2022 Astrophysics Senior Review

Rest of Missions Report

2022 Astrophysics Senior Review Rest of Missions Report

March 29 - April 1, 2022

Panel:

Dr. Marcel Agüeros	Columbia University
Dr. Supriya Chakrabarti	University of Massachusetts, Lowell
Dr. Eric Charles	SLAC National Laboratory
Dr. Kelle Cruz	Hunter College, City University of New York
Dr. Erin Hicks	University of Alaska, Anchorage
Dr. Jeyhan Kartaltepe	Rochester Institute of Technology
Dr. John O'Meara	W. M. Keck Observatory - **Chair**
Dr. David Weinberg	Ohio State University

1. Missions and Budgetary Scope

The Rest of missions (ROM) panel of the 2022 Astrophysics Senior review evaluated six missions from the Astrophysics Division (APD), and a new entrant into the Review by a mission from the Planetary Science Division (PSD) with a mission extension component of APD relevance and funding request. These missions are listed below along with their launch date and in-guide and average yearly over-guide budget requests. As a representative value, the FY23 total for the in-guide requests is $51.5M and over-guide requests would add a total of just under $4M.

Abbreviated Name	Full Name	Launch Date	FY23 In-Guide Budget ($M)	Approximate Yearly Over-Guide Budget ($M)
XMM-Newton	X-ray Multi-Mirror MIssion - Newton (*ESA mission*)	1999	3.8	1
Swift	Neil Gehrels Swift Observatory	2004	5.9	0.5
New Horizons	New Horizons	2006	0	1
Fermi	Fermi Gamma-ray Space Telescope	2008	14.1	0.4
NuSTAR	Nuclear Spectroscopic Telescope Array	2012	8.8	0.3
NICER	Neutron Star Interior Composition Explorer	2017	4.3	0.3
TESS	Transiting Exoplanet Survey Satellite	2018	14.6	0.3

Table 1: Relevant details of the operating missions under review

2. Overall Findings

The Rest of Missions Panel finds no scientific reason to discontinue or substantially reduce the funding or scope of any of the six APD missions under review. Furthermore, the Panel recommends that no APD mission be funded below the in-guide requests, at the expense of any over-guide allocations as needed.

Each APD mission under review produces broad-range, high-impact science and is operating well. No significant risks are foreseen in the next five years that threaten the science viability of the missions in the portfolio. Each mission presented a detailed, high-quality proposal, along with informative presentations that were responsive to questions from the panel. The panel thanks each of the teams for the quality of the work presented, and recognizes the significant effort that was required to craft the proposals and presentations.

The panel reinforces the assessment of the 2019 Senior Review ROM panel that “the complementarity of these missions makes the overall capability of the portfolio more than the sum of its parts.” Since the 2019 Senior Review, the missions have made significant advances in leveraging this complementary, for example by enabling new capabilities to respond jointly to the needs of transient, time-domain, and multi-messenger astrophysics. These advances have allowed the missions to be immediately responsive both individually and collectively to the “New Messengers and New Physics” science theme in the 2020 Astrophysics Decadal Survey.

The panel considered a wide range of over-guide budget requests for the APD missions, and highlights our top recommendations for over-guide funding below. The recommendations do not necessarily follow our overall ranking of the missions, but are certainly informed by them. **Should APD funding allow, the panel recommends funding the over-guides in the order we list below**. There are a few specific over-guide requests that we do not recommend funding and these are explained in the over-guide discussion of the report below, and/or in the individual mission reports.

The Panel further recommends that APD/PSD make an effort to execute the astrophysics observations requested by the New Horizons mission, but make funding for the data analysis available to the community for competition.

Finally, the Panel wishes to highlight the importance of new efforts by NASA, NASA centers, and the individual missions to make positive change in the areas of Diversity, Equity, Inclusion, and Accessibility (DEIA). Some missions included funding for their DEIA efforts in their in-guide budget requests, others in their over-guide. **The Panel recommends that the Science Mission Directorate fund the coordinated DEIA Initiative for the Guest Observer Facilities at NASA Goddard without impact on mission budgets for these activities.** The panel strongly feels that if inclusion is a core value at NASA, these important efforts should not come at the expense of the already strained resources of the missions. We elaborate further in Section 5 of the report below.

3. Ranking Method and Results

After a review of the mission proposals and presentations, the panel thoroughly discussed each mission, with the discussion broken into the three criterion areas where an adjectival ranking was assigned. The panel separately and anonymously provided a score for each mission criterion, and the averages were calculated. The weighting function of the criteria (50% weighting for Criterion A, Scientific Merit; 25% for Criterion B, Relevance and Responsiveness;

and 25% to Criterion C, Technical Capability, Management, and Science Productivity Given the Costs) were used to derive the overall numerical score for the missions.

The overall numerical scores were taken as the basis for the ranking of the missions. While there was a discussion of a possible reordering of the ranking based on the scores given the relative closeness in score of the APD missions, the panel chose not to reorder the missions.

The adjectival ratings are given in Table 2 below, ordered by overall ranking with the highest ranked mission at the top. It is important to note that within the APD portfolio, there was a very small separation in the overall numerical scores used to derive the adjectival rankings. This speaks to the fact that each mission produces high-quality science, shows little technical risk, and has an engaged team and community.

The panel notes that the adjectival for the New Horizons mission proposal was impacted by a number of factors, which we explain in detail below. Likewise, the adjectival assigned to Criterion C for XMM-Newton is given further explanation below. As the adjectival ratings suggest, the panel scores for NICER, NuSTAR, Fermi, and XMM-Newton are nearly indistinguishable. **It is the panel's assessment that these missions' rankings should be regarded effectively as tied.**

Mission	**Criterion A**	**Criterion B**	**Criterion C**	**Overall Score**
Swift	E	E/VG	E/VG	**E**
TESS	E	E/VG	E/VG	**E/VG**
NICER	E/VG	E/VG	E/VG	**E/VG**
NuSTAR	E/VG	E/VG	E/VG	**E/VG**
Fermi	E/VG	E/VG	VG	**E/VG**
XMM-Newton	E/VG	E/VG	VG	**E/VG**
New Horizons	VG	VG/G	VG/G	**VG/G**

Table 2: Rankings of the missions under review, including the individual criterion rankings

4. Distinctive Strengths of the Missions

Fermi – Fermi provides unique access to the gamma-ray portion of the electromagnetic spectrum and the largest simultaneous field-of-view of any space telescope. Its data give us a time-domain view of the entire gamma-ray sky and are a crucial asset for gravitational-wave and multi-messenger astrophysics.

New Horizons – Although New Horizons is a planetary mission, its location in the outer solar system provides unique advantages for some astrophysical observations. The proposed astrophysics program, which would use a small fraction of the observing time during New Horizons' second extended mission, exploits this vantage point beyond most of the zodiacal light and geocoronal Lyman-α mission.

NICER – NICER has the largest effective area for soft X-ray spectroscopy of any operating mission, rapid slew capability, and millisecond-level timing capability. These capabilities are essential to its prime mission objective of constraining the masses and radii of neutron stars, and they make NICER a powerful asset for many other X-ray astronomy applications.

NuSTAR – NuSTAR is the first focusing hard X-ray mission, with unprecedented sensitivity at 10-80 keV energies and high spectral resolution. This hard X-ray sensitivity is crucial for understanding a wide range of astrophysical phenomena, including the hot coronae of accreting black holes, the sources of the cosmic X-ray background, and the properties of ultra-luminous X-ray sources.

Swift – Swift provides a wide field of view in its Burst Alert Telescope and the ability to slew rapidly to observe targets of opportunity at X-ray and UV/optical wavelengths. It provides time-series photometry for a wide range of sources. These capabilities are especially valuable for gravitational-wave and multi-messenger astrophysics.

TESS – The ultra high-precision and high cadence photometry of bright stars makes TESS an excellent resource for transiting exoplanet science and for stellar astrophysics, including through asteroseismology. In its first extended mission, TESS expanded its total sky coverage and the fraction of the sky it observed more than once, and shortened the cadence of its typical full-frame images from 30 to 10 min, while continuing to provide 20 s and 2 min data for pre-selected targets. TESS proposes to further shorten the cadence of full frame images to glean new information from its full possible data set.

XMM-Newton – More than two decades after launch, XMM-Newton remains (with Chandra) one of the world's premier general purpose X-ray facilities, with good imaging and excellent spectroscopic capabilities, especially at soft (0.2-2 keV) energies. In particular, it is the most powerful facility for studying diffuse hot gas in galaxy groups, clusters, and the intergalactic medium. Because XMM-Newton is operated by ESA, all NASA funding goes directly to support US investigators, making the science-per-dollar return of XMM-Newton exceptionally high.

The panel notes that the weaknesses identified throughout the review process were relatively minor, and were mainly identified as weaknesses when considered with respect to an exceptional standard set by other missions. Other weaknesses were self-identified by the missions either in their reports, or in response to our questions. The missions aim to address these weaknesses, subject to their limited resources. The panel notes that often, addressing these weaknesses transcend any individual mission, but instead requires addressing and changing culture at NASA centers and/or universities.

