A 5-Year Plan for Hydra-CTIO

Author: Knut Olsen

Background

The Hydra-CTIO multifiber spectrograph has been in operation since 1999, during which time it has been used for a variety of projects requiring large spectroscopic samples. Hydra offers a wide range of possible spectral resolutions (R~600 -- 50000), making it useful e.g. for confirming candidate targets selected from imaging and measuring galaxy redshifts, stellar velocities, and stellar abundances in clusters. It has frequently been used in conjunction with target samples selected from space missions, e.g. Chandra and Spitzer. Once long-slit spectroscopy moves to SOAR, Hydra will provide the only spectroscopic capability on the Blanco 4-m, where it will share time with Mosaic/DECam (optical imaging) and ISPI/NEWFIRM (IR imaging).

Hydra's field of view and multiplexing capability make it a good match to the Blanco's imaging capabilities. However, whereas Blanco's optical and near-infrared imagers will be replaced or complemented by newer, more capable instruments, no new optical spectrograph is planned for the telescope. Since 2003, Hydra has been competing for projects against instruments that include GMOS on Gemini South, IMACS on Magellan, FLAMES and VIMOS on the VLT, and 2dF on the AAT. Hydra is unique in providing high-resolution, wide-field multiobject spectroscopy of the southern sky, a niche that could (and, I think, should) be exploited further (see Fig. 1). In its lower resolution capability, it is clearly outclassed. The demand for Hydra has remained steady, however, and has arguably grown, in the seven years since commissioning (Fig. 2).

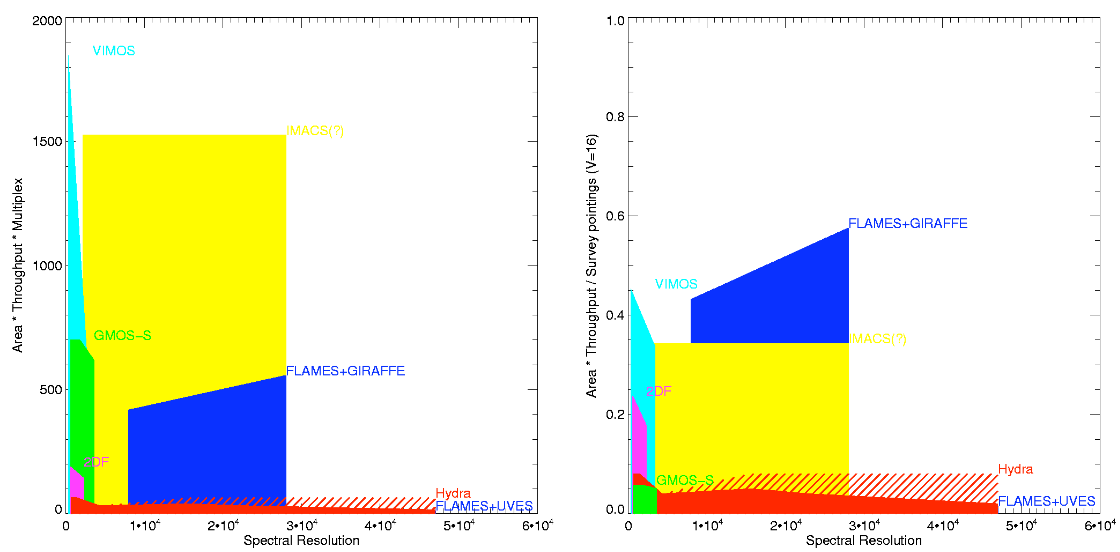

Figure 1. Left: Comparison of multiobject spectroscopic merit of various instruments. Right: Comparison of merit of same instruments to perform a survey of all stars down to V=16.

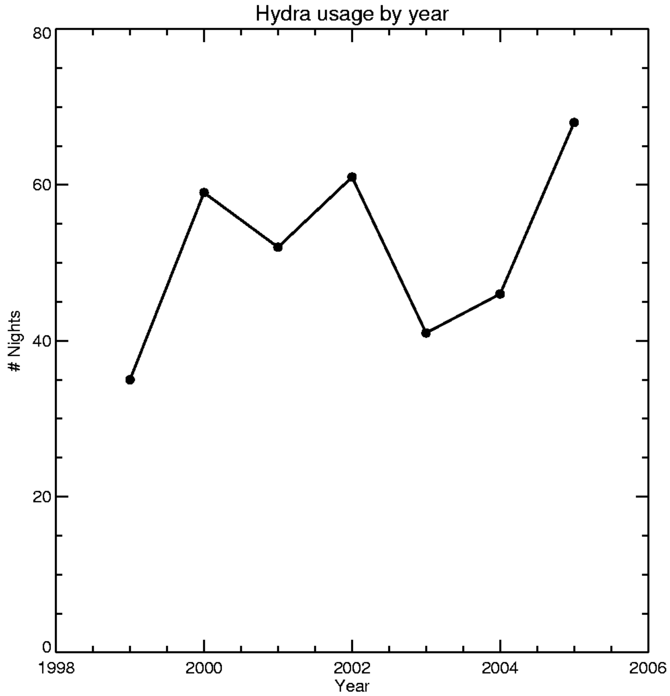

Figure 2. Hydra usage since 1999.

