**MICRO/NANOSATELLITE MARS NETWORK FOR GLOBAL LOWER ATMOSPHERE CHARACTERIZATION.** M. L. Tinker, NASA Marshall Space Flight Center; Systems Development, Integration and Test Division/ES60, Huntsville, AL 35812; mike.tinker@nasa.gov.

**Overview:** To address multiple key challenge areas for robotic exploration of Mars, to achieve scientific goals and reduce risk for future human missions, a micro/nanosatellite constellation for lower atmosphere characterization is proposed. A microsatellite design is discussed that can operate (1) in tandem with another microsat or (2) as a "mother-ship" to deploy a network of nanosatellites (CubeSats). Either configuration of the network would perform radio occultation-based atmospheric measurements. Advantages of the proposed network are low development cost based on an existing microsatellite bus, and proven performance of the bus to date. Continued efforts in miniaturization of instruments are needed to fully enable the mother-ship/nanosat version of the proposed network.

**Science Goals and Human Exploration Risk Reduction:** Global measurement of lower atmosphere winds, densities, and additional characteristics will not only address major Mars science goals but also reduce risk for human missions to the surface. For example, understanding and prediction of lower atmosphere winds and large-scale dust events could greatly enhance successful/safe execution of crewed landings. Further, goals for Mars atmospheric science in the coming decade include (1) wind structure from the surface to upper atmosphere, (2) dust distribution, particularly during dust storms, and causes of global dust events, (3) water distribution, (4) trace gas chemistry, and others [1]. To help answer these questions, high vertical resolution observations of the atmosphere from orbit to determine global variations of pressure, temperature, winds, and other components from the surface to upper atmosphere are needed.

**Description of Micro/Nanosatellite Network:** The proposed architecture shown in Figs. 1-2 is based on development and flight experience with a microsat bus (FASTSAT) and deployed payloads that are currently in operation in low earth orbit. A Mars orbiter version of the microsatellite would provide average power of at least 100W, to accommodate the sensor suite required for atmospheric profile measurements.

The proposed micro/nanosat constellation could be configured in two different mission architectures for Mars atmospheric measurements using satellite-to-satellite radio occultations (RO), depending on progress in miniaturized instrument technology in the near future: (1) network of two or more microsatellites using existing technology (Fig. 1), or (2) network of microsat (mother-ship)-deployed CubeSats with advanced technology RO system (Fig. 2).

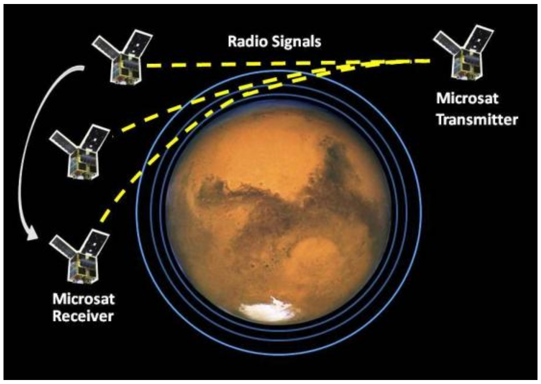


Figure 1. Dual Microsatellite Version of Proposed Network Performing Radio Occultation Measurements

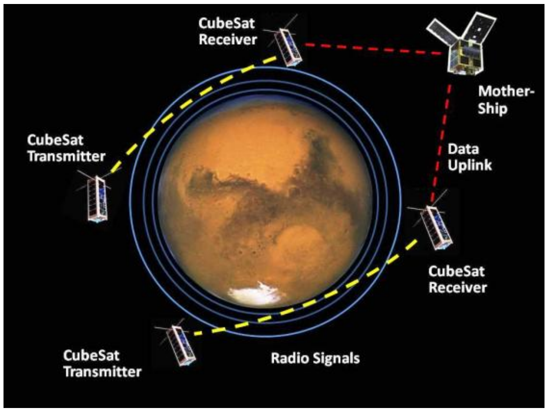


Figure 2. Mother-Ship/Nanosat Network Performing Radio Occultation Measurements

**Radio Occultation Measurements and Feasibility of Micro/Nanosat Network:** The RO measurement technique has been proven in previous missions (Mariner 4 and Mars Global Surveyor) [2]. Additionally, occultation sounding has been demonstrated for earth climate monitoring [3-5]. The RO method is based on refraction of radio waves passing through a planetary atmosphere (Figs. 1-2). Atmosphere refractivity gradients depend on gradients of density, temperature, pressure, and water vapor, and electron density [5], and can be processed to determine atmospheric variables.

