Spectroscopic and Imaging Surveys for Cosmology

– A European Research Training Network Proposal

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1a. Research Topic

We should never forget to be amazed that the questions of the origin and ultimate fate of our Universe are potentially answerable by the relatively straightforward processes of scientific measurement. Although these questions are clearly global ones, it so happened that it was the European, Albert Einstein, whose theory of gravity posed the basic possibilities for the evolution of our Universe more than 80 years ago. However, only today has observational astronomy advanced to the point where these questions have a realistic chance of being answered. The reason is that technology has finally overtaken the photographic plate, that great 19th Century leap for survey astronomy, with electronic detectors now extending their huge efficiency advantage over fields that are comparable to those for photography. Moreover, the new technology detectors are sensitive in the infra-red bands as well as in the optical and these bands have huge advantages for survey astronomy at high redshift. Finally, new technology has also revolutionised survey spectroscopy, with fibre optics and multi-slits giving today's spectrographs a huge multiplex advantage for making redshift surveys over traditional instruments. These advances have given astronomers a new ability to make panoramic sky surveys to deeper depths than ever before and reach the redshifts where new and accurate tests of cosmological models are possible, as will be described in detail below.

This proposal aims to maximise the scientific exploitation of European astronomical survey facilities that are either in existence already or are in the process of being constructed, with particular reference to those routes that bear directly on the cosmological questions. Prime examples are the 2.5-m VST optical and the 4-m VISTA optical/NIR imaging telescopes being constructed at Cerro Paranal, the UK's 2dF multi-object fibre spectrograph at the 3.9-m AAT the WFCAM NIR imaging instrument being built for the 3.8-m UKIRT, and also the Omega 2000 NIR instrument being built for the Calar Alto 3.5m. These facilities are all in excellent position to consolidate the European lead in surveys of the sky in the Southern Hemisphere and compete successfully with the US Sloan Survey in the Northern Hemisphere. The proposal aims to encourage communication and cooperation both in the analysis of the currently available survey data and to help promote maximum coordination of the new surveys so that the cosmological model can be determined as efficiently as possible. Alongside the direct cosmological tests, an imaging and spectroscopic database covering all the Southern sky will be produced which will be the basis for an entity that might be called VESO - the Virtual European Southern Observatory. This will be the legacy data product that will allow future data-mining of the Southern Sky. We have carefully chosen our nodes to include the European centres most involved with the above facilities to help maximise the coordination between them. Several of our nodes have great experience in the numerical N-Body and Hydrodynamical simulations which are needed to create mock spectroscopic and imaging surveys which are vital to test the analysis software used on the actual data. We believe that encouraging the vital institutes to work close together on the current survey data and close to the basic science aims, is the best way to maximise the efficiency of the future European surveys. The imminent arrival of VISTA, VST, WFCAM, and Omega 2000 means that EU RTN support for this network approach to European survey cosmology could not be more timely.

1b. Project Objectives

Here we are requesting funds first of all to support the European Survey Astronomy effort at 5 University nodes using PDRAs and at another University node using a PhD student and finally at ESO by simply funding networking costs. All the nodes have been selected as being central for the 2dF, VST, VISTA, ESO, UKIRT and Calar Alto Surveys. The funds at the 5 nodes where we are requesting PDRA support will be used in the first instance to give further support to the activities that are already in existence there. These activities include our highest priority science goals. The second aim is to improve the exchange of information between these surveys in order to strengthen the scientific foundations of the astrophysical virtual observatories of the future. This proposal may also be seen as promoting early *scientific exploitation* of the virtual observatories - the technical development of which is being funded or proposed for funding now through various other channels (e.g. ASTROGRID, ASTRO-WISE, AVO).

The overall objective is support the European effort in making astronomical surveys for cosmology and so promote a coherent European approach to cosmological surveys, particularly in the S. Hemisphere. In detail, the proposed network thus has four principal objectives as follows:

(a) Exploitation of Existing Cosmological Surveys. All of the network nodes are currently involved in the analysis of currently existing surveys. The first task of the PDRAs will be to assist with the scientific exploitation of these surveys as described below:

2dF Galaxy and QSO Surveys. The 2dF Galaxy and QSO Redshift surveys currently comprise 200000 B<19.5 galaxy spectra out of a target total of 250000 plus 20000 B<20.85 QSO spectra out of a target total of 25000. The initial phase of the 2dF surveys is due to be completed by January 2002. Both surveys aim to map the large-scale structure of the Universe by determining the clustering power-spectrum on scales of hundreds of Megaparsecs with the galaxies and thousands of Megaparsecs with the QSOs. However, the galaxy survey provides more detailed information on smaller scales than the QSOs. In both cases the form of the power spectrum can give cosmological information; the slope and any turnover detected in the spectrum can constrain the CDM shape parameter, $\Gamma = \Omega h$, but there is also the hope of detecting the baryonic acoustic oscillation second peak as a feature in the power spectrum (Eisenstein & Hu, 1998, ApJ, 496, 605).

The measurement of redshift space distortions is another key aspect of the 2dF surveys. At the galaxy mean redshift of z≈0.15, the main distortion is expected to be from peculiar velocitiess. Here constraints on the cosmological density parameter and the bias parameter b can be estimated and these tests currently imply a value of $\Omega_m = 0.3$ if the bias parameter is about 1 (Peacock et al. 2001, Nature, 410, 169). At the higher QSO mean redshift of z≈1.4 the effects of the cosmological geometry are more serious and this becomes another important source of redshift space distortion. Although the dynamical and geometric effects are degenerate in Ω_m and b, the degeneracy can be broken by introducing a further constraint on the QSO bias parameter from the evolved amplitude of QSO clustering.

The galaxy and QSO surveys will also be able to be analysed by higher order correlation functions to further disentangle the effects of bias and Ω_m. The 2dF QSO survey will be able to be used for lensing studies by looking at the cross-correlation of foreground galaxies and clusters with background QSOs. This should lead to direct, new lower limits on Ω_m associated with galaxy groups and clusters.

CADIS. The Calar Alto Deep Imaging Survey (CADIS) has been established as the extragalactic key–project of the Max-Planck-Institut für Astronomie in spring 1996. It combines a very deep emission line survey (limiting line flux $F_{lim} \simeq 3 \times 10^{-20}\,\mathrm{W\,m^{-2}}$) with a deep multi-colour survey in 15 broad and intermediate band filters between 400 nm and 2100 nm (limiting magnitude $R_{lim} \simeq 23.5^{\mathrm{mag}}$).

On the basis of the current results we are confident that CADIS will provide the database to make significant progress in understanding three areas of extragalactic astronomy: (i) The emission line survey will be sensitive enough to detect about a dozen of primaeval galaxies. The search technique is based on detecting Ly-α in three windows between 700 and 920 nm (that is at redshifts $4.7 < z < 6.6$). (ii) At redshifts $z > 2.5$ neither the space density nor the luminosity function of quasars is well known. Our current results indicate that the CADIS multi-colour approach is about 3 times more efficient than previous surveys to detect faint quasars ($R > 21^{\mathrm{mag}}$). The 100 faint, $z > 2.5$ QSOs which will be detected in this survey will reshape our understanding of QSO evolution and the epoch of QSO formation. (iii) The emission line survey will uncover about 1500 objects in the redshift range $0.2 < z < 1.0$ and measure their radial velocity cz to $\approx$150km s^{-1}. A large fraction of them will be “faint blue galaxies” and our survey should allow us to study their luminosity function and clustering, which are crucial properties for an understanding of their nature and evolutionary state. CADIS will determine the multi-colour redshifts of about 10 000 galaxies down to I = 23 with an accuracy $\sigma_z \lesssim 0.02$.

ESO Imaging Survey. The ESO Imaging Survey project was established in 1997 with the aim of carrying out cosmological imaging surveys, which could be spectroscopically followed-up using VLT. Muilti-band surveys are being made over a relatively wide-area and to a moderate depth to enable searches of rare populations (e.g. high-redshift clusters, quasars) and deep optical/infrared surveys for the selection of statistical samples of galaxies at high-redshift for studies of clustering evolution. The data for the wide-area survey have been used to identify clusters of galaxies over a broad range of redshifts. The current sample consists of over 300 cluster candidates in the redshift interval ($0.2 < z < 1.3$) which are being used for spectroscopic follow-up using 2dF for candidates with $z < 0.4$ and VLT for high-redshift candidates. The available infrared data are also being currently used to identify concentrations of red objects which could represent signposts of proto-clusters at $z > 1$. The deep optical/infrared survey is being used to assign photometric redshift for galaxies to extract samples of $z < 1$ galaxies, search for intermediate and high-redshift quasars, and U- and B-dropouts for studies of the large-scale distribution of galaxies at $z > 3$ using the multi-object spectrograph VIMOS at the VLT, allowing the first reliable measurement of the 3-D correlation function of Ly–break galaxies over such large volumes. These measurements are crucial for a better understanding of the evolutionary connection between the star-forming galaxies at z $\sim$ 3 and star–forming and 'quiescent' galaxies (e.g. EROs) at z $\sim$ 1.

Kapteyn Cluster Lensing Survey. Both the masses, and the shape of the mass distribution in clusters of galaxies form a prime cosmological test. The Groningen node is currently gathering wide-field imaging data on a number of galaxy clusters with the aim to (i) study the mass distribution out to large (Mpc) radii with weak gravitational lensing; (ii) look for the transition between mass associated with the cluster, and surrounding large-scale structure filaments 'feeding' it, as predicted by simulations; and (iii) look for substructure in the mass distribution of clusters, which is important evidence for dynamical youth and can be compared directly with modern cosmological structure formation simulations.

