High Resolution Optical Spectroscopy for the Gemini Observatory

A White Paper prepared by Stuart Ryder (sdr@aao.gov.au) on behalf of the Australian Astronomical Observatory (AAO), with significant contributions from Gayandhi de Silva, Fred Watson, and Michael Goodwin.

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1. Background

The ideas presented in this document grew out of a brainstorming session that was held in August 2010 among members of the Astronomy and Instrumentation Science workgroups at the AAO. Since many of the science and technology themes of interest to AAO staff are likely to be addressed in other White Papers, it was decided to focus on areas where the AAO has particular strengths and may bring a unique perspective. The AAO's longstanding interest and track record in optical fiber development and robotic positioning technology for multi-object spectroscopy drives much of this, as does the AAO's current focus on building the next major instrument for the AAT. The High Efficiency and Resolution Multi-object Echelle Spectrograph (HERMES – http://www.aao.gov.au/AAO/HERMES/) will use the existing Two Degree Field robotic fiber positioner to observe up to 400 stars simultaneously, and deliver high-resolution (R~28,000), high-quality (S/N=100 in 1 hour for *V*=14) spectra in four simultaneous spectral bands covering ~100 nm in total.

2. Follow-up of GAIA and HERMES targets

Over the next decade, ESA's GAIA mission will provide unprecedented details of positions and kinematics for a billion stars in the Milky Way. However radial velocities will only be determined for stars with $V < 17$, and it will be limited to low resolution spectroscopy (R~11,000). In order to fully exploit science from the GAIA dataset, high resolution follow-up will be essential. HERMES on the AAT and the planned million stars survey, will provide high resolution coverage for the brighter stars with $V < 14$, but on a 4 m telescope it is unable to explore the fainter targets. A high resolution optical spectrograph on Gemini can obtain the radial velocity measurements for some of the fainter stars, and more importantly provide detailed elemental abundances to complement the kinematical data. The expected science would be analogous to HIPPARCOS data giving rise to the identification of moving groups, which are now being confirmed with elemental abundance studies.

It is clear that chemical information is the key to unraveling the Galaxy formation history and that kinematical information alone cannot provide insight into how the Milky Way came to exist (e.g., Bland-Hawthorn, Krumholz, & Freeman 2010). The still-new techniques such as chemical tagging will mature over the coming years, with more accurate atomic data and stellar model atmospheres. The availability of abundance analysis pipelines will make the process of deriving accurate abundances faster and greatly expand the growing field of "Galactic Archaeology". While much of the current effort is focused on the solar neighborhood, there is growing evidence of accretion events in the outer disk, beyond a Galactocentric radius of ~12 kpc. The ability to both reach fainter magnitudes, and cover the northern sky allows one to study the outer components of the disk, where currently high resolution spectroscopic data is lacking.

To meet these basic science goals, the proposed instrument must have a spectral resolution of 40,000 or higher, covering a significant range of UV, visual, and IR wavelengths. The most informative range though would be from ~450nm to ~700nm. The exact wavelength coverage could be selected to suit a particular list of elements, as is done for HERMES; however having flexibility over the wavelength range will make the instrument significantly more competitive and allow targeting of individual lines of interest. The high resolution will enable study of the weak elemental lines to greater accuracy of <0.05 dex, which is needed to look for detailed chemical abundance patterns. Degrading the resolution to ~30,000 can provide abundances of Fe-peak and α-elements, but will result in a loss of accuracy for weak lines such as the neutron-capture lines, to >0.1 dex. Since existing and planned spectrographs are already able to provide much of the above requirements, having a *larger field of view* and *multi-object capability* on Gemini will significantly increase its competitiveness. At V~17 the number density of stars will vary between hundreds to thousands of stars per square degree, depending on galactic latitude. Therefore having a multiplex option of hundreds of stars would make all the difference.

3. Air core fibers

Rayleigh scattering within the core remains the fundamental blue-light loss mechanism in conventional (core/cladding) optical fibers. Thus, the possibility of air-cored photonic bandgap fibers optimized for UV transmission is an interesting one for astronomical applications. Photonic crystal fiber (PCF) technology has developed rapidly within the last few years, and photonic bandgap fibers are a particular type that allow propagation along a core with lower refractive index than the photonic cladding material, in contrast with conventional step-index fibers. In particular, propagation can be achieved along a hollow, or air core. Following recent work on novel bandgap PCFs at the University of Bath (Fig. 1) and elsewhere, genuine multi-mode air-core fibers with reasonably broad-band transmission now look possible (e.g., Knight et al. 2008). Whether such fibers could be developed with appropriate characteristics for astrophotonics (e.g., satisfactory numerical aperture and focal ratio degradation characteristics), and on what timescale and cost, remains to be seen. It is suggested that this emerging technology is something to keep abreast of, however.

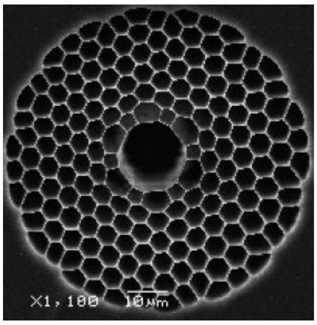


Figure 1: Air-cored fiber developed by the University of Bath Photonics Group.

4. Starbugs technology for parallel fiber positioning

The instrument concept of a high-resolution optical spectrograph (HROS) for Gemini can be significantly enhanced with a multiplex gain through the utilization of Starbugs technology (see Fig. 2). Starbugs (semi-autonomous miniature robots) is an ongoing R&D project of the AAO to allow parallel configuration of optical fibers suspended from the telescope focal plane (Goodwin et al. 2010; Haynes et al. 2006; McGrath & Haynes 2006; McGrath & Moore 2004). Starbugs advantages include:

- fast field configuration times (1–2 minutes);
- sufficiently compact (6–8 mm diameter) and lightweight (no heavy pick-and-place robots with multiple field plate exchanges having separate fiber bundle runs);
- providing modularity and versatility with different payload options, e.g. image slicers, IFUs, or hexabundles (Bland-Hawthorn et al. 2010);
- scalable and flexible to meet future upgrades and new/unforeseen science cases.

