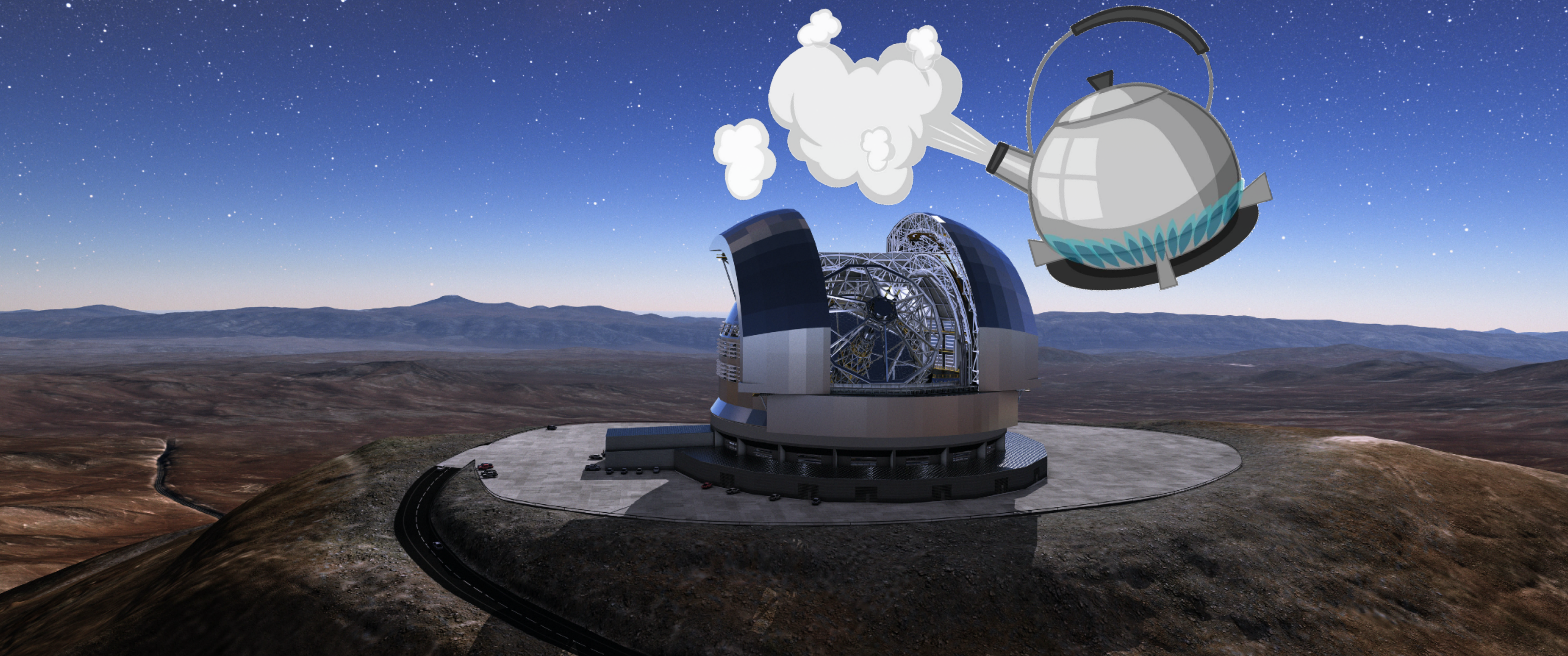
Influence of water vapor on ELT/METIS high contrast imaging performance



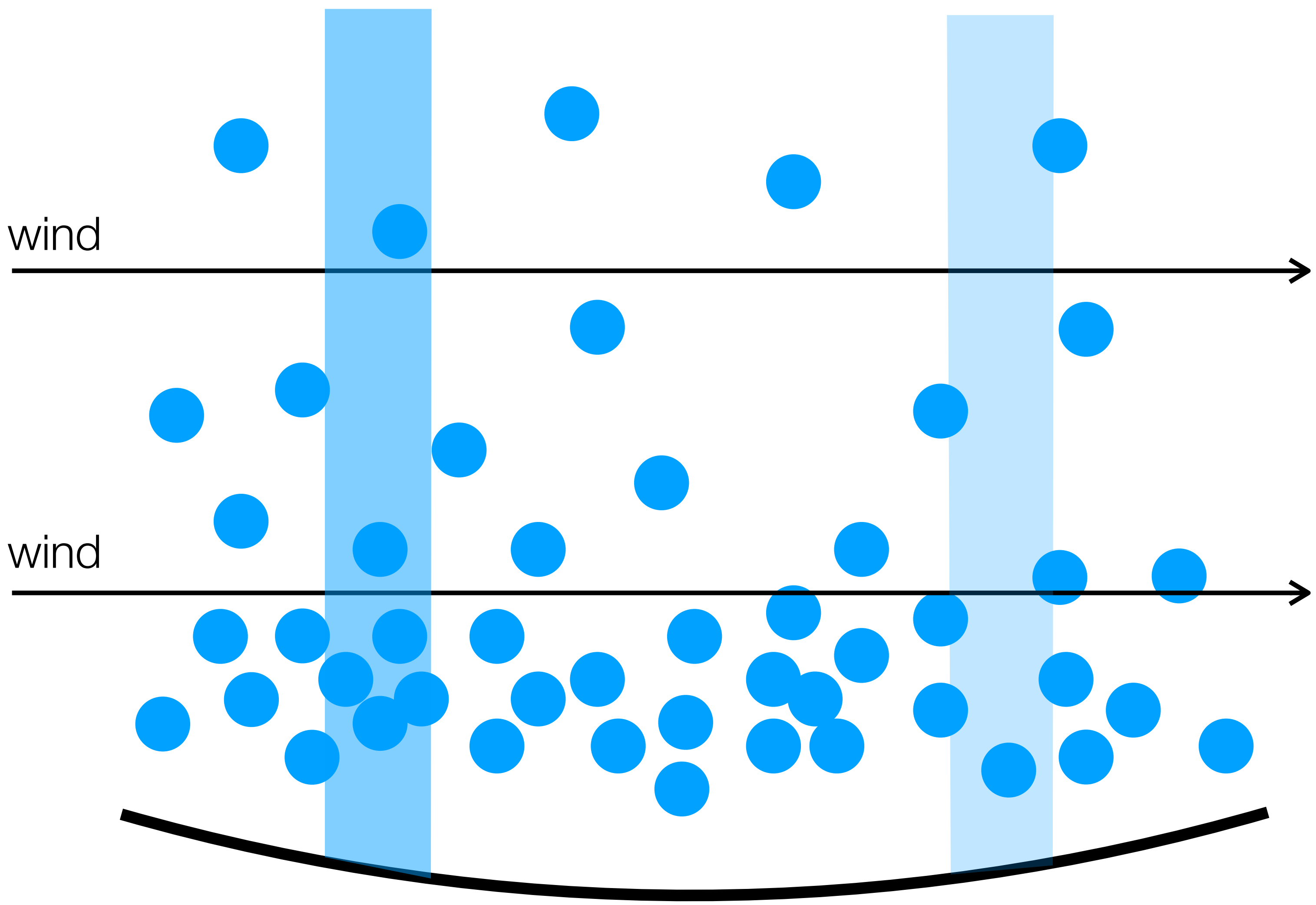
Olivier Absil — University of Liège

with strong contributions of C. Delacroix, G. Orban de Xivry, M. Willson†, P. Berio

