A Segmented, Deployable, Primary Mirror for Earth Observation from a Cubesat Platform

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Science & Technology Facilities Council
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A Segmented, Deployable, Primary Mirror for Earth Observation from a Cubesat Platform

- Who we are
- Why deployable optics for Nanosats
- How
  - To sense
  - To deploy and align
  - To test
- Current conclusions and next steps

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UK Astronomy Technology Centre (STFC)

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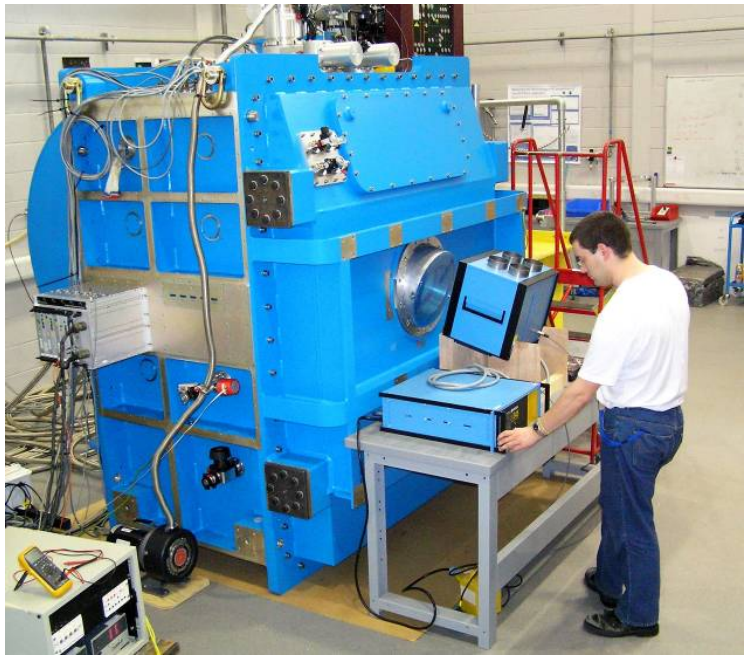
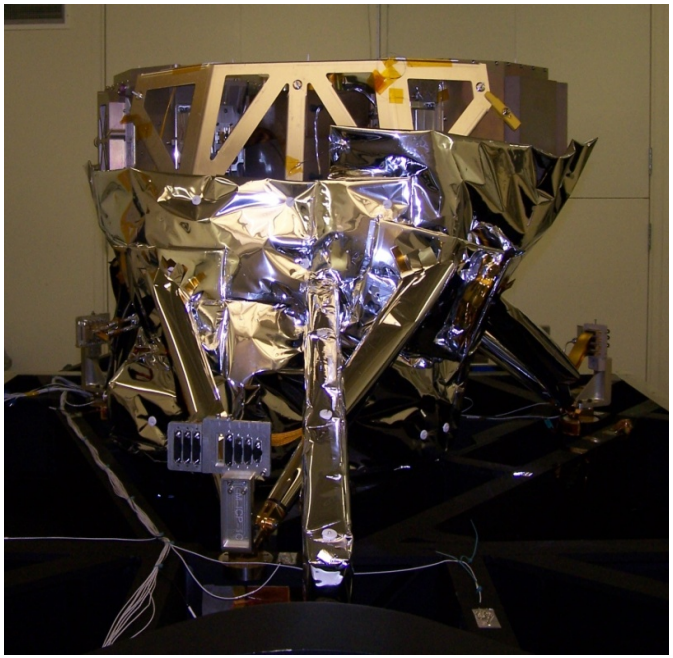
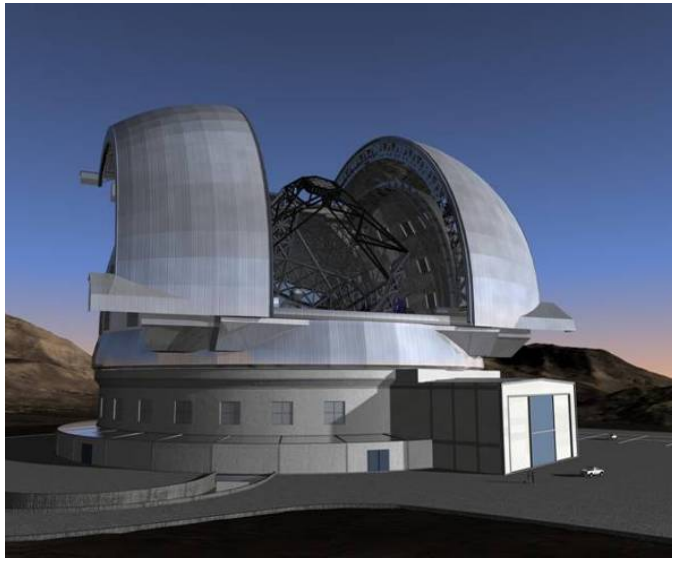
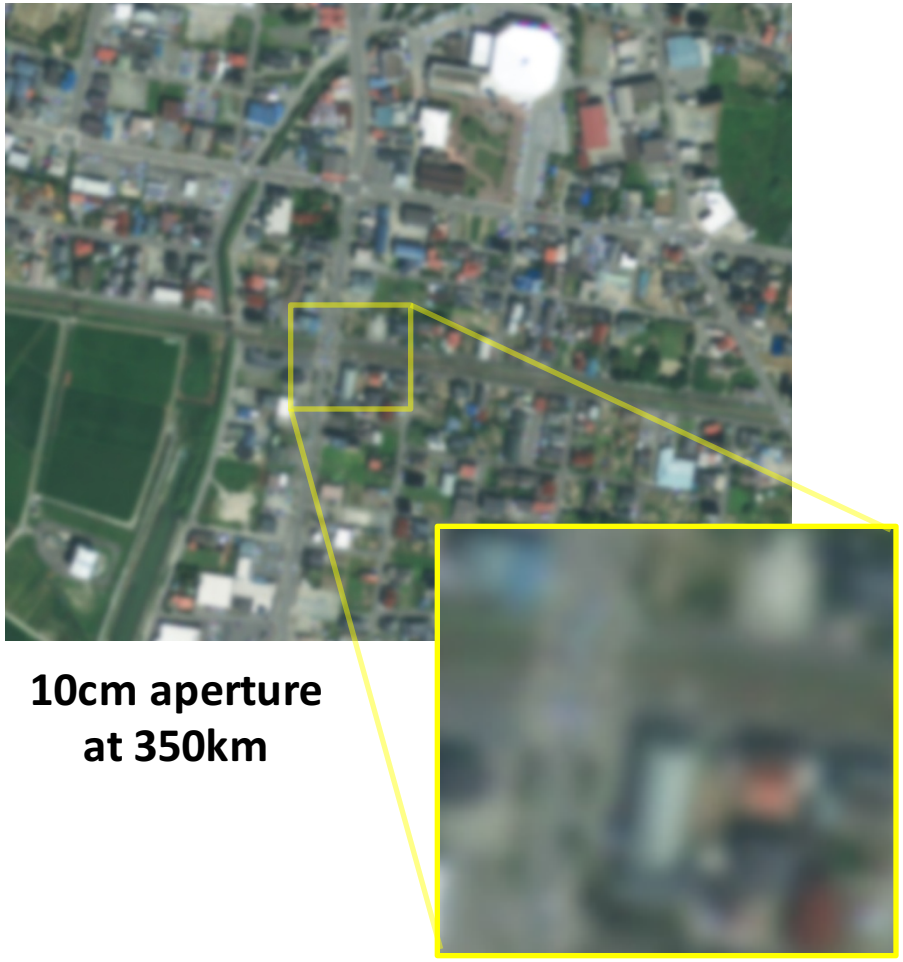






