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Good morning, Mr. Chairman and members of the Committee. My name is Fran Bagenal and I am a professor at the University of Colorado. I served on the committee for the NRC decadal survey for solar and space physics and chaired a committee that assessed the role of solar and space physics in space exploration.

I am here today to provide an evaluation of the impact of the NASA's FY07 budget on solar and space physics – a field of research that corresponds to what is labeled, as of last week, the Heliophysics Division of NASA's Science Mission Directorate. Heliophysics has previously been called Sun-Earth Connections (SEC) and, until last week, sat with Earth Science within Earth-Sun Systems. This evaluation yields six conclusions that are summarized as follows:

1. NASA's investment in science has had a high payoff; it has spurred advances in leading edge technologies and has been instrumental in educating the next generation of scientists.
2. The claimed increase in science's share of the NASA budget is not reflected in science activity and in part arises from a change in accounting rules.
3. There will be a precipitous drop in launches of science missions beginning in 2010 and continuing forward.
4. The Explorer program is experiencing dramatic cuts and set-backs.
5. The Sounding Rocket Program, which serves our nation as a space academy, is withering after more than a decade of flat funding.
6. The FY07 budget makes major cuts in the Research and Analysis Program, which will affect disproportionately the youngest space scientists, and place the health of the space science "workforce" at risk.

To understand these conclusions I would like to begin by giving some context for this area of science.

Heliophysics

The Sun is the source of energy for life on Earth and is the strongest modulator of the human physical environment. In fact, the Sun's influence extends throughout the solar system, both through photons, which provide heat, light, and ionization, and through the continuous outflow of a magnetized, supersonic ionized gas known as the solar wind. The realm of the solar wind, which includes the entire solar system, is called the heliosphere. In the broadest sense, the heliosphere is a vast interconnected system of fast-moving structures, streams, and shock waves that encounter a great variety of planetary and small-body surfaces, atmospheres, and magnetic fields. Somewhere far beyond the orbit of Pluto, the solar wind is finally stopped by its interaction with the interstellar medium.

Thus, interplanetary space is far from empty – an often gusty solar wind flows from the Sun through interplanetary space. Bursts of energetic particles arise from acceleration processes at or near the Sun and race through this wind, traveling through interplanetary space, impacting planetary environments. It is these fast solar particles, together with galactic cosmic rays, that pose a threat to exploring astronauts. The magnetic fields of planets provide some protection from these high energy particles, but the protection is limited and variable, and outside of the planetary magnetospheres there is no protection at all. Thus, all objects in space – spacecraft, instrumentation and humans – are exposed to potentially hazardous penetrating radiation, both photons (e.g., x-rays) and particles (e.g., protons, heavy ions and electrons). Just as changing atmospheric conditions on Earth lead to weather that affects human activities on the ground, the changing conditions in the solar atmosphere lead to variations in the space environment – space weather- that affects activities in space.

Decadal Survey & Vision for Space Exploration

In 2002, the National Research Council published the first decadal strategy for solar and space physics: *The Sun to the Earth—and Beyond: A Decadal Strategy for Solar and Space Physics.*[1] The report included a recommended suite of NASA missions that were ordered by priority, presented in an appropriate sequence, and selected to fit within the expected resource profile for the next decade, which was anticipated to increase substantially through ~FY08.

In early 2004,[2] NASA proposed to adopt major new goals for human and robotic exploration of the solar system, consistent with the Bush Administration's Vision for Space Exploration. Any exploration will depend, in part, on developing the capability to predict the space environment experienced by exploring spacecraft and humans. Also in 2004, the Space Studies Board of the National Research Council tasked a committee to assess the role of solar and space physics in NASA's Exploration Vision.[3] This committee stated that:

> NASA's Sun-Earth Connection program depends upon a balanced portfolio of spaceflight missions and of supporting programs and infrastructure, which is very much like the proverbial three legged stool. There are two strategic mission lines-Living With a Star (LWS) and Solar Terrestrial Probes (STP)-and a coordinated set of supporting

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[1] National Research Council, *The Sun to the Earth--and Beyond: A Decadal Strategy for Solar and Space Physics*, The National Academies Press, 2002

[2] National Aeronautics and Space Administration, *The Vision for Space Exploration*, NP-2004-01-334-HQ, NASA, Washington, D.C., 2004.

