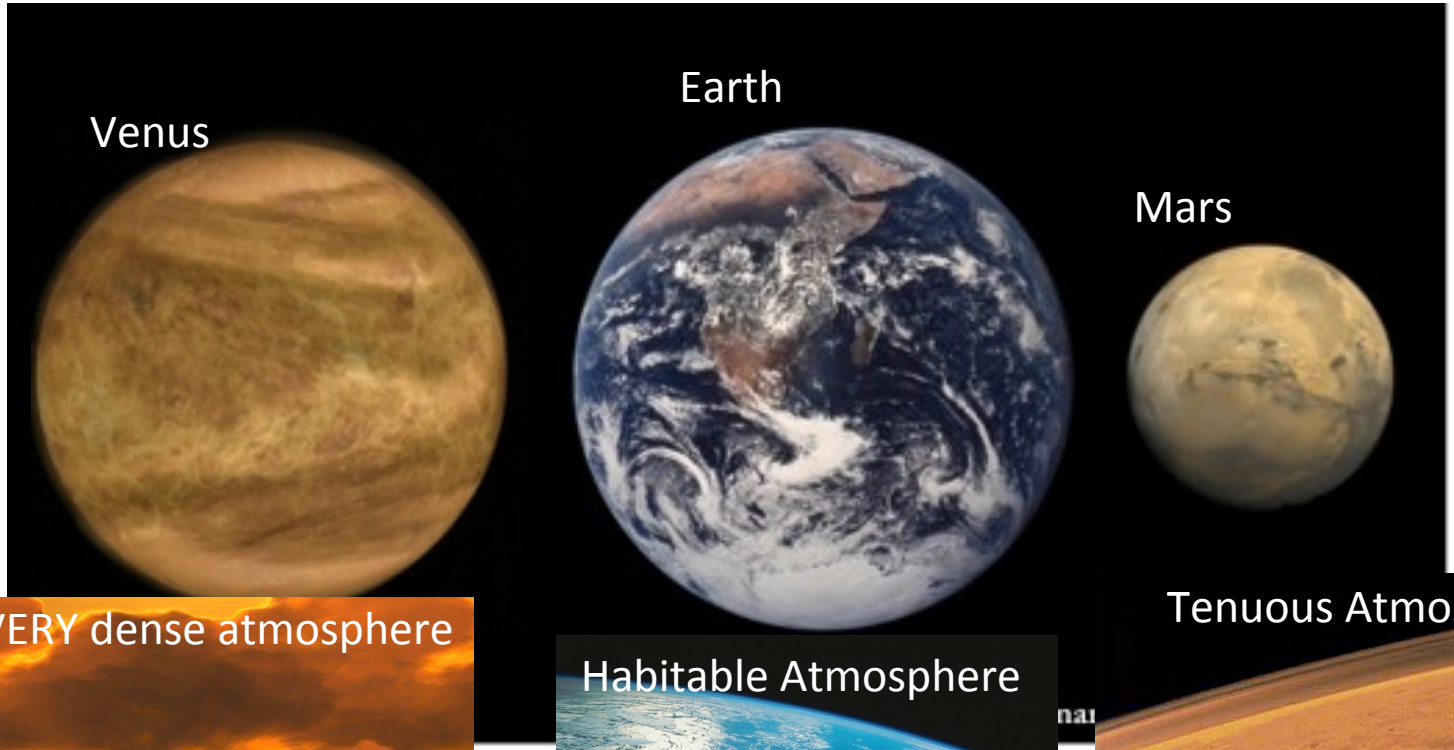
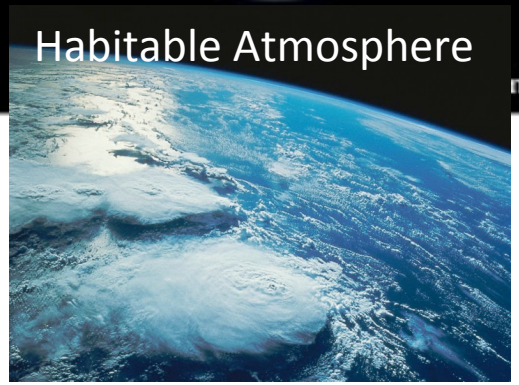
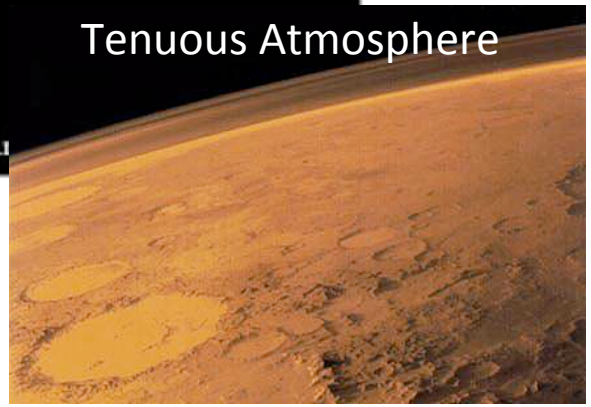
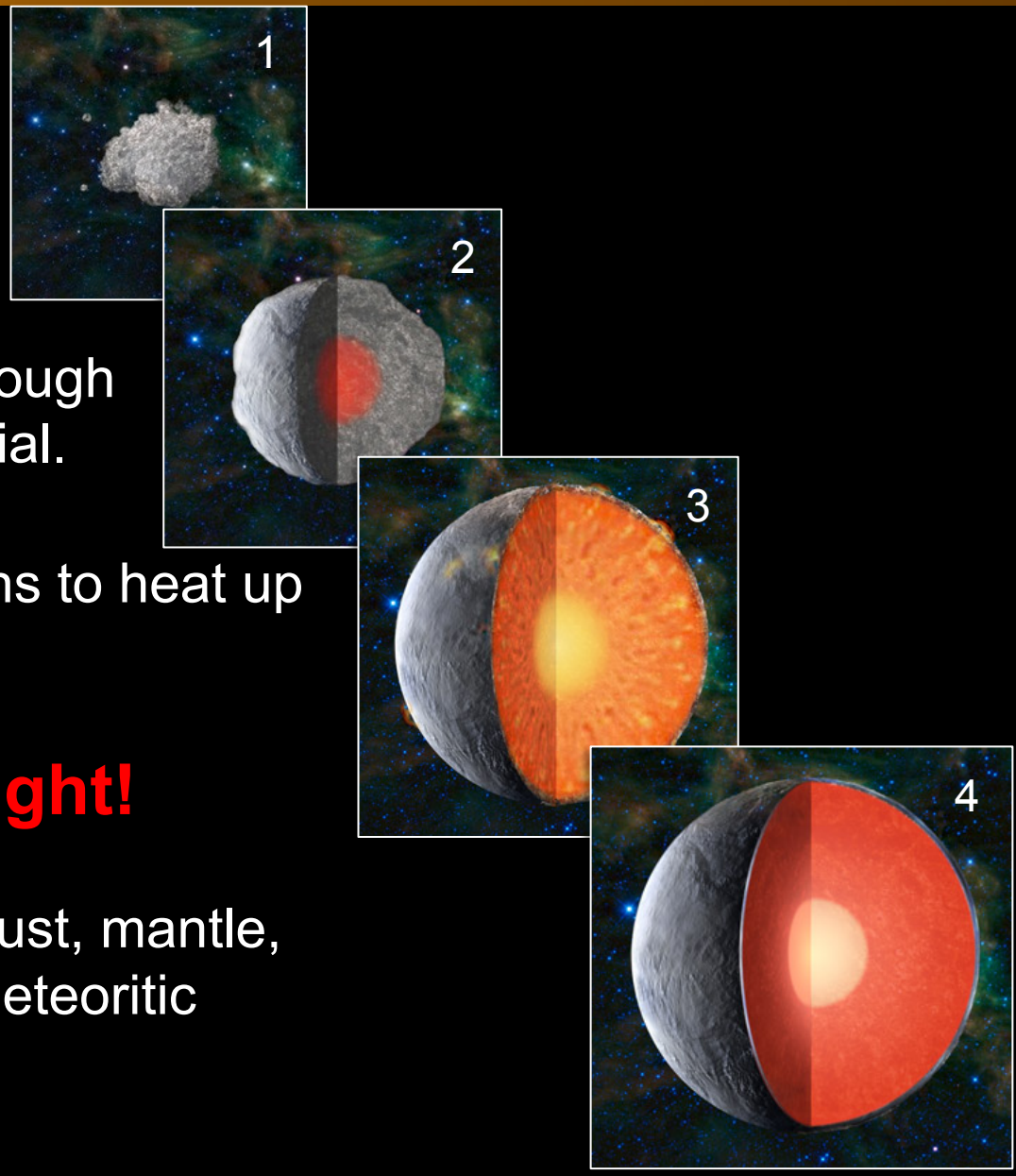
Three planets : three different fates







How Does a Terrestrial Planet Form?



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

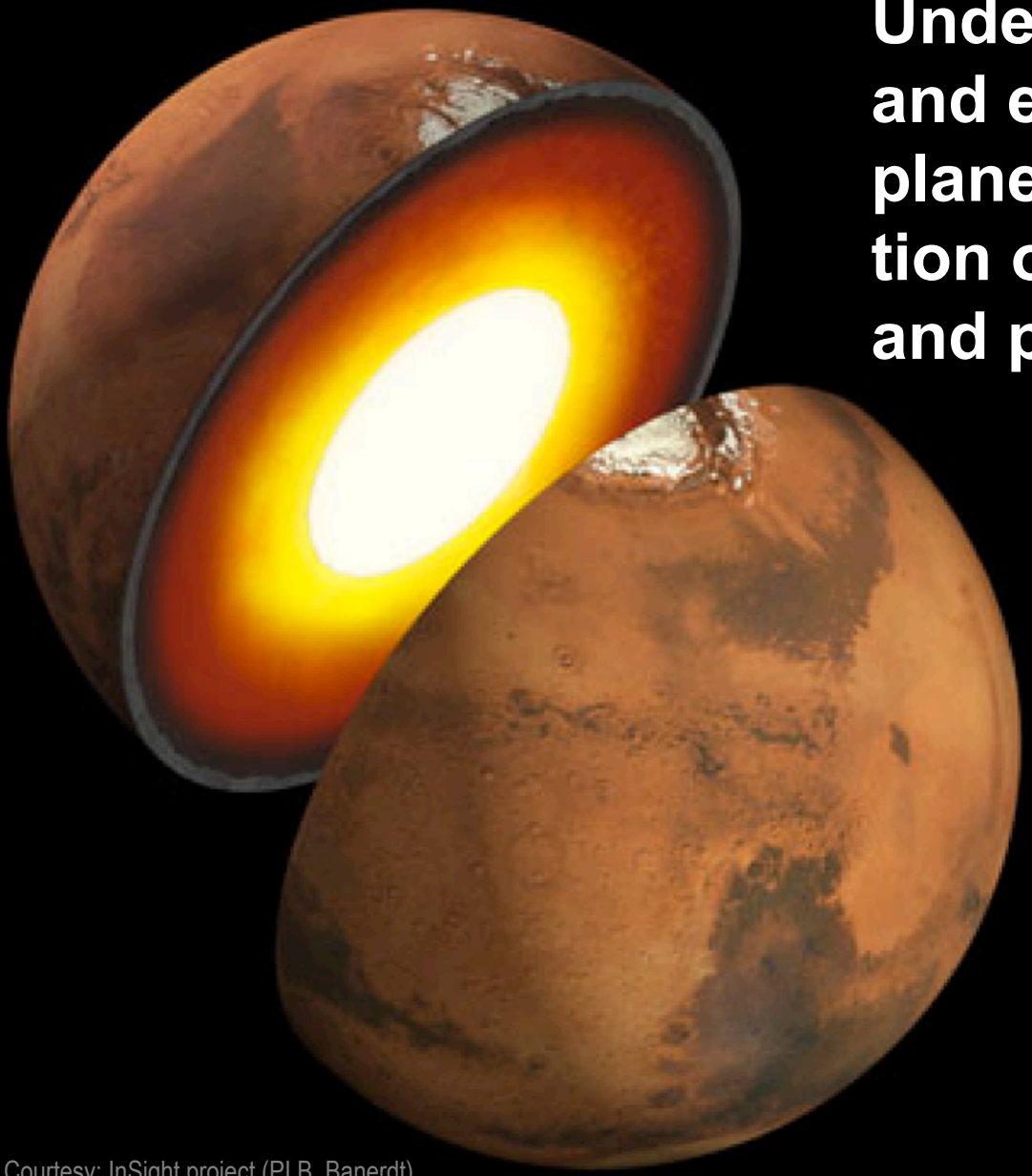
2. As it grows, the interior begins to heat up and melt.