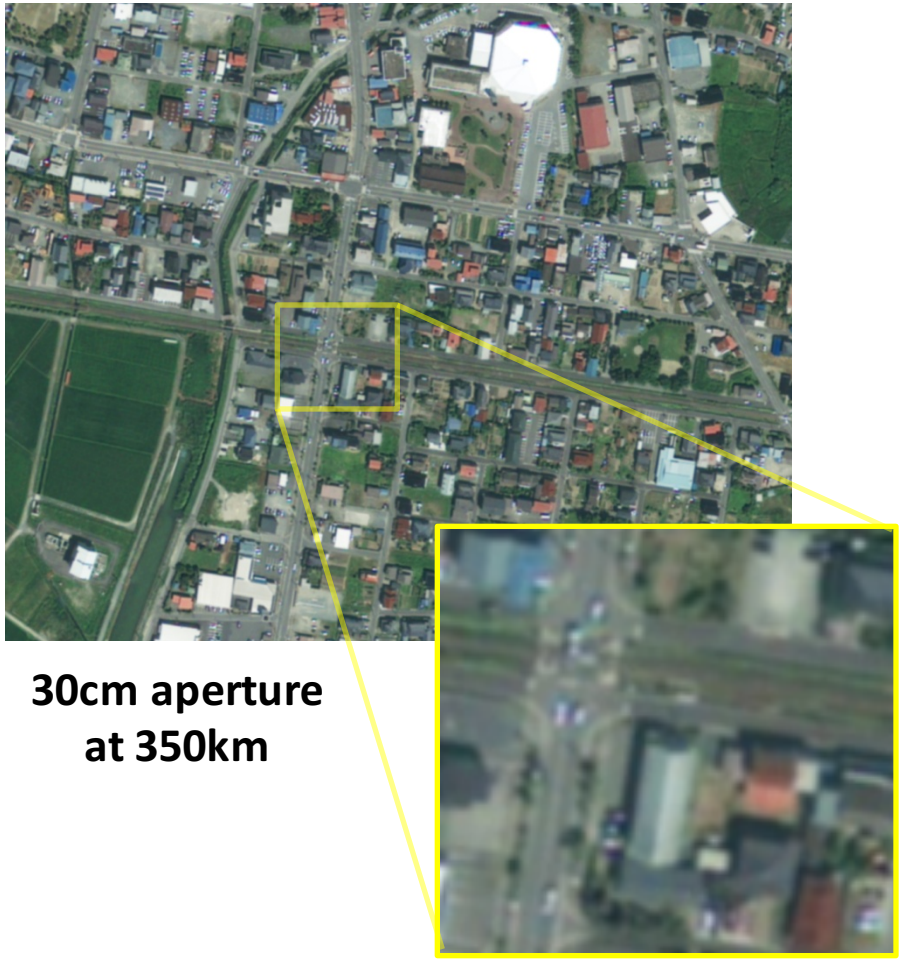
Why deployable optics for Nanosats

2.1m resolution



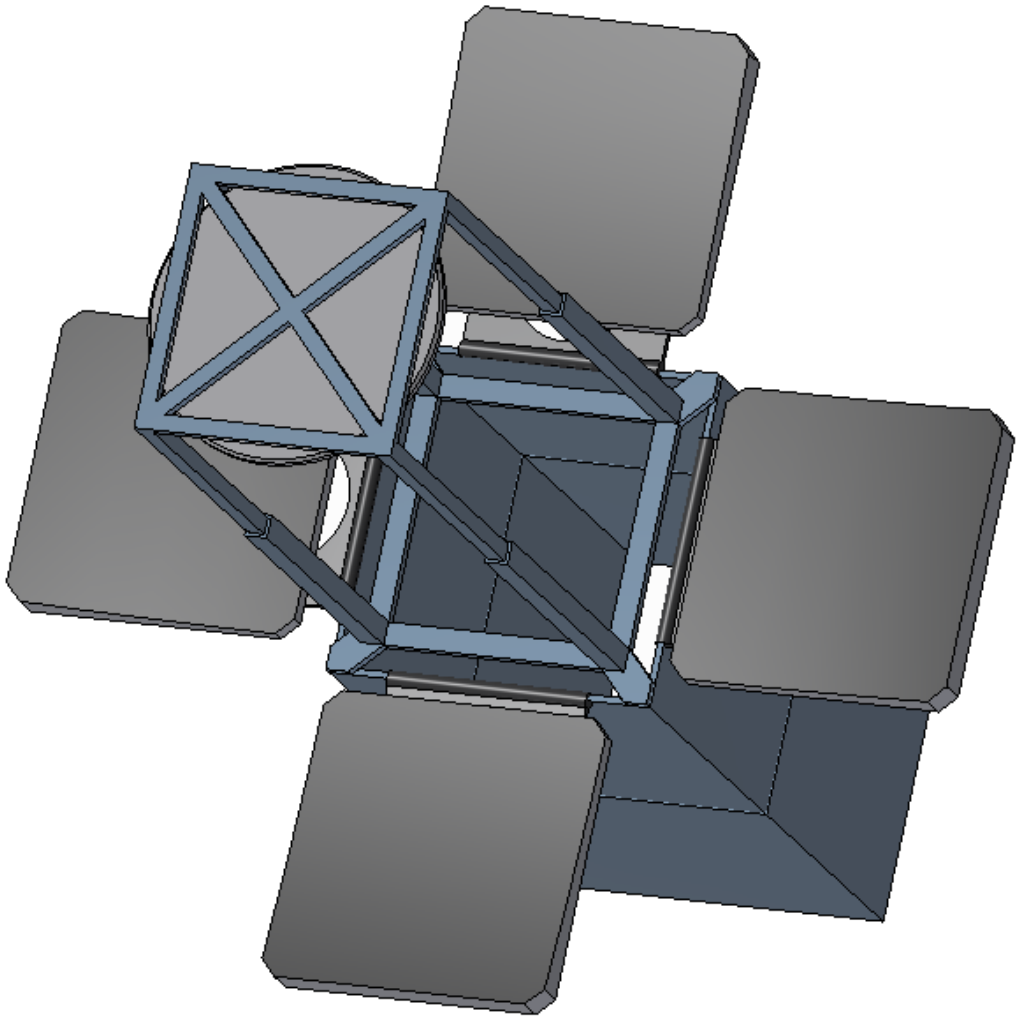
10cm aperture at 350km

0.7m resolution



30cm aperture at 350km

Solution: deployable optics



The spatial resolution is limited by the aperture

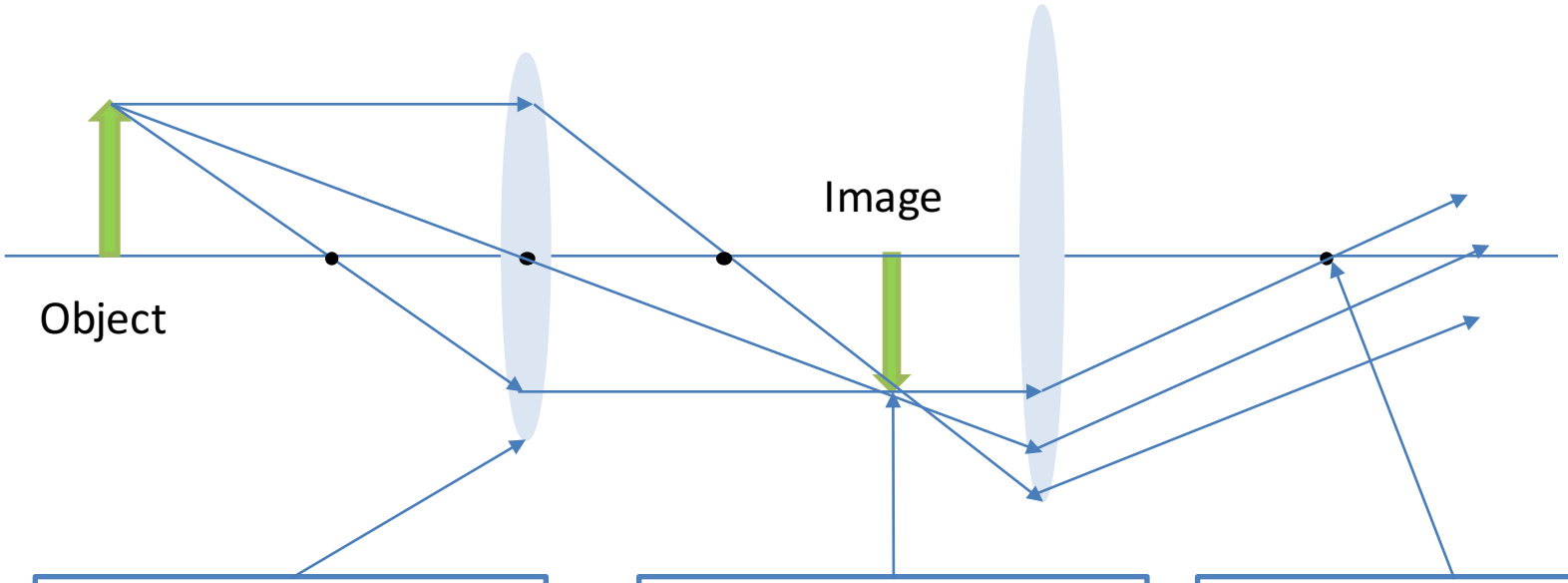
$$\mathrm{R}(radians) = 1.22\frac{\lambda}{\mathrm{D}}$$

