ESO
European Organisation for Astronomical Research in the Southern Hemisphere

Monitoring Site Parameters for AO

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Monitoring Site Parameters for AO

ABSTRACT

The various ELT project have deployed a very uniform instrumentation suite, often using similar measurement methods (DIMM) and even in some cases identical instruments (MASS).

A review is proposed of what has been achieved and what is now available, and the compatibility with the requirements from AO is examined

Monitoring Site Parameters for AO: the requirements

VLT AOF Site Monitoring Requirements (draft)

-For MUSE-WFM the turbulence content below 500m is an important parameter to judge expected performance of the AO system.
-For Hawk-I (with its much larger corrected FoV) the turbulence content below 300m is more relevant since the AO system performance significantly decreases above this altitude.

Therefore, for the operation of the AOF in ground layer mode two different key altitudes are relevant: 300m and 500m.

It is envisaged that the displayed information
provides comfortable access to the relevant parameters in real time

Monitoring Site Parameters for AO: the requirements

LIST OF SURVEYABLE E-ELT SITE PARAMETERS RELEVANT FOR ADAPTIVE OPTICS BASED INSTRUMENTS AND POST-FOCAL MODULES)
Doc. E-TRE-ESO-528-0795

The values of the vertical profile of the atmospheric refractive index structure constant Cn2 should be available every minute for the following altitudes *h above the E-ELT site and with the respective resolution:*
h < 0.5km, resolution < 100m
h > 0.5km, resolution < 500m
Whenever possible, the direction along which the Cn2 vertical profile is measured should be within 15 degrees (TBC) with respect to the one of telescope's observation at the same moment.

(…)

Monitoring Site Parameters for AO: the requirements

Input for instrument performance simulations

Table 2. Good, Median, and Bad Atmospheric Profiles Used in This Paper

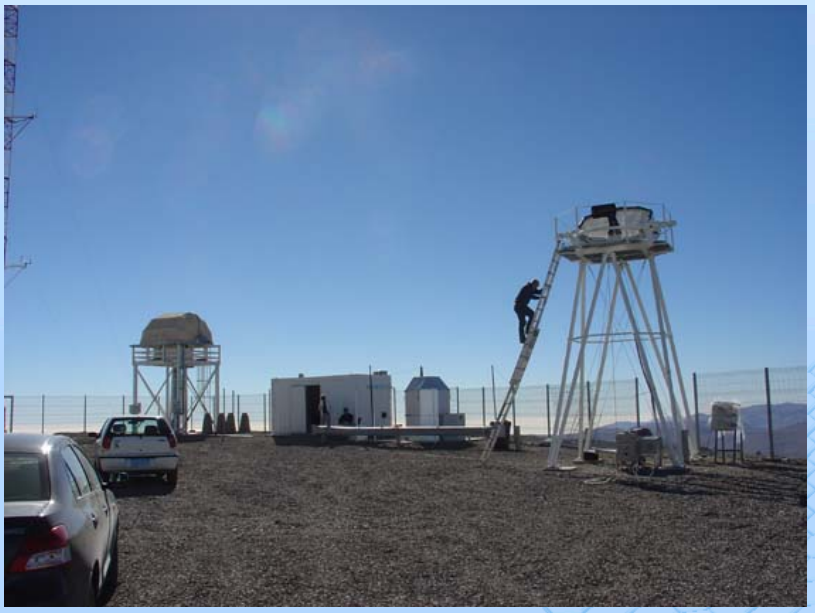
Layer	Height (m)	% of C_N^2 Good	% of C_N^2 Median	% of C_N^2 Bad	Wind Speed (m/s)
1	47	53.28	52.24	48.91	15.0
2	140	1.45	2.60	4.25	13.0
3	281	3.50	4.44	7.26	14.0
4	562	9.57	11.60	13.91	10.0
5	1125	10.83	9.89	9.56	9.0
6	2250	4.37	2.95	1.87	15.0
7	4500	6.58	5.98	5.92	25.0
8	9000	3.71	4.30	4.11	40.0
9	18,000	6.71	6.00	4.21	21.0

2011ApOpt..50..473C: Clare,+: Laser guide star wavefront sensing for ground-layer adaptive optics on extremely large telescopes

Standard Site Monitoring Station

Working Together

TMT & ESO use identical instruments for turbulence profiling
MOU ESO-TMT for sharing site data in Northern Chile



Cross-comparison of MASS-DIMM and Paranal MASS-Lite, July-October 2006

TMT and ESO at Cerro Armazones, Nov. 2009

MASS-DIMM

From prototype to small series: a success story

Feb. 2003: MASS prototype in operation at Paranal
2004: TMT MASS-DIMM site monitoring starts
2007: E-ELT MASS-DIMM site monitoring starts

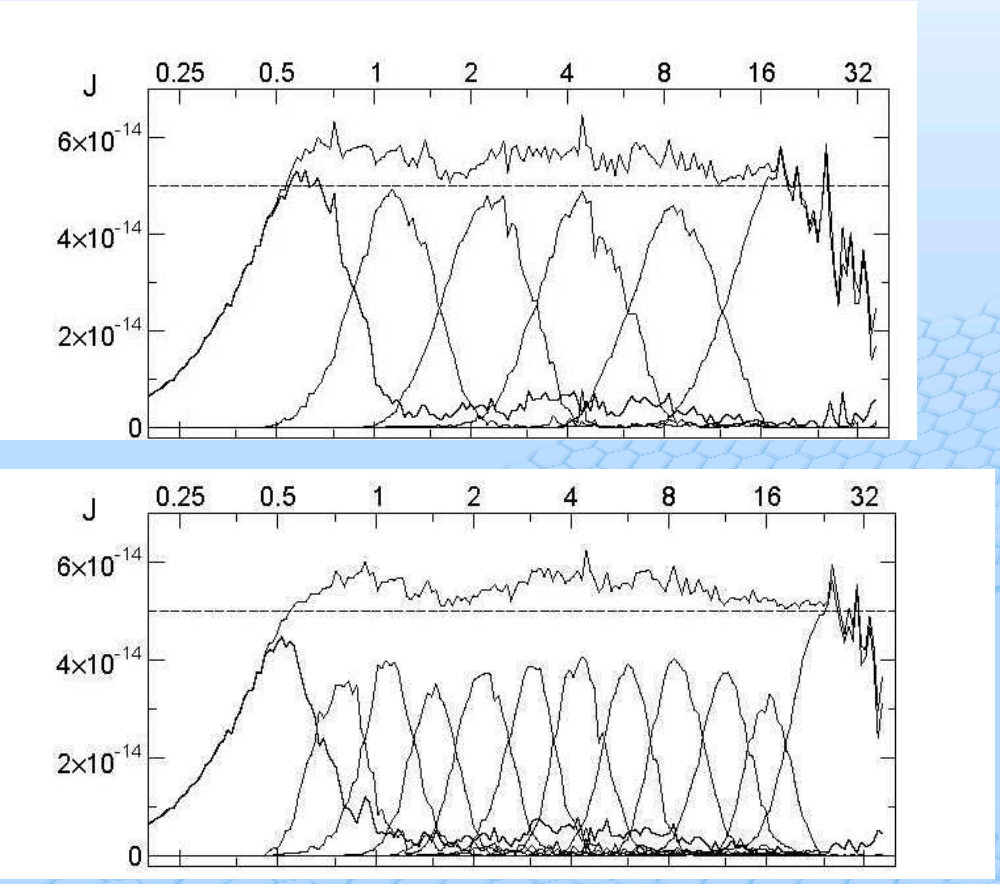
A. Tokovinin (CTIO) aligning the MASS prototype in Feb. 2003 at Paranal

Victor Kornilov (Sternberg, Moscow) assembling the 4 ELT Design Study MASS-DIMM instruments in June 2006

MASS-DIMM

2010: MASS in HD mode

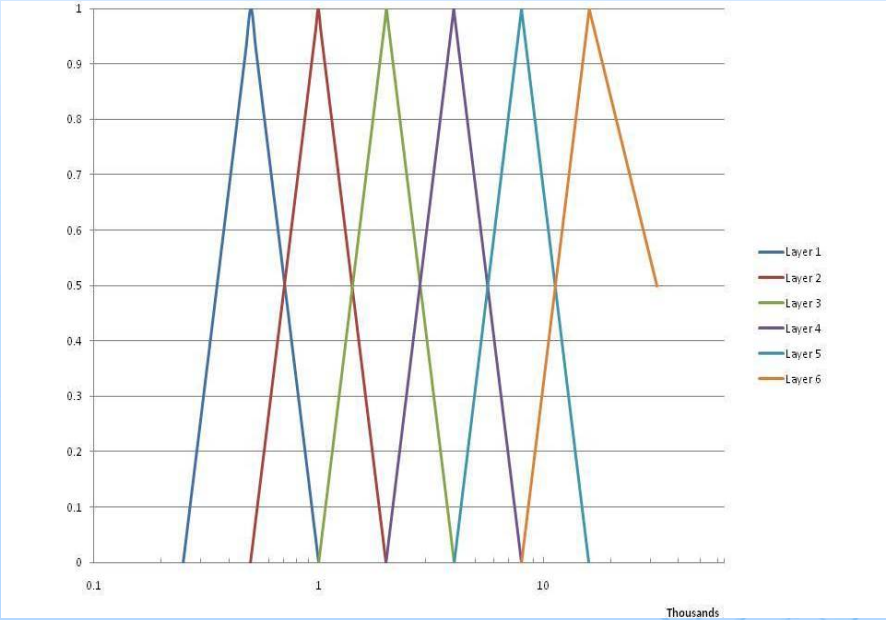
MASS algorithm response to a thin turbulent layer J=5.10-14m+1/3 real including scintillation noise in 6 layer mode (top) and in HD mode (bottom)

