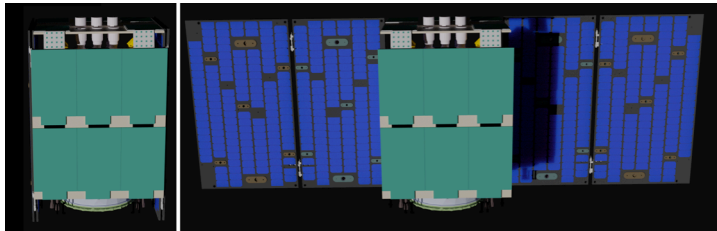


### Three Small Mars Missions based on Common Spacecraft Systems: 1. Mars Stationary Orbiter (MSO)).

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**Introduction:** We are presenting three different Mars mission concepts based on common spacecraft subsystems. We followed a component approach, similar to 20<sup>th</sup> century audio entertainment systems, as opposed to pre-packaged systems. The focus is on finding the highest quality subsystems for deep space environments to mix and match for planetary application; as opposed to choosing from fully integrated systems designed for Earth orbit. Deep space missions are primarily distinguished from terrestrial missions by the need for high delta velocities ( $\Delta V$ ), deep space telecommunications compatibility, large data volumes, variable power requirements and



MSO in Launch Configuration (left) and Deployed (right)  
Ka-band antennae are green, payload of cameras at top  
Vehicle is Standard ESPA dimensions ~ 100 cm x 67 cm x 60 cm

availability, and broad operating temperature ranges.

Our mission objectives are to send vehicles to Mars, diversify the launch opportunities beyond dedicated Mars trajectories, and address both scientific and technical goals. This abstract first describes the subsystems we have developed for a self-funded Mars spacecraft, with the intention of addressing the primary major weakness of our previous NASA proposals, *i.e.*, that we had not previously built a spacecraft. The abstract concludes by describing the simple orbiter mission, science objectives, science payload, and costs.

#### Spacecraft Subsystems:

*Flight Computer and Telecommunications (Radio):* We selected the Rincon AstroSDR, a combined flight computer and software defined radio with flight heritage. The main ASDR device is executing Linux on a dual core ARM Cortex A9 processor, supported by a large FPGA 1GB ECC RAM, and 8GB radiation tolerant NAND flash memory. A 2TB flash memory allows storing all science data onboard for long portions of the mission for downlink flexibility as datarates vary significantly. Onboard *Python* support enables flexible scripting and fast development.

GNU Radio running on the ASDR supports features of a functional DSN compatible transceiver,

including, BPSK/QPSK modulation with residual and suppressed carrier downlink, turbo codes, DDOR, and PN and sequential ranging. A Prox-1 compatible UHF radio is under development. The radio is capable of generating arbitrary waveforms and is easily software upgradeable in Mars orbit. Possible future uses include generating a GPS-like navigation signal (using the onboard atomic clock) and upgraded encoding/modulation schemes for inter-asset links. Maximum radio bandwidth is ~50MHz operating nominally at a UHF intermediate frequency. UHF is upconverted to X- and Ka-Band and converted down from X-Band to UHF for DSN uplink. The downlink system performance is 85.6 dBm EIRP at Ka-Band. An additive manufacturing process produced Ka-Band slotted waveguide antennas to form a 2x3 array for the primary downlink. X-Band patch array medium gain antennae support the primary uplink and contingency downlink. Expected peak downlink from Mars is 815kb/s (Ka-Band January 2025), X-band uplink 30kb/s. UHF Prox-1 Forward link 39kb/s, UHF Prox-1 Return link 88kb/s from areostationary orbit.

*Flight Software:* We chose Advanced Solutions, Inc. for the flight and attitude control subsystem software. ASI's modular, reconfigurable MAX flight software allows mission specific solutions to be created using standard interfaces, configuration files and tools to minimize development time. MAX includes the On-board Dynamic Software Simulator (ODYSSy) which allows "test like you fly" operations at all stages of integration. ASI also provides their Ground Data System (GDS) for a complete software solution that allows commanding, telemetry display and logging and ground operations to be included from the start of I&T.