So a bigger aperture provides a finer spatial resolution image, and it increases the light gathering power $\propto \mathrm{D}^2$

Issues and limitations

- To achieve the resolution you need to align the mirrors to λ/10, = 50nm in the visible.
- To turn this resolution into a ground sample you need to take account of ground speed
  - Sub mS exposure times
- The reference image is an extended source, as opposed to a point source……..
- Plus all the usual limits (power, space, …)

Sensing optical aberrations

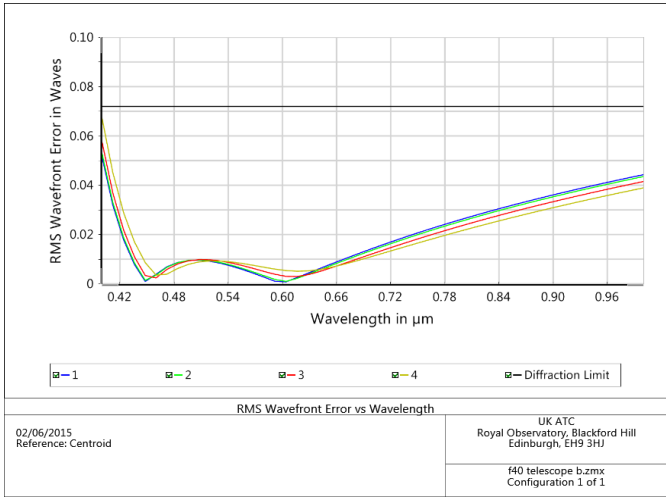


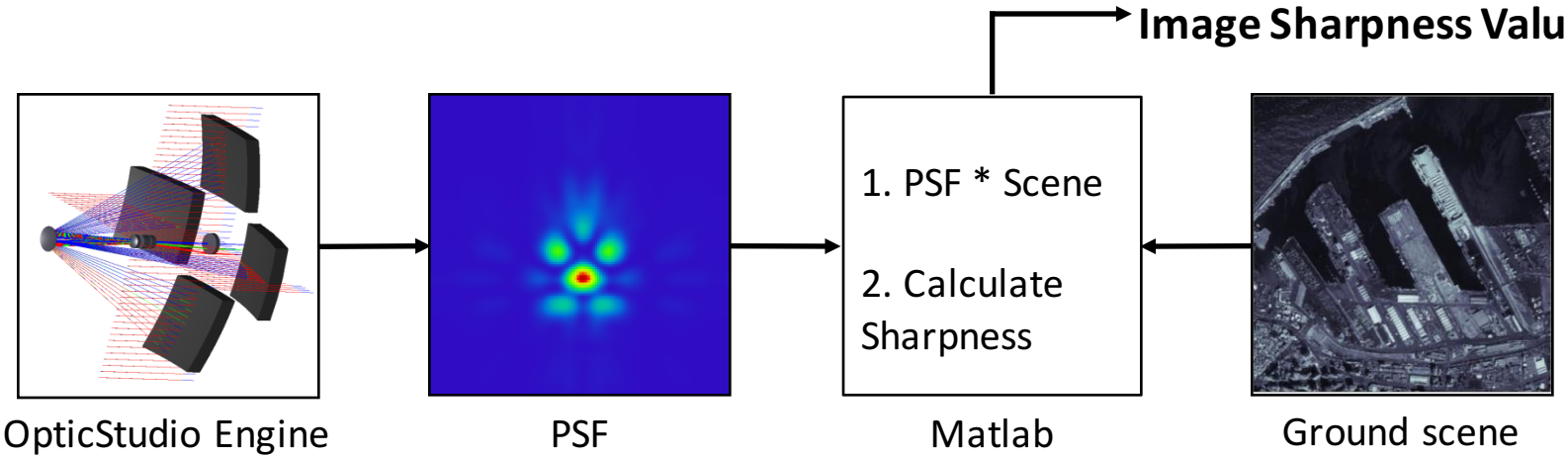
Measure the optic (the mirror) itself	Measure the image	Measure the wavefront (the phase/amplitude)
Need to have a reference object as large as optic, or be very far away, or use local sensors (10nm!)	Not a 1:1 relationship between phase and image, forming an image loses information	Needs extra hardware, uses up signal (in practice) and can be compute intensive

