Three planets: three different fates

Venus: VERY dense atmosphere
Earth: Habitable Atmosphere
Mars: Tenuous Atmosphere
How Does a Terrestrial Planet Form?

1. The planet starts forming through accretion of meteoritic material.

2. As it grows, the interior begins to heat up and melt.

3. Stuff happens! **InSight**!

4. The planet ends up with a crust, mantle, and core with distinct, non-meteoritic compositions.

Courtesy: InSight project (PI B. Banerdt)
InSight Science Goal:

Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars.

- Seismology
- Precision Tracking
- Heat Flow

Mission proposed by JPL, selected by NASA in August 2012 (Discovery program), to be launched in March 2016
Les outils de radiographie

This document contains export-restricted data.

InSight Mission to Mars Payload

IDS
Instrument Deployment System

RISE
Rotation and Interior Structure Experiment

HP³
Heat-Flow and Physical Properties Probe

APSS
Auxiliary Payload Sensor Suite
(Weather station and Magnetic sensor)

SEIS
Seismic Experiment for Interior Structure
Terrestrial seismology

Earthquake in Tokyo, M=5.8

von Rebeur-Paschwitz (Nature, 1889)
Oldham (1897)
Oldham (1903)
A. Mohorovičić (1910)
Lehman (1936)

Lehman (1936)
Terrestrial seismology

Thousands of earthquakes related to plate tectonics

>20000 seismic station
Mars has a crust, a mantle, a core, but ...

- Core size uncertainty ±250 km.... Does Mars have a lower mantle?
- Did Mars lose its lower mantle during its evolution?
- Is the core still liquid?

*Courtesy V. Dehant*
Deployment of the (single) seismometer SEIS

Video: Insight JPL
Martian Seismology – Multiple Signal Sources

Is there a seismic activity on Mars? Not sure...

What is sure:

- Faulting

- Atmospheric Excitation

- Meteorite Impacts

- Meteor airbursts

Daubar et al., 2010

Courtesy: Insight Science Team
February 15, 2013

400 kton TNT explosion

Efficient excitation of seismic surface waves

Propagation velocity and waveform of Rayleigh surface waves provide information on crust and upper mantle structure
Atmospheric (infrasonic) waves sensing

TWINS Infrasounds sensors (PI D. Banfield)

Spacecraft in Landed Configuration (photo: JPL)
The atmosphere is sensitive to ground shaking.

Earthquake in India, measured in Mongolia.

Seismometer

Pressure sensor

EARTHQUAKE = SIGNAL

T. Farges (CEA)
Fully-coupled seismo-atmospheric waves modeling

Spectral element modeling / 600 CPU-hours

Fully-coupled methods (spectral elements and normal modes) can be used to compute seismic waves in the ground and pressure signal in the air, with sources in the ground (quakes) or in the air (blast).

Rolland, Larmat et al. (in prep)
Wind effects on acoustic propagation (Martian atmosphere)

Seismic source = Airburst at 30 km of altitude

Anisotropic propagation
Atmospheric waveguides
Shadow zones

Source localization (=difficult)

Atmosphere sounding
Atmospheric attenuation

- Mars atmosphere is known for its high attenuation, due to CO$_2$ relaxation
- At 10 Hz, the attenuation factor is $\sim$1 Np/km, which means that a pressure wave will be attenuated by 20 db over 2.3 km
- This will be the major difference with Earth infrasounds (or with viscous only attenuation), for which no attenuation is done over 10000 km...

A.Petculescu web page: http://www.peppermintleafresearch.net

Bass and Chambers, 2001

Slide courtesy: P Lognonné
Atmospheric attenuation

- Mars atmosphere is known for its high attenuation, due to CO$_2$ relaxation
- At 10 Hz, the attenuation factor is ~1 Np/km, which means that a pressure wave will be attenuated by 20 db over 2.3 km
- This will be the major difference with Earth infrasounds (or with viscous only attenuation), for which no attenuation is done over 10000 km

Simulation with wind and attenuation

+ Simulations performed with the Martian GRAM model with and without attenuation and with north winds ($w_x$).

