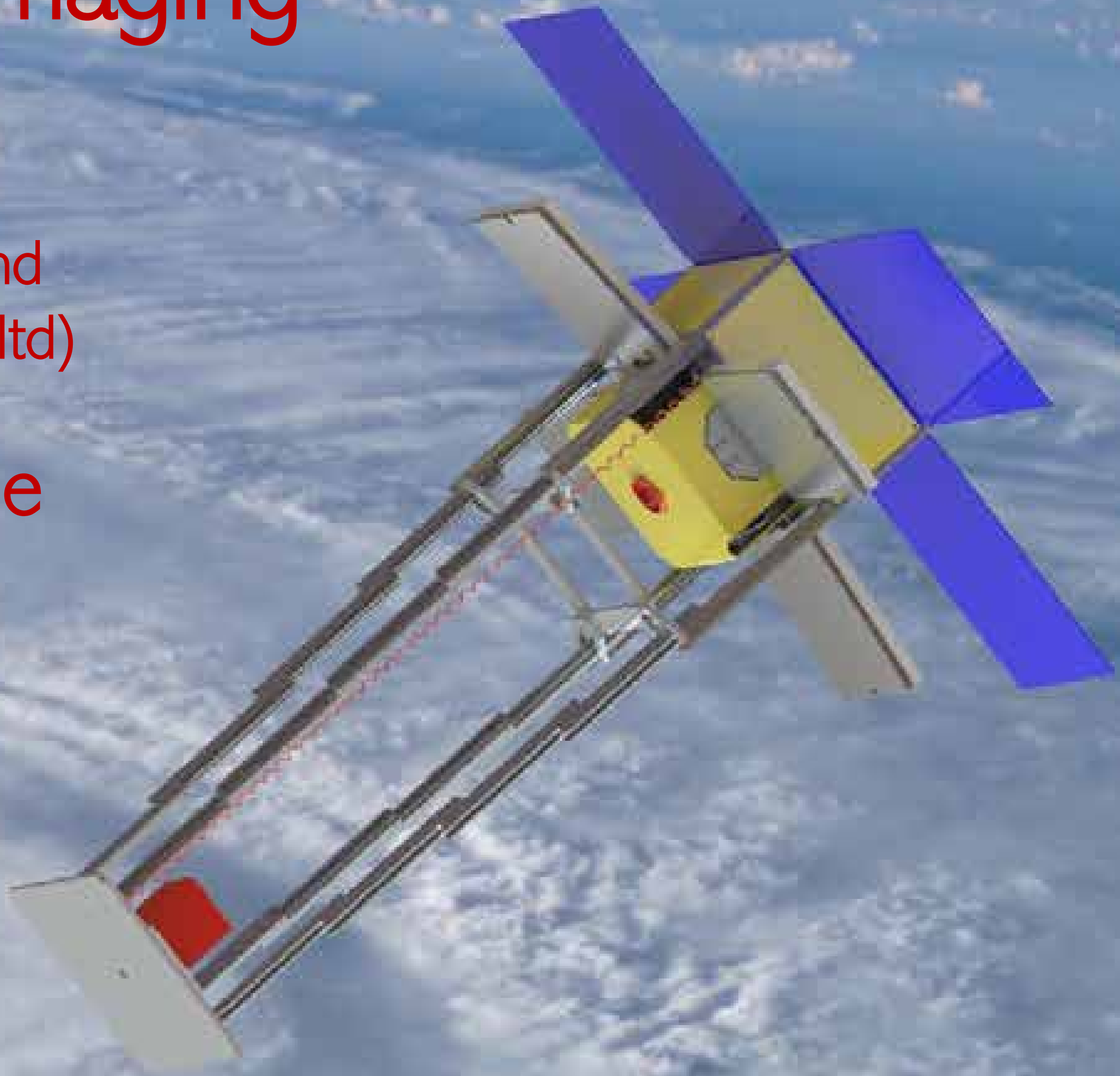
Deployable optics and TIR imaging

Ian Parry, George Hawker, Marco Gomez-Jenkins and
Sergio Gonzalez (University of Cambridge and S4 ltd)

CEOI Emerging Technologies Challenge
Workshop April 2021



Team

Institute of Astronomy

Current core team members

Ian Parry (opto-mechanical design), George Hawker (optics/self-alignment), Marco Gomez-Jenkins (business and project management) and Sergio Gonzalez (electronics).

