Chapter 1

"If you thought that science was certain - well, that is just an error on your part." (Richard Feynman (1918-1988), American Physicist)

Introduction

Knowledge about properties and processes that shape conditions on Earth gives us the ability to arrange our lives to them. To know about natural[h] potentials (e.g. energy generation, natural resources), to predict conditions (e.g. weather forecast, natural disasters, climate changes) and to understand correlations is the base to use our planet without abusing it.
The arising question now is: "What could be the reason to study other planets?".

- Knowledge about other planets will increase the understanding of our own planet. The physics behind processes on different planets are the same as on Earth. They are determined by parameters like characteristic location in the solar system, specific spin/orbital dynamics, chemical composition and distribution, geological properties and activity, energy budget, etc. Studying other planets will lead to $crossfertilization$ of ideas between different planetary environments.

- The description of a global system like the climate is established by complex models. The precision of such models is especially important if predictions are needed (e.g. forecast). Application of the same modeling methodology to more than one planet with enough "common ground" between them opens a new field for validation and verification and leads to a better understanding of the entire system.

- Eventually, we will need to extend our living space beyond the planet Earth. Therefore the exploration of our solar system neighborhood is mandatory.
- And not to forget there is the natural human "thirst for knowledge" which has always and will always motivate mankind to explore and to find answers to open questions.

Therefore, studying other planets is important for a comprehensive understanding of nature and future environmental developments.

The closest planets which can be addressed are Venus and Mars. Having solid bodies surrounded by a thin layer of atmosphere, Venus, Mars and Earth are called the terrestrial planets. Though different in many ways they show several likenesses. Some relevant parameters are listed in Tab. 1.1.

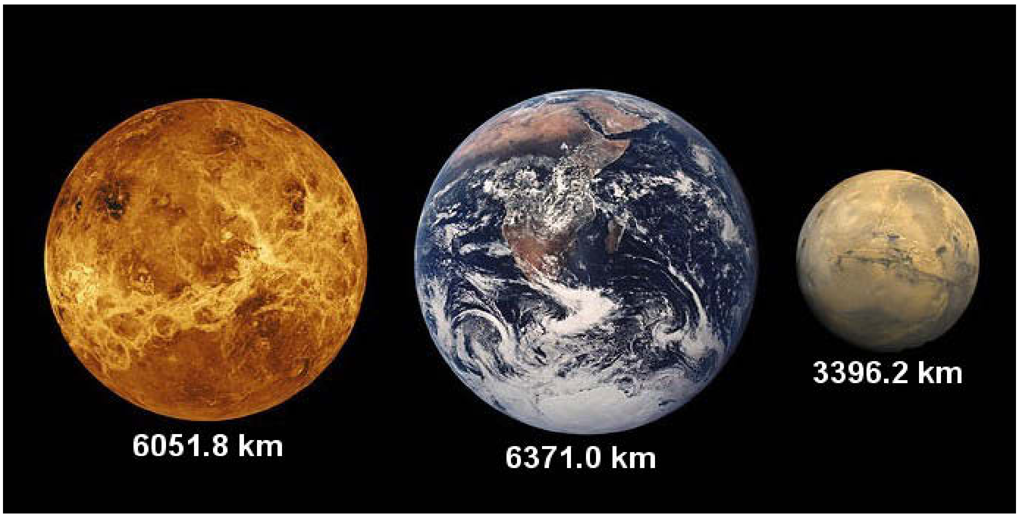

Figure 1.1: *Shown are the terrestrial planets Venus, Earth and Mars (from left to right). The mean radius of the planets are given. Realistic relative sizes are pictured for comparison (NASA [1]).*

Venus and Earth have almost the same size whereas the Martian radius is half of the others. The axial tilt of Mars and Earth is substantial and similar causing e.g. seasonal changes while Venus is more or less upside down with only a small inclination to the ecliptic. Also, Venus is the only planet in the solar system to rotate retrograde, i.e. versus its orbital rotation. The orbital rotation period of Venus is very long (243 Earth

