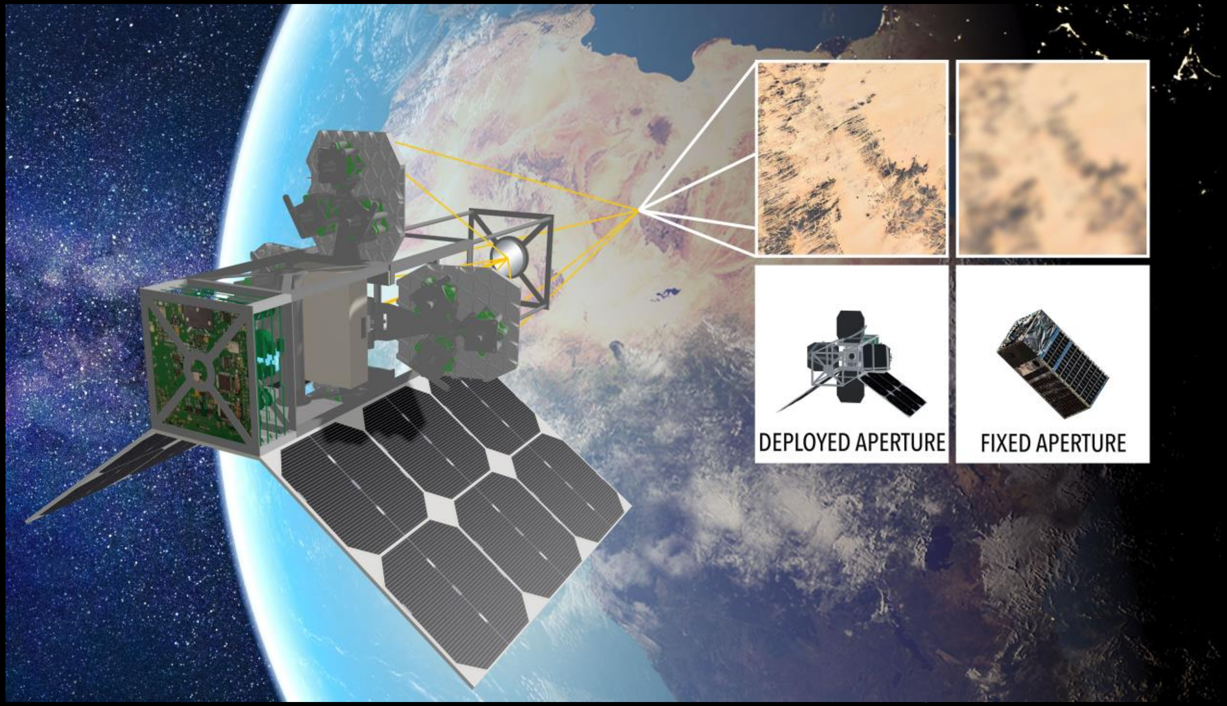
Science and Technology Facilities Council

A-DOT

A small deployable telescope for EO and astronomy

Noah Schwartz, Douglas Harvey, Éamonn Harvey, Katie Morris, Junyi Zhou, Maxime Dumont, Jean-François Sauvage, Carlos Correia, Jay Stephan, Samuel Pinilla Sanchez, Siu-lun Yeung

Science & Technology Facilities Council
UK Astronomy Technology Centre



High spatial resolution in the optical

ADOT
ACTIVE DEPLOYABLE OPTICAL TELESCOPE

New space era (circa 2000s) still limited by *old* physics (circa 1660s)

Resolution limited by diffraction

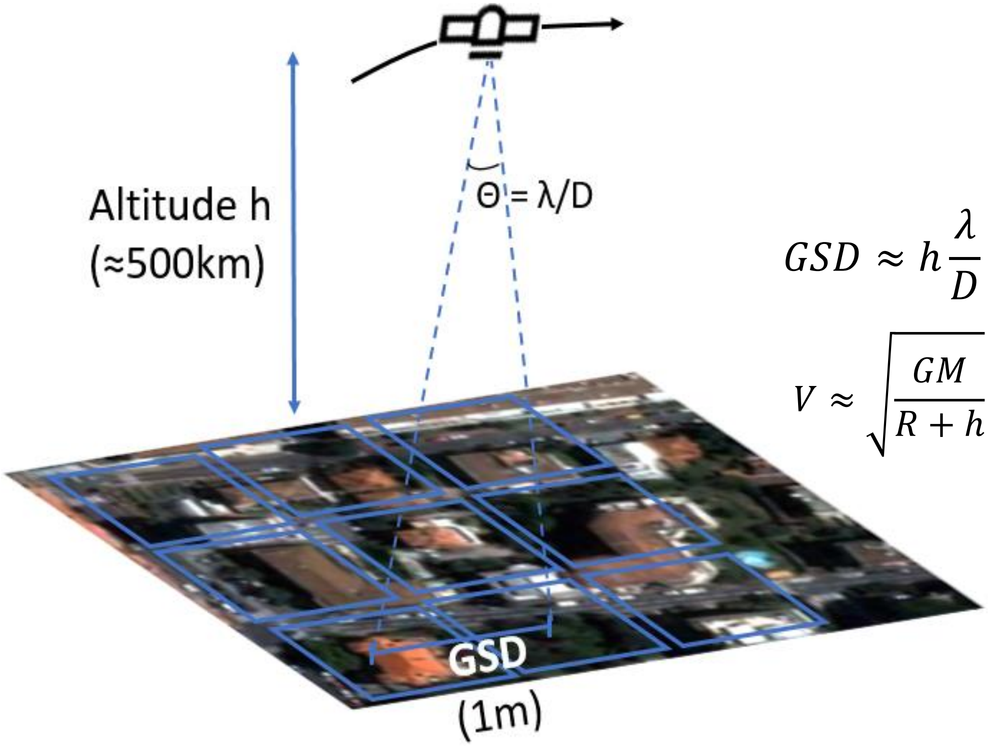
Pupil of 30cm

λ (µm)	GSD
0.5	1 m
2.5	5 m
5	10 m

GSD = 1m

D
0.3 m
1.5 m
3 m

Revisit period limited by orbit (& cost)



