Systems Engineering in Venus Satellite

How to benefit from system engineering process in designing a microsatellite

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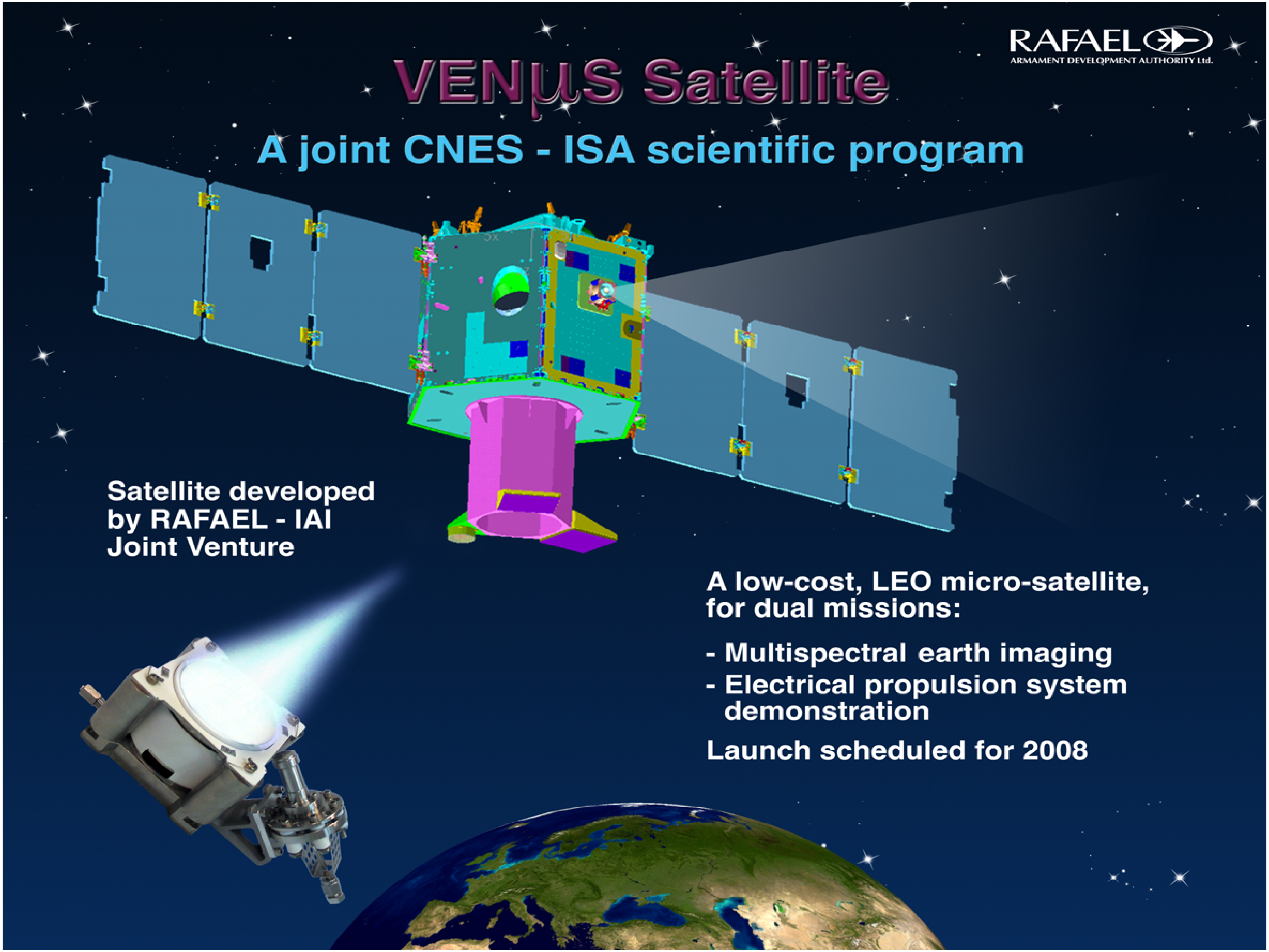
Presentation Contents

- Introduction of the Venus program
- Description of the synthesis step of the Systems Engineering Process (SEP)
- Example of synthesis in Venus Program:
  - Solar panels and Thrusters configuration
- Conclusions

Presentation goal:

- To demonstrate the applicability of SEP and Conceptual design (preliminary design) in context of spacecraft and space mission engineering.


RAFAEL
ARMAMENT DEVELOPMENT AUTHORITY Ltd.
VENμS Satellite
A joint CNES - ISA scientific program
Satellite developed
by RAFAEL - IAI
Joint Venture
A low-cost, LEO micro-satellite,
for dual missions:
- Multispectral earth imaging
- Electrical propulsion system
demonstration
Launch scheduled for 2008

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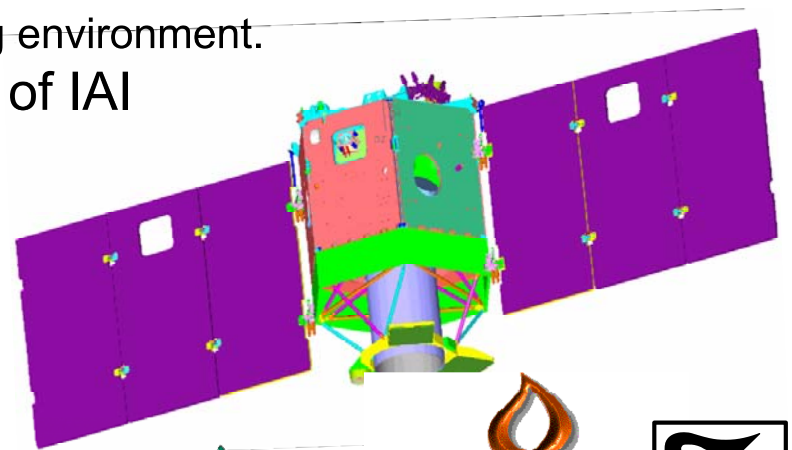
Venμs Program

Vegetation and Environment New μSatellite

- A Joint Israeli (ISA Via IAI and RAFAEL) French (CNES) Program
- Dual missions:
  - **Scientific Mission:** A research demonstrator mission for the GMES program (Global Monitoring for Environment and Security), dedicated to monitoring vegetation and water quality – using a Multi-Spectral camera
  - **Technological Mission**: Validation of the Israeli Hall Effect Thruster (IHET) and demonstration of its mission enhancement capabilities:
    - Orbit maintenance,
    - LEO to LEO orbit transfer
    - Enabling imaging mission in a high drag environment.
- Venus platform based on IMPS design of IAI
- Estimated launch weight: 230 kg
- Launch in 2009
- Planned lifetime of 4¼ years



ISA

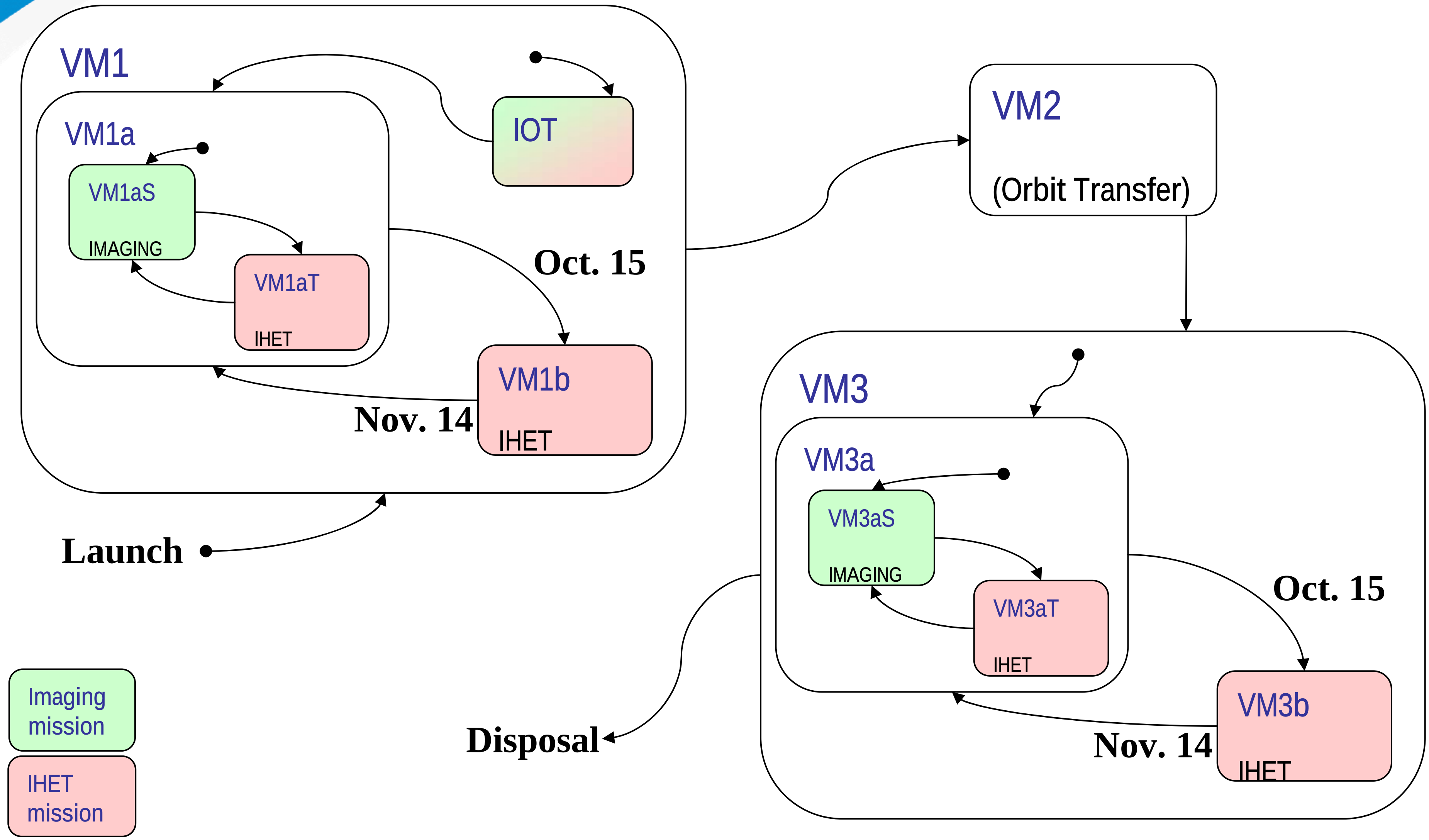
cnes
CENTRE NATIONAL D'ETUDES SPATIALES

IAI MBT SPACE DIVISION
Systems Missiles & Space Group
ISRAEL AIRCRAFT INDUSTRIES LTD

CESBIO

Ben Gurion University

Venus Mission



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VM1 Mission Characteristics

- Orbit: near polar, sun-synchronous, earth repeating
- Altitude: 720 km
- Inclination: 98.27°
- Revisit time: two days (29 revolutions)
- Equator crossing time: 10:30 AM, descending mode
- Mission start & duration: June 2009, for ~4.25 years
- Imaging:
  - Swath: 27.56 km
  - Spatial resolution: 5.3 m
  - Number of spectral bands: 12 (VIS-NIR)
  - Tilting capability: +/-30° across and along track
  - Radiometric resolution: 10 bits

Monitoring of Temporal Dynamics

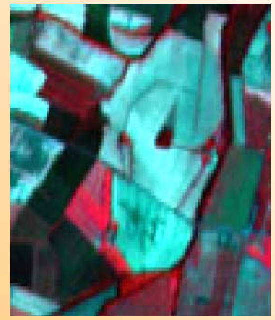
Crop evolution as seen by the SPOT constellation every month

