

The InSight Mission HP³ Experiment: The First Heat-Flow Determination on Mars, and an Opportunity for Collecting Parameters for Use of Heat Pumps on Mars*

Paul Morgan¹ and Matthew A. Siegler²

Search and Discovery Article #42140 (2017)**

Posted October 16, 2017

*Adapted from oral presentation given at AAPG 2017 Annual Convention and Exhibition, Houston, Texas, April 2-5, 2017

**Datapages © 2017 Serial rights given by author. For all other rights contact author directly.

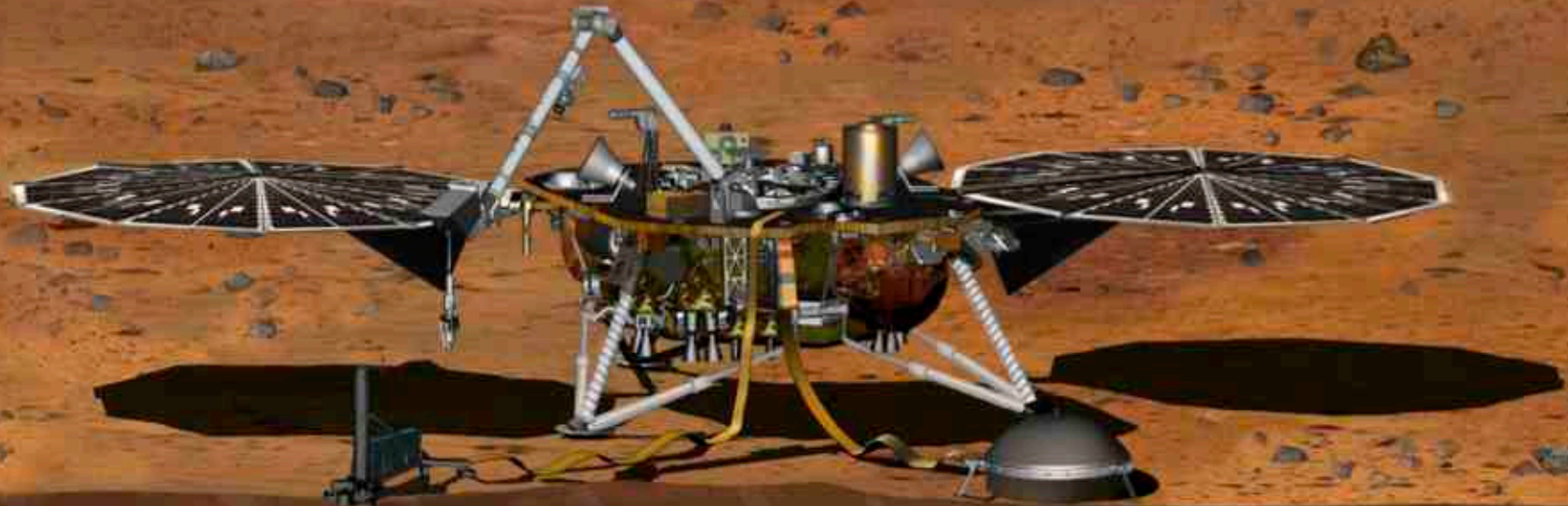
¹Colorado Geological Survey, Colorado School of Mines, Golden, Colorado, United States (morgan.pablo@gmail.com)

²Planetary Science Institute, Tucson, AZ

Abstract

With a launch window starting on May 5, 2017, the InSight (Interior exploration using Seismic Investigations, Geodesy and Heat Transport) Mission to Mars will be the first lander dedicated to geophysical measurements on the closest planet to Earth in terms of habitability. Landing is scheduled for November 26, 2018, and the landing site is in the lowlands at about 40N. The instruments to be deployed on the surface are a broadband seismometer, and a self-penetrating temperature and thermal conductivity probe (HP³) to determine heat flow up to a depth of 5 m (~16.4 feet). The main goal of InSight is to help understand how rocky planets formed and evolved. The primary mission is for the seismometer and heat-flow probe to collect data for one Mars year (687 days). Mars heat flow is likely to be low (~25 mW/m²), and the potential for recovering heat from the Mars interior for heating human habitations or for other direct heat use is low. However, ground-source heat pumps, powered by solar energy, may be a viable option for producing domestic, agricultural, and low-grade industrial heat on Mars. The InSight heat-flow experiment will produce the first measurement of the thermal gradient in the Mars regolith and measurements of the thermal conductivity and thermal diffusivity of the upper layers (upper 5 m) of the regolith. These parameters are required to assess the possibility of using ground-source heat-pumps on Mars. In addition, the penetration of the heat-flow probe will provide geotechnical information about the upper layers of the regolith and seismic signals recorded from the probe penetration may yield information about layering in the subsurface at the landing site. Thus, although the scientific goals of the InSight are planet-wide in extent, important data will also be collected at the habitation module scale relevant to human exploration of Mars.

The InSight Mission HP³ Experiment: The First Heat-Flow Measurement on Mars, and an Opportunity for Collecting Parameters for Use of Heat Pumps on Mars



Paul Morgan and Matthew A. Siegler
for the HP³ Instrument Science and Instrument Team

100 AAPG Anniversary ACE 2017 Annual Convention & Exhibition
Monday, April 2, 2017, Houston, Texas
AAPG Astrogeology Session



InSight

JPL



cnes



ETH

MPS

ISAE



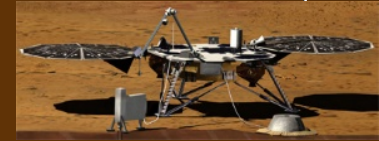
Imperial College
London



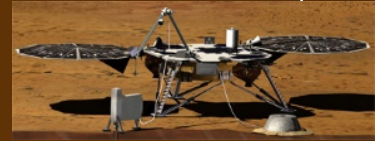
CAB

SMU





- **InSIGHT**: Interior exploration using Seismic Investigations, Geodesy and Heat Transport.
- 1st geophysics mission to Mars; 1st specifically to study Mars interior.
- Joint NASA/JPL, multi-US-institutional, multi-national mission.
- NASA/JPL/Lockheed-Martin providing launch vehicle (Atlas 5 rocket) and spacecraft; European agencies providing most of the scientific instruments.
- Launch window opens: May 5, 2018
- Landing: November 26, 2018
- Primary mission surface operations: 728 days/708 sols
- Scientific instruments: Heat-flow probe; Seismometer;
Doppler-shift ranging; Air temperature & pressure; Magnetometer; Cameras.

