

# Telescope Project Development Seminar

### Session 2: Site, Enclosure and Facilities

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#### Topics

- Site Selection
- Enclosures & Facilities
- Enclosure Thermal Engineering
- Magellan Enclosure Development



### Site Selection

## World Sites (optical telescopes > 6m)





#### Visiting Professor Lecture

- 1. Hawaii US Keck (10m) Gemini N (8m) Subaru (8m) TMT (30m)
- 2. San Pedro Martir, Mexico TSPM (6.5m)
- 3. Arizona, USA MMT (6.5m) LBT (2 x 8m)
- Texas, USA 4. Hobby-Eberly (10m)
- 5. Chile Gemini S (8m) VLT (4 x 8m) Magellan I & II  $(2 \times 6.5m)$ LSST (8m) GMT (25m) EELT (39m) TAO (6.5m)
- La Palma, Canary Islands 6. GTC (10m)
- 7. South Africa SALT (10m)

**Telescope Project Development** 

*Italic = under development* 



- Site conditions strongly affect the design, construction and operation of an observatory including the science that can be done
- Site selection starts early in the telescope project development process
- Characterizing a site is a multi-year (>2) process, especially for an undeveloped site.
  - Testing is required at each prospective site.
  - Monitoring should cover all observing seasons
  - Even a developed site may need additional testing to support new operating modes (e.g. adaptive optics)
- Securing the rights to a site and performing environmental impact studies can take years. Best start early to avoid surprises.
- Appoint a team to conduct the site evaluation and selection process
  - Selection process requires approval from the top-management and the Board
  - The procedure and criteria for selecting a site needs to be specified at the start to ensure the process is comprehensive and fair.



- Science
  - North or south hemisphere (galactic center vs. pole)
  - Synergy with other observatories
  - Opportunity for unique science (e.g. high-altitude site)
- Site conditions
  - Weather
  - Geotechnical
  - Seismic exposure
- Development
  - Ease of shipping and transporting equipment and structures to the site during construction & operations.
  - Local building construction conditions
  - Existing roads and facilities that are available
  - Available services (power, water, communications, etc.) nearby
- Legal
  - Availability and terms required to acquire the right to build on and operate at the site
  - Jurisdictions and permitting
  - Building codes and environmental restrictions
- Impact on operations
  - Remote operation
  - Accessibility for users (travel time, visas, import/export restrictions, etc.)
- Cost

# Plus any additional constraints imposed by the stakeholders.



- Testing starts with gaining access to the site.
  - Permission from owner or controlling institution
  - Getting physical access to the site for installing equipment roads, trails, etc.
  - Sites at established observatories are obviously a lot easier to characterize and can provide a baseline of recorded conditions and support infrastructure.
- Site test team
  - Assemble test equipment
  - Install equipment on site
  - Collect data over an extended period of time.
  - Compile data into a report for comparison with other sites.
- Site selection review and ranking
- Negotiate lease or purchase for top ranked site



- On-site measurements
  - Weather statistics (temperature, wind speed and direction, humidity)
  - Transparency/cloud cover
  - Precipitable water vapor (PWV)
  - Light pollution
  - Atmospheric parameters ("seeing",  $Cn^2(h)$ , AO coherence time  $\tau_0$ , Na layer)
  - Dust
- Environmental conditions are captured in a top-level document maintained under change control.
  - Operational and Survival Conditions are specified.



- Weather station mounted at the proposed telescope site
  - Set height to sample the conditions above ground effects
- Recorded quantities
  - Temperature
  - Humidity
  - Wind speed & direction
- Sample data fast enough to compute rates of change
- Store the readings in a data base for post processing statistics
  - Tag data with observed sky conditions (e.g. "clear suitable for astronomy") when the data were taken.



