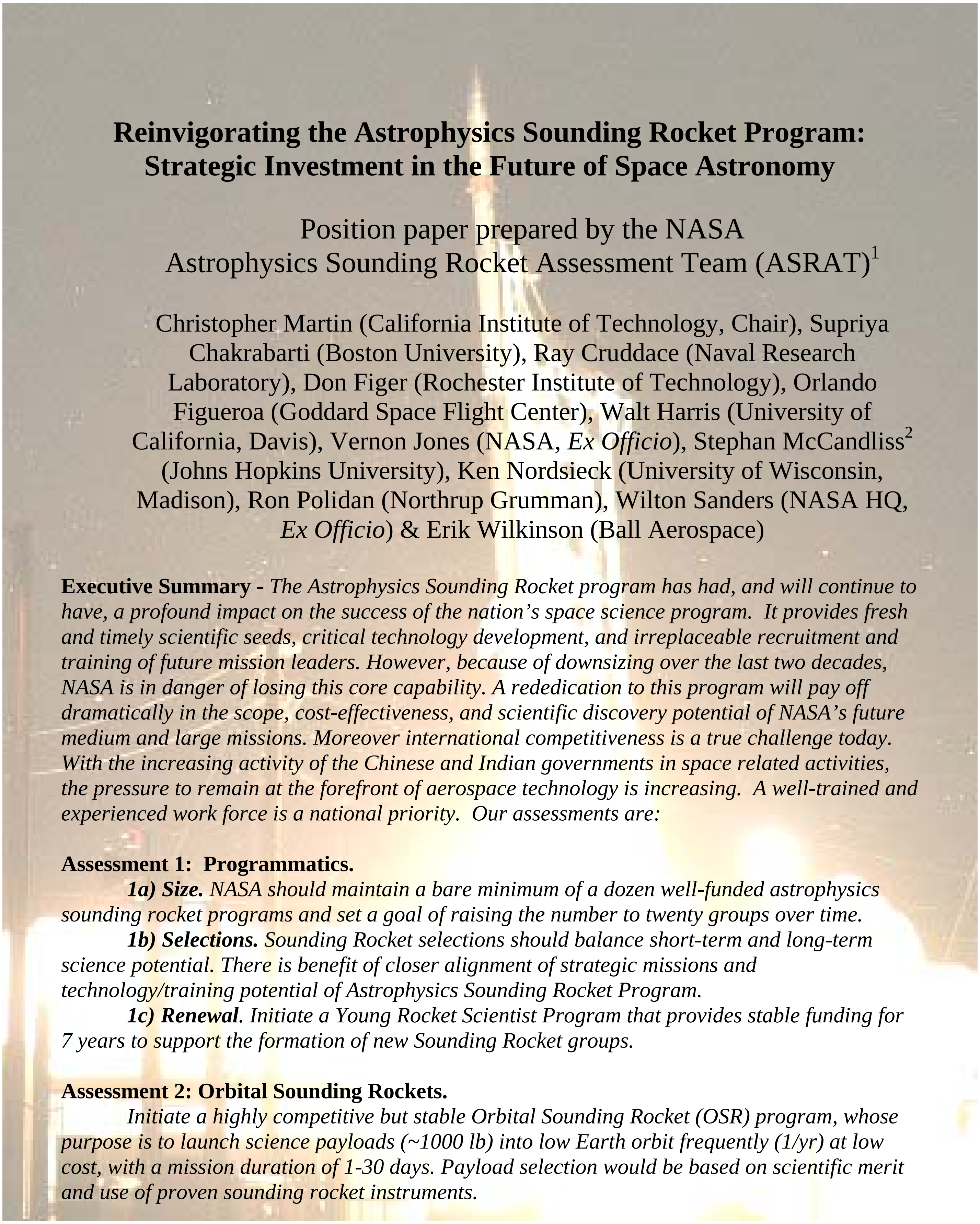

Reinvigorating the Astrophysics Sounding Rocket Program: Strategic Investment in the Future of Space Astronomy

Position paper prepared by the NASA Astrophysics Sounding Rocket Assessment Team (ASRAT)[1]

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Executive Summary - *The Astrophysics Sounding Rocket program has had, and will continue to have, a profound impact on the success of the nation's space science program. It provides fresh and timely scientific seeds, critical technology development, and irreplaceable recruitment and training of future mission leaders. However, because of downsizing over the last two decades, NASA is in danger of losing this core capability. A rededication to this program will pay off dramatically in the scope, cost-effectiveness, and scientific discovery potential of NASA's future medium and large missions. Moreover international competitiveness is a true challenge today. With the increasing activity of the Chinese and Indian governments in space related activities, the pressure to remain at the forefront of aerospace technology is increasing. A well-trained and experienced work force is a national priority. Our assessments are:*

Assessment 1: Programmatics.

