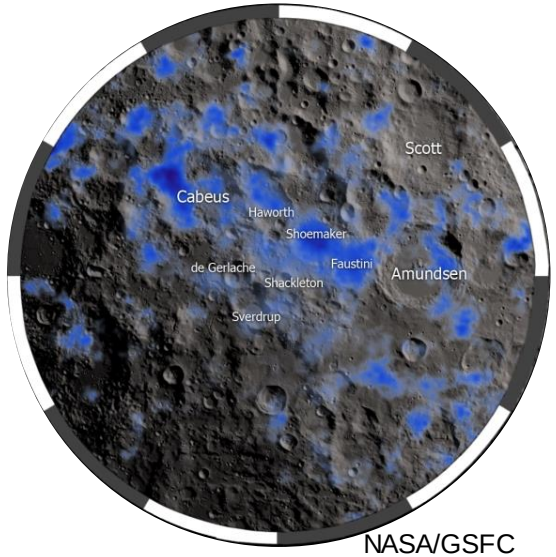
Lunar Drilling

Motivation

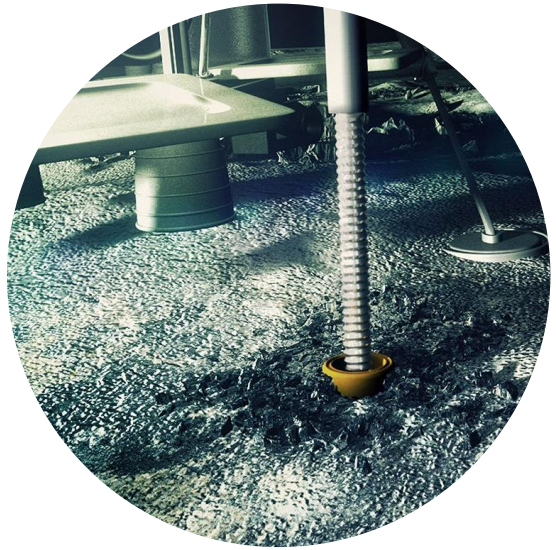
- Discovery of water on Moon
- Drilling in PSRs
- Sample preservation

Research Topics

- Sublimation modelling of subsurface ice in PSRs
- Thermal modelling of drill
- Integration of heat probe with drill



NASA/GSFC



Supervisor:

Dr Siddharth Pandey

Head

Centre of Excellence in Astrobiology

Amity University

Presenters:

Neha Maanju

Sipra Sonali Pradhan

Vedanth Sharma

Indian Institute Of Technology, Bombay

Modelling sublimation rates of pure water ice under the regolith in the lunar south poles

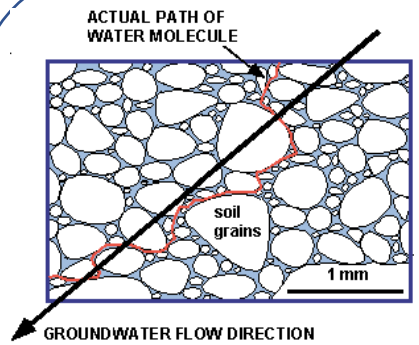
WHY?

Avoid too much dissipation of heat into the regolith to prevent the ice from getting sublimated during coring and drilling.

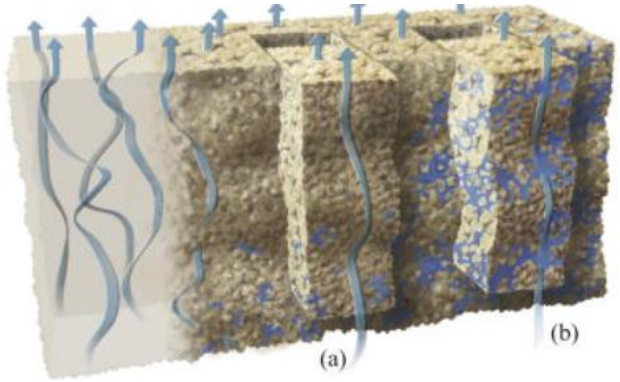
HOW?

Need to find out the right kind of simulant to use for the regolith in the lunar south pole

- From the albedo or reflectance of sunlight from LOLA it was found that the bulk material of the regolith at the south poles is similar to that of Luna 20 and Apollo 16 sample, **NU-LHT series,** a lunar highland simulant. Thus the particle size properties of NU-LHT 2M was used.