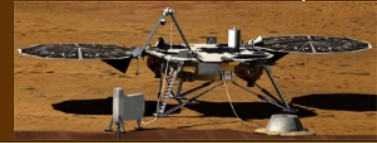


- Determine the size, composition, physical state (liquid/solid) of the Martian core;
- Determine the thickness and structure of the Martian crust;
- Determine the composition and structure of the Martian mantle;
- Determine the thermal state of Mars' interior;
- Measure the magnitude, rate, and geographical distribution of Mars' internal seismic activity;
- Measure the rate of meteorite impacts on the surface of Mars.

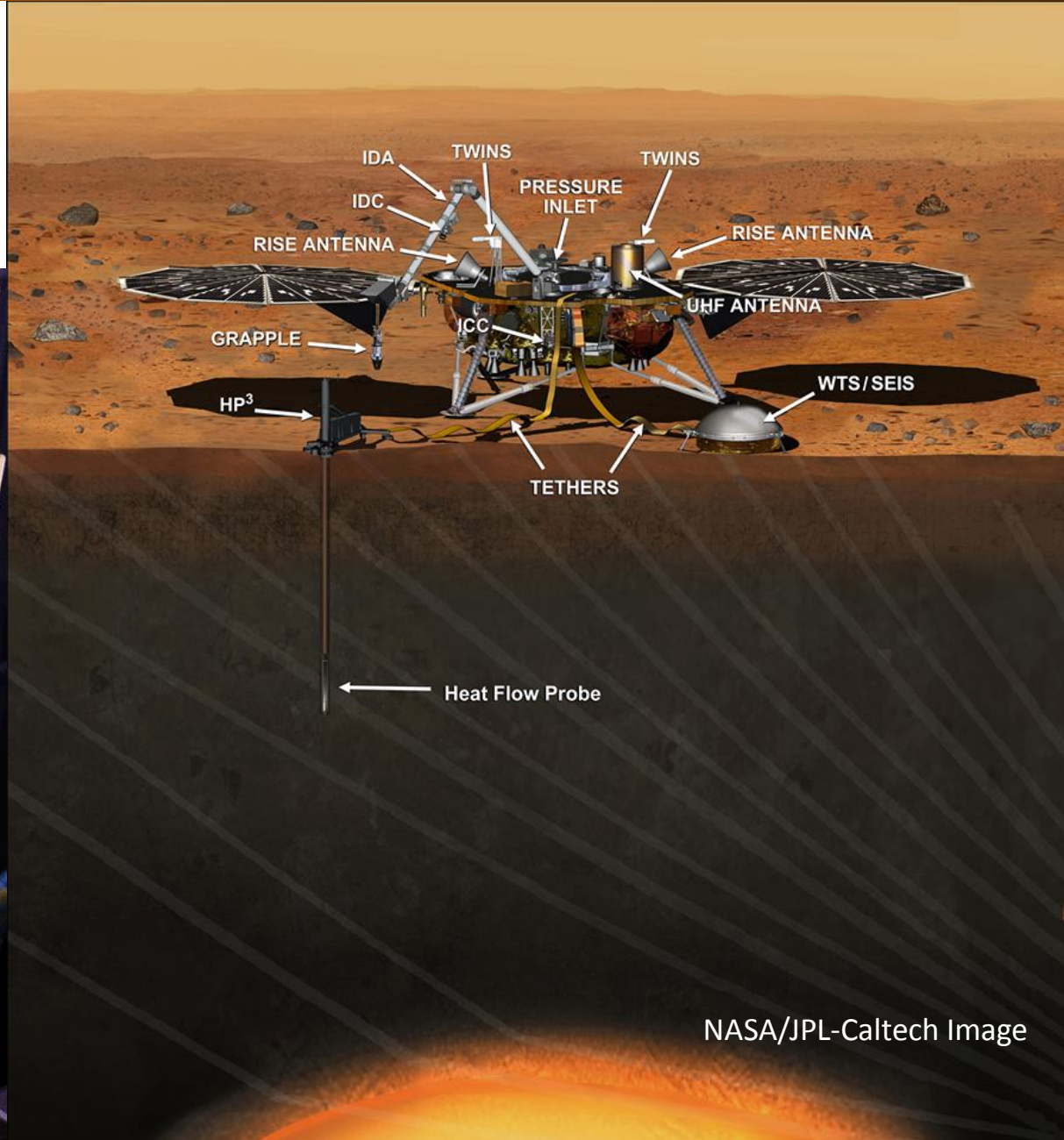


InSight

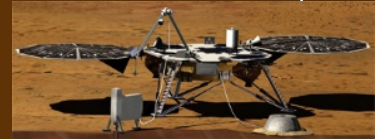
Tested successful spacecraft: all new science



- 12th NASA Discovery Mission (competitive mission selection), based on the successful 2008 Phoenix lander spacecraft.



NASA/JPL-Caltech Image



- InSight would fly a near-copy of the successful Phoenix Flight System
 - System (including hardware, procedures, and personnel) has already operated on Mars
 - Only minor changes required for InSight
 - Proven procedures and personnel available
 - Much fewer instruments with a simpler Science mission