$$GSD \approx h\frac{\lambda}{D}$$

$$V \approx \sqrt{\frac{GM}{R+h}}$$

ADOT: high resolution at low costs

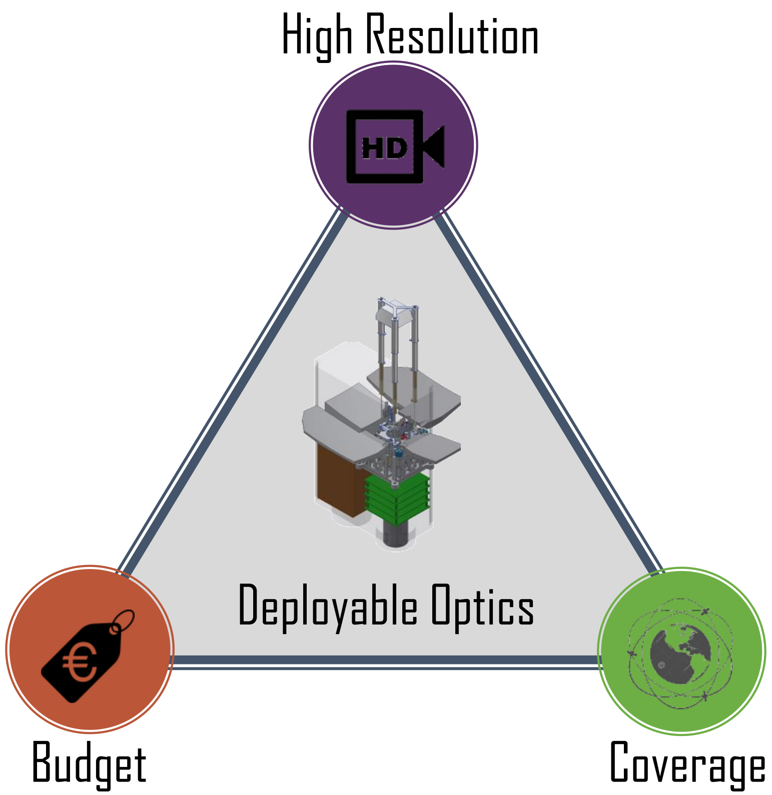
High resolution optical imager

- 1 m GSD from LEO & 5 km swath
- λ = 500-800 nm (optical wavelength)
- Small and lightweight platform

→ Deployable optics

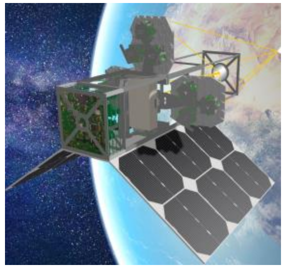
Active Optical Deployable Telescope

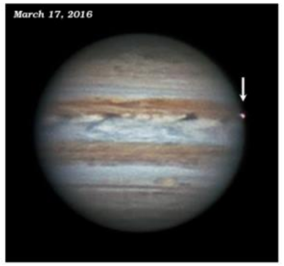
- 30 cm deployable aperture
- 6U CubeSat platform
- Compared to non-deployable 6U
  - x3 resolution, x7 flux, x10 mass reduction



Predicted impacts of new technologies

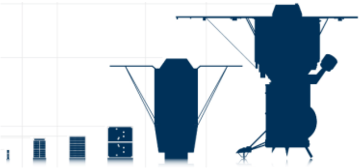
ADOT
ACTIVE DEPLOYABLE OPTICAL TELESCOPE

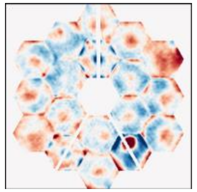




Enabling (very) high-resolution images

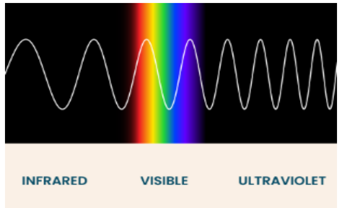
- On small platforms
- Potential for high-revisit rates
  - EO: Earth climate monitoring and protection, defence and security, natural disasters monitoring and management plans…
  - Astronomy



