

Trajectory Options for a Potential Mars Mission Combining Orbiting Science, Relay and a Sample Return Rendezvous Demonstration

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Abstract: Mars sample return is a major scientific goal of the 2011 US National Research Council Decadal Survey for Planetary Science [1]. Toward achievement of this goal, recent architecture studies have focused on several mission concept options for the 2018/2020 Mars launch opportunities [2]. Mars orbiters play multiple roles in these architectures such as: relay, landing site identification/selection/certification, collection of on-going or new measurements to fill knowledge gaps, and in-orbit collection and transportation of samples from Mars to Earth. This paper reviews orbiter concepts that combine these roles and describes a novel family of relay orbits optimized for surface operations support. Additionally, these roles provide an intersection of objectives for long term NASA science, human exploration, technology development and international collaboration.

Keywords: Mars, Relay Orbit, Sample Return, Surface Operations

1. Introduction

The progression of Mars Sample Return mission architectures has converged on a multiple mission concept that retires risky elements through early demonstrations and relies on both orbiters and landers to ultimately return samples that maximize science objectives. With missions such as the Mars Exploration Rovers, Phoenix and the Mars Science Laboratory, safe landing and sample collection are considered proven elements. Remaining to be demonstrated is: launch to low Mars orbit and orbiting sample detection, rendezvous, and capture.

Ideally, all elements would be verified prior to a first sample return campaign. Looking forward to the 2018 Earth to Mars launch opportunity, combining an orbiting sample detection, rendezvous, and capture demonstration with an orbiting science mission would be a cost effective way to retire those elements. In addition, the orbiter could serve as an *in-situ* communications relay for surface assets such as MSL or the recently selected Discovery class mission called InSight – a Mars lander planned to begin surface operations in late 2016. Trajectory options are presented in this paper to accomplish the combination of these functions in a single mission.

Recently a NASA Mars Program Planning Group (MPPG) released a report [2] detailing technical pathways for robotic demonstrations and human precursor missions in support of Mars sample return. The trajectory options presented in this paper are consistent with the architectures proposed by the MPPG.

2. Orbiter Science for Sample Return

2.1. Detection and Source Location of Key Atmospheric Gases

An orbiter with good global coverage (i.e., high inclination) and an orbit plane motion that repeats several times during a Mars year enables collection of a comprehensive set of atmospheric solar occultation measurements. From these measurements many types of atmospheric gases can be detected and their surface origin determined. Detection of trace gases such as methane may reveal subsurface organic processes and influence the selection of the location for surface samples. Instrumentation required for detection and localization includes a highly sensitive mass spectrometer and a high resolution imaging system.

Due to budgetary constraints, NASA recently decided to cancel participation in the ExoMars/Trace Gas Orbiter (TGO) mission with the European Space Agency (ESA). The joint mission was to launch in January 2016. As the name implied the TGO mission was ideal for collecting atmospheric measurements. Presently, the mission is expected to continue as collaboration between ESA and the Russian Federal Space Agency (Roscosmos). It remains unclear if the restructured mission will retain the capabilities to detect and localize key atmospheric gas sources such as methane.

Prior to NASA's withdrawal from the ExoMars/TGO mission, an extensive orbit design was completed [3]. The result was a near circular, low altitude (~393 km) orbit inclined 74 degrees. The orbit would provide excellent global occultation distribution at the poles and the equator while producing repeating ground tracks with spacing less than 8 km apart at the equator over a long period of time.

3. Orbiting Sample Detection, Rendezvous, and Capture

Many Mars sample return studies have assumed multiple launch options [4]. A lander mission with an ascent vehicle places the sample in low, circular Mars orbit and a separate orbiter mission performs detection, rendezvous and sample capture followed by a transfer back to Earth. Constraints on the Mars Ascent Vehicle (MAV) limit the circular orbit altitude of the delivered sample to less than 500 km. The inclination could be targeted to the rendezvous orbiter without a serious propellant penalty.

Detection is ideally performed from a higher altitude orbit with a significantly different orbital period. After detection and determination of the orbiting sample trajectory, the orbiter matches the injected inclination, eccentricity and altitude. Terminal rendezvous and capture are then executed. These functions are simplest in the resulting circular orbit.

For the 2018 opportunity, without a MAV component, an experimental sample canister could be carried by the orbiter and released in the low, circular orbit to enable detection, rendezvous and capture in an operational environment. The resulting technology readiness level would then be raised to eight for those elements.