*Feasibility of Architecture 1: Dual or Multiple Microsat Network.* Comparison of the mass and power requirements for science instruments required for Mars RO atmospheric measurements shows that the first architecture appears feasible using existing technology. Example calculations are presented for the enhanced FASTSAT described in Fig. 3 and Table 1. Instruments described in [2] for a Mars climate mission are (1) 300GHz RO system (estimated 30kg, 38W), (2) thermal IR limb emission ice/dust sounder (est. 9kg, 2W), (3) near-IR solar occultation instrument (est. 7kg, 17W), and (4) thermal emission spectrometer (est. 15kg, 18W). The total estimated mass and power budget for these instruments (divided between two microsats) is 61 kg and 73W, and comparison with Table 1 suggests feasibility of the multiple microsat architecture for RO atmospheric measurements.

Larger numbers of satellites increase the number of possible occultation profiles per day, but also increase complexity and cost of the mission. A mission with 2-4 microsatellites and potential nanosatellite payloads appears feasible for a single launch platform.

Figure 3. Enhanced Microsat with CubeSat Deployers

*Feasibility of Architecture 2: Mother-Ship/Nanosat Network.* The second proposed architecture for Mars atmospheric measurements is a network of microsat-deployed nanosats, as shown in Fig. 2. One FASTSAT -type microsat can deploy 12 1U or four 3U CubeSats. This architecture as shown for CubeSat-to-CubeSat radio occultation to the Martian surface is expected to require continued technology advancement for miniaturization of transmitters and receivers, and improved signal-to-noise ratios. As described in [6], the use of nanosatellites for science applications is still in its infancy. In the examples for CubeSat earth atmospheric missions that follow, it is recognized that the instruments would require different designs and specifications for application to Mars missions.

As a first example that suggests feasibility of CubeSats for Mars radio occultation atmospheric measurements, [6] describes a unique mission to determine variations of several key constituents and parameters in earth's lower thermosphere (90-320 km) with a network of 50 double CubeSats having identical sensors. Observables could include total mass density, densities of atmospheric constituents, temperature or wind speed, and signal sounding using GPS L-band signals.

| | |
|---|---|
| **Total Mass (kg)** | 180 |
| **Stabilization** | 3-Axis |
| **Attitude Control/Knowledge** | 0.1°, 0.02° |
| **S-Band Downlink (Mbps)** | 5 |
| **S-Band Uplink (kbps)** | 19.2 |
| **Mission Life** | 2 yr |
| **Payload Mass (kg)** | 60 |
| **Payload Power (W)** | 100 - 120 W Avg<br>250 - 350 W Peak |
| **Payload Volume (cc)** | 120,000 |
| **Payload Data (MB)** | 7,800 |

Table. 1. Properties of Enhanced Microsat

The second example potentially demonstrating feasibility of CubeSats for Mars atmospheric measurements is the CanX-2 mission [7], which utilized a miniaturized (100x60x16mm, 60g, 1.6W) GPS receiver. The CanX-2 mission accomplished ionospheric radio occultations, but the current system was not able to deliver tropospheric occultation measurements due to low carrier-to-noise-density ratios. The operation of the CanX-2 GPS receiver is also limited to short data takes, due to power and onboard data storage constraints. Use of the mother-ship shown in Figs. 2-3 for communication and data uplinks from CubeSats could relieve such operational concerns.

**Mission Cost and Launch/Transportation Concepts:** The proposed micro/nanosat network could be transported to Mars using a low-cost system such as the Russian Zenit launch vehicle and Phobos-Grunt probe, which carried the Chinese Yinghuo-1 microsatellite. Total cost of the failed Phobos-Grunt mission was reported as approximately $160M.

Costs for micro/nanosatellite development are reduced based on existing platforms such as FASTSAT and CubeSats. Considering the launch/transportation system costs, total mission cost could be as low as $330M for Architecture 1 with dual microsats and $250M for Architecture 2 with microsat mother-ship and four 3U nanosats. Improved redundancy of satellite systems could increase these costs more than 50%.

