Venus, the “morning star”
or “evening star” ...
Venus and Earth Orbits
when we get lucky…
(unfortunately not for the next 100 years… until Dec 2117)
Venus-Aphroditia
goddess of beauty and love
Venus has been followed by all civilizations
First research before the Space era

1610
Galileo Galilei observed phases of Venus.

Therefore Venus rotates around the Sun contradicting Ptolemaic geocentric theory, triggering acceptance of Copernicus theory (under discussion since 1543)
Early research before the Space era

1639
Venus transit first predicted and used to measure Earth distance to the Sun using parallax from various observing points

1761
discovery of the atmosphere by Lomonosov
Venus just before the Space era

20th century
birth of spectroscopy

1920s
cloud top temperature
~240K

1930s
CO2 composition, low H2O

1950s
radio investigations: planet rotation, hot surface

Just before space era, Venus still seemed a nice place to be ...

Venus surface according to S. Arrhenius in 1950s
The Space Race: Who will be the first to reach Venus?

1957: Sputnik
First ever earth satellite

1960-1961
Sovietic Veneras 1-2 both failed.
First launch failed, second one succeeded but communication was lost.

1962
USA Mariner-2
Venus fly-by and first data returned
First successful planetary mission flyby!

Venus surface temperature ~400ºC!!!
Next Goal: reach the surface!

1960s: Venera-4, 5, 6 reached ~20 km

1970: Venera-7: “soft” landing
First data from surface of another planet
Temperature ~475°C!!! Pressure 90bar!!!

Russia rules Venus!
Second generation of the Venera spacecraft (70s)
1975-1982 First views of the surface!

Venera-9

Venera-13

Venera-14
Pioneer Venus multiprobe (1978)

Carrier and 4 descent probes
- 1 big probe with parachute
- 3 small probes without parachute

All probes got to the surface
Only 1 small probe survived for 1h
Carrier also down to 110km height
Pioneer Venus orbiter (1978-1992!!!)

Atmospheric studies from orbit
In-situ plasma investigations
First surface radar mapping

dipole in the north pole???
1984 Russian VEGA balloons 1,2

2 earth days flying over venus clouds ~54km

Mariner 10 Image of Venus

Zonal superrotation
1990s: Venus unveiled...

Magellan, US, 1990, SAR images (100-200 m), radiophysical properties, gravity
Venus Surface

Global resurfacing 500~700 My ago

No plate tectonics

Impact craters: very few and uniformly distributed

Lowlands
Tesserae
Volcanoes
Earth and Venus

“Twin” Planets
(separated at birth, with a very different fate...)
Life on Earth is quite nice
but Venus looks like hell…

Sulfuric acid clouds
400 km/h winds
90 bars pressure

97% CO₂

450°C at surface
## Climate and atmosphere composition

<table>
<thead>
<tr>
<th>Properties</th>
<th>Earth</th>
<th>Venus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface P, bar</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td>Surface T, °C</td>
<td>+15</td>
<td>+450 (!)</td>
</tr>
<tr>
<td>Composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{N}_2$</td>
<td>78%</td>
<td>3.5%</td>
</tr>
<tr>
<td>$\text{O}_2$</td>
<td>21%</td>
<td>~0</td>
</tr>
<tr>
<td>Atmospheric $\text{H}_2\text{O}$</td>
<td>&lt; 3%</td>
<td>40 ppm</td>
</tr>
<tr>
<td>Total $\text{H}_2\text{O}$</td>
<td>~3 km</td>
<td>~3 cm</td>
</tr>
<tr>
<td>$\text{SO}_2$</td>
<td>~0</td>
<td>~200 ppm</td>
</tr>
<tr>
<td>Clouds</td>
<td>$\text{H}_2\text{O}$</td>
<td>$\text{H}_2\text{SO}_4$ + ?</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td>300 ppm</td>
<td>96.5%</td>
</tr>
</tbody>
</table>
Venus Atmosphere Chemical Composition

Summary of Basic Atmospheric Elements

- Carbon dioxide (96.5%)
- Sulfur dioxide (150 ppm)
- Argon (70 ppm)
- Water vapor (20 ppm)
- Carbon monoxide (17 ppm)
- Neon (7 ppm)
- Helium (12 ppm)
- Other (3.5%)
Habitability zone in the Solar System

- **MARS**: 1.52 AU
- **EARTH**: 1 AU
- **VENUS**: 0.72 AU
- **MERCURY**: 0.39 AU

**Global fridge**

**“Paradise”**

**Greenhouse oven**

**Thin atmosphere frying pan**
Greenhouse effect

Solar radiation

Thermal emission
Water balance on an Earth-like planet (Greenhouse effect and atmospheric escape)