[3] National Research Council, *Solar and Space Physics and Its Role in Space Exploration*, The National Academies Press, 2004.

programs. LWS missions focus on observing the solar activity, from short-term dynamics to long-term evolution, that can affect the Earth, as well as astronauts working and living in near-Earth space environment. Solar Terrestrial Probes are focused on exploring the fundamental physical processes of plasma interactions in the solar system. A key assumption upon which the LWS program was designed was that the STP program would be in place to provide the basic research foundation from which the LWS program could draw to meet its more operationally oriented objectives. Neither set of missions can properly support the objectives of the Exploration Initiative alone. Furthermore, neither set of spaceflight missions can succeed without the third leg of the stool. That leg provides the means to (a) conduct regular small Explorer missions that can react quickly to new scientific issues, foster innovation, and accept higher technical risk; (b) operate active spacecraft and analyze the LWS and STP mission data; and (c) conduct ground-based and sub-orbital research and technology development in direct support of ongoing and future spaceflight missions.

I will return to this issue of balance between these 3 legs of basic, applied and supporting research later in my testimony.

This re-evaluation of the Decadal Survey endorsed the original scientific and mission priorities – emphasizing a balance in the fundamental and applied aspects of space physics - but recognized that the schedule of missions would have to be considerably stretched out to fit a leaner budget.

Science Mission Directorate FY07 Budget

With this background, let me proceed to NASA's FY07 budget. First, may I commend Administrator Dr Griffin's bold leadership of NASA and his clear command of the technical issues involved. We all recognize the enormous challenge of enacting the Vision for Space Exploration while fulfilling international obligations associated with Space Station. NASA is being asked to do Apollo with a post-Apollo budget. Yet we must also remember that science is a vital part of the Vision for Space Exploration. I repeat the refrain "Exploration without science is just tourism."

In his February 16th statement to this committee, Dr Griffin quoted that fraction of the NASA budget allocated to science had grown from 24% to 32% between 1992 and 2007. These figures were emphasized in his oral presentation with the explicit implication that this fraction should be reduced by having the science budget slow down to a 1% growth rate while NASA as a whole grows three times faster. First of all, I do not claim to know what fraction of the NASA budget is the "correct" value to be spent on science. But I submit that the dramatic close-up views of our Sun from SOHO and Trace as well as the exciting new worlds revealed by Voyager, Hubble, Mars rovers, and Cassini have permanently changed the American people's view of space science. ***Investment in science has paid off for NASA – not only in terms of cultural and intellectual benefits but also in enabling technology and inspiring young scientists and engineers.***

Secondly, I accept that the science budget has seen net growth – and a third of the NASA's $17 billion budget is a substantial amount to spend on science. The reason for this growth is partly because of demonstrated successes. But I point out that over the past

15 years there have been significant changes in the way NASA has been bookkeeping different components of the budget (e.g. project management & operations, salaries of civil servants, and particularly launch costs which have doubled in the past ~5 years). I suggest that the quoted 8% increase in the share of the NASA budget being labeled as science does not necessarily reflect a corresponding increase in scientific activity. It might be useful for your committee to task one its support agencies; for example, the Government Accountability Office, to evaluate of how these budget figures are tracked. At the very least, I caution against taking this simple statistic at face value and using it to rationalize the diminishment of what has been one of NASA's great successes - science.

