UNSW Australia's Off Earth Mining Research

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Never Stand Still | Faculty of Engineering | School of Mining Engineering

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School of Mining Engineering
UNSW Australia

February 2013 – 1st Off-Earth Mining Forum

Wires
Australian Associated Press (AAP)
Agence France Presse (AFP)
APN News (Australian Regional Media)

International Coverage
BBC Radio – world update
BBC Radio 5
BBC segments aired across multiple US and UK radio stations (x6)
The Telegraph (UK)
Voice of America News
Yahoo News (US, Singapore)
Times of India
Bangkok Post
New Zealand Radio
Epoch Times
New Scientist Magazine

Australian coverage

Print - Metropolitan
The Age (Melbourne)
The Sunday Telegraph (Sydney)
The Canberra Times
The West Australian (Perth)

Print – Regional
Townsville Bulletin (QLD)
Daily News (warwick, QLD)
Daily Examiner (Grafton, NSW)
Northern Star (Lisomore, NSW)
Gympie Times (QLD)
Sunshine Coast Daily (QLD)
Gladstone Observer (QLD)
Daily Mercury (Mackay, QLD)
Queensland Times (Ipswich, QLD)
Morning Bulletin (Rockhamton, QLD)
Fraser Coast Chronicle (QLD)
Chronicle (Toowoomba, QLD)
Launceston Examiner (Tasmania)
Burnie Advocate (Tasmania)
Ballarat Courier (Victoria)
Geelong Advertiser (Victoria)

Online
Crikey
The Conversation x 3
Yahoo News (Australia)
The Australian Newspaper Online
The Sydney Morning Herald Technology
The Age Technology
The Brisbane Times Technology
The West.com.au
Daily Telegraph Online
Herald Sun Online
SBS Online
Channel 9 Online

Radio
ABC 702 (Sydney) PM program
ABC Radio National Drive
2GB Money Matters
2GB Drive Program
ABC Illawarra
2GO FM (Gosford, NSW)
98.5 FM (Perth, WA)

Television
SBS World News Australia
ABC News 24 Interview
Channel 9 Weekend Today
Channel 9 Money Matters
Fairfax Technology Videos
AFP video (distributed worldwide)
Associated Press TV (worldwide)

Trade Magazines
Australian Mining Magazine
Engineers Australia
Quarry Magazine
Industry Week

Future coverage
BBC World Service Australia
Channel 9 segment
ABC Radio National Future Tense
Popular Science Australia
ABC Catalyst

Off-Earth **MINING**

- Engineers like to overcome challenges.
  - gravity, inertia, energy, materials handling, friction, temperature and so on …
- What mining method will we be using?
- None of the current methods will be applicable.
  - May be strip mining for lunar regolith as in surface coal.
  - TBM, Micro-tunnelling

The motivation for Off-Earth Mining

- An abundance of valuable resources that can feed our technologically driven society
- Can mineral resources be Sustainable?
- Critical ‘rare-earth’ minerals
    - Yttrium, Lanthanum, and Samarium are increasingly critical in the making of high-tech products, such as tablets, missiles, electric vehicles and wind turbines.
    - Helium-3 is a non-radioactive nuclear fusion fuel, considered by some to be the safe energy source of the future and is also abundant on the moon.
- Ice – water, hydrogen, oxygen

The Moon

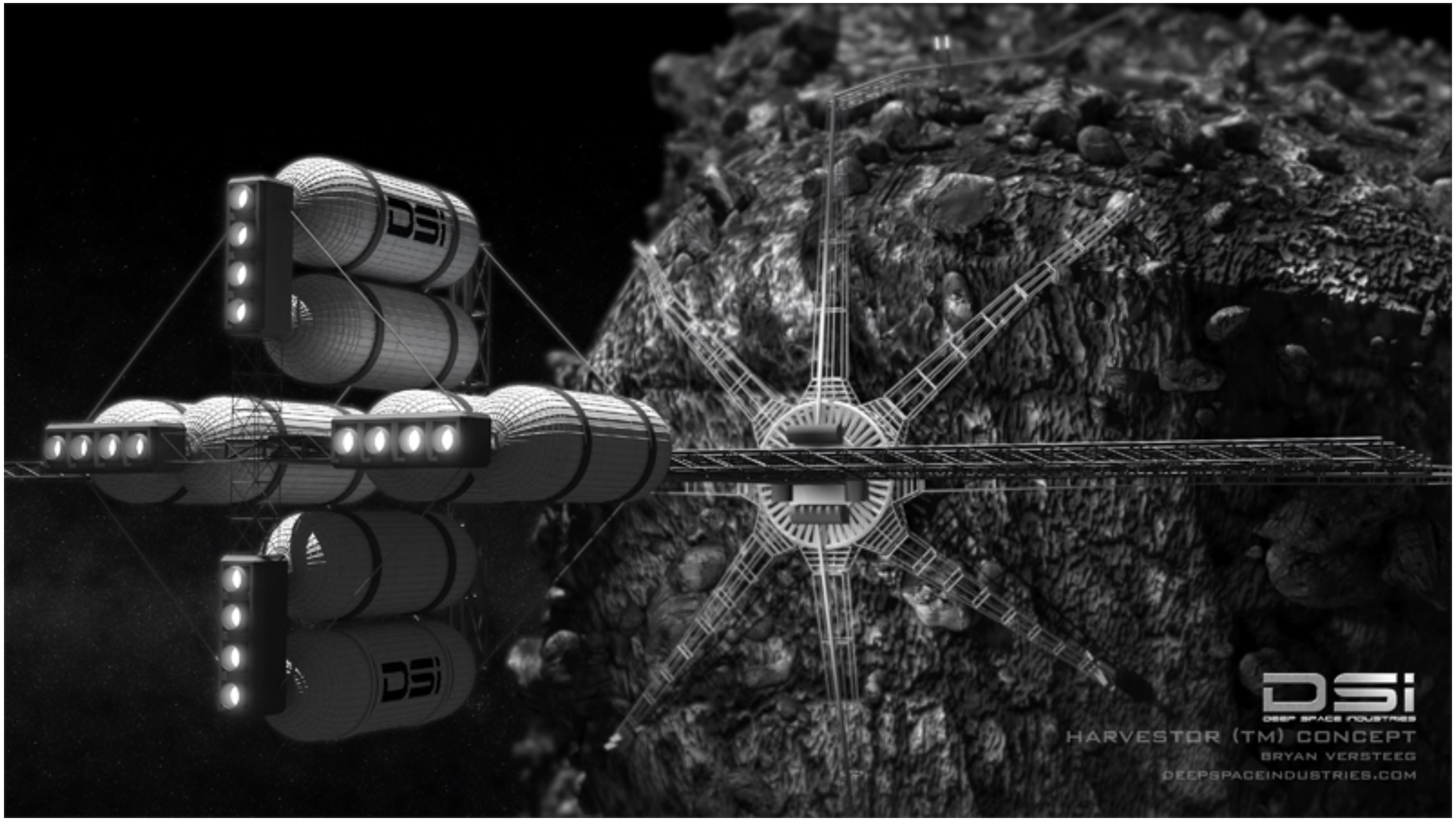
- Moon Regolith
- He, H, N, C, O …

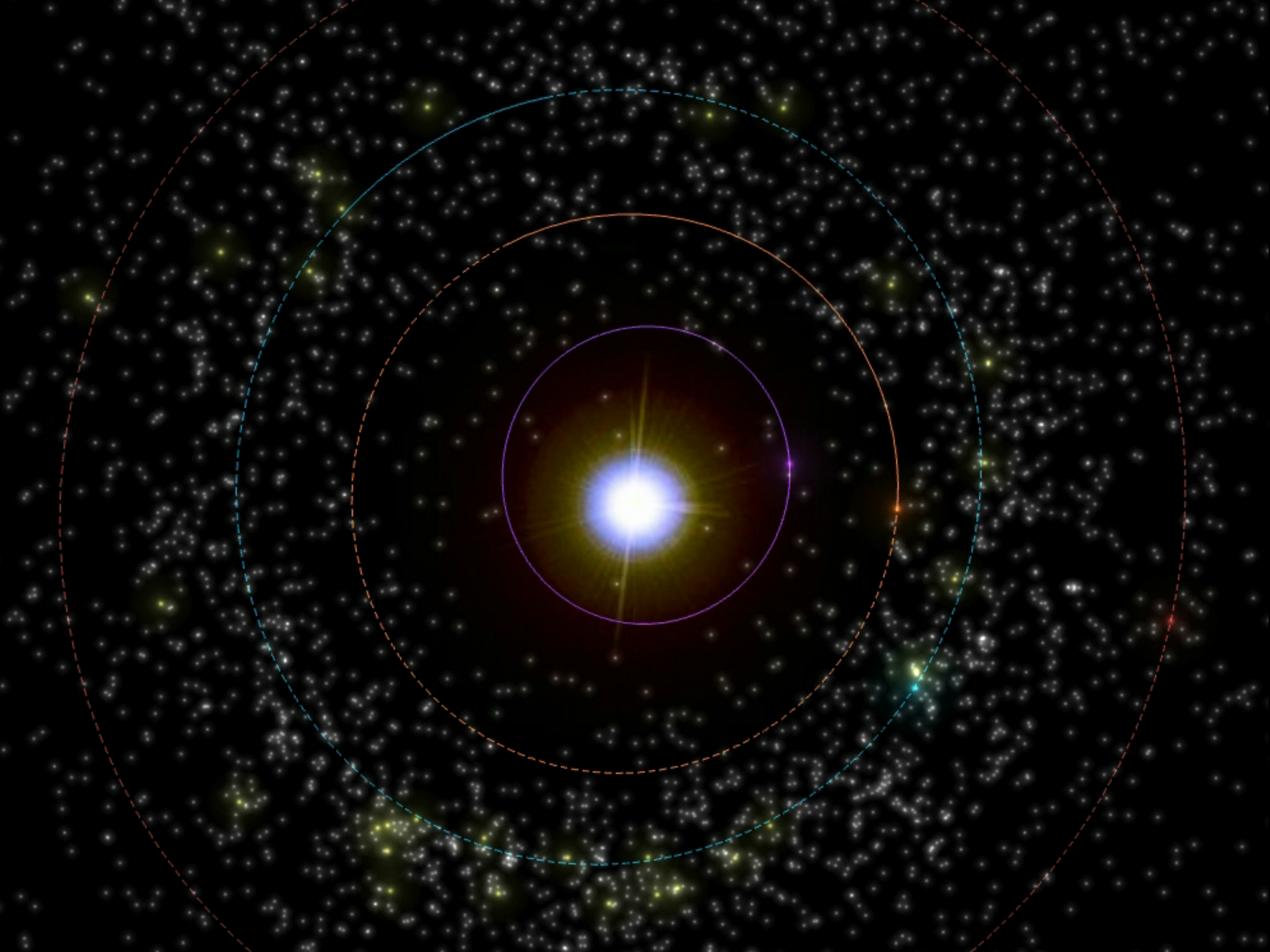
Mars

- Mars Regolith
- Ice and other minerals

Asteroids & Comets

- Can mineral resources be Sustainable?