5. Advancing Diversity, Equity, Inclusion, and Accessibility

Since the 2019 Senior Review, NASA has adopted Inclusion as an agency core value, and has begun a number of new initiatives across SMD that bear directly on the operating missions the panel was tasked with reviewing. Diversity, Equity, Inclusion, and Accessibility (DEIA) factored into two evaluation criteria in the panel's ranking.

The panel was struck by the fact that although the overall rankings for criteria which incorporated DEIA were very close in final assigned value, the efforts by individual missions were in fact very different. Many of the missions considered by the panel have been in the extended phase for some time, while others are fairly recent entries. As a result, the degree to which missions identified DEIA work as central to their success from the onset varies significantly. The panel does note that each mission directly addressed DEIA in their proposals, their presentations to the panel, and in response to the panel's questions. Each mission is making important efforts on DEIA, but no mission truly stood out as either exceptionally strong or exceptionally lacking.

The panel felt strongly that both the missions and future Senior Review panels would benefit from better guidance in the call for proposals with regards to DEIA activities. NASA should request prime mission objectives (PMOs) for DEIA efforts, and in response missions should provide a clear statement of their DEIA objectives, preferably with measurable outcomes. The panel recommends that NASA create more concrete and robust DEIA guidance to give the missions the ability to formulate DEIA PMOs well in advance of the next Senior Review.

Acknowledging a lack of expertise in DEIA issues, along with a lack of sufficient individual mission resources, the missions that have a Guest Observer Facility (GOF) at NASA Goddard Space Flight Center (GSFC) chose to jointly participate in a DEIA initiative that pools resources to fund DEIA efforts and to hire a dedicated DEIA expert to advise the mission staff and coordinate activities. Each mission identified the same baseline funding request amount for these efforts, but some missions chose to make this request through their in-guide requests, while others did so via their over-guide requests. As stated above, the panel feels that if inclusion is truly a core value at NASA, it should be funded as such, and not through small additions to already resource-strapped missions charged with lowering costs. The panel has a number of additional observations about this initiative at GSFC, but notes that these thoughts can be generalized across NASA's fleet of operating missions.

The panel strongly endorses DEIA efforts that span multiple missions and allow for coordinated efforts so that the impact of these efforts can be larger. However, the panel is concerned that the initiative is under-scoped. Given the systemic nature of DEIA issues and the significant work that needs to be done to make real and lasting impacts, the task of advancing positive change in DEIA both inwardly at GSFC and outwardly from GSFC is very likely too large a task for one individual. Moreover, the panel felt that the climate at GSFC must be addressed first before the missions can proceed on community-facing, joint or individual initiatives. Moreover, the panel felt that this effort should focus on addressing the climate within GSFC before the missions proceed with community-facing, joint or individual initiatives.

The panel notes that many missions are now executing science programs well beyond the original aims of their prime missions, yet are tasked with finding new ways to lower costs. The panel heard and is concerned that the push to efficiency in missions can have negative impacts on morale and retention by splitting individuals across too many efforts. The panel sees this issue as being systemic for extended missions, and is concerned that leadership at NASA is focused on 'new business' efforts to the extent that these issues are not given adequate attention.

Finally, the panel notes the power imbalance between PIs and Project Scientists and the rest of a mission team. This imbalance can have significant DEIA impacts, and at the present time, there is little in the way of an ability to assess if there is appropriate accountability in mission leadership. The panel recommends that every mission conduct a regular set of climate surveys, and that the survey results be available for external review. Additional tools are likely necessary to properly gauge DEIA strengths and weaknesses within teams.

6. Over-Guide Budget Recommendations

The panel considered multiple budget over-guide requests. Absent a specific set of over-guide requests we note below, the panel viewed the requests favorably, as we feel they will increase either the efficiency of the missions, the scientific yield, the community grasp and responsiveness, or some combination of these three factors. Our top recommendations below are in ranked order, but fall in three distinct tiers.

1. The XMM-Newton mission request for a programmer to meet new SOC requirements and to retire a significant succession planning risk.
2.
    a. The joint Swift/NICER over-guide requests to fund a postdoctoral scientist to improve efficiency and remove redundancy in scheduling coordinated observations.
    b. The Swift initiative to improve the photometric precision of Swift UVOT data.
    c. The full suite of NuSTAR over-guide requests.
3.
    a. Augmentation of GO funding support across the missions, beginning with augmentation of GO funding of TESS, followed by the XMM-Newton request to augment GO support to allow for C-ranked proposals to receive more funding.
    b. The Swift initiative to document and publicly release the BAT software.

The panel was positively disposed towards NICER's over-guide request for a calibration scientist, but did not feel the proposal presented an adequate enough explanation of the proposed work to warrant a recommendation.

The panel did not support those over-guide requests whose focus was to bring software and data in compliance with SPD-41, given the guidance presented to the missions on this SMD policy, and the other more highly ranked over-guide requests considered.

Further discussion of some over-guide requests can be found in individual mission reports below.

Additionally, the panel recommends funding related to the expansion of cloud computing and data storage, which we highlight in the following section.

7. Cloud Computing and Software Support

As part of its over-guide budget, the TESS team requested support ($1M total) to prepare a transition to cloud storage and data access, arguing that the need for a cloud-based approach will become needed in the event of a 3rd extended mission (which would be proposed at Senior Review 2025) motivated by the potential increased costs associated with growing the archive during EM3 within a flat or declining overall budget and the end user issues faced by the data volumes TESS will occupy. We applaud the team for planning ahead, but we also feel that the issue of transitioning to cloud storage and access is a broader consideration for NASA APD and should not be approached through the lens of a single Explorer mission. The Fermi mission also discussed the potential to consider cloud computing, but largely on the data analysis side as opposed to addressing issues of data volume.

The pressure for cloud storage and access may become much stronger with the advent of the Roman Space Telescope and other data-intensive missions. There is a good argument for using TESS as an opportunity to test out the transition to this mode of work and to understand its benefits and limitations. We recommend that NASA APD task its archiving experts at MAST with evaluating future cloud storage needs and strategies and making a funded, staged transition to such an approach where it is warranted. One outcome of this process may be supporting the two staff positions suggested in the TESS over-guide, but we do not think the Senior Review is the right place to make this decision.

There were a number of over-guide requests for software developers where the proposals did not provide sufficient explanation of the proposed work. Additionally, some missions support software development with GO/GI funding, all the missions have different models for incorporating user-provided software into their public tool set and/or for curating publicly provided software tools, and do so to lesser or greater effect. These issues combined to make the assessment of over-guide requests for software support difficult to evaluate and endorse, with the exception of for XMM-Newton, where the lack of the proposed software engineer was assessed to be a risk to the mission going forward.

Support for software development is a long-standing issue in astronomy. The distinction between professional software developers and scientists who also happen to develop software can be detrimental. Given that all of these missions are operating with minimal resources, they need to find ways to maximize team and community contributions. Providing grants to develop tools is one way to elevate the importance of this work, however, forcing this into the GI/GO programs can only go so far.

Rest of Missions Report
Individual Mission Evaluations

Fermi

Summary of Mission and Proposal

The Fermi Gamma-ray Space Telescope, launched in 2008, is a probe-class mission providing all-sky monitoring over eight decades in energy. No other mission covers the wavelength window from X-rays to gamma-rays, and Fermi is thus an essential component of NASA's portfolio. The mission consists of two instruments which monitor the entire sky once per orbit for the Gamma-ray Burst Monitor (GBM; 8 keV-30 MeV) and once every three hours for the Large Area Telescope (LAT; 20 MeV-300 GeV). Fermi fills the role of a finder, follow-up, and survey mission and as such is a central element in multi-messenger and time-domain astrophysics. Further strengthening this mission is a strong synergy with many space- and ground-based facilities.

The Fermi team proposes to continue operations for the next three years with a FY2023 budget of $14.1M. The proposed budget includes maintaining $3M for its Guest Investigator grants and funding to train a new deputy to assist with the coordination of multi-wavelength and multi-messenger observations.

Criterion A: Scientific Merit

The unique capabilities of the Fermi gamma-ray mission place it as an essential component in both multi-messenger and time-domain astrophysics. Fermi supports a wide range of science (stellar, galactic, AGN, cosmological) and has been, and will continue to be in years to come, positioned to take a leading role in addressing key science questions across the high-energy universe. A significant strength of the Fermi mission is its synergies with complementary on-going and upcoming wide-field surveys such as Rubin/LSST and ZTF in optical, MeerKAT and SKA in radio, and HAWC and CTA at VHE. These synergies facilitate advancing understanding of a range of high energy processes, including shock acceleration by novae, the population of transitional millisecond pulsars, the connections between magnetar giant flares and short gamma-ray bursts, the production of fast radio bursts, jets in binary supermassive black hole AGN, and short timescale flaring of AGN. Fermi is also an excellent complement to gravitational wave observatories in studies of compact binary mergers, as well as neutrino observatories investigating relativistic outflows in blazars. As demonstrated with the joint GW170817/GRB 170817A detection, the combination of a prompt GBM localization with that of the GW network greatly reduces the localization area, and thus facilitates key follow-up observations. With multiple detections anticipated in the next 3-5 years, studies of Fermi-LIGO/Virgo/KAGRA joint detections will have a significant impact on fundamental questions such as the neutron star equation of state and the speed of gravity. Fermi also provides an independent nanohertz gravitational wave pulsar timing array that is highly complementary to radio pulsar timing arrays and over the next few years will provide crucial constraints on the gravitational wave background.

