SWIR at The Nordic Optical Telescope: NOTCam

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ABSTRACT

We describe the Nordic Optical Telescope's facility short-wavelength infrared (SWIR) instrument, NOTCam. The instrument will be capable of wide-field and high-resolution imaging, long-slit and multi-object grism spectroscopy, coronography, and imaging- and spectro-polarimetry. First light will be in mid-2000. Current progress is summarised and some problems we have encountered and overcome are discussed.

Keywords: instrument, imaging, spectroscopy, polarimetry, coronagraphy, infrared, SWIR

1. INTRODUCTION

The Nordic Optical Telescope (NOT) is a 2.56-m (Super) Ritchey-Chretien telescope sited on the Roque de Los Muchachos, La Palma, Canary Islands and built by a consortium of the Nordic countries (Denmark, Finland, Norway, Sweden and later, Iceland). It obtained first light in late 1988. It has an alt-az mount, active primary mirror, active cooling and accepts instruments only at the Cassegrain position. Although primarily used in the optical, some consideration was given in its design for use at SWIR and MWIR wavelengths.

The NOT provides excellent imaging quality over a large field ($\sim 20'$) with an uncorrected median seeing of $\sim 0.6''$. As such, and together with planned adaptive optics systems, the NOT can compete effectively with larger, optical and near-IR optimized telescopes. The lack of a facility near-IR instrument was an obvious deficiency in the NOT's capabilities and in June 1996, we committed to augmenting our standard instrument suite with a multi-mode infrared instrument based on the 1024^2 HAWAII HgCdTe detector.

The primary intention was to provide facilities for i) wide-field deep imaging (e.g. primeval galaxy surveys, brown dwarf surveys, star formation region surveys) and ii) high spatial resolution imaging (e.g. host galaxies around quasars/radio galaxies, disks around young stellar objects, details in shock-excited outflow structures, evolved stars, planetary nebulae). The growing interest in spectroscopy in the near-IR prompted the inclusion of low-resolution, grism-based, long-slit and multi-object spectroscopy capabilities. Finally, considerations were introduced into the design for polarimetry and coronography, extending these already established community interests to the near-IR.

At the time of writing the instrument, named NOTCam, has nearly completed electromechanical and optical integration at Copenhagen University Observatory (CUO). The engineering grade detector is being installed and verified before shipment to La Palma for integration of the science grade detector and optimisation for imaging use. We anticipate that the instrument will see first light mid-summer 2000.

The overall optical and mechanical design were contracted to the Royal Observatory Edinburgh, Scotland; mechanical detailing and fabrication to Prototech AS, Bergen, Norway; detailed optical design to Graseby Specac, UK. The detector was purchased from Rockwell Science Center, USA - a standard HgCdTe HAWAII $1024 \times 1024, 18.5\mu$ pixel array.[1] All other work, including electrical and electronic design has been done at CUO by the authors of this paper.