Simulating metric response

Simulation strategy

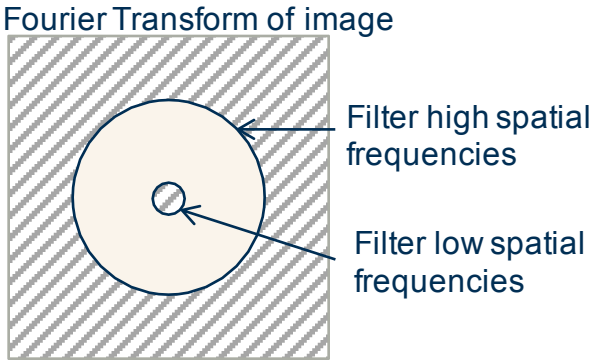
- OpticStudio (Zemax)
  - Generates diffractive PSF
- Matlab
  - PSF convolved with scene (Assumes spatially invariant PSF)
  - Calculates image sharpness metrics

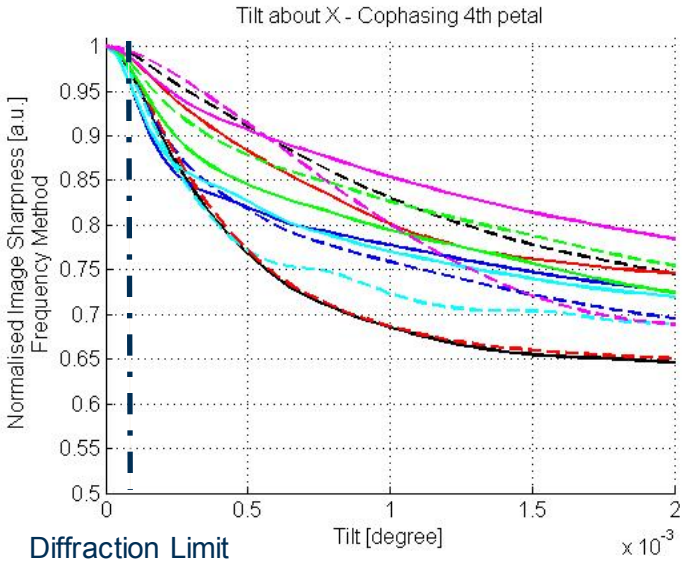




So many metrics

- What is a good metric to use?
  - Square intensity
  - Standard deviation
  - Edge detection filter: Sobel
  - Haar wavelet
  - Frequency method
  - …
- Monotonicity better in practice than we suspected
- Sensitivity and scene independence are the key issues.



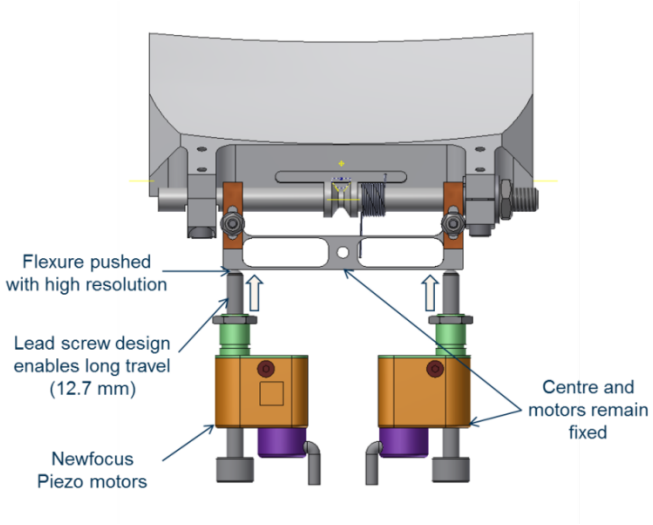


Bread-boarding the system

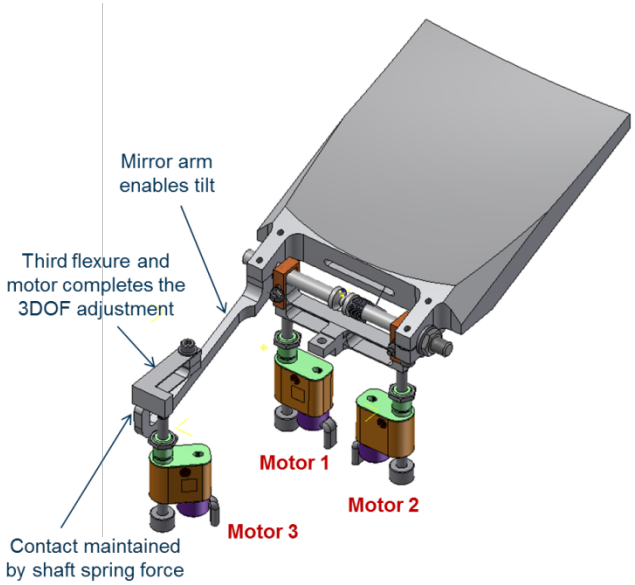
A high-precision deployment and adjustment strategy that can operate in space environments is required

