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HIRES: A High Resolution Echelle

Spectrometer for the Keck Ten-Meter Telescope
Phase C: HIRES Core

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and
HIRES Science Advisory Team Members

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A Proposal To the California Association
For Research in Astronomy

Submitted: July 1, 1988.

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HIRES: A High Resolution Echelle Spectrometer for the Keck Ten-Meter Telescope

ABSTRACT

We propose to build a stripped down 'core' version of HIRES, a high resolution optical spectrometer described in detail in the Phase B proposal, for first light of the Keck Ten-Meter Telescope. The instrument is a grating cross-dispersed echelle located at the Nasmyth focus. The beam size will be 12", and the echelle will be a 1x3 mosaic of 12"x16" R-2.6 echelles, yielding an overall 'throughput' (resolution × slit width) product of R S = $35000''$, including camera aberrations and finite detector pixel sizes. Eventually, up to 7 different cross-dispersers will be available, though only one, a 2x1 mosaic of 12" by 16" 300 gr/mm gratings blazed at 7000 Å in 1st order, will be available in the core. It provides order separations of 9-18 arcsecs in the ultraviolet (2nd order), and 12-36 arcseconds in the visible and near-IR. There will be only one camera in the core, a short-focus f/1.1 camera for resolutions up to about 59,000 with a Tektronix 2048^2 CCD. Typical wavelength coverage per exposure is 3100-4300 Å in the UV/blue, and 4500-7000 Å in the visible/IR. Resolutions up to 85,000 will be possible, though with light loss at the slit and with very much less wavelength coverage, using a TI 800^2 CCD. Though the core does not include a fully-optimized suite of multi-fiber modes, as an interim solution, it will use 20 fibers which are brought down the telescope cable wrap from the LRIS instrument. Five to seven fibers can be used in the red with the core cross disperser, and all twenty can be used if a single order is isolated with an interference filter. Fibers of 1 arcsecond diameter will yield a resolution of about 28,000 (4.2 pixels per resolution element), and will be quite powerful for cluster abundance studies.

Future upgrades to the HIRES core will include a Very High Resolution Package, a Multi-object/Longslit Package, a UV Package, and a Bright Star Package.

INTRODUCTION

This is the Phase C proposal for HIRES, a high resolution optical spectrometer for first-light of the Keck Ten-Meter Telescope. A detailed description of the full-blown HIRES concept was presented in the Phase B proposal, and was estimated to cost \$2.8 to \$4.9 million. This Phase C proposal describes the 'core' version of HIRES, which has been considerably cut-back in an attempt to fall within a budget limit of \$1.7 million. The Phase B proposal described the full instrument, as well as a number of less ambitious approaches to the HIRES concept, with nicknames such as *core*, *seed*, and *husk*. To eliminate any further confusion, we will henceforth refer to the instrument described in this Phase C proposal as the 'core' version of HIRES. This core is not the same as the core described in Phase B. But the concept of 'core' has been retained to emphasize that, although the initial configuration of HIRES will not have the full complement of options and accessories, it will be designed in such a way that all such enhancements envisaged for the full HIRES instrument will be relatively straightforward to add later as funds become available.

The core of HIRES is simply a stripped down version of the full HIRES scheme proposed in Phase B. Many components have been deleted to save money. They include the image rotator, extra echelles and cross-dispersers, the echelle server, the cross-disperser carousel, and the long (80") camera with its image slicers. The TV/autoguide camera has been simplified, sacrificing field for cost and simplicity. At the request of the SSC, a limited fiber-input mode has been added, which uses up to 20 fibers brought down the telescope cable wrap from LRIS.

What is left is a nasmyth echelle spectrometer which, including camera aberrations, and 27 micron CCD pixel sizes, achieves a net overall throughput (slit width times resolving power product) of 35,000 arcsecs, (i.e. a 1 arcsec slit produces a spectral resolving power of 35,000. It features a single echelle, a single grating cross-disperser and a single 30" focal length f/1.1 prime focus Schmidt camera with 'blue' and 'red' correctors. The echelle is still, as in Phase B, an R-2.6, in a 1x3 mosaic, and the cross-disperser is a 2x1 mosaic. A 'non-disperser' or flat mirror will also be provided to be used in place of the cross disperser for some multi-fiber or longslit work.

The collimated beam size is still 12". There will be two collimators, one optimized for the UV, and the other for the visible/IR. A separate fiber collimator fed by 20 fibers from LRIS will allow some multi-object work at first light. The primary detector will be the mythical Tektronix 2048^2 'vaporchip' CCD. There will be the usual complement of calibration lamps and slit accessories. Guiding and target acquisition will be done with a simple fixed CCD TV camera staring at the slit, and guiding off light spilled around the slit jaws at 0.125 arcsecs per pixel. The TV field of view will be about 36 by 49 arcsecs. The entire instrument will be kinematically supported on the nasmyth deck, and housed in a light-tight, thermally insulated enclosure with filtered air and cleanroom traps. HIRES will be remotely operated under control of a Sun/4 instrument computer. Control of HIRES will be possible either on the mountain, in Waimea, or from the mainland.

1.0 Instrument Science Rationale

As per instructions from the SSC letter of April 18, 1988, the science rationale section has been deleted. A detailed discussion of the science can be found in the Phase B proposal.

The P.I. was asked by the SSC to look into pursuing the 'R-1.5' option discussed in Phase B for the core, that is, using an R-1.5 echelle instead of the R-2.6. This would have saved some money since the echelle mosaic needs then only be a 1x2, rather than 1x3. Also, the feeling was that an R-1.5, optimized for somewhat lower resolution, might better fill in the gap left by the demise of MRIS, and might better bridge the resolution gap between LRIS and HIRES. After much thought, it was decided to retain the R-2.6 approach for HIRES for the following reasons.

- The R-1.5 mode described in the Phase B proposal was really a 'wide wavelength' UV mode, and did not have to also work in the red. However, for the core HIRES, an R-1.5 mode cannot really be made significantly wider than the R-2.6 mode in UV wavelength coverage for two reasons. First, we also require a decent spectral format in the visible/red, and if we try to increase wavelength coverage in the UV by making the echelle rulings finer, holes appear in the red as the orders overfill the detector. As one increases UV coverage, one moves the wavelength at which gaps appear in the spectrum blueward. At present, that wavelength is set at about 6950 Å. Secondly, camera designs make it very difficult, if not impossible, to make good use of increased wavelength coverage in the UV/blue. Without going to some exotic achromatic corrector, which would be well beyond our budget, one just cannot control chromatic aberrations well enough over the entire 3100 Å to 5300 Å region with a corrector that core HIRES could afford.
- The incremental *cost* in going from the R-1.5 to the R-2.6 is small, but the performance payoff is large. The echelle is where instrument dollars are working hardest. The R-2.6 has almost twice the throughput of the R-1.5, for only about $65K more cost, or about 3.8% of the total budget.
- Given the very real uncertainty about initial telescope optical performance, and the very real possibility that first-light images may be a little 'soft' for a few years, one really wants as much slit throughput as possible at first light. The R-2.6 beats the R-1.5 by factors of 1.5 to 1.8 in seeing of 1 to 1.5 arcsec and resolutions of 18,000 to 36,000.
- One may want to lean the instrument dispersion to somewhat larger values in case the 27 micron pixel CCD detectors do not come through, and one is forced to use larger pixel Ranicons, Mama's, or future 'pixel-addressable' detectors which are likely to have relatively large pixels.
- Much of the disadvantage of 'oversampling' at a given resolution by the detector, in the important 'intermediately-high' resolution range between LRIS and HIRES (R= 6000 to 30,000) because of dispersion being higher than optimal for a given project, can be gotten around for faint-end work by binning on the CCD, and, for photon-counters, it really doesn't matter how badly the image is oversampled. S/N simulations show that both the R-1.5 and the R-2.6 are very nearly equivalent in 1 arcsec seeing at a resolution of 18,000, even down to V=20.1 in gray time and with no binning. This is partly because extra skylight entering the R-2.6's wide slit is not an important noise source since it is measured between orders accurately enough for good subtraction. Also, the R-2.6 does have less Å/pixel, but correspondingly more photons get through the slit. And with virtually noiseless on-chip binning, any potential S/N disadvantages of the R-2.6 at 'intermediate' resolutions become even less likely.
- Dropping back from the R-2.6 to the R-1.5 drops the maximum achievable broadband resolution from 59,000 to 36,000. This cuts out many important scientific projects, and adds 'insult to injury' to real high resolution users since the long camera has already been deleted from the core, making very high resolution work (R $\geq$100,000) already impossible at first light.

- Much of the personal research of the Principal Investigator is just not possible to carry out at resolutions below 36,000. Thus, the P.I. will lose most of his motivation for building HIRES if one goes with the R-1.5 approach.

In defining the core, high weight was given to the science needs of QSO absorption line work, stellar abundances, and other projects involving resolutions in the 20,000 to 60,000 range. Projects requiring resolutions above 100,000 or so were effectively canned by the removal of the 80" camera and its slicers. Some limited high resolution work (70,000-85,000) will still be possible, though with much light loss at the slit and with very restricted wavelength coverage, by using a CCD with 15 μm pixels, such as today's TI 800^2 CCDs. Presently, there are no funds in the budget for an 800^2 CCD, though it might be possible to borrow one from either Lick or Caltech. Of course, it is also possible that large CCDs will not become available, in which case all we may get is an 800^2 CCD, and the high resolution people may be in the best shape of all first-light users.

Since there will be only one cross disperser in the core, the instrument will not have much flexibility of spectral format, nor will it be totally optimized for efficiency at all wavelengths. However, the one disperser included in the core has been chosen to provide reasonable efficiency over most of the optical and UV, and to provide a good balance between having enough order separation for threshold work, while still allowing a reasonable amount of wavelength coverage per exposure.

The absence of an image rotator does not greatly impact the science. Most work will be done on point-like objects, where slit orientation on the sky is not a concern, even when the slit orientation rotates during long exposures. However, any 'longslit' work requiring spatial resolution across an extended object will be difficult. Short 'longslit' exposures will still be possible if not too near the zenith, but one would not have any control over the slit position angle, and would have to schedule for the right time of the evening to get a desired position angle. The core cross disperser is not really well-suited to serious longslit work anyway, providing as it does, only 10 to 20 arcsecs of order separation and hence useable slit length. Of course, a single order could be isolated with an interference filter behind the slit, and then the entire 1 to 2 arc-minutes of slit length could be used. The absence of an image rotator makes TV autoguiding more difficult, since a guide star will move in a circle around the optical axis as the telescope tracks. However, one will generally guide directly off the image entering the HIRES slit itself.

Since a very key science driver for first-light is the study of abundances in clusters, some multi-object capability is very desirable. A relatively cheap interim solution proposed for the core will be to use 20 fibers from LRIS which are committed to HIRES, and which snake down the telescope cable wrap. With the core cross disperser, there will be enough room (12 to 20 arcsec) for 5 to 7 fibers between adjacent echelle orders, and perhaps more if one is sufficiently clever in interlacing fibers and orders. A non-disperser (flat mirror) in place of the cross disperser will provide an additional 30% speed, and allow all 20 fibers to be used when a single echelle order is isolated. A more detailed discussion of this mode is presented in the instrument description section.

2.0 Instrument Description

2.1 Overall System Performance

The Keck will have about 12 times the collecting area of the Lick 3-m, and slightly over 4 times that of the Palomar 5-m. The seeing is expected to be generally better than 1 arcsecond, so a typical 1.0 arcsecond by 10 arcsecond slit should have reasonable throughput (50% or so), and allow good sky subtraction. The sky will be darker by about a factor of 2 than at Lick or Palomar, since there's less scattering of moonlight in the atmosphere, and the atmospheric transmission will also be better (and no H_2O lines). It is hard to know what the CCD performance will be, three years from now, but we've assumed a read-out noise of 4 electrons, a dark count of 2 electrons per pixel per hour (about a factor of 10 better per unit area than a TI 800^2), and a quantum efficiency of 30% at 3000 Å, 70% at 5500 Å, and 15% at 1 micron.

We have tried hard to make realistic estimates for the efficiency of the spectrograph, recognizing that mirrors get dirty, surfaces degrade on exposure to air, echelles and gratings are never used in Littrow, etc. The bottom line is that the throughput on the sky (i.e. with no atmosphere or slit losses), averaged over the echelle blaze function, for the entire telescope, spectrograph, and detector combination, is expected to be about 1% at 3500 Å, 2% at 4000 Å, 5% from 5000-6500 Å, 2.5% at 8300 Å, and 1% at 1 micron. The spectrograph throughput alone would peak at around 15%, about the same as that observed (in practice) for the Lick Hamilton echelle.

We'll assume a slit size of 1.0 by 10 arcseconds. If we allow for 30-40μ (1.1-1.5 pixel) images from the camera, the real resolution is about 36,000 (8.3 km sec^{-1}). The sampling is 3.3 pixels per resolution element, which makes sky subtraction much easier (sky, in our case, will often be a fairly high quality spectrum of our local G2V star). The CCD is binned by 2 perpendicular to dispersion to reduce read-out noise. The seeing is assumed to be about 0.8 arcsecond at V, and the moon is 3-5 days from full moon. Long exposures (more than 2 hours) will usually be two separate exposures, since the cosmic ray rate is high on Mauna Kea.

Armed with all these assumptions, we can estimate typical limiting magnitudes for the system. The listed magnitudes (below) are in real stellar magnitudes, and the S/N's are S/N per pixel, not per resolution element. For S/N per resolution element, which is usually what one is most interested in, multiply the S/N numbers by the square root of the number of pixels per resolution element. The limiting magnitudes, as a function of wavelength, for a few combinations of exposure time and S/N are:

	3500Å	4000Å	5000Å	6500Å	8300Å	10000Å
6 hours, S/N=5	17.6	19.4	20.1	20.1	19.4	18.6
4 hours, S/N=10	16.3	18.2	19.0	19.0	18.2	17.3
1 hour, S/N=30	13.2	15.2	16.2	16.1	15.2	14.2
1 hour, S/N=100	10.6	12.7	13.7	13.6	12.7	11.7

In very dark time, in 0.5 arcsecond seeing, the limiting magnitudes might be a magnitude better at the faint end, but only 0.5 magnitude better at the brighter end. With a narrow slit, say 0.65 arcsecond (which would yield R=50,000 with 2.4 pixels per resolution element), the loss would be around 0.25 magnitude.

2.2 Configuration

Figures 1 and 2 show a general configurational view of the HIRES optical train and Keck telescope structure. The instrument occupies about half of the 'left' Nasmyth platform. In essence, it is the equivalent of a giant Cassegrain echelle, with most instrument changes and functions operable from the read-out room, or from Waimea, or from any other remote observing site. Figure 3 shows a schematic outline of the enclosure and the kinematic support system. It will be housed in a light-tight, thermally-controlled, clean-room enclosure with a welded frame supporting the various components. The frame will sit on a kinematic mounting on the Nasmyth platform. There will be access to the interior of the enclosure through various doors and windows. The interior of the spectrograph enclosure will be maintained at the dome air temperature by slightly overpressurizing the spectrograph with highly filtered dome air. A separate electronics vault will be maintained at slightly above 0°C and cooled by the observatory freon coolant system. The slit area will be a sub-enclosure separated from the main enclosure (except for the hole due to the spectrograph slit) and separated from the outside world by a remotely-operated hatch.

Expanded views of the HIRES optical train are shown in Figures 4 and 5. A brief description of the light path at this point is useful, starting with the side view of Figure 4. The converging f/13.7 beam from the telescope enters from the left along the elevation axis, proceeds past an assortment of optical components (not yet shown) in the slit room area, and comes to focus (Nasmyth) at the spectrograph slit, at a point just beyond the azimuth bearing journal. Guiding will be with a simple CCD TV system looking at the slit, with a roughly 36 by 49 arcsec field of view. There will be the usual set of slit room accessories (calibration lamps, slit, decker, etc.). The slit runs horizontally (into the plane of the page in Figure 4), and the slit plane is tilted slightly for guiding. Behind the slit, two filter wheels and shutter are provided.

The light then passes to a spherical collimator (one of two mounted on a collimator slide) where it is collimated into a 12" diameter beam, and deflected upwards by 3.5°. A fiber-fed collimator (not yet shown) can be lowered into position in front of this collimator slide for multi-object work.

The collimated beam then passes to an echelle, and the chief ray of the dispersed light is deflected downwards by an angle of 10° (still in the plane of the page) to a cross disperser located beneath the collimator. After hitting the cross disperser, the chief ray is deviated by 40° into the plane of the page (see top view of Figure 5).

The light then enters a 30" focal length f/1.1 Schmidt camera, where it is brought to prime focus onto a Tektronix 2048^2 CCD. Two correctors are required, one for the UV/blue, and one for the visible/near-IR. Eventually, a long focus camera (80") may be added, so the f/1.1 camera mirror is mounted on a lifting mechanism for stowage.

2.3 Optical Functional Description

2.3.1 Calibration Lamps

The standard complement of calibration lamps will be provided for flat fielding and wavelength calibration. These will include a selection of incandescent bulbs for flat fielding, and a selection of hollow-cathode lamps for wavelength calibration and measurement of the instrumental resolution profile. Also, an Edser-Butler fringe source will be provided for additional wavelength calibration, and a laser will be included for alignment and resolution checks. A fiber optic feed which can bring in daylight for daytime calibration may also be provided. Eventually, it may be possible to fiber couple HIRES to an auxiliary telescope located near the Keck for projects requiring lots of time coverage.

All calibration sources will be mounted above the optical axis in the slit room, and their light fed into HIRES by means of a small diagonal mirror which drops down in front of the slit. The light sources will be mounted on a simple linear translating table and switching from one source to another will be done remotely simply by moving the table. A filter wheel will be required in front of the lamp stage for bandpass control of the various light sources, and either a wobbling block or some sort of condensing lens system will be required for long-slit illumination. Some flat fielding may also be done using the white-painted rear surface of the entrance hatch of the instrument.

2.3.2 Slit Accessories

The slit for HIRES is horizontal, parallel to the Nasmyth platform, and the slit plane will be tilted slightly for guiding purposes. The slit plane will be highly reflective for guiding, and will provide some 2-3 arc-minutes of guiding area, though not all of that area will be covered by the initial guide camera. The slit width will be remotely controllable and a shutter will be provided behind the slit for starting and stopping exposures. This shutter is necessary since there is not enough room near the detector to do rapid shuttering without vignetting.

Two filter wheels behind the slit will be provided for isolating orders of the cross dispersers and/or the echelle. All broad-band filters will be anti-reflection coated.

2.3.3 Normal Collimators

The collimated beam size of the instrument is 12 inches. The full aperture f/ratio at Nasmyth is f/13.7 (the primary is really 10.9 meters across), and the collimator thus fits onto the Nasmyth platform without needing any additional fold mirrors. There will be two 'normal' collimators. These are simple spherical mirrors, tilted 1.75° to provide a 3.5° upward beam deviation, and oversized for handling image slicers and a 1-2 arc-minute long slit. The two normal collimators will be carried on a stage and switching between the two will be done remotely.

One of these two collimators will probably be coated with the new Lick "Holy Grail" surface, with reflectance like silver in the visible and red, and like aluminum down to 3390 Å. The other will be an enhanced aluminum or multi-layer all-dielectric coating designed for high reflectivity in the 3100 Å to 4300 Å region.

The Phase B designs for MRIS and LRIS use a collimator scheme involving an on-axis grating and on-axis parabolic collimator with an off-axis entrance pupil. Such a scheme will not work for HIRES since it requires that the entire instrument rotate as the telescope tracks. In any event, a simple spherical collimator at low tilt angle seems to work just fine for HIRES.

The normal collimators are concave spherical mirrors made of fine annealed Pyrex approximately 17 inches in diameter by 3 inches thick. The front will be diamond generated concave to the specified radius of curvature, ground on ceramic tiles and routinely polished to test plates and interferometric references to better than 1/8 wave sphericity. The technology and methodology for producing very accurate spherical surfaces is well known and fairly straightforward.

2.3.4 Fiber Collimator

In order to provide some high resolution multi-object capability at first light, 20 fibers of the LRIS Auto-fib device will be committed to HIRES and brought down to HIRES through the telescope cable wrap. These fibers could be identical to the LRIS fibers, about 290 microns in diameter, with f/6.0 input and f/4.4 output. This fiber diameter is equivalent to about 1 arcsecond on the sky and, according to Oke (LRIS proposal), these f/ratios give about 90% coupling efficiency. While it is probably convenient to stay with the same fiber diameter and f/ratios as LRIS, other f/ratios and fiber diameters could as easily be used if required. The final choice will be made at a later date, based upon a more careful study of the coupling of typical Mauna Kea seeing disks into fibers.

The fibers will be about 50 meters in length and will require fiber-optic connectors at the LRIS end to allow LRIS to be easily removed from the telescope. While such connectors are generally never used in astronomical fiber applications, since they lose some light, the light loss is not too serious, and, if done properly, focal ratio degradation should also not be a problem. While this solution is certainly not optimum, it should provide a very cost effective option until funds can be obtained for a dedicated Auto-fib device for HIRES.

At present, the best connector for astronomical applications seems to be the STC type. They are available with either stainless steel or ceramic ferrules, with the ceramic ferrules given lower losses. However, ceramic ferrules are only available in a few small sizes and would probably have to be custom-ordered at some expense for our application.

STC connectors are keyed and spring-loaded, thus minimizing the degree of expertise required of the person doing the connection. The stainless variety produces typical attenuations of 0.3 to 0.8 dB (7% to 17% loss) in the 125 micron fiber size. With larger fibers, the attenuation will be even less as alignment tolerances become less critical. To avoid focal ratio degradation, one will have to pay careful attention to avoiding stress on the fiber end as it is glued into the connector ferrule. The use of selected low-shrinkage epoxies should solve this. Multi-fiber connectors are available, but are quite lossy. Since the STC connectors are only available in single-fiber versions, one will have to unplug 20 STC connectors (similar to unplugging 20 BNC-type connectors) when demounting LRIS. These connectors can be unplugged and reconnected at least 500 times without any increase in attenuation. Five spare fibers will also be included in the bundle in case of breakage. Considering typical losses in the connectors, and the 50 meters of fiber length, the total loss in the fibers should be not more than 20% or so in the red, and almost certainly not as bad as 50%.

Once inside HIRES, the fibers will end in a fan-shaped pseudo slit at the focus of a simple spherical mirror. This mirror collimates the f/4.4 beams from the fibers and directs them to the echelle. Figure 6 shows the fiber collimator scheme. The fiber collimator assembly is normally stowed above the input beam to the normal collimators and is simply lowered into place when used. The spherical collimator mirror functions simply as an f/4.4 Schmidt camera without a corrector, and with its center of curvature (entrance pupil) near the echelle. The spherical aberration of the collimator yields an image diameter of about 148 microns (enclosing 100% of the light), about one-half of the fiber diameters, and should thus not significantly degrade the image quality, but ray trace studies need to be carried out here.

The fiber collimator is a single concave spherical mirror made of fine annealed Pyrex approximately 20 inches in diameter by 4 inches thick. As with the normal collimators, the front surface will be diamond generated to the specified radius of curvature, ground on a ceramic radius tool and polished to test plates and interferometer tests at the radius of curvature. The figure can be made as acccurate as deemed necessary to produce the desired image, with 1/8 wave sphericity considered routine. The size of this collimator will make figure tests a little more involved and time consuming than with the normal collimators, but is still quite straightforward.

The fibers will be separated by 2-4 times their own diameter. At a conservatively wide spacing of 3.5 equivalent arcsec (each fiber being 1 arcsec in diameter) there is room for about 97 fibers across the full width of the CCD. A pair of 2" by 0.1" interference filters in front of the fiber-fan will provide the capability of isolating a single order if more than 5-7 fibers are required at once. One will have to special order these filters tailored to each order isolation task, and since the beam through these filters is fairly fast, the effects of beam divergence and tilt will have to be factored into each filter design. Using two 2" filters (instead of one 4") makes the filters easier to purchase, and allows one to remove some of the beam tilt (caused by the curved fiber fan) by tilting each of the filters slightly. A shutter will also be provided.

One could imagine many different ways of configuring the fiber input to maximize scientific information for a particular task. Isolation of full individual orders is hard with interference filters, especially in the blue since the orders are closely spaced in wavelength and filters do not cut off sharply, particularly in fast beams. So there can be contamination from adjacent orders. If one needs to get a full order, one could imagine using a somewhat broader filter, that accepts 2-3 orders, and the cross-disperser, and then spacing out the fibers to allow room for these orders in the cross-dispersed mode. The cross-disperser would provide clean order separation for adjacent orders, and the interference filter would get rid of distant orders. Thus at one location on the detector, there would be several orders from one fiber. Separated from this would be the same several orders from another fiber. One might even be able to interleave orders and fibers cleverly to maximize spectral coverage.

Since order separation varies with wavelength, one would need to be able to optimize the fiber separations for the particular problem. Thus, the placement of fibers in the collimator fan should be reconfigurable, i.e. a qualified technician should be able to reposition fibers in the fan to suit the needs of each observer's program. If engineered properly, this reconfiguring should only require a few minutes for 20 fibers. Eventually, when HIRES gets its own fiber positioner, we can just fill up the fiber fan with fibers and do this reconfiguration in software at the Autofib end.

The beams from the fibers suffer vignetting at various places down the optical train. The block holding the fiber fan vignettes about 1%. Vignetting is small at the echelle since it is near the center of curvature of the collimator, and this vignetting is masked anyway by other vignetting further down the optical train. The Schmidt camera's corrector vignettes about 6% of the No. 1 fiber's beam on the way into the cross disperser, and 8% of the No. 97 fiber's beam on the way into the camera. The vignetting source of most concern is the CCD dewar at prime focus of the Schmidt. This vignettes some 15% of the on-axis fiber's beam (assuming the intensity to be uniformly distributed across the beam). Typical overall vignetting for the fibers will thus run about 16% for the central fibers, and 23% for the end fibers. The vignetting problem is not really all that bad anyway since each fiber will have a well-known total throughput, and the program objects (which are generally all of different brightnesses anyway) can be sorted among the fibers to minimize exposure differences, or in whatever way is required to maximize scientific information.

Flat-fielding of fiber exposures will be aided by dithering the cross disperser or non-disperser during the exposure on the flat field source. Dithering could also be done if desired during the exposure on the target objects to provide the equivalent of 'trailed' spectra which sometimes aids in higher S/N work.

Wavelength calibration of the fibers will require that the LRIS instrument provide a Th-Ar hollow-cathode lamp source in its calibration lamp complement. Presumably, the LRIS fiber flat-field lamp source will suffice for HIRES's fibers.

In addition to feeding the fiber collimator with a bundle from LRIS, it would be possible to use the many other unused fiber slots for other fiber feeds. A daylight fiber feed might be useful for instrument stability and set-up checks. Also, the fiber collimator might prove very useful for stellar seismology, using a bundle of fibers from a 'dense-pack' slicer/scrambler near the HIRES slit. The fiber-bundle slicer/scrambler at the spectrograph input could be a bundle of 7 fibers, each 100 microns in diameter, with 10 micron cladding. The input end of the slicer/scrambler would then be a circular 'densepack' array of fibers, with a diameter of 1.2 arcsecs and a filling factor of about 58%. At the output, the fibers would be arranged along a line in the fiber collimator fan, forming an effective narrow 'slit' for higher resolution. At each end and at the middle of this line of fibers could be fibers piped in from a Th-Ar hollow cathode lamp. These Th-Ar fibers would be used to accurately track instrumental instabilities at the meter/sec level to allow extremely accurate relative radial velocities of the star to be obtained.

This effective output slit (stack) of some 10 fibers would be 1.3 pixels wide by 25 pixels tall at the detector. Assuming 27 micron pixels and 20 micron rms camera images, the resolution would be about 59,000, not as high as one would optimally like, but high enough to take a serious shot at stellar seismology. With the CCD masked so that only half the chip is used for recording spectrum, a rapid frame-transfer readout mode becomes possible, which maximizes the observing duty cycle. In the frame transfer mode, the spectral coverage would be from 4700 Å to 5900 Å with the **'Red'**cross-disperser. Again, the cross disperser is not really optimized for seismology since it provides more order separation than necessary, but one will still get at least 1200 Å of spectrum in one shot.

2.3.5 Echelle

There will eventually be provisions for several echelles, though only one is included in the core instrument. The echelle will be replicated from a new (custom) master ruled on the rebuilt MIT 'B' engine at Milton Roy Company (formerly Bausch and Lomb, Inc.). Milton Roy can now rule echelles in sizes up to 12"x16", so with a 12" collimated beam, one needs to mosaic in only one dimension. The core echelle will be a 1x3 mosaic of 69° blaze angle (R-2.6) echelles, about 12"x48" in total size, and is shown in Figure 7. This will require a new master, with about 46.5 gr/mm, a groove spacing which has been optimized to bring the maximum number of astrophysically interesting wavelengths near blaze center. The final choice of echelle ruling density may also wait until the exact detector format is firmly established.

Milton Roy recently (May, 1988) completed the successful ruling of a large (12" x 16") high quality grating from its rebuilt B engine. This was a 632 gr/mm 57° blaze angle grating for Zeiss which came out perfectly. It achieves theoretical resolution and has virtually no ghosts. In particular, the previous 'tool bounce' problem which produced modulation along the grooves of coarse echelles, and hence cross-grating scattered light problems, has been solved.

The echelle will be used in-plane, with $\theta=5°$, and will yield a nominal resolution of 39,000 with a typical 1.0 arcsecond wide slit. It is equivalent in throughput to a 16" beam R-2 echelle system, and, *unlike most previous astronomical echelle spectrographs, suffers no vignetting at the echelle.*

The echelle mosaic will be totally passive, and, once aligned in the optical shop, should never need realignment. We are currently experimenting with a mosaic mounting scheme which seems to offer adequate longterm stability. To insure that there will not be any mismatch between groove spacings of gratings, all gratings will be replicated onto zerodur substrates at a controlled temperature.

All grating blanks are made of Schott Zerodur, measuring 16.5 inches by 12.6 inches and approximately 3 inches thick. Three Echelle Replica blanks and two Cross Disperser blanks will be fine ground before the back support holes are drilled and undercut in each piece. The Master blanks, one each for the Echelle and the Cross Disperser, will not require holes. The parallelism of the front to the back surface on the blanks will be roughed-in during grinding, measuring mechanically. Each piece will be ground individually to a uniform thickness. A polishing machine with a 60 inch diameter table will be modified and used to polish each piece in a ring polisher fashion, weighting to adjust the front to back wedge to < 60 seconds. The flatness will be on the order of 1/10 wave, using a 6 inch aperture plano interferometer to monitor figure and parallelism. Zerodur spacers will be used as platforms between the sub-plate and back surface of the grating blanks for adjusting the grating surface alignment. These will all be a uniform thickness and plano-parallel. A study of this grating configuration concept was performed that illustrated the feasibility of the design. It was found that four 6.5 inch by 8.5 inch blanks could be attached to an aluminum sub-plate and adjusted with a maximum misalignment of the segments of 0.6 arcsec, as measured interferometrically, and remained stable and aligned over a many month period of time in any degree of tilt or rotation.

The difficult aspects of manufacturing include: figuring rectangular shaped pieces to 1/10 wave flatness out to the edges and corners; and meticulous final alignment adjustments on the spacers when the blanks are assembled as a whole on the subplate. We will be repeating the methodology learned and used on the Mosaic study.

2.3.6 Cross Disperser

The core instrument will include only one cross disperser called **Red/Blue**. **Red/Blue** is a 300 gr/mm grating, blazed at 7000 Å in first order (**Red**), and at 3500 Å in second order (**Blue**). It gives just enough order separation at all wavelengths for threshold work, but still allows for a reasonable amount of wavelength coverage per exposure. Separate red and blue first-order gratings would have been preferable here, but using a single grating in different orders is almost as good and costs half as much. However, to satisfy a large variety of scientific interests, a large number of cross dispersers will eventually be required.

Figure 8 shows a view of the cross disperser mosaic. The cross disperser will be 2×1 mosaic of custom ruled 12" by 16" low blaze angle gratings. Each cross disperser mosaic will thus act like a single grating with a groove length of 24", and 16" of ruled length in the grating's dispersion plane. The master for this will also be ruled on Milton Roy's MIT 'B' engine. Milton Roy has now successfully ruled an essentially perfect 12" by 16" 632 gr/mm grating on this engine. Like the echelle mosaic, the cross disperser mosaic will be totally passive, and aligned once and for all in the optical shop. As with the echelle, the final choice of cross disperser ruling density will wait until the detector format is firmly established.

A detailed discussion of the tasks involved in optical manufacture of the cross disperser was given in the preceding section (2.3.5) on echelle mosaicing.

Figure 9 shows the spectral format in the UV/blue. The format is also presented numerically in Table 1. With **Blue**, you get about 1200 Å of spectrum in one exposure. For example, you could cover 3400 Å to 4600 Å in 31 orders, with just under 10 arcseconds minimum order separation. If you move further to the red, the order separation will increase; for example, you could get 3850-5050 Å in 25 orders, with 12.7 arcseconds minimum order separation. The order separation is down to about 8 arcseconds at 3100 Å. One can't get a whole lot more wavelength coverage, because we're in second order with the cross-disperser, so one needs a filter to block first and third orders. This alone limits one to, for example, 3400-5100 Å in one exposure, if the filter cut-off were infinitely sharp. One actually gets 3600-4800 Å.

Figure 10 shows the spectral format in the visible/IR. This format is also listed numerically in Table 2. With **Red**, one gets about 2400 Å of spectrum, e.g. 5250-7650 Å in 24 orders, with 12 arcseconds minimum separation. However, the orders get longer than the chip beyond about 7000 Å, so at 7650 Å the coverage would only be about 91%. Again, moving to the red would increase the order separation and the gaps. One could cover 6450-8850 Å to get Hα and the Ca IR triplet, but the spectral coverage would be about 80% at the red end, and the order separation would be up to about 18 arcseconds minimum.

