To: *The After Sloan 4 Steering Committee c/o Juna Kollmeier, Chair* *May 2, 2016*

Dear Colleagues,

Last year many of the undersigned authored a white paper on time-domain (TD) applications of the APOGEE spectrograph in the After Sloan 4 (AS4) era. The white paper process led the AS4 Futures Committee to form a Time-Domain Astronomy (TDA) subcommittee, which endorsed TD science as a "compelling" AS4 opportunity. Building on these efforts, we wish to express our intent to propose and fully support an AS4 program entitled **The APOGEE Time-Domain Legacy Survey (ATLaS)**.

ATLaS Summary: The five year ATLaS program builds on the foundation laid by the APOGEE and APOGEE-2 programs for a comprehensive spectroscopic survey of Galactic stars featuring dual-hemisphere, long temporal baseline, multi-epoch, high resolution spectroscopy. A principal objective will be to exploit the APOGEE spectrographs, upgraded to achieve RV precision of tens of m/s, as well as the legacy databases of the APOGEE surveys to create an unparalleled, pan-Galactic survey of stellar companions of both stellar and substellar mass, probing systematically with a "stellar populations" mindset. This scientific objective is furthered by a complementary campaign to capitalize on the APOGEE systems as the most efficient all-sky facilities for critical follow-up spectroscopy to other surveys with exoplanet dimensions, such as *K2*, *TESS*, *PLATO*, *Gaia*, and *LSST*. A third capability to enhance companion host characterization will be diffraction-limited, wide-field, mulit-object speckle imaging using coherent fiber bundles. All three campaigns will allow for parallel targeting for other science applications.

A. Scientific Prospects and Survey Scope

The overarching scientific theme of ATLaS is the exploitation of the unique, wide-field, multi-object targeting capabilities of the Sloan and du Pont Telescopes for characterization of star *systems* across all stellar populations and Galactic environments. We envision this multi-faceted project to consist of several complementary, but independent components:

1. *A Systematic Pan-Galactic Search for Stellar Companions*

Motivation: With just three years of data from DR12, Troup et al. (2016) have demonstrated APOGEE's promise in the search for stellar and substellar companions. APOGEE-1&-2 will leave a legacy of nearly a *decade* of observations to build upon. The addition of a five-year AS4 survey would create *one of the longest baseline RV monitoring programs to date.* Reobservations of a strategic subset of APOGEE-1&2 fields to find long period, higher mass companions, combined with pushing the Troup et al.-like search for short period companions to even lower masses in a greater variety of Galactic environments is a primary focus for ATLaS. The resulting Galactic census of star systems will yield an unparalleled opportunity to explore how the distribution (and thus, formation) of stellar binaries, brown dwarfs, and gas giant exoplanets depends on host chemistry, age, Galactic position and matter and radiation density.

2020 Context: The APOGEE spectrographs will remain unrivaled in efficiency and reach due to their multiplexing capabilities over large FOVs, high resolution and infrared sensitivity. Novel and systematic large-scale probes of stars in the bulge, Galactic satellites (MCs, Sgr, etc.), star clusters spanning all densities, metallicities and ages (including the the most nascent and embedded), as well as field stars across all disk radii and out into the halo ensures that ATLaS will be the most comprehensive and homogenous, pan-Galactic exploration of binary stars, brown dwarfs, and planetary mass stellar companions for the forseeable future.

Allocation and Yield: The optimal targeting distribution remains to be modeled but is anticipated to include (a) revisits to APOGEE-1&-2 fields for which $\sim$12-18 new AS4 visits will yield $\geq$ 24 net visits *for all/most previously established targeting cohorts* in each field (see §B), and (b) high cadence ($\geq$ 24 visit) AS4-only fields probing new and unique Galactic domains. Baselined at $\sim$40-50% of the current yearly APOGEE-2N+2S time allocation, this program would encompass $\sim$90k stars, which, even in 2020, *will be the largest many-epoch spectroscopic sample of its kind.* The most conservative expected detection rate (5%) projects a catalog of $\sim$4500 detected stellar companions (with a huge, robust control sample of non-detections), but instrument improvements (§B) and longer baselines will increase the yield.

2. *Synergy with Planet-Hunting Surveys*

Motivation: A major challenge for planet transit surveys (*Kepler*/*K2*, *COROT*, *TESS*) is the determination of stellar parameters and abundances of the host stars, which is crucial for determining the nature of the transiting object, and to understand planet formation and evolution across a wide range of environments. The large FOVs of the Sloan and duPont telescopes and ideal sensitivity match to target brightness, grant the APOGEE instruments a uniquely efficient and valuable role in tackling this vital but difficult task.

