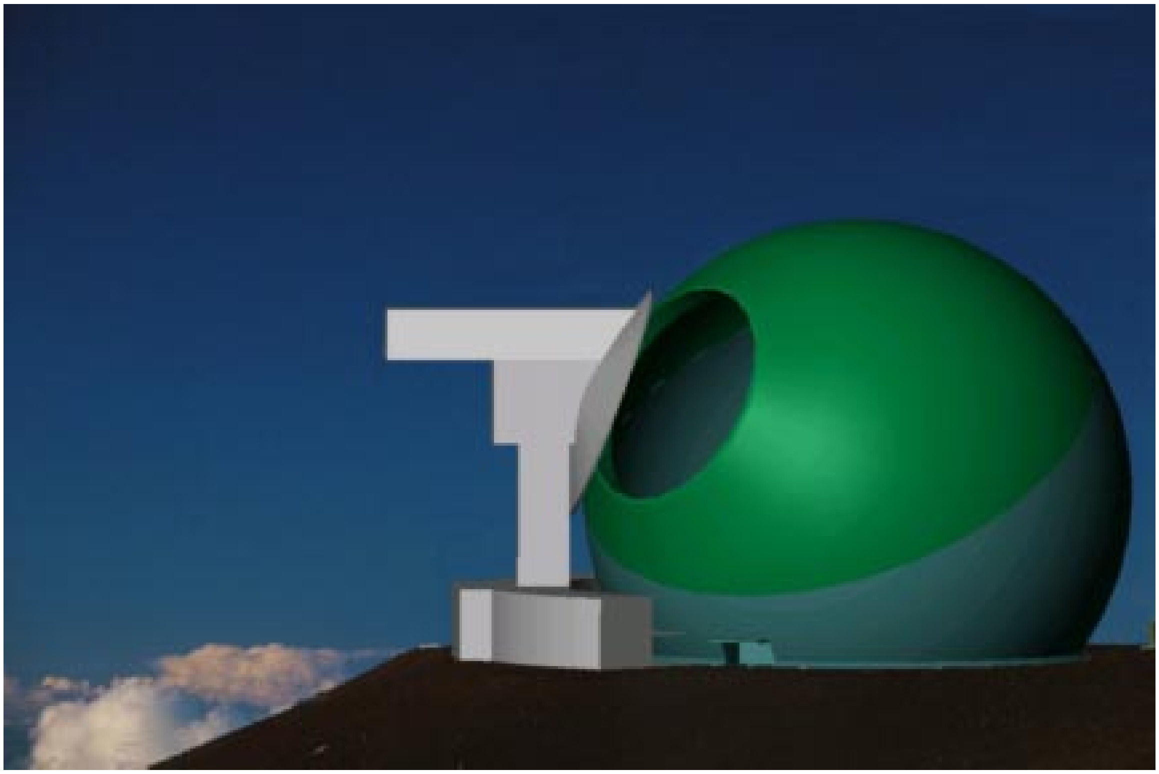


Renewing the Canada-France-Hawaii Telescope:

A Wide-Field, High-Angular Resolution Telescope

Final Report of the Canadian Large Telescope Working Group to CFHT

Executive Summary

The CFHT Corporation was formed to operate arguably the best telescope in the world. New facilities now significantly surpass the general user capabilities of the current 3.6m telescope. In order for the CFHT Corporation to move forward there must be a scientifically exciting, technically viable and financially feasible plan.

Scientific and strategic considerations indicate that the important technical frontier is to emphasize near-diffraction limited angular resolution with a field approaching one degree. In a number of ways this realizes anew the unique status of the current CFHT. For example:

- Direct imaging of the extra-solar planetary systems of hundreds of nearby stars. This will allow study of the physical properties of the constituents as well as orbital motions of other solar systems over a wide range of ages.
- Crowded field photometry of individual stars at the distance of the Virgo Cluster to give a very detailed insight into the makeup and formation history of a large and representative sample of galaxies.
- Multi-object, high spectral resolution spectroscopy of stars, quasars and absorbing gas along the sight line to provide new information on fundamental stellar physics, the complexities of the interstellar medium and the enrichment history of gas in the universe.
- Very large samples of distant galaxies to study galaxy evolution, the large scale structure of the universe and, in conjunction with imaging observations, the properties of the dark matter and dark energy dominating the universe.
- High angular resolution spectroscopy of the internal motions and chemical abundances within galaxies during the throws of major episodes of star building.
- The search for and physical understanding of “first light”, the very earliest phases of galaxy formation in the universe.

These scientific goals are common with other frontline projects, such as the Atacama Large Millimeter Array and the Next Generation Space Telescopes. The ngCFHT complements their capabilities in the optical and near-infrared part of the spectrum.

Our design takes as a requirement that the cost must be significantly less than the extrapolation of current 8 meter class telescopes and assumes that this telescope is built on the Mauna Kea ridge, hence subject to height limitations. We present, in conceptual form, an optical design capable of realizing these capabilities, a mechanical structure that supports the optics, an enclosure that protects this very large, but light, structure and suggestions for an initial suite of instruments. The cost is approximately $228M for a powerfully instrumented telescope. We believe that the design is sufficiently advanced that a funding phase partnership discussion should now be initiated.

The Scientific Case for ngCFHT

The largest aperture, highest angular resolution telescope in existence will have no shortage of scientific frontiers to probe. Current questions in Astronomy and Astrophysics are at the limits of both sensitivity and angular resolution. A single attribute: aperture, addresses both of these limitations. All aspects of the telescope must ensure that this benefit is preserved and utilized to provide scientific measurements that probe new frontiers. Fixing the detailed properties of the telescope depends critically on a detailed consideration of the technical feasibility of a range of fundamental, currently unanswerable, astronomical questions for which optical and infrared imaging and spectroscopy will contribute key information.
The ngCFHT will be valuable for the entire range of astrophysical origins problems. These include the formation and evolution of:

- planets, with possible searches for signatures of life,
- stars as individuals and their relations to their environment,
- galaxies, as determined by cosmological conditions and gas processes, and
- the universe as a whole, particularly the problems of dark matter and dark energy.

This telescope will be the first of a new type that knits together the processes of star formation, its fascinating byproduct, planets, with the detailed contents of galaxies nearby to us, and, well resolved studies of the precursors of those galaxies at very high redshift.

Consideration of quantitatively precise observational programs are an important tool to evaluate the science requirements of the telescope and the relative benefits for different programs of this telescope as opposed to others, such as NGST, or 20 and 30m versions of this telescope. It also helps to highlight the roles of various instruments and the required matching to the telescope.

