These slides summarize an SPIE paper:

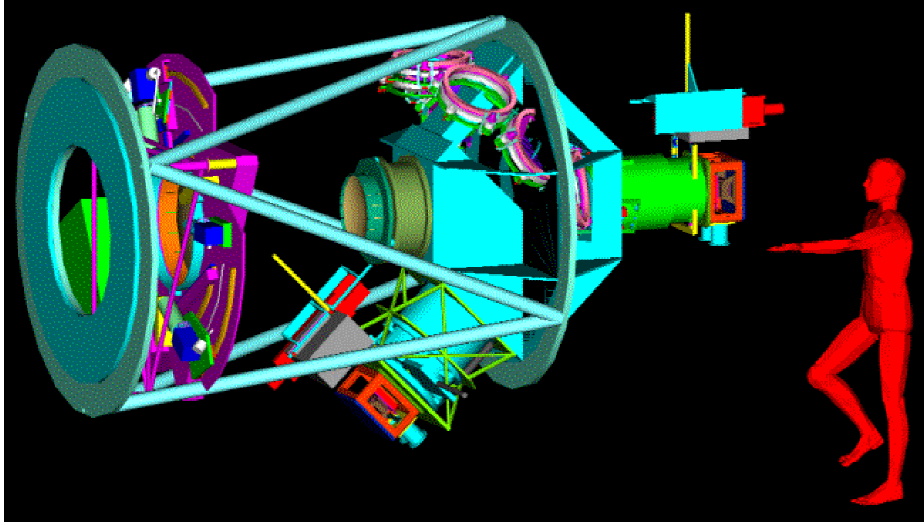
- Dressler, B. Bigelow, & Brian Sutin

“Science with IMACS on Magellan”