2000 m

21 March

23 April

15 May



14 June

20 July

14 August

14 September

6 October

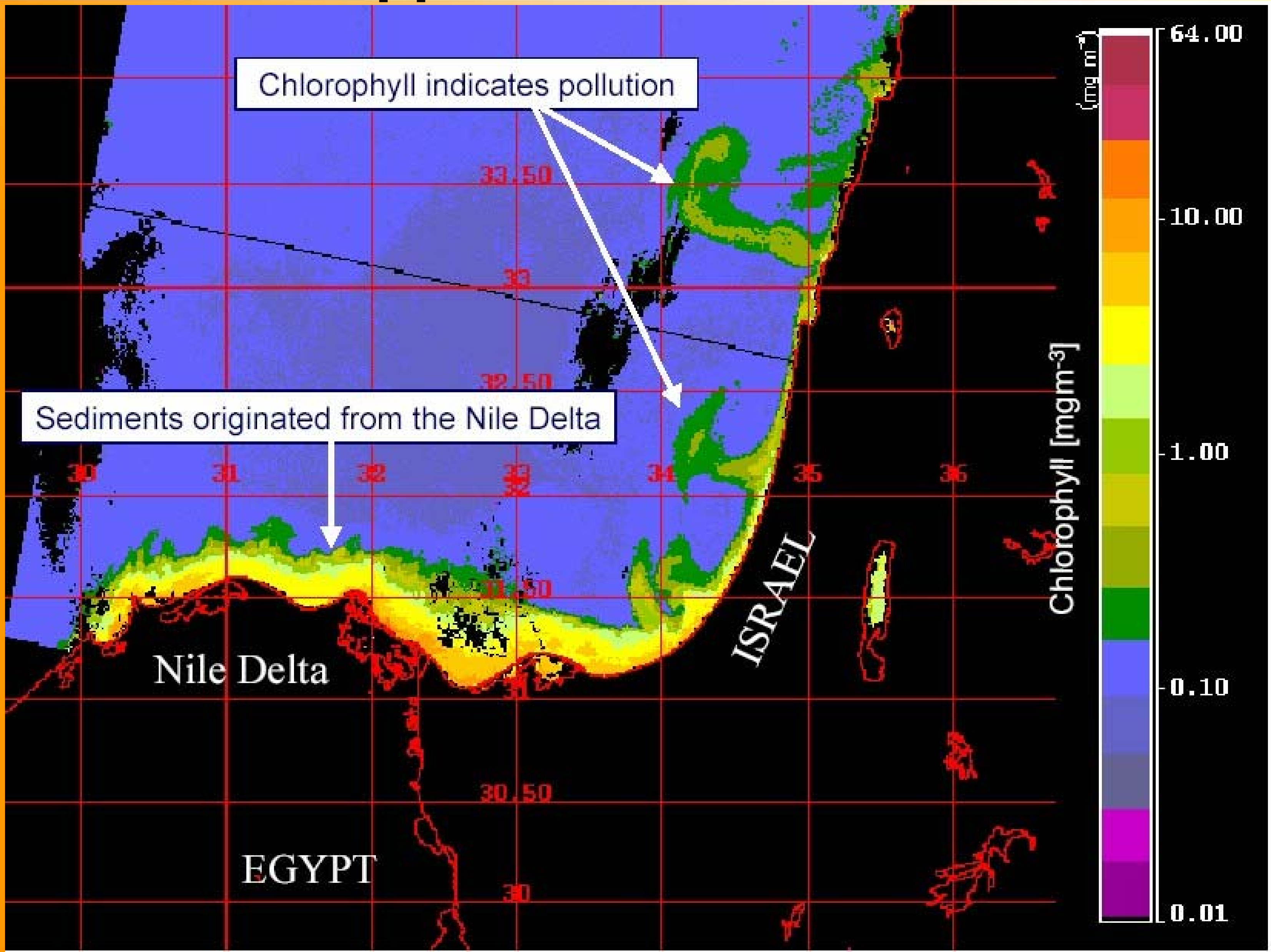
27 October

22 November

After compositing procedures for eliminating clouds, VENμS will provide images with improved spectral information every 10 days

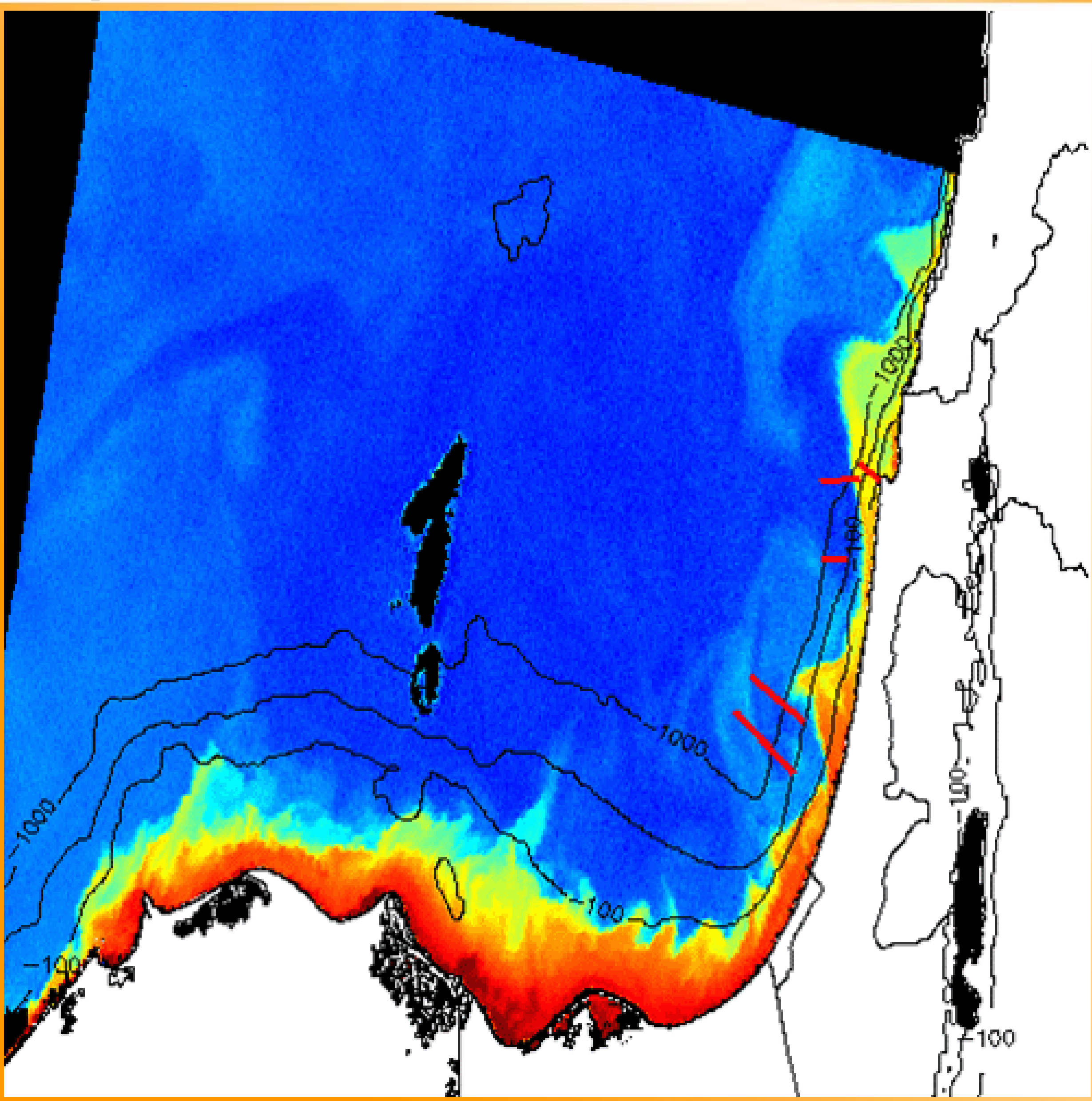
Science from Above

Coastal Zone Applications

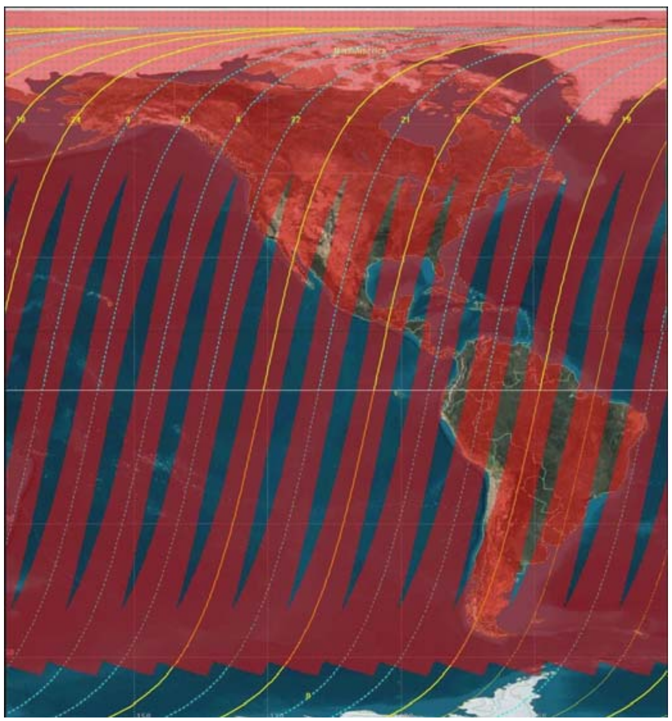


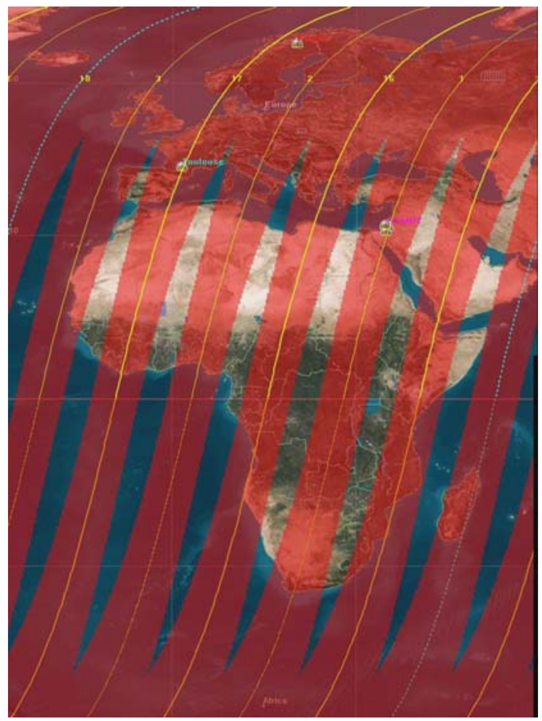
Science from Above

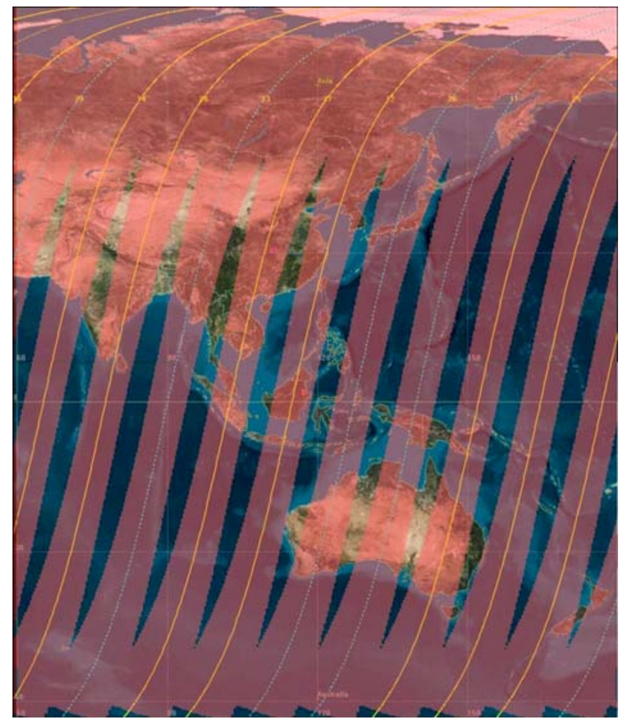
Pollution Dispersion – 11 – 25, June 2001



