Feedback from the Instrument User Groups for the November 2006 meeting on strategic mid- and long-term planning for the CNO and NOT

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NOT Instrument User Group for Optical Imaging

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This IUG report is submitted in preparation for the Copenhagen meeting on scientific and instrumentation strategies for the future of the Nordic Optical Telescope and a future Common Northern Observatory (CNO) on La Palma.

Our group was given the task of reviewing current and planned future instrumentation for optical imaging at NOT and CNO and point out possible redundancies. Furthermore, we were asked to address particular questions concerning FRED (is it still worthwhile to have it commissioned?) and ALFOSC (should the current CCD be replaced with a more red-sensitive chip?). While we discuss these issues in our report, we strongly believe that the answers must ultimately depend on the merit of science cases for the use of these instruments, and we do not attempt here to make, or guess the content of, such science cases. Finally, we briefly review some options for future instruments or instrumentation upgrades.

We start, however, with some general concerns about NOT and CNO which we believe should be taken into consideration:

Some decisions on post-2009 instrumentation will depend on the typical operations mode of CNO. Will the instrumentation and telescope operation be coordinated such that there will always be an imager available on one of the CNO telescopes (e.g., for ToO and monitoring-type observations)? Will there e.g., be a possibility for coordinated (near-)simultaneous observations in different wavelength regions by different CNO telescopes, or should NOT still be regarded as a standalone telescope, e.g., with emphasis on maximum flexibility, compared to the other telescopes? A related question is how many similar instruments will be needed at the CNO; e.g., (an extreme case) would it be enough that TNG is for spectroscopy only, NOT for imaging and WHT for IR observations? The need for future instrumentation at NOT will clearly depend on such issues.

The fact that NOT is a smaller telescope than either TNG or WHT makes it somewhat difficult to identify a highly competitive niche for NOT within a CNO collaboration. Given the optical quality and good seeing at NOT, it makes sense to ensure the availability of high-quality imaging instrumentation at NOT. One of the main current advantages of NOT is the flexibility of the telescope (ToO- and monitoring type observations are generally accommodated; possibility for quick shifts between observing modes), and we believe it would be worthwhile to explore how this flexibility can be expanded even further within the CNO context.

Instrumentation for optical imaging

Here, we briefly review the current and planned future NOT and CNO instrumentation for optical imaging.

Existing instrumentation

Some basic properties of NOT and CNO instruments for imaging are listed in Table 1.

Table 1. Comparison of the characteristics of instruments for optical imaging at La Palma. Refer also to the plots of instrument sensitivities vs. wavelength in Figure 1, which also accounts for differences in transmission/reflectivity of optics, size of telescope, and detector QE.

Telescope/Instrument	Detector	pixel size	FOV	max. # filters
NOT/ALFOSC	2k x 2k E2V	0.188"	6.4'	7 + 12
NOT/MOSCA	2x2 2k x 2k Loral	0.11"	7.7'	12
NOT/StanCam	1k x 1k SITe	0.176"	3'	7
NOT/FRED	2x1 2k x 4k E2V	0.25"	17.5'	6
WHT/PFIP	2x1 2k x 4k E2V	0.24"	16'	7
WHT/AUX	2k x 2k E2V	0.11"	1.8'	5
INT/WFC	4 2k x 4k E2V	0.33"	34'	6
TNG/OIG	2x1 2k x 4k EEV	0.072"	4.9'	10
TNG/DOLORES	2k x 2k Loral	0.275"	9.4'	11

