Mars Ion and Sputtering Escape Network (MISEN)

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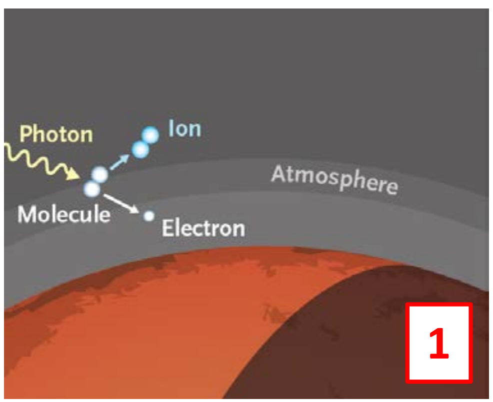
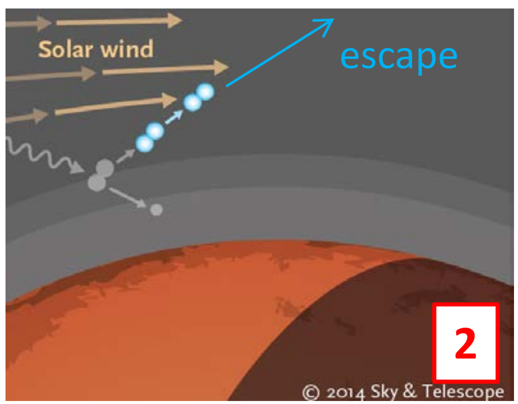
Outline

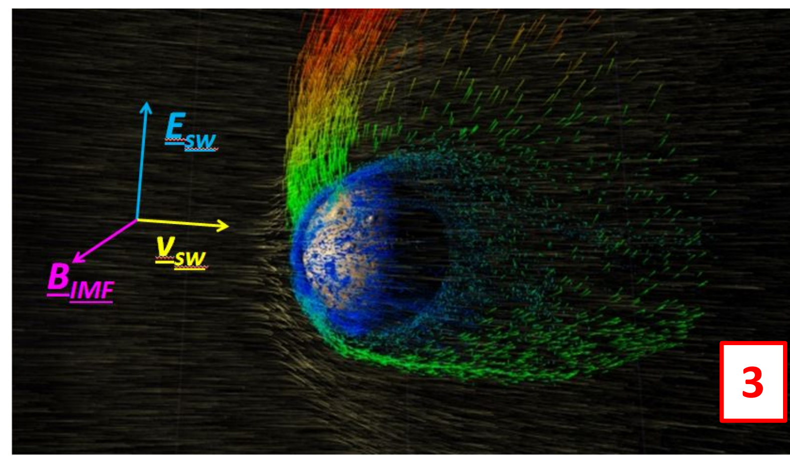
- The Science Gap: why planetary aeronomy needs multi-point measurements.
- The MISEN Mission Concept for PSDS3
  - Science Goals & Requirements
  - Science Payload
  - Mission Design/Architecture
  - Bus Architecture, science ops
  - Study Team
  - Parallel Efforts & Interconnections
  - Trade studies

Plasma & magnetic field measurements in planetary environments: why do we care?

- Understand structure, composition, variability and dynamics of planetary magnetospheres (e.g. MAVEN).
- Atmospheric Escape Processes: **ion** and **sputtering** escape are important for climate evolution of terrestrial planets







Pickup Ion Escape

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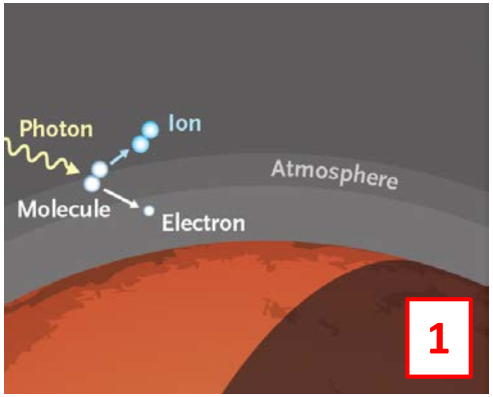
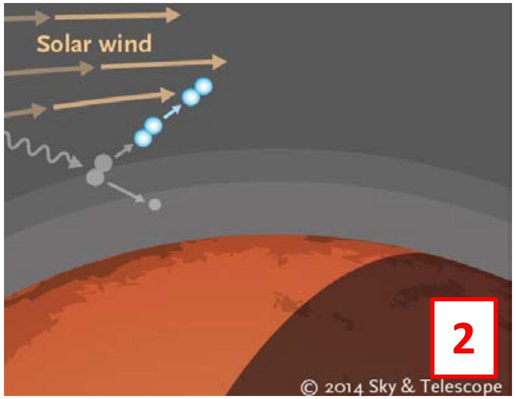
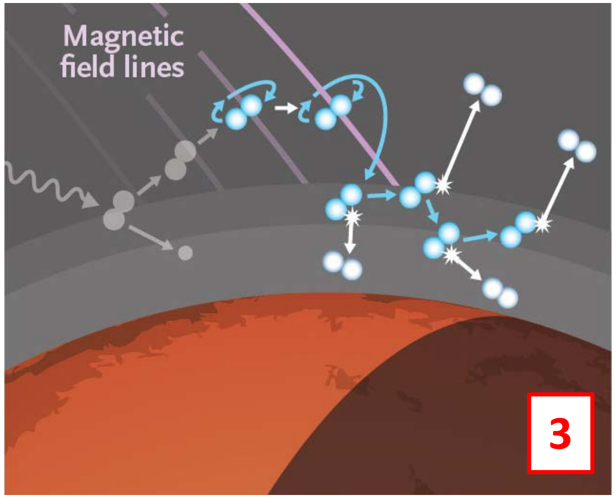






