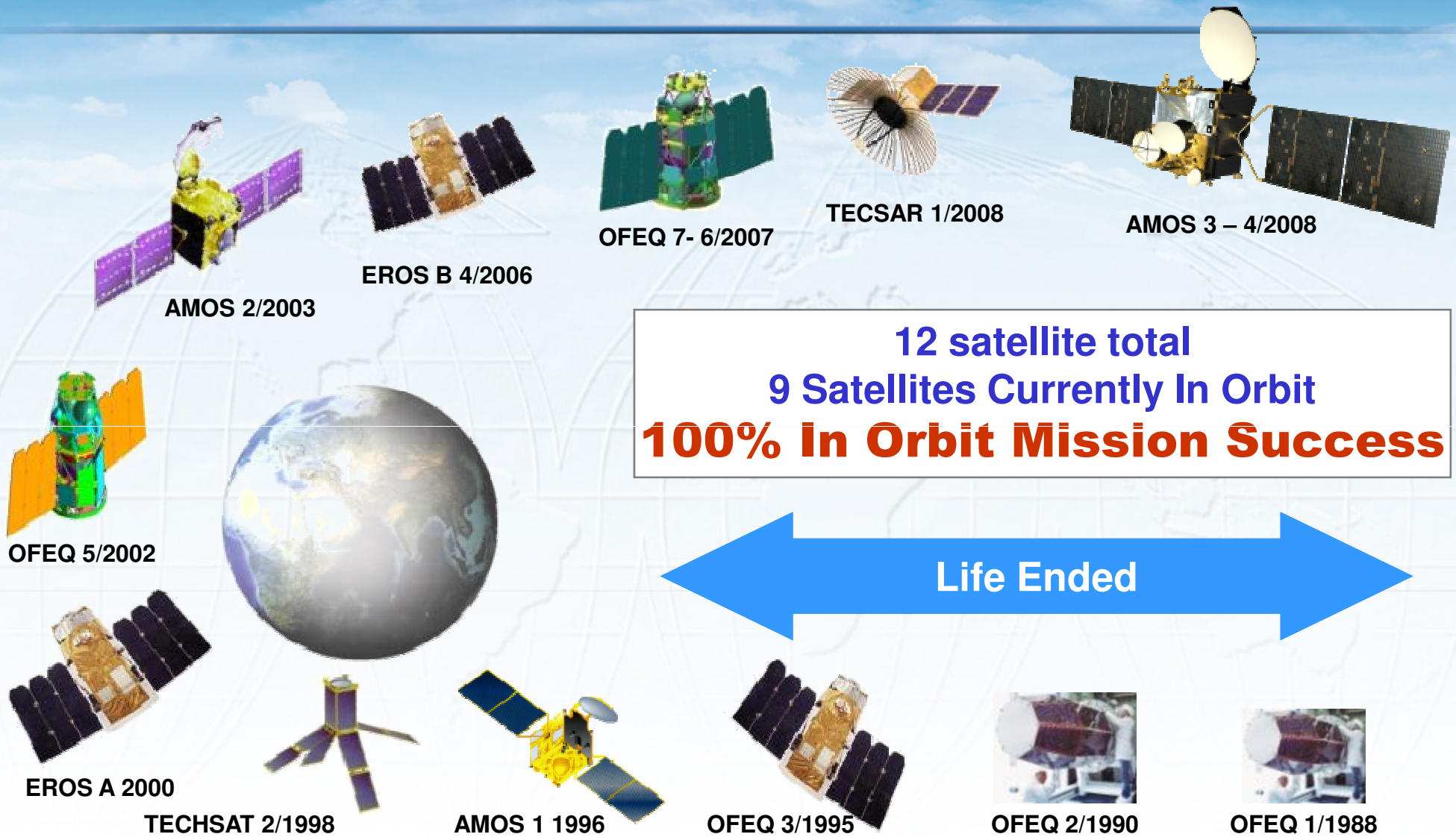


# Using Differential Drag for Management of Nano-Satellite Constellations

**Yonatan Winetraub, Dr. Raz Tamir**

**Israel Aerospace Industries  
Israel Nano-Satellite Association**

# MBT/Space Achievements



**12 satellite total**  
**9 Satellites Currently In Orbit**  
**100% In Orbit Mission Success**

# INSA – Building