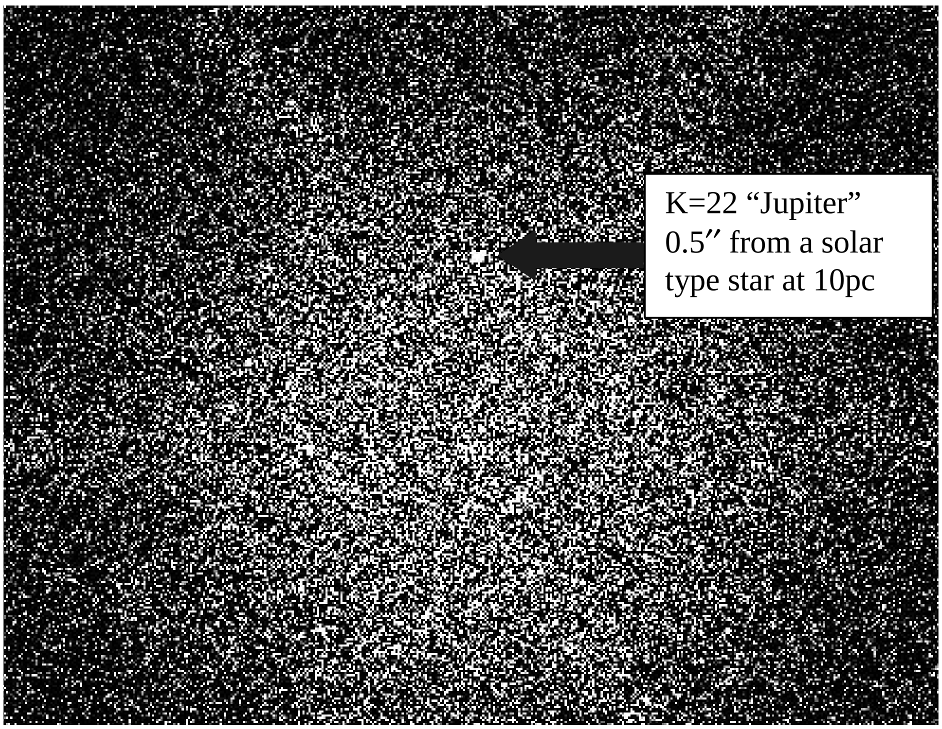
20m: Limiting Magnitudes (R=5, S/N=10, AB magnitudes, 10,000 sec)

Image Quality	B	I	K
NS 0.3″	28.7	27.9	25.6
AO	31.4	30.8	28.4

These limiting magnitudes allow planets to be followed around stars within 10pc, color magnitude relations to the main sequence within the local group, quiescent globular clusters to about redshift 0.3, recently formed globulars to about redshift one, galaxies with 1/10 of the mass of those today in the process formation and reaches the “first light” regime between redshift 7 and 15 in the K band. Reducing the S/N requirement to 5 will give another 0.75 mag for point sources. Increasing the aperture to 30m gives 0.44 mag more depth for fixed image quality and 0.88 if the AO system achieves near diffraction limited performance at both aperture sizes. Below we present detailed simulations based on PSFs calculated for a 20m equipped with an AO system that gives about 90% correction at the K band.

Planetary Imaging

The goal of learning about other solar systems in the Universe is a quest of humankind. Current discovery techniques estimate planetary masses and orbital parameters for a restricted set of planets. We need to undertake a broader census of planets using direct imaging and we need to begin to study their physical characteristics with spectroscopy. Although the planets may be as bright as 22 mag in K, the very high surface brightness of the wings of the PSF makes this a challenging observation for even a 20m telescope.

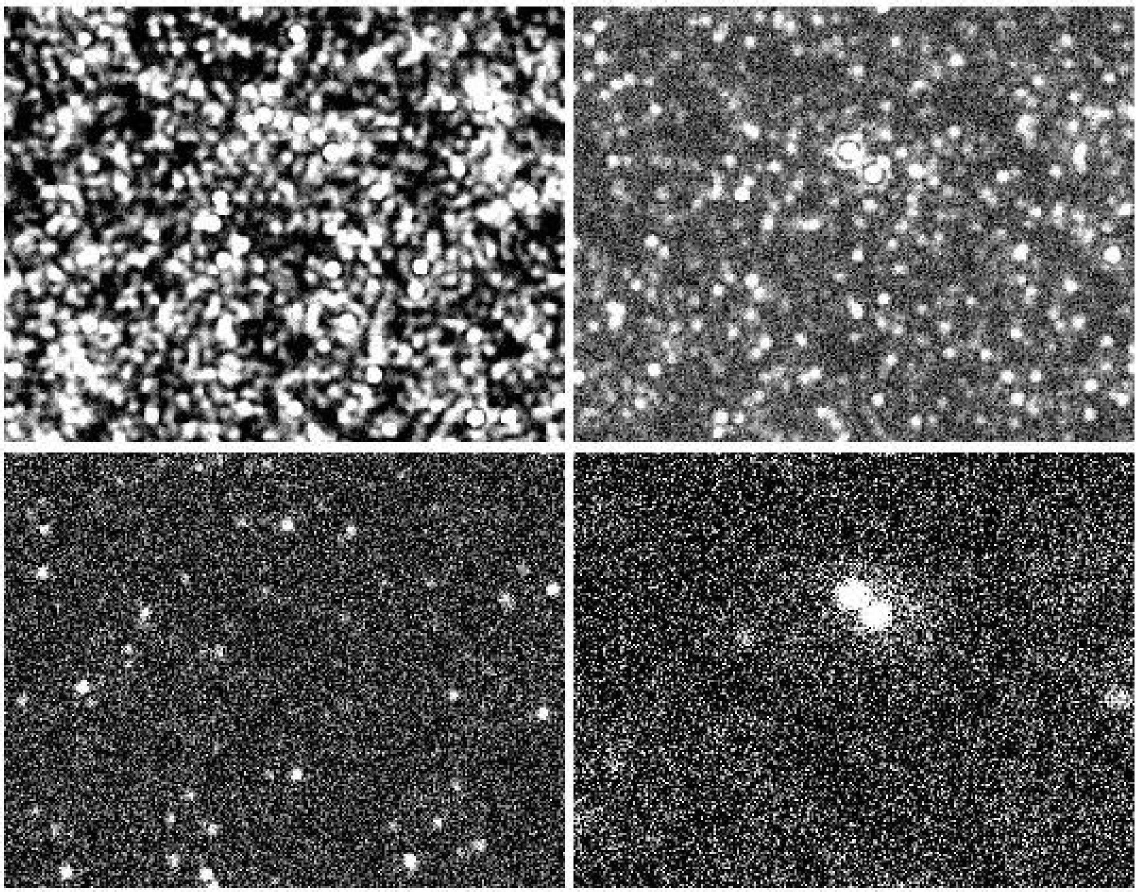


This simulated 3 hour integration with a 20m, segmented mirror telescope in the K band shows the result of PSF subtraction to reveal a planet 20 magnitudes fainter at a distance of 0.5 arcsecond from the star. The PSF is visible as ehanced noise. A coronograph will lower the wings of the PSF by about a factor of 10 although this gain must be offset against the scattered light which we have not yet incorporated.

The gains of a 20m over an 8m for planetary imaging are two-fold. The greater aperture will have a smaller diffraction disk allowing planets a factor of 2.5 closer to the star to be observed, and, the greater aperture allows planets 2.5 times fainter to be detected in the same time. Although we look forward to planetary imaging with 8m telescopes it is expected to uncover only the most massive planets in a fairly narrow range of separations from the stars, where they are bright enough to be detectable but not overwhelmed in the wings of the PSF of the central star.

Crowded Field Photometry

A challenging large telescope application is to use photometry to disentangle the ages and metallicities of individual stellar populations in nearby galaxies. An important scientific goal here is to reach the distance of the Virgo cluster, where the first good examples of elliptical galaxies are found. Below we show simulated images, 3 hr integration in the K' filter, of a Virgo elliptical as a function of radius, as quantified by integrated surface brightness of 19.5, 22.5 and 24 V mag per square arcsecond (upper left, upper right, and lower left, respectively). The lower right shows the same field as the upper right, except as viewed with an 8m telescope. All of these are calculated with AO PSFs.



20m, V=19.5 per sq arcsec	20m, V=22.5 per sq arcsec
20m, V=24.0 per sq arcsec	8m, V=22.5 per sq arcsec

Simulated 10,000 sec images of crowded star fields at the distance of Virgo. The dramatic improvement over an 8m observation is a consequence of both angular resolution and aperture.

