



# Reference Mission Scenario Selection for Main Belt Asteroid Mining Missions

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CIM Convention 2015, 12.05.2015, Montréal

## → The Challenge of Asteroid Mining Mission Design

### → Mission Concept Selection Approach

- Mining Phases
- Trade-off Method & Trade Criteria

### → Application: KaNaRiA

- The Project KaNaRiA
- Mission Elements & Reference Scenario

### → Mission Analysis

- Parking Orbit Selection
- Target Selection Strategy

### → Conclusion



## → The Challenge of Asteroid Mining Mission Design



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## Science Mission:

1. Scientific Goals & Objectives
2. Payload Definition
3. Target Definition



**Mission Analysis and Mission Concept Selection**

# The Challenge of Asteroid Mining



- Character of an asteroid mining mission **differs** from conventional scientific space missions:

- Economic revenue



- No target object associated with the mission objectives



# The Challenge of Asteroid Mining

- Character of an asteroid mining mission **differs** from conventional scientific space missions:

- Economic revenue



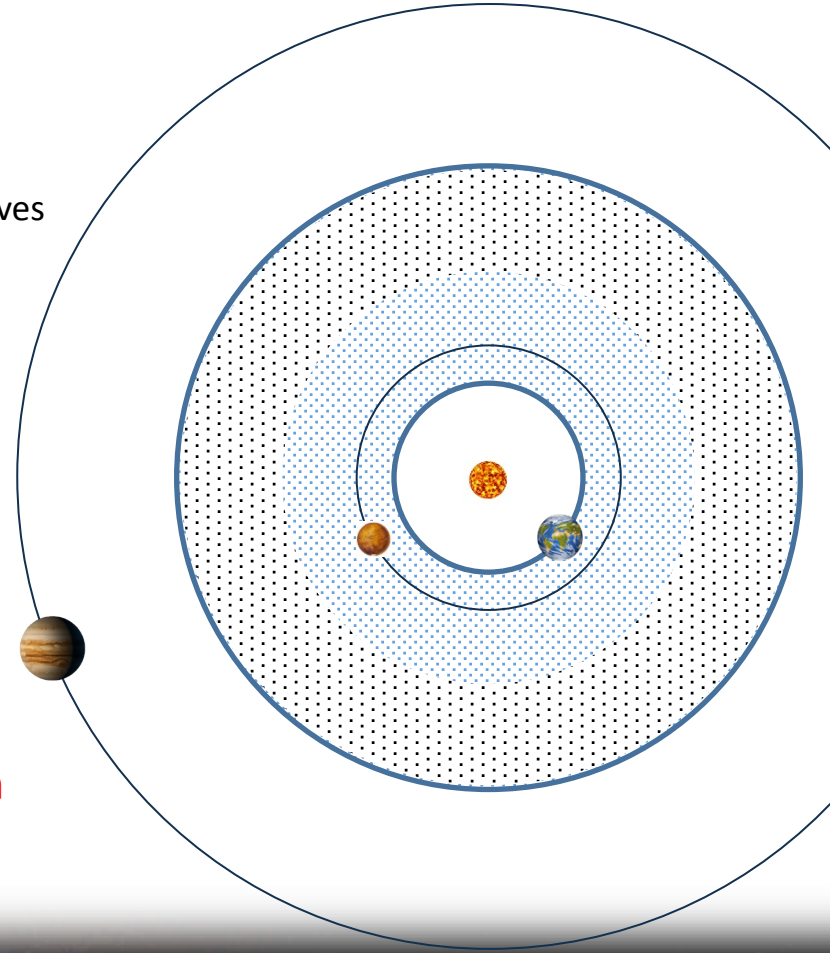
- No target object associated with the mission objectives

- In our case:

- Object space > **679.000** possible targets
- Distributed in an area of 31.07 AU<sup>2</sup>  
( ~7e<sup>10</sup> Canadas)



**New Approach for Mission Design  
and Analysis necessary**



# The Challenge of Asteroid Mining

## → The Challenge of Asteroid Mining Mission Design

### → Mission Concept Selection Approach

- Mining Phases
- Trade-off Method & Trade Criteria



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- Four processes for the industrial exploitation of space bodies:

- Mapping, Characterization and Resource Determination
- Resource Extraction and Exploitation
- Maintenance
- Logistics



Mining Phases

# Mission Concept Selection Approach

Reference Mission Scenario for a Main Belt Asteroid Mining Mission, A.Probst, SRR-PTMSS 2015



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# Asteroid Mining Operations Chart:

## Asteroid Mining Process Timeline

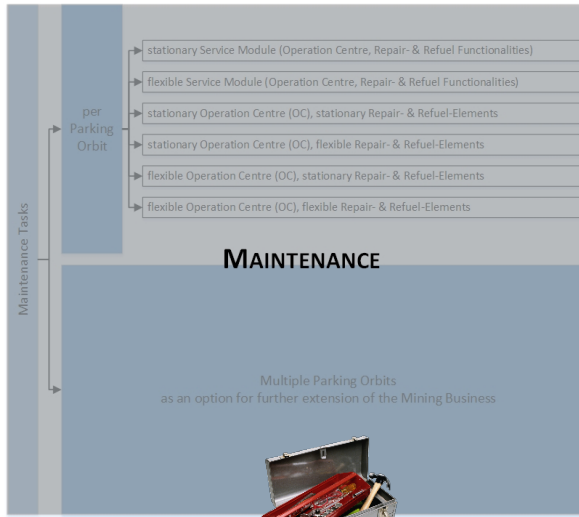
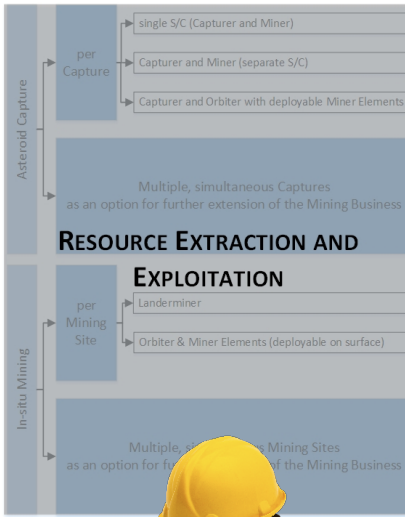
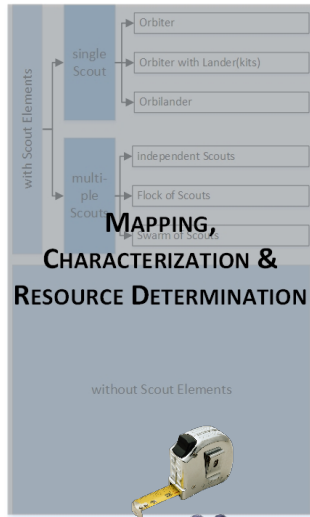
Mapping, Characterization and Resource Determination

Resource Extraction and Exploitation

Maintenance

Logistics

Asteroid Mining Mission Architecture Options



Mining Phases

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- Method:
  - **Numerical approach** based on **relative judgments** between options
  - With respect to **trade criteria**
- Approach:
  - **Definition** of trade criteria relevant for each phase
  - 3 step calculation of a **ranking** of the options

Trade-Off Method

# Mission Concept Selection Approach

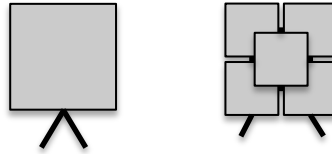
Reference Mission Scenario for a Main Belt Asteroid Mining Mission, A.Probst, SRR-PTMSS 2015



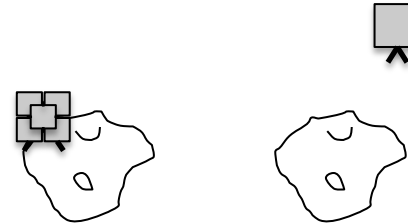
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## 1. step Definition of trade criteria