Understand the geotechnical properties of the simulant like porosity and tortuosity



Use a particular diffusion and adsorption model based on the desired criteria and find the necessary coefficients in the porous media

Used **Knudsen Diffusion** and **Dusty Gas Model** because its following assumptions were convenient in modeling-

- It is not influenced by the presence of other species of gas.
- the dust particles (regolith particles) are spherical

Simulate at different depths to obtain the concentrations of water vapor

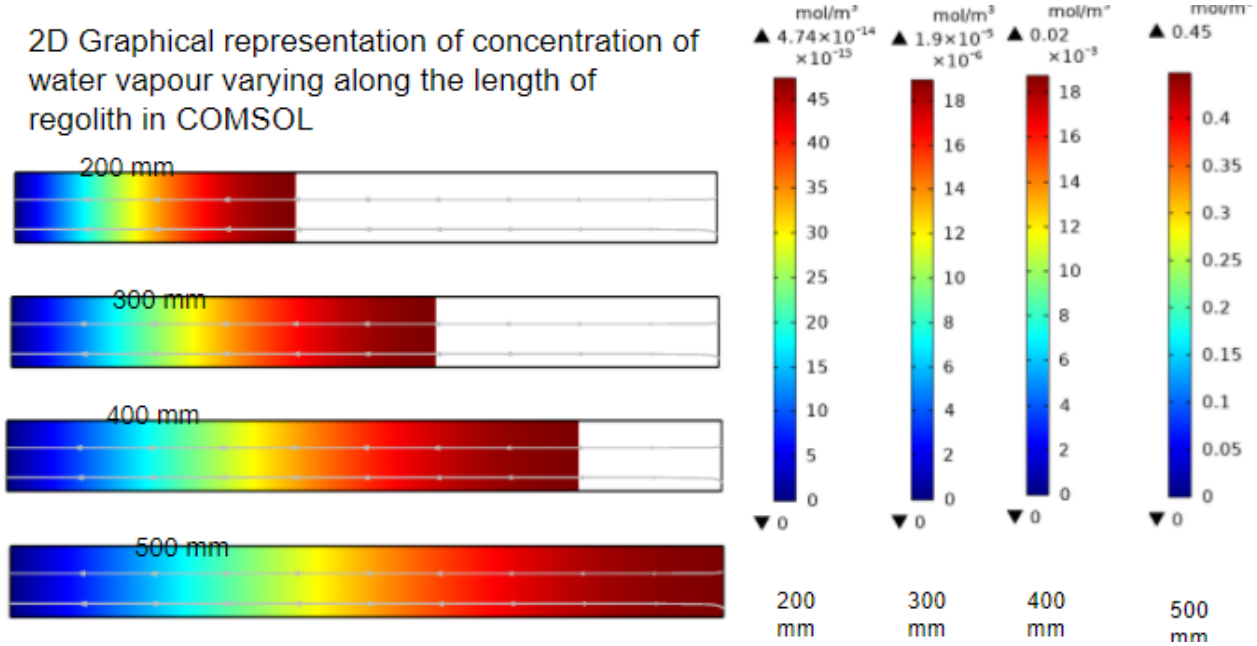
Assuming it to be an ideal gas, obtain the vapor pressure

Using this vapour pressure I formulated sublimation rates proposed by Edgar Andreas U.S. Army Cold Regions Research and Engineering Laboratory

