

Atmospheric characterisation with Stereo-SCIDAR at Paranal

James Osborn



Statistics

On-sky atmospheric parameters

Atmospheric Characterisation

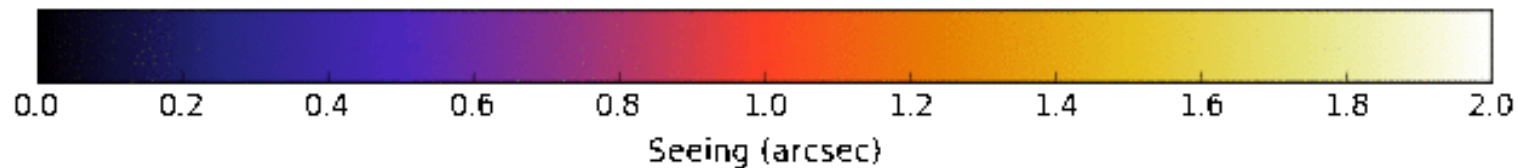
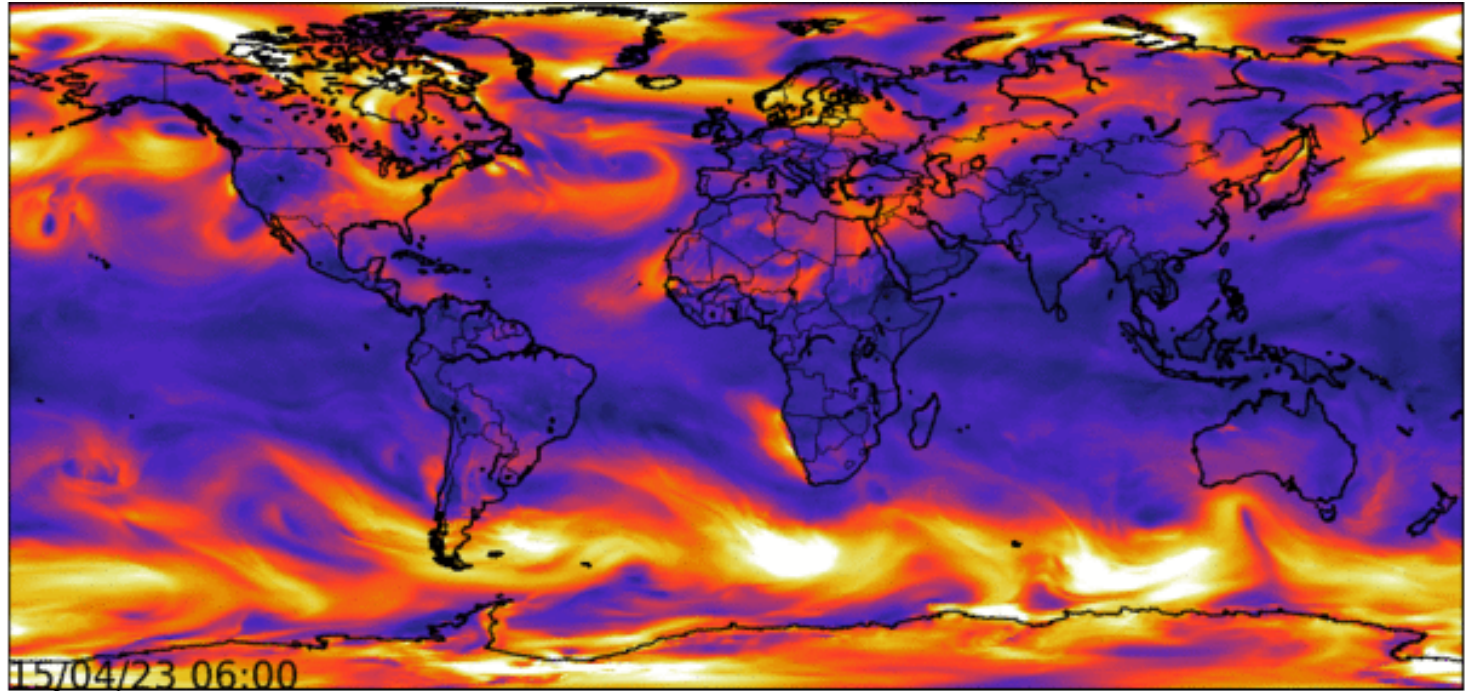
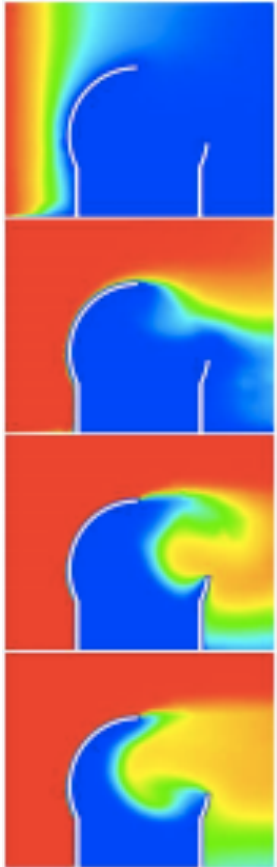
- Site characterisation (E-ELT)
 - Instrument / algorithm development and design
- PSF reconstruction (field varying PSF and field aberration)
 - Model of atmosphere, telescope (adaptive?, rubber?), AO, instrument
 - Wide-field AO optimization, calibration and performance validation
 - Instrument performance monitoring
 - Instrument comparisons
 - Instrument automation and robustness
 - Minimize dome seeing and structure induced turbulence
 - AO reconstructor pre-computation
 - Predictive AO controller
 - Scintillation noise for time-resolved photometry
 - Others?

Atmospheric Parameters

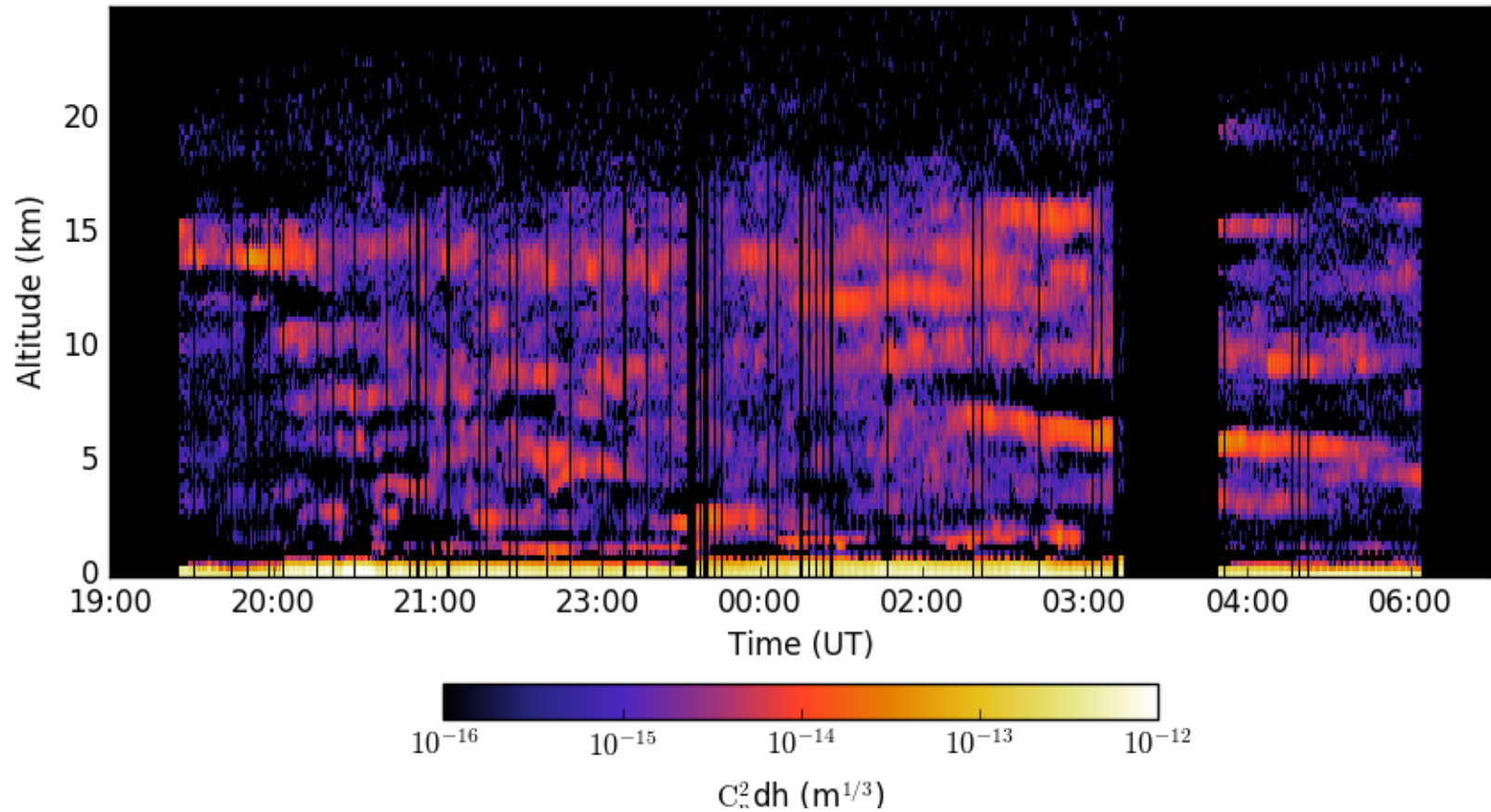
- Vertical profile of turbulence strength
- Vertical profile of turbulence velocity
- Vertical profile of the outer scale of turbulence
- Local dome turbulence
- Temporal evolution of these parameters

Atmospheric turbulence

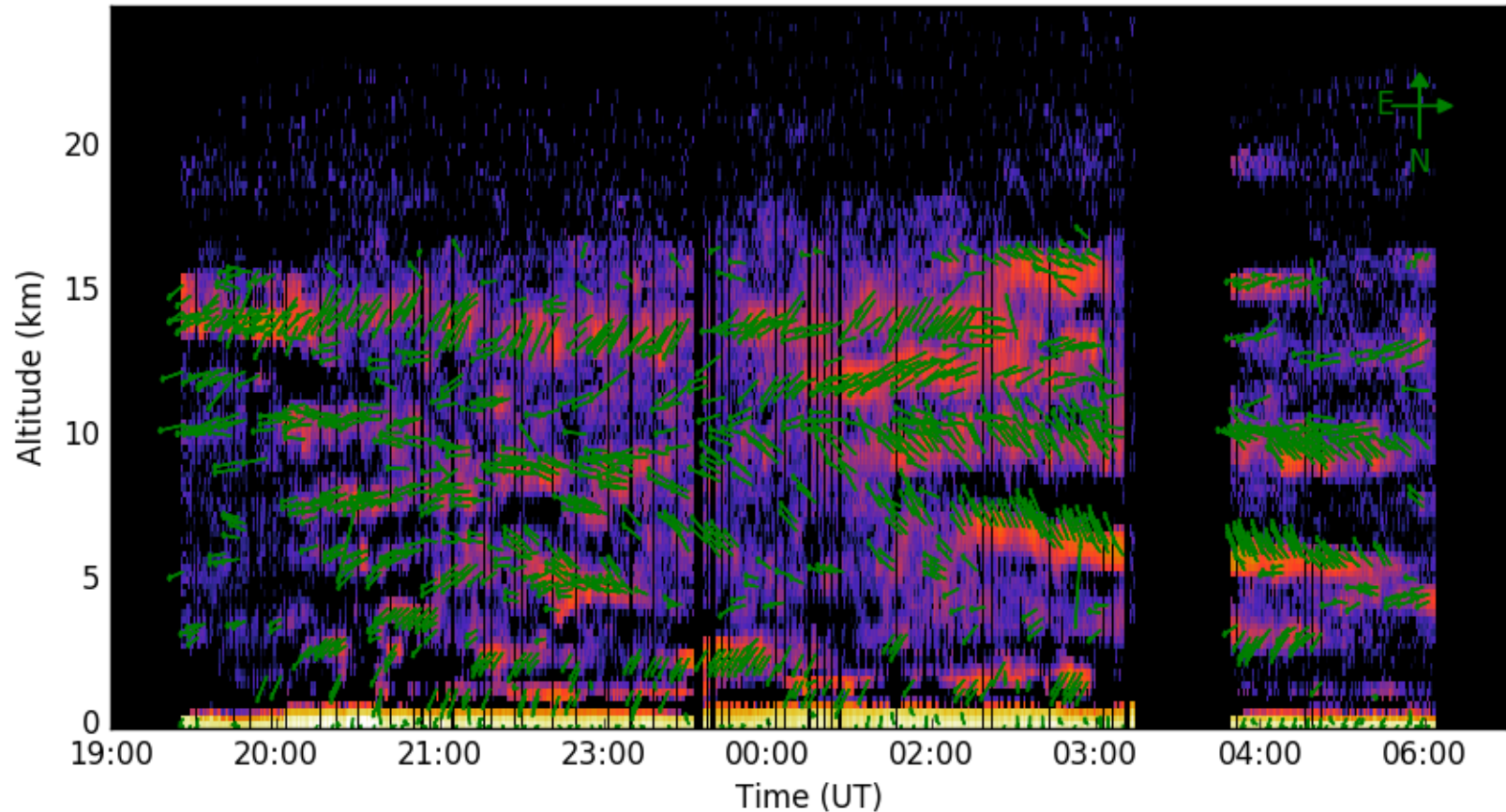
- Global and local scales



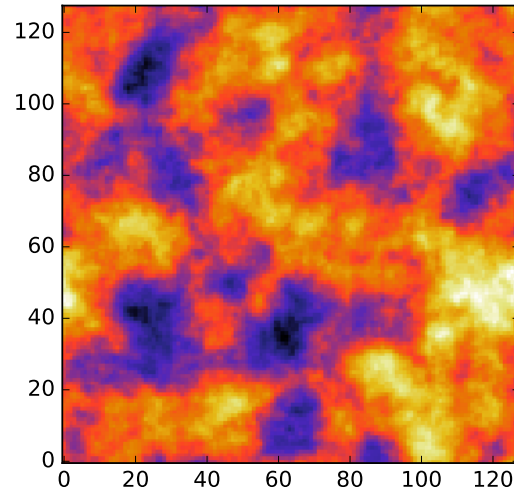
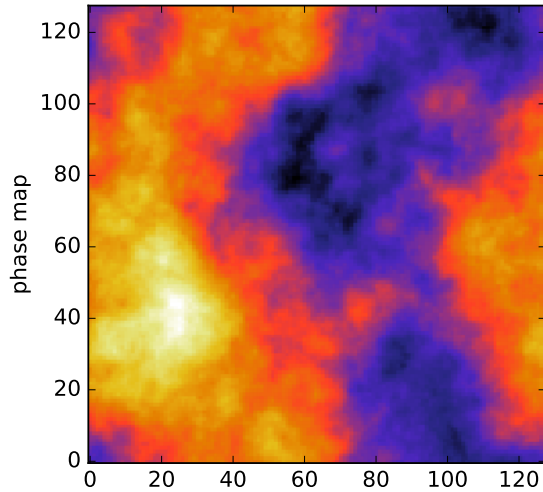
Turbulence Strength



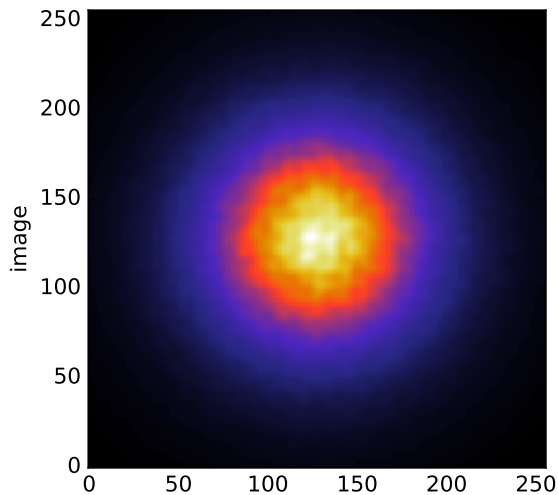
Turbulence Velocity



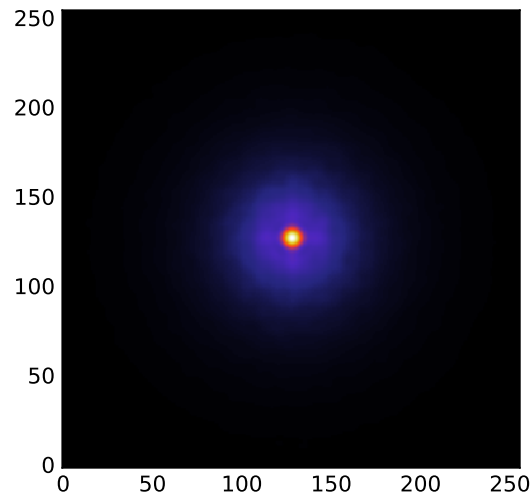
Outer Scale



- Vertical profile of outer scale
 - Important for all model based analysis
 - PSF reconstruction
 - AO optimization



