Low wind-effect origin and mitigation

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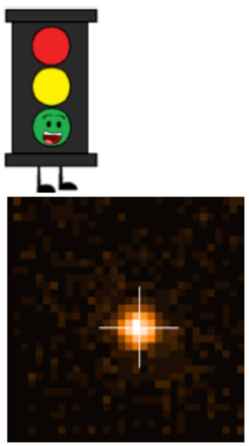
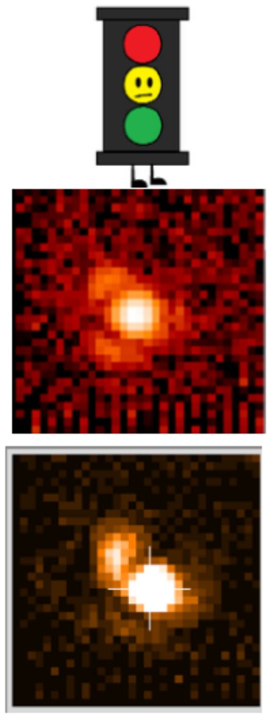
LWE phenomenology

Various realisations of the "low-wind effect"
on the SPHERE PSF (DTTS images)

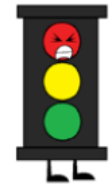
No Effect

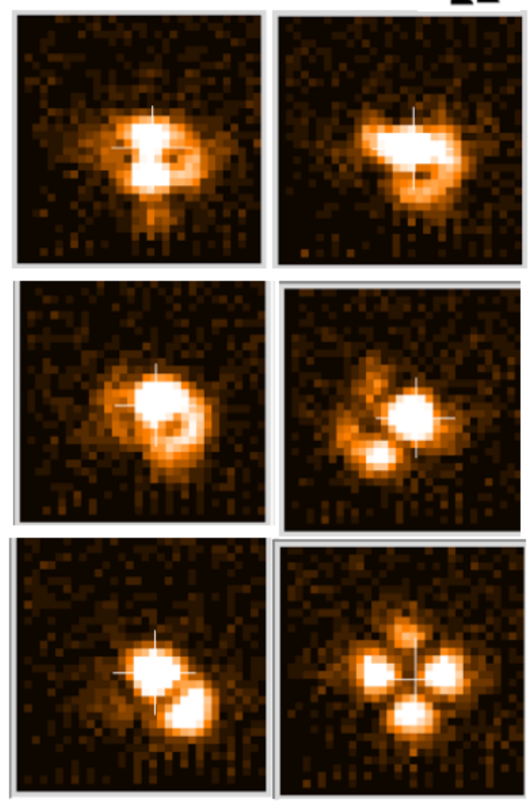


Typical Effect
"Mickey ears"



Strong cases

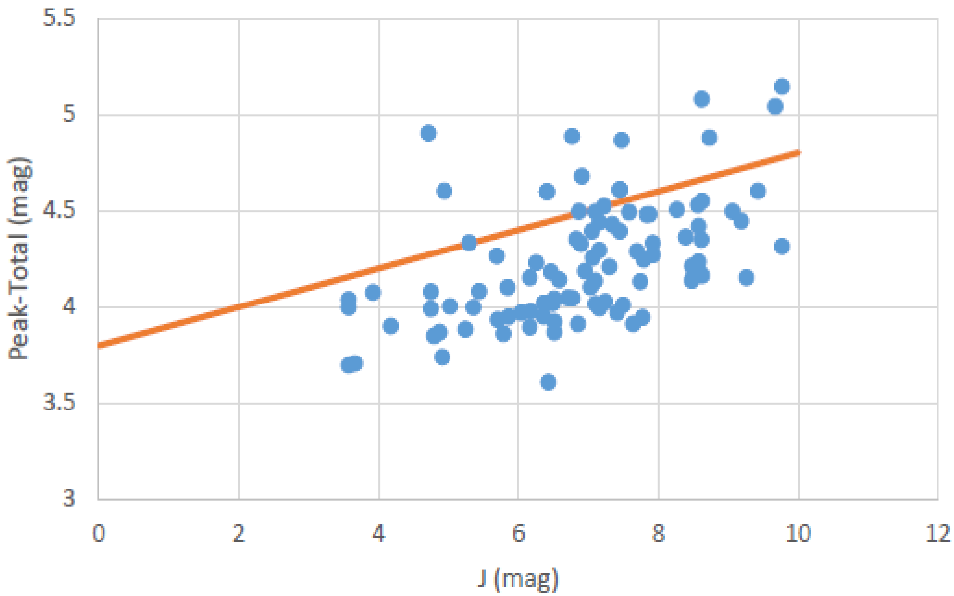


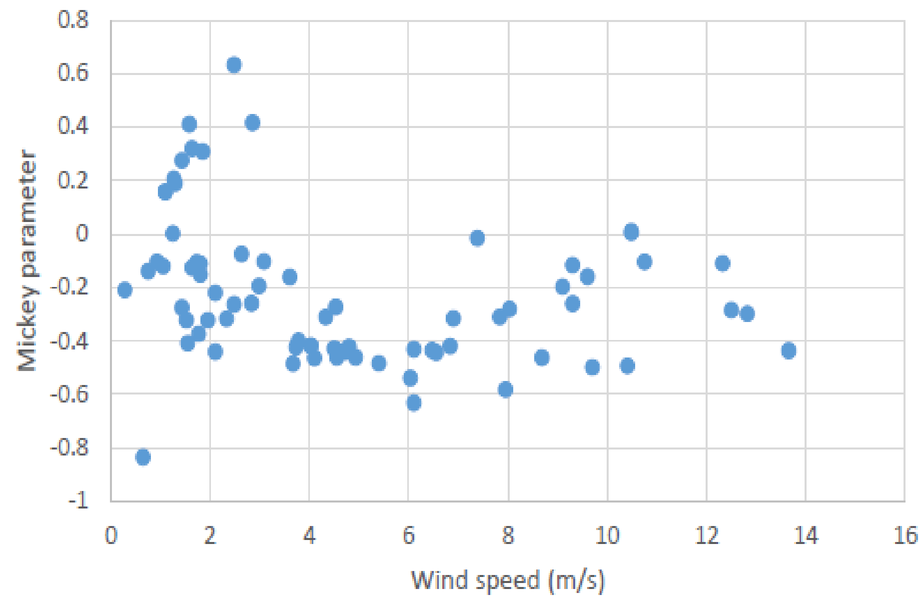


Created by J. Girard

Statistics

- Metric (R. Gratton): Peak(pixel)/EE(2.5λ/D)
- Similar to Strehl, emphasizing impact of low-order aberrations