Israel's First Nano-Satellite



## InKlajn-1

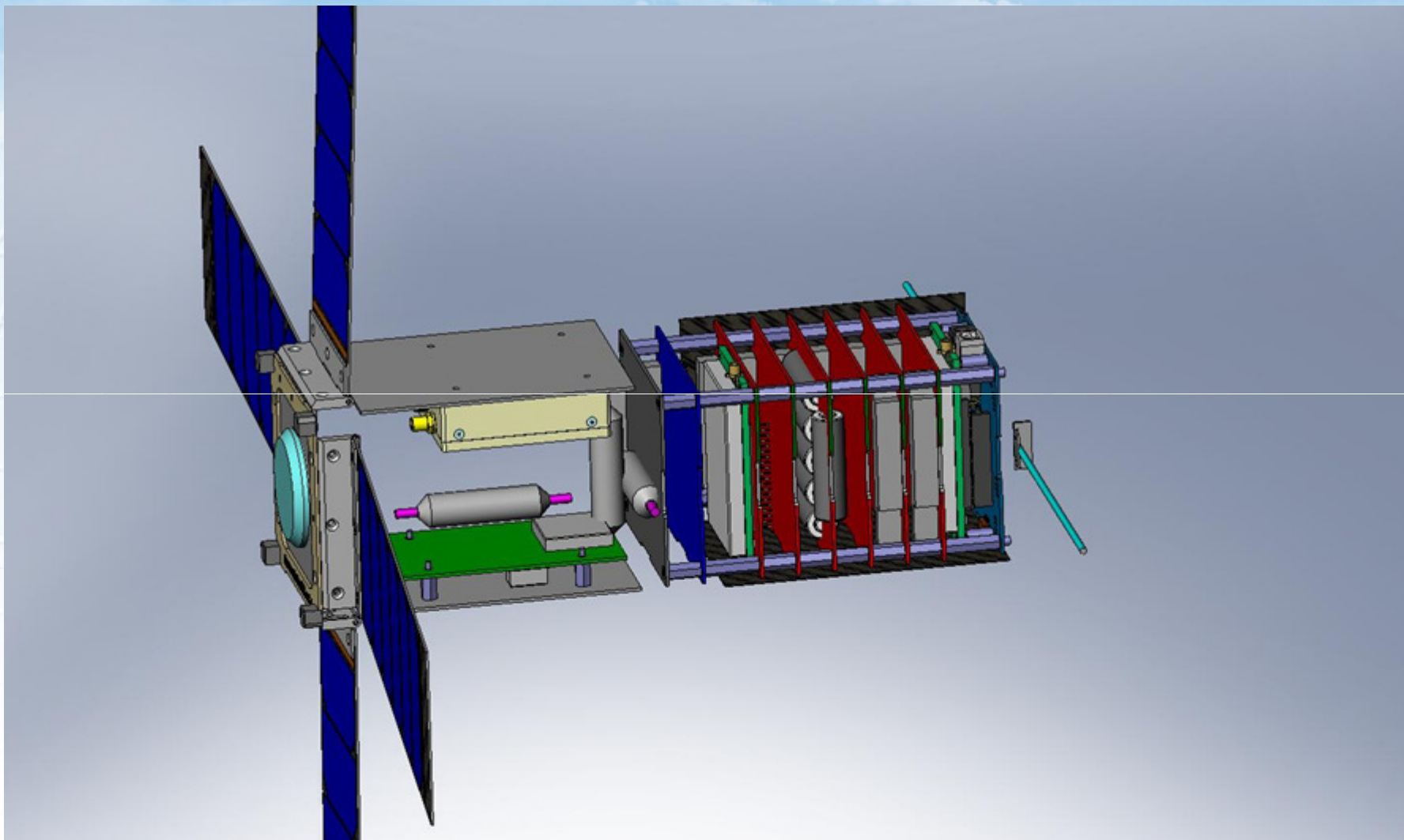


# What Will the Future look Like?

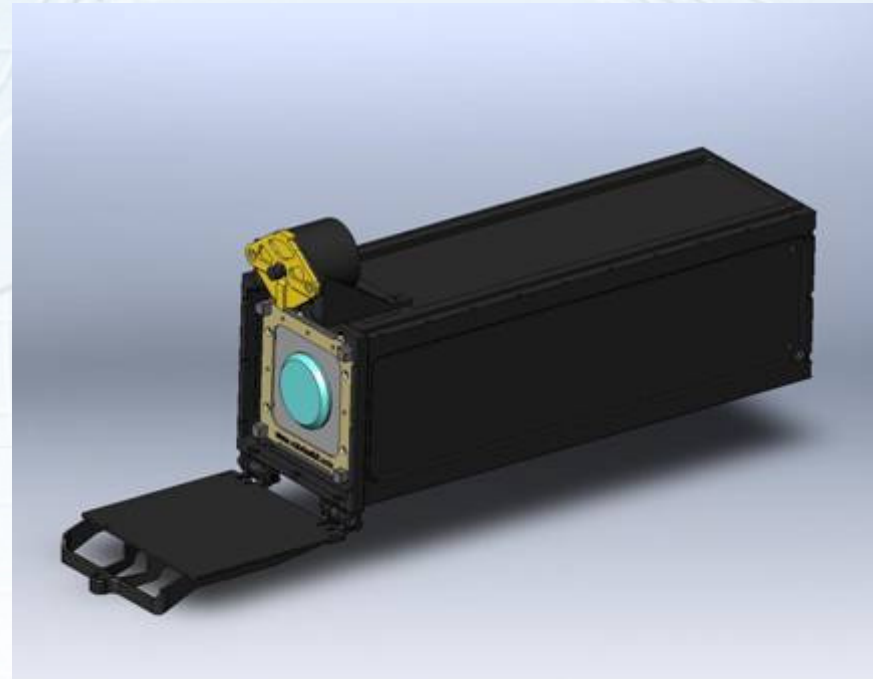
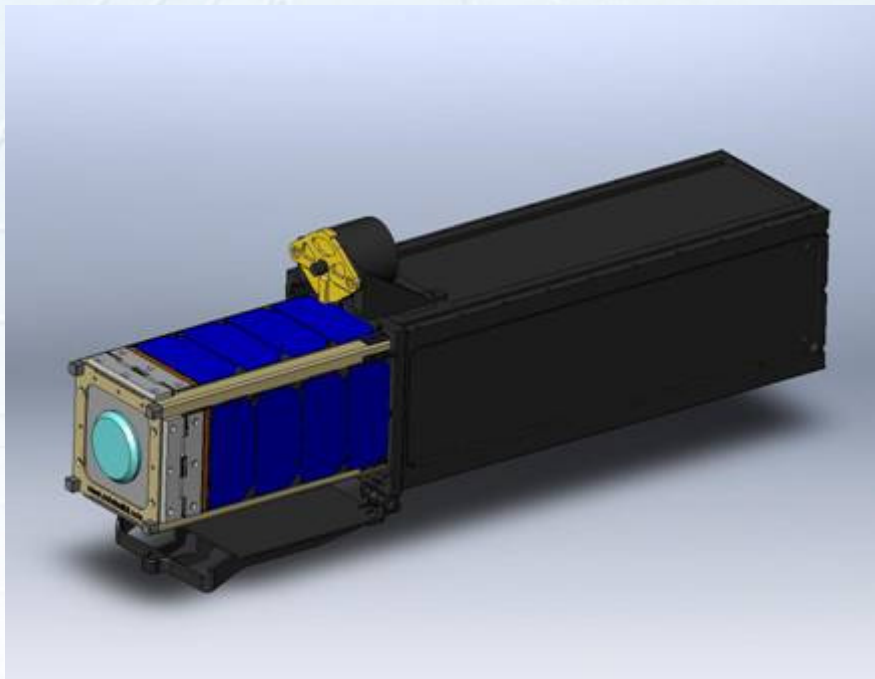
- “Prediction is very hard, especially when it's about the future”
- “I did it because I did not know it was impossible”
- “Our only limitation is your imagination”