$L0 = 100 \text{ m}$



$L0 = 8 \text{ m}$

- Adaptive Optics telemetry
 - Preferred
 - Can be complicated (lots of calibrations, AO, telescope, convergence...)
- Numerical Model
 - Convenient
 - Awaits thorough validation
- Dedicated Profiler Instrument
 - Unbiased measurement
 - Different line of sight

Methods of measurement

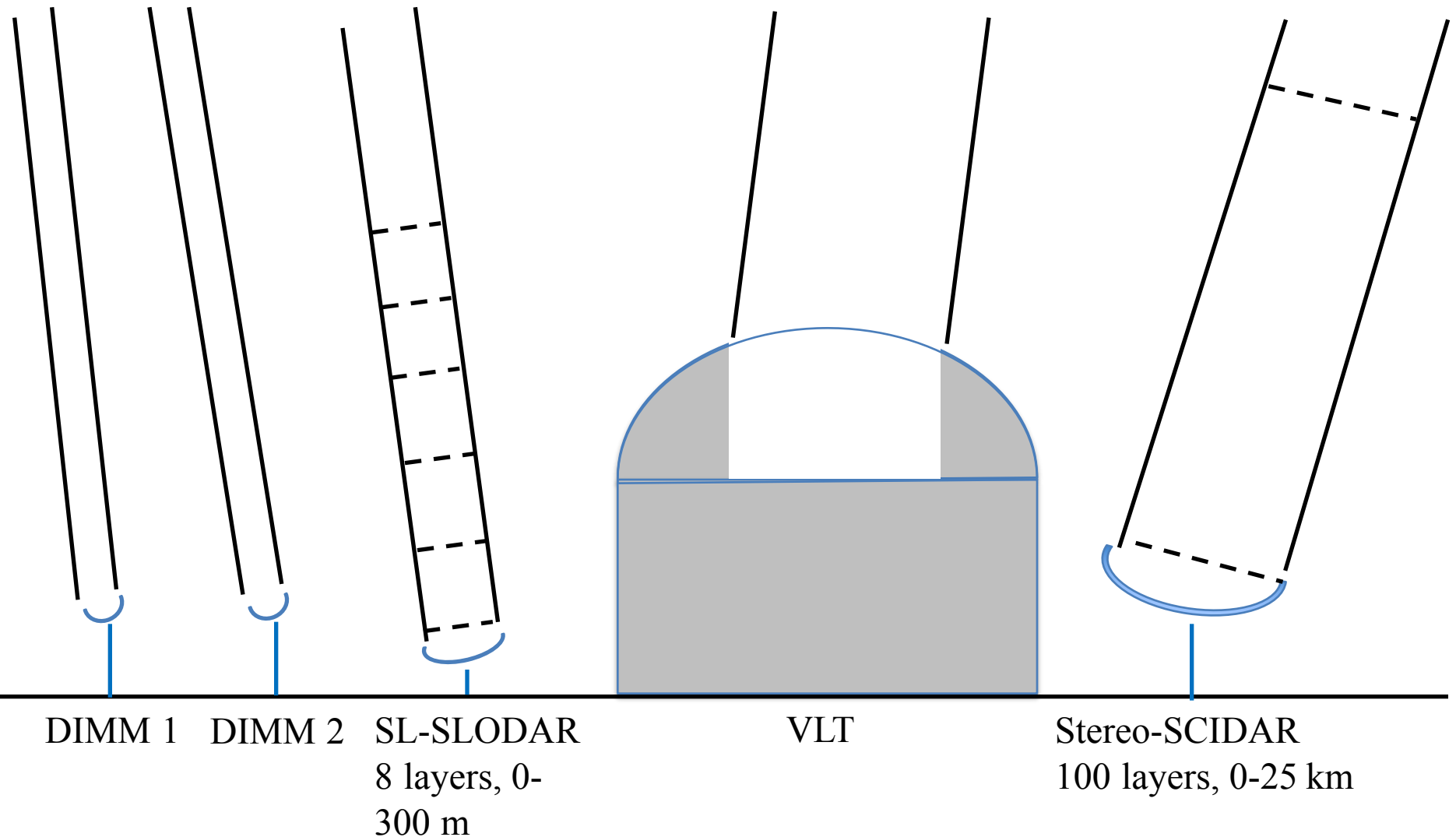
AO telemetry vs dedicated profiler vs numerical model

Methods of measurement

AO telemetry ~~X~~ dedicated profiler ~~X~~ numerical model
and *and*

- Use the right tool for the right job
- Correlations for validation
- Not for calibration/correction

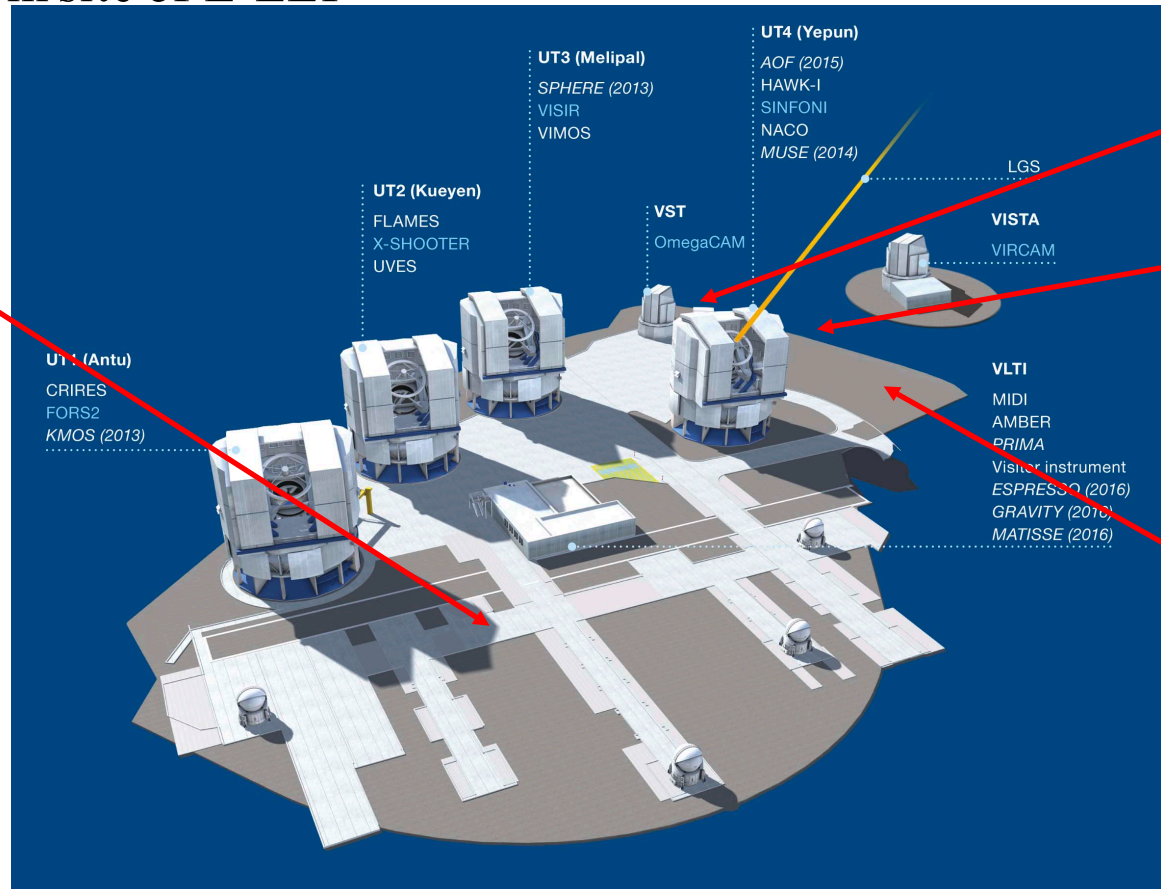
Atmospheric Characterisation at Paranal



ESO Stereo-SCIDAR

- Developed a Stereo-SCIDAR for ESO, Paranal (April 2016)
 - Located on an AT (1.8 m) focal station
 - Will be used ~5 nights per month for at least one year
 - 20 km from site of E-ELT

