`Imaka: a wide field GLAO demonstrator for advanced diagnostics and control

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Wavefront Sensing in the VLT/ELT Era V
AO Workshop Week II. October 13-15 2020

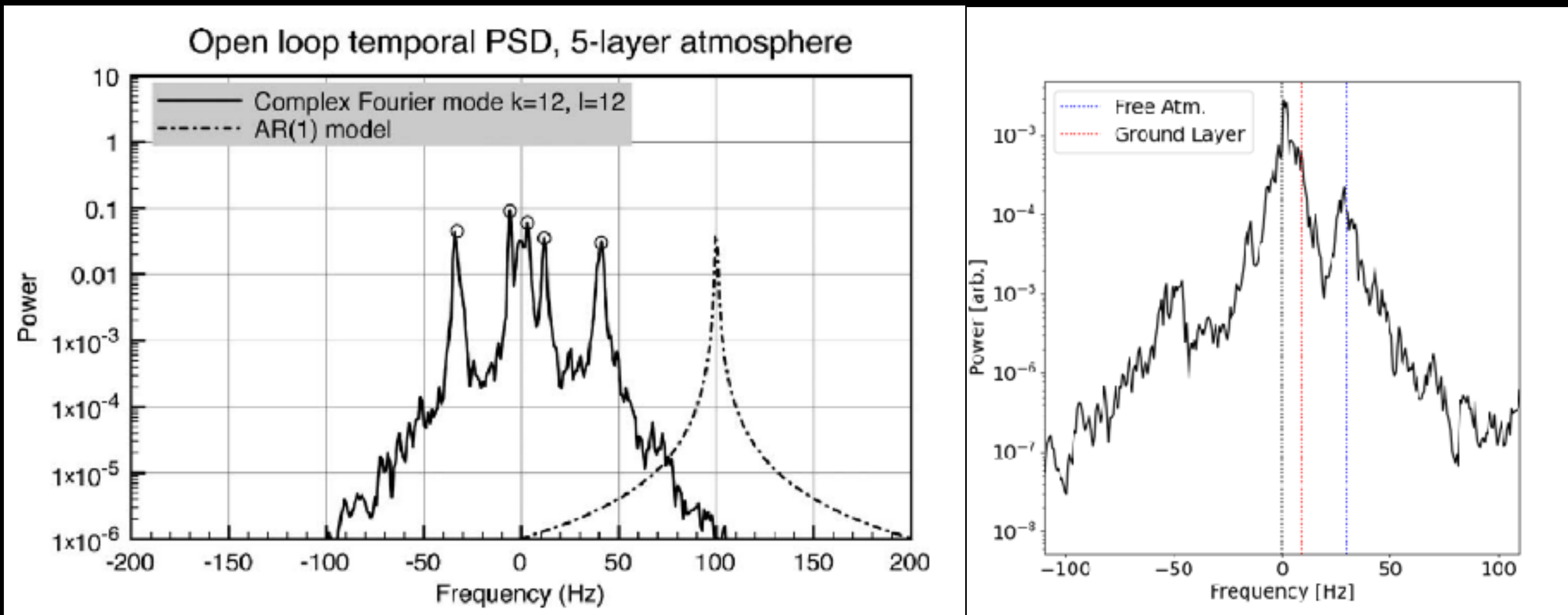
`Imaka

- Very wide field GLAO demonstrator and development platform on UH2.2m telescope, to explore theoretical and practical limits to very wide fill AO.
- 5 SH WFS with 8x8 subapertures to control 36 element bimorph mirror.
- Wavefront sensors on fixed plate, 18’x24’ patrol field
- STA1600 monolothic 10kx10k detector covering 11’x11’ science FoV (Hawaii 4RG with 7’ soon!)
- Demonstrated and quantified GLAO performance (Abdurrahman 2018)
- Current developments include:
    - Predictor control (to better separate GL from FA)
    - Layer identification (useful for predictor but also site monitoring)
    - Adaptive Secondary Mirror (TNO) demonstrator using new actuators.

Predictor control

- The goal is achieve a better GLAO correction using fewer guide stars
- Achieve this through what we call “temporal tomography”
  - Atmospheric layers usually have different velocities
  - Use principles in predictive control to identify specific layers
  - Filter out layers that do not match the ground layer wind speed, which we can pull from the CFHT weather tower
- Based on Predictive Fourier Control (Poyneer et al. 2007)
  - Each Fourier mode oscillates at a frequency determined by the spatial mode and wind speed
  - Facilitates filtering out temporal frequencies from layers we identify as coming from the free atmosphere