1a) Size. *NASA should maintain a bare minimum of a dozen well-funded astrophysics sounding rocket programs and set a goal of raising the number to twenty groups over time.*

1b) Selections. *Sounding Rocket selections should balance short-term and long-term science potential. There is benefit of closer alignment of strategic missions and technology/training potential of Astrophysics Sounding Rocket Program.*

1c) Renewal*. Initiate a Young Rocket Scientist Program that provides stable funding for 7 years to support the formation of new Sounding Rocket groups.*

Assessment 2: Orbital Sounding Rockets.

Initiate a highly competitive but stable Orbital Sounding Rocket (OSR) program, whose purpose is to launch science payloads (~1000 lb) into low Earth orbit frequently (1/yr) at low cost, with a mission duration of 1-30 days. Payload selection would be based on scientific merit and use of proven sounding rocket instruments.

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[1] Full disclosure statement – Two former members of the team, Webster Cash and Dan McCammon, took part in initial discussions but declined participation in the preparation of this position paper.

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Table of Contents

1. Overview

The early days of NASA space astrophysics were heady times of excitement and discovery. The NASA Sounding Rocket program played a central role in this drama. Early rockets gave us the discovery of x-rays from an extra-solar source, the discovery of the x-ray background, the first UV spectrum of a quasar, and the first extreme ultraviolet spectrum of a dying star. Sounding rockets provided a platform for quick access to space to test exciting and powerful if immature new technologies and instrument concepts that could break open new areas of science. Sounding rockets provided an irresistible venue for talented young experimenters to test new ideas and approaches as students, post-docs, and young faculty. This fertility and vitality attracted the best experimenters of their generation to enter Space Science, providing the future leaders of complex and demanding orbital missions.

While astrophysics has grown enormously in the last three decades, the Astrophysics Sounding Rocket Program (ASRP) has suffered from attrition, diminished funding, and a lowered scientific profile in comparison to NASA's large portfolio of successful astrophysics missions. It has become a challenge to build new experiments that obtain cutting-edge science from 5 minutes of sounding rocket data. The number of active astrophysics sounding groups is greatly diminished, and the number of flights per year has dropped to a handful. The Astrophysics Sounding Rocket Assessment Team (ASRAT) has been charged with evaluating the role of the ASRP in the NASA Strategic Roadmap, and to recommend changes to the program to fulfill its critical strategic potential.

We find that in the present day, as missions grow in scale, complexity and development time, the unique contribution of the ASRP is more critical than ever. The huge expense of major missions can only be justified if the technology required to make orders of magnitude gains is ready years before the launch of the mission. Frequent ASR flights provide both the motivation to develop the highest performance technology (to squeeze the most exciting science from minutes of data), and the platform on which to test it. Perhaps even more importantly, the synoptic training provided while designing and flying a sounding rocket maintains a cadre of experienced people that cannot be duplicated. This experience encompasses the full range of issues that any space mission faces, and forces deep thinking about the balance of science, cost, and risk. The broad opportunities and freedom of the program attract capable and versatile talent that otherwise might be lost to other fields. *The level of success of many NASA missions can be traced directly to the presence or absence of such experience in leadership positions.* The long chain of experience originating in the early days of the space program is in danger of being broken.

The NASA Astrophysics Program has long held a position of world leadership in observational capabilities and scientific advancement. We have taken as our overarching goal the continued renewal of this achievement. Our recommendations flow from the desire to maintain ASR as a unique source of new science and technology, and a training ground for new talent that NASA can leverage to accomplish goals that are literally out of this world. We commend NASA's recent moves to revitalize the ASRP by increasing flight frequency and urge that those initial efforts be fully actualized and sustained over time. We believe that to maintain vitality a minimum flight rate must be set to effectively utilize ASRP in the pursuit of NASA priorities.

2. Strategic Impact – Science, Technology and Training

Sounding rockets today play as critical a role in the development of space astronomy as they did over half a century ago. Their primary purpose is to enable unique science by exploiting new technologies and training the next generation of space experimentalists. Maintenance of this core capability holds a strategic importance for NASA as it pursues a broad science portfolio within a limited fiscal environment. We discuss here the foundations of science, technology development and workforce training that the ASRP brings to the space astronomy enterprise.

