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# I. Observing Jupiter

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*Jupiter is a world that can fascinate in many different ways.*

*To amateur astronomers, Jupiter can be an object of interest on every timescale. Over a matter of minutes, one can watch a moon and its shadow gliding across the edge of the planet, while one scrutinises the patterns in the clouds below. Over an hour or more, the planet's rotation brings a parade of diverse storms round to view. Over several days or weeks, these features move or evolve. Over months or years, the overall pattern of features and colours may change, often comprising great cycles of disturbance. And reviewing the observations over a span of decades, one finds that the nature of these cycles themselves has subtly changed, so that patterns may reappear that had last been seen a century before.*

*To physicists, Jupiter is the greatest laboratory for atmospheric dynamics. It has weather and climate and circulations that dwarf those of the Earth. Many of the largescale phenomena are still unexplained. Moreover, it has a magnetic field and radiation belts greater than those of any other planet.*

*To cosmologists, Jupiter may be a tiny speck, but it is the only representative that we can study of a huge class of objects: bodies intermediate in scale between the other planets and the stars. Indeed, bodies such as Jupiter may dominate the universe. As most of the mass of the galaxies cannot be seen, rival theories for the 'missing mass' range from exotic subatomic entities such as WIMPs ('weakly interacting massive particles') to more conventional bodies such as MACHOs ('massive compact halo objects'). MACHOs could be planets like Jupiter.*

*To lovers of landscape, Jupiter's moons offer outlandish vistas, of icy ridges or frozen oceans or rugged mountains or sulphur-spurting volcanoes.*

*And to art-lovers, Jupiter displays the structured but spontaneous patterns, the unpredictable symmetries, and the swirling colours, that produce an absorbing work of art.*



Fig. 1.1. Jupiter is the brightest 'star' in the mid-night sky. Here it stands in front of the star cluster called Praesepe in the constellation Cancer. Photograph by R. Néel on 1991 Feb. 2.



Fig. 1.2. Jupiter and its moons as seen through a telescope at low power. One can see the main belts, the Great Red Spot, the shadow of one of the moons, and the four moons themselves lying approximately in the planet's equatorial plane.

# 1: Observations from Earth

## 1.1 A VIEW OF JUPITER

To gaze at the giant planet Jupiter through a fair-sized telescope is to be transported to a wonderfully alien world. This largest planet in the solar system is partitioned by bands of variously tinted clouds, some straight and others ruffled with the turbulence of fierce winds. White and dark ovals mark atmospheric storms, some as large as the Earth. The planet rotates in front of your eyes; after no more than 10 minutes you can see that the rapid rotation is carrying the features across the disc. If you know the planet well, these features may mark out familiar patterns, but sometimes they reveal new and fascinating forms of upheaval in the clouds. Meanwhile, orbiting around the planet, you see the four ‘stars’ that are its four great moons. Often one of them will be seen slipping behind the planet, or gliding in front of it and casting its shadow on the clouds.

All that we see on Jupiter is clouds. The dark *belts* and the bright *zones*, and the various types of spots, are clouds of different thicknesses and colours. The belts and zones are marked out by powerful jetstreams, which are permanent winds blowing eastward or westward. Spots lying between them are storms which drift eastward or westward at slower rates.

The reason why the belts and the winds all run east–west is the planet’s rotation. With a period of 9 hours 55.5 minutes, this is so fast that the poles are noticeably flattened; the polar diameter is only 14/15 of the equatorial diameter. So all the motions are channelled along lines of latitude.

The main belts and zones have been given names, and although they may change or disappear now and then, they always reappear in the same positions (Fig. 1.3). We know that the belts and dark spots are warmer than the zones and bright spots, due to heat emerging from deep in the interior. The highest and coldest feature is the Great Red Spot, which is a reddish oval circulation with twice the diameter of the Earth. The Voyager spacecraft have shown that all the ‘spots’ are vortices, which appear to roll between the jetstreams.

All these motions take place in an impenetrably deep atmosphere. A visible sign of the atmosphere is ‘limb-darkening’<sup>1</sup>, that

<sup>1</sup> The following definitions may be useful. The *limb* is the edge of the visible disc. The *terminator* is the boundary between the illuminated and darkened sides of the disc. The *phase angle* is the angle between Sun, planet, and observer; for observers of Jupiter it never exceeds 11.7°.

is, a diffuse shading close to the edge of the visible disc, which is caused by absorption and scattering of light in the atmosphere.

The atmosphere, and indeed the whole planet, are composed mostly of hydrogen and helium, mixed with smaller amounts of ammonia, methane, and simple hydrocarbons. The clouds are believed to consist mainly of ammonia ice crystals, ammonium hydrosulphide, and water ice. There is probably no solid surface. In fact, the composition of Jupiter is believed to be much the same as that of the Sun or of the galaxy as a whole, because Jupiter, unlike Earth, has powerful enough gravity to hold onto even the lightest gases.

Jupiter orbits the Sun 5.2 times further out than the Earth. At this distance the sun’s light and heat are only 1/27 as strong as at Earth, so without any other source of heat the planet and its satellites would be very cold. However, the atmosphere gets almost as much heat from the interior of the planet as it does from the Sun, and this seems to be what drives the storms. The interior heat is a result of the planet’s great size; it heated up so much when it was forming 4600 million years ago, and it has such a great mass, that it has not yet cooled down.