Partners

Open Cosmos ltd, Cambridge Enterprise (UoC) and Cambridge Zero (UoC).

Previous workers

Tony Gosnell, Jeremy Spinks, Seb Cosnefroy, Michael Johnson, Karia Dibert, Richard Jakob.

Funding

~£600k received so far from

- UKSA
- UKRI/STFC
- Royal Society of Edinburgh
- Santander
- Cambridge Enterprise Seed Funds
- Solid works

UK SPACE AGENCY

Science and Technology Facilities Council

UNIVERSITY OF CAMBRIDGE enterprise

RSE The Royal Society of Edinburgh

Santander UNIVERSITIES

SPONSORED Entrepreneur SOLIDWORKS

Why do we need deployable (unfolding) optics?

- Because unfolding means bigger and bigger means sharper
- For a given payload size, by unfolding we can have an improvement in Ground Sampling Distance (GSD) of 3-4x
- For the very largest telescopes, unfolding is essential, simply to fit it into the rocket fairing.

- R is the smallest resolvable feature in the image (similar to GSD).
- H is the orbital height.
- λ is the wavelength.
- W is the width of the optical aperture.

$$R = 23cm\left(\frac{H}{450km}\right)\left(\frac{\lambda}{500nm}\right)\left(\frac{100cm}{W}\right)$$

Electro-optical

$$R = 460cm\left(\frac{H}{450km}\right)\left(\frac{\lambda}{10\mu m}\right)\left(\frac{100cm}{W}\right)$$

TIR

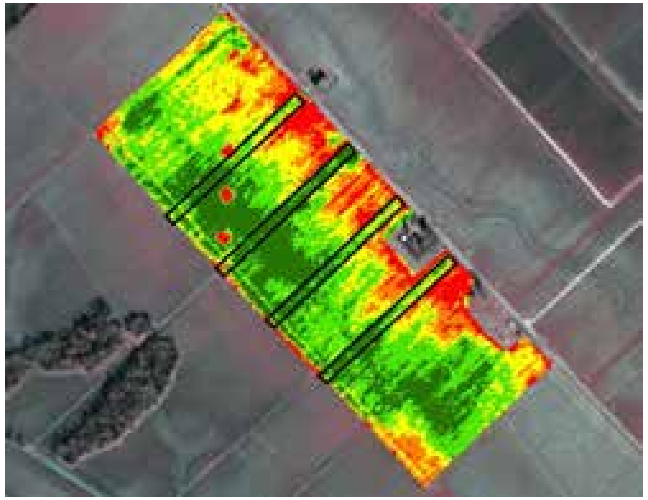
Why are we targeting the Thermal Infrared (TIR)?

- The TIR wavelength of ~10 microns makes the accuracy of the metrology and nano-positioning (alignment) of the telescope ~20× easier than for a system working at λ=0.5 microns
- The TIR EO market is currently very under-populated (because high definition for TIR imaging needs large telescopes). Current best GSD available is ~100m with low revisit rates.
- There are many commercially viable applications for TIR imaging as soon as better GSD and revisit rates become available.

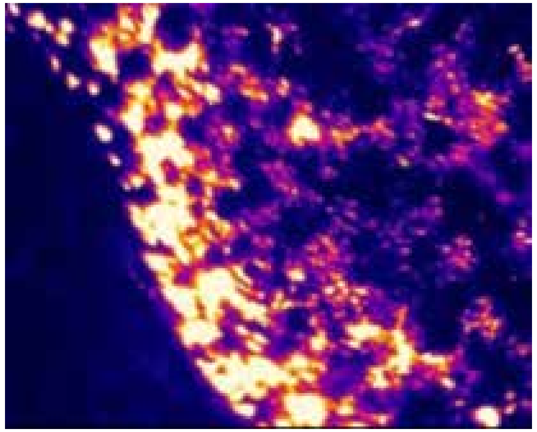
$$R = 4.6m\left(\frac{H}{450km}\right)\left(\frac{\lambda}{10\mu m}\right)\left(\frac{1m}{W}\right)$$

