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REMOTE OBSERVATORY ACCESS VIA THE ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE

FINAL TECHNICAL REPORT

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REMOTE OBSERVATORY ACCESS VIA THE ACTS

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Abstract

An investigation of the potential for using the ACTS to provide the data distribution network for a distributed set of users of an astronomical observatory has been conducted. The investigation consisted of gathering the data and interface standards for the ACTS network and the observato-
ry
instrumentation and telecommunications devices. A simulation based on COMNET was then developed to test data transport configurations for real-time suitability. The investigation showed that the ACTS network should support the real-time requirements and allow for growth in the observatory needs for data transport.

Observer Network

Modern astronomical observatories are rarely owned by one institution. Rather, they are usually funded and operated by consortia of many institutions - often with a national distribution of partners. The Apache Point Observatory (APO) is a case in point being owned and operated by a consortia of five member universities. What makes the APO truly unique is the from the start, the observatory was designed to have all instrumentation and control segments interface with telecommunications and networking ports to allow for **distributed real-time** data acquisition and control.

The APO member sites are illustrated in Figure 1. The observatory itself is located in south-central New Mexico near Sunspot New Mexico and also near NASA's White Sands Ground Terminal. This location is important because the observatory should be within the ACTS dedicated spot beacon for White Sands. Other observer locations include Las Cruces New Mexico, Chicago Illinois, Princeton New Jersey, and Seattle and Pullman Washington. With the distributed data philosophy, users do not come to the New Mexico observatory location. Rather, the observer stays at the home institution and the data is delivered over a telecommunications network to a desk-top computer, in this case a MAC II. The observer then controls the telescope pointing in real-time and the data is delivered in a timely, periodic manner.

There are two present modes whereby data can be exchanged between the APO and the observers: commercial phone lines, and the Internet. Commercial telephone service is not desirable because of expense and available bandwidth for instrumentation data. Internet has the available bandwidth but not the delivery guarantees for real-time operations. Because of these two constraints, a communications satellite link seemed to have desirable properties for exploitation.

ACTS Simulation Model

In order to determine if the ACTS would make a suitable data transport delivery mechanism, a simulation model of the end-to-end observatory data network was developed. This would include the spacecraft data transport and ground terminal interfaces as well as the computers in the observatory. Important issues to deal with were

(a) could real-time tracking and control information be delivered to the user in a regular manner,
(b) would real-time data from the instrumentation be delivered prior to the next instrumentation data dump, and
(c) would there need to be excessive data buffering at any point within the network.

Because the observer would not be physically co-located with the telescope and would only communicate through a computer interface, a means to give some form of feedback of the observatory conditions is needed regardless of where the observer is physically located. It was determined that a simulation model to estimate the data delivery times and buffering requirements would go a long way, prior to satellite launch, to provide the observatory planners with the required data to determine if the user interface under development would be adequate.

Model Elements

The basic elements to be modeled are illustrated in Figure 2 with the details of the APO network given in Figure 3. The ACTS TDMA frame structure used is that given in [1]. The T-1 VSAT interface parameters are those given in [2]. The ACTS data propagation details through the spacecraft are those given in [1] and [2]. For the observatory telecommunications links, the standard ETHERNET and T-1 interface protocols were used. The simulation was configured as a datagram service which means that each node in the ground network needed to perform routing decisions on the individual data packets. As mentioned above, the actual satellite link was modeled as a slotted Aloha link between the ACTS and the source ground terminal then as a point-to-point link between the ACTS and the destination ground terminal. This simplification allowed the link dynamics to be kept, i.e., waiting for a slot time at the transmitting ground terminal, using existing COMNET modeling structures.

Traffic Model

The data traffic from the observatory consists of two traffic classes: instrumentation data traffic which is of high volume (>1 Mbit per message) but not with a guaranteed data delivery time and housekeeping data which is of low volume but with guaranteed data delivery time. The data traffic is summarized in Table 1. For the simulation runs, no return traffic from the user remote terminal was used. This would be low-rate, housekeeping-type traffic that would not stress the link parameters and would be nearly invisible when compared with the APO side of the link.

Table 1. APO Data Traffic Model			
Source	**Sensor**	**Max Size (bits)**	**Rate**
Camera -1	CCD	4,194,304.00	1/min - 1/hour
Camera-2	CCD	67,108,864.00	1/min - 1/hour
Camera-3	CCD	268,435,456.00	1/min - 1/hour
2.5-m survey	CCD	2,013,265,920.00	1 Mbps - 5 Mbps
Housekeeping	Tracking	131,072.00	1/min
	Pointing	1,024.00	1/min
	Status	1,024.00	1/min

COMNET Simulation

The method chosen to model the data network was to use the simulation package COMNET distributed by CACI [3]. COMNET is a general telecommunications modeling tool which can be used for modeling datagram, virtual circuit and call circuit networks. COMNET is written in Simscript and available for a number of host platforms. This makes the model transportable for other users or for running at different simulation facilities. The simulation model used here, employed the datagram components for modeling the transmission of the data. Within the modeling package, the user needs to define the following types of parameters by making appropriate entries in menus presented by the simulation package:

a) data message interarrival time and size,
b) transport-level protocol PDU size (including overhead),
c) data link parameters (transmission speed, propagation delay, etc.), and
d) data link level PDU size (including overhead).

The interaction between the data message (instrumentation or tracking messages) is illustrated in Figure 4. COMNET produces the data message of the user-specified size at the user-specified interarrival time. Because os the nature of astronomical observation, these were of fixed size and interarrival time. In principle, these could both be statistical variables drawn from a probability distribution.

The various links used in the model represented both the internal data links (ETHERNET local area networks) and the satellite Time Division Multiple Access (TDMA) frame. When standard frame sizes were encountered as in the LANs, those frame sizes were used for the Data Link PDU. The satellite link was more of a challenge since COMNET does not have a TDMA frame structure built in, we used the internal Slotted Aloha network to model the TDMA structure. Figure 5 illustrates how the link PDU is configured.

Figure 6 illustrates the end-to-end COMNET model for the data transport network. Included within all of the links are the individual PDU size, link speed, propagation time, and protocol details.

NMSU Simulation Laboratory

The simulations were developed and run at the Computer Aided Design and Simulation Laboratory at NMSU. VAX workstations were used to run the actual COMNET package. The lab is composed of five (5) VAXstation 3100 workstations networked to one VAXserver 3800 with 2.2 GBytes of disk space, and a LN-03+ printer. The computers run VMS version 5.4 and have a variety of high-level language support in addition to the simulation packages.

Results

Typical results obtained with COMNET for the APO data network, including using the ACTS, are given in Figures 7 though 10. Figure 7 shows the network throughput as a function of message interarrival time for three sizes of message traffic. Notice that the trend is not entirely linear and for some values of the data packet size, larger throughput can be obtained than with larger data packets. Figure 8 gives the end-to-end message delay as a function of packet size for differing initial message sizes. Again, a smaller-than-maximum packet size will yield better performance than will the largest packet size available. Both of these results show the effect of internal data link message sizes affecting the overall characteristics.

COMNET can also be used for analyzing resources. Figure 9 shows the percentage of allocated buffering capacity utilized as a function of packet size. Figure 10 shows what percentage of packets undergo blocking at some point as a function of initial message size and packet size.

All of these results are derived from typical model run data. The value in COMNET lies in its ability for us to perform "what if" experiments to change traffic loads, interarrival times, and protocol details and see what effects are propagated to the output. Since the observatory is contemplating the addition of new telescopes to the mountain, this model allows us to easily add that new load and check for throughput changes.

Conclusions

The need to transport real-time data around the CONUS is a need which users are beginning to demand. The astronomical observatory makes an excellent test bed for these concepts. Prior to the launch of the ACTS we have modeled the expected data links and protocol interfaces for such a network. The traffic driving the network came from two types of sources: high-rate, low-volume immediate data and lower-rate, high-volume less immediate data. The ACTS system appears to have the capacity to provide both real-time command and control data transport as well as bulk data transport with acceptable delays for both types of data. The COMNET simulation package allows for us to model varying network loads and configurations without major modeling re-workings.

References

[1]NASA, *Experiments Applications Guide,* NASA TM-100265, Lewis Research Center, Cleveland, OH, January 1990.

[2]Comsat Laboratories, "Advanced Communications Technology Satellite (ACTS) Ground Segment Low Burst Rate TDMA Network Control Performance Specification," ACTS A140001, Rev. B, DRD302, October 23, 1990.

[3]CACI Products Company, *COMNET II.5 User's Manual, Release 5*, CACI Products Company, La Jolla, CA, 1992.

