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# The Visible & Infrared Survey Telescope for Astronomy

*VISTA's 4-metre primary mirror and 1.65-degree diameter infrared field of view feeds a 64 megapixel (0.34″ pixel) camera. Rapid deep IR (0.85–2.3μm) imaging surveys will both select objects for follow-up with VLT, and directly study a wide variety of astronomical topics.*

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VISTA (Visible and Infrared Survey Telescope for Astronomy) is the result of a 1998 application, to the UK's Joint Infrastructure Fund, by the VISTA Consortium of 18 UK Universities (see acknowledgments) for funding for a 4-m wide field survey telescope, which was approved in summer 1999. The purpose of the wide field (1.65° diameter in the IR) survey telescope and camera facility is to perform extensive surveys of the southern skies whose sensitivity is matched to the needs of today's 8-m class telescopes. Imaging surveys not only generate much science directly but also are needed to efficiently choose objects for further study by the VLT. IR surveys particularly target the cold universe, the obscured universe, and the high redshift universe.

The VISTA Consortium used competitive tendering to choose the UK Astronomy Technology Centre (UKATC) in Edinburgh to take on the technical responsibility for design and construction and a VISTA Project Office was accordingly set up. Their preliminary conceptual design studies resulted in Technical Specifications and Statements of Work for various work packages, which were awarded through a process of open competitive tenders. After investigating various potential telescope sites in Chile, and discussions with the site sponsors, the VISTA Consortium decided that the Cerro Paranal Observatory was the best site for maximizing the survey speed of VISTA. Interestingly this decision by the VISTA Consortium helped considerably in bringing about the subsequent decision by the UK to join ESO. As an ESO telescope, VISTA and its large surveys will now be fully exploited by the whole ESO community. This article provides an overview of some aspects of the system.

## Design drivers

The purpose of VISTA is to survey both spatially and over time, through monitoring. Good image quality is required both to

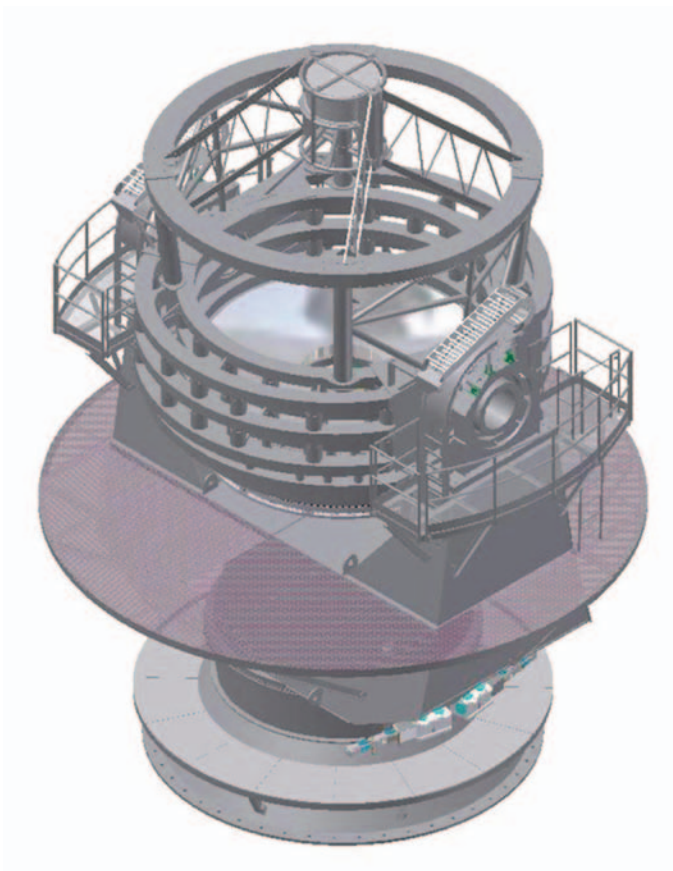

**Figure 1:** Drawing of VISTA telescope (camera not mounted).

**Table 1:** Design Reference Program for IR System Design.

| Survey name | Area Sq. deg | Limiting magnitude | | |
|---|---|---|---|---|
| Band | | *J* | *H* | $K_s$ |
| Wide high galactic latitude | 3000 | 21.2 | 20.0 | 19.5 |
| Wide low galactic latitude | 1500 | 20.5 | 19.5 | 19.0 |
| Deep | 100 | 22.8 | 21.5 | 21.0 |
| Very Deep | 15 | 23.8 | 22.5 | 22.0 |