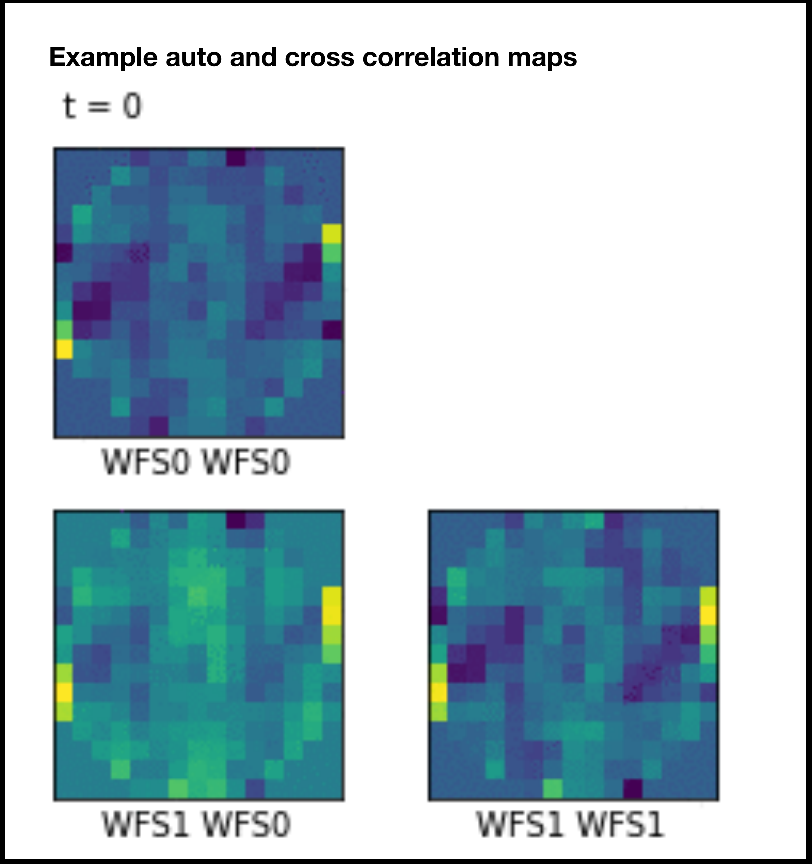
Figure from Poyneer et al. (2007)



A challenge we need to overcome is our lower resolution WFS (8x8 vs 48x48)

Layer identification
Temporal Cross Correlation Maps

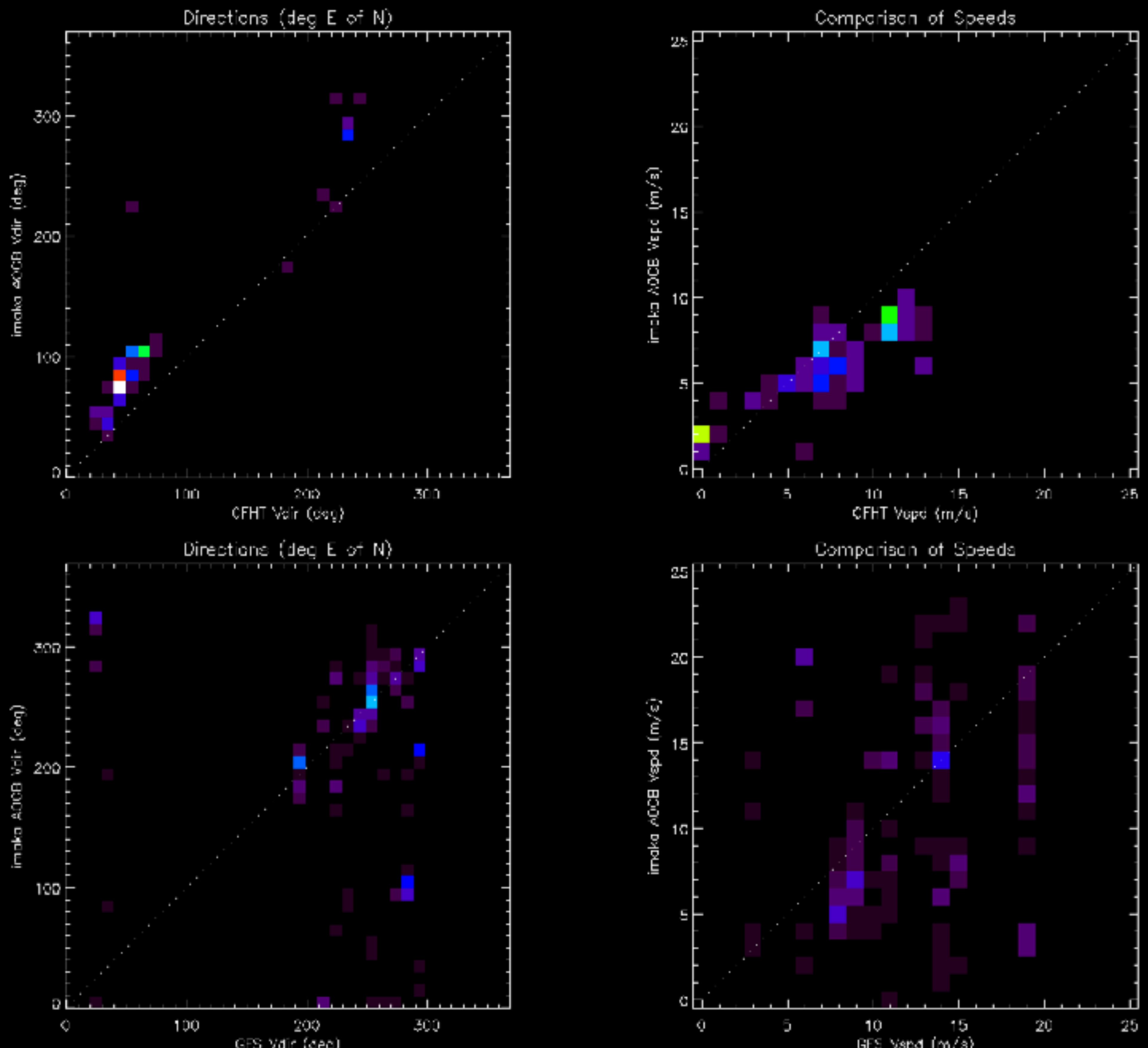
- Basic Method:
  - Uses WFS Slopes from open loop telemetry
  - Pre-subtracted average slopes and static aberrations
  - Generated time averaged covariance maps and cross covariance maps across WFS



