Instrument Concepts for the OWL Telescope

Sandro D'Odorico (ESO)

During the past year ESO has coordinated a number of instrument concept studies as a complement to the OWL Observatory Design Study. Eight teams of scientists and engineers from different institutes in Europe and ESO have identified a variety of science programmes at the frontier of astrophysics and developed concepts of instruments at OWL which would be able to carry them out. This exercise has provided a first view of the unique astronomical observations at Blue to IR wavelengths which will become possible with a future European Extremely Large Telescope.

Table 1: Instrument Capability and Primary Science Goals.

Instrument	Wavelength range	Main capability	Primary science goals
CODEX	0.4–0.7 µm	High-velocity-accuracy, visual spectrograph	To measure the dynamics of the Universe
QuantEYE	0.4–0.8 µm	Photometry at 10^{-3}–10^{-9} second resolution	Astrophysical phenomena varying at sub-millisecond time scale
HyTNIC	1.1–1.6 µm	High-contrast diffraction-limited imaging	Imaging of massive planets, bright galactic and extragalactic sources
EPICS	0.6–1.9 µm	Camera-Spectrograph at diffraction limit	Imaging and spectroscopy of Earth-like planets
MOMFIS	0.8–2.5 µm	Near IR spectroscopy using many deployable IFUs	First galaxies in the Universe
ONIRICA	0.8–2.5 µm	NIR Camera at diffraction limit	Faint stellar and galaxy population
T-OWL	3–24 µm	Thermal, Mid-Infrared Imager and Spectrograph	Search, study of planets, high-redshift Hα galaxies
SCOWL	350–450–850 µm	Imaging at sub-millimetre wavelengths	Surveys of dusty regions, of extra-galactic fields for star-forming galaxies

Table 2: Instrument Teams.

Instrument	PI	ESO scientist	Institutes
CODEX	Luca Pasquini	–	ESO, INAF – Trieste, Observatoire de Genève, IoA Cambridge
QuantEYE	Cesare Barbieri Dainis Dravins	Robert A. E. Fosbury	University of Padova and Lund University
HyTNIC	Olivier Lardière Virginie Borkowski Antoine Labeyrie	Guy Monnet	LISE – Collège de France
EPICS	Norbert Hubin Markus Kasper, Christophe Verinaud	–	ESO and external experts from 10 institutes
MOMFIS	Jean-Gabriel Cuby	Mark Casali	LAM, GEPI, CRAL, LESIA, ONERA
ONIRICA	Roberto Ragazzoni	Enrico Marchetti	INAF – Arcetri, Bologna, Padova, Roma and MPIfA Heidelberg
T-OWL	Rainer Lenzen Bernhard Brandl	Hans-Ulrich Käufl	MPIfA Heidelberg, Leiden University, ASTRON, ESO
SCOWL	William Dent	Ralf Siebenmorgen	UK ATC

Establishment and overview of the studies

It is generally recognised in the astronomical community that it is essential to develop instrument concepts very early in the design of a new telescope. Instruments represent the vital link between the photon-collector, however sophisticated and powerful, and the scientific goals of the project. Instrument studies effectively probe the telescope interface and operation scheme and they verify whether the required scientific observations can be obtained with feasible and affordable instruments. This path was followed by the VLT project, in which an instrumentation plan was developed almost a decade before first light (Reference 1). For OWL, ESO launched eight instrument concept studies in 2004 (see Tables 1 and 2) in collaboration with several European institutes.

In the selection of the initial instrument concepts, we have been guided by the Science Case for the European ELT (a generic 50–100-m telescope) prepared within the OPTICON Network (Editor Isobel Hook) and by preliminary studies on the OWL scientific goals. The selected instruments offer various imaging and spectroscopic modes of observing and operate in different bands from the blue to submillimetre wavelengths. They are well representative of the different possible modes of operation of OWL and probe well the telescope's ultimate capability. The sample is however by no means exhaustive of all potentially unique observations to be done with an ELT of the OWL class. High resolution spectroscopy in the near infrared and astrometry at the diffraction limit are two scientifically very interesting modes not explored in this phase.