FDTD solution of linearized Navier-Stokes equations

Brissaud, Garcia, Rolland et al. (in prep)
And before Venus ... Back to Earth again
The upper atmosphere is sensitive to ground shaking. Air acts as an amplifier (kinetic energy conservation). The thermosphere and ionosphere are sensitive to ground shaking, and the sound speed varies with altitude. The formula for sound speed is given by:

\[ c = \sqrt{\gamma \cdot \frac{p}{\rho}} \]
Imaging coseismic atmospheric waves

11 March 2011
05:45:30
M9 earthquake offshore Japan

The upper atmosphere motions are sensed using GPS radio sounding.

Transient oscillatory signal: The upper atmosphere is strongly shaken (hundreds of meters):
Haida Gwaii Tsunami
2012/10/28, Mw 7.8

Model and video A. Sladen
Atmospheric waves by surface waves driven from below inform on the internal structure of the planet (here the ocean depth or crust thickness) and the propagation medium (atmospheric properties)
Haida Gwaii Tsunami
2012/10/28, Mw 7.8

Model and video A. Sladen
Rolland et al., 2014
Haida Gwaii Tsunami
2012/10/28, Mw 7.8

630 nm airglow emission

\[
\begin{align*}
\text{Charge exchange} & \quad O_2 + O^+ \rightarrow O_2^+ + O \\
\text{Dissociative recombination} & \quad O_2^+ + e^- \rightarrow O + O(1D) \\
\text{Airglow emission} & \quad O(1D) \rightarrow O(3P) + h\nu
\end{align*}
\]

Grawe & Makela (2015)
Japan 2011 tsunami

Haida Gwaii 2012 Tsunami

630 nm airglow emission

+ 2 other events show
Ionospheric airglow signature
(2011, 2015)
The future: probing the interior of Venus (orbiter)

Probing the Interior Structure of Venus 18

Travelling first has an impact on the neutral atmosphere but then induces changes in the local temperature and species ionic equilibrium. A cascade of physical events arises (see Figure 4-8) and the resulting changes in the physical parameters of the upper atmosphere such as pressure, total electron content (TEC), or even the modulation of airglow emission, can be used as a tracer of the seismic wave.

If the atmospheric density variation, such as the one on Earth with the GOCE (Gravity field and steady-state Ocean Circulation Explorer) or GRACE (Gravity Recovery and Climate) satellites, (see Garcia et al., 28 Yang et al. 29) remains small and is not detectable without great attention, the state of the ionosphere equilibrium can be monitored through the changes in the TEC variations (Rishbeth and Garriott 30).

The local temperature increase also excites the airglow emission of local chemical species, such as O$_2$ (infrared [IR] Airglow) and CO, CO$_2$ (UV Airglow). Airglow is an electromagnetic radiation located in the UV, visible, and infrared spectrum. It is generated by the de-excitation of atoms and molecules spread over certain layers in the atmosphere (see Garcia et al. 28). Airglow emission testifies for the evidence of the relaxation of ionic species (O$_2$, CO, CO$_2$) subsequent to local temperature variations.

4.2.3 A 'Generalized' Seismology Approach

Since coupling of seismic energy into the atmosphere is very efficient on Venus and since the amplification of the signal amplitudes with height in the atmosphere is also very important due to the sharp decrease of the pressure as a function of the altitude, we are not limited to measuring seismic signatures in the high-temperature surface environment.

Balloon platforms in the middle atmosphere in the 55–70 km altitude region, where the atmospheric pressure and temperature are near Earth ambient, could measure the infrasonic disturbance directly as pressure fluctuations. Spacecraft orbiting Venus could measure other signatures resulting from the disturbances higher in the thermosphere and ionosphere (see Figure 4-9).

We can therefore envision 'flying' seismometers attached to balloons in the Venus atmosphere, or orbiting seismometers around Venus.

Figure 4-8. Simplified 'cascade' of physical events in the upper atmosphere.

Atmospheric Density Variations

Adiabatic Temperature Variations

TEC Variations

Venus IR Airglow (here at 1.74 microns)

UV Airglow (here at 480 nanometres)

Credits: KISS Venus Seismology study team
Solid/Atmosphere coupling on Venus

Credits: KISS Venus Seismology study team
Martian Seismology – Single-Station Analysis Techniques

Background “Hum”

Normal Modes

Surface Wave Dispersion

Receiver Function

Arrival Time Analysis

The InSight Mission to Mars – EBIS All-Hands Meeting

Courtesy: P. Lognonné