A Flexible Multi-Purpose AO System for DAG

The New East Anatolia 4 m Telescope

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DAG, the project, the team

- **Owner** : Atatürk University (ATAUNI), Erzurum, East Anatolia, Turkey
- **Direction** : ATASAM (ATAUNI Astrophysics Research and Application Center)
- Started 2009, 1st light 2021-2022
- Near city of Erzurum - Site altitude 3100 m - 260 / 365 clear nights

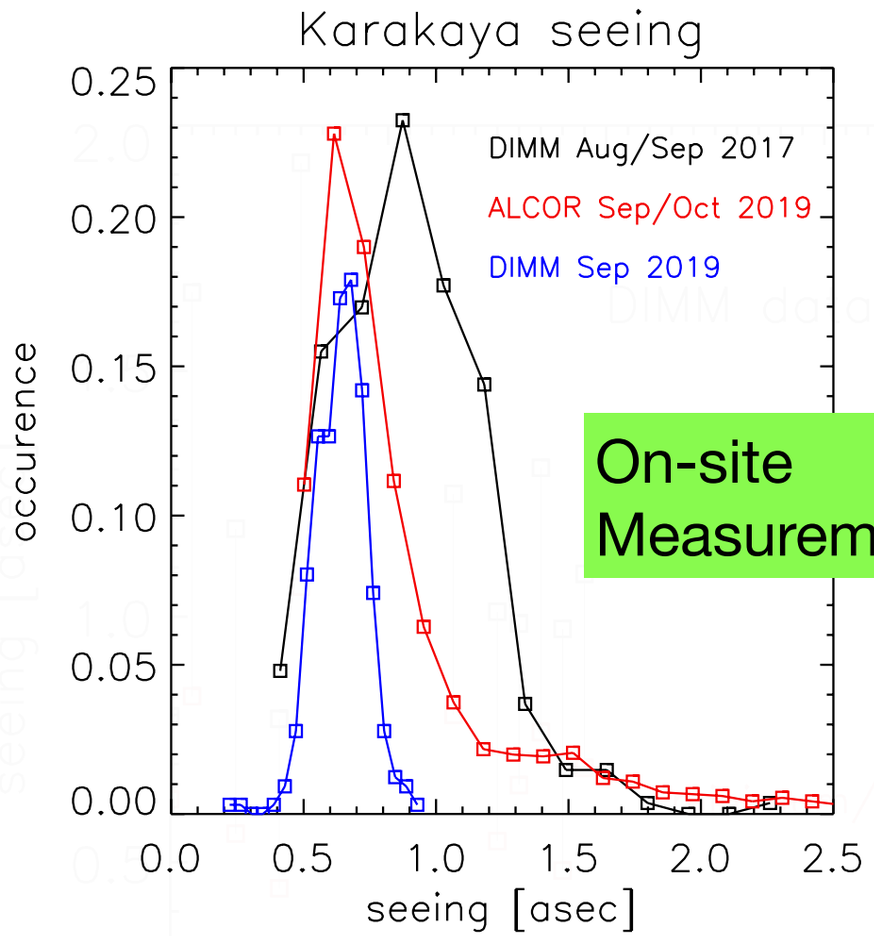
- 4 m in diameter, 56 m focal length
- Ritchey-Chrétien
- 2 Nasmyth platforms
- Field optical derotator integrated in telescope arms
- Active optics, 66+12 actuators

- Active optics & optics : AMOS (Liège, Belgium)
- Project management : AMOS
- Mechanics : EIE (Mestre, Italy)
- Telescope delivery readiness review *in progress*

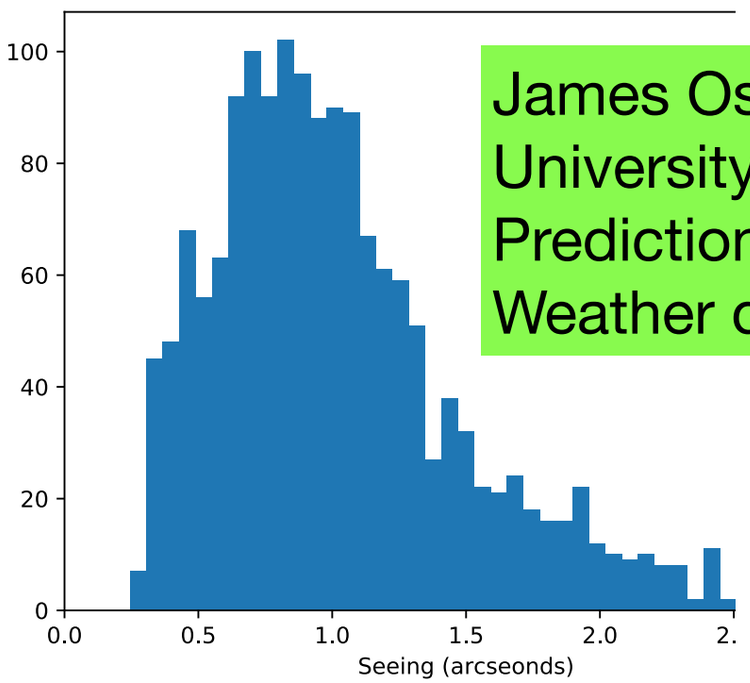
- First light instruments
  - Pyramid based AO system (HEIG-VD, ISIK, ALPAO)
  - NIR camera (AAO, Uni. Sydney)
  - Stellar coronagraph (Uni. Bern)
  - No seeing limited instrument yet

