An Overview on CubeSats and Space Mission Concept Design

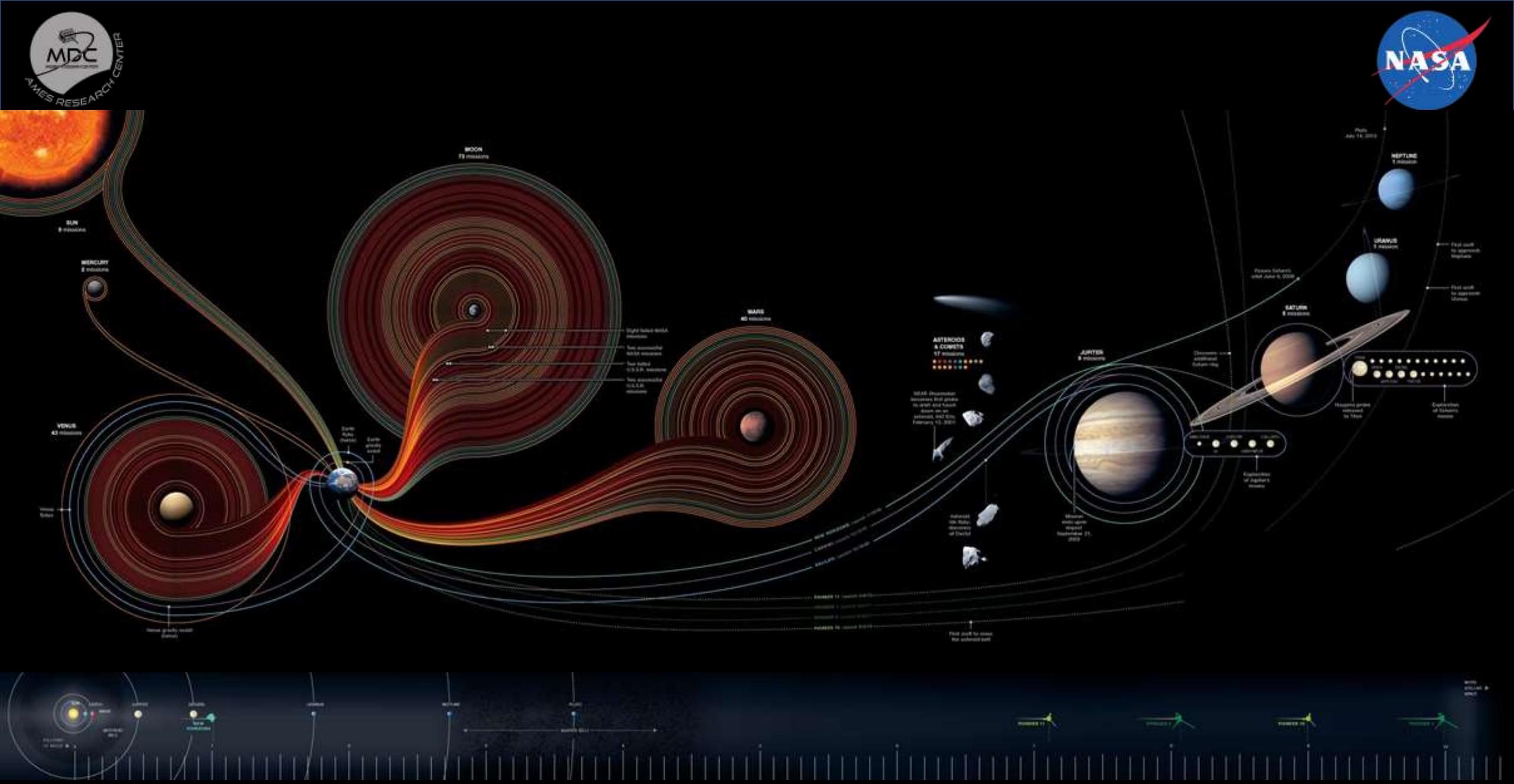
NASA Ames Visitor Center

6 March 2020

David Mauro, KBR / NASA Ames Research Center

Agenda

- Introduction
  - What is Space Mission Concept
  - What is the Ames Mission Design Center
- Overview of Cubesats: From Sputnik to BioSentinel
- Space Mission Concept Design at NASA Ames
    - Aeolus: an example of a mission concept study for Mars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AMES RESEARCH CENTER
NASA
SUN
8 missions
MERCURY
2 missions
VENUS
43 missions
MOON
73 missions
MARS
40 missions
ASTEROIDS & COMETS
17 missions
JUPITER
8 missions
SATURN
8 missions
URANUS
1 mission
NEPTUNE
1 mission

Mission Design Center - What is it?

About the Mission Design Center

The Mission Design Center (MDC) is a facility within the Spaceflight Division that specializes in conceptual mission design. While experienced in multiple levels of design and mission implementation, the MDC focuses on low-cost, small spacecraft missions.

The MDC possesses full, end-to-end mission design capability with sophisticated analysis and simulation tools in a collaborative concurrent design environment. Services include:

- Concept Maturity Level (CML) progression
- Spacecraft design and trade studies
- Scientific instrument selection
- Feasibility assessments
- Proposal support and partnerships

These capabilities allow the MDC to support the Ames Engineering Directorate's ability to support all phases of engineering and project management for flight and mission projects from research and development to close-out.

Point of Contact:
Ryan Vaughan, Division Chief
Ryan.Vaughan@nasa.gov
650-604-3109

Examples of MDC-supported projects

2019 | 2018 | 2017 | 2016 | 2015 | 2014 | 2013 | 2012 | 2011 | 2010 | 2009 | 2008 | 2007

2019

Luna Lynx

Preliminary feasibility assessment for a small spacecraft lunar communication relay with a Lunar South Pole asset.

Mission Concept Study report for the Dark Ages Polarimeter Pathfinder (DAPPER)

Mission concept study report designed to search for deviations from the standard cosmological model by measuring the global 21-cm spectrum.

Miniaturized Distributed Occulter Telescope (mDOT)

Mission concept study to provide unprecedented detection and direct measurements of brightness of extrasolar dust disks visible to ultraviolet wavelength using a small spacecraft starshade and a 6U telescope spacecraft. mDOT was selected as part of the Astrophysics Science SmallSat Studies solicitation.

https://www.nasa.gov/centers/ames/engineering/mission-design-center/about

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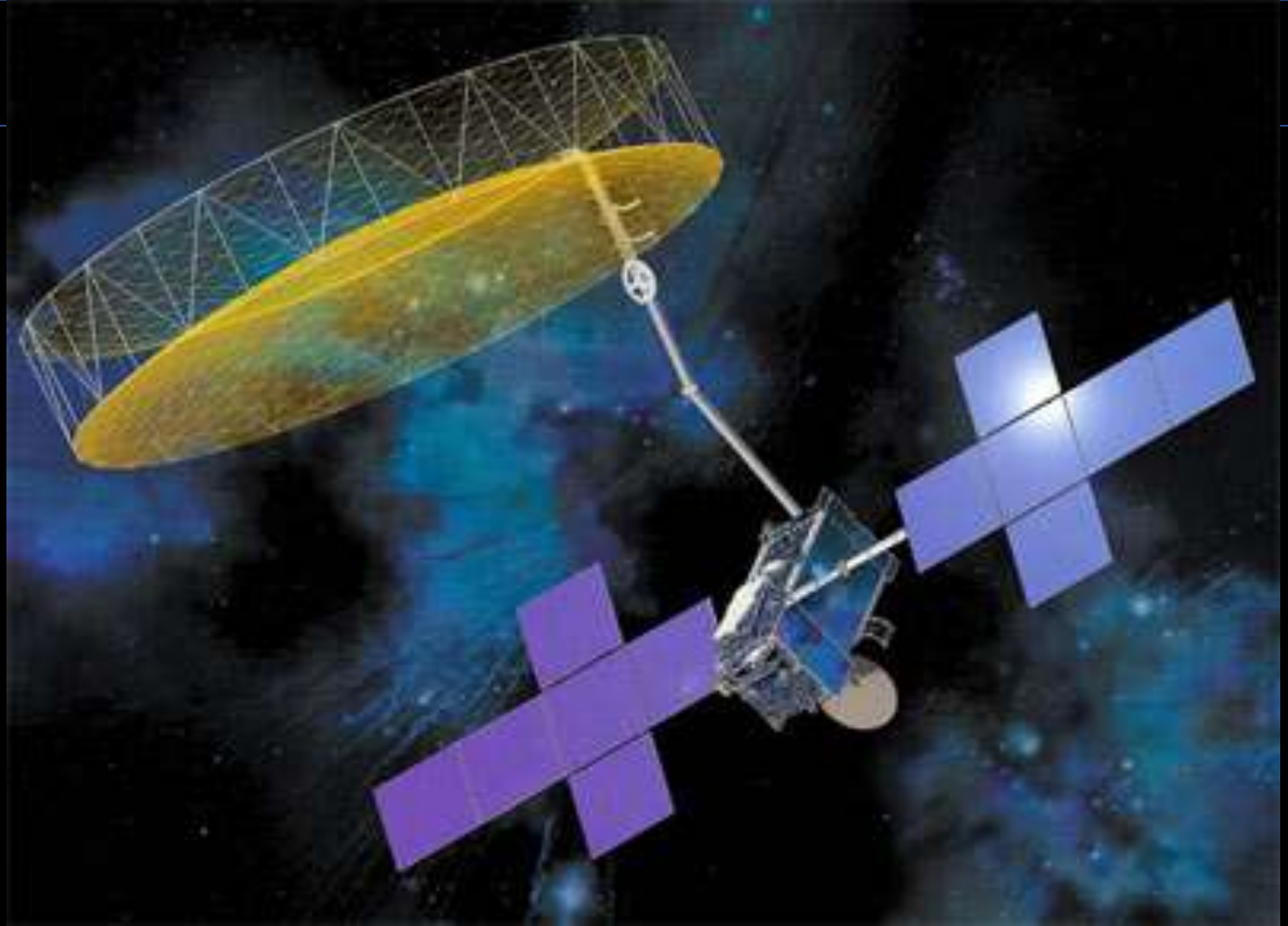
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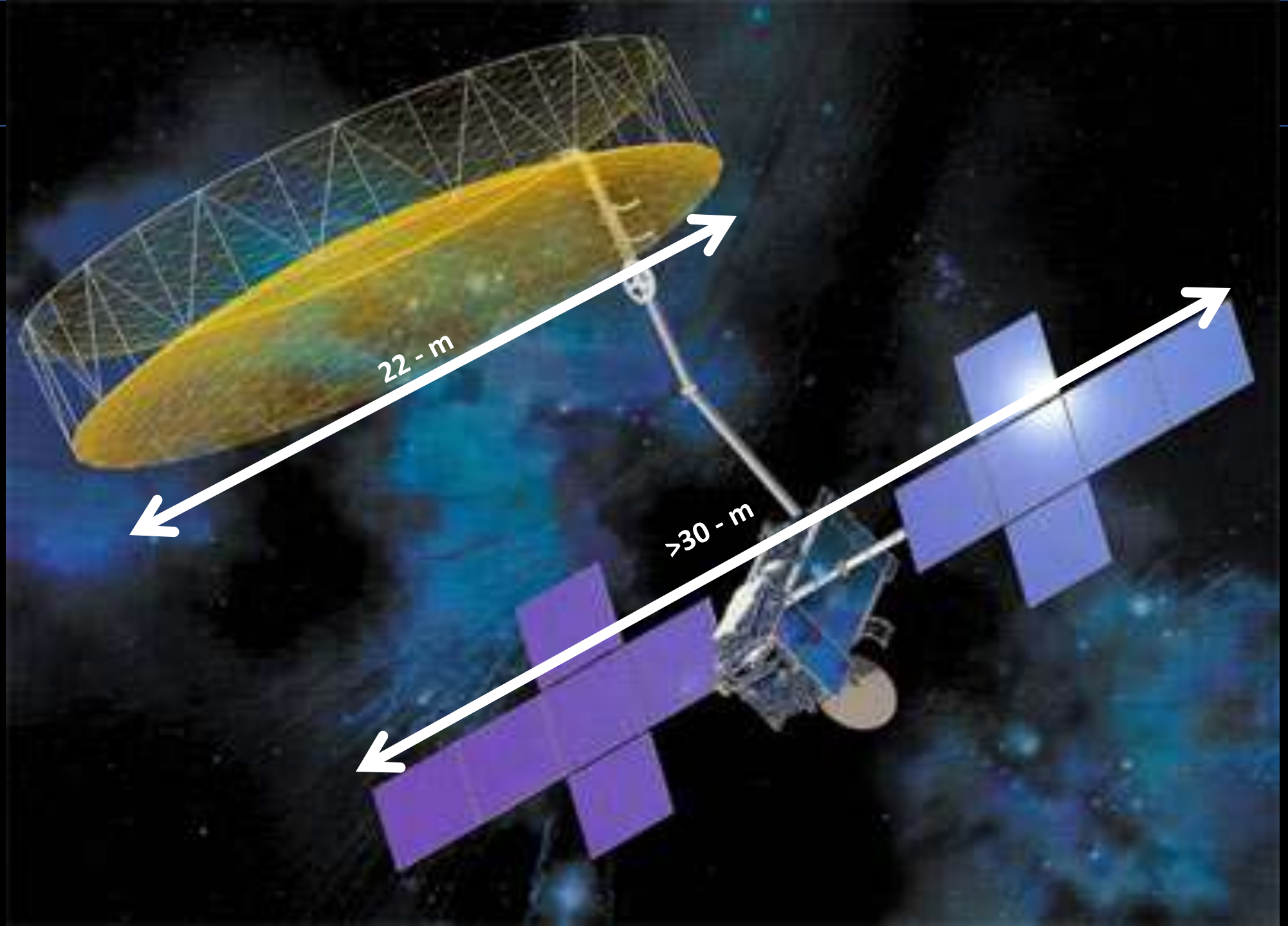
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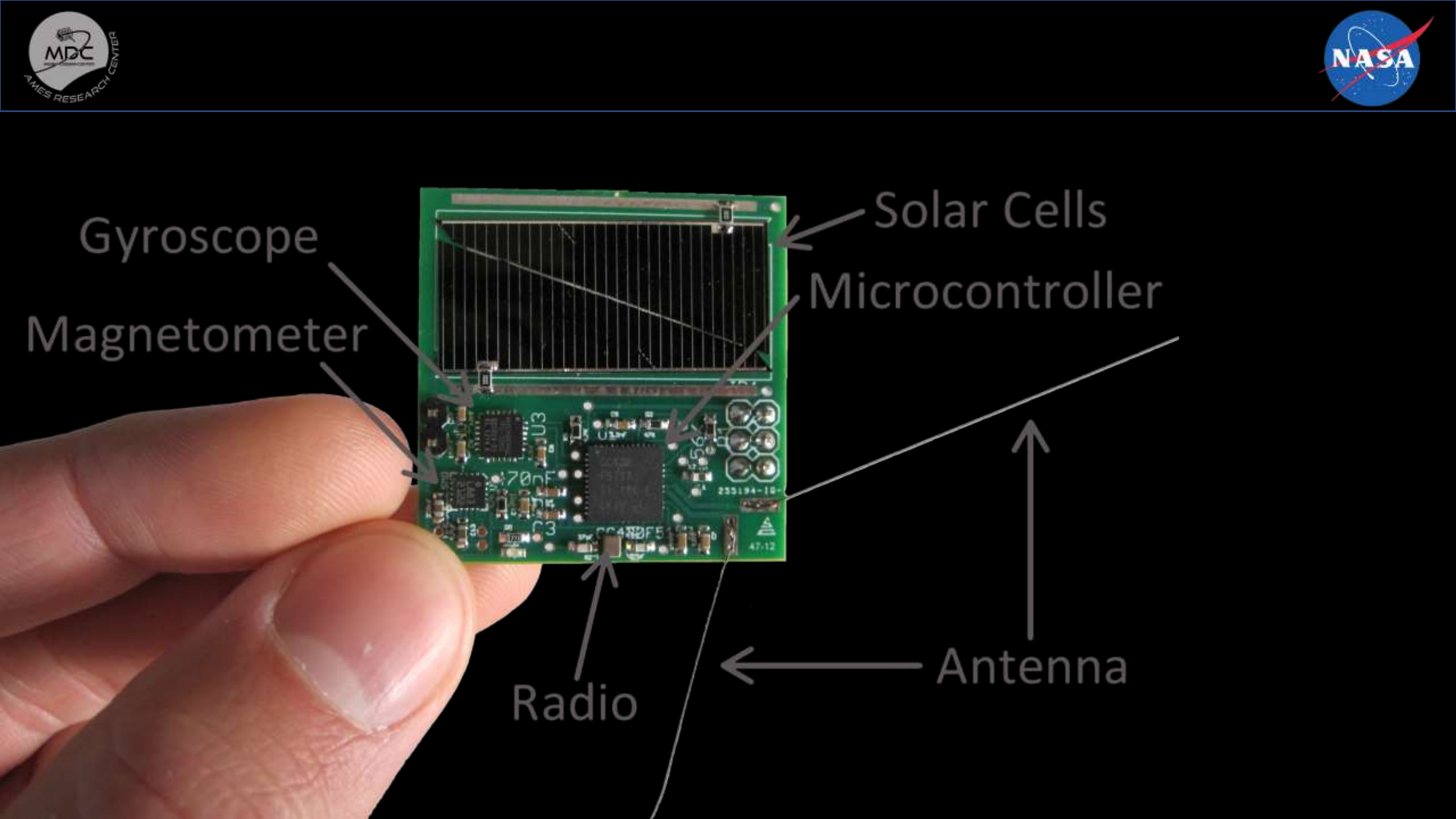
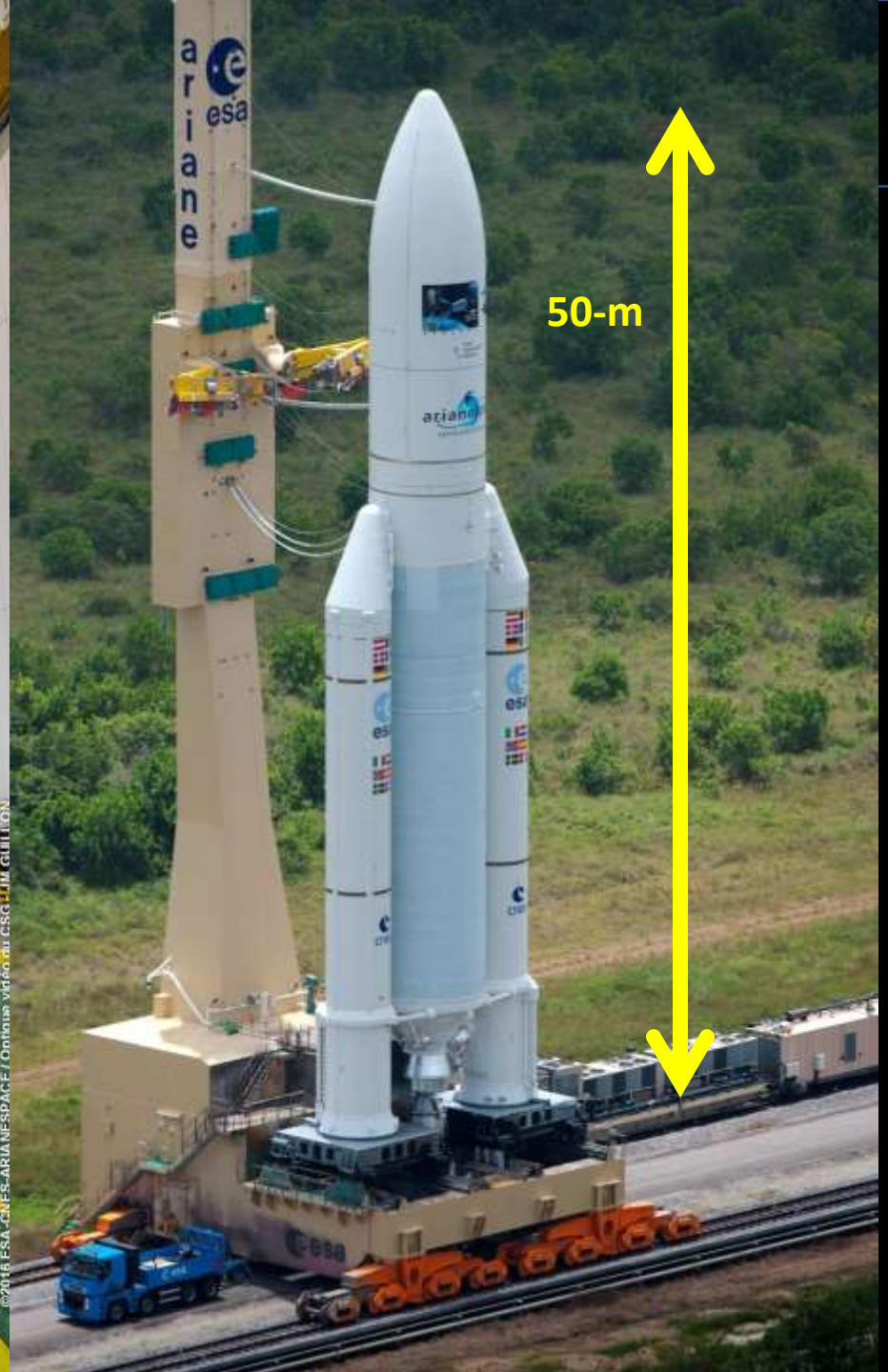