The Fermi mission will focus on three prioritized mission objectives over the next five years: exploring multi-messenger sources, capitalizing on big surveys, and modeling the high energy universe. Technical initiatives for advancing each of these objectives are outlined in the proposal and include strategies for improving searches for transient sources and counterpart assessments, distributing additional pulsar analysis resources, and broadening accessibility to Fermi data. The proposed objectives, and initiatives to support them, were reviewed favorably by the committee.

The Fermi mission continues to be highly productive, with a sustained ~480 publications per year and over 400 Ph.D. theses to date. The mission also continues to attract new proposers with each cycle and has a healthy oversubscription rate of ~3. The GI program supports a broad range of science and proposal types (data analysis, theory, and correlated observations). The continued growth of synergistic science with on-going missions and those scheduled to come online within the next 3-5 years will support the continued high productivity of the Fermi mission.

The usability of Fermi data and user support for data analysis are strong. This includes the recent addition of LAT Light Curve repository, which was released to the public in 2021, and provides a tool to extract a decade of temporal behavior for gamma ray sources. Other valuable products provided and maintained by the mission include the LAT GRB Catalog, the Fermi-GBM Gamma-Ray Burst Catalog, and the GBM Accreting Pulsar Program. These publicly available resources are anticipated to contribute to the sustained productivity of the mission and broaden community participation in Fermi science.

Criterion B: Relevance and Responsiveness

Fermi’s prioritized mission objectives are tightly coupled to the "New Messengers and New Physics" theme of the most recent Decadal Survey and are well aligned with SMD Science Plan’s objectives. In particular, Fermi is recognized in the Decadal Survey report as one of “NASA’s workhorse hard X-ray and gamma-ray transient facilities” and that it plays a vital role in the Priority Science Area: New Windows on the Dynamic Universe. For example, established and anticipated coordinated observations with multiple ground- and space-based facilities, including with the LIGO/Virgo/KAGRA collaboration and high energy neutrino telescopes (e.g. IceCube), aligns well with the emphasis of the Decadal Survey on multi-messenger and time-domain astrophysics. Furthermore, the focus on matching wide-field capabilities to those of other new facilities and missions (e.g. CHIME, TESS) supports the high priority area of time-domain astrophysics and will allow for exciting progress in the study of a range of transient sources.

The Fermi mission demonstrated a strong commitment to integrating DEIA into all aspects of the project operations. The project science, Science Support Center, and instrument teams all share the common core principle that "everyone should have the opportunity to participate in Fermi science." DEIA initiatives within the project, many of which are already in place, include participation in the Multi-messenger Diversity Network, development of a Code of Conduct for instrument teams, role rotations and shared leadership, and promotion of early career scientists into more senior roles. The team has done an excellent job of providing publicly accessible data and data analysis tools as well as providing opportunities for community training including workshops held for prospective new proposers. Over Cycles 12-14, early career scientists led 20% of selected proposals (compared to 12% in earlier cycles) and the Fermi GI program continues to draw new unique proposers each cycle. Future DEIA goals identified by the team include further reducing barriers to community use of Fermi data and promoting early career researchers to join and fully participate in multi-wavelength and multi-messenger science. The mission plans to inspire new participants through continuing to hold its successful Fermi Summer School and by organizing new online workshops to promote broader engagement with Fermi data.

Progress towards 2019 SR goals and technical initiatives is well documented in the proposal with most PMOs achieved or substantially underway. PMOs still in progress aim to detect and interpret more neutron star mergers with gravitational wave counter parts, increase prompt alerts for TeV observational events, and correlate gamma-rays with ultra-high energy cosmic rays. A plan is also in place to reduce the latency of the GBM sub-threshold triggers and work will soon begin on this initiative. Average GI grant amounts were increased following the recommendations of the 2019 SR. As recommended by the 2019 SR, a report on Efficiencies in Fermi Science Operations was completed in October 2019. This effort concluded that the level of task automation is high and the modest efficiencies that were identified were successfully incorporated.

Criterion C: Technical Capability, Management, and Science Productivity Given the Costs

Operation needs and costs are well understood as the mission has been in operation for multiple years. The mission cost is relatively high, but it is recognized that this is in large part due to the complexity of the required data analysis, particularly for LAT. The 2019 Efficiency report recommended by the 2019 SR found that “Smooth and stable operations of the instruments, the data processing, and prompt communication of high-interest events is accomplished through significant automation, but still requires a minimal level of support.” The report concluded that there was a “high level of efficiency in Fermi science operations.”

Despite being four years beyond the original 10-year goal for the mission, the spacecraft and instruments are operating well with no significant degradation of performance. In fact, improvements in the data acquisition and software mean that the two instruments are more sensitive today than after launch. A failure of one of the Solar Array Drives prevents motion of the solar arrays, but a change in observing mode has maintained observing efficiency. There has been an increase in the frequency of collision avoidance planning; however, collision remains at low risk for the mission since the observatory can maneuver to mitigate any high-probability events. The team is examining options for handling such events efficiently in preparation for future increases in collision risk. Multiple DEIA initiatives are in place within the team and appear to contribute to an inclusive team environment.

Overall Assessment

Fermi remains a strong mission both scientifically and technically, and the mission received an overall Excellent/Very Good score from the panel. With growing focus on multi-messenger and time-domain astrophysics, as highlighted in the Decadal Survey, Fermi’s role as the only mission covering the MeV-GeV regime is vital and supports the pursuit of a range of fundamental science questions. Strong synergies with other surveys, in particular new surveys that represent new technical capabilities, has and will continue to be a significant strength of the Fermi mission. The mission has continued a strong publication record and supports a diversity of science through its GI program, which has a sustained funding level. There is an increasing community interest in the Fermi supported science, likely promoted by the team’s efforts to encourage broad usage of Fermi data. Both the LAT and GBM are healthy and show no signs of degradation in performance. The mission’s operating model includes multiple components promoting DEIA within the team. While the high cost of the mission was a concern for the panel, the panel recognizes the team’s efforts to identify improvements in mission efficiencies and automation and encourages the team to continue to pursue opportunities for further operational efficiencies.

NICER

Summary of Mission and Proposal

NICER, the Neutron Star Interior Composition Explorer, is a payload attached to the International Space Station (ISS), with a high-speed soft X-ray spectrometer (covering 0.2–12 keV). NICER has a high telemetry rate and continuous commanding capability. These capabilities place NICER in a unique position to contribute to multi-wavelength, multi-messenger, and time-domain studies of energetic phenomena. The dynamic range of NICER enables it to study both faint and very bright sources, and Galactic and extragalactic sources.

NICER is supporting science across a wide array of topics, taking advantage of its large effective area, spectral resolution, timing capability, and rapid targeting capability. NICER has significantly impacted our understanding of neutron stars and fundamental nuclear and gravitational physics. Additionally, it has been used for a range of targets, including AGN and TDEs.

Mission philosophy is to maximize science return through coordination with other efforts/missions which is comparatively easy for NICER due to its fast slewing and flexible operations.

Criterion A: Scientific Merit

The NICER mission has been doing groundbreaking science in its key science area, the study of neutron stars, using the high-time and energy resolution spectroscopy that is the signature strength of this instrument. In terms of capabilities, NICER is unique in its temporal and energy resolution for X-rays, and stands out for its agility in tracking sources. It has achieved spectacular results in the study of neutron stars, measuring the mass and radii of two neutron stars with high precision. It has contributed immensely to our understanding of the equation of state of neutron stars, and is still the best instrument for pursuing this work. Measuring the parameters of a handful of other systems will have substantial further impact here. Similarly, its measurements of the timing stability of pulsars are exceptional.

The GO program has also started to deliver on the instrument's potential. In particular, the measurement of reverberation signals in 8 BH-LMXB in a systematic search of the NICER data archive stands out as work that will have high impact in the field in coming years. The GO program supports several different approaches to studying accretion physics in different systems (e.g., QPOs, reverberation mapping, and source monitoring). Similarly, the ToO program is studying energetic systems such as Black Hole binaries, SMBH, and following up on events such as TDEs and compact object birth. The OHMAN science program is promising. The observation flexibility is excellent and the mission is using this flexibility well.