DAG Site seeing : 0.8-0.9”

- Site selection: based on humidity, initial seeing crude estimate, and site accessibility
- DIMM data in 2009 - est. seeing 1”
- ATASAM bought a MASS/DIMM (Russia)
- Also ALCOR seeing monitor (angle-of-arrival)
- Installation took some time, now running (by hand) only summer data, waiting for winter
- Good surprise : quite good seeing !
  - 0.8”-0.9” median, sometime excellent at 0.4” or even 0.2”
  - Confirms predictions by James Osborn, AO team at Durham, University

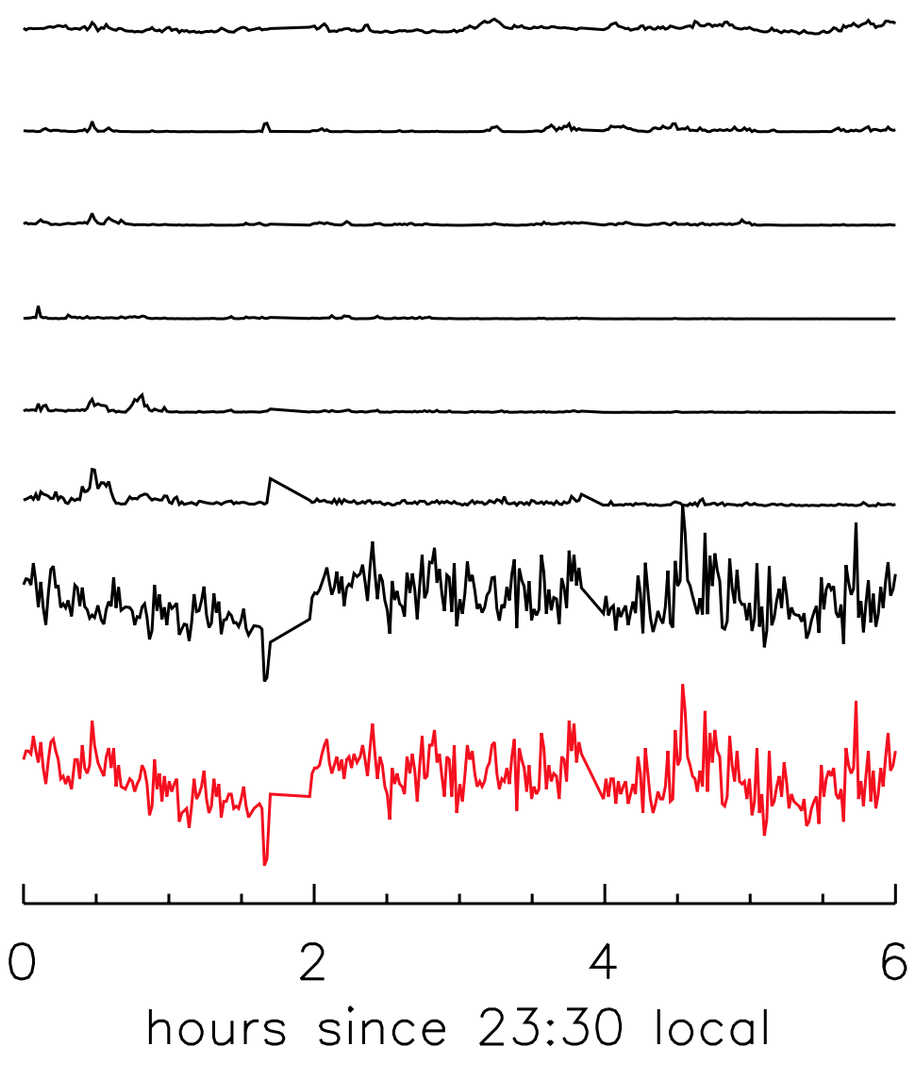


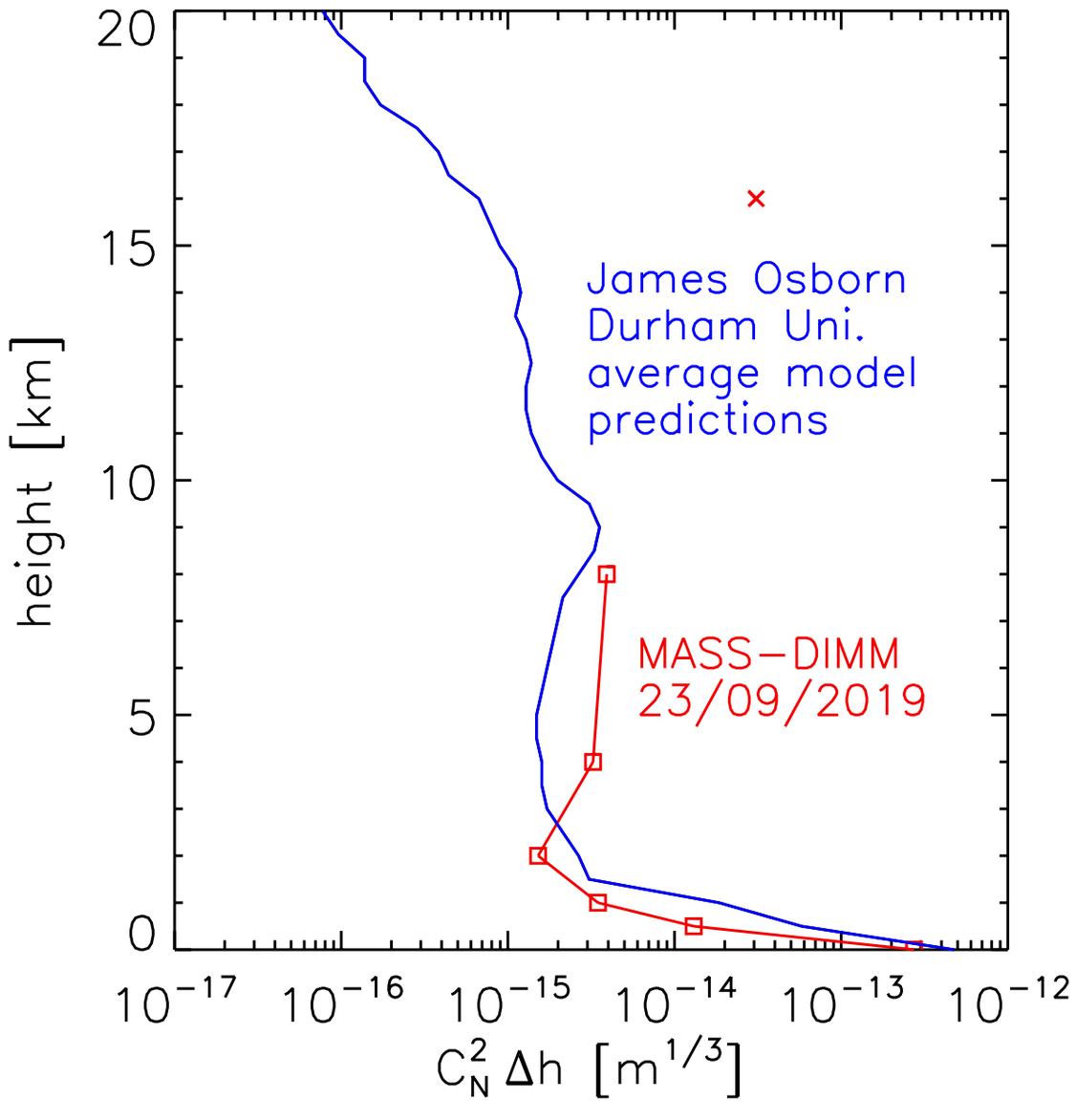
On-site Measurements



James Osborn
University of Durham
Predictions from Weather data

Predicted profile & MASS data





our AO system concept

- In principle, for 1” and a 4 m, we would need 80 actuators for a classical AO
- Laser way too expensive and complicated for a first tel.
- we immediately decided to use a pyramid WFS = a SH where you adjust the number of lenslets and sensitivity
- And an ALPAO deformable mirror - no TT mirror required
- But if we can do lots with the PWFS, then why not buying an expensive DM with many more actuators ? -> DM 468 !
- We can do ExAO … *in principle*