**References:** [1] Mischna M. A. et al. (2009) *Planet. Sci. Dec. Surv. White Paper.* [2] Kursinski E.R. et al. (2009) *Planet. Sci. Dec. Surv. White Paper*. [3] Steiner A. K. et al. (2001) *Phys. Chem. Earth (A), 26*, 113–124. [4] Wickert J. et al. (2005) *Annal. Geoph. 23*, 653-658. [5] Luntama J.-P. et al. (2008) *BAMS, Am. Meteor. Soc.*, 1863-1876. [6] Gill E. et al. (2010) *IWSCFF-2010-Paper-4-2, 6th Intl. Workshop on Sat. Constell. and Form. Flying.* [7] Kahr E. et al. (2011) *GNC 2011, 8th Intl. ESA Conf. on Guid., Nav. and Ctrl. Sys.*


# Micro/Nanosatellite Mars Network for Global Lower Atmosphere Characterization

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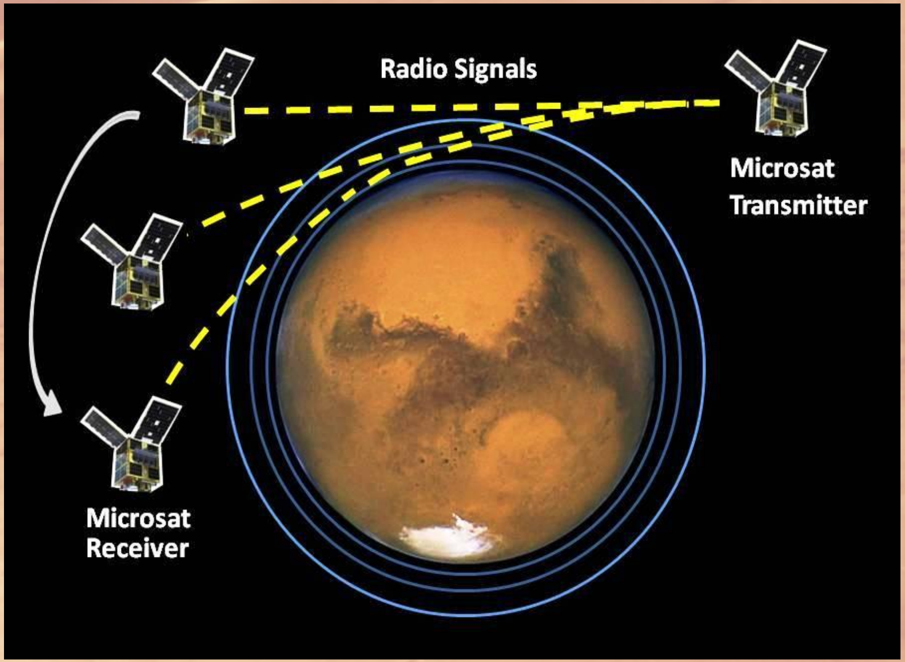
# Human Mission Risk Reduction and Science Goals

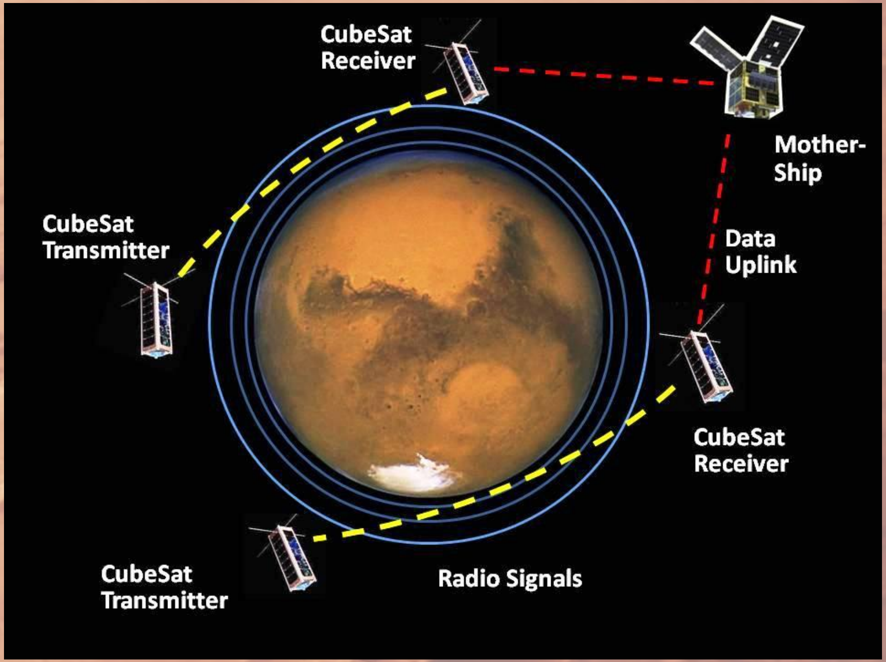
- **Global measurement of lower atmosphere winds, densities, and additional characteristics will not only reduce risk for human missions to the surface, but also address major Mars science goals:**
  - **Understanding and prediction of lower atmosphere winds and large-scale dust events could greatly enhance successful/safe execution of crewed landings**
  - **Mars atmospheric science measurement goals in the coming decade include (Ref. 1):**
    - **(1) Wind structure from the surface to upper atmosphere,**
    - **(2) Dust distribution, particularly during dust storms, and causes of global dust events,**
    - **(3) Water distribution,**
    - **(4) Trace gas chemistry, and others**

