Report of Planetary Comparative Review
Mission Operation and Data Analysis Programs (MO&DA)

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John Caldwell, Bruce Campbell, Anita Cochran, Michael Combi, Ted Maxwell, Melissa McGrath, Roger Phillips (Chair)

Introduction

The Planetary Senior Review Panel met July 25-26, 2000, to review requests from four missions (DS1, Galileo, MGS, NEAR) for funding within the FY01-FY03 time frame. The panel was carefully chosen to provide expertise over the scientific disciplines covered by the four missions. The charge to the panel was to evaluate the science merits - on a "science per dollar" basis - of the expected returns from the proposed programs during 2001 through 2003 within the context of the science goals and objectives described in the Space Science Enterprise Strategic Plan. As secondary evaluation criteria, after science merit, the panel was charged with assessing the cost efficiency, technology development and dissemination, data collection, archiving and distribution and education/outreach aspects of each mission. Based on these considerations, the panel was asked to recommend an implementation strategy for SSE extended missions that would include a mix of: continuation of programs "as currently baselined"; continuation of programs with either enhancements or reductions to the baseline; mission extensions beyond the prime mission phase, subject to the "Mission Extension Paradigm"; or program terminations.

All four mission requests were responsive to the SSE Strategic Plan (1997) science goal (6): "Understand the nature and history of our Solar System, and what makes Earth similar to and different from its planetary neighbors."

In general, the proposals were well written, although the panel suggests that NASA request more detailed budget information in future reviews so that a panel will have more insight into expenditures on the various tasks proposed. In particular, more breakdown between mission operations and science data analysis would be useful.

With the exception of the Galileo project, the presenters ignored instructions about not repeating details in the proposals, particularly past accomplishments. In some cases this did not leave adequate time for questions and answers.

The panel viewed the review process as worthwhile and will be interested to see if its deliberations have any impact on the four programs. The format of the review process worked well, and to complete the review process and write the summary report for the four missions took nearly all of the two days of time allotted. To evaluate more missions in this same time frame will require that mission presentations be limited to questions and answers only.

Priority Ranking of Missions

The panel ranked the future activities of the four missions on a "science per dollar" (i.e., value) basis with the following results from highest to lowest: NEAR, MGS, Galileo, DS1. On absolute science alone, the rankings were MGS, NEAR, Galileo, DS1.

The End-to-End Scientific Process

In addition to the discussion of priorities for the extended missions themselves, the panel wanted to emphasize the importance of maintaining the integrity of the scientific process from end to end. While the extended mission scenarios necessarily concentrate on data collection and calibration, careful attention also needs to be paid to the underlying infrastructure whereby data are efficiently archived and made readily accessible to the scientific community. In an era of increasing numbers of missions, even the smallest of which has the potential to collect a large volume of data, it is important to support the infrastructure in a manner commensurate with the data collection and calibration efforts. The goal is to provide a high quality data product in a user-friendly environment so that the archive becomes a viable source of discoveries and basic research for many years to come. Several panel members noted the successful archives and archival research programs maintained for astrophysics missions as well as sites created and maintained by individual PI teams, and felt that there might be potential for adopting some of the positive aspects of these programs into the PDS.

The panel recommends that NASA review the status of PDS in light of the new era of multiple missions with large data sets. NASA should ensure that PDS has: sufficient funding and adequate storage capacity to support the current data volume; consistency among different instrument teams in providing data to PDS; community standards such as a consistent header format; an efficient validation and review process required before data can be ingested; user friendly interfaces; and adequate user support.

Specific Mission Recommendations

Deep Space 1

The panel concluded that the proposed effort satisfies the SSE Strategic Plan (1997) Science Objectives 16 and 19.

The mission team is requesting support for scientific observations of comet Borrelly in September 2001. Requested funding totals about $700K over the baseline guidance, and there is approximately $6M in remaining mission costs. The bulk of the requested augmentation would cover over-runs incurred during recovery from tracker system failure and switchover to MICAS for optical navigation.