enhance sensitivity and resolution, and to minimize confusion, leading to the requirements for an excellent site and a pixel scale matched to sample at least the median seeing at the site. Good sensitivity is required (e.g. to go deep in a reasonable integration time, and to enable monitoring of faint objects) leading to a requirement for a 4-m diameter primary mirror. To get statistical samples of sky area/objects (for example to study intrinsic scale sizes of clustering, to find rare objects, and to generate the large samples needed to get accurate properties) large areas must be surveyed, leading to a requirement for a large field of view. Both near-IR and visible surveys were required.

The design of VISTA was thus driven by the requirements of good image quality in both the near-IR (0.5″ fwhm) and visible and over a large (1.5–2.0°) diameter field of view with a 4-m class telescope, together with the ability to change between use of a visible or an IR camera. Finally, design trade-offs were to be resolved whenever possible in favour of maximizing the survey speed (in square degrees/hour for a specified set of surveys taking into account the overheads of changing filters, slewing, reading out etc) within the available financial budget. As the funding needed to build the visible camera is not yet available we focus here on the IR, without forgetting that VISTA is potentially an extremely powerful visible 2.1° diameter survey telescope with 50 red-optimized 4096×2048 CCDs with 0.25″pixels to complement the blue-optimized VST.

To turn the concept of survey speed into a quantitative tool, the surveys that VISTA might be expected to undertake were defined to assist the VISTA Project Office in optimizing VISTA for survey work. By examining the science drivers the VISTA Consortium defined a Design Reference Programme (Table 1) to match the science aims. Each survey is primarily defined by a solid angle of sky, a set of pass bands, and a detection limit to be reached in each pass band. In addition monitoring programmes involve a number of repeat observations of each field, and there is a goal of a southern sky atlas using the worst-quartile seeing time over 4 years, this would cover the hemisphere in two bands to over 3 mag deeper than the 2MASS survey. [N.B. There is also a *Y* (1.02 micron) filter available, narrow band filters could be purchased, and the detector system would allow use of a $z_{IR}$ filter.]

The surveys that VISTA will actually undertake remain to be decided, and will depend on the properties of the final commissioned system, progress in survey science by 2006, and the deliberations of the ESO bodies that will determine the actual time usage.

VISTA's strength, in addition to its specifications, is that it is a survey machine with time dedicated to ambitious, communally planned legacy programmes. The key, apart from the performance of VISTA itself, is to design survey strategies that maximize the utility of the data to many different science programmes. Thus, for example, many surveys will likely be constructed in multiple passes to enable completion of monitoring programmes and some key fields will be monitored over many years. VISTA is conceived as a blend of 75% of 'public' time (e.g. Schmidt-like sky surveys) used for pre-planned large survey and monitoring programs together with 25% of competitively (traditional) based time.

## Design concept

To cover large areas of sky rapidly enough to produce timely results requires as large a field of view as possible. At the same time off-axis (and chromatic) aberrations over the large field must be kept down to a level that does not much degrade the size of the stellar images incident at the telescope. VISTA adopts an unusual design solution where the primary and secondary mirror conic constants are optimised jointly with the IR camera lenses to optimise image quality over the entire field of view. This leads to a quasi-Ritchey-Chretien solution but with significant aberrations for the 2 mirrors alone. The two mirrors provide most of the power of the system, whereas three lenses in the Cassegrain camera act as a reasonably conventional field corrector mainly serving to correct the off axis aberrations, without introducing much chromatic aberration, out to a field diameter of 1.65° (or 2.1° in the case of the visible camera design). As the telescope alone produces significant spherical aberration and off-axis coma, it must be used with the camera to produce good images. (This leads to challenges in testing the telescope and camera separately). The 4-m diameter primary is f/1 and with a 1.24-m diameter secondary, the resulting beam at the focal plane is f/3.26 producing 0.34″ pixels with the 20-micron pixel size of the IR detectors. For pixels at either extreme of the large focal plane not to look off the primary, any individual pixel cannot use the entire primary physical diameter. In fact any indi-