- ***To reduce risk for human missions and address these science goals, high vertical resolution observations of the atmosphere are needed to determine global variations of pressure, temperature, winds, and other components***

# Proposed Mars Satellite Network



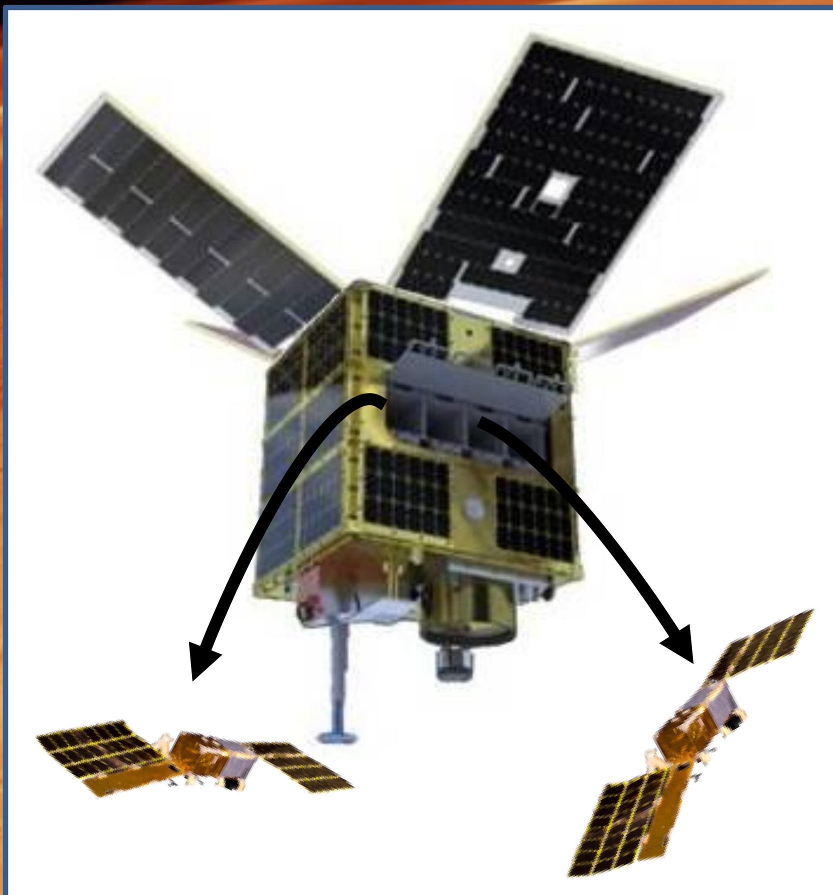

**Dual Microsat Architecture**




**Mother-Ship/CubeSat Architecture**

# Microsat Bus for Proposed Network

## Characteristics for LEO Version



| | |
|---|---|
| Total Mass (kg) | 190 |
| Bus Dimensions | 24" x 28" x 38" |
| Stabilization | 3-Axis |
| Attitude Control | +/- 1 - 2° |
| Attitude Knowledge | 0.1° |
| Downlinks (Mbps) | 1 (S-band)<br>150 (X-band) |
| Uplink (kbps) | 300 max (S-band) |
| Mission Life | 6 months - 1 yr |
| CubeSat Payload Capacity | 2x6U or 4x3U CubeSats |
| Total Payload Mass | 24 kg |
| Payload Power (W) | 100 - 120 W Avg<br>250 - 350 W Peak |
| Propulsion Capability (m/s) | 174 Delta-V |
| Propulsion Mass (kg) | 42 |
| Propulsion Volume (cc) | <50,000 |

