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THE UTAH-BAS AIRGLOW IMAGING EXPERIMENT

OPERATION MANUAL

by

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Halley V
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The Utah-BAS Airglow Imaging Experiment

1. Introduction

The Utah-BAS Airglow Imager Experiment is a collaborative program between the Physical Sciences Division at British Antarctic Survey and the Space Dynamics Laboratory at Utah State University, USA. Funding for this program is provided by BAS/NERC under the Geospace-Atmosphere Transfer Function (GATF) program and by the US National Science Foundation Office of Polar Programs. The imaging system comprises a rugged solid state CCD camera specially designed to obtain high quality images of faint emissions from the night sky, termed "airglow". The camera system is mounted under a perspex dome in the Optical Caboose which is located about 1 km to the southwest of the Piggott Platform at Halley V. This report contains a description of the experiment, set up and operation of the camera system including some notes on the system components and on trouble shooting.

What is airglow?

Airglow is the name given to naturally occurring light emitted by the earth's atmosphere. There are several prominent airglow emissions arising in the earth's upper mesosphere and lower thermosphere (MLT) region (altitude range 80-100 km). They are caused by chemical reactions between various constituent atoms and molecules which result in the formation of a layer of excited species that subsequently emits light at a characteristic wavelength called an emission "line" or a group of lines termed a "band". For example, the most prominent emission in the night sky arises from the hydroxyl (OH) molecule which is formed by an exothermic reaction between hydrogen (H) and ozone (O3), both of which are present as minor species in the MLT region. The resultant excited OH molecules then radiate light as they return to their unexcited "ground" state. The spectrum of light emitted by the OH molecules is complex consisting of several emission bands extending over the visible and infrared (IR) wavelength interval ~400-4000 nm. This layer of glowing gas envelopes the earth at an average height of 87 km and has a mean thickness of about 8 km. There are several other prominent (but weaker) airglow emissions which also form in layers of similar thicknesses to the OH layer but at different mean altitudes within the MLT region. The following list summarizes these emissions and the filters used by the camera:

Emission	Designation	Emission Wavelength	Layer Height	Filter
Hydroxyl	OH	400-4000 nm (bands)	87 km	715-950 nm
Sodium	Na	589.2 nm (line pair)	90 km	589.2 nm (2.5 nm)
Oxygen	O2	865.5 nm (bands)	94 km	865.5 nm (10 nm)
Green Line	OI	557.7 nm (line)	96 km	Not measured
Background	Bg	572.5 nm (no emission)	-	572.5 nm (2.5 nm)

Note: the numbers in brackets indicate the full width at half maximum (FWHM) bandwidth of the filters.

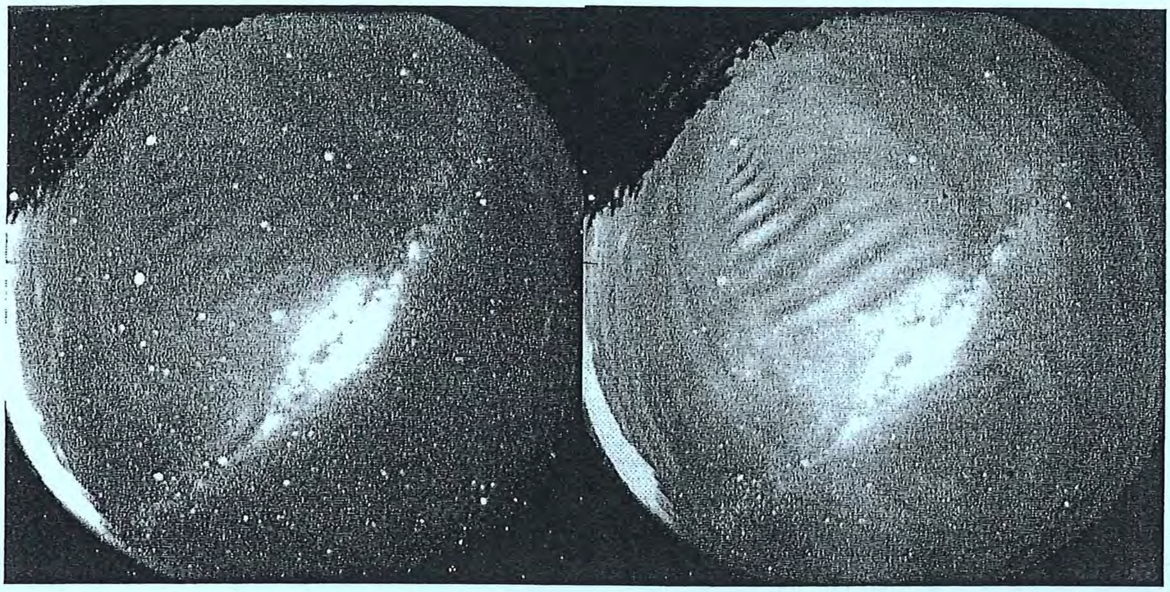
As the airglow emissions are relatively faint (much weaker than the aurora), they cannot usually be seen by eye and thus require very sensitive instruments. Historically the OH emission was the first layer to be studied in any detail due to its greater luminosity. The second brightest emission is the near infrared O2 bands followed by the visible wavelength green line and Na D line emissions. However, the airglow imager installed at Halley V is designed to obtain high quality images of even the faintest nightglow emission with good spatial and temporal resolution. Such images have revealed a wealth of "structure" in the emission layers due primarily to the propagation of acoustic-gravity waves (AGW) through the MLT region, the detection and identification of which are the prime focus of this experiment.

What are Gravity Waves?

Acoustic-gravity waves (AGW), or simply "gravity waves" as they are often referred to are a naturally occurring family of oscillations which can propagate within the atmosphere. They are an extension of sound (acoustic) waves but have much longer wavelengths measured in tens and hundreds of kilometers and periods of several minutes to many hours. Sound travels through the atmosphere by alternately compressing and rarefying the air very quickly (thousands of cycles/sec). However, as AGW have much longer periods (several cycles/day) the force of gravity has time to act on the wave motion altering its propagation characteristics away from the purely acoustic mode. In general, an AGW has both compressional and gravitational restoring forces, hence its name "acoustic-gravity wave". However, the longer the wave period the less the influence of compressional forces and the wave motion is said to be a pure "gravity wave". A simple example of a gravity wave occurs on the surface of the ocean (very big ones in the Southern Atlantic!), where the restoring force is the action of gravity on the displaced body of sea water. Ocean waves exist at the surface because of the abrupt change of density from water to air. However, in the atmosphere the air density decreases exponentially with increasing height (reaching a near vacuum at 100 km) and gravity waves are therefore free to propagate throughout the atmosphere. Lenticular clouds are one example of an atmospheric gravity wave and are formed by strong winds blowing over large mountains. The CCD imager is capable of imaging the signatures of gravity waves as they propagate to much higher altitudes.

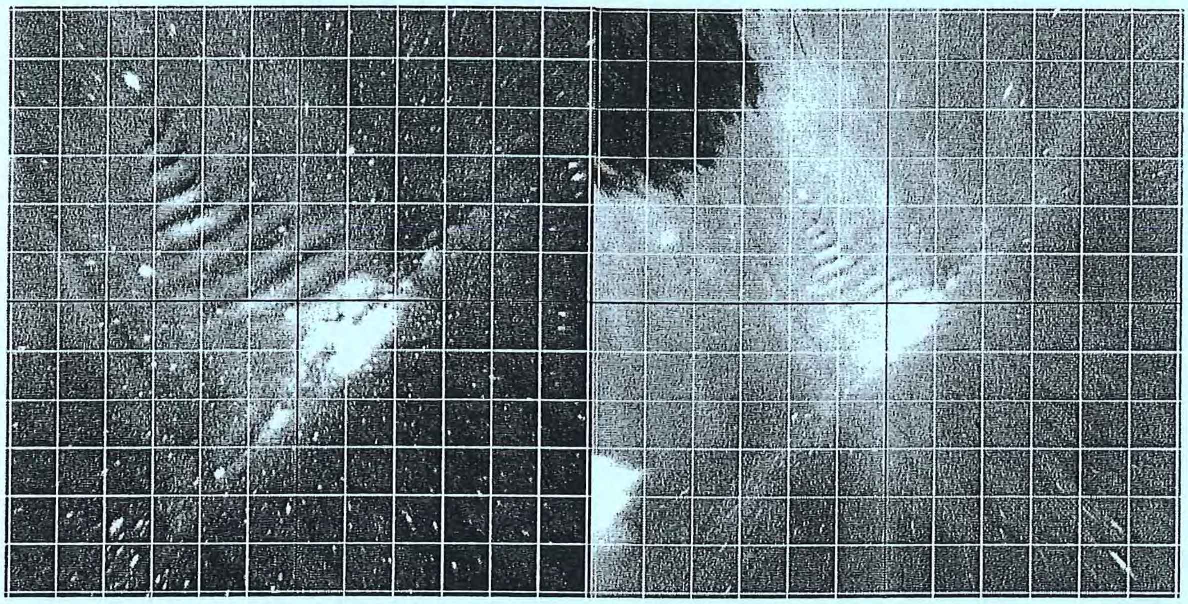
Why Study Gravity Waves in the Antarctic?

Most gravity waves are thought to be generated near the earth's surface by strong winds (orographic forcing), by strong convection by weather systems (lows and thunderstorms) and by weather fronts and jet streams. As theses wave propagate obliquely upwards they grow in amplitude (as the density decreases) and at the heights of the airglow layers they become saturated (cannot grow any more) and they break. As the waves break they give up their energy and momentum into the background atmosphere which we now know can affect profoundly the "weather" in the upper atmosphere. Indeed, gravity waves have been shown to be responsible for the unexpected reversal in direction of the prevailing winds at MLT heights and also for a remarkable reversal in the mesopause temperature (the boundary between the mesosphere and thermosphere) so that it is coolest in the summer months! Furthermore, the smaller scale waves (wavelengths of a few tens of kilometers and periods of less than one hour) have been shown to be the most important drivers contributing to this wave-mean flow forcing at MLT heights.



O_2 (13 july)   OH(13 july)

Unwarped Image



256 x 256 km   512 x 512 km

Figure1. Two example all-sky images showing identical gravity wave structure in the O2 and OH emissions from Brazil (top row). The bottom row shows a projection of these data into geographic coordinates. Note the bright band is the Milky Way.

The airglow emissions provide a novel way of remote sensing such waves in the 80-100 km region close to where they are break and imaging techniques provide a simple yet powerful way of investigating their characteristics. As the sources of gravity waves are thought to vary geographically (i.e. they may be more plentiful over mountains and stormy regions) and with the seasons it is important to study them from a number of geophysically interesting sites. Halley V, Antarctica is such a site as the variety and number of sources are expected to be lower (e.g. no thunderstorm convection) and therefore easier to identify. Halley is also in the distant lee of the Antarctic peninsular which may prove to be a prolific source of gravity waves reaching the MLT region. Finally, Halley is well situated to study possible wave generation by auroral currents flowing in the ionosphere associated with magnetic disturbances. As this is the first attempt of airglow image measurements from this site it is very important to obtain as much data as possible to help characterize the high latitude Antarctic mesosphere.

The CCD Imaging System

The imager utilizes a bare 1024 x 1024 pixel array of high quantum efficiency (~80% at visible and ~50% at near infra-red (NIR) wavelengths). The large dynamic range and low noise characteristics (dark current less than 0.5 electrons/pixel/sec) of this device provides an exceptional capability for quantitative measurements of faint, low contrast, gravity wave structure. The camera uses a fast (f/4) fish-eye (180 deg) telecentric lens system and a six position, thermally stabilized, filter wheel to obtain all-sky images of a selection of airglow emission lines and bands. A Penitium computer is used to control the system which is capable of automatic or manual operation. Both types of operation can be instigated, monitored and changed remotely via the local area network. Under normal operations the different filters are sampled sequentially to create a times series for each airglow emission. Currently four filters are installed: O2, OH, Na and Bg. The background (Bg) filter is used to help identify clouds in the data and to provide a measure of night sky and stray light contamination, important for the Na (and any other) emission line measurements. Exposure times are different for each filter (see section 4) and they have been set initially to be the same values as those used by a similar camera located in Utah, USA. Data are stored automatically on the "OH Server" local area network drive with an optional "fail safe" storage available on the computer controller (10 GB hard disk) in the Optical Caboose. Figures 1 and 2 show an example all-sky airglow image of gravity wave structure. Figure 1 (top) shows two images of a small-scale wave pattern in the NIR OH and the O2 band (from Brazil). The bottom row shows the same data projected into geographical coordinates (the bright band is the Milky Way). Figure 2 shows a more extensive, short period wave pattern observed at the same time in the NIR OH and the green line emission from Utah, USA. Sunlight is causing the broad band OH image to overload whereas the narrow band green line data are not yet affected. Similar type images are expected to be recorded at Halley by the new camera.

