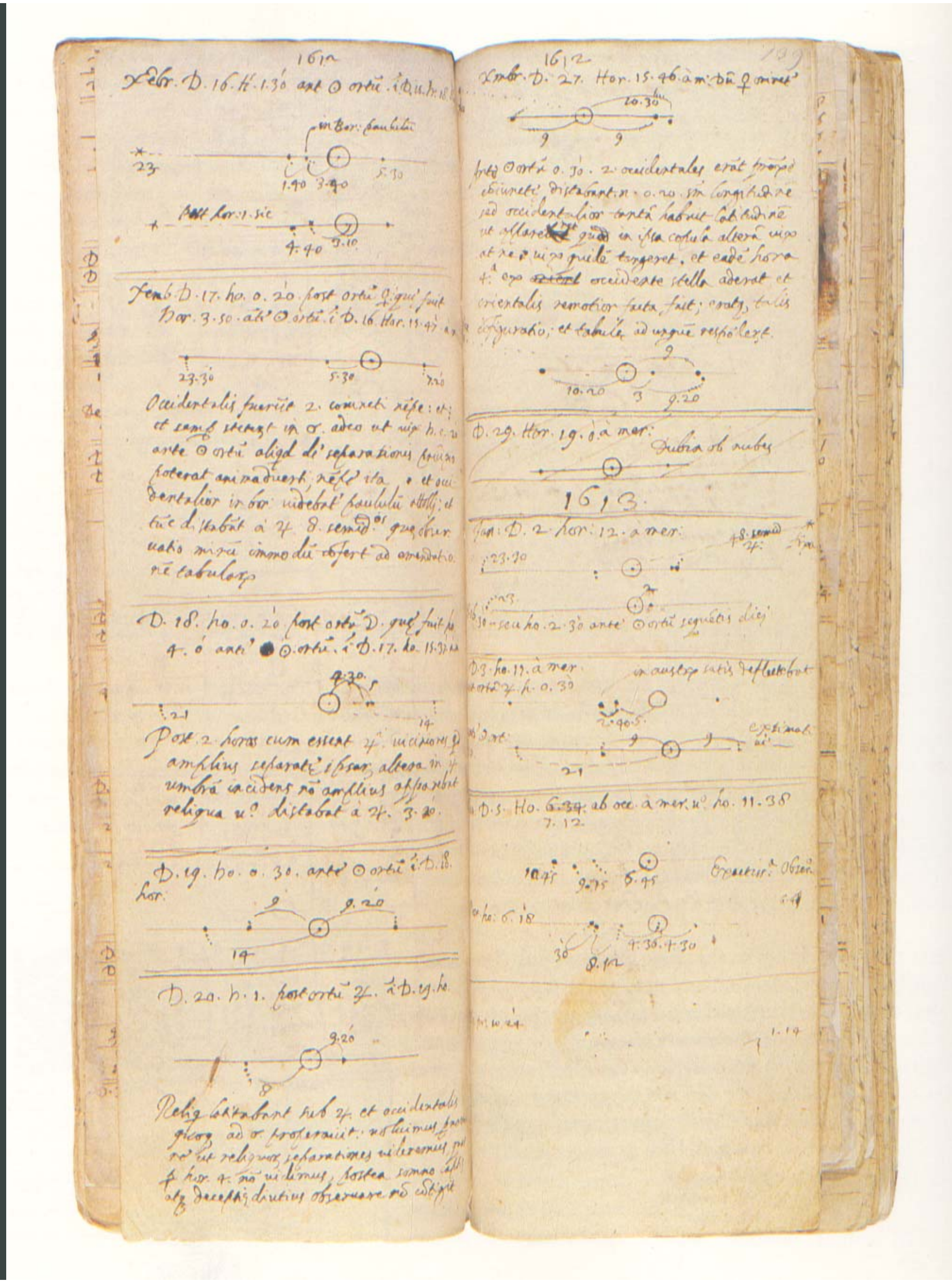
LAYERING AND SEPARATION



SMALL MULTIPLES

COLOR AND INFORMATION

NARRATIVES OF SPACE AND TIME



1612

Xbr. D. 16. H. 1.30 ant. ☉ ortū

1.40 3.40 5.30

Post hor. 1. sic

4.40 3.10

Xemb. D. 17. ho. 0.20 post ortū ♃ qui fuit Hor. 3.50 ant. ☉ ortū i D. 16. Hor. 15.47

23.30 5.30 7.20

Occidentalis fuerūt 2. coniuncti, et semp steterūt in ☌ adeo ut ... ante ☉ ortū aliqd de separatione ... poterat animaduerti ... et occidentalior ... distabat a ♃ ... tabulorum

D. 18. ho. 0.20 post ortū ♃ qui fuit ... ante ☉ ortū i D. 17. ho. 15.37

9.30

21 14

Post 2 horas cum esset ♃ ... amplius separati ... umbrā incidens nō amplius apparebat reliqua u° distabat a ♃. 3.20.

D. 19. ho. 0.30 ante ☉ ortū i D. 18.

9 9.20

14

D. 20. h. 1. post ortū ♃ i D. 19. ho.

9.20

8

Reliq ... sub ♃ et occidentalis ... ad ☌ ... nō ... separationes ... hor. 4. nō videmus, postea somno ...