4. Surface Relay Support

To optimize communications relay capabilities for surface assets, there exist families of low inclination orbits that are ideal for the tactical surface operations cadence used by the MER, Phoenix and MSL missions. For 2018, following Mars Orbit Insertion, the orbiter could be placed temporarily in one of these optimal relay orbits prior to transferring to the final low circular science, relay and rendezvous demonstration orbit. Another possibility is for the orbiter to carry and deploy a dedicated smallsat/cubesat to serve as a relay element and extend the overall Mars relay infrastructure.

4.1 Relay Orbits Optimized for a Specific Surface Location

Recent Mars lander surface operations use a morning relay orbiter pass to receive instructions for the upcoming sol's activities. In the afternoon another relay pass is used to transmit science and engineering data collected before configuring the lander into a low power or sleep mode for the Martian night. There exist families of relay orbits that maintain regular morning and afternoon over flight geometries. These are derived by matching the sum of the orbit's line of apsides and nodal rates projected in the equatorial plane to the planets average orbital rate around the sun as follows:

$$\dot{\bar{\theta}}_{Mars} = \dot{\bar{\omega}} \cos(\bar{i}) + \dot{\bar{\Omega}} \quad (1)$$

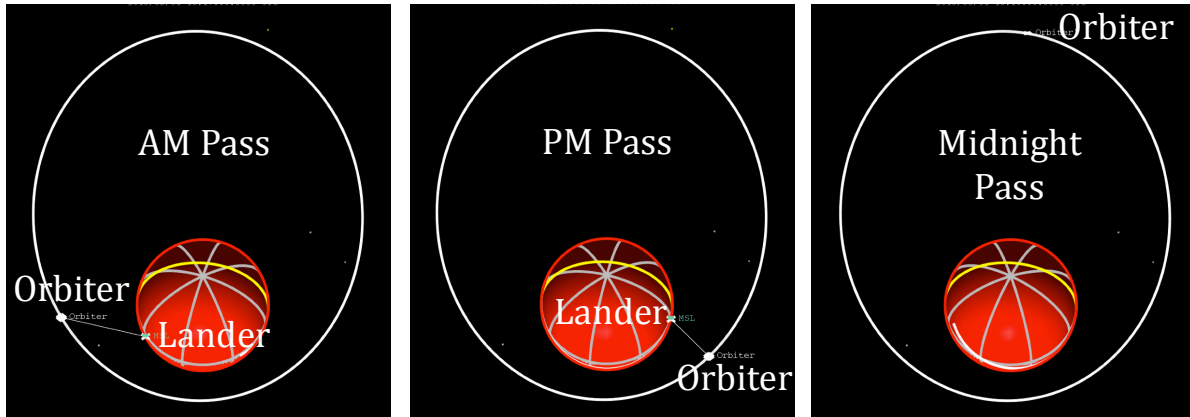
where: $\dot{\bar{\theta}}_{Mars} = \text{Average Mars orbital rate about the Sun}$

$\dot{\bar{\omega}}(\bar{a}, \bar{e}, \bar{i}) = \text{Average orbiter line of apsides rate}$

$\dot{\bar{\Omega}}(\bar{a}, \bar{e}, \bar{i}) = \text{Average orbiter longitude of ascending node rate}$

$\bar{a}, \bar{e}, \bar{i} = \text{Orbiter mean semimajor axis, eccentricity and inclination}$

By selecting an orbital period that is an integer fraction of a Mars solar day, the periapsis location remains fixed over the same integer number of equally spaced meridians. Designing the periapsis to be at Mars local noon equalizes the pass durations for the lander morning and afternoon passes. Figure 1 shows one such orbit with a period of 1/3 of a Martian day (sol), inclined 15 degrees and a periapsis altitude of about 1000 km. The combination of repeating AM/PM pass times, long duration passes at relatively short slant ranges (<6000 km) provides regular high data volume relay opportunities.