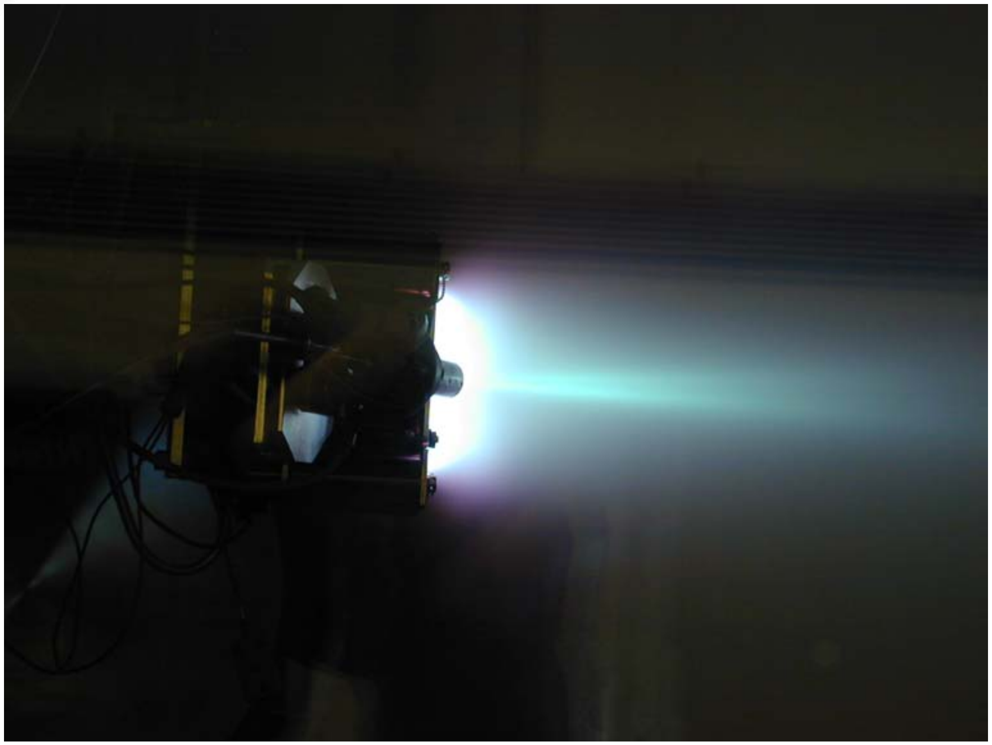
VM1 Imaging Access

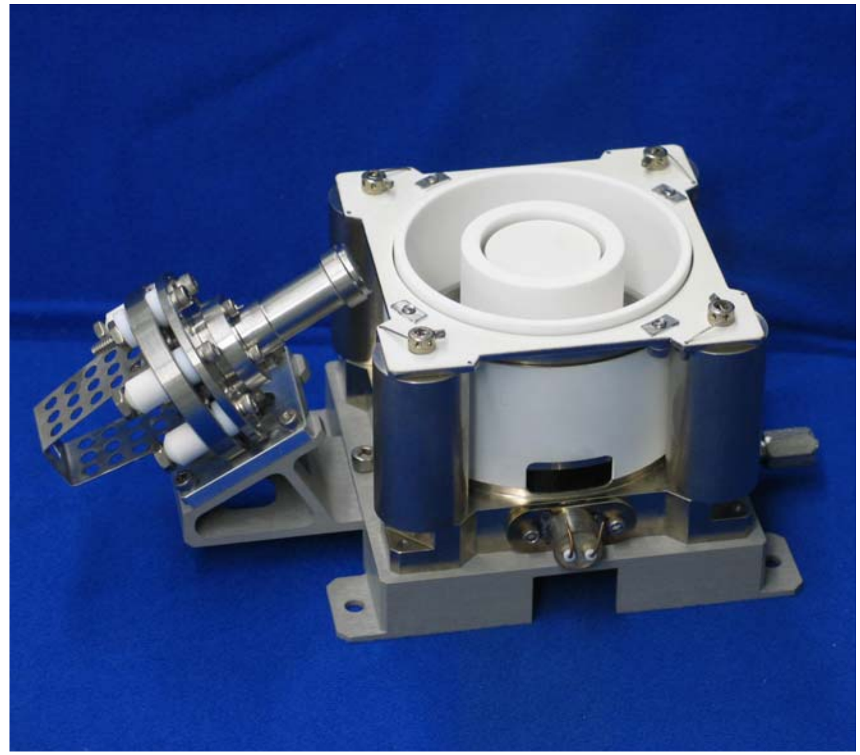






IHET- 300W

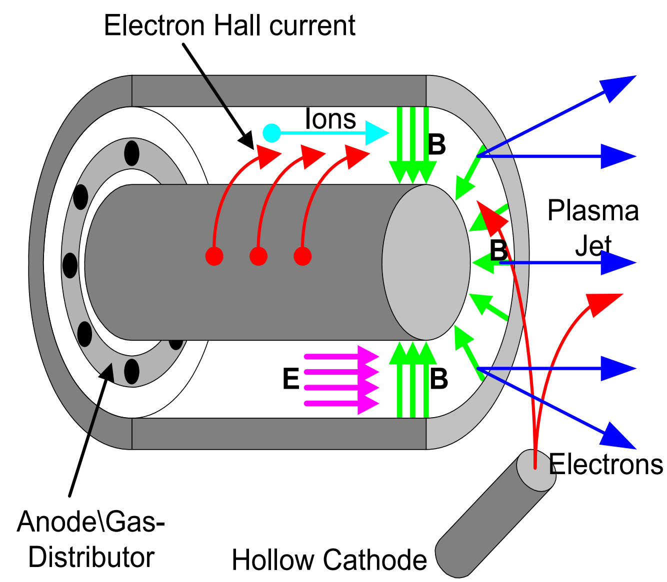




Isp @ 300W :	>1300s
Thrust @ 300W:	≥15mN
Total Impulse:	>50 KNs

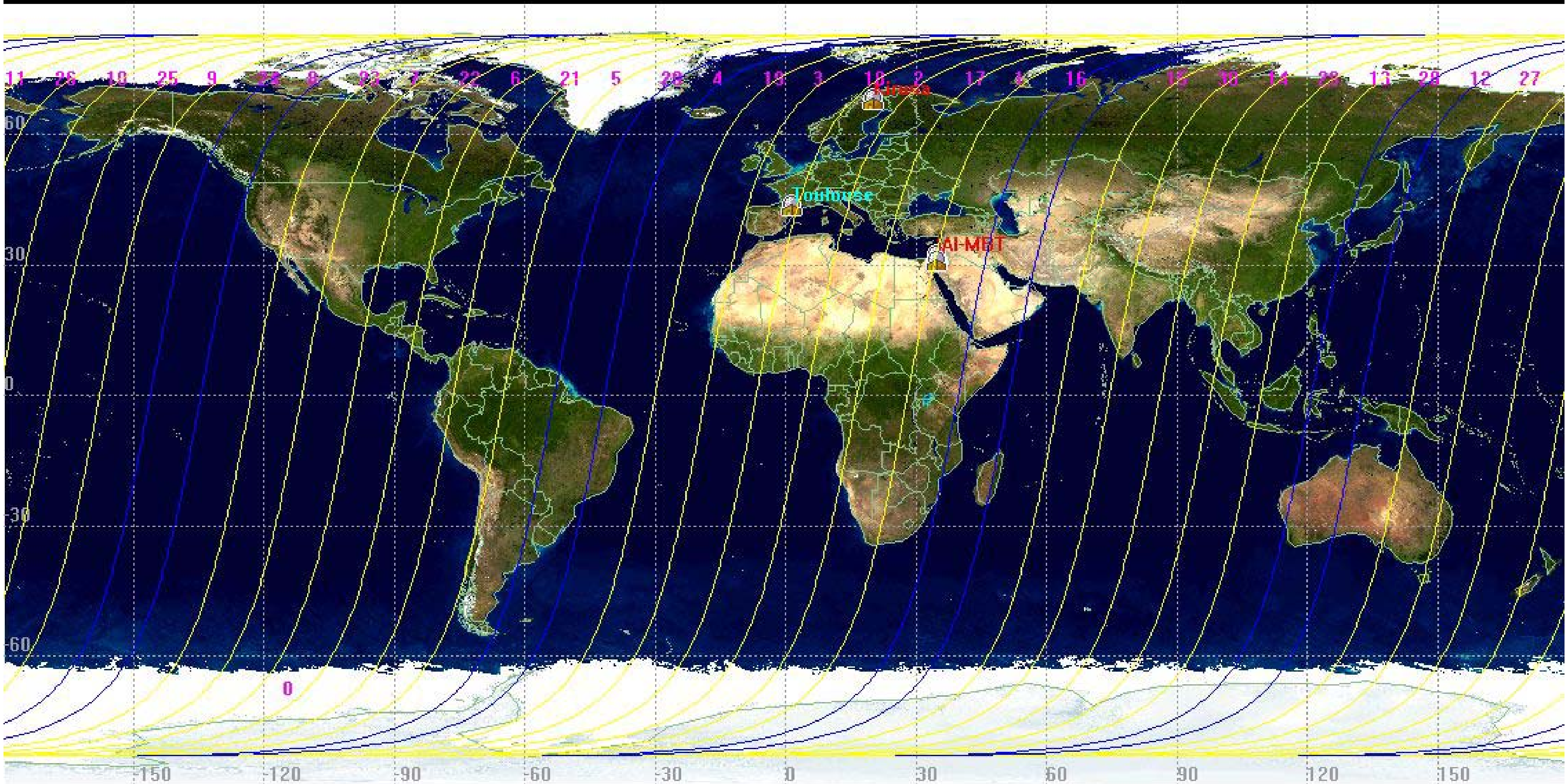
Thruster operating principles

- Xe gas directed through distribution channel (Anode)
- Electrons emitted from cathode, collide with Xe atoms, and ionizing them.
- Induced magnet field, spiral ions movement in the thruster channel.
- Electric field accelerates ions out of the channel.
- Ions neutralization at exit by electrons from the cathode.