2.1 Scientific Foundations of Space Astrophysics

Initially, Sounding Rockets provided the only scientific access to space. Starting just after World War II, scientists used V2's and early Aerobees to perform basic new probes of the space environment. The pioneering astronomical discoveries and developments of the day: the ultraviolet (UV) radiation emitted by hot stars in Orion (Kupperian et al. 1958); the first extra solar x-ray (Giacconi et al. 1962); observing the galactic center with a cryogenic infrared (IR) telescope (Harwit et al. 1966); were seminal events that opened the doors of astronomical inquiry into entirely new portions of the electromagnetic spectrum only accessible from space. These early missions laid the scientific, technical and leadership foundations for the Great Observatories: *Hubble Space Telescope* (*HST*), *Chandra*, and *Spitzer*.

Figure 1: In this archival photo, Professor Garmire of Penn State (then Caltech) explains a piece of sounding rocket equipment to a student.

Of these early pioneering missions, Giacconi, Gursky, Paolini and Rossi (1962) flying an x-ray proportional counter on a sounding rocket was uniquely successful. Ostensibly the experiment was to check that the Moon was not awash in x-rays and a health hazard to astronauts, but instead they found the sky glowing in x-rays; the "Isotropic X-ray Background". It took forty years to understand that discovery; that the sky is sprinkled with giant black holes in the centers of forming galaxies. Indeed, in 1962 the term "black hole" had not even been coined. In that same flight these sounding rocket PI's found a star-like source of x-rays in the constellation Scorpius. ScoX-1, as it is now known, may have been the first direct detection of a neutron star, before even the discovery pulsars. Forty years later Giacconi received the Nobel Prize in Physics, **"for for pioneering contributions to astrophysics, which have led to the discovery of cosmic X-ray sources."**

Opening up the sky to new astrophysical diagnostics proceeded quickly and over the years produced with the many unique discoveries and observations, a subset of which are listed here:

- Kupperian et al. (1958): Far-UV photometry of Orion and α Vir.
- Giacconi et al. (1962): Extra solar X-ray sources.
- Morton (1965): High mass loss stellar winds from hot stars in Orion (P-Cygni profiles).
- Bowyer (1965): X-rays from the Galactic Center.

- Harwit et al. (1966): First cryogenic IR telescope (galactic center detected; not reported).
- Felten et al. (1966): X-rays from the Coma Cluster of Galaxies
- Fritz et al. (1969), Bradt et al. (1969): X-ray Pulsar in the Crab Nebula.
- Bowyer and Field (1969): Detection of the Soft X-ray Background Flux
- Bowyer et al. (1970): X-rays from the quasar 3C 273.
- Carruthers (1970): Molecular hydrogen in the interstellar medium.
- Novick et al. (1972): First detection of X-Ray Polarization of the Crab Nebula.
- Catura et al. (1975): X-rays from the red giant star Capella.
- Morre and Garmire (1975): X-ray map of the Vela supernova remnant.
- Davidsen et al. (1977): Ultraviolet spectrum of quasi-stellar object 3C273.
- Clarke et al. (1980): Spatial imaging of hydrogen Lyman-alpha emission from Jupiter.
- Malina et al. (1982): Extreme ultraviolet spectrum of hot DA white dwarf Hz 43.
- McCammon et al. (1983): All sky map of diffuse soft x-ray background (10 flts, 7 yrs).
- Durrance et al. (1983): Far-UV spectroscopy of the Io Torus
- Woods et al. (1987): Far-UV long slit spectroscopy of Comet P/Halley (coincident with Giotto Flyby).
- Martin and Bowyer (1989): Far-UV extragalactic background.
- Jenkins et al (1989): Spectroscopy of molecular hydrogen in the ISM at $R > 130{,}000$.
- Cash et al. (1989): Far-UV observation of SN1987A.
- Green et al. (1992): EUV spectroscopy of Capella.
- Wilkinson et al. (1992): First observation of HeII ionization edge in a White Dwarf.
- Cole et al. (1999): UV imaging polarimetry of the Large Magellanic Cloud.
- McPhate et al. (1999): Far-UV long slit spectroscopy of Comet Hale-Bopp (TOO).
- Cruddace et al. (2002): High-Resolution EUV Spectroscopy of G191-B2B.
- Burgh et al. (2002): First dust optical constants below Lyman alpha.
- McCammon et al. (2002): High spectral resolution observation of the soft X-ray diffuse background with a microcalorimeter array
- Cook et al. (2003): Wide-field tomographic image spectroscopy of Scorpio to 912 Å.
- France et al. (2004): Extremely “Blue” far-UV dust in IC 405.
- Lupu et al. (2008): First spectrum of Θ^1 Ori C to 912 Å with far-UV sensitive CCD.

