W I N N I N G  N A S A  S P A C E  M I S S I O N  P R O P O S A L S

Section D. Science

by Ejner Fulsang

“I have the best job in NASA!”

(650)274-1310  efulsang@comcast.net

Ejner Fulsang © June 2011

DISCLAIMER
This document is based on my experience as a contractor with NASA Ames Research Center, Moffett Field, California. These are my personal observations and should in no way be taken as official NASA policy or the views of my parent company Orbital Sciences.

Abstract

NASA’s robotic space missions—the Phoenix Mars lander, the Magellan Venus radar mapper, etc.—are awarded through a competitive proposal process. These missions can cost from $100 to $750 million dollars, not including launch services and inflight propulsion devices. They are presented to the public first as planning documents and later as announcements of opportunity, or AOs. These AOs are released by NASA’s Science Mission Directorate about once per year for cheaper missions and every few years for higher cost missions. Team makeup usually includes a NASA Center such as Goddard Space Flight Center, the Jet Propulsion Lab, or Ames Research Center. The science team usually comes from academia, although scientists from other government agencies may participate as well. Instrumentation and spacecraft usually come from the better known prime contractors such as Northrop Grumman, Orbital Sciences, and Ball Aerospace. Producing these proposals can cost upwards of $1 million of Bid & Proposal money. Hence, it would behoove participants to know their way around the process. This article will focus on Section D of your proposal—how to develop and present a compelling science mission. Particular emphasis will be placed on the most misunderstood part of the AO, the Science Traceability Matrix.
Introduction

The easiest way to understand an Announcement of Opportunity, or AO, released by NASA’s Science Mission Directorate (SMD) is to think of it as a recipe for a science experiment such as you might have done with your high school science fair… only with a bigger budget. Back then the best science projects were the ones that followed the scientific method:

- Observe nature.
- Identify some unexplained phenomena.
- Formulate a testable hypothesis.
- Conduct an experiment; evaluate the results.

The approach that won you a trophy in high school is exactly the approach SMD is looking for and they craft their AOs accordingly. Make no mistake—SMD is in business to maximize science return, not develop new technology. If you have new technology on your mind, NASA’s Exploration Systems Mission Directorate (ESMD) is for you, not SMD.

Assuming you have a phenomenon that is worthy of a space mission, there are some key criteria to be considered:

- Do you really need to go to space? Going to space is, after all, pretty expensive.
- Is it compelling? SMD is in the breakthrough science business. If you are only offering incremental science, do it on the ground.
- Can you do it reliably? SMD wants ‘edge’ science, not edge technology. Edge technology needs to go through ESMD until it may be relied upon to get the job done with as little excitement as possible.

**SMD wants breakthrough, not incremental science.**

**Incremental:** “add six decimal places to the speed of light”

**Breakthrough:** “find an anisotropic variance in the speed of light?”

Einstein said the speed of light was constant, yet a small fringe group of physicists continue to look for an anisotropy—a directionally dependent variance—in the speed of light, on the order of the Planck scale. Finding such an anisotropy could be done in space—definitely Nobel-class science!

**How do you know your science is compelling?**—The scientific merit of your proposal is worth
40% of your overall score.

The factors for scientific merit include the following:

- **Factor A-I.** Compelling nature and scientific priority of the proposed investigation's science goals and objectives. This factor includes the clarity of the goals and objectives; how well the goals and objectives reflect program, Agency, and National priorities; the potential scientific impact of the investigation on program, Agency, and National science objectives; and the potential for fundamental progress, as well as filling gaps in our knowledge relative to the current state of the art.

“The potential for fundamental progress” What makes an idea fundamental? Here’s a handy check list with some examples:

- **Eliminate roadblocks to progress**
  - “Stop looking for the ether. The speed of light is constant.”

- **Resolve competing theories**
  - “There are two dominant theories for the origin/evolution of the solar system—the in situ condensation model and the Nice model. The one place they predict different outcomes is in the Jupiter Trojans. —New Frontiers Odysseus”

- **Upset conventional wisdom**
  - “The sun does not orbit the earth. The earth orbits the sun.”
  - “There really is water on the moon.”

