Report of the 2010 Senior Review of the Astrophysics Division Operating Missions
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Overview

The Astrophysics Division (AD) convened the 2010 Senior Review Committee (SRC) with the charge to rank the scientific merit of the extended mission proposals from the following eleven missions on a "science per dollar" basis, based on the expected returns from the projects being reviewed in the immediate future years FY2011 and FY2012:

Chandra	Swift
GALEX	Warm Spitzer
INTEGRAL	Warm WISE
Planck	WMAP
RXTE	XMM-Newton
Suzaku	

Given the varying status and performance capabilities of these missions, the SRC interpreted "science per dollar" in terms of the science of the whole portfolio under review for the total allotted budget.

The SRC reviewed proposals from each of the mission projects. The SRC read all of these proposals before convening. One primary and two secondary reviewers were assigned to each proposal, with one of the secondary reviewers being a "non-expert" on that particular mission. Two telecons were held, on March 25 and April 2, in preparation for the committee meeting. Representatives of each mission project made presentations and responded to questions from the SRC members.

The proposals included budget requests for (in most cases) two scenarios: an "in-guide" budget specified in advance by the AD and an augmented budget, in most cases for the four-year run out FY2011 – FY2014. Before our deliberations began, the SRC was provided with a budget agreed upon by NASA and OMB for support of each of the missions under consideration and the corresponding totals per fiscal year. These numbers were the basis for the FY2011 budget proposal submitted to Congress on February 1 and constitute the FY2011 President's Budget with the FY2010 Initial Operating Plan. These "President's Budget" numbers sometimes differed from the in-guide early planning numbers that were provided to each mission in late 2009 on which the mission teams based their Senior Review proposals. Our funding recommendations are therefore made in view of the differences between those in-guide numbers and the newer numbers in the President's budget. In addition to our prioritization, the SRC recommended funding levels that are consistent with the total pool available in the President's Budget.

In the judgment of the SRC, all the missions under review are currently doing valuable science. The task of the SRC is to consider the proposals for the future extended missions. The SRC considered the overall scientific merit of the extended missions and the incremental and synergistic benefit to the overall AD portfolio, the budget costs of each mission, and the overall budget constraints. A preliminary poll was taken on the value of the proposed extended missions within the context of the available budget. After further discussion, the rankings were reconsidered, but no changes were made. The resulting rankings are displayed below:

1. Planck
2. Chandra
3. Warm Spitzer
4. Swift
5. XMM-Newton
6. WMAP
7. Suzaku
8. GALEX
9. RXTE
10. INTEGRAL
11. Warm WISE

The SRC unanimously endorses this rank-ordering.

Detailed summaries of the scientific merits of each mission and recommendations for funding follow. In ranking these missions, the SRC took these details into full account. The SRC placed particular emphasis on the science to be accomplished during FY2011 and FY2012 in anticipation that the Senior Review of Operating Missions will reconsider the situation for FY2013 and FY2014.

The SRC notes with concern that US investigators are often not receiving the financial support that would ensure timely analysis and publication of highly competitive projects. As resources permit, the SRC recommends that such resources be made available along with observing project time allocations.

The SRC noted that funding per guest observer program varied widely from mission to mission, ranging from $0 to an average of about $50,000 per year per investigator. The Committee recommends that some consideration be given to this inhomogeneity, ideally resulting in some guidelines for proposers.

The SRC has several recommendations regarding the process for future Senior Reviews.

1. Mission teams should respond explicitly to recommendations in this Review in their proposals for the 2012 Review.
2. The SRC Chair should assign primary and secondary reviewers in advance of the meeting.
3. To the extent possible, primary and secondary reviewers should collect and organize questions for the presenters in advance for the sake of thoroughness and efficiency during the meeting. General questions applicable to all the missions should be presented to the mission teams in advance so that they have time to prepare responses. Questions specific to given missions should be held for the committee meeting in order to avoid uneven opportunity for the proposal team.
4. To the extent that NASA wants the Senior Review to evaluate EPO strategies, there should be clear instructions to that effect in advance and representatives on the committee with that expertise.

Planck

Planck is an ESA-led CMB mission designed to map the temperature and polarization anisotropies over the full sky. Planck has two instruments sharing the focal plane: The Low Frequency Instrument (LFI) uses 20K high electron-mobility transistor (HEMT) detectors in bands at 30, 44 and 71 GHz, while the High Frequency Instrument (HFI) uses 0.1K bolometers in six bands from 100 to 857 GHz. Science observations began in August 2009.

Spacecraft/instrument health & status:

The spacecraft is in good health. Consumables should allow a 30-month mission for the HFI, while the LFI may be capable of observing as long as 42 months.

Science strengths:

CMB temperature and polarization anisotropies contain a wealth of information about cosmology. Planck will significantly improve measurements of the temperature anisotropies at the third and higher-order acoustic peaks and of polarization over the whole range measured. These gains will lead directly to significant improvements in estimates of cosmological parameters as well as improved constraints on neutrino mass, the epoch of reionization, and B-mode polarization from inflationary gravitational waves. Planck also promises great improvements on constraints of extensions to the standard model, such as non-gaussianity and isocurvature modes.

The full sky maps will also be very useful for a variety of other science programs. A large number of massive galaxy clusters will be detected via the Sunyaev-Zeldovich effect, and a large point source catalog and full-sky maps of galactic dust will be produced.

The extension from a 15-month mission (the prime mission duration) to 30 months is very well motivated. This extension will provide significant gains in signal to noise ratio, but more importantly will lead to much-improved understanding of calibrations and systematic effects.

ESA is funding most of the mission cost. The US team provided essential detector and cooling hardware, and so plays a vital role in the mission. The US team is well positioned to play a very strong role in the data analysis.

Relevance to NASA priorities:

By measuring the CMB, Planck directly addresses the NASA strategic goals “What are the origin, evolution, and fate of the Universe?” and “How do planets, stars, galaxies and cosmic structure come into being?” The all-sky maps of galactic dust will also provide important input to our understanding of star formation.

Data accessibility:

Data have not yet been released to the public due to the early stage of the mission. Planck is expected to release a Compact Source Catalog in early 2011, and the first CMB maps and power spectra (including polarization) near the end of 2012.

Synergy with other missions and ground-based work:

Planck will significantly improve the CMB-based cosmological parameter estimates provided by WMAP. These will become the new standard for all joint parameter estimation by other missions and experiments investigating cosmological parameters and extensions to the standard cosmological model based on supernovae, weak lensing, baryon acoustic oscillations, and structure growth (using both space missions, and a host of ground-based facilities). The HFI instrument will make all-sky measurements of galactic dust over a wide wavelength range. This complements a wide range of missions, including WISE, GALEX, and Herschel. Planck temperature anisotropy maps will also be very valuable for the calibration of suborbital and ground-based CMB experiments.