A shift in the role of sounding rockets from simple exploration was marked by the launch of the first orbiting UV and X-ray observatories in the late sixties and early seventies. By the late seventies astrophysics satellites were being launched regularly, but there was still a role for sounding rockets. Rockets were used to extend the wavelength coverage into the soft X-rays and Extreme Ultraviolet (EUV) bands that would not be studied from orbit for years to come. They became the workhorses for development and demonstration of new science in a variety of spectral bandpasses with more powerful

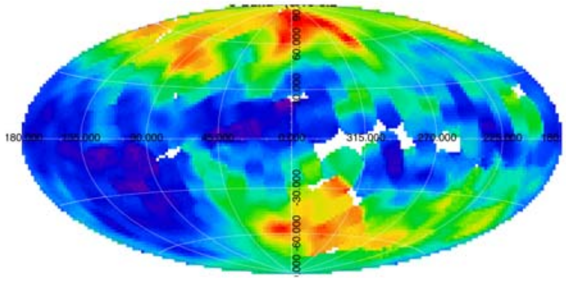

Figure 2: In the 1970’s the Wisconsin group flew a series of sounding rockets to map the soft x-ray background of the entire sky, leading to a better understanding of the Milky Way’s interstellar medium.

technologies, such as grazing incidence telescopes, photon counting imaging detectors, wide-field spectral imagers high resolution spectrographs 3-dimensional X-ray detectors and polarimeters; many of which have yet to be implemented in orbital missions. These efforts provided first glimpses of the X-rays from galaxy clusters, the Lyman alpha bulge of Jupiter, all-sky mapping in soft X-rays, and the far-UV properties of dust, to name a few. Some of these observations are completely unique and unchallenged by orbital missions twenty years later. For example, Jenkins et al. (1989) flew a far-UV echelle spectrograph with resolution of over 130,000 to observe H_2 absorption lines in the interstellar medium (ISM) between 912 – 1120 Å, a record that still stands today. Solar system exploration has no flight opportunities of scale smaller than Discovery. New programs are beginning research into the Jovian upper atmosphere and magnetic field, the Io plasma torus, Mars and Venus, and the interplanetary medium.

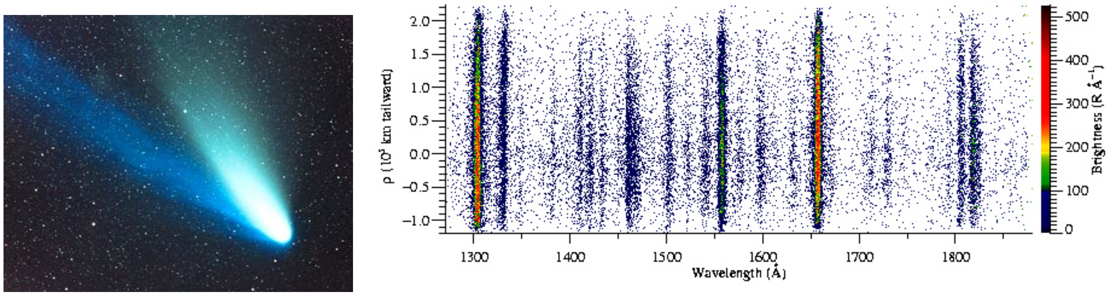

Figure 3: Spectrum of Comet Hale-Bopp was captured by a sounding rocket in 1997. The strong lines are OI λ1304, CII λ1335, CI λ1560, CI λ1657, SI $\lambda\lambda$1807 – 1826, SI $\lambda\lambda$1474 – 1487, and SI $\lambda\lambda$1425 – 1437. The remaining lines show that CO was remarkably rich in Hale-Bopp.

Sounding Rockets also provide a platform for responding rapidly to targets of opportunity (TOO) such as supernova and comets. Shortly after the loss of the shuttle borne SPARTAN mission to observe Comet P/Halley from Challenger in January of 1986, sounding rockets missions were quickly organized and launched in February and March, the latter within 13 hours of the *Giotto* encounter with Halley (Woods et al. 1987). Similarly, in 1987 the first naked eye supernova in nearly 400 years was spotted in the Large Magellanic Cloud and a coordinated campaign of X-ray and far-UV missions was mounted from Woomera Australia within months (Cash et al 1989). Sounding rockets are sometimes the only means to make TOO observations of transient phenomena in a specific bandpass. In 1997 the UV community mounted a campaign to observe Comet Hale-Bopp near perihelion, at peak activity, when it was too close to the sun (< 45°) to be observed safely by the instruments on HST (McPhate et al. 1999, Harris et al. 1997).