And Jupiter is truly immense (Table 1.1). It measures 11 times the diameter of the Earth, 1323 times its volume, and 318 times its mass. In fact it has more mass than all the other planets put

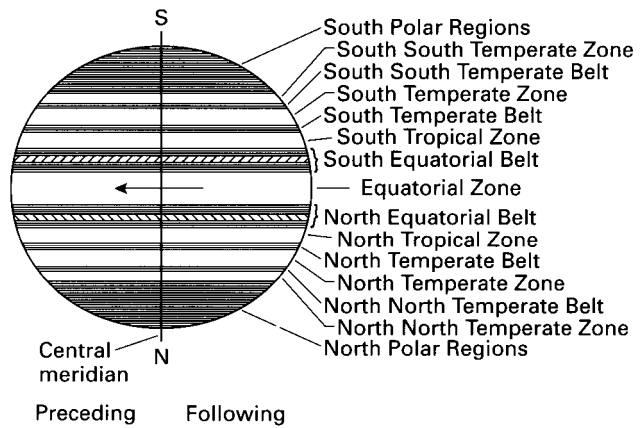


Fig. 1.3. The normal belts and zones, with the standard nomenclature. (BAA diagram.)

Table 1.1 Physical parameters of Jupiter and Earth

	Jupiter	Earth
Diameter, equatorial*	143 082 km	12 756 km
Diameter, polar*	133 792 km	12 714 km
Rotation period:†		
System I	9h 50m 30.003s (877.90°/d)	
System II	9h 55m 40.632s (870.27°/d)	
System III	9h 55m 29.711s	23h 56m 4s
Tilt (relative to orbit)	3.12°	23.44°
Mass	1.899 x 10 <sup>27</sup> kg	5.974 x 10 <sup>24</sup> kg
Density	1.32 g/cm <sup>3</sup>	5.52 g/cm <sup>3</sup>
Surface gravity**	2.69 g	1.00 g
Mean geometric albedo††	0.52	0.37

Data are from the *BAA Handbook (1991)* unless otherwise stated.  
\* The diameters of Jupiter ( $\pm 8$  km) are from Lindal *et al.* (1981), at the 100-mbar level. Subtract approx. 50 km for cloud-top level and 100 km for 1-bar level.  
† Rotation periods are sidereal, i.e. measured with respect to the fixed stars. The exact definition is the value in degrees per day (24 hours).  
\*\* The effective surface gravity at the equator of Jupiter is 9% less due to the centrifugal force of rotation.  
†† Albedo is a measure of the fraction of light reflected from an object. The geometric albedo is the ratio of the object's brightness to that of one which diffusely reflects all incident light, under vertical illumination. Another measure of albedo, the absolute reflectivity, varies from 0.62 in NEB to 0.76 in STropZ (Orton, 1975).

together. In volume, it is close to the largest possible size for a gas giant planet – as more massive planets, having stronger gravity, would have smaller radius.

Jupiter's orbit

Jupiter takes 11.86 Earth years to complete one revolution around the Sun (Table 1.2). As a result, it moves around the zodiac by about one constellation per year. *Opposition* is the time when, from our point of view, the planet is opposite the Sun in the sky, reaching its highest altitude at midnight (Fig.1.4); the average interval between oppositions is about 13 months. (The interval varies slightly because both Jupiter and Earth have elliptical orbits; the actual dates of opposition are given in Appendix 3.) *Solar conjunction* is the time when Jupiter is on the other side of the Sun from us, and therefore cannot be seen for a few months. *Quadrature*, when the planet is 90° away from the Sun in the sky, is when the planet shows the maximum phase; in Jupiter's case the true phase is too small to be detected, although the limb away from the Sun does appear noticeably darkened.

The interval between solar conjunctions, during which we can observe Jupiter, is called the *apparition* and lasts between 8 and 10 months. Each apparition starts with the planet rising just before the sun as a 'morning star', proceeds through opposition, and ends with descent into the evening twilight. The best oppositions, regrettably but inevitably, come at the coldest time of the year, when the planet is highest and the sun lowest in the sky; then the planet rides high during the long winter nights. In summer apparitions, it is not so easy to observe from latitudes as high as that of Great Britain,

Table 1.2 Orbits of Jupiter and Earth

	Jupiter	Earth
Mean distance from Sun	5.20280 AU	1.00000 AU
Perihelion distance	4.951 AU	0.983 AU
Aphelion distance	5.455 AU	1.017 AU
Eccentricity	0.04849	0.01671
Period (sidereal)	4332.59 d	365.26 d
Inclination	1.304°	0.000°
Mean synodic period (time between oppositions)	398.88 d	—