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:



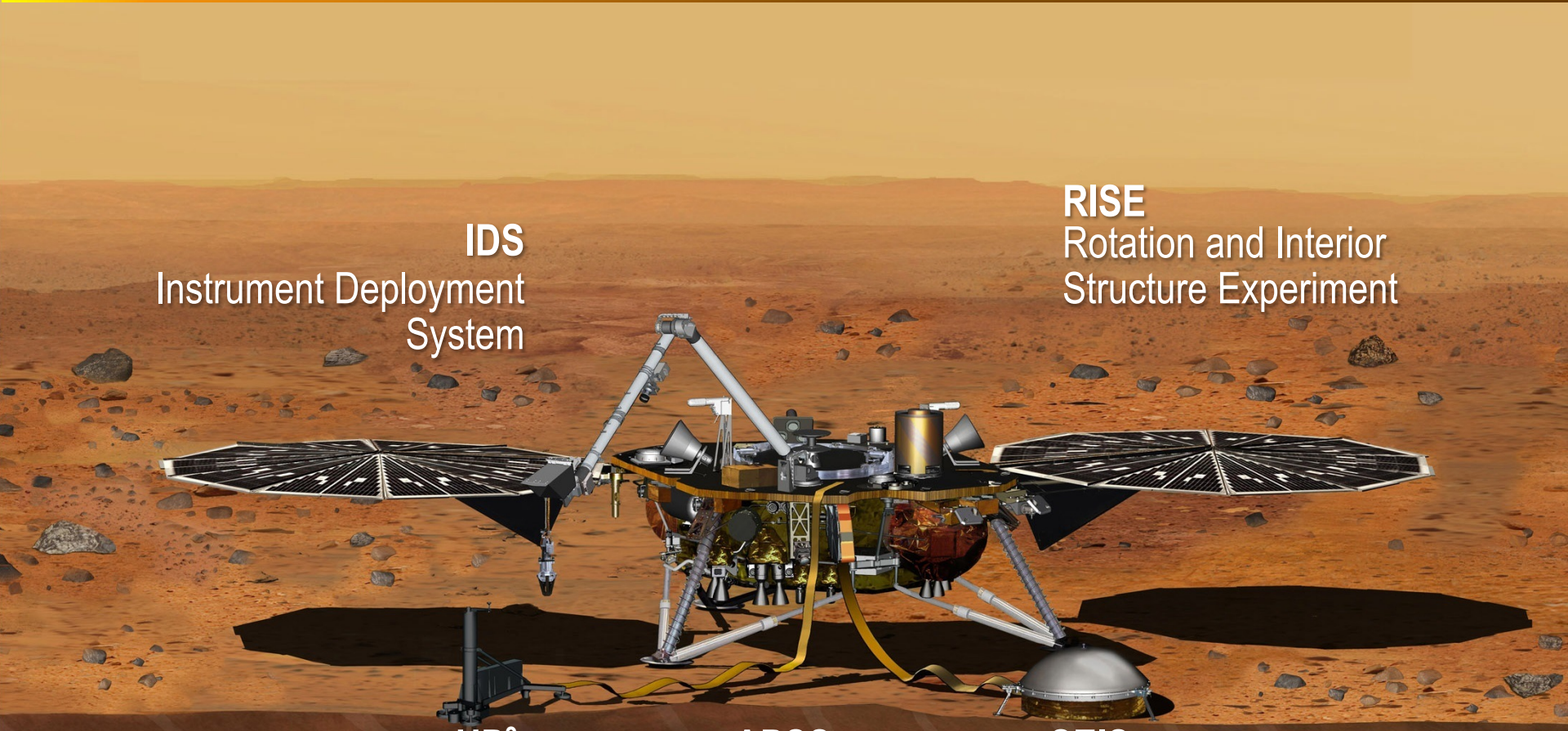
Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars.

- **Seismology**
- **Precision Tracking**
- **Heat Flow**

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

Courtesy: InSight project (PI B. Banerdt)

InSight Mission to Mars Payload



IDS
Instrument Deployment System

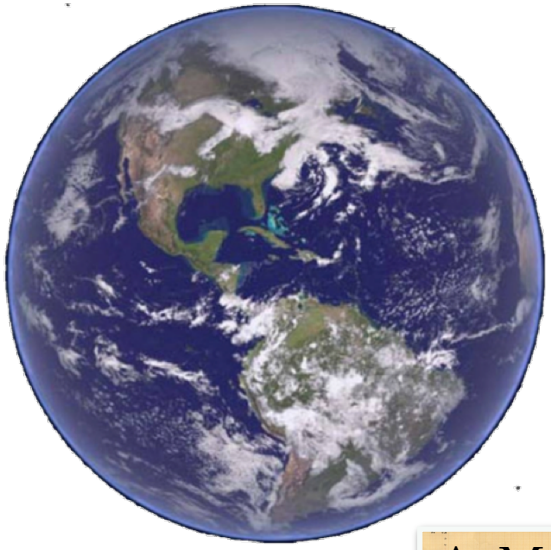
RISE
Rotation and Interior Structure Experiment

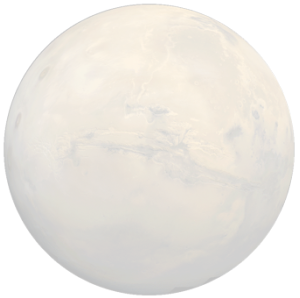
HP³
Heat-Flow and Physical Properties Probe

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

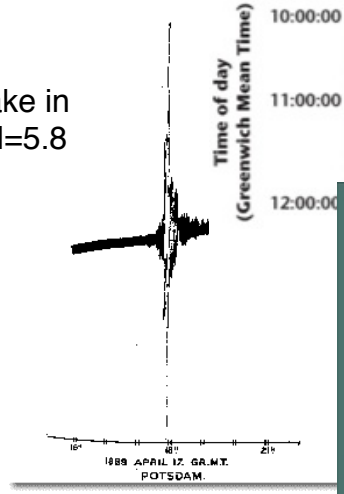
SEIS
Seismic Experiment for Interior Structure

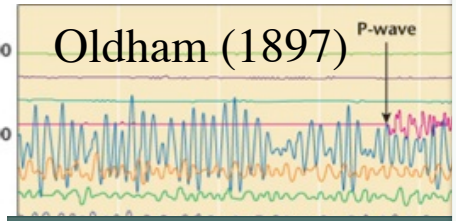
Terrestrial seismology

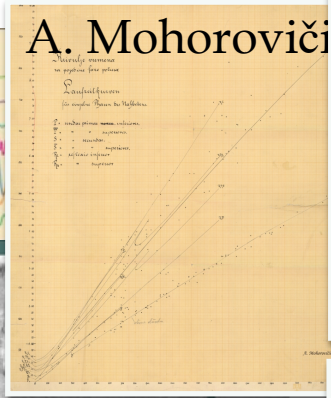


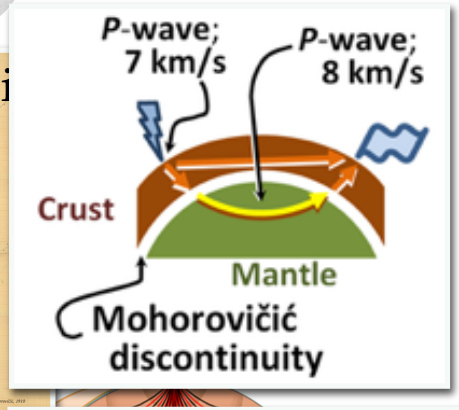


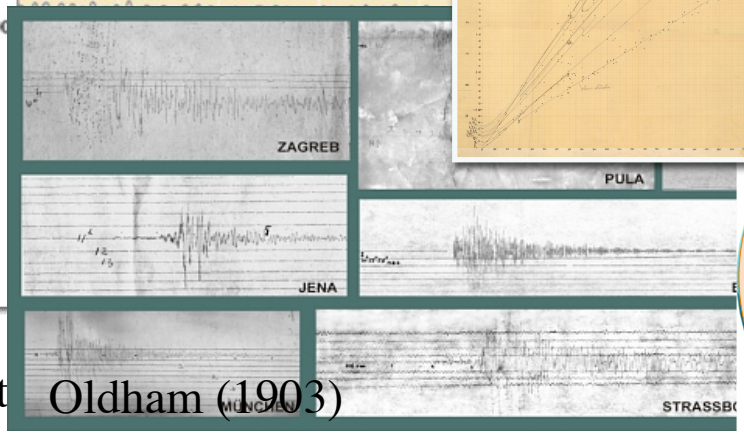
Earthquake in
Tokyo, M=5.8

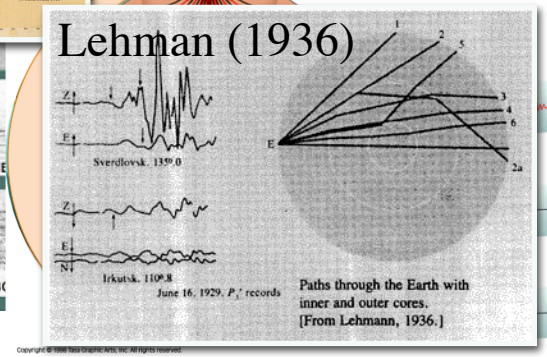






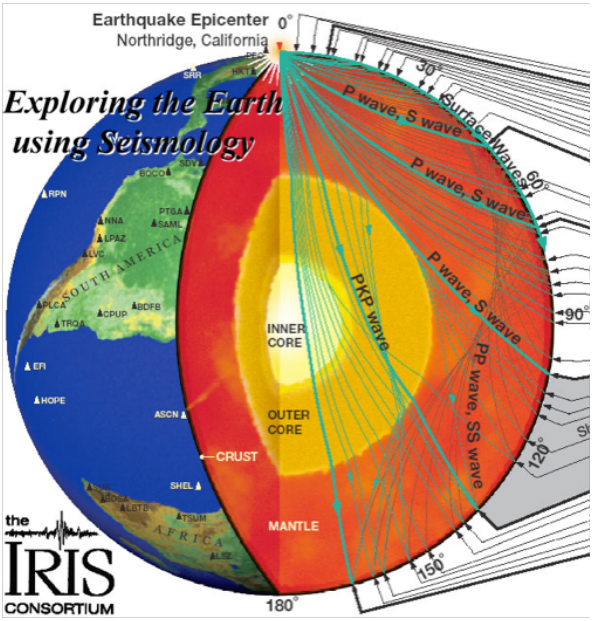


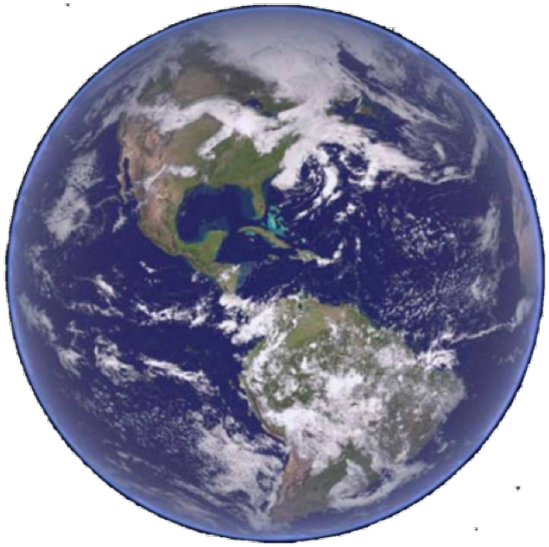


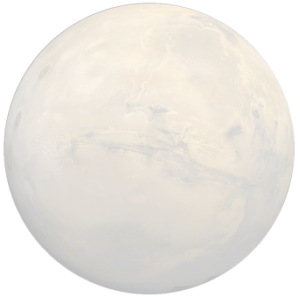


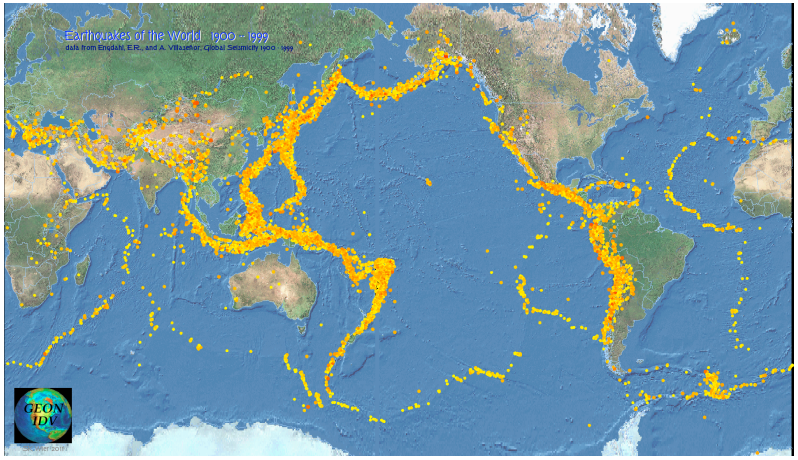
von Rebeur-Paschwitz (Nat

Terrestrial seismology

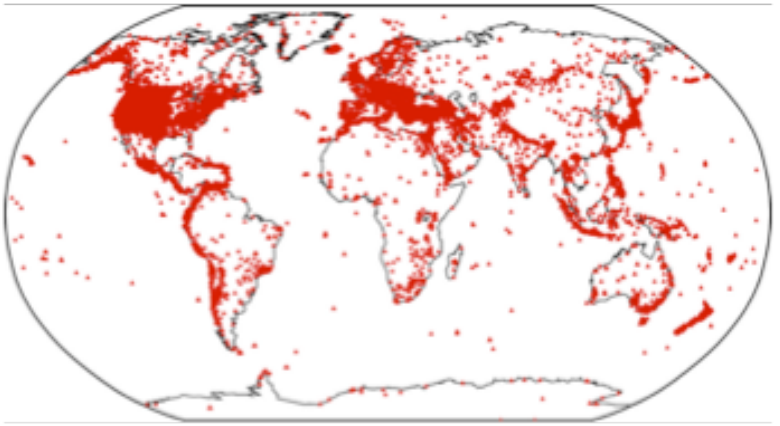








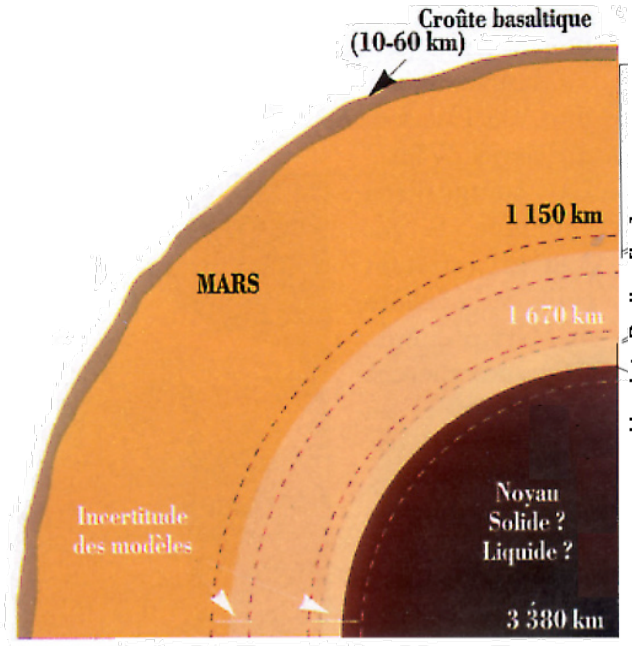
Thousands of earthquakes related to plate tectonics