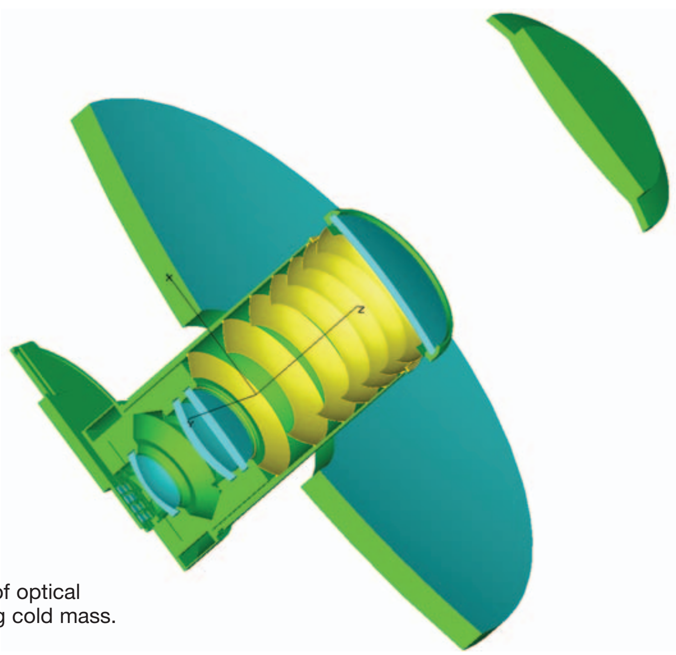

**Figure 2:** Cutaway of optical assemblies including cold mass.

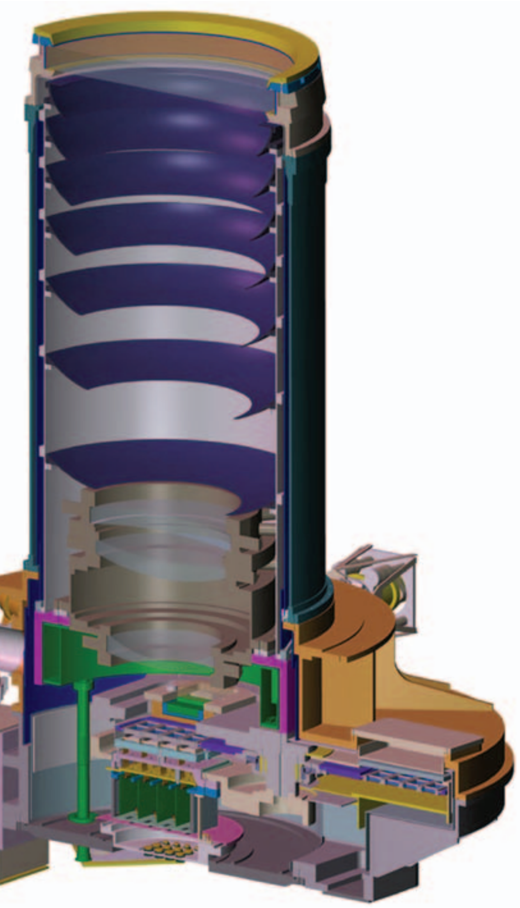

**Figure 3:** Cross Section of IR Camera Design.

**Table 2:** VISTA's 1st VIRGO science detector properties.

| Parameter | First Science detector VM301-SCA-22 (72K) |
|---|---|
| Quantum efficiency | 71% (*J*)<br>74% (*H*)<br>75% (*Ks*) |
| Well depth | 156 k$e^-$ (0.7 V bias) |
| Dark generation | 1.7 $e^-$/pix/sec |
| Read noise | 17 $e^-$ (rms) |
| No. of outputs | 16 outputs (1.001s) |
| Non-linearity | 3.3% (100 k$e^-$ FW) |
| Pixel defects | <1% |
| Flatness | ~6 µm (p-v) |
| Conversion gain | 3.58 µV/$e^-$ |
| Output DC level | 3.23 V |
| Operability (%) | 99.18% |

vidual pixel in the focal plane uses 3.7-m diameter of the primary. The f/1 primary allows a relatively squat telescope that helps contain construction costs, and delivers a fast Cassegrain focus with an acceptable secondary diameter. The curvature of the primary is unusually high for such a large mirror.