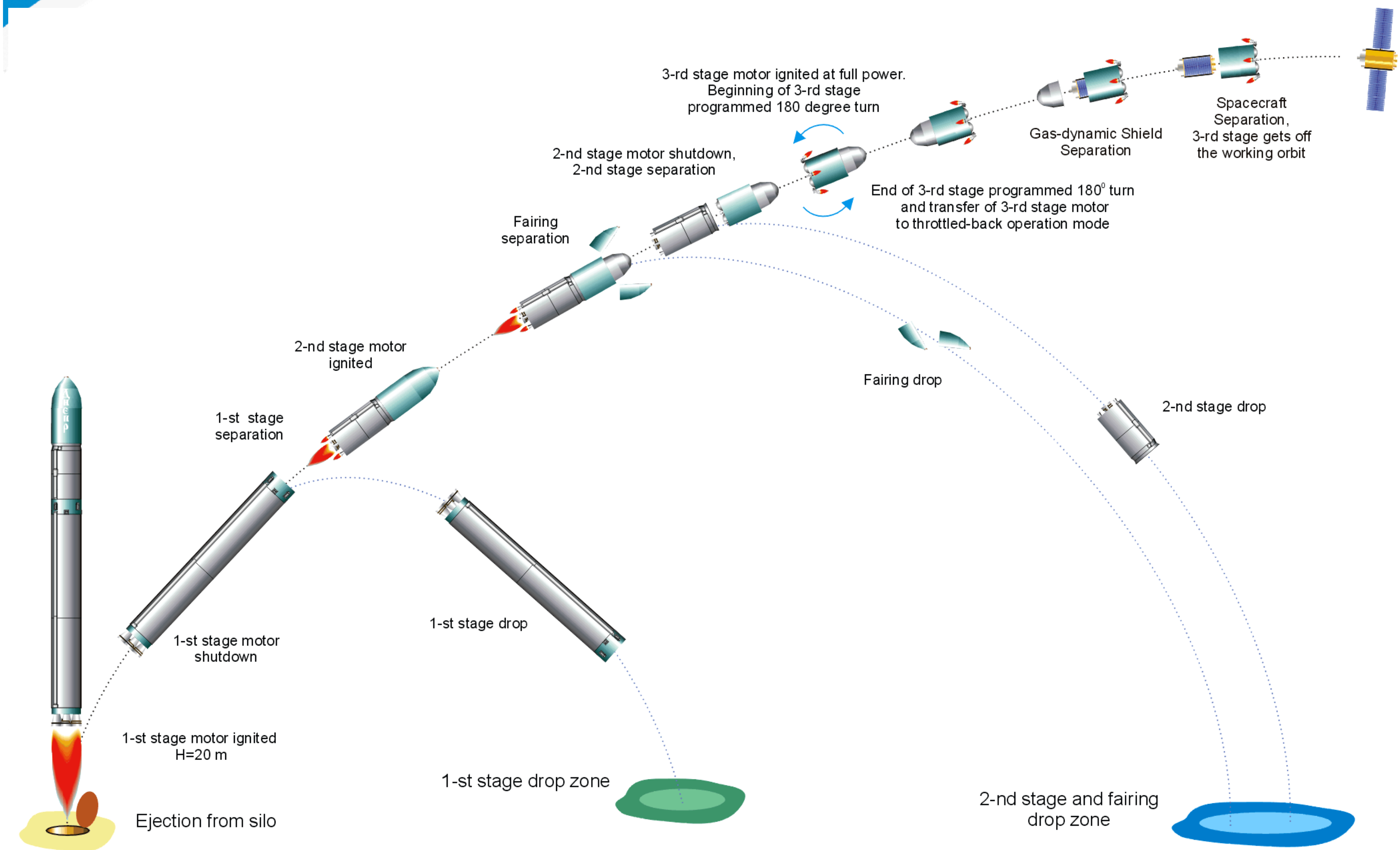


VM3 Combined Scientific and Technological Missions

Imaging orbits in Yellow, IHET orbits in blue

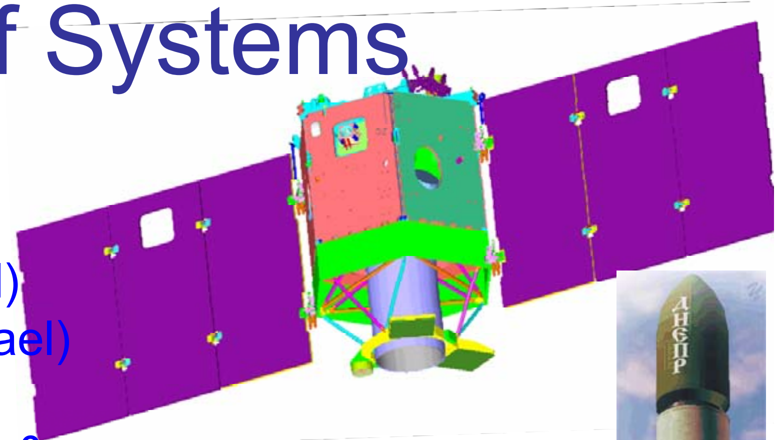


Venus Launch

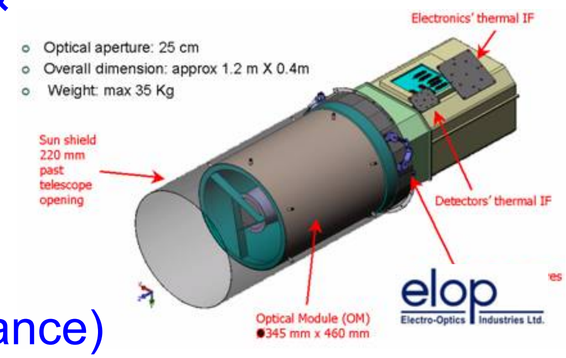


Venμs – System of Systems

- **Space segment** – Venus satellite:
  - Venus platform (IAI & Rafael, Israel)
  - Venus Super Spectral Camera (ELOP, Israel)
  - Israeli Hall Effect Thruster- IHET (Rafael, Israel)



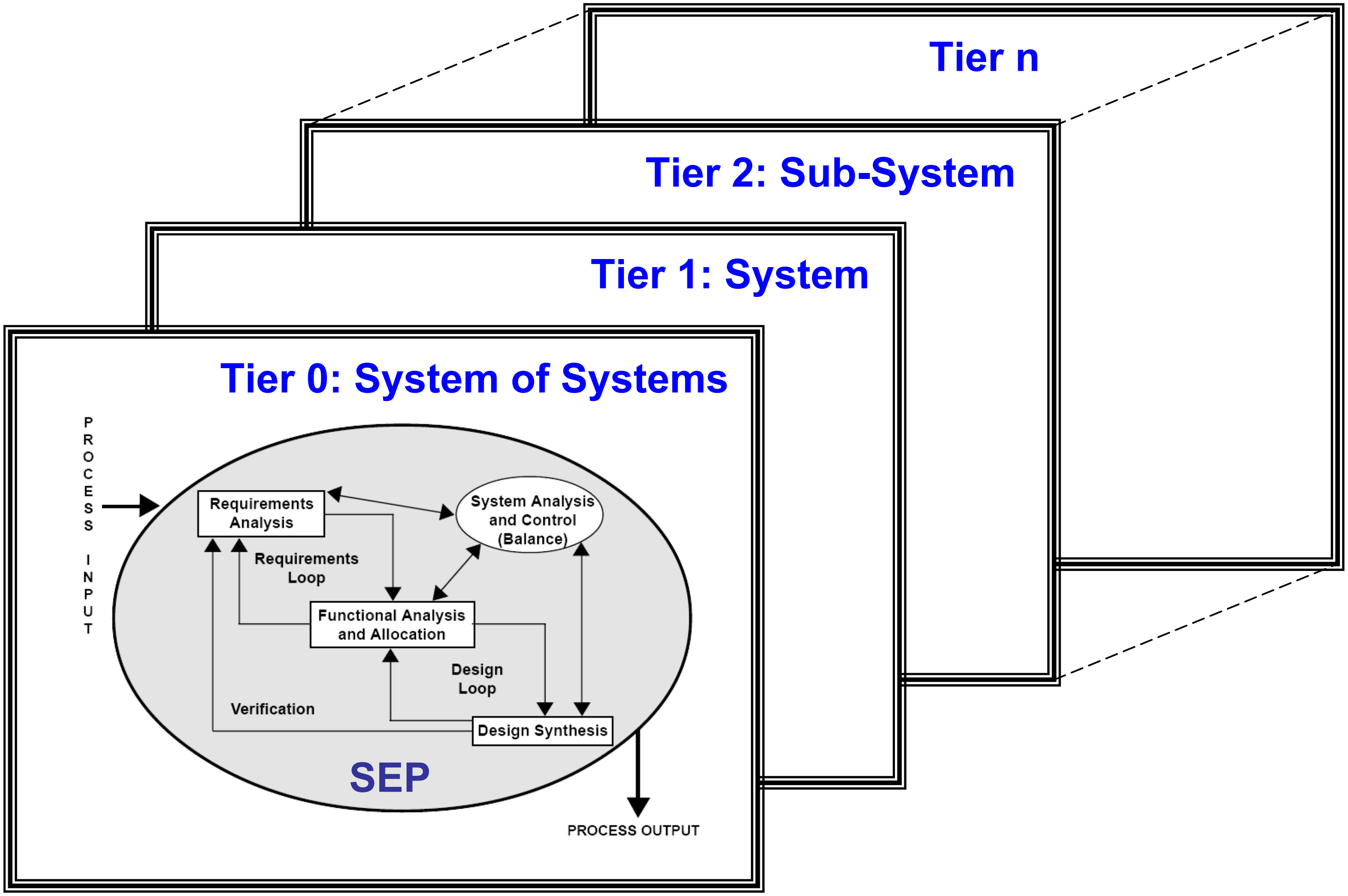
- **Launch segment** – DNEPR (Kosmotras, Russia & Ukraine)



- **Ground segment**:
  - Command and control center (MBT, Israel)
  - X-band receiving station (Kiruna, Sweden)
  - Image processing center (CNES Toulouse, France)
  - Technological Mission Center (Rafael, Israel)

- **Orbits and Missions**
  - Scientific mission: Multispectral imaging for agriculture, vegetation and water quality
  - Technological mission: Validation of IHET and mission enhancement demonstration
  - Orbits: Initial orbit (720km), LEO to LEO transfer and Final orbit (410km)

SEP (Systems Engineering Process) Performed in System Tiers



Example of synthesis in Venus Program:

Solar Panels and IHET Architecture for
Venus Satellite

Define the Design Problems:

Main Functional Requirements:

- Provide power:
  - 350W for IHET
  - 150W for platform,

  for maximum duration (Required: > 20 mins, Desired: ~60 mins)
- Provide maneuverability in orbit
- Provide propulsion redundancy
- Provide camera protection from ATOX

Constraints:

- Venus orbits: Sun-Synchronous, descending node @ 10:30
- Restricted maneuvers of "*ROLL*" about thrust vector.

Define Solar Panels and IHET geometric placement architecture on the Venus satellite (orientation of panels to IHET and satellite platform).