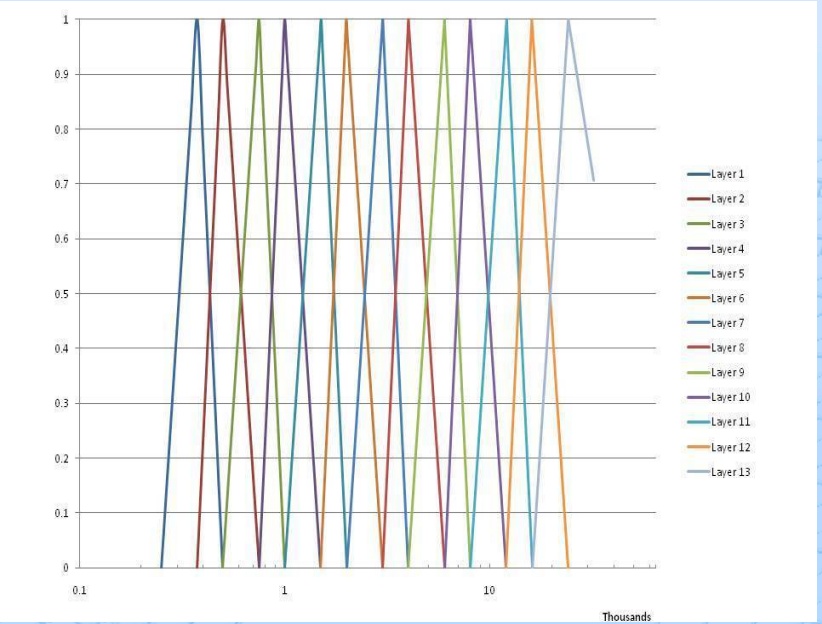


See Kornilov, V., & Kornilov, M. 2011, Exp. Astron., 29,155

MASS-DIMM

Reprocessing MASS database in HD mode



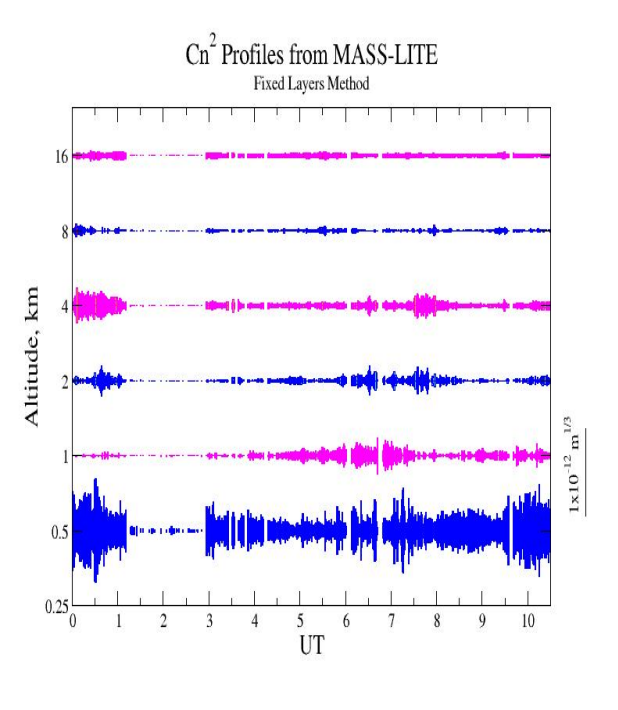


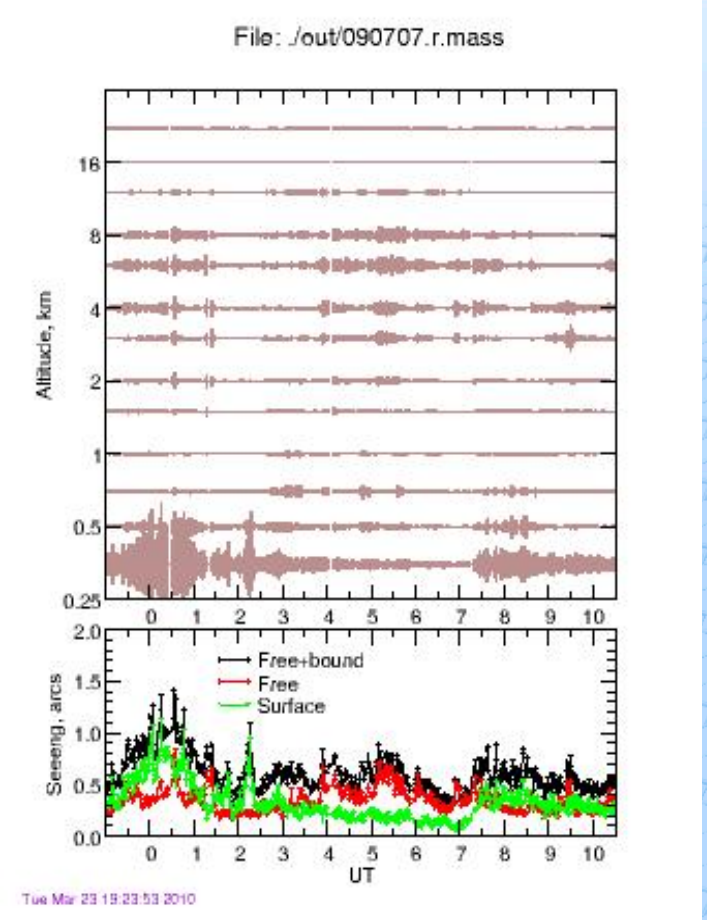
6-layer: *0.5, 1, 2, 4, 8 and16 km*

13-layer: 0.375, 0.5, 0.75, 1, 1.5, 2, 3, 4, 6, 8, 12, 16 and 24 km

MASS-DIMM

2010: MASS in HD mode

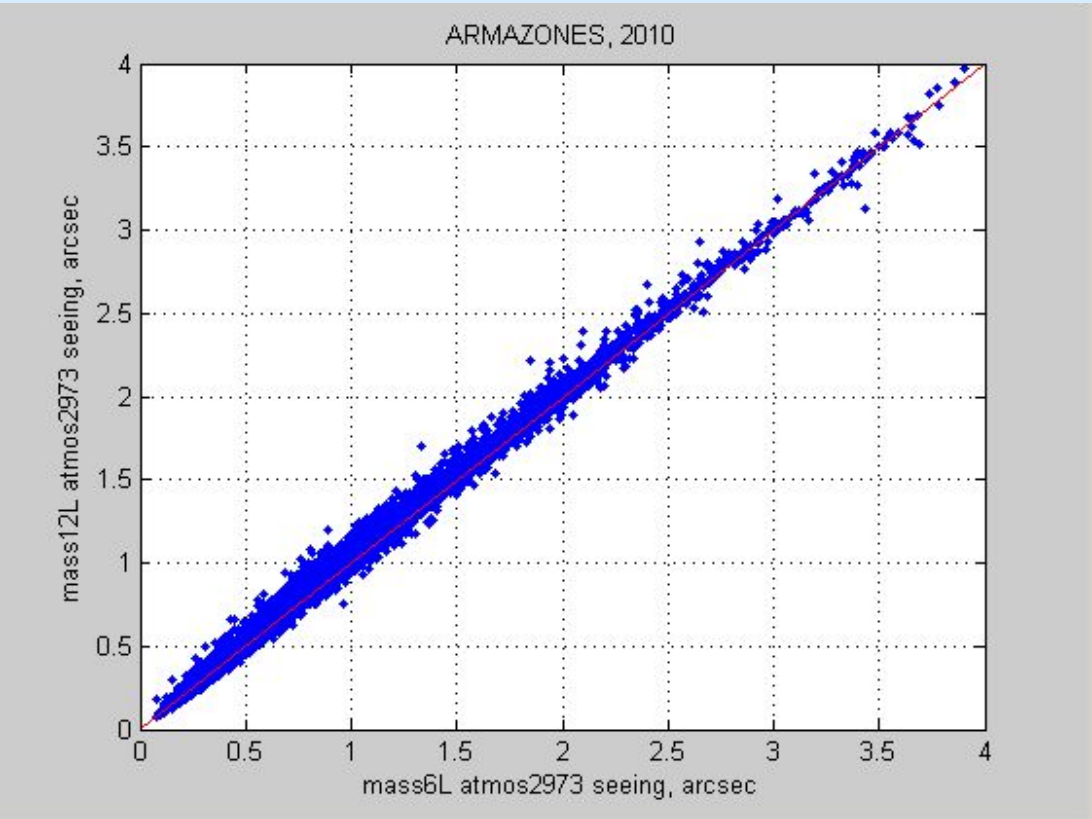




See Kornilov, V., & Kornilov, M. 2011, Exp. Astron., 29,155

MASS-DIMM

MASS in HD mode

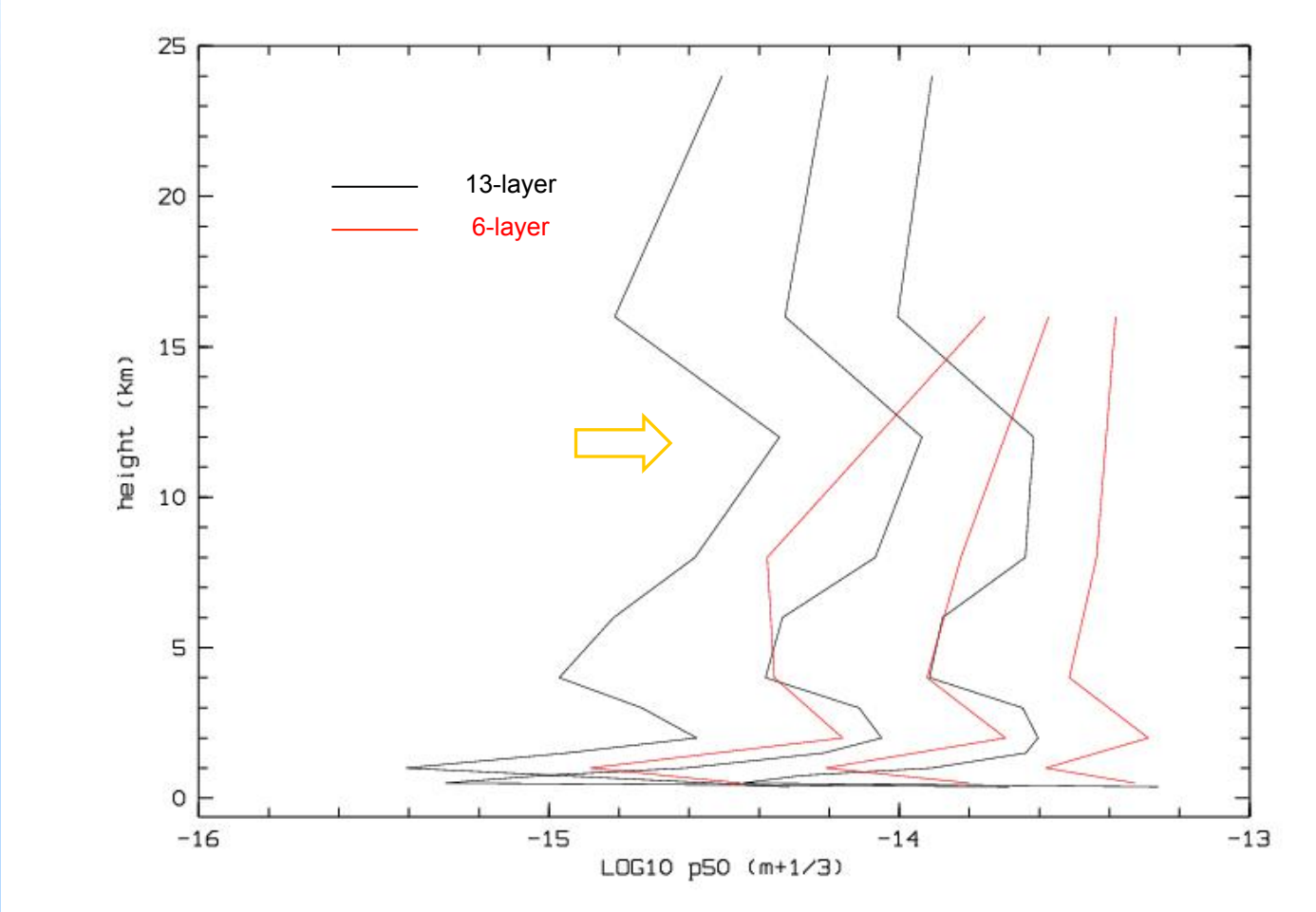


Comparison of MASS total seeing in 6-layer and 13-layer modes after reprocessing with version 2.97.3

