Deployable Optics for Very Small Satellites

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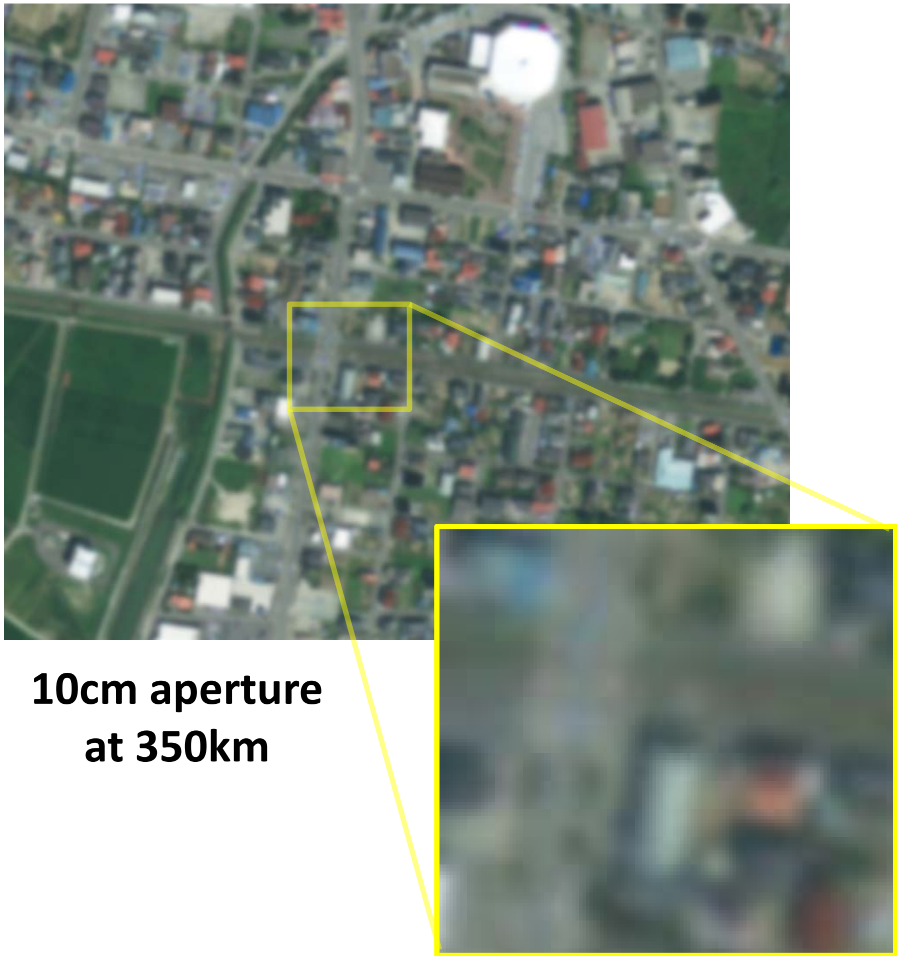
(STFC)