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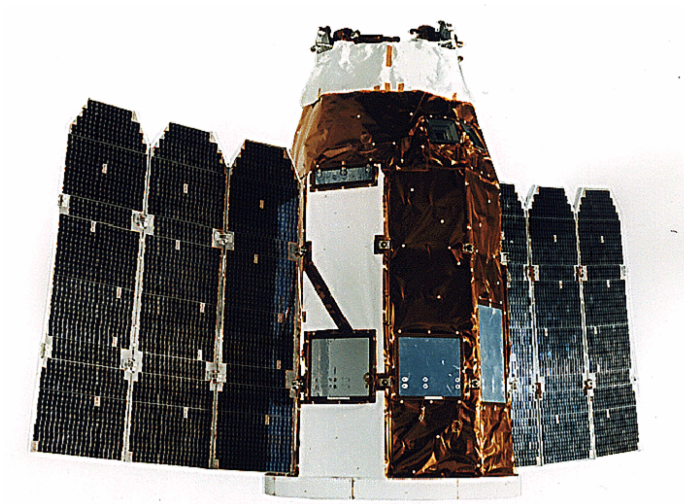
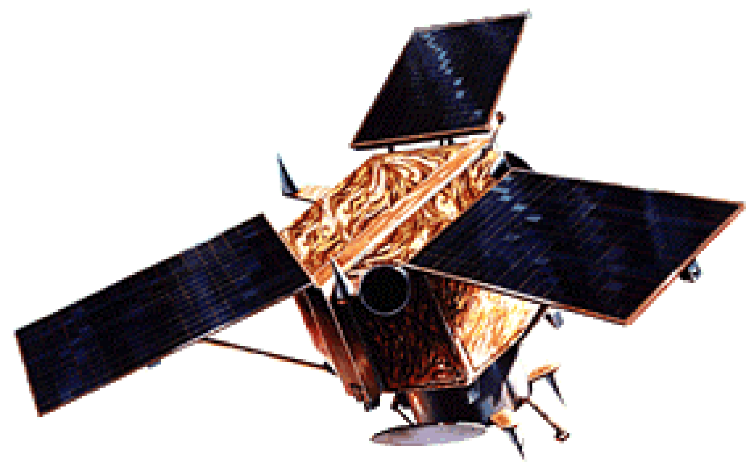
Possible Solutions to Solar Panels Problem

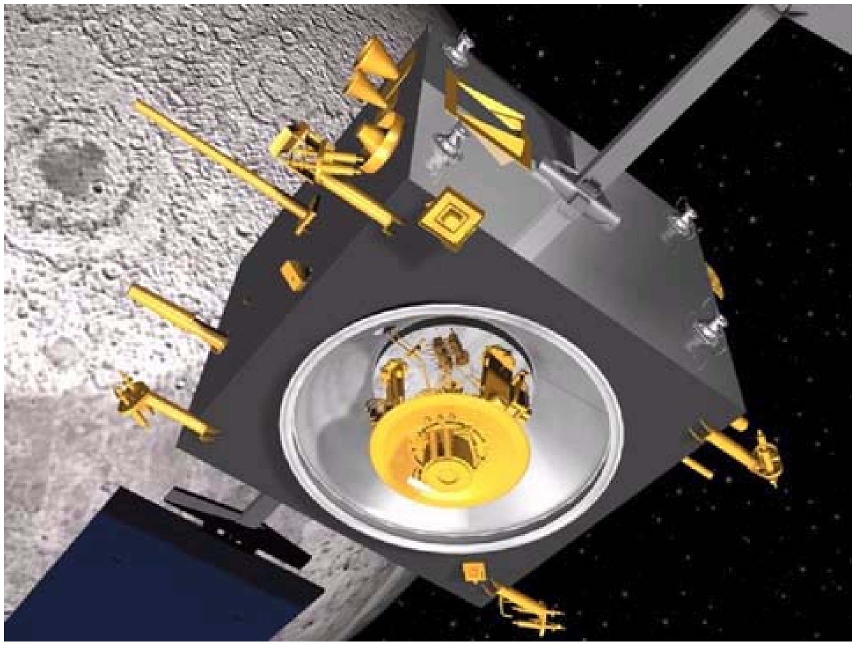


IAI-MBT "*Ofeq*"

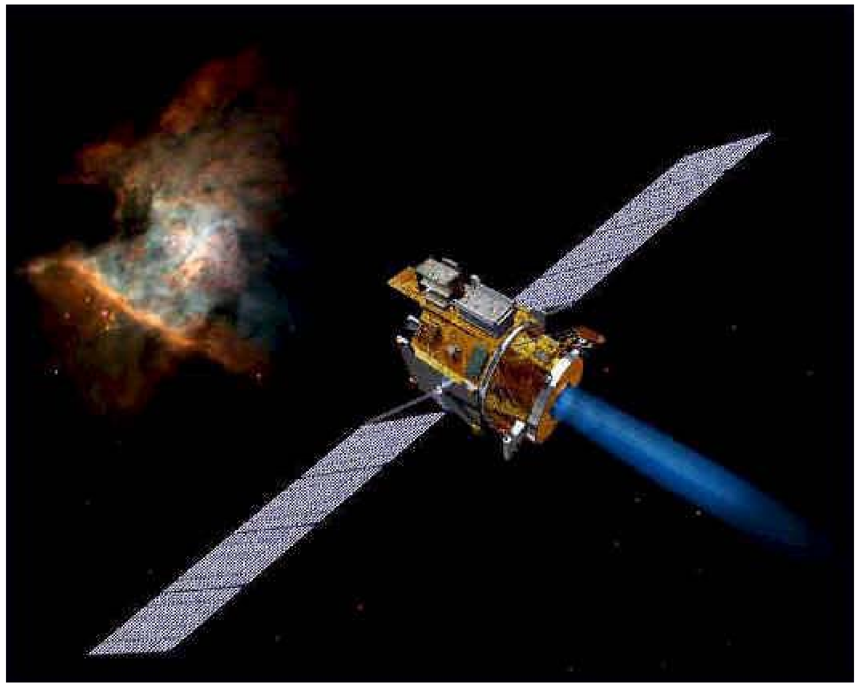


Lockheed Martin "*Ikonos*"