Hydra is Blanco's most complex instrument, and will probably remain so for the foreseeable future. Because of this complexity, the amount of time lost has been historically higher (~0.8 hr/night) than the imaging instruments (Mosaic: 0.43 hr/night; ISPI: 0.33 hr/night), though notably lower than the RC Spectrograph (0.93 hr/night). While the failures have occurred at a fairly regular frequency (Fig. 3), raising worry that we are still in the mode of fighting unpredictable fires, the last major failure resulted in the replacement of the gripper motor, which is thought to have been at the root of many of Hydra's most recent problems. In the 30 nights of use since that motor was replaced, Hydra's failure rate has been comparable to that of ISPI and Mosaic at 0.33 hr/night. There is thus some reason to hope that Hydra can be maintained to operate as reliably as the imaging instruments.

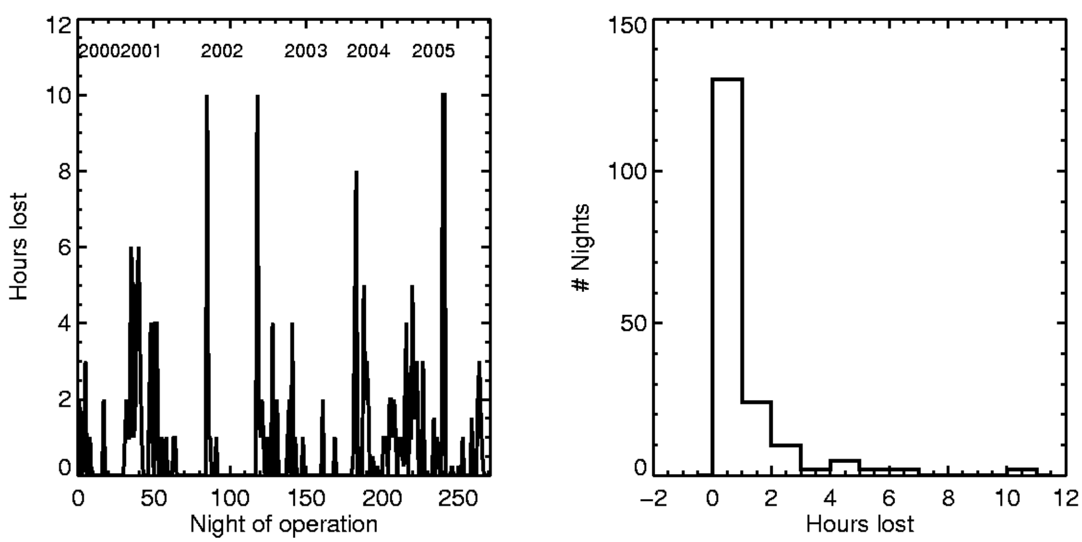

Figure 3. Left: Number of hours lost as a function of time. Right: Distribution of hours lost per night.

Goals

With the aim of ensuring that Hydra-CTIO remains a viable and reliable instrument for an additional 5 years of operation, this document will:

1. Review the general performance of Hydra's subsystems
2. Identify areas where maintenance needs to be further developed
3. Identify areas for upgrade

How much should we spend on this effort? Given that the amount of time that will likely be used by Hydra over the next 5 years will cost ~$2.5 million (at $10,000 per 4-m night), or roughly equal to the cost of a completely new instrument, spending 5-10% of this amount on improving Hydra's performance seems like a good investment, particularly if it improves reliability and enhances areas where Hydra is unique.

Following the Light Through Hydra's Subsystems

A. Calibration system
Hydra's calibration system (Fig. 4) resides in the Cass cage and inside the chimney. Light is either produced by one of the lamps present in a box in the Cass and is passed to the chimney through a liquid light guide and redirected by an immobile flat mirror (Flat Mirror 1), or by a set of "penray" bright He-Ne-Ar-Xe comparison lamps that sit on a mobile swinging arm in the chimney; when in use, the penray lamps bypass Flat Mirror 1. The box in the Cass cage contains a quartz lamp, a Thorium-Argon lamp, a weak set of HeNeAr comparison lamps (almost never used), and an etalon (illuminated by the quartz lamp in the same box); a selection mirror moves to the appropriate source as set by a parameter in the file instrpars, which is maintained by the Arcon software.