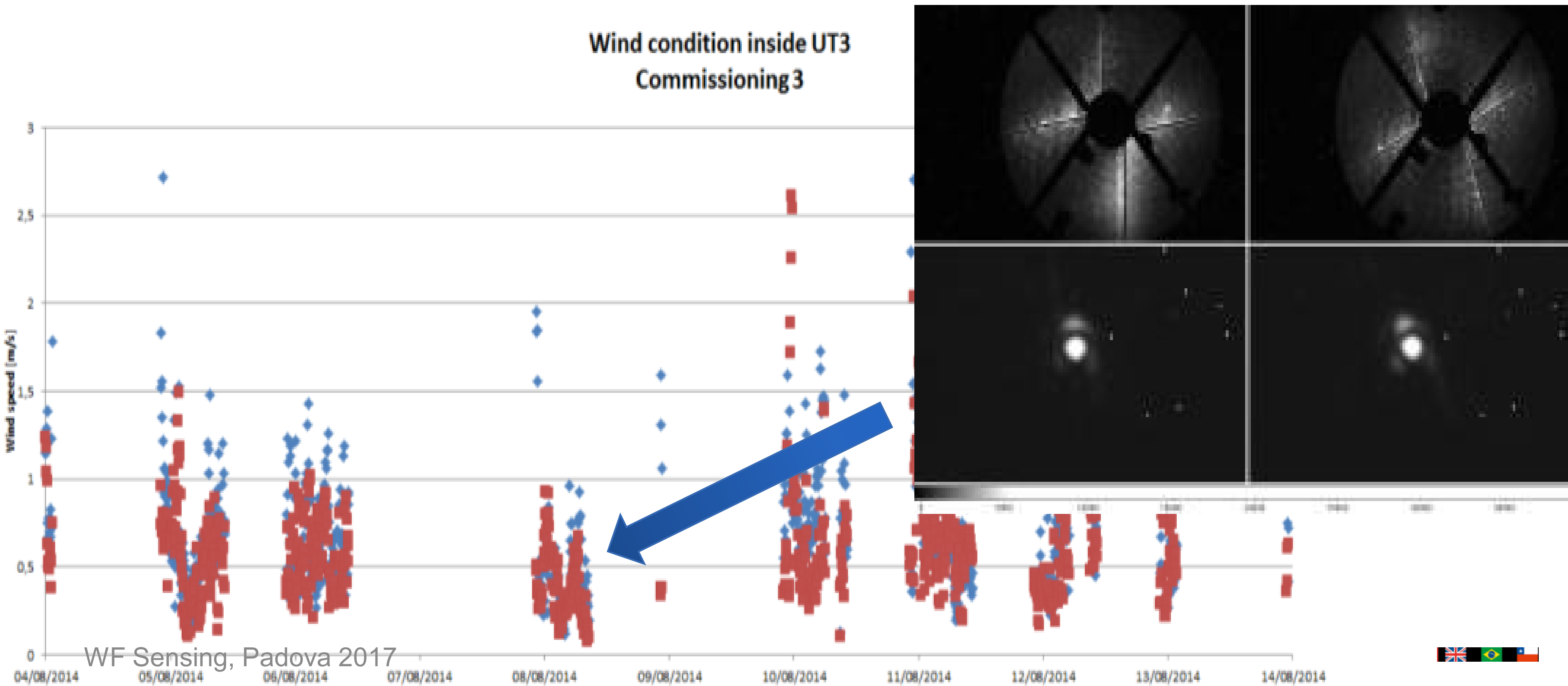




- $v_w < 3$m/s is a necessary (but not sufficient) condition
- LWE ~16% of the time (SPHERE IS estimate 15-20%)

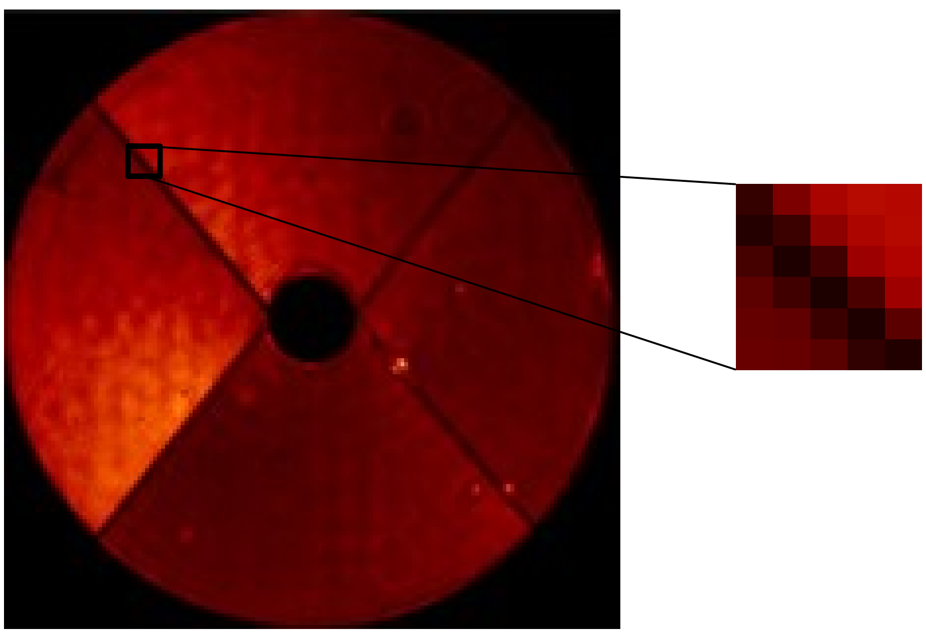
1st LWE: SPHERE commissioning

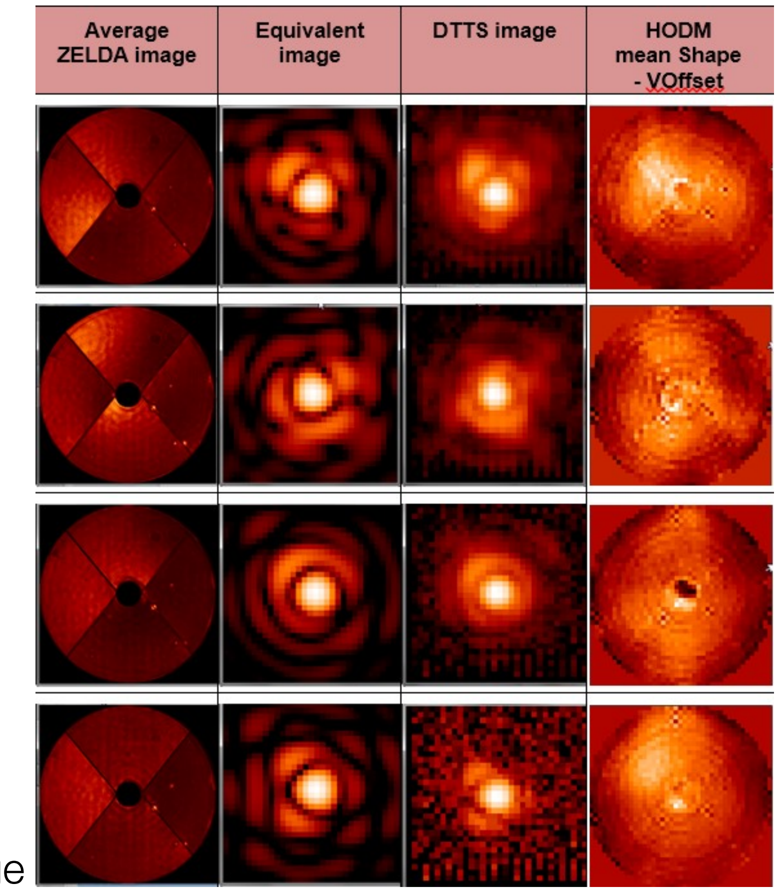
- Coronagraphic pupil plane indicates phase errors around spiders
- Low SF slowly variably aberrations when wind at top ring (M2) is <1m/s
- Things tried without success: Fewer/more corrected modes, dome ventilation on, different SHS COG algs, disabling subapertures across spiders…



