Astronomy and NASA – Rewards and Challenges

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Good morning, and thank you for inviting me to speak at this meeting of the American Astronomical Society, our nation's foremost group of astronomers and astrophysicists. Someone initially advertised my talk this morning as "NASA: A View from the Top", so if you are expecting such grand illusions, let me apologize now. I know how gravity works, I know what flows downhill in Washington, and I know what I deal with every day. There is no possible way I can be at the top of anything.

More seriously, I would like to take some time this morning to discuss a few things which I hope you will find meaningful: the intersection of science and engineering and the revolution which has occurred in astronomy, astrophysics and cosmology as a result; the implications of that revolution for our society; and some of the challenges I see ahead.

Let me begin by looking back twenty-five years. In early 1983, I was a mid-thirties engineer working on the arcane aspects of fine guidance for the Hubble Space Telescope. Even then, the project was overrunning and behind schedule; Congressional hearings were being held to investigate. Sound familiar? None of us then had any idea of what was yet to come, another decade of turmoil and trouble before, finally, Hubble began to fulfill its promise. Which, despite its long and costly birthing, it has done, possibly beyond what anyone imagined.

Today, just outside my office, I have a poster-sized version of the Hubble Ultra Deep Field exposure, built up over a million seconds of integration time through a tiny keyhole in the sky in the direction of the southern hemisphere constellation Fornax. This picture shows about 10,000 young galaxies as they were almost 13 billion years ago. That famous *Star Wars* introduction, “a long time ago in a galaxy far, far away”, doesn’t begin to encompass the reality of the Hubble Deep Field.

Such photographs inspire the same questions that mankind has asked for millennia – how our universe began, how our galaxy and solar system were created, which elements coalesced under what forces to form the Earth, whether there are other planets like ours, whether life exists elsewhere and, if so, whether there are other cognitive species, and, finally, the eventual fate of the universe. Such questions, once the realm only of religion and mythology, now lie at the forefront of scientific investigation: Birth. Life. Death. Elements. Forces. Eternity. Infinity. Astrophysicists today are dealing with questions that societies everywhere have pondered for thousands of years.

And there is more. We're not just answering abstract questions having little connection to everyday life. The cosmos is the frontier for re-defining physics in the 21st Century. The thread connecting the understanding of dark energy and matter to economic prosperity and the quality of life may be long and tenuous, but the technological advances that have propelled modern civilization have always been rooted in new knowledge about how the universe around us works. There were no more esoteric fields of inquiry a century ago than quantum mechanics and relativity, which were then the frontiers of theoretical physics at scales both large and small. Today, the applications of quantum mechanics underpin a significant fraction of the world's economy, and the GPS system requires correction for the effects of both Special and General Relativity in order to function properly. What we do in astronomy and astrophysics is not only impossibly audacious, it matters in human lives.

Astronomy and astrophysics have flourished at NASA since the 1960s. This community certainly knows of the groundbreaking advances in infrared, optical, ultraviolet, and x-ray astronomy achieved by the IRAS, Copernicus, IUE, and Einstein Observatory missions, to name only a few from the ‘70s and early ‘80s. But beginning in the late 1980s with COBE, and continuing for the next two decades with the Great Observatories – Hubble, Compton, Chandra, and Spitzer – as well as smaller missions like XTE, EUVE, FUSE, WMAP, GALEX, and Swift, astrophysics at NASA has, quite simply, revolutionized mankind’s view of the universe. Allow me, if you would, to review a few of the key discoveries of these last two decades.

I have to start with the Hubble Space Telescope. We've used it to refine the Hubble Constant – and thus the age of the universe – to within 10%, for key contributions to the discovery and confirmation of dark energy and the accelerating universe, for the first observations of the detailed structure of protoplanetary disks in the Orion Nebula and other star forming regions, and for the first direct detection of the atmosphere of a planet around another star. In company with the Chandra X-Ray Observatory, HST has provided direct evidence for dark matter in galactic clusters, and time-lapse observations from Hubble and Chandra have mapped the detailed structure and rapid evolution of the synchrotron emission from the Crab Nebula pulsar. These are just a few of the landmark accomplishments of this incredible instrument.

