IMAGE QUALITY AT LAS CAMPANAS OBSERVATORY

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Las Campanas Observatory

LCO is a developed site with a 30 year history of excellence

- Negligible light pollution; should remain so for decades
- 60-65% of time photometric
- 80-85% of time useable
- Quality of seeing is as good or better than at any other developed site in Chile
- Weather pattern stable over the past 30+ years
- Southern hemisphere location provides strong scientific synergy with existing and future facilities (Magellan, ALMA, LSST, SKA)
- Carnegie has clear legal access to the site
- Well-understood and economical operation costs
The GMT site testing effort has concentrated on identifying the best peak within LCO in terms of seeing and wind speed.

Cerro Las Campanas:
- Longitude 70° 41.0 W
- Latitude 29° 02.9’ S
- Elevation 2551 m
- Highest peak on LCO ridge
Wind Speed

GMT Science Requirement: < 3% loss of clear time to high winds

<table>
<thead>
<tr>
<th>Site</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>95%</th>
<th>97%</th>
<th>99%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manquis Ridge</td>
<td>3.1</td>
<td>5.4</td>
<td>8.9</td>
<td>13.4</td>
<td>14.8</td>
<td>17.0</td>
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<tr>
<td>Cerro Manqui</td>
<td>3.1</td>
<td>5.8</td>
<td>9.4</td>
<td>14.8</td>
<td>15.6</td>
<td>17.9</td>
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<tr>
<td>Cerro Alcaino</td>
<td>2.7</td>
<td>4.9</td>
<td>8.0</td>
<td>13.0</td>
<td>13.9</td>
<td>15.6</td>
</tr>
<tr>
<td>Cerro Las Campanas</td>
<td>3.6</td>
<td>6.3</td>
<td>9.8</td>
<td>15.6</td>
<td>17.4</td>
<td>19.7</td>
</tr>
</tbody>
</table>

Notes: (1) 17.4 m/s = 39 mph; (2) weather stations mounted on 10 m towers
Wind Direction

• Wind direction at all three sites is highly bimodal: ~80% of the time from NE, ~20% from S to W

• SW component is stronger in summer than in winter, and occurs preferentially during the first half of the night
Site Monitoring Equipment

DIMM

MASS/DIMM

CASCA

LuSci

Vantage Pro

IRMA

SLODAR

Magellan

Wednesday, 16 June 2010
• KE transfers from “infinity” to smaller and smaller scales.
• Rate of viscous dissipation $\varepsilon_0 = \text{rate of production of turbulent KE}$
• Velocity $V$ of motions at scale $L$ (dimensional argument):
  $$V \sim \varepsilon_0^{1/3} L_0^{1/3}$$
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Atmosphere typically has fully developed turbulence: $Re \sim 10^6$

Inner scale $l_0 \sim \text{mm-cm}$

(KE dissipates to heat by viscous friction)

(Image: NY Times)
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Outer scale, \( L_0 \neq \infty \)

Injection of KE

Inner scale \( l_0 \approx \text{mm-cm} \)

KE dissipates to heat by viscous friction

(Image: NY Times)

Wednesday, 16 June 2010
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The Differential Image Motion Monitor (DIMM)

DIMM measures variance of differential image motion, \( \sigma_d^2 \), across 2 apertures

\[
\sigma_d^2 = K \lambda^2 r_0^{-5/3} D^{-1/3}
\]

“Seeing” FWHM:

\[
\epsilon_0 = \frac{0.98 \lambda}{r_0} = 0.98 \left(\frac{D}{\lambda}\right)^{0.2} \left(\frac{\sigma_d^2}{K}\right)^{0.6}
\]

Seeing is a simple measurement of Fried’s parameter, \( r_0 \).

Implicitly assumes energy injected into atmosphere at \( \infty \)

(Tokovinin 2002)
The Multi-Aperture Scintillation Sensor (MASS) measures turbulence above 500 m in distinct layers.

Spatial scale of scintillation variation depends on distance to layer in which the turbulence giving rise to the wave front phase disturbance exists.

**Turbulence profile,** $C_n^2(z=0.5, 1, 2, 4, 8, \text{and} \ 16\text{km})$: from differences between the scintillation in four concentric apertures.

MASS also measures free atmospheric seeing (~integral of the turbulence profile).

Difference between DIMM and free atmosphere MASS turbulent integrals is a measure of the portion of the total seeing contributed by a ground layer (below 500 m).

Measures turbulence above 500 m in distinct layers.
The Multi-Aperture Scintillation Sensor (MASS)

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**Measures turbulence above 500 m in distinct layers**
Outer scale, $L_0$

$L_0 = 1000 \text{ m}$

$L_0 = 25 \text{ m}$

Kolmogorov
($L_0 = \infty$)

\{ von Kármán \}
FWHM: $0.504 \pm 0.014$

(With thanks to Becky Sobel, MIT)
"Seeing" compared

Magellan science vs DIMM seeing

Magellan science vs guidecam

Correct to 500nm and 1 airmass using: \( \varepsilon_0 \sim \lambda^{-1/5} \) \( (r_0 \sim \lambda^{6/5}) \) and \( \varepsilon_0 \sim \text{airmass}^{3/5} \)
Cumulative distributions

Overall

By instrument
Numbers

DIMM: 0.66±0.21
DIPSF: 0.59±0.15
Guide: 0.70±0.17

Magellan image quality better than DIMM seeing 69% of the time, and better than the guide camera image quality 90% of the time.

