TMT/NFIRAOS/MCAO ORM/Maunakea Relative Performance

Angel Otárola[1], Christophe Dumas[1]

[1]TMT International Observatory

$$PSS \propto f_c D^4 \frac{S(X,\lambda)^2 t(X,\lambda)^2}{R(X,\lambda)}$$

Abstract

The preferred site for the deployment of the Thirty Meter Telescope is the 13N site at Maunakea (HI, USA). However, an alternate site located at the Observatorio Roque de Los Muchachos (ORM, La Palma, Canary Islands, Spain) has been explored.

The 13N site main advantages are given by its altitude and geographic location. The site is dry and cold which make it a great site for astronomical observations in the mid-infrared spectral bands; the thermal stability of the area, as well as mild upper troposphere turbulence, make it a good site for diffraction limited adaptive optics observations in the near-infrared spectral bands, and its altitude and fraction of clear available nights make it suitable for observations in the visible spectral bands down to the UV region.

Confronted with the possibility that the Maunakea site may not be available for the installation of TMT within a reasonable time, and considering two other next generation large aperture telescopes are committed for installation in the southern hemisphere, the TMT's Scientific Advisory Committee supported the idea for TMT to remain in the northern hemisphere. And importantly, recommended the ORM site as the alternate location for the project.

Here, we present results of simulations, using the Multi-Thread Adaptive Optics Simulator (MAOS), to estimate the relative performance of TMT — performing diffraction limited observations, at near-infrared and mid-infrared spectral bands— at the ORM site respect to Maunakea.

In either case, but specially at the ORM site, TMT will benefit from having a flexible queue scheduling of the observing program.

Site Coordinates

SITE	LAT.	LON.	ALTITUDE
Maunakea	19.82º N	155.48º W	4050 m
ORM	28.80º N	17.90º W	2250 m

Site Characteristics (Note: for seeing 60m and up)

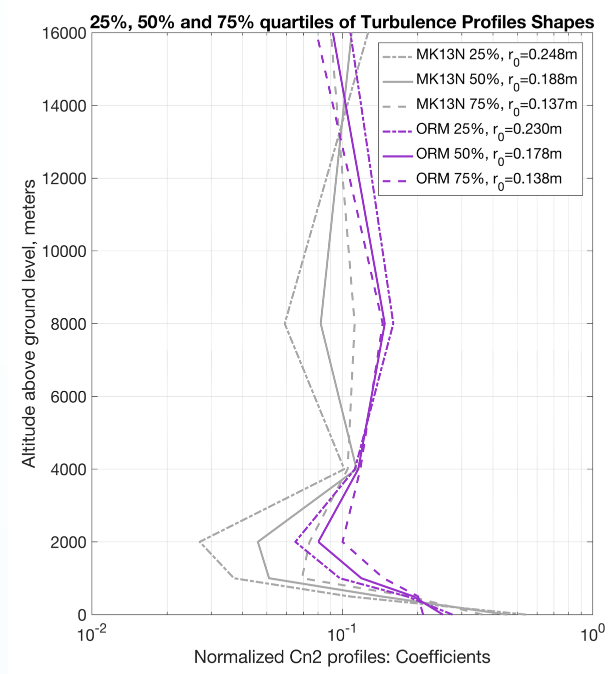
Percentile	Seeing	PWV	Night Temp.	Seeing	PWV	Night Temp.
	arcsecs	mm	ºC	arcsecs	mm	ºC
	ORM (2250m)			MK13N (4050m)		
5%	0.29	1.0	-1.9	0.28	0.6	-2.3
10%	0.35	1.4	-0.8	0.33	0.8	-1.3
25%	0.44	2.2	+2.8	0.41	1.1	+0.4
50%	0.57	4.2	+8.1	0.54	1.9	+2.3
75%	0.73	7.0	+11.9	0.74	3.5	+3.9

Simulations

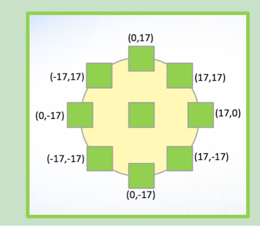
The simulations for relative performance in the near-IR, using the Narrow Field Adaptive Optics System (NFIRAOS), are based on estimating the residual Wavefront Error (WFE), for various conditions of atmospheric turbulence strength and turbulence profile for each site, and as a function of zenith angle.