IR2022 workshop

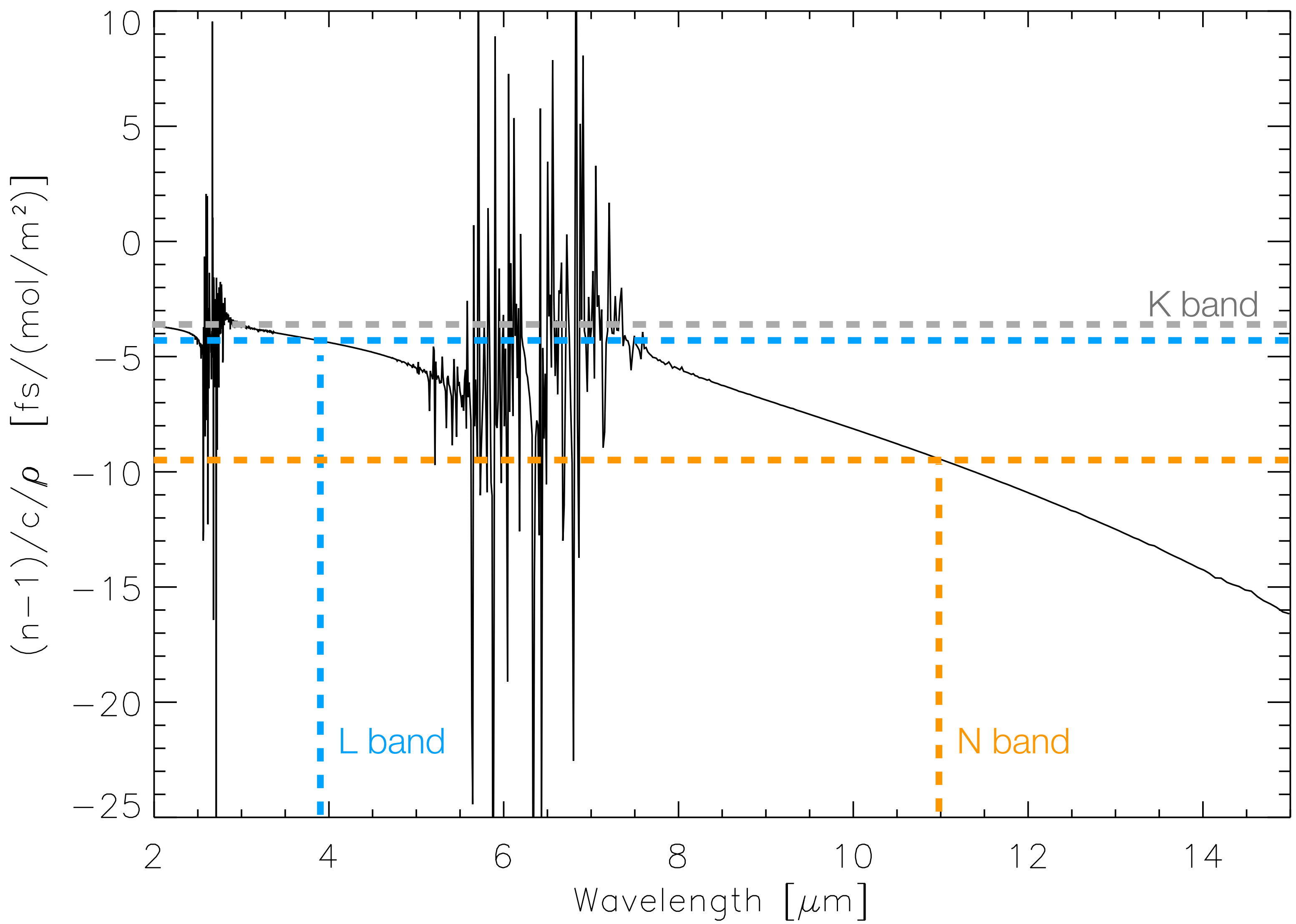
Water vapor seeing

- WV column density is variable
- Expected to follow Kolmogorov - von Karman spectrum
- Highly chromatic, especially in mid-IR
  - AO correction at K band not valid at L/N bands



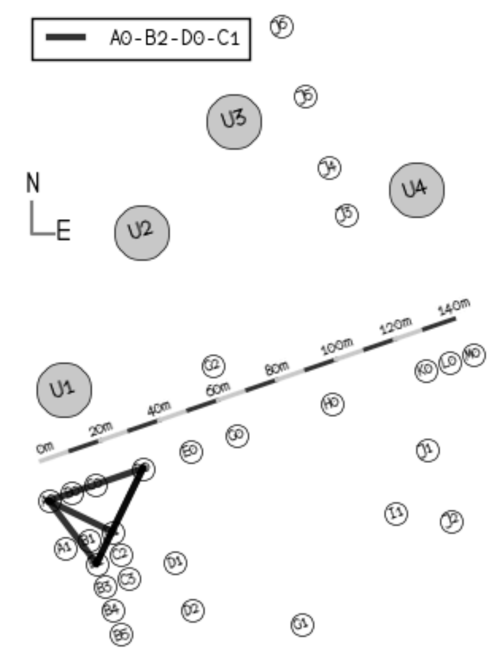
Additional path length: ‘water displacing air’

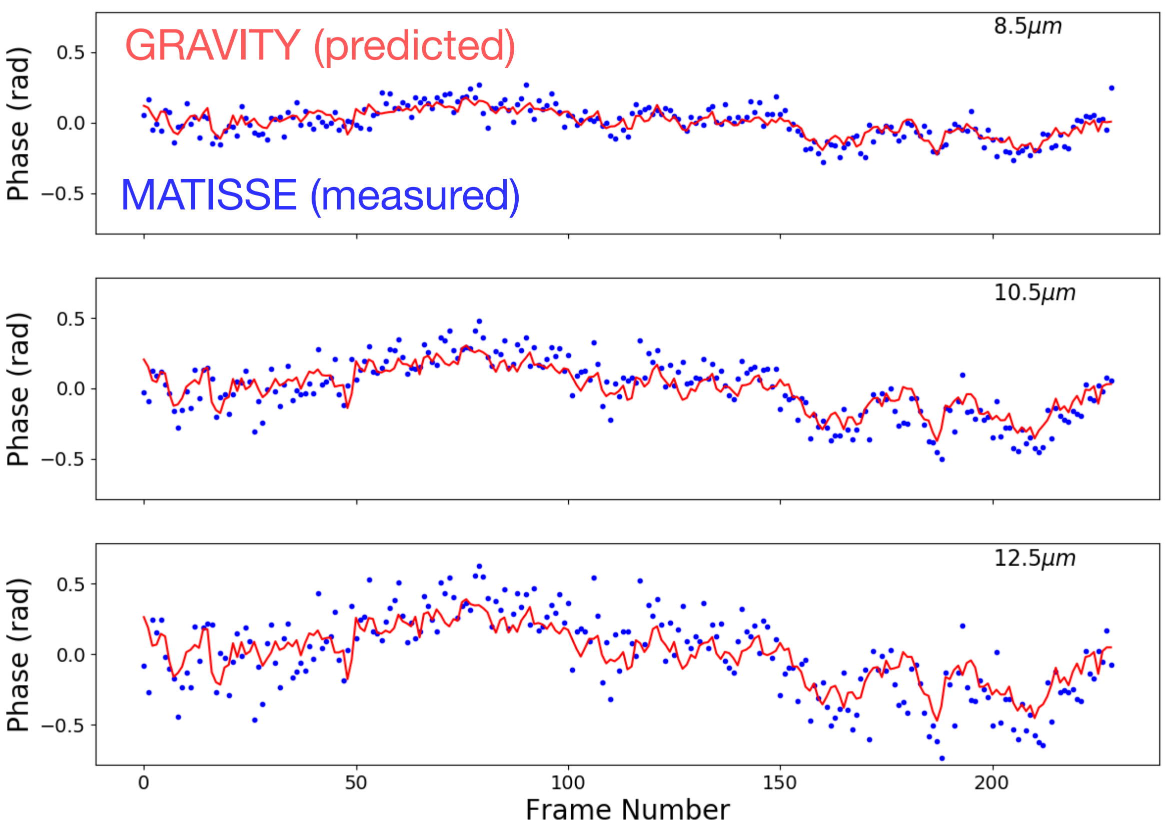
- Holding P (and T) constant, added humidity reduces dry air
- $\hat{n}_{WDA} = \hat{n}_{WV} - \hat{n}_{air}$
  - $\hat{n}_{WDA}(L - K)$ = 0.5 fs / (mol/m^2)
  - $\hat{n}_{WDA}(N - K)$ = 6 fs / (mol/m^2)