2.3.7 Non-Disperser (flat mirror)

A flat mirror will be provided for use with the fiber input and/or longslit modes. Normally, this mirror will be stowed. When one wants to use more than 5-7 fibers, or when one wants the highest possible throughput in any single-echelle-order mode, one can manually remove the cross disperser (with the help of a small electric winch) and mount this mirror in its place on the cross disperser rotary stage. This mirror will be coated with the 'holy grail' enhanced silver recipe and will be at least 25% more efficient than the cross disperser at all wavelengths redward of about 3400 Å.

2.3.8 Camera

The core camera will be a prime-focus Schmidt, with a focal length of about 30 inches and with two correctors initially. The camera will be fast, f/1.1 full aperture. A view of two typical preliminary camera designs is presented in Figure 11. With the core R-2.6 echelle and a Tek 2048^2 CCD (with 27μ pixels), a 1.0 arcsecond wide slit would project to 3.1 pixels on the short camera, yielding a projected resolution of about 35,000 (assuming 20 micron images from the camera). The order lengths will fit onto a Tek CCD out to the B band at 6850 Å. The pixel scale perpendicular to dispersion (for long-slit work, for example) is 0.20 arcsecond per pixel, and we will be able to accept up to about a 2 arc-minute long slit (this parameter awaits further detailed ray trace studies).

A large number of camera designs have been explored by the P.I., working with optical design consultant Harland Epps. There are a number of trade-off issues involving cost, wavelength limits, image sizes, etc. which require careful consideration and input from the instrument science advisory team. It is clear that one cannot span the entire wavelength range from 3100 Å to 1.1 microns with a single corrector. The necessary optical glasses for such a corrector are just not available in the required sizes. So the camera will have two correctors at the start, a 'UV/blue' corrector and a visible/IR corrector. Hereafter, we will refer to these as the 'blue' and 'red' correctors.

It was clear that the blue corrector design problem was the most difficult of the two since the index of refraction of glass changes rapidly in the 0.3 to 0.45 micron region. So we first explored the blue camera optical design. Figure 12 shows a sample of blue designs. The short wavelength end was defined by the cosmologically important Be II line at 3130 Å. Clearly, one pays a price for getting that last 200 Å of spectrum below 3300 Å. Most notably, the full-field image quality in the 4400 Å to 5000 Å region suffers significantly as one pushes the UV limit to 3100 Å. One is basically trading off image quality at full field, i.e. do you want your bad full-field images to be at 4400 Å to 5000 Å, or at 3100 Å to 3500 Å. Perhaps at 3100 Å, one is only interested in getting the single Be II line, in which case the line could be moved on-axis by appropriate settings of echelle and cross disperser, and full-field image quality is less of a concern. These types of decisions will involve input from the science advisory team. A number of these blue designs look quite reasonable for HIRES, but it is not yet clear which, if any, will be selected in the final design.

We then took blue design No. 567 and, keeping the same primary mirror and fused silica field flattener, tried to design a matching red corrector. Thus, the user would simply push a button to switch from blue to red, and a new corrector would slide into place. There would be little or no refocussing, and no exchanging of the field flattener.

Figure 13 shows a sample of red designs which mate with the No. 567 blue design. Design No. 6741 is a BK-7 corrector, while No. 2063 is fused silica. Clearly one does not gain anything in going from the relatively cheap BK-7 corrector to the expensive fused silica corrector. Design No. 5789 is an FK01 corrector, and does show significantly better imagery, but the glass is harder to come by. OHARA Glass is the best source for this glass and the largest piece they've yet tried is 14" diameter. We need one 29" in diameter. They are very optimistic about the possibility of being able to make one in the size we need, but would require some up front ($25,000) money for modification of their fine annealing oven to pull it off. This cost would then be recovered as part of the final purchase price. Epps is working with their sales representative on this issue.

Finally, we ran a doublet achromat design (No. 3337) which is shown at the bottom of Figure 13. This doublet consists of FK01 and BaLK3 elements, with aspheres of 0.07" to 0.1" amplitude on both outer surfaces. It would be much harder to manufacture, and not affordable initially, but perhaps could someday be retrofitted into HIRES. Unfortunately, even though image quality could be held all the way down to 3100 Å, these glasses do not transmit well in the UV and so one could not just do away with a separate UV-optimized corrector.

Some high resolution work (up to 70,000-85,000) will be possible, though with much light loss at the slit, and with very restricted wavelength coverage, by using a CCD with 15 μm pixels, such as today's TI 800^2 CCDs. The image quality from preliminary designs of the core camera get as good as 20 μm rms over much of the camera field. With a 0.3 arcsec slit, one should thus be able to achieve a resolution (FWHM) of about 77,000 with 8 orders of 14 Å each at 3800 Å , or with 7 orders of 22 Å each at 6000 Å. Of course, since there will be no slicers in the core, observers will have to accept some slit losses. In 1 arcsec seeing, the 0.3 arcsec slit passes only 25% of the light, and in 0.5 arcsec seeing, it passes 45% of the light. Presently, there are no funds in the budget for an 800^2 CCD, though it might be possible to borrow one from either Lick or Caltech. Likewise, observers will have to buy their own image slicers.

The concave spherical camera mirror is again made of fine annealed Pyrex, approximately 33 inches in diameter by 4 inches thick (the value of 7" on Figure 11 is incorrect). Since the present maximum diameter diamond generating capability in the shop is 24 inches, the generation of the radius of curvature will be subcontracted to a qualified glass machining facility. This mirror will then be ground and polished in the same manner as the collimators and tested interferometrically. The larger size will require more processing time, but follows the usual spherical mirror manufacturing methods.

The two large Schmidt correctors are approximately 27 inches in diameter, with a spherical concave radius and an aspherical convex radius, and a finished center thickness of about 1 inch. Radius generation will again be subcontracted for both sides of both correctors. Though each corrector has different radii and aspherical values, they are both roughly the same shape and of about the same aspherical amplitude. The spherical concave sides are fairly straightforward to manufacture, following the usual procedures and figuring to interferometric tests. To manufacture the convex asphere, the surface is first generated and loose abrasive ground to a Best Fitting Sphere radius. The order of magnitude of departure from the B.F.S. of both aspherical correctors is approximately 0.50 millimeters. This departure will be ground into the surface using calculated wear pattern lap facet shapes designed to systematically and progressively remove glass from the surface, ultimately converging on the desired contour. This process is labor intensive, requiring frequent checks of the removal rate and pattern, and adjustment of lap and machine parameters. These checks will be accomplished with a precision two (or possibly three) axis profilometer being developed by Lick that will be capable of measuring to a fraction of a wavelength of light after calibration against a known. Contour measurements at radial coordinates will be made and compared to the desired contour that defines the aspheric, to arrive at wear patterns to be used in each progressive run until the final shape is converged upon. Polishing will be accomplished with soft pitch on a flexible backing tool, and final testing will incorporate an optical test for cross checking surface smoothness and slope errors.

The aspheric magnitude of these correctors can be described as difficult to manufacture but attainable. The difficulty is determined by the maximum departure from spherical, the surface smoothness required in terms of slope error, overall figure peak-to-valley, and the cosmetic surface finish and roughness specified. In illustration, assuming we can define these parameters nominally as: departure from B.F.S. = 0.513 mm; slope error $\leq$ 2 waves per inch; overall peak-to-valley $<$ 4 waves over the full aperture; Scratch-Dig = 80-50; R.M.S. surface roughness $<$ 50 Å; we can compare these specifications to results achieved in the past or with envisioned achievable results. As an example, the Hamilton Schmidt corrector at approximately 1/2 the diameter of these correctors and about 1/6th the aspheric magnitude was manufactured well within these specifications using the described techniques. It is felt that these techniques, coupled with creative inventiveness and tested with the precision profilometer, will produce the desired correctors.

One final requirement of cutting off an edge section for clearance would be performed with a diamond saw, followed by protective beveling and final testing to assure compliance with figure specifications after machining operations.

The field flattener is a fused silica lens about 4 inches in diameter by about 0.25 inch thick with spherical and aspherical convex surfaces. The spherical surface can easily be manufactured using classical techniques. The magnitude of the aspherical surface has not been finalized, but it is felt that the correction is well within reach of profile polishing techniques and using the profilometer or a B.F.S. test plate for fringe counting to qualify the asphere.

Core Operating Modes

BLUE (Figure 9 and Table 1)

- typical wavelength range per observation: 3400 to 4600 Å
- order separation: 9 to 18 arcseconds
- **Red/blue** cross disperser: 300 gr/mm in 2nd order, λ_b=3500 Å, $\theta_b = 6.0°$
- R×S = 35,000 arcseconds
- maximum practical resolution (Tektronix CCD): 59,000
- maximum practical resolution (TI CCD): 85,000

RED (Figure 10 and Table 2)

- typical range per observation: 4700 to 7100 Å, gaps above 6850 Å
- order separation: 10 to 45 arcseconds
- **Red/blue** cross disperser: 300 gr/mm in 1st order, λ_b = 7000 Å, $\theta_b = 6.0°$

- R×S = 35,000 arcseconds
- maximum practical resolution (Tektronix CCD): 59,000
- maximum practical resolution (TI CCD): 85,000

2.4 Detector Functional Description

The detector of choice for HIRES is the Tektronix 2048^2 CCD with 27 micron pixels. The echelle format and camera focal lengths have been optimized to provide the best match to this detector geometry for the anticipated science.

Since the detector is at the prime focus of the camera, light loss by the centrally obstructing dewar is a serious concern. Figures 14 and 15 show a preliminary layout of a possible dewar scheme for the 2048^2 CCD. The portion of the dewar body which projects into the beam is a coldhead which is about 6" in diameter. This head and its attached spider, coolant line, and electrical wiring vignette about 5% of the on-axis incoming beam to the camera (it actually blocks about 10.8% geometrically, but 5.8% was already lost by the telescope's central obstructions and thus the dewar contributes only a net 5.0% loss of photons). This coldhead is attached via a vacuum-jacketed cold probe to a much larger LN_2 reservoir outside the beam.

In the event that the Tektronix CCD fails to materialize, several less attractive, but still viable options exist. One fall-back option is to mosaic several smaller available CCDs. This approach is being pursued by Oke for the soon-to-be-completed Norris spectrograph. His mosaic approach, which is also described in his LRIS report, uses ten Thomson-CSF TH 7863 CCDs. Each CCD is a 384x576 array of 24 micron square pixels. One could imagine configuring the mosaic to best match the HIRES echelle format, perhaps such that complete coverage of the mosaic area could be achieved in two exposures. Another option is to mosaic CCD's under development at Reticon for Lick. Figures 16 and 17 show some very simple-minded mosaic possibilities in the blue and red with the Reticon CCD. In the blue, for example, one could achieve complete wavelength coverage in 3 exposures. If we were to adopt a mosaic of the Reticon CCD's (which is probably unlikely), we would adjust the echelle ruling density to shorten the lengths of the orders a bit in the UV/blue such that there were no gaps produced by overfilling the CCD in the long direction. These are the sort of games one can play in the final optimization of echelle and cross disperser ruling densities. At this time, it seems pointless to work up a detailed mosaic option since CCD detector technology is changing so rapidly.

The HIRES P.I. is also a co-investigator on a proposed National Science and Technology Center for Faint Light Imagers to be headquartered at Lick. If funded, one of the prime goals of the center will be to develop large format CCD's, either by butting smaller devices, or by scaling up individual chips. Another avenue to be explored by the Faint Light Imaging Center will be to develop large format (50-100 mm diameter) 'pixel-addressable' silicon detectors. In this approach, each pixel will have its own complete amplifier which attaches to the pixel from behind via an Indium bump bond. This approach separates the imaging area of the detector from the amplifier area and thus allows one to separately optimize semiconductor processing for each. Since each pixel is independent, one avoids many of the charge-coupling-related problems which already severely limit yields on present CCD devices, and which become even more acute as one attempts to scale up the detector area. If a pixel is bad, you just lose one pixel, unlike a CCD where a bad pixel, row, or column can destroy large portions of the imaging area. Since these 'pixel-addressable' devices require an amplifier beneath each pixel, it is likely that their pixels will be a bit larger than present 27 micron CCD pixels. Amplifier designs which require only 30 microns have already been explored. Again, it seems wise to balance the HIRES design to use larger pixels in case these detectors become available.

Another option is to use large format (70 mm) Ranicons, MAMA's, or IPCS systems. While such photon counting systems don't have nearly the same dynamic range and wide wavelength sensitivity as CCDs, at the faint limit, for low S/N work in the UV/blue, and/or very long exposures, such detectors are still very competitive in DQE to today's best CCD's. Large format (46 mm) IPCS systems are now under development at University College London. Large format Ranicon's are available but with somewhat larger pixels than optimal. Again, this was one reason for making the short camera a bit longer focal length, in case we have to fall back to detectors with larger pixel sizes. I recently received a price quote on a large (75 mm) format Ranicon from Dr. Mike Lampton of Berkeley Photonics, Inc., Berkeley, CA. They quoted a price of $370,000 for the first turnkey system, including cold box, and data system (interfaced for a Sun 4/110). Each additional tube start would be $43,000. Though Berkeley Photonics would bid only on a 'best effort' basis, they are well experienced with the processing and pretty confident about achieving the following performance characteristics:

- Imaging field diameter: 75 mm
- Overall DQE: 8% (S-20 at 5600Å); 13% (Bialkali at 4000 Å)
- Count rate capability: 100 khz (10% deadtime)
- Spatial resolution: 50 microns (rms), 120 microns (fwhm)
- Digital address pixel size: 32 microns
- Oversampling: 4 pixels/fwhm spot
- Digital image format: 4096 x 4096 pixels
- Delivery: 12 months

Very large format MAMA's are currently under development for STIS, one of the second generation Space Telescope Instruments, and STIS also uses Tektronix 2048^2 CCDs. If the Tek CCD fails to materialize, STIS will develop the MAMA as an optical detector to be used in its place. So there should be considerable support for a large optical MAMA in the event that the Tektronix CCD does not come through.

Finally, a simple though not very attractive option, is to use smaller CCD's now in existence or under development, and accept drastically less total wavelength coverage per exposure, with perhaps less than optimum pixel match. Such an approach largely throws away the main reasons for using an echelle in the first place (i.e. high resolution with wide spectral coverage), but would be reasonably effective for higher resolution studies of individual lines.

In summary, the Tektronix 2048^2 CCD is the detector of choice for HIRES, but in case it does not become available there exist a number of promising alternatives. At present, the best one can do is to delay final specification of the format and detector as long as possible, until detector options become clearer. The match of the echelle format to the detector need not be done until the detector choice is certain. Once known, the final decision of ruling densities for echelle and cross-disperser will be made in consultation with members of the HIRES science advisory team.

2.5 Electronic Functional Description Block Diagrams

A block diagram of the Keck Observatory Local Area Networks (LAN's) and initial complement of instruments is shown in Figure 18. HIRES is essentially a collection of motor-driven devices and sensors under control of a local VME-based instrument controller (target computer). It also has a CCD detector which is run by a local VME-based CCD controller (another target computer). Both target computers are connected to a Sun 4/280S host computer via the scientific instrument LAN. The host computer can be any one of several available at the mountain.

2.5.1 CCD Dataflow

The CCD Controller will be connected to the Sun 4/280S host computer via the scientific instrument Ethernet cable. This CCD Controller will be a VME chassis containing the following cards:

CPU:	Heurikon	HK68/V2F
Ethernet:	Excelan	Exos 302
Memory:	Force	Dram-E4M/s & Dram-E4S12 (16Mb)
Ports, out:	Xycom	XVME-220
Ports, in:	Xycom	XVME-212
DMA:	Ikon	10089
CCD control:	CIT	special design

The CCD data will be transferred via the DMA card to the 16Mb of memory. The Sun can then read that memory via the Ethernet. The clocks for the CCD are generated on the CIT-designed controller card which is connected via a ribbon cable to the dewar. A box on or near the dewar will contain several cards designed by CIT and built by Lick. These cards will provide the clock drivers and signal amplifier for the CCD. The port cards in the controller chassis will control other devices associated with the CCD and not controlled by the special CIT card.

2.5.2 Instrument Control

A block diagram of the HIRES Instrument Controller concept is shown in Figure 19. The Instrument Control electronics will consist of the following units mounted in a 19" rack:

- A VME bus controller.
- Two chassis using Eurobus format containing Galil motor driver boards (ESA-5/75RC).
- An interconnection chassis to allow the control signals from the VME cards to be broken out and routed to the stages to be controlled.
- A VME power supply. This will power both VME chassis.
- Motor power supplies (+28V, 13A).
- Three Opto-22 16-position single channel mounting racks (model PB16T).
- A 3000VA UPS capable of keeping the instrument powered for up to two hours, allowing the astronomer time to go into the HIRES electronics bay and manually request that the CCD dump the image into RAM. This will also keep the clocks applied to the CCD so that it stays alive during the power down.

The Instrument Controller VME chassis will consist of the following cards:

CPU:	Heurikon	HK68/V2F
Ethernet:	Excelan	Exos 302
Motor Cntrl:	Galil	DMC 330-10 (6 cards)
Ports, input:	Xycom	XVME-212 (4 cards)
Ports, output:	Xycom	XVME-220 (3 cards)
Analog logic:	Xycom	XVME-540

The CPU will have the VRTX kernel in ROM and will be running VxWorks. Thus the control software will be written and maintained on the Sun and will be uploaded via the Ethernet link from the Readout Room.

There are at present a total of 13 DC motors used in HIRES to position various stages. As future upgrades are added, more motors will be added. Each motor consists of a 50 inch-ounce motor with an incremental encoder (1000 pulses per rev) mounted on the motor shaft. These motors are purchased from Galil as a package and will be driven by purchased controllers (DMC-330) and drivers (ESA-5/75) from Galil. The motors and controllers will provide a resolution of 4000 pulses per revolution (using x4 mult. on the controller card) and a maximum speed of about 2700 RPM. Some of the stages will require greater precision. In these cases, a second linear encoder with a resolution of 0.0005" is mounted on the stage.

Figure 20 shows a typical stage wiring schematic. One of the control channels of the Galil motor controller card is used to keep track of the encoder position of the second encoder. Each motor that needs limits will have a double set; a primary limit set to tell the logic to stop driving in that direction, and a secondary set to directly break connection to the motor in case the logic fails. In order to calibrate the position of the stage, a fiducial (which is essentially a single bit encoder) is installed on each stage. This is referred to as the rough fiducial. Those stages with a second encoder use the index from the second encoder as a fine fiducial. On power up, or during calibration, the stage will be driven until a transition in the rough fiducial is seen. The direction of motion is determined by the level of the fiducial. When the transition is detected the motor will reverse and, at slow speed, will search for the fiducial edge again. When the second encoder is present, the index of the encoder will be searched for at slow speed. When both of these conditions are met, the encoder counters are zeroed and the stage is considered calibrated. From then on, the CPU can request moves relative to that calibrate point by sending commands to the appropriate motor controller. Local control of the motors is provided via switches mounted on the front panel of the interconnect chassis. These switches bypass all of the control logic allowing the astronomer to position motors in case of total failure of the electronics.

There are a number of AC devices in the instrument; such as 1/2 HP motors, brakes, lamps, and covers. These are driven by solid state relays mounted on Opto-22 control panels. These control panels also contain logic to sense that the devices powered by the solid state relays have functioned.

The input and output ports allow the CPU to sense the state of switches, motors, lamps, etc., and to provide control for those functions not controlled by the motor controllers. These ports are optically isolated from the devices they control to protect the rest of the logic from some failure in an external component.

The Analog logic provides for analog control of the current needed in the Hollow Cathode comparison lamps. It also allows the CPU to sense the status of the various power supplies in the system and the temperature and humidity in the room.

2.6 Mechanical/Structural Functional Descriptions

2.6.1 Slit area

The slit area contains the standard assortment of slit items. (A minimum due to budgetary limitations.)

a.) The slit is bilateral, that is, both jaws move precisely so that the center of the opening remains fixed. The slit length is oriented horizontally and is about 2" long (exact length TBD after further ray tracing). The slit width can be varied from 0 to 1/4" (about 7 arcsec). This is done remotely. The slit is inclined at about 5 degrees so that the light reflected goes to a fixed TV camera.

b.) The decker slide is arranged ahead of the slit and very close to the plane of the slit. This is a series of reflective plates which define the ends of the slit or divide the slit into two or more slits. The TV sees light from all 4 sides of the entrance aperture(s). The decker is controlled remotely. There will be 4-10 positions per plate and perhaps 4 plates. Specialized decker plates can be exchanged manually.

c.) A 6-position calibration lamp stage is located ahead of and above the slit/decker assembly. Each of the 6 positions can have an integrating sphere with up to 3 light sources attached. The individual lamps are remotely controlled. The stage is remotely controlled as well. A feed mirror can be positioned in the light path ahead of the slit to direct light into the spectrograph. This is a remote function using a simple air cylinder. The sources will have a remotely-controlled filter wheel with 12 positions.

d.) An Ilex electronic shutter is arranged beyond the slit. This is for timing all exposures except when using the fiber collimator. Thus, the spectrograph housing must be light-tight and dark. The shutter is the largest made by Ilex, 62mm. We are using 7 of these at Mt Hamilton and UCSC and have found them to be reliable.

e.) There are 2 filter wheels behind the slit and shutter. These are 12 position wheels with one of the positions being a large hole. The rest have holders for standard 2" filters. The filter holders can be loaded with user-supplied filters and the wheels can be exchanged with user-supplied wheels. This is of course done manually. Once mounted, the wheels are rotated remotely.

f.) The TV is a purchased item, probably a cooled CCD camera with a reducing lens. More design work is needed here as the camera selection nears. The remote-controlled features for the TV include: a focus motor with encoder, a shutter, an aperture adjuster, and 2 filter wheels with 6 positions each. The TV looks at the center of the slit/decker and does not move in any direction.

2.6.2 Collimator cells and selector

The collimator mirrors are spherical. This means that alignment is simple as compared with an off-axis parabola. The 2 mirrors are identical except for the coatings. The reflectivity is optimized for the red (red collimator) and for the blue (blue collimator). The fiber collimator is discussed in section 2.6.3. It is not part of this two-position stage. The stage for moving the collimators is remotely-controlled with a 1/2 Hp motor. The drive is not unusual. The stage is about 30" long. Each mirror has its own air-operated mirror cover. Each mirror is aligned in its cell by manual adjustments. We do not expect any realignment to be required after initial alignment at UCSC or after re-aluminizing. The blanks are Pyrex to reduce costs. (Zerodur would be preferred.) The axial support is a standard 3-point support (the mirrors are 17" in diameter) and the radial support is a temperature-compensated steel cell and delrin block design. (See TMT Technical Note #28, Nelson)

It is important to point out that we will be focusing the spectrograph by moving the detector and not the collimator as is commonly done. (There are 3 collimators to focus.) The collimators will be focussed manually during the test and integration stage.

2.6.3 Fiber collimator

The fiber collimator uses fibers which originate in the Low Resolution Imaging Spectrograph (LRIS). An initial 20 fibers will be used and dedicated to HIRES. In this mode, guiding is done with the LRIS TV system.

The bundle of fibers will be disconnected from LRIS to allow LRIS to be removed from the telescope. A bank of 20 low loss STC connectors will be arranged near the electrical disconnects at the Cassegrain cable wrap. It is 50 meters from the top of LRIS to the fiber collimator in HIRES, and the fibers must go through 2 cable wraps. The fibers will be flexing during exposures. The shutter for exposures will not be the HIRES slit area shutter. This shutter will be more like a fast darkslide which flips into the beam just after the fiber block. The fibers are arranged in a line. See Figure 6. The collimator mirror is spherical and is located so that its radius of curvature is close to the Echelle to minimize light loss. (The exit pupil for the collimator is 14" short of the Echelle.) The final complement of fibers might be 80 to 120 depending on the optimum spacing to fit the detector. The filters go near the shutter so that they can be small. This is not ideal but the angles are no more than 3 degrees from parallel light. These filters have to swing remotely into and out of the beam.

The assembly of fibers, fiber block with its spider support, and collimator mirror and cell is mechanically held together as a unit and is moved remotely into and out of position with a 1/2 Hp motor. This is a fairly straightforward thing to do. The fiber collimator will initially be focussed during integration and testing. The final focus is again done by moving the detector. It may be necessary to include dummy interference filters in the beam to keep the fiber collimator from defocussing when not using interference filters. Alternatively, there may be enough focus adjustment at the detector to compensate for this. Further ray trace studies are required.

2.6.4 Echelle cell and mount

A mosaic project was done in 1986 and 1987 to demonstrate the feasibility of using a passive support system for a 2 by 2 mosaic of grating blanks. This was successful. The HIRES Echelle is a 1 by 3 mosaic. (See Figure 7). The blanks are 12" x 16" and 3" thick. They are zerodur and the echelle rulings are replicated from a custom master blank by Milton Roy.

The blanks will be machined at UCSC. Holes will be installed on the back and sides. Then the front and back will be polished flat. The supports are glued into the various holes. The adjustments will be made to bring the 3 blanks into coplanar alignment. A Zygo interferometer will be used. We feel that 1/4 arcsecond tolerance can be measured easily. (The 1987 tests showed that less than 1/2 arcsec was seen for 0 to 90 degrees rotation.) Then a series of flexure and temperature tests is planned. Once the mosaic concept is proven, the blanks will be sent out for replication. After this process, the finished gratings will be realigned, since Milton Roy cannot guarantee that the rulings will be in the same plane as the original front surface. The alignment will also deal with the rotation of each grating and bring the ruling axis into alignment with the mosaic pivot axis. This alignment will probably be done with a long focal length lens and a sensitive detector monitoring the resultant composite spectrum (actually 3 spectra).

The gratings are not cleanable, so dirt accumulation is a serious concern. For this reason, the Echelle mosaic is "down-looking." A remote-controlled dust proof cover will also be provided.

The largest range of travel required is plus and minus 2.8 degrees, to accommodate the Ultra High Resolution mode (UHR) which may be implemented some day. This means that the change of the gravity vector will be small.

The rotator will be built such that echelle mosaics can be exchanged. Each mosaic will weigh about 600 lbs. We are considering this as a manual exchange and allowing room for lifting equipment and a rail system similar to that used in the coude spectrograph at McDonald Observatory.

2.6.5 Echelle rotator

A small DC motor/encoder will move the Echelle grating and its pivot will not be at the center of the ruled surface. Instead, since the travel is small, a pivot with mechanical flex joints will be arranged near the rigid cell support points. The motor will move only plus and minus 2.8 degrees. The position will be found in software since there is no rotary encoder at the grating pivot axis. Ten arcsecond resolution and repeatability will be needed. An air-operated brake will be applied to maintain the grating position during calibration and exposure.

2.6.6 Cross disperser cell and mount

The cross disperser is a 2 by 1 mosaic. (See Figure 8). The support, cell, cover and alignment are similar to the Echelle. The rotator is a bought item: an Anorad rotary table. The table will be mounted with its pivot axis 12.5 degrees from vertical. The front surface of the grating mosaic will be aligned with the turntable centerline. The travel will be at least 30 degrees in both directions. An air-operated brake will be used.

The cross disperser assembly will weigh about 400 lbs. For the single-echelle-order fiber mode, the cross disperser will be removed manually with lifting equipment and a flat mirror will be mounted on the rotary table in its place.

2.6.7 Cross disperser rotary table

The Anorad table comes with a 3.5 arcsecond incremental encoder. This will encode the cross disperser directly. The chosen table has a 1000 lb. capacity along the axis and 350 lbs. in the other direction. For future upgrades, a carousel of up to 8 cross dispersers is planned, and might have one of these rotary tables at each carousel location. The carousel would eliminate manual grating changes. The fiber mode requires a "dither" motion. This will be done with the cross disperser rotary table.

2.6.8 Non-disperser cell and mount

This is a flat mirror for use with the fiber collimator. It replaces the cross disperser grating mosaic and is positioned so the mirror normal is 20 degrees to the Echelle and 20 degrees to the camera axis. The flat is 24" in diameter with the bottom "ear" cut off (to minimize the distance to the rotary table). The cell uses a kinematic support with provisions for aligning the mirror. A protective cover is fitted to the cell. This is operated by a remotely controlled air cylinder. The core instrument will require manual changing of the cross disperser and cell with the non-disperser (flat) and cell. Kinematic mountings will be used for repeatable coupling of each cell to the rotary table. Future upgrades include a carousel with 8 positions. One of the positions will be this non-disperser mounted to its own rotary table.

2.6.9 Camera

The camera is a prime-focus Schmidt design. The detector is mounted at the prime focus which is inside the camera and thus blocks light. There are 2 corrector elements: a red and a blue. These are about 27" in diameter. The camera mirror is about 33" in diameter. The correctors are fused silica and the camera mirror is Pyrex (to save money). The camera is detailed in Figure 11. The focal length is 30". Focusing of the spectrograph is done by moving the detector on its stage. The camera mirror and corrector remain fixed. For future cameras (only the 80" has been designed) the detector and corrector positions will remain fixed and the camera mirror will be located its focal distance away from the detector. This approach requires a precision mechanism with a very short travel for the detector. The core instrument will include a lift mechanism for the 30" camera mirror to allow access to a future 80" camera. This will operate remotely.

2.6.10 Detector mount

The detector is planned to be a Tektronix 2048^2 CCD with 27 micron pixels. The spectrograph has been optimized for this chip. Alternative detectors are being explored. The CCD will be cooled with liquid nitrogen or liquid air, whichever is available at the observatory. The plan is to operate the CCD at -120° C. The dewar is as small as possible since it fits inside the camera and blocks light. Figures 14 and 15 show preliminary dewar drawings. The present dewar design uses a 0.2" thick 4" diameter sapphire window. The 4 spider support arms are small. One of them contains a vacuum-jacketed cooling bar which connects the CCD with a liquid nitrogen container. The electronics box will be 20" away from the CCD so certain electronic components will be located beside or in the dewar. The CCD controller box will be 10 feet away in an insulated room.

The dewar and spider structure are mounted on a precision stage which is driven remotely. There is a linear encoder on the stage for position information. An air-operated brake will be used for clamping the stage. The resolution of this focus stage is on the order of 10 microns. The total travel will probably be less than 5 mm.

2.6.11 Instrument Frame

The instrument frame is a triangular weldment of steel boxbeams with bolted joints similar to the telescope yoke structure. A schematic of the frame was shown in Figure 3. The frame is fastened to 3 smaller structures which each pick up 3 of the attachment posts on the Nasmyth deck (3 M12 screws). The small structures can each be moved independently to allow alignment of the spectrograph with respect to the elevation axis. The main supports are kinematic: one spherical joint, nearest the slit; one cylindrical joint, near the collimator; and one planar joint, near the future 80" camera. This allows the Nasmyth deck to change shape without disturbing the internal alignment of HIRES. As much as possible, we will be building "hooks" into the frame for future expansion, though this can never be completely successful since we don't know what all of the possible future mechanisms will look like.

2.6.12 Instrument Enclosure

We have selected a Bally modular enclosure to house HIRES. Figure 21 shows a view of the Bally enclosure system. Its function is to provide a long time constant for thermal changes, to keep the optical components clean and to provide a dark box to operate in. Since this is a stripped-down version of the deluxe HIRES, we expect a lot of human traffic inside the enclosure. Thus we will provide a clean room interlock with sticky mats for shoe cleaning.

The Bally enclosures are double wall modular panels which are foamed in place with urethane. The wall, floor, and ceiling panels are all 4" thick. The panels use cam-lock joining mechanisms for assembly so that HIRES can be built and operated at UCSC, disassembled, shipped and then re-assembled easily. Pre-shipment testing at UCSC can be done at typical Mauna Kea (0° C) temperatures.

There will be a fan and filter to provide a positive pressure inside the enclosure. This will help keep HIRES clean. The building is 18 ft by 14 ft and 11 ft tall. The outer skin can be painted any appropriate color. The ceiling can not carry loads. We expect that the ceiling can be removed for installing large pieces. The smaller pieces can go through the 6 ft wide by 8 ft tall sliding door. Human access is via a standard size, insulated door after first traversing a clean ante-room. There are lights and convenience outlets for occasional use.

A separate insulated compartment will be provided for the electronics equipment. This room will be maintained above 0° C to protect the electronic components.

2.7 Physical Characteristics

The core weight will be around 12,000 lbs. Future additions will increase the weight but will stay within the 20,000 lb. design limit. The enclosure measures about 18' by 14' by 11' tall (see Figure 21).

2.8 Mechanisms

2.8.1 Access Port

The access port is a hatch to cover HIRES at the entrance to the slit area. This is to keep the HIRES slit area clean when not in use and to allow HIRES to use its calibration lamps while other instruments are scheduled on the telescope. A remotely-controlled solenoid-actuated air cylinder opens the hatch. The solenoid will be driven by a solid state relay and will have two limit switches to indicate to the CPU the status of the access port.

2.8.2 TV Mechanisms

There are two TV filter wheels, each being 12 position wheels with one blank hole. Neutral density filters go in one wheel and colored filters go in the other. These are user-changeable manually. The wheels are remotely operated. Focus and aperture adjustment of the TV lens are remotely operated with readouts. The user determines best focus. A shutter is also provided for the TV camera. The shutter is made by Ilex and is controlled by a Lick-designed shutter controller. This controller is presently used on all shutters at Mt. Hamilton. The control for the shutter is provided by one of the I/O ports. The shutter provides a switch to indicate when it is open. The focus and aperture have limits while the filters do not need them. There is one rough fiducial for each motor (for calibration). Further discussion is in section 2.6.1.