The simulations were done using the Multi-threaded Adaptive Optics Simulator (MAOS) which consists of an end-to-end adaptive optics simulator for TMT (Wang et al., AO4ELT2, 2011). NFIRAOS consists of a 60-by-60 dual-conjugate wavefront correction, including two deformable mirrors optically conjugated to 0 and 11.8 km above ground, six order 60-by-60 laser guide star (LGS) wavefront sensors (WFSs); one on-axis, and five in a pentagon with a radius of 35 arcsecs. The correction loop operates at 800 Hz (800 frames per second). For the simulations we have taken each LGS to produce 900 photons per sub-aperture and per-frame.

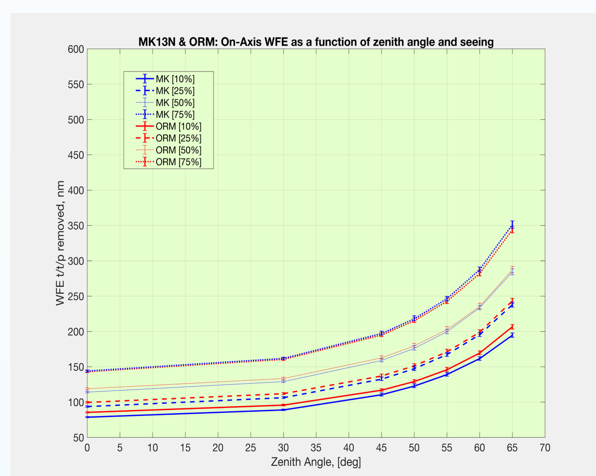
Relative Efficiency in the Near-IR

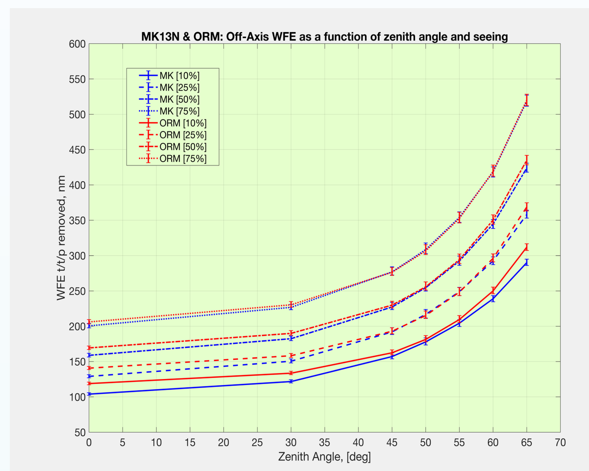


MAOS produces various results, one of those consists of the residual wavefronts, (tip, tilt, piston) removed, for 9 science positions in the 34x34 arcsecs corrected field-of-view delivered to the IRIS instrument. Those 9 science fields are located: one on-axis, and the other 8 are equidistance along the perimeter of a circle 17 arcsecs in radius.



