

SmallSat Technology Accelerated Maturation Platform-1: a proposal to advance ultraviolet science, workforce, and technology for the Habitable Worlds Observatory

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ABSTRACT. The National Aeronautics and Space Administration's (NASA) Great Observatories Maturation Program (GOMAP) will advance the science definition, technology, and workforce needed for the Habitable Worlds Observatory (HWO) with the goal of a phase A start by the end of the current decade. GOMAP offers long-term cost and schedule savings compared with the "technology readiness level (TRL) 6 by preliminary design review" paradigm historically adopted by large NASA missions. Many of the key technologies in the development queue for HWO require the combined activities of (1) facility and process development for validation of technologies at the scale required for HWO and (2) deployment in the "real-world" environment of mission integration and test prior to on-orbit operations. We present a concept for the SmallSat Technology Accelerated Maturation Platform (STAMP), an integrated facility, laboratory, and instrument prototype development program that could be supported through the GOMAP framework and applied to any of NASA's future Great Observatories (FGOs). This brief describes the recommendation for the first entrant into this program, "SmallSat Technology Accelerated Maturation Platform-1 (STAMP-1)," an ESPA Grande-class mission advancing key technologies to enable the ultraviolet capabilities of HWO. STAMP-1 would advance new broadband optical coatings, high-sensitivity ultraviolet detector systems, and multi-object target selection technology to TRL 6 with a flight demonstration. STAMP-1 advances HWO technology on an accelerated timescale, building on current research opportunities in space and earth sciences (ROSES) strategic astrophysics technology (SAT) + astrophysics research and analysis (APRA) programs, reducing cost and schedule risk for HWO while conducting a compelling program of preparatory science and workforce development with direct benefits for HWO mission implementation in the 2030s.

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1 Introduction: Technology Maturation for the Habitable Worlds Observatory

The Astro2020 Decadal Survey¹ prioritized a large infrared/optical/ultraviolet (UV) space telescope [later coined the Habitable Worlds Observatory (HWO)] to pursue an ambitious program of exoplanetary discovery and transformative cosmic origin astrophysics. The decadal survey report recognized that many of the galactic ecosystem, exoplanet, and stellar science goals of HWO require high-throughput imaging and spectroscopy at UV to optical wavelengths (100 to 1000 nm). The Astro2020 Panel on Electromagnetic Observations from Space 1 recommended that "... [the] mission will also need focal plane instrumentation to acquire images and spectra over the range of 100 nm to 2 microns with parameters similar to cameras and spectrometers proposed for ... LUVVOIR and HabEx." These instrument capabilities are required to enable compelling science across the whole scope of the survey.

The decadal survey also recognized that flagship astrophysics missions are multigenerational projects that present complex technical and management challenges. In the prominent case of the James Webb Space Telescope (JWST), these challenges caused numerous budget issues and programmatic delays.² The lessons learned from JWST informed the Astro2020 recommendation that the National Aeronautics and Space Administration (NASA) adopt an early program of technology maturation ahead of the pre-phase A start of HWO to reduce cost and schedule risks to the mission. NASA is now implementing this recommendation in the form of the Great Observatories Maturation Program (GOMAP), a program that will refine the HWO science requirements from Astro2020 and prepare the requisite technologies for HWO prior to its formal new start later this decade.

Astro2020 highlighted the critical role that NASA's suborbital missions play in the advancement of critical path technologies for small missions (National Academies of Sciences, Engineering, and Medicine, NASEM 6-7,8).¹ However, many of the key technologies in the queue for development for HWO are best demonstrated through the combined activities of instrument and observatory level integration and test (I&T) and long-duration on-orbit use. The long-term performance and stability demonstration of advanced broadband optical coatings and ultraviolet-sensitive detectors can only be completely verified by their use as a system in the operational environment of space. Flight prototype demonstration fulfills the standard technology readiness level (TRL) requirements but goes beyond traditional metrics by providing "real-world" tests of the individual technologies as a system, presenting a true prototype-level demonstration of hardware as it will be used on HWO. This approach, long recognized as one of the motivations for the longevity of NASA's sounding rocket program, provides not only a path to TRL advancement but also real-time feedback to the technology community that is conducting the hands-on work of developing these components. Instead of waiting for HWO's instrument I&T in the mid-2030s to learn how this hardware works, we can learn these lessons a decade earlier and at a fraction of the cost.

1.1 Current Technology Maturation Avenues for Flagship Missions

Why are the current funding and development efforts insufficient for accelerating technology development on the timescale and at the scope needed for HWO? As part of its recommendation for HWO, the Astro2020 decadal survey required that "prior to commencing mission formulation, a successful [GOMAP] program must be completed, and a review held to assess plans in light of mission budgetary needs and fiscal realities."¹ The key to this recommendation is that critical technology and infrastructure should be matured (or have a path to maturation) ahead of the phase A start of the mission, a recommendation also made by the large UV/optical/IR mission (LUVVOIR) concept study report (LUVVOIR Final Report 2019).