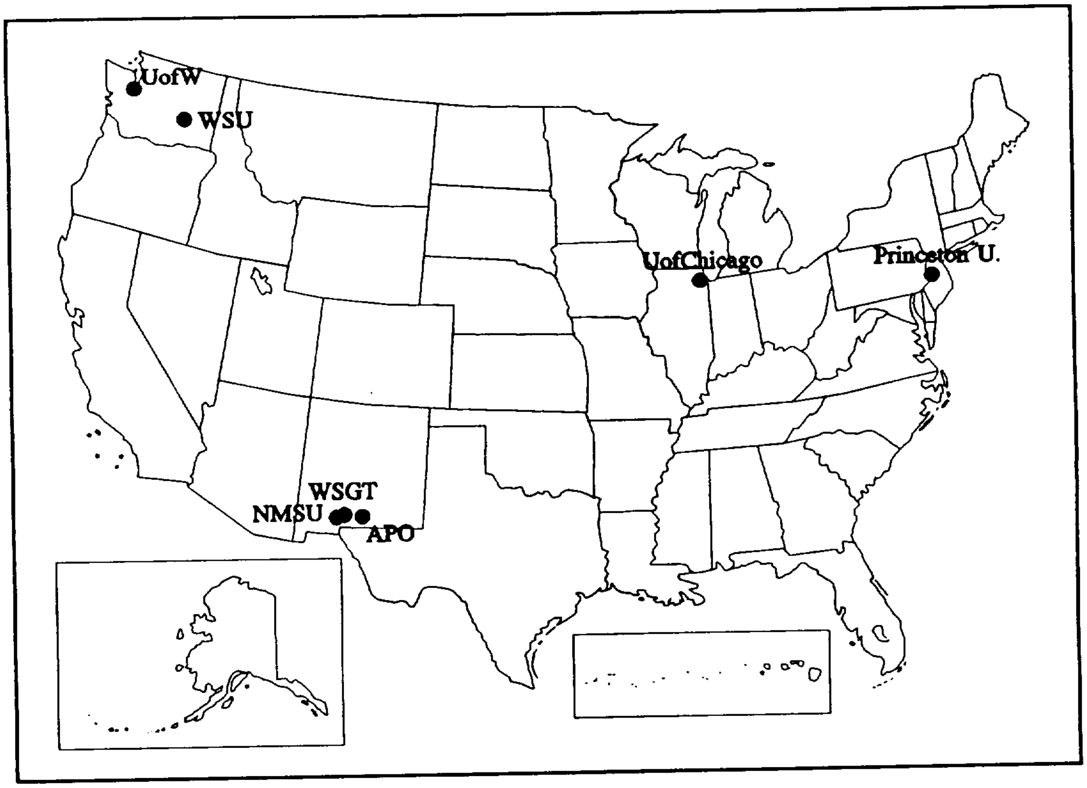

Figure 1 - APO Partners

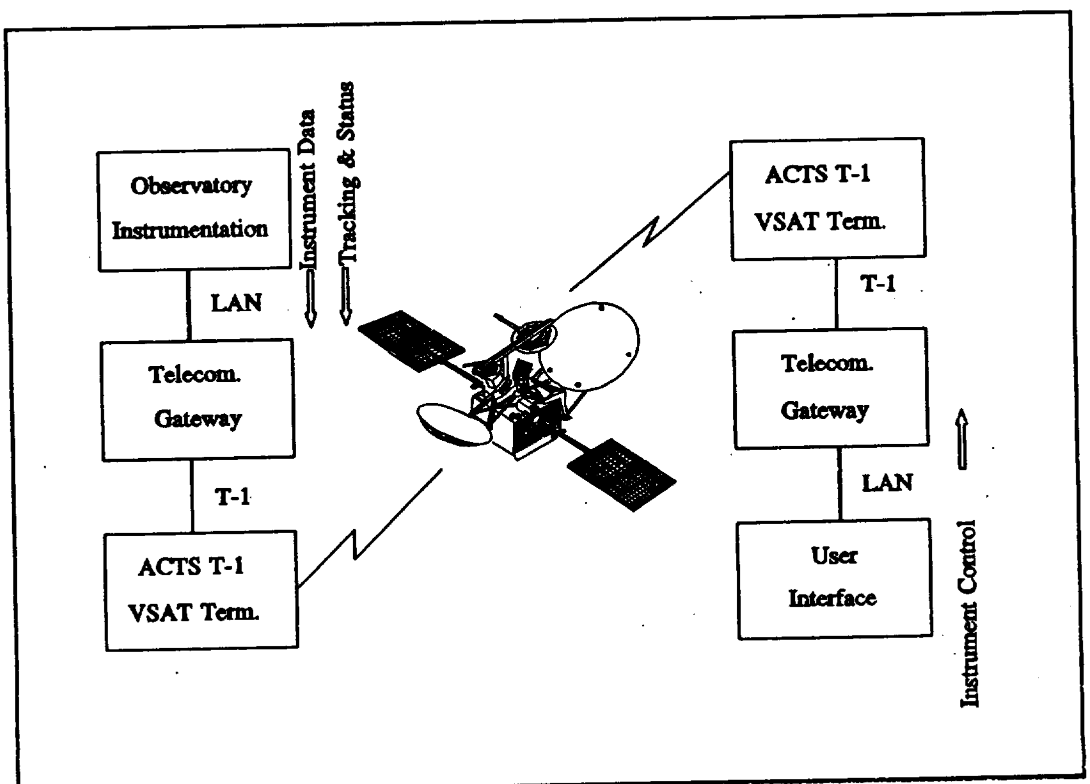

Figure 2 - Observatory Data Network Through the ACTS.