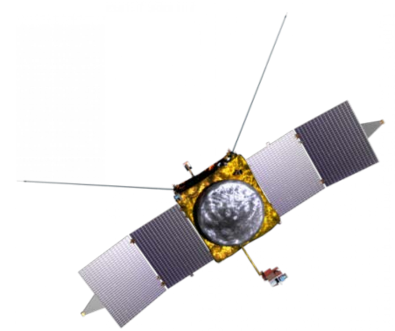
Sputtering Escape

A single measurement platform leaves major questions unanswered

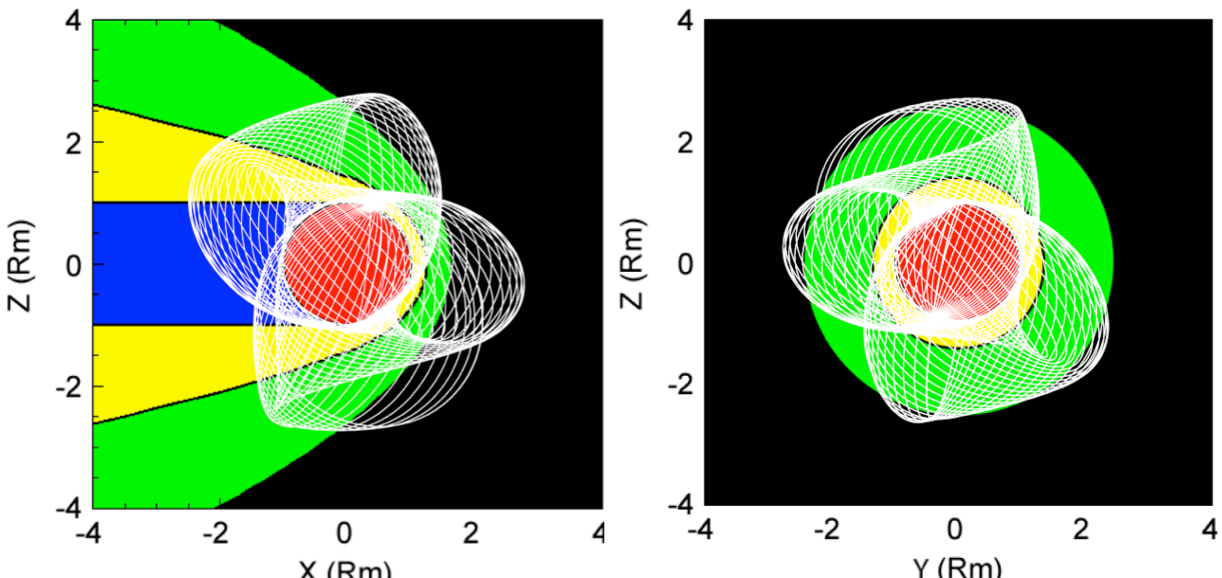
a) spatial and temporal variations in escape fluxes cannot be distinguished

b) responses of escape fluxes to changing solar wind conditions (~1 minute) can only be measured with a time-lag of an hour or (much) more

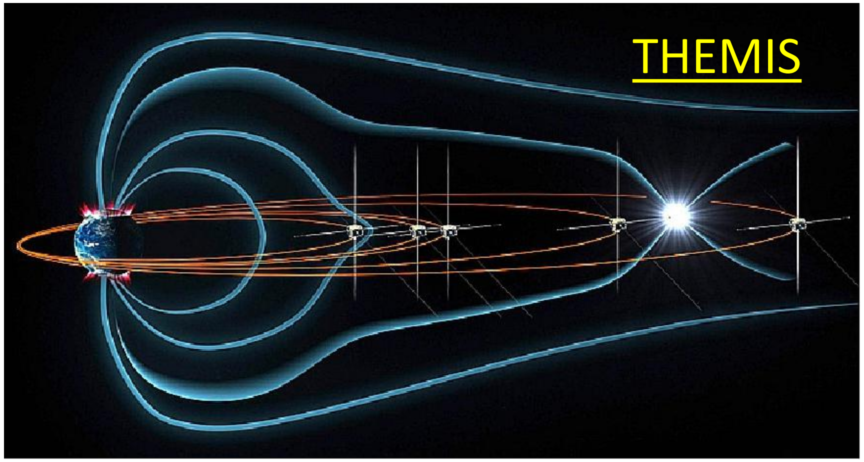
c) global escape rate variability in response to space weather "storms" (much more common and intense in the early solar system) must be estimated (poorly) from a single orbit track.