The current paradigm, where technology is incrementally matured through a combination of Strategic Astrophysics Technology (SAT) and Astrophysics Research and Analysis (APRA) grants, is insufficient to achieve this maturation on the timescale needed for HWO. SAT awards are component-focused technology grants, in most cases designed around a limited number of formal lab-based maturation metrics that do not take into account how the hardware will be used as part of an integrated system. Furthermore, these programs often target metrics that do not derive from up-to-date mission science requirements. Because they are often not tied to specific

science-driven capabilities, SAT and APRA have a disconnect with the groups defining scientific objectives and the system-level hardware testing that reveals new challenges (and opportunities) for the practical application of specific technologies.

APRA grants have led to key advancements in component-level hardware (see, e.g., the Cosmic Origins Program Analysis Group (COPAG) UV working group report³), but these grants are too small to support scaling up of basic technology (and the Astro2020 decadal report notes “basic technology grants are too small to support infrastructure”), and rocket/balloon/CubeSat missions have durations or volume allocations that are too short/small to demonstrate full prototype instruments in their relevant environments. Furthermore, APRA and SAT awards are financially insufficient to support the facility, technical, and workforce development required to rapidly advance the state of the field to support an HWO gate review later this decade. The number of 3-year grant cycles required at the current level of SAT and APRA funding makes completing HWO’s technology maturation this decade through SAT and APRA alone impossible. Finally, mid-scale flight programs are not viable pathways to major technological advancement at the scope and timescale needed for HWO because they do not have technology as part of the program goals and therefore have risk-averse technology postures (Pioneers, Explorer), long development timescales (Pioneers, Explorer), and/or sufficiently infrequent proposal opportunities (Explorers) that make these avenues infeasible for major technological advancement at the scope and timescale needed for HWO.

1.2 Technology, Science, and Workforce Advancement with the SmallSat Technology Accelerated Maturation Platform (STAMP)

With these considerations in mind, we envision a new technology maturation concept that can be applied to all of NASA’s future Great Observatories (FGOs): the STAMP. The STAMP is a dedicated laboratory development and flight demonstration program, where accelerated facility development advances technology that feeds a parallel small satellite demonstration mission. The lessons learned from the demonstration mission inform the ongoing technology and scaling efforts such that the final technology developed through GOMAP is ready to meet all the requirements of the full HWO mission, including how the hardware would be integrated and operate in its real-world setting. The STAMP combines the three pillars of GOMAP’s charge: to advance science definition and technology for the FGOs while providing an inclusive mission framework that develops the science and engineering workforce that will lead the FGOs in the 2030s, 2040s, and beyond. We want to emphasize that the STAMP program is recommended in addition to the existing APRA and SAT program lines; APRA and SAT support the development of a range of technology at various maturation levels, and APRA supports novel science investigations and technology development for a balanced astrophysics portfolio. STAMP focuses on scaling up and systems-level validation of specific high-impact technologies; therefore, STAMP should be an augmentation of NASA’s technology development efforts to support the FGOs (ideally funded through the GOMAP; we roughly estimate the cost of the STAMP technology and workforce maturation mission outlined below, a laboratory and flight demonstration to advance ultraviolet technologies, to have a budget of ~50M, which can be compared with the anticipated \$600M to \$800M lifecycle GOMAP cost for HWO) and not be implemented in place of existing development programs.^{4,5}

A more general description of the STAMP program and its potential application to the full range of FGOs will be presented in future work. This brief focuses on a concept for a first entrant into this program, the STAMP-1 mission. As the initial prototype of this new technology development pathway, STAMP-1 advances key technologies to enable the ultraviolet capabilities of HWO, including advanced broadband optical coatings, high-sensitivity ultraviolet detector systems, and multi-object selection technology (Sec. 2). The technology maturation mission would do this while carrying out a compelling program of preparatory science for HWO: a near- and far-ultraviolet (NUV and FUV) spectral imaging survey of nearby galaxies to identify the agents of galactic feedback and quantify the relationship between galactic outflows and the surrounding circumgalactic medium. This work addresses key topics in Astro2020’s cosmic ecosystem theme (Sec. 2). In the process, STAMP-1 would feature early-career researchers (ECRs) as deputies to every major science and instrument leadership position within the mission and a science and instrument team that is comprised of more than 50% ECRs (Sec. 3). STAMP-1 engages and trains the scientists and engineers who would lead the implementation and execution of

HWO as the mission moves toward phase A at the end of the current decade. Finally, STAMP-1 will include lessons about the overall viability of this development pathway for the X-ray and far-infrared flagships intended to follow HWO into GOMAP.