The same simulation shows that it is possible to reach the tip of the AGB in Coma galaxies in a 100 ksec image. These observations will be fundamental in uniting our view of galaxies nearby with distant galaxies.

High Dispersion Spectroscopy

An efficient, very high-resolution, bench-mounted spectrograph on a 20 meter class telescope will provide an incredible tool for investigations of elemental and molecular abundances in dense clouds and over a considerably large volume of the Galaxy than is currently possible. Such an instrument will make high signal-to-noise, high-resolution Astronomical observations of the elemental, isotopic, and molecular abundances of the interstellar medium provide the means to determine the source of the elements as well as their abundance evolution since the formation of the Galaxy some 15 billion years ago. Interstellar abundances can also be used to identify the sites and processes in which the observed depletion of various elements and molecules arise and are maintained, and thus also provide information about the formation, composition, and evolution of dust grains, and the formation of complex molecules.

A resolution of 300,000 or 1 km s^{-1} (approaching the intrinsic thermal width of the interstellar features) will enable the resolution of individual clouds with very small line-of-sight velocity differences, and make it easier to detect extremely weak interstellar lines observed through very low-density clouds or from heavier, less abundant elements. Only recently have 8m class telescopes opened the frontier of radioactive nuclei age dating of individual stars using Uranium and Thorium lines in very metal poor halo stars. Expanding the sample beyond the few bright examples will require a 20m telescope.

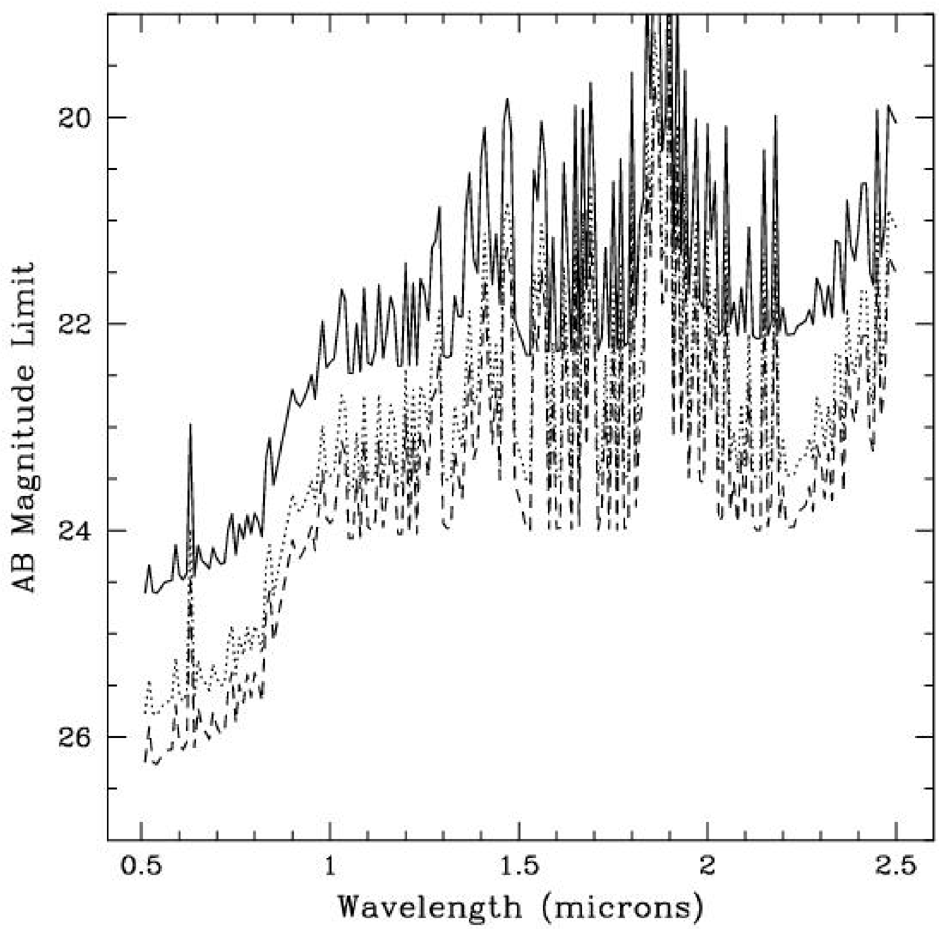
Wide-field Multi-Object Spectroscopy

Current results indicate that most active period of star formation in the Universe occurs between redshifts one and about four. Steidel and collaborators have successfully identified 2000 luminous star-forming (4-20 solar masses per year) galaxies at z~3. These galaxies are highly clustered, with biasing factors estimated in the range 2-4. The comoving volume density of these Lyman-break galaxies is low, somewhat less than present-day L* galaxies. Furthermore, the Steidel sample sees only the brightest 20\% of the star formation. The spectral resolution is low, approximately 10-12 Angstroms resolution or 3 Angstroms in the rest frame, corresponding to a velocity resolution of about 300 km s^{-1}. These data are only the tip of the iceberg of the high redshift Universe. They do not probe down to the star formation rates of the normal star-forming population at those redshifts. Moreover, the spectral resolution is too low to determine galaxy masses or the masses of the proto-groups and clusters which they presumably inhabit. Thus we have little information about the environment, masses or clustering properties of the bulk of star-forming galaxies.

The call for spectra of order 10,000,000 faint galaxies in redshift 0.3 to 10 regime is needed to advance our understand of the dark matter in the universe, the dark energy, and the process which leads to creation of galaxies.