**Figure 1. Optimal relay orbit for near equatorial surface operations
(Orbit: 1/3 sol period, 15 deg inclination)**

For tactical surface operations the 1/3, 1/4, and 1/5 sol orbit periods are most practical. These yield Mars daylight passes separated by 8.2, 6.2 and 4.9 hours respectively. Three daylight passes are possible with 1/5 sol orbits. Orbit inclinations from -30 to 30 deg are possible. For the 1/5 sol orbit the inclination is narrowly defined near 30 deg. For the 1/3 sol orbit the maximum inclination is about 24 deg. Figure 2 shows the families of orbits with their apoapsis and

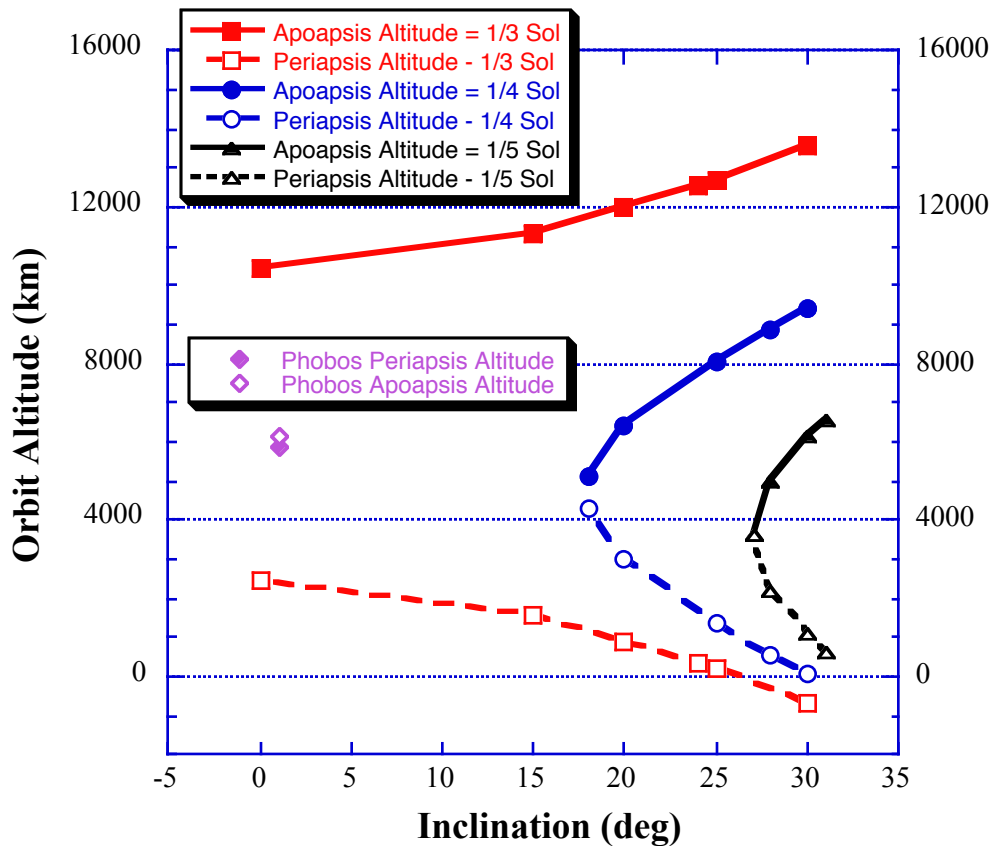
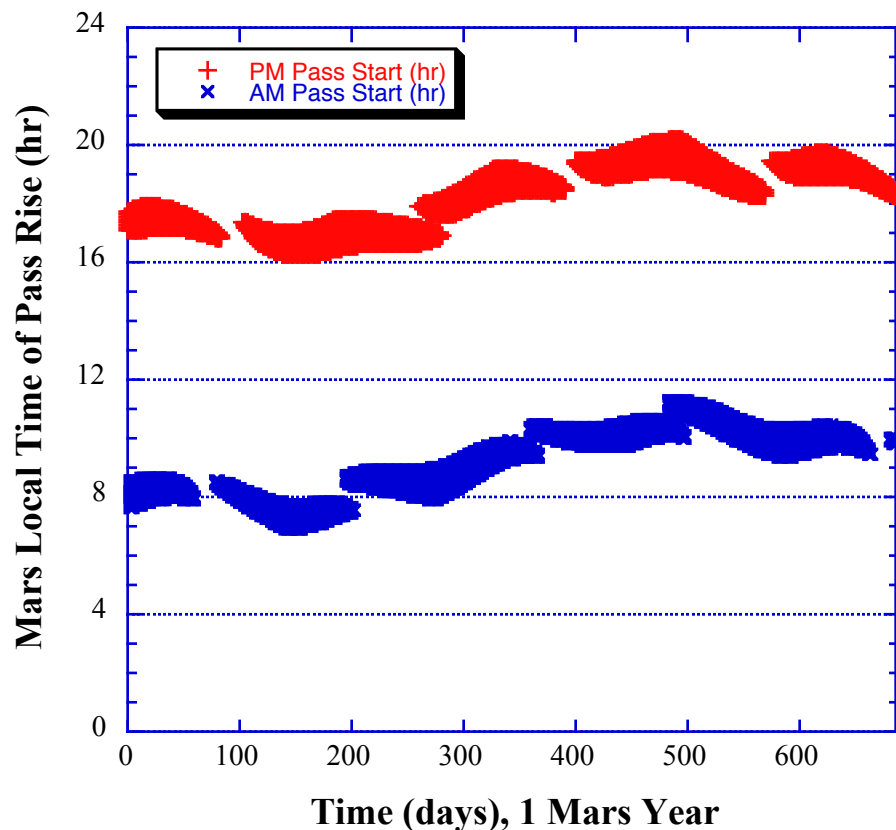