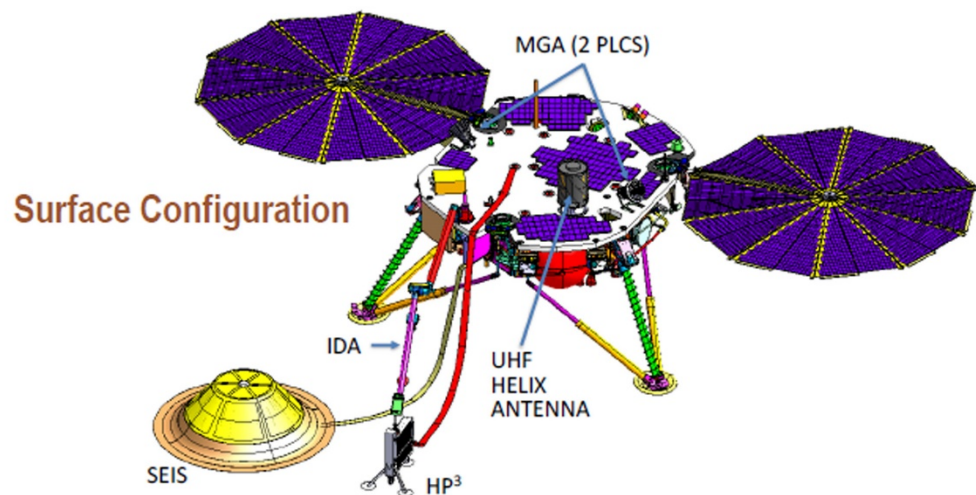
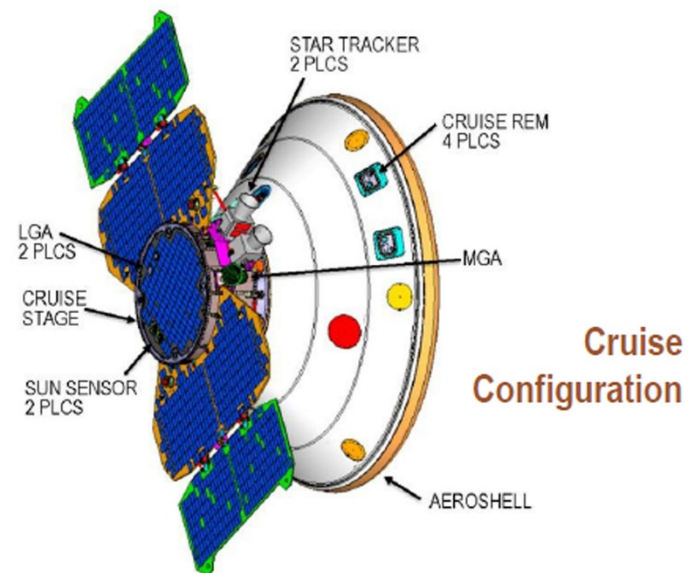
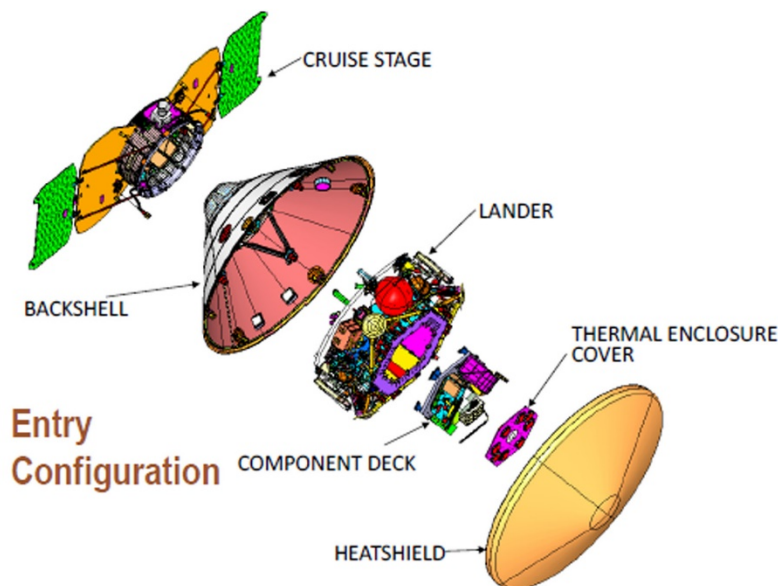
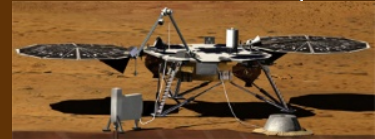