Light from the calibration system is directed to a unit that sits on a swinging arm and contains a flat mirror (Flat Mirror 2), a diffuser, and an upward pointing lens. The diffused light is reflected from a retractable spherical mirror at the top of the chimney onto the ADC and the Hydra focal plane.

Interaction with the calibration system by the observer is mainly handled by Arcon, and secondarily by the Hydra GUI. Communication goes through the TCS.

While the calibration system overall has performed well, there remain a number of issues:

1. Burnout of penray lamps, particularly Ne. The power supply has been checked (spare available), and spare penrays are available. The supply of spares needs to be maintained.
2. The etalon is used infrequently, despite the fact that it should provide better wavelength calibration in a shorter exposure time than the ThAr lamp, once the zero point has been set by a ThAr or penray exposure. KO needs to reduce a set

of data using the etalon (data in hand), and write up a procedure for using the etalon.

3. The quartz lamp + chimney system does not provide a static flat field. As originally designed, the system was intended to provide a record of the fiber traces and the fiber-to-fiber throughput during the night. However, as seen in Figure 5, the quartz lamp flats are not flat compared to dome flats. The apparently smooth variation with position in the field suggests that the non-uniformity might be tuned out by a combination of better alignment of the optics and software. However, even stronger variations in the quartz flat field shape are seen as the telescope is moved across the sky, as seen in Figure 6. It was early on thought that flexure in the spherical mirror was responsible for the behavior, so a rim was installed in the chimney to better support the mirror. However, this did not fix the problem. The sense of the variation with position in the field when the telescope is pointing due west, as seen in Figure 6, hints that vertical flexure in the diffusing lens arm may be the culprit. Further investigation is needed, with the aim of developing an optical alignment maintenance procedure for the calibration system and identifying a fix for the flexure.