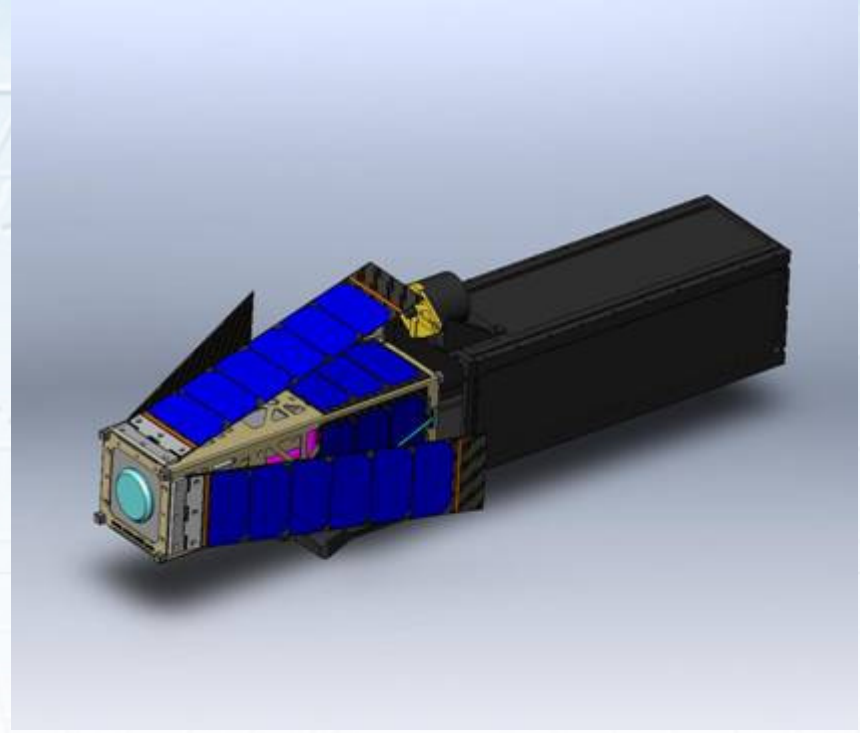
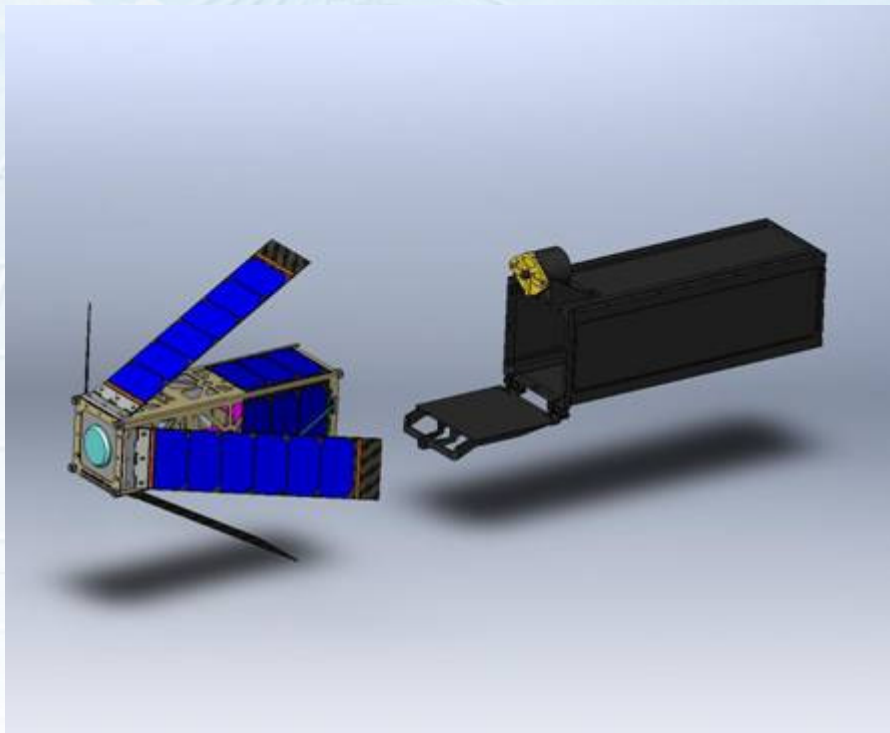
# InKlajn-1 'X-Ray' Look