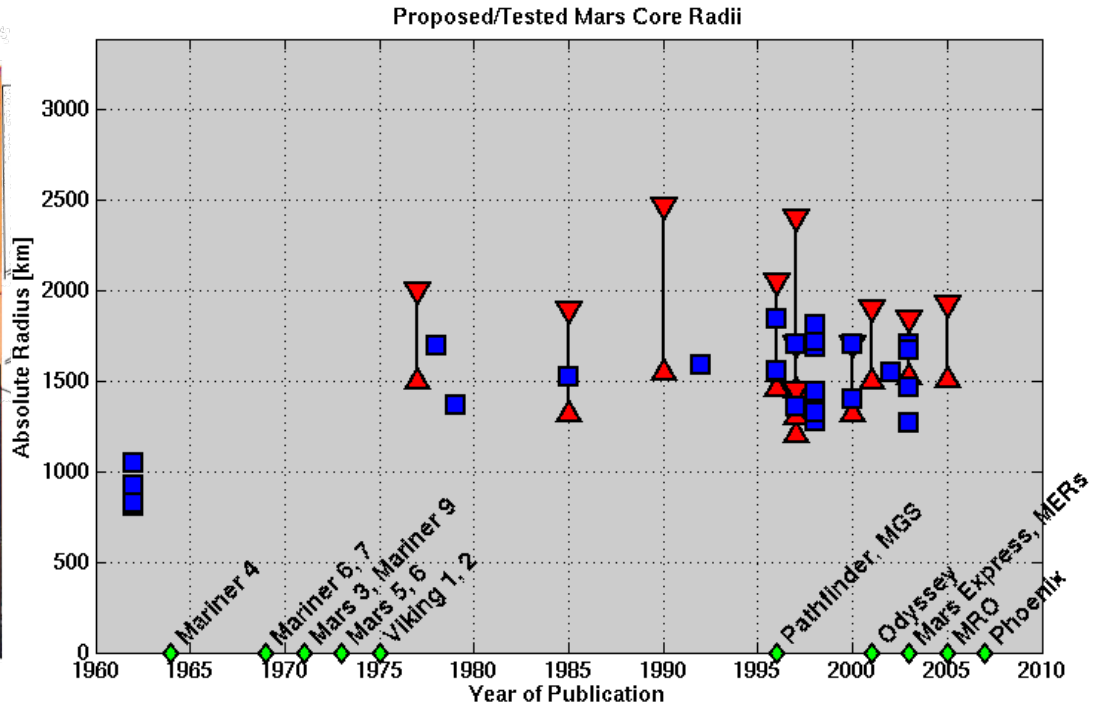


>20000 seismic station

Mars has a crust, a mantle, a core, but ...

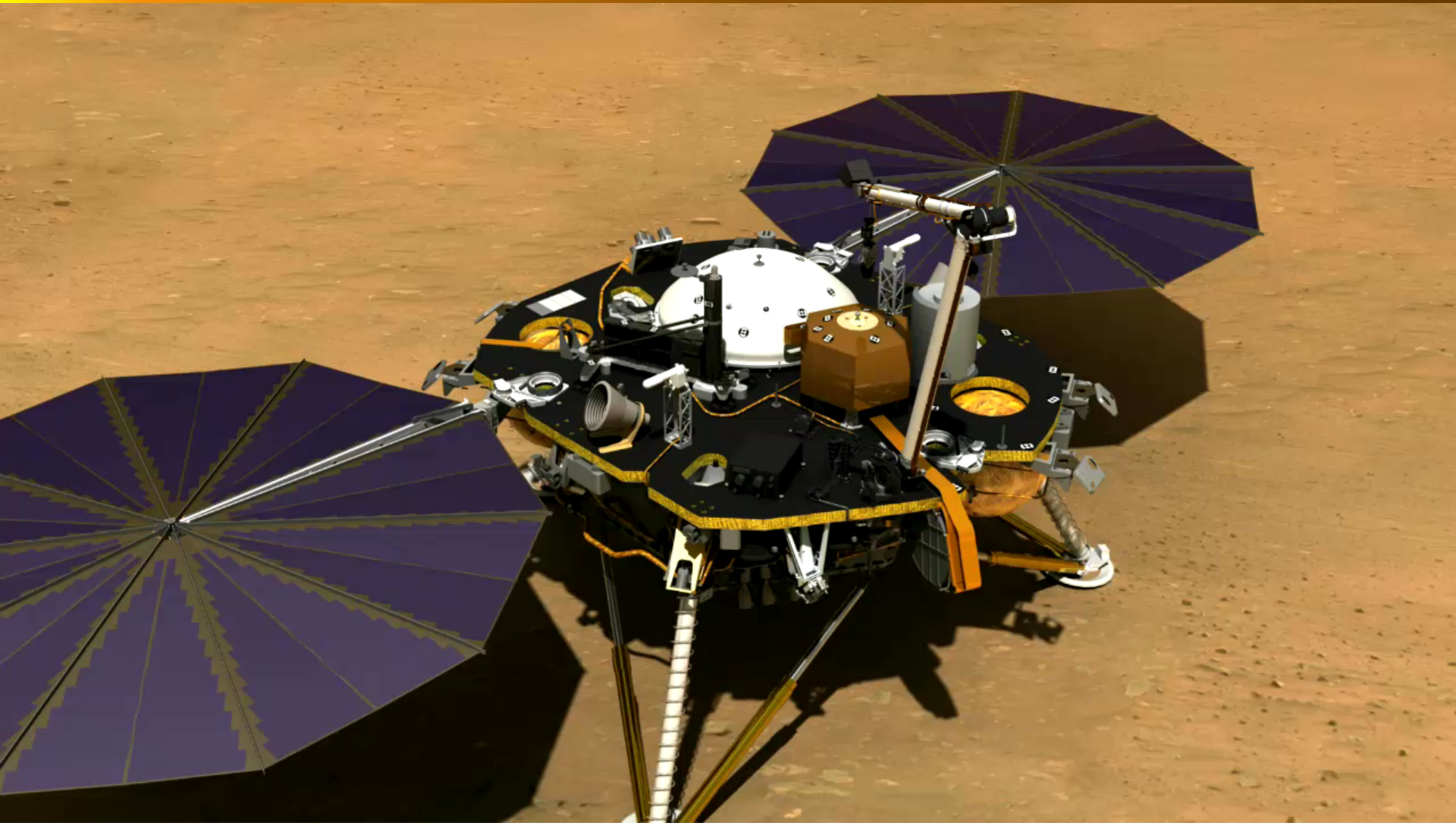
- Core size uncertainty ±250 km.... Does Mars has a lower mantle ?
- Did Mars lost its lower mantle during its evolution ?
- Is the core still liquid ?





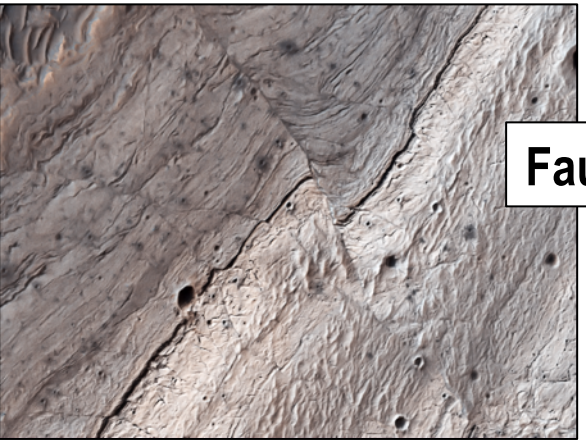
Courtesy V. Dehant

Deployment of the (single) seismometer SEIS

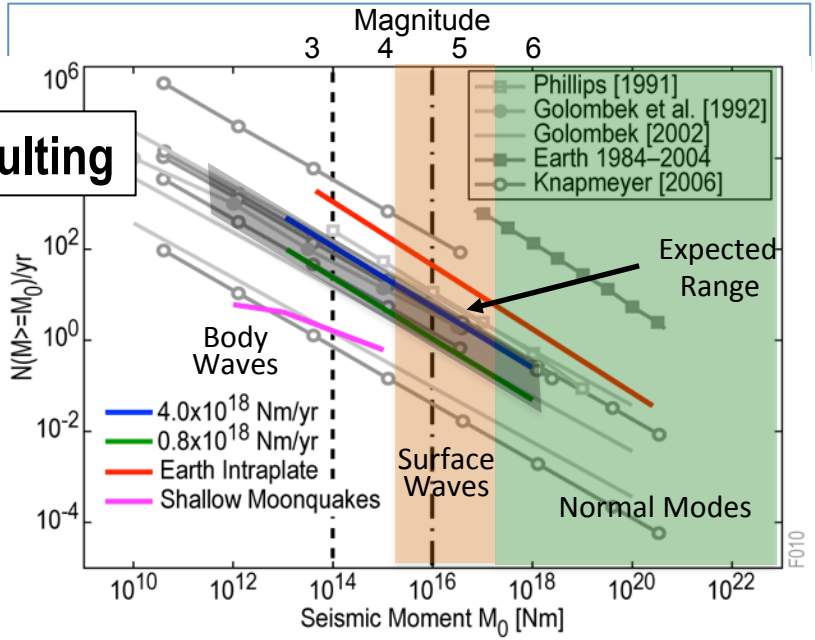


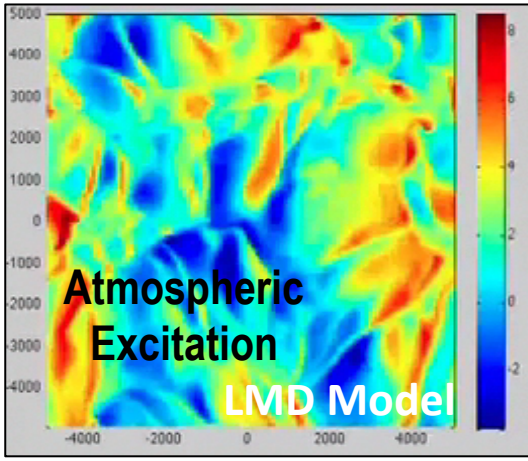
Video: Insight JPL

Martian Seismology – Multiple Signal Sources



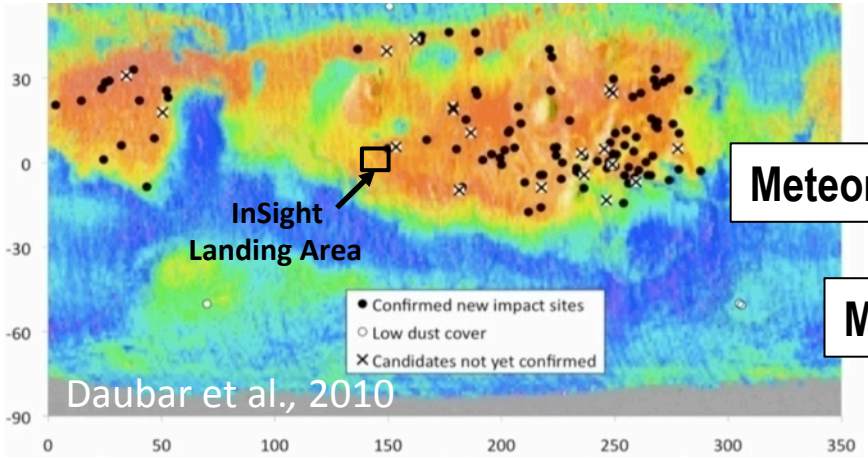
Faulting





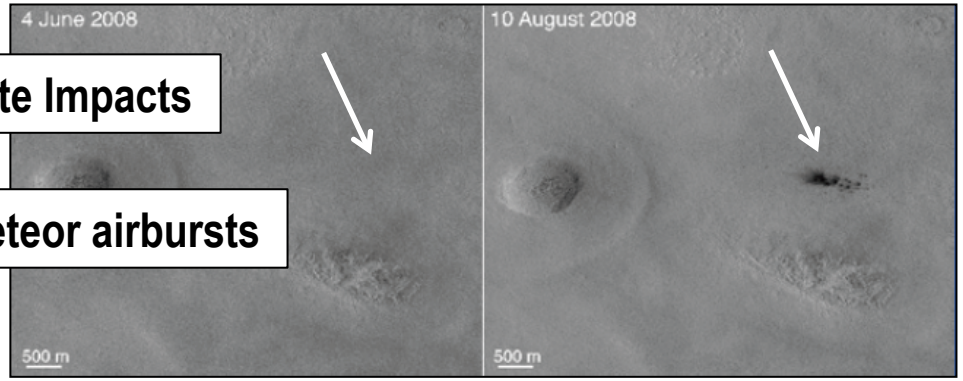
Is there a seismic activity on Mars ? Not sure ...