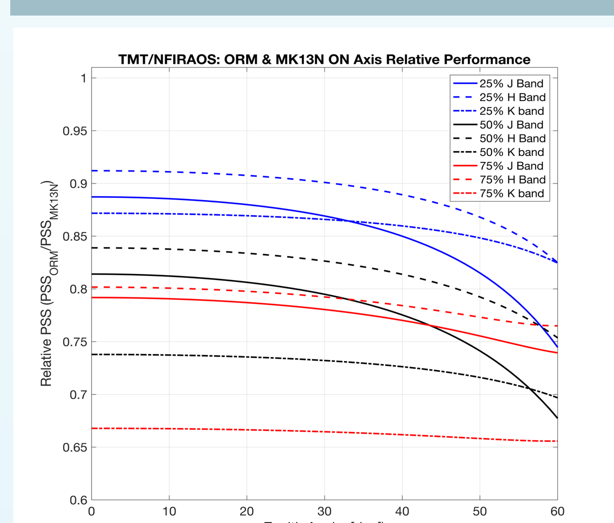
ON-axis and OFF-axis WFE

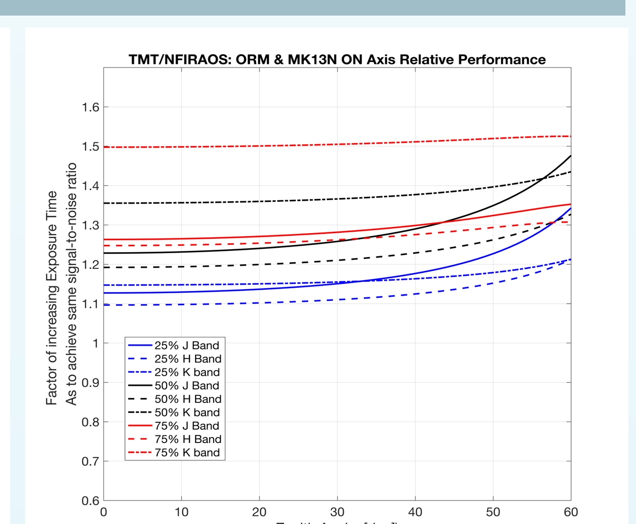


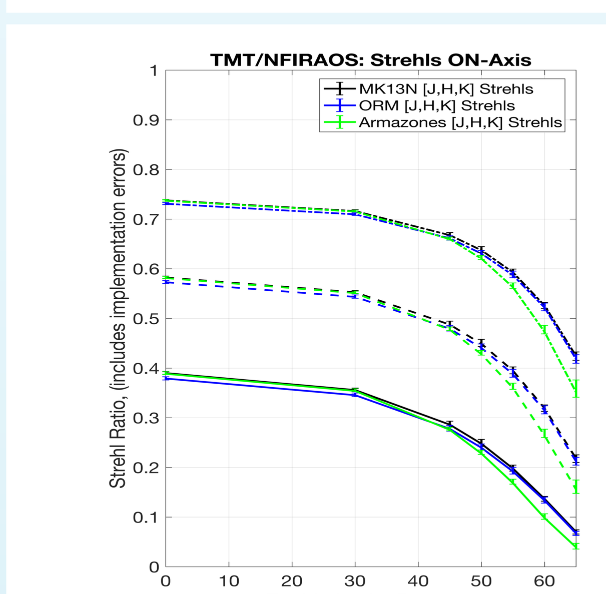


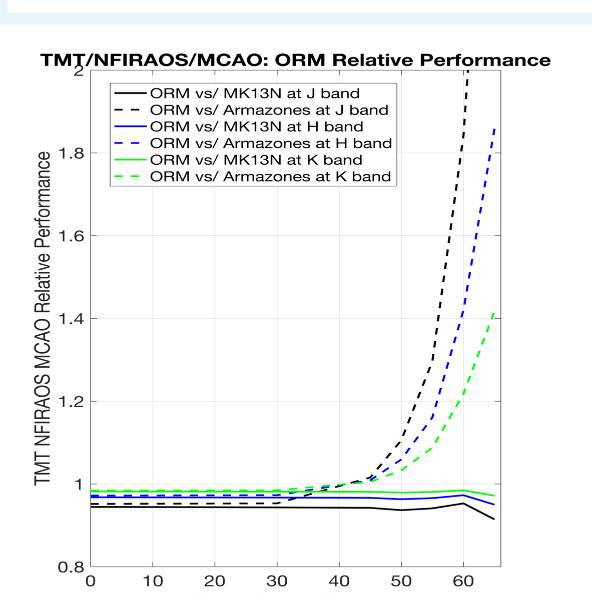
These WFE are only accounting for the profiles and strength of the atmospheric turbulence at each site. **At median conditions of atmospheric turbulence the overall ON-axis uncompensated wavefront residual delivered by NFIRAOS is 193 nm (and 206 nm averaged in a 34x34 arcsecs field**). Consequently, to the On-axis WFE (left figure) 156 nm need to be added to obtain the total WFE (156nm are the so-called implementation errors).The implementation errors stay relatively constant with zenith angle, and are are not expected to vary much from site-to-site.