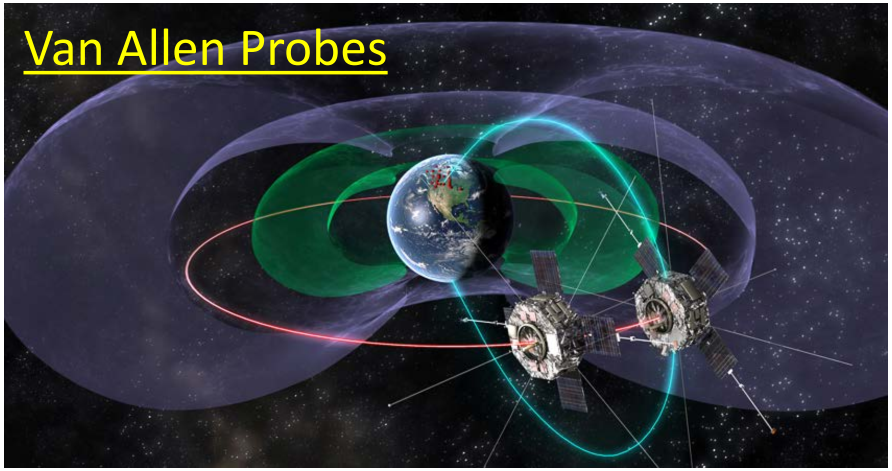


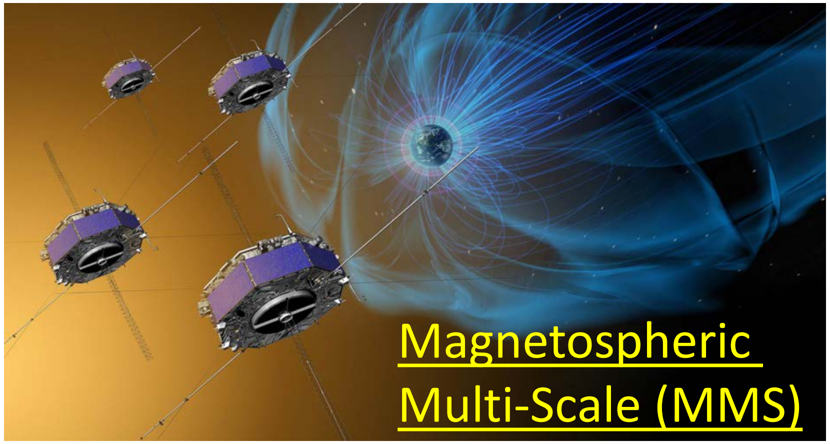
MAVEN's precessing orbit



A Multi-spacecraft Revolution

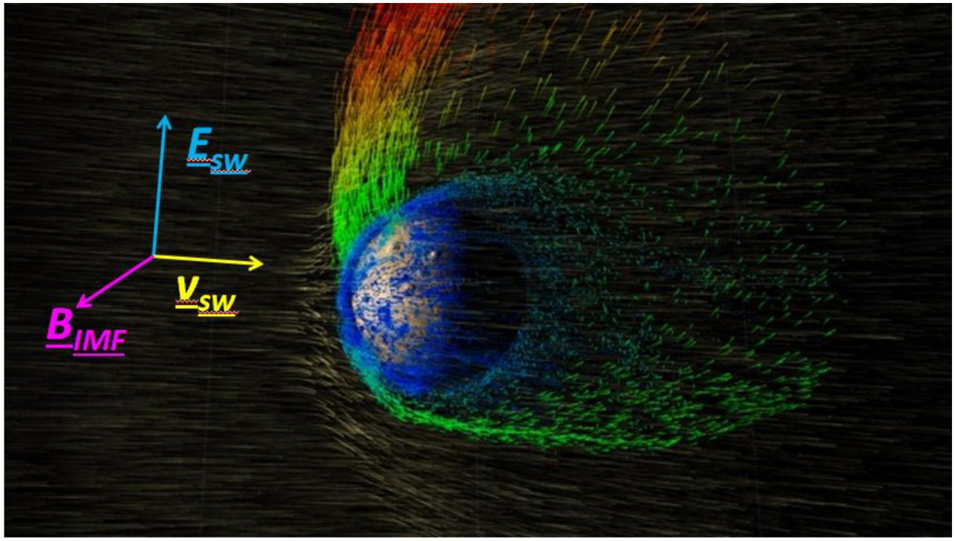


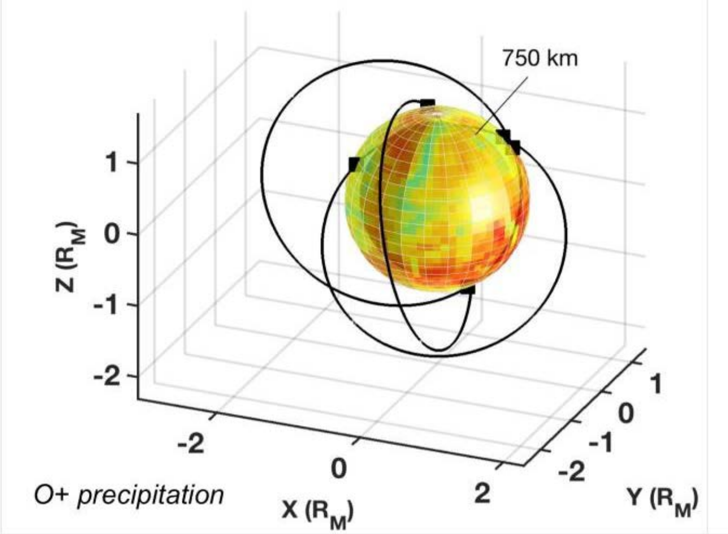




MISEN Mission Goal

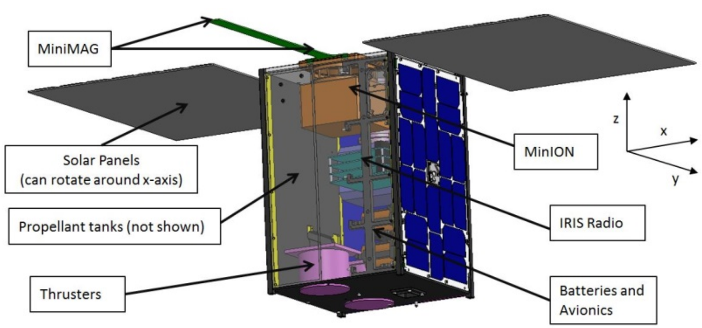
- Science Objective: Characterize the magnitude, global patterns, variability, and real-time response to changing solar wind conditions, of ion escape and precipitation at Mars.

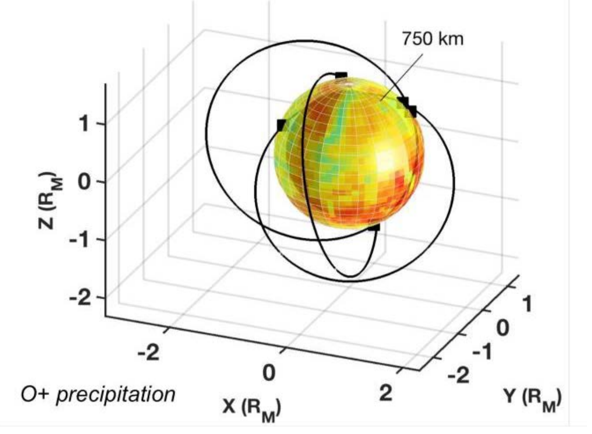




MISEN Mission Concept

- Ions, electrons and magnetic field measurements.
- 3 to 4 smallsats in inclined, elliptical orbits (~300 x 7000 km TBD), separated appropriately in longitude.
- Upstream solar wind measurements >90% of the time.
- Solar electric propulsion.
- Launched from GTO, cis-lunar or trans-Mars injection.
- Relay or direct-to-earth downlink.





Science Traceability matrix

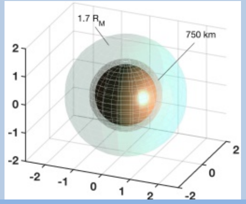
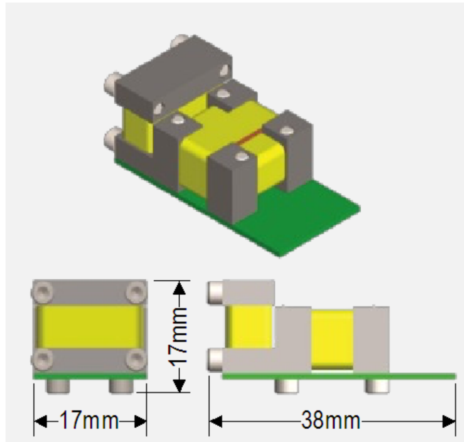
<table>
<tr><th>MISEN Science Objectives</th><th>MISEN Science Requirements</th><th colspan="2">Mars spatial coverage and solar wind monitoring requirements (initial guesses in red to be optimized during this study)</th><th>Physical parameter requirements</th></tr>
<tr><td>i. Characterize the magnitude, global patterns, variability, and real-time response to changing solar wind conditions, of ion escape at Mars.


