# High resolution thermal infrared space telescopes for globally monitoring the energy efficiency of buildings

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CEOI Session on future EO missions

# Project overview

SUPER-SHARP SPACE SYSTEMS

OPEN COSMOS

CAMBRIDGE ZERO UNIVERSITY OF CAMBRIDGE

UNIVERSITY OF CAMBRIDGE enterprise

IoA UNIVERSITY OF CAMBRIDGE Institute of Astronomy

## Main Aim

Develop space technology to help tackle climate change

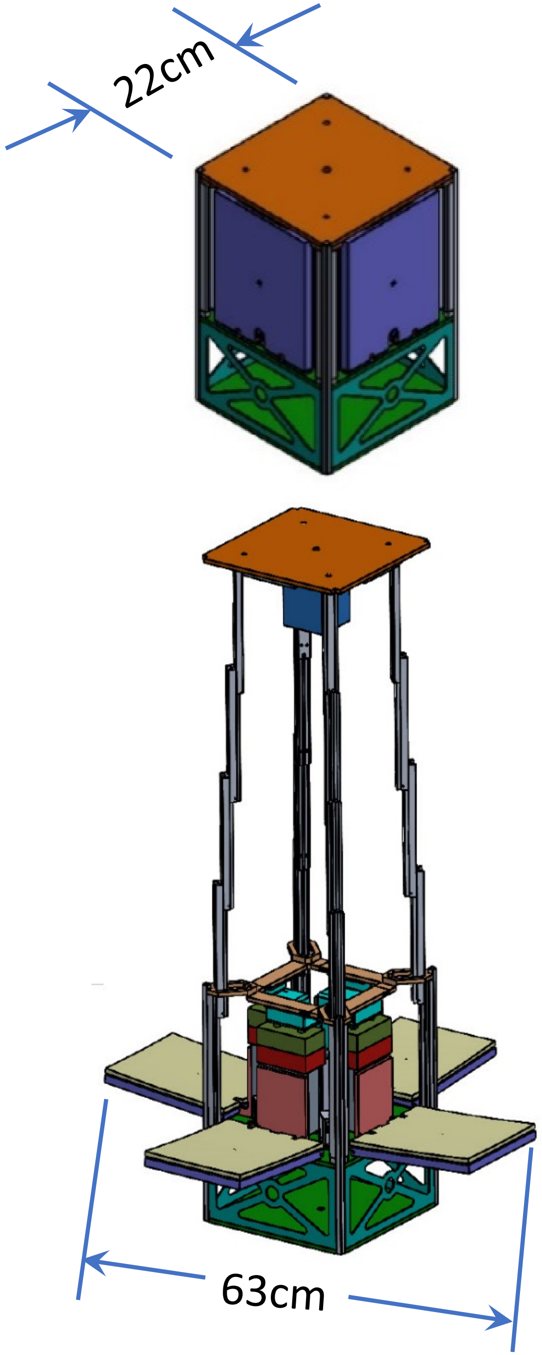
## Funding

Funded via the UK Space Agency's National Space Innovation Program (NSIP) under the theme "Earth Observation to Tackle Climate Change". Project ran for 5 months from Nov 2020 to March 2021

## What and How

- Thermal infrared (TIR) earth observation satellites can monitor the energy usage of buildings **globally**.
- With a Ground Sampling Distance (GSD) of 6m and a constellation of 5-10 satellites, **most** individual buildings can be monitored with a monthly revisit rate. This allows the biggest CO2 emitters to be identified, prompting remedial **action.**
- High impact because 28% of global CO2 emissions come from heating or cooling buildings. Anomalously high emitters that are easily identified, contribute a significant fraction of the total.

# NSIP Project Proposal




## 1) Develop an unfolding space optics payload (IoA and S4)

- A GSD of 6m can be achieved in the TIR with a 12U CubeSat – but only if the telescope unfolds (the telescope primary mirror must be 63cm across at $\lambda$=10µm).
- Why bother? Because a CubeSat constellation costs substantially less than a small-sat constellation. Or alternatively, a small-sat constellation gets 3 - 4x better GSD.

