This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824135.

Work Package 7

Multi-Conjugate Adaptive Optics for EST

O. von der Lühe, KIS

with the project partners

Annual Meeting Prague Jan. 23, 2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

Objectives

- Develop and prototype MCAO systems which represent the EST MCAO,
- Test the prototypes in the laboratory and at the GREGOR solar telescope in Tenerife,
- Develop and test alternative concepts based on neural networks for controlling the MCAO,
- Develop tools to characterize the performance of solar MCAO as an input to WP 5,
- Characterize the high altitude turbulence at the EST sites and investigate turbulence prediction,
- Develop EST-specific wave front sensor and deformable mirror technology.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

Description of Work - Subworkpackages

- **Prototype development** — **KIS**, IAC, Durham, Oviedo, ALPAO
- **Neural Network Control** — **Oviedo**, IAC, KIS
- **Performance characterization** — **SU**, HES-SO KIS, IOSB
- **Technology development** — **INAF**, ALPAO

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

7.1 Prototype Development at KIS and IAC

- On-Sky Test of an MCAO system for a 1.5 m pupil with the complexity of the EST MCAO
  - Demonstrate compensation of a 1 arcmin field with five DMs
- Laboratory Test of MCAO technology and control for a 4m EST
- Use prototype to test/verify new wavefront sensing and control concepts

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

KIS Prototype Development Objectives

- Build, test and verify a version of the EST MCAO system which is scaled down to a 1.5 m pupil
- Perform on-sky testing and verification at GREGOR
  - Goal is to demonstrate compensation of a 1 arcmin field
- Integrate four volume control DMs
  - Use existing pupil conjugate DM at GREGOR
- Use existing GREGOR SCAO and MCAO prototype to test/verify new wavefront sensing and control concepts

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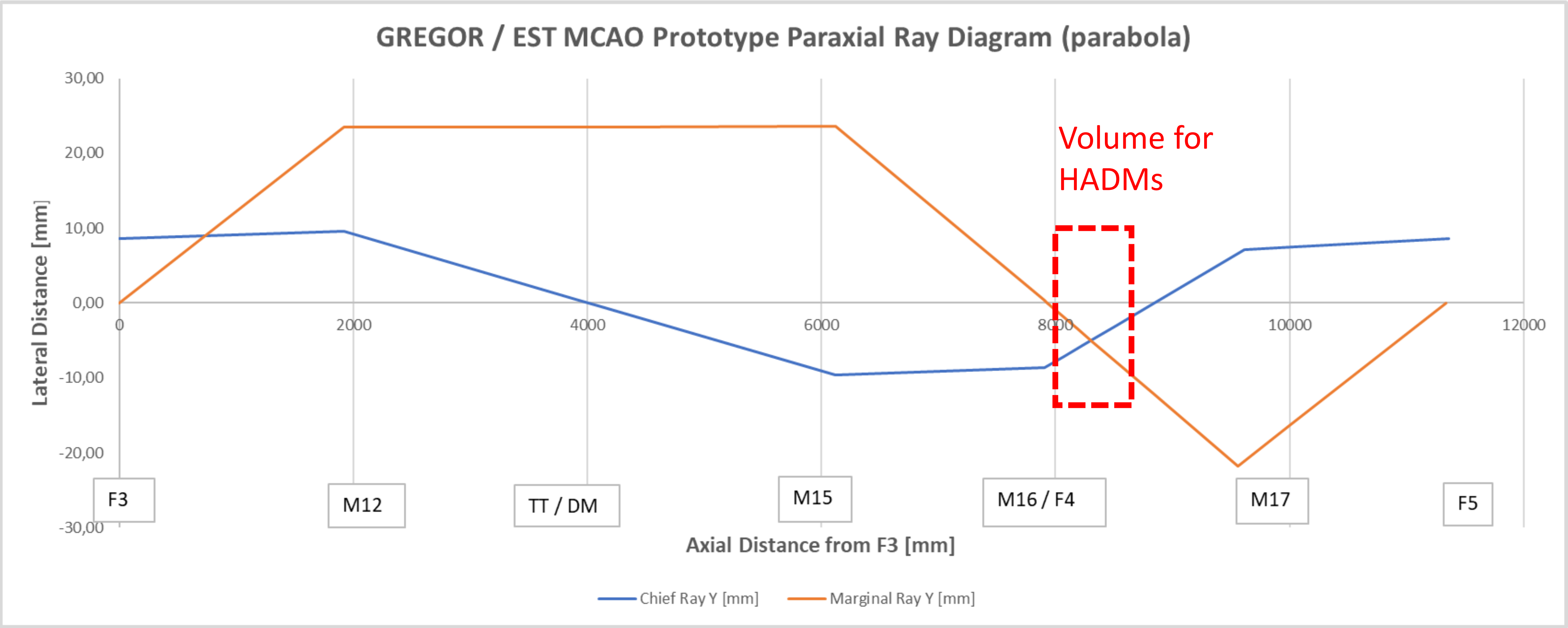
Paraxial Diagram F3 – F5*



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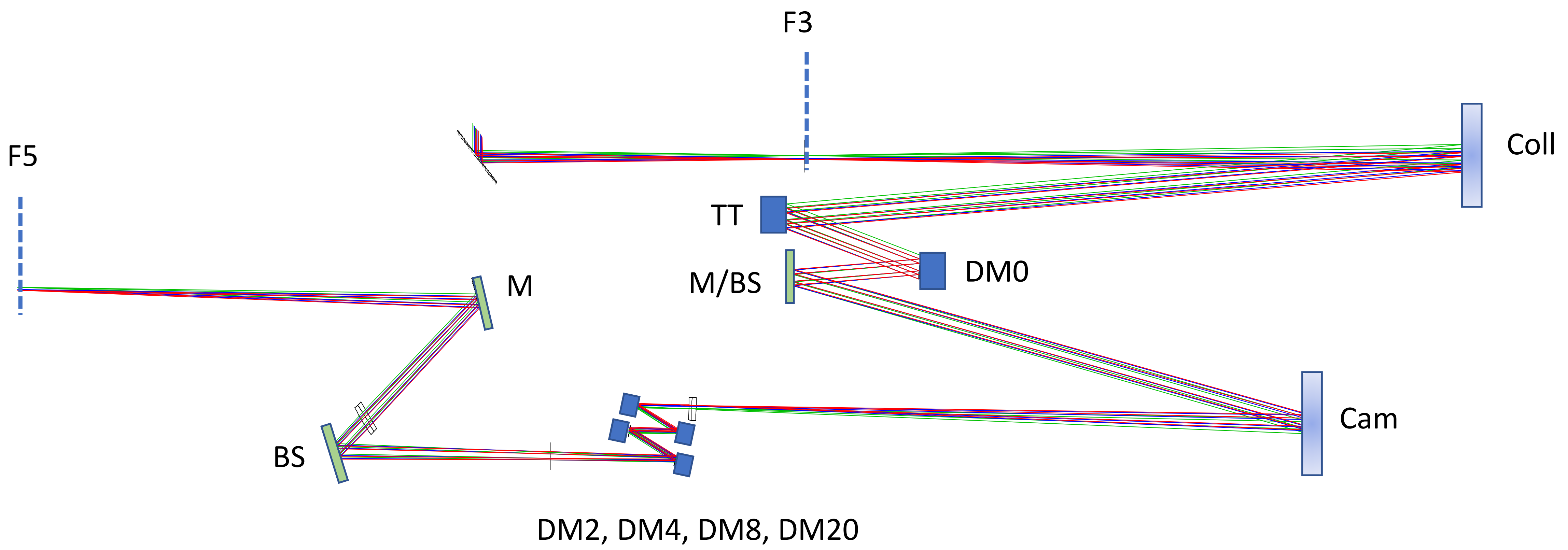
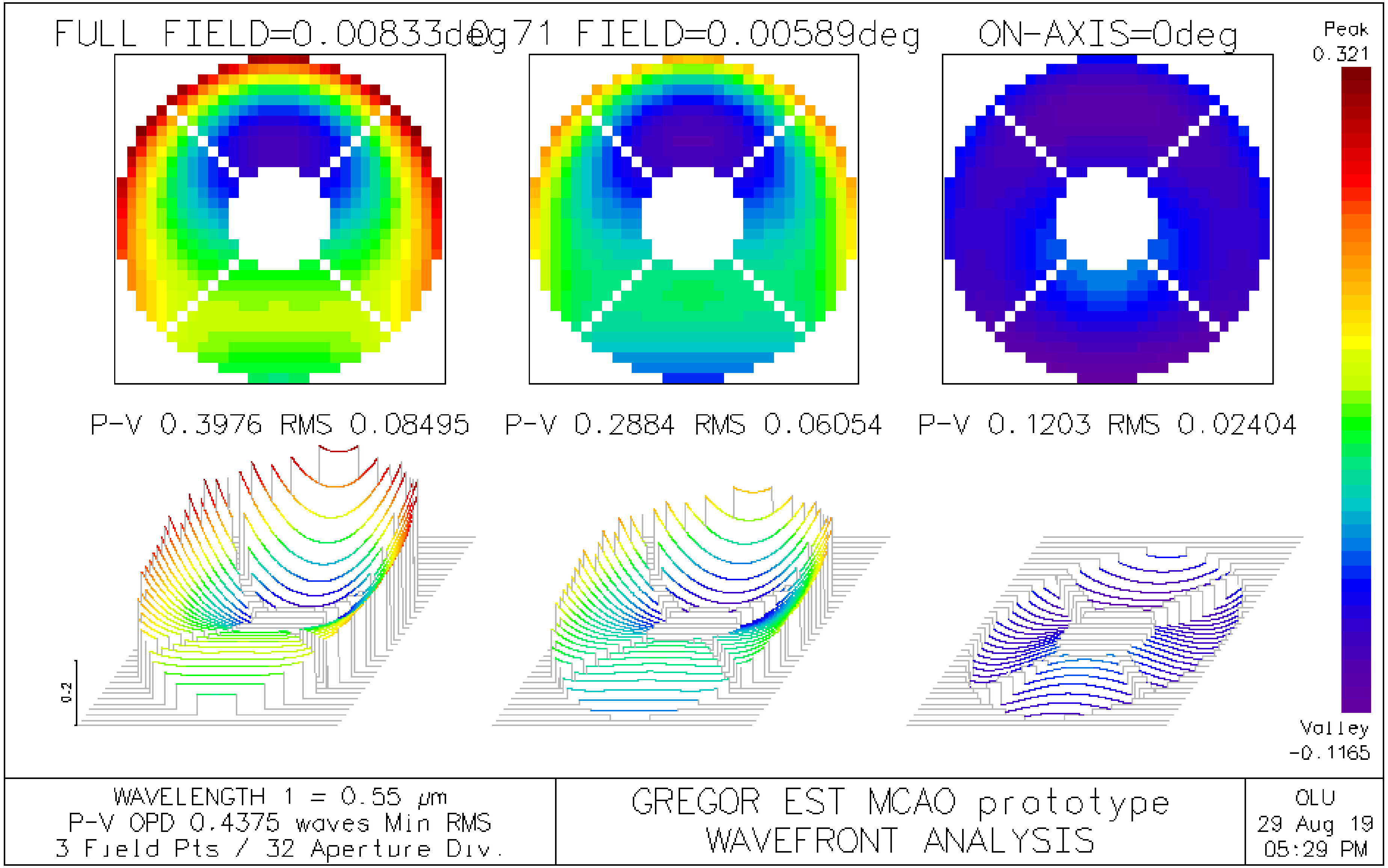
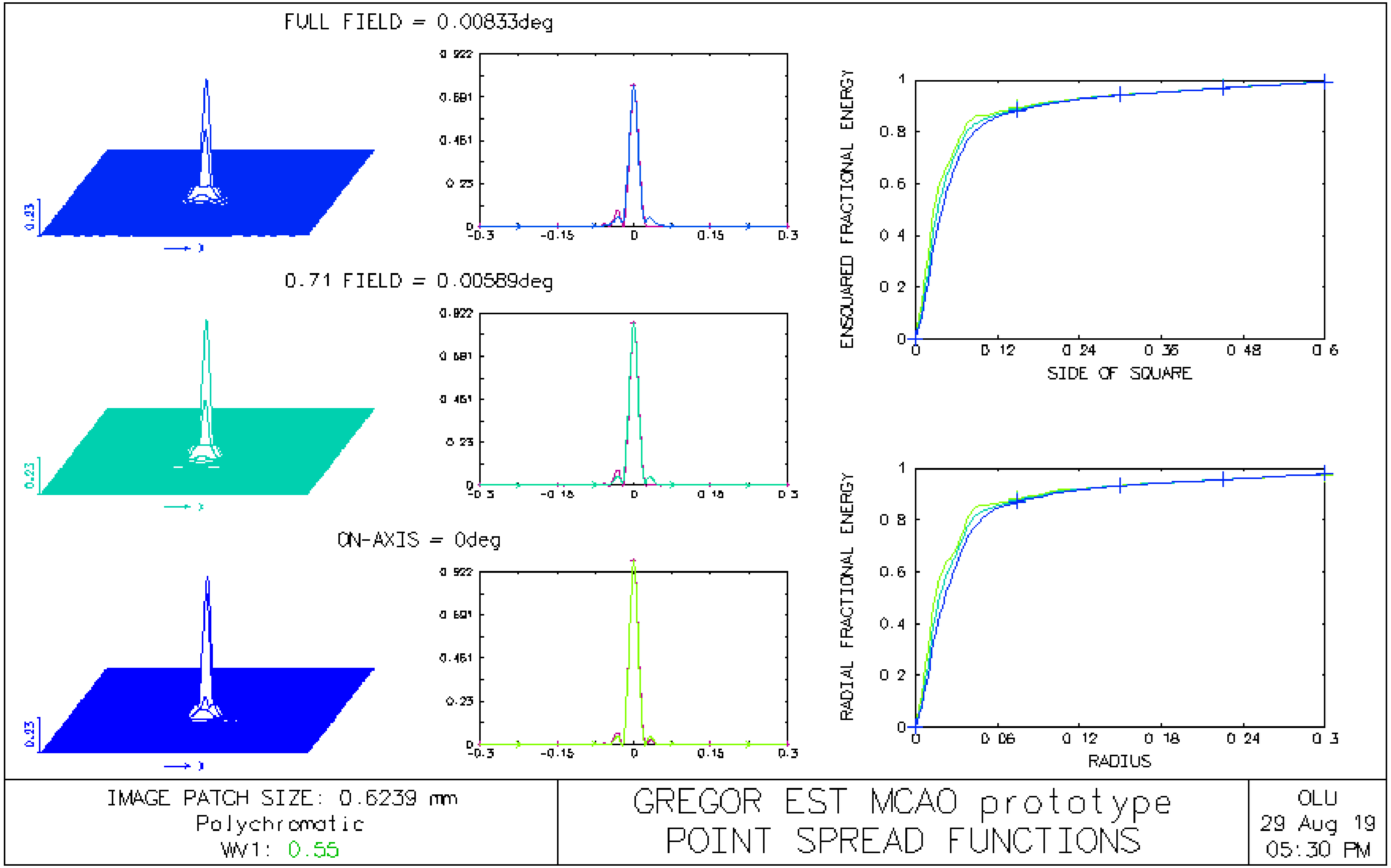
Layout with Lenses for M16 and M17



