Science with IMACS on Magellan

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ABSTRACT

The Inamori-Magellan Areal Camera and Spectrograph is nearing completion. This reimaging spectrograph will have fields of view of 15 arcmin and 27 arcmin in its relecting grating and grism spectrographic modes, respectively, the largest such areas available on one of the new generation of large optical-IR ground-based telescopes. In addition to wide field imaging and a range of low- to medium-resolution spectroscopic modes, IMACS will have a 2×1000 fiber-fed integral field unit built by Durham University, an ecellette mode, and the potential for a full-field tunable filter. We review some of the planned science programs for IMACS, ranging from spectroscopy of stars in the Galactic halo and nearby dwarf spheroidal galaxies, the search for stars between galaxies, internal kinematics in normal galaxies and AGN, and the evolution of high redshift galaxies and galaxy clusters.

Keywords: spectroscopy, multi-object, high-resolution, echellette, abundances,galactic bulge,local group galaxies,globular clusters galaxy evolution, galaxy clusters

1. INTRODUCTION

The Inamori-Magellan Areal Camera and Spectrograph, IMACS, is a project at the Carnegie Observatories to develop a wide-field imaging spectrograph for general use at the Magellan I Baade Telescope. The Carnegie Observatories, formerly the Mount Wilson and Las Campanas, and Hale Observatories, has a rich tradition in deep wide field imaging and multi-object spectroscopy. The telescopes at Mount Wilson and Palomar Observatories included many wide-field cameras, including the 48-inch Schmidt and the Hale 200-inch prime focus, and the 2-sq-deg field of the 2.5-m du Pont telescope at Las Campanas Observatory has provided exceptional imaging and spectroscopic opportunities. Around 1980, staff members Gus Oemler and Alan Dressler were among the first to develop and use multi-slit spectroscopy, around 1980, which they used to study intermediate-redshift galaxies, and Steve Shectman's fiber-feb spectrograph for the du Pont telescope enabled the ground-breaking Las Campanas Redshift Survey and a host of other programs.

As the plans developed for the Magellan Project at Las Campanas, the Observatories' staff expressed a strong interest in a world-class capability in these areas in order to pursue their interests in the evolution of our Galaxy within the context of the formation and evolution of all galaxies. Therefore, provision of a wide field capability for the new Magellan telescope was a very high priority.

2. THE DESIGN OF IMACS

Early plans for Magellan were for an 8-m SOML mirror telescope in collaboration with the University of Arizona; plans for this telescope included an f/5.4 Cassegrain focus with a 45-arcminute field. The project was subsequently scaled down to 6.5-m, eventually the first of two to be installed in a multi-partner project named Magellan. In 1990 plans for the implementation of a wide field of this telescope were reconsidered. Inspired by the 5-m Hale telescope, Carnegie astronomers expressed a strong preference for its ability to switch relatively rapidly between several instruments. This led to the decision to station instruments at the two Nasmyth and three auxiliary-Nasymth foci, so that each could be addressed in a matter of minutes using a rotating tertiary mirror.

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A particular feature of this new plan was developed by Steve Shectman, who sought an internally-baffled wide field imaging spectrograph. Without the anticipated large baffles of the wide field f/5.4 system, such a spectrograph would not compromise IR performance (planned for a separate, insertable secondary for the Cassegrain focus) and would enable a self-contained, permanent installation of a very large spectrograph feasible, making it rapidly accessible. An added operational benefit to the Las Campanas Observatory was a much reduced schedule for instrument removal and re-installation. Shectman accomplished these aims by borrowing an idea from Harland Epps: employing a Gregorian focus instead of the usual Cassegrain, the reversal in the field curvature allowed Shectman to design a refracting 6-inch-beam collimator composed of spherical elements of readily available glasses. The design, subsequently "tuned up" by Harland Epps, produces exceptional images over a full 30-arcmin diameter field ($FWHM < 0.10$ arcsec). This collimator was designed for what became the IMACS spectrograph; to a large extent the Gregorian secondary on Magellan I is the first element in this collimator.