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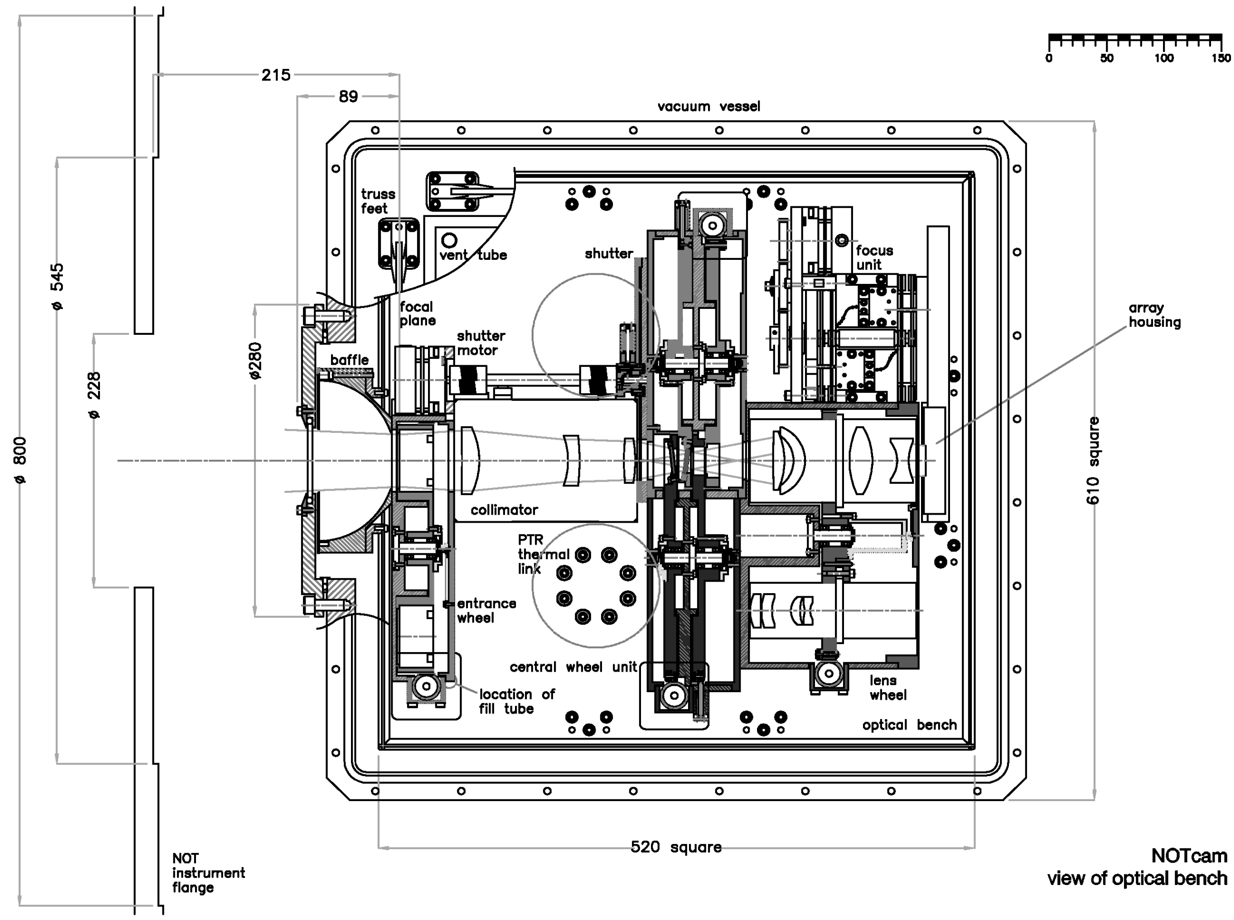

Figure 1. NOTCam instrument layout (dimensions in mm).

2. INSTRUMENT DESIGN

The instrument follows a typical design strategy, with focus on modularity for ease of maintenance. The cold table is oriented at 90° to the focal plane of the telescope and the optical axis follows a straight line through the instrument onto the detector. The cold table supports, in sequence from the dewar window:

1. A hemispherical, gold-coated baffle to reject light from outside the telescope beam.
2. An aperture wheel at the telescope focal plane to carry slits and masks.
3. Collimator
4. Rotating vane shutter
5. 2 filter wheels
6. pupil/stop wheel
7. grism wheel
8. camera optics wheel
9. detector

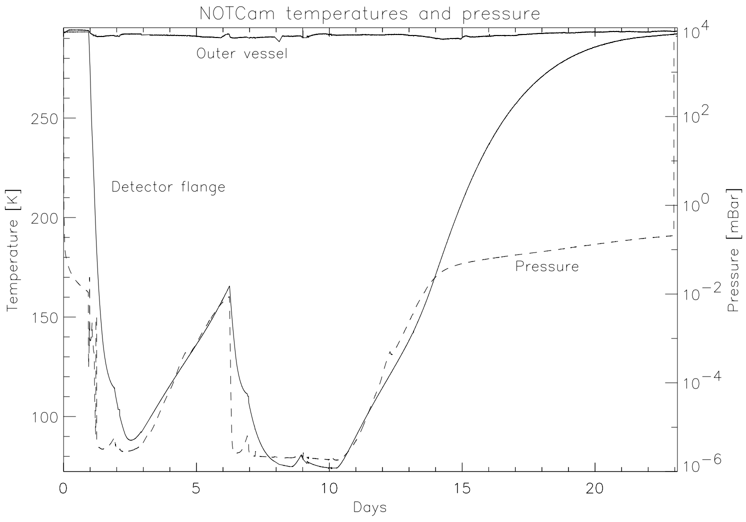

Figure 2. The profile of pressure and temperature changes through a cooling cycle. The solid lines are the temperatures of the outer vessel and detector flange, the dashed line is the variation of pressure within the dewar. The triangular spike centered on day 6 shows the effects of a partial warmup of the dewar on exhaustion of LN_2. The PTR was not used and the dewar not pumped during this cycle. Note the very slow convergence to LN_2 temperature of the detector flange; efforts are being made to shorten this time.