1 AU (astronomical unit) = 149 597 870 km.  
Data are from the *BAA Handbook (1991)*.

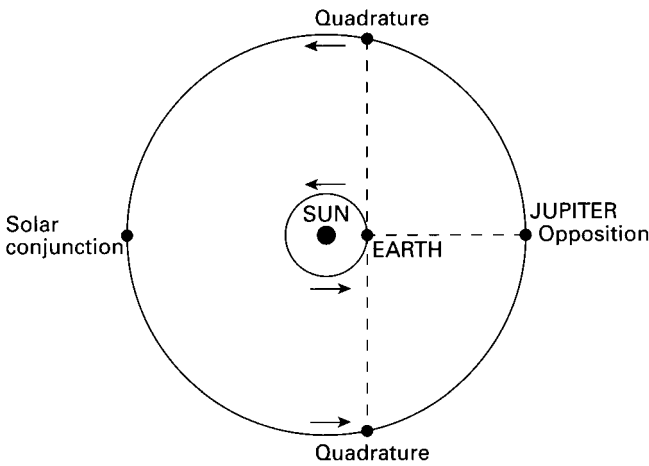


Fig. 1.4. Relative positions of Jupiter and Earth in orbit around the sun. (Because Earth's orbit is tilted by 1.3° relative to that of Jupiter, the alignments at opposition, conjunction, and quadrature are not always exact. They are defined more precisely as the times when the longitudes of the Sun and Jupiter differ by 180°, 0°, and 90°, measured along the ecliptic plane.)

because the planet is always low in the sky. Accounts of events on Jupiter are usually dated to the apparition, which will be written in the form 1990/91 when it bridges two calendar years.

The ellipticity of the planet's orbit also makes some difference to observations. At oppositions when it is furthest from the Sun (at *aphelion*), the magnitude is  $-2.3$  and the apparent diameter is 44 seconds of arc. At oppositions when it is closest to the Sun (at *perihelion*), the magnitude is  $-2.9$  and the apparent diameter is 50 seconds of arc. These perihelic oppositions fall in October, and as they also combine high altitude in the sky with a reasonable chance of good weather for northern hemisphere observers, these apparitions tend to be the best observed of all.

If you have a telescope of only 5 cm aperture, you will be able to see the main belts. A 7.5-cm telescope will reveal the largest spots and irregularities, and the shadows of the satellites. A 15-cm telescope will show enough detail for useful observations to be made. A 25- or 30-cm telescope will show most of the important features of the planet.



1.2 HISTORY OF VISUAL OBSERVATION

The first person to look at Jupiter with a telescope was Galileo Galilei, in 1610 January (Fig. 1.5). His telescope was too small to show anything on the planet itself, but he could see the four moons. It was this discovery that convinced him that the Earth was not the centre of all motions in the universe. He described his discovery in *Siderius Nuncius* ('Message of the Stars'), published in 1610 March, declaring on the title page that he was:

Revealing great, unusual, and remarkable spectacles . . . above all in FOUR PLANETS swiftly revolving about Jupiter at differing distance and periods, and known to no one before the Author recently perceived them and decided that they should be named THE MEDICEAN STARS.

(Nowadays, anyone can see them with a pair of binoculars, and they are named not after the princes Medici who were Galileo's patrons, but after the discoverer himself: the Galilean moons.) He described them thus:

On the seventh day of January in this present year 1610, at the first hour of night, when I was viewing the heavenly bodies with a telescope, Jupiter presented itself to me; and because I had prepared a very excellent instrument for myself, I perceived (as I had not before, on account of the weakness of my previous instrument) that beside the planet there were three starlets, small indeed, but bright. Though I believed them to be among the host of fixed stars, they aroused my curiosity somewhat by appearing to lie in an exact straight line parallel to the ecliptic, and by their being more splendid than others of their size. Their arrangement with respect to Jupiter and each other was the following:

East            \*            \*            O            \*            West



Fig. 1.5. Galileo Galilei. (From the frontispiece to his collected works; by courtesy of the Institute of Astronomy, Cambridge.)

[Observing them over the next three nights, he found that they moved to and fro around Jupiter, and on Jan. 13 he first saw four moons at once . . .] I had now decided beyond all question 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 similar occasions which followed. Nor were there just three such stars; four wanderers complete their revolutions about Jupiter . . . the revolutions of these planets are so speedily completed that it is usually possible to take even their hourly variations. (Galileo, 1610; translation by Drake, 1957)

Discovery of features on the planet itself had to wait for several decades while telescope optics were gradually improved.<sup>2</sup>

The banded appearance of the disc was first described by Niccolo Zucchi in 1630, and soon confirmed by other Italians (Fig. 1.6). The transits of satellite shadows were first seen by G. Riccioli about 1643.

The earliest reported sightings of true spots were in 1664 by Robert Hooke in England and in 1665 by Guiseppe Campani of Rome. (Campani was famous as the best telescope maker of his day.) These spots revealed for the first time the rotation of the planet. The reports consisted simply of two paragraphs in the very first issue of the *Philosophical Transactions* of the Royal Society of London (1665), viz.:

Campani affirms he hath observed by the goodness of his glasses certain protuberancies and inequalities, much greater than those that have been seen therein hitherto. He addeth, that he is now observing whether those sallies in the said planet do not change their scituation; which if they should be found to do, he judgeth that Jupiter might then be said to turn

<sup>2</sup> The 17th century observations were reviewed by Denning (1899), Antoniadi (1926), Chapman (1968), and Falorni (1987). The history of published observations of Jupiter up to 1878 was reviewed in detail by Hockey (1989). See also original descriptions by Cassini (1666, 1672).