Six of the studies were led by PIs from different European Institutes, and two were coordinated by ESO. The instrument study teams were asked to identify the specific science drivers and use them to define the requirements, to develop an instrument concept and to evaluate its performance at OWL. They had to compare them with the expected capability of major planned ground-based and space-borne facilities like ALMA and the JWST. They had also to address the dependence on telescope diameter in the range 50–100-m and to underline any critical aspects in the interface to the telescope. Critical aspects in cost or the required technical developments also had to be identified.

This first effort on possible OWL instruments saw the active involvement of more than 150 astronomers and engineers from over 20 institutes in seven European countries. Through this exercise they become familiar with ELT concepts and produced a first batch of attractive opto-mechanical solutions for the instruments. For most of those who were involved it was a first impact with the "overwhelming" capabilities of a 100-m aperture telescope but also with the differences with respect to the 10-m-class telescopes we are used to work with. All responded in an enthusiastic way to the new challenge. The eight studies were completed in a time frame of 12 months.

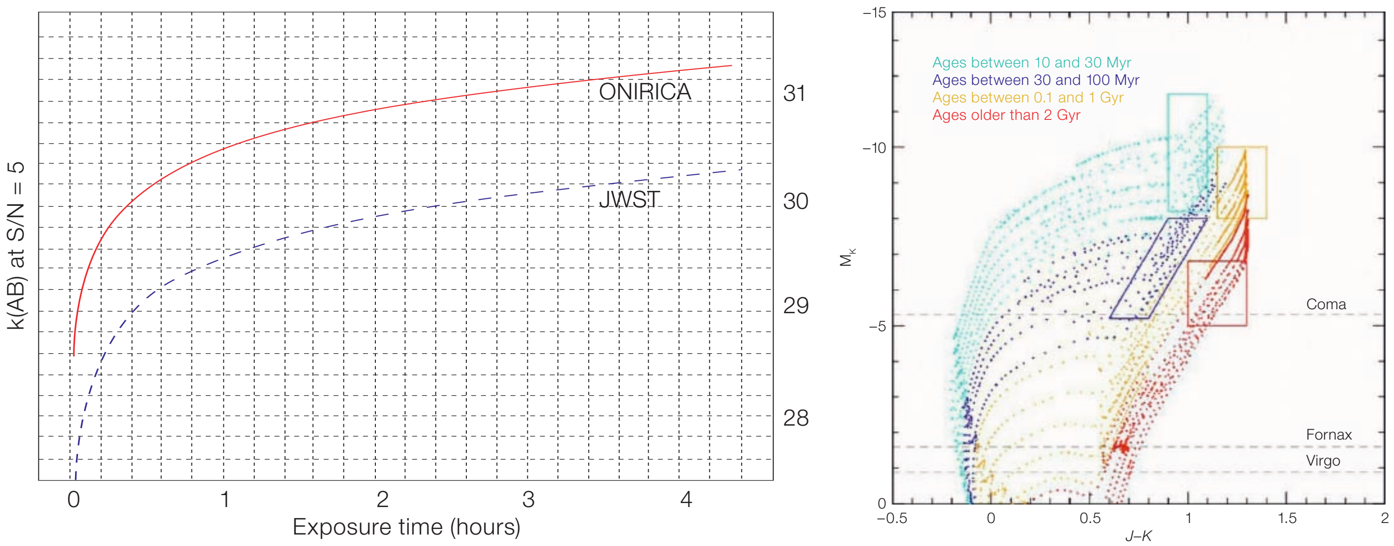


Figure 1a and b: The potential capability of a diffraction-limited NIR camera at OWL for the study of stellar populations in distant galaxies is illustrated in these figures. On Figure 1a the K limiting magnitudes for ONIRICA for stellar sources are compared to JWST. The advantage of ONIRICA would be even larger in the *J*-band. With a 60-m or a 30-m telescope the curves would have to be lowered by ~ 1 and ~ 2.5 mag respectively. Figure 1b shows a theoretical Colour-Magnitude diagram of an evolved galaxy population in which stars of different ages are identified. The dashed lines correspond to an m_K = 30 star at the distance of different clusters of galaxies (see Reference 7 for details).