The movement is created using high force piezo motors and guide flexures

Mechanical requirements		Adjustment resolution	Adjustment stroke	Deployment repeatability
DOF	Tip	± λ/14 (± 45 nm)	1 mm	± 10 µm
	Tilt	± λ/14 (± 45 nm)	1 mm	± 10 µm
	Piston	± λ/14 (± 45 nm)	1 mm	± 10 µm

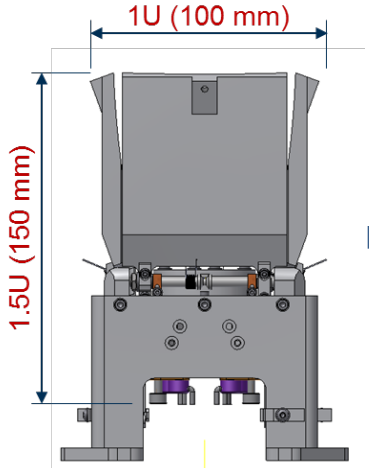


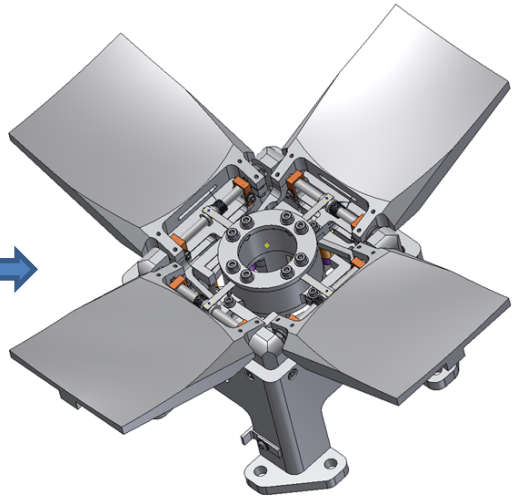
- Three motors on each mirror are required to provide tip/tilt/piston performance
- Mirror is suspended by a hinge on machined parallel flexures
- Piezo motors push the three flexible mounting points with a resolution of 30 nm



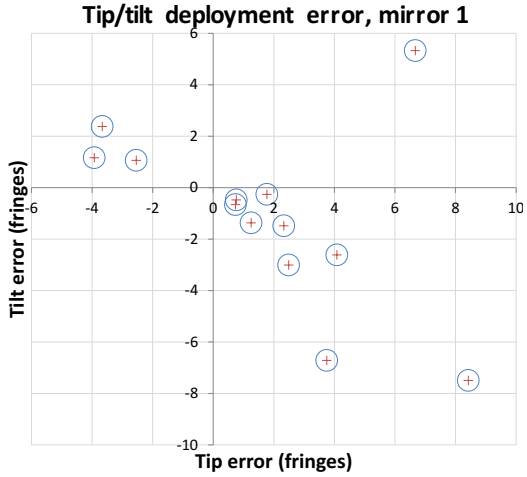
Mechanism performance

The mirrors are packaged into a 1.5U volume prior to deployment. Deployment can be initiated simultaneously or individually.