Thermal Infrared (TIR) Satellite Imaging Application Examples

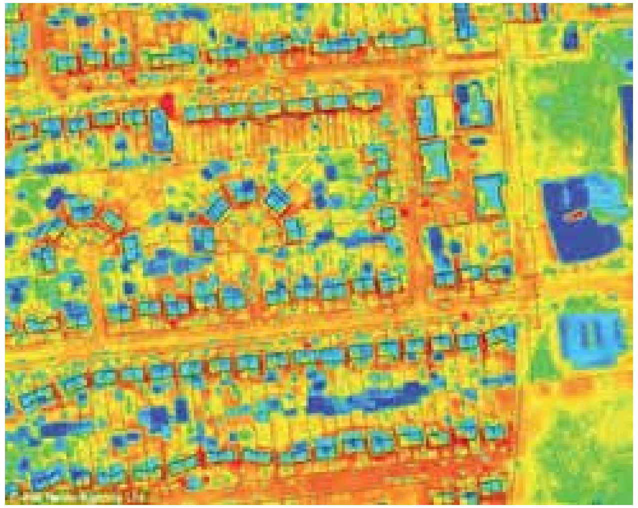
1. Monitoring the energy usage of buildings globally to check how governments, companies and individuals are doing with respect to their carbon emission commitments.
2. Early detection of wildfires.
3. Monitoring crops for early detection of water stress and disease.
4. Improved predictions for the financial sector.
5. Detection of illegal fishing.
6. Security and Defence.
7. Management of valuable infra-structure assets (e.g. pipelines and electricity power lines).
8. Finding and exploiting geo-thermal energy sources.



Early detection of dehydrated crops to increase crop yield



Early detection of wildfires to prevent property losses



Energy consumption of buildings to reduce carbon emissions

Why are we designing for a 12U Cubesat?

- A CubeSat is the least expensive route to an in-orbit demonstrator.
- We initially explored 3U and 6U solutions. However, we found the volume constraints to be too restrictive.
- Also, TIR applications need large optics to provide a useful GSD and this is not feasible with 3U and 6U platforms.
- 12U is big enough to be interesting but small enough to be affordable.

- In the longer-term we will develop a larger telescope for a larger satellite bus to give better GSD.

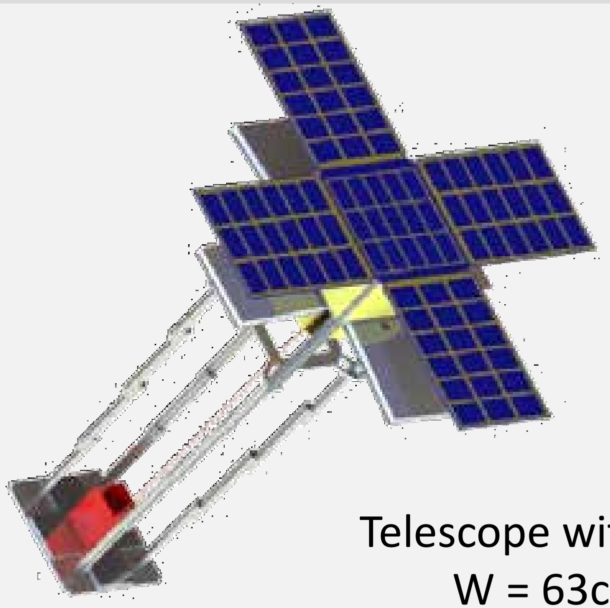
Our imaging solution: SUPER-SHARP

A microwave-oven-sized satellite…

12U CubeSat 23cm x 23cm x 36cm

that unfolds to become

…a self-aligning telescope

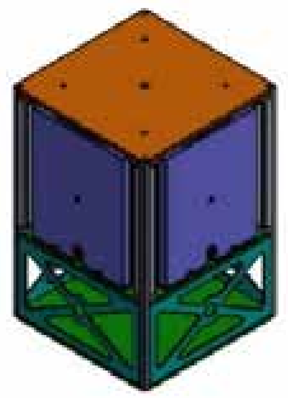


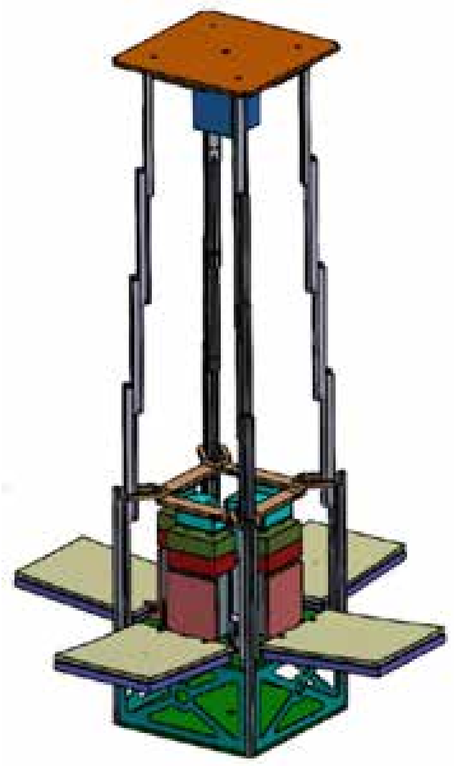
Telescope with W = 63cm

4x greater resolution and much lower cost than the current state-of-the-art solution

The lower cost enables constellations.
Our technology therefore offers better GSD and better revisit rates.