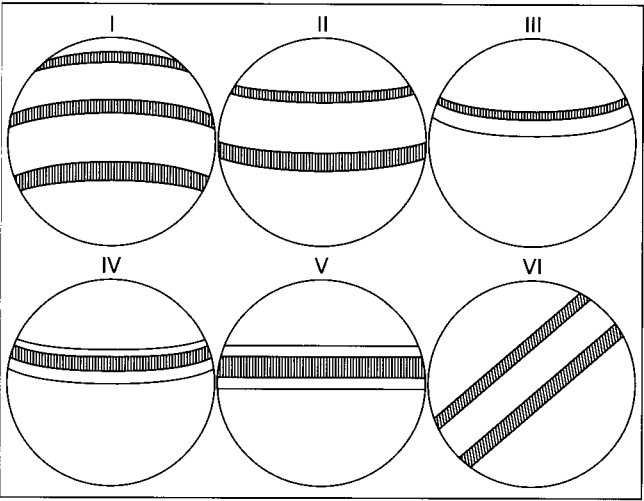


Fig. 1.6. First observations of Jupiter's belts. Drawings by Italian Jesuit priests, from *Almagestum Novum* by Father Riccioli (1651). I: 1639 (Fontana, at Naples). II: 1644 (Zupo, at Naples). III,IV,V: 1643 (Grimaldi, at Bologna). VI: 1648 (Grimaldi, at Bologna).

upon his Axe, which, in his opinion, would serve much to confirm the opinion of Copernicus [which however was considered to be that the moons dragged the planet round!]. Besides this, he affirms, he hath remarked in the belts of Jupiter the shaddows of the satellites, and followed them, and at length seen them emerge out of his disk.

The ingenious Mr. Hook did, some moneths since, intimate to a friend of his that he had, with an excellent twelve-foot [focal length] telescope, observed, some days before he then spoke of it (viz. on the 9th of May 1664, about 9 o'clock at night) a small spot in the biggest of the three obscurer belts of Jupiter, and that, observing it from time to time, he found that, within two hours after, the said spot had moved from east to west, about half the length of the diameter of Jupiter.

It is commonly assumed that this spot of Hooke's was the same as the long-lived dark spot followed by G.D. Cassini from 1665 to 1694. This claim was made in *Phil.Trans.* at the time and supported by the Royal Society thereafter; but this support may have owed something to Hooke's senior position, not to mention his notoriously argumentative and jealous character. The claim is inconsistent with Hooke's actual description quoted above, which seems to place the spot in the North Equatorial Belt.

The 'permanent spot', which may be identical with the present Great Red Spot, was first recognised by Giovanni Domenico Cassini in Italy in 1665. In fact the first sighting, on 1665 July 9 alongside the shadow of Ganymede, was by Cassini's friend and instrument maker (and Campani's rival), Eustachio Divini of Rome. But it was Cassini who identified it as a fixed feature and followed it on and off for many years thereafter. It was a large dark oval spot in the STropZ, but it seems to have been smaller than the present GRS (though its form cannot have been clearly observed with the primitive optics of the time). Its rotation period of just under 9h 56m was much slower than the present GRS has ever shown.

Cassini began his Jupiter researches in Italy, determining rotation periods, but carried out most of his work at Paris, as Director of the newly-built Royal Observatory of Louis XIV (Figs. 1.7–9). Among his many important researches on the solar system, he began the serious visual study of Jupiter. The telescopes of that time were bizarre contraptions with lenses of extremely long focal length, typically suspended on a mast, with the eyepiece in a separate framework that had to be guided to follow the planet. This arrangement was needed to overcome the problems of chromatic and spherical aberration that plagued lenses of shorter focal length. (At that time, neither achromatic lenses made of two pieces of glass, nor reflecting telescopes, had not yet come into use.)

Cassini discovered not only Jupiter's 'permanent spot', but also its equatorial current, its polar flattening (codiscovered by Picard), and its limb darkening (with his nephew Maraldi). He noted changes in the widths of the belts, and the birth and evolution of bright spots, and he realised that these must be clouds in a substantial atmosphere.

When the Great Red Spot was recognised in 1879, it was soon suggested that it was a rediscovery of Cassini's spot, and this has often been quoted as fact. But the identity of the two spots is by no



Fig. 1.7. Jean-Dominique Cassini. (From the Observatoire de Paris.)

means certain. There were no observations of any such feature between 1713 and 1831 – an apparently unbridgeable gap.

In the eighteenth century, few astronomers paid any attention to the surface markings of the planets. Newton's theory of universal gravitation set the agenda of astronomy for over a century; the main aim was to measure positions and movements of planets, stars, and comets with ever-increasing accuracy, and so to work out the dynamical structure of the universe. Even when planetary surface observations were made it was mainly to determine accurate rotation periods.

William Herschel (1781) published sketches and timings of spots on Jupiter in 1777–1778, but abandoned the planet on finding that the rotation periods were diverse and variable; for his purpose of providing a check on the constancy of the rotation of the Earth, he turned to observations of Mars instead.

The most assiduous work was done in Germany. Johann H. Schröter, a magistrate in Lilienthal, observed from 1785 to 1797, and published his reports in 1788 and 1798 with woodcuts showing belts and dark spots (Figs. 1.10–12). He re-observed the Equatorial Current and discovered the North Tropical and South Temperate Currents, and noticed yellow colouring in the Equatorial Zone.

Samuel Heinrich Schwabe in Dessau trained as an apothecary but then became a full-time astronomer, and his decades of meticulous sunspot observations revealed the solar cycle for the first time.



