Synergies between solar and night-time AO

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EST

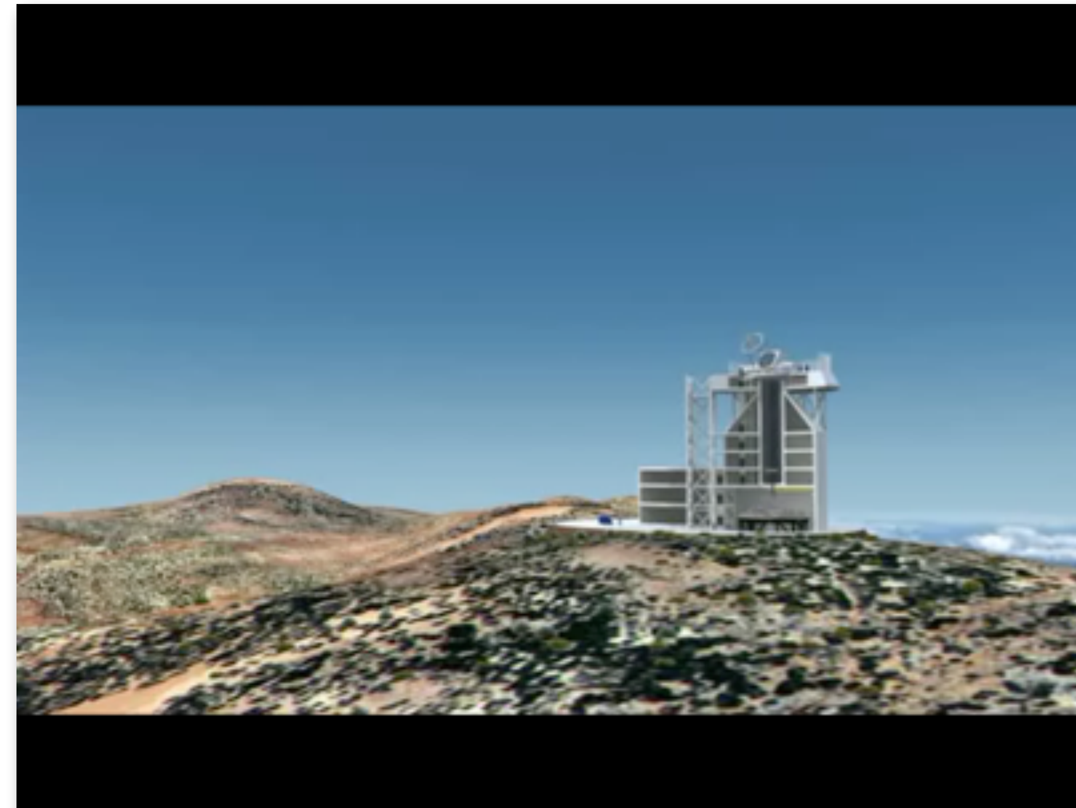
ESO

SOLAR PHYSICS UTOV

European Solar Telescope EST

EST is a pan-European project involving 29 partners from 15 countries

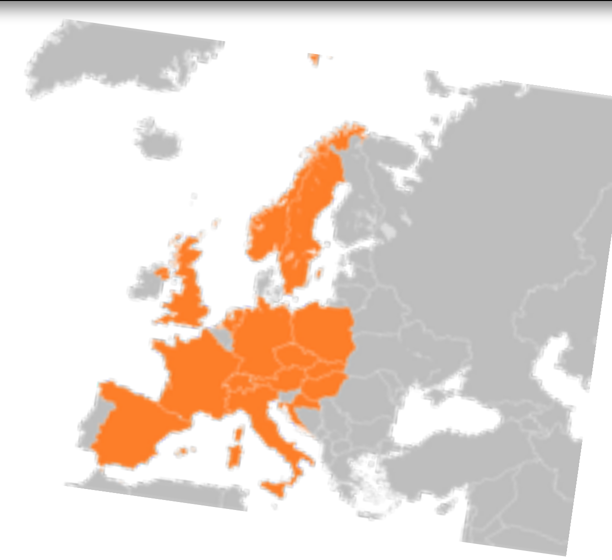
One month ago, EST entered the ***ESFRI 2016*** EU roadmap



Design Study EU Grant Agreement 212482

FP7, Grant Agreement 312495 SOLARNET

H2020-INFRADEV-1-2014-1 GREST



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- **EST** is a 4-meter class telescope optimized for high precision **polarimetric measurements** in the solar atmosphere

- It will be equipped with a **polarization-free** MCAO system, this is of paramount importance to achieve the required $\mathbf{10^{-5}}$ polarimetric sensitivity (same order of magnitude of the required sensitivity for polarimetric observations of exoplanets in reflected light)

- Need to resolve the small scale magnetic fields in the solar photosphere (30 km)