The standard method of rejecting the unwanted IR background from telescope structure, dome etc. in most IR instruments is to form an image of the pupil and to place a cold stop at that image to baffle out the unwanted background radiation. This ensures that the detector "sees" only cold surfaces inside the cryostat, the highly reflective low emissivity telescope optics, and the sky being imaged. VISTA's large diameter and large field of view, together with the need to maintain image quality, led to severe difficulties with cold stop designs, either using lenses (e.g. no IR glasses available in ~600mm size and with the achromatic properties needed) or using mirrors (e.g. packaging and obscuration problems). VISTA's solution (see Fig. 2) is to dispense with the traditional cold stop, and incorporate a long cold baffle at the front of the camera to reduce the background on the detectors. If the cryostat/baffle system is long enough, ensuring that the detectors see the smallest possible solid angle out of the cryostat, and the secondary slightly undersized to form the system stop, the field of view of all pixels is limited and does not overlap the edge of the primary mirror, or see other parts of the telescope structure. The cold baffle tube forward of the corrector contributes negligibly to the background in the focal plane.

There could however be an extra thermal component due to emission from the sky (mainly OH) that enters around the secondary mirror. This extra sky emission is blocked with a warm reflective annular (1.65-m) baffle around the (1.24-m) secondary mirror, so all that the detectors see from this annulus is the reflection of the cold interior of the camera. The result is that the total

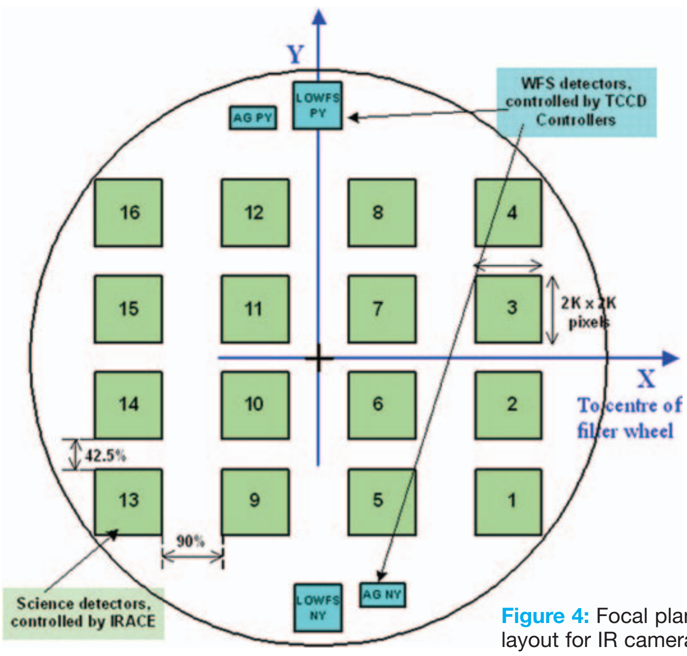


**Figure 4:** Focal plane layout for IR camera.

background is limited to unavoidable thermal emission from the primary, secondary, spider, and cryostat window, plus a modest contribution from the reflective baffle. Thermal contributions from the optics are of course present whether or not a cold stop is used. Analysis shows the system delivers performance certainly no worse than an (impractical) cold stop system would have done.

## IR Camera

The camera includes the entrance window, cold baffle tube, lenses, filter wheel and detectors and is being constructed by a consortium of Rutherford Appleton Laboratory, UKATC and Univ. of Durham (Dalton et al 2004). A cross section is shown in Fig. 3. The cold baffle approach inevitably results in a large (950mm IR grade fused silica) entrance window which potentially delivers a large heat load to the cryostat, potentially requiring a large number of closed cycle coolers to maintain the required temperatures. The solution adopted is to coat the reflecting baffle surfaces in the cryostat with a selectively reflective coating with high reflectivity around 10 µm, where the thermal emission peaks, and good absorption below 3 µm, where the detectors are sensitive, so that much of the heat load is returned to the window. Normally the window should not be subject to dewing or frosting, and measures to prevent this during ambient conditions when it is a danger are designed in. The baffles and lenses are mounted in a tube so that when mounted on the telescope the camera protrudes through the primary. The all-up camera system has a mass of 2900 kg.