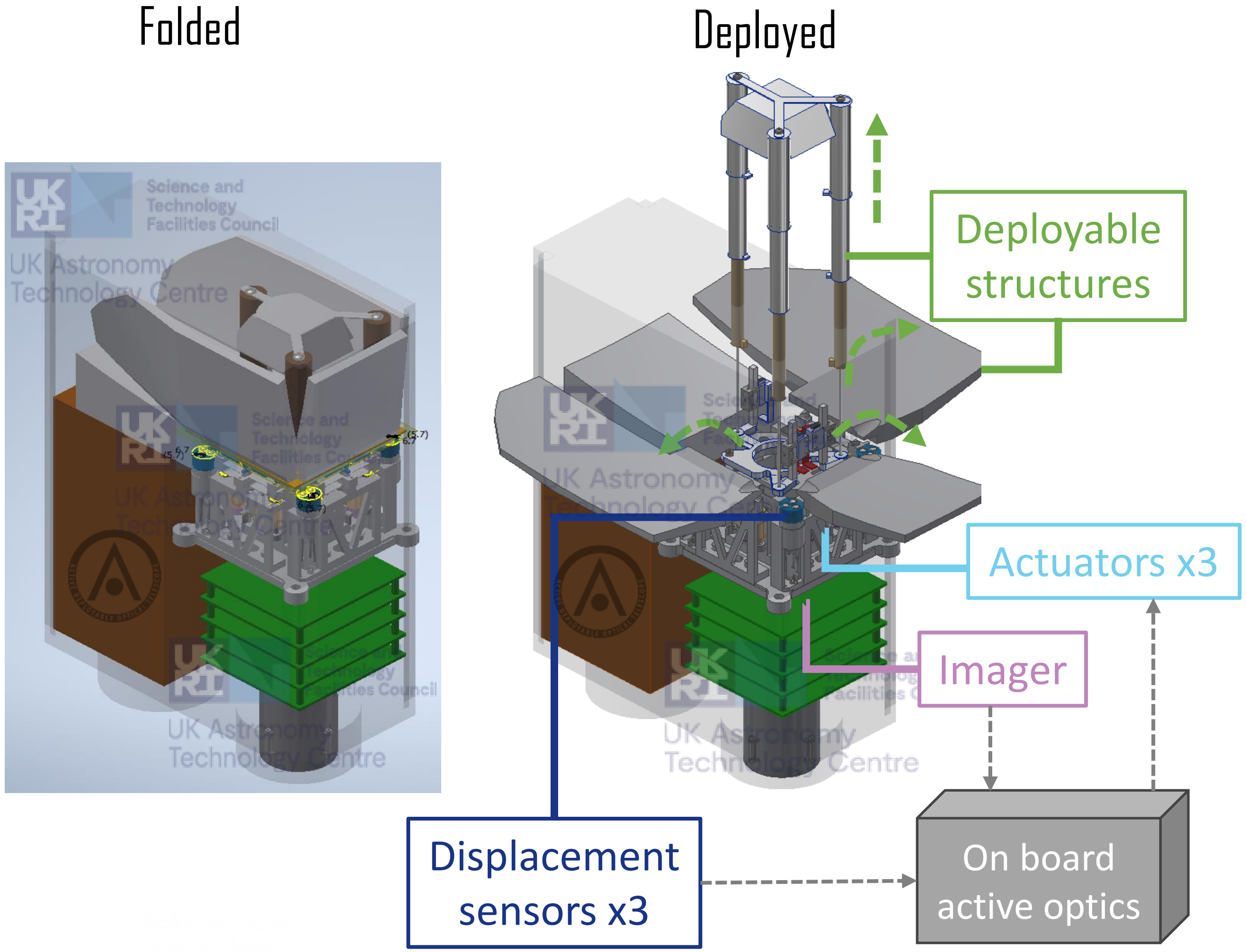


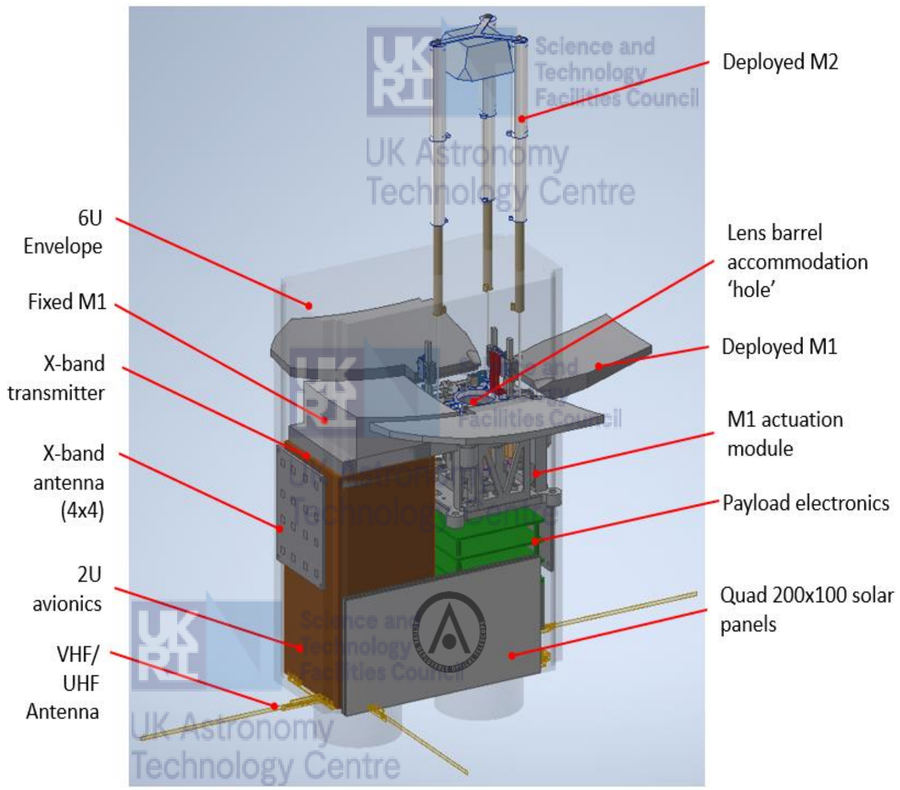
Building technology to allow affordable HR imaging

- Wavefront control is at the heart of ADOT
- Potential for missions with large aperture telescopes
- Potential for longer wavelengths & different applications (e.g. LiDAR)
- We hope that the UK can get a lead in this and place ourselves at the heart of these missions



Active Deployable Optical Telescope





Key technical challenges

Image quality criterion

- Maintain diffraction-limited system
- **70 nm RMS** residual error

Opto-mechanical design

- Thigh volume allocation
- Precise control of optics
  - Deploy ≲10 μm of nominal position
  - Control within ≲ 10 nm