Davis weather station









Cumulative wind speed statistics for four LCO sites on clear nights over 3 years



North 0.06 30 60 Wind direction (deg) 0.10> 90 East 0.06 120 150 180 South 0.06 210 240 0.10 270 West 0.16 0.20 300 0.10 330 0.08360 8 12 16 20 24 4 () UT-4h

> 0 0.08 0.16 0.24 Normalized wind speed (m/s)

TAO is located on the summit of Cerro Chajnantor in the Northern Chile Science preserve. It is another site like LCO with highly bi-directional wind direction. This makes optimizing the site and enclosure layout simpler.

Diurnal wind speed histogram for the TAO site on Cerro Chajnantor.

Max. wind speed 68 m/s





#### Transparency/Cloud Cover

- Transparency and cloud cover can be monitored with an all sky camera similar to the ones deployed at Cerro Tololo and Las Campanas Observatory.
  - The camera is mounted on a mast under a transparent dome and operates automatically to record sky conditions throughout the night.
  - Data is processed and the results are archived in a database.
- If the proposed site is located at or near an existing observatory, the nightly telescope operator logs can be mined for this information.



Tololo All-Sky Camera

Smith, R., Walker, D., and Schwarz, H., (2004)

#### **Nightly Statistics for LCO**

	Clear (%)	Clear and Partly Clear (%)			
Spring	70	87			
Summer	79	92			
Fall	63	81			
Winter	51	67			



- Differential Image Motion Monitor (DIMM)
  - Measures the differential motion between a pair of star images taken through a pair of apertures
  - Differential motion gives the wavefront slope errors from which image size on a much larger telescope can be calculated using Kolmogorov theory
  - The measurement integrates line-of-sight contributions though the whole atmosphere
  - DIMM provides no information about the height of turbulent layers
  - DIMM is mounted high enough to get above ground effects that are not relevant for the telescope
  - Monitor can run through the night in untended automatic mode
- Records from existing telescopes are another source of seeing data
  - Correct for "dome seeing" and instrumental effects



DIMM Tower & Weather Station mast



DIMM



- Slope Detection and Ranging (SLODAR)
  - SLODAR retrieves the turbulence layer strength and height from the spatial covariance data of wavefront gradients (spot motions) taken from observations of a bright double star.
  - Measures ground-layer turbulence structure.
- Lunar Scintillation
  - Measures low altitude turbulence from spatial correlations of the lunar scintillation signal in a linear array of detectors.
  - Sensitive to turbulence below 1 km.
- Multi-Aperture Scintillation Sensor (MASS)
  - Measures turbulence at discrete, fixed heights and free atmosphere seeing.
  - Measures the isoplanatic angle and adaptive optics time constant,  $\tau_{o}$ .
  - Insensitive to low altitude turbulence below 500 m
  - Operates concurrently with DIMM

Source: "GMT Site Testing at Las Campanas Observatory Final Report"









### MASS/DIMM Results from 2 Nights





### Normalized Seeing Histogram

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1.0 free atmosphere seeing (") 0.2 0.0 0.0 0.2 0.6 0.8 1.0 0.4 ground layer seeing (") 0.1 0.2 0.4 0.5 0.6 0.7 0.8 0.9 0.0 0.3 1.0

Plot shows the potential improvement that can be expected with effective ground layer adaptive optics (GLAO)

> Source: "GMT Site Testing at Las Campanas Observatory Final Report"

Site: Co. Manqui (Magllan)





Cumulative FWHM seeing measurement for four LCO sites on clear nights over 3 years Monthly FWHM DIMM seeing measurements for four LCO sites on clear nights over 3 years



- Infrared observations are sensitive to the integrated column density of water vapor (PWV) above the telescope
  - Column heights less than 2 mm are optimal for thermal IR obserations
- High altitude sites are preferred if IR capability is a key science driver (e.g. TAO) to get above lower altitude PWV.
- Various instruments and techniques are used for measuring PWV
  - 225 Ghz tipping Radiometer
  - 20 micron tipping infrared radiometer
  - The PWV column height can be calculated from high resolution spectroscopic measurements of stellar water vapor absorption line widths in the band 590-730 nm if a suitably instrumented telescope is available nearby.