Image Bruce Banerdt & Sue Smrekar, NASA/JPL

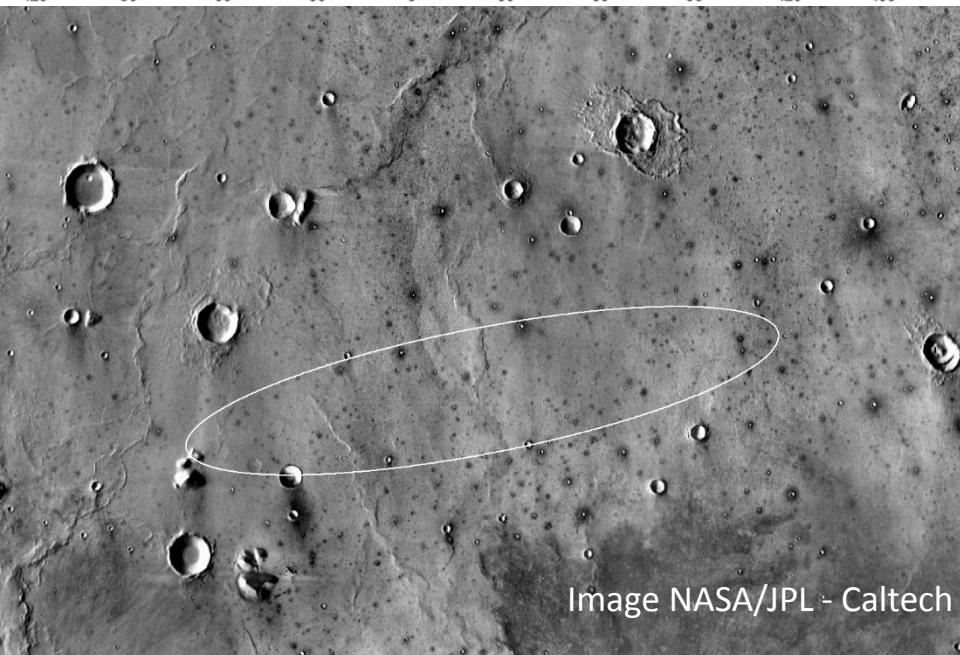
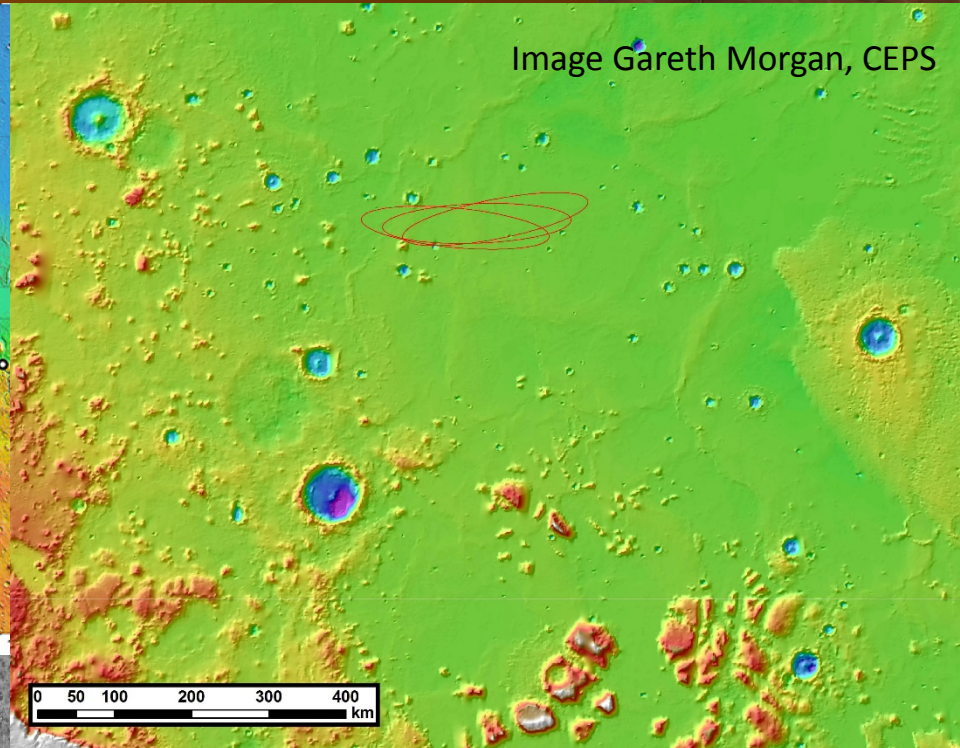
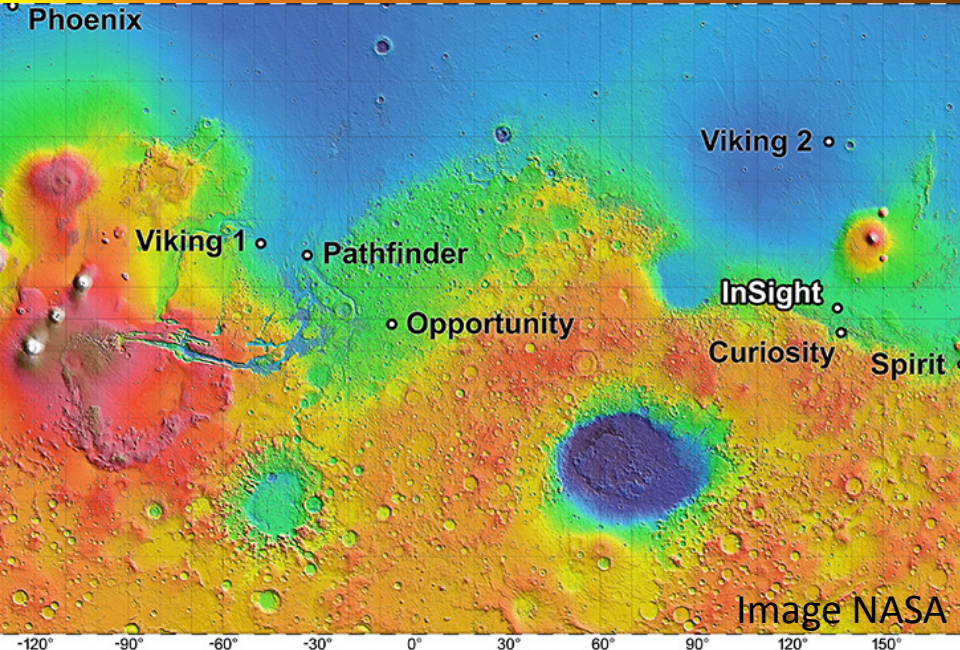


InSight

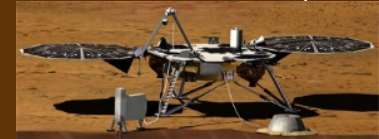
InSight Landing Ellipse 130 km x 27 km



Phoenix



- Elysium Planitia Region Selected:
 - Relatively flat;
 - Low rock abundance;
 - No large craters;
 - No steep slopes;
 - > 3-5 m thick regolith (HP³).
- 16 original landing ellipses:
finally down-selected to 1.



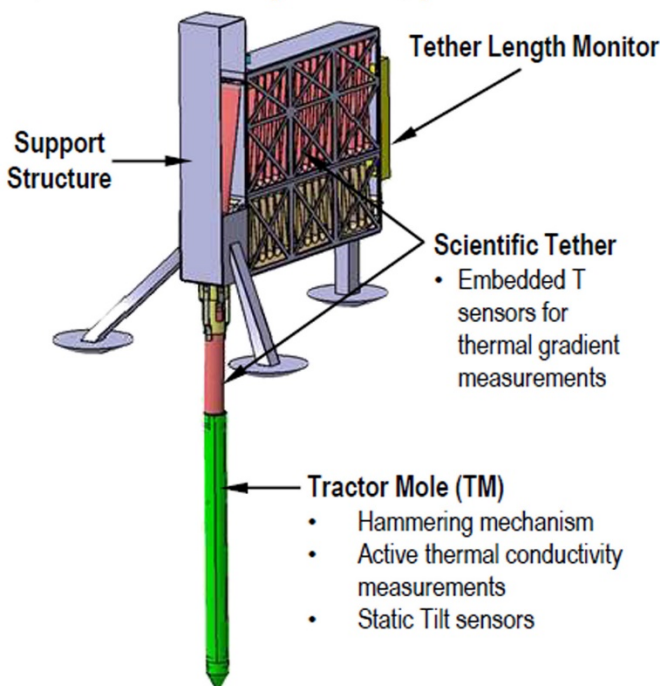
Small Deep Space
Transponder

RISE (S/C)