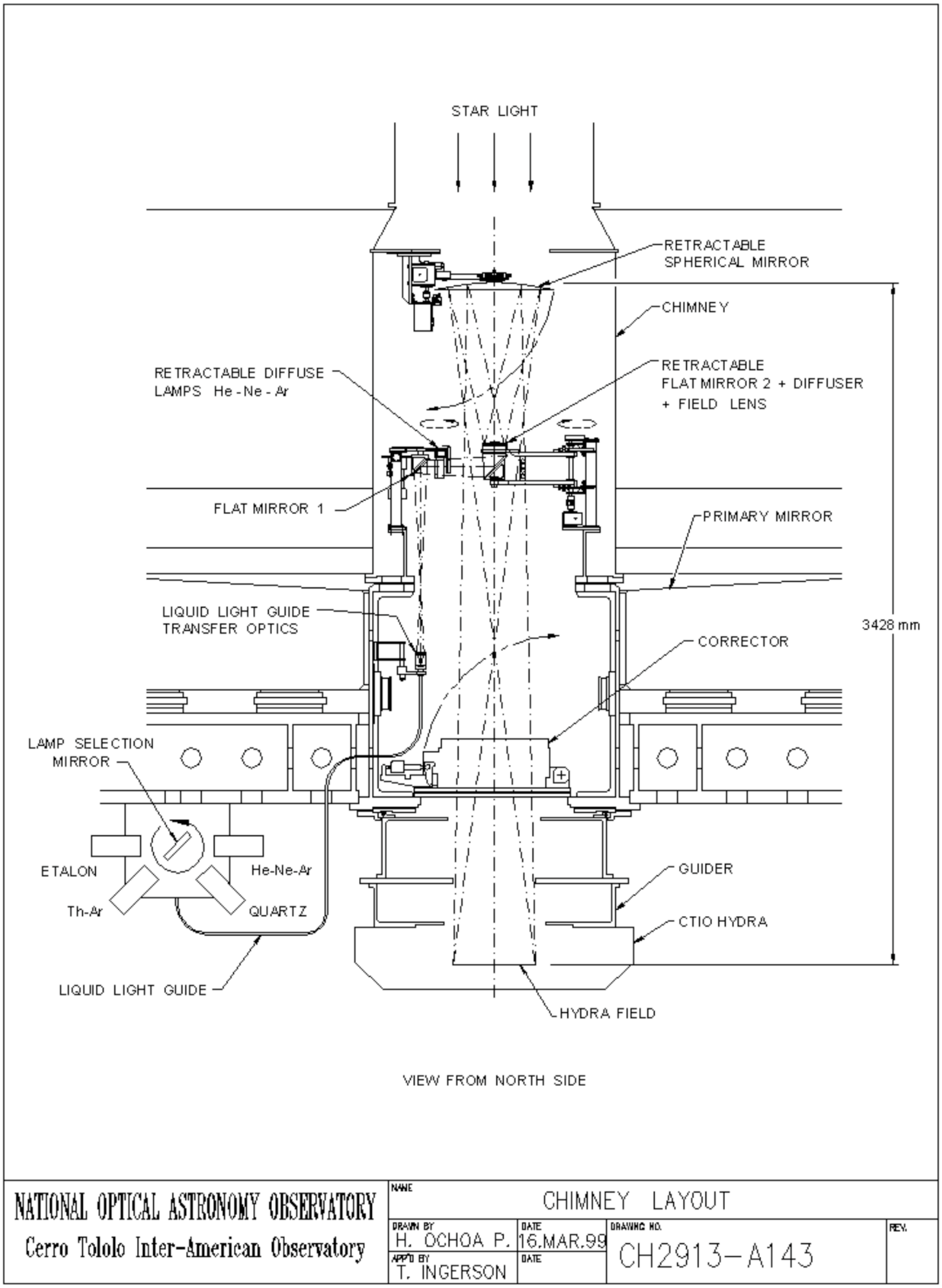

Figure 4. Layout of Hydra calibration system.

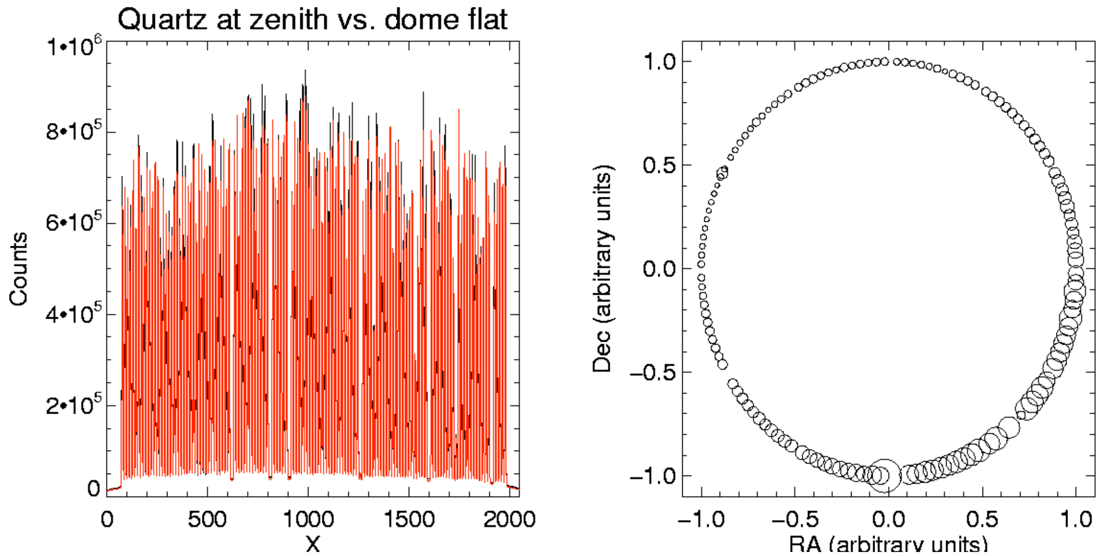

Figure 5. Left: Spatial profile of a dome flat (black) compared to a quartz flat taken with the Hydra calibration system (red), with the telescope at zenith. Right: Ratio of quartz lamp flux to dome flat flux, indicated by point size, as a function of position in the Hydra field.