225 GHz Tipping radiometer



20 micron IRMA (Infrared Radiometer for Millimeter Astronomy)



### Light Pollution



SW USA and Northern Mexico

- Faint object astronomy requires a dark sky.
- Light pollution from growing metropolitan areas imperils nearby observatories.
- Careful planning involves looking ahead ~50 years to predict city growth and avoid premature obsolescence.

Light pollution maps: http://www.lightpollution.it







- Prime sites for optical observatories are often located in seismically highly active regions (e.g. Hawaii and Chile)
- Building codes provide design criteria for structures based on local zone classification
  - These are adequate for conventional buildings in low-medium seismic risk regions.
  - Telescopes and enclosures are specialized structures that respond differently to seismic disturbance and require more detailed analysis in seismically high-risk areas.
- Telescope
  - Telescopes structures are usually stiffness critical rather than strength critical. However, internal stresses need to be limited to safe values in the event of a major earthquake.
  - Ground accelerations will be amplified in high-performance stiff, lowly-damped telescopes. Amplifications of 4 or more at points within the structure are possible.
  - Fragile optics and instruments rigidly mounted in the telescope will be subjected to accelerations well in excess of what they experience during normal operation.
- Enclosure
  - The enclosure upper structure has no internal bracing in the telescope chamber to resist accelerations.
  - Openings for the vent windows and shutters weaken the upper structure.
  - The structure is interrupted across the azimuth track.



#### Northern Chile Seismic Events



Earthquakes Magnitude 7.0 & greater



- SSSHA tasks
  - Detailed review of the site geological and topographical characteristics.
  - Analysis of ground motion and frequency for recent and historical seismic events in the area surrounding the site.
  - Modeling of the propagation paths from areas where seismic sources are likely to originate.
  - Computation of the probability of occurrence of seismic events of various magnitudes.
  - Generating probabilistic predictions for ground accelerations at the site for use in FEA models.
- Analysis is performed for specified risk criteria and configurations
  - Operating Level Earthquake (OLE) with a 200 year mean return period
    - Repairs can be made and the facility can be put back in operation in a short time (~weeks).
  - Survival Level Earthquake (SLE) with a 500 year mean return period
    - The facility will survive without collapsing but repairs could take a long time.
- SSSHA Output
  - Response spectra as functions of structure vibration frequency and damping.
  - Time series ground accelerations at the pier base.
  - Enclosure and telescope structures are analyzed dynamically using the SSSHA accelerations.



### Shock Response Spectra (SRS) example: LCO

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#### SSSHA Time-series example: LCO





## Enclosures and Facilities



- Summit
  - Enclosure
  - Roads, parking and staging areas
  - Utilities (power, water systems, chilled liquid plants, cryogens, compressors, communications)
  - Environmental monitoring equipment (weather station(s), seeing tower(s), etc.)
  - Storage areas (instruments, service and handling equipment, supplies, etc.)
  - Maintenance yard and equipment
- Mirror Coating Plant
- Work shops and technical offices
- Dorms and commissary
- Headquarters (in-country and remote)
- Remote observing and data archive sites



- Best practices
  - Optimize enclosure design and orientation to best take advantage of prevailing wind direction.
  - Locate heat generating equipment (transformers, compressors, chillers) cross-wind and away from the enclosure.
  - Separate heated living spaces and offices, laboratories from the enclosure.
- Coating plant
  - Periodic mirror washing and/or re-coating is a high risk operation. Locating the plant near or in the enclosure reduces the risk of damage during transport even if it violates the principle of separating heat producing equipment from the immediate telescope vicinity.



#### Magellan Site & Facilities



Elevation: 2,500 m

- Closely associated facilities at a moderate elevation site.
- Mirror coating plant is on the upper floor of the Auxiliary Building across bridges to the telescope chambers.
- Instrument storage is located on the ground floor in the Auxiliary Building.
- The predominant (80%) wind is from the NE perpendicular to the line joining the two telescopes.
- The sea—level office is in La Serena, Chile.