2.1. Cryogenics

Cryogenic operation is maintained with an LN2 tank directly under the cold table and which is supported by a pulse-tube refrigerator (PTR, from Iwatani, Japan). The cold table is mounted on eight G10 fibreglass legs providing thermal and electrical isolation, and high mechanical rigidity. The entire assembly is surrounded by a heatshield which, together with the bottom of the cold table, is wrapped in 30 layers of alternating aluminized-Mylar/nylon-mesh superinsulation (Jehier, France), and then covered by the dewar shell. An activated charcoal getter provides cryogenic vacuum maintenance. A profile of temperature and pressure variations throughout a cooling cycle is presented in Fig. 2.

The $\sim$ 16 litre LN2 tank, hold time $\sim$ 48 hrs, is supported by a PTR which was found to draw $\sim$ 8.5 W at 77K, although this does vary with orientation and temperature (Fig. 3). The lack of moving parts in the cold head removes the need for sophisticated vibration isolation as required with other, Stirling cycle units. A valve unit does vibrate minimally, and will be mounted on the back of the telescope away from the instrument. The compressor unit will reside on the dome floor and water cooling is already installed at NOT.

2.2. Optical components

The collimator, imaging optics and pupil re-imager are all factory-aligned, sealed units. While providing a somewhat higher initial expense, this considerably simplifies the instrument assembly and alignment tasks.

The camera optics and pupil reimager all reside in the final wheel before the detector. There are two plate scales: $0.23''$/pixel (FOV: $4' \times 4'$) and $0.08''$/pixel (FOV: $1.5' \times 1.5'$), the latter sampling at the diffraction limit of the NOT at 1.6μm ($0.16''$) and appropriate for use with future adaptive optics systems. The collimator consists of 3 elements and the cameras and pupil imager have 4 each. Lens materials are BaF_2 and LiF.

The design emphasised the need to minimise ghosts. A scattered light analysis was done as part of the original design, and all lens barrels have been internally baffled and blackened to minimise stray light in the instrument.

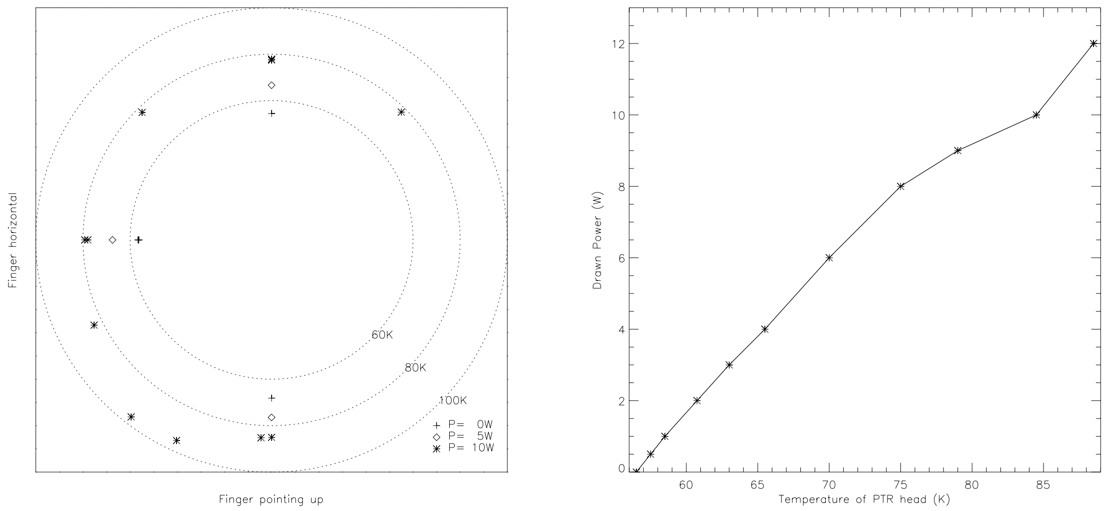

Figure 3. Variation of PTR cooling power with orientation (left) and operating temperature (right).

