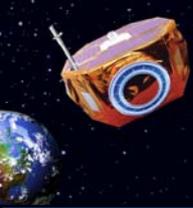


# The Interstellar Boundary Explorer (IBEX) Mission Design: A Pegasus Class Mission to a High Energy Orbit



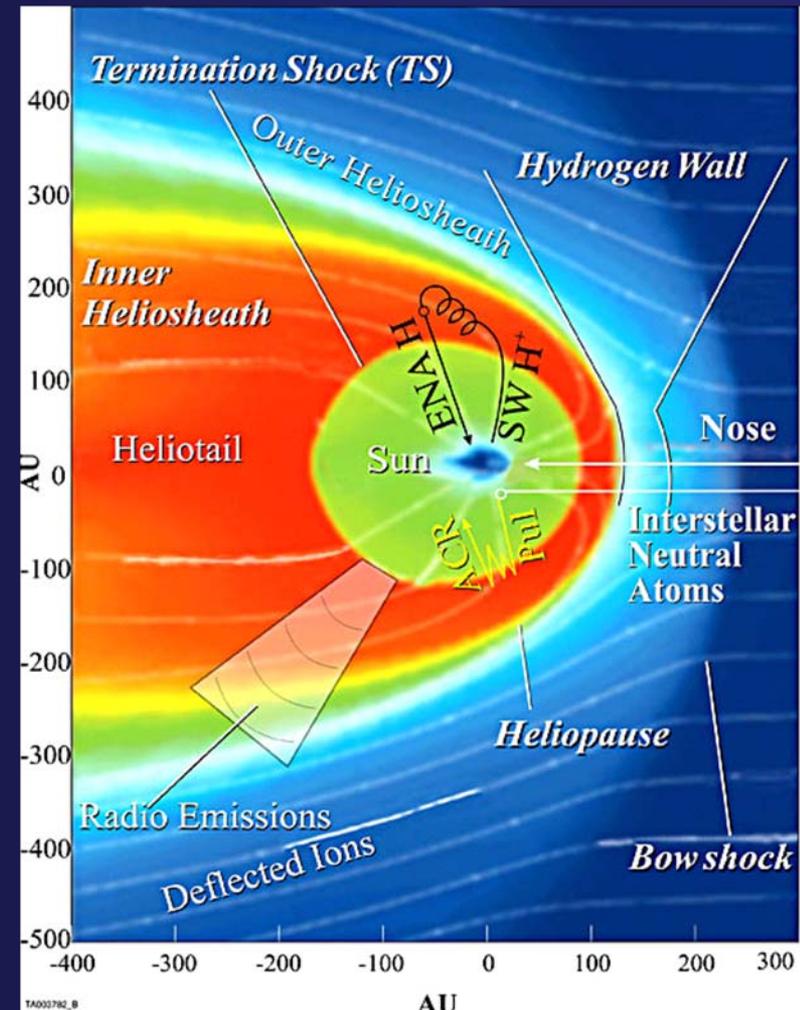
Ryan Tyler, D.J. McComas, Howard Runge, John Scherrer, Mark Tapley