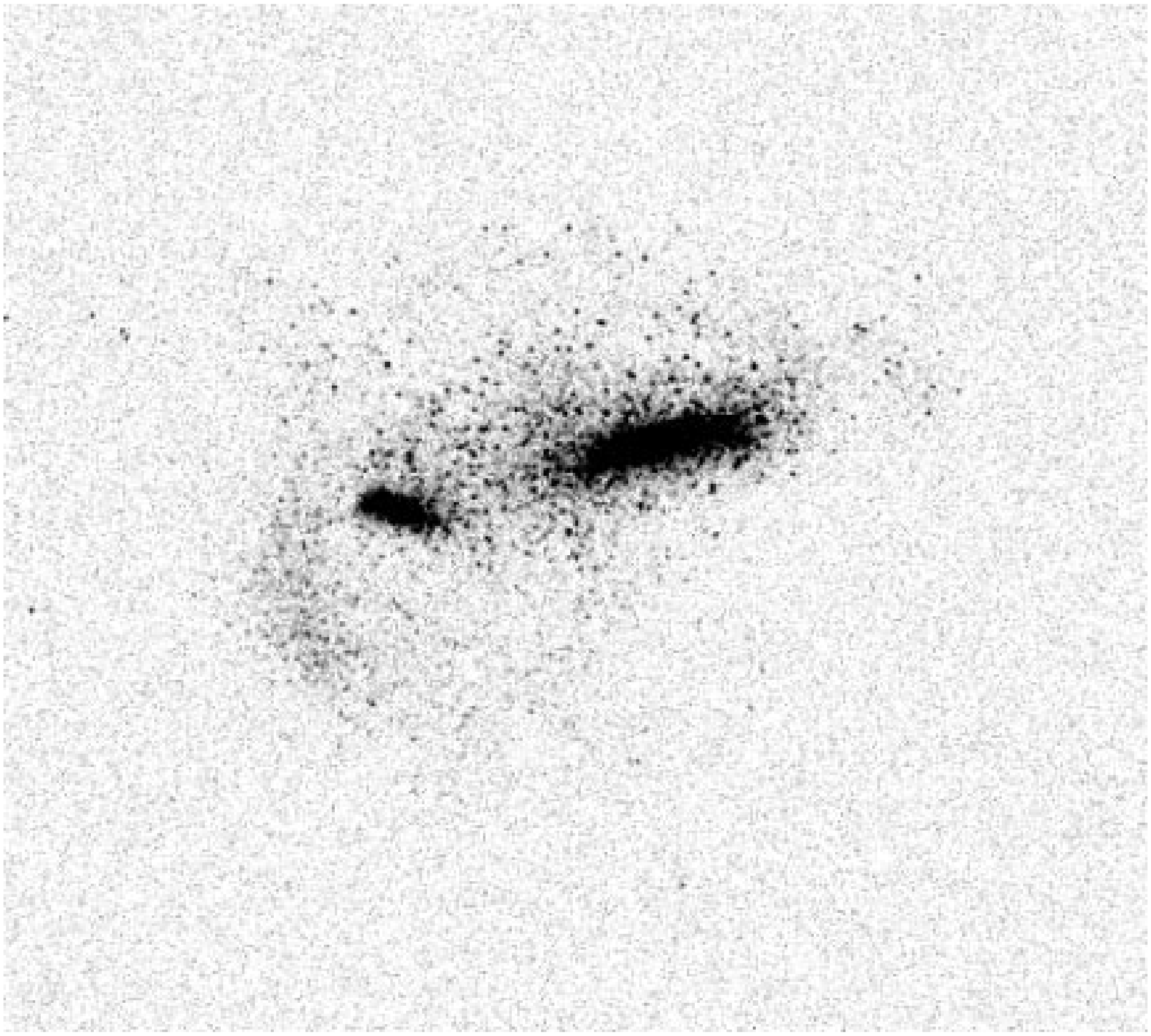
- Imaging surveys over the next decade will cover areas of several hundred square degrees to a depth of I(AB) of about 26 magnitude, reaching sky densities of about 100,000 per square degree and total numbers of 10,000,000. At very low redshift the Sloan survey will obtain about 1,000,000 redshifts. To fully utilize the imaging data to interpret the weak lensing due to intervening dark matter requires a very large sample of redshifts. Samples out to redshift one will be available, but probing the dark matter distribution between redshifts one and three will require a sample of 100,000 or so in the redshift 3 regime.

- The primary goal of the SDSS is to understand the power spectrum and relate it to the Cosmic Microwave Background fluctuations. To fully understand the relation of galaxies to the dark matter distribution will require measures of the clustering of galaxies as a function of redshift, ideally with samples at each redshift range comparable in size to the SDSS, hence of of order 10,000,000 redshifts.
- At this stage the mystery of the dark energy that is driving the acceleration of the expansion of the universe is unsolved. One of the best tools we have to understand the properties of the dark energy is supernovae which can be reached to redshift two. Supernovae are time variable and random, which requires monitoring fields of about one square degree every second night. Supernovae Ia will occur at an average rate of nearly two per night, and type II's likely even more frequently, requiring spectroscopy of the supernovae themselves at I=26.8. The 5100A Silicon line will be in the J and H bands 25 magnitude. AO spectroscopy will be the fastest, although these brightnesses are nearly within the reach of the IMOS.



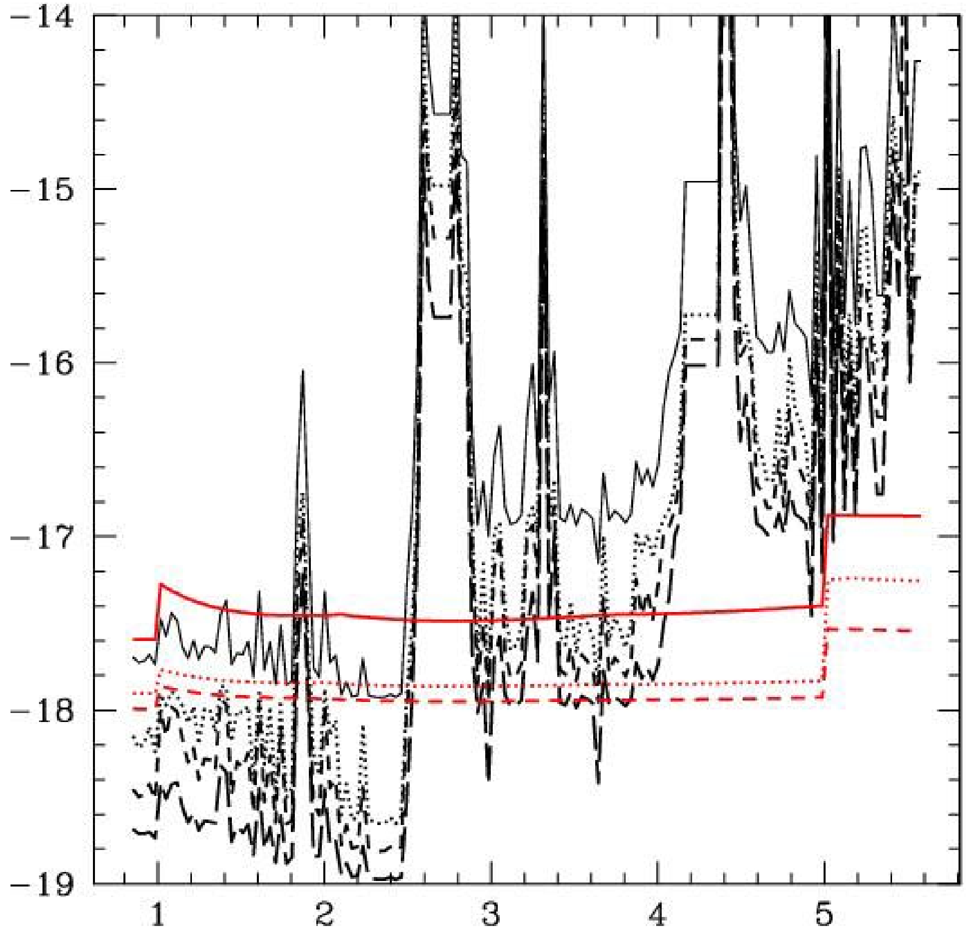
The limiting magnitude for a natural seeing IMOS obtaining S/N=10 per 3.5A bin in 10,000 seconds for telescopes with apertures of 8, 20 and 30m, from top to bottom, respectively. Lower S/N spectra will go proportionally deeper.

Adaptive Optics Imaging of Faint Galaxies



AO imaging in two hours on a 20m of two galaxies at redshift 0.7 that have undergone a burst of starburst associated with their interaction. The angular resolution of the telescope exceeds that of the simulation, whose smallest mass is that of a globular cluster. Note that individual bright globular clusters are readily visible. Although fainter the telescope will be able to provide similar angular resolution for galaxies at redshifts around three.