## 2) Investigate how EO TIR data can be used to get the required insights (Cambridge Zero)

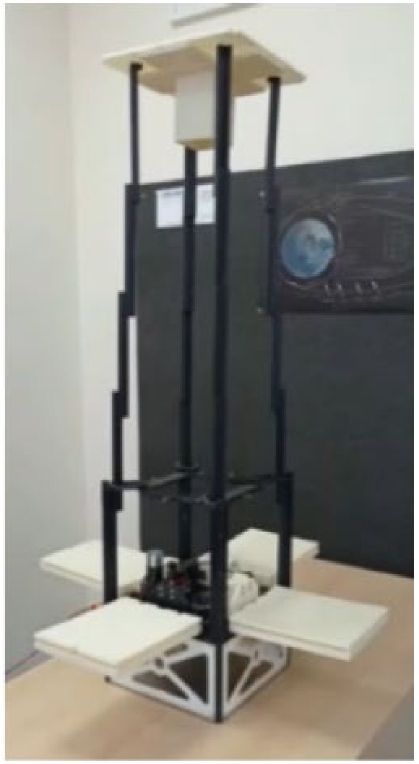
- Use drone data to emulate space data (the space data does not exist yet).
- Monitor UCAM buildings with known energy and use the data to look for trends
- Study the effects of GSD, local weather, viewing angle, etc. on measured temperature.
- Engage with stakeholders to find out what they want.

## 3) Develop the CubeSat bus and mission (Open Cosmos)

- Confirm that the unfolding payload design is compatible with a 12U CubeSat bus
- Establish the technical budgets for power, comms, ACS, etc.
- Develop the mission parameters (orbit, duration, etc.)

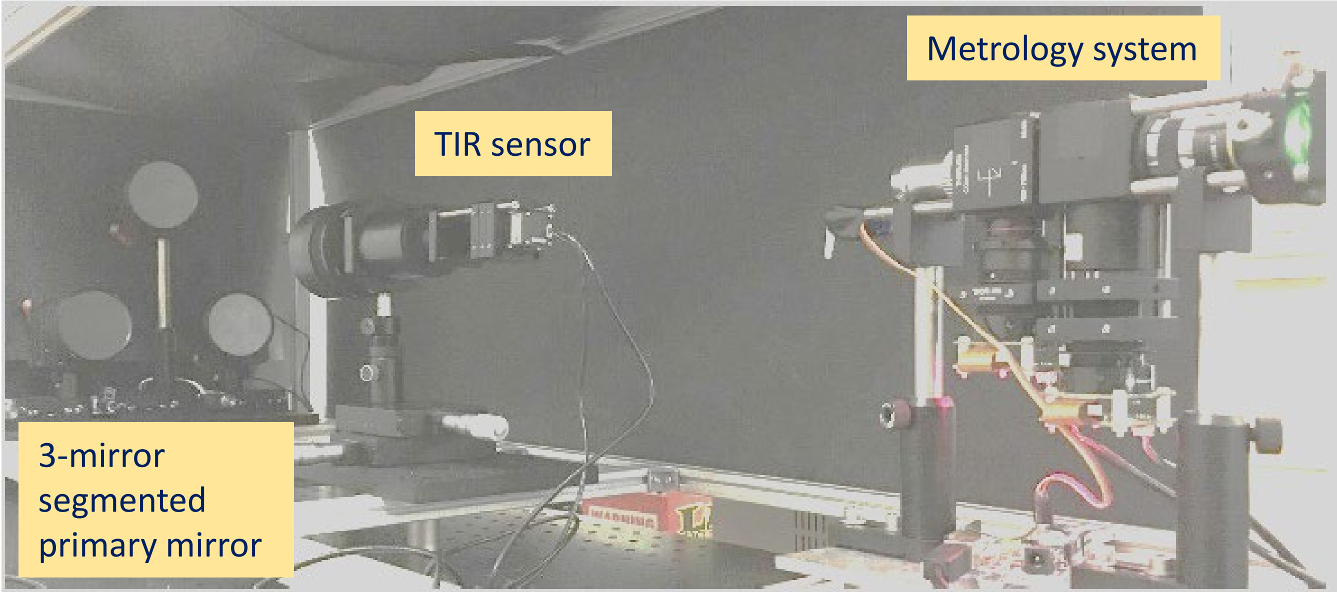
# A prototype of a unfolding telescope payload for a 12U CubeSat (S4 Ltd).