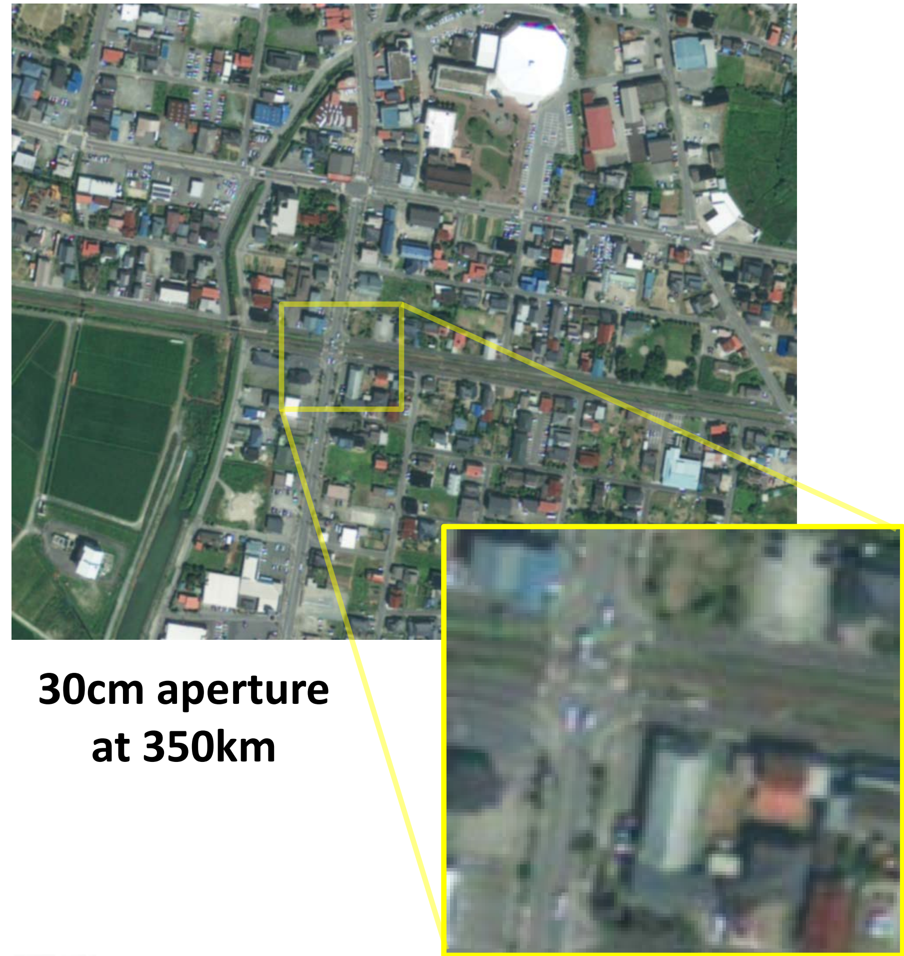
1) The human scale problem

2.1m resolution



10cm aperture at 350km

0.7m resolution



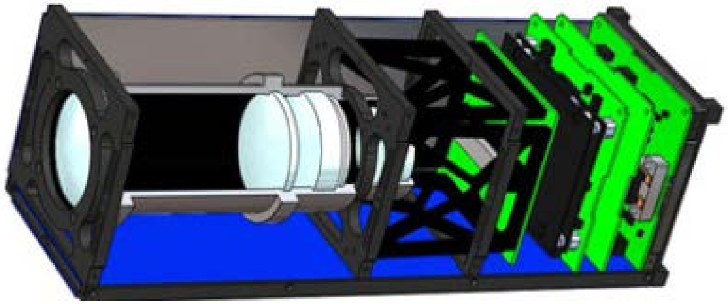
30cm aperture at 350km

2) Spatial resolution problem

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

Spatial ground resolution is limited by the diameter of the aperture

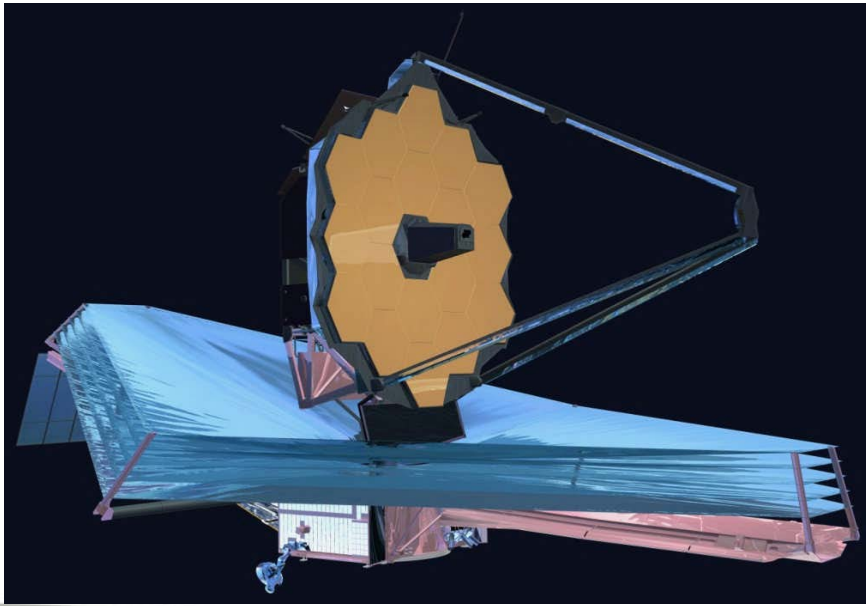
At radio wavelengths you can use heterodyne interferometery with sparse apertures to increase the effective diameter. At optical/NIR wavelengths the frequencies are too high to allow heterodyne detection, and direct interferometery requires phasing all the apertures to better than λ/10.



So a 3U Cubesat, with a <10cm aperture, will limit you to a few metres of ground resolution

Deployable optics

- Deployable optical systems already developed for JWST
- Reduces the amount of “empty” space in the design
- Segmented mirrors are the basis of current and next generation ground based astronomical telescopes
- Individual optical elements can potentially be lighter weight
- Ideal for nano-sats?