What is sure :



Meteorite Impacts

Meteor airbursts

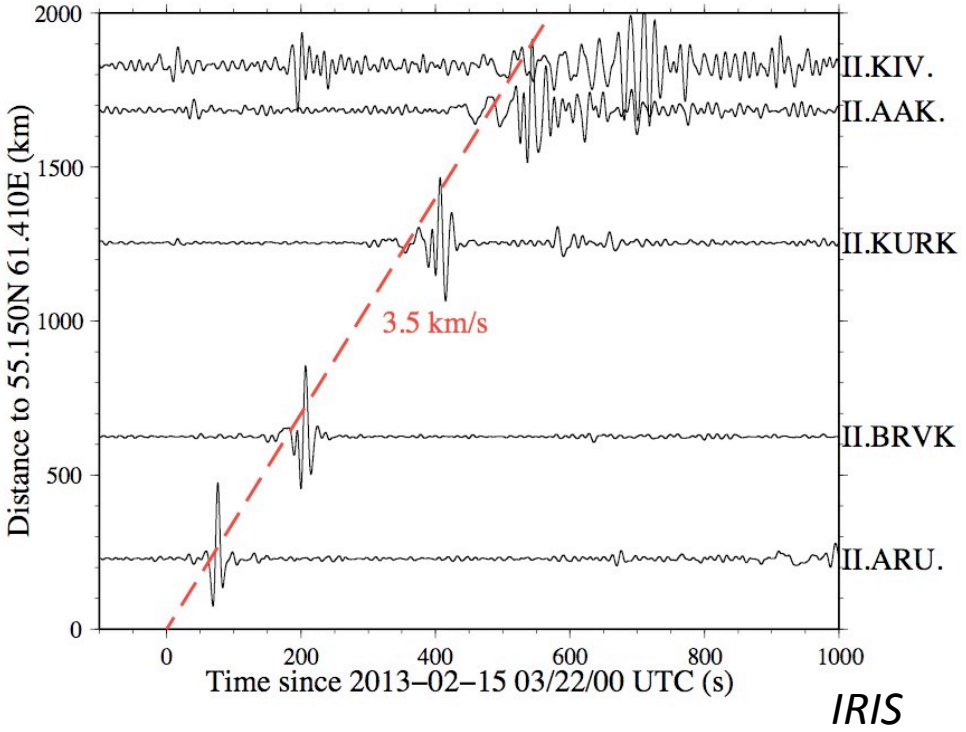


Back to Earth: Chelyabinsk meteor airburst

February 15, 2013

400 kton TNT explosion

Seismic records 10-100s

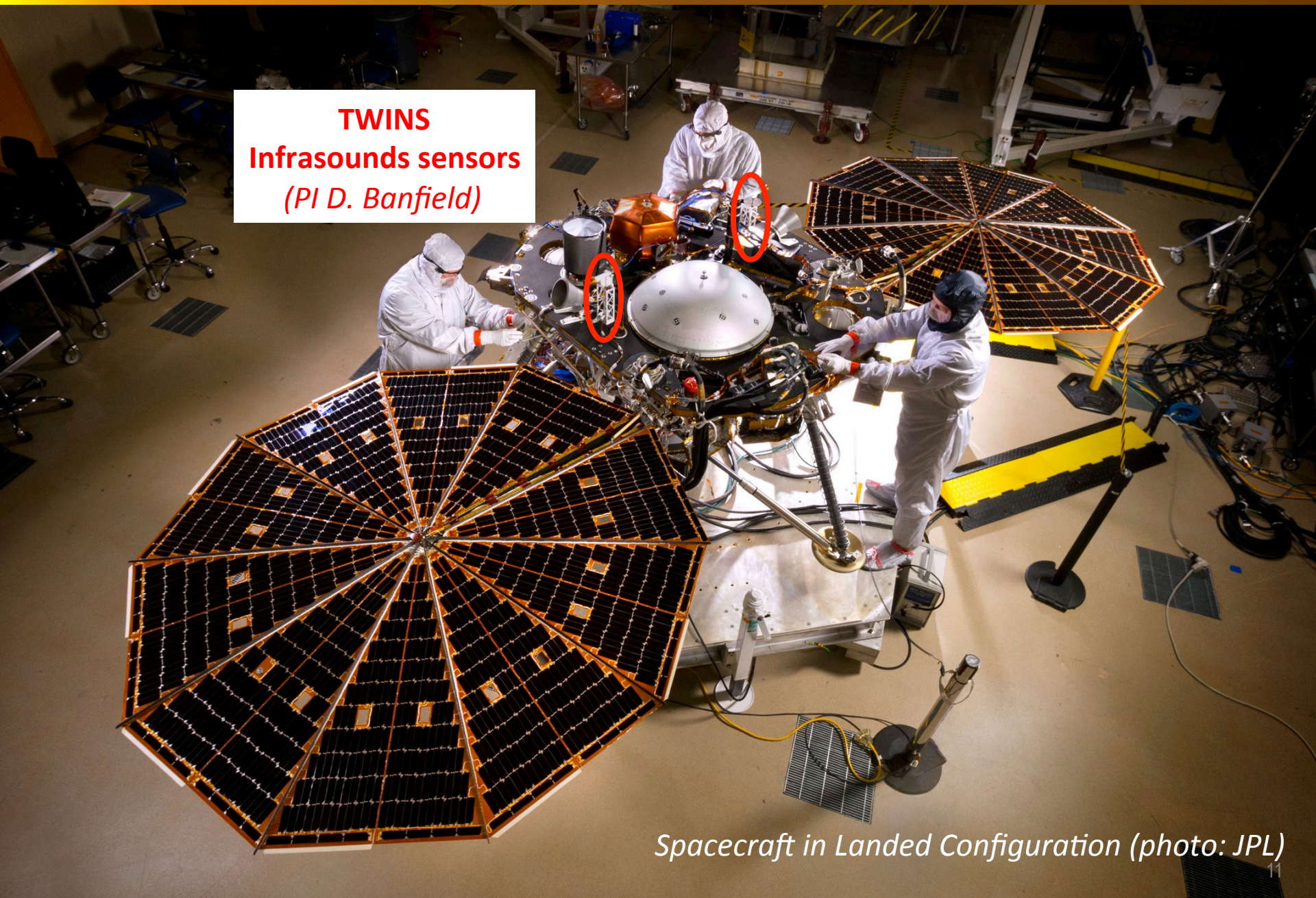


IRIS

Efficient excitation of seismic surface waves

Propagation velocity and waveform of Rayleigh surface waves provide information on crust and upper mantle structure

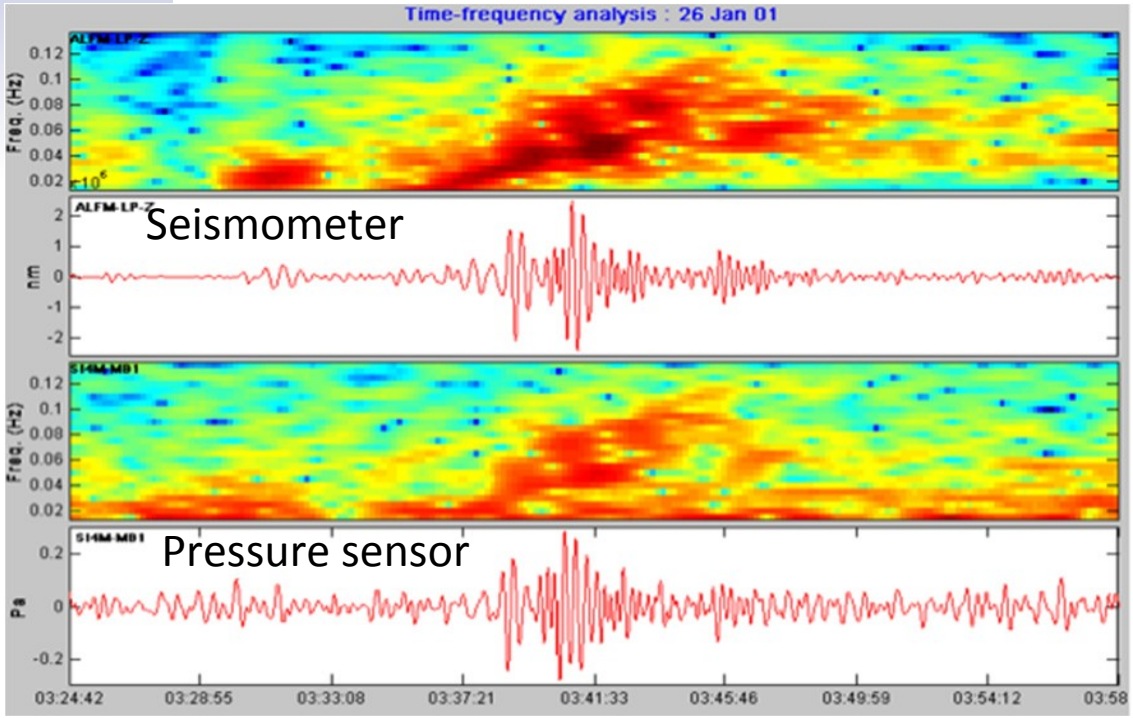
Atmospheric (infrasonic) waves sensing



Spacecraft in Landed Configuration (photo: JPL)

The atmosphere is sensitive to ground shaking

Earthquake in India, measured in Mongolia



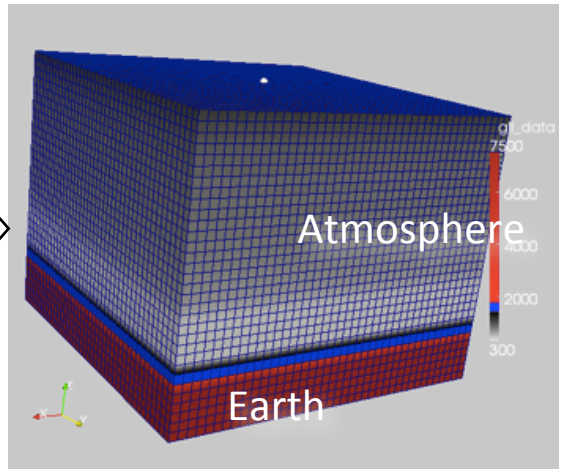
T. Farges (CEA)

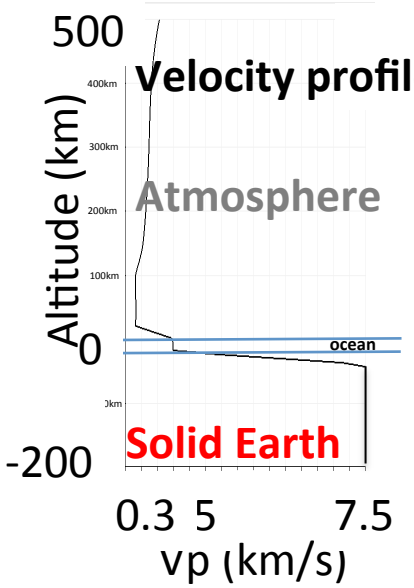
troposphere

EARTHQUAKE = SIGNAL

Fully-coupled seismo-atmospheric waves modeling

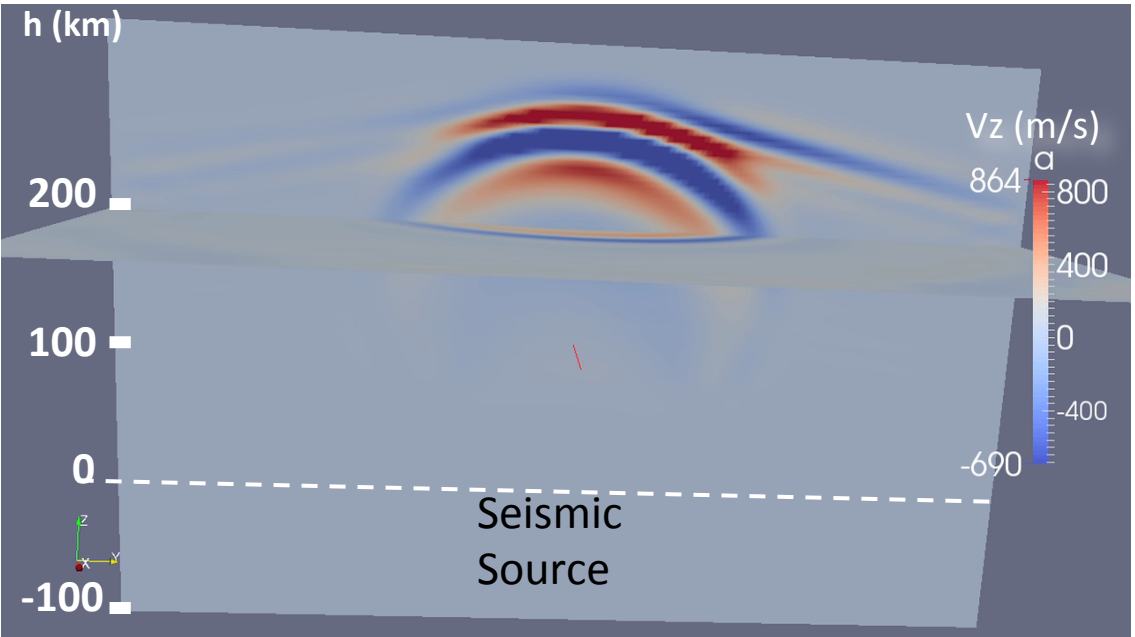
Seismic source

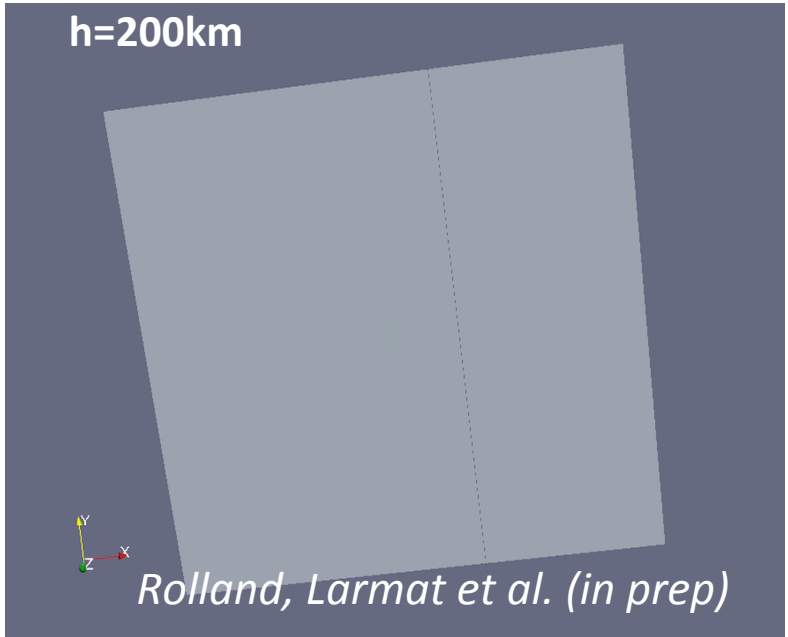




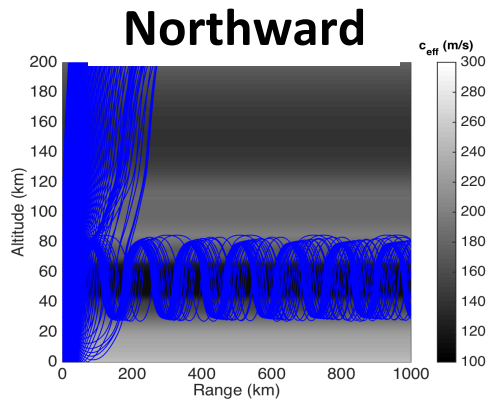
Fully-coupled methods (spectral elements and normal modes) can be used to compute seismic waves in the ground and pressure signal in the air, with sources in the ground (quakes) or in the air (blast)