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.



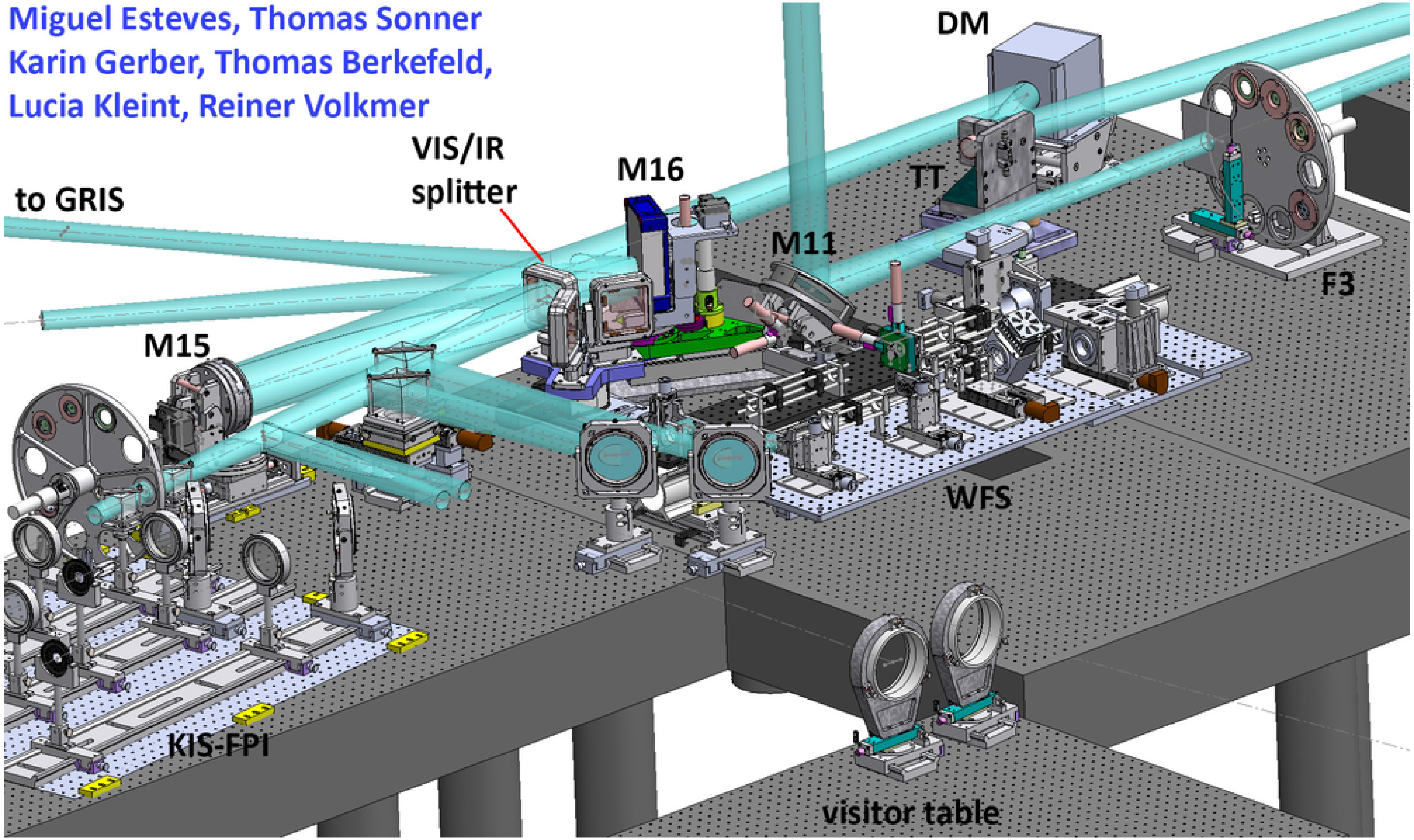


FULL FIELD = 0.00833deg
0.71 FIELD = 0.00589deg
ON-AXIS = 0deg
ENSQUARED FRACTIONAL ENERGY
SIDE OF SQUARE
RADIAL FRACTIONAL ENERGY
RADIUS
IMAGE PATCH SIZE: 0.6239 mm
Polychromatic
WV1: 0.55
GREGOR EST MCAO prototype
POINT SPREAD FUNCTIONS
OLU
29 Aug 19
05:30 PM

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

New Laboratory Layout of GREGOR

Miguel Esteves, Thomas Sonner
Karin Gerber, Thomas Berkefeld,
Lucia Kleint, Reiner Volkmer



This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824135.

KIS MCAO Prototype Status

- Optical design completed
- Finalization of O-M layout hinges on completion of GREGOR lab layout
- One DM purchased, others to follow this year

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IAC Laboratory Prototype - Main Objectives

- Develop, validate and optimize stable and robust MCAO strategies that can be used in EST to correct a FoV of 40‘‘x40‘‘
- Validate mathematical models in a real bench (including pupil misregistration)
- Select the optimal deformable mirror and wavefront sensing configuration for EST MCAO
- Test and optimize control strategies in a real system.