SPHERE FPWS: ZELDA

- ZELDA: Zernike WFS installed in SPHERE coro wheel (N'Diaye et al. 2013)
- Phase discontinuities around spiders covering ~1/3 subaperture
- Mostly Piston, Tip and Tilt on each segment



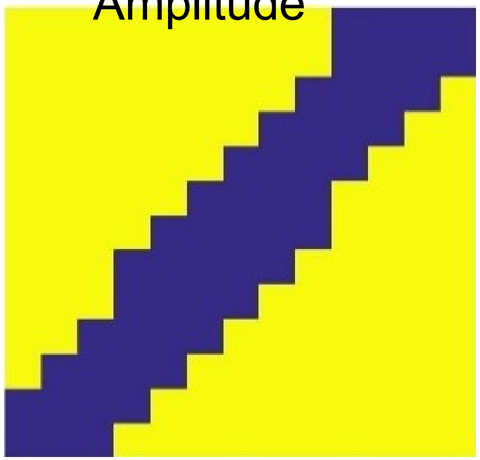


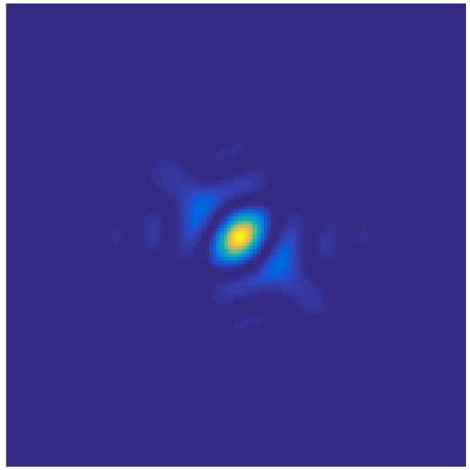
Figures and analysis by J.-F. Sauvage

SHS cannot see it

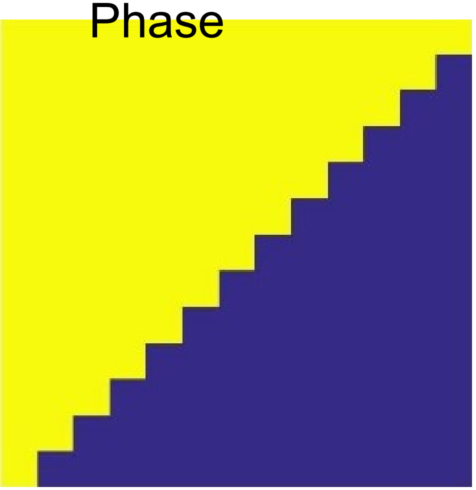
PSFs

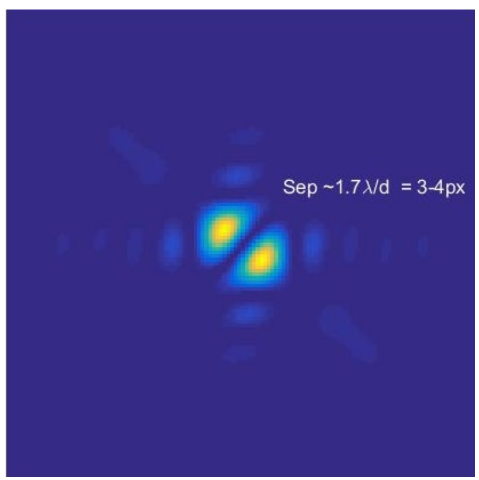
Amplitude





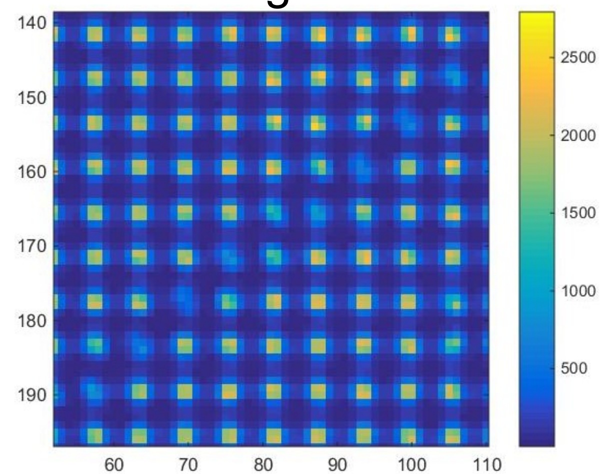