Table 1.1: *Overview of important orbital, physical and atmospheric properties of the terrestrial planets Venus, Earth and Mars.*

Orbital Properties			
	Venus	Earth	Mars
semi-major axis	108 208 930 km	152 097 701 km	227 939 100 km
orbital period (year)	224.70 days	365.256 days	686.971 days
synodic period	583.92 days	-	779.96 days
inclination	3.39471 deg	0 deg	1.850 deg
Physical Properties			
	Venus	Earth	Mars
mean radius	6051.8 km	6371.0 km	3396.2 km
	0.9499 Earths		0.533 Earths
heliocentric distance	0.72 AU	1 AU	1.52 AU
surface temperature	737 K	297 K	210 K
solar day	117 days	24 h	24 h 40 min
axial tilt	177.36deg	23.439281deg	25.19deg
apparent magnitude	up to -4.6	-	+1.8 – -2.91
angular diameter	9.7″-66.0″	-	3.5″ – 25.1″
Atmospheric Properties			
	Venus	Earth	Mars
surface pressure	93 000 mbar	1000 mbar	6.9 mbar
major components	~96.5 % CO_2	~78.08 % N_2	~95.3 % CO_2
	~3.5 % N_2	~20.95 % O_2	~2.7 % N_2
	~.015 % SO_2	~.93 % Ar	~1.6 % Ar
	etc.	~.083 % CO_2	~.2 % O_2
		etc.	etc.

days) and in combination with its synodic period resulting in a Venusian solar day of 117 Earth days compared to Earth and Mars days of $\sim$ 24 h.

The environments of the three planets differ drastically. Venus is a hot planet with high surface pressure and a dense atmosphere containing sulfur dioxide. On Mars we find very cold temperatures and a thin atmosphere with low surface pressure. In spite of their different atmospheric parameters the major constituents and their mixing ratios are almost identical on Venus and Mars (mostly CO_2) differing completely from the atmospheric composition on Earth.

General Circulation Models (GCMs) have been developed for the Earth's atmosphere and were later adopted to Mars and Venus. These models improved the general understanding of atmospheric processes but especially one of the key parameters, the dynamic is still not very well understood. Validation of the output values generated by this models is necessary and measurements of atmospheric parameters are therefore needed. Besides occultation observations (at radio and UV wavelength), spectroscopy (in the infrared, microwave and UV region) is widely used as a remote sensing method to gain information about atmospheres of distant objects.

In recent years IR heterodyne spectroscopy has emerged as a powerful tool for atmospheric studies. Many useful information was gathered in the Earth's atmosphere as well as in the atmospheres of other solar system objects [2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12]. Whenever highest spectral resolution is required heterodyne systems are advantageous because of their high optical throughput compared to direct detection methods like grating spectrometers or Fourier-Transform-Spectroscopy [2, 13, 14].

So far mostly gas lasers (CO_2 lasers) have been used as local oscillators (LO) in infrared heterodyne systems [15, 10]. The main restriction to such instruments is imposed by the fixed gas laser frequencies. Given a typical detector bandwidth of 2 GHz observations are only possible within this small interval around the few laser lines available so that only about 15 % of the spectral range between 9 and 12 μm can be observed this way [15].

This major limitation was overcome by tuneable lead salt diode lasers (TDL) which are commercially available at emission wavelengths ranging from 1 to 34 μm [16]. These lasers were implemented to the Cologne heterodyne receiver THIS (Tuneable Heterodyne Infrared Spectrometer) several years ago. Unfortunately, the system noise temperature of advanced TDL pumped systems proved to be worse by a factor of 3–5 compared to gas laser instruments which is due to the lack of power, incoherent background emission, and the critical response of TDLs to optical feedback [15, 10, 17, 18, 11, 19]. Only recently, quantum cascade lasers (QCL) became available as local oscillators for heterodyne systems. They provide sufficient optical power to reach the shot-noise detection limit and convenient handling compared to TDLs. The use of QCLs improved the performance of the heterodyne receiver THIS to the level of CO_2 laser based systems and made it competitive and with respect to wavelength coverage even advantageous. A detailed description of the parameters and properties of the QCL-LOs used in our system can be found in Sonnabend et al. [20] and Wirtz [21].