1612

Xmbr. D. 27. Hor. 15.46 a m. ...

10.30

9 9

... ☉ ortū 0.30. 2 occidentales erāt prope ... distabant ... 0.20 ... longitudine ... occidentalior ... latitudine ... ut ... et eadē hora ... occidente stella aderat et orientalis remotior facta fuit ... configuratio, et tabulę ad ...

9

10.20 3 9.20

D. 29. Hor. 19. 0 a mer.

Dubia ob nubes

1613

Jan. D. 2 Hor. 12 a mer.

23.30

... seu ho. 2.30 ante ☉ ortū sequētis diei

D. 3. ho. 17 a mer.

in austrum satis deflectebat

2.40.5

21

D. 5. Ho. 6.39 ab occ. a mer. u° ho. 11.38

7.12

10.45 9.15 6.45

ho. 6.18

36 9.12 4.30 4.30

1.14

6 *Narratives of Space and Time*

MANY information displays report on the world's workaday reality of three-space and time. Painting four-variable narrations of space-time onto flatland combines two familiar designs, the map and the time-series. Our strategy for understanding these narrative graphics is to hold constant the underlying information and then to watch how various designs and designers cope with the common data. Examined first are accounts of the motion of Jupiter's satellites, beginning with Galileo's notebooks. Other case studies in our space-time tour are itinerary design (schedules and route maps) and, finally, various notational systems for describing and preserving dance movements.

Two pages from Galileo's notebooks, recording observations of four satellites of Jupiter between December 16, 1612, and January 5, 1613.

The Galilean Satellites of Jupiter

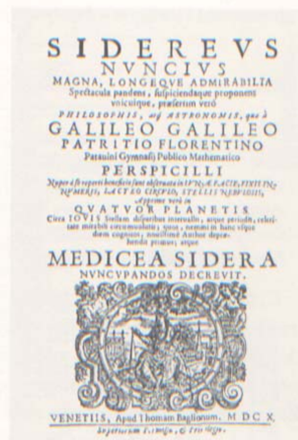
On the evening of January 7, 1610, Galileo first turned his new telescope toward Jupiter and saw three small, bright starlets near the planetary disk. His book, *The Starry Messenger,* records the series of observations.[1]

> Though I believed them to belong to the host of fixed stars, they somewhat aroused my curiosity by their appearing to lie in an exact straight line parallel to the ecliptic, and by their being more splendid than other stars their size. Their arrangement with respect to Jupiter and to each other was as follows:
>
> East * * ◯ * West
>
> That is, there were two stars on the easterly side and one to the west; the more easterly star and the western one looked larger than the other. I paid no attention to the separations between them from Jupiter, since at the outset I thought them to be fixed stars, as said before.

But either Jupiter or the starlets or both were moving, for next evening a different arrangement appeared. The three starlets were now all west of Jupiter, closer together than before, about equally spaced:

> East ◯ * * * West

[1] The title page of *The Starry Messenger* reads, "Unfolding great and surpassingly wondrous sights, and offering everyone, but especially philosophers and astronomers, the phenomena observed by Galileo Galilei, a Gentleman of Florence, Professor of Mathematics in the University of Padua, with the aid of a telescope, lately invented by him, on the surface of the moon, an innumerable number of fixed stars, the Milky Way, and Nebulous Stars, and above all in four planets swiftly revolving around the planet Jupiter at different distances and periods, and known to no one before this day, the author recently discovered them and decided to call them The Medicean Stars. Venice. Published by Thomas Baglionus. 1610. With permission and approval of superiors."


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, praesertim verò
PHILOSOPHIS, atq ASTRONOMIS, quae à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
QVATVOR PLANETIS
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.
VENETIIS, Apud Thomam Baglionum. M DC X.

> At this time I did not yet turn my attention to the manner in which the starlets had gathered together, but I did begin to concern myself with the question how Jupiter could be east of all these stars when on the previous night it had been west of two of them. I commenced to wonder whether Jupiter might not be moving eastward at this time, contrary to the computations of astronomers, and had gone in front of them by that motion.

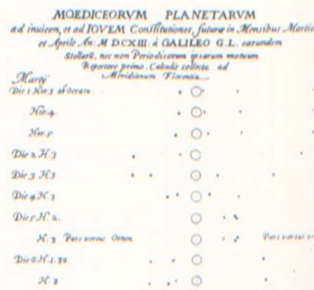
Galileo awaited the next night with great interest, but clouds blocked his view. Then on January 10, 1610 he did see Jupiter and was able to separate out motion of planet from that of the starlets, a sequence of observation and logic adding up to one of the most important scientific discoveries ever made:

> On the tenth of January, however, the stars appeared in this position with respect to Jupiter:

> That is, there were but two of them, both easterly, the third (as I supposed) being hidden behind Jupiter. As at the beginning, they were in the same straight line with Jupiter and arranged exactly in the line of the zodiac. Noticing this, and knowing that there was no way in which such alterations could be attributed to Jupiter's motion [alone], yet being certain that these were still the same stars I had observed [before]—in fact, no other star was to be found along the line of the zodiac for a long distance on either side of Jupiter—my perplexity was now turned into amazement. Certain that the apparent changes belonged not to Jupiter but to the observed stars, I resolved to pursue this investigation with greater care . . .
>
> I decided beyond all doubt that there existed in the heavens three stars wandering about Jupiter as do Venus and Mercury about the sun, and this became plainer than daylight from observations on occasions that followed. Nor were there just three such stars [as I was soon to learn]; four planets do complete their revolutions around Jupiter, and I shall give a description of their alterations as observed more precisely

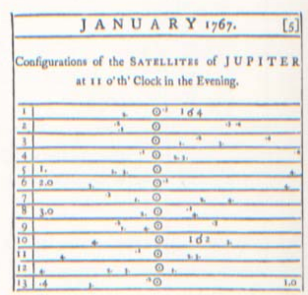
> later on. Also I measured the distances between them by means of the telescope, using the method explained earlier. Moreover, I recorded times of observations, especially when more than one was made on the same night; for the revolutions of these planets are so swiftly completed that it is usually possible to note even their hourly changes.[2]

Continued observation soon established that four satellites revolved around Jupiter. Longer time-series, flickering with discontinuities, were plotted by Galileo in 1613 and Cassini in 1668. Satellite motion could be forecast precisely enough to serve as a worldwide signaling clock for determining longitude (since 24 hours corresponds to 360°). Data were entabled—even gridlocked—in ephemerides such as this 1766 *Connaissance des Temps* issued by the Bureau des Longitudes in Paris.



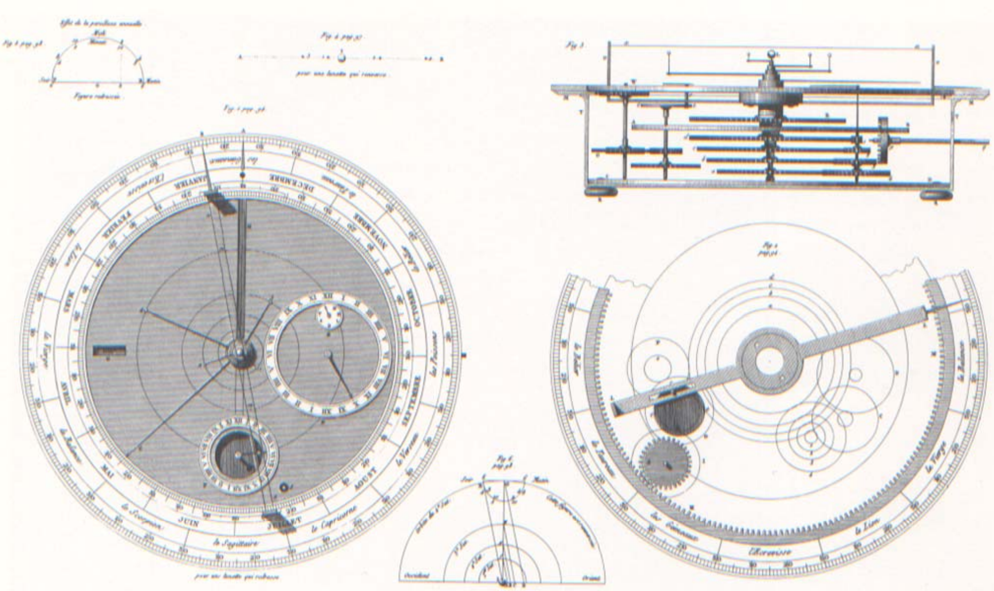
Galileo Galilei, *Istoria e dimostrazioni intorno alle macchie solari* . . . [Welser sunspot letters], (Rome, 1613), illustration of satellites (called by Galileo "Medicean stars" in honor of his patron) following p. 150.

Jean Domenique Cassini, *Ephemerides Bononienses Mediceorum syderum ex hypothesibus, et tabulis Io*, (Bologne, 1668), p. 34.



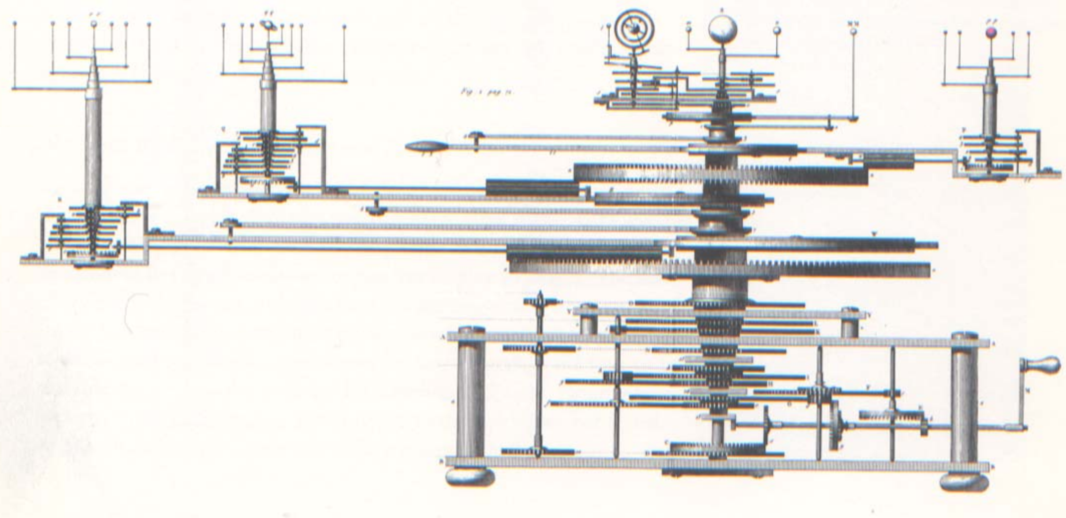
Bureau des Longitudes, *Connaissance des Temps* (Paris, 1766), p. 5.