2. Mechanical and Electrical Integration

The imaging system consists of four basic parts: (1) the telecentric optical system, (2) the filter wheel assembly, (3) the camera head and control unit, and (4) the computer system. In addition there is a circulating water pump to assist the cooling of the CCD detector and an aluminium mounting frame to fix the camera system under the perspex dome in the roof of the Optical Caboose. The imaging system was built at Utah State University, USA and

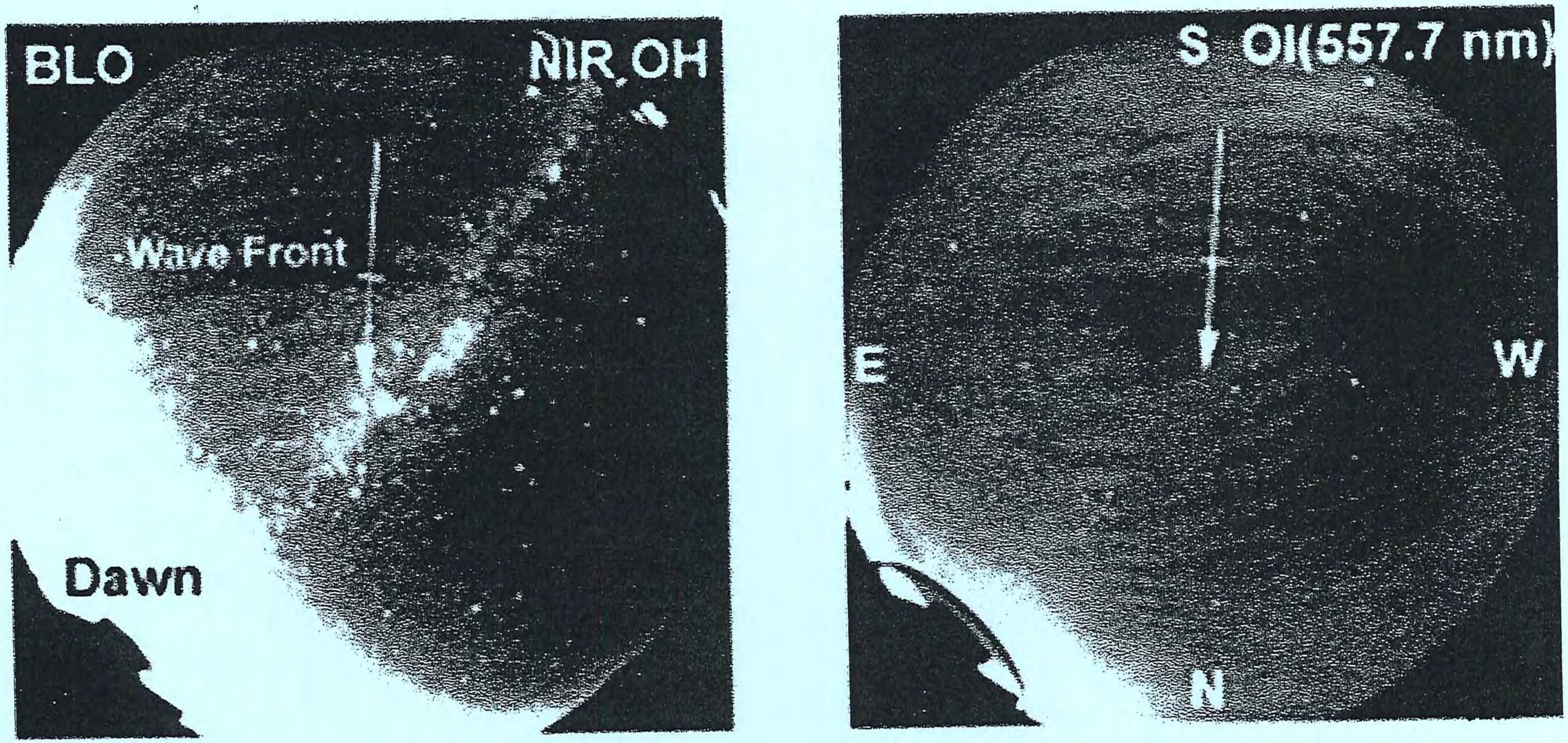


Figure 2. Two example all-sky images showing small-scale wave patterns in the OH and OI (green line) emissions from Utah, USA. The images were taken at the same time but show different wave characteristics at the two different emission heights, this situation is often observed.

with the exception of the **filter wheel** all units have been modified to operate on 240v, 50/60 Hz power.

The Mounting Frame

The aluminium frame is purpose built and provides a strong, rigid housing for mounting the camera. All components are either bolted or screwed together so that the frame can be broken down easily for transportation. The mount has already been assembled and fixed under the dome using four long screw rods (see Figure 3). However, if (when) it becomes necessary to break it down again each component should be marked uniquely with a pen to aid its reconstruction. The camera system is fixed to this frame by sliding the camera U channel between the two vertical L shaped brackets and pushing up so as to align the four mounting holes in the brackets with those in the U channel. Four Allan bolts are then used to fix camera in place. To aid this operation one of the L brackets may be loosened slightly from its mounting on the main frame and then tightened immediately afterwards. Mounting the camera should be done by two people and care should be taken not to hit the front lens or the filter wheel during this procedure.

Once firmly in place the optic axis of the camera must be adjusted to be vertical (for all-sky imaging). This is achieved easily using a spirit level placed alternately on the filter wheel housing and the long black optical extension tube and adjusting the four large supporting nuts located on the screw rods on the underside of the camera mount (loosen top nuts first). Once level, tighten the four retaining nuts on the topside of the aluminium frame to hold it in place. Finally, check that the top (all-sky) lens is sufficiently high within the perspex dome so that it can see down to the horizon with no local obstructions (see Figure 4 for a schematic diagram of the camera system and its placement).

Telecentric Lens System

The optical system consists of several parts, a Mamiya all-sky lens, a light shutter, two telecentric lenses, an optical tube and the Canon re-imaging lens. The filter wheel is sandwiched between the front lenses and the optical extension tube. Together these lenses form a telecentric system that permits the night sky to be imaged over a very large area (180 deg) at "discrete" emission wavelengths (using a set of narrow band filters) (see Figure 5). The Mamiya all-sky lens is operated at its maximum aperture of f/4. This lens also has a mount in it which permits the insertion of various coloured glasses. For this experiment the mount selection should be SL1B (i.e. clear glass). Immediately behind the all-sky lens is a light shutter which is used to protect the camera during daylight. It opens automatically when the camera is running in "automatic data capture" mode and closes at the end of each data period. It is **not** used to control the image exposure. Power to this shutter is provided through the short (grey and white) twisted pair cable which is connected from the shutter to the upper part of the camera U rail at the socket marked "shutter". The Front lens/shutter assembly simply screws into the top aperture of the filter wheel housing. Similarly, the optical extension tube screws into the bottom of the filter wheel housing and is also supported lower down on the U channel mount (Figure 5). The front of the re-imaging Canon lens screws into the lower end of the extension tube (at the felt ring) and is connected to the camera head by a bayonet joint to complete the optical system. A full description of how to mount the camera head and Cannon lens to the optical chain is given later in this section. The Canon lens is operated at full aperture of f/1.2.

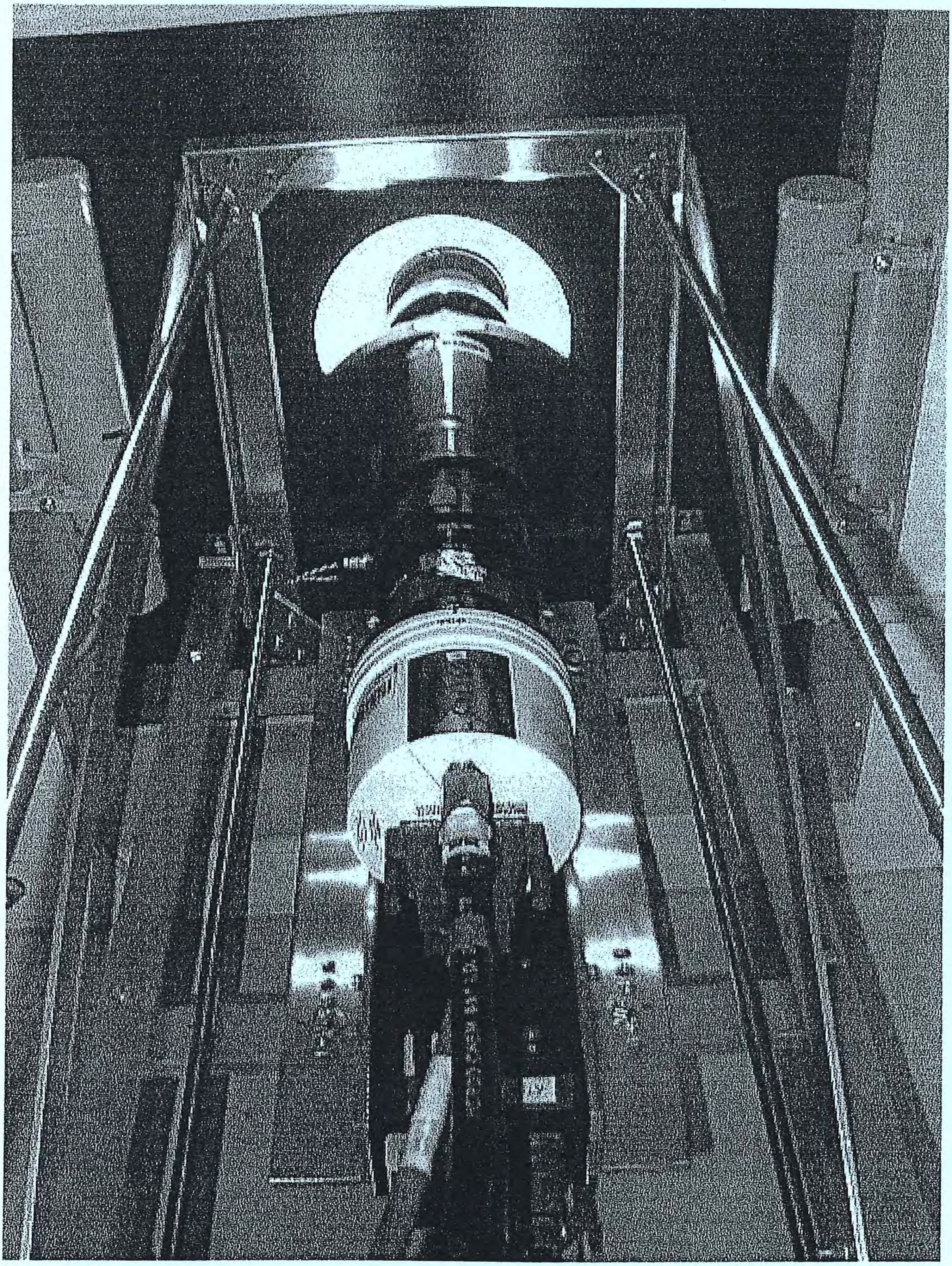


Figure 3. Photograph showing the camera system mounted in aluminium frame under dome at Optical Caboose, Halley V.

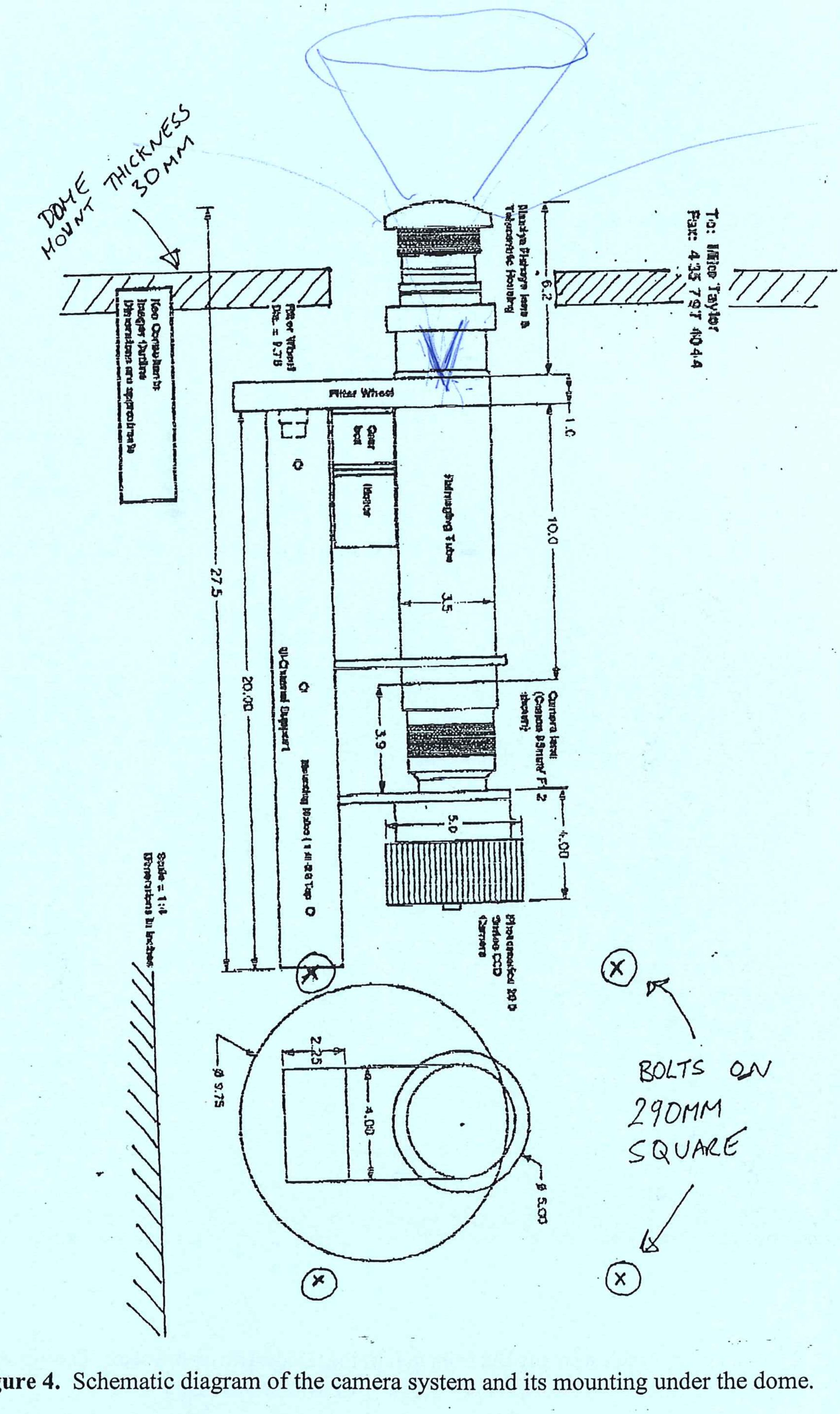


Figure 4. Schematic diagram of the camera system and its mounting under the dome.