2.8.3 Calibration lamp stage, filterwheel and feed mirror

The calibration lamp stage is a 6-position linear stage. Each of the positions can have up to 3 lamps. The lamps or hollow cathode tubes are all remotely controlled. A single filter wheel is provided with 12 positions. It does not move with the stage. Position encoding is via the incremental encoder on the motor shaft. A feed mirror moves into position to send calibration light into HIRES. Lenses will be required to produce an F/13.7 beam of light. A spinning wobble-block may be required to achieve long slit illumination. Further discussion is in section 2.6.1.

This stage has two motors; one to position the lamps, and one to drive the filter wheel. Fiducials are provided for both motors, while limits are provided for the positioning motor only. The feed mirror is driven by a solenoid. The stage contains, at present, 3 quartz lamps, 1 mercury lamp, 1 laser, and 3 hollow cathode lamps. The quartz lamps are driven by 5V, 20A power supplies which are controlled by solid state relays. The output of each of the power supplies is sensed by a logic module and returned to an input port on the VME bus. The mercury lamp and the laser are driven directly by solid state relays controlled by ports on the VME bus. Each has a 100VAC sense module to report back to the ports the status of the lamps. The hollow cathode lamps are driven by a special Lick-designed controller (identical to one used in the Hamilton spectrograph at Mount Hamilton). This controller sets the current in the lamps to correspond to a command sent to it by the Analog I/O module on the VME bus. The controller returns the value of the current actually present in the lamps to the Analog module.

2.8.4 Slit

The slit mechanism was discussed in detail in section 2.6.1. The slit stage contains one motor and has two encoders; one on the motor shaft, and one on the stage. The slit is protected with limit switches. There are two fiducials for calibration; a rough fiducial and an index from the stage encoder.

2.8.5 Decker

The decker mechanism was discussed in detail in section 2.6.1. This stage contains one motor and its associated encoder. The stage is protected with limits, and a rough fiducial is provided for calibration.

2.8.6 Filter wheels

These were also discussed in section 2.6.1. This stage contains two motors and their associated encoders to position two filter wheels. No limits are needed. A rough fiducial is provided for each motor for calibration.

2.8.7 Collimator selector

The collimator selector was discussed in detail in section 2.6.2. This stage is driven by a 1/2 hp motor that moves between two limits. The motor is controlled by solid state relays which are driven by ports on the VME bus. In addition, a brake is provided to keep the stage in position, and two covers for the mirrors are provided. Each of these is driven by solid state relays which are controlled by ports on the VME bus.

2.8.8 Fiber collimator stowage

The fiber collimator and fiber block are moved as a unit into and out of the light path leading from the slit to the collimator mirror. This was discussed in section 2.6.3. The fiber collimator unit requires a 1/2 hp motor which drives to two positions, several filters which are solenoid operated, and a simple shutter which is also solenoid operated.

2.8.9 Echelle rotator

The Echelle rotator was discussed in detail in section 2.6.5. The electronics for this stage are similar to the slit stage. In addition a brake and cover are provided; both driven by solid state relays.

2.8.10 Cross disperser rotator

The Cross disperser rotator was discussed in detail in section 2.6.7. This stage is controlled in a manner identical to the Echelle Rotator except that there will probably be no brake on this stage.

2.8.11 Cross disperser exchanger

The core instrument will not have a cross disperser carousel. A single rotary table will be provided. A single cross disperser mosaic in its cell will be fastened to the rotator. For fiber work or longslit work, a flat mirror will be mounted on the rotator. The exchange is done manually, as is done in the coude spectrograph at McDonald Observatory. An overhead rail and lifting hoist will be built into the HIRES structure. The cross disperser will be moved and stored when the non-disperser, or flat mirror, is to be used. The air line for the covers will have a quick disconnect. There are no electrical disconnects. The attachment to the rotary table will be kinematic and hence, repeatable. There will not be any hand tools required to do the exchange. Hand-operated knobs and locking levers will hold the cross disperser and cell in position. The manual exchange of cross-dispersion will be done only by trained observatory personnel.

In the future, when more cross dispersers become available, an automated carousel mechanism will be installed for cross disperser exchanging.

2.8.12 Corrector selector

The short camera (30" focal length) will have both red and blue correctors. These are large lenses (about 36" in diameter including their cells). The correctors are to be positioned remotely. Each corrector has a mechanical slide and 1/2 Hp motor for moving it. They are designed to slide the correctors into the exact same position. Interlocks and safety switches will be used to prevent damage.

The lenses do not have covers, but will probably be stowed in protective housings. When each lens is in its operating position, it will be defined by a kinematic set of stops. The motor provides a spring force at the end of the slide travel. This has proven reliable with previous optics of this size.

2.8.13 Camera stowage

The 30" camera mirror will be lifted to clear the light path for the 80" camera when it is built. We feel that it is best to design this function for the core instrument rather than wait and try to redesign the mirror mount later. The camera stowage function will never be used until the 80" camera is installed. This is also discussed in section 2.6.9.

2.8.14 Detector mount

The detector mount was discussed in detail in section 2.6.10.

2.9 Power

All of the electronics for HIRES, with the exception of the motors, encoders, and solenoids, are mounted in a single 19" rack contained within a small thermally insulated room. The power for this rack is normal 110VAC provided via an Uninterruptable Power Source (Deltron model TP30 S12A). Over the past several years at Mauna Kea, there has been a loss of power about 12 times for an average of 2 hours each time. Even though the power to the telescope and the data taking computer will be lost, it is highly desirable to keep power supplied to the electronics controlling the instrument during a power outage. This UPS will be able to continue to supply power to the instrument for approximately 2 hours. This will keep proper signals applied to the CCD and proper alignment of the stages until the power can be restored. In the case of a crucial exposure being in process when the power is lost, the astronomer will have time to go to the electronics rack and manually request the CCD to dump an accumulated exposure into the VME memory for storage until power is restored. The electronics bay is separate from the HIRES enclosure and can be entered from the outside, so this can be done without disturbing the spectrograph.

The input line voltage to the UPS will be monitored by the two VME computers. When they sense a power loss, they will know that communications with the Sun host will be lost and that power for them will remain for about 2 hours. In the event of a power loss that exceeds 2 hours in length the VME computers will shut down gracefully. The memories in the two VME computers will continue to be supplied with battery backup for about an additional 4 hours if necessary, so that valuable data and position information will be preserved. Hopefully, a method for preserving the CCD clocks for this period will be found as well.

2.10 Thermal

HIRES will be enclosed in an insulated room 18 ft by 14 ft by about 11 ft tall. Electrical power consumption (and heat dissipation) will be less than 1500 watts and this can be adequately carried away by the freon cooling system available at the Nasmyth platform.

2.11 Control

This was discussed in Section 2.5.2.

2.12 Data Handling

This was discussed in Section 2.5.1 and will also be discussed in Section 4.0.

2.13 Alignment/Calibration

All internal alignment/calibrations of HIRES will be done at the Lick labs. and we feel that disassembly, shipping and re-assembly at Mauna Kea will not change the alignment or calibration significantly. Standard pinning and clamping procedures will be used at all mechanical joints. Any minor residual internal realignment and calibrations will be done as necessary during the first 6 months of observing.

Alignment to the elevation axis will be done at the telescope. The frame of HIRES can be adjusted until dial indicators mounted on a stub axle and bearing on a metal pin located at the slit indicate zero runout. This metal pin is a tooling device used to do the internal alignment during construction and initial assembly. The pin is removed and an alignment telescope located behind the collimator mirror is used to find the reflection of the secondary mirror in the tertiary mirror (the collimator mirror is removed for this). The frame is now moved at its furthest end up and down and side to side, pivoting about the slit end, until the center of the secondary mirror is in the cross hairs of the alignment telescope. A second iteration will finish the alignment. We are not concerned about the last two adjustments, namely focus and rotation about the optical axis. *The alignment will be simplified if the 32 attachment points on the Left Nasmyth deck are well-surveyed with respect to the elevation axis, and the information available by February, 1990.*

2.14 Autoguider Finder

Target acquisition and guiding will initially be done with a simple fixed CCD TV camera staring at the slit, guiding at 0.125 arcsecs per pixel on light reflected off the slit/decker jaws. Though this will make autoguiding harder than if using an offset guide star, it should prove adequate for most needs, and saves the expense of adding another TV camera and motorized stage for offset guiding. Guiding directly off the object as it enters the HIRES entrance aperture will generally require that either a decker or an aperture be used above the slit to provide reflected light for guiding to keep the object from wandering along the slit. Thus, an object and its associated sky spectrum will have to be isolated with separate apertures. This will not be quite as good as holding the object at the center of a long decker and thus being able to take sky information right up to and under the object from both sides, as would be possible if one had an offset guider system.

The exact choice of the TV camera will not be known for some time and is being postponed as long as possible. Figure 22 shows the present Lick CCD TV guide camera, which is one potential option. It uses a Canon 85 mm f/1.2 lens and a GEC CCD. We can imagine a very simple and relatively inexpensive TV camera for HIRES, based on the Lick camera and Canon lens. Figure 23 shows the optical layout. The image scale at the CCD was set to be 0.125 arcsec/pixel, high enough power for guiding directly on light reflected off the slit. The CCD was assumed to have about 400 pixels of 22 microns (about what you get with the GEC or TI virtual phase or Thomson CCD's). The field covered at the slit is then about 50 arcseconds in the longest direction. There is no vignetting over this full field with the Canon lens. Of course, the field is too small to do much in the way of offset guiding, but it should almost always be possible to guide directly off the program object anyway. If a decent offset guiding system is later required, a second TV off to the side, mounted on an x-y stage, with intelligent control can be added.

A filter wheel is also required, near the TV camera focal plane for bandpass control. Another filter wheel containing neutral density filters might also be highly desirable since one could imagine requiring a dynamic range of some 22 magnitudes from brightest to faintest sources. Control of the lens aperture would also help here. The camera would probably require cooling to allow deep exposures. The dark current should be below 2 electrons per pixel per second. A shutter should also be provided to allow a staring mode for deep imaging.

Since HIRES has no direct imaging mode, it will be highly desirable to have the ability to record the TV image for later use by writing it on one's data tape as though it were just another CCD image from HIRES. An on-line hard-copy facility for such TV frames would also be enormously useful. For remote observing, we will include a TV frame-grabber/transmitter so that the TV image can be sent over the phone lines to a distant remote observer in essentially real time. For $650, such devices are available which can grab and transmit a 256 x 244 x 6 bit image in about 20 seconds at 19,200 baud. This should be adequate, as long as autoguiding is handled locally.

In the fiber mode, HIRES will be using the TV system of the LRIS instrument.

2.15 Instrument-Provided Support Equipment

A 150-200 liter LN_2 dewar will be provided, along with an insulated hose to fill the HIRES CCD dewar. This dewar will sit next to the HIRES enclosure and will require refilling by observatory personnel perhaps weekly or monthly.

Custom containers will be provided for all optical components, and some principal mechanisms. The optical containers will be required for periodic re-coating and cleaning of mirrors, etc. Any required handling fixtures for maintenance of the optics will also be provided.

Various alignment fixtures and calibration aids will be provided as needed.

2.16 Operational Characteristics

All mechanisms except the exchanging of cross-disperser with flat mirror, loading of the user's custom interference filters in the fiber collimator, and positioning of fibers in the fiber collimator fan, will be under computer control. The instrument control system will monitor and display the status of all such mechanisms, and will display this information on the user's screens.

Both LRIS and HIRES controllers will have the same display and control words. Each instrument will have a unique computer-readable code so that programs in any of the instrument computers can run any of the optical instruments. To the user, the optical instruments should look quite similar.

In case of power loss, a UPS will keep HIRES's mechanisms and CCD detector powered up for up to two hours, allowing the astronomer time to dump any exposure in progress into RAM, and perhaps to ride out the outage without having to recalibrate any stages.

All HIRES mechanical functions can be tested and controlled from any instrument computer at the mountain or in Waimea, or from the mainland via a 9600 baud dialup.

LN_2 will be replenished automatically in the CCD dewar by a level-sensing feed system. A larger external LN_2 tank will require refilling perhaps weekly or monthly.

3.0 Description of Instrument to Observatory Interfaces

3.1 Mechanical

A schematic of the HIRES support frame and kinematic support system was shown in Figure 3. The frame is fastened to 3 smaller structures which each pick up 3 of the attachment posts on the Nasmyth deck (3 M12 screws). The small structures can each be moved independently to allow alignment of the spectrograph with respect to the elevation axis. The main supports are kinematic: one spherical joint, nearest the slit; one cylindrical joint, near the collimator; and one planar joint, near the future 80" camera. This allows the Nasmyth deck to change shape without disturbing the internal alignment of HIRES.

3.2 Power

The total power consumed by the electronics in HIRES is typically 600 Watts. If all motors were to be in motion at the same time (at full speed) the power would rise to 1300 Watts for that period of time (which would be very short). Thus the instrument will consume about 6A (12A max) from the 110VAC provided by the observatory.

We will need compressed air at 100 PSI and about 10 CFM to power air-actuated devices.

3.3 Thermal

The electronics in the VME chassis puts out about 600 watts of heat and thus requires cooling to avoid dumping that heat into the dome. Also, the electronics are only specified to operate down to 0°C. Thus, in addition to cooling, it will be necessary to keep the electronics from going below about 5°C. Observatory-supplied coolant will be used in a small cooler mounted in the electronics rack. Temperature sensors in the rack, and solenoids controlling the coolant flow will allow the VME computer to keep the temperature above limits and fairly constant. The 600 watt load is well below the available capacity of the observatory coolant system.

3.4 Control

This was discussed in Section 2.5.2, and will be further discussed in various subsections of Section 4.0.

3.5 Data Handling

This will be discussed in Section 4.0.

3.6 Support Equipment and Facilities

It is assumed that the observatory will provide facilities for periodic cleaning and recoating of the various HIRES optical components, including enhanced silver, multi-layer dielectric coatings, and AR coatings. The availability of a multi-pocket e-beam coating system (and coating technician) which can handle optics up to about 33" in diameter would be greatly appreciated.

A clean vacuum pumping/leak detector station should also be provided for maintenance of the CCD dewar.

The observatory is also expected to provide a supply of LN_2 or liquid air for CCD cooling.

The standard complement of oscilloscopes, and electronic test equipment should also be available.

3.7 Documentation

The following documentation will be provided at Lick, Waimea, and on the mountain top.

- A complete set of mechanical, electrical, and electronic drawings for the instrument, plus a drawing index.
- A description of the electronics, including timing diagrams, key test points and their waveforms, and recommended voltage adjustments, etc.
- A description of any required optical realignment procedures.
- Video tapes of all principal instrument maintenance procedures.
- Complete software documentation, including software source files and system build files.
- A list of weights of all principal components, and total weight.

3.8 Instrument Handling Equipment

We will need several 1000 lb. carts, and a small wheeled hoist for lifting parts onto the carts. Also, a small machine shop facility and tools will be required at the mountaintop for the commissioning phase, and for minor repairs and modifications.

4.0 Data Processing

4.1 Representative Data Flow

A block diagram of the various data paths was shown in Figure 18. Images from the HIRES CCD detector will be read into the CCD controller buffer (16 mb of RAM), as specified by Fred Harris, and then transmitted to the instrument computer over the instrument LAN. This LAN will be used only for bidirectional communication between the Keck instruments and instrument computers. Within the instrument computer, the CCD image will be captured to disk and RAM by the Data Acquisition System (see 4.2.1 below), and then will be available to the Quick-Look Data Reduction System (see 4.2.1h).

The instrument host computer (a SUN-4/280) will communicate with the instrument target computer (controller), a VME-68K crate, to control the motion or state of various motors, solenoids, brakes, and lamps on the spectrograph and to monitor these motions and states as well as the environment inside the instrument chassis (i.e. voltages and temperature). It will also communicate with the telescope drive and control computer via the Observatory LAN to command telescope moves and to obtain information about the telescope pointing. There will be a communication link between the instrument computer and the mirror control system (ACS) and the autoguider as well.

Remote control of the spectrograph will be possible from Waimea, via a microwave link providing a logical extension of the Observatory LAN, as well as from California initially via a 9600 baud dialup.

4.2 Data Acquisition and Reduction Software

The software will include separate programs for data acquisition and data reduction, and is described below.

4.2.1 Data Acquisition Software

The data acquisition software will be modeled on the CCD Data Acquisition System (DAS) developed by Richard Stover and currently in use at Lick Observatory. It will provide a user interface to the HIRES instrument (including its CCD) and to other observatory systems (telescope drive, mirrors, TVs, tape/optical disk farm), as well as to the LRIS instrument and to the Quick-Look Data Reduction Software (provided by CIT). Besides providing these interfaces to the user, the primary responsibility of this package will be to save CCD images on disk and in RAM in a format accessible to the data reduction and analysis software.

Contract # 101021
Exhibit A
Dated SEP 21 1988
Page COVER of PROPOSAL

HIRES: A High Resolution Echelle Spectrometer for the Keck Ten-Meter Telescope

Phase C: HIRES Core

A Proposal To the California Association
For Research in Astronomy

Submitted: July 1, 1988.

From:

Dr. Steven S. Vogt, Principal Investigator
Lick Observatory, University of California at Santa Cruz,
Santa Cruz, CA. 95064

And

HIRES Science Advisory Team Members:
Dr. Gibor Basri UCB
Dr. Ann Boesgaard UH
Dr. Michael Jura UCLA
Dr. Ken Libbrecht CIT
Dr. Don Penrod UCSC
Dr. Wallace Sargent CIT

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ASTRONOMY AND ASTROPHYSICS
LICK OBSERVATORY

SANTA CRUZ, CALIFORNIA 95064

RECEIVED
SEP 14 1988
W.M. KECK OBSERVATORY
PROJECT OFFICE

September 13, 1988

Contract # 101021
Exhibit B
Dated SEP 21 1988
Page 1 **of** 11

Mr. Colin Silvio
Administrative Manager
CARA 1-42
535 S. Wilson Ave.
Pasadena, CA 91106

Dear Mr. Silvio:

Enclosed is, hopefully, all of the remaining information required by CARA to release the contract for HIRES. A revised schedule is being prepared, but is not yet quite ready, and will be mailed shortly under separate cover.

The name of the administrator at Lick Observatory with whom you should be in communication for final approval is Mr. Joseph T. Calmes, Assistant Director, Administration.

Sincerely,

Steven S. Vogt

Steven S. Vogt,
Professor of Astronomy and
Astrophysics

SSV: vax

HIRES Addendum

September 13, 1988.

This addendum describes changes and deletions in the scope of the HIRES Phase C proposal which was submitted on July 1, 1988. Thus, the Phase C proposal, as amended by this addendum constitutes an accurate description of the work to be performed by Lick Observatory for CARA under the HIRES contract.

Deletions in Scope of the Work

At the request of the Science Steering Committee, the UV-optimized mode and the fiber-fed mode were deleted, and the HIRES instrument computer was descoped. Removal of the UV-optimized mode means that the UV corrector for the short camera will be left out, though its cell and the mechanical parts for eventually switching between several correctors will remain. The UV-optimized collimator mirror will also be left out, though again, its cell and the mechanisms for collimator exchange will remain. Deletion of the fiber-fed mode means that the fiber collimator (Fig. 6 of HIRES proposal), fiber bundle, and fiber connectors will be left out, as well as the Flat (non-disperser) and the mechanical equipment for manual exchange of cross dispersers.

The HIRES instrument computer has been descoped by omitting the separate image display (called 'add-on video subsystem' on page 63 of the proposal), and omitting also the 16 serial ports.

Budget Adjustments

The revised budget reflecting the above deletions is attached. Aside from direct cost savings from deleting the above major items, an additional $11,636 was cut from the budget, as we found that some tooling costs under Optical and Mechanical had been incorrectly double-entered. In addition, Director R.P. Kraft has agreed to underwrite (donate) $108,618 in labor costs, with the understanding that, funds permitting, CARA will restore these funds as second priority after restoration of the fiber-mode to LRIS.

Contract # 101021
Exhibit B
Dated SEP 21 1988
Page 2 of 11

Revised HIRES Sun Instrument Computer

Item #	Description	UC Discount Price
1	Sun 4/280S-P12 12 slots 32 MB memory (4x8 MB) 892 MB disk 6250 BPI 1/2" tape drive	59,563.00
2	Color W/S	8,040.00
3	2 nd ethernet	934.65
4	2-year maintenance contract	8,279.25
	TOTAL	76,816.90

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Dated SEP 21 1988
Page 10 of 11

9/7/88

Major Procurements Over $10K
Mechanical/Optical/Electronics
(see page 62 @ HIRES proposal)

1.	$84,000	CCD(s) - Ref. B. Oke
2.	17,000	Bally Enclosure (HIRES Housing)
3.	18,000	Anorad rotary table
4.	51,000	Grating 1 Milton-Roy
5.	51,000	" "
6.	51,000	" "
7.	51,000	" "
8.	51,000	" "
9.	45,620	Corrector blank with generating.
10.	12,120	Camera Mirror blank with generating.
11.	12,000	TV - SSC suggestion for "generic" television

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Dated SEP 21 1988
Page 11 of 11

Contract 101021
Exhibit C
September 26, 1988
Page 1 of 2

SCHEDULE OF INCREMENTAL FUNDING
W. M. KECK TELESCOPE INFRARED INSTRUMENTS

(in thousands of dollars)

QUARTER	AMOUNT
3rd Quarter 1988	327
4th Quarter 1988	239
1st Quarter 198~~8~~9 JTG	230
2nd Quarter 1989	168
3rd Quarter 1989	112
4th Quarter 1989	396
1st Quarter 1990	246
2nd Quarter 1990	45
3rd Quarter 1990	26
4th Quarter 1990	41
	1,830

LICK
OBSERVATORY
1888 · 1988

Contract # 101021
Exhibit C
Dated SEP 2 6 1988
Page 2 of 2

September 21, 1988

Mr. Herbert Morris
CARA I-42
535 So. Wilson Avenue
Pasadona, California 91106

Re: Amendment to High Resolution Spectrograph Proposal Budget

Dear Herb:

As per our telephone conversation of this afternoon, Lick Observatory will begin supporting labor costs (in the total amount of $108,618) beginning in the seventh quarter of the project and extending through the tenth quarter. Should CARA funds be sufficient to cover labor costs for the duration of the project, Lick Observatory support will, of course, not be necessary.

Cordially,

Joe

Joseph T. Calmes
Assistant Director, Administration

Lick Observatory • University of California, Santa Cruz • Santa Cruz, California 95064 • 408/429-2513

The DAS user interface will exist in two forms: a menu system designed to help the infrequent user remember what operations are available, and a command language interface providing more flexible operation for the more sophisticated user (language TBD).

A description is provided here of the major functional divisions of the Data Acquisition Software.

(a) Instrument Setup

All of the instrument setup parameters will be displayed for the user to accept or alter. The parameters may be set individually, or all at once from a setups file. For HIRES, these parameters include the echelle grating angle, cross-disperser angle, collimator selection and position, camera corrector selection and position, slit and decker position, slit shutter control, fiber position, filter selection, and calibration lamp selection. The system will be written such that more parameters can be added as the instrument is upgraded. The parameters for LRIS are TBD.

(b) Exposure Timing and CCD Readout Control

The actual exposure timing and readout of the CCD frames will be handled by the CCD controller but will be commanded by the DAS. The CCD data will be buffered in the CCD controller and transmitted to the instrument computer over the instrument LAN. Provision will be made to allow independent control of more than one CCD. Control will be provided for various readout parameters, such as binning, window size, and readout mode.

(c) Environmental Monitoring

The temperature and voltages inside each of the instrument motor clusters will be monitored, as well as the temperature and voltages of the CCD detector, and the temperatures of the HIRES enclosure and electronics vault. An error message will be displayed if any of these indicators reaches a critical stage, and this information will be saved in an error log file.

(d) Status and Diagnostics

Besides environmental monitoring, the DAS will keep track of other instrument and system status indicators, such as devices in motion, devices at limit, exposures in progress, magnetic tapes off-line, and other options TBD. It will also provide diagnostics for various functions of the CCD controller.

(e) Telescope/Autoguider Interface

The DAS DCS/autoguider interface will allow the user to receive telescope status concerning telescope position, UT, current level of seeing, track rates, and other information TBD. The user will also be able to send commands to offset the telescope, adjust rates, request a digitized autoguider TV image, and other tasks TBD.

(f) Data Recording

CCD and autoguider TV image data will be recorded to disk, and optionally to tape, in FITS format. A selected subset of images, including those most recently acquired, will be cacheted in an area of RAM that is accessible to the Quick Look Data Reduction Software. Associated with each image will be a complete FITS header, providing not only image dimensions but all relevant parameters of the observation, such as telescope position, UT, dewar temperature, exposure time, instrument set-up parameters, etc.

(g) LRIS interface

The DAS will provide a user interface to the LRIS instrument, including the multislit and multifiber assemblies, filter wheels, lamps, and other options TBD.

(h) Help

At any time, the user will be able to call up a help screen to explain the operation of any section or command of the Data Acquisition System.

(i) Quick-Look Data Reduction

Although these routines will be provided by CIT and have still to be determined, they will be integrated into the DAS so that the user can perform basic operations such as flat fielding, centroiding, plotting, and video display of CCD images during an observation, without exiting the DAS.

(j) Display

TBD with CIT. This category may be combined with (i).

4.2.2 Data Reduction and Analysis Software

The data reduction and analysis software will consist of two separate packages: a Quick-Look Data Reduction package based on the FIGARO system and provided by CIT, and a full-blown General Purpose Data Analysis package for HIRES. The Data Analysis software package will be either VISTA, or IRAF, or FIGARO, with routines added (if necessary) to handle instrument-specific reduction tasks such as wavelength calibration, extraction, and linearization. If VISTA is used, it must also be altered to allow it to handle data from 2048^2 CCDs. The choice of which of these three packages to use for HIRES data reduction will be postponed until experience can be gained with all three on a Sun 4/280S.

To aid in the development of software prior to availability of HIRES, a program to model the instrument will be designed. This program will simulate the operation of the HIRES instrument as well as portions of the telescope environment, and will allow the user to experiment with the effect of different instrument setups on count rates, spectral formats, and signal to noise ratio. With this instrument simulator, an observer will be able to simulate and store all the set-ups of an observing run before actually going to the mountain. It will also assist the programmer in developing appropriate data reduction routines.

4.3 Required Facilities

4.3.1 The Instrument Computer

The instrument computer will be a SUN 4/280S-P12. It will consist of a 12-slot backplane, a 10 MIPS cpu, 32 Mb of memory, an 850 Mb disk, a Fujitsu 6250 BPI tape drive, two network interfaces (one for the instrument LAN and one for the Observatory LAN), sixteen serial ports, a color workstation with a 19" monitor, keyboard, and mouse, a separate color video display, and a two-year maintenance contract.

4.3.2 The Instrument Controller and the CCD Controller

The instrument controller, as well as the CCD controller, will be a 68020-based embedded VME-bus system, running the VxWorks realtime executive. This instrument chassis was described in Section 2.5.2. The CCD controller VME chassis was described in Section 2.5.1.

4.3.3 Links to the DCS, the ACS, and the Autoguider TVs

The instrument computer will communicate with the DCS, ACS, and autoguider TV via the observatory LAN. Through the DAS, a user will be able to receive telescope status from and send commands to the DCS (see section 4.2.1e). The DCS is also expected to provide digital image data from the instrument's autoguider TV, and the user should be able to demand this data at least as often as once every 30 seconds. The DAS will store this autoguider image in a file just as it does with a regular CCD image, where it will be available to the Quick Look Data Reduction Software.

A user interface to the ACS will also be provided by the DAS. The nature and use of this interface remains TBD.

4.4 Control Software

The DAS will control all moving parts of the instrument, including motors and brakes, and will query environmental monitors and run internal diagnostics. This communication will occur over the instrument LAN using appropriate TCP/IP protocols. The DAS will also provide for simultaneous operation of active and standby instruments without collision, allowing a user to setup the standby instrument without interfering with the operation of the active instrument; only the active instrument would be allowed telescope and mirror control in this situation. Similarly, both local and remote use of the DAS will be provided without collision.

5.0 Management Approach

5.1 Management Structure

The HIRES project will be managed by the Lick Observatory, in similar fashion to other Lick projects. A management structure is in place which has overseen the successful completion of many complex instrument projects. Figure 24 shows the management structure for the HIRES project. Overall control of the HIRES project rests with Robert P. Kraft, the director of Lick Observatory, however most global management issues will be handled by Joe Miller, the Assistant Director of Engineering and Technical Facilities. Steve Vogt, the Principal Investigator, is responsible for providing overall scientific guidance, conceptualization, and execution of the instrument. He reports directly to Kraft, and is advised by a 6-member Instrument Science Advisory Team, made up of a cross-section of prospective users from the Keck observer community.

HIRES will be designed, fabricated, and tested in the Lick Labs (Optical. Engineering, Electronic, Instrument, and Coatings) under the direction of Mr. Neal Jern, the Superintendent of Technical Services. Most detailed day-to-day project management issues will be handled by Mr. Jern. The facilities of the Lick Business Office will also be available, under the direction of Mr. Joe Calmes, the Assistant Director for Administration. The HIRES project will be managed in the business office by Marlene Couture, the Business Service Manager. The business office will handle the HIRES budget and provide detailed accounting reports throughout the duration of the project. The software development effort will be managed by Specialist Kibrick, who will report directly to P.I. Vogt. R. Stover will act as expert consultant on software.

Not shown on Figure 24, though a key player in the HIRES project, is Dr. Lloyd Robinson. Lloyd will be deeply involved in the development of the CCD detector system for HIRES. Lloyd has been the chief creative and technical force at Lick behind all of our CCD detector systems, and, if the proposed NSF Science and Technology Center for Faint Light Imaging is approved, Lloyd will be its director.

5.1.1 Science Team Roles

The Principal Investigator will be Dr. Steven S. Vogt, Professor of Astronomy and Astronomer at Lick Observatory of the University of California at Santa Cruz. A science advisory team will also assist in the design and construction of HIRES. The team members and their primary areas of input are as follows:

Dr. Gibor Basri	U.C. Berkeley	Science, stellar spectroscopy
Dr. Ann Boesgaard	U. Hawaii	Science, stellar spectroscopy
Dr. Michael Jura	U.C. Los Angeles	Science, interstellar lines

Dr. Ken Libbrecht	CalTech	Science, stellar seismology
Mr. Don Penrod	Lick Observatory	Science, instrument design
Dr. Wallace Sargent	CalTech	Science, QSO's, extragalactic

Of course, in addition to their respective areas of primary input, all team members will be expected to provide as much guidance and input as possible on all aspects of the project.

The HIRES project will also employ Dr. Harland Epps of UCLA as principal consultant on optical design.

5.2 Staffing Plan

In the engineering group, we currently have a staff of three full-time mechanical engineers, one volunteer engineer, and one draftsperson. We anticipate hiring at least one more draftsperson.

The instrument lab will provide a staff of three instrument makers plus perhaps one new hire if needed.

The electronics staff provided by Lick for this instrument consists of two electronics engineers and two technicians (one of which will be devoted to purchasing).

The optical lab will provide a staff of two opticians, plus one coating technician.

The business office will provide a staff of seven.

A staff of five is planned for the software development group for the duration of the HIRES project (8/1/88 to 1/31/91). They are:

- Specialist Kibrick (allocated at an average of 50% time) will serve as manager of the group, and will coordinate the HIRES software development with CIT and CARA (and with LBL and SSL as needed).

- Associate Research Astronomer Stover (allocated at an average of 20% time), wrote the Lick CCD Data Acquisition System on which the HIRES/LRIS Data Acquisition System will be based, and will serve as expert consultant.

- Computer Systems Manager Clarke (allocated at an average of 10% time) will assist with the acquisition of the HIRES Sun-4/280 instrument computer, installation of operating system software, and connection of this machine to the appropriate networks.

- Programmer/Analyst Atwood (allocated at an average of 75% time), will provide the bulk of the programming support for the Data Acquisition System.

- Research Assistant Allen (allocated at an average of 60% time) will provide the bulk of the programming support for the development of instrument-specific data reduction routines and for programs to model the instrument.

Lick Observatory has found that having Research Assistants (i.e., Astronomy graduate students) working in conjunction with staff programmers provides an extremely effective combination for the development of data reduction and instrument modeling software.

5.3 Special Facilities

Lick Observatory has the following technical facilities:

Instrument Lab: We have a complete machine shop capable of supporting a staff of seven. This shop has fabricated all the instrumentation in use on Mount Hamilton. Work has ranged from CCD dewars to a complete 1-meter telescope. Equipment includes all standard machine tools for turning, milling, drilling, and grinding as well as a full complement of sheetmetal and welding equipment. We have a very full complement of measuring and test instruments including alignment lasers and autocollimators. A 25' × 65' high bay facility is scheduled for completion in November 1988. This area will be serviced by a two-ton bridge crane with a 20' hook height.

Optical Lab: The Lick Optical Lab's machining capabilities include diamond generation and edging to 24" diameters, dicing, and ultrasonic milling. With a variety of grinding and polishing machines, we can produce flat, spherical and aspherical surfaces on glass, crystals, and metal. We can accommodate diameters from 1/8 inch to over 10 feet, producing surfaces to a fraction of a wavelength accuracy.

Our 75 foot metrology tunnel houses two Zygo interferometers interfaced with computer fringe analysis software for state-of-the-art optical testing. For aspheric testing, we are developing a 60-inch travel mechanical profilometer capable of probing surface contours to 0.02 micron resolution. Mirror handling is accommodated by overhead hoists traveling on monorails.

Engineering Group: We currently have a staff of three full-time mechanical engineers, one volunteer engineer, and one draftsperson. We anticipate hiring at least one more draftsperson. Our engineering office is equipped with all standard equipment as well as three IBM PC AT's. Software includes AUTOCAD and NISA II finite element analysis.

