Critical science with the largest telescopes: science drivers for a 100m ground-based optical-IR telescope

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ABSTRACT

Extremely large filled-aperture ground-based optical-IR telescopes, or ELTs, ranging from 20 to 100 m in diameter, are now being proposed. The all -important choice of the aperture must clearly be driven by the potential science offered. We here highlight science goals from the Leiden Workshop in May 2001 suggesting that for certain critical observations the largest possible aperture - assumed to be 100 m (the proposed European OverWhelmingly Large telescope "OWL") - is strongly to be desired. Examples from a long list include:

COSMOLOGY:
- Identifying the first sources of ionisation in the universe, out to $z \geq 14$
- Identifying and studying the first generation of dusty galaxies.
- More speculatively, observing the formation of the laws of physics, via the evolution of the fundamental physical constants in the very early Universe, by high-resolution spectroscopy of very distant quasars.

NEARER GALAXIES:
- Determining detailed star -formation histories of galaxies out to the Virgo Cluster, and hence for all major galaxy types (not just those available close to the Local Group of galaxies).

THE SOLAR SYSTEM: A 100-m telescope would do the work of a flotilla of fly-by space probes for investigations ranging from the evolution of planetary surfaces and atmospheres to detailed surface spectroscopy of Kuiper Belt Objects. (Such studies could easily occupy it full-time.)

EARTHLIKE PLANETS OF NEARBY STARS. A prospect so exciting as perhaps to justify the 100 -m telescope on its own, is that of the direct detection of earthlike planets of solar-type stars by imaging, out to at least 25 parsecs (80 light years) from the sun, followed by spectroscopic and photometric searches for the signatures of life on the surfaces of nearer examples.

Keywords: Cosmology and cosmological constants; Galaxy Evolution; Solar System; Terrestrial Exoplanets; Overwhelmingly Large Telescope

1. INTRODUCTION: A BRIEF OVERVIEW OF "OWL"

The "OverWhelmingly Large" telescope, OWL, is a radical proposal by the European Southern Observatory (ESO) (Dierickx & Gilmozzi, 2000 & refs therein; see also http://www.eso.org/projects/owl/) to build an optical-IR telescope 100 metres in diameter, an order of magnitude larger in diameter than the current 6-10 m "Very Large" telescopes. This jump in size is comparable to that from the naked eye to Galileo's telescope. Industrial studies suggest that, for D $\geq$ 70m, cost can scale as $D^{1.2}$ instead of D^2, for a modest array of identical telescopes, or $D^{2.6}$, as normally assumed for a single telescope. These costings suggest that a 100-m optical-IR telescope could be built for under €10^9. This is a very low estimate for such a behemoth, but certainly large enough to require thorough scientific justification. Here we examine some of the many experiments which would exploit this facility to carry out unique and exciting science which could not realistically be attempted with significantly smaller telescopes. Most of these experiments were identified at a workshop in Leiden, NL, in May 2001, reports from which can be found at http://www.astro-opticon.org/ELT.html (where links to other current ELT projects can also be found).

OWL's current conceptual design employs a spherical F/1.42 primary mirror composed of ~2000 hexagonal segments with total area ~6300 m^2. Their baseline material is low-expansion glass-ceramic, though SiC would reduce (!) the moving mass to ~7000 tonnes. A 34-m flat segmented secondary directs the beam to a spherical aberration corrector preceding a folded prime focus. The corrector is a four-mirror system comprising two 8-m and one 4-m powered surfaces and a 2-m articulated (tip-tilt-correcting) flat, which directs the final F/6 beam to a selected instrument. The design is diffraction limited in the visible over a 3.'0 FOV and images are $\leq$0."07 over a 10' field. The figures of all the mirrors will be maintained by active optical control, Two of the corrector mirrors are conjugated, respectively, to the boundary layer and to an altitude of 8 km, thereby offering the potential for Adaptive Optics (AO) correction of seeing to be included in the telescope design in an integral way. Providing an AO capability is considered essential to the facility: see below.

The telescope will be protected during daytime and in bad weather by a large roll-off enclosure, similar to one currently in use near Berlin as an airship hangar. The construction and operation of the telescope will generate a small industry (one of the keys to its relatively low predicted cost).

Critical to the potential achievements of the 100-m telescope will be its instruments. Their design poses challenges unique to facilities with such a huge aperture. In particular, seeing-limited operation will not be an option if the full aperture is employed, as realistic detector sizes will demand unrealistically fast final F-ratios if the seeing disc is not to be grossly oversampled. In what follows we assume that the 100-m telescope will be equipped with a "standard" suite of instruments, providing imaging and low- and high-resolution spectroscopy at optical, near-IR and mid-IR wavelengths in conjunction with Adaptive Optics systems delivering near-diffraction-limited resolution in all these bands: in the near-IR and mid-IR, at least, over FOVs of order an arcminute.