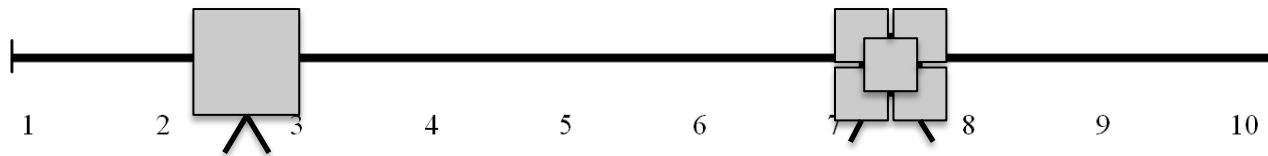
- System Complexity:



- Landing Capacity:  
ability to land and surface operations capabilities



- Characterization Efficiency:



Trade-Criteria

# Mission Concept Selection Approach

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2. step: Weighting importance of criteria with respect to their relative importance

Criteria

	System Complexity	Operational Complexitiy	Landing Capacity	Characterization Efficiency	Line Sum	Weight Factor: Line Sum / Total
System Complexity	1	1	0	0	2	0.2000
Operational Complexitiy	0	1	0	0	1	0.1000
Landing Capacity	1	1	1	0	3	0.3000
Characterization Efficiency	1	1	1	1	4	0.4000
Total					10	

weighting factors WF

relative judgement

Weighting Factors

# Mission Concept Selection Approach

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### 3. step: Weighting options against each other per criterion

System Complexity

	Orbiter	Orbiter with Landerkits	Orbilander	line sum	Figure of Merit
Orbiter	1	1	1	3	0.5000
Orbiter with Landerkits	0	1	0	1	0.1667
Orbilander	0	1	1	2	0.3333
Total				6	

Operational Complexity

	Orbiter	Orbiter with Landerkits	Orbilander	line sum	Figure of Merit
Orbiter	1	1	1	3	0.5000
Orbiter with Landerkits	0	1	1	2	0.3333
Orbilander	0	0	1	1	0.1667
Total				6	

Landing Capacity

	Orbiter	Orbiter with Landerkits	Orbilander	line sum	Figure of Merit
Orbiter	1	0	0	1	0.1667
Orbiter with Landerkits	1	1	0.5	2.5	0.4167
Orbilander	1	0.5	1	2.5	0.4167
Total				6	

Characterization Efficiency

	Orbiter	Orbiter with Landerkits	Orbilander	line sum	Figure of Merit
Orbiter	1	0	0	1	0.1667
Orbiter with Landerkits	1	1	1	3	0.5000
Orbilander	1	0	1	2	0.3333
Total				6	

unweighted  
figures of  
merit (uFoM)

Unweighted Figures of Merit

# Mission Concept Selection Approach

4. step: Weighting factor \* unweighted FoM = weighted FoM

MCRD, single scout design		Orbiter		Orbiter with Lander(kits)		Orbilander	
Trade Criteria	weighting	unweighted	weighted	unweighted	weighted	unweighted	weighted
System Complexity	0.2000	0.5000	0.1000	0.1667	0.0333	0.3333	0.0667
Operational Complexity	0.1000	0.5000	0.0500	0.3333	0.0333	0.1667	0.0167
Landing Capacity	0.3000	0.1667	0.0500	0.4167	0.1250	0.4167	0.1250
Characterization Efficiency	0.4000	0.1667	0.0667	0.5000	0.2000	0.3333	0.1333
<b>Total</b>		1.3333	<b>0.2667</b>	1.4167	<b>0.3917</b>	1.2500	<b>0.3417</b>
<b>Ranking</b>		<b>3</b>		<b>1</b>		<b>2</b>	

the higher the number the more suitable the option

Trade-Off Results

# Mission Concept Selection Approach

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## → The Challenge of Asteroid Mining Mission Design

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### → Application: KaNaRiA

- The Project KaNaRiA
- Mission Elements & Reference Scenario





## Cognitive Autonomous Navigation for Deep Space Asteroid Mining

- Objectives:
1. Development of bio-inspired, autonomous navigation algorithms
  2. Testing and Verification in a virtual reality simulator



The project KaNaRiA

# Application KaNaRiA

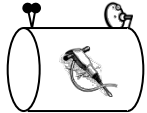
Reference Mission Scenario for a Main Belt Asteroid Mining Mission, A.Probst, SRR-PTMSS 2015



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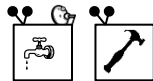