COBE measured the stunningly perfect blackbody temperature curve of the cosmic microwave background in 1990, and small temperature fluctuations in 1992. WMAP has since confirmed the flat geometry of the universe, measured the temperature fluctuations in the infant universe more accurately, and shown that dark energy makes up about 70% of the mass-energy content of the universe.

Gamma-ray bursts were first detected in the 1960s by the military's Vela nuclear burst detection satellites, and were determined to be of extra-galactic origin by the Compton Gamma Ray Observatory; Swift and HETE have recently shown that the short, hard bursts are due to mergers of two compact objects. And speaking of compact objects, Chandra's extraordinary capabilities were demonstrated by the discovery of a long-sought compact object near the center of the famous Cassiopeia A supernova remnant in its first-light image.

From the first confirmed detections in the 1990s, the number of confirmed exoplanets – I think we now know of over 250 – and our knowledge about them has continued to increase. The first thermal IR spectra of direct light from extrasolar giant planets were recently made by the Spitzer Space Telescope, and Spitzer observations have recently been used to map the temperature distribution over the surface of the giant gas exoplanet HD 189733b by measuring the intensity of the infrared light from the system at different times in the planet's orbit.

But NASA is not about the past. This speech is not about the past. We are far from done. I look forward to the next round of astrophysics missions to fly, like GLAST in 2008, SOFIA and Kepler in 2009, NuStar in 2011, and JWST in 2013. We are soliciting a new round of Explorers. New themes have emerged in Dark Energy and Exoplanets, with good prospects for missions flying by the middle of the next decade if plans unfold as we hope. And, for those with a broader view, I would note that all of this is taking place in company with vigorous planetary, heliophysics, and Earth science programs, a seminal change in direction for our aeronautics program, completion of the International Space Station, and a rebirth of the human space exploration program that was stillborn in the 1970s.

We are living in a true renaissance era for NASA, and for astronomy and astrophysics, answering questions about our universe and extending our reach and knowledge in ways that Galileo and Newton, Einstein and Hubble, could hardly have imagined. This revolution has occurred largely as a result of two things.

The first is our nation's investment in astronomy and astrophysics. NASA's astrophysics budget has averaged over $1.5 billion per year (in FY08 dollars) in the decade since 1999, when we separated the heliophysics and astrophysics budget lines. This is about the same size as the entire JAXA budget – allocated to NASA astrophysics alone. In the same FY08 currency, astrophysics will average over $1.2 billion/year through FY12. The combined total devoted to astronomical sciences at NSF and high-energy physics at DoE is just under a billion dollars in FY08. So the nation's science agencies, and especially NASA, are making continuing, significant investments to understand the physics of the universe.

Truly, we study the brush strokes of physics in our particle accelerators, and the grand portrait of those strokes as it is painted on the night sky.

Second, life in today's renaissance era for astronomy and astrophysics is a direct result of the science community working hand-in-hand with the engineers who build the instruments, spacecraft, and launch vehicles that enable such discoveries.

Scientists and engineers share in common much of their early training, but they practice their professions in different cultures, with different values and different ways of thinking. Often we never notice. When we're carrying out a slightly more sophisticated version of a well-understood observation, designing yet another new building, or adding a refinement to an established theory, these separate cultures do not much intrude upon each other. Away from the frontier, the engineering and scientific cultures can exist each in their own milieu. But at the frontiers of either engineering or science, I firmly believe the opposite is true, that it requires iterative, hands-on engagement between these cultures to make progress in advancing the state of the art.