Gyroscope
Magnetometer
Solar Cells
Microcontroller
Antenna
Radio


STARS AND THEIR
NUMBERS,
WHEREWITH
THE SEA...


ariane
services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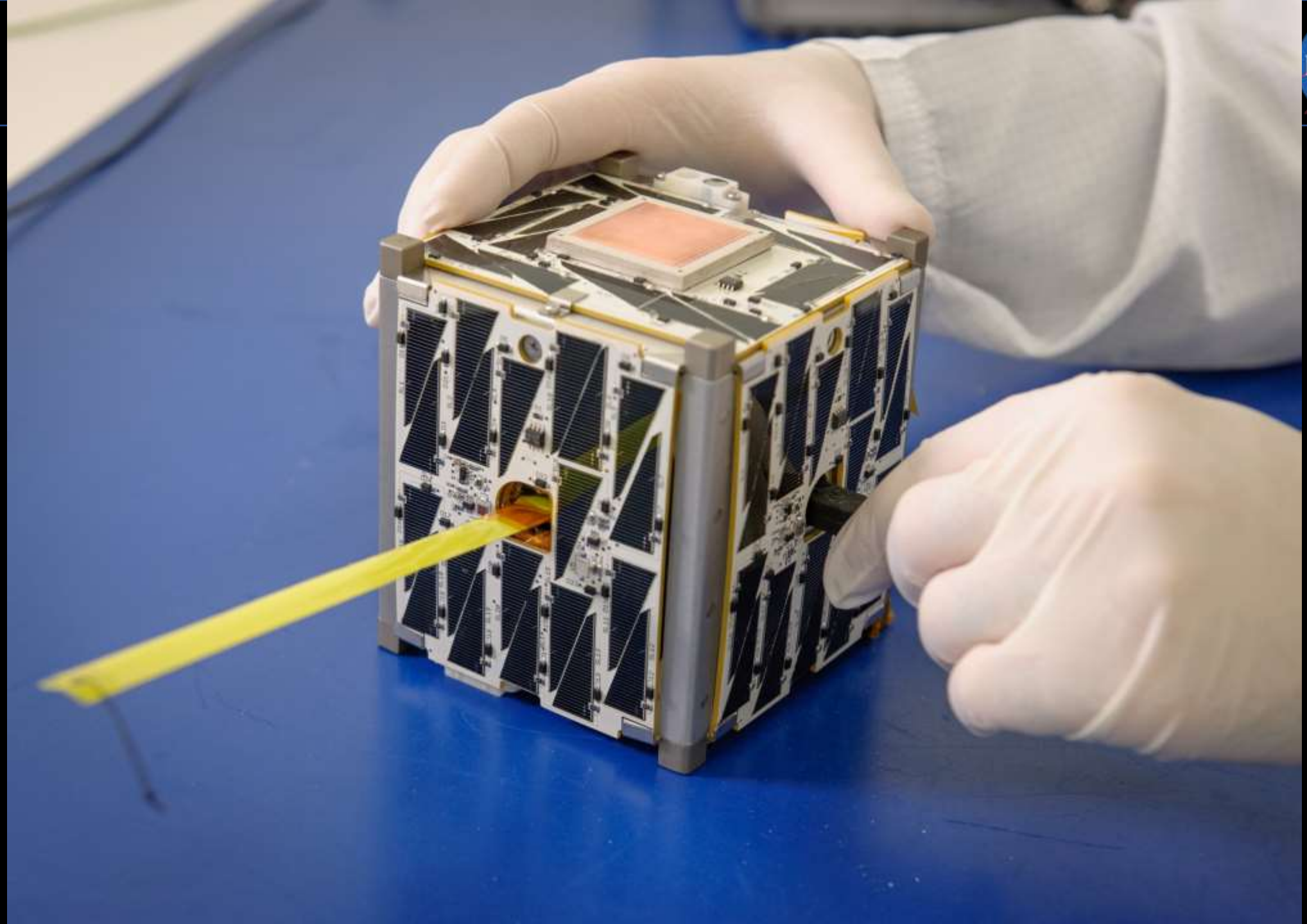
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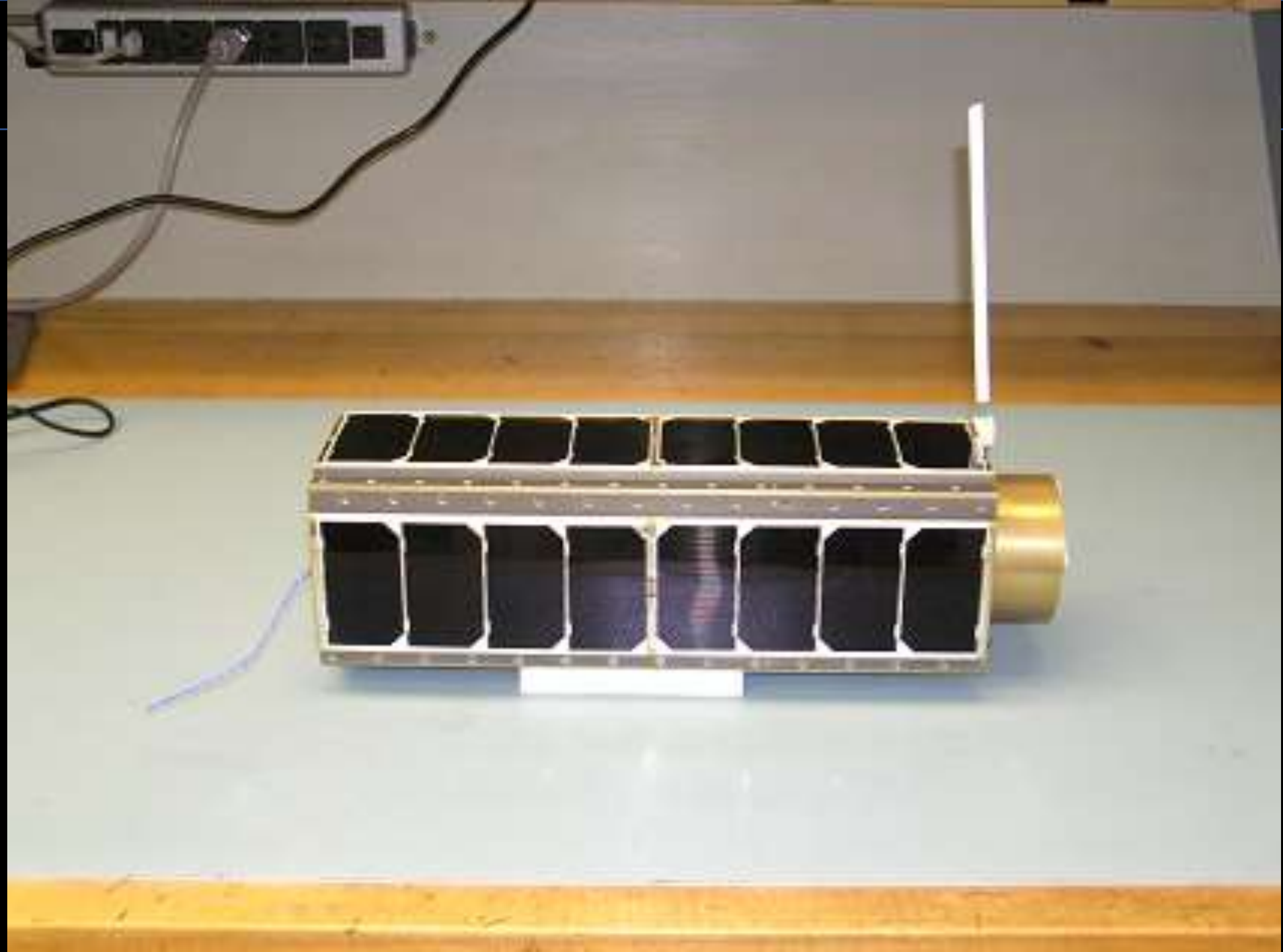

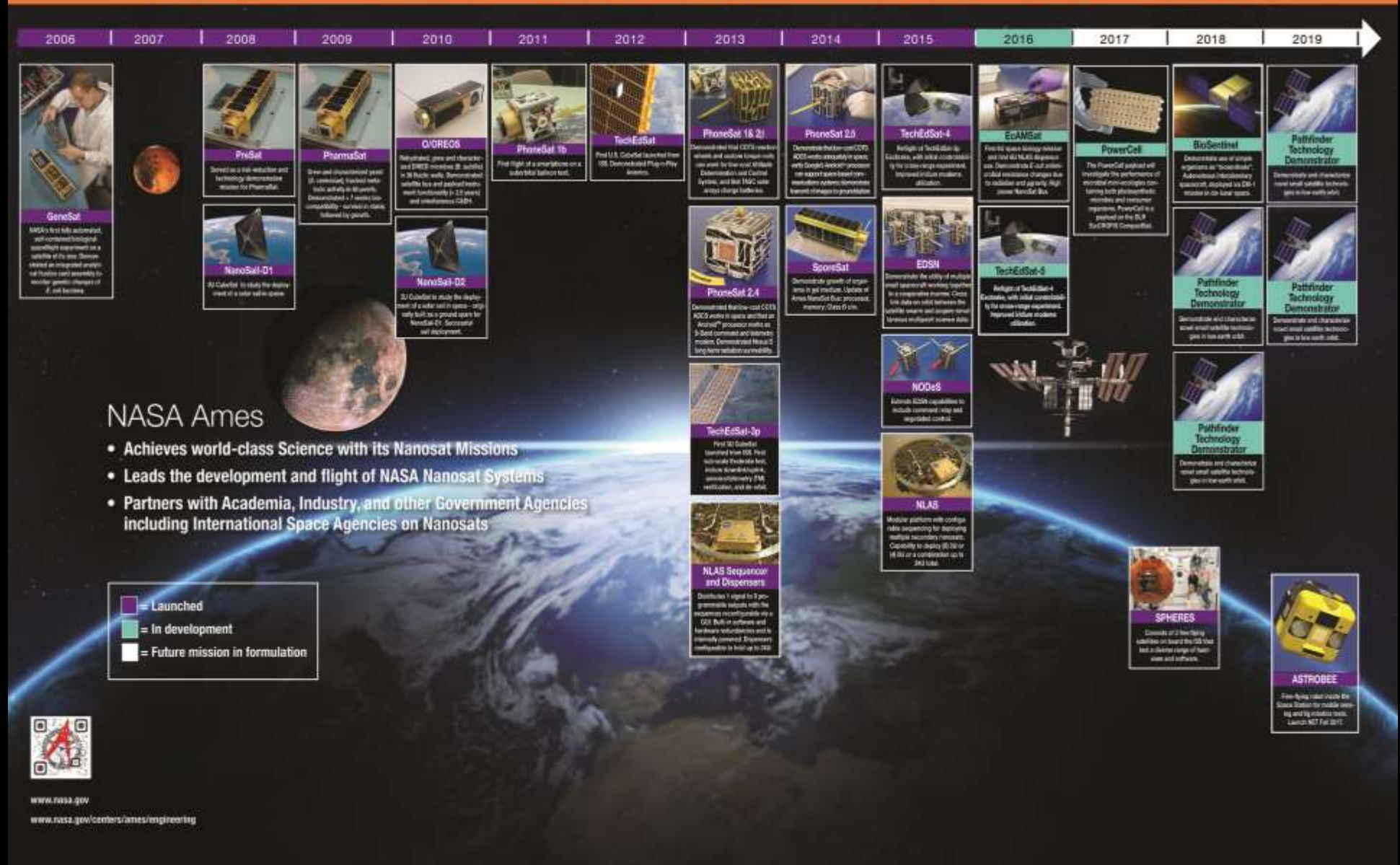
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NASA
Nanosat Missions and Plans at NASA Ames
Supporting the Goals of Science Investigations, Technology Development, and Advanced Exploration Systems
2006
2007
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2019
GeneSat
PreSat
PharmaSat
O/OREOS
NanoSail-D1
NanoSail-D2
PhoneSat 1b
TechEdSat
PhoneSat 1& 2/
PhoneSat 2.0
PhoneSat 2.4
TechEdSat-3p
SporeSat
TechEdSat-4
EDSN
NODeS
NLAS
NLAS Sequencer and Dispensers
EcAMSat
TechEdSat-5
PowerCell
BioSentinel
Pathfinder Technology Demonstrator
Pathfinder Technology Demonstrator
Pathfinder Technology Demonstrator
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SPHERES
ASTROBEE
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• Leads the development and flight of NASA Nanosat Systems
• Partners with Academia, Industry, and other Government Agencies including International Space Agencies on Nanosats
= Launched
= In development
= Future mission in formulation
www.nasa.gov
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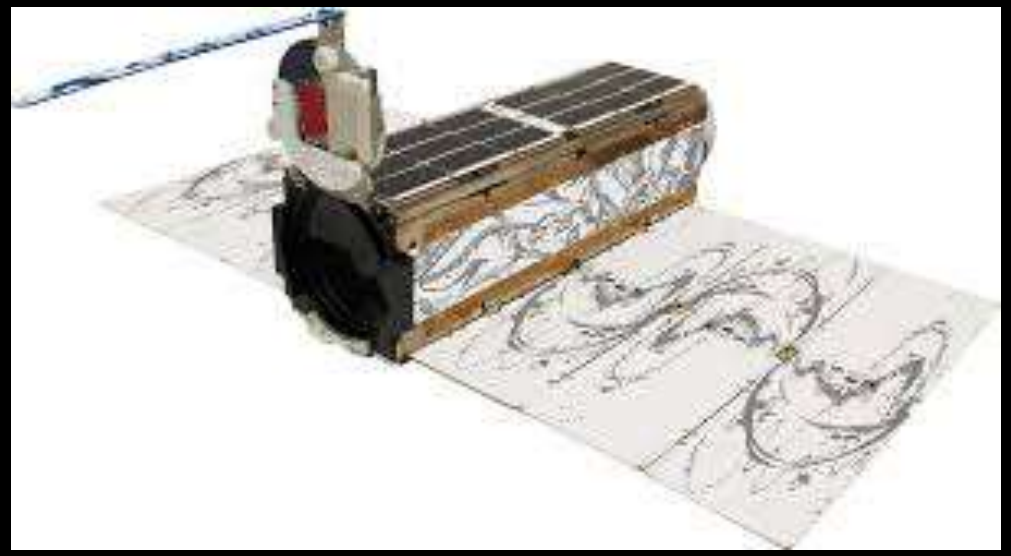
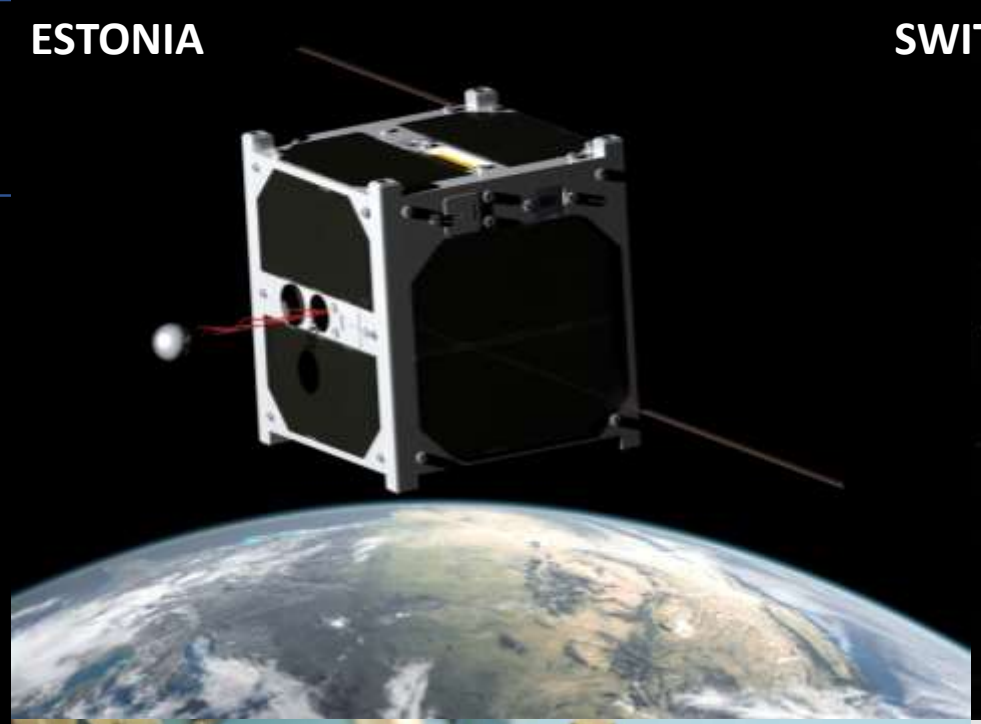