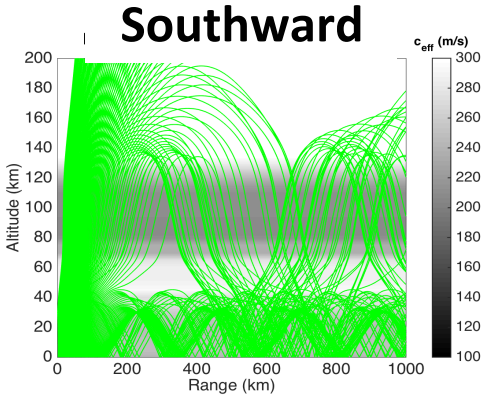
Spectral element modeling / 600 CPU-hours

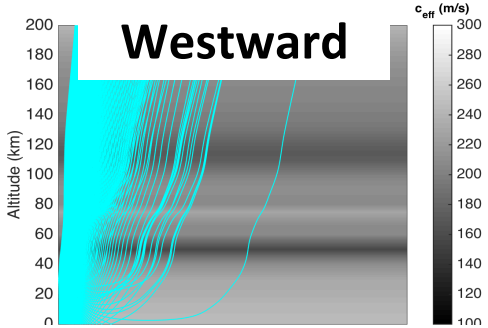


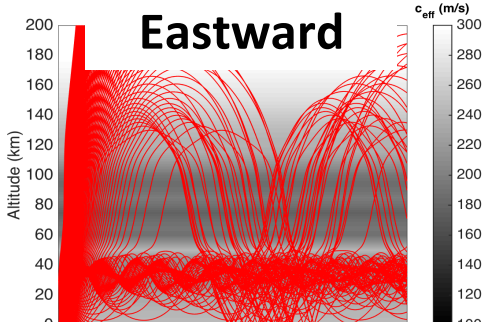


Wind effects on acoustic propagation (Martian atmosphere)





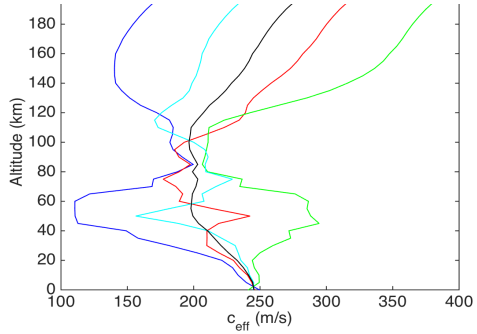




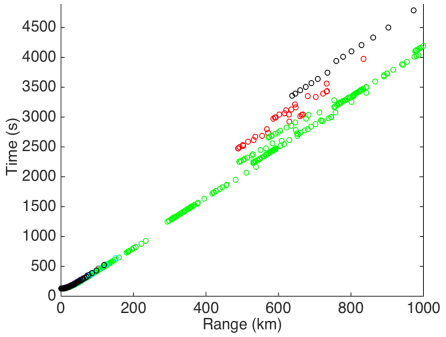
Seismic source =
Airburst at
30 km of altitude

Anisotropic propagation
Atmospheric waveguides
Shadow zones

Effective sound speed



Arrival Times at surface



Source localization (=difficult)

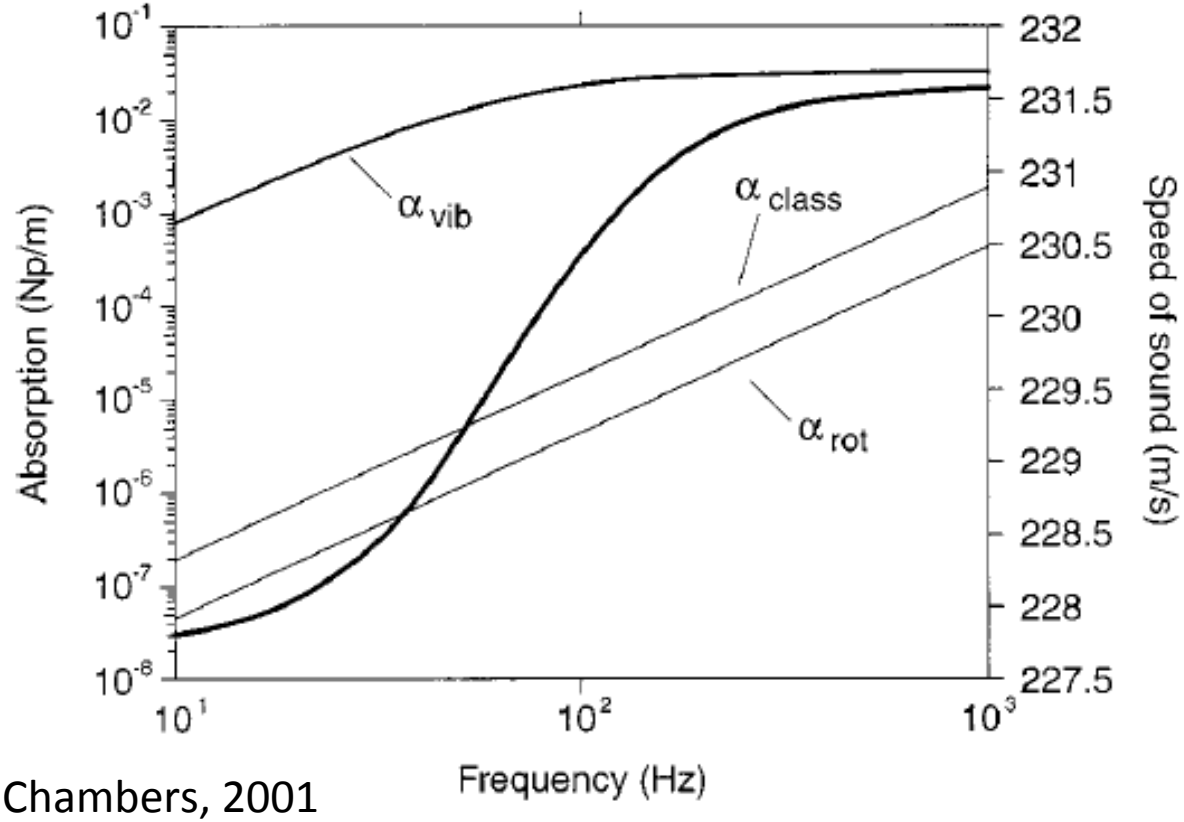
Atmosphere sounding

Atmospheric attenuation

- Mars atmosphere is known for its high attenuation, due to CO_2 relaxation
- At 10 Hz, the attenuation factor is ~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…

Bach
- on Earth
- on Mars

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



Bass and Chambers, 2001

Slide courtesy: P Lognonné

Atmospheric attenuation

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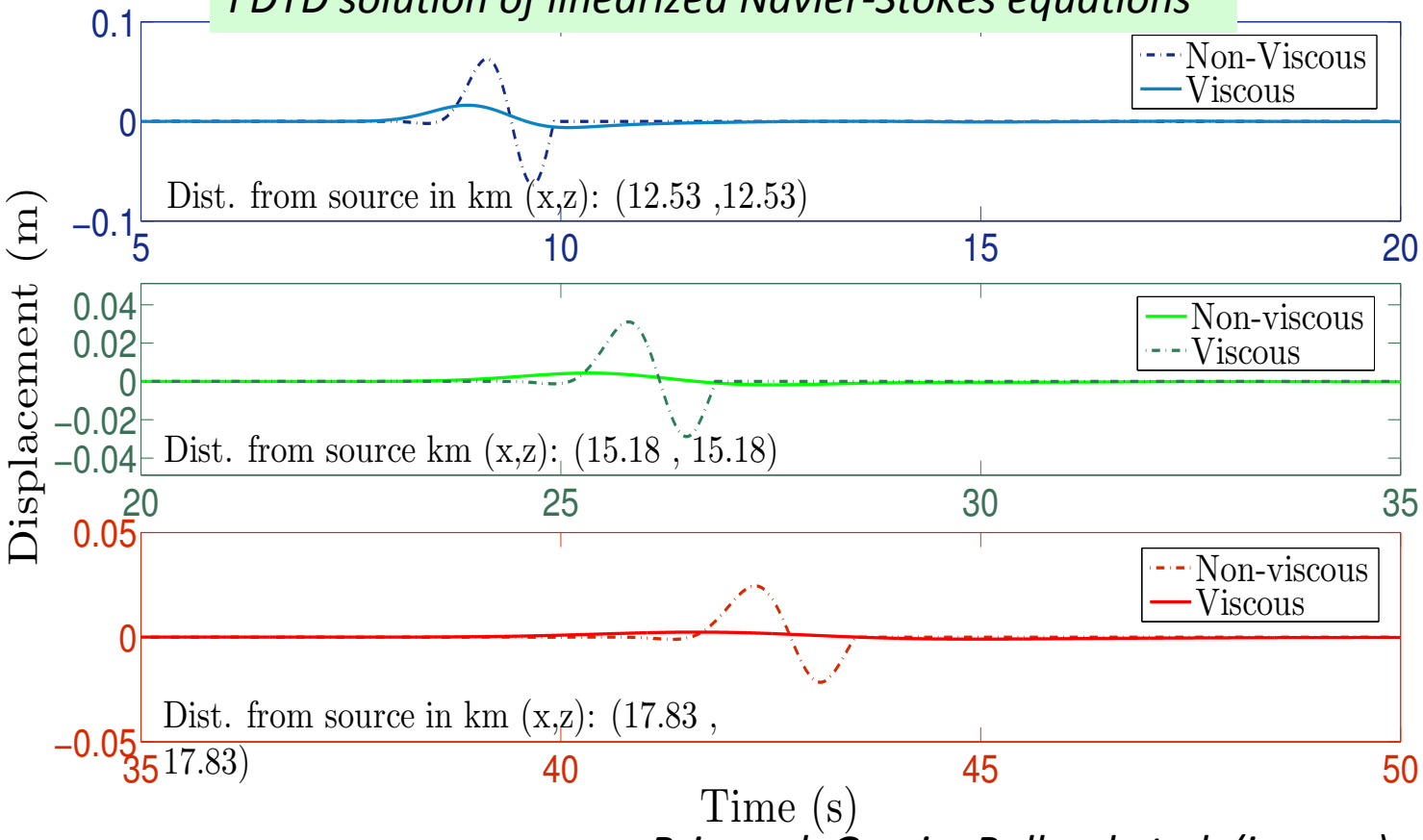
- This will be the major difference with Earth infrasounds (or with viscous only attenuation), for