Potential Target Characterization Modules PTCMs



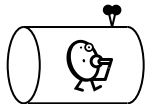
KaNaRiA Miner Spacecraft

KMS



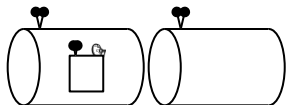
Repair- and Refuel Elements

RP / RF



Operational Centre

OC



PTCM Carrier / Transporter

Mission Elements

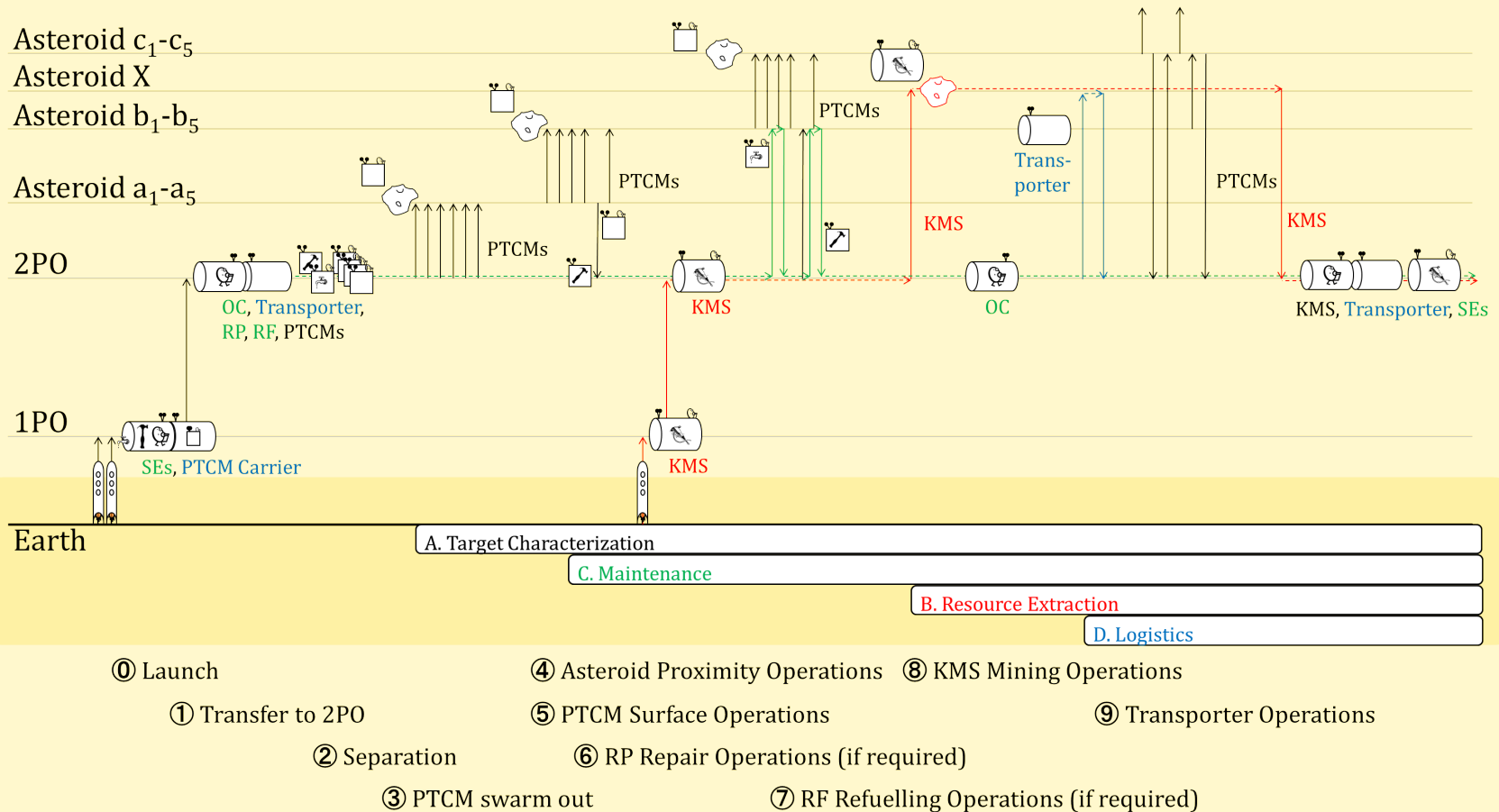
# Application KaNaRiA

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## Mission Profile and Major Events