2.3. Filters, masks and grisms.

NOTCam may contain up to 11 slits and masks, 30 filters, 13 grisms and 15 stops or pupil masks (plus one more of each if an unobstructed light path is not required). These large numbers reflect the need to open the dewar for configuration changes as infrequently as possible. Grisms and filters will all be $\sim$ 25mm in diameter.

A full complement of filters suitable for the range of sensitivity of the HAWAII detector is being purchased from the Gemini IR Filter Consortium (coordinated by Alan Tokunaga, IfA, Honolulu).

At this time, project delays have forced us to concentrate on the imaging capability of the instrument, but initial designs for grisms have been explored and a spectral resolution of $\sim$ 1000 will be obtained in J, H and K.

2.4. Electromechanical/electrical/electronics

Electromechanical and detector control are managed by separate units designed and built at CUO and based on previous CCD and instrument control systems built there and in current use at NOT. Control intelligence is provided by Motorola 68XXX microprocessors throughout. The 5-phase Berger-Lahr stepper motors used to drive the wheels all reside on the cold table and are therefore cold when in operation; their bearings have been replaced to remove greasy lubricants. Every effort has been made to eliminate any hydrocarbons from within the dewar - wheel bearings are lubricated with sprayed-on and baked MoS_2, and electrical insulation is provided by PTFE jackets. Solder joints have all been cleaned thoroughly. Bolts are drilled for improved outgassing.

2.4.1. Detector controller

The detector controller is a modified, even simplified, version of the standard CUO CCD controller. It comprises 4 basic elements:

1. A host computer (PC/Linux) with a custom, 10 Mbit/s optical MMF interface.
2. Controller box with linear power supply, MC68020-based sequencer, clockdriver (20 lines), 2 video boards carrying two bias generators and video-chains each, and an opto-coupled I/O board for communications with external units (shutter, temperature control, etc.)
3. 2 dewar support boxes, coupled directly to the vacuum connectors, each with protection circuits and preamplifiers for 2 video channels.