2 STAMP-1: Technology Maturation, Instrument Implementation, and Demonstration in a Cosmic Ecosystem Science Program

HWO has three primary areas of technology development to carry out ahead of the mission confirmation review (expected prior to the end of the decade), as summarized in the Technical Assessment Group (TAG) Technology Working Group technology gap list: (1) ultrastable telescope systems, (2) starlight suppression technology, and (3) components and observatory-level development for high-efficiency UV imaging and spectroscopy. Ultrastable telescope systems are being developed under the ROSES D.19 element, and starlight suppression is being advanced through SAT, Roman/coronagraph instrument development, and Exoplanet Exploration Program investments. Although the STAMP concept can provide an on-orbit demonstration of telescope and high-contrast technologies (which could ultimately be developed into concepts for STAMP-2 and STAMP-3), we focus here on STAMP-1 as a coherent, integrated approach to advancing the key UV technology needs for HWO. This section presents the high-priority ultraviolet hardware that would be matured under the STAMP-1 program (Sec. 2.1), gives an overview of the demonstration instrument where they would be employed (Sec. 2.2), and presents a sample real-world HWO preparatory science investigation that would close the loop on the lifecycle demonstration of this hardware and pave the way for the development of HWO's ultraviolet instrument (Sec. 2.3).

2.1 Technology Demonstration Goals

For STAMP-1, there are three key enabling technologies, identified by the LUVOIR and HabEx study teams, reaffirmed by the HWO TAG, and subsequently prioritized in NASA's biennial technology gap list, to be matured:

1. **Advanced broadband coatings:** The telescope coatings for HWO are a focal point because their properties have an impact across the full mission, and any adopted technology must provide UV sensitivity, high-broadband efficiency, and deposition uniformity to support both high-contrast imaging and science requiring access to ultraviolet wavelengths. STAMP-1 provides a unique development platform to scale current state-of-the-art coatings to the size required for HWO while meeting key demonstration milestones (Fig. 1).
2. **Large-format, photon-counting ultraviolet detector systems:** HWO requires next-generation detector systems working at FUV and NUV wavelengths; STAMP-1 demonstrates advanced microchannel plate (MCP) and UV-optimized complementary metal-oxide semiconductor (CMOS) flight arrays (Table 1).
3. **Multi-object selection devices:** Multi-object spectroscopy for HWO requires selection devices beyond the microshutter array (MSA) technology demonstrated on JWST. STAMP-1 provides the real-world use of these next-generation devices in an orbital pathfinder instrument ahead of implementation on HWO.

As an example of the interplay between the laboratory and flight mission development aspects of the STAMP program, we consider the maturation of broadband mirror coatings (Fig. 1). At present, advanced lithium fluoride (LiF)-based protected aluminum optics offer the best combination of UV-through-near-infrared (NIR) reflectance to achieve the full suite of HWO's science objectives, with hot deposition and chemically catalyzed deposition techniques offering as much as 20% higher reflectance per bounce in the FUV.^{6,7} However, deposition facilities and processes need to be scaled to the ~2-m size required for HWO. In addition, the uniformity and polarization properties need to be thoroughly characterized at this size scale, and optical coatings using the fabrication processes planned for HWO need to be tested in a long-term relevant environment. STAMP-1 kicks off the engineering efforts needed to address all of these issues, which require investment and schedule acceleration beyond what can be achieved in the current research opportunities in space and earth sciences (ROSES) strategic astrophysics technology (SAT) + astrophysics research and analysis (APRA) paradigm.

STAMP-1: Prototype multi-object spectrograph

- Scaling up coating technology
- Ultraviolet detector maturation
- Flight test NGMSA (EM)
- Local galaxy survey

STAMP-1 tech development plan informed by TAG WGs; reports to START, TAG pre-Phase A HWO Teams

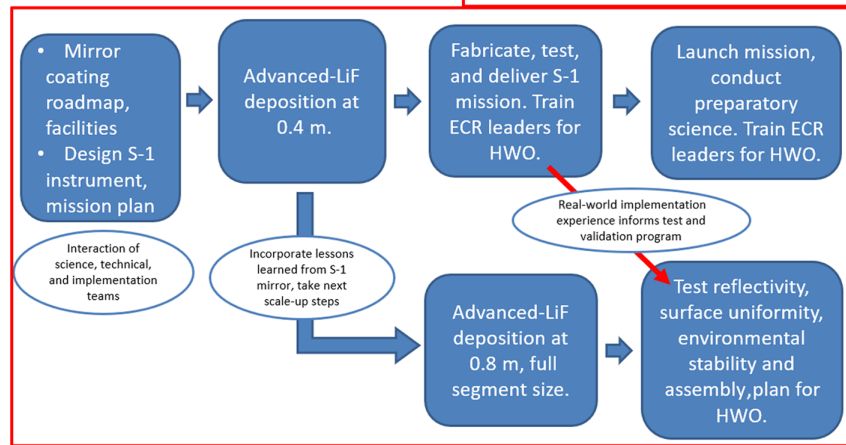


Fig. 1 Block diagram representation of the technology maturation path for HWO optical coatings in the STAMP framework. Unlike traditional technology maturation activities, STAMP provides direct interaction between the technology development and instrument implementation teams, providing process optimization feedback in nearly real time to mitigate cost and schedule risks associated with telescope development on HWO.