Photo taken from the lodge and dining hall. 29

Telescope Project Development



#### Keck Observatory Site

#### <u>Summit</u>

- Telescopes
- Observing Rooms
- Maintenance areas
- Coating Plant
- Instrument Storage
- Infrastructure roads, support utilities (power, water systems, communications)

#### **Basecamp**

• Commissary & Dorms

#### **Headquarters**

- Administrative staff
- "Remote" observing rooms
- Dorms
- Visitor Center



Keck 1 and 2 on Mauna Kea (elev. 4,145) m)



Hale Pohaku basecamp (elev. 2,800 m)



Keck Observatory Headquarters, Waimei (elev. 760 m)



#### Enclosures



- 1. Traditional spherical dome with bi-paring or up-andover shutters
- 2. Cylinder or modified cylinder
- 3. Cube
- 4. Octagonal
- 5. Calotte
- Co-rotating
  - Co-rotating: telescope and enclosure rotate together (examples: MMT, LBT, Apache Point Observatory)
  - Independent: telescope and enclosure rotate independently of each other.







2. Subaru



3. MMT



4. WIYN







- Protect the telescope and instruments from damage under all operating and survival conditions.
- Open up and rotate to provide an unobscured view over the full telescope azimuth and elevation observing range.
- Shield the telescope from wind turbulence and moonlight.
- Provide a good thermal environment within the telescope chamber during observing.
- Have good aerodynamic design to minimize the seeing effects of ground layer.
- Provide access and equipment for handling and servicing equipment
  - Telescope mechanisms
  - Optics including mirror re-coating
  - Science instruments.
- Provide a safe working environment for personnel.



### Spherical Dome

#### <u>General</u>

- Smooth contour for wind flow around
- Wind screen to reduce buffeting
- Curved inside surface not best suited for a bridge crane
- Primary mirror segment removal
  - Single mirror from below
  - Small segments from the side
- Structurally efficient

#### **Bi-parting shutter**

• Cantilevered shutters project into the wind.

#### Up-and-over shutter

- Close fitting to telescope permits large shutter opening relative to dome diameter (A/D).
- Examples: Hale 5m Telescope, Keck 1 and 2 10m, Gemini North & South 8m



Hale 5m Telescope, Mt. Palomar



Gemini North 8m, Mauna Kea HI



### Cylindrical with Bi-parting Shutter

Visiting Professor Lecture

- Smooth air-flow contour around sides
- Accommodates bridge crane
  - Larger dead air volume at top.
- Bi-parting shutters
  - Can disrupt air flow around sides for large A/D
  - Wind screen required to reduce telescope buffeting
- Vents in upper rotating section for thermal control
- Flat top can collect snow/ice.
- Primary mirror service
  - Remove single primary mirror from above or below and small segments from side
- Structurally efficient: Direct load path through the bogeys down to ground
- Rotation: Independent (VLT) and co-rotating (Subaru)
- Examples: VLT, Subaru, TAO



ESSO 8m VLT





### Co-rotating Cube

- Telescope and enclosure upper structure rotate together
- Minimum internal volume
- Fiber-fed instrument labs and additional technical space on rotating structure
- Cabling between telescope and enclosure simplified
- Bi-parting shutters
- Accommodates a bridge crane
- Squared off walls may create air turbulence at corners.
- Observing floor cantilevered indirect load paths require extra structure
- Wind vents in rear. Vents in side walls blocked by work spaces.
- Flat top can collect snow/ice.
- Examples: MMT, LBT, ARC 3.5m



MMT 6.5m, Mt. Hopkins



LBT twin 8.4 m, Mt. Graham



- Close fitting to the telescope
  - Large A/D.
  - Telescope and enclosure rotate independently.
  - Wind screen and moon roof required to reduce telescope buffeting.
  - Overhead bridge crane is not practical.
  - Primary mirror is removed from below for re-coating.
  - Large bi-parting shutters disrupt air flow over the structure.
  - Snow/ice can collect on flat top.
- Optimized for thermal performance
  - Large (25%-30%) shutter and vent openings for flushing.
  - Low-mass, thermally responsive structure
  - Flat walls use commercially available insulated panels
- Examples: WIYN 3.5 m, Magellan 6.5 m