Eden McEwen

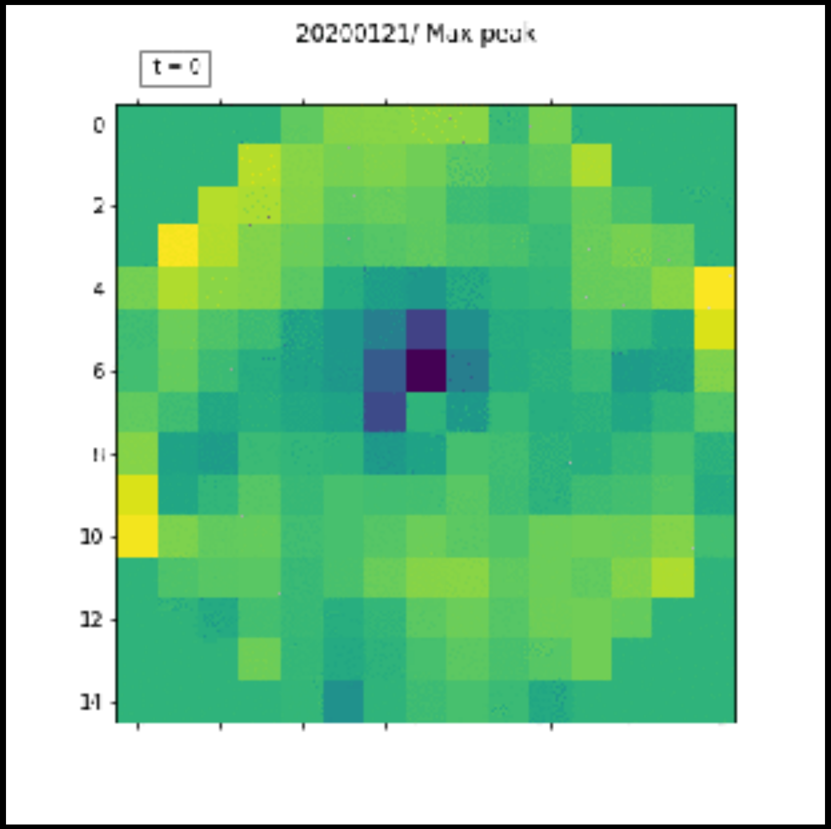
Year	Observing Dates	Num. Nights	Num. Data Files	Field	Num. GSs
2018	03/01 - 03/02	2	75	Beehive-W	5
2018	05/25 - 06/04	9	351	1056-03106-1	3
2018	08/21 - 08/22	2	58	1056-03106-1	3
2018	12/18 - 12/24	7	618	Orion2	5
2019	02/26	1	52	Beehive-W	5
2020	01/17 - 01/29	7	92	Beehive-W	5