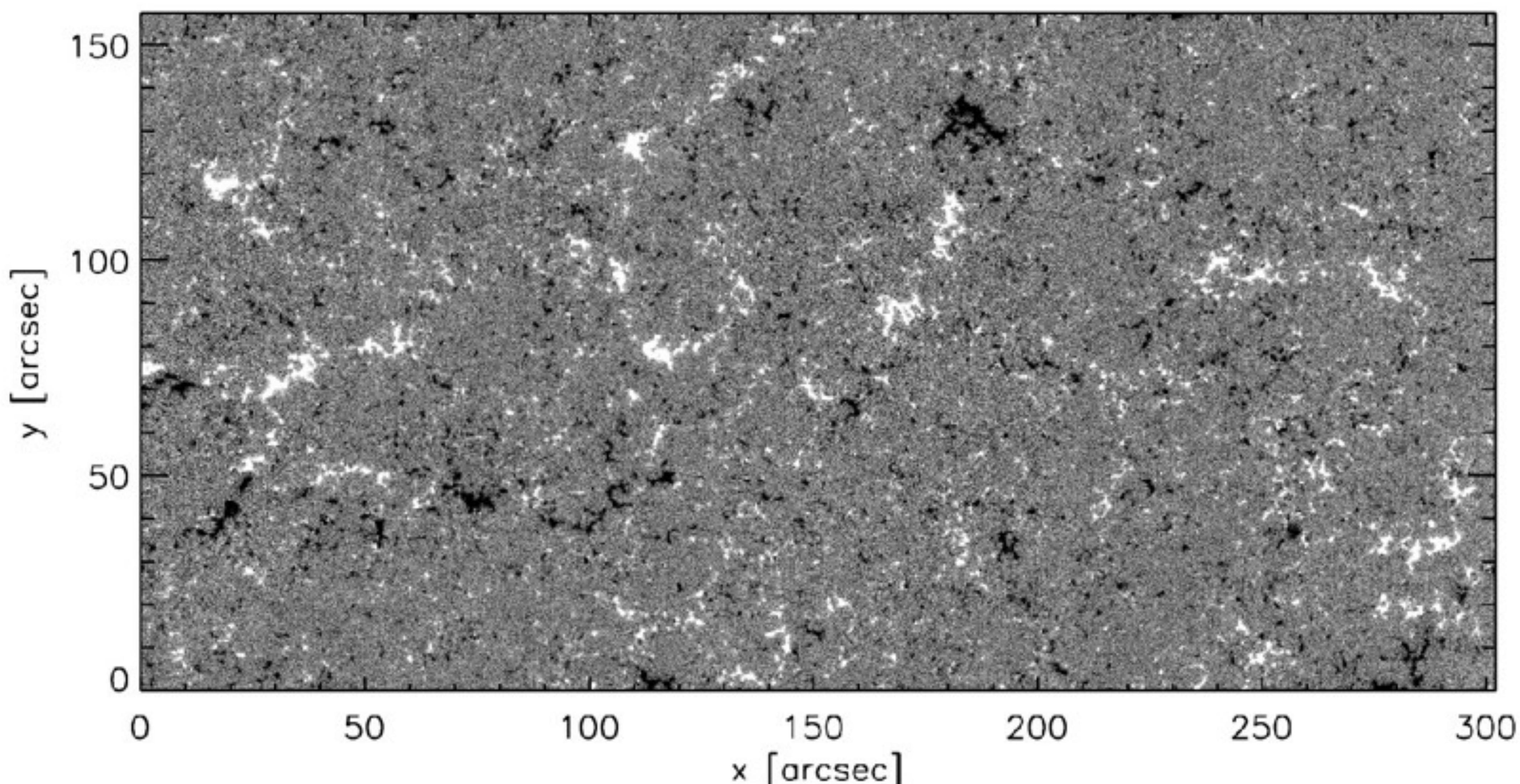
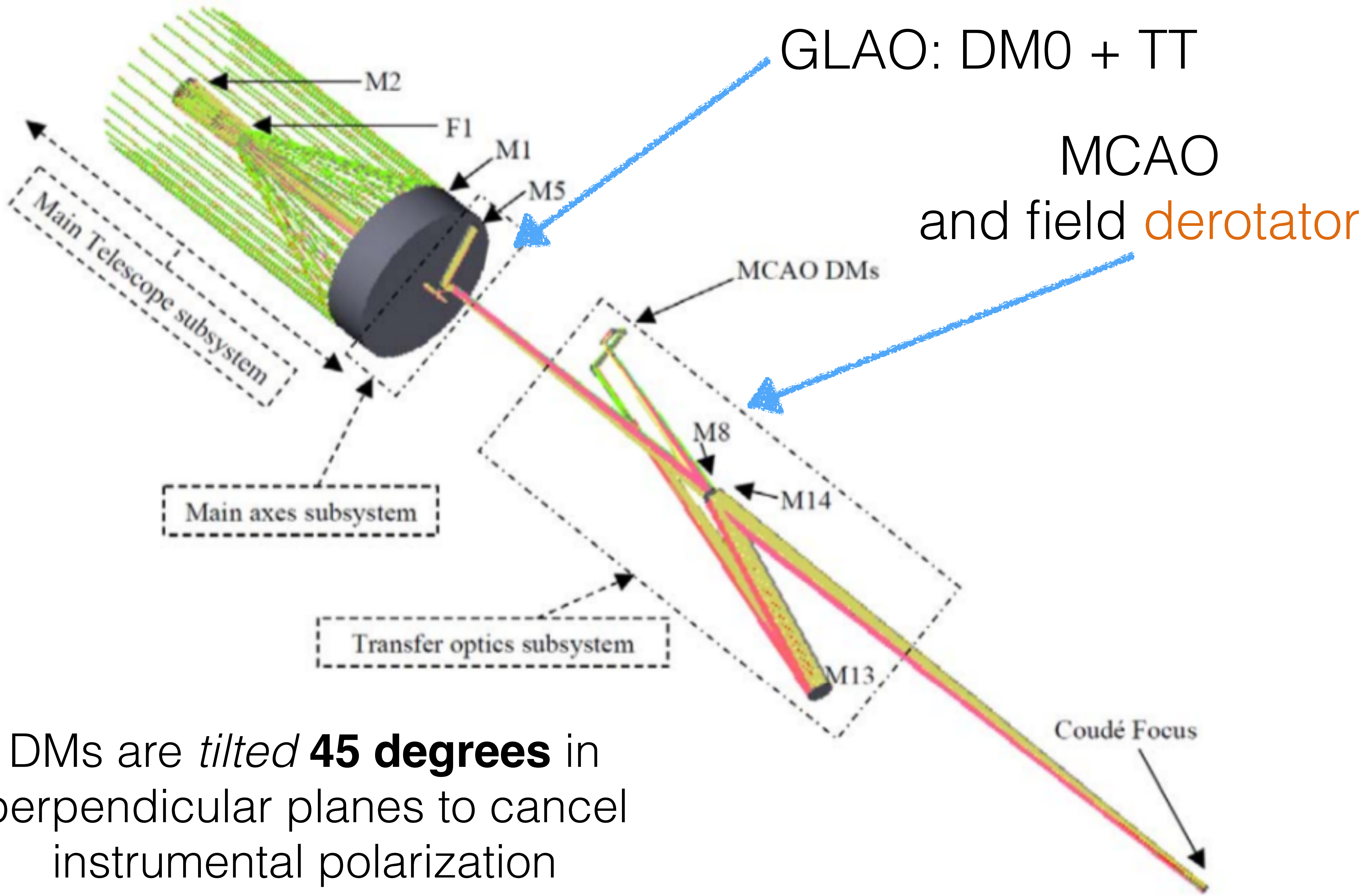


