National Aeronautics and Space Administration

Analysis of Near Rectilinear Halo Orbit Insertion with a 40-kW Solar Electric Propulsion System

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Summary

- **Purpose**
- **SLS Co-Manifested Payload to NRHO**
  - Reference Transfer
  - Date Sensitivity
- **Earth Elliptical Orbit to NRHO**
  - Methodology
  - Results
- **Conclusion**

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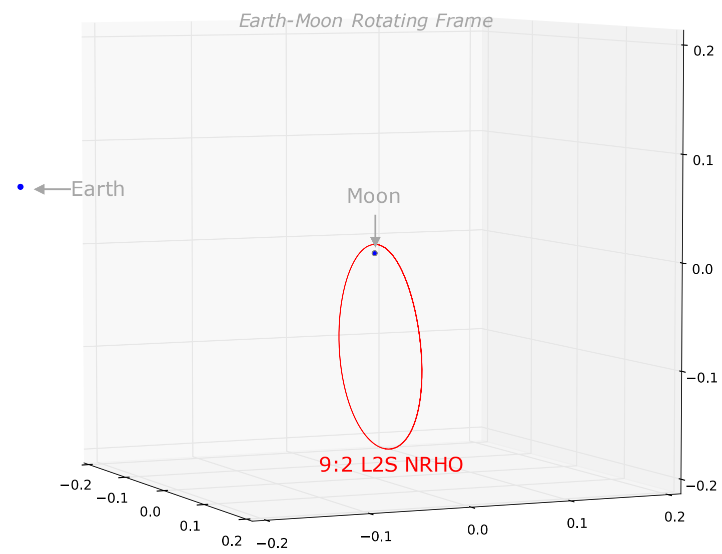
Purpose

Analysis of options to insert a 40 kW SEP spacecraft into a
9:2 Lunar Synodic Resonant L2 Southern NRHO (L2S NRHO):

1. **SLS Co-Manifested Payload**
   - TOF < 100 days
   - Constrained to Upper Stage Disposal Trajectory
   - Understand Launch Date Sensitivity

2. **Earth Elliptical Orbit to NRHO**
   - Low thrust spiral after commercial launch
   - Trade NRHO mass, TOF, propellant, solar array degradation



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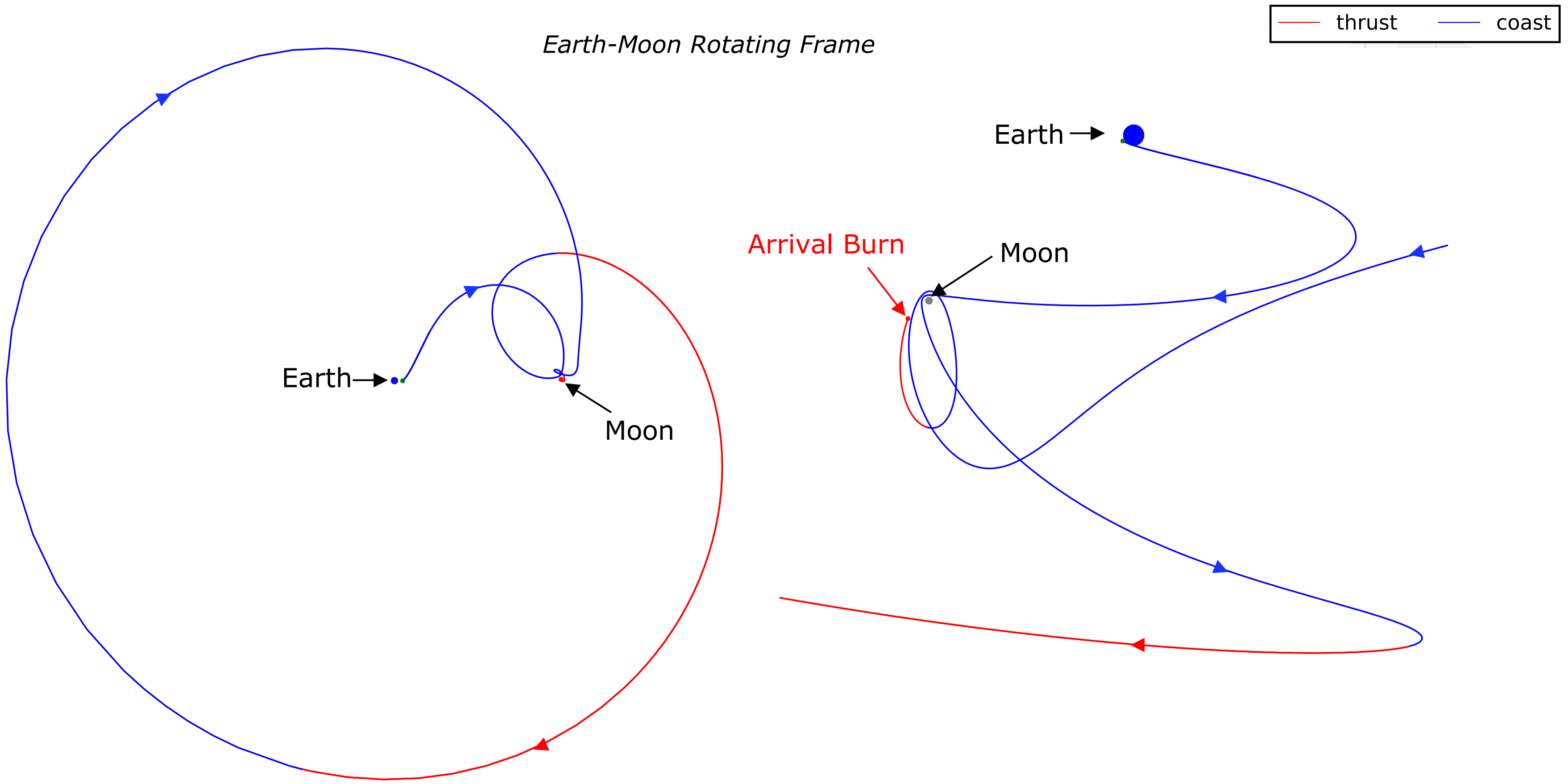
Reference Insertion