Layer identification

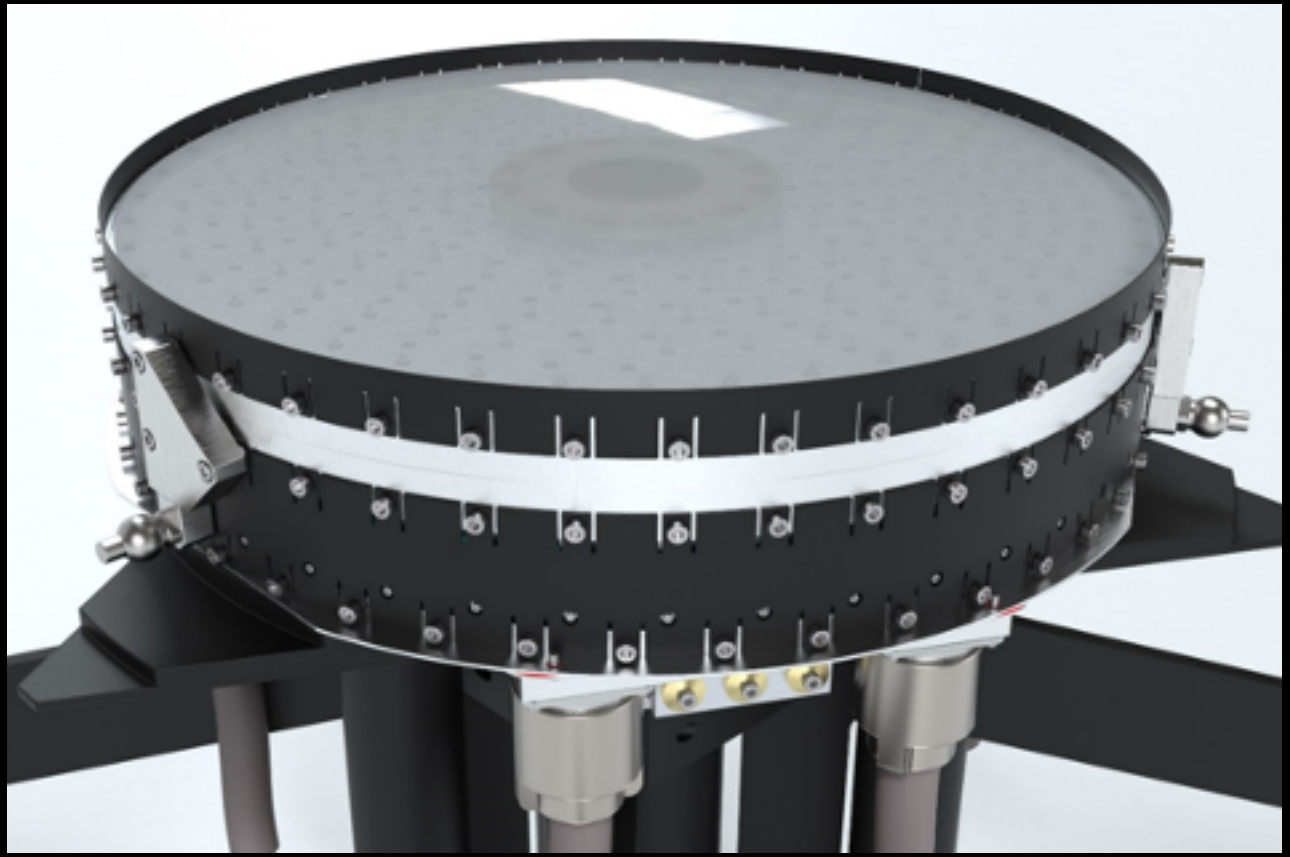


Layer identification
Layer Analysis

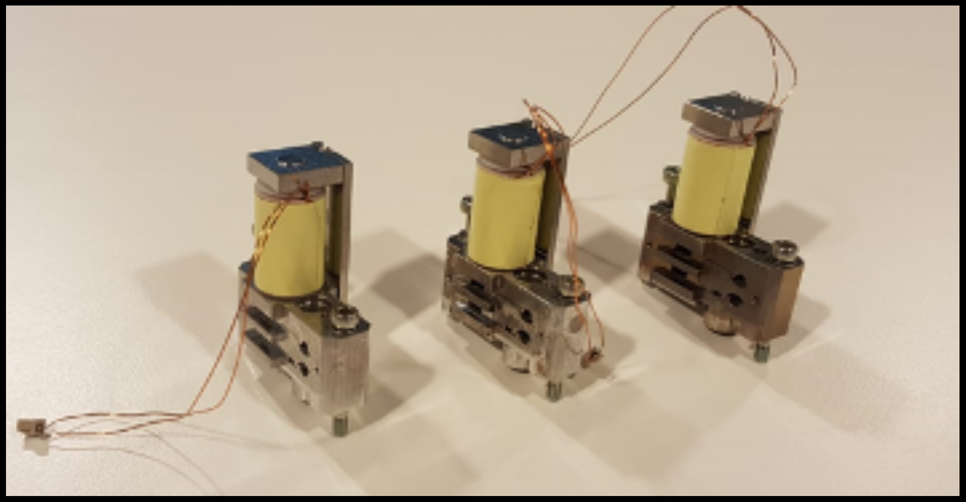
- Challenges in Analysis: tracking peaks evolution of correlation peak, comparison of different nights worth of data
- Tracking methods tried: algorithms, shortcomings of each (star finder (SF), radial method (RM), maximum peak (MP))
  - SF: weak to peak evolution, spotty detections
  - RM: assume peaks start at center, and multiple peaks
  - MM: sensitive to noise and data w/o peaks
- Post correlation subtraction and windowing provides variable improvements to tracking and analysis