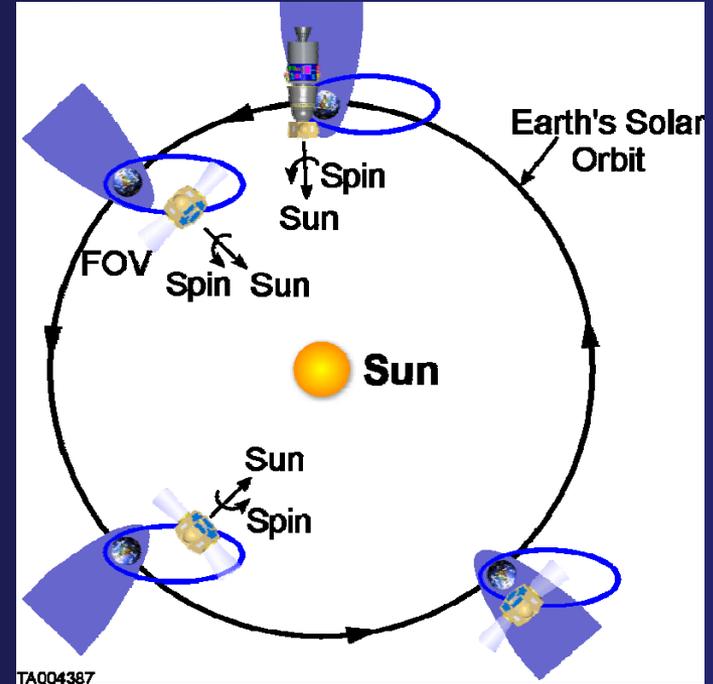
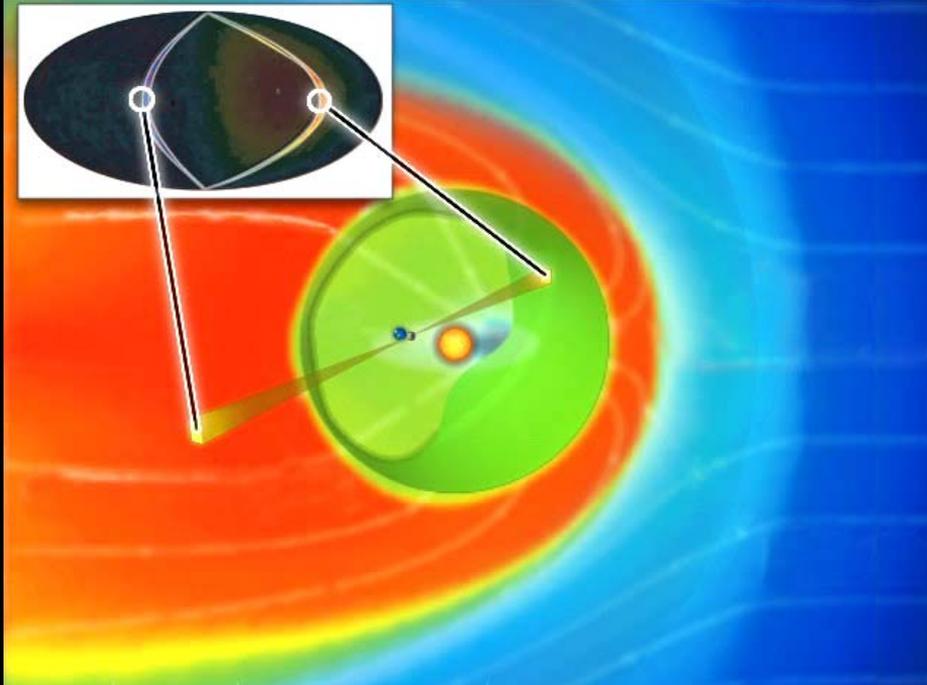
# IBEX Science Requirements



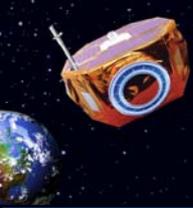
- IBEX makes full-sky measurements of the interaction between the sun's heliosphere and the interstellar medium by measuring Energetic Neutral Atoms (ENA) that come from this interaction
  - Based on statistical extrapolation, so significant sample size needed
    - The attitude must remain constant over long periods of time
  - ENAs from Earth's magnetosphere will drown out ENAs from this interaction so IBEX must maximize time above the magnetosphere
    - Apogee altitude 25-50 earth radii ( $R_E$ )
    - Goal: maximize apogee altitude to 50  $R_E$