FDTD solution of linearized Navier-Stokes equations



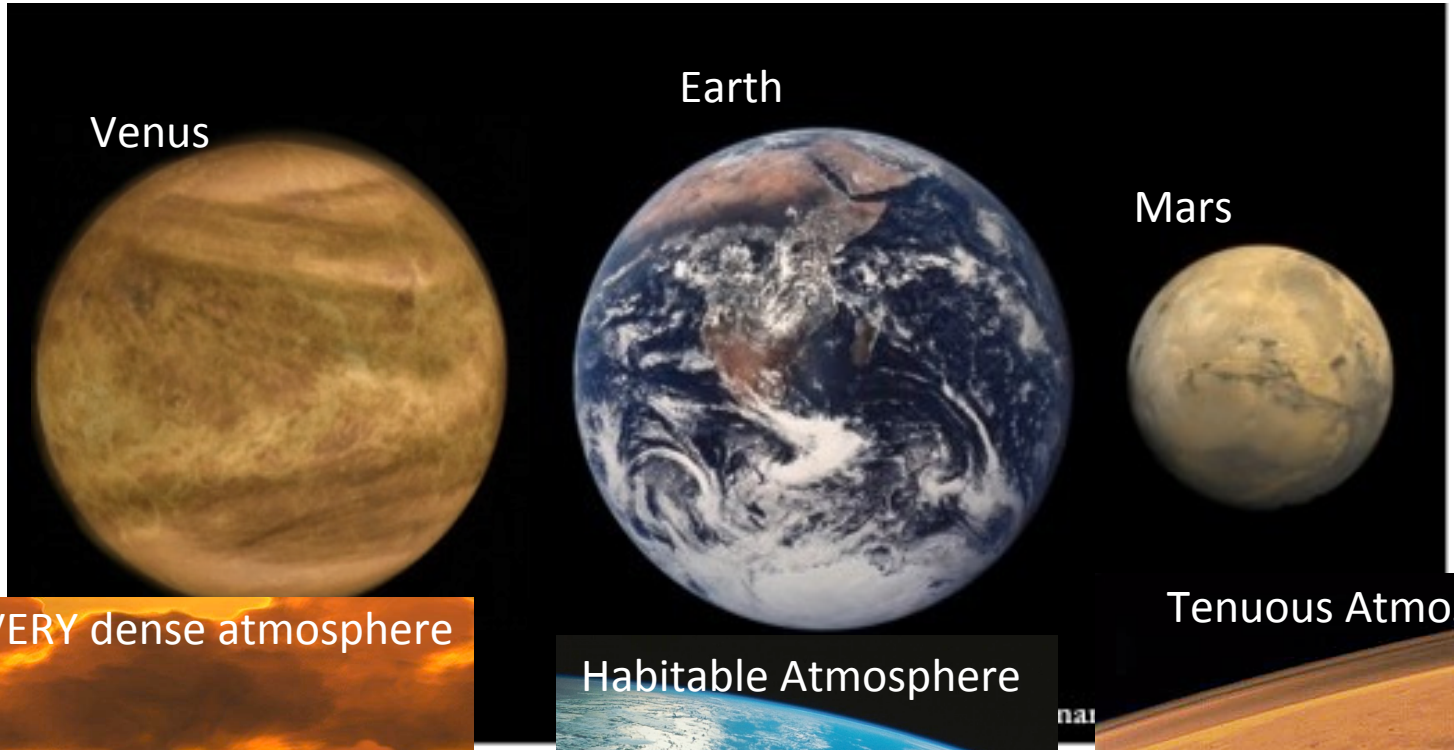
Bach
- on Earth
- on Mars

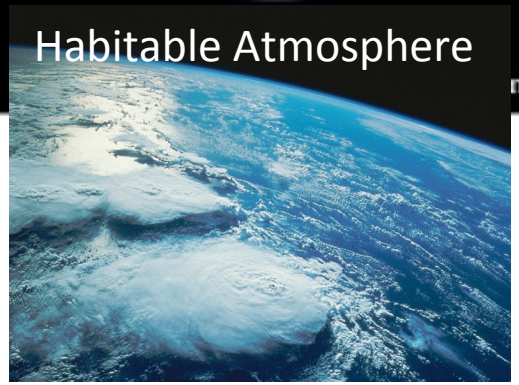
A.Petculescu web
http://www.pepp

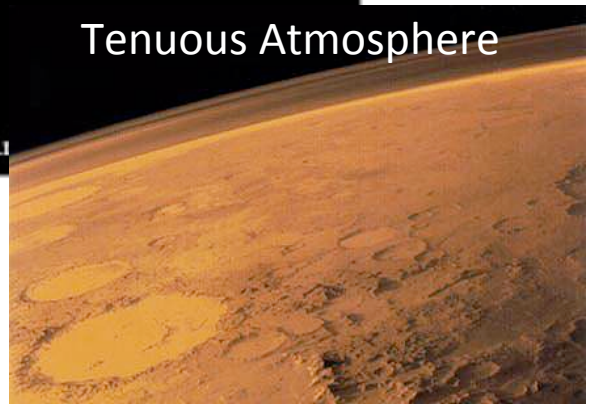
Brissaud, Garcia, Rolland et al. (in prep)

Slide courtesy: P Lognonné

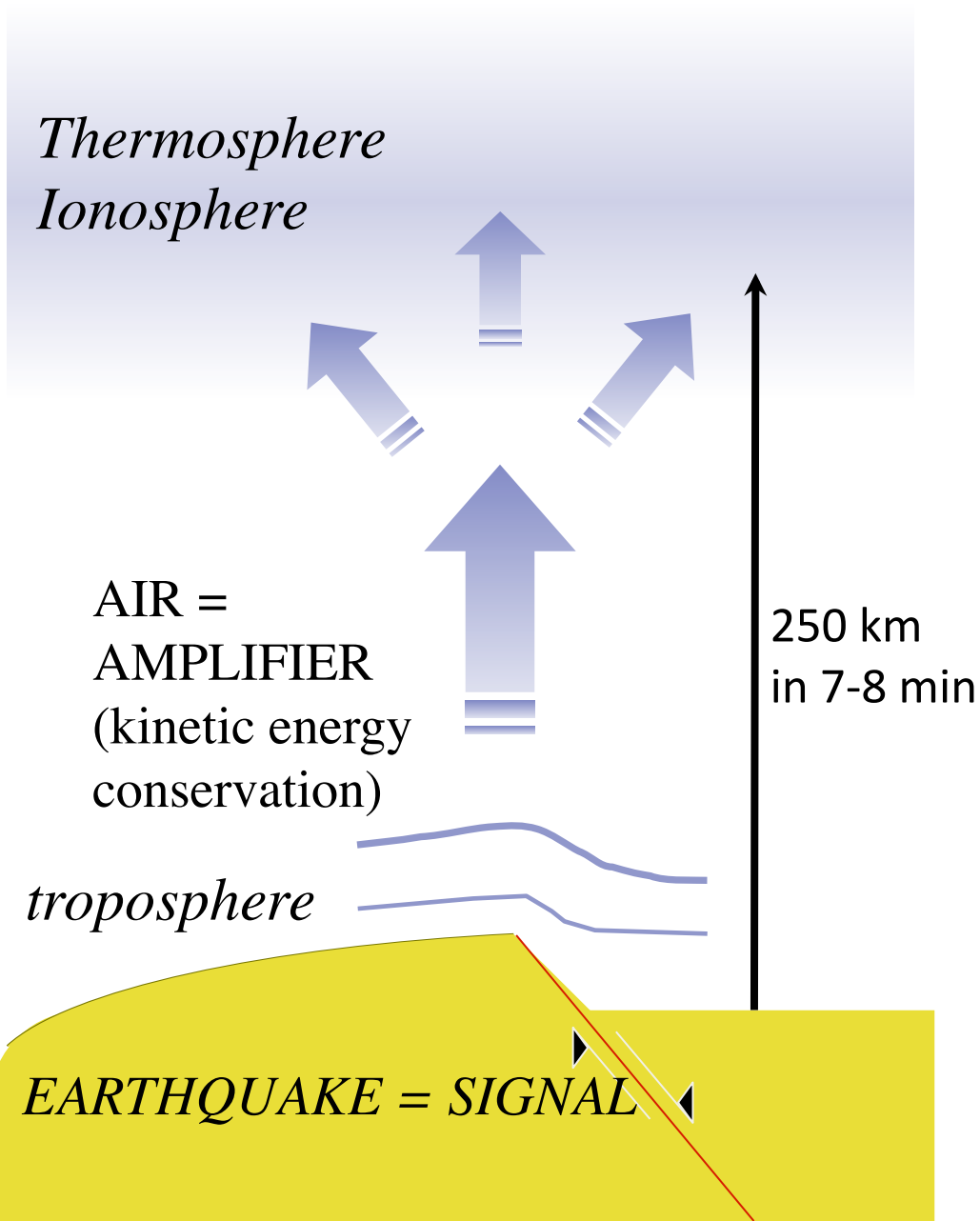
And before Venus ... Back to Earth again

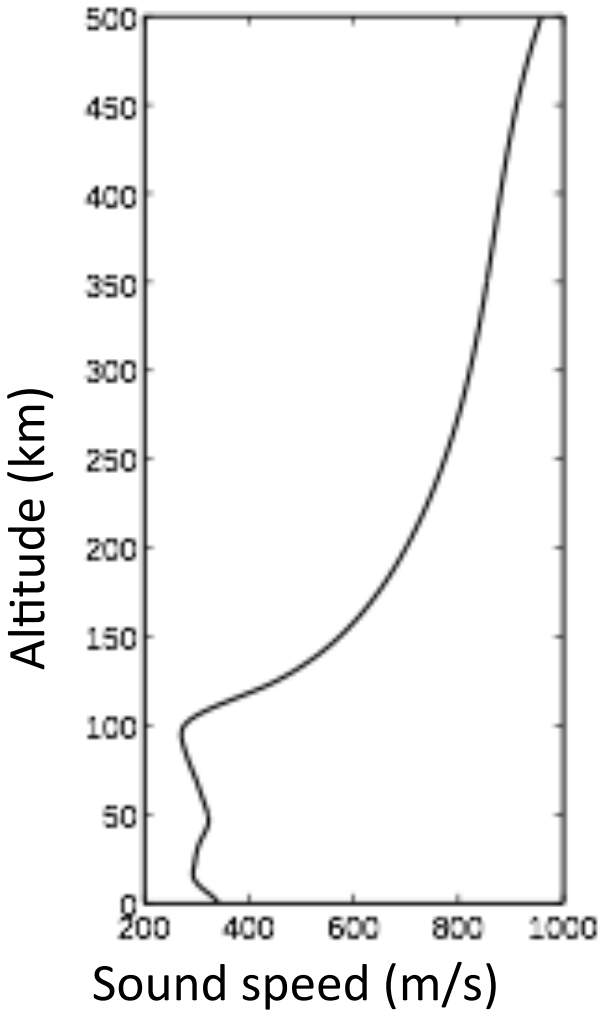






The upper atmosphere is sensitive to ground shaking



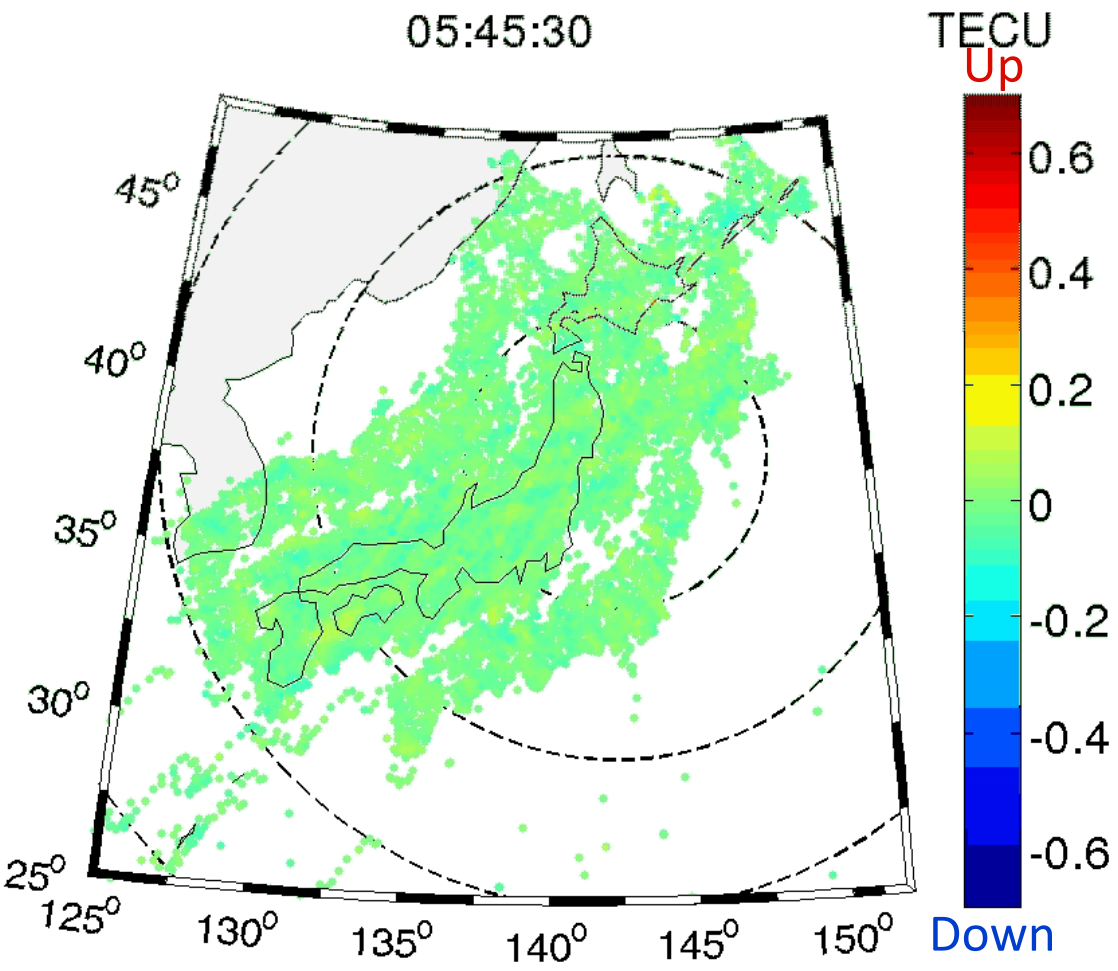


$$c = \sqrt{\gamma \cdot \frac{p}{\rho}}$$

Imaging coseismic atmospheric waves

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

The upper atmosphere motions are sensed using GPS radio sounding.