Figure 2. Mars Relay Orbit Families for Surface Operations

periapsis altitudes verses inclination. For reference, the orbit of the Martian moon Phobos is also shown. The near equatorial 1/3 sol orbit solution provides flyby opportunities when phasing permits.

The 1/3 sol orbit with 15 deg inclination solution was evaluated in greater detail using osculating orbit elements to analyze the gravitational perturbations over an entire Mars year. A 20x20 degree and order gravity field was used and the eccentricity was computed to satisfy equation (1). The Mars Science Laboratory (MSL, a.k.a. Curiosity lander) surface location was used to examine variations of local time for the morning and afternoon passes. Figure 3 shows the local mean zonal time [5] (similar to local mean solar time). It is Coordinated Mars Time (MTC) adjusted for time zone by +9 hours. The resulting variations confirm that morning and afternoon pass times are stable to within about two hours.



**Figure 3. Local Time of Passes from an Osculating Orbit
(Orbit: 1/3 sol period, 15 deg inclination)**

Passes were constrained to be above 15 deg elevation and a maximum range of 6000 km. Figure 4 shows the duration for both the morning and afternoon passes. Both range from 75 and 80 minutes.

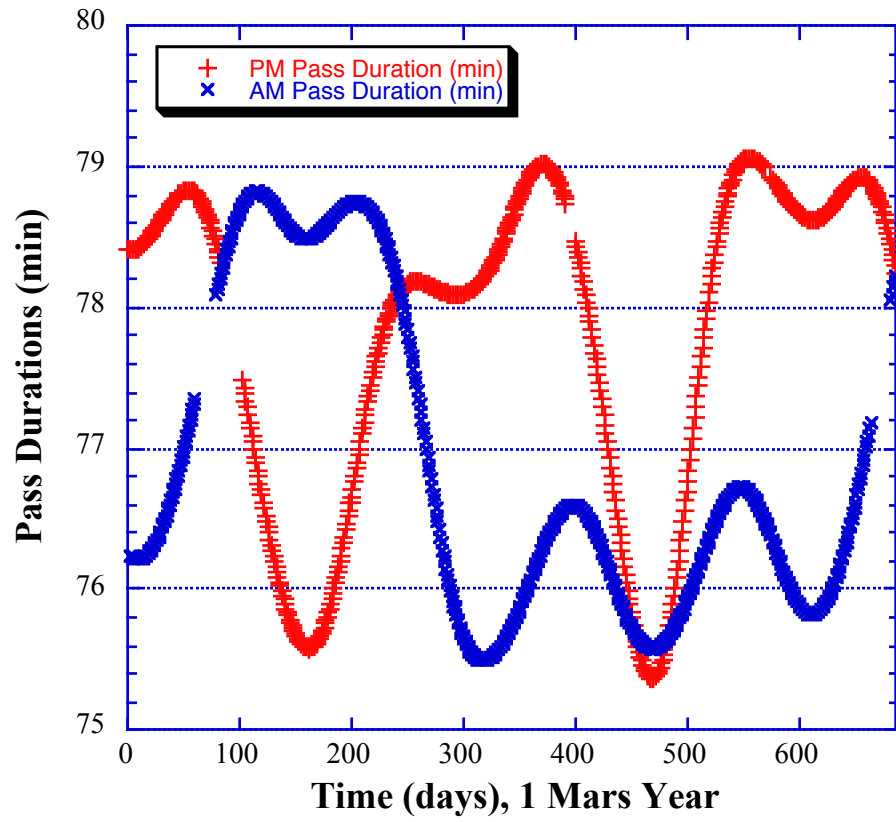


Figure 4. Pass Durations

Figure 5 shows that the elevation angles remain below 40 degrees. As a result, the minimum slant ranges are around 2000 km. Even with the low elevation and 6000 km maximum slant range constraint the passes retain ample data return due to their long duration. For example, about 500 Mbits of data could be transferred over a 70 minute pass at a relatively low average data rate of 128kb/s.

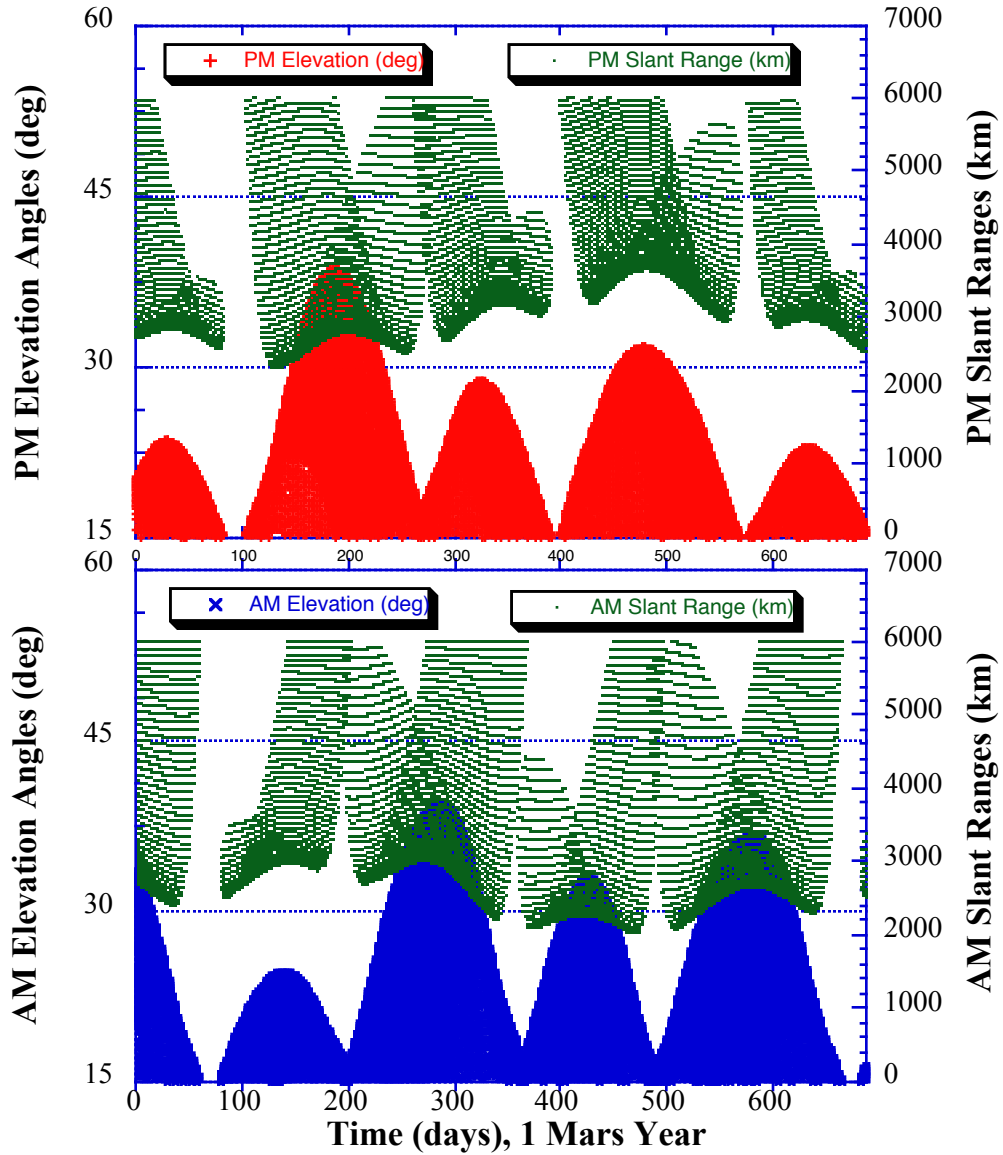


Figure 5. Pass Elevation Angles and Slant Ranges

Ground tracks are equally distributed in latitude and longitude about the MSL landing site for the AM and PM passes. For this inclination, outages are few and no longer than 20 days over an entire Mars year. With some orbit trimming it is likely these gaps could be closed and the local time of the morning and afternoon passes controlled to tighter bounds.

