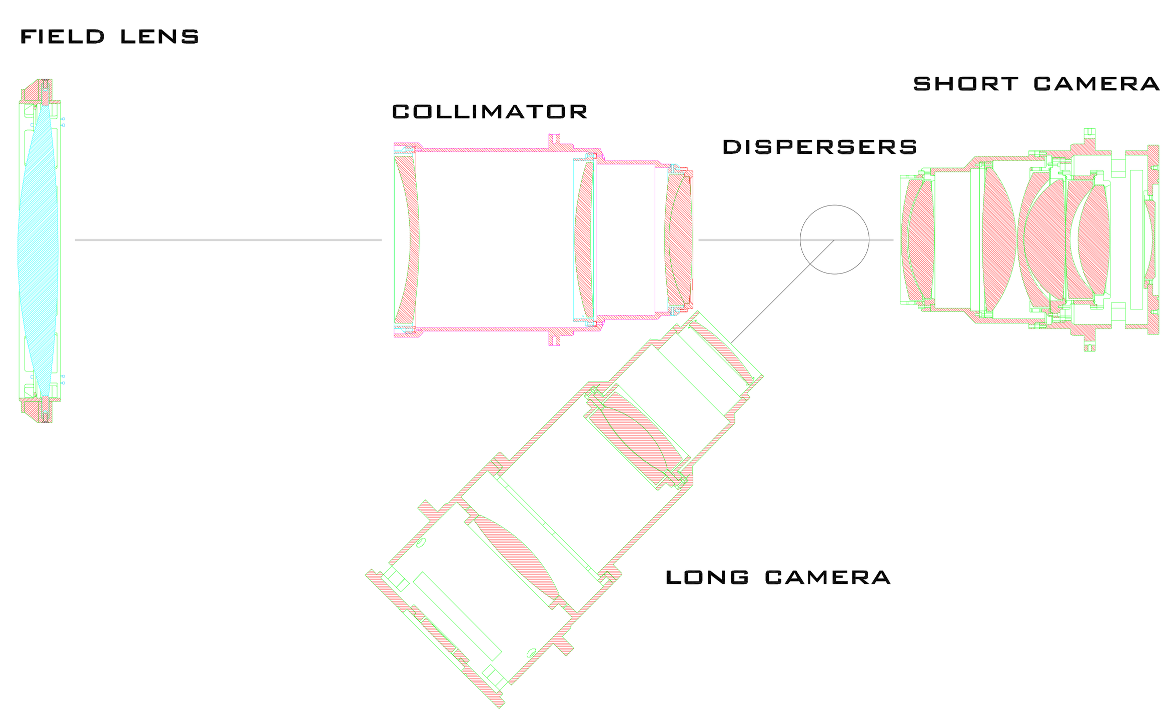
Multi−Object High−Resolution Echellette Spectroscopy with IMACS