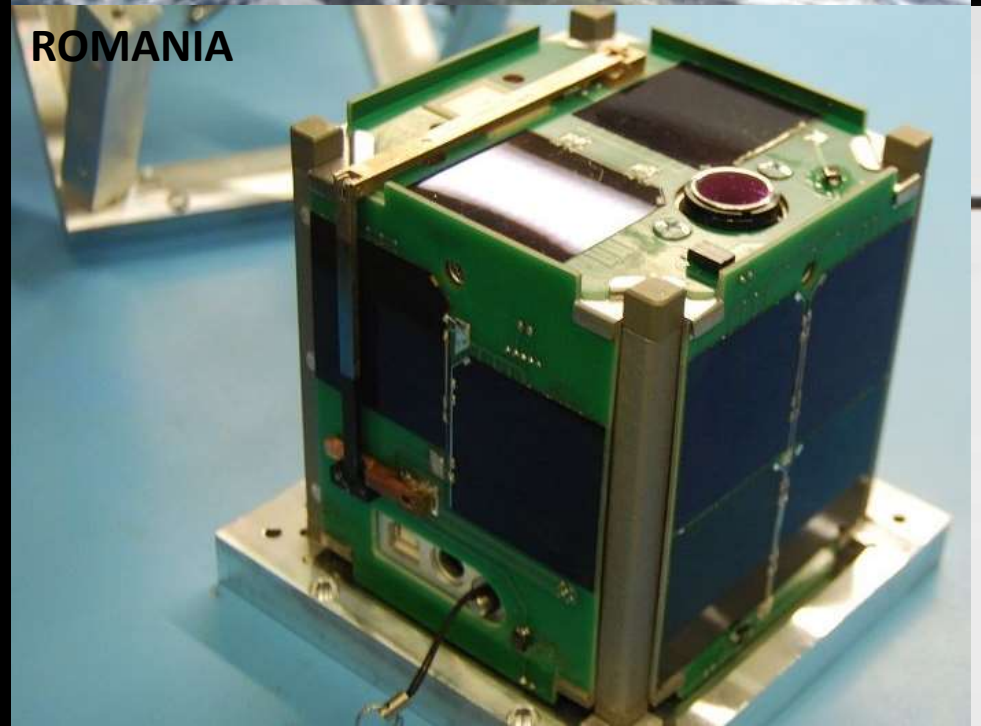
Credit: spire.com

ESTONIA



SWITZERLAND

ROMANIA



LITHUANIA

CubeSats

CubeSat Launch Initiative
ELaNa
CubeSats Launching on EM-1

Related Links

Small Satellite Missions
Small Spacecraft Technology Program
Office of the Chief Technologist
Space Technology Mission Directorate

Related Topics

Commercial Resupply
Space Station
Journey to Mars
Space Station Research
Technology
All Topics A-Z

CubeQuest

NASA Awards $30,000 to Top 5 Teams in Third Round of Cube Quest

Sun

New Info. from Small Satellite on Solar Flares Study

Solar System and Beyond

Mini Satellite Begins Environmental Testing

NASA's CubeSat Launch Initiative Opens Space to Educators, Nonprofits

CubeQuest CHALLENGE

A NASA CENTENNIAL CHALLENGES COMPETITION

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Related Links

- Space Technology Mission Directorate
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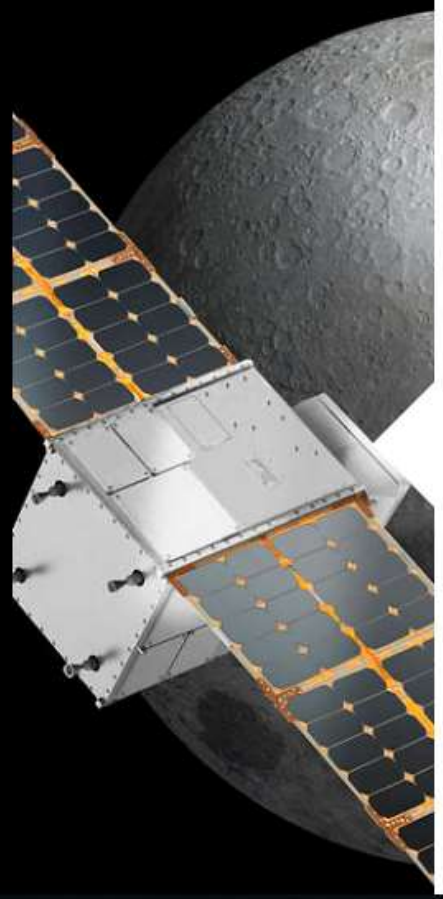

Recent SmallSat News

NASA Awards Contract to Launch CubeSat to Moon from Virginia

NASA has selected Rocket Lab of Huntington Beach, California, to provide launch services for the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) CubeSat.

Rocket Lab, a commercial launch provider licensed by the Federal Aviation Administration, will launch the 55-pound CubeSat aboard an Electron rocket from NASA's Wallops Flight Facility in Virginia. After launch, the company's Photon platform will deliver CAPSTONE to a trans-lunar injection.

Archived SmallSat News

NASA Astrophysics CubeSats and SmallSats

Community of Practice Webinar Series

NASA Small Spacecraft Strategic Plan

NASA has supported small spacecraft mission development for more than a decade as small spacecraft capabilities have rapidly advanced with tangible results.

State of the Art of Small Spacecraft Technology

Welcome to the new online home of the 2018 NASA State of the Art Report of Small Spacecraft Technology.

This online version of the NASA State of the Art (SoA) Report provides an overview of the current state of the art of small spacecraft technology. It was first commissioned by NASA's Small Spacecraft Technology Program (SSTP) in mid-2013 in response to the rapid growth in interest in using small spacecraft for many types of missions in Earth orbit and beyond, and further revised in mid-2015. In 2016 the decision was taken to migrate from a written to an online report.

For the sake of this assessment, small spacecraft are defined to be spacecraft with a mass less than 180 kg. This report provides a summary of the state of the art for each of the following small spacecraft technology domains: Complete Spacecraft, Power, Propulsion, Guidance Navigation and Control, Structures, Materials and Mechanisms, Thermal Control, Command and Data Handling, Communications, Integration, Launch and Deployment, Ground Data Systems and Operations, and Passive Deorbit Devices.

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STMD: Small Spacecraft Technology

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State of the Art Report

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Cubesats

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Learn more about our ghostly "Solar White" coating that could enable cryogenic storage for missions to Mars & beyond bit.ly/2fxSj4w

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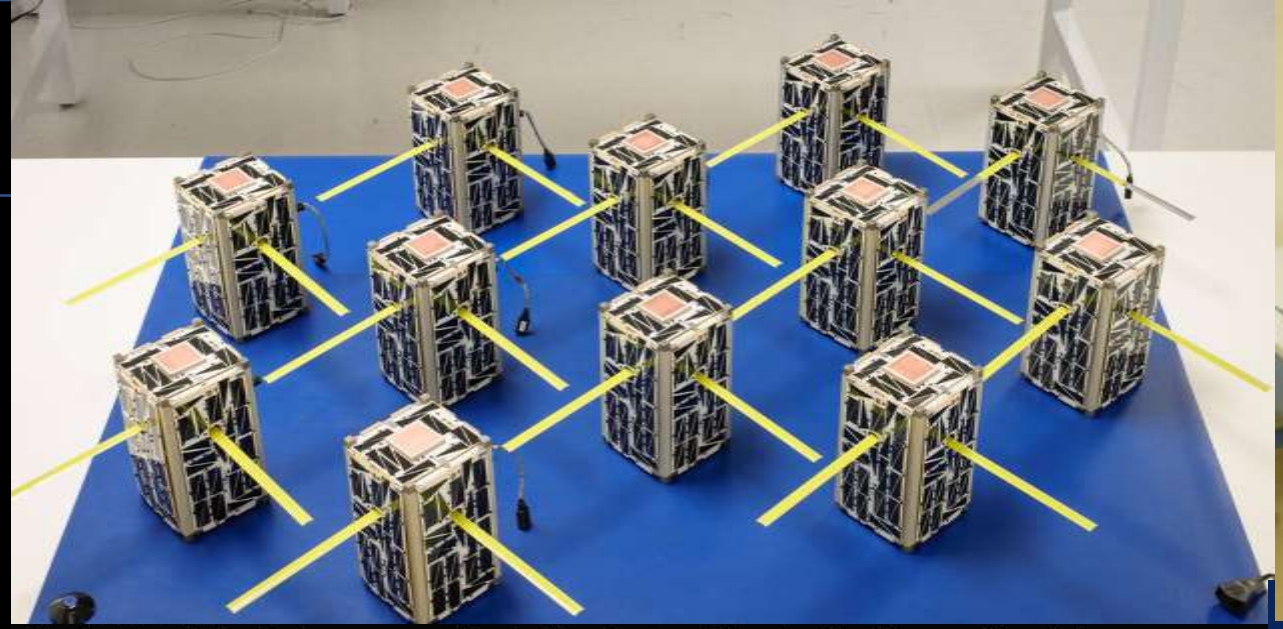
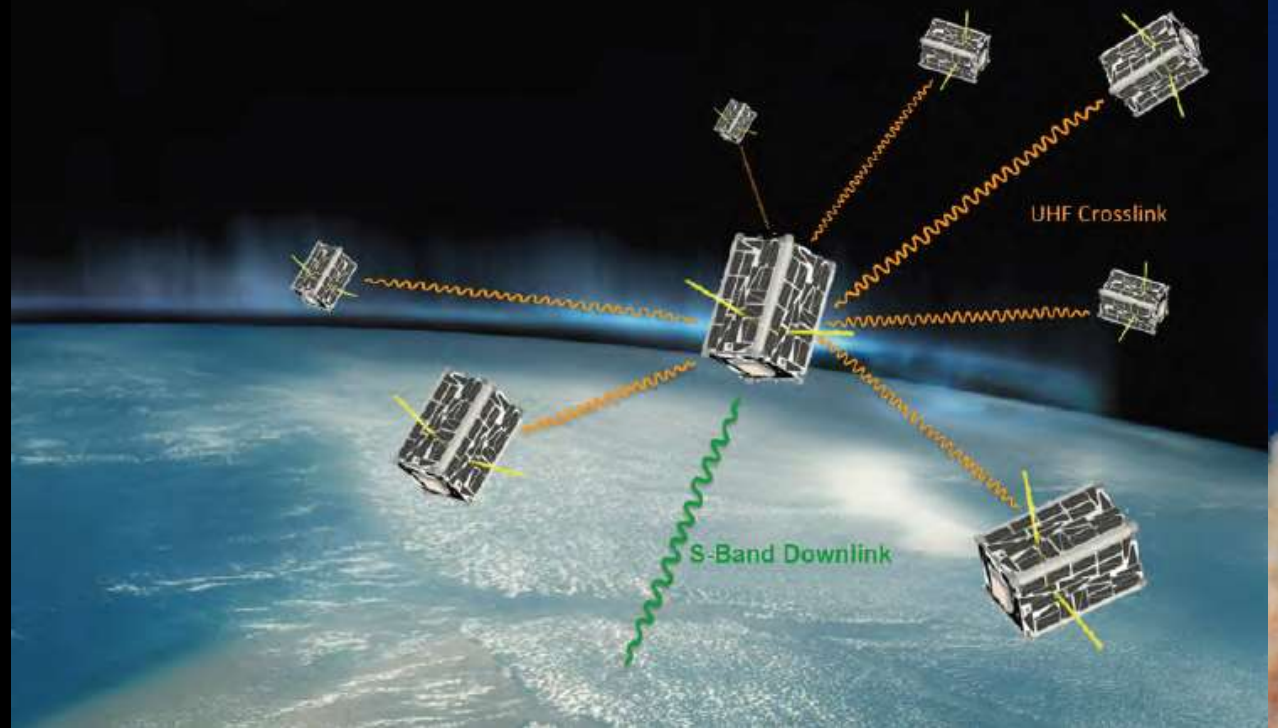
Small Spacecraft Technology Program

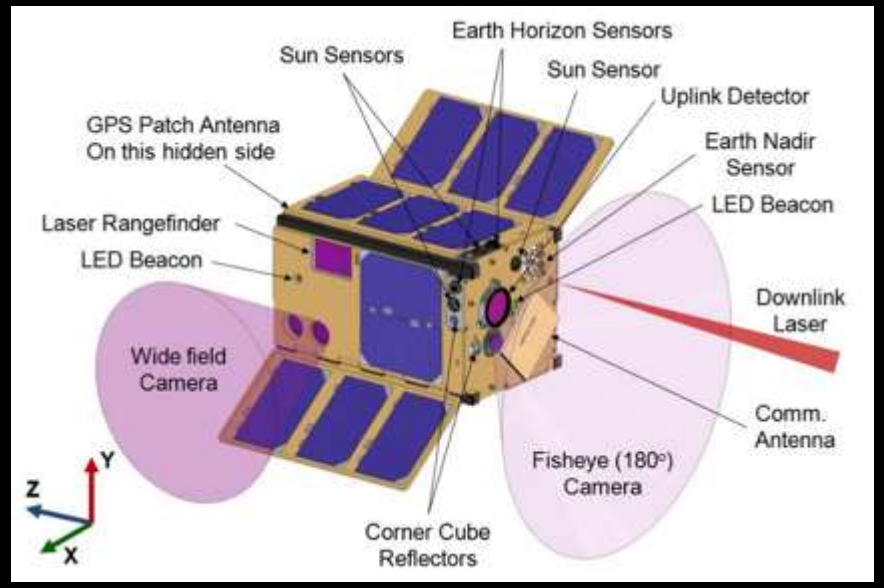
SSTP develops and demonstrates new small spacecraft technologies and capabilities for NASA's missions in science, exploration, and space operations. The program promotes the small spacecraft approach as a paradigm shift for NASA and the larger space community.

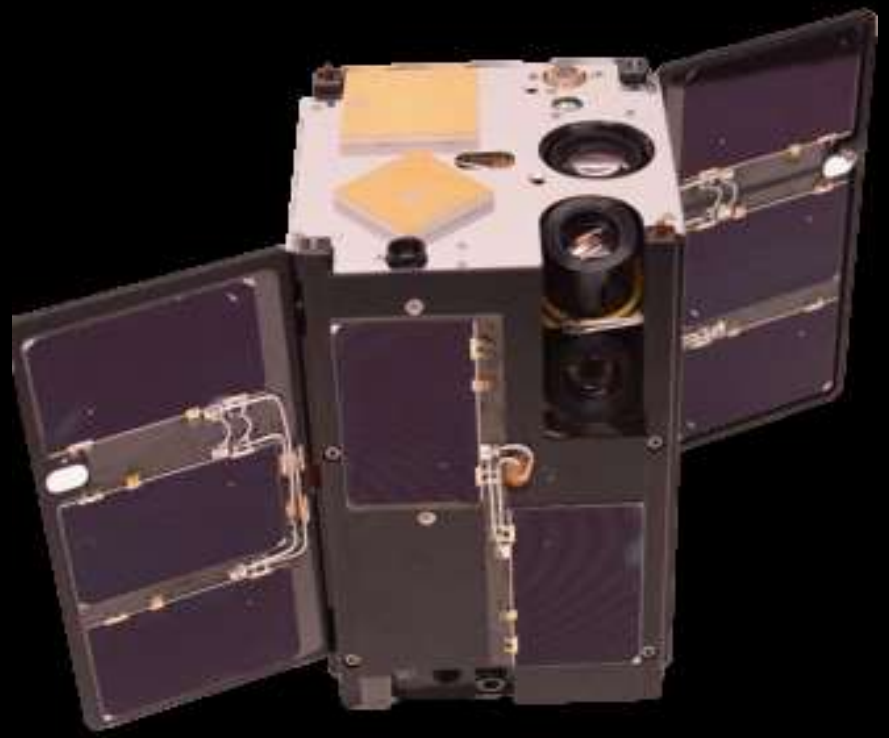
Learn more about SSTP



To demonstrate that a swarm of satellites is capable of collecting multi-point science data and transferring the data to the ground




Earth Horizon Sensors
Sun Sensors
Sun Sensor
Uplink Detector
GPS Patch Antenna
On this hidden side
Earth Nadir
Sensor
LED Beacon
Laser Rangefinder
LED Beacon
Downlink
Laser
Wide field
Camera
Comm.
Antenna
Fisheye (180°)
Camera
Y
Z
X
Corner Cube
Reflectors

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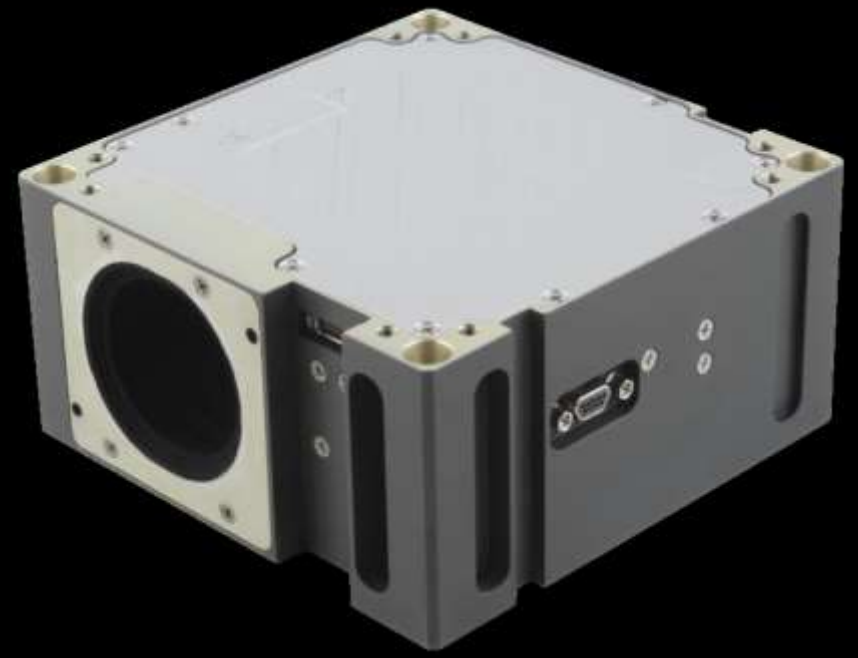
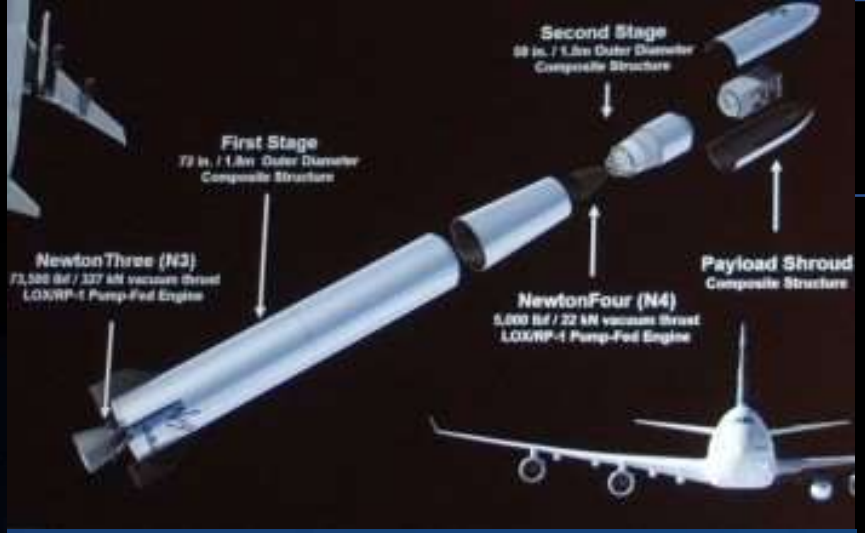




7 At the end of this sequence, LauncherOne will deploy the on-board satellite into its orbit.

6 Typically, the second stage will burn multiple times for almost six minutes.

8 Both stages of LauncherOne will be safely deorbited, and the jet will return to the airport.

5 After stage separation, the single upper stage engine, called the 'NewtonFour' will carry the on-board satellite into orbit.