Prop. Mass (kg)	TOF (days)	ΔV (m/s)
106.9	76	370

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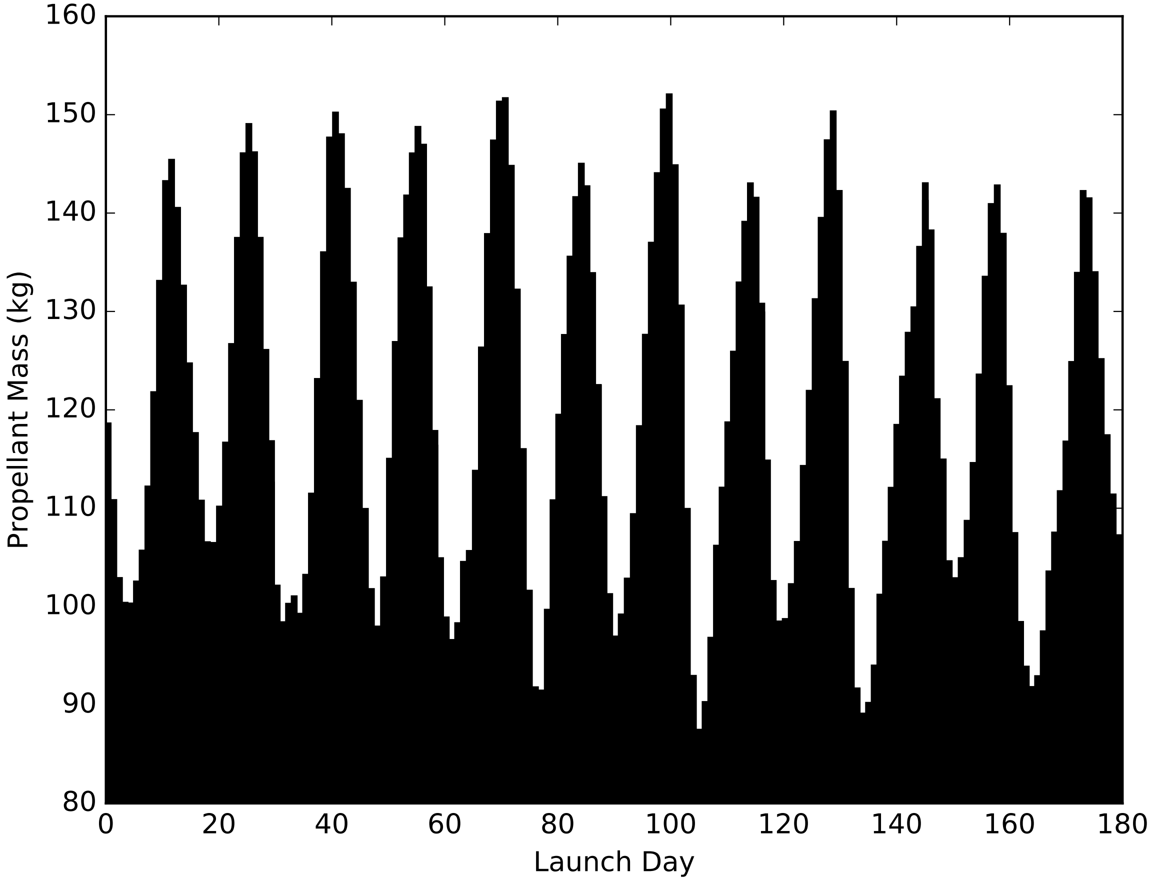
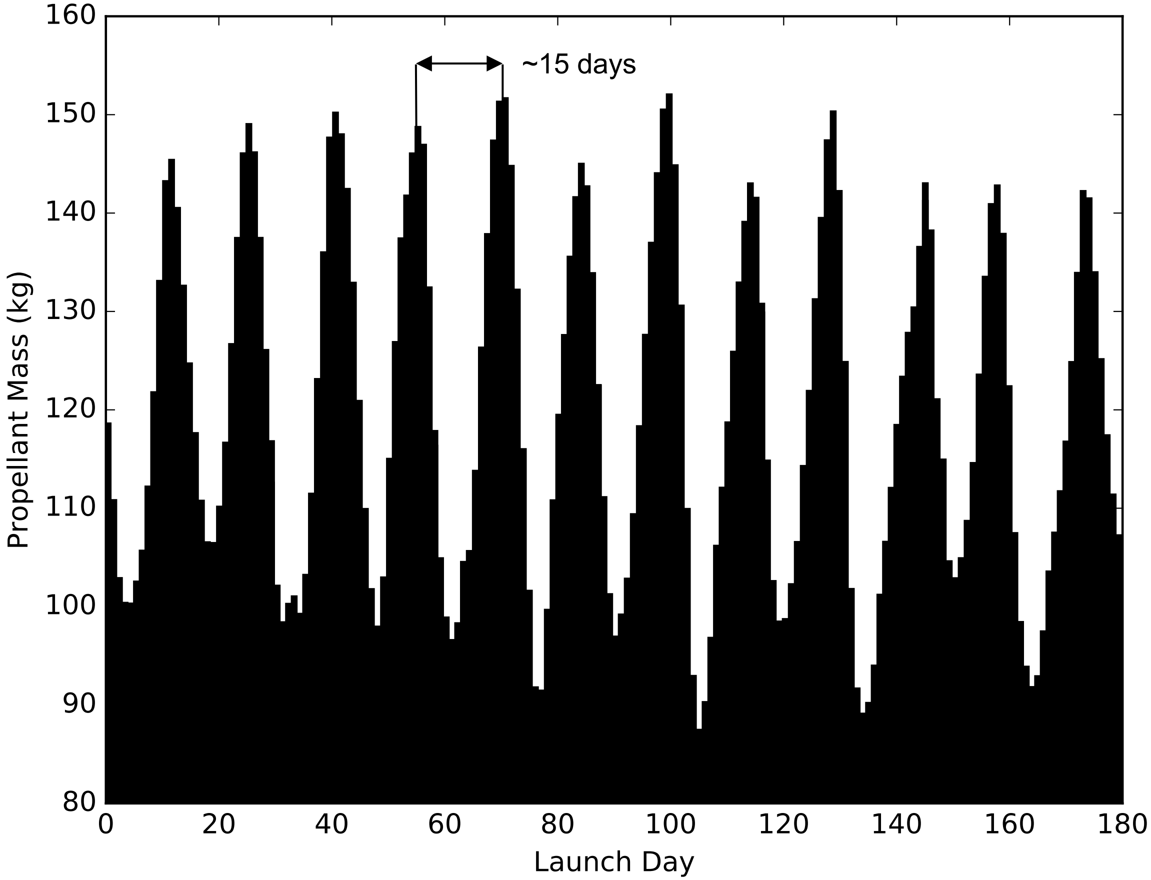
Launch Date Sensitivity

- **Launch every day for 6 months**



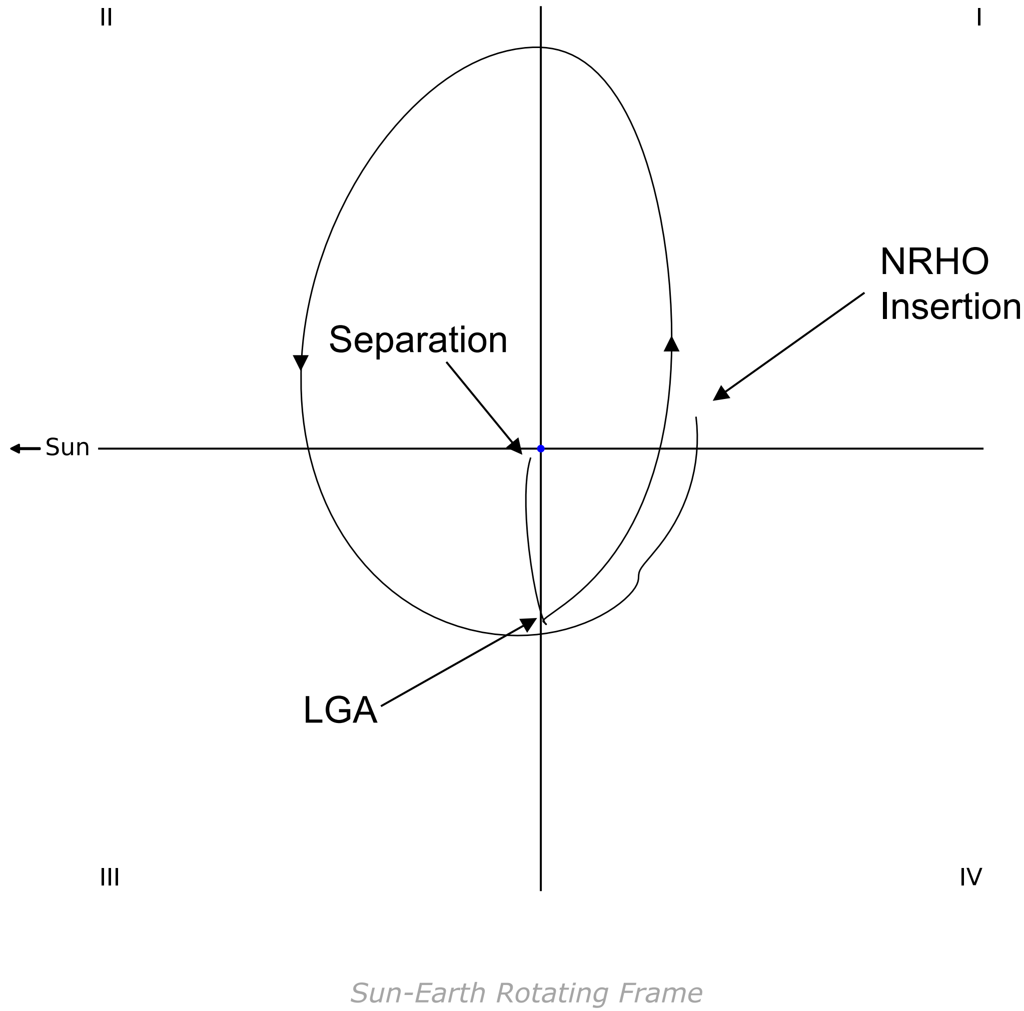
Launch Date Sensitivity

- **Launch every day for 6 months**
- **Peaks occur every 15 days, but why?**



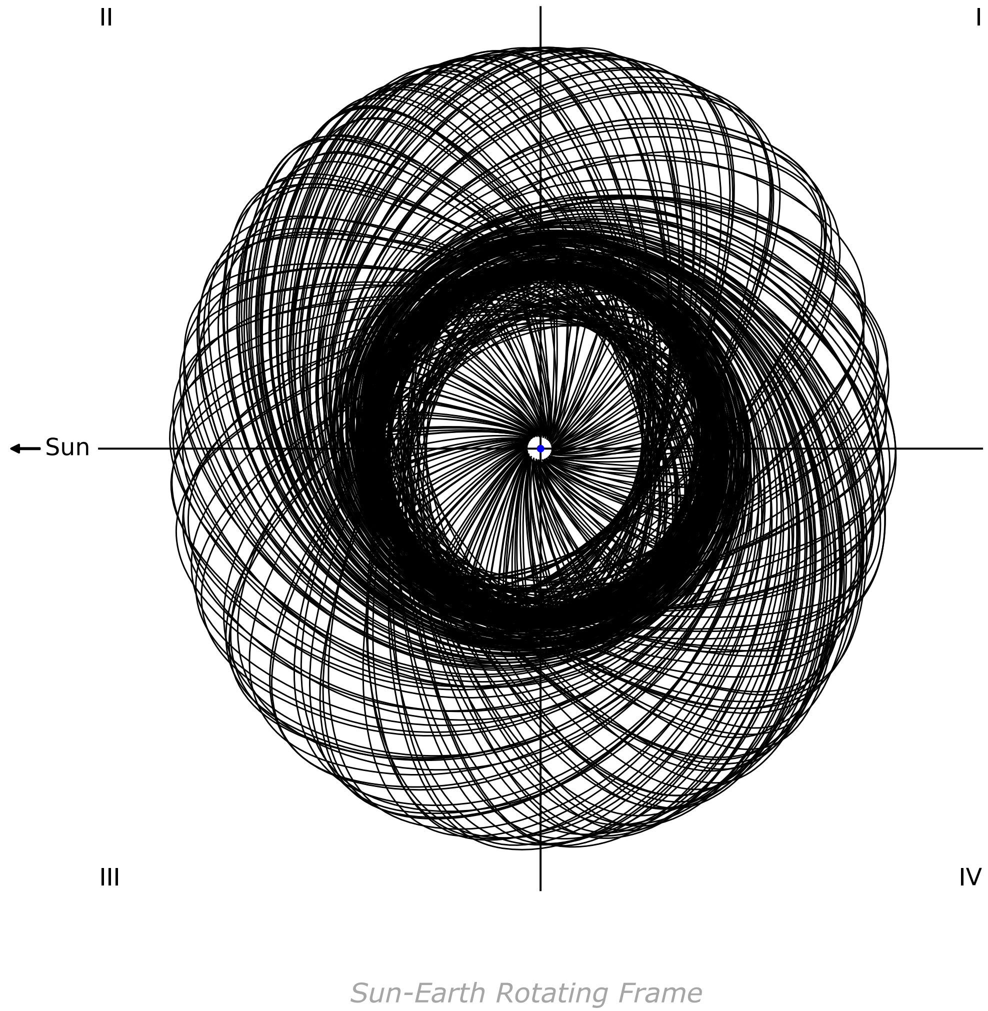
Is There a Pattern?

