Chapter 2
History of Venus Observations

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2.1 Knowledge of Venus Before the Space Age

Our image of Venus is that of a hellish, hot planet, permanently covered by fast-moving clouds, with its surface inaccessible to any Earth-based observer. But the perception and knowledge of our sister planet has been very different in the recent and more remote past.

Venus has been a prominent object in the sky since pre-historic times, being highly visible both at dawn and dusk. Also, contrary to many other planets, its apparent size did not change dramatically with time, due to a combined and inversely proportional effect of variable distance and phases (Goldstein 1972, and notes therein). In fact, the Latin name for Venus for its dawn appearance is lucifer (star carrying light) and for dusk, vesper (evening star), as derived from pre-existing Greek terms, respectively Phosphoros ($\Phi\omega\sigma\phi o\rho o\varsigma$) and Eosphoros ($E\omega\sigma\phi o\rho o\varsigma$).

Several ancient civilizations had knowledge of the existence of Venus, including, only to mention a few: Assyrians, who considered the planet under the rule of the Goddess Ishtar, Phoenicians (under the name of Astarte), Hindus (as Sukra), Greek, Roman and Mesoamerican peoples. A summary of the many different names attributed to Venus by various civilizations is provided by Grinspoon (1997).

Such clear visibility and awareness of Venus led to the creation of myths, stories and religious importance. As an example, the great importance attributed to Venus by Maya led them to precisely measure and predict its appearance in the sky.

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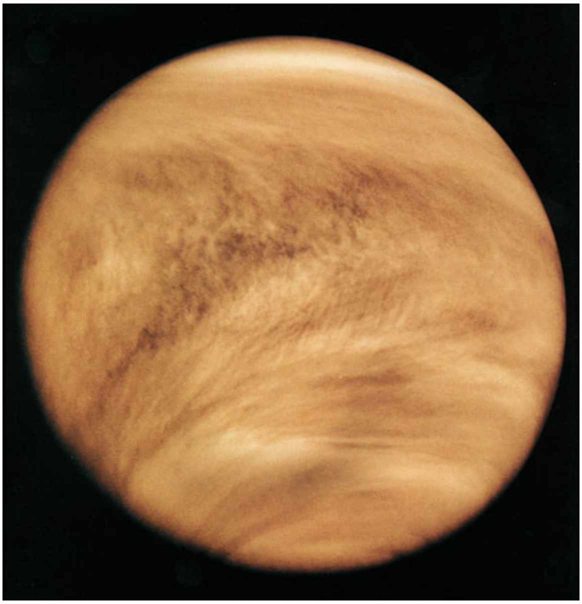

Fig. 2.1 Full disk image of Venus (from Pioneer-Venus, Credit: NASA/JPL)

Besides myths and stories, several accounts of astronomical observations and knowledge of Venus can be found among many different ancient peoples (e.g. Grinspoon 1997), including Babylonian, Greek and Mesoamerican such as the Aztecs, Mayans and Toltecs.

In the Middle Ages, Venus' position in the Ptolemaic system was considered below the Sun by Avicenna.

2.2 Telescopic Observations

Early telescopic observations of Venus, among other planets, were conducted by Galileo Galilei, who first measured Venus' phases in 1610 (e.g. Drake 1997; Palmieri 2001), determining its crescent disc shape and spherical geometry, confirming also its passage behind the Sun and thus validating Copernicus theory. Giandomenico Cassini observed Venus around 1666–1667 (Marov and Grinspoon 1998), detecting albedo variations, which, later in the eighteenth century were interpreted as possible continental and oceanic masses (Figs. 2.1–2.3).

Venus played a crucial role in measuring the distance between the Earth and the Sun, the so-called astronomical unit (AU): at its closest distance, the apparent disk of Venus, assuming to a first approximation the planet to have a size similar to that of the Earth, occupies an angle in the Sky of about 1 min of arc, from which it was possible to derive both the Venus-Earth and Earth-Sun distance, using Kepler's laws.