2. COSMOLOGY: THE ERA OF FIRST LIGHT AND BEFORE

We here present only three of the numerous fields of cosmology where a 100-m telescope will offer critically important capabilities.

2.1 Seeing the First Generation of stars: back to the era of re-ionisation

The first stars in the universe must have formed from neutral gas which had previously concentrated into the gravitational potential wells of "mini-halos" after the era of recombination when the Cosmic Background Radiation decoupled from matter. (These may be detectable by their 21 cm emission: c.f. Iliev et al., 2002.) They would have contained no heavy elements and as a result were markedly hotter than stars formed later. They would have produced copious amounts of UV radiation, enough to re-ionise the less dense phases of the interstellar and intergalactic gas (the ISM and the IGM). Simple models (e.g. Miralda-Escude & Rees, 1998) suggest that these first-generation galaxies are detectable with a 100-m telescope by the well-established "drop-out" technique. This selects objects which are visible on images at long wavelengths but not at shorter ones because of absorption of UV light by residual neutral hydrogen in the intervening space. The drop-out technique is available to redshift z ~ 14, when the hydrogen Lyman α line (λ_{rest} =121.6 nm) - "forests" of which, at intervening redshifts, are the source of the absorption - leaves the atmospheric H window centred at λ ~ 1.65 μm. Confirmation of the nature of the objects thus selected will require spectroscopy with the 100-m telescope to recognise the absorption by, or emission at, Ly α. This is in fact possible for redshifts $z \leq 19$, above which the line is redshifted out of the K window at $\lambda = 2.0 - 2.4$ μm, the longest at which high-sensitivity observations can be made from the ground. Establishing that these objects are indeed those responsible for the re-ionisation of the universe (and hence that they are in fact the very first generation of stars ever to form) requires detecting a characteristic *asymmetry* of the Lyman α line caused by absorption of its blue wing, a more challenging undertaking than mere detection of the line to confirm their redshifts, even for a 100-m facility.

At $z \leq 14$ confirmation that a target object is indeed of the first generation of galaxies will also be possible by spectroscopy of the bright 164.0 nm line of HeII (singly-ionised helium), excited by the strong UV emission from the first-generation stars and emitted by the ionised interstellar medium surrounding them. At this limiting redshift the HeII line will be observable in the K window, while the Lyman α line emitted by the hydrogen component of the same gas (or the long-wavelength edge of its "forest" of absorptions by intervening neutral gas, which may obscure the emission line completely) falls in the the 1.65 μm H window. Even if the reionising galaxies are fainter than currently expected, their strong emission in one or other of these lines will allow them to be found – somewhat more laboriously – by searches using giant integral field units or suites of narrow-band (perhaps tunable) filters.

A 100-m ELT will find the first stars in the Universe.

2.2 The earliest dusty galaxies

The first stars will produce large amounts of the heavy elements (in the quaint terminology of astrophysics, those from carbon on up the periodic table) in the interior nuclear reactions which provide the energy by which they shine. As soon as this material is injected into the interstellar medium by supernovae and planetary nebulae, the raw materials for the formation of dust will be present. Dust both obscures objects which are luminous in the UV and visible wavelengths and re-radiates the energy absorbed in that process, mostly in the far-IR and particularly the submillimetre wavelength range. Observations in the FIR are not possible from the ground, but the submm régime *is* accessible from high, dry sites.

A submillimetre imaging camera (SCOWL: Submm Camera for OWL) has been suggested by Holland et al (2002: this conference) as a particularly powerful facility for use when the seeing is too poor to allow operation of the AO system in the optical and IR. On a 100-m telescope with optics designed for visible wavelengths such a system would offer (sub)arcsec resolution and immense sensitivity, even in the deep sub-millimetre 200 μm band which is from time to time transparent at the very best ground-based sites (see Figure 1.).

More sensitive even than the Atacama Millimetre Array (ALMA), and able to survey large areas of sky *millions* of times faster, SCOWL will exploit the serendipitous fact that the sensitivity of a submillimetre telescope to dusty starforming galaxies is essentially *constant* between redshifts $1 < z < 10$ (equivalently, over the timespan from 5% to 50% of the present age of the universe). It will assemble an unbiassed sample of galaxies over this whole redshift range and extending to quite low mass limits. This will provide an animated history of the universe, starting from the second generation of stars.

Subsequent OWL observations of these galaxies by imaging and spectroscopy in the near-IR will reveal the merger and other evolutionary processes which have governed their assembly into the galaxies of today.

2.3 How the laws of physics came to be: evolving "constants" in the earliest universe.

A most fundamental issue in physics and philosophy is to understand how the laws of physics came into being. There is a tantalizing possibility that extremely large telescopes may be able to probe how these laws may have "evolved" in the extremely early Universe (EEU).