Reference Trajectory



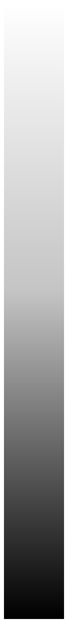
Is There a Pattern?

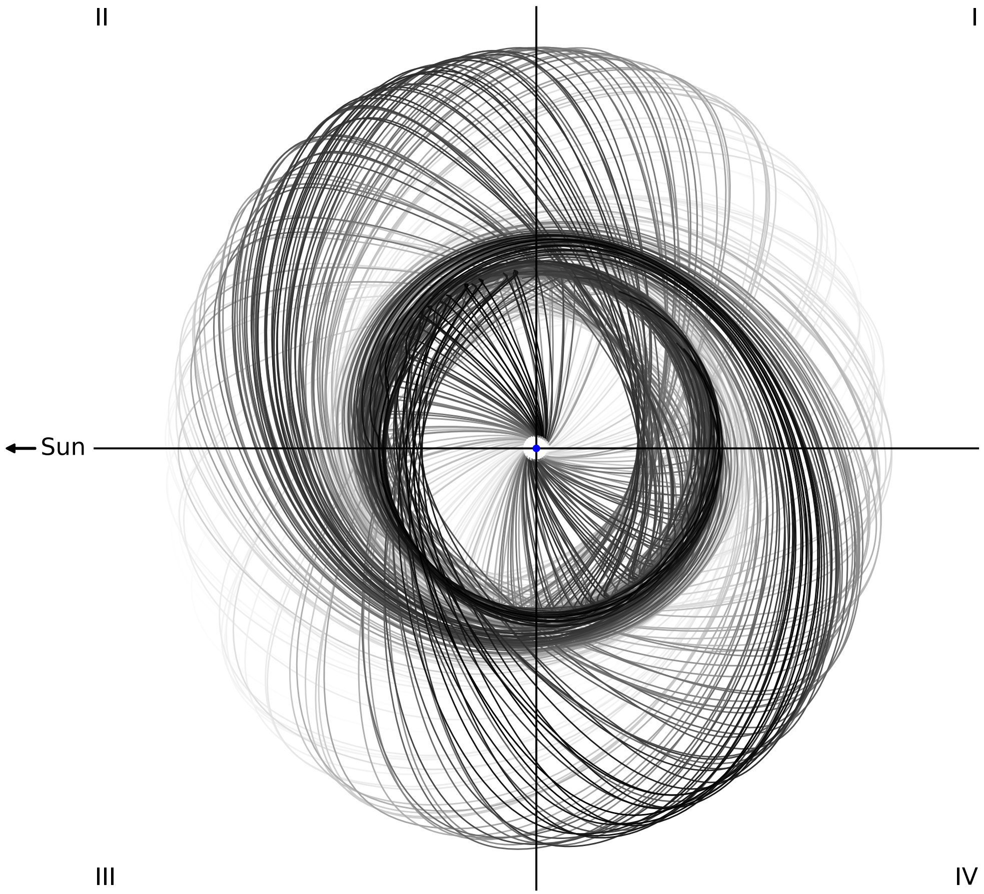
6-Months of Solutions



Is There a Pattern?

Color solutions by propellant mass:

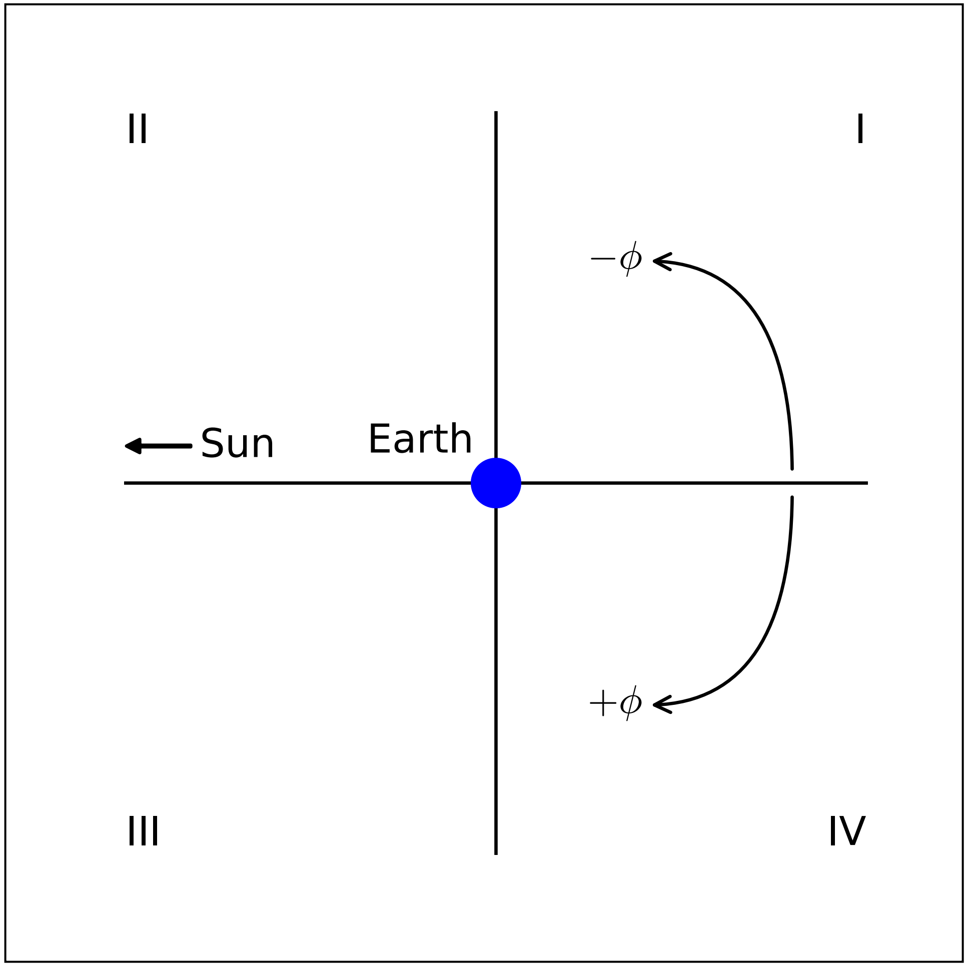




Sun-Earth Rotating Frame

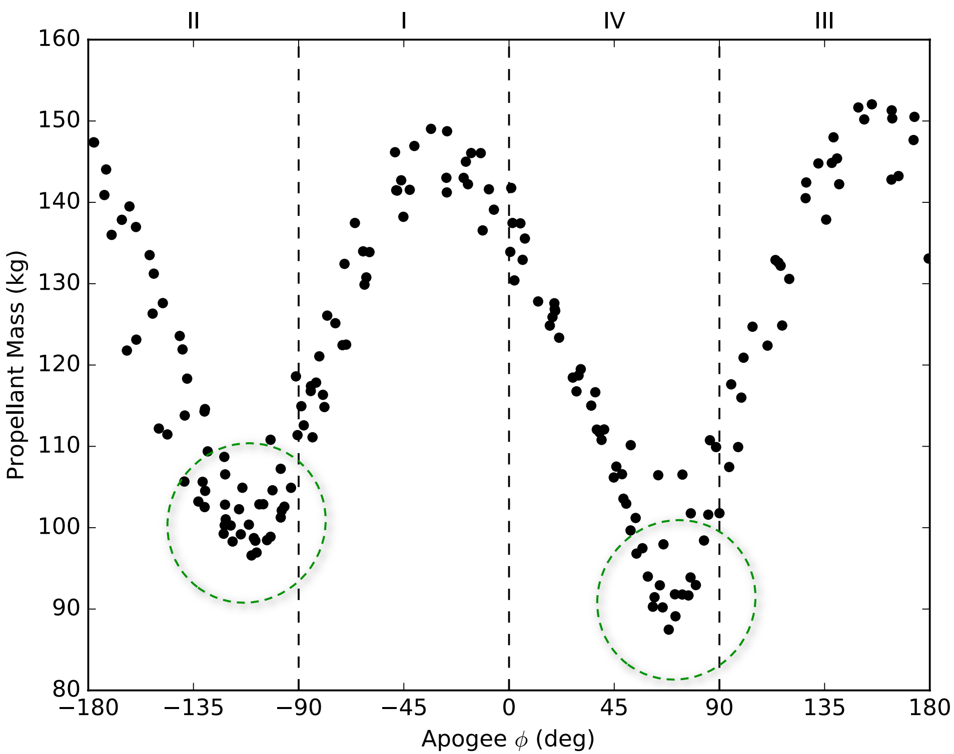
Solar Quadrants and Solar Angle

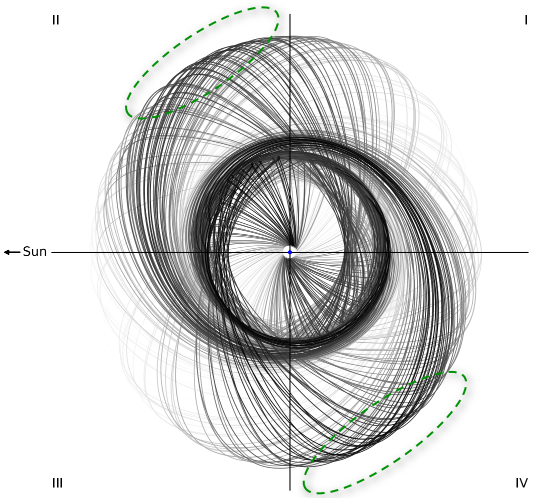
- **Divide Sun-Earth rotating frame into quadrants (I – IV)**
- **Solar Angle defined by ϕ**
- **Moon traverses through all four quadrants in 1 synodic period (29.5 days)**



Propellant vs. Solar Angle (ϕ) at Apogee

- **Plot ϕ at apogee for each trajectory**





Sun-Earth Rotating Frame

- **Why? Solar gravity raises perigee in quadrants II and IV and lowers perigee in I and III**

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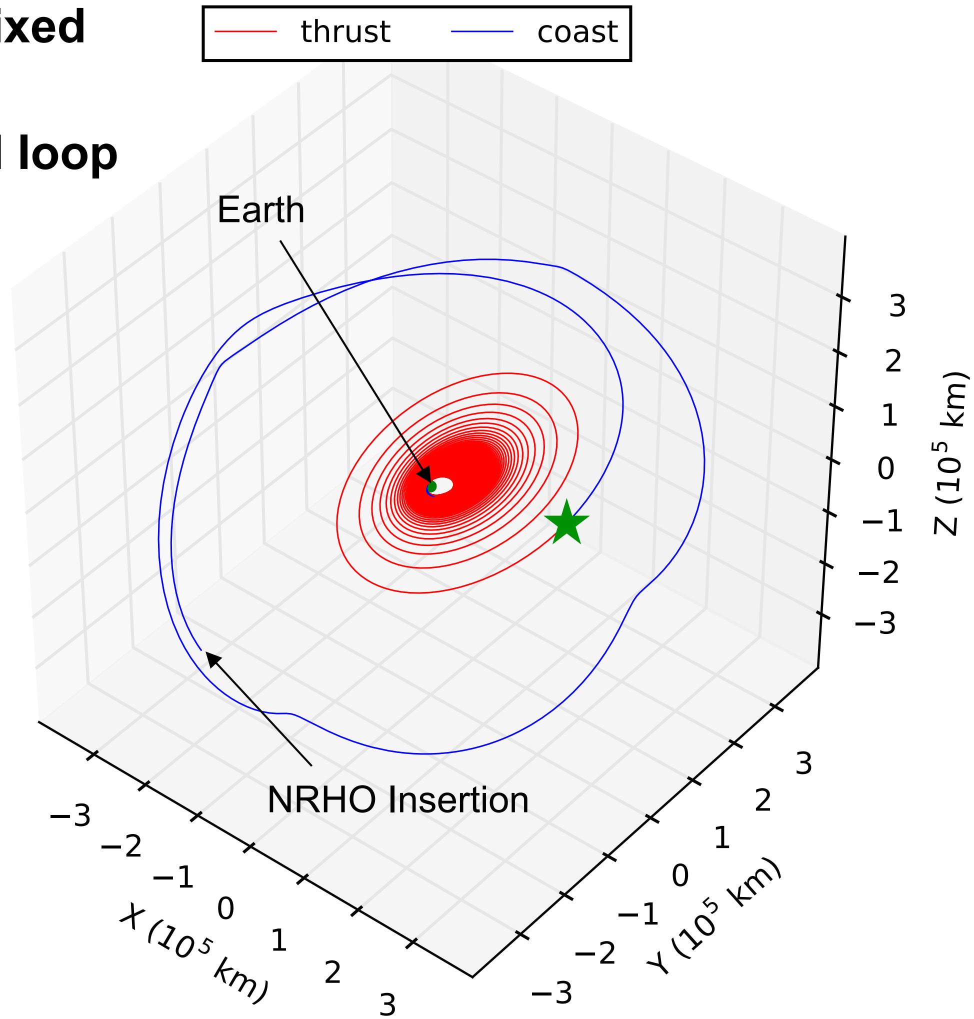
Earth Elliptical Orbit to NRHO

1. **Start with a given mass at a fixed intermediate state (★)**
2. **Use OTIS with optimal closed loop targeting to optimize spiral in reverse (min ΔV)**
3. **Generate data over range of masses and apogee altitudes (perigee altitude = 400 km)**
4. **Relevant Quantities:**
   - TOF
   - Propellant Mass
   - ΔV
   - BOL Power