- $T_s < 0 \, ^\circ\text{C}$
- $T_s \sim 22 \, ^\circ\text{C}$
- $T_s \sim 100 \, ^\circ\text{C}$
- $T_s >> 100 \, ^\circ\text{C}$

Runaway greenhouse

Moist greenhouse

Solar flux, W/m²

Earth now 300

Venus now 625
Greenhouse effect and water loss

Earth and Venus: Similar volatile inventories at origin:

Present water amount: $H_2O_{VENUS} \sim 10^{-5} \ H_2O_{EARTH}$

Deuterium enrichment: $(D/H)_{VENUS} \sim 150 \ (D/H)_{EARTH}$
History of Venus: A Unified Scenario

- $\approx 2.5 - 3 \text{ Gy (??)}$ Loss of surface water. Subduction of hydrated sediments ceases.
- Mantle becomes desiccated.
- Lack of water makes lithosphere thicker & more difficult to break.
- Loss of asthenosphere $\Rightarrow$ lithosphere is tightly coupled to mantle.
- $\approx 1 \text{ Gy}$ Plate tectonics ceases, Venus becomes a “1 plate planet”
- $\approx 700 \text{ My}$, global resurfacing rate declines precipitously.
- 700 My to present: localized volcanism and tectonism, conductive heat release, production population of craters.
- Venus may have been a habitable planet for a significant portion of Solar System history.

Courtesy of D. Grinspoon
So if Earth and Venus were born similar, why did they end up so different??

Can Earth end up like Venus??

we need to know more...
Venus Express
2005-2014
V1 launch, 1961
Venus Orbit Insertion April 2006
after 10 years, we’re back at Venus
Venus Express

- **Launch 09 November 2005 04:43 UTC**
  - Venus Orbit Insertion 11th April 2006

- **Polar elliptical orbit**
  - Pericentre ~250 km
  - Apocentre ~66,000 km
  - Period ~24 hours

- **Scientific Objectives**
  - Atmosphere composition
  - Cloud morphology and structure
  - Atmosphere/surface interaction
  - Thermal mapping (and vulcanism)

- **Instrumentation**
  - VIRTIS (Imaging Spectrometer IR-VIS)
  - PFS (IR Spectrometer)
  - SPICAV (UV Spectrometer)
  - VMC (VIS-UV Camera)
  - ASPERA (Plasma science)
  - MAG (Magnetometer)
Science operations focusing on the atmosphere
Clouds layers

- Haze
- Upper
- Medium
- Lower

- Haze

<table>
<thead>
<tr>
<th>Particle size</th>
<th>[micron]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.5</td>
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<tr>
<td>2.7-3.2</td>
<td></td>
</tr>
<tr>
<td>3.2-3.8</td>
<td></td>
</tr>
<tr>
<td>1.8-3.2</td>
<td></td>
</tr>
<tr>
<td>&lt;0.5</td>
<td></td>
</tr>
</tbody>
</table>

Day side

Night side, infrared
(atmospheric windows)

This part is not accessible by visible light neither for day time nor for night time!

We need the infrared light and only in night time!

Surface is very hot > Venus unveil in the night
Surface
Surface thermal radiation

Surface study in the windows
Mapping the surface of Venus
Surface brightness temperature

Thermal map of VIRTIS
(constant emissivity)

Syntetic thermal map from MAGELLAN (GTDR)

Müller, et al., JGR 2008
Idunn Mons

Lat -46°

Long 214.5°

Lava flow more recent than 250ky, perhaps much younger

“Fresh” lava, darker in IR, higher emissivity

Smrekar et al., Science 2010
Comparison VIRTIS-MAGELLAN reveals a deviation in longitude indicating a rotation of the planet not fully described by the body fixed coordinate system.

Revised period of rotation of Venus of $243.023 \pm 0.001$ days is significantly different from the value of $243.0185 \pm 0.0001$ recommended by IAU.

*~6.5min difference!*
A bad day on Venus gets even worse

Agence France-Presse
7:43 am | Thursday, March 1st, 2012

10 February 2012

ESA’s Venus Express spacecraft has discovered that our cloud-covered neighbour spins a little slower than previously measured. Peering through the dense atmosphere in the infrared, the orbiter found surface features were not quite where they should be.

Using the VIRTIS instrument at infrared wavelengths to penetrate the thick cloud cover, scientists studied surface features and discovered that some were displaced by up to 20 km from where they should be given the accepted rotation rate as measured by NASA’s Magellan orbiter in the early 1990s.