Active optics

- Maintain alignment of telescope
- Automatically during operations

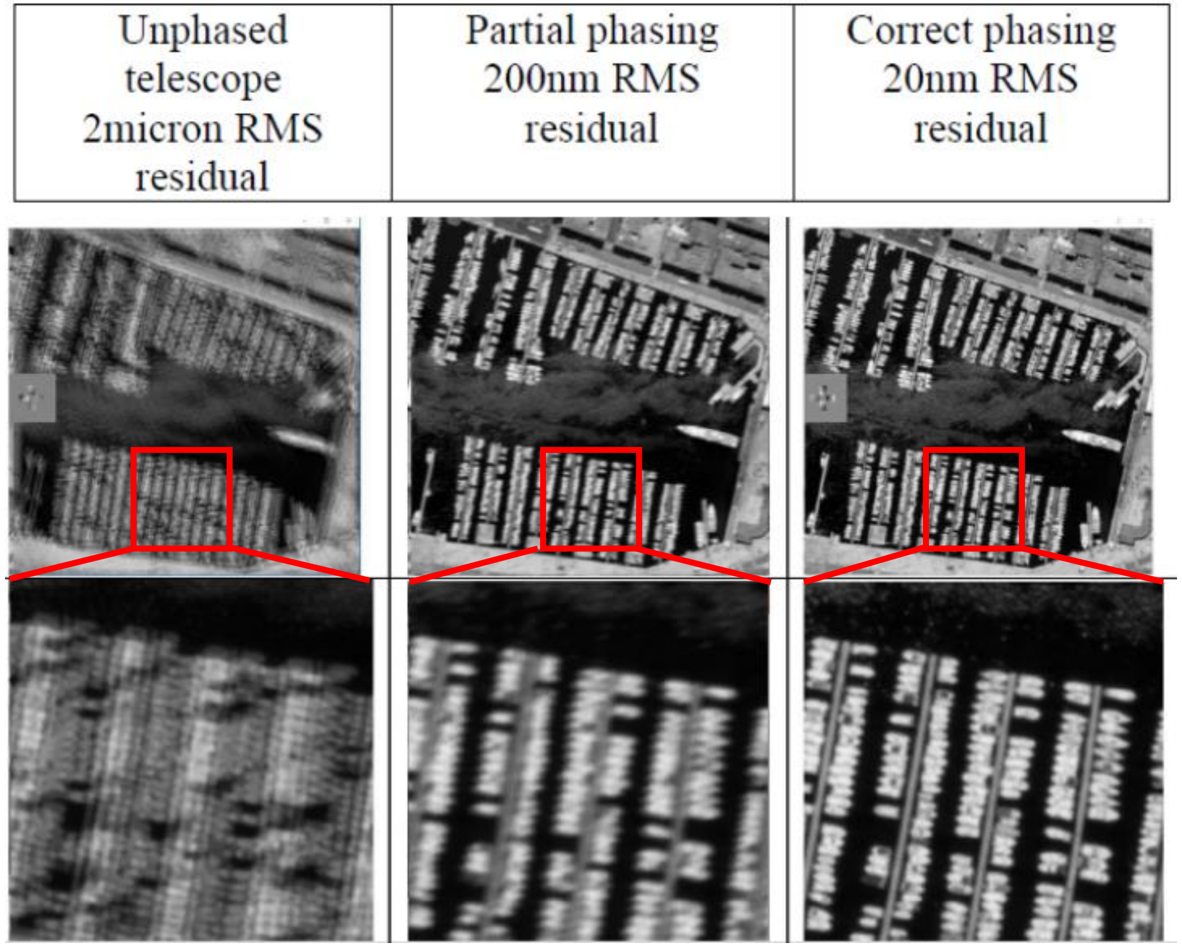


Image Quality error budget

Category	Definition	Error Source	Comment	Error #	WFE budget
Intrinsic optical errors	Quality of optics	Manufacturing	Low-order residual manufacturing error of the optics (mostly M1 and M2)	1	20
		Polishing	Polishing errors, mainly high-orders	2	30
	Initial alignment (on the ground)	Integration / alignment	The optical residual of the optics after alignment of the system in laboratory, excl. segment phasing residuals (e.g., lenses aligment, M1 positioning accuracy)	3	30
	Ground to space degradation (static or one-time events)	Launch impact	Degradation of the optical quality due to the launch (e.g. vibrations move optics / detectors arround)	4	10
		Space environment	Degradation of the optical quality due to the difference of environment between ground and space	5	10
	ent (dynamic)	Thermal load	Varying thermal load will modify the optics and degrade the optical quality (e.g., shape of the M1 and M2 optics)	6	31
		Drift and jitter	Effect of the high-freq vibrations and LoS drift during integration	7	20.2
M1 deployable segments	Differential piston residual	Pist. Error between segments	Phasing residual between M1 segments, after active optics correction. Only tip, tilt, piston is controlled. Lateral X-Y movements are not, leading to additional WFE error.	8	20
	Differential tip-tilt residual	TT Error between segments	Orientation residual between M1 segments, after active optics correction.	9	20
		Focus error between M1 and M2	Compensation of focus error with M1 (i.e. individual segments have wrong RoC).	10	10
	M1 deployment precision	M1 deployment error	Only tip, tilt, piston is controlled. Lateral X-Y movements are not, leading to additional WFE error.	10.1	0
M2 deployable segments	Secondary mirror deployment precision	M2 deployment error	Only tip, tilt, piston is controlled. Lateral X-Y movements are not, leading to additional WFE error.	11	0
	Tip-tilt residual	M2 control	Residual M2 tip-tilt error (rX, rY)	12	15
	Focus residual	M2 control	Residual M2 focusing error (Z)	13	15
Contingency	Other unaccounted errors	Misc.		14	10
					72

