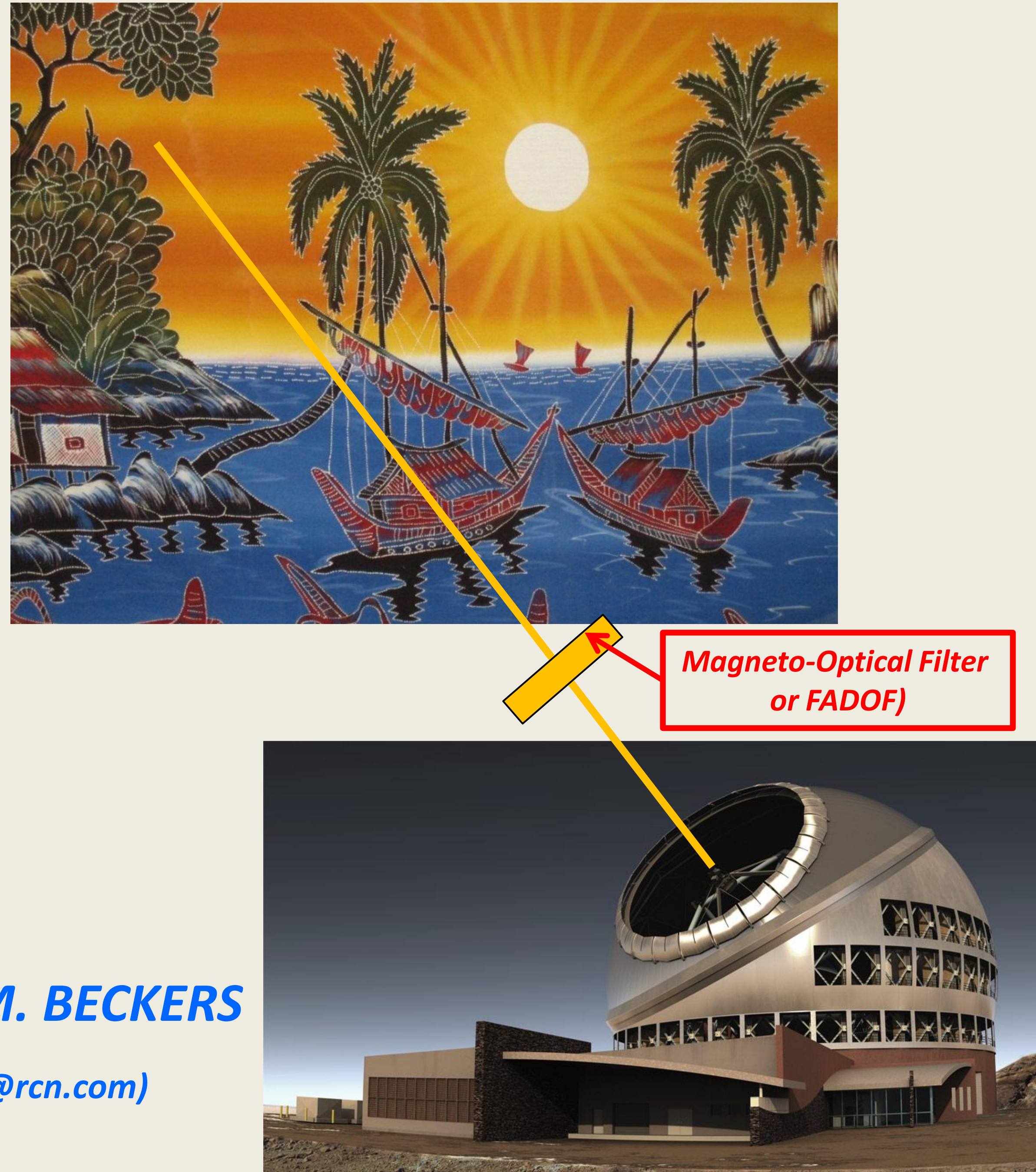
DAYTIME OBSERVATIONS WITH ELTs IN THE THERMAL IR USING LASER GUIDE STAR ADAPTIVE OPTICS



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ABSTRACT

Using Magneto-Optical Filters (MOFs; also called FADOFs = Faraday Anomalous Dispersion Optical Filters) it is possible to clearly see Sodium Laser Guide Stars (LGS) in the daytime sky. This makes it possible to use ELT Adaptive Optics systems for diffraction limited observations 24 hours/day. Because of the bright daytime sky this LGS AO application is only of astronomical interest in the mid-infrared wavelength region (4 – 25 µm) where the thermal radiation of the atmosphere-telescope system dominates the atmospheric scattering of sunlight thus making the day- and night- sky background comparable.

