Recommendations of the Steering Committee for After-SDSS-IV

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Summary

We recommend that the ARC Board of Governors (BoG) initiate aggressive development, collaboration building, and fundraising for an After Sloan 4 (AS4) program involving 5 years of observations on both the Sloan Foundation Telescope at APO and the Irenee du Pont Telescope at Las Campanas Observatory (LCO). Use of LCO would, of course, be conditional on the concurrence and participation of Carnegie Observatories.

The flagship programs of AS4 would be an All-Sky/Synoptic Spectroscopic Survey (AS^4!) of Milky Way stars and quasars and galaxies. The unprecedented Milky Way star survey, which constitutes the most highly ranked “flagship” program, will vastly expand our knowledge of the distribution of chemical elements across the Galaxy, and will yield powerful insights into the structure and evolution of stars and the properties of exoplanet hosts. The quasar and galaxy survey will probe the physics of black hole accretion over timescales from days to decades, provide the spectroscopic redshifts for the largest ever samples of X-ray selected quasars and galaxy clusters (from the *eROSITA* mission), and create a 3-d galaxy map with the comprehensive sky coverage needed to support studies of the transient universe.

In addition to these flagship surveys, **we recommend further exploration of opportunities for integral field spectroscopy of galaxies** that can be accommodated within the cost, hardware, and observing time constraints of the AS4 program as described below.

The landscape for highly multiplexed wide-field spectroscopy will be much more competitive in the 2020s than it is today, in part because the SDSS has inspired so many other ambitious projects with its example. Nonetheless, the capabilities of the APOGEE spectrographs remain unique, and the combination of the Sloan and du Pont telescopes gives AS4 the unmatched opportunity to cover the whole sky.

To take full advantage of this opportunity and to allow more flexible observing strategies that can accommodate a wide range of targets, **we recommend construction of robotic fiber positioners for each telescope, drawing on designs that have been developed for the Dark Energy Spectroscopic Instrument (DESI).** The fiber robots increase the upfront costs for AS4, but their cost should be at least partly recouped through reduced staffing needs at the observatories during subsequent routine operations. It may prove desirable to continue use of fiber plug plates during the first year of AS4 in case the fiber robots are not ready by 2020 to avoid delayed start of the survey. With the fiber robot, we anticipate that AS4 will adopt 10-15 minute exposures as the baseline time unit for spectroscopy, though some targets may be observed multiple times on different passes. Five years of dark+bright time operation with the fiber robots on two telescopes would enable tens of millions of spectra in total. **We recommend constructing one additional BOSS- or DESI-style optical spectrograph** to be installed at the du Pont telescope, with a fallback plan being to move one of the BOSS spectrographs to the du

Pont to enable optical spectroscopy in the Southern hemisphere. We also **recommend that AS4 consider the possibility to reserve a fraction** (for example, 5-20%) of fiber-visits for assignment by participating institutions, and possibly by the broader community in the event of a large investment by the NSF, as a strategy to raise funding.

This report offers a proposed time allocation among program elements and discusses ways that those elements might operate in concert. However, **we recommend that the AS4 Management Committee, once formed, prepare a detailed plan for an integrated observing program to be presented to an external review committee in June 2017.** The Management Committee will respond to the evaluations of this committee before preparing funding proposals for the integrated AS4 program.

As with previous generations of the SDSS, **we recommend pursuing a hybrid funding model that combines foundation support, government support, and contributions from a large number of participating institutions.**

Process

Letters of Intent were solicited from interested parties in spring of 2016, enabling fruitful exchanges between the Steering Committee (SC) and the proposal teams. SC discussions during this phase, and in response to the Letters of Intent, also led to the ``AS4-**β**" implementation concept, which had significant impact on some of the eventual proposals and on the recommendations here. The description of AS4-**β** is available at http://www.sdss.org/future/. The SC issued a Call for Proposals in August and final proposals were submitted by the September 23rd deadline.