Brian M. Sutin and Andrew McWilliam

The Observatories of the Carnegie Institution of Washington

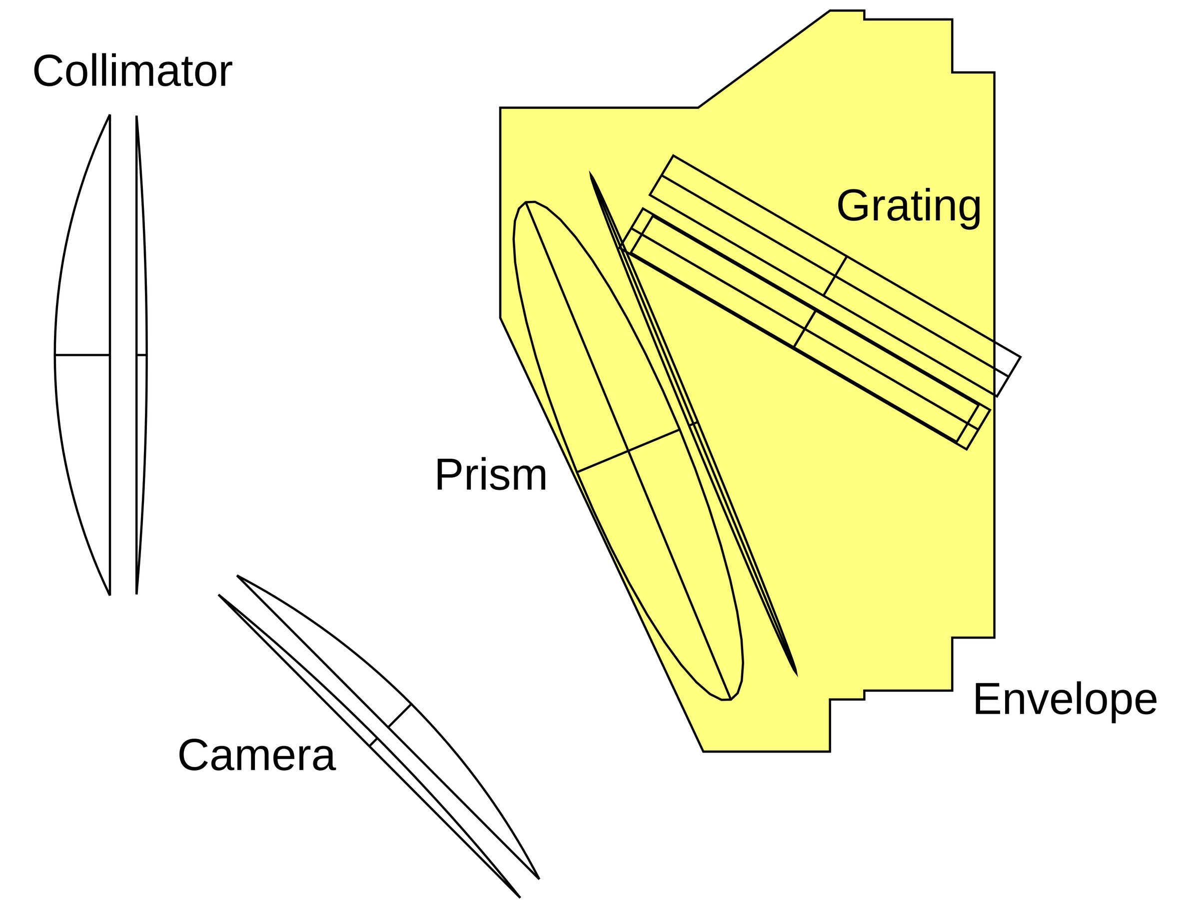
By adding a prism-cross-dispersed echellette grating as an optional module to the Inamori Magellan Areal Camera and Spectrograph (IMACS), complete spectra from (0.34 - 1.10) microns of 12 simultaneous objects may be achieved with a resolution of R = 20,000 for 0.5-arcsec slit width and a 6.0-arcsec slit length. The additional cost of this module is on the order of $50,000.

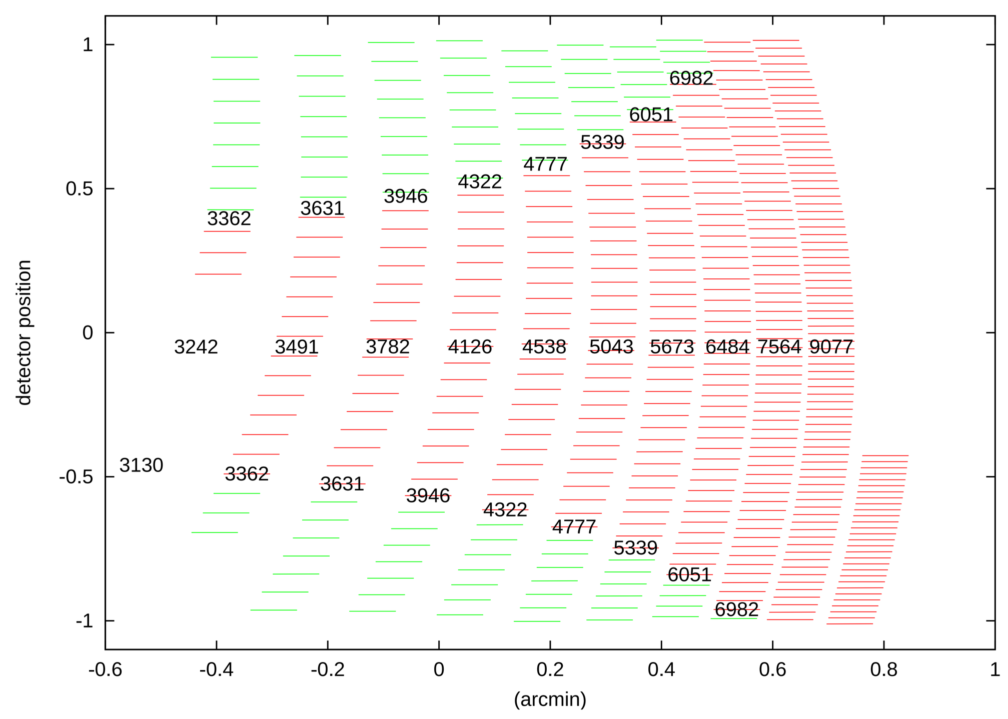
This echellette module is intended for studies of stellar abundances where the targets are sufficiently dense over the 15-arcmin IMACS field of view to take advantage of the multi-slit capability. Such applications include the study of Galactic bulge stars, stars in local group galaxies, stars in Galactic globular and open clusters, and the integrated light of extragalactic globular cluster systems.