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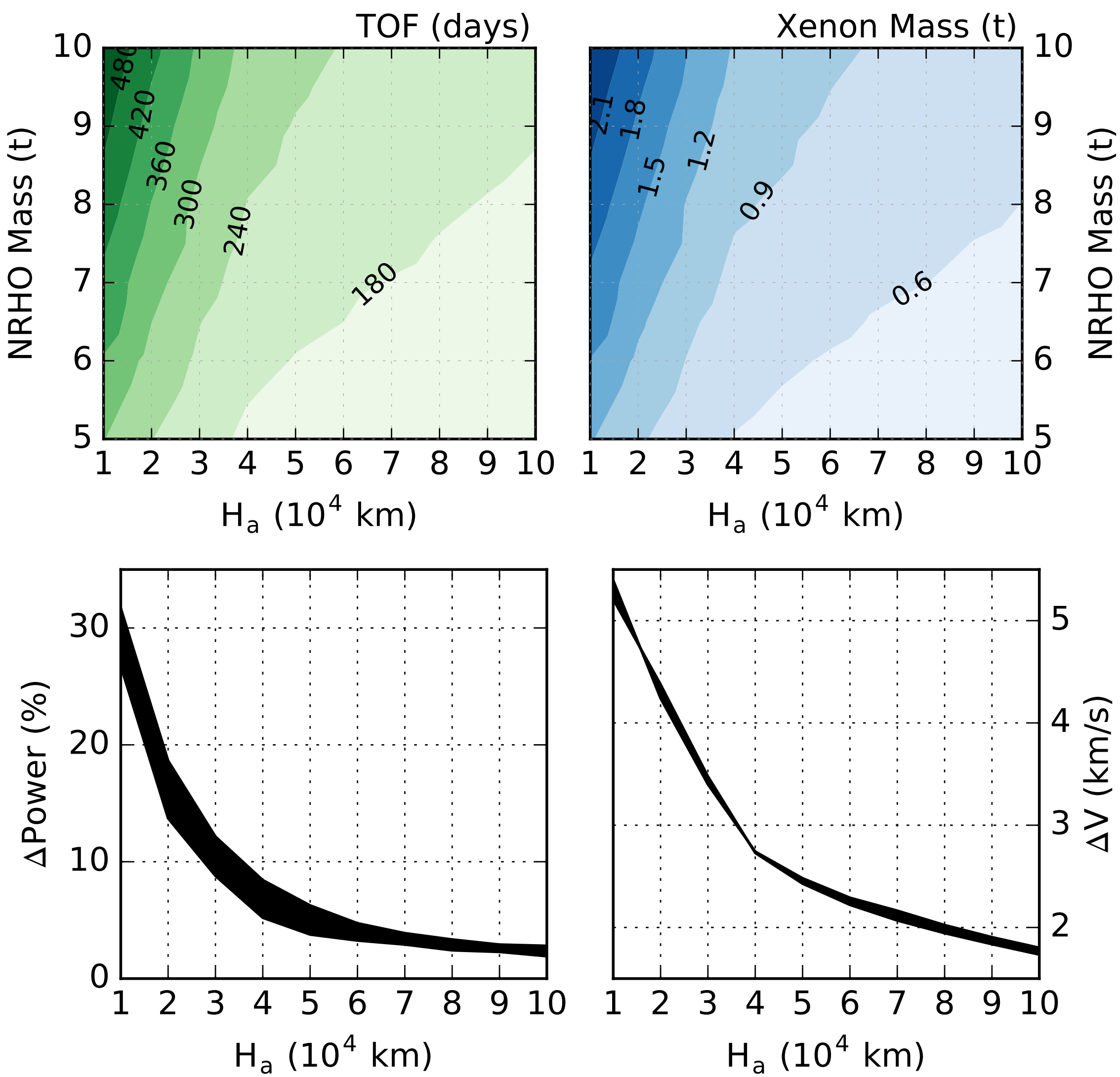
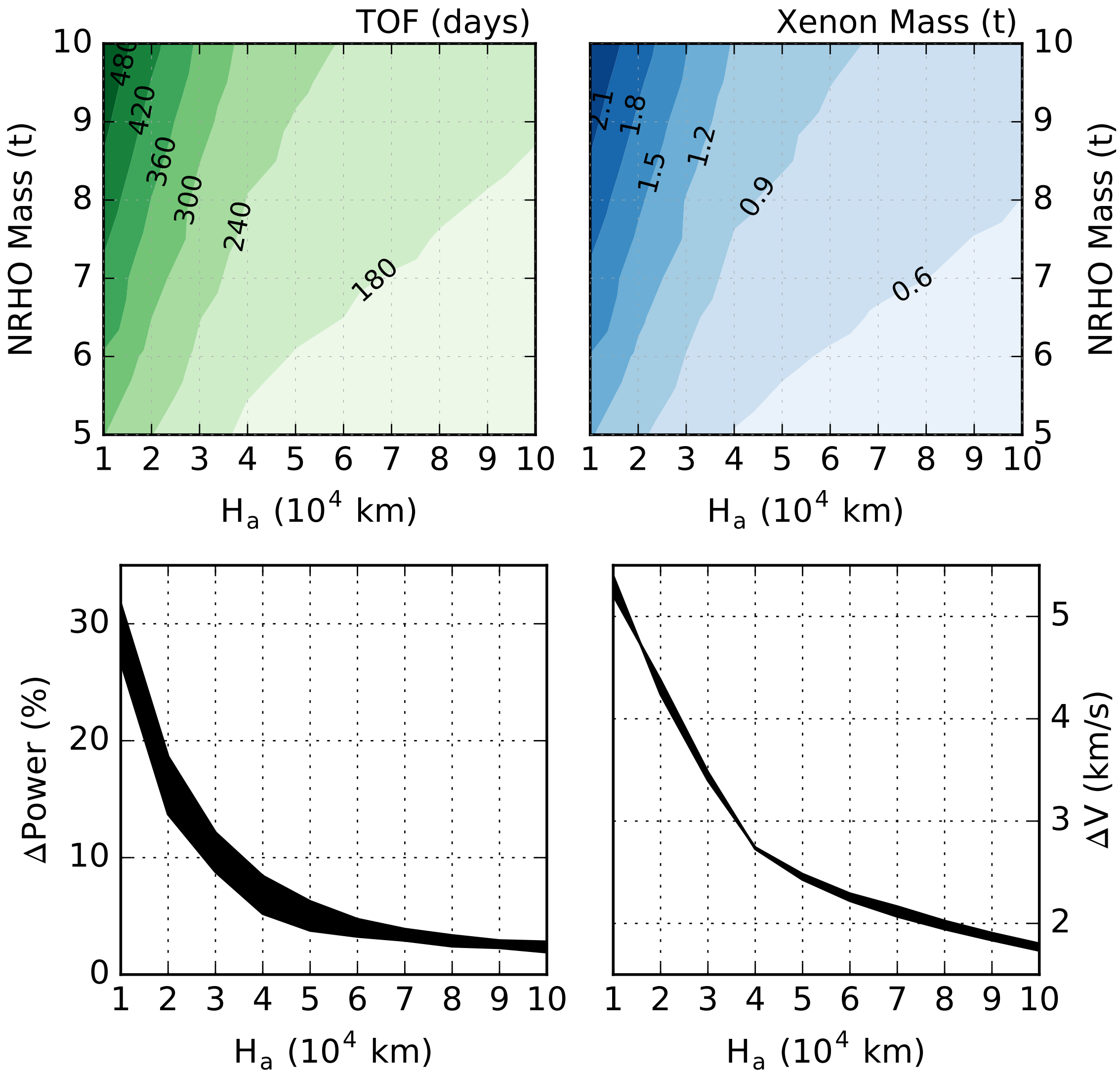
Launch Vehicle Independent Results



Launch Vehicle Independent Results

Example Mission:

6,500 kg to NRHO
in 180 days



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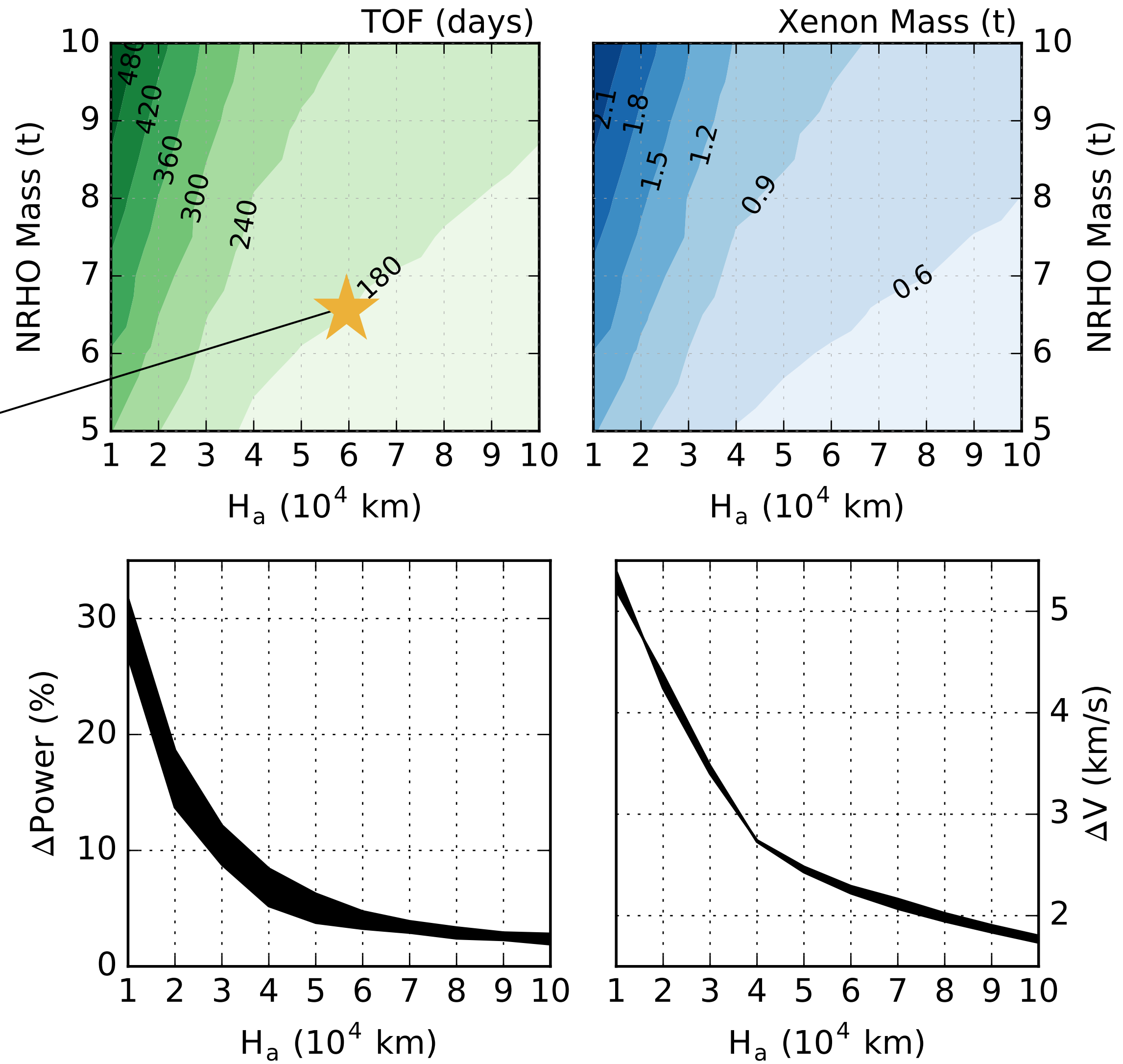
Launch to
$H_a \simeq 60{,}000$ km