The instrument THIS is easily transportable and therefore widely usable at Cassegrain, Nasmyth or Coudé foci of IR or optical telescopes (see chapter 4) and is intended to be a 2nd generation instrument for the airborne observatory SOFIA. In addition interferometric applications are feasible which would then require at least two identical receivers and phase-locked LOs.

Chapter 2

"It often is more spirit and brilliance in a mistake than in a discovery." (Joseph Joubert (1754-1824), French Author)

Dynamics in Planetary Atmospheres

General Circulation Models (GCMs) are commonly used to predict weather and climate of planets and they are a widely used tool for meteorological research. A set of partial differential equations (PDEs) of fluid mechanics can describe the motion of an atmosphere. Theoretically an exact solution exists though solving the equations is limited by computing power. In addition, initialization and boundary conditions at any particular location and time are not known exactly. Therefore, many approximations and assumptions have to be made in order to produce a closed dynamical system.

Attempts to apply terrestrial GCMs to Mars and Venus were made from the beginning. Validation of these models through measurements are obviously much harder to perform than on Earth. Only in recent years with increasing data from ground-based and space-based observations these models and with them our knowledge about atmospheric conditions improved significantly. In the following chapter some historical aspects and the current knowledge about the atmospheric conditions on Venus and Mars with emphasis on their dynamical properties are presented. In addition a brief overview of the general circulation in the Earth's atmosphere is given.

2.1 Dynamics in the Venusian Atmosphere

During the transit of Venus across the Sun on June 6^{th} 1761 the blurriness of the disc was assigned to the existence of an atmosphere by Mikhail Lomonosov. This theory was confirmed later on with the increase in quality of observations. For many years information about the atmosphere and the dynamics was gathered exclusively by ground-based observations. The presence of CO_2 for example was established in 1932 using infrared-sensitive photographic plates [22]. Little more was discovered until 1958 when radio astronomers found much higher surface temperatures than expected. These observations at microwave wavelength of 3.15 cm indicated an extreme version of the greenhouse effect [23], a theory confirmed by observations of following space missions (see 2.2).

A large number of missions have been devoted to study the atmosphere of Venus. NASA started missions to Venus in 1962 with Mariner 2, 5 and 10, flybys followed by the Pioneer Venus Orbiter and Multiprobe in 1978. A windless environment with almost no temperature variation due to high thermal capacity of the massive atmosphere at the surface of Venus was found by the Pioneer Landers.

First dynamical observations at higher altitudes in the atmosphere of Venus were accomplished from the Earth and yielded astonishing results [24, 25]. Near UV imaging measurements detected a 4 day superrotation (see Fig.2.1 [26]) resulting in high wind velocities of $\sim$110 m/s near the equator compared to a sidereal rotation period of 243 days of the planet causing a equatorial rotation velocity of only $\sim$2 m/s.