- **Open-ended enough to invite further research**
  - “The discovery of DNA initiated a golden age of biology.”

- **Provide seminal data**
  - “This mission to the Main Belt Comets will be the first visit to a new class of Solar System Object.”
  - Use seminal data with caution. There are millions of places in the Universe that have yet to be visited—why should SMD pick yours?

**Remember:** breakthroughs don’t have to be Nobel-class whoppers like relativity, the Big Bang, DNA, Plate Tectonics, etc. Acceptable to Nature is probably breakthrough. Acceptable to The Journal of Pithy Papers is probably incremental.

**A word about cost caps**—SMD missions are usually capped at some amount, e.g., Discovery 2010 was capped at $425 million, New Frontiers 2009 was $650 million. Your bid must not exceed that amount, but unlike government RFPs, you won’t do yourself any good by trying to low bid the competition. Remember SMD is all about maximizing science return. They’d like you to spend every last nickel they give you bringing home the science.

**A word about awards**—In most cases, there are multiple awards for Phase A studies. Phase A studies are like longer proposals, with the emphasis shifted away from the science and onto the instrumentation, mission, spacecraft, management, schedule, and more detailed cost. You can count on up to a million dollars to fund your Phase A study. Usually two out of three Phase A’s will be selected to go on to full mission development (subject to funding).
SMD selects three major classes of missions through Announcements of Opportunity.

Copies of these AOs are obtained through NSPIRES. http://nspires.nasaprs.com Select either CLOSED or PAST solicitations and the year for old AOs. Then search on:

- **Explorer 2011**: NNH11ZDA002O
- **Discovery 2010**: NNH10ZDA007O
- **New Frontiers 2009**: NNH09ZDA007O

Current solicitations may be found under OPEN. The solicitation number will be announced on the mission home pages NEWS (see URLs under the appropriate mission).

AOs are usually released in draft form about six months from the due-at-NASA date and in final form about three months from the due-at-NASA date. A month or so before the draft release, there will usually be a heads up announcement citing the particulars of the release—schedule, cost cap, etc. These announcements are posted in the NEWS page on each mission’s home page.

**Explorer Class**—usually capped at $200 million although Small Explorers (SMEX) can come in at $120 million. They usually focus on astrophysics and heliophysics and are released every year or so. Since 1958 there have been 92 Explorer missions.

http://explorers.gsfc.nasa.gov

**Discovery Class**—The next Discovery release in fall of 2012 is expected to be capped at $500 million. They usually focus on planetary science and are released every 1-3 years. Since 1995 there have been 11 Discovery missions.

http://discovery.nasa.gov/

**New Frontiers Class**—A spin-off of the Discovery program, they are usually capped at $650 million. New Frontiers usually focus on planetary science.

http://newfrontiers.nasa.gov/

**Flagship Class missions** usually cost several billion dollars and are typically the product of study groups such as the Mars Exploration Program Analysis Group (MEPAG) or the Venus Exploration Analysis Group (VEXAG). They are generally not announced through AOs.

http://mepag.jpl.nasa.gov/
http://www.lpi.usra.edu/vexag/

SMD telegraphs its research interests with planning documents.