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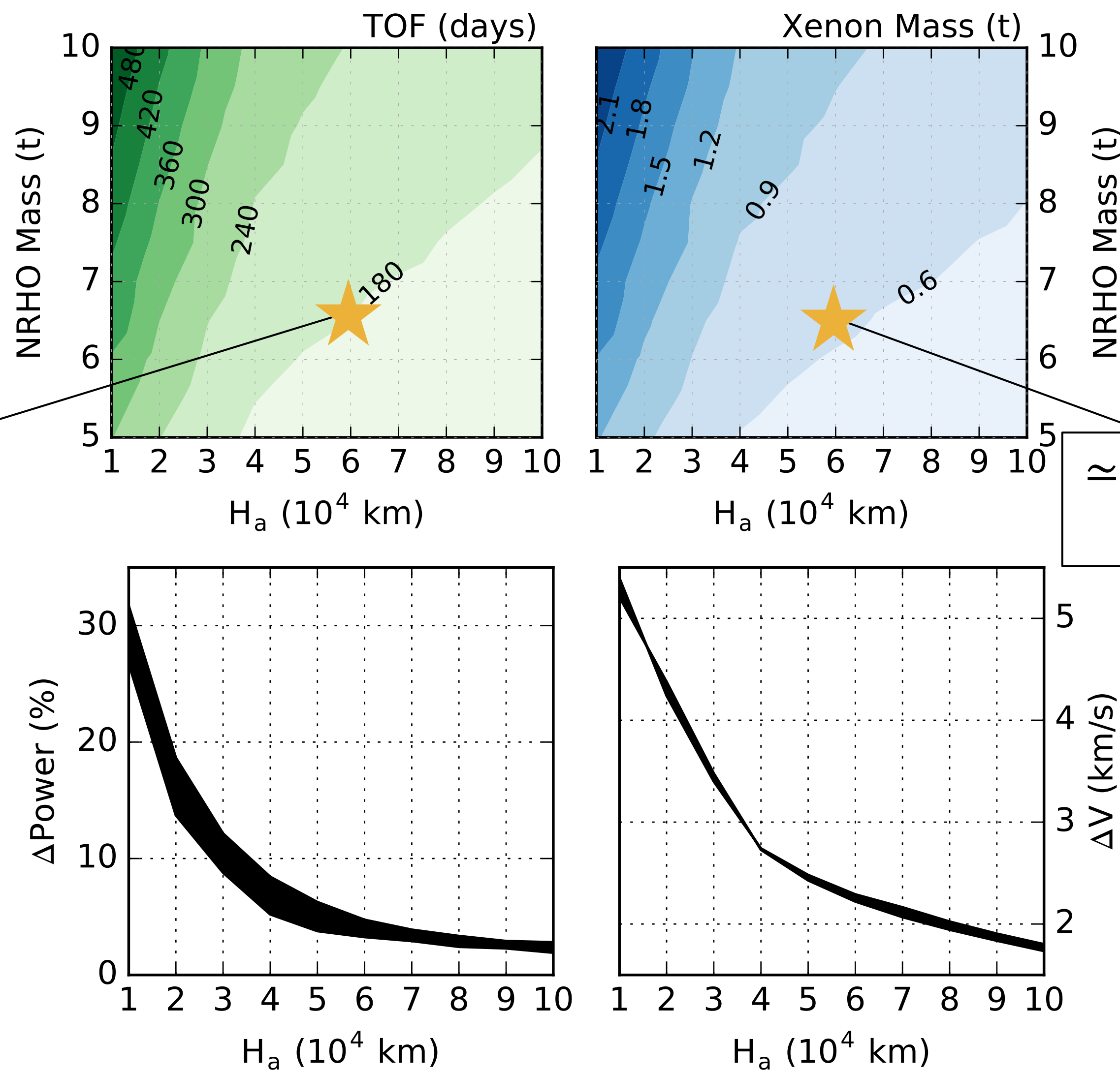

≃ 650 kg
Prop

Launch Vehicle Independent Results

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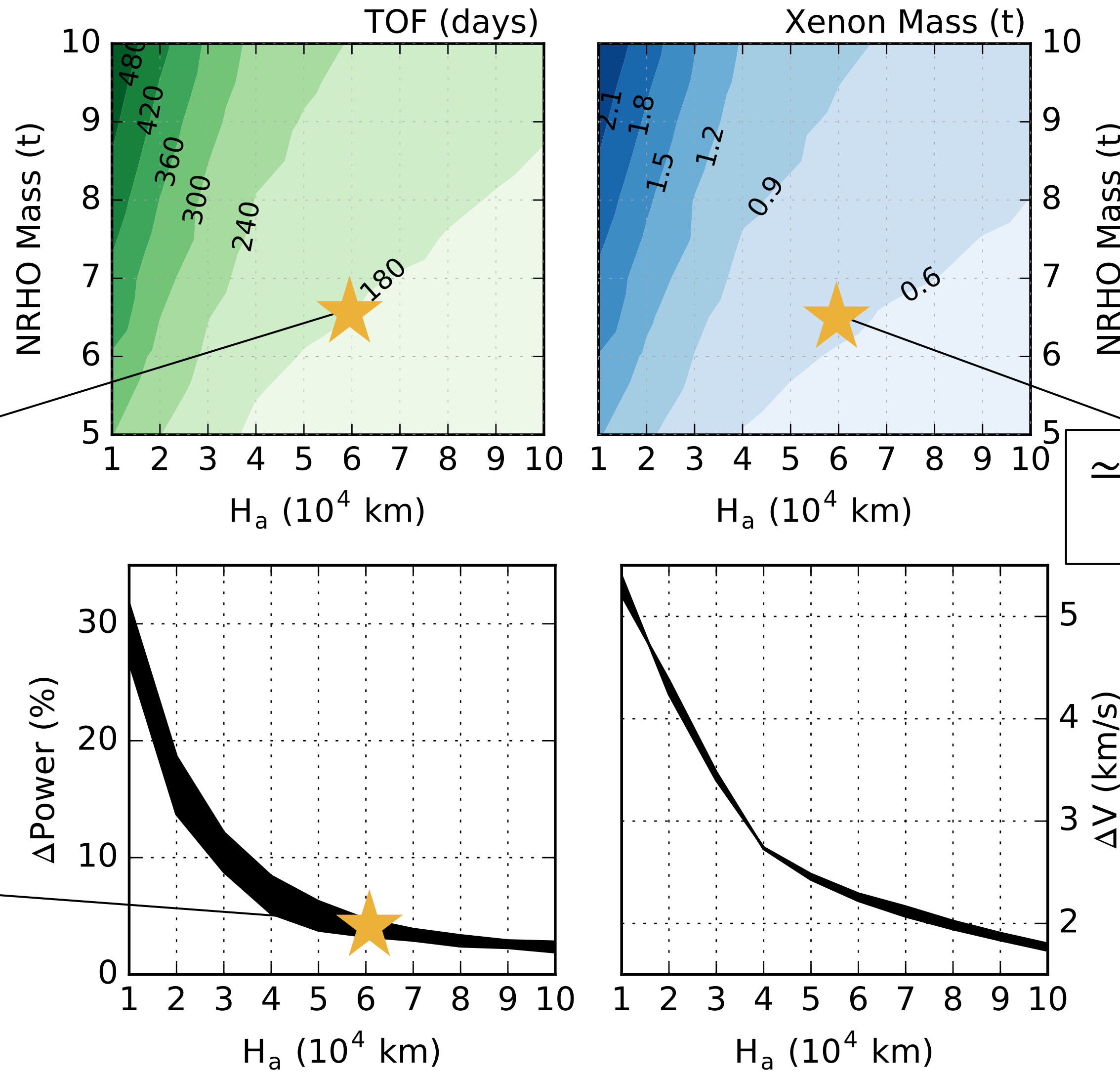

Launch to
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$\simeq$ 650 kg
Prop