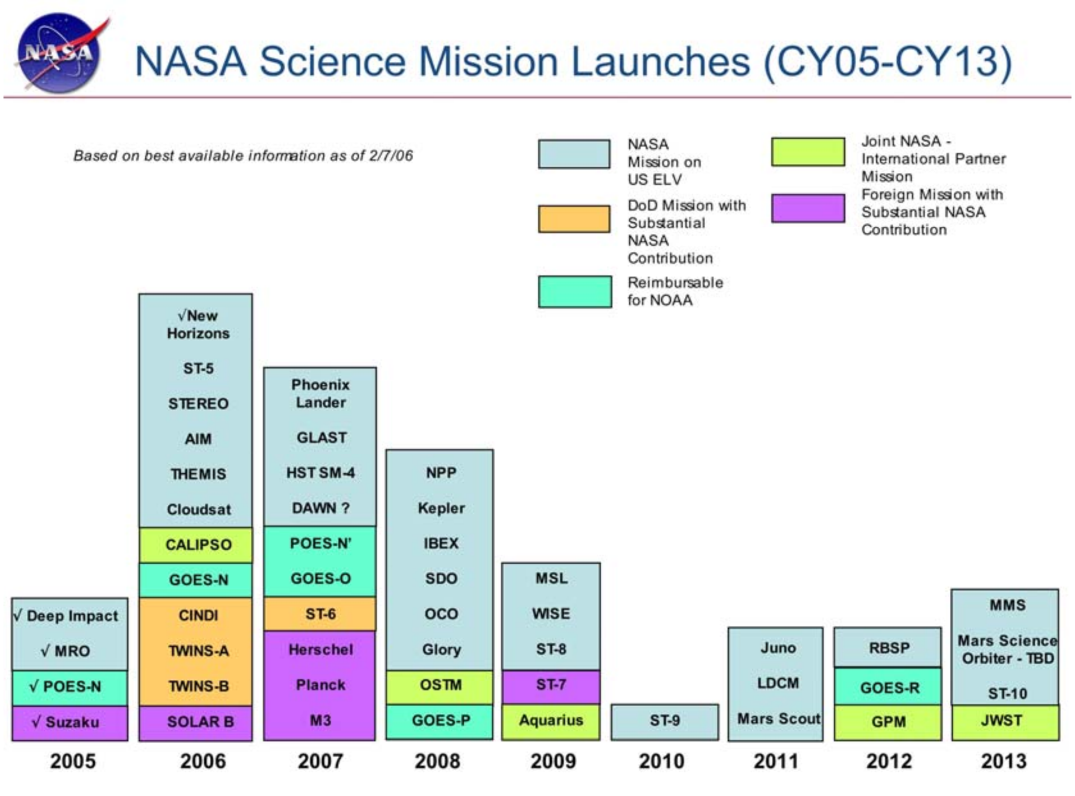
Heliophysics Budget

I have been asked to address the following specific questions:

1. *What do you see as the most serious impacts on your field of the proposed slowed growth in the Science Mission Directorate? Clearly, it would be better to conduct more science than less, but what is the real harm in delaying specific missions? At what point do delays or cutbacks become severe enough to make it difficult to retain or attract scientists or engineers to your field?*

Science Mission Launches

The impact of elimination of growth in SMD is most dramatically illustrated by the following chart of science mission launches for the next seven years. An impressive list of missions to be launched in the next couple of years is followed by a precipitous drop to only one launch in 2010 (ST-9, a small technology demonstration mission) and few launches per year thereafter.



Since each mission takes several years of development and construction before launch (~3 years for small missions, over a decade for the largest missions) this paucity of missions beyond 2010 reflects a slowdown in mission opportunities over the past ~5 years and a lack of launch opportunities for several more years. Factors contributing to this dearth of launches are the escalation in launch costs, the impact of full-cost accounting, the under-costing of larger missions, and – most significantly – the elimination of any funding wedge for new missions from here onwards. ***The net result is that there is a significant gap during which it is inevitable that expertise will be lost and it will be hard to attract and train junior scientists and engineers*** - the very people who will be needed to implement the Vision for Space Exploration. ***While the lack of any large missions on the horizon is a concern, the priority for Heliophysics must be a steady cadence of smaller missions.***

The Explorer Program

In the past, the Explorer program has offered frequent opportunities to carry out small and medium sized missions that can be developed and launched in a short (approximately four-year) timeframe. The Explorer Program straddles both the Heliophysics and Astrophysics Divisions with roughly equal numbers of launches in each division.