MASS integrated Cn2 Profiles

6-layer versus 13 layer models

25, 50, and 75 %tiles of Cn2 integrated within each individual MASS layer



MASS integrated Cn2 Profiles

6-layer versus 13 layer models

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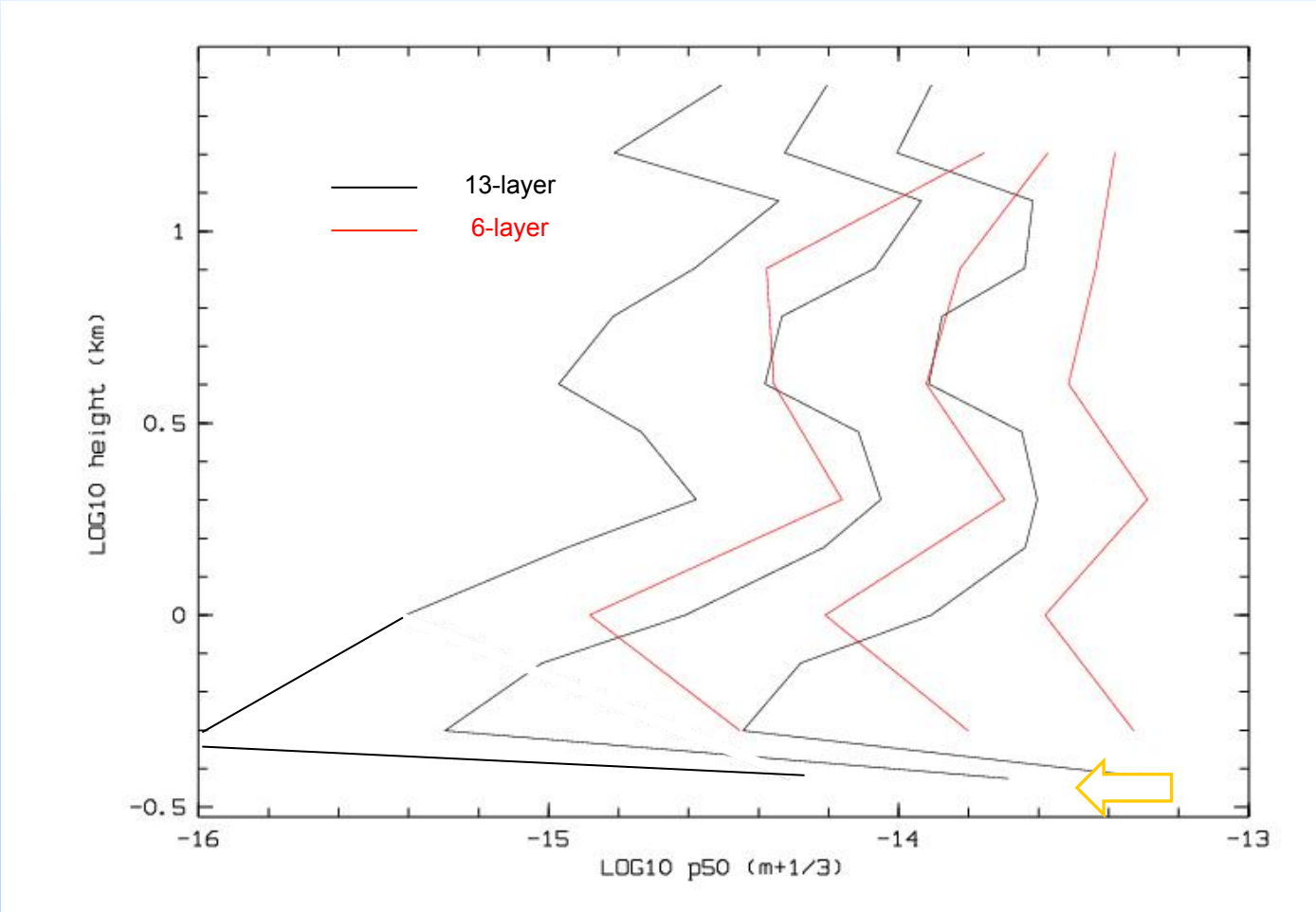
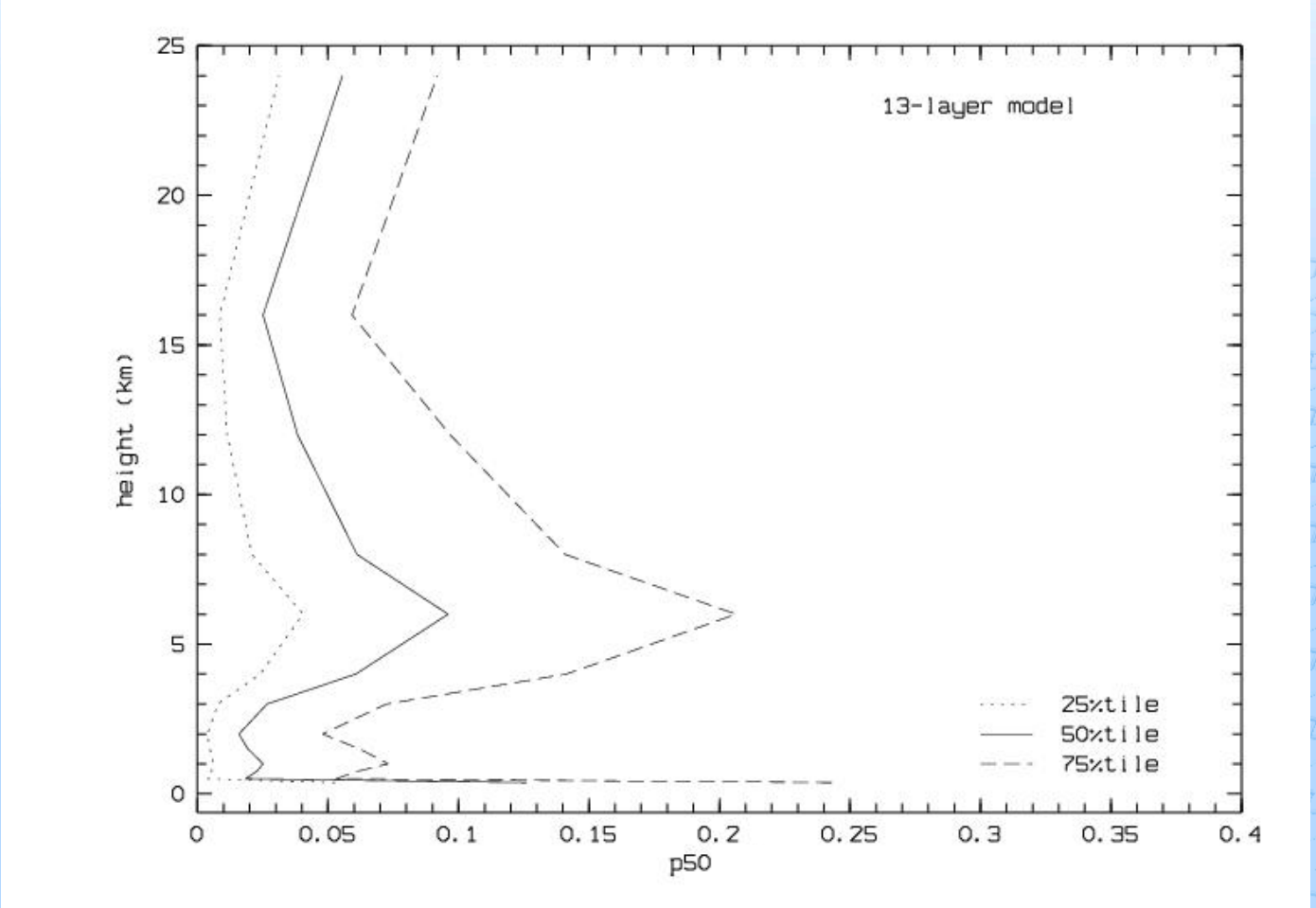


