AS4 Beta Operations Concept

The LOIs submitted to the AS4 SC describe an impressively diverse and exciting range of science programs, often making different assumptions about the hardware capabilities and operations modes that will be available to AS4. After reviewing these LOIs, the SC has decided to propose a concrete potential implementation of AS4, which we refer to here as "AS4 Beta," to help shape the next round of science proposals and review.

We emphasize that AS4 Beta is *not* intended as a final program, nor does it preclude other concepts from continuing consideration, including concepts that require more ambitious or differently ambitious hardware development.

Our beta concept includes two paths of hardware development that may enable well-justified science programs. The first path is the development of a rapidly repositioning fiber robot which can feed APOGEE and optical spectrographs at both the Sloan Foundation Telescope and the du Pont Telescope. The second path is the inclusion of an integral field unit (IFU) system, whose scale could range from a single roughly 400-fiber IFU, to a much larger set of fibers fed by multiple telescopes. Either path could create a uniquely powerful facility in the 2020-2025 time scale. Both path require substantial hardware development, though the first tier is the lesser cost. They are not necessarily mutually incompatible hardware systems, but important trade-offs exist between how each system is used.

The AS4 Beta fiber robot is a fairly well defined hardware concept, consisting of a 300 robot positioners, each with an optical and IR fiber. The science program has multiple tiers in area and depth, ranging from deep drilling fields visited 120 times to 4-visit coverage of the full sky (with 8-minute exposures per visit and co-addition to gain depth as desired). We have adopted a nominal time breakdown for these tiers, but the actual breakdown ultimately adopted will depend on how compelling the science case is for each tier. This program could enable many (not all) of the science programs proposed in the LOIs to be carried out, while taking full advantage of "feeder" surveys such as Kepler, Gaia, ZTF, TESS, and LSST. By taking advantage of existing strengths of the SDSS -- wide-field telescopes in both hemispheres equipped with highly multiplexed infrared and optical spectrographs and a collaboration culture that can effectively execute and exploit powerful surveys aimed at multiple science goals -- the AS4 Beta platform would enable an exciting science program that is competitive with and complementary to those from other facilities anticipated in the 2020s.

The AS4 Beta IFU hardware and its science program is less well defined in scope. The minimal hardware variant would include a single IFU feeding one BOSS spectrograph at APO. The maximal hardware variant would include 14 DESI spectrographs, with about 5000 fibers at each of APO and LCO, fed by multiple telescopes. The cost of the maximal variant is likely to be of order $20M extra, but we do not know that number with fidelity. The minimal science program would involve co-observing with the robot positioner where its program happens to cover nearby

galaxies. The maximal science program would occupy 50% of the dark time on one or both telescopes. The larger science programs would effectively reduce the all sky tier of the AS4 Beta robot positioner program. We note here that, among the LOIs, there were few that relied on any IFU concept; pursuing the IFU through major hardware development will require greater specificity regarding the science cases that require them.

We request that each science team respond to the following questions before July 15:

(a) Whether your science program could be accomplished within this AS4 Beta framework. If so:
(b) Which tiers you would expect to use, with which spectrograph (optical or IR), with what target densities and trade-off between sampling and multiple observations for depth and/or time-domain information.
(c) What changes to the implementation concept, from moderate changes of observing strategy to significant changes of hardware, would make your program significantly stronger.
(d) How elimination or factor-of-two reduction of the all-sky tier would affect your science program.
(e) How the presence or absence of a *dedicated* IFU program rather than one that co-observes with the robot positioner would affect your science case.

Any other feedback on the concept is also welcome. Please contact us if you want clarification about any of this before July 15!

The SC is developing a Call for Proposals which will be issued in July, with proposals due in September. This intermediate request for information is meant partly to communicate the current state of our thinking, and partly to evaluate how best to frame that Call.

HARDWARE:

AS4 Beta has a Fiber Robot with 300 patrol regions over the full 3 degree field of the Sloan Foundation Telescope, and over the 1.9 degree field of the du Pont Telescope.

At the Sloan Foundation Telescope, each patrol region is equipped with a single APOGEE fiber feeding the APOGEE spectrograph and a single BOSS fiber feeding one of the BOSS spectrographs. It also has a large, roughly 400-fiber (55 arcsec diameter) IFU at the center of the system feeding the second BOSS spectrograph to allow the simultaneous mapping of nearby galaxies or other extended objects.

At the du Pont Telescope, each patrol region is equipped with a single APOGEE fiber feeding the APOGEE South spectrograph and a single BOSS fiber feeding a BOSS-like optical spectrograph. One or more fibers intended for external instruments could also be included in the focal plane, likely as fixed positions.