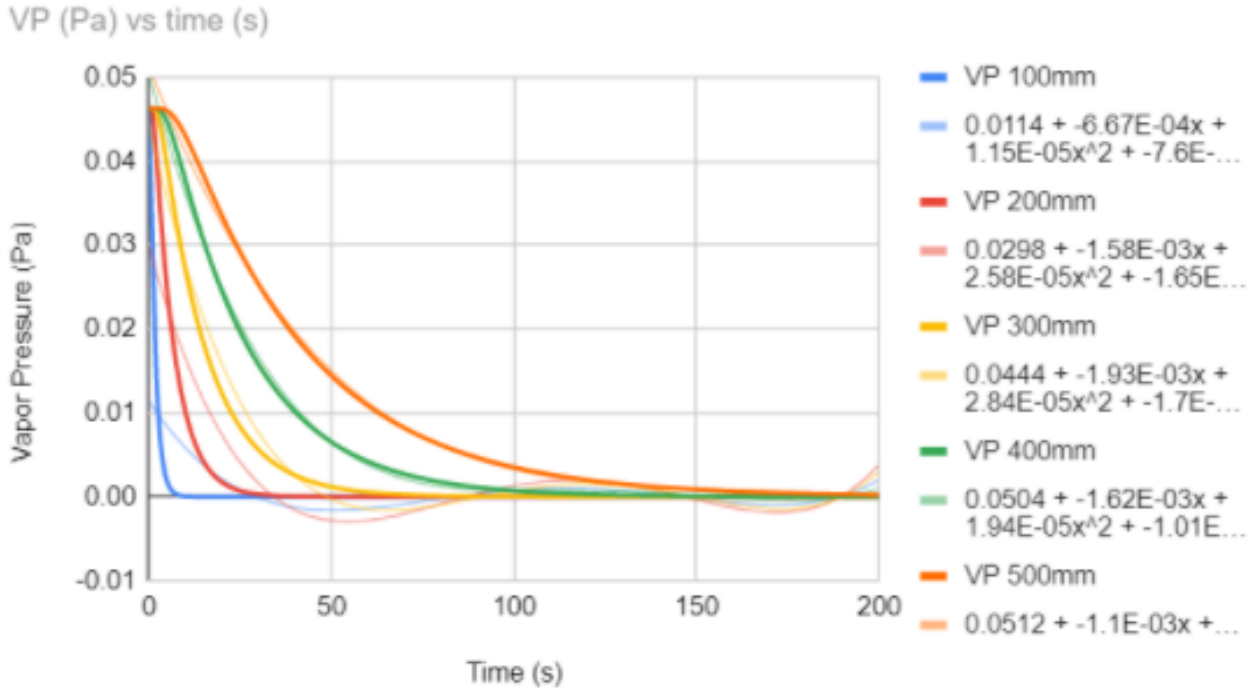
Concentration of water vapor through varying depth of regolith

Temperature	260K
Porosity	0.3775
Tortuosity	1.6924 (isotropic)
Knudsen Diffusion Coefficient	0.004799466
Depth of soil (mm)	100,200,300,400,500
Width (mm)	50
Time	200s
C_0 (Initial Concentration)	100mol/m^3
Mechanism	Convection, Knudsen Diffusion

2D Graphical representation of concentration of water vapour varying along the length of regolith in COMSOL



Vapour Pressure of water vapor varying with depth of regolith



Modelling heat generation, partition and distribution while drilling in high vacuum lunar environment

Why

- Dry drilling process in a high-vacuum environment
- Lunar ice might thaw and freeze leading to a cement like regolith mixture
- Sublimation of ice before concentration determination

Lunar Drill Designs

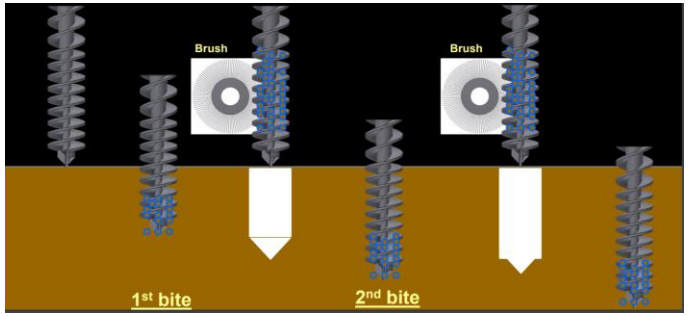
- *MoonBreaker* - The drill algorithm slows down the drill.
- *The Regolith and Ice Drill for Exploration of New Terrains (TRIDENT)* - Bite sampling concept

Method

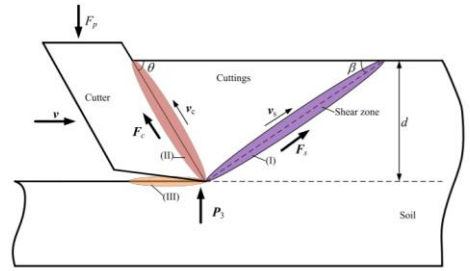
- Heat generation - Model developed by Tao Zhang et al.
- Heat Partition – No robust theoretical heat partition model available.
- Heat Distribution - Fast numerical method proposed by Jinsheng et al

Solutions

- Implementation of cooling strategies
- Estimation of volatile lost due to sublimation
- Design and development of new drills



Bite Sampling Concept of TRIDENT Drill
Credit: Honeybee Robotics

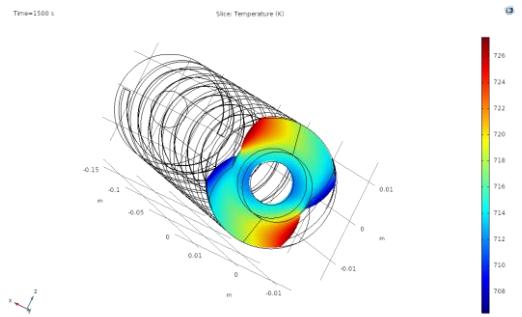


a) Three heat generation zones

Tao Zhang et al.