4 Once released, the rocket will fire up its single main stage engine called the 'Newton-Three' for three minutes.

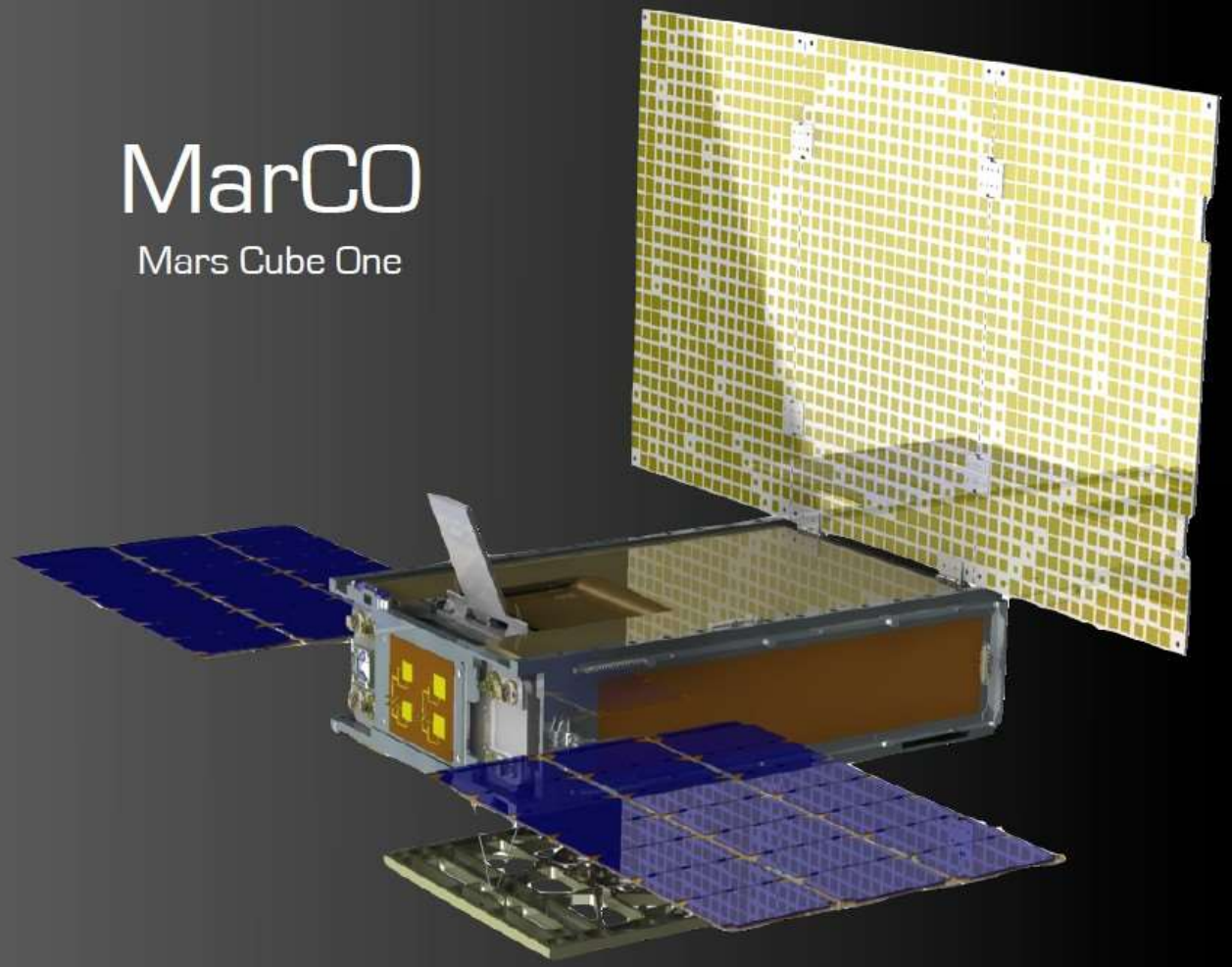
1 The LauncherOne rocket will be mounted to the Boeing 747-400 under the left wing

2 By 'piggybacking' on the Boeing jet, it can be deployed from commercial airports

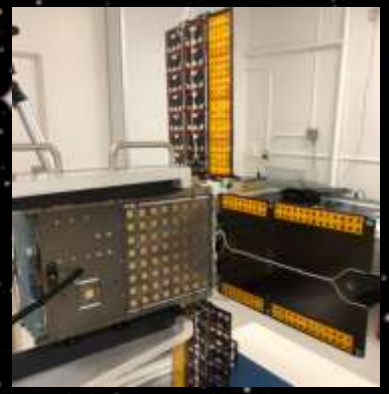
3 LauncherOne will be released at an altitude of approximately 35,000ft (10,668 metres).

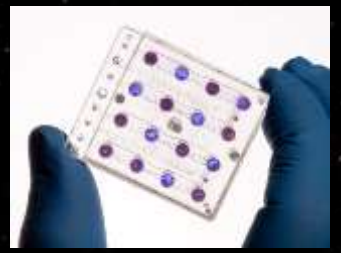
MarCO

Mars Cube One



BioSentinel





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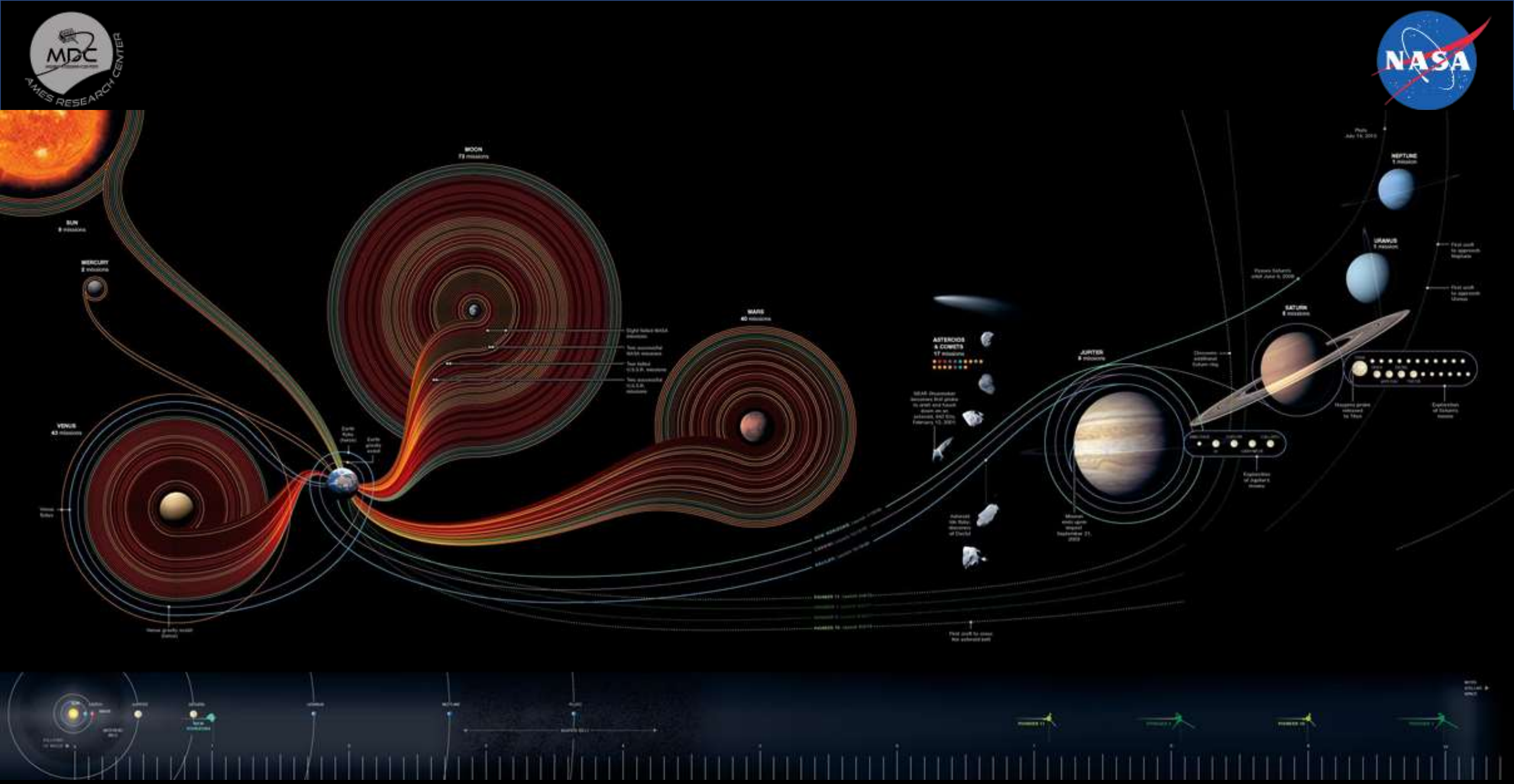
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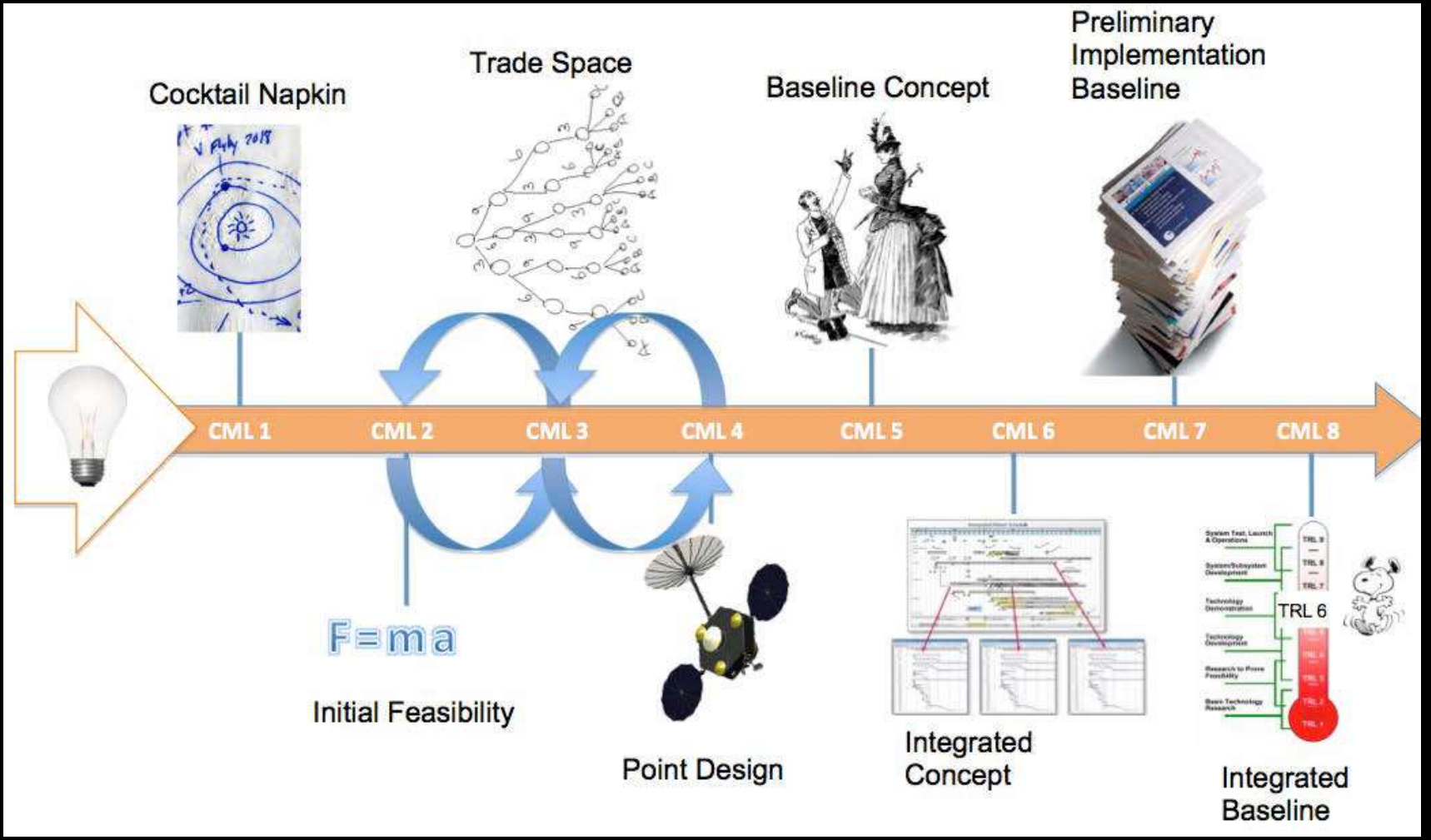
Aeolus: an example of a mission concept study for Mars

A framework for space mission ideas
The Concept Maturity Levels



From: Space Mission Concept Development Using Concept Maturity Levels, Wessen et al., 2013

Aeolus: an example of a mission concept study for Mars

CML 1
“Cocktail Napkin”

Aeolus: an example of a mission concept study for Mars

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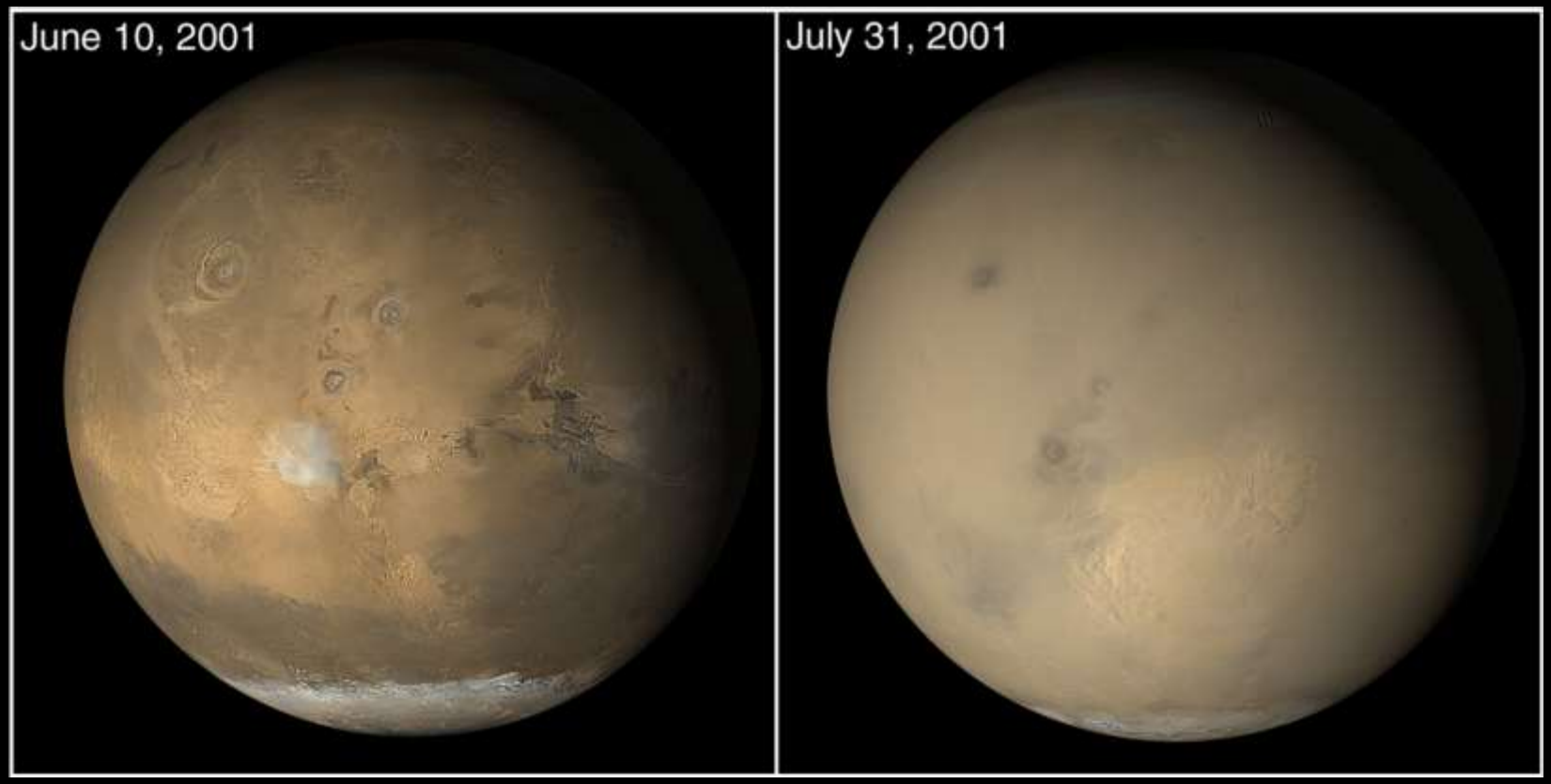
CML 1
“Cocktail Napkin”



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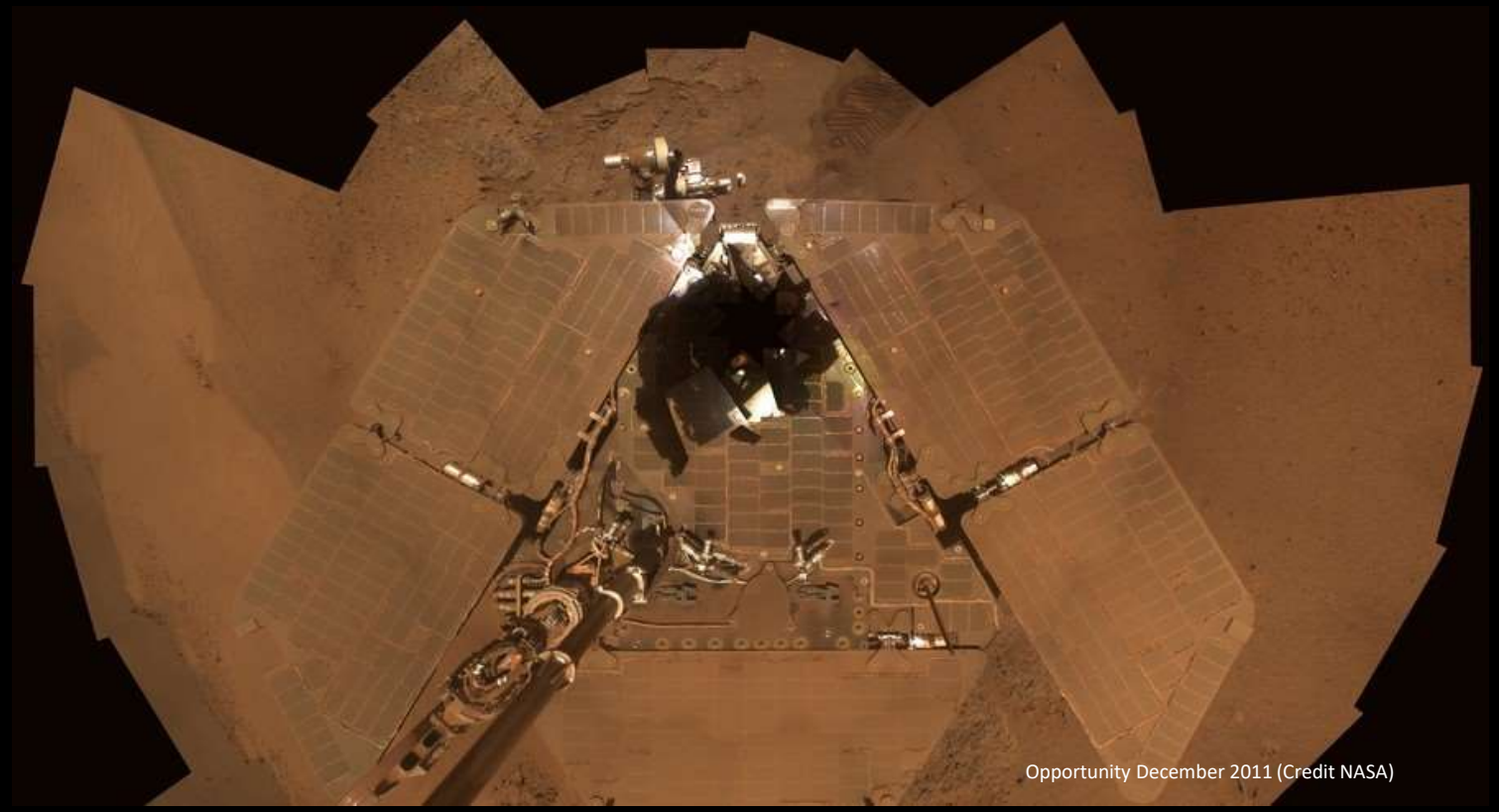
“Cocktail Napkin”



