3-Year Plan for Improvements at Apache Point Observatory

1. Introduction

Development plans for the next 3 years at Apache Point are proposed. The current state of affairs is marginal at best, with a telescope not performing to design specifications and instrumentation outdated by technological advances. Our premise is that telescope and instrument performance should be better than those at other observatories and provide unique capabilities that encourage innovative observational astronomy.

An outline of the proposed work is presented in this first section and details in the following sections. At the end, a rough schedule and budget are shown.

1.1 Telescope

For the telescope, the following should be done:

1.1.1 Image quality

- Repair primary mirror support
- Replace secondary mirror
- Improve or replace secondary support truss
- Remove 20 Hz vibration from altitude axis
- Enhance offset guider (slow guiding)
- Install high bandwidth guider using PZ controls (fast guiding)
- Automatic focusing

1.1.2 Photometry

- Install baffling

1.1.3 Operations

- Enhance instrument rotator
- Automate tertiary
- Install diagnostic subsystems

Current instruments

- Refurbish DIS
- GRIM2
- Echelle
- Improve and automate calibration systems
- Overhaul data acquisition and instrument control systems

1.2 New instruments

Building all of these is not part of the 3 year plan, but consideration of the next step is essential now because of the long lead time for new instruments.

- Build a 1-chip imager
- Build a wide field spectrograph
- Build a 4-chip imager
- IR spectrometer

1.3 Computing and networking

- Improve network speed and reliability, reduce latency
- Rewrite software to consolidate capabilities on one platform

1.4 Scope

The telescope work is required. Unless we improve imaging to meet site performance, it makes little sense to run a 3.5 m telescope.

The instrument plan is more flexible: we have many choices, most of them good. The short term plan is to refurbish DIS and build a single-chip imager. In the longer term, new instruments should be built on a timeline that guarantees one or two state-of-the-art capabilities at all times.

The observatory should be equipped with a suite of facilities class instruments satisfying common research needs. The minimum set includes a wide field imager and a wide field spectrograph, both working at CCD wavelengths, and a high resolution near IR (JHK) imager. These instruments must be the best of their kind in the world and take full advantage of the telescope and observing site. Beyond these, more specialized instruments such as a high resolution optical echelle spectrograph and a moderate resolution IR echelle spectrograph should be available.

Beyond standard equipment, the observatory must also support riskier endeavors that explore uncharted parameter space. In most cases, these will be developed at member institutions and will not be solicited by the ARC community. We must recognize that these experiments require support at the site, however, and in some cases the level of support may match or exceed that required for normal maintenance of the facilities instrumentation. The implication is that maintenance support beyond the standard instruments will be needed.

2. Telescope

The telescope points to 8-10 arc seconds, has image sizes on the order of 1 arc second FWHM, and tracks those 1 arc second images only for 10 minutes. It cannot delivery precision photometry because stray light is not controlled.

We would like to see pointing to 5 arc second accuracy, an image size of 0.5 arc seconds, the ability to guide indefinitely, and the addition of baffling for high precision photometric observations.

2.1 Imaging

The telescope imaging is not up to what the site can provide. A floor of about 1 arc second is seen while the site can probably deliver 0.6 arc seconds with reasonable frequency. We would like to close the gap.

Four things are believed to contribute about equally to image degradation: the primary mirror support, the secondary mirror figure, the secondary support truss, and the altitude drive 20 Hz oscillation. Fixing these problems and adding a high frequency guider should give us the site-limited imaging.

2.1.1 Primary mirror support

The primary mirror is supported by pneumatic pushers that adjust their force based on telescope altitude. The control system has insufficient bandwidth to maintain the correct mirror position and oscillates in certain common conditions. These oscillations add a couple of tenths of an arc second to the image diameter.

York Brown, a consultant at the University of Washington, has been contracted to design either a repair or a new control system to fix this problem and is scheduled to try it out during the December 1996 shutdown.

2.1.2 Secondary mirror

The current secondary mirror was installed unfinished and degrades the images. A new secondary blank has been generated to a sphere and currently resides at JHU. We are negotiating with polishing endors to finish the job.

2.1.3 Secondary support truss

The secondary mirror is supported by a rectangular box of steel tubing that hangs on tensioned steel rods. Although the design tension in the tubing is 10,000 pounds, the current tension is lower, allowing the secondary support to shake in the wind.

An engineering analysis by Jon Davis (July 1996) shows that increasing the tension to 10,000 pounds leaves an insufficient safety margin against damage and possibly catastrophic failure. Jon is designing a new secondary mirror support.

2.1.4 20 Hz vibration

The altitude axis motion control induces a 20 Hz vibration in the telescope that degrades images.

2.1.5 Slow guider

An offset guider was installed but had low sensitivity. These have been addressed by Chris Stubbs & Co. at U. Washington and a repair is imminent.