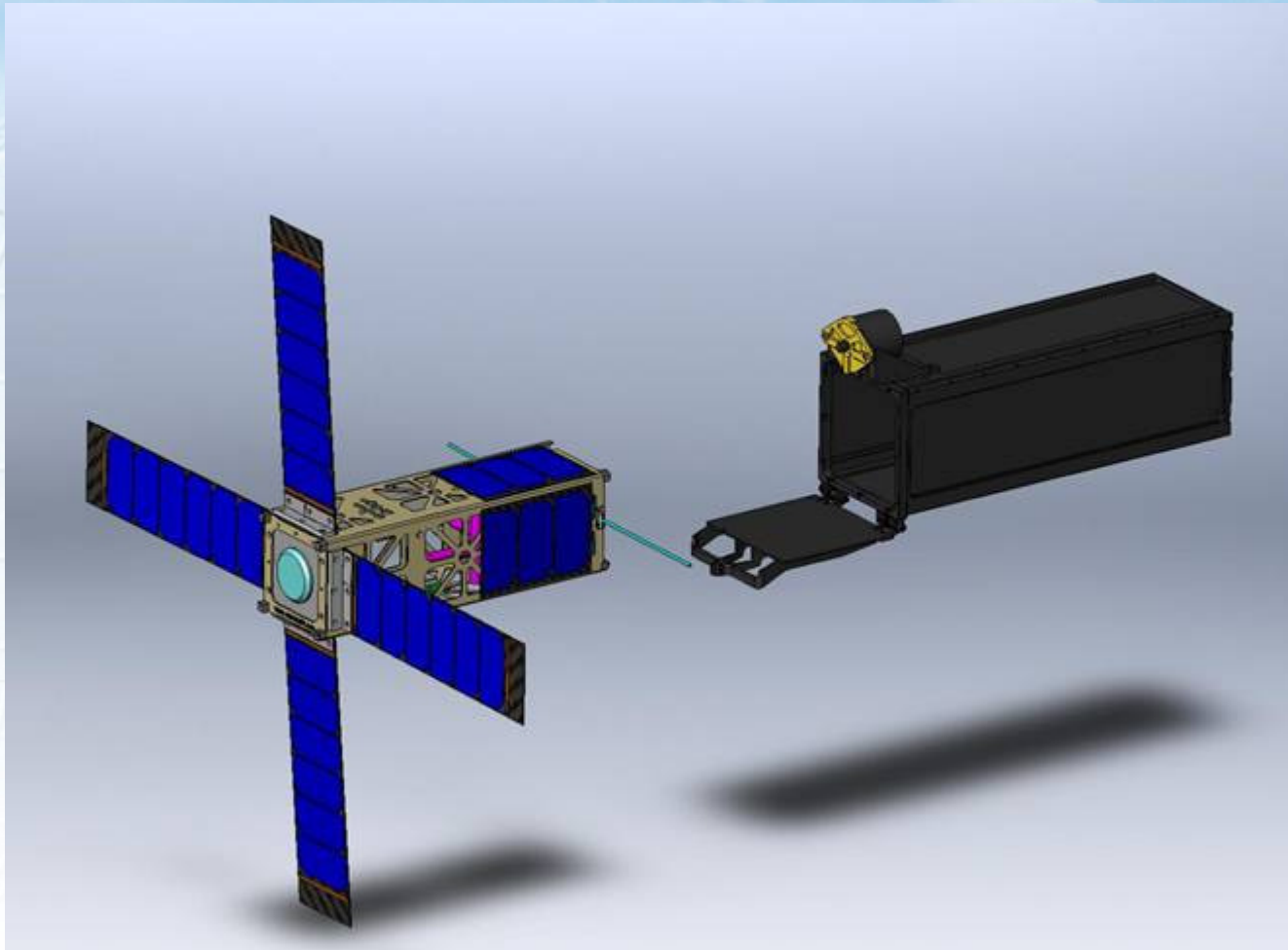
# Deployment Concept



# Deployment Concept- cont



# Deployment Concept - cont



# Motivation

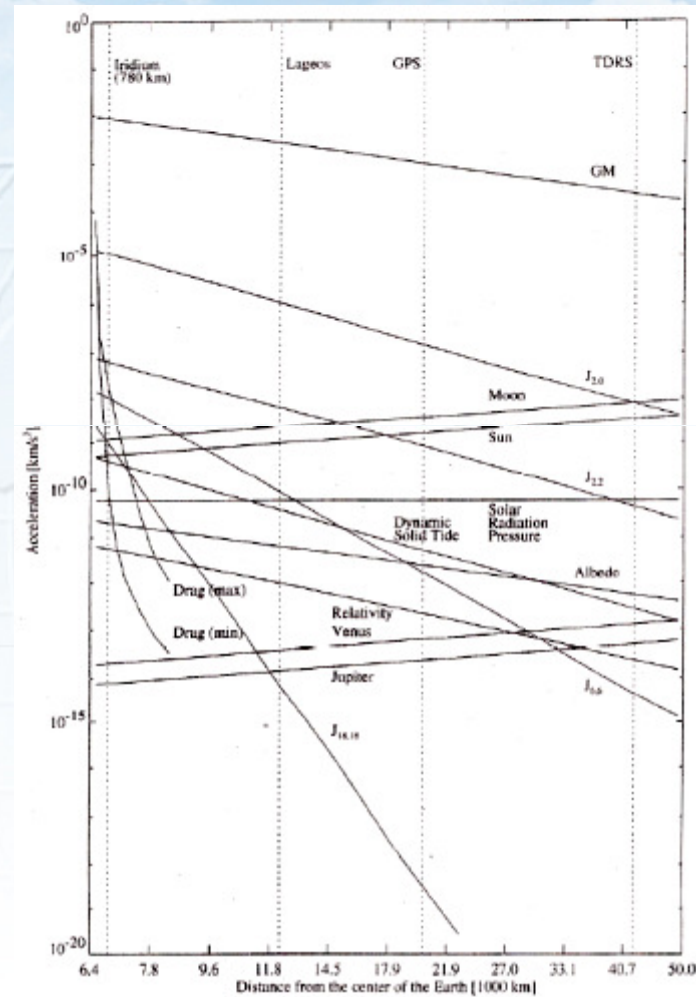
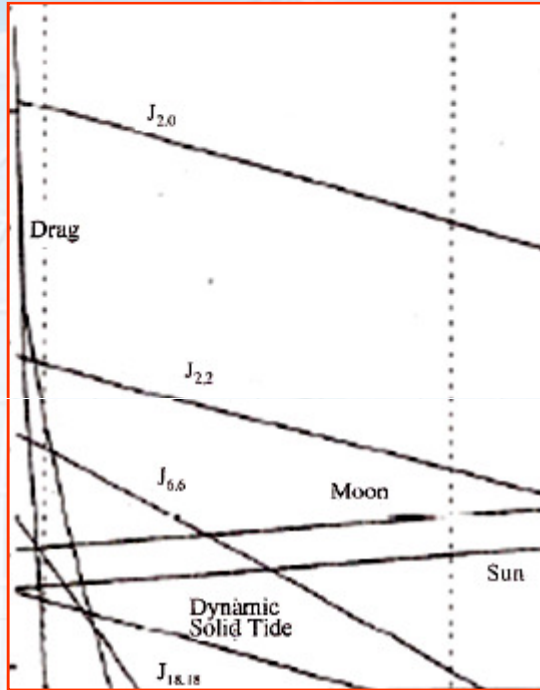
- Deploy and maintain a constellation of Nano-Satellites using a single launcher
- Multiple satellites
- LEO circular orbit
- **No propulsion system!**
- Simple attitude control system
  - Magnetometers
  - Magneto-torquers
- Low band communication with ground station
  - Single command per satellite per day