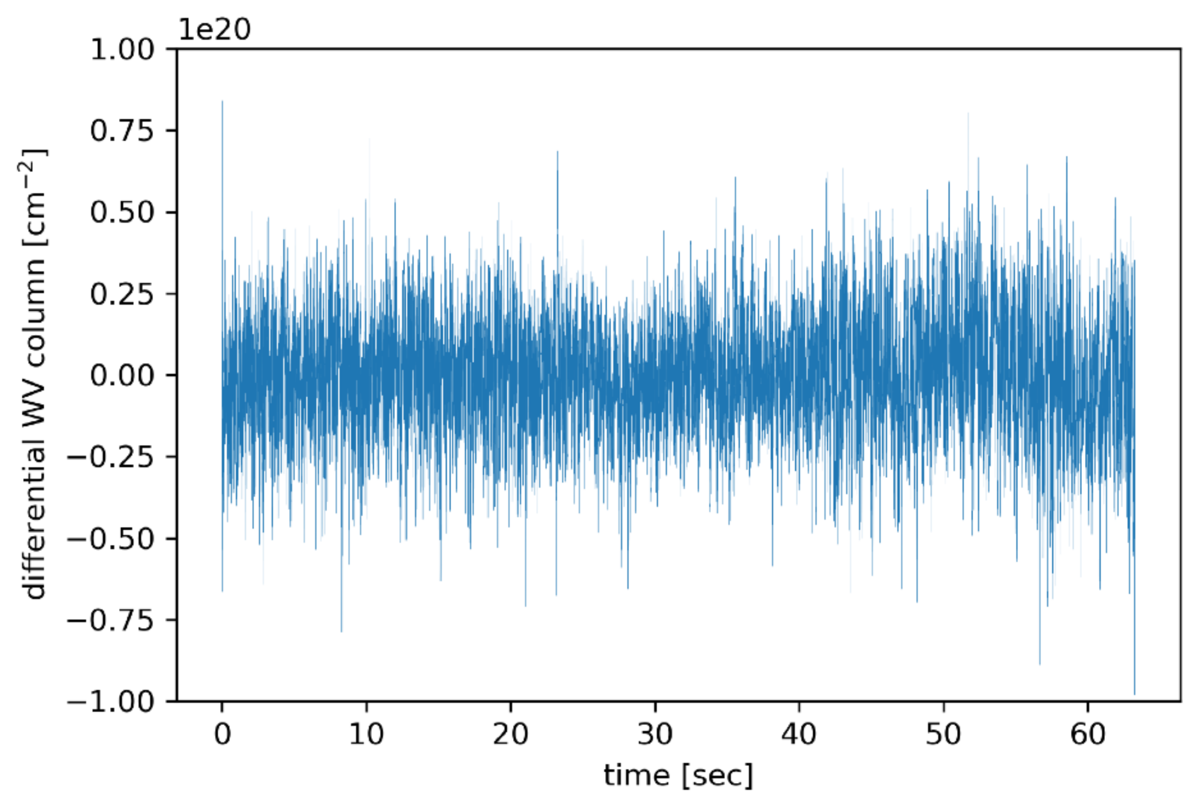


Measuring path length variability @ Paranal

- Use GRAVITY K-band fringe tracker to predict WV contribution
  - relies on chromaticity phase across a few spectral channels in K band
- Use MATISSE to check prediction @ L & N bands
  - assumes that differential phase is fully explained by WV







Berio et al. (in prep)

First results from GRAVITY/MATISSE

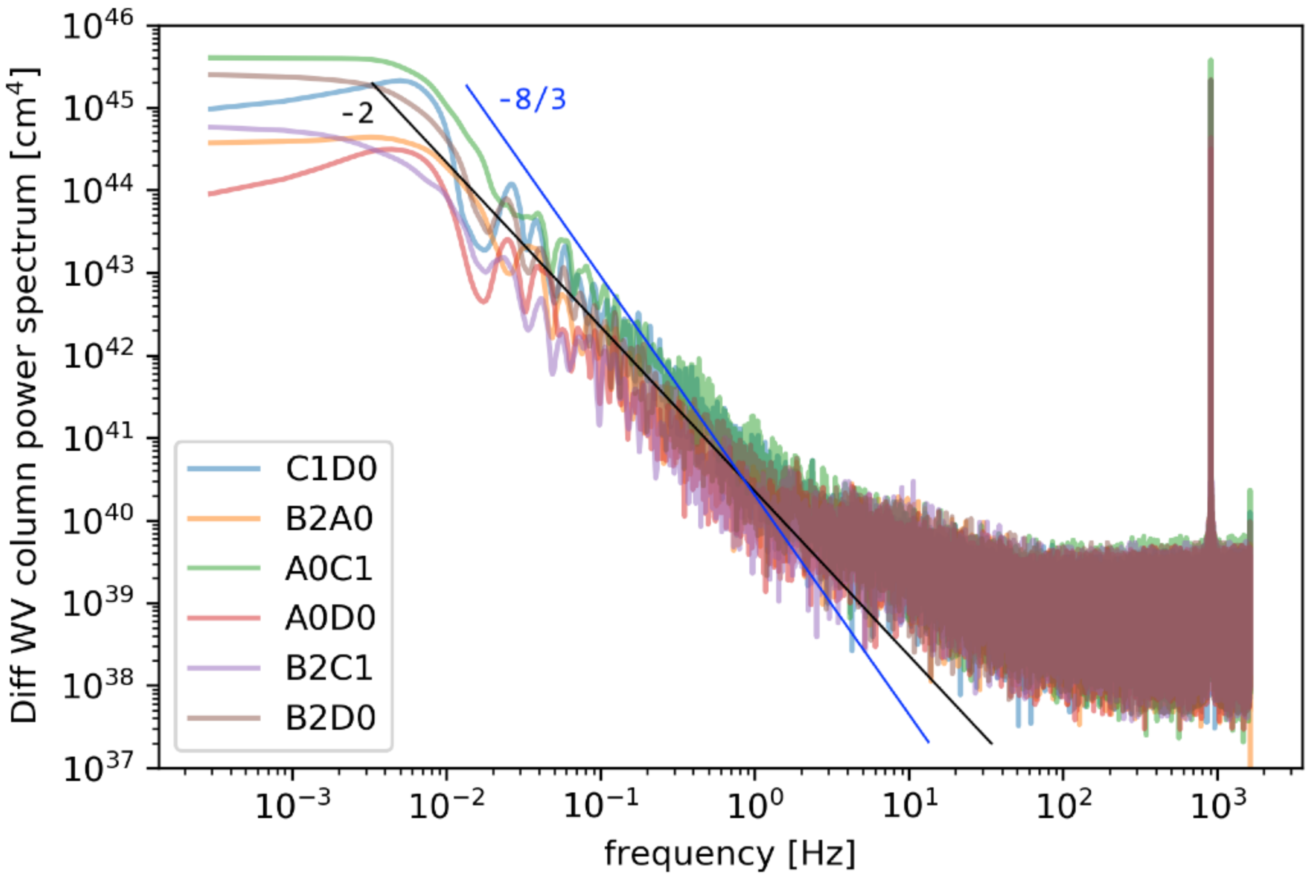
PWV (mm)	1.4 mm	2.0 mm	6.6 mm	7.0 mm
1-min rms WV column density (cm^{-2})	1.3×10^{19}	1.8×10^{19}	2.2×10^{19}	2.4×10^{19}