# The IBEX Mission (1 of 2)



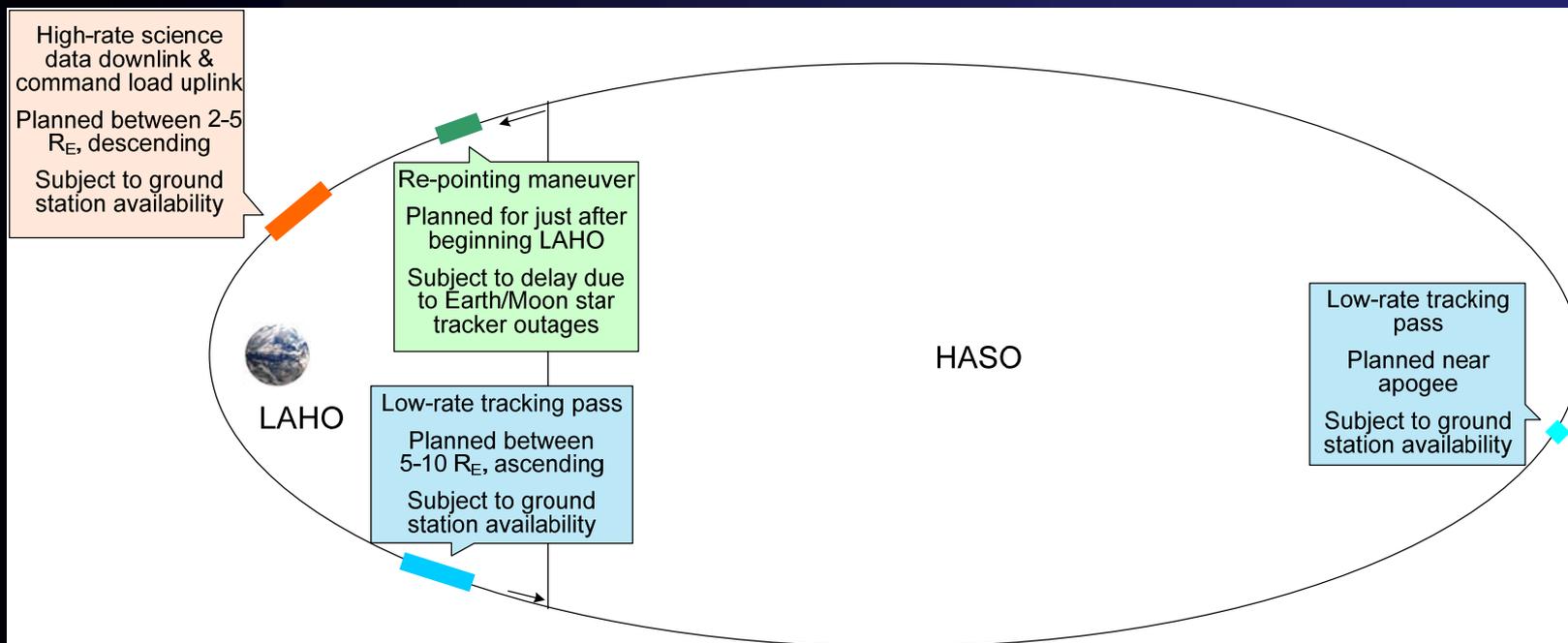
- IBEX is a sun-pointed spinner with payload sensor pointed out radially
- Target orbit altitude is 7000 x 318900 km
- Every orbit (~8 days) S/C re-points to track the sun
- A single full sky image is completed every 6 months by re-pointing to maintain sun pointing once per orbit



# The IBEX Mission (2 of 2)



- Orbit is broken into 2 pieces:
  - High Altitude Science Operations (HASO)
    - Above  $10 R_E$  (corresponds roughly to extent of Earth's magnetosphere), inertially fixed attitude, lasts  $\sim 7.5$  days
  - Low Altitude Housekeeping Operations (LAHO)
    - Below  $10 R_E$ , includes re-pointing maneuver & high-rate data downlink,  $\sim 1/2$  day



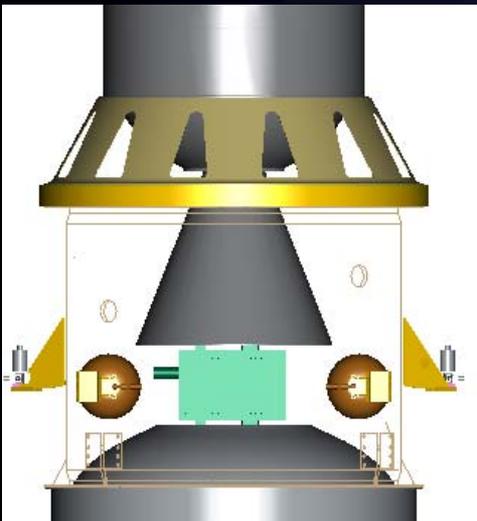
# Flight System Configuration



- Flight system includes spacecraft, solid rocket motor (SRM), and launch vehicle adapter cone
  - Following completion of the SRM burn, only the spacecraft remains

