Part I

Views of Venus, from the beginning to the present day

Observations of Venus with the naked eye as a prominent planet or 'wandering star' were recorded by the Babylonians around 3000 BC, and have continued ever since. All the major civilisations have contributed knowledge and myth to a recondite and, until recently, quite abstruse concept of our nearest companion in space beyond the Moon. With the invention of the telescope in about 1610 it became clear to Galileo that Venus shone in reflected light from the Sun and had phases like the Moon, leading eventually to an understanding that Venus is not any kind of star, but an Earthlike object, one that orbits closer to the Sun than we do. The presence of an atmosphere on Venus, filled with cloud that veiled the entire planet at all times and prevented the observation of surface features, was recognised and refined from the 1760s onwards, and the principal composition of the atmosphere was established in the 1930s.

Most of what we now know about our planetary neighbour has come from observations by spacecraft that flew to the planet and collected data during flybys, from orbit, or in a few cases during descent to the surface on parachutes. This phase of exploration began in 1962 and has continued fitfully up to the present, including one spacecraft, *Venus Express*, still operating in orbit around the planet at the time of writing (February 2014). A complete list of missions to Venus is given in Appendix A, and the outline description of the planet that has been gleaned from these, and from ongoing observations with telescopes on the Earth, is summarised in Appendix B.

This first section of the book elaborates on these early studies and sets the scene for the discussion in Part II of the most recent work, including studies carried out by space missions to Venus from Europe and Japan, as well as the pioneering ventures from Soviet Russia and the United States. The progress made shows Venus is indeed Earthlike, but with many features that are curiously different and some that remain difficult to explain even after 5,000 years of observing and wondering.

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Excerpt
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Chapter 1
The dawn of Venus exploration

The Evening Star and the Morning Star

Everyone has seen Venus, as a bright, starlike apparition in the evening sky, following the Sun down towards the horizon and setting a few hours later. At various other times of the year, there comes a brief season where an early bird can see Venus rise brilliantly before the Sun, climbing higher until it seems to dim and vanish as the sky brightens after sunrise. When it rises before the Sun, people have long called Venus the Morning Star; half an orbit later, when on the other side of the Sun so that the Sun sets first, Venus is the Evening Star. Before Copernicus promoted the idea that planets orbit the Sun, it was not obvious that these two phenomena were the same body, and early civilisations had distinct names for them. To the Greeks, they were Phosphoros and Hesperos.

For much of the year, Venus sets and rises so near the Sun that we tend not to notice it. During the day, like the true stars at vastly greater distances, Venus is still overhead and just as bright, of course, but it is hard to see because the contrast with the dark sky is lost when the Sun is up. It can be studied during the day if a telescope is used to shut out most of the sunlight, and even with ordinary binoculars if you know where to look.[1] In any observations made over a period of a few months, Venus can be seen to exhibit lunarlike phases (Figure 1.1).

As viewed from the Earth, Venus traces a flattened 'figure eight' pattern with the Sun at the centre (Figure 1.2). Sometimes, but rarely, Venus travels across the disc of the Sun when at its closest to the Earth, or behind the Sun when at its farthest, and we witness a transit.

At closest approach to the Earth (inferior conjunction), not only is Venus near the Sun in the sky, making viewing difficult, but also the side facing us is dark (Figure 1.2). A fully illuminated disc can be seen, again with difficulty, only when Venus is on the far side of the Sun, at so-called superior conjunction.

[1] There are also reports of Venus seen with the naked eye during the day. The most famous of these involved Napoleon Bonaparte, whose attention was called to the phenomenon while he was delivering an open-air, midday address to a crowd in Luxembourg in 1796. A similar apparition was reported in Washington DC on the day of Abraham Lincoln's second inauguration in 1865.