Harland Epps was engaged to provide optical designs for two cameras, an f/4.3 system which provides a 15-arcmin square field at 9 (15μm) pixels per arcsecond, operating over the wavelength interval $3650 < \lambda < 10500$ Å, and an f/2.4 camera with a 27-arcmin diameter field at a scale of 5 pixels per arcsec, with a blue wavelength limit of $\lambda > 4000$ Å. The latter is a state-of-the-art design that employs two strong aspheric elements which are being fabricated by Tinsley Laboratories. The f/4.3 camera is fed by 6×8-inch gratings producing spectral resolutions of up to $R \sim 10,000$ FWHM (1.0 arcsec slitwidth). The f/2.4 camera is fed by 6-inch grisms that produce dispersions up to $R \sim 5000$. Both these cameras address a 8192×8192 pixel mosaic CCD camera, whose mechanics were fabricated by Gerry Luppino (IFA, U. of Hawaii), with Greg Burley and Ian Thompson providing the electronics and physical installation of the SITe 2K $\times$ 4K 15μm pixel detectors.

The IMACS user plans for use of one of the two modes, grating or grism, and the mosaic camera is mounted accordingly (a daytime change). Each camera includes a linear-motor shutter designed and built by Tyson Hare that can take a 1-sec exposure with 1% accuracy over the entire field, and a cassette filter server that holds up to 15 filters, 6.5-inch square, 12mm thick, enough for a wide variety of programs. The "disperser server" carries three gratings and two grisms at a time (in addition to the open aperture and reflecting mirror for direct imaging); the gratings can be set to arbitrary angles and brought in and out of the spectrograph in less than a minute, which should allow great flexibility for complex observing programs. For initial operation IMACS is supplied with 6 gratings that can be swapped in and out of 4 grating tilt mechanisms, an operation done off the telescope.

A team of engineers led by Bruce Bigelow was assembled at the Observatories starting in 1997. Preliminary Design Review occurred in May 1999 and final design and fabrication began immediately afterward. First assembly of the system, and first light for the collimator + f/4.3 camera + Magellan guide camera, occurred in May, 2002, and the 8K $\times$ 8K mosaic camera was first used in July. We anticipate that IMACS will be completed by the end of this year with first observations planned in January, 2003. A full cost accounting of the finished instrument totals approximately \$5.5M. A more detailed description of IMACS can be found in Bigelow & Dressler.[1]

3. HOW IMACS WILL BE USED

We intend IMACS to be permanently installed at the west Nasmyth platform of the Baade telescope; with continuously operating Cryotigers cooling the CCD camera, IMACS will be available on any night after a 10-minute repositioning of the telescope's tertiary (flat) mirror. An intended consequence is that observers will be able to divide a single night's observations among IMACS and whatever instruments are mounted at the other foci. Nevertheless, allocations of observing time to the Magellan partner institutions are made in full nights in the classical observing mode (observers present at the telescope). An exception to this is the plan for "Interrupt Mode Observing," which will set aside as much as one hour each night for time-critical or target-of-opportunity observing. The principle instrument for this is the Magellan Instant Camera, MAGIC, provided by MIT, and an infrared imager, PANIC (Eric Persson, P.I.), will soon be available. Observers may choose to operate these instruments from their home institutions, with the help of the telescope operator (and sometimes, by arrangement, with the night's observer).

Figure 1. The conceptual layout of IMACS

We intend that IMACS will also be available for such Interrupt Mode Observing, providing the opportunity for simple single-object spectroscopy. IMACS includes a rapidly engaged mode for single-object spectroscopy where a multi-width slit is introduced into the center field in a few seconds. The slit is polished and viewed directly by a CCD camera, for object access and guiding. Because the Baade telescope sets to an rms accuracy of a few arcseconds, the centerfield slit and its acquisition camera will allow for rapid cycling through the brighter objects that are typical of some science programs. Setting up for wide field multi-object spectroscopy is a more involved procedure, described below, requiring 10-15 minutes per setup.