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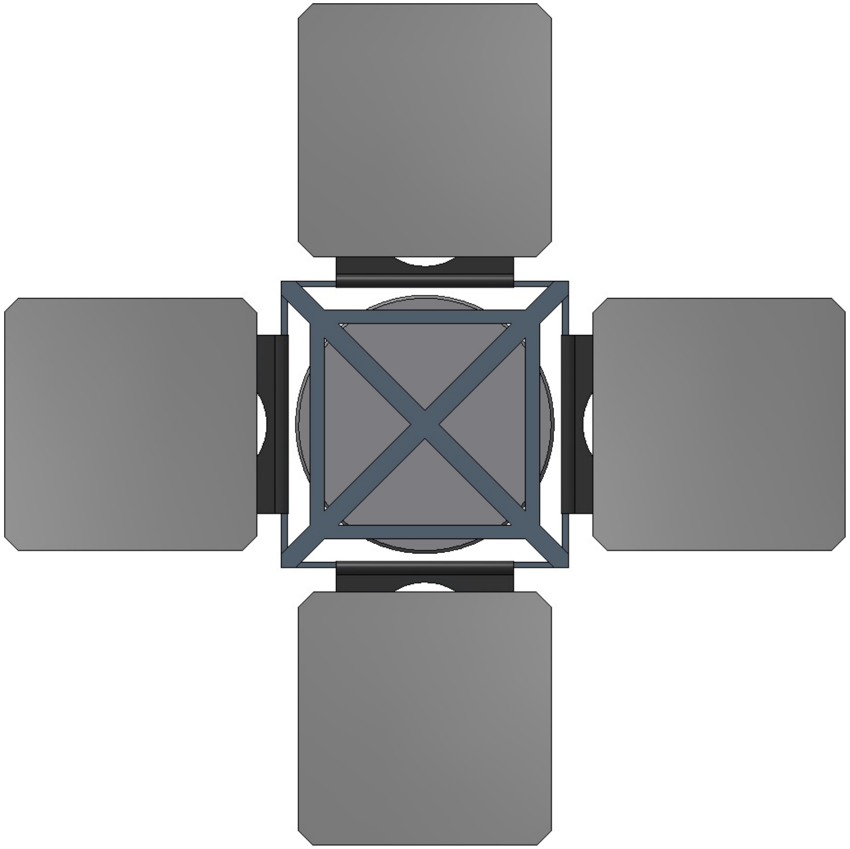
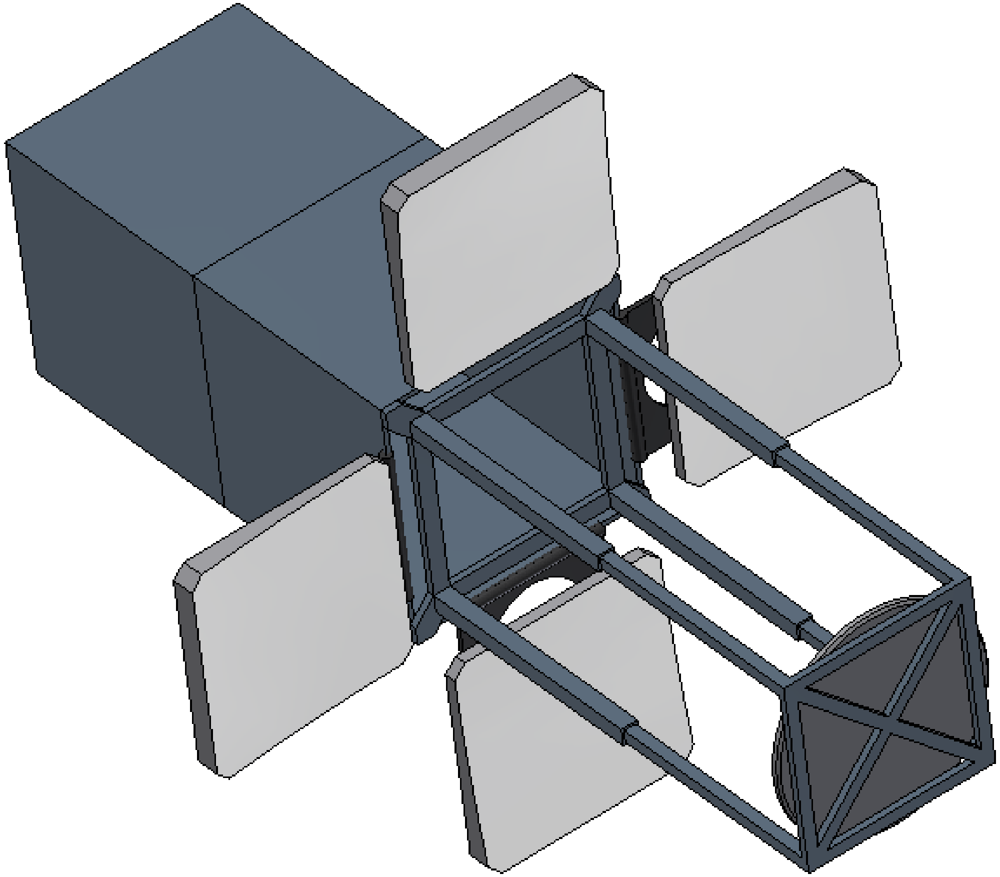
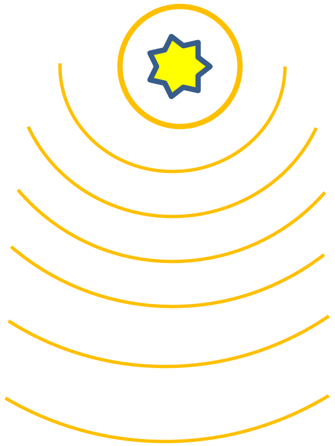
3U Cubesat with deployable optics