In addition to science program proposals, the SC solicited and received Letters of Intent and a full proposal for AS4 data archiving, including outreach and education activities. We do not address this program in this report, as we are focused here on the new-observations science program.

In parallel with the activities of the SC and the proposal teams, a fiber positioning working group has been investigating technical options for robotic fiber positioners and associated requirements on the optical correctors.

In the end, the SC received 28 Letters of Intent followed by eight science program proposals, listed below. For each of these proposals we requested written reviews from four external reviewers (i.e., not on the SC or the proposal teams). Proposals were reviewed in three groups -- stellar and Galactic astrophysics, quasars/AGN and galaxy clusters, and integral field programs --- with the same reviewers submitting reviews for all proposals in a group. Informed by these reviews, the SC discussed all of these proposals in multiple telecons in the course of preparing this report.

The eight proposals are:

Dynamic Ranger -- high-spatial-resolution integral field spectroscopy of nearby galaxies including M31, M33, and the Magellanic Clouds, with a major investment in new DESI-style optical spectrographs to enable two 4500-fiber integral field units (one in each hemisphere)

4Haloes -- integral field spectroscopy of galactic haloes out to four effective radii, using moderate modifications of the MaNGA integral field system

ReSpeQ -- repeat spectroscopy of quasars, with an intensive campaign of reverberation mapping in 5 fields and longer timescale sampling over wide areas

SPIDERS-II -- a 10,000 deg^2 redshift survey of X-ray sources (principally AGN and quasars) from the eROSITA satellite, and integral field spectroscopy of the cores of the brightest eROSITA clusters

Disco -- a chemical abundance survey of roughly 5 million Milky Way stars, analogous to APOGEE but using shorter exposures of brighter ($H<11$) stars to enable contiguous mapping over the full sky

ATLaS -- A trio of programs aimed at characterizing stellar and sub-stellar multiplicity throughout the Galaxy and enabling novel stellar astrophysics tests, with multi-epoch spectroscopy of APOGEE wide binaries as the largest core program

Galactic Star Formation -- A multi-epoch spectroscopic survey of star forming regions and young stars, particularly in young open clusters

Stellar Astrophysics 2020-- An umbrella proposal describing multiple programs, already including the topics of ATLaS and Galactic Star Formation, and further aimed at a variety of topics in stellar astrophysics, with spectroscopy of binary and/or asteroseismic targets of all masses, as well as planetary transit hosts from the future *TESS* and *PLATO* missions as a major component.

Broadly speaking, our recommended stellar/Galactic program consists of Disco and portions of the Stellar Astrophysics and ATLaS proposals, and with possible incorporation of elements of the Galactic star formation proposal. Taken together this makes for a transformational spectral survey to understand the physics of stars and of chemodynamical evolution in our Galaxy. Our recommended extragalactic program consists of elements of ReSpeQ and SPIDERS-II, and the possible addition of a galaxy redshift survey to $r \sim 16.5$-17 in regions of the sky not previously surveyed to this depth. We have not incorporated either the Dynamic Ranger or 4Haloes programs for reasons discussed below, but we recommend further exploration of options for integral field programs over the next six months.

As indicated in the call for proposals, **we recommend that PIs of the AS4 programs be selected through an open application process** (see “Next Steps”' below). This process should result in the minimal number of PIs required to achieve the programs, but no more. Our reading of the programs indicates this will likely involve consolidation into two or three unified programs.

There are many issues in interleaving and optimizing these programs that require a more fully specified hardware concept and investigations at a level of detail beyond what could be carried out thus far. We therefore focus our recommendations on broad time allocations and priorities, recognizing that detailed program formulation is the next step.

Time Allocation

We recommend adopting a five-year program as baseline, with the possibility that the first year may operate with a plug-plate system in the event of schedule delay for the fiber robot. Four years would be a minimal fallback. Six years would be a stretch goal if fundraising is sufficiently successful and an additional year of observations is determined to be higher priority than infrastructure investments.