It is expected that the principle use for IMACS will be wide field imaging and spectroscopy. Imaging applications are straightforward, with an imaging mirror used for the f/4.3 camera and a clear aperture for the f/2.4 camera with its full 27-arcmin field. The two guiders, sampling just outside the observing field, are moved to find 17th mag or brighter stars, one for simple guiding, the other for a Shack-Hartman sensor that monitors and corrects the figure of the primary mirror and the position of the secondary mirror. This setup will take a few minutes, limited by the time for the Shack-Hartman sensor to converge on a set of mirror corrections. Setup for multi-slit spectroscopy has the additional step of aligning the slit mask to the actual object positions, which is planned to take 10-15 minutes. The slit masks for IMACS are stainless-steel spherical dishes, with slits or apertures cut by a Gemini laser system. A cassette loader on IMACS carries 6 of the slit masks, with the possibility of easily swapping masks during the observing night. Alignment of the mask on the sky uses the mosaic CCD camera itself to measure the position of pre-selected stars or target galaxies.

With a relatively simple addition IMACS will become an echellette spectrograph similar to ESI on Keck. A cross-dispersing prism mounted to the face of a 245 lines/mm RGL grating will provide full spectral coverage (no gaps) from $3400 < \lambda < 11000$ Å at a spectral resolution of $R = 21,000$ for a 0.5-arcsec slit. The unit will fit into the envelope of the standard IMACS grating mount, so it will be carried on the disperser wheel when needed and brought into the beam like any other grating, in a minute or less. Because of the large 8k x 8k format of the detector, such a spectrum can be obtained for 15 objects simultaneously, if they are chosen from 1×10 arcminute strips. For partial spectral coverage, obtained with a blocking filter, the number of simultaneous objects can be, of course, even higher. A more complete description of the echellette mode can be found in Sutin & McWilliam.[2]

Within the first year of operation an Integral Field Unit will be added to IMACS. As part of a collaborative scientific arrangement with Carnegie, the device is being fabricated by the University of Durham, UK, who have built a similar such unit for Gemini. The IFU contains two groups of 1000 fibers, fed by a hexagonal lens pack, which sample a 5×7 arcsec rectangle with 25×40 elements for the f/2.3 camera. The f/4.3 camera can also be used with the IFU; in this case 25×24 elements sample a 4×6 arcsec rectangle centered on the 5×7 arcsec field. The IFU reformats these rectangular areas into a long slit that utilizes most of the detector array. The unit is self-contained and can be inserted into the mask server cassette in place of three slit masks, ready for use as needed in combination with other IMACS capabilities. A detailed description of the IFU can be found on the IMACS website at www.ociw.edu.

4. SCIENCE PROGRAMS FOR IMACS

IMACS will be available to a broad community at MIT, Harvard/CfA, U. of Michigan, U. of Arizona, and of course Carnegie. My description of the science capabilities of IMACS will center on the programs at Carnegie, but a wider variety of uses is anticipated, and participation by a large fraction of the relevant astronomical community through participation of these other institutions and collaborations with them.

4.1. Direct Imaging Applications

The combination of large field and large aperture is achieved with some difficulty. The f/4.3 camera of IMACS produces an unvignetted 15-arcmin square field, comparable to DEIMOS on Keck, VIRMOS on VLT, and the planned Binospec on MMT, and an order-of-magnitude larger than LRIS or GMOS. The 27-arcmin diameter field of IMACS f/2.5 camera (unvignetted field 635 sq arcmin = 0.18 sq deg) is a factor of 3 larger still, comparable to SuprimeCAM on Subaru and MegaCam on MMT, which are imaging cameras but not spectrographs.

These large fields of IMACS have been achieved with little compromise to the superb imaging performance of the Baade telescope. The rms image diameter averaged over the field of the collimator + f/4.3 camera is 0.15 arcsec, sharp enough to result in only 10% degradation of the best images that are expected, FWHM ~ 0.25 arsec. The f/2.4 camera's performance is remarkable considering the field size, with rms image size of 0.25 arcsec over the field. The working performance of the cameras with band-limiting filters should be somewhat better than this, since these are polychromatic images over the operating range.

