Astrophysics Science SmallSat Studies (AS^3)
Abstracts of Selected Proposals
(NNH19ZDA001N-AS3)

Below are the abstracts of proposals selected for funding for the Astrophysics Science SmallSat Studies (AS^3) program. Principal Investigator (PI) name, institution, and proposal title are also included. **32** proposals were received in response to this opportunity. On May 11, 2020, **8** proposals were selected for funding.

Derek Buzasi/Florida Gulf Coast University
MAGIC: The Massive star AsteroseismoloGy Instrument Cubesat

Massive stars, while few in number, play an outsized role in the evolution of the universe through their roles in chemical enrichment and as Type II supernova progenitors, as well as serving as the progenitors of gamma-ray bursts and neutron star collisions such as those responsible for recently-detected gravitational wave events. Accordingly, understanding the nature of these objects is fundamental to our understanding of astrophysical topics as diverse as the early universe, star formation, stellar winds, and the evolution of the interstellar medium. However, our current models are limited by our understanding of processes such as internal differential rotation and angular momentum transport, core overshooting, chemical mixing, and the effects of magnetic fields. Furthermore, massive stars in particular are frequently understudied, simply because they are bright.

Improvement of the models can only come through confrontation with observations. Since many (and perhaps most) massive stars oscillate, high-precision asteroseismology constitutes the ideal observation set for this purpose. We propose a small spacecraft to perform asteroseismology on several hundred late O and B stars using photometry in the NUV (200 -300 nm) regions of the spectrum. This is the ideal spectral range for observing these objects for three reasons:

1. Since this spectral region lies closer to the peak of the blackbody spectrum, the stars themselves are relatively brighter, allowing the use of small apertures (and small spacecraft) to observe them. 2. The relative amplitudes of the oscillations are larger at shorter wavelengths. Current modeling efforts are hampered by the limited number of modes detectable, and working in the NUV will allow detection of more oscillation modes at higher signal-to-noise ratios. 3. Two-color photometry will allow mode identification (in particular, mode degree l) by use of relative oscillation amplitudes and phase differences. Identifying modes is key to making detailed modeling possible, and the lack of regularly-spaced modes in these stars in contrast to those seen in solar-like stars makes identification impossible using information in one color only. Working at NUV wavelengths where more modes will be accessible at higher SNR will solve this problem.

Massive stars are clustered near the galactic plane, which will allow us to observe multiple (up to 60) targets simultaneously. Potential targets with 4 < V< 7 give adequate count rates to achieve the ~ppt photometric precision we require without exceeding local count rate limitations for the detector. Our notional mission profile would observe 6 fields in succession for two months each, followed by a second similar visit six months later. This would optimize both the number of targets and the temporal baseline; the latter is essential to obtaining the (temporal) frequency resolution required for successful asteroseismology.

Asantha Cooray/University of California Irvine
Mid-Infrared Sky Explorer

We propose Mid-Infrared Sky Explorer (MISE) as a small satellite astrophysics mission with a broad range of scientific capabilities spanning top-level NASA astrophysics science goals. MISE will carry out astronomical observations through a ride-share launch opportunity, using ESPA-grande architecture. While MISE is capable of a wide range of astronomical observations, from near-Earth asteroids to cosmological measurements, the final design is expected to be based on technical requirements on two key scientific objectives. In particular, MISE will address the NASA 2014 Science Plan Question How does the universe work? by measuring the Extragalactic Background Light (EBL) at mid-infrared wavelengths, the integrated brightness from all sources of emission since the Big Bang. The EBL is a cornerstone measurement for leading to an understanding of the fossil record of galaxy assembly from the first stars to the present day. To help address the NASA Question How did we get here? , MISE will focus on astrophysical properties of dust in near-by galaxies in a range of environments and galaxy physical properties such as the stellar mass and active galactic nuclei (AGN) activity. MISE is a mid-infrared (5 10 micron) instrument capable of R=60 spectro-imaging over its 10 deg2 field of view using a compact telescope with a 10 cm aperture. MISE will also carry out R=100 spectroscopy of near-by galaxies using part of the detector at higher spectral resolution centered on specific emission lines. Using only high-readiness technologies, MISE is designed to make use a small satellite ride-share platform. The instrument plans to use a single well-developed HgCdTe detector array with mid-IR sensitivity. Spectro-imaging observations will make use of narrow-band filters on top of the detector with the full spectrum obtained through shift-stare mode of the spacecraft. The proposed study funds will be used to develop the MISE instrument over the next year, including a detail scope of hardware and engineering, launch and operations, and science analysis requirements. The assembled team is well-qualified to develop the proposed mid-IR 3D spectroscopy imager. We propose a Team-X session at JPL. Our primary objective is to establish a small satellite mission in the mid-infrared as a premier vehicle for key breakthroughs in our knowledge related to the universe and nearby galaxies. The proposed mission design study is aimed at carrying out a number of key technical trades to establish MISE as a competitive small satellite maximizing the total science return and using existing technology investments in the mid-infrared.