Phase

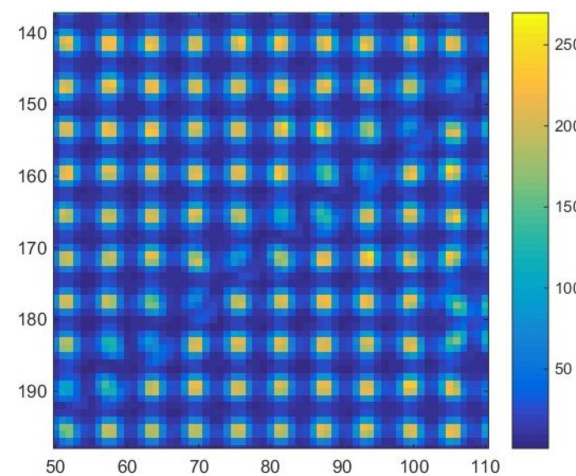




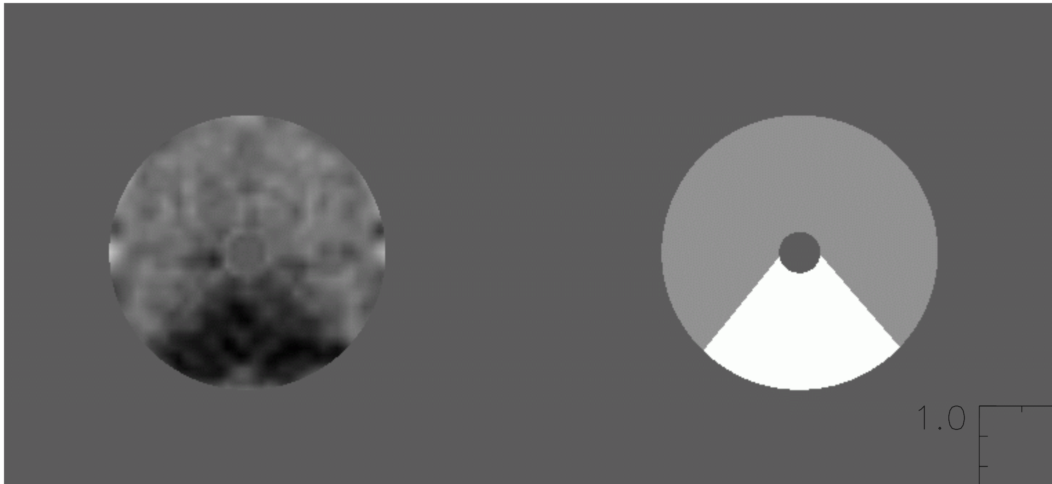
PSF morphology changes,
Centroid stays

SPHERE on-sky spots
weak/strong LWE

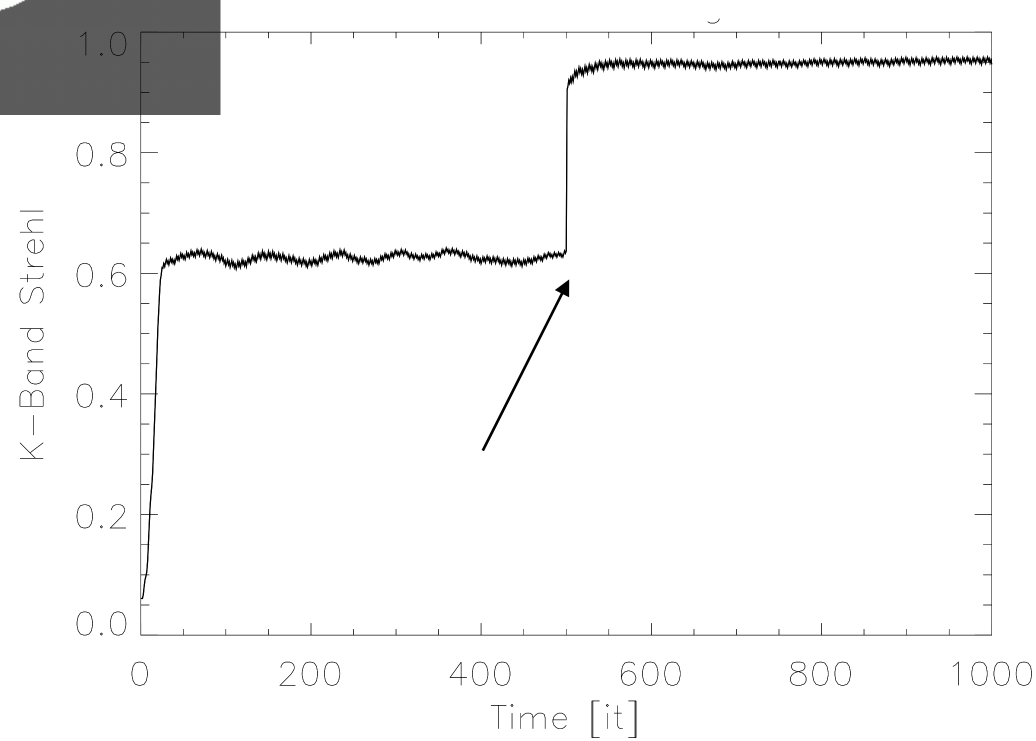




Pyramid, ZELDA, FPWS... can see it



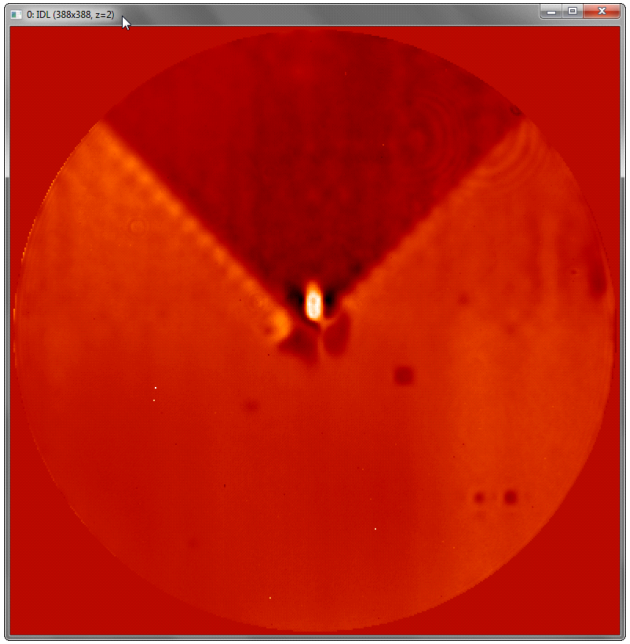
Simulation (Le Louarn) of LWE seen by PWS"



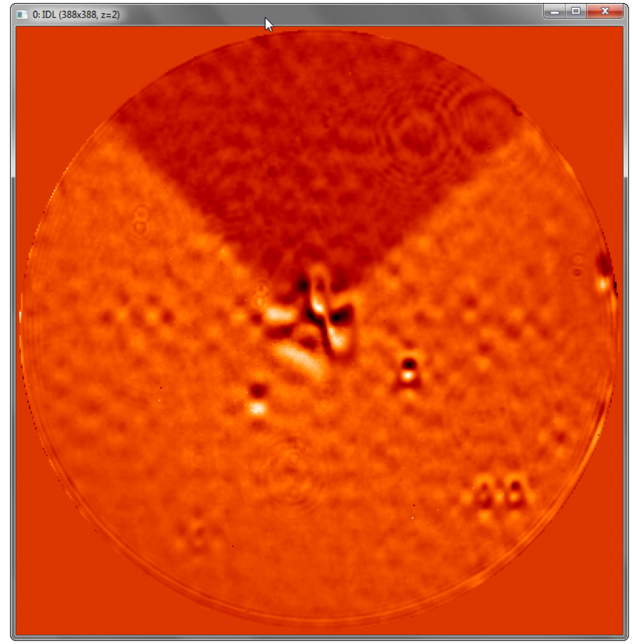
The monochromatic simulations can converge to a 1-λ piston (700 nm in this case).