A wide-field imaging capability of this size and quality on a 6.5-m aperture telescope opens up a range of possibilities. In a few nights, IMACS will produce a multicolor survey of many square degrees of sky to $V \sim 26.5$, $I \sim 25.5$, deep enough to reach L* galaxies at redshift $z \sim 1$. Dressler and Oemler will in particular be using IMACS in this way to mine the fields of intermediate redshift clusters and their surrounding superclusters, acquiring field galaxies to even higher redshift in the process. Their goal is to chart the morphological and spectral evolution of galaxies as they transition from the low-density field, through the group environment, and are incorporated into a cluster. The photometric redshifts that will be obtained will be used to separate samples for more efficient spectroscopy. The ability of the f/2.4 camera to cover large areas of sky to great depth should also make IMACS an ideal instrument to follow-up non-optical searches for galaxy clusters at $z \sim 1$, for example, surveys for the Sunayev-Zel'dovich effect, and deep x-ray surveys.

The Observatories has a long history of stellar population research through color-magnitude (C-M) diagrams. Because of its superb resolution, the Hubble Space Telescope can produce C-M diagrams in regions of much greater crowding than can be achieved from the ground, however, an exposure with ACS on HST covers is only a ~ 10 sq arcmin. The IMACS f/4.3 camera is capable of recording, ever its entire 239 sq arcmin field, the very best images the Baade telescope is expected to provide, FWHM ~ 0.25 arcsec. This means that IMACS will play an important complementary role to HST by pushing C-M diagrams to great depth in less crowded regions, for example, Local Group dwarf galaxies, the outskirts of globular clusters, and the halos and disks of nearby bright galaxies. Ian Thompson has done extensive work on in the fields of globular clusters to probe mass function of the lower main sequence and to study the effects of mass segregation. Wendy Freedman and Barry Madore are studying the history of star formation in dwarf galaxies and also in looking for population gradients in the halos of nearby brighter galaxies such as those of the Sculptor group. They are particularly interested in using the tip of the red giant branch as a distance indicator to nearby galaxies with a wide range of metal abundances, as a check of possible dependences of Cepheid-based distances on metallicity.

Steve Shectman and Rebecca Bernstein intend to search for intergalactic stars in the Virgo cluster and in groups out to V = 2000 km s^{-1} through narrow band imaging $\Delta\lambda \sim 30$ Å of [O III] lines coming from the planetary nebula stage of these stars. The space density of such objects is very low, probably less than 100 per square degree, so the IMACS f/2.4 camera with its 0.18 sq deg (636 sq arcmin) field offers a considerable advantage. Michael Rauch plans to use narrow-band filters to search for high-redshift galaxies through the detection of Lyα. Again, at a given redshift these systems are sufficiently rare that a large imaging field offers a crucial advantage.

Alan Dressler has been measuring the distances to galaxies in the local universe using the Surface Brightness Fluctuation technique developed by John Tonry. Some early results using a single Tektronix 2048 × 204824μm pixel CCD have shown that the Baade telescope can extend these measurements, which typically produce distance measurements that are accurate to 5%, to galaxies with $V \sim 5000$ km s^{-1} or beyond. The field of the Tektronix CCD camera is adequate for a single galaxy, but the IMACS f/4.3 camera has field an order-of-magnitude larger, which means that for groups and clusters beyond the Local Supercluster, where the f/4.3 camera subtends 300 kpc, the field is large enough to include two and sometimes three galaxies suitable for SBF measurements. It is crucial that ghosting and stray light be held to very low levels for this program, and the Epps camera designs, and the internal baffles in IMACS, are intended to reduce these to an extremely low level.

4.2. Spectroscopic Applications

Imaging spectrographs are usually built to "go deep" over relatively large areas of sky. Achieving very wide fields typically requires a compromise in image quality compared to a spectrograph designed for a slit of an arcminute or less. IMACS has been designed to be both a wide-field deep object spectrograph and the general-purpose 'workhorse' spectrograph on the Baade telescope, therefore, excellent on-axis performance is needed so that small slits can be used to obtain dispersions $R \sim 10^4$ or in cases of very high background, for example, a Cepheid variable star or supernova against the background of its galaxy. The Baade Gregorian secondary and Field corrector/ADC deliver to IMACS images that can be as small as 0.20 arcseconds. As was mentioned earlier, the f/4.3 camera produces excellent images: on axis, the contribution to the psf is only 0.10 to 0.15 arcsec FWHM (depending on wavelength). To take full advantage of we have built into IMACS a centerfield slit and viewing system that will provide this capability on a minute's notice, allowing rapid acquisition of targets of opportunity, for example, for spectra of supernovae and gamma-ray bursts. The stepped multi-width slit in this unit allows the observer to exploit the best seeing available. In addition to its use for these synoptic observations, we expect IMACS to be used in a single-object mode a significant fraction of the time, for example for moderate resolution of high-redshift quasars detected with multi-band surveys, and rare halo stars, for example, $Z/Z_{sun} < 10^{-3}$ which are presently being discovered and investigated by Greorge Preston, Shectman, Thompson and Andrew McWilliam.