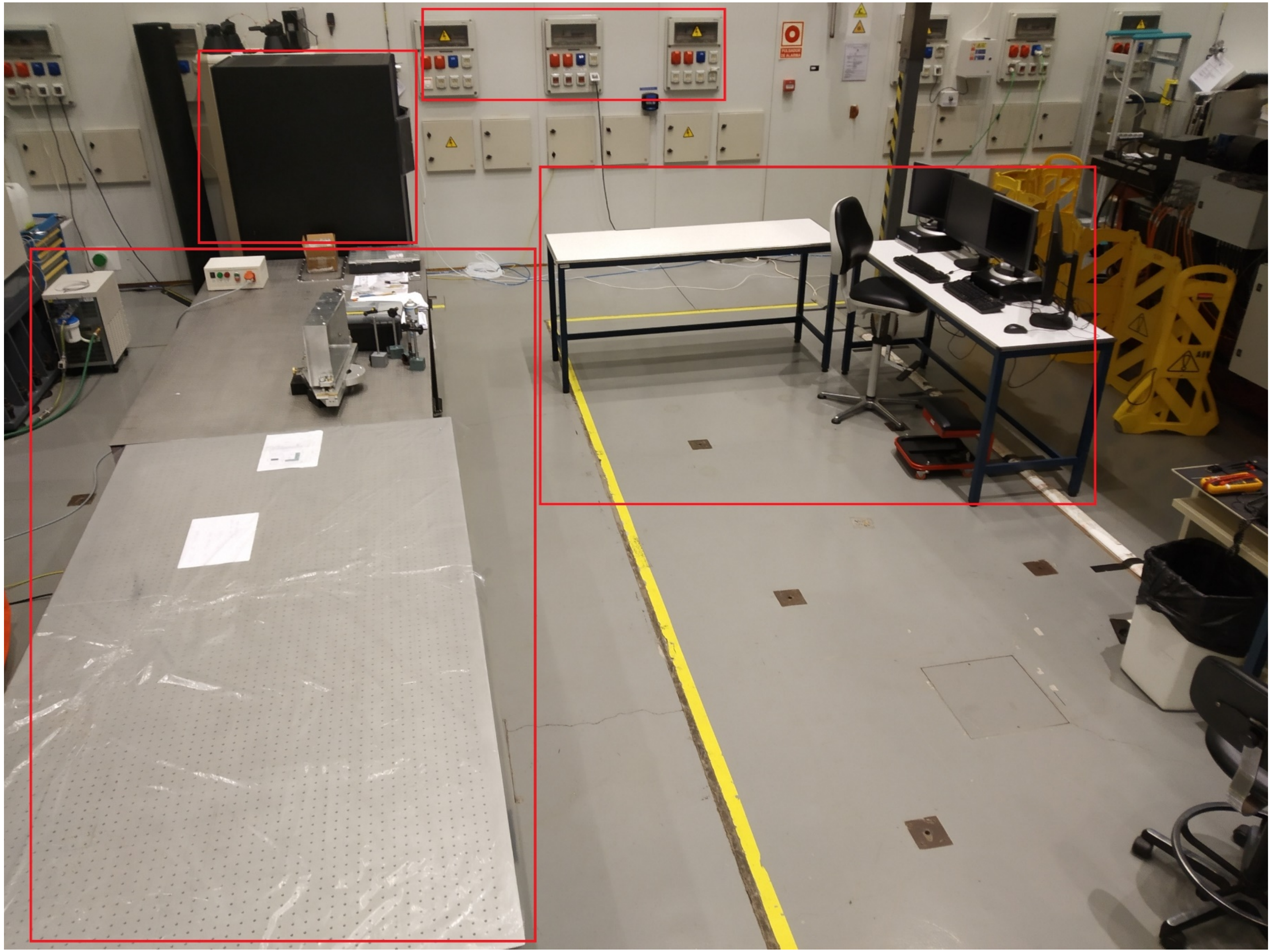
This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 824135.

Present Status

- Cameras arrived and tested
- Phase screens partially arrived
- MCAO Simulations in progress
- Optical design and optical integration reports completed and procurement in progress
- Deformable mirrors call for tender complete
- Illumination system design report completed
- Real time software customization (DARC) In progress
- System engineering updated
- Electronics design report and Mech. Requirements completed

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

Tables and electronic cabinet for MCAO



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

Simulations in progress

- Simulations with DASP (telescope 1.5m, limited so far by computer power):
  - Atmosphere configurations. r0(500nm)=8cm, 15cm,25cm
  - Closed loop integrating simulator and real time controller (DASP+DARC)
- Simulations with Proper to study pupil distorsion (telescope 1m):
  - 2 WFS configurations:
    - 1 WFS right after DM0, another after altitude DMs. Stable but low performance.
    - WFSs after all the DMs. Better performance and it is confirmed that the pupil misregistration is a dominant factor.
  - 2 different reconstructor strategies are being simulated:
    - Classical reconstructor. Only stable with good seeing.
    - Pseudo open Loop. It increases stability for bad seeing.

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Simulations in progress

- Telescope configuration for 1m (8x8 subaps). Limited by computing power to be solved with the new RT computers.
- Atmosphere configurations. r0(550nm)=8cm, 15cm,25cm
- 2 WFS configurations:
  - WFS right after DM0. Stable but low performance.
  - WFS after all the DMs. Better perfornace and it is confirmed that the pupil misregistration is a dominant factor.
- 2 different reconstructor strategies are being simulated:
  - Classical reconstructor. Only stable with good seeing.
  - Pseudo open Loop. It increases stability for bad seeing.
- Debugging simulations with real time controller integrated (DARC+DASP)

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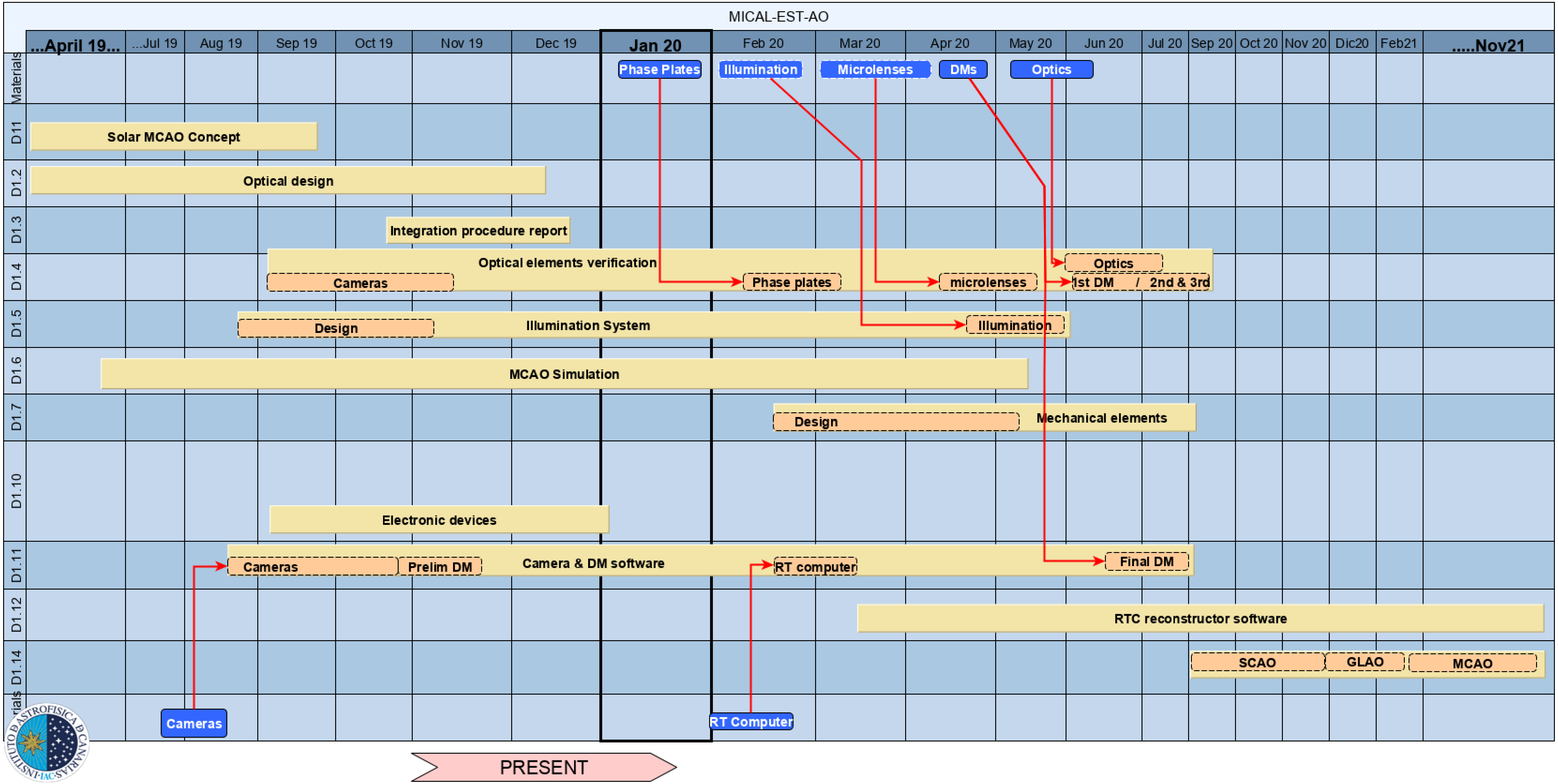

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

7.2 Neural Network Control System

- Evaluate the feasibility of a tomographic reconstructor based on Convolutional Neural Networks (CNN)
- Take advantage of the high potential of deep-learning techniques which are especially adapted to the problem
  - Oviedo has already successfully implemented such a technique for night time AO applications
- Integrate CNN control system into prototype for on-sky evaluation/verification