Science cases and instrument concepts

Two of the instruments are foreseen for the *Blue-Visual and Red* wavelength bands with natural seeing image quality: CODEX and QuantEYE. They both use the outstanding collecting power of OWL to do unique science. CODEX makes use of the photon plethora to achieve high S/N ratio, high-resolution spectroscopy of faint stars and quasars with unmatched (~ 1 cm/s) velocity accuracy. The main science goal is the direct measurement of the dynamics of the Universe, but several other fields of astrophysics will be boosted by CODEX observations, as discussed in Reference 2 and summarised in a separate article on CODEX in this issue of The Messenger (page 10). QuantEYE (Reference 4) explores the temporal dimension of the photon flux. By covering the time resolution range 10^{-3}–10^{-9} s, it will permit for the first time the exploration of the quantum properties of the light from a variety of astrophysical sources.

There are two "wide"-field instruments for *NIR wavelengths (0.8–2.5 μm)*: ONIRICA (Reference 7), the imaging camera, and MOMFIS (Reference 6), the multi-field spectrograph. Both address many of the "classical" ELT science cases and as such reveal the power but also the peculiarities of observing with OWL. The ONIRICA team has identified diffraction limited imaging over a field of ~ 30″ as the primary observing mode. Using a MCAO system one can expect up to 30 % of the light to be concentrated in the diffraction peak of the PSF over the entire field in periods of very good natural seeing. With this performance the imaging capability of ONIRICA clearly surpasses that of the future James Webb Space Telescope (JWST) in terms of limiting magnitudes of stellar sources. Detailed studies of stellar population in Virgo and up to Coma become possible (see Figure 1). In particular we will be able to investigate for the first time the old populations of giant elliptical galaxies, a key to understanding the star formation history in the early Universe.

The baseline concept of MOMFIS foresees 30 IFU units which can be positioned over the 3′× 3′ scientific field of OWL. Its main scientific goal is spectroscopy of high-redshift galaxies ($z >> 3$) to trace the first sources which reionised the Universe. Their expected half-light sizes are typically ~ 0.1″ and this value drives the IFU size to sub-arcsec and the sampling to 20–30 mas. At a spectral resolution of 4 000, MOMFIS would be more powerful than JWST in spectroscopy of faint high-redshift candidates identified by multi-colour JWST imaging. While working far from the diffraction limit, MOMFIS requires a distributed AO system (MOAO) to deliver a moderate concentration of light at the sampling resolution. A first run of simulations with natural guide stars has shown that this might be possible but with limitations on the sky coverage. The use of laser guide stars at a 100-m telescope has its own problems and will require further studies.

One of the key science cases for OWL is the search for Earth-like planets close to nearby stars. Starting from the results of the Planet Finder studies for the VLT, the EPICS study (Reference 8) addresses various observational approaches to detect and characterise Earth- and Jupiter-like planets. Using differential imaging and a coronograph, the EPICS study investigated the possibility to detect the planets in polarimetry and at the wavelength of biomarkers such as water and Oxygen. A NIR IFU and FTS spectroscopy for planet light characterisation are also briefly discussed. The spectral range in which these modes should operate spans from the *Visual to the J-band*. EPICS will require a third-generation AO system (XAO) to achieve the diffraction limit with high Strehl and the required contrast with respect to the star light at the wavelengths of operation. A set of first-order simulations carried out during the study suggest that an Earth-like planet could indeed be detected with EPICS at a 100-m OWL telescope (see Figure 2). The selection of the final instrument configuration, of its primary observing modes and the prediction on its ultimate performance will have to wait for more extensive modelling and prototyping in the next phase of the project.

T-OWL is an imager-spectrograph to operate in the thermal infrared between *3 and 24 μm*. In this spectral region the requirements on the AO system are relatively modest. A wide range of targets from dusty planetary systems (see Figure 3) to black holes in the nuclei of active galaxies will be the primary science goals of T-OWL. In the bands where the atmosphere is transparent, T-OWL will outperform the Mid-Infrared Imager MIRI at the JWST in the observations of point-like sources and offer unique angular resolution. In spectroscopy, T-OWL can be especially competitive in the observations of narrow emission and absorption features at high resolving power (Reference 3).

SCOWL is a large field (~ 2.5′ × 2.5′) submillimetre camera to observe in the three submillimetre bands at *350, 450 and 850 μm*. It capitalises on the expertise acquired with the SCUBA1 and SCUBA2 instruments and uses it to draw the concept of a powerful survey instrument. SCOWL would supply the ALMA interferometer with a wide range of newly-discovered sources for detailed investigation. It benefits from the diffraction limit given from the OWL size (~ 1–2″) at submillimetre wavelengths without the need of an AO system. The advantage with respect to ALMA in the mapping mode is outstanding as shown in Figure 4. SCOWL requires the telescope to be installed at a very high and dry site and most likely a tip-tilt mirror correction linked to a water-vapour monitor to achieve its full potential (see Reference 5).