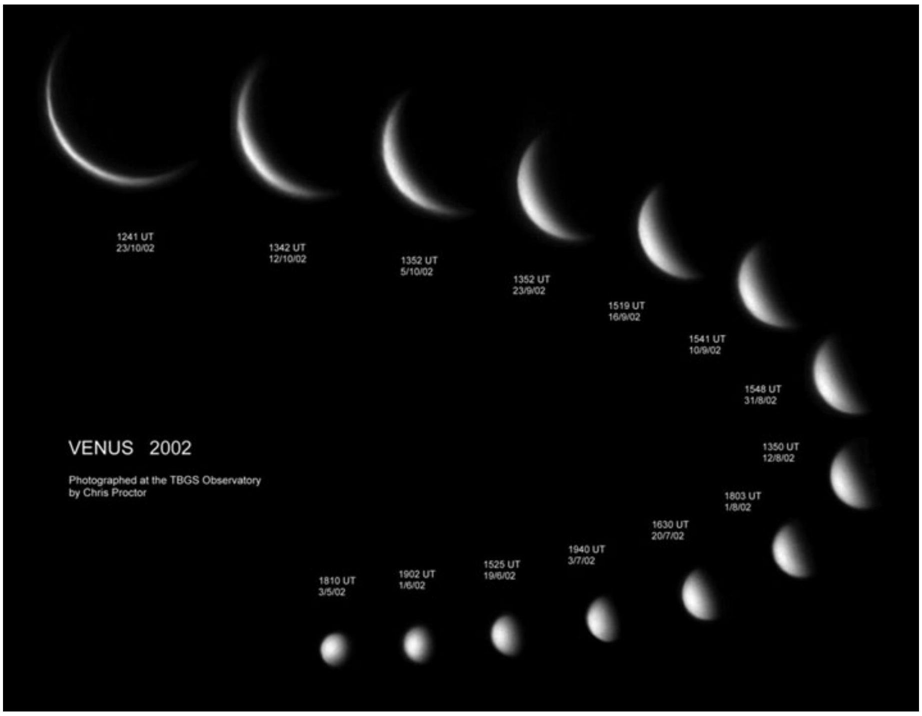

Figure 1.1 Venus at different points in its orbit, showing the phases from near superior conjunction (beyond the Sun, at bottom) to near inferior conjunction (closest to Earth, top).

The time between sunset and Venus's disappearance below the horizon, and vice versa, is greatest when it appears at its greatest separation from the Sun, called opposition, and viewing conditions are usually best then. However, the time when Venus appears brightest to us is not in fact exactly at opposition, but halfway between opposition and inferior conjunction, when the trade-off between size of the disc and the portion illuminated, what astronomers call the phase, is optimum.

Because it is at times such a brilliant object, Venus has been observed since the earliest times and used as an object of veneration[2] and as a celestial calendar by many early civilisations, most notably the Mayans in South America. There has been some interesting debate as to whether pre-telescopic observers could see the crescent shape of Venus with the naked eye. Written references to 'horned Venus' and implications that some symbolic crescents in art and heraldry might relate to Venus rather than the Moon would seem to support this idea, but the difficulty we have in achieving the feat today suggests otherwise (Plate 2).

The angle between a line from the observer on Earth to the centre of the Sun, and the corresponding line to Venus, is never more than 47.5 degrees (Figure 1.2). So, when the Sun is just set and our eyes are shielded from most of its light, allowing Venus to appear

[2] Nowadays of course most frequently associated with the Roman goddess of love, from whom the planet takes its modern name (Plate 1).