Image from HINODE/SOT-SP

Polarization-free MCAO



DMs are *tilted* **45 degrees** in perpendicular planes to cancel instrumental polarization

Tilted DMs: drawbacks

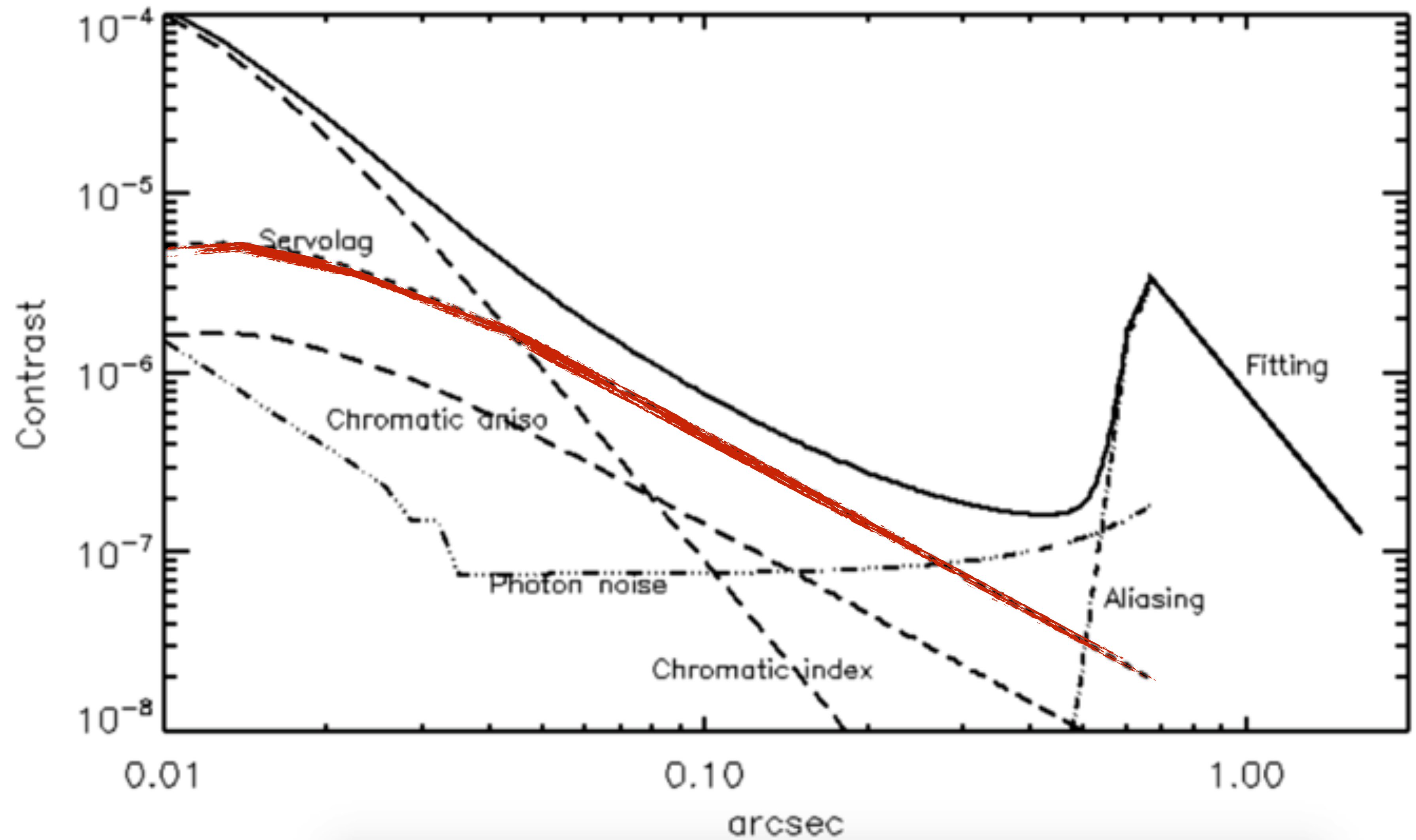
- Non-standard configuration for the DMs:
  - Elliptic pupils
  - Conjugation height dependent on the position on the DM
  - Sensitivity to misalignments due to the rotation between the pupil and the MCAO DMs
  - Different spacing of the projected pitch on the entrance pupil

Solar AO peculiarities

- Polarimetric constraints: high sensitivity & accuracy + small instrumental polarization —> GREST
- Lack of AO tracking points for both disk (quiet Sun) and limb observations
- Time lag —> low contrast and extended target

Five error sources in AO systems

- Fitting error
- WFS aliasing error
- **Servo-lag**
- WFS noise
- Anisoplanatism