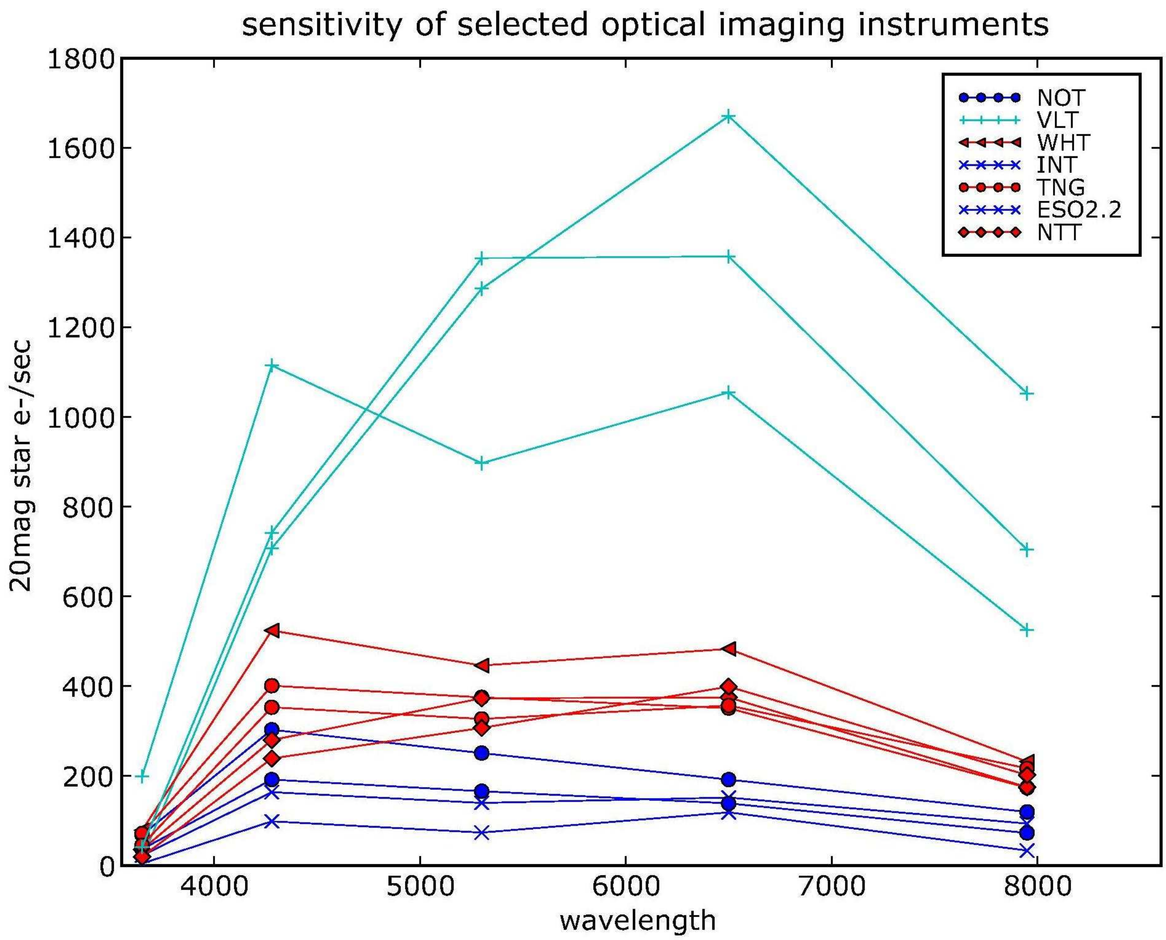

Figure 1. The wavelength dependence of the sensitivity of MOSCA and ALFOSC, compared to other telescope/instrument combinations on La Palma and at ESO. The plotted curves are based on the online exposure time calculator of each instrument, and refer to the number of electrons detected from a point source of magnitude 20.0 (in each respective passband), in one second of exposure time. The U-band sensitivity of the various instruments is more easily seen from Figure 2. The most blue-sensitive VLT instrument in this plot is VIMOS; the other two are FORS1 and FORS2.

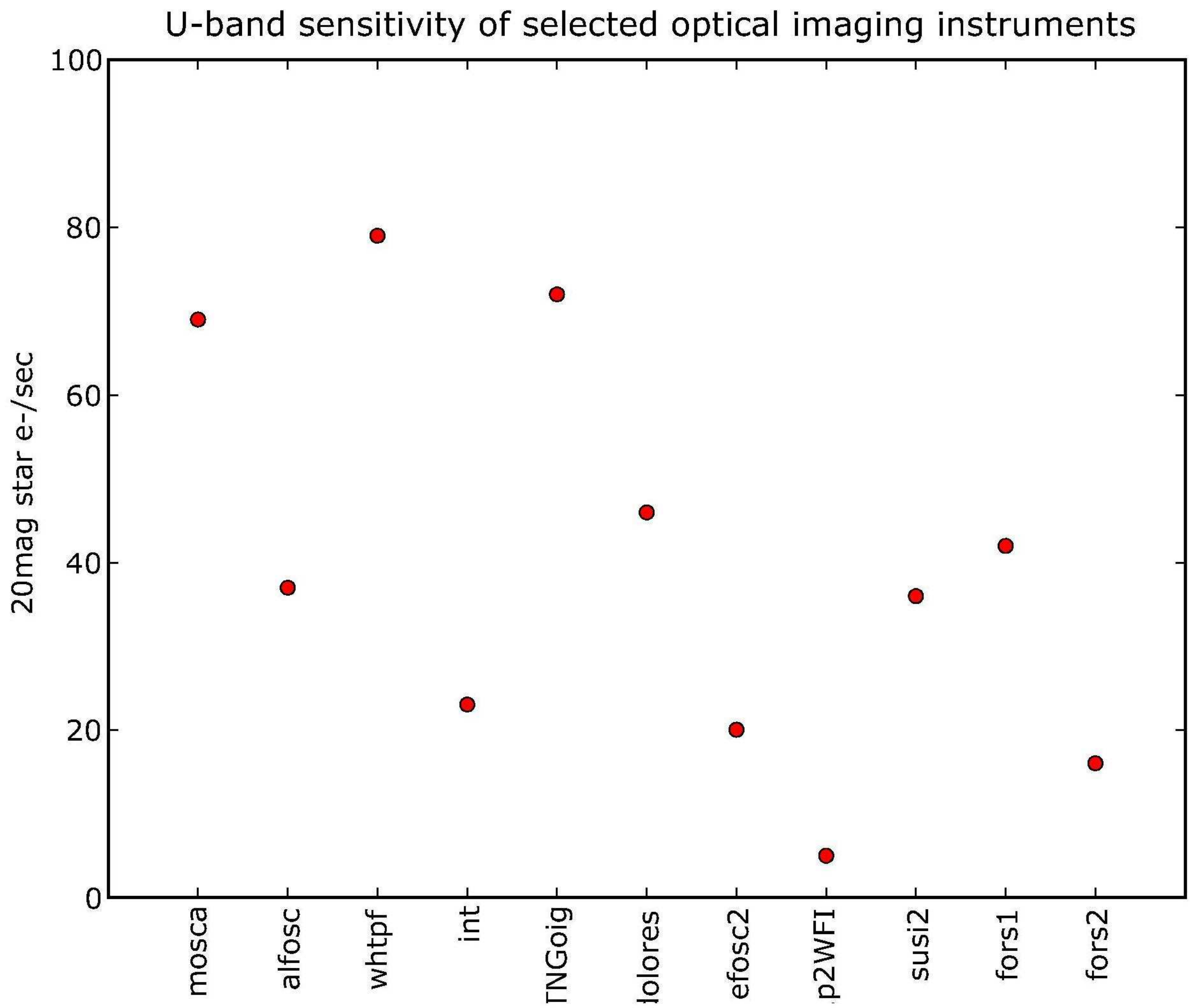

Figure 2. The *U*-band sensitivity of MOSCA and ALFOSC, compared to other instruments on La Palma and at ESO. The units of the plot are the same as in Figure 1.

ALFOSC

Since its commissioning in late 1996, the 2048^2 ALFOSC has been - and continues to be - the main workhorse for optical imaging and overall the most popular instrument at the NOT. The new Auxiliary port imaging Camera (see below), which should be available at WHT from 2008, seems to have rather similar capabilities to ALFOSC, but its detailed characteristics are not certain yet.