[2] Translation of *The Starry Messenger* by Stillman Drake, in his *Telescopes, Tides, and Tactics* (Chicago, 1983), pp. 59–63.



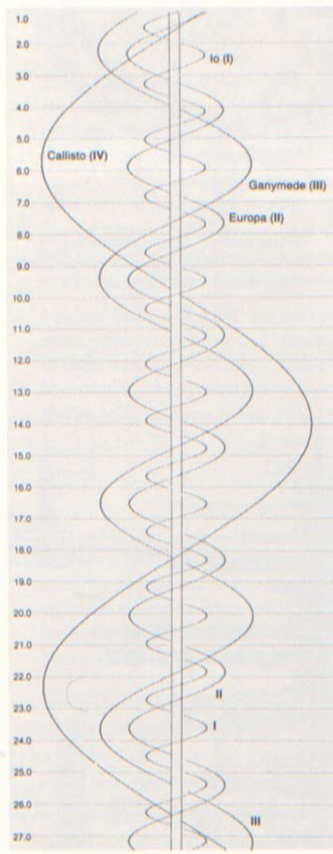
To animate flatland, Galileo and then others constructed Jovilabes, nomogram-like computation devices that recounted orbits of Jupiter's satellites (above). Mechanical models of the solar system in motion showed the interplay of Sun, Earth, and Jupiter, as our shifting vantage point and Jovian shadows masked Galilean satellites from Earth view.

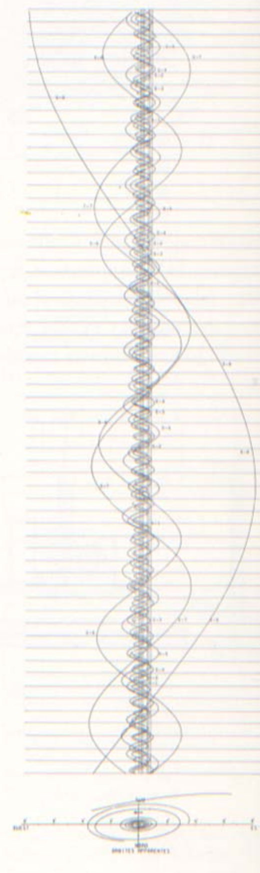
Antide Janvier, *Des révolutions des corps célestes par le méchanisme des rouages* (Paris, 1812), plate VI and plate IV.