Electronics Lab: The Lick Electronics Lab has at present two engineers and two technicians, with room for one more. It has for many years been the sole source of all electronic instruments which have been used on Mount Hamilton and has made a number of large instruments. There is ample test equipment and electronic stock for building most instruments. The facilities have recently been upgraded by the addition of personal computers running PCAD for schematic design and board layout, as well as a "silicon foundry" for chip design. An Ethernet cable is presently being installed to connect the shop to the Lick offices in Natural Sciences II. This will allow programmers in that building access to the equipment being developed in the shop.

Optical Coating Lab: The Lick Observatory Optical Coating Facility has four vacuum coaters that range in size from 18 inch to 144 inch diameter and are capable of both resistance and electron beam coating in all but the largest, which is resistance only. Both metallic and dielectric coatings can be produced including anti-reflection coatings, enhanced front surface reflectors, beam splitters, and neutral density filters.

Software Group: Space will be required to house the HIRES Sun-4/280 instrument computer and its two color workstations. This space must include a 240-volt 30-amp circuit, and sufficient cooling to maintain the air temperature within the computer's specifications. Natural Sciences 2 Room 105 (which is in close proximity to the offices of the HIRES programming staff) meets these requirements, and will be made available to the HIRES project on or about January 1, 1989. Delivery of the HIRES Sun-4/280 will be deferred until that time.

During the period between the nominal start date of the project (8/1/88), and the installation of the HIRES Sun-4/280 in Room 105, the software development group will require computer time and disk space on Lick Observatory's Sun-4/280 departmental server machine, which is currently located in Room 105. Accounts will be established on this machine for the HIRES software development effort, and charges for computer time, connect time, and disk space will be paid by the HIRES project. (It is expected that the cost of these charges will be offset by a reduction in total maintenance costs for the HIRES Sun-4/280 machine that result from deferring its purchase until late 1988.) Once the HIRES Sun-4/280 becomes available, the disk files and software activity associated with the HIRES project will be moved from the departmental server machine to the HIRES machine.

Since the Lick departmental server machine does not include any workstation, access will also be needed to the Observatory's SUN-4/110C workstation, which will be networked to the departmental server. The HIRES software effort will be given priority access to this workstation as needed, until such time as the workstations associated with the HIRES Sun-4/280 system become available. As an interim solution, it may prove useful to purchase one or both of the HIRES workstations in advance of purchasing the HIRES Sun-4/280 system, and to temporarily connect these to the departmental server machine. Lick Observatory has agreed to make available to the HIRES project three of the VME slots in the departmental server machine. This would allow temporary installation of the video controller cards associated with the two HIRES workstations, as well as the installation of an additional ethernet card to simulate the Keck instrument LAN. These cards would be removed from the departmental server machine and installed in the HIRES machine once it becomes available.

An ethernet connection between the HIRES software development group (located in the Natural Sciences building) and the Lick Observatory Electronics Lab (located approximately 0.25 mile away) will be needed for coordination of the software and electronics efforts, and connection of the instrument controllers (VME crates located in the lab) with the instrument computer (HIRES Sun-4/280 or departmental server machine located in Natural Sciences). This installation of this connection is already in progress, and should be completed by the Fall of 1988. A local lockout at the instrument end will be provided for safety of those working on the instrument.

5.4 Program Implementation and Control Approach

A preliminary design review will be conducted by an independent consultant.

Detailed design work will start about August 1, 1988. Fabrication will be done in a modular fashion following a critical design review on each module. Construction is expected to begin about February 1, 1989.

Informal written status reports on the software development will be provided monthly, and formal written reports of software progress provided quarterly. A software PDR is tentatively scheduled for mid-November 1988, and a CDR is tentatively scheduled for March 1989.

The project will be tracked against established milestones using Pertmaster Advance project management software. Progress will be monitored on a weekly basis by project manager Neal Jern. Progress and Financial reports will be generated on a quarterly basis. The Instrument Team will have bi-weekly meetings to monitor progress and to identify problem areas. See Section 7.1 for Gantt charts and a discussion of milestones.

5.4.1 Reporting Schedule

See previous section.

5.5 Operational Phase Support Plan

During at least the first year or so after commissioning, the technical staff of the Lick Observatory will be available for helping with the debugging and operation of HIRES. Hopefully, much of this support can be done from Santa Cruz, in much the same way as we now support the facilities at Mount Hamilton. We will be able to exercise all of HIRES's mechanisms, and to run diagnostics over the standard phone lines. More extensive work with software may require an identical instrument computer at Lick. However, we expect that on a number of occasions, a programmer and/or technician will have to travel to Mauna Kea as required.

A high level of standardization and modularity will be designed into HIRES so that maintenance at the mountain will generally be reduced to simple board-swapping-level tasks by observatory technicians, under the supervision of engineers at Lick Observatory.

A plan will be developed, in coordination with Keck Observatory, for transferring technical expertise on the operation and maintenance of HIRES to the Keck observatory technical staff.

5.6 Integration and Test Plan

As each module is completed, it will be tested mechanically, optically, and electronically to assure that the unit meets specifications. When all modules are completed and tested, the entire instrument will be assembled, aligned, wired, and tested in its housing in the high bay area of the Lick Instrument Lab.

5.7 Critical Components Plan

The first critical area will be to prove the Mosaic Grating concept. When this is done, the CCD will be selected and the grating blanks can be sent out for replicating. Another critical area is the Schmidt Camera design. All optical designing must be finalized before mechanical layout of the camera module can be started.

6.0 Budget

6.1 Design Salaries

6.2 Fabrication salaries

6.3 Materials and other costs

6.4 Summary of total costs

6.5 Overall summary by quarters

REVISED AS PER 9/13/88 ADDENDUM

Page 1 of 7

Detailed Proposal Budget
High Resolution Spectrograph
HDCORE.W21

SALARIES
Design

MAJOR TASKS	RISK	Optical Hours	Optical Amount		Mechanical Hours	Mechanical Amount		Electronic Hours	Electronic Amount	Software Hours	Software Amount	TOTAL Hours	TOTAL Amount
COLLIMATORS													
Specialist V/Engineer	1			200	200	10572						200	10572
Pr Drafting Tech.	1			100	100	2200						100	2200
Sr. Dev. Engineer	1						32	32	1352			32	1352
Sr. Electronics Tech.	1						8	8	212			8	212
Assoc. Dev. Engineer	1												
ECHELLE													
Specialist V/Engineer	1			440	440	23258						440	23258
Pr. Drafting Tech.	1			300	300	6600						300	6600
Sr. Dev. Engineer	1						32	32	1352			32	1352
Sr. Electronics Tech.	1						8	8	212			8	212
CROSS DISPERSER													
Specialist V/Engineer	1			380	380	20087						380	20087
Pr. Drafting Tech.	1			200	200	4400						200	4400
Sr. Dev. Engineer	1						32	32	1352			32	1352
Sr. Electronics Tech.	1						8	8	212			8	212
CAMERA AND CORRECTOR													
Specialist V/Engineer	1			350	350	18501						350	18501
Pr. Drafting Tech.	1			200	200	4400						200	4400
Sr. Electronics Tech.	1						8	8	212			8	212
Assoc. Dev. Engineer	1						40	40	1468			40	1468
CAMERA SELECTOR													
Specialist V/Engineer	1			100	100	5286						100	5286
Pr. Drafting Tech.	1			100	100	2200						100	2200
Sr. Electronics Tech.	1						8	8	212			8	212
Assoc. Dev. Engineer	1						32	32	1174			32	1174
CCD DETECTOR													
Specialist V/Engineer	1			450	450	23787						450	23787
Pr. Drafting Tech.	1			400	400	8800						400	8800
Sr. Dev. Engineer	1						304	304	12841			304	12841
Sr. Electronics Tech.	1						64	64	1697			64	1697
Astronomer	1						80	80	0			80	0
STRUCTURE + ENCLOSURE													
Specialist V/Engineer	1			540	540	28544						540	28544
Pr. Drafting Tech.	1			400	400	8800						400	8800
Asst. Dev. Engineer	1			965	965	23662						965	23662

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SALARIES
Design

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SLIT AREA												
Asst. Dev Engineer	1	2076	2096	51394							2096	51394
Sr. Dev. Engineer	1				128	128	5407				128	5407
Sr. Electronics Tech.	1				56	56	1485				56	1485
Assoc. Dev. Engineer	1				176	176	6459				176	6459
INSTRUMENT CONTROL SYST												
Sr. Dev. Engineer	1				200	200	8448				200	8448
Sr Electronics Tech.	1				56	56	1485				56	1485
SOFTWARE												
Prog./Analyst. III	1							320	320	10790	320	10790
Specialist III/Prog.	1							640	640	28909	640	28909
Prog./Analyst. II	1							920	920	25337	920	25337
Research Assistant	1							680	680	10241	680	10241
Assoc. Res. Astronomer	1							480	480	0	480	0
SUB TOTALS		7221	7221	242491	1272	1272	45578	3040	3040	75276.8	11533	363347

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Detailed Proposal Budget
High Resolution Spectrograph
HFCORE.W21

SALARIES
Fabrication

MAJOR TASKS	Optical Hours	Optical Amount	Mechanical Hours	Mechanical Amount	Electronic Hours	Electronic Amount	Software Hours	Software Amount	TOTAL Hours	TOTAL Amount
COLLIMATORS										
Pr. Lab. Mech.			500	15265					500	15265
Sr. Optical Tech.	40	1036							40	1036
Specialist III/Opt.	60	2522							60	2522
Assoc. Dev. Engineer	4	147							4	147
Electron. Tech. Traine					40	702			40	702
ECHELLE										
Specialist V/Engineer			168	8880					168	8880
Pr. Lab. Mech.			668	20374					668	20394
Sr. Dev. Engineer					20	845			20	845
Sr. Optical Tech.	445	11521							445	11521
Specialist III/Opt.	280	11768							280	11768
Electron. Tech. Traine					32	562			32	562
CROSS DISPERSER										
Specialist V/Engineer			168	8880					168	8880
Sr. Lab. Mech., St. 5			670	18633					670	18633
Sr. Dev. Engineer					4	169			4	169
Sr. Optical Tech.	430	11133							430	11133
Specialist III/Opt.	260	10928							260	10928
Electron. Tech. Traine					24	421			24	421
CAMERA AND CORRECTOR										
Pr. Lab. Mech.			770	23508					770	23508
Sr. Dev. Engineer					8	338			8	338
Sr. Optical Tech.	180	4660							180	4660
Specialist III/Opt.	420	17653							420	17653
Assoc. Dev. Engineer	20	734			32	1174			52	1908
CAMERA SELECTOR										
Pr. Lab. Mech.			540	16486					540	16486
Sr. Dev. Engineer					4	169			4	169
Assoc. Dev. Engineer					16	587			16	587
CCD DETECTOR										
Sr. Lab. Mech., St. 5			1038	28867					1038	28867
Sr. Dev. Engineer					64	2703			64	2703
Astronomer					16	0			16	0
Electron. Tech. Traine					440	7726			440	7726
STRUCTURE + ENCLOSURE										
Sr. Lab. Mech., St. 4			1650	43758					1650	43758

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SALARIES
Fabrication

SLIT AREA										
Sr. Lab. Mech., St. 5			1412	39268					1412	39268
Sr. Lab. Mech., St. 4			840	22277					840	22277
Sr. Dev. Engineer					56	2365			56	2365
Electron. Tech. Traine					176	3091			176	3091
Assoc. Dev. Engineer					152	5578			152	5578
INSTRUMENT CONTROL SYST										
Sr. Dev. Engineer					32	1352			32	1352
Electron. Tech. Traine					200	3512			200	3512
Sr. Lab. Mech., St. 5			40	1112					40	1112
SOFTWARE										
Assoc. Res. Astronomer							320	0	320	0
Specialist III/Prog.							1440	65045	1440	65045
Prog./Analyst, II							2320	63893	2320	63893
Research Assistant							2080	31325	2080	31325
Prog./Analyst, III							160	5395	160	5395
TEST										
Pr. Lab. Mech.			1110	33888					1110	33888
Sr. Dev. Engineer					628	26527			628	26527
Electron. Tech. Traine					362	6357			362	6357
Assoc. Dev. Engineer					312	11450			312	11450
COMMISSIONING										
Specialist V/Engineer			400	21144					400	21144
Sr. Dev. Engineer					56	2365			56	2365
Electron. Tech. Traine					24	421			24	421
Assoc. Dev. Engineer					32	1174			32	1174
SUB TOTALS	2139	72101	9974	302361	2698	79591	6320	165658	21131	619711

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Detailed Proposal Budget
High Resolution Spectrograph
HIMCORE.W21

MATERIALS AND OTHER COSTS

MAJOR TASKS	Optical Materials Amount	Mechanical Materials Amount	Electronic Materials Amount	Detectors Amount	Shipping Crates Amount	Storage Boxes Amount	Other Amount	TOTAL Amount
Collimators	4800	5400	680			500		11380
Echelle	171600	7500	2470			1500		183070
Cross Disperser	116400	25000	470			1000		142870
Camera and Corrector	60340	53700	610			2500		117150
Camera Selector		5600	410					6010
CCD Detector	2600	15000	53880	84000		500		155980
Structure + Enclosure		37500						37500
Slit Area		35000	20080			4500		59580
Instrument Control System			49000					49000
SUN 4/280G-P12			76817					76817
Test			11300		3000			14300
Commissioning								
Subcontract (Epps)							25000	25000
Travel								
Design Reviews							8000	8000
Commissioning/Hawaii							13404	13404
Secretarial							13500	13500
Purchasing (Campus Fee)							2000	2000
Shipping					1000			1000
Supplies and Expense							6000	6000
Administration Project Management							33000	33000
SUB TOTALS	355740	184700	215717	84000	4000	10500	100904	955561 A

ASee attached list of major purchases in excess of $10,000.

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Detailed Proposal Budget
High Resolution Spectrograph
HITCORE.WP1

TOTAL COSTS

MAJOR TASKS	Salaries Design Amount	Salaries Fabrication Amount	Materials and Other Costs Amount	TOTALS
Collimators	14336	19672	11380	45388
Echelle	31422	53970	183070	268462
Cross Disperser	26051	50164	142870	219085
Camera and Corrector	24581	48067	117150 A	189798
Camera Selector	8872	17242	6010	32124
CCD Detector	47125	39296	155980	242401
Structure + Enclosure	61006	43758	37500	142264
Slit Area	64745	72579	59580	196904
Instrument Control System	9933	5976	49000	64909
SUN 4/280S-P12			76817 B	76817
Test		78222	14300 C	92522
Commissioning		25104		25104
Subcontract (Epps)			25000	25000
Travel			21404	21404
Secretarial			13500	13500
Purchasing			2000	2000
Shipping			1000	1000
Supplies & Expense			6000	6000
Administration			33000	33000
Software	75277	165658		240935
TOTALS	363348	619708	955561	1938617 D 1938617

[A] Tool costs were double entered under Optics and Mechanical -- reduction in cost = $11,636

[B] See Revised Sun 4/280 price list (attached) -- reduction in cost = $12,183

[C] Costs for testing originally entered under separate tasks are here grouped under "test."

[D] Of this total, $108,618 in labor costs are to be supported by University of California Observatories, if needed. This commitment by Director R.P. Kraft is with the understanding that, funds permitting, CARA will restore the $108,618 as a second priority following the restoration of fibers to LRIS.

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Detailed Proposal Budget
High Resolution Spectrograph
HIG.W20

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TOTAL BUDGET BY QUARTERS

MAJOR TASKS	First Quarter	Second Quarter	Third Quarter	Fourth Quarter	Fifth Quarter	Sixth Quarter	Seventh Quarter	Eighth Quarter	Ninth Quarter	Tenth Quarter	TOTAL
Collimators	25,716			5,233	13,739	700					45,388
Echelle	45,463	40,356	28,236	1,407		153,000					268,462
Cross Disperser	42,434	12,763	45,138	16,750		102,000					219,085
Camera + Corrector	58,490		60,340	22,900	11,157	11,891	14,105	10,915			189,798
Camera Selector			14,882			17,242					32,124
CCD Detector	3,974					30,255	193,618	13,654	900		242,401
Struc. + Encl.				48,263	42,432	24,958	17,859	8,752			142,264
Slit Area	34,281	52,758	39,576	31,689	14,064	24,536					196,904
Inst. Control Syst	58,933	5,976									64,909
SUN 4/280S-P12		76,817									76,817
Test	11,300	6,052		1,801		6,741	9,682	16,649	25,702	14,595	92,522
Commissioning										25,105	25,105
Subcontract	11,500	11,500	2,000								25,000
Travel		1,600		1,600		1,600		1,600	800	14,204	21,404
Secretarial	1,350	1,350	1,350	1,350	1,350	1,350	1,350	1,350	1,350	1,350	13,500
Purchasing	2,000										2,000
Shipping										1,000	1,000
Supplies & Expense	600	600	600	600	600	600	600	600	600	600	6,000
Administration	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	3,300	33,000
Software	26,882	25,537	34,747	33,863	25,418	17,616	32,484	14,600	20,412	9,376	240,935
TOTALS	326,223	238,609	230,169	168,756	112,060	395,789	272,998	71,420	53,064	69,530	1,938,618[A]

[A] Of this total, $108,618 in labor costs are to be supported by University of California Observatories, if needed. This commitment by Director R.P. Kraft is with the understanding that, funds permitting, CARA will restore the $108,618 as a second priority following the restoration of fibers to LRIS.

BUDGET NOTES

1. $51,570 from Ricketts, "CCD Controller" 6-16-88
   + 2,140 from Ricketts, "HIRES Estimate" 6-15-88
   $53,880

2. $49,000 from Ricketts, 6-15-88

3. $11,300 from Ricketts, 6-15-88

4. $84,000 from Oke letter to Steve Vogt, 5-26-88

5. $89,000 SUN 4/280S-P12 De Clarke memo date 5-19-88

6. Includes $17,000 Bally enclosure

7. Includes $18,000 Anorad (or Klinger) rotary table

8. Milton-Roy 1987 quote: $51,000 per grating x 3 = $153,000

9. Milton-Roy 1987 quote: $51,000 per grating x 2 = $102,000

10. Two Fused Silica Corrector Blanks and generating is $91,240.
    Pyrex Camera Mirror Blank and generating is $12,120.

11. Generic TV cost is $12,000 per SSC suggestion

12. $38,000 for Osborne "Mechanical Costs," 6-24-88

13. $15,000 is from Osborne 6-24-88

14. $45,000 is for 6 tools: 2 per surface (both correctors share)

15. $10,500 for fibers, connectors and end parts.

16. $40,000 for optical designs - H. Epps.

17. Travel to Hawaii and back during Commissioning is $13,404

18. $450 per month average for 30 months.

19. Neal Jern, Manager, at 13% time is $33,000

HIRES Estimate T. Ricketts
Electronics Lab 6-15-88

A. Main Controller Chassis

1. PARTS

	each	Total
a. VME cards		
1. CPU	$2500	$ 2500
2. Ethernet	$2300	$ 2300
3. Test CPU & Forth	$1100	$ 1100
4. Motor control	$1900	$13300
5. Ports	$ 900	$ 8100
6. A/D - D/A	$1800	$ 3600
b. Chassis		
VME chassis	$1500	$ 1500
Motor Driver chass.	$ 500	$ 1000
Interconnect chass.	$ 500	$ 500
c. Power Supplies		
1. VME	$1000	$ 2000
2. Motors	$ 400	$ 1200
3. Lamps	$ 250	$ 1000
4. HC lamps	$ 300	$ 600
d. Motor Drivers	$ 500	$ 7000
e. Opto 22 controller	$ 200	$ 600
f. Opto 22 modules	$ 15	$ 600
g. Cables	$ 5	$ 100
h. Software VRTX, VXWRKS	$2000	$ 2000
i. Misc		$ 500
	TOTAL	$49,000

2. LABOR

a. Design	(Ricketts)	10 days
b. Documentation	(Ricketts)	15 days
c. Purchasing	(Cantrall)	7 days
d. Chassis const.	(mach. shop)	5 days
e. Chassis wiring	(new hire)	25 days
f. Supervision	(Ricketts)	4 days
g. Test	(Ricketts)	15 days
	(new hire)	7 days

Mauna Kea Sun System Budgets: 4/260 vs 4/280

Mauna Kea Sun budget	List Price	UC discount 33.00% HARDWARE 17.00% MAINT	difference
Option 1			
Sun 4/260-P1	$85,500.00	$57,285.00	
12 slots			
32 MB memory (4x8MB)			
560MB disk			
60Mb 1/4" cartridge tape			
19" color display etc			
16 serial ports	$3,495.00	$2,341.65	
2nd ethernet interface	$1,395.00	$934.65	
Add-on Video subsystem	$9,500.00	$9,500.00	
2 years' maintenance		$8,715.00	
Total		$78,776.30	
Option 2			
Sun 4/280S-P12	$88,900.00	$59,563.00	
12 slots			
32 MB memory (4x8MB)			
892 MB disk			
6250 1/2" tape drive			
Color w/s 19" etc.	$12,000.00	$8,040.00	
16 serial ports	$3,495.00	$2,341.65	
2nd ethernet	$1,395.00	$934.65	
add-on video subsystem	$9,500.00	$9,500.00	
2 year's maintenance		$8,279.25	
Total		$88,658.55	9,882.25
Cost of 6250 tape add-on	16,900	11,323	9,313
cost of 1/4" tape add-on	3,000	2,010	
Cost of 892MB disk subsys	22,900	15,343	-3,082
Cost of 2X280 disk subsys	27,500	18,425	
adjust price diff for hdwr			6,231
real diff			3,651.25

prepared by De Clarke, Lick Observatory, 5/19/88

B. STAGES

1. ECHELLE

a. Parts

1. Motor-encoder	$ 270
2. Linear encoder	$2000
3. Solenoids	$ 100
4. Limits-fiducial	$ 30
5. Cable	$ 50
6. Misc	$ 20
TOTAL	$2470

b. Labor

1. Design	(Ricketts)	1 day
2. Documentation	(Ricketts)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(new hire)	4 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Ricketts)	2 days
	(new hire)	1 day

2. CROSS DISPERSER

a. Parts

1. Motor-encoder	$ 270
2. Solenoids	$ 100
3. Limits-fiducials	$ 30
4. Cable	$ 50
5. Misc	$ 20
TOTAL	$ 470

b. Labor

1. Design	(Ricketts)	1 day
2. Documentation	(Ricketts)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(new hire)	3 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Ricketts)	2 day
	(new hire)	1 day

3. DEWAR FOCUS

a. Parts

1. Motor-encoder	$ 270
2. Linear encoder	$2000
3. Solenoid	$ 50
4. Limits-fiducial	$ 20
5. Cable	$ 50
6. Misc	$ 20
TOTAL	$2410

b. Labor

1. Design	(Ricketts)	1 day
2. Documentation	(Ricketts)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(new hire)	4 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Ricketts)	2 days
	(new hire)	1 day

4. SHUTTER

a. Parts

1. Controller	$ 50
2. Cable	$ 20
3. Shutter	$ 700
TOTAL	$ 770

b. Labor

1. Design	(Delaney)	1 day
2. Documentation	(Delaney)	2 days
3. Purchasing	(Cantrall)	1/2 day
4. Wiring	(Delaney)	3 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Delaney)	1 day

5. FILTERS

a. Parts

1. Motors-encoders	$ 540
2. Fidicials	$ 20
3. Cable	$ 50
4. Misc	$ 20
TOTAL	$ 630

b. Labor

1. Design	(Delaney)	1 day
2. Documentation	(Delaney)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(Delaney)	4 days
5. Supervision	(Ricketts)	1 day
6. Test	(Delaney)	3 days

6. TV STAGE (filters, focus, aperature)

a. Parts

1. Motors-encoders	$1080
2. Limits-fidicials	$ 80
3. Cable	$ 150
4. Shutter	$ 700
5. Shutter contrl.	$ 50
6. Misc	$ 20
TOTAL	$2080

b. Labor

1. Design	(Delaney)	3 days
2. Documentation	(Delaney)	9 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(Delaney)	10 days
5. Supervision	(Ricketts)	2 days
6. Test	(Delaney)	7 days

7. COMPARISON LAMPS

a. Parts

1. Motor-encoder	$ 540
2. Solenoid	$ 50
3. Limits-fiducial	$ 50
4. Cable	$ 100
5. Lamps	$1000
6. Misc	$ 20
TOTAL	$1760

b. Labor

1. Design	(Ricketts)	2 days
2. Documentation	(Ricketts)	6 days
3. Purchasing	(Cantrall)	2 days
4. Wiring	(new hire)	14 days
5. Supervision	(Ricketts)	2 days
6. Test	(Ricketts)	3 days
	(new hire)	1 day

8. DECKER

a. Parts

1. Motor-encoder	$ 270
2. Limits-fiducial	$ 20
3. Cable	$ 50
4. Misc	$ 20
TOTAL	$ 360

b. Labor

1. Design	(Ricketts)	1 day
2. Documentation	(Ricketts)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(new hire)	4 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Ricketts)	2 days
	(new hire)	1 day

9. SLIT

a. Parts

1. Motor-encoder	$ 270
2. Linear encoder	$2000
3. Limits-ficucial	$ 20
4. Cable	$ 50
5. Misc	$ 20
TOTAL	$2360

b. Labor

1. Design	(Ricketts)	1 day
2. Documentation	(Ricketts)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(new hire)	4 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Ricketts)	2 days
	(new hire)	1 day

10. CAMERA MIRROR MOVER

a. Parts

1. Motor	$ 250
2. Solenoid	$ 50
3. Limits	$ 40
4. Cable	$ 50
5. Misc	$ 20
TOTAL	$ 410

b. Labor

1. Design	(Delaney)	1 day
2. Documentation	(Delaney)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(Delaney)	2 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Delaney)	1 day

11. COLLIMATOR MIRRORS

a. Parts

1. Motor-encoder	$ 400
2. Solenoid	$ 50
3. Limits-fiducial	$ 60
4. Cable	$ 50
5. Misc	$ 20
TOTAL	$ 680

b. Labor

1. Design	(Ricketts)	1 day
2. Documentation	(Ricketts)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(new hire)	5 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Ricketts)	2 days
	(new hire)	1 day

12. CORRECTOR LENSES

a. Parts

1. Motors	$ 500
2. Limits	$ 40
3. Cable	$ 50
4. Misc	$ 20
TOTAL	$ 610

b. Labor

1. Design	(Delaney)	2 days
2. Documentation	(Delaney)	3 days
3. Purchasing	(Cantrall)	1 day
4. Wiring	(Delaney)	4 days
5. Supervision	(Ricketts)	1 day
6. Test	(Delaney)	1 day

13. Access Hatch

a. Parts

1. Solenoid	$ 50
2. Limits	$ 20
3. Cable	$ 30
4. Misc	$ 20
TOTAL	$ 120

b. Labor

1. Design	(Delaney)	1 day
2. Documentation	(Delaney)	2 days
3. Purchasing	(Cantrall)	1/2 day
4. Wiring	(Delaney)	2 days
5. Supervision	(Ricketts)	1/2 day
6. Test	(Delaney)	1 day

C. SYSTEM INTEGRATION & TEST

1. Parts

a. Ethernet to shops	$4000
b. Motor cntrl test for PC	$3100
c. UPS	$4200

2. Labor

a. System interconnections	(Ricketts)	10 days
	(Delaney)	10 days
	(new hire)	10 days
b. Interconnection panel	(Ricketts)	3 days
	(new hire)	6 days
c. System test	(Ricketts)	15 days
	(Delaney)	5 days
	(new hire)	10 days

D. INSTALLATION (in Hawaii)

(Ricketts)	4 days
(Delaney)	4 days

CCD Controller Estimate
Electronics Lab

T. Ricketts
6-16-88

A. Main Controller

1. Parts

	each	total
a. VME cards		
1. CPU	$2500	$ 2500
2. Ethernet	$2300	$ 2300
3. 16 M RAM	$7500	$15000
4. ports	$ 900	$ 1800
5. DMA	$1800	$ 1800
6. CIT board	$2500	$ 2500
b. Chassis		
1. VME	$1500	$ 1500
2. interconnect	$ 500	$ 500
c. Power Supplies (provided as part of instrument controller)		
d. cables	$ 10	$ 70
e. Software VRTX, VXWRKS	$2000	$ 2000
f. Misc.		$ 500
TOTAL		$30,470

2. Labor

a. Design	(Ricketts)	4 days
b. Documentation	(Ricketts)	10 days
c. Purchasing	(Cantrall)	3 days
d. Chassis const.	(Mach shop)	3 days
e. Chassis wiring	(new hire)	5 days
f. CIT board load	(new hire)	3 days
g. Supervision	(Ricketts)	2 days
h. Test	(Ricketts)	12 days
	(new hire)	6 days

B. DEWAR

1. Parts

	each	total
a. CIT boards	$ 2500	$20000
b. CCD(s)	$84000	$84000
c. chassis	$ 500	$ 500
d. connectors, misc		$ 500
TOTAL		$105,000

2. Labor

a. Design	(Ricketts)	5 days
	(Robinson)	10 days
b. Documentation	(Ricketts)	15 days
c. Purchasing	(Cantrall)	4 days
d. load CIT brds	(new hire)	20 days
e. wire chassis	(new hire)	8 days
f. wire dewar	(new hire)	15 days
g. Supervision	(Ricketts)	5 days
	(Robinson)	2 days
h. Test, align	(Ricketts)	10 days
	(new hire)	10 days

C. System Integragion & Test

1. Parts

a. cabling	$100

2. Labor

a. System interconnection	(Ricketts)	2 days
	(new hire)	5 days
b. System test	(Ricketts)	10 days
	(Robinson)	10 days
	(new hire)	14 days

D. Installation in Hawaii

(Ricketts)	3 days
(new hire)	3 days

MECHANICAL ESTIMATES

Osborne 6-24-88

HIRES (hiest6.24)

1. Slit Area

Ricketts included motors, limit switches, wires, connectors, power supplies, and encoders in Electronic Estimate.

Other mechanical items:

Linear Slides, THK	$6000
Ball bearings, seals, sprockets, belts	900
Aluminum and anodizing	1500
Couplings, shafts, clamps	500
Air Cylinders, valves, regulators, gages, fittings, and plumbing accessories	3000
Lenses	1500
Filters $100 x 60 =	6000
Stainless Steel	2500
Glass	300
Enclosure for slit area	4000
Sheet metal and insulation	1600
Hatch, hinges, seals	100
TOTAL	$ 28,300

Outside services:

Machining large pieces	$6000
Foundry (castings)	4000
	$10,000

Total Material estimate is $ 38,000

2. Structure + Enclosure

Bally Walk-in "Room" 18' x 14'	$17,000	quotation
Bally Walk-in "Vault" 3' x 4'	2,000	
Bearings for kinematic mounts	3,500	
Welding support equipment, wire and consumables	1,500	
Steel	6,000	
Outside services- cutting, stress relieving, blanchard grinding large steel parts	7,500	
TOTAL	$37,500	

3. Dewar and Focus Stage

Sockets, wire, connectors and chassis parts are in Electronics estimate by Ricketts.
Sapphire window is $900 and is in Optical estimate.

Estimate is $15,000: (Based on previous dewar constructions.) Ion pump and power supply is $2500. Cryogenic and high vacuum parts, and leak detection consumables. Focus stage is large and moves to very close tolerances (less than 1 micron). THK slides, bearings, air cylinders and control like "Slit Area". O-rings, Torr-Seal vacuum epoxy, hermetic connectors, vacuum valves and operators. Stainless steel, copper, aluminum material. Liquid nitrogen storage vessels and transfer equipment.

4. Camera

Estimate is $53,700 as follows:

6 tools for optical grinding and polishing of 5 surfaces: The pyrex mirror is 34" in diameter, the 2 fused silica corrector lenses are 27" in diameter. Each tool is estimated to be $3000 for the pattern and casting and $4500 for outside machining. $7500 times 6 is $45,000.

Air cylinders plus acces.	$2000
THK slides	3000
Mercury belt	900
Steel, aluminum	400
Outside services*	1500
Bearings	900
	$8700

TOTAL:	$45,000
	8,700
	$53,700

Does not include:
1. Aluminizing fixtures for camera mirror
2. No outside machining. Assumes Bullard vertical turret lathe can machine all large round parts.

---

* Metal fabricator to roll steel rings for cell, sandblasting, heat treating and blanchard grinding.

5. Camera Mover (or Camera Selector)

$5600 large screw/nut assemblies and gear reducers for moving mirror and cell assembly up and down. Motor included in Electronics estimate. Also, some small costs for defining components (ball and cones) and steel.

6. Cross Disperser

Estimate is $25,000.
Anorad rotary table quotation is $18,000. This includes on-axis encoder for 4 arc-sec resolution. This rotary table is marginal for the load we are working with. Klinger makes a similar rotary table for $18,000 but with the encoder mounted at the motor and not on the table axis. This is Klinger's largest rotary table. Either will do.
Glass parts are included in the Optical materials budget. Other mechanical parts are as follows:

Spacers and diamond tools	$ 600
Subplate, aluminum	500
Supports	60
Adjusters	260
Springs	130
Anchors	180
Misc	30
Basic mosaic.....................	$1760
Air cylinder parts (see Slit Area)	1500
Motor (see Ricketts estimate)	nc
Adapter: mosaic cell-to-turntable	800
Protective cover	50
Adapter: turntable-to-main frame	1000
Mechanical parts total	$ 5,110
Rotary table	18,000
Outside services (drill, tap subplate)	1,890
TOTAL	$ 25,000

7. Echelle

Spacers and diamond tools	$ 900
Subplate, aluminum	700
Support mounts	100
Adjusting parts	400
Spring parts	200
Anchor supports	250
Misc	50
Basic mosaic cost....................	$2600
Air cylinder parts (see Slit Area)	1500
Drive motor, switches, wire, connectors (see Ricketts estimate)	0
Metal for cell, base, flex pivot, cover, cover seal, hinge	900
Outside services (drill, tap subplate)	2000
TOTAL	$7500

8. Collimators

There are 2 and they switch back and forth. Cost of motor, limit switches and wiring and connectors is in the Electronics estimate. Each mirror has a cover. A clamp locks each in position.