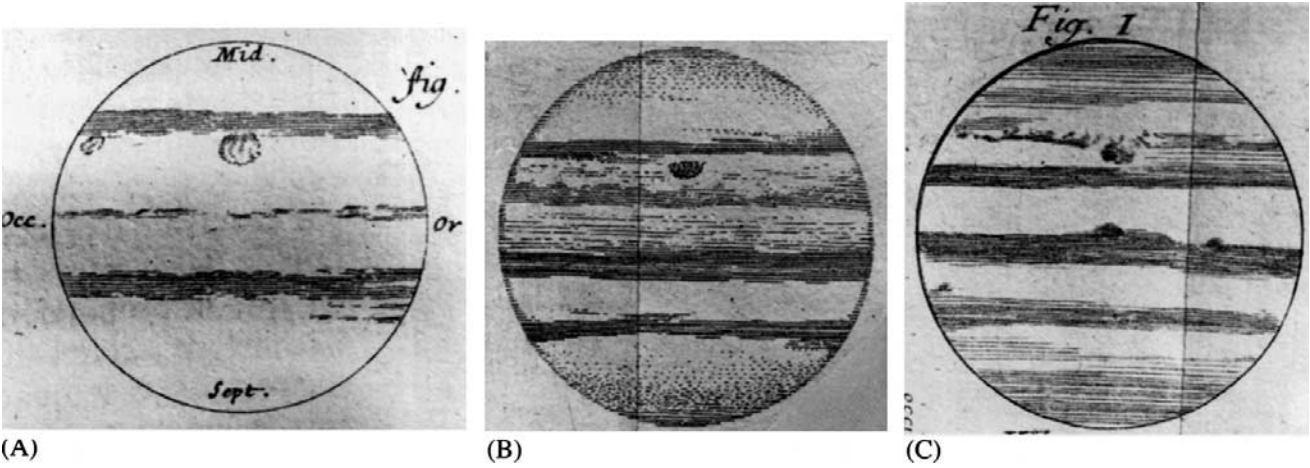


Fig. 1.8. Drawings of Jupiter by Cassini, including the ‘Permanent Spot’. A: 1672 January; B: 1677 July; C: 1691 January. South is up. (From *Memoires de l’Académie Royale de Paris*, tome 10; reprinted from Falorni (1987); by courtesy of M. Falorni.)

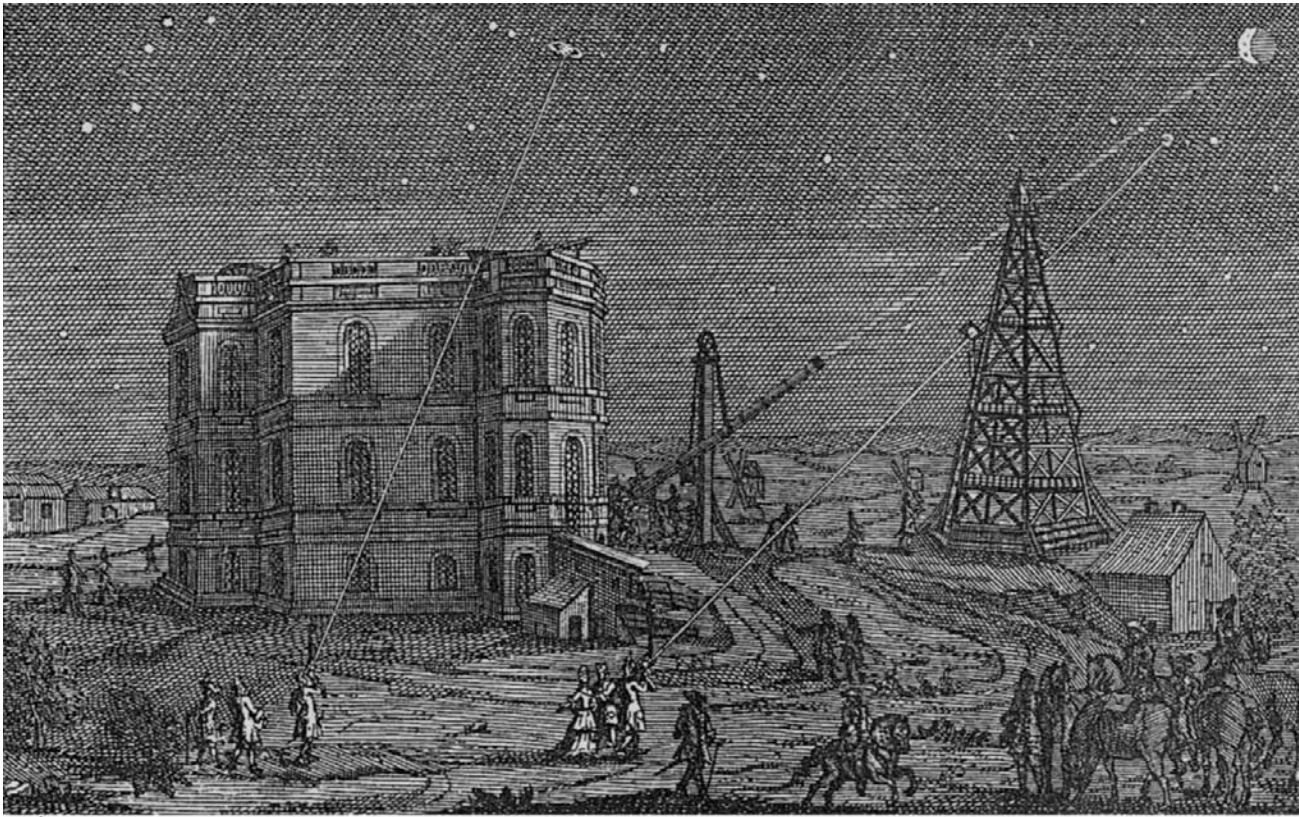


Fig. 1.9. Paris Observatory in the early 18th century. (From *Tables astronomiques du Soleil, de la Lune, des planètes...* by J.J. Cassini (1740).)