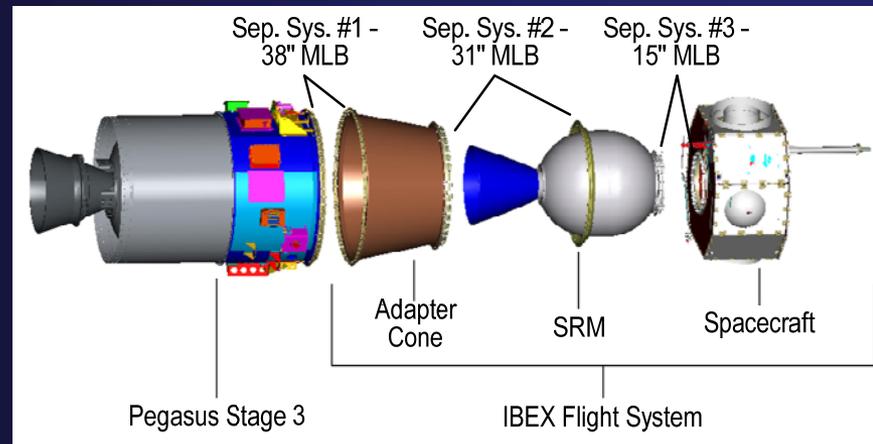
## Initial Concept

- SRM nozzle embedded in Pegasus
- Adapter cone attached to SRM during burn



## Design Innovation

- Nozzle not embedded, 3<sup>rd</sup> separation system added to separate adapter cone
  - Allows clean separation from Pegasus
  - SRM propellant savings outweighs mass of additional separation system





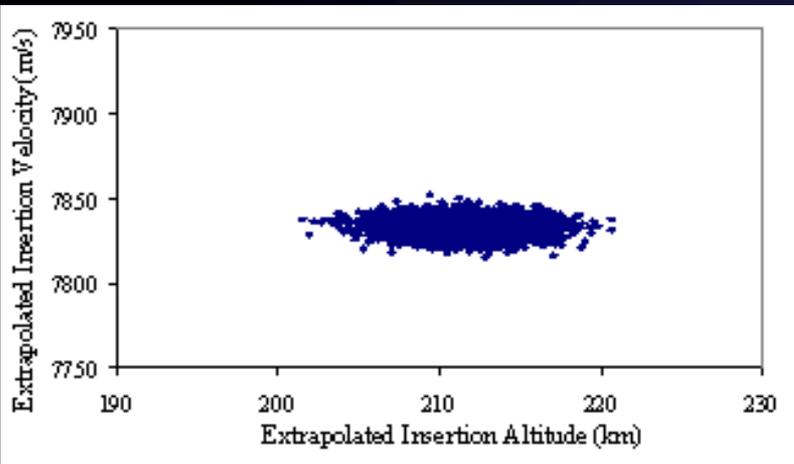
# Launch Vehicle Insertion



- Pegasus provides a low-cost launch to a 200 km target insertion orbit
  - 200 km selected as min. safe altitude; SRM fires 22 sec after Pegasus sep.
  - Pegasus points IBEX in proper burn direction and spins IBEX up to 60 rpm

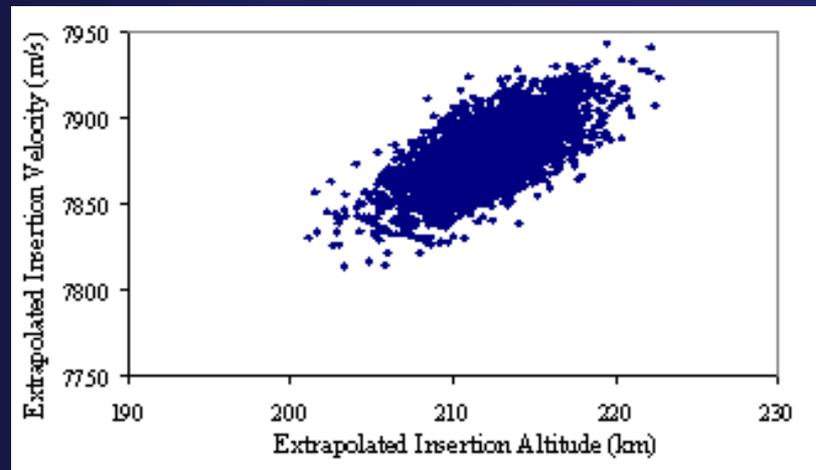
## Initial Concept

- Pegasus performs energy scrubbing to minimize insertion errors
  - SRM dispersions already fairly large, so want to minimize insertion dispersions