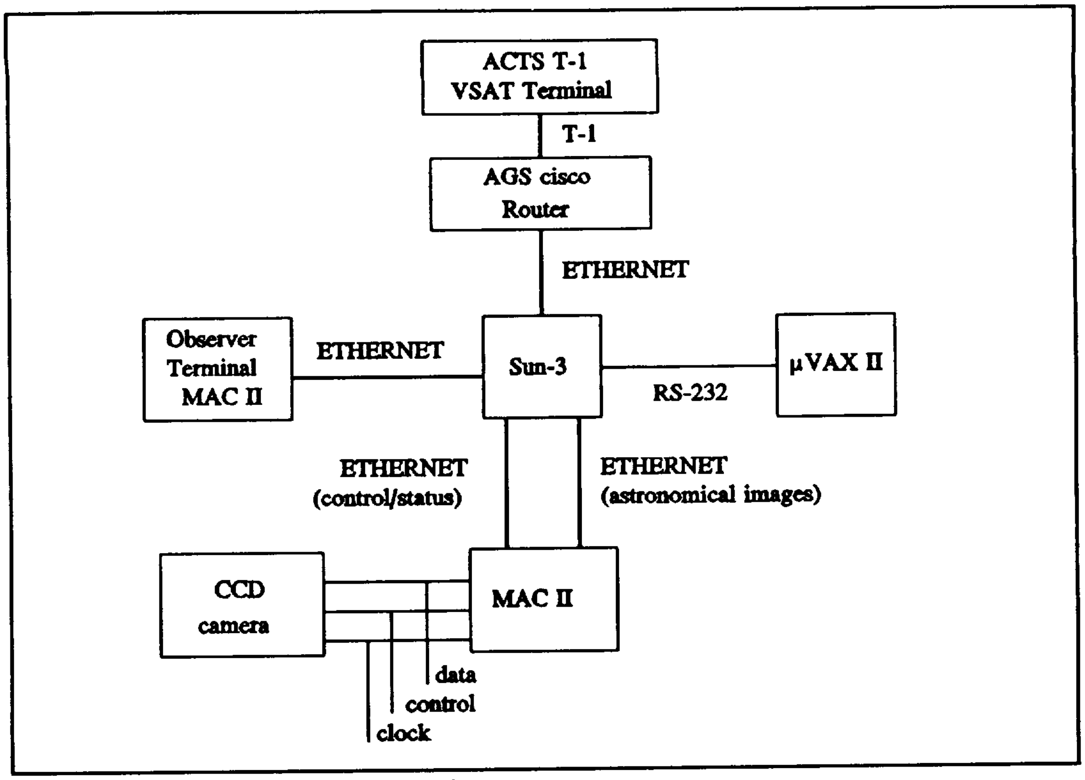

Figure 3 - Internal APO Network

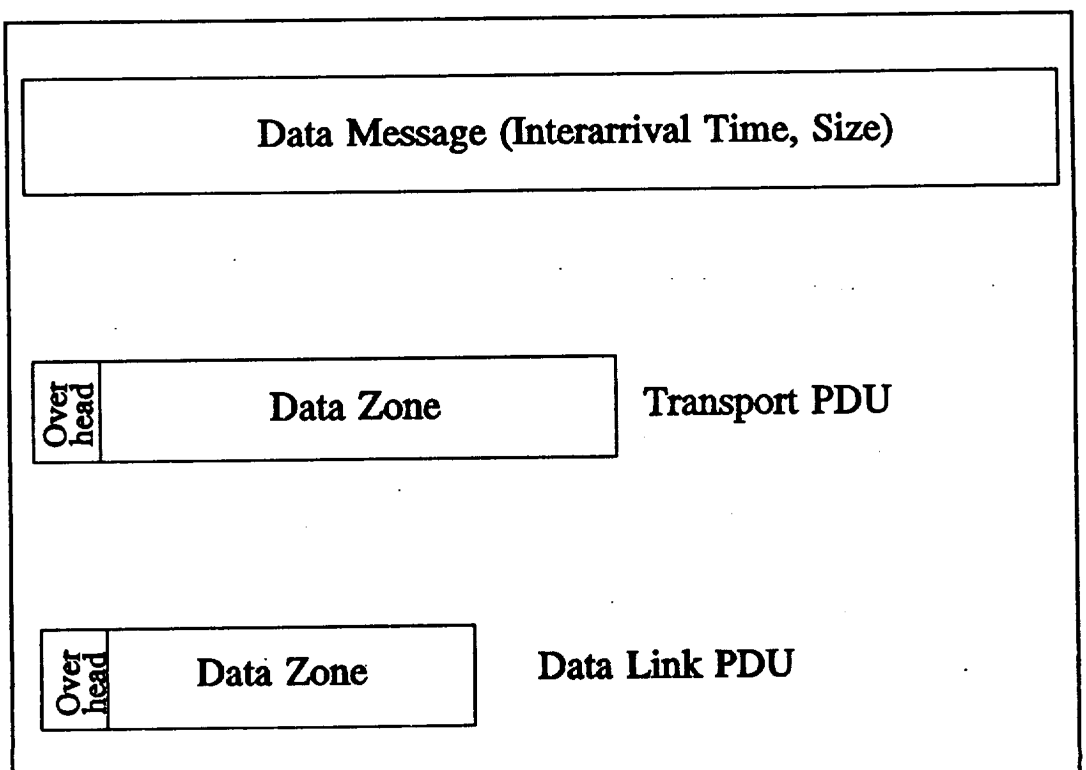

Figure 4 - COMNET PDUs

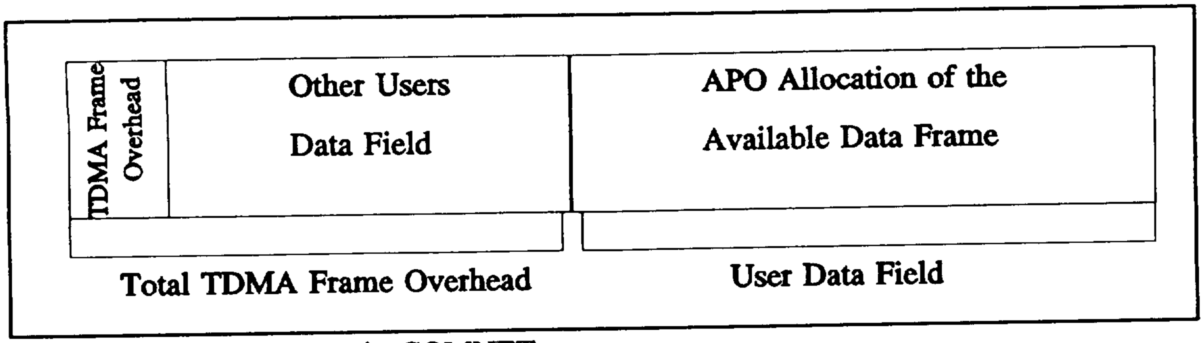

Figure 5 - TDMA Frame in COMNET

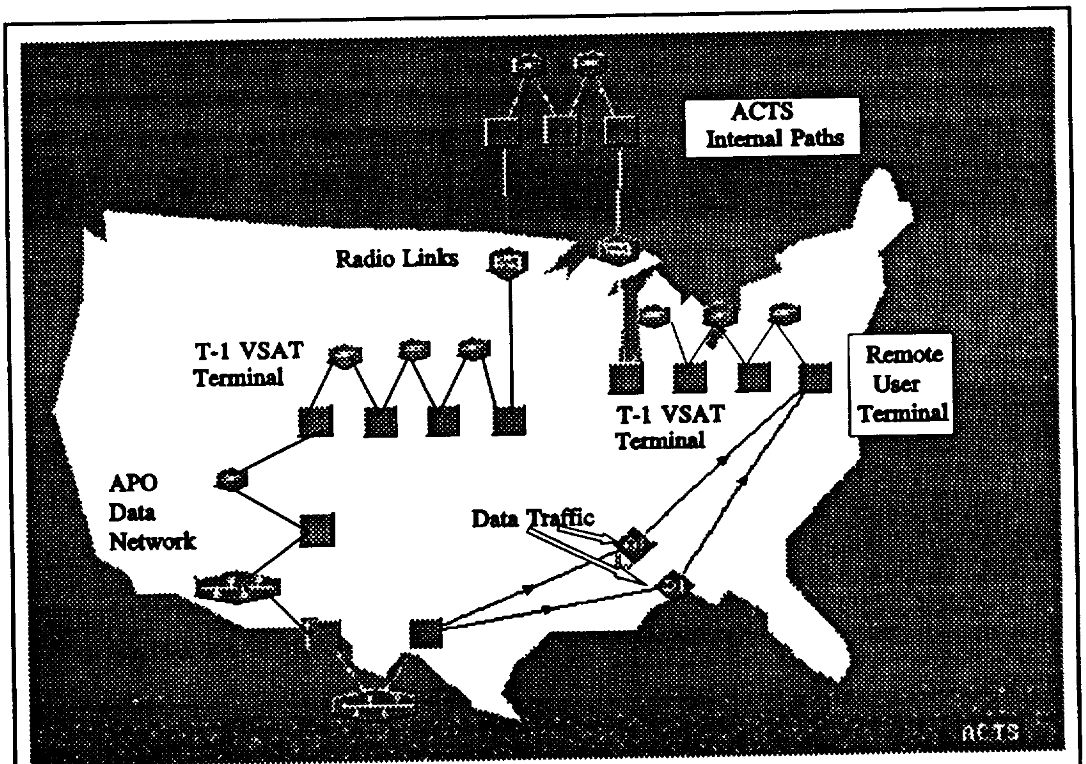

Figure 6 - End-to-End Comnet Model

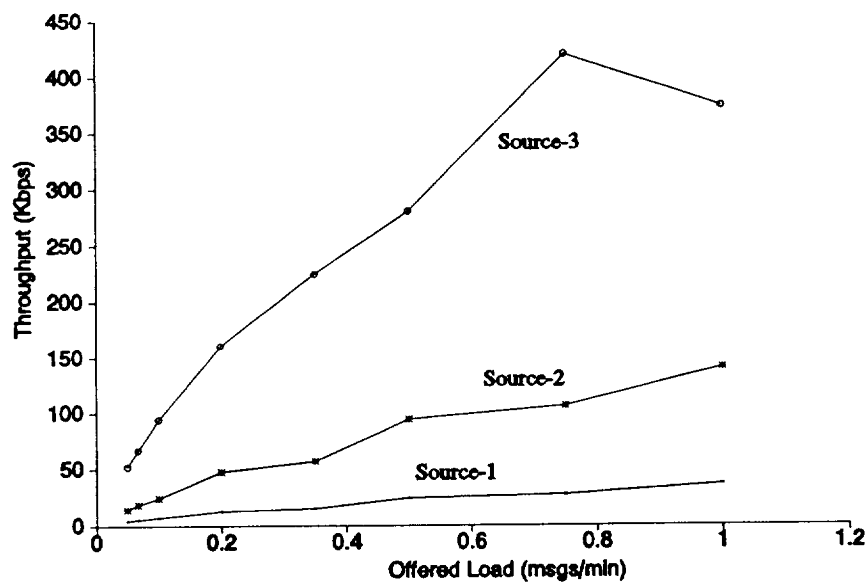

Figure 7 - End-to-End Throughput as a Function of Source Load

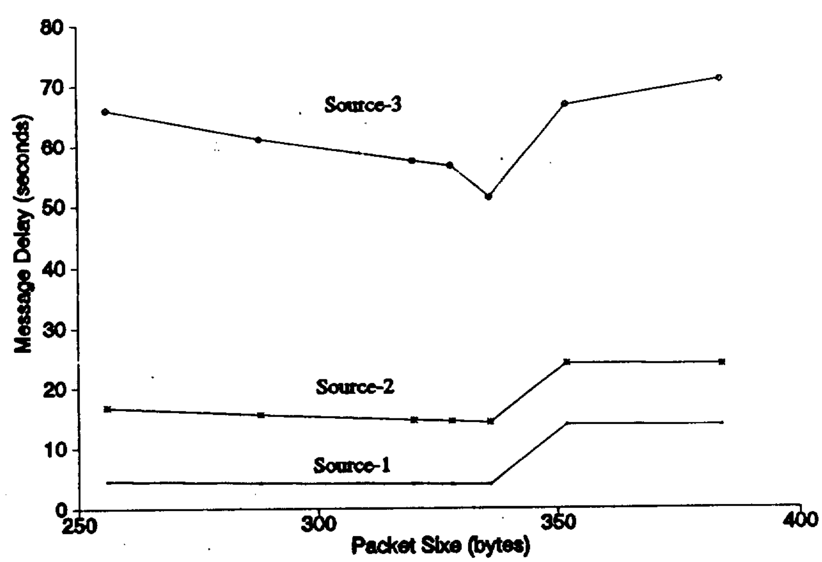

Figure 8 - End-to-End Message Delay as a Function of Packet Size

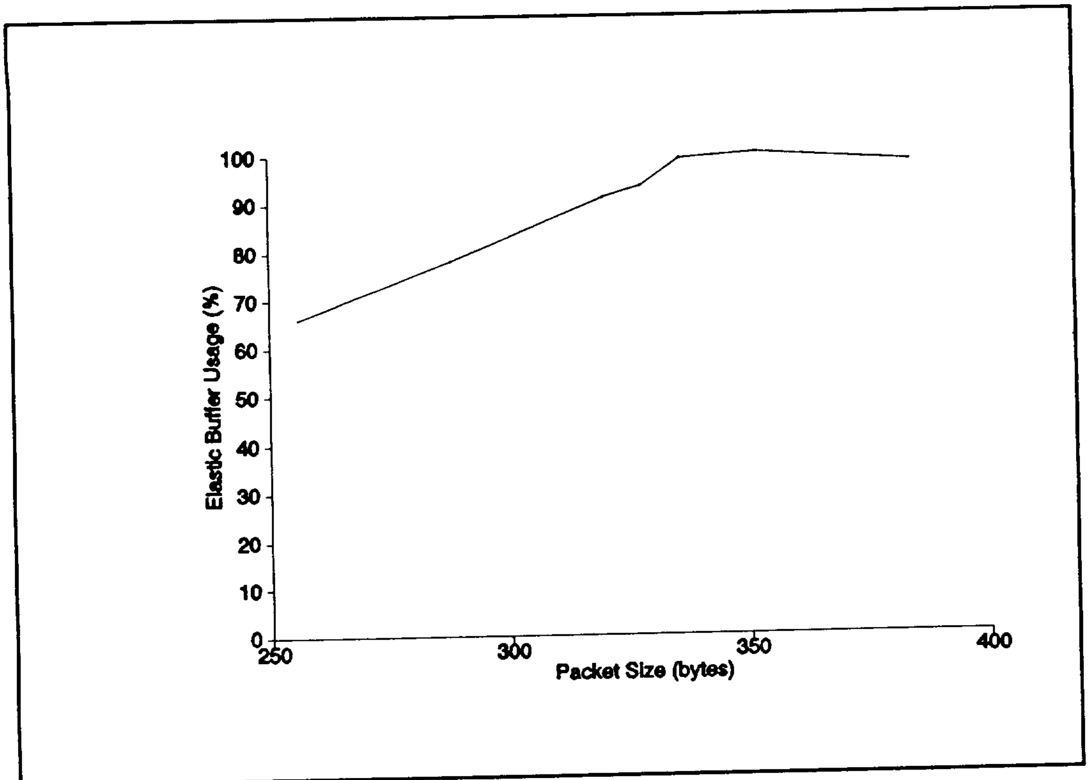

Figure 9 - Buffer Usage as a Function of Packet Size

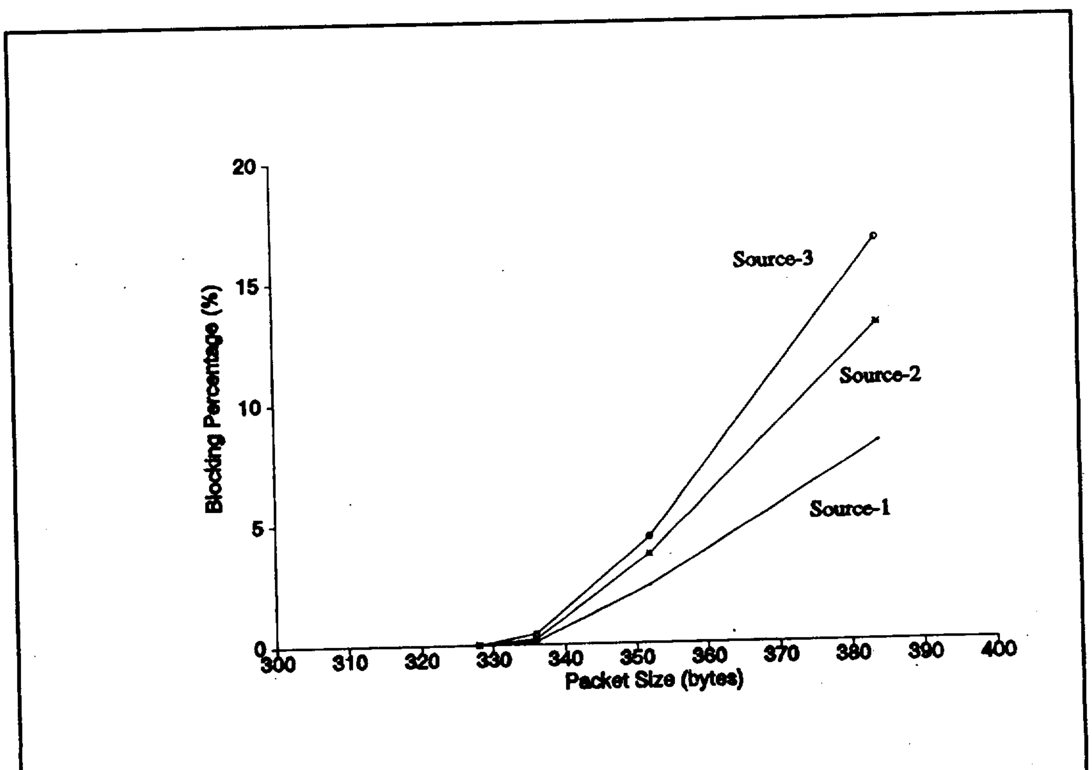

Figure 10 - Packet Blocking Percentage

SECTION II. USE OF THE ACTS WITH THE APACHE POINT OBSERVATORY

The Apache Point Observatory Communications Networks

Apache Point Observatory:

The Apache Point Observatory (APO) runs a Ethernet (10MHz) local area network among the principal operations computers. An Appletalk network is used to connect printers and about eight peripheral Macintosh computers. A Shiva Fastpath-4 provides gateway services between the AppleTalk and Ethernet networks. The observatory presently operates two SUN 3/260 machines, one of which is the principal operations computer; it is this device which communicates with the individual computers which more directly control the telescope, instruments, and other observatory systems. The latter group includes Macintoshes of various sorts, MicroVaxes, and PC-based machines.

Remote Connections:

Apache Point Observatory is currently linked to the institutions of the Astrophysical Research Consortium (ARC) and other remote observers via the NSFnet backbone. There is a dedicated T1 link between APO and the New Mexico State University (NMSU) campus in Las Cruces, New Mexico. Connection between NMSU/Las Cruces and the University of New Mexico (UNM) in Albuquerque, New Mexico, is via 1/3 of a dedicated T1 line supplied by New Mexico Technet. A full T1 line extends from UNM/Albuquerque to an NSFnet gateway at UCAR in Boulder, Colorado. The NSFnet backbone is presently of T3 capacity. All of the ARC institutions but one maintain T1 connections to the NSFnet backbone; Washington State University has a 56K connection.

Sacramento Peak Solar Observatory:

The National Solar Observatory at Sacramento Peak, New Mexico, (SPO) is only two kilometers from Apache Point Observatory. Their external communications are presently via a 56K link through APO. They will shortly be acquiring a 56K direct link to the Jet Propulsion Laboratory in Pasadena, California, with line and associated equipment to be supplied by NASA NSInet. The existing 56K APO-to-SPO line and hardware will then be used to provide a faster link between the two facilities. This will provide alternative back-door communications links for both observatories.

Reliability:

The first formal tests of network reliability were performed in July 1989 at which time the APO-NMSU link was of only 56K capacity. First-try connectivity success rate between APO and NMSU was then about 98%. A 70% rate between APO and Princeton University was the poorest performance. These results are based upon large file transfers made at random times during the day. The few interruptions were brief. (A one-day communications loss did result from the interaction between the T1 fiber cable near Albuquerque and an overzealous backhoe operator.) Science operations at the observatory began in April 1991 with over 90% of operations being conducted remotely. We have had no problems with remote operations due to the network being down nor have we had problems with slow or noisy connections.

An ACTS Connection:

The ACTS Experimenter's documentation is somewhat vague when describing of the options, protocols, and physical connections available to the experimenter. It does appear that the simplest method of connecting an ACTS earth station to current APO computers and communications devices would be to treat the earth station as just another T1 line. The only new equipment required at APO (other than the earth station itself) would be a new interface board for the Cisco gateway and a CSU/DSU line interface. ACTS would then be treated as just another network link available to APO users. A shortcoming of this approach is that it would limit us to using the Internet protocols.

An increased capacity might provide the ACTS system with a competitive edge over the present (essentially) T1 system with its heavy traffic load. This would require more substantial upgrades in the interface electronics at both the observatory and the ARC institutions.

The principal advantage of an ACTS link is that it would allow single hop communications between APO and the ARC institutions. The present arrangement typically requires about eleven. Transmission times would probably be appreciably reduced. On the other hand, the earth stations themselves represent hardware systems which must be maintained by observatory or institutional personnel whereas the present links are largely maintained and supported by others. Moreover, the reliability of the ACTS connection cannot be appreciably better than the present value of esentially 100 percent.

External Communications Tests

Procedures:
Tests of different link configurations were made by measuring round-trip transmission times between Apache Point Observatory and the various institutions of the Astrophysical Research Consortium (ARC). This was done with the UNIX command "ping." One hundred individual packets, each of 1000 byte length, were sent. The average single-packet round-trip travel time was then computed. This was done on three occasions for the three different link configurations described in the following section. The results, for each ARC institution and for three link configurations, are tabulated below under the heading "Transmission Time Results."

System Configurations:
Prior to 15 May 1992 the external links between Apache Point Observatory and the various institutions consisted of the following segments:

• A 56K dedicated commercial telephone line between Apache Point Observatory and New Mexico State University in Las Cruces, New Mexico. This contained twisted-pair, microwave, and fiber-optic components.

•One-third of a dedicated T1 link was provided between NMSU/Las Cruces and the University of New Mexico in Albuquerque, New Mexico, by New Mexico Technet.