This history underscores some truths about sounding rockets. The fast turnaround, “can-do”, exploratory culture of the sounding rockets inevitably leads to cutting edge results when allowed to blossom. Scientifically and technically they create an atmosphere of excitement and competition that spurs all to perform better. They allow complete systems to be vetted, rather than relying upon extrapolation from bench measurements. They give astronomers a taste of what can be accomplished in many new directions.

2.2 Enabling Technologies for New Missions

The hallmark of the ASRP is entrepreneurial PIs, in competition with each other, working to develop the most innovative and cost effective instrumentation that can survive the rigors of space flight and yield either a large improvement in capability or a completely new observational approach. The inherent lack of observing time forces instrument designs that are innovative and efficient. The technologies matured by pushing-the-envelope in a risk tolerant sounding rocket experiment are regularly incorporated into satellite missions where failure is not acceptable. Emerging technologies provide new pathways for enabling science thrusts, allowing unique measurements in less time with fewer optics or clever measurement techniques. When properly aligned with the NASA technology development roadmap, sounding rockets can quickly and inexpensively find out what works, functionally and procedurally, to the benefit of orbital missions. We briefly discuss three modern cases of sounding rocket developed technology that have had, and are having, major impacts on the development of UV and X-ray missions: Aberration-corrected holographic gratings for the UV used with micro-channel plate detector readout systems, FUV optical coatings and X-ray calorimeters.

The HIRES instrument (Sarlin et al. 1993, 1994) is a classic example of the migration of sounding rocket instrumentation, as it was the first flight demonstration of two key technologies; aberration-corrected, holographic gratings in the UV and a time-delay anode readout for a UV micro-channel plate detector. The HIRES instrument was a far-UV spectrograph with a spectral resolving power of 30,000 that was the key to demonstrating enabling technologies that were ultimately used on both the FUSE (Moos et al. 2000) and *HST*/COS (Green et al. 2003) missions.

Another successful migration was the flight proof-of-concept for large normal incidence SiC optics (McCandliss et al., 1994), which was essential to the scientific success of the Hopkins Ultraviolet Telescope (HUT) on Astro-2 (Kruk et al., 1995, Davidsen et al. 1996). Normal incidence optics proved to be the crucial technology that ultimately enabled the successful development of the FUSE instrument, reducing costs by more than a factor of two relative to the baseline grazing incidence design (Moos and Sonneborn, 2006, & Moos private communication).

Quantum calorimeters were invented in the early 1980’s as a promising new technology to perform high efficiency spectroscopy in the x-ray. They have been well supported by NASA in development for orbital missions ever since. Yet, a quarter century later, the only astrophysical data captured with these devices are a few spectra of the soft x-ray background from Wisconsin/GSFC sounding rocket flights (McCammon et al. 2002, Crowder et al. 2008). Without these flights, multi-billion dollar planned missions like the International X-ray Observatory would have no demonstration that they would be able to accomplish their goals. A list of Astrophysics Sounding Rocket enabling technologies and maybe found at http://www.galex.caltech.edu/ASRAT/index.php/Main_Page

2.3 Training - Missions in Microcosm

The first space astrophysics missions in the late 1950’s and early 1960’s were launched on sounding rockets under the aegis of NRL, the USAF and NASA. In those early experiments, consisting of relatively simple single element photon counters with coarse angular collimators, investigators began to wrestle with the demands of this new, risky and failure prone space environment. The first experimenters were senior scientists and post-docs associated with national laboratories or private university research corporations with defense department ties. As launch and payload subsystems matured and exciting scientific results began to flow, academic institutions soon realized the educational potential of those entrepreneurial sounding rocket pioneers and a new class of experimenter emerged who expanded frontiers of astrophysics while simultaneously addressing the challenges of space-based instrumentation.

Ultimately, they became mentors, overseeing unique and empowering experiences for scientists, students and engineers early in their careers, carefully leading young experimenters through the diverse aspects of a spaceflight mission conducted from sounding rockets. Mission design and execution, exploiting emerging technology, subject to the unforgiving rigors of space flight, formed a crucible for experience that has consistently produced leaders in space science. The lessons were captured and passed on, in affect creating a space guild with a strong oral tradition. The consequence was a steady increase in the science success rate, the creation of increasingly sophisticated space-qualified systems, and an educated workforce that expanded our concept of the Universe in ways unimagined by those first sounding rocket pioneers.