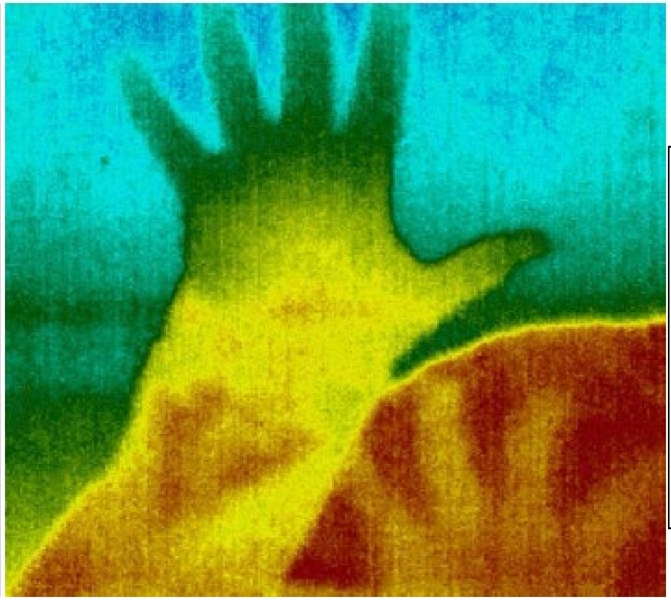
- Because of the very tight schedule and the general difficulties of working during a pandemic, we used in-house 3d printing to manufacture most of the parts.
- The **opto-mechanical prototype** was able to successfully unfold autonomously and it met the space and weight requirements for a 12U CubeSat payload.
- In the time available, we partially integrated it with the Open Cosmos *Openkit* and some detailed interface issues were unresolved. However, with some minor modifications on both the payload and CubeSat bus sides, we are confident that these issues will be resolved.



# A lab prototype for continuous self-alignment of an unfolding space telescope (IoA, University of Cambridge).

- Immediately after unfolding, the telescope will be poorly aligned so we have to have a system to initially align it and then continuously maintain the alignment.
- 3 mirror segmented primary with nano-positioning, computer controlled actuators.
- A reflective metrology system to measure the tip, tilt and piston errors of the alignment.
- Closed-loop self-aligning was achieved and diffraction limited imaging was demonstrated at TIR wavelengths.
- Four types of diffractive coating technology (for our patented diffractive metrology method) were explored and 2 were manufactured (diamond-turned optics and e-beam lithography). The diamond-turned method is the one we will take forward.