As MOSCA has sensitivity superior to ALFOSC at all wavelengths, particularly in the blue, there may be a case for replacing the ALFOSC detector with a more sensitive CCD, in either the red or in the blue. A replacement of the CCD is recommended, but this must be seen in connection with the desired spectroscopic capabilities of ALFOSC and the strongest science cases provided by the community. Arguments in favour of a red-sensitive CCD include the strong fringing of the current CCD, even in the R band and the synergy with NOTCam, e.g. for probing very red objects or the very high-redshift universe. The main argument in favour of a blue optimization, from the imaging point of view, is that ALFOSC will probably be more competitive in the blue than it would be in the red (compared to instruments at other telescopes), even with a more red-sensitive CCD, as indicated by Figs. 1 and 2.

MOSCA

While MOSCA has superior sensitivity to ALFOSC at all wavelengths, and also has a slightly larger field, ALFOSC is more often the instrument of choice for imaging observations. This is probably mostly due to the additional work of reducing data from 4 chips rather than one, and the greater flexibility of ALFOSC, compared to MOSCA.

As indicated by figure 2, the outstanding feature of MOSCA is an excellent U-throughput, caused by the simplicity of the instrument and high UV sensitivity of the CCD. This makes NOT/MOSCA highly competitive in this wavelength band, also compared to instruments at significantly larger telescopes, which tend to have more optical surfaces and red-optimized CCDs. Considering the choice of existing CNO instruments,and also considering the optimal use of overall telescope time at CNO, MOSCA should be the instrument of choice for programs that require deep imaging blueward of the *V*-band, with a moderate field of view. One of the MOSCA chips is currently not working, and the instrument has been sent to Copenhagen for repair.

StanCam

The purpose of StanCam is to offer optical imaging at times when an optical imager is not available as the main instrument. This makes it possible to run optical monitoring and ToO-type programs continously at NOT, independent of the main instrument schedule. In combination with NOTCam, Stancam offers near-simultaneous imaging over a very wide wavelength range (*UBVRIJHK*), which is rarely available at other telescopes.

Thus, in the pre-CNO era, StanCam is clearly enhancing the capabilities of NOT in important ways, ensuring high flexibility and versatility. However, in the context of CNO, the future of such standby instrumentation will depend on the degree of coordination of the operations modes of the CNO telescopes. For example, the future Auxiliary port imaging Camera at WHT (see below) will also be available most of the time for imaging, probably with a significantly higher sensitivity at all wavelengths (the existing Tek chip of StanCam has 70% and 80% of the sensitivity of ALFOSC in blue and red, respectively).

Instrumentation funded and/or in construction

FRED

FRED is a yet-to-be-delivered part of the core instrumentation plan that was conceived for NOT in the mid-90s. This instrument was originally intended to make NOT competitive for wide-field survey work. The efficiency of a telescope/instrument for projects that aim to cover as much sky as possible to a given depth, can be simply defined in terms of a ``figure of merit'' $A\Omega$, where A is the mirror area and Ω is the solid angle of sky covered by the detector. FRED will have an $A\Omega$ value which is less than 5% of the value of Megacam at CFHT and Suprime-Cam at Subaru. Hence, FRED has not been competitive for such survey work for the past 5 years, and any motivation for this instrument will be quite different from what was originally intended.

However, the availability of this instrument would enhance the capabilities of NOT, particularly for observations of objects that do not fit within the current FOV of ALFOSC or MOSCA, e.g. star clusters, nearby galaxies and galaxy clusters, and observations of small bodies in the solar system with uncertain orbits.

Having five more optical surfaces than MOSCA, the expected sensitivity of FRED is expected to lie somewhere between MOSCA and ALFOSC. As seen from Table 1, the existing PFIP instrument at

WHT has characteristics that are quite similar to FRED. There is a question of how many similar instruments are needed at the CNO, but if PFIP continues to be available at WHT after 2009, the case for FRED within the context of CNO may be quite weak. However, if there are compelling science cases that require the use of FRED before 2009, a case could still be made for this instrument.

The demand for FRED can be gauged from the scientific group reports submitted, so we will not speculate further on this in our report.

AUX

A new Auxiliary port imaging camera for WHT has been funded. It is to be permanently mounted and therefore always available except when WHT is set up for prime focus observations. This instrument will carry out both scheduled and ToO-type observations and will be capable of both imaging and low-resolution spectroscopy.

The following specifications are not confirmed and subject to change, as the project is still in the concept stage:

- Field of view: 8'
- Wavelength coverage: 380-850 nm
- Detector: 2k x 2k, with 13.5 micron pixels
- Sampling: 0.3”/pixel
- Image Quality: < 0.5” across full field

The instrument should be available some time in 2008. Being apparently quite similar to ALFOSC at NOT, this instrument again raises the question of how many similar instruments are needed at different CNO telescopes.

Possible new instruments

We strongly recommend that any new instrument/device at NOT and CNO should be motivated by a strong science case, and be ensured adequate manpower, commitment and resources for its timely completion. We do not intend this report to fill the role of making such a science case, but mention below some of the possibilities that have been discussed.

Lucky imaging

The “LuckyCam” imager offers fast readout with low readout noise, together with frame-selection. This can be used to make close to diffraction limited images (under excellent seeing) for wavelengths redward of $H\alpha$, within a field of view up to 30”. The most obvious advantage of this type of instrument is use of an optical detector, offering studies at shorter wavelengths than AO systems at other telescopes, which typically use IR detectors. To achieve the improvement in resolution, a star with $I<16.5$ has to be available within the field. This requirement limits the sky coverage to ~7% at Galactic latitudes 60-70˚, increasing to ~30% at 20-30˚, while the sky coverage is virtually complete close to the Galactic equator.

Service observations with LuckyCam have been offered at NOT during the past few years, the actual observations being carried out by the British group which developed the instrument. Currently, these efforts are limited by lack of manpower, so there will not be any new data in the near future.