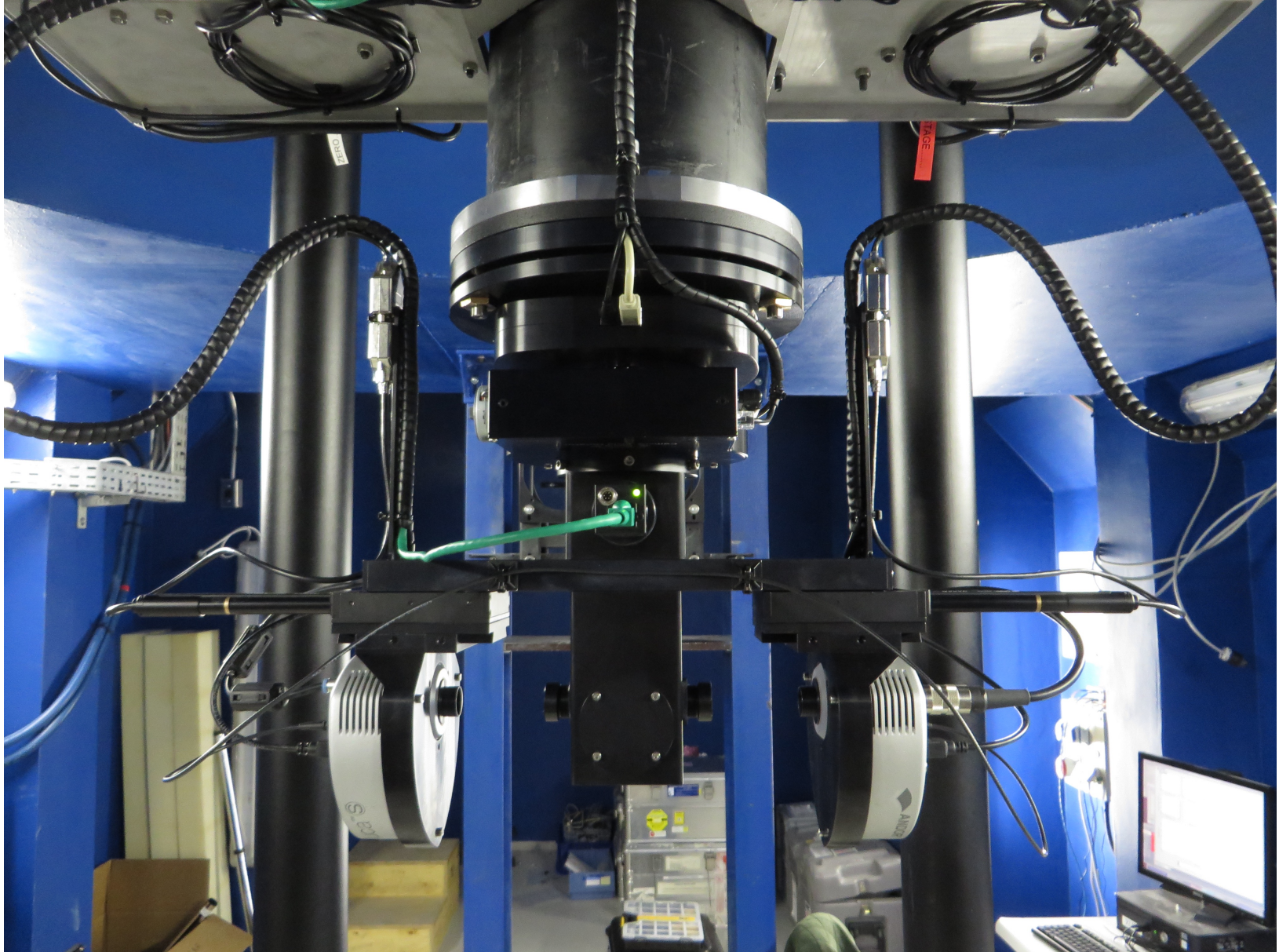
Stereo-SCIDAR



DIMM 1

SL-
SLODAR

DIMM 2

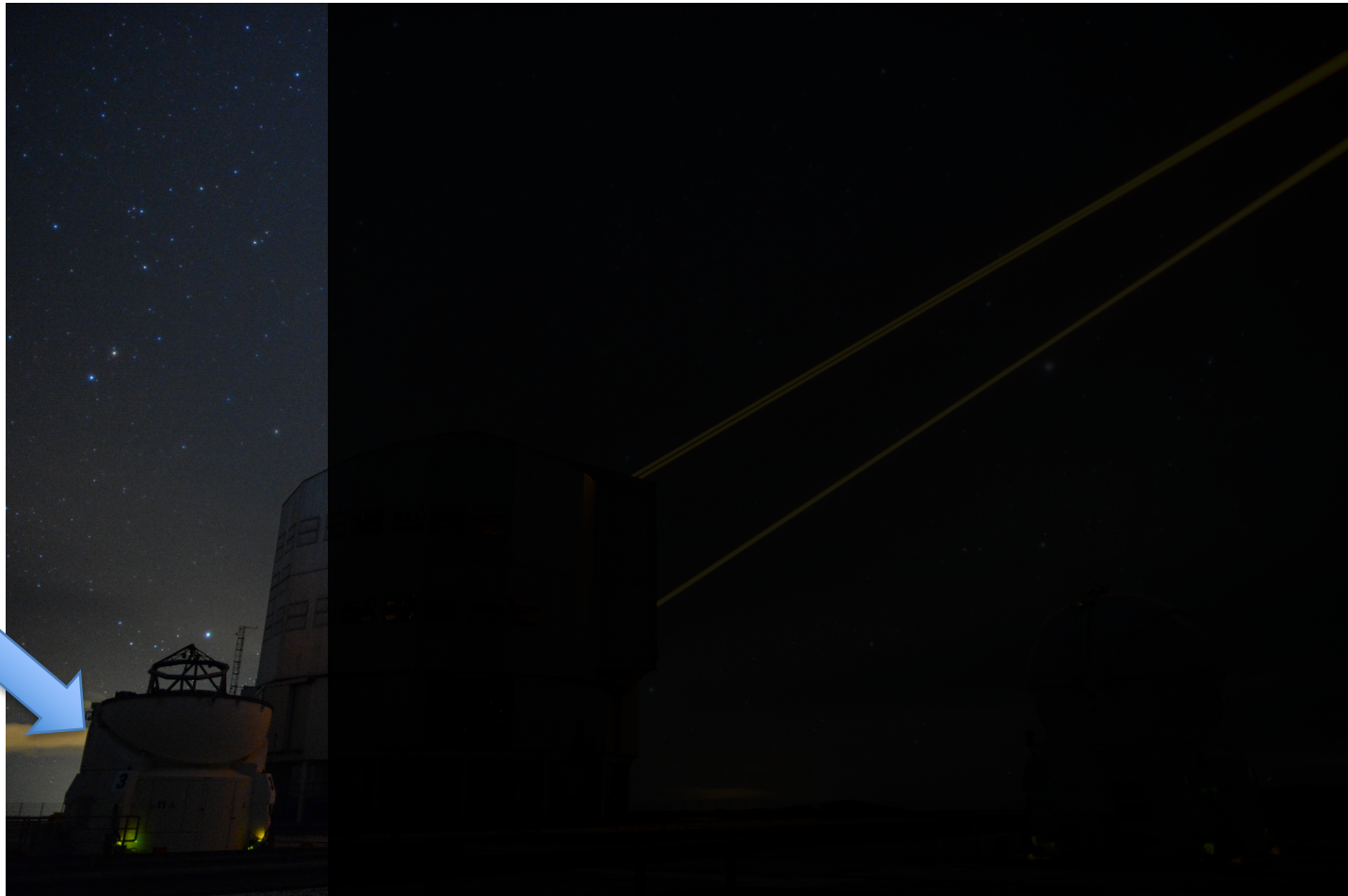


Stereo-SCIDAR on AT3



ESO/F. Kamphues

Stereo-SCIDAR on AT3

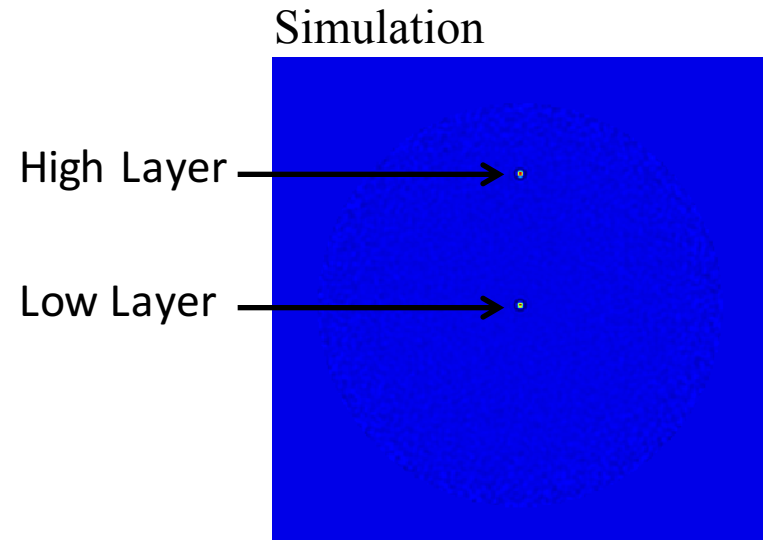
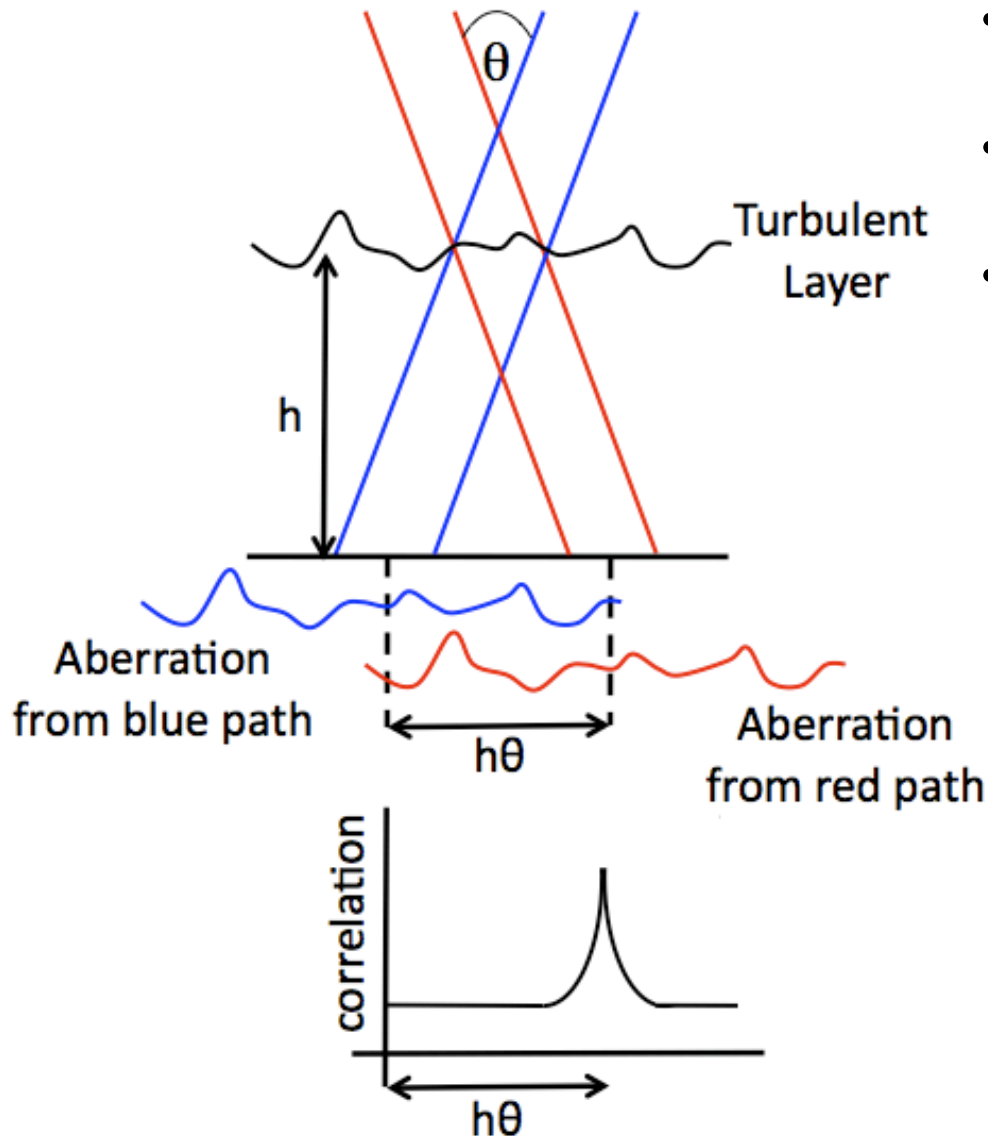


Stereo-
SCIDAR

ESO/F. Kamphues

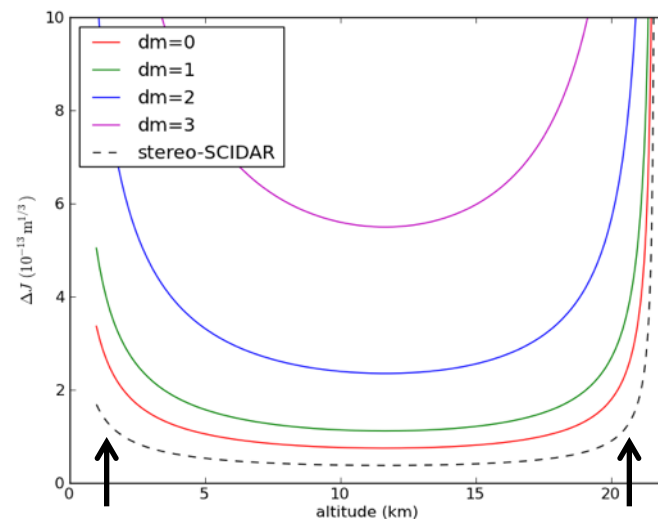
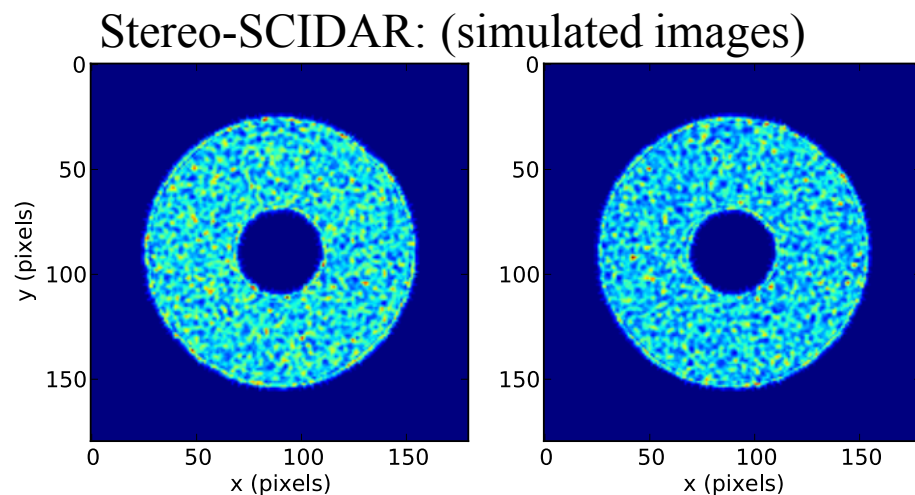
SLODAR and SCIDAR

- Profile from fit of covariance with set of response functions
- Position of peak \rightarrow Altitude of turbulent layer
- Magnitude of peak \rightarrow Strength of optical turbulence



Stereo-SCIDAR

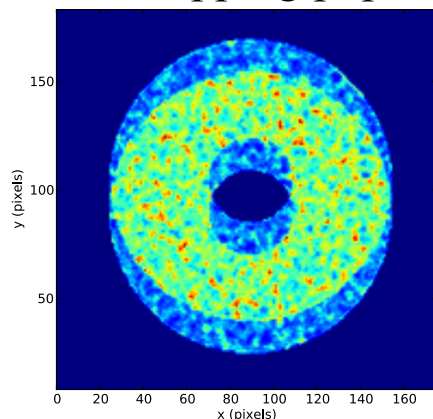
Profile sensitivity



Drop due to altitude dependence on covariance function (high altitude layers = larger signal = higher SNR)

Increased noise due to reduced area of overlap of high altitude meta-pupils

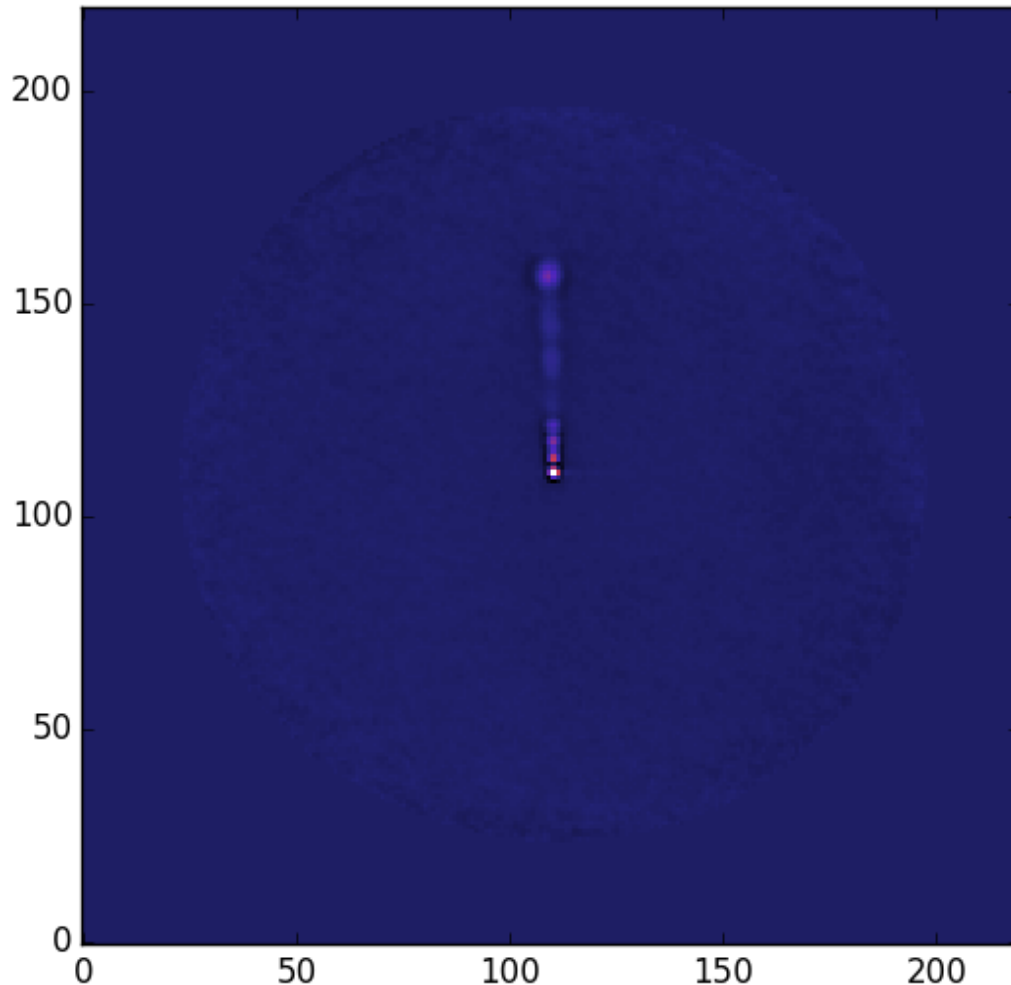
Overlapping pupils:



Generalised SCIDAR with each pupil image separated by reflective prism near focal plane

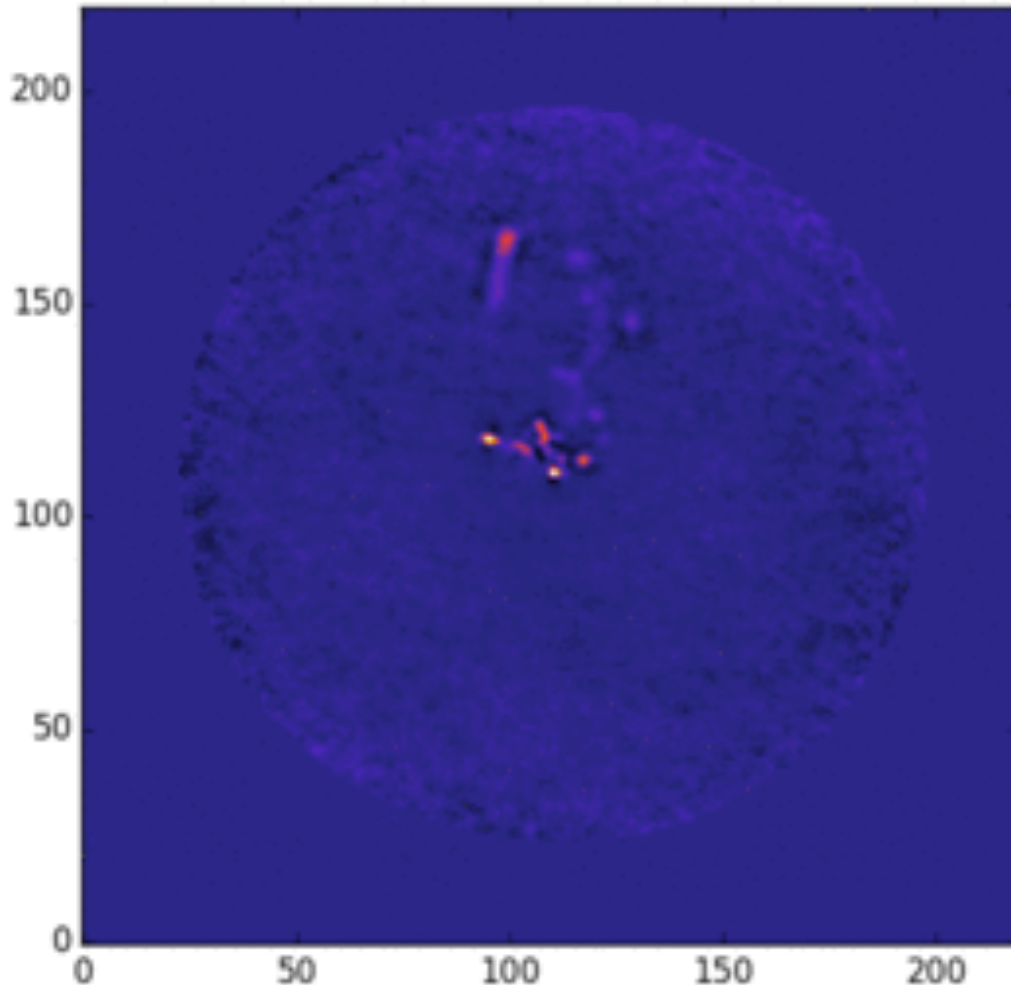
- Higher visibility of covariance peaks
- Better SNR
- Can use stars with different brightness with no loss of precision
- Better clarity of covariance peaks for turbulence velocity profiling

Turbulence Velocity



Stereo-SCIDAR cross
covariance function

Turbulence Velocity



Stereo-SCIDAR cross covariance
function with temporal offset
-> Turbulence velocity profile

- Dome turbulence
 - Complicated structure near the ground
 - Continuous turbulence
 - Layer dispersion (especially at the tropopause)
 - Complicated profile
-
- Increased altitude resolution
 - Reduced false positive layer detection
 - Detection of weak layers

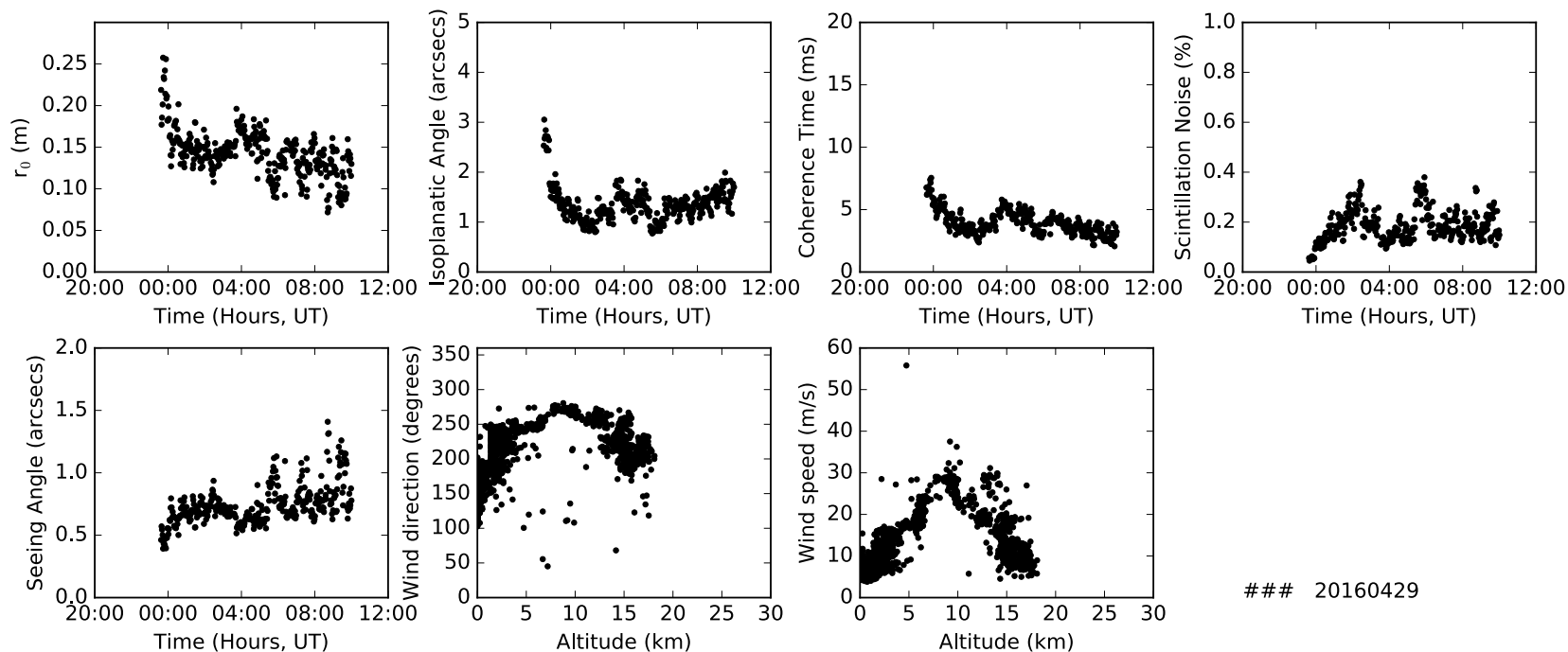
Atmospheric parameters

Measured parameters:

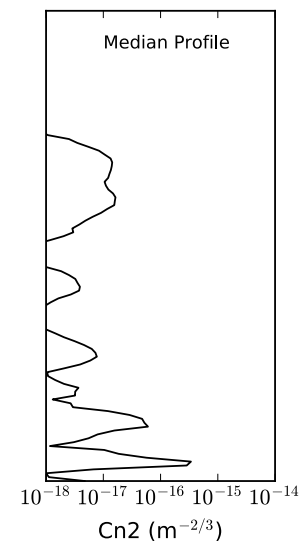
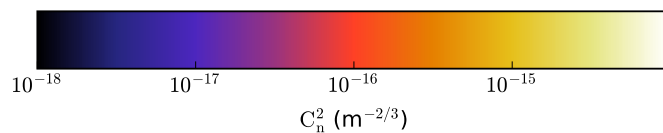
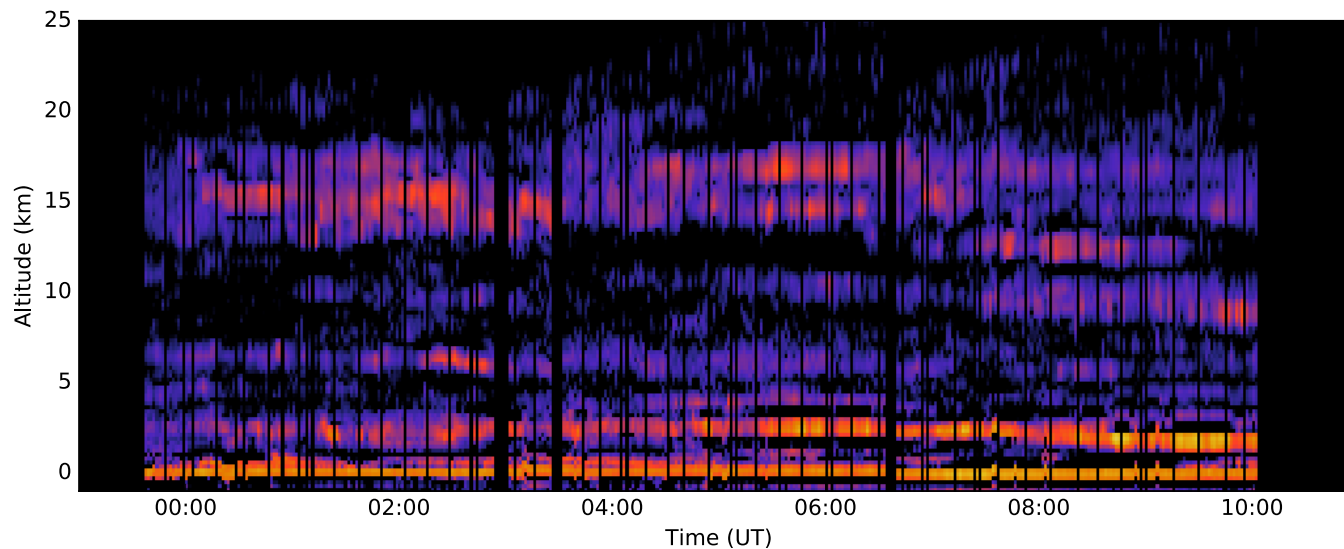
- Optical turbulence profile, $C_n^2(h)$
- Turbulence velocity profile, $V(h)$
- Scintillation decorrelation time

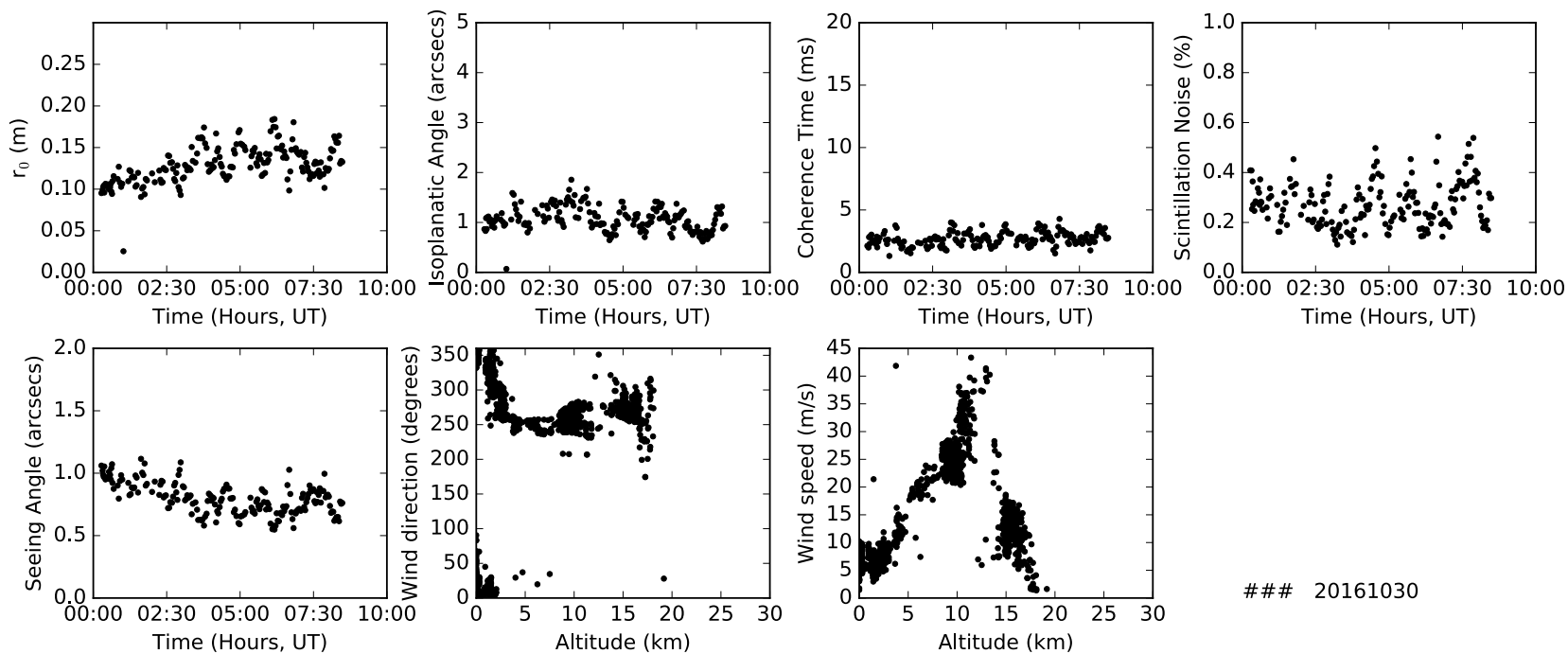
Derived parameters:

- r_0 , seeing
- Coherence time
- Isoplanatic angle
- Scintillation index

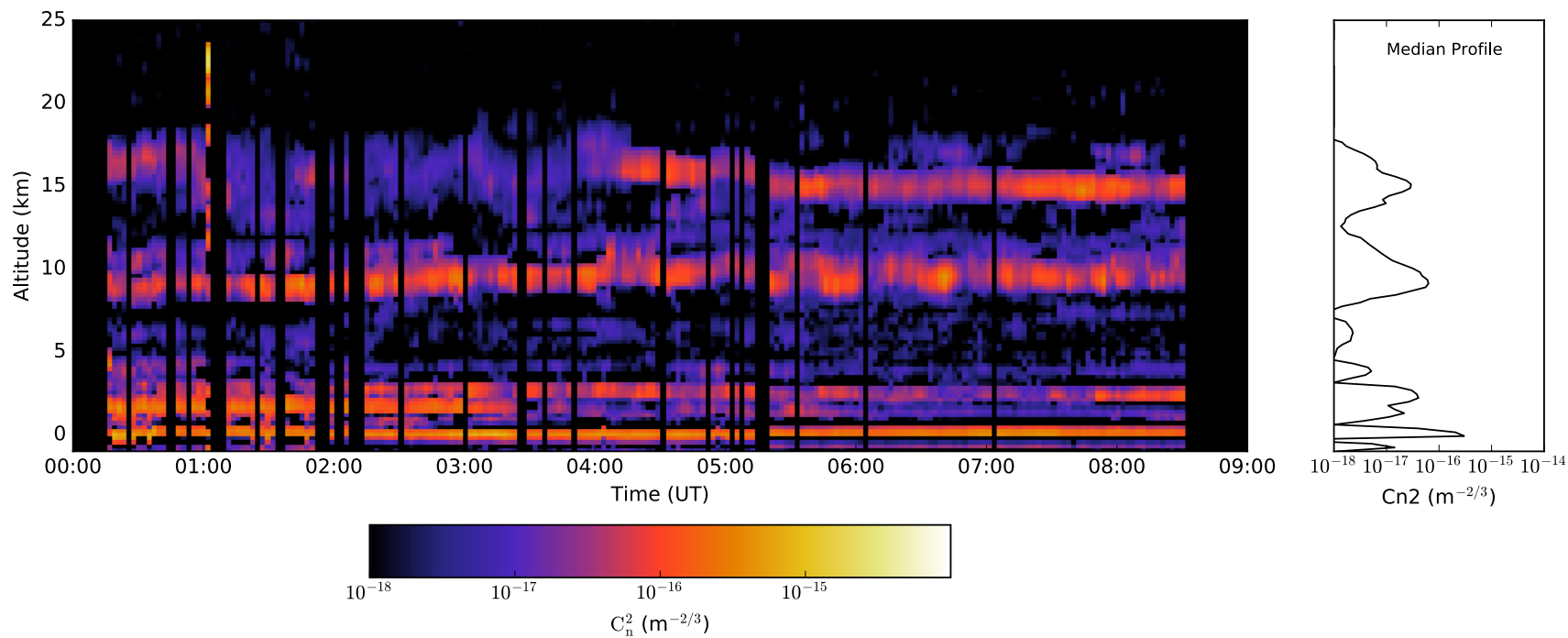


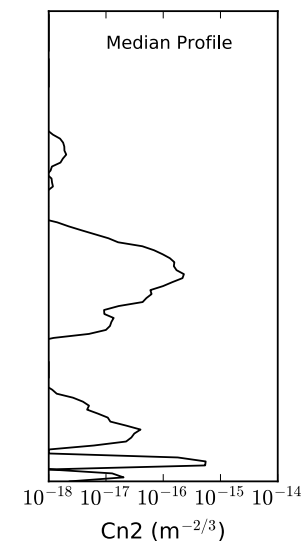
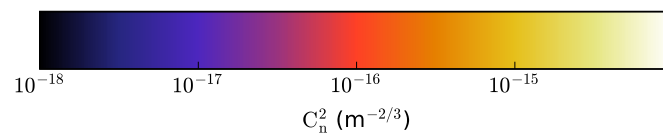
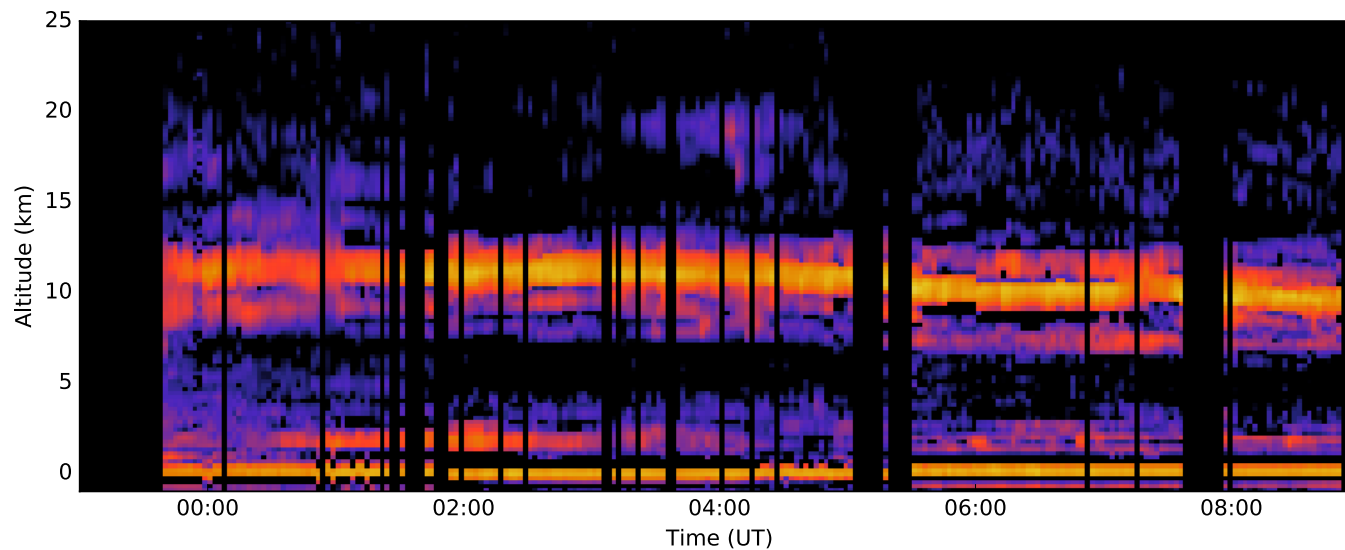
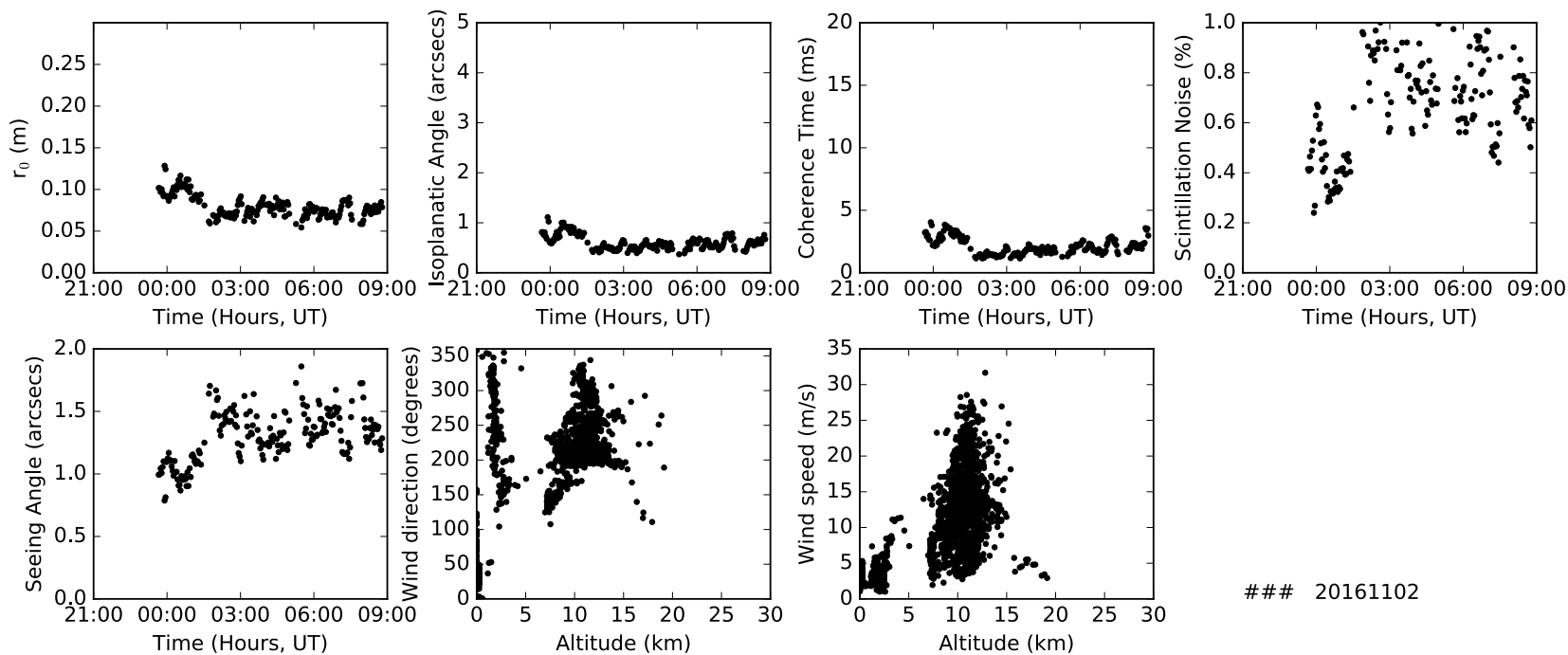
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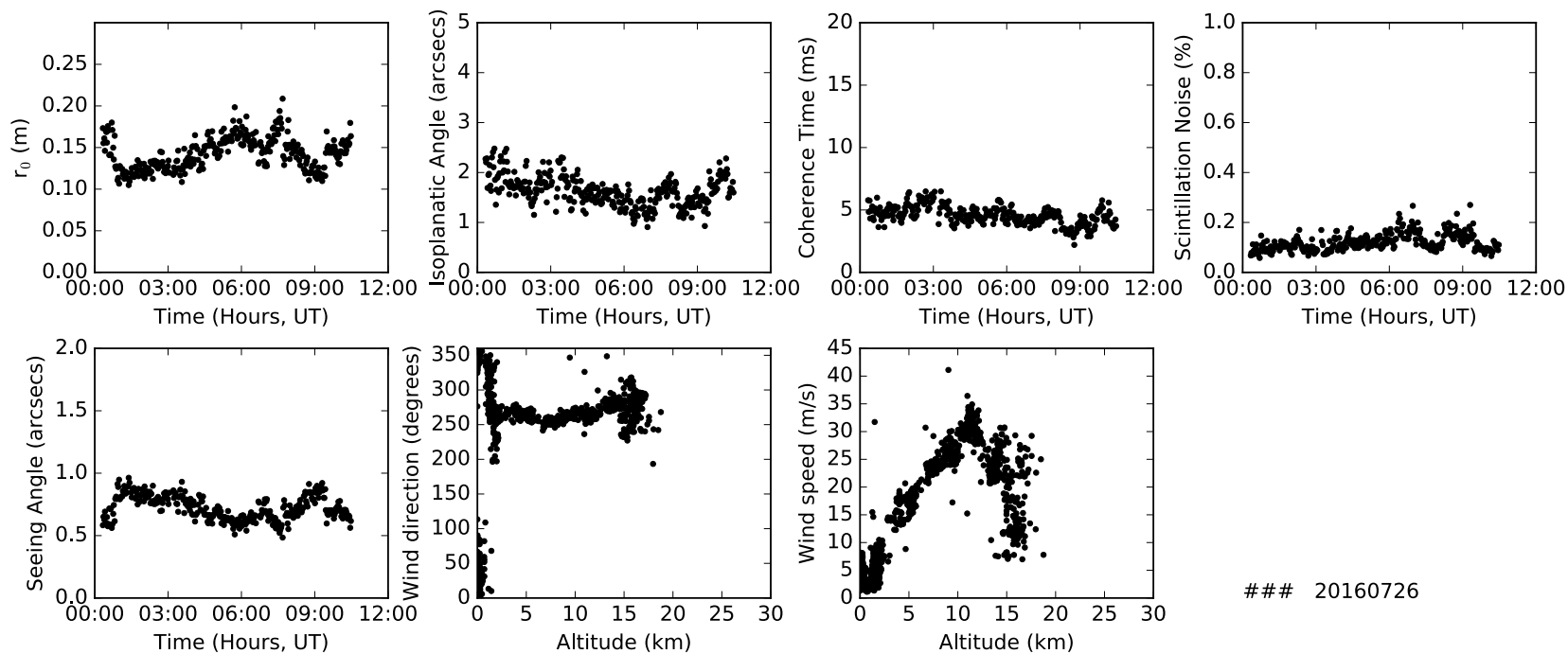