We anticipate that the main AS4 observing strategy will divide into three tiers: referred to briefly as "disk", "deep", and "full-sky".

Disk: Low-latitude observations, covering the roughly 3000 square degrees at low Galactic latitudes where most of the stars in our Galaxy are, using the APOGEE spectrographs, primarily during bright time, aimed at Galactic evolution and stellar astrophysics science.

We recommend that 45% of the telescope time at both APO and LCO, tilted toward brighter lunation, be devoted to these low-latitude observations to achieve the science goals within the Disco (primary) and Stellar Astrophysics/ATLaS (secondary) proposals. With 10-15 minute exposures, this would enable at least 7M fiber-visits, including calibration targets. We anticipate about 36 visits to each sky location in this area, but the AS4 team may opt to spread the time heterogeneously. The primary science goal will be a sample of ~5M H<11 stars to sample the chemical and dynamical state of the Galactic disk. Secondary goals include time-domain studies of stars, stacked deeper exposures on fainter stars, other rare low-latitude target classes, and low-latitude variables and transient targets of opportunity.

Deep High-Latitude: **We recommend AS4 undertake observations of roughly 2000 square degrees in regions of moderate-to-low extinction, using the APOGEE and BOSS spectrographs, combining Galactic evolution, stellar astrophysics, and extragalactic science goals.** AS4 could provide an average of 6-hour depth in this region, broken into

10-15-minute exposures. Our expectation is that such a program would be dark time where possible and receive approximately 25% of the telescope time at APO and approximately 10% at LCO. The primary science goals are Galactic time-domain work, stellar astrophysics, X-ray clusters and AGN, and time-resolved spectroscopy of quasars. The choice of fields, distribution of visits, and split of target classes will be determined by the AS4 collaboration, but we note the compelling interest of the K2 and TESS CVZ regions for stellar and exoplanetary work, the eROSITA deep region for X-ray targets, and the LSST deep-drilling fields (of potential interest to reverberation mapping to measure black hole masses) for higher cadence photometric sampling, perhaps contemporaneous with AS4 spectroscopic sampling.

Full-sky: **We recommend AS4 undertake a survey of most of the sky, comprised of two 15-minute visits from APO and one from LCO.** This program could be achieved with 30% of the telescope time from APO and 15% from LCO, using dark time where possible. The primary science goals are an abundance survey of the most interesting *TESS* stars, wide-field Galactic abundances and dynamics, and coverage of optically brighter X-ray targets and other rare targets and long time-scale QSO variation.

In terms of allocation priorities, we give highest priority to the Galactic Archaeology and Chemical Evolution program (Disco) along with the Stellar Astrophysics/ATLaS bright-time programs that are integrated. In dark time, we envision the QSO/Galaxy program operating, with a larger fraction of the fibers to extragalactic programs and a smaller, but important, fraction going to the Milky Way and its stars program.

The reverberation mapping program of ReSpeQ would operate in a different mode, likely using all of the available fibers in long exposures of a few fields visited repeatedly, and the number of exposure hours above will be reduced by the fraction of time devoted to this program.

For purposes of recommending time allocation, it is sensible to work in terms of fiber-hours. Most Disco targets require exposure times of only 8-10 minutes, so a field devoted entirely to Disco could observe as many as 1800 targets (including calibration targets) in 300 fiber-hours. For a more complex example, a one-hour observation of a high-latitude field might devote 200 fibers to 8-minute exposures of 1200 Disco targets and 100 fibers to 60-minute exposures of 100 quasar targets; this would be accounted as 200 fiber-hours for Disco and 100 fiber-hours for the quasar program. We specifically recommend fractional allocations of fiber-hours so that the recommendations do not depend on the duration of the survey or the outcome of weather.