THK slides	$2500
Drive parts and gear reducer	600
Air cylinders and related hardware	1500
Air clamp parts	750
Metal (not included)	0
Outside services (none)	0
TOTAL	$5350

9. Fiber Collimator

Cell material cost is small.

Fiber costs:

25 fibers: 50 meters each + 5 meters = 55 m (outside + LRIS)

55m x 25 fibers x $5 per meter = $ 6875

Connector cost: $20@ x 25 fibers x 2 ends = 1000

Install "lenslets" (Oke): ($103 material + $27 labor = $130 each x 20 fibers = $2600) 2600

Total fiber cost (no jackets) $10,475

Fiber Collimator Mover like "Camera Mover"	5,600
Cross Disperser changer (manual)*	4,000
TOTAL MECHANICAL	$20,075

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* This is rails, small gantry crane, hoist, and storage platform for interchanging the flat mirror in its cell with the cross disperser grating mosaic in its cell. It is a manual operation for HIRES CORE.

SOFTWARE SPLIT HIRES/LRIS

Osborne, 6-24-88
SPLIT.1

	HIRES	LRIS
Atwood:	1840 hrs = $50,674	360 hrs = $ 9,914
Kibrick:	1440 hrs = 65,045	760 hrs = 34,329
Clarke:	360 hrs = 12,139	120 hrs = 4,046
Allen:	2180 hrs = 32,831	580 hrs = 8,735
Stover:	500 hrs = 17,800	300 hrs = 10,680
	$178,489	$67,704

7.0 Schedule

7.1 Design, fabrication, testing phases of major subassemblies

Mechanical/Optical Milestones

Figure 25 shows the Gantt chart for the Mechanical, Electronic, and Optical tasks of HIRES. The designated milestones (not in chronological order) on this chart are as follows.

1. Preliminary Design Review (PDR) of HIRES' Mechanical, Optical and Electronic designs. This will happen mid August 1988.

2. The detector (CCD) will be chosen as late as possible: by December 1989. This impacts dewar design, Echelle and Cross Disperser selections and parts of the CCD Controller.

3. The instrument lab facilities will be finished January 1989. The new high bay and expanded shop areas will house HIRES.

4. The optical fabrication is schedule to be complete by April 1990.

5. The testing of the Echelle mosaic concept happens soon in the project: May 1989. This is the first major assembly to be built. We are encouraged by the present mosaic testing at Lick and thus have no "fall back" options.

6. The TV camera is selected by February 1989. The design of the slit accessories waits for this decision.

7. The testing of the Cross Disperser mosaic will occur about May 1989.

8. In November 1989 the collimator mirrors will be fitted into their cells and the changing mechanism tested.

9. The static and dynamic load testing of the structure should be finished by November 1990.

10. Testing the CCD response and adjusting waveforms and clocks will begin July 1990 and run through October 1990.

11. In December 1989, the master blanks for Echelle and Cross Disperser grating will be sent to Milton Roy for ruling. The decision of which CCD to use (Milestone 2) will have to be done by this time.

12. June 1990: The 5 blanks will be sent to Milton Roy for replicating.

13. The electronics fabrication will be finished by November 1990.

14. The preshipment review will be late November 1990.

15. The optical design of the short camera will be finished in March 1989.

16. The fiber collimator will be installed in its cell in July 1990. The fibers will be installed into the fiber fan and the collimator/fiber fan assembly will be exercised in its lifting assembly.

17. Critical Design Review (CDR) will be January 1989. (Details of the CDR's are in Section 7.3).

18. CDR 2 will be August 1989.

19. CDR 3 will be February 1990.

20. CDR 4 will be mid-June 1990.

Electronics Milestones

The electronics lab will finish the VME instrument controller (target machine) by Dec. 1988, in time for Software Milestone 3.

By April, 1989, the wiring of the interconnect chassis and the two motor driver chassis will be complete.

The CCD VME controller will be done by July, 1989, in time for Software milestone 8.

By July, 1990, the wiring and installation of all HIRES stages will be complete and tests will begin. The electronics will be completely finished by Nov. 1990 (Figure 25 milestone 13).

Software Milestones

The Gantt chart for software production is shown in Figure 26. The designated milestones (not in chronological order) on this chart are as follows.

1. Sept. 15, 1988: delivery of baseline UNIX Figaro. This is the version of Figaro that CIT is porting to their Sun (UNIX) system. We can't begin studying Figaro until we receive it (and its documentation). Since the Keck instrument DAS (Data Acquisition System) will use Figaro for many of its I/O functions and as a model for its command language interface, we need a copy of Figaro to work with.

2. Aug. 1, 1989: delivery of Keck Figaro. This is the version of Figaro that will contain the extra features requested by the PI's in the May 12-13 meeting on LRIS and HIRES coordination. These features are to include implementation of FITS format images, use of the UNIX shared-memory concept, and optimization for speed. Since the DAS will be using Figaro I/O routines, we will need to study, implement, and test any changes in Figaro that effect the DAS.

3. Dec. 1, 1988: delivery of complete VME target machine. We can't bring up the VRTX/VxWorks system until we have a VME target system, and our preliminary HIRES motor controller routines can't be tested until we have a working target machine.

4. Aug. 1, 1988: delivery of VRTX/VxWorks software and documentation. We will need to study and experiment with the VRTX/VxWorks software to learn how it operates, how to download code, etc. This will be integral to the development of the HIRES/DAS interface.

5. Jan. 1, 1989: vacate SUN room (space available). Due to space and temperature requirements for a Sun computer, we will have no place to put the HIRES Sun at Lick until space opens up in either the department Sun computer room (NS 105) or the VAX room (NS 168). This will force the software team to use the department Sun until space is available for the HIRES Sun; and when this space is available, some time will be spent setting up the HIRES Sun, transferring software from the department machine to the HIRES machine, etc. The HIRES Sun will initially be installed in NS 105. It is not known whether it will need to be moved to NS 168 at a later date.

6. May 1, 1989: vacate VAX room (space available). See Milestone 5 above.

7. June 1, 1989: delivery of specifications for CCD controller. Detailed specifications for the CCD controller are needed in order to develop a software interface between it and the DAS.

8. July 15, 1989: delivery of CCD controller. Testing of the DAS interface to the CCD controller cannot be done until we receive the controller.

9. Oct. 1, 1988: specification of Figaro-like command language. The DAS command language interface cannot be implemented until the command language has been specified. At this time, suggestions have been made that it should be either the C shell or Magic-L.

10. Sept. 15, 1989: delivery of LRIS specifications. Detailed specifications of the LRIS are required for development of the DAS to LRIS interface. These specifications will also be helpful in development of the HIRES shared fibers interface.

11. Sept. 15, 1988: delivery of complete (including autoguider image) DCS interface specifications. As communication with the telescope and autoguider are crucial to instrument operation, these specifications are needed for development of the DAS interface to the DCS.

12. Oct. 15, 1988: delivery of complete ACS interface specifications. This is required for development of the DAS-mirror interface.

13. Nov. 15, 1988: Preliminary Design Review. This review is required by CARA. The primary purpose of the PDR is to verify that the functional requirements are understood and that a preliminary design exists that meets those requirements.

14. March 1, 1989: Critical Design Review. This review is required by CARA. The primary purpose of the CDR is to verify that the detailed design is complete and ready for implementation and meets the functional requirements. It should be held when the final design is complete but before any major implementation has begun.

15. March 15, 1990: delivery of preliminary version of DAS to LRIS. The LRIS instrument group will need to test the operation of the DAS with their instrument prior to delivery of LRIS so that any needed changes or fixes can be made to the software or hardware.

16. Oct. 1, 1988: delivery of SUN-4/110C. This is the first Sun-4 workstation we will have access to for evaluating various options for graphics. This workstation will be used in conjunction with the departmental server machine until the HIRES Sun and its workstations become available.

7.2 Assembly, integration and testing, shipping, telescope installation and testing

Our plan is to construct HIRES in a large dedicated area of an assembly bay attached to the Lick Instrument Lab. Here, the instrument will be close to all the Lick technical resources such as engineering, optical, instrument, electronic, and coating labs. Once assembled, the instrument will be run both locally from a nearby instrument computer, and also remotely from the Lick Observatory Offices 0.25 miles away.

Once HIRES is fully operational, it will be disassembled into a small number of major sub-components and packed securely in a standard shipping container. The container will then be shipped to Hawaii by sea freight and trucked to the top of Mauna Kea. An engineer will be sent to Hawaii to receive the container and accompany it to the observatory.

Installation and initial debugging is expected to require at least several weeks, though HIRES will be engineered so as to require a minimum amount of assembly and alignment at the telescope. After this initial installation is complete, a formal commissioning period of 6 months is planned for complete shakedown. During this commissioning period, the routine operation, testing, and debugging of HIRES will be under the supervision of the P.I. This debugging period is almost an unavoidable fact of life due to cost savings, and the first astronomers to use HIRES can expect the usual unexpected gremlins and bugs, which can only be fully ironed out by actual use in scientific research.

7.3 Design Reviews

Mechanical/Optical/Electronic design reviews are labelled along the top of the Gantt chart in Figure 25.

The Preliminary Design Review (PDR) is to be held in August 1988.

The first Critical Design Review (CDR) is in January 1989 and is a PDR for the optical design. This CDR will be for the complete electronics design but for a partially complete mechanical design. The main emphasis will be on the Echelle

Mosaic design. Also reviewed at this time will be the collimator mirror design and certain of the slit area accessories.

The second CDR will be in August 1989 and will evaluate the grating mosaic concept, both the Echelle and Cross Disperser will have been tested by then. The structure and housing designs will be preliminarily reviewed. The TV and more of the slit area will also be reviewed. The CDR for the optical design will also be done at this time.

The third CDR will be in February 1990. This review will be a final review of the structure and housing designs. The CCD was selected two months earlier and the CCD dewar design will be reviewed. The fiber collimator system design will be reviewed also.

The fourth CDR will be in June 1990 (first light and 6 months before delivery of HIRES to Mauna Kea). The progress at Milton-Roy will be evaluated: the grating replicas should be done. This CDR will concentrate on the assembly, alignment, testing, disassembly, shipping and reassembly of HIRES. The scenario is complicated and needs to be reviewed.

The PDR's and CDR's for software are shown at the top of Figure 26. The first software PDR will occur at the end of November, 1988, and a software CDR will occur in March, 1989. Of course, reviews of software progress will also occur as part of the design reviews of the mechanical/optical/electronic areas (see Figure 25). A uniform format for software reviews is still being developed by the SSC, and the Data Acquisition Working Group.

8.0 Maintenance and Future Upgrades

After the formal 6-month commissioning period, supervision of the routine operation, testing, debugging, and enhancement of HIRES will be transferred to the Keck Observatory director.

The HIRES P.I. and the technical support staff at Lick Observatory will be available for at least 1 year after the close of the formal commissioning period to assist with operation and maintenance of HIRES. Travel and related expenses incurred by the HIRES support team after the commissioning period will be borne by Keck Observatory.

HIRES is designed to be quite flexible and to be easily upgraded in the future. The following are a number of possible enhancement "packages". Details of some of these packages were given in the HIRES Phase B proposal.

The Very High Resolution Package

This package is to install the long (80") camera, a complement of image slicers, and the 'tight white' cross disperser. It would yield resolutions of 40,000 to 200,000 and would be used for such things as interstellar line work, stellar magnetic fields, and stellar seismology. The present short camera cost about $258,000 and the long camera would probably cost about the same. Each slicer costs about $7,000 and there would be about 10. The tight white cross disperser would cost about the same as the present one, without any costs for engineering or rotary table: $175,000. So the total package would be about $500K.

The Multi-object/Long-slit Package

This mode would be to optimize HIRES for multi-object work by providing its own fiber positioner and adding more dispersive cross dispersers to allow more fibers to be packed between orders. It would include adding a dedicated Autofib fiber placer (probably a copy of the one designed for LRIS), with 100 to 130 fibers, 2 'long-slit' cross-dispersers (see phase B proposal), a cross disperser carousel, a bunch of interference filters, and an image rotator. Thus instead of 20 objects at once, one would get about 100, plus sky channels. No new technology is required here. As a wild guess, $500,000 might cover it. This mode would be optimized for cluster abundance studies and dynamics of small stellar systems. It could be a very strong NSF proposal if the right people get behind it.

The UV Package

This would be a "wide wavelength coverage UV package, optimized primarily for QSO absorption line studies. One would get an R-1.5 echelle, an echelle server, a UV-optimized cross-disperser, a new wide wavelength high tech UV corrector for the short camera, and hopefully a new coating for the short camera, with silver-like reflectivity in the visible and red, and aluminum-like reflectivity down to the atmospheric cut-off. The coating and camera corrector would be at the limit of present-day optical technology. This mode would yield a resolution of about 25,000 with a 0.7 arcsec slit and would span 3350 Å to 5250 Å in a single shot. As a wild guess, the price tag might be around $500,000. It should also be a very strong NSF proposal if the right people get behind it.

The Bright Star Package

This mode would use a coarser echelle to get shorter orders in the red and thus eliminate gaps in the red, and do much better in the IR. It would include a very coarse R-2.6 echelle (26.3 gr/mm), another cross-disperser (for wide wavelength coverage and minimal order separation), a 50-inch camera, an extra CCD, etc. The coarse echelle couldn't be ruled very efficiently right now, but in a few years it may be possible. Perhaps $750,000 would do it.

The IR Package

All the optics will transmit to beyond 2 microns. Suppose in 10 years the germanium CCD is perfected, with a large format (maybe 1024^2 54 micron pixels?) and with decent quantum efficiency out to 1.7 microns or so. All we need is the detector and all its associated support, plus a new IR cross-disperser, and perhaps a new corrector, Again, $500,000 looks like a reasonable guess.

The Principal Investigator expects to remain closely involved with the instrument long after the formal one-year consulting period. His interests and scientific goals are likely to remain strong in the area of high resolution spectroscopy, and he would like to see HIRES eventually grow to its full potential through these and other upgrades. He is willing to help, as time permits, with the preparing of proposals to support these or other upgrades to HIRES, and to assist in getting these upgrades fabricated in the Lick shops and installed on the instrument.

FIGURE CAPTIONS

Figure 1- General layout of the HIRES optics on the Keck TMT.
Figure 2- Top view of the left Nasmyth platform showing the HIRES optics.
Figure 3- HIRES enclosure and support schematic.
Figure 4- Side view of HIRES optics.
Figure 5- Top, side, and end views of the HIRES optical train.
Figure 6- The fiber collimator scheme.
Figure 7- The echelle mosaic.
Figure 8- The cross disperser mosaic.
Figure 9- The HIRES UV/Blue spectral format.
Figure 10- The HIRES Visible/IR format.
Figure 11- HIRES Schmidt cameras.
Figure 12- Blue camera design image quality.
Figure 13- Red camera design image quality.
Figure 14- The CCD dewar concept.
Figure 15- More views of the CCD dewar.
Figure 16- Some CCD mosaic possibilities.
Figure 17- More CCD mosaic possibilities.
Figure 18- The Keck Observatory Computer Network.
Figure 19- HIRES instrument controller block diagram.
Figure 20- HIRES typical stage wiring diagram.
Figure 21- The Bally enclosure concept.
Figure 22- The Lick CCD TV camera.
Figure 23- A simple optical concept for the HIRES Autoguider TV.
Figure 24- The HIRES Management Structure.
Figure 25- HIRES Mechanical/Electronic/Optical production schedule.
Figure 26- HIRES software production schedule.

Table 1- The HIRES UV/Blue spectral format.
Table 2- The HIRES Visible/Red spectral format.

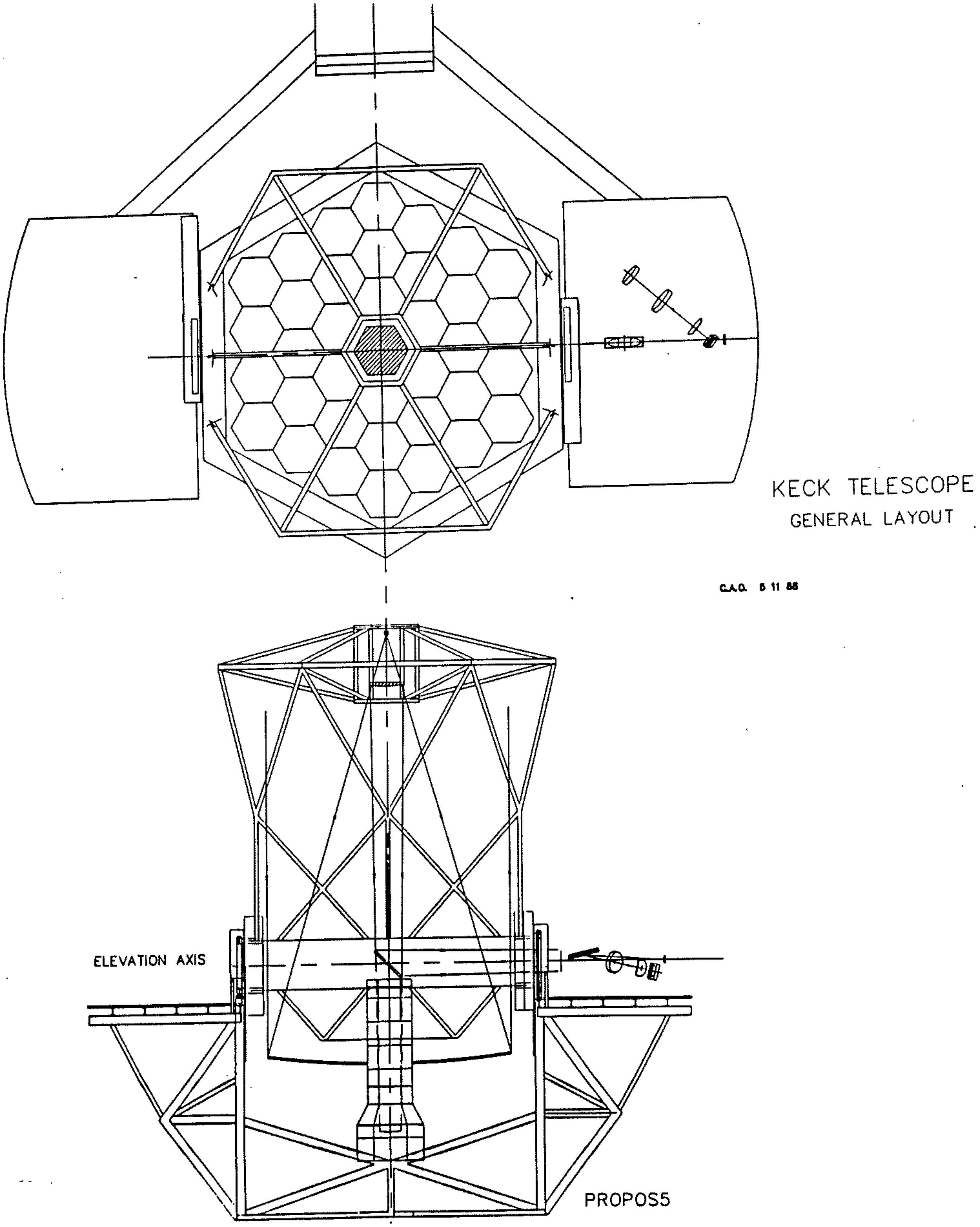

KECK TELESCOPE
GENERAL LAYOUT
C.A.O. 5 11 86
ELEVATION AXIS
PROPOS5

Figure 1

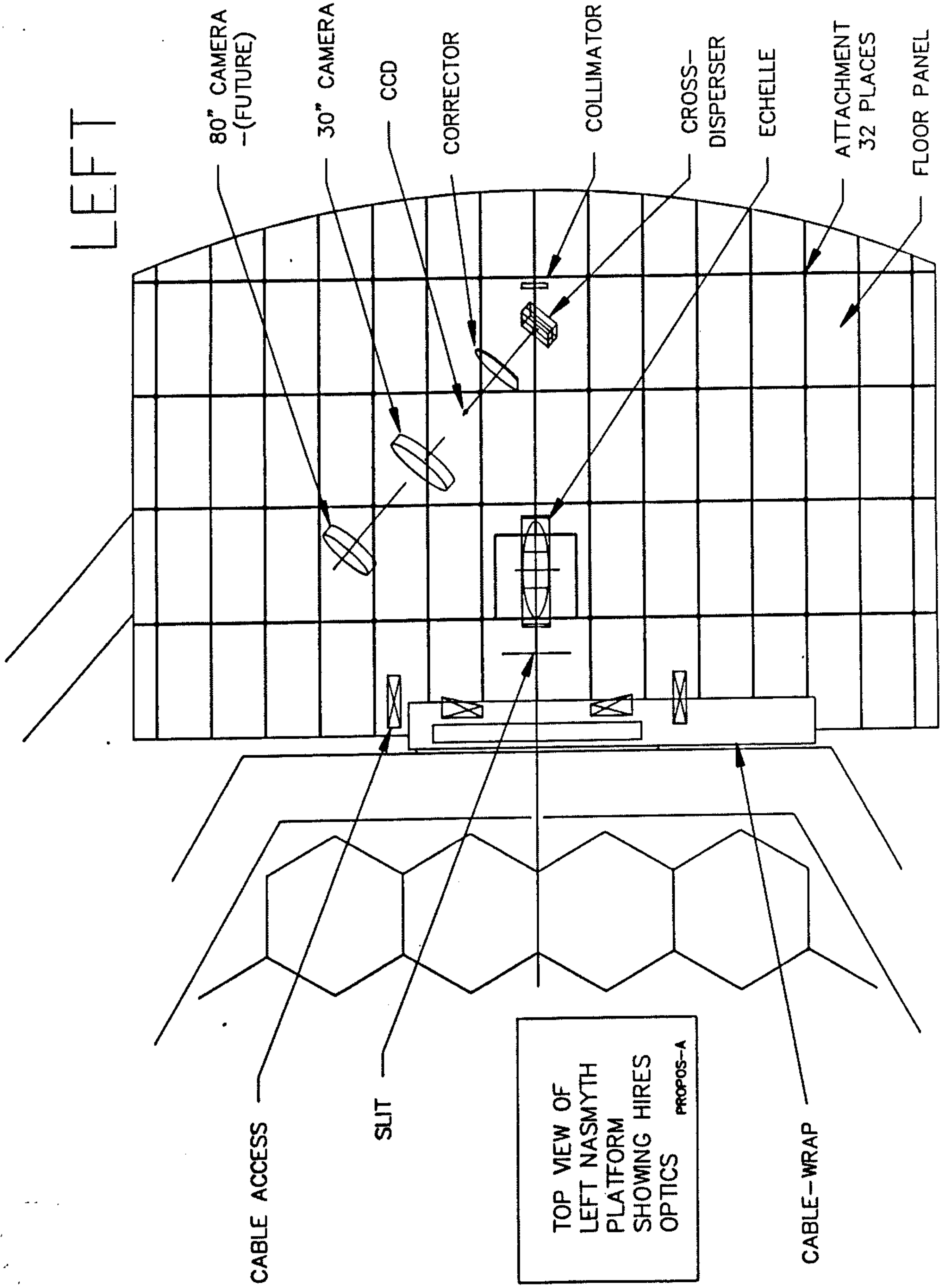

LEFT
80" CAMERA -(FUTURE)
30" CAMERA
CCD
CORRECTOR
COLLIMATOR
CROSS-DISPERSER
ECHELLE
ATTACHMENT 32 PLACES
FLOOR PANEL
CABLE ACCESS
SLIT
TOP VIEW OF LEFT NASMYTH PLATFORM SHOWING HIRES OPTICS
PROPOS-A
CABLE-WRAP

Figure 2

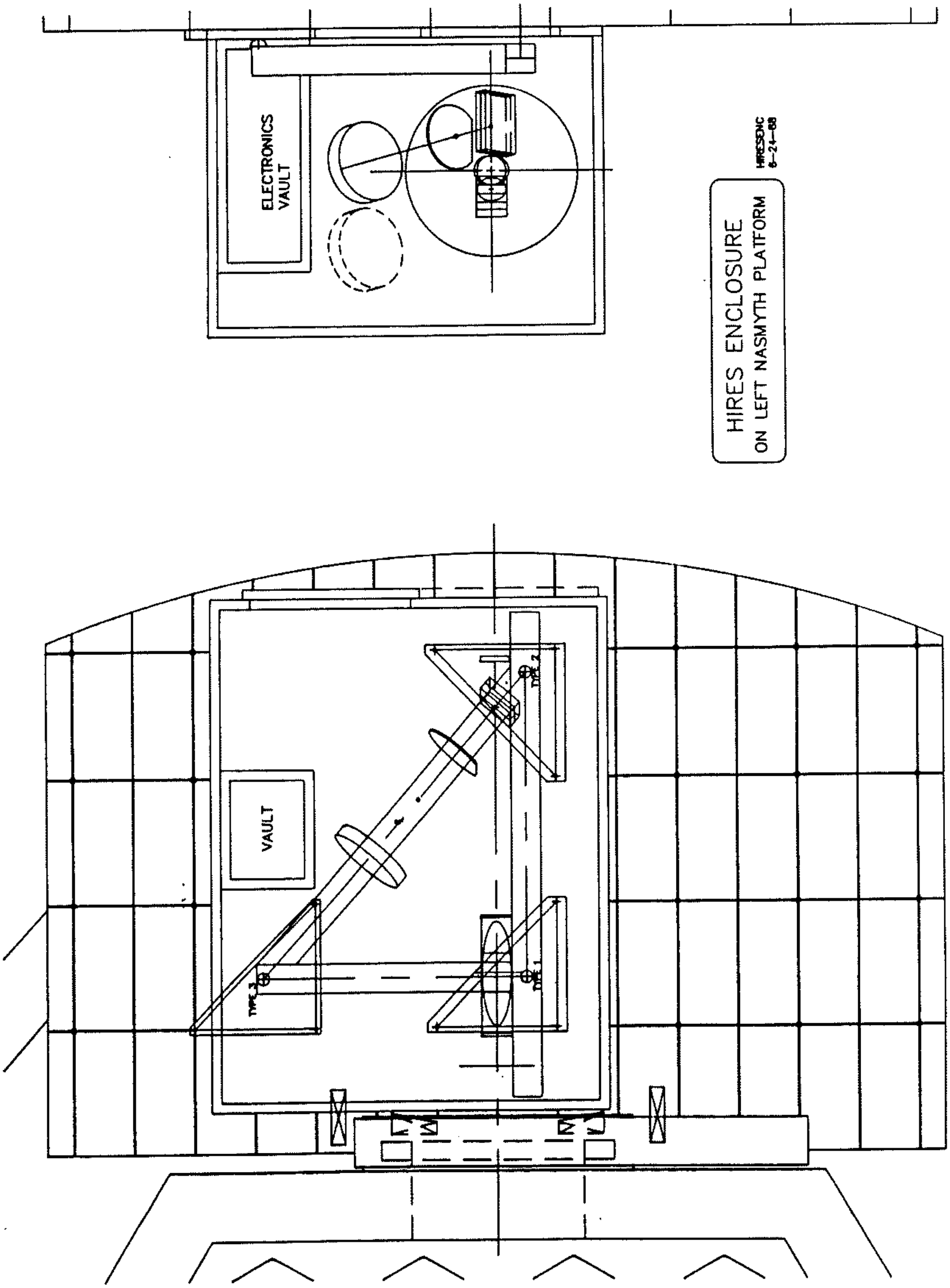

ELECTRONICS VAULT
HIRES ENCLOSURE
ON LEFT NASMYTH PLATFORM
HIRESENC
8-24-88
VAULT
TYPE 2
TYPE 1
TYPE 3

Figure 3

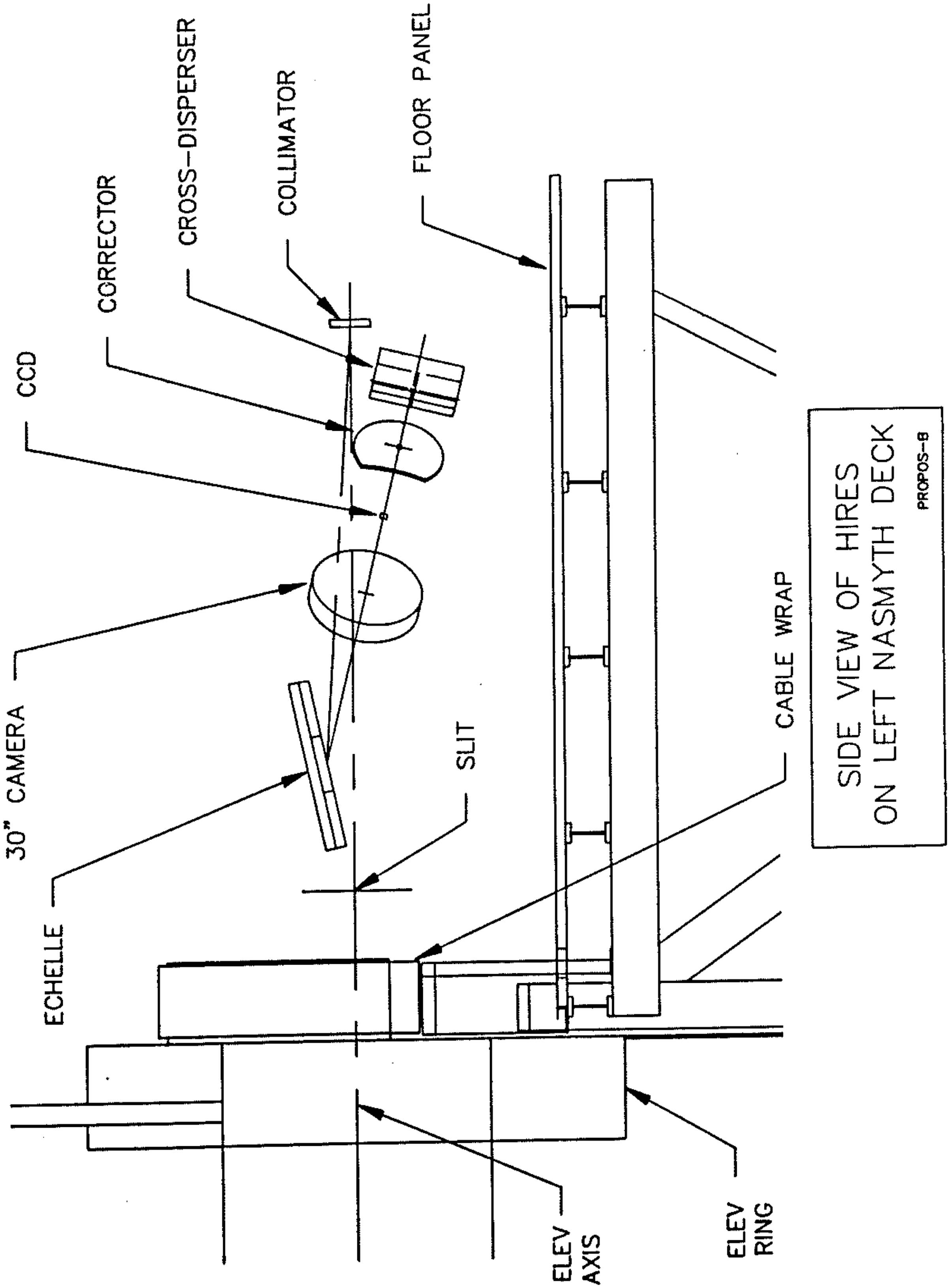
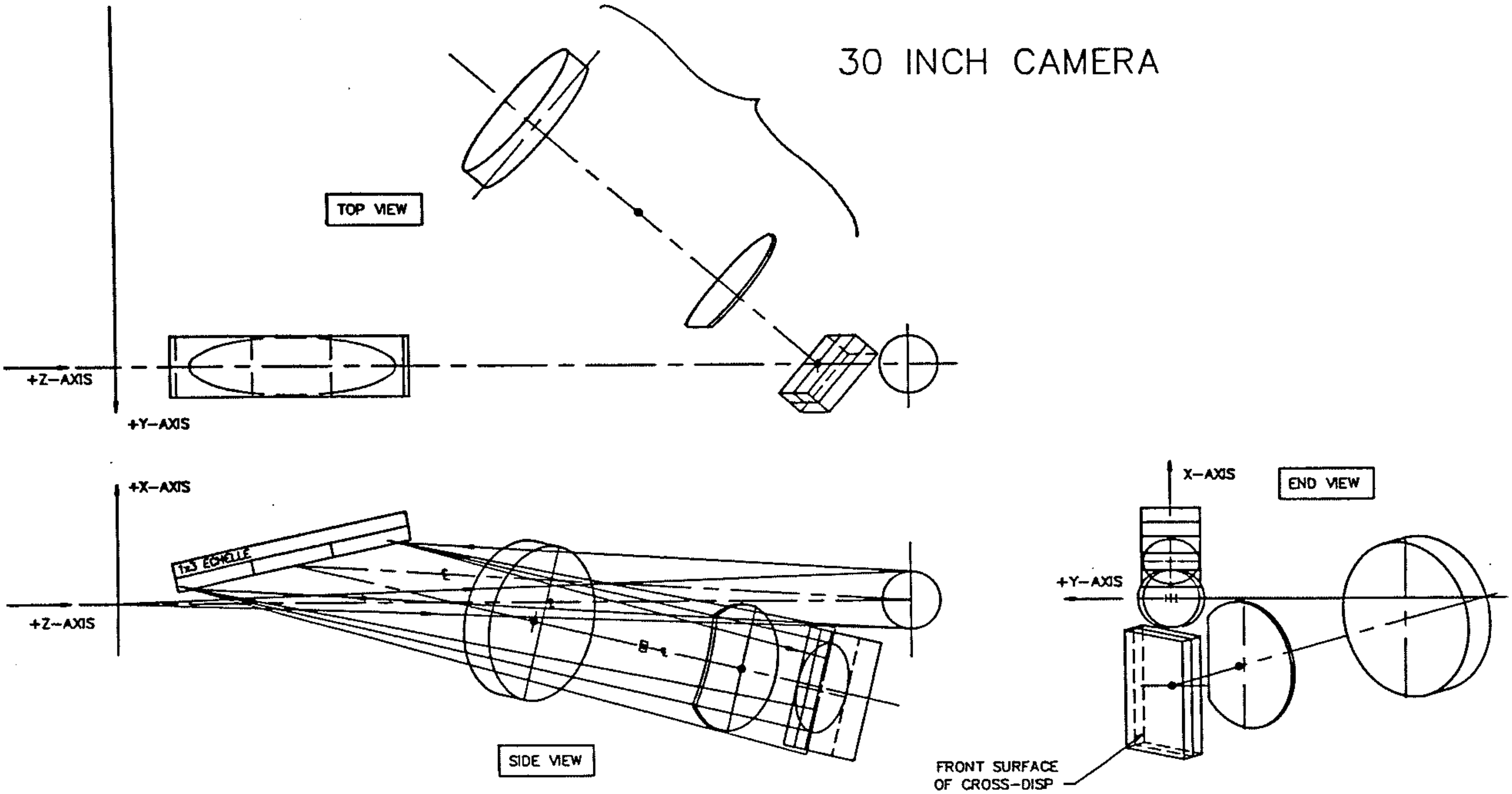