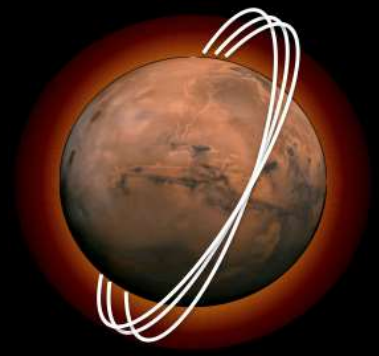
Opportunity December 2011 (Credit NASA)

CML 1: Initial Cartoon

Meaningfulness & Uniqueness
Identify Knowledge Gaps

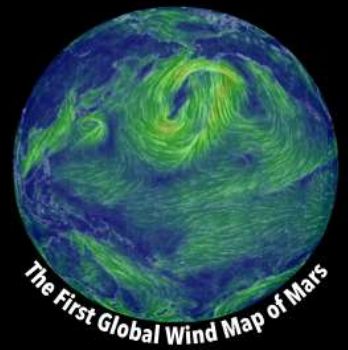
State Broad Science Objective

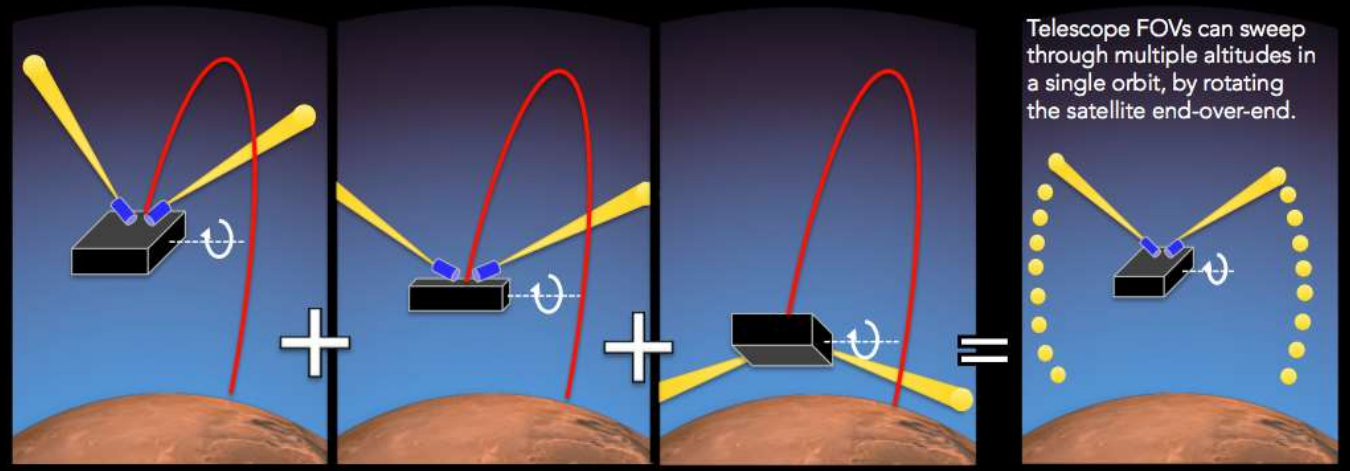
One-sentence description of measurement(s)



Atmospheric wind speeds have never been measured at Mars.

By measuring temperatures and Doppler shifts in atmospheric spectral lines, Aeolus will determine wind vectors and atmospheric temperatures at all longitudes and times of day, and multiple altitudes, creating the first global wind map of Mars.





Aeolus: an example of a mission concept study for Mars

CML 1
"Cocktail Napkin"

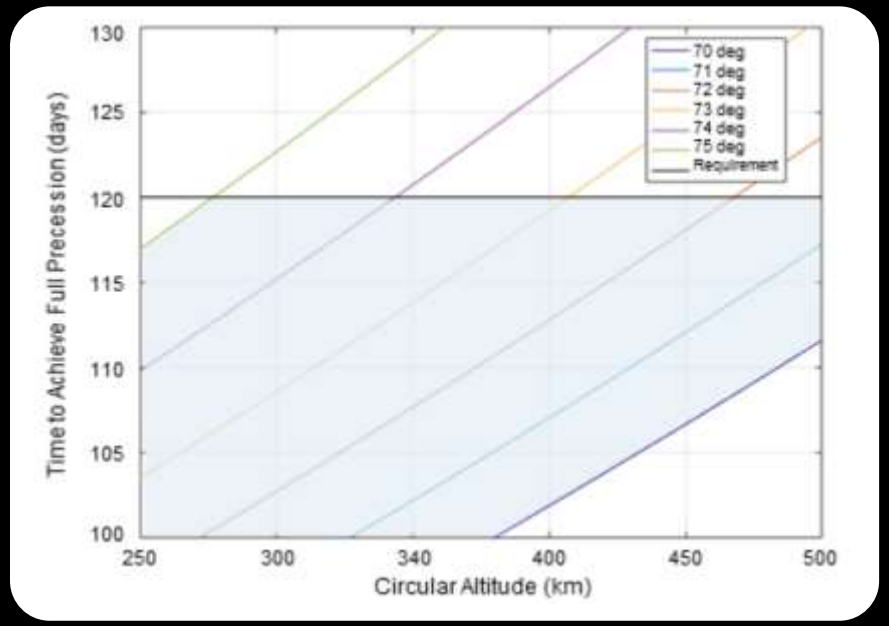
CML 2
Feasibility

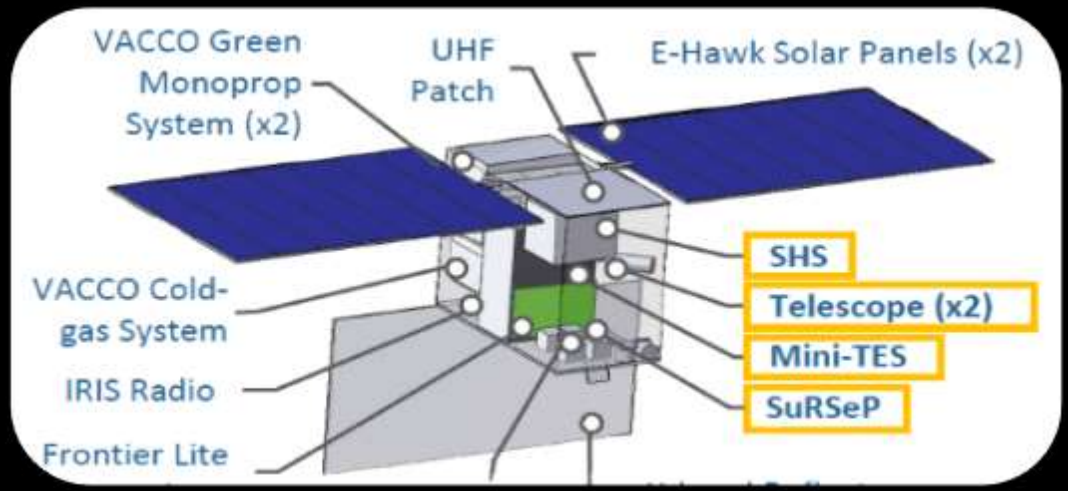
Does any solution exist?

CML 2: Feasibility Study

- Draft of Science Traceability Matrix
- Mission Architecture – main elements
  - Environmental driving parameters
  - Identify required tech development
  - Launch opportunities
  - Delta-V calculations
  - Orbital solutions
  - Mission ops
  - Spacecraft CAD model
- Rough cost estimate
- Rough schedule
- Initial risks & mitigation identified
- Future trades identified

Resource	CBE
Volume	45 x 35 x 52 cm
Total Launch Mass	37.6 kg
Total Power	53 W
Spacecraft Delta-V	237.5 m/s
Solid State Data Storage (Vol)	8GB
Data Throughput (UHF Downlink)	1Mbps