2020 Context: The first run of *TESS* will be complete in 2020. As a low target density, all-sky survey, *TESS* is not well-matched to multiplexed spectroscopy; however, a high density of *TESS* detections are expected in the continuous viewing zones (CVZs) within 12 degrees of the celestial poles. Our dedicated fields for this effort will be concentrated here. The WIYN 3.5m is is the only facility currently foreseen for dedicated TESS support and follow-up. ATLaS would provide further support the northern hemisphere TESS survey and (as of now) would be *the sole follow-up survey in the southern hemisphere.* Combining AS4 observations with detections in the APOGEE Legacy fields will allow us to build robust correlations between companions and the properties of their host stars. There will also be asterosiesmic applications of these observations.

Allocation and Yield: TESS targets are expected to be bright, so the CVZ fields (as well as *Kepler/K2 /COROT* fields) will be slated for 1-3 visits each for stellar characterization to the nominal $S/N > 100$ standard for abundance analysis. In addition, 10% of fibers for the §1 program will be reserved for observing the most interesting non-CVZ *TESS* detections that land in those fields. Depending on whether a South-only, or dual CVZ campaign is undertaken, this program would require 15-25% of the current yearly APOGEE-2 time allocation, and *characterize ∼200-300k stars from these transit surveys.* In addition, the ATLaS team is contemplating use of APOGEE links to the NMSU 1-m and APO 3.5-m for one-at-a-time follow-up of other prime, non-CVZ targets. Because the CVZs are at moderately high Galactic latitudes, this program provides a prime opportunity for co-observing with a MaNGA-like AS4 survey.

3. ***Multi-Object Speckle Interferometry***

Motivation: Another challenge in the followup efforts of companion-search surveys is vetting candidates for false positive scenarios, such as a grazing eclipsing binary or blended background stars. Recently, speckle interferometry has made a resurgence as a way to perform this vetting for bright stars, like those observed by *TESS*, without the need for an AO system.

2020 Context: In keeping with the Sloan tradition of innovating multiplexing technology, the ATLaS team intends to propose a completely novel, multi-object H-band speckle intereferometor, pending further technical investigation (see §B). Primary targets for this effort will be planet-hunting fields to check for false positive scenarios. However, additional scientific uses for such an instrument include simultaneous many-source probing of long-period binarity in star clusters, disentangling blended stars in crowded fields, and statistically sampling known short-period companion hosts to determine the importance of the Kozai mechanism in their formation. The §1 RV program gives us a good grasp of *short period* companions, whereas a speckle survey would allow us to do the same with long period companions. Therefore, this truly unique component of our survey is very complementary to the others.

Allocation and Yield: Given somewhat uncertain throughputs, this program is admittedly less well-developed. We currently estimate that at 5-10% of the yearly APOGEE-2 time allocation (∼300 hours per hemisphere), an instrument with 200 coherent bundles could observe ∼40k stars per hemisphere.

4. ***Community-Driven Time-Domain and Other APOGEE Spectrographic Science***

Motivation: Following SDSS tradition, a fraction of ATLaS would be shaped by community input, exploring science cases beyond companion hunting and follow-up.

2020 Context: APOGEE has established a precedent for discovery and exploration of time-variable spectroscopic phenomena (Eikenberry et al. 2014, Chojnowski et al. 2015), and can contribute to the study of diverse phenomena such as flaring stars, novae, pulsational variables, stars with circumstellar disks, and YSOs. With the start of *LSST*, the continued influx of data from *Kepler-K2*, and the completion of *Gaia*'s primary mission, there will be no shortage of other interesting transient objects to follow up with TD spectroscopy in 2020 using remaining fiber hours, including dedicated plate visits.

Allocation and Yield: We appreciate the value and interest in the APOGEE instruments for a variety of unique applications. The notional ATLaS plan described here is baselined against the current APOGEE-2 yearly time allocation, but, within that, reserves 20-25% of the total fiber-hours for other science, including ∼10% of fibers on scheduled ATLaS plates, as well as 300-500 fully dedicated APOGEE visits.