Reference Scenario

# Application KaNaRiA

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Parking Orbit Selection

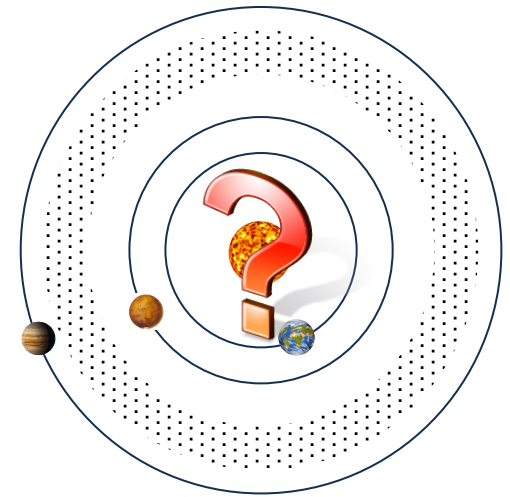
# Mission Analysis

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- Method:
  - From which orbit can I reach the most asteroids within a certain  $\Delta v$ -limit?
- Assumptions:
  - **Hohmann-Transfer**, impulsive manoeuvres
  - **Accessibility** of all asteroid ( $\Delta v$ ) starting from **circular orbit**
  - Iteration of semi-major axis **from 1 AU to 5 AU** in steps of **0.1 AU**
- JPL Small Body Database
  - ~680,000 asteroids per parking orbit
  - In total: 27 Mio trajectories