On-axis Relative Performance (ORM/MK13N)







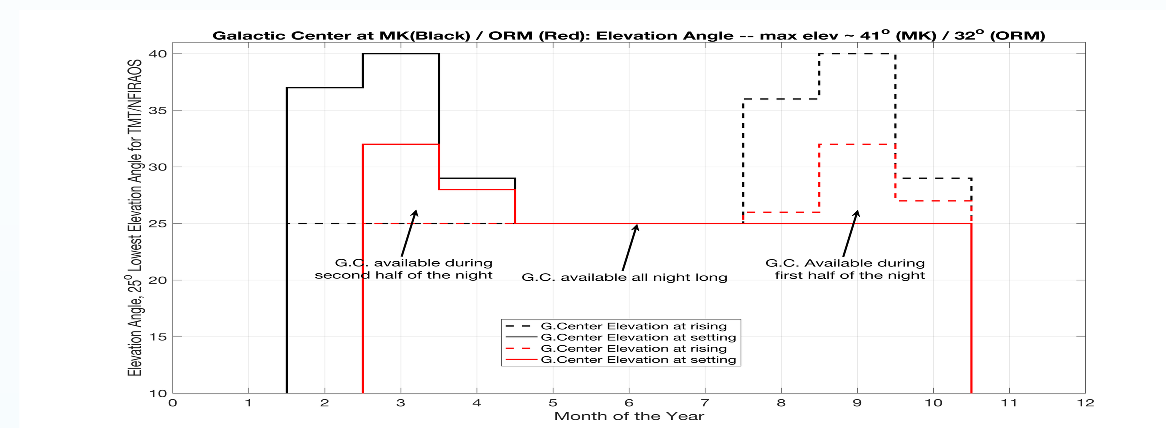


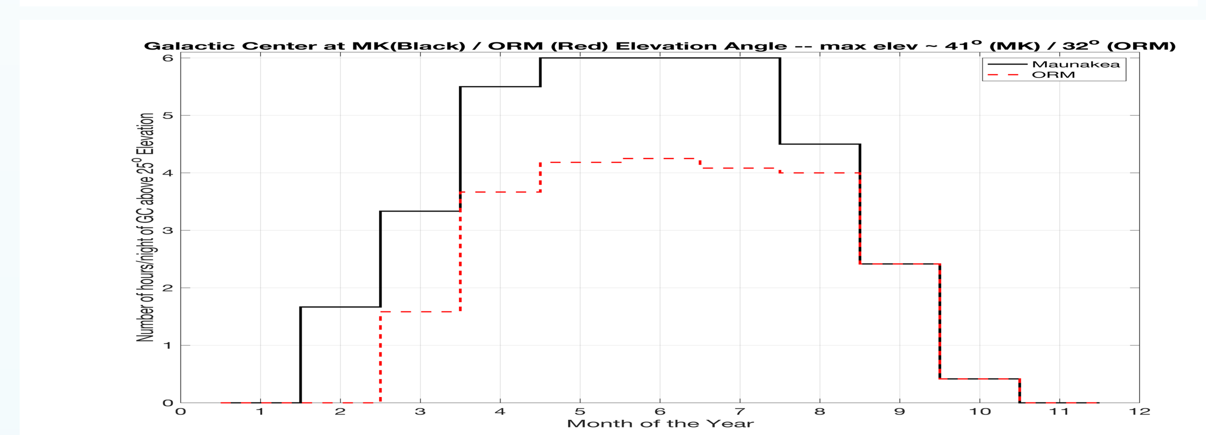
Relative Efficiency in the Galactic Center

One target of great interest among some members of the TMT scientific community is the ability of TMT to perform observations, with a regular cadence, of the Milky Way galactic center region, the place of the closest super-massive black hole (Ghez et al., The Astrophysical Journal, 509, 1998).