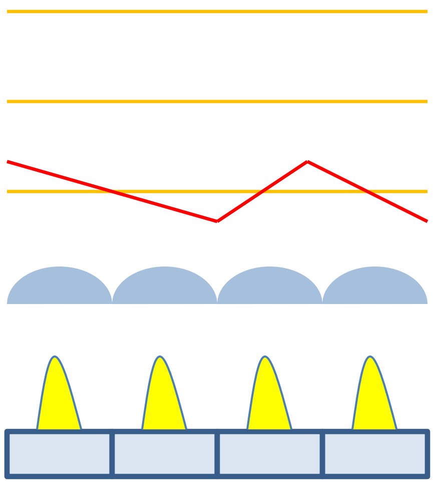


Co-phasing (aligning) mirrors



Deriving the phase of a wavefront is (relatively) simple if the object is a point source at infinity.

For example, using a Shack-Hartman scheme, any phase shifts (in this case misalignments of the mirrors) cause offsets to the sub images.



But this assumes that intensity of the wavefront across the aperture is uniform. When the object is an extended scene this is assumption isn't valid.

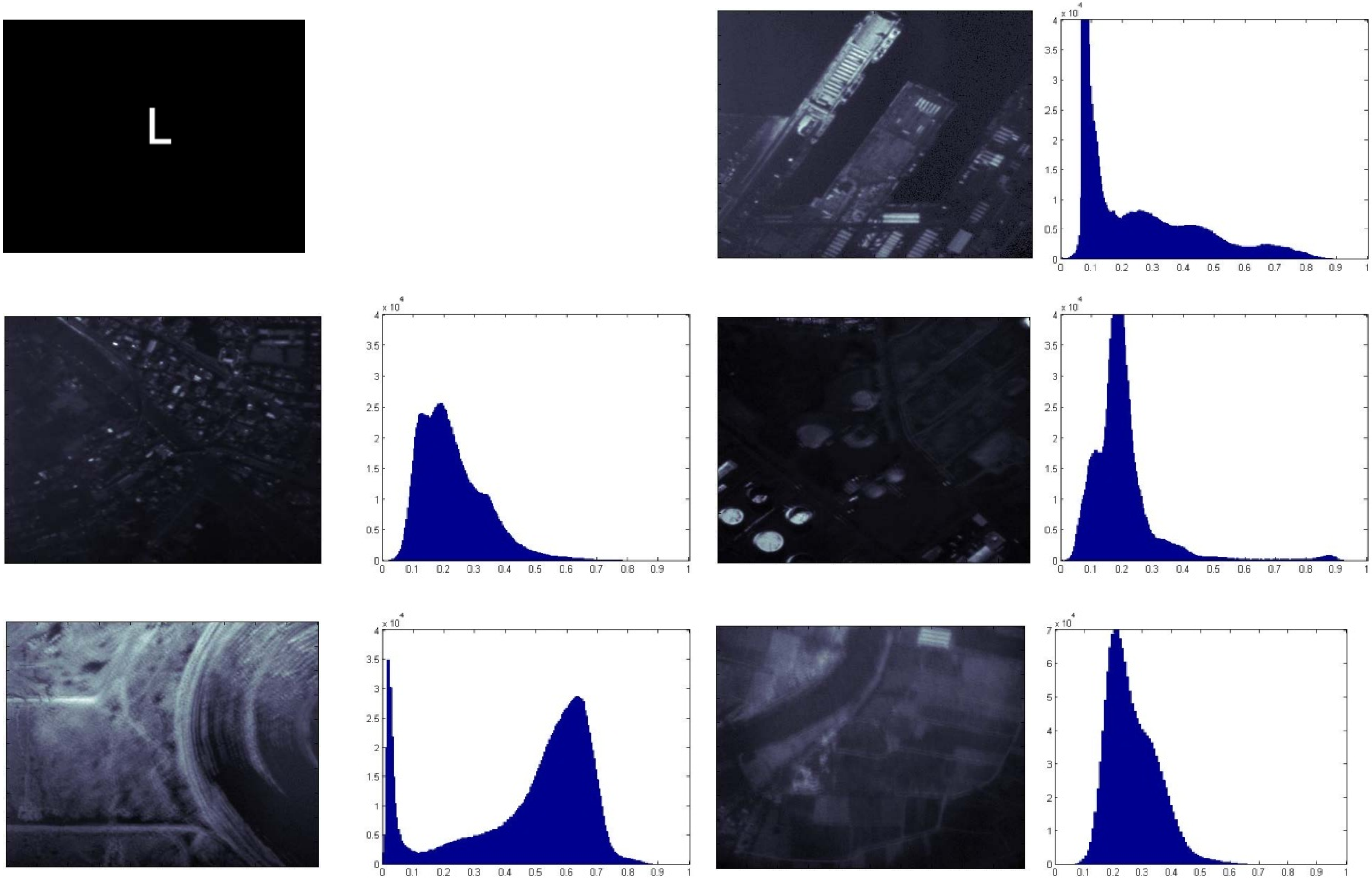
Other wavefront sensing techniques, using diversity, can deal with extended scenes.