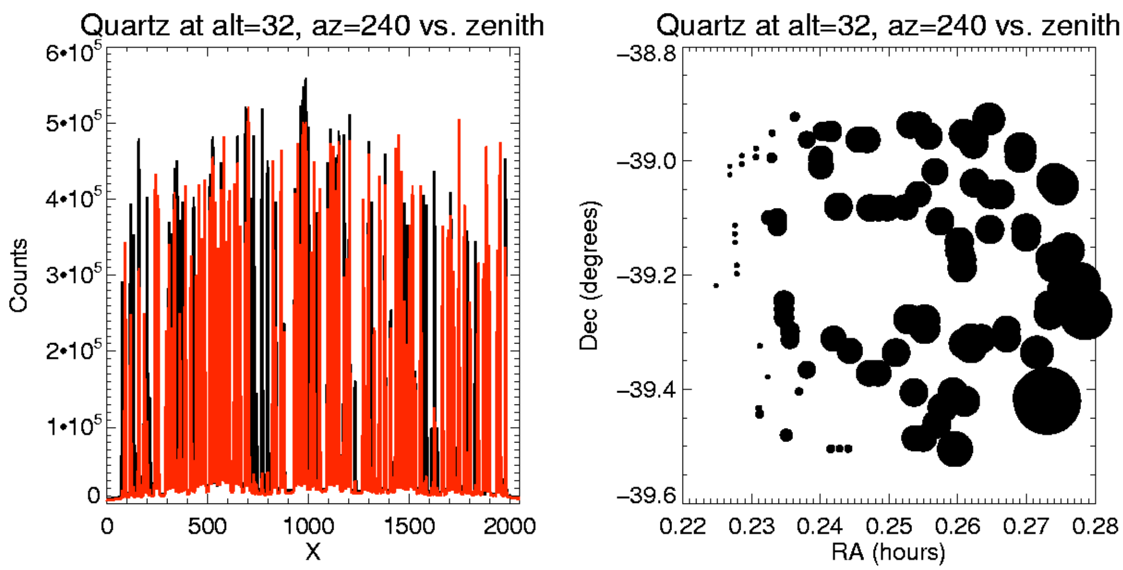

Figure 6. Left: Spatial profile of a quartz flat at zenith (black) compared to a quartz flat at high airmass (red). Right: Ratio of quartz lamp flux at high airmass to quartz lamp at zenith, indicated by point size, as a function of position in the Hydra field. The sense of the variation suggests that the flexure is in the vertical direction of the diffusing lens.

B. Atmospheric Dispersion Corrector (ADC)

The ADC consists of rotating prisms that correct for differential atmospheric refraction. The ADC is always used with Hydra.

Comments:

1. Tests with the Prime Focus ADC (which is similar to the Hydra's ADC) indicate that using the ADC does not introduce any astrometric distortions in the field. These tests should be repeated with Hydra, but have not yet been performed for lack of time.
2. In its first years of use, the ADC was discovered to have broken glass near its edge. This should continue to be monitored.
3. The Hydra plate collects dust, so it follows that the ADC must also be getting dirty. Can this dust be blown off?

C. Fiber Positioner

The fiber positioner is Hydra's most complex subsystem; it contains hardware, supported by software, for configuring fields and for verifying the configuration and telescope pointing. Its components include:

1. An x-y stage coupled to drive motors by two large screws.
2. A mechanical gripper with motorized motion in the z-direction and with jaws coupled to a rotary wheel with its own stepper motor.
3. Limit switches that define various states of opening of the gripper jaws and fiducials and allowable ranges of the x,y, and z motion
4. A Galil motion control box that issues the basic movement commands
5. A periscope that allows simultaneous view of the plate and the sky at the current location of the positioner.
6. Software with a GUI front end that translates positions on the sky to positions on the plate, feeds high-level movement commands to the Galil box, and allows interaction with the positioner and other Hydra subsystems.

Failures of the fiber positioner have been responsible for the majority of the lost time with Hydra, although the exact fraction is difficult to quantify. While the complete list of problems is documented in the Hydra engineering and GNATS reports, I will mention a few of the worst failures here. A period of severe problems in mid to late 2001 was fixed by mechanical and software tuning of the gripper's limit switches, as documented on Hydra's web site. A number of other problems were traced to problems both in the primary Galil motor control box and the spare, both of which have been modified in-house after no useful response from the Galil Co. Gripper failures were previously exacerbated by faulty assignment code that caused the code to lose memory of previous assignments made, producing a possibly endless loop while configuring. The spate of problems leading up to complete failure in June 2005 were traced to mechanical wear and eventual breakage of the stepper motor's wire leads; this motor was replaced.

The fact that the latest fix led to one of the most problem-free string of Hydra nights in the instrument's history provides hope that with continued periodic maintenance, we will be able to avoid the periods of severe faults that we have experienced until now (Hydra has, however, surprised us before). In any case, we now have the institutional knowledge to repair failures of most of the positioner's components. We see no need for major upgrades to improve the positioner's performance. Some critical maintenance procedures and pending items are, however, worth mentioning:

- Retaining or transferring knowledge of the positioner's mechanics, electronics, software, and support will be crucial for operating Hydra for another five years. The software is well enough documented that support could be picked up by someone other than Rolando Cantarutti, while in the area of electronics, Javier Rojas, Enrique Schmidt, and Humberto Orrego have overlapping support knowledge. Mechanical tuning of the gripper by Andres Montané has been needed once every ~2 Hydra blocks. This procedure is difficult to document, as it requires an evaluation and understanding of the gripper's current mechanical state. Ricardo Venegas has unique general knowledge of Hydra, but is overlapped by Hernan Tirado.
- The x-y stage screws need periodic lubrication, which is a delicate procedure also performed by Andres.
- The gripper's stepper motor suffers from a problem with mechanical wear of wires. We now have the last two available spares, which should last well beyond the five-year projected lifetime of Hydra, as well as a more powerful motor that could be used. One of the spares should be modified to prevent the mechanical wear of its wires.
- The periscope that feeds the gripper camera contains a very fragile pellicle beam splitter. While we have one spare, plastic sandwich wrap can be used in a pinch.