•A dedicated T1 line links UNM/Albuquerque and UCAR in Boulder, Colorado.

•Connection to the NSFnet backbone is made at UCAR/Boulder. This backbone was T1.

•With one exception, the universities of the Astrophysical Research Consortium are connected to NSFnet with T1 capacity. Washington State University has a 56K connection. We also have data for Yerkes Observatory which is connected to NSFnet by way of a 56K link to the University of Chicago.

Results for this initial configuration are given in the column headed "56K/T1" in the table.

The Apache Point to NMSU link was upgraded to full T1 capacity in mid-May of 1992. At this point the principal "bottleneck" in terms of line capacity was the 1/3 T1 connection between NMSU/Las Cruces and UNM/Albuquerque for most institutions and the 56K link for WSU and Yerkes. Times for this upgraded configuration are in the column headed "T1/T1" in the table.

The NSFnet backbone was upgraded to T3 in late May, 1992. Subsequent transmission time tests gave the results included in the table under the column headed "T1/T3." The present capacity bottlenecks in the configuration are the 56K segments for Washington State University and Yerkes Observatory or the 1/3 T1 NMSU/Las Cruces-to-UNM/Albuquerque connection for the other institutions. This last link is scheduled to be upgraded to full T1 capacity in late summer 1992.

Transmission Time Results:

University	Average Round-Trip Time (ms)		
(Machine Address)	56K/T1	T1/T1	T1/T3
University of Chicago (oddjob.uchicago.edu)	572	259	121
University of Washington (phast.phys.washington.edu)	601	295	332
Princeton University (astro.princeton.edu)	611	363	148
New Mexico State University (hubble.nmsu.edu)	327	40	30
Washington State University (beta.math.wsu.edu)	925	929	645
Yerkes Observatory (otto.yerkes.uchicago.edu)	882	602	446

Analysis:
The three sets of measurements were made at different times so the tabulated results reflect not only line capacities but also the effect of traffic levels at the time of the tests. The Apache Point-to-NMSU link, for example, does not make use of the NSFnet backbone so the difference between the tabulated 40ms and 30ms entries for NMSU is largely attributable to traffic differences over the APO-to-NMSU T1 line. However, certain general trends are apparent:

The first upgrade, of the APO-to-NMSU link from 56K to T1, gave a major improvement for traffic to NMSU. The improvement factor for those other institutions with T1 connections to the NSFnet backbone was about a factor of two. This was not as great as for NMSU since the configuration linking these institutions was at least partly limited by the 1/3 capacity T1 NMSU-to-UNM link (plus traffic level effects on subsequent segments). We anticipate transmission times might be reduced by as much as 50% once this segment is upgraded to full T1 capacity.

The NSFnet backbone is heavily used and its upgrade from T1 to T3 produced reductions of roughly 40% in typical transmission times. This was true even for those connections with a final 56K connection.

APO User Interface

We have implemented a Graphical User Interface (GUI) to the Apache Point Observatory on a Macintosh computer. Figure 1 shows a particular layout of the Macintosh GUI currently used for APO. Shown are the telescope status display, the telescope control panel, the CCD camera control panel, a returned image and its histogram, a satellite image, a UNIX-like 'talk' window, and a source selection window. Thumbwheel controls accept both typed or mouse driven entries; menu selections open up alternate windows and configuration dialogs, select instruments, and handle image storage and retrieval; control buttons, when clicked on by the mouse driven cursor, issue the appropriate commands (in protocol) to the MC. Each user may uniquely configure the layout to fit his screen space, save frequently used settings, and store the configuration into a personal file. In this manner the same program may be molded to fit most users' preferences.

On-line help is available for most functions in the form of Apple's Balloon Help facility.

Figure 1. The APO User Interface

Figure 2 shows the telescope display and control panels. The Telescope Position graph in the upper right displays the current position of the telescope as a dark circle in an altitude and azimuth polar plot. As an example of how the GUI gives continual feedback during a telescope move, consider the case in which the user has entered a coordinate in the lower left thumbwheel boxes. The destination position of the telescope appears as a gray circle. After the user hits the 'slew' button, the timer in right of the display counts down to show the time remaining for the move and the dark circle gradually moves to the destination position of the gray circle. In this manner the user is kept informed while the entire telescope and enclosure rotate to the desired location.

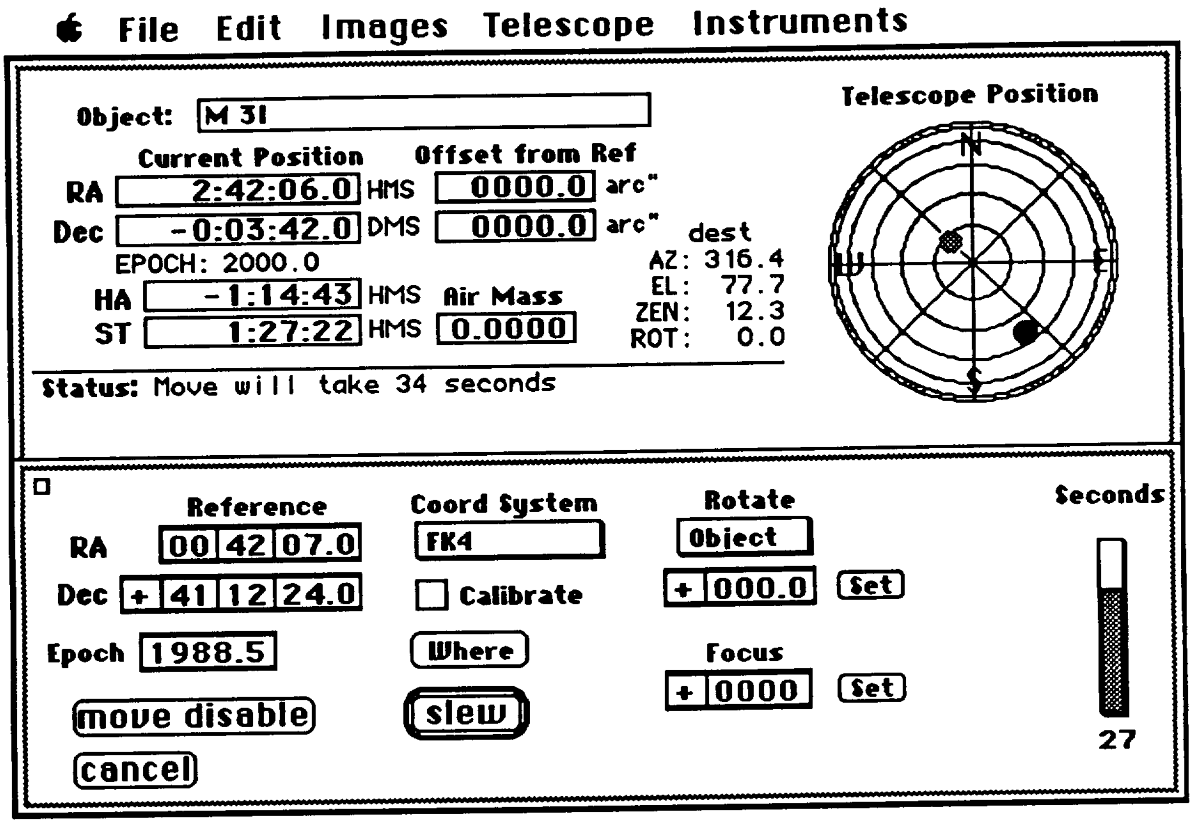

Figure 2. The Telescope Control Panels

Various camera functions may be selected and executed using the CCD camera control panel shown in Figure 3. Like the telescope panels, the user is kept informed during an operation: the figure shows that 22 seconds have elapsed into an exposure, with the circular 'clock' ticking away as well as the digits in the elapsed time display.