Off-Earth Miners?

2007

SHACKLETON ENERGY COMPANY

FUELING THE SPACE FRONTIER

2012

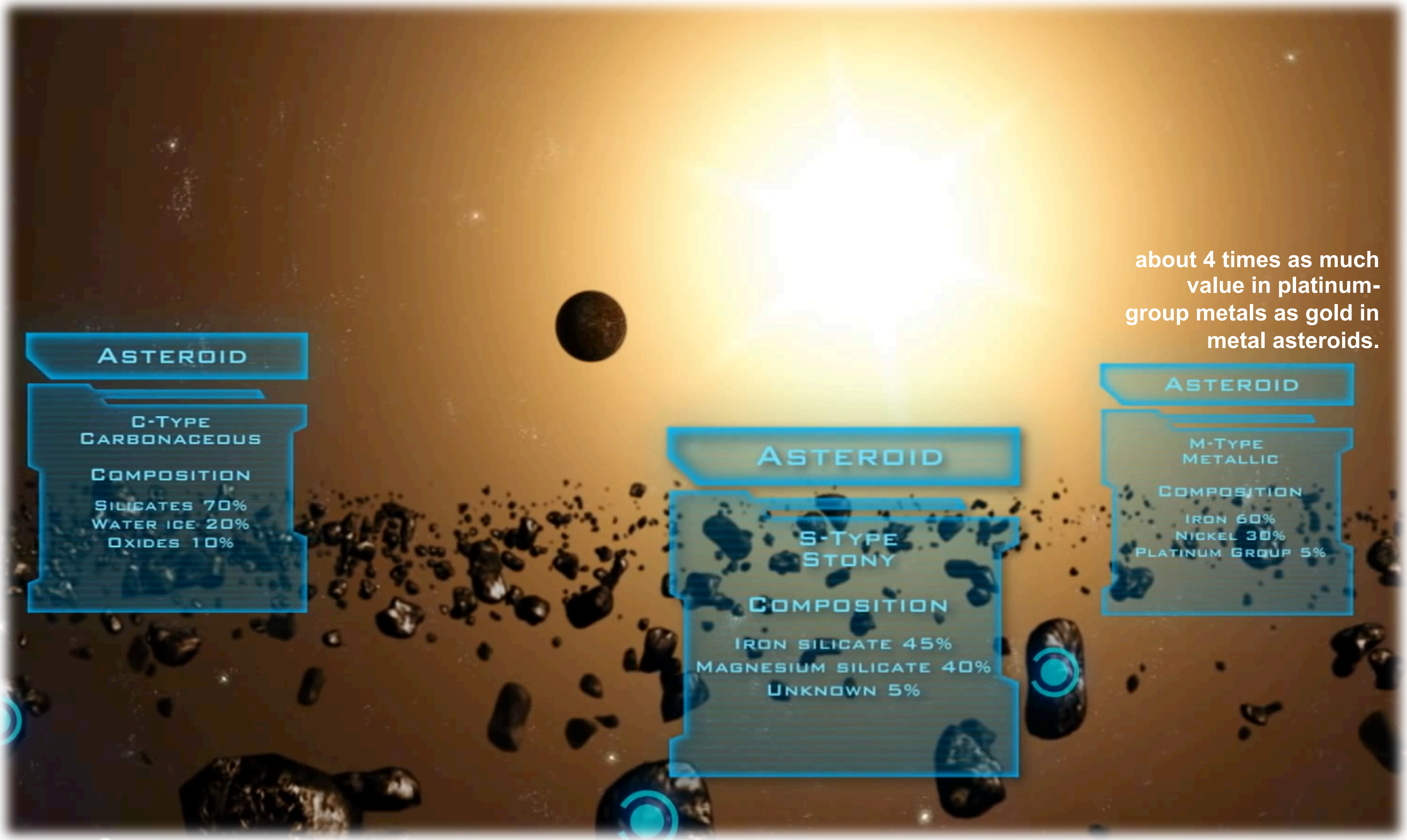
PLANETARY RESOURCES

2013

DSi™

DEEP SPACE INDUSTRIES

- **WHY ARE THEY INTERESTED?**



about 4 times as much value in platinum-group metals as gold in metal asteroids.

http://deepspaceindustries.com

Market for Off Earth Mining

- Communications satellites - propellant to extend life


http://deepspaceindustries.com
100 - 500 m/s
Delivering asteroid resources requires ~1% of the energy of launch from Earth
12,000 meters/second

Market for Off Earth Mining

- Communications satellites - propellant to extend life
- High-impact corporate sponsorships - bringing the Crowd to Space – tapping consumer markets
- Moon/Mars expeditions - fuel, water, structures, radiation shielding
- Platinum, gold, silver - exported to the Earth as by-products or use at the colony.
- Planetary Defense - missions to investigate threats and test deflection technologies

Off Earth Mining

An Investigation Into The Feasibility of Mining Off-Earth Minerals, With A Focus on Sourcing From Asteroids

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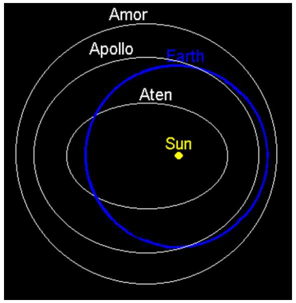
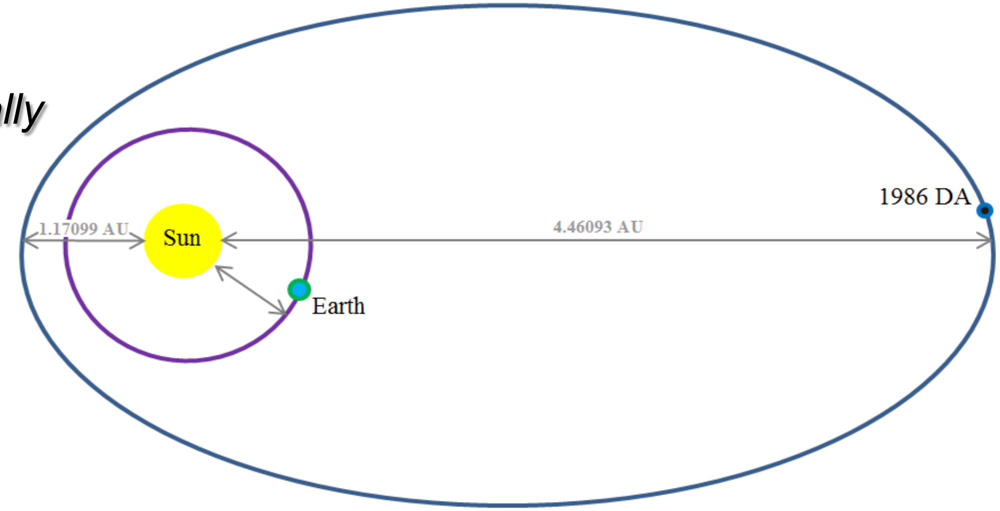
By Georgia Craig

Supervisor – A/Prof Serkan Saydam



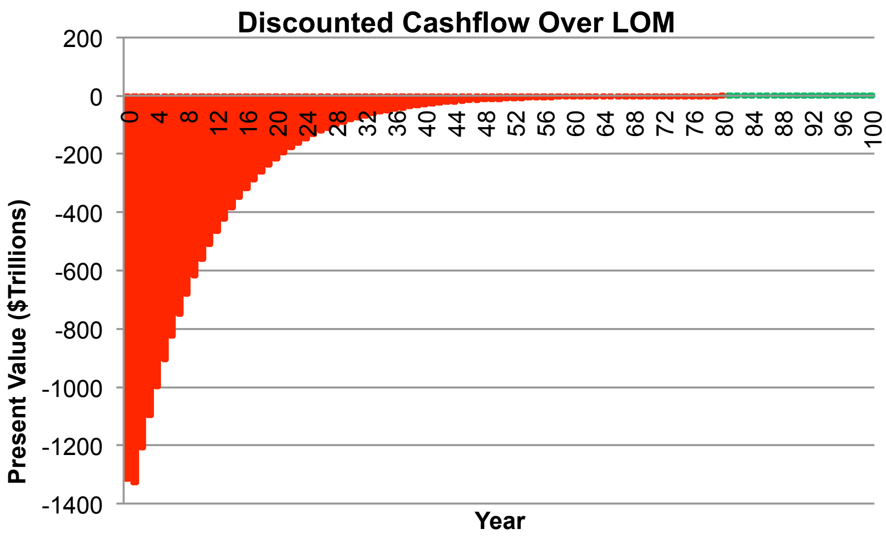
1986 DA

- M-type asteroid 88% Fe, 10% Ni, 0.5% Co *(Ingebretsen, 2001)*
  - It is essentially made up of *"naturally occurring stainless steel"*

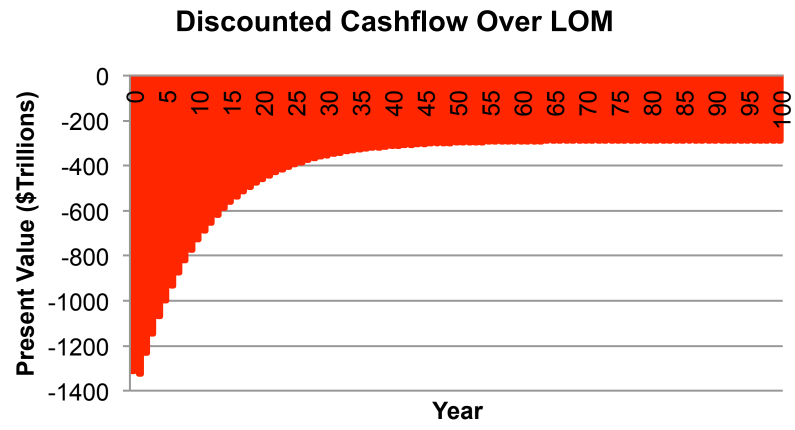


- 2.3 km diameter
- 0.5 Astronomical Units (AU) away (75Mkm) from Earth, periodically.
- 1986 DA is classified as an "Amor" asteroid because it approaches the Earth's orbit from the outside, but does not cross it.
- Approximately, 8 months to travel between Earth and the asteroid, similar to the Mars.