Figure 1: Surfaces for characterizing ion escape (1.7 Mars radii) and precipitation (750 km).</td>
<td rowspan="2">i) measure solar wind density and velocity and IMF direction and strength.
ii) Measure fluxes of planetary ions and magnetic fields such that simulated global ion escape and sputtered escape rates can be estimated with an average <50% uncertainty within a 4-hour period, for a range of conditions: a) solar wind velocities (300-1000 km/s), b) solar wind densities: (2 – 30 cm^{-3}), c) Interplanetary magnetic field strengths (2 – 30 nT) and directions and d) planetary subsolar longitudes (0°, 90°, 180°, 270°).</td>
<td>Above 1.7 Mars radii (R_m), measurements must be made:
• In Mars-solar-electric field (MSE) coordinates, in each 4-hour period:
o within 500 km of points mapping inward to 30% of the area of a sphere at 1.7 R_m.
o In at least three of the eight 45° octants in MSE longitude, with a gap of no more than two octants.
• In planetocentric coordinates, at least once per sol:
o Within 500 km of 75% of points mapping inward to 30% of the area of a sphere at 1.7 R_m.</td>
<td rowspan="2">Measurements must be made in the upstream solar wind at least 90% of the time.</td>
<td rowspan="2">3-D Ion distributions:
• Flux: $10^5 – 10^{10}$ /s/cm^2/sr/eV
• Energy: 5 eV to 20 keV with ΔE/E < 25%.
• Angle: full-sky (4π) coverage with 30° angular resolution in both polar and azimuth angles.
• Cadence: 8 seconds (spacecraft travels ~40 km at periapsis)

3-D Magnetic field:
• Range: 0-700 nT, Accuracy: 1 nT
• Cadence: 4 Hz (32 samples per 16 second spacecraft spin period). 32 samples per spin is required to adequate reconstruction of magnetic vector [Auster et al., 2008]</td></tr>
<tr><td>ii. Characterize the magnitude, global patterns, variability, and real-time response to changing solar wind conditions, of ion precipitation into the Martian atmosphere, and the resulting sputtered escape of neutrals.</td>
<td>Below 750 km altitude, measurements must be made:
• In Mars-solar-electric field (MSE) coordinates, in each 4-hour period:
o within 500 km of points mapping ouward to 30% of the area of a sphere at 750 km altitude.
o In at least three of the eight 45° octants in MSE longitude, with a gap of no more than two octants.
• In planetocentric coordinates, at least once per sol:
Within 500 km of 75% of points mapping outward to 30% of the area of a sphere at 750 km altitude.</td></tr>
</table>

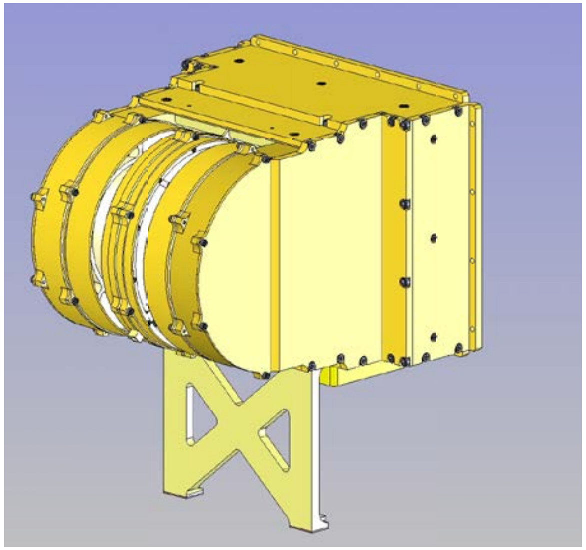
Science Payload 1: MiniMAG

- Developed by UCLA (C. Russell)
- Clone of Insight Mars magnetometer
- Two mounted on short-boom (30 cm, 150 g) i.e. gradiometer configuration
- 0.3U, 144 g, 0.8 W per sensor
- ±5000 nT range
- 48 bits per readout up to 64 Hz



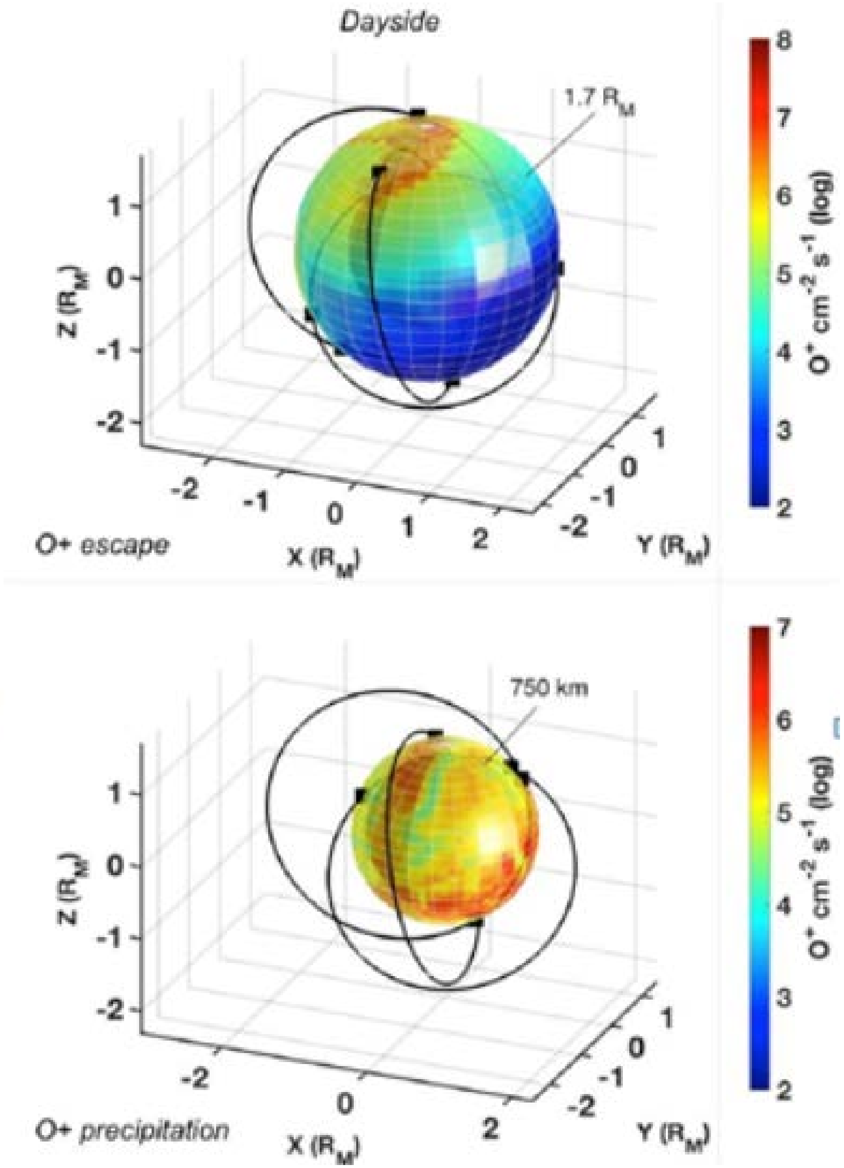
Science Payload 2: electron & ion analyzer

- UCB/SSL heritage top-hat design
- Mass 1.8 kg
- Power: 1.7 W.
- 4π FOV via spinning platform
- 22.5° x 6° resolution
- 3 eV-25 keV energy range
- DE/E = 18%
- Mass composition is an ongoing trade