AO Faint Object Emission Line Spectroscopy



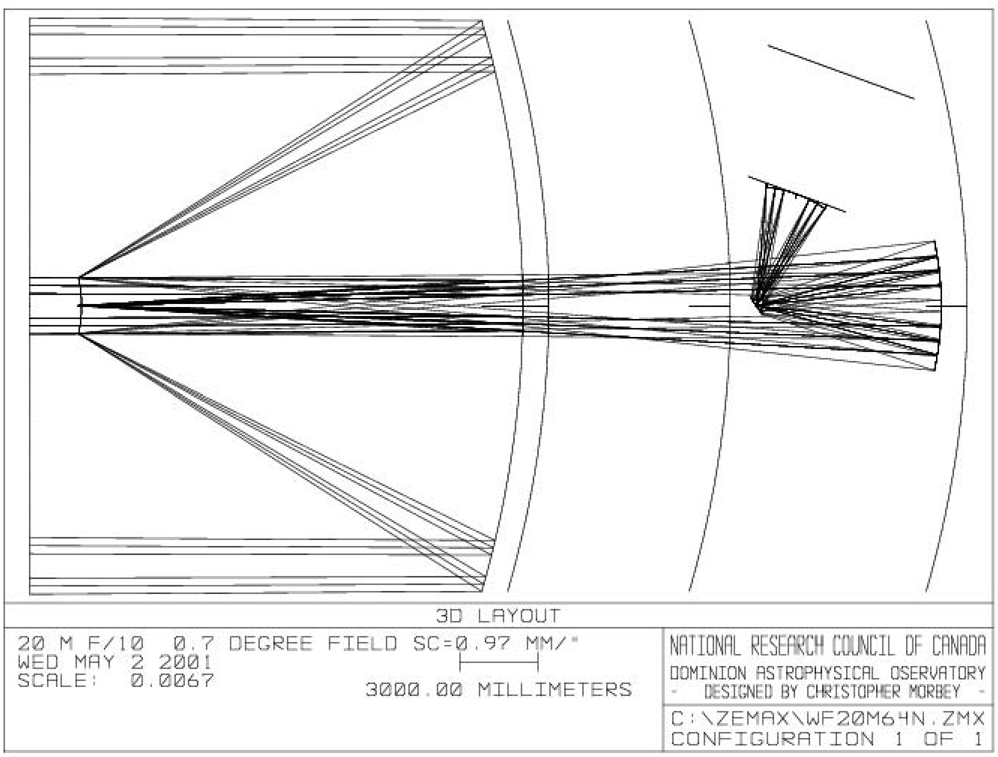
The line flux in erg cm^{-2} s^{-1} detectable at S/N=10 in 10,000 seconds as a function of observed wavelength in microns. The black lines are for ground based 8, 16, 20 and 30m telescopes. The red lines are for cold space based 4, 6.5 and 8m telescopes. This assumes "goal" level AO image quality. A 20m is competitive with a 6.5m NGST in the L and M bands, with superior angular resolution.

Understanding the internal constitution of galaxies as they form is a fundamental goal of astrophysics. Even the simple exploration of what lies beyond redshift five is largely a task for the next generation of telescopes. A key goal is exploring the conversion of a pure gas universe with very low ionization into the largely ionized universe that we have today as the result of the formation of stars and AGN at high redshift. This is arguably the most fundamental of all Origin searches and will require the full power of both radio and optical facilities to detect the 1nano-Jansky sources expected to play the key role in the process.

With a 20 meter telescope, we will obtain spectra at S/N=10 per 3.4 Angstrom resolution element at R_AB=25.5 in a 10000s exposure in 0.5 arcsec seeing. The resolution gives a rest-frame velocity resolution of 100 km/s. Thus one could obtain accurate redshifts as well as internal kinematic information for galaxies about a magnitude deeper than Steidel's limit, and 1.2 magnitudes below L* at that redshift. For redshifts with no kinematic information (S/N=3) one could reach down to R_AB=26.8, nearly two magnitudes below the Keck limit. The gain over Keck comes from the aperture as well as from the improved image quality. There is also a very large gain in efficiency with the wide-field spectrograph. At a nominal depth of R_AB=26.5, one is reaching 2 magnitudes below L*, thus observing typical z=3 galaxies as well as the bulk of the star-forming population in the Universe at that epoch. The areal density is approximately 4.2 galaxies per square arcmin.

A square of 300 comoving h^-1 Mpc has an area of nearly 4 degrees on a side and would require require 168 IMOS fields, yield 330,000 galaxy spectra, comparable to the 2dF and SDSS at z=0. Since each field will take two pointings of about 6 hours, this program would require 200 nights. If one relaxed the depth by about a magnitude it would be possible to obtain about 10 times more redshifts of comparable quality.

Design Considerations



The current optical design arose from a highly interactive series of meetings with a large and diverse group of astronomers and engineers. The combination of wide field and high angular resolution was immediately identified as key requirements that were technically compatible and financially reasonable. The aperture is somewhat arbitrary, however must be at least a factor of two larger than current telescopes, i. e. 20m, to be scientifically attractive. The Mauna Kea summit ridge site considerations likely limit a replacement telescope to 40m total height, and minimal new excavation. To evaluate consistency with site limitations, relative costs and scientific benefits we have carried a 30m design as well. Finally, in the design it is crucial to identify new approaches that will lead to substantial cost savings from the outset.

Optical Design

A four element, all reflecting optical design was selected as the best approach after examining 18 different options (see table) at the 20m scale. A number of changes were made based on matching to instruments and considerations of the problems of going to the 30m scale. The design is diffraction limited everywhere in the field. The central 10 arcmin is obscured by the flat, but a second instrument with its own corrector can use the on-axis light. The distance from secondary to tertiary is about 33m. Clearly the most straightforward scaling to a 30m design will not work within the height constraint.

This particular design was optimized to produce a small secondary, 2.5m, leave a substantial space between the back of the mirror and the instrument mount point to allow a stiff, light mirror support frame to be inserted, and the focal surface is slightly curved to allow relatively easy mounting of full field instruments. However the design has enough flexibility that it modified to accommodate instrument and mechanical requirements.

15 metre and 6 metre-off-axis telescope ideas considered **(C. Morbey April, 2000)**