SIDE VIEW OF HIRES
ON LEFT NASMYTH DECK
PROPOS-B
FLOOR PANEL
COLLIMATOR
CROSS-DISPERSER
CORRECTOR
CCD
30" CAMERA
SLIT
ECHELLE
CABLE WRAP
ELEV AXIS
ELEV RING

Figure 4



30 INCH CAMERA

Figure 5

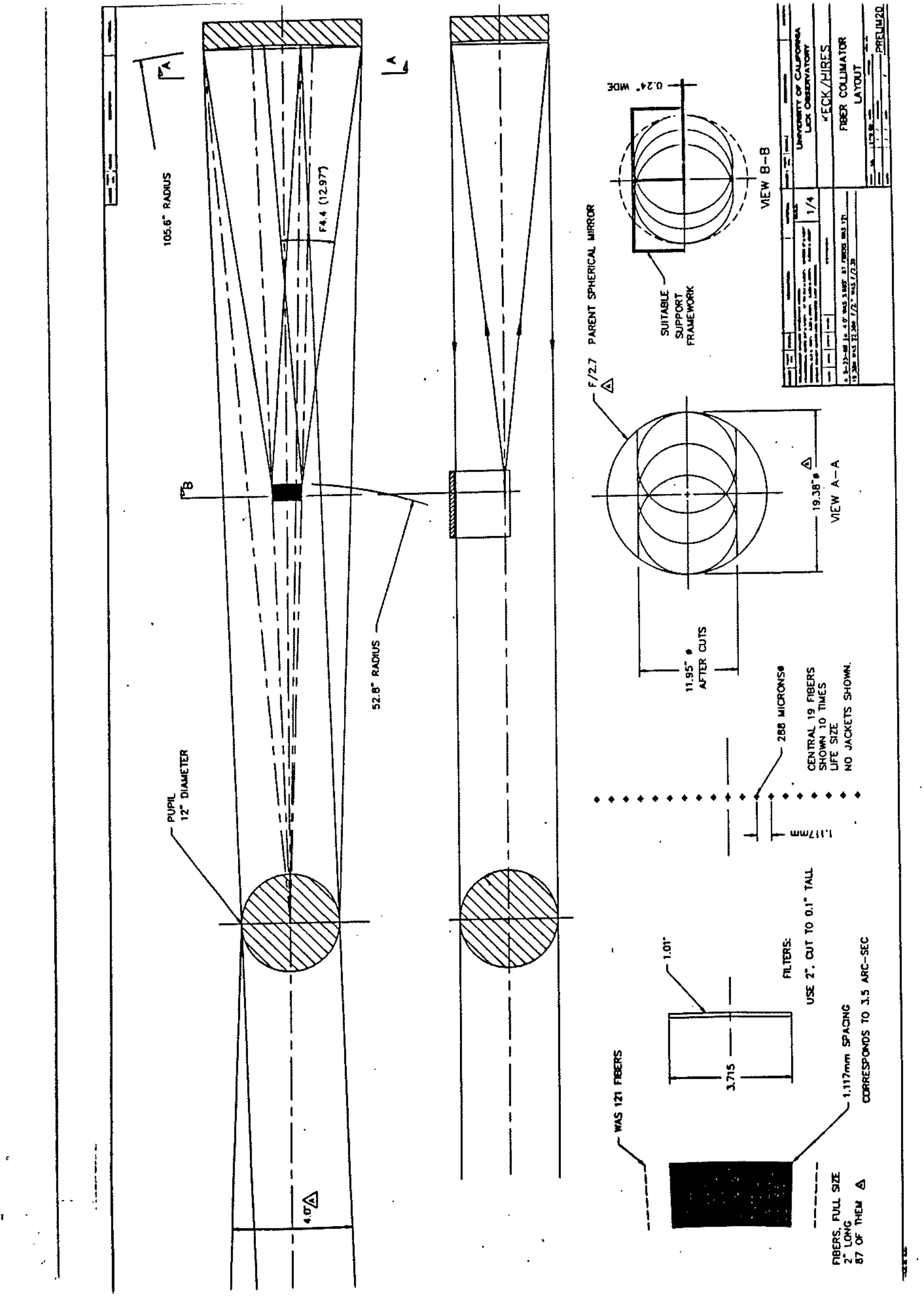

105.6" RADIUS
A
A
F4.4 (12.97")
B
52.8" RADIUS
PUPIL
12" DIAMETER
4.0"
F/2.7
PARENT SPHERICAL MIRROR
0.24" WIDE
SUITABLE
SUPPORT
FRAMEWORK
VIEW B-B
19.38" ⌀
VIEW A-A
11.95" ⌀
AFTER CUTS
288 MICRONS⌀
CENTRAL 19 FIBERS
SHOWN 10 TIMES
LIFE SIZE
NO JACKETS SHOWN.
1.117mm
1.01"
FILTERS:
USE 2", CUT TO 0.1" TALL
3.715
WAS 121 FIBERS
1.117mm SPACING
CORRESPONDS TO 3.5 ARC-SEC
FIBERS, FULL SIZE
2" LONG
87 OF THEM
UNIVERSITY OF CALIFORNIA
LICK OBSERVATORY
KECK/HIRES
FIBER COLLIMATOR
LAYOUT
1/4
PRELIM20

Figure 6

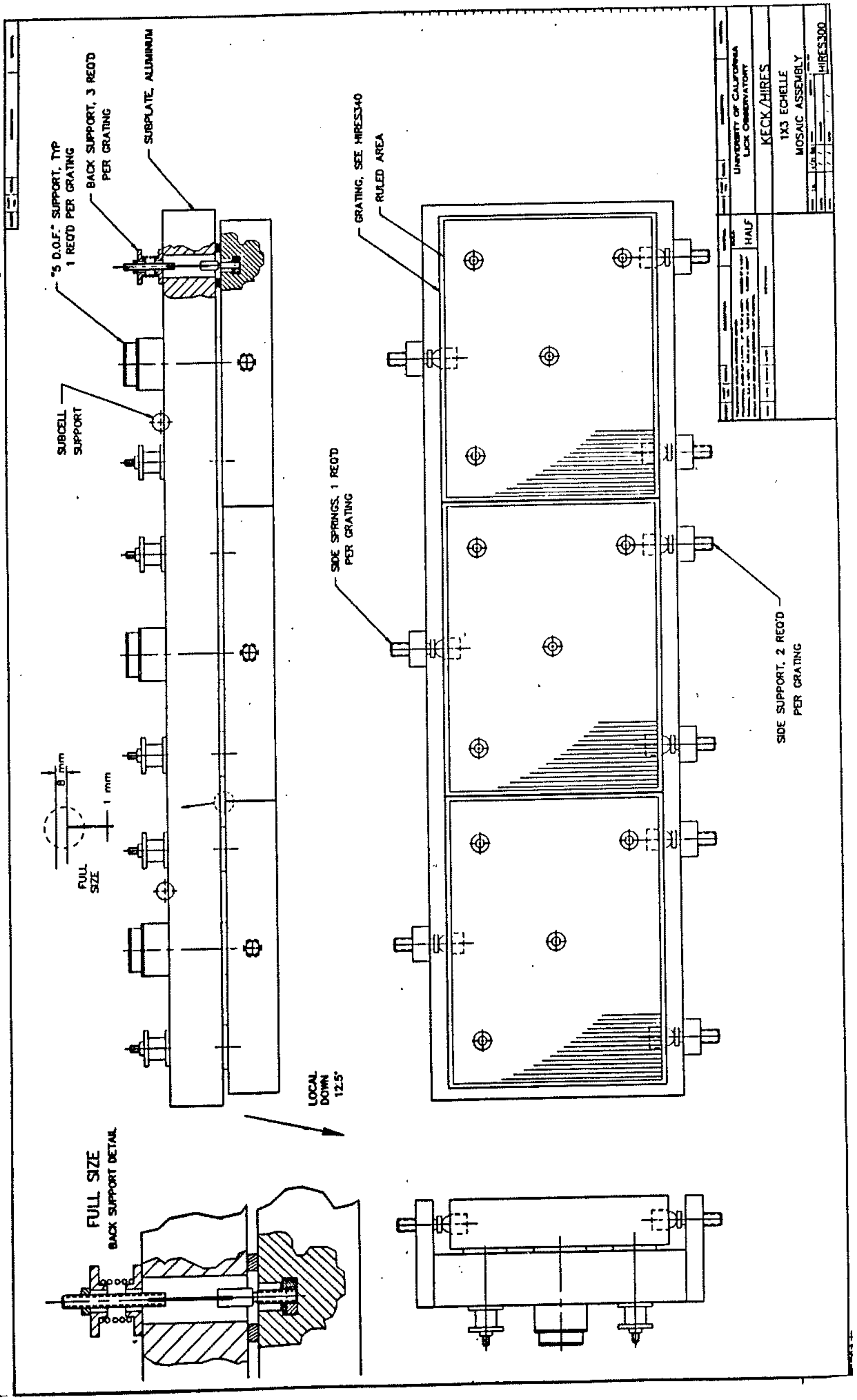

"5 D.O.F." SUPPORT, TYP 1 REQ'D PER GRATING
BACK SUPPORT, 3 REQ'D PER GRATING
SUBPLATE, ALUMINUM
SUBCELL SUPPORT
8 mm
1 mm
FULL SIZE
LOCAL DOWN 12.5°
FULL SIZE
BACK SUPPORT DETAIL
GRATING, SEE HIRES340
RULED AREA
SIDE SPRINGS, 1 REQ'D PER GRATING
SIDE SUPPORT, 2 REQ'D PER GRATING
HALF
UNIVERSITY OF CALIFORNIA LICK OBSERVATORY
KECK/HIRES
1X3 ECHELLE MOSAIC ASSEMBLY
HIRES300

Figure 7

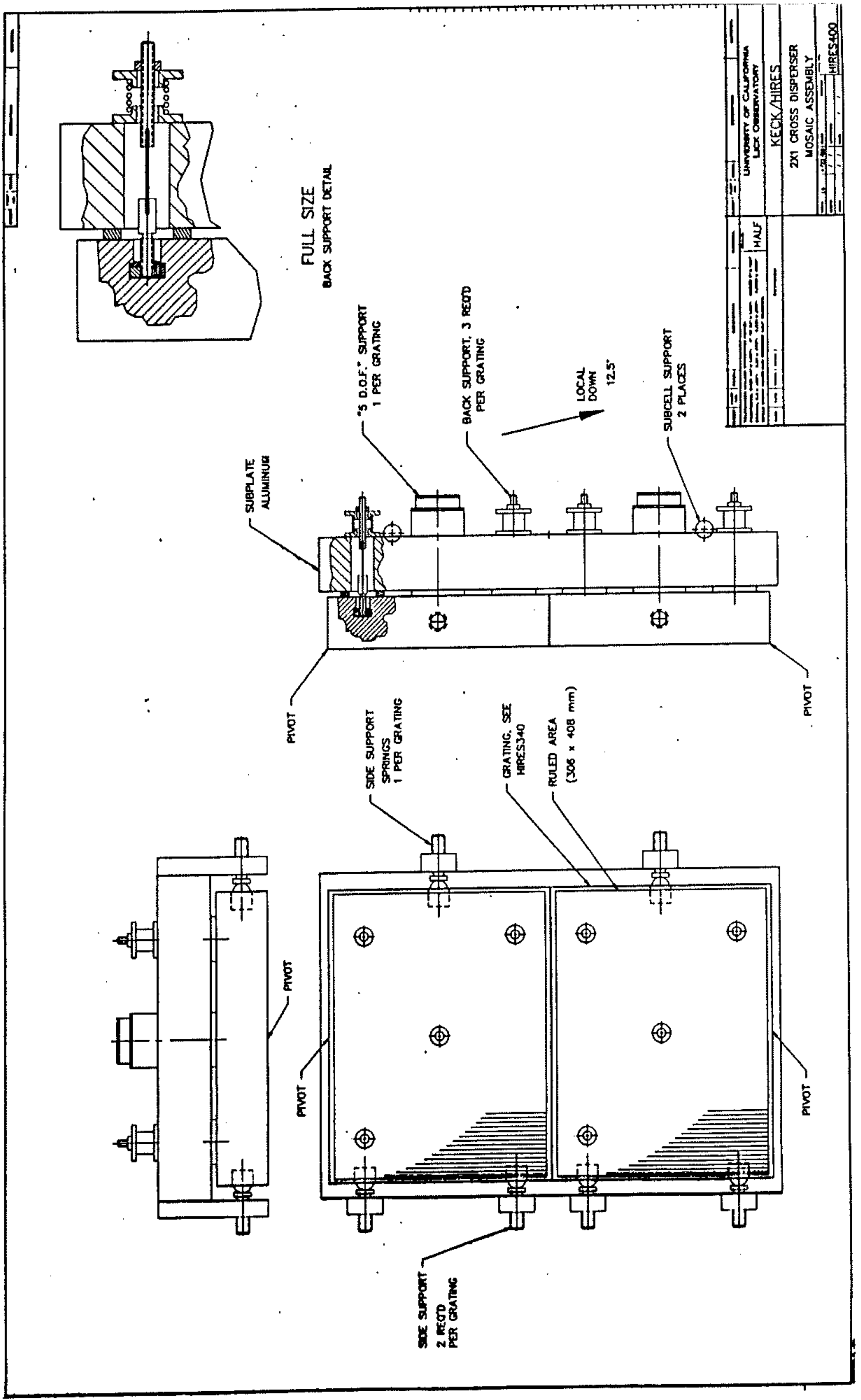

UNIVERSITY OF CALIFORNIA
LICK OBSERVATORY
KECK/HIRES
2X1 CROSS DISPERSER
MOSAIC ASSEMBLY
HIRES400
HALF
FULL SIZE
BACK SUPPORT DETAIL
SUBPLATE
ALUMINUM
"5 D.O.F." SUPPORT
1 PER GRATING
BACK SUPPORT, 3 REQ'D
PER GRATING
LOCAL
DOWN
12.5°
SUBCELL SUPPORT
2 PLACES
PIVOT
PIVOT
SIDE SUPPORT
SPRINGS
1 PER GRATING
GRATING, SEE
HIRES340
RULED AREA
(306 x 408 mm)
PIVOT
PIVOT
PIVOT
SIDE SUPPORT
2 REQ'D
PER GRATING

Figure 8

HIRES UV/Blue Format

Echelle: 46.5 gr/mm θ = 5.0
X-Disp: Grating with 300. gr/mm Order = 2
Camera: 762.0mm f.l.

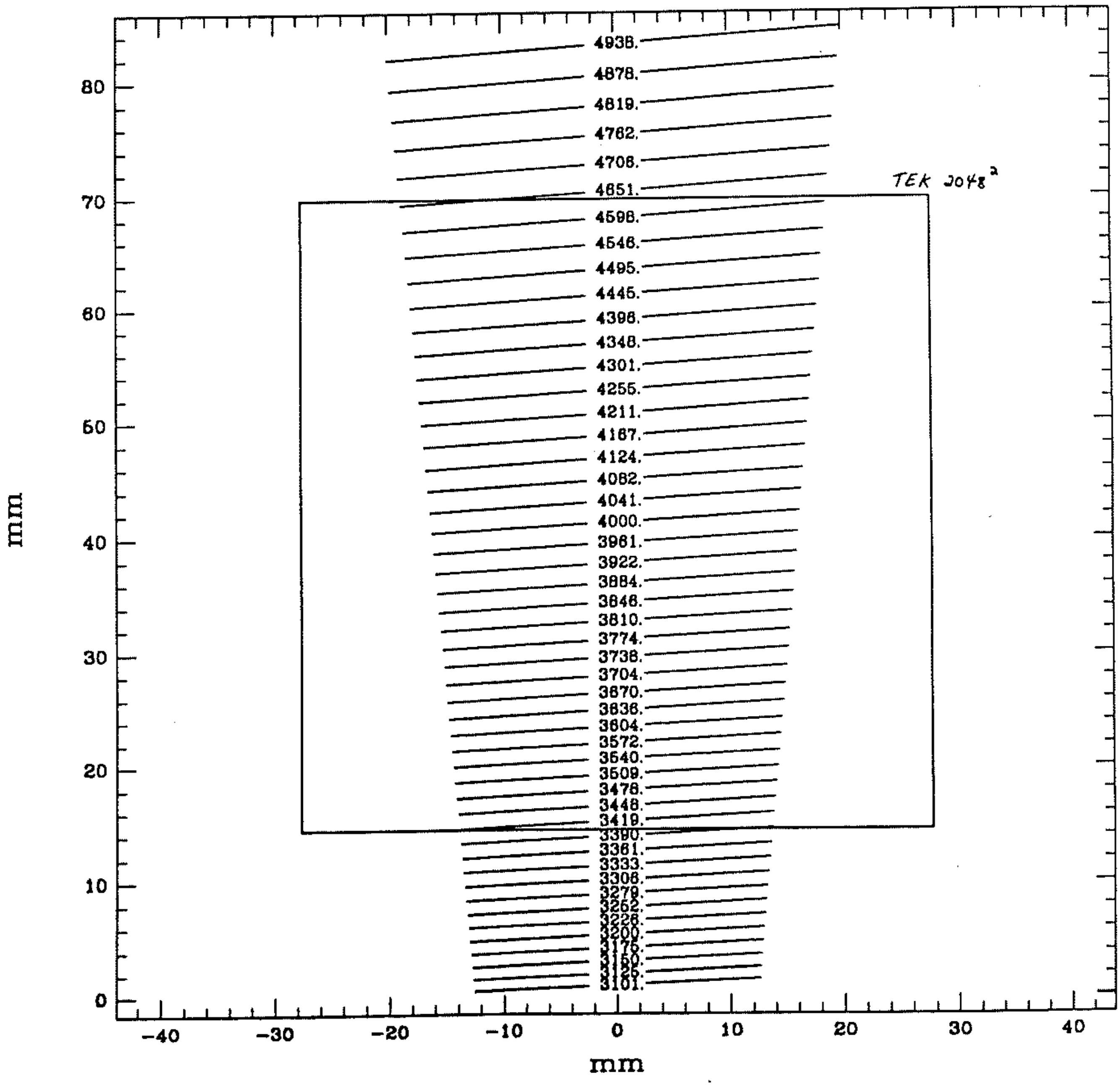


Figure 9

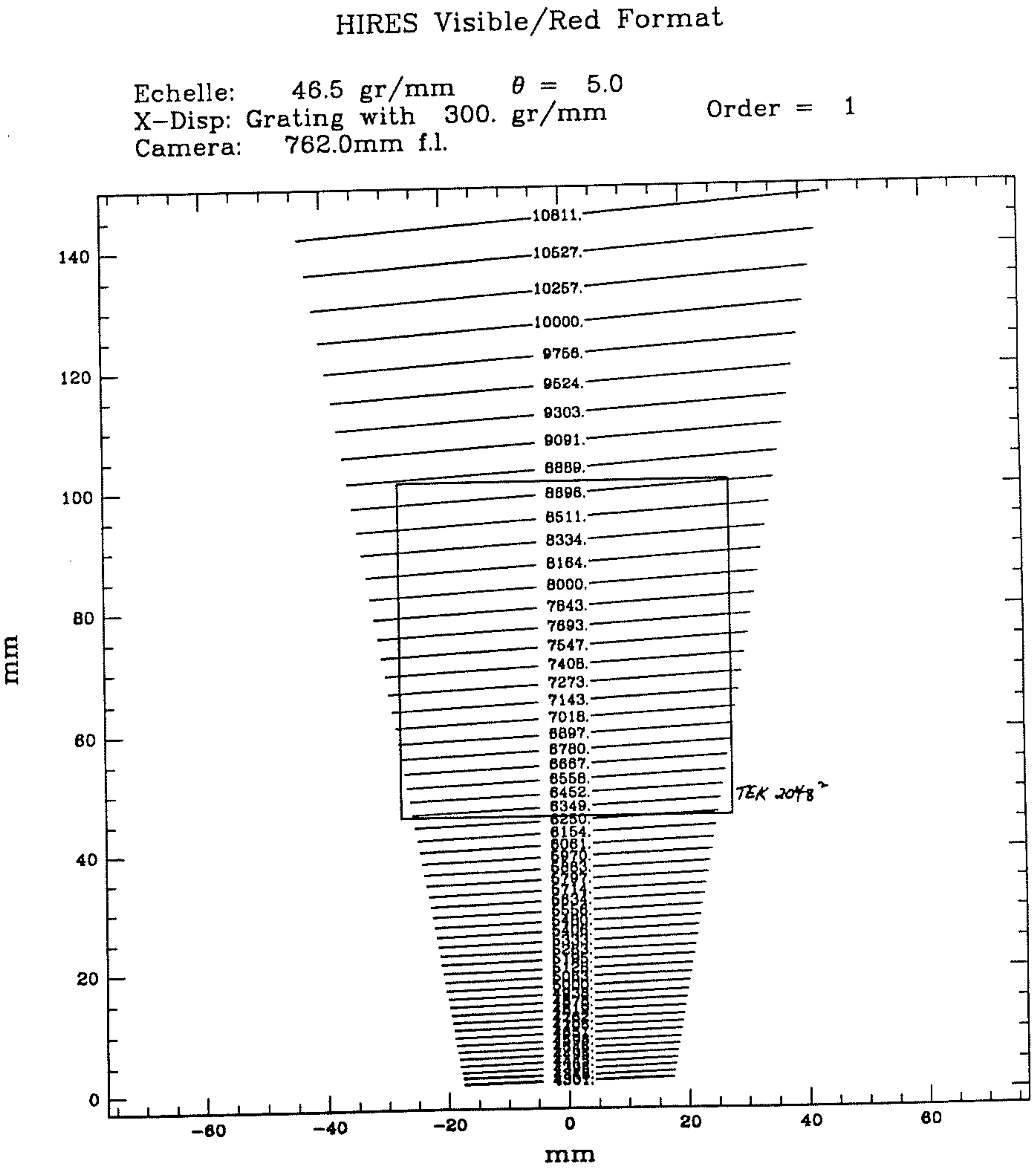

HIRES Visible/Red Format
Echelle: 46.5 gr/mm θ = 5.0
X-Disp: Grating with 300. gr/mm
Order = 1
Camera: 762.0mm f.l.
10811.
10527.
10257.
10000.
9756.
9524.
9303.
9091.
8889.
8696.
8511.
8334.
8164.
8000.
7843.
7693.
7547.
7408.
7273.
7143.
7018.
6897.
6780.
6667.
6558.
6452.
6349.
6250.
6154.
6061.
5970.
5883.
5797.
5714.
5634.
TEK 2048²
140
120
100
80
60
40
20
0
mm
-60
-40
-20
0
20
40
60
mm

Figure 10

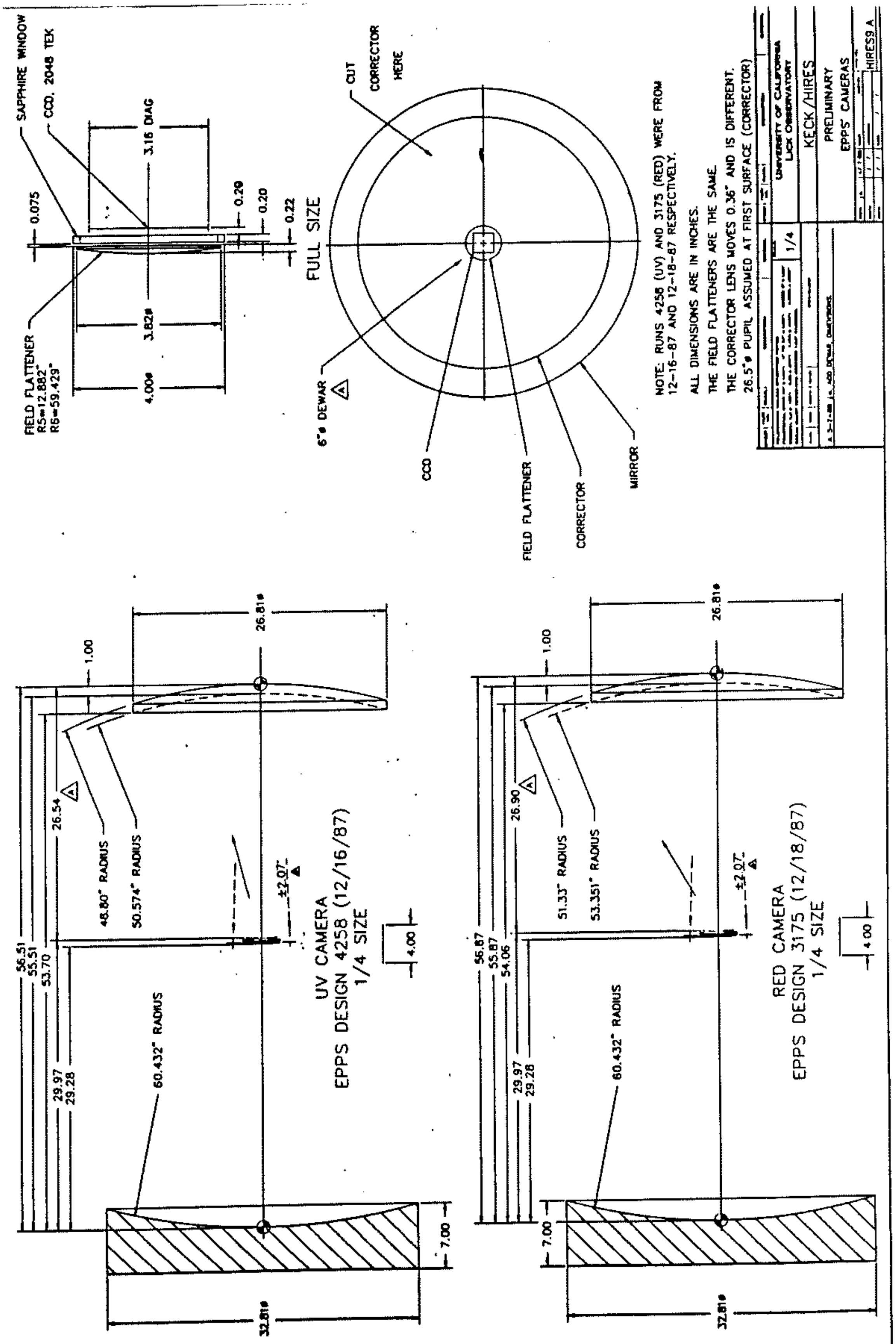

SAPPHIRE WINDOW
CCD, 2048 TEK
3.16 DIAG
0.075
0.29
0.20
0.22
FIELD FLATTENER
R5=12.882"
R6=59.429"
3.82⌀
4.00⌀
FULL SIZE
CUT CORRECTOR HERE
6"⌀ DEWAR
CCD
FIELD FLATTENER
CORRECTOR
MIRROR
NOTE: RUNS 4258 (UV) AND 3175 (RED) WERE FROM 12-16-87 AND 12-18-87 RESPECTIVELY.
ALL DIMENSIONS ARE IN INCHES.
THE FIELD FLATTENERS ARE THE SAME.
THE CORRECTOR LENS MOVES 0.36" AND IS DIFFERENT.
26.5"⌀ PUPIL ASSUMED AT FIRST SURFACE (CORRECTOR)
UNIVERSITY OF CALIFORNIA
LICK OBSERVATORY
1/4
KECK/HIRES
PRELIMINARY
EPPS' CAMERAS
HIRES9 A
26.81⌀
1.00
26.54
48.80" RADIUS
50.574" RADIUS
±2.07
56.51
55.51
53.70
4.00
UV CAMERA
EPPS DESIGN 4258 (12/16/87)
1/4 SIZE
60.432" RADIUS
29.97
29.28
7.00
32.81⌀
26.81⌀
1.00
26.90
51.33" RADIUS
53.351" RADIUS
±2.07
56.87
55.87
54.06
4.00
RED CAMERA
EPPS DESIGN 3175 (12/18/87)
1/4 SIZE
60.432" RADIUS
29.97
29.28
7.00
32.81⌀

Figure 11

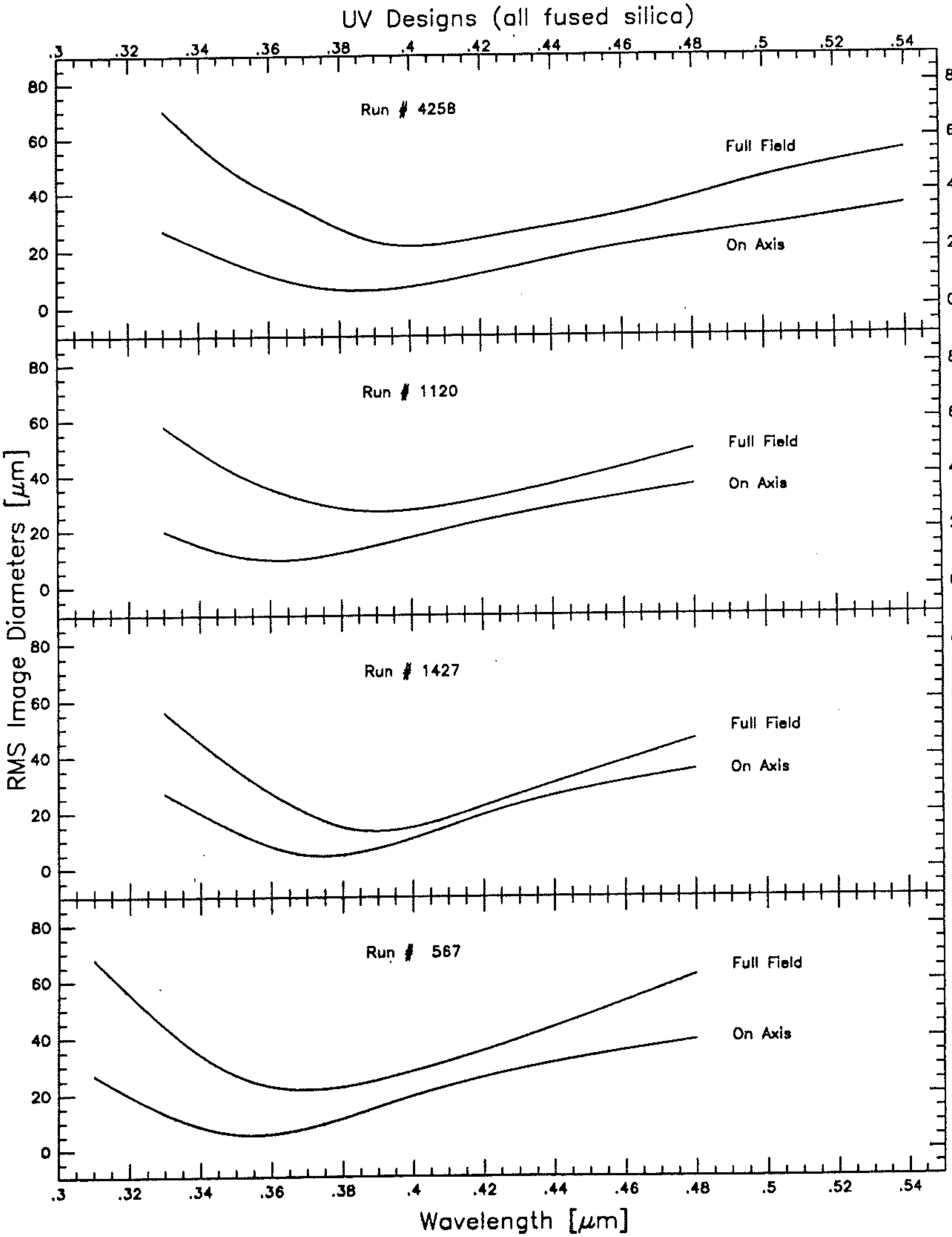

UV Designs (all fused silica)
Run # 4258
Full Field
On Axis
Run # 1120
Full Field
On Axis
Run # 1427
Full Field
On Axis
Run # 567
Full Field
On Axis
RMS Image Diameters [μm]
Wavelength [μm]
.3
.32
.34
.36
.38
.4
.42
.44
.46
.48
.5
.52
.54
0
20
40
60
80