Jeremy Drake/Smithsonian Astrophysical Observatory
The Normal-incidence Extreme Ultraviolet Photometer

The evolution and loss of planetary atmospheres depend critically on the host star extreme ultraviolet (EUV) spectrum and flux. There are only a handful of accurately measured EUV stellar fluxes, all dating from Extreme Ultraviolet Explorer (EUVE) observations in the 90's, and current models of stellar EUV emission are uncertain by more than an order of magnitude. The objective of this proposal is to design and optimize the Normal-incidence Extreme Ultraviolet Photometer (NExtUP) mission. NExtUP will use efficient normal-incidence multilayer technology to form sharp images of stars in 5 EUV bandpasses down to flux limits two orders of magnitude lower than EUVE. A focal plane detector will measure the EUV fluxes formed at different temperatures in stellar outer atmospheres and the results will map the EUV radiation conditions of exoplanet host stars, and F-M type stars in general, as a function of stellar mass and magnetic activity level. Secondary science includes using EUV dimming to detect stellar coronal mass ejections, probing EUV transits of hot Jupiters, and mapping out the structure of the local interstellar medium. The results from NExtUP will be essential for understanding exoplanetary atmospheric survivability, evolution and habitability. NExtUP is central to NASA Objective 1.6 in NASA Strategic Plan 2014 to Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars, as well as NASA's 2014 Science Plan strategic objective to Discover and study planets around other stars, and explore whether they could harbor life. NExtUP is also core to the new Strategic Objective 1.1: Understand the Sun, Earth, Solar System, and Universe of the 2018 NASA Strategic Plan which has as a core context Searching for Life Elsewhere . This goal will require us to understand the atmospheres of exoplanets and their interplay with their stellar hosts.

Varoujan Gorjian/JPL
BHAGERA: Black Hole Accretion and Growth Experiment with Reverberation Analysis

A key question identified by the 2010 Decadal Survey is: How do black holes grow&and influence their surrounding? Although significant advances have been made in the basic idea that an accretion disk provides gas for a black hole to grow and that growth is connected to the evolution of its host galaxy, recent observations of Active Galactic Nuclei (AGN) have indicated that the AGN continuum emission region differs significantly from the predictions of standard accretion disk models, calling into question the basic understanding of accretion disk size and structure. In the case of observations of the nearby Seyfert 1s NGC 5548 and NGC 4593, the radius of the continuum emitting region is 3x larger than expected based on standard thin disk models.

Unfortunately direct observations of disks, even at the distances of the closest galaxies, are not possible, but we can exchange time resolution for spatial resolution.

Reverberation Mapping (RM) provides the best close-in probe of the structure of the supermassive black hole (SMBH) environment at the centers of galaxies. RM measures the time delay between fluctuations in the continuum arising from close to the black hole (likely originating from its corona) and the subsequent response of the accretion disk continuum and gas in the broad line region (BLR). The drawback is that RM is a telescope intensive process, requiring regular observations (1/day) over a long period (months). So far NGC 5548 and 4593 are the only two AGN that have had their UV/optical continuum RM measured spectroscopically due to the scarcity of observing time on general facilities like HST.