NICER has important synergies with other observatories across the spectrum and has made significant effort toward undertaking collaborations with other instruments, most notably NuSTAR. This partnership has been particularly productive as the two missions have very complementary capabilities. NICER's new initiatives for the coming years include new collaborations with TESS, SWIFT, and other new missions to facilitate a more efficient science return. The planned joint observations with TESS and Swift are very promising, and in particular, the discussions with Swift about how to respond optimally to ToO requests could be extremely helpful to maximizing the strengths of both missions. NICER plays an important role in coordinating ToOs for the community with quick follow up of MAXI and Swift/BAT identified sources to inform subsequent monitoring strategies with initial reports and analyses often circulated to the community on the same day the data were collected.

NICER has been highly productive since its launch in 2017. It has produced 180 publications and engaged over 85 students, including 10 PhDs that used NICER data and an additional 10 that are in progress. Community interest in the facility is growing with an increase of 30% in GO submissions since the start of the program. All source code, calibration products, and supporting documents are available to the public and all data are generally available in the archive within two weeks of observation.

Criterion B: Relevance and Responsiveness

NICER is relevant to NASA's SMD Science Plan goals 1 and 2 through advancing understanding of BHs, gravity, and the evolutionary endpoints of massive stars. NICER science is also well-aligned with Astro2020 in that it fulfills a need for sensitive, rapid-response X-ray follow-up and addresses high priority science in time domain and multi-messenger astronomy. In particular, in the time domain NICER plays a bidirectional role by both triggering multi-wavelength follow-up of transient events and conducting follow-up observations on events identified by other facilities. The vision for NICER's science has clearly grown well beyond initial goals, as illustrated by e.g., participation in Sellers Exoplanet Environments Collaboration (SEEC), for which it is contributing valuable studies of the high-energy emission from exoplanet-host analog

GKM stars, aligning it with another Decadal Survey priority, the study of conditions for habitability.

DEIA appears to have been a focus for the team from an early point in the mission with established mentoring, opportunities for early-career and students on "front lines", diversity in the team, and an emphasis on transparency and open communication. NICER involves students at a range of levels and clearly makes student training an important and genuine focus of the mission. The panel noted that student work and achievements were highlighted throughout the team's presentation. NICER will also provide observing time for local workshops to provide a hands-on experience, which the panel felt was an excellent way for users to gain real experience and highlight's the NICER team's dedication to training. NICER will participate in the larger GSFC DEIA effort that will pool resources across the GOF missions and the panel noted that this effort was included within the in-guide funding request, again highlighting the dedication of the team toward these efforts. Furthermore, the NICER User Group will in the future be tasked with evaluating DEIA efforts and providing recommendations.

The NICER team has mostly fulfilled the PMOs from the 2019 Senior Review, which included high impact neutron star science, increased time devoted to the GO program, improved ToO/DT response time, development of the OHMAN system, and establishing the NICER User Group. Major improvements were also made in calibration and software and the associated documentation. In particular, NICER is excelling at its key science goals of characterizing neutron stars, with some paradigm-building results coming from detailed observations (PMO-1). The GO program (PMO-2) is growing and is leading to several publications. The OMHAN initiative (PMO-3) has dramatically improved the response time for MAXI-triggered ToOs. Several new initiatives build nicely on these PMOs, particularly those to build on collaborations with other missions and broaden the mechanisms for community input. Overall, this is a smart and effective way to grow the NICER user and scientific community and is directly tied to the 2019 Senior Review's finding that NICER should seek to expand these communities. The creation of analysis threads and the development of end-to-end data analysis tools are also good steps toward building a working community.

The panel finds that further work is needed to continue to grow NICER's scientific community and increase the GO AO response rate and publications/citations in areas outside of the key neutron star science. The NICER team has not done as much as other missions in terms of organizing scientific meetings, data analysis workshops, and community organization. While the implementation of OHMAN is a great step towards faster ToO response times, it is not clear that much progress has been made towards making NICER faster to respond to ToOs originating from other sources. Most of the recommendations of the NUG report (April 2021) focused on increasing the accessibility of the NICER data.

Criterion C: Technical Capability, Management, and Science Productivity Given the Costs

The panel finds that the NICER mission is very efficient and cost effective, with just over 3 FTEs in mission operations and 2.5 FTEs in science. Given the size of the team it is impressive what they have accomplished. Part of this efficiency is due to the fact that much of the communication and command infrastructure is provided by ISS. NICER has an especially efficient observing program due to its ability to observe several targets in rapid succession in one ISS orbit.

The over-guide request includes a shared scientist for Swift ToO response, which the panel viewed favorably as a way to increase collaboration and observing efficiency with Swift. The budget also includes an increase in GO grants, which have remained flat in past cycles despite an increase in GO allocation (and inflation). While the panel feels this is a worthy goal, they also note that this GO program is overall less oversubscribed than that of other missions. In general, the over-guide budget would have benefited from a more detailed justification, particularly for the second calibration scientist. The panel noted that NICER was one of only two missions to include its share of the cost of supporting DEIA efforts at GSFC in its in-guide budget.

Overall, NICER is in excellent condition with no significant degradation in performance since the start of the mission. The mission operations are very efficient; NICER spends ~85% of its time tracking targets and 15% of the time slewing with less than 1% of the time spent idle. The interplay between the NUG, the science teams and the instrument was not clearly described in the proposal. Given that the instrument team is small, it is clear that the project will have to tap the science teams for significant software development & maintenance. Developing clear and good working relationships between these entities that allow for fruitful collaboration in developing tools for the community will benefit the mission.

Overall Assessment

NICER has unique capabilities because of its large effective area, spectral resolution, time resolution, and ToO capability. It is the first competitively selected astrophysics mission on the ISS and is also its most successful science experiment ever. It has produced 180 peer-reviewed papers as of January 2022 and estimates ~30 PhDs based at least in part on mission data in the next few years. NICER is enabling a wide range of science investigations while making continued progress in the area of neutron star properties and nuclear equation of state. Increasing ToO capabilities are a significant strength for EM2. Overall, the strengths of the NICER mission far outweigh any weakness. The main weakness of the proposal is the limited success of developing a strong user / scientific community. This lies in part in the tools that people need being less than fully ready, in part in the absence of easily accessible high-level data products such as automated analyses of observations, and in part due to a lack of enough outreach to the user community in the form of workshops. Some of this is also likely due to the novel nature of the NICER data and the need to develop robust scientific dialog to be able to make the best use of NICER data in novel contexts. In short, NICER has tremendous scientific potential, but it has not yet been fully tapped.

NuSTAR

Summary of Mission and Proposal

NuSTAR was launched in 2012, and was the first focusing hard X-ray mission. It has unique sensitivity and spectroscopic capability in hard X-rays, and is the only community-access, high-sensitivity hard X-ray mission; as such NuSTAR is a key ingredient in the NASA astrophysical portfolio. In the 2019 Senior Review process NuSTAR proposed to change its focus from its legacy science programs to being a community observatory. In this proposal, the NuSTAR team reports on this transition: NuSTAR observing time is almost entirely allocated through various guest observer programs, with some additional target-of-opportunity (TOO) observations done with the Director's Discretionary Time. Over the same period, the NuSTAR team has increased cross-mission coordination: by 2021, the majority of NuStar observations were coordinated with other observatories. The NuSTAR team proposes to continue operating as a community observatory, manage a robust guest observer program, and requests funding for initiatives that will allow it to better serve the community, in particular by increasing its ability to schedule and execute TOO observations.

Criterion A: Scientific Merit

Scientific output and community interest is high, with an oversubscription rate of 4 for GO programs and 6-13 for ToO programs over the past four AOs. The current publication rate is high, with about 150 papers per year across a broad range of science topics. Being sensitive to both thermal emission from accretion driven heating and non-thermal emission from shock acceleration and neutron-star dynamos, NuSTAR is especially well-suited for "Probing the Extreme Physics of Neutron Stars and Black Holes". Studies using several different approaches, such as reflection spectroscopy and mapping, (including studying gravitationally distorted radiation), studying flares and outbursts, and obtaining constraints on the radius of Cygnus X-2 have all resulted in impactful papers.

Similarly, NuSTAR has also carried out impactful observations of ULX sources and established strong Dark Matter constraints.

NuSTAR data are easily accessible and the publicly available tools are easy to use and well maintained. Data processing and data delivery are all working well and efficiently at this point. NuSTAR data-taking is observation based, the data are organized by observation, and the browsing and searching interfaces provided by HEASARC facilitate high-level data exploration. Furthermore, NuSTAR have made several catalogs available via HEASARC, and these catalogs have enabled a number of interesting population studies and targeted observations.

Criterion B: Relevance and Responsiveness

This proposal is highly relevant both to the SMD science plan and to the 2020 Decadal survey. As described above, NuSTAR has excelled at “Probing the Extreme Physics of Neutron Stars and Black Holes” in a number of ways.