**Enhanced Microsat with CubeSat Deployers**

# Feasibility of Dual Microsatellite Network

•*Assessment of the mass and power budgets for science instruments required for Mars RO atmospheric measurements (Ref. 2) shows that the first architecture appears feasible using existing or near-term technology:*

| Instrument | Mass (kg) | Power (W) | Reference |
|---|---|---|---|
| 300GHz RO system | 10-30 (estimate) | 18-38 (estimate) | Blackjack and Metop/GRAS (GPS receiver units only) |
| Thermal IR limb emission ice/dust sounder | 9 | 2 | MCS |
| Near-IR solar occultation instrument | 7 | 17 | SOIR |
| Thermal emission spectrometer | 15 | 12 | MGS |
| TOTALS | 41-61 | 49-69 | |

- **Comparison of total mass/power with FASTSAT capabilities suggests feasibility of the dual microsat architecture for RO atmospheric measurements. Dual microsats would each need approximately 20-30 kg and 25-35 W payload capability.**

•**Larger numbers of satellites increase the number of possible occultation profiles per day, but also increase complexity and cost of the mission. A mission with 2-6 microsatellites and potential nanosatellite payloads appears feasible for a single ESPA launch platform.**

# Readiness of Microsats for Mars Network

## *Technical Community Assessment*

- ***Numerous authors and organizations have proposed use of small satellites for Mars missions, including Abstracts 4357, 4273 , 4124, 4155 for this workshop, and Refs. 13-14***
- **Microsats for Mars missions were described by JPL researchers in the late 1990's and early 2000's (Refs. 13-14)**
- **Microsats and small sats appear to be ready for ambitious Mars atmospheric missions as described in Ref. 2, utilizing current and near-term technology:**
    - **Current dual microsat concept was shown to be feasible for accommodating instruments required for human precursor and science atmospheric missions**
    - **<u>Abstract 4124</u>: Mother-ship deployer is also suitable with current technology as a relay for CubeSats, passing data to earth through a standard radio**
    - **<u>Abstract 4155</u>: Mars orbiting constellation can be augmented by having ESPA-sat (mother-ship) host CubeSats, which would be deployed after ESPA-sat is in Mars orbit**
- **Microsats are compatible with mission for sub-millimeter wave spectrometer (SWS) in Mars orbit (Abstract 4105) to provide precise wind, temperature, and trace gas constituent measurement capability**

# Readiness of CubeSats for Mars Network
## *Technical Community Assessment*

- ***Many organizations have proposed use of CubeSats for Mars atmospheric missions, including Abstracts 4124, 4155 , 4099, 4277 (presented) for this workshop and Refs. 6-7***
- **Use of nanosatellites for science applications is still in its infancy, though CubeSat earth orbital missions have been successful (CanX-2, FASTSAT/CubeSat/NanoSail-D, RAX and RAX-2)**
- **Current study/proposal suggests ambitious atmospheric mission (Ref. 2) requires efforts in miniaturization of instruments for CubeSat-to-CubeSat RO, thermal IR limb emission ice/dust sounding, near-IR solar occultation, and thermal emission spectrometry (Table on Chart 6)**
- **Use of constellations with more limited instrumentation and redundant CubeSats appears feasible using current and near-term technology:**
    - **CanX-2 mission described in Ref. 7, which utilized a miniaturized (100x60x16mm, 60g, 1.6W) GPS receiver, accomplished ionospheric radio occultations, but the system was not able to deliver tropospheric occultations due to low carrier-to-noise-density ratios**
    - **Operation of the CanX-2 receiver is also limited to short data takes, due to power and onboard data storage constraints**
- **Abstract 4124/4277: CubeSats can be launched with up to 90% volume available for payloads (1U if CubeSat has propulsion), including deployable antennas, power systems, batteries, C&DH, and UHF radios capable of communication with nearby spacecraft; cost per unit typically < $50K**
    - **Current CubeSat technology can provide up to 30W at Mars**
    - **Instruments can provide wide range of science applications, including radio science, geology, chemistry, astrobiology**
- **Abstract 4155: Mother-ship/CubeSat constellation would provide high spatial/temporal resolution for monitoring of dust/CO2/H2O cycles**
    - **Each CubeSat would carry a single science instrument, with 1-3 duplicates in constellation**
    - **Parent ESPA-sats serve as data relays from CubeSats to earth**