WIYN 3.5 m, Kitt Peak AZ



Magellan 6.5m, Las Campanas Chile

Octagonal





- The novel calotte design is extremely compact.
- Its smooth exterior, even while open for observing, is significantly less affected by unbalanced wind forces and should shed snow and ice much more quickly than some other enclosure concepts.
- The dome rotates in azimuth about a vertical axis independently from the telescope and the cap rotates on an inclined plane to allow the telescope to look out through the offset opening in the cap in all directions above a minimum elevation angle.
- Wind vents in the side of the dome provide flushing of the telescope chamber.
- Flaps around the aperture reduce wind buffeting at the top end of the telescope.
- A cap (not shown) closes off the dome during the day and in inclement weather.
- An overhead bridge crane is not feasible.
- Mirror segments are removed from the side. 2/9/2017



TMT

See the automated model in the NAOJ visitor's gallery at Mitaka.



### Extremely Large Telescope (ELT) Projects



25.4m Giant Magellan Telescope (GMT) 30m Thirty Meter Telescope (TMT)



39m European Extremely Large Telescope (EELT)

Clearly there is not one agreed upon ELT enclosure concept.



Telescope Project Development



# Enclosure Thermal Engineering



### **GMT Enclosure PDR Concept**

- GMT PDR shutter concept
  - Vertical front and horizontal top shutters operated independently of each other.
  - Telescoping panels could be deployed part way to close down around the telescope beam and to act from above and below as a wind screen and a moonlight shield. Concern: panel mass.
- The enclosure rotates independently of the telescope.
- The structure was analyzed to determine wind flow around and through the structure.
  - Wind tunnel testing including surrounding terrain.
  - Computation Fluid Dynamics numerical analysis.
- Current enclosure concept uses bi-parting shutters.







Shutters and vents open 40

Telescope Project Development

### **GMT Enclosure Cut-away**



- The top and front shutters can be closed around the telescope beam to shield the telescope from wind buffeting and moonlight.
- Vent openings in the walls are adjustable to control air flow through the structure.
- The current design uses biparting shutters.

Building height: 62 meters



- Wind tunnel testing at Cermak, Peterka and Petersen (CPP), Fort Collins CO.
- Scale model tests of the GMT enclosure and telescope
  - Turntable top simulated the terrain on site and rotated to investigate flow from different directions.
  - 660 pressure taps recorded pressure on the enclosure exterior and interior structure.
  - Shutters and vent windows could be opened or masked to simulate various operating conditions.
  - Telescope mounted on a 6-axis balance scale to measure wind forces on it.
  - Smoke injected to visualize air flow and flushing times.
- Cases examined
  - Dome closed, partially open, fully open
  - Wind from all directions
- Wind tunnel results
  - Determined wind loading for the enclosure design
  - Set boundary conditions for CFD analysis. 2/9/2017



Enclosure and terrain model on turntable

#### Test parameters:

- Terrain & summit facilities
- Vent & shutter configuration
- Wind approach angle
- Telescope elevation angle 60°



#### Model Details







(L) Closed enclosure model and terrain on turntable. (Center) 50% open model. (R) 100% open model.

Enclosure base detail showing pressure taps.



GMT model on balance stand.







- Smoke is injected up stream of the model to show wind flow through and around the structure and flushing.
- Walls are colored red to enhance visualization.



Smoke wand.



Ground layer flow under enclosure base.



Shutters and vents 50% open.



#### CFD Wind Flow analysis



 Computational fluid dynamics (CFD) analysis calculates the wind flow through the enclosure from the boundary conditions determined from the wind tunnel tests.

Flow through GMT for the open enclosure, 0° wind direction, 3 m/s case. Vertical cut.