The NuSTAR team has done an excellent job achieving the PMOs from SR 2019 and in the process, re-defining the NuSTAR as a community driven observatory. As regards PMO-1-2019 (maintaining the observatory and the GO program) several initiatives have improved both the4 scientific impact and the flexibility of the GO program (e.g., adding large programs, moving time from Legacy surveys to the GO program, instituting joint GO programs with other facilities and improving the data analysis tools). The NuSTAR team has also increased support, allocation for and coordination of TOOs and DDT to better support MW observations (PMO-2-2019). Finally, the team has also continued to support the Swift/BAT legacy survey (PMO-3-2019) in a flexible and intelligent fashion by finding a good balance between observation time spent on the Swift/BAT sources and on TOOs.

The NuSTAR team was also highly responsive to the findings of the 2019 SR, redirecting effort, observing time and funds from the legacy science programs to support what had originally been identified as over-guide efforts.

Going forward, the 2022 PMOs are clear, well-justified and achievable with the requested funding. The proposed changes & rebalancing of the GO program to match the new MW landscape with the addition of new missions (IXPE, XRISM) is well thought out (PMO-1-2022). Similarly, devoting additional resources to upgrade the SOC to better support TOOs will have long term benefits for NuSTARs scientific reach (PMO-2-2202). Finally, the scientific return of the Swift/BAT survey easily balances the observing time and resources used. Finally, the work proposed to support the NuSTAR user community is clearly described, well-justified and likely to improve the scientific return of NuSTAR.

NuSTAR was not designed for extensive TOOs or fast slewing. This has added to the challenge of transforming NuSTAR to a community-driven observatory with a significant fraction of TOO time. This NuSTAR's observational efficiency of 53%, and the 6~ T00s per month are lower than other missions. These are largely set by design and observational considerations, (in particular, the slow slew speed of the observatory caused by the 10 meter mast, and the need to coordinate most observations with other observatories) but they do affect the overall scientific productivity of NuSTAR. The team has focused on overcoming these challenges, and in particular, all of the over-guide budget requests are for new resources to tackle this challenge. This is extremely responsive to the current scientific ecosystem, in particular the explosion of time-domain astrophysics and the advent of multi-messenger astrophysics.

NuSTAR has a diverse team and was the first mission after Hubble to shift to a dual anonymous peer review process. Current DEIA efforts include professional DEIA workshops for the team, mentoring, support for student internships, and participation in and support for HEAD outreach program activities.

Criterion C: Technical Capability, Management, and Science Productivity Given the Costs

Overall, NuSTAR continues to be in excellent condition. A few specific issues have either been dealt with (e.g., a very small number of bad pixels) or are being tracked (i.e., battery degradation). Several specific risks were described and analyzed in the proposal. When appropriate, exploratory work on mitigation strategies has been undertaken (e.g., the decay of the metrology laser signal is being mitigated by developing control loops that do not require the laser). Overall, it is clear that the team is taking very good care of the observatory and its instruments. The observation can continue to operate safely and effectively over the current funding period. Similarly, the instrument is well-calibrated, and the data and tools needed to analyze the data are well-curated, and several community-driven or community-requested upgrades to the analysis tools have been integrated. The value of the tools, and the effort required to produce, validate, and package them for community use justifies the size of the SOC and Science Team support requested.

As described above, many of NuSTAR's operational initiatives and all of their over-guide budget requests are largely aimed at improving the observational efficiency and TOO scheduling. This is a very sensible strategic choice, as these are both areas of potential improvement.

Overall Assessment

NuSTAR is a key part of the NASA astrophysics mission portfolio, providing X-ray observations of a number of types of sources and generating both some extremely high-impact science on specific topics and an overall breadth of science. The NuSTAR mission team has been extremely successful in doing coordinated observations with other observatories, thus helping to drive a golden era of MW observations and time domain science.
This NuSTAR team is highly responsive to the changes in their ecosystem, successfully navigating the transition to a community observatory, and identifying and implementing additional ways to improve on that transition. In particular, given that NuSTAR was not designed to make frequent TOOs, the fact that over 50% of observations are coordinated with other observatories is impressive, while underscoring the challenge of efficiently and effectively scheduling observations.

All four of the over-guide requests are among the set that the panel would like NASA to prioritize. While each request has significant value on its own, the synergies between them are also significant. As a whole they would greatly improve the team's ability to do TOO observations.

Swift

Summary of Mission and Proposal

Swift is a mission designed to locate and characterize transient events, with the initial primary mission goal to study Gamma-Ray Bursts (GRBs). Over time, the mission focus has expanded to include multi-messenger and time domain astronomy. Swift has three instruments: a large field of view Burst Alert Telescope (BAT) covering 15-350 keV; a pointed X-Ray (0.3-10 keV) telescope (XRT); and a pointed UV/Optical telescope (UVOT). The pointed telescopes provide localization of transient sources with accuracies of ~2” (XRT) or 0.5” (UVOT). The observatory can very rapidly slew to respond to a large number of Target of Opportunity (ToO) requests.The Swift team proposes to continue operations with an in-guide budget of approximately $6M per year. There are five overguide requests, not prioritized within the proposal: (1) Personnel for BAT software and documentation upgrade; (2) Purchase of additional USN passes to reduce data latency; (3) Contribution to the unified GOF DEIA program at GSFC; (4) Personnel for improved coordination with NICER; (5) Personnel for improving photometric precision of UVOT data.

Criterion A: Scientific Merit

Swift plays a critical role in localization and characterization of transient sources, making it a key asset in the mission portfolio, especially in the fields of multi-messenger and time-domain science. It is the only mission in the portfolio capable of extremely rapid multi-wavelength follow up capabilities. Swift is highly synergistic with other space observatories and with ground-based observatories. Swift localization of a transient event often leads to follow-up observations by other missions and from the ground. Conversely, Swift is often the go-to resource for rapid follow-up of transients identified by other observatories, a mode that has been especially evident in the recent extended mission thanks partly to optical time-domain monitoring surveys such as ZTF and ASAS-SN and to X-ray transient detections by eRosita. This mode will become even more important with the advent of the Vera Rubin Observatory. Swift also provides long term monitoring of UV/Optical and X-Ray for time varying sources, often in concert with other space and ground assets.

Science highlights since the 2019 Senior Review include studies of the periodically repeating nuclear outburst source ASASSN-14ko, characterization of a TDE

(AT2019dsg) potentially associated with a high-energy neutrino event, multi-wavelength (UVOT and X-ray) monitoring of Mrk817 as part of the STORM2 campaign, joint observations with NICER and NuSTAR demonstrating that AT2022cmc is a relativistic TDE (the fourth known), and further examination of the relations between short GRBs, kilonovae, and neutron star mergers detectable with GWs. The LIGO O4 run, upgrades of IceCube, and the advent of the KM3net neutrino telescope provide bright prospects for multi-messenger astrophysics during the proposed extended mission. High-redshift GRBs are promising targets for JWST spectroscopy and host identification. Follow-up of sources identified by ULTRASAT UV transient satellite will provide unique insights on the early UV light curves of supernovae and other transients. Follow-up of eRosita transients may provide new insights on the seemingly distinct populations of X-ray and optically identified TDEs. High-precision UVOT light curves can provide novel constraints on exoplanet atmospheres from transit depths.

As in previous Senior Review cycles, Swift provides a model of effective community engagement in its extended mission and of synergistic observations that complement those from other space missions and ground-based telescopes. The demand for Swift observations remains high, and the rate of publications that incorporate Swift data remains high at ~ 400 per year. Swift's record of averaging nearly 5 ToO observations per day is impressive.

Criterion B: Relevance and Responsiveness

The two proposed PMOs are: "Realizing the Promise of Multi-Messenger Astronomy" and "Rubin and the Time-Domain Revolution." These PMOs and the Swift science program more generally are perfectly aligned with the *New Messengers and New Physics* theme articulated by Astro2020, and some Swift programs contribute to the *Worlds and Suns in Context* theme (e.g., stellar flares and other time-domain stellar phenomena) and to the *Cosmic Ecosystems* theme (e.g., high-redshift GRBs as probes of early star formation and the intergalactic medium). They are also well aligned with NASA SMD objectives.

These PMOs are quite similar to those from the 2019 Senior Review. Arguably the MMA results from the most recent extended mission are less exciting than those that preceded the 2019 review (GW170817 and TXS0506+056), but this is a matter of luck rather than shortcomings of Swift. Progress in time-domain astronomy has been strong thanks to synergy with ZTF, ASAS-SN, and other X-ray observatories, and there are good reasons to expect major MMA results in the next extended mission. The initiative to develop an API for automated ToO request submission, enabled by SR19 over-guide funding, has been successfully implemented.

The large number of observing opportunities and low barrier to entry makes Swift accessible to new users and a diverse community. In Cycle 18, first-time PIs made up 41% of successful proposals and 27% of funded proposals. The proposal for “on-sky training” that includes ToO observations through workshops at HBCUs and MSIs is a novel and promising idea for engaging young scientists from underserved communities.