We distinguish Northern Bright (NB), Northern Dark+Grey (ND), Southern Bright (SB), and Southern Dark+Grey (SD) time. Assuming clear weather fractions of 0.45, 0.50, 0.55, and 0.60 in these four categories, respectively, 300 fibers available per field, 100% of APO and 70% of LCO we estimate a total of 1.0 million, 1.3 million, 0.8 million, and 1.1 million fiber-hours in these four categories over the course of a five-year program. Some fraction of these fiber-hours would go to calibration targets, depending on program needs.

The SC came to a general prioritization of the Stellar Astrophysics, ATLaS, and Galactic Star Formation proposals, giving priority to those stellar programs that are most synergistic with the overall scientific questions addressed Galactic chemical evolution survey, corresponding approximately to Disco. In particular, a focus on how chemical enrichment due to single, binary, and multiple star evolution is intertwined with the dynamical evolution of the Milky Way to shape its structure and evolution was considered timely and highly complementary to the goals of Disco. We leave the detailed breakdown among stellar astrophysics to the future AS4 MC, but we give high priority to observing a large fraction of the Kepler/K2, TESS, and PLATO stars for which BOSS and/or APOGEE can obtain scientifically useful spectra. With this in mind, we recommend unifying the additional stellar programs to the extent possible into coherently targeted sets of stars, with roughly 20%, 5%, 20%, and 10% (NB, ND, SB, SD) allocation of time in addition to the 75%, 5%, 75%, and 15% for Disco.

This allocation profile is a reduction of the ATLaS-1 program focusing on multi-epoch spectroscopy of 100,000 stars previously observed in APOGEE. Owing to the exposure-expensive multi-epoch requirement at the APOGEE-I/II survey magnitude limit (~1 hour exposures to yield precise velocities), the SC recommends targeting a smaller, but scientifically interesting, sample of such long-orbit low-mass systems with a focus on the brighter stars within this class. Specifically, we recommend that the ATLaS-1 component be allocated at least 10% but not more than 25-30% of the fiber-hours of the overall stellar astrophysics program. We recommend that 5-10% of the stellar astrophysics program be devoted to young stars and star-forming regions along the lines described in the Galactic Star Formation proposal, but the specifics of these observations should be planned after the hardware complement and observing strategies for other aspects of Disco and stellar astrophysics have been more fully defined.

For quasars and galaxy clusters we recommend allocations of roughly half of the dark time (ND+SD), divided equally between the ReSpeQ and SPIDERS-II programs, with SPIDERS-II a focus in the Southern Hemisphere and ReSpeQ a focus in the Northern hemisphere.

We have deliberately kept the recommended observing allocations below 100% for three reasons, all of them needing further exploration.

First, we recommend that the AS4 Management Committee and Steering Committee evaluate the benefits and costs of reserving a small fraction of fiber visits for flexible assignment. For further discussion, see “Reserved Fiber Plan” below.

Second, we recommend that the AS4 Management Committee, once formed, consider the potential of an “all-sky galaxy redshift survey”, using up to 5% of SD and ND time. The goal of this project would be to create, *in combination with existing or contemporaneous surveys*, a redshift survey of galaxies complete to a magnitude limit r ~ 16.5-17 over all regions of the sky not severely affected by extinction and/or stellar confusion. The magnitude limit would be chosen so that a single visit in the full-sky tier would yield high redshift completeness. Galaxies that already have redshifts from the SDSS or other surveys (e.g., 2dFGRS, GAMA, DESI, Taipan) will not be observed, so the effective sky area to be observed is much less than 4π sr, especially in the North. For further discussion, see “Rationale” below.

Third, we anticipate that if the Dynamic Ranger hardware is not built, AS4 will still incorporate an integral field spectroscopy program using fiber bundles integrated with the fiber robot. While this program would be carried out mainly in parallel with other dark time programs, we recommend reserving a substantial fraction (roughly 10%) of the dark time in each hemisphere for an integral field spectroscopy program to “control the telescope”,' with other programs using other fibers operating in parallel if they can do so effectively.