Table 1 Instrument parameter goals specified for the STAMP-1 instrument in the FUV (S1-FUV) and NUV (S1-NUV) channels. Both the spectral resolving power and angular resolution are limited by the ~ 5 -arcsecond pointing stability anticipated for the small satellite attitude control system. The intrinsic instrument performance specifications are listed in parentheses in these categories.

Instrument parameter	S1-FUV	S1-NUV
S/C-limited spectral resolving power	2000 (4000)	2500 (4000)
Optimized spectral bandpass	100 to 155 nm (rest frame O VI—C IV)	240 to 300 nm (rest frame Fe II—redshifted Mg II)
S/C-limited angular resolution	7 arcseconds (3.5 arcseconds)	7 arcseconds (3.7 arcseconds)
Temporal resolution	1 msec	1 s
Field of view	32' \times 32'	

2.2 Prototype Instrument Implementation

The power of the STAMP-1 instrument is in its multiplexing capability, a feature that derives directly from the combined advances in coatings (sensitivity to faint sources), high-sensitivity and low-background detectors (sensitivity to faint sources), and multi-object slitmasks (mapping large areas and different physical regions simultaneously). The STAMP-1 design maps stellar populations (by observing FUV ions that are diagnostic of the effective temperature), mass outflow rates (by observing diagnostic FUV and NUV neutral and low-ionization tracers), and FUV emission lines from the circumgalactic halo (see Sec. 2.3).

The science payload employs the highest priority enabling UV technologies for HWO to both advance their component-level TRL and demonstrate their application as an integrated system, providing a direct TRL and heritage link for their implementation on HWO (Fig. 2). The telescope is a 40-cm-diameter primary mirror Ritchey–Chrétien system. The light passes through a prototype “next-generation” microshutter array (NG-MSA) device, which creates an electrostatically actuated slit mask⁸ that allows light from targets of interest into the spectrograph while

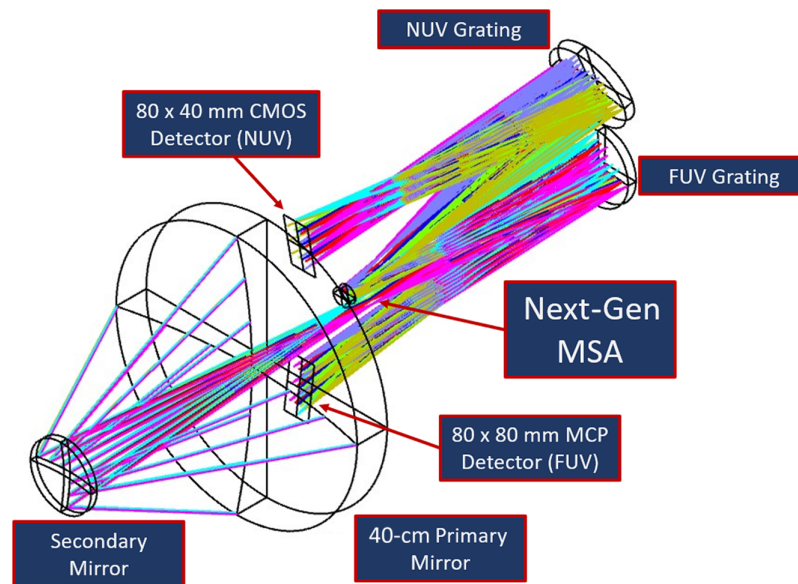


Fig. 2 Schematic raytrace of the STAMP-1 instrument. Forty-centimeter primary mirror feeds a two-channel spectrograph with a next-generation microshutter array as the multi-object selection mechanism at the telescope focus.

excluding the remainder of the field. The prototype NG-MSA is a single wafer of 256×128 shutters (a unit cell of the 3×3 grid in development for HWO), where each shutter has a $100 \mu\text{m} \times 200 \mu\text{m}$ pitch, and builds on earlier devices flight-tested on sounding rocket missions.^{9,10} The light that passes through the MSA continues to a holographically ruled diffraction grating; FUV light is diffracted in the -1 order and directed to a photon-counting detector. The zero-order light of the FUV grating is directed to a second NUV grating that diffracts the light and directs it to the NUV focal plane array. Combining the area of the illuminated NG-MSA with the size of the FUV grating, the total field of view of the STAMP-1 instrument is 32×32 arcminutes with each shutter subtending an angular size of $\sim 9 \times 18$ arcseconds.