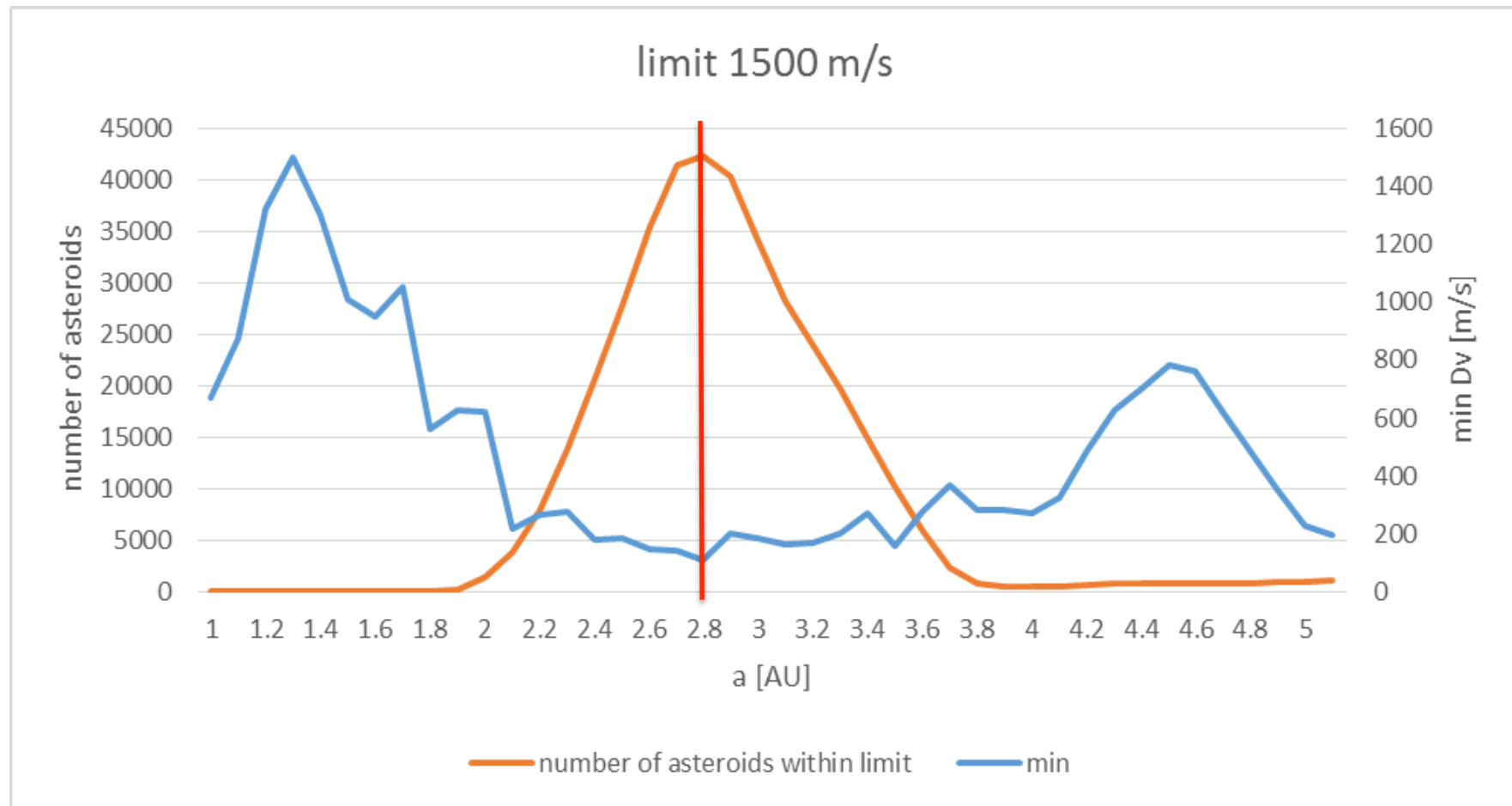
Parking Orbit Selection

# Mission Analysis

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Selection Parking Orbit:  $a_{2PO} = 2.8 \text{ AU}$  / circular, ecliptic orbit

Parking Orbit Selection

# Mission Analysis



Target Selection Strategy

# Mission Analysis

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- Challenge:
  - **Little** data and **knowledge** on asteroids available
  - Characterize **more than one** asteroid
- Strategy:  
Target selection is based on
  - date of departure
  - remaining fuel stock
  - transfer time

Target Selection Strategy

# Mission Analysis

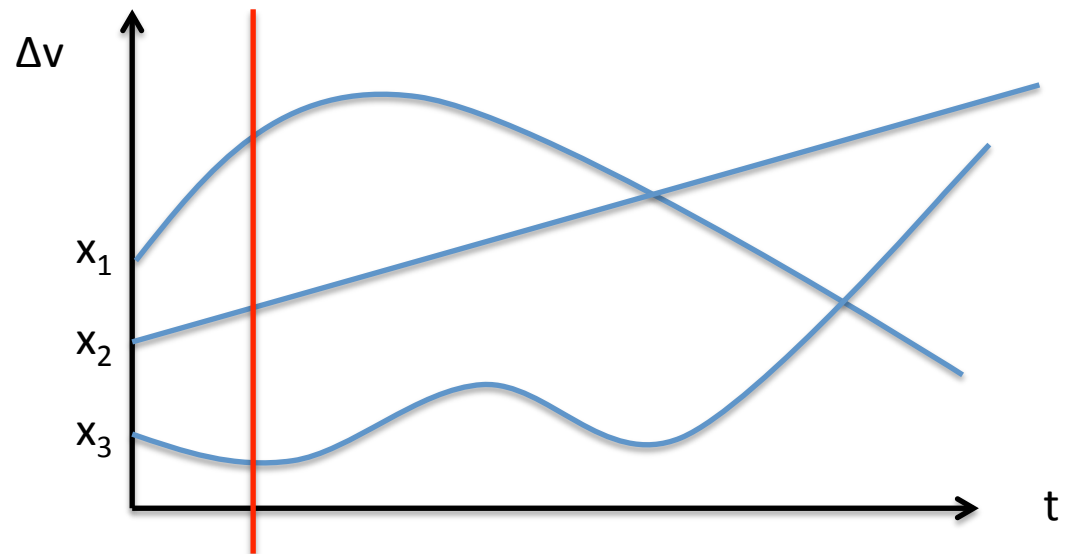
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Target Selection Strategy