Proposal weaknesses:

The proposed augmentation for archive software was not clearly linked to specific strong science goals, though it is likely to be of general value to the community.

The 12-month extension for LFI (from 30 to 42 months) was not well supported, primarily due to the early stage of the mission. ESA has not decided whether to fund this extension. Further data analysis will be required to evaluate the potential scientific benefit.

Overall assessment and recommendations:

The expected scientific impact of Planck is very high, and is greatly improved by the proposed extension from 15 to 30 months duration for the full (HFI+LFI) mission. This proposal received the highest ranking of the SRC.

The proposed augmentation for archive software is less compelling, but should be funded if possible.

It is too early to assess the benefits of the proposed extension for LFI operations from 30 to 42 months. The SRC recommends that NASA revisit this question when Planck data have been analyzed to a level needed to assess the potential benefits of that extension, and when there are clear indications from ESA that they will support it.

The SRC recommends funding the extension of Planck from 15 to 30 months of operation at the level of the President's budget for FY2011 with the requested augmentation in FY2012 and in FY2014.

Chandra

The Chandra X-ray Observatory is one of NASA's Great Observatories. It carries a high resolution mirror, two imaging detectors, and two sets of transmission gratings for high resolution spectroscopy. Important Chandra features are: subarcsecond spatial resolution, sensitivity to soft X-rays up to 10 keV, and the capability for high spectral resolution observations over most of this range. Chandra will continue its strong heritage in a broad range of X-ray investigations, notably in the areas of cosmology, galaxy clusters, star formation, neutron stars and black holes, AGN feedback and dispersal of elements. Chandra will continue to support a strong community-based program that leverages capability across the spectrum of existing space and ground-based observatories.

Spacecraft/instrument health & status:

Chandra has aged and some issues have emerged. The multilayer insulation has degraded, elevating temperatures on the sun-facing side. This has reduced the ability to provide uninterrupted long exposure times. Contamination on the ACIS optical blocking filter has diminished the instrument's low energy efficiency. In addition, the Integrated Electron Proton Helium Instrument (IEPHIN) and the Aspect Camera have degraded. Operational work-arounds have been applied to solve many of these issues. While this has added operational complexity and slightly impacted efficiency, the science quality of the data has not been compromised and Chandra continues to operate as a full facility-class mission.

Science strengths:

Chandra has contributed to our understanding of the dark energy, dark matter, and baryonic matter that comprise the Universe; the physical processes that govern the formation and evolution of stars, galaxies, and galaxy clusters; the formation and dispersal of heavy elements needed for planets and life; and the nature of the laws of physics under extreme conditions.

The future science return will be defined by observations to be selected by peer review, but there are identified subject areas that will guarantee a continuing strong scientific return. Chandra will perform studies of dark energy, dark matter decay, missing baryons, accreting black holes, AGN unification and the cosmic X-ray background, AGN feedback in clusters, interaction of supernova blast waves with the circumstellar and interstellar media, measure the equation of state of ultradense matter, determine black hole parameters and will provide insight into stellar and planetary formation and evolution. Demand for Chandra observing time remains high, science productivity and impact remain very high, and there are strong synergies with other observatories in areas of complementary and overlapping science.

Chandra has subarcsecond spatial resolution with spatially resolved spectra on the same scale. These attributes do not exist in any other mission and will not be seen again for several decades. Chandra also has a strong calibration program.

Relevance to NASA priorities:

Chandra is relevant to three of NASA's strategic goals: providing progress in understanding the origin and destiny of the universe, phenomena near black holes, and the nature of gravity; progress in understanding how the first stars and galaxies formed and how they changed over time into the objects recognized in the present Universe; and progress in understanding how individual stars form and how those processes ultimately affect the formation of planetary systems.

Data accessibility:

Data are typically proprietary to the proposing observer for a year, after which they become publicly available. The archive maintains all Chandra data on line, including all reprocessed versions of each observation. The Chandra archive makes non-proprietary data accessible to users worldwide by means of web-based search and retrieval tools. After an observation, processed data products are typically delivered to the proposing observer within about 30 hours.

Synergy with other missions and ground-based work:

The scientific return from Chandra is becoming increasingly multiwavelength in nature. This is a strength of NASA's astrophysics portfolio and a goal of the great Observatories Program;the SRC endorses this evolution. Chandra's time allocation committee allocates time on XMM-Newton, HST, Suzaku, Spitzer, and at NOAO and NRAO facilities. Chandra science projects leverage synergies with other missions including SWIFT, WMAP, Fermi, Kepler, and Planck, as well as ground-based observatories such as MDM, SOAR, Gemini, ACT, and SPT. Chandra Deep Fields constitute a valuable resource in combination with similar deep fields by other observatories. Chandra also characterizes the X-ray properties of galaxy clusters discovered by ground-based Sunyaev-Zeldovich effect observations.

Proposal weaknesses:

Augmented funding was requested to address two areas. The first is to enable funding more archive and theory proposals, and the second is to develop flight software modifications in advance of future potential anomalies. The argument for augmented funding is not compelling and lacks sufficient justification in the context of the science opportunities presented for FY2011 and FY2012 to be accommodated within the constrained budget environment.

Overall assessment and recommendations:

After a decade in operation, Chandra remains an immensely powerful observatory in its prime, and it is well managed. The broad nature of the science program, as well as the interwoven synergistic nature of science investigations using observations from other missions in other wavelengths is one of the strengths expected from the Great Observatory series, and is paying off handsomely.

It is important to note that Chandra has subarcsecond resolution and that this capability is not found in any other mission currently flying or in development. This spatial resolution and the spatially-resolved spectra on the same scale, are key assets enabling Chandra science. The operation of other X-ray missions would not fill the science gap should Chandra be lost.

Chandra operations have become streamlined over the past decade, allowing much lower staffing levels. The committee encourages reconsideration of automated operations (going to 8 hour /5 day operations) if it can be done without jeopardizing the health and safety of the observatory.

The SRC notes that the Guaranteed Time Observer program is still in effect more than a decade after launch, and the committee questions whether this is appropriate when considering the inevitable pressures on observing time and funding that will persist in future years.

The SRC recommends that Chandra be extended with an augmentation with respect to the FY2011 President's budget and at the in-guide level for FY2012 and beyond. A planned tool for subpixel resolution in standard pipeline processing, user analysis tools, and full archive reprocessing planned for FY2012 should be completed. The SRC recommends restoration of funds sufficient for that purpose in FY2011, recognizing that the recommended level falls short of the in-guide numbers.

Warm Spitzer

Spitzer is the fourth Great Observatory and is devoted to infrared astronomy. Spitzer was launched in August 2003, and completed its cryogen mission in May 2009 when the liquid helium cryogen was expended, as per mission schedule. In its prime cryogenic mission, Spitzer had three independent operating imaging and spectroscopic instruments on its 0.85m telescope that covered the wavelength range 3-180 μm. It was the only pointed space telescope operating in this spectral regime. Two of those instruments, and half of the third instrument have become unusable in this non-cryogenic extended phase of the mission. Responsibility for flight and mission operations are handled at Lockheed Martin and JPL. Science operations are provided by the Spitzer Science Center, which is the primary interface to the user community.