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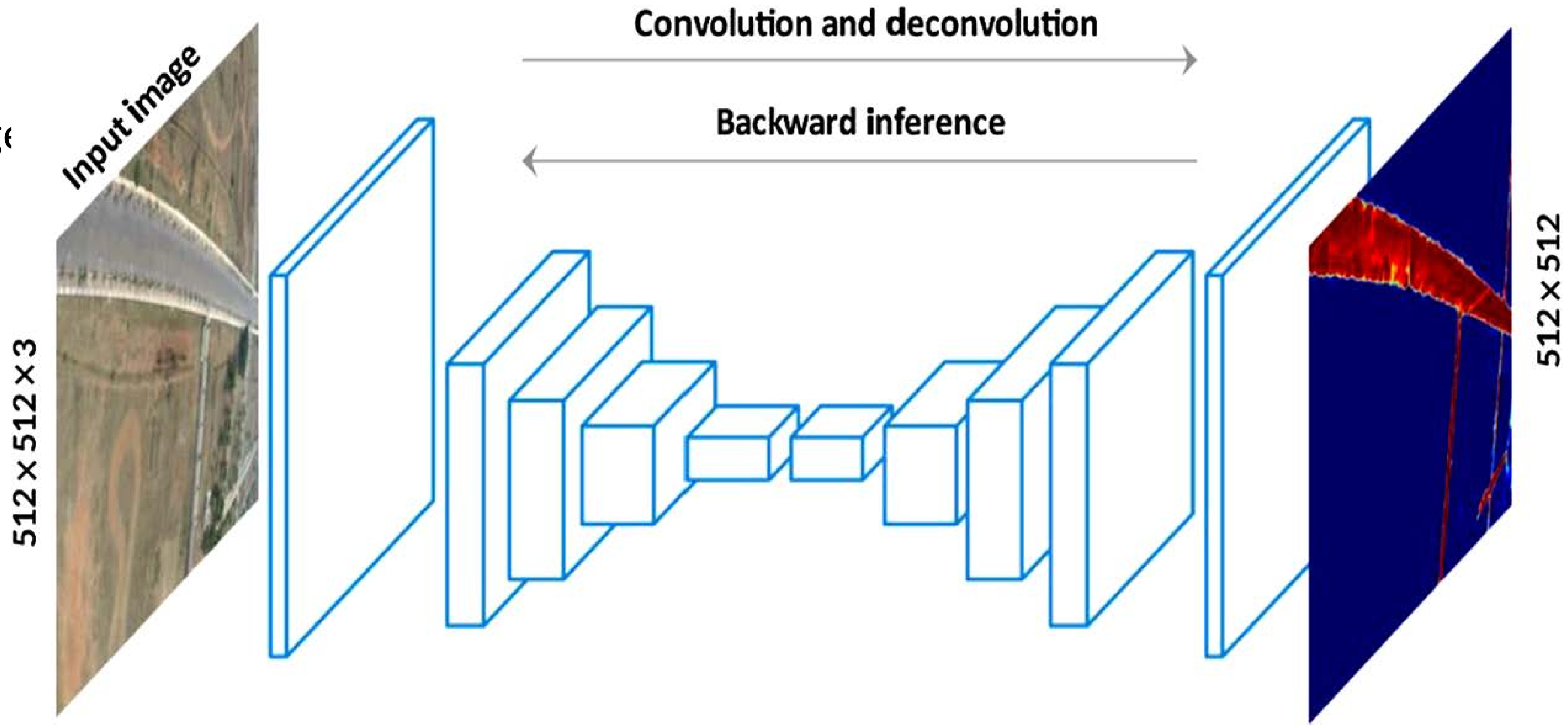
Fully-convolutional ANN

- The inputs are images.
- The outputs are new images.
- It combines convolutional layers and deconvolutional layers to obtain a new image



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Fully-convolutional ANN

Main Problem

- In order to generalize a huge training dataset is needed
- "We need to feed our net, during the training, with many images from different parts of the Sun"

Potential Solutions

- Simplify the input (Correlation Images)
- Simplify the output (DM actuators)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

Simplifying the Imput

Our inputs are directly the images of the correlations of the Shack-Hartmann WFS.

The ANN directly reconstructs the image of the phase from the correlations.

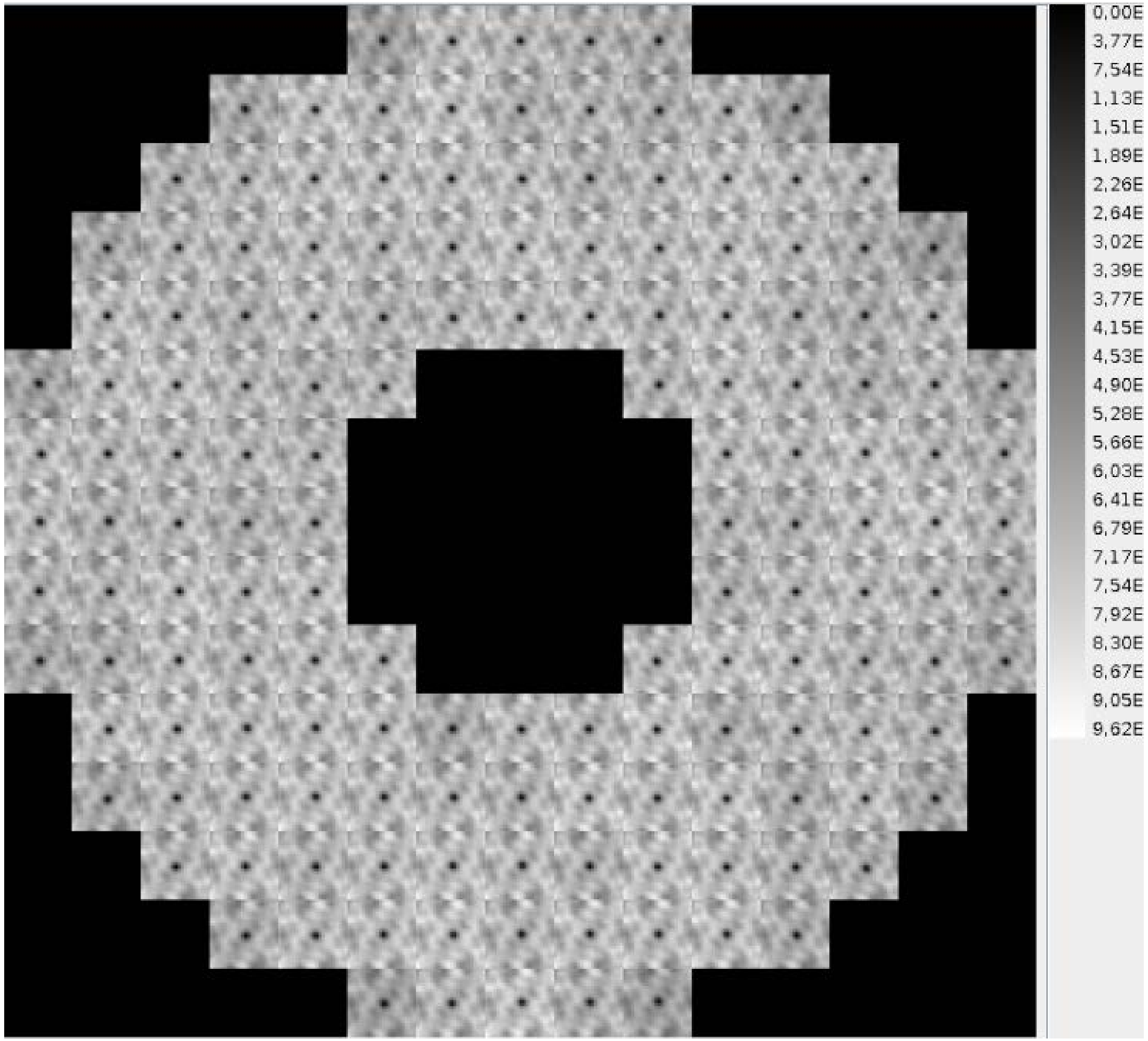
They generalize, that is, they can obtain good results in regions of the Sun where they have not been trained.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

Inputs

Images of the correlations that are calculated by the SH.

- Parameters:
  - SCAO Configuration.
  - Shack-Hartmann WFS 15 subapertures.
  - Diameter = 1.5m
  - $r_0 = 10cm$



ICTEA

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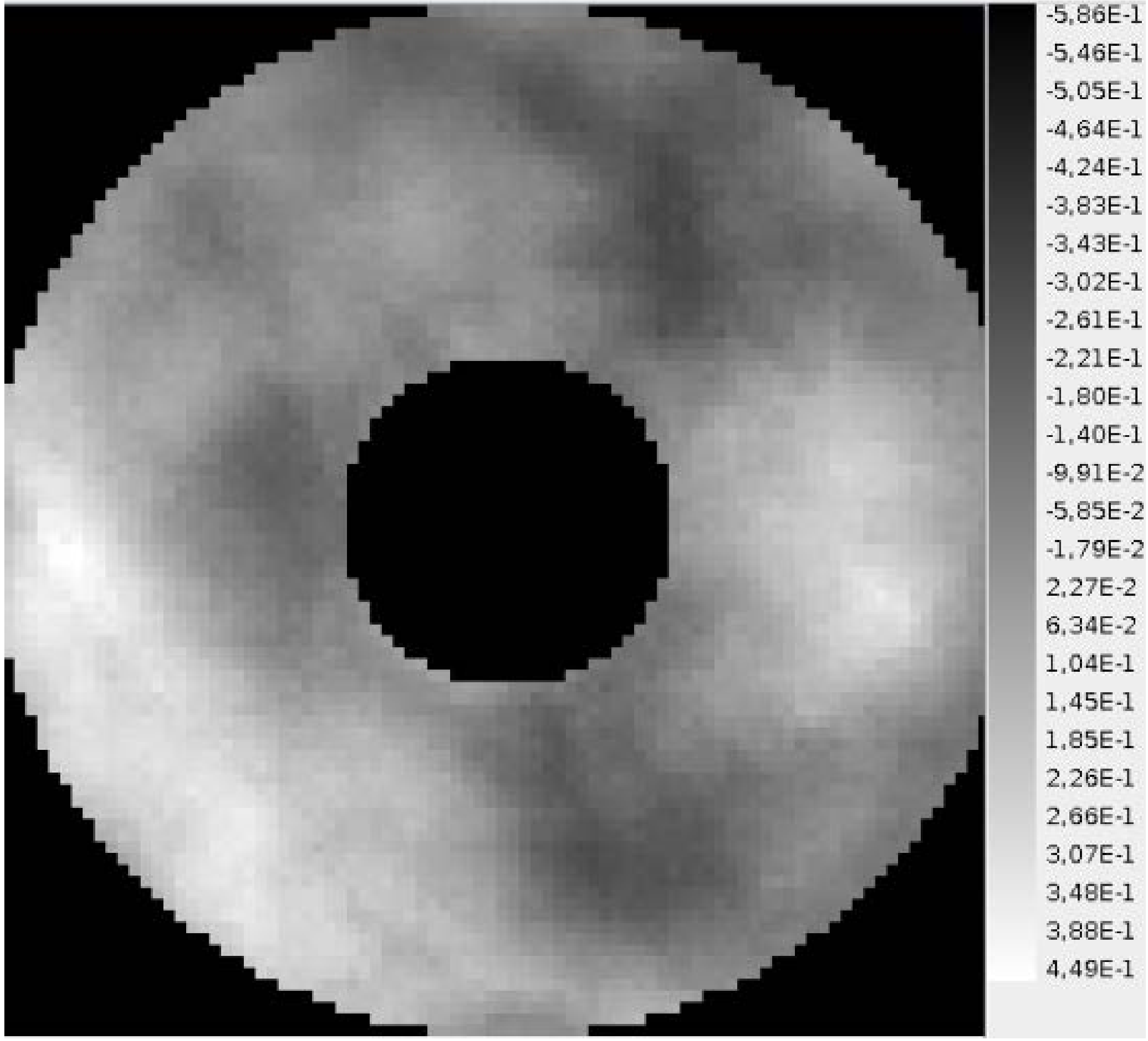
Outputs