Most theories for the earliest Universe require an initial set of 10 or so spacetime dimensions. The majority of these then "compactify", reducing the effective total to the present four, over a short but finite time during which various "constants" of nature approach their present values. If we can observe suitable phenomena at epochs so early that the extra dimensions were not yet negligibly small, deviations from the present-day values of these "constants" (including the fine-structure constant, the proton-to-electron mass ratio, the gravitational constant and the speed of light) should become apparent.

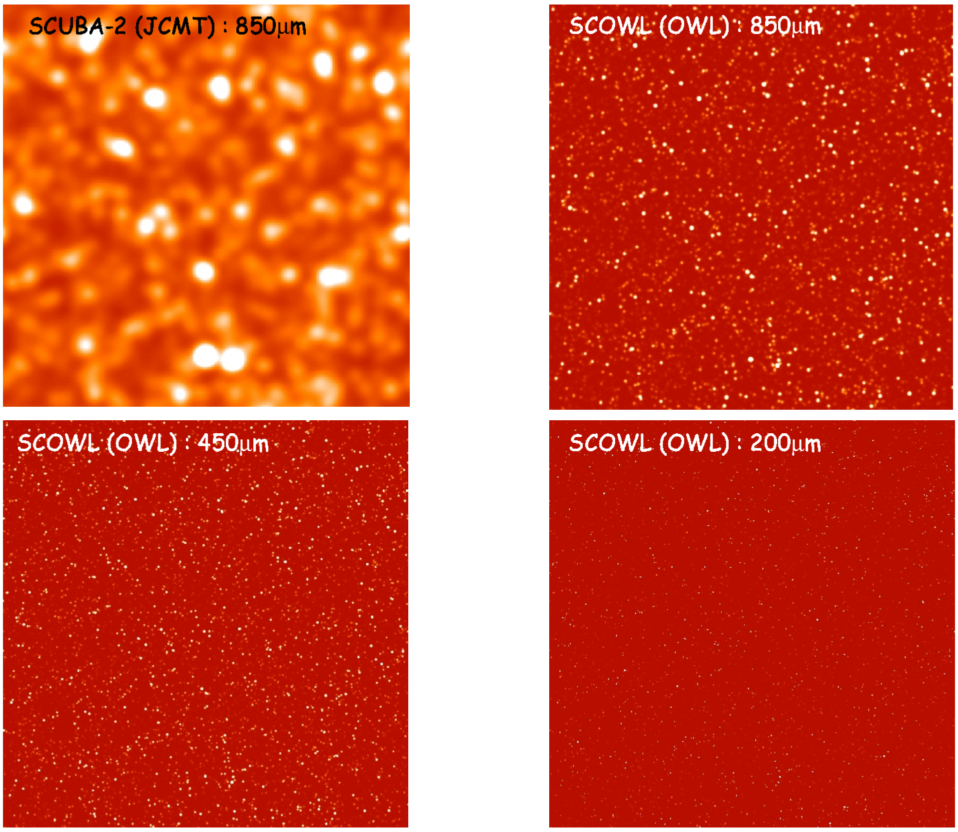


Figure 1: Confusion limited surveys of 0.1 deg^2 of sky with JCMT/SCUBA-2 (near-future state of the art) at 850μm and SCOWL at 200, 450 & 850μm. From models by Hughes & Gaztanaga (2001).

Several experiments have sought such deviations. Analyses of the natural nuclear reactor that operated about 2 billion years ago in Gabon constrain the time-variability of the fine-structure constant; a review of other approaches can be found in Murphy et al. 2001 and references therein. A particularly promising approach is the observational study of atomic line parameters in absorption spectra of quasars. Recent results from an analysis of some hundreds of such spectra, observed with the HIRES spectrometer on the 10-m Keck I telescope (Murphy et al. 2001, and unpublished), suggest a fine-structure constant that was smaller in the past. Reliably distinguishing intrinsic from cosmological wavelength shifts will require significant further theoretical effort as well as optical spectra with $R \geq 300{,}000$ and $S/N \geq 500$, ideally at different resolved locations in and around the quasar core.