Spacecraft/instrument health & status:

Spitzer has been operating in "warm mode" since cryogen exhaustion and re-equilibration in July 2009 and is now referred to as the "Warm Spitzer Mission." In this passively-cooled mode, at an focal plane temperature of 27K instead of the 15K for the cryogenic mission, the 3.5 and 4.6 μm channels of IRAC retain sensitivity and image quality virtually unchanged from the cryogenic mission values. The sensitivity of these channels is two orders of magnitude greater than any other current telescope. In this mode, the instrument is not dependent on any consumables that might otherwise limit the life of the mission. The spacecraft and observatory continue to be highly reliable and fully redundant, with sufficient propellant for reaction wheel unloading. Spitzer is in an Earth trailing heliocentric orbit. As a result the mission cannot be operated beyond December 2013 when, at a distance of more than 1AU, communication via the low gain antennae will no longer be considered reliable, and Spitzer could not be confidently commanded out of safe mode. By the conclusion of the mission, the lower bandwidth associated with the high gain antenna due to the increasing distance to Earth will result in a doubled downlink time, with only a slightly reduced observing efficiency.

Science strengths:

The proposed new emphasis on characterization of exoplanets is a strategy of high scientific value. Diameters, orbits, and atmospheres will be measurable for a variety of exoplanets, including those in habitable zones around red dwarf stars, which are especially prominent in the remaining Spitzer near- to mid-IR bandpasses. With this new emphasis Warm Spitzer essentially has a new prime mission goal that was not anticipated at launch. The required photometric stability and sensitivity needed for such observations have been confirmed. In view of concurrent work on exoplanets by Kepler, the SRC regards this capability of Spitzer as being most timely. Spitzer's heliocentric orbit enables long duration (> 100 hour) observations of planetary transits. This is a special capability of Warm Spitzer.

Warm Spitzer remains important for extragalactic studies. Anticipated proposed new work on the space distribution of massive clusters and the stellar mass of high-redshift galaxies will be important to studies of galaxy evolution.

Spitzer is proposing a 100% community-driven science program.The SRC believes this is adequately funded in their proposal. The SRC understands that the operations plan for the warm mission and the evolution of the staffing to a one-instrument observatory hve been recently independently reviewed and endorsed. The SRC appreciates the efforts to economize (staffing is now ~30% of that for the prime mission, when all instruments were operating). The SRC cannot add significantly to that endorsement.

All programs greater than 20 hours in length receive data analysis funding to the extent such funding is allowed by the Agency. Page charges are generally covered for all investigators.

The plans in the proposal appear to maximize science productivity with a combination of ambitious key-project "Exploration Science" emphasizing the high-priority science described above, and regular GO science. The oversubscription rate for the warm mission remains high and the committee expects that demand will remain high for the proposed part of the extended mission.

Relevance to NASA Priorities:

Warm Spitzer is relevant to NASA's strategic goals: how the Universe evolves, how planets, stars, galaxies, and cosmic structure come into being and the existence of life elsewhere. Warm Spitzer studies of extragalactic sources bear directly on research objectives to understand how the first stars and galaxies formed and how they changed over time into the objects recognized in the present universe and to understand how individual stars form and how those processes ultimately affect the formation of planetary systems. Warm Spitzer studies of exoplanets bear directly on the research objective to create a census of extrasolar planets and measure their properties

Data Accessibility:

In accord with the Great Observatory mission model, data are highly accessible to the science community. Warm Spitzer science will be 100% community derived through independent peer review. For the most part, data have no proprietary period.

Synergy with other missions and ground-based work:

The exoplanet database generated by Kepler will be an important resource for Warm Spitzer. Warm Spitzer will offer unmatched follow-up potential for special targets seen by WISE. Warm Spitzer offers several times higher spatial resolution and a hundred times higher sensitivity than the two shortest WISE survey wavelengths. Photometric verification and measurement of proper motions of brown dwarfs discovered by WISE will be important functions of Warm Spitzer, as will be study of very cold extragalactic sources. Finally, deep surveys with Warm Spitzer will locate targets for future study with JWST. The first GO proposals for JWST are expected to be in the final Warm Spitzer cycle, so the heritage of Warm Spitzer will be especially strong for JWST. The sensitivity of JWST is about a factor of a hundred larger than Warm Spitzer, such that photometric detections by Warm Spitzer will be accessible with low-resolution spectroscopy.

Proposal Weaknesses:

The Warm Spitzer warm mission is costly, especially in view of operations with what is essentially half of one of the three original instruments. With the understanding that this high cost is largely dictated by a Great Observatory infrastructure, the SRC believes that it is very much in the interest of the project to seek out further economies.

The limited remaining time with Warm Spitzer will make it difficult to do follow-up on the longer-period exoplanets until JWST is operational.

Overall Assessment:

This proposal would extend the period of warm mission operations by two years, up to the December 2013 end-of-mission. The SRC recommends that operations be extended for at least one more year, through 2012. A final year of operations would be decided upon by the next Senior Review on the basis of the productivity of the next two years, especially with regard to the proposed exoplanet studies.

The committee considers it critical that Warm Spitzer respond promptly to Kepler data releases. Careful coordination between the missions and the exoplanet user community is essential in this regard. It is especially important that Kepler data be made publicly available as soon as possible after observation in order to optimize this opportunity.

The SRC recommends funding at the level of the FY2011 President's budget for FY2011 and with an augmentation over the FY2011 President's budget of $7M for each of FY2012 and FY2013, with the latter to be reviewed by the next Senior Review.

Swift

The Swift mission is a multi-wavelength observatory on a robotic fast-slewing platform used to detect and monitor gamma-ray bursts and other transient or time-variable astronomical phenomena. Instruments on Swift are a Burst Alert Telescope (BAT) that detects gamma-ray bursts, an X-ray telescope (XRT) used to improve the positions of detected bursts to better than about an 1 arcsecond, and a UV-optical telescope (UVOT) that sets the context of the detected bursts.

The BAT has an energy range of 15-150 keV. Its field of view is more than 1 steradian, and it is able to locate a detected GRB to within a few arc minutes in roughly 10-15 seconds. The XRT has an energy range of 0.2-10 keV and a 23.6 arc minute field of view. In addition to quickly improving the positions of bursts, it can be used to photometrically monitor light curves or obtain low-resolution spectra, both of which are important in understanding GRBs and other transients. The UVOT is a 30cm diameter telescope with sensitivity over the 1700-6500 Å band, a 17 arc minute field of view, and a photon-counting microchannel-plate intensified CCD. It provides rapid optical images of the transient so that any optical/IR counterpart can be quickly identified for follow-up studies. Stars in the UVOT images provide an astrometric grid for the GRB field. UVOT also has grisms for spectroscopic studies.