1D vs. 3D Comparison

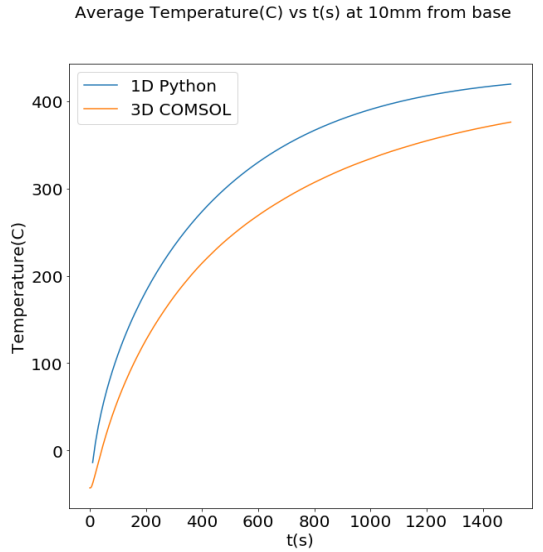
Mesh of drill of Mars Rover Team, IIT Bombay



Temperature profile 10 mm from base 3D simulation

Method	1D Python	3D Simulation
Time	31.3 s ± 1.81 s	2604s (~43 min)

Table 1: Simulation time comparison

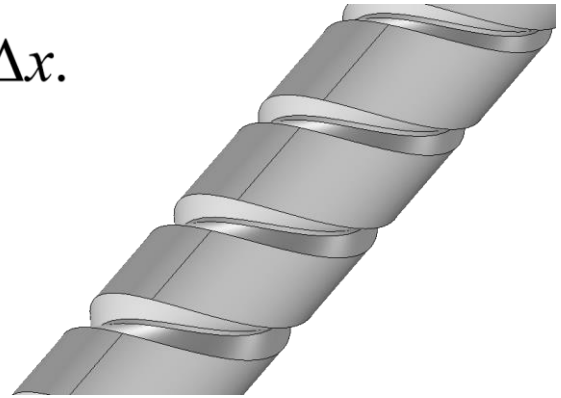


Simulation Results comparison

Model Simplification Error (K_{ms})