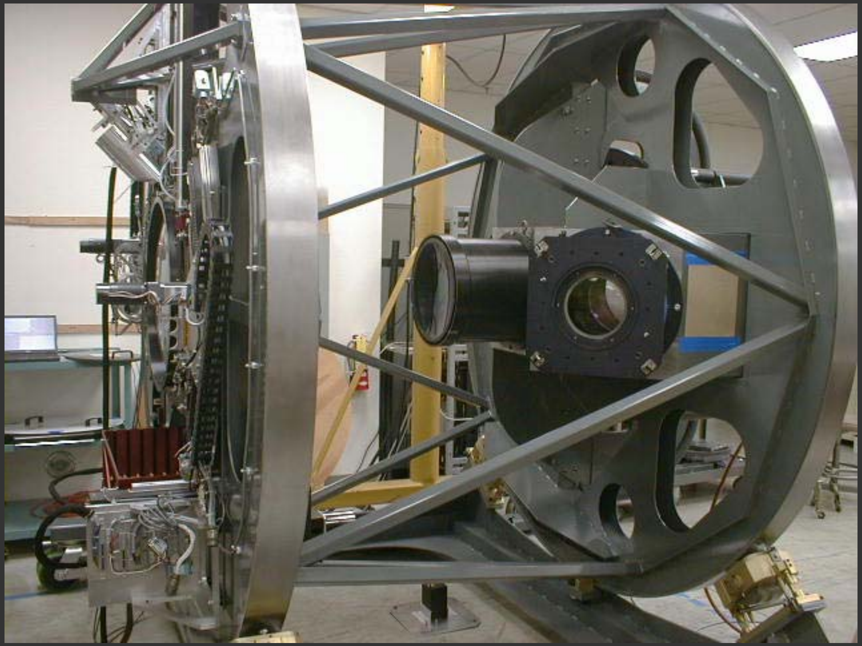
on the IMACS website

www.ociw.edu/instrumentation/imacs

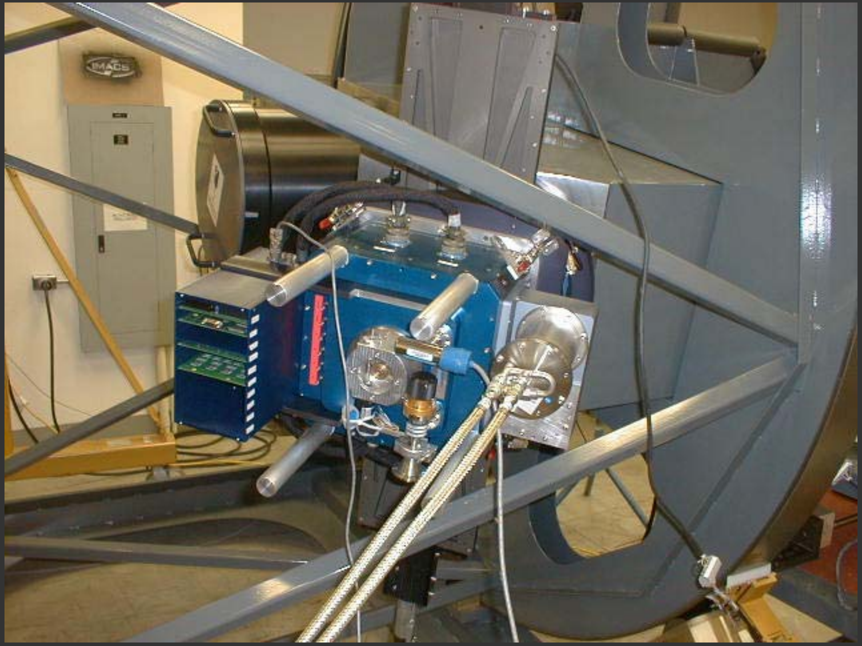
design goals for IMACS



- Provide an efficient, wide-field reimaging spectrograph (no change of baffles required) with an uncompromised single-object (small field) capability, a broad range of spectral resolutions (up to 20,000 FWHM), wavelength coverage 3400 Å < λ < 11,000Å, and a wide field capable of exploiting the best seeing, 0.25 arcsec FWHM.