These focused missions address science of crucial importance to these two division roadmaps and NRC Decadal Surveys: The 2004 NRC report "Solar and Space Physics and Its Role in Space Exploration" states that; Explorers "*are the lifeblood of SEC research because they provide core research, flexibility, innovative technologies, and invaluable training for the next generation of workers for our nation's space enterprise. The Explorer program provides innovative, fast-response missions to fill critical gaps.*" The report recommends "*these programs should continue at a pace and a level that will ensure that they can fill their vital roles in SEC research*". The 2001 NRC report "Astronomy and Astrophysics in the New Millennium" finds that "*the Explorer program is very successful and has elicited many highly innovative, cost effective proposals for small missions from the community*." Specifically they recommend "*the continuation of a vigorous Explorer program,*" and that "*NASA should continue to encourage the development of a diverse range of mission sizes, including small, moderate, and major, to ensure the most effective returns from the U.S. space program*."

In the last decade, 10 Explorers were launched; 6 small explorers (SMEX) and 4 medium explorers (MIDEX). These have allowed NASA to respond quickly to new scientific and technical developments, and have produced transformational science, including:

- The best determination of the age of the universe: 13.7 billion years.
- Images of solar flares that show that ions and electrons are accelerated in different locations.
- The discovery of "baby" galaxies still in the process of forming, long after the vast majority of galaxies formed during the early universe
- Measurements of record-speed solar winds (at ~5 million mph) from the large "Halloween" 2003 solar eruptions.

- The discovery that the plasmasphere rotates with the Earth at only 85-90% of the Earth's rotation rate as opposed to the 100% assumed by all models of magnetospheric convection.
- Direct evidence that galactic cosmic rays originate in associations of massive stars (where most supernovae occur).
- Proof that short-duration gamma-ray bursts (lasting less than 2 seconds) have a different origin than long bursts, likely resulting from the fiery mergers of binary neutron stars.
- These are a small fraction of highlights selected to illustrate the astounding breadth and productivity of the program.

The Explorer program has taken dramatic cuts in the last few budget cycles, resulting in:

- The cancellation – for purely budgetary reasons – of a peer-reviewed, selected mission, the *Nuclear Spectroscopic Telescope Array (NuSTAR)* SMEX, chosen (along with the *Interstellar Boundary Explorer (IBEX)*), from the 2002 announcement that solicited two flight missions.
- Delay in the next Announcement of Opportunity until mid 2008 at the soonest (associated mission launch beyond 2014).

The result is a minimum gap from 2008 – 2014 without any Explorer launch, in a program that is vital to both Heliophysics and Astrophysics, and which in the past has seen an average of one launch per year.

As noted in numerous NRC reports, in addition to its scientific importance, there are compelling programmatic, technical and educational reasons to maintain a line of small and moderate-sized competed missions. Explorers have strong involvement of the university community (eight of the ten most recent Explorers have been led by university scientists), and they provide an excellent training ground for young experimental researchers, scientists, engineers and managers, many of whom go on to play lead roles in large missions. The time from development to launch is consistent with PhD degree programs, as well as timescales for the career development of young professional scientists.

This decimation of the Explorer program will have a lasting and significant impact on the Nation's academic research base. Universities and research laboratories make significant internal investments in infrastructure to support experimental space science. Decisions on faculty and staff hires, on accepting graduate students, and the institutional investment in specialized laboratory facilities all depend on existence of a vital research and analysis (R&A) program, and opportunities to develop instrumentation for space flight. Both of these are threatened in the current NASA budget. In particular, the cancellation of missions after they have completed the arduous competitive process and been selected, as happened in the most recent budget process, is a particularly dangerous precedent. Universities, research laboratories, and their international collaborators necessarily rely on the well-established Explorer selection process in their decision to undertake such long term commitments. ***The precedent will be detrimental to the strong partnership between NASA and university researchers, a partnership that***

has been key to much of NASA's scientific productivity and has provided critical opportunities for developing scientists and engineers in experimental space science.