For the Sloan Foundation Telescope, the notion is that the tiling positions of fields would be nudged to place an interesting object (such as a UGC galaxy) at the field center for the IFU. We are studying whether placing the IFU off-center would (with field rotation) increase flexibility for IFU targeting while maintaining acceptable wide-field tiling patterns. We note that target densities of order 0.05-0.5 per square degree for IFU objects would probably be needed if one is to produce mostly filled sky coverage while doing simultaneous IFU and wide-field observations.

For fixed fibers on the du Pont Telescope, a specific example matching LOI science would be to run one or more fibers to an optical echelle, which would allow us to take tens of thousands of stellar spectra during bright time while simultaneously observing with APOGEE.

In the above description, the IFU mode is minimal. The more ambitious IFU programs could include: building more spectrographs to support a larger number of fibers; an independent but compatible positioning system for a small number (~ 5-10) of IFUs; an interchangeable but not compatible positioning system for the IFUs (possibly including plug-plates); fiber systems for the smaller and larger telescopes at APO to feed the spectrographs. In the AS4 Beta concept, we have assumed as a starting point that if the IFU system is run independently of the single-fiber robot, it would be devoted at the 50% level for the 2.5-m dark time at APO.

OBSERVING MODES:

The observing base-unit consists of short 8-minute exposures. Overhead between exposures for slewing and reconfiguration is typically 2 minutes for short slews, setting a fundamental “tile unit” of 10 minutes per pointing. The idea behind a short base-unit exposure is that one can always co-add to build SNR, and the shortest unit that is not limited by overhead or read-noise allows maximum flexibility in (a) accommodating bright targets, (b) obtaining time-domain information, and (c) shaping the tradeoff between number of targets and SNR per target.

Each telescope would observe in several tiers. The estimate of number of visits per tier below is based on 6 years of observations from each telescope, in bright time and dark time, with reasonable assumptions about weather. The observing strategy need not be the same in all years -- for example, one could concentrate some or all of a particular tier in time so as to sample shorter time intervals.

Tiers:

1. All Sky
Full sphere with roughly 4 visits per field -- 8 per field in the 10k square degs of N+S overlap

2. Medium Area

Roughly 24 visits over 4500 square degs, for example K2 fields and the TESS continuous viewing zone. Some flexibility in breakdown between dark/bright and APO/LCO.

3. Low-latitude Disk
Roughly 36 visits over 3000 square degrees, assumed to be bright time observations with APOGEE.

4. Deep Drill/High Cadence
Approximately 120 visits over 100 square degrees. This corresponds to 4 visits/month for 5 months/year, though it could be concentrated to get higher cadence over a shorter time interval.

Further details are on the accompanying spreadsheet created by Daniel Eisenstein.
The numbers above are based on allocating roughly 45/15/35/0 percent of available bright time and 55/20/0/7 percent of available dark time to modes 1-4, respectively (see spreadsheet for APO/LCO breakdown), with some time left over to accommodate ancillary programs.
The actual time breakdown would be based on maximizing the combined strength of the science programs.

If a dedicated IFU observing program took 50% of the dark time, the program above could be adjusted by eliminating the All Sky tier, replacing it by a Galactic Plane survey of the same cadence and depth but limited to $|b| < 15$ deg. Other trades are available within the dark time available.

VARIATIONS:

There are many possible variations on this program, and science teams are welcome to identify variations that would benefit their science.

AS4 Beta assumes a zonal fiber positioner (where each fiber has a defined patrol region), rather than plug-plates or pick-and-place, to allow rapid reconfiguration. It assumes that both BOSS spectrographs remain at APO and at least one new optical spectrograph is built for LCO; this could be a clone of a BOSS spectrograph, or it could be built to different specifications. A lower cost option would be to move one of the BOSS spectrographs to LCO, though this might preclude simultaneous IFU/optical-multi-fiber observations.

As noted above there are a variety of possible modifications to the IFU concept. These include using an entirely different system (e.g., plug-plates) for IFU observations and allowing one instrument change per night between the zonal robotic positioner and the IFU system. It might be possible to accommodate multiple (e.g., 6) independently positioned IFUs alongside 300 patrol-region fiber pairs in the same robotic hardware system.

The SC deems that the AS4 Beta concept proposed here has sufficient odds of addressing enough of the science cases raised in the LOIs that we want the LOI teams to evaluate the concept in detail.

However, at this point we are not ruling out other proposals that came in through the LOIs or that may await at the proposal stage. We encourage interested parties to persue those LOIs and contact the authors if there is strong interest or possible synergies between them that the SC has not identified.