Theodore von Karman, a founder of the Jet Propulsion Laboratory, noted that "Scientists discover the world that exists; engineers create the world that never was." Respect for each of these roles – opposite faces of the same coin – is what allows us to work in concert to further the range of human thought with new science, and the range of human activity with new engineering. Nowhere is this more apparent than in astrophysics at NASA, where we are teaching ourselves to build the most outlandishly audacious new instruments to achieve the goal of transcending our present understanding of our universe.

These are the "real reasons" why our nation spends more than a billion dollars per year on astrophysics at NASA, and why there was such broad public debate about the risks and rewards of another Space

Shuttle mission to upgrade the Hubble Space Telescope. Astrophysics awes the public, revolutionizes our knowledge of our surroundings, inspires school kids to study science and engineering, and indirectly advances the high tech sector of our economy.

Let me turn now to some of the challenges I see in front of us as we seek to continue this vision. Trying to understand the laws of nature can be frustrating, but I think most of us here today would agree that it pales in comparison to trying to understand the laws of man.

As most of you know, the Congress recently passed, and the President signed into law, a $555 billion omnibus appropriation for the current fiscal year. In one paragraph of that law, the Congress directed NASA to study the delivery of the Alpha Magnetic Spectrometer (AMS) cosmic ray instrument to the International Space Station with the Space Shuttle. This report is due in less than 30 days, so it is fortunate that we at NASA have already studied the issue, along with the costs and risks of flying the AMS on an expendable launch vehicle.

This could become a matter of significant import to the astrophysics community, so let me review the bidding on this issue.

In the 1990's NASA committed to DoE and its international partners in the AMS project to fly this experiment to and host it on the Space Station. This made good technical sense. However, in the wake of the Space Shuttle *Columbia* accident five years ago, almost everything in U.S. space policy changed. We analyzed the results, findings, and recommendations of the Columbia Accident Investigation Board, a sobering report which I would ask advocates for additional Shuttle flights to read carefully. Based upon this report, Administration policy has been to restrict the number of Space Shuttle flights to those flights necessary to fulfill our commitments to our international partners on Space Station, and then to retire the Shuttle in 2010.

Subsequent to that determination, the Congress added a specific appropriation for a final Hubble servicing mission, if it was found to be technically feasible to perform. The NASA team determined – after eighteen months of hard work – that it was, and also deemed such a mission to be worth the additional cost and risk. Accordingly, the Administration accepted NASA's recommendation to add the mission to the Shuttle manifest; it will fly later this year.

No other mission for the Space Shuttle has been deemed sufficiently important to justify a further addition to the manifest. Not the dozen ISS utilization flights that we had planned to accomplish during the Station's construction phase, and not the AMS.

AMS could be placed in orbit by other means, either as a free-flyer or delivered to ISS by means of automated systems, as with ISS logistics cargo. Such alternative means will not be cheap; current estimates are on the order of $400 million. NASA lacks the budget allocation for such a mission, so, should it be directed by Congress, it would have to "come out of hide". Astrophysics hide. Thus, I will be asking the National Academy to assess the priorities of the missions in the Beyond Einstein program set forth in their report last September, where the Joint Dark Energy Mission was recommended to be launched first, compared to the scientific priority of the AMS.

There is no free launch. All of these missions carry an opportunity cost. Thus, we must hear from the astrophysics community concerning their relative priorities.

Another provision in the omnibus appropriation which is relevant to the astrophysics community is the unrequested funding for the Space Interferometry Mission (SIM). The specific language in the law is as follows:

"A total of $60,000,000, an increase of $38,400,000 above the request, has been provided for the Space Interferometry Mission (SIM). … It should be noted that this mission was recommended by the National Academies Decadal Astrophysics in 1990 and 2000, and should be considered a priority. With the funds proposed, NASA is to begin the development phase of the program in order to capitalize on more than $300,000,000 already invested by the Agency. The SIM program has successfully passed all its technological milestones and is thus ready for development."