Suborbital Sounding Rocket Program

Suborbital sounding rocket flights and high-altitude scientific balloons can provide a wide range of basic science that is important to meeting Heliophysics program objectives. For example, sounding rocket missions targeted at understanding specific solar phenomena and of the response of the upper atmosphere and ionosphere to those phenomena have potentially strong relevance. This science is cutting-edge, providing some of the highest-resolution measurements ever made and, in many cases, providing measurements that have never been made before.

The Suborbital program serves several important roles, including:

- Conducting important scientific measurements in support of orbital spaceflight missions,
- Providing a mechanism to develop and test new techniques and new spaceflight instruments, and
- Providing effective training to develop future experimental scientists and engineers.

Development of new scientific techniques, scientific instrumentation, and spacecraft technology is a key component of the Suborbital program. Many of the instruments flying today on satellites were first developed on sounding rockets or balloons. The low cost of sounding rocket access to space fosters innovation: instruments and technologies warrant further development before moving to satellite programs. Development of new instruments using the Suborbital program provides a cost-effective way of achieving high technical readiness levels with actual spaceflight heritage.

The fact that any long-term commitment to space exploration will place a concomitant demand on the availability of a highly trained technical work force makes the training role of the Suborbital program especially important. For example, a 3-year sounding rocket mission at a university provides an excellent research opportunity for a student to carry a project through all of its stages—from conception to hardware design to flight to data analysis and, finally, to the publication of the results. This "hands on" approach provides the student with invaluable experience in understanding the spaceflight mission as a whole. Indeed, over 350 Ph.D.s have been awarded as part of NASA's sounding rocket program. Not only have some of these scientists have gone on to successfully define, propose, and manage bigger missions such as Explorer, many more have brought valuable technical expertise to private industry and the government workforce.

NASA budgets for the Suborbital Sounding Rocket Program have remained flat. When one allows for inflation and the dramatically escalating launch costs, the net effect is a significant reduction in the capabilities of the program. ***Given the valuable educational, training and technology development roles of sounding rockets, any small saving derived from limiting this minor program has a major impact on future technical capabilities.***

Research and Analysis Programs

Research and Analysis (R&A, sometimes called Supporting Research and Technology SR&T) programs are crucial for understanding basic physical processes that occur throughout the Sun-heliosphere-planet system, and for providing valuable support to exploration missions. The objectives of R&A programs include:

- Synthesis and understanding of data gathered with spacecraft,
- Development of new instruments,
- Development of theoretical models and simulations, and
- Training of students at both graduate and undergraduate levels.

R&A programs support a wide range of research activities, including basic theory, numerical simulation and modeling, scientific analysis of spacecraft data, development of new instrument concepts and techniques, and laboratory measurements of relevant atomic and plasma parameters, all either as individual projects or, in the case of the SEC Theory program, via "critical mass" groups. Theory and modeling, combined with data analysis, are vital for relating observations to basic physics. Numerical modeling can also be a valuable tool for mission planning. Insights obtained from theory and modeling studies provide a conceptual framework for organizing and understanding measurements and observations, particularly when measurements are sparse and when spatial-temporal ambiguities exist. Theory and modeling will be especially important in the context of the space exploration initiative as exploration missions become more complex and the need for quantitative predictions becomes greater. ***These programs also are especially valuable for training students, at both the undergraduate and the graduate level, who will likely play a vital role in the NASA space exploration initiative or join the larger workforce as capable scientists/engineers/managers who cut their teeth on rigorous problems.***

NASA administration has suggested that the 2010 mission gap justifies an immediate 15% cut in R&A across the Science Mission Directorate. The high launch rate in 2006, the extensive list of on-going productive missions and the Nation's need for a technically-trained workforce all argue that R&A should be increased rather than cut.