B. Survey Requirements

Telescope Time: ATLaS is envisioned as a “flagship” umbrella for APOGEE observations, with allocation for other programs as described in §4, and following the dual hemisphere, APOGEE-2 yearly time allocation model. Specifically, this includes all of the available bright time and some gray time (overall a ∼50% share of the total time) on the Sloan 2.5m (∼2400 visits, or 3600 hours). With observations of the bulge, Sgr, MCs, and the *TESS* CVZ around the South Celestial pole as high priorities, the use of the soon-to-be commissioned SDSS/APOGEE facilities at LCO will be essential to the success of ATLaS, but at no more than the current SDSS-IV level (∼75 nights/year). We will also advocate for the continued use of the fiber link between the APOGEE instrument and the NMSU 1m, and the creation of a link to the ARC 3.5m for increased ability to probe high-priority but low sky-density transients.

Instrument and Telescope Upgrades: To ensure the highest yield for this survey, we will propose several upgrades to the APOGEE instruments and Sloan facilities. Our highest priority in this area would be to improve the stability of the APOGEE spectrographs. Through installation of a precision calibration source and other simple modifications, such as decoupling the LN_2 tank from the optical bench in the northern spectrograph, strict fiber management, and deactivation of the dithering mechanisms, we believe the APOGEE spectrographs can achieve RV precision of tens of m/s for under $400k (obviously, the latter modification is contingent on other AS4 program needs). We also will advocate for installation of an H-band optimized spectroscopic corrector, interchangeable with the current corrector, to improve the throughput of the Sloan 2.5m telescope for NIR observations; for $500k this improvement translates to significantly improved efficiency (equivalent to enabling many more fiber-visits). Finally, because our targets span a wide range of magnitudes and are in highly populated fields, we will propose construction of a “fiber switchyard” upgrade to the APOGEE fiber system, as presented by S. Majewski in a white paper submitted to the SDSS-IV MC; this system will allow the instrument to observe up to 700 targets (all cohorts in a typical APOGEE targeting scheme) in a single, nominal-duration APOGEE visit. This multiplexing strategy with manual plates is preferable to a robotic positioner for our purposes. We estimate that this improvement will cost $400k per each cartridge for which fiber switching capability is implemented.

New Instrumentation: The most unique instrument upgrade proposed is the construction of a novel, multi-object H-band speckle interferometer, where short coherent fiber bundles will take the speckle images from the telescope focal plane and place them in a grid on one or more telescope-mounted IR detectors reading out at ∼10 Hz. We believe that appropriate fiber bundles, NIR cameras and macro lenses can be bought off the shelf, which keeps this truly unique instrumentation, including software development, modestly priced (perhaps <$1M). Observing with this instrument would require some schedule flexibility, as speckle imaging is best done under good seeing conditions. For the same reason, we would prioritize building such a system in the south to take advantage of the generally better seeing at LCO compared to APO. In a standard 1.5 hour visit, we believe this instrument could produce quality results for primary stars as faint as $H \sim 12.5$.

The undersigned concur wholeheartedly with the findings of the TDA subcommittee that the SDSS collaboration can remain leaders in innovative, cost-effective, ground-breaking science into the next decade by expanding its efficient multi-object surveys further in the TD dimension. This survey will fulfill this mission not only by building the largest database of objects with high-resolution time-domain spectroscopy ever built and incorporating many Galactic environments previously inaccessible to optical surveys, but will also complement and greatly multiply the impact of all-sky TD photometric surveys such as *TESS* and *LSST*. This survey will also give Sloan the opportunity to bring yet another traditionally single-object observation technique, speckle interferometry, into the era of large-scale multiplexed surveys.

Sincerely, **The ATLaS Team:** Nicholas Troup (UVa*), Steven R. Majewski (UVa*), Carles Badenes (Pitt), Chad Bender (PSU), Joleen Carlberg (NASA GSFC), Yilen Gómez Maqueo Chew (UNAM), Kevin Covey (WWU), Katia Cunha (NOAO), Nathan De Lee (NKU), Scott Fleming (STScI), Fred Hearty (PSU), Elliott Horch (SCSU), Jinyoung Serena Kim (SO), Suvrath Mahadevan (PSU), Robert Mathieu (UWisc), David Nidever (SO), Robert O'Connell (UVa), Joshua Pepper (Lehigh), Marc Pinsonneault (OSU), A. Roman-Lopes (ULS), Carlos Román-Zúñiga (UNAM), Michael Skrutskie (UVa), Verne Smith (NOAO), Jennifer Sobeck (UVa), Guy Stringfellow (CU), Johanna Teske (Carnegie), John Wisniewski (OU), Jason E. Ybarra (Bridgewater) **Primary Contacts*: nwt2de@virginia.edu, srm4n@virginia.edu