Well, as the language says, SIM is a priority; in fact it was named in each the last two Astrophysics Decadals. However it is, in the judgment of all who are familiar with it, a flagship mission well beyond the scope – especially in cost – originally recommended in the 1991 NRC Decadal Survey. To be blunt, we have the money to fund, and are executing, the top priorities of the previous Decadals. We do not have the capability to support another astrophysics flagship mission in the same timeframe as JWST.

Now, SIM addresses what to me is one of the most exciting endeavors within our science portfolio; it goes directly to one of those basic questions I raised earlier: are we alone? I'm sure I'm not alone in my interest; in fact, on JPL's website for SIM, I noticed a humorous analysis concerning detection of Mr. Spock's home planet, Vulcan. As I noted earlier, more than 250 exoplanets have been found to date, and this field of endeavor is growing. A little over a year ago, ESA and CNES launched the COROT planet-finding mission, and later this year ESA will be launching Herschel, and in early 2009, we will launch Kepler, both of them planet-finding missions.

So it is not that I wouldn't like to proceed with implementing SIM, but moving a second flagship mission into development now will eliminate diversity and balance in the Astrophysics program. JWST consumes 60% of the astrophysics budget; HST and SOFIA and grants use another 25%. If we initiate SIM now, we will have to delay JWST or GLAST or cancel Explorers to fund it. Moreover, there are other approaches to the goal of finding planets in other star systems, approaches which can be afforded in the near term if SIM can be deferred. They cannot accomplish all that can be accomplished by SIM, but they can be afforded with the resources we expect to receive. This is the path I am advocating for exoplanet research.

But let me be clear. As it stands now, my recommendations have not been adopted. The Fiscal Year 2008 Congressional direction for NASA "to begin the development phase" of SIM is quite clear. It disregards the community-based recommendations of the NRC and NASA's other advisory committees for maintaining a balanced portfolio of large and small missions, along with basic research and technology investments. The Congress does not dream up such direction on its own; clearly, external advocacy for SIM has been successful. If it stands, then the mission will be executed, and the remainder of the astrophysics portfolio will suffer. I hope this is what you want, because it appears likely to be what you will get.

I recommend that in future Decadal Surveys, the community should prioritize the science and missions from previous Surveys that have not yet entered development against each other, and against any new initiatives, and include cost "trip wires" for missions, so that if they grow above a certain threshold, the mission priority order would be revisited.

I'd like now to change course again, and talk about some challenges of a different type, challenges that I face in trying to integrate the scientific community, its goals and its culture, into the broader NASA community. I would, frankly, like your help with this.

My relationship with the scientific community during my time at NASA has been frustrating at times, despite the fact that I think there has not been an Administrator who understands and appreciates, at a relatively deep level, the richness of what you do – not just the astronomers, but all of science. But from my first days at NASA, as with one voice, there has been a single concern – the budget is not what once was promised – and little further discussion has been possible.

Now, if only for the record, I have to point out that exactly the same budgetary reductions have been made across NASA's other enterprises. Few scientists seem to know, or care, that the human spaceflight community has lost a third of its planned flights to the ISS, that we are facing a five-year gap with no human space launch capability at all, that aeronautics is today operating at budget levels well below the historical average, or that technology development at NASA has been reduced to minimal levels. And, true, the science budget at NASA is not what was once promised.

In early 2004, when President Bush announced the Vision for Space Exploration, NASA was allocated an extra billion dollars over the five-year runout from 2005-09. But a year later, about two weeks after I was privately informed that I had been selected to be the new Administrator, that increase was rescinded and, further, an additional $2 billion dollar reduction incurred. I often wonder if someone was sending me a message.

But, more significantly, the Shuttle and Station accounts were not, prior to 2005, funded at the level required to match the nation's commitment to complete the ISS and retire the Shuttle in 2010. I fixed that, rather than allowing a budgetary sham to be continued, but it was a $4 B problem, and it was painful to fix.