# Engineering Considerations for Use of Microsats and CubeSats in Mars Network

- Propulsion requirements must be determined for orbit achievement/maintenance
- Attitude control system options affected due to absence of magnetic field and GPS:
  - Magnetic torque rods cannot be used
  - Reaction wheels combined with cold gas thrusters are an option
  - Star trackers required for determining position/altitude in absence of GPS or magnetic field map
- Solar power available at Mars is approximately 600 W/m², requiring solar array area approximately doubled in comparison to earth orbit, with corresponding mass increase
  - Could present particular challenge for CubeSats, requiring large deployable solar arrays or power beaming from mother-ship
- Radiation-hardened or redundant electronics are needed:
  - Micro/nanosats in Mars orbit are exposed to deep space radiation environment, which can cause “upsets” or loss of electronic components
  - CubeSat components typically not designed for long exposure to space environments
  - Use of shielding, rad-hardened electronics or systems with single upset immunity increase the costs significantly
    - For CubeSats, multiple spacecraft can provide redundant instruments
- Propellant depot could be required for long-term micro/nanosat Mars mission:
  - Orbit maintenance could exhaust propellant supply and shorten life of mission
  - Existing microsat or an additional one could provide propellant depot function
  - Remaining micro/nanosats would require propulsive and automated rendezvous and capture capability to allow refueling

# Mission ROM Cost and Launch Concepts for Mars Network

- The proposed micro/nanosat network could potentially be transported to Mars using a low-cost system such as the Russian Zenit launch vehicle and Phobos-Grunt probe, which carried the Chinese Yinghuo-1 microsatellite
    - Total cost of the failed Phobos-Grunt mission was reported as approximately $160M
- Other launch/transportation options include Minotaur IV, Falcon, Delta, and Atlas launch vehicles with probe to carry micro/nanosats to Mars orbit
- Costs for micro/nanosatellite development are reduced based on existing platforms such as FASTSAT and CubeSats:
    - Considering the launch/transportation system costs, total mission ROM cost could be on the order of $500M for Architecture 1 with dual microsats, and $375M for Architecture 2 with microsat mother-ship and four 3U nanosats
    - These costs include ROM estimates for improved redundancy of satellite systems, including rad-hardened electronics or duplicate instruments (assumed 50% increase over bus instruments/electronics for LEO satellite)

# Backup

## *Related Abstracts and References*

# Additional Abstracts for Mars Small Sats

- Abstract 4357, An Orbiting Mars Atmosphere, Gravity, Navigation and Telecommunications System, E.R. Kursinski, et al.:
  - Proposed constellation of several small satellites to provide (1) global weather, climate, and trace gas observing system, including precise wind and density data needed for Entry, Descent and Landing (EDL), (2) radio navigation for EDL and rendezvous with orbiting sample return canisters, (3) high resolution gravity mapping, and (4) telecommunications relay
  - Precise knowledge of wind and density structure in lower atmosphere critical for safe EDL for future human missions and for sample return
  - Understanding Mars climate (particularly $CO_2$, $H_2O$, and dust cycles, and initiation of dust storms) remains fundamental science focus
  - Establishing trace gas inventory is critical to search for life and a successful sample return mission
  - Core instrument capable of answering these questions would probe the Martian atmosphere in the 320-360 GHz frequency bandwidth:
    - Instrument would operate in three modes: satellite-to-satellite radio occultation (RO), solar occultation (SO), and thermal emission (TE)
      - Instrument would profile line-of-sight winds by profiling absorption or emission by CO and its isotopes via RO, SO, and TE
    - Prototype has been developed for earth climate/weather applications
    - Strength of radio occultation (RO) for science and EDL is high vertical resolution (60m) right to the surface, with reasonable cost compared to other approaches
      - RO is well established in planetary science, and GPS RO is one of most important data sets for earth numerical weather prediction
      - RO can profile boundary layer height and strength of turbulence, providing new information critical to NWP modeling of winds
      - Two counter-rotating satellites could yield about 40 daily atmospheric profiles of pressure, density, temperature, winds, turbulence and trace gas concentration
    - Adding near-IR solar occultation spectrometer such as SOIR or ACE would add a number of key trace gas species
    - TE wind measurements are also valuable because both horizontal components can be measured continuously between RO and SO events
    - Addition of small thermal IR instrument derived from MCS would allow measurement of aerosols , which with the other measurements could increase understanding of dust storm formation

# Additional Abstracts for Mars Small Sats

- <u>Abstract 4124, Secondary Nanospacecraft Survey of the Martian Moons, A.T. Klesh and J.C. Castillo-Rogez (Print Only):</u>
  - Deployment of multiple nanosats at Phobos, with ESPA-class mother-ship similar to LCROSS
  - CubeSats can be launched with up to 90% volume available for payloads, including deployable antennas, power systems, batteries, C&DH, and UHF radios capable of communication with nearby spacecraft; cost per unit typically < $50K
  - Current CubeSat technology can provide up to 30W at Mars
  - Mother-ship deployer can work as a relay, passing data to earth through a standard radio
  - CubeSat engineering considerations for Mars: Protect from deep space environment during cruise phase, use rad-hard processors, shield avionics boxes, or provide multiple spacecraft with duplicate instruments for redundancy
  - Instruments can provide wide range of science applications, including radio science, geology, chemistry, astrobiology