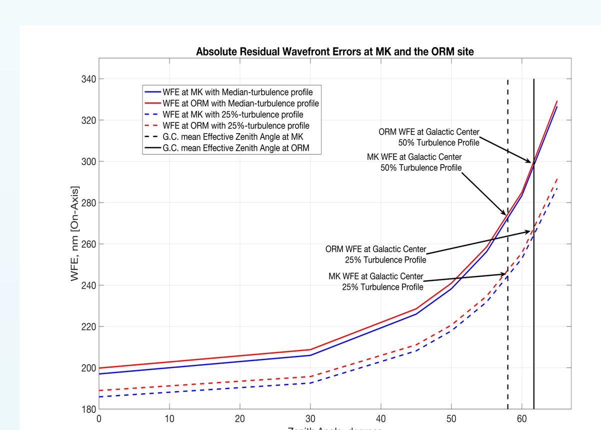
We looked at the availability of the Galactic Center above an elevation of 25º (lowest elevation angle for TMT to meet all performance requirements). The effective elevation angle of the G.C. at Maunakea and ORM are 32º and 28º, respectively.

Availability of the G.C. above 25º Elevation





On-axis Relative Performance (ORM/MK13N) at G.C.



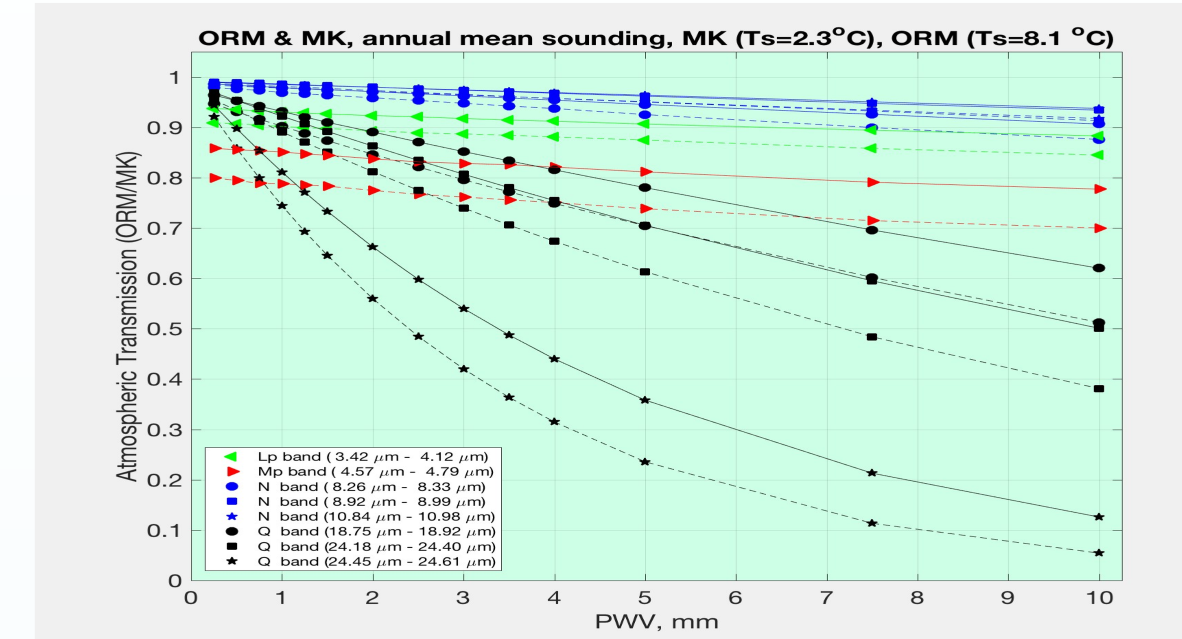
Total (includes implementation errors) WFE On-Axis in the direction of the G.C.