Fig. 12

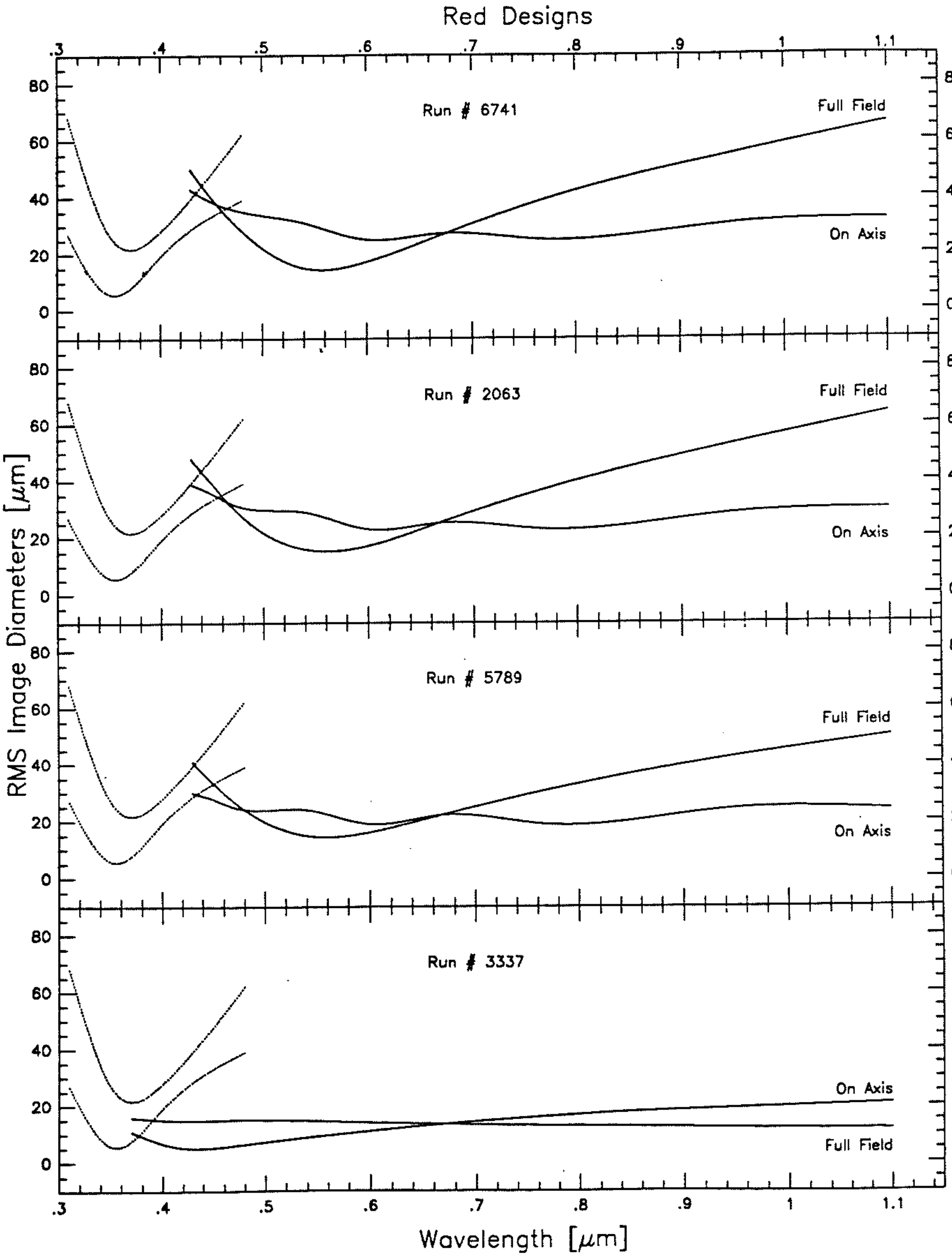

Red Designs
Run # 6741
Run # 2063
Run # 5789
Run # 3337
Full Field
On Axis
RMS Image Diameters [μm]
Wavelength [μm]
.3
.4
.5
.6
.7
.8
.9
1
1.1
0
20
40
60
80

Fig. 13

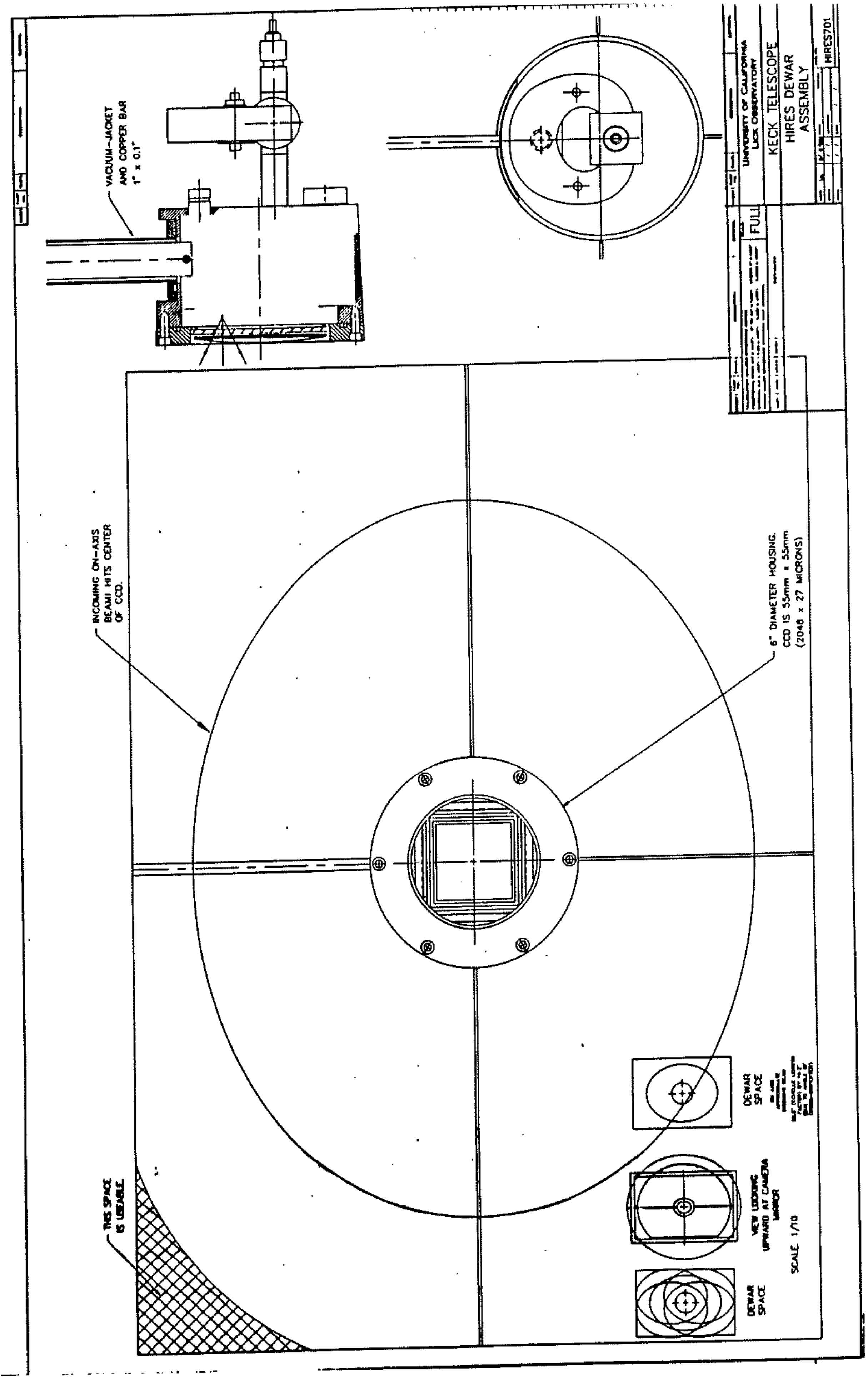

VACUUM-JACKET AND COPPER BAR 1" x 0.1"
INCOMING ON-AXIS BEAM HITS CENTER OF CCD.
6" DIAMETER HOUSING. CCD IS 55mm x 55mm (2048 x 27 MICRONS)
DEWAR SPACE
VIEW LOOKING UPWARD AT CAMERA MIRROR
SCALE 1/10
DEWAR SPACE
THIS SPACE IS USEABLE.
UNIVERSITY OF CALIFORNIA LICK OBSERVATORY
KECK TELESCOPE
HIRES DEWAR ASSEMBLY
FULL
HIRES701

Figure 14

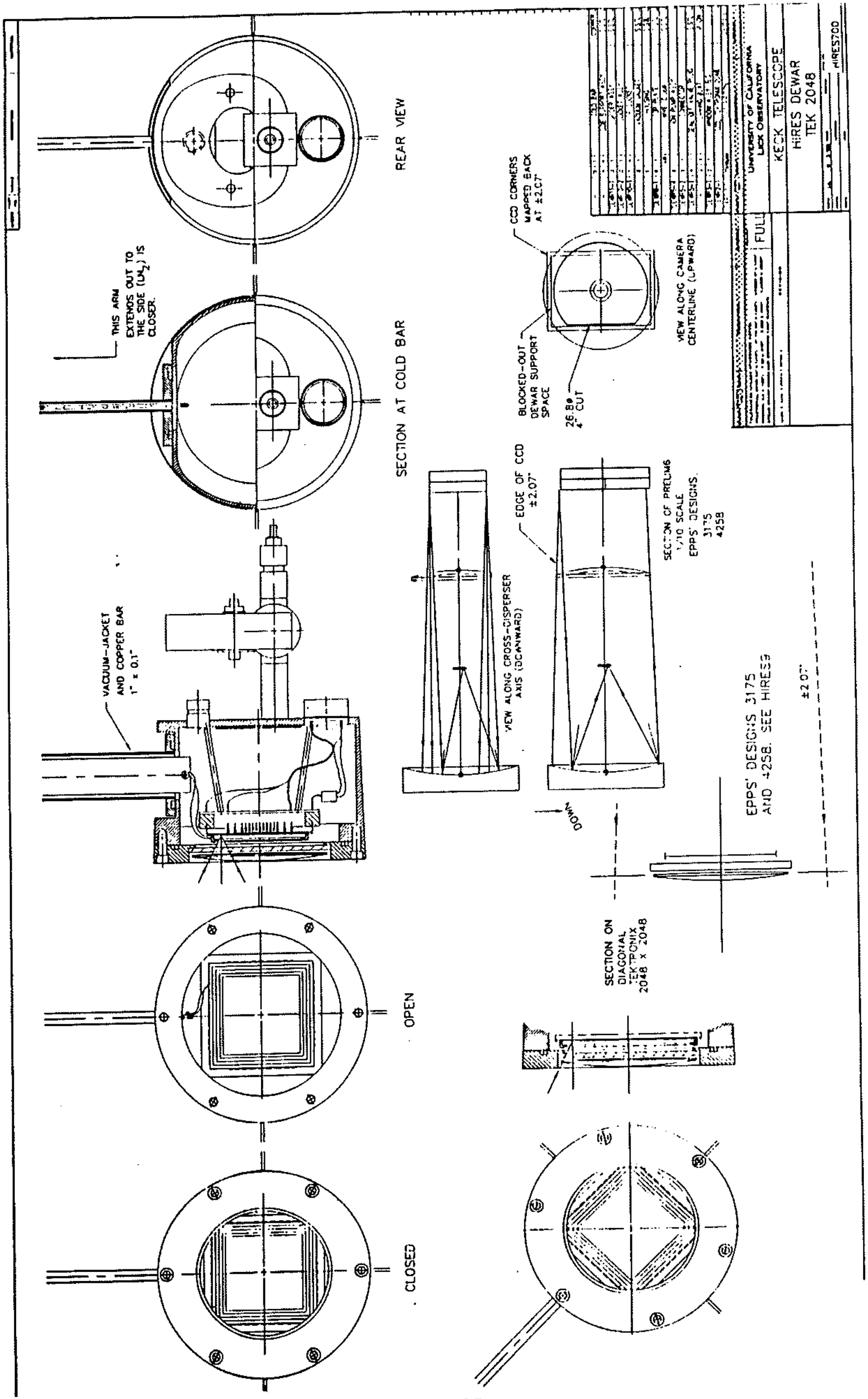
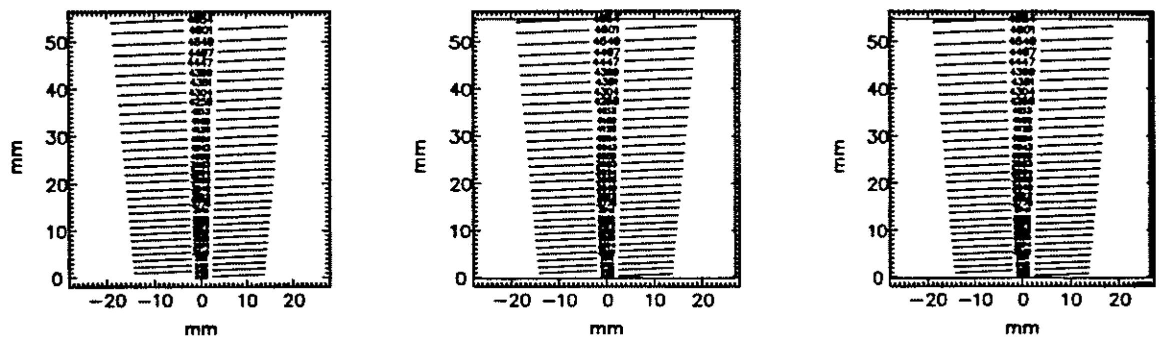
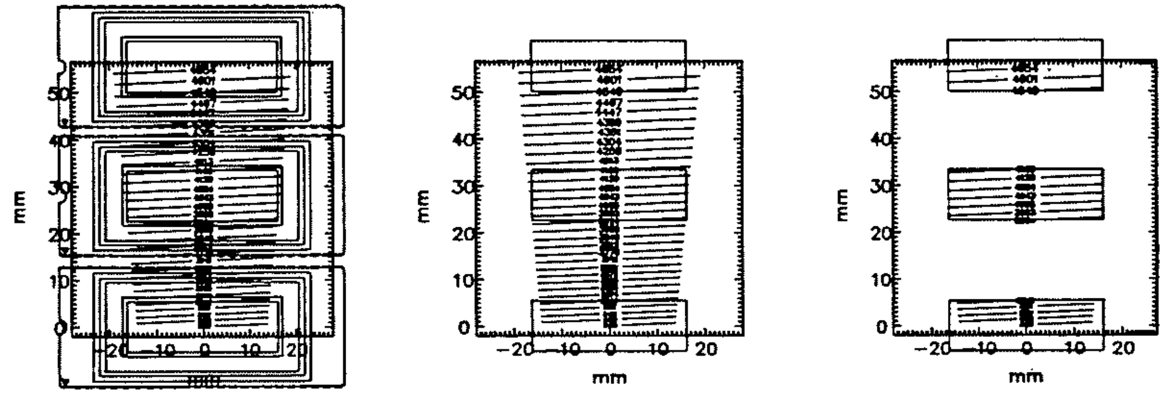

REAR VIEW
SECTION AT COLD BAR
THIS ARM EXTENDS OUT TO THE SIDE (LN$_2$) IS CLOSER.
VACUUM-JACKET AND COPPER BAR 1" x 0.1"
OPEN
CLOSED
CCD CORNERS MAPPED BACK AT ±2.07°
BLOCKED-OUT DEWAR SUPPORT SPACE
26.8° 4" CUT
VIEW ALONG CAMERA CENTERLINE (UPWARD)
EDGE OF CCD ±2.07°
SECTION OF PRELIMS 1/10 SCALE EPPS' DESIGNS 3175 4258
VIEW ALONG CROSS-DISPERSER AXIS (DOWNWARD)
DOWN
EPPS' DESIGNS 3175 AND 4258. SEE HIRES9
±2.07°
SECTION ON DIAGONAL TEKTRONIX 2048 x 2048
UNIVERSITY OF CALIFORNIA LICK OBSERVATORY
FULL
KECK TELESCOPE
HIRES DEWAR TEK 2048
HIRES700

Figure 15



TEKTRONIX
2048 x 2048 CCD WITH 27 MICRON PIXELS

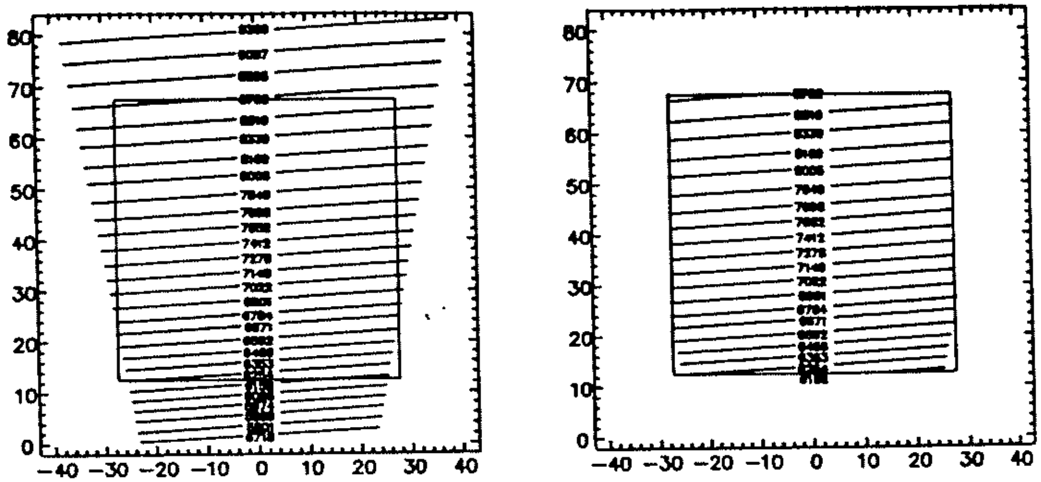


RETICON ARRAY
400 x 1200 CCD WITH 27 MICRON PIXELS

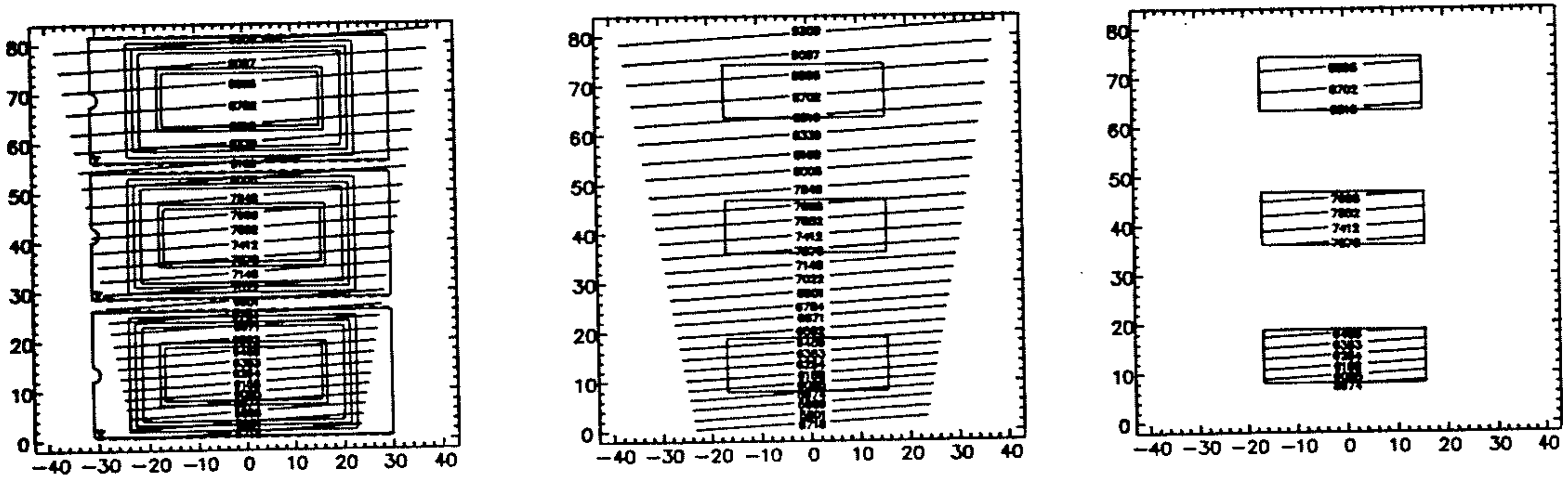
BLUE FORMAT, SHORT CAMERA

PROPOS8

Figure 16



TEKTRONIX
2048 x 2048 CCD WITH 27 MICRON PIXELS



RETICON ARRAY
400 x 1200 CCD WITH 27 MICRON PIXELS

RED FORMAT, SHORT CAMERA

PROPOS7

Figure 17

KECK OBSERVATORY NETWORK

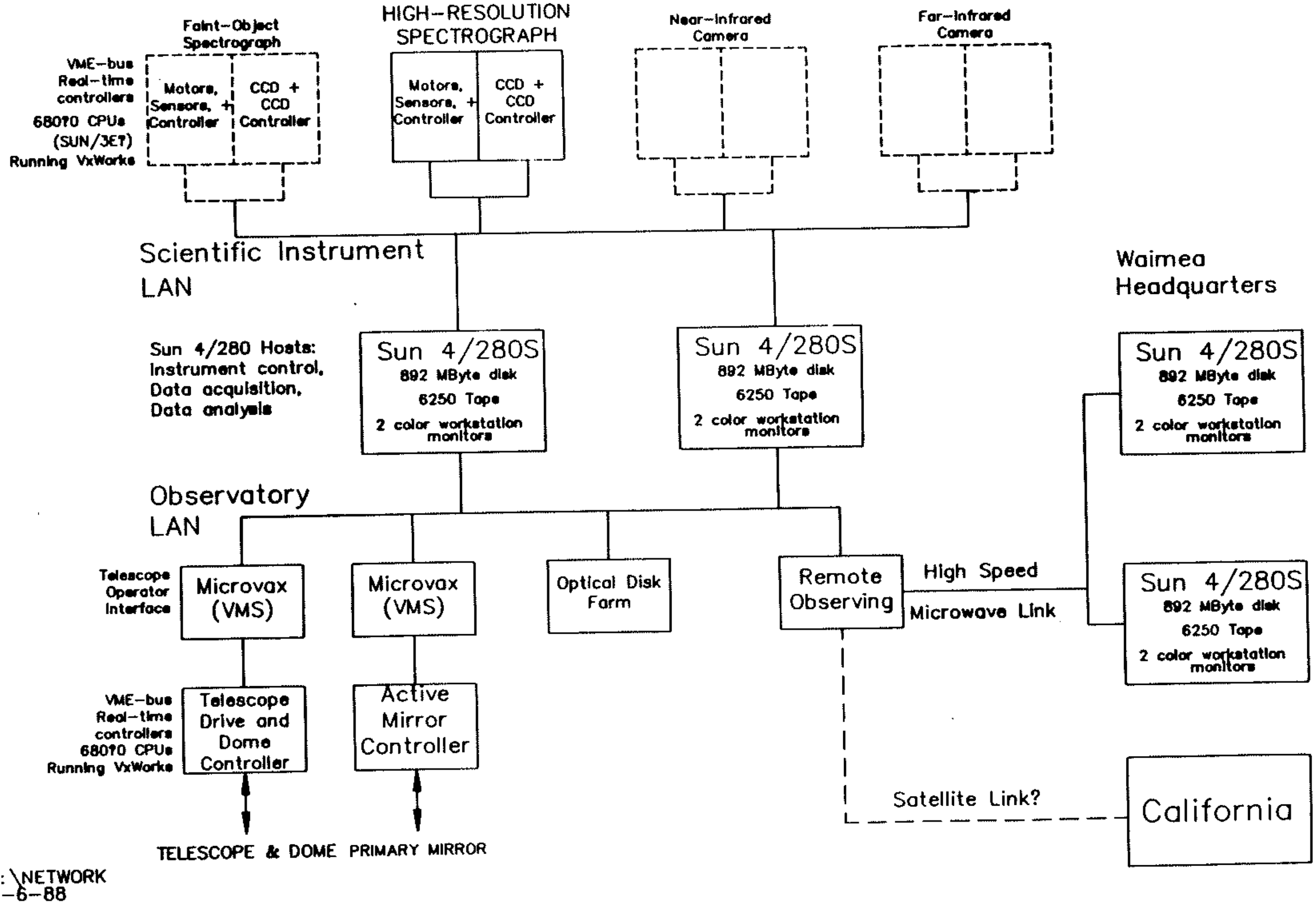


Figure 18

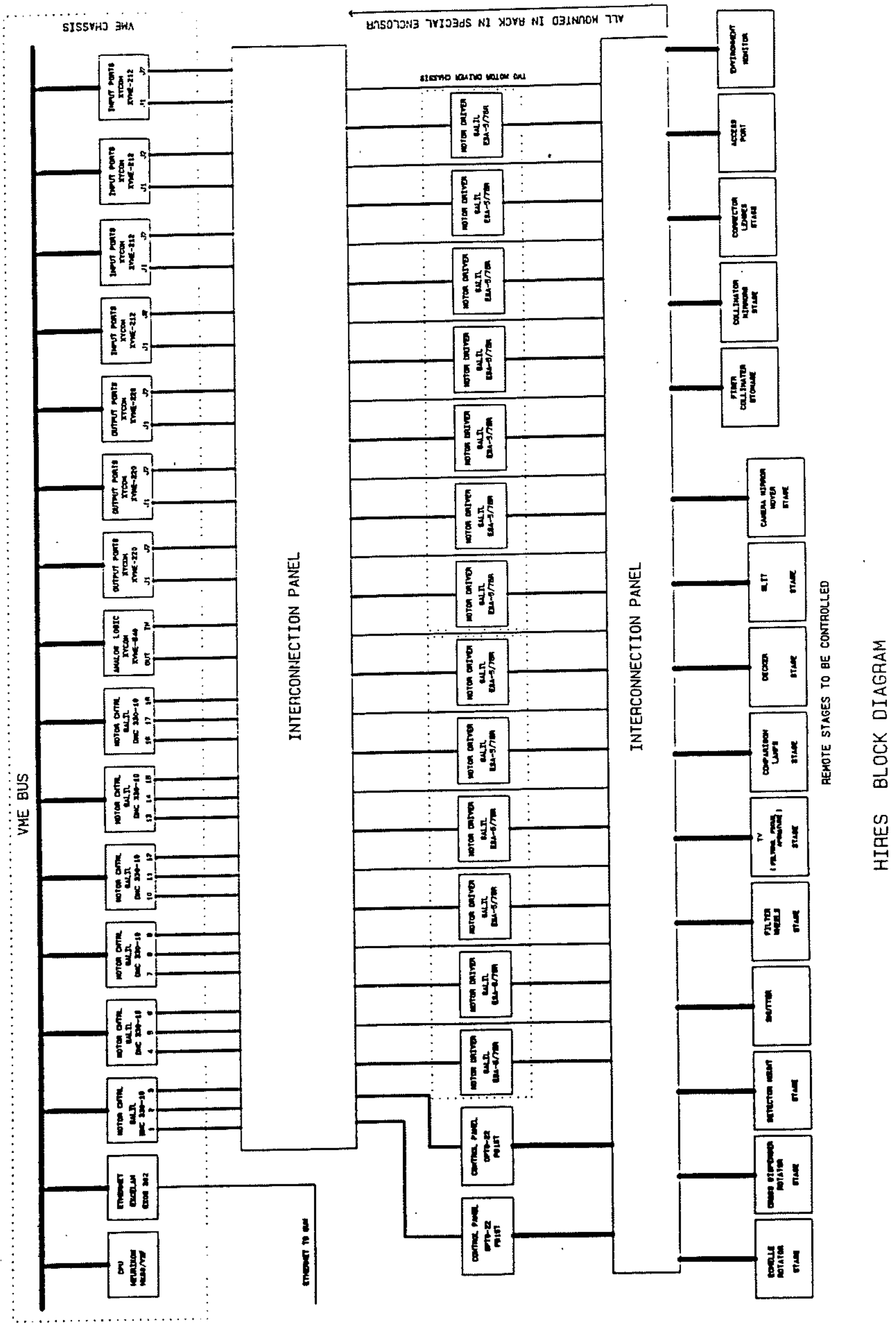

HIRES BLOCK DIAGRAM
VME CHASSIS
VME BUS
INPUT PORTS XYCOM XVME-212 J1 J2
INPUT PORTS XYCOM XVME-212 J1 J2
INPUT PORTS XYCOM XVME-212 J1 J2
INPUT PORTS XYCOM XVME-212 J1 J2
OUTPUT PORTS XYCOM XVME-220 J1 J2
OUTPUT PORTS XYCOM XVME-220 J1 J2
OUTPUT PORTS XYCOM XVME-220 J1 J2
ANALOG LOGIC XYCOM XVME-540 OUT IN
MOTOR CNTRL GALIL DMC 330-10 16 17 18
MOTOR CNTRL GALIL DMC 330-10 13 14 15
MOTOR CNTRL GALIL DMC 330-10 10 11 12
MOTOR CNTRL GALIL DMC 330-10 7 8 9
MOTOR CNTRL GALIL DMC 330-10 4 5 6
MOTOR CNTRL GALIL DMC 330-10 1 2 3
ETHERNET EXCELAN EXOS 302
CPU HEURIKON
ETHERNET TO SUN
INTERCONNECTION PANEL
ALL MOUNTED IN RACK IN SPECIAL ENCLOSUR
TWO MOTOR DRIVER CHASSIS
MOTOR DRIVER GALIL EBA-5/75R
CONTROL PANEL OPTO-22 PB16T
CONTROL PANEL OPTO-22 PB16T
INTERCONNECTION PANEL
ENVIRONMENT MONITOR
ACCESS PORT
CORRECTOR LENSES STAGE
COLLIMATOR MIRRORS STAGE
FIBER COLLIMATOR STOWAGE
CAMERA MIRROR MOVER STAGE
SLIT STAGE
DECKER STAGE
COMPARISON LAMPS STAGE
TV (FILTERS, FOCUS, APERTURE) STAGE
FILTER WHEELS STAGE
SHUTTER
DETECTOR HEIGHT STAGE
CROSS DISPERSOR ROTATOR STAGE
ECHELLE ROTATOR STAGE
REMOTE STAGES TO BE CONTROLLED

Figure 19

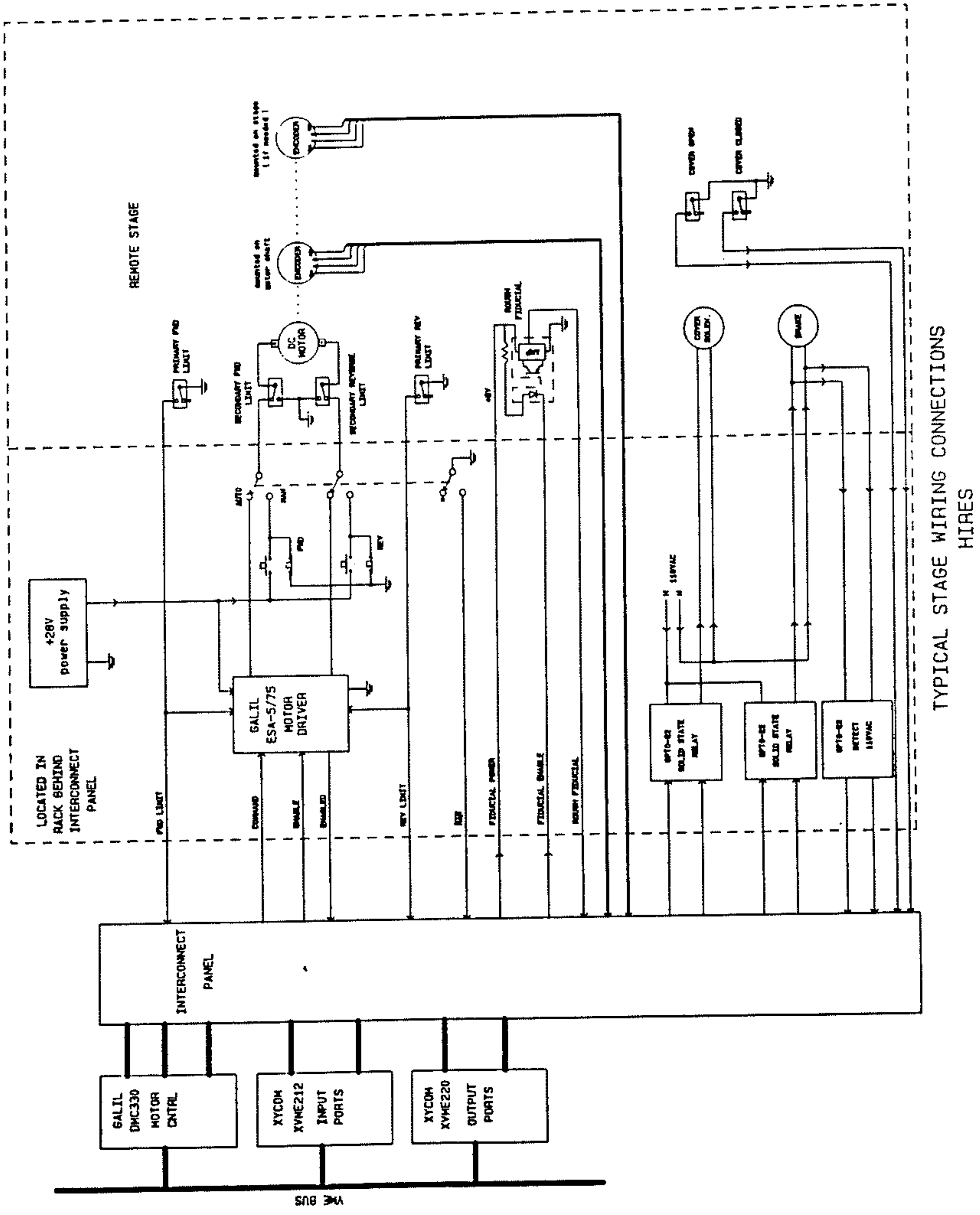

TYPICAL STAGE WIRING CONNECTIONS
HIRES
REMOTE STAGE
LOCATED IN RACK BEHIND INTERCONNECT PANEL
+28V power supply
GALIL ESA-5/75 MOTOR DRIVER
DC MOTOR
ENCODER
mounted on motor shaft
ENCODER
mounted on stage (if needed)
PRIMARY FWD LIMIT
SECONDARY FWD LIMIT
SECONDARY REVERSE LIMIT
PRIMARY REV LIMIT
ROUGH FIDUCIAL
+5V
AUTO
MAN
FWD
REV
COVER OPEN
COVER CLOSED
COVER SOLEN.
BRAKE
H
N
115VAC
OPTO-22 SOLID STATE RELAY
OPTO-22 SOLID STATE RELAY
OPTO-22 DETECT 115VAC
FWD LIMIT
COMMAND
ENABLE
ENABLED
REV LIMIT
FIDUCIAL POWER
FIDUCIAL ENABLE
ROUGH FIDUCIAL
INTERCONNECT PANEL
GALIL DMC330 MOTOR CNTRL
XYCOM XVME212 INPUT PORTS
XYCOM XVME220 OUTPUT PORTS
VME BUS

Figure 20

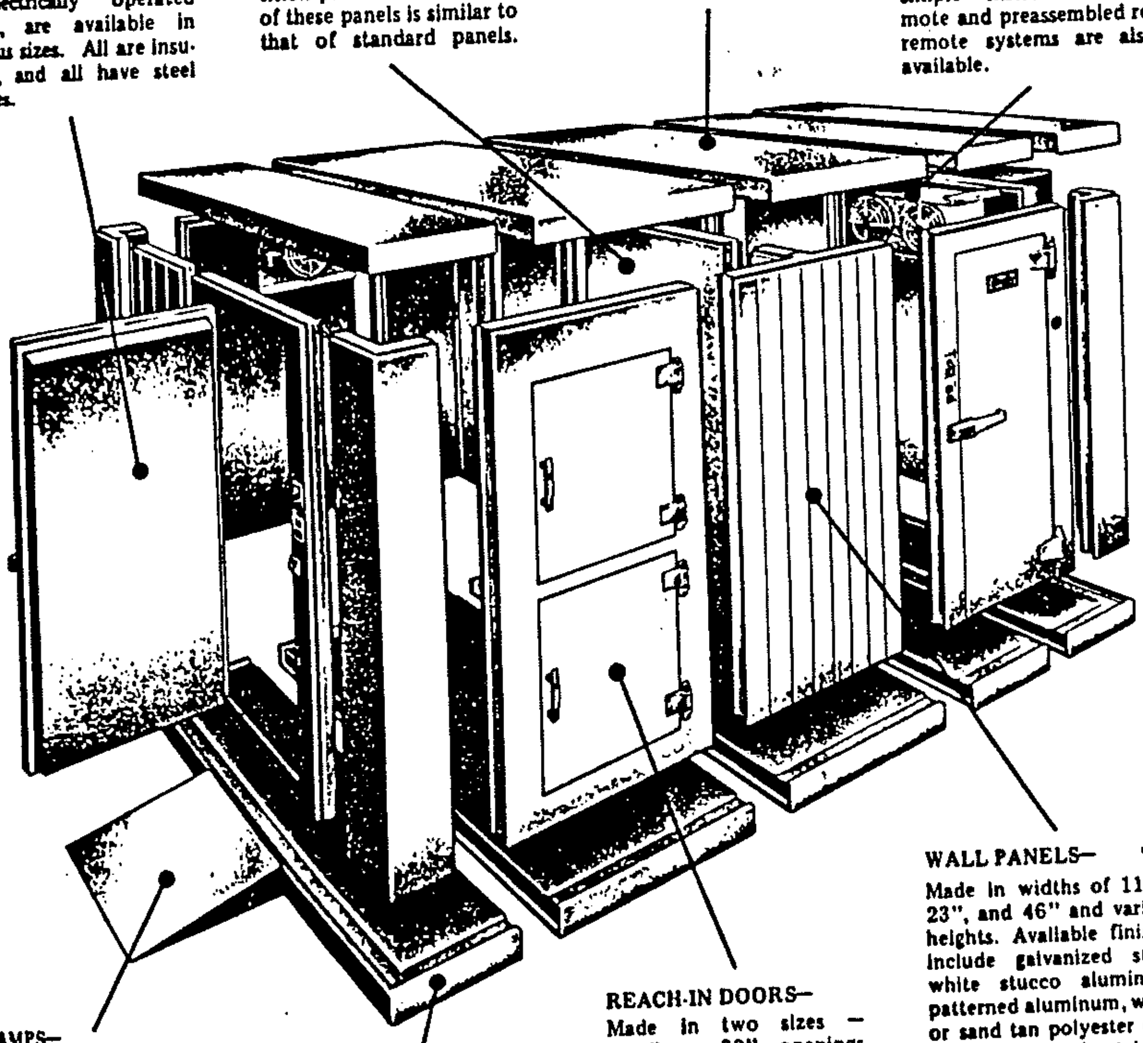
Modular construction and quality features make Bally walk-ins the best available

ENTRANCE DOORS–
A wide variety of hinged, sliding and overhead doors, in either manually or electrically operated types, are available in various sizes. All are insulated, and all have steel frames.