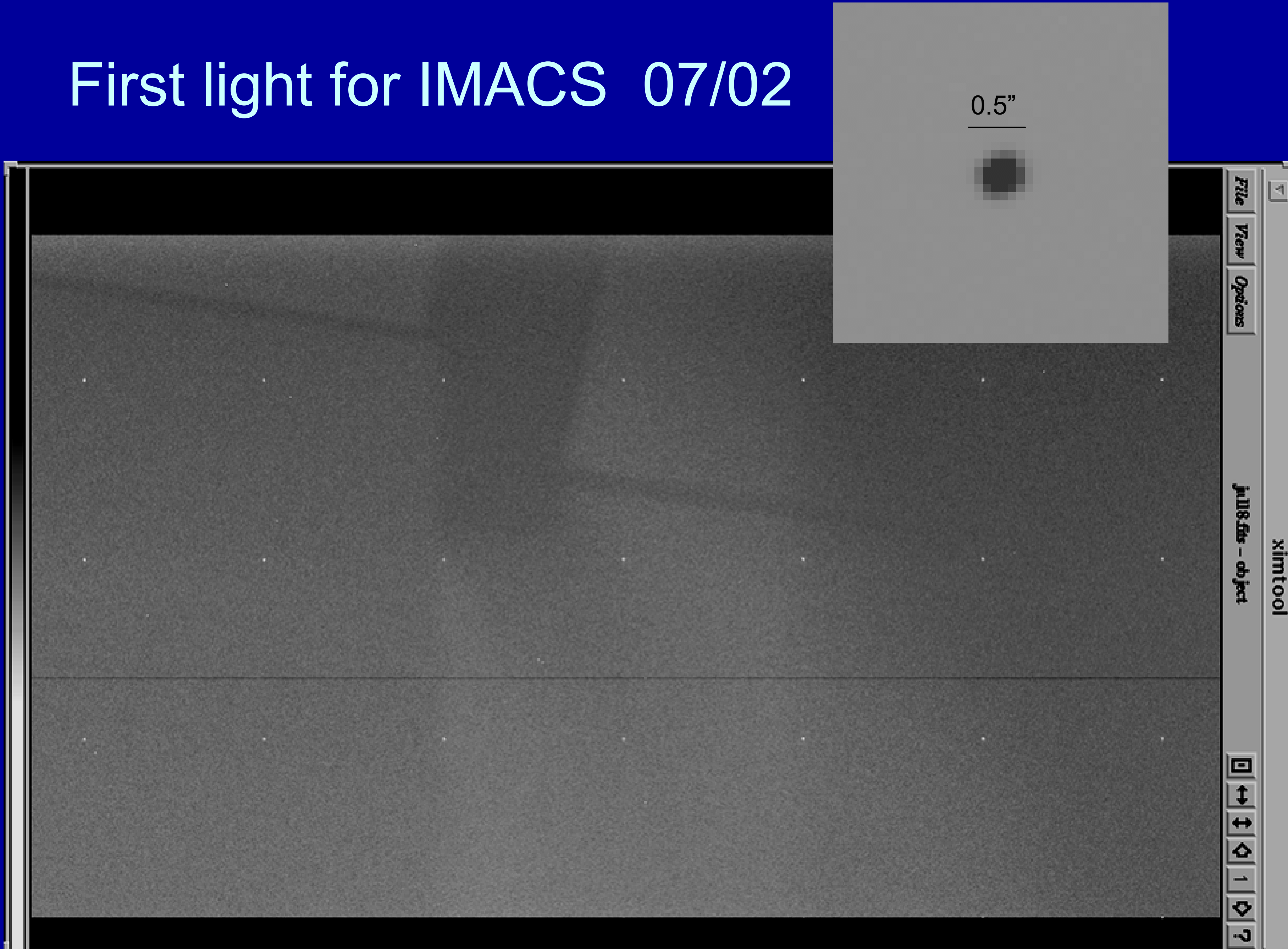



CAP 2 TON

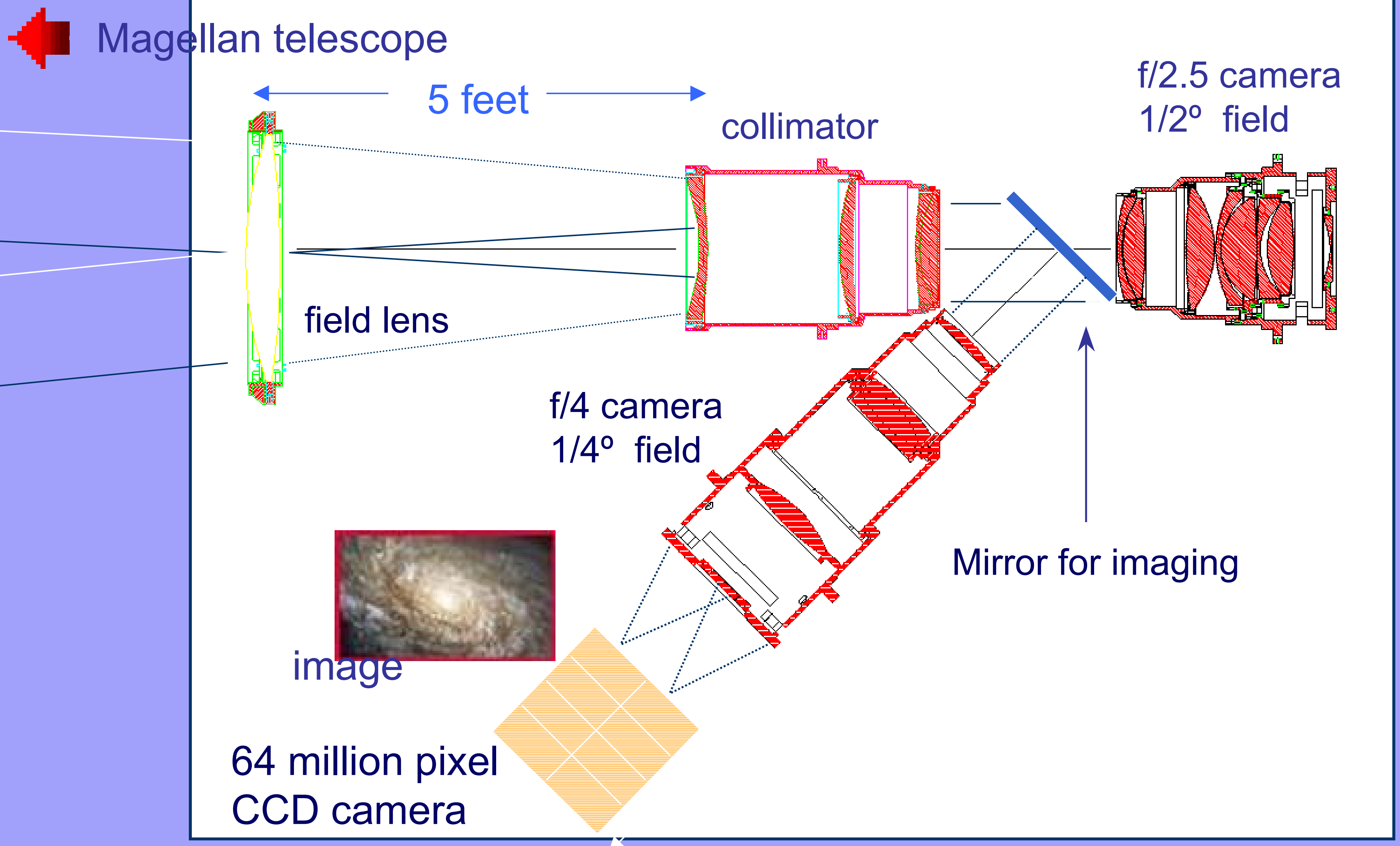



CAP 2 TON

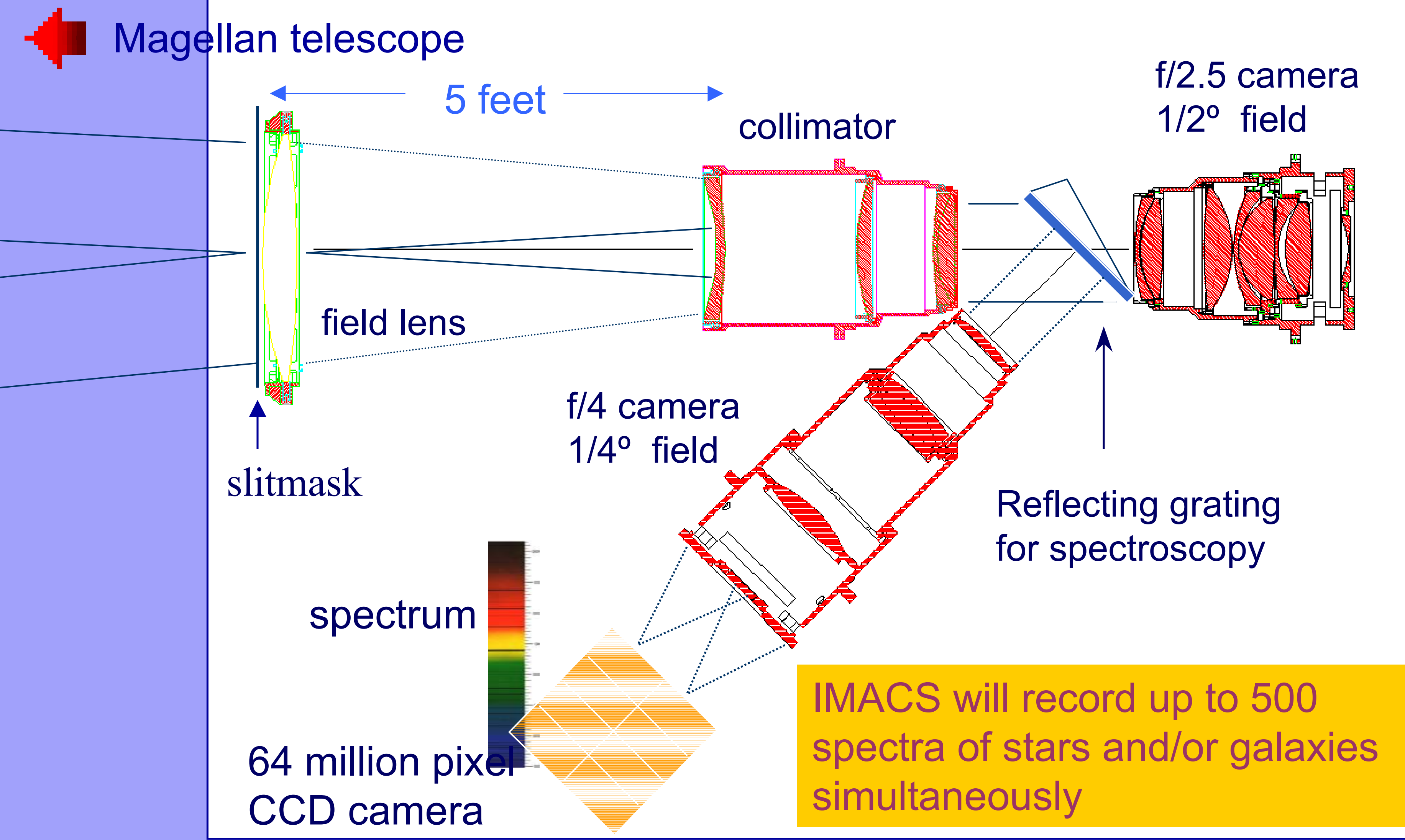
First light for IMACS 07/02



IMACS optical layout -- imaging



IMACS optical layout – spectroscopy



IMACS will record up to 500 spectra of stars and/or galaxies simultaneously

Basic description of IMACS

- f/11 Gregorian secondary + ADC + 30' dia refracting collimator with excellent images!
- Internally baffled, reimaging spectrograph is always available, without changing baffles or mirrors in telescopes – addressed by tertiary mirror

  On-board Shack-Hartmann correction for primary, secondary mirrors
- 6-inch beam. Two refracting cameras with different scales:
  - f/4.3 camera → 0.11 arcsec/pixel, 15' x 15' field -- psf < 0.15" FWHM

    Converted to spectrograph with 6x8-inch reflection gratings (3650 -10,500Å) Resolutions of R = 600 to 10,000 FWHM with 0.7 arcsec width slit
  - f/2.4 camera → 0.20 arcsec/pixel, 27' diameter field, vignetted -- psf < 0.25"

    Converted to spectrograph with 6-inch grisms (3950 – 10,500Å) Resolutions of R = 500-5000 FWHM with 0.7 arcsec width slit

Basic description of IMACS (cont.)

- 8K x 8K mosaic CCD camera, SITE 2K x 4K thinned CCDs. **Cryotiger** – always cold

  -- standard readout or "nod-and-shuffle" (rotate camera)

- Filter jukebox (holds 15) + 2-blade linear-motor shutter for each camera – 1 s at 1%!

- Instrument holds up to 6 multislit masks in a cassette, easily swapped (masks are 26-inch dishes of 0.010" stainless steel cut with a commercial laser (fast!)

Scientific capabilities of IMACS

- Observer picks f/2.4 or f/4.3 camera option before night begins (only one CCD camera available at this time)

- Instrument can be used in classical mode or "interrupt observing"

- Imaging or spectroscopy – rapid changeover (< 1 min to return to imaging)

- IMACS normally carries 3 (of 6) gratings, each tilted individually and a mirror, and normally 2 grisms, but could be as many as 5 – a daytime change

- In addition to multislit-mask mode, IMACS carries a *center-field guider* with a 2-arcminute multi-width, reflective slit for rapid acquisition of brighter objects

Scientific capabilities of IMACS (cont.)