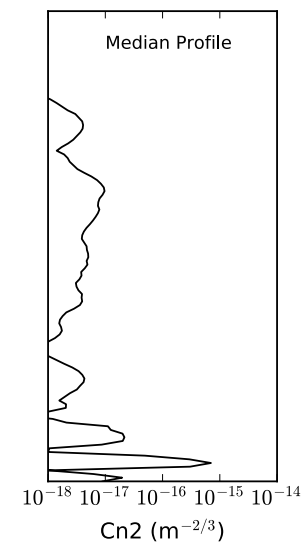
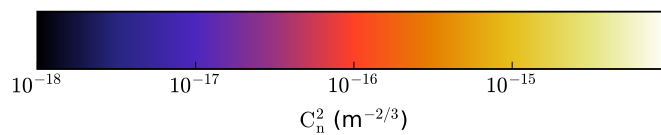
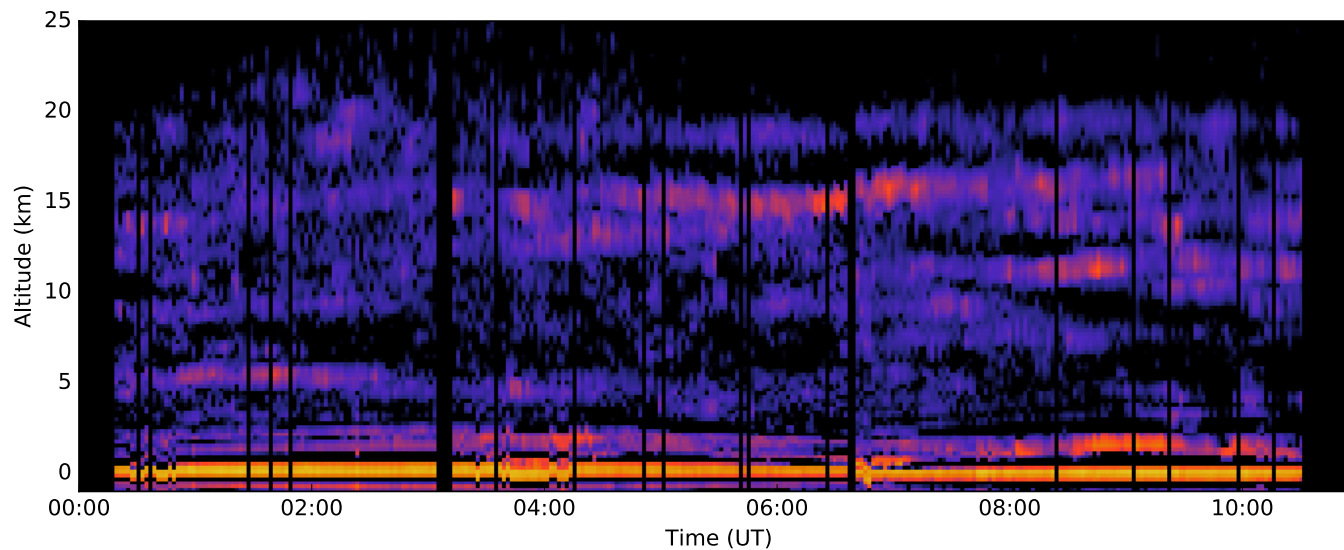
20161030





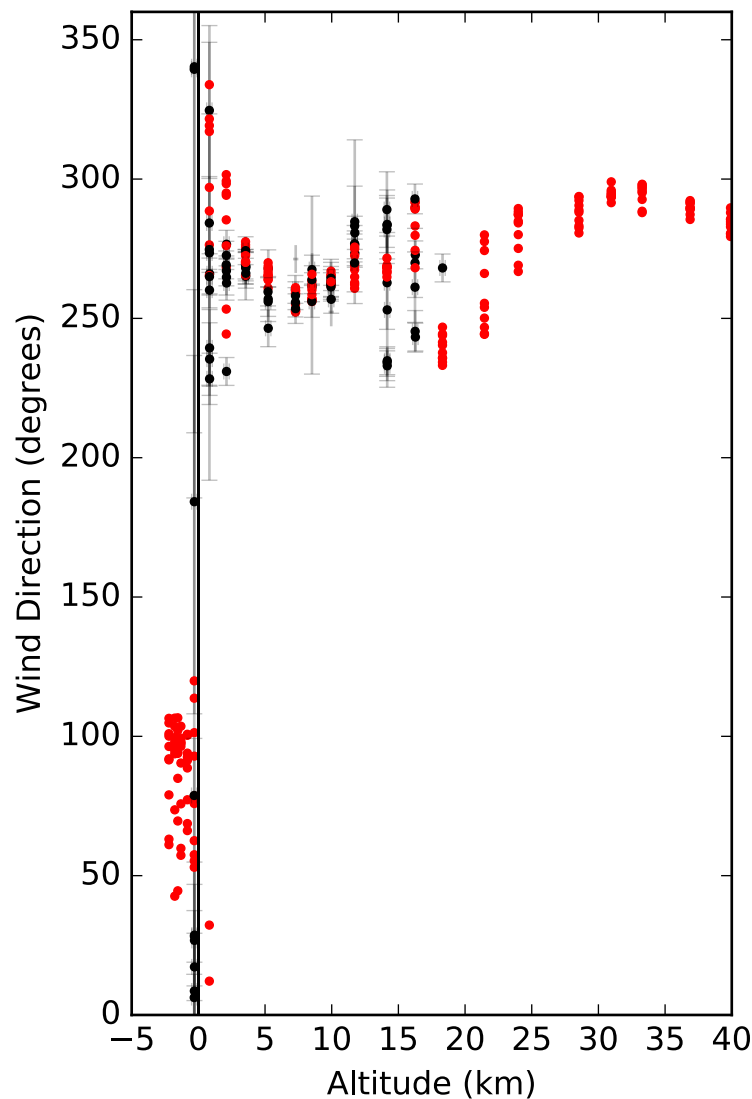
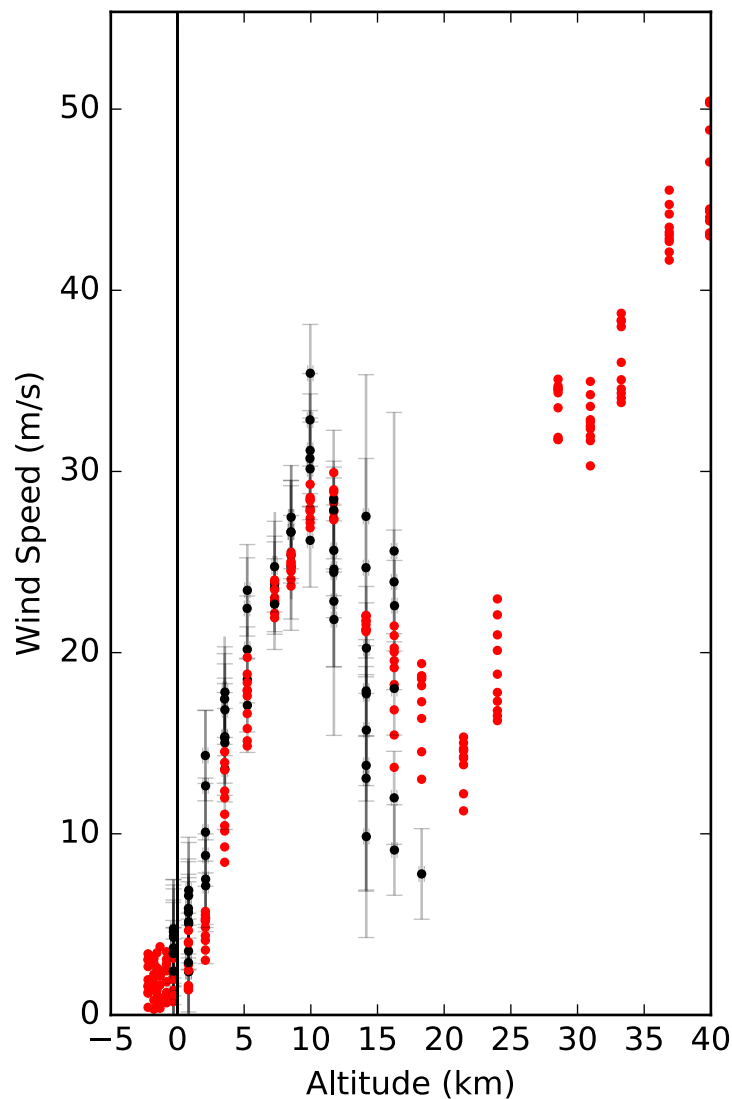


20160726



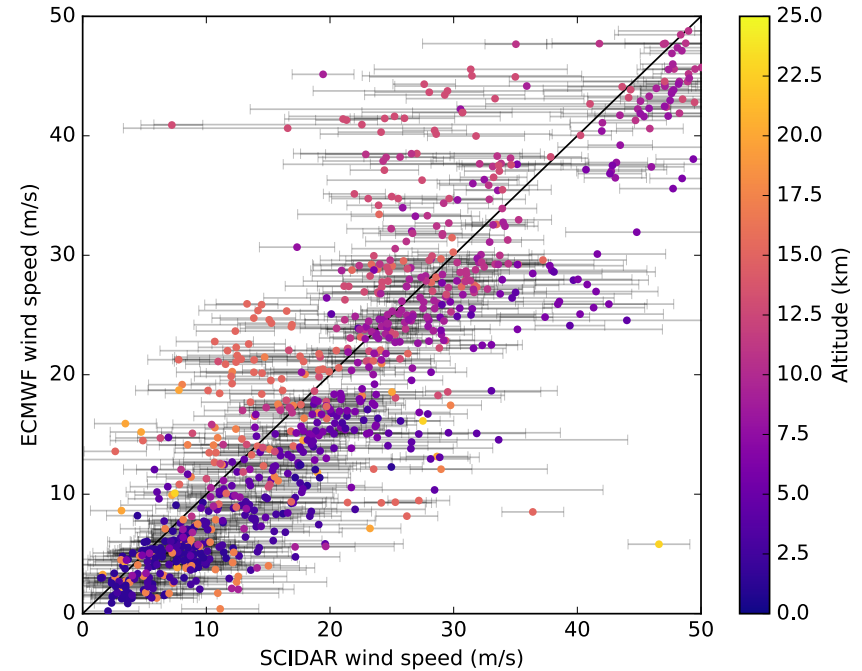
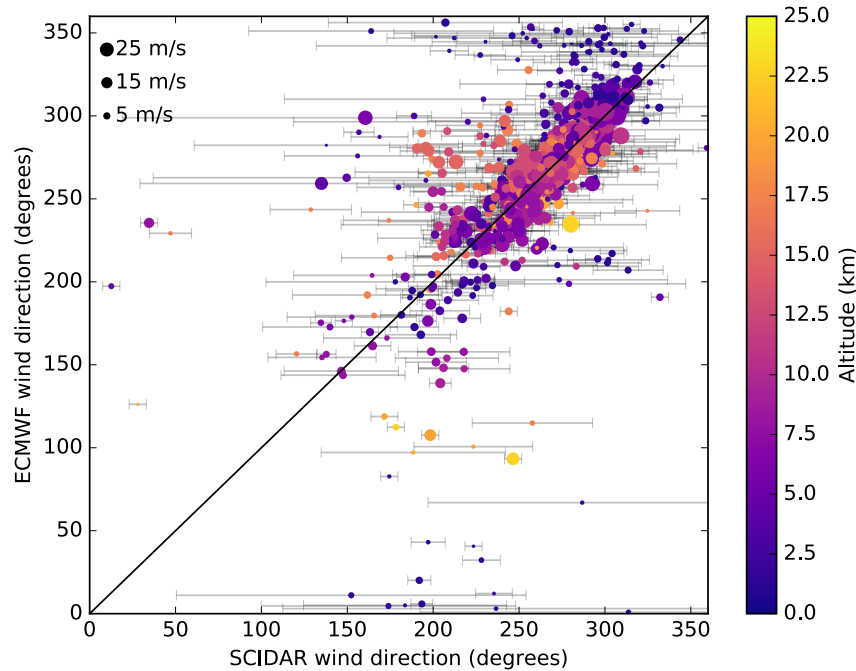
Turbulence Velocity