Need a little "push" in the right direction

HODM can fit LWE



Via voltages in open loop

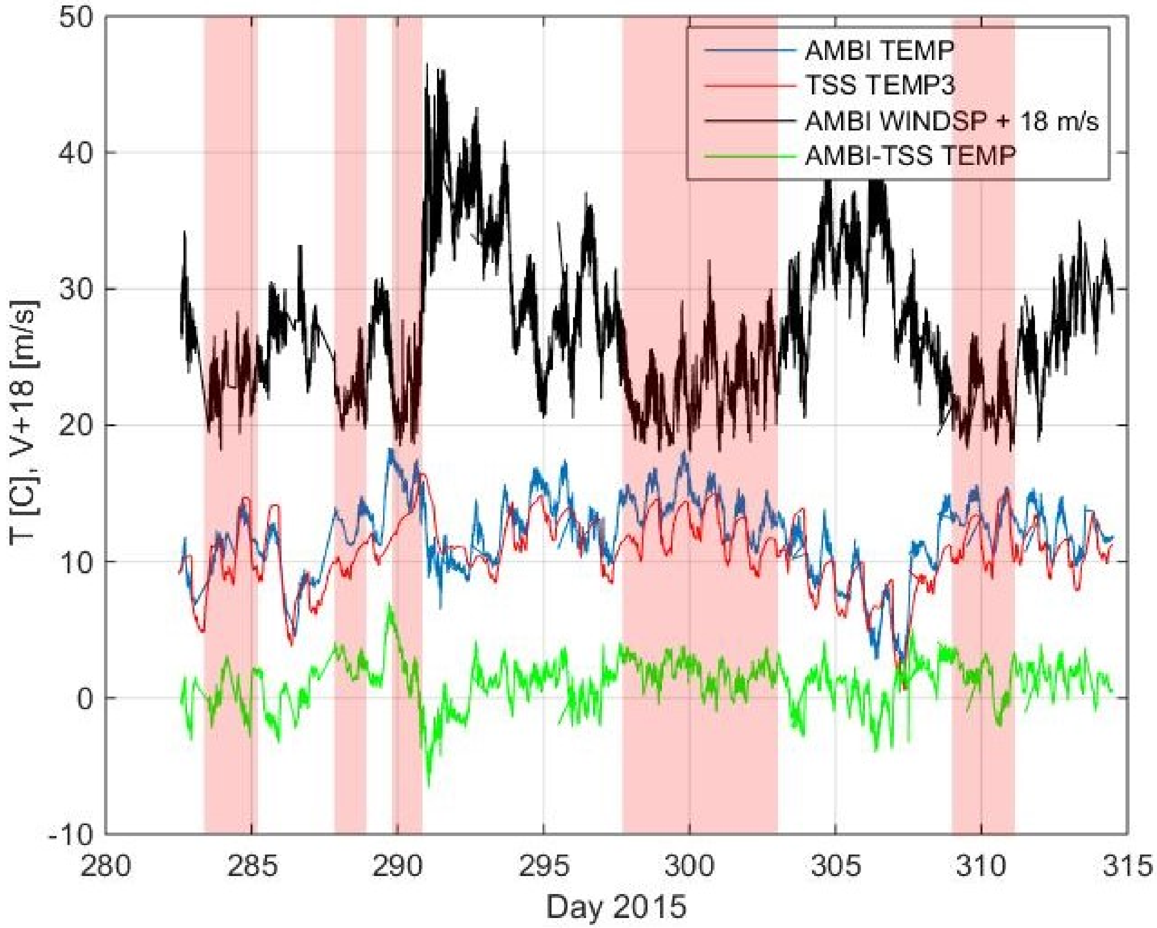


Via slopes in closed loop

Test by
J.-F. Sauvage,
J. O’Neal

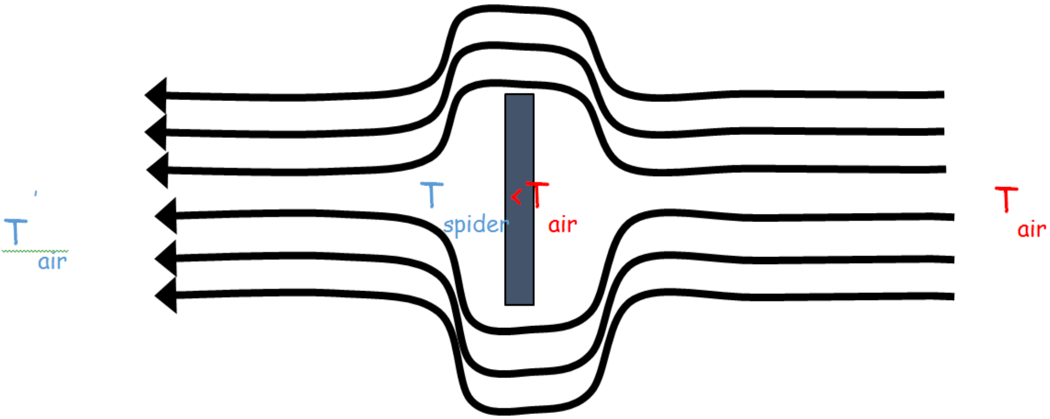
- ZELDA measurement of wave-front error, after introducing the LWE pattern in internal source
- Qualitatively: Should be possible to reproduce LWE with small residuals

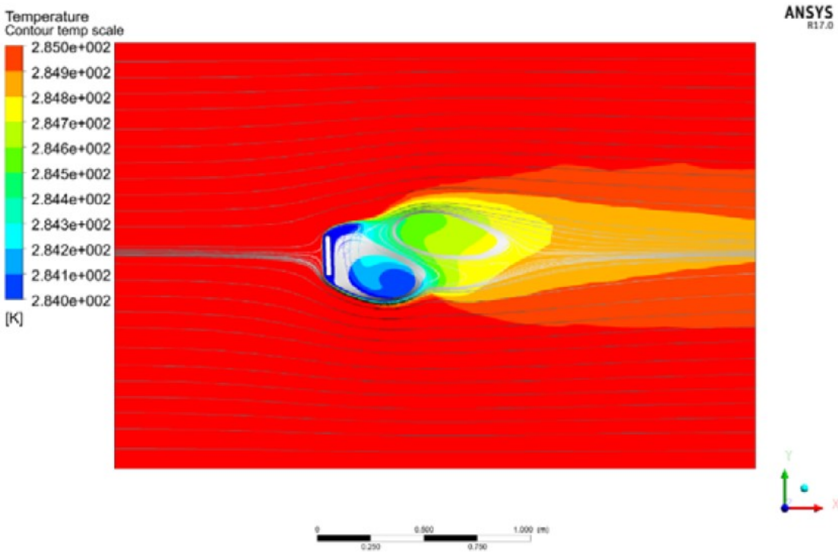
Root cause: Cold spiders?



Temperature differential. Spiders 1-2 degrees colder than ambient
Effect somewhat pronounced during low wind speed

LWE model





CFD modeling, M. Brinkmann

- Spider sees cold night sky, looses heat through radiative cooling
- Heat removed from ambient air through convection while in contact
- The air leeward of the spider has therefore a reduced temperature
- Stronger convective coupling for lower windspeeds
- Colder air has higher density and refractive index -> phase step across

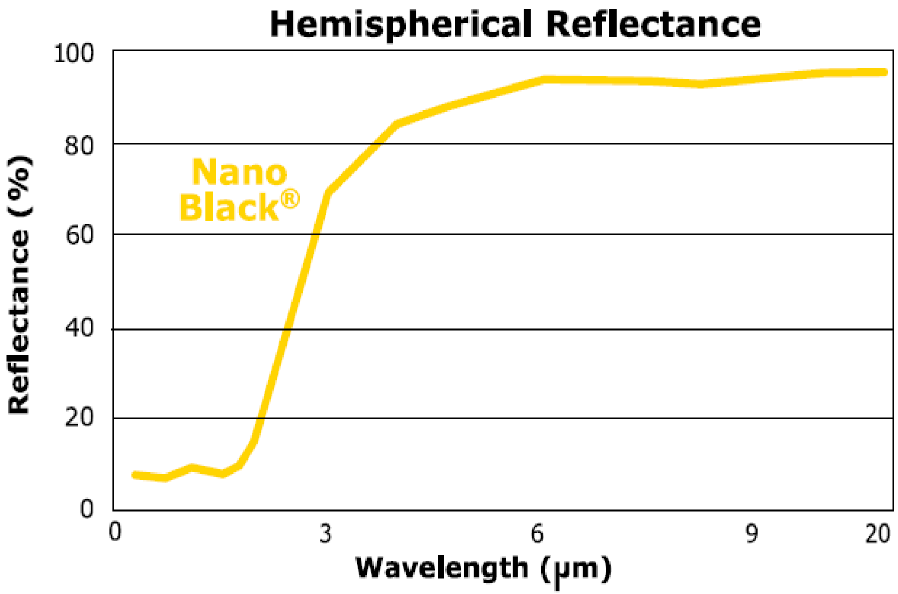
Can radiative cooling explain LWE?