Kasper et al. 2012

Servo lag represents one of the most severe limitations in AO systems

Predictive control

- A process can be predicted if:
  - is stationary
  - its future evolution depends of its past states
- The turbulence is predictable (frozen) over a short time (a few ms, see Dessenne et al 1998, Jorgenson & Aitken 1992, Jackson et al. 2015, Tesch 2015)

Predictive control with Fors

Closed Loop Forecasting System

- We have developed a predictive control software module based upon ARMA (**A**uto**R**egressive **M**oving **A**verage) processes

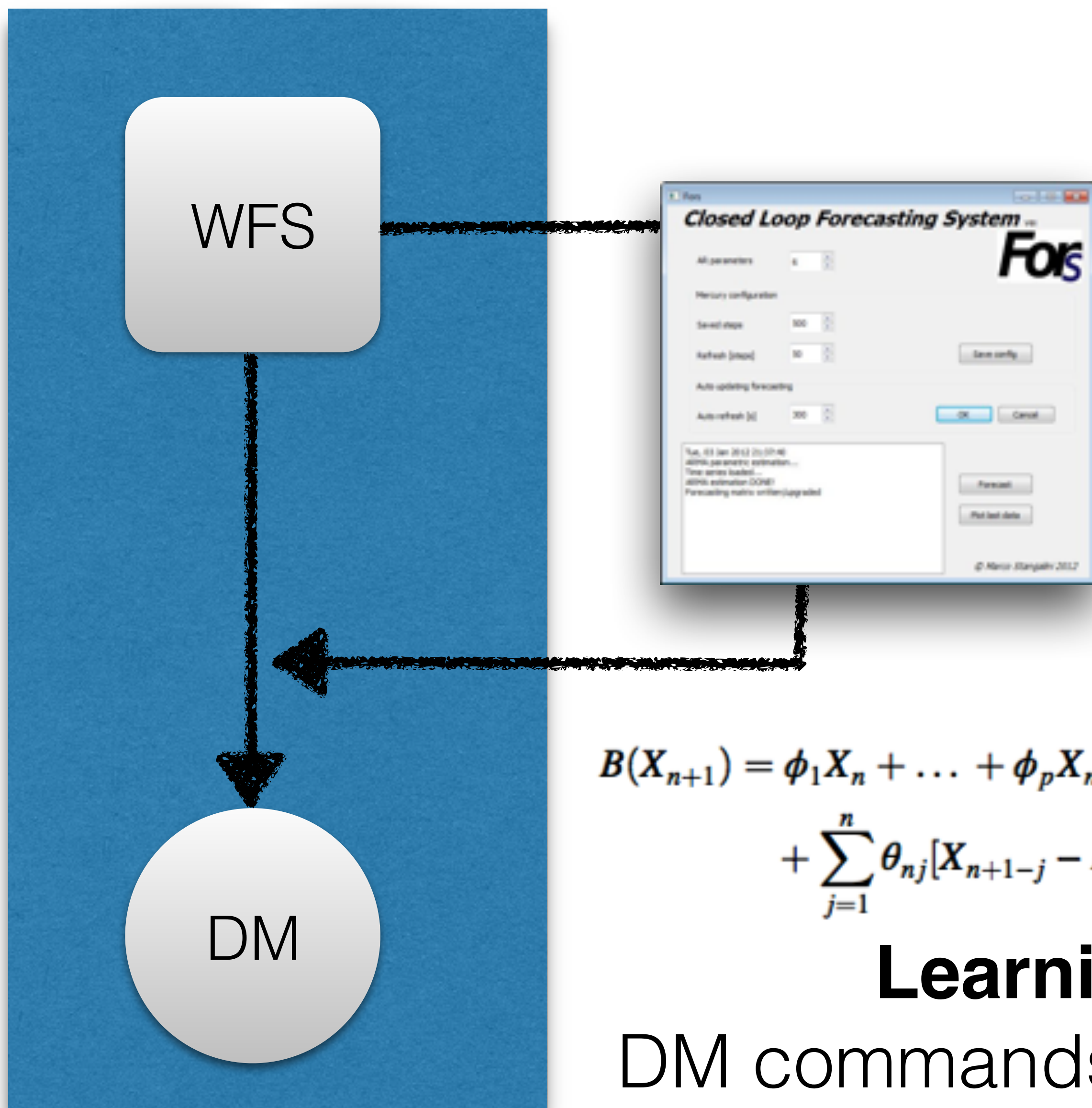
- If a process is stationary then there will be AT LEAST one ARMA(p,q) statistical process describing it

$$B(X_{n+1}) = \phi_1 X_n + \ldots + \phi_p X_{n+1-p} + \sum_{j=1}^{n} \theta_{nj} [X_{n+1-j} - B(X_{n+1-j})] \quad \text{if } n > m.$$

Coefficients of the ARMA process. The future evolution at time n+1 can be written as a **combination of the past states** of the process

https://sites.google.com/site/pyfors/

- Parallel (offline) learning/modeling
- Periodic update of the ARMA coefficients