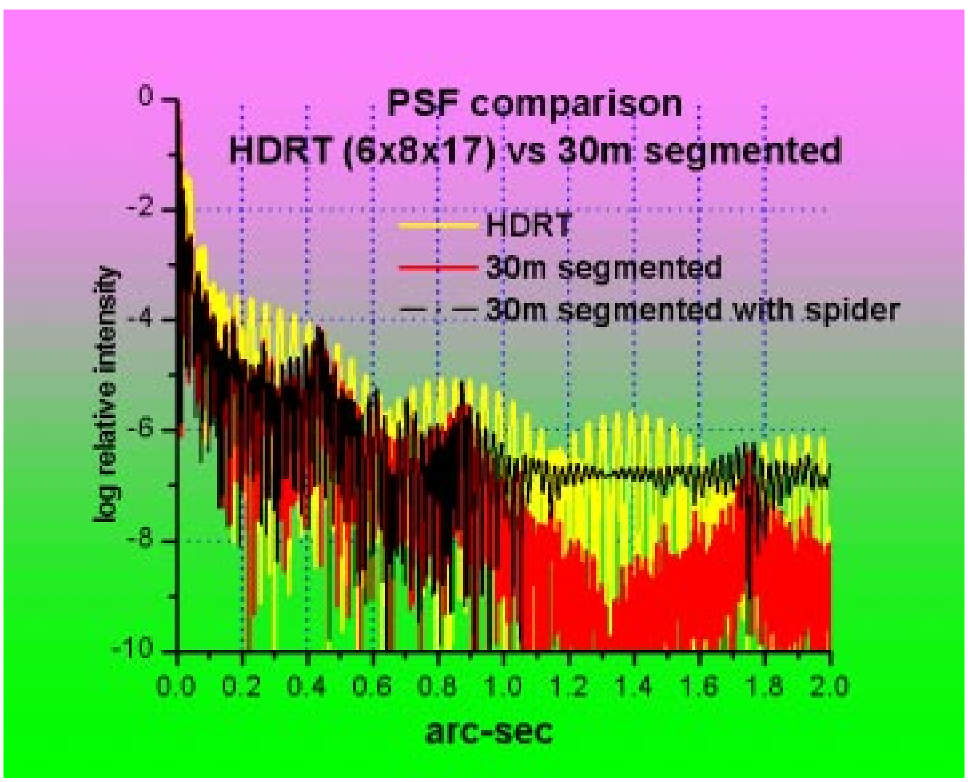
	Telescope type	f/#	field	strehl	obs	footp	trans
			deg		%	mm	Ir %
1	15 m 4 mirror + 2 el cor	3.3	1.4	1	20	1210	63
2	15 m 4 mirror + 2 el cor	3.5	1.4	1	20	1284	63
3	15 m 4 mirror + 2 el cor	1.5	2	0.9	43	788	63
4	15 m 3 mirror + 2 el cor	2	2	1->0.8->0.15	16	1050	63
5	6 m 4 mirror off-axis + 3 el cor	3	1	0.8	0	329	55
6	6 m 4 mirror off-axis + 3 el cor	3	1	0.6->0.8->0.5	0	327	50
7	6 m 4 mirror off-axis + 1 el cor	5	1	0.3->0.5->0.2	0	525	95
8	6 m 4 mirror off-axis + 3 el cor	5	1	0.3->0.5->0.2	0	525	85>60
9	15 m 4 mirror(aspherics) + no cor	2.5	1	0.9->0.8->0.5	8	660	100
10	15 m 3 mirror + flat (hole) (Korsch)	4.4	1	>0.8	2+	1174	100
11	15 m 3 mirror + flat (hole) (Korsch)	3.6	1	>0.9	3+	944	100
12	15 m 4 mirror + 3 el cor	1.8	1	~0.7	8+	480	80>45
13	15 m 4 mirror + 3 el cor	2.2	1	~0.9	8+	586	80>50
14	6 m 4 mirror off-axis +3 el cor	5	1	0.8->0.95->0.8	0	525	75>50
15	15 m 4 mirror + 3 el cor	2.1	0.5	0.9	7+	272	80
16	6.5 m 3 mirror +2 el cor (Roger Angel)	1	3	0.02	14+	344	~90vis
17	15 m Korsch combo	3.3 /11.5	1-.033	0.9 / 0.8	3+ / 2	866 100	100
18	15 M 4/3 mirror combo 1 el cor	2.4 / 14	1-.016	0.7 / 0.9	8+ / 8	620 61	88 100

It has been pointed out that there is some difficulty producing off-axis segments that deviate significantly from a sphere. Whereas Keck segments deviated by up to 100 microns and Celt proposes 19 microns, our present 20m design shows only about 8 microns deviation to a best fit sphere profile.

Point Spread Functions (PSFs) are of fundamental issue for this large telescope which is required to achieve near-diffraction limited performance. We have undertaken two types of study for the pure diffraction limited regime and then for the adaptive optics recovery of the diffraction limited regime. The best mirror is clearly an unobstructed monolith. For realistic telescopes we make the following general observations, which should be considered fully for a specific design.

- The width of the spider arm, provided that it is less than about 5cm and aligned with the mirror segmentation pattern, has little impact on the PSF.
- The segment size and spacing makes little impact, provided that the total gap area is kept under about 2%.
- Creating the aperture from relatively low filling factor set of off-axis, unobscured segments offers generally does not improve the PSF over a segmented mirror design.

We have initiated a program of calculating the PSFs recovered from various degreees of Adaptive Optics (AO) correction of the images. So far this modeling does not account for the spiders or segment gaps. Small segments are cheaper, will have support systems with absolute metrology but have much more “gap area” which make it much harder for the AO system to maintain phase coherence over the entire mirror.



A preliminary analysis of the positioning requirements helps to set the requirements for the mirror support system of the telescope. Segment positioning needs to maintain the following limits for a 0.1 arc sec image radius:

- Decentre error < +/- 0.006 mm,
- Tip/tilt/rotate error < +/- 0.0216 arc sec, and
- Piston error < +/- 0.06 mm.

In this regime the errors are almost exactly linear in the precision of these positions. The most restrictive condition is the tip/tilt/rotate error, which corresponds to about 100nm. Current information suggests that systems accurate to about 10nm are now obtainable, which would, in principle, allow the primary to be maintained very near to the diffraction limited shape.

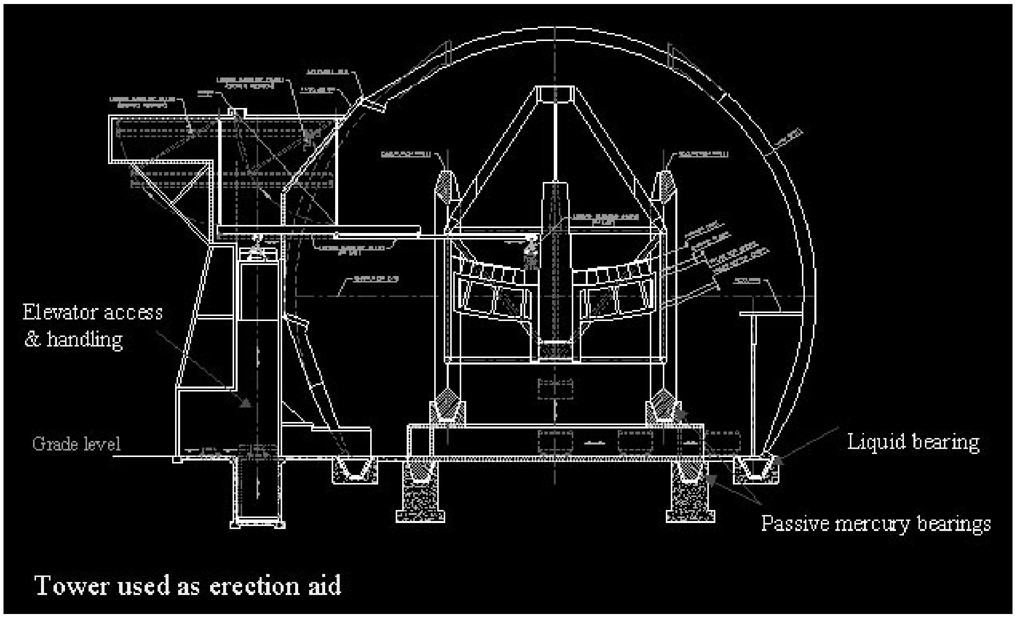
Mirror Fabrication costs

We have received two quotes for mirror components. Schott will provide an 8.2m Zerodur blank, slumped to curvature of about 25m for 6.14M Euro. To create a 20m aperture requires seven of these if the center is filled, with six of them being off axis. The total cost for the primary is then US$38.7M, assuming 0.9US$=1 Euro. Corning will provide 1m flat segments of ULE material for US$16,000. Four hundred blanks, which allows for spares at all radii, will then be US$6.4M, a factor of six less expensive. A rule of thumb is that a figured, polished mirror costs about three times the cost of the blank although this is clearly subject to a serious study, particularly the reliability and speed of the two very different segment scales. If we adopt a factor of three for both small and large segments then we have rough budgets for small and large segment primaries of $20M and $120M, respectively.