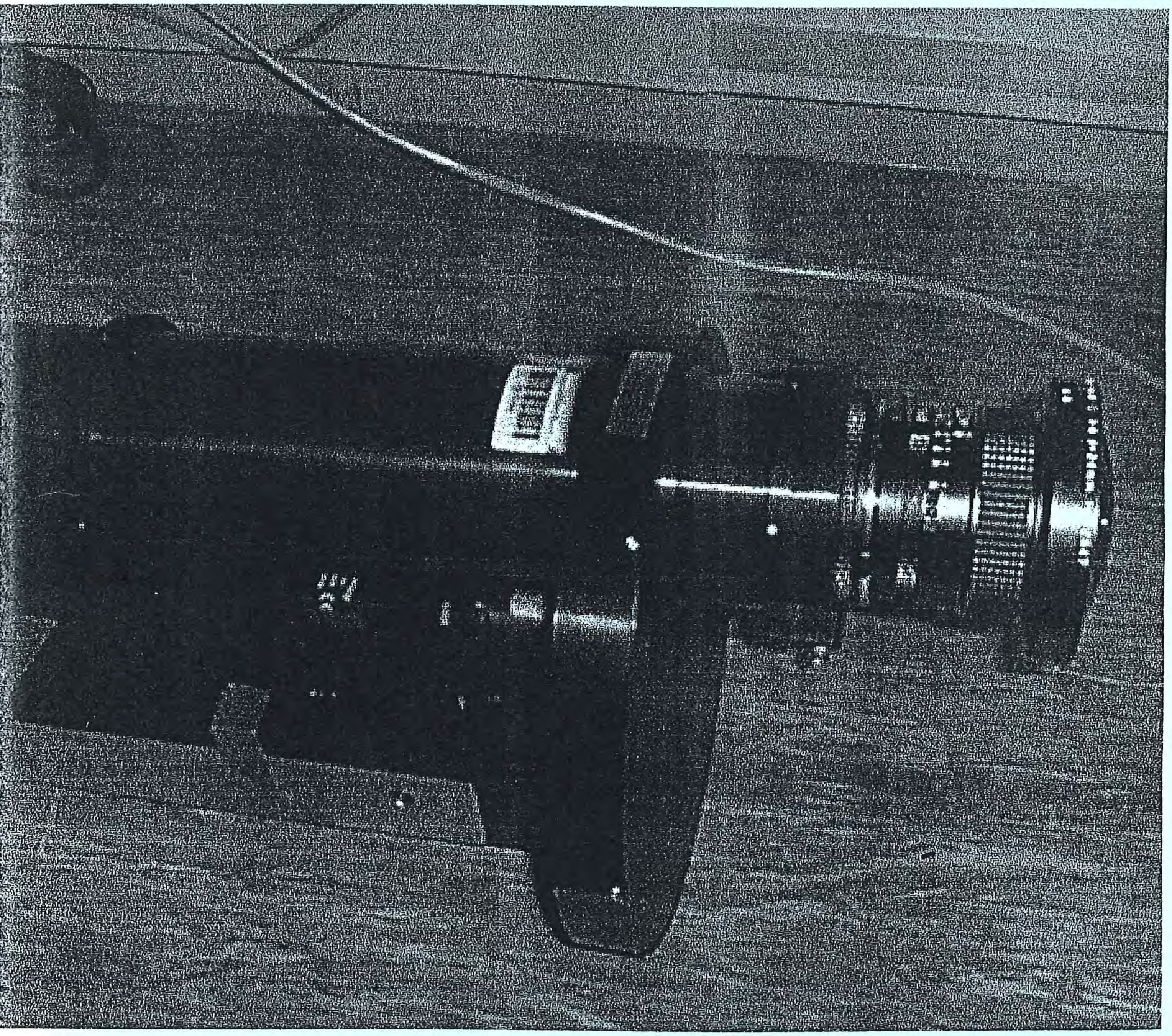


Figure 5. Close up photograph showing the front half of the telecentric lens system. The all-sky lens is mounted above the filter wheel (large disk) and the extension tube below it.

Filter Wheel and Filters

The Filter wheel assembly is the large diameter black disk that is mounted towards the top of the optical system. Inside there are six ~75 mm diameter holes for mounting the interference filters used to image the night sky (Figure 6). It is necessary to keep the filters at a constant temperature of about 25 C (as their transmission wavelength is sensitive to temperature) and two heater pads located within the filter wheel are used for this purpose. To aid the thermal stability of the filter wheel during the cold Antarctic winter the whole assembly is cocooned in a foam clam shell covered with aluminium tape. In practice, however, temperature variations of up to +/- 5 degrees can be tolerated as the bandwidth of the filters is reasonably broad (2.5 nm). The temperature of the filter wheel is adjustable (heat only) and its current value is displayed on the Athena unit located at the base of the U channel. (Note, this information is also logged automatically by the computer during each exposure.) The filter wheel electronics are all housed within the base of the U channel (covered by metal screen). The power switch is located on the top side of the U channel near its base. Unfortunately, the heater pads require 110V and so the **whole filter wheel system must be powered will 110 v only**. This is provided by a step down transformer connected to the filter wheel power input next to the Athena unit. A serial port for communicating with the computer is also located at the end of the U channel.

The filters used for this experiment are very expensive glass interference filters designed especially for this camera system. Each filter is 75 mm in diameter and has a protective metal ring around the circumference on which the filter designation/peak transmission wavelength is marked. Care should be taken when handling the filters: use the metal ring to hold the filters and avoid fingerprints and dust. The filters should be cleaned with the lens cloth provided (or one suitable for camera lenses). For very persistent grease marks use (sparingly) some "RS Optical Instrument Cleaner" foam and then clean with lens cloth. **do not use any other solvents**. A description for mounting the filters is given later. The filters are used to isolate light from different airglow emissions which originate in layers at different heights in the upper atmosphere. Currently four filters are mounted in the filter wheel. The filter position and filter designations are follows:

Filter position
1. O2: Central emission 865.5 nm
2. OH: A broad band filter ~710-950 nm with notch to block O2 light
3. clear: no filter
4. Na: Central emission 589.1 nm
5. Bg: Central wavelength 572.5 nm
6. Silvered card: used for "parking position" when camera not in use.

These filters are changeable but make sure you enter the new position and filter designation into the "Utah Capture" program via the "Filter Wheel" menu (Section 6).

Important Note: The Na and Bg filters currently installed in the filter wheel (February, 2000) have an **interference pattern** imbedded into them. These patterns are caused by a defect in the manufacturing process and will appear like a large thumbprint in the image data that is especially evident under low light conditions. We need good examples of these defective images to show the manufacture. If the patterns prove to be detrimental to the image quality then the filters will be replaced in 2001.

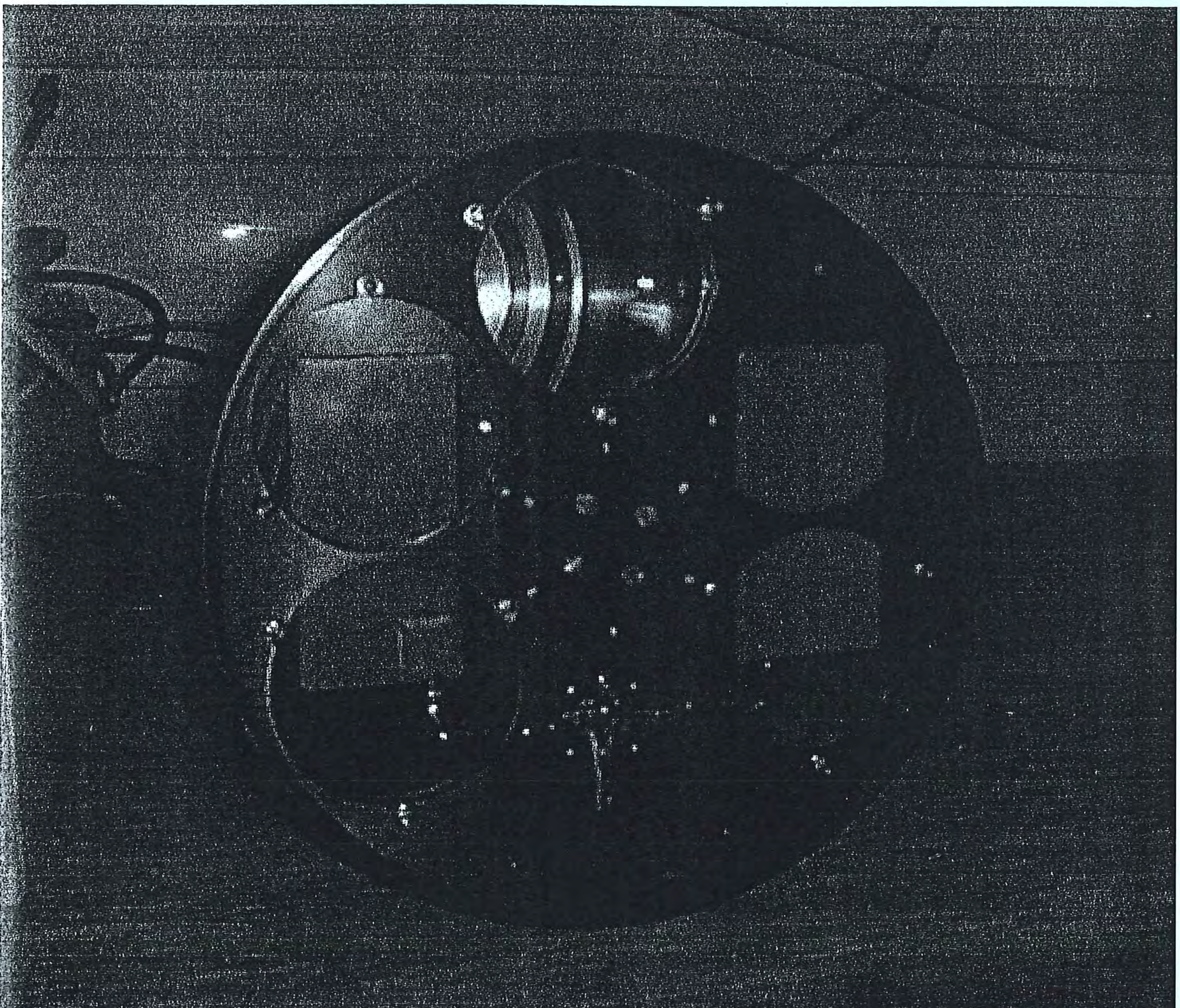


Figure 6. Close up showing the six position filter wheel with the front cover removed. A smart motor is used to rotate the filters to their desired position. The two red pads are the heaters used to keep the unit at +25 C.

The filter temperature is set using the Athena control and display unit mounted on the base of the camera U channel. This unit displays the current filter wheel temperature (red LED display) and the selected temperature (green LED display). To raise (or lower) the set temperature simply press the up (or down) arrows in steps until the green display reads the desired temperature. The filter wheel temperature has been set to +25 C, which is above room temperature but there should be no problem maintaining this value as the system is in a thermal cocoon.

Camera Head and Control Unit

The Photometrics Camera consists of a cylindrical camera head mounted at the bottom of the optical system and a stand alone electronics control unit. The two units are connected by a single ~1.5 m multi-way cable (which cannot be lengthened). The CH350 camera head contains the main shutter used for controlling exposures, the CCD detector, a two stage Peltier cooler (aided by a water circulation unit) and some low level processing electronics (Figure 7). The control unit is located on a wall shelf next to the camera and is connected to the computer via the SCSIII port and a dedicated interface card. This unit provides power and, via the computer, all commands to the camera head for shutter opening and closing, exposure length, data downloading. This unit also controls the temperature of the CCD and has an LCD readout on the front panel and a digital output to the computer for logging temperature (Figure 8). The power switch is located on the rear of the unit.

Connecting up the Camera Head

When connecting up the camera system it is **vital to connect the camera head last** (in order to limit the possibility of electrostatic damage to the detector). Once the control unit is connected (and earthed) the short (1.5 m cable) can be connected, first to the back of the control unit and **only then** to the base of the camera head. Remove the blue shorting plug (see Figure 7) from the connector on the base of the camera head **only** when you are ready to make the final connection. Likewise, when disconnecting the camera system, the plug at the base of the camera head **must be removed first** and the shorting plug inserted. For convenience this plug is kept on the shelf next to the control unit in the camera room.

The CCD Detector

Light from the telecentric lens system is imaged onto a sensitive solid state Charged Coupled Device (CCD) which consists of a 25 mm square 1024 x 1024 pixel array. The CCD is mounted in an evacuated cell and cooled for operation at below -40 C. Cooling is necessary to keep the electronic "dark noise" to a minimum. At room temperature this noise would completely swamp the sky signal but at -40 C (or colder) the dark noise is less than 0.5 counts/pixel/sec. Very weak airglow emissions (such as the Na emission) require a long exposure time (typically 90-120 s). However, as the dark noise increases with temperature and with exposure time it is **vital** to operate the camera cold in order to clearly image structure in these emissions. Cooling is achieved using a two step process. The primary cooling is provided by a two stage Peltier (electronic) cooler that is mounted on the underside of the chip. On its own this device can initially cool the detector to about -25 to -30 C. However, the camera system may rapidly become very hot (as there is no place to dissipate the waste heat) and care must be taken **not** to operate the camera in this mode. To extract the waste heat from the Peltier device a 50-50 mixture of water and antifreeze is continuously circulated through the camera head. In this configuration an

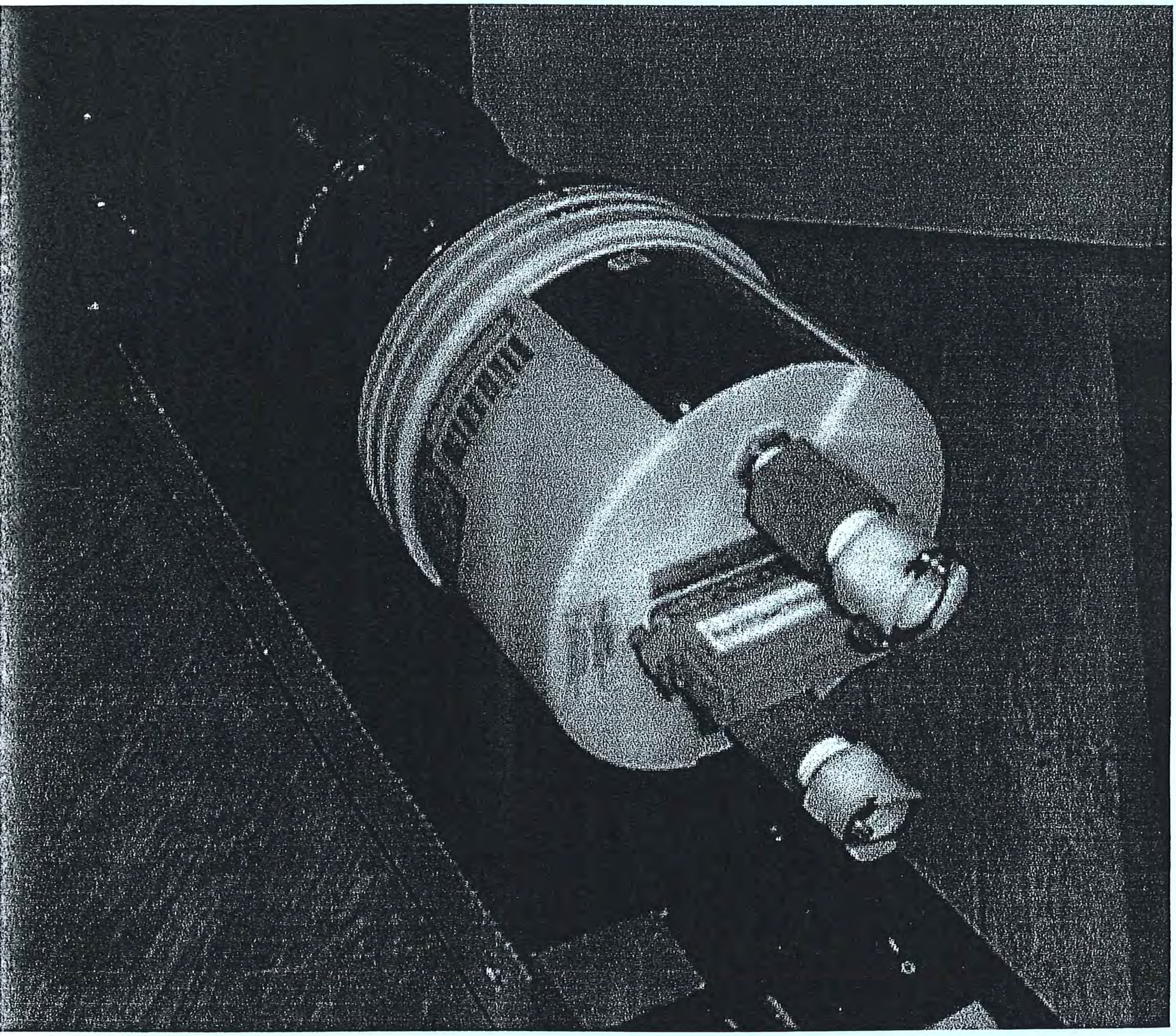


Figure 7. Close up of the Photometrics camera head mounted on the lower part of the U channel. The blue shorting plug prevents damage due to static discharge when not connected to control unit. The two large brass connectors are for circulating cooling liquid (50-50 water-antifreeze) within the camera head to help cool the CCD.