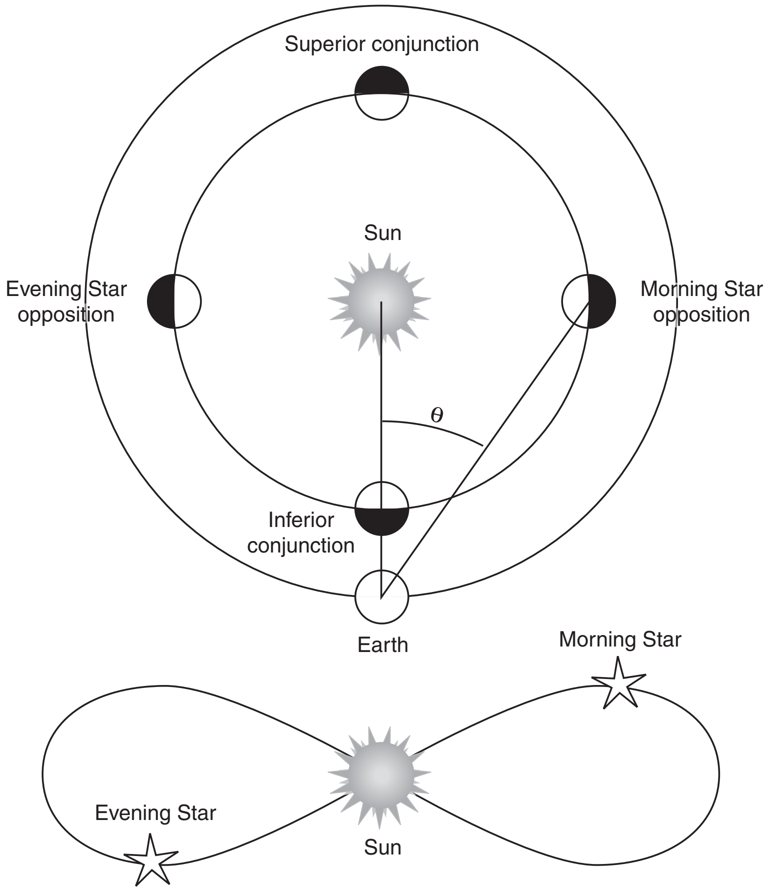

Figure 1.2 The orbits of Venus and Earth seen from above (top), and the apparent motion of Venus in the sky as viewed from Earth (below). It appears brightest at the points marked by stars, while approaching maximum elongation (i.e. the greatest apparent distance from the Sun). At that time, through a telescope it has the appearance of a crescent, as illustrated in Figure 1.1.

brightly, the planet is never more than halfway between the horizon and the zenith, that is, its elevation is always in the lower half of the sky. Mercury rises only half as far as Venus. The earliest recorded interpretation of these easily and much observed facts as meaning that Venus and Mercury orbit the Sun, and not the Earth, was made by Heraclides around 350 BC. Also in Greece, around 70 years later, Aristarchus surmised that the Earth, and everything else in the Universe, did the same.

The idea that the Earth was not the centre of the universe was too radical in those days, especially for the clerics, and of course was reluctantly accepted only much more recently. The breakthrough came in the early 1600s when the arrival of even very crude telescopes soon had Galileo following Copernicus and proclaiming the phases of Venus as a Moonlike phenomenon ('Cynthiae figuras aemulatur mater amorum') and making the heretical deduction that Venus must orbit the Sun. Not only that, but the 'Morning and then Evening' Star behaviour and the crescent phases must occur because Venus, and the much-dimmer and less well-observed Mercury, orbit closer to the Sun than the Earth. The other planets, which behave quite differently in the sky, lie outside the Earth's orbit.

In particular this must be true of the fourth member of the inner planet family, Mars. Mars is our second-nearest planetary neighbour, but Venus is larger (nearly as large as the Earth, see Plate 3) and significantly closer. Venus also has more cloud cover than the other three inner planets, not excluding the Earth, which makes its visible surface more reflective.[3] These three factors – size, proximity and albedo – explain why Venus can appear so bright.

Once it became an accepted principle for heavenly bodies to orbit the Sun and each other, it also became logical to wonder whether Venus had any satellites. It has been pointed out that if Venus had a moon on the same scale as the Earth's, it would be easily visible to the naked-eye observer here, including, of course, the ancients.[4] Under optimum conditions, the Venusian moon as seen from the Earth would be separated by more than a solar diameter from its parent in the night sky, and would be as bright as Saturn. Asimov points out that this obvious demonstration of one planetary-sized object orbiting another would have had a profound effect on the philosophers who pondered the nature of the universe, comparable to that after Galileo's observation of four large moons of Jupiter following the invention of the telescope. The Copernican revolution might have come thousands of years sooner, and Galileo might have been spared persecution, amongst many other consequences.[5]

Transits: Venus crosses the disc of the Sun, but rarely

If Earth and Venus orbited in exactly the same plane, we would see the disc of Venus as a dark spot crossing the Sun (a 'transit') every time the planet reached inferior conjunction, that is every 1.6 years, and then passing behind it 288 days later. However, the two orbital planes are tilted with respect to each other at an angle of 3.4 degrees, and this, plus the timing of the alignments of the three bodies in a straight line, means that transits are actually quite infrequent phenomena. Most of the time, Venus passes above or below the solar disc as seen from Earth.

About once a century, however, the path traced by Venus does cross the Sun, and then it does so twice in eight years, once in the upper and once in the lower solar hemisphere, as it moves from above the Sun to below, or vice versa. The pattern repeats every 243 years, with pairs of transits 8 years apart separated by gaps of 121.5 years and 105.5 years, the most recent pairs being in June 2004 and June 2012 (Plate 4). Before that, they were in December 1874 and December 1882, while the next will not take place until December 2117 and December 2125.

[3] Cloudy Venus has an albedo (from the Greek meaning 'whiteness') of about 0.76, which means it reflects all but 24 per cent of the sunlight that falls on it. Mars, by contrast, has little cloud cover and most of the reflected radiation comes from the relatively dark, rocky surface. The result is an albedo of only about 0.2. Earth is somewhere in between, with partial cloud, ice and ocean cover which together deliver an albedo in the region of 0.3.