# Methodology

- Drag is dependent on velocity, effective area and density
- Changing effective area can create drag variations between satellites
- Deployment and station keeping is performed by controlling the relative effective area throughout the mission

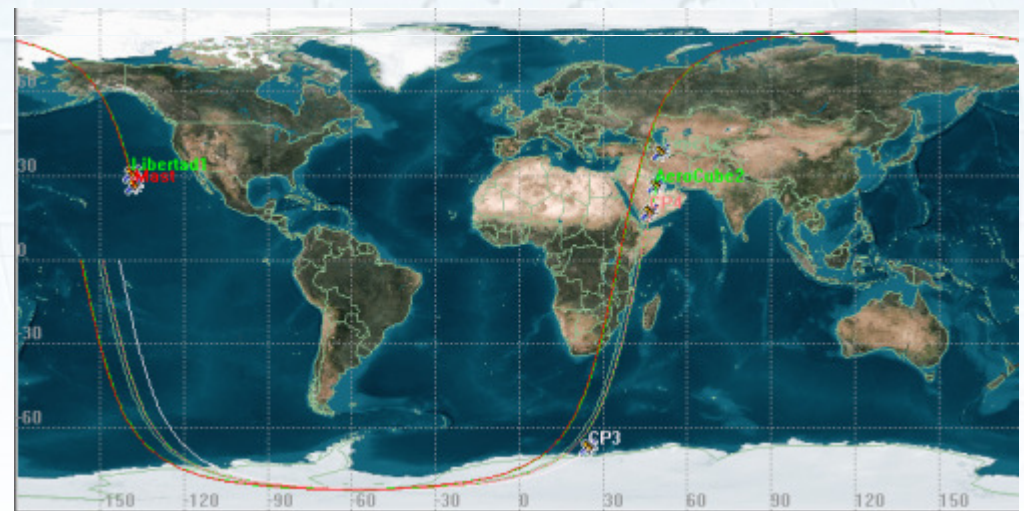
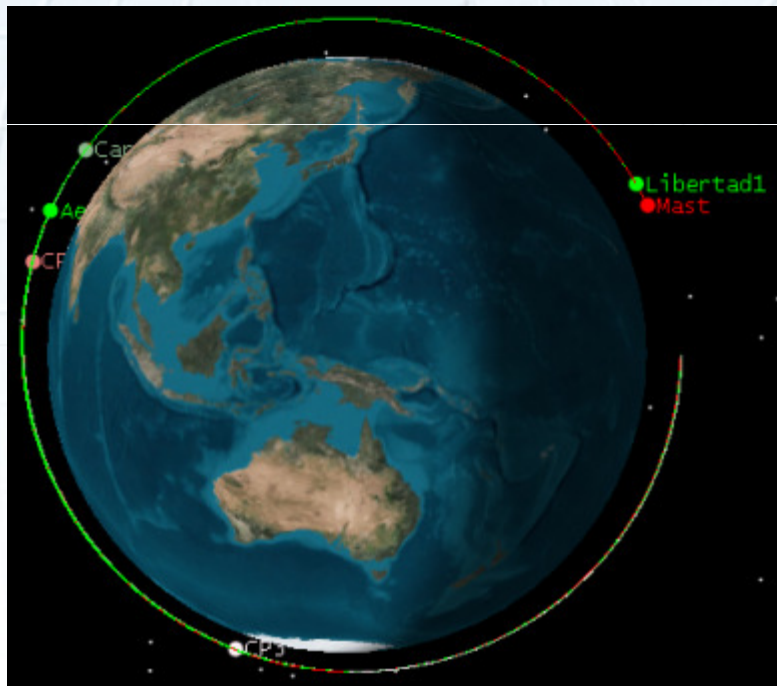
# Drag Effectiveness vs. Altitude