STAMP-1 leverages recent advances in detector process development and readout electronics to provide long-duration flight demonstrations of large-format, photon-counting detectors for both the FUV and NUV spectral regions, following the payload design originally recommended for LUVOIR.¹¹ The FUV detector is a large format ($80 \text{ mm} \times 40 \text{ mm}$) MCP detector employing a cross-strip anode readout system. The cross-strip readout allows the MCP gain to be dropped by factors of ~ 10 relative to conventional delay line readouts, providing a correspondingly longer detector lifetime and building on flight development for rocket missions. For the NUV focal plane, STAMP-1 would employ an array of δ -doped CMOS detectors, including band-optimized anti-reflection coatings that suppress red response in silicon detectors. These devices leverage laboratory development through the APRA and SAT programs.¹² The peak effective areas of the STAMP-1 instrument are $\sim 120 \text{ cm}^2$ ($\lambda_{\text{peak}} \sim 110 \text{ nm}$) and $\sim 70 \text{ cm}^2$ ($\lambda_{\text{peak}} \sim 280 \text{ nm}$).

Upon “authority to proceed,” the facility development to process meter-class optics with the necessary overcoating would be developed (the capability for Al+LiF deposition of optics as large as 1.5 m diameter at NASA/Goddard Space Flight Center (GSFC) is being developed as part of an existing SAT). The optics demonstrated in this facility would proceed incrementally, moving from today’s maximum of a 20- to 40-cm demonstration mirror. Following laboratory reflectance and uniformity testing, the 40-cm primary mirror (as well as secondary mirror and diffraction gratings) would be delivered to the STAMP-1 instrument team where they would be integrated into the optomechanical structure of the payload ahead of instrument I&T. Mirrors developed in his program would also support testbed characterization of high-contrast imaging systems with HWO coating prescriptions. The full payload would undergo in-band performance and characterization testing, with witness samples tracked at every step to monitor coating stability. Any anomalies and lessons learned would flow back to the coating deposition team for process optimization when scaling up to the next milestone (80 cm) mirror and ultimately to a full HWO primary mirror segment demonstration (final size to be determined, pending HWO project

office development). The interaction between the technology development team and the instrument development team provides the conduit to incorporate real-world lessons before the final HWO hardware is fabricated, reducing the schedule and cost risk to the full HWO implementation.

Beyond the advanced broadband coatings, spacecraft, telescope, gratings, detectors, and prototype NG-MSA at the scale and specification for STAMP-1 are part of the existing commercial or NASA-supported development efforts. We would expect telescope delivery within 12 months of order, and deposition coating runs at this scale would begin immediately. Spacecraft, detectors, grating, and MSA would be expected between 18 and 21 months after receipt of funding, leaving 9 months for instrument assembly, calibration, and test and 6 months for integration with the spacecraft, observatory I&T, and delivery to the launch service provider. Although we envision a 24-month science mission, all major technical milestones would be achieved with 6 months of in-flight operations.

2.3 Demonstration Science Program

Astro2020 highlighted three key science themes for astronomy and astrophysics in the 2020s and 2030s: cosmic ecosystems, worlds and suns in context, and new messengers and new physics. A central element of cosmic ecosystems (NASEM Secs. 1.1.3 and 2.3)¹ is how “stellar feedback” drives the mass, energy, and chemical evolution of galaxies and the surrounding circumgalactic medium (CGM) with energetic radiation fields, stellar winds, and supernova explosions of the most massive stars. Understanding this feedback cycle was highlighted as a top priority for the cosmic ecosystem theme in the current decade and was a primary driver for the multi-object capability in the LUVOIR and Habex studies. The decadal survey specifically called for close study of the relationship between star formation and the flows of matter in/out of nearby galaxies, where these processes can be observed “in dramatic detail, revealing the full multiphase complexity of the local ecosystem” (NASEM 1-8)¹ and advance our understanding of how cool, warm, and hot gases are driven into the halos of galaxies, the properties of the gas within halos, and ultimately how that gas is recycled into future generations of stars.

While advancing the technology and workforce that will enable UV imaging and spectroscopy on HWO, STAMP-1 will map the lifecycle of galaxy feedback, producing a dataset that will complement the high-spatial-resolution local galaxy and higher-redshift halo studies to be carried out by HWO. STAMP-1 will use multi-object spectroscopy to simultaneously characterize the most massive stellar clusters with FUV photospheric and wind lines, measure the galactic outflows that drive gas into the circumgalactic medium through neutral and intermediate ionization FUV and NUV absorption lines, and trace that gas in emission in the CGM through FUV emission line mapping. The half-degree field of view of STAMP-1 enables this simultaneous mapping of nearby galaxies in a single observation, whereas HWO will likely have an angular footprint ~ 100 times smaller. This makes STAMP-1 an ideal tool to investigate the cycle of baryon feedback in the low-redshift universe where galaxies and galaxy halos are tens of arcminutes in angular extent. In addition, STAMP-1 will provide a precursor target list of particularly rich outflow and CGM sightlines for high sensitivity and high-angular resolution follow-up with HWO. STAMP-1 accomplishes this preparatory science program by implementing the first orbital multi-object spectrograph operating at FUV and NUV wavelengths, a pathfinder instrument for future UV imaging and spectroscopic instrument on HWO.