… compared to literature measurements

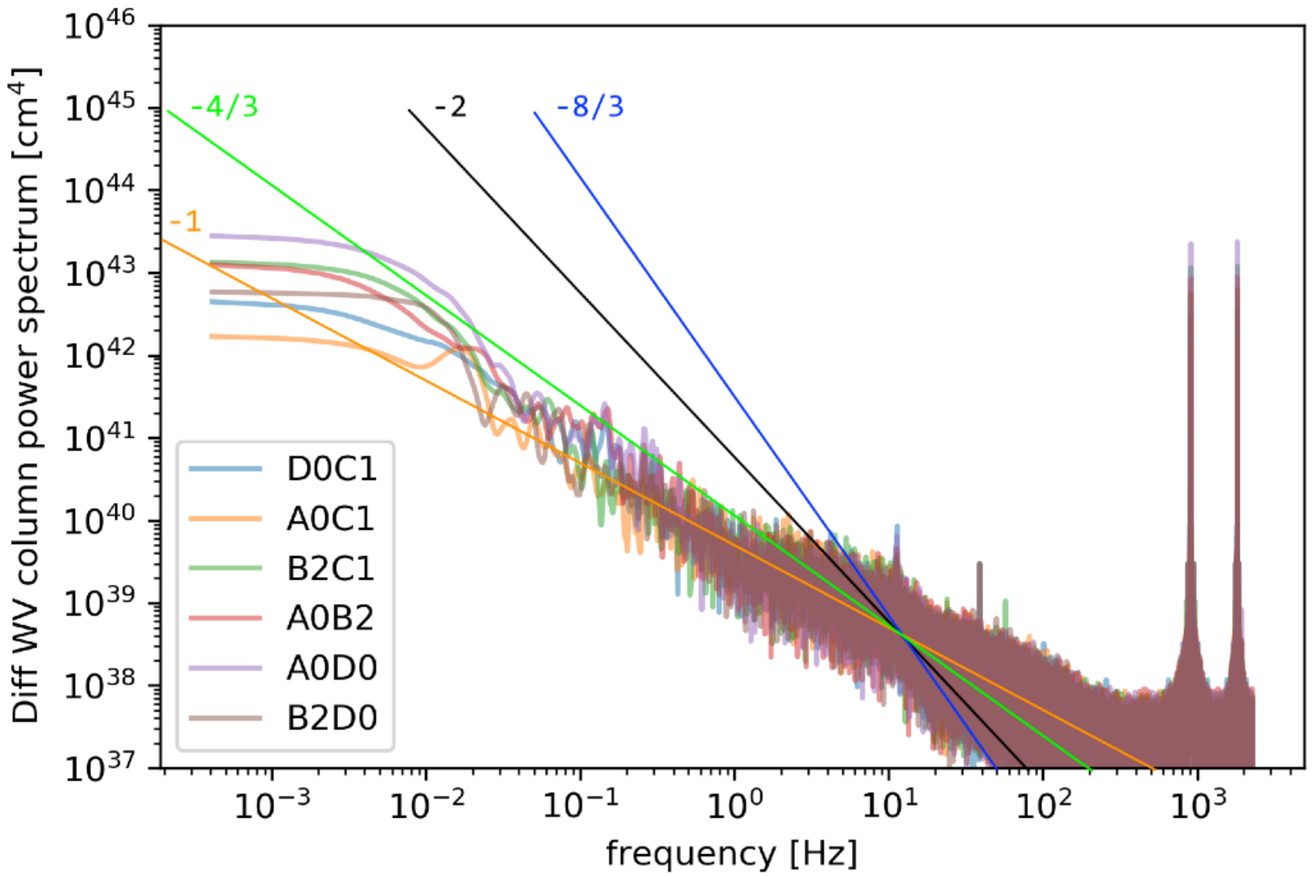
	Masson1994 (Mauna Kea)	Lay1997 (OVRO)	Meisner+2002 (Paranal)
Wavelength	sub-mm	sub-mm	near-IR
Baseline	100 m	100 m	**16 m** / 66 m
Timescale	15 min	1 h	100 sec
rms WV column density	4×10^{19} cm^{-2}	10^{20} cm^{-2}	**~3×10^{19}** / 10^{20} cm^{-2}

Does it really follow Kolmogorov?

worst conditions



best conditions



we will assume Kolmogorov - von Karman from now on
(more power at low frequencies)

How much additional nuisance?