Alternative alignment methods

- Absolute positioning (JWST)
  - Mechanically complex, static
- Position sensing (E-ELT)
  - Complex, static reference, noise sensitive
- Dedicated wave-front sensor
  - Complex, in beam, extended object problem
- Object based alignment
  - Simple, dynamic, extended object issues

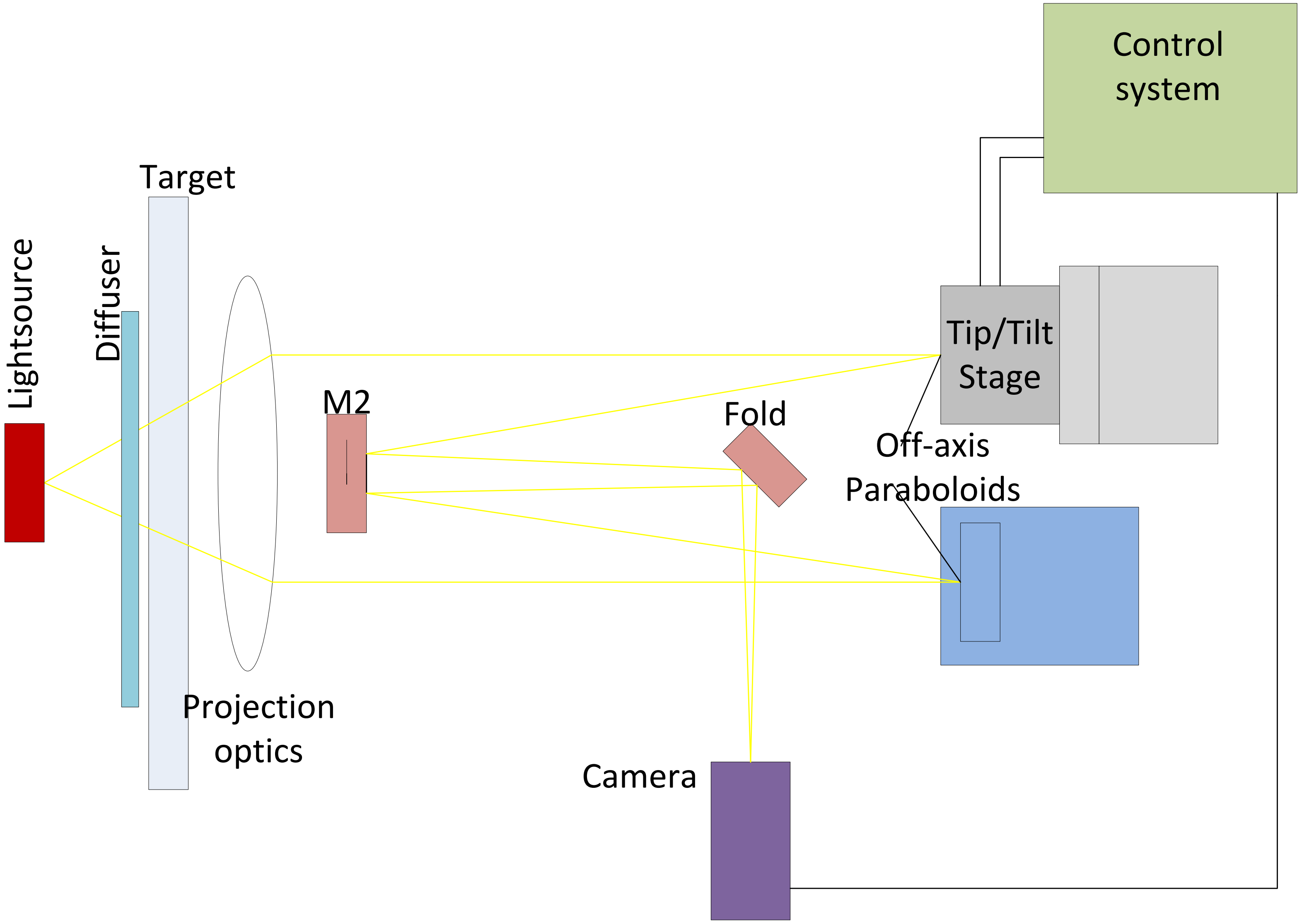
Proof of Concept (DSTL/UKSA)