IMACS is an optical spectrograph intended for use on the Magellan I telescope at Las Campanas, Chile. IMACS mounts at the Nasmyth focus and has two cameras available, one with a grating dispersion and and one with grism dispersion. The grating-driven camera has an unvignetted 15x15-arcmin field of view on the sky, imaged onto an 8192x8192-pixel CCD detector array, resulting in an imaging scale of 9 pixels per arcsec. The Magellan I telescope has an atmospheric dispersion corrector which does not vignette over this field of view.

Shown at the left are the IMACS optics. The telescope focal surface is just to the left of the field lens. The field lens funnels the light from the telescope's 30-arcmin field of view into the collimator, which forms a pupil at the circle. A large wheel with six positions may hold mirrors, gratings, grisms, Fabry-Perot etalons, and the IMACS-E echellette module described here. Light traveling straight through goes to the short focal length camera on the right, while light from IMACS-E goes to the long focal length camera at the 45-degree angle below.

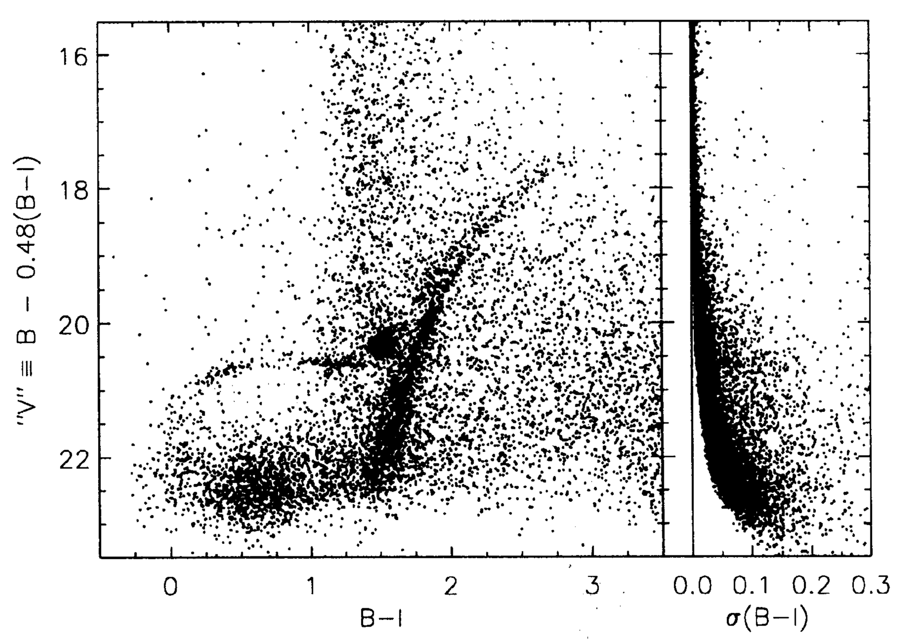


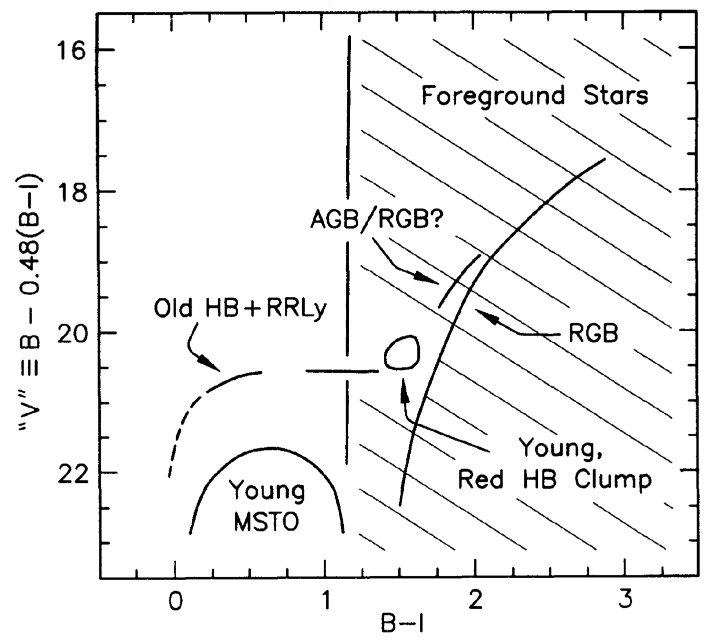


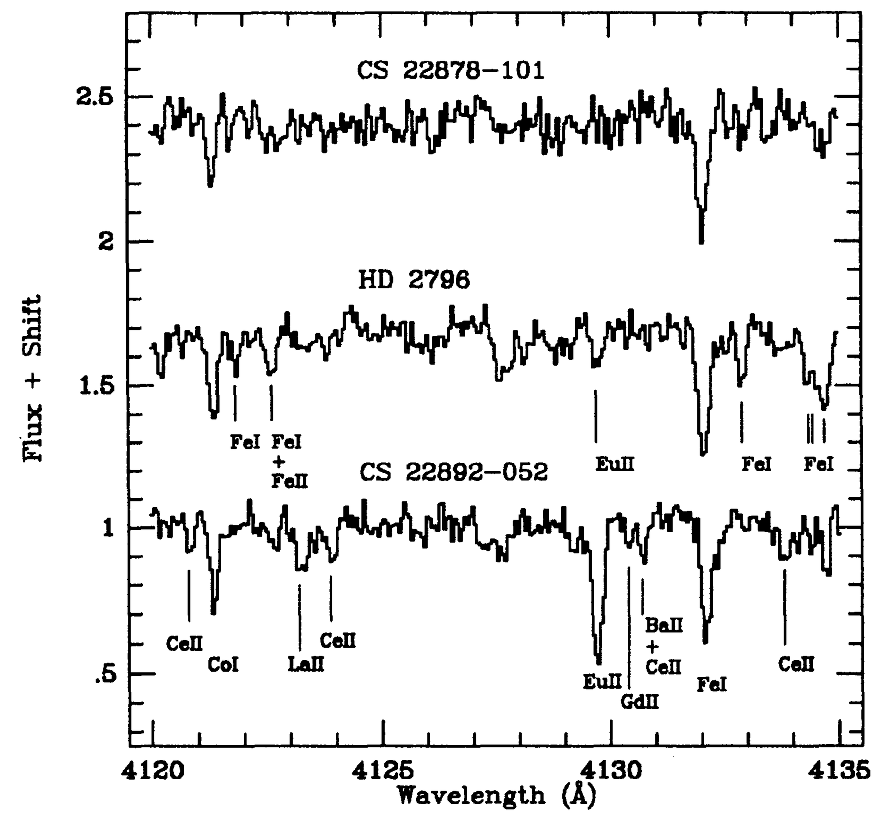
Shown at the left is the echellette pattern at the detector. Note that the vertical and horizontal scales are not the same; the entire pattern, spanning {0.34 to 1.04}-microns in 10 orders, is actually about 1.2 arcminutes wide and 15 arcminutes long. The mimumum slit length is 5.0 arcsec which should be more than adequate for the typical {0.5 to 0.8}-arcsec seeing conditions expected for the Magellan telescopes. The resolution is R=50,000/pixel, or R=21,000/{projected 0.5-arcsec slit}.