Possible Solutions to IHET Problem

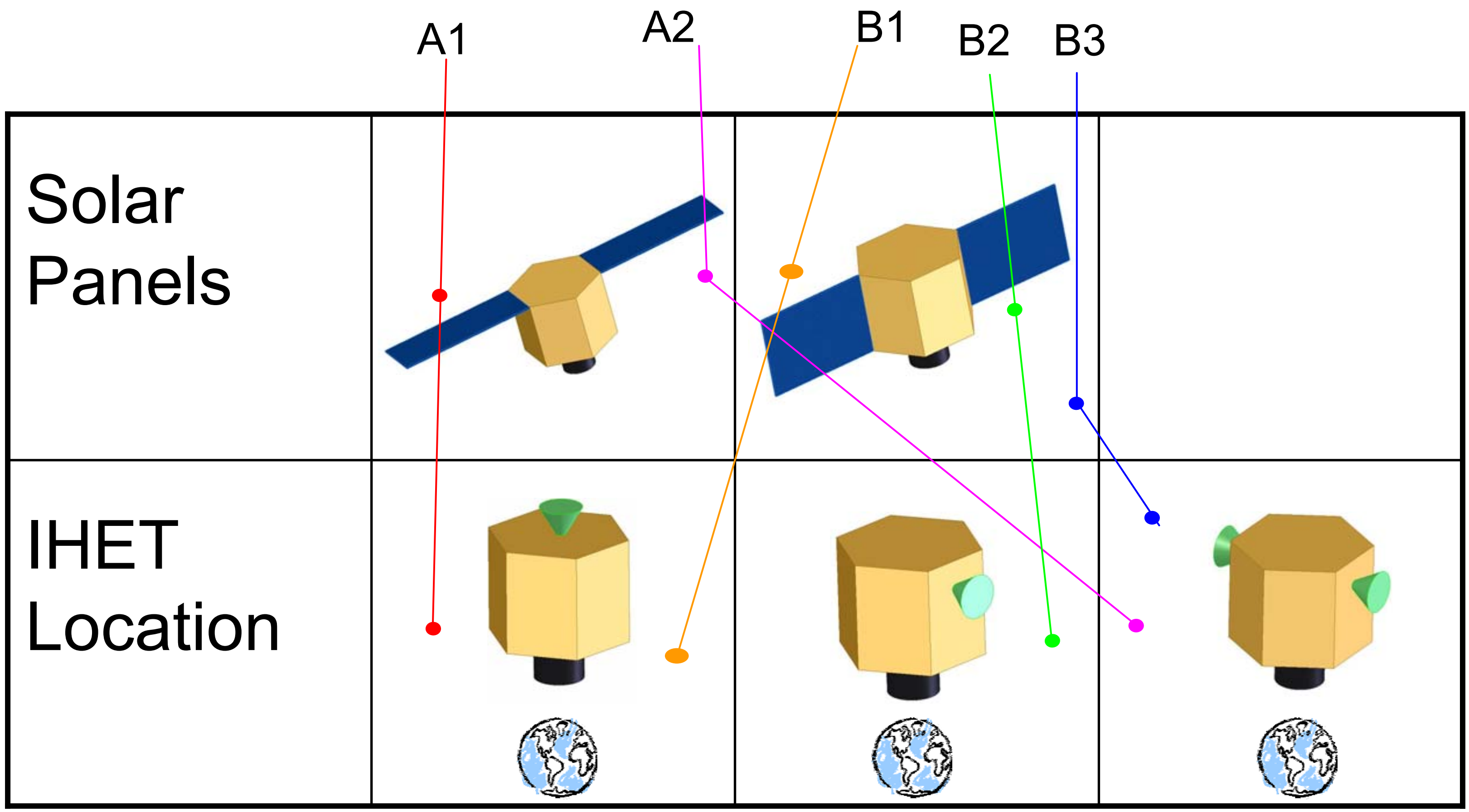


ESA *"Smart1"*

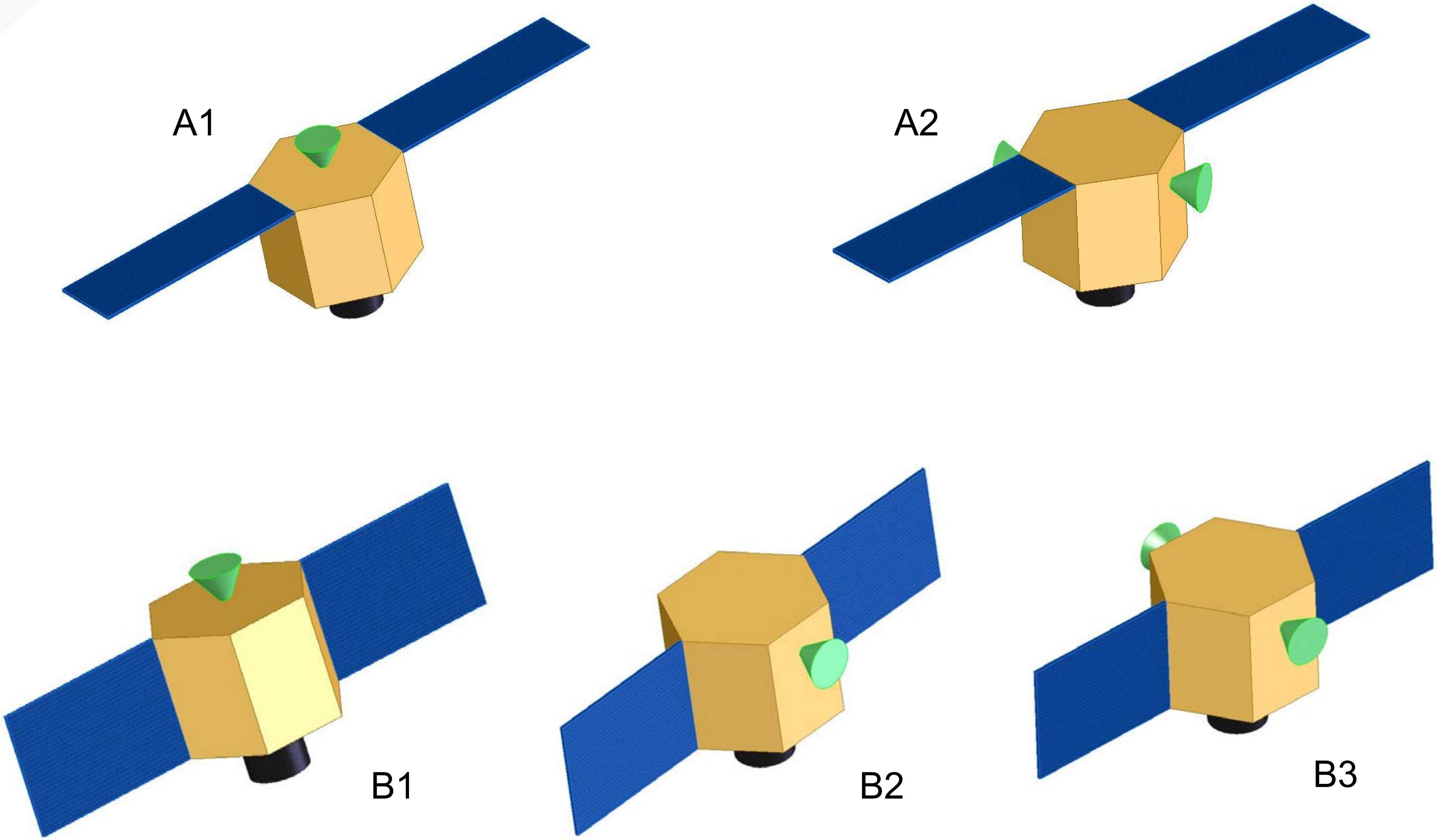


NASA & JPL *"Deep Space 1"*

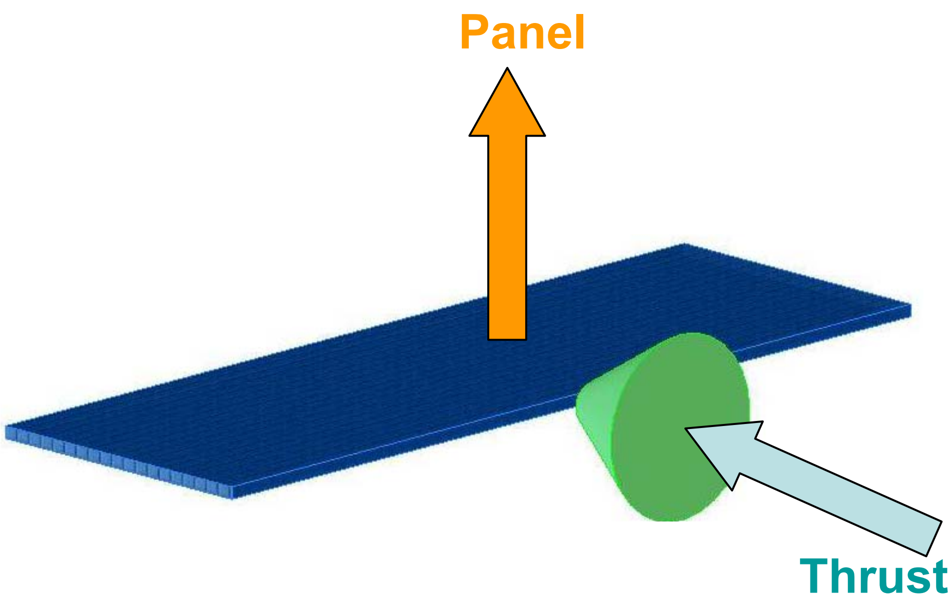
Panels & IHET configuration



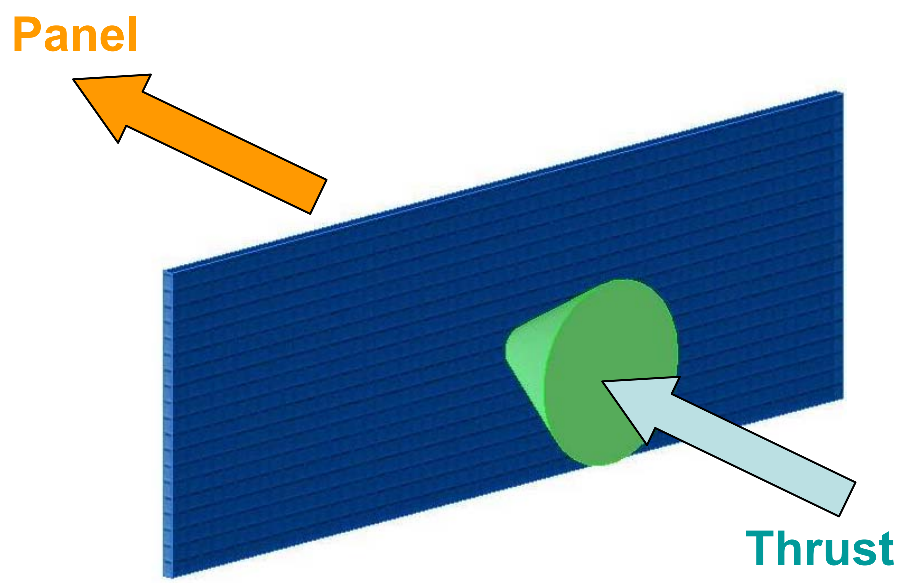
The 5 Concepts



Basic Solar Panel and IHET Architecture Alternatives

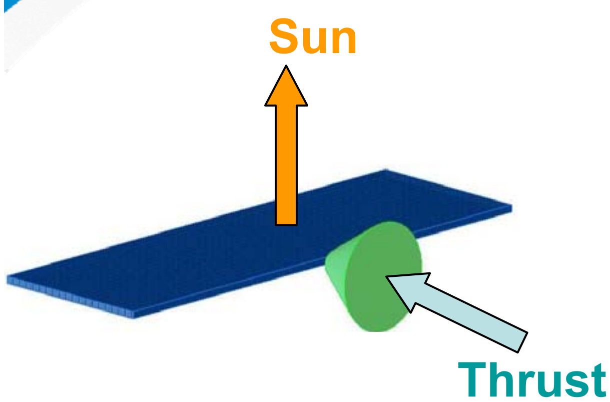


"Normal"

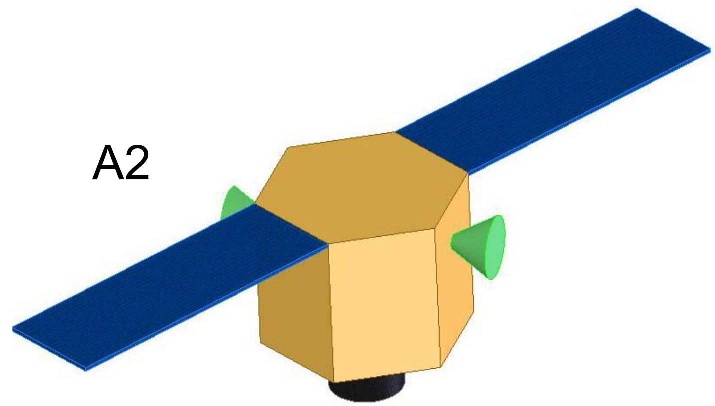


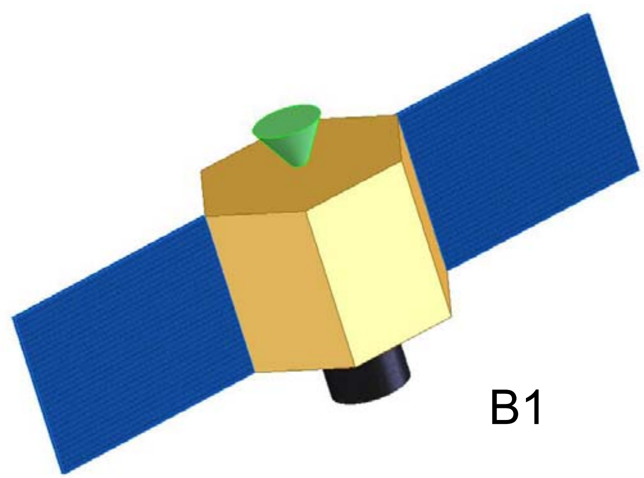
"Parallel"

Alternatives ***"Normal"***

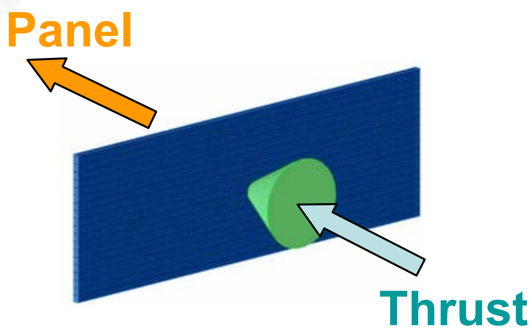


"Normal"