(b) Preparation for Future Cosmological Surveys. The network's first objective will be to communicate the lessons learned in the previous imaging and spectroscopic surveys to the institutes most concerned with implementing future surveys. Thus the experience gained in the above ongoing surveys will be shared with all other nodes.

Another important objective is to encourage the maximum exchange of information between the institutes who will be most closely connected with making future imaging surveys with telescopes such as VST, VISTA and UKIRT. These telescopes can all be used in complementary ways and the more communication there is between the various institutes, the more efficient the European survey effort will be.

It is also vital to encourage the maximum exchange of information between the spectroscopic survey projects and the imaging survey projects. One clear improvement that can be made over the current spectroscopic surveys is that their extensions should be based on CCD rather than photographic data. This will require cooperation between the VISTA, VST, UKIRT and 2dF observing teams. An immediate objective will be to prepare the imaging material on which an early extension of the 2dF galaxy and QSO spectroscopic survey could be based.

Preparation for the new surveys will also be made by the PDRAs being asked to innovate new analysis procedures to carry out direct cosmological tests on the reduced data. This will include particular effort on galaxy photometric redshifts.

The preparation for the new generation of NIR surveys is also clearly crucial. Cosmological tests here include the search for high redshift galaxy clusters and the use of the NIR in improving photometric redshifts for survey galaxies. The input of the NIR will also be vital for the selection of high redshift galaxies and QSOs for follow-up spectroscopy by 2dF and VLT VIMOS.

VLT VIMOS and the 2dF complement each other very well in terms of spectroscopic follow-up of the VST, WFCAM and VISTA imaging surveys. The current spectroscopic limits of 2dF are B=22mag for galaxies and B=23 mag for broad-line QSOs which are relatively faint, considering the huge 3 deg^2 field-of-view of 2dF. VLT VIMOS extends the optical spectroscopic limit to R=25.5 over a 20arcmin field and will be ideal for reaching objects in the deeper surveys proposed for VST and VISTA. Gemini-N and -S GMOS form a further route for spectroscopic follow-up and with the help of adaptive optics may extend these limits fainter over a narrower field-of-view for stellar targets.

We shall also prepare for future surveys by investing time in creating mock survey catyalogues from N-Body/hydrodynamical/semi-analytic cosmological simulations. These mock survey catalogues are vital for interpreting data. For spectroscopic surveys, the Virgo Consortium's Hubble Volume N-body simulation has already been a vital source of mock catalogues for the 2dF QSO and Galaxy Redshift Surveys. For the imaging surveys, again some work has already been done in simulating CCD frames of the Herschel Deep Field to test out simple models. In future, we will aim to create simulated surveys of the whole sky from ab initio simulations.

(c) Exploitation of Future Cosmological Surveys. Increasingly in the later network years, the objective will be to exploit the first data from the new surveys. In chronological order of when they are likely to start producing data, the extended 2dF Galaxy and QSO survey is likely to start after 250000 galaxies and 25000 QSOs from the first phase of the survey are publically released in July 2002. We would envisage the second phase of the survey starting in August 2002 and continuing through until the end of the grant in January 2006. The VST optical imaging survey data will start to come in from mid-2002 and analysis of the data will also continue until January 2006. Work on the UKIRT WFCAM near-IR survey data will start in mid-2003 and continue through until January 2006. The VISTA optical and NIR Imaging surveys will commence in mid-2005 and again continue until January 2006. It is the relatively late start of some of these surveys, particularly the VISTA surveys, which argue for full 4 year PDRA positions at five of the network nodes.

(d) Forward Look to Next Generation European Cosmological Surveys. Clearly, a further objective of the network will be to look beyond 2006 and help assess what surveys will be required for cosmology beyond those that are currently planned. Sections in our network meetings will always be reserved for discussing the form that the next generation of European astronomical surveys will take.

2. Scientific Originality

The state-of-the art spectroscopic surveys are the current 2dF galaxy and QSO redshift surveys. These surveys currently have measured redshifts for 20000 of a currently targetted total of 25000 QSOs and 200000 galaxies out of a targetted total of 250000 galaxies. These survey use the 2dF instrument at the 3.9-m Anglo-Australian Telescope (AAT). The world-class potential of AAT 2dF to probe the large scale structure of the Universe can be seen even in a cursory glance at the galaxy and QSO wedge plots which are shown in Figures A1, A2 in the Appendix. More detailed structures can be seen in the galaxy wedgeplot but the largest, 3000 h^{-1} Mpc, scales are sampled best in the 2dF QSO survey. Both surveys have started to produce estimates of the power spectrum of clustering at large scales.

These surveys currently lead the US Sloan Digital Sky Survey (SDSS) in the spectroscopic survey areas. The SDSS spectroscopic surveys at the moment have about 100000 galaxies and 8000 QSOs. The SDSS is being made from the Apache Point Observatory in New Mexico at latitude +32 deg using a 2.5-m telescope.

The state of the art imaging survey is the US Sloan Digital Sky Survey (SDSS). SDSS uses 30 2k×2k CCDs each with a field of 13.′5. It observes in the Gunn u,g,r,i,z bands simultaneously in a 0.3 deg^2 field. It is to cover the whole Northern Galactic Cap to about B=23 in exposure sof about a minute at each point. At lower priority, SDSS is also to cover a Southern 2.5×90deg^2 strip at Declination 0 degrees to about B=25 over a period of 5 years. So far, the SDSS has imaged up to $\approx$ 1000 deg^2 for the B=23 survey and are publically releasing a few hundred deg^2 in mid-2001.

Once constructed, VISTA and VST themselves will represent the new state-of-the-art for Survey Telescopes overtaking the Sloan 2.5-m Telescope. The VST is a 2.6-m telescope designed to work in the optical wavebands. The *OmegaCAM* detector will sit at prime focus with a mosaic of 16k×16k CCD with 0.22arcsec pixels and covering an area of 1deg^2. VISTA has a fast, f/1, 4-m primary mirror with separate optical and IR instruments which are interchangeable at Cass. The optical CCDs cover a 1.4deg×1.4deg area at 0.25 arcsec per pixel with 50 4k×2k EEV

CCDs. The VISTA IR camera comprises 9 2k×2k Rockwell HgCdTe chips covering 0.25 deg^2, deployed so that in 4 pointings a mosaic of area 1deg^2 will be covered. The pixel size will be 0.3arcsec.

Pan-European Survey Coherence. While giving important support to these specific key data analysis areas, the principal originality and added value for this network over the national funding route for these activities is in its pan-European network character. This will mean the network can act as a vital conduit for the exchange of information between the principal institutes involved in the design of the European Surveys. The network PDRAs will naturally develop into key figures in European Survey astronomy with a unique view of the value of cooperation in making the European Survey programme coherent and with a clear view of the survey capabilities of their host nation. In the regular network meetings we shall invite all others interested in cosmological survey programmes to join us to make this network a real driving force for a coordinated European approach which will enable us to compete efficiently with our competitors. This is by far the most important potential outcome of funding our proposed network. The opportunity is there for Europe taking the lead in exploiting the imaging and spectroscopic Virtual Observatories of the future and working towards this goal is the ultimate and overriding aim of this network proposal.

3. Research Method

Clearly our basic research method is to make complete surveys using a range of European survey telescopes such as VST, VISTA, UKIRT WFCAM, AAT 2dF and Calar Alto 3.5-m. Below we outline the most important methods that will be used to achieve the network objectives listed above.

Future Extensions of the 2dF Spectroscopic Surveys. A prime objective is the integration of the European photometric and spectroscopic surveys. The current 2DF Galaxy and QSO Redshift Surveys are based on APM measurements of photographic plates. Clearly a future extension of these spectroscopic surveys should be based on CCD photometry. The VST wide angle survey which may extend to the same depth as the Sloan survey of 23rd magnitude would be ideal. The addition of the i and z bands to ugr would make the QSO survey sensitive to QSOs at $z > 3$. If the JHK bands were available from VISTA or WFCAM, again from a moderately deep survey to K=20 then the 2dF could include searches for QSOs up to z≈7. QSOs could also be selected by K-excess (Warren, Hewett, & Foltz, 2000, MNRAS, 312, 827) which may improve selection completeness of QSOs obscured by moderate amounts of dust. It is almost certain that such wide surveys to these limits will be made by VST, WFCAM and VISTA and wherever the VST and WFCAM Southern surveys are made, the AAT 2dF will be able to follow-up spectroscopically. The work that needs to be done here will be to optimise the colour selection in trial areas using the VST passbands and then making 2dF test exposures to optimise QSO selection at all redshifts.