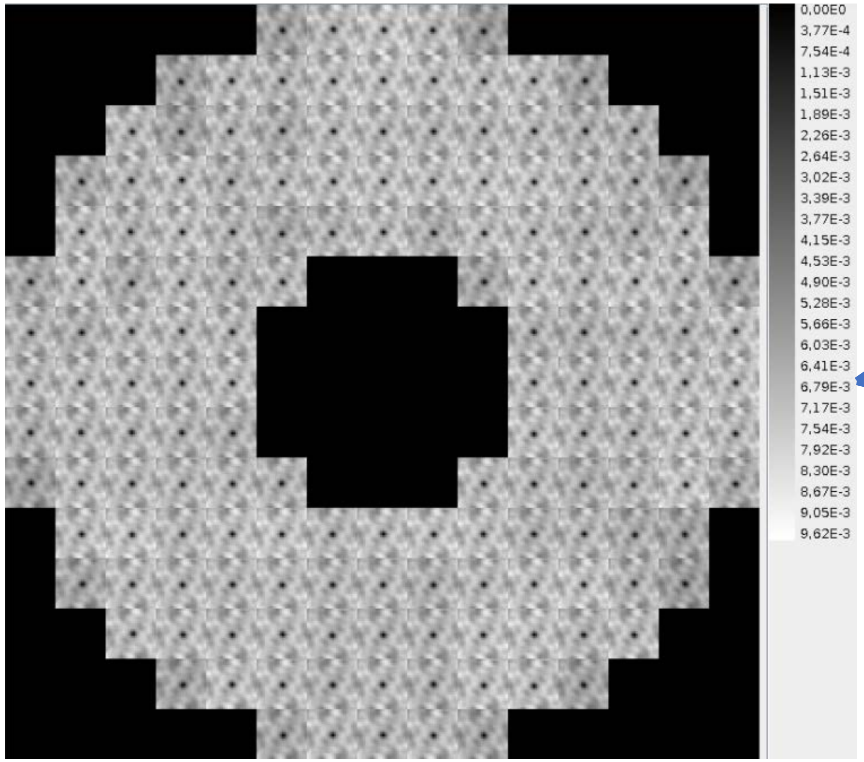
The reconstructed image of the phase



SOLARNET

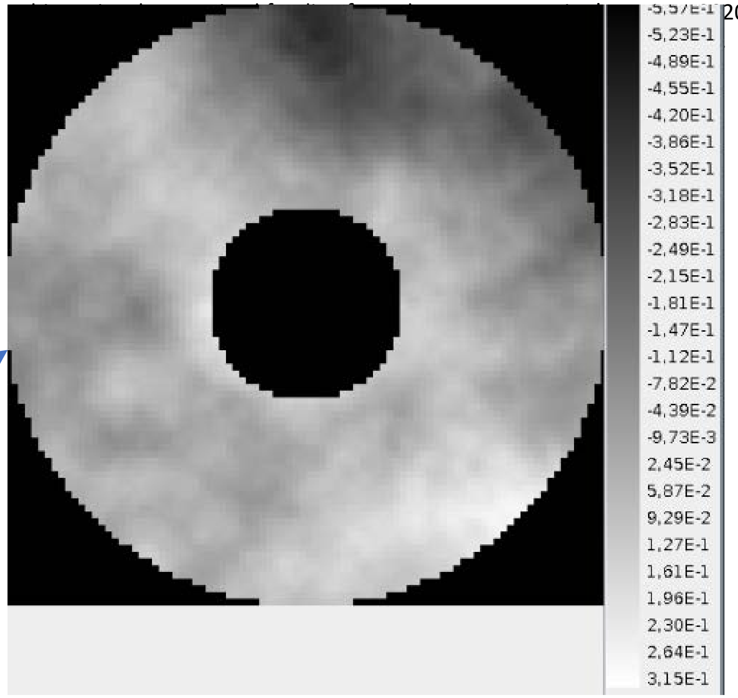
Results

We obtain better results using the reconstructor in pre-trained areas of the Sun.