Of course, IMACS mutli-object spectroscopy capability is where most of the design has been concentrated. The f/4.3 camera produces a field that is large enough for many programs, for example, the spectroscopy of galaxies in distant clusters (out to $r \sim 5$ Mpc from the core) and stars and star clusters in nearby galaxies. Mike Gladders will use IMACS to pursue his work on the remarkable clusters of the Red-Sequence Cluster Survey (RCS). The broad wavelength coverage and large field will allow Gladders to obtain, with unprecedented efficiency, hundreds of redshifts in each cluster, necessary for a complete characterization of the dynamics and hence the derivation of mass over a large range of cluster richness and redshift. By accounting for systematic changes in the galaxy population and subtle evolutionary effects, such a detailed study will realize the full power of the RCS (and an envisioned much-larger survey) in specifying the cosmological model.

Francois Schweizer plans to use IMACS to study the evolution of globular-cluster systems formed during galactic mergers. Scant spectroscopic evidence with 4-m class telescopes suggests that there may exist an evolutionary link between the young metal-rich halo globulars observed in 0.5 − 1 Gyr old merger remnants and the old metal-rich globulars found in most elliptical and S0 galaxies. To survey this possible link, the Magellan 6.5-m telescopes and IMACS will be used to study the metallicities, ages, and kinematics of globular clusters in a series of E and S0 host galaxies thought to form an age sequence. Spectra obtained with the long camera, 600 l/mm grating, and 0.6 arcsec slitlets will cover the wavelength range of $3700 < \lambda < 6600$ Å at about 2 Å resolution for several dozen globular clusters at a time. When compared with new libraries of high-resolution spectra computed for model star clusters of different ages and metallicities, these IMACS spectra should permit the age dating — via globular-cluster chronology — of past merger events in galaxies ranging from $\tau < 1$ Gyr-old merger remnants to $\tau > 10$ Gyr-old E and S0 galaxies.

The f/2.4 camera will be the instrument of choice for those projects where areal coverage is the limiting factor. Eric Persson led the Carnegie effort to place the Wide-field IR Camera on the du Pont telescope in collaboration Richard Ellis and the instrumentation group at Cambridge University. Persson, Pat McCarthy, Ray Carlberg, and their collaborators are using the mapping mode for this instrument to produce 26×26 arcmin fields, ideally suited to spectroscopy with the IMACS f/2.4 camera. With the near-IR data and deep optical imaging, the group has identified a sample of roughly 5000 galaxies at $z > 1$. Spectra with IMACS will be used to measure the luminosity function of various galaxy types at $z > 1$ and to measure the 3-D clustering length over this epoch, a sensitive test of cosmology and structure growth. The survey depth is set by a K-short imaging limit of $K_s = 20.8$, although a significant fraction of the K-detected objects will fall below the spectroscopic limits of IMACS over the $6000 < \lambda < 9000$ Å interval. To go as deep as possible, the team will use IMACS in the "nod-and-shuffle" mode that has been shown to produce the very best sky subtraction for extremely faint objects. A principle design feature of IMACS is the ability to rotate the dewar by 90-degrees on either camera, which is necessary to make nod-and-shuffle measurements using small holes as apertures. We believe that the typical IMACS user will choose to align spectra along the long axis of the CCD chips in order to have only one break in the spectrum caused by the gap between adjacent CCD's. The right-angle rotation, which produces three small gaps in every spectrum, is however necessary if the charge is to be shuffled back and forth between the apertures.