HyTNIC explores the application of the concept of a hyper telescope (Reference 9) as a multi-element imaging interferometer array with a densified pupil to the OWL construction phase. It allows direct imaging with enhanced resolution during the segment-filling phase of the M1 with a *NIR* camera and without adaptive optics, providing observations of unique scientific value before OWL's completion.

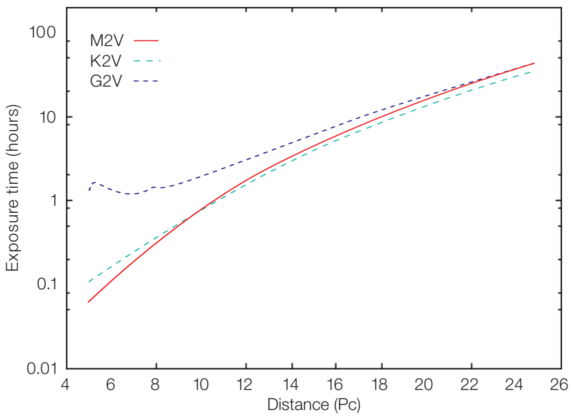
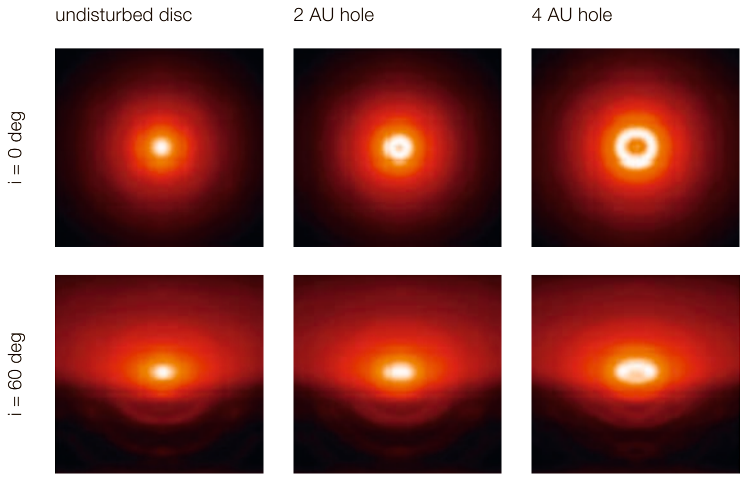


Figure 2 (left): Time to detect an Earth-like planet orbiting a Main-Sequence star at 5 σ with differential imaging in water bands in the *J* region. Assumptions: 80 nm bandwidth, 0.44 atmospheric transmission, 0.32 contrast, t_0 = 4 ms, r_0 = 20 cm. See Reference 8 for additional details.

Figure 3 (below): Simulations of the re-emitted light at 10 microns, for an undisturbed circumstellar disc and a disc with a hole of radius 2 AU and 4 AU, respectively, as seen at two different inclinations and convolved with the OWL PSF (see Reference 3 for more details). The Herbig Ae star is assumed to be at 140 parsec.



Feedback to the telescope design and future prospects

The studies have identified some critical aspects of the instrument–telescope interface and pinpointed a number of critical components which will require special developments. This feedback will be taken into account in the next phase of the project.

The present OWL Concept Design underwent an external review at the beginning of November 2005 and the outcome together with financial and science policy considerations by the ESO management will be a subject of discussion at the ESO Council in December. If, as we hope, a consensus on the construction of a European ELT will mature in the next months, the work done on the Instrument Concept Studies will have to be further expanded and tuned to the science goals and the revised telescope design.

In the meantime, probing of instrument concepts is also going on within the ELT Design Study (a network funded under the EC FP6 initiative). At the kick-off meeting of the ELT instrument "Small Studies" in September 2005, eight instruments were identified which will extend or complement the work carried out for OWL. Many of the OWL Instrument Concept Study teams are involved in this effort and will put to best use their newly-acquired expertise there.