- Take representative hi-resolution scenes
- Build an optical ray trace model to test algorithms;
  - The metric itself
  - The minimisation strategy
- Build a lab demonstrator of a 2 mirror system with realistic tolerances
- Prove the co-phasing in the lab using projections of the scenes

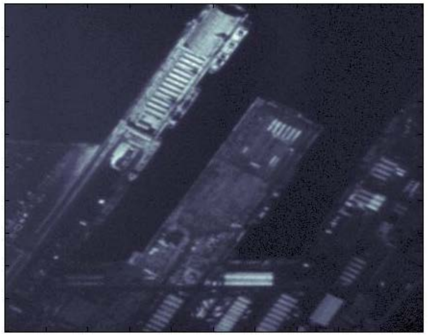

L
x 10^4
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

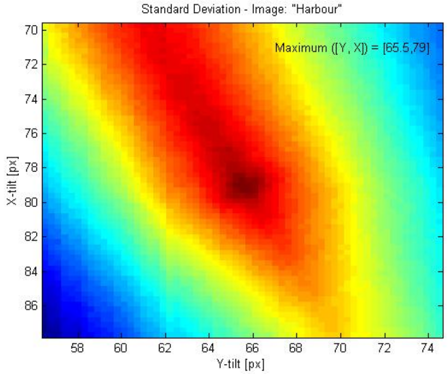
The metric function

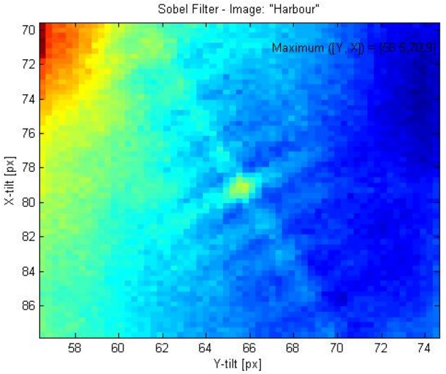
- One Extremum: The metric must have only one extremum (maximum or minimum point) and this must be obtained for aberration-free images.
- Monotonicity: The metric must exhibit some continuous variations on either side of the extremum.
- Effective Range and Sensitivity: The image sharpness metric must give sufficient variation over a large range of distortion amplitudes and be sensitive to small distortion variations.
- Robustness: Finally the metric must exhibit a consistent behaviour regardless of the images content, be insensitive to noise and to illumination variations. It also needs to be robust in the case of varying scene


Control system
Target
Lightsource
Diffuser
Tip/Tilt Stage
M2
Fold
Off-axis Paraboloids
Projection optics
Camera