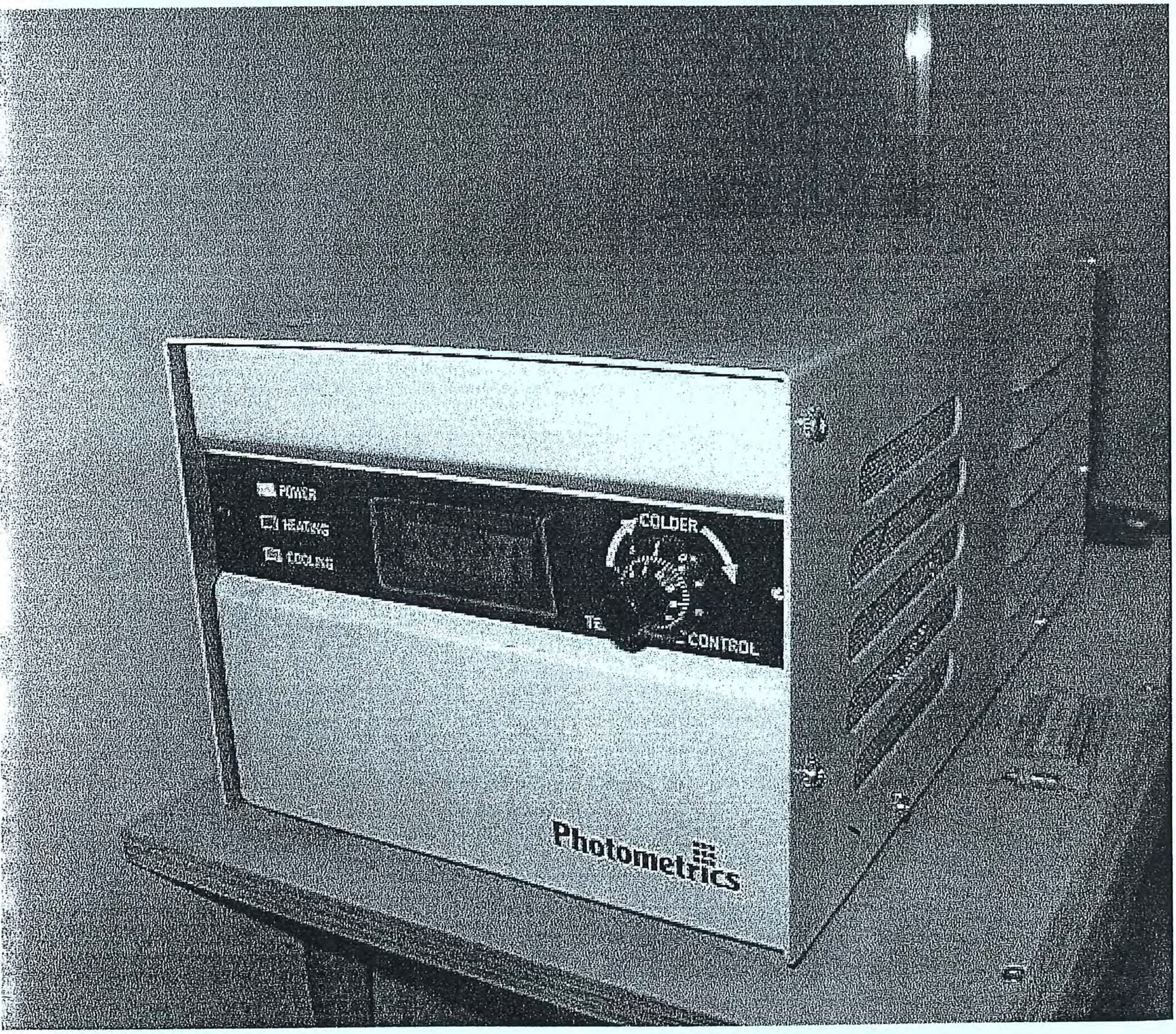


Figure 8. Photograph of the Photometrics camera control unit (mounted on shelf in camera room). This unit controls the CCD temperature and runs at -42 +/- 2 C.

operational temperature of - 42 +/- 2 C is readily achievable which is sufficient for the nightglow measurements.

Connecting Camera Head to Lens Assembly
First join together the CH350 camera head to the Canon 85 mm lens by lining up the notch in the silver ring on the back of the camera head with the red spot on the rear of the lens and then mating by twisting clockwise about an eighth of a turn. You should feel the lens click in place. (To remove the lens depress the recessed silver button on the black ring on camera head and twist lens anti-clockwise.) After mating the camera head to the lens insert the lens (lens first) through the black metal loop that is attached to lower third of the camera U channel until the black plate of the camera head buts up against the mounting loop. Now fix the camera in place by tightening the three grub screws. Note there is no need to over tighten the grub screws as they penetrate into a grooved recess in the mounting loop. Next locate the black ring in the end of the extension tube (its held in place by felt) and screw onto the front of the camera lens. This completes the optical integration. By twisting the focus ring on the Canon lens the "felt ring" should slide smoothly in or out of the long extension tube without disconnecting from it. To change the orientation of the camera head (i.e. to rotate the image) loosen the three grub screws and gently rotate camera head to desired position and then re-tighten screws.

Computer System
The camera system and filter wheel are controlled by purpose built software operating on a dedicated Pentium PCI computer (Figure 9). The filter wheel is connected to the camera at two serial ports marked 1 and 2 using the filter wheel adapter cable. Port 1 is for the filter wheel temperature read out and port 2 is for controlling the filter wheel. Make sure the adapter cable is well mated to the main filter cable. The camera control unit is connected to the computer using a standard SCSIII cable (a long spare is provided) via a Photometrics PCI interface card (mounted inside the computer) and the SCSIII port. The computer is connected to the local area network for data storage but has an 10 GB hard disk to temporarily store image data should the communications network fail. Information on the "Airglow Capture" operating software can be found on the local area network on OHSERVER at //ohserver_nt/ohimager/utahair/capturedoc/index.html and on the OHIMAGER PC in the Optical Caboose at c:\utahair\capturedoc\index.html (Section 6).

Liquid Circulation Pump
A Caron 2050 liquid circulating unit is used to help cool the CCD detector. A mixture of 50-50 water and antifreeze is continuously circulated from the pump to the camera head via the specialized black hose and water connectors (Figure 10). Care should be taken when connecting/disconnecting the hoses to avoid liquid spillage. Make sure you hear a distinct "click" when connecting the hose to confirm it is seated properly, otherwise it will leak as soon as the pump is activated. The hoses are interchangeable and there is no specific "input" or "output" configuration for connection to the camera head. The male connectors on the hoses are all "direct feeds" and will allow the liquid to flow out when disconnected, so be careful. The female connectors on the pump are "self sealing" and will not allow liquid to flow until hoses are connected. The pump can be operated as a liquid circulator or as a "temperature stabilized bath" when the refrigeration/heater switch (yellow) is activated. This provides liquid to the camera head at a constant temperature (within 0.1C) and is the **required mode** of operation for the camera to achieve stable CCD operating

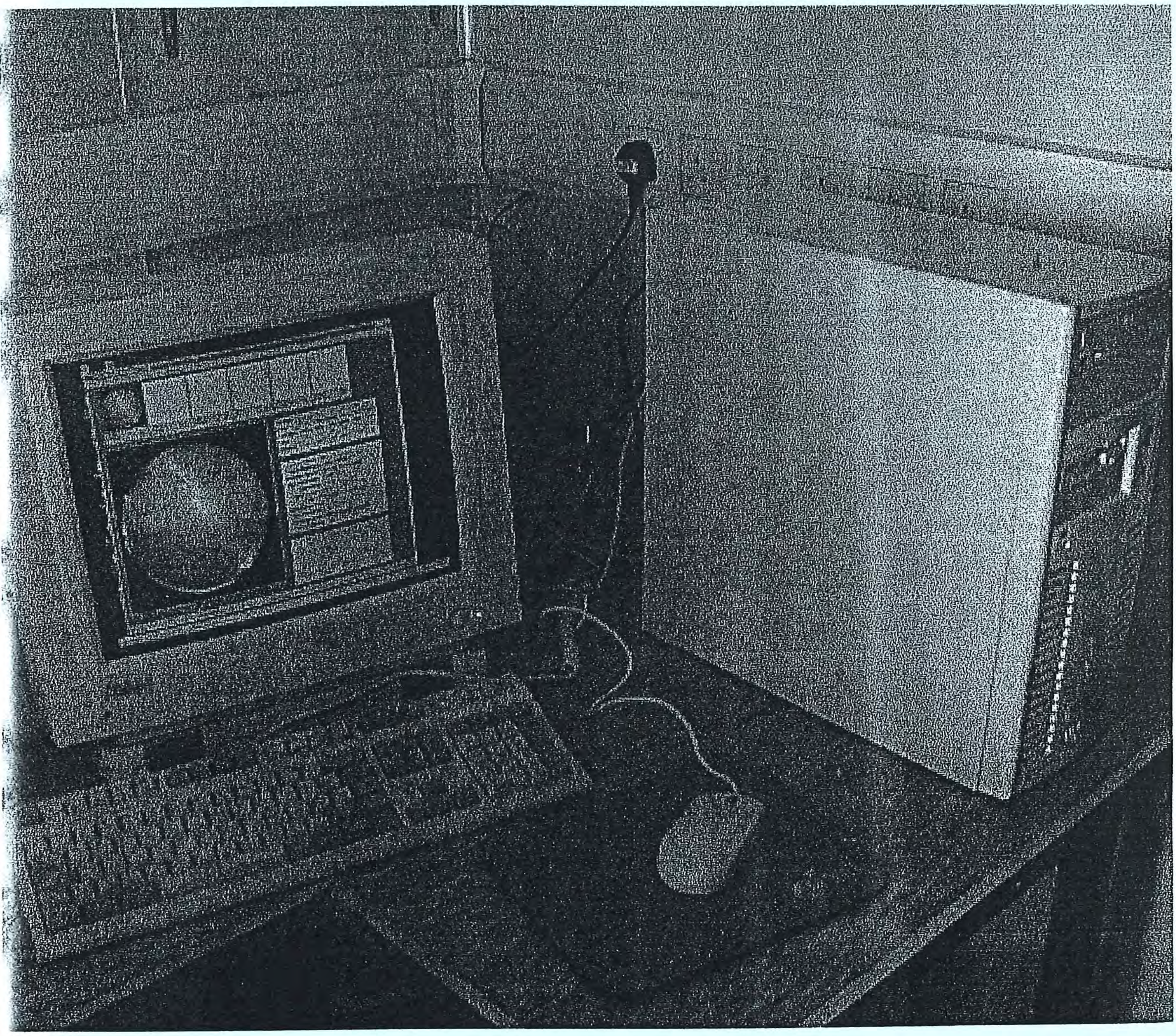


Figure 9. Photograph of the computer system.

temperatures. A range of stabilized liquid temperatures (-15 to +90 C) can be selected (via the Watlow controller, see later) but under normal operating conditions the expected liquid temperature will be around +5 to +10C. See Section 4 for the current camera system setup.

Pump Operations
Once activated at the beginning of the observing season the pump will run throughout the winter months. Certain procedures are necessary to ensure correct operation.

Prior to filling the tank make sure the liquid container is clean and that there are **no bits inside** that would block the flow of liquid to the camera. In the past, impeded flow has been a problem on several occasions and care **must be taken** to keep the tank clean. You will need about 6-8 lt. of 50-50 mix to fill the tank. Before filling the tank make sure the nylon plug is screwed into the drain hole near the base of unit (it is not necessary to over tighten this as it could shear off!). Add the liquid using the funnel provided and fill to cover the heater coil in tank (on left as view from above) to about 20 mm from the top. DO NOT overfill as this could cause damage to the pump. There is also a "low liquid" light/beeper that will activate if liquid level is too low. Switch on the pump power (green switch) and you should see the liquid churning around inside. (Note: as the input/output connectors are "self sealing" liquid will not come squirting out.) Power the system off and connect both hoses to the pump and then to the camera head to (no input-output order required) to complete the circuit. Clean the connectors first and make sure the black rubber rings are not perished (replacement ones in tool box). The connectors should make a click as they seat correctly. If in doubt disconnect and try again. To disconnect depress the silver paddle on the female connector and then pull the male connector (attached to hose) out. Once satisfied that the pipes are correctly joined re-start the pump and check that there are no leaks. Now add about 10 drops of anti-fungal (blue) liquid to protect the system from fungal growth (from algae possibly present in pipes during tests). Finally, activate the cooling (refrigerant) switch (yellow) and select the liquid operating temperature.