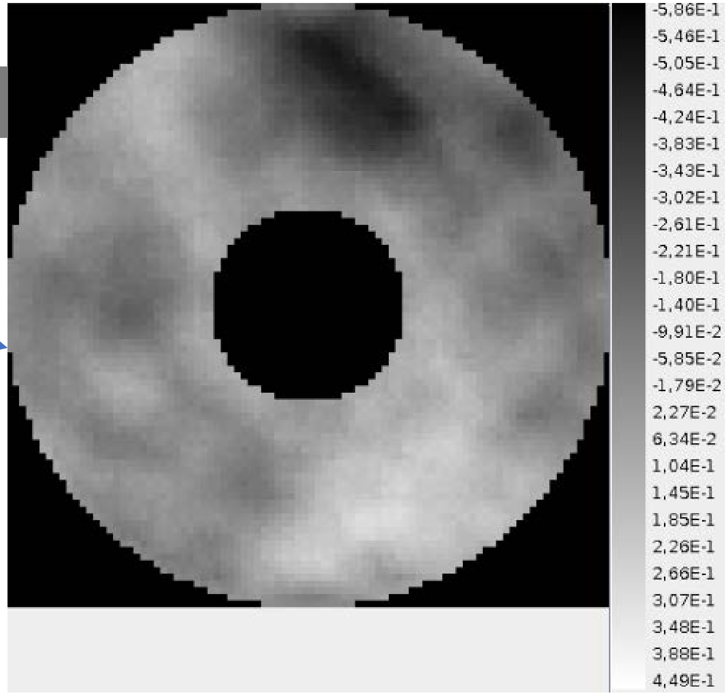
$r_0 = 10cm$

Original phase



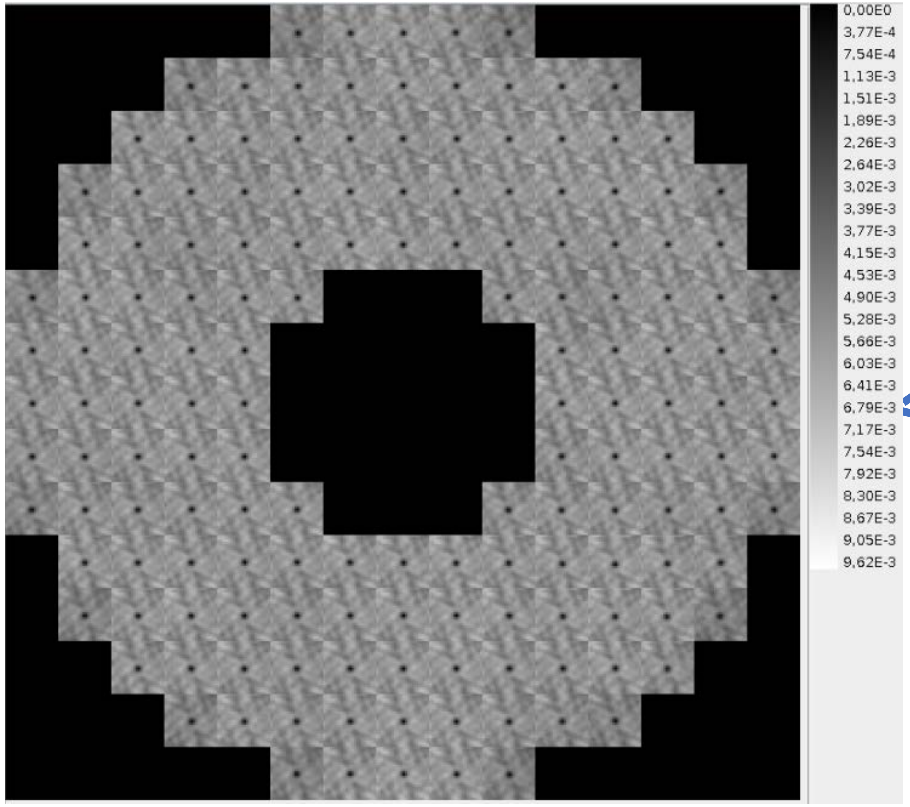
Residual WFE (rad) =1.85

Reconstructed phase



ICTEA

Untrained areas 1

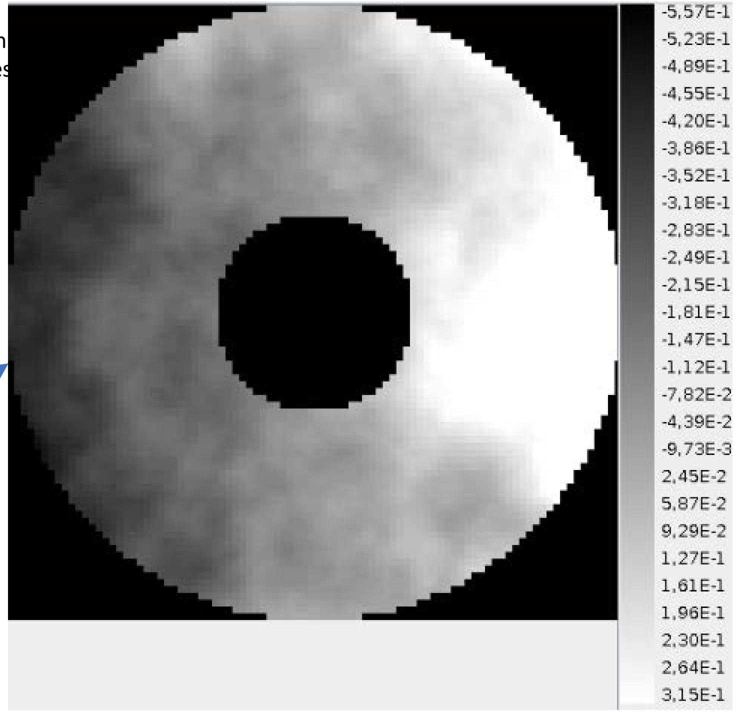


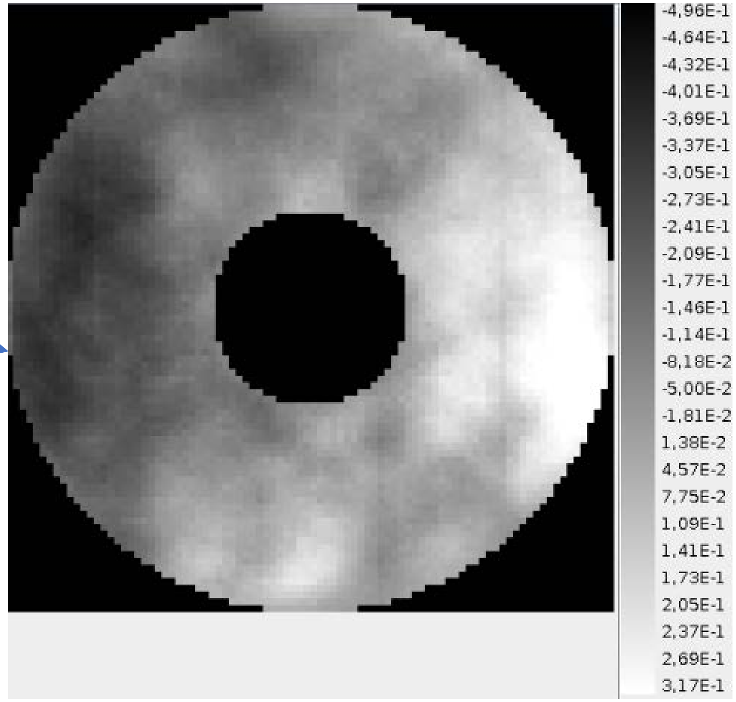
$r_0 = 10cm$

Original phase

Residual WFE (rad) = 3.81

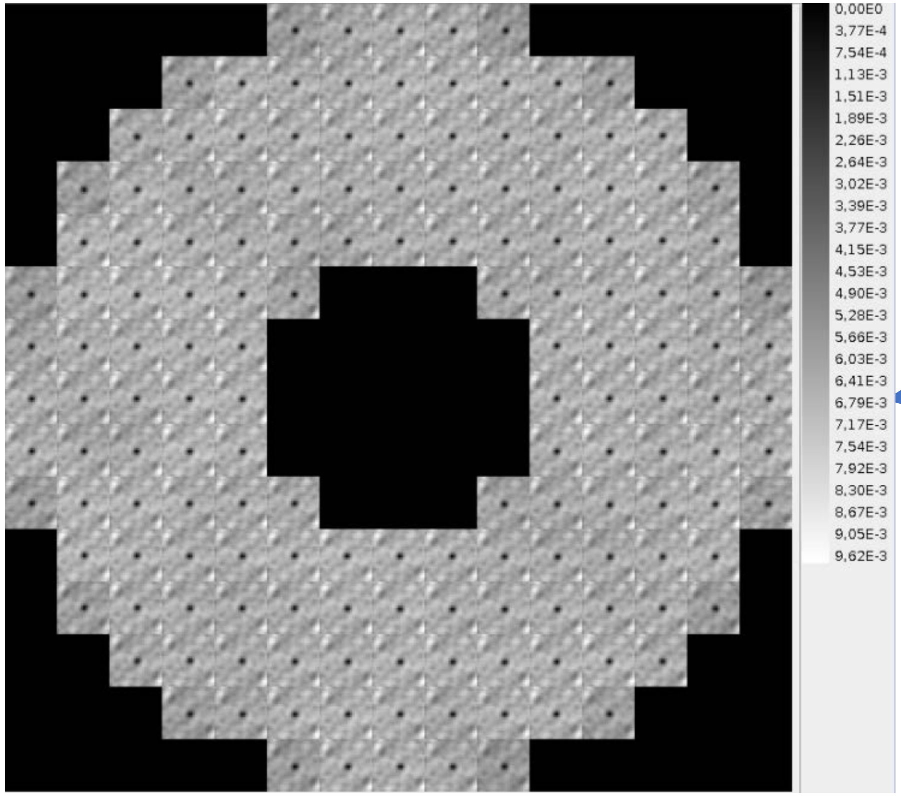
Reconstructed phase





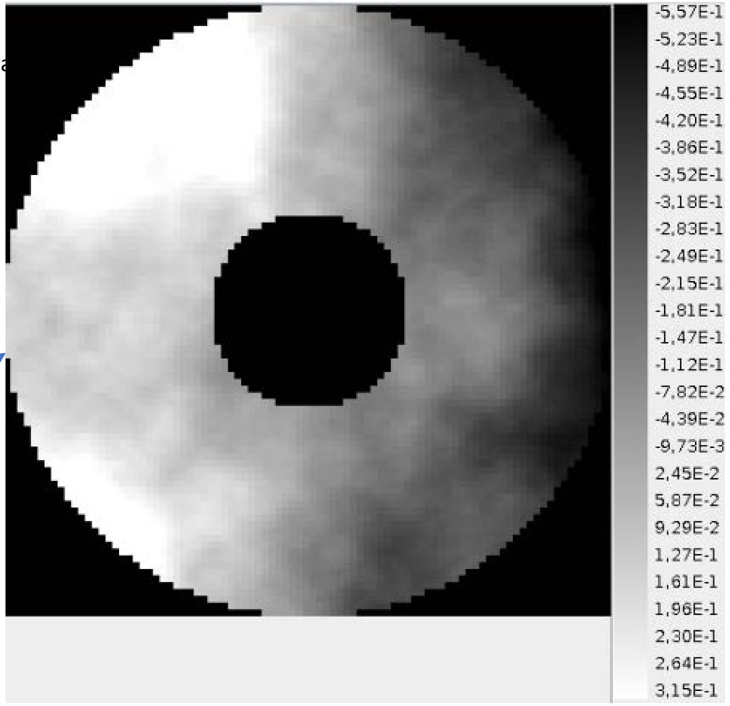
This
resea

Untrained areas 2



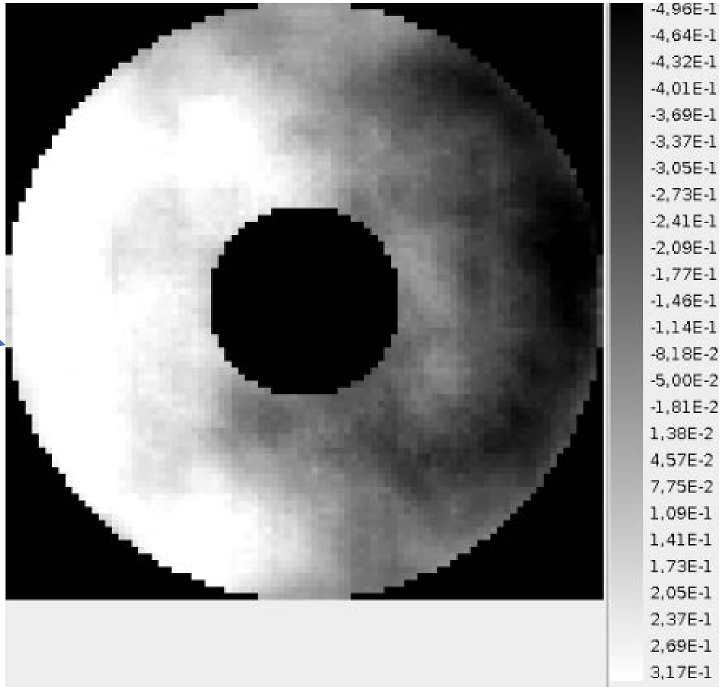
$r_0 = 10cm$

Original phase



Residual WFE (rad) = 4.21

Reconstructed phase



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Global Results

- Test 1500 different images (500 images from a pretrained area of the Sun and 1000 images from two different "unknown areas")
- Different atmospheric conditions
- Residual WFE mean = 4.05 rad

  - Results can be significantly improved
  - Simplifying the output (actuators) still remain to be tested.