He also drew Jupiter from 1827 to 1865, several times a year on average, carefully recording the surface features; it was in his drawings of 1831 that the Great Red Spot, or rather the ‘Hollow’ that it impresses in the South Equatorial Belt, was first recorded (Plate P1). (Most of his material is unpublished, in the archives of the Royal Astronomical Society.) In 1843, Franz von Paula Gruithuisen, a professor in Munich, published drawings showing the changes in the major belts from 1836 to 1843. In the 1860s,

Julius Schmidt, director of the Athens Observatory, confirmed the same currents that Schröter had recorded. In England, the Rev. William Rutter Dawes and William Lassell began their noted planetary observations in the 1840s. From 1857 onwards, more observers with good-quality reflecting or refracting telescopes began to take interest in the markings on Jupiter, and many detailed and beautiful drawings began to appear in the *Monthly Notices of the Royal Astronomical Society*, *Astronomical*





Fig. 1.10. Johann H. Schröter. (Painted from a copperplate of 1791; by courtesy of Dieter Gerdes, Schroeter Museum, Lilienthal.)

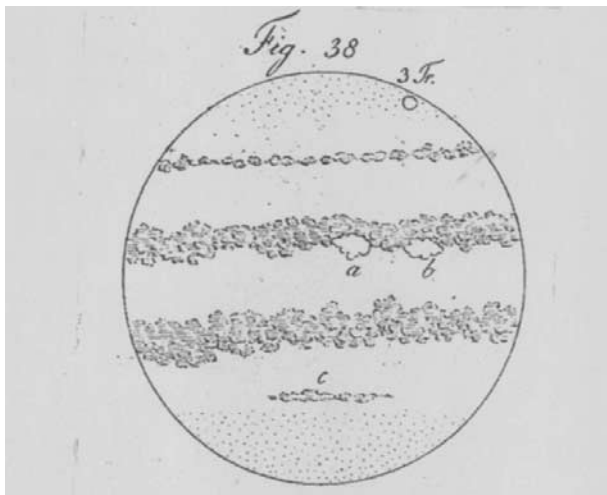


Fig. 1.11. Drawing by Schröter in 1796/97. South is up. (From Schröter, 1798.)

*Register*, and later in *The Observatory* – at least in the years when the planet was at high altitudes for British observers, around 1857–1860, 1869–1872, and 1879–1883. Interest was maintained by the fortunate occurrence of striking phenomena in these favourable apparitions, so these years saw the discovery of equatorial coloration episodes, South Temperate ovals, and the NTBs jetstream. Other features recorded in these years can now be recognised as revivals of the South and North Equatorial Belts, and South Tropical Disturbances. (See Plates P1–P3 and P12.)

Most striking of all, in 1878–1881, was the emergence of the Great Red Spot. This enormous and vividly red marking, which was unlike anything seen before, attracted so much attention from astronomers worldwide that the planet was never again to be left unobserved.

There was also a technical reason for the great upsurge of observations around this time: the invention, in the mid-nineteenth century, of silver-coated glass as a material for telescope mirrors. Compared with the previous mirrors ground from the ‘speculum’ metal alloy, silver-on-glass mirrors (or aluminium-on-glass mirrors, as are now used) were cheaper, lighter, more reflective, and easier to maintain. Thus good telescopes came within the reach of amateurs with only moderate financial means.

The physical nature of the planet was an open question in the nineteenth century. Early astronomers tended to assume, for lack of contrary information, that the planets were like the Earth with a solid surface and atmosphere. Indeed, there was a widespread feeling that the planets, as creations of divine purpose, must be inhabited by intelligent beings. So the presence of clouds on Jupiter did not come as a surprise; the question was whether any markings represented a solid surface. At one extreme, the planet was considered cold, the white markings being attributed to snow. Conversely many writers in the late nineteenth century, considering its low density, great brightness, and general turbulence, concluded that it was very hot, and perhaps even glowing like a feeble sun. Extensive parallels with the Sun were noted: the limb darkening, fast equatorial current, changeable spots in definite bands, and cycles of activity.<sup>3</sup> Fortunately, these theories do not seem to have had much influence upon the serious observers. The final outcome has been a compromise. The cloud-tops are indeed frigid, as was established in the 1920s; but the turbulence of the atmosphere is indeed powered largely by internal heat, as discovered in the 1960s. E.M. Antoniadi, writing in 1926, was not far wrong:

Thus the idea that Jupiter is a chilled sun, like the other planets, conforming to the cosmogonical hypothesis of Laplace, seems the only one admissible. Its temperature is closer to that of the Earth than to that of the Sun; and perhaps it is not totally lacking its own light. However all that does not get us much further; for, even if the material is the same on that world as this, the conditions of temperature are so different that the nature of its phenomena, like those of the Sun, is inaccessible to us. (Author’s translation.)