To solve this problem, we propose the Black Hole Accretion and Growth Experiment with Reverberation Analysis (BHAGERA) which uses a 20 cm telescope coupled to a UV/optical spectrograph spanning 1150 - 5000 Angstroms and with a resolving power of R ~ 100 on a SmallSat in Geostationary graveyard orbit. By monitoring the changes in continuum emission starting from very close to the black hole all the way out to the optical emitting region, we will distinguish between continuum emission from the disk, and continuum emission from elsewhere (e.g. potentially from the BLR). By observing 10 nearby AGN we can sample the diversity of AGN properties over a range of BH masses and accretion rates to gain insight on the fundamental physics of accretion disks.

Chiumun Hui/NASA/MSFC
MoonBEAM: A Beyond Earth-orbit Gamma-ray Burst Detector for Multi-Messenger Astronomy

The joint detection of two merging neutron stars in gravitational waves (GWs) and across the entire electromagnetic (EM) spectrum in 2017 ushered in the multi-messenger era of astrophysics. Joint observations of short gamma-ray bursts (SGRBs), the type of GRB associated with compact binary mergers, provide a unique probe of the central engine, insights into the composition of relativistic jets, and enable strict constraints on the timescales for their formation and propagation. Additional joint detections will not only advance astrophysics, but also our understanding of gravitation, cosmology, nuclear and particle physics, and fundamental physics. The next decade is an unprecedented time to study these merger events from the multi-messenger perspective, with major GW detector network upgrades funded and deployed by the mid-2020s. Therefore, we seek to study a gamma-ray instrument on a SmallSat in a unique orbit to maximize the number of well-localized SGRBs, and to enhance multi-messenger science in support of the GW observations.

The main objective of our mission is to detect a large number of SGRBs and provide context for multi-messenger merger observations and EM followup to identify the GRB afterglow and kilonova. A gamma-ray detection could increase the confidence of a simultaneous, but marginal, GW signal, effectively extending the GW detection horizon. Having a SmallSat at an orbit further away from Earth would also allow for additional localization refinement when the GRB is detected by multiple instruments. Reducing the

localization region will enable faster afterglow identification so rapid on-source observations can cover early phases of the emission. It will also decrease the chance of source confusion between transients and enable robust association of the SGRB, its afterglow, and the GW observation.

To achieve the sky coverage and duty cycle needed for maximizing SGRB detections, we propose Moon Burst Energetics All-sky Monitor (MoonBEAM), a SmallSat concept in cislunar space. Its orbit will minimize Earth blockage and variation in the radiation environment, while also providing a long enough baseline for localization refinement using the timing triangulation technique. When a SGRB is detected by multiple instruments, the difference in detection times will constrain the arrival direction to an annulus on the sky and aid in reducing the localization area. In a previous study, we have a preliminary design of a 12U CubeSat with gamma-ray detectors capable of reaching cislunar space. This concept study will explore the design of an integrated science spacecraft addressing mission critical areas. The two main challenges faced by MoonBEAM are propulsion and rapid communication, which will be the key areas of the mission study. Since our preliminary study, there have been further development in SmallSat propulsion and they will be evaluated during the design study. Regular communication to cislunar instruments is possible with the Deep Space Network, and this study will evaluate the rapid downlink needed for triggers by exploring options available with the Space Communication and Navigation Office and through commercial options. Preliminary analysis did not reveal any significant issues with single event effects and total ionizing dose, and an analysis of the radiation environment of all subsystems is planned for the mission study. After the mission design study finishes all key trades, the science team will explore the phoswich operating mode for increasing the instrument sensitivity and refining the science performance of the mission.

Herman Marshall/Massachusetts Institute of Technology
Globe Orbiting Soft X-ray Polarimeter (GOSoX)

We propose to advance a concept for a soft X-ray polarimeter that follows from our design of a sounding rocket instrument, the Rocket Experiment Demonstration of a Soft X-ray Polarimeter (the REDSoX Polarimeter1, [1, 2] aka REDSoX). The proposed mission study will assess the overall cost estimate of the Globe Orbiting Soft X-ray Polarimeter (GOSoX), an orbital version of REDSoX that will operate in the 0.2-0.8 keV band. These goals are to 1) test models of vacuum birefringence and proton cyclotron lines in at least 4 neutron stars, 2) test inverse Compton and synchrotron emission models of blazar spectra in at least 4 sources, 3) provide a broader view of polarized emission across the electromagnetic spectrum via complementary measurements in the by the Imaging X-ray Polarization Explorer (IXPE, 2-8 keV), optical instruments, or radio telescopes, and 4) assess the prevalence of polarized emission in systems where soft X-ray polarization may not be expected. The science instrument leverages previous funding from ight projects and APRA and SAT grants to make focusing optics, multilayers, gratings, and CCDs. Together, these high TRL technologies enable us to build GOSoX.