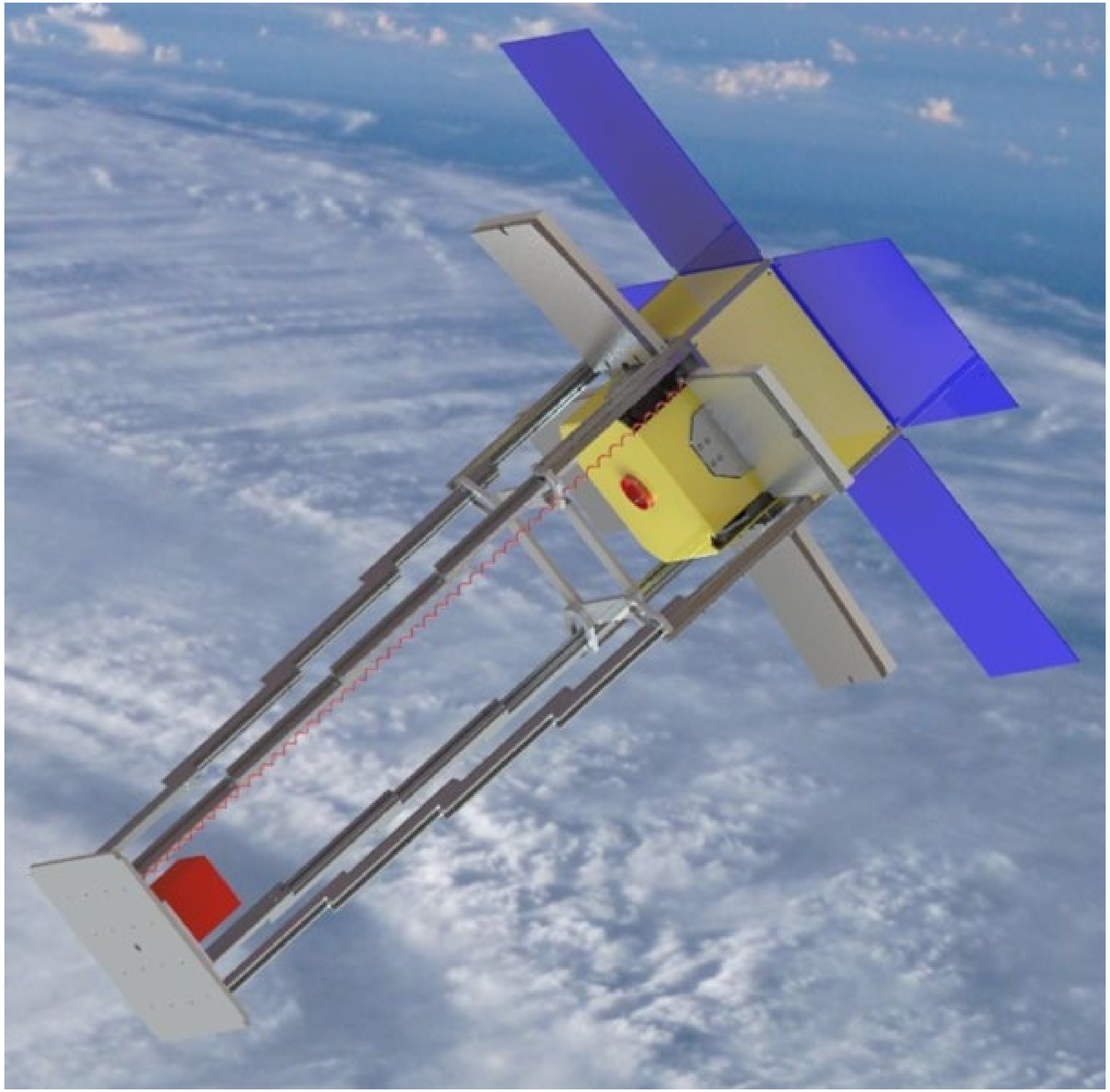


Left: the telescope with a 3-segment primary mirror. Right: an image taken with the telescope of a target 30m away