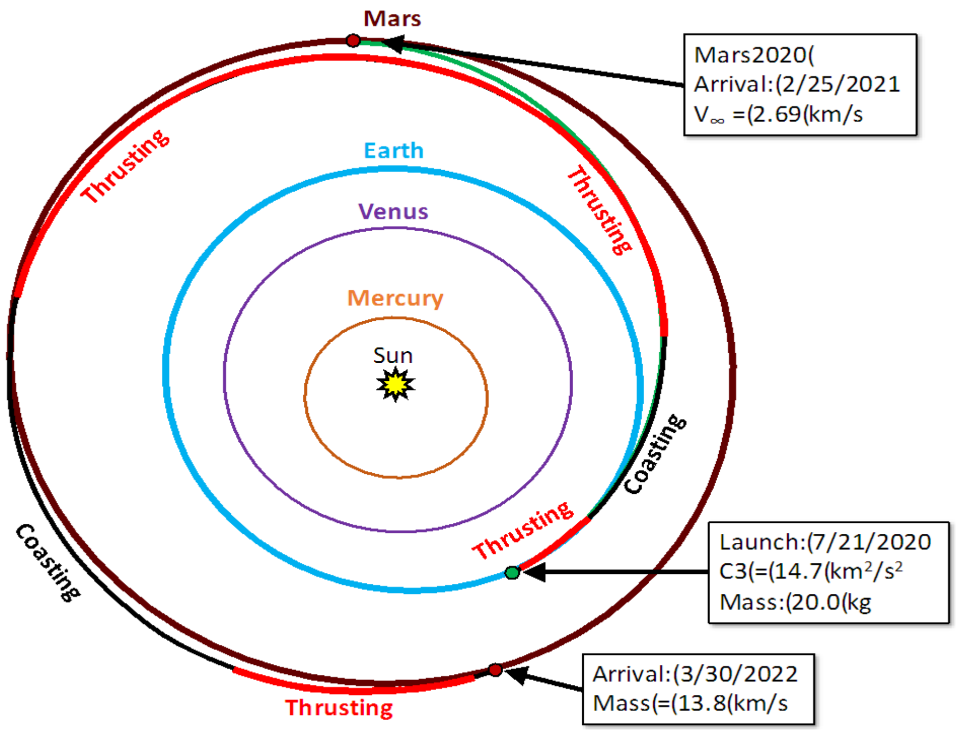
Scientific Mission architecture

- Elliptical orbits are:
  - High enough to ensure outward particles are escaping.
  - Low enough to ensure inward particles are precipitating.
- MHD simulations let us:
  - Calculate total solar wind measurement coverage
  - Calculate 'error' in ion escape and precipitation and how it varies over one Mars year of orbital precession.
- Orbit characteristics will be optimized during study.



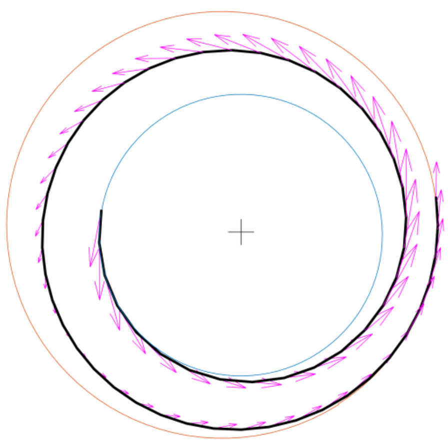
Preliminary Mission Design (1)

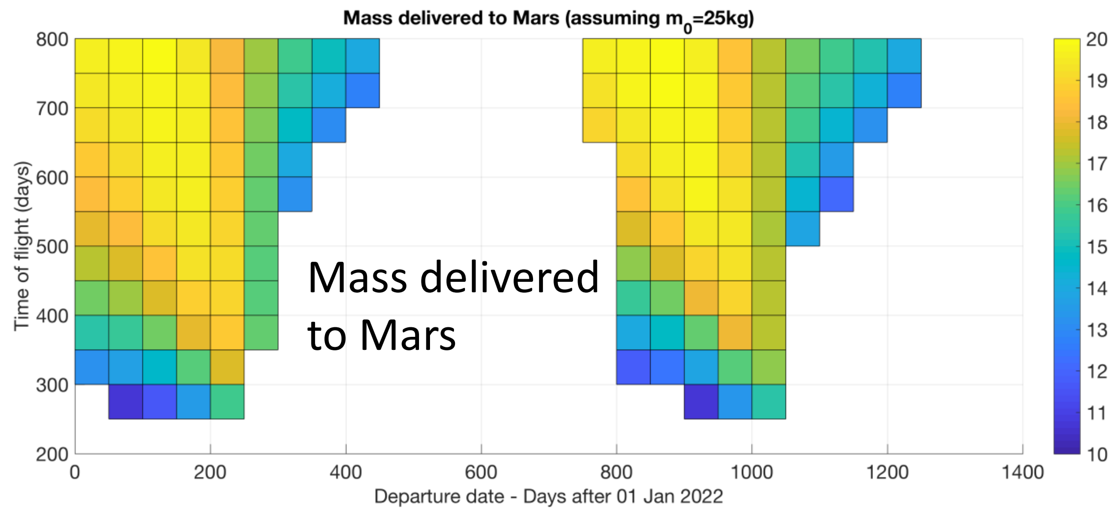
- Piggy back to Mars not studied: rare opportunities & plane change maneuvers very fuel-expensive.
- Earth escape trajectory (20-month cruise) studied for proposal. Needs ~35% fuel mass fraction & 2 mN of thrust.

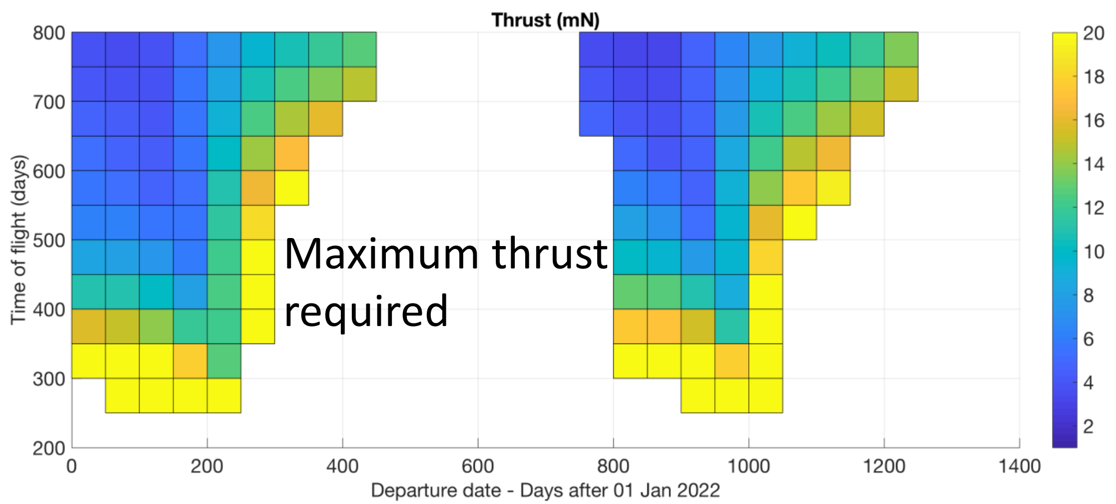


Preliminary Mission Design (2)