Swift's achievements include the discovery of 3 GRBs beyond redshift 6 (one of which is at $z = 8.3$), observation of the X-ray flash from a supernova shock breakout, ultraviolet measurements of a large number of supernova light curves, and determination of arcsecond positions for short GRBs that indicate a different origin than for long GRBs. While designed as a facility for detecting and studying gamma-ray bursts, more than half of the science currently being published is non-GRB science in areas such as supernovae, cataclysmic variables, and active galactic nuclei.

Spacecraft/instrument health & status:

Swift was launched on November 30, 2004 and is presently operating well.
There are no known issues that would prevent operation for many more years.
In addition to other sustaining engineering activities, approximately $200K/year is being spent at General Dynamics to monitor gyro performance and to develop software necessary to maintain the attitude control system should gyros malfunction.

Science strengths:

Swift is producing many new discoveries on a wide variety of astronomical objects (GRBs, jets, AGN, supernovae, cataclusmic variabless, comets, galaxies). By concentrating on the most interesting gamma-ray bursts for follow-up studies, the remaining observing time is being used effectively in these other areas.

Swift provides NASA with an important ability to detect, locate, and study some of the most energetic phenomena in the Universe. Swift's capabilities are highly complementary to those of other X-ray missions (Fermi, Chandra, XMM, Suzaku, RXTE), and as such add additional value to studies conducted by these other missions in NASA's space science portfolio.

The next few years of operation should see a significant maturation of the BAT survey. That survey, and the public availability of time series observations of sources, will be important resources for the community.

Relevance to NASA priorities:

Swift is relevant to NASA's strategic goals of how the Universe evolves, how stars, galaxies, and cosmic structure come into being, phenomena near black holes, and the nature of gravity.

Data Accessibility:

Swift data are immediately publicly available on short turn-around times. The data are presently stored at HEASARC and at mirror archives outside the US. UVOT data are available through simple retrievals from the MAST archive.

Synergy with other missions and ground-based work:

By its very nature, Swift has considerable synergy with other observatories and ground-based telescopes. It is also part of the Gamma-ray burst Coordinates Network (GCN). The GI program funding is in part being used for coordination of follow-up observations with ground-based facilities.

Synergy with Fermi LAT is particularly strong. The Swift team has proposed several initiatives that could improve these synergies (e.g., lowering the GRB trigger threshold for GRBs near galaxies, automated tiling of larger areas to cover the LAT area, coordination/overlap of BAT with Fermi LAT pointings, rapid automatic target of opportunity observations for Fermi-detected GRBs).

Using GRBs as cosmological "beacons" for star formation in the high-redshift Universe is an important precursor study for JWST, which will be able to conduct follow-up observations of the GRBs. The Swift and JWST studies need not be contemporaneous.

Proposal weaknesses:

Even though the proposed augmentation initiatives are interesting, quantitative information about the expected impact to future science productivity was lacking.
For example, the fraction of LAT sources that could benefit from automatic tiling was not specified, and the increase in source detections from using a lower trigger threshold near bright galaxies was not provided.

While the complementarity of Swift to other missions is described, the proposal did not address to what extent Swift-only information may lead to revolutionary discoveries, as opposed to incremental advances in areas that have already been explored (e.g., ultraviolet afterglow light curves of supernovae).

Information about the UVOT and how it complements non-X-ray missions (e.g., GALEX, HST) would have been helpful in understanding the importance of this instrument for future non-GRB science investigations.

Overall assessment and recommendations:

Swift is a productive and important mission making significant contributions to astronomy. The Swift Guest Investigator program is producing very good science and should continue to be a key component of the mission. The SRC recommends continued operation of the mission in FY2011 and FY2012, with an extension to FY2013 and FY2014 pending the outcome of the next Senior Review's assessment of the science productivity of the observatory in the next two years. Given the very tight constraints on the availability of funding in the next two years, the SRC encourages the Swift team to consider implementing some of proposed initiatives within the existing funding available for the mission, in particular the initiatives to increase data downlink capabilities and the automated error box tiling. Both efforts would improve synergy with other missions and enable more rapid identification and follow-up of transient phenomena.

The SRC recommends funding at the level of the FY2011 President's budget for FY2011 and FY2012 and at the in-guide level for continued operations in FY2013 and FY2014, pending evaluation by the next Senior Review.

XMM-Newton

XMM-Newton, launched in 1999, is a facility-class X-ray observatory that is a cornerstone of ESA's Horizon 2000 program. It retains strong European support, and in the most recent review of extended ESA missions it was among the most highly rated.

The instruments on XMM-Newton are the European Photon Imaging Camera, which contains three imaging devices (EPIC, 0.2-12 keV, 30' FOV, 6" FWHM), two Reflection Grating Spectrometers (RGS, 0.33-2.5 keV, 3-38A, spectral resolution of 0.06A), and the Optical Monitor (OM) with a 16' FOV operating from 1800-6500 Å. US teams contributed the gratings along with part of the Optical Monitor. The Guest Observer Facility at GSFC provides support and expertise for US investigators. US PIs are successful in the competition for time, including that devoted to large projects.

In its energy band, XMM-Newton offers the most collecting area for imaging and spectroscopic studies (below 2.5 keV), and a field of view larger then Chandra or Suzaku.

Currently, support for US PIs is not provided along with the award of time, although support can be sought through the ADP program. The proposal argues for direct financial support for successful proposers.

Spacecraft/instrument health & status:

After a decade of operation, the spacecraft health and performance remain satisfactory. The performance of EPIC is nominal, with one CCD lost to a micrometeorite in 2005, and some loss of CCD CTE. Early in the mission, the RGS lost 2 CCDs but retains full spectral coverage. There has been a slow loss of sensitivity (30%) at longer wavelengths. In the OM, there has been a modest loss of efficiency due to degradation of filters (at the 10-15% level). The instrumental calibration is good.

Science strengths:

In imaging mode, XMM-Newton is well suited for observations of objects that are not bright but require sufficient counts to establish morphological information or spectral properties, from which temperature or elemental abundances may be extracted. The RGS can provide spectra of both point sources and extended sources, such as clusters of galaxies and supernova remnants.

XMM-Newton has been used to observe nearly every class of astronomical object, and these observations have led to a significant rate of publication.

XMM-Newton has made fundamental contributions to the study of galaxy clusters by determining masses, baryon fractions, metallicities, the lack of cooling flows, feedback, cosmological evolution, and constraints on cosmological model parameters. For supermassive black holes, XMM-Newton has been used to study the accretion disk, the spin of the black hole, and the outflow. The large field of view has enabled surveys of

M31, M33, and the Coma cluster of galaxies. The large projects that are ongoing or about to begin should provide important contributions in a variety of fields.