Although the specific scientific and technical requirements for HWO’s instrument suite are still being refined by NASA’s Science, Technology, Architecture Review Team (START), TAG, and nascent HWO project office, there is already a strong case for multi-object UV spectroscopy. This capability was highlighted as a driving requirement in Astro2020’s cosmic ecosystem theme, it was recommended by the Astro2020 Electromagnetic Observations from Space-1 panel, and the HWO TAG has adopted the LUVOIR MultiObject Spectrograph (LUMOS)-B instrument^{11,13} as a baseline concept for HWO’s UV capability. The STAMP-1 instrument will provide multi-object spectroscopy at a spacecraft-limited angular resolution of ~ 7 arcseconds, enabling many tens of star-forming regions to be observed simultaneously (Fig. 3). The spectral coverage and spectral resolution of the instrument (1) allow key mass and age diagnostics of the stellar population and the properties of the associated interstellar medium to be resolved (driving the short-wavelength FUV coverage, e.g., O VI 1032, 1038 Å; S IV 1063, 1073 Å; and P V 1118,

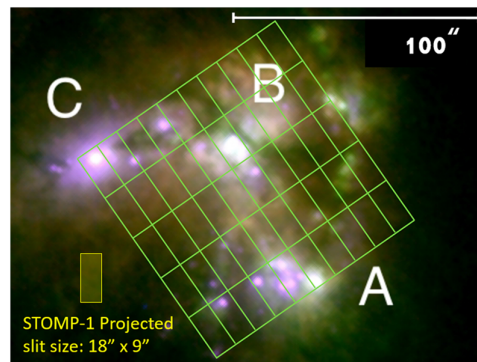


Fig. 3 Simulated overlay of the STAMP-1 MSA “footprint” on the central region of a nearby galaxy. Each shutter is represented as a yellow box, $\sim 18''$ (cross-dispersion) $\times 9''$ (dispersion direction). This is an image of the starburst galaxy Haro 11, moved to a distance of 4.5 Mpc for this schematic figure (images reproduced with permission from Refs. 14 and 15); overlay is meant to be illustrative only. This image highlights the ability of the STAMP-1 footprint to isolate various star-forming regions within a single galaxy, but the full field of view of the STAMP-1 footprint is over 0.5 deg.

1128 Å for stellar masses and H₂ and CO, 1000 to 1120 Å, for the interstellar medium) and (2) provide direct measurements of the outflows driven by the combined effects of stellar winds and supernovae in these star-forming regions. Strong outflow lines motivate FUV spectral coverage (Si II 1190, 1193, 1526, 1533 Å) and drive the NUV spectral bandpass (rest frame and low-redshift Fe II and Mg II; 2400 to 3000 Å).

The 40-cm telescope is sized to enable the survey goal of spectrally mapping 200 nearby galaxies in a 2-year primary science mission (noting that the technical mission would be achieved after 6 months). The unique combination of multi-object spectroscopy and high-sensitivity coverage down to 100 nm is beyond the capability of Hubble or any other proposed mission. We note that neither Hubble Space Telescope (HST) nor Ultraviolet Explorer (UVEX) covers rest frame O VI in an imaging spectroscopy mode. The bandpass and spectral resolution requirements of STAMP-1 are driven by the need to cover the full set of stellar and gas diagnostics (FUV and NUV), with sufficient velocity resolution (~ 150 km/s) to resolve outflows from stellar clusters (typical outflow velocities range from 10 s to ~ 1000 km/s¹⁶ and references therein) while demonstrating the technology at the key wavelengths targeted by HWO.

STAMP-1 simultaneously measures the ionization state and composition of the halo gas using low-resolution spectroscopy of wide angular fields in the halos of the target galaxies. The coverage of the most important cooling lines for gas between 10,000 and 300,000 K (O VI, Ly α , and C IV; rest wavelengths 1032 to 1550 Å, another driver of the FUV spectral coverage) over large angular extents with high sensitivity would allow STAMP-1 to map diffuse emission from circumgalactic halos in unprecedented detail and numbers (a key component of the “Unveiling the Drivers of Galaxy Growth” science priority area, NASEM 1-8).¹ Taking into account the telescope collecting area and realistic component efficiencies, this low-redshift galaxy survey (200 nearby galaxies) would be sensitive to ($>8\sigma$) O VI surface brightness to $\sim 1 \times 10^{-18}$ erg cm⁻² s⁻¹ arcsec⁻² per $9'' \times 7''$ angular bin (this is the full slit width in the dispersion direction and the observatory angular resolution in the cross-dispersion axis) in a 200-ksec observation and correspondingly lower surface brightness limits when binning over multiple shutters. This galaxy + halo survey would serve as a pathfinder scientific dataset for galaxy halo investigations over a wide range of redshifts and at much higher angular and spectral resolution with HWO. In addition, these observations will be made with an instrument similar in design and data format to the HWO UV instrument, providing a training ground to develop analysis and data calibration techniques that will ultimately be needed for HWO.