When it comes to shear science productivity, R&A grants deliver the most "bang for the buck." These usually 3-year grants of ~$100k/year are highly competitive with only the very best 10-20% being selected via rigorous peer review. Even the most established scientists have to compete with everyone else. R&A programs provide the main basis of support for junior scientists – graduate students and post-doctoral researchers. ***Any cutbacks to R&A acutely impacts the most vulnerable and productive sector of space science.***

2. *Do you believe the decisions NASA has made concerning which missions to defer or cancel are consistent with the most recent National Academies Decadal Survey that you released? Have there been any developments since the Decadal Survey that need to be taken into account, and has NASA considered those? Given the FY07 budget*

request, do you see any need to update the most recent survey or to change the process for the next Decadal Survey?

The 2004 NRC report, *Solar and Space Physics and Its Role in Exploration,* examined the 2002 Decadal Survey made the following three recommendations:

1. *To achieve the goals of the exploration vision there must be a robust SEC program, including both the LWS and the STP mission lines, that studies the heliospheric system as a whole and that incorporates a balance of applied and basic science.*
2. *The programs that underpin the LWS and STP mission lines -- MO&DA, Explorers, the suborbital program, and SR&T -- should continue at a pace and level that will ensure that they can fill their vital roles in SEC research.*
3. *The near-term priority and sequence of solar, heliospheric, and geospace missions should be maintained as recommended in the decadal survey report both for scientific reasons and for the purposes of the exploration vision.*

These recommendations remain valid today. The mission priorities within the basic science (STP) and applied science (LWS) mission lines as listed in the original Decadal Survey are generally reflected in the Heliophysics budgets for these two mission lines. Where NASA has deviated from the Decadal Survey is in putting greater weight on Living With a Star missions and losing the balance between applied and basic science. Such a priority of emphasizing short-term capability of predicting space weather over the long term goal of understanding the underlying physical principles may have some practical expedience. A more critical issue, however, is the fact that small missions and supporting research have not kept pace. If these programs - the components that comprise the third leg of the stool and the training grounds for new scientists and engineers - are allowed to wither, Heliophysics will quite quickly topple over.

The 2002 Decadal Survey, *The Sun to the Earth-and Beyond,* was the first conducted by the solar and space physics community (though smaller NRC committees have generated many shorter planning documents). The Decadal Survey involved hundreds of scientists in discussions that spanned nearly two years. The scientific priorities set out the survey remain valid today and I see no community movement to change them. But Decadal Surveys are not just a list of science priorities. To design a coherent program across a decade, it is essential to have a realistic budget profile as well reasonably accurate estimates of both technical readiness and costs of each mission. he Decadal Survey committee worked hard with engineers and NASA management to develop realistic mission costs and a program architecture that fit within budget profiles anticipated in FY03 budget. But changes to the budget profile in FY04 necessitated a substantial stretching of the mission schedule in the 2004 re-assessment of the Decadal Survey in light of the Vision for Space Exploration.[4] Furthermore, under-costing of just a few missions – Big Digs in space – wreck havoc with even the best-laid plans. The scientific community needs to work with NASA to find ways to accurately cost missions,

[4] See charts on page 26 of *Solar and Space physics and Its Role in Space Exploration*, The National Academies Press, 2004.

particularly large missions (e.g., by applying lessons learned from management of smaller, PI-led missions as appropriate and greater accountability).

3. *How should NASA balance priorities among the various disciplines supported by its Science Mission Directorate? Do you believe the proposed FY07 budget, given the overall level of spending allotted to science, does a good job of setting priorities across fields?*

Each of NASA's scientific themes makes breakthrough discoveries that hit the press headlines. Rather than distinguish between them, I would argue that budget priorities be made within each division and, should a project exceeds its budget, any accommodation be made within the division. This would enforce accountability.

NASA conducts an outstanding program of scientific research within its Science Mission Directorate. The market place for scientific ideas – whether for a $100,000/yr research grant or a $1 billion mission – is a highly competitive world where only the very best ideas survive. NASA's science missions excite the public's interest in the universe around them, inspire young students to study math and science, and provide opportunities to generate a technically-trained workforce who contribute to the Nation's economy. Heliophysics not only has cultural and intellectual value but also adds practical and economic value as the Nation embarks on its next wave of space exploration.