To select or change the liquid operating temperature refer to the "Watlow" display on the front of the pump. This will show the current liquid temperature. Depress the "select" button to see the previously set temperature to the liquid. To change this continue to hold down the select button and depress either the "up arrow" or "down arrow" button to raise or lower the preset temperature. Release the blue button and the pump will now cool (or heat) to this new value. To check you have entered the correct bath temperature simply press the "select" button again and it should show the new value. Note, it may take the pump some time to achieve its required operating temperature, about an hour (at most) after switch on, but once reached it should be able to hold this value during the camera operations with a high precision (0.1 C).

It is **very important** to empty and clean the pump at the start of each observing season (or whenever it becomes contaminated) in order to remove any particulates or algae that may block the liquid circulation. To empty pump disconnect the hose cables from the pump (use a bucket to collect discharge) but leave other ends connected to the camera head. Put a plastic bag over the hose ends to keep them clean. Gently unscrew the nylon drain plug on the lower left side of the pump and pour the liquid out into bucket for disposal. Replace the screw (there is only one spare in tool box so don't loose it). Clean the bath with thick

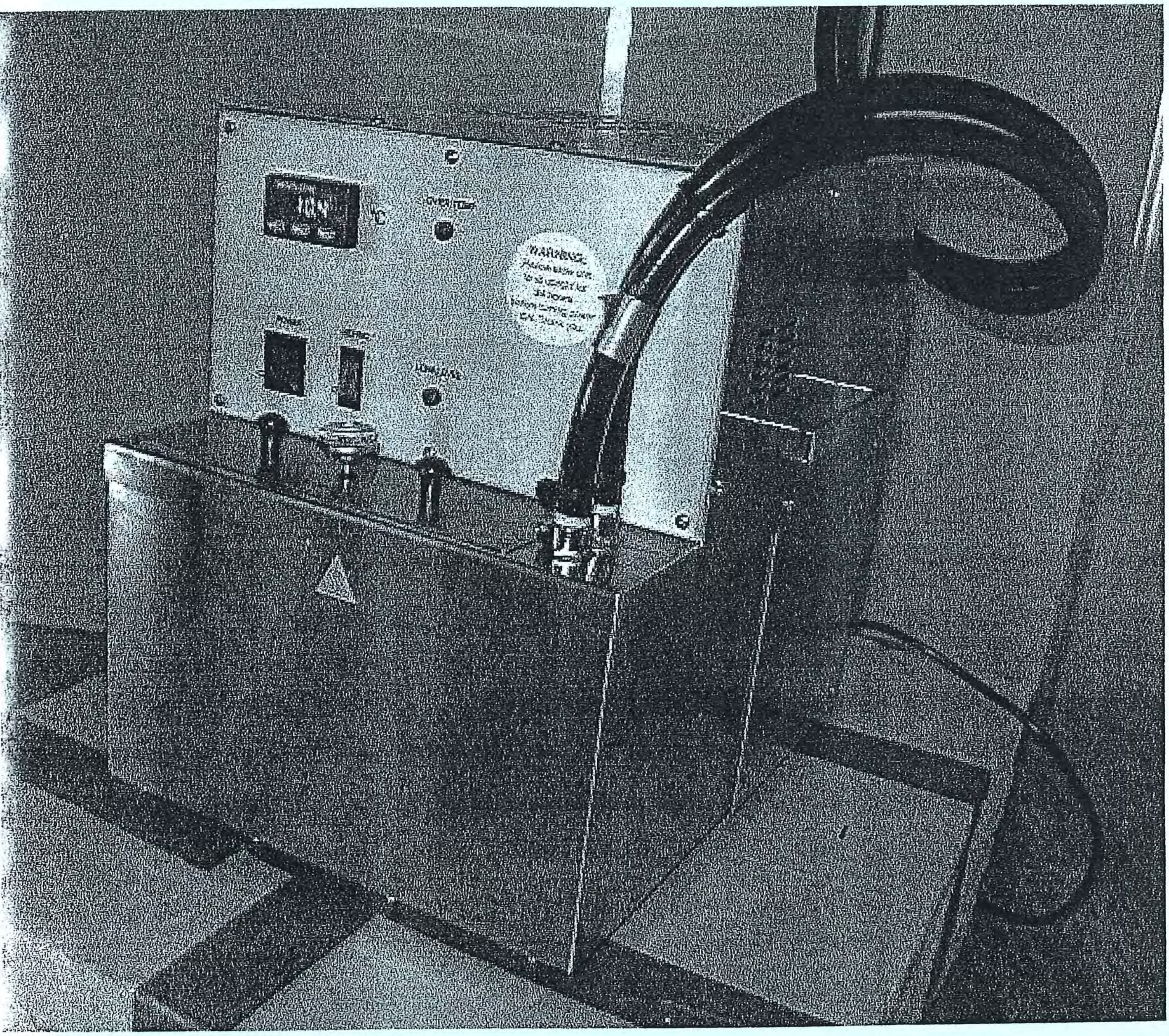


Figure10. Photograph of a Caron liquid circulation unit. This pump provides temperature stabilized liquid to the camera head to help cool the CCD.

paper towels and make sure there are no bits left inside that could later block the pipes. Next re-fill tank following procedures described above.

3. Operational Procedures

The airglow camera is very sensitive and can only take data during the hours of darkness when the sun is over 12 degrees below the horizon (termed "nautical twilight") and when the moon is down or its phase small. A list of start-stop times (in UT) for the camera is given in the Schedule.txt file (Section 6). The Halley winter measurements will start about mid-March and end in late September providing about 150 night of measurements during which there will be two periods of continuous "24-hr" operations lasting about 12 days each. Data are taken regardless of weather conditions.

Preparation for System Start-Up
Prior to the start of an observing season (in March):
Remove dome box and clean outside of perspex dome with glass cleaner
With lens cap on clean inner surface of perspex dome with a dampened cloth
Temporarily remove lens cap and give all-sky lens a wipe with lens cloth
Disconnect hoses from pump and drain tank (keep hose ends clean using a plastic bag)
Flush the pump bath through with clean water then wipe with strong paper cloth or jay cloth making sure not to leave any bits behind.
Vacuum dust out of pump filter (if necessary)
Re-fill tank with a fresh 50-50 water-antifreeze (Delcol) mixture, add in 10 drops of blue algaecide and re-connect hoses.
Test pump operation and look for any leaks, check it reaches its stable preset temperature.
Power up camera control unit and filter wheel system and check that the camera cools to the correct operating temperature (-42 +/- 2 C) and that the filter wheel heats to +25 C.
Power up the dome heaters and the fan(s).
Check all parameters and settings are correct (see Section 4)
Run the camera in manual mode to test images are being generated and stored correctly.
Next load up the new "schedule.txt" file for controlling the camera (to be provided by BAS/USU). Do NOT use the built in schedule file generator as possible error.
Edit path for image storage to reflect new data year (e.g. 2001) in the "Set Save Paths" under the "Settings" menu. The system is now ready for operation.
Power systems down (see the computer sequence file for start of operations date).

System Start-Up
On the first night of operations, prior to the automatic start up time, remove lens cap
Power up all systems and check correct operation and temperatures
Check for any lights or light leaks in the camera room
Check for correct automatic start up of data taking sequence
On first clear night thereafter make fine adjustments to focus to achieve optimum position. (Note, the best focus is a compromise to accommodate a range of filters, see Section 5).

Send example images of each filter to BAS, Cambridge (attn.: Mike Rose) for inspection to see if focus is acceptable etc.

Daily Procedures
Each day the image file from the previous 24 hour period should be inspected using the fast viewing (or movie option, if available) to determine the status of the data. Also check the schedule.txt file (see Section 6) to make sure data taken for correct period. A one line entry into the data log summarizing this data **must** be made together with the date of file. This log should contain information on presence of wave structure, aurora or cloud to assist the analysis of the data. Example comments are listed below but feel free to use your own. You can also flag the really good nights with an asterisk.

Example comments:
Clear with some wave structure moving east
*Excellent night with lots of waves
Cloudy all night
Part cloudy, some waves seen to north
Clear but no structure seen
Clear with some aurora to south, some structure later
Fantastic meteor storm....etc.

Finally, whilst looking at the data check image quality; does it look noisier than usual? Are the stars in focus? Are there less stars than normal? Make appropriate comments in log.

Weekly Procedures
In addition to daily procedures prepare Keograms for transmission to Cambridge together with a summary of the weekly log. Indicate any interesting data nights.

Plot the dark image data for that week to determine whether camera operation was optimal. The dark value is strongly dependent on CCD temperature (and exposure time) and thus provides a good way of monitoring the health of the camera. A dark value of about 950 counts (range 900-1000) is typical for a 90 sec exposure at a CCD temperature in the range -42 +/- 2 C. If the CCD temperature is not cold enough the dark current will increase dramatically (to several thousand counts). Make appropriate comments in log and if problem try to perform correctional procedures/or contact Cambridge for help.

At the Optical Caboose: examine drive d: for any image data that may have been stored during temporary network drop outs. Copy over to appropriate drive (n:) and delete from d: drive. (Note, the camera automatically reverts to saving data on d: drive if the network goes down but it does **not** inform you of this action.)

Monthly Procedures
These are **very important** and should be performed weekly for the first month or so to establish correct long term operations of the system:

At the Optical Caboose:
Clean dome (if necessary)
Check liquid level and clarity in pump resoviour (if low top it up), add a few drops (about 5) of algaecide and check hoses and connectors for leaks
Check pump water temperature (should be unchanged), record value in log book

Check pump health: is it very noisy? Are the sides of pump hotter than normal? This may be due to dust build up in air filter. If so try to clean (vacuum) out. If the unit does not improve consider changing over to the spare unit.
Check CCD temperature (should be -42 C, nominal range +/- 2 C). If CCD is warmer than -40 C lower coolant temperature to compensate (about 1deg/deg of cooling).
Quickly look over camera room for any obvious problems (Note, try to keep time in camera room to a **minimum** to reduce problems with frosting on the dome.)
Record temperature of camera room in log book.

Camera Shut-Down Procedure (end of September):
Turn off the camera control unit and filter wheel power and **lastly** the pump power.
Turn off the dome heaters and fans.
Fix wooden box cover over dome to protect camera from sunlight during the summer.
Put all-sky lens cap on, and cover control unit and pump to keep clean.

4. Quick-look Parameter and System Settings

Optics
Fish eye lens (front) set to f/4, infinity focus and SL-1B mount position
Canon (rear) lens set to fully open (f/1.2). Use this lens to focus the camera.

Filter Wheel and Exposure Times (Temperature set to +25 C, limits +/- 5 C)

Filter Number	Emission	Exposure Time
1	O2	90 sec
2	OH	15 sec
3	none	-
4	Na	90 sec (may need to increase to 120 sec)
5	Bg	90 sec
6	none	-

Exposure Sequence
OH, Na, OH, Bg, OH, O2 (corresponds to filter positions: 2, 4, 2, 5, 2, 1)
(One cycle completed every ~5.5 min, producing ~3 GB/cycle)

Dark Image Information
A dark image is taken once every six cycles (i.e. about every half an hour)
Average dark signal = 950 +/- 50 counts (for 90 sec exposure at -42 C)
Average bias signal = 800 +/-20 counts

CCD Temperature
Nominal CCD temperature = - 42 +/- 2 C. (Current value = -43.5 C, February, 2000) This may warm a little with time due to out-gassing in the CCD cell.

Liquid Coolant Temperature
Current value = +10 C. This can be set to a lower value to keep the correct CCD temperature. However, if bath temperature has to be lowered to below + 4 C to achieve a correct CCD temperature please contact Cambridge to seek advice.

13 min cycle 3 min integ
15s integ 3 min cycle

5. Optical Set Up

Aperture Settings

To operate the camera at its maximum sensitivity set the front Mamiya (all-sky lens) aperture to f/4. Set its focus to infinity and check the mount (ring on front lens) is set to SL-1B (i.e. clear glass). Next set the rear Canon lens to f/1.2 (or fully open). Focus adjustment is then made using the Canon focus ring **only** (see later in this Section).

Cleaning Lenses and Filters

Lenses and filters should be cleaned with the lens cloth provided or with a similar type camera lens cloth. Use the small brush to remove any dust or particulates. Remove all finger prints by gently cleaning with the cloth. For very persistent grease marks use (sparingly) some "RS Optical Instrument Cleaner" foam and clean afterwards with lens cloth. **Do not use** any other liquid cleaners or solvents on lenses or filters.

Installing and Changing the Filters

Great care should be taken when handling the glass interference filters as they are difficult to manufacture and could break if dropped. First clean the filters using the lens cloth provided (to remove finger prints or smears) and the brush (to remove dust particles). Hold the filters by the black metal ring and try not to handle too much. The installation/replacement of the filters is best done with the camera system lying on a clean bench with the front propped up so that the filter wheel is tilted well back (to stop the filters falling out). Disconnect the front shutter cable (twisted pair) and unscrew the front all-sky lens assembly from the filter wheel housing (large diameter black disc). This will expose the filter wheel aperture. Next remove the six small retaining screws (around filter wheel edge) and gently remove the front filter wheel cover. This will expose all the filters and their mounts within the wheel (Note, the two orange pads are the filter heaters, see Figure 6). Each filter position is uniquely marked from 1 through to 6. Select the filter to be inserted (e.g. OH) and note its position number (this information must be entered into computer later). Hold the filter by its edges and if desired attach a piece of Scotch tape (provided in box) to outer "shiny" surface of filter and gently use this and fingers to lower filter into chosen position (see Figure 11). Do this slowly and carefully as the filters are made to fit snugly and will come to rest on a narrow metal lip at the back of each hole. Examine the filter to make sure it is seated correctly (i.e. resting firmly on the lip all round) so that its plane is perpendicular to the optic axis (this is very important as the transmission of the filter varies with angle of incidence). Next use three filter screws (fitted with rubber grommets) to hold the filter in place. Do not over tighten them as the expansion of the grommet will grip the filter. Remove the Scotch tape, re-examine the filter to make sure everything is still OK and clean again (if necessary). Now go on to the next filter. (Note, its is best to mount the filters with their shiny surface directed outwards and towards the front of the optics but it is not essential.) When finished re-attach the filter wheel cover, and make sure the filter wheel can turn freely by gently rotating it using your finger through filter aperture (don't touch the filters!). Then re-assemble the front optics and attach shutter cable. Finally, as the filters are only gently held in place to stop them from dislodging it is very good practice to keep the camera system in an elevated (front up) position until the system is fixed vertically in place under the dome.