The science payload consists of Wolter type I X-ray optics and Critical Angle Transmission (CAT) gratings on an optical bench and a focal plane with two or four X-ray detectors and one or three multi-layer mirrors. The instrument senses polarization by matching the dispersion of the gratings to the lateral grading of a multilayer (ML) coated mirror set at about 45 to the incoming light and viewed by a CCD. By orienting three ML coated mirrors at position angles 120 apart or rotating the instrument by 180 about the optical axis, we can measure the three Stokes parameters I, Q, and U. These three parameters are used to determine the fraction of linearly polarized light, P = (Q2 + U2)1=2=I, and the polarization phase angle - arctan U=Q. Based on our goals and our instrument design, we have selected a representative sample of sources to observe and goals for minimum detectable polarizations (MDPs). Consequently, requirements on the mission concept include allowing the instrument to be reoriented 1-2 times per week, surviving for at least one year, and having some exibility in scheduling to allow for joint observations with IXPE or other observatories. We wish to evaluate two potential con gurations of the instrument. The rst is most similar to REDSoX, which has undergone signi cant design work but was not designed for long orbital operations. In this con guration, the baseline objectives can be satis ed in one year. The second is a more compact design, with less eective area and instrumentation but is capable of carrying out thebaseline mission in two years. There is a dierence in technical readiness of the components of the two con gurations, which may result in dierent schedule and cost margin. The rstcon guration is more massive, with implications regarding attitude control, while the second con guration requires large attitude roll variation. The best way to determine which of these con gurations will satisfy mass, power, cost, and size requirements is to conduct a mission concept review that can trade o
 between designs.

Eliad Peretz/NASA
ORCAS Orbiting Configurable Artificial Star.

NASA relies on large ground-based telescopes to provide confirmation and follow-up observations, without which the science remains incomplete. Such telescopes, such as the Keck Observatory on Mauna Kea, use adaptive optics (AO) to provide partial correction of the atmospheric turbulence which blurs the images. Currently, AO uses either a bright star in the vicinity of the target to provide the atmospheric correction, known as natural guide star (NGS) or lasers projected from the ground known as laser guide stars at a few particular wavelengths (LGS). However, for more than 99.9% of astronomical targets there is no suitable NGS bright star (magnitude of 6 or less) in the close vicinity of the target. Conversely LGS used at near IR wavelengths are fainter and suffer from the cone effect, tip tilt, wavelength-dependent AO correction errors, other limiting factors, and cannot work well at visible wavelengths. An innovative way to provide the observations at the needed clarity is to provide a modest laser signal (< 1 W) from an orbiting small satellite, pointed at the observatory, to provide an enhanced AO correction that provides for nearly diffraction-limited images across a range of visible and NIR wavelengths, an improvement of orders of magnitude over traditional AO.

Our Team at NASA Goddard Space Flight Center has joined with the Keck Observatory to develop the Orbiting Configurable Artificial Star (ORCAS) concept (Peretz et al. 2019). ORCAS consist of a small satellite with the laser and calibrated flux illumination system in a steerable astro-stationary orbit, and an enhanced AO system at the observatory. Space telescopes provide diffraction-limited imagery; the ORCAS laser system will allow ground-based telescopes to provide nearly diffraction-limited observations at visible wavelengths for the first time. The onboard calibrated flux source will also enable absolute flux precision of <1% for the first time from the ground. In anticipation of the launches of the James Webb Space Telescope (JWST, 2021) and the Wide Field Infrared Survey Telescope (WFIRST, 2026), it is imperative that NASA develop ORCAS to provide the required near diffraction-limited and precise absolute flux-calibrated observations at visible and NIR wavelengths for confirmation and follow-up by large format ground telescopes. Current AO telescopic observations are not adequate to address the anticipated science questions. Arguably as important, ORCAS can provide observations in the visible in a post-Hubble world. The potential of near-diffraction limited and precisely absolute flux-calibrated imaging and spectroscopy at NIR and visible wavelengths from the ground is immense and will profoundly affect planning priorities for astronomy. ORCAS will prove to be an enabling technology for a number of types of observations of urgent interest to NASA, including exoplanets, galaxy evolution, black holes, extreme stellar dynamics, general relativity, the dynamics of the galactic center, dark matter and dark energy.