#### CFD Wind Flow analysis





Velocity vectors low in enclosure, 100% opeň, 3 m/s approach wind speed, 50-deg wind approach direction

- Different wind directions with respect to the enclosure opening can be investigated in the models.
- Cuts at varying heights allow estimation of the wind forces at different points on the telescope.

We'll see later how these results can be used to analyze telescope wind shake.

wind speed, 0-deg wind approach



- The pressures measured by the taps on the outside of the closed enclosure are used to determine wind loading on the structure in the design of the wall system.
- The thermal performance of the enclosure affects image quality. The wind flow results are used to determine flushing of the structure and estimate the magnitude of this effect.
- Telescope windshake is another major contributor to the image quality budget.
- We'll see in a later section how the wind flow results are also used to analyze wind shake for various configurations of vents and windscreens.





- Good enclosure thermal performance is critical for meeting image quality requirements.
- Effects that can degrade performance include:
  - "Dome seeing" (Non-thermalized air in the telescope chamber at a temperature different from ambient)
  - Air warmed/cooled by convection from the exterior wall panels flowing in front of the beam.
  - Transport of ground layer air turbulence into the telescope beam





- Dome seeing
  - Dome seeing is the degradation in image quality (IQ) that results when the air temperature in the telescope chamber is at a different temperature from ambient.
  - IQ contribution = 0.1  $\Delta T^{1.2}$  (arc-sec FWHM/°K) where  $\Delta T = T_{chamber} T_{ambient}$
  - $\Delta T_{ave} \leq 0.22$  K for a 0.017 arc-sec FWHM dome seeing allocation in the GMT image quality budget.
- Heat sources
  - Powered sources (pumps, motors, fans, electronics, etc.)
  - Cooling of the telescope structure (†)
  - Cooling of the internal dome structure (†)
  - Heat conduction and convection from sources in the base of the enclosure
- Cooling mechanisms
  - Wind forced ventilation (†)
  - Active cooling of the structure
  - Radiative losses to the sky through the shutters and vents
- Radiation to the night sky will cool the external skin of the enclosure.
  - Air blowing across the shutter opening cooled by the outside skin will also degrade seeing.

(†) could be positive or negative depending on the sign of the temperature difference.

References: Racine, R., et. Al. 1991 Zago, SPIE 2871, 7017 Vogiatzis, SPIE 6271 Pazder, SPIE 7017



- Calculate the net heat gain/(loss) in the telescope chamber that will cause dome seeing.
- Heat sources
  - Cooling/(heating) of the telescope and dome structure
  - Active sources
  - Neglect heat conduction/convection from below
- Cooling mechanisms
  - Wind driven conductive air flow through the shutters and vents.
  - Radiation to the night sky.
- Model assumptions:
  - Enclosure pointed away from the wind.
  - Shutters may be closed down to approx. 50% open to throttle ventilation and reduce radiation losses.
  - Vents can be adjusted from 0% to 100% open.
  - Air flow through enclosure is the projected vent and shutter open area
  - Steady-state ambient air temperature change rate.





Heat Released as a Function of Temperature Rate of Change (kW)							
		Power	ΔT/Δt (°K/hr)				
	Effective Mass	per K/hr	10%	25%	50%	75%	90%
Heat Sources	metric tons	kW/K/hr	-0.80	-0.44	-0.12	0.22	0.67
Telescope Structure	680	92	73	40	11	-20	-62
Enclosure Structure	1888	255	204	112	31	-56	-171
Active Sources	na	10	10	10	10	10	10
Total (kW)			287	163	52	-66	-222

- Nighttime temperature rates of change statistics for GMT/LCO
- Heat transport from below neglected.
- Only enclosure interior structure contributes to the heat load.
- Power is calculated from the steady-state rate of heating/cooling and the heat capacity of the enclosure and telescope steel.
- Allowance is made for the fact that some parts of the telescope (ie. M1 assembly) are actively cooled.