Alignment of the optics after unfolding

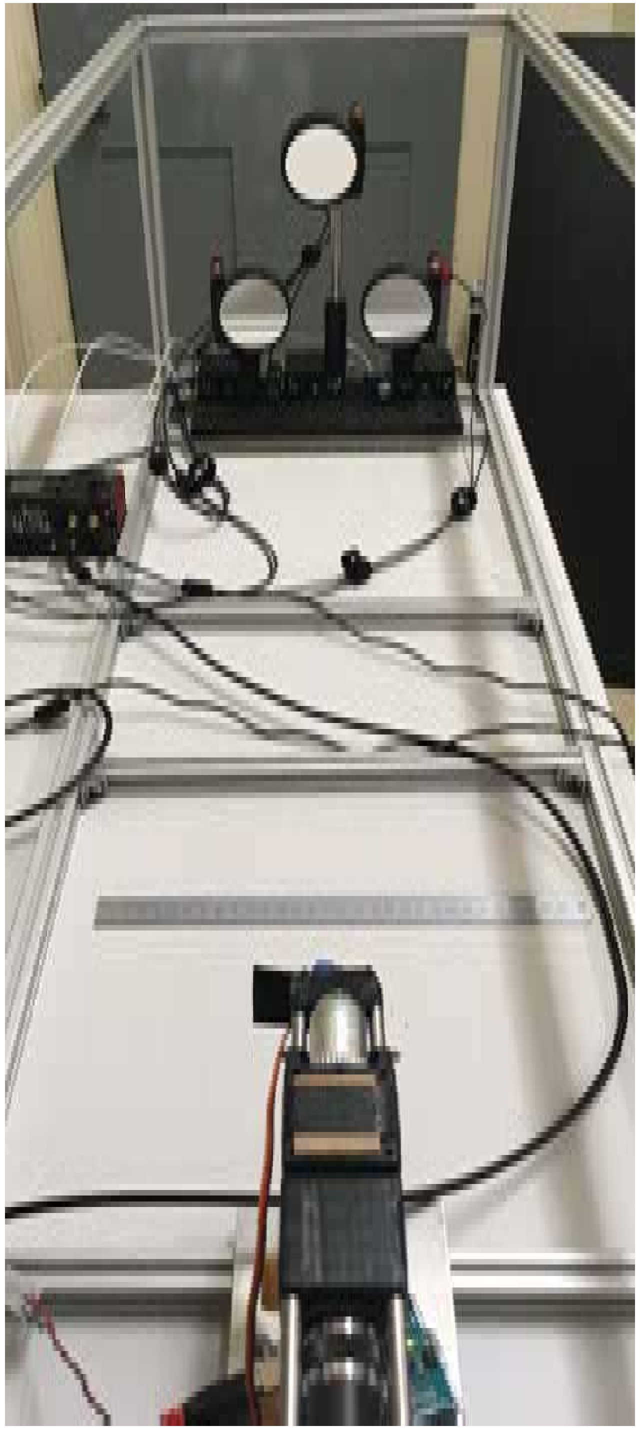




- Our primary mirror has 4 segments and each segment has three degrees of freedom (tip, tilt and piston).
- Each degree of freedom is controlled by an actuator with ~4000 steps and for only ~4 of those steps is the system accurately aligned.
- The system therefore has 1×10^{36} (a trillion, trillion, trillion, trillion) unaligned states for every aligned state. The chances of the system being aligned after unfolding are essentially zero.
- Need to set the 12 actuators to the correct values to achieve system alignment or the images will be blurred. And alignment has to be maintained.
- This is difficult – how do we know what positions to set the actuators to?
- To open a safe you need to know the combination.
- To tune a piano you need to know exactly how much tension to put in to each string.