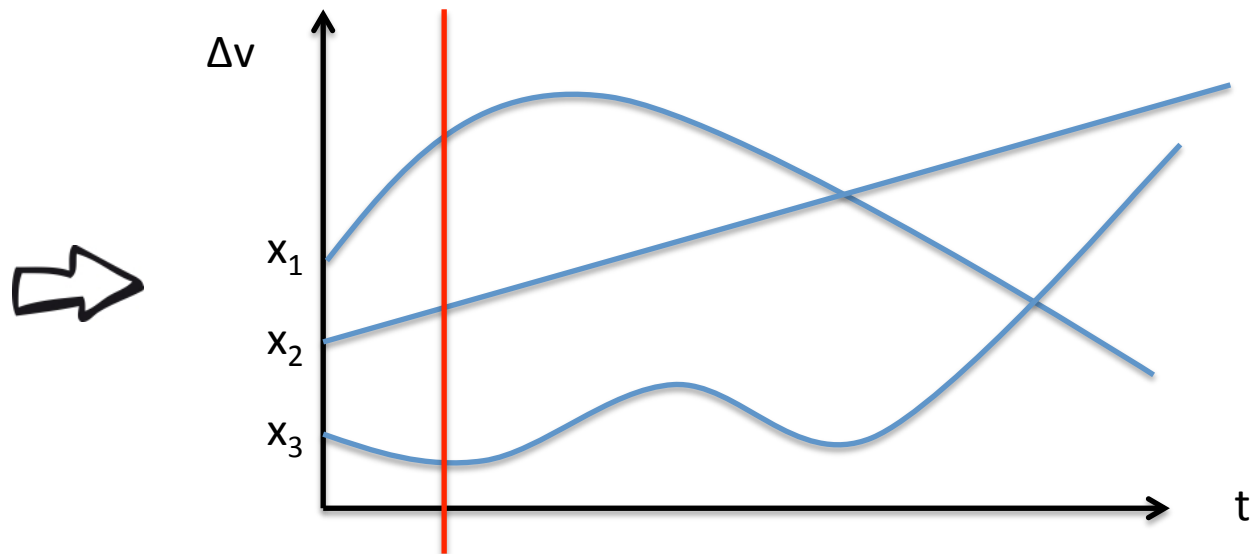
# Mission Analysis

- Assumptions:

- Chemical engines = Lambert Solver

Input: start- and end-position, transfer time

Output:  $v_1, v_2$  vectors of the transfer trajectory



Target Selection Strategy

# Mission Analysis

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## → **The Challenge of Asteroid Mining Mission Design**

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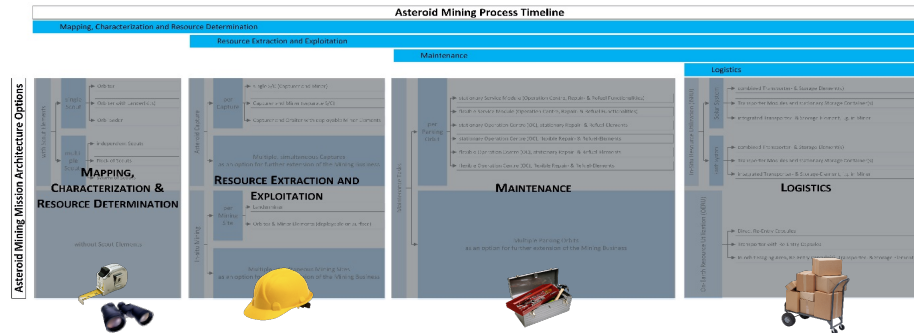
### → **Mission Analysis**