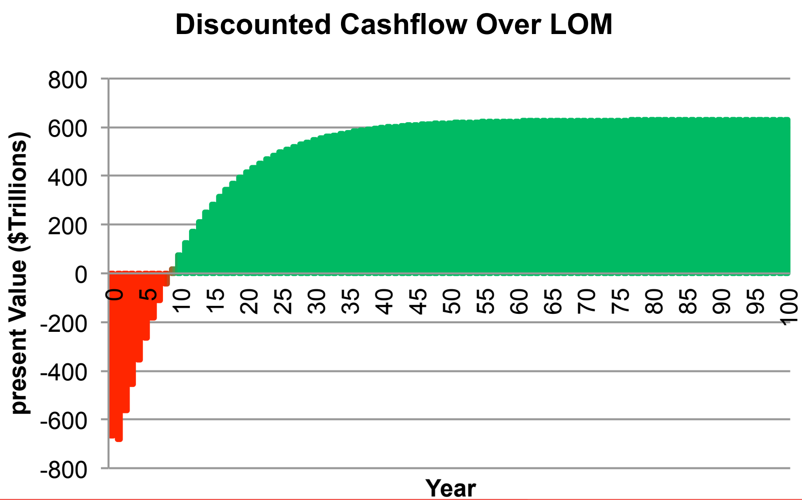
Base Case: 100% returns to Earth



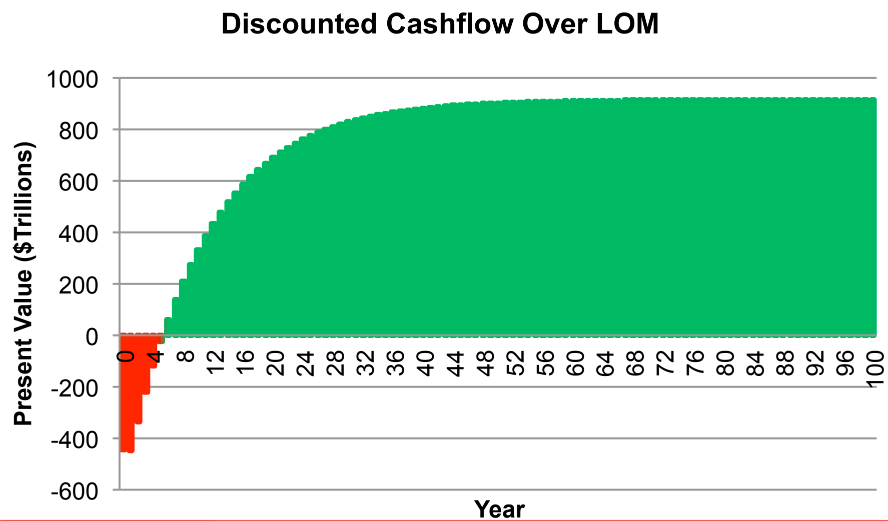
Case Study 1: 80% of mined product is sold



Case study two: Asteroid is half the distance from Earth



Case Study 3: Market is near 1986 DA



Mining off-Earth minerals: a long-term play?

by G.A. Craig*, S. Saydam*, and A.G. Dempster†

Synopsis

The Moon, asteroids, and planets of the solar system represent the most distant caches of wealth that humanity has ever considered recovering. Yet, in addition to the potentially recoverable values represented there, harvesting off-Earth resources has a second, almost incalculable sustainable benefit in that they can be retrieved with absolutely no damage to Earth.

Previous research mostly assessed the potential of asteroids and the Moon for mining purposes from a theoretical and scientific point of view. These studies investigated drawbacks that could be experienced in this type of operation, but no detailed economic evaluation that is meaningful for mining project management has been conducted and the parameters that are most likely to make an operation feasible are unknown. This paper provides a preliminary economic and sensitivity analysis of a possible off-Earth mining business extracting minerals from an existing asteroid.

Keywords
off-Earth mining, space mining, *in situ* resource utilization, future mining.

Background

first off-Earth mining studies and identified that the surfaces of the Earth's Moon, Mars's two moons, and an asteroid named 1982 DB have the potential for developing missions for space mining. However, he focused on a manned mission, which entails high operational and safety risks. Duke *et al.* (1997) designed three operational scenarios to extract water ice at the lunar poles, using microwave energy for heating the ice, thermal processing and steam pipe transportation, and using a dragline with thermal processing. Their designs were conceptual and did not consider the economic feasibility of the operations.

Sonter (1997) investigated the design process for feasibility studies of off-Earth mining operations and developed a net present value (NPV) analysis including variables based on orbital mechanics, rocket fuel requirements, mining and processing methods, product mass returned, and duration of the return trip. A new analysis concept was also utilized by Sonter (1997; 2001), the 'mass payback ratio', which illustrates the need to expend mass in

Off Earth Mining

Mining water from Comets and the Moon

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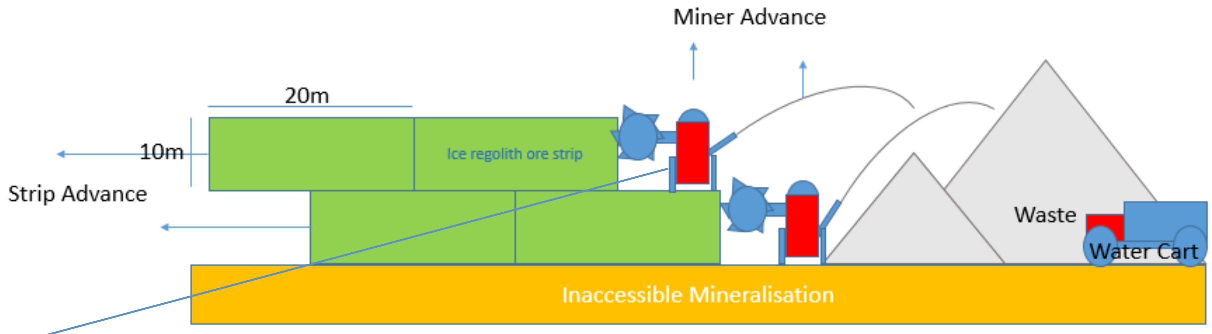
By Timothy Pelech