In this proposed study, we will explore the ORCAS mission concept in detail. While most of the components of the satellite have TRL 9 heritage, we will start at the ground floor to build it in a small satellite format. A one-week Mission Planning Lab study at Wallops Flight Facility is anticipated, as well as a science trade study to further develop the Science Tractability Matrix. Absolute pointing and jitter constraints for ORCAS are proven feasible. Modifications to the AO ground system will be trade studied and recommended. The small satellite and enhanced AO components will allow for a total mission budget of well under $35 Million. The ORCAS-enabled ground observations will provide the JWST and WFIRST missions with science return of incalculable value and will provide the required observation capabilities in a post Hubble and large ground-based telescopes world.

Sara Seager/Massachusetts Institute of Technology
A Constellation of Small Satellites to Search for a Transiting Earth-Size Planet in an Earth-like Orbit about a Bright Sun-Like Star

The search for another Earth is a compelling goal of modern astronomy. We propose a constellation of small satellites to search for Earth-size planets in Earth-like (i.e. approximately one year or 1 AU insolation equivalent) orbits, transiting the brightest sun-like stars. Because the brightest sun-like stars are spread all across the sky, a single telescope will not do. With the proposed constellation-based approach, each satellite

would monitor a single sun-like star for as long as possible, before switching to another star, with targets only limited by the Sun, Moon, and Earth exclusion constraints. Despite several different mature exoplanet finding techniques and a number of past, present, and future transiting exoplanet missions, the proposed constellation is unique in its ability to find transiting Earth analogs across the entire sky. Exoplanet transits provide the opportunity to conduct follow-on spectroscopic measurements of exoplanetary atmospheres, including the search for biosignature gases.

We envision the constellation in three phases. Phase I, now complete, is the technology demonstration for precision pointing and thermal control via the ASTERIA technology demonstration pathfinder. Phase II is what we propose for here, a small constellation of a half dozen 12U CubeSats to focus on the brightest (Vmag<6) sun-like stars. Phase III would be the growth of the constellation with up to several dozen satellites to probe all relevant target stars with magnitudes brighter than Vmag=8.

This concept builds on the ASTERIA pathfinder, which deployed from the International Space Station (ISS) on 20 November 2017. Over the prime mission, ASTERIA reached or surpassed its technology demonstrate goals by achieving: line-of-sight pointing stability of approximately 0.5 arcseconds root mean square (RMS) over 20-minute observations; pointing repeatability of 1 milliarcsecond RMS from one observation to the next, and focal plane temperature stability better than ±0.01 K over 20-minute observations. These capabilities enable precision photometry i.e. the careful measurement of stellar brightness over time needed to discover transiting exoplanets. ASTERIA successfully detected the transit of known super-Earth 55 Cancri e.

Each satellite in the constellation would utilize ASTERIA s precision pointing and thermal control capabilities, operate independently from the others, but will have a larger aperture, different orbit, and improved detector technologies in order to operate beyond the capability of ASTERIA. We propose to design the constellation in terms of number of spacecraft, orbits, instrument capabilities, and concept of operations to enable the constellation to reach the ultimate goal of finding a transiting Earth analog orbiting a nearby sun-like star, if one exists.

The proposed objectives are to:

1. Develop the Design Reference Mission, evaluate the science return, and derive the detailed science requirements;
2. Perform engineering trades and detailed design work to evolve the ASTERIA pathfinder into a 12U constellation;
3. Validate the design and mission cost via JPL s Team X concurrent design center.