- Parking Orbit Selection
- Target Selection Strategy

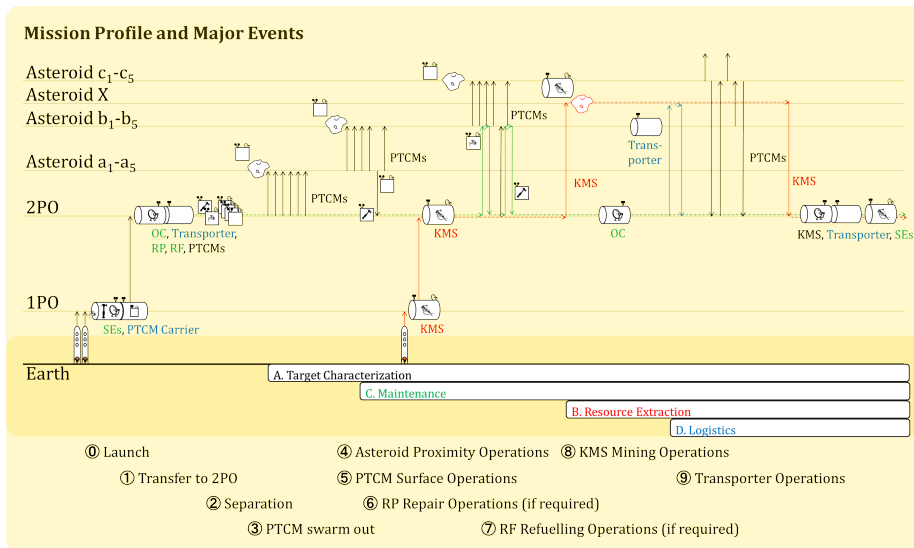
### → **Conclusion**



## Mining Phases

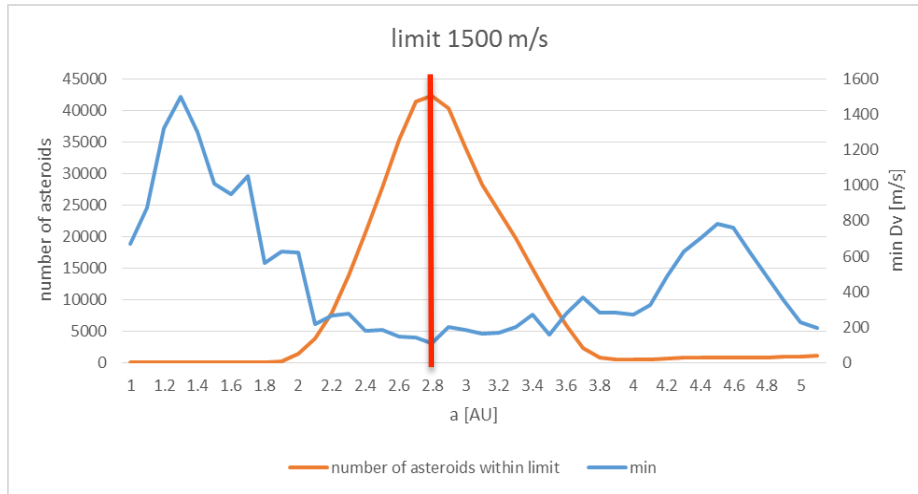


## KaNaRiA Reference Scenario



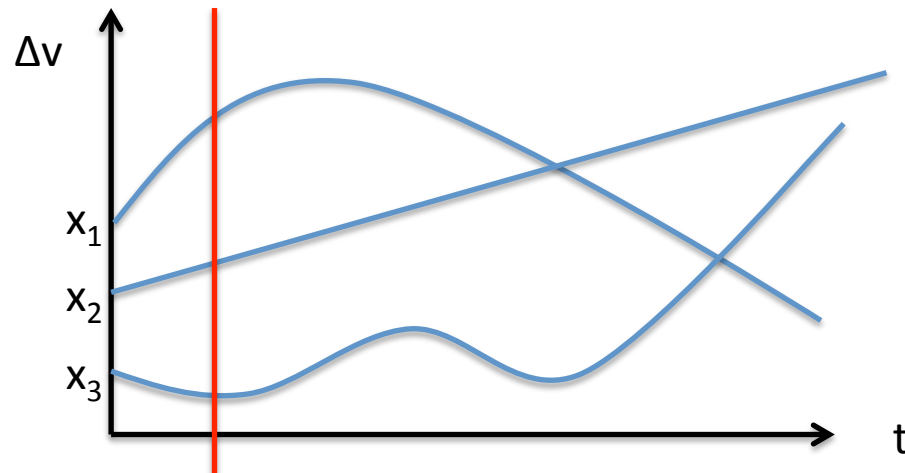
## Conclusion

- 



## Parking Orbit Selection

- 



## Target Selection Strategy

# Conclusion



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