- Initial mass 25 kg
- For 600 day transfer:
  - 5-7 kg of fuel expended
  - 5 mN of thrust required

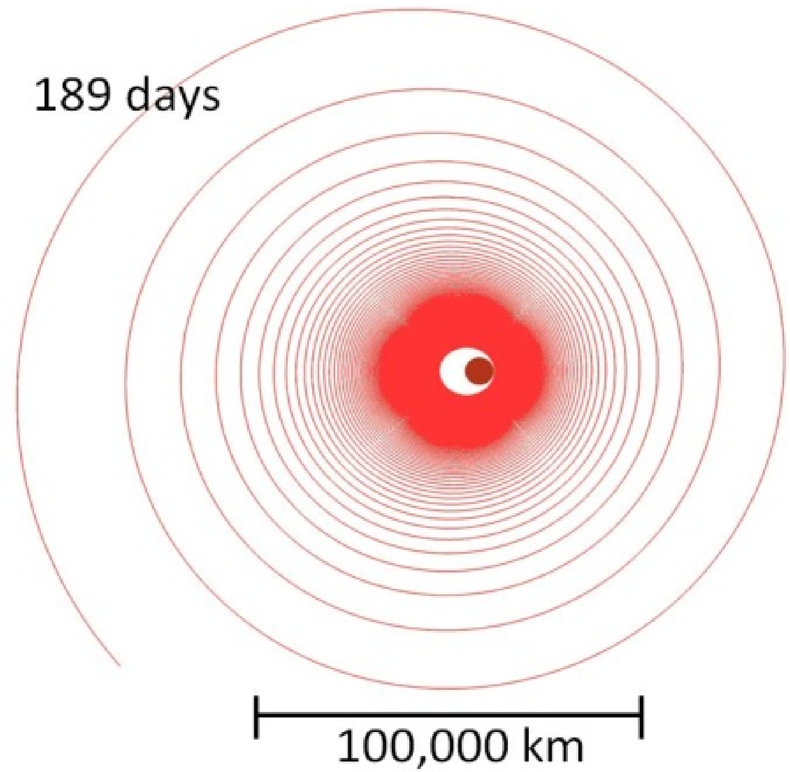




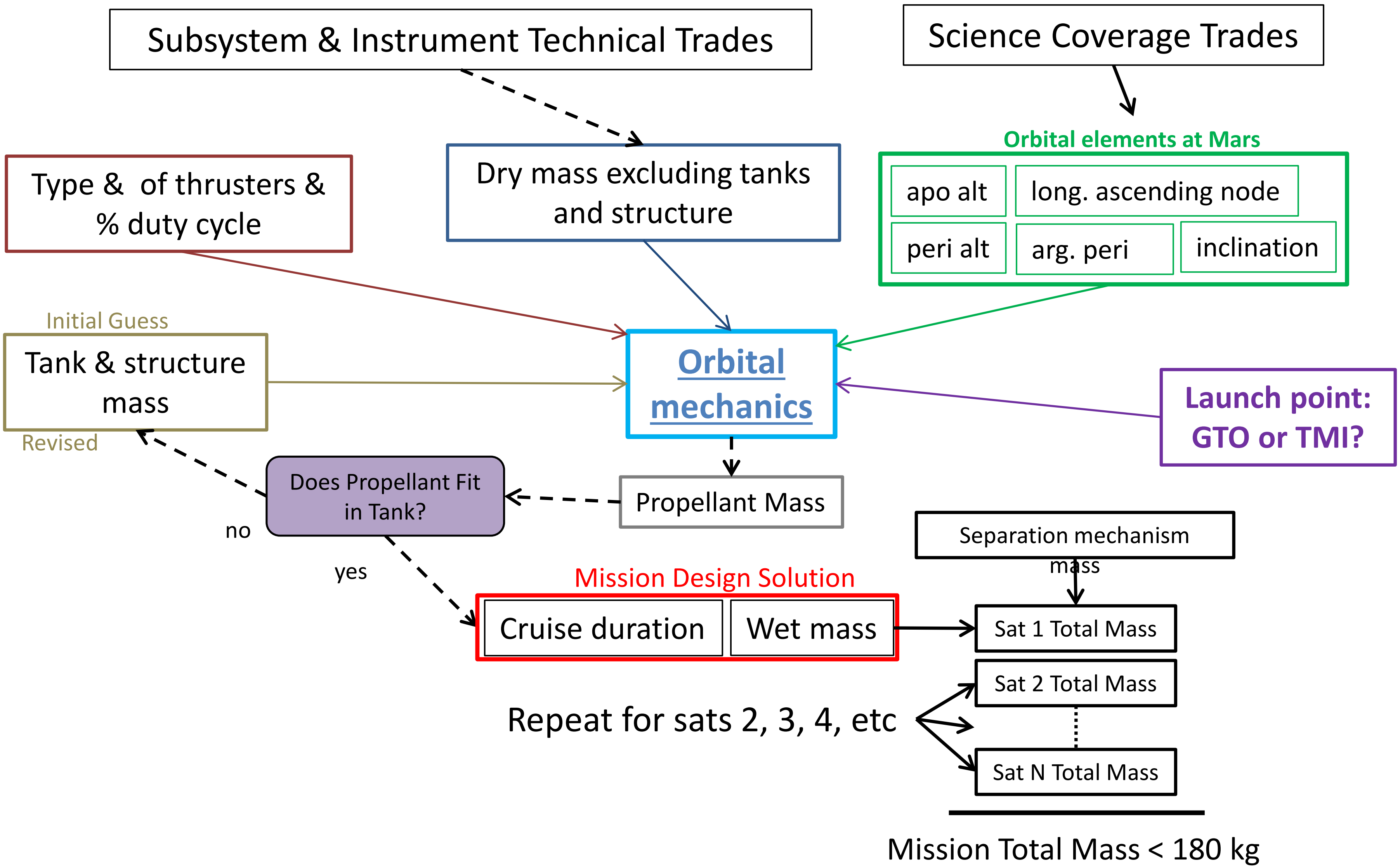


Preliminary Mission Design (3)

- Spiral into final Mars orbit over ~6 months.
- Can choose any inclination or RAAN
- ~3 mN of thrust required.
- For 18 kg initial mass, need ~1.5 kg of fuel.
- Can deliver ~19 kg to final desired orbit for initial ~42 kg wet mass.