This is an overwhelming task that indeed demands an overwhelmingly large telescope, but the potential rewards, in terms of our fundamental understanding of the universe and its laws, are immense. Since different string and brane theories predict different rates of change for different fundamental physical "constants" during the evolution of the Universe, definitive measurement of such variations will be a huge stride towards understanding the EEU. Some theories, indeed, postulate multiple universes: the observations proposed here would be the first *experimental investigation of whether our Universe is unique or not.*

3. HOW THE GALAXIES WERE MADE: RESOLVING SEPARATE STELLAR POPULATIONS IN ALL GALAXY TYPES

Galaxies are one of the basic building blocks of the Universe. They display a rich variety of shapes and structures, from spectacular complex spirals like our own Milky Way to almost featureless elliptical objects. As yet, basic questions as to how these systems formed and why they differ so much in morphology remain only partially answered. In the case of the formation of the Milky Way, our view has evolved from a monolithic picture of a collapse to form the finished article (Eggen, Lynden -Bell & Sandage 1962) into a hierarchical picture whereby the Galaxy formed from a series of mergers (Searle 1977). In reality, both of these ideas must be part of the truth: our galaxy clearly contains a number of old elements of about the same age (globular clusters, halo stars), yet we also find the late-arriving Sagittarius Dwarf Galaxy in the process of being dismembered and incorporated into the Milky Way (Ibata, Gilmore & Irwin 1995).

A key tool for unraveling the importance of these competing processes in the formation of a galaxy comes from studying the properties of its constituent stars. Measuring the colour and absolute magnitude of a star allows us to place it in the colour -magnitude diagram (CMD). Stars of the same age and chemical composition make up identifiable sequences in such a plot, allowing us to measure these basic properties. If a galaxy is formed in several distinct events, or is made up from the merger of galaxies of different ages, then multiple closely-spaced sequences will appear in the CMD, allowing an astronomical equivalent of dendrochronology to unravel its history (see Figure 3).

Further evidence is provided by the kinematics of stars: even after apparently merging completely into their new home, the similar velocities of the stars from a “cannibalized” infalling galaxy will betray their origins. The nature of the orbits the stars follow offers clues to how they got there: a plunging merger would tend to produce radial orbits while a gentle inward spiral would produce circular motions. In addition, since the orbits of stars are dictated by the total mass that binds them, stellar kinematics offer a tool for studying the distribution of dark matter in a galaxy; since this dark matter makes up perhaps 90% of most galaxies, we cannot possibly claim to understand these systems until we can map out this distribution.

For our Milky Way, ESA’s forthcoming GAIA mission (Perryman et al. 2002) will measure the brightness, colours, spectra and motions of billions of stars, to address exactly these issues. However, given their wild variety of structures, extrapolation of the life histories of all galaxies from the biography of one example would be foolhardy. With the advent of AO-corrected ELTs, however, we will be able to resolve the stellar populations in many external galaxies, and thus obtain similar data for these systems.

Figure 2 (from AURA, 2002) shows a simulation of the CMD of stars in the outskirts of the nearby dwarf elliptical M32 (a member of our own Local Group of galaxies) obtained with a 30-m telescope. Here, the multiple sequences arising from the extended formation of this system are readily apparent. The bright giant star sequences toward the top right of the figure are mainly separated because of the differing heavy element abundances of the various stellar populations, and therefore provide clues to the chemical evolution of this system. The main indicator of the ages of the separate poulations is their main sequence turn-off, showing where stars are just ending the lengthy phase where they burn hydrogen to helium in their cores. This turn-off is identified by the points toward the bottom left of Figure 2 where the lines through the stellar sequences become vertical.

Although a 30-m telescope can do this in a relatively near neighbour like M32, it would not allow us to investigate a representative sample of galaxies. In particular, there are no clusters of galaxies within the reach of such a telescope. Since the featureless giant elliptical galaxies are mostly to be found in these high -density clusterings, we cannot expect to understand the formation of these systems without a larger telescope. The closest clusters that contain significant populations of elliptical galaxies are the Virgo Cluster in the northern hemisphere and the Fornax Cluster in the south. As discussed above, a critical point in these population studies is provided by the main sequence turn-off, which in the oldest systems occurs at an absolute optical magnitude $M_V \sim 4.5$. At the distance of these clusters, this luminosity corresponds to an apparent magnitude $m_V \sim 35$. Such faint fluxes lie beyond what can realistically be measured by a 30-m telescope, and absolutely require the greater collecting area of a 100-m-class telescope.

In addition, a 100-m telescope will allow us to measure properties of stars in the closer galaxies that are inaccessible to smaller telescopes. With so much collecting area, the light of these stars can be split into high-resolution spectra, allowing a much more direct measure of their heavy element abundances from absorption line strengths. Further, the Doppler shifts in these lines give an immediate measurement of the stars' line-of-sight velocities, allowing the stellar-kinematic perspective described above to be explored in external galaxies. Such spectra also provide a tool for studying individual stars in the densest regions of galaxies where even the resolving power of an AO-corrected