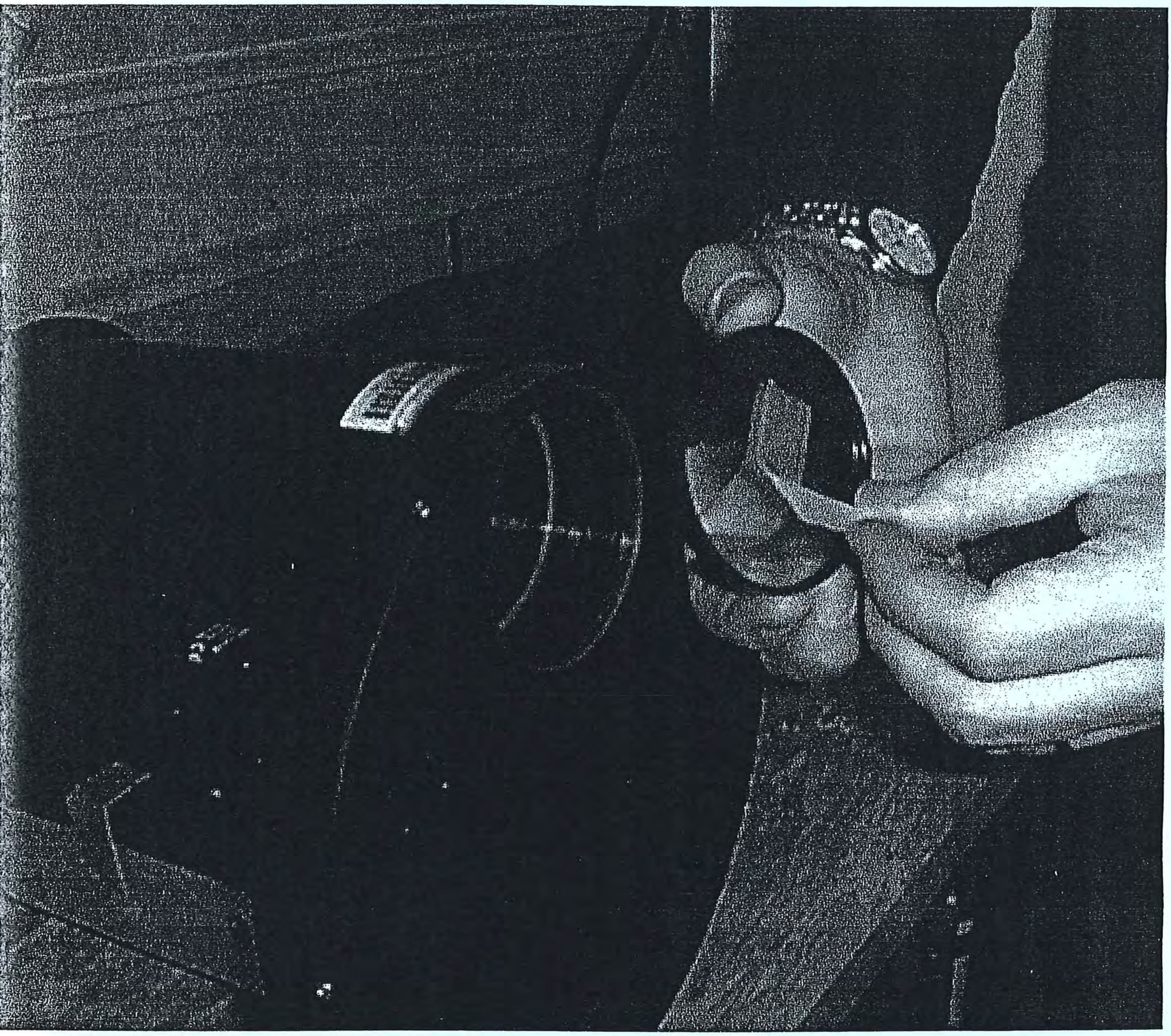


Figure 11. Photograph showing the installation of a filter. This is normally performed with the front cover removed. A small amount of "Scotch tape" (kept in the spares box) can be attached temporarily to the filter to help lower it into place in the filter wheel hole.

Focusing the Camera

Focusing the camera is **extremely important** as it seriously affects the quality of the data recorded. An out of focus image is of little use and care must be taken to maintain good focus. Focusing is performed by rotating the focus ring on the Canon lens connected to the CCD camera head. Because several different filters are used for this experiment a "compromise focus" position must be used. Focus is achieved at night using the star background and with the lights off in the Caboose. You may need frequent access to the camera room but keep your visits short to limit any problems with frosting in the dome (if this happens you will not be able to focus). Use a torch to see what you are doing when adjusting the focus, it will not damage the camera. The focus is already set to an approximate position (based on test measurements in Utah) but needs further tweaking to achieve optimum data. Some examples of good (and poor) focus data are available for viewing on the Utah Data CDROM. The following iterative procedure describes how to determine the best focus position and requires patience:

1. Assuming automatic data taking has already started, select "pause" under the "Control" menu to gain manual control of the camera
2. To capture a single image first click on "Camera" menu and then on "camera" followed by "capture image"
3. Select filter number 3 (i.e. clear) and select exposure time of 5 sec and click "OK"
4. This will create an image and display it in the main window
5. Examine the image: are the stars in focus? If it looks quite good then gently tweak the focus ring on Canon lens (about 1 mm as focus is very sensitive) and re-expose. Examine image again: Is there any improvement? Continue in same direction until you have establish that you have passed through focus position. Then reverse direction and repeat exposing to find best focus position. At this point the stars throughout the image (except near the edge) should be in focus. This is the visible wavelength focus position. We now need to find the NIR focus position.
6. Repeat procedure for filter position 2 (OH), and a 5 sec exposure and grab an image.
7. Examine the image at this new wavelength. The image will appear to be a little out of focus. Gently tweak the focus ring (rotate it anti-clockwise away from visible focus position, i.e. to left), again about 1 mm at a time and repeat exposure to improve focus. The NIR focus position will be up to several mm from the visible focus position.
8. Next repeat a capture for no filter (position 3) at a 5 sec exposure. This will show you how much the visible focus has changed in order to accommodate the NIR measurements.

9. Now we can select the **compromise focus** position. It will be just over half way between the OH and the visible focus positions. Try setting lens focus to about half way and re-expose a visible followed by an OH filter. The star fields in each image should appear to be of similar focus quality (i.e. still good but not perfect).
10. Now select "Manual Sequence" mode under "Control Menu" and initiate an image capture sequence using correct exposure times for filters (see Section 4).
11. Observe each image as it is produced and compare its focus with others **the most critical filters for this experiment are the Na and OH.** If the images of these emissions are of equal goodness then you have achieved an acceptable compromise focus position. Note: because the O2 filter is deeper red than OH it will not look quite as good but should still be acceptable. Likewise the Bg filter is shorter wavelength than Na and its focus may

be ever so slightly worse. However, you will probably need to tweak the focus again very slightly (towards the OH focus position) to achieve **best compromise position.** Please do this procedure carefully as it will ensure the best possible data.

12. Now mark the focus position on lens system and fix lens in place using strong black tape (taking care not to move lens). Note: if in subsequent weeks the sharpness of the stars appears to decrease check that the lens focus has not moved because of wind buffeting the caboose.

Important note: If the focus is almost correct - fine-tune using steps 9 -12.

Auroral Contamination

Due to the high latitude of Halley V there will be times when aurora will be present within the camera field of view. Indeed during the winter months it is expected that aurora will be seen by the camera on almost every clear night. On many of these it will appear as a set of faint, near east-west aligned, bands of light at low elevations (less than 20 deg) close to the southern horizon. Under these conditions it is possible to image the aurora and airgow structure at the same time. However, during times of enhanced magnetic activity (which are expected to occur more often as we reach solar maximum period in 2000/2001), the aurora will often brighten and move overhead creating a strong display that will mask any airglow signal and may completely overload the camera (the image will turn totally white). This will **not** damage the camera as light from the aurora is not that intense and is temporary. However, the camera should **not be operated in daylight** as any exposure to strong light sources such as sunlight will burn a picture into the detector that is very difficult to remove. When the aurora subsides the camera should recover on its own and will continue to display any airglow structure (and/or faint aurora) present. It is therefore not necessary to adjust filter exposure times during these periods.

All of the airglow emissions will be compromised in this way during an auroral display. However, the Na emission is expected to be least affected and will therefore be important for investigating any relation between the auroral and airglow structures. In contrast, the "green line" airglow emission is also a very prominent auroral emission and consequently even faint aurora could contaminate the airglow data. For this reason green line measurements will not be made during the first year of operation at Halley V. The OH (and O2) airglow data will also be affected by strong aurora but like the Na they are still expected to show airglow structure in the presence of limited auroral activity (e.g. aurora off to the south).

6. Description of Software

A full description of the camera control software can be found on the World Wide Web. For Halley operations this software document is stored on the local area network at //ohserver_nt/ohimager/utahair/capturedoc/index.html and on the OHIMAGER PC in the Optical Caboose at c:\utahair\capturedoc\index.html. Except during focusing or trouble shooting the camera will be operated in the "automatic capture" mode using a built in list of start-stop times (schedule.txt file) covering the whole winter period (see below) and a pre-set filter sequence (edited under Filter Wheel Menu/Filter Wheel Sequencing). To access the software for manual operation etc., run "Utah Capture", or simply click on the short cut screen icon called "Airglow Capture". With this software running:

To Initiate the Automatic Capture Program
Under "Settings Menu" click on "Preferences".
Select "start auto sequence on launch"
Select "auto save images".
Click "OK"

The computer is now under the control of the schedule.txt file and will automatically take and store data accordingly (time of next sequence will be indicated in the on screen information box under "Auto Start/Stop"). To interrupt this procedure: Under "Control" menu select "Pause". This will temporarily stop the sequence. Tasks such as changing the filter wheel sequence etc. can then be performed. To resume the image capture sequence click on "Start Automatic Sequencing" under the "Control" menu.

To Capture a Dark or Bias Image
Under "Camera" menu click on "Dark Image"
Select exposure time e.g. 90 sec
Select camera gain = high
Click "OK"

This will generate a dark image (i.e.camera shutter closed). It will be displayed on screen and, if desired, can then be stored manually under the current day directory. Dark images are important and are used to monitor the health of the camera. In automatic mode the camera will capture a dark image every six cycles (selectable under Filter Wheel/Dark Sequencing).

The same procedure is used to capture a bias image, which is a measure of the electronic offset in the camera. The bias is a fixed level and has been set to ~ 800 +/-20 counts.

To View a Stored Image/Sequence
Under "File Menu" click "open" gives you the "file dialogue window"
Select "My Computer", and select drive with the data in it
Single click on directory you wish to open; image files will be listed under each filter
Click in desired filter/image
Use up/down arrows to scroll the images (hold arrow key down for fast viewing).

Schedule.txt file
This file is used to control the automatic start and stop dates/times of the camera and is located at **c:\utahair\capturebin**. It is installed for the winter 2000 operations but will need revising for subsequent years (file to be provided by BAS/ USU). Do not use the "Airglow Capture" program to generate a new file as its not tested. The file format is:

Start date (d/m/y) Start time (hh:mm) Stop date (d/m/y) Stop time (hh:mm)

Dates and times are in Local Time (which is set to UT for Halley observations).

7. Local Area Network and Data Storage

The airglow imager is set up to store its data to a networked drive supplied by OHSERVER. By this method the data are immediately available for viewing or analysis anywhere at Halley.

The connection to OHSERVER_NT is automatically made at boot and is mapped to drive N:. Normally the OHIMAGER (this is the name of the PC controlling the camera) would store its data to N:\DATA. The airglow imager automatically logs into both its local NT account and the network account on OHSERVER_NT using the user name **ohimager** and password **ohimagerdata**. The airglow imager capture program starts automatically and has an option to allow the automatic running of a schedule file.

Two remote access systems are provided for connection to the OHIMAGER PC should the need arise (for instance to change a filters exposure or to reboot the system). Both of these systems automatically start when the PC starts NT. Reachout is the preferred system, clients need to log on to the OHIMAGER PC using the normal NT account. VNC is also provided, its slow and clunky but has the advantage of having both UNIX and NT clients - it uses its own password to log on which is Halley 5 (NB case).

When Windows NT boots, it has a delay time of 999 seconds (set in control panel, system, startup) to give the OHSERVER chance to boot up. IF the OHSERVER does not boot in time or if connection is not made then the airglow imager capture program will save its data locally. The network connection can be manually, or the OHIMAGER can be rebooted using one of the remote access systems discussed above.

Time synchronization is by TIMESYNC, syncs to //OHSERVER which in turn is sync'd to CHRONOS. Copies of VNC and TIMESYNC are stored on both the OHIMAGER PC and on the OHSERVER. Reachout is supplied on the manufacturers CD.

8. Trouble Shooting

Reduction in Image Quality

One of the most common problems encountered in the past is an unexpected reduction in image quality. If at any time the quality of the images starts to reduce or they become noisier first check the parameters settings are nominal (see section 5). The most likely cause of a loss of quality are (1) change of focus or (2) insufficient cooling for the CCD. If the latter case first investigate the liquid pump and determine if liquid flow is being impeded. Try to clear the blockage and if successful resume measurements. A spare pump is available if pump has failed. However, it is also possible that the reduced image quality is due to an impending problem with the camera control unit. Feel the sides of control unit to determine if they are unusually hot (they are normally luke warm). This may be due to the unit being too close to the wall or to a much hotter room than normal? If the unit is hot for no obvious reason report problem to Cambridge immediately. Then assess overall system performance carefully (i.e. do the image data still look good enough to see airglow structure?) and if so leave system to take data unless deemed dangerous.

Pump Checks

The best way to test the pump is operating correctly is to observe the CCD temperature. If its at its nominal temperature of ~ -42 C then all is well. If the temperature of the CCD is only about -25 to -30 C then this indicates that the water flow has probably stopped (if temperature is somewhere in-between this may indicate impeded liquid flow). Note, if the Peltier coolers fail the CCD will be much hotter, possibly hotter than room temperature. If so shut power off immediately as it will damage the camera. In general, whenever you suspect a pump problem, first stop camera operations and power off the control unit. Examine the hose connectors for any possible obstructions. Is the tank liquid clear and free from algae? If so follow cleaning procedures (see Section 2). If necessary, replace the pump with the spare (use new liquid) and connect up and test as described above. Don't panic, remember to set the pump to the current operational temperature. Power up the pump and then the camera and if all is well the camera should achieve temperatures below -30 C in a matter of minutes (takes longer to reach the nominal operating temperature). If for any reason you replace the pump please clean the old one and try to get it repaired.