ASM

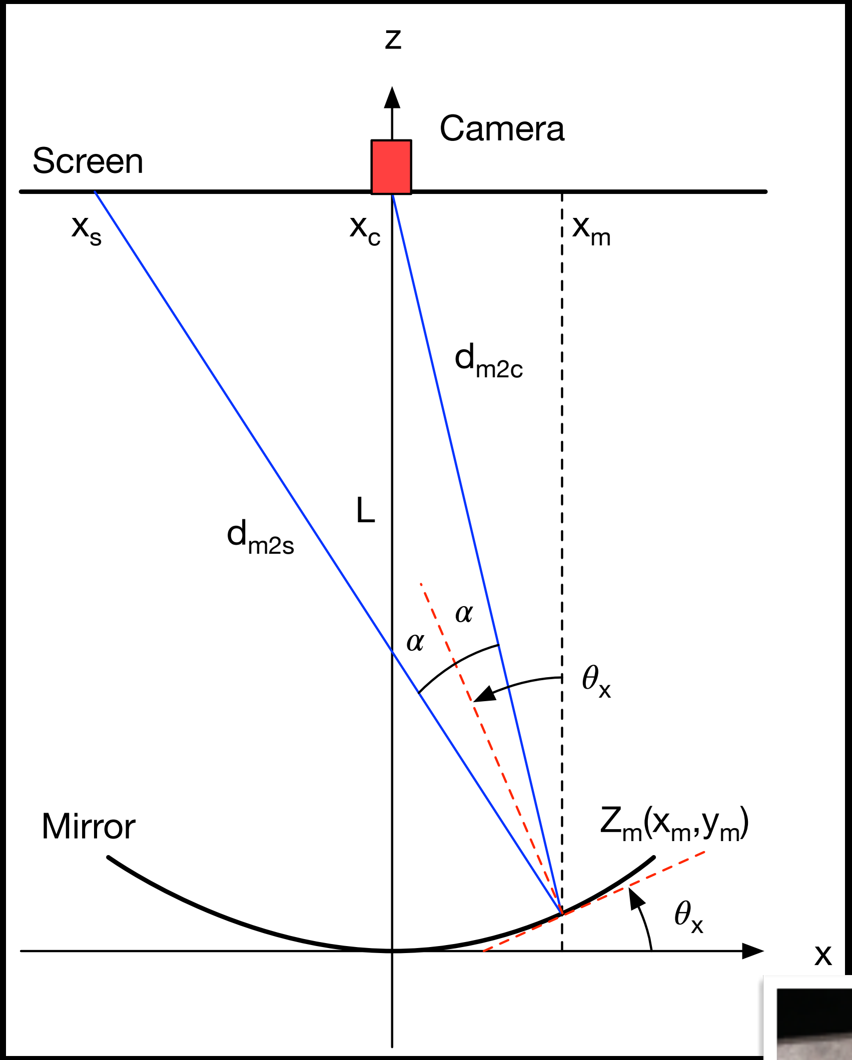


- Adaptive Secondary Mirror using new technology developed by TNO
- Uses magnetic reluctance actuators
  - Strong force, low current, many advantages:
    - Shell can be thicker, rigidly supported, actuators can be spaced further apart, no need for cooling or actuator feedback.
- UH ASM prototype will have 211 actuators with 620mm diameter,
  - Used with 16x16 Robo-AO SH-WFS,
  - and modal control (64 modes) with imaka 8x8 SH-WFS.



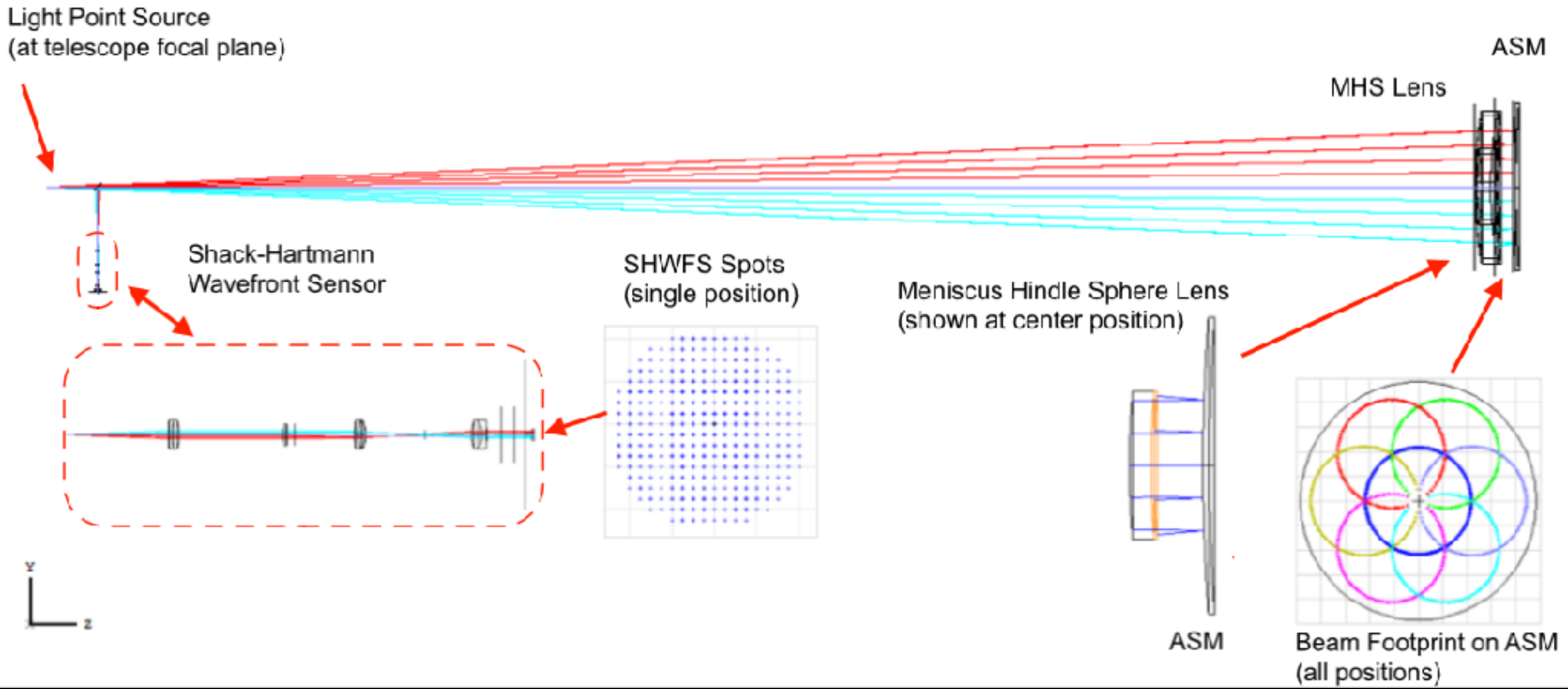
Deflectometry

- Problem of convex (Cassegrain) secondary is measuring influence functions and interaction matrices.
- Usually requires optics larger than ASM itself.
- To avoid such expensive equipment, we will use:
  - Partial illumination with transmissive Hindle spherical lens.
  - Deflectometry