Scientific return at comet Borrelly may provide the first multispectral image cube for a comet nucleus, 25-m per pixel visible imaging, and ion flux and TOF mass spectroscopy for the coma. These are valuable scientific returns and should be achieved if the spacecraft performs nominally. Technology demonstration of auto-navigation will be severely constrained to prevent repeat of system failure at asteroid Braille. Fully testing the MICAS instrument during the flyby is deemed important.

End of mission is planned for immediately after Borrelly encounter due to lack of hydrazine attitude control fuel. Final burn of ion engine for technology validation may be desirable, but is not supported under extended mission funding.

There was some concern about the potential for scientific output from the mission due in part to the fact that the spacecraft itself has a poor performance history and that future missions will likely return considerably more robust data for similar comets. The panel recognizes that all comet missions have inherent risk due to the dusty environment. The environmental risk for Deep Space 1 is acceptable.

Summary Recommendation:

The total funding required to complete the DS-1 Borrelly flyby is relatively modest, but significant concerns regarding the value of scientific observations at the comet dictate that no further resources be allocated in the event of system failures or other anomalies.

Galileo

The panel concluded that the proposed effort satisfies the SSE Strategic Plan (1997) Science Objectives 9,12, 16, and 19.

Galileo is clearly a valuable and unique scientific resource, but one that is very expensive. In the context of limited resources for all of NASA's planetary exploration program, it may not be possible to afford the entire extended mission program as proposed by the Galileo project. The review panel has therefore prioritized the elements of the proposed Galileo extended mission with the understanding that higher priority items deliver higher science value. The panel believes that a total extended mission budget $6.5M less than the requested proposal should cover most of the highest priority elements of the proposed program. NASA Headquarters should work closely with the Galileo project to optimize the mission profile with these budgetary resources.

The panel's prioritization for the Galileo Millennium Mission (GMM) proposal's science elements is:

1. Cassini phase (G29).
2. Particle and field science during high latitude flybys of Io (I31 and I32) and a low latitude flyby (I33).

3. Imaging science during one high latitude flyby of Io (I31 or I32).
4. Particle and field science for the inner magnetosphere (A34).
5. Imaging science during a second high latitude flyby of Io (I32).
6. Imaging science for Io's Jupiter-facing side (I33).
7. Imaging science for Callisto (C30).
8. Amalthea mass measurement (A34).
9. Amalthea imaging (A34).

Priority Rationalization

1) The highest priority science in the proposed GMM is the Cassini phase, including all types of science measurements. The proposed orbital design will permit coordinated observations by the two spacecraft at two positions, one inside Jupiter's magnetosphere and one outside. It will be possible to correlate conditions in the solar wind with one local position in the magnetosphere. The complementary properties of the respective spacecraft infrared instruments will result in spectra of the Great Red Spot and of a 5 micron hot spot over a much greater spectral range than would be possible with either spacecraft, thereby extending the vertical range of temperature sounding in these regions. It will be possible to correlate dayside observations of anticyclonic regions in Jupiter's atmosphere with nightside lightning flashes, to improve the understanding of the production of lightning on Jupiter. Coordinated multispectral observations of Jupiter's aurorae (also including HST observations) will be made. At the time when Cassini is closest to Jupiter, Galileo's Dust Detector Subsystem and Cassini's Cosmic Dust Analyzer will make nearly simultaneous observations at two points along a magnetospheric dust stream originating at Io.

   This well-designed period of diverse observations will certainly be a unique opportunity to study a wide range of dynamic Jovian system phenomena in a way that no single spacecraft ever could.