If Watlow unit flashing "hi" then its possible that the refrigerant has leaked from the pump (this happened to pump Serial No 072999-2823-02 during the voyage to Antarctica). It was refilled at Halley and has performed well to date (February 2000) but its long term condition is not yet known. Note pump S/N (-01) had a compressor fault and was repaired at Cambridge prior to shipping to Halley. If necessary, swap over to this pump and get the unit repaired and re-filled.

Replacing the Camera Shutter

The camera "exposure" shutter is a very sensitive but robust device that is designed for many thousands of operations. It is mounted in the camera head immediately behind the Canon lens and will wear out after a few seasons. The computer commands a solenoid on the shutter to fully open for a set time (the exposure time) and then close to complete the exposure. A sign that the shutter is failing is incomplete opening of the shutter. The images will appear to be smaller and could show irregular shapes around the edge (as it images the shutter leaves). In which case the shutter needs replacing. There is one spare shutter available.

To replace the shutter it is necessary to disconnect the camera head from the lens system. First power off all units and disconnect the liquid hoses from camera head (they will leak so have a bucket ready). Next disconnect the camera cable from the base of the camera head (be gentle) and immediately screw in the blue shorting plug into the camera socket to prevent static discharge problems. There is no need to disconnect the cable from the control unit end. Now, referring to the camera head assembly procedure first unscrew the Canon lens from the "felt ring" in the optics extension tube. Then mark position of camera head with respect to the mount (so you can put it back with the same alignment) and carefully undo the three retaining grub screws in the black ring (at the front of camera head) and withdraw the attached Canon lens through the retaining ring. This can be done with the camera system still mounted in its vertical position in frame but **be very careful** when unscrewing the grub screws as the camera head could drop suddenly! At a bench separate the Canon lens from the camera head by depressing the silver button on lens base and twisting (as per assembly instructions). Next remove the black front cover from the camera head (three Allan screws). Make a note of the alignment of the black cover with the beige camera shell (as the screw holes are not symmetric). The shutter is system is now visible. Disconnect the white connecting plug. Unscrew the shutter and replace with new unit. Reconnect shutter plug and check cables are well positioned and do not interfere with image aperture. Now reconnect system following reverse order.

9. Transportation

When transporting the camera system care must be taken to protect the optical system and camera head as they are easily damaged. Use the following procedure:

1. **Critical first step:** Disconnect the short (1.5 m) camera cable from the base of the camera head and then screw the shorting (blue) plug into camera base to prevent static discharges. Next disconnect all other electrical and computer connectors.
2. Disconnect liquid hose from the camera head. The hoses contain a fair amount of liquid which will leak out so they should be discharged into a bucket. Next disconnect hoses from pump (again expect a discharge) and extract pipes through the wall duct.
3. Carefully remove cocoon from around filter wheel head (a clam shell in six parts).
4. Unscrew the four Allan screws holding the U channel to camera mount and lower camera system onto a bench in the main Caboose room (takes two people).
5. Disconnect the shutter cable (twisted pair) at the top and unscrew the top lens/shutter assembly from the filter wheel housing. Put all-sky lens cap on and wrap up lens system in bubble wrap. Cover filter wheel aperture with a cardboard disk to keep system clean.
6. Remove all filters from the filter wheel and place in their protective boxes (on shelf in main Caboose area). Re-assemble filter wheel and cover aperture with cardboard disk.
7.. Remove camera head and Canon lens from bottom of camera system. Cover extension tube with plastic cap (stored tool box).
8. Separate camera head from Canon lens. Place protective cover over camera aperture (stored in camera head box) and wrap paper towels around hose sockets on base of camera head (to soak up any excess liquid). Carefully pack camera head in special box (on shelf in main Caboose area). Pack Canon lens separately in bubble wrap.
9. Bubble wrap the remaining camera/filter wheel unit and the electronics unit.
10. Empty and clean pump. Don't loose the nylon drain plug.
11. Dismantle the camera mount.

10 List of Components

OH01: Photometrics CH350 CCD camera head, S/N A98B2115 (USA)
OH02: Photometrics CE300 camera control unit, S/N A98A9138 (USA)
OH03: Caron 2050 W cooling units (two), S/N 072999-2823-01/02 (USA)
OH04: Keo Consultants Telecentric lens system, S/N E07506 (USA)
OH05: Canon 85 mm, f/1.2 lens, S/N 41155 (Japan)
OH06: Mamiya-Secor 24 mm, f/4 Fish-eye lens and shutter, S/N 12847 (Japan)
OH07: Aluminium frame for camera, S/N none, (USA)
OH08: Athena digital display (spare for filter wheel), S/N 9928-85892 (USA)
OH09: Animatics smart motor (spare for filter wheel), S/N E04767 (USA)
OH10: Photometrics camera shutter (spare), S/N 9903625 (USA)
OH11: Viglen Genie P3 computer, 450 MHz, S/N 1320652-SE2 (UK)

OH12: Viglen 17 inch monitor, S/N ON792501995 (UK)
OH13: Weyrad 240-110v Transformer (two), Part No Z3328 (UK)
OH14 Barr Assoc. Interference filters in filter wheel assembly (OH,O2,Na, Bg) (USA)
OH15: Photometrics shorting plug for camera head, S/N D100201 (USA)
OH16: Photometrics PCI Model II computer interface card, S/N 01-376-001 (USA)
OH17: Photometrics SCSIII cable (spare for camera), (USA)
OH18: Ryan-Herco 8 m hose for Caron cooling unit (USA)
OH19: Spares (contains connectors for pump, filter wheel screws, lens cleaner, and tape)
OH20: System operating software (on CDROM) and instrument manuals
OH21: Laboratory algaecide for Caron pump.

11. Contact Numbers and Addresses

If at any time you are uncertain about procedures or if you need help with operating or maintaining the camera please e-mail/fax (or phone if urgent) one of the following people:

Mike Rose (Research Engineer, BAS)
e-mail: mcr@pcmail.nerc-bas.ac.uk
Phone: UK (44) 1223-221-584
Fax: UK (44) 1223-221-226

Mark Clilverd (PSD Research Scientist, BAS)
e-mail:m.clilverd@bas.ac.uk
Phone: UK(44) 1223-221-541
Fax: UK (44) 1223-221-226

Mike Taylor (Research Scientist, Utah State University)
e-mail:mtaylor@cc.usu.edu
Phone USA (01) 435-797-3919/3519
Fax: USA (01) 435-797-4044
(Note: Time difference is 7 hrs. behind UT)

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All-sky measurements of short period waves imaged in the OI(557.7 nm), Na(589.2 nm) and near infrared OH and $O_2(0,1)$ nightglow emissions during the ALOHA-93 campaign

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Abstract. As part of the ALOHA-93 campaign a high performance all-sky CCD imaging system was operated at Haleakala Crater, Maui, to obtain novel information on the properties and sources of short period gravity waves over an extended height range ~80-100 km. Sequential observations of the near infrared OH and $O_2(0,1)$ bands and the visible wavelength OI(557.7 nm) and Na(589.2 nm) line emissions have enabled a unique comparison of the morphology and dynamics of the wave motions and their occurrence frequency at each emission altitude to be made. Two major findings are: (a) the detection of significantly higher amounts of wave structure at OI altitudes (~96 km) compared with that in the OH emission (~87 km) and (b) the discovery of an unusual morphology, small-scale wave pattern that was most conspicuous in the OI emission and essentially absent at OH heights. These data provide strong evidence for the presence of ducted wave motions in the lower thermosphere.

Introduction

The naturally occurring nightglow emissions provide an excellent medium for the remote sensing of short period (<1 hour) gravity waves in the upper mesosphere and lower thermosphere. In particular, image data give unique information on the two-dimensional horizontal parameters of these waves. To date, most imaging studies have been made of the bright near infrared (NIR) hydroxyl (OH) band emissions which originate from a well defined layer centered at ~87 km. Occasional observations have also been made of the NIR $O_2(0,1)$ At band (peak altitude ~94 km) [Hecht and Walterscheid, 1991] and the visible wavelength OI(557.7 nm) line (peak altitude ~96 km) [Armstrong, 1982], while measurements of the faint Na(589.2 nm) D lines (peak altitude ~90 km) are exceptionally rare [Taylor et al., 1987]. Measurements of more than one nightglow layer are uncommon, yet they provide a simple and powerful tool for exploring the propagation of gravity waves over an extended height region in the vicinity of the mesopause [Noxon, 1978; Taylor et al., 1987]. For the ALOHA-93 campaign a novel imaging system was developed to investigate the morphology and dynamics of gravity waves that existed in the ~80-100 km height range.

Instrumentation

The monochromatic imaging system utilized a bare (1024 x 1024 pixel) charged coupled device (CCD) of high quantum efficiency (~80% at visible, 50% at NIR wavelengths). The large dynamic range and low noise characteristics (dark current <0.5 e^-/pixel/sec) of this device provided an exceptional capability for quantitative measurements of faint, low contrast (<5%) gravity waves. The camera used a fast (f/4) all-sky (180°) telecentric lens system and a five position filter wheel. Table 1 lists the filter characteristics and exposure times. Four emissions were measured: the NIR OH and $O_2(0,1)$ bands and the OI (557.7 nm) and Na (589.2 nm) lines. A background measurement (Bg) was also made at 572.5 nm to aid the analysis of the visible wavelength data. The exceptional sensitivity of the imager enabled sequential measurements at a high repetition rate of 3-5 min for the OI emission and ~9 min for the other emissions.

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Observations and Results

Observations were made from 6 to 23 October, 1993 from the DOE Facility, Haleakala Crater, Maui (20.8°N, 156.2°W, 2970m). The weather conditions were good but deteriorated around the new moon. Nevertheless, excellent image data were obtained on ten nights and limited observations on a further four occasions. In total nearly 6,000 images were recorded.

Wave Morphology and Dynamics

Well-defined wave patterns were observed in all four nightglow emissions. Comparison of these data sets reveals that the most commonly imaged structure consisted of extensive, large-scale waves, termed "bands", which are generally believed to be the signature of freely propagating short-period (<1 hour) gravity waves [Taylor et al., 1987]. Although reports of multiple wave events are relatively rare, complex wave patterns consisting of two or more band events were routinely observed, especially in the OI emission. Several examples of wave structure are given in Figure 1. Figure 1a shows two near orthogonal band patterns imaged in the OI emission on 22

Table 1. Filter details and exposure times for the imager.

Filter	Wavelength (nm)	Bandwidth (nm)	Transmission (%)	Integration Time (sec)
OI	557.7	2.65	~83	90
Na	589.1	2.5	~80	120
Bg	572.5	2.67	~83	90
$O_2(0,1)$	865.5	12.0	~85	90
OH*	715-930	215	~80	20

* with a notch at 865 nm to suppress the $O_2(0,1)$ emission

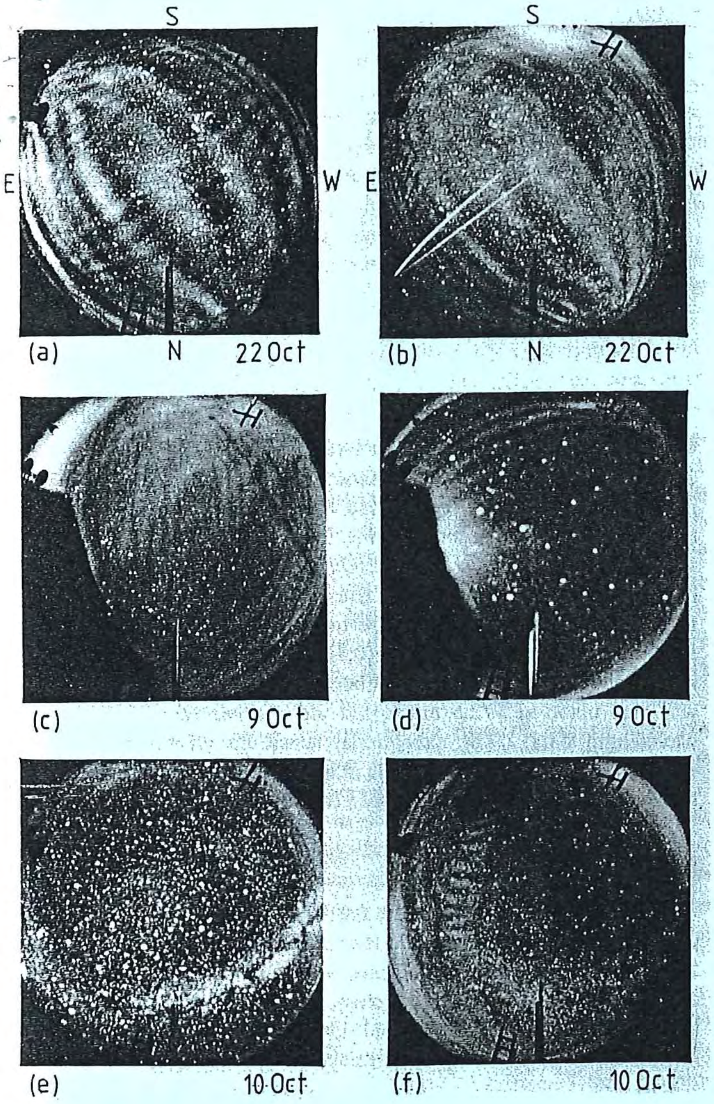

Figure 1, Images a-d show four examples of gravity wave "band" structure: (a) is an OI image recorded on 22 October at 14:45 UT, (b) is an Na image taken on the same night as 'a' but at 12:44 UT (note the bright lines show the University of Illinois Na lidar beam pointing at two azimuths during the 120s exposure), (c) is a complex OI image recorded at 11:28 UT on 9 October and, (d) is an O_2 image on the same night as 'c' at 13:24 UT. The shield in images 'c' and 'd' blocks out the rising moon. Image (e) shows an isolated NIR OH ripple event (top right of image) recorded on 10 October at 09:00 UT. Finally, (f) shows a new wave pattern consisting of a row of short wavelength waves imaged in the OI emission on the same night at 'e' as 09:30 UT.