- Effective thickness

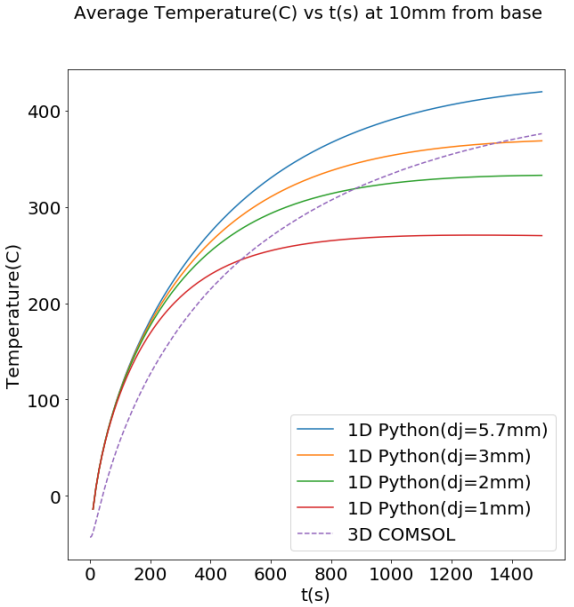
$$d_j = V_j / 2\pi r \Delta x.$$



Profile of Drill

dj(mm)	%Error in Area
5.7	20.8560
3	11.1526
2	3.5581
1	-11.4421

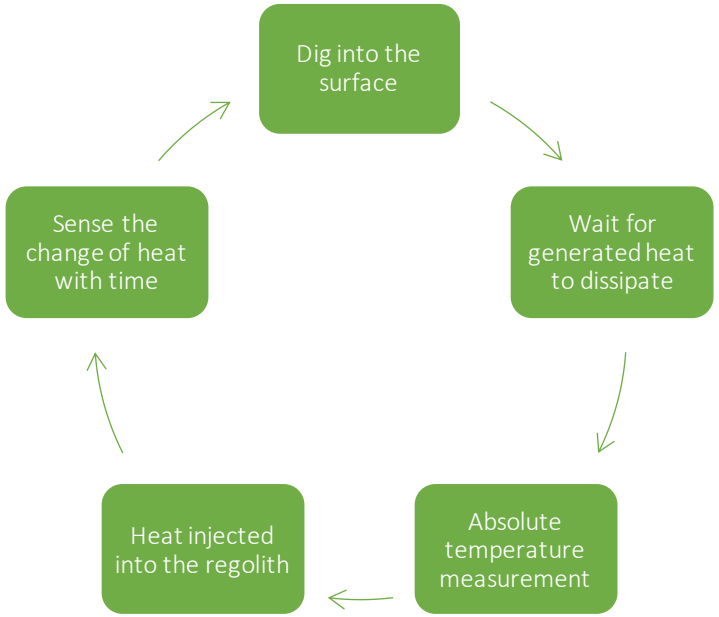
Table 2: Curve Similarity Measure



Parametric Analysis

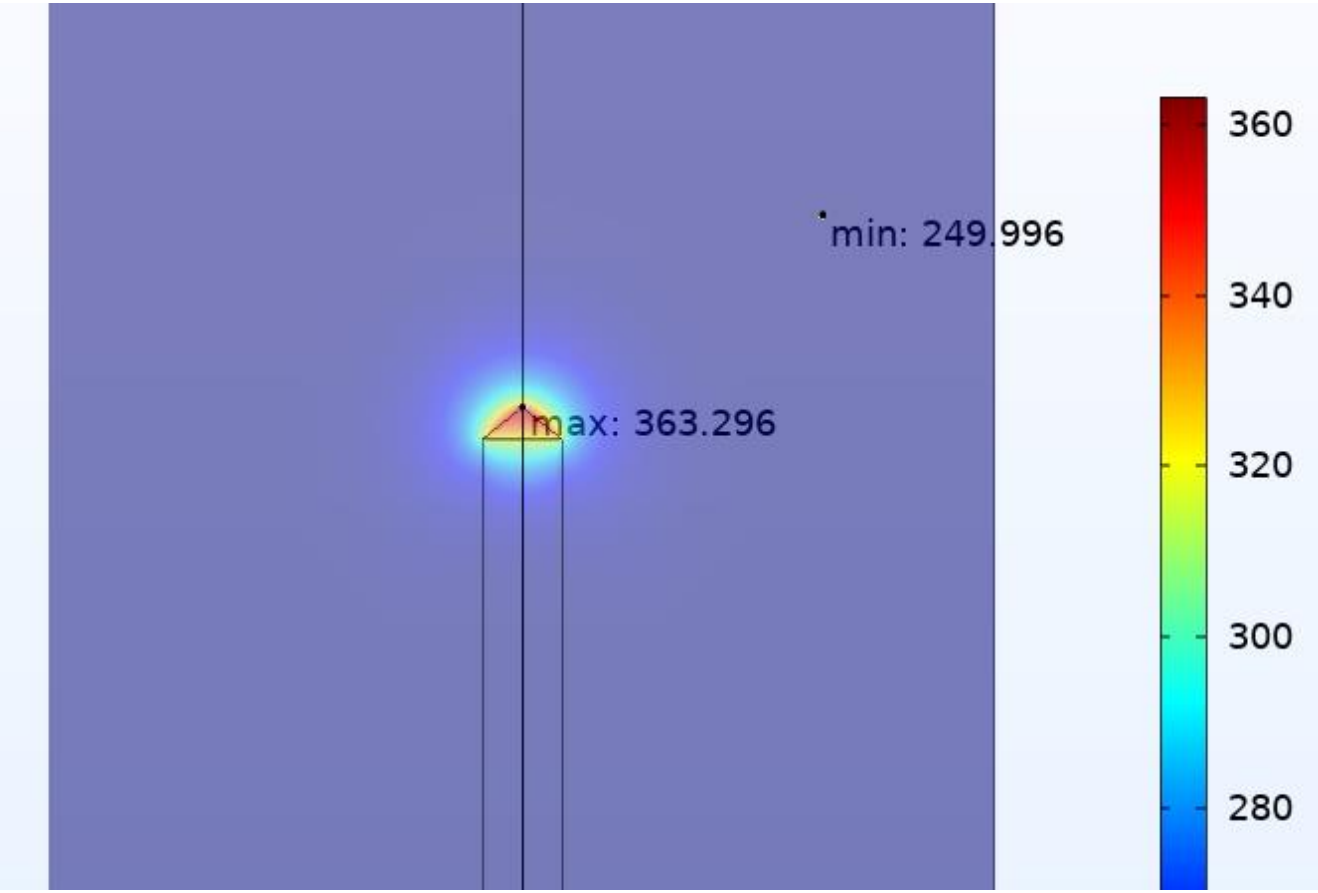
Integrated Probe And A Drill

- Measuring the planetary body temperature and the heat flowing out gives insight on
  - Composition
  - Interior "heat engine" : Evolution and geology
- Apollo 15 &17: Human missions , localized data
- Insight HP3 mission: Could not reach the desired depth, unexpected soil properties encountered
- Incorporating a drill with a heat probe ensures easy penetration; Multiple measurements can be taken if mounted on a rover