*Attitude Control:* ASI also supports MSSS with attitude control design and analysis, applying the experience they gained on numerous missions including Osiris-Rex, Juno, MRO, and Mars Insight. Our team surveyed available ACS components and selected a set of robust, flight proven hardware from vendors who are leaders in their fields. The Sinclair Interplanetary Star Tracker ST-16-RT2 delivers 5" (arcsec) cross-boresight accuracy and 55" about the boresight, featuring a 15 x 20° FOV in a radiation tolerant design. Sinclair will also supply the GEO rated 1.0 Nms reaction wheels. These units are rated for over

60 krad total dose and LET immunity to 50 MeV-cm<sup>2</sup>/mg and deliver up to 100 mNm of torque. The Sensoror STIM377H IMU provides precise stable gyro and accelerometer data with better than 0.3 °/hr bias instability and 0.15 °/hr<sup>1/2</sup> angular random walk. New Space Systems Sun Sensors provide sun reference for rapid safe mode recovery. Sixteen Stellar Exploration 0.25N hydrazine thrusters provide roll control during main engine burns and precise orbit adjustments and desaturation of the reaction wheels. The system provides 0.10° control with 0.05° knowledge for staring during data collection and transmission to earth and 0.5 deg control during slews at up to 1.4 °/sec.

#### **Mission-specific Sub-systems:**

*Propulsion:* MSSS has teamed with Stellar Exploration Inc, to provide propulsion and power subsystems as well as mission support. The propulsion system utilizes hydrazine and nitrogen tetroxide as the propellants for the eight 5-N axial thrusters which are used for the major maneuvers. 152 kg of propellant is stored in the common-bulkhead titanium tank that is the largest single component of the spacecraft and used as the primary structure to which the rest of the components are attached. This large propellant mass fraction gives MSO a 3200 m/s  $\Delta V$  capability, enabling it to reach Mars Synchronous Orbit from a GTO starting point. The pump-fed thrusters can be throttled to control pitch and yaw during main engine burns. The low pressure tanks simplify launch integration even for rideshare payloads, and is preferable from launch safety risk perspective.

*Power:* Six Stellar Exploration flight proven battery modules have extensive heritage from the Iceye radar satellites and others missions. This 400 Wh battery supports continuous science and communication activities even for the longest 79 minute Mars eclipse period. The power distribution and regulation electronics is similarly based on heritage designs. DHV is providing the MSO solar array producing at least 172 Watts at the maximum distance from the sun while the spacecraft is Earth-pointed.

*Payload:* MSO features seven cameras from MSSS to image the entire disk of Mars including  $\geq 100$  km above the limb. The visible light C50 camera will provide RGB color images of Mars with a Bayer pattern filter on its 1944x2592 pixel CMOS detector at 3.2 km Nadir scale and 7.7 km scale at the edge of the FOV. Six mid- to long-wave infrared IR3C cameras employ the uncooled SCD 640x480 microbolometer with custom optics and filters to provide between 26.7 and 32.1 km Airy Disk scale at the edge of the FOV. The mid-wave IR channels are centered around 7.9  $\mu\text{m}$ , 9.3  $\mu\text{m}$ , and 11.8  $\mu\text{m}$  to observe surface temperature, atmospheric dust opacity, and water ice

opacity respectively. The long wave IR channels are designed to observe between 14.1 and 15.0  $\mu\text{m}$  to recover atmospheric temperature over three altitude bands. Observations will be made of the entire visible Mars disk every 15 minutes for an entire Mars year in the baseline mission.

**MSO Objectives:** The primary objective is to get into Mars orbit. We selected a Mars synchronous orbit at 0°N, 254° W, that views the Curiosity, InSight, and Perseverance landers at about 11° emission angle. MSO can communicate at maximum data rates with all three landers simultaneously, and at any time of day (on Earth or Mars), enabling 24/7 operations. MSO is a tech demo for legacy surface comm systems. A network of  $\geq 3$  would provide global coverage.

The primary science objectives are to continue 27 years of orbital monitoring of the surface and atmosphere of Mars at visible and thermal IR, at scales amenable to analysis by GCMs and other models. A constellation would provide global coverage.

To meet the objective of increasing the number of Mars launch opportunities, we recognized that GTOs provide a perigee velocity of 90% of escape velocity. GTO rideshare launches are much less expensive and greatly outnumber launches to Mars. We designed our ESPA-class S/C and propulsion system (220 kg wet mass) to launch before the nominal Mars launch date during a given opportunity, providing flexibility for finding a ride. Early launches then raise their apogees to cis-lunar storage orbits, and phase the perigee to occur on the date of the requisite TMI.

**Costs:** Prior to starting development of MSO, we spent ~\$6M performing concept and design studies. Our total Phase A-D costs, of which ~38% has already been spent, is ~\$16M. Phase E costs, including pre-launch DSN testing, launch, DSN tracking and data collection during Cruise and in-orbit, and mission operations in orbit, are estimated to be ~\$6M. Duplicate S/C would cost \$16M, and ~\$3M for operating each. A four S/C network costs ~\$75M, or \$100M with 33% reserve.