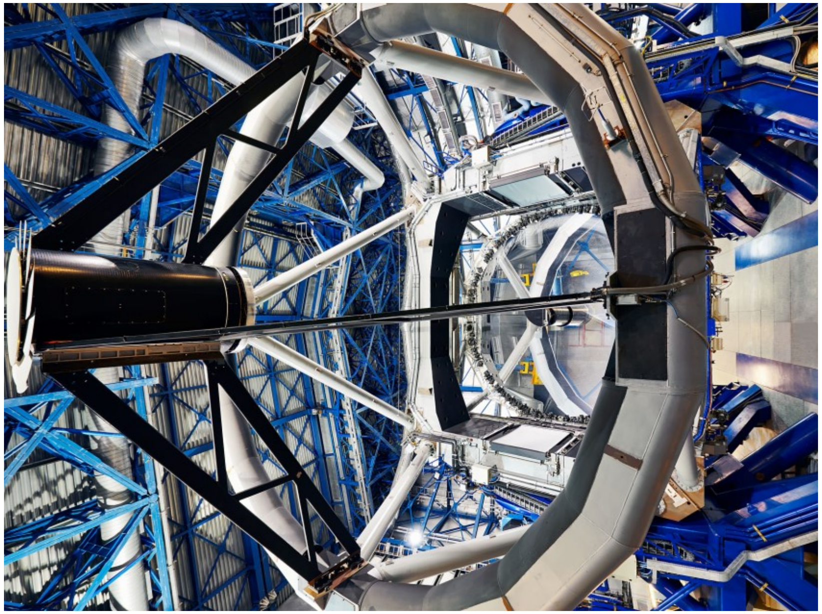
- Stefan-Boltzmann says $P_{spiderOut} = \varepsilon \times 5.67 \times 10^{-8}\, Ts_{pider}{}^{4}\frac{W}{m^2} = \boldsymbol{\varepsilon} \times \mathbf{315}\frac{\boldsymbol{W}}{\boldsymbol{m^2}}$
- It is also $P_{sky} \sim 100\ W/m^2$ and $P_{dome} \sim 315\ W/m^2$, spiders see 50:50 dome and sky, so $P_{spiderIn} = \varepsilon(\frac{100}{2} + \frac{315}{2}) = \boldsymbol{\varepsilon} \times \mathbf{207.5}\frac{\boldsymbol{W}}{\boldsymbol{m^2}}$
- Spiders have to extract $\sim\boldsymbol{\varepsilon} \times \mathbf{100}\frac{\boldsymbol{W}}{\boldsymbol{m^2}}$ from somewhere
  -> from ambient air through convection
- Order of mag estimation
  - heat capacity of air of $C_p = 1\ kJ/(kg\ K)$ (sea level, dry, 273.15 K)
  - air density on Paranal of $\sim 1\ kg/m^3$
  - 10cm-thick air layer ($\sim 0.1\ kg/m^2$) in thermal contact with the spiders for $\sim 1s$
- $\boldsymbol{\varepsilon} = \mathbf{1}$: $\Delta T = 100\ {}^{W}/_{m^2} \times \frac{1s}{1000\frac{J}{kg\ K} \times 0.1\frac{kg}{m^2}} = \mathbf{1}\ \boldsymbol{K}$
- $\Delta_{OPD} = (n-1) \times \frac{\Delta T}{273K} \times 1m = \mathbf{0.88}\ \boldsymbol{\mu m}$ => correct order of magnitude

Active correction is possible, but difficult

- Active heating of spiders
  - 50-100 W/m^2 needed, i.e. 1–1.5 kW / UT
- Active correction
  - SPHERE HODM and AOF/DSM can take out most of LWE
  - Need phase sensor: ZELDA, PWS, focal plane WFS
  - Not easy to retrofit in existing instruments
  - Need sufficient pupil sampling by DM, probably not effective for NACO and MACAOs / CIAOs