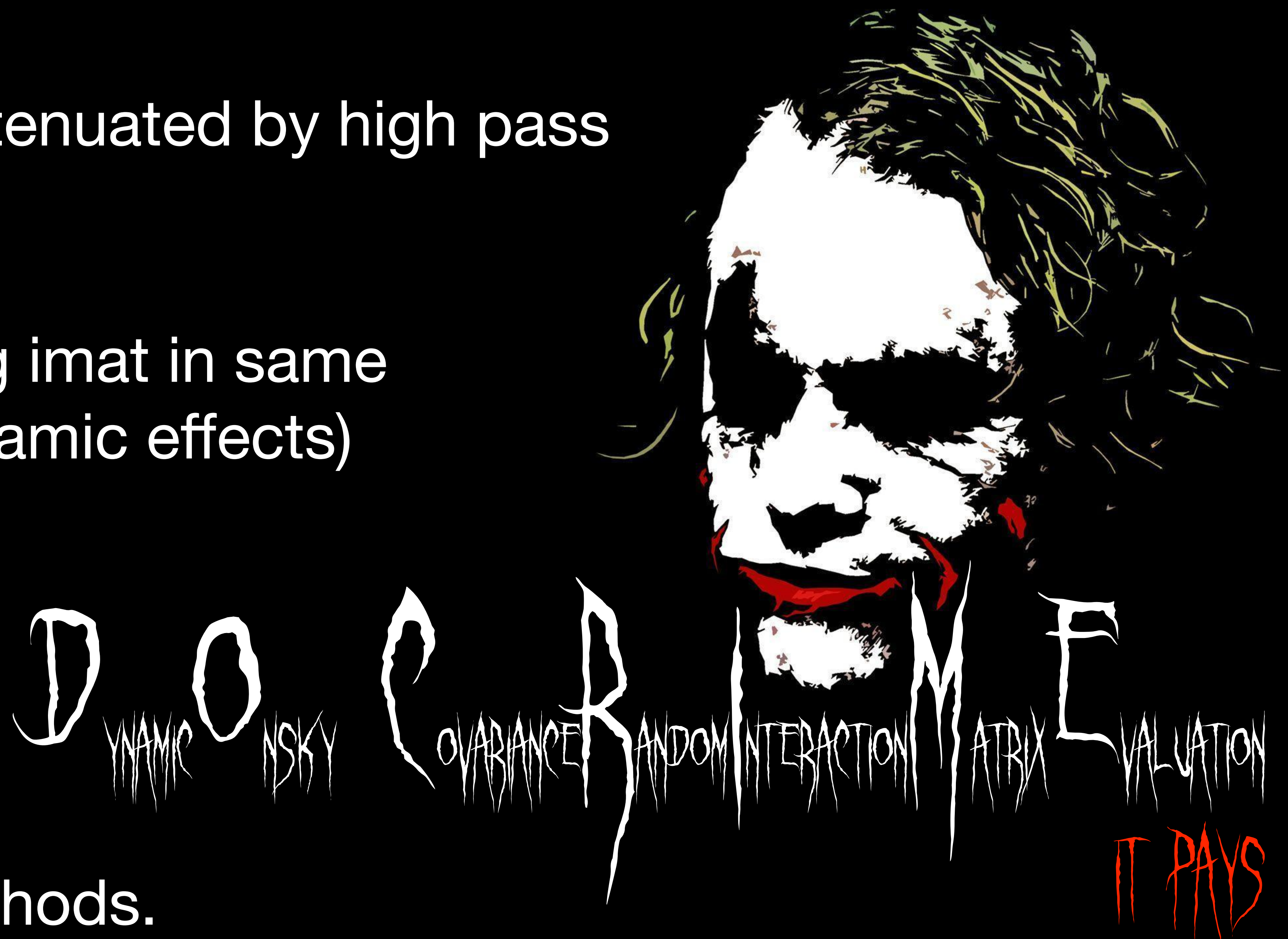


Small prototype based on two AMOLED 4k screens and a Raspberry Pi

Hindle sphere lens



- Developed a method to measure interaction matrices on sky in the presence of turbulence.
- Dynamic On-sky Covariance Random Interaction Matrix Estimation
- Method applies small random (but known) commands to deformable mirror (in open or closed loop) and records WFS measurements.
  - Turbulence can be attenuated by high pass temporal filtering,
- Advantage of measuring imat in same conditions as used (dynamic effects)
- Tested with current imaka where access to entrance focus allows direct comparison of both methods.



- $\mathbf{m} = D \cdot \mathbf{c}$

  $\mathbf{m}_\xi(t) + \mathbf{m}_a(t) = D \cdot \mathbf{c}_\xi(t)$,

  Multiply both sides by $\mathbf{c}_\xi(t)^T$ and take time average

  $< \mathbf{m}_\xi(t) \cdot \mathbf{c}_\xi(t)^T > + < \mathbf{m}_a(t) \cdot \mathbf{c}_\xi(t)^T > = D < \mathbf{c}_\xi(t) \cdot \mathbf{c}_\xi(t)^T >$

  we measure $\mathbf{m} = \mathbf{m}_\xi + \mathbf{m}_a$ but $< \mathbf{m}_a(t) \cdot \mathbf{c}_\xi(t)^T > \to 0$