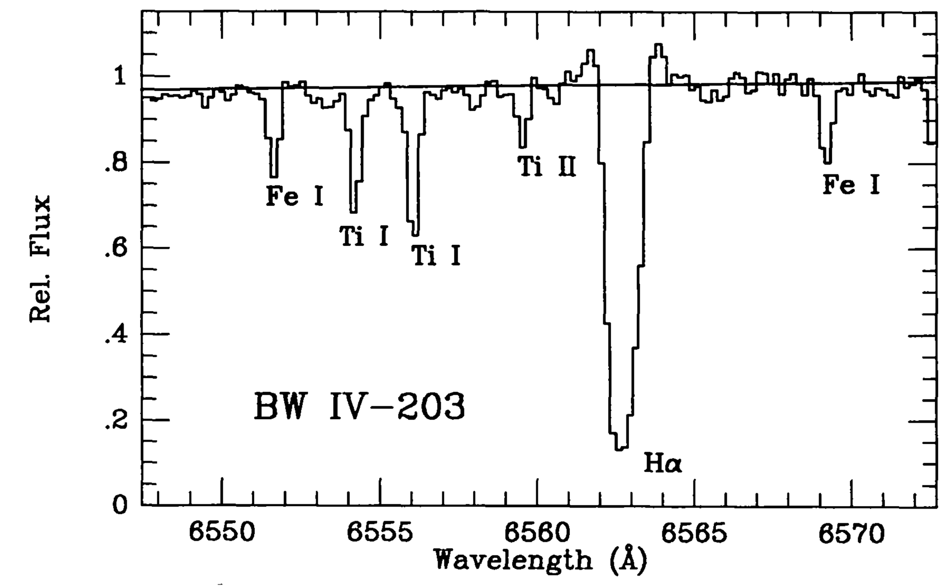
Objects may be placed anywhere over a 10x15-arcmin area on the sky, depending on how much of the red orders one is willing to lose. By using order-separating filters, the number of objects may be increased dramatically. The most extreme case would be separating out one order, in which case IMACS-E cross-dispersion serves to separate unwanted orders, preventing contamination. This mode would allow up to about 80 objects to be observed simultaneously.

Above is a drawing of the physical layout of IMACS-E, showing the front and back surfaces of each of the optics. The outline is the available space envelope into which the module must fit. Also shown are the last lens element of the collimator and the first lens element of the long camera. The cross-dispersing element is a 13-degree fused silica prism, which operates in double pass. The grating is a 245 lines/mm, 37-degree blaze-angle grating. The steep grating angle gives an anamorphic demagnification of about 1.9, making both the slit and the sky appear narrower in the dispersion direction, boosting both the dispersion per slit and the sky area over which slits may be placed. The back corner of the grating peeking beyond the envelope will probably be ground off.









IMACS-E on the Magellan telescope will be perfectly suited to study the detailed chemical composition of stars in the Galactic bulge, Local Group galaxies, in particular the dwarf spheroidal galaxies (dSphs), and the Magellanic clouds. In all these cases, high resolution spectra are required of objects which have a high spatial density, taking advantage of IMACS-E's multi-object capability.

Because metals in the atmospheres of stars reflect the sum of the metal production from all previous generations, the chemical abundances derived from the spectra provide a fossil record of the integrated chemical evolution history. This is greatly aided by the fact that red giant branch (RGB) stars have main sequence lifetimes ~1-15 Gyr; thus it is possible to study the chemistry of RGB stars with a large range in age, which can provide a detailed view of galactic chemical evolution. The chemical composition depends upon the details of such factors as the star formation rate, nucleosynthesis yields as a function of stellar mass, the initial mass function, mass loss from the system, and the mixing efficiency of interstellar gas. Although theoretical predictions exist for these parameters our understanding will be greatly enhanced by observational constraints, which could be obtained with IMACS-E.

The Carina dSph is an especially interesting object, as its CMD shows that it contains multiple stellar populations with distinct ages; these are indicated in the figures above. Another peculiar aspect of the Carina CMD is its RGB, which observed to be quite narrow, and indicates that the spread in giant branch width due to age is nearly exactly made-up for by a spread in metallicity. The spectra of the Carina RGB stars are expected to resemble the S/N and resolving power of the Galactic halo red giant spectra shown in the above figure. With IMACS-E we expect to obtain spectra of at least 15 to 30 Carina RGB stars per night; a conventional single-object high-resolution spectrograph would be unable to compete with the efficiency of our proposed echellette.

The final figure above shows part of a spectrum of a red giant star in the bulge of the Galaxy with [Fe/H]=-1, at R=17,000 and S/N ~ 50, which were used for an early measurement of the bulge chemical composition. The IMACS-E spectra will produce superior resolving power and S/N in a fraction of the time, but will be useful for the more metal-poor bulge stars.