- *Integral field unit* (Durham University) 2 x 1000 fibers, packed hexagonal lenses sample 5” x 7” @0.20” per element (also f/4.3 camera mode 4” x 6”) IFU takes the place of 3 slitmasks

- *Echellette mode:* by adding a prism onto a 245 l/mm RGL grating, IMACS has a capability very similar to ESI on Keck. Full spectral coverage (no gaps) 3400Å < ? < 11,000Å at a spectral resolution of R=21,000 for 0.5-arcsec slit. Multi-object capability: full coverage for 15 objects!

- *6-inch Tunable filter* proposed to NSF by Veilleux et al. 10-100Å bandpass over 27 x 10 arcmin

Direct Imaging Applications -- characteristics

- f/4.3 camera: 15’ x 15’ unvignetted field, 0.11” pixels
  - comparable to DEIMOS (Keck), VIRMOS (VLT), Binospec (MMT)
  ~10% degradation of telescope images down to 0.25”

- f/2.4 camera: 27’ diameter field, vignetted corners, 0.20 pixels
  - 635 sq arcmin (0.28 sq deg) comparable to SuprimeCam (Subaru) MegaCam (MMT)
  ~10% degradation of telescope images down to 0.35”

- Magellan + IMACS is capable of producing a multi-color survey over many square degrees of sky to *V* ~ 26.5, *I* ~ 25.5 in a few nights – deep enough to reach L* galaxies at redshift z ~ 1

Sample imaging applications

- Faint galaxy surveys:

  - A. Dressler & A. Oemler (Morphs) – deep photometry of extended fields of rich clusters, 0.4 < z < 1.0, also producing field galaxy surveys simultaneously
  - Optical imaging of non-optical searches, such as Sunayev-Zel'dovich effect and deep x-ray surveys (Hornschemeier 4834-02)

- Color-magnitude diagrams: HST dominates for crowded fields, but IMACS will be excellent for extended, lower density fields.

  - W. Freedman & B. Madore – the history of star formation in local dwarf galaxies – dissection of the color-magnitude diagram (Gallart)
  - I. Thompson – low end of stellar mass function in globular clusters; mass segregation over many core radii
  - W. Freedman & B. Madore – studying population gradients in the halos of nearby brighter galaxies such as the Sculptor Group. Using the tip of the RGB as a distance indicator in galaxies with a wide range of metal abundances – a check of Cepheid distance scale

Sample imaging applications (continued)

- Wide-field narrow-band imaging
  - S. Shectman & R. Bernstein -- search for intergalactic stars in the Virgo cluster. $\Delta\lambda \sim 30$Å of [O III] emission from the planetary nebula phase of these stars. Estimates of < 100 per sq deg require extensive coverage – IMACS f/2.4 camera
  - M. Rauch – narrow band filters to search for Lya from high-redshift galaxies. Sufficiently rare to require large fields (van Breugel 4834-04)
- "Precision" imaging
  - A. Dressler & J. Tonry – SBF measurements of distances to early-type galaxies. Requires exceptional seeing (target of opportunity!) oversampled images, precision flat-fielding, very low levels of ghosting and scattered light. IMACS 15' x 15' field will be large enough to include multiple galaxies in some groups and clusters

Spectroscopic applications

- Single-object spectroscopy. IMACS centerfield slit/guider with f/4.3 camera provides seeing-limited image quality and very high spatial resolution with a setup time of minutes. Stepped multi-width slit exploits the best available seeing.

  - P. McCarthy and collaborators – target of opportunity ?-ray bursts in distant galaxies

  - M. Phillips, M. Hamuy, E. Persson, W. Freedman – spectroscopic follow-up to planned LCO supernovae searches with du Pont and Swope telescopes

  - G. Preston, S. Shectman, I. Thompson, A. McWilliam – moderate resolution follow-up (to low-resolution selection) of very-metal-poor ($Z/Z_{\odot} < 10^{-3}$) Galactic halo stars

  4. M. Rauch – moderate-resolution spectroscopic studies of quasars identified in multi-band surveys (Lya forest, Ly-limit, damped Lya…)

Spectroscopic applications (continued)

- Multi-object spectroscopy. IMACS has the largest single field available for multi-object spectroscopy of any of the new generation large telescopes. Magellan telescope pointing accuracy of ~2 arcsec; IMACS guiders acquire catalog guide stars to sub-arcsec accuracy ➔ rapid multi-slit setups *t* < 10 min

  - M. Gladders – Red-Sequence Cluster Survey: broad wavelength coverage and large field will allow hundreds of redshifts per cluster necessary for complete characterization of dynamics (mass) over a large range of cluster richness and redshift ($0.5 < z < 1.2$). With a very large new sample, eventual derivation of equation of state?