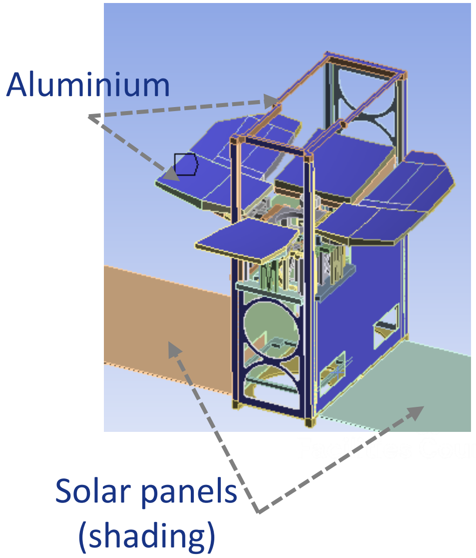
STOP analysis → 31 nm RMS

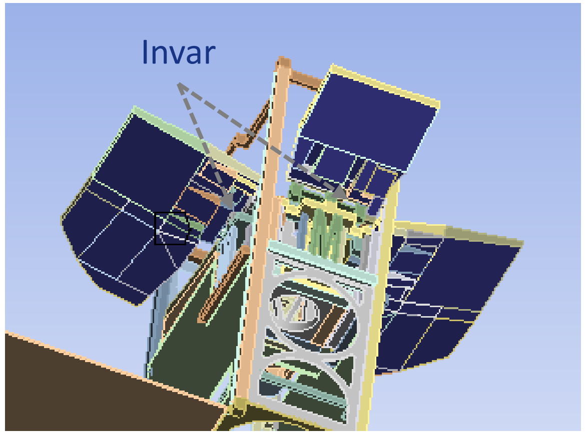
Active Optics → 36 nm RMS

STOP analysis

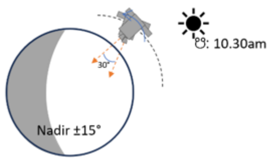
Structural-Thermal-Optical-Performance (STOP) Analysis

- The thermal environment changes the shape of the structure & optical elements
  - Aluminium frame and mirrors. Solar panels. Invar joints for segments
  - Sun radiation + Earth
- Modelling
  - ANSYS Workbench + OpticStudio

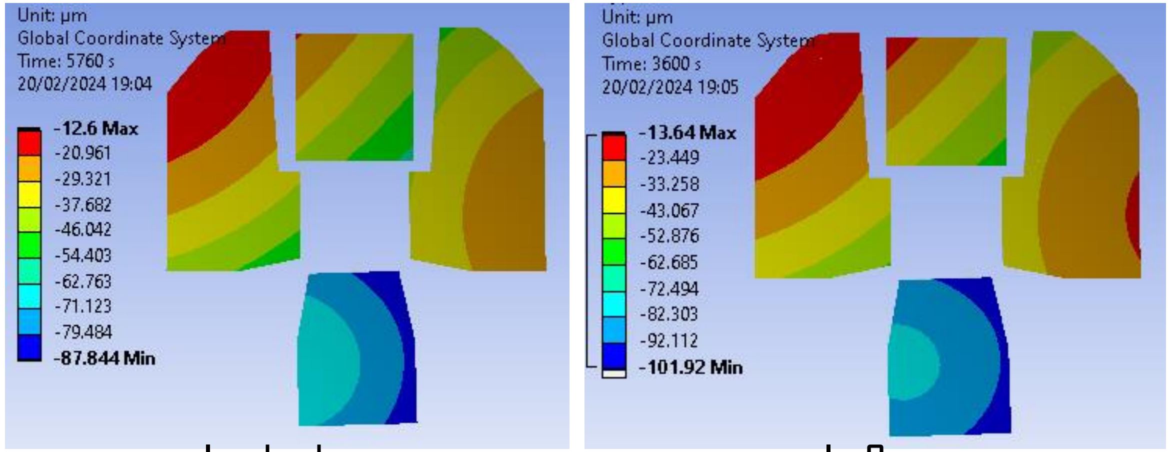




Preliminary results



- Several loading scenarios investigated
  - Sun synchronous orbit
  - Both for EO and astronomy scenarios
- Thermal deformations
  - Last instance in Sun/shadow are quite similar
  - Aberrations are mostly Piston, Tip-Tilt, Focus
  - Aberrations still high for visible wavelength
- Investigating mitigation strategies



In shadow | In Sun

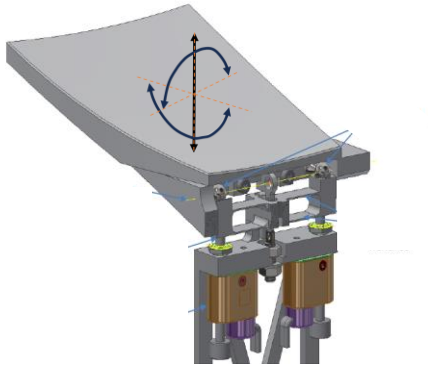
Active optics control

Align and phase telescope

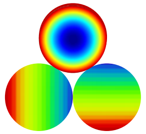
- After initial deployment
- Maintain during observations