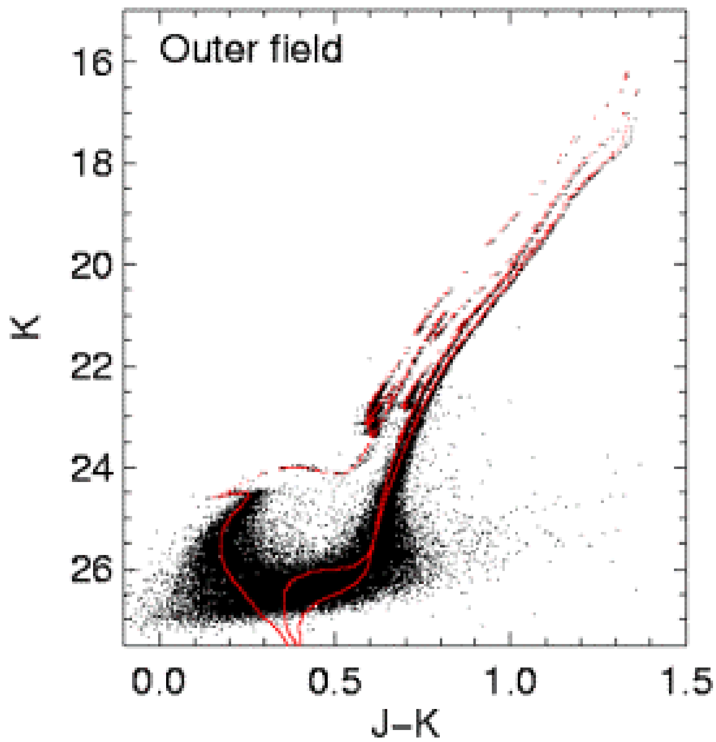


Figure 2. A simulated colour-magnitude diagram (CMD) of the outskirts of the nearby dwarf elliptical galaxy M32 (a satellite of the Andromeda Galaxy M31) as it might appear if observed with a 30-m AO-corrected ELT. Several stellar populations, of differing ages and compositions, can be distinguished.

100-m telescope is unable to resolve individual stars: due to their differing velocities, the spectral lines of the various stars within a single resolution element can be disentangled, allowing their individual properties to be studied.

It will only be via the technological leap to a 100-m telescope that we will be able to unlock the clues contained within the stellar populations in a representative sample of galaxies, and thus finally unravel the formation and evolution of these most dramatic of astronomical objects.

4. THE SOLAR SYSTEM: OWL EQUIVALENT TO A FLOTILLA OF SPACECRAFT

All solar system bodies more distant from the Sun than Venus will be accessible to a telescope like OWL. For an enormous range of solar system studies its extraordinary spatial resolution, its immensely powerful spectroscopic capabilities throughout the optical, near and mid-IR wavebands, and its ability to secure deep, high-resolution images both quickly and efficiently, will lead to a revolution in Planetology.

OWL's resolving power, in particular, approximates to that of a planetary probe close to a target object. But OWL can observe any and all targets and can do so repeatedly, so that it will, indeed, afford research opportunities which could only otherwise be achieved by a flotilla of *dozens* of spacecraft.

The resolution offered by a 100-m telescope operating at its diffraction limit is summarised in the Table.

Object	Surface resolution (km)	Res. Elements across typ. Disc	Notes
Moon	0.003	$\sim 10^6$	…illustrative. Did flag fall down?
Mars	~2	3400 (!)	Fortunately, there are orbiters….
Asteroids	3-7	≤200	Ceres, Vesta, many smaller bodies
Jupiter & moons	8	≤500	Galilean satellites (see figs.)
Saturn	15	≤300	Titan
Uranus	30	~25	Ariel
Neptune	45	~90	Triton
Pluto	60	~90	
20,000 Varuna	~65	~15	= large Trans-Neptunian Object (TNO, ≡ KBO)

It is obvious that these resolutions offer a dramatic leap forward in solar-system astronomy, filling the huge gaps in our spacecraft-based knowledge and opening the barely-touched field of monitoring objects for expected (and unexpected!) changes over time, in many cases at resolutions not much inferior to those offered by weather satellites of Earth. OWL's huge collecting area, too, offers the ability to carry out spectroscopy of the resolved surfaces of solar system objects as a part of such monitoring campaigns. Amongst the most urgent and important of these will be studying the collapse of the atmosphere of Pluto which is expected in the next couple of decades (see Fig. 3).