The ones you are interested in for a particular AO will always be referenced in

The New Horizons New Frontiers class mission launched in 2006. It will arrive at Pluto in 2015 and continuing on to the Kuiper Belt beyond Neptune.
Mars used to be excluded from New Frontiers since it had its own Mars Scout Program. The policy was cancelled in 2010 to focus on landed science missions such as the Mars Science Lab (MSL).
Hypothetical Venus Hi-Res Radar Mapping Mission—Conventional wisdom holds that Venus has no small craters because its atmosphere is so dense (90 bars) that anything smaller than a km in diameter will burn up on entry. This has been corroborated by the Magellan 120-meter resolution SAR instrument. However, our hypothetical PI posits that Venus did not always have a dense atmosphere. Upsetting a conventional wisdom is an excellent way to assure breakthrough science potential. His hypothesis is that Venus used to have a much thinner atmosphere and the minimum crater size detected on the surface could be used to calculate how thin. Models run by scientists at Ames Research Center in the mid-70s indicated that the smallest craters that would form by (80 m) stony meteorites would be 300-400 m, and 150-200 m by (30 m) iron meteorites; anything smaller would not form because the bolides would be essentially broken up, melted, etc. by the dense atmosphere. This means that if smaller craters than those predicted were found, it would imply that the atmosphere was less dense in the past. The smallest well-defined crater seen on Magellan images is about 1.5 km in diameter. The required 3D data could be collected by an astronaut team equipped with tape measures and surveyor’s transit levels, or by a laser radar, or it could be collected by a Synthetic Aperture Radar (SAR). At this point you don’t care so long as you get the data. When you get to section E (Instruments), you will use the data under the Science Traceability Matrix’ Instrument Functional Requirements columns to select an instrument from a ‘catalog’.

Magellan radar image of a 30-km crater on Venus (left image) compared with Mars Global Surveyor crater (right image). MGS used an optical camera at 1.5-12 meters per pixel.
The Science Traceability Matrix is the most misunderstood part of the AO.

Here’s all they say in the AO:

Requirement B-17. Traceability from science objectives to measurement requirements to instrument performance requirements, and to top-level mission requirements shall be provided in tabular form and supported by narrative discussion. Projected instrument performance shall be compared to instrument performance requirements. Table B1 of this appendix provides an example of a tabular Science Traceability Matrix, with examples of matrix elements. This matrix provides the reference points and tools needed to track overall mission objectives, provide systems engineers with fundamental requirements needed to design the mission, show clearly the effects of any descoping or losses of elements, and facilitate identification of any resulting degradation to the science.

The example from the AO is shown on the next page:

Key to doing a proper job on this matrix is the notion that you are outlining a scientific experiment—the hypotheses to be tested and the data needed and resolution for same needed to resolve the hypotheses. An Instrument Systems Engineer and a Mission Systems Engineer should be able to use your Science Traceability Matrix or STM to select an instrument suite, orbit, and spacecraft to implement your mission. Let’s walk through this using the hypothetical Venus mapping mission (see sidebar). Here are some definitions of the column headings.

- **Science Goals (Source)**—These come from NASA’s various planning guides, e.g., decadal surveys, roadmaps, etc. State the document used and the goal you will address from within it. Do not waste space selling NASA on the importance of their goals—they already know they’re important. They are deliberately vague, so as to give the scientist some intellectual wiggle room to define his Objectives.

- **Science Objectives**—These are your objectives defined so as to address NASA’s Goals. Where NASA’s goals are vague, your objectives will be very specific. They should be stated as testable hypotheses. Do not use words like ‘characterize’ or ‘explore’—they make you look

Venus has been mapped in the past at various resolutions. The best of them was the Magellan orbiter of 1990-94. Its radar got down to 120-meter resolution, enough to pick out impact craters a few kilometers in diameter. This along with Venus’ dense atmosphere (96 bar vs. 1 bar on Earth) has caused scientists to speculate that there are no smaller craters on Venus. [http://en.wikipedia.org/wiki/Magellan_probe](http://en.wikipedia.org/wiki/Magellan_probe)
like you are on a data hunt rather than pursuing precisely defined, compelling science questions. Do not presume that because we have not been there before, a general purpose data hunt is justified. There many places we have not been to before—tell why we should go to this one. You need a compelling, testable hypothesis that shows you have good reason to go here and look for your data.