Incorporating Magneto-Optical Filters in the LGS wavefront sensor thus could more than double the ELT observing time for mid-infrared astronomy and would make sources in almost the entire sky available for observation at any time of the year. Even though the AO would increase the brightness of point-sources, it would not compete with the James Webb Space Telescope in terms of detectability. The gain with respect to the JWST lies in the 5 to 6 times better linear angular resolution. The contrast gain in brightness at near-IR wavelengths is sufficient to give also sufficient natural guide stars there for tip-tilt control.

Magneto-Optical Filters have been shown to function with Na lasers in daytime LIDAR applications (see Beckers and Cacciani, Experimental Astronomy 11, 133, 2001). The main complication associated with incorporating Magneto-Optical Filters in ELT AO systems for daytime observations is likely the requirement to make the telescope and its enclosure robust in the daytime environment. Poorer daytime seeing conditions may also be detrimental. I refer to my paper in SPIE Proceedings 6986 (2008) for a recent reference on this topic.

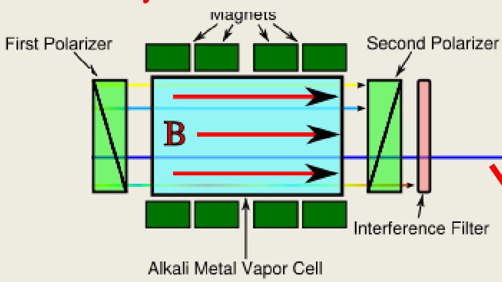
CONCEPT OF MAGNETO-OPTICAL FILTERS

- *INVENTED BY YNGVE ÖHMAN (1956)*
- *THEORY BY BECKERS (1970)*
- *FIRST IMPLEMENTATION AND USE FOR SOLAR RESEARCH BY CIMINO & CACCIANI (1968). USED BY CACCIANI FOR SOLAR AND LIDAR OBSERVATIONS*
- *REINVENTED (~1990) FOR GROUND-SPACE LASER COMMUNICATION USE AS FADOFs (= Faraday Anomalous Dispersion Optical Filters)*
- *PROPOSED FOR LGS-AO DAYTIME USE BY BECKERS & CACCIANI (2001)*

- *USES GAS CELL FILLED WITH SODIUM (or other atom) VAPOR*
- *PLACES CELL IN MAGNETIC FIELD DIRECTED ALONG LINE-OF-SIGHT*
- *ZEEMAN SPLITTING IN BOTH ABSORPTION COEFFICIENT AND ANOMALOUS DISPERSION (or "Complex Absorption Coefficient")*
- *PLACED BETWEEN CROSS-POLARIZERS RESULTING CIRCULAR BIREFRINGENCE ("Faraday Rotation") CAUSES NARROW BAND TRANSMISSION CENTERED ON SODIUM LINE.*
- *SECOND SODIUM CELL (B $\perp$ LOS) BLOCKS σ-COMPONENT SIDE BANDS*
- *RESULTING BANDWIDTH (FWHM) IS 0.006 nm (0.06A)*
- *PEAK TRANSMISSION FOR POLARIZED LIGHT IS 25 – 50%*