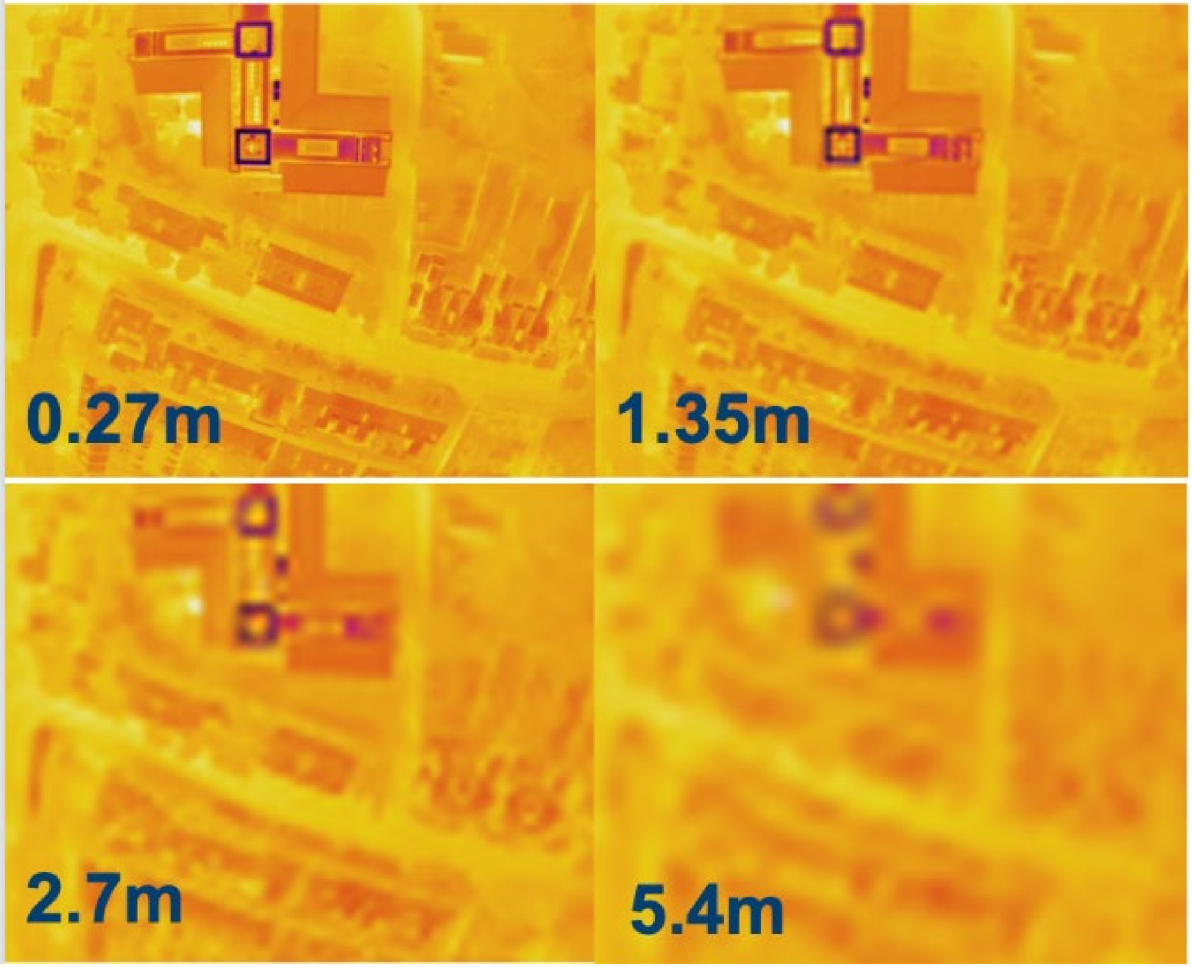
# Specifications

| 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 (baseline) | 640 x 512 pixels |
| FOV (baseline) | 3840 x 3072 metres |