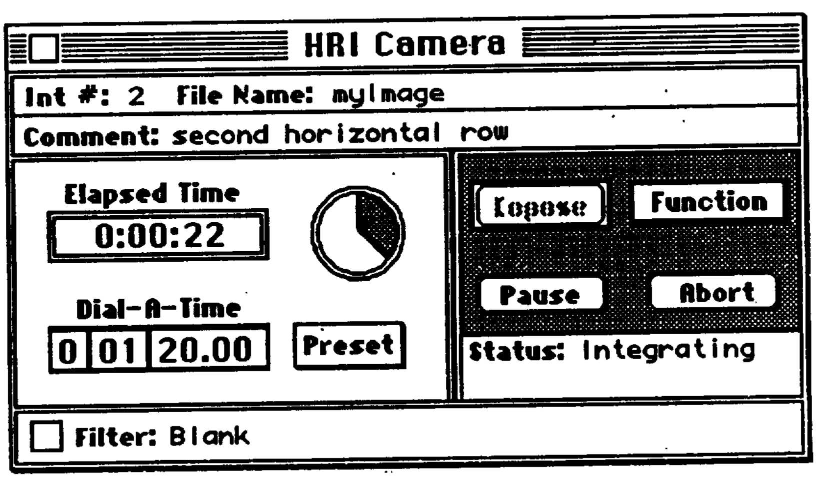

Figure 3. The CCD Camera Control Panel

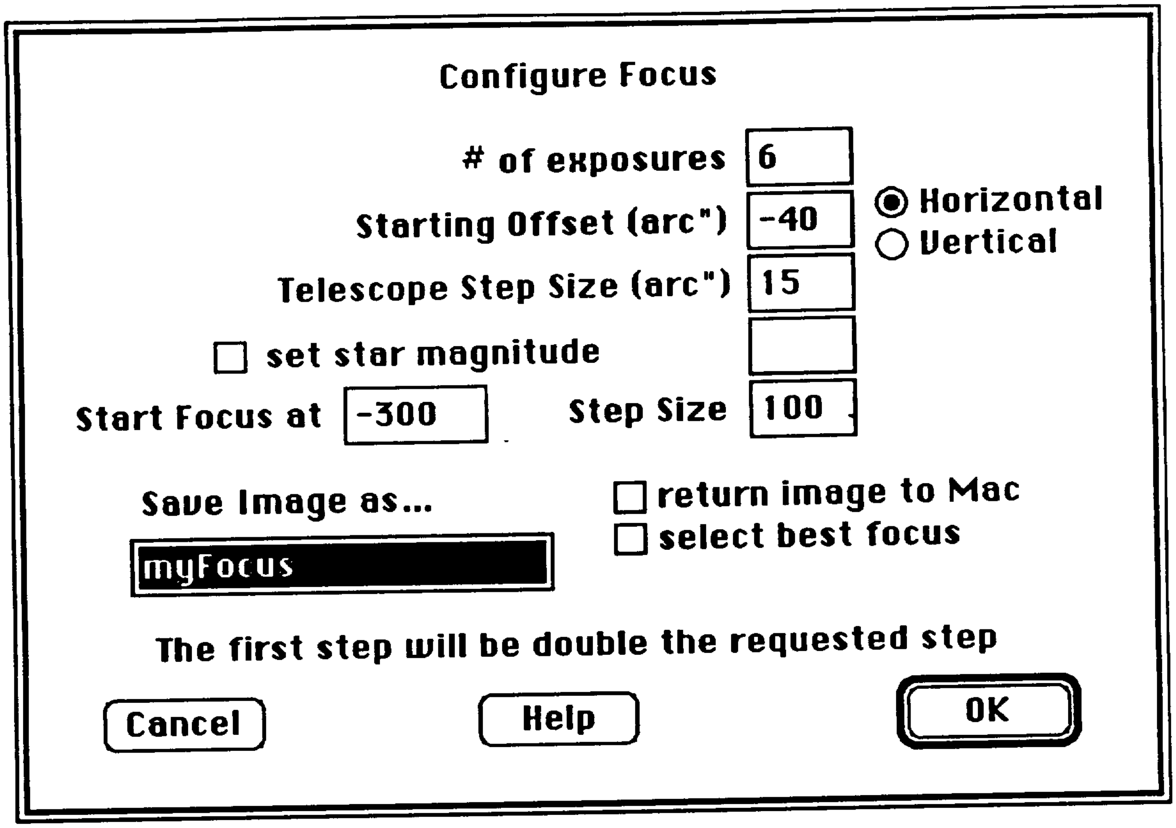

Figure 4. The Focus Configuration Dialog Window

Certain type of orchestrated commands, those that require actions by several instruments, are set up using dialog windows. Figure 4 shows the example of a Focus command coniguration. Here six exposures will be taken at six different focus settings, starting at -300 and incrementing by 100 for each exposure. The CCD chip will be read out at the end, so a multiple exposure of the six images will be saved to disk as 'myFocus.' The telescope initially offsets by -40 arc seconds, and moves 15 arc seconds for each exposure. When the focus command is finally issued to the telescope, the information included in this dialog will be used to create the appropriate string of commands.

This interface has grown out of several predecessors developed to investigate how GUI's may be applied to a telescience environment.[1,2] In all implementations, the interfaces have reduced learning time and casual users are brought up to speed very quickly. In evaluating these previous interfaces and the one outlined here, we have identified certain requirements that we feel are desirable:

1. Easy to learn and use
2. Intuitive and obvious
3. As modeless an environment as possible[3]
4. Timely and meaningful feedback
5. Audible as well as visual cues
6. Minimal required keyboard use
7. Control Panel Simulation within a GUI
8. Keep things uncluttered

The GUI can create a direct analog to the real device that one is controlling. This type of representation aids the user in thinking about the device and its actions rather than a program and its actions. In addition to being easier to learn and use than a command language, the GUI also reduces the amount of typing required. Typing a command, particularly one that is long, requires knowledge of the language and syntax, as well as an extra thought process to translate what is to be done into words; also there is always the risk of typographical errors. For power users, the GUI has a facility where any command may be typed in the UCL if so desired.

Displaying too much information can be confusing. Rather than supplying all status of all subsystems, only that information which is necessary should be displayed. If a warning situation occurs, an alert window with an audible alarm could be automatically brought up to explain the situation.

The Macintosh GUI provides quick-look, simple methods of data assessment and reduction. More complex reductions can continue in parallel using other hardware (VAX, SUN, etc.) and software (IRAF, AIPS, SAOIMAGE, etc.). As images are returned to the Macintosh, they may be routed over a local ethernet to the data reduction computer, they may be simultaneously FTP'd from the site, or they may be sent from the site at a later time.

The software is an evolving entity and certain aspects of the GUI will undoubtedly change to address the various users' suggestions as we learn how the telescope and instruments are best used in a remote situation.

References:

1. R. F. Loewenstein and D. G. York, *Proceedings of the SPIE*, **627**, ed. L. Barr, (SPIE 1986) p. 162.
2. R. F. Loewenstein, *Wheels for the Mind*, **4**, ed. P. Olivieri (Boston College 1988) p. 59.
3. L. Tesler, *Byte*, **6**, (McGraw-Hill 1981) p. 90.

Kurt S. J. Anderson
4 June 1992

Remote Observations at APO

1: STANDARD HARDWARE

The standard hardware at a remote observing facility consists of a Macintosh II computer with one or two monitors for display. The computer will usually be in communication with the system at Apache Point Observatory through the NSFnet backbone. The connnection at the observatory is through the machine named kepler . Its address is "kepler.apo.nmsu.edu"

The Master Computer (MC), kepler, is a SUN 3/260 which speaks to the Telescope Control Computer (TCC, a MicroVax) and the various Instrument Control Computers (ICC's). The ICC for the High Resolution Imager, for example, is a Macintosh II.

It is assumed that the user is familiar with basic aspects of the Macintosh interface, particularly mouse/cursor operations such as selection by clicking, opening by double-clicking, click-and-drag operations for moving windows and icons, traversing menus and sub-menus, and the like. Window are rendered active by clicking on them and many are provided with a close box. Windows with title bars can be moved to convenient locations on the screen by clicking and dragging. Many windows of the remote interface are provided with **Help** buttons; additional information can be obtained by invoking the **Balloon Help** facility of System 7.0. Beginning users of the remote observing interface are strongly encouraged to make use of these aids.

2: LOGGING ON REMOTELY

Logging On

First contact the observer/operator at the site for observatory status information and for permission to to log on remotely. It might be wise to ensure that no one else is connected. The observer/operator must, in any case perform certain tasks such as opening the enclosure before you can begin observing. When your Macintosh is booted up, double-click on the icon corresponding to the latest version of the remote observing program. It is currently "Remark 1.80". This will presumably reside in a remote observing file of some sort on your Macintosh hard disk. The menu bar across the top of the screen should then read:

** File Edit Telescope Instruments**

(If it reads something else just click on one of the displayed windows)

A number of windows should appear on your monitor below this menu bar:

>a TELESCOPE POSITION window gives right ascension (RA), declination (DEC), hour angle (HA), sidereal time (ST), and air mass. The window includes a graphic display of telescope position. The epoch of the equatorial coordinates plus current values of altitude, azimuth, zenith angle, and image rotator angle are also shown.

>a SLEW CONTROL window into which you will enter positional information, set image rotator angle, and from which you will issue commands to move the telescope.

>a TESTER "paddle" with various commands on it. This is a temporary feature. It is principally used is to request the display of images stored on disk. Time updates can also be requested; responses are displayed in the DEBUG window.

>a DEBUG window in which debugging information will be printed if a program problem arises. This window also contains information about program options which you may have selected and gives requested update information on times, weather, position, etc.

Opening Communications
In order to start the observing session, you need to open communications with the Master Computer. Move the cursor to the **File** menu and hold the mouse button down. Drag the cursor down to **Communications...** and then release the mouse button. (Alternatively, simply type **#U**). In the dialog window that appears you may insert your **User Name**. The buttons for **Network** and **MC Main** should be 'on' while those for **Modem** and **MC Backup** should be 'off'. Now click the **Hang Up** button; in the TRANSCRIPT box you should see the message:

```
The specified TCP stream is not open
```

Now click the **Connect** button. You should get the following responses:

```
reconnecting
reconnecting
mc establishing callback connection
ok, you're connected
```

An audible tone accompanies the last line. At this point you should click the **OK** button. The dialog window will vanish, and a window will appear giving current warnings and observatory status informations. This can be closed with its **OK** button.

If connection fails, you might get messages like:

```
The network came up halfway and died.
The net might be down.
```

If this happens, try **Hang Up** followed by **Connect** again. If this does not work, try quitting the remote program and restarting it. It is generally a good idea to begin any reconnection attempts with a **Hang Up** request, particularly if communications were interrupted by a crash of the remote Macintosh. It this also fails, call the observer/operator for assistance.