780km

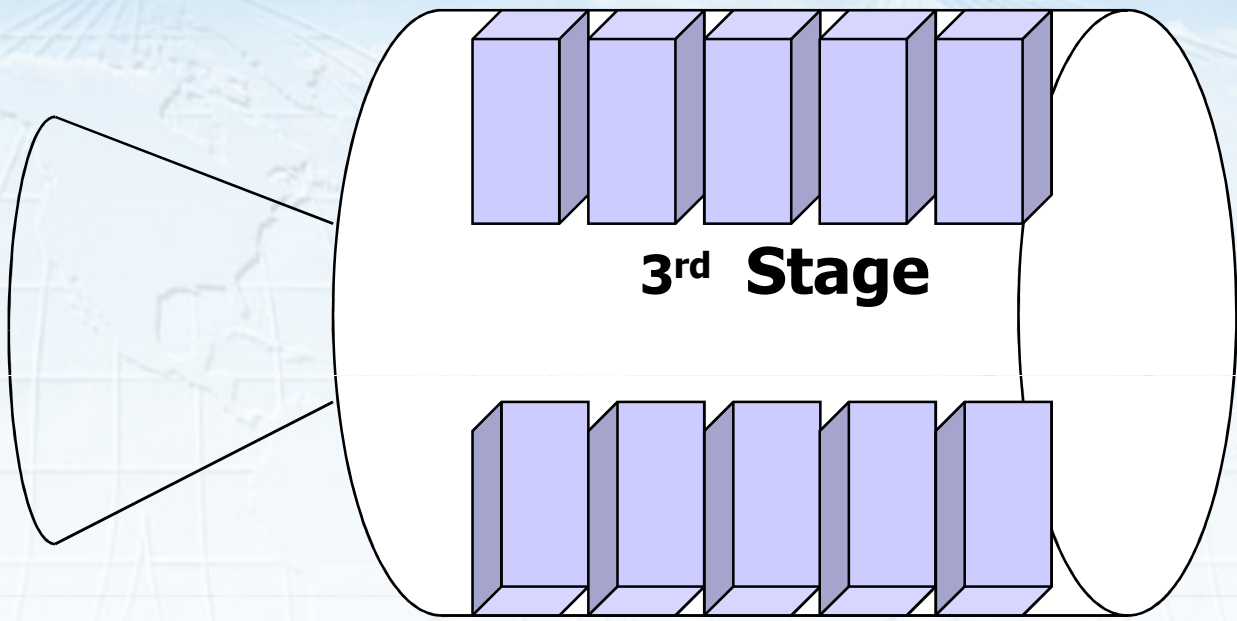


# Results from DNEPR-2 Launch at 17/4/2007

- 7 Satellites
- Altitude 700Km
- Analyze was done using TLEs from 19/3/2008

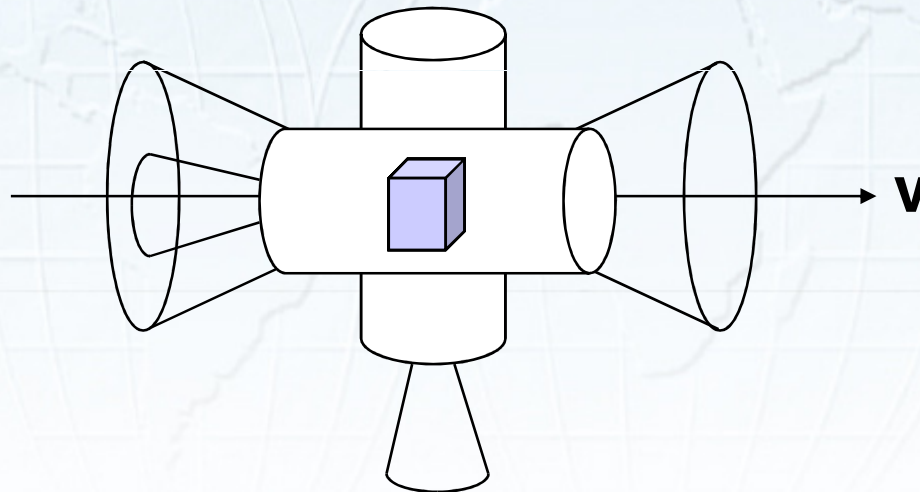


# Suggested Initial Deployment Methodology



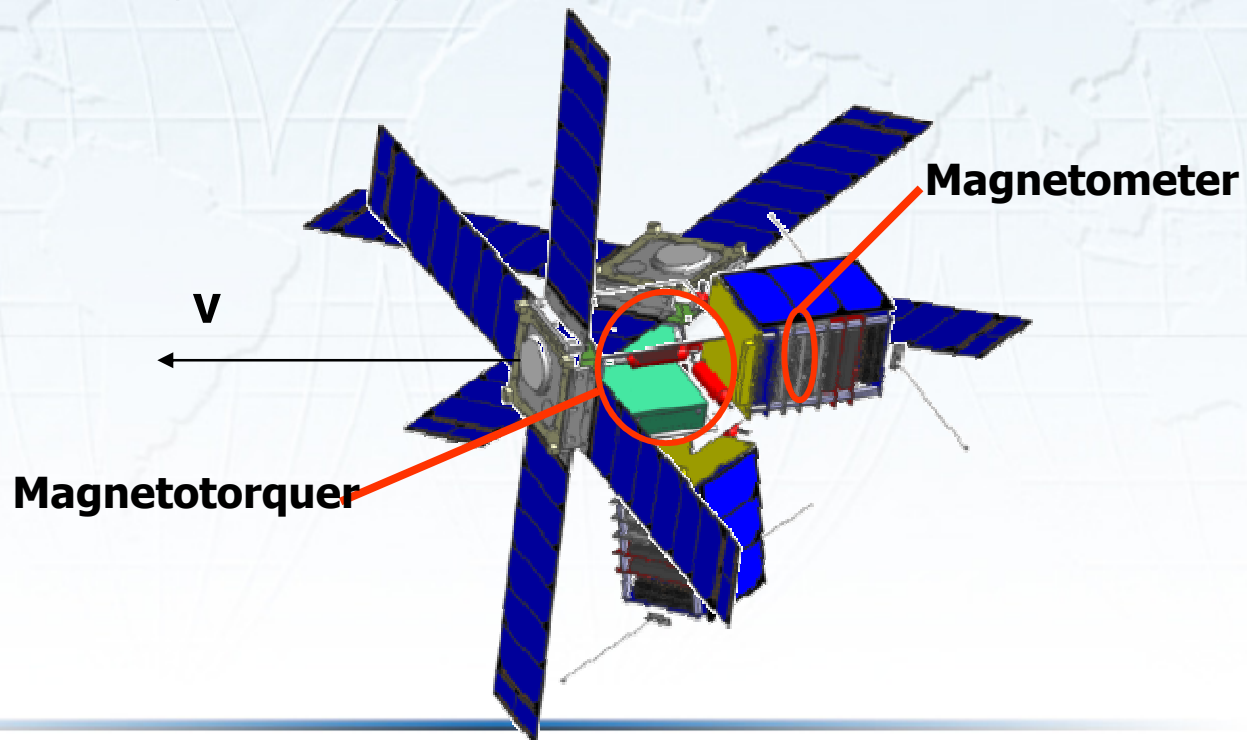
# Suggested Initial Deployment

- Deployment speed: 10 m/sec
- Deployment cone angle  $\psi$  is  $30^\circ$



# Attitude Control

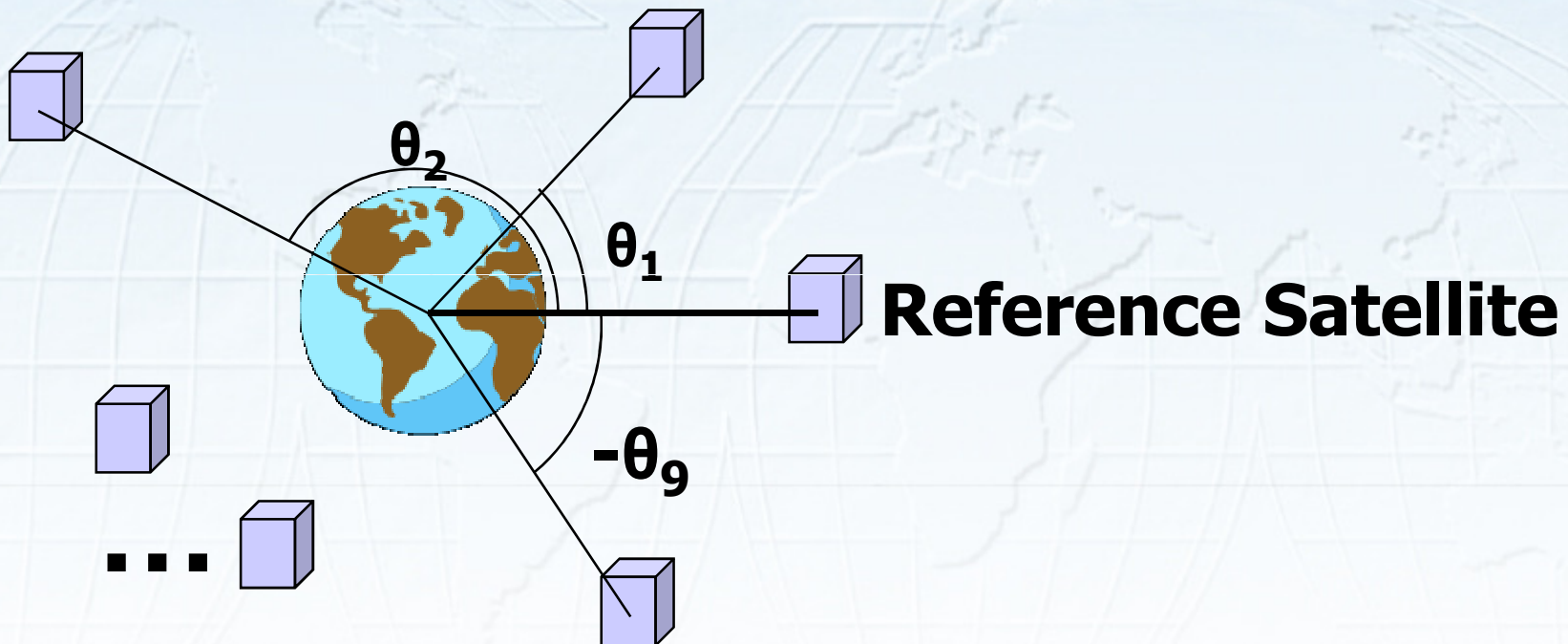
- Each day GS uploads required effective area for each nano-satellite
  - By upload required magnetic vector
- Nano-satellite use earth's magnetic field to maintain requested area (attitude)