Starbugs technology has been demonstrated in the laboratory and is a proposed baseline technology for the MANIFEST instrument concept (Saunders et al. 2010) for the Giant Magellan Telescope. A prototype test bench has been developed at the AAO and it is expected that the feasibility of the Starbugs concept will be fully proven by the end of 2010.

For Gemini, Starbugs are best located at the Cassegrain focus (f/16 with scale 1.610 arcsec/mm) to fiber-feed a stable bench-mounted HROS with multiplex gains over the widest fields. Based on preliminary calculations the Starbugs (current prototypes) for HROS could achieve a multiplex of up to 500 over a field of view (FoV) of 20' (or 125 over a FoV of 10') with a minimum angular separation of 10" between closest allocated targets. The Starbugs require integrated fore optics to efficiently couple the light from f/16 into the fibers consisting of single aperture (0.7") modes for moderate resolution (e.g. R~35,000), or image slicing modes with 7× lenslet or hexabundle (0.25") for high resolutions (e.g. R~100,000). To fulfil these requirements the Starbugs need a positioning accuracy of about 0.05", or 30 microns on the field plate with a speed of 5 mm s^{-1} – well within the performance of the current laboratory prototypes (see Fig. 3).

The advantages of Starbugs technology for a fiber-fed HROS are:

- Reduced instrument complexity and efficient use of resources requiring only a single field plate and fiber bundle, as opposed to a sequential pick-and-place robot requiring two field plates and two fiber bundles.
- Similarities of fiber positioning technologies with the MANIFEST concept for GMT providing the opportunity for technology re-use.
- Micro tracking during exposure couples maximum light into each fiber.
- Modular/different payload configurations are possible.
- Feed multiple spectrographs simultaneously for diverse science, e.g. some Starbugs feed HROS, while others feed GMOS.
- Facilitates high multiplex for efficient HROS surveys.

Starbugs is a maturing technology with ongoing R&D efforts. We are confident this technology could be successfully applied to the Gemini HROS instrument concept.

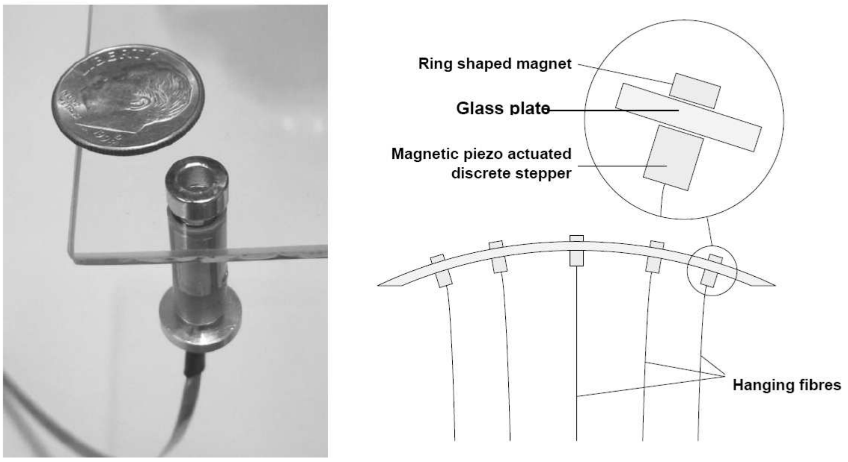
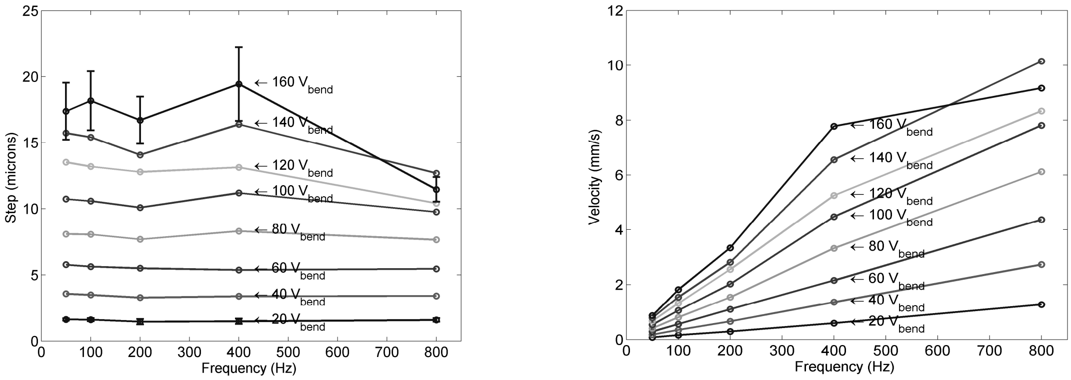


Figure 2: Overview of focal plane fiber positioning technologies developed by the AAO for MANIFEST on the GMT may also prove useful for a Gemini HROS. Starbugs 'lift-and-step' method prototype is shown hanging underneath a glass field plate for parallel configuration operation without the need for fiber retractors.



(a) Positional accuracy (step size) measured for increasing inner tube voltage amplitude (bend)

(b) Velocity measured for increasing inner tube voltage amplitude (bend)

Figure 3: Measured averaged step size (accuracy) and velocity of a typical 'discrete step' Starbug prototype (averaged over all four movement directions) obtained from 40 different calibration routines. The variation in step size (error bars) between movement directions can be individually calibrated.

References

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