Relevance to NASA priorities:

XMM-Newton is relevant to NASA's strategic goals of understanding the origin and destiny of the universe, phenomena near black holes and the nature of gravity, and progress in understanding how the first stars and galaxies formed and how they changed over time into the objects recognized in the present Universe.

Data accessibility:

The ESA XMM-Newton Science Operations Center receives and processes the data that are distributed electronically to US scientists from the US GOF. Data are subject to a proprietary period for one year after data delivery to the PI. For some large programs and targets of opportunity, PIs give up their proprietary period. Archived XMM-Newton data are available through the HEASARC. Software for processing and analysis has been developed collaboratively by both centers. The science analysis software can be difficult to install and maintain, so the US GOF offers remote processing through the HERA system.

Synergy with other missions and ground-based work:

XMM is being used with a variety of other missions, including Fermi, Spitzer, RXTE, Chandra, Suzaku, and HST. On the same proposal, observers can jointly apply for observing time with Chandra, INTEGRAL, and the VLT (only for ESA member states). XMM is also involved with characterizing the X-ray properties of galaxy clusters discovered by ground-based Sunyaev-Zeldovich effect observations.

Proposal weaknesses:

After a decade of operation, with contributions to many different fields, new observations with XMM-Newton generally tend to extend existing lines of research rather than open entirely new areas.

There remain calibration issues in the EPIC imager at energies below 1 keV, which should be resolved.

The RGS is useful for bright sources, but due to background considerations, it will be difficult to significantly expand the number of sources observed by going to fainter levels. Half of the RGS sensitivity was lost in a wavelength regime that contains some important lines (e.g., OVII).

The Optical Monitor plays only a minor role in most scientific investigations.

Overall assessment and recommendations:

Ten years after launch, XMM-Newton remains in good operating condition and is consistently making important contributions to several branches of NASA astrophysics. At this point, the XMM-Newton mission has made a transition to placing more emphasis on long programs, a natural and appropriate modification. Proposal pressure is very strong. The mission leads to a significant rate of publication of scientific papers that are well cited. Despite this being a primarily ESA mission, XMM has been open to US investigators who have obtained a significant fraction of the observing time at very low cost to NASA.

The US GOF makes an important contribution in both expertise and in the ease by which investigators can analyze their data that is especially important to the non-expert users. The SRC recommends continuation of this facility and its activities.

The SRC recommends that guest observer funding be maintained if at all possible.

The SRC recommends funding with an augmentation with respect to the FY2011 President's budget of $1M for FY2011and $2M for FY2102 – 2014, with the latter two years subject to review by the next Senior Review.

WMAP

The Wilkinson Microwave Anisotropy Probe (WMAP) is a dedicated NASA Explorer mission to map temperature and polarization anisotropies in the CMB in five frequency bands between 22 and 90 GHz. WMAP was launched June 30, 2001, and began observations at the Earth-Sun L2 point three months later. Since then it has been mapping the full sky once each 6 months, with improvements in CMB maps and cosmological results stemming from both the increased integration time and the improved understanding of instrument characteristics.

WMAP is scheduled to cease flight operations after 9 years of data are gathered, in September, 2010. Data in the form of maps and associated products have been made public using observations from years 1-7. In this proposal, the WMAP team requests funding to complete the analysis of the full 9-year data set and to make the associated data products public.

Spacecraft/instrument health & status:

The spacecraft remains in good health, with only very minor disruptions in data gathering. The main transponder has become intermittent, and the spare is currently in use. Only 6 months of data acquisition remain before the mission operations are scheduled to end.

Science strengths:

WMAP has played an important role in establishing the standard model of cosmology (ΛCDM): a flat universe dominated by dark energy and dark matter with adiabatic density fluctuations from inflation seeding the formation of galaxies and large-scale structure. The team has used their CMB temperature and polarization power spectra to set tight constraints on cosmological parameters, including baryon, dark matter, and dark energy densities, the global curvature of space, the amplitude and spectral index of density fluctuations, and the optical depth to reionization. Other results include measurements of the primordial Helium abundance, the effective number of neutrino species and a limit on the sum of the neutrino masses. The detailed measurements of the acoustic peaks also confirm the adiabatic nature of the initial perturbations, setting tight limits on non-adiabatic modes.

WMAP's data products (maps, power spectra, and cosmological parameter chains and constraints) are widely used by the community for a variety of purposes, including tests of extensions to the standard cosmological model, investigation of foregrounds, and calibration of suborbital and ground-based instruments.

The WMAP proposal seeks funding to complete and make public the final, 9-year analysis of WMAP data. Improvements in the final maps lead directly to improvements in cosmological parameter estimates, tests of model extensions, and other community uses of those maps.

The external community has noted a variety of anomalies in the WMAP CMB maps, and has been investigating them as potential signatures of interesting new cosmological physics. The WMAP team believes that the most significant of these, the quadrupolar power asymmetry, may be caused by instrumental effects and has proposed to investigate this asymmetry and to clean the maps of those instrumental effects. Additionally, they will improve the calibration of the brightness of Saturn, mostly in the disk component, by including observations during the 2009 ring-plane crossing. These tasks will both be of significant service to the external community.

Relevance to NASA priorities:

WMAP directly addresses the NASA strategic goal to address "What are the origin, evolution, and fate of the Universe?"

Data accessibility:

The data products are publicly available on the web, and very widely used by the cosmology community.

Synergy with other missions and ground-based work:

WMAP cosmological constraints are used by nearly all researchers investigating cosmological parameters or extensions to the standard cosmological model. As such, they are very relevant to such studies from space, suborbital and ground-based platforms.

The WMAP temperature anisotropy maps are now used by nearly every suborbital and ground-based CMB experiment to calibrate their instruments. The planet calibrations will be important for future experiments as well.

WMAP complements the Planck LFI channels by virtue of the different band choices, and will be valuable even in the post-Planck era for investigating, understanding, and constraining the impact of low frequency foregrounds in future CMB measurements, including Planck.

Proposal weaknesses:

WMAP has produced very good results from the 7-year data, so the statistical gains from an additional two years of data are not large. Especially for high frequencies, the Planck HFI is significantly more sensitive and will offer greater angular resolution. The scientific gains from the analysis of the full 9-year WMAP data set are therefore likely to be significant, but evolutionary in nature.

Overall assessment and recommendations:

The WMAP mission has been very successful to date. The team is nearly done taking data. The SRC supports the analysis of the full 9-year dataset, resulting in useful data products (maps, power spectra, likelihood chains, etc) for the community and completion of a CMB product that is entirely independent of Planck. These analyses, along with the investigation of the quadrupolar power asymmetry and the work required to improve the planet calibrations, can only reasonably be done by the team that is currently in place. This work is both timely and valuable enough to warrant full funding.