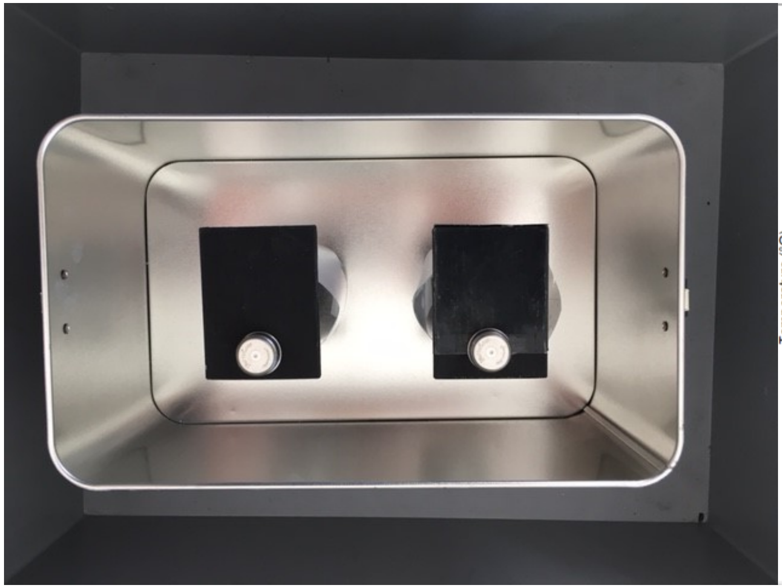
Passive option: Selective Coating

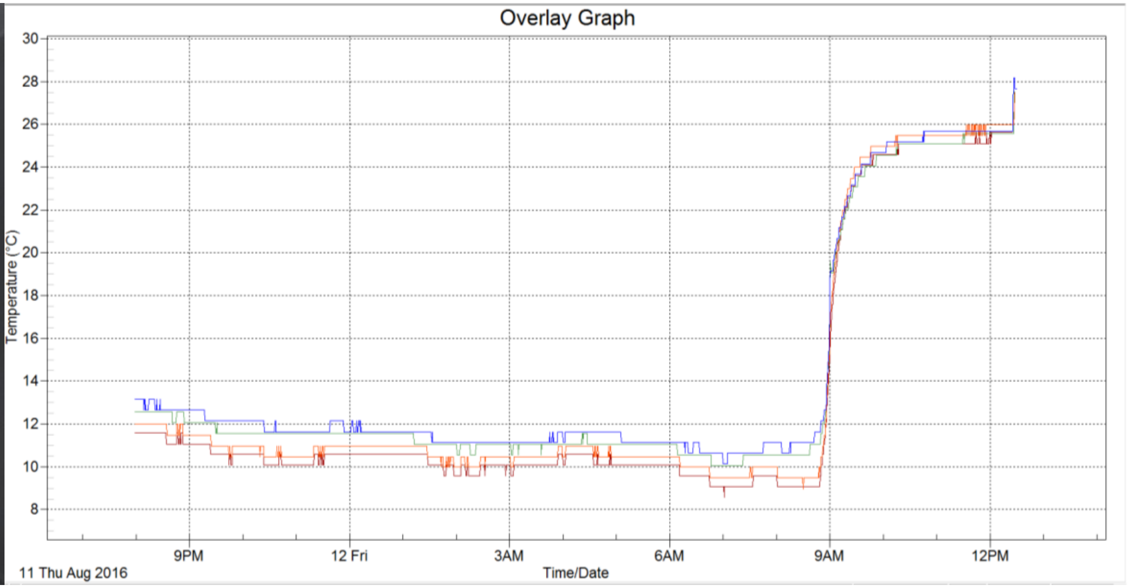


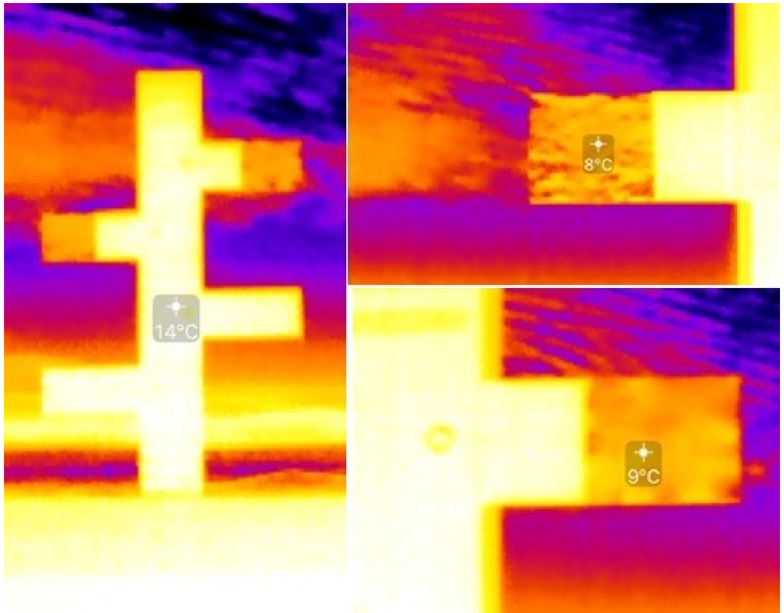


- Black in Optical/NIR (low scatter), white in MIR, $\varepsilon \sim 10\%$ (low emission)
- Has trouble to radiate at room temperature
  -> Structure maintains ambient temperature
- Surface of VLT spider structure ~16 m^2 / UT or ~64 m^2 for all 4 Uts
- Acktar Nanoblack coated foil or tape (width 20 cm): need 80-m / UT, price: ~10 kEur / UT

Nanoblack sample tests (P. Bourget)







- Upper left: Two test samples (foil and tape) exposed to Paranal Sky
- Upper right: The Nanoblack samples were always ~1.5 degrees warmer than Chemglaze ones (current spider surface)
- Lower left: Although being warmer, the samples show significantly lower thermal emission.