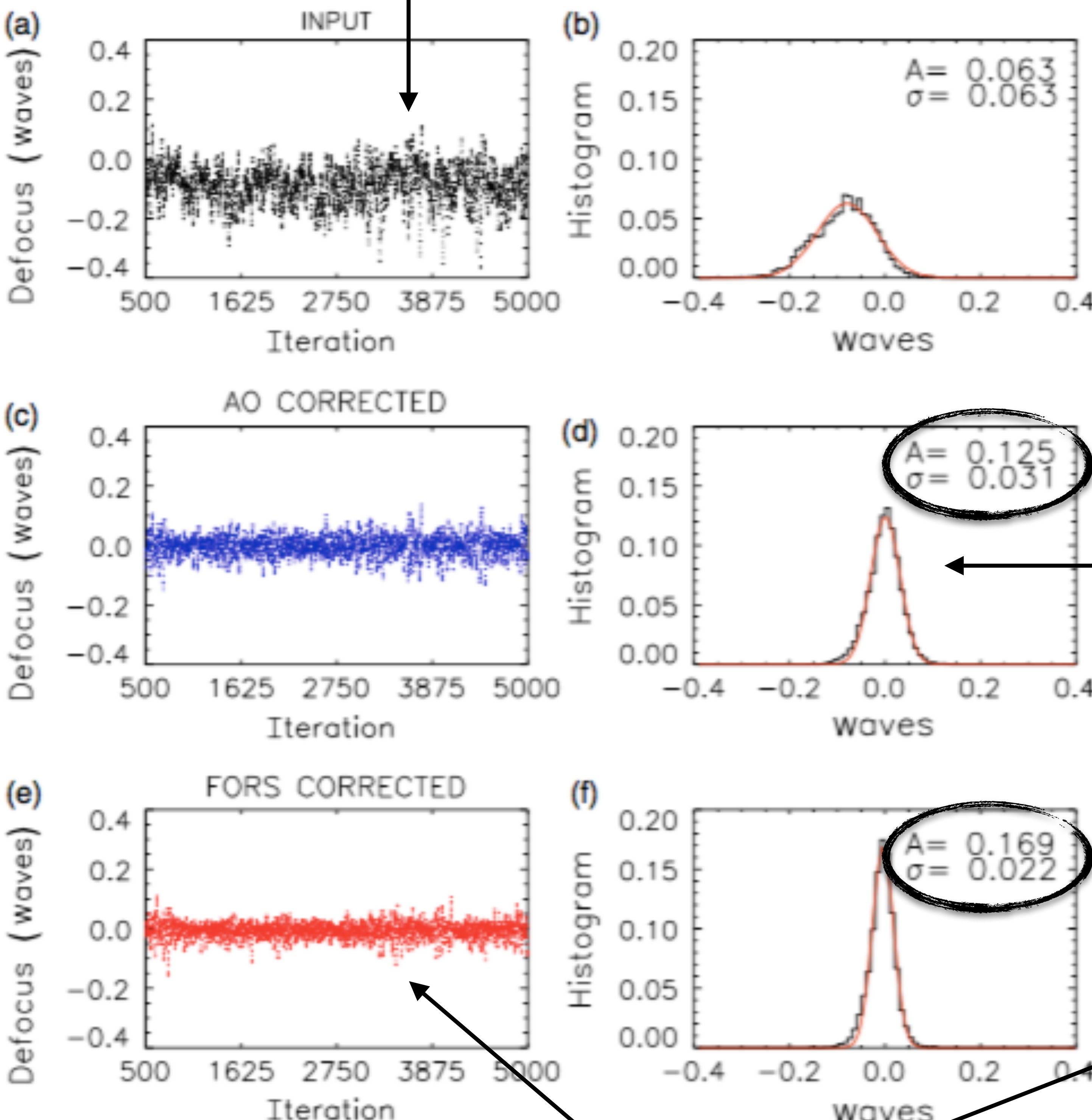


$$B(X_{n+1}) = \phi_1 X_n + \ldots + \phi_p X_{n+1-p} + \\ + \sum_{j=1}^{n} \theta_{nj}[X_{n+1-j} - B(X_{n+1-j})] \quad \text{if } n > m.$$

Learning layer

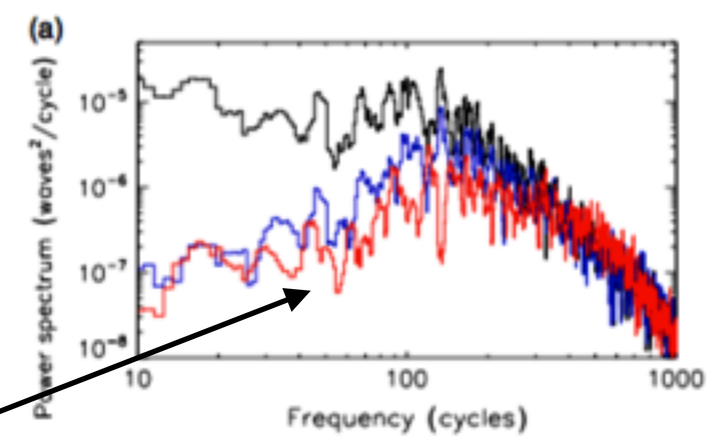
DM commands are modified to drive the mirror ahead of time and follow the short time evolution of the process