-ECMWF comparison



Turbulence Velocity

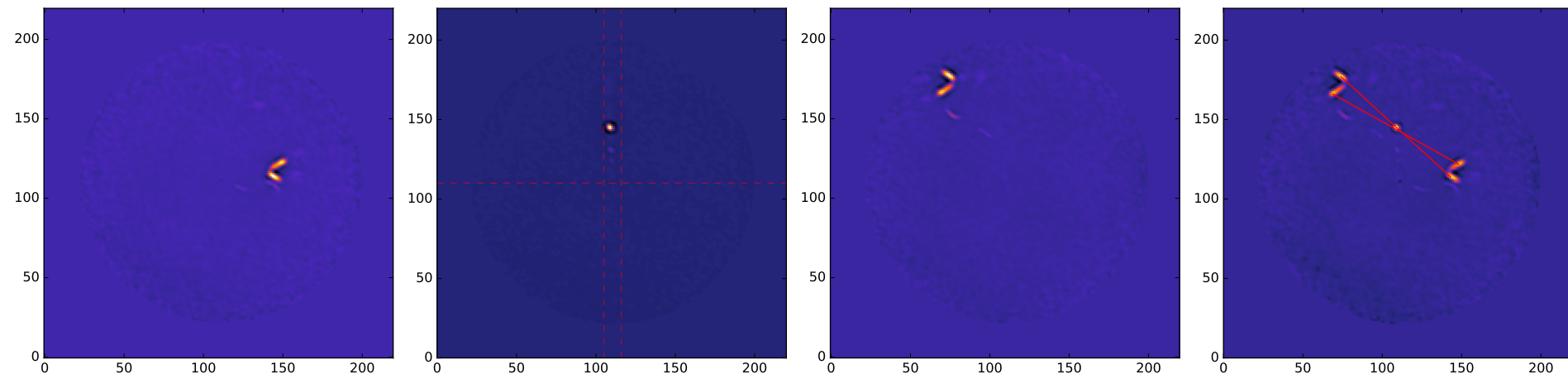
-ECMWF comparison



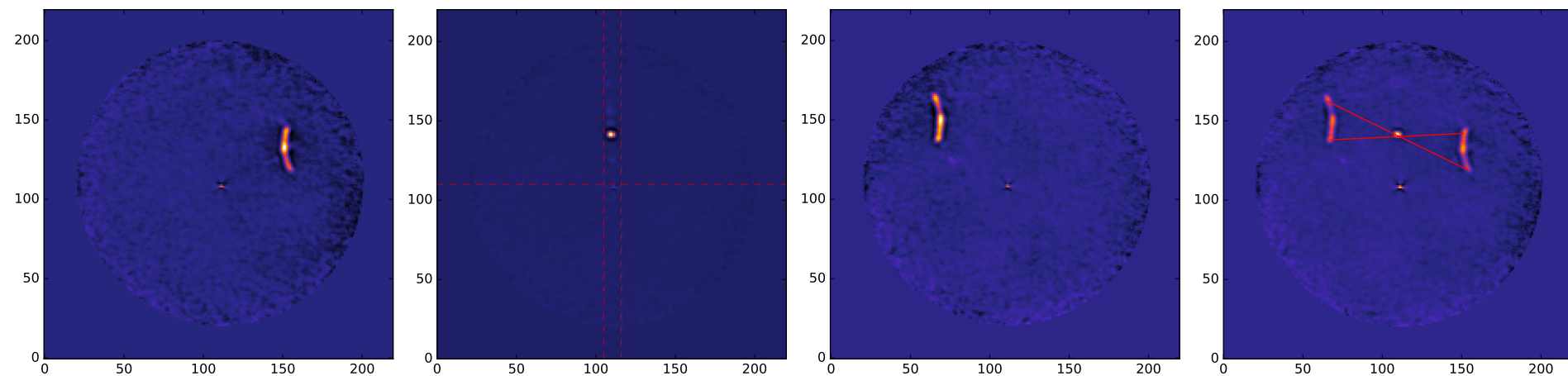
	Correlation	Bias	RMSE
Speed	0.90	-0.8 m/s	1.9 m/s
Direction	0.93	-2.6 degrees	12.5 degrees

Turbulence Structure

2 layers with different velocity

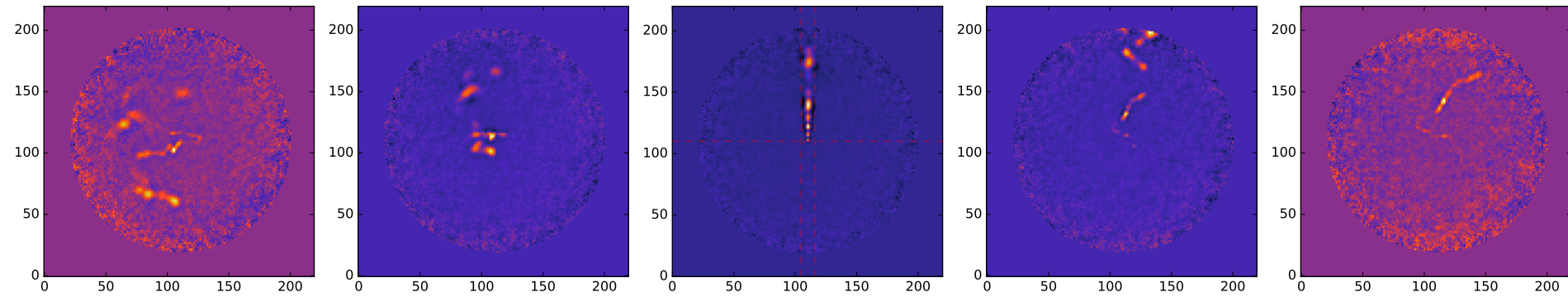


Velocity dispersion

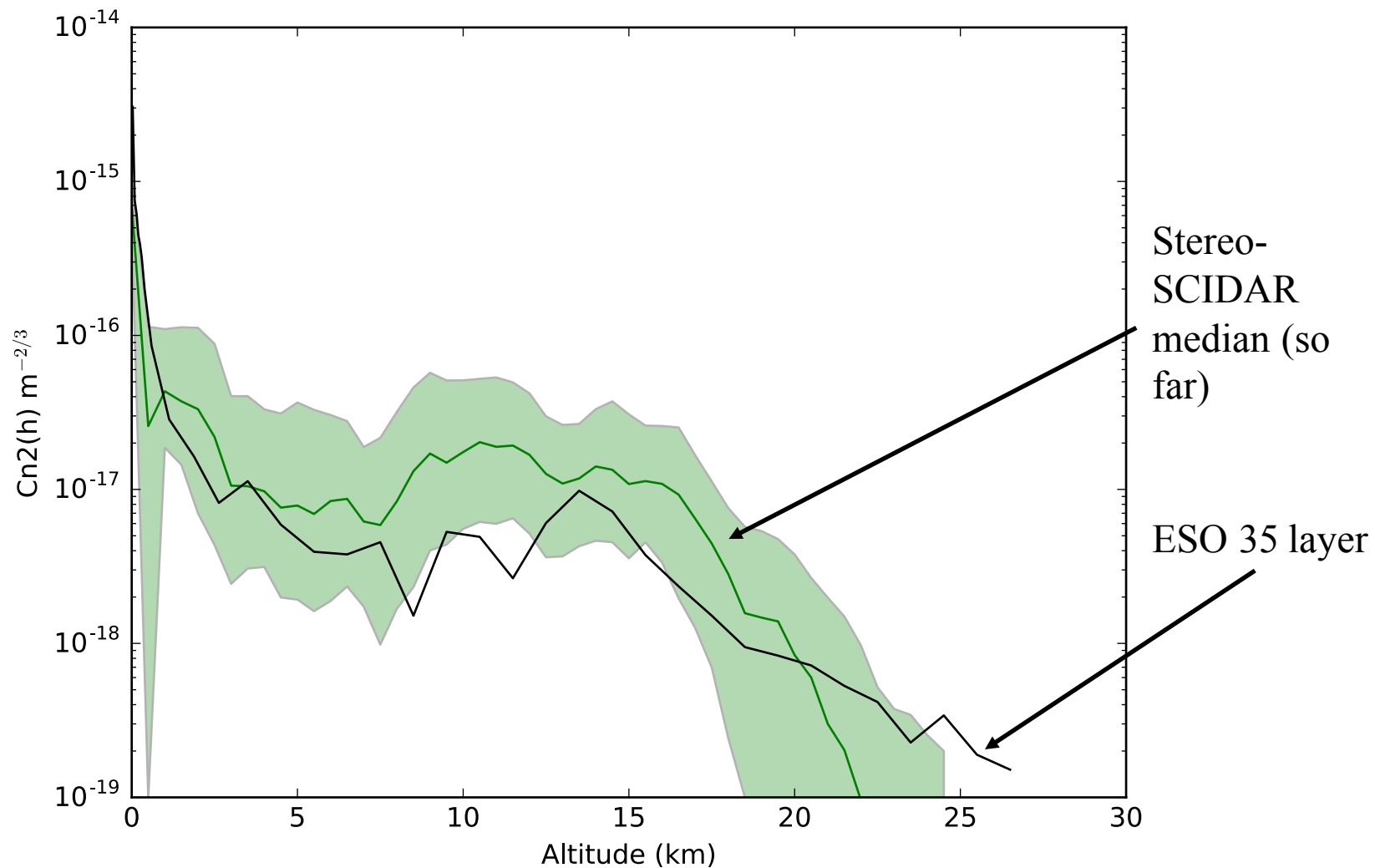


Turbulence Structure

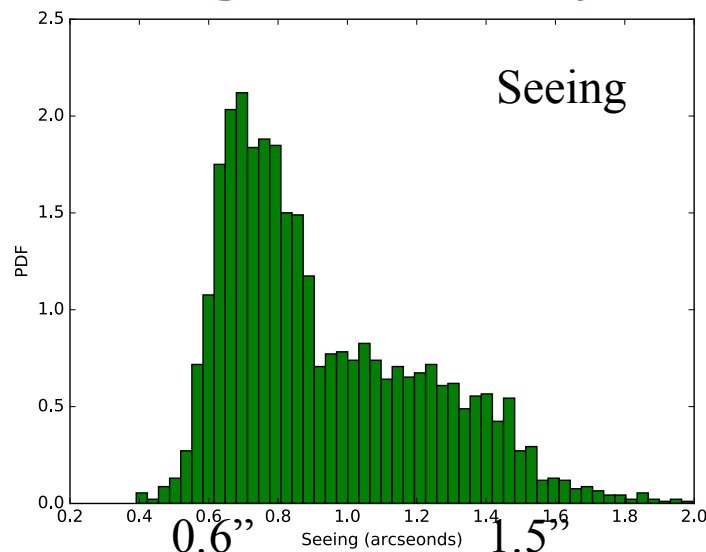
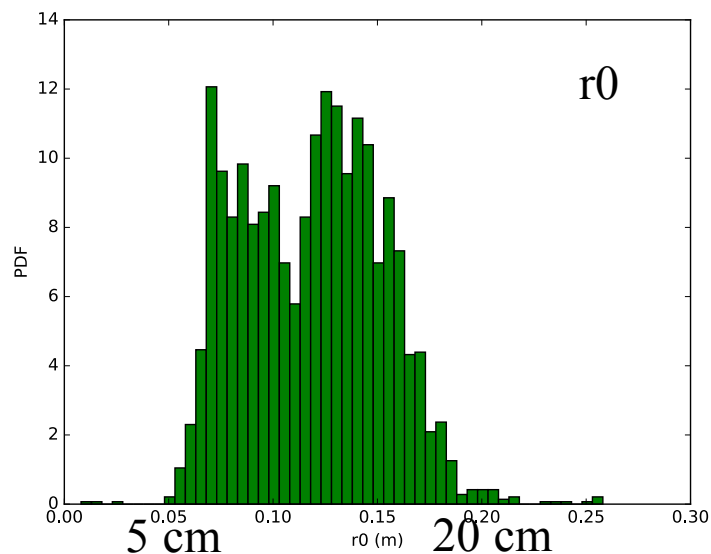
Typical example



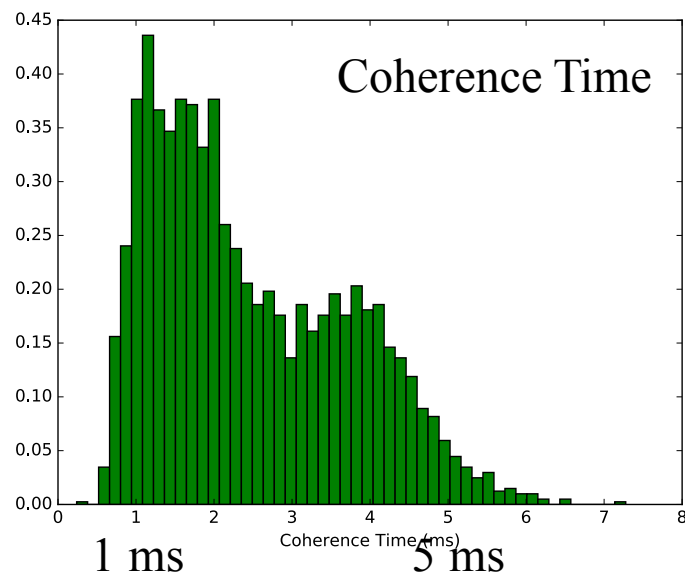
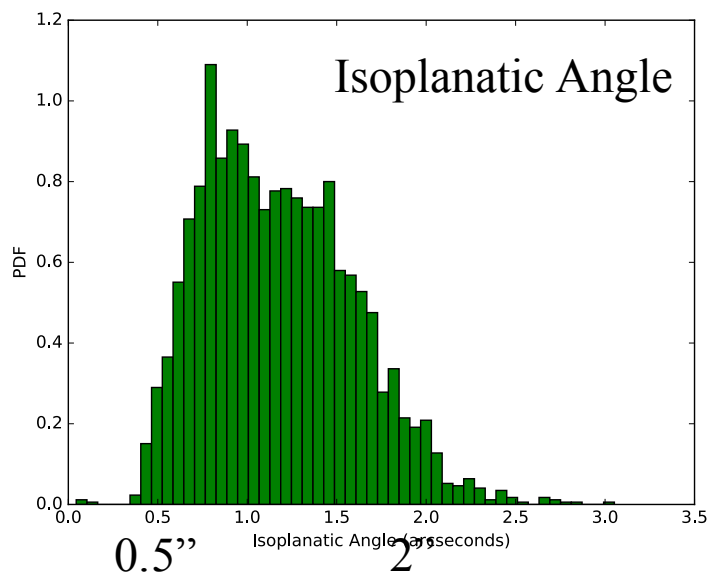
Median Profile



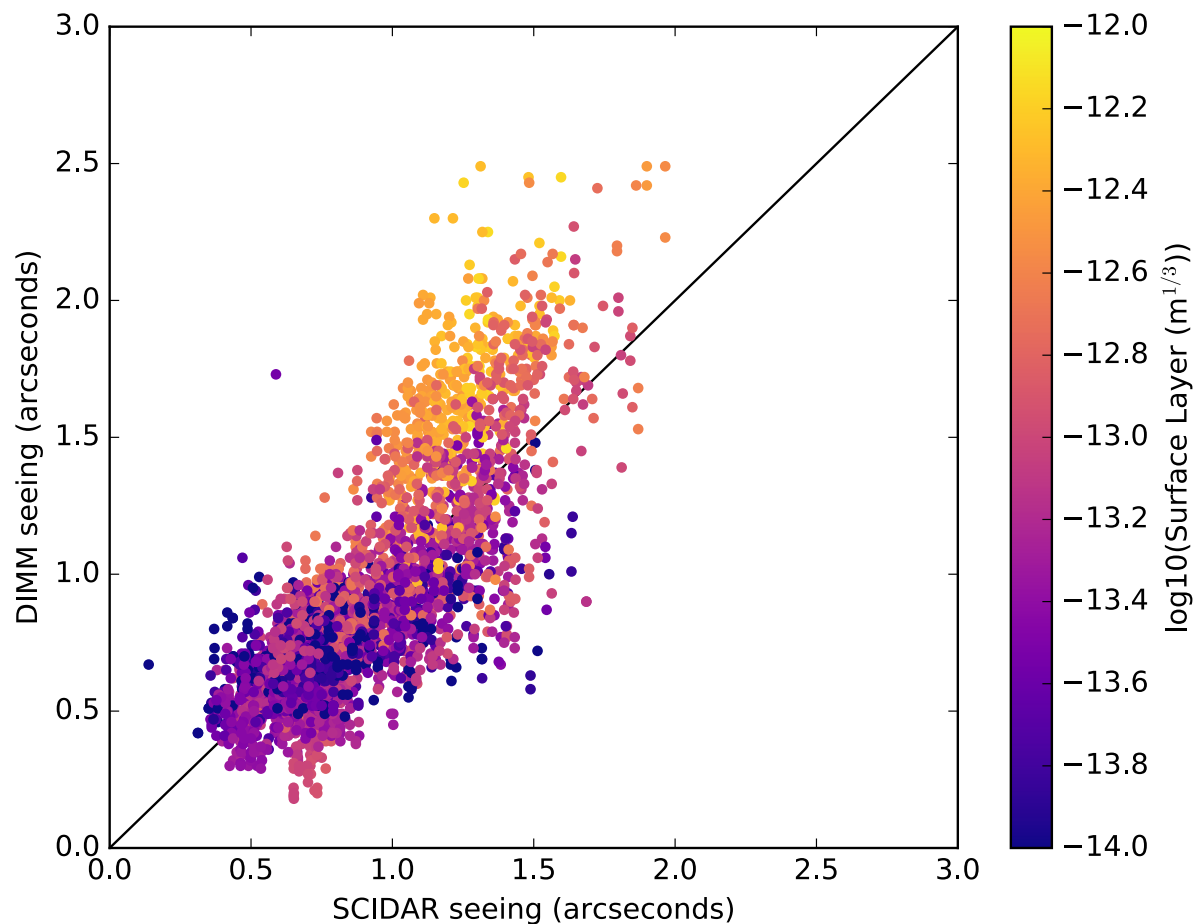
Not enough data yet...