By the 1880s, it was apparent that different latitudes showed different rotation periods, implying a regular pattern of winds, and so a major observational aim was to determine this pattern in detail. This task was made easier when longitude systems were defined and tables of central meridian longitudes published, by A. Marth (routinely referred to as Marth’s Invaluable Ephemerides). The definitions of Systems I and II were stabilised by Marth in 1892.

A total of nine currents or jetstreams were known when A.S. Williams made the first systematic listing in 1896. He had himself measured many of these currents in 1887 and 1888 (published in 1889, 1909). But measurement of currents was first done exten-

<sup>3</sup> Readers interested in the knowledge and opinions about the planet at various historical times may enjoy reading the reviews by: Green (1887), Hough (1905), Kritzing (1914), Phillips (1915), Denning (1923), Antoniadi (1926), and Wildt (1969). For reviews just before spacecraft arrived, see Newburn and Gulkis (1973) and the special issue of *Journal of Atmospheric Science*, vol.26 (no.5.I) (1969 September).



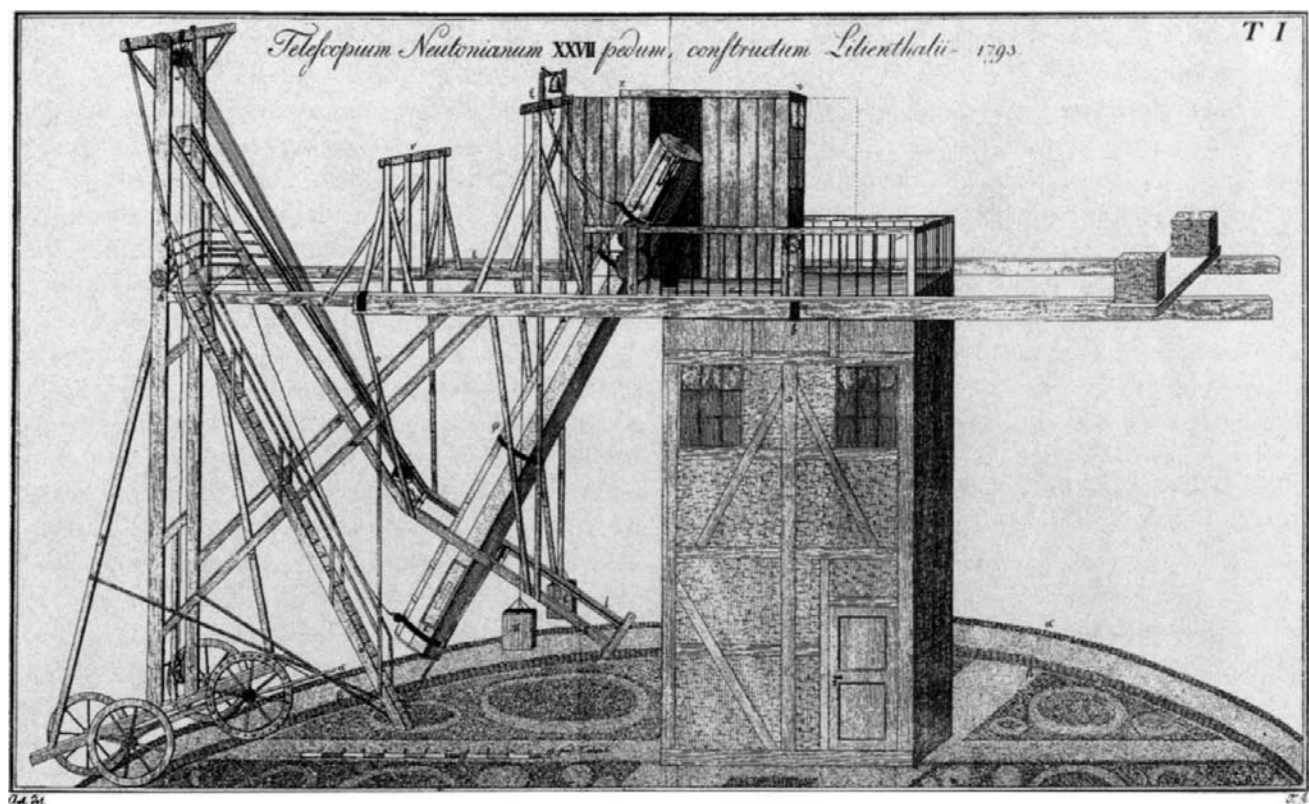


Fig. 1.12. Schröter’s great reflector of focal length 27 feet (8.2 metres), used for his later Jupiter observations. (His earlier observations were made with a Herschel reflector of focal length 7 feet, 2 metres. From

*Aphroditographische Fragmente* by Schröter (1796); by courtesy of Richard Baum.)

sively in 1898, by W.F. Denning, P.B. Molesworth, J. Gledhill, and T.E.R. Phillips. They measured longitudes simply by estimating the time at which spots crossed the central meridian – the imaginary line down the centre of the disc.

