Science Case for a ~300 fiber connection from the APO 3.5m to the SDSS spectrographs

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Below, I outline of several science cases for a ~300 fiber connection from the APO 3.5 m telescope to the APOGEE spectrograph. Additional capability would be enabled by the addition of a visual-wavelength fiber bundle that could be coupled to either existing SDSS visual spectrographs, or a future replacement for DIS.

Some general comments about the options presented on the wiki as a result of the 14 Jan 15 telecon. I'm much less enthusiastic about the 30 fiber option to the echelle focal plane (NA1 port) than about the more ambitious "original proposal". The multiplex advantage grows directly with the number of fibers. The full 300 fiber compliment at the NA2 port would open-up many novel science opportunities, making the 3.5 meter / APOGEE combination a unique world-class facility. To my knowledge, the most ambitions IFU facility today is MUSE on the VLT which delivers R ~ 3,000 over a square-arcminute field, sampled at 0.2". R ~20,000+ with APOGEE would be a new regime in resolution, and by matching the APO's ~1" seeing, could cover a comparable or larger FOV. For most science I envision, the IFU does not have to be closely packed. Micro-step dithers can be used to fill-in a hexagonal, sparse array.

Utility of a fiber-bundle feed to APOGEE:

The following parameters are assumed for APOGEE:
R=22,500 from 1.51 - 1.70 um. 300 2 arc-second diameter fibers (good match to seeing – would require matching optics), 15% throughput, S/N = 100/pix for H > 12.2 in t = 3 hrs radial velocity to 100 m/sec (~1% of the spectral resolution by template spectrum fitting).

I assume that the fiber bundle can be coupled to the NA2 port and used with the image rotator.

I imagine three types of focal plane coupling:
A Dense pack integral field unit (IFU).
A "plug-plate enabling random targeting of objects in an 8' FOV at the NA2 port.
A linear-array of fiber feeds resembling a long-slit.

In each of these focal-plane coupling schema, matching of the f/10 beam to the fibers can be achieved with micro-lenses attached to the fiber ends, or possibly with a large re-imaging focal reducer. I suspect that micro-lenses might be much less expensive, and could be fabricated with relatively low required precision (possibly molded from plastic) since they are located in, or very close to, the focal plane, and the APOGEE bandpass is relatively small.

Key Science Areas: Galactic Science

Nearby Galactic star and star cluster formation: T Tauri and Herbig Ae/Be stellar classification, multiplicity, variability, and radial velocity determination. Jet and outflow kinematics, Nebular kinematics.

Tens of thousands of young (< 10 Myr) stars are located within the forming star clusters and OB associations located within a few kpc of the Sun. Most form in compact, sub-parsec, groups and dozens to hundreds of potential targets can fit within the FOV of the 3.5 meter NA2 port. Examples include the Orion Nebula Cluster (ONC), NGC 1977, OMC2, OMC3, L1651N clusters in Orion A, the NGC 1333 and IC 348 clusters in Perseus. These groups contain between 100 and 1,000 stars, dozens of [FeII] bright outflows, and shocks.

An IFU containing hundreds of fibers can be use to efficiently measure the radial velocity field of the shocks and jets using the 1.644 micron [FeII] line to trace radial velocity structure of Herbig-Haro (HH) jets, map HH object kinematics in moderately embedded regions with $A_V < 10$ magnitudes. Centroiding line profiles will enable radial velocity and velocity determination to a 1 to a few km/s.

A MOS capability with custom-drilled plug plates would enable precision radial velocity determination for the stars themselves by the use and fitting of template stellar photospheric spectra.

Nearby HII regions and post-main-sequence objects:

The 1.644 um [FeII] line is a strong emission line produced in shocks, photo-ionized nebulae, planetary nebulae, and supernova remnants. An IFU can be used to trace supernova shocks and flows in planetary nebulae, and the younger proto-planetary nebulae. Galactic HII region radial velocities, velocity dispersions, and flow structure can be measured. To date, such studies have only been conducted for a handful of bright nebulae using slit-scanning with long-slit high-R spectrometers, and in a few cases IFUs. Examples of targets for which [FeII] kinematic mapping would produce new science include PNe, SNe, WR-star and LBV-like envelopes (e.g. NGC6888 or P-Cygni), and some RSGs.

The nature of stars and clusters in the Central Molecular Zone (CMZ) and nearby starburst galaxies:

The contains the highest pressure, and densest ISM in the Galaxy and may serve as a template for starbursts galaxies and high-redshift star formation. The Spitzer Space Telescope has revealed a large population of compact sources whose SEDs peak around 24 microns which tend to avoid the densest star forming clouds. If they represent recently formed massive stars (MYSOs), as proposed by Yusef-Zadeh et al. (2009, ApJ, 702, 178), their numbers would imply a large star-formation rate (SFR) in the CMZ. But, if many are post-main-sequence red-supergiants (RSGs as suggested by An et al. 2011, ApJ, 736, 133) or main-sequence (MS) stars in unusually dense regions of the CMZ ISM (Koepferl et al. 2015, ApJ 799, 53), their older ages would imply a much lower SRF, in violation of the commonly used Schmidt-Kennicutt prescription ("star-formation-law") of SFR on gas surface-density. APOGEE high-R spectroscopy can be used to classify those 24 micron compact sources which have H-band counterparts (many of the ones not associated with dense gas are visible in the H-band) as MYSOs, MS, or post-MS objects such as RSGs, WR-stars, or LBVs.

Young Massive Clusters (YMCs) and Super Star Clusters (SSCs)

The IFU could be used to probe the internal velocity dispersion, center of mass radial velocity, and stellar make-up of young massive clusters (YMCs) similar to the Arches and Quintuplet in the CMZ, and the even more massive super-star clusters (SSCs) in M82, NGC 1275, and similar starburst systems. The [FeII] radial velocity field of the M82 (and similar) galactic nuclear superwinds can be used to link individual sub-bubbles and outflow components to specific SSCs or recent supernova explosion sites.

Massive Stellar Transients Nearby Galaxies

A large multi-year program (SPIRITS) on the Spitzer warm mission let by Dr. Mansi Kasliwal (Carnegie) is discovering luminous IR-only transients in ~200 nearby galaxies. Bally is a co-I on SPIRITS and the PI of an LCOGT follow-up which monitors these galaxies once a month in the r and i bands. LCOGT is obtaining visual (r and i-band) photometry. The APO 3.5 meter equipped with a fiber fee IFU connected to APOGEE could be used to classify both the transients (if detected in the H-band) and the surrounding star-field to determine the nature of the surrounding stellar population – old stars or young OB associations or clusters.

Blind Emission-Line Searches of Deep Extra-Galactic fields.

A key advantage of high R spectroscopy in the H-band is that the strong OH airglow-lines can be removed from the spectra, thus enabling extremely deep blind searches for serendipitous emission line objects such as high-redshift Lyman-alpha, [MgII], [OII], or H-alpha emitters. With ~ 10 km/s resolution such blind surveys would be sensitive to dwarf-galaxy or galactic halo type emission as well as the broader emission from "normal" starburst galaxies at high redshift.

A Visual-Wave fiber bundle for the APO 3.5 meter?

Either feeding a bench-spectrograph or one of the SDSS visual-wavelength spectrographs would enable many new types of science at APO. Extending the IFU/MOS capabilities of the 3.5 meter into the J, K, or visual bands would provide even broader unique science. Should APO proceed with the APOGEE fiber bundle proposal, it is important to keep in mind the future possibility of running additional fiber bundles.