[4] By Isaac Asimov, for example, in *The Tragedy of the Moon* (London, 1975).

[5] By an unusually, for him, arcane argument, Asimov suggests that these consequences would also mean that mankind nowadays 'may well be approaching the end of its days as a technological society' (ibid., pp 15–26).

The reason for this somewhat bizarre pattern of events has to do with the orbital periods of both planets, as well as their inclinations. It takes 243 years for Earth and Venus to return to the same relative positions because Venus travels around the Sun exactly 395 times in that many Earth years. A second orbital resonance, also probably coincidental, has thirteen Venus orbits in almost exactly eight Earth years, giving the eight-year separation of transits when the line from Earth to Venus at inferior conjunction intersects the Sun.

Other factors, such as the eccentricity[6] and precession[7] of both orbits, complicate the calculation, so the task of determining the timing of transits accurately is best done on a computer. Johannes Kepler attempted some predictions as early as 1627, but although he got the year of the next Venus transit right (1631), he did not realise that it would not be visible in Europe, nor that another was to come eight years later that would be. Improved calculations by Jeremiah Horrocks led him to make observations of the transit in 1639, from which he estimated the size of Venus and computed the first modern value of the distance from the Earth to the Sun,[8] allowing a scale to be put on the rest of the Solar System using Kepler's laws of planetary motion.

Later observers, most famously those travelling with Captain Cook on his first voyage around the world at the time of the transit of 1769, used the method derived by Edmond Halley (Figure 1.3) to get an improved value for the astronomical unit by simultaneous measurements from widely separated baselines on Earth.[9] Cook's observations (Figure 1.4)

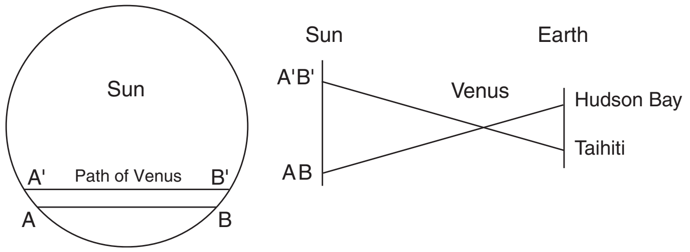

Figure 1.3 Halley's method for determining the Earth–Sun distance (1 AU) by observations of the transit of Venus across the solar disc from two widely separated locations on Earth. The observers measure the separation AB to A'B' as accurately as possible from the time taken for Venus to cross the solar disc in both cases, and use the fact that the Sun–Venus distance is 0.723 AU as determined from Venus's orbital period using Kepler's third law.

[6] The eccentricity of an orbit is a measure of its departure from a perfect circle, something which changes slowly over long periods of time. The current values for Earth and Venus are 0.0167 and 0.0068, while a circle is of course 0.0000.

[7] 'Precession' refers to how the alignments of the two non-circular orbits vary with respect to each other under the influence of gravitational perturbations from other large bodies, especially the Sun and Jupiter.

[8] Horrocks's result for the Earth–Sun distance, published after his premature death in 1641 aged only 22, was 'at least 15,000 semidiameters of the Earth'. This corresponds to a lower limit of about 60 million miles, much larger than generally believed at the time, and highly controversial, but still about 30% smaller than the modern value.

[9] The mean Earth–Sun distance is known as the Astronomical Unit (AU), so called because the scale of the Solar System could be estimated in AU well before the distances between the planets were known in absolute terms.