Rotation and Interior
Structure
Experiment

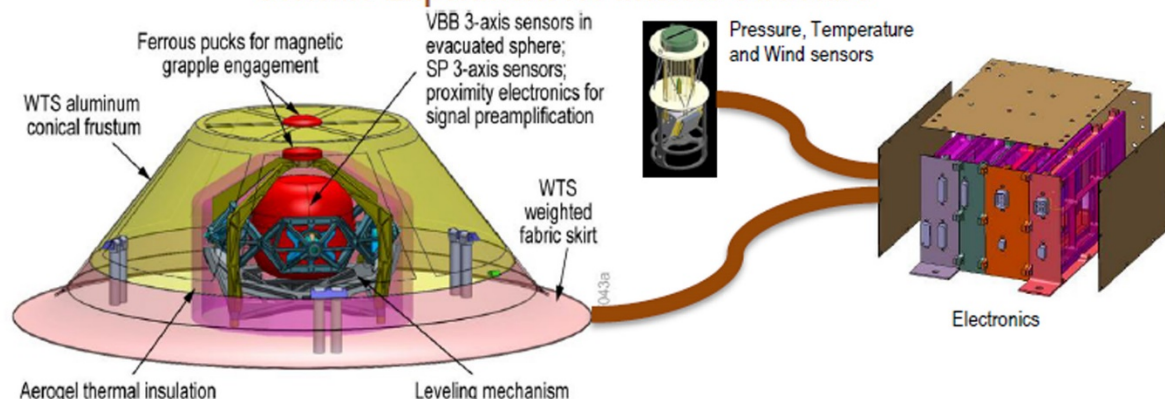
HP³ (DLR)

Heat Flow and Physical Properties Probe



SEIS (CNES)

Seismic Experiment for Interior Structure



Surface Deployment
Test Bed

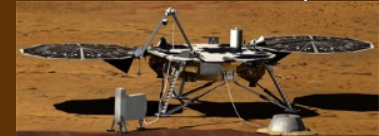
IDA (JPL) – Instrument Deployment Arm)



IDC (JPL) – Instrument Deployment
Camera)

ICC (JPL) – Instrument Context
Camera)

Image Bruce Banerdt & Sue Smrekar, NASA/JPL



Support Structure (SS)

Tether Length Monitor (TLM)

Engineering Tether

Connects to Back End Electronics (BEE) on S/C

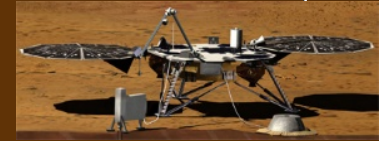
Science Tether (TEM-P)

Embedded T sensors for passive thermal gradient measurements

Mole

- Hammering mechanism
- Heater foils / sensors for active thermal conductivity measurements (TEM-A)
- Static Tilt sensors (STATIL)

Image Tilman Spohn, DLR



Hammer is pulled back against *force springs* by rotation of *cylindrical cam*. Step in *cam* releases *hammer* to drive mole forward. Process repeats.

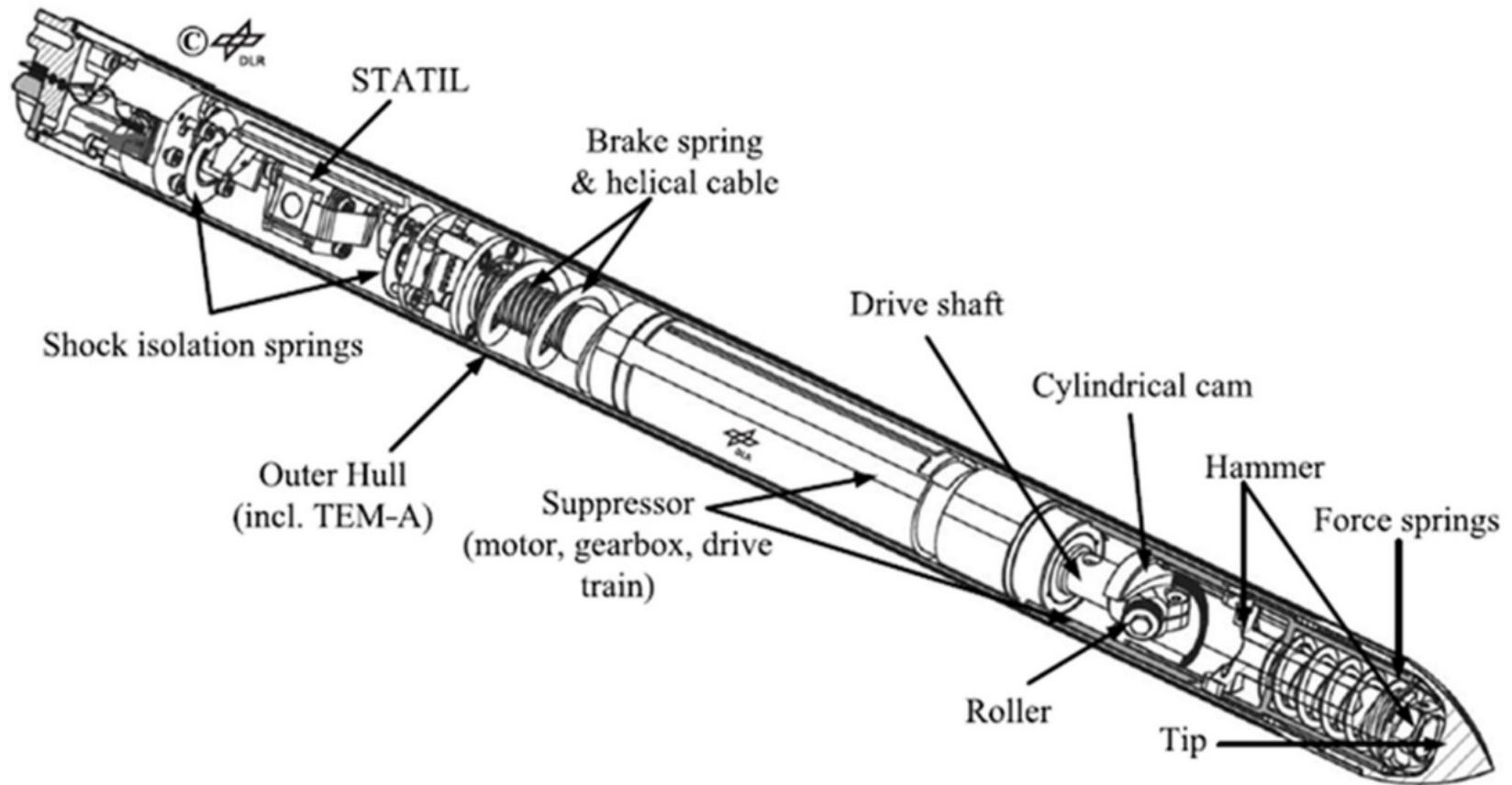
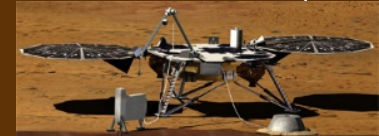