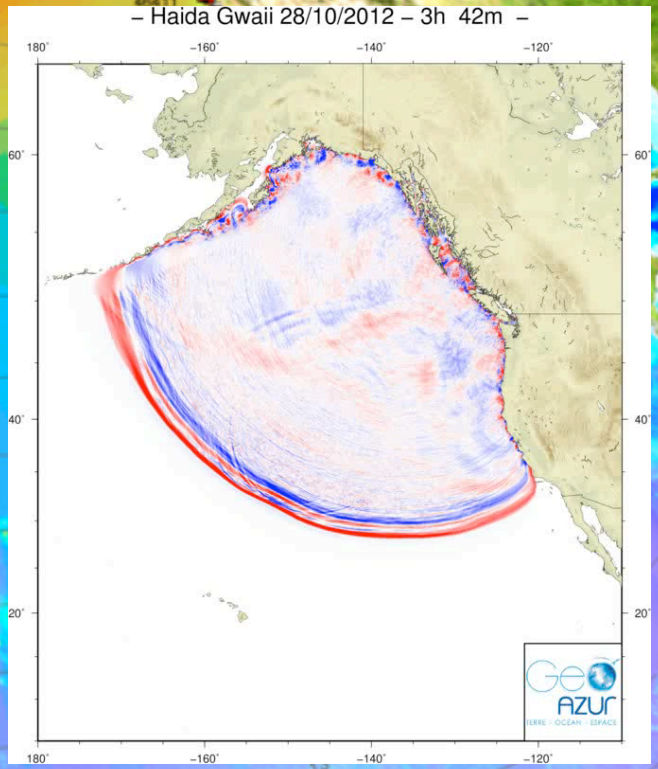


TEC data filtered from 1 to 10 mHz

Transient oscillatory signal: The upper atmosphere is strongly shaken (hundreds of meters):

Haida Gwaii Tsunami

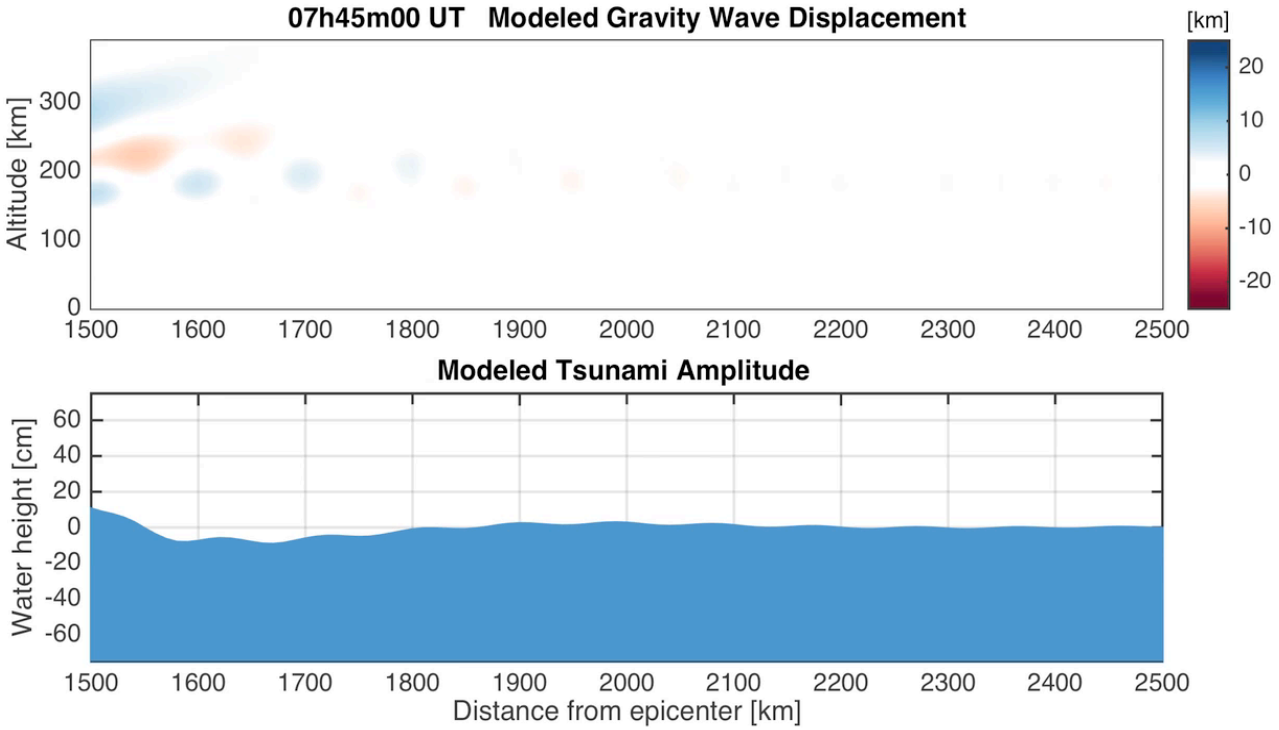
2012/10/28, Mw 7.8



Model and video A. Sladen

October 27, 2012 Queen Charlotte Island Tsunami
NOAA Center for Tsunami Research

Tsunami-induced gravity waves

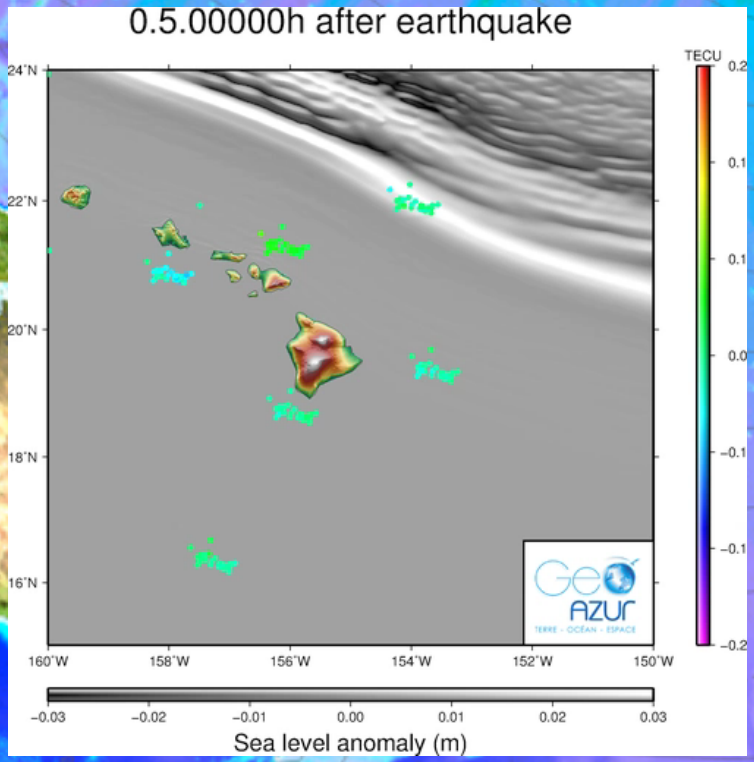


Rolland et al. (2014), Coïsson et al. (2015)

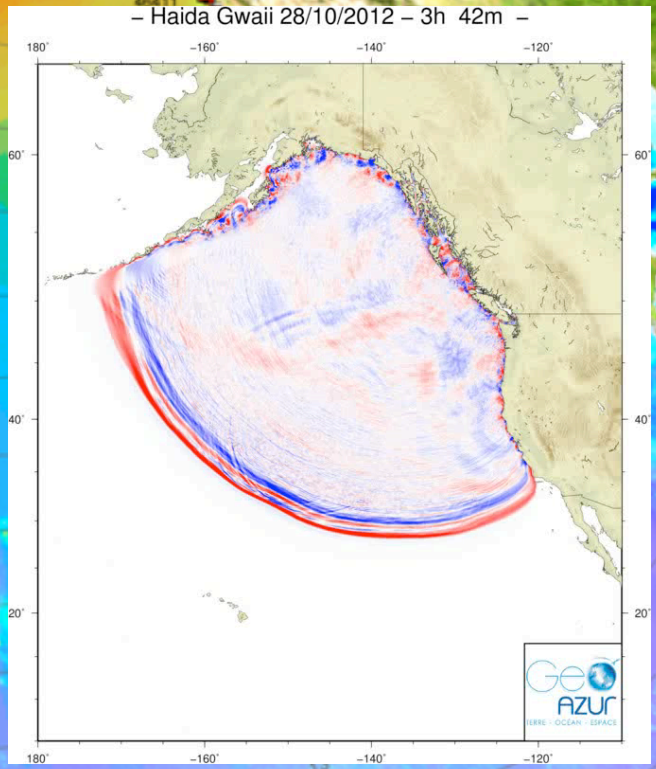
Atmospheric waves by surface waves driven from below inform on the internal structure of the planet (here the ocean depth or crust thickness) and the propagation medium (atmospheric properties)

Haida Gwaii Tsunami

2012/10/28, Mw 7.8



Rolland et al., 2014



Model and video A. Sladen

October 27, 2012 Queen Charlotte Island Tsunami
NOAA Center for Tsunami Research

Haida Gwaii Tsunami

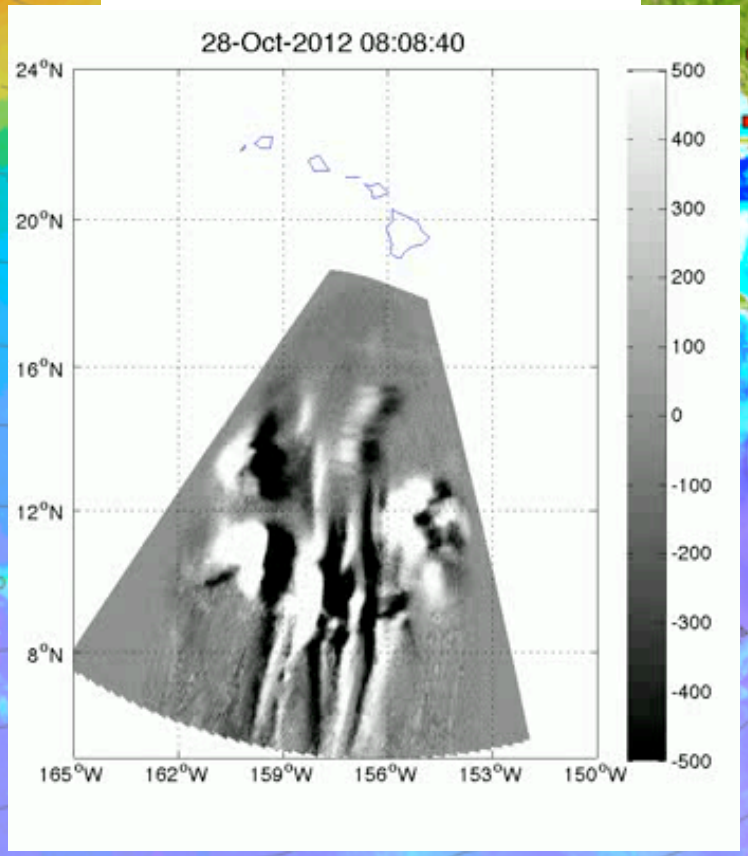
2012/10/28, Mw 7.8

Charge exchange $O_2 + O^+ \rightarrow O_2^+ + O$

Dissociative recombination $O_2^+ + e^- \rightarrow O + O(^1D)$

Airglow emission $O\left(^1D\right) \rightarrow O\left(^3P\right) + h\nu$

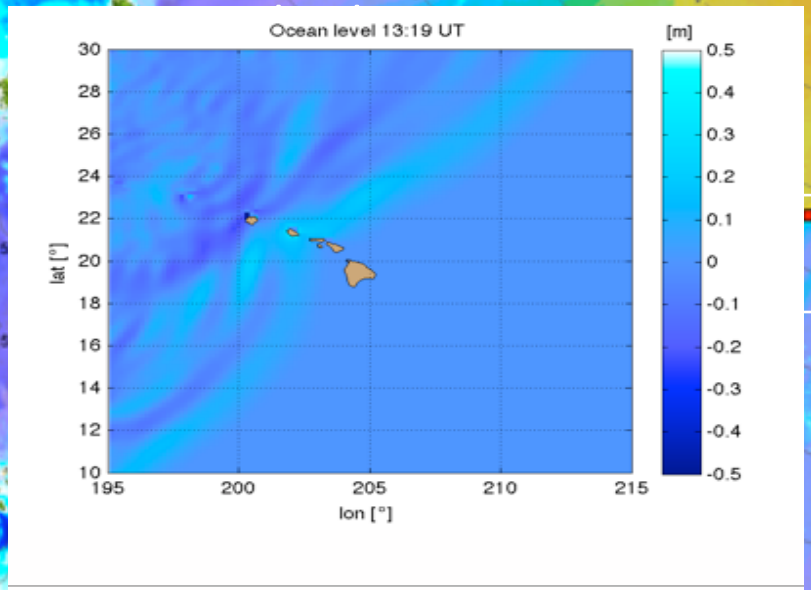
630 nm airglow emission

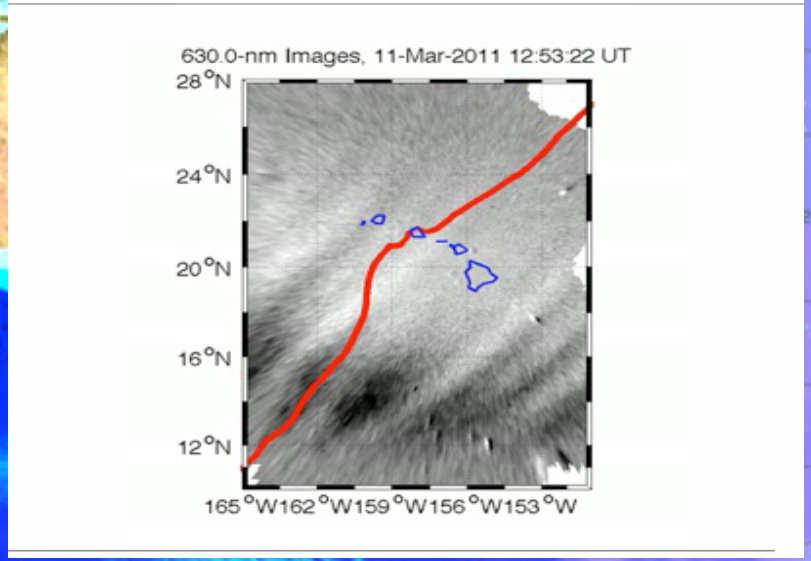


Grawe & Makela (2015)