D. Fibers

Hydra contains 288 fibers around its plate and an additional small number of spares in its cables. 12 of the 288 fibers are bundles of seven fibers ("FOPS") used for guiding, 138 are 2-arcsec "large" fibers, and the remaining 138 1-arcsec "small" fibers. The fibers pass from the plate to the cables, through connectors, and through additional cables to the spectrograph and guide camera. The small fibers have highly variable throughput, and so have never been used. One of the FOPS fibers is broken, while 7 large fibers are unused because they are either broken or have low throughput, leaving 11 active FOPS and 131 active large fibers. The fibers are attached to magnetic buttons that are placed on the plate; below the plate is a vacuum chamber that bends the plate to the shape of the focal surface for carrying out observations.

Comments for consideration:

1. The FOPS guide fibers and useful guide stars on the sky are both sparsely distributed, making the loss of a FOPS fiber painful. We do not have the ability

to repair broken fibers, but there may be spare FOPS fibers in the cable. Fabian Collao estimates ~2 days work to replace the one broken fiber, if possible.

2. Replacement of the seven broken/poor large fibers would be nice, but is of lower priority than the FOPS fiber. The time needed to replace them would be ~2 days/fiber. The majority were broken in the first three years of use, and none have been lost since March 2003. With our better control of problems with the positioner, it is reasonable to presume that we will lose fewer fibers in the next 5 years than we have in the past 5, such that we will retain at least 90% of Hydra's fibers in working order.
3. We need a system to feed high-intensity light through the fibers into the spectrograph while Hydra is not in use, primarily for optical alignment of the spectrograph. A secondary use for such a system would be to perform spectrograph setups and checkout in advance of observing runs.
4. We need to maintain an adequate supply of sol-gel for optically coupling the fibers in the connectors.

E. Bench spectrograph

The layout of the bench spectrograph is shown in Figure 7, while a description written by Tom Ingerson is available on the Hydra web page. In brief, the main components are:

1. Fiber mount. The fibers are positioned on the curved focal plane of the collimator mirror. The fiber mount tilts to remove the change in central wavelength across the focal plane that is produced by the off-axis grating reflection and has focus adjustment.
2. Slit plates of 100μ and 200μ widths that may be mounted in front of the fiber array to improve the spectral resolution.
3. A filter wheel with four slots sits in front of the fiber mount. One of the slots is permanently occupied by an LED array to allow light to be sent back up the fiber cable, while the other three are open and accept 4"x0."5 filters.
4. Collimator.
5. Grating mount that accepts RC Spec gratings ~8"x10"x2" in size or the 316 line/mm echelle grating, which is slightly longer and thicker than the RC Spec gratings.
6. Smart motor control box, providing motion control for the grating mount, fiber mount, and filter wheel.
7. The camera, which contains:
    - Shutter with open and close positions, controlled by a QuickSilver motor with a control program embedded into the motor's program area memory, commanded by Arcon.
    - Corrector.
    - Collimator.
    - Mount containing wiring for the CCD which also serves as a cold finger
    - CCD window.

   - SITe 2Kx4K CCD.
   - Manual adjustments for focus and tilt of the CCD in two directions.
   - Dewar.
   - Cover to protect the camera from stray light.
   - Nitrogen fill flask and reservoir.
   - Arcon controller box, kept covered with cloth to contain IR light produced by it.
   - Hose connecting to external vacuum pump. The dewar must be continually pumped in order to allow nitrogen in the dewar to solidify, as the cold finger provides inadequate thermal conductivity to allow the CCD to cool sufficiently with liquid nitrogen.
8. Curtains to provide secondary protection from stray light entering the bench.
9. The room, which must be considered as the walls of the instrument. Care must be taken to keep the room sealed from external light and clean.