These detailed measurements from orbit are helping scientists determine whether Venus has a solid or liquid core, which will help our understanding of the planet’s creation and how it evolved.
Atmospheric Clouds
morphology & dynamics
Radiation gets trapped forcing global circulation on Venus

Energy transport by atmospheric dynamics
Venus atmosphere global circulation

- Hadley cell
- Poleward transport of warm air
- Equatorward transport of cool air
- Slow rotation of planet
- Sunlight
- Hadley cell (transports heat away from subsolar point)
- 4-day superrotation of upper atmosphere
Main dynamic regimes:

- Equator $\rightarrow$ chaotic
- Mid latitudes $\rightarrow$ laminar
- Polar $\rightarrow$ spiraling

General large scale features seen in UV

- Chaotic mottled clouds
- Convective sub-solar region
- Streaky clouds
- South polar “cap“
- Bright mid-latitude band

ESA/VMC (W. J. Markiewicz)
Waves and convection on a very dynamic planet

Gravity waves were discovered in the deep atmosphere at 55º S, 50 km altitude, in the night side.

Convection cells at local midday were found to be 10 times smaller than thought previously.

These phenomena contribute to the global dynamics and energy re-distribution.
and we can study the dynamics ...
Great variability of Venus clouds

ESA/VMC (W. J. Markiewicz)
Clouds as probe for the wind speed

The atmosphere is up to **60 times** faster than the solid body rotation.

Wind speeds can be as strong as 400 km/h.

**how is this amazing powerful dynamics sustained?**

**Examples of wind measurements** in the equatorial region:

- about 400 km/h at 70 km altitude
- about 200 km/h at 50 km altitude
Cyclostrophic wind in the mesosphere

Piccialli, Tellmann et al
Venus Polar Vortex
Polar vortex in 3D and its temperature

- The vortex sometimes displays an inverse S-shape, and it extends 2700 x 890 km
- The vortex shape varies with time
- The clouds temperature within the vortex is the highest found on the planet, in contrast with the much colder air-collar around it
- The cloud tops are much lower (45-50 km)
Polar depression and vortex “eye”

Cloud top altimetry

74 ± 1 km

66 ± 3 km

A. Cardesín 2007

N. Ignatiev 2009
Wavelength = 1.7 microns
Clouds top thermal radiation

Deep atmosphere view
Polar vortex 3D solid body rotation

Clouds top radiation (65 km)
Deep atmosphere (50 km)
Detailed unexpected complexity of the dynamics in the polar vortex

C.Wilson 2008
Upper atmosphere
First direct measurements of CO$_2$ fluorescence (day) and O$_2$ nightglow (night)

Side looking (limb) to explore the skin of a planet!

**CO$_2$ (day side)**

- CO$_2$ emission at limb (4.3 $\mu$m) peaks at 115 km

**O$_2$ (night side)**

- O$_2$ emission at limb (1.27 $\mu$m) peaks at 96 km
Oxygen Circulation on Venus

EUV flux → CO2 photodissociation
Solar heating

Free oxygen atoms
Recombination of O atoms into O2
Airglow at 1.27 μm

Dawn
South Pole
Dusk

R.Hueso et al
Dayside CO$_2$ non-LTE emission
Nightglow emissions at different altitudes

García Muñoz et al.

Migliorini et al.
Science Highlight 1: Dynamic polar vortex
Science Highlight 2: Volcanic lava flows

Evidence for active volcanoes on Venus

Atmospheric changes:

- The rise and fall of sulfur dioxide (SO₂) in the upper atmosphere of Venus over the last 40 years, seen by NASA's Pioneer Venus and other spacecraft between 1978 and 1992. A possible explanation is the injection of SO₂ into the atmosphere by volcanic eruptions.

Young lava:

- Venus Express found that the area around Sirenum Fossae in Ishtar Regio was unusually dark compared with its surroundings, suggesting a different, younger composition, pointing to lava flows within the last 2.5 million years. The map shows near-infrared emissivity; red/orange is the highest emissivity (darker), purple is the lowest emissivity.

Transient hotspots:

- Four transient hotspots were detected by Venus Express in the Ganano Chasma rift zone in Atla Regio, labelled Objects A-D in the radar map, right. Changes in relative brightness (top row) and temperature (bottom row) are shown for Object A. Same changes due to clouds are also visible in the top row. The bottom row shows the temperature, assuming average surface background temperature. Taking into account atmospheric effects, hotspot A is likely only 1 square km with a temperature of 1330°C.

European Space Agency
Science Highlight 3: Venus Spin slowing down
Science Highlight 4: Increasing super-rotation
Science Highlight 5: Venus CO2 snow?
Science Highlight 6: Water escape
Science Highlight 7: Magnetic reconnection
Science Highlight 8: Lightning detected by magnetometer
Science Highlight 9: Venus Ozone layer
Venus Express disappeared in the atmosphere in Dec 2014 after a series of aerobraking experiments probing down to 130km.
Let’s hope we don’t have to wait 10 years for the next mission to Venus