Active optics

- Measurement
  - Displacement sensors
  - Image sensor

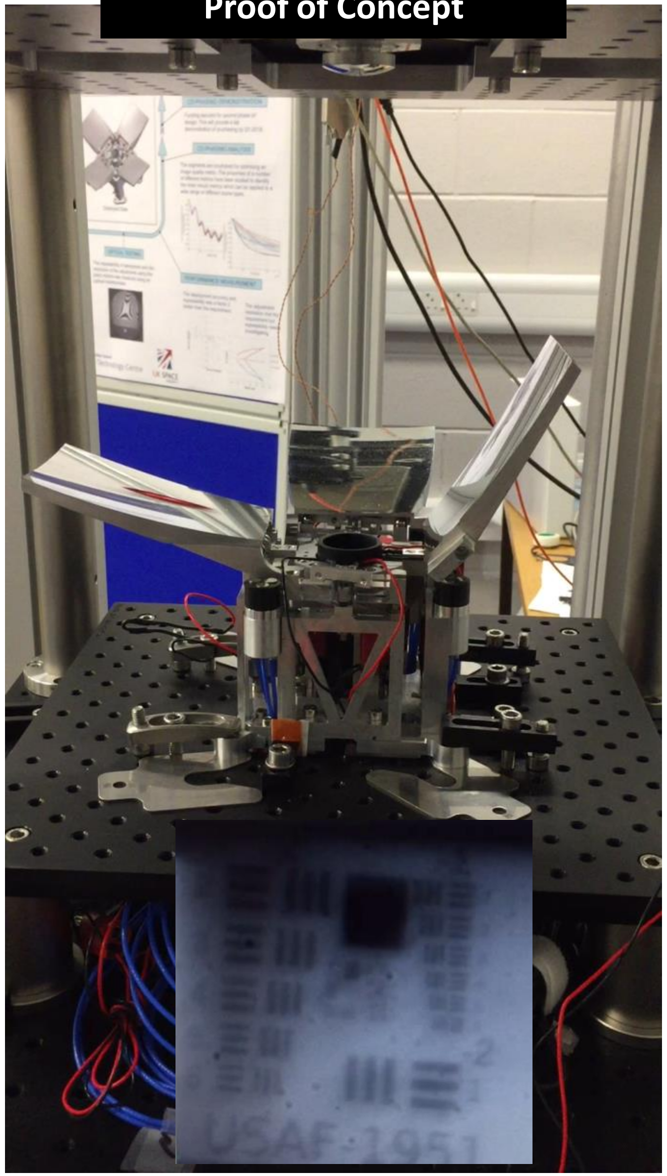


- Linear actuators
  - M1 & M2: correction tip, tilt, piston/focus



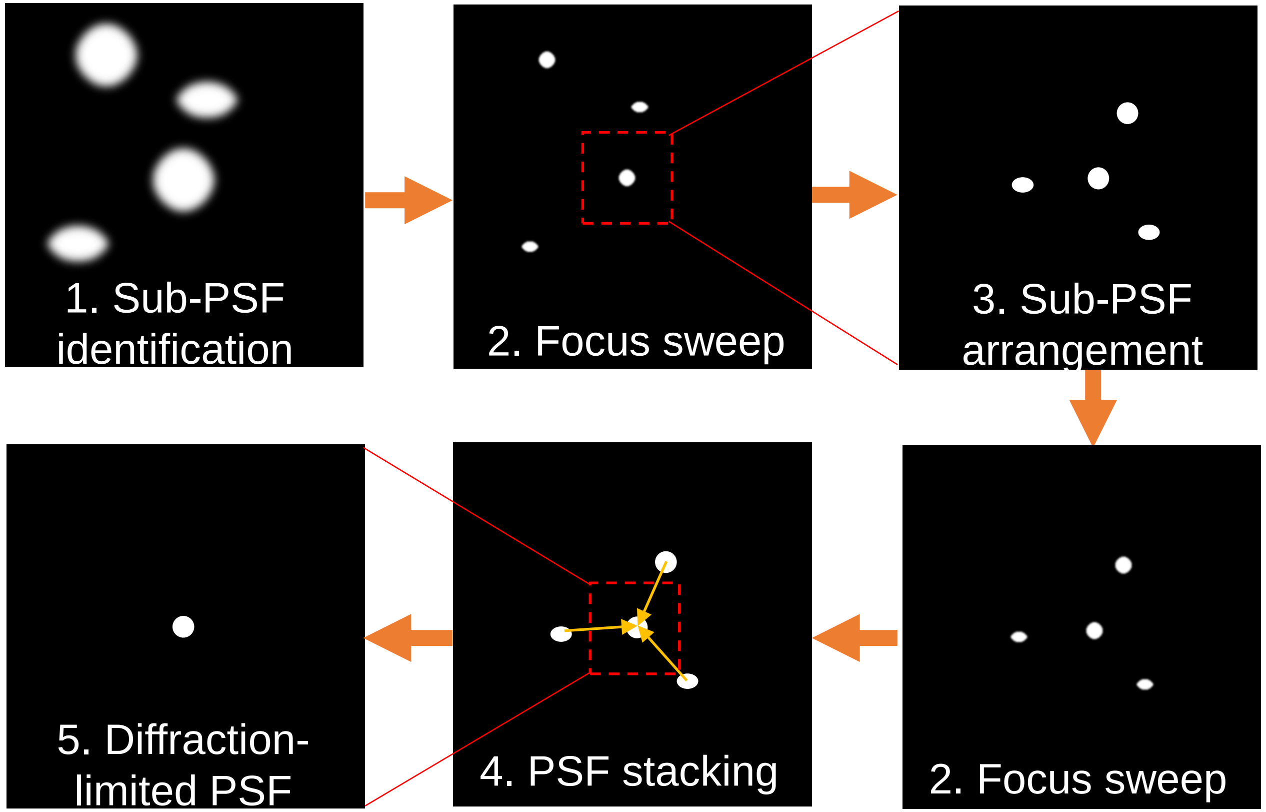
- Control algorithm
  - Accurate, light (on-board), robust
  - Work on point-source & extended objects

Proof of Concept



Active control

Classical approach (sequential)