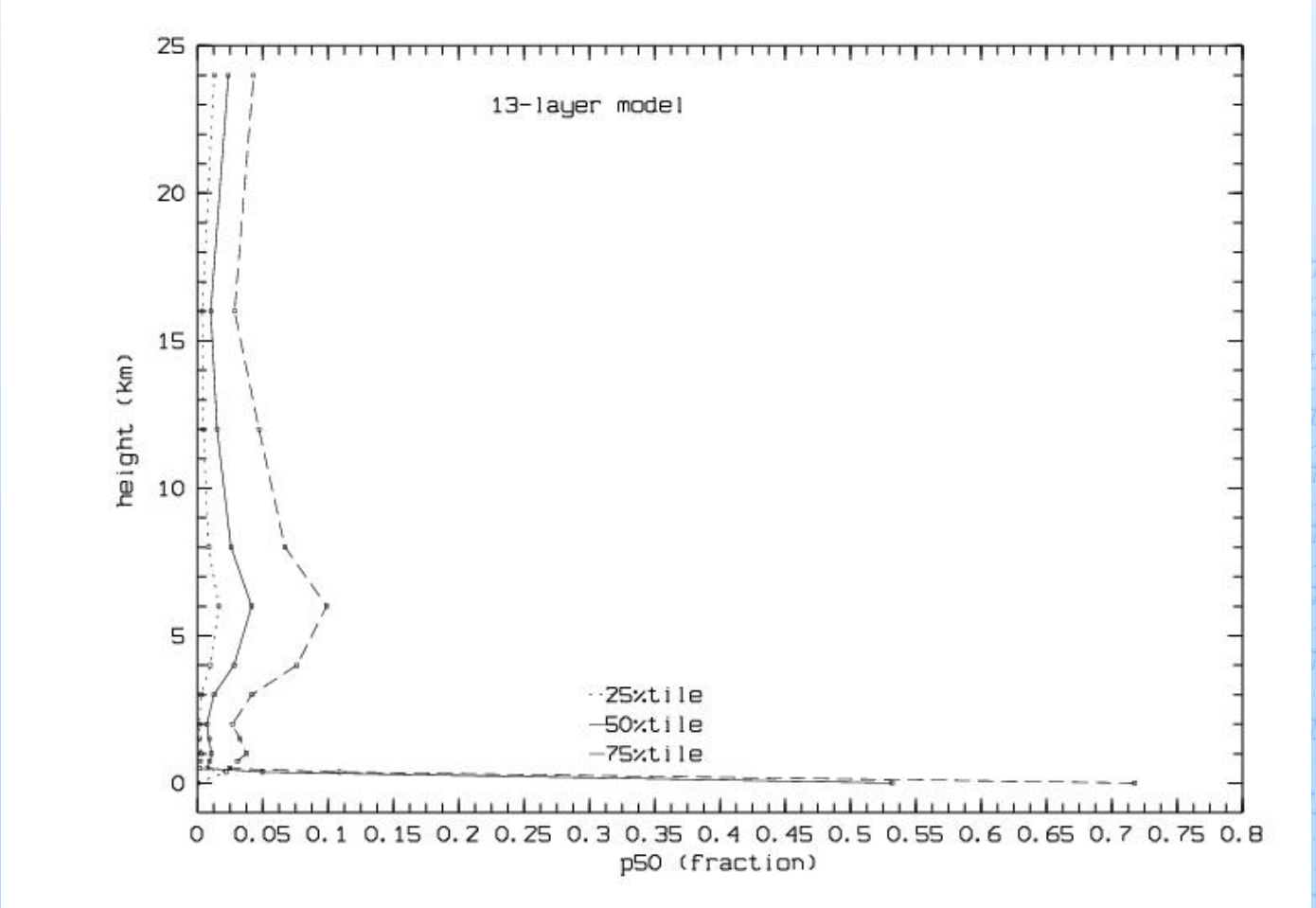
MASS fractional Cn2 Profiles

25, 50, and 75 fraction of the relative (to MASS) strength of each MASS layer



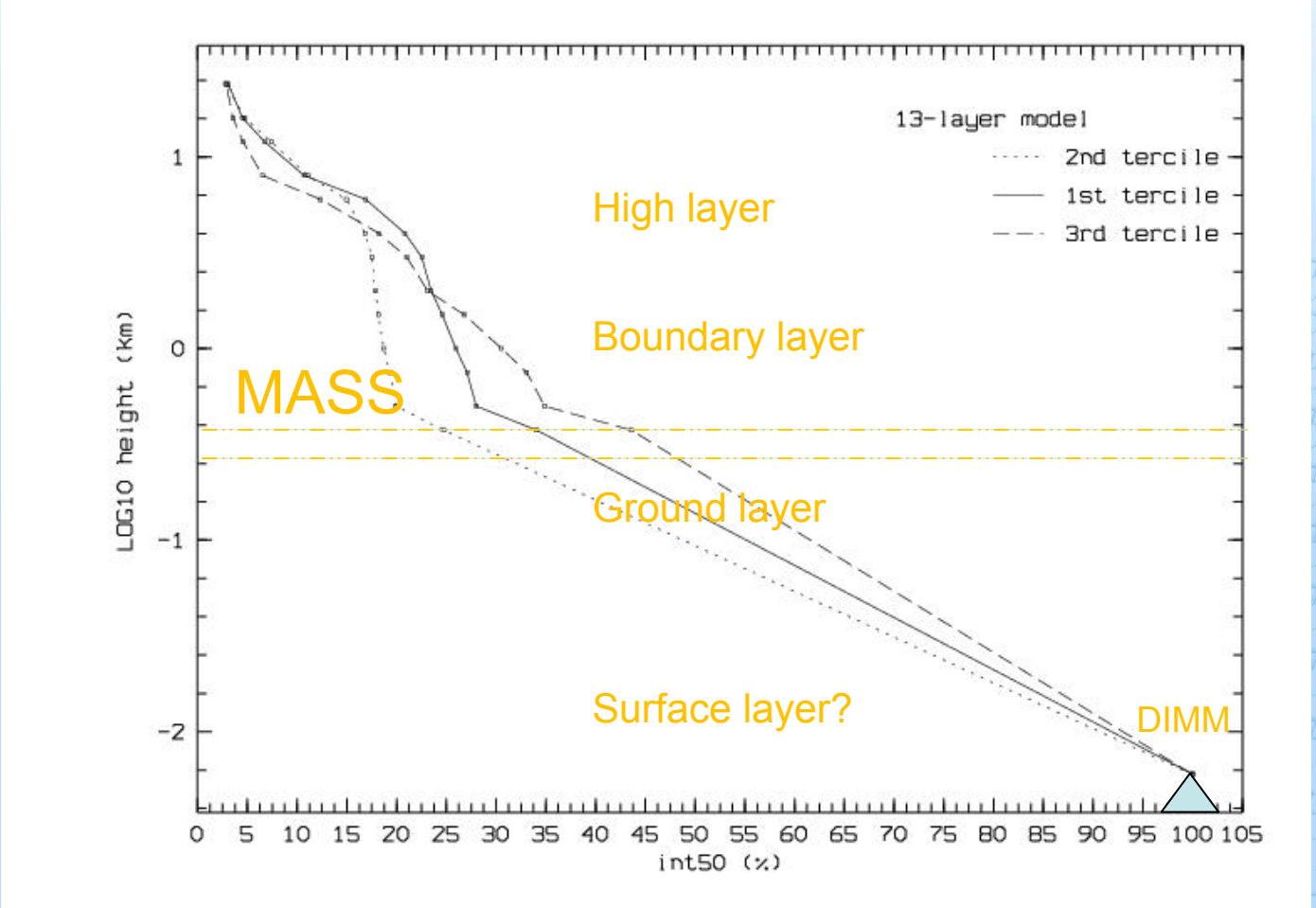
MASS-DIMM fractional Cn2 Profiles

25, 50 and 75 %tile of the relative (to DIMM) strength of each MASS layer + lower layer (DIMM minus MASS)



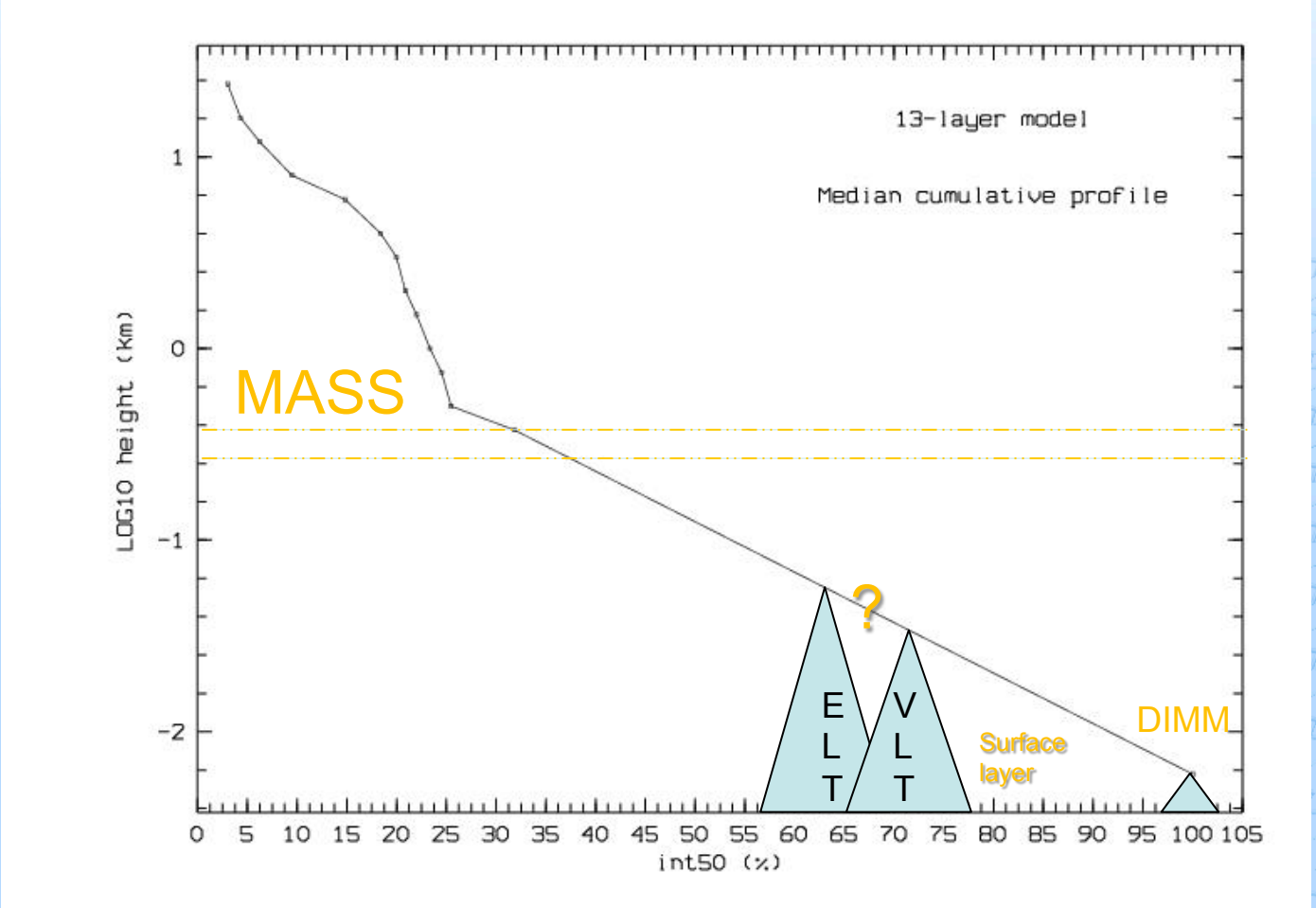
MASS-DIMM cumulative Cn2 Profiles

Relative integrated profiles: MASS layers + lower layer (DIMM minus MASS) for terciles of total MASS seeing



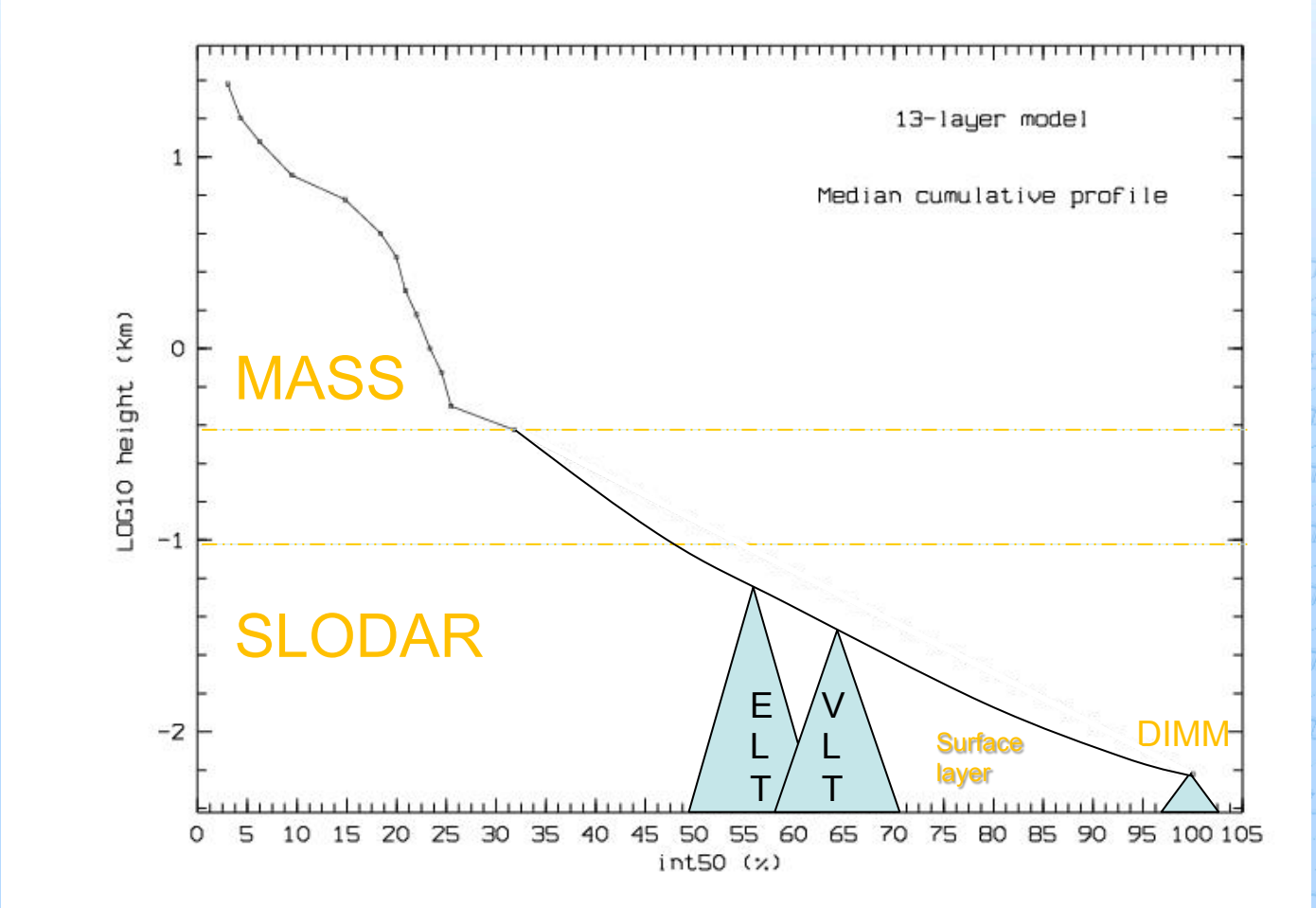
MASS-DIMM cumulative Cn2 Profiles

Median relative integrated profile: MASS layers + lower layer (DIMM minus MASS)