- <u>Abstract 4155, ESPA-Based Multiple Satellite Architecture for Mars Science and Exploration, A.S. Low, et al. (Print Only):</u>
  - Deployment of multiple LCROSS-type satellites (approx. 600 kg) in Mars orbit
  - Use of ESPA-ring design to allow stacking of up to four satellites in an EELV-class launch vehicle
  - Interior of ESPA ring can accommodate diverse set of science instruments
  - One constellation option is to use mother-ship for major communications/propulsion equipment, and to function as relay satellite for the other ESPA-sats
  - After orbit insertion, ESPA-sats separate and use their own propulsion to move to desired orbits
  - ESPA-sat fleet can provide global atmospheric monitoring for winds, dust storms, and $CO_2/H_2O$ cycles; can provide GPS-like system for tracking of surface assets and for communication with earth
  - Mars orbiting constellation can be augmented by having ESPA-sat host CubeSats, which would be deployed after ESPA-sat is in Mars orbit:
    - Constellation would provide high spatial/temporal resolution for monitoring of dust/$CO_2/H_2O$ cycles
    - Each CubeSat would carry a single science instrument, with 1-3 duplicates employed in the constellation
    - Parent ESPA-sats serve as data relays from CubeSats to earth

# Additional Abstracts for Mars Small Sats

- <u>Abstract 4099, CubeSat Constellation for Communications and Mars Radio Monitoring, T.B.H. Kuiper, et al. (Print Only):</u>
  - Constellation of small communication relay satellites, providing a time-delay-tolerant packet-switched network, could operate as array of orbiting sensors for Mars atmospheric electrical activity
  - This constellation could be flown as augmentation of larger mission, not requiring separate launch
  - Delay Tolerant Networking (DTN) technology can autonomously manage disconnections and disruption of the communications network
  - Relative motion between CubeSats and main relay orbiter allows data mule relay networking even when inter-CubeSat distances are very long
  - Complete coverage of Mars would require approximately 60 CubeSats at altitude like MRO:
    - CubeSats could be delivered in stages as part of series of missions
    - Altitude and degree of coverage balanced against satellite complexity/cost
    - Patch antennas, 1W transmitters, and 1 km separation provides baud rate of 600
    - Similar CubeSat-based networks have been studied for earth orbit

- <u>Abstract 4277, Interplanetary Sample Canister for Mars Sample Return, N.J. Strange, et al.:</u>
  - Development of sample canister for lower cost Mars Sample Return mission using CubeSat technology
  - Rapid pace of CubeSat development in recent years is bringing technology close to level needed for deep space missions
    - Existing or near-term technology provides capability for power, communications, thermal control, attitude control, and C&DH at Mars
    - CubeSat package would include: propulsion, flight computer for C&DH, data storage, S-Band and UHF radios, battery, MEMs gyros and sun sensors for pointing, solar arrays for 40W at 1AU, and 1U payload
      - Computer, power system, battery, UHF and S-Band radios, and antenna switch have LEO flight heritage from RAX and RAX-2; solar panels and deployment mechanism flew on USC Mayflower
    - Technology development basically limited to propulsion: authors' low-mass/low-power, high specific impulse system would enable 3U CubeSats to travel from Mars to earth

# Related Abstracts for Atmospheric Missions

- <u>Abstract 4105, Direct Measurement of Winds from Mars Orbit, M. Allen, et al. (Print Only):</u>
    - A central Mars exploration goal identified in 2013-2022 Decadal Survey is to characterize Mars' atmosphere and climate; global atmospheric wind structure is one top measurement goal
    - A sub-millimeter wave spectrometer (SWS) in Mars orbit would provide precise wind, temperature, and trace gas constituent measurement capability:
        - Wind/temperature measurements could help complete picture of Mars circulation
        - Trace gases in atmosphere could be signatures of subsurface biological/geological sources
        - Measurements could address human exploration knowledge gaps in atmospheric winds/temperature
        - Vertical resolution could enable probing of winds within dust storms, provide direct measurements of circulation patterns and quantify water transport as it sublimates off the polar cap
        - Conceptual SWS instrument is TRL 6 or higher ultrahigh resolution spectrometer, covering 530-590 GHz
            - Mass/power estimates are 19 kg and 73 W, respectively; cost approximately $50M