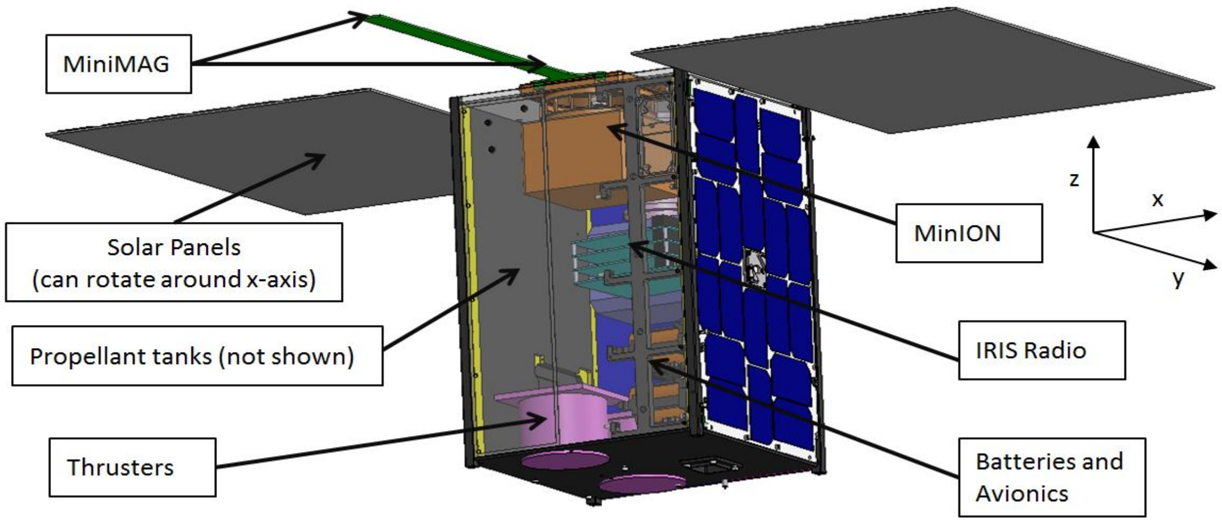


MISEN Mission Design Trade



Bus architecture & Spacecraft Ops

Proposal design:



- Three axis stabilized until science orbit.
- Spinning at 16s period after that
- Volume will depend on launch point.
- 1-axis gimballed solar panels
- IRIS radio X or Ka-band
- MarCO or RainCube-style antenna

Ongoing SC bus & ops trades:

MEL update	Need more fidelity on all subsystems, including 3 tank sizes & 2 solar panel sizes
Spin Attitude determination	Spin phase determination requirement. Use star trackers/scanners?
Spin during downlink	Earth-pointed spin axis simplifies ops. Requires accurate spin axis pointing. Should present both options, spinning and non-spinning.
Power system	Solar Cell efficiency? Battery mass vs current/wattage maximum output?
Antenna	Size for X and Ka-band? Linked to data trade.
Solar panel gimballing	Normal to plane of ecliptic allows flexible thrusting.
Data Storage	3+ months of data can be stored on board. Downlinked when convenient.
Receiver duty cycle	Turning off receiver saves 8 W. Help with thrusting at Mars.

Navigation & Science ops

- The low-thrust cruise to Mars is inherently mistake-tolerant requiring only biweekly ground contacts.
- More frequent contacts during the spiral to final science orbits.
- Once science orbits are achieved and the spacecraft are spun up to a 16-second spin period, data collection is ‘dumb’ and continues indefinitely.
- Orbits are predictable, don’t require station-keeping more than a few times per year.

Study Team

<u>UC Berkeley Space Sciences Lab</u>

- PI: *Rob Lillis*
- Systems engineering & Management: *Dave Curtis*
- Science Requirements: *Rob Lillis* and *Shannon Curry*
- Ion & electron analyzer: *Davin Larson, Roberto Livi, Phyllis Whittlesley*
- Science advisory: *Janet Luhmann*

<u>University of Colorado Boulder</u>

- Science advisory: *David Brain*

<u>UCLA Earth and Space Sciences</u>

- Magnetometer: *Chris Russell*

<u>Advanced Space LLC</u>

- Mission Design & Navigation: *Jeff Parker & Nathan Parrish*

<u>Tyvak LLC</u>

- Spacecraft bus (structure, avionics, processor, thermal, propulsion, ADC, EPS): *Jordi Suig-Puari*

Four interconnected efforts

<u>Science & instruments</u>

Lead: Rob Lillis

- Science Objectives
- Measurement re ments
- Instrume ements
- Accon dation Requirements
- Resource Requirements

<u>Mission Design Trades</u>

Lead: Jeff Parker

- Thrust profile
- Initial wet ma
- Launc
- Trans er duration
- Earth/Mars spiral out/in

<u>Science orbit optimization:</u>

Lead: Shannon Curry

- Coverage of escape and precipitation wrt S ers
- Solar wind ng
- Glo nse to heliospheric dis ances (CIR, CME etc).
- Preferred orbits

<u>SC Bus/Subsystem trades</u>

Leads: Dave Curtis & Jordi Suig-Puari

- Battery & solar panels
- Comm system
- DPU & instru accomm
- A det. & control.
- opulsion system
- Structure, Mass & Volume

Four interconnected efforts

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Mission Design Trades

- Thrust profile
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- Launch date
- Transfer duration
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Science orbit optimization:

- Coverage of escape and precipitation wrt SW drivers
- Solar wind monitoring
- Global response to heliospheric disturbances (CIR, CME etc).
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MISEN Study Trades

- Trade studies identified at kickoff meeting 9/11-12
- For each trade, identified:
  - Lead/responsible
  - Group
  - Due date
  - Interdependencies.
- Not all trades have to close within 6 months:
  - This is a concept study.
  - Multiple options can remain on the table at the end.