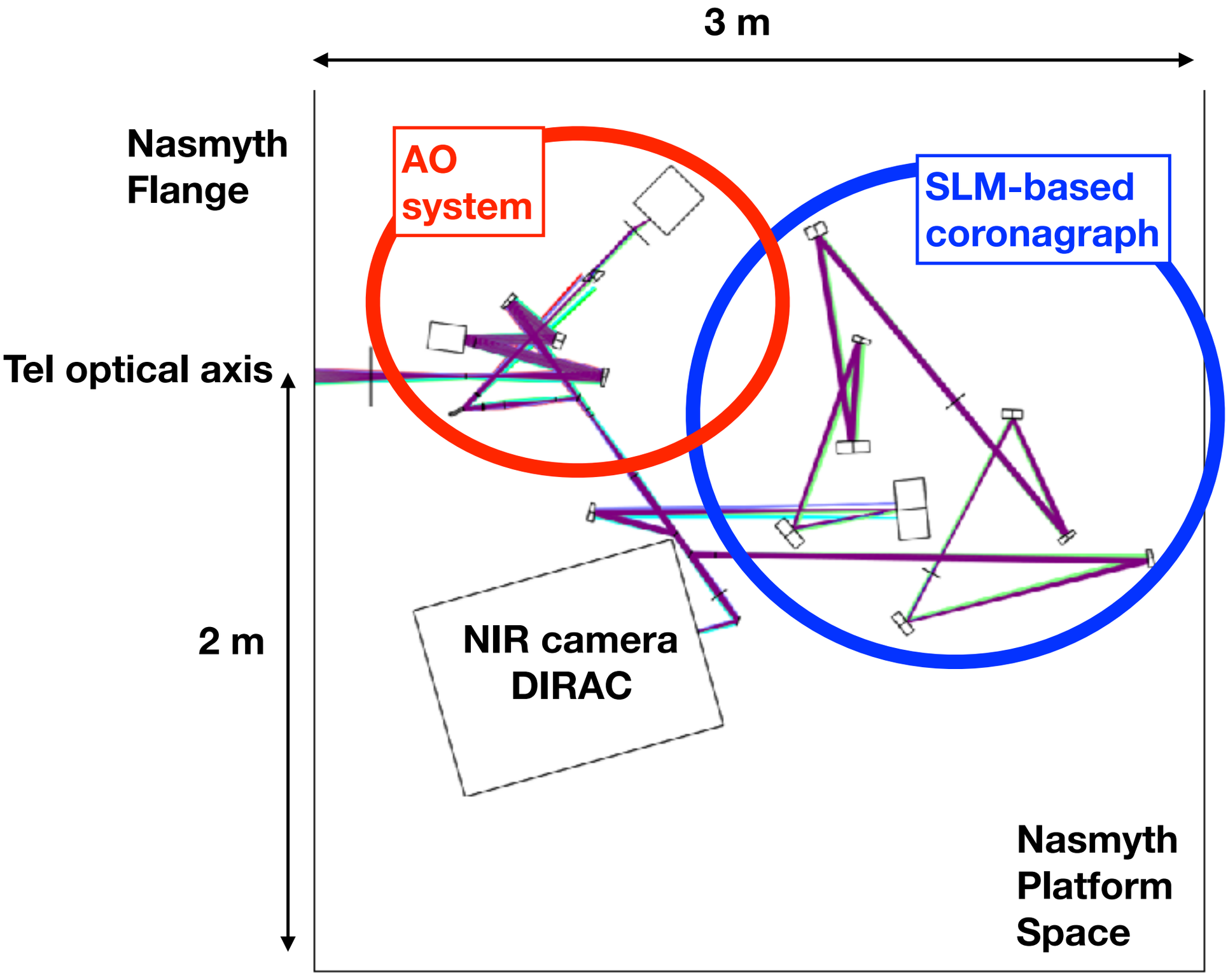
our AO system concept

- What if bad seeing and/or dim NGS ?
- Adjust the PWFS sensitivity and resolution, reduce the number of modes
- Means changing the number of pixels/pupil arbitrarily
- Impossible, except if we use a noiseless camera
- Any numerical resampling sampling is possible - no noise !
- NÜVÜ 128 camera
- Jean-Pierre Véran & Olivier Lardière : “and now you do not need super high manufacturing accuracy for the prism because you can compensate numerically the pyramid prism manufacturing errors. Oversample by a factor 1.5 and you will be happy”