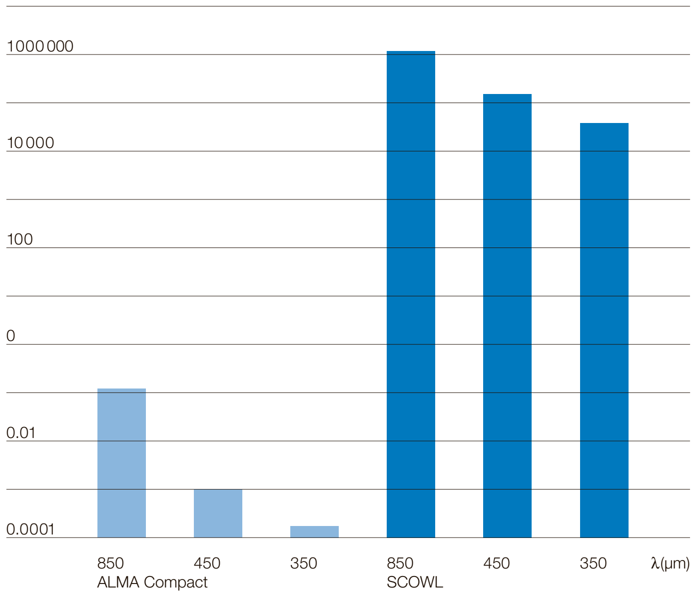


Figure 4: Relative mapping speed of SCOWL versus the ALMA Compact Configuration.

References

The OWL Instrument Concept Studies have been published as ESO internal reports. They can be obtained from the PI's or ESO.

(1) D'Odorico S., Moorwood A. F .M., Beckers, J. 1991, Journal of Optics 22, 85
(2) CODEX, Cosmic Dynamics Experiment, OWL–CSR-ESO-00000-0160, October 2005
(3) T-OWL, Thermal Infrared Imager and Spectrograph for OWL, OWL–CSR-ESO-00000-0161, October 2005
(4) QuantEYE, OWL–CSR-ESO-00000-0162, October 2005
(5) SCOWL, Submillimeter Camera for OWL; OWL–CSR-ESO-00000-0163, September 2005
(6) MOMFIS, Multi Object Multi Field IR Spectrograph, OWL–CSR-ESO-00000-0164, September 2005
(7) ONIRICA, OWL NIR Imaging Camera, OWL–CSR-ESO-00000-0165, October 2005
(8) EPICS, Earth-like Planet Imaging Camera and Spectrograph, OWL–CSR-ESO-00000-0166, October 2005
(9) HyTNIC, Hyper-Telescope Near Infrared Camera, OWL–CSR-ESO-00000-0167, October 2005

The Centre of the Active Galaxy NGC 1097

Near-infrared images of the active galaxy NGC 1097 have been obtained by a team of astronomers[1] using NACO on the VLT. Located at a distance of about 45 million light years in the southern constellation Fornax, NGC 1097 is a relatively bright, barred spiral galaxy seen face-on. It is a very moderate example of an Active Galactic Nucleus (AGN), whose emission is thought to arise from matter (gas and stars) falling into a central black hole. NGC 1097 possesses a comparatively faint nucleus only, indicating that the infall rate is small.

The new images probe with unprecedented detail the very proximity of the nucleus. The resolution achieved with the images is about 0.15 arcsecond, corresponding to about 30 light years across. The newly released NACO near-infrared images show in addition more than 300 star-forming regions, a factor four larger than previously known from Hubble Space Telescope images. These "H II regions" can be seen as white spots in the image shown here.

See ESO Press Photo 33/05 for more details.

[1] M. Almudena Prieto (Max-Planck Institute für Astronomie, Heidelberg, Germany), Witold Maciejewski (University of Oxford, UK), Juha Reunanen (ESO).

A colour-composite image of the central 5 500 light-years wide region of the spiral galaxy NGC 1097, obtained with NACO on the VLT. More than 300 star-forming regions – white spots in the image – are distributed along a ring of dust and gas in the image. At the centre of the ring there is a bright central source where the active galactic nucleus and its supermassive black hole are located. The image was constructed by stacking *J*- (blue), *H*- (green), and *Ks*-band (red) images. North is up and East is to the left. The field of view is 24 × 29 arcsec^2.