- **Science Measurement Requirements**
  - **Observables**—The object or phenomenon you need to detect, identify, or measure to prove your hypothesis.
  - **Physical Parameters**—The measurable parameters of that object or phenomenon that allow you to confirm its presence or evaluate it in some way essential to your hypothesis.
<table>
<thead>
<tr>
<th>Science Goals</th>
<th>Science Objectives</th>
<th>Scientific Measurement Requirements</th>
<th>Physical parameters</th>
<th>Instrument Performance Requirements</th>
<th>Projected Instrument Performance</th>
<th>Mission Requirements (Top Level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal 1</td>
<td></td>
<td>Absorption line</td>
<td>Column density of absorber</td>
<td>Alt. Range XX km ZZ km</td>
<td>Launch window to meet nadir and limb overlap requirement. Window applies day to day.</td>
<td></td>
</tr>
<tr>
<td>Goal 2</td>
<td></td>
<td>Emission line</td>
<td>Density and temperature of emitter</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Etc.</td>
<td>Objective 1</td>
<td>Size of features</td>
<td>Vert. Resol. XX km ZZ km</td>
<td></td>
<td>Need AA seasons to trace evolution of phenomena.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Morphological feature</td>
<td>Horiz. Resol. XX deg x XX lat x XX long ZZ deg x ZZ lat x ZZ long</td>
<td></td>
<td>Need AA months of observation to observe variability of phenomena.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rise time of eruptive phenomenon</td>
<td>Temp. Resol. XX min ZZ min</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rate of change of observable phenomenon</td>
<td>Precision XX K ZZ K</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Instrument Functional Requirements**—The units of measurement and the resolution needed for your measurements.
- **Projected Performance**—Assuming you can make your measurements at the resolution required, how well will you be able to satisfy your Objective? This is often stated as a degree of certainty.
- **Mission Functional Requirements (Top Level)**—Assuming the instrument has been chosen, the Mission Systems Engineer needs this information to craft an orbit and spacecraft that will position the instrument so as to collect the data at the correct resolution.
Sample Science Traceability Mission based on hypothetical Venus mapping mission

<table>
<thead>
<tr>
<th>Science Goal (NASA SSE Roadmap 2006)</th>
<th>Science Objectives</th>
<th>Scientific Measurement Requirements</th>
<th>Instrument Functional Requirements</th>
<th>Projected Performance</th>
<th>Mission Functional Requirements (Top Level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Determine how the processes that shape planetary bodies operate and interact</td>
<td><strong>Hypothesis:</strong> Venus used to have a thinner atmosphere, on the order of Earth’s present day atmosphere (1 bar). A thinner atmosphere would allow smaller meteorites to impact the surface than are presently observable with Magellan data.</td>
<td><strong>Small Impact Craters</strong> (&lt;100 meters diameter)</td>
<td><strong>Shallow disk-shaped depressions</strong> lying in otherwise flat terrain. <strong>Rims</strong> that protrude above the surrounding terrain.</td>
<td><strong>3D image data:</strong> Vertical resolution: ± 1 meter</td>
<td><strong>Craters</strong> as small as 50 meters in diameter can be detected with a certainty of 70%; 100 meters with 80%; 200 meters with 90%. <strong>An instrument systems engineer would not even consider the astronaut option for obvious reasons.</strong> The lidar is likely to be ruled out as well because of the difficulty penetrating Venus’ cloud layers. The SAR offers potential if you can balance the wavelength necessary to meet resolution requirements with the difficulty of getting through Venus’ atmosphere. <strong>Full surface examination required.</strong></td>
</tr>
</tbody>
</table>

The above table shows how the definitions are applied to the Venus mapping mission. Note: there is no mention of instruments or spacecraft in the STM. You want to preserve the illusion that you really did have a question and then thought of a way to answer it, even though the reality is the other way around.
Conclusion
The competitive pressure for these missions is intense. Academia sees them as career makers for their scientists. NASA centers need the prestige they bring for the budget battles on Capitol Hill. Prime contractors need them to stay in business. And yet every one of them—academia, the centers, the primes—ends up fielding a team of amateurs to do the grunt work of writing proposals. Nobody seems to remember that the million dollars spent on B&P is wasted if you don’t win. There are many excellent professional consultants for conventional government proposals. The same cannot be said for NASA space missions. If you are looking to hire one, find out how much of his career he spent in the war rooms where the real work was done.


---

1 http://nasascience.nasa.gov/
2 http://exploration.nasa.gov/
4 Ibid., p.53.
6 Ibid.
7 Ibid., p. B-31.