Solar System Astronomy could clearly utilise a large fraction of a 100-m telescope's time with huge guaranteed scientific returns. Indeed, we have here a useful reckoner of costs and benefits: the huge and invaluable archive of data returned by the probes and orbiters of the world's space programmes will probably be doubled in value by a decade of work with OWL. This would not replace the high-resolution images of the closer flybys, or in-situ

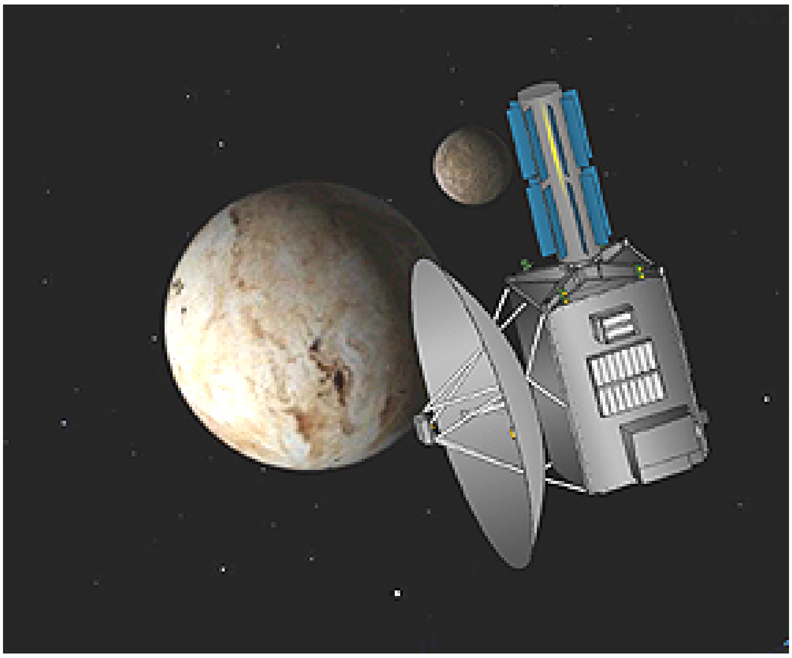
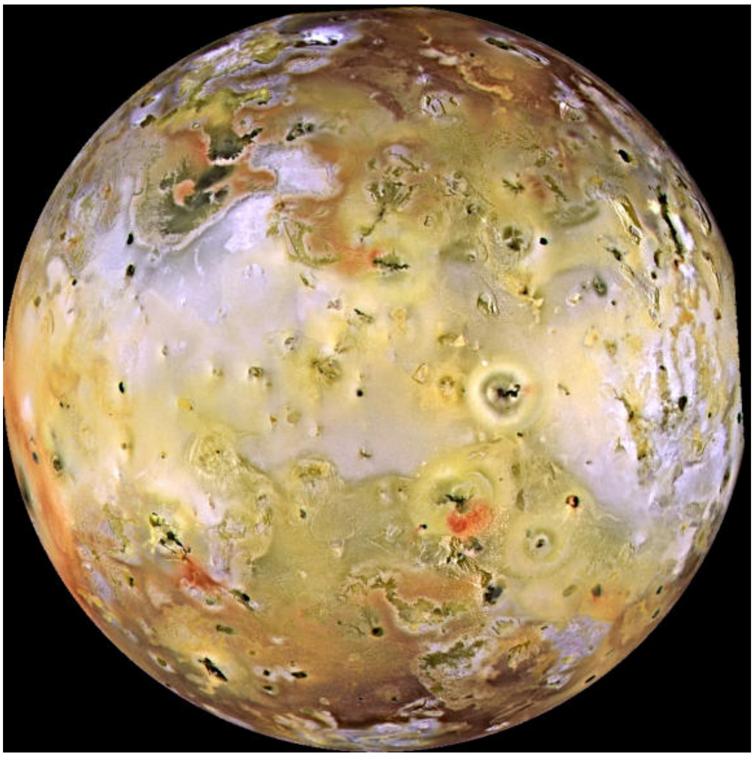


Figure 3. The (erstwhile) Pluto-Kuiper Express passes Pluto and Charon. OWL will offer resolutions at the surfaces of these objects about twice that in this artists rendering (courtesy JPL). It will also offer the ability to monitor the evolution of surface and atmosphere, thereby complementing and greatly extending the results of the probe (now under study in a successor design as the "New Horizons" proposal). Pluto's atmosphere is expected to vanish (by condensing onto the surface or related processes) as the planet moves further from the sun, probably between the years 2010 and 2020. An event like this has never been observed before but will take far longer than a probe flyby.

Figure 4. Jupiter's satellite Io as seen by the Galileo orbiter. OWL will be able to provide visible-light images resembling this one, but at least 5 times sharper. Even in the mid-IR OWLs resolution will permit experiments such as the measurement, at 5 to 10 points, of the temperature gradient of the lava flow from the crater Prometheus (the prominent circular feature slightly right of the centre of the disc: the lava flow is the black worm-like feature to the right of the central vent). Targets for long-term monitoring include eruptions like that of Pillan (just visible at the left edge of the disk) which changed dramatically between this and a later pass of the Galileo spacecraft.



physical measurements, e.g. of the magnetic effects which revealed the sub-surface oceans of Europa, Ganymede and Callisto. However the ability to perform long-term monitoring at a consistently high level of spatial and spectral resolution will clearly be a critical and complementary element of future Solar System science.