We suggest that if there is going to be any major NOT efforts in this direction, one would first need to determine more precisely how competitive the LuckyCam data are, compared to other instruments for high-resolution imaging within small fields. To our knowledge, "lucky" imaging of very faint sources (*R*~25-26) has not been reported, and we would like to see a proof of concept for imaging of very faint sources, which is required to be competitive for HST type science. As noted below, the experimental CorPol instrument could have similar capabilities, and could (having a coronagraphic mask and a polarimetric option) be more versatile than the current LuckyCam. The manpower problem will also need to be resolved, if the LuckyCam version is chosen for "lucky" imaging at NOT. Obvious wishes for future improvements of such an instrument are a larger field of view, and perhaps also two parallel cameras, one for guiding (using a broadband filter), and one slightly offset for on-target science, e.g. with a narrowband filter or a grism.

The LuckyCam proposals so far have been (outside the LuckyCam team): Young Stellar Objects, Hα imaging of supernova remnants in M31, optical pulsars and pulsar winds, environments of QSOs host galaxies, and QSO jet properties.

Polarimetry

There is an interest in a Wedged Double Wollaston (WeDoWo) polarimetry device for ALFOSC which would enable simultaneous measurements of the Q and U Stokes parameters. This concept has already been tested on a similar instrument (AFOSC at the Asiago 1.8m telescope), and has a moderate cost. Upgrades to FAPOL (e.g., a new calcite plate which could increase throughput by up to 15%) would enhance the performance of this instrument, and should also be considered in this context. We recommend that a study (discussing the relative merits of WeDoWo and FAPOL for the main scientific interests of the NOT community) should made by NOT users interested in polarimetry.

CorPol

This instrument has had a test run (unfortunately with bad weather) at NOT in October 2006. Although still in prototype mode, the instrument seems in principle to combine several interesting features (both fast, "lucky"-type readout and slow readout/ polarization coronography mode/ polarization mode and imaging mode). If offered as a standby camera, an instrument of this type could make NOT even more versatile than it is today.

Multi-arm imager

A multi-arm imager with beamsplitters, offering simultaneous imaging in at least two passbands, would clearly enhance the efficiency of NOT for a range of programs. Such an instrument could have CCDs and optics optimized for particular wavelength ranges, and would allow for differential colour photometry to be obtained even in non-photometric conditions. A spectroscopic option could also in principle, but with a considerable additional cost in terms of money, complexity and probably some loss of sensitivity. In any case, the lead time of such an instrument would be fairly long, making it necessary to consider it in the context of other CNO instrumentation.

NEAR-INFRARED IMAGING

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1. INTRODUCTION

The aim of the Nordic Optical Telescope (NOT) near-infrared imaging Instrument User Group (IUG) is to advise the Scientific-Technical Committee (STC) and the Director on the current performance of NOTCam, and on the desirability and priorities of instrument upgrades in the short and long term.

2. CURRENT TASK

The long-term future of NOT will probably be as part of the proposed Common Northern Observatory (CNO). The IUGs are asked to review the instrumentation now available or being constructed at NOT and at the other telescopes of CNO (primarily the WHT and TNG) and assess which of these answer Nordic needs that are not currently covered by NOT, where redundancies of instrumentation seem to exist, and also where there are gaps that should be filled in for the future CNO to serve the Nordic community properly in the northern hemisphere.

3. CURRENT INSTRUMENTATION FOR NIR IMAGING AT THE CNO

3.1. OVERVIEW

Instrument (Telescope)	Detector	Scale ("/px)	FoV (')	Notes
NOTCam (NOT)	HgCdTe 1024x1024	0.23	4.0	WF
		0.08	1.4	HR
NICS (TNG)	HgCdTe 1024x1024	0.25	4.2	LF
		0.13	2.2	SF
		0.08	1.4	LF+AdOpt
		0.04	0.7	SF+AdOpt
NAOMI/INGRID (WHT)	HgCdTe 1024x1024	0.04	0.7	
NAOMI/INGRID/OSCA (WHT)	HgCdTe 1024x1024	0.04	0.45	
LIRIS (WHT)	HgCdTe 1024x1024	0.25	4.3	

3.2. NOTCAM (NOT)

NOTCam is the 0.8 - 2.5 micron multimode instrument at the NOT, based on a HgCdTe Hawaii 1024x1024 array. In its imaging mode, NOTCam is capable of both wide field imaging (0.23 arcsec/px; 4 arcmin fov) and high resolution imaging (0.08 arcsec/px; 82 arcsec fov) in broad and narrow band filters, and imaging polarimetry (with four polaroids).

3.3. NICS (TNG)

NICS (Near Infrared Camera Spectrometer) is the TNG 0.9-2.5 micron multimode instrument, based on a HgCdTe Hawaii 1024x1024 array. Its capabilities include imaging in broad and narrow band filters over two field-of-views (0.25 arcsec/px; 4.2 arcmin fov and 0.13 arcsec/px; 2.2 arcmin fov), imaging polarimetry, and, when coupled to the adaptive optics (AdOpt) module, nearly diffraction limited imaging (0.08 arcsec/px; 1.4 arcmin fov and 0.04 arcsec/px; 0.7 arcmin fov). At the moment, the AdOpt module only provides tip-tilt correction.

3.4. INGRID/NAOMI/OSCA (WHT)

INGRID (Isaac Newton Group Red Imaging Device) is a NIR camera at the WHT, based on a HgCdTe Hawaii 1024x1024 array. INGRID is permanently attached to the adaptive optics system, NAOMI, and delivers near diffraction limited broad and narrow band imaging in the J, H and K bands (0.04 arcsec/px; 41 arcsec fov). Furthermore, INGRID can be used in conjunction with an AO coronagraph, OSCA (Optimised Stellar Coronograph for Adaptive Optics; 0.04 arcsec/px; 27 arcsec fov).

3.5. LIRIS (WHT)

LIRIS (Long-slit Intermediate Resolution Infrared Spectrograph) is a NIR imager/spectrograph at the WHT. LIRIS uses a 1024x1024 HgCdTe HAWAII array in the 0.8 - 2.5 micron range. The pixel scale is 0.25 arcsec/px, yielding a field of view of 4.3 arcmin.

4. FUTURE NEAR-INFRARED INSTRUMENTATION AT THE CNO

4.1. NOT

NOTCam will be upgraded with Wollaston prisms for imaging polarimetry.