October 27, 2012 Queen Charlotte Island Tsunami
NOAA Center for Tsunami Research

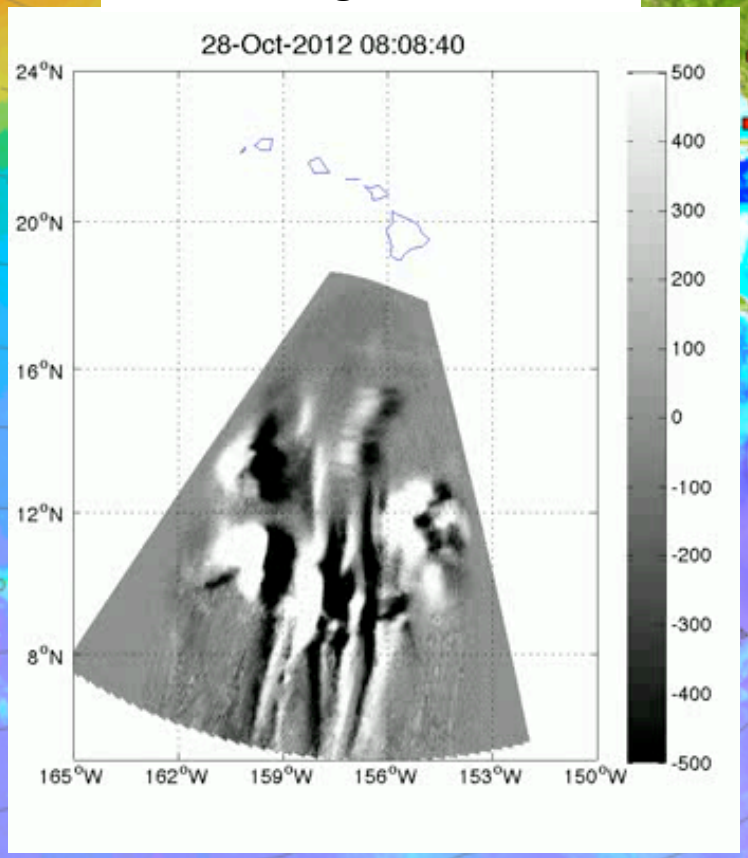
Japan 2011 tsunami





Haida Gwaii 2012 Tsunami

630 nm airglow emission



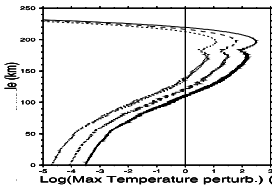
Grawe & Makela (2015)

+ 2 other events show Ionospheric airglow signature (2011, 2015)

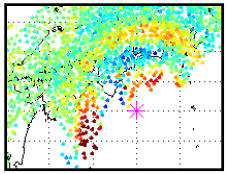
October 27, 2012 Queen Charlotte Island Tsunami
NOAA Center for Tsunami Research

The future: probing the interior of Venus (orbiter)

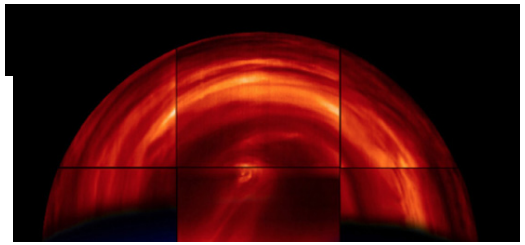
Atmospheric
Density Variatic



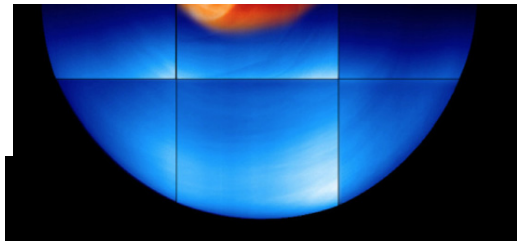
Adiabatic
Temperature
Variations



TEC Variations



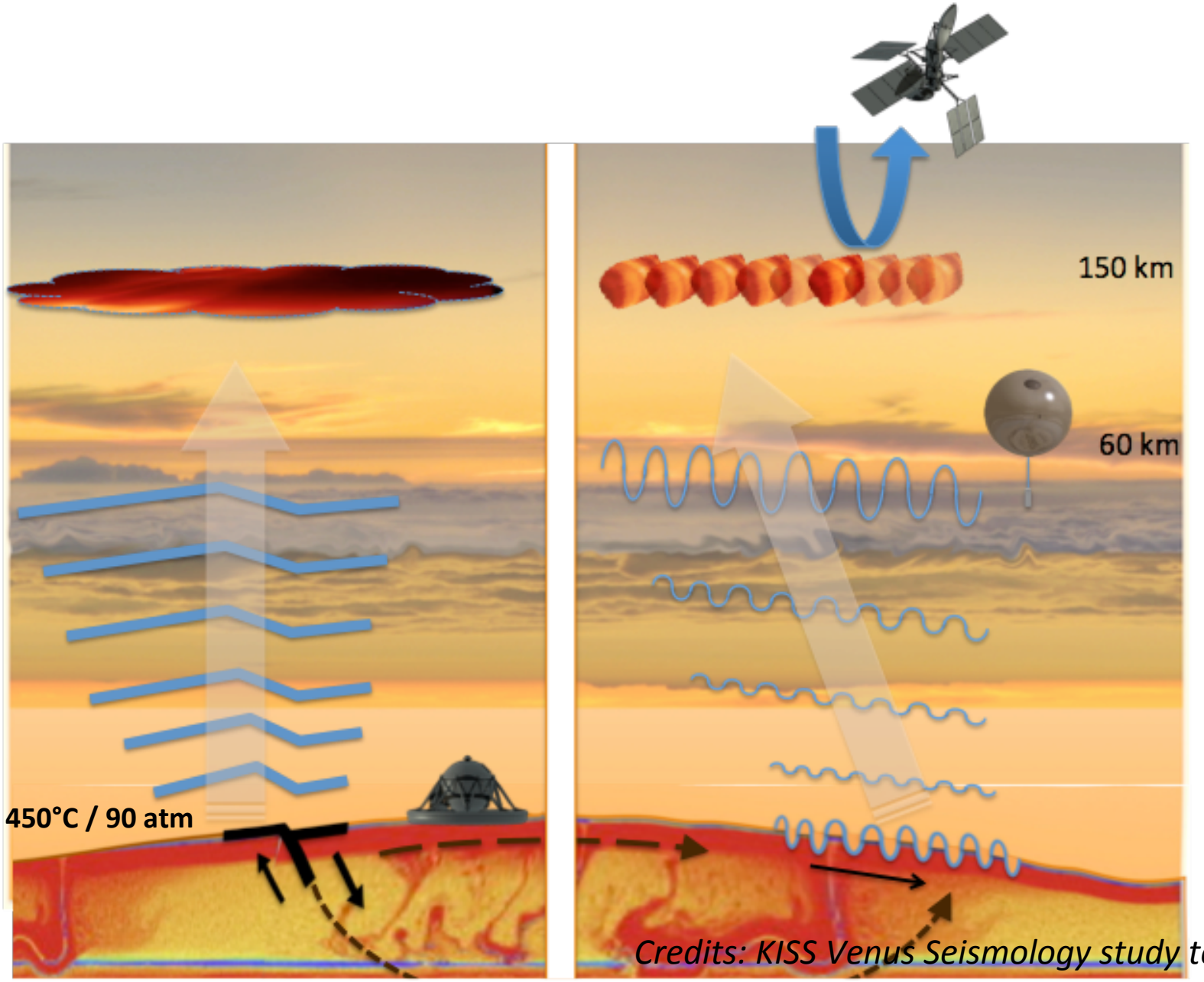
Venus IR Airglow
(here at 1.74
microns)



UV Airglow
(here at 480
nanometres)

Credits: KISS Venus Seismology study team

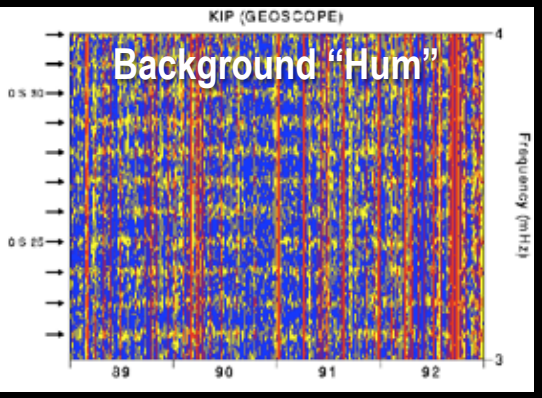
Solid/Atmosphere coupling on Venus

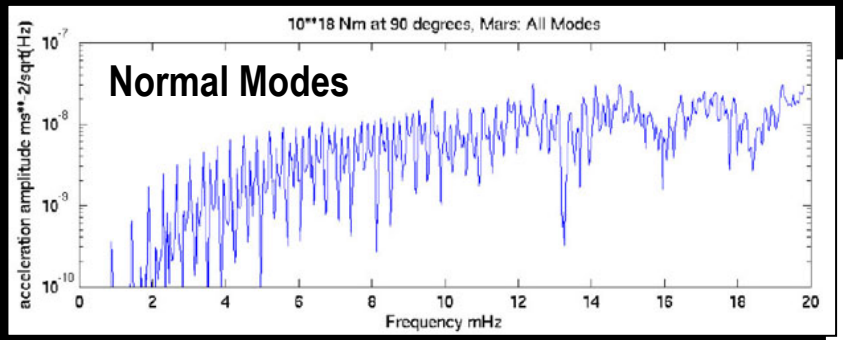


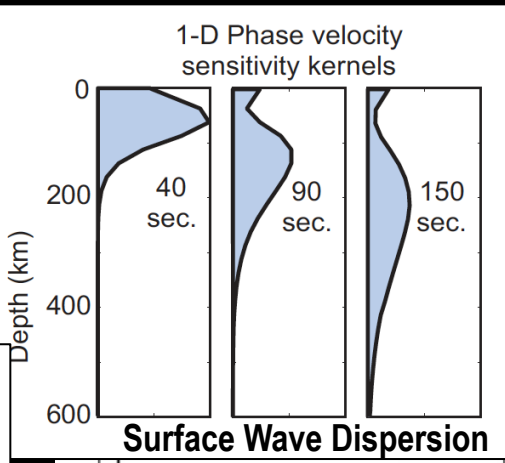
Credits: KISS Venus Seismology study team

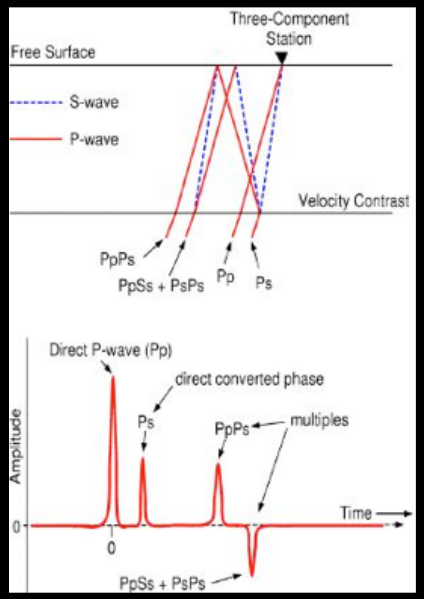
Supplementary materials

Martian Seismology – Single-Station Analysis Techniques

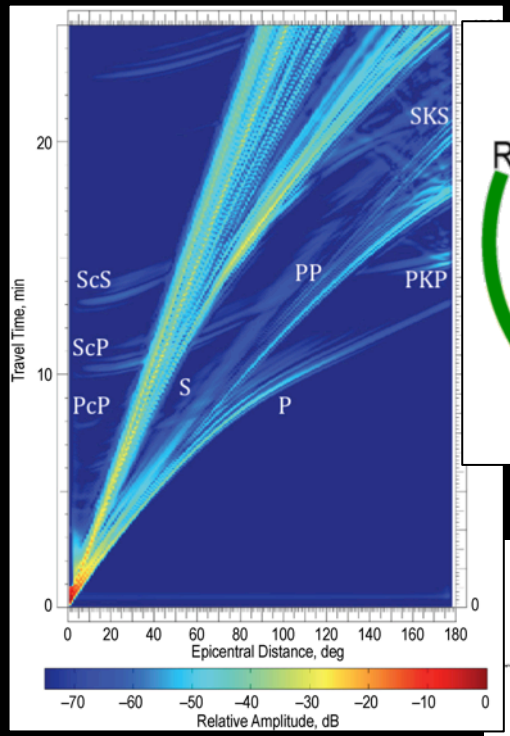


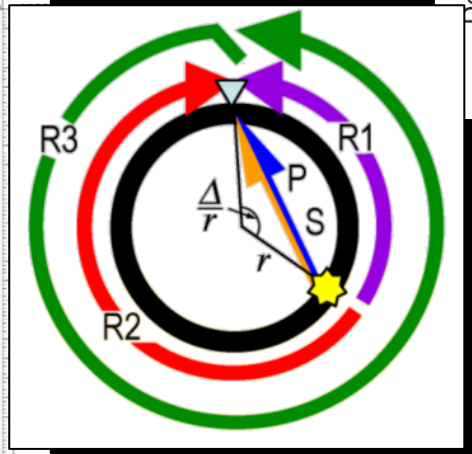






Receiver Function





Arrival Time Analysis