Finally, if the Dynamic Ranger hardware is built, we anticipate that all of this reserved dark time (approximately 30%) will be given to Dynamic Ranger observations on the 2.5-meter telescopes, in lieu of the reserved fiber, all-sky galaxy redshift survey, and separate IFU program.

All of these numbers are necessarily mere starting points. As detailed planning of AS4 proceeds, the Management Committee and Steering Committee may recommend alterations or refinements to achieve the optimal observing program in line with the prioritized topics. The MC should prepare detailed recommendations for the June 2017 external review (see "Next Steps") and consider modifications in response to that review prior to writing funding proposals.

Rationale

The Galactic chemical evolution envisioned in the Disco proposal makes extremely good use of the unique capabilities of the existing SDSS hardware with the augmentation of a fiber robot, namely the access to both hemispheres, the APOGEE spectrographs and analysis software, and a combination of field-of-view and rapid reconfiguration that makes it feasible to observe bright targets over the entire sky. The science area is one that is advancing dramatically, thanks especially to APOGEE, GALAH, and *Gaia*, and to other large spectroscopic surveys including SEGUE, RAVE, and LAMOST. The ability to obtain high resolution spectroscopy of 5 million stars with contiguous coverage of the entire sky including regions of high optical extinction promises to make Disco the single most powerful program in this high profile field in the 2020 time frame.

APOGEE observations, especially in combination with asteroseismic data from the *Kepler* and *CoRoT* missions, have opened many new opportunities to test the theory of stellar structure evolution and reveal new physics of stellar interiors. AS4 can make enormous strides in this field by observing, in addition to Disco targets, roughly one million targets chosen specifically for their ability to advance understanding of stellar physics and exoplanetary companions. The highest priority in this area is to observe stars with asteroseismic, binary, and/or planetary transit measurements from *Kepler*, *K2*, *TESS* (scheduled for launch at the end of 2017), and *PLATO* (scheduled for launch in 2025). *Gaia* astrometry also offers a powerful means of selecting interesting targets, including binary systems and white dwarfs. For some targets, optical spectroscopy with the BOSS spectrographs will be desirable in addition to or instead of near-IR spectroscopy with APOGEE. Although there will be many spectroscopic follow-up programs for *TESS* and *PLATO*, the ability of AS4 to cover a large fraction of all stars from these missions in a homogeneous way will be unique. For exoplanet science, precise stellar parameters and abundances of transit hosts *and* matched control samples are needed to infer the parameters of transiting planets and to investigate correlations between the composition of stars and their planetary systems. We therefore view this program as an opportunity to attract scientists and institutions with strong interest in exoplanets, and possibly as an avenue to seek funding from NASA or ESA member states, as well as other countries.

ATLaS also proposes building multi-object fiber-fed speckle interferometers and using them for H-band companion searches during times of exceptional seeing. This is a clever idea, and it would allow speckle imaging of large numbers of target stars over the course of AS4. However, the SC views this program as low priority compared to other aspects of ATLaS specifically and AS4 generally, in part because we consider it crucial to focus on fundraising and infrastructure development for the core spectroscopic programs, and in part because an AS4 speckle imaging program would face stiff competition from other facilities specialized for direct imaging.

Even after two decades of extragalactic optical spectroscopy from the Sloan Foundation telescope, the wide field capability and efficiency of the SDSS systems enable powerful new extragalactic programs. The recommended programs exploit these capabilities to (1) undertake time-domain spectroscopy of quasars and AGN going well beyond the programs incorporated in SDSS-III and IV, and (2) achieve comprehensive spectroscopic follow-up of the eROSITA X-ray mission, which improves on the best existing all-sky X-ray survey (*ROSAT*) by 1-2 orders of magnitude. The reverberation mapping and long-term monitoring elements of ReSpeQ will allow systematic investigation of black hole accretion phenomena that have been largely anecdotal until now. The SPIDERS-II program is expected to provide follow-up for redshifts of hundreds of thousands of X-ray selected AGN and thousands of X-ray selected galaxy clusters.