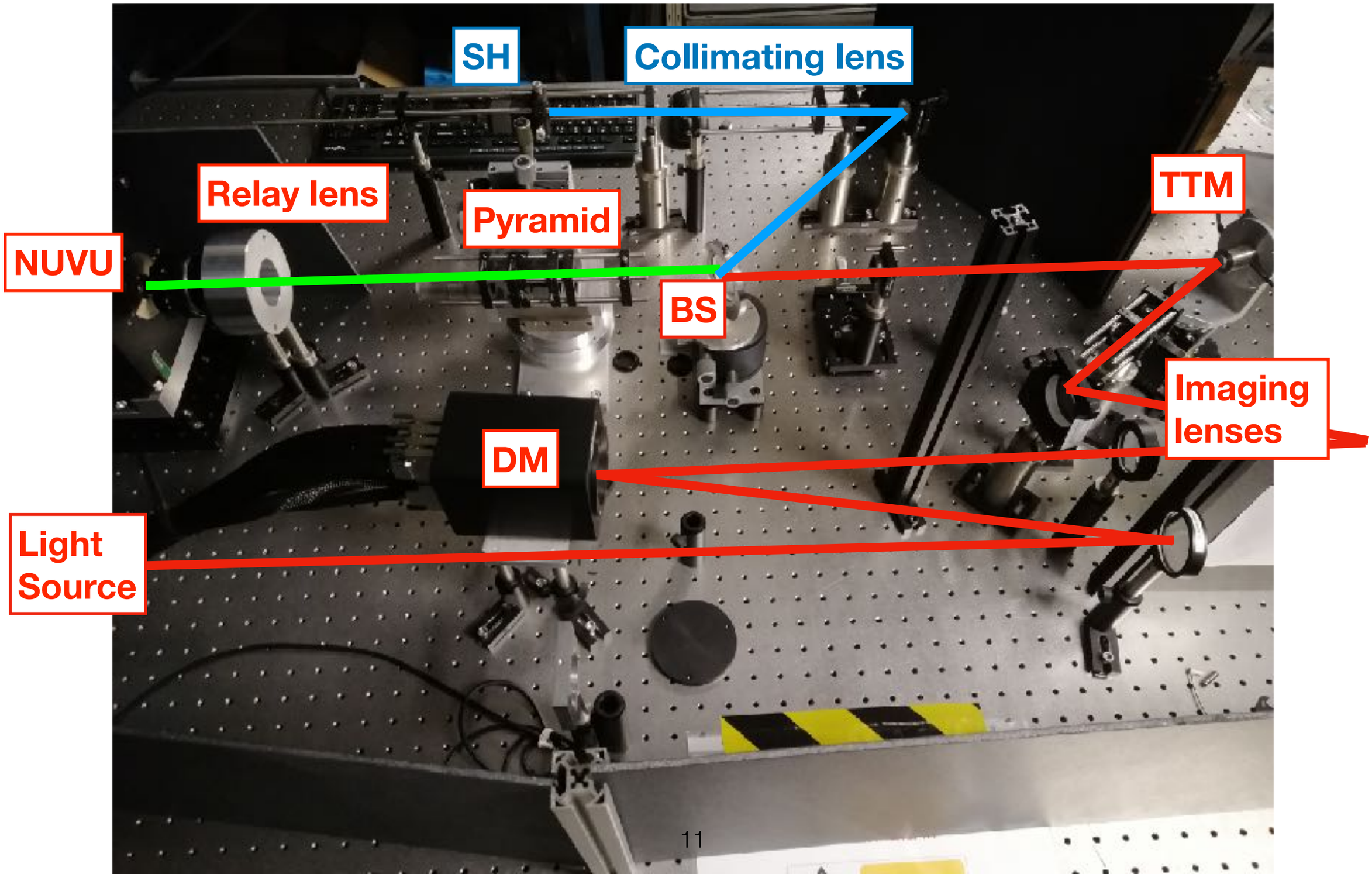
our AO hardware

- Double achromatic pyramid prism from BMV (design Audrey) - being polished right now, delivered end of Nov.
- NÜVÜ 128x128 pixels no noise EM-CCD (in the lab)
    - 33 pixels / diameter, need 22 in principle
- 468 actuators DM from ALPAO (built, tested)
- Controller : ACE from ALPAO, adapted to PWFS

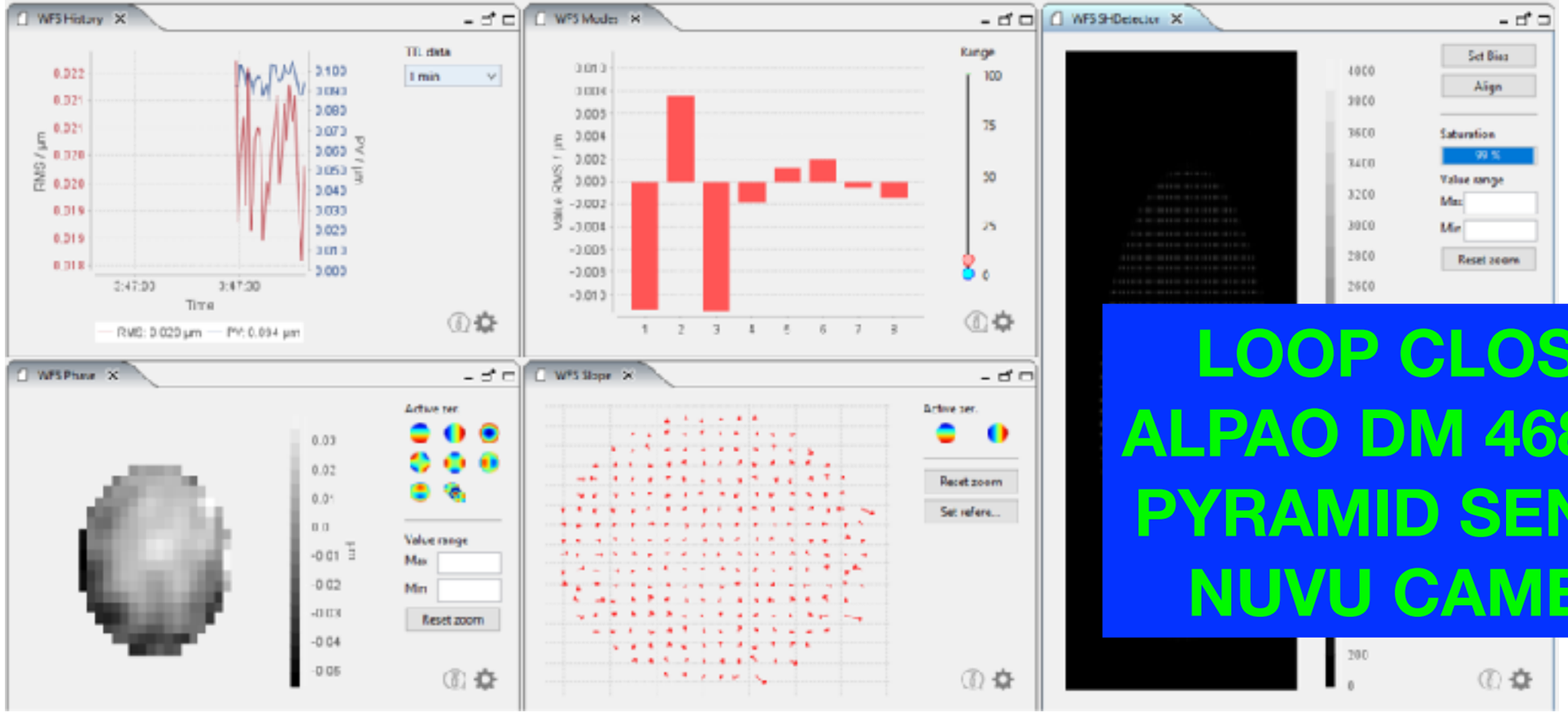
The AO design & the coronagraph & the NIR camera