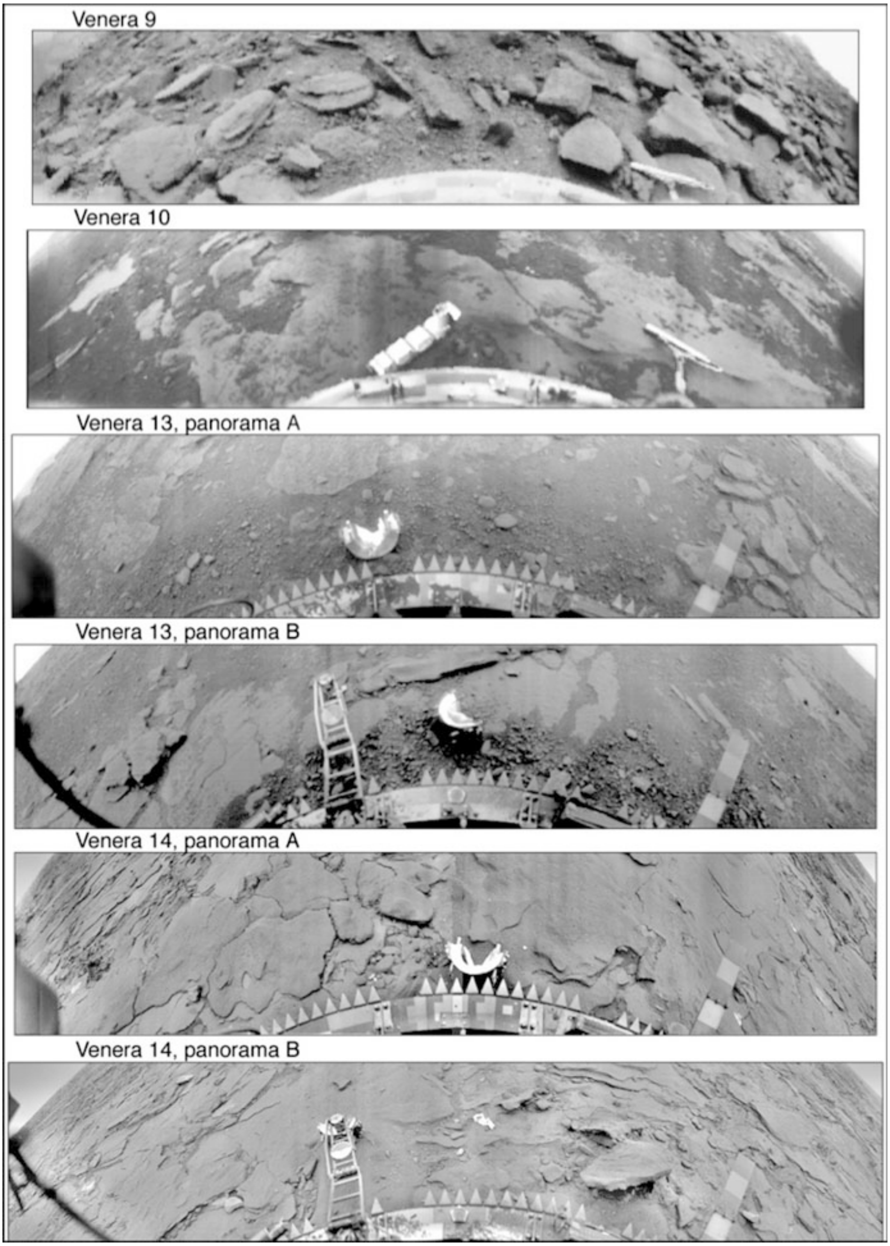

Fig. 2.2 Venera landings (Credit: Courtesy of Russian Academy of Science)