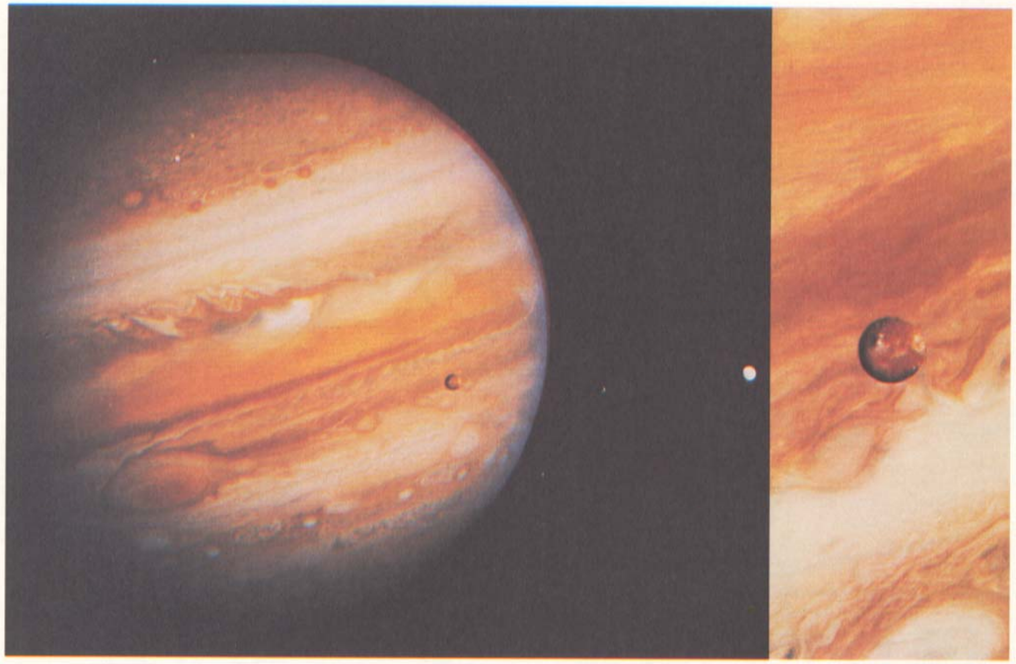


Now, in modern portrayals of Jupiter's satellites, all the individual observations are connected in the corkscrew diagram, with continuous spirals traced out by Io, Europa, Ganymede, and Callisto. These micro/macro diagrams work on a grid of one spatial dimension stretched by time, just like graphical timetables. In our redrawings, the flickering prison bars of the horizontal slices are muted, thus avoiding the clutter of 1 + 1 = 3 effects. It was not until the 20th-century, 300 years after Galileo's discovery, that the dots were linked into continuous curves—an advance in design that came slowly despite the intellectual skills of the astronomers involved. The smooth trajectories of the modern diagram report *every* position of the moons—fitting data for even a few hours of viewing, because of the rapid journeys of the inner satellites. At right is a similar chart for Saturn, including an orbital planview.

Redrawn from: *Sky & Telescope*, 76 (1988); *Satellites Galiléens de Jupiter*, Bureau des Longitudes (Paris, 1987); and *Configurations des Huit Premiers Satellites de Saturne pour 1987, 1988*, Bureau des Longitudes (Paris, 1987, 1988).







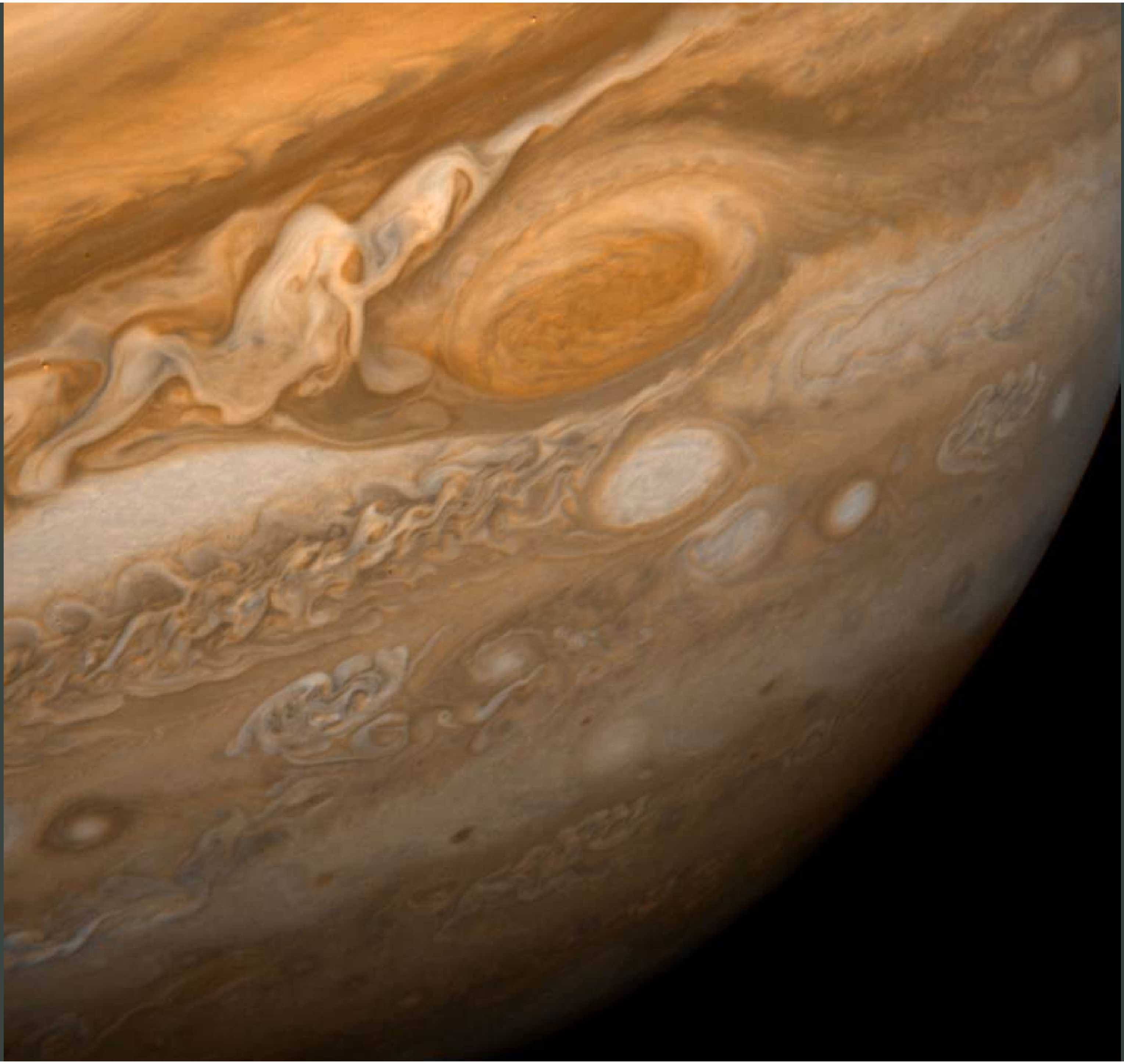
Our story concludes with a new perspective, a very close look at the Galilean satellites. The remarkable 1979 flights near Jupiter by Voyager spacecraft revealed not the luminous pinpoints of reflected sunlight tracing out swift cycles of an elegant and reliable geometry—as had been seen through telescopes for centuries—but, instead, satellites that appeared, frankly, a bit on the lumpy side.[3]