- <u>Abstract 4232, Some Requirements for Future Orbital Assets to Support Safe and Productive Landed Missions, L. Keszthelyi, et al. (Print Only):</u>
    - Landing safely on Mars in a location allowing productive science requires support from orbital assets
    - Nature of the atmosphere (density, temperature, wind profiles) greatly impact Entry, Descent, and Landing (EDL) safety; atmospheric models provide more accurate results if constrained by observations
    - Existing data sets include measurements from the Mars Reconnaissance Orbiter (MRO) MARCI and MCS instruments, providing global coverage of Mars' atmosphere useful for constraining circulation models
        - Data sets also provided by Mars Express, Mars Global Surveyor, Viking, and Mariner 9
        - Additional orbital data is required due to year-to-year changes in the atmosphere (particularly dust storms) that can alter timing of EDL events; not having up to date atmospheric information will require larger margins to be built into a landing system
    - There is a compelling need for new orbiter when MRO or MO cease to operate; minimum instrument set are (1) imager with 0.3 m/pixel ground sampling and high signal/noise ratio; (2) thermal infrared imager capable of viewing surface and atmosphere with high temporal and spatial resolution
    - Ability to quickly point instruments in different directions allows acquisition of better stereo data and eliminates the need to carry multiple instruments to observe surface and atmosphere

# Related Abstracts for Atmospheric Missions

- Abstract 4288, Mars Orbiter Optical Link Science Demonstration for Atmospheric and Interior Structure, S.W. Asmar, et al. (Print Only):
  - Radio scientists have used microwave links on Mars and other planetary orbiters to accomplish atmospheric investigations
  - A hybrid radio/optical link experiment (Radio-Light) is proposed to demonstrate first deep space link using lasers combined with radio signals typically utilized for mission communications/navigation
  - Radio-Light would be used for occultation sounding of the thermal structure and distribution of aerosols in Mars middle atmosphere:
    - Results would include accurate high-resolution profiles of number density, temperature, pressure, and opacity vs altitude
    - In one-way optical link required for these measurements, the spacecraft ultra-stable oscillator (USO) will limit performance, as it does with current radio links; high quality USO required
    - Difficult to extend optical link profiles below 10-20 km due to large opacity of atmosphere at wavelength of operation (1-1.5 microns); however, interference from ionosphere negligible at this wavelength, so profiles could be extended 20-25 km higher altitude than X-band experiments

- Abstract 4273, A Communications Network Architecture for Future Mars Missions, R. Gilstrap, et al. (Print Only):
  - Future Mars mission data must be distributed among variety of entities on Mars and earth
  - Technologies to support these missions includes small communications relay satellites with benefits due to less complex design, and cost savings due to shortened development time, simpler implementation, lower mass/power, and economies of scale from manufacture of multiple units
  - Additional key technologies include the Internet Protocol, laser communications, delay tolerant networking, mobile ad hoc networking, and wireless sensor networks
  - Each of these technologies has been proven in commercial applications and recommended for NASA missions by various individual NASA centers and the Constellation Program
    - Integrating the technologies into a single communications architecture insures interoperability among assets on Mars and earth
    - Interoperability will yield long term cost savings by enabling future assets to utilize the network

# References


[1] Mischna M.A. et al. (2009) *Planet. Sci. Dec. Surv. White Paper.*

[2] Kursinski E.R. et al. (2009) *Planet. Sci. Dec. Surv. White Paper*.

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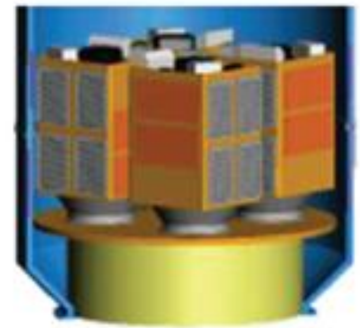
[14] Hastrup R.C. et al. (2003) *Acta Astro. 52, 227-235.*

# Microsat ESPA Launch Configuration Minotaur IV

- **Multi-payload Adaptor Plate**
  - Developed to support ESPA class SC
  - Holds up to 4 ESPA SC
  - Utilizes all lift capability
  - First demonstration STP-S26
  - ILC early FY10



**Small ESPA rings can enable launch of up to six microsats**