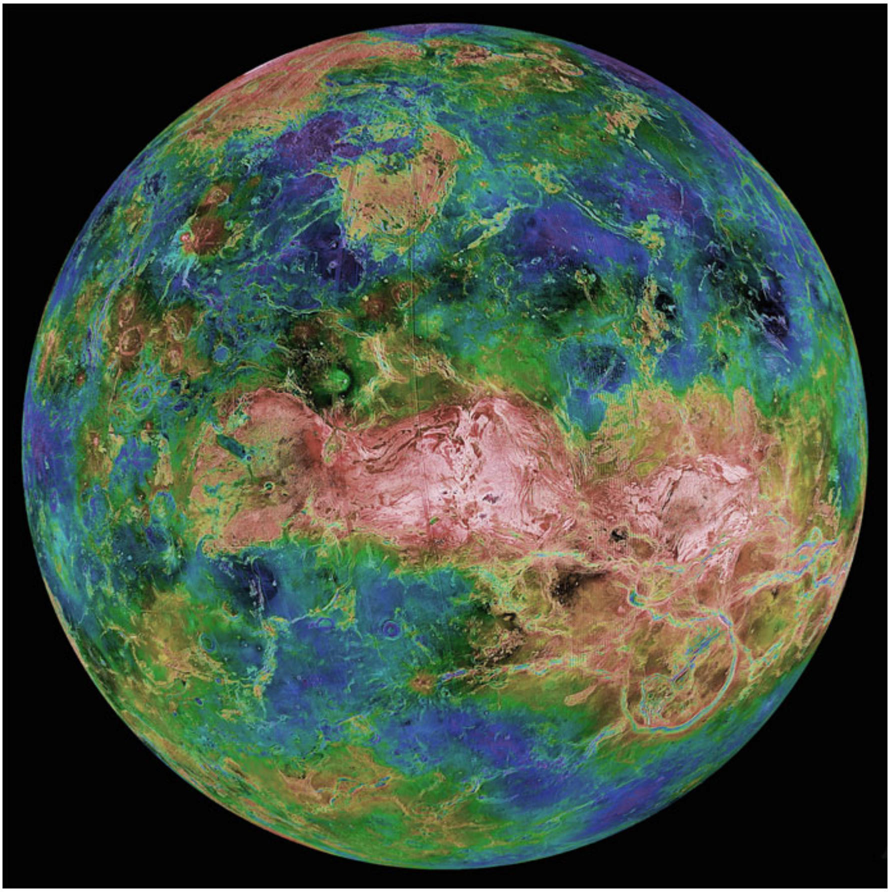

Fig. 2.3 Magellan view of Venus (Credit: NASA)

Transits of Venus in front of the Sun were particularly important for a variety of measurements (e.g. Chapman 1998; Teets 2003). In fact, transits were considered so important that even during exploration expeditions such as those of James Cook in the second half of the eighteenth century, they were studied systematically (e.g. Woolley 1969) and specific expeditions were organized for observing transits under favorable conditions. In fact, thanks to transits, the actual measurement of Venus' diameter was possible. Finally, the determination of the solar parallax, by means of measurements during the transits, was of paramount importance for determining the scale of the Solar System (e.g. Chapman 1998).

Therefore the determination of orbital and geometrical properties of Venus were of great importance for problems much wider than Venus itself, even before any hint about its surface conditions could be obtained.

The discovery that Venus actually has an atmosphere was made by M. Lomonosov in Russia during the observation of the Venus transit in 1761 (Lomonosov 1761; Marov and Grinspoon 1998). In fact, the existence of an atmosphere had already been proposed by William Herschel and Johann Schroter Grinspoon (1997).

Given the very similar sizes of the Earth and Venus, and the closer vicinity of the latter to the Sun, surface conditions were expected to be rather similar, Venus being possible slightly warmer than Earth. Based on the (false) assumption that the thick cloud cover of Venus was essentially due to water vapor, Nobel laureate Arrhenius in 1918 stated that "everything on Venus is dripping wet" which turned out, with subsequent astronomical and planetary exploration, to be far from the truth.

The determination of Venus' rotation rate, based on the search for surface periodic movements, was unsuccessful, due to its dynamical atmosphere. The first attempt was made by Cassini in 1667 (see Baum and Sheehan 1992). Optical (e.g. Slipher 1903; Richardson 1958) and radar (e.g. Dyce et al. 1967) measurements were performed in last few decades. Earth-based and space observations provided the currently known rotation rate of 243 days for an entire (retrograde) rotation. On a longer timescale, Venus' rotation itself, due to its chaotic evolution (Laskar and Robutel 1993), could have a resulting limited set of possible states due its dense, thick atmosphere (Correia and Laskar 2001). Compared with the solid planet rotation of 243 days, Venus' atmosphere rotates extremely fast (about 4 days at the equator). Such 'superrotation' was discovered in the 1960's (e.g. in Schubert 1983), mainly by Doppler experiments on the Soviet Venera 4 to 7 probes (reviewed by Dollfus (1975) and by Earth-based observations (e.g. Traub and Carleton 1975). CO_2 in Venus' atmosphere was first discovered and measured from the ground ((e.g. Adams and Dunham 1932), although its concentration was underestimated in these early observations. On the other hand, Earth-based measurements of H_2O have been much more challenging, given the strong absorption by the Earth's atmospheric water vapor: early measurements nevertheless already showed a very low concentration of H_2O (e.g. Spinrad 1962; Dollfus 1964). The discovery of hot millimeter waves radiation omitted by Venus made from Earth-based radioastronomy observations at the end of the 1950's was the first evidence that Venus is a hot planet Mayer et al. (1958).