Criterion C: Technical Capability, Management, and Science Productivity Given the Costs

The Swift spacecraft experienced an antenna anomaly in May 2021, leading to a switch to a secondary antenna. The resulting risk to the mission appears moderate, as the primary antenna could be restored with reduced capability should the secondary antenna become inoperable. The failure of one of six reaction wheels is a greater concern, though still moderate. The observatory could operate successfully with four reaction wheels, but if two of the remaining reaction wheels fail (reducing the number to three) then performance might be seriously compromised.

The mission maintains high science productivity relative to its costs, and it is exceptionally successful at engaging and responding to its community of users. Of the over-guide requests, the panel places highest priority on the contribution to the GOF DEIA program at GSFC (common to all missions), followed by the personnel support for improved ToO coordination with NICER (shared between the two missions), followed by personnel support to improve UVOT photometric precision. The BAT software/documentation upgrade and extra USN passes to reduce latency are low priority because they achieve only modest improvements in mission performance.

Overall Assessment

Swift has established its place as an essential component of the NASA mission portfolio, highly synergistic with other space and ground-based observatories. Its capabilities are especially well suited to emerging scientific priorities in multi-messenger astrophysics and time-domain astrophysics. The Swift team has consistently identified the needs of the community and has adapted to them. Based on its broad, high-impact science reach and its excellent record of community engagement, the RoM panel gives Swift the highest overall rating among the suite of outstanding missions being considered in the panel’s 2022 review.

TESS

Summary of Mission and Proposal

The Transiting Exoplanet Survey Satellite (TESS) is a NASA mission to discover exoplanets, enable advances in stellar astrophysics, and explore the bright and time-variable sky. TESS monitors large swaths of the sky with high photometric precision in the optical and is approaching full sky coverage. The primary goal of the mission – to detect and measure the masses of 50 planets smaller than Neptune – was achieved. As part of its first Extended Mission, TESS expanded its total sky coverage and the fraction of the sky it observed more than once, and shortened the cadence of its typical full-frame images (FFIs) from 30 to 10 min, while continuing to provide 20 s and 2 min data for pre-selected targets.

TESS proposes for its second Extended Mission to further shorten the FFI cadence from 10 min to 200 s to increase the overall planet detection rate, widen the type of stars accessible to asteroseismology, and increase the likelihood for serendipitous discoveries. This increased time resolution will result in an increased data volume and thus necessitates a modification to the downlink schedule. Further, this Extended Mission will expand cumulative sky coverage to more than 95% and will visit more than 80% of the sky twice, giving access to longer-period planets.

Criterion A: Scientific Merit

The mission is providing groundbreaking data and supporting a broad and vibrant community that is turning that data into groundbreaking science. Despite being primarily an exoplanet mission, the data have had substantial impacts on fundamental stellar astrophysics, asteroseismology, and variable star studies; the discovery and characterization of explosive and variable extragalactic transients; and the study of solar system objects. The proposed extended mission will enable continued advancement in all of these areas.

Planets: The mission has more than met its primary goals by identifying the planets whose atmospheres will be prime targets for transmission spectroscopy with the James Webb Space Telescope, finding young exoplanets with which to study planet evolution, and identifying long-period planets (for which the first extended mission has turned out to be essential for confirmations). TESS has identified some rare configurations of planets, each of which is interesting on its own. The proposed extended mission will allow the detection of planets around a wider range of stellar types, ages, and irradiation levels and enable more opportunities for serendipitous discoveries of unexpected phenomena.

Stars: TESS's contributions to stellar astrophysics have been novel and broad, with exciting advances in the study of variability, pulsations, seismology, and binarity. The proposed extended mission will enable studies of rapid stellar variability, further enhancing synergies with other missions. Extending the time baseline will allow studies of galactic archaeology, more types of red giants and massive stars, long period variables, and stellar activity cycles.

Distant Transients: TESS also contributes significantly to our understanding of energetic transient events such as supernovae, gamma ray bursts, active galactic nuclei flares and tidal disruption events. The proposed extended mission will result in more such observations, enable multi-wavelength follow-up of rapid transients, and help localize multi-messenger events.

The Solar System: TESS also enables studies of comets, asteroids, and trans-Neptunian objects. The proposed extended mission will provide more opportunities to study comet outbursts and asteroid light curves and to detect TNOs and to discover or put tighter constraints on the hypothesized Planet Nine.

The TESS mission has notable synergies with many other astronomical missions, including Hubble, JWST, and NICER.

The extension of sky coverage and "re-coverage" of the extended mission (i.e., returning to fields viewed in the prime mission) is scientifically extremely compelling. Further, the addition of the longer time frame to the shortened cadence viewing in essence provides a new view of the dynamic sky.

The effort to coordinate follow-up observations through the TESS Follow-up Observing Program and the success of the ExoFOP is an impressive accomplishment. In addition to the funding available to support ground-based followup, this encouragement and support for obtaining and sharing complementary ground-based data should serve as a model to other missions.

Criterion B: Relevance and Responsiveness

This proposal is clearly highly relevant both to the SMD science plan, to the 2020 Decadal survey, and has synergies with many other missions. TESS is clearly the leading NASA exoplanet mission, and its power as an instrument for time-domain astrophysics has resulted in significant impacts in understanding stellar evolution and environments and as well as extreme, extragalactic transient events. These strengths are directly in support of three 2020 Decadal Science Priority Areas: Pathways to Habitable Worlds, Suns and Worlds in Context, and New Windows on the Dynamic Universe and two elements of the NASA SMD Science Plan: Are we alone? and How Does the Universe Work?.

The TESS team has done an excellent job in building up a user community, focusing on early career scientists, and in expanding its scientific community beyond the initial focus of the mission. The team, dominated by early career scientists, is to be commended for bringing in new approaches and insights and demonstrating their import and impact. In particular, the mission is notably engaged with the user community via social media channels and TESS Hack Weeks.

TESS is a model for how to engage the public, with a number of stories featured in the news and social media as well as successful citizen science projects.

DEIA: In the area of DEIA, the TESS team has demonstrated dedication and taken the initiative by forming a dedicated working group of individuals from the partner institutions. One of the partner institutions, MIT-Kavli, has an independently funded DEI officer which could also be an asset to the mission. While these efforts are laudable, and more significant than some other missions, it is not clear if the working group is active yet, beyond establishing a charter. The over-guide request for an external DEIA expert to assess the working group (in addition to the GOF shared DEIA consultant) was not well described or motivated. Further, both of these requests were also the lowest priority over-guide requests. The proposal aligns with others in requesting over-guide funding to support hiring of a DEIA mentor and this is addressed in Section 5 above.

The 2019 SR proposal laid out six PMOs and as described below, the TESS team successfully implemented all of them.

- The first PMO was purely scientific, “Discover hundreds of additional transiting planets with periods longer than 20 days” and has been achieved.

- The second and third were operational and observational goal (i.e., to “Re-observe and double the time coverage for 80% of the Prime Mission fields.” and to “Observe 70% of the portion of the sky that was not surveyed during the Prime Mission, including the ecliptic”, respectively). Both goals have been achieved in essence.

- The fourth PMO specified the quality of calibrated photometric performance “Maintain photometric performance corresponding to 200 ppm in 1 hour at T = 10 (TESS magnitude 10)” and has been achieved.

- The fifth and sixth PMOs detailed specific data products that would be delivered to the community (FFIs at 600s sampling and 120-second and 20-second data for tens of thousands of specific sources) and have also been achieved.

Criterion C: Technical Capability, Management, and Science Productivity Given the Costs

The proposal identifies six PMOs for the second extended mission. These are further improvements on the PMOs from the first extended mission and are all well thought out ways to improve on the scientific return of the mission. While their scientific return will be excellent, the proposal did not adequately justify how the PMOs require the mission to maintain the same level of staffing and effort to achieve.

In the 2019 SR report suggested that the TESS team explore ways to reduce costs, yet the budget essentially continues at the level of the previous funding period. However, it is worth noting that they have identified and implemented a few operational improvements and efficiencies and diversified the available data products, in essence choosing to improve the mission at the same funding level.

The explicit inclusion of funding for ground-based follow-up programs in the GI program is commendable and should serve as a model to other missions.

Given the high scientific merit of the mission and its broad community reach to several areas of astrophysics (exoplanets, stellar, extragalactic, and solar system), the motivation for the requested increase in the GI grant funding is very compelling. If there are any increases to GI/GO grant funding, we rank TESS GI increase as the highest priority.

The request for funding to move to cloud computing are addressed above in Section 8.

The GOF shared DEIA implementation plan is addressed above in Section 5.

The over-guide requests for increases in the Science Processing Operations Center for data production and analysis and to the Missions Operations Center for the refreshment of operating systems are clearly important to the continued success of the mission. However, the panel felt that these needs appear to be foreseeable and fundamental and are more appropriately paid for by the in-guide budget.

Overall, the TESS spacecraft is in excellent condition. There has been no real degradation since launch and efforts are underway to remove the inertial measurement unit (which has a finite lifespan) from the fine pointing control loop, thus removing this as a potential mission limiting factor.