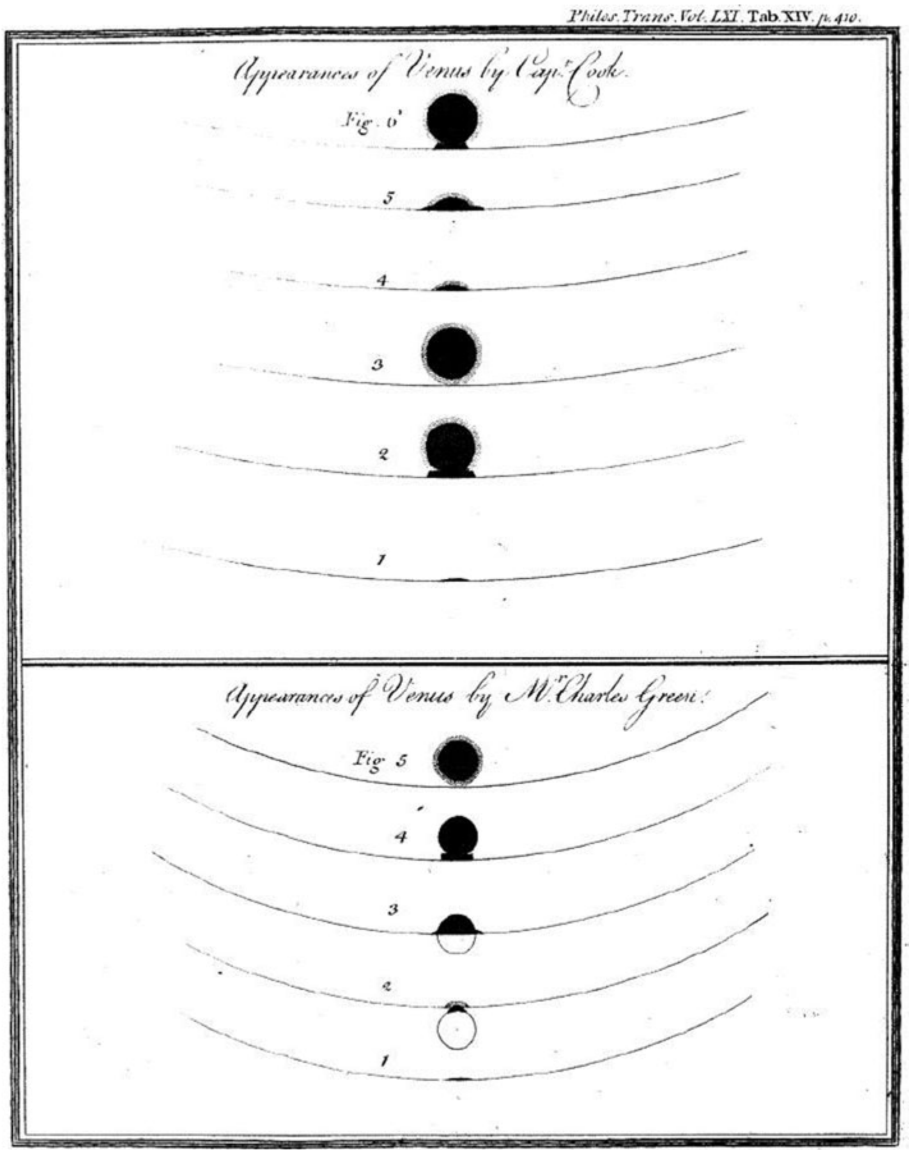

Figure 1.4 Captain Cook's drawing of the Venus transit of 1769.

from his base at Venus Point (still so called) in Tahiti, combined with others in Norway and Canada, yielded a value for the Earth-Sun distance of '93,726,900 English miles', which is correct to better than 1 per cent.

Early observations: another planet with an atmosphere

Dark, blotchy features on the disc of Venus had been reported by Cassini as early as 1666, and by other astronomers at various times since. When they thought they had seen something, it was generally assumed that these features were on the surface, or perhaps the combined effect of patches of cloud moving over the visible surface. Today, credit for discovering the atmosphere of Venus is generally given to a Russian observer, Mikhail Lomonosov, who recorded in the journal of the observatory at St Petersburg that the disc of Venus showed a halo during the solar transit of 1761. From this he deduced that the planet 'is surrounded by a considerable atmosphere, equal to, if not greater than, that which envelops our earthly sphere'.

At various times in the 1790s, the German astronomer Johann Schroeter reported observations of diffuse and variable markings on Venus, which he attributed to atmospheric phenomena. These markings may not have been real, but the limb darkening and the extension he saw of the 'horns' of the crescent Venus right around the planet probably were, and are also indications of a substantial atmosphere. Writing in 1793, William Herschel reported from his own observations of 'faint and changeable spots' that it was evident that Venus 'has an atmosphere'. These changes led him also to report that the fact that 'Venus has a motion on an axis cannot be doubted', although they 'surely cannot be on the solid body of the planet'. Indeed they are not.

Observations of surface features

As telescopes got better, and observers strained to see features on Venus that could tell them something about the nature of the nearest planet, reports of various phenomena filtered into the journals of professional scientific societies around the world. In the second half of the nineteenth century, these included occasional bright spots that were sometimes inferred to be snow-covered mountain peaks catching the sunlight. Bright polar caps were also seen by a large number of highly reputable astronomers using the latest instruments, and generally assumed to be icy like those on Earth and Mars. Today, transient bright clouds are seen on Venus from orbiting spacecraft and also from the Earth, and there is a spirited debate as to their cause, the two most popular theories being volcanic plumes or some as yet unexplained meteorological phenomenon. The polar caps are certainly present as well, but as semi-permanent features in the cloud cover, rather than ice on the surface. Whether the Victorian astronomers actually saw these through their telescopes is debatable; nowadays we require special photographic observing techniques not available before the 1920s.