PARTITIONS–
Structures with two or more compartments can be made by installing partition panels. Construction of these panels is similar to that of standard panels.

CEILING PANELS–
Made in widths of 11½", 23", 34½", and 46" and in lengths up to 11'6" outdoors and 17'4" indoors.

SELF-CONTAINED REFRIGERATION SYSTEMS–
Systems provide economical, trouble-free use and simple installation. Remote and preassembled remote systems are also available.



RAMPS–
Interior and exterior types available.

7'9" x 13'6" x 7'6" model illustrated.

FLOOR PANELS–
Available for those installations requiring a well-insulated floor. Panels are made in widths and lengths similar to those of ceiling panels.

REACH-IN DOORS–
Made in two sizes — 18½" x 30" openings in 23" wide panels, and 30" x 30" openings in 46" wide panels. Single door can be placed at height user desires. Two-door panels have one door above the other.

WALL PANELS–
Made in widths of 11½", 23", and 46" and various heights. Available finishes include galvanized steel, white stucco aluminum, patterned aluminum, white or sand tan polyester over galvanized, and stainless steel. Also available are profile exterior skins and several custom colors. Contact factory for details.

For more information, call our toll-free number: 1-800-24-BALLY (in Pennsylvania, 1-800-26-BALLY).

Figure 21

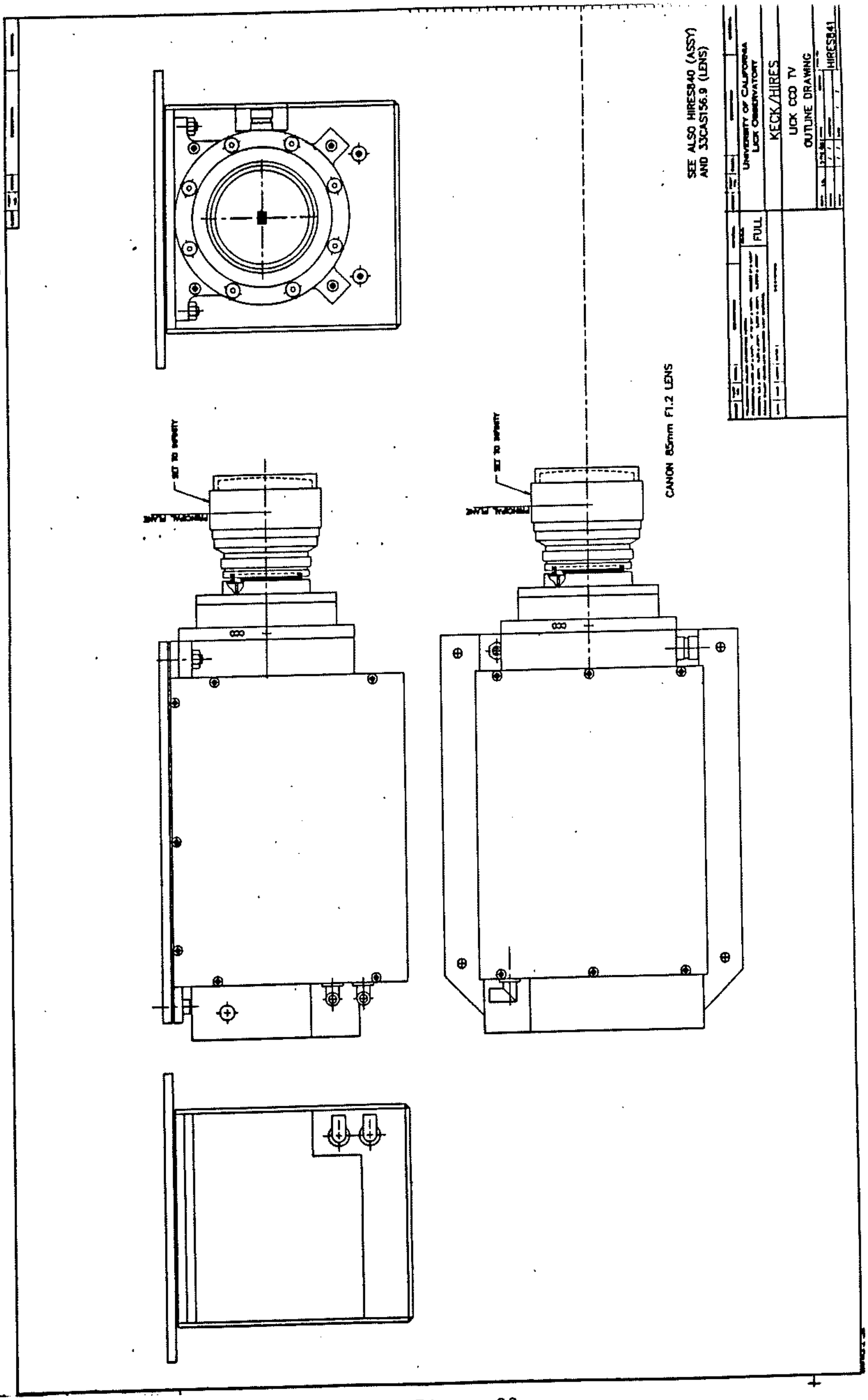

SEE ALSO HIRES840 (ASSY)
AND 33CAS156.9 (LENS)
CANON 85mm F1.2 LENS
SET TO INFINITY
PRINCIPAL PLANE
SET TO INFINITY
PRINCIPAL PLANE
UNIVERSITY OF CALIFORNIA
LICK OBSERVATORY
KECK/HIRES
LICK CCD TV
OUTLINE DRAWING
FULL
HIRES841

Figure 22

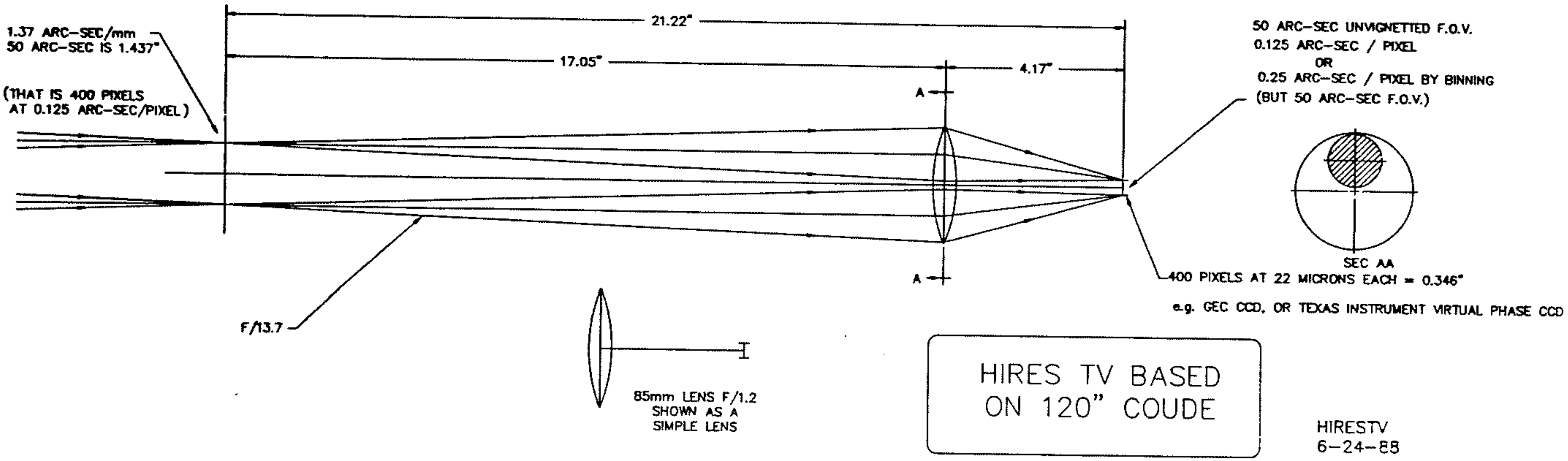

21.22"
17.05"
4.17"
1.37 ARC-SEC/mm
50 ARC-SEC IS 1.437"
(THAT IS 400 PIXELS
AT 0.125 ARC-SEC/PIXEL)
A
A
50 ARC-SEC UNVIGNETTED F.O.V.
0.125 ARC-SEC / PIXEL
OR
0.25 ARC-SEC / PIXEL BY BINNING
(BUT 50 ARC-SEC F.O.V.)
SEC AA
400 PIXELS AT 22 MICRONS EACH = 0.346"
e.g. GEC CCD, OR TEXAS INSTRUMENT VIRTUAL PHASE CCD
F/13.7
85mm LENS F/1.2
SHOWN AS A
SIMPLE LENS
HIRES TV BASED
ON 120" COUDE
HIRESTV
6-24-88

Figure 23

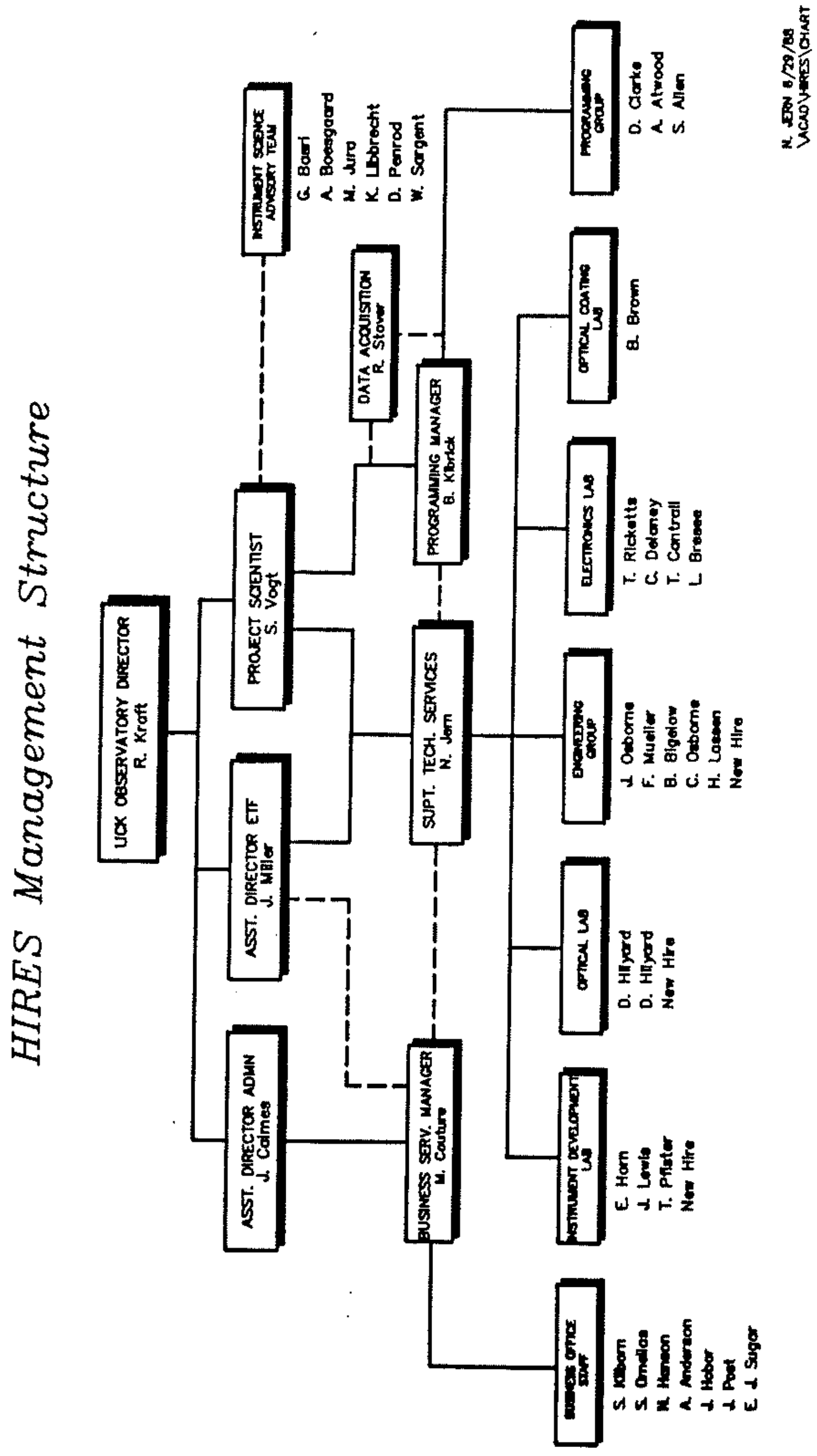
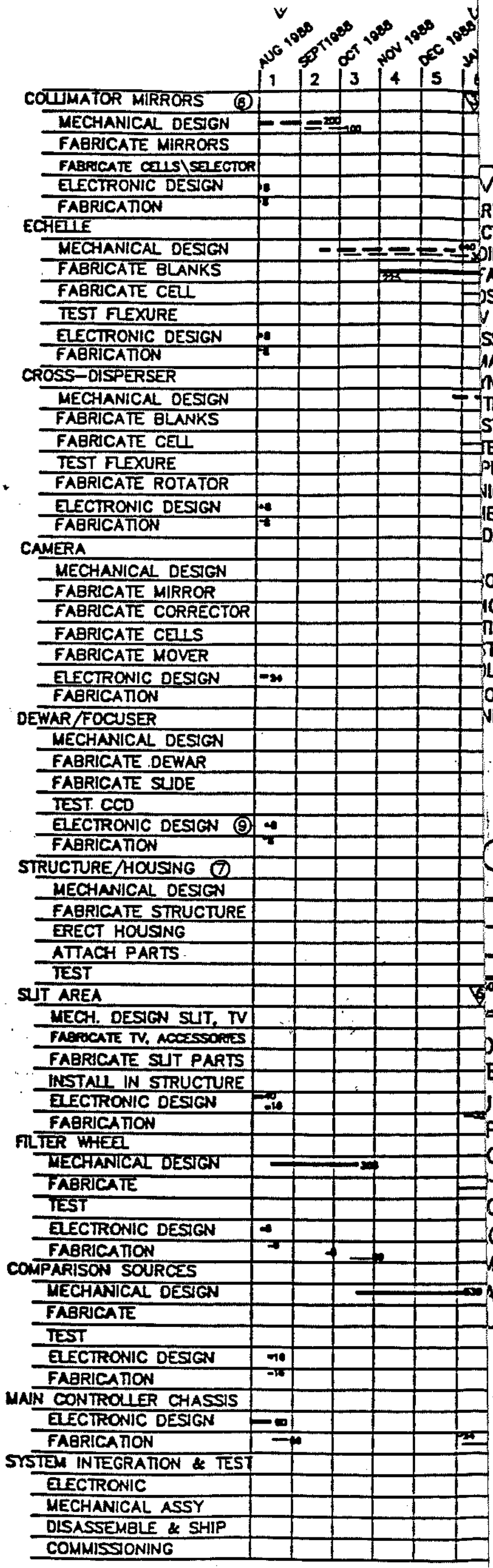

HIRES Management Structure

Figure 24



RY DESIGN REVIEW
CTED (PURCHASE)
DIFICATIONS COMPLETE
ABRICATION COMPLETE
OSAIC CONCEPT (ECHELLE)
V CAMERA
SS DISPERSER MOSAIC
MATOR MIRRORS INTO CELLS
NAMIC TEST OF STRUCTURE
TH CCD IN DEWAR
STERS FOR RULING (PURCHASE)
ER MILESTONE 2.
PLICAS FOR RULINGS (PURCHASE)
NICS FINISHED.
IENT REVIEW
DESIGN OF CAMERA COMPLETE
COLLIMATOR INTO CELL AND INSTALL FIBERS
OLLIMATOR, ECHELLE, SLIT. OPTICAL PRELIM REVIEW.
IOSAIC EVALUATION, CAMERA DESIGN.
TICAL DESIGN.
TRUCTURE, DEWAR & STAGE,
LLIMATOR. REVIEW GRATING RULINGS.
OY PROGRESS (RULINGS). CDR 4: ASSEMBLY
NMENT REVIEW.

123 (MAN HOURS IN TASK)

— 80% ENGINEER
— 60% DRAFTER
— 100% ENGINEER
— 100% OPTICAL SPEC/TECH
= 75% ASTRONOMER

LLIMATORS AND
ER) A FIBER COLLIMATOR

UCTURE DESIGN:
PACE FRAME LAYOUT
ODAL DETAILS
HOP FAB DRAWINGS
OUSING DESIGN

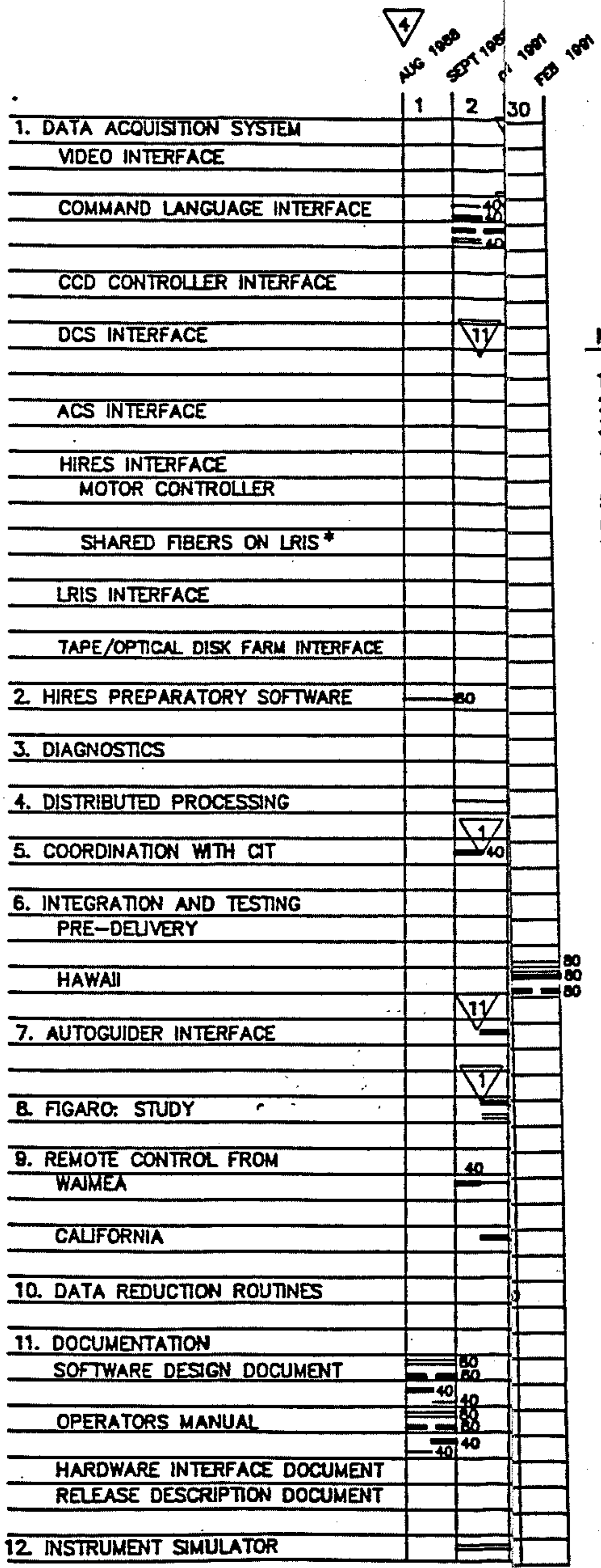
CTION OF GRATING (AND SPECTRUM
MAT) DEPENDS ON CCD(S) CHOSEN.

AR ELECTRONIC DESIGN
UDES CCD CONTROLLER

PRODUCTION SCHEDULE
MECHANICAL/ELECT/OPTICAL

GANTT1A
6–24–88

Figure 25



* LOW RESOLUTION IMAGING SPECTROGRAPH

MILESTONES ▽

1. DELIVERY OF BASELINE UNIX FIGARO
2. DELIVERY OF KECK FIGARO
3. DELIVERY OF COMPLETE VME TARGET MACHINE
4. DELIVERY OF VRTX/VXWORKS SOFTWARE AND DOCUMENTATION
5. VACATE SUN ROOM
6. VACATE VAX ROOM
7. DELIVERY OF SPECS. FOR CCD CONTROLLER
8. DELIVERY OF CCD CONTROLLER
9. SPECIFICATION OF FIGARO-LIKE COMMAND LANGUAGE (MAGIC/L ? C SHELL ?)
10. DELIVERY OF LRIS SPECS.
11. DELIVERY OF COMPLETE (INCLUDING AUTOGUIDER IMAGE) DCS INTERFACE SPECS.
12. DELIVERY OF COMPLETE ACS INTERFACE SPECS.
13. PDR (PRELIMINARY DESIGN REVIEW)
14. CDR (CRITICAL DESIGN REVIEW)
15. DELIVERY OF PRELIMINARY DAS VERSION TO LRI
16. DELIVERY OF SUN-4/110C

NOTES:

1. ━━━80 IS KIBRICK 50% FOR TIME SHOWN (80 HOURS)
2. ═══80 IS CLARKE 50% FOR TIME SHOWN (80 HOURS)
3. ━ ━80 IS ATWOOD 50% FOR TIME SHOWN (80 HOURS)
4. ═══80 IS ALLEN 50% FOR TIME SHOWN (80 HOURS)
5. — —80 IS STOVER 50% FOR TIME SHOWN (80 HOURS)
6. NO WORK IS SCHEDULED FOR THE PERIODS JULY 1 TO JULY 15 OR DECEMBER 15 TO DECEMBER 31. THESE ARE CONSIDERED SLACK TIMES FOR HOLIDAYS/VACATIONS. ONLY 4 WEEKS OF TIME (20 DAYS, OR 160 HOURS) ARE ALLOCATED PER MONTH, THUS ALLOWING 2 DAYS/MONTH FOR SICK LEAVE, HOLIDAYS, ETC.
7. ALLEN IS ONLY ALLOCATED AT 50% TIME DURING THE PERIOD OCTOBER 1 TO JUNE 30, AND AT 100% TIME BETWEEN JULY 1 AND SEPTEMBER 30.

PRODUCTION SCHEDULE
SOFTWARE

GANTT2A

Figure 26

TABLE 1
HIRES UV/Blue Format

ECHELLE: 46.5 gr/mm

$\theta_{blaze} = 69.0°$ $\theta = 5.0°$

DIAMETERS: Collimator = 305 mm

Telescope = 10.9 m

CAMERA FOCAL LENGTH = 762 mm

CROSS DISPERSER: 300 gr/mm   Order = 2

Order	Blaze(Å)	FSR(Å)	Δ(mm)	Δ(arc-sec)	Location(mm)	Length(mm)
129	3101.	24.	1.09	8.26	0.000	25.06
128	3125.	24.	1.11	8.39	1.091	25.26
127	3150.	25.	1.13	8.52	2.198	25.46
126	3175.	25.	1.14	8.66	3.323	25.66
125	3200.	26.	1.16	8.80	4.466	25.87
124	3226.	26.	1.18	8.94	5.627	26.07
123	3252.	26.	1.20	9.08	6.807	26.29
122	3279.	27.	1.22	9.23	8.006	26.50
121	3306.	27.	1.24	9.38	9.225	26.72
120	3333.	28.	1.26	9.54	10.464	26.94
119	3361.	28.	1.28	9.70	11.723	27.17
118	3390.	29.	1.30	9.86	13.004	27.40
117	3419.	29.	1.32	10.03	14.307	27.63
116	3448.	30.	1.35	10.21	15.631	27.87
115	3478.	30.	1.37	10.38	16.979	28.12
114	3509.	31.	1.40	10.57	18.350	28.36
113	3540.	31.	1.42	10.75	19.745	28.61
112	3572.	32.	1.45	10.95	21.164	28.87
111	3604.	32.	1.47	11.14	22.609	29.13
110	3636.	33.	1.50	11.35	24.081	29.39
109	3670.	34.	1.53	11.55	25.578	29.66
108	3704.	34.	1.55	11.77	27.104	29.94
107	3738.	35.	1.58	11.99	28.657	30.22
106	3774.	36.	1.61	12.21	30.240	30.50
105	3810.	36.	1.64	12.45	31.852	30.79
104	3846.	37.	1.67	12.69	33.496	31.09
103	3884.	38.	1.71	12.93	35.170	31.39
102	3922.	38.	1.74	13.19	36.878	31.70
101	3961.	39.	1.78	13.45	38.618	32.01
100	4000.	40.	1.81	13.72	40.394	32.33
99	4041.	41.	1.85	13.99	42.204	32.66
98	4082.	42.	1.89	14.28	44.052	32.99
97	4124.	43.	1.92	14.57	45.937	33.33
96	4167.	43.	1.96	14.88	47.861	33.68
95	4211.	44.	2.01	15.19	49.825	34.03
94	4255.	45.	2.05	15.51	51.830	34.40
93	4301.	46.	2.09	15.85	53.878	34.77
92	4348.	47.	2.14	16.19	55.970	35.14
91	4396.	48.	2.18	16.55	58.107	35.53
90	4445.	49.	2.23	16.91	60.292	35.92
89	4495.	51.	2.28	17.29	62.525	36.33
88	4546.	52.	2.34	17.69	64.808	36.74
87	4598.	53.	2.39	18.09	67.143	37.16
86	4651.	54.	2.44	18.51	69.532	37.60
85	4706.	55.	2.50	18.95	71.976	38.04
84	4762.	57.	2.56	19.40	74.478	38.49
83	4819.	58.	2.62	19.87	77.040	38.95
82	4878.	59.	2.69	20.35	79.663	39.43

TABLE 2
HIRES Visible/Red Format

ECHELLE: 46.5 gr/mm

$\theta_{blaze} = 69.0°$ $\theta = 5.0°$

DIAMETERS: Collimator = 305 mm

Telescope = 10.9 m

CAMERA FOCAL LENGTH = 762 mm

CROSS DISPERSER: 300 gr/mm Order = 1

Order	Blaze(Å)	FSR(Å)	Δ(mm)	Δ(arc-sec)	Location(mm)	Length(mm)
85	4706.	55.	1.25	9.47	0.000	38.04
84	4762.	57.	1.28	9.70	1.251	38.49
83	4819.	58.	1.31	9.93	2.532	38.95
82	4878.	59.	1.34	10.18	3.843	39.43
81	4938.	61.	1.38	10.43	5.187	39.92
80	5000.	63.	1.41	10.69	6.563	40.42
79	5063.	64.	1.45	10.96	7.975	40.93
78	5128.	66.	1.48	11.24	9.422	41.45
77	5195.	67.	1.52	11.53	10.906	41.99
76	5263.	69.	1.56	11.84	12.428	42.54
75	5333.	71.	1.60	12.15	13.991	43.11
74	5406.	73.	1.65	12.48	15.595	43.69
73	5480.	75.	1.69	12.82	17.243	44.29
72	5556.	77.	1.74	13.18	18.935	44.91
71	5634.	79.	1.79	13.55	20.675	45.54
70	5714.	82.	1.84	13.94	22.464	46.19
69	5797.	84.	1.89	14.34	24.304	46.86
68	5883.	87.	1.95	14.76	26.197	47.55
67	5970.	89.	2.01	15.20	28.146	48.26
66	6061.	92.	2.07	15.66	30.153	48.99
65	6154.	95.	2.13	16.14	32.221	49.74
64	6250.	98.	2.20	16.65	34.352	50.52
63	6349.	101.	2.27	17.18	36.551	51.32
62	6452.	104.	2.34	17.73	38.818	52.15
61	6558.	108.	2.42	18.31	41.160	53.00
60	6667.	111.	2.50	18.92	43.577	53.89
59	6780.	115.	2.58	19.57	46.076	54.80
58	6897.	119.	2.67	20.24	48.659	55.75
57	7018.	123.	2.77	20.95	51.331	56.72
56	7143.	128.	2.86	21.70	54.097	57.74
55	7273.	132.	2.97	22.49	56.962	58.79
54	7408.	137.	3.08	23.32	59.931	59.87
53	7547.	142.	3.20	24.20	63.010	61.00
52	7693.	148.	3.32	25.13	66.205	62.18
51	7843.	154.	3.45	26.12	69.523	63.40
50	8000.	160.	3.59	27.16	72.971	64.66
49	8164.	167.	3.73	28.27	76.557	65.98
48	8334.	174.	3.89	29.45	80.289	67.36
47	8511.	181.	4.05	30.70	84.177	68.79
46	8696.	189.	4.23	32.04	88.230	70.29
45	8889.	198.	4.42	33.46	92.460	71.85
44	9091.	207.	4.62	34.98	96.877	73.48
43	9303.	216.	4.83	36.61	101.496	75.19
42	9524.	227.	5.06	38.35	106.329	76.98
41	9756.	238.	5.31	40.22	111.392	78.86
40	10000.	250.	5.58	42.23	116.702	80.83
39	10257.	263.	5.86	44.40	122.278	82.90
38	10527.	277.	6.17	46.74	128.140	85.09