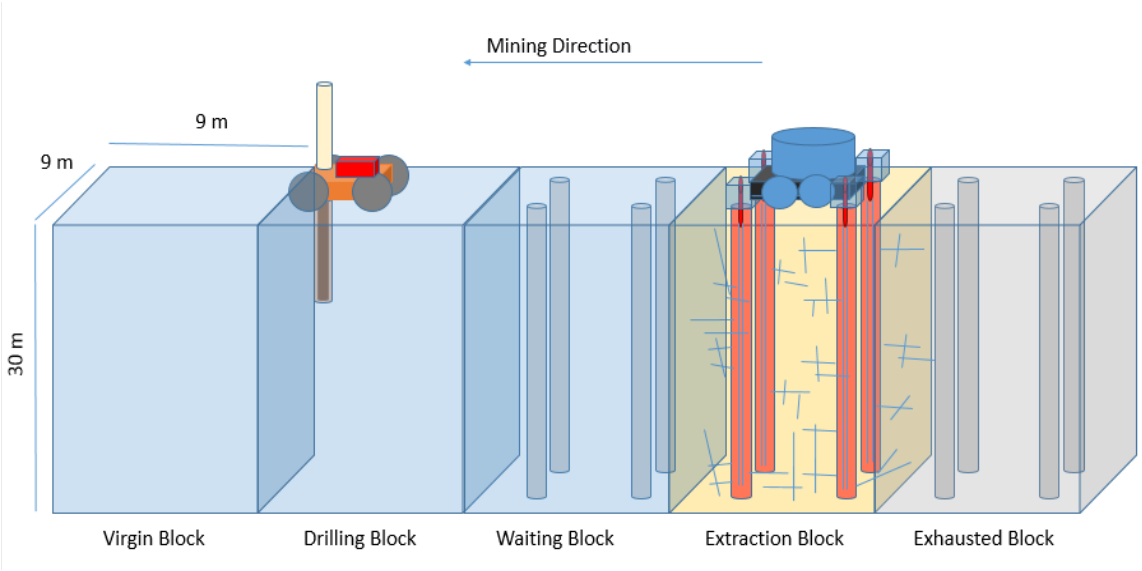
Supervisor – A/Prof Serkan Saydam

Mining Systems – Lunar Crater

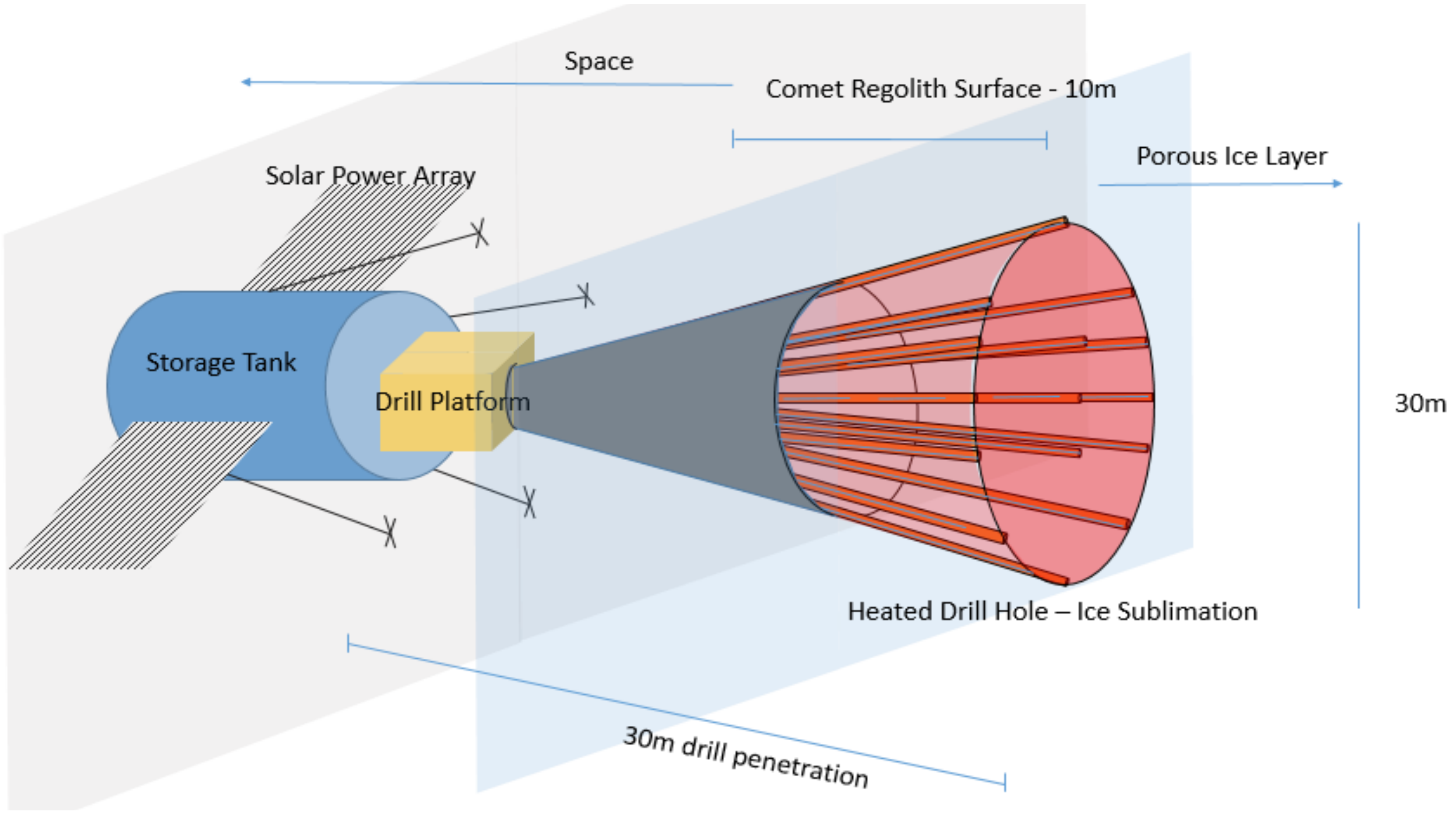
Strip Mining



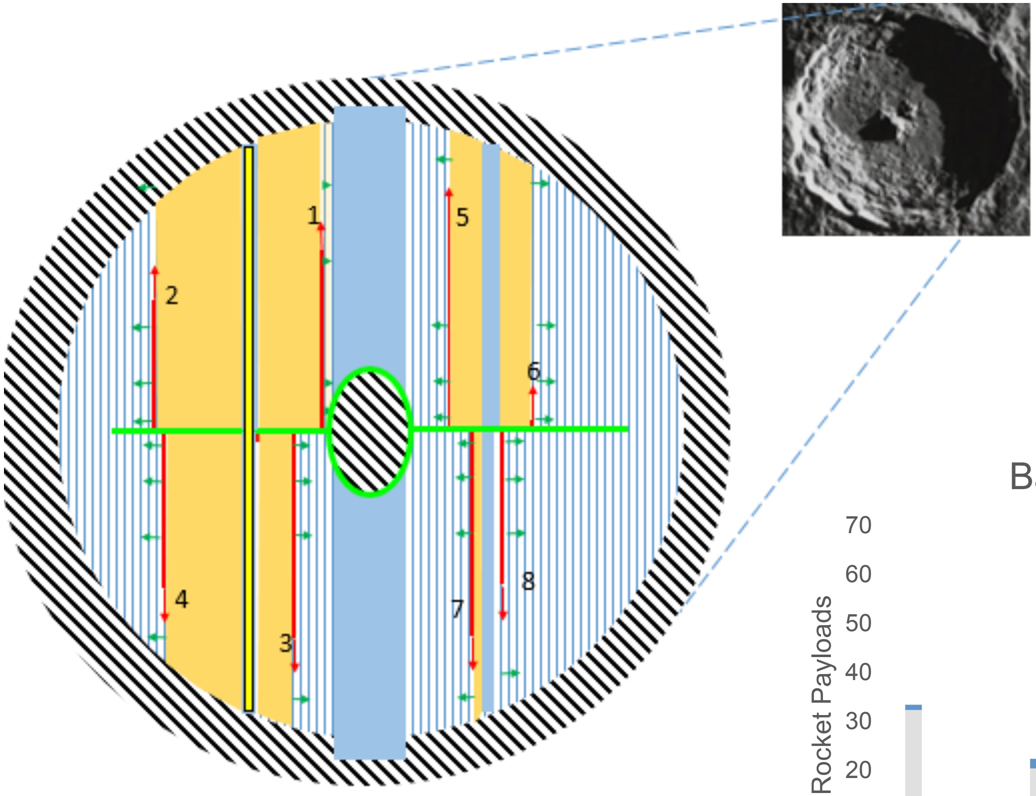
In Situ Water Sublimation

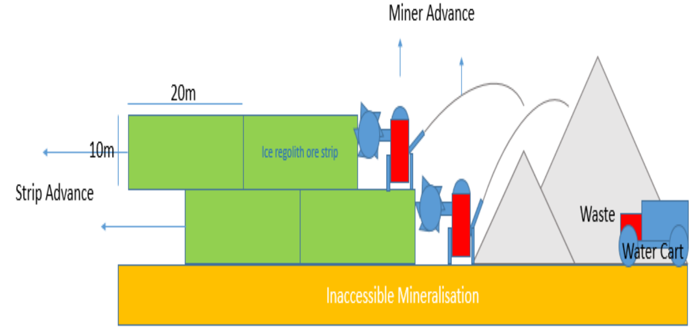


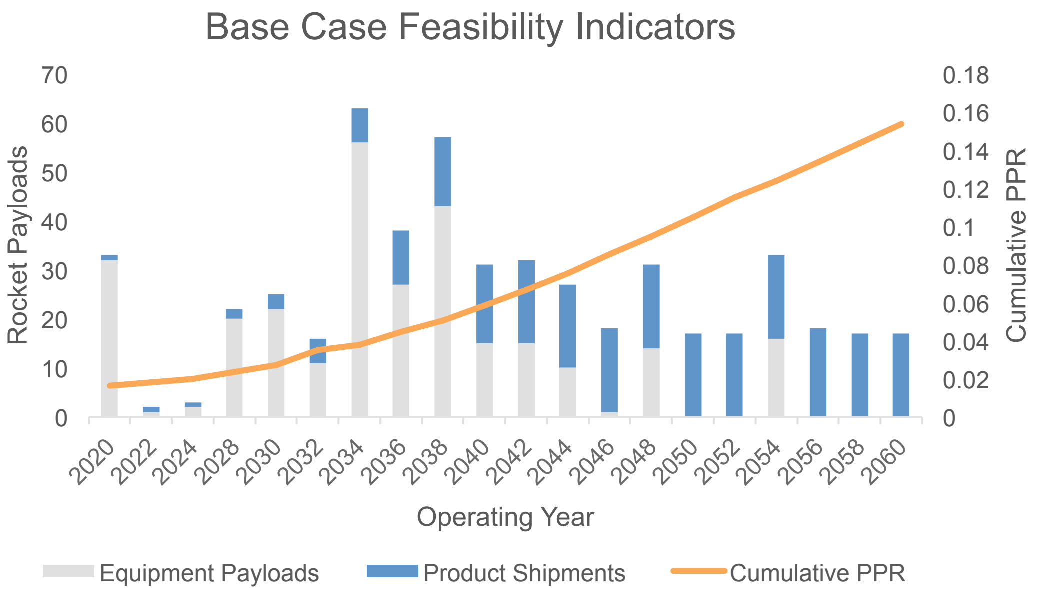
Mining Systems – Comets



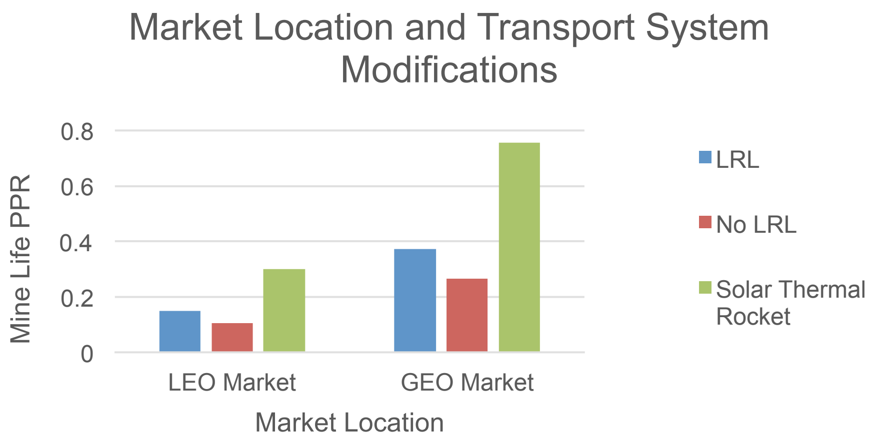
Scenario 1 - Lunar Strip Mine

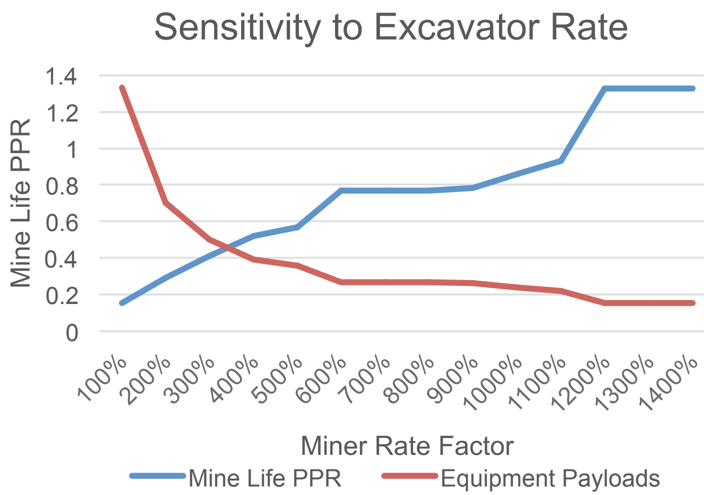


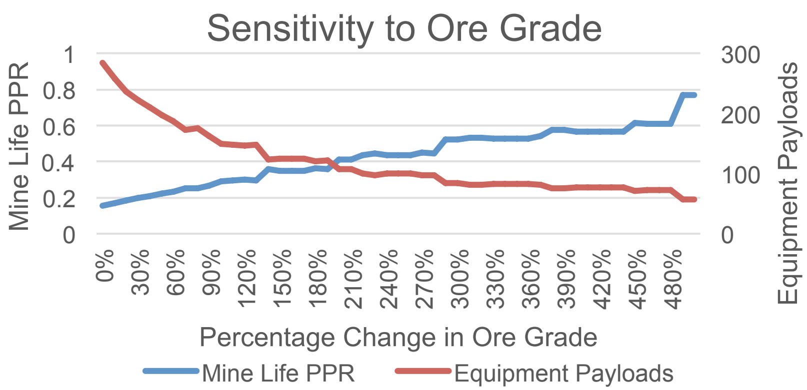


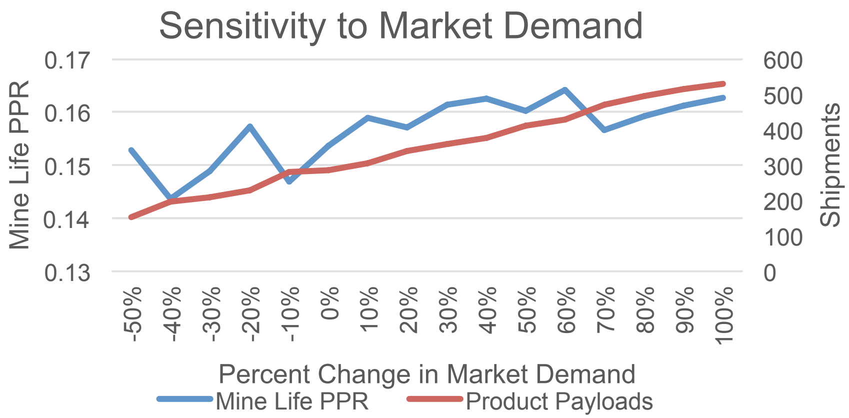


1- Sensitivity Analysis

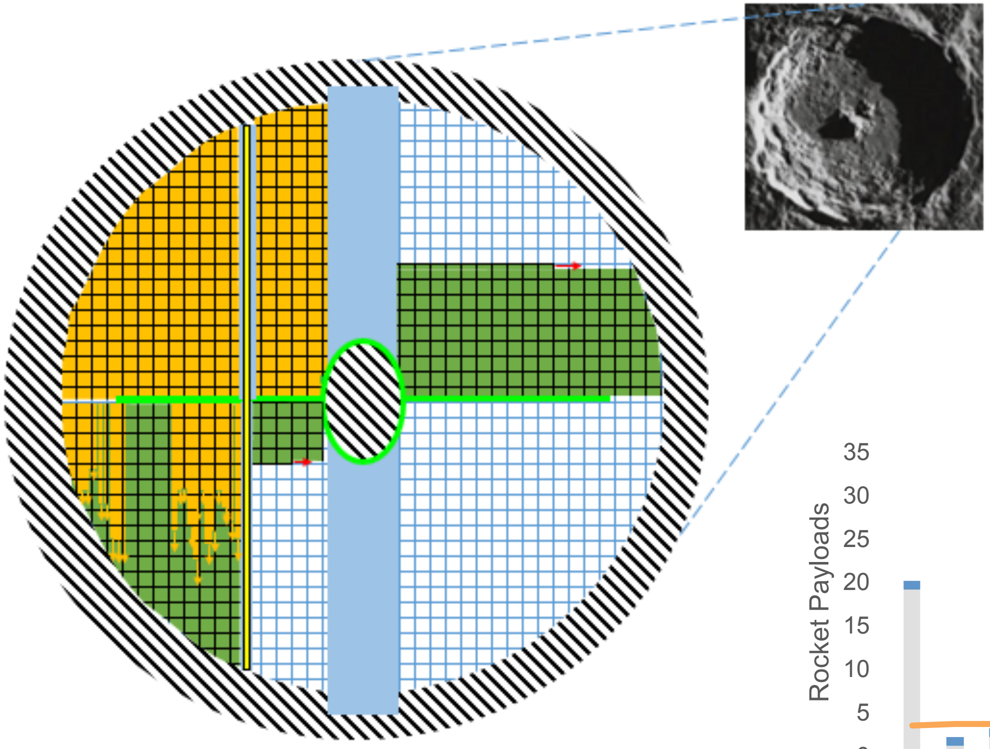