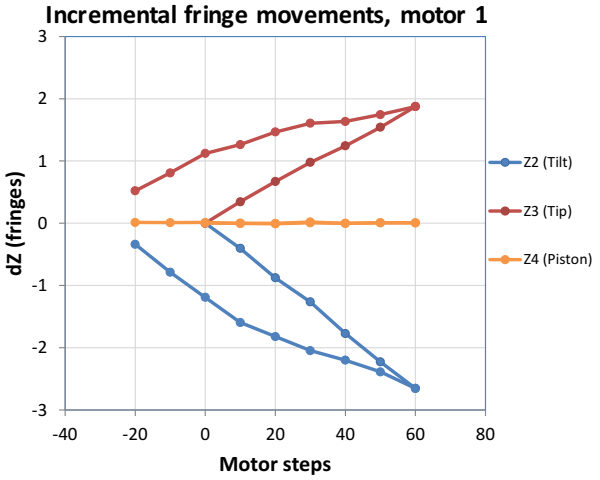




Deployment repeatability



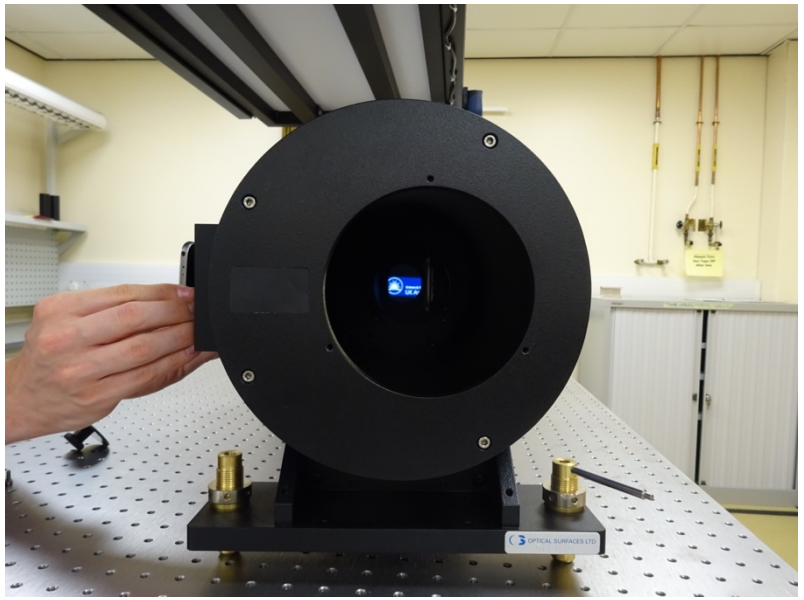
Adjustment resolution

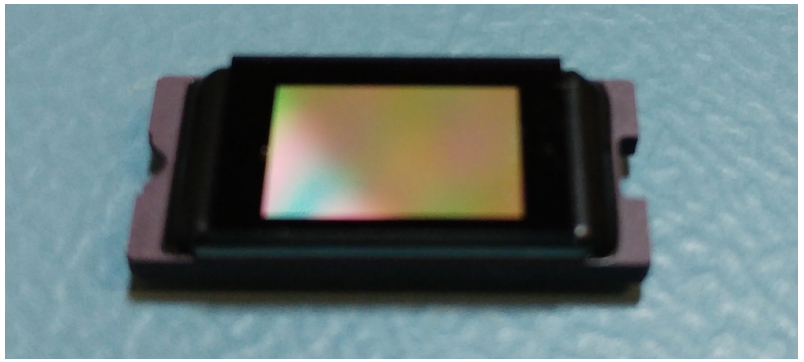


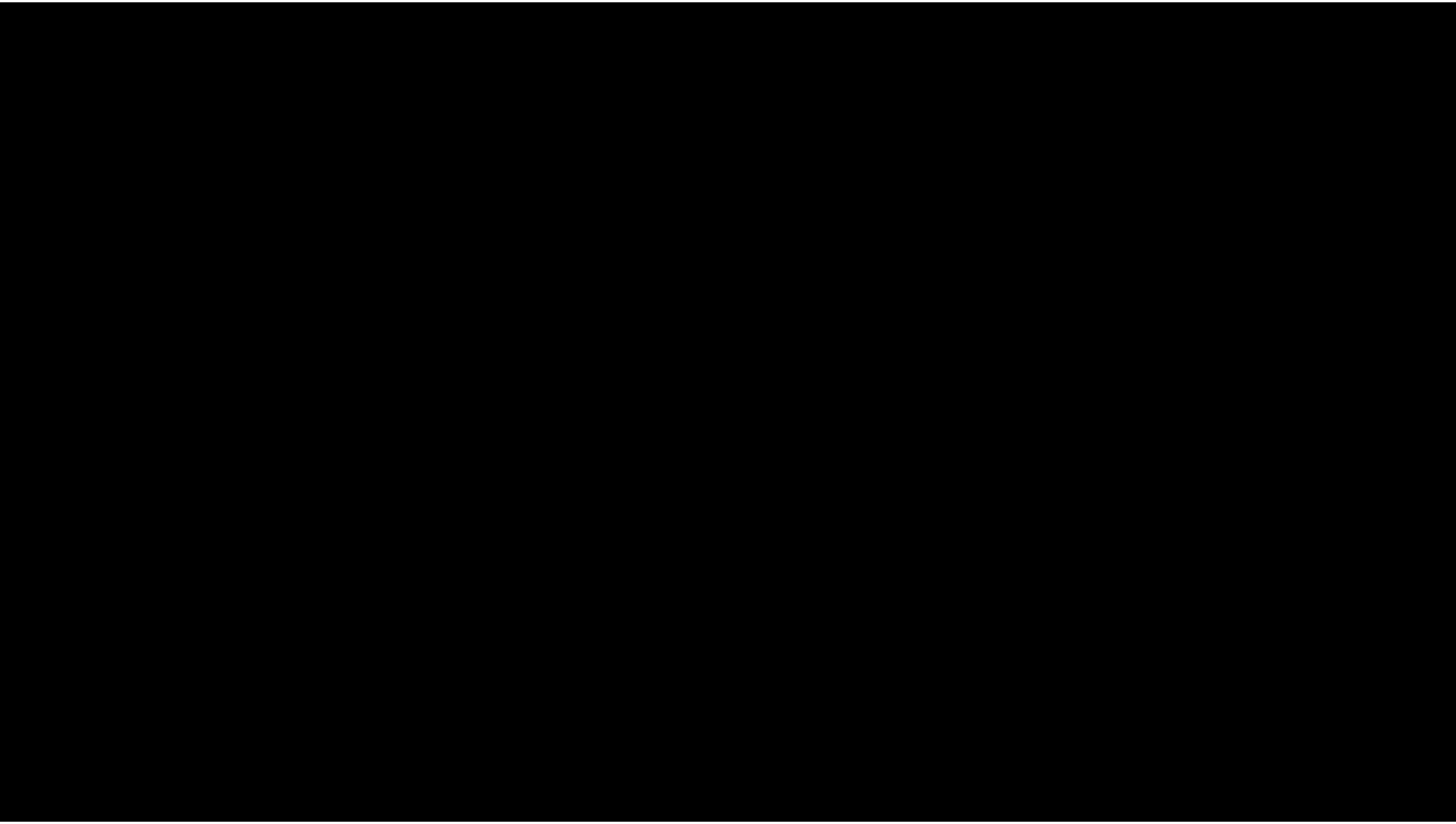
Interferometric lab tests of the mechanisms show the deployment precision and adjustment resolution exceed the optical specification