2) The I31 and I32 encounters will feature high latitude flybys of Io. Together with the low latitude flyby of I33, they will enable particle and field measurements of a potential intrinsic magnetic field. It is more difficult to separate induced and permanent magnetic fields at Io than it is for the other Galilean satellites. The planned Io flybys will occur at different orientations of the Jovian dipole moment relative to Io, enhancing the possibility of detecting an intrinsic Io field. Measurement of Io's intrinsic field is important for understanding its internal structure and dynamics.

3) Imaging Io at high latitudes has the potential for determining new features of Io's remarkable surface. However, due to the high cost of maintaining the capability for carrying out imaging sequences, on a "science per dollar" basis, it is not ranked as highly as the magnetic field measurements.

4) The terminal phase of the mission (A34), which is a targeted impact on Jupiter, will provide a unique opportunity to measure the charged particle environment and the radial variation of Jupiter's magnetic field down to 1 R_J, with the consequent capability of improving models of Jupiter's magnetic field, including high order components. The science per dollar value is very high because of the relatively simple operations required.

5) Imaging Io's other polar region is of interest but, due to the high cost of continuing imaging operations, it has a lower "science per dollar" value.

6 and 7) Imaging Io's Jupiter-facing side at high resolution is another high cost, high science activity. The "science per dollar" value is not as high as for the other objectives. The same is true for Callisto at C30, but of the two, I33 is ranked more highly on a "science per dollar" basis.

8) The Amalthea mass measurement has a lower science value, because the achievable accuracy may not be enough to produce a useful value of the density. However, the cost of tracking Galileo as it flies by Amalthea, so that its gravitational perturbation may be measured, is low.

9) Imaging Amalthea is deemed lower priority than the mass measurements. The high cost of maintaining remote sensing capability through the end of the mission coupled with the high risk that the data may not be recovered gives this objective the lowest "science per dollar" value.

Mars Global Surveyor

The panel concluded that the proposed effort satisfies the SSE Strategic Plan (1997) Science Objectives 13, 14, 18, and 19.

The Mars Global Surveyor Mission has proposed to continue operations from February 1, 2001 to April 22, 2002 emphasizing a) continued mapping utilizing all five MGS experiments, b) an increase in the number of high resolution images for future landing site investigations along with supporting MOLA and TES data acquisition, and c) additional spatial coverage by MOLA, TES and MAG to reduce gaps in coverage. The in-guideline budget for this activity consists of termination of data acquisition on February 2, 2001, followed by quarantine orbit and science data archiving. A "bare-bones" operational scenario is proposed that includes continuation of only nominal data acquisition (no landing site targeting) until April 22, 2002, and only level 1 data products (noncalibrated) delivered to the PDS. The requested budget includes full mission operations through April 22, 2002, nearly full funding for investigators at their current mapping level, a small increase for participating scientists, a "guest observer" program including up to 15 scientists (at $20K each), and additional off-nadir data acquisition for studies of potential landing sites.

The consensus of the reviewers was that the need for additional data of MGS quality was well justified in the context of future studies and planned missions, and that the spacecraft health was apparently sufficient to allow these further observations to take place. (The proposed cycling of the MOLA laser would allow additional mapping gaps to be filled despite the reduced life of the instrument.) Consequently, a termination (in-guideline) strategy was not considered a wise use of NASA funding. [Subsequent to the panel meeting, plans for a lander mission for Mars '03 were announced. This further enhances the science return for the continued operation of the MGS orbiter.]

The proposed 'bare-bones' scenario, to collect data and archive without calibration was deemed completely unacceptable for several reasons. It does not provide the options for selection of specific targets for detailed study (needed for future landing sites), nor does an archive of uncalibrated data allow future investigations without a significant expense for re-constituting the calibration files and implementing procedures necessary to make the data useful.