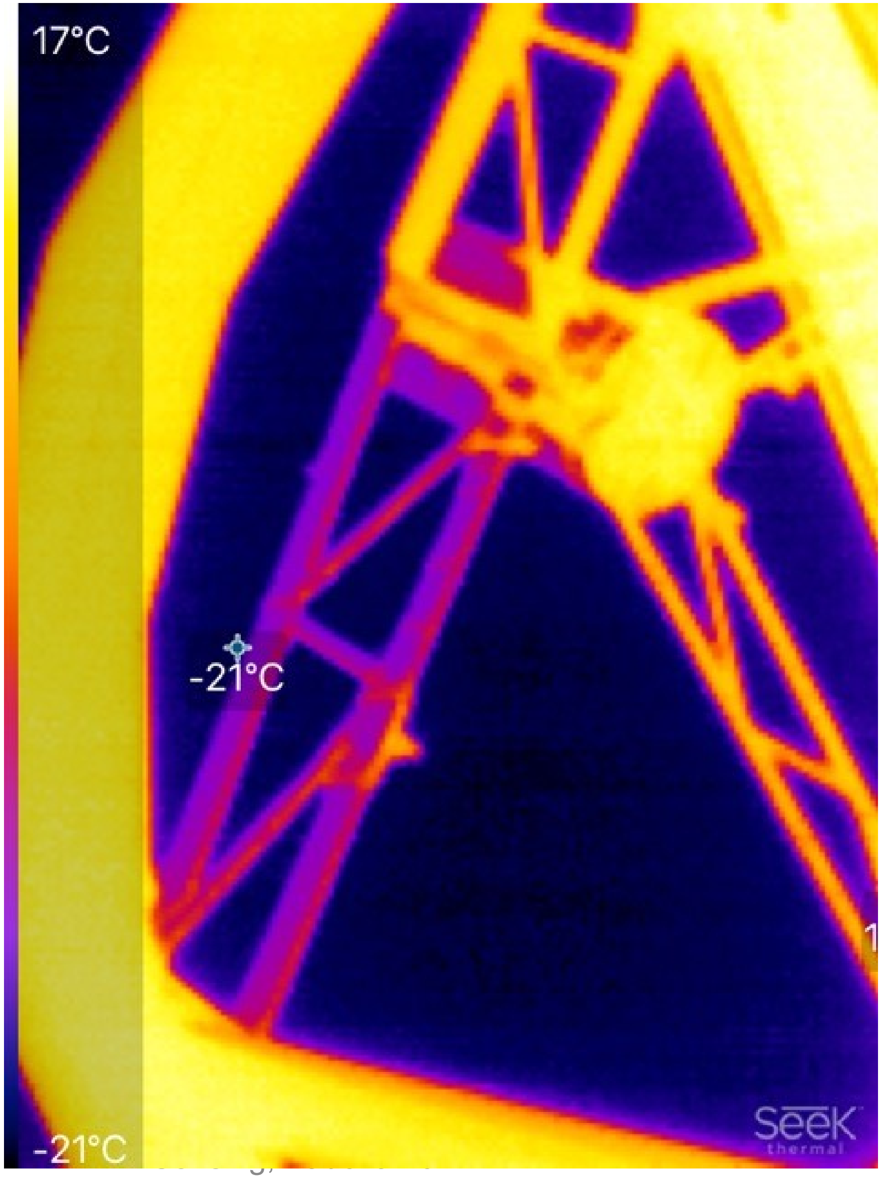
Implementation UT3

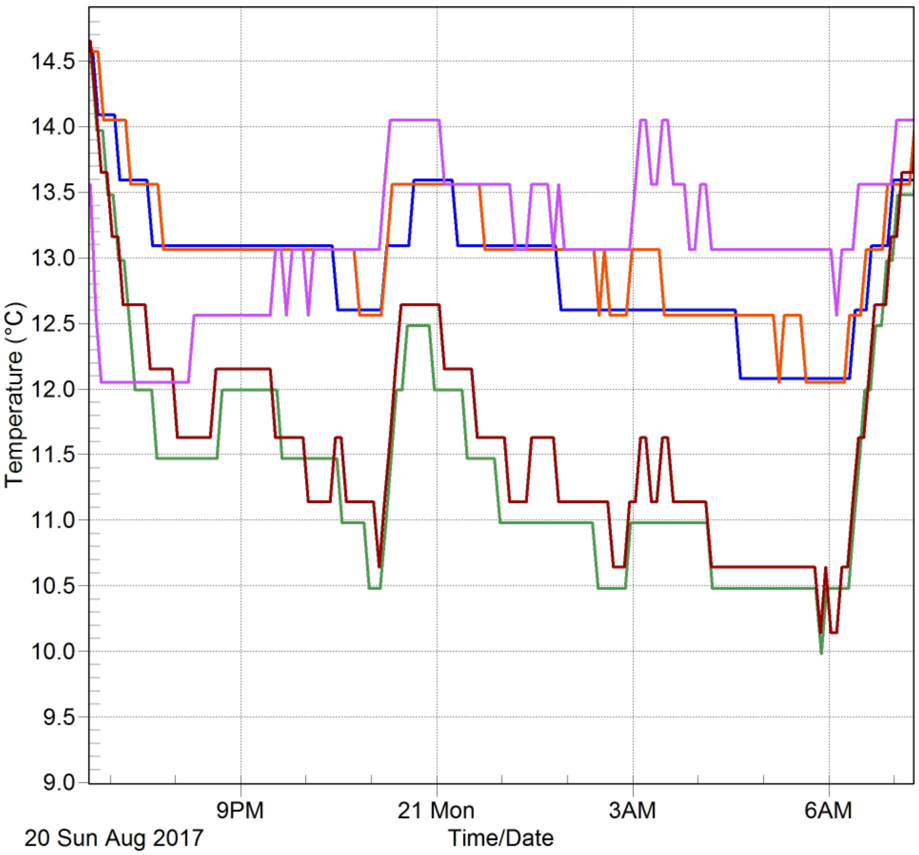
test	requirements*	sample size	findings*	pass/fail	notes
Visual examination - unaided eye or magnifying glass	No evidence of flaking, peeling, cracking, uncoated spots, etc. No evidence of loose drops/globules. Local areas with light colorfulness are acceptable provided that reflectance is within spec.	100%		Pass	
Emissivity	Emissivity <= 15 %; wl range 3-30nm	Measurements were carried out in central and two lateral points at the beginning and end of every roll.	NB117: 13% NB118: 13% NB119: 14%	Pass	
Hemispherical reflectance	Reflectance < 5%; wl range 450 – 1100 nm	Measurements were carried out in central and two lateral points at the beginning and end of every roll.	NB117: 2.96% NB118: 2.86% NB119: 3.3%	Pass	
Adhesion	No evidence of coating removal when 3M853 crystal clear tape (strength of 13N per 25mm) is pressed firmly against the coated surface and removed at 0.2 cm/min. The tape shall be applied for 1 minute minimum	one witness piece per batch		Pass	

* All quantitative data carry a tolerance of +/- 10% unless stated otherwise.

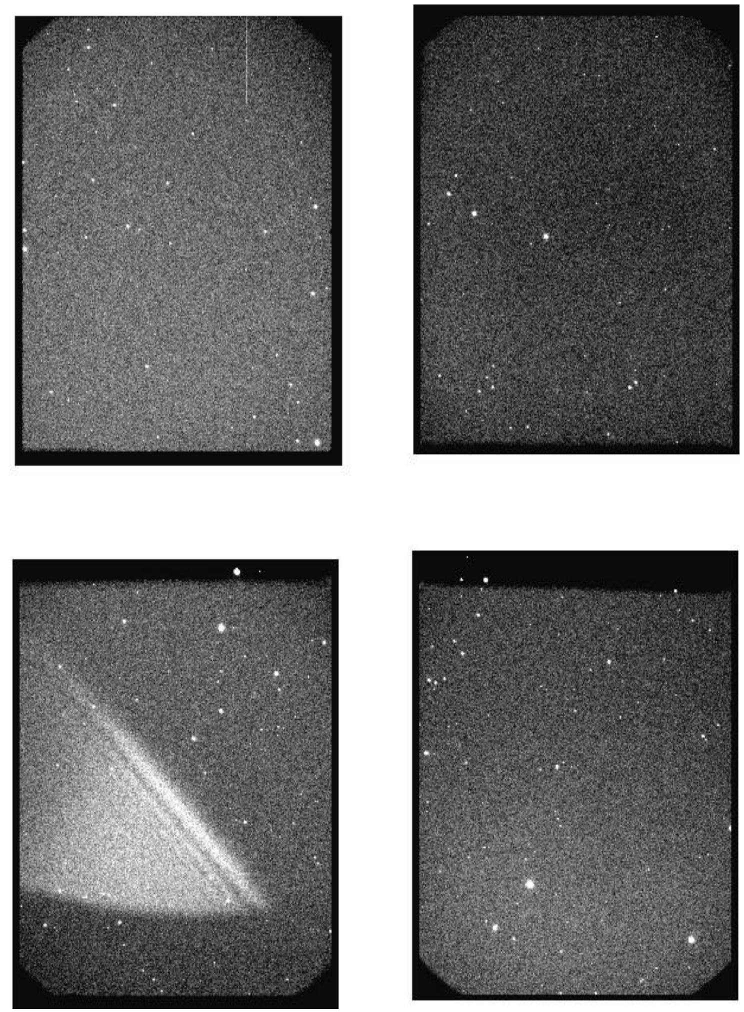
- Spider 1 coated on 29th August 2017
  Spider 2 on 2nd September,
  Spider 3+4 very soon

The thermal benefit is confirmed





Side effects: Shiny at grazing angle



VIMOS: Stray light from nearby moon. Archive data shows similar effect with old coating. Rarely observes close to the moon anyway -> no showstopper

VISIR: Selective coating has no significant impact on the thermal emission of the spiders (bottom no coated).

Conclusions

- LWE hampers AO observations (and SPHERE in particular) 15-20% of the time.
  - … and more often during the best nights
- It is a problem that MUST be solved, in particular for the ELT (much more massive spider structure, same WFE requirements)
- Passive correction through selective coating
  - Reduces the temperature difference spider/air
  - 2/4 covered so far. Quantitative results on WFE residuals soon
- Active correction possibly needed in addition (almost certainly for the ELT)
  - HODM can fit LWE, sensing possible to implement