$\simeq$ 5% Array
Degradation

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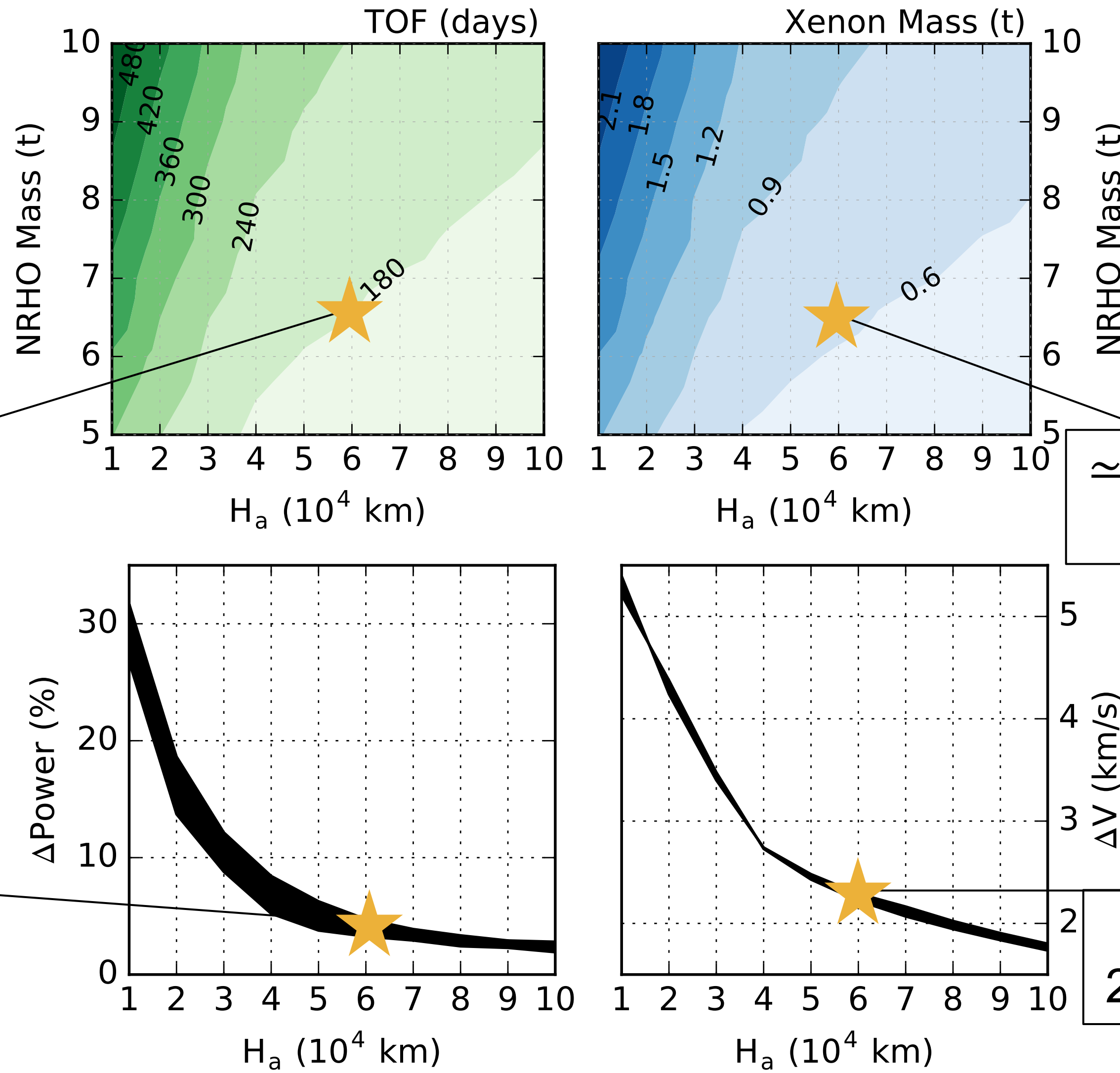

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$H_a \simeq 60{,}000$ km

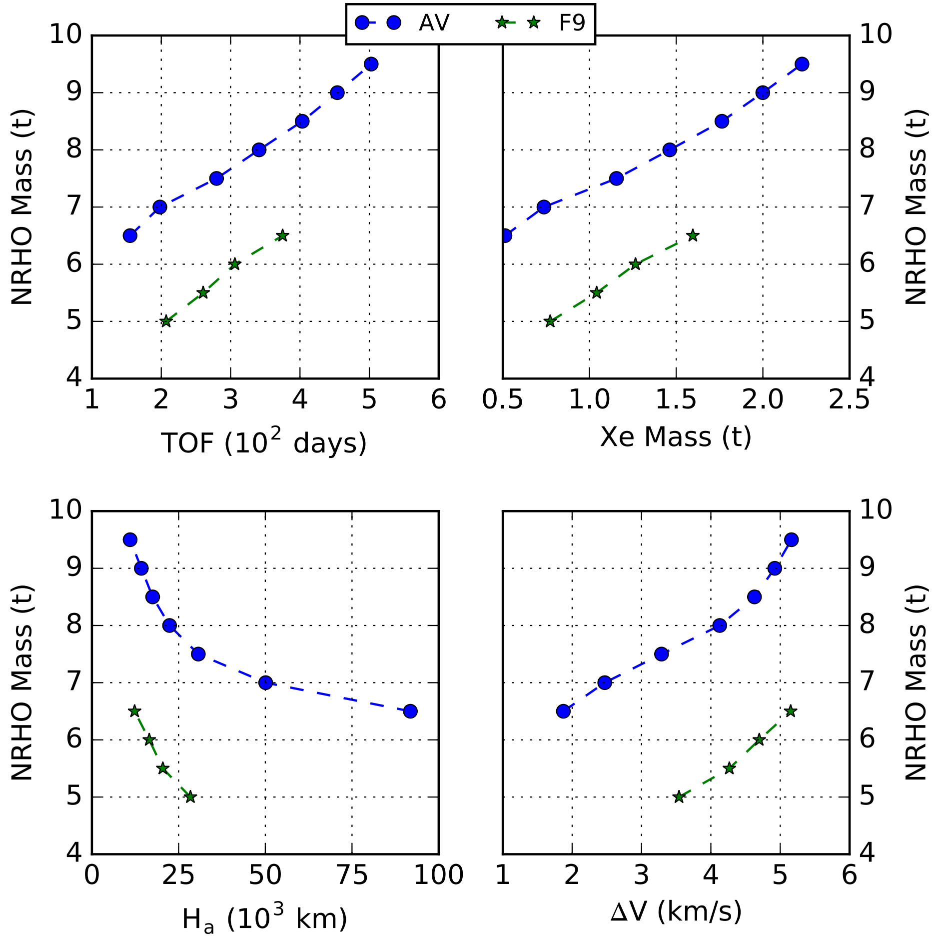
≃ 650 kg
Prop

≃ 5% Array
Degradation

$\Delta V \simeq$
2.3 km/s

F9 & AV Results: Mass and Time

- **Also generate results specific to Atlas V 551 and Falcon 9 performance**



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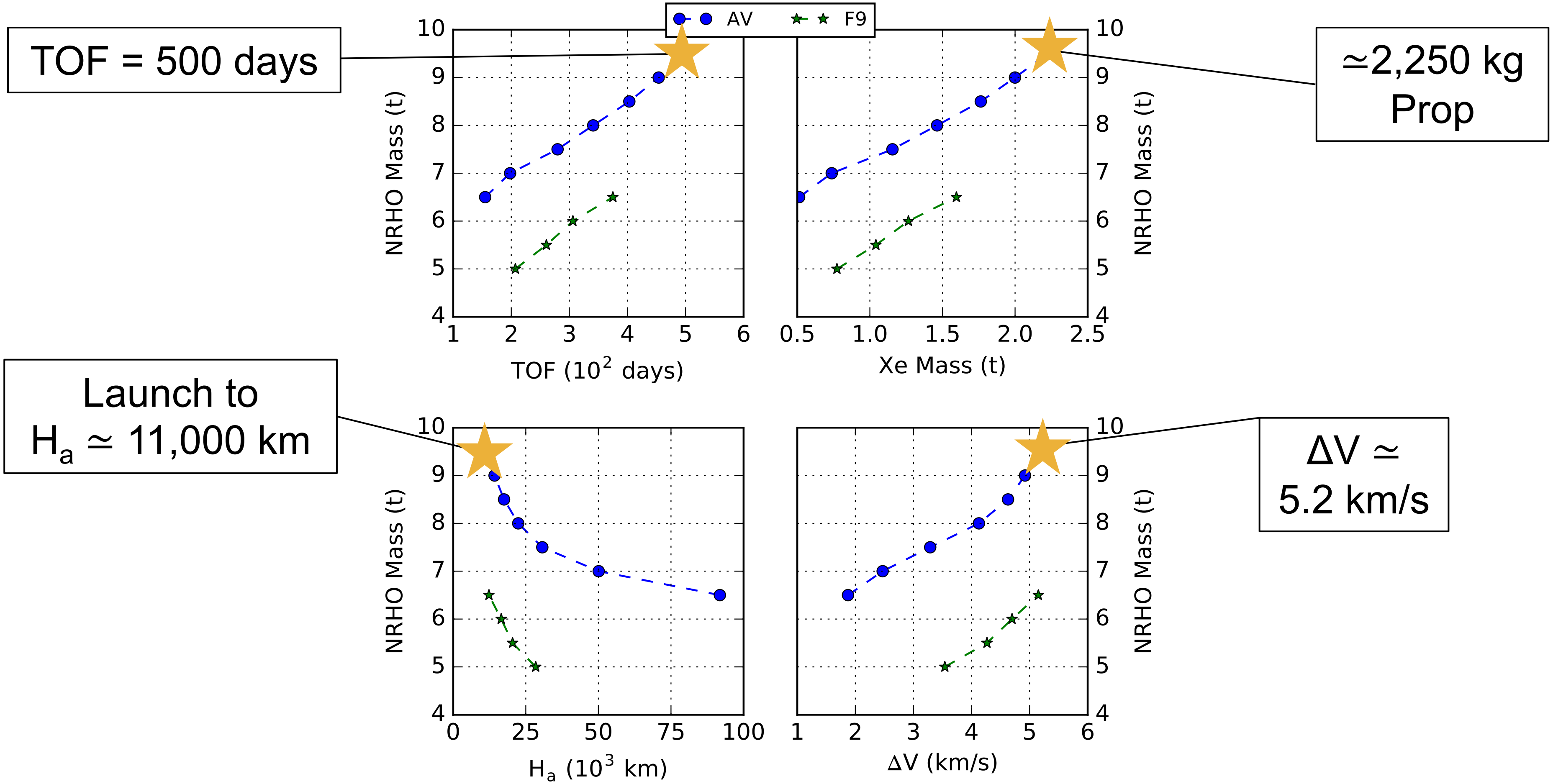
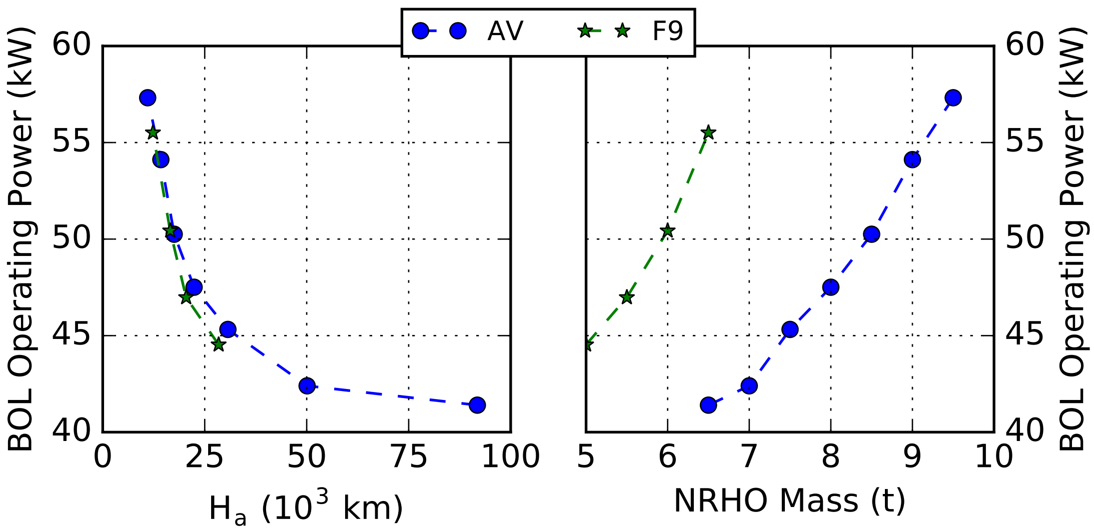