Similarly, we would be looking to extend the 2dF Galaxy Redshift Survey. The 2dF instrument will easily permit us to cover a larger area of sky to the current 2dFGRS limit (B=19.45), and also to go more than 1 mag. deeper. If we base these extensions on good ugriz colours from the VST, this will yield a comprehensive catalogue of galaxy magnitudes, positions and colours over the whole Southern sky. This will allow, for example, the galaxy luminosity function and its dependence on colour and environment to be determined to remarkable precision, placing strong new constraints on theories for galaxy formation. Similarly, we could explore the degree to which dynamical properties of galaxies are modulated as a function of their environment, by measuring the redshift-space distortions for sub-classes of galaxies divided according to luminosity, colour and type. This detailed knowledge of the influence of environment galaxy type would inevitably lead to new breakthroughs in understanding of the standard-candle properties of spirals and ellipticals such as the currently enigmatic Tully-Fisher relation and the Fundamental Plane of early-type galaxies. Finally, when combined with the SDSS galaxy redshift survey in the Northern Hemisphere, the data would definitively map out the structure of the Universe within 600h^{-1}Mpc, finally unravelling the local web of galaxy clusters, filaments, sheets and voids.

Near–IR Surveys A second prime research area will be to capitalise on the near–IR JHK surveys to be produced by the UKIRT Wide Field Camera (WFCAM) in the North, and to prepare for the even more ambitious NIR surveys to be made by VISTA in the South. WFCAM is a two-by-two mosaic camera for UKIRT covering 0.21 square degree in each exposure, due to start taking data in 2003. The main focus is on a very large survey known as UKIDSS (UKIRT IR Deep Sky Survey). The extragalactic survey is designed as a kind of 'wedding cake', covering 4000 square degrees to K=19, 70 square degrees to K=21, and 1 square degree to K=23. The combination of the shallow large area survey and the Sloan data in the same region is particularly powerful. The UKIDSS consortium has come together to design and implement the survey, but does not own the data, or have any dedicated resource for scientific exploitation of the expected huge database. Our proposal here concentrates on the scientific exploitation of the expected UKIDSS and VISTA databases. Basic aims relevant to cosmology of both instruments are to make surveys to detect galaxy clusters out to $z > 1$ to determine the evolution of the cluster space density and hence make a powerful test for Ω_m. Another aim will be to extend the wavelength range to determine photometric redshifts more accurately, particularly for early type galaxies at higher redshift. These two areas are related since the photometric redshifts will be vital in helping to reduce foreground noise from $z < 1$ galaxies when detecting high redshift galaxy clusters. We thus propose to investigate the efficiency of combining colour and overdensity as ways of detecting high redshift clusters in K limited data. We also propose to use the currently existing photometric and redshift data to evaluate the methods for estimating photometric redshifts including the weighting given to the various bands. These issues can be subtle; for example, the strong effect of metallicity on giant stars in the NIR may mean that the effect of metallicity on NIR galaxy colours may add noise to the photometric redshift measurement for galaxies at low and intermediate redshifts - paradoxically the optical spectra, through containing less information on metallicity, may be more robust for the narrow task of measuring redshifts. It may turn out that the NIR data will trace the metallicity evolution of the galaxies via the optical photometric redshifts. We shall therefore combine 2dF galaxy redshifts with Sloan optical and UKIDSS NIR data to determine the most efficient weighting of colour information to determine photometric redshifts from wide-angle surveys. We shall also investigate the effects of photometric errors on redshift accuracy.

Imaging Dark Matter via Weak Lensing. Deep Optical imaging with VST and VISTA forms one clear route to imaging Dark Matter using the Weak Lensing. Weak lensing has evolved in the last ten years into a quantitative tool in cosmology. The goal is no longer to demonstrate a convincing detection of the effect, but to make real measurements of the shear, and turn these into real measurements of the projected mass density in a given direction. An important aspect of this quantitative work is to control systematic effects. While it is now relatively straightforward to demonstrate convincingly a coherent alignment of galaxy distortions around a massive foreground cluster, for example, it is much harder to quantify the amount of this shear in the presence of seeing, camera distortions, or uncertain redshift distributions of the source galaxies. Considerable work has gone into controlling these systematic effects—see for example the mass distribution around a cluster at redshift $z = 0.83$ (see figure A3) by Hoekstra, Franx, & Kuijken (2000, ApJ, 532, 88)—and ever-more refined technique are continuing to be developed.

The payoffs for this type of work are considerable: a direct measurement of the total mass distribution in a given direction, independent of assumptions of dynamical equilibrium, mass-traces-light, hydrostatic equilibrium of hot gas, etc, which need to be made when applying other more classical mass measurement techniques. There is also potential for weak-lensing studies behind $z \approx 0.2$ clusters in QSO redshift survey areas where we have three lensing handles on the cluster's mass - from the enhanced background QSO density at bright magnitudes, from the reduced background QSO density at faint magnitudes and from the shear measurements. Overall, lensing offers a unique perspective on the mass distribution in the universe, and large surveys are required to exploit its possibilities in order to beat down measurement noise. As an example, the Sloan survey team has recently detected a very significant, but very weak, lensing signal by averaging the lensing around over 20,000 galaxies, derived from over 1,000,000 galaxy lensing measurements.

Narrow-band imaging. As seen above, the photometric redshift technique has pivotal importance for many of the galaxy and galaxy cluster survey projects. Nevertheless, the redshift accuracy of the technique is usually only quoted at ±15% and much better accuracy may be possible using narrower bands. The CADIS collaboration has the leading experience world-wide in making narrow-band surveys and could offer new insights into significantly reducing the error on photometric redshifts. We shall therefore be investigating the potential advantages of narrow band imaging for photometric redshifts using both a theoretical approach based on models such as those of Bruzual & Charlot (1993, ApJ, 405, 538) and also using the available data from the CADIS survey. Particularly interesting are areas where the CADIS Survey overlaps the 2dF galaxy survey where narrow band 'spectra' and fibre spectra can be compared. Another powerful potential use of narrow-band imaging is for detecting primaeval galaxies at high redhift where the stellar continuum is absent but Lyman alpha emission from the proto-galactic gas may be detectable. Spectral searches for such emission lines behind lensing clusters are underway at Groningen, using facilities at ESO-VLT and Keck.

High Redshift Galaxy Z-space Distortion The success of the UV dropout technique in detecting z=3 galaxies means that there is the future possibility of carrying out studies of the large-scale structure of the Universw at $z \approx 3$, using spectroscopic redshifts from such instruments as VLT VIMOS. $z \approx 3$ galaxies at $R < 25.3$ have a sky density of $\approx$1 arcmin^{-2} and so even a 50deg^2 survey will contain 180000 such galaxies. Typical U band exposures are 4 hours on a 4-m class telescope to reach the depth required. With spectroscopic redshifts it will also be possible to use geometric and dynamical redshift space distortion techniques similar to those used for 2dF QSOs to obtain new constraints on Ω_Λ and Ω_m. We propose to compare the strength of statistical constraints available on these parameters from the high redshift galaxy surveys to see what size of high redshift galaxy survey may be competitive with that from the 2dF QSOs.

Variability Surveys - SNIa Searches and Lensed QSO pairs. Again there is scope for stimulating survey coherence in these areas. For example, if the searches for high redshift supernovae to determine the cosmological constant via the SNIa Hubble Diagram were searched for in areas that have already been surveyed by the QSO redshift survey then monitoring of QSO lenses could be carried out simultaneously. By comparing light curves from QSO lensed pairs, we shall then be able to make new estimates of Hubble's Constant. Supernova searches are expected to be one of the main cosmological applications of the VST.

Mock Surveys via Cosmological N-body and Hydrodynamic Simulations The final, vital, strand to this project is to facilitate the comparison of real survey data with simulated mock surveys, both for imaging and spectroscopy. We are convinced that the development of simulated Universes will become ever more important and the level of realistic detail will increase. For example, initial attempts have already been made to produce mock CCD deep image frames from theoretical simulations, based on coupling the gravitational N-body approach to the semi-analytic approach. Soon this approach will be extended to hydrodynamical codes. These simulated CCD frames are as vital to interpreting astronomical data as the real CCD data frames themselves. For example, in a case where the isophotal angular size of a faint resolved galaxy is required, the same software that is used on the data should also be applied to the mock CCD frame where the same systematic and rms errors occur as in the data and where the actual size of the galaxy is known. Only after this comparison is made can the result of applying the same software to the data be securely interpreted. These simulations will also allow ray tracing (Jain, Seljak, & White, 2000, ApJ, 530, 547) so that the procedures which measure detection of shear due to gravitational lensing can be applied to realistic imaging mocks to test for systematics. The same combination of numerical and semi-analytic approaches will also allow the creation of mock galaxy and QSO redshift surveys.

4. Work Plan

Table 1 shows how the tasks are to be distributed by institution. The first 3 overall objectives of Section 1b are represented. As can be seen, it is envisaged that in the first instance, the institutes currently exploiting their particular surveys continue to do so under ‘ Analysis of Current Surveys’. Then in the intermediate years, under ‘Preparation for Future Surveys’ there is much more cross-institute collaboration in drawing the lessons from the previous surveys and on this basis developing the new techniques which will be applied to the future surveys by VST, VISTA, AAT, UKIRT, ESO etc. These specific techniques are described in Section 3. Then this process of cross-institute collaboration is taken to its hoped for limit under ‘Analysis of Future Surveys’ where all nodes effectively contribute to the analysis of the above surveys. This situation also applies to the objective ’Forward Look to Next Generation European Surveys’, although not shown in Table 1.

Table 1. RTN Network Tasks.