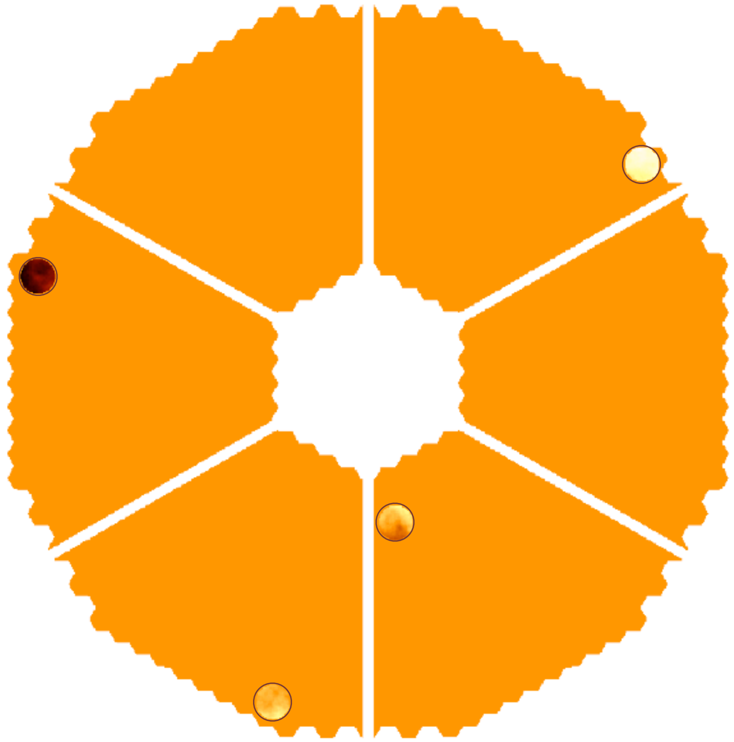
- Convert rms column density in other units

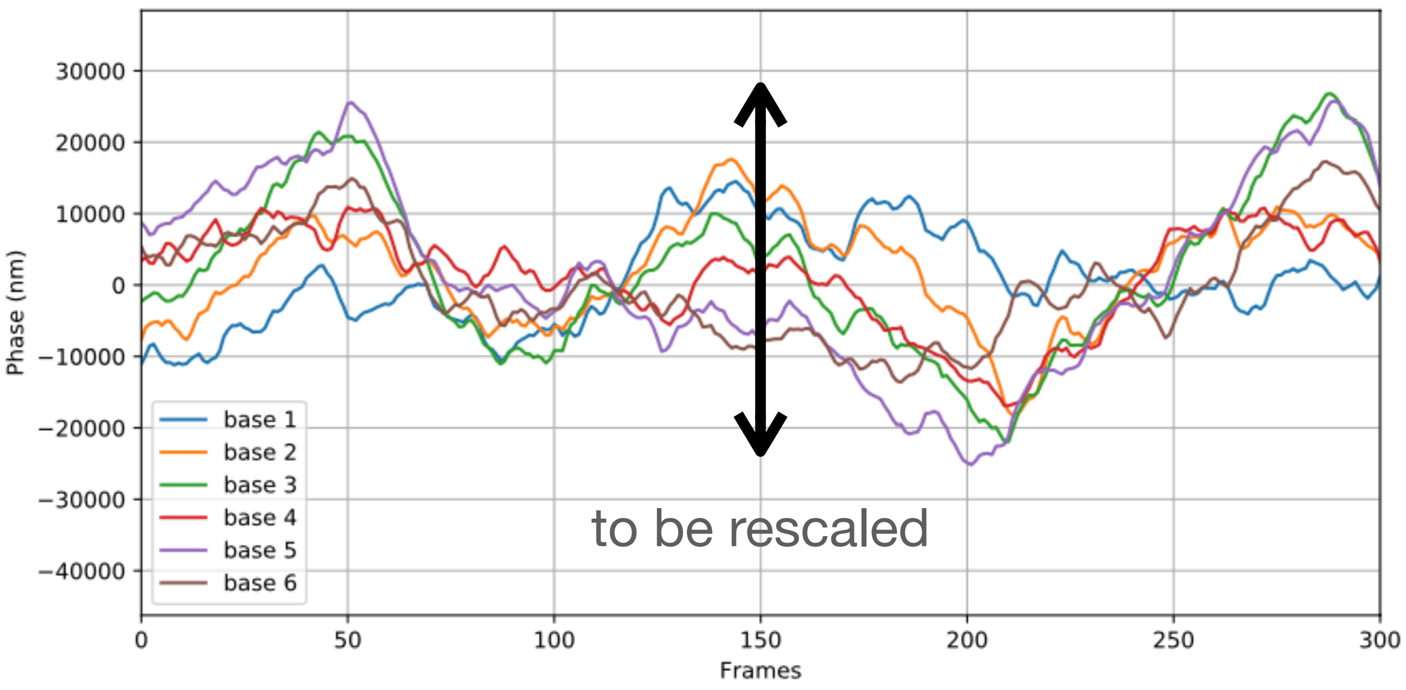
rms column density: 2×10^{19} cm^{-2} → rms column density: 0.33 mol/m^2 → rms PWV: 6 µm

- RMS additional **local** delay (in 1 min)
    - L band: $\hat{n}_{WDA}(L - K)$ = 0.5 fs/(mol/m^2) —> 0.17 fs —> 50 nm
    - N band: $\hat{n}_{WDA}(N - K)$ = 6 fs/(mol/m^2) —> 2 fs —> 600 nm

Translating to ELT wavefront quality

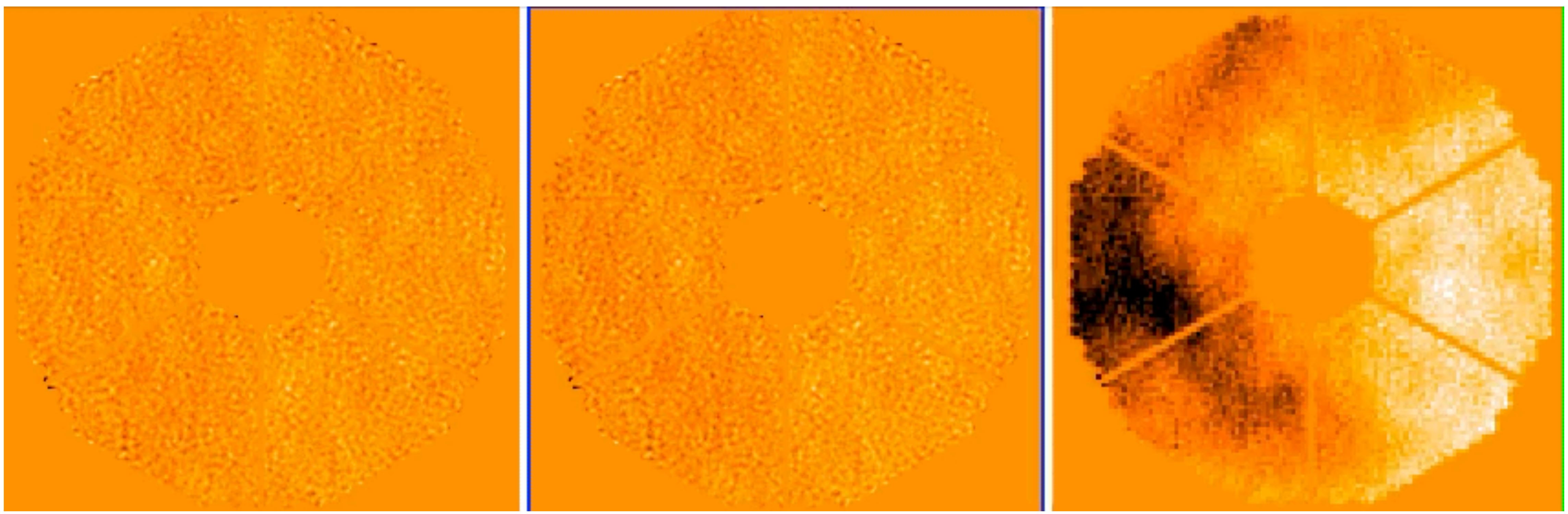
- Generate open-loop sequence of atmospheric turbulence phase screens
- Measure rms piston between VLTI-like sub-apertures
- Scale cube of phase screens to match rms piston measured at VLTI
- Add scaled cube of water vapor turbulence to AO residuals