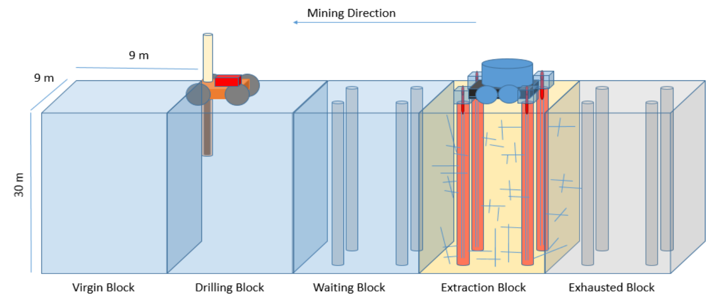


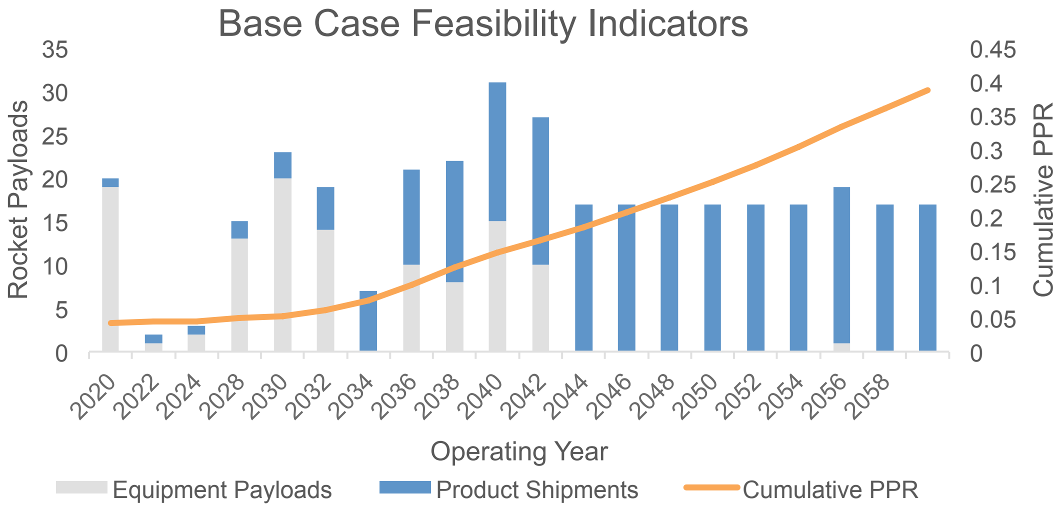




Scenario 2 - Lunar In-Situ Sublimation





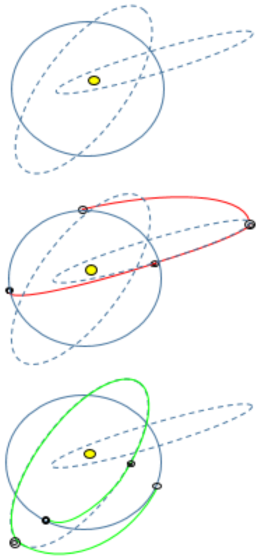


Scenario 3 - Comet Single Miner In-Situ Sublimation

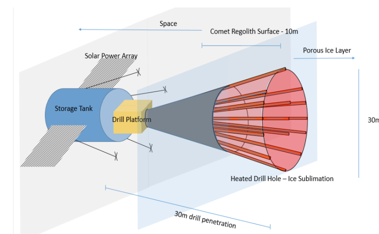
Missions Available

Object 1 Mission
Launch Date: Apr 2020
Mission Duration: 650 days
PPR: 1.6

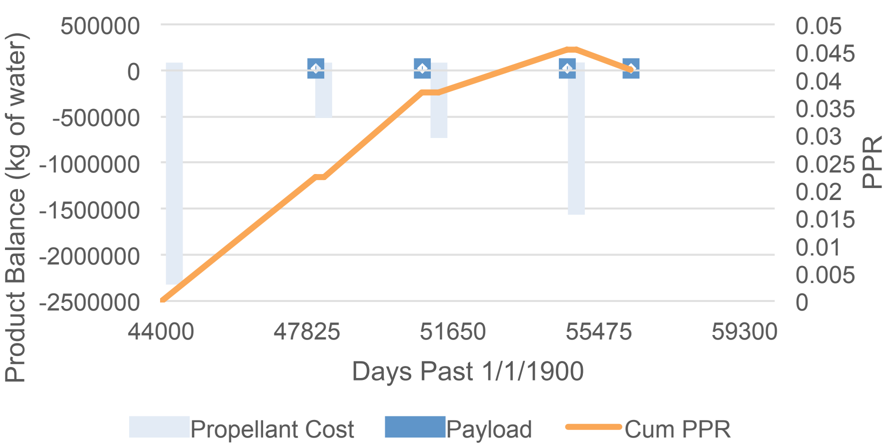
Object 2 Mission
Launch Date: May 2024
Mission Duration: 510 Days
PPR: 1.2



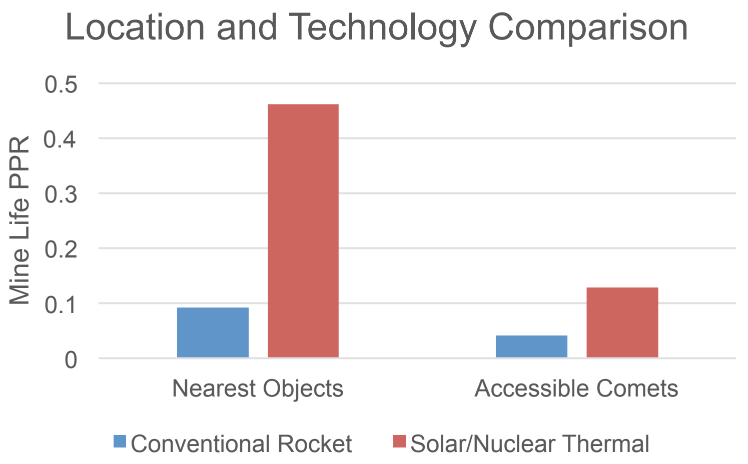
- Asteroid Orbit
- Earth Orbit
- Depart Earth
- Arrive Asteroid
- Depart Asteroid
- Arrive Earth