Speaking forthrightly, I think I can say that, broadly, the scientific community simply does not support the Nation's commitment to the Station. But it remains a fact, sustained across four Administrations and over twenty Congressional votes. Like it or not, the Space Station is a feature of American space policy. At this point, the failure to recognize that, accept it, and deal with the consequences in a mature fashion consigns one, in my mind, to the "kids table", while the adults converse elsewhere.

Returning specifically to budget matters, and adding it all up, NASA has absorbed almost $12 B in budget reductions and unplanned expenses in the FY05-12 period that were not in the plan a mere three years ago.

And yet –please hear me on this – *NASA is doing well* compared to other non-defense domestic discretionary budgets. With all the above having been said, we have received approximately inflationary increases. With few exceptions, domestic non-defense discretionary spending at other agencies has received actual reductions.

I think sometimes we simply refuse to see that from the perspective of other communities supporting other interests, NASA is not special, science is not special, and astronomy is not special. We are one of many constituencies clamoring for the ever-dwindling fraction of the U.S. budget over which there is any practical control – the domestic, non-defense discretionary piece, around $400 billion out of a nearly $3 trillion dollar total.

This may not be a cause for hope, but neither is it a cause for fear. The forward-looking budget for NASA and for science within NASA is approximately constant in real dollars. We would do best to plan accordingly.

Finally, I need to ask, plainly and simply, for recognition from the science community that NASA is not solely, or even primarily, about science. Yes, science is a very important part of NASA, and I have in numerous speeches, including this one, reinforced its seminal importance to me, to the agency, and to the nation. The goal of scientific discovery is a noble one. I will never feel otherwise. I am incapable of believing otherwise.

But does the science community understand it when I say, with equal emphasis, that expanding the range of human presence is a goal *fully as noble* as that of scientific discovery? Where is the mutual respect for goals that are linked by the common disciplines of flight in air and space, but disparate in their specifics, that is necessary if we are ever truly to be a "space community"? I believe this is not only desirable, but needful, in the sense that Ben Franklin meant when he said, "We must all hang together, or most assuredly we will all hang separately."

The manned spaceflight community supported the astrophysics community on Hubble, finding a way to enable a servicing mission that many others, believing that they spoke for those on the pointy end of the spear, believed was too risky. And today's NASA did what was necessary to protect JWST when a $1.5 billion "overrun" was revealed in 2005. These things didn't help and don't help the human exploration community, they help the astrophysics community, and through that, all of NASA. They were done despite the fact that breathing new life into human spaceflight after the loss of *Columbia* was the President's, the Congress', and my primary policy objective for NASA.

Imagine, if you will, the increased support for NASA – all of NASA – that could result if science community leaders utilized their prestige and their talent for advocacy to promote all of NASA, and not just the individual missions and portfolios of greatest interest to them. Imagine if we put aside self-interest, and all hung together.

The fantastic pictures we get from Hubble, or Cassini, or the detailed, multi-wavelength views we obtain of the Earth, or Neil Armstrong making that giant leap for mankind, show that what binds us together is far more important than the issues that separate us. And there is a certain unquantifiable measure of security there, something that policy analysts tend to forget to mention in many of the published rationales for undertaking space exploration.

So, let me conclude with this reminder of the darkest day in recent memory for America's space program – February 1st, 2003, when the Space Shuttle *Columbia* disintegrated upon re-entry. That crew, like the

Apollo 1 and *Challenger* crews, joins the long and sobering list of those who over the last century have, in Lincoln's words, given "the last full measure of devotion" to the conquest of air and space.

They were forced to give that measure because we at NASA failed them, because we did not hold ourselves up to the high ideals and exacting standards necessary for space exploration. We were complacent. We must fight against such complacency if we are to continue our journey, to extend the scope of human knowledge and the range of human activity. We need your help – all of you here – to make that happen. We must never lose sight of that sense of purpose, that feeling that what we are doing along the way in this great journey is part of something much greater than ourselves and our individual interests.

So, let us all hang together.

Thank you.