Metrology – measuring the alignment errors

- We have developed a metrology system that independently and accurately measures the tip, tilt and piston errors of the individual primary mirror segments.
- Independent and continuous measurement of the errors is important to avoid errors due to degeneracies and drifts.
- This is how safe-crackers and piano-tuners operate. They listen to the individual tumblers or strings one at a time. They don't listen to them all at the same time.
- We use an internal light source (λ~500nm) for metrology.
- The telescope can take pictures of the Earth while the metrology system and the closed-loop control of the actuators are running.
- We (mainly George Hawker) have successfully demonstrated this self-alignment technique in the lab – *this is the key to making a self-aligning, unfolding telescope, actually work.*



TIR sensor: An Uncooled Micro Bolometer Array (UMBA)

- Baseline: COTS TIR camera core (e.g. FLIR boson 640), **640x512** pixel uncooled VOX bolometer array sensor.
- UMBAs have **space heritage** (e.g. the CUMULOS instrument on the 3U ISARA CubeSat).
- **Larger formats** (1024x768 and 1920x1200) are available.
- Being able to use a **small sensor package** with no cooler is very important for our CubeSat implementation.
- A bulky **cooled sensor is not essential** because the surface of the Earth, with T~300K, glows very brightly at TIR wavelengths.
- The FLIR boson has a **temperature sensitivity** of 30mK with an f/1.0 lens. Our fill factor of 0.45 and f-ratio of f/1.4 gives a temperature sensitivity of 30mK × $(0.45)^{-2}$ × $(1.4)^{2}$ = **300mK** or about a third of a degree which is more than sensitive enough for most applications.

FLIR Boson 640
(USA)

TE-DB1024-12C-A
(Korea)

BAE Systems Athena 1920
(USA)

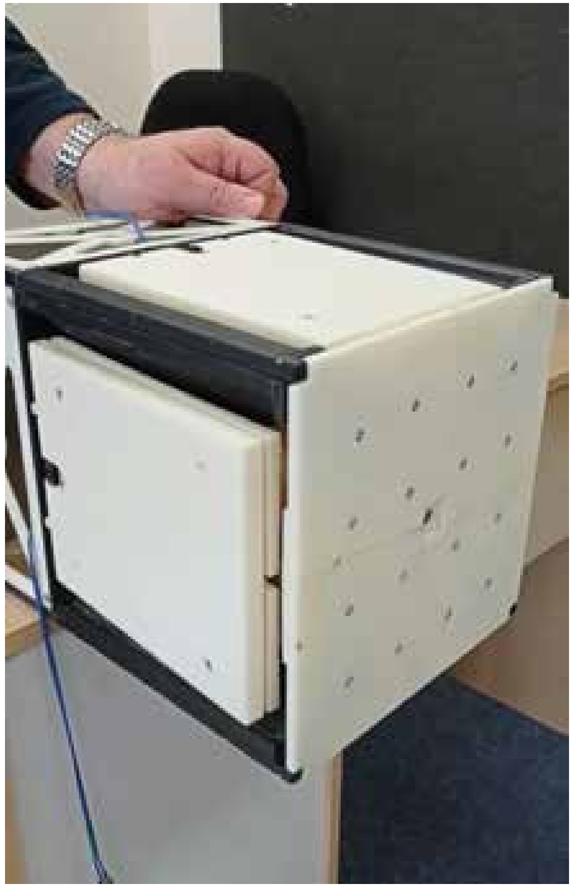
ULIS Pico1024E
(France)

Current Status

1. We have an **unfolding** space telescope prototype. This demonstrates the mechanical operation of the telescope and CubeSat packaging. It's an 8U module for use in a 12U satellite. It has no optics.
2. A 3 mirror lab optical-bench prototype including hardware and software which successfully demonstrates the **self-alignment** process for a telescope operating at 10µm (TIR). An important part of our metrology technique is protected by a patent.
3. A well developed **business plan** including engagement with CubeSat providers and potential end-users.
4. An established and operating **spin-out company**, Super-sharp Space Systems Ltd (S4).

Mechanical prototype unfolding

3D printed parts
No optics



Specifications

Specification	Value
Launch mass	20 kg
Optical aperture	63 cm
Launch configuration	12U CubeSat
Wavelength	8 – 13 microns
GSD (from 450 km)	6 metres per pixel
NEDT	300mK
Sensor	UMBA
Sensor format	640 x 512 pixels
FOV	3840 x 3072 metres