Develop Feasible Mission Architecture

CAD Visualization

Propellant budget

Power Budget

ADCS

Orbital Mechanic

Concept of Operations

Risks & Tech Dev

Data Budget

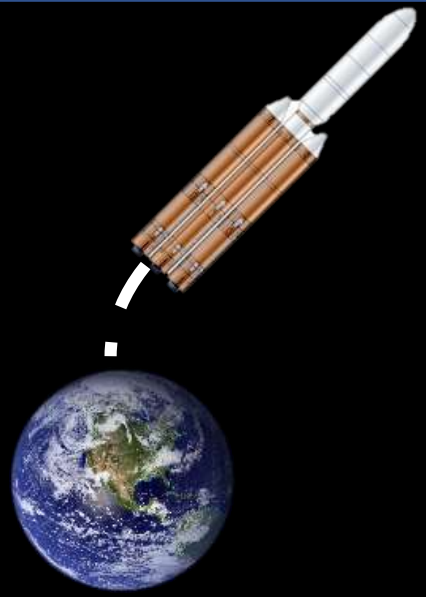
Science

Cost

Link Budget

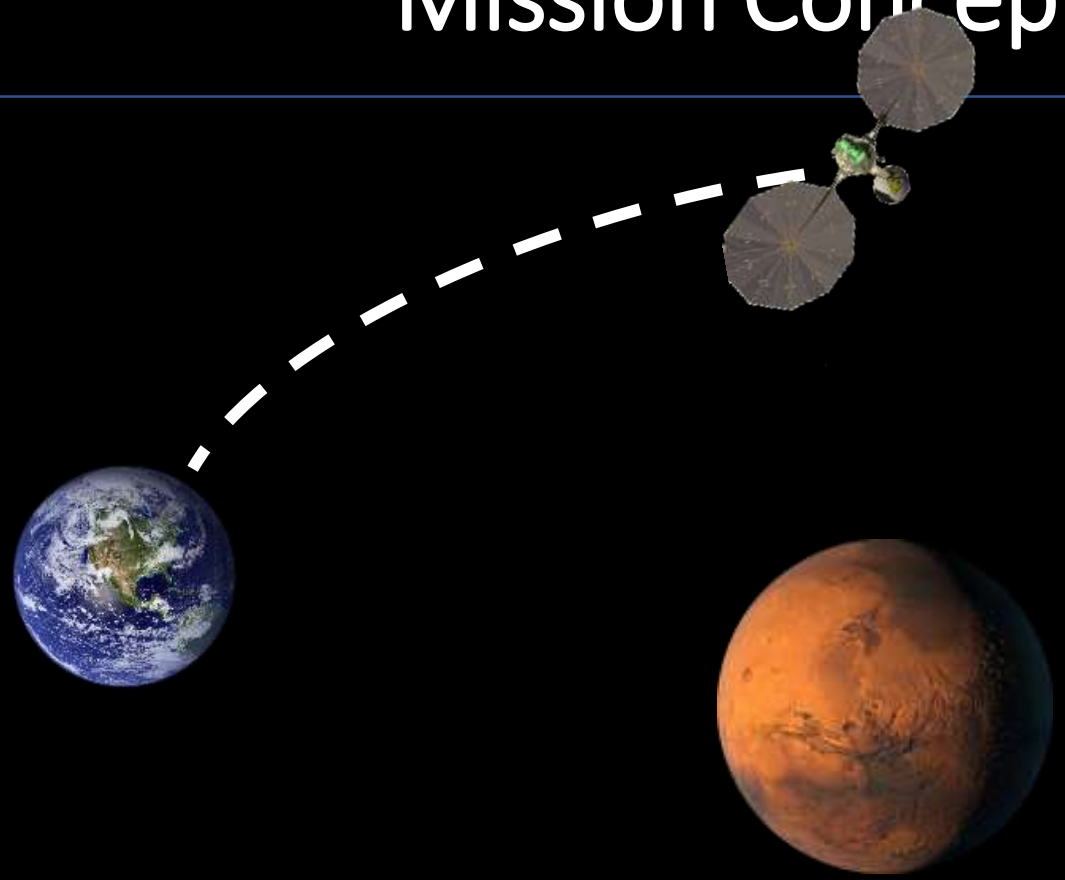
Mass Budget

Mission Concept



Launch

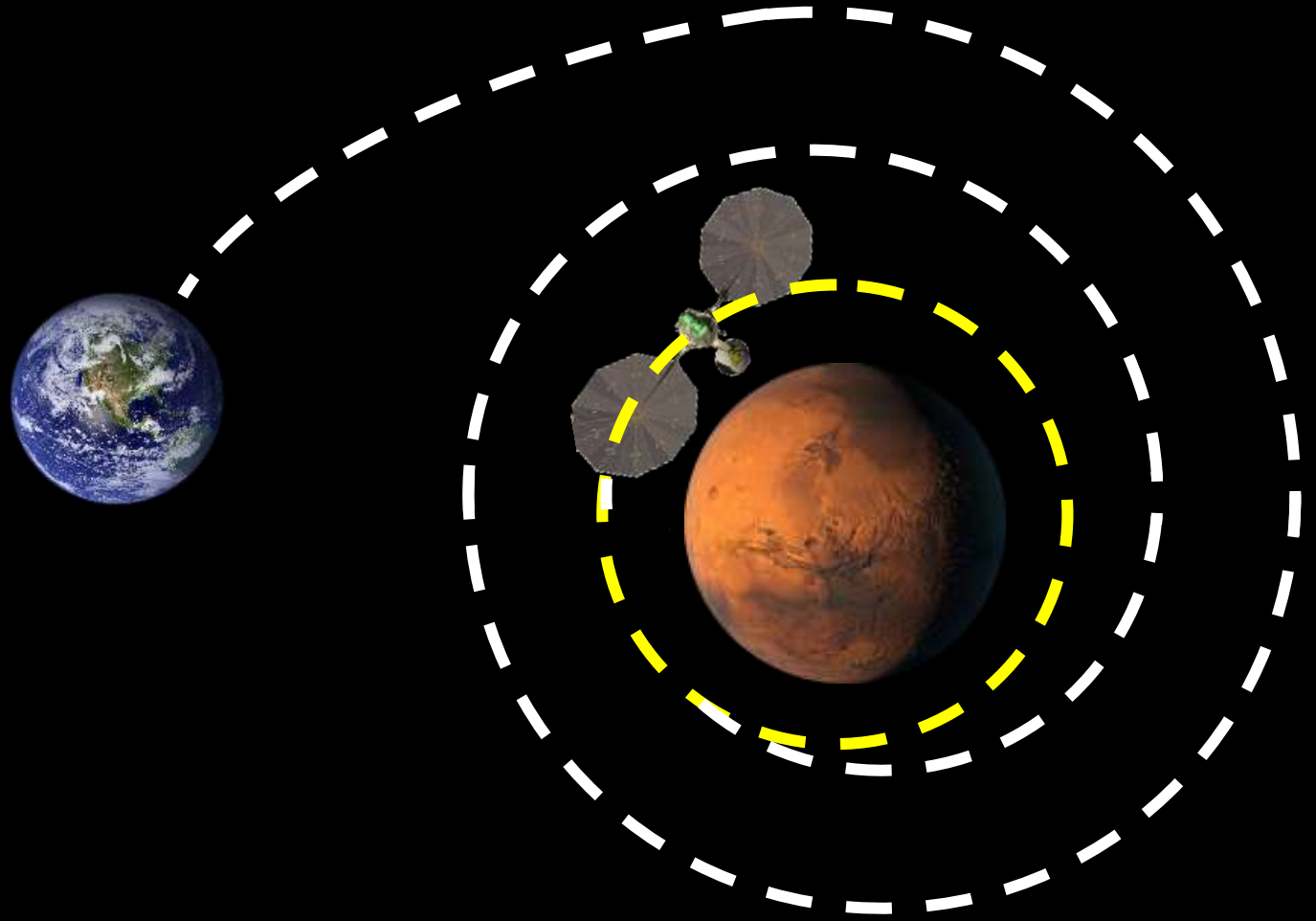
Mission Concept



Launch

Cruise
15 months

Mission Concept

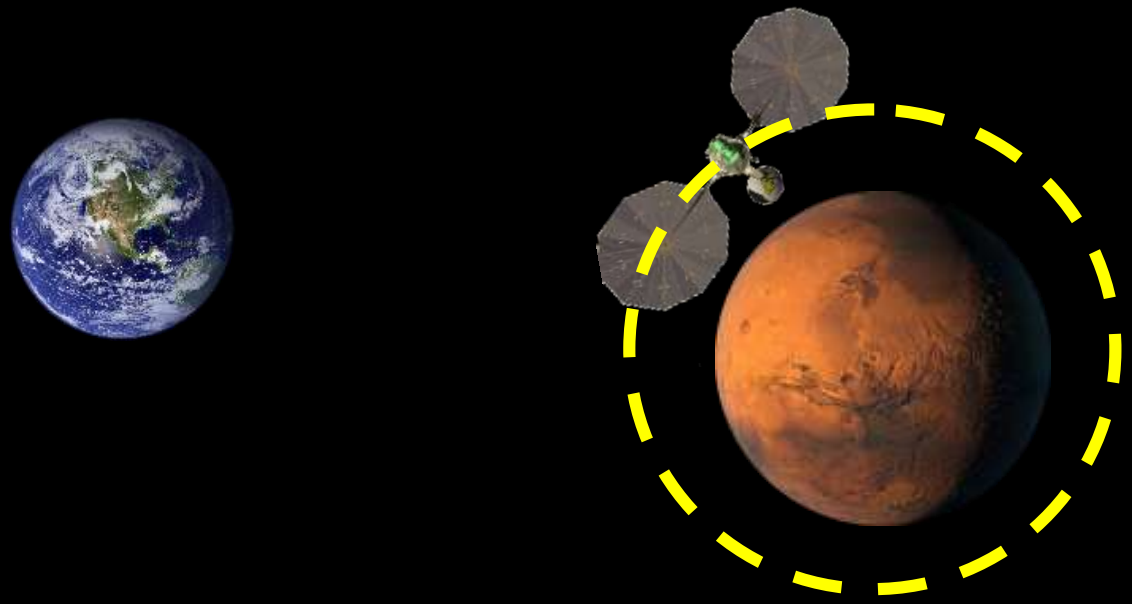


Launch

Cruise
15 months

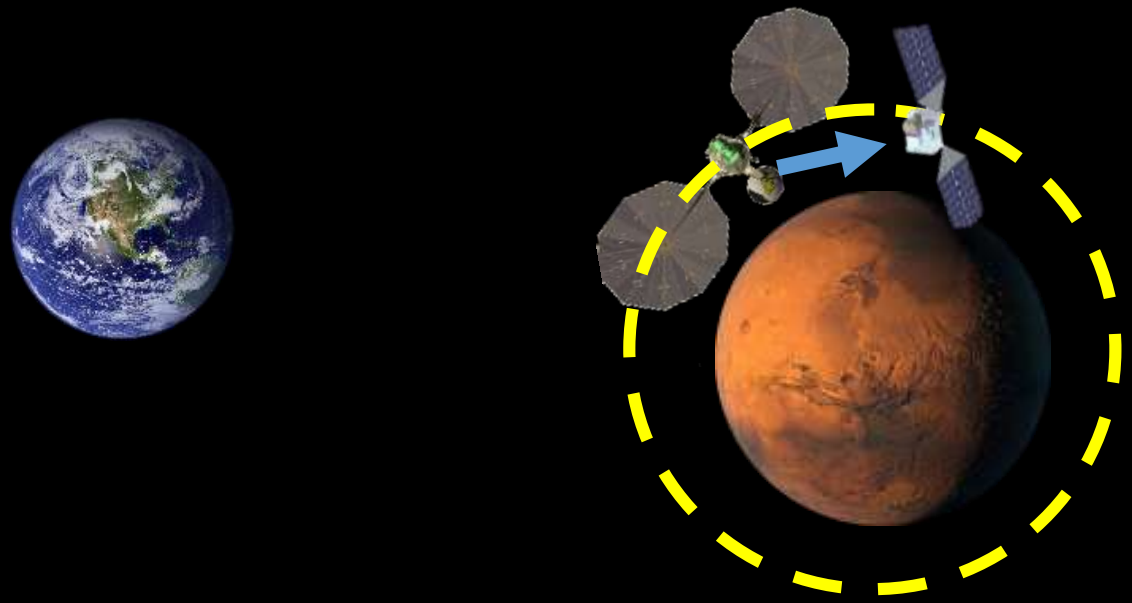
NeMO LTT
10 months

Mission Concept



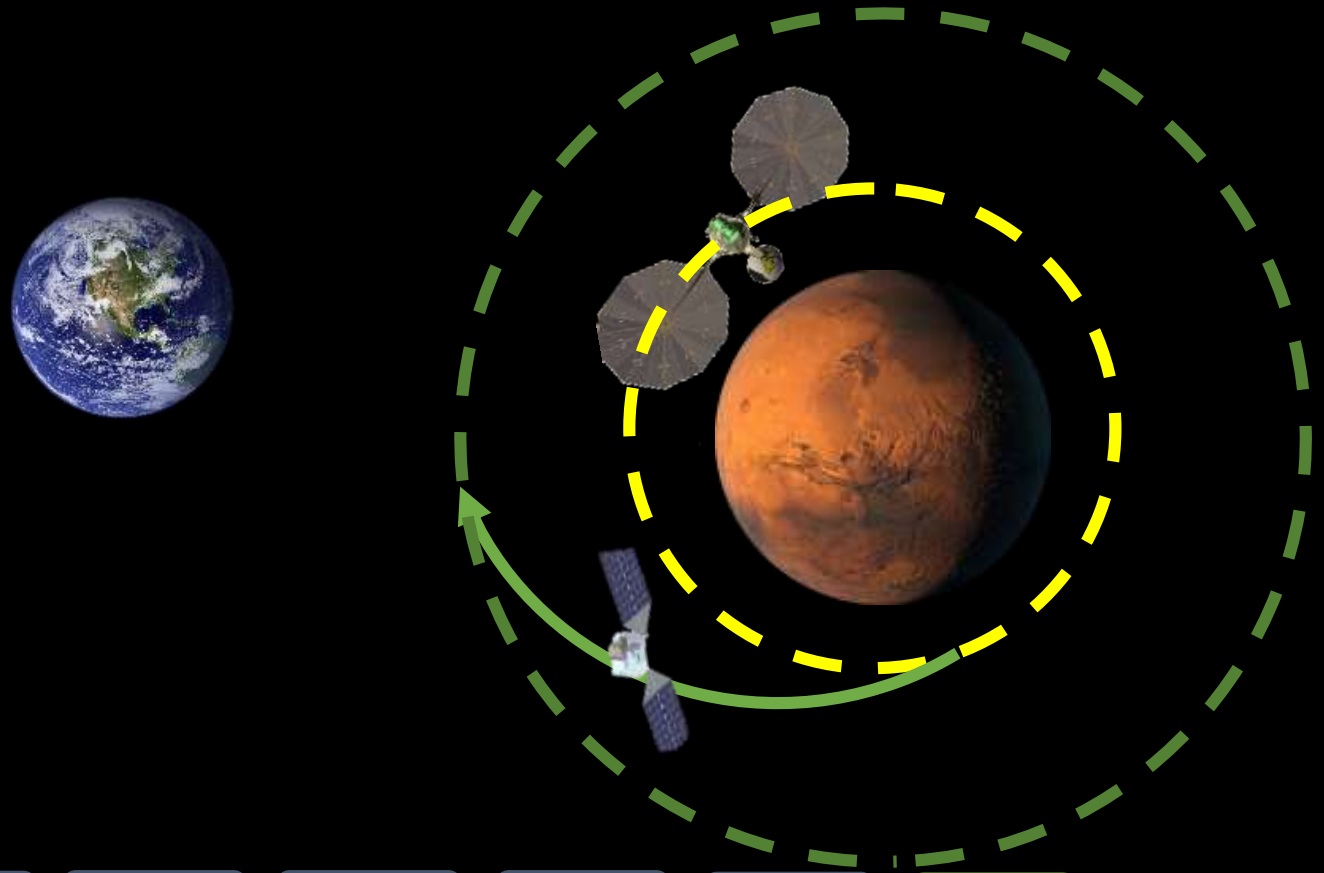
Launch | Cruise 15 months | NeMO LTT 10 months | Aeolus Stowed

Mission Concept



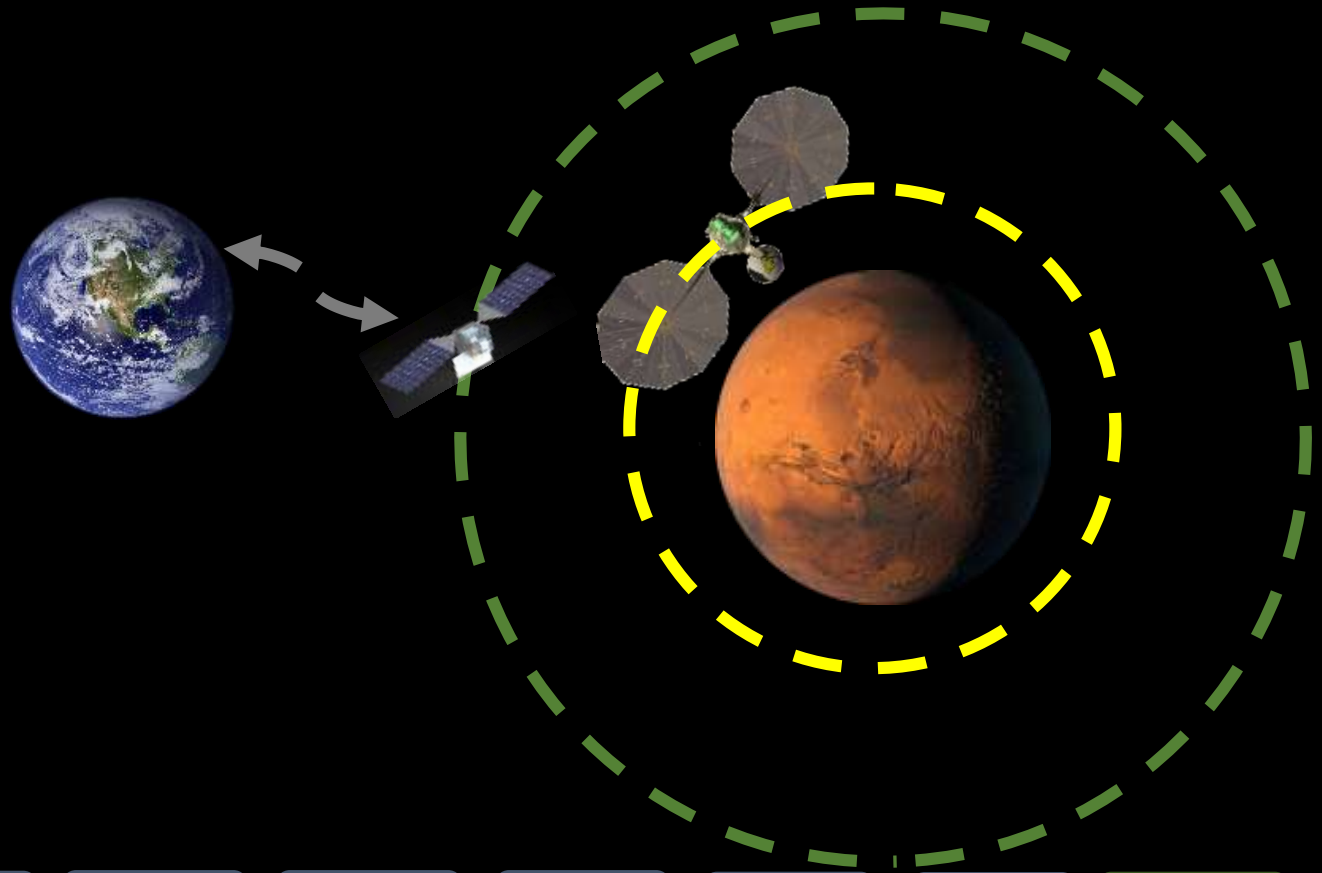
Launch | Cruise 15 months | NeMO LTT 10 months | Aeolus Stowed | Aeolus Deploy

Mission Concept



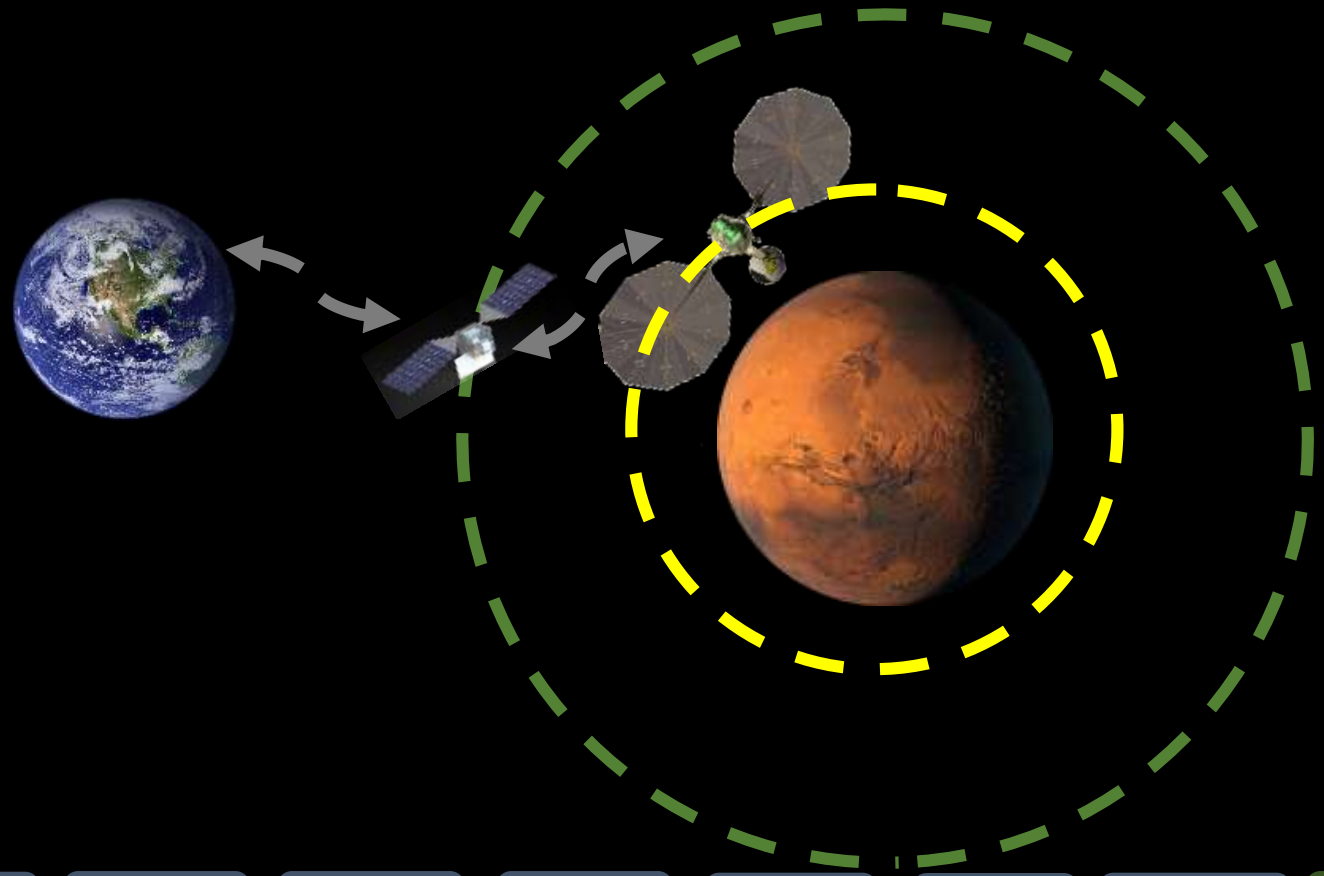
Launch | Cruise 15 months | NeMO LTT 10 months | Aeolus Stowed | Aeolus Deploy | Orbit Transfer

Mission Concept



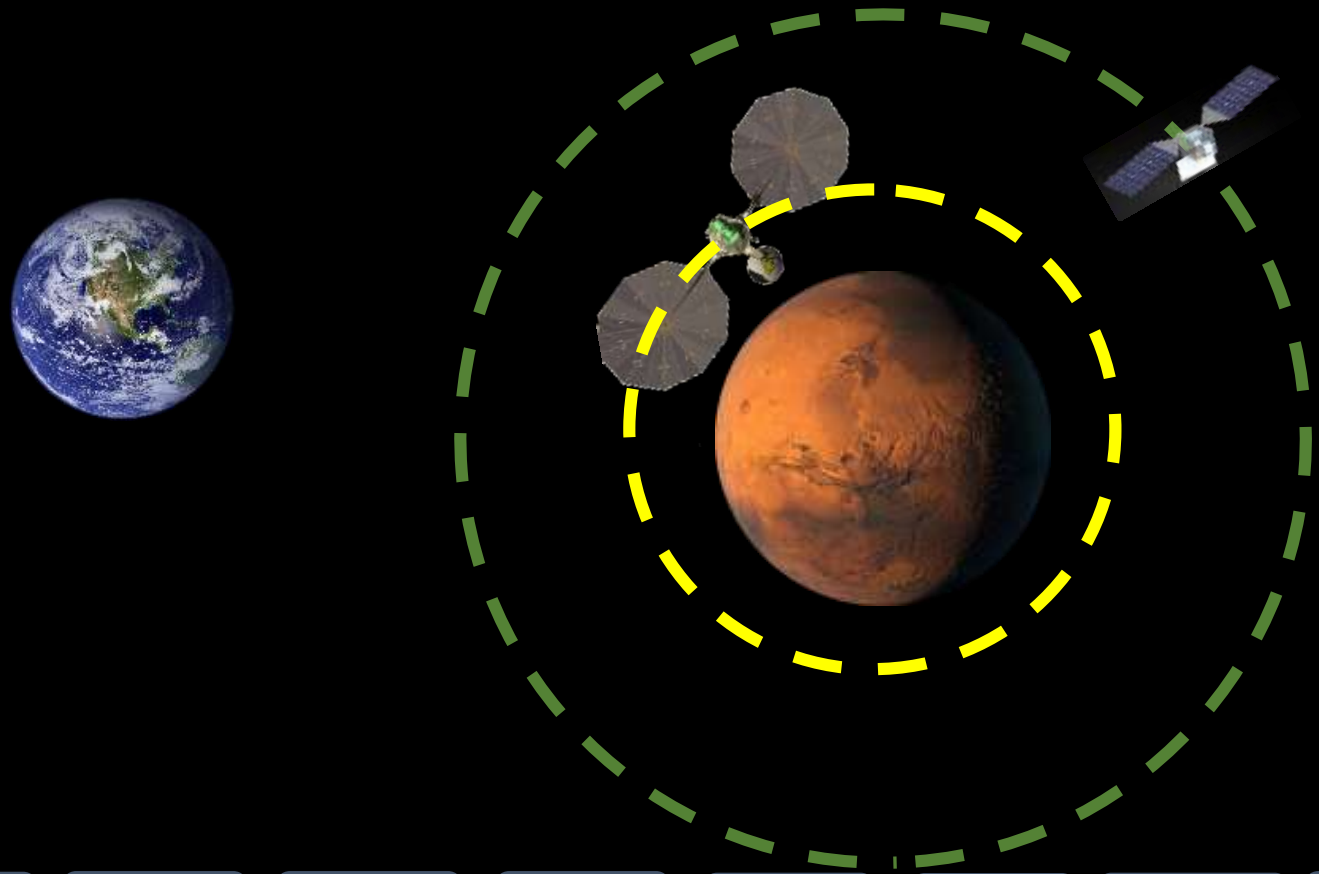
Launch | Cruise 15 months | NeMO LTT 10 months | Aeolus Stowed | Aeolus Deploy | Orbit Transfer | Commiss. 3 months

Mission Concept



Launch	Cruise 15 months	NeMO LTT 10 months	Aeolus Stowed	Aeolus Deploy	Orbit Transfer	Commiss. 3 months	Science 24 months

Mission Concept



Total Mission Duration
52 months

Launch | Cruise 15 months | NeMO LTT 10 months | Aeolus Stowed | Aeolus Deploy | Orbit Transfer | Commiss. 3 months | Science 24 months | Decommission