The SRC recommends funding at the requested levelthat is equivalent to an augmentation with respect to the FY2011 President's budget of $0.9M in FY2011 and $1M in FY2012.

Suzaku

Suzaku is the fifth Japanese X-ray satellite. It was launched by JAXA in 2005. This mission continues an ongoing Japanese-US collaboration in X-ray astronomy for which the US provided an instrument (and components) along with software and personnel. This is the most ambitious Japanese X-ray mission yet, containing an original complement of four instruments (the quantum microcalorimeter), one of which failed before it could be used for science observations. Even with only three operating instruments, the capabilities of Suzaku are closer to a facility-class mission than to an explorer class mission. The instrument package comprises the XIS CCD imager (17' square; 3 operating cameras, 0.2-12 keV), and the hard X-ray telescope (HXD), consisting of the PIN (10-70 keV; 34' FOV) and the GSO (40-600 keV; 4.5 degree FOV), both of which have good time resolution. The third instrument is a hard all-sky monitor (WAM; 50keV-5MeV) for transient detection, with energies extending above the SWIFT band.

Suzaku offers the widest energy range of the high-throughput X-ray observatories by more than an order of magnitude. Suzaku has the lowest soft X-ray background compared to other X-ray missions, making it particularly well-suited for low surface brightness soft X-ray observations. Suzaku also has superior spectral resolution in imaging mode (XIS), because it possesses a recent generation of X-ray CCDs. The proposal pressure is strong, although somewhat less than for competitive missions.

Spacecraft/instrument health & status:

The X-Ray Spectrometer (XRS; quantum microcalorimeter) failed shortly after launch, and since that time one of the four CCDs in the XIS failed. Some contamination on the XIS devices was noticed during the first year of operation, but further sensitivity losses have been modest. The spectral resolution of the XIS remains very good. There has been a gradual noise increase in the soft energy part of the PIN (< 8 keV, in the region where the XIS can collect data), but above 8 keV instrument performance is nominal. The calibration has improved for the GSO, as was promised in the previous review.

Science strengths:

The XIS is a very capable instrument, with an effective area at 1-10 keV that is larger than Chandra, although not as large as XMM-Newton. Suzaku has been used for a wide range of science programs. Suzaku contributes to studies of black hole spin in both supermassive and stellar-mass black holes, accretion physics, and jet physics that are central to high energy astrophysics. Suzaku is often the instrument of choice for compact object studies because the hard X-ray instruments provide important constraints on models. Suzaku is also the instrument of choice in the study of galaxy clusters beyond the central region. These studies probe the structure and accretion out to and beyond the virial radius (a recent achievement) that address structure formation models in a way not previously possible. This is enabled not only by the lower background, but because the background is fairly consistent orbit-after-orbit. The good soft X-ray spectral resolution gives Suzaku an advantage in the study of the Galactic hot ISM and in the study of supernova remnants, where elemental abundance measurements are important.

Relevance to NASA priorities:

Suzaku is relevant to two of NASA's strategic goals: understanding the origin and destiny of the universe, phenomena near black holes, and the nature of gravity; and understanding how the first stars and galaxies formed and how they changed over time into the objects recognized in the present Universe.

Data accessibility:

GO observations have a proprietary period of one year after the delivery of the processed data. Calibration observations and target of opportunity observations during the GO phase have no proprietary time. Data are provided over the web to US investigators and archive scientists through the US GOF and the HEASARC. Pipeline processing has been developed by the US and Japanese scientists and the resulting data flow easily into the suite of existing software that is common to many missions (FTOOLS, XSPEC). The US and Japanese teams continue to collaborate on this effort.

Synergy with other missions and ground-based work:

The three large throughput X-ray telescopes (Chandra, XMM, and Suzaku) often complement each other and perform cross-calibration measurements. Coordinated Suzaku and Chandra observations are available directly through the Chandra program. Suzaku has worked closely with Swift, HESS, MAXI, and Fermi, both in follow-up mode, and in coordinated observations of variable sources. For example, there have been coordinated observations to probe the emission mechanism and nature of jets. Suzaku will serve as a pathfinder for NuSTAR and the high-energy instruments on Astro-H.

Proposal weaknesses:

As is the case with many mature missions, new observations with Suzaku tend to strengthen existing lines of research rather than opening entirely new discovery space.

The hard all-sky monitor (WAM) has not become a strong part of the mission, although efforts are being increased to address this issue.

Overall assessment and recommendations:

The Suzaku mission is a key instrument in the wide range of endeavors being pursued in high-energy astrophysics. It has been consistently oversubscribed in time and has led to a strong publication rate that is growing. The key projects, which are demanding in terms of observing time, should lead to high-impact results in the coming years.

Suzaku is an example of a highly fruitful international collaboration where the Japanese and US teams have grown increasingly effective in working together. They do not "reinvent the wheel," but adapt previously developed software for subsequent missions. Although most of the cost of the mission was borne by Japan, US scientists receive a significant portion of the observing time and are first authors or co-authors in a majority of the publications. This strong science return is provided at a very modest cost to NASA.

The operation of the mission depends, in part, on US scientists and software developed and maintained by the US GOF. If support for these activities were withdrawn, the mission would be in peril and might be cancelled, since it is unlikely that JAXA could devote the additional resources. Our strongest recommendation for Suzaku is that the GOF and its services be maintained without significant cuts.

The SRC recommends that guest observer funding be maintained if at all possible. This is most important for those undertaking large programs that place the greatest demands on the scientists.

The SRC recommends funding at a level corresponding to an augmentation with respect to the FY2011 President's budget of $0.1M in FY2011 and $2.64M in FY2012 – 2014, with the latter reviewed by the next Senior Review.

GALEX

The GALEX mission performs ultraviolet imaging and spectroscopy in the Far Ultraviolet (FUV) and Near Ultraviolet (NUV). The prime mission performed a sky survey covering a significant fraction of the full sky in both bands (the AIS) as well as targeted deeper surveys. GALEX is requesting an extended mission, primarily to support the continuation of the GALEX Legacy Survey (GLS), but also to continue the guest investigator program and perform a spectroscopic survey. When complete, the GLS will provide 1500 seconds of exposure on each sky element over the same area as the AIS, which provided 100 seconds of exposure. The GLS has completed 6000 deg^2 of survey, and will, for nominal operations, complete 3000 deg^2 in each subsequent year.

Spacecraft/instrument health & status:

The FUV detector is currently non-operational for planning purposes. While the GALEX team continues to try to restore detector functionality, for the purposes of this review the SRC assumed that the FUV channel was permanently non-operational. All other aspects of the spacecraft and instrument performance are nominal.

Science strengths:

GALEX provides the only wide-field imaging capability in the ultraviolet and is the only instrument capable of performing efficient sky surveys in its wavelength range. GALEX deep images have led to several significant scientific results and discoveries. The survey data have proven to be a great utility to the community, as evidenced by the archive downloads and community publication and citation rate.