In poor seeing ($\geq 1''$) Magellan does better than DIMM 98% of the time.

At good seeing we are limited by the telescope optics, and the two readings converge, while at poor seeing, the Magellan telescopes appear to do progressively better.

IMACS does worse than the other instruments and this is traced to the Shack-Hartmann active optics systems on the different instrument ports
(Modal Gaussian S-H PSF FWHM = 0''.30 FHWM, cf 0''.17 for MagIC)
Seeing “residual”:

\[ r_s = \text{FWHM}_{\text{DIMM}} - \text{FWHM}_{\text{science}} \]

Correlates with DIMM seeing, not with Magellan seeing

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Seeing & residual with telescope orientation

Magellan Seeing
FWHM_{science}

Seeing “residual”
\[ r_s = \text{FWHM}_{DIMM} - \text{FWHM}_{science} \]

No directional problems
Seeing residual with wind

Seeing residuals

Wind Speed (m/s)

Seeing residuals

-0.4
-0.2
0.0
0.2
0.4

[0.1:0.0]
[0.0:0.1]
[0.1:0.2]
[0.2:0.3]
[0.3:0.4]
[0.4:inf]
High windspeeds removed
High windspeeds removed

- **Raw**
- **+Telescope optics (0.3”)**

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AO Parameters

- MASS insensitive to AO time constants > 5 ms
- MASS free-atmosphere time constant needs to be corrected by including the ground layer contribution
- MASS free-atmosphere isoplanatic angle needs no such correction

<table>
<thead>
<tr>
<th></th>
<th>10%</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>free atmosphere</td>
<td>5.18</td>
<td>4.11</td>
<td>2.93</td>
<td>1.96</td>
<td>1.27</td>
</tr>
<tr>
<td>total</td>
<td>4.45</td>
<td>3.57</td>
<td>2.60</td>
<td>1.78</td>
<td>1.22</td>
</tr>
</tbody>
</table>
Turbulence Profiling Campaigns

- Agreement between MASS, SLODAR, and LuSci gives confidence in our instrumentation

- Turbulence in the LCO vicinity is temporally variable and site-dependent, especially in the ground layer

- A strong ground layer contribution is common

- Low resolution LuSci and MASS profiles are sufficient to characterize the statistics of the turbulence profiles
MASS results
MASS results

Dominant Turbulent Layers

2007-8

+2009

Altitude / km

Seeing / arcsec
MASS results

Dominant Turbulent Layers

Good seeing occurs when there is little ground layer seeing.

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Site has $L_0 \sim 25$ m on average

“Perfect” median image quality for large telescope at LCO:

- $0.52”$ @ $500$nm $\rightarrow 0.6”$ Magellan
- $0.41”$ @ $1$μm $\rightarrow 0.51”$
- $0.29”$ @ $2$μm $\rightarrow 0.42”$
- $0.26”$ @ $5$μm $\rightarrow 0.40”$

Kolmogorov ($L_0 = \infty$)

$L_0 = 1000$ m

$L_0 = 100$ m

$L_0 = 25$ m

$\lambda/\mu m$
The Case for Cerro Las Campanas

Cerro Las Campanas is the ideal site for GMT

- Seeing is superb
- Wind is not a problem
- It is the highest of the four sites studied (optimal for PWV)
- It has the best layout for a large telescope
Contributors to GMT site testing and talk

- **Carnegie Observatories / Las Campanas Observatory**
  Alex Athey, Christoph Birk, Pablo Castro, Emilio Cerda, Felipe Daruich, David Floyd, Javier Fuentes, Gaston Gutierrez, Matt Johns, Pat McCarthy, Andrew McWilliam, Cesar Muena, Frank Perez, Myriam Perez, Mark Phillips, Gabriel Prieto, Miguel Roth, Steve Shectman, Joanna Thomas-Osip, Josefina Urrutia, Sergio Vera

- **NOAO / Cerro Tololo Inter-American Observatory**
  Amokrane Berdja, Robert Blum, Edison Bustos, Sebastian Els, Hugo Schwarz, Andrei Tokovinin, Alistair Walker, David Walker

- **Australian National University / Univ. of New South Wales**
  Michael Goodwin, Charles Jenkins, Andrew Lambert

- **Univ. of Lethbridge**
  Regan Dahl, David Naylor, Robin Phillips, Richard Querel, Greg Tompkins

- **Univ. of Arizona**
  Thomas Folkers, Lucy Ziurys

- **European Southern Observatory**
  Florian Kerber, Gianluca Lombardi, Marc Sarazin

- **Others**
  Victor Kornilov (Sternberg Astron. Inst.), Matthias Schoeck (TMT), Jacques Sebag (LSST), Paul Schechter (MIT), Becky Sobel (MIT)

Challenges for the GMT, Melbourne, June 15-16, 2010