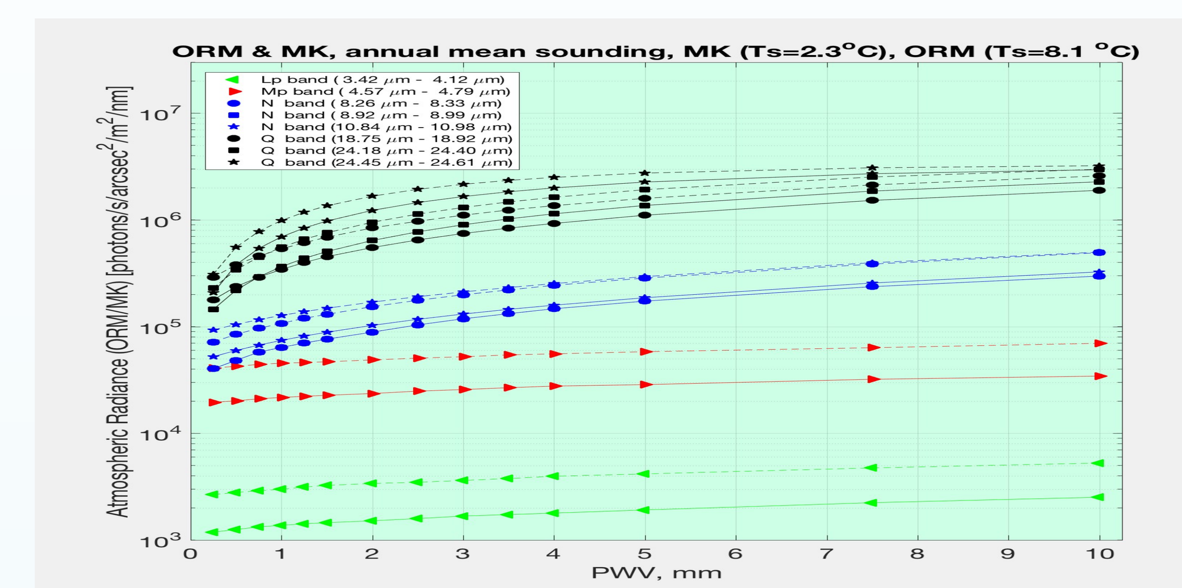
Turbulence Profile	MK13N WFE on-axis [nm]	ORM WFE on-axis [nm]
25%	244.3	267.7
50%	272.7	300.2

Turbulence	Strehl	Strehl	S^2_{ORM}/S^2_{MK}	PSS ORM/MK Ratio	Exposure Time Increase factor
25% percentile	**MK**	**ORM**			**At ORM**
J	0.22	0.16	0.55	0.47	2.1
H	0.42	0.35	0.71	0.61	1.6
K	0.61	0.56	0.82	0.68	1.5
50% percentile					
J	0.15	0.10	0.45	0.35	2.8
H	0.34	0.27	0.63	0.50	2.0
K	0.55	0.48	0.77	0.54	1.9

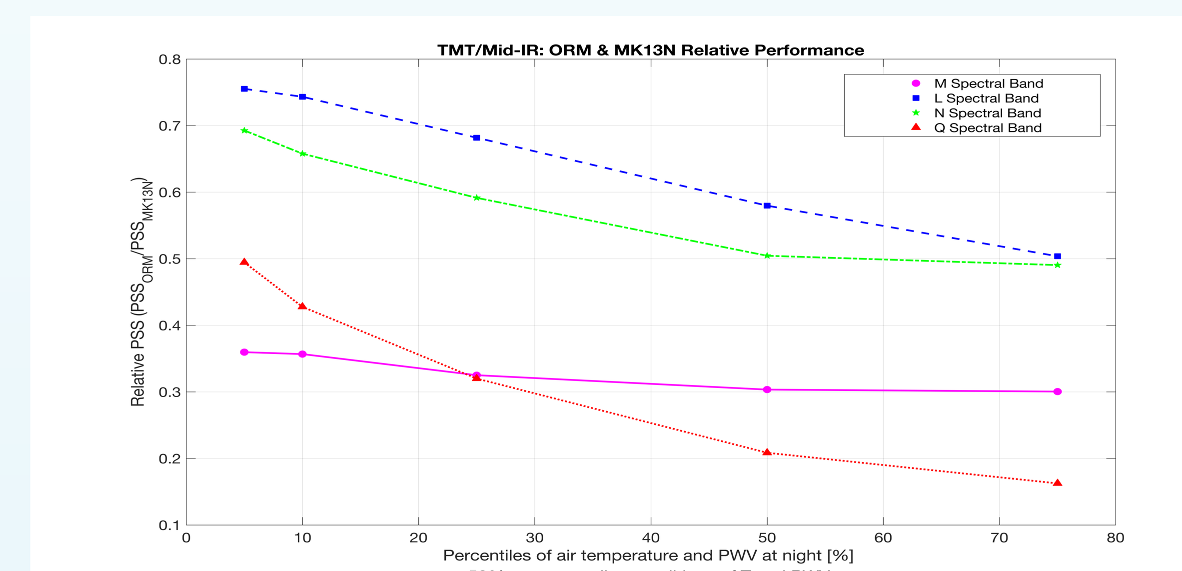
NOTE: The Point Source Sensitivity ratio also includes the effects of the atmospheric transmission and the atmospheric radiance at each site and as a function of the air temperature and water vapor content in the atmospheric column. In the Near-IR, atmospheric extinctions and transmission are computed using the Tokunaga et al (2002, Table 2), and atmospheric radiances using data from Cohen (2007).