Image Tilman Spohn, DLR



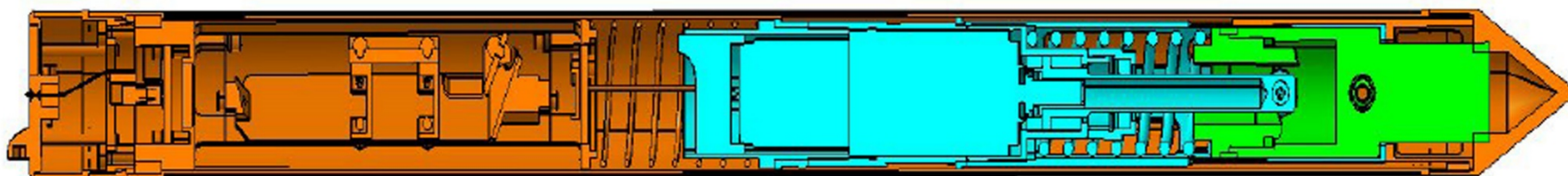
InSight

HP³: Prototype Mole



STATIL

Motor



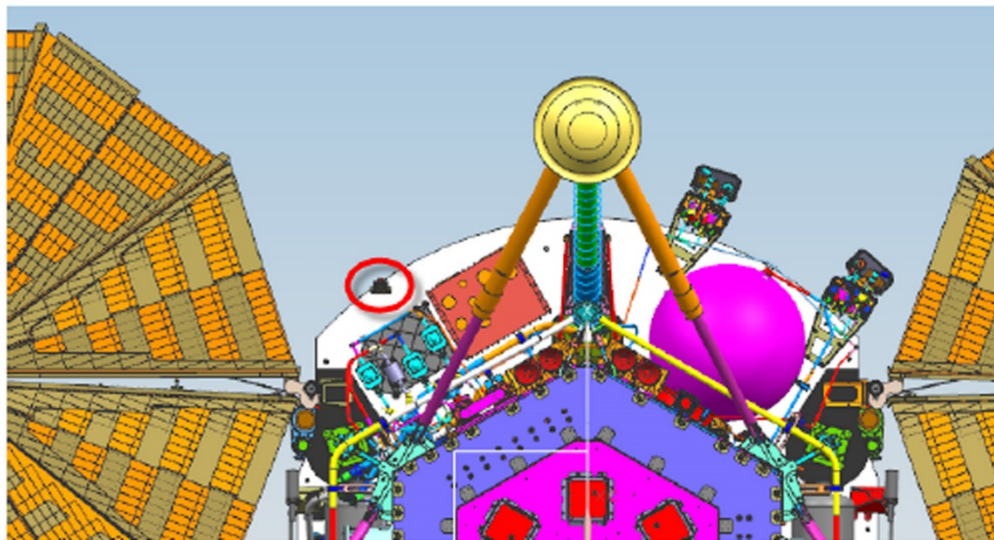
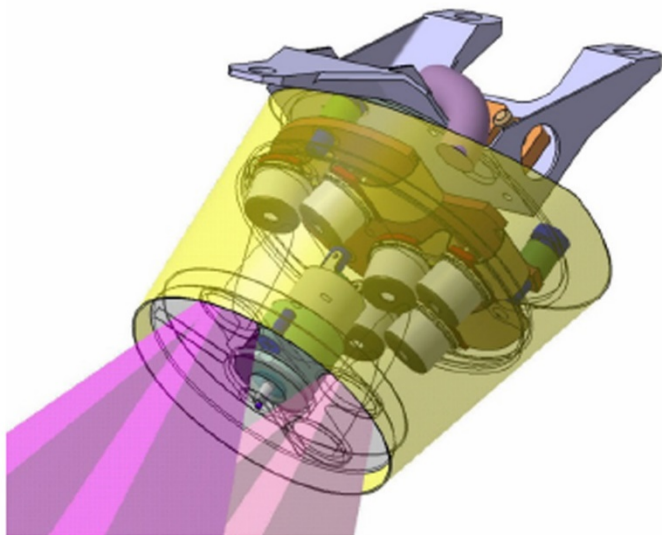
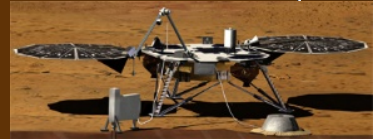
TEM foils (TEM-A: foils within mole outer hull)