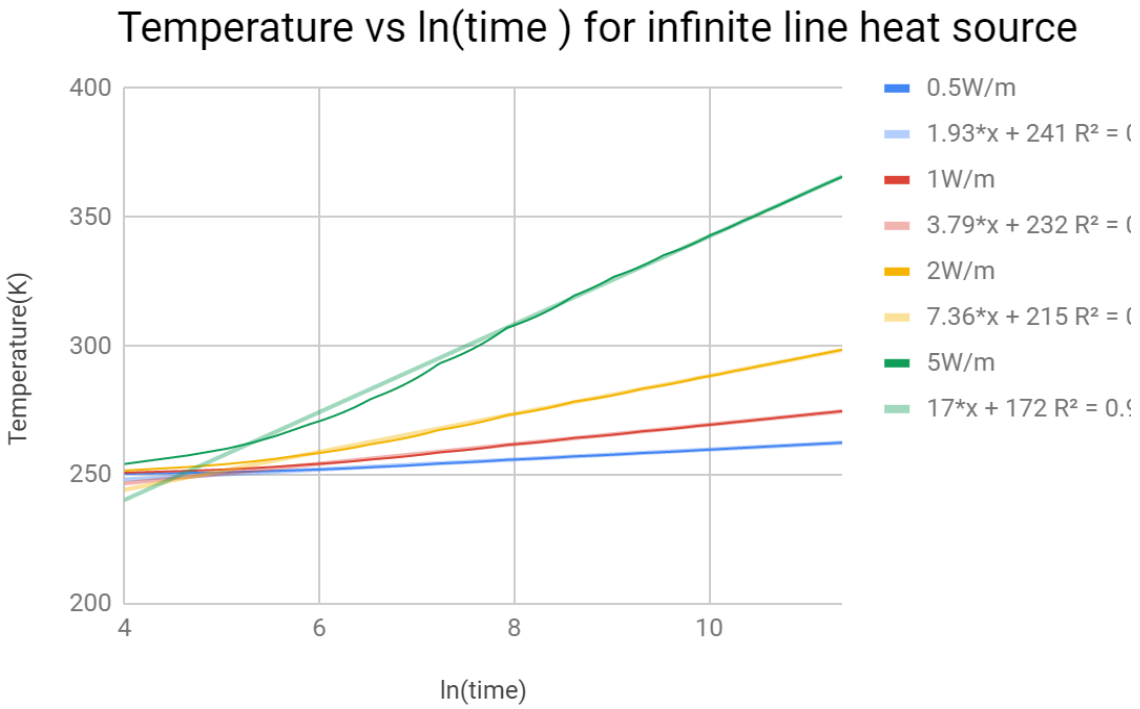
Mission	Status	Description	Planetary body
Apollo 15	Successful	Heat probe into a pre-drilled hole	Moon
Apollo 17			
LISTER	Under Development	Pneumatic Excavation	
Lunar A	Project Cancelled	Penetrator	
Chandrayan 2 - ChaSTE	Contact lost with lander	Penetrator	
InSight HP3	Could not be deployed at desired depth	Penetrator	Mars
Phoenix-TECP	Malfunction	Onboard sample analysis	
Philae-MUPUS		Penetrator	Comet

Simulation Results



Heat affected zone on application of heat flux on the drill bit

Property	Value	Units
Density	1825	kg/m^3
Thermal conductivity	0.02	W/(m.K)
Specific heat at constant pressure	840	J/(kg.K)
Ratio of specific heat	1	1
Porosity	0.5	1
Water content	0	kg/m^3
Initial temperature	250	K



Infinite line heat source method

Thank you!