Task		DUR	UEDIN	RUG	MPIA	OAC	ESO	OXF
Analysis of Current Surveys	2dF QSO	√						√
	2dF Galaxy	√	√					√
	CADIS				√			
	EIS						√	
	WHT CNOC Lensing			√				
	CroNario					√		
Preparation for Future Surveys	2dF QSO	√		√	√	√		√
	2dF Galaxy	√	√	√		√		√
	Photometric Redshifts	√			√	√	√	
	Hi-z Cluster Detection		√		√		√	√
	Weak Lensing Shear		√	√			√	
	Variability	√	√	√		√		
	z-space Distortion	√	√					√
Analysis of Future Surveys	2dF	√	√	√	√	√	√	√
	VST	√	√	√	√	√	√	√
	VISTA	√	√	√	√	√	√	√
	WFCAM	√	√	√	√	√	√	√

Table 2 shows the four timelines associated with this network. The first shows when the various new European survey telescopes and instruments begin operations. this is clearly the framework which will dictate how our resources are used.

The second timeline shows the length of time that the relevant nodes from Table 1 will continue to work on the current surveys. Broadly speaking it is the first 2 years for all surveys except CADIS which continues on till the grant finishes in 2006.

The third timeline shows that the relevant nodes from Table 1 will also start to work on preparation for future surveys from 2002. The task of analysing the current surveys is clearly intimately connected with the task of preparing for future surveys. It is envisaged that at most nodes there will be a gradual transfer of focus of activity to the new surveys near the times of the various telescopes being commissioned.

Finally, the fourth timeline shows how we plan to exploit the various futrure surveys. generally these follow the opening of new telescopes or instruments except in the case of the AAT 2dF where we expect the extended galaxy and QSO surveys to begin in mid–2002, 6 months after the first phase of the surveys have finished and around the time of the 2dF public data release.

Table 2. The four timelines associated with this network.

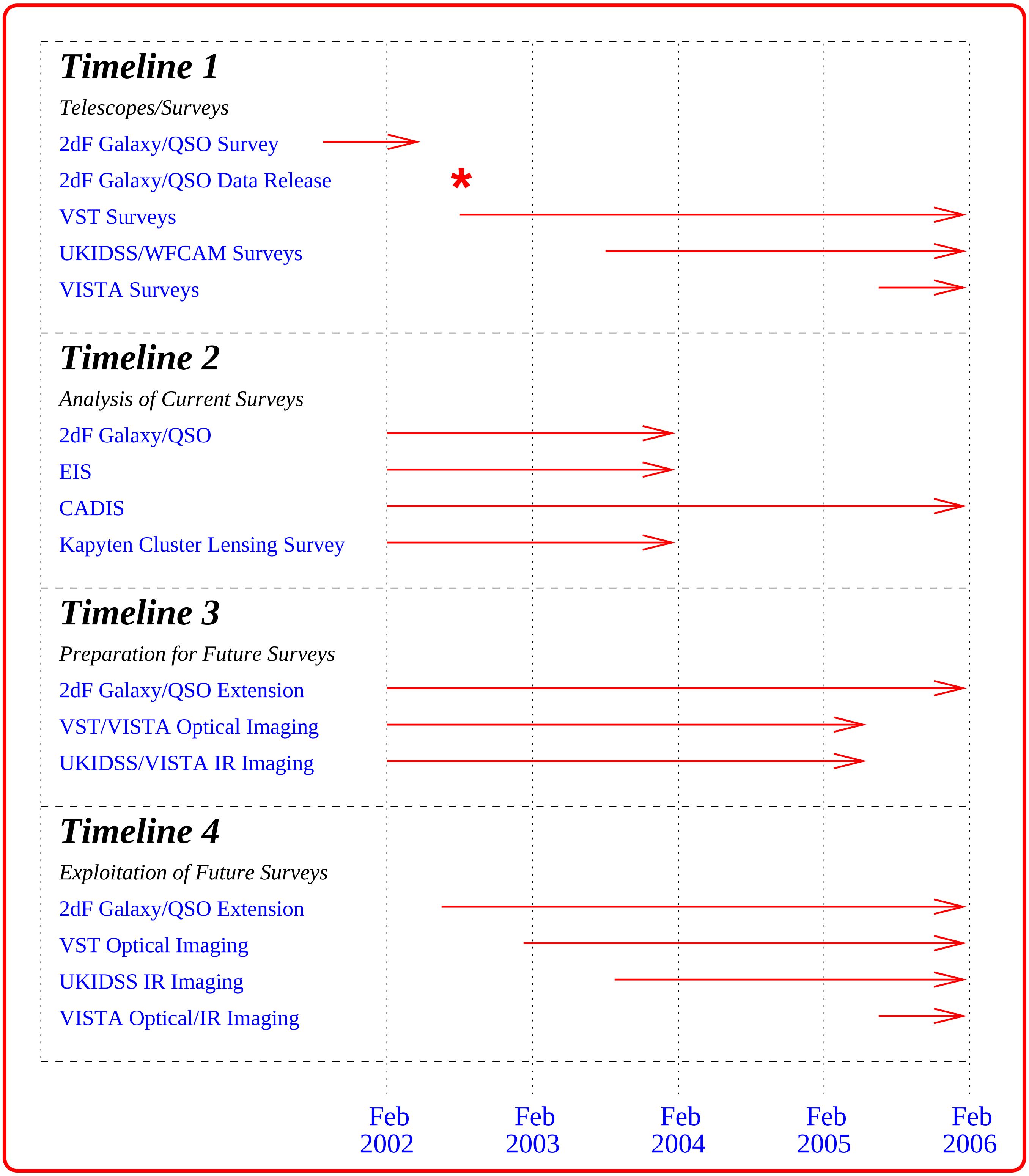

Table 3 shows the division of RTN funded researchers and others professional research effort associated with project in units of person months, split by institute. These numbers are derived from the percentages of researcher time associated with the project given in Section 5.

Table 3. The division of RTN funded researchers

Professional research effort on the network project			
Participant	Young researchers to be financed by the contract (person-months) (a)	Researchers to be financed from other sources (person-months) (b)	Researchers likely to contribute to the project (number of individuals) (c)
1 DUR	48	144	13
2 UDEIN	48	125	8
3 RUG	48	58	5
4 MPIA	48	101	7
5 OAC	48	82	8
6 ESO		60	5
7 OXF	36	65	7
Totals	276	635	53

5. Collective Expertise

5a. Department of Physics, University of Durham.

Over the past 10 years, Durham observers have been involved in photographic surveys using the APM and COSMOS measuring machines, including the ROE-Durham Galaxy catalogue covering 1500deg^2 of sky. This catalogue formed the basis for the Durham-UKST Redshift Survey of 3000 B<17 galaxies made using the FLAIR fibre optic spectrograph at the UK Schmidt Telescope. Durham was also heavily involved in the first redshift surveys of QSOs and galaxies using fibre optic spectrographs using the FOCAP and AUTOFIB fibre-optic spectrographs at the AAT. The commissioning of the 2dF instrument at the AAT in 1998, with an increase in fibre-optic field-of-view from 40' to 2°, heralded a new era for spectroscopic surveys.

The current themes of Durham research which defines our network role are as follows:

The 2dF Redshift Survey: Shanks acts as UK PI of the 2dF QSO Survey team with PDRA assistance from Outram and PhD students, Hoyle and Myers. The current 2dF QSO Survey now has 20000 QSO redshifts out of a target of 25000 and is a collaborative project with Oxford, LJMU and AAO. Durham also acts as a major node of the 2dF Galaxy Survey with Frenk, Cole and Norberg playing key roles. The 2dF Galaxy Survey has currently obtained 200000 galaxy redshifts out of target of 250000. This survey is a collaborative projects with many UK and Australian Universities including Edinburgh and Oxford. Durham will be a leading member of the consortia which will start the extensions to the galaxy and QSO redshift surveys.

The William Herschel Deep Field: Some 170 hrs of 4-m class telescope imaging time at the WHT, UKIRT and Calar Alto has been devoted to the William Herschel Deep Field which has UBRI photometry to B=28.2 and HK photometry to K=23. The WHDF has also recently been the subject of a long exposure by the Chandra X-ray satellite. Key personnel in this area are N. Metcalfe (PDRA), G.S. Busswell, M. Vallbe (PhD students) and T. Shanks. This research team has also been involved in the exploitation of the Hubble Deep Fields -N, -S data. The WHDF is a prime target for the Gemini GMOS spectrograph currently being commissioned. We shall be continuing to exploit Deep Imaging Surveys and we will use our experience in modelling the evolution of faint, high redshift galxies to help develop new photometric redshift techniques

X-ray Surveys: T. Shanks has been involved with deep ROSAT, ASCA, BeppoSAX, and Chandra surveys, first establishing that QSOs were a signicant source of the soft and hard X-ray backgrounds. The X-ray team led by Shanks, includes Outram, and Vallbe (Durham) plus collaborators at AAO, Athens, Leicester, Edinburgh and Carnegie Mellon.

Bulk motions: R.L. Davies and J.R. Lucey are also involved in searches for bulk motions such as SMAC which uses fundamental plane distances for elliptical galaxies in Abell clusters to search for backside infall into the Great Attractor and so investigates whether bulk flows may extend to the super-large scales previously claimed by Lauer and Postman (1997).
Theoretical Cosmology: Durham houses the powerful Computational Cosmology Group led by C.S. Frenk. For the past 10 years this team has worked at the cutting edge of numerical simulations for cosmology, first using N-body techniques but now also using hydrodynamic techniques, via both Smooth Particle Hydrodynamics and Adaptive Mesh codes. The group has been successful in getting UK JIF funding to build the Institute for Cosmological Computing and UK JREI funding for a massively parallel computer to increase the size of their numerical simulations. They are partners in the Virgo Consortium (which also includes Edinburgh) that has produced the Hubble Volume N-Body simulation which is extensively used to make mock QSO and Galaxy Catalogues for the 2dF Surveys. The N-body and hydrodynamical simulations run by the Durham theory group will be the basis for attempting to set up mock spectroscopic and imaging all-sky surveys. The theorists will work closely with the observers to ensure that the resulting virtual Universes are as realistic as possible, in terms of instrumental effects.