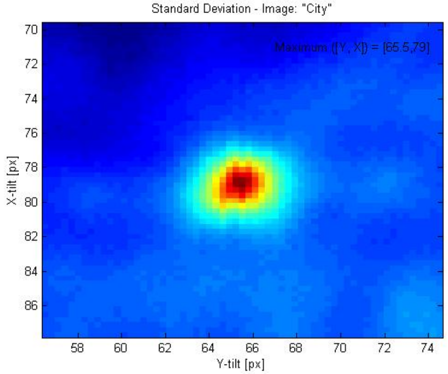
Harbour
scene

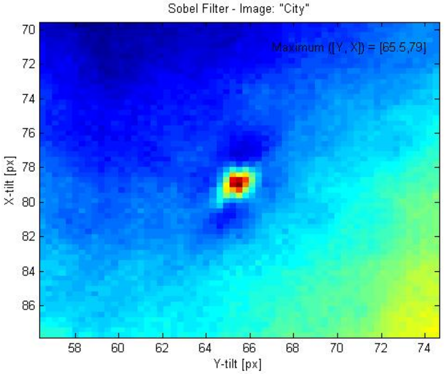




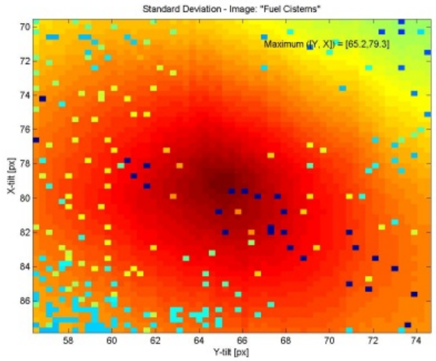


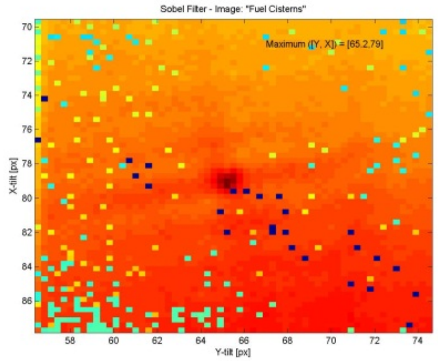
City
scene





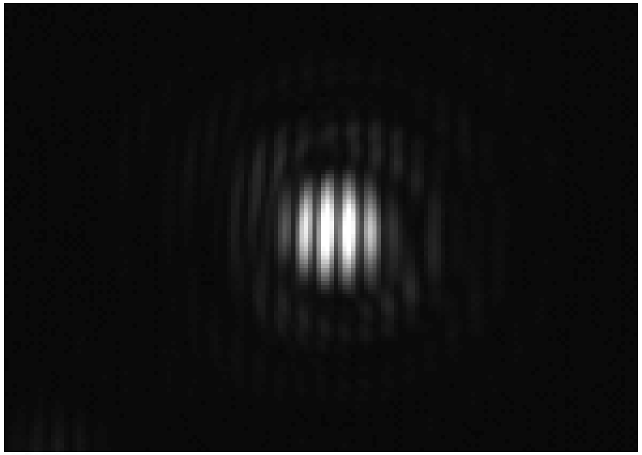
Low
clouds



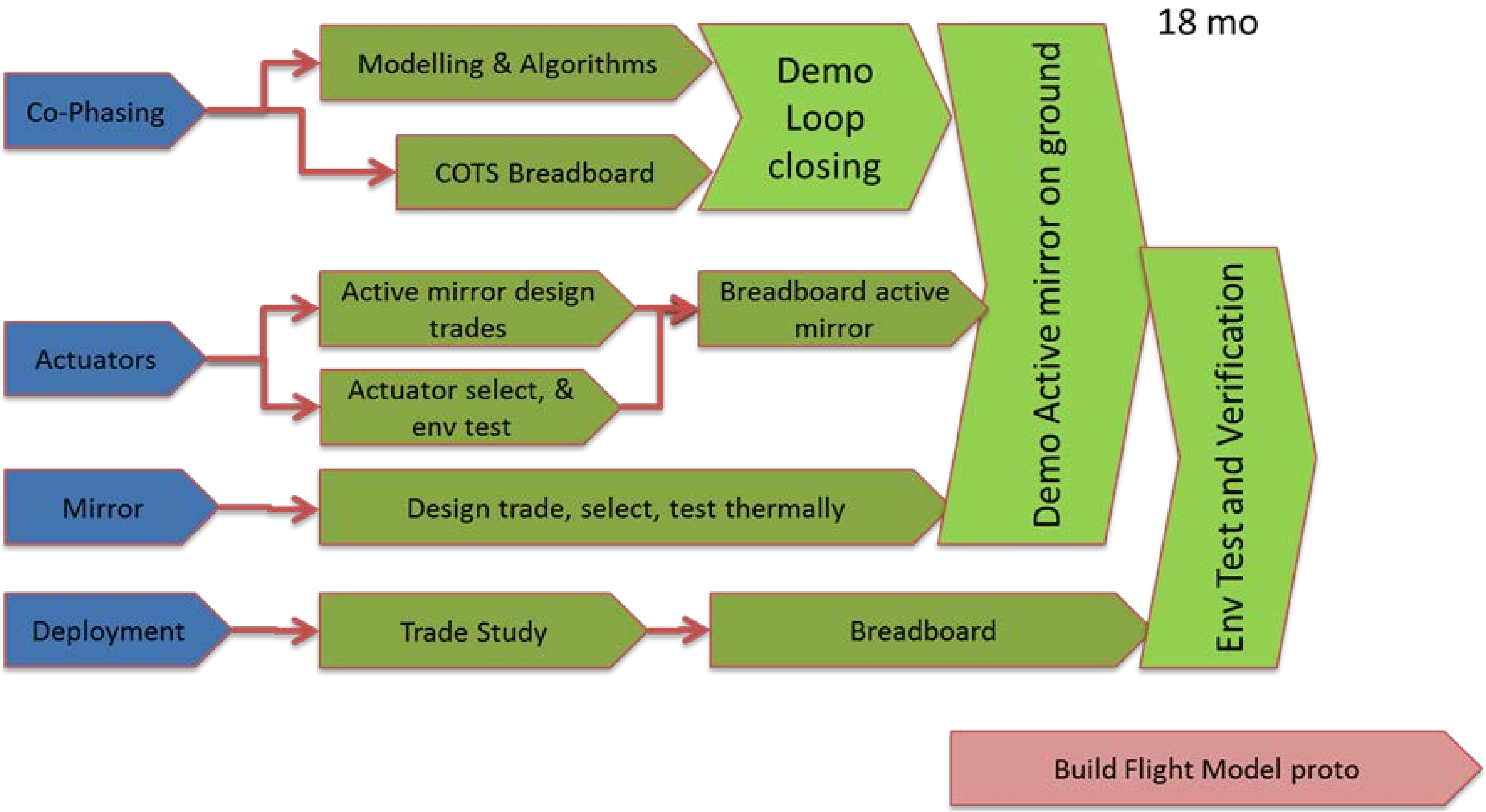


Results

- Most metrics have some image content dependence
- All the metrics we tried are feasible on a nano-sat platform
- Co-phasing will take ~10 iterations
- We can co-phase the mirrors, in the lab, to a few fringes.