Air Temperature Rise (°K) – Vents 100% Open									
			Ambient Air Heating/cooling Rate						
			10%	25%	50%	75%	90%		
					K/hr				
			-0.80	-0.44	-0.12	0.22	0.67		
N N	Wind speed			Heat Production (kW)					
Percentile	speed	P/K	287	163	52	-66	-222		
	(m/s)	(kW/°K)	(°K)	(°K)	(°K)	(°K)	(°K)		
10%	1.6	1,133	0.25	0.14	0.05	-0.06	-0.20		
25%	4.0	2,833	0.10	0.06	0.02	-0.02	-0.08		
50%	6.5	4,564	0.06	0.04	0.01	-0.01	-0.05		
75%	9.4	6,610	0.04	0.02	0.01	-0.01	-0.03		
90%	12.4	8,719	0.03	0.02	0.01	-0.01	-0.03		

#### GMT spec. $\Delta T_{max}$ = 0.22 K

- Nighttime wind speed statistics for GMT/LCO
- Wind approaching from the side or back.
- Ventilation windows 100% open.
  - P/K scales linearly with projected vent openings
- Temperature rise is calculated from the volume rate of air exchange, heat capacity of the air, and the input heat load.
- Radiation losses are not included here.



Air Temperature Rise (°K) – Vents 25% Open								
			Ambient Air Heating/cooling Rate					
			10%	25%	50%	75%	90%	
					K/hr			
			-0.80	-0.44	-0.12	0.22	0.67	
Wind speed			Heat Production (kW)					
Percentile	speed	P/K	287	163	52	-66	-222	
	(m/s)	(kW/°K)	(°K)	(°K)	(°K)	(°K)	(°K)	
10%	1.6	283	1.01	0.57	0.18	-0.23	-0.78	
25%	4.0	708	0.41	0.23	0.07	-0.09	-0.31	
50%	6.5	1,141	0.25	0.14	0.05	-0.06	-0.19	
75%	9.4	1,653	0.17	0.10	0.03	-0.04	-0.13	
90%	12.4	2,180	0.13	0.07	0.02	-0.03	-0.10	

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- Nighttime wind speed statistics for GMT/LCO
- Wind approaching from the side or back.
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- Radiation losses are not included here.



Radiation to the cold night sky will cool the interior of the enclosure. Shutter & vent openings

<ul> <li>Upper shutter (fully opened)</li> </ul>	1,390 m²
<ul> <li>Vertical shutter (fully opened, 50% sky view factor)</li> </ul>	1,500 m²
<ul> <li>Vents (fully opened , 50% sky view factor)</li> </ul>	1,828 m²
Radiative coefficient:	70 W/m <sup>2</sup>
Cooling rate:	
<ul> <li>Shutters 50% open, vents closed *</li> </ul>	56 – 97 kW
<ul> <li>Shutters and vents 50% open *</li> </ul>	116 -161 kW

- Shutters and vents 100 % open
- Compare to telescope heat load (previous slide)

-222 kW to +287 kW

213 kW

\* Depends on telescope zenith angle

# Conclusion: Radiation is a significant contributor to the heat balance within the telescope chamber that can offset heat sources.



### **CFD** Thermal Modeling

- The heat balance calculation indicates that the high level of flushing in the GMT enclosure provides a good thermal environment for the telescope with adjustability for different wind conditions and orientation with respect to wind direction.
- A heat balance calculation gives only a first-look estimator of dome seeing effects.
- The locations of heat sources and the transport of heated air through the telescope beam requires a more sophisticated analysis to get an accurate assessment of image quality effects.
  - Computation fluid dynamics models coupled with a model of wavefront propagation through the shutter into the telescope.
  - Estimate compensation of dome seeing by the adaptive optics system.
  - Compare to the appropriate IQ error budget.
- References:
  - "Dome CFD Analysis", Doc. E-TRE-IDO-327-5058-1, ESSO feed study for E-ELT, 2014.
  - "Enclosure and Facilities System Preliminary Design Report", GMT-EF-RVW-00406. 2013.
  - and other projects.