The roster of past rocket graduate and post•doctoral students is proof of the creative and supporting influence generated by the rocket program that has diffused through academic and industrial communities. Lead positions (e.g. principal investigator, instrument scientist, project scientist, or chief system engineer) within a mission are routinely held by people with past rocket experience thus demonstrating the value of the experience to the major NASA space missions. A list of Astrophysics Sounding Rocket Graduate NASA mission experience and a Mentor and Student Genealogy may be found at http://www.galex.caltech.edu/ASRAT/index.php/Main_Page

3. State of the Profession

3.1 Workforce at Risk

The foundation of NASA success is its creative and experienced work force, built through years of experience in designing, qualifying, and flying space flight hardware. This foundation is being eroded on two fronts. Retirement is decreasing the ranks of those with the most experience, and today's generations are choosing alternate careers where they perceive more opportunities. The current leaders of the aerospace community recognize this:

'The space workforce is fundamentally a craft-based "guild", where knowledge is passed from generation to generation. However ... process-profit focus has profoundly affected the aerospace workforce ... science and engineering is treated as a commodity ...[which]... has broken ... the generation-to-generation training thread within the entire aerospace enterprise.'
Steven Battel, 2008 – President, Battel Engineering

The breaking of the generation-to-generation thread is an erosion of our competitive position as noted in the National Academy of Sciences Study entitled, **"Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future,"**

`In a world where advanced knowledge is widespread and low-cost labor is readily available, U.S. advantages in the marketplace and in science and technology have begun to erode. A comprehensive and coordinated federal effort is urgently needed to bolster U.S. competitiveness

and pre-eminence in these areas.'
Norman R. Augustine (Chair) 2007 - Retired Chairman and CEO, Lockheed Martin Corporation

A federally coordinated effort is required to recruit and train new talent that will execute future, ever more complex, space missions. Industry alone cannot do this. A matrix-based organization, driven by market forces, cannot afford to educate and mature multidisciplinary system engineers with the breadth of experience necessary to define and lead complex space missions - it is just not cost effective.

A sounding rocket investigation requires that every scientist and engineer function at a system level, in contrast to aerospace industry practice. The result is a team of broadly-trained experimentalists: each member understands how a mission is conceived, how requirements are derived and designs defined, and ultimately how to execute a successful space mission. Experimentalists armed with this complete mission perspective provide the backbone of program leadership required to guide a larger team through the diverse and demanding process of building space flight hardware. Leaders armed with this experience know how to balance cost, risk, and performance for the overall benefit of the program.

`In general, students with hands-on experience - ones that suffer through the pain of designing something, struggling to make/fabricate/build the system, figure how to … test them, fly them and even enjoy the possibility of a failure (and if it fails the drive to find the why) - are worth their weight in gold.'
Gopal Vasudevan, Sr. Staff Scientist, Lockheed Martin ATC 2008

3.2 Falling Support

Recent trends toward reducing sounding rocket support facilities have combined with the expansion of other opportunities in suborbital research (balloons) to sharply reduce both the number of flight programs and the availability of launch services. Figure 4 shows the number of Astrophysics Sounding Rockets flights has fallen to historic lows, as has the number of supported institutions (Table 1).

While falling support may have diluted recent returns from sounding rocket research, the competition for opportunities to conduct new scientific explorations continues to be very strong. The core program aims of sub-orbital research in developing new scientific techniques, technologies, and instrument scientists have only increased in their relevance to NASA's future