The focal plane contains a sparse 4×4 array of Raytheon VIRGO 2048×2048 HgCdTe IR detectors (Love et al 2004) and will be the largest IR focal plane ever built. The parameters of the first delivered science detector are given in Table 2 as measured at the UKATC. A specially developed version of ESO's IRACE controller will be used to synchronously control the 16 VIRGO detectors (Bezawada et al 2004) .

As the detectors are not 4-edge buttable, some gaps are inevitable. Analysis has shown that the most effective way to maximize the survey speed, given the available field of view and detectors, was to space the detectors by 90% of a detector width in one (X) direction and 42.5% of their width in the other (Y) direction (Fig. 4).

A single exposure with this focal plane produces a 0.6 square degree 'pawprint' on the sky, and other exposures must be used to fill in the gaps between the 16 detectors to produce a contiguous image or 'tile' of sky of minimum size 1.5 degree × 1.0 degree. The simplest way to achieve this is with a series of 6 suitably offset exposures (Fig. 5): first expose at position 1, then move up 0.475 of a detector in Y to position 2 and

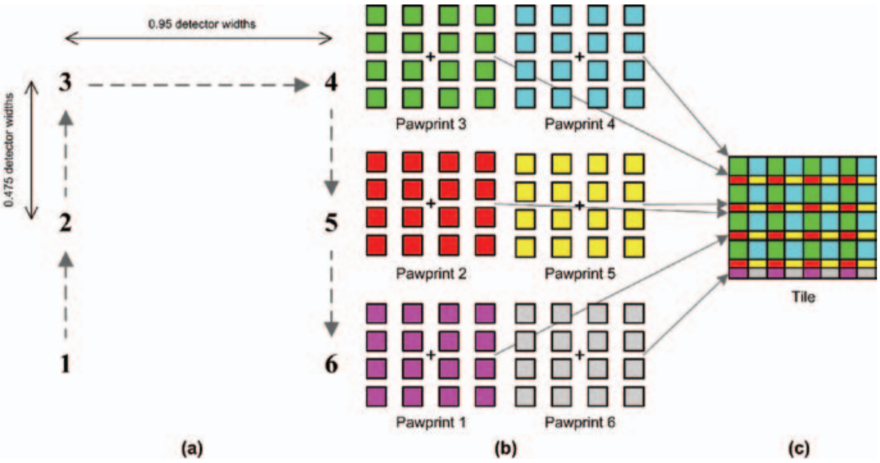


**Figure 5:** Making a filled tile (c) from 6 pawprints (b) at various offsets (a). Each sky position is observed at least twice.