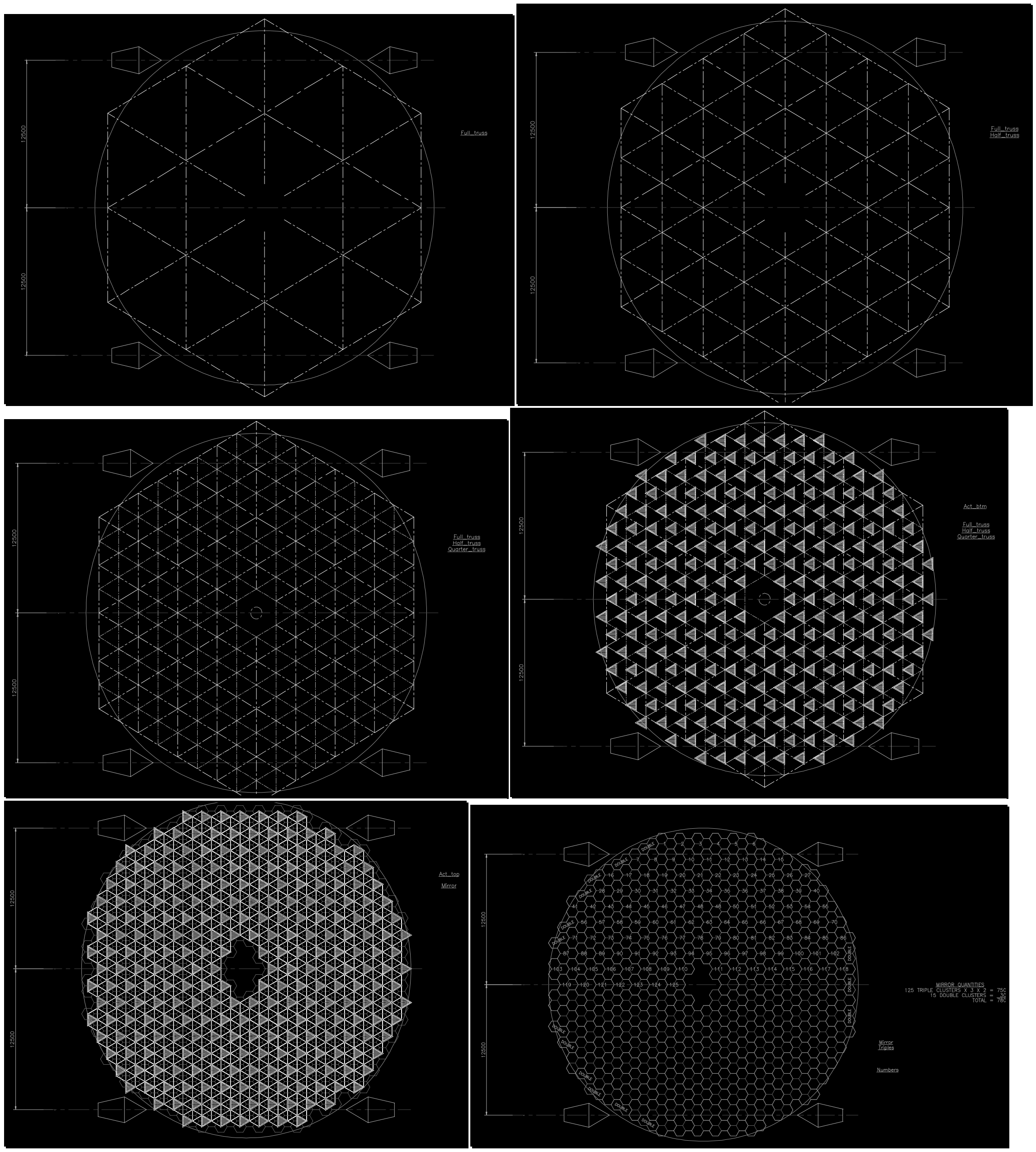
The Telescope Structure and Enclosure

Telescopes of the 20 and 30m scale cannot reside in scaled versions of current domes, for at least two reasons. The Keck dome, weight 600T, has a slot of 10m width in a 37m diameter dome. If scaled to a 20m this implies a 74m dome with a weight of at least 2400T. At the 30m scale the dome becomes truly immense and costly. Our 20m dome has a diameter of 50m with a weight comparable to the current Keck dome. The aperture is circular, with a split dome so that any point above 60 degrees zenith angle can be reached. The aperture is weight compensated so that the entire structure remains as symmetric as possible in its weight distribution.

Control of air movement is crucial to the success of the telescope. The dome is vented and heat sources minimized to reduce air temperature gradients. The goal is to keep these to 0.1C or less. Although flushing is essential, wind buffeting of this large structure, the primary mirror and the secondary needs to be minimized. An approach that has been studied elsewhere is to create a "wind fence", composed of triangular rods that extend out from the aperture, similar to eyelashes. These can be extended varying amounts depending on wind speed and direction. The entire issue of air flow will be modeled by one of our industrial partners. Our proposed enclosure is shown on the title page of the report. The dome is a tight fit with minimal heat sources. The mirror handling crane (one aluminization per day for complete renewal in a year) is external to the dome and will be part of the day-time air-conditioning system.



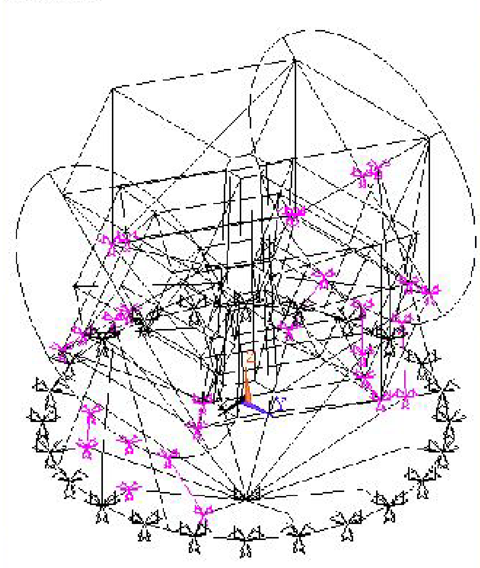
The telescope structure itself has two very large “cartwheels” on the elevation axis which support the mirror cell. The mirror support is a “triangles on triangles” design which is very nearly symmetric, very strong and relatively straightforward to model. The preliminary design has a first free oscillation frequency of about 5 Hz. The telescope can carry several 20T instruments and has a total weight of about 915T.



The mirror support structure, showing the buildup of triangles on triangles. The bottom layer is steel and the top layer is a lightweight composite material. Since 1m segments (0.5m edges) require a nine-point support system and still have support point print-through problems we are considering a backing air-bag system which would carry >95% of the weight of the segments. This design is very stiff, relatively light, readily scaled to different apertures and can work with segments of varying sizes.

An attractive approach to the major bearings is sealed mercury baths. These dissipate no heat and are very cheap to fabricate relative to the relatively high precision required for the normal alt-az bearings. The telescope is given a pre-load so that it does not “sail” or “rock”. It would be possible to realize these baths in oil, however this comes at the cost of about 15 times the volume which must be created in the flotation wheel. These baths do not need to be machined to very high precision, although a locating track needs to be made very accurately. The main concern with mercury is one of environmental risk, however the approach is so attractive that we believe it should be thorough evaluated before it can be dismissed.

A 30m telescope poses a problem for consistency with the Mauna Kea Master Plan. If the summit is lowered about 5m and is allowed to have a basement then it is just possible to put an 30m f/0.6 telescope in a dome no higher than the current CFHT. However, this both presses the site plan somewhat, and the very fast optics increase the risk that the primary mirror will be difficult to fully phase. At this stage we believe that a 30m is possible, but only marginally consistent with summit ridge placement.



Finite Element model of the 20m telescope. The lowest mode of oscillation is at 4.5 Hz. Further design variations and additional stiffness will raise this to about 10Hz

Science Requirements of the Telescope

The telescope must meet the following scientifically motivated requirements.