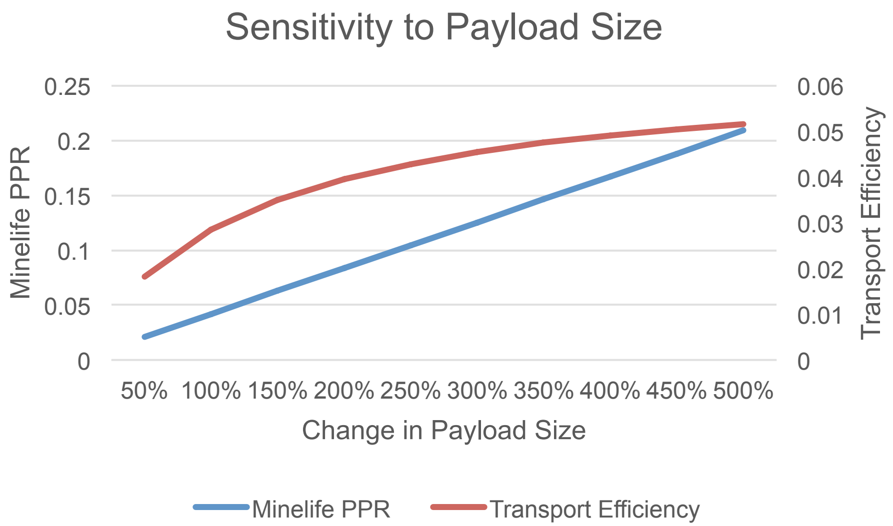


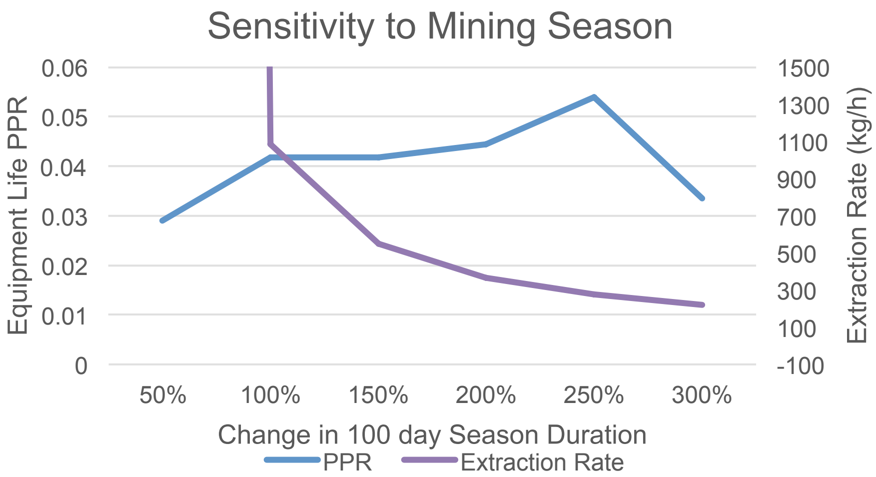
Single Miner System Base Case

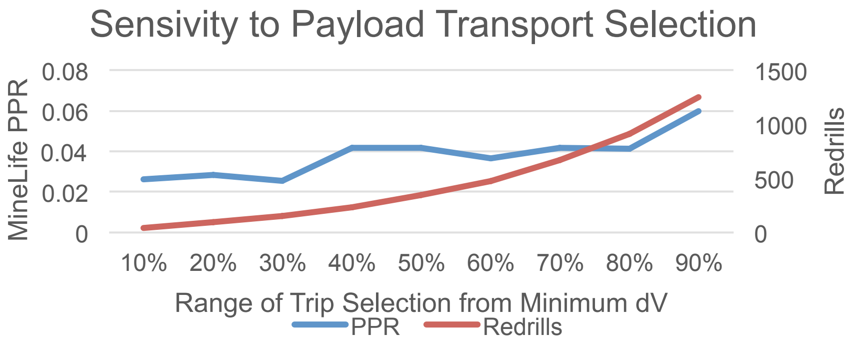


3 - Sensitivity Analysis







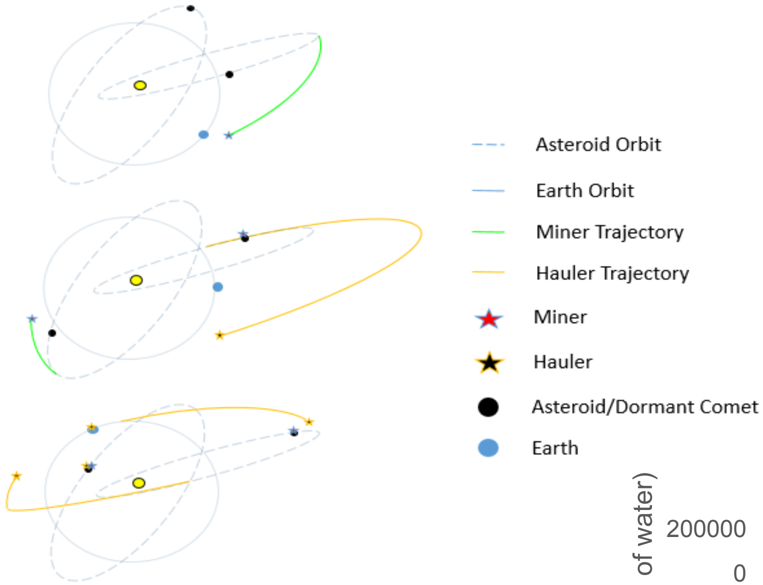


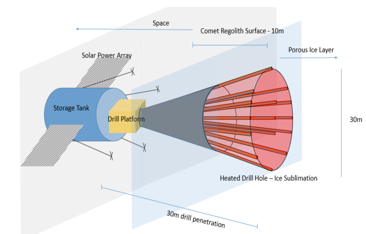
Scenario 4 - Comet Miner/Hauler In-Situ Sublimation Plan

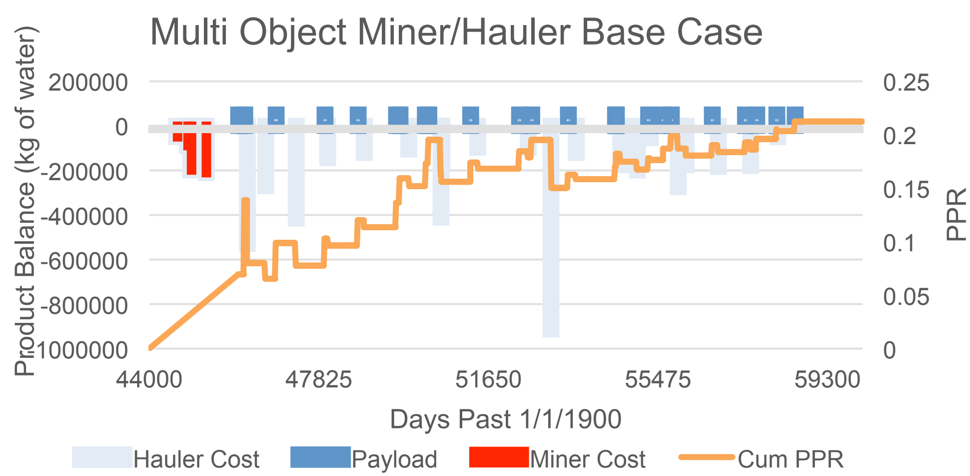
Jun 2025
- 1st Miner unit en route to asteroid

Jul 2030
- 1st Miner ready to load hauler
- 2nd Miner unit en route
- 1st Hauler en route to pickup

Feb 2038
- 1st Miner mining
- 2nd Miner waiting to load hauler
- 1st Hauler returning with payload
- 2nd Hauler en route







Comparison of pneumatic and conventional rock breakage systems in an off-world environment

Mark Lucas

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Comparison of Excavation Methods

Advantages and disadvantages of Mining Excavation systems
(Mackey, Gaskins and Lally, 1996, Zacny et al, 2009)

Lunar Condition	Conventional Pick Cutting	Pneumatic Excavation
Reduced Gravity	Reduced efficiency	No known effect
High soil abrasivity	Increased pick wear	No known effect
Electrostatic soil	Seizure of moving parts	No known effect
Soil compaction	No negative effects	Requirement of blasting to loosen soil
Vacuum	No known effect	Need for efficient seal
Dust suppression	Dust suppression required	No dust suppression needed
Transport cost	High cost for initial equipment transport, transport of new picks	Lower initial equipment transport cost, high cost for transport of explosives

Applicability of Shock Heating and Freezing on Regolith Found on Asteroids for Exploration Drilling

P X Nguyen[1] and S Saydam[2]

ABSTRACT

There will be a time when resources and minerals will be scarce as the Earth is a finite body. Research into novel and/or unconventional techniques must be completed to ensure we are ready for when off-Earth mining becomes a reality. It is apparent that there is a lack of innovation in the design of suitable equipment and reasonable explanations that would otherwise attract investments into space mining. One idea is to utilise the concept of heating and freezing to weaken rock that is based on the ancient rock-breakage technique known as fire-setting. This paper investigates the applicability of utilising shock heating and freezing when it comes to fracturing rock. To achieve this goal, a simulated vacuum chamber and asteroid sample was created using regolith samples. The application of heating and freezing was compared with samples that were not subject to heating and freezing through the use of a universal testing machine to determine the uniaxial compressive strength (UCS) of the samples. It was found that as more cycles of heating and freezing were performed on the regolith samples, the UCS values decreased.

AN INTEGRATED ECONOMIC MODEL FOR ISRU IN SUPPORT OF A MARS COLONY

Caltech/Jet Propulsion Laboratory (JPL)
University of New South Wales, Australia
School of Mining Engineering
School of Electrical Engineering and Telecommunications/
Australian Centre for Space Engineering Research (ACSER)

January 22, 2015

- NASA Office of Emerging Space
- NRA NNA14ZVP001K

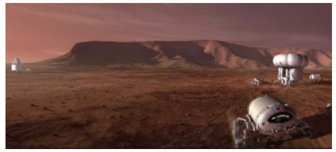
JPL

Three Giant Leaps

Scope of This Task

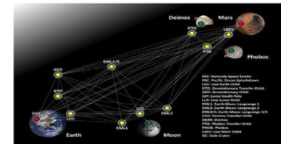
2014

2030's



2040's

2050's - ?