The TESS mission team is strong. Particularly notable is the strong emphasis on training and promoting early career scientists both through access to data (~60% of publications in 2021 were led by junior scientists) and leadership opportunities.

Overall Assessment

The panel ranked the proposal Excellent/Very Good overall. Scientifically TESS is excellent, doing groundbreaking science across several fields of astrophysics and continually improving the data products provided to the community. The proposed objectives for a second extended mission are well justified. While the highest priority over-guide request for an increase in GI program is compelling and recommended for funding by the panel, the panel feels the proposed enhancements to data production and analysis and operating system refreshments should be done by finding efficiencies in the in-guide budget.

XMM-Newton

Summary of Mission and Proposal

Launched in 1999, XMM-Newton is a Great Observatory-class X-ray mission that has a broad array of capabilities across the 200 eV-12 keV band. XMM-Newton has very good spatial resolution (bettered only, among the X-ray missions, by Chandra), a wide field of view, and the ability to produce both moderate- and high-resolution spectra. In addition, XMM-Newton has excellent timing resolution, is currently the only X-ray mission capable of long continuous observations (up to 140 ksec, or just over 1.5 days), and through the use of its Optical Monitor can also provide simultaneous X-ray and optical/UV observations of its targets.

XMM-Newton is operated by the European Space Agency, and NASA participates in the mission through its support of a Guest Observer Facility at Goddard Space Flight Center, of the US-based members of the Reflection Grating Spectrometer (RGS) team, and of US-based principal investigators selected through XMM-Newton's guest observer program.

The proposal requests continued support for the Guest Observer Facility and the US RGS team (for a total of about $0.9M per year), for the Guest Observer Facility's mission-specific DEIA activities ($0.02M per year), and for the guest observer program (at approximately $2.9M per year). The proposal also requests an augmentation to the grants program of $0.7M per year, funding to support two additional programmers (at $0.14M per year each) and to support the planned joint DEIA position for all of the Goddard Guest Observer Facilities (at $0.05M per year).

Criterion A: Scientific Merit

XMM-Newton continues to excel scientifically, and it is particularly notable how many different science areas are impacted by its data. The mission is enabling observations from the very nearby to the very distant, engaged in single-object and survey science, and is therefore helping to advance investigations in many of the areas called out by the most recent Decadal Survey as community priorities through the 2020s.

Furthermore, XMM-Newton is highly synergistic with other NASA missions. Joint observations have led to very impactful results, including the detection of gravitational delays using reverberation mapping (enabled by observations with NuSTAR) and breakthrough determinations of the masses and radii of two neutron stars (with NICER).

It is therefore unsurprising that the mission's scientific output remains very strong, with an average of 400 publications a year since the last Senior Review (and indeed over the last decade). Over that period, about 23% of these publications have had US-based lead authors, and another 35% have had US-based co-authors.The impact of these publications does not appear to be decreasing, with more than 30 papers published in the last three years already having more than 60 citations. About a third of these highly cited papers have US-based first authors.

This strong involvement of the US community in the mission is further reflected by the fact that US-based investigators have regularly led between 35 and 45% of successful XMM-Newton observing proposals, while another 20% of the successful proposals in the most recent call had at least one US-based co-investigator. Overall, US-based scientists have received immediate access to data from 65% of XMM-Newton programs, including Target of Opportunity observations. This success is all the more remarkable given the continued high demand for XMM-Newton time, with the oversubscription rate being a factor of about 7 in the latest cycle.

Finally, we note that there is currently no X-ray mission operating or planned that can fully replicate XMM-Newton's capabilities. While eROSITA does have a number of similarities, it is not a spectroscopic mission, nor can it conduct simultaneous observations in the X-ray, UV, and optical. And the fact that XMM-Newton is a guest observer-driven mission makes it uniquely valuable as a resource for the community, as e.g., it is available to acquire key data needed as part of multi-wavelength observation campaigns.

Criterion B: Relevance and Responsiveness

Given the broad range of investigations enabled by XMM-Newton, it is naturally well-aligned with the SMD Science Plan and with the most recent Decadal Survey. In particular, the proposal highlighted contributions made with XMM-Newton observations to numerous areas of importance described in "Pathways to Discovery in Astronomy and Astrophysics for the 2020s."
To list just a few: XMM-Newton has been used to study the Jupiter/Io system, the X-ray environments of exoplanet-hosting stars, and to construct broadband spectral energy distributions for low-mass stars, contributing directly to our understanding of "Worlds and Suns in Context," and particularly to investigations of the "Pathways to Habitable Worlds." It is also contributing significantly to "New Messengers and New Physics," as XMM-Newton data and catalogs have been used recently to identify potential counterparts to high-energy neutrino events and to investigate tidal-disruption events. Its studies of gamma-ray bursts, of neutron stars and pulsars, and of ultra-luminous X-ray sources are all examples of its ability to provide "New Windows on the Dynamic Universe." And finally, through its observations of the gas in the interstellar medium and in galaxy clusters, and of AGN and supermassive black holes, XMM-Newton is playing a significant role in characterizing "Cosmic Ecosystems" and "Unveiling the Drivers of Galaxy Growth."

XMM-Newton has also been very responsive to both the 2019 Senior Review and to its user community. For example, the 2019 Review asked that the Guest Observer Facility help the community decide which X-ray instrument is best suited to a given investigation. This is now summarized in a very useful table available on the mission's webpage that describes the capabilities of instruments on all of the NASA-supported high-energy missions considered by this review.[1]

In response to the 2019 Review, the Guest Observer Facility also conducted a user survey to solicit input on how best to distribute funding to approved programs, which are divided into categories A, B, and C. In a typical cycle, roughly half of the category C targets are observed, but these programs have been unfunded for most of the mission's history. The user survey led to a new funding opportunity for US-based investigators with category C programs. One important consequence of this initiative is that it may present an opportunity to fund more student and early career proposers, an important step in broadening participation in the mission.

XMM-Newton has completed nearly all of its 2019 Prioritized Mission Objectives. The first was to keep the guest observer program, which has continued to be the Guest Observer Facility's central activity. Two of the other 2019 Prioritized Mission Objectives were the support of the first US-led Heritage Program (requiring multiple years of observations totaling more than 300 ksec), which was completed in 2021, and the re-alignment of the timing of grant awarding to better match the proposal cycle. This latter effort was derailed somewhat by the pandemic and should therefore remain as a priority for the mission over the next three years.

Criterion C: Technical Capability, Management, and Science Productivity Given the Costs

XMM-Newton continues to be in excellent condition. Although its various instruments have all undergone some amount of expected degradation, their performance is still well within requirements. A few specific issues have either been dealt with (e.g., lost CCDs), or are being tracked (e.g., energy resolution degradation). The European Space Agency has extended the mission through 2028, and current predictions are that its instruments will continue to perform at a high level through at least 2030.

Since all operations are covered by the European Space Agency, and the NASA funding for XMM-Newton primarily covers the guest observer program, XMM-Newton is extremely cost-efficient for NASA. The US community essentially gets access to a significant fraction of the mission's observing time for little beyond the costs of supporting the analysis of these observations.

The XMM-Newton team has proactively identified providing funding to C-ranked projects as potentially high-impact action to increase the diversity of its user community. Given that the

[1] See https://heasarc.gsfc.nasa.gov/docs/xmm/mission_comparison_table.html.

mission team is small, focusing on the impact achievable through changes to the guest observer program seems like a very good choice. The two DEIA activities proposed as mission-specific in the in-guide request, to support the installation and use of mission-specific software, and to spotlight student and early career scientists, are modest, but useful initiatives.

The XMM-Newton Guest Observer Facility relies on a very small team. Furthermore, many of the team members are continuing in roles that they have had for quite some time, and at which they are expert. In short, this is an extremely efficient management model, with a remarkable 75% of the requested funding dedicated to the guest observer program, a fraction matched by no other mission.

The proposal highlights the possibility of importing the mission's Science Analysis Software into Matlab and/or Mathematica. While there may be good reasons for this, the panel would prefer an emphasis on importing the software into Python, since it is now the open-source language of choice for most scientists.

Overall Assessment

XMM-Newton is one of the most capable X-ray observatories ever built, and it continues to be a top-level facility available at a comparatively very low cost to the US community. US astronomers are making excellent use of NASA's participation in the mission, with a high number of US investigators involved in successful proposals, including as principal investigators, and leading impactful publications based on XMM-Newton data.

As the Decadal Survey has emphasized, time-domain and multi-messenger astrophysics are central to progress on key questions over the coming decade. XMM-Newton has played and will continue to play an important role in addressing these questions, both on its own and in conjunction with other NASA missions.

The Senior Review believes the over-guide request to support a second programmer so that the Guest Observer Facility can meet its current obligations while also improving existing software packages for data analysis (notably its Extended Source Analysis Software) and paving the way to public releases of key source code (namely the Science Analysis Software) is essential to the mission's long-term viability.