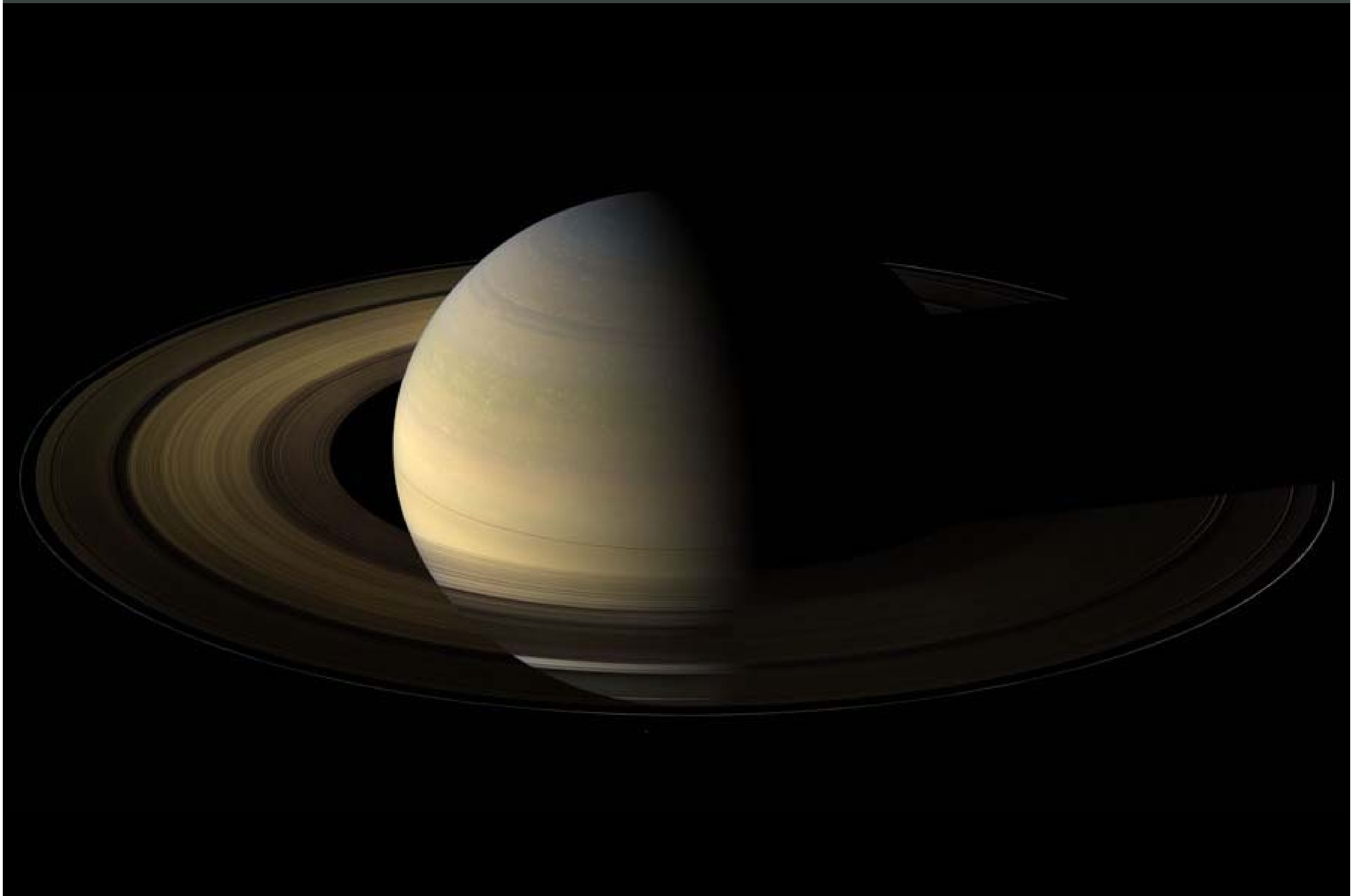
[3] At left, two inner Galilean satellites—Io (in front of Jupiter) with an active volcano, and, right, the ice-covered Europa. Both are about the size of Earth's Moon; the Red Spot on Jupiter is larger than Earth. At right, a closer view of Io and Jupiter.