Prototype Mole: Under construction



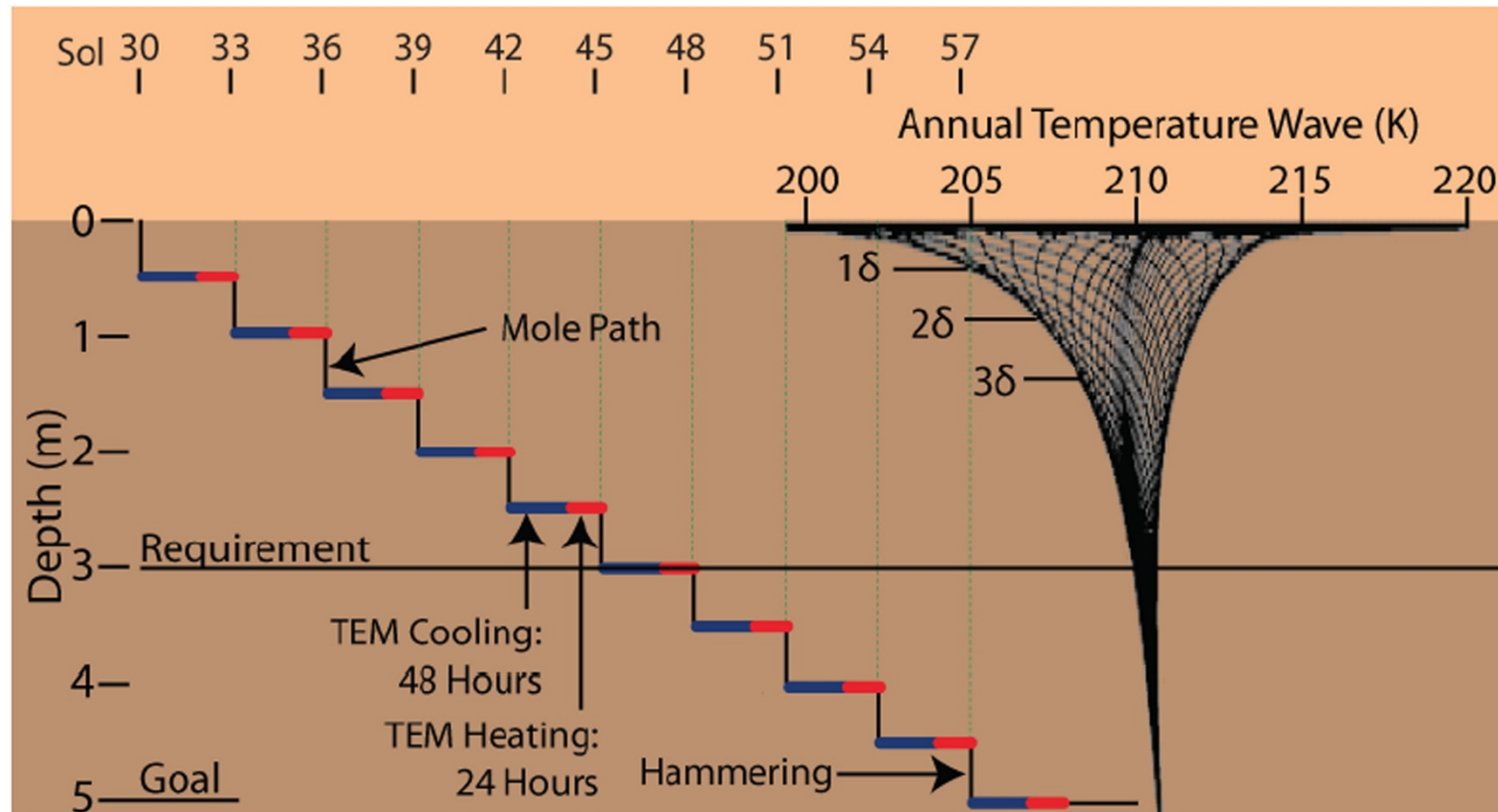
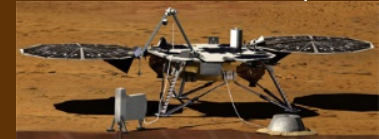
Breadboard mole: Currently used for part 1 of TRL 6 test at JPL

Image Tilman Spohn, DLR



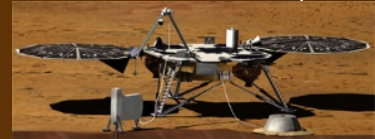
- 2x3 channels to determine the flux in different wavelength bands
- Employs thermopile sensors to measure the temperature of the surface
- To be mounted below the lander deck and measure the surface temperature in an unshadowed region unobstructed by hardware (HP³, SEIS)

Image Tilman Spohn, DLR

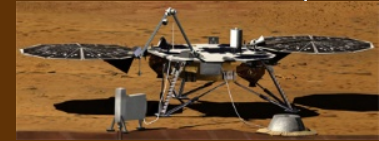


- HP³ is deployed by the Instrument Deployment System (IDS)
- The penetration phase lasts ~ 30 Sols and incorporates thermal conductivity measurements between hammering cycles.
- During penetration STATIL and TLM are used to determine the mole path

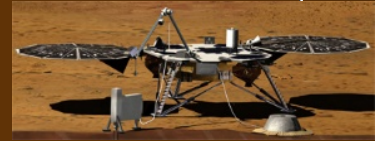
Image Tilman Spohn, DLR



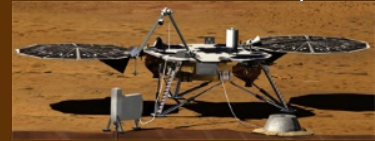
- Regolith temperatures extrapolated from *Mole* temperature during cool-down period;
- Mole depth from *Tether Length Monitor* in *HP³ Support Structure*;
- Regolith temperatures also measured for 1 Mars year after full penetration by platinum resistance devices embedded at depth intervals in capton Science Tether;
- Temperature gradient, $\partial T/\partial z = \frac{\text{(difference in temperature)}}{\text{(difference in depth)}}$;
- Thermal conductivity, K , measured by measuring rise in temperature of Mole when outer layer of *Mole* heated by electrical resistance heaters;
- Heat flow, $Q = K \partial T/\partial z$.



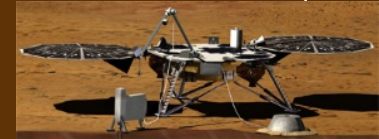
- Changes in surface temperature:
 - Diurnal/annual surface temperature variations – mostly predictable but also thermal effects of long-lasting dust storms;
 - Surface modification during landing; pulsed rocket engines will remove layer of fine-grained surface material changing position of surface and surface albedo;
 - Shadowing and reflected solar radiation from the spacecraft;
 - The effects of surface modification and of shadowing and reflected radiation from the spacecraft may be compensated by modeling.
 - They may also be avoided by using only data collected at depth before the effects of surface temperature modifications associated with the spacecraft have propagated to depth, *e.g.* using only data collected from below 3 m during the first 100 sols after landing.