Real on-sky recorded aberrations



Reduction of the residual aberrations up to 30%

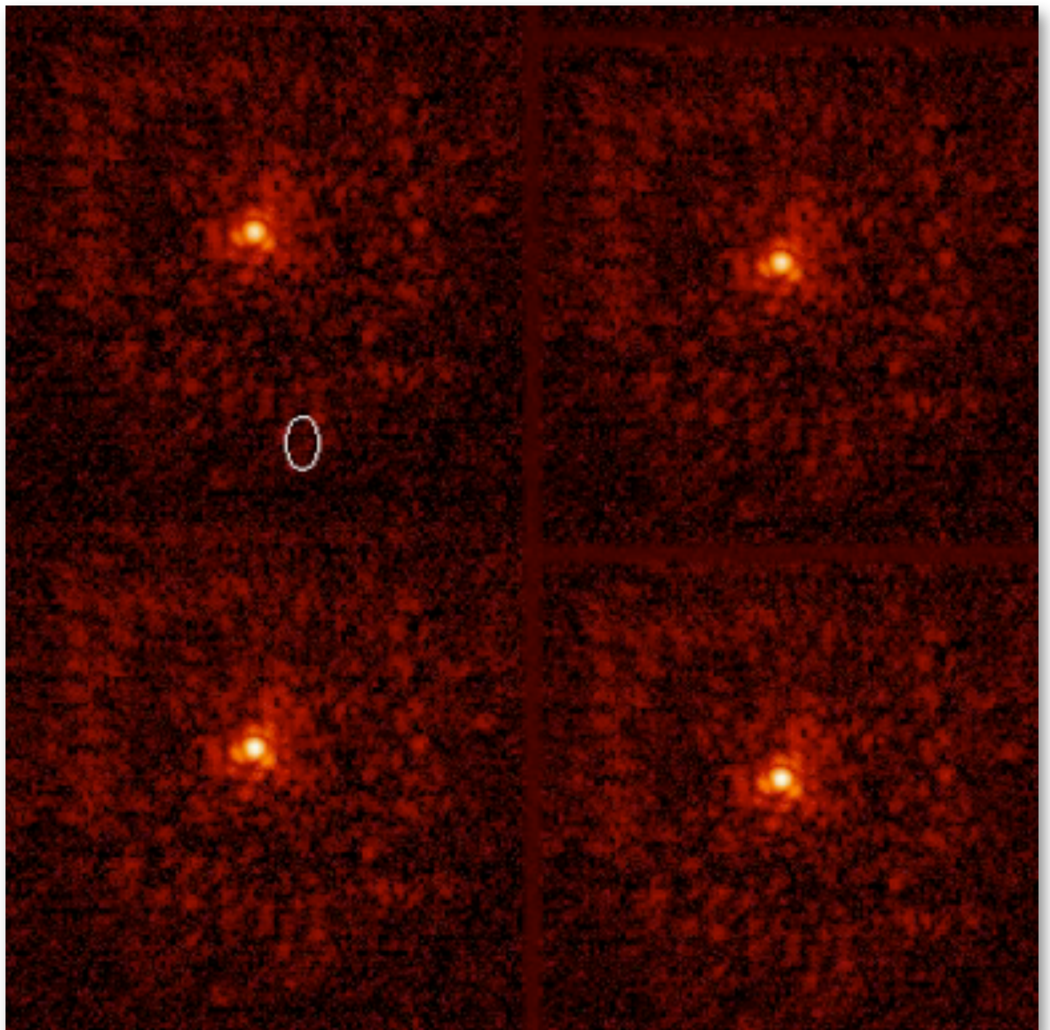
Without prediction



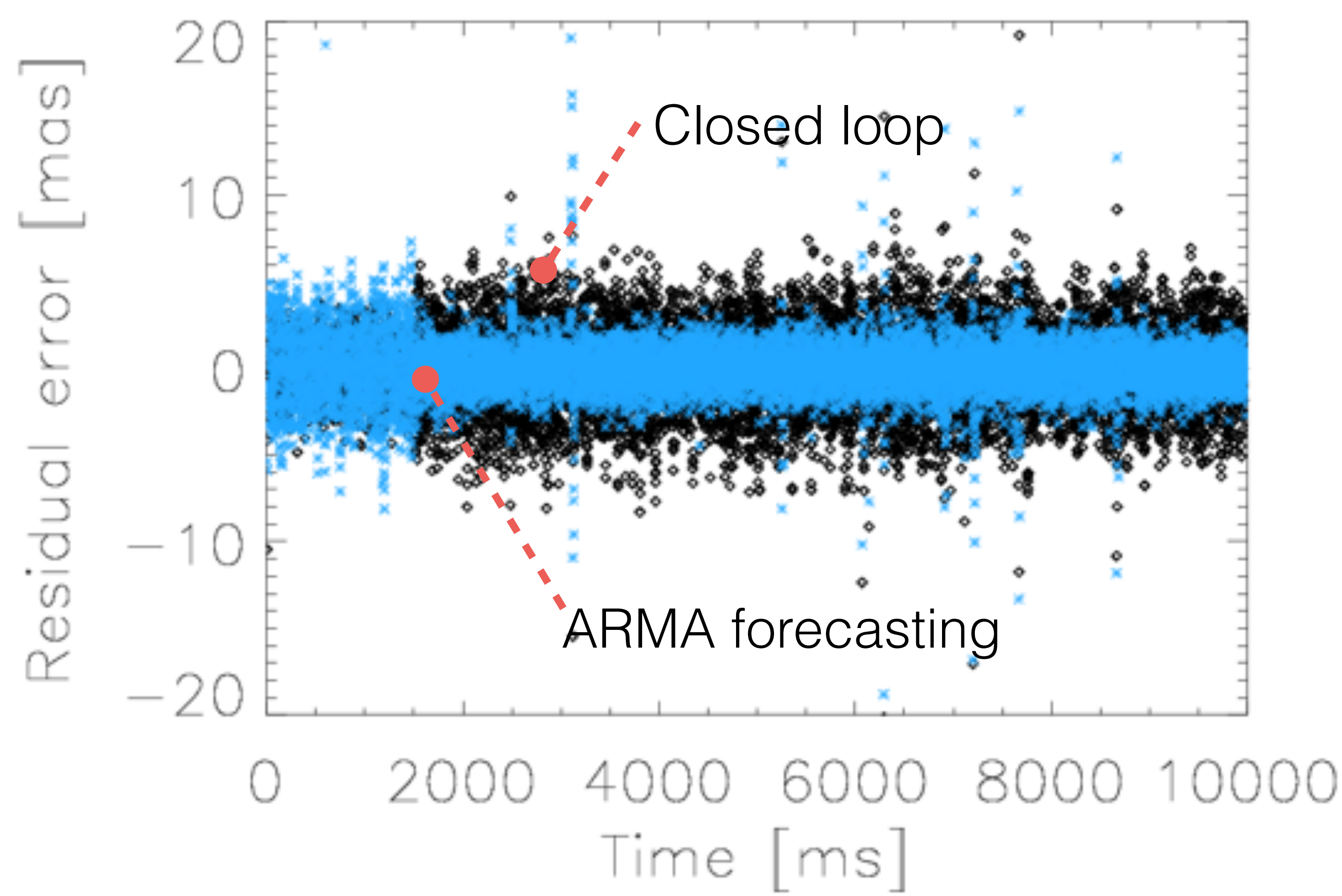
Predictive control

Del Moro et al. 2014

Testing ARMA on LBT-SHARK residual vibrations