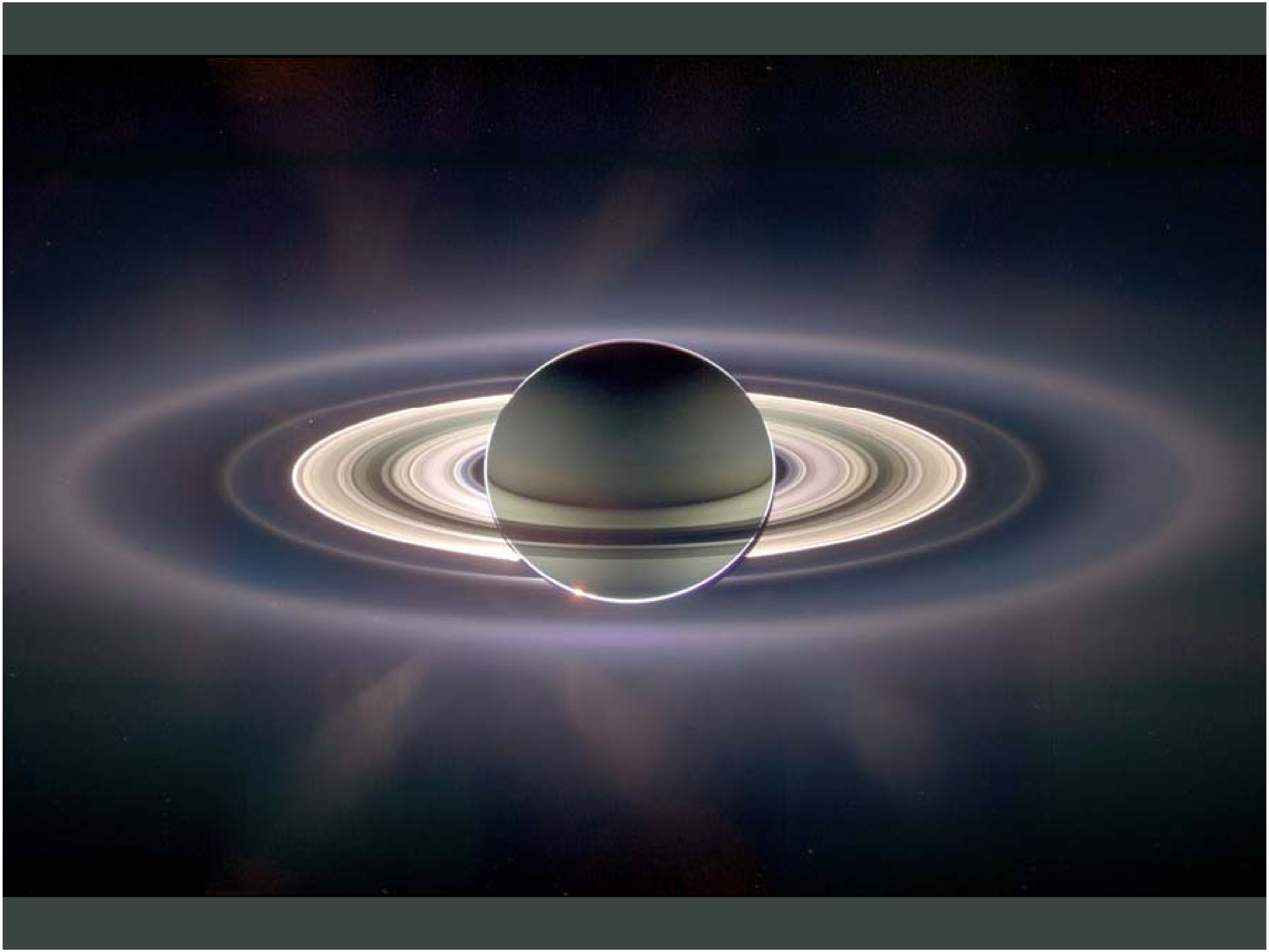
Narrative Itineraries: Timetables and Route Maps

Schedules are among the most widely used information displays, with a sheer volume of printed images comparable to road maps, daily weather charts, catalogs, and telephone books. Design efforts for 150 years the world over have yielded some imaginative display strategies. The issues of timetable design are at the heart of envisioning data—large arrays of fussily annotated numbers, thick information densities, type and image together, and multivariate techniques for narrating what is a four or five variable story.[4] And the audience for schedules is diverse, ranging from experts at timetables such as travel agents to those who are not travel agents, an audience of uncertain skills, eyepower, patience.

[4] Among the scant literature is Christian Barman, "Timetable Typography," *Typography*, 5 (Spring 1938), 9–17; Ruari McLean, *Typography* (London, 1980).







The University of Michigan Galileo Manuscript at 400 Years

THE UNIVERSITY OF MICHIGAN GALILEO MANUSCRIPT provides a unique glimpse of Galileo the man as well as Galileo the great scientist. It is just one page long, and provides no new data, but reveals instead the habits of mind of a man widely regarded as the first modern scientist – the first to base his conclusions on data and evidence rather than fitting data into existing philosophical beliefs.

The top portion of the letter lets us see Galileo in August of 1609. He had heard about a Dutchman coming to Venice to try to sell the government a magnifying instrument that would give them a military advantage. Galileo was an instrument maker himself, and after he heard from a friend who saw the closely guarded Dutch instrument that it had two lenses in a tube, he set to work trying to replicate it. He needed less than a day of experimentation to come up with the design.