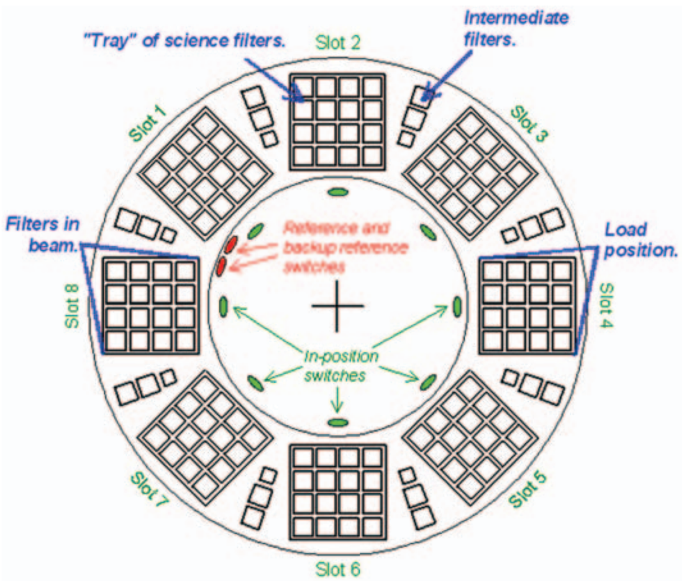


**Figure 6:** Filter wheel schematic.

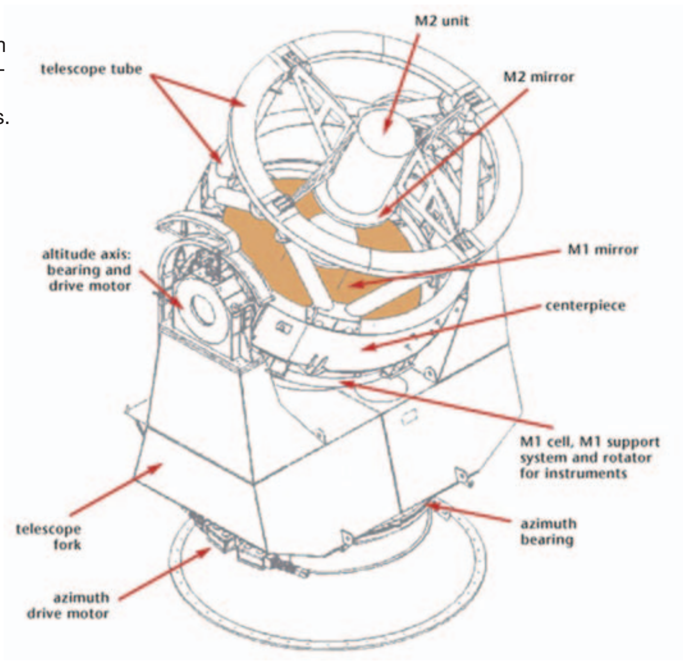


**Figure 7:** Diagram of telescope structure showing the major components.

expose, then up another 0.475 in Y to position 3 and expose, then move across 0.95 of a detector in X to position 4 and expose, then down 0.475 in Y to position 5 and expose, and finally down 0.475 in Y to position 6 for the final exposure which completes the tile. This ensures each piece of sky is covered at least twice, except for single exposures at the upper and lower extremes in Y, which will find matching single exposures when the next tile is made.

Inspection of Fig. 4 also shows two fixed autoguider visible (red) CCDs (AG +Y and –Y). Only one chip will be used to autoguide at any time, but a suitably bright guide star may be chosen from either. A patrolling mechanism for acquiring a guide star was rejected to minimize moving cryogenic mechanisms. There is also a curvature sensing device near each autoguider chip. These are used to feedback signals to the secondary and mirror support to allow adjustments to maintain the image quality.

Filters can be changed via a 1.37-m diameter filter wheel (Fig. 6) which has space for 7 sets of 16 filters (each filters covers one detector) and an (opaque) position for taking dark frames. The filter wheel also contains slots between the science filters for sets of auxiliary optics. These are occasionally used with the IR detectors in a wavefront sensing mode to monitor the figure of the primary, perhaps once just before observing and once again during the night.

With 16 detectors, each 2048×2048, and 4-byte output, each pawprint will be 268.4 Mbytes. Exposures are frequent in the IR so a typical night's observing should produce several hundred Gbytes of raw data. As VISTA will be a dedicated survey facility, this leads to around 100 Tbytes per year. Processing this data rate requires very careful attention to standardizing data taking procedures and calibrations.

## Telescope & Mirrors

The telescope is an altitude azimuth design with the azimuth axis above the primary mirror (Fig. 7). It will be produced by Vertex-RSI, who have recently completed the 4-m SOAR telescope on Cerro Pachon.

The f/1 primary zerodur blank was figured to a meniscus shape of 17cm thickness by Schott Glas (Fig. 8), and is being polished by LZOS near Moscow, who also polished the mirrors for the VST. The primary is supported on 84 active pneumatic axial and 24 lateral pneumatic supports, the forces on which are controlled to ensure the mirror keeps its shape and position at various elevations. The f/1 design keeps the telescope relatively short but a consequence of the fast primary is that the image quality is very sensitive to the exact position of the secondary mirror. Therefore the results from the wavefront sensors near the focal plane are used to slowly adjust the position, tip and tilt of the


**Figure 8:** Preparing the f/1 meniscus primary to leave Schott.

**Figure 9:** Telescope support base. The central column takes the azimuth encoder, the inner ring is the pier on which the telescope itself will be supported, and the enclosure will sit on the outer wall. The VLT on Cerro Paranal can be seen in the background.

Table 3: Anticipated performance with IR camera.

| IR camera Band | *Y* | *J* | *H* | *Ks* |
|---|---|---|---|---|
| Assumed Sky Brightness mag /arcsec | 17.2 | 16.0 | 14.1 | 13.0 |
| Assumed Extinction coefficient mag /airmass | 0.05 | 0.1 | 0.08 | 0.08 |
| Sensitivity 5σ 15 min limiting (Vega=0) mag | 22.5 | 22.2 | 21.0 | 20.0 |

secondary by sending signals to a hexapod secondary mirror support system provided by NTE SA of Barcelona.