2.1.6 Fast guider

To record sub arc second images, accurate guiding for long periods is essential. Experience at other observatories shows that update frequencies of 10 Hz or more are needed. This can be implemented at the focal plane or by tilting the secondary mirror. Piezoelectric actuators are already installed on the current secondary support so "only" a guide camera and control system need to be done. The guide camera to be installed by UW has readout speed sufficient for 10 Hz tip-tilt on the secondary.

At the recent Baltimore meeting, the problem of reaction kickback from moving the secondary was raised, and a redesign of the secondary mount might be required to implement fast guiding.

2.1.7 Automatic focusing

The current focusing scheme uses a lookup table to find corrections to the focus based on temperature and altitude. The new guider will be able to monitor the telescope focus and apply corrections in a feedback loop eliminating the need to maintain a focus table.

2.2 Photometry

2.2.1 Baffling

The 3.5 m telescope is not properly baffled making stray light a problem that sometimes prevents accurate photometry. Peering into an open Naysmith port, one sees not only the tertiary mirror but also the primary mirror surface, the telescope structure on the far side, and even the walls of the telescope enclosure. It is difficult, if not impossible, to block this light within instruments (except those with only a point source field of view). Baffling a Naysmith port is difficult, but will be necessary if we are to obtain photometric data from this telescope.

2.3 Operations

2.3.1 Instrument rotator

The current instrument rotator has minor problems requiring major work. It stalls in some situations because the motors are underrated and cables are sometime damaged because it lacks a rotation limit sensor. Neither problem is a technical challenge, but repair will require significant effort and some downtime.

2.3.2 Tertiary motion

Tertiary mirror rotation is manual and requires about 20 minutes to complete. It has always been intended that this operation be automated but no plans exist to make this happen. Because rapid instrument changes are a highlight feature of this telescope, implementing automatic tertiary motion should be a priority item.

2.3.3 Collimation tools & procedures

The telescope is not grossly out of alignment, but the best procedure for precisely collimating the mirrors is not known and the tools needed to do so do not exist. It is probably a good idea to build the equipment and develop the procedures so each collimation effort does not turn into a research task.

2.3.4 Diagnostic subsystems

The hardware and software systems on this telescope are sufficiently complex that troubleshooting subtle problems can be time consuming and perplexing. A useful tool is a status log showing commands issued and their effect on the telescope. Besides providing immediate feedback for gross errors ("this sensor is broken"), the logs can also be analyzed to fix the more perplexing, infrequent anomalies ("the telescope jumped twice last night"). The SDSS telescope will have a diagnostic system installed for this purpose. If it works and is useful, the 3.5 m should install a similar system.

3. Current Instruments

3.1 DIS

The Dual Imaging Spectrograph suffers from outdated detectors and throughput below design values. Since any comparable replacement instrument is at least three years in the future, refurbishment of this instrument on a one-year time scale would be good. The plan for incremental upgrades includes the following:

- UV throughput repair
- Overall throughput repair
- Removing noise from CCD readouts
- Fast slit viewer camera
- Reflecting air gap slits
- New (different dispersion) gratings
- Automatic calibration lamp control

Besides these items, new detectors and a new slit viewer computer are also potential upgrades.

3.2 GRIM2

GRIM II is perhaps simultaneously the most complex and successful instrument available for general use on the 3.5m. Many people are using it to obtain good data. Nevertheless, it has limitations compared with other infrared instruments at national and private observatories, and the enhancements listed here would make a better fit to the user community.

3.2.1 Chip Cosmetics

The chip is fine compared with others we've seen at national and private observatories; it's slightly worse than some and significantly better than others. There is an annoying clump of bad pixels near the center.

3.2.2 Filters

There is no narrow band continuum filter for use with 2.16 micron Br-gamma or 2.12 µm H2. This situation is like having filters for H-alpha and [SII] but no line-free continuum, only worse because of severe color gradients within the K band in many dusty sources. We should have filters at 2.14 and 2.18.

3.2.3 Bias Noise

The bias structure is variable, leading to variable banding across the chip with amplitudes of 20-30 DN in 80% of frames and about 100 DN in 20% of frames. The lower right hand quadrant also has noticeable bias ripples.

3.2.4 Read Noise

The read noise of the chip is about 110 electrons and there are no provisions for multiple reads. This is adequate for H and K broad band imaging and narrow band imaging at f/5 but inadequate for J band and narrow band imaging at f/10 and f/20 and for spectroscopy. (The gain is about 5 electrons so read noise equals photon noise at about 2500 DN. The f/10 backgrounds in J broad band filters and the K narrow band filters are about 2000 DN in 60s. The f/10 backgrounds in K spectroscopy are about 100 DN in 60s.)

Other similar instruments we have used have had read noises of about 35 electrons and provision for multiple reads giving effective read noises of about 10 electrons.

Reducing the effective read noise by a factor of 4 (by implementing 16x multiple reads) would allow background limited operation with the J broad band and K narrow band filters. Reducing the effective read noise by a factor of 10 (by dropping the read noise to 40 electrons and implementing 16x multiple reads) would allow background limited K band spectroscopy.