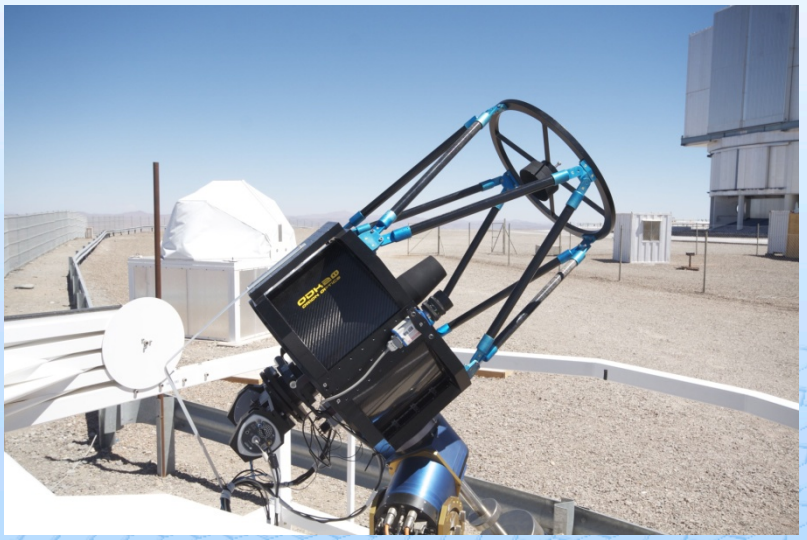
MASS-SLODAR cumulative Cn2 Profiles

Median relative integrated profile: MASS layers + lower layer (SLODAR, simulation)

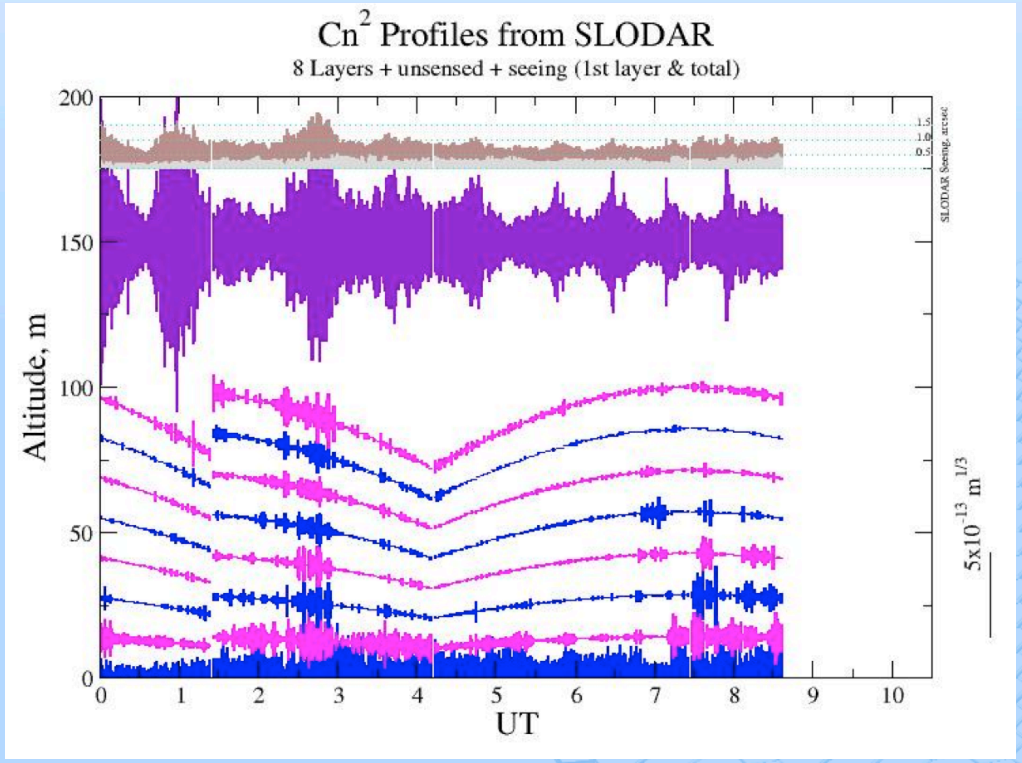


Surface-Layer SLODAR

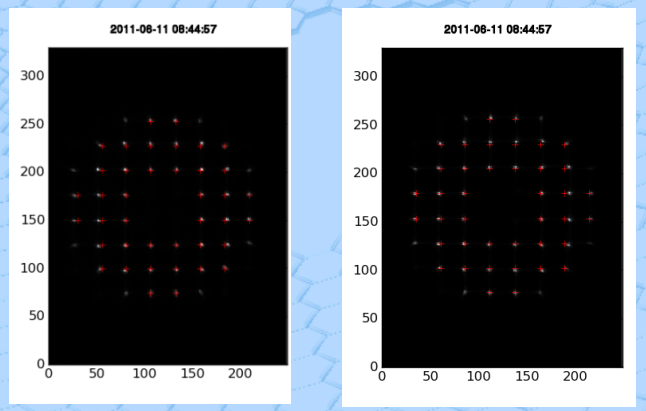
- Durham CfAI / ESO development (since 2004)
- Dual-Beam SH-WFS, 50cm telescope (2011)
- Optical turbulence profile in first 100m
- Altitude resolution ~ 12m
- + total turbulence strength



Automated Surface-Layer SLODAR Instrument at Paranal



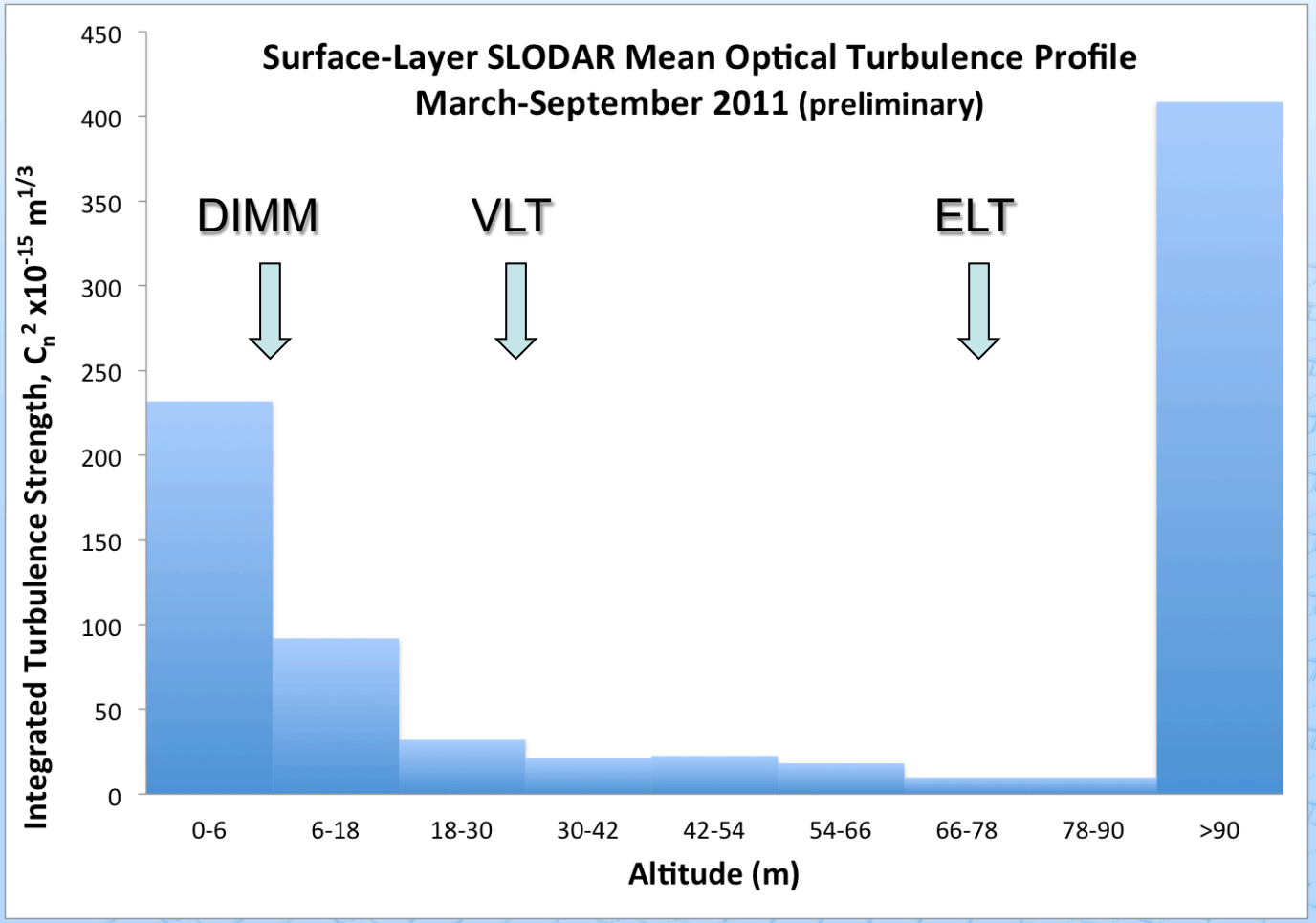
Example Surface Layer Profile Sequence (09/04/2011)



WFS on binaries,12 to 16 arcmin separation
Same principle as used by MOAO with asterisms