Adding WV to adaptive optics residuals

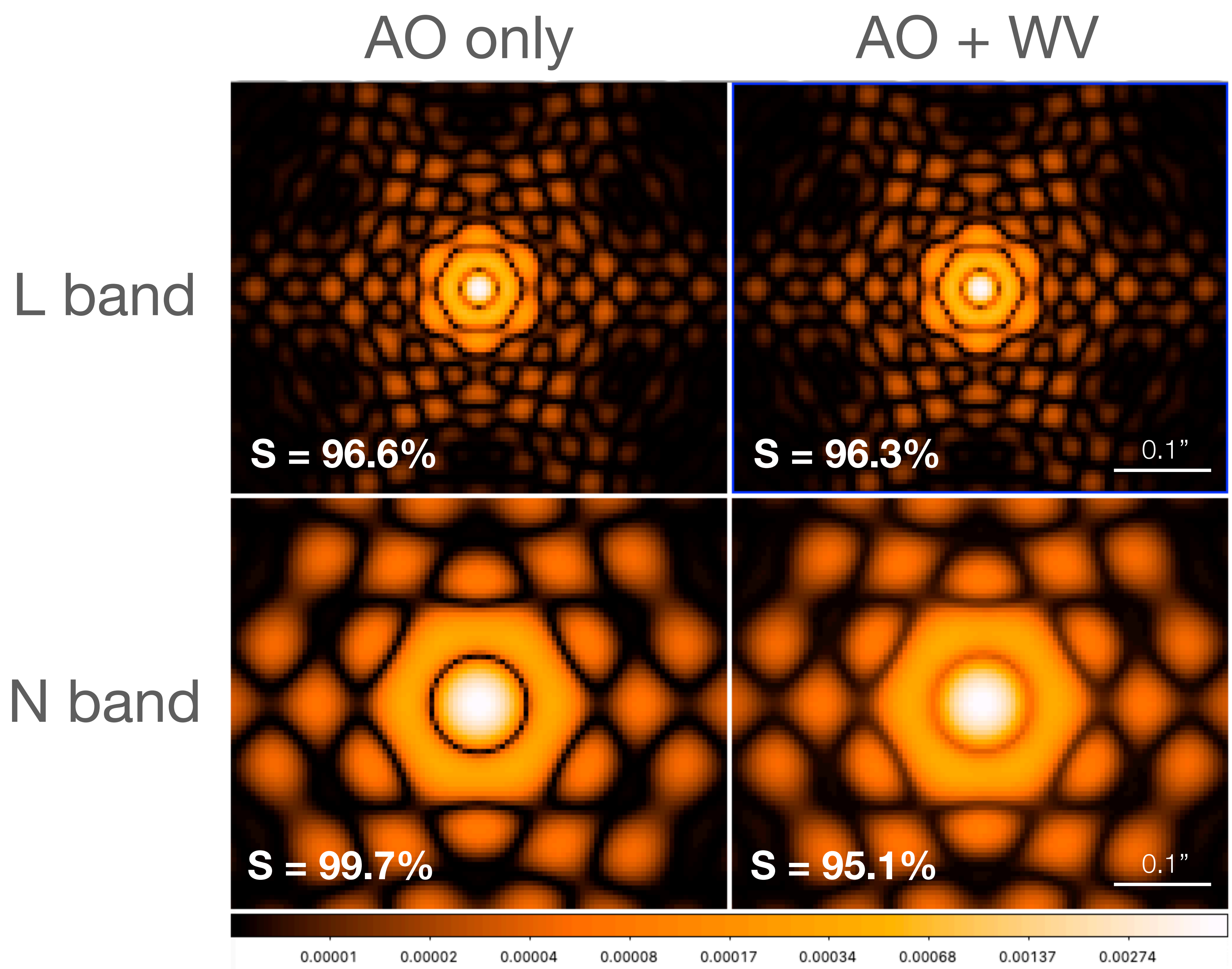
AO only | AO + WV (L band) | AO + WV (N band)



~140 nm RMS WFE | ~25 nm RMS additional WFE | ~300 nm RMS additional WFE

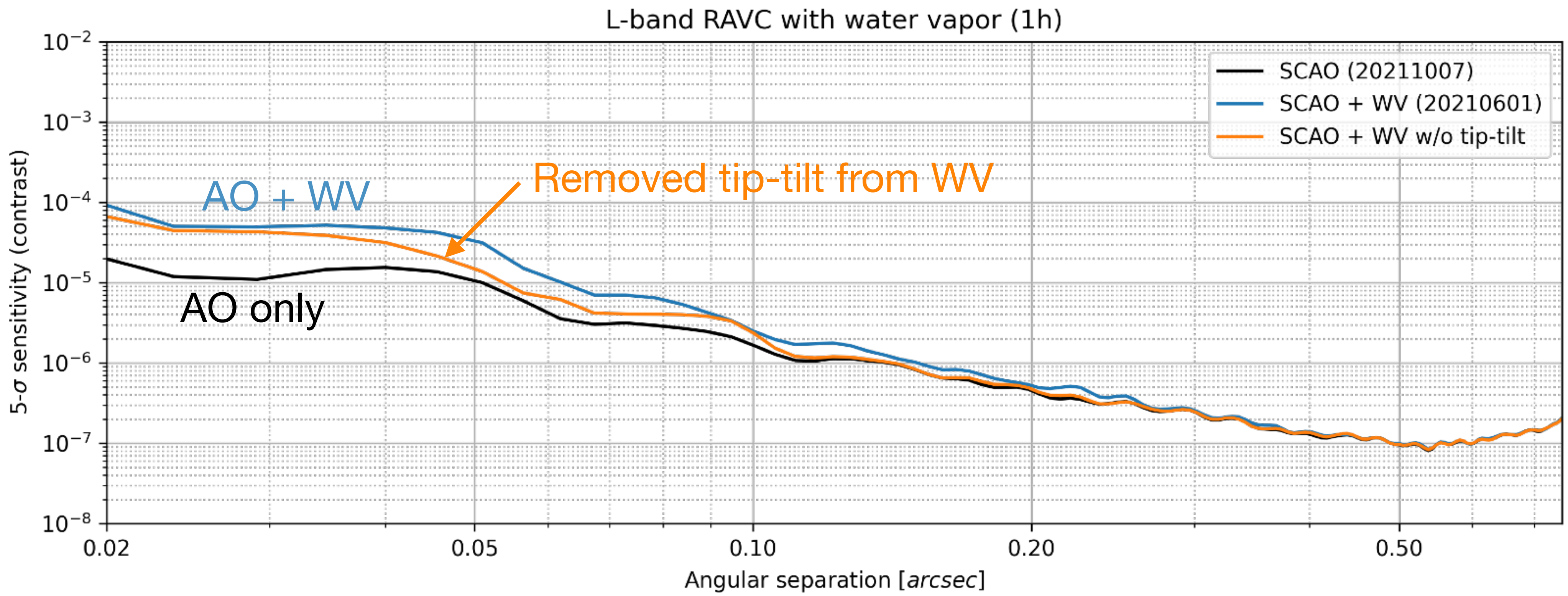
Strongly dominated by low spatial frequencies (Kolmogorov - von Karman)