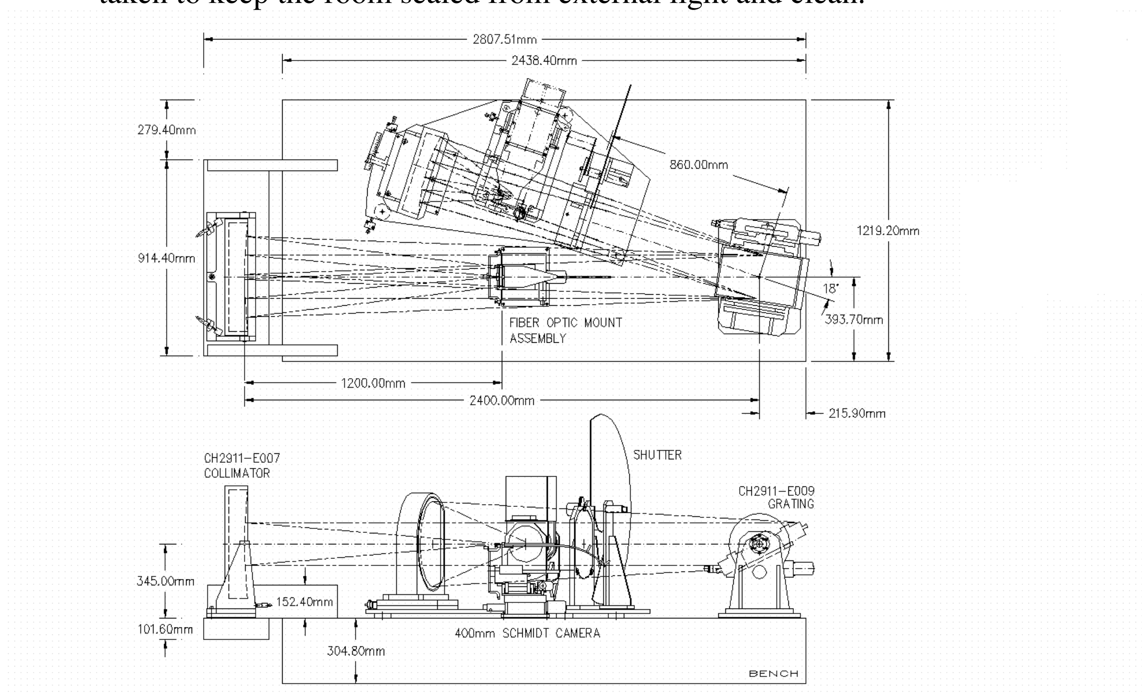

Figure 7. Layout of Hydra bench spectrograph.

The bench spectrograph is the area where we imagine that most of the improvements can be made. In particular:

1. Configuring the spectrograph to use high groove density VPH gratings would provide much greater efficiency for high resolution spectroscopy, the area where Hydra stands to be most competitive. The reconfiguration would require placing a flat mirror ahead of the current grating mount, designing a VPH grating mount, and changing the grating-to-camera angle (see proposed layouts by Roberto Tighe in separate document). While an optical design is necessary to specify the needed

grating characteristics, KOSI has VPH gratings with 11 cm widths available at groove densities of up to 6000 lines/mm, and has recently acquired the equipment needed to make larger gratings. Grating prices in this size range start at ~$6,000. Hydra-WIYN is in the process of upgrading its bench spectrograph to use VPH gratings of 700 and 3300 line/mm densities purchased from CSL, and is spending $30,000 on the gratings.

2. The focus mechanism for the camera currently needs to be operated manually, making spectrograph focus a fairly time-consuming process. Our plan is to motorize the mechanism and provide software control through the spectrograph GUI.
3. We should plan for the possibility of failure of Hydra's CCD by preparing a spare Arcon controller/CCD system using the old Mosaic #3 CCD, which still has one working amplifier. We will need to requisition the "Green dewar" from NOAO North for testing and characterization of the spare system.
4. The fact that the CCD needs solid nitrogen to cool down to the proper temperature is cause for some concern. However, the system has worked this way for 4 years with the only significant problem being the failure of the original vacuum pump. This failure resulted in a redesign of the pumping system that has worked very well. Blockage of the tube and warming of the CCD has lately been occurring once per block, but is easily fixed, and could perhaps be a sign that water has leaked into the nitrogen flask, which can be cleared. Improving the thermal conductivity would require a new cold finger design that would probably cut down the spectrograph throughput somewhat.
5. The echelle narrowband filters were made by cutting 2-inch filters together and gluing them together in the middle, a process which leaves ~10 fibers unusable. Replacing the five filters that have been used in the history of the instrument would cost ~$20,000 based on quotes by Barr.
6. The spectrograph curtains are made of black wool that is not entirely opaque and produces dust. The curtains should be replaced by a more opaque, less dusty material. Candidates are 16 oz black commando cloth (cotton; used in theater stages in place of velour to block light; is also flame retardant): ~$500.00 for 100 yard roll -- Super Black Serge (wool; also used in theater; fire retardant): $16.75/yard (i.weiss.com) -- 9.5 oz vinyl-coated polyester fabric (Coverlight Select; fire retardant; sounds similar to material used by Sandia Nat'l Labs for darkrooms): $ 5.75/yd -- 16 oz Neoprene coated fabric (fire retardant): $16.75/yd (http://www.mauritzononline.com).
7. The sticky mat by the entryway needs to be replaced, cost $207 for 4 with 30 sheets each (http://www.terrauniversal.com/products/GowningProducts/cleanlinemats.php).