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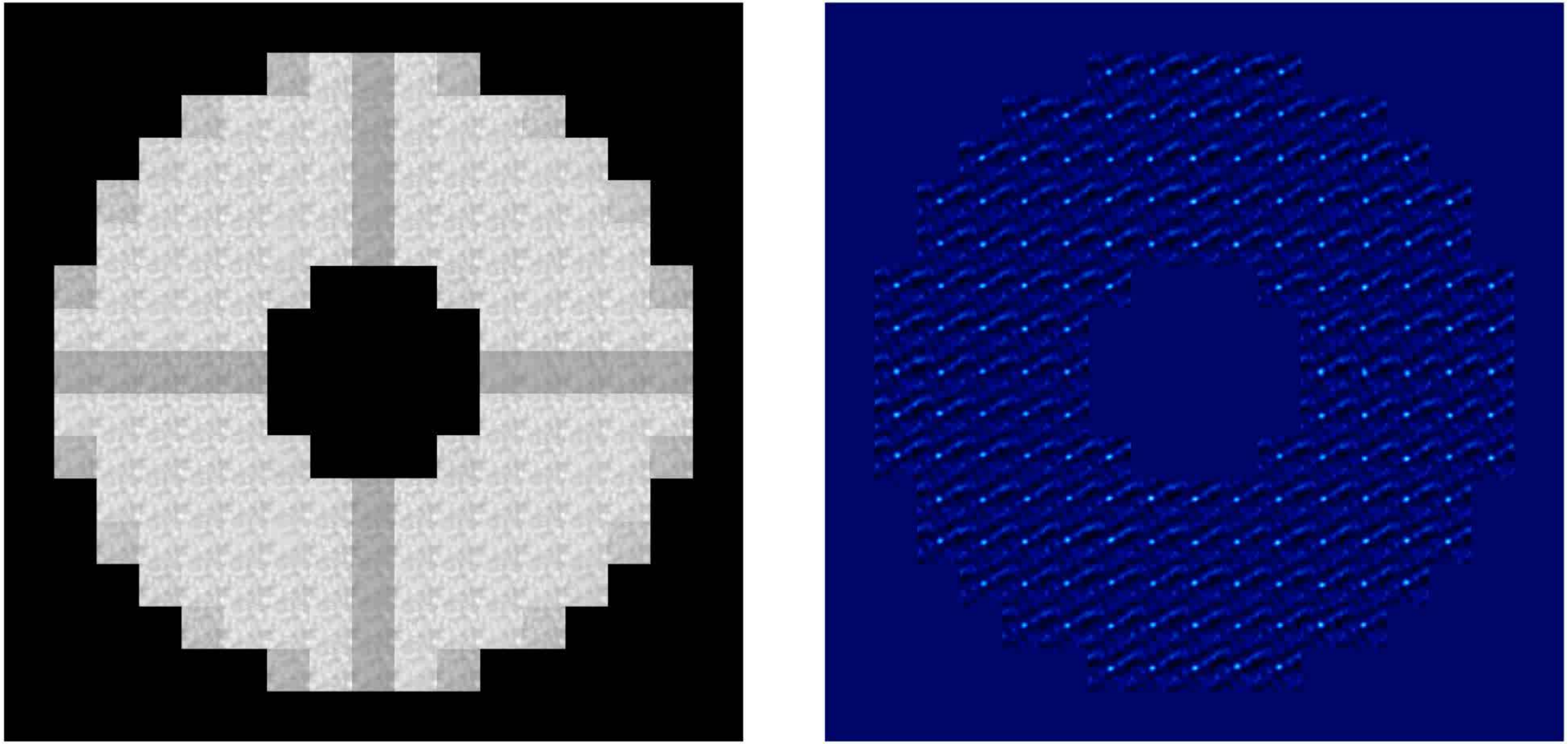
WFS Simulation with anisoplanatism (r_0 = 10 cm)



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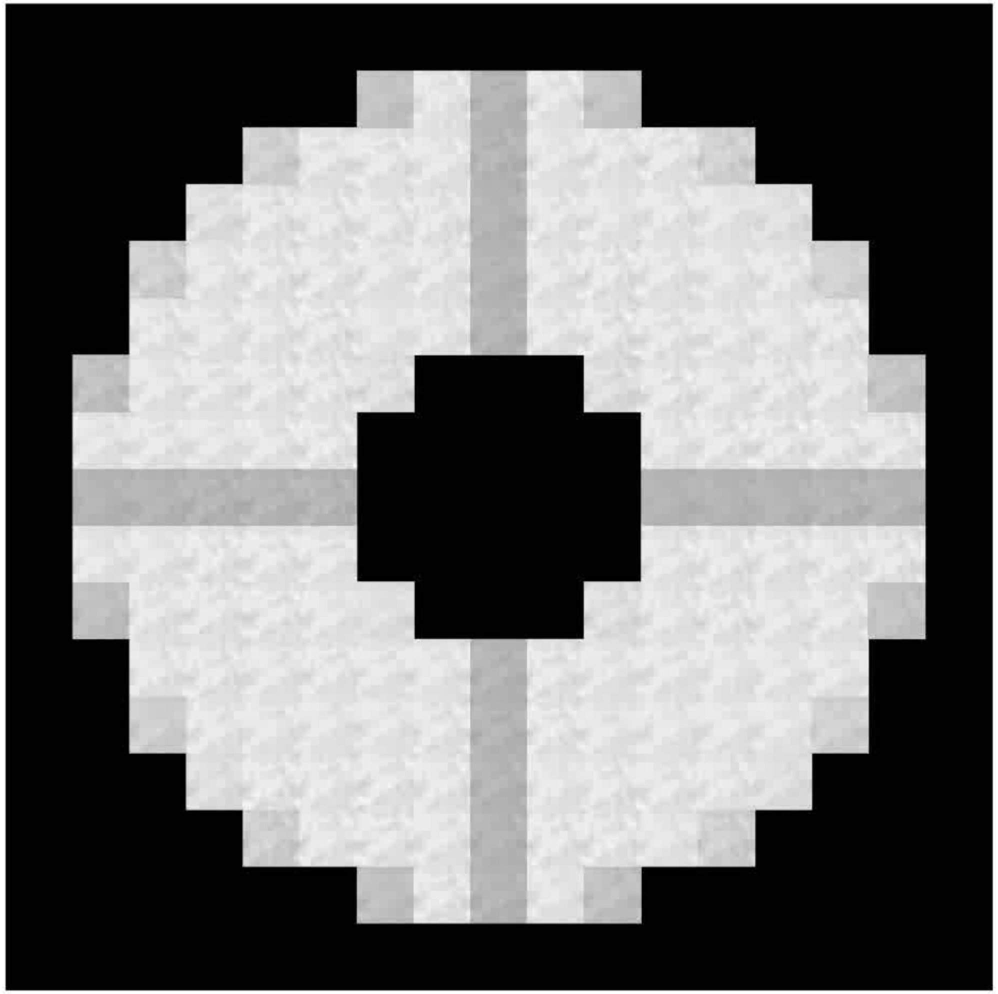
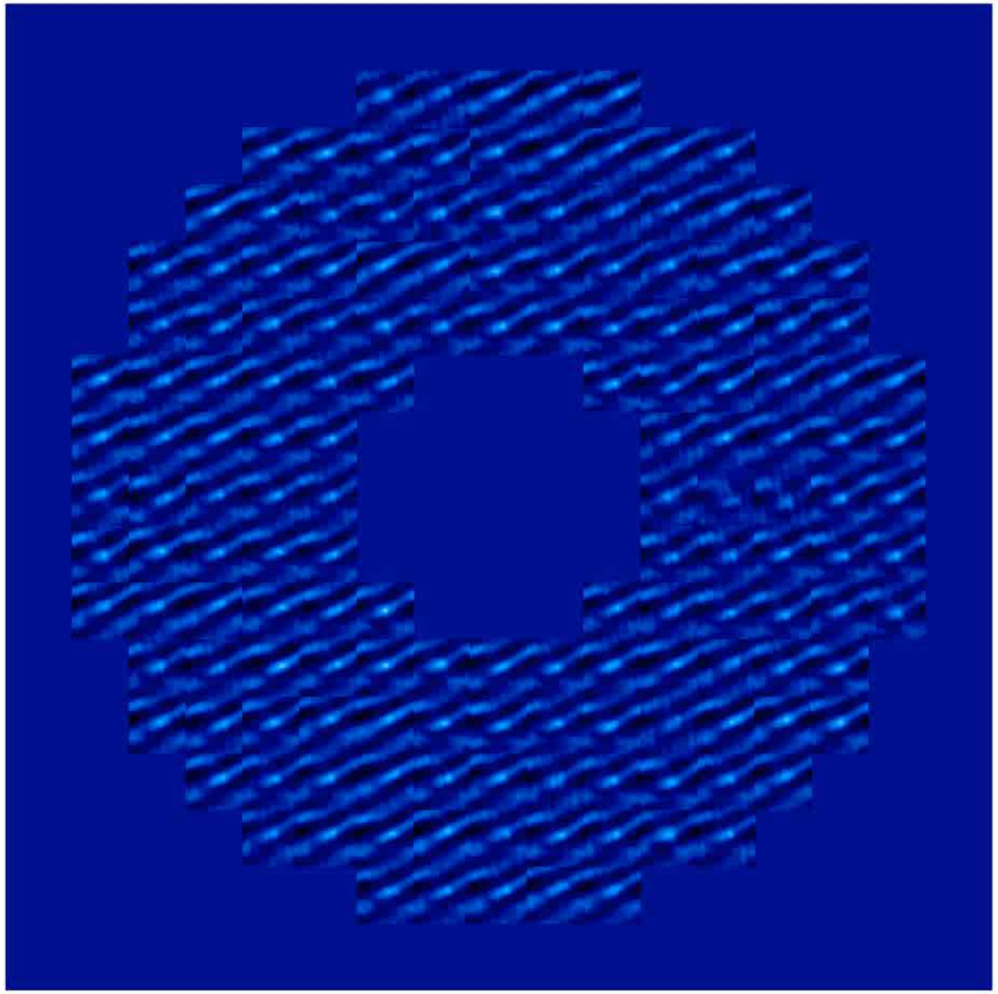
WFS Simulation with anisoplanatism (r_0 = 5 cm)





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7.3 Performance Characterization and Prediction

- Develop tools to characterize the performance of the EST MCAO system and to generate the information needed to remove the residual disturbances from observed data (LE-PSF; interface to WP 5)
- Differential Characterization of RdlM and OT sites
- Evaluate forecast techniques for relevant atmospheric parameters

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Wide-Field Wave-Front Sensor

WFWFS OPERATING at SST (Roque) and VTT (Izaña)

WFWFS SST and VTT live seeing: *(Now closed for the Winter)*
http://sst.iac.es/wfwfs/

SST live seeing data: *(Now Closed for the Winter)*
http://www.royac.iac.es/seeing.html

Things that do work

- Live WFWFS plots working. For SST, comparison is made with r_0 from AO system
- Previous plots had sign error that caused completely wrong "small" subfield measurements of r_0. Now OK.
- Live r_0 plots use same "triangular" orientation of sub-fields at VTT and SST
- Both SST and VTT systems fully operational and storing data as far as we can tell
- Limit for storing data currently is set at r_0=8 cm for large field-of-view. Criteria for this are still open for discussion. At VTT, we almost never reach r_0 = 8 cm, limit now is 6 cm at VTT.
- Daily log files of quick-look r_0 are produced
- SST SHABAR (on top of SST tower) is operational

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Wide-Field Wave-Front Sensor
Simultaneous Campaigns

- VTT must be open during the camping (VTT) *low operation*.
  - IAC will help on opening an closing VTT telescope for WFWFS operation during the campaigns.

Plans

- VTT WFWFS in full in operation. **TBC (Solving telescope problems)**
- Continue work on data processing pipeline
- Compare SST r0 data from WFWFS and AO
- Prepare release of single data set from SST to those (if any!) that intend to develop independent method and software for analyzing WFWFS data.