Effect on Strehl — METIS standard imaging mode

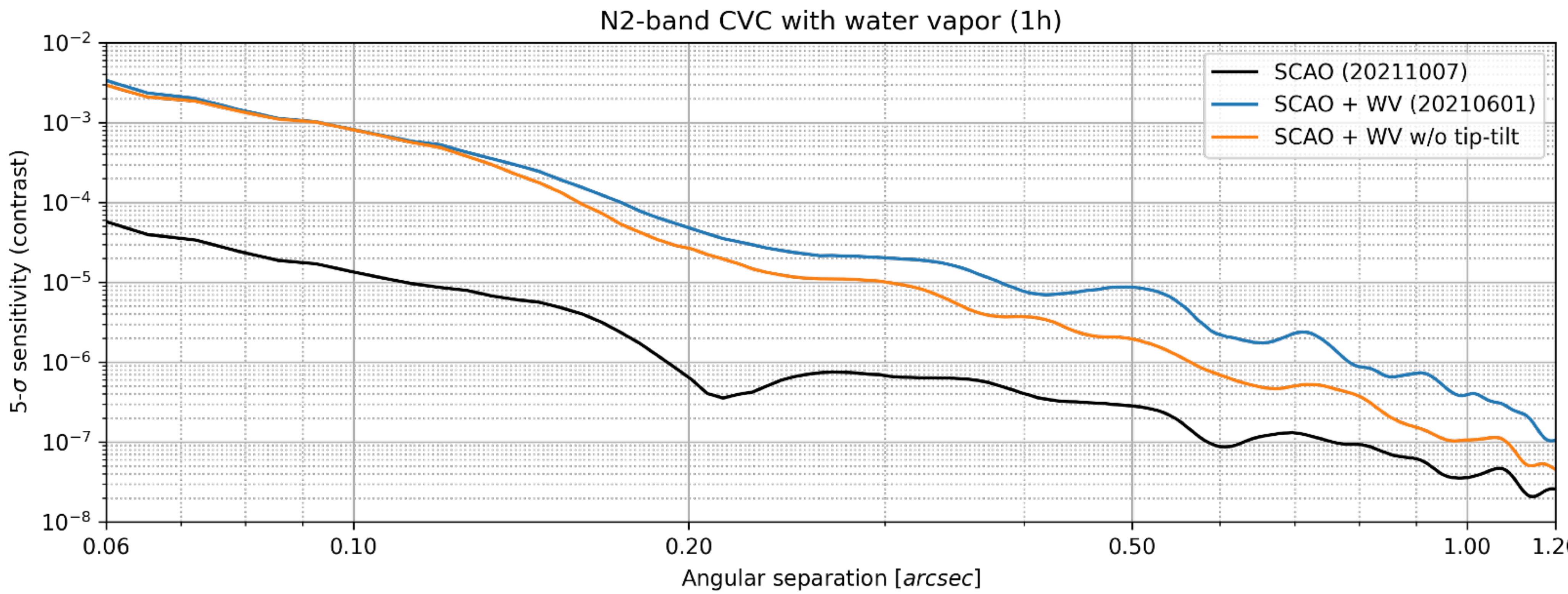


Effect on high-contrast imaging performance

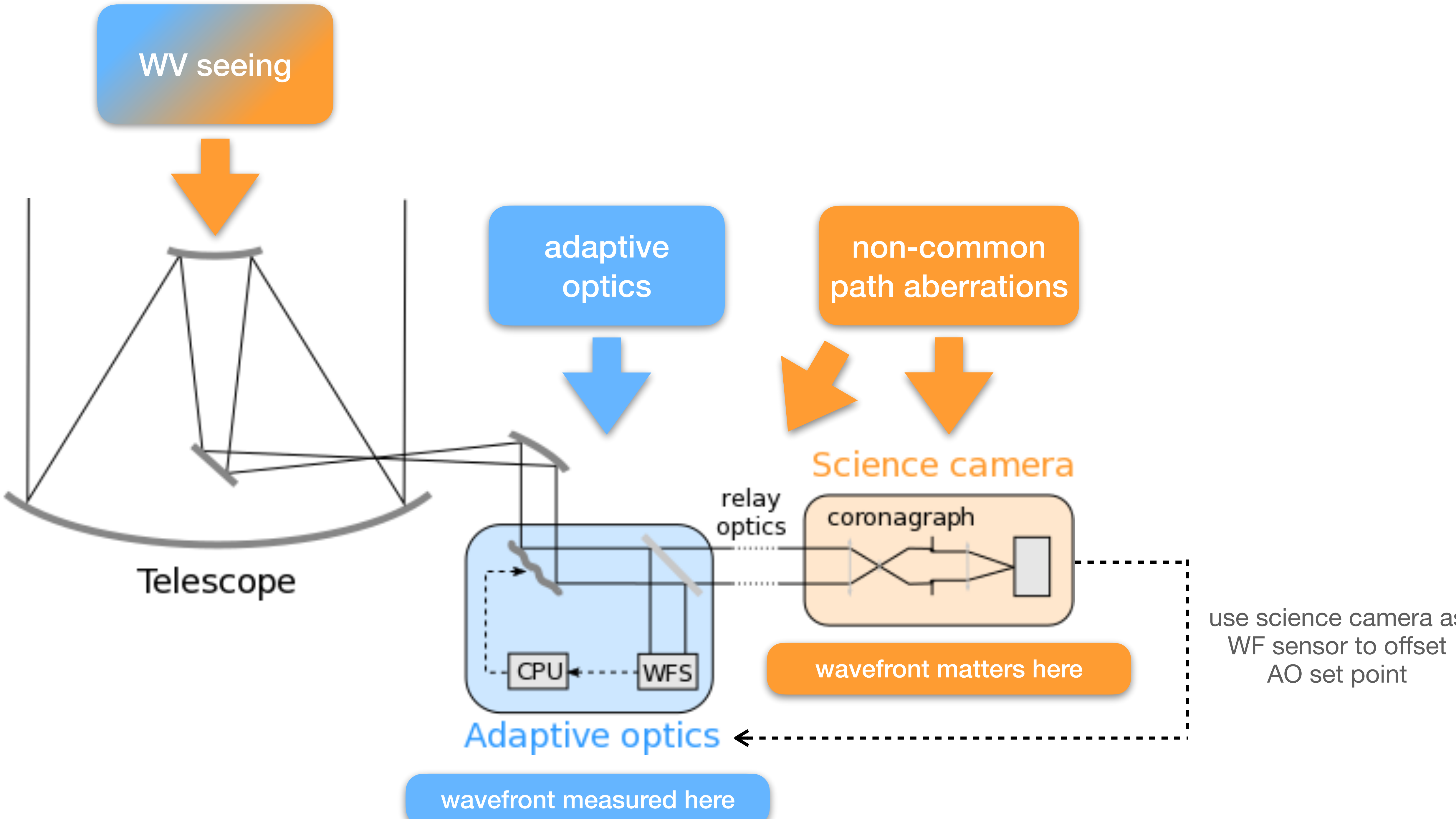
L band



N band



Mitigation: focal-plane wavefront sensing

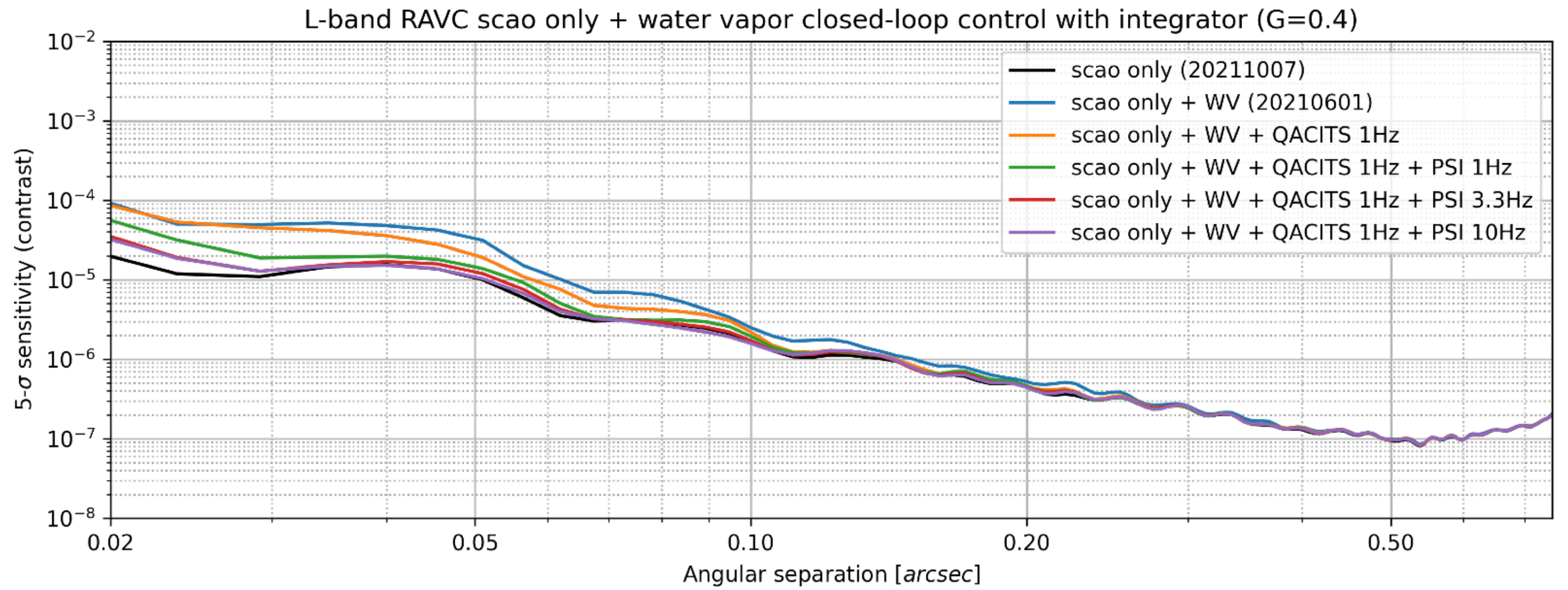


Mitigation plan for METIS

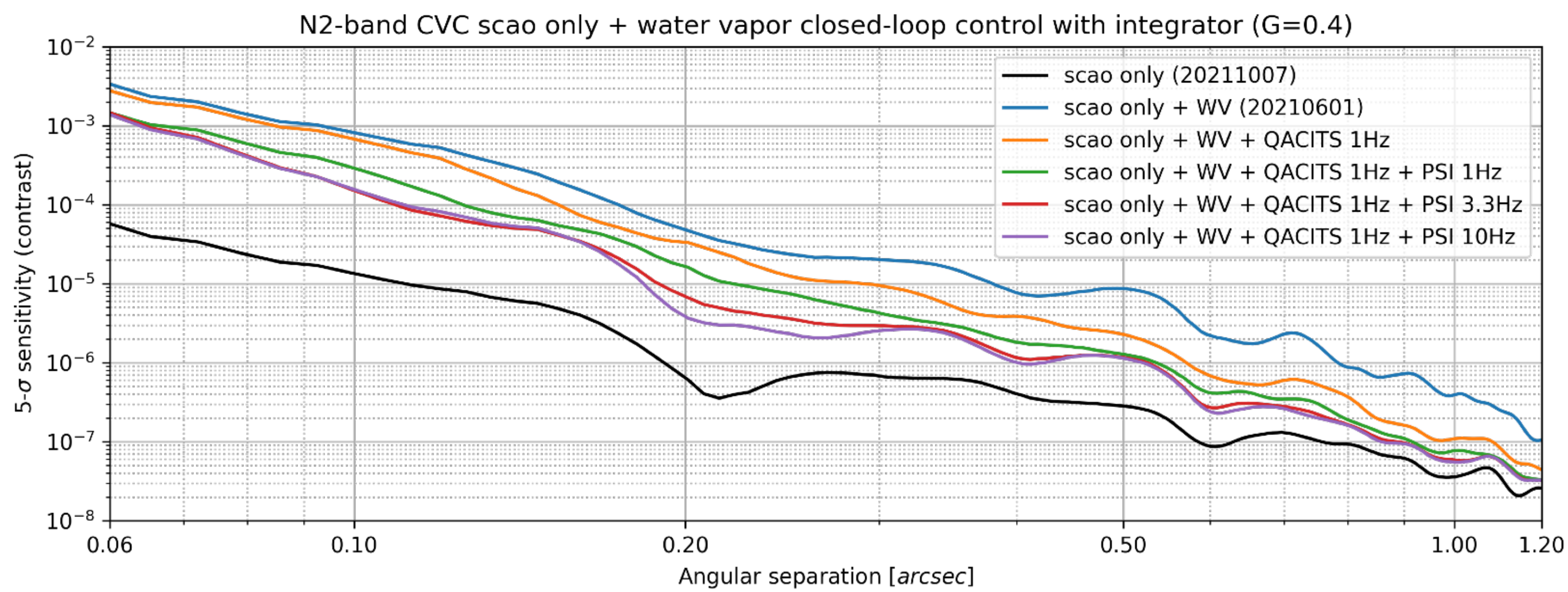
- Science images fed back to AO system for focal-plane wavefront sensing @ 1 Hz
- Pointing errors: QACITS
  - uses asymmetry in coronagraphic PSF
- Next ~100 Zernike modes: Phase Sorting Interferometry
  - uses phase diversity introduced by AO residuals
  - PSI output introduced as slope offsets in Pyramid WFS

Expected performance improvement

L band



N band



Conclusions

- Investigated wavefront variability in the mid-infrared due to water vapor at Paranal
- N-band image quality at ELT scale is dominated by water vapor turbulence
    - Strehl ratio remains high (~95%)
    - … but high-contrast imaging strongly affected!
- Taking advantage of low-PWV events will be more important than ever
    - more statistics would be useful to pinpoint WV seeing vs PWV trend