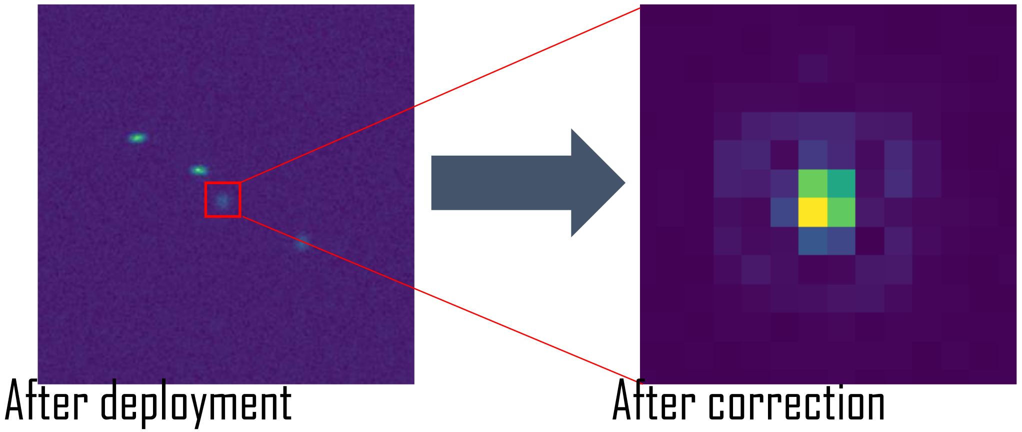


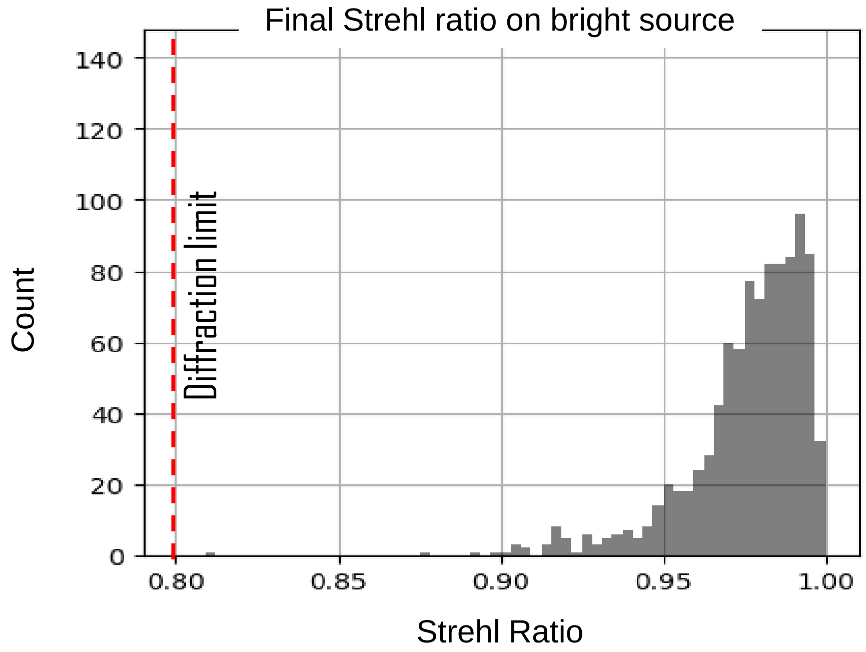
Active control

Classical approach (sequential)

- Sequential image sharpening
  - 40−50 images needed
  - $M = \sum_{x,y} I_{x,y}^2$
  - Low computational complexity
  - Robust, with error handling

- Excellent performance
  - SR>85-90% for good SNRs (>60-70)
  - Working on improving performance for differential piston in low flux
  - Currently testing on optical bench

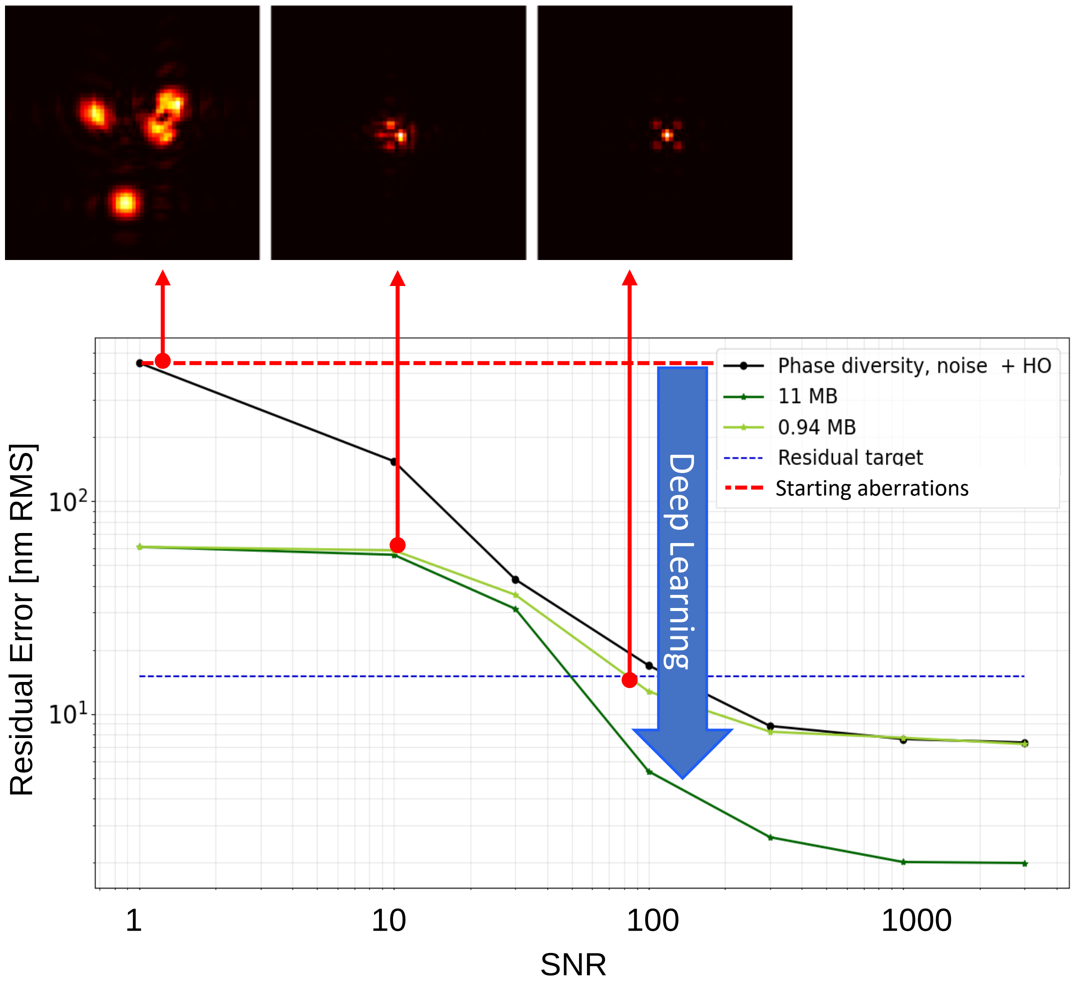




Active control

Deep Learning

- CCN adapted light ResNet architecture
  - 1st network for large tip-tilt
  - 2nd network for small tip-tilt & piston
- Only requires 2 images!
  - Reaches diffraction-limit
  - Small computational burden
  - Robust & stable