October. The prominent wave progressing towards the SW was conspicuous in all four emissions (indicating that it extended throughout the ~80-100 km region), but the fainter wave progressing towards the NW was evident only in the higher altitude emissions. This is illustrated in Figure 1b which shows the same wave field imaged in the Na emission ~2 hours earlier. The dominant SW-ward wave motion is clearly seen but there is very little evidence of the second, orthogonal wave pattern. This situation arose often during the campaign indicating that a significant fraction of the waves exhibited ducted or evanescent behavior rather than freely propagating characteristics (i.e. they existed over only a restricted height interval). The horizontal parameters of these wave motions are given in Table 2.

Table 2. Horizontal wave parameters for the images of Figure 1.

Fig. 1	Emission	Height (km)	Time (UT)	Heading	λ_h (km)	v_h (ms^{-1})	T_{obs} (min)
(a)	OI	96	14:45	SW	38	34	19
(a)	OI	96	14:45	SE	19	40	8
(b)	Na	90	12:44	SW	36	27	22
(c)	OI	96	11:28	E	10	61	2.7
(c)	OI	96	11:28	NE	16	80	3.4
(c)	OI	96	11:28	SE	22	40	9
(d)	O_2	94	13:24	SE	25	37	11
(e)	OH	87	09:00	-	11	-	-
(f)	OI	96	09:30	N	12	53	3.9

An even more complex OI wave display is shown in Figure 1c which was recorded on 9 October. The contrast of the structures is not as high as in the previous image but at least three band-type motions progressing in markedly different directions can be distinguished. The predominant wave motion consisted of a large number (>12) of well formed, N-S aligned bands of short horizontal wavelength (~10 km) moving eastwards. The leading crests of the second set of waves (evident to the SW) exhibited pronounced curvature (Figure 2) suggesting a "point-like" wave source. (Note, these waves appear linear in the image due to the all-sky format.) The third wave pattern consisted of a set of faint bands (that are visible near the zenith and at low elevations to the NW) progressing towards the SE. While the first two wave motions were present primarily in the OI emission, these bands were evident in all four emissions. Figure 1d shows this wave motion in the O_2 emission ~2 hours later. The three leading O_2 wave crests are also plotted in Figure 2 and show similar horizontal scale sizes to the OI bands but the wave field has rotated ~20° during the intervening period. These measurements indicate wave generation by three distinct sources, however, only the SE-ward wave motion exhibited extensive vertically propagating characteristics.

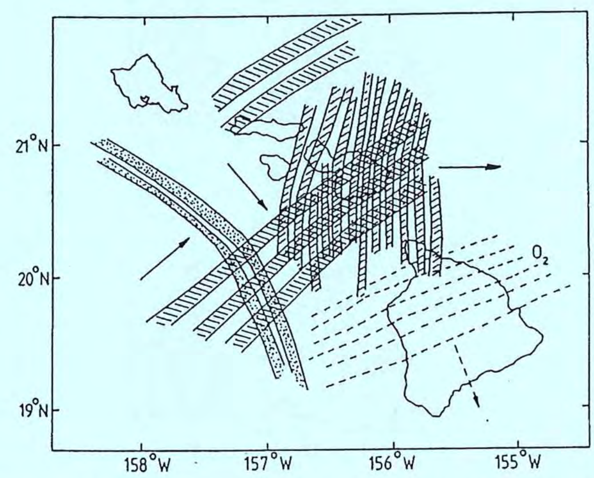

Figure 2. Map showing the geographic positions and scale sizes of the three OI wave motions evident in Figure 1c (assuming an emission height of 96 km). For comparison some of the O_2 data of Figure 1d are also plotted (assuming a height of 94 km).

In contrast to the band measurements, Figure 1e shows an example of a small-scale wave event termed a "ripple". Ripples are quite distinct from bands, exhibiting short horizontal wavelengths (typically 5-15 km) and extending over much smaller geographic areas. The ripples in Figure 1e were imaged in the OH emission and are typical of an isolated event lasting <30 min. However, ripples were also observed to occur in the presence of much larger-scale bands with no apparent association. An important new result of our ALOHA-93 measurements is that ripples were rarely (if ever) observed in all four emissions at the same time.

On several occasions we detected a novel morphology wave pattern which outwardly resembled a ripple event but which was considerably larger in spatial extent and had a much longer lifetime. Figure 1f is an example of this type of wave pattern. The image is dominated by a set of small-scale waves consisting of many crests (>14) aligned in a row. Occasionally these waves would appear as a single row (as in this image), but they were most often seen in groups of two or more rows, oriented in the same general direction and dispersed over a large area of sky. The apparent width of the rows was restricted to typically <50 km but their overall length spanned hundreds of kilometers. In this example the horizontal wavelength (λ_h) of the waves was 12 km (Table 2) and the row length >160 km. These unusual patterns were imaged on several occasions and were most conspicuous in the OI emission, less contrasted in the O_2 and Na emissions and were rarely imaged at OH wavelengths suggesting ducted wave motions. A detailed investigation of these patterns is presented in Taylor et al. [1995].

Frequency of Occurrence

Histograms of the frequency of occurrence of structure for each emission are given in Figure 3. The shaded areas indicate the amount of time that structure of any type (primarily bands) was detected somewhere within the camera's field of view (>600,000 km^2). The solid areas indicate the fraction of that time that small-scale structure, mainly in the form of ripples, was imaged. The total clear sky observing time for each emission was similar at ~80 hours, but as already indicated, theamount and type of structure detected in each emission varied considerably from night to night. Structure was most frequently imaged in the OI emission at ~95% of the observing time, and least frequently in the OH and O_2 emissions at ~57%. Likewise, ripples were most common in the OI emission (57% of structure time), while the OH and O_2 emissions again showed the lowest occurrence frequency (19% and 25% respectively). Of considerable surprise was the fact that wave structure was routinely detected in the faint Na emission at over 70% of the time, of which 35% was in the form of small-scale waves.

For most of the time the OI and Na emissions exhibited considerably more structure than the OH emission suggesting a preponderance for ducted (or evanescent) waves in the higher altitude emissions. However, from 18-22 October all four emissions showed similar wave activity with band structure detectable for much of the time suggesting a change in the prevailing conditions towards freely propagating waves. Observations of structure in the O_2 emission were anomalously low (compared with that in the OI emission) throughout the campaign.

Discussion

Data gathered during ALOHA-93 reveal a wealth and diversity of wave structure throughout the upper mesosphere and lower thermosphere showing that short period gravity waves are commonplace over the mid-Pacific ocean. Surprisingly, the occurrence of wave structure was considerably higher in the OI (>35%) than in the OH emission which was similar to previous measurements [Taylor and Hill, 1991]. As observations of the visible wavelength emissions are relatively rare, it is not known whether this situation was atypical. Recent measurements using the same imager at Bear Lake Observatory, Utah (41.6°N) also indicate a significantly higher occurrence of OI wave structure on many nights. This result provides persuasive evidence for the existence of ducted short period wave motions in the higher

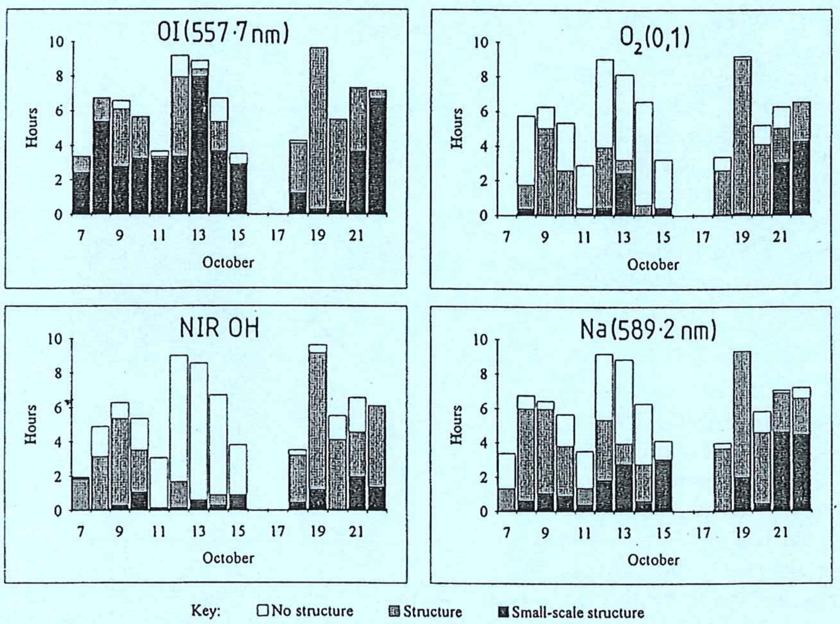

Figure 3. Frequency of occurrence of wave structure in each nightglow emission. No data were obtained on 16 and 17 October due to bad weather.

altitude emissions. These waves may have originated in distant tropospheric weather disturbances or alternatively they may have been generated in the upper atmosphere by the breakdown of large-scale motions possibly of tidal origin. An assessment of the relative percentage of ducted versus freely propagating short period waves is important (but has yet to be made) as ducted waves propagate over much larger horizontal distances before they impart their momentum into the background medium.

It is also possible that gravity waves may have been more easily detected at OI altitudes (~96 km) due to their growth in amplitude with height (assuming no dissipation). The higher occurrence frequency for Na structure (~90 km) compared with OH structure is consistent with this idea. However, images of the O_2 layer (which exists in close proximity to the OI emission at ~94 km) exhibited much less wave structure (similar to that of the OH emission) and do not support this notion. This point together with numerous observations of extensive, band-type displays in the OI emission that were essentially absent in the OH emission, indicates that other important factors, such asducting, can affect significantly the abundance of waves in the higher altitude emissions. Indeed, the short observed periodicities of many of the wave motions discussed here (Table 2) are close to the local Brunt-Väisälä period (~5 min) and are therefore susceptible to ducting in the vicinity of the mesopause.

Small-scale wave motions in the form of ripples were observed in abundance on some nights but were virtually absent on other nights. On several occasions OI ripple patterns were also observed simultaneously in different areas of sky but at acute angles to each other. Together with the fact that ripples were rarely observed simultaneously in all four emissions these observations provide strong support for the hypothesis that ripples are generated in-situ over a limited height range by short-lived velocity shears [Taylor and Hapgood, 1990].

The detection of a novel, row-like, wave pattern has prompted considerable interest. The elongated morphology of the rows of waves is a characteristic that clearly discriminates them from other small-scale "ripple" events. These patterns tended to occur on nights when there was marked gravity wave activity in the form of extensive bands and they often appeared to be aligned orthogonal to the larger scale waves. However, it is not thought that they are the signature of large-scale gravity waves breaking as their horizontal wavelengths (typically 10-20 km) are too large and their lifetimes (>1 hour) too long to result from such an instability [Fritts et al., 1993]. One possible explanation of this type of wave pattern, based on the interference of two ducted short-period band motions exhibiting similar characteristics, but slightly different propagation headings, is discussed in Taylor et al. [1995].

In summary, the CCD imager developed for this campaign has proven to be exceptionally sensitive, providing an abundance of data on short-period wave motions particularly at visible wavelengths. Initial analysis of these data have revealed:

1. copious amounts of wave structure in the OI emission,
2. first detailed image measurements of Na wave structure,
3. different occurrence frequencies for waves in each emission,
4. evidence of ducted, as well as, freely propagating waves, and
5. a novel type of ducted wave pattern, mainly at OI heights.

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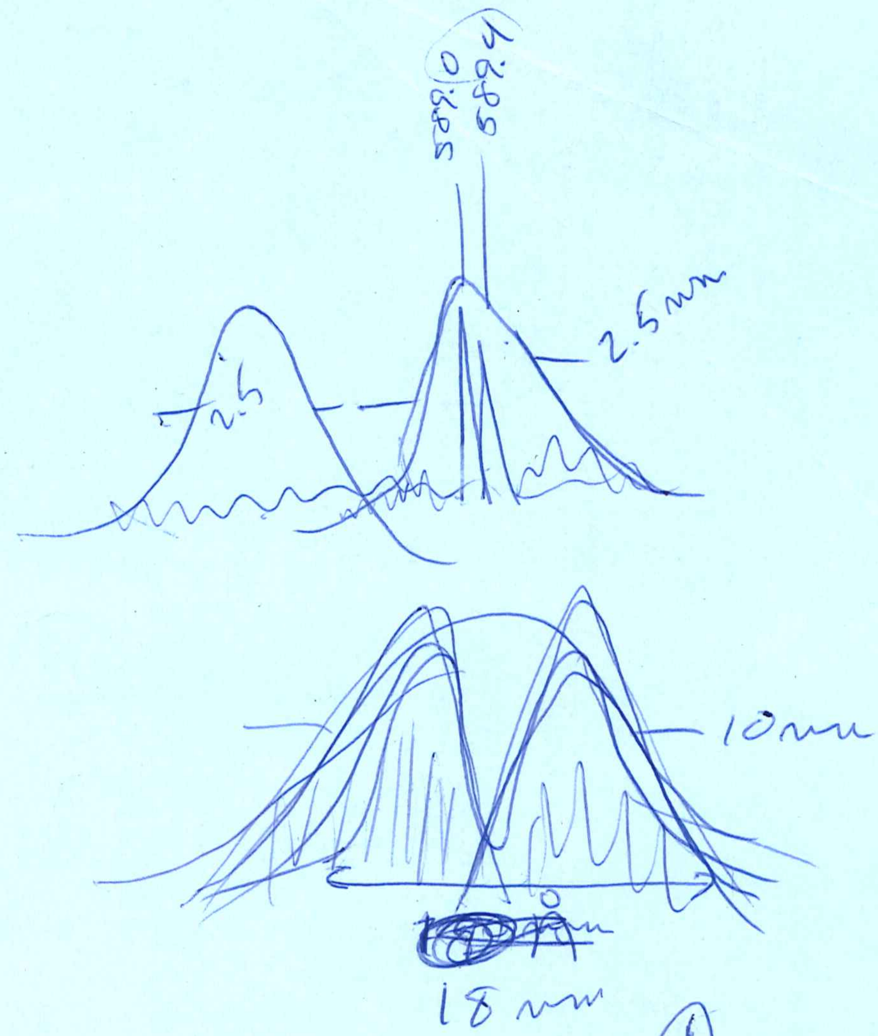

200 cm⁻¹ at 860 nm

$dk = \frac{d\lambda}{\lambda^2}$

$\lambda^2 dk$

$(860\times10^{-9})^2 \cdot 200\times10^{-4}$