5. EXTRASOLAR PLANETS: DETECTING EXO-EARTHS AND EXO-LIFE

Because of its huge aperture, OWL offers a vast range of possibilities for resolution of faint companions: most dramatically, it appears capable of ***direct imaging of Earth-like extra-solar planets*** out to respectable distances. At 1.0 µm in the J window the FWHM of the central diffraction-limited spike delivered by OWL's AO system will be 2 milli-arcsec (mas). An Earth-analogue exoplanet at 10 pc (32 light years) would lie 100 mas from the central star, *i.e at 100 times the radius of the central spot.* ***This is the key to its detection:*** since it is well outside the bright image core structures, the main background component is the so-called AO halo of uncorrected wavefront errors, a diluted (Lorentzian) seeing disc that surrounds the central peak (Figure 6).

The performance for planet detection of an ELT and its AO system can be characterised by the Strehl Ratio S, the ratio of the central intensity in the delivered image to that expected in a perfect image. This should be high, as the AO requirements are almost the least demanding possible: all targets come equipped with (all too) nearby reference stars, so sophisticated and as-yet-unproven wide-field AO techniques are not required. Scaling rules for the detectability of a planet as a function of the properties of the planet and of the telescope can be summarised:

- Signal: $I_{planet} \propto D^2_{tel}\ (SAd^2\phi)/(D^2r^2)$, S=Strehl ratio of telescope+AO system, D_{tel} = telescope aperture; A=albedo, d=diameter, ϕ=phase function, r=orbital radius, of the planet; D = distance of the exo-solar-system.
- Noise: $N \propto [a_{image}\ D^2_{tel}\ (1-S)(\ s/(\theta^2+s/2)^2 + C)]^{1/2}$ where a_{image} = solid angle of image ~$(\lambda/D_{tel})^2$, so N does not depend on D_{tel}]; s= seeing FWHM, θ = r/D = ang. distance from star, $s/(\theta^2+s/2)^2$ = profile of the AO halo.

Sensitivity (S/N) therefore scales as D^2_{tel}, strongly favouring a 100m over a 30m by a factor of 10. Note that *the speed of a given observation* scales as D^4, i.e. a 100m will be *100 times faster than a 30-m.*)

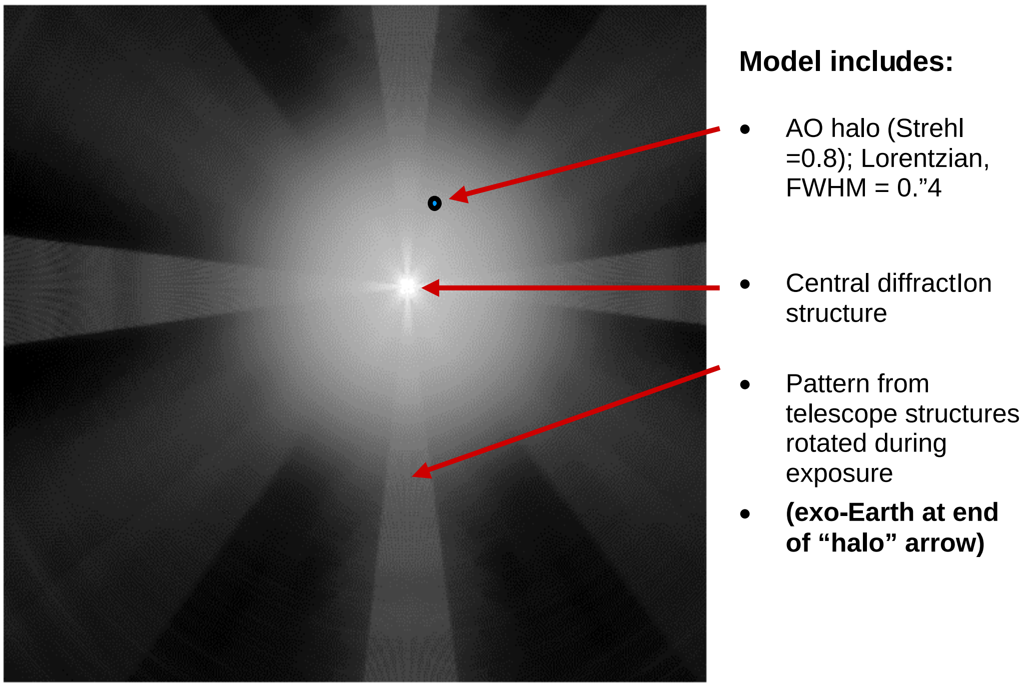


Figure 5: Simulated Point Spread Function of OWL (log scale), including diffraction from the segmented primary mirror and telescope structures, scattering, and the AO halo. An Earthlike planet of a sunlike star at 10 pc might be located at the circle.