## Design Innovation

- No energy scrubbing, allowing Pegasus to use all of its performance to provide energy to IBEX
  - Results in significantly higher average orbit energy
  - Large insertion errors





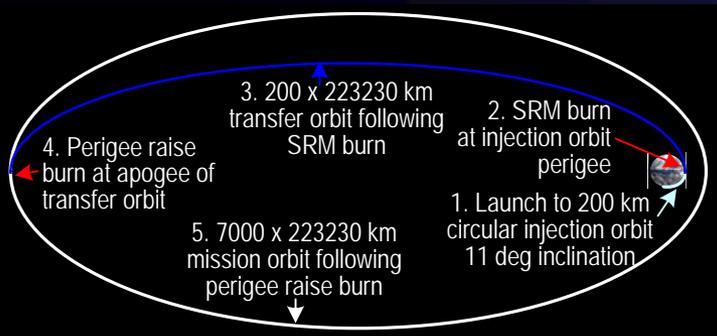
# Ascent Profile



- Perigee altitude raised to 7000 km by Hydrazine Propulsion System (HPS)
  - Perigee raising propellant goes down as apogee goes up

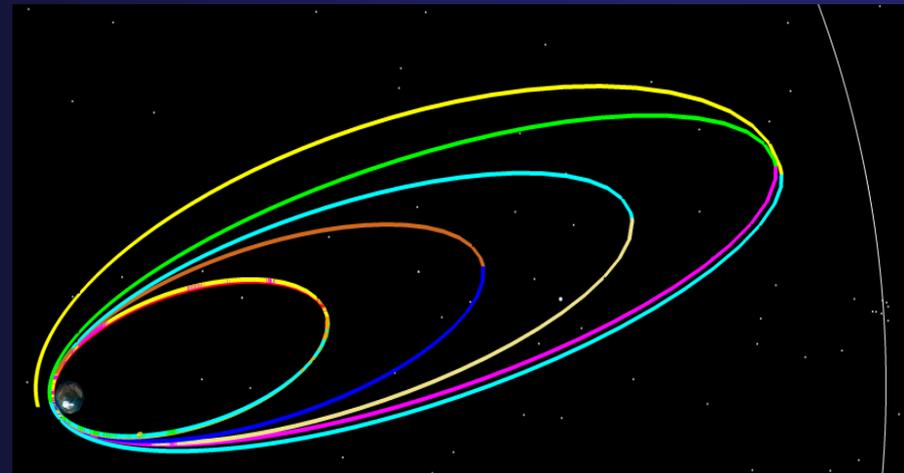
## Initial Concept

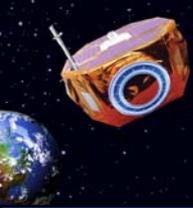
- SRM performs entire apogee raise
- HPS performs perigee raise



## Design Innovation

- HPS performs part of apogee raising in addition to perigee raise
  - SRM offloaded some, HPS prop increased by a similar amount
  - Apogee increased over several orbit raising burns during LEOps