3 Workforce Development in the Stamp Framework

Astro2020 emphasized the lack of diversity at all levels of NASA mission leadership (NASEM Section 3; 6-10).¹ NASA, and more specifically the GOMAP, has made inclusive workforce development, a priority area for the pre-phase A development of HWO. In the context of

Explorer-class missions, Astro2020 noted: “A first step to achieving a more diverse leadership pool is to broaden participation in technical, instrument, and leadership teams as a whole” (NASEM 6-10);¹ this initiative can extend to the science and technology preparatory efforts for HWO kickstarted by STAMP-1.

The organizational layout of the mission features “deputies” in all key mission science roles (Fig. 4), including deputy Principal Investigator (dPI), deputy project scientist (dPS), and deputy instrument scientist (dIS) and in all the major engineering and program management positions (program manager, project systems engineer, instrument systems engineer, etc.). These positions would be fully funded within the STAMP-1 PI-managed budget and provide a direct route for the training of the scientists and engineers with the expertise to lead the future of HWO.

The STAMP-1 science and instrument teams would be made up of >50% early-career researchers (defined as less than 10 years from receipt of terminal degree); this builds the framework for critical relationships between observers, theorists, and instrumentalists that enables open communication and a cohesive development environment that can be applied to the forthcoming HWO science, instrument, and technology teams while maintaining a connection to current space-flight mission expertise in science, engineering, and program management. The >50% early-career researcher goal is achieved through pairing major mission leadership roles with early-career deputies (as implemented on the Aspera SmallSat mission¹⁷); the envisioned STAMP-1 mentoring approach emphasizes investment in hands-on mission experience for the group that will lead HWO in the 2030s and 2040s while taking advantage of NASA’s investments today. The STAMP program would recruit from a broad pool of early career scientists and engineers in a manner consistent with NASA Science Mission Directorate strategic priorities for inclusion, diversity, equity, and accessibility¹⁸ and following the recommendations of the Astro2020 State of the Profession and Societal Impacts recommendations. Across the deputies, ~8 to 10 early-career science team members, and ~8 to 10 early-career engineers and

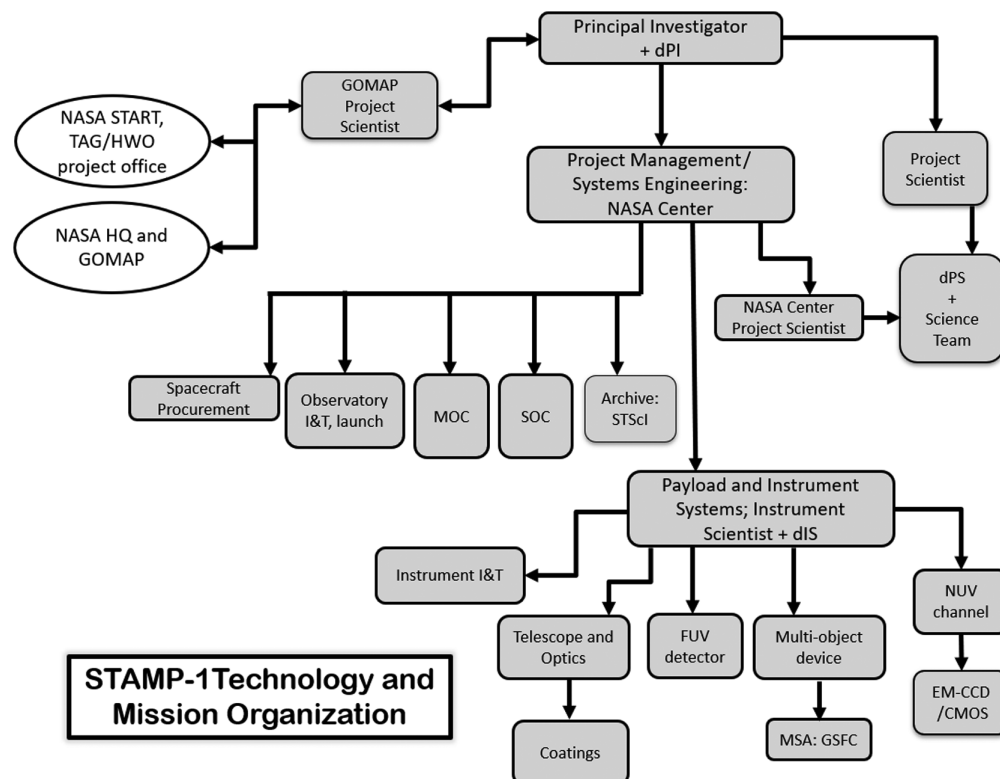


Fig. 4 Notional organizational block diagram for STAMP-1, leveraging existing NASA investments in institutional infrastructure and component-level technology while providing an inclusive federal/academic partnership that advances the development of early career scientists and engineers for leadership roles in the development and execution of HWO.

program management personnel, we would imagine roughly two dozen early-career scientists and engineers could train in key mission roles as part of an individual STAMP mission.