SL-SLODAR Cn2 Profiles

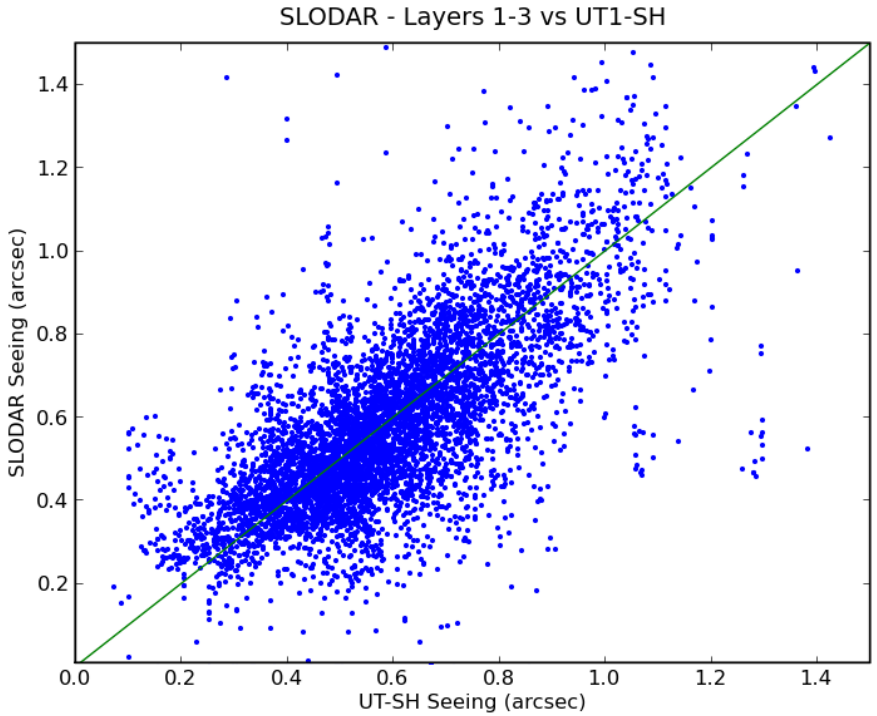
The SL-SLODAR using wide binaries delivers 8 bins of 12m in the first 100m

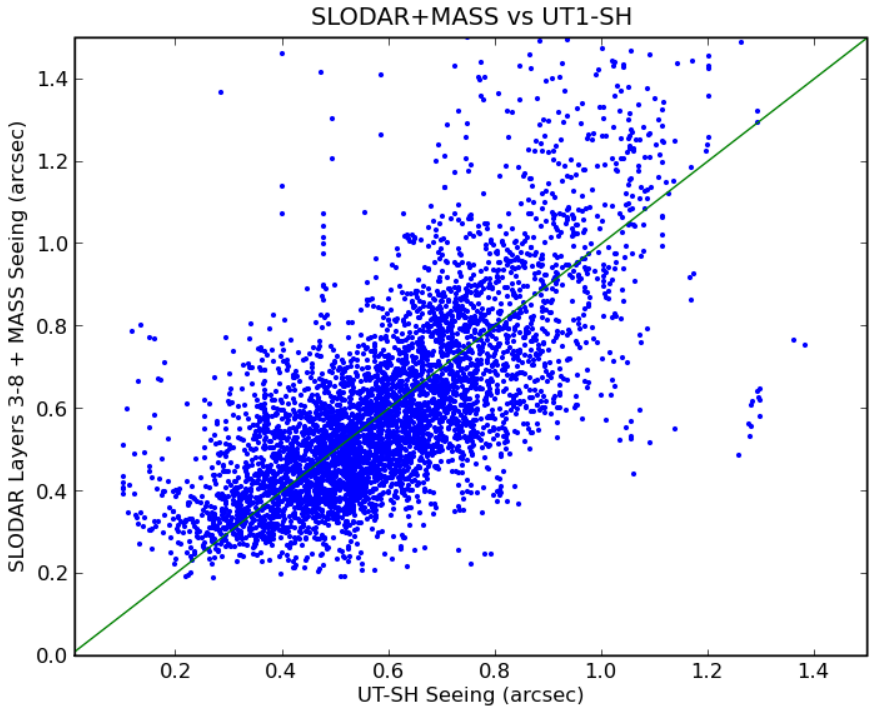


Comparison of SLODAR estimates with UT Seeing

Preliminary results, March-May 2011

UT seeing is measured on active optics S-H spots (Martinez et al, A&A 516, 2010)





SLODAR total seeing minus first 3 layers (first 30m approx)

MASS total seeing plus SLODAR last 6 layers

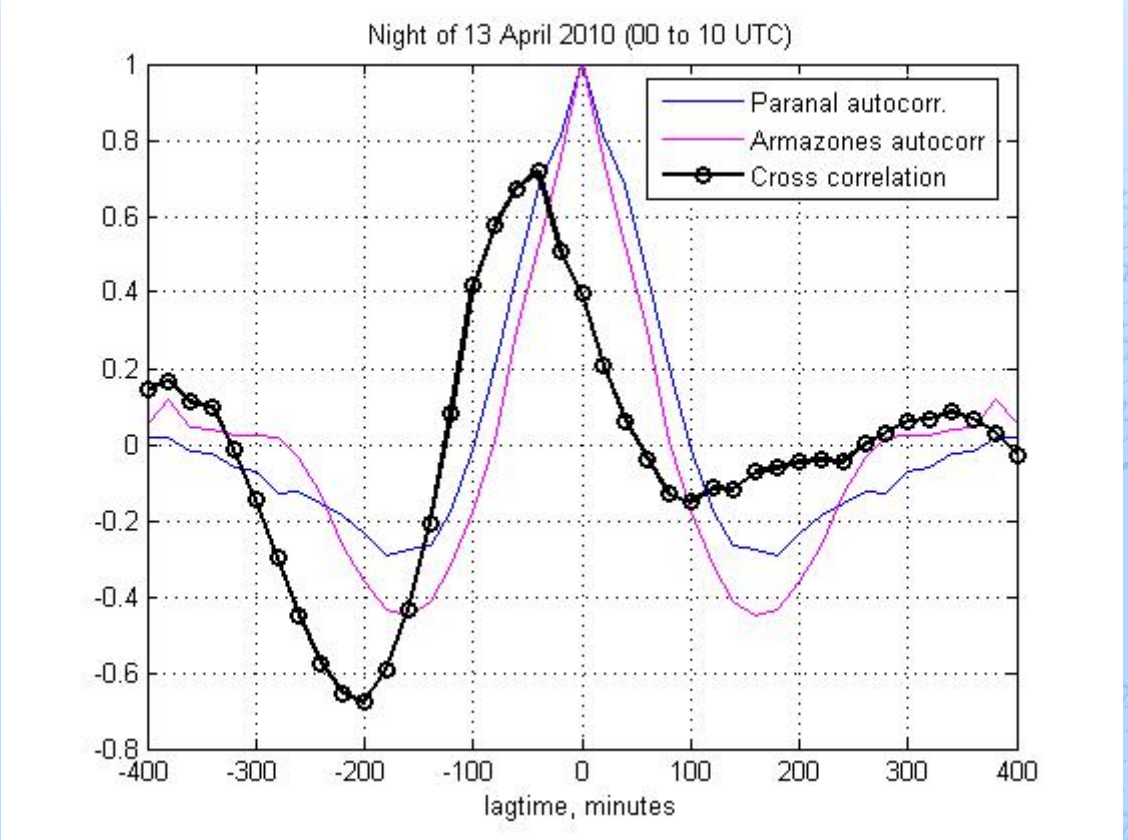
Intermezzo: Taylor or not Taylor?

Is it feasible to predict the turbulence profile from stations a few km upwind?

Taylor or not Taylor?

Temporal correlation of one night of simultaneous total MASS seeing records from Paranal and Armazones (20 km distance, same target)

Should work even better on individual MASS layers



Monitoring Site Parameters for AO: the requirements

LIST OF SURVEYABLE E-ELT SITE PARAMETERS RELEVANT FOR ADAPTIVE OPTICS BASED INSTRUMENTS AND POST-FOCAL MODULES)
Doc. E-TRE-ESO-528-0795

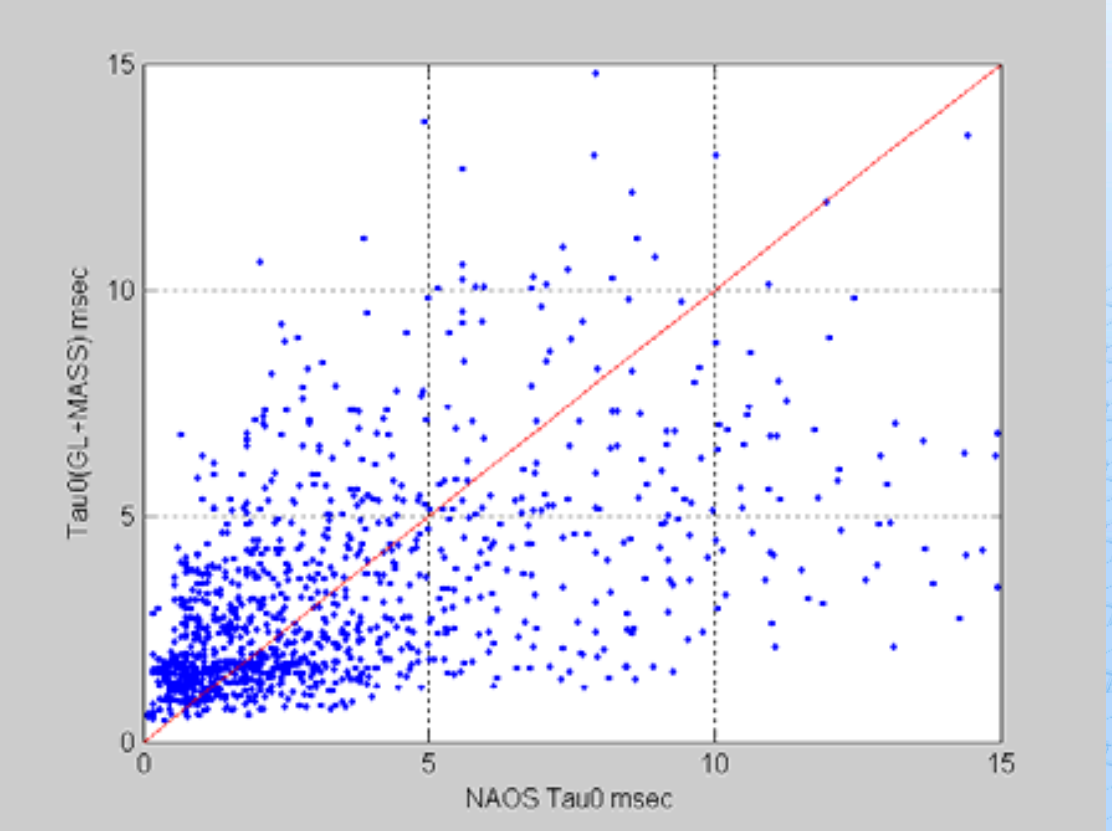
The atmospheric coherence time τ0, and the wind speed vertical profile should be available every minute.

Whenever possible, the direction along which τ0 is measured should be within 15 degrees (TBC) with respect to the one of telescope's observation at the same moment.

How to estimate Tau0 from an AO Instrument?