Galaxy Survey

In an era where synoptic imaging surveys (ASAS-SN, ZTF, LSST) and novel astrophysical messenger searches (Auger, IceCube, gamma-ray and gravitational wave experiments) are covering the full sky, an exhaustive redshift map of the local universe becomes increasingly valuable. By filling in areas not previously surveyed, we anticipate that AS4 could complete an all-sky map to a limit roughly one magnitude shallower than the SDSS main galaxy redshift survey while using only a small fraction of available fiber-visits. Such a survey would have significant legacy value, and **we recommend that this possibility be further assessed by the AS4 Management Committee.** The Taipan galaxy survey is expected to cover much of the Southern sky to approximately this limit, and the DESI Bright Galaxy Survey will go much deeper over 14,000 deg^2 (including the SDSS footprint). Thus, the need for, but also the cost of, such a survey may be limited.

Time Domain Targets of Opportunity

We note that the flexibility of a robot can allow a substantial survey of bright time-domain targets of opportunity. Having defined many hundreds of possible tiles that could be observed on a given night, the choice of the few dozen tiles to actually observe could be steered by the availability of bright transients, e.g., from LSST, ZTF, ASAS-SN, or others. Target densities of order 1 per few hundred square degrees would be enough to feed such a program. While AS4 exposure times are short, this could yield tens of thousands of spectra during the program, including many at low galactic latitude.

IFU Science

The most difficult decision for the SC has been the recommendation regarding Dynamic Ranger, designed to achieve 10-50 pc resolution integral field spectroscopy of nearby galaxies. At full scope, Dynamic Ranger is extremely ambitious, building 14 new DESI-style spectrographs and two 4500-fiber IFUs to achieve transformative new capabilities in integral field spectroscopy in both hemispheres. To probe a variety of angular scales, Dynamic Ranger would use the APO and LCO 2.5-meter telescopes, the NMSU 1-meter telescope, and newly constructed 0.16-meter and 0.25-meter telescopes in each hemisphere. The proposal presented a descoped option, which would still represent a substantial advance over any other facility for moderate resolution integral field spectroscopy over large solid angles.

External reviewers and the SC rate the scientific promise of the Dynamic Ranger program as very high and well matched to the complementary information at similar angular scales from ALMA and the VLA. However, the estimated hardware cost of Dynamic Ranger is approximately \$18 million at full scope and \$8 million at reduced scope (six spectrographs), which excludes the costs of labor (estimated at approximately 55 FTE-years), survey software development, and operations. Early commitment of funds would be needed to enable hardware construction. The SC was unable to determine a clear pathway for funding this program in the baseline program while fulfilling the requirement that the full-sky spectroscopy surveys would not be placed at existential risk. **The SC is thus not recommending that the Dynamic Ranger be incorporated in the AS4 baseline program. Instead the SC is recommending that the Dynamic Ranger leadership, in consultation with the AS4 management team, continue to work over a well-defined period of time to explore funding and development possibilities and identify potential funding sources to achieve a compelling program to incorporate into AS4 while not elevating the risk to the rest of the AS4 program** (see “Next Steps’’ below).

MaNGA is a pillar of SDSS-IV, and the SC believes that AS4 should build on its success, with a galaxy IFU program in addition to the cluster IFU program proposed for SPIDERS-II.
We are not convinced that 4Haloes is the right program, in part because of technical and scientific questions raised in the external reviews, but also because it requires a large investment of dark time in an observing mode that is incompatible (because of very long exposure times) with the wide area surveys. **We recommend that further investigation of potential IFU programs at the 200-1000 fiber level proceed in parallel with the further consideration of Dynamic Ranger over the next six months.** This may involve moderate hardware modifications and can operate largely in parallel with AS4 programs that use the high multiplex fiber system. For example, a large (e.g., 300-1000 fiber) IFU at a fixed field position could observe during multiple reconfigurations of other fibers. As noted above, **we recommend that a suitable fraction of dark time be reserved for an IFU program to control observing strategy, with multi-fiber programs observing in parallel if they can make good use of the time.**