  2. F. Schweizer – Evolution of globular cluster systems formed during galactic mergers. Are the young globulars found in such systems the ancestors of old-metal rich globulars found in most elliptical and S0 galaxies? Spectra ($3700 < \lambda < 6600$ Å) at 2Å FWHM resolution (0.6” slits) for several dozen globulars at a time ➔ comparison with high-resolution models of spectral evolution of star clusters of different ages and metallicities will permit age-dating of past merger events from 1 Gyr < τ < 10 Gyr

Spectroscopic applications (continued)

- Multi-object spectroscopy (cont.)

  - P. McCarthy & E. Persson (R. Carlberg, R. Ellis) – IMACS spectra of ~5000 galaxies at redshifts $z > 1$ selected with the Wide-field IR camera on the 100-inch du Pont telescope. The 26' x 26' field of each IR camera field matches the IMACS f/2.4 camera. The survey depth is $K_s = 20.8$ – a significant fraction of the sample will fall below the IMACS spectroscopic limits for $6000 < \lambda < 9000$Å. Nod-and-shuffle will be used to obtain the very best sky subtraction.

4. E. Persson, A. Dressler, P. McCarthy (in collaboration with SIRTF Legacy "SWIRE" team, Lonsdale et al.). This is a 10 sq deg survey expected to produce a density of several thousand per square degree with a median redshift $z > 0.5$. The luminosity function will reveal the rate of evolution of dust-obscured galaxies at earlier epochs. IMACS will be used in its densest sampling mode: multiple tiers of objects, ~500 per field.

Spectroscopic applications (continued)

- Multi-object spectroscopy (cont.)

  - A. Dressler, A. Oemler (+ Morphs) will use IMACS to follow the evolution of cluster galaxies $0.4 < z < 0.8$. In particular, their finding of abundant starbursts in many (most?) intermediate-redshift clusters has led to clues to the mechanism of S0 production from spirals. The starbursts and morphological transformations seem to start far from the cluster core, probably in the infalling groups through local interactions/mergers. The team will obtain, for each cluster, spectra of hundreds of galaxies infalling into clusters at $2 < r < 10$ Mpc radii, at the same time accumulating a 5000-10,000 galaxy field sample $0.4 < z < 1.0$ which is crucial for understanding the cluster behavior. Rotation curves for early types to distinguish E from S0 galaxies.

  - A. McWilliam plans several stellar population studies, for example:

    Multi-object grism spectroscopy with Ca-triplet lines to survey RGB stars in Local Group dwarfs. For example, how does the [Fe/H] of field stars and globulars in Fornax compare? Are there gradients in [Fe/H]? This work is prepartory for a Magellan Echelle (MIKE) study for measuring compositions in greater detail.

Spectroscopic applications (continued)

- Multi-object spectroscopy (cont.)

  - A. McWilliam stellar population studies (cont):

    McWilliam is exploiting the Preston et al. survey for very metal poor stars, measuring with higher-resolution the abundances of r- and s-process and a-elements. He finds these to depart strongly and finds these to depart strongly from normal halo giant compositions. McWilliam's studies are pointing to highly inhomogeneous chemical evolution in the Galaxy at early times, thought to arise from non-uniform yields from supernovae sub-types. Could be useful for theoretical models of Pop III SN.

7. M. Rauch will use the IMACS wide field with narrow-band filters ($\Delta\lambda$ = 50-100Å) to make random field detections of Ly-α emitting galaxies ($2 < z < 3$) that would be too faint in the continuum to show up in the popular Lyman-break technique – these should be the most common objects at this epoch. Follow-up spectroscopy will provide accurate velocities that can be used to trace the filamentary large-scale structure.