Comparison of DIMM & MASS tau0 with NACO tau0
J. Navarrete & M. Sarazin, ESO Internal Report 11 July 2008 –update 07 July 2009

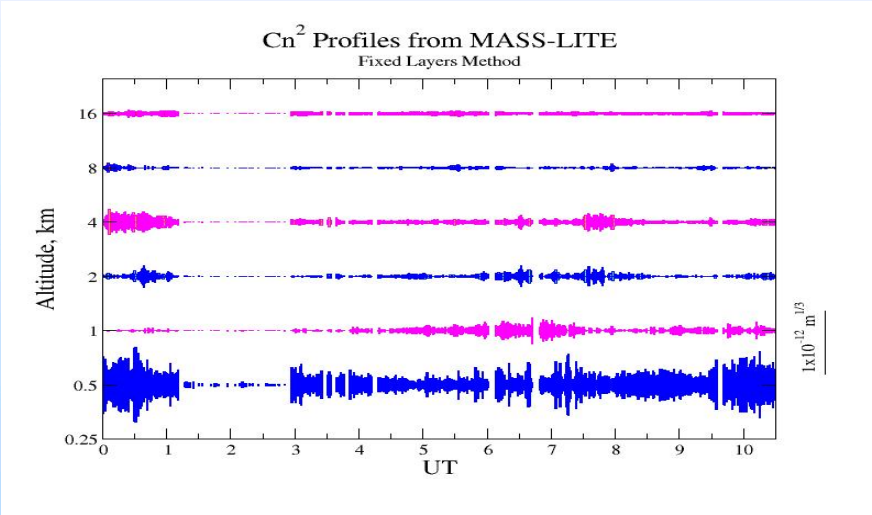
NAOS (Shack-Hartman adaptive optics system at UT4 - ESO Paranal) delivers tau0 in closed loop during measurements on photometric standard stars following Fusco et al., 2004, J. Opt. A 6, 585-596. Instrumental conditions can however strongly influence the measurements. NAOS database (Sep 2004 – June 2008) was filtered along the study conducted by Ageorges et al, 2007 (Modes: 1-1 to 1-9 (except 1-7) & 2-1 to 2-3, DIT*NDIT>12s).



Comparison of Tau0 from MASS (C=1.27) & DIMM to NAOS

$\tau 0_{MASS+GL}\text{^-5/3} = (1.27\tau 0_{MASS})\text{^-5/3} + (0.057)\text{^-5/3}\ (\lambda_0)\text{^-2}\ (V_{GL})\text{^5/3}\ (Cn2dh)_{GL}$

How to estimate Tau0 from Cn2 profiles?



But V(h) is not (yet[1]) available in real time and with the required temporal resolution

$$\tau_0 = 1.5654 \times 10^{-6} \left(\int C_n^2(h) V(h)^{5/3} dh \right)^{-3/5}$$

(1): See talk by E. Masciadri in this session

How to estimate Tau0 from MASS?

Direct estimate from MASS photometry:

- DESI, differential scintillation index is the variance of the logarithm of intensity ratio for different exposure times (1 & 3 ms)

Tau0MASS = 0.175 (σ2 DESI)^−0.6 (ms) - Tokovinin 2002

Tau0 = C . Tau0MASS, C=1.27, valid for tau0<5ms http://www.ctio.noao.edu/~atokovin/profiler/timeconst.pdf

-TMT conducted independent re-analysis 2008: C=1.73

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, 121:787–796, 2009 July© 2009

-MASS developer delivers new processing code 2011: no fudge factor and agreement with TMT

Kornilov, V. 2011, Astron. & Astroph. 530, A56

How to estimate Tau0 from MASS?
'Old' processing software

A comparison of the MASS coherence time with radiosonde profiles and NCEP reanalysis

Travouillon T., 2008, TMT report

Note:
The NCEP/NCAR reanalysis data set consists of a 2:5 deg×2:5 deg global grid of weather parameters covering 17 pressure levels logarithmically spaced from 1000 to 10 mB available 4 times per day

Radiosonde: in the case of the Chilean sites, MASS profiles are compared to the nearest balloon data (3 to 4 hr different, depending on the season)

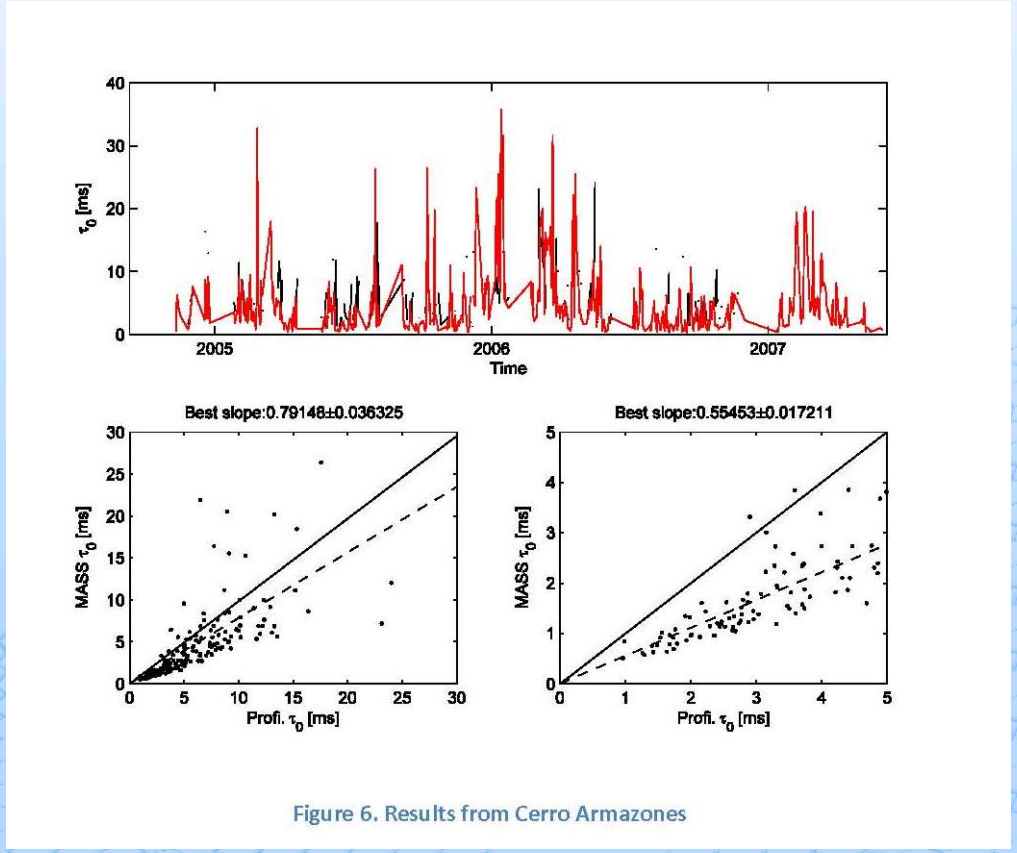


Figure 6. Results from Cerro Armazones

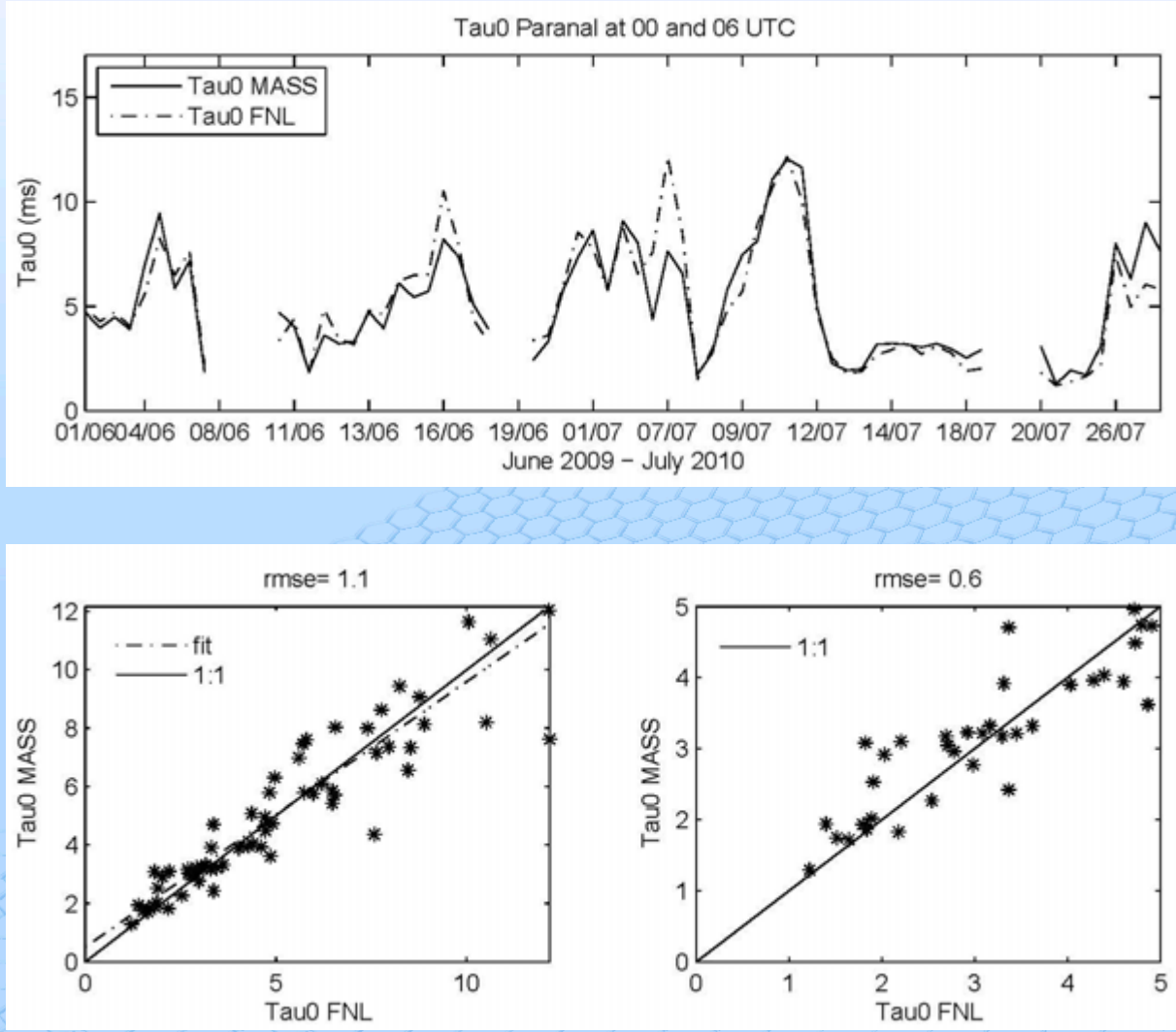
PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, 121:787–796, 2009 July© 2009

How to estimate Tau0 from MASS?