F. FOPS guider

The FOPS guider consists of an ICCD camera and software that records and reports the intensity of each fiber in the FOPS bundles, computes the intensity-weighted centroids of the bundles, and sends the necessary guide signals to drive the telescope towards the centers of the FOPS bundles. The FOPS guider is also used to focus the telescope by finding the focus that produces the highest degree of central concentration in the FOPS illumination, a procedure that is currently done entirely by eye.

Comments for discussion:

1. Focusing the telescope is currently made difficult by the choppy motion of the secondary screws.
2. We need an automated focus procedure. One exists in the current software, but it depends on smooth motion of the secondary. An alternative approach would be to store the guide camera images during a focus sequence, and analyze the sequence with external software; we intend to adopt this procedure.

G. User interface

Hydra's user interface has three components:

1. Hydra GUI. Provides interaction with positioner, guider, and calibration system. Works very well. The only minor upgrades that would be useful would be to replace the x-y "handpaddle" with an r-θ version and to add a progress meter for field configuration.
2. Bench spectrograph GUI. Will need to add component to interact with spectrograph focus once this is motorized.
3. Arcon interface. No changes needed.

H. Safety

There are a few known safety issues with Hydra:

1. Hydra's positioner is heavy and moves at high velocity and is thus capable of causing severe bodily harm. In recognition of this, the positioner has a number of features designed to reduce the risk:
   - Clear indication of the area within the positioner carriage where it is dangerous to insert hands and arms
   - Emergency panic button that cuts power to the positioner
   - Automatic power shutoff if the carriage is lowered
   - Documented safety procedure for recovering from fiber and positioner problems
2. Because the bench spectrograph room is sealed to prevent entry of stray light, there is an oxygen safety risk should a large nitrogen spill occur or a fire start up in the room. The room has an oxygen monitor installed with an alarm sounding if the oxygen drops below a safe level.
3. The curtains and cloth used in the bench spectrograph room are not fir hazards, but are not fire retardant, either. They should be replaced by fire retardant curtains.

Proposed upgrade and maintenance plan

A. Items that need further investigation

1. How to stiffen the flat field system
2. ADC effect on throughput

B. Summary of upgrades proposed

Item	Effort needed	Material cost	Priority
Modify spectrograph to use VPH gratings	- ~2 weeks Optical design -Mechanical design and fabrication -Electronics -Software control	>$30,000 estimated	High
Design system to feed light to spectrograph while Hydra is not in use	TBD	Small	High
Motorize camera focus mechanism	- 4 weeks M.E. - 6 weeks M.D. - 8 weeks M.F. - 2-3 weeks Electronics - Software	Small	High
Prepare spare Arcon controller/CCD system	~1 month R.G.	Requisition test dewar from NOAO North	High
Modify gripper motor to prevent mechanical wear of wires	Mechanical (small)	Small or none	High
Replace broken FOPS fiber	2 days F.C.	None	High (if possible)
Create automated telescope focus procedure	1 day software (R.C.) 1 week software and testing (K.O.)	None	High
Replace spectrograph curtains	~1 day sewing and mounting	~$500	High

Replace 5 echelle filters	Mount fabrication	Up to ~$21,000	Medium to High (dependent on VPH project)
Replace 7 useless large fibers	2 days per fiber	None	Medium
Redesign camera to cool on liquid instead of solid N_2	At least 8 weeks M.D.	Unknown	Undecided
Add configuration progress meter to GUI	Software	None	Low
Make GUI handpaddle work in *r*-θ instead of x-y	Software	None	Low

C. To be included in maintenance list

1. Maintain supply of penray spares
2. Maintain spare pellicle supply
3. Careful lubrication of x-y stages
4. Maintain supply of sticky mats to collect dirt upon entering room ($207 for 120 sheets, http://www.terrauniversal.com/products/GowningProducts/cleanlinemats.php)
5. Maintain supply of sol-gel for fiber connectors
6. Mechanical tuning of gripper
7. Check ADC for dust and dirt
8. Check nitrogen flask for presence of water

D. Documentation needed

1. Procedure for using etalon to perform wavelength calibration
2. Attempt to document Andres' knowledge concerning gripper tuning
3. Review all documentation