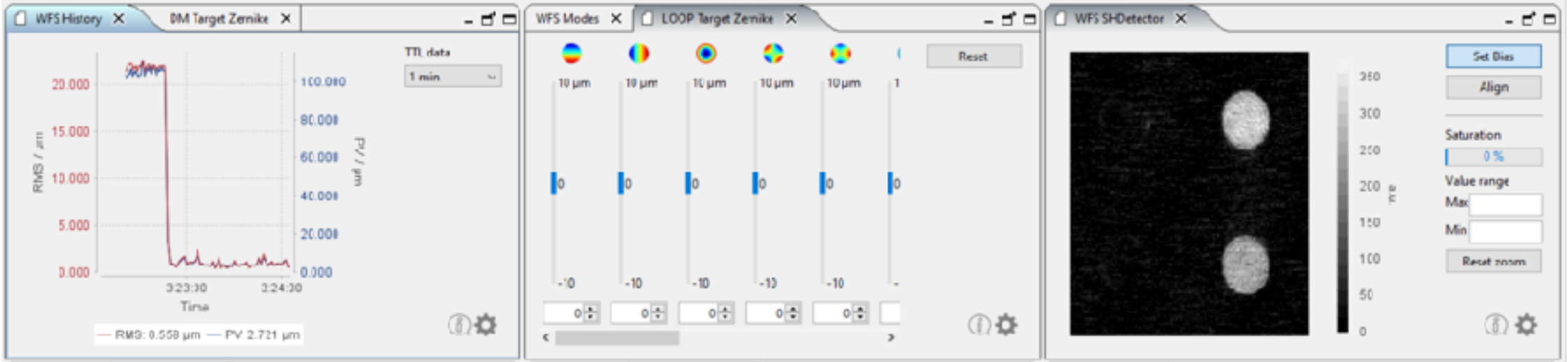


Loop has been closed @ ALPAO last Thursday



An enormous
<u>thank you</u>
<u>to Adriano Ghedina & TNG team</u>
for providing us with the prism
we are using while waiting for
our own


WFS History
TTL data
1 min
RMS / µm
PV / µm
Time
RMS: 0.020 µm
PV: 0.094 µm
WFS Modes
Range
WFS SHDetector
Set Bias
Align
Saturation
Value range
Max
Min
Reset zoom
WFS Phase
Active ser.
Reset zoom
WFS Slope
Active ser.
Reset zoom
Set refere...
LOOP CLOSED
ALPAO DM 468 ACT
PYRAMID SENSOR
NUVU CAMERA


WFS History
DM Target Zernike
TTL data
1 min
RMS / µm
PV / µm
Time
RMS: 0.559 µm
PV 2.721 µm
WFS Modes
LOOP Target Zernike
Reset
WFS SHDetector
Set Bias
Align
Saturation
Value range
Max
Min
Reset zoom
WFS Phase
DM Control
Reset
Reset zoom
Normalized command
WFS Slope
LOOP Control
Reset
Calibr.
Stop
TTL data
1 min
RMS / µm
Time
DM History
TTL data
1 min
Maximum command value
Minimum command value
Time

big question : optimised control

Seeing & NGS Parameters

- NGS brightness
- Seeing angle
- Wind velocity

System Parameters

- Loop frequency
- Loop gains/mode
- Modal/Zonal ?
- PWFS sampling
- TT modulation

Performance Metrics

- Strehl
- Rejection ratio
- Integrated energy

AO control scientists have developed many tools to optimise the system parameters

But which one suits our needs best ???

