Very Large Optical Telescope Concepts

“Continued progress in optical astronomy requires a telescope of aperture and resolution significantly larger than that of present instruments” – Next Generation CFHT Committee

Aperture in the range 30-100 meters is needed

Major Optical Telescope Projects/Proposals

<table>
<thead>
<tr>
<th>Project</th>
<th>Aperture</th>
<th>Cost</th>
<th>First Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGST</td>
<td>8 m (space)</td>
<td>~ 800 M$</td>
<td>2007</td>
</tr>
<tr>
<td>CELT</td>
<td>~ 30 m</td>
<td>~ 600 M$</td>
<td>2010?</td>
</tr>
<tr>
<td>MAXAT</td>
<td>~ 50 m</td>
<td>~ 1000 M$</td>
<td>2012?</td>
</tr>
<tr>
<td>OWL</td>
<td>~ 100 m</td>
<td>&gt; 1000 M$</td>
<td>2015+</td>
</tr>
</tbody>
</table>
Primary Science Goals

- Detect and study the first luminous systems
- Study the process of galaxy formation and evolution from redshift $z \sim 20$ to the present
- Determine the star formation history of the Universe
- Determine the cosmological parameters
- Resolve the innermost regions of AGN and QSOs
- Detect and study the oldest and faintest stars
Observing Galaxy Formation

Photo Credit: NASA.
Finding The First Galaxies

- Wavelength range $0.4 < \lambda < 2.5 \, \text{um}$
- Lyman-$\alpha$ visible to $z = 19.6$
Importance of Resolution

HST 2.4m  NGST 8m  LAMA 60m

Photo Credit: NASA
Star-Formation History of the Universe?
Supernova Detection

- LAMA 2um 300s flux limit
- Type II, k = 0, lambda = 0
- Type II, k = 0, lambda = 1
## Object Counts (per square arcmin)

<table>
<thead>
<tr>
<th>Flux (nJy)</th>
<th>10 ($K_{AB} = 28.9$)</th>
<th>1 ($K_{AB} = 31.4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galaxies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z &lt; 5$</td>
<td>781</td>
<td>2628</td>
</tr>
<tr>
<td>$5 &lt; z &lt; 10$</td>
<td>708</td>
<td>1757</td>
</tr>
<tr>
<td>$z &gt; 10$</td>
<td>67</td>
<td>778</td>
</tr>
<tr>
<td>Lyman-a emitters ($R = 100$)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z &lt; 5$</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>$5 &lt; z &lt; 10$</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>$z &gt; 10$</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Supernovae II per year</td>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>Active Galactic Nuclei</td>
<td>78</td>
<td></td>
</tr>
<tr>
<td>$z &lt; 5$</td>
<td>74</td>
<td></td>
</tr>
<tr>
<td>$5 &lt; z &lt; 10$</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>$z &gt; 10$</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Strong Gravitational lenses</td>
<td>3</td>
<td>17</td>
</tr>
</tbody>
</table>
Performance Goals

- 0.4 - 2.5 um wavelength range
- < 0.1 nJy detection limit for point sources
- < 1 nJy detection limit for galaxies
- Milliarcsec resolution
- ~ 100 square arcmin survey area:
  - > \(10^5\) galaxies
  - ~ 100 supernovae per year
Emerging Technologies

- Adaptive Optics
- Optical interferometry
- Large mercury mirrors
- Near-zenith tracking optics
- OH absorption cell
- Large VIS/NIR arrays
Adaptive Optics

FWHM = 0.08 arcsec

FWHM = 0.8 arcsec

Credit: Gemini Project
Adaptive Optics Performance

Distance from Guide Star (arcsec)

Strehl

Credit: Matt Mountain
Image Intensity

Graph showing the relative value of FWHM, Strehl, and Intensity versus wavelength (um). The graph indicates the variation of these parameters across different wavelengths.
Optical Interferometry
Optical Interferometry

- Frontier technology
- Phase closure with independent telescopes has been demonstrated
- Prototype arrays: I2T, MkIII, IRMA
- Operational arrays: PTI, IOTA, NPOI, ISI, GI2T, SUSI
- Upcoming arrays: COAST, VLTI, Keck
- Phase errors within individual apertures are corrected with adaptive optics
- Moving mirrors remove zero-point (piston) phase differences
- Phase tracking on light from natural guide star
- LBT design gives interferometric imaging over 40 arcsec
LBT Imaging Interferometer