## Site & Enclosure

As there was not enough space to fit VISTA on the Cerro Paranal summit as originally envisaged, the "NTT peak", which is ~1,500m north-east of the VLT, was assigned to VISTA. By February 2003 the summit was lowered by 5-m to a height of 2518m to produce a ~4,000m$^2$ platform on which to construct VISTA, and by June an asphalted road was constructed to the summit. This was accompanied by conduits to hold the necessary electrical, communications and other services needed at the summit. In July 2004 the foundations for all the buildings were in place and the circular base on which the enclosure will sit was completed (see Fig. 9).

The design of the enclosure is along similar principles to those of the VST to minimise seeing effects due to the enclosure. An auxiliary building will sit next to the enclosure to contain all the necessary equipment and materials for maintenance. There is space to store a second camera (if the visible camera is eventually funded) and some office space. The auxiliary building will also contain mirror washing and stripping facilities, and a coating plant. This has been contracted to Stainless Metalcraft, and will be capable of coating with protected silver because of its lower IR emissivity than traditional aluminium. Both the enclosure and auxiliary buildings are contracted to EIE (Mestre, Italy) who are also responsible for the enclosure for the VLT Survey Telescope.

## Expected Performance

Table 3 gives the anticipated 5σ 15 minute magnitudes on the Vega scale for photometry at 1.2 airmass in a 1.6 arcsec diameter software aperture, for a median site seeing of 0.66″ at 0.5µm, using the predicted system performance with protected silver coated mirrors, and assuming the given sky brightness and atmospheric extinction.

The survey speed actually achieved for large-area surveys depends on the limiting magnitudes sought, the detailed observing strategy used and the overheads for the various dithers, steps and readouts, and control activities needed. For large-area surveys the combination of VISTA's collecting area and field of view will make it the world's leading facility for large-area near-IR surveys from 2007.


## Acknowledgments

We thank: the Office of Science and Technology and the Higher Education Funding Council for England for funding through the Joint Infrastructure Fund; the Particle Physics and Astronomy Research Council for additional funds; the Particle Physics and Astronomy Research Council and their UK Astronomy Technology Centre for organizing the realization of VISTA through the VISTA Project Office, and ESO for providing the site and advice. None of this could have been achieved without the help of more than 50 people from the 18 Consortium Universities, ESO, and PPARC establishments who continue, with others, to work for the realization of VISTA, and who are too numerous to acknowledge individually.

VISTA is supported by a grant from the UK Joint Infrastructure Fund to Queen Mary University of London on behalf of the 18 University members of the VISTA Consortium of: Queen Mary University of London; Queen's University of Belfast; Universities of Birmingham; Cambridge; Cardiff University; Universities of Central Lancashire; Durham; Edinburgh; Hertfordshire; Keele University; Leicester University; Liverpool John Moores University; Universities of: Nottingham; Oxford; St Andrews; Southampton; Sussex; and University College London.


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# ALMA News

T. Wilson

The first edition of the European ALMA newsletter is now available at: http://www.eso.org/projects/alma/newsletter/

This contains information about progress in the planning and construction of the Atacama Large Millimeter Array. A staff consisting of Carlos De Breuck, Martin Zwaan, and Tom Wilson assembles and edits project information. The newsletter will appear quarterly, so the next edition will appear in October 2004.

In the the first edition are short descriptions of: the ALMA Construction site near San Pedro de Atacama; the ALMA Regional Centers (ARCs); new personnel; the current state of the antenna selection process; the plans for ALMA community day (Sept 24, 2004, in Garching); and upcoming events.

The newsletter can be viewed as a web page or can be downloaded as a PDF file. You can also add yourself to the mailing list by sending an email to: majordomo@eso.org with "*subscribe alma-newsletter*" in the first line of the body. You will then receive email announcements when new editions become available.

# La Silla News

L. Germany

It is with a very heavy heart that I have had to bid farewell to La Silla after my four years there as an ESO fellow. I have really enjoyed the work, my colleagues, and meeting a substantial fraction of the European observational community during that time.

Arriving to fill the service queues at the 2p2m is a new OPA, Mauro Stefanon. Mauro is not a stranger to La Silla Observatory – he was involved in setting up the REM project. We welcome him back and wish him well for his year as part of *SciOps*.