This emphasis on early-career development builds on the long-standing success of NASA's suborbital rocket and balloon programs ("the program has demonstrated its efficacy in producing leaders for space missions" NASEM Section 6.2.1.1),¹ which has recently been adopted by CubeSat and Pioneer missions such as Colorado Ultraviolet Transit Experiment (CUTE), Star-Planet Activity Research CubeSat (SPARCS), Supernova Remnants and Proxies for ReIonization Testbed Experiment (SPRITE), and Aspera.^{17,19–21} It would be anticipated that some of the members of the STAMP-1 team would form part of an eventual science and engineering team for HWO's UV instrument—training people for this role is one of the goals of the STAMP program—but the expectation for HWO is that all instruments will be solicited through open calls to the community; participation in a STAMP program is not a pre-requisite for involvement in other HWO activities.

The early-career focus of the STAMP-1 concept authors is balanced by mid-career leaders in ultraviolet science and instrumentation, leveraging their experience and NASA's investment in the institutional infrastructure and mission leadership to drive the preparation of HWO through the 2020s and into phase A and B activities in the 2030s. The STAMP early-career training and leadership mentoring framework is responsive to Astro2020 workforce development charge: "... important that experienced PIs establish team roles that enable emerging leaders to gain experience" (NASEM 6-11).¹ The primary mission management and systems engineering would be at NASA/GSFC to provide additional NASA guidance to the STAMP-1 program and connection to the larger HWO development. The connection between the NASA management and STAMP-1 science and instrument teams would develop personal and institutional relationships that could be leveraged into the implementation of HWO. We would envision that the HWO project office at GSFC would also assign a "GOMAP project scientist" to the STAMP-1 project.

Finally, the connection between the STAMP-1 team, the NASA HQ, the current START and TAG, and/or the HWO project office is essential. These stakeholders would be regularly briefed on the progress of STAMP-1 and the implication for the technology readiness of the ultraviolet hardware for HWO. These groups can then make informed instrument trade decisions based on current and projected performance through open and established lines of communication. To support this open connection between STAMP-1 and the relevant stakeholders, the STAMP-1 team supports a funded "NASA START/TAG or project office liaison" position as part of the mission leadership team.

4 Summary and Next Steps

This brief has presented the SmallSat Technology Accelerated Maturation Platform concept, a dedicated laboratory development and flight demonstration program where accelerated facility development advances technology that feeds a parallel small satellite demonstration mission. This joint facility, laboratory, and prototype instrument development path follows the spirit of the Astro2020 GOMAP concept, as a way of advancing key technologies for all of NASA's future Great Observatories on a faster track than is possible with the current SAT and small flight mission programs in the ROSES portfolio. Scaling technology while incorporating real-world performance metrics reduces cost and schedule risks to the implementation of large missions—the true purpose of GOMAP. The STAMP combines the three pillars of GOMAP's charge: to advance (1) science definition and (2) technology for the FGOs while (3) providing an inclusive mission framework that develops the science and engineering workforce that will lead the FGOs in the 2030s, 2040s, and beyond.

As an example of the STAMP program, we have described a notional design for "STAMP-1": a focused technology, scientific, and workforce-building program to advance the technological readiness of ultraviolet hardware for the Habitable Worlds Observatory. Building on the UV technology development roadmap laid out in the LUVOIR Final Report, the cost and development timescale of Pioneers and Explorer Missions of Opportunity, and the short implementation cycle, we estimate STAMP-1 would require a budget of roughly \$50M. Funding for the STAMP program should derive from the FGO/GOMAP line and not pull from or replace existing

technology development and small flight opportunities (e.g., the ROSES APRA, SAT, and Pioneers programs).

At the end of the STAMP-1 mission, the major UV technology and infrastructure maturation efforts for HWO would be complete, and team members would be ready to support NASA's plans for the full HWO mission implementation. The timeframe for initiating the STAMP program for Habitable Worlds is short—the decadal survey requires a gate review of the progress for Habitable Worlds later in this decade. Therefore, for this project to advance the necessary technology development to a clear path to TRL 5 to 6 ahead of this gate review, NASA should consider developing the necessary programmatic framework to allow STAMP project initiation by 2025, so that the technology and mission development phase for STAMP-1 can begin in 2025–2026.

Code and Data Availability

Data sharing is not applicable to this article as no new data were created or analyzed.

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