The GALEX survey capability is unlikely to be replicated in the next several decades.

Relevance to NASA priorities:

GALEX is relevant to NASA’s strategic goals to understand the origin and destiny of the universe and how the first stars and galaxies formed and how they changed over time into the objects recognized in the present Universe.

Data accessibility:

The archive is heavily used by the community, and results in substantial publications. Improved software tools for extraction, particularly of archival spectroscopic observations, should lead to an even more useful archive.

Synergy with other missions and ground-based work:

The GALEX sky survey provides an archive of UV imaging that is available for most of the sky. Observations in other bands, e.g. X-ray, optical, IR, gamma ray, often use the GALEX archive images of their fields of interest to provide the broadest possible multi-wavelength information.

Proposal weaknesses:

The proposal did not provide an adequately quantitative evaluation of the science that would be gained by increasing the survey volume. It was not clear what specific improvements in our understanding would result from doubling the GLS survey volume over the next two years.

The value of the spectroscopic survey was not well defined.

The scientific productivity (with respect to the level of funding) of the PI and GI efforts is low compared to other missions at this level of maturity. The requested level of funding is high for the potential scientific return, compared to other mature missions. While community publications have grown substantially, the PI team and GI publication rate has not matched this growth. The SRC felt this reflected the mature state of the program, and that the survey archive, as opposed to new targeted observations, has become the primary source of scientific productivity.

The proposal did not address the relationship between GALEX and the UV imaging capabilities on other missions, in particular the Swift UVOT and the XMM OM. Since these cameras have capabilities in the same waveband, with less field of view but better angular resolution, some scientific objectives might be better pursued with these instruments. An assessment of the science objectives, other than the surveys, that require the GALEX wide field of view should have been included in the proposal.

Overall assessment and recommendations:

The Committee recommends that the program be continued for two more years and closed out in FY2013. During this time, the program should emphasize the completion of as much of the GLS as possible and the development of software to maximize community utilization of the archive. By concentrating on the GLS, the project will map more sky per year, increasing the archival value of the mission accordingly.

The Committee feels that moving the Missions Operations Control center to Cal Tech, which was suggested as a long-term cost-saving measure, would introduce unnecessary risk into the mission operations and provide no cost savings given the limited remaining mission lifetime. The panel strongly recommends that the mission operations control facility not be moved.

The Committee does not recommend funding the GI program nor the execution of the spectroscopic survey.

The SRC recommends that GALAX receive a budget that is $1M less than that in the FY2011 President's budget for FY2011 and FY2012 followed by closeout in FY2013.

RXTE

The main and unique niche of RXTE is microsecond timing in the X-rays. This enables the study of QPOS, millisecond pulsars, anomalous X-ray pulsars, accreting millisecond pulsars, and magnetars.

The satellite contains a Large Area Proportional Counter array of 6500 cm^2. Only 1 out of 5 proportional counters is now being used most of the time. The instrument is restricted to observations of sources that are strong enough to carry out fast timing. This means that the prime targets are Galactic X-ray sources, but sufficiently strong AGNs are observed as well. With these restrictions, RXTE continues to provide science that is in demand by the community.

Spacecraft/instrument health & status:

The spacecraft is beginning to deteriorate. The HEXTE cannot chop so it is quite limited. In the past, when proposers have prepared their technical feasibility calculations they have assumed that all 5 PCU will be turned on, but the average number of PCUs active per observation is 1.6. At times only 1 PCU is enabled; however this setting is also driven by the science. For example, observations with the goal to simply measure the flux do not benefit from having more than one PCU enabled. As a percentage of total good time, the number of PCUs on is: 50%, 40%, 5%, 3%, and 2% for 1 through 5 PCUs, respectively. There is no status report on the ASM after 1998, but it seems to be operating satisfactorily.

Science strengths:

The strength of RXTE is the study of time variability, particularly for galactic X-ray pulsars and black holes on time scales of milliseconds. After over 40 years of X-ray astronomy, new forms of rapid time-variable phenomena continue to be discovered that tell us more about compact objects. RXTE is the only mission that can do this.

RXTE is still a very fruitful mission. Even without direct GI support there were 84 submitted proposals in the last cycle. There were six complete downloads of the archival data. The publication rate based on RXTE remains high, similar to the rate for the previous seven years.

Relevance to NASA priorities:

RXTE is relevant to NASA’s strategic goal to understand phenomena near black holes and the nature of gravity.

Data accessibility:

The data are made immediately available to the public.

Synergy with other missions and ground-based work:

RXTE provides monitoring to supplement observations in space from IR to GeV and optical/IR, as well as TeV, from the ground. There is substantial benefit to maintaining RXTE in the Fermi era to observe flare events when they occur.

Proposal weaknesses:

The proposal did not make a convincing case for how continued observations would qualitatively enhance the large body of work already collected. The proposal described the ways in which RXTE is complementary to other current missions, but the committee does not believe that these supporting observations by themselves are sufficient to justify a further extension of the mission with the current tight budget constraints.

Overall assessment and recommendations:

Because of the special capabilities for millisecond timing, the small cost of operation, and the continued high interest in RXTE data in the community, NASA could justifiably consider maintaining the RXTE mission, including the GOF, were funds available.

The SRC recommends no funding for FY2011 and beyond.

INTEGRAL

INTEGRAL (the INTErnational Gamma-Ray Astrophysics Laboratory) was launched in October 2002. INTEGRAL has now completed more than seven years of successful operations and has recently been approved by ESA for an extended mission through 2012. NASA has been a partner in the mission since its selection by ESA in 1995. INTEGRAL carries two main instruments, the high-resolution gamma-ray spectrometer, SPI, and the high-angular resolution gamma-ray imager IBIS, as well as X-ray and optical monitors. NASA currently provides 5% of INTEGRAL funding.

Spacecraft/instrument health & status:

The INTEGRAL spacecraft and its various subsystems are functioning well. The spacecraft orbit allows for a ~90% duty cycle for science operations (consistent with pre-launch predictions). The solar arrays have shown little degradation and the full 40^{o} range in sun angle is anticipated to persist through 2012. The attitude control system has enough fuel for another 15 years. Early problems with saturation of the telemetry bandwidth have been circumvented. There were a few problems with the instruments early in the mission, but they have been extremely stable since then. The JEM-X detectors exhibited a worrying rate of loss of anodes shortly after power up. The problem was solved by reducing the operating voltages and only using one of the two units at a time to protect the other. The IBIS/ISGRI array still has less than 3% bad pixels. Two of the 19 SPI Ge detector elements failed about one year into the mission and a third has failed within the last year. This has led to a sensitivity decrease of ~8%. The bottom line is that the instrument seems capable of running well for 5-15 years.