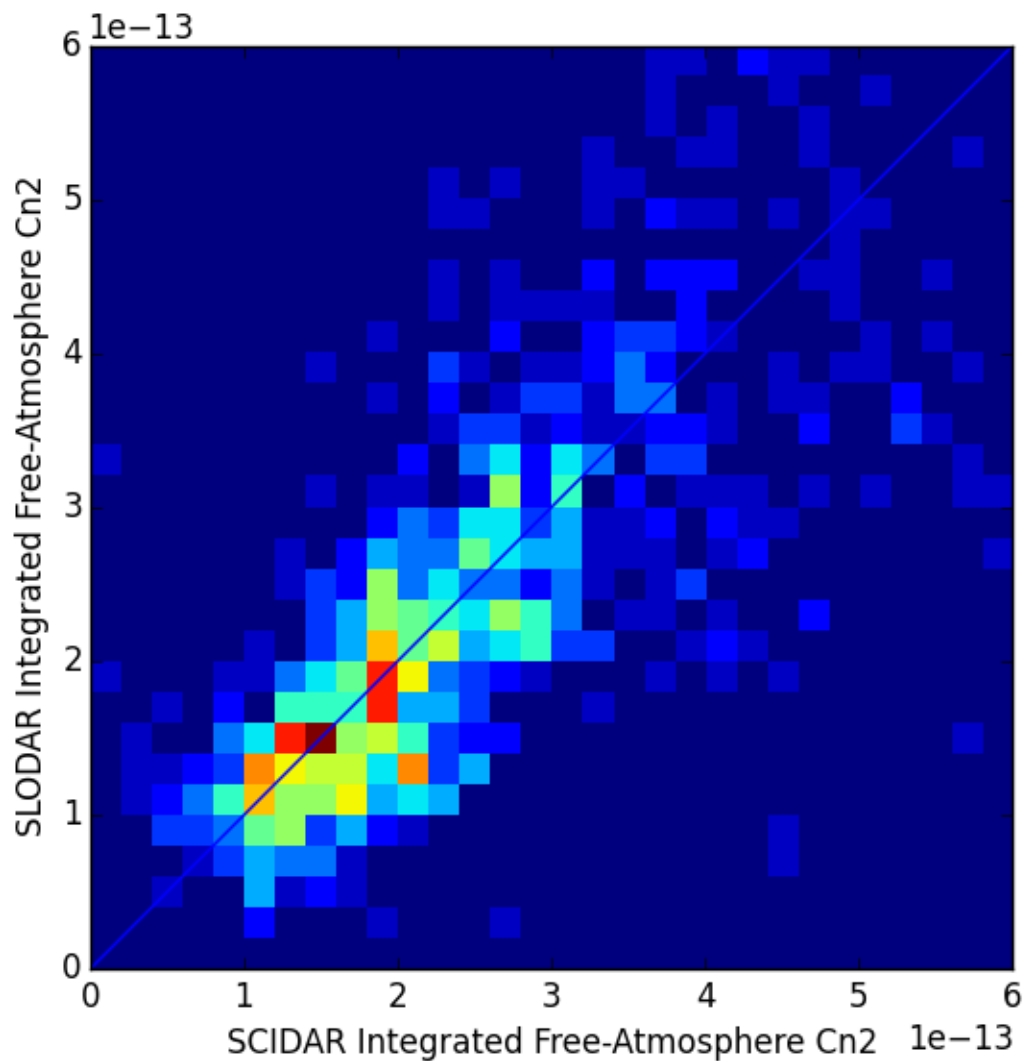
13 nights in
April
July
November
December



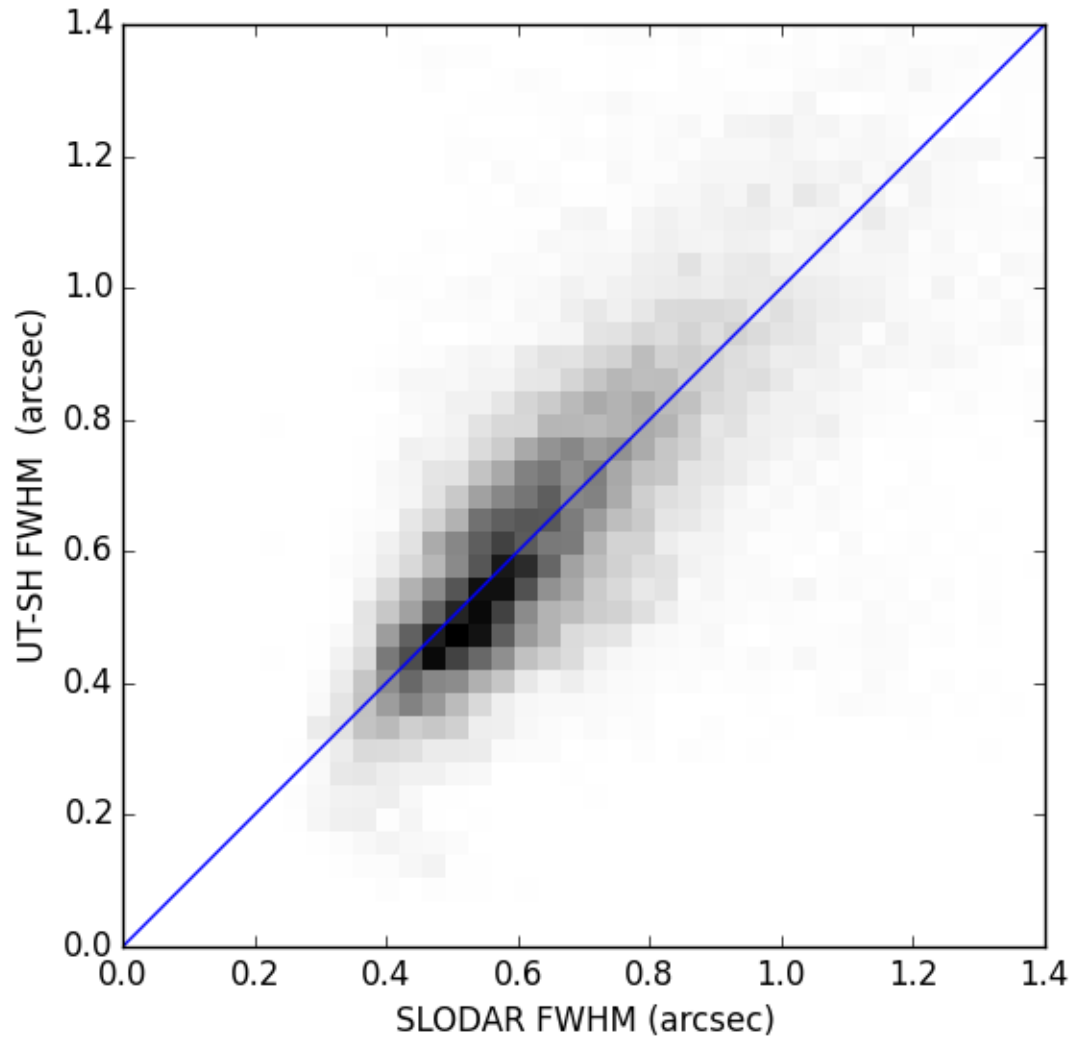
SCIDAR – DIMM Seeing



SCIDAR – SL-SLODAR



SL-SLODAR - UT



ESO Stereo-SCIDAR

Measured parameters:

- Optical turbulence profile, $C_n^2(h)$
- Turbulence velocity profile, $V(h)$
- Scintillation decorrelation time

Derived parameters:

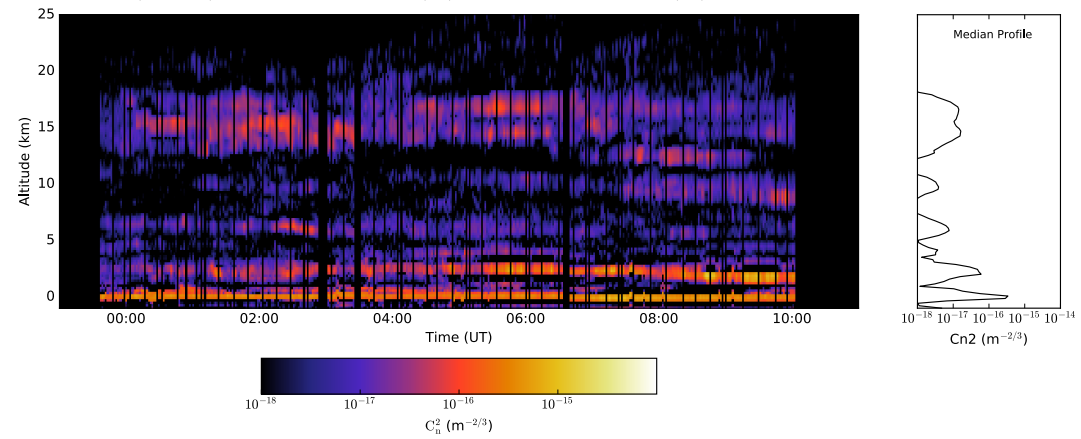
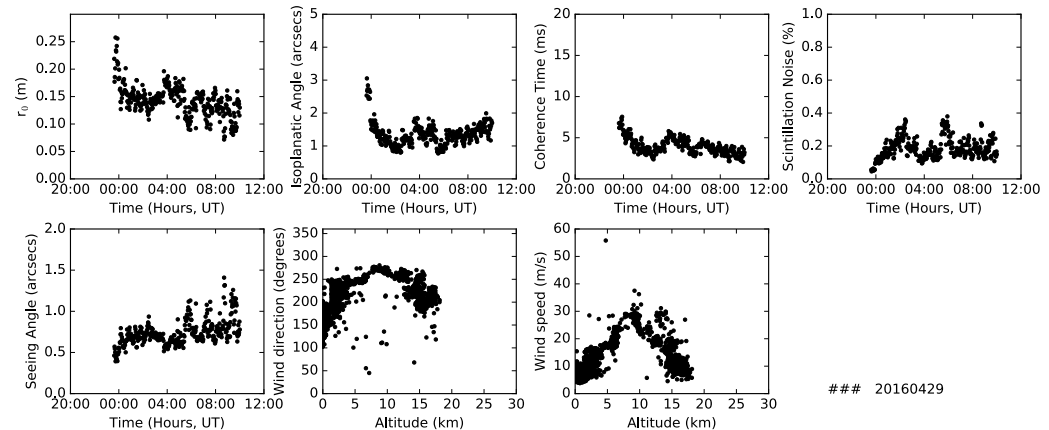
- r_0 , seeing
- Coherence time
- Isoplanatic angle
- Scintillation index

Applications:

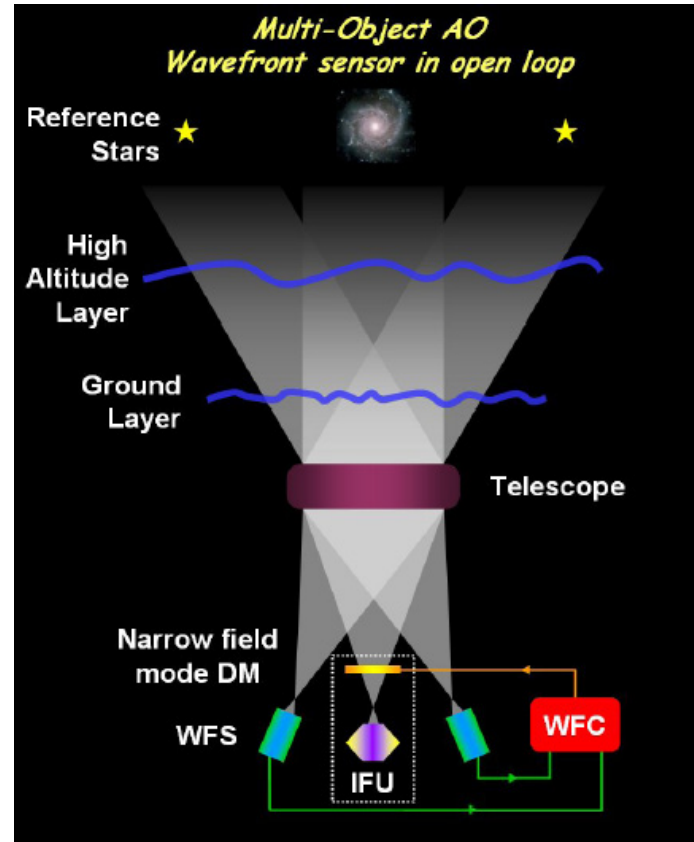
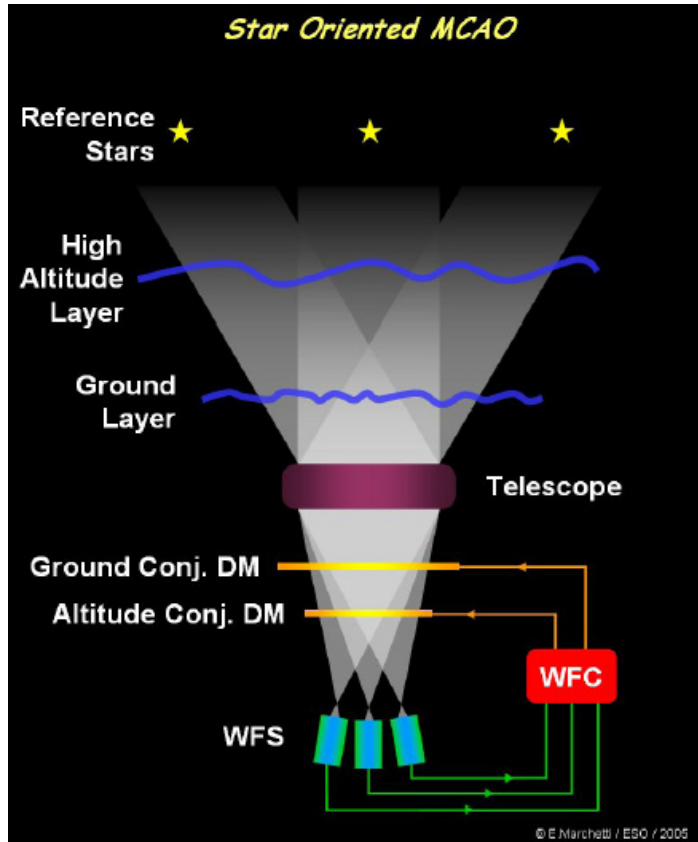
- Instrument design
- Performance monitoring
- Optimisation

ESO operations:

- 4 or 5 nights per month
- Every month (not clustered)
- At least one year



Tomographic AO

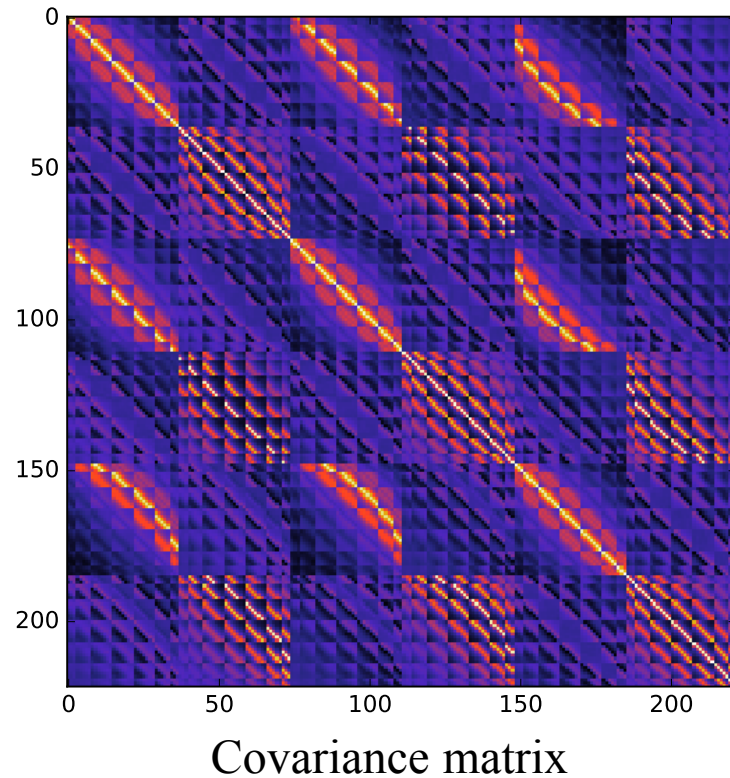
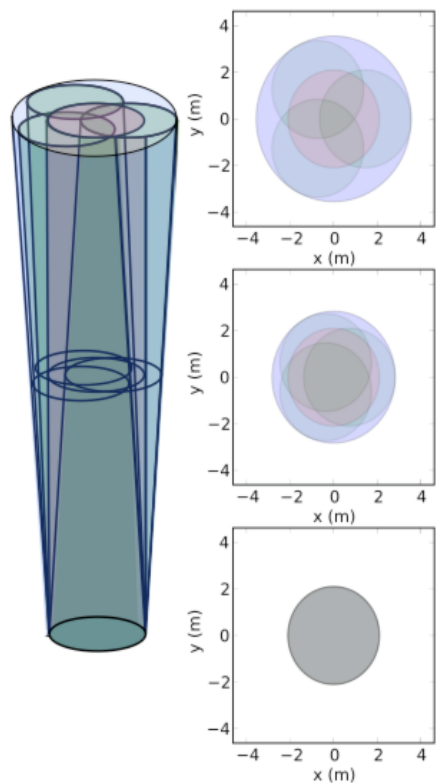


External profiler for:

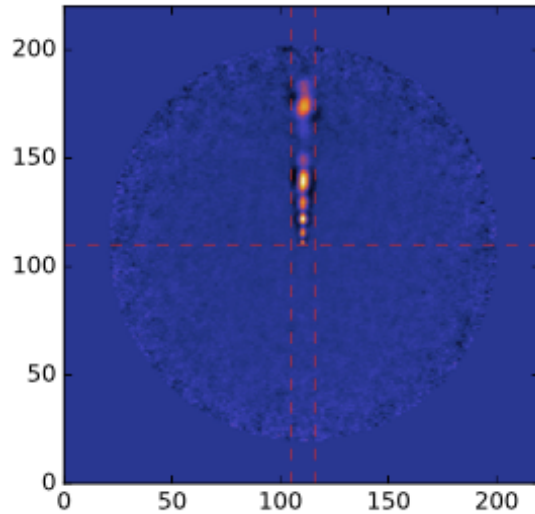
Reconstructor performance modelling (development and monitoring), robustness, automation, optimisation and pre-computation

Wide-field AO

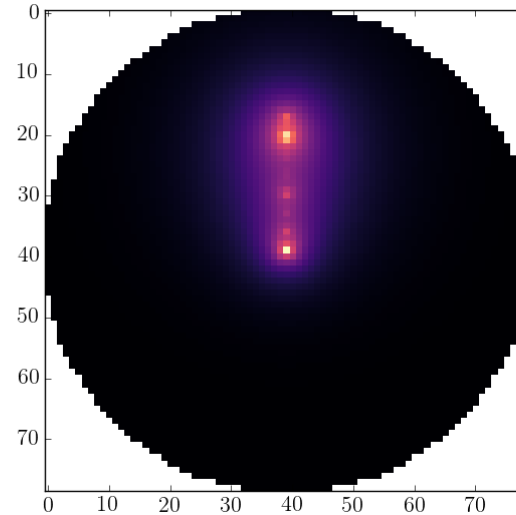
- Tomographic reconstructor optimisation
- (Make volumetric model of atmospheric turbulence)



AO telemetry



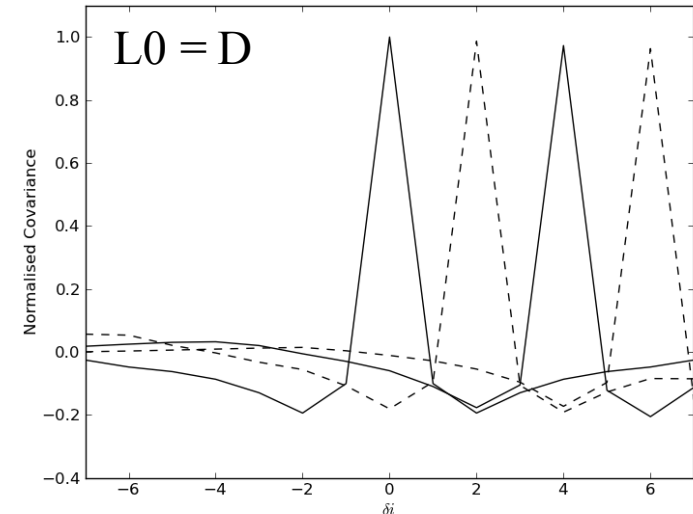
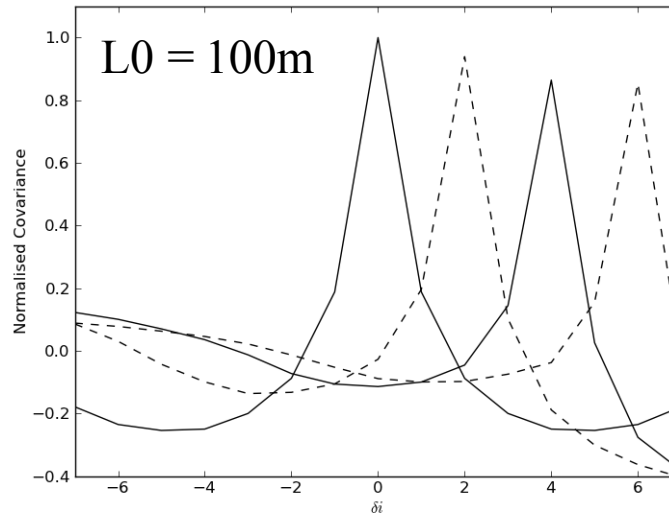
Example SCIDAR data



Simulated AOF data (no noise)

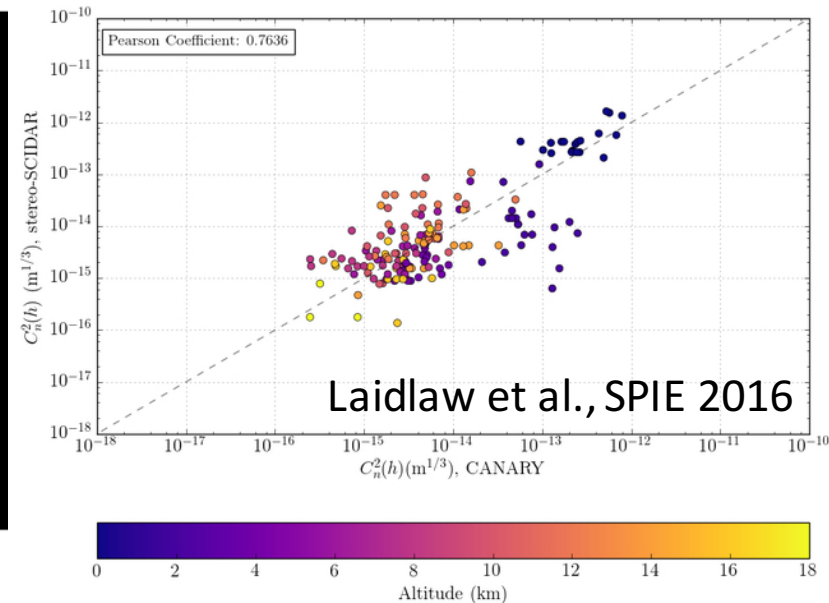
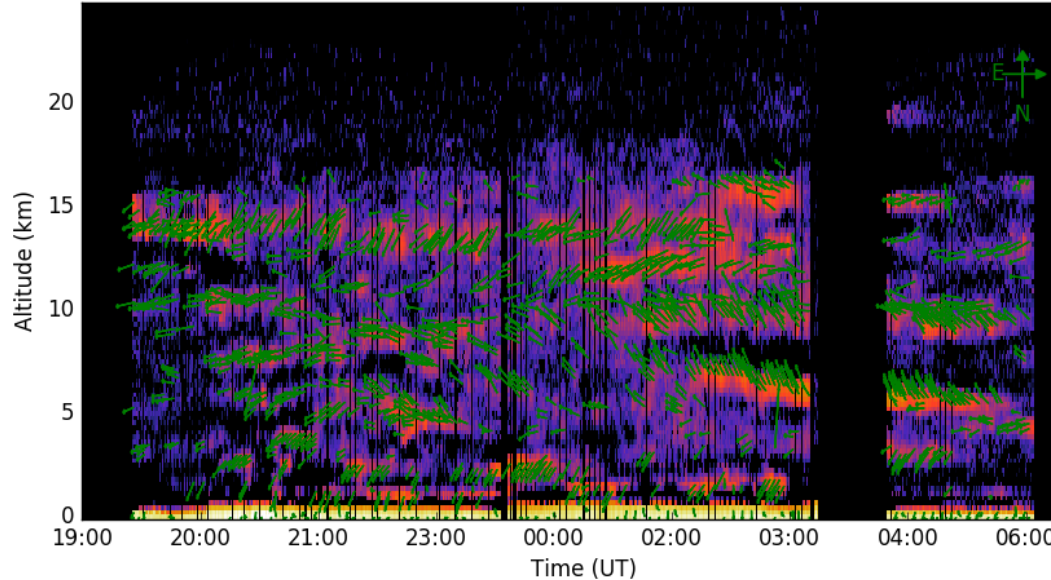
Ground layer
suppressed
for clarity

- Simultaneous fitting of:
- Turbulence strength
- Outer scale
- AO Performance depends on fidelity of this model



Independent Profiler

Eg Stereo-SCIDAR, turbulence strength, velocity

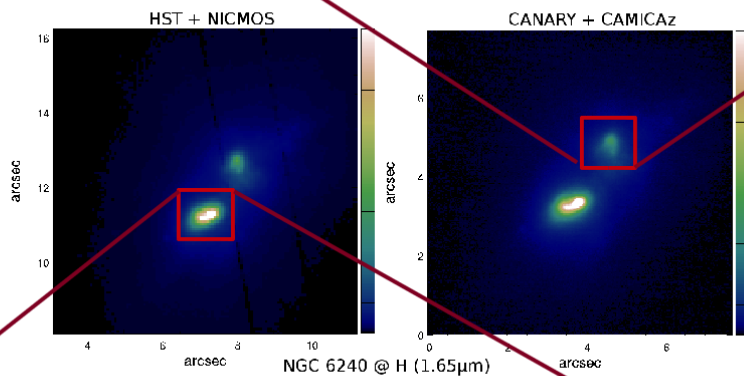
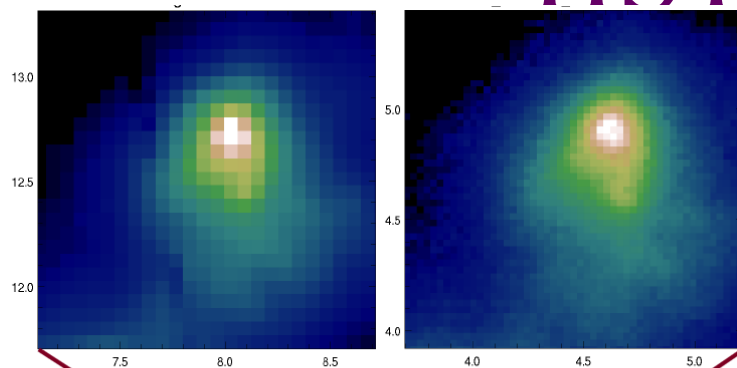


- Turbulence strength
- Turbulence velocity
- No convergence issue
- No outer scale issue
- Unbiased
- Validated
- Different line of sight

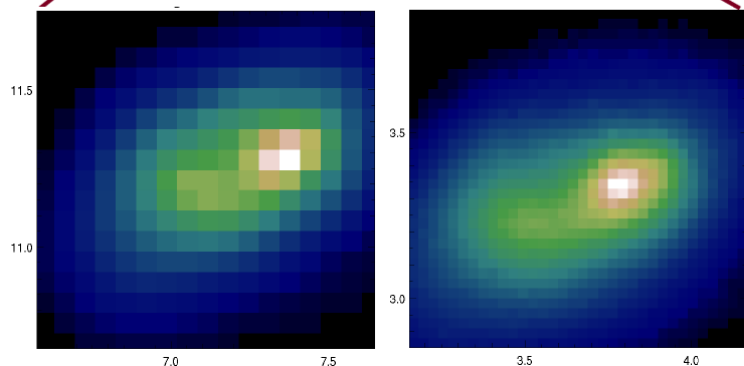
Canary comparison with HST



Tomographic AO

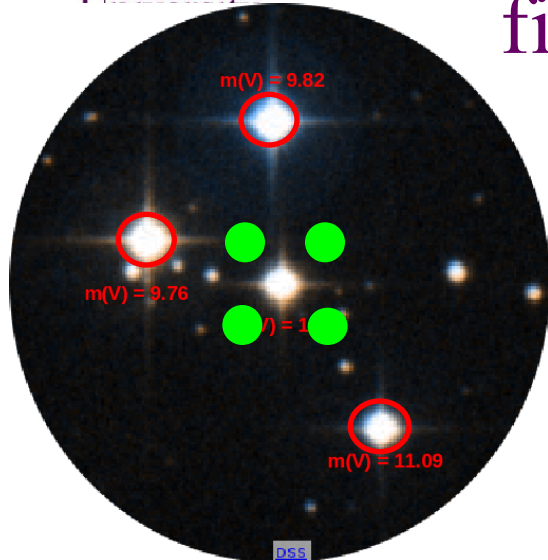


NGC 6240 @ H (1.65 μ m)



LQG tomographic MOAO:

first on-sky results with CANARY

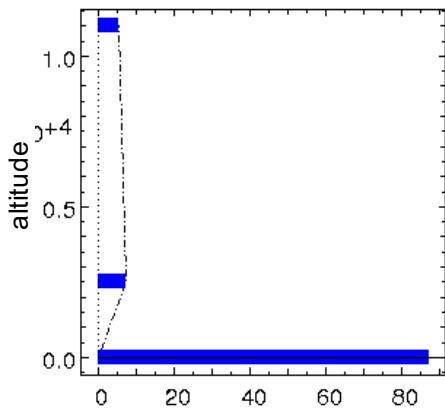
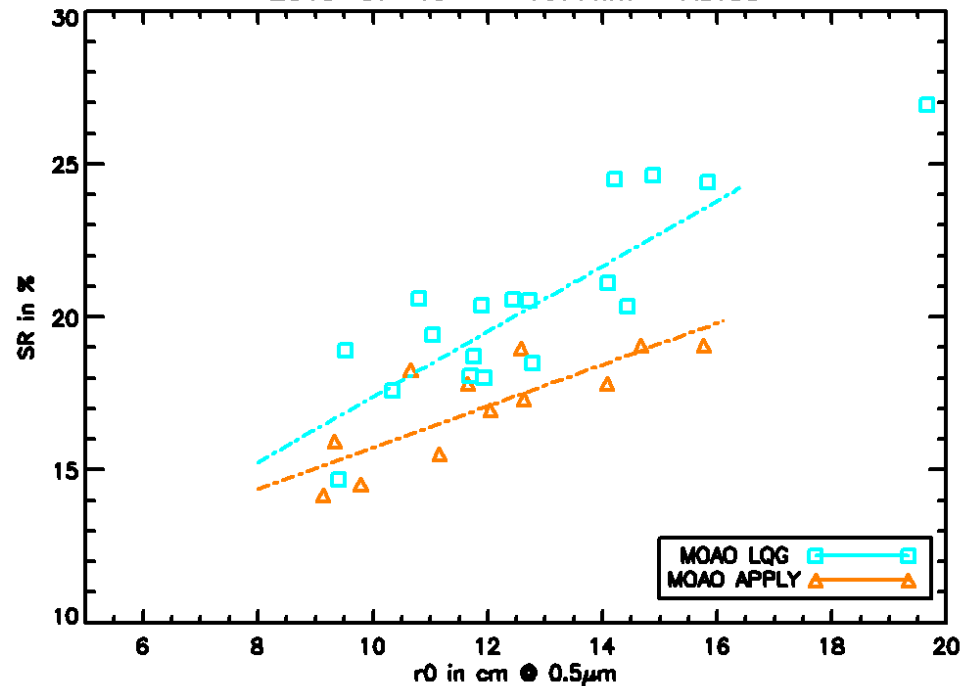


Asterism 53

- 19th July 2013, H band – 4LGS + 3NGS

Simple perturbation model that relies on wind norm in each layer

2013-07-19 – 1677nm – AST53



SCIDAR | Model
14 m/s | 10 m/s

9 m/s | 6 m/s
3 m/s | 2 m/s

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