Maxime Dumont, et al, "*Phasing segmented telescopes via deep learning methods: application to a deployable CubeSat*," J. Opt. Soc. Am. A 41, 489-499 (2024)

Conclusions & next steps

ADOT
ACTIVE DEPLOYABLE OPTICAL TELESCOPE

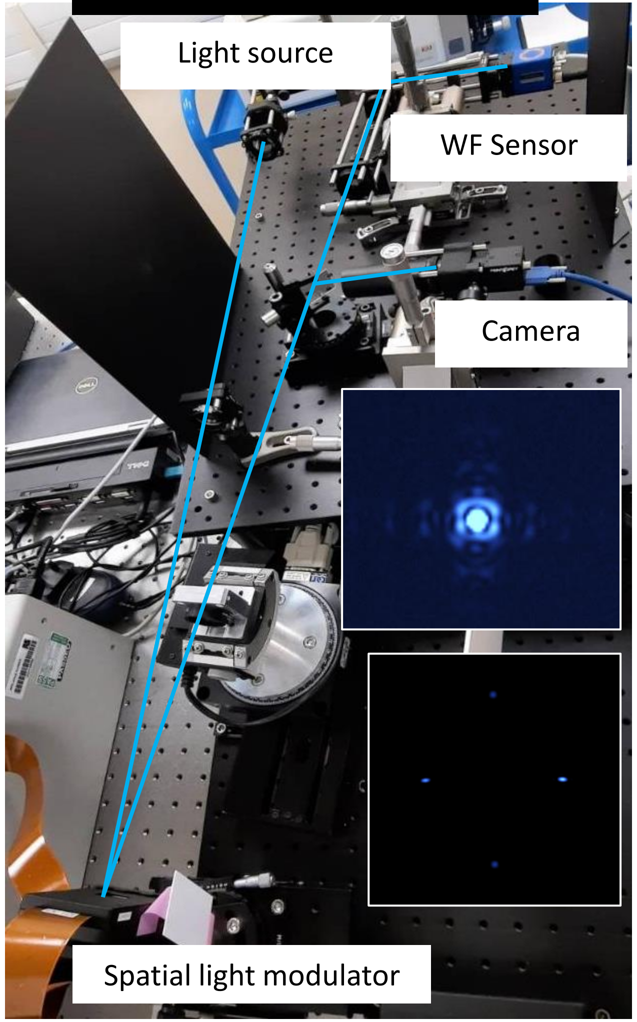
ADOT

- Development of new technology
- High-resolution in the optical
- Cost reduction over traditional platforms

Next steps

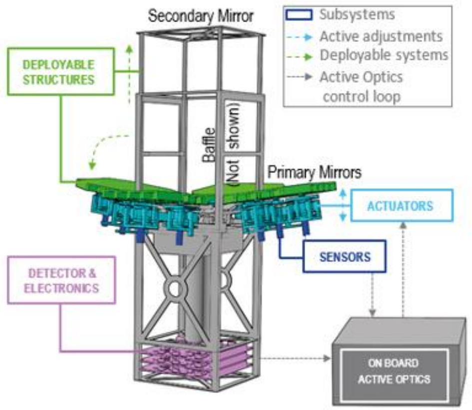
- Adaptive optics
  - Laboratory validation
  - Improve differential piston correction
  - Fully extended objects
  - Data fusion (T°C and displacement)
- Optical-mechanical design
  - Improve thermal behaviour
  - Deployable M2

AO Experiment



Thank you for your attention

ISAAC - CLASP (2020-2022)

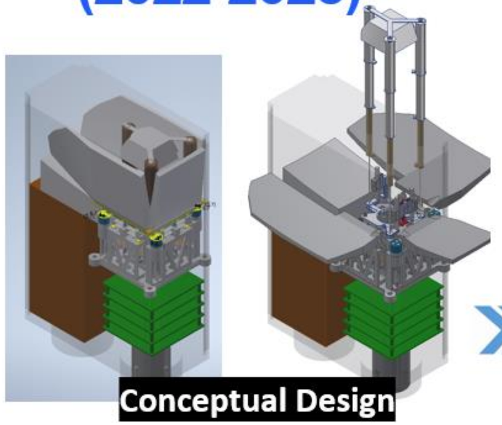


6U ground demonstration

Satellite (payload + bus) concept
Deployable M1 validation
Full optical design
Preliminary AO control

TRL3/4

A-DOT (2022-2025)

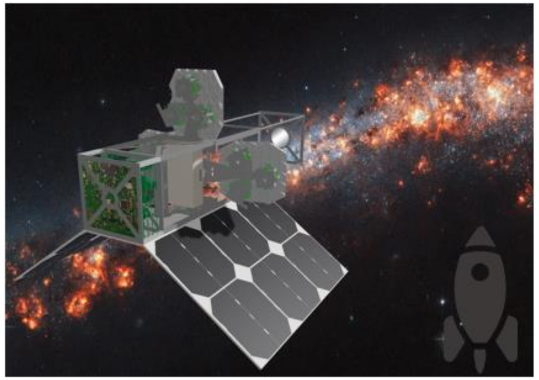


6U ground demonstration

Deployable M2 validation
Preliminary electronics
Full end-to-end AO control

TRL4

A-DOT+ (2025-2028)



Full spacecraft

Payload prototype qualified in operational environment

TRL7