F9 & AV Results: Power

- **BOL operating power required to guarantee 41 kW in NRHO**



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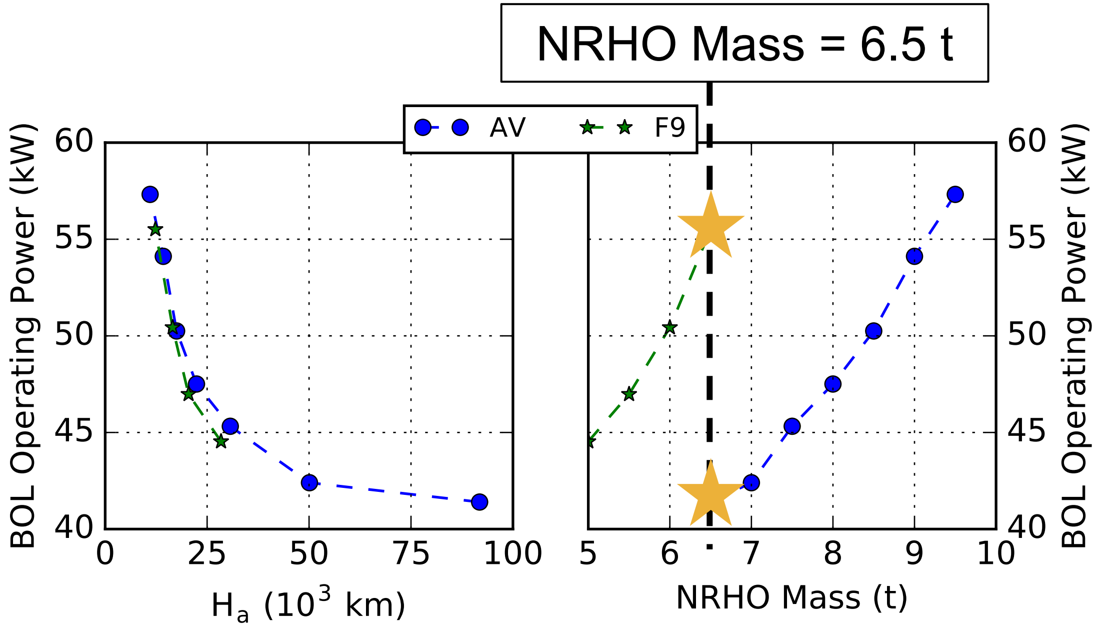

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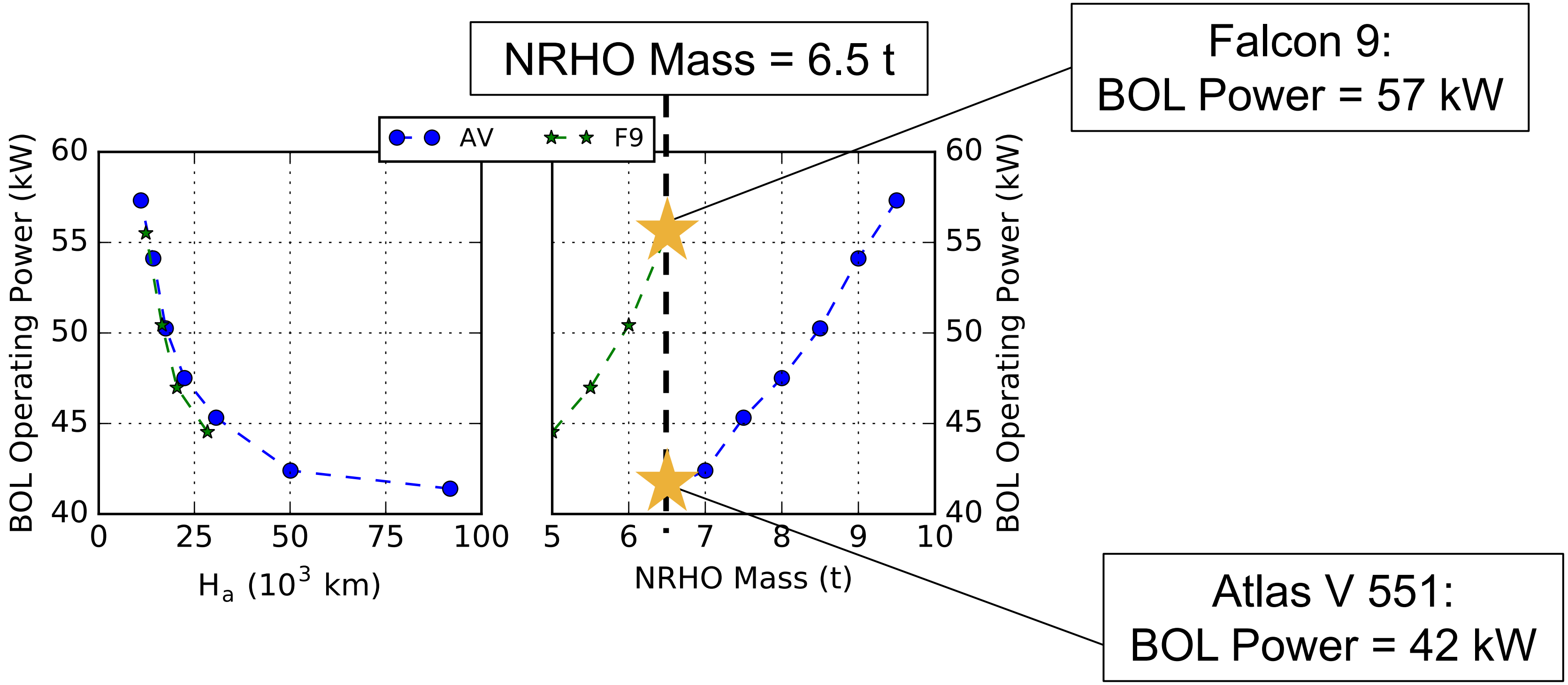

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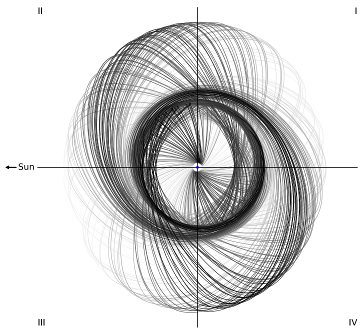
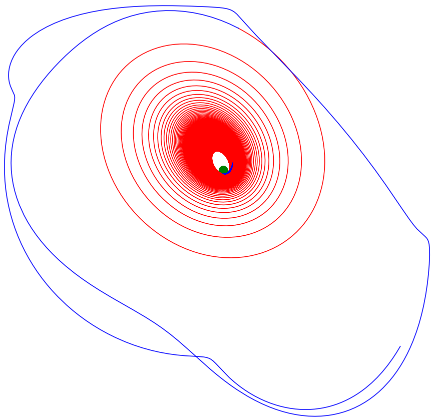
Conclusion

Analyzed two NRHO insertion options:

1. SLS Co-Manifested Payload
   - Two monthly optimal launch opportunities
   - Trends applicable to other TLI launches



2. Commercial Launch w/ Spiral Out
   - Large trade space:
     - NRHO mass
     - TOF
     - Propellant mass
     - Solar array degradation
     - Launch vehicle performance



Thank You.