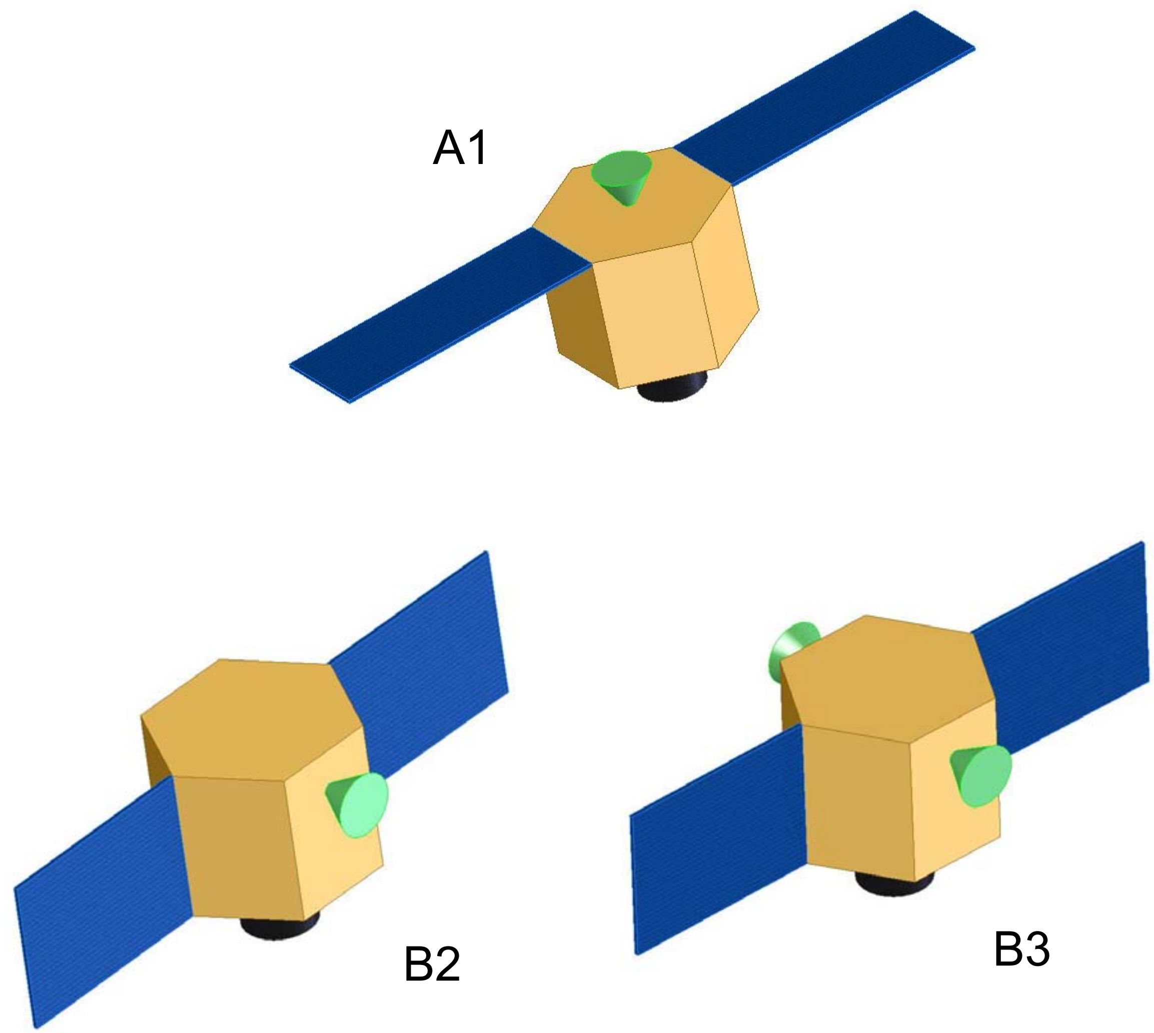


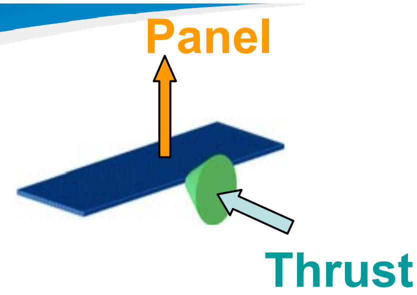


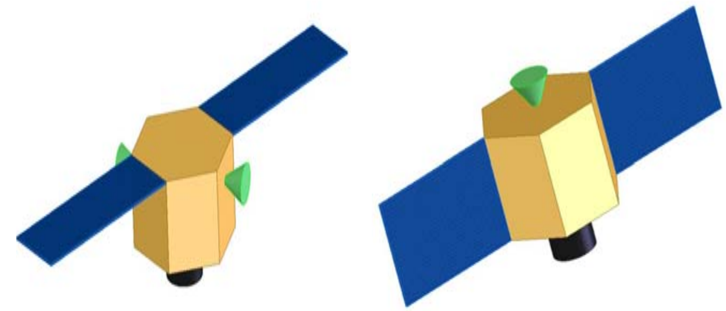
Alternatives *"Parallel"*



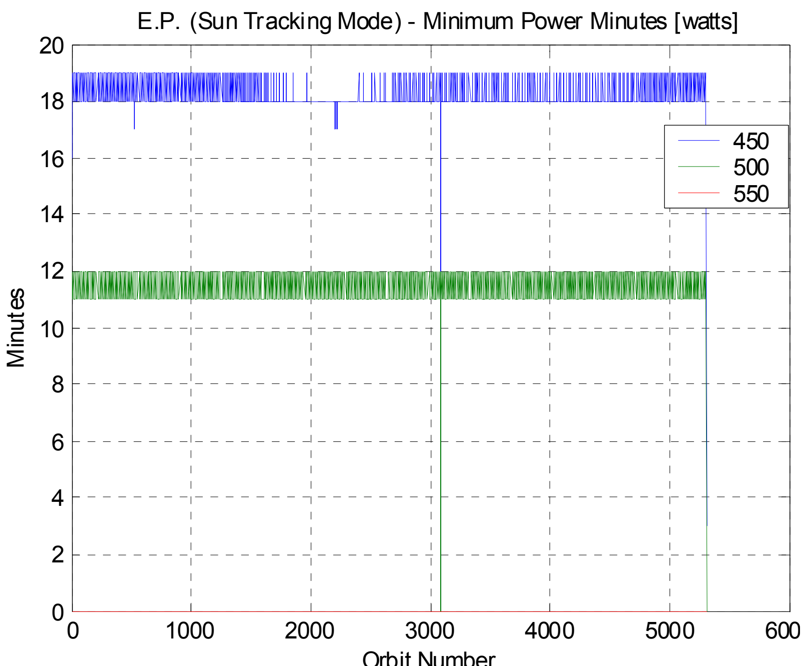
"Parallel"



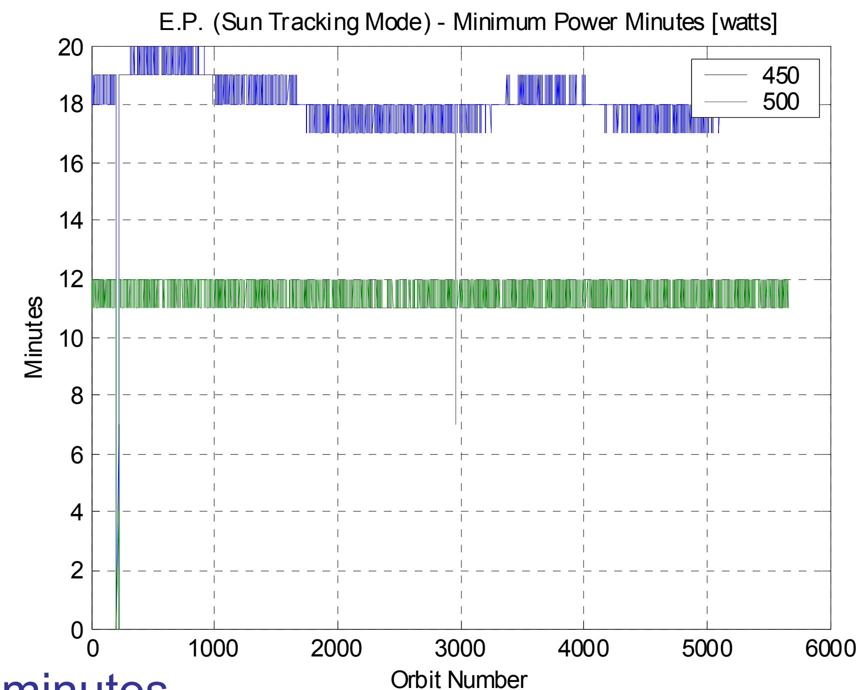




Power Generation Analysis for Solar Panels – IHET Architecture “***Normal***”

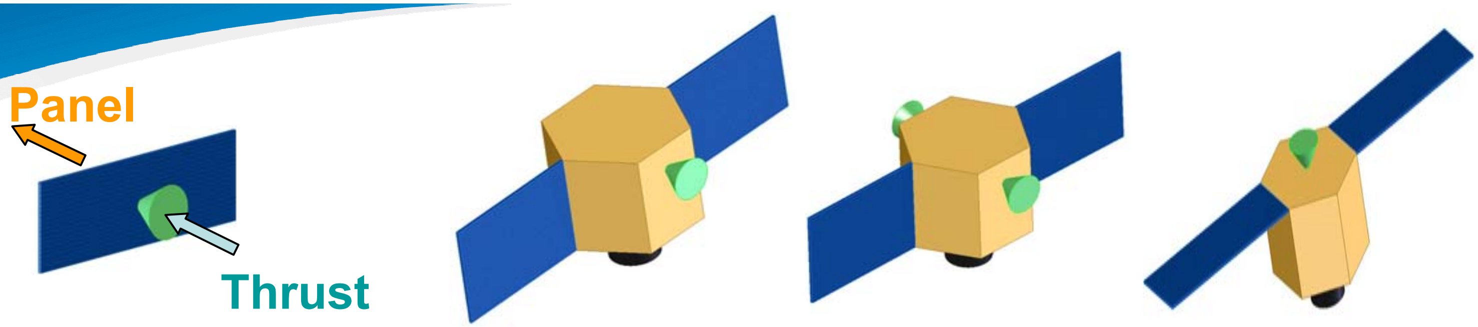


VM1 (720km)

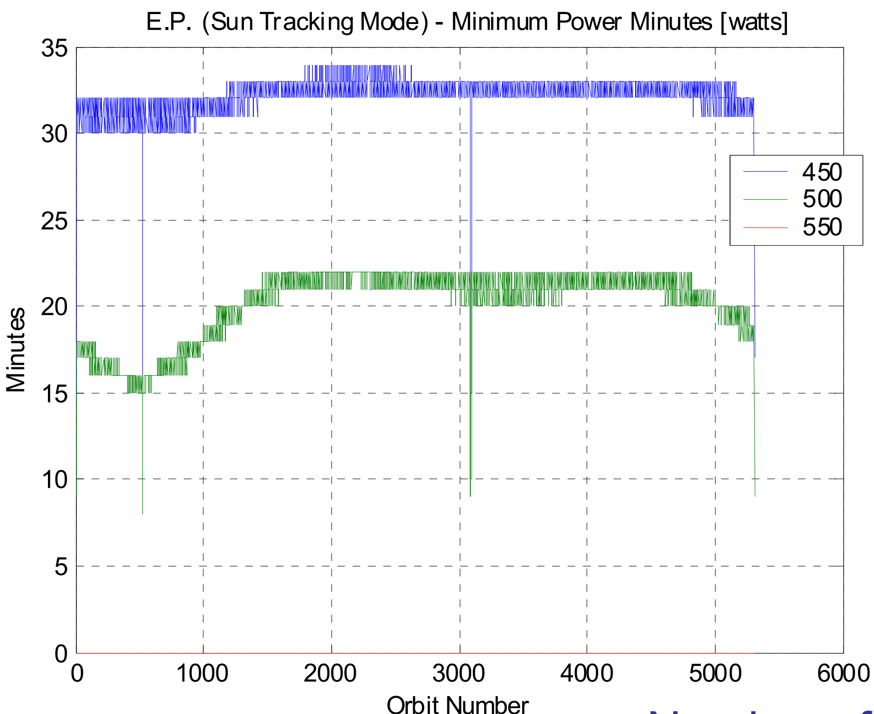


Number of orbit minutes with minimum power

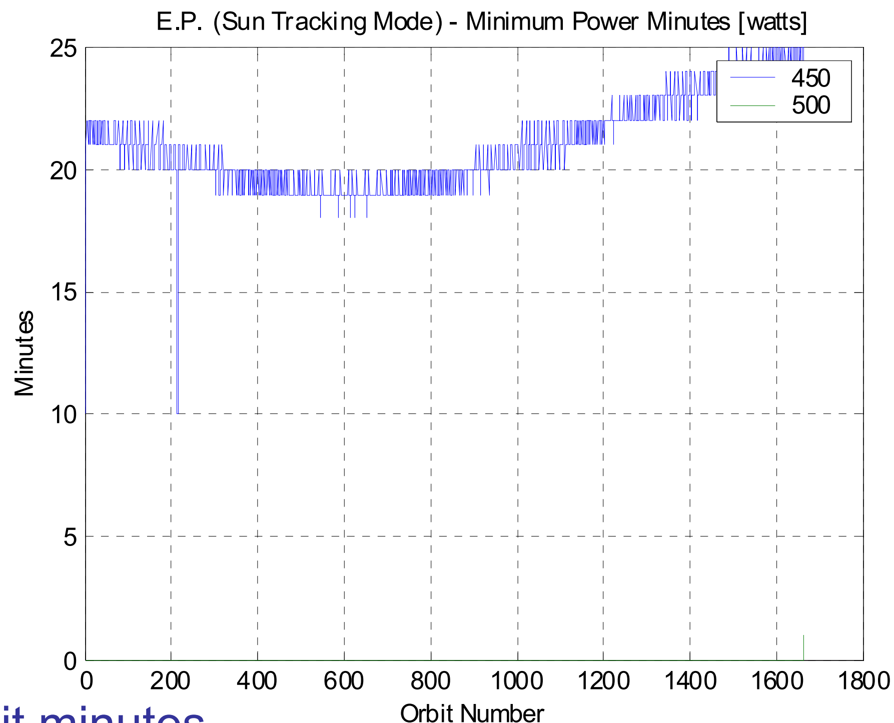
VM3 (410km)



Power Generation Analysis for Solar Panels – IHET Architecture "***Parallel***"



VM1 (720km)

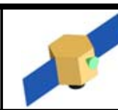


Number of orbit minutes with minimum power

VM3 (410km)

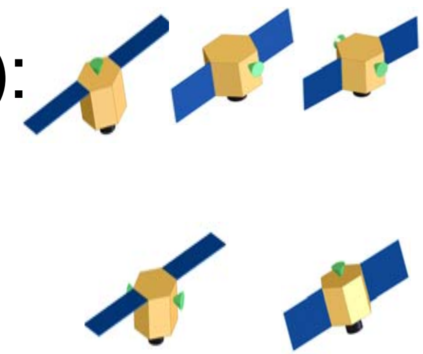
Drag Consideration

- Computations for VM3 @ Altitude: 410 km
- Satellite mass: 150 kg
- Panels area: 2.5 m^2
- Satellite body area: 1 m^2
- Assume Solar-Max conditions (*)
  (year 2010)