Next steps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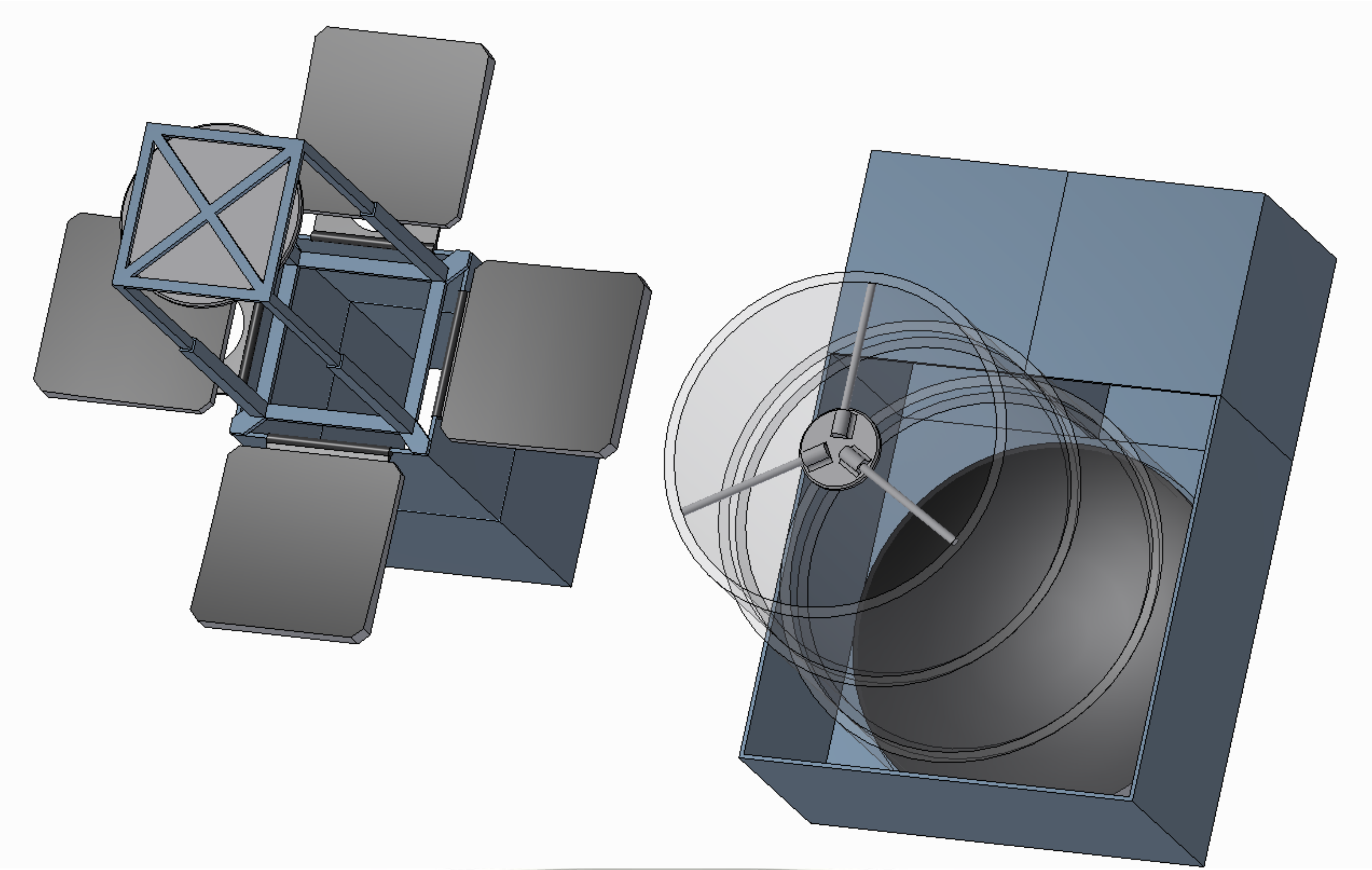
Co-Phasing
Modelling & Algorithms
COTS Breadboard
Demo Loop closing
Demo Active mirror on ground
Actuators
Active mirror design trades
Actuator select, & env test
Breadboard active mirror
Mirror
Design trade, select, test thermally
Env Test and Verification
Deployment
Trade Study
Breadboard
Build Flight Model proto

Further consideration

Two recent issues

- With large detectors, coded apertures or a plenoptic camera might provide a better co-phasing metric (diversity)

- The current design is very difficult to baffle. We still want to see what we can do with a 3U Cubesat, but a deployable 2nd mirror would be a good PoC.



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