PRINCIPLE OF MAGNETO-OPTICAL FILTER

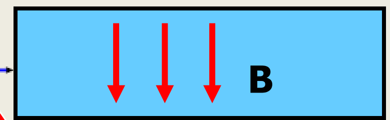
Na Vapor Cell

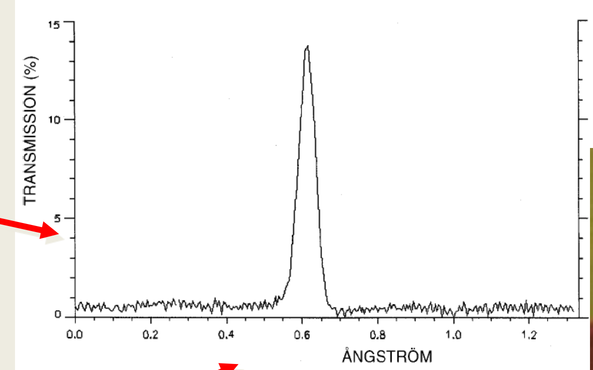


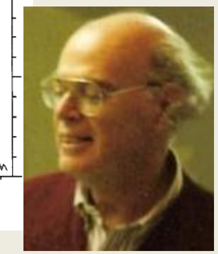
Second Na Vapor Cell

Absorbs σ Components

Transmit π Component

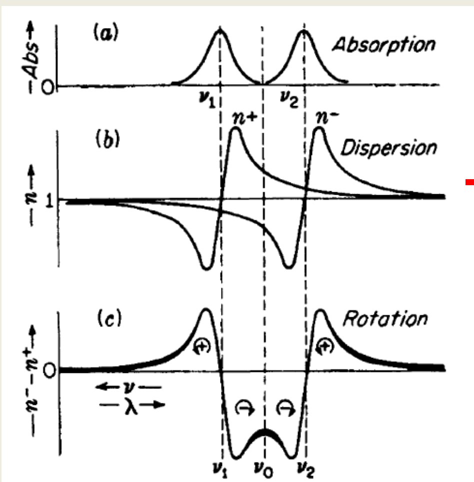


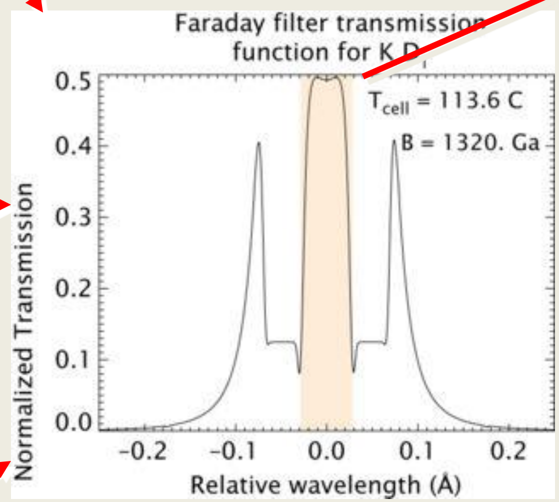


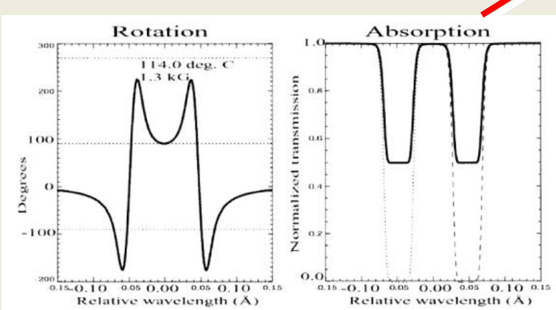


Cacciani filter for 589 nm (D_2)

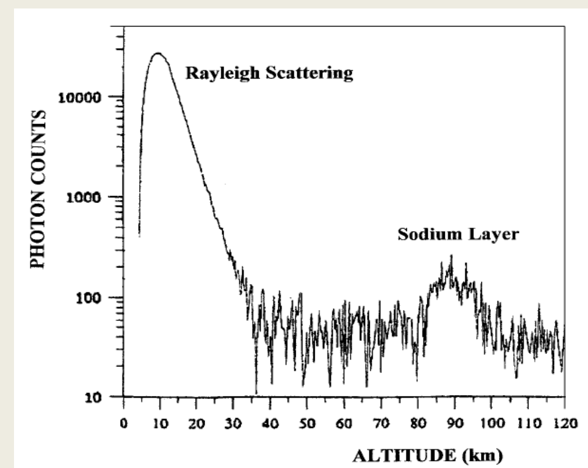
ZEEMAN TRIPLET







LIDAR RETURN



Daytime Return at l' Aquila (Italy) LIDAR

EFFECT OF MAGNETO-OPTICAL FILTER ON SPECTRUM OF THE DAYLIGHT SKY & LASER GUIDE STAR SPECTRUM

VARIOUS FACTORS CONTRIBUTE TO HIGH VISIBILITY OF Na-D_2 LASER GUIDE STAR IN THE DAYTIME SKY. THEY ARE:

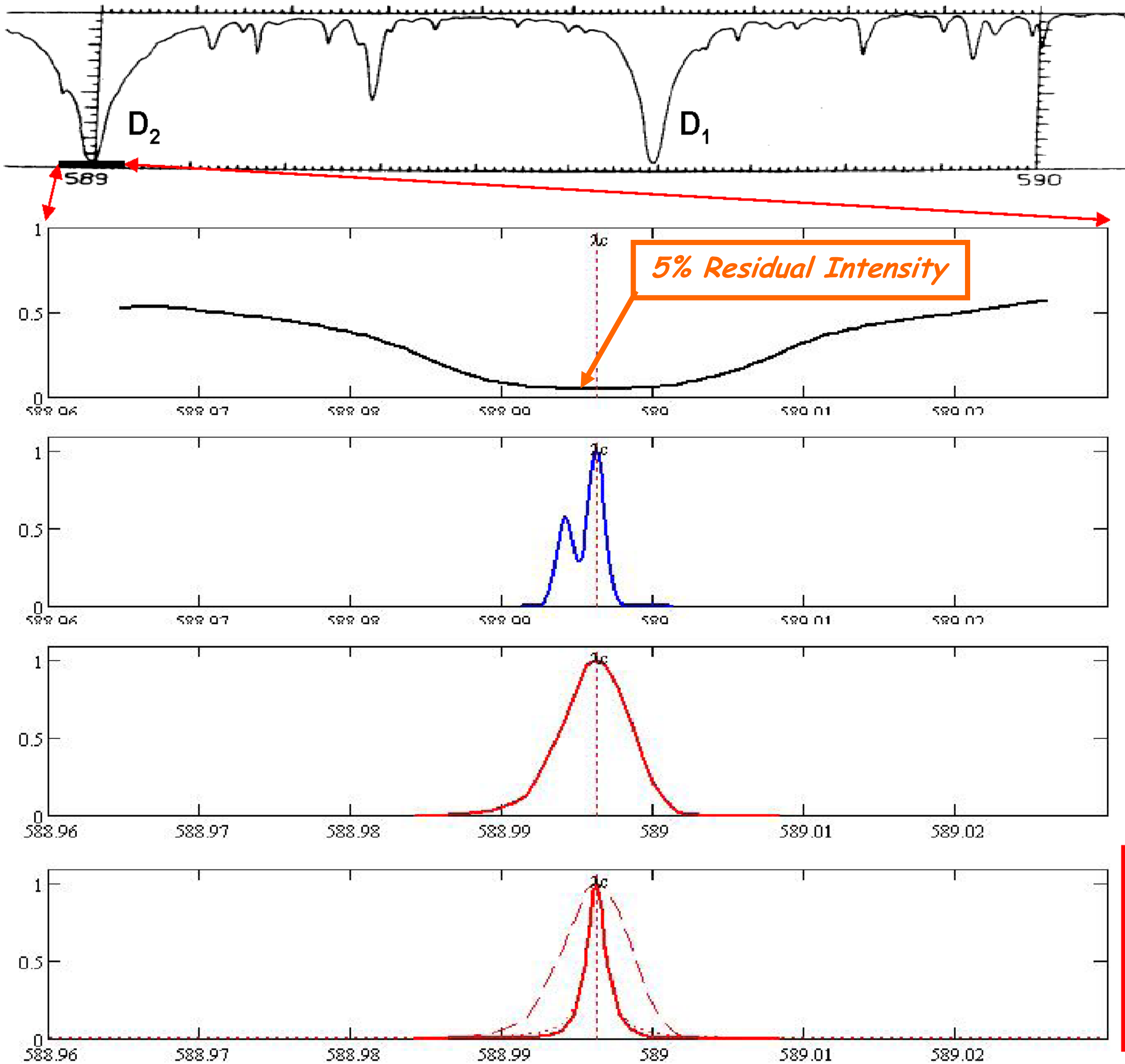
(1) SKY/SOLAR FLUX Na-D_2 LINE HAS ONLY 5% INTENSITY AT ITS LINE CENTER

(2) LGS LINE WIDTH IS VERY NARROW AS COMPARED TO THE SKY SPECTRUM LINE WIDTH

(3) MAGNETO-OPTICAL FILTER TRANSMISSION PROFILE IS ONLY SLIGHTLY WIDER THAN THE LGS LINE WIDTH. IT ALONE SUFFICES TO MAKE THE LGS CLEARLY VISIBLE AGAINST THE DAYTIME SKY

(4) IN ADDITION ONE MIGHT ADD A FABRY-PÉROT ETALON TO THE MOF. IT WOULD ISOLATE THE PEAK OF THE LGS SPECTRUM AND INCREASE THE CONTRAST FURTHER

SOLAR FLUX & LASER GUIDE STAR SPECTRUM & SPECTRAL FILTERS



Solar Spectrum near Na D-Lines. Wavelength in nm.

Expanded Spectrum In D_2 Core

Spectrum of Na Laser Guide Star

Magneto-Optical Filter (MOF) Transmission Profile

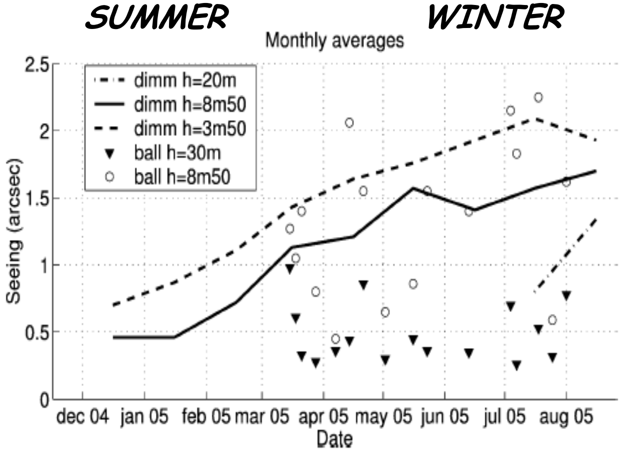
Combined MOF & Fabry-Pérot Profile.