4.2. WHT

A laser guide star system GLAS (Ground-layer Laser Adaptive optics System), is being developed at the ING, and will be integrated into the adaptive optics system NAOMI in the near future. This will be a unique opportunity at the CNO to open up virtually the whole sky for AO observations with INGRID.

4.3. TNG

Higher order corrections for AdOpt will be available in the near future.

4.4. GTC

Neither of the two GTC commissioned science instruments (OSIRIS, CanariCam) are in the field of NIR imaging. A second generation instrument for the GTC, EMIR, will be a wide-field NIR multi-object spectrograph. In addition to the MOS mode, it will be capable of NIR imaging in broad and narrow band filters (0.2 arcsec/px; 6 arcmin fov).

5. NOTCAM COMPARED TO OTHER CNO INSTRUMENTS

Here we wish to point out areas where NOTCam is (and is not) scientifically competitive within the field of NIR imaging, compared to other current instruments at the CNO.

5.1. GOOD SEEING OVER A LARGE FOV

The field-of-view of NOTCam is ~4 arcmin with the 0.235 arcsec/px scale. This field is similar to that obtained with NICS and LIRIS, and considerably larger than that of INGRID. In this respect, NOTCam is scientifically competitive, also because of the consistently good seeing over this relatively large field.

5.2. NOTCAM + STANCAM

NOTCam used in combination with StanCam is a clear strength, allowing nearly simultaneous observations over a large wavelength base (UBVRIJHK), without complicated instrument setup changes. Nearly simultaneous optical and NIR imaging is currently not possible with the other CNO instruments.

5.3. DYNAMICAL RANGE

NOTCam is capable of handling short exposures through the use of a cold shutter. In addition, small cold stops have recently been installed in the pupil stop wheel to diminish the telescope area by a factor of up to 10, to enable photometry of very bright objects (e.g. planets, bright stars).

For example, NICS can not obtain exposures shorter than 3 sec, and offer grey filters for bright sources, resulting in diminished photometric accuracy. Also, in a deep, saturated, exposure of a field with bright stars, the crosstalk of the NICS array gives additional noise in the resulting image. Therefore, NOTCam is superior for bright targets and also in imaging over a large dynamical range (e.g. observing clusters).

5.4. AVAILABLE FILTERS

NOTCam has by far the best and largest selection within the CNO of high quality imaging filters available. Nevertheless, an upgrade has been suggested to the STC to purchase broad filters Z (0.84 - 0.93 micron) and Y (0.97 - 1.07 micron), which are part of the UKIDSS photometric system. A narrower Y filter Yn (1.00 - 1.05 micron) is already available. Such an upgrade would allow observing in the blue end of the NIR spectrum and have an overlap with the optical Z band. With a corresponding upgrade of grisms it would allow a better throughput than ALFOSC for the Z wavelength region. The factor of 3 - 5 improvement calculated for the engineering grade array would be further improved by the science array.

Also, if it is considered interesting by the community, another niche would be high accuracy NIR photometry using the narrower filters recommended by the Infrared Working Group (IRWG; Milone & Young 2005, PASP 117, 485).

5.5. SYSTEM EFFICIENCIES

The following table compares the total efficiencies of the respective instrument + telescope systems.

Zeropoint (1 e/s) magnitudes for JHKKs filters:

	J	H	K	Ks	A_{eff} (m^2)	gain (e/adu)
NOTCam/NOT	24.0	24.0	-	23.3	4.5	2.2
NICS/TNG	24.4	24.6	24.1	-	9.0	8
LIRIS/WHT	25.0	25.1	-	24.3	12.5	5
INGRID/NAOMI/WHT	24.1	24.2	-	23.5	12.5	4

In order to compare the instruments as such, one needs to scale all telescope sizes down to the NOT size, resulting in the following table:

	J	H	K	Ks
NOTCam/NOT	24.0	24.0	-	23.3
NICS/TNG	23.6	23.8	23.3	-
LIRIS/WHT	23.9	24.0	-	23.2
INGRID/NAOMI/WHT	23.0	23.1	-	22.4

This comparison shows that NOTCam is highly competitive in terms of sensitivity with the other CNO instruments, although it is limited by the size of the NOT. Similar comparison can be made for e.g. read noise, readout time, background, linear range, percentage of bad pixels, persistency upon saturation, and deviation from flat QE across the detector, which also show NOTCam to fare quite well with respect to the other instruments.

5.6. OVERHEADS AND TIME EFFICIENCY

NOTCam has a focus pyramid which saves a lot of observing time. In addition, telescope focus offsets between filters have been determined in good seeing conditions, so that focusing is safely and accurately done in only a minute or two. Telescope dither offsets of 15" steps with autoguiding take about 6 sec, and 130" offsets without autoguiding take about 9 sec.

This compares well with other CNO telescopes which have: 15 sec irrespective of offset size (TNG), and 7 sec to change dither position (WHT). The main contributor to the overhead for NOTCam is the large readout time of 3.6 sec causing a total readtime of 7.2 sec for each image. This situation should be improved with the new CUO controller. Overheads due to changing filters are similar to or less than those for the other CNO instruments.

5.7. AO IMAGING

NAOMI/INGRID on the WHT offers AO-assisted, diffraction limited high resolution imaging in J, H and K. Likewise, the AdOpt module of TNG provides nearly diffraction limited imaging with NICS, although currently only through tip-tilt correction.

No AO imaging is currently available with NOTCam, but a long-term goal of the NOTCam could (should) be diffraction limited imaging. For example, NOTCam would benefit from tip/tilt correction through the use of a tip/tilt secondary mirror.

5.8. POLARIMETRY

Currently, imaging polarimetry at the CNO is available with NOTCam and NICS. Polarimetry is also available with LIRIS, but it is not yet characterized.