Several of these English gentlemen were memorable individuals. A. Stanley Williams was professionally a solicitor, and in his spare time a keen yachtsman. Although his observations were made with a mere 6½-inch (16.5-cm) reflector, he will figure repeatedly in this book for his systematic records both of drifts and of colours on Jupiter. William F. Denning, an accountant, persevered with astronomy despite his lack of private funds and, in later years, poor health; he laid the foundations of meteor astronomy as well as recording Jupiter’s currents. Captain P.B. Molesworth (later Major; Fig. 1.13) was stationed with the Royal Engineers in Ceylon (now Sri Lanka). Viewing the planet at high elevation in the clear tropical skies with a 12½-inch (32-cm) reflector, he was the most indefatigable measurer of longitudes; in 1900 he recorded 6758 central meridian transits! And the Rev. T.E.R. Phillips (Fig. 1.14), one of a distinguished line of Anglican clergymen who became famed for their researches in natural science, would later become the greatest director of the BAA Jupiter Section.<sup>4</sup>

<sup>4</sup> One should also note the drawings from the 1880s by Nathaniel E. Green, a much-travelled professional artist and art teacher (whose pupils once included the royal family). The RAS published his Jupiter Memoir in 1887. Noting that it had once been said of him that he preferred an artistic drawing to a correct one, he replied ‘I know of no difference between the two’. The 18-inch (46-cm) reflector used by Green was the same one later used by Phillips.



Fig. 1.13. Major P.B. Molesworth. (From *Memoirs of the BAA*, vol. 16 (1910).)

Thanks to their work, by 1901 all the now-recognised slow currents had been recorded, as well as the equatorial and North Temperate jetstreams.

The distinction between amateurs and professionals was increasing in the late nineteenth century. This led to the founding, in 1890, of the British Astronomical Association (BAA), as an offshoot of the Royal Astronomical Society catering especially for amateurs. This was the start of a long, systematic, and fruitful study of Jupiter which continues to the present day. The BAA Jupiter Section's first director was the Rev. W.R. Waugh who, at the age of 72, published its first Memoir for the apparition of 1891. (The present names of the belts were defined in the second Memoir, for 1892.) The BAA Memoirs continued in an unbroken series until 1943, and reports have also been produced for almost every apparition since, either in the BAA Journal or as occasional Memoirs (Appendix 3).

In reviewing the work of observers in those years, one has to bear in mind that people differed in their abilities then as now. Some observers, though good at certain observations, may be unskilled as artists, or inaccurate in timing transits, or uncritical in analysing them. It is the function of an amateur society to encourage interest among many members, but it is the function of a director of an observing section to assess the observations and to base the published report on those that are reliable. Further comments about the skills of some observers will follow as they pertain to particular topics. In spite of these comments, one must re-emphasise that the early visual observers were great and pioneering researchers, who applied their observing skills and their scientific instincts to establish a great deal of knowledge about the planet. Their work has stood the test of time.

The first BAA Memoirs were simply compilations of separate members' descriptions and drawings. Within a few years, measurements of rotation periods grew more numerous, particularly by Denning and Molesworth from 1898 to 1903.

The Rev. T.E.R. Phillips, as Director of the BAA Jupiter Section, in 1914 began to plot more reliable drift charts by combining the transits from all the best observers. Thus he commenced the detailed and rigorous analysis that distinguished the BAA Memoirs under his directorship (1901–1934) and that of his successor, Bertrand M. Peek (director 1934–1949; Fig. 1.15). Both men were also outstanding observers, and with F. James Hargreaves they formed a group who often observed together at Phillips' observatory at Headley, Surrey, where Phillips was rector of the church. Phillips was known as a most kind and unassuming man who was the natural leader in his field. Peek was a school headmaster at Solihull, and Hargreaves was a patent agent in Coulsdon, Surrey, who eventually became a professional telescope-maker. These three colleagues observed diligently with sizable reflectors, and persevered through the vagaries of the English weather so as to produce a thorough record of the activity on the planet. Peek rounded off his observing career by writing his book, *The Planet Jupiter*, published in 1958, which ever since has been the definitive work on the visible features on the planet.

After 1942, the BAA team was broken up by distractions and disabilities and deaths. Although the Section still included keen

observers (notably William E. Fox, a hydraulic engineer of Newark, Nottinghamshire, whose directorship from 1957 to 1988 occupied him during his years of retirement) they did not have the large telescopes and the intensiveness of observation to produce such detailed reports as in previous years. Some useful reports were published by European groups, and Japanese amateurs made some fine observations, but coverage was uneven. From 1949 to 1964, the most consistently good reports were from the American amateur group, the Association of Lunar and Planetary Observers, most of whose reports were compiled by Elmer J. Reese. Even these depended mainly on small apertures; so some smallscale phenomena, such as jetstream outbreaks, might have been missed during the 1950s. Reese initially worked in his family's grocery store, and used only a 6-inch (15-cm) reflector, but had a critical eye that enabled him to see much detail that was independently confirmed. In 1963/64 he joined the New Mexico State University Observatory as a professional astronomer, and inaugurated an era of professional photographic coverage of Jupiter.

1.3 METHODS OF VISUAL OBSERVATION

What can amateur astronomers do in the way of serious study of Jupiter? Much the same as they have done for a century – leaving aside for now the modern possibilities of photography and digital imaging. Visual observers can see what types of spots are present, how fast they move in the zonal winds, and what changes occur in



Fig. 1.14. The Rev. T.E.R. Phillips. (BAA.)