$\sigma=2.6\ mas \rightarrow \sigma_{ARMA}=1.5\ mas$



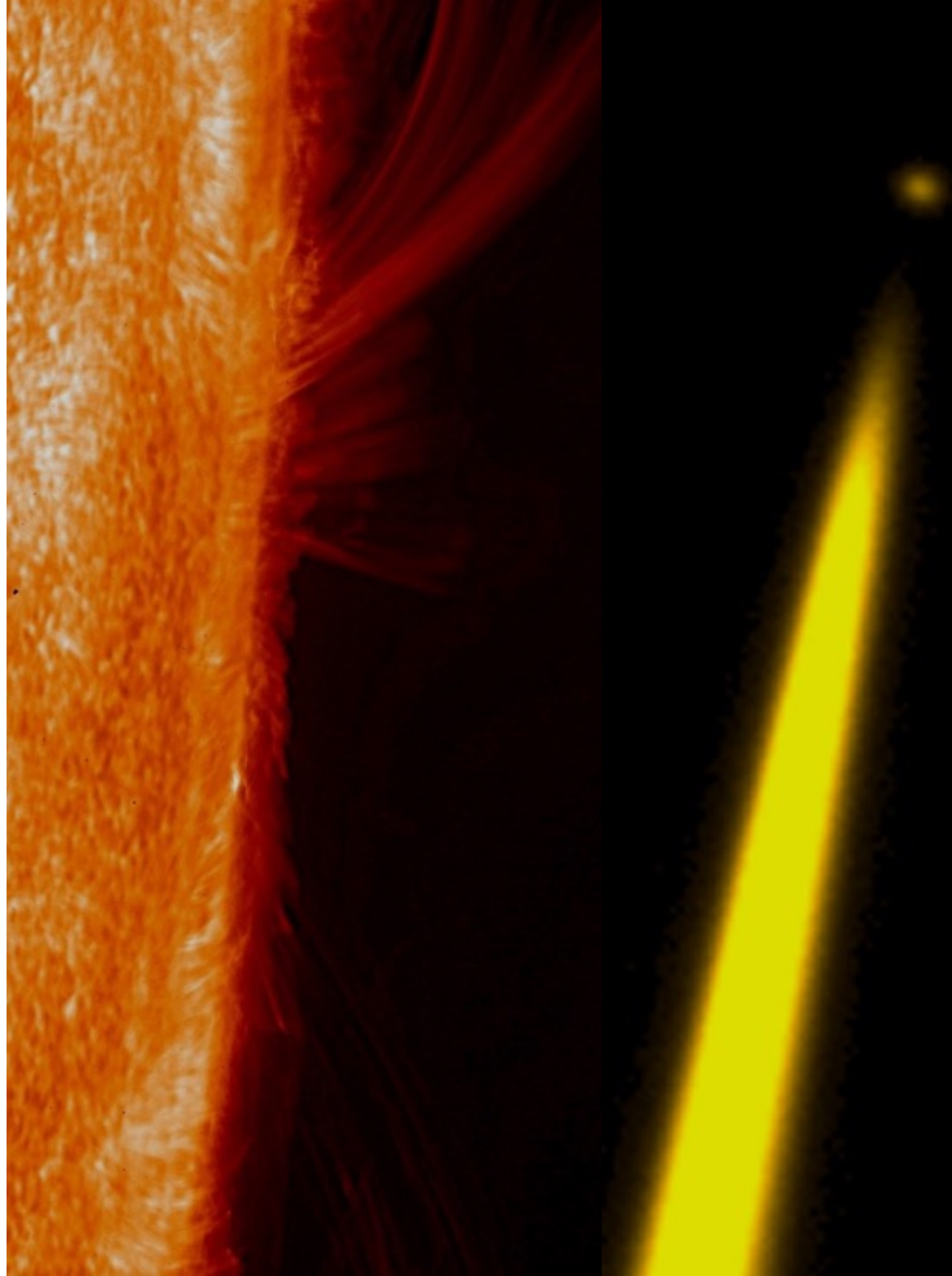
Using real on-sky LBT-SHARK data (1 ms cadence), we have simulated the performances of the ARMA forecasting reducing residual vibrations