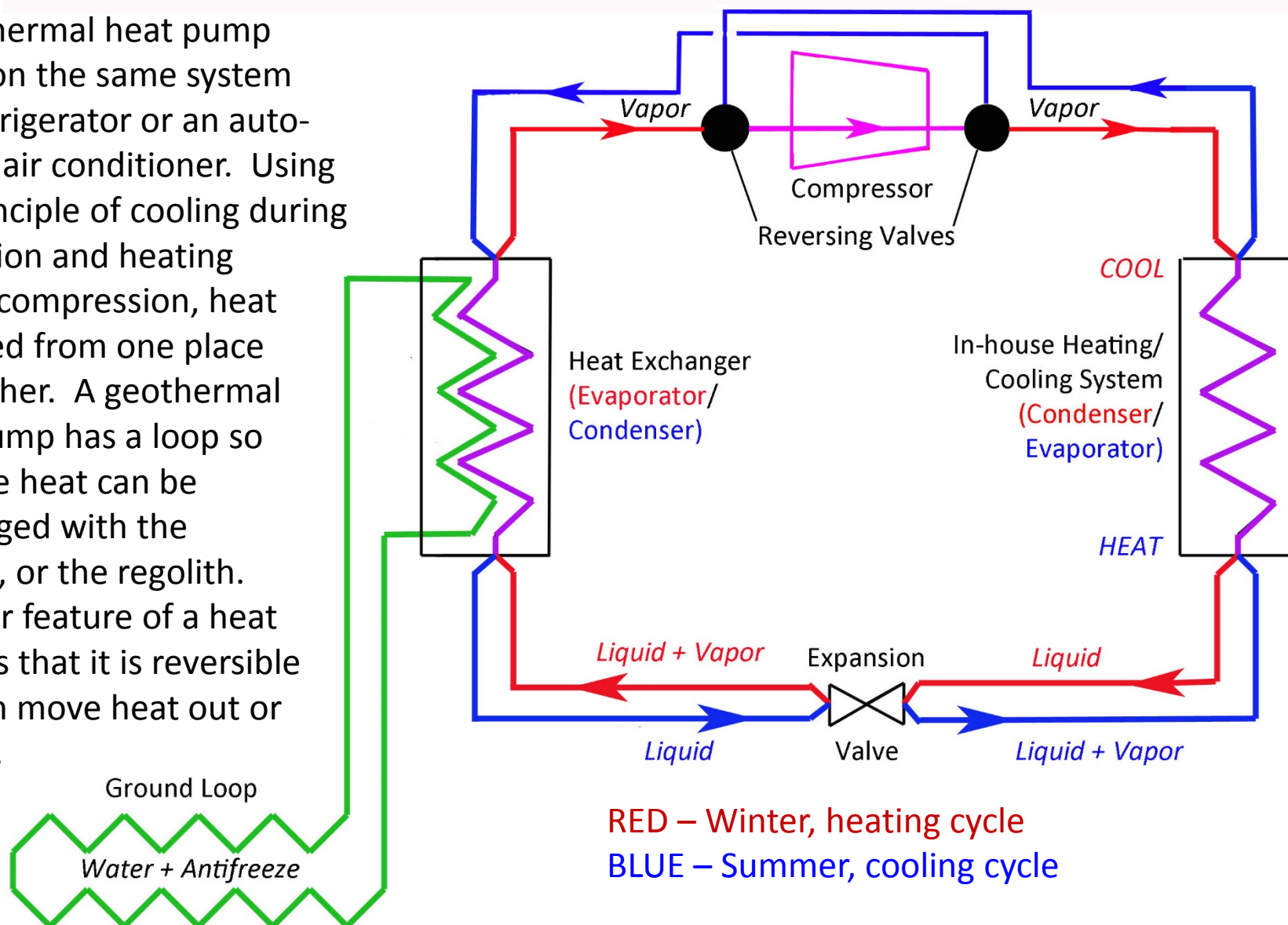
- Barometric pumping – movement of CO_2 in and out of the regolith with changes in atmospheric pressure could convect heat that would not be measured with the conductive heat-flow measurement;
 - Calculations indicate that this should not be a significant effect, but it would be apparent in an increasing thermal gradient with depth;
- Failure of the Mole to penetrate to planned depth (5 m) because regolith is too consolidated, too thin, or Mole is obstructed by a rock;
 - Minimum depth of penetration for optimum measurement is 3 m. However, a useful heat-flow determination could be made with shallower penetration but would require corrections for the annual wave a definitely require corrections for surface temperature changes associated with the spacecraft.

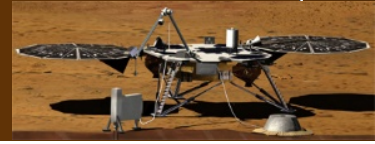


- Temperature at the equator of Mars can rise as high as 20°C (68°F) during the day at some locations in summer but drop as low as -100°C (-150°F) at the equator at night. At all other locations corresponding temperatures are lower. For humans, staying warm on Mars will be an important factor.
- Solar energy will be weak because of the distance of Mars from the Sun (average about 1.5 x distance of the earth from the Sun): solar energy is $\sim 1/(1.5)^2$ or ~ 0.44 x the energy at the earth. This will probably be useful for making some solar PV electricity, and some indoor greenhouse heat, but a backup heating system will be required at night.
- We do not expect to measure a high thermal gradient on Mars, but with a firm measurement of the regolith temperature and thermal conductivity, we have the data required to design a geothermal heat-pump system.

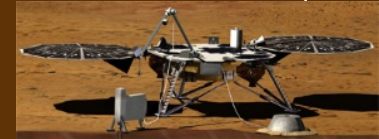


A geothermal heat pump works on the same system as a refrigerator or an automobile air conditioner. Using the principle of cooling during expansion and heating during compression, heat is moved from one place to another. A geothermal heat pump has a loop so that the heat can be exchanged with the ground, or the regolith. Another feature of a heat pump is that it is reversible and can move heat out or heat in.





- In winter, a Mars-thermal (geothermal) heat pump would take heat from the regolith and pump it into human habitation space. If necessary, the pump would be reversed during summer days to cool the habitation space and replace heat in the regolith.
- If the system cause a significant drain on heat in the regolith, heat could be replaced by having a surface loop similar to a direct solar hot water system. The heat pump could boost the temperature of the ground water loop fluid during the day to replenish the regolith heat.
- The system would require electricity, but heat pumps make much more efficient use of electricity than electrical resistance heaters. Run on solar (or wind?) electricity, they require no fuel transported from the earth to Mars, and have no emissions.



- The InSight Mars lander project is an investigator initiated mission that will be the first mission to collect significant geophysical data to study the interior of Mars;
- One of the primary science components in the mission is a heat-flow experiment that includes a self-hammering mole that will make penetrate up to 5 m into the Mars regolith at the landing site, make temperature and thermal conductivity measurements, and continue to make temperature measurements for a full Mars year (687 days);
- These data will be used together with seismic and other data to gain an understanding of the structure and composition of the interior of Mars.
- A bonus product will be direct measurements of the thermal properties of the Mars regolith. These properties are important in the consideration of the use of Mars-thermal (geothermal) heat pumps for space heating of human habitation modules for Mars.