Together with the SWIRE Legacy Team (Lonsdale et al.), Persson, Dressler, and McCarthy will also use the f/2.4 camera to identify and obtain redshifts for thousands of mid- and far-IR sources detected by SIRTF. The source density reached by SWIRE (a ten-square degree survey) is expected to be in the several thousand per square degree and the median redshift could be well over $z = 0.5$, depending on the amount of evolution for these very red galaxies. Redshifts obtained with IMACS will allow the group to determine the luminosities of the SWIRE sources and hence the rate of evolution in luminous, dust-obscurred galaxies at early epochs.

As part of the Morphs collaboration, Dressler and Oemler have been studying the evolution of galaxies in rich clusters over the redshift range $0.3 < z < 1$. The work has emphasized the surprisingly large fraction of starburst galaxies in both the field and cluster galaxies as compared to similar environments today. The most recent observations, of the outer regions of CL0024+1654 and Abell 851, both clusters at $z = 0.4$, show that, to a large extent, the starbursts in the cluster galaxies must have begun far from the cluster core, perhaps triggered by interactions in the environment of infalling groups. Dressler, Oemler, and Gladders will pursue this line of investigation by greatly extending the areal coverage and numbers of galaxies that are infalling into intermediate-redshift clusters. The f/2.4 camera will provide a wide-enough field to probe well out into the supercluster environment of these clusters, and a spectral resolution of a few Angstroms will allow accurate measurements of the emission lines and Balmer absorption lines that record the star formation history of these galaxies. Scott Trager and Dan Kelson are particularly interested in the star formation history of the early type galaxies in these clusters. The intention is to follow up with longer exposures to achieve the higher S/N necessary to detect the weaker features indicative of past star formation in these elliptical and bulge-dominated galaxies.

According to hierarchical scenarios and current ideas about star formation rates, most high redshift galaxies are too faint to show up in broad band, color-selected surveys, for example, the Lyman-break approach. Michael Rauch intends use the wide field of IMACs with narrow band filters ($\Delta\lambda = 50-100$ Å) to make very deep searches of random fields with low Galactic extinction. It should be possible to reach sensitivities of 10^{-18} $ergs\ s^{-1}\ cm^{-2}$ A^{-2} or better, sufficient to reach sub L* galaxies at $z \sim 2-3$. The aim is not to probe to as high a redshift as possible, but to sample the luminosity function, essentially unknown at this point, as deeply as possible. The weak Ly-α emitters will be sufficiently numerous to be useful tracers of filamentary large scale structure in the high redshift universe, and should be bright enough for follow-up observations of many objects to measure continuum luminosities and colors.

Andrew McWilliam has a number of stellar population projects that will exploit the wide-field spectroscopic capability of IMACS. One is deep multi-object grism spectroscopy in the Ca-triplet lines in oder to survey for

RGB stars in Local Group dwarfs. For example, Fornax has a range in [Fe/H] and contains two globular clusters. Is there an age-metallicity relation in Fornax, and are there radial metallicity gradients? A sample with a range of [Fe/H] will subsequently be the subject of a Magellan echelle study to ask more detailed questions about chemical composition.

The search for very metal-poor stars in fields near the Galactic Bulge by Preston, Shectman, Thompson, and McWilliam is being made with narrow-band filters centered on the Ca-K line. Due to the significant number of spurious detections for stars of very-low-metal abundance, spectroscopic follow-up is required. The program is presently hampered by the rate at which this can be done on the du Pont telescope, but 600 l/mm grism spectroscopy with the IMACS f/2.4 camera (at its blue wavelength limit) will yield confirmative spectra over the 27×27 arcmin field in only 15 minutes.

McWilliam is exploiting this survey to find stars with [Fe/H] < -2.5 for high resolution spectroscopy. McWilliam has found for these stars heavy element abundances which depart strongly from normal halo giant compositions. These results indicate that early chemical evolution in the galaxy was remarkably inhomogeneous, thought to result from non-uniform yields of heavy elements from supernova sub-types. The non-standard abundance trends are particularly useful to theorists trying to make models of Population III supernovae.