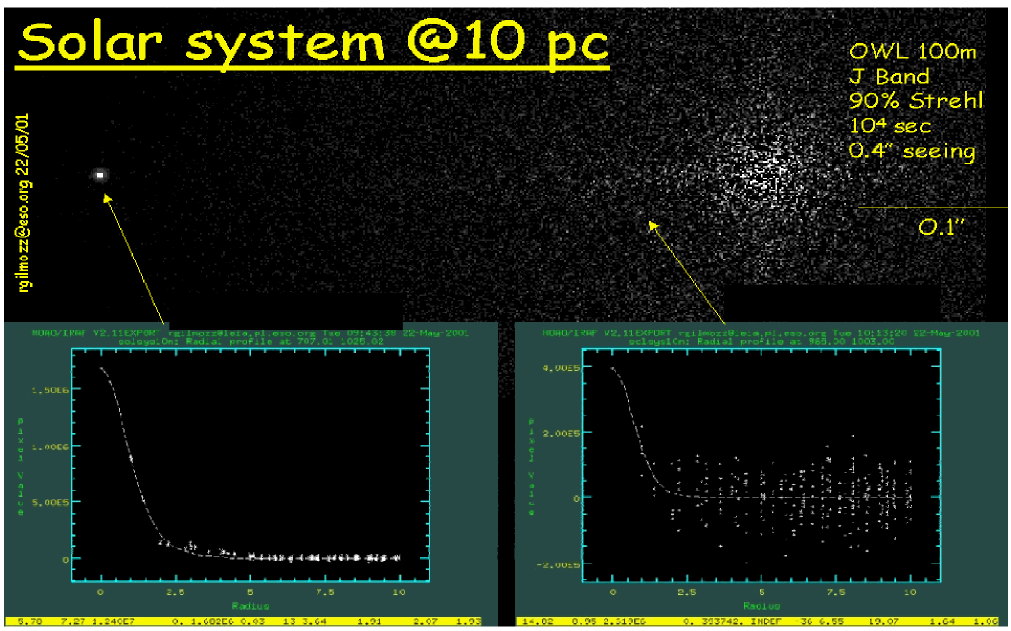


Figure 6. Simulation of a 10,000s OWL J band image of a solar-type star at 10 pc, with Jupiter-like (L) and Earth-like (R) planets. To make the planetary images detectable in the reproduction, the image of the star has been removed, leaving its noise signature.

Figure 6 shows a simulation of a solar-type star, accompanied by an Earth-like and a Jupiter-like planet (to R and L respectively), seen by OWL at a distance of 10 pc. The exo-Jupiter in Fig. 6 is detected at hundreds of sigma (high-resolution spectroscopy of this object could be secured in a night) and the exo-Earth is detected at around 10 sigma (for albedos of 0.7 and 0.4 respectively). While a 30-m will be hard put to detect an earth beyond ~3pc, OWL's range should be ≥25 pc. A year's observing would allow a census of the 2600-odd stars (including 360 "solar type" single F, G, K stars) within this radius, yielding orbital parameters for innumerable planets.

This encouraging result is obtained using only simple coronagraphy: in Fig. 6 the star has been simply subtracted, leaving its full noise contribution. The advent of nulling interferometric coronagraphs will significantly improve this situation; the present simulations can be taken as a conservative minimum estimate of the performance of a 100-m in a decade's time. For most of the detected exo-Earths photometric light-curves will be measured with sufficient precision to detect seasonal and other changes (c.f. Ford, Seager & Turner, 2001). Out to ~10pc suitable instrumentation, employing photon counting detectors, will permit a spectroscopic search at medium resolution for atmospheric biomarkers (e.g. O_2, H_2O, CO_2) in observing times of the order of weeks. The detection of telluric-like features through the telluric atmosphere may require orbital doppler shifts (~50 km s^{-1}) to be enlisted to disentangle spectral features.

The detection of atmospheric oxygen in the presence of water vapour is considered to be a reliable indicator or the presence of photosynthetic life, as no other process is known which can maintain a significant oxygen partial pressure for more than a few tens of millions of years. OWL evidently offers the capability to explore the planetary population of the solar neighbourhood in remarkable detail. If terrestrial planets prove common, the sample of systems may be big enough to establish the incidence habitability (as the presence of liquid water). Given knowledge of the ages of the parent stars, it should be possible to investigate the timescale for the evolution of analogues to terrestrial eukarya (including photosynthetic species). On Earth the latter appeared about 2.7 Gy ago, and atmospheric oxygen in large enough concentration to end the anaerobic era about 0.5 Gy later. Is this timescale an accident of local evolution, or does life have a universal rate of progression though its major stages?

OWL will initiate the first era when these fundamental questions can be adressed.

6. ACKNOWLEGDEMENTS

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