‘New’ processing software

Verification of the reprocessed (V-2.97.3) MASS coherence time

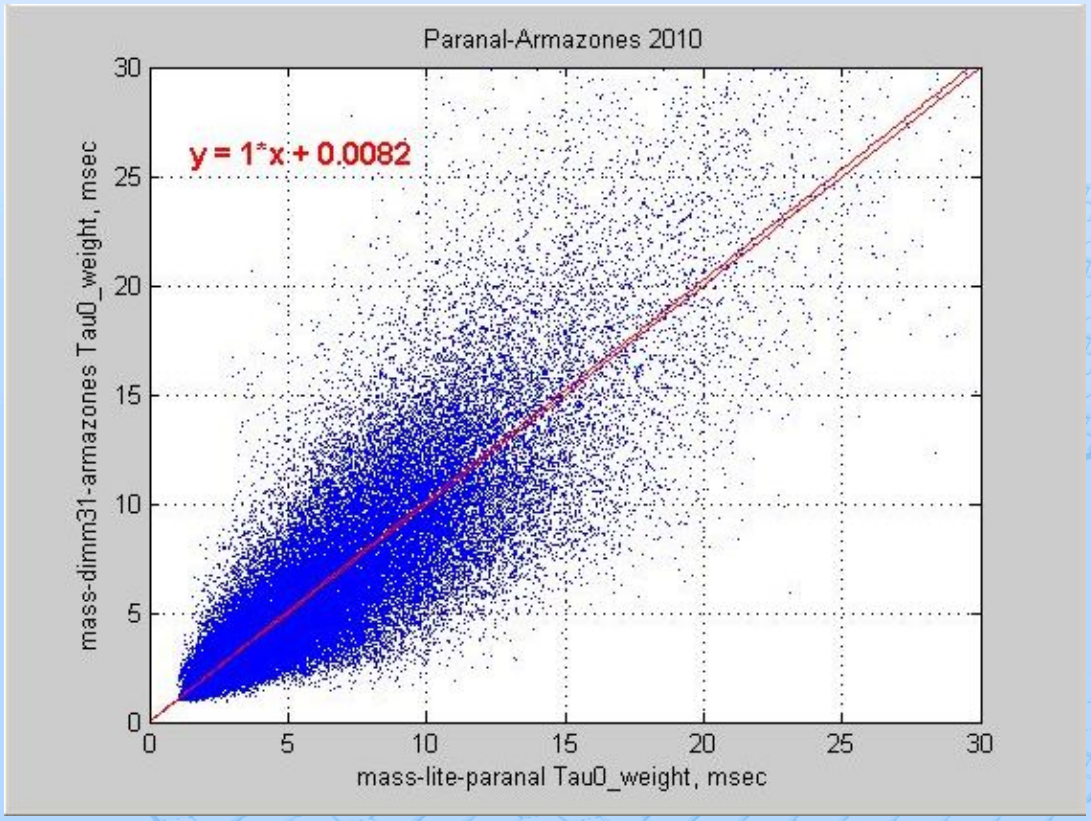
Comparison of the coherence time computed from MASS Cn2 and wind velocity profiles with MASS-DIMM output at Paranal in June 2009 and July 2010, 13-layer model: time series (top), regression for all data (bottom left) and for tau0 <5ms (bottom right).



Sarazin, M., Cuevas, O., Navarrete, J. 2011, RMAA, submitted

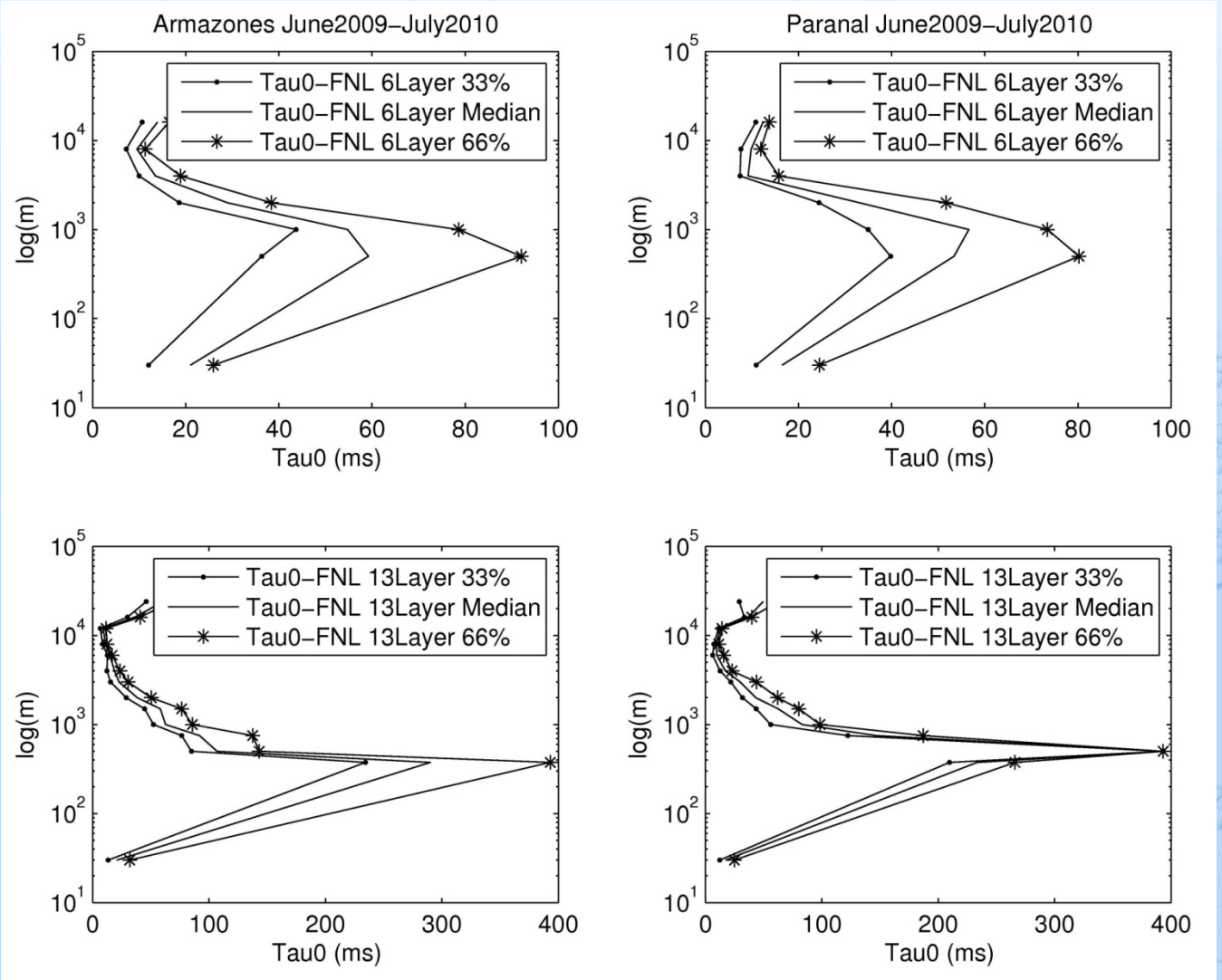
Tau0 spatial scales

simultaneous MASS tau0 records from Paranal and Armazones
(20 km distance, same target)



Tau0 Vertical Profiles

from Model wind and MASS Cn2 profiles in HD mode



Each “independent” MASS layer, supposed to move at speed V (Taylor), has its own Tau0:

$$\tau = 0.31 \frac{r0_{\mathrm{ind}}}{V}$$

See talk by E. Masciadri in this session

How to estimate Tau0 from MASS?

Problem!

The ‘New’ MASS processing software does not consider the $5/3^{rd}$ moment of the velocity but the 2^{nd}

Definitions of τ_0 and θ_0

- D. Fried used 5/3 moments of wind speed and altitude to define τ_0 and θ_0 :

$$\tau_0 = 0.314\, r_0/V_{5/3}$$

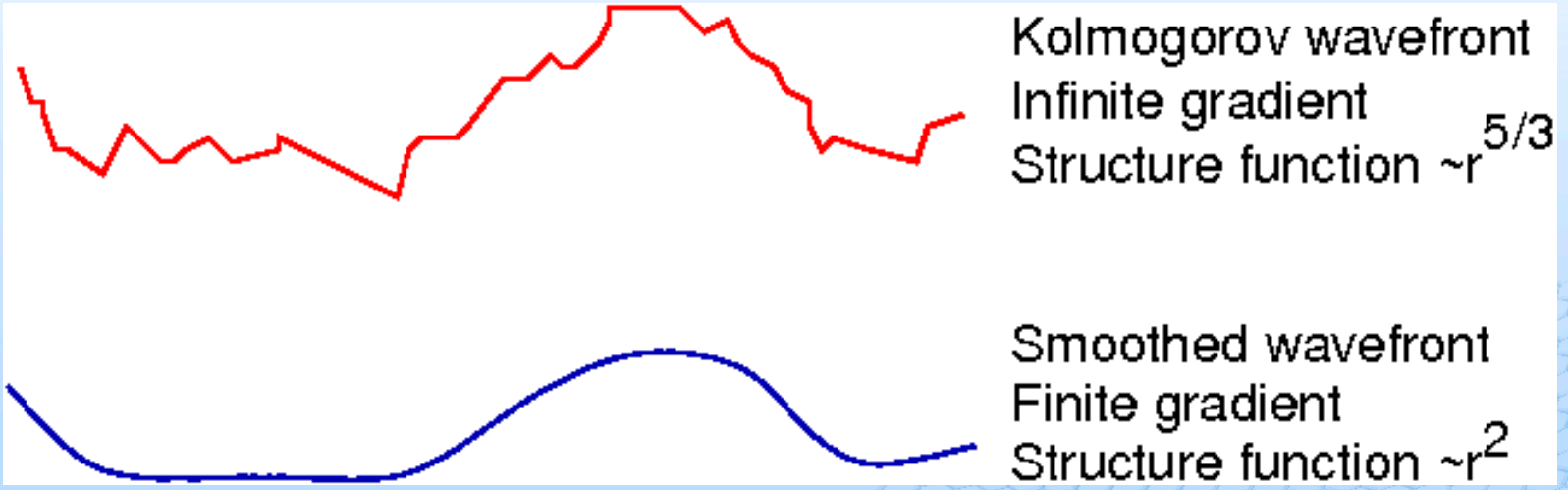
- AO error formula: $\sigma^2_{time} = (t/\tau_0)^{5/3}\ rad^2$,

$$\sigma^2_{AO} = \sigma^2_{noise} + \sigma^2_{fit} + \sigma^2_{time} + \sigma^2_{isoplanatism}$$

Problems:

- Small perturbations are counted 3 times
- Includes piston, $\rightarrow\infty$ as $t\rightarrow\infty$
- Wavelength-dependent

Which moment to use, 5/3 or 2 ?



All atmospheric-related quantities (piston, tilt, Zernikes etc.) are smoothed, have finite gradient and **quadratic** structure functions (difference proportional to argument).

$$\sigma^2_{time} = (t/\tau_0)^2 \text{ !}$$

Use and measure 2nd moments!

Use

- Tilts: Tyler 1994
- Zernikes: Roddier et al. 1993
- Piston: Kellerer & Tokovinin 2007

Measure Tau0

- Fast Defocus (FADE)
- MASS (Kornilov 2010)
- SLODAR* or any AO system!
- DIMM, if fast enough (~1ms)

New definitions
for performance characterization

- τ_0 [ms] → V_2 [m/s]
- θ_0 [rad] → H_2 [m]

- System-independent
- Do not depend on λ
- Modify the formulae slightly (e.g. $D^{1/3}$ enters)

This is evolution, not revolution
Changes are small

Conclusions

- The existing site monitoring instrument suite fulfills most current AO requirements. Non-common line of sight errors must be quantified.
- The vertical profile of the wind speed should be made available
- The seeing at the telescope should be measured more accurately.
- The AO instruments should produce reliable estimates of atmospheric constants during operation.