ESTIMATE OF V MAGNITUDE OF SKY AND Na LASER GUIDE STAR

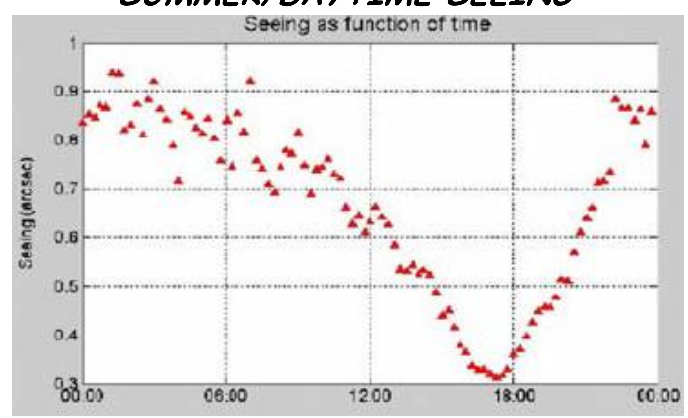
COMMENTS:

(I) ASSUMPTION: LASER GUIDE STAR SIZE EQUALS 1 $arcsec^2$
(II) ΔV REFERS TO CHANGE IN V RESULTING FROM ITEM LISTED
(III) ELTs (THIRD COLUMN) REFER TO CURRENT PLANS (TMT, E-ELT, GMT) WHICH WILL BE LOCATED AT MID-LATITUDES (20^o TO 30^o)
(IV) DOME C REFERS TO THE FRENCH-ITALIAN (-EUROPEAN?) ANTARCTIC SITE. ITS "DAY" AND "NIGHT" SEEING TEST SHOW DAYTIME SEEING TO BE MUCH BETTER THAN NIGHTTIME SEEING:

SUMMER WINTER



SUMMER/DAYTIME SEEING



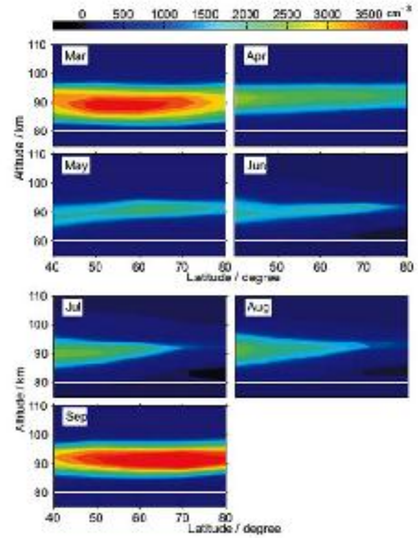
Time of Day

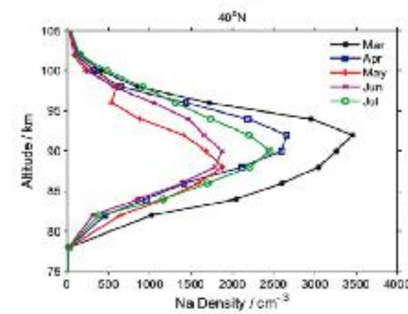
DAYTIME SKY BRIGHTNESS & LGS MAGNITUDE

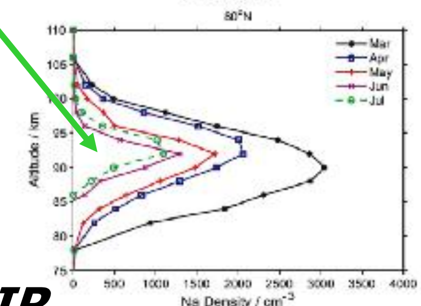
SKY MAGNITUDE (V)	ΔV	ELT'S (mid-latitude)	Dome C (-75°)
Total Solar Disk		-26.7	-26.7
Solar Disk/arcsec^2	16.2	-10.5	-10.5
Clear Sky (10^{-6})/arcsec^2	15.0	+4.5	+4.5
Sky: Add Filter Bandwidth (MOF only:.0053 nm vs. 55 nm)	10.0	+14.5	+14.5
Sky: Add Center D_2 Line (5%)	3.2	+17.7	+17.7