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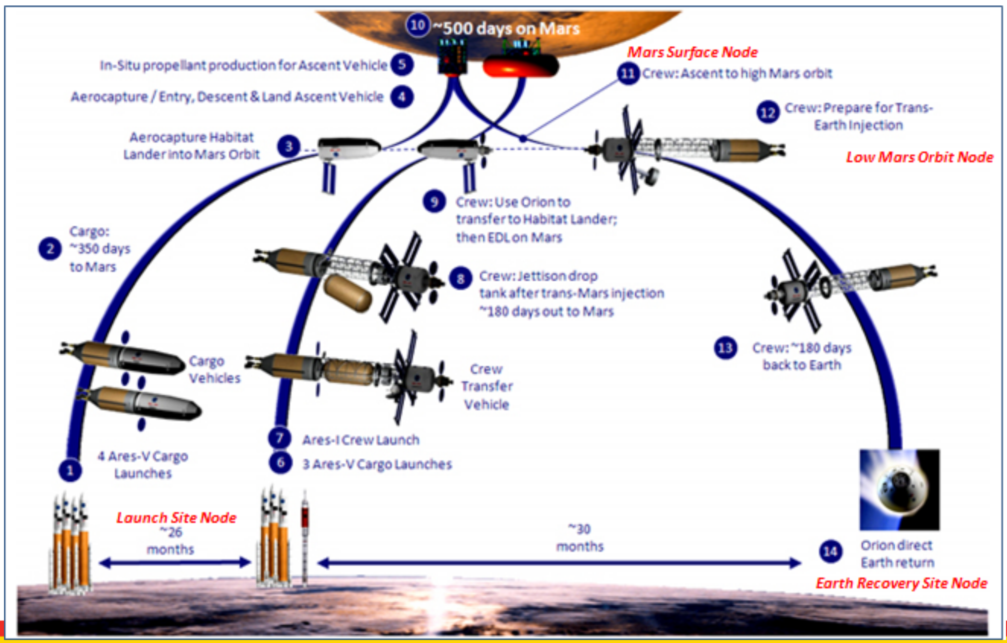
Orion ETF-1

First Human Landing On Mars

Establishment Of A Mars Colony

Economic Viability



Stakeholders	Concerns
National Space Agencies	Public Support; Safety
Private Enterprises	Profitability
Science Communities	Science Opportunities
Space Enthusiasts/Influencers	Frequent Progress
Colonists	Survival; Sustainability

An Integrated Economic Model for ISRU in support of a Mars Colony

Extraction Process Model

Literature search + Team A + physics

- Production technology
- Technical risk & uncertainty
- Production rate potential
- Transport / storage mechanisms
- Technology Gaps

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Mars Colony Model

Literature search + architecture description

- Time Phasing
- # of humans
- Support functions
- Resource requirements

JPL

Colony Build-up Time Phased relationships

Extraction/delivery model

Economic Integration Model

Team workshops with Venture Capitalist

- Risk / Uncertainty
- Capitalization
- Commercial ROI / Real Options Valuation
- Technology spin-in/out

JPL+UNSW

Infrastructure and ILS Model

Mining expertise + Team X (Delivery missions)

- Time-phased capacity
- Means of production-(equipment)
- Earth vs. *in situ* cost curves
- Logistical supply chain
- Operations model

JPL+UNSW

Colony Build-up Time Phased relationships

Time Phased infrastructure and ILS model

Economic opportunity and business model

Team Members, Others, and Communications

UNSW

- Associate Professor, Serkan Saydam
- Professor, Andrew Dempster, ACSER, UNSW
- Dr. Jeff Coulton, Australian School of Business, UNSW

Caltech/JPL

- Dr. Robert Shishko, Principal Systems Engineer / Economist
- Rene Fradet, Deputy Director for Engineering & Science Directorate
- Others (Mars Program Chief Engineer, A-Team, . . .)

MIT (Others)

- Professor Oli deWeck, Department of Aero/Astro

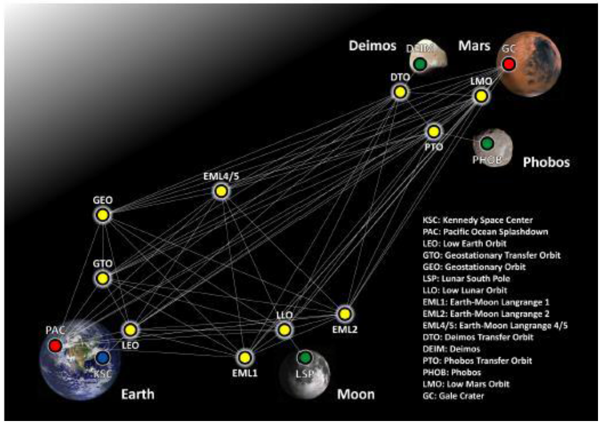
Mars Colony Architecture Model (MCAM)

Data model based on DoDAF 2.02 with “for-purpose” extensions

Slightly modified terminology to conform to existing software applications

MCAM Key Constructs

- Operational Nodes (Surface Locations, Orbits, Lagrange Points)
- Systems (Transport, Mining, Habitation, etc.)
- Operational Activities/Functions
- Resources (People, Material, Information, etc.)
- Milestones
- Needlines
- Operational Resource Flows
- System Resource Flows
- Measures (Mass, Capacity, Reliability, etc.)
- Rules



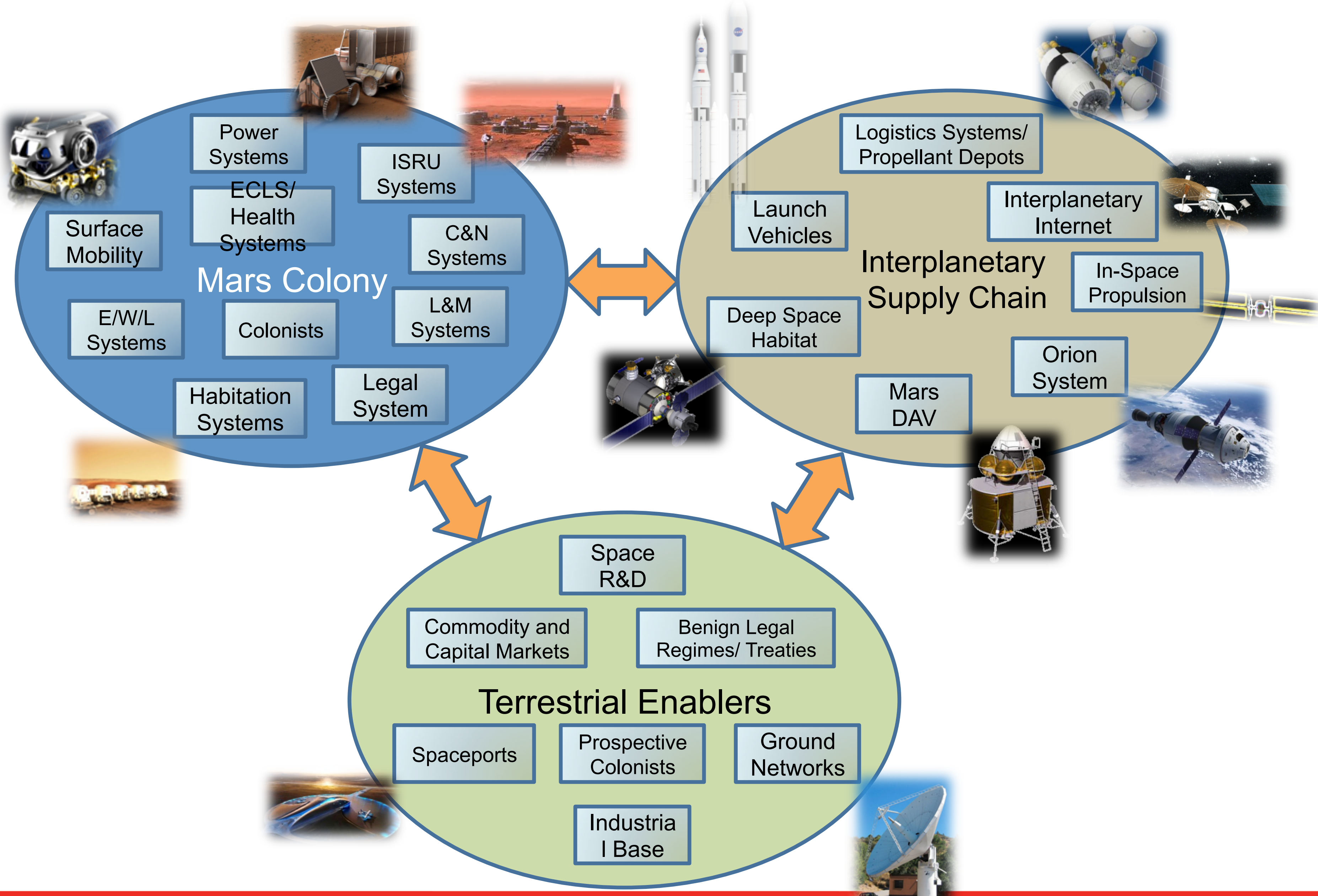
“For-purpose” extensions permit quantitative analyses

Key quantitative relationships are needed for ISRU (i.e., extraction output (kg) of mining operations based on technology, number of mining systems deployed, number of persons by personnel type, etc.)

Mars Colony Architecture Model (MCAM)

Resources Table

Resource ID	Resource Name	Units Type ID	Units Type	Class of Supply ID	Unit Mass (kilograms)	Unit Volume (cubic meters)	Packing Factor (kilograms)	Environment (U/P)	Resource Description
0	Information	32	Gb						
1	Labor	18	workhours/year						
2	Water	8	kg	201	1	0.001			
3	Oxygen	8	kg	203	1				
4	Hydrogen	8	kg	203	1				
5	Carbon Dioxide	8	kg	203	1				
6	Electric Power, DC	31	watts						
7	Mars Icy Regolith	8	kg		1				
8	Lunar Ice/Icy Regolith	8	kg		1				


Power Systems
ISRU Systems
ECLS/ Health Systems
Surface Mobility
C&N Systems
Mars Colony
E/W/L Systems
Colonists
L&M Systems
Habitation Systems
Legal System
Logistics Systems/ Propellant Depots
Launch Vehicles
Interplanetary Internet
Interplanetary Supply Chain
In-Space Propulsion
Deep Space Habitat
Orion System
Mars DAV
Space R&D
Commodity and Capital Markets
Benign Legal Regimes/ Treaties
Terrestrial Enablers
Spaceports
Prospective Colonists
Ground Networks
Industria l Base

UNSW’s Task

- Mining water/ice
- Mining system
- System requirements
- Developing a “financial” model
- Dollar vs Human Life support
- How much water do we have to extract to support a colony?
- Is it feasible?