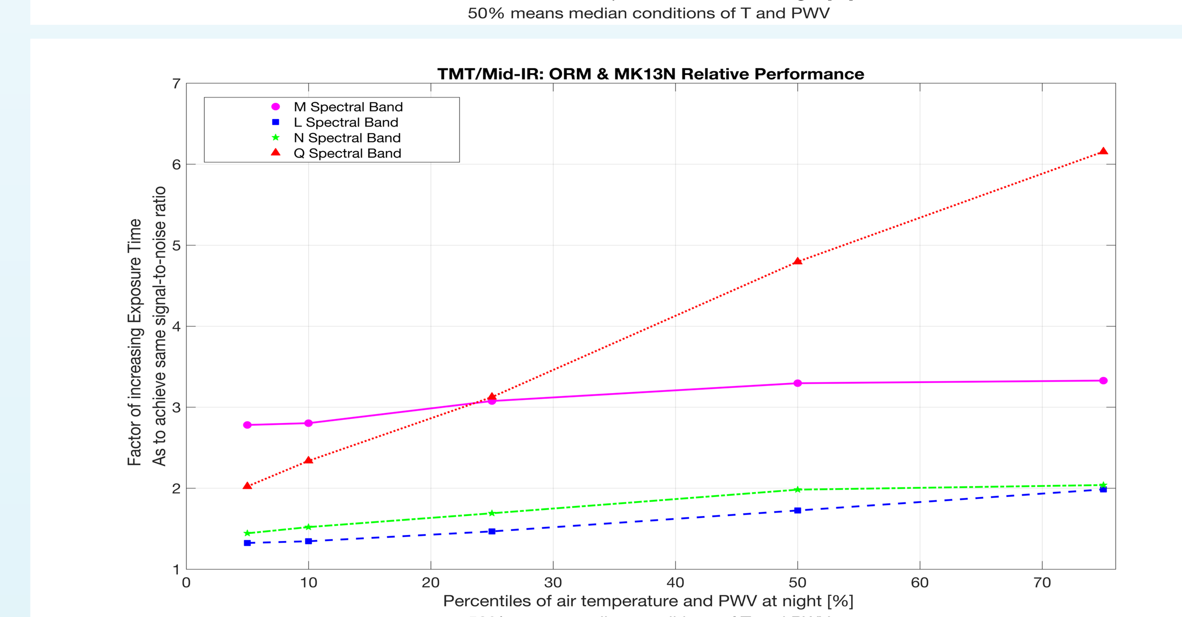
Relative Efficiency in the Mid-IR





A multi-layer, line-by-line radiative transfer model (NIRFIRmod, Otarola et al., 2015; Otarola 2017), updated with the HITRAN spectral lines information as 2016, including the most abundant Earth's atmospheric molecules (all isotopes of H_2O, CO_2, O_3, CH_4, N_2O, CO, O_2) was used to compute the median for the atmospheric transmission and atmospheric radiance, **at zenith**, at various spectral bands of interest in the mid-IR (**solid lines/Maunakea**; **segmented lines/ORM**, see insert in the figures for details of the spectral range included in the calculation). The L' and M' spectral range as defined in the work of Tokunaga et al. (2002).





At ORM, for M and N spectral bands, the same S/N than in MK13N can be obtained increasing the exposures in a factor of 30% – 70% for the best 25% of the atmospheric conditions. And a factor of 2x larger for atmospheric conditions up to 75% percentile, or for median conditions up to 55 degree zenith angle. L band is also quite sensitive to PWV, but it can be done increasing the exposure times in a factor of 3.