Now the hunt for the best optimisation concept is open

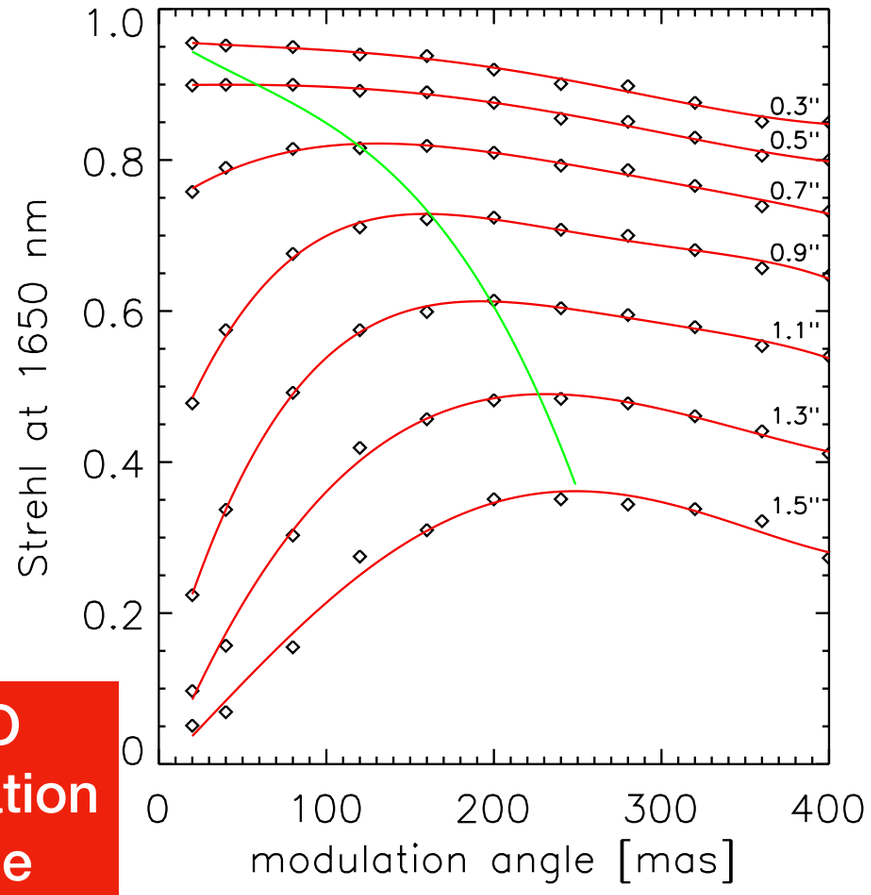
Machine learning for AO ?

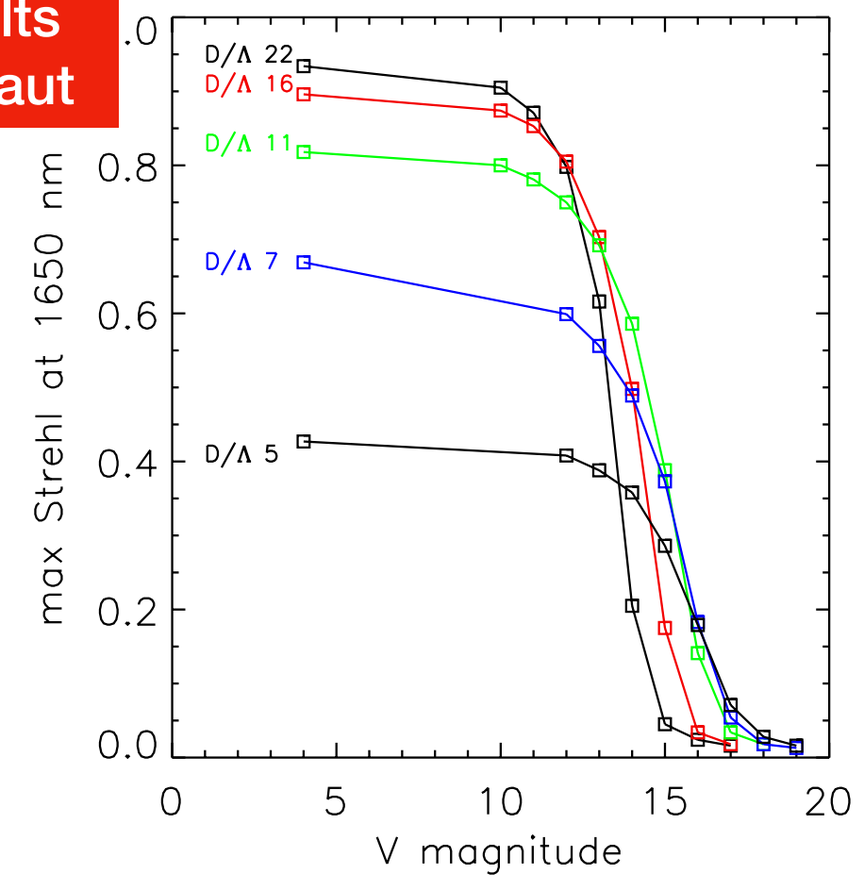
- OK now I look ridiculous
- Fact : for a given seeing/NGS condition, there is only one optimal set of AO parameters (exp time, gains etc.)
- The advantage : no assumptions, or missing components of the error for which we have no math model
- How to ?
    A. an accurate physical model, we feed it with realistic phases, we look for the best parameters
    B. on sky with the real telescope we may improve the “knowledge”
    C. Once the system knows, we can start using it
- MUST be a research project, NOT the main control scheme