ARMA forecasting: from solar to night-time AO

- Our contribution to ELT-MOSAIC

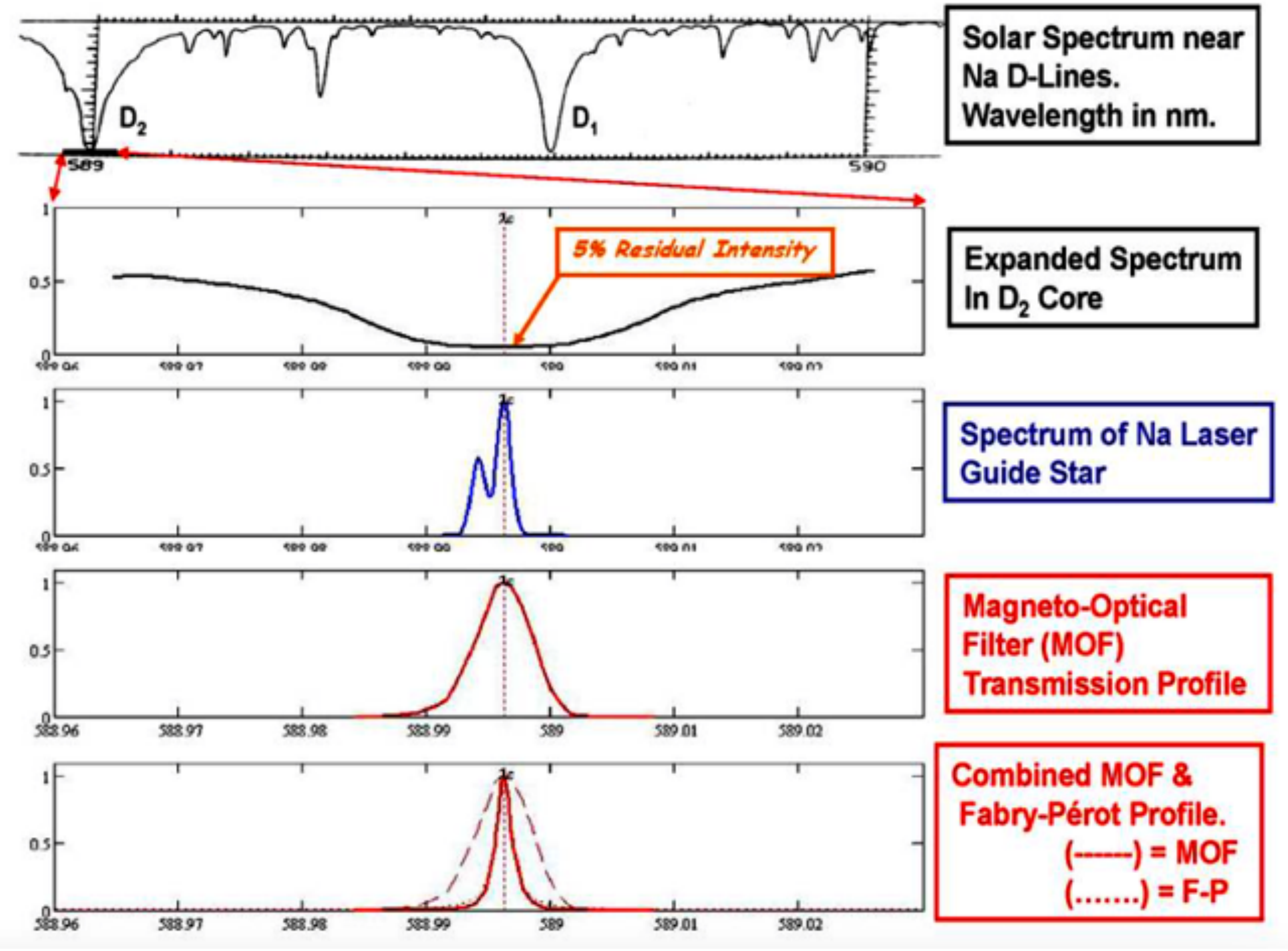
- Ongoing integration into DARC, the real-time control system of CANARY@WHT

LGS in daytime?



Suppressing the sky background

- The feasibility of LGS in daytime was demonstrated by Beckers (2008). This is strategic for both solar and thermal IR observations



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KIS
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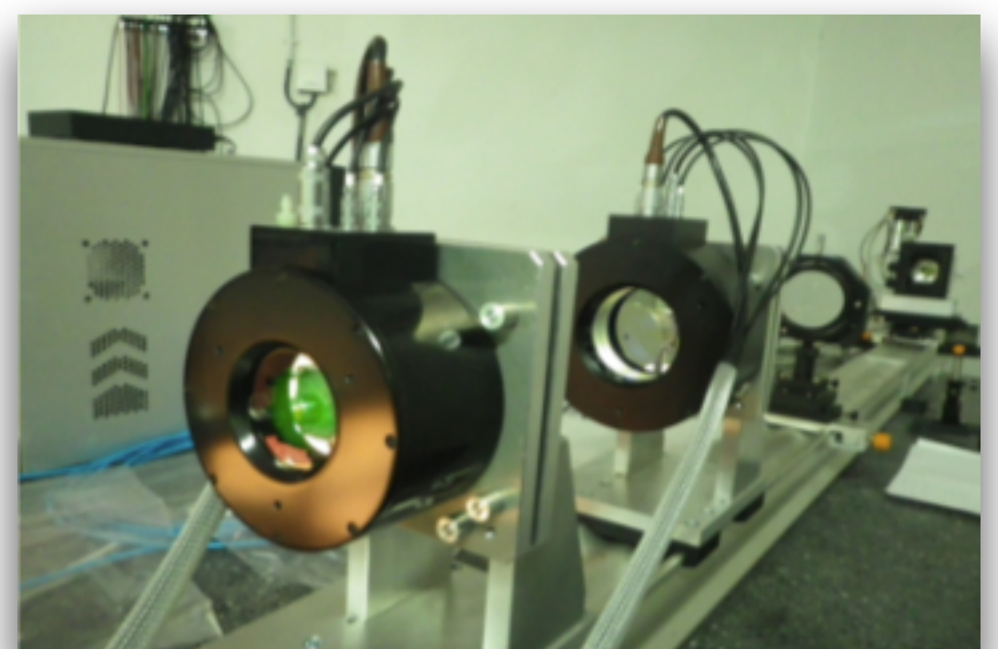
Baseline 190 m:
large spot elongation



Receiver: ***HELLRIDE@VTT*** a dual Fabry-Perot 2D spectrograph

- Extrafocal positioning
- 200 x 200 arcsec FoV
- 25 mA bandpass
- Tunable wavelength