Key Staff: Tom Shanks (40%), Carlton Baugh (10%), Shaun Cole (10%), Roger Davies (10%), Alastair Edge (10%), Carlos Frenk (10%), John Lucey (10%), Nigel Metcalfe (30%), Ben Moore (10%), Adam Myers (50%), Phil Outram (50%), Ian Smail (10%), Marc Vallbe (50%)
Most relevant recent references
Hoyle, F., Outram, P.J., Shanks, T., et al., 2001, submitted to MNRAS (astro-ph/0102163)
Metcalfe, N., Shanks, T. et al., 2001, MNRAS, in press (astro-ph/0010153)

5b. Institute for Astronomy, University of Edinburgh.

The IfA's main research areas consist of a broad but coherent programme of studies in extragalactic astronomy and cosmology, in which both observation and theory are closely interlinked. The key themes may be summarized as follows:

1. Deep surveys, particularly in X-rays and sub-mm, intended to study new classes of high-redshift galaxy. We play a leading role in the UK SCUBA survey consortium, and we hold the largest single UK allocations of time on the X-ray satellites Chandra and XMM.
2. New extensive redshift surveys of the local universe, mapping the large-scale structure in unprecedented detail. The 2dF Galaxy Redshift Survey is one of our major projects, and we are managing the new 6dF survey.
3. Detailed studies of high-redshift galaxies, especially active galaxies, with the aim of understanding their origin and evolution.
4. Modelling of structure formation, including both the history of the dark-matter component and the IGM, and novel approaches to understanding where galaxies form in relation to the dark matter.
5. Confrontation of galaxy-formation models with observations, via our leading work on the evolution of composite stellar populations, including the critical issue of evolution of the dust content.
6. Studies of the large-scale mass distribution, including techniques for analyzing both microwave-background and gravitational-lensing data, and applications to forthcoming surveys.

The main expertise at Edinburgh that is relevant to this network lies in three areas: analysis of redshift surveys, gravitational lensing, and data management for large imaging surveys.

- Some of the main 2dF Galaxy Redshift Survey analyses have been performed at Edinburgh (e.g. Peacock et al. 2001), and we have played a major role in working with other leading surveys, such as PSCz. We are also playing a leading role in the new 6dF spectroscopic survey instrument, which is now being commissioned. Oxford and Durham are members of these consortia.

- We have developed some of the leading techniques in reconstructing mass distributions from gravitational lensing. We already have a very successful collaboration with MPIA in applying these techniques to multicolour data, incorporating photometric redshifts (Dye et al. 2000).
- The Wide-Field Astronomy Unit is a large research unit within the Institute for Astronomy. It grew out of the library for photographic plates from the UK Schmidt telescope, with SuperCOSMOS as the machine to digitize this material. The WFAU is very strongly involved in the major issues to do with the construction of next-generation digital surveys, including: reduction pipeline; archiving; photometric redshifts; data mining.

Key Staff: John Peacock (30%), Alan Heavens (30%), Andy Lawrence (10%), Bob Mann (50%), Avery Meiksin (30%), Quentin Parker (50%), Nathan Roche (30%), Andy Taylor (30%)

Most relevant recent references

Dye S., Taylor, A.N., Thommes, E.M., Meisenheimer, K., Wolf, C., Peacock, J.A., 2000, MNRAS, **321**, 685

Peacock J.A. et al., 2001, Nature, **410**, 169

5c. Kapteyn Institute, University of Groningen.

The Kapteyn Institute at the University of Groningen is the chief center for the development of data handling techniques for OmegaCAM/VST. Much technical and scientific work is going into defining not only surveys to be done with the VST, but also the system with which the data may be calibrated, processed, analyzed, filtered and archived. A key functionality of the system will be to allow users at other sites to access and manipulate the VST data archive. This work towards a Virtual Observatory fits very naturally into a project such as this. Other imaging data will be linked to this database as it becomes available through a 'federation' of other European data centers. A link-up with spectral surveys would be a tremendous enhancement.

The main cosmological interests for the exploitation of the VST and VISTA at the Institute lie in the fields of gravitational lensing, of large-scale structure and cluster studies, and of searches for QSOs and supernovae. In addition Groningen has a long track record in the study of the local universe, which is expected to continue with these new survey facilities. The local universe forms a crucial boundary condition on any cosmological model!

The Kapteyn Institute is a node of the FP5-TMR LENSNET network, which concentrated on weak gravitational lensing. Over the past few years we have/have had three postdocs, two staff members, one Phd and one undergraduate student working on weak lensing projects. This activity continues to be an important one at the institute, and is now geared to exploiting data from the ESO Wide-Field Imager and preparing for VST and VISTA.

On-going variability searches at Groningen, particularly in the field of microlensing, are yielding many tools with which variables can be identified automatically from a time-series of exposures, even in very crowded regions (Sackett, Kuijken). These techniques can also be applied to the search for supernovae, which will be a major application of the VST archive. Multi-colour QSO surveying is being carried out by Barthel, on the basis of red wide-field imaging data from ESO and CTIO.

The Kapteyn Institute is a friendly, interactive department with a rich history in astronomy. It provides a fertile ground for the training of young researchers.

Key Staff: K.H. Kuijken (30%), P.D. Barthel(30%), J.M. van der Hulst (15%), E.A. Valentijn (30%), R. van de Weygaert (15%)

Most relevant recent references

Valentijn, E.A., Deul,E., Kujken, K 2000: 'Observing and Datamining with OmegaCAM', Proc's New Era Wide Field Astronomy, Preston, UK

Hoekstra, H., Franx, M. & Kuijken, K. 2000, ApJ, 532, 88.

5d. Max Planck Institute für Astrophysik, Heidelberg.

On the basis of its ongoing multi-colour surveys, CADIS and COMBO-17, the survey team at MPIA has gained unique experience in how the pseudo-spectra obtained for each object via the imaging observations in more than a dozen medium band filters can be used to extract spectral-type and redshifts for many thousands of faint galaxies, stars and QSOs.

Both by spectroscopic control observations and extensive Monte-Carlo simulations, we could prove that the medium-band technique is capable of improving the redshift accuracy of conventional photometric redshift methods by almost a factor of 10 (c.f. Wolf, Meisenheimer and Röser, 2001 and Wolf et al, 2001).

Thus medium-size survey telescopes (2-4m) with their square-degree field-of-view are able to deliver datasets of galaxies and QSOs which are for many cosmological applications equivalent or superior to those which will be obtained by extensive spectroscopic surveys planned at 8 to 10-m class telescopes. (VIRMOS, DEEP). When employed at large telescopes this technique can reach as deep as $I > 25$ which is well beyond the capability of spectroscopic surveys.

The MPIA node will:

• Significantly extend the samples of faint galaxies and QSOs in both number and redshift.

• Further develop the muti-colour technique both by invetsigating optimum combinations of red optical and NIR bands which are essential to probethe poorly explored but cosmologically extremely relevant galaxy redshifts, $z > 1$. Additionally, the library of template spectra will be extended such that redshift errors caused by the mismatch between templates and real galaxy spectra are minimised.

• Distribute experience and software throughout the network in order to enable an optimum design of future surveys.

Narrow-band surveys like CADIS aiming for a complete census of emission-line galaxies at $z > 0.2$ are pretty unique worldwide. Thus the MPIA experience with CADIS and a narrow-band survey in the COMBO-17 fields (currently under way at WFI) will be essential in this area of research.

There are two topics in the field of galaxy formation and evolution in which emission line samples will play a central role;

(1) Star-formation history of the universe since the H_α luminosity (and with some caution the [OII]λ 3727 luminosity) provides the best measure of the actual star-formation rate which is much less affected by extinction than the UV continuum.

(2) Primeval galaxies which form their first generation of massive stars from primordial material are charcterised by their very strong Lyman - α line. Optimised narrow-band surveys can reach several magnitudes deeper.

The MPIA node will:

• Carry out emission line surveys at the Calar Alto telescopes, with the ESO 2.2-m WFI and with the VLT.

• Provide emission-line selecetde galaxy samples both at intermediate ($z < 1.2$) and very high redshift ($z > 5$. These have to be compared with the continuum selected galaxy samples.

• Design and promote narrow-band surveys with the next generation of survey telescopes (VST, VISTA).

• Model the formation and spectral properties of Lyman - α bright primaeval galaxies at very high redshift.

Key staff: Klaus Meisenheimer (40%), Josef Fried, (20%), Hans Hippelein (40%), Martin Kümmel (30%), Hans-Walter Rix (10%), Hermann-Josef Röser (20%), Christian Wolf (50%)

Most relevant recent references

Fried, J., von Kuhlmann, B., Meisenheimer, K. et al., 2001, A&A 367, 788-200.

Wolf, C., Meisenheimer, K., Röser, H.-J., 2001, A&A, 365, 660-680.