- Raise openings above the boundary layer.
- Minimize the thermal mass of the telescope and enclosure structure.
- Maintain the daytime inside air at the predicted early-evening ambient temperature.
- Seal & insulate the observing floor to prevent heat influx from below.
- Promote wind-forced ventilation to remove heat from the enclosure at night and drive the inside temperature to ambient.
- Seal & insulate walls & openings to prevent daytime heat influx.
- Trap active sources of heat within the enclosure.
- Apply low emissivity coatings around shutter & vent openings to reduce over-cooling of these surfaces from radiation to the cold sky.
  - MMTO Technical Memorandum No. 81-1, 1981
  - Gemini Project Document No. RPT-TE-G0039.



#### Active daytime cooling

- Expensive and may not be necessary with other measures.
- Not implemented on Magellan.



# Magellan Enclosure Development



#### Magellan Enclosure Concept

Bi-parting shutters

Rotating dome

Fixed base Open below

Exhaust tunnels and fans below grade



Insulated wall panels

Reflective tape on upper structure

Ventilation louvers in fixed and rotating structures



- Enclosure design usually starts with a baseline concept developed through engineering and cost trade studies initiated by the project during the Conceptual Design Phase.
- An architectural/engineering (A/E) firm is contracted to advance the concept through preliminary design (20% completion) including analyses of performance, cost and schedule.
  - More than one concept may be developed to this level of maturity in which case a down-select takes place.
  - The preliminary design should be compliant with level 3 requirements including interface control documents and ready for final design.
- Final design
  - 80% completion
  - The design is completed to a state where it can be handed off to a contractors for construction.
  - Review
- Contracting strategy
  - The procurement is broken down into logical bid packages (enclosure structure, foundations, civil works, etc.)
  - A/E prepares tender documents for construction in collaboration with the Project and assists in the procurement process.
  - Carnegie acted as its own construction manager on the Project.



- Survey and Geotechnical measurements
- Hire local contractor to do the site work
- Site clearing and grading
- Staging
  - Worker's camp and contractor's offices
  - Laydown areas
  - Access roads
  - Concrete batch plant
  - Temporary power
- Civil works (roads, water systems)
- Power and communications systems
- Foundations and the pier.



GMT Site





- Enclosure structure
  - The steel structure for the fixed and rotating parts of the Magellan enclosure was fabricated at Schwartz Hautmont in Barcelona.
  - They provided the rotation mechanisms, shutters, dome cranes, vent windows and wind screens.
  - They also fabricated the steel structure for the Auxiliary Building.
  - The shutters and azimuth track and bogies were assembled and tested separately in their yard but a full assembly of the enclosure was not done in Spain.
- Other parts of the enclosure and Auxiliary Building were procured from vendors separately and first assembled on site by the project.
  - Insulated wall panels
  - Windows and doors
  - Building exhaust fan
  - Mechanical systems
  - Equipment elevator
  - Controls
- The enclosure was assembled on site using 50 ton hydraulic and 140 ton mobile cranes purchased by the project and a local assembly crew supervised by the Project.



### Magellan 2 Enclosure Assembly on Site

Visiting Professor Lecture















### Magellan 2 Enclosure Assembly on Site

Visiting Professor Lecture



Of course, it isn't so pleasant assembling the enclosure on some days!



#### Telescope installed in the Enclosure



#### Interior view of the enclosure



Shutters in background with jib crane



### Assembled Magellan Enclosures



But eventually the enclosures are ready for telescope installation and commissioning.





## End of Session 3





### CFD windflow analysis

CD-adapco

pro-STAR 4.14

2-Dec-11 Velocity Magnitude m/s TIME = 900.898 \*PRESENTATION GRID\*

> 3.000 2.786 2.571

2.357 2.143

1.929

1.714 1.500 1.286 1.071 0.8571 0.6429

0.4286 0.2143

0.000

\_\_\_Y



Velocity vectors above telescope, 25% open, 3 m/s approach wind speed, 0-deg wind approach

Velocity vectors above telescope, 25% open, 3 m/s approach wind speed, 50-deg wind approach direction