Develop Feasible Mission Architecture

CAD Visualization

Propellant budget

$$\Delta V = g \cdot Isp \cdot \ln \frac{Mfinal}{Minitial}$$

Power Budget

ADCS

Orbital Mechanic

Concept of Operations

Risks & Tech Dev

Data Budget

Science

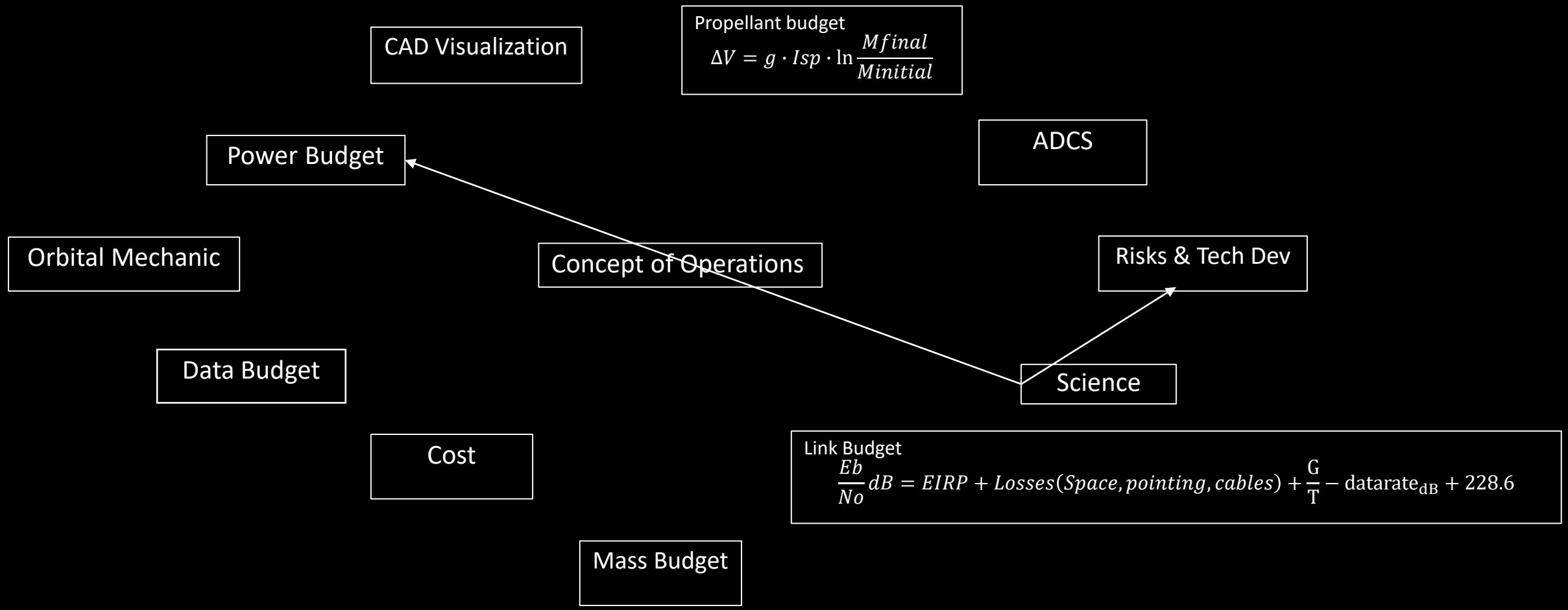
Cost

Link Budget

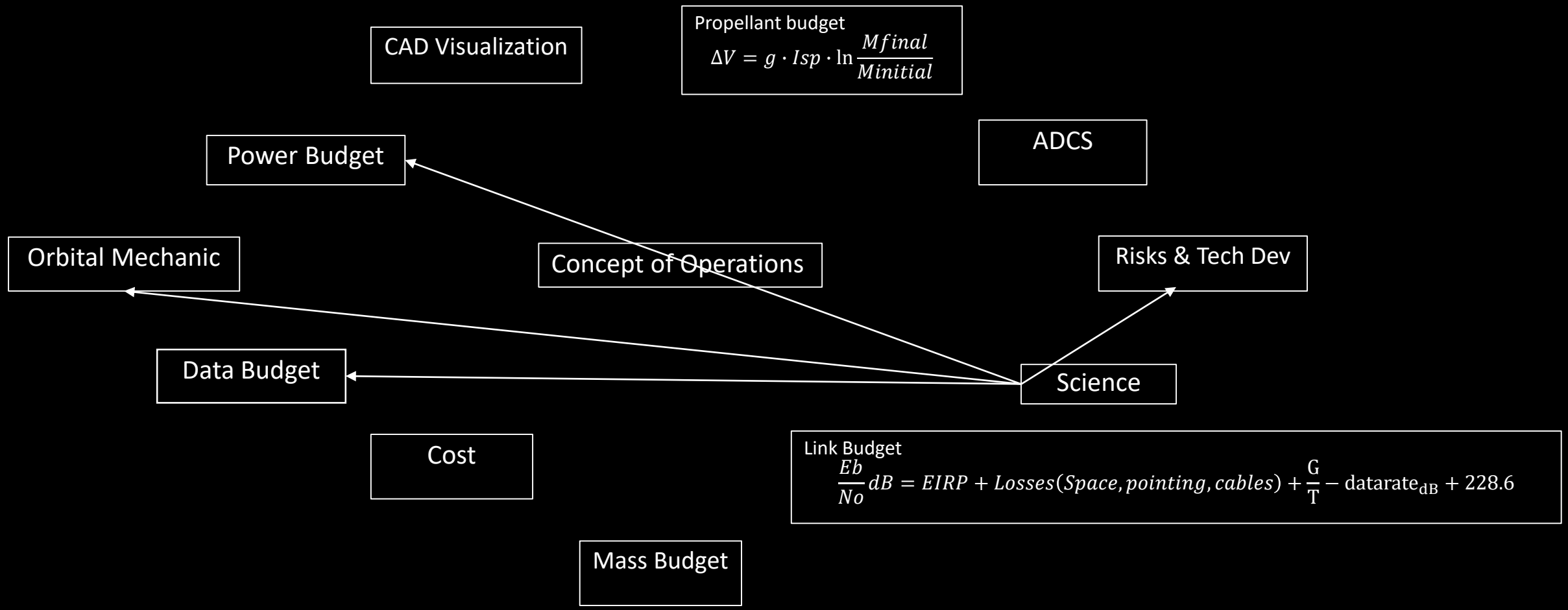
$$\frac{Eb}{No} dB = EIRP + Losses(Space, pointing, cables) + \frac{\mathrm{G}}{\mathrm{T}} - \mathrm{datarate}_{\mathrm{dB}} + 228.6$$

Mass Budget

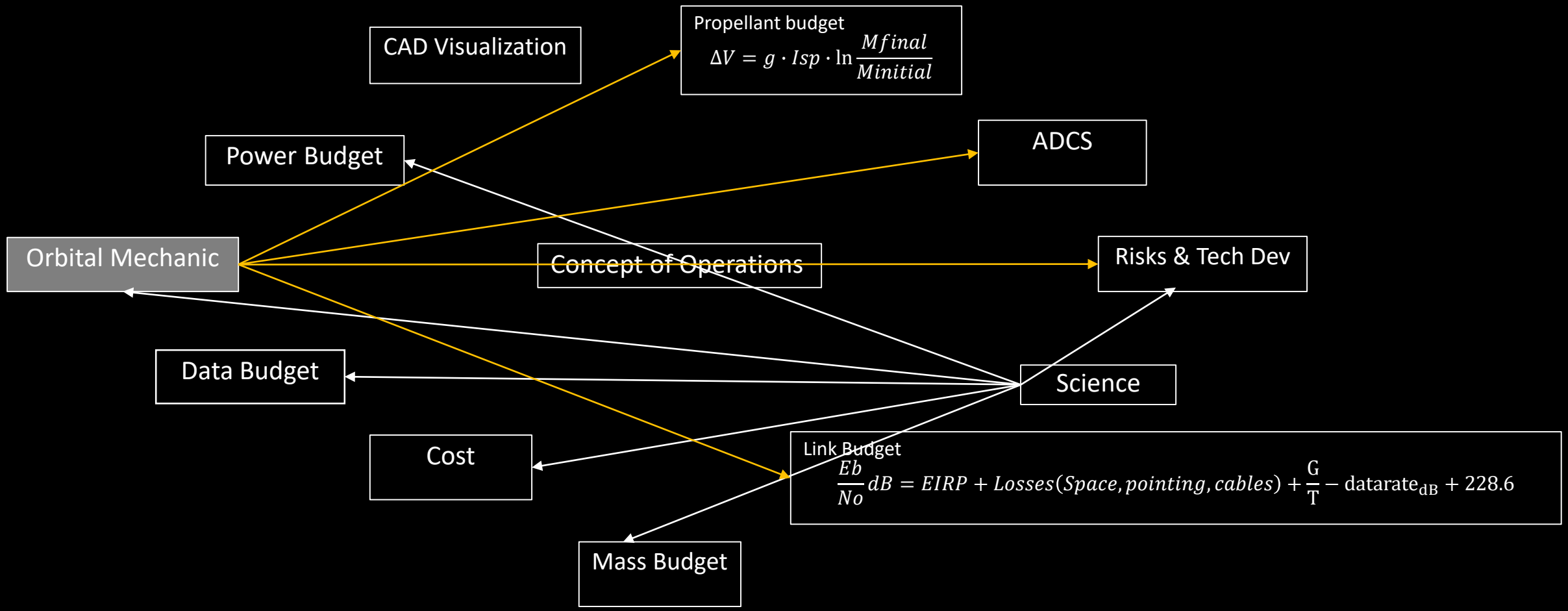
Develop Feasible Mission Architecture



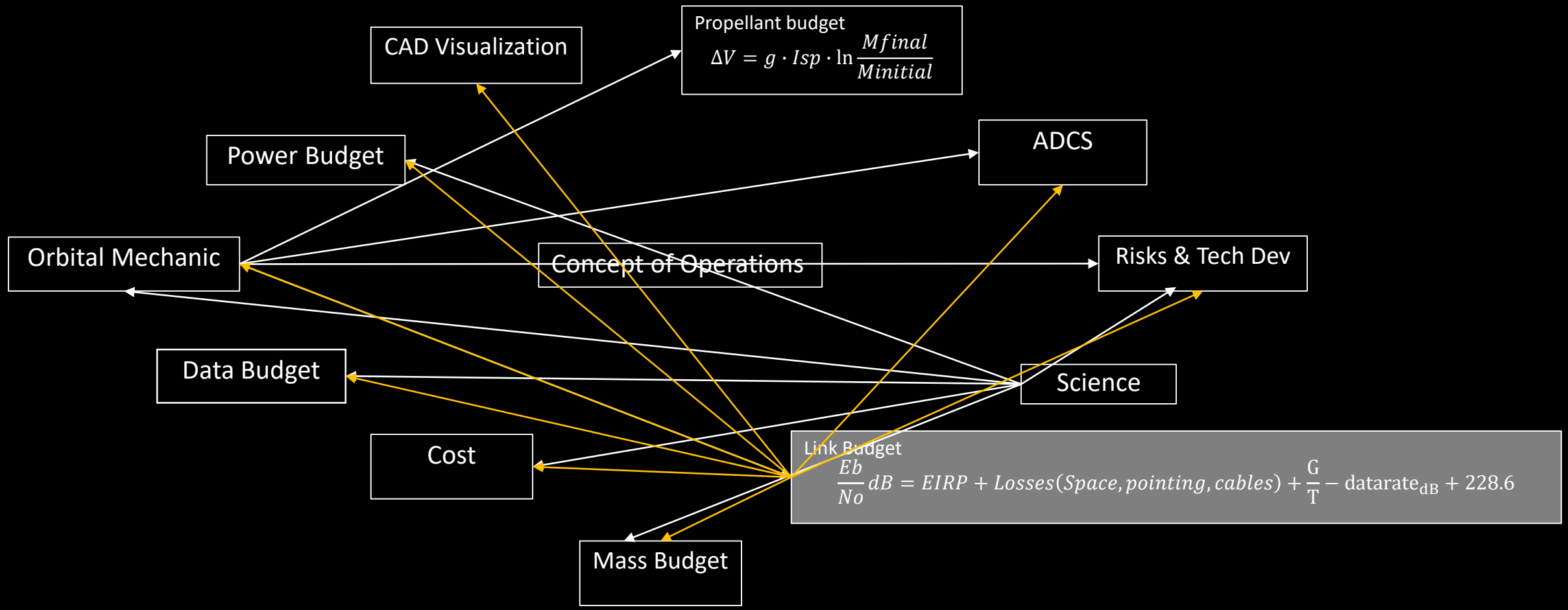
Develop Feasible Mission Architecture



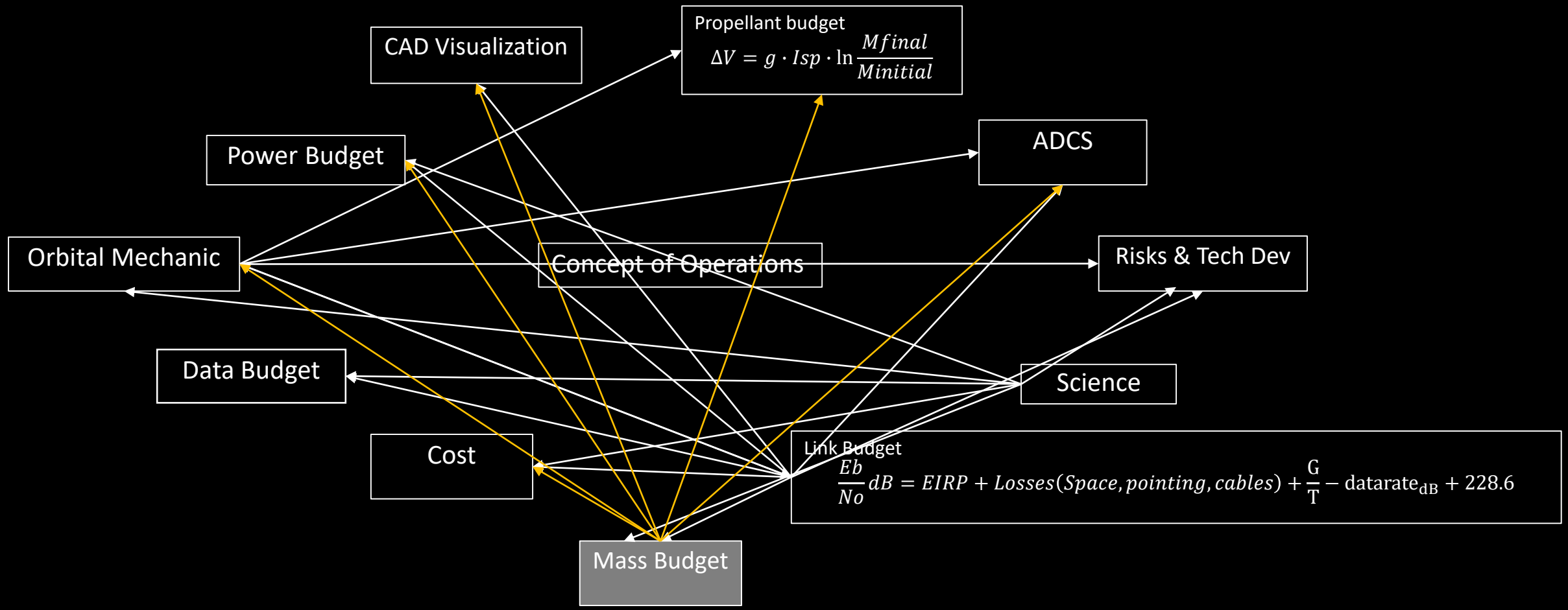
Develop Feasible Mission Architecture



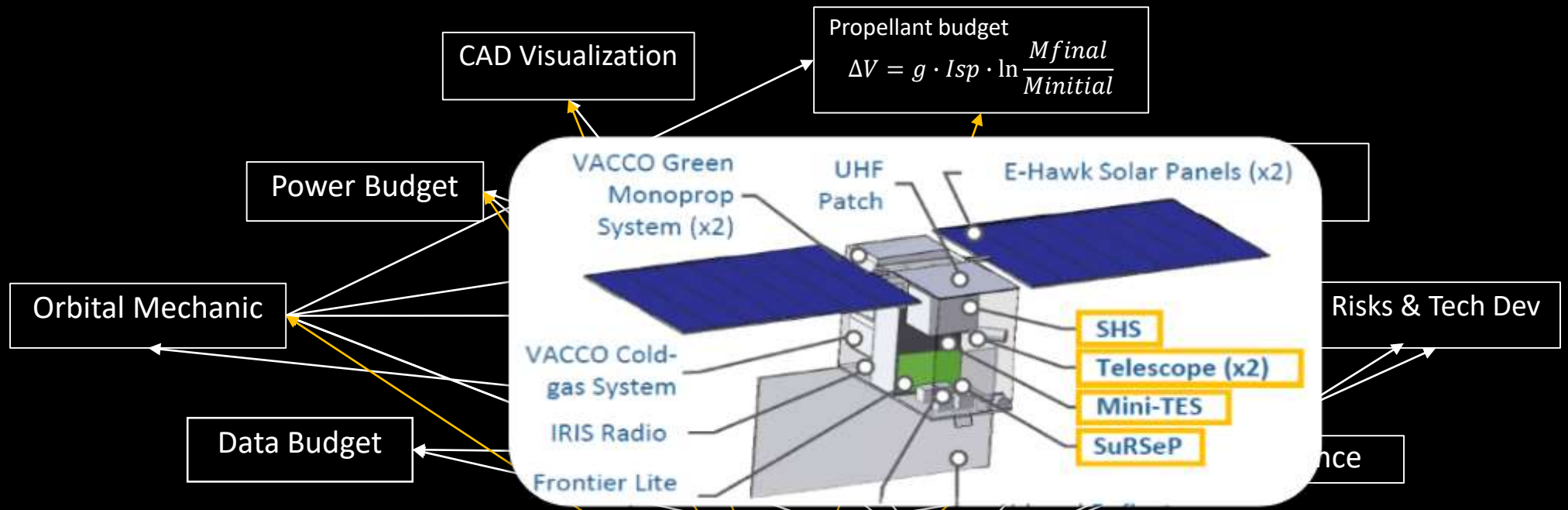
Develop Feasible Mission Architecture



Develop Feasible Mission Architecture



Develop Feasible Mission Architecture



Aeolus: an example of a mission concept study for Mars

CML 1
"Cocktail Napkin"

CML 2
Feasibility

Does any solution exist?

CML 3
Expanded Trade Space

What other solutions exist?

CML 3: Expanded Trade Space

Divergent Phase:

Explore different mission architectures

primary vs. secondary

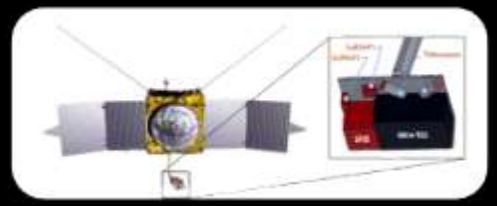
launch options

number of spacecrafts

et cetera

Convergent Phase:

Identify rejection criteria & pick architectures to pursue.