Integral Field Spectroscopy with IMACS

- The Durham University IFU for IMACS will sample a 5” x 7” area with 0.20” resolution. The IFU will be a powerful tool for the study of kinematics and stellar populations of nearby and distant galaxies.

  - P. Martini will use the IFU to study the kinematics of stars and gas in the immediate surroundings of AGN. His program aims to understand the fueling mechanism for AGN by measuring the motion and angular momentum of material within reach of the central massive black hole.

  2. OH megamesars are 18cm masers produced in massive merging galaxies; they are observable at cosmological distances. J. Darling will investigate the kinematics of the stars and gas in a sample of OHMs at redshifts $0.1 < z < 0.3$. The hope is that, with a full investigation of the properties of these objects at low-redshift, it will be possible to study mergers in the very early universe by sampling for OHM’s as a function of environment, luminosity, etc.

Integral Field Spectroscopy with IMACS

- The Durham University IFU for IMACS (cont.)

  - A. Dressler and A. Oemler would like to know the distribution of A-stars and [O II] emission in the numerous intermediate-redshift cluster starburst galaxies they have found. Merger models in particular show strong concentration of the starburst in the center of the system, but there are well known nearby examples where the starburst is widely distributed.

  - M. Rauch proposes to study high-redshift QSO environments by looking for Ly-a emission from infalling gas within a few arcseconds of the quasar to see if the sheets and filaments remain intact in the presence of the QSO. The QSO should strongly ionize the gas, causing it to radiate strongly. Watching this over a range of redshifts will be informative about the fueling of QSO's as the universe evolves.

The IMACS Echellette mode

- The IMACS Echellette mode will provide full spectral coverage at R ~ 20,000 for 15 objects in 1’ x 10’ slices This capability is particularly well-suited for study of stars or stellar groups with sufficient density on the sky, for example, giant stars in the Galactic bulge or Local Group dwarfs, stars in Galactic globular and open clusters, and extragalactic globular cluster systems. (See B. M. Sutin & A. McWilliam (SPIE 4823) for a more complete description)

  - A. McWilliam’s study of the abundance pattern in Local Group dwarf galaxies is particularly well suited for this IMACS capability. The multiplexing ability makes possible higher resolution studies of more stars than would be practical one at a time. The Carina dwarf spheroidal is of particular interest – it contains stars from a number of discrete star-formation epochs separated by many Gyr. If the production timescales of a-elements, iron-peak elements, and s-process elements are all very different, as is thought, the yields of previous generations of stars can be derived from stellar populations with discrete ages.

The Maryland-Magellan Tunable Filter

- The MMTF is a collaboration led by S. Veilleux between U. of Maryland and Carnegie, based on the TTF developed for the AAT by Bland-Hawthorn & Jones. It will provide a high-throughput tunable bandpass of 10-100Å over a 10' x 27' field and be 5-10 times more capable than any similar instrument for a 4-10m telescope. By frequency switching the etalon in synchronization with charge shuffling in the CCDs, the MMTF is expected to reach a sensitivity of 10^{-18} ergs s^{-1} cm^{-2} at S/N = 3σ in t = 1 hr.
  - S. Veilleux and collaborators intend to use the MMTF to continue their study of superwinds and fountains in nearby galaxies, tracking the energy and matter flow and their effects on the surrounding IGM. Such processes are detailed manifestations of "feedback" crucial to CDM models of structure growth.
  - M. Rauch will make blind searches for Lyα emitters at high redshift, both galaxies and ionized intergalactic gas clouds.
  - A. Dressler and A. Oemler will search clusters of galaxies for [O II] or Hα emitting galaxies with unprecedented efficiency.
  - Because of its large field, the MMTF will be an efficient tool for studying Galactic star-forming complexes, planetary nebulae, supernova remnants – enabling the mapping of gas kinematics and excitation in dynamic regions of the Galaxy.