LGS MAGNITUDE (V) (assume LGS area = 1 arcsec^2)			
10 Watt Laser MK & VLT ++		+10.0	
10 Watt Laser Dome C	2.0		+12.0
MOF Transmission ~ 57%	0.6	+10.6	+12.6
$V_{LGS} - V_{SKY}$		-7.7	-5.7
λ Range for LGS AO (μm)		> 0.8	> 1.4

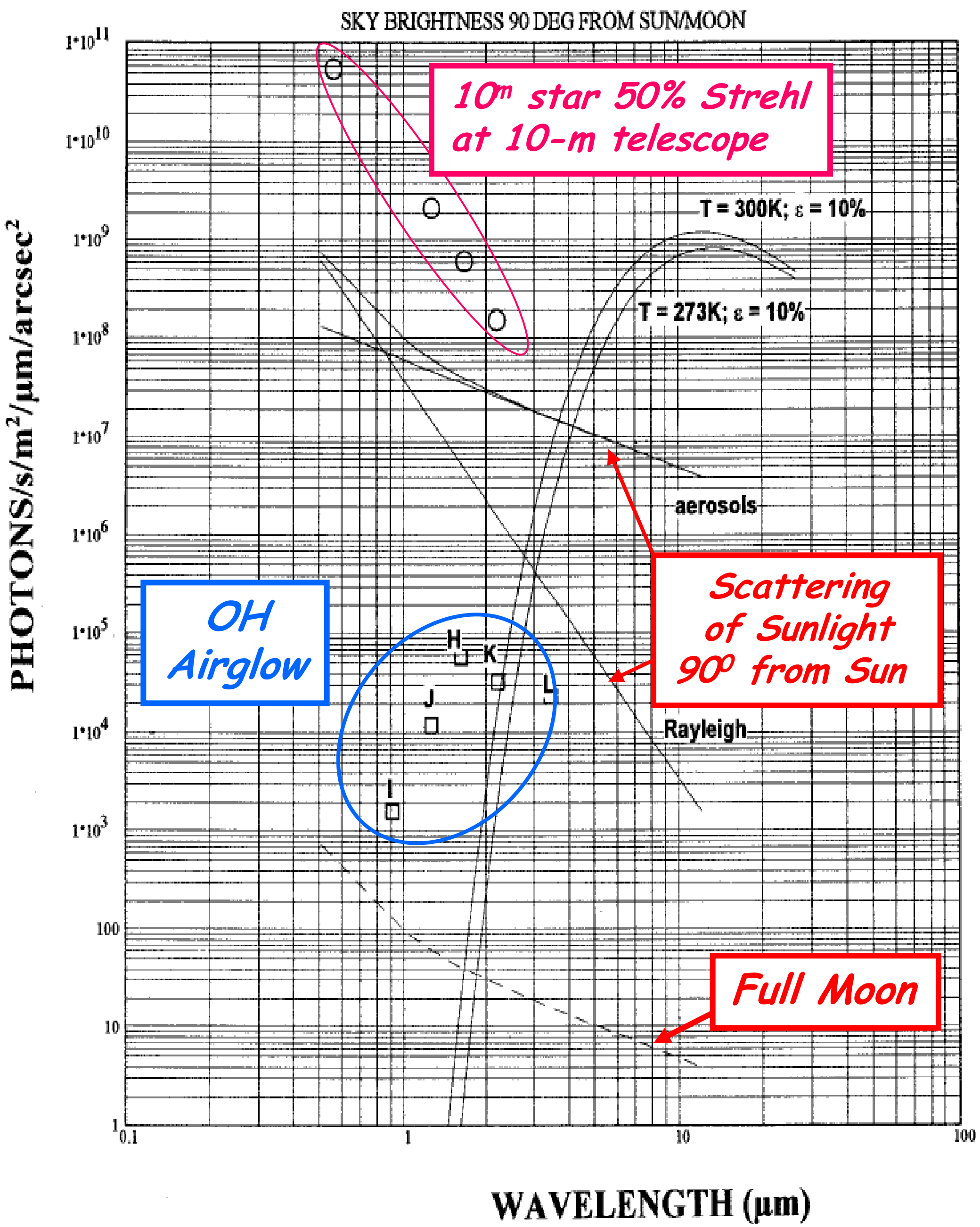
for Northern Hemisphere







CONCLUSION: Daytime Sky OK; LGS Brightness OK for IR



CONDITIONS:

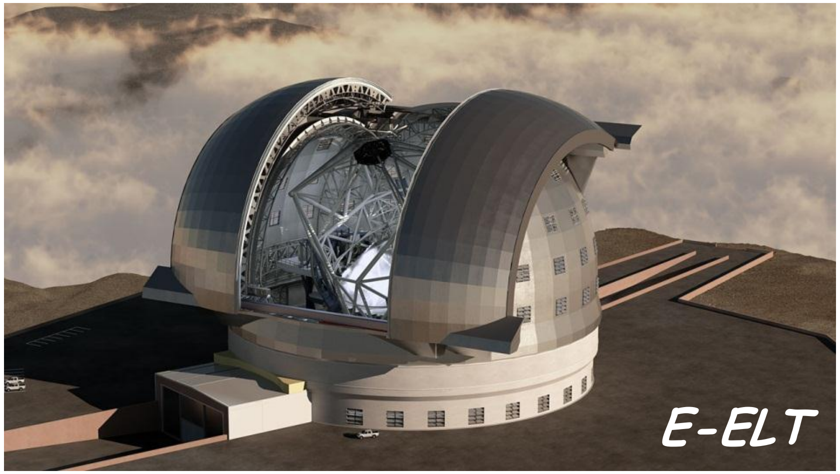
- Observatory at h = 3000m
- Good, "Coronal" Sky
- OH Airglow in Full Spectral Band
- Emissivity Sky & Telescope 10%
- Seeing is 1 arcsec

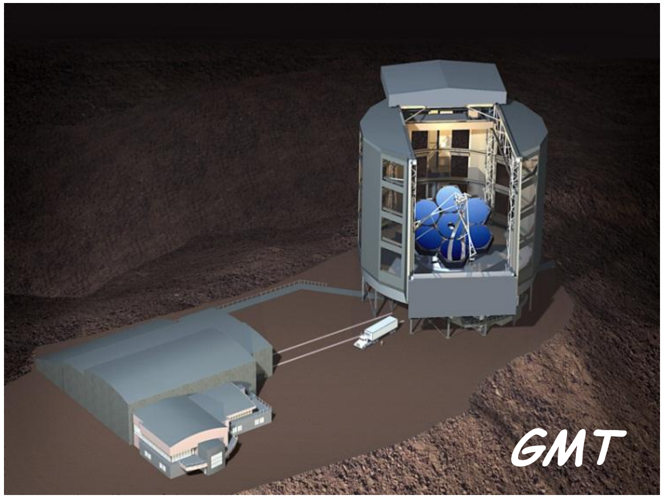
- At λ > 3.5 μm Background Emission Dominates Scattered Sunlight
- Daytime Observing Gain is Therefore in Thermal IR
- Adaptive Optics Needs to be Good at Wavelength of Tip-Tilt Control Star (J, H, or K)
- At J, H, and K There Are Enough Stars for Tip-Tilt Control in Galactic Belt, only Partial at Galactic Pole

ADDITIONAL OBSERVING TIME FOR DAYTIME THERMAL (λ > 3.5 Mm) IR OBSERVATIONS

- ASSUME ASTRONOMICAL OBSERVATIONS ARE MADE ONLY FOR ZENITH DISTANCE ≤ 60^0
- ASSUME MINIMUM ANGULAR DISTANCE TO SUN IS 90^0
- THIS APPEARS ACHIEVABLE WITH THE TMT IN ITS CURRENT DESIGN. SMALLER SUN ANGLES AND/OR OTHER ELT's REQUIRE DESIGN CHANGES
- ~ 2 X 0.75 HR = 1.5 HRS GAIN RESULTING FROM ASTRONOMICAL TWILIGHT OBSERVATIONS
- FOR FIRST AND LAST 2 HOURS OF THE DAY ABOUT 30% OF THE SKY AT ZENITH DISTANCE ≤ 60^0 IS > 90^0 FROM SUN