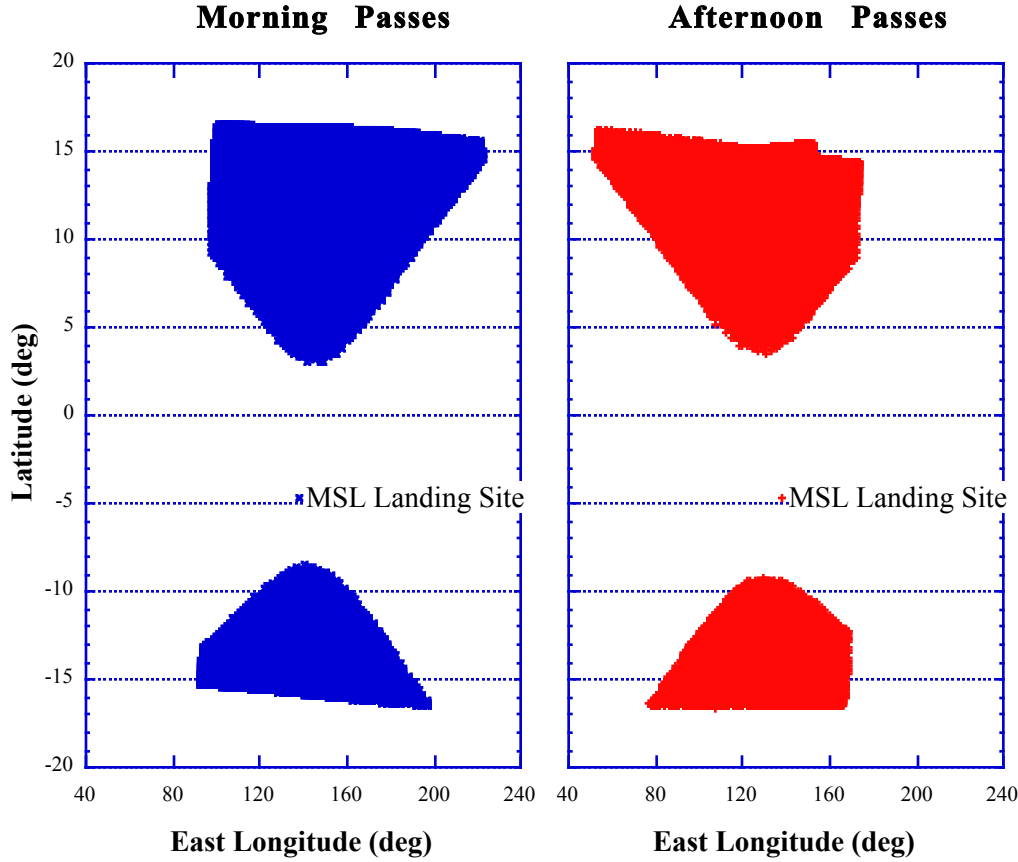


Figure 6. Ground Tracks over a Mars Year

4.2 Relay Orbits for Entry Descent and Landing Monitoring

Since the relay orbits for surface operations are tailored to support morning and afternoon communication sessions they are ideally suited to support Entry, Descent and Landing (EDL) activities that normally are constrained to take place during Martian daylight. Also, due to the significant eccentricity of the orbits the relay orbiters could be phased to high altitudes that would provide long over flights of the EDL area.

5. Conclusions

Combining science, communications relay and orbiting sample detection, rendezvous and capture into a single mission provides a cost effective way to continue high priority science recommended by the National Research Council's recommendations set forth in the recent decadal survey for planetary missions and provides an intersection of objectives for long term NASA science, human exploration, technology development and international collaboration.

6. Acknowledgements

This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California under contract to National Aeronautics and Space Administration. Copyright 2012 California Institute of Technology. Government sponsorship acknowledged.

7. References

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