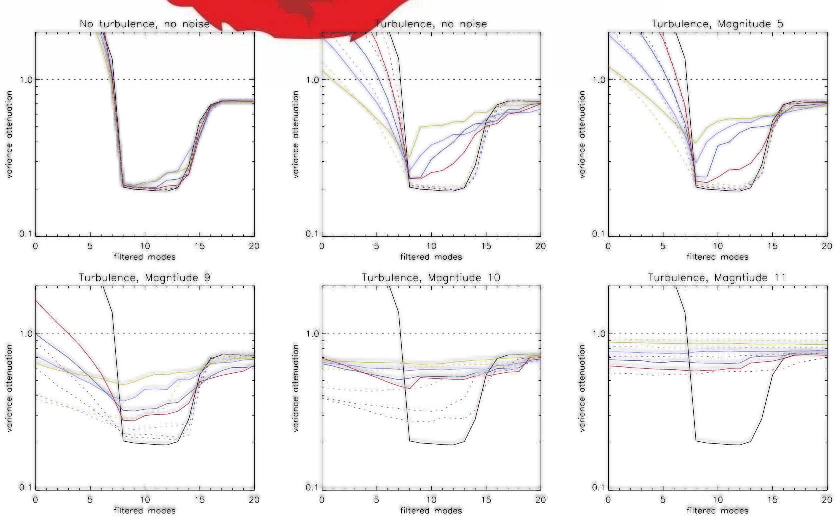
  Therefore $D = < \mathbf{m}_\xi \cdot \mathbf{c}_\xi^T > \cdot < \mathbf{c}_\xi \cdot \mathbf{c}_\xi^T >^{-1}$

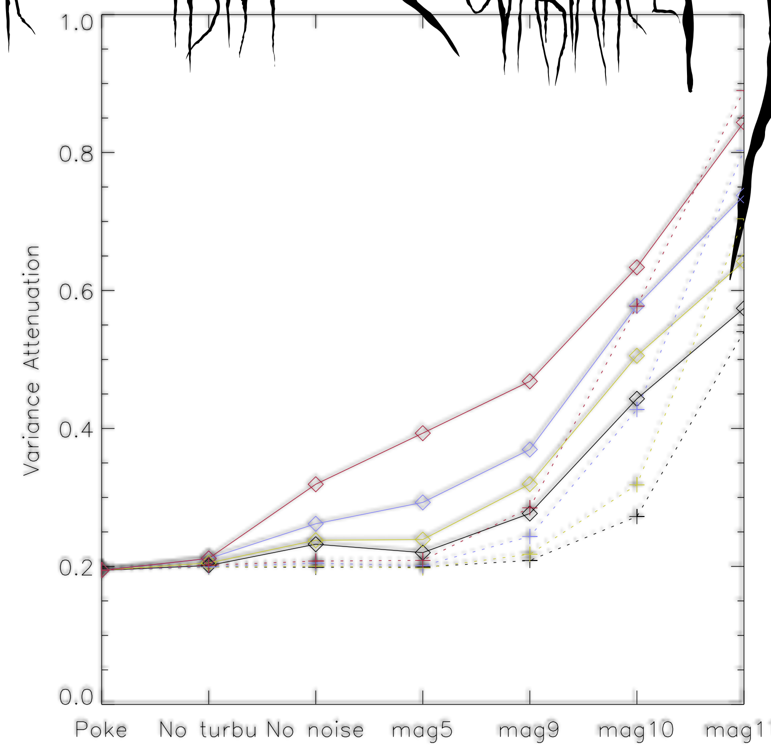
  NB. Random commands covariance matrix $< \mathbf{c}_\xi \cdot \mathbf{c}_\xi^T >$ is diagonal, accurate inversion.

DOCRIME

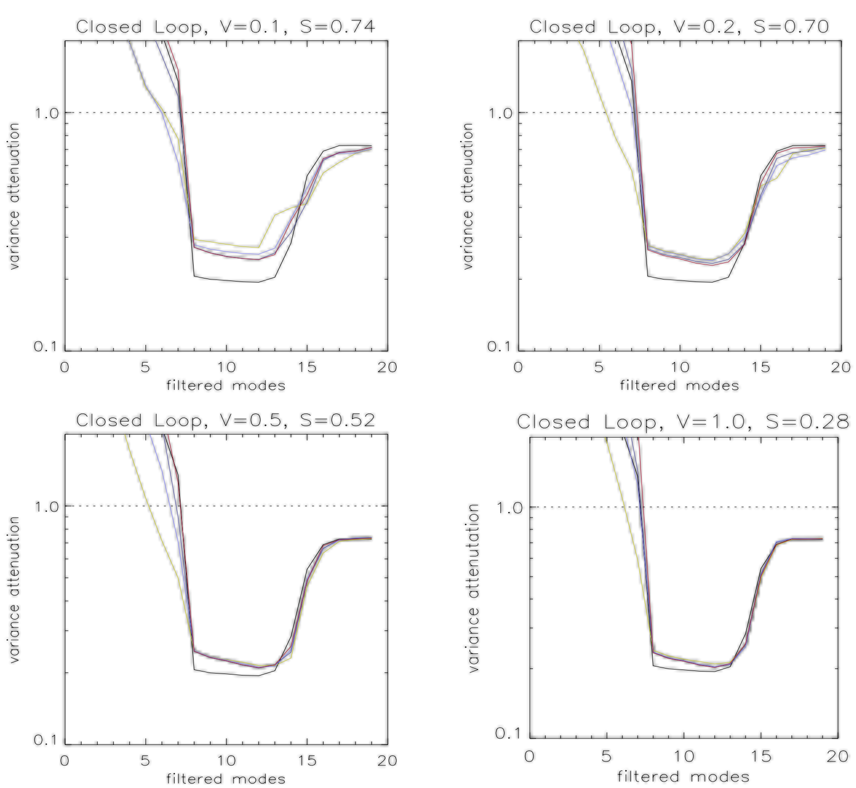
Dynamic Onsky Covariance Random Interaction Matrix Evaluation