Attribute	Requirement	Goal
Aperture	20m	30m
Field of View	0.7 degree	1 degree
Image Degradation at telescope focal plane, including dome effects	0.15 arcsec	0.10 arcsec
Detected AO Image Quality	Power within 1.22λ/D >35% K	>45% K, >13% R, 10%V
AO Field of View	10" diameter at 1micron	MCAO
Atmospheric Dispersion Correction	20% relative loss of power for a broadband filter >45 degrees elevation	5%
Wavelength Range	0.36-2.3micron	0.30-24 micrcon
Emissivity	<50% of average sky	<3%
Reflectivity	>97% per surface	>98% per surface
Elevation Angle	30 to 89 degrees	15 to 89 degrees
Science Availability	>330 nights per year	
Site image quality (free air)	Median IQ <0.5"	Median IQ < 0.4"
Queue scheduling possible	Yes	Yes
Remote Observing	Yes (local)	Yes (office)

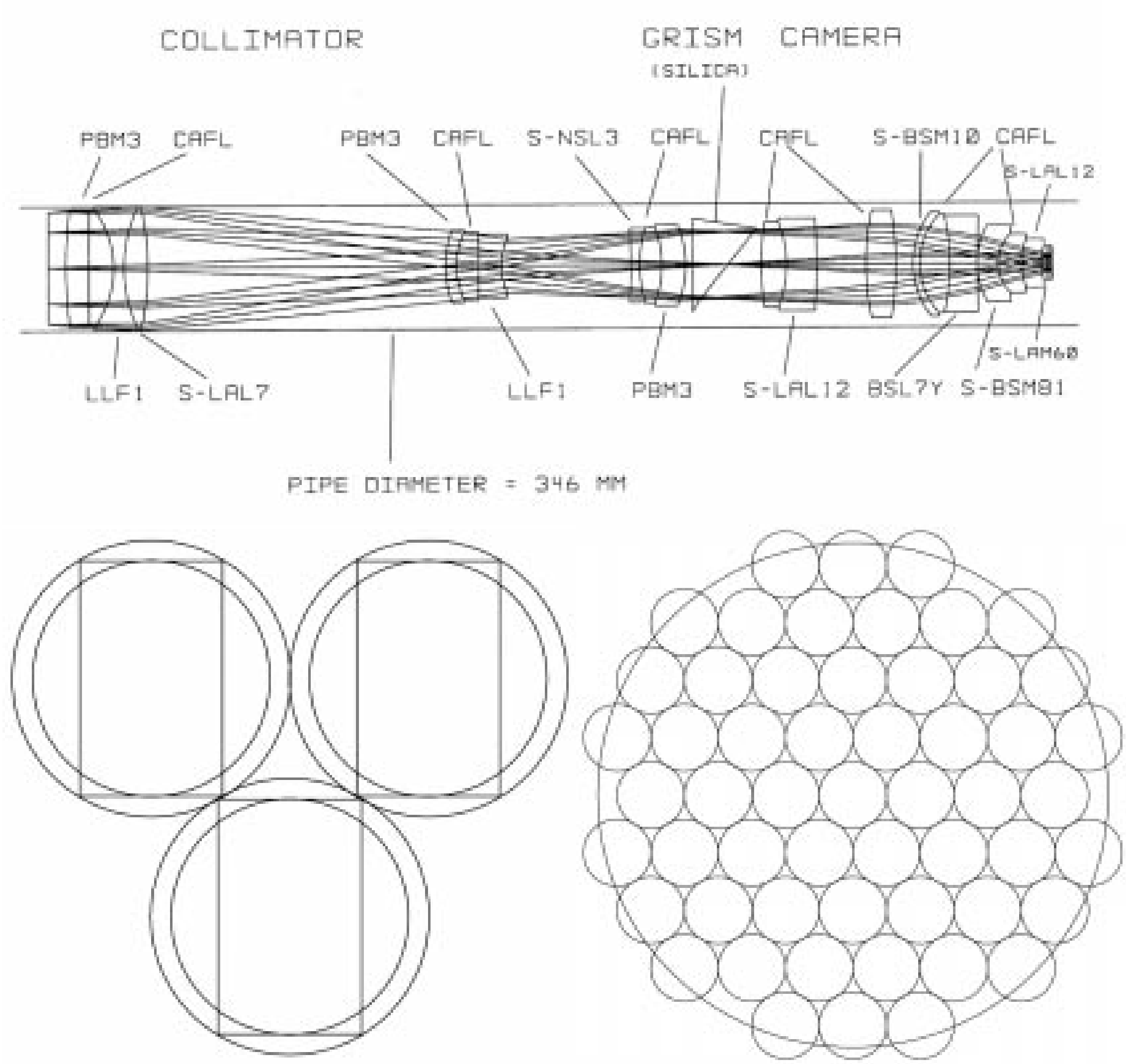
Instruments

We suggest a minimal initial suite of three instruments. We note that given the wide field that there is the potential of having all of these operating in parallel.

- At least one "classical" AO fed, IFU spectrograph, optionally equipped with a coronograph. Given that there will be about 30 14th magnitude guide stars in our accessible field low-order AO units deployable anywhere in the field should be a goal.
- A multi-object high dispersion spectrograph, capable in the range of 30,000 to 300,000. Approximately one dozen objects at a time is the minimal multiplexing. The wavelength range required is 0.36-1 micron, the goal is 0.30-1.5micron.
- A full field imaging multi-object spectrograph (IMOS), consisting of a mixture of optical and infrared units.

At this stage the best-developed instrument is the Oke-Morbey MOS (2001 PASP 113, 346). The idea is to build a spectrograph from many smaller spectrographs. Each cell is similar to a straight-through Gemini GMOS. The current design would have about 47 moveable slits, each 5” long, per spectrograph. For 36 cells this would give 1692 spectra at a time, with exactly half of the field accessible. From the Oke-Morbey paper we take a weight estimate of stainless steel outer support tube of 113 kg, optical glass of 166 kg, internal aluminum barrels which support the optics of 170, and dewar 10 kg for a total weight of a single spectrograph cell is about 460 kg. Thirty-six of these cells weigh 16,500 kg. To this must be added the weight of the structure which holds the 36 cells. This is likely to be an additional 1000 kg.

The cost can be estimated by scaling from GMOS. The glass will cost about $250,000, figuring is an additional $150,000, $25,000 for a grism, and allowing $50,000 for fabricating the mountings, the cost per cell is about $475,000. For 36 cells the cost is $17 million. To this must be added the costs of the CCDs and dewars. In quantity these should be about $500,000 each, brining the price to about $40M for a complete instrument.



The Oke-Morbey IMOS design, as published in PASP 113, 346.

Estimated Costs of Conceptual Design

20m enclosure	$20M
20m telescope structure	$80M
Primary mirror one of:	
1.0m segments	$6.4M x 3 = $ 20M
8.2m segments	$20 M x 3 = $120M
Secondary (2.5m)	$ 2M
Tertiary (4m)	$ 6M
Control Systems	$10M
Adaptive Optics	$20M
IMOS	$40M
High-Res MOS	$20M
Site Preparation	$10M
Total	$228M (1m) $328M (8m)

Note that the telescope itself is $158M. Astronomer support facilities not included.

Timeline

This telescope takes full advantage of recent experience in building large telescopes but is designed to minimize risk in function and in cost. The concept is at a stage where the performance can be evaluated and a funding phase partnership could be initiated. The Canadian project office now has a combined manpower of about 6FTE and will make considerable progress over the next year.

There is no scientific or technical reason to delay the beginning of the construction phase beyond 2005 with a plan to begin operations in 2010. To maintain this schedule it is imperative that there be a final, accurately costed, design available in 2005.

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