Subscriptions & Sequences
You should now subscribe to the various message windows. To do this, pull down the menu under the **File** heading and choose the **Messages** and **Monitor** options under the **Subscriptions** menu item. Two new windows with these names will appear. (Windows with title bars can be dragged to convenient locations on your monitor with the mouse and cursor.)

You may talk to other users or to the on-site observer using the MESSAGES window. To do so, move the cursor to the window, click, and then type your message with a <return>. A "beep" will indicate that the message was sent; a copy will appear in the bottom half of the MESSAGE window. Incoming messages will appear here. (Both can also be read in the MONITOR window.)

The MONITOR window displays a text version of the commands (or messages) you issue from the interface.

You may also have certain time-varying parameters updated regularly. To accomplish this, go to the **Sequences...** entry under the **File** menu. A DATA TIME SEQUENCES window will appear. You may choose to have any of the items in this window (**Weather, Guide Images, Time, Position)** regularly updated by clicking on their corresponding boxes. For each entry you select a box will appear into which you should insert an update interval.

3: CONTROLLING THE TELESCOPE

Moving the Telescope
The items under the **Telescope** menu are:

Slew Control
Offset Control
Tweaker
Special Moves>
....
Get Catalog...
....
Star Plots

Either **Slew Control** or **Offset Control** will be selected, as indicated by a check mark, and the corresponding SLEW CONTROL or OFFSET CONTROL window will be opened. (You can also switch between these windows by clicking on the small boxes in their upper left-hand corners.)

The SLEW CONTROL window contains boxes for inserting telescope pointing positions, setting the focus, and orienting the image rotator. Move the cursor to the window and click to make it active. To enter positions, you first choose a coordinate system. A click on the box gives you a pop-up menu of choices (**FK4, FK5, Geocentric, Engineering**). Positions (with their epochs) can be entered one of three ways:

1. You can use the cursor as a thumbwheel control: Place the cursor just above (or below) the digit you wish to raise (or lower). The cursor changes to a downward (or upward) pointing arrow when properly positioned. Depress the mouse button to make the indicated digit change. (To set thumbwheel speed, go to **Preferences** under the **File** menu.)

2. You can enter values from the keyboard: Select the box by clicking and dragging with the mouse and cursor. Type coordinate values using tabs as spacers. A format example for right ascension is: HH<tab>MM<tab>SS.S (Subsequent <tab>'s would then move you through the corresponding boxes for declination, coordinate epoch, rotator angle, and focus.)

3. Values can be entered from a previously constructed list: To do this, click **Get Catalog** under the **Telescope** menu. This gives a SELECT OBJECT window containing a list of objects. You may select among alternative lists from this window. An object on the list is then picked by clicking on it. A click on the "Apply" button then enters this object's coordinates (with epoch) into the SLEW CONTROL window and its name in the **Object** box of the TELESCOPE POSITION window. If you are a confident sort, you can click the "Select" button instead; this has the same effect as "Apply" but also causes the SELECT OBJECT window to close. The catalog or list is a named text file, with entries in the format:

object_name<tab>HH<tab>MM<tab)SS.S<tab>dd<tab>mm<tab>ss.s<tab>epoch

Entries are separated by a <return>. The object_name is any alphanumeric string of characters. "HH" and "MM" of the right ascension, and "dd" and"mm" of the declination, are integers while" SS.S", "ss.s", and "epoch" are decimal entries. Only the degrees entry (dd) has a sign.

To point the telescope to the entered coordinates, click the **move enable** button (it will then read **move disable**) to activate the **slew** buttons in the SLEW CONTROL window. Then click on **slew**. An indicator in the right of the window will indicate the time required and remaining to accomplish the position change. Telescope positioning during the slew will be graphically indicated here and in the TELESCOPE POSITION window. When the move is completed the coordinates will appear in the TELESCOPE POSITION window and and the words "move complete" will be heard.

Note that the Main Computer (MC) updates catalog coordinates to the present epoch.

Focus and image rotator angle can also be set from the SLEW CONTROL window. Desired values can either be typed directly into the appropriate boxes, after selecting the box with the cursor and mouse, or by using the cursor as a thumbwheel control. Rotator angle can be in either **Object** or **Horizon** coordinates; the box just below the word **Rotate** indicates the implementation. A pop-up menu appears when you click on this box and permits you to switch between these options. With the **Object** option the instrument rotates to maintain a fixed orientation with respect to equatorial coordinates as projected on the plane of the sky. In

Horizon the instrument orientation is fixed in angle with respect to the horizon. Normally one uses **Object**-based rotation for imaging. **Horizon** might be used in spectroscopy to place the atmospheric dispersion along the slit.

Checking the **Calibrate** box in the SLEW CONTROL window causes the telescope to move to an FK5 star close to the desired final position, center it, establish a coordinate correction, and then go to the desired position with that correction applied.

Finally, clicking the **Where** box in the SLEW CONTROL window updates the quantities displayed on the TELESCOPE POSITON window.

Selecting **Offset Control** under the **Telescope** menu, or clicking the small box in the SLEW CONTROLwindow, gives the OFFSET CONTROL window. In this window the user can offset the telescope's position from the coordinates given in the SLEW CONTROL window. The type of offset may be **object** coordinates (in right ascension and declination) or **instrumental** coordinates (X and Y on the HRI detector, for example). The offset type is selected from a pop-up menu that appears when one clicks on the **Offset Type** box and is indicated in that box. Offsets in equatorial coordinates are in seconds of arc both for right ascension (RA) and for declination (Dec). Positive offsets correspond to motions eastward and northward on the sky, respectively. The X and Y offsets in instrumental coordinates depend on the instrument. For the HRI they correspond to motions along rows and columns, respectively, on the CCD chip. These motions are also measured in arcseconds. To apply the specified offset, click on the **offset** box.

Offsets can be absolute (**abs**) or relative (**rel**) depending upon which of these buttons is "on". Absolute offsets are always relative to the reference position given in the SLEW CONTROL window. If you request/apply the same absolute offset a second time, the telescope will not move since it has already applied that offset to the reference position. Each request for a relative offset, on the other hand, moves the telescope the specified offset amount from its present position, whatever the original reference position. This feature is used if you wish to move stepwise off in some direction in sky or instrument coordinates. The actual pointing direction of the telescope, including offsets, is always given as **Current Position** in the TELESCOPE POSITION window. This is updated after every motion. The reference position is always given in the SLEW CONTROL window.

The **Tweaker** can be selected from the **Telescope** menu. It acts like a manual "slow motion" paddle. As long as the mouse button is held down in in one of eight particular directions, the telescope will move in that direction at a constant velocity . This feature is not intended to be used remotely, since there is no visual feedback.

Selecting **Special Moves** under the **Telescope** menu produces a sub-menu with three selections. They are:

>Move To nearby FK5 Star: The telescope does just that. An examination of the field can then be used to give pointing accuracy information.
>Recalibrate: Moves to a nearby FK5 star, centers, determines coordinate corrections, and then returns to the previous coordinate setting having applied the correction. This correction is retained in subsequent moves of the telescope.
>Home Telescope: This moves the telescope to its parked position. (azimuth =100.8°, elevation=+6.0°). An audible "move complete" indicates the telescope has successfully homed..

4: CHOOSING AND OPERATING AN INSTRUMENT

Instrument Choice
The **Instruments** menu offers the following selection:

HRI
Echelle
GRIM

Guider

Weather Window

At present, only the first and last of these are implemented. Selecting **Weather Window** produces a small window which gives current weather information. This can be updated by clicking the appropriate box or can be set to update automatically at regular intervals.

The High Resolution Imager (HRI)

Go to the **Instruments** menu and select **HRI.** A new entry, **HRI**, will appear on the menu bar. Under it you will find:

Camera Control
- - - - - - - - - - -
Filters...
Exposure...
Focus...
Image Xfer...

Camera Control

A click on **Camera Control** will give you the HRI CAMERA window . Into this window you can enter a **File Name** for the image. There is also space for a **Comment** which will go in the resulting image header. In this window you also select the type of exposure, and the exposure time. One box gives the status of your exposure (once you've initiated it) while another tells you which filter is in place.

Exposure Time

Exposure time is set using the **Dial-A-Time** boxes; the format is hh mm ss.s. Times can be entered in three ways. First, you can use the boxes as a cursor-operated thumbwheel (as was done for setting telescope coordinates). Second, you can enter a time from the keyboard, using <tab> to move from hours to minutes to seconds. Third, you can select from a list of five preset integration times. To do this, click on the **Preset** box and make your selection from the resulting pop-up menu. Selecting the last entry in this menu, **Set Presets...**, gives another window within which you can alter the choices of preset times.

Exposure Type

Clicking on the **Function** box results in a pop-up menu offering the following choices:

Expose
Focus
Dark
Flush
Flat
Send

Only the first three are highlighted and available.

Expose starts the exposure sequence with a preset number of flushes of the chip. The shutter is opened for the preset exposure time then closed. The image is then read out. Various conditions on the exposure and subsequent processing of the image are set using the window obtained by selecting **Exposure...** from the **HRI** menu. See below.