NICS is capable of NIR imaging polarimetry by the use of a Wedged Double Wollaston (WeDoWo). However, while it works well in principle, there is substantial internal polarisation from the M3 and M4 mirrors (of the order of several per cent). While the contribution from M4 is constant, M3 is rotating and produces variable instrumental polarization. This problem would not be present at the NOT, with the suggested upgrade of NOTCam with Wollaston prisms, e.g. a WeDoWo. NOTCam would here be very competitive, as the experience from optical polarimetry shows that the NOT is a very good telescope for polarimetry due to its simple optics.

5.9. UTILITIES FOR THE OBSERVERS

NOTCam users currently have access to: Exposure Time Calculator (SIGNAL), Observing Script Generator (which also calculates the total overheads), Quick-Look tools (e.g. to show sky subtracted images while observing), and a flat-field archive. There is also a detector quality control program performing tests upon NOTCam every time it is mounted on the telescope. An imaging quality control, monitoring flat fields, zeropoints, backgrounds and extinction coefficients is under development. Also a small NOTcam reduction tool package (written in IRAF) is in preparation.

The other NIR imaging instruments at the CNO have their associated quick-look packages for basic on-line data reduction at the telescope. With INGRID, there is both an IRAF package at the telescope, and a freely available INGRID data reduction pipeline (INREP) written in IRAF. With NICS, a pipeline, SNAP (Speedy Near-IR data Automatic reduction Pipeline) is available to produce fully reduced NIR images from the raw data.

6. CONCLUSIONS

In conclusion, we feel that NOTCam is competitive with, or even superior to, the other CNO NIR imaging instruments in the fields of:

- wide field imaging in good seeing conditions (despite the fact that NOT is the smallest telescope within the CNO)
- simultaneous optical and NIR imaging
- imaging (and spectro-) polarimetry

Areas where other CNO instruments currently are preferable over NOTCAM are:

- very high resolution imaging (AO; INGRID, NICS). However, one should keep in mind that the high optical quality of the NOT ensures that the NOTCam HR camera is capable of delivering 0.2 - 0.3" FWHM images *without the use of AO*.
- imaging of very faint objects (GTC/EMIR in the future)
- data reduction pipelines

While INGRID and NICS have their advantages over NOTCam, LIRIS on the WHT appears to be redundant compared to NOTCam, although it reaches deeper because of the larger telescope size.

LOW-RESOLUTION SPECTROSCOPY

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The purpose of this report is to review the instrumentation for low resolution spectroscopy now available or being constructed for each of the proposed CNO telescopes (primarily the WHT, TNG, and INT) and assess which of these, in our opinion, answers Nordic needs that are not currently covered by NOT, where redundancies of instrumentation seem to exist, and also where we see gaps that should be filled in for the future CNO to serve the Nordic community properly in the northern hemisphere.

Current availability and performance of low-res spectrographs at the NOT

Currently the offered low resolution spectrographs at the NOT is Alfosc operating in the optical range from about 3500 Å to 11000 Å at resolutions from 200 to 10000 and NOTCam operating in the near-IR from 11000 Å to 22000 Å with resolution 2500 or 5500.

Since our last report from 2003 the situation has improved substantially both for Alfosc (where there are now good arc spectra available below 3888 Å as well as spectroscopic flats without reflections) and for NOTCam (which now has a calibration unit). However, the current Alfosc CCD suffers very strongly from fringing in the red, making spectroscopy redwards of about 6700 Å almost impossible for faint targets.

Also since 2003 FIES has arrived at the NOT. A special skew mode readout is under development that will allow medium resolution spectroscopy (R~5000) down to about 16-17th magnitude. In principle the program exists to define these read-out schemes and send the set-up to the CCD controller. Data has been taken in this way at the telescope, but no fully reduced spectrum has been provided up to now, and issues such as proper data extraction, wavelength calibration and in the end the effective gains that are made in this way are still somewhat open questions. It will still take some time before this option might be offered.

Planned developments at the NOT

ALFOSC

VPH grisms: These are grisms providing R~5000-10000 and an efficiency of ~90%. Grisms #17 is an example of this, where the overall efficiency of the system at a similar resolution for ALFOSC at the NOT is as good as for ISIS at the WHT (using a normal grating). One limitation of these grisms is that they cover a small, specific wavelength range where the efficiency drops off very quickly away from the central wavelength. One can also get lower resolution VPH grisms, but the gain with respect to normal grisms becomes less and less, being as little as only ~10% relative to the current set of grisms for the lowest resolution grisms.

CCD/optics: The new CCD and camera optics have improved the response in the blue (by ~10%) but it falls off rapidly towards the red, with the efficiency being relatively down by ~30% in I. The main reason for this were problems with the special coatings for the optics. The new CCD provides the better blue response and also does not suffer from charge diffusion in the blue like the old CCD. For spectroscopy the charge diffusion effectively reduces the resolution. However, this really only is an issue when using a narrow slit (0.5") and for a 1" slit there is little effective difference between the old and the new CCD in that respect. The worse problem with the new CCD is fringing which already is significant at Hα. This is very hard to remove completely even when taking flat fields with the telescope still pointing at the object, and/or taking several spectra dithering along the slit in a similar way as in the IR. Also, there is clearly more scattered light and ghosts than before, which we believe is related to the poor throughput in the red (i.e., the large fraction of the light that is reflected).

Simply speaking, for low-resolution spectroscopy the old set-up with the old camera and old CCD would be better: higher efficiency except in the U-band, and much less fringing in the red.

An important issue is the read-out time of the CCD which at 90 sec for the whole CCD is very slow. This does not effect low-res spectroscopy as much as the exposure times are typically long and/or one can window the CCD, but it is important for the programs at the NOT that need fast photometry. The main bottleneck is the arrival of a new CCD controller, which has been promised by Copenhagen for the last few years.

NOTCam

Medium resolution spectroscopy: R~5000 resolution spectroscopy is now also offered in the JHK bands using the current grism with the HR-camera.

With the current grism the wavelength ranges covered in the J and Z band are split over two orders. A new grism similar to the existing one could sample these wavelength ranges in a single order for each filter. Note that for the Z filter one would expect this set-up to be significantly more efficient than ALFOSC with substantially less fringing.