Science strengths:

The major strength of INTEGRAL is in gamma-ray line studies, especially ^{26}Al and the 0.511 MeV annihilation line, a capability unique among current operating missions. INTEGRAL employed this capability to reveal clues to the nature of ongoing nucleosynthesis. The ^{26}Al and ^{60}Fe mapping provides information for massive star inventories in nearby star-forming complexes. INTEGRAL gave confirmation of disk asymmetry for the e+/e- annihilation line. INTEGRAL also carried out population studies of HMXBs and SFXTs. The recently developed gamma-ray polarization capability is unique among current missions and potentially important. The polarized emission from GRBs and pulsars has been measured. INTEGRAL would contribute substantially to our understanding of novae or Type Ia supernovae by observing gamma-ray lines if such events were to occur locally during the next two years, but the probability is low. Other studies include those of black hole binary accretion, cyclotron line sources, magnetars, cataclysmic variables, and AGN.

Relevance to NASA priorities:

INTEGRAL observations of ^{26}Al and other radioactive elements address element formation and hence the NASA strategic goal to understand how the Universe originated and evolved to produce the galaxies, stars, and planets we see today and how life originated.

Data accessibility:

The data are made public one year after they are processed.

Synergy with other missions and ground-based work:

INTEGRAL impacts the scientific return of other missions through coordinated multi-wavelength observations with other satellites (e.g., Fermi, XMM-Newton, Swift, RXTE). INTEGRAL gives the only energy coverage for energies above those of RXTE and SUZAKU until one reaches Fermi energies of about 20 MeV. The synergy between INTEGRAL and Fermi will be beneficial to a number of scientific endeavors. The complimentary energy band and superior angular resolution of IBIS is important to identify and study the large number of sources detected with Fermi. Several Fermi Guest Investigations refer to INTEGRAL coordination or refer to INTEGRAL results. These include the multi-wavelength study of blazars, pulsars, pulsar-wind nebulae, Galactic microquasars, and Be star transients. Solar physics observations by INTEGRAL complement lower energy observations. The low positional accuracy of INTEGRAL means that only sources for which one has some high expectation of the identification can be confidently monitored across wavelength bands.

Proposal weaknesses:

The proposal did not make a strong case that this mission has not reached a point of diminishing return. The proposal did not list the number of GOs that need to be funded per year or the oversubscription rate. The SRC estimates that only about 20 proposals a year are submitted and accepted. The proposal did not, therefore, make a case that there is strong community interest in the new results that will come from continued US participation.

The archival data is lightly used. The community does not find the INTEGRAL archive to be as important a resource as the archimes of other missions.

Overall assessment and recommendations:

Even though INTEGRAL has produced good science in the past, the SRC cannot recommend continued US funding in a constrained budget.

The SRC recommends no funding in FY2011 and beyond.

Warm WISE

The WISE mission will produce a survey of the entire sky at wavelengths 3.4, 4.6, 12, and 22 μm. WISE was launched into a Sun-synchronous orbit on 2009 December 14, and began its prime survey mission on 2010 January 14. WISE has a cryogenic primary mission utilizing a solid hydrogen cryostat, a 40 cm telescope, and four infrared detector arrays. The focal plane has four 1024x1024 infrared detector arrays, HgCdTe for the two shorter wavelengths and Si:As for the two longer wavelengths. The former will remain available after cryogen exhaustion. WISE maps the sky in a highly redundant manner by scanning the sky continuously, taking out the orbital smearing by using synchronized motions of a scanning mirror. WISE produces a complete sky map in 6 months. Data products for the primary mission include an Image Atlas and a point source catalog. Cryogenic WISE will also identify and characterize a number of Near Earth Objects (NEO) using the 12 and 22 μm windows. These bands will not be available after exhaustion of the cryogen, thus no NEO work is anticipated in the warm mission phase. The proposal to the SRC included two main elements: a three-month extension of WISE flight operations after cryogen depletion to complete the second-pass sky coverage in the 3.4 and 4.6 μm bands, and enhanced data products and enhanced data analysis tools.

Spacecraft/instrument health & status:

WISE is currently conducting its prime cryogenic mission. All systems on the instrument payload and spacecraft are performing well. The first pass on the sky should be complete in July 2010, and the solid hydrogen cryogens are expected to last until October 2010. The 9-month cryogen lifetime should be sufficient to cover half the sky for a second pass.

After the depletion of the cryogens, the focal planes and optics are predicted to radiatively equilibrate at 72 ± 4 K. This temperature should be low enough to continue operation of the two shorter wavelength channels with little change in performance.

Science strengths:

The WISE cryogenic survey will be orders of magnitude more sensitive than previous all sky surveys at these wavelengths. The WISE survey is expected be an important astronomical database for decades to come.

The team is highly experienced and includes experts in both the instrumentation and the processing of very large astronomical data sets.

Relevance to NASA priorities:

WISE is relevant to NASA priorities since the WISE catalog will contain positions and infrared photometry for all types of astronomical objects ranging from solar system objects to sources in the distant universe. In particular, Warm WISE would contribute to the NASA strategic goal of understanding the formation of low mass stars and the properties of massive exoplanets by increasing the sample of known objects.

Data accessibility:

The final release of the Warm WISE data is scheduled for the fourth quarter of CY2012.

Synergy with other missions and ground-based work:

It is expected that the WISE data will be important as a general source of infrared information for other missions as well as for ground-based work. In particular, WISE will provide targets for Spitzer verification and further characterization.

Proposal weaknesses:

The proposal did not convincingly demonstrate to the SRC the need for the three-month extension for the warm mission. The primary science example, the detection of ultra-cool brown dwarfs, would certainly benefit from the warm mission, but the transformational benefit of increasing the sample size from, for example, 85 to 170 objects, was not shown. Most of the other examples were statistical in nature and could reasonably be performed over the half of the sky covered twice in the cryogenic mission. In terms of the general survey sensitivity, only the 4.6 μm band is expected to show a significant improvement in sensitivity from the extension. While the enhanced reliability in the repeated regions is desirable, the requested funding seems high for the anticipated improvement.

The science return for the investment in the Absolute Brightness Calibrated Atlas was not well demonstrated. For many studies of extended structures, manual background corrections of the individual 1.56ºx1.56º images should be sufficient. The WISE Variability and Proper Motion Database will likely have limited utility given the several-year delay between the observations and the availability of the tool. Moreover, the cadence of the WISE observations is far from optimal for synoptic studies. The requested funding for the WISE Extended Source Catalog appears to be very high for the perceived effort required to produce the catalog.

The SRC was unconvinced about the need for the Custom Image Co-adder Tool and the Custom Source Extractor given their costs.

Overall assessment and recommendations:

The WISE prime mission should produce a catalog and image atlas of great utility to the entire astronomical community. Although it is impressed with the promise of the cryogenic mission, the SRC did not find adequate scientific justification in the proposal for the cost of either the Warm Extension or the Enhanced Data Products.

The SRC recommends no funding for the extended Warm WISE mission nor for the enhanced tool development.