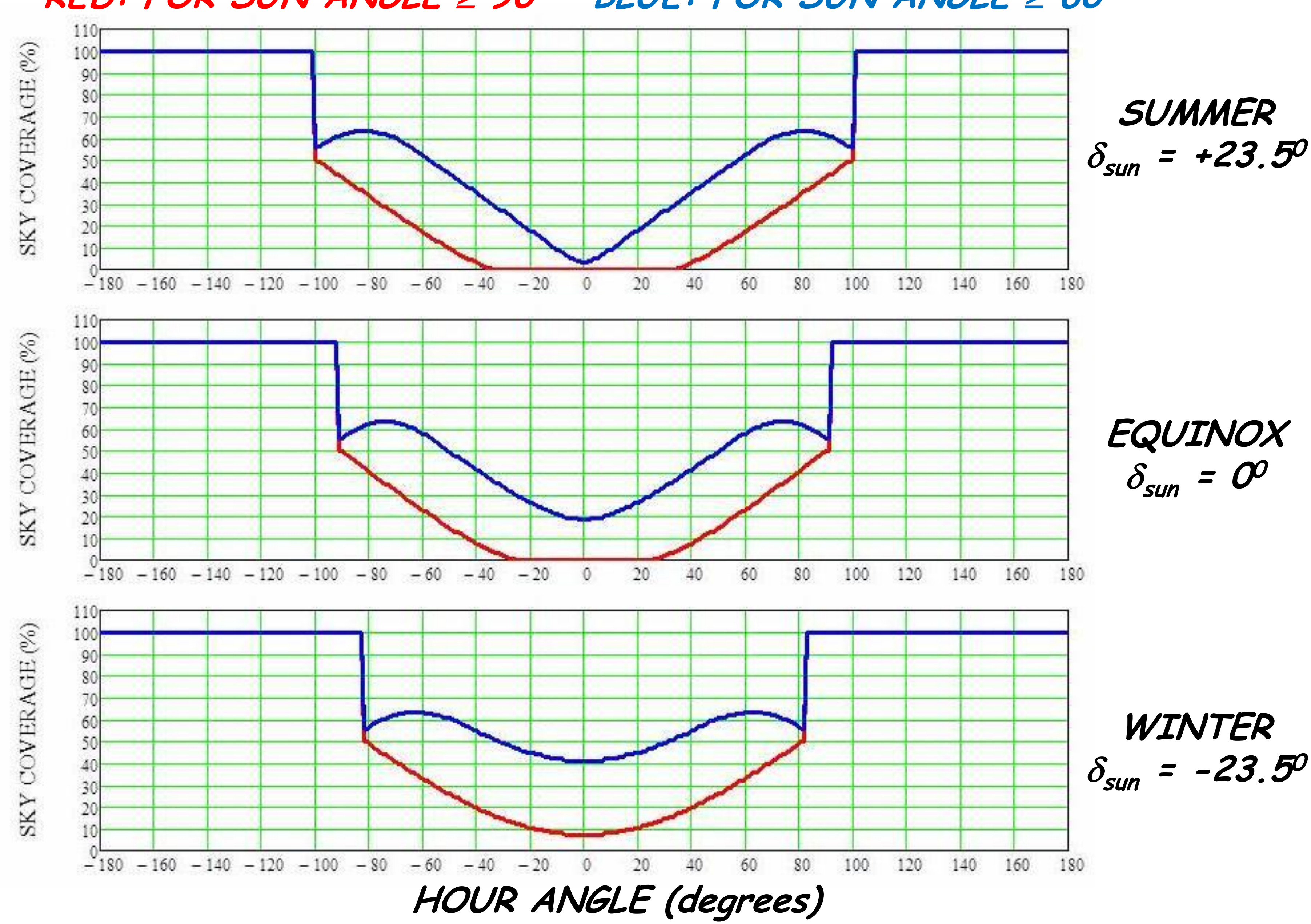
→ THERE IS AT LEAST 50% INCREASE OF USEFUL ASTRONOMICAL OBSERVING TIME FOR THERMAL IR OBSERVATIONS





SKY COVERAGE FOR AIRMASS ≤ 2 FOR TMT

RED: FOR SUN ANGLE ≥ 90⁰ BLUE: FOR SUN ANGLE ≥ 60⁰



SYNOPSIS

- INCORPORATION OF Na MAGNETO-OPTICAL FILTERS LASER GUIDE STAR WAVEFRONT SENSORS ENABLES DAYTIME ATMOSPHERIC TOMOGRAPHY
- THIS MAKES ADAPTIVE OPTICS (including MCAO etc) FOR ELTs IN DAYTIME POSSIBLE
- USEFUL ONLY IN THERMAL INFRARED WHERE DAYTIME AND NIGHTTIME SKY BRIGHTNESSES ARE EQUAL
- GAIN OF ELTs OVER JAMES WEBB SPACE TELESCOPE LIES IN 5x HIGHER LINEAR ANGULAR RESOLUTION (40x FOR SPITZER SPACE TELESCOPE)
- DAYTIME OPERATION OF ELTs REQUIRES SUNSHIELD FOR TELESCOPE
- $\geq 90^0$ ANGLE SUNSHIELD GIVES ALREADY SUBSTANTIAL SKY ACCESS (eg 100% IN WINTER FOR TMT).
- $\geq 60^0$ ANGLE SUNSHIELD GIVES SKY ACCESS 24 HRS/DAY AT ALL DAYS OF THE YEAR
- POORER DAYTIME SEEING SHOULD HAVE LITTLE EFFECT ON THE THERMAL IR ADAPTIVE OPTICS
- DAYTIME OPERATION OF TELESCOPE & DOME MAY HAVE DETRIMENTAL EFFECTS ON NIGHTTIME OBSERVING QUALITY (ENGINEERING ISSUE?)