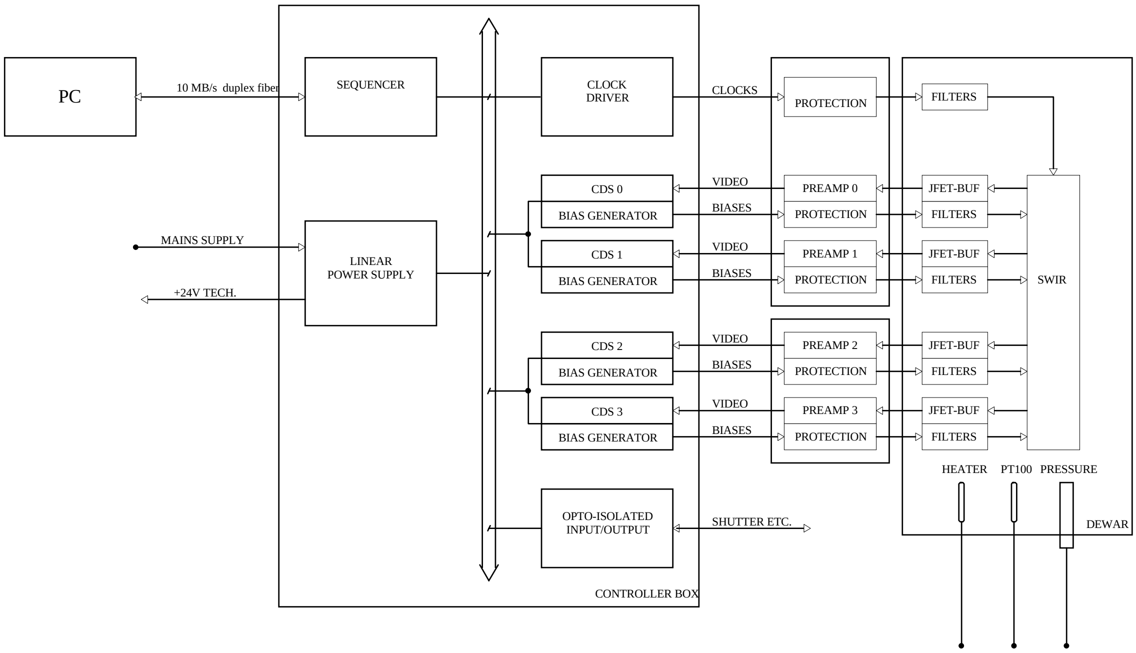

Figure 4. Block diagram of CUO detector controller as adapted for use with HAWAII detectors.

Since the HAWAII array multiplexer is a purely 5V device, it is driven directly by the digital control lines of the board controller (a PLD) without the need for level-shifters normal for CCDs. Each detector quadrant requires 6 clocks, but the four LSYNC and four FSYNC lines can respectively be driven in parallel without compromising functionality, thus we use a total of 18 clocks, leaving two spare.

To minimise readout noise and suppress amplifier glow, the on-chip MOSFETs are not used; instead a JFET follower is placed nearby within the dewar. The new, DC-coupled preamplifier, with baseline provided by one of the controller bias generators, uses a noninverting, FET-buffered, bipolar op-amp input stage which provides the majority of system gain. The second stage is a Sallen-Key, two pole filter. The resulting 3-pole Bessel transfer function guarantees an optimal compromise between settling time and frequency cutoff.

The system is limited by the fibre-link bandwidth – in practice, the minimum transfer time of 4 pixels (one from each quadrant) is $\sim 10\mu$s, providing a fastest readout time of ~ 2.5s. Noise performance is still unknown, but is expected to be around 10 electrons/pixel.

2.5. Coronography

The Instituto de Astrofisica de Canarias (IAC) in Tenerife is constructing focal plane and apodising masks which will allow study of the faint faint environment surrounding bright objects. This is a complex assembly which includes a rotating apodising mask – necessary in alt-az telescopes – and glassless, back-supported, obscuring spot masks.

2.6. Polarimetry

NOTCam will carry a Wollaston prism in its pupil wheel and a mask in the aperture wheel, and a rotating waveplate assembly will be placed before the instrument in order to allow both imaging- and spectro-polarimetry in the SWIR.

3. SOME LESSONS LEARNED

3.1. Dewar Contamination

Near the beginning of 1999, it was discovered that some form of greasy contamination was present within the dewar. The precise cause is not known, as every effort had been made to keep the dewar free of greases and dry vacuum pumps had been used. The contaminant was discovered in the form of greasy droplets on vacuum pump couplings and cool components when the dewar was pumped and baked. A repeated procedure of washing with acetone and baking and pumping was found to be the only reliable method of removing this contamination. A satisfactorily clean dewar was obtained after repeating this procedure over a dozen times.

A residual gas analyzer (RGA, Stanford Research Systems, USA) was used to help diagnose the problem, but in the end helped more by rejecting hypothesised causes than by identifying any specific source. Nevertheless, we recommend the use of RGAs as invaluable tools for vacuum quality test and diagnosis; they are small, cheap and easy to use.

3.2. Anodisation

In the early design stages, it was decided to black anodise as many internal components of the dewar as possible. The motivation was to reduce the affects of scattered light and the increased porosity of the cold, anodised surfaces was expected to provide additional gettering. Dry, dyeless anodising was intended but unfortunately, in the event, wet anodising with a purple dye was applied. The anodisation has probably contributed to the contamination in the dewar through trapping and subsequent outgassing of water. While the water itself is not a significant danger to the instrument components, it has increased the pumping time necessary after opening the dewar.

Tests using samples in a small test dewar have demonstrated that gettering by the anodization is unlikely to be significant. In restrospect, this should have been anticipated. We may eventually remove as much of the anodising as we can by immersion in NaOH solution followed by bead-blasting, but for the moment, we are continuing with it present.

ACKNOWLEDGMENTS

We are grateful to the subscribers of the CCD-world mailing list (ccd-world@astro.ku.dk) for providing valuable information at several points.

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