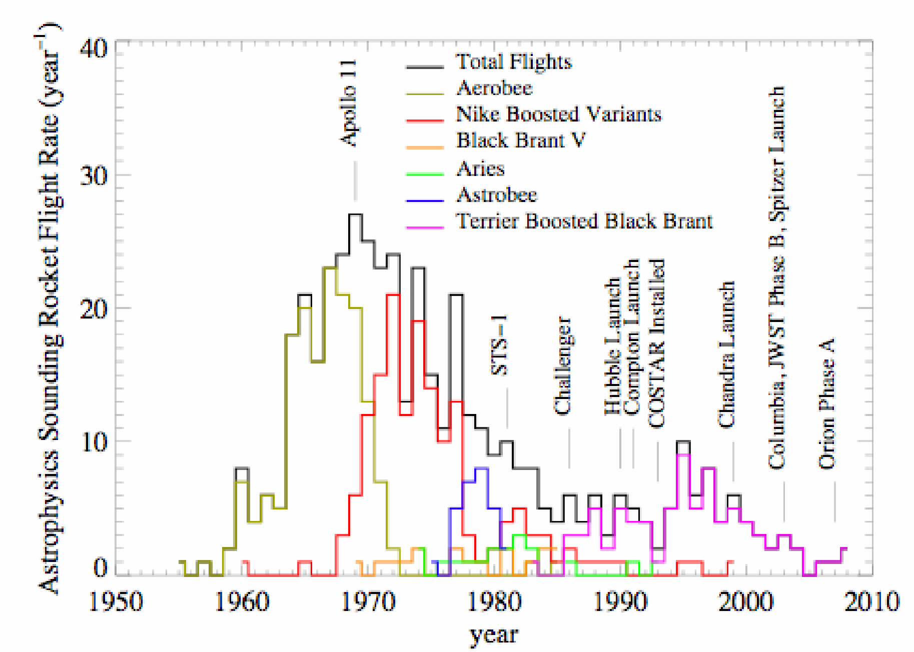

Figure 4: Sounding rocket flight rate for astrophysics missions from 1955 – 2008 broken down by launch vehicle. The total number of astrophysics missions was 477, most of which (391) were supported by NASA. The newest launch vehicle, the Terrier Boosted Black Brant, dates to 1983.

as the opportunities for flight exploration have far outstripped our ability to supply the personnel and experiments necessary to fully exploit them. In addition, since the generation of scientists and the experiments they produced during the ‘golden age’ of rocketry from 1960-1980 are approaching their collective retirement, the existing system is poorly positioned to maintain the critical scientific infrastructure necessary to maintain a world-class space program.

There is a belief in some segments of the community that the exploration opportunities for 5-minute rocket experiments have been exhausted. This belief is based on a fundamental misunderstanding of the purpose and approach of sub-orbital research. The primary goal of rocket experimentation is to develop new observational opportunities that cannot be met with existing facilities or approaches. As such, the short duration of a rocket flight continues to represent an **infinite** increase in the time that would otherwise be available. Moreover, while it is true that the available mission duration has not increased significantly in the past 3 decades, 5 minutes in space in 2008 is **not** what it was in 1968.

Continuing technological improvements in, for example, optical manufacture, coatings, detector performance, attitude control, bandwidth, memory, and automated control have increased the potential return of those 5 minutes by factors of up to 3 or more orders of magnitude. Far from an exhausted list of opportunities, there are many previous sub-orbital targets that merit an additional look to go along with the new ones that these enhancements have enabled. A modern sub-orbital experiment is easily capable of outperforming orbital missions from 2 decades ago while still improving our technological inventory and training new scientists to exploiting it.

Supported Institutions	7	22	19	15	10	3
Decade	1960	1970	1980	1990	2000	2008

Table 1: Number of US institutions launching ASR.

While we argue strongly here for a NASA initiative to develop short-term orbital missions using an extension of the current sounding rocket development models of low-cost, uniformity, and moderate risk, we **do not** propose this as an alternative to sub-orbital missions. Rather we see synergy in this mission mix, with the sub-orbital missions serving as the developmental test-bed for the short-term orbital missions, which in turn enhance our ability to more fully vet the science, technology and training in a realistic orbital environment before fully committing to the expense of a long duration mission.

3.3 Portrait of a Healthy Program

The NASA sounding rocket program provides a fertile base to the “mission food chain” by enabling the initiation and maturing of new science thrusts incorporating innovative technology developments and workforce training. This base allows NASA to reduce risk and cost for long duration astrophysics missions. Without a health base more of the burden of new technology development, maturation and workforce training is borne by large programs with tight schedules and a risk adverse culture, which inevitably leads to cost overruns. Here we address the question of what is an appropriate level of support for the sounding rocket program.

Over the past six decades the United States Government supported 32 different institutions (laboratories and universities) launching rockets. These institutions often had multiple PIs receiving support. In the period between 1985 and 2005 approximately 12 groups were supported, launching at a rate of ~ 6 flights/year. A healthy rocket program typically involves six to seven people – a PI, a post-doc, a technician, two graduate students and a couple of undergraduates, all working in various capacities for a different percentage of time. With this workforce, it is possible to build new payloads in timely manner and launch regularly. New payload starts take three to five years to be ready for launch. Major upgrades of an existing payload can occupy up to two years, while reflights of an experiment that has sustained little or no damage can be accomplished in a matter of weeks to months. A launch rate of ~ 0.5 flight/group/year is the result and since most, but not all, flights lead to a Ph.D., this is also the approximate Ph.D. production rate, each yielding one science and two technology publications.

So what does the community require? *GALEX* provides a case study. They employed 6 Ph.D. instrumentalist and required the development of ~ 4 new technologies with sounding rocket heritage. So the combined yearly output of 12 sounding rocket programs, assuming **no attrition,** is just able to sustain the workforce and technical needs of 1 Explorer program per year.