New Horizons

Summary of Mission and Proposal

New Horizons is a Planetary Sciences Division mission that has transformed our understanding of the outer solar system, through its spectacular observations of Pluto and its moons during the prime mission and its detailed view of the Kuiper Belt object Arrokoth in its first extended mission. The proposed second extended mission includes a large solar system component being evaluated by PSD and heliophysics and astrophysics components budgeted as overguides and being evaluated by the corresponding divisions' Senior Review panels. The proposed astrophysics program has four components: (1) a measurement of the cosmic optical background using the LORRI imager; (2) a measurement of the cosmic UV background using the Alice FUV-EUV spectrograph; (3) an all-sky map of Lyman-α emission with Alice; (4) monitoring of long-duration microlensing events with the LORRI imager with the goal of detecting one or more isolated stellar mass black holes. Each of these components takes advantage of New Horizons' location in the outer solar system.

The proposed APD budget is approximately $3.25M over the three-year period covered by the Senior Review, of which $1M is for mission operations to execute the required observations, $0.25M is for instrument engineering support, and $2M is for data analysis. The APD budget is approximately 10% of the proposed New Horizons budget over this time period.

Some Difficulties of Evaluation

The panel appreciated the opportunity to learn about the New Horizons astrophysics program and provide an assessment to inform APD's decisions regarding this program. Before presenting our evaluation, we note two challenges we found in assessing New Horizons astrophysics relative to other missions.

The first challenge is the difference in scope. The astrophysics program will occupy a small fraction of the observing time during the extended mission on a probe designed for solar system observations, so it is unavoidably much narrower in scope than the full-time programs of missions designed for astrophysics. In budget and science impact, the four components of the proposed New Horizons astrophysics program are closer in scale to four large programs on the Hubble Space Telescope than they are to the other missions considered by our panel.

The second challenge is the difference in culture between PSD and APD missions. In APD, there is a strong expectation that extended mission phases are community driven, with GO/GI programs as a major, usually dominant component. In PSD, our impression is that extended missions remain much more driven by the PI-led science team.

Criterion A: Scientific Merit

The four proposed astrophysics programs take advantage of the unique opportunity to observe the sky from a vantage point in the outer solar system. Each of them is a creative use of this opportunity, targeted at important science questions. The panel ranked the importance of these programs in three tiers, with the cosmic optical background measurement being the most important, the UV background measurement and all sky Lyman-α map in the middle, and the microlensing parallax measurement in the third tier.

(1) The cosmic optical background (COB). The COB is a fundamental measurement of the integrated visible light output of all sources over the history of the universe. All previous attempts to measure the COB have been plagued by the challenge of subtracting the zodiacal light background, leading to large statistical and systematic uncertainties. The preliminary measurements from New Horizons shown in the proposal have much smaller uncertainties. Strikingly, they lie a factor of ~2 above the COB predicted from galaxy counts or inferred from gamma ray attenuation. By observing 16 fields, the proposed extended mission program will allow smaller statistical uncertainties and, most importantly, a much tighter check of systematic effects. It would be a mistake to miss this unique opportunity to measure the COB from a vantage point beyond the zodiacal light.

(2) The cosmic UV background (CUVB). The CUVB is a similarly fundamental measurement, though it is overall more challenging to interpret because of the greater impact of dust extinction and Galactic emission. GALEX measurements from 1 AU are intriguingly high, but they are hampered by geocoronal and inner heliosphere emission. The New Horizons program will obtain deep spectroscopic observations on seven selected fields, exploiting both the vantage point of the observatory and the information about sources afforded by the SED.

(3) All-sky Lyman-α emission map. Lyman-α emission is expected to arise from the interaction of the heliosphere with the local interstellar medium. Existing observations provide hints of interesting complexity, but this is largely unknown territory. New Horizons offers the chance to make maps that will not be possible again for the foreseeable future.

(4) Microlensing parallaxes to find isolated black holes. All known stellar mass black holes have been discovered because they are members of binary systems. Gravitational microlensing is the only practical method to discover isolated stellar mass black holes, but

measurements from a single location are usually ambiguous because of degeneracy among parameters such as mass, distance, and transverse velocity. Because of the large baseline, simultaneous ground-based and New Horizons observations of the same events can break these degeneracies and yield an unambiguous mass determination. Monte Carlo simulations predict that observing about 10 long duration microlensing events has a 53% chance of making the first detection of an isolated stellar mass black hole, though the uncertainties are large because of limited knowledge about the black hole population. Although this program takes good advantage of the New Horizons vantage point, the panel rates it as lowest priority among the four because there will be future opportunities for microlensing discoveries of isolated black holes and because a successful detection still provides limited information about the underlying black hole population because of the small number of events.

Our rating of the New Horizons science merit as Very Good balances the creative use of a unique opportunity against the relative narrowness (compared to other missions) of the astrophysics science program.

Criterion B: Relevance and Responsiveness

The proposed scientific investigations are all relevant to SMD science objectives and to priority science areas in the 2020 decadal survey. The COB measurement is relevant to topics of galaxy formation and black hole evolution and potentially to understanding dark sector physics by revealing novel sources of photons or inconsistency with gamma-ray attenuation constraints. The CUVB measurement is similarly relevant to topics of galaxy formation and black hole evolution and mapping the circumgalactic medium. The Lyman-α emission map can provide unique insights into the very local structure of the interstellar medium and more generally to processes that govern the structure of interstellar gas. The microlensing program addresses the decadal goal of characterizing the population of isolated neutron stars and stellar mass black holes. Although the reach of the New Horizons astrophysics program is less broad than that of the astrophysics missions, each investigation is connected to one or more important astrophysics science questions.

As previously noted, the expectation for astrophysics extended missions is that they will be community-driven, aimed at producing data sets that are broadly accessible and useful and offering analysis support through GO/GI fundings. The New Horizons astrophysics program took shape partly through a 2015 community solicitation to identify astrophysics investigations for the *first* extended mission, with findings summarized in a white paper and publication by Zemcov et al. (2018). This study provided a starting point for the astrophysics program proposed for this second extended mission, but the program itself was put together by the New Horizons science team. The proposed analysis teams, which include external collaborators, were also assembled by the mission team. The proposed investigators are highly qualified, but the panel was nonetheless concerned that the approach is counter to the more open spirit of astrophysics extended missions.

The relatively narrow science scope and these process concerns are the reason that the panel ranked the mission lower than others on this criterion (Very Good/Good). Our recommendation below on analysis funding is motivated by these concerns.

Criterion C: Technical Capability, Management, and Science Productivity Given the Costs

The mission appears to be performing well technically. As already emphasized, its vantage point beyond most zodiacal light and geocoronal Lyman-alpha emission gives it a unique opportunity to perform the proposed measurements.

The panel's concerns about process have been noted in Part B above.

The cost for the extended mission astrophysics program is a tiny fraction of the overall cost of the New Horizons mission, and in that sense the proposed program is highly leveraged. The cost is also lower than that of the other missions considered by the panel. However, the science scope is also much narrower than that of the other missions, which is as expected given that the astrophysics program occupies a small fraction of the New Horizons extended mission observing time. Although the cost does not appear unduly high relative to either the demands of the program or the anticipated science return, we recommend below that the budget be reduced with some of the analysis funding being provided instead through the Astrophysics Data Program.

Overall Assessment

The location of the New Horizons spacecraft in the outer solar system provides unique opportunities for observations that are either impossible or much more difficult from any other space telescopes. The proposed astrophysics program is well tailored to these unique opportunities. Of the four proposed observing programs, the panel rates the COB as the top priority, CUVB and all-sky Lyman-α as medium priority, and black hole microlensing search as lower priority. The overall science program is narrower in scope than that of the other missions considered by the panel, which is as expected given the relatively small fraction of the New Horizons observing time that would be devoted to this program. The process for designing the program involved broad community input, but overall the program design and proposed analysis approach are less community-driven than is typical for astrophysics extended missions. This difference is partly due to the smaller scope of the program and partly due to differences in standard practice between astrophysics and planetary science extended missions.

The balance among these factors led to the panel's rating of Very Good for Scientific Merit and Very Good/Good overall.

Recommendation

Assuming that the New Horizons extended mission is approved and supported by PSD, we recommend that the mission operations and instrument engineering support components of the astrophysics over-guide be fully funded. The primary objective should be to obtain and archive the data for the COB, CUVB, and all-sky Lyman-alpha maps in ways that enable analysis by the astrophysics community. We recommend reducing the data analysis budget, with priority on producing and archiving accessible reduced data from these programs. The data products proposed in the team's presentation to the panel (fully reduced LORRI images, fully reduced 1D Alice spectra, FITS images and tables of calibrated UV flux/line intensities) seem appropriate. We recommend that funding proposals for analysis of the New Horizons data be considered by the Astrophysics Data Program once the data are available.

Although we rate the microlensing program as the lowest priority, we leave it to the New Horizons team to decide whether the proposed observations can be executed within its resources.