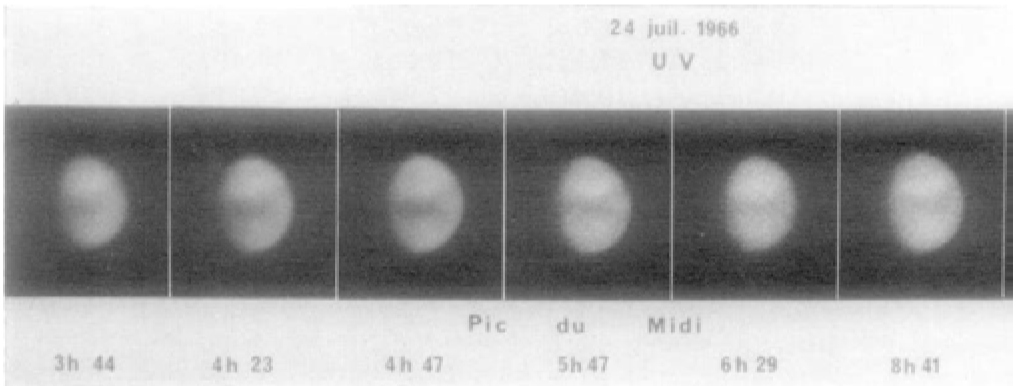

Figure 2.1: *Excerpt of UV observations of the rotation of Y shaped cloud formation observed in 1966 by Boyer and Guérin [26] yielding the 4 day superrotation.*

These patterns where supported by more recent Pioneer Venus Orbiter observations. Profiles of zonal and meridional winds at selected locations on Venus [27, 28, 29, 30, 31] and temporal snapshots of horizontal and vertical wind velocities [32, 33, 34, 35, 36, 37, 38] were yielded by entry probes and ground-based measurements. Later on also the Jupiter-bound spacecraft Galileo took pictures of cloud circulation during flyby. In 1991 the spacecraft Magellan retrieved first temperature profiles (shown in Fig. 2.2) and pressure profiles.

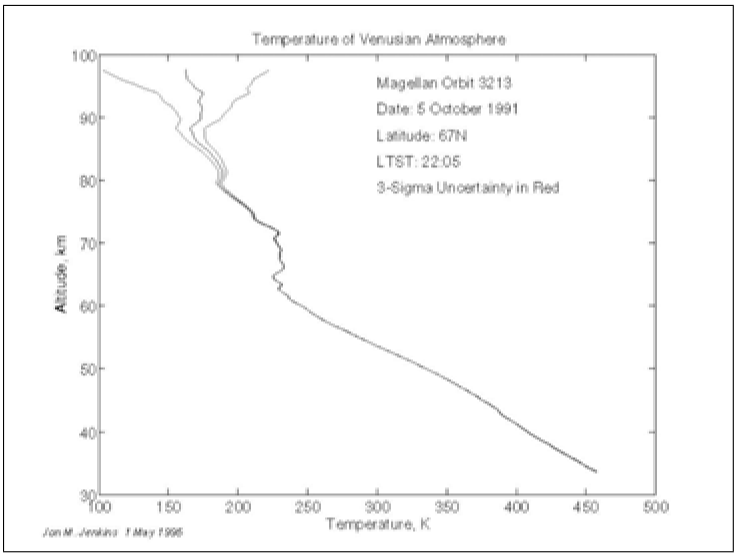

Figure 2.2: *Venus temperature profile measured by the spacecraft Magellan in 1991.*

Also the Soviet Union launched orbiters, flybys, descent and entry probes with Venera 4 – 14 and the radar mapper Venera 15 and 16 followed by VeGa 1 and 2.

Currently, ESA's orbiter Venus Express (launched Nov. 2005) supplies scientists with astonishing new data providing new insights into atmospheric conditions and leading to new theories. Fig. 2.3 shows recently published [39] temperature profiles from radio-sounding observations with Venus Express Radio Science Experiment (VeRa) from 2006.

In addition, the Japan Aerospace Exploration Agency (JAXA) is building the Venus Climate Orbiter VCO (to be launched in 2010) to study the atmospheric properties of Venus with emphasis on dynamical properties.

The most striking feature in the Venusian atmosphere is a cloud layer consisting of small sulfuric acid (H_2SO_4) particles with a bimodal distribution of 0.5 to 2 - 3 μm. Enclosed by a optically thin haze this cloud layer around 45 - 75 km altitude conceals the surface of Venus for visible wavelengths affecting ground-based observations as well as satellite