- 2 x 8.4 m interferometer
- 22.8 m baseline
- f/15 phase-combined beam
- Laser guide-star AO on individual telescopes
- Phase tracking on natural guide star
- 40 arcsec FOV
- 5 mas resolution in optical
- 80-96% Strehl ratio in interferometric image
Liquid-Mirror Telescopes

- Three 3m telescopes in operation
- A 6m nearing completion
- A 4m project in Chile
**Liquid-Mirror Technology**

- **Strehl Ratio**
  \[ S = \frac{\text{central intensity}}{\text{ideal central intensity}} \]

- \( S = 0.81 \) measured in lab tests of 2.5m LM

- \( S \sim 0.5-0.7 \) estimated for NODO 3m telescope

- \( S \sim \exp(-k^2\sigma^2) \)
  \[ k = \frac{2\pi}{\lambda} \]
  \[ \sigma = \text{RMS OPD error} \]

*Images courtesy of Dr. E. Borra, Universite Laval*
Liquid-Mirror Interferometric Testing

Image courtesy of Dr. E. Borra, Universite Laval
Liquid-Mirror Surface Quality

- 85 nm RMS error $\Rightarrow S = 0.93$ at $\lambda = 2$ um

Image courtesy of Dr. E. Borra, Universite Laval
Scattered Light

Credit: Dr. E. Borra, Universite Laval
Mercury Telescopes

Photo credit: Mark K. Mulrooney
LMT Imaging

Distant Cluster
Large Zenith Telescope
6m Primary Mirror Truss
LZT Mirror Truss
Making the mirror-segment mold
LZT Air Bearing
LMT Tracking Optics
Preliminary Design
(Single element)

- M1: 10 m f/1.5 parabolic
- M2: 0.75 m hyperbolic
- M3: 0.2 m flat
- 2 compensation lenses
- 5 min tracking
- RMS spot dia < 150 mas
- Strehl ratio > 0.1 @ 2 um
Background Light

Typical background at best sites

1 AU NGST

3 AU NGST

Wavelength (microns)

Credit: Space Telescope Science Institute
**OH Absorption Cell**

- NIR sensitivity is directly proportional to background
- Gain of ~ 100 is possible
- OH Production: \( O_3 + H \rightarrow OH + O_2 \)
- Radiative excitation by Meinel photons
- Collisional deexcitation in ~100 us
- Column density > \( 10^{18} \text{ cm}^{-2} \)
- Path length ~ 10 m
- Pressure ~ 0.1 Torr
- Lifetime ~ 10 ms
- Gas consumption ~ 2 kg/hr \( O_3 \), 40 g/hr \( H \)
OH Absorption vs Column Density

\[ \lambda = 1.5 - 1.7 \, \mu m \]
Sample Model Calculation \( (N = 10^{18} \text{ cm}^{-3}) \)
Cerro Chanjnantor

- 5000 m high desert in Northern Chile
- Site of ALMA millimeter array
- Proposed site of Cornell IR telescope and several others

Photo credit: S. Radford
Chajnantor Seeing vs Paranal (ESO VLT)
LAMA Concept

- Optical-NIR interferometer
- Near-zenith pointing and tracking
- Survey fields around natural guide stars
- Wavefront control on each element (AO)
- Phase tracking on all beams
- Diffraction limit of 60m telescope
- Equivalent area of 42m telescope
- Fully sample isoplanatic area
- Background reduction by gas-phase OH absorption cells
- 0.1 nJ point source sensitivity (AB = 33.9)
- Mercury primary mirrors
- High dry site (eg. Alto-Plano)
- Low project cost (~ $50M)
Array Geometry

60m
Array Transfer Function
Single-Element PSF
PSF Profile

- Intensity
- Encircled Energy

radius (mas)
Conceptual Design
10m Array Element
Survey Mode

~ 360 survey fields, each 30 x 30 arcsec
~ 150 observations per year for each field

90 square arcmin in one year
~ 40,000 sec integration time

100 pJy detection limit for galaxies (0.1"")
10 pJy detection limit for point sources
Summary

- A Very-Large Optical Telescope is feasible now
- A 60 m optical interferometer would provide unprecedented sensitivity and resolution
- Gains of an order of magnitude or more over NGST are possible for survey-type observations
- Liquid-Mirrors provide a way to beat the cost curve by a factor of 10-50
- Such a telescope could be built on a relatively short timescale (~ 6 yrs)