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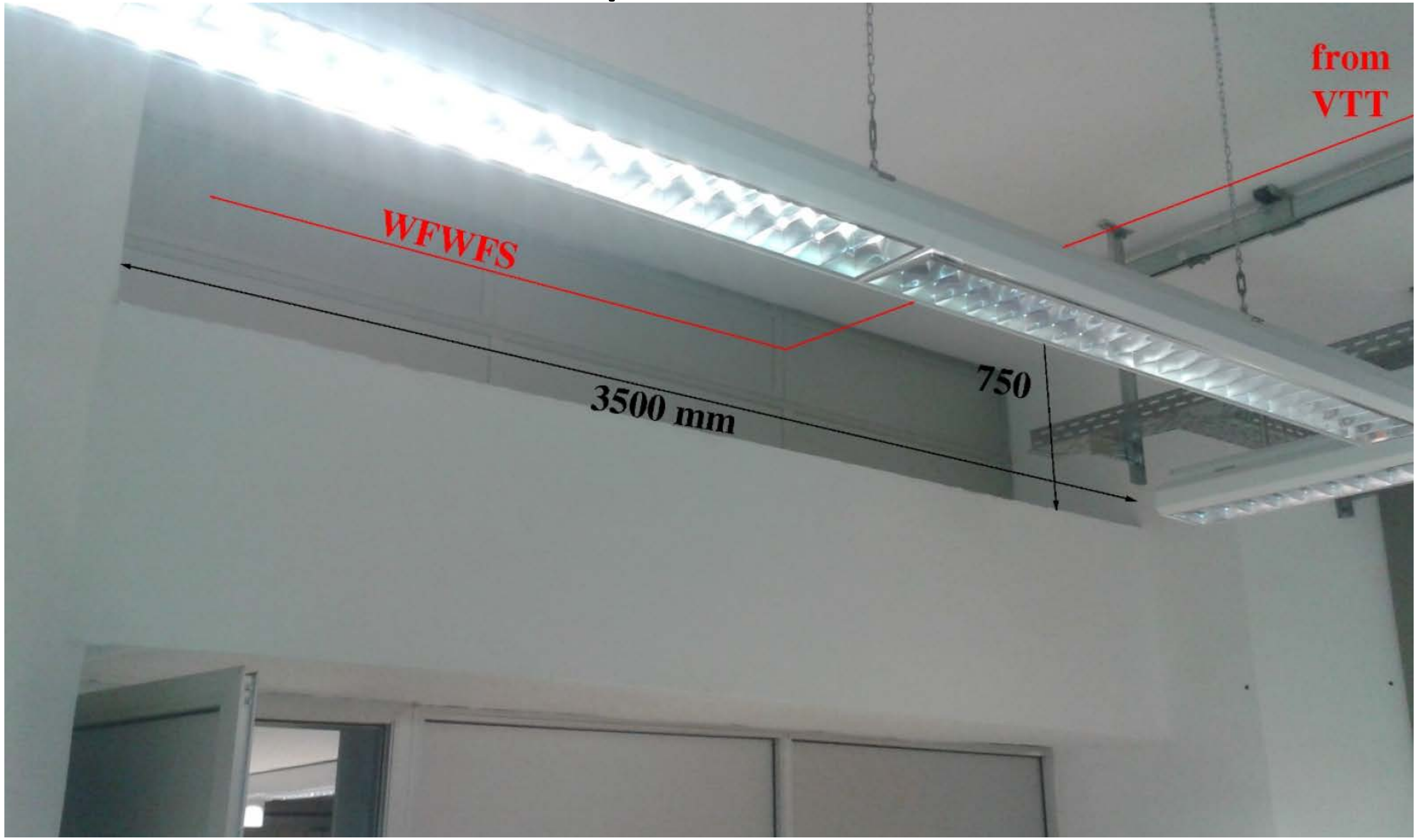
WF-WFS Setup at VTT



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Performance Characterization and Prediction Status

- WF-WFS measurements under way at SST and VTT
  - Issues with low quality at VTT not understood. May be related to entrance window which so far was missing, but requires further investigation.
- Report on data survey for turbulence prediction delivered by INAF (D7.11)
- IOSB carried out observing campaign at RdlM in Summer 2019
- HES-SO is working on MCAO and AO telemetry data

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7.4 Technology Research

- Strategies to parallelize wave front sensing for a 4m aperture telescope
  - Distributed wave front sensing with several cameras

- Deformable mirror technologies
  - Heat management for large format DMs for solar applications
  - Migration of CHARA anisotropic actuator patterns for 45° illumination for solar applications

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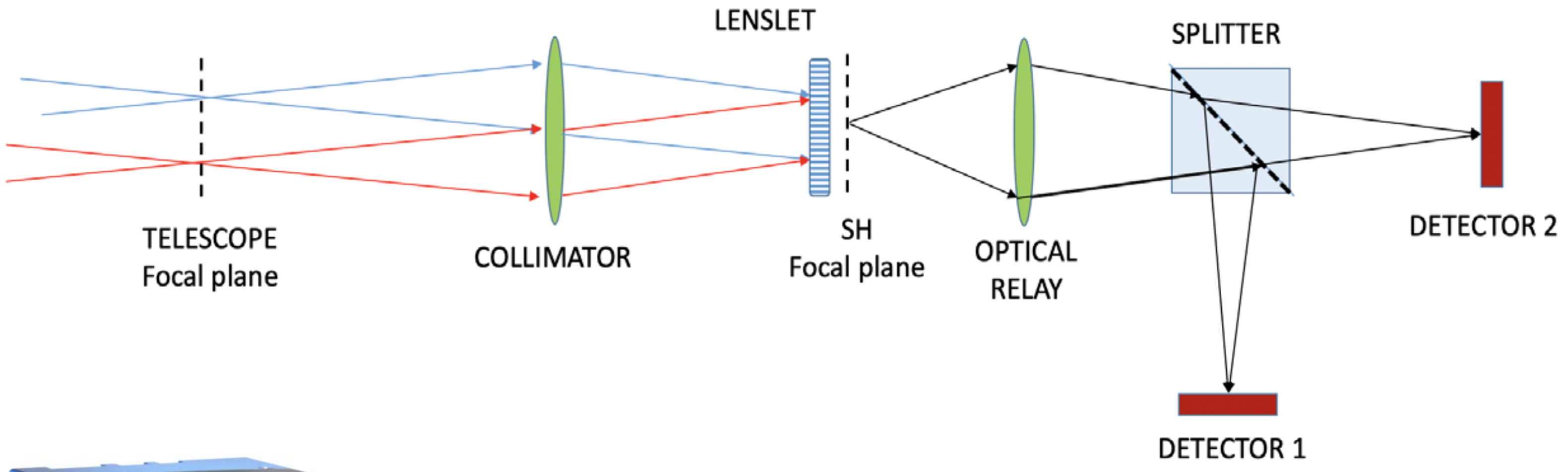
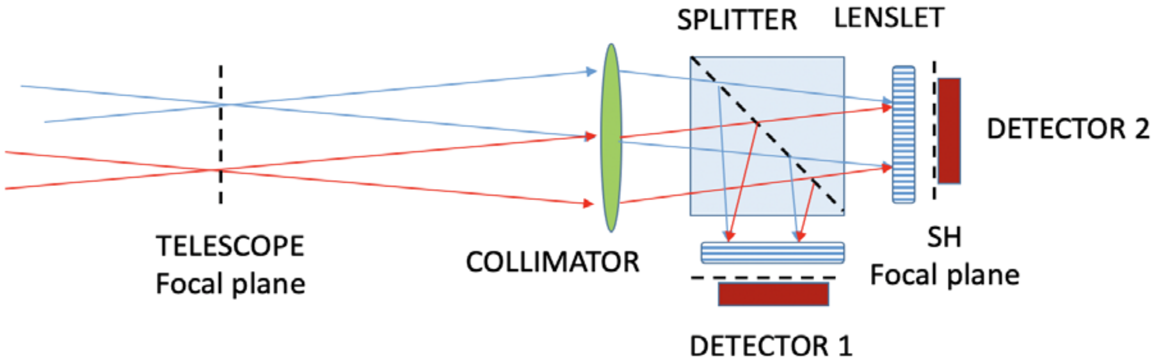
Large Format Detectors for MCAO

- Size and framerate requirements for wide-field WFS cannot be met by current technologies
- Investigate possibilities for multi camera designs



EoSens 3CXP



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Deliverables

Deliverables (brief description and month of delivery)
D7.1 Report on Prototype Opto-Mecanical Design (T0+8)
D7.2 Laboratory Integration and DM Test Report (T0+18)
D7.3 Prototype Lab Test Report (T0+30)
D7.4 Prototype On-Sky Test Report (T0+48)
D7.5 Prototype Final Report (including data evaluation report) (T0+48)
D7.6 Simulation Results (T0+15)
D7.7 Neural Network Lab Integration and Test Report (T0+27)
D7.8 Neural Network On-Sky Integration and Test Report (T0+39)
D7.9 Report on PSF Estimation (T0+30)
D7.10 Report on Data Analysis and Transfer to WP 5 (T0+42)
D7.11 Results of Turbulence Profile Comparison (T0+30)
D7.12 Turbulence Prediction Report on available measurements (T0+12)
D7.13 Turbulence Prediction Report model geometry (T0+24)
D7.14 Turbulence Prediction Report on preliminary analysis of model performances (T0+36)
D7.15 Turbulence Prediction Final report on strategy for model calibration and validation (T0+48)
D7.16 Modular WFS Report on the preliminary opto-mechanical design of the demonstrator (T0+12)
D7.17 Modular WFS Report on hardware implementation and integration of the WFS prototype (T0+30)
D7.18 Modular WFS Report on laboratory tests (T0+36)
D7.19 Modular WFS Final report on system performances (T0+48)
D7.20 Combined Study Report on DM Cooling and Actuator Geometry (T0+42)

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Participants and Personnel

Work package number	7	Lead beneficiary				KIS		
Work package title	JRA3 Multi-Conjugate Adaptive Optics for EST							
Participant number	1	2	6	34	33	4	35	
Short name of participant	KIS	IAC	INAF	Durham	Oviedo	SU	HES-SO	IOSB
PMs per participant:	25	28	29	12	26	12	10	2
Start month	1		End month		48			