Wolf, C., Meisenheimer, K. et al., 2001, A&A, 365, 681-698.

5e. Osservatorio Astronomico di Capodimonte, Naples.

The Osservatorio Astronomico di Capodimonte (OAC) is one of the 12 Italian Astronomical Observatories. Its Italian role may become even more important in the coming years, with the advent of the National Institute for Astrophysics (Istituto Nazionale di Astrofisica or INAF) which will co-ordinate the national facilities and the activities of the individual observatories. OAC was the first observatory in Italy to be built directly for the purpose and according to the typical criteria of a modern astronomical research institute. It was erected in the period 1812-1820, The present Director (since 1993) is Massimo Capaccioli, who is full professor (Professore Ordinario) of Astronomy at the University Federico II of Naples. During the last decade, as a result of the generous allocation of funds (special funds for the development of the South) , the growth of the Astronomical Observatory of Naples has continued, with a steady increase in staff, a significant broadening of the scientific interests, and a major impulse given to technological programs.

VST/OmegaCam History. In October 1997, the Scientific and Technical Committee of ESO approved a proposal by the Osservatorio Astronomico di Capodimonte (OAC) for the construction and installation of a 2.6-m Altazimuth Telescope to be used solely for wide-field imaging at Paranal. The telescope, which is now known as the VLT Survey Telescope or VST (see figure A4), will be fully devoted to survey work with the goals of excellent image quality over a large field-of-view, high operational efficiency, high reliability, and compliance to VLT standards. The VST is now being built by the OAC and will be managed by ESO, with the main purpose of conducting long-term surveys and providing the selection of targets required for VLT science.

Since the OAC proposal did not include plans for the delivery of the wide-field camera for which the VST optical design was optimized, ESO issued in March 1998 an Announcement of Opportunity (AO) for the design, construction and procurement of an optical wide-angle CCD camera to be installed at the Cassegrain focus of the VST.

In response to the call, a European consortium formed and in October 1998 submitted a proposal to ESO to deliver OmegaCam as the wide-field optical imager for the VST. OmegaCAM is an optical 16k $\times$ 16k camera, and the $\approx$ 1 square degree of the sky with a pixel size of 0.22 arcsec. OmegaCAM will be the only instrument for the VST, at least during the first 5 years of operations, which are expected to start during the summer of 2002. OmegaCAM will be used at visual wavelengths with a wide variety of pass-bands and will be offered to the user community allowing the users to conduct their own defined programs.

The design of the instrument is centered around a mosaic of 32 2k$\times$4k pixels CCDs that will cover the VST's field of view of one square degree and at the same time will adequately sample the best seeing foreseen at Paranal.

The telescope optics has been designed to deliver a pixel scale of about 0.21"/pix assuming a pixel size of 15microns. The goal is to obtain a responsive quantum efficiency better than 80% in the B,V band , still reaching 50% at 350 nm and at 800 nm. Read-out noise should not exceed 5e$^-$. The dewar has a huge entrance window which in itself formspart of the optical corrector train of the VST.

Apart from VST and OmegaCAM, we list examples of the other OAC research interests that are relevant for the SISCO projec: Galaxy evolution , Global and individual properties for galaxy clusters Compact groups of galaxies Detailed photometric and kinematical studies of Early Type galaxies Galaxy stellar populations in the UV, Photometric redshift and Determination of cosmological parameters through gravitational lensing. Projects in which OAC are pusuing these research interests include CroNaRio, VST, VIRMOS, CDF, XMM, GHOSS, SLOTT-AGAPE, NEXT.

Key staff: G. Busarello (30%), S. Andreon (20%), M. Arnaboldi (20%), L. Buson, (20%), M. Capaccioli (20%), G. Longo (20%), P. Merluzzi (20%), A. Rifatto (20%)

Most relevant recent references

Arnaboldi, M. et al., 2000, in 'From Extrasolar Planets to Cosmology: The VLT Opening Symposium', edited by Jacqueline Bergeron, Alvio Renzini, 204.

Kudritzki, R.-P. et al., 2000, ApJ , 536, 19

5f. European Southern Observatory.

The main contribution of the ESO Imaging Survey (EIS) project to the present proposal will be the experience accumulated over the past four years in pipeline processing optical and infrared images from large surveys and routinely producing fully astrometrically and photometrically calibrated images, especially where these issues impinge most directly on the scientific exploitation of the surveys. EIS astrometric accuracy is limited only by the reference catalog used and is typically < 0.2 arcsec, as required for feeding multi-object spectrographs. The survey software being used by EIS is an end-to-end system for the un-supervised reduction of image data, source catalog extraction, preparation of color catalogs, classification of objects and estimation of photometric redshifts, using a χ^2 fitting technique of template spectra to the observed SED of objects as measured through broad-filters, and search for cluster of galaxies based on the identification of overdensities in the projected distribution of galaxies and/or in color or photometric redshift space. The system is instrument independent and can be used to combine imaging data from different telescopes and survey strategies and produce image mosaics. The pipeline is associated to a relational database where critical information regarding the observing setups and the processed data are stored. A search engine has also been developed to support a variety of queries enabling the retrieval of archived data as well as full descriptions of the pipeline products. The end-to-end survey system includes standardized procedures, software tools to assess the quality of the derived products and to explore the available datasets in a systematic and consistent way to search for astronomical objects of potential scientific interest.

The EIS survey system provides a solid basis from which one can ramp-up to handle the significantly larger data rates expected from future public imaging surveys using VST and VISTA. It represents a major step towards the ultimate goal of routinely producing a steady stream of images and derived products that can be used to prepare statistical samples for spectroscopic surveys. In order to validate the pipeline products, tools have been developed to handle, visualize and analyze multi-color data, to compare results with models or other empirical data and to correlate the derived catalogs with other databases. These tools are a modest first step towards the implementation of a virtual observatory, as required for the full scientific exploitation of the data from ongoing and future imaging surveys.

ESO astronomers are also involved in many of the scientific exploitation areas of observational cosmology and so are ideally placed to input technical expertise that will keep the project close to its basic science aims.

Key staff: Luiz daCosta (25%), Stephane Arnouts (25%), Evanthia Hatziminaoglou (25%), Charles Rite (25%), Benoit Vandame (25%)

Most relevant recent references

ESO Imaging Survey. Deep Public Survey: Multicolor Optical Data for the Chandra Deep Field South Arnouts, S. et al. 2001 , submitted to A&A (astro-ph/0103071)

ESO Imaging Survey. Deep Public Survey: Infrared Data for the Chandra Deep Field South Vandame, B. et al. 2001 , submitted to A&A (astro-ph/0102300)

5g. Department of Astrophysics, University of Oxford.

The Oxford node has a long history of direct involvement in large optical and infrared surveys, which defines its network role as folows:

1) The observations for the 2dF Galaxy Redshift Survey were organised by Oxford (Dalton). This process involved developing optimisation software for placing fibres on each if the 300,000 targets, and configuring each observing run in advance. The complex interface between the photometric input data and the spectroscopic observations were organised as part of this process. Dalton also participates in the analysis of the results from this survey.

2) Oxford (Miller + 2 PhD students) is one of the co-investigators for the 2dF Quasar Redshift Survey. Oxford was responsible for developing the fully-automated spectroscopic analysis that allowed target spectroscopic classification and redshift determination to be carried out. Miller continues to be involved in the analysis of data from this survey, especially the measurement of large-scale structure and its evolution, and the determination of cosmological parameters. The 2dF galaxy and quasar redshift surveys are in collaboration with groups that include Durham.

3) Oxford (Dalton, Miller, Rawlings + 5 PhD students + 1 postdoc) also has constructed a wide-area optical and infrared photometric survey from data obtained with the wide-field camera on the INT 2.5-m. and the MDM 1.5-m. The aim is to survey up to 30 sq degs in five optical and one infrared waveband, and the survey is about 50 percent complete. The principal scientific aims are: to measure the evolution of faint galaxy clustering; to quantify the luminosity function and spatial distribution of extremely-red objects (EROs), with a view to linking the populations that constitute EROs to galaxy evolution models; to carry out a large-area weak-lensing survey to directly measure the power-spectrum of mass fluctuations; and to produce a deep identification database that can be cross-correlated with deep radio and X-ray surveys.

4) Oxford is developing significant activity in semi-analytical approaches to large-scale structure (Devriendt, Silk), in cosmological numerical simulations (Taylor), in cosmological hydrodynamic simulations of galaxy formation (Slyz), and in population synthesis applied to distant galaxies with the aim of mock deep image construction (Yi). Silk has active collaborations with MPIA (Burkert) on galaxy formation.

Key Staff: Joseph Silk (15%), Gavin Dalton (20%), Julien Devriendt (25%), Lance Miller (20%), Adrianne Slyz (15%), James Taylor (25%), J Sukyoung Yi (15%)

Most relevant recent references

Dalton, G.B. et al., 2000, AAS, 196, 5605
Silk, J., 2000, PASP, 112, 1003

6. Collaboration

Due to the sheer size of the latest generation of cosmological surveys, together with the wide variety of applications of the data, close interaction between a large number of experienced researchers with diverse skills and expertise is required to realise the full scientific potential of these surveys. As an example, the largest cosmological survey currently being undertaken, the Sloan Digital Sky Survey, aims to map 100 million celestial objects, and obtain redshifts for over a million galaxies. To analyse this huge quantity of data, a collaboration of well over 100 scientists from 11 institutions, including MPIA from this network, have pooled their knowledge, skills and resources.