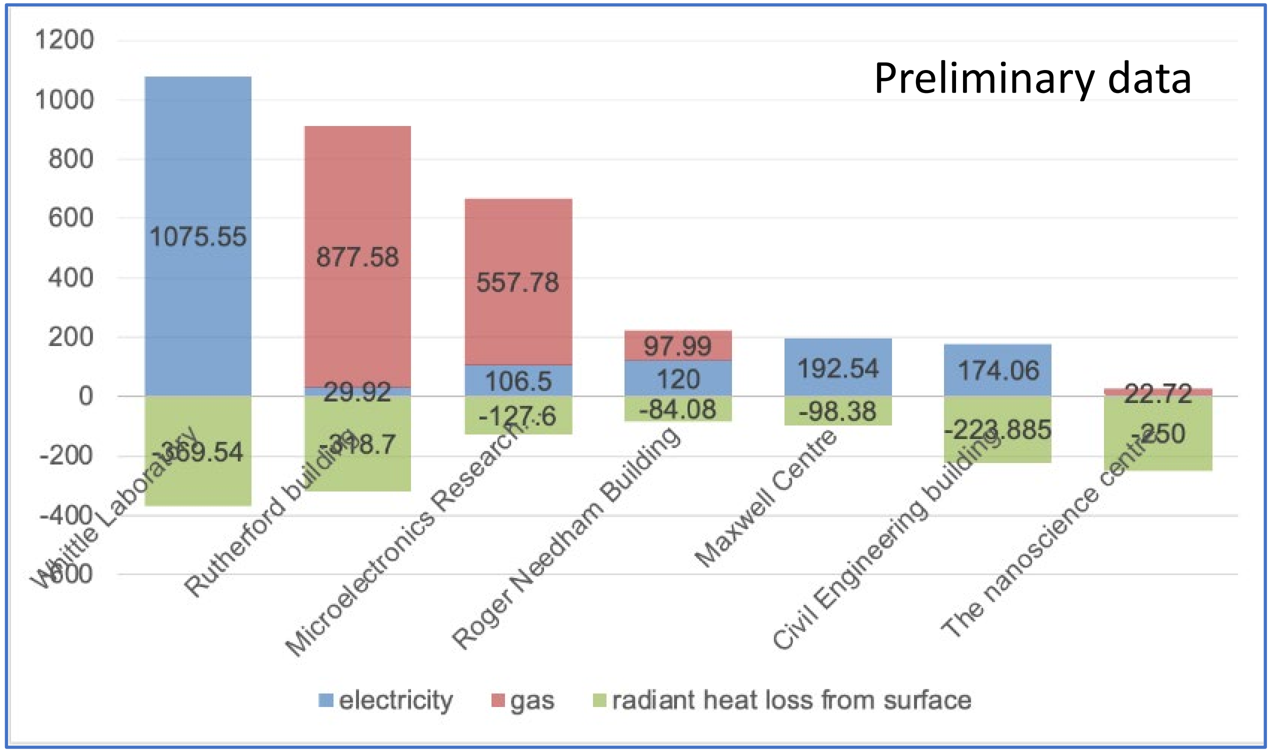


# Comparing TIR drone data with actual energy use data (Cambridge Zero)

- >100 buildings with energy usage data sampled
- Surface temperature measured depends on how energy is used (e.g., thermal management of computers v heating), weather conditions and surface material type.
- A GSD of 6m is sufficient.




The Cambridge University Gleeson building at different GSD resolutions to emulate the TIR data to be acquired by the satellite.