Unclassified

# Attitude Control Principle

● Minimize  $\Delta\theta = \theta_{sat} - \theta_{slot}$  and  $\frac{d\theta}{dt}$



# Simulation

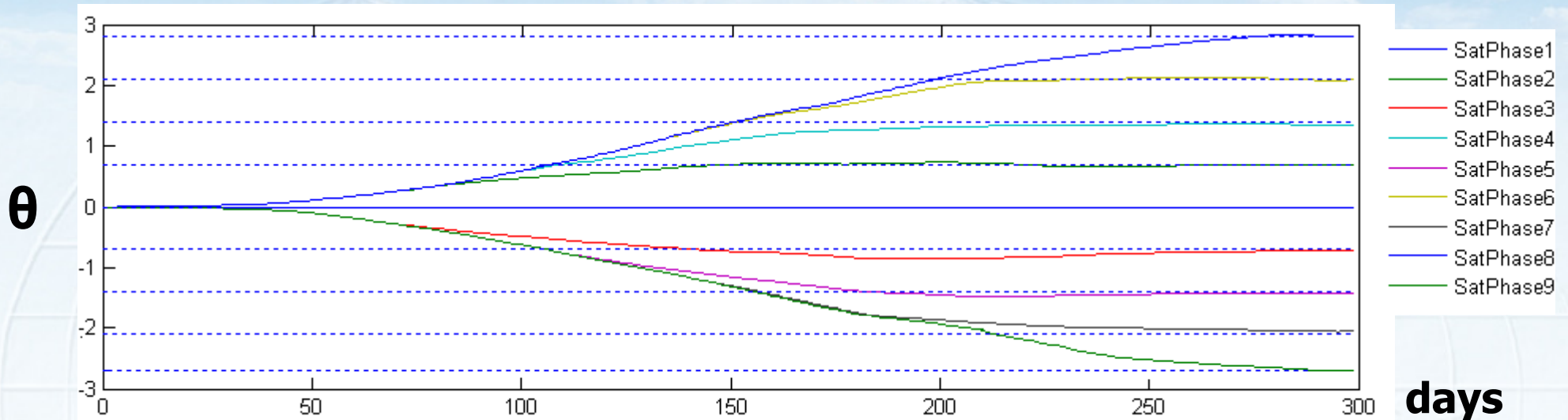
- Control Law: 
$$\Delta a_{wind} = k_1 \cdot \Delta \theta + k_2 \cdot \frac{d\theta}{dt}$$

$k_1$  and  $k_2$  are orbit and station depended and are calculated prior to the experiment

- Simulation's acceleration model includes EGM96 of degree and order 70 as the Earth gravity model, CIRA72 as the atmospheric density model, Moon and Sun gravity with low precision Solar and Lunar coordinates.