With the advent of the VST and VISTA telescopes, Europe is set to recapture the leading edge in the field of survey science. In order to coherently design the most scientifically useful surveys to be undertaken with these new facilities, and then efficiently and maximally exploit the vast legacy data products, it is clearly vital to integrate at least the aims of the key European groups working in this field. Each institution will bring to the network a unique set of skills and experience gained from ongoing surveys, and through close cooperation we will capitalise on the exceptional concentration of expertise in these network institutions, to achieve our broad research goals. To maximise the impact of these state-of-the-art European facilities when they come online it is imperative that we begin preparations immediately.

Importantly, this network brings together the collaborative teams most heavily involved with the VST/Omegacam (Groningen, Capodimonte, ESO) and VISTA (Durham, Edinburgh, ESO, Oxford) projects. There are many other ongoing active collaborative projects between network participants, and some of these are listed in the table below, including the 2dF spectroscopic redshift surveys, the Wide Field Imager at the MPG/ESO 2.2-m telescope on La Silla, Chile; currently the most powerful survey instrument available for European astronomers, and the COMBO-17 survey using this instrument. Through this network we aim to bring these collaborations together to form a formidable team and train a new generation of European scientists to become world leaders in cosmological survey science.

Ongoing active collaborations within the network	
Project	Collaborating partners (in network order)
VST/Omegacam	Groningen, Capodimonte, ESO
VISTA	Durham, Edinburgh, ESO, Oxford
Gemini GMOS spectrographs	Durham, Edinburgh, Oxford
2dF QSO Survey	Durham, ESO, Oxford
2dF Galaxy Survey	Durham, Edinburgh, Oxford
WFI on MPG/ESO 2.2m telescope	MPIA, Capodimonte, ESO
COMBO-17 Survey	Edinburgh, MPIA
UKIDSS WFCAM Survey	Durham, Edinburgh, Oxford
N-body simulations (VIRGO)	Durham, Edinburgh, MPIA
Galaxy formation	MPIA, Oxford
Photometric redshifts	Edinburgh, MPIA

7. Organisation and Management

The seven research teams in the network are of similar size and intend to make approximately equal contributions to the scientific work of the network. The European Southern Observatory (ESO) is an intergovernmental European organisation responsible for operating, and developing instrumentation for the telescopes at the La Silla and Paranal observatories in Chile, including the VLT, and when construction is completed the VST and VISTA survey telescopes. Whilst interaction and collaboration with ESO research staff is central to this proposal, we are not requesting funding to host a young researcher there. The researchers hosted elsewhere, however, will still be encouraged to make extended collaborative visits to ESO as required.

The network coordinator is Prof. Tom Shanks at Durham, the coordinating partner of the network. Each of the other research nodes has a principal local contact who, together with the network coordinator as chairman, will form a Network Management Committee which will direct the operation of the network. In particular, the committee will monitor the hiring and exchange of young researchers, plan regular meetings and workshops, identify opportunities to stimulate and enhance collaboration between the partners and ensure the proper coordination of network activities at each node.

The principal local contacts will be responsible for directing network research activities at their own node, as outlined in the previous sections, and reporting these activities to the rest of the network. They will also have responsibility over the local training of young researchers at their node. In cooperation with the Management Committee they will actively encourage the exchange of other young network researchers to their node, supporting existing network collaborations and seeking out new ones.

We plan to hold annual meetings of all the scientists involved in the network, the first to be held as soon as possible after signing the contract. These meetings will allow the results of ongoing collaborations to be presented to network scientists, allowing a thorough discussion and review of existing joint projects. Perhaps more importantly, these meetings will allow network scientists to join existing collaborations, bringing with them new perspectives and expertise, and also they will promote the development of new collaborative projects. In light of these discussions, the overall strategy of the network will be reviewed and revised as required. In addition to the annual meetings, smaller focused workshops will be arranged on a regular basis to pool the expertise of researchers in particular specialist areas.

The results obtained will be promptly published in international journals. An internet site for the network will also be designed containing an overview of research progress in the network, ranging from the very latest developments and results for internal network use only, to an educational page aimed specifically at the general public, and in particular students. The site will also contain a list of all the network publications, together with news of any network job opportunities. It will be used to make any detailed numerical results available (e.g. catalogues, images, spectra etc.), or provide a link to other network database sites where such information is stored.

As P.I. of the 2dF QSO Redshift Survey team, the network coordinator has considerable experience managing a team of astronomers distributed across several locations, and in the planning of a challenging research programme. The principal local contacts are also all active and experienced research scientists, well qualified for their roles as local team leaders and members of the Network Management Committee.

8. Training Need

Recent advances in detector technology and the huge multiplex gains from fibre optics and multi-slit technology have given astronomers a new ability to make panoramic sky surveys to deeper depths than ever before, where new and accurate tests of cosmological models are possible. To answer the fundamental cosmological questions we need to maximise the scientific exploitation of European astronomical survey facilities, such as the 2.5-m VST optical and the 4-m VISTA optical/IR imaging telescopes being constructed at Cerro Paranal, the UK's 2dF multi-object fibre spectrograph at the 3.9-m AAT, the WFCAM IR imaging instrument being built for the 3.8-m UKIRT and the Wide Field Imager on the MPG/ESO 2.2-m telescope.

To achieve this goal, the crucial aim of this network is to train young European observers and theorists to obtain and exploit the next generation of cosmological surveys. The imminent arrival of VISTA, VST and WFCAM, means that European survey cosmology will continue to be at the forefront of astrophysical research for at least the next decade, as long as we can ensure that European scientists remain among the leaders in the field.

We believe that the best way to maximise the efficiency of the future European surveys in the global race to produce the Virtual Observatory of the future is through close collaboration between the various European survey institutions. The proposed network is essential to realising this goal, and in particular the regular exchange of young researchers between network institutions will enhance and stimulate communication, spreading the expertise of individual groups and training the researchers in different environments. By combining the different approaches and ideas of all the network institutions with access to the very best astronomical survey facilities, the young researchers will be in an ideal position to produce the coherent scientific stategies required to keep European survey cosmology at the forefront of research.

The skills and experience that well-motivated young researchers will gain by working within a competitive, transnational European team on a major and prominent research project will greatly enhance their future career prospects within the field of astronomy.

9. Justification of the Appointment of Young Researchers

We are requesting funding to finance a young pre-doctoral researcher for three years, and post-doctoral research positions at five institutions, each for four years duration. Therefore we will provide an overall minimum total of 276 person-months employment for young researchers within the proposed network project. A detailed breakdown by institution is shown in the table below.

All of the network participants are major research and educational institutions and hence have the staff available to provide a dynamic and interactive research environment for the young researchers. They have ample previous training experience, and the diverse technical and astronomical expertise required to support fully all of the researchers training requirements. Through collaborative network exchanges and meetings, young researchers will have the opportunity to work with the other research teams, sharing data and ideas to develop a broad range of knowledge and expertise.

The positions will be advertised in accordance with an agreed network policy in astronomical institutions throughout Europe through the internet sites of the participating research teams, email distributions, international job registers such as U.K. Starlink, as well as in science journals such as Nature. Whilst we will actively encourage applications from researchers within the network, the recruitment process will be open.

We intend that all of the post-doctoral positions will normally be offered initially for a two year period, as a shorter tenure is unlikely to attract suitable candidates. We will offer competitive salaries in order to ensure a high level of interest and attract the very best candidates. All of the institutions involved in the network are committed to equal opportunities and to selection on merit. Therefore, when the vacancies are published, applications from all sections of society, including women, ethnic minorities and disabled persons, will be encouraged, and appointments will be made on merit alone.

Young researchers to be financed by the contract				
Participant	Young pre-doctoral researchers to be financed by the contract (person-months) (a)	Young post-doctoral researchers to be financed by the contract (person-months) (b)	Total (a+b) (c)	Scientific specialities in which training will be provided (d)
1 DUR		48	48	P-08
2 UEDIN		48	48	P-08
3 RUG		48	48	P-08
4 MPIA		48	48	P-08
5 OAC		48	48	P-08
6 ESO				
7 OXF	36		36	P-08
			Overall Total	
Totals	36	240	276	

10. Training Programme

The training programme is a crucial and prominent element of the network activities. Young researchers will be trained by the local staff through their incorporation into the research programmes of the different network nodes. As all of the network participants are major research and educational institutions, the staff available have a wide range of technical and astronomical expertise and experience, including the development and use of a wide range of state-of-the-art astronomical instrumentation, data analysis techniques to maximise the extraction of information from observations with these instruments, and theoretical modelling techniques to help interpret and explain the observations, and to use them to make predictions about the cosmological structure of the universe. New techniques being developed for the handling and statistical analysis of very large datasets are of particular importance to this network project. With comprehensive computer facilities and expertise of staff in this area, the network nodes will provide the ideal environment for the young researchers to become leaders in this field.

Collaborative network exchanges will be central to the young researchers training programme. We will actively encourage all the young researchers to spend several months of their tenure in network institutions other than their own, giving them the opportunity to work with the other research teams, sharing data and ideas to develop a broad range of knowledge and expertise. In suitable cases we may split the tenure of a post-doc between two partners. As well as broadening their scientific experience we hope that this will stimulate new and fruitful collaborations that will continue beyond the conclusion of this network project.