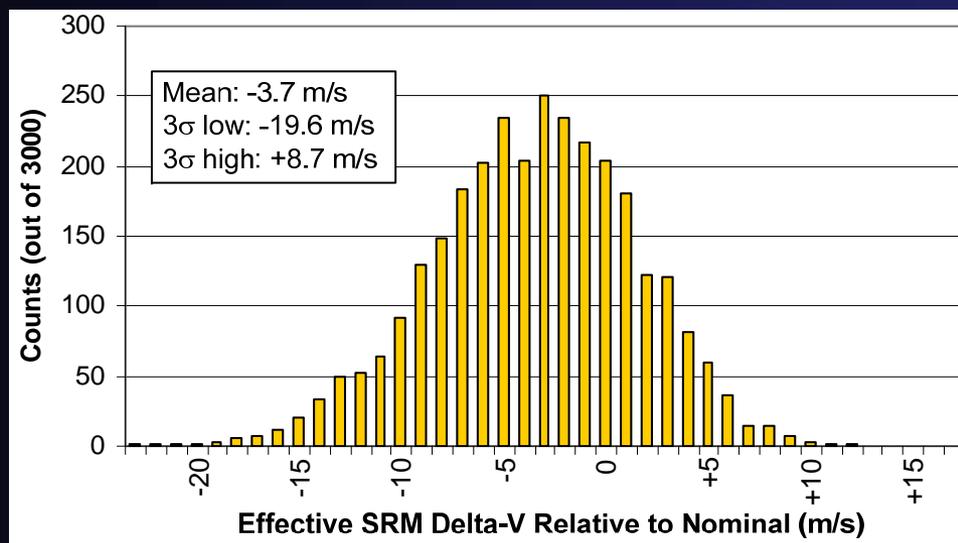




# Achieved Orbit Statistics (1 of 2)



- Uncertainty in SRM performance from several sources:
  - Uncertainty in specific impulse delivered by motor
  - Uncertainty in loaded SRM propellant mass
  - Uncertainty in pointing and nutation provided by Pegasus
  - Uncertainty in nutation growth due to dynamics of separations and sloshing liquid HPS propellant in a minor axis spinner
- End-to-end Monte Carlo dynamic analysis shows “effective” SRM performance statistics
  - The amount of delta-V that that was produced in the velocity vector





# Achieved Orbit Statistics (2 of 2)

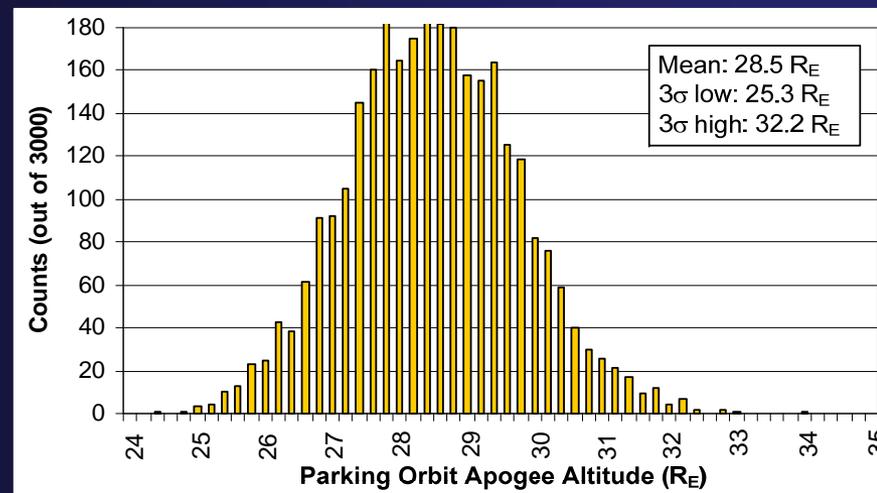


## Initial Concept

- Total uncertainty from effective SRM delta-V and Pegasus insertion velocity uncertainty +28 / -39 m/s
  - 3-sigma is 50  $R_E$
  - Nominal is 39.5  $R_E$
  - Mean is 38.0  $R_E$
  - 3-sigma low is 30.4  $R_E$

## Final Design

- Post-SRM parking orbit is lower and has larger delta-V dispersions



- However, in all 3000 Monte Carlo runs, there is enough hydrazine to then raise apogee to 50  $R_E$  in subsequent orbits

- Pegasus over-performance greatly outweighs any SRM under-performance
- Use of HPS allows taking advantage of Pegasus over-performance without risk
  - Hydrazine for apogee raising can be used or not used, as needed



# Conclusions



- IBEX is the first Pegasus-class mission to reach such a high energy orbit
  - Can be a pathfinder for future missions looking to get beyond LEO on a low budget
    - Potential for lunar missions, libration points, even Earth escape
    - Mass is the key limiting parameter – IBEX is a very simple spacecraft
- The IBEX team has addressed many issues inherent to the unique mission design, including:
  - Analysis of the dynamics of a minor axis spinner with onboard liquid propellant through the SRM burn phase
  - Dynamics of multiple spinning separation events
  - Operational strategy for dealing with significant lunar effects on the orbit as well as potential for eclipses longer than 12 hours
  - Autonomy and fault detection & correction for a spacecraft that only talks to the ground once every 4 days
  - Assessment of the radiation environment from both inner & upper belts
  - And many more!
- **IBEX is currently scheduled to launch on October 5th**