Testing the optics

- Phase-shifting Interferometer
- Scene based demonstration
  - Off-axis collimator
  - Fixed conjugate optics
  - On-axis collimator
- Dynamic scene demonstration
  - Digital light processor
  - Spectral testing



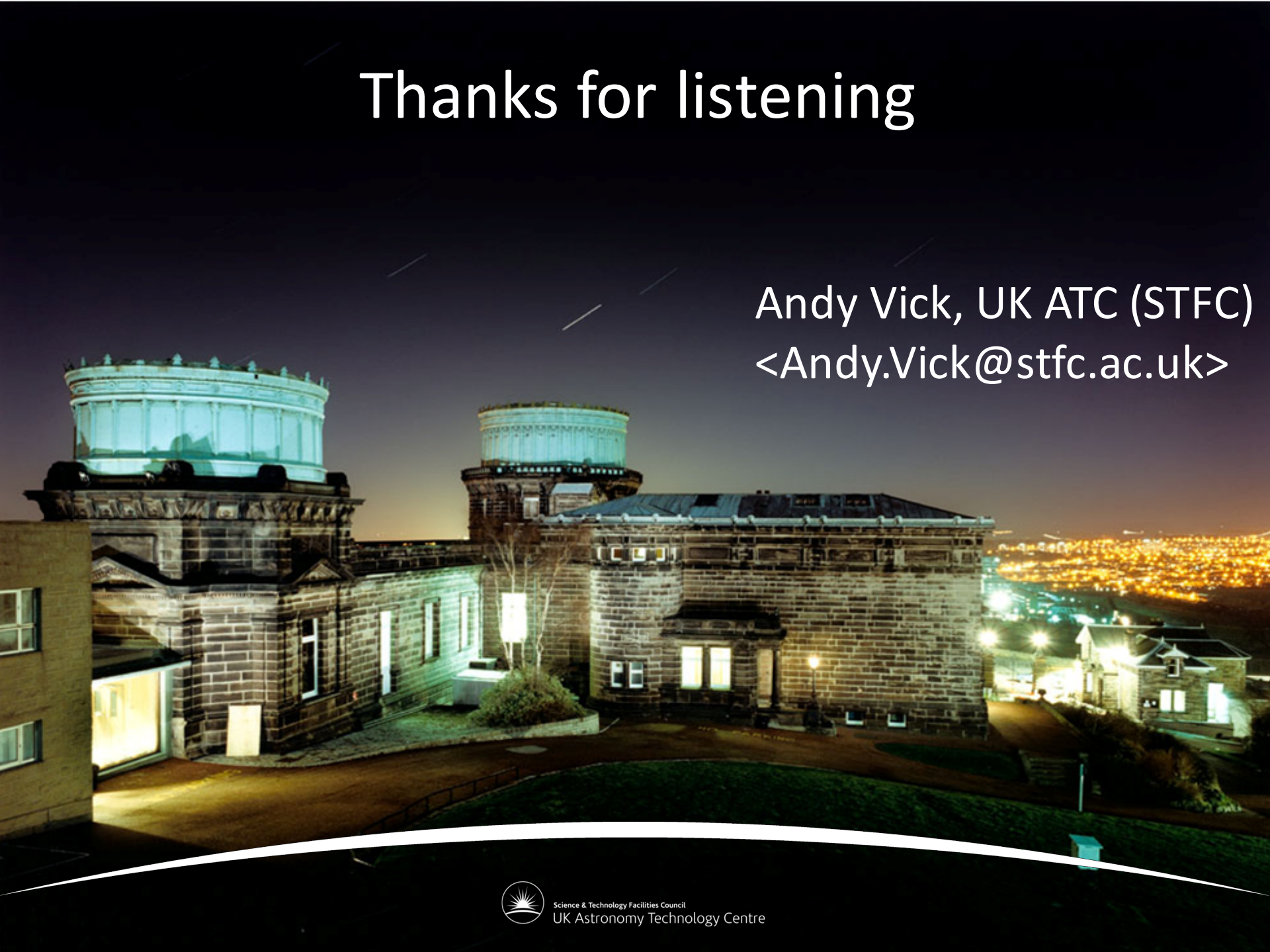




Current conclusions and next steps

- Fitting deployable optical systems in a Cubesat is feasible.
- Alignment of optics using EO ground targets works, but is tricky;
  - Problems with feature dependence; SNR
- Next steps;
  - End to end breadboard
  - Minimize hysteresis effects: Displacement sensors
  - Static and dynamic scene tests – either fixed conjugate optical system or on-axis collimator.
- Once the method is established there are lot's of potential implementations.

Thanks for listening



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