A possible improvement might be a new R~700 grism where either the ZJ, the JH or the HK range can be covered in one go using suitable filters, similar to what is available with Nics and LIRIS.

Also for NOTCam there is the issue of slow readout, though this is probably not really important for low-resolution spectroscopy, as the exposure time will be relatively long. Again, a new detector controller would/should improve things.

Review of low-res spectrographs available or planned at WHT, INT and TNG

WHT

The multi-object wide-field fibre-fed spectrograph, AF2+WYFFOS. Spectroscopic resolution 150-4000, with multiple (160) fibers over a fairly wide field of view (about half a square degree). This provides something that is not available at the NOT or the TNG.

The med-res longslit spectrograph ISIS, resolution about 4000. One of the features of ISIS is that it has a blue and a red arm which are used simultaneous with the help of dichroics (~90% efficiency). One advantage is that each arm can be optimized (e.g., high efficiency in the blue, low fringing in the red). Also spectropolarimetry can be done with ISIS.

The AO unit NAOMI can also be used with the integral-field spectrograph OASIS. This provides spatial coverage from ~3x3 arcsec (at 0.09 arcsec resolution) to 10x10 arcsec (at 0.26 arcsec resolution). Spectral resolution is in the range R~1000 to ~4000. Integral-field spectroscopy is also not available at the NOT or the TNG.

LIRIS is a near-IR camera and spectrograph, similar to NOTCam. LIRIS has a wider range of grisms, including an R~700 grism covering ZJ and HK. They also have a R~2500 grism for the K-band which is under commissioning and they are going to buy R~2500 grisms for the Z, J and H bands. These separate grisms are the equivalent of the single grism in NOTCam, where broad-band filters are used to separate the orders. We expect the overall efficiency of these grisms for each wavelength range separately to be slightly better than the single grism NOTCam has (apart from the aperture difference). LIRIS also allows a Multi-Object Spectroscopy mode using multi-slit masks (which will have to be prepared well in advance as the instrument will need to be warmed-up to install them).

A very recent development is a plan at the ING to make a standby optical camera (A-Cam) for the WHT with imaging and spectroscopic capabilities. The precise specifications have not been defined yet, but the general requirements for the instrument seem to be something like ALFOSC at the NOT, i.e., a focal reducer with imaging and (grism) spectroscopy over a ~8x8 arcmin field. The time scale for the project seems to rather short (~1 year) where the idea is to `outsource' the building of the instrument (were it not for X-shooter, Copenhagen would be a very good candidate for this).

INT

The IDS spectrograph at the INT is a grating spectrograph which in general has a lower efficiency than ALFOSC. Given that the INT has the same aperture as the NOT, while the latter generally has better seeing, the combination of ALFOSC+NOT is in principle the better one, but it could be that for very specific applications IDS+INT would be an option.

TNG

The near-IR imager and spectrograph Nics. TNG/Nics has a full set of R~700 and R~2500 grisms. One special feature not offered by either NOTCam or LIRIS is a very low resolution (R~50) prism for spectroscopy. It covers the range 0.8-2.5 micron and has a very high efficiency (> 80%) over practically the whole range. We think that this could be a very efficient way to look at the SED of objects (including drop-out for very high-z objects?).

One thing to note is that the performance of the detector on NICS is significantly worse than for the NOTCam detector, with the former having higher noise, remanence effects, and crosstalk.

Dolores: A focal reducer instrument similar to ALFOSC. It has slightly bigger pixels, the readout is somewhat shorter, and the RON is relatively high at 9 e-, but none of this would generally have a big effect on low resolution spectroscopy.

Dolores has a full set of VPH grisms with resolutions ranging from R~2000 to ~5000. This would largely correspond to new VPH grisms one could consider for ALFOSC. The R~2000 grisms compare a bit to grism \#8 at ALFOSC; the overall efficiency of Dolores at the TNG is somewhat higher than ALFOSC@NOT, while the higher efficiency of the VPH grism more than compensates the light loss due to the extra mirror at the TNG to direct the light to the Nasmyth focus. One negative side of Dolores is the low efficiency in the blue. From the peak efficiency in the red, we would assume it to be a thick CCD, where we would also expect little fringing in the red. We cannot find much information about fringing, but the little we found seems to be indicating that this is indeed the case. In that sense the grisms and the reduced level of fringing would be the interesting side of Dolores, though the precise wavelength coverage of the available VPH grisms might be good or bad for specific programs.

Dolores also provides a multi-slit mode, based on custom masks manufactured by a dedicated cutting machine.

A proposed optimal setup for the NOT within CNO

Currently, in general all that can be done at the NOT can also be done at either WHT or TNG. Here we suggest a setup that would make the NOT a very powerful complementary ingredient within the CNO, even with its smaller aperture.

Much of the science interest in the community is related to transient phenomena, and the NOT is already today a competitive observatory in this science due to its flexible and efficient operations. The combination of a standby FOSC along with a permanently mounted NOTCam would make NOT a unique telescope within CNO where one could always obtain both optical and near-IR images as well as spectroscopy. Over the past few years the possibility of a `standby' FOSC has been discussed (to replace StanCam). This was discussed to some extent with Copenhagen, but since they got involved with work on the X-shooter, this has stopped.

If we got a standby FOSC, and given that we would have FIES in standby mode as well, it would be natural to have NOTCam basically permanently at Cassegrain. In this way NOT would have three instruments permanently available covering low, medium and high resolution spectroscopy, and imaging from U to K. If a rapid response mode similar to the one existing at the VLT could be delivered, NOT would a very powerful observatory for the study of the transient Universe. An alternative would be a 'lucky-Cam' standby camera rather than a FOSC, but in this case we would have to rely on WHT, INT or TNG for optical low or medium resolution spectroscopy. On the other hand a LuckyCam-type instrument would strengthen programs requiring high spatial resolution and/or high temporal resolution.