Hardware Recommendations and Priorities

To implement the proposed science program, the highest priority hardware investment is two robotic fiber positioners, one each for APO and LCO. There are a number of choices to be further investigated here, but we envision building on the zonal design done for DESI, with (at least) 300 actuators, each able to feed either an APOGEE or a BOSS spectrograph. This concept is described more fully in the AS4-**β** document, and several of the proposals; most notably Disco and SPIDERS-II, adopted it as a baseline capability. We anticipate that the fiber robot would also include some integral field capability, perhaps with a single large fiber bundle at a fixed field position and perhaps with numerous smaller IFUs on “fishing poles”. Total hardware cost is expected to be ~$2M per robot not including labor which is currently budgeted at 27 FTE years.

As part of the Fiber committee, a report was commissioned on potential upgrades to the 2.5m corrector. This corrector upgrade is likely required for a robotic upgrade of the SDSS telescope. There are several options here and the most favorable option depends on the ultimate survey hardware. Cost of the new corrector is not well understood at this time, but it is expected to cost on order of $2 - $3M based on early designs from JHU.

Expanding spectroscopic surveys to full-sky scope, a unique competitive edge in the 2020’s, requires the capability to take short exposures, roughly 10-15 minutes including overhead. An alternative to the robotic fiber positioner is to expand the gang-connector system for connecting fibers to spectrographs so that a plate can be plugged with, say, 1500 fibers, which are switched to feed the APOGEE spectrographs 300 at a time by changing connectors rather than changing cartridges. This idea has been worked out in some detail in the ATLaS and Stellar Astrophysics proposals, where it is described as ``AS4-ε.'' We prefer the fiber-robot solution because it adds flexibility and leaves both telescopes in a better position post-AS4. In addition, over the life of the survey we expect the up-front cost of the fiber robot to be approximately recovered through lower operations costs. However, the upgraded plug plate method is a *desirable fallback* if the early funding needed for the fiber robot cannot be obtained.

We recommend that a fraction of the fiber robot development effort be devoted to developing integral field capability integrated with the fiber robots. The appropriate level of investment depends on what decisions are reached with respect to Dynamic Ranger.

The next highest priority is a new optical spectrograph, modeled on either the BOSS or DESI spectrographs, to enable high-multiplex optical spectroscopy from LCO. The fallback here is to move one of the existing BOSS spectrographs from APO to LCO. Further analysis will be needed to decide whether the benefits of such a move would outweigh the cost and risk.

Further investments in integral field capabilities could be warranted once funding for a 5-year program is fully in place.

Reserved Exposures

The fiber robots and full-sky coverage open the possibility of integrating new spectroscopic targets during the life of the survey much more flexibly than with plug-plates. Depending on the details of the exposure time and survey duration, there may exist a substantial number (*although still a relatively small fraction*) of fiber visits that AS4 wishes to allocate in a substantially different manner than has been done previously. Historically, these would be allocated through a call for "Ancillary Science Proposals" and vetted by the collaboration.

Given the flexibility the robot offers, however, it may be a substantial attraction for potential partners and/or national funding agencies if 10-20% of fiber-visits are reserved to be observed in the course of, and *without impacting*, the ongoing surveys. With roughly tens of millions of fiber-exposures over the course of AS4, 10% of the fiber-visits would correspond to a large number of potential exposures per institution. These reserve fibers, if they are indeed included in the AS4 observing plan, may be allocated in a number of different ways, each of which will require careful consideration by the MC.

We suggest that several options be considered regarding how to assign such reserve fibers. Considerations should not be limited to these options. In addition, AS4 may choose ultimately not to have reserve fibers at all.

MSIP-like Option: In a proposal to the NSF MSIP program, offering community access to 10% of fiber-visits could be a very attractive incentive. We anticipate that these would be allocated by NOAO through a proposal process analogous to awards of observing time through the TSIP program. While NSF MSIP is the most obvious avenue for offering community access in exchange for a large investment, there may be other opportunities to consider, potentially through NASA or other funding agencies.