The panel supports the proposed work at the requested operational level to ensure acquisition, processing and archiving of data at the appropriate level, but not with the particular mix of additional programs as outlined in the proposal. Specifically:

The "guest observer" program is not well enough defined in the proposal to determine how these individuals will be chosen, and the amount requested seems to be only for minimum support of these outside investigators. The panel suggests that NASA HQ investigate a range of methods to allow the community to propose sites for acquisition of data that supports scientific investigations. The panel feels that implementing a method for community involvement in choosing observing targets is more important than requiring associated funding for data analysis. The panel notes that the data acquisition and processing for these studies is included in the mission and science operations, so that another method of providing input to the mission for targeting – at no or little cost to NASA – should not require additional operational funding.

Although the proposed benefit from off-nadir targeting is well justified, it should not be undertaken without a thorough review of the trade-offs between fuel usage and the mapping capabilities that nadir viewing allows for filling in gaps (particularly near the equator). This mode of operation should be used sparingly only to obtain data for areas where nadir imaging will not be possible during the extended mission.

Because of the significant cost of the proposed operation budget, the panel notes that NASA management could justifiably request an additional iteration on the budget and its impact on operations and science. The panel suggests that NASA request additional detail regarding funding to the science team and check that this is commensurate with the additional responsibilities of the extended mission. In particular, carrying the science operations and data analysis funding at a level comparable to that of the primary mission may not be justified in the present budget climate.

With the exception of the magnetometer team, the instrument groups are doing an acceptable job of data archiving within the context of the prime mission data release policy. During the extended mission phase, the panel encourages the MGS project to speed up the data release process either through archiving data more quickly, archiving data in smaller time blocks, or a combination of these two strategies.

The panel wishes to note that Malin Space Science Systems (MSSS) is presently providing imaging data [Mars Orbiter Camera (MOC)] to the community in a scientifically useful form once it has been released. It is not clear what additional value the PDS adds during the one-year validation period, but the PDS will ultimately provide a permanent archive for the MOC data (as well the other data sets from the mission).

NEAR Shoemaker

The panel concluded that the proposed effort satisfies the SSE Strategic Plan (1997) Science Objectives 16, 17, and 19.

The panel expressed its appreciation of the excellent data set that has been and is being gathered by the NEAR mission and acknowledged that the mission's current need for more funding for archiving is driven by the fact that the mission has obtained much more data than anticipated and data reduction is more intricate than anticipated. The added value of the calibration of the data prior to submittal to the PDS is substantial because the team members are the most knowledgeable about the properties of the various data sets and the unique calibration issues. The panel noted in particular the difficulty of registration of images and spectra for an irregularly shaped object. It also agreed that the XGRS data will improve with continued observations and advocated that the mission should collect these data for as long as possible. The requested $1.8M is appropriate in light of the large task ahead.

While acknowledging the excellent data and the overwhelming data volume, the panel noted that the NEAR mission to Eros has actually produced twice as many images as both Viking missions to Mars. While much of the data offer new views and details, some of the data are repetitive in nature and just represent different spatial resolutions. The panel does <u>not</u> advocate that the mission cease to collect and calibrate data but is concerned that the project may not be able to complete all of the proposed archiving tasks within the proposed budget and schedule. Thus it would be prudent to prioritize the processing of imaging data, and the panel's suggestion is that the team focus first on the highest spatial resolution data and create four specific data products: 1) co-registered imaging and spectral data, 2) ephemeris, 3) high quality stereo pairs, and 4) a mosaicked image of the complete body at a single resolution (e.g., the USGS Clementine product for the Moon). While the panel believes that all imaging data should be archived in the PDS in calibrated form, it emphasizes that the greatest focus should be on the highest resolution data.

With the substantial volume of data that will be archived, the panel feels that it is crucial that a catalogue of data, especially imaging data, be created that accurately identifies the data subject and gives a measure of the quality. Otherwise, it will be very difficult for non-team members to utilize the database in any efficient manner. The panel noted with some concern that the quantity of data that NEAR is likely to archive will probably strain the PDS Small Bodies node. This is a problem for NASA and the PDS, and it should not discourage the mission from its archiving tasks.