4.3. An Integral Field Unit for IMACS

Under contract, and as part of a collaborative science program, Durham University is constructing an integral field unit for IMACS. The unit will sample two rectangular areas separated by an arcminute in Magellan's f/11 focal plane, at a resolution of 0.2 per fiber. The unit can be used with either the f/2.4 or f/4.3 camera, which allows a wide choice of gratings and grisms, however, the smaller field-of-view of the f/4.3 camera means that only the central 3×5 of the two 4×6 fields will be sampled.

The IFU will be a powerful tool in the study of the kinematics of nearby and distant galaxies. Specifically, Paul Martini will use the IFU to study the kinematics of gas and stars in the immediate surroundings of AGN nuclei. His program is aimed at understanding the fueling mechanism for AGN by investigating the motions and angular momentum of material that is within reach of the central massive black hole.

OH megamasers (OHMs) are luminous 18 cm masers produced in massive merging galaxies and are observable at cosmological distances. Jeremy Darling has assembled a sample of galaxies $0.1 < z < 0.3$ with OHM, which trace star formation, mergers, and possibly the formation of massive black hole binaries from the present up to $z = 3 - 5$. Use of OHMs as tracers of high-redshift merging requires an understanding of the stage of merging marked by OHMs, the lifetime of OHMs, and the connection between merger stage, OHM production, and OHM properties. A high angular resolution spectroscopic study with the IMACS IFU of the kinematic states of OHM galaxies at $z = 0.1 - 0.3$ can address these issues and provide an understanding of the environments responsible for such remarkably luminous molecular emission lines. This study will also significantly enhance the sample of (U)LIRGs with dynamical information.

Dressler and Oemler's study of starburst galaxies in intermediate-redshift clusters has raised important questions about the spatial distribution of the starbursts: N-body simulations show a strong preference for gas to be funneled to the centers of galaxies, particularly in mergers, with the resulting starburst being strongly concentrated. On the other hand, there are well known nearby examples of starbursts, for example, NGC 5102 and M82, where the starburst has apparently been widely distributed over the galaxy. Most observations to this point of the more distant starbursts have had little or no spatial resolution, so the IFU will offer an excellent opportunity to test to what degree mergers are driving the starbursts.

Rauch proposes to study the environment of QSOs using the IMACS IFU, focusing in particular on the questions of how and when are QSOs fed by their environment — does all the surrounding matter fall in early on, or is this a continuous process? Martin Rees and others have suggested to look for Ly-α emission from hydrogen within a few arcseconds of of high-redshift QSOs at high redshift to see whether the filaments and sheets of gas expected to surround the higher density region around a QSO are still intact. This gas should highly ionized by the QSO itself and therefore radiate very strongly. With the IMACS IFU searching for this effect to unprecedented depths should only require a few hours per QSO. This program delivers the strongest constraints at the highest redshifts of course, but it should be done for QSOs with a range of redshifts to see how the matter flows into the QSO as a function of cosmic time.

4.4. The IMACS Echellete Mode

The f/4.3 camera of IMACS achieves a resolution of $R \sim 10^4$ (1.0 arcsec slitwidth) with a 1200 l/mm grating. As the success of ESI on Keck has shown, resolutions higher by a factor of two open up great opportunities in, for example, the absorption line studies of intervening gas using quasars as background sources, and the investigation of chemical evolution through intermediate-resolution observations of the study of stars in the Milky Way and nearby galaxies.

By adding a prism-cross-dispersed echellette grating as an optional module to IMACS), complete spectra from $3400 < \lambda < 11000$ Å can be obtained in a single setting. Furthermore, the echellette addition to IMACS allows the unique combination of two usually disparate spectrograph characteristics: high resolution without cross-order contamination, and a multi-slit, wide-angle field of view. The unique combination in IMACS will provide a powerful multiplexing capability, which will allow up to 15 objects to be observed simultaneously at a resolution of $R = 20,000$ (0.5 arcsec slit width). Each of the objects can be selected from anywhere in 15 adjacent 1×10 arcminute rectangles covering most of the field of the f/4.3 camera. (By choosing less than full wavelength coverage, the number of objects can be increased substantially.) Particularly well suited for study are any stars or stellar groups with sufficient density on the sky, for example, Galactic bulge stars, stars on Local Group galaxies, stars in Galactic globular and open clusters, and extragalactic globular clusters. Details of this system are found in Sutin & McWilliam.[2] The areal coverage and spectral resolving power are well suited for detailed abundance analysis of metal-poor RGB stars in crowded regions.