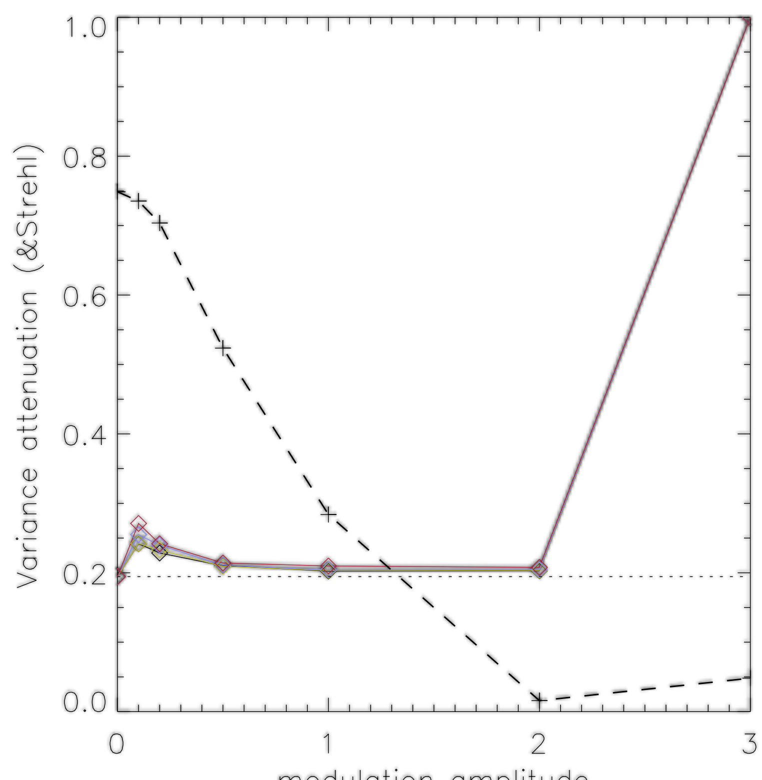
IT PAYS





Open loop simulation showing variance attenuation for different noise levels (variance attenuation of control matrix as a function of number of filtered modes).



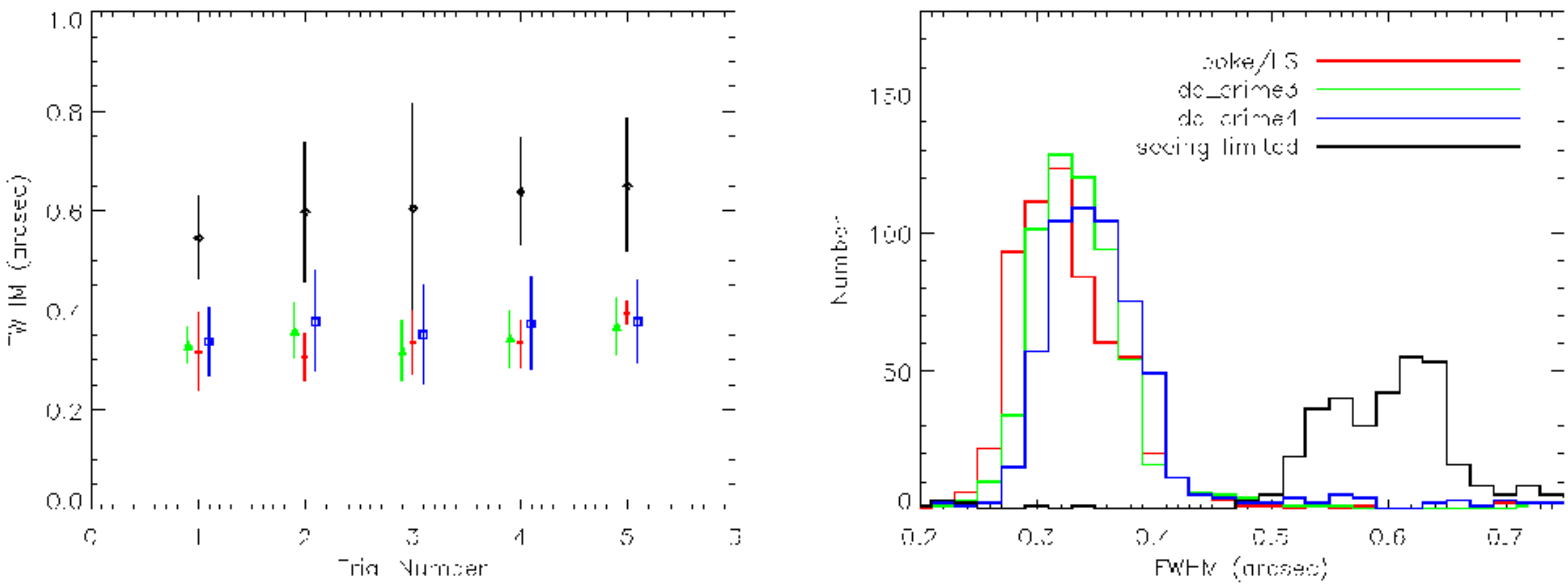


Closed loop simulation with different amplitude modulation, showing impact on Strehl ratio compared to variance attenuation .

DO CRIME: Dynamic Onsky Covariance Random Interaction Matrix Evaluation

IT PAYS

GLAO FWHM with different cmats (5 sequences)



Conclusion

- Predictor controller is being developed
- Covariance maps used to identify layers and their speed
- TNO ASM to be integrated in Netherlands in early 2021, integration at Telescope Summer 2021
- New method to obtain on-sky interaction matrices in open and closed loop, DOCRIME
- Groundwork for Keck ASM and GLAO