Focus initiates a series of exposures, at the preset exposure time, accompanied by motions of the telescope and changes in the focus setting. Images on the resulting multiple exposure can then be examined to select the best focus. The details of telescope offsets, focus steps, and the like, are set in the window obtained by selecting **Focus...** from the **HRI** menu. Again, see below.

Dark is identical to **Expose** except the shutter is not opened. This option is used to get frames from which the dark count and bias levels can be ascertained

Filters...

Selecting **Filters...** from the **HRI** menu gives a SELECT FILTER window describing the filter choices available. A **Help** box explains the various command options. Ordinarily you would **Re-Init** (reinitialize) the filter controller only at the beginning of your run and an **Update** wouldn't be required unless you changed filter sets subsequently. **Reset** is used only when something gets hopelessly fouled up. Usually all you have to do to implement your filter is to click the appropriate filter's button and then the **Move** box. The filter presently in place is also indicated in the HRI CAMERA window.

Exposure...

In the CONFIGURE EXPOSURES window, obtained from selecting **Exposure...** under the **HRI** menu, you set the principal characteristics of the exposure and the reduction steps which might be applied to the image(s). Only the exposure time and the shutter opening decision are controlled elsewhere (the HRI CAMERA window). The quantities set are:

>**Save Image As...** This is the name of the output image(s). For multiple images a numerical suffix is added to the name you provide in the format "name.1", "name.2", "name.3", etc. This is true for processed images such as means and medians as well. The last image name used is saved as the default name (with incremented numerical suffix) for the next image if no changes are made to the CONFIGURE EXPOSURES window entries. The name inserted here appears in the CAMERA CONTROL window, and vice-versa.

>**Number of Exposures** This is the number of (identical) exposures that will be made and used for any subsequent processing.

>**Number of Flushes** This is the number of flushes performed before each exposure. A flush is a readout of the chip to clear the pixels and registers. This image is discarded.

>**Binning** These are the on-chip binning options. Only the 1x1 and 2x2 options are implemented in the HRI.

>**Bias Image (from disk)...** This is the name of an image from the MC disk which will be subtracted froml images if **debias** is selected from among the **Reduction choices**

>**Flat Field (from disk)...** This is the name of an image from the MC disk by which images will be divided if **flatfield** is selected from among the **Reduction choices. If debias** is also selected, its subtraction will be performed first.

>**FITS Comment...** A comment entered here will be included as part of the FITS header.

>**Reduction Choices**

There are a number of reduction choices which can be applied to individual images of a series as well as to final images derived from the individual images. These choices are:

•median: computes the median on a pixel-by-pixel basis for a sequence of n images. At least three images are necessary. The median is saved as the last image, numbered n+1.

•average: computes the average of n images on a pixel-by-pixel basis and saves the result as the (n+1)- st image.

•debias: subtracts the named bias frame stored on disk from the indicated images. The resultant image replaces the original.

•flatfield: divides the indicated images by the named flat field frame stored on disk. The resultant image replaces the original. This follows bias subtraction if debias is also chosen.

•Save>Tape: writes the indicated images to tape. Not presently implemented.

•Send>FTP: forwards the images to the remote user's address with the ftp protocol.

•Send>Mac: sends the indicated images to the remote Macintosh for display.

Certain combinations are undesirable: You would not, for example want to debias the average of a series of images which had been individually debiased. Similarly, if you only wish to save the average of a series, it is computationally more efficient to debias or flatfield just that final image rather than each of its components.

Focus....

Selection of **Focus...** gives the CONFIGURE FOCUS window in which you set the parameters which will govern the sequence of images taken when you issue the **Focus** command from the HRI CAMERA window. The focussing sequence consists of a number of exposures on a single frame. Both the telescope pointing and its focus setting are changed between exposures. In the CONFIGURE FOCUS window you can insert an image name in the **Save Image As...** box. You also set:

># of exposures: Enter the number of exposures in the sequence (usually 6-12)

>Starting Offset (arc"): The telescope will offset this amount from its initial position (presumably centered on your focus star) before making the first exposure. This entry is customarily negative. If you are centered, this dimension should be somewhat less than the field radius.

>horizontal/vertical: Choose the focus star image to translate either horizontally or vertically on the detector display between exposures of the focus sequence.

>Telescope Step Size (arc"): This is the distance the telescope moves between the second and subsequent exposures. The motion between first and second exposures is twice this value. This entry is generally positive if the starting offset is negtive.

>set star magnitude: A magnitude for the focus star can be entered in the the right box if the left box is checked. A catalog search is performed for a star of similar magnitude in the vicinity of the current telescope position. If the search is successful, the star will be used for a focus star. This feature is not presently implemented.

>Start Focus at: Enter the initial focus setting. Under normal circumstances, best focus will be within a few hundred units of zero.

>Step Size: Enter the focus step size. The focus setting will be incremented by this amount between exposures. An initial value of 50 to100 is about right.

The focus image can be sent to the Macintosh by checking the **return Image to Mac** box. The **select best focus** option is not yet implemented.

Image Xfer

Selection of **Image Xfer** gives the TRANSFER SETTINGS window within which one sets the parameters governing the transfer of images to the remote Macintosh. You can chose to have either 8 or 16 bit images sent. (The TRANSFER SETTINGS window can also be summoned by selecting **Transfer>Transfer Setings** under the **Images** menu.)

The **Shift bits** entry indicates the number of the least significant bits which are not sent when the 8 bit option is selected. If the **Shift bits** entry is **n,** bits **1,2,...,n** are discarded, bits **n+1, n+2, ...,n+8** are sent, and bits **n+9,..,8-n** ar e discarded. A value of 6 seems to be about right for **n**.

Generally **Autoblock** should be checked, and the **delay** set at 0.2 seconds. **Autoblock** causes the image to be divided into blocks for transmission and the **delay** is the interval between transmission of the blocks. The intent is to avoid problems caused by limited line capacity and/or traffic congestion.

If you only wish to transfer part of the image, check **Sub frame**. Boxes will then be highlighted into which you can insert coordinate values which define the rectangular subimage you wish to send. To avoid grief, make sure that the **X lo** and **Y lo** entries are smaller than the corresponding **X hi** and **Y high** values. These entries are in column number for **X** and row number for **Y**.

5: VIEWING IMAGES

In order to see your images that you've taken so far, you can use the TESTER WINDOW. Click on **Image.** This will produce a SELECT FILE window listing the images on the MC disk. With the cursor, select the image you want to display then click the **select** button. The image will appear on the Macintosh screen. A histogram of the image will also appear. (If not, go to the **Instruments** menu and select **Histogram**. See below.) A small COORDS window also appears with the displayed image; as the cursor moves over the image this window will display cursor coordinates (in detector and sky coordinates) plus the pixel value on an 8 bit (0-255) scale.

Most image display is accomplished using the entries under the **Images** heading of the main menu. These entries and their applications are:

Load... is used to display and image currently on the Macintosh disk. Selection of **Load...** gives a window listing the available images. Select an image and click **Open**.

Save As... saves the current (frontmost) image to the Macintosh disk in its existing bits/pixel format. You insert an image name and indicate a save location (i.e. a folder) in the window which appears.

Save As 8 bit...is the same as **Save As...** except that the image is saved in 8-bit format.

Fits Comments... provides a window into which you can enter comments which are added to the fits header either for the current Macintosh image or for a selected image on the MC disk.

View Fits Header provides a window containing the fits header information for the current Macintosh image. If no image is presently opened, a list of available images is presented.

Transfer> gives four options in a sub-menu. **CCD** is used to display images from the MC disk. Selection is made from a list of available images which appears when this entry is selected. **Satellite** gives a listing of weather satellite images available for display. These are stored on the MC and the image names contain the time they were taken. The most recent image is the last one listed. **Stop Transfer** is used to abort an image transfer in progress. Finally, **Transfer Settings...**gives the TRANSFER SETTINGS window described earlier.

Histogram opens a window giving a histogram of pixel values for the current (foremost0 Macintosh image. By using the scrollbar on the right side of the window you can more clearly examine the histogram. The cursor can also be used to drag the vertical dotted lines at either side of the histogram to limit the range of pixel values corresponding to the range of display intensities. Intensities below the leftmost dotted line are assigned a display value of zero, those above the rightmost line a value of 255, and those in between are scaled over the 0-255 interval.

6: TRANSPORTING IMAGES

The Macintosh images are not in a format suitable for AIPS or IRAF; they are only Macintosh readable. The easiest way to get your images down from the site in useable form is to employ IRAF to place them into suitable form and then ftp the images to your home institution. First you will need to log in to the site ("kepler.apo.nmsu,edu") and supply a suitable username and password. Once logged on, you start IRAF by typing cl. The following command sequence will change your images (named" filename" in the example below) to FITS format:

```
kepler% cl
cl>cd /arc/apotop/New/iraf
cl>dataio
da>ls                              (to see the list of images stored on disk)
da>wfits filename filename.fits    (to convert image to FITS format)
da>logout
kepler% logout
```

You can then FTP to the site and retreive your images in FITS format. You first log onto kepler from your machine, with the command "ftp kepler@apo.nmsu.edu" supplying a username and password. To get the image named " filename.fits" requires the commands:

```
ftp>cd /arc/apotop/New/iraf
ftp>binary
ftp>prompt
ftp>get filename.fits
ftp>quit
```

(If you are already in kepler you can send the file to your home institution. First ftp your machine from kepler and then use "put" or "send" instead of "get".)