2.3 History of Spacecraft Observations

In the space age, the robotic exploration of Venus was long and complicated, with variable, but in general positive results. In fact, the success rate for Venus space missions is higher than 50 % (higher than for Mars, overall): since 1961 space missions, including flybys, orbiters and landers performed successfully in 56 % of the cases, while failing in 44 %. Soviet missions constituted the bulk of these missions, counting for almost 3/4 of the total (43 so far). In addition to NASA (8 dedicated missions), ESA and Japan (JAXA) launched one mission each.

The first successful flyby of Venus was performed by the NASA Mariner 2 spacecraft whose radiometer confirmed the radioastronomy observations of an extremely high surface temperature of 460 °C, under a cloud-topped carbon dioxide atmosphere (Sonett 1963). The Soviet Venera programme revealed for the first time the atmospheric structure of the planet and its surface conditions through the use of different orbiters, atmospheric probes and landers. Venera 4 was the first mission to perform in situ atmospheric measurements, including temperature, pressure and density, from the surface to about 30 km (Vakhnin 1968). Venera 4 to 7 indeed confirmed earlier evidences of the super-rotation circulation (Dollfus 1975). The discovery of hot millimeter waves radiation omitted by Venus made from Earth-based radioastronomy observations at the end of the 1950's was the first evidence that Venus is a hot planet. Modern understanding of the Venus' atmosphere is derived largely from the heritage of Pioneer Venus (Colin and Hunten 1977) and from later Venera missions (e.g. Keldysh 1977; Avduevsky 1983). Their results included the measurement of atmospheric physical and chemical parameters and the determination of cloud microphysical properties, in addition to wind speeds. The Soviet VEGA mission in 1985 also carried French-built balloon experiments, which performed in situ measurements of pressure, temperature, wind velocity, ambient light, for more than 30 h (Blamont 1987, 2008).

Apart from several limited failures, most Venera landings were successful and provided data and imagery for slightly more than 2 h, a limitation imposed on the equipment by the very high surface temperature (e.g. Garvin et al. 1984). Among the many results of the Venera landings (e.g. Moroz 1983), elemental composition measurements were performed (e.g. Surkov et al. 1984), and widespread surface small-scale layer-like rock weathering was observed, most likely due to surface-atmospheric interactions (e.g. Barsukov et al. 1982; Wood 1997).

Late Venera missions (Venera 15 and 16) were equipped with imaging radars (e.g. Kotelnikov et al. 1985) allowing near-global coverage with low to moderate spatial resolution. That was later surpassed by the NASA Magellan mission launched in 1989 (Saunders et al. 1992). The combined results from Synthetic Aperture Radar imaging on board both Veneras and, in much higher resolution on board Magellan, provided the foundation for the reconstruction of Venus' geological history (e.g. Basilevsky and Head 1998).

A thorough review of Venus' spacecraft exploration and main scientific results until the late 1990's is provided by Marov and Grinspoon (1998). A further concise update until the mid 2000's, just before the launch of the European Space Agency (ESA) Venus Express (VEX) mission in 2005, the latest active mission to Venus, can be found in Titov et al. (2006). A more surface-oriented perspective on Venus landings is provided by Basilevsky et al. (2007). VEX is the first mission in two decades devoted to the study of Venus' atmosphere (Svedhem et al. 2007a,b). VEX has observed the dynamical features in the atmosphere with unprecedented spatial and temporal detail (Fig. 2.4). In particular it observed the detailed morphology of cloud patterns Markiewicz et al. (2007); Titov et al. (2011) and the complex atmospheric dynamics (e.g. Drossart et al. 2007). Several parameters of the cloud population have also been measured through imagery and tracking of their spatial