Iteration:

Repeat CML 2 as needed on selected architectures

Trade Dimensions	Tradable Options					
Mission Type	Primary	Secondary				
Approach Type	Flyby	Atmospheric Entry	Orbit	Landing on Phobos		
Measurement						
Surface	Lander	Rover	Impactor			
Atmospheric	Balloon	Dirigible	UAVs	long probe		
On-orbit	Single fixed	Single Variable	Swarm	Constellation		
Primary Power	Nuclear	Solar	Battery			
Drop-off	Earth	Helio	Outside Earth SOI	Intermediate Mars drop-off	Direct to final orbit	
Prop System	Solar sail	Solar EP	Chem	Nuclear EP		
Orbit Characteristics	Circular	Elliptical				
Periapsis/Altitude	Low Mars Orbit 200-600 km	~1000 km	≥17000 km			
Inclination	0 deg	1-60 deg	60-89 deg	90 deg		
Instruments	SHS	SURSeP	Mini-TES	Lidar	Imager	Radio (occultation)
Mass/Size	6U	12U	24U	ESPA (<180 kg)	>180 kg	
Science Pointing	rotating optics	Rotating SC	Imaging Array (fixed)	gimbaled instrument platform		
Ops and Data Return Technology	Direct to Earth	Relay				
Launch Vehicles/Options	Mars 2020	Mars 2022	EM-2	Dedicated		
Science Duration	3 Earth Months Full Surface Coverage (<1 Martian Season)	6 Earth Months 1 Martian Season	12 Earth Months 2 Martian Season	1.5 Earth Yrs 3 Martian Season	2 Earth Yrs 1 Martian Year (4 Martian Seasons)	4 Earth Yrs 2 Martian Yrs

LEGEND

- Elements selected in at least one architecture
- Technical rejection
- Science rejection
- Programmatic rejection
- Allowable but not selected (white), e.g. out of scope

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Does any solution exist?

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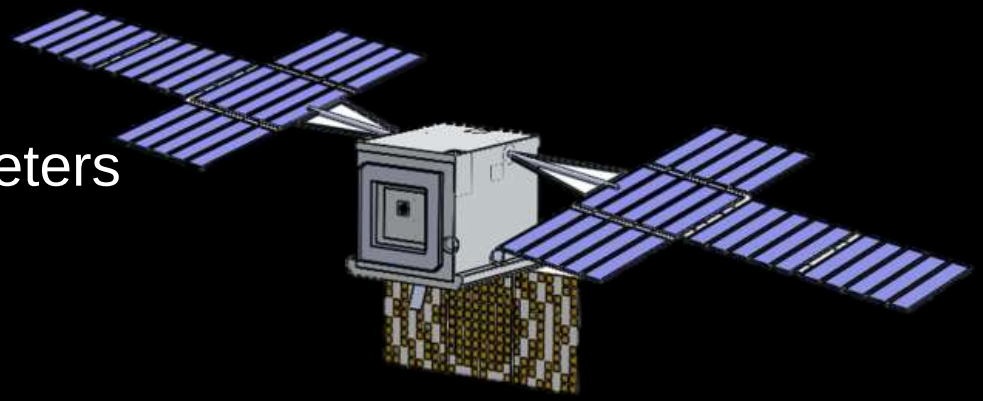
What other solutions exist?

CML 4
Point Design

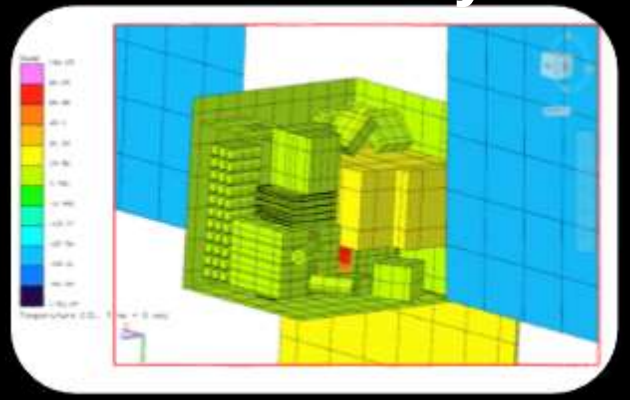
What is a good approach, given our circumstances?

CML 4: Point Design

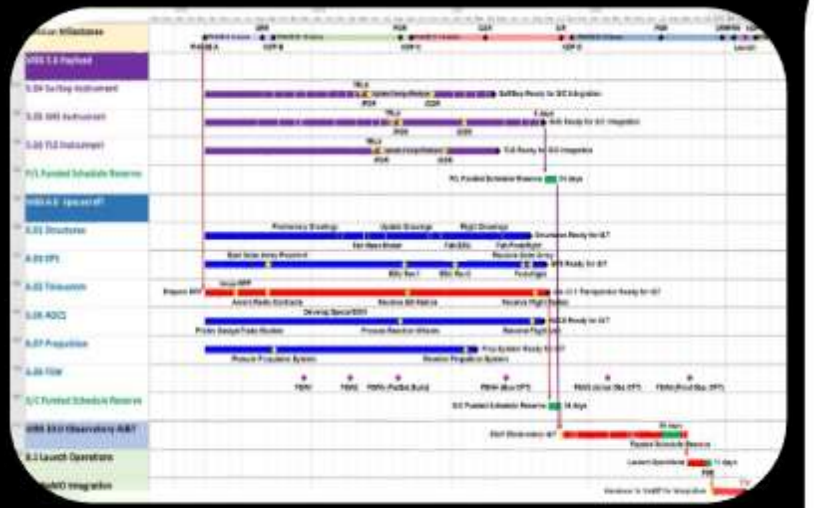
- Science Traceability Matrix
- Mission Architecture
  - Driving environmental parameters
  - Launch vehicle
  - Delta-V calculations
  - Orbital solution
  - Radiation Analysis
  - Mission ops
  - Identify required tech development
  - Spacecraft CAD model
  - Power Analysis
  - Thermal Analysis
- Better Cost Estimate
- Refined Schedule
- Risks Matrix & Mitigation



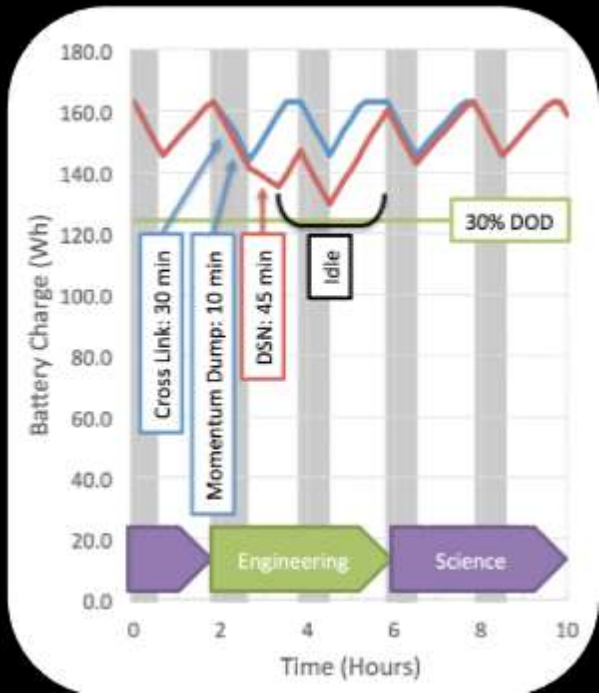
Thermal analysis



Schedule



Power analysis

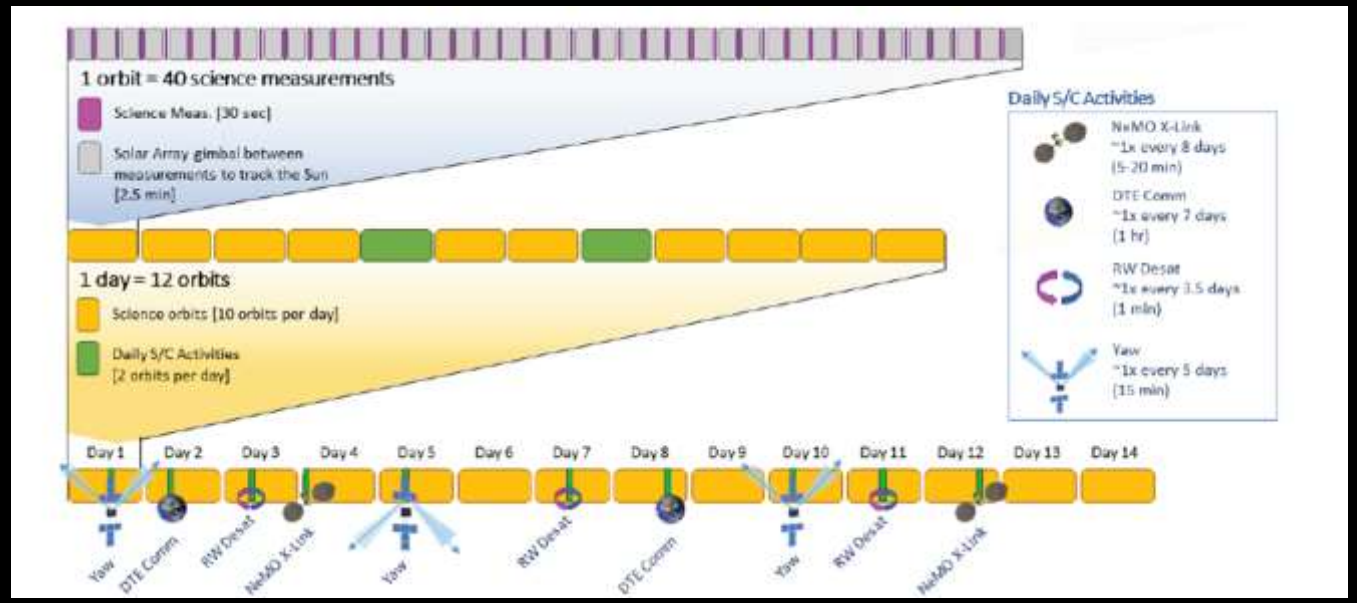


CML 4: Point Design

Science Traceability Matrix
Mission Architecture
- Driving environmental parameters
- Launch vehicle
- Delta-V calculations
- Orbital solution
- Radiation Analysis
- Mission ops
- Identify required tech development
- Spacecraft CAD model
- Power Analysis
- Thermal Analysis

Better Cost Estimate
Refined Schedule
Risks Matrix & Mitigation

2 weeks operational cycle



CML 4: Point Design

Science Traceability Matrix
Mission Architecture
- Driving environmental parameters
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  - Delta-V calculations
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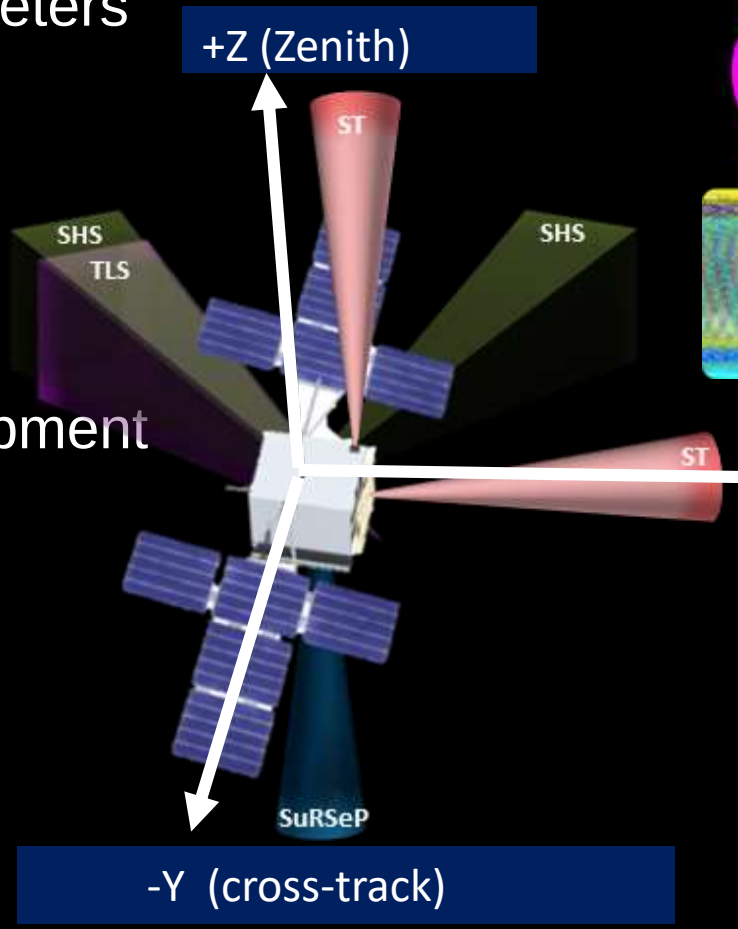
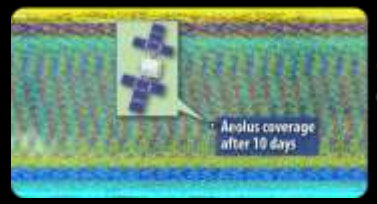
  - Thermal Analysis

Better Cost Estimate
Refined Schedule
Risks Matrix & Mitigation

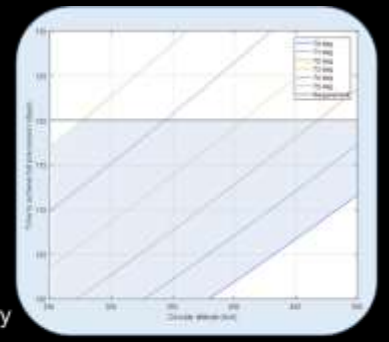
Refined Flight system capabilities



Orbit precesses over all *local times* within 2 months



Global spatial coverage every 10 days



Refined Orbit

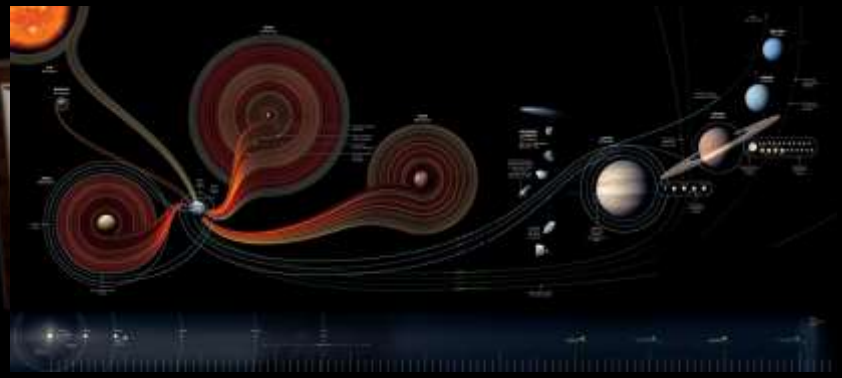
Maturation of a Concept from CML 1 to CML 4

CML 4

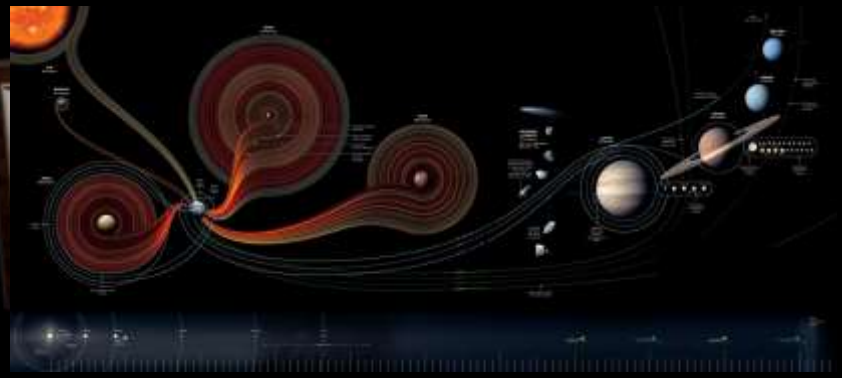
CML 2

CML 1

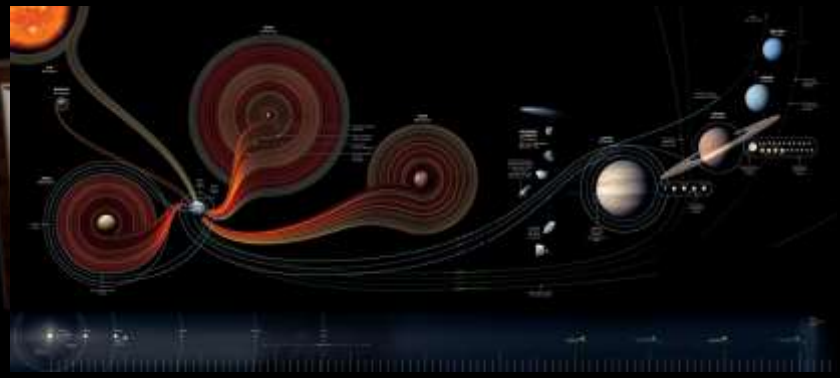
Summary & Conclusion



Summary & Conclusion



Summary & Conclusion



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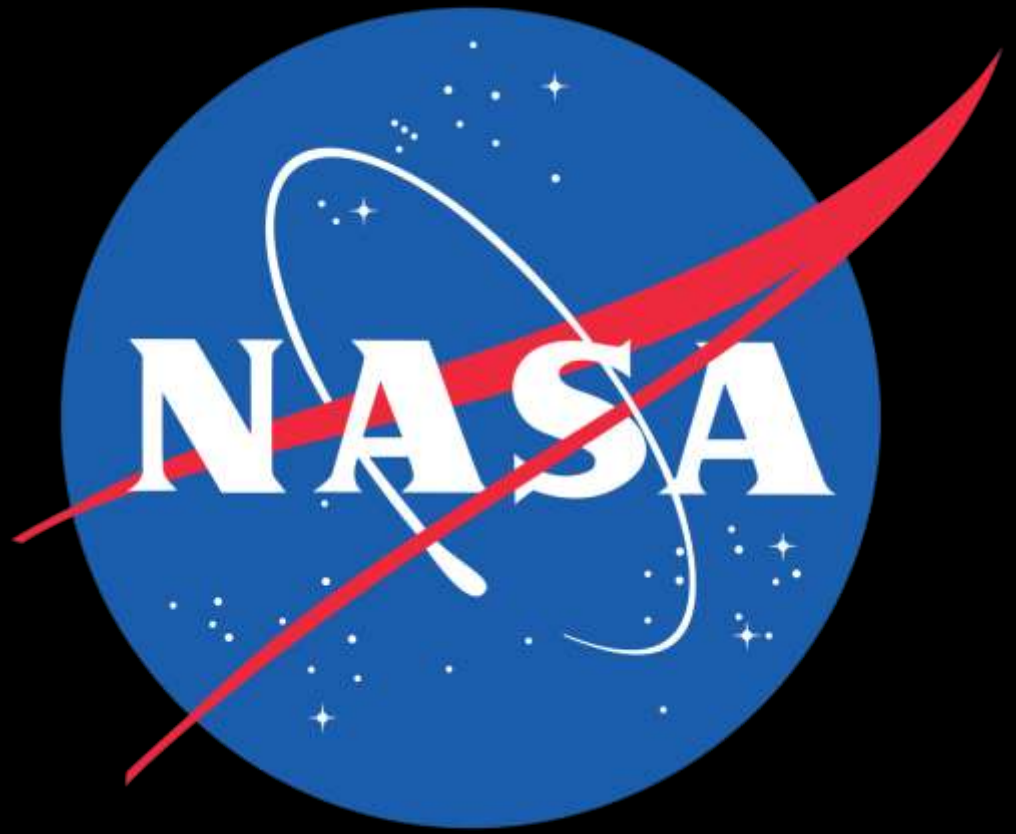
NASA