Whatever is chosen…

- Because the PWFS can always adapts itself to the conditions
- And because we have many more actuators than we need
- We should be able to get, always, the maximum performance “theoretically,, achievable
- ExAO on one side, with coronagraph on/off
- SCAO in the median conditions
- Seeing improvement in the not so good conditions

YAO Simulation Code Results F. Rigaut





NCPA, vibrations…

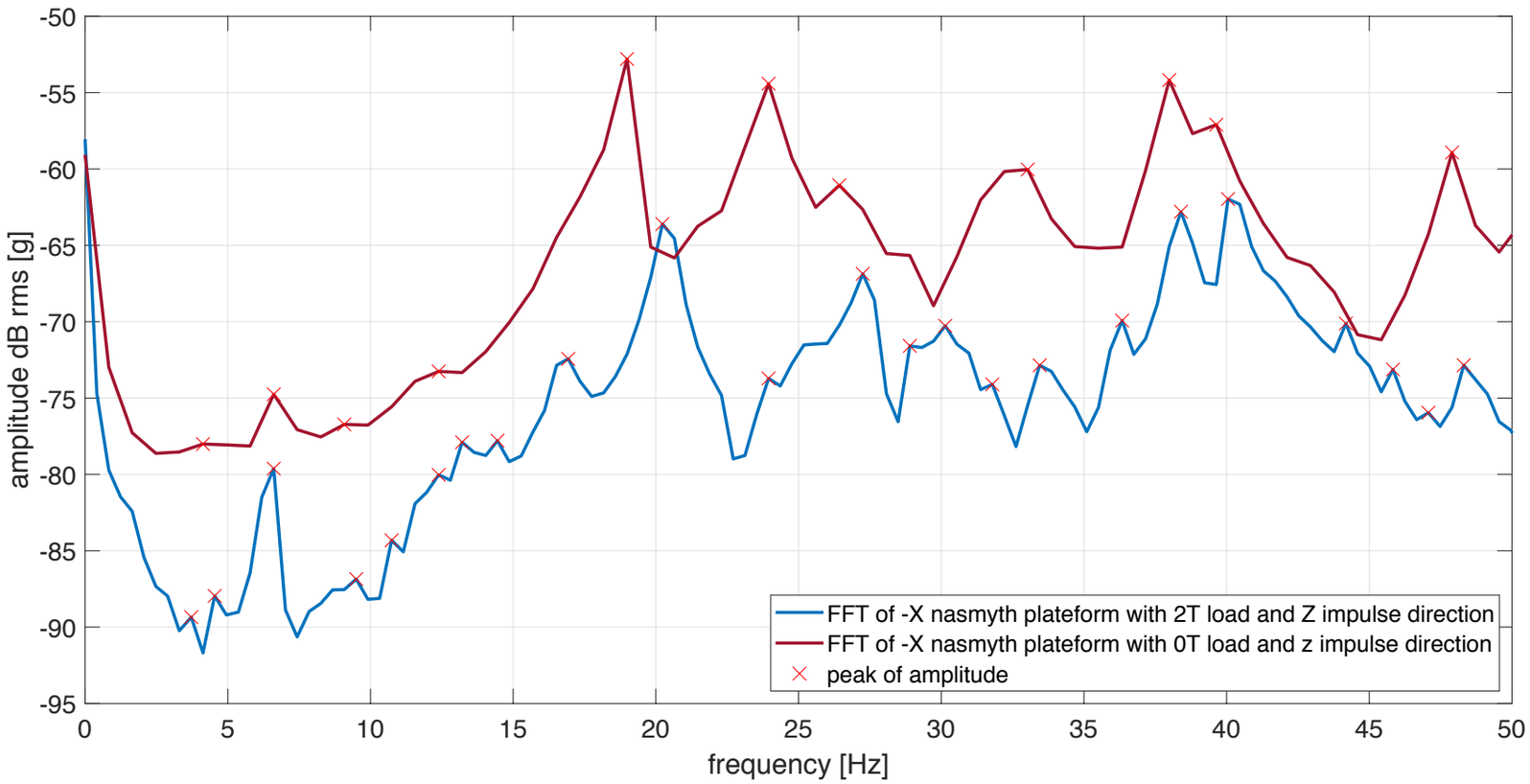
- We have developed our own phase diversity algorithm, a recursive concept using the DM, tested in the lab, works well - unpublished for now.

- We have measured the vibrations landscape on the Nasmyth Platform

    - Consequence for ExAO still to be examined (similitudes with SCExAO vibration issues)

    - Passive damping on optical table legs, counter vibration on the table, smart TT control ?

6.6 Hz
19 Hz
20 Hz
23 Hz



Conclusions

- DAG telescope has been accepted, M1 still in production
- Everything on the mountain by summer 2021 ?
- Flexible AO concept - do seeing improvement and ExAO on the same system - FAO
- Require smart adaptive control - waiting for propositions :)
- Machine learning ?
- Loop closed now, the trouble is starting…
- Side note : 4 PhD thesis starting January 2020 on AO, coronagraph, AO integration, seeing monitor at ATAUNI