	Concept					
IHET Operation	Area [m^2]	3.5	1	1	3.5	3.5
	Drag [mN]	1.46	0.42	0.42	1.46	1.46
Imaging Operation	Area [m^2]	1	1	3.5	3.5	3.5
	Drag [mN]	0.42	0.42	1.46	1.46	1.46

Drag Results Analysis

- Drag impulse of one orbit (Altitude = 410km, Orbit period = 92 min):
  - For concepts A1, B2, B3 (A = 3.5m^2): 8.1 Ns
  - For concepts A2, B1, (A = 1m^2): 2.3 Ns



- Typical IHET impulse (13mN for 20 min.) operation: 15.6 Ns

Evaluation Criteria

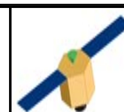
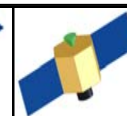
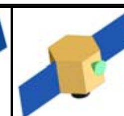
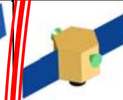
- IHET operation minutes / orbit (for 500W consumption in 720km and 410km orbits)
- Need for Camera Cover
- ΔV flexibility – Capability of ± ΔV for orbit maneuvering
- Heritage – usage of legacy components
- Integration complexity – IHET and satellite integration effort due to modularity and coupling

- VM1 (2 years) specific:
  - N/A
- VM3 (3rd year) specific:
  - Drag during Imaging and IHET operation
  - Enough IHET power during orbits for orbit maintenance

Concepts Evaluation

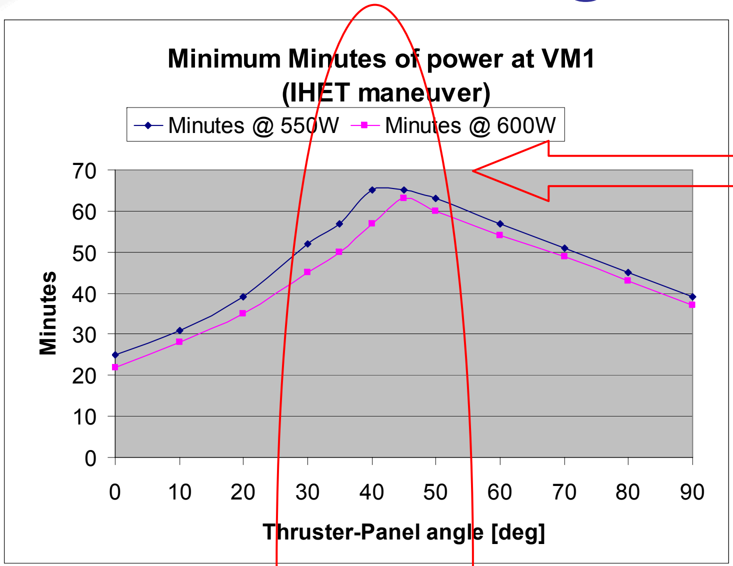
Criteria \ Concept		 A1	 A2	 B1	 B2	 B3
Drag (1) [mN]	**Imaging**	0.42	0.42	1.46	1.46	1.46
	IHET	1.46	0.42	0.42	1.46	1.46
500W minutes / orbit (2)		15 - 22	11	11	15 - 22	15 - 22
Camera Cover		Must	Optional	Must	Optional	Optional
ΔV flexibility		-ΔV @ dawn +ΔV @ dusk	±ΔV @ noon	±ΔV @ noon	-ΔV @ dawn +ΔV @ dusk	±ΔV @ dawn ±ΔV @ dusk
Heritage		New	New	Existing	Existing	Existing
Integration Complexity (4)		Low	Moderate	Low	Moderate	Mederate

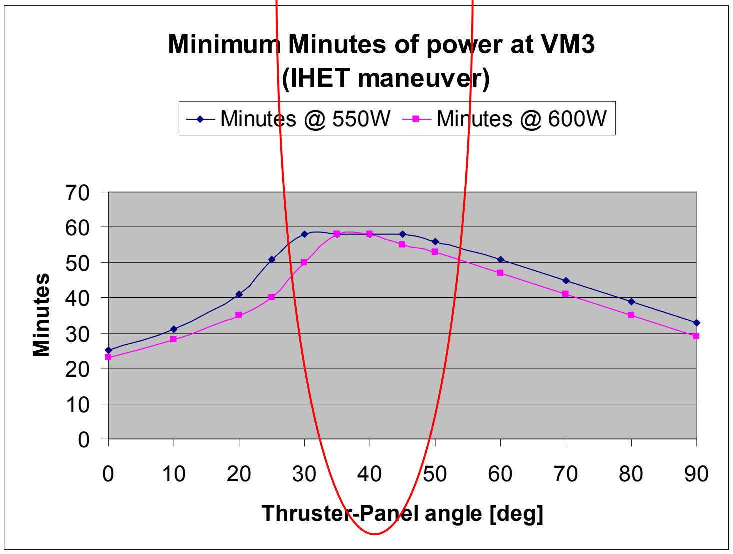
Concept Selection

Criteria	Weight	 A1	 A2	 B1	 B2	 B3
Drag Considerations	10		1	0	-2	-2
Power Production Capability	25	D	-2	-2	0	0
Camera Risk (Need for camera cover)	20	A	3	0	3	3
ΔV flexibility (maneuverability)	25	T	-2	-2	0	3
Heritage Design (Solar Panels)	15	U	0	2	2	2
IHET Integration Complexity	5	M	-2	0	-2	-2
Total	**100**	**0**	**-40**	**-70**	**60**	**135**

Pairs Comparison	Grade
Much better than *datum*	3
Better than *datum*	2
Slightly better than *datum*	1
Same as *datum*	0
Slightly worse than *datum*	-1
Worse than *datum*	-2
Much worse than *datum*	-3

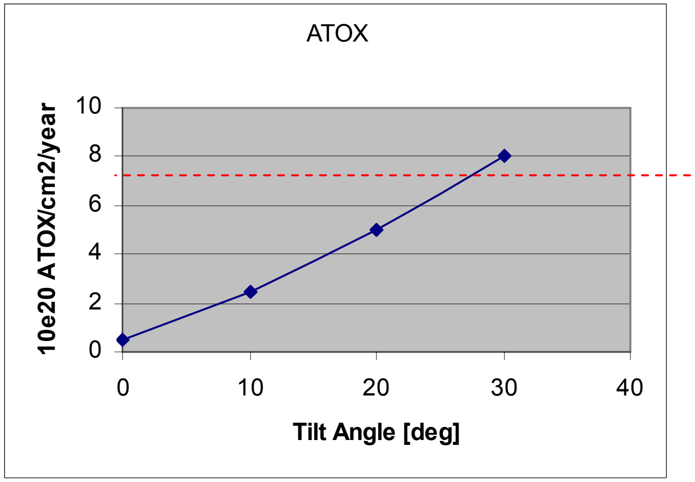
Design Improvements



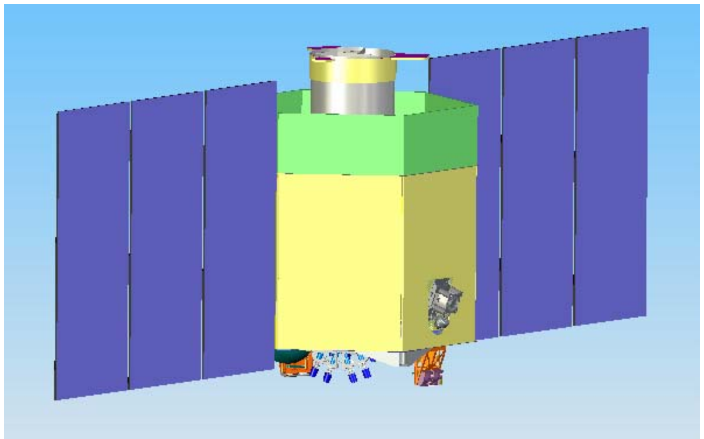


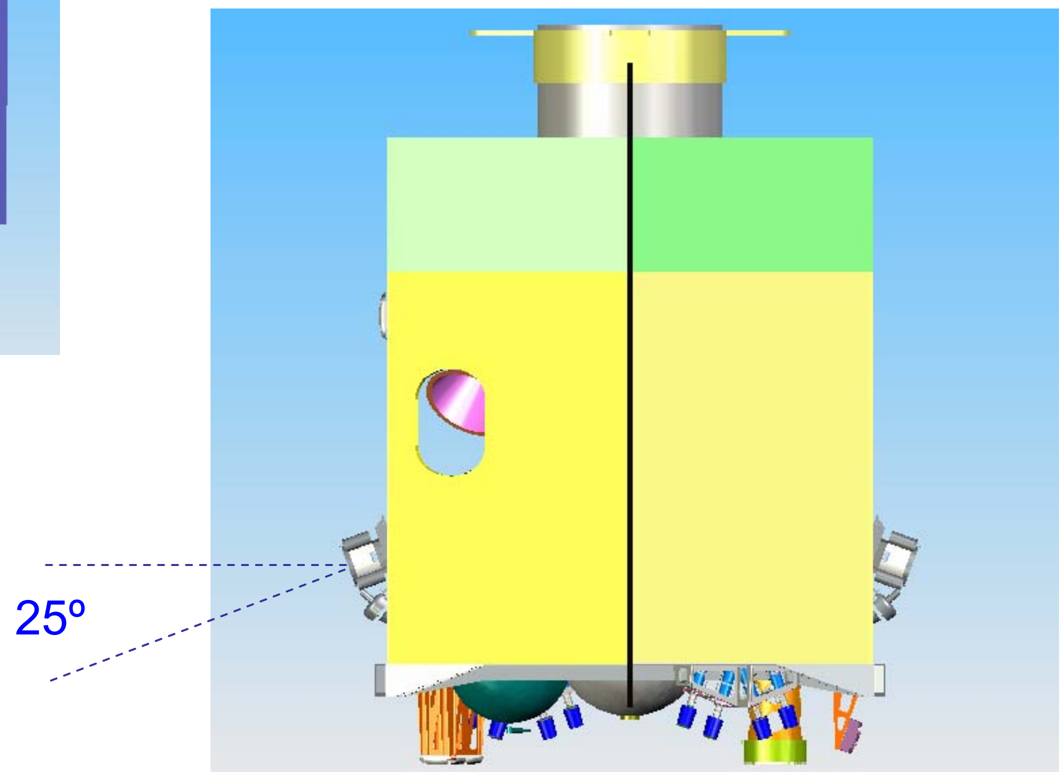
Optimal power

Camera Tolerance:
7.3 10^{20} ATOX/m^2/Y



Final IHET Configuration





Conclusions

- System of systems design process can benefit from applying the SEP starting from the initial conceptual design phase
- SEP and synthesis tools are easily applicable to the first tiers of system engineering, as they are to the detailed design tiers
- The applicability of SEP and Conceptual design (preliminary design) was demonstrated in the context of spacecraft and space mission engineering
- Using quantitative synthesis methods can produce a reasonable and rational design

Thank You

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- Dr. Hezi Atir - Chief Scientist, Space Systems Directorate, Rafael
- Danna Linn-Barnett – Mission Analyst, Space Systems Directorate, Rafael
- David Reiner – Propulsion Section Head, Rafael
- Yoram Yaniv & Meidad Porat Pariente – Program Management & System Engineering, MBT-IAI
- Prof. Arnon Karnieli - The Remote Sensing Laboratory, Ben-Gurion University of the Negev