McWilliam will study the chemical composition of large numbers of stars in Local Group dwarf spheroidal galaxies (dSphs) to understand the chemical evolution history of these systems, and provide a test for the chemical evolution paradigm.

The Carina dSph is of particular interest, as it contains stars from a number of discrete star formation epochs separated by many Gyr (e.g. Smecker-Hane et al[3]). It is thought that the production timescales for alpha elements (O, Mg, Si, S, Ca, Ti), iron-peak elements, and s-process elements (e.g. Sr, Rb, Y, Ba, La) are very different, due to the masses of the progenitor stars. If the younger populations are composed of material synthesized by the previous generations the observed abundances of these elements will enable a test of the theoretical yields from stellar populations with discrete ages.

4.5. The Maryland-Magellan Tunable Filter

Sylvain Veilleux at the University of Maryland has assembled a consortium, including many Carnegie astronomers and members of the Magellan consortium, to build the Maryland-Magellan Tunable Filter for IMACS. Based on the highly successful TTF developed for the AAT (Bland-Hawthorn & Jones 1998), the MMTF will use high-performance, low-order Fabry-Perot etalons to produce monochromatic images over a 10×27 arcmin field. The MMTF will provide a high-throughput tunable bandpass of $10 - 100$ Å over a broad range of wavelengths, $5000 < \lambda < 9200$ Å. Considered as a product of raw sensitivity and areal coverage, the MMTF will be 5-10 times more capable than any other instruments for 4-10m telescopes. Frequency switching with the etalon, synchronized with charge shuffling in the CCDs of the mosaic array, will average out temporal effects associated with atmospheric and instrumental variations, resulting in an expected sensitivity emission line point sources of $\sim 10^{-18}$ $ergs\ s^{-1}\ cm^{-2}$ at $S/N = 3\sigma$ in an exposure of $t \sim 1\ hr$.

This unprecedented sensitivity offers some unique observational opportunities. Veilleux and his collaborators will continue their study of superwinds and fountains in nearby galaxies, tracking the energy and matter flow in these systems and their effects on the surrounding intergalactic medium. Such processes are detailed manifestations of the "feedback mechanism" that is believed to be so important for young galaxies in influencing their structural development and star formation rate within the growth of dark matter halos. Michael Rauch intends to use the MMTF to provide observational constraints on faint Lyα emission from high-redshift galaxies and intergalactic gas clouds. Blind searches for Lyα emitters at high redshift will be very effective: from $3 < z < 6.5$ MMTF searches will be able to detect (dust free) star formation rates of less than 1 $M_\odot$ yr^{-1}.

This same capability will be even more effective when the redshift is already known, for example, searching for emission from QSOs. Dressler and Oemler are planning to use the MMTF to map emission-line galaxies in intermediate redshift clusters; the large field and excellent sensitivity will make possible a very efficient search of [O II] and Hα-emitting galaxies that can be used for study cluster assembly or the effects of environment on star formation for infalling cluster galaxies. Again, because of the large areal coverage, the MMTF will be an efficient tool for studying Galactic star-forming complexes, planetary nebulae, supernova remnants, etc., enabling the mapping of the kinematics and excitation of gas in dynamic regions of the galaxy.

5. CONCLUSIONS

Our design goal for IMACS was to provide a very versatile spectrograph that could support many types of scientific investigations, with as little compromise as possible in the quality and sensitivity of any of these diverse modes. The sample of projects we have presented here is just that, only a sample of the kind of studies that IMACS on Magellan will make possible. We look forward to seeing members of our and other astronomical communities exploit the capabilities of IMACS and develop even more inventive, productive ways to use it.

ACKNOWLEDGMENTS

The authors acknowledge the enormous efforts and dedication of the entire team toward making IMACS a reality. We also thank the scientists of the Carnegie Observatories for unselfishly sharing some of their scientific plans in this public forum.

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