Galileo then used this piece of paper to draft ideas for a letter to the Doge of Venice, Leonardo Donato, offering his "occhiale" ("eyeglass") and pointing out the military advantages of owning it. He sent a final version to the Doge on August 24, 1609. (It survives in the State Archives in Venice.) Galileo demonstrated his telescope for the leaders of Venice a few days later, and made the sale.

The remaining four months of 1609 were exciting and incredibly fruitful ones for Galileo, as he made new telescopes of increasing power and started using them to observe the heavens. This piece of paper was saved and then pulled out again by Galileo in January 1610 when he needed scratch paper to help him think through a perplexing problem regarding objects he was seeing close to the planet Jupiter.

On the night of January 7, 1610 Galileo had noticed three bright objects near Jupiter. The fact that they formed a straight line going across the planet probably made them memorable as he scanned the night sky, and so caused him to take special note the next night when he saw them again, but in a radically different configuration. If they were stars beyond Jupiter that just appeared to be near it, they should not have changed positions so quickly.

Galileo was by now keeping a full record of his nightly examinations of the skies in what we would today call "lab notebooks," and from this record he pulled together all the data on Jupiter he had collected by January 15 and transferred it to this manuscript. As he tried to make sense of it, he drew the diagrams in the lower righthand corner, which may show what the movements of these objects would be if seen looking down at Jupiter.

You can almost see the "aha" moment on the night of January 15, 1610 when Galileo suddenly started writing in Latin instead of his normal Italian in the notebooks. He had realized that if the three or four bright "stars" near Jupiter were orbiting that planet, his data fit. This was earth-shaking news, and he knew he must publish something about it as quickly as possible (hence, the switch to Latin). Less than two months later, on March 4, 1610, his book Sidereus Nuncius (The Starry Messenger) was approved for publication by the censors of the Roman Catholic Church.

The University of Michigan manuscript helped Galileo understand that he had the first real evidence in history for the existence of bodies orbiting anything other than the Earth. This evidence not only suggested that the Earth was not as unique as we inhabitants assumed it was, but also gave credence to Copernicus's theory that Earth was but one of six known planets orbiting the Sun.

Peggy E. Daub
Director, Special Collections Library

GALILEO GALILEI (1564-1642)

Draft of a letter to Leonardo Donato, Doge of Venice, and Observations of the Moons of Jupiter
August 1609 and January 1610.
Gift of the Estate of Tracy W. McGregor, 1938

Most Serene Prince

Galileo Galilei, most humble servant of your Serene Republic, is assiduously watching with all spirit of willingness in order to be able not only to satisfy the duties he has for the teaching of mathematics at the University of Padua ….

Writes of having decided to present to your most Serene Prince the eyeglass ["l'occhiale"], and since it will be of inestimable value for all affairs and enterprises maritime or terrestrial, I assure you I intend to keep this new device a great secret and have it at the disposal of only your government. The eyeglass draws on the most profound theories of perspective and has the advantage of being able [1] to reveal ships and sails of the enemy two hours and more before the time they can first be seen with natural vision; [2] to distinguish the number and kind of ships to judge their forces and prepare to chase, fight, or flee; or also [3] in the open country to see and particularly to distinguish all details of his movements and preparations.

On the 7th of January
Jupiter is seen thus

On the 8th thus

It was therefore direct and not retrograde

On the 12th day it is seen in this arrangement
The 13th are seen very close to Jupiter 4 stars *or better so*
On the 14th it is cloudy

The 15th *the nearest to Jupiter was smallest the 4th was distant from the 3rd about double.*
The spacing of the 3 to the west was no greater than the diameter of Jupiter and they were in a straight line.

Ser.mo Principe.

Galileo Galilei Humiliss.o Servo della Ser.tà V.a invigilando assiduam.te, et con ogni spirito per potere non solam.te satisfare al carico che tiene della lettura di Matematiche nello Studio di Padova,

Scrivere d'havere determinato di presentare al Ser.mo Principe l'Occhiale et poter essere di giovamento inestimabile per ogni negozio et impresa marittima o terrestre stimo di tenere questo nuovo artifizio nel maggior segreto et solam.te a disposizione di S. Ser.tà L'Occhiale cavato dalle più recondite speculazioni di prospettiva ha il vantaggio di scoprire Legni et Vele dell'inimico per due hore et più di tempo prima che egli scuopra noi et distinguendo il numero et la qualità dei Vasselli giudicare le sue forze pallestirsi alla caccia al combattimento o alla fuga, o pure anco nella campagna aperta vedere et particolarm.te distinguere ogni suo moto et preparamento.

Adì 7. di Gennaio Giove si vedde così * * ⊛ * così:

10. ⊛ * * — 11. ⊛ * * *

Adì 8 così ⊛ * * * era dunq. diretto et non retrogrado

Adì 12. si vedde in tale costituzione * * ⊛ * così:

Il 13 si veddono vicinissime à Giove 4 stelle * ⊛ * * * o meglio così * ⊛ * * *

Adì 14 è nugolo

Il 15 ⊛ * * * * così: la pross.a à ♃ era la minore la 4.a era distante dalla 3.a il doppio in circa.

Lo spatio delle 3 occidentali non era maggiore del diametro di ♃ et erano in linea retta.

♃ long. 71.38 lat. 1.13