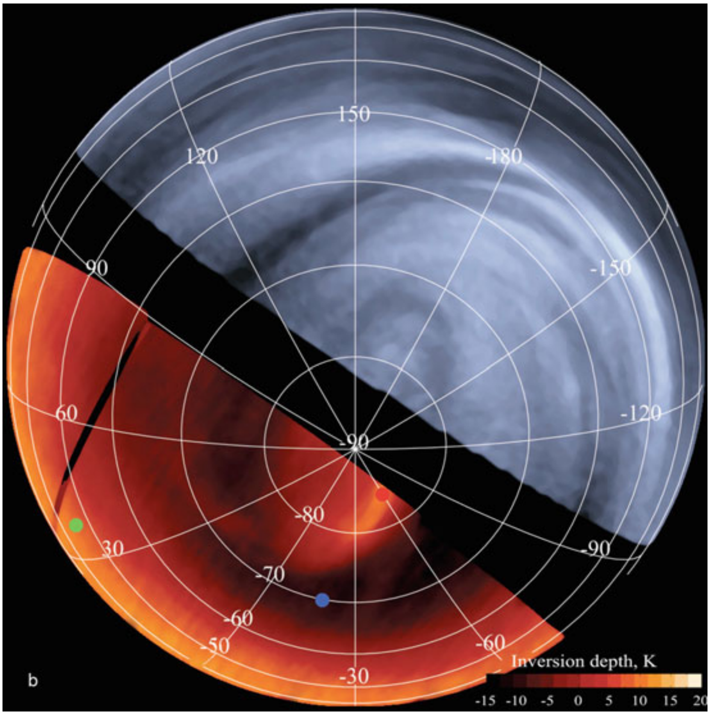

Fig. 2.4 Figure from VEX, the first ESA mission to Venus. Reprinted by permission from Macmillan Publishers Ltd: (from Titov et al. (2008))

and temporal variations, also allowing the derivation of wind velocities. Venus Express has also provided the first possible evidence of recent, possibly current, volcanic activity on Venus Smrekar et al. (2010), Svedhem et al. (2009), Titov et al. (2009).

The Japanese mission Akatsuki, launched 20 May 2010 also known as Venus Climate Orbiter or Planet-C (Nakamura et al. 2007) was designed for a wide range of meteorological studies and to scientifically and operationally benefit from synergic observations with VEX, in addition to the join data analysis and exploitation. In particular Akatsuki was meant to globally map clouds and minor atmospheric constituents thanks to a set of multispectral and hyperspectral imaging experiments, capable of sampling multiple depths within Venus' atmosphere. The failure of Akatsuki to achieve Venus orbit in December, 2010 was a set-back for Venus science. Plans are to relaunch Akatsuki in a strongly elongated orbit in 2015.

The future exploration of Venus will most likely have to rely on advanced mission architecture, involving multiple orbiters, landers, rovers and atmospheric probes (e.g. Bullock et al. 2009), such as balloons (e.g. Chassefiere et al. 2009). More advanced and complex mission scenarios will likely be put forward. Indeed ESA mission studies in the mid 1990's focused on the very challenging prospect of collecting samples from the Venus surface and bringing them back to Earth (Scoon and Lebreton 1998), which would obviously constitute an extraordinary technical achievement, most likely lying outside the financial boundaries of any space agency in the present and near-future state of the necessary technologies.

Whatever will be the nature and elements of future Venus scientific exploration, an element of paramount scientific importance, and also technically challenging, will be a deeper understanding of the atmosphere properties and dynamics. In order to achieve this ambitious goal, more data should be gathered through instruments as those included onboard VEX and Akatsuki. But even more importantly, modeling efforts should be increased, coordinated and focused, as observational data should be assimilated into comprehensive models able to reproduce, reconstruct and predict the dynamical behavior of the atmosphere of the Morning Star.

Finally, a better understanding of the mechanisms at the base of Venus atmospheric circulation and processes would provide us with the best, although extreme, planetary analogue to Earth's own atmosphere. The following sections of this book provide an attempt for advancing our knowledge in this direction.

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