3.2.5 Minor things

- Hangs. GRIM hangs about half a dozen times a night, always at the same place. This causes problems for MC scripts, which are essential for effective single-handed observing. (This is probably an MC problem.)

- Columns 1 and 129 are offset by 1 row from the rest of the chip. This can be fixed during reduction.

- Exposure times in the header are wrong by a constant offset that has to be indirectly calibrated. Confidence in the exposure times could be greatly increased if this were not the case.

- Documentation. What exists is scattered and incomplete.

3.3 Echelle Installation

This instrument expands considerably the 3.5 m capabilities. We note it here to remind us that this is another dewar to feed, more electronics to maintain, etc., and its arrival will impose a cost to the mountain operations.

3.4 Calibration systems

The current calibration lamp system is clumsy and the on-site observer is needed to close the mirror covers. Giving control of the calibration system to the remote observer is a relatively inexpensive task that can provide a major enhancement in remote observing.

3.5 Instrument controls

The current software set is a mix of programs that work well together but require multiple operating systems and hardware platforms to run. From a maintenance standpoint, it makes sense to consolidate these functions into one machine using one operating system. This major task will probably take two years to complete but will pay off in the long run with well documented easily maintained software.

4. New Instruments

A modern astronomical instrument can sit on the cutting edge for 3-5 years after which technology allows something significantly better. Because new instruments take 3-5 years to build, we must start the next instrument immediately upon acceptance of the previous if we want at least one top performance device at all times. In some cases we can upgrade current systems, but this is not guaranteed because cost considerations usually constrain the initial design.

4.1 Single chip imager

We do not have a high quality imager equipped with a useful filter set nor do we have a clean path to obtaining one. Possibilities include upgrading the drift scan camera (unlikely), adding support to Chris Stubb's prototype 2048 camera (possible), or fast-tracking the JHU spectrograph detector and filter box (longer lead time).

4.2 Wide Field Spectrograph

Preliminary design work is in progress at JHU for a spectrograph with the following characteristics:

- 12 arc minute diameter field of view
- Slit mask or robotic slitlets
- Wavelength coverage from 3800 to 7600 A [check this]
- SIT/e 2048 x 4096 x 15 µm CCD

The instrument components will be modular so simple modifications will allow a wide variety of spectral analyzers and filters at moderate cost.

4.3 Wide Field Imager

Missing from the current set of instruments at APO is a high performance wide field optical imager that takes full advantage of the telescope and site. This instrument should provide filtered images with no compromises. Baseline features might include:

- Seeing limited imaging on long guided exposures
- A 15 arc minute field of view
- Fast filter changes
- Trivially easy operation
- Dual filter wheels

The UW mosaic camera may meet many of these requirements and we might be able to set up a situation where the equipment is available as "almost facilities class."

4.4 IR Spectrometer

A common wish-list item is an IR spectrometer with somewhat higher resolving power than GRIM2, particularly at longer wavelengths.

5. Computing

5.1 Networking

The one thing that will contribute the most to remote observing efficiency is the ability to see imaging data quickly. The bottleneck is internet bandwidth, something we have little control over except near the mountain. We can probably expect continued upgrades nationwide, however, and need to make sure that the bottleneck is never the link at the observatory.

While improvements in compression and decimation techniques can help, long dropouts seen on the internet make the system sufficiently unreliable that if you require image data to observe, you must be on-site.

5.2 Software rewrite

Observing at APO requires multiple computers, each running a different operating system (System 7 for the Mac, SunOS for tycho, MS-DOS for the slitviewer) and multiple keyboards (not counting the TCC or ICC, which the observer doesn't see directly). This hodgepodge is the result of a natural evolution and works surprisingly well. In the long term, however, it is expensive and difficult to maintain because of the diversity of programmers, coding styles, and platforms. In principle, these should be easily maintained by the mountain staff.

6. Schedule, Budget, and Workload

The three-year period is as much a reflection of our patience as a schedule imposition. With unlimited resources, the telescope and instrument refurbishment work might happen in 18 months and the computing work within 24. In reality, a few things may by unfinished after 3 years, but we intend to have imaging performance sufficient to claim that the APO 3.5 m telescope is better than any other comparable facility. Furthermore, a sensible plan to maintain the telescope and develop new instrumentation should be in place.

Preliminary budgets for the telescope work are in Chris Stubb's telescope status document and the DIS budget is in the DIS Refurbishment Plan. The telescope work requires approximately $560K, the DIS refurbishment about $80K.

At the Baltimore community meeting in August 1996, priorities and estimated completion dates (schedule) were assigned to the telescope tasks. The table shows the results. Items with asterisks are currently in progress.

ITEM	Time (months)
High priority	
*Primary mirror support	6
*New secondary	18
*Secondary support upgrade	TBD
Baffling	TBD
*Slow guider	3
*Enclosure wheels	4
Medium priority	
Tertiary automation	24
Rotator upgrades	24
On-line diagnostic system	12
Low priority	
Automate calibration system	12
Fast guiding	12
Collimation tools	24
Altitude servo (20 Hz)	24
Real time focus control	12