High Resolution Optical Spectroscopy

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1. High resolution Spectroscopy at NOT

Currently the NOT has the following high resolution spectrographs: SOFIN, FIES and IACUB. IACUB is supported solely by IAC staff and offered within the Spanish CAT time. Therefore IACUB will not be covered in this report. During periods 29-34 (i.e. the most recent scheduled 3 years) 142 nights have been scheduled for high resolution optical spectroscopy at NOT. Since 2000 roughly 15-20% of the NOT publications have been based on high resolution spectroscopy.

1.1 SOFIN

The SOFIN high resolution spectrograph has been in use at NOT since 1991. Although it has never officially been a common user instrument, it has in practice been fully available for the Nordic and international users. Potential users have to contact the SOFIN support team prior to applying for observation time. SOFIN is supported by the University of Helsinki and presently also by AIP (Astrophysikalisches Institut Potsdam) at little cost for NOT. During periods 29-34 SOFIN was allocated 98 nights of observations and 5 nights technical time. SOFIN can be used in three different resolution modes (R= 30,000, 80,000 and 170,000). SOFIN can be used for spectro-polarimetry, the accuracy of which has been greatly improved recently. The fully tested observing software and continuously developed spectral reduction software are openly available.

1.2 FIES

FIES is a common user and standby instrument. FIES offers three resolutions (R=25,000, 45,000 and 65,000). The fixed wavelength range of 340-740 nm can be covered in one CCD frame without gaps. The total efficiency is high (9%) for the low and mid-resolution and an improved fiber unit for the high resolution will be installed in the near future. In terms of exposure time vs. S/N, FIES is/will be roughly 1.5 times more efficient than SOFIN, the main advantage being minimal 'slit-losses'. A 'pipeline'-reduction package for FIES data has been produced by NOT and is available for anyone to use. The first visitors' run with FIES will take place in October-November 2006. During period 34 FIES is allocated 14 nights of observation and 11 nights technical time.

2. High Resolution Spectroscopy at other ORM telescopes

The following High Resolution Spectrographs may be available through a CNO-agreement: SARG (TNG) and GIANO (TNG, under development). In addition there are preliminary plans for a HARPS-like instrument at WHT. Spectrographs at ORM telescopes not included in the CNO at this stage will be HERMES (ready in 2008, Mercator) and a future spectrograph at GranTeCan.

Due to the larger telescope diameter of TNG, the efficiency of SARG is roughly 2 times that of FIES/NOT, but two settings are needed to cover the wavelength range of FIES. The maximum spectral resolution is 164,000 and SARG has a polarimeter. GIANO (max. resolution R=50,000) will be a near-infrared (0.9-2.5 microns) spectrograph.

3. Scientific needs and possibilities

Currently the high resolution spectrographs at NOT are used especially for studies of stellar structure and evolution, stellar magnetic activity, and exo-planets, but also interstellar matter and galactic structure. FIES is foreseen to fulfil scientific needs in studies of e.g. asteroseismology, stellar activity and stellar parameters but is also important as a 'target-of-opportunity' instrument. As a stand-by instrument, it will be easy to use FIES parallel with any other instrument enabling new types of scientific programmes.

SOFIN is particularly valuable for long-term studies and monitoring of stellar magnetic cycles, where spectropolarimetry is of particular importance. The scientific programmes often need observations spread out on a longer period than the number of nights awarded to the programme. This has been possible through the practice of shared nights during SOFIN runs.

Many of the current projects carried out at NOT are particularly suitable for a NOT-size telescope, since they need long runs but would not especially benefit from a larger telescope size. Nevertheless, the availability of SARG will be very valuable, especially for studies of fainter objects. The GIANO near-IR spectrograph will certainly open new possibilities.

4. Redundancies and gaps

In spectral resolutions R=30,000-60,000 FIES, SARG and SOFIN all cover a similar "parameter-space". On the other hand, they all have specific features that differ: FIES will be efficient and easy to use, but has limits in spectral range and resolution. SARG reaches a high spectral resolution and is most efficient in terms of S/N vs. exposure time. SOFIN reaches high spectral resolution, spectral regions beyond the set-up of FIES and has an outstanding Stokesmeter, but is dependent on outside support.

One should also remember that high resolution spectroscopy stands for a considerable time of the bright and grey time observations, so one single high resolution spectrograph is certainly not enough for the CNO. It is also unlikely that the TNG could be used for some of the current programmes carried out on FIES and SOFIN, since these demand long runs and flexible scheduling.

Currently the biggest gap is that all instruments are limited at the infrared. This will be remedied when GIANO is in operation. It might also be worthwhile to expand the wavelength range of either SOFIN or FIES, which in practice is limited by fringing starting at wavelengths 6300 Å (FIES) and 6600 Å (SOFIN).

5. Spectropolarimetry with FIES

A polarimeter for FIES has been manufactured at the University of Uppsala. Some technical problems remain to be solved before installing it and there is no clear schedule for this work. A polarimeter would increase the scientific value of FIES and should therefore be realised. Nevertheless, the absence of spectropolarimetry does not make FIES an obsolete instrument.

6. Conclusions

The CNO opens new possibilities for high resolution spectroscopy. SARG and the planned GIANO will be important complements, making it possible to observe fainter objects and extend observations to the near-IR. Nevertheless SARG cannot alone fulfil the present needs of high resolution spectroscopy and FIES, as well as SOFIN, will still be needed at NOT. The allocated part for high-resolution spectroscopy at NOT during periods 29-34 was about 13%. Many of the scientific programmes carried out at NOT are of long-term and monitoring nature and it is unlikely they could be realised at TNG.

The IUG recommends that the current practise with the AIP support of SOFIN is continued. Furthermore the IUG recommends that the developing of FIES is continued. The plans for a polarimeter at FIES should proceed, but this should not be seen as a condition for the future operation of FIES. The IUG also recommends that a comparison study between FIES, SOFIN and SARG should be carried out in order to identify the areas of best performance. As a common user instrument FIES will become the standard high resolution spectrograph at NOT, but SOFIN is still needed for higher resolution, wider wl-range and spectropolarimetry. The IUG also recommends that the practice of shared nights, which has been used for SOFIN observations, is continued within the CNO and could be used for FIES as well.