MISEN Master List of Trades

#	Title	Description	Lead(s)
1	**Instruments& science**		
1a	Required Cadence	Plasma (8s or 16s) & magnetic field (?Hz) cadence	Rob
1b	Science data rate	• Ion distribution data rate. • Electron data rate. • Is 12 bits per mag direction sufficient? • Cadence of inboard versus outboard?	Dave, Chris & Rob
1c	Ion mass determination	Mass discrimination is preferable. 4 options: 1. No mass discrimination 2. Two thresholds and swap between them. 3. Pulse shape analyzer (new FPGA?) 4. Full TOF section needs 15 kV supply	Roberto, Davin, Dave Rob
2	**Comms/telemetry**		
2a	Total data rate	Flesh out science, ancillary and housekeeping data	Dave
2b	Downlink method	Multiparameter trade: • Frequency (Ka vs X-band) → antenna size. • Direct vs Relay • Optical?	Dave
3	**Spacecraft & Ops**		
3a	MEL update	Need more fidelity on all spacecraft subsystems, including 3 tank sizes & 2 solar panel sizes	Jordi & Dave
3b	Spin Attitude determination	Spin phase determination requirement? Can we use star trackers or need star scanners? IR limb finder?	Jordi
3c	Spin during downlink	Earth-pointed spin axis simplifies ops. Requires accurate spin axis pointing. Should present both options, spinning and non-spinning.	Jordi/Dave
3d	Power system	• More efficient solar cells? • Battery current/wattage maximum output?	Dave
3e	Antenna	Size for X and Ka-band? Linked to data trade.	Dave
3f	Solar panel gimballing	Normal to plane of ecliptic allows flexible thrusting?	Dave
3g	Receiver duty cycle	Turning off receiver saves 8 W. Could help with thrusting at Mars.	Dave
4	**Navigation**		
4a	Cruise contact cadence	Both downlink cadence and thruster profile cadence	Jeff
4b	Ephemeris accuracy	Accuracy requirements for three mission phases: cruise (coarse), spiral down, final science orbit.	Jeff/Rob
5	**Mission design**		
5a	Trajectory to Mars	Multiparameter trade involving propulsion system, power system, launch point and duration. We have three dimensions to evaluate & present. • Attributes: delta-V, hours of thrust, # of thruster cycles, dry mass, wet mass, total mass, days of transfer to Mars capture, power required. • Ride Options: GTO, GEO, Lunar Flyby (zero energy), Trans-Mars Injection • Thruster Options: BHT 200, 2 x BHT 200, XIPS, wishlist?	Jeff
5b	Science orbits at Mars	Orbital elements & numbers of spacecraft will be optimized on the basis of the following metrics: • solar wind coverage (per orbit and per minute) • Precipitation coverage (low is better) • Ion escape coverage (high is better) ***Science resiliency in the event of loss is a key selling point. Higher orbits can be lowered but not vice versa.*** Several approaches will be evaluated using MHD simulations of the Mars-solar wind interaction. • 4 elliptical orbits • 3 elliptical orbits + 1 low orbit. • 2 elliptical orbits + 1 low orbit, etc etc.	Shannon

MISEN Study: Goals

- **Feasibility**: can we come to a detailed mission concept that closes scientifically, technically?
  - Preliminary indications say yes
- **Tech Dev**: what components of the concept need further testing or development?
  - Cubesat parts, particularly ion thrusters
- **Cost & Schedule**: when can we do this & what's the price tag? <$100M credibly?
  - Independent Cost Estimate is budgeted.

Summary

MISEN will:

- Provide simultaneous multi-point measurements of the Martian plasma environment.
- Elucidate the real-time response of the this environment to solar wind changes & disturbances (CMEs, SEPs etc)
- Reveal for the first time the global patterns of ion and sputtering escape and how and why they vary.
- Build on MAVEN's legacy for a fraction of the cost.

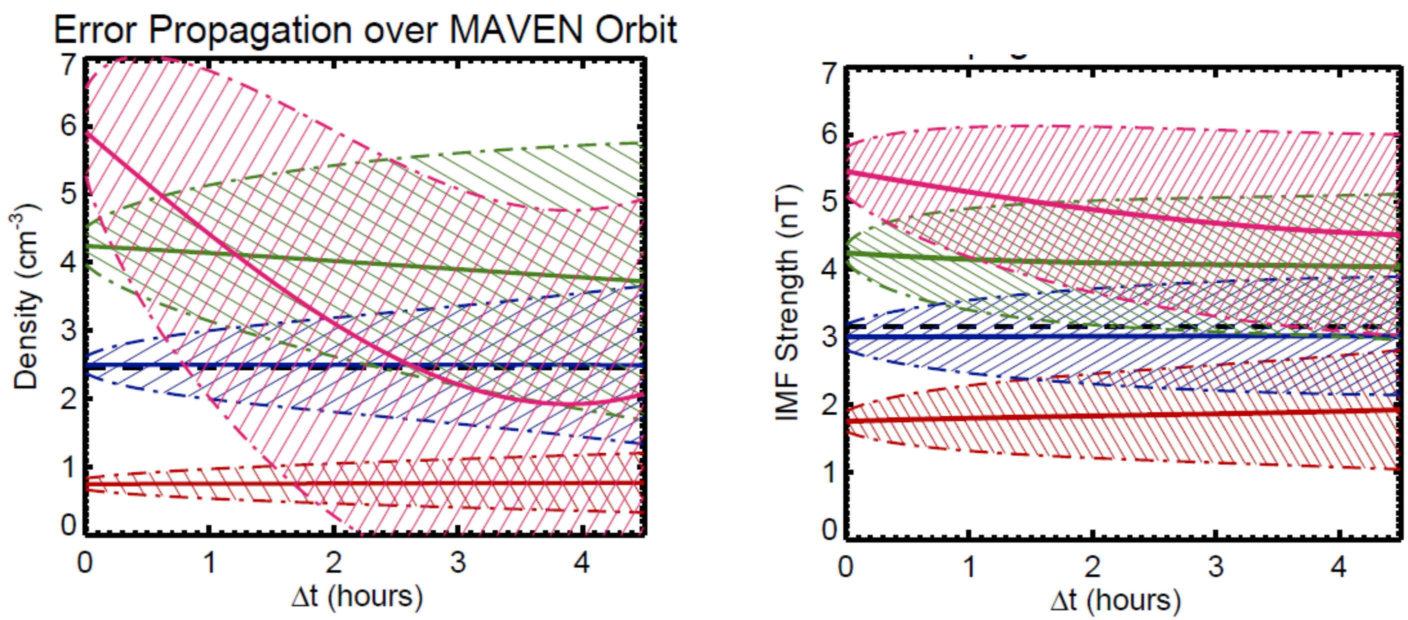
BACKUP SLIDES

A single measurement platform leaves major questions unanswered

a) spatial and temporal variations in escape fluxes cannot be distinguished

b) responses of escape fluxes to changing solar wind conditions (~1 minute) can only be measured with a time-lag of an hour or (much) more

c) global escape rate variability in response to space weather "storms" (much more common and intense in the early solar system) must be estimated (poorly) from a single orbit track.



Credit: M. Marquette

Feasibility Study flowchart