Full-Member Incentive Option: The AS4 MC may find that it is a significant incentive for full institutional participation to distribute reserved fibers for allocation by member institutions. This option may prove an attractive mechanism for funding the survey and be an exciting opportunity for institutions that would not otherwise join the survey. We note that such an option potentially brings difficulties with software scheduling and prioritization. Alternately, some members may opt to pay "above and beyond" the nominal institutional buy-in for the right to allocate these fibers.

There are numerous important details about procedures for data access and publication policy that will require careful consideration. We have not attempted to address these here. This option is only feasible with the flexibility afforded by robotic fiber placement. We do not regard it as worthwhile to pursue this idea with a plug-plate system.

Next Steps

Our recommendations, if adopted by the ARC Board of Governors, imply a sequence of near-term steps.

1. Notify the Carnegie Observatories Director of ARC's interest in pursuing an AS4 program that involves LCO.

2. Allocate a budget for CY2017. We suggest allocating funds to be spent at the discretion of the AS4 Director including summer salary and travel of the Director in CY2017.

3. Finalize and disseminate these recommendations via the SDSS-IV mailing lists and futures web site.

4. Authorize a search committee to solicit applications for the position of Director, review applications, and recommend a candidate to the BoG for ratification. Simultaneous with this, the SC will refine this document and produce a final report.

5. Once approved, the Director would become an *ex officio* member of the SC. Working with the SC, he or she would solicit applications for other key positions of the AS4 Management Committee (MC), for example Project Scientist, Program Manager, Survey PIs, and Lead Engineer.

6. Fill these positions, thus forming the MC.

The MC takes responsibility for further design and trade assessments, and for writing proposals. The SC would continue in operation to provide a sounding board for the Director, work with the

MC to develop a fundraising strategy, and build the collaboration. Reaching agreement with Carnegie Observatories on a plan and scope for using LCO is a crucial early step on this path.

In the initial stages, we recommend formulating AS4 as two unified programs, one on stellar astrophysics and Galactic structure and one on quasars, AGN, and galaxies. Each of these two programs would have a single PI (or, at most, a team of two co-PIs). Scientific organization of the multiple sub-programs would occur within these two broader teams. It may eventually be desirable to establish a third PI-level program centered on IFU observations.

7. Further investigate options for integral field programs, ranging from full scope Dynamic Ranger to modifications of the existing MaNGA IFU system. The Director and MC will work with the Dynamic Ranger (DR) team to develop

- (a) concrete options for reduced scope or staged implementation of fully scoped DR
- (b) differential budget estimates for AS4 with and without DR, at full scope and at the reduced scope levels defined in (a), including all costs (operations, software, etc.)
- (c) fund-raising plans for AS4 under different scenarios.

By June 15, 2017, the Director will present the results of these investigations to the BoG along with his or her recommendations. The BoG will then decide whether to incorporate DR into AS4.

8. Continue work to define the scope, cost, and schedule of the fiber robots. This may include the start of design work or prototyping required for modest modifications of the DESI design to a larger patrol region. This work also should determine the need for new corrector optics. The construction of the robot and any new large optics must proceed expeditiously if it is to be ready by 2020, and a firm design is a prerequisite to a compelling funding proposal for this construction.

9. The MC should aim to meet the following goals by June 2017 for presentation to an external review committee

- Firm up science plan and allocations beyond sketch provided here
- Write out and vet a budget for the survey
- Create a funding plan
- Create an institutional collaboration structure

Data Management and Archive

In parallel to our process for evaluating possible AS4 science programs, a separate call was made for the SDSS Legacy. This call pertains specifically to the long-term data archive and management as well as education and public outreach. The SC received a single comprehensive proposal for this activity. At the writing of this document this proposal is still under review. The SC recommends a separate report for moving forward on this proposal pending the outcome of the review process,