To sustain a healthy, vital community twelve programs is the absolute minimum necessary for the short term. Twenty programs is a good target for the long term. With twelve to twenty programs active, the PhD production would be five to ten per year. If half leave astrophysics the other half would reach a steady state level of 75 to 150 instrumentally trained astrophysicists available to the community, and would represent 3 to 5% of the NASA astrophysics community

4. Strategic Investment – Steps to Maintaining and Revitalizing

The environment we face is one in which large missions are becoming very large and complex with long development cycles. Technology development costs are rising exponentially
The cost of bad decisions has exploded. Many in leadership positions, with significant responsibility for high-cost missions, have no flight experience. Program innovation, timeliness, excitement and attractiveness to new talent are challenged. A core feeder for science innovation, technology, & trained mission leaders has badly eroded. ASRP flights had fallen to 0 in 2005. Sounding rocket flights are competed against conventional and long-duration balloons with more than 5 minutes to offer. Many established groups have lost funding. It is challenging for a new Sounding Rocket group to establish itself. Young talent chooses alternate careers.

4.1 Programmatics

4.1.1 Program Size

NASA should maintain a bare minimum of a dozen well-funded astrophysics sounding rocket programs and set a goal of raising the number to twenty groups over time. The benefits of such support will grow non-linearly.

4.1.2 Selections - Invest in the Long and Short Term

Sounding Rocket Research and Analysis selections should balance short-term and long-term science potential. There is benefit to be gained from a closer alignment of strategic missions goals with the science, technology and training potential of ASRP. Selections must balance short-term science payoff with long-term strategic investments in enabling technology and training of the next generation of space experimentalists. Equal weighting of science, strategic technology, and training is appropriate in the selection process. Strategic mission should take advantage of the low cost development track that ASRs provide in terms of precursor science, targeted technology development (TRL 6-7) and targeted intellectual capital development. Programs that bundle detector and technology development, sounding rocket flight validation, and Orbital Sounding Rocket (see below) flight migration in their long-term program design, should be encouraged. Review panels should include experienced sounding rocket scientists as either primary or secondary reviewer. The panels should also include experienced technologists with long-term strategic perspectives. Programs with new payloads should have 4 - 5 year durations, as 3 years is appropriate for reflights, but is insufficient time for a new experiment.

4.1.3 Renewal

There are formidable challenges to starting a new sounding rocket program. We recommend the initiation of a Young Rocket Scientist Program that provides stable funding for 6-7 years (2 yrs to build a new laboratory plus 4-5 yrs for experiment development), to support the formation of new Sounding Rocket groups. We envision a renewal a rate of one young scientist per 2-3 years with talent attracted by the prestige and stability of the award. The long period of funding will attract scientists trained outside of existing sounding rocket groups, who will be encouraged to partner with established groups, labs or centers. Matching startup money should be encouraged.

4.2 Orbital Sounding Rocket

Our efforts to improve the sophistication and capability of our payloads have outpaced any effort to develop reliable low cost delivery systems. There currently is no proven orbital analog to the highly reliable commercially maintained, Terrier Boosted Black Brant (the BB IX), which since the mid 1980’s has been vehicle of choice for suborbital astrophysics missions. The BB IX and its suite of standardized, modular support systems, can provide 3-axis sub-arcsecond pointing to a 1000 lb payload and an exo-atmospheric time of over 400 seconds above 120 km for ~ $2M. This cost is approximately two orders of magnitude lower than the current lowest cost orbital opportunity provided by NASA’s Explorer program.

We envision a highly competitive but stable Orbital Sounding Rocket (OSR) program that would provide extended duration sounding rocket flights of 1 – 30 days. The OSR program would be managed and operated by the NASA Wallops Flight Facility (WFF), whose low-cost, risk-tolerant culture is ideally suited to this effort. The OSR program is analogous to the highly successful Long Duration Balloon Program, in which Astrophysics Balloons perform breakthrough science. OSR payloads will be competitively chosen from successful sounding rocket experiments based on scientific and implementation merit. The goal is ~ 1 flight/year for 1000 lb payloads. This program would also provide routine opportunities for small (1-100lb) secondary payloads. The OSR cost, based on a preliminary WFF study is $15M/flight, including payload modification, test and integration, launch vehicle procurement and processing, launch and mission operations. If a launch vehicle, for example the SpaceX Falcon 1, really can deliver a previously proven sounding rocket payload to orbit for several days, then it would provide much more that a factor of 100 improvement in science return in comparison to 400 seconds. Such frequent access would allow the pursuit of high-risk high-value science, be a boon to new and innovative approaches, and rekindle the competitive spirit of the early years. We will provide more details of the scientific benefits, implementation and cost of the OSR in a response to the Program Prioritization Panel, Request for Information.