In the summer of 1886, Percival Lowell, soon to become notorious for his interpretation of features seen on Mars as canals built by an intelligent civilisation, turned his new, state-of-the-art 24-inch refracting telescope on Venus. He had used his considerable wealth to build this facility on Mars Hill near Flagstaff, Arizona, in order to make better observations of the red planet and the civilised artefacts that excited him so much. However, when the new observatory was commissioned, Mars was not well located in the night sky over Arizona, so he looked at Venus instead. The markings he saw (Figure 1.5) seemed sufficiently reproducible for him to become convinced that he was observing features on the surface, providing 'evidence for slowness of rotation'. Unlike his vision for Mars, he did not claim the features looked artificial, describing them as 'perfectly natural' and the result of 'rock or sand weathered by aeons of exposure to wind and sun'.

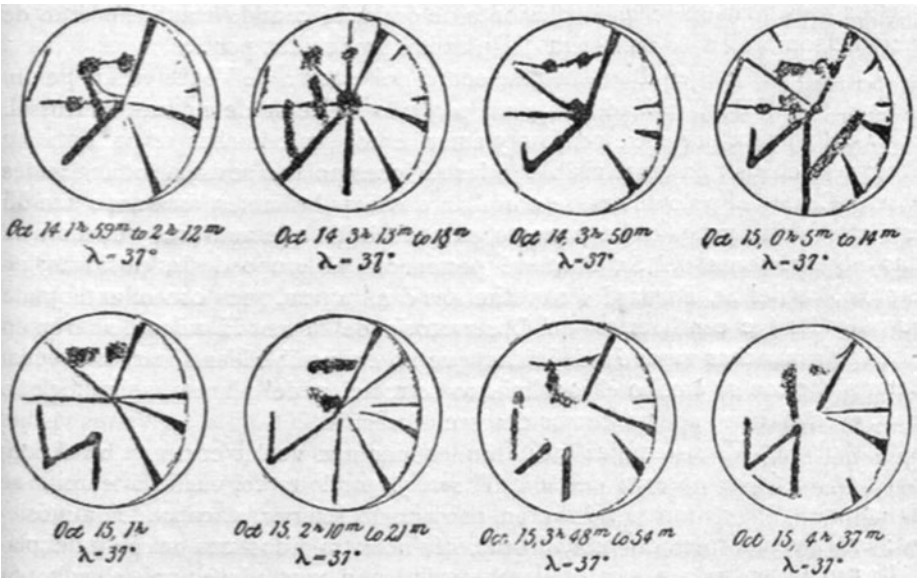

Figure 1.5 Sketches of Venus obtained by Percival Lowell from his observatory in Flagstaff, Arizona in August 1896, showing what he took to be surface features viewed through the 'brilliant straw-color veil' of Venus's atmosphere[10].

Other astronomers, including some of Lowell's own assistants using the same telescope, were sceptical, and reported that they could not see the features which Lowell described as 'perfectly distinct'. A plausible theory has been advanced which suggests that Lowell was observing the blood vessels in his own eye, reflected in the lenses of his telescope. He suffered, and in 1916 died suddenly, from high blood pressure, a condition that most likely made his retinal arteries more prominent than normal. This, plus his ambitious and excitable nature, may account for why Lowell thought he saw features on Venus that were invisible to others, and that we can now be certain do not exist.

The ashen light

One of the earliest discoveries about Venus was that the night side is not completely dark. Many observers, since the Jesuit priest Giovanni Riccioli of Bologna as long ago as 1643, have reported the emanation of a mysterious glow from the main disc when observing the planet at times when the sunlit side presents itself as a narrow crescent (Figure 1.6). The purported glow, which became known as the ashen light, is extremely faint and not always present even under good observing conditions. Some astronomers say they have

[10] This quote is from an article Lowell wrote in the German journal *Astronomische Nachrichten*, in 1897. There he went on to state emphatically that the markings on Venus were to him as distinct as those on the Moon, that they 'disclosed the rotation period unmistakably', and 'are not obscured at any time by clouds. In other words there are no clouds on the planet'.