# Simulation Results (650Km)

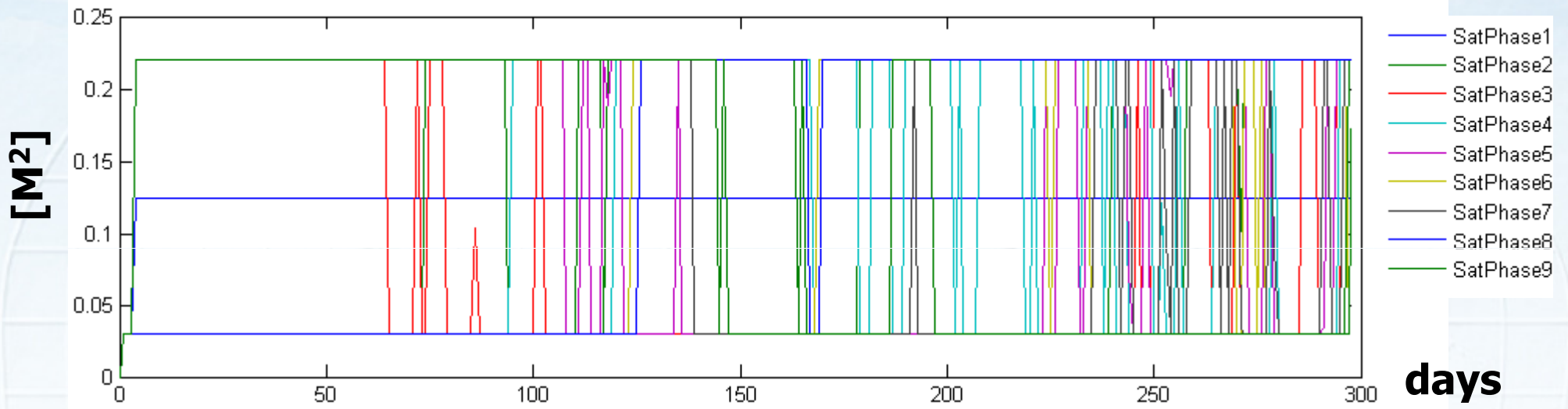
## Satellites Relative Position vs. Time



- 9 satellites
- De-orbiting of 15Km per year.
- Life expectancy of 10 Years
- Deployment is calculated for minimal solar activity

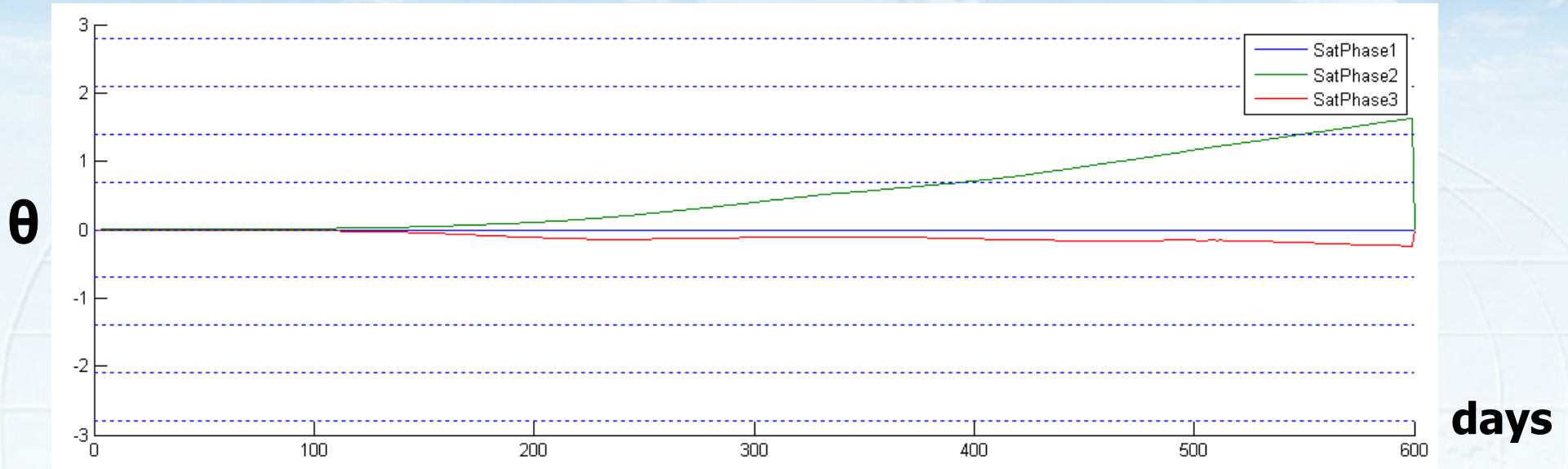
# Simulation Results (650 km)

## Effective Area vs. Time



# Simulation Results (1000Km)

## Satellites Relative Position vs. Time



- 3 satellites
- Constellation is not created even after 2 years

# Conclusions

- It is possible to deploy and maintain constellation using effective area variations
- A simulation, Using existing CubeSat design, converged in less than a year at 650 [Km]
- Algorithm success is strongly dependent upon altitude
  - High altitude – relative drag is not sufficient for timely deployment
  - Low altitude – low mission life
- Recommended altitude – ~650 Km
  - Less than a year to deploy
  - Mission life span of about 10 years
  - If deployed at a maximum solar activity – deploy higher

# Acknowledgments

- E. Yossi IAI – MBT Space
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- Dr. Y. Nissim IAI – MBT Space
- D. Rockberger IAI – MBT Space

# More Question?

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