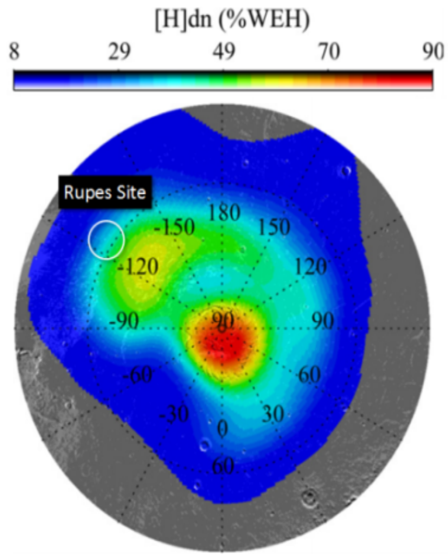
System Engineering of a Martian Ice Miner for In Situ Resource Utilization in Support of a Mars Colony

Thierry de Roche
M.Sc. Thesis
Final presentation
16.03.2015

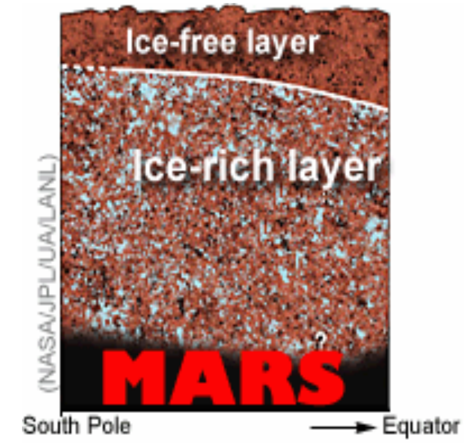
Supervision:
Anton Ivanov
Serkan Saydam
Andrew Dempster

Hydrology

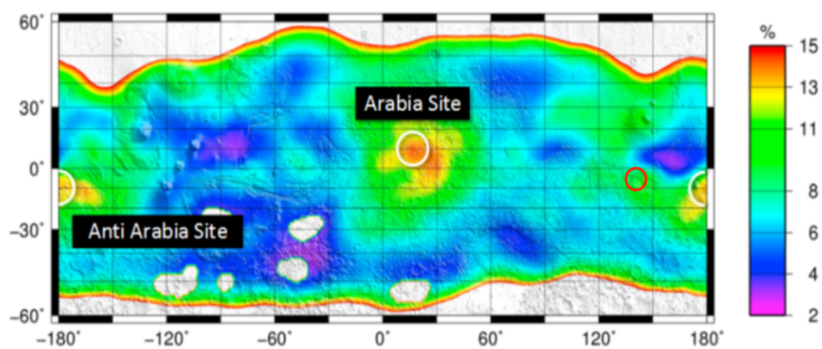
- Mars Odyssey Gamma Ray Spectrometer [Maurice et al., 2011]
  - Hydrogen detection, hypothesised as water ice
    - Equatorial region: 15 wt %
    - Mid-latitudes: 40 wt %
  - Two layer model
  - Consistent with ground truth for landing sites
  - Resolution: 300x300 km
- Fresh meteoroid impacts [Byrne et al., 2009]
- Seasonal ice caps
- Stability of subsurface ice deposits [Mellon and Jakosky, 1993]



[Diez et al., 2008], edited



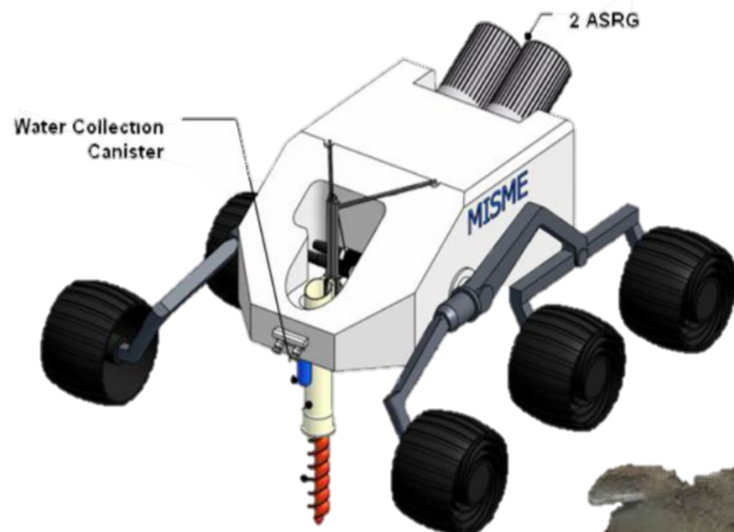
NASA/JPL/UA/LANL

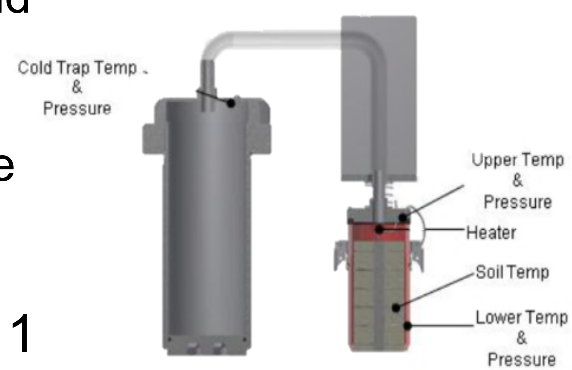


[Maurice et al., 2011], edited

Mining system

- Mars In Situ Water Extractor [Zacny et al., 2012]
- <u>Sequence of Operation:</u>
  - Auger drill selectively retains ice rich soil
  - Sealing trough sleeve and preloading against soil surface
  - Heat is conducted trough the auger into the icy soil
  - Contained ice melts, vaporises and bleeds trough a valve into the condenser
  - Drill is exposed and rotated to free it from dry soil
- Technology demonstration test → 1 Wh/g of water [Zacny et al., 2012]



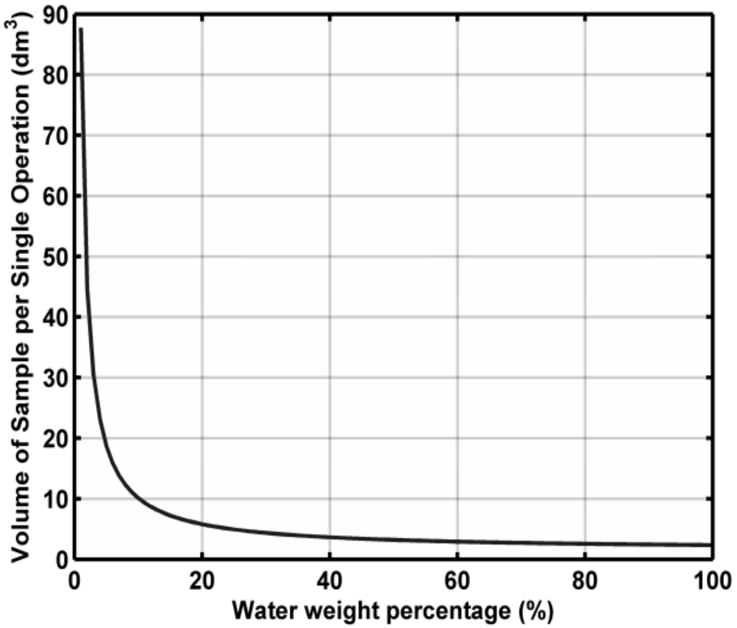


Water extraction test set-up

Mars soil simulant (JSC-1A): 12 wt % water

Mining subsystem

- Mining rate: 11 tons/year → 1.9 kg/h with a duty cycle of 68 %
- Definition of the mining rate links volume to water wt % (see top Figure)
  - Rupes site: 40 wt % → 3.6 dm^3
- Drill sizing: scaled with auger test drill for permafrost [Zacny et al., 2012]
  - Minimize energy consumption
  - → Ø23x15 cm
    - 2 kW
    - 1.5 min
    - 50 Wh



Auger drill with cartridge heater for extraction testing, from [Zacny et al., 2012] Ø5x10 cm

An Evaluation of Mars Water Extraction Mission

Serkan Saydam*[1], Carlos Tapia Cortez[1], Thierry de Roche [1,2] and Andrew Dempster [3]

Since the earliest explorations that NASA conducted on Mars in the 1960's, search for natural resources has been a major research topic to evaluate the viability of future human colony in the red planet. Water, as essential resource for life, has been largely addressed in the space related research.
Lander and orbiter missions have shown significant evidence of water in Mars. The interpretation of the recent data from Mars Odyssey Gamma Ray/Neutron Spectrometer (MONS) suggests that water exists in the poles and the equator region. Despite of this physical evidence, in the same manner that mining projects on the Earth, water exploration in Mars also will have to face geological, technical and meteorological uncertainties. To study and understand these uncertainties it is crucial to determine the production rate, mining equipment, processing technology and the infrastructure requirements to analyse the viability of water extraction missions.
This paper aims to analyse the main uncertainties associated for a possible water extraction – as a mining operation - in different regions of Mars and evaluate the viability of future missions.

- Where to mine the ice?
- Polar regions vs. Equator
- Mining method considerations
- Risks…

http://www.futuremining2015.ausimm.com.au/

- Full papers due next week.
- **In parallel with the Second Off-Earth Mining Forum – 5-6 November, 2015**
- Presentation only. So places are still available.
- **Around 300+ attendees expected for both events.**

- The Hon Ian Macfarlane, Minster of Industry and Science of Australia
- Craig Stegman, Chief Growth and Innovation Officer, Copper & Coal, Rio Tinto
- Nick Holland, Chief Executive Officer, Gold Fields, South Africa
- Rene Fardet, JPL, Deputy Director
- James Humphrey, *Senior Mining Market Professional, Caterpillar*

Research Opportunity

- Enormous interdisciplinary research opportunities
  - Developing new mining systems for extreme environment
  - Modifications of current mining systems
  - Business case for possible mining scenarios
  - Developing new technologies
    - **to enable these missions will generate spin-off technologies, such as robotics, ITC, autonomous mining, effective energy consumption technologies etc. that can be used in terrestrial mining.**
  - Taxation, laws and regulations must be developed.

Current Research

- Aerospace Engineering PhD – Asteroid Accessibility
- Mining Engineering, Economic Uncertainties
- Mining Engineering, Automated Mining System for Mars
- Mining Engineering, 3D Laser Printing for Infrastructure