Regular network meetings and specialised workshops will give further opportunities for the young researchers to exchange skills and ideas and to present their research to an international audience. These meetings will enable the researchers to review and discuss progress of the network in detail, to plan joint strategies, and to modify their programme in light of the experiences of others.

12. Connections with Industry in the Training Programme

We do not anticipate significant direct industrial involvement with our programme. As a result of their training, however, in computer software and numerical and data analysis techniques, together with forefront astronomical instrumentation and detectors, the skills developed by the young researchers involved in this programme will be of great interest in a number of high-tech industries.

13. Financial Information

We are requesting financial support for a four year programme to develop state-of-the-art techniques to exploit the latest generation of European survey facilities such as VST and VISTA in the quest to answer the fundamental cosmological questions. A detailed breakdown of the proposed funding for each network participant is shown in the table below.

With 7 network nodes from 4 countries, the proposed network is internationally balanced. The U.K. has the largest representation, with 3 nodes requesting 39% of the total contribution to fund one pre-doctoral and two post-doctoral researchers. The network will also fund post-doctoral researchers in the Netherlands, Italy and Germany. There are also no major imbalances between the teams in terms of the financing requested. The largest contribution requested, by MPIA, is for 291200 Euros; considerably less than twice the average requested contribution per node of 199000 Euros.

The personnel costs for each of the post-doctoral researchers were calculated with reference to the rates for Marie-Curie Fellows. A small adjustment was made in the case of Edinburgh to account for local pay and conditions. The costs of a graduate student at the University of Oxford, including fees and stipend were calculated according to local rates. We believe that these rates will provide competitive salaries, and so should not lead to recruitment difficulties.

In addition to the personnel costs, we have requested 8000 Euros per year per institution to cover the mobility costs associated with the activities of the network, including staff exchanges and network meetings. We anticipate that each active member of the network will on average travel to two network meetings per year. Collaborative exchanges of one to three months duration by the young researchers to partner institutions will also be funded. Finally the funding will also cover network related telephone and internet costs, and the cost of network publications. We are not requesting funds to procure durable equipment.

Overhead costs were calculated according to the official rate of each individual institution and differ slightly. In all cases the total overhead requested (C) does not exceed 20% of the total allowable costs (A+B). A total of 70% of the requested contribution to the network will be spent on those costs directly associated with the appointment of young researchers (category A).

Financial information on the network project				
Participant	Personnel and mobility costs related to the appointment of young researchers (Euro) (A)	Costs linked to networking (Euro) (B)	Overheads (Euro) (C)	Totals (Euro)
1 DUR	150144	32000	30029	212173
2 UEDIN	153744	32000	37149	222893
3 RUG	202800	32000	40560	275360
4 MPIA	216200	32000	43200	291200
5 OAC	183024	32000	36605	251629
6 ESO	0	32000	0	32000
7 OXF	64000	32000	12000	108000
Totals	969712	224000	199543	**Grand Total** 1393255

14. Appendix

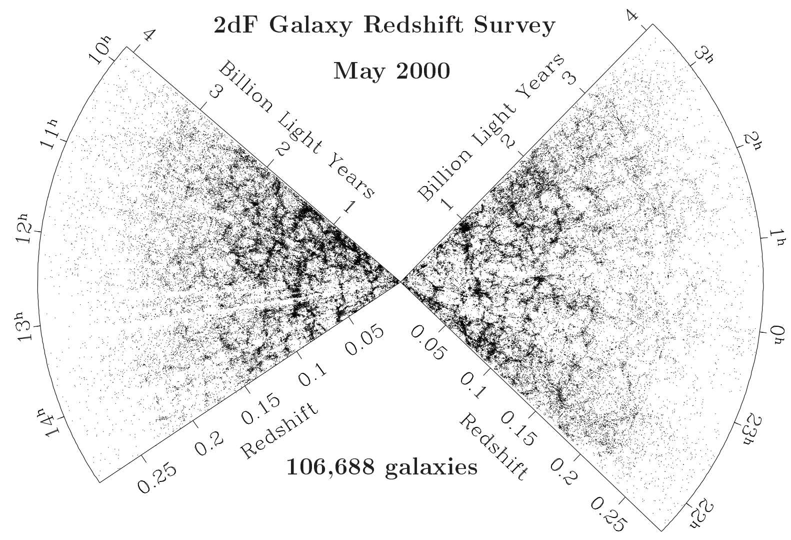

Figure 1: 2dF Galaxy Redshift Survey: The distribution of ~ 100000 2dF galaxies with currently measured redshifts from the AAT 3.9-m 2dF instrument. When completed the survey will contain 250000 galaxy redshifts out to $z \approx 0.3$

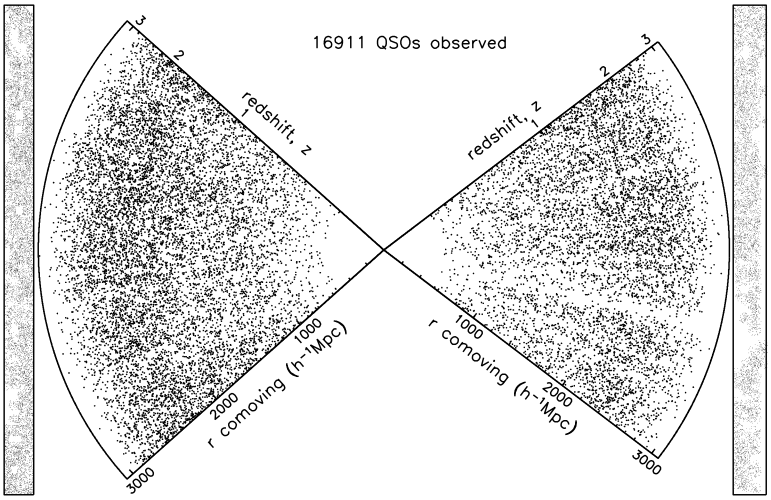

Figure 2: 2dF QSO Redshift Survey: The distribution of $\sim$ 17000 2dF QSOs with currently measured redshifts from the AAT 3.9-m 2dF instrument. The panels at the edge show the current sky completeness in the two $5^o \times 75^o$ survey areas. When complete the survey will contain 25000 QSO redshifts out to $z \approx 3$

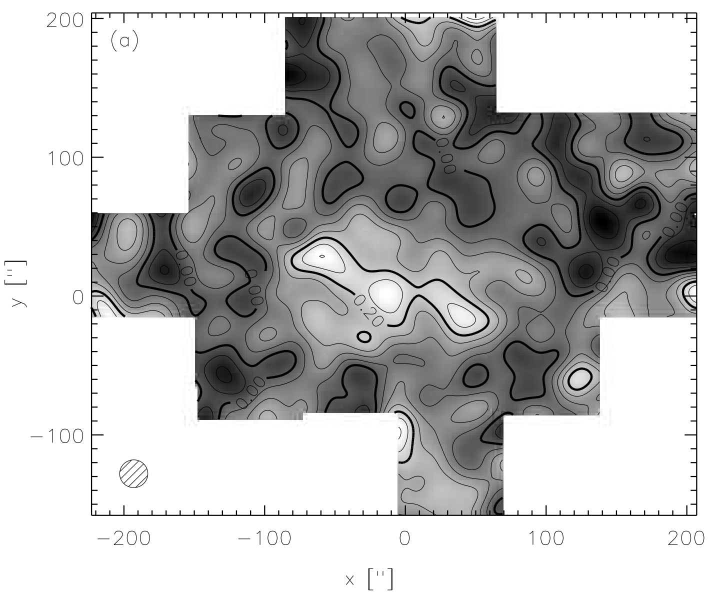

Figure 3: Weak lensing shear mass map of the $z = 0.83$ cluster MS1054-03 by Hoekstra et al (2000). Imaging surveys probe the distribution of invisible, as well as visible matter.

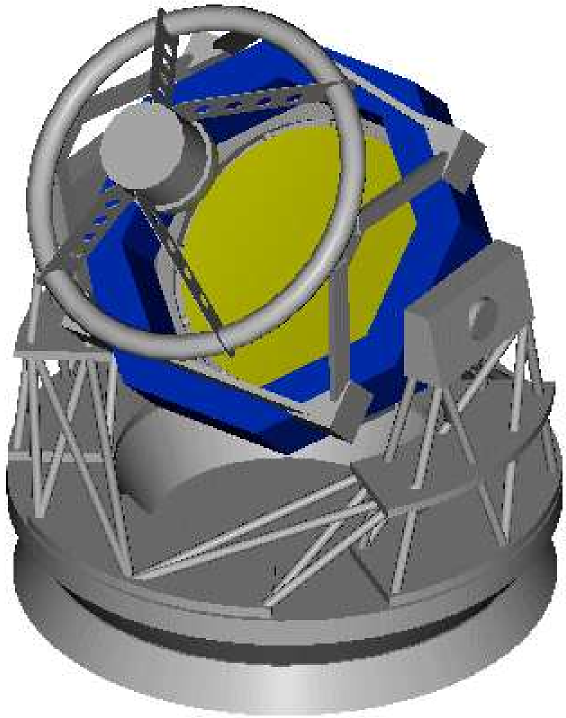

Figure 4: VST: The VLT Survey Telescope. A 2.6m telescope dedicated to wide field optical imaging surveys. The VST is being built to operate at Cerro Paranal in Chile, close to the VLT.