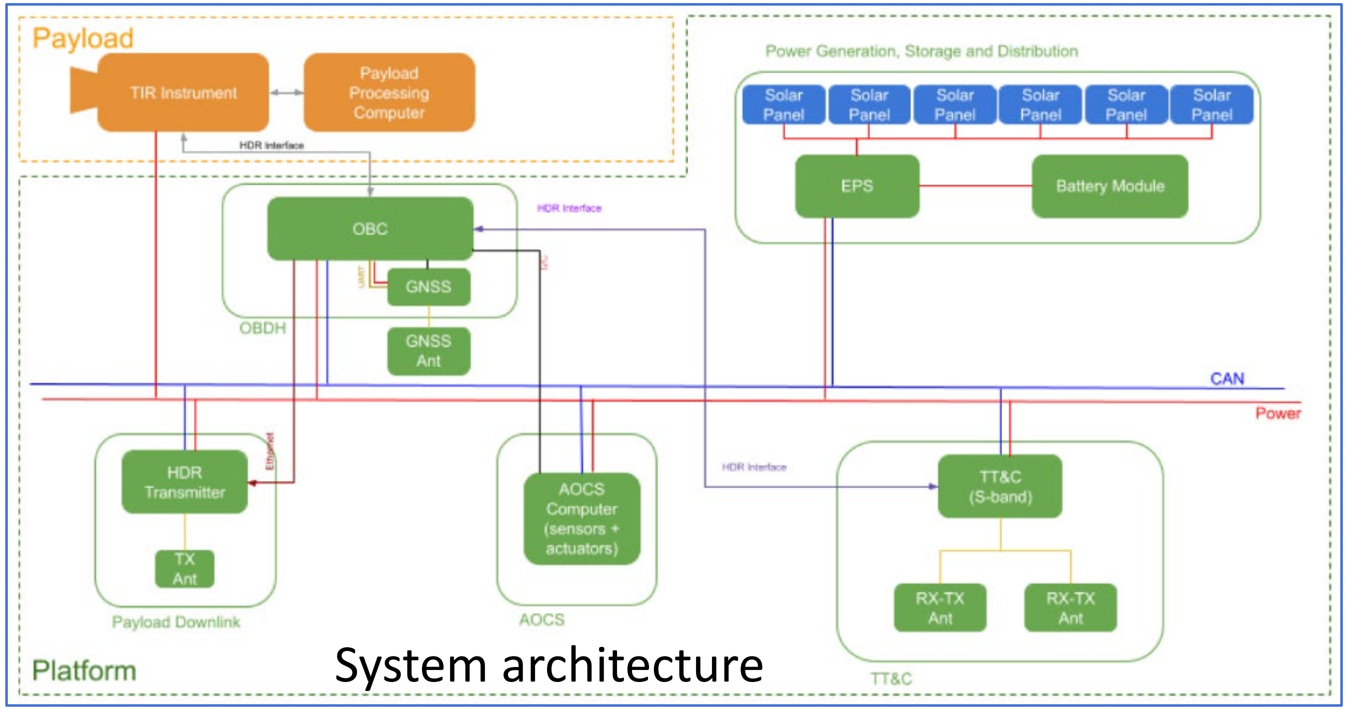

Comparison with live energy use data for 7 example buildings from the Cambridge University campus, to derive a relationship between observed thermal signature from TIR and live building energy use (Units: kWh).

# Climate change stakeholder engagement interviews for TIR space telescopes (Cambridge Zero)

- Uncovered **a range of potential uses** for TIR satellite data and improved our understanding in respective requirements and financial considerations.
- Key use cases identified include: a) investment **decision making**, initiating and identifying projects such as which buildings to target; b) **quality control**, tracking and verification; c) **advice and recommendations** on building energy performance and retrofit; d) **encouraging behavioural change** towards better practice.
- User requirements focused on revisit rate, data resolution and format. Most stakeholders preferred annual, **seasonal** or bi-annual frequency, with angled view to see **facades** and a resolution that can identify individual buildings, equating to a range of **3 – 6m GSD**, considering domestic properties being the smallest.
- Some stakeholders prefer visual data output, while others favour both **images and value derived products** such as U values that can be incorporated into their existing data analytics (i.e., modelling).
- Larger companies want a good return of investment **(ROI)** and **superiority** over other similar market products
- Smaller companies want **added value** and being within budget.
- Some **licensing models** may pose challenges for certain stakeholders who intend to share such data or derived data products with their clients or relevant third parties.

# Mission concept and satellite technical requirements (Open Cosmos)

- Perform the necessary calculations and studies associated to the mission definition
- Establish the mission requirements to ensure that the TIR telescope is correctly integrated
- Confirm the level of performance that can be theoretically achieved by the satellite mission.



System architecture

- The results of this activity included the system's budgets (mass, volume, power, link, pointing & data) as well as the development roadmap to describe the activities required to proceed with the mission development and to address the key factors contributing to uncertainty on the mission
- The mission orbit, lifetime and ground segment were also defined.
- The conclusion was that a 12U mission with the unfolding telescope payload is indeed feasible although the system budgets are tight and close to the margins.

## Summary: Project achievements (Nov 2020 – Mar 2021)

1. Built a prototype to demonstrate the **unfolding mechanical architecture** of a 63cm aperture telescope as a 12U CubeSat payload.
2. Built a separate working lab prototype to demonstrate **self-alignment** of a TIR telescope with a segmented primary mirror.
3. Realistic **emulation of TIR satellite images** using drone data.
4. Development of how TIR EO data can be used to **help tackle climate change** by looking at buildings with known energy use.
5. Engagement via stake holder interviews to **identify customer needs**.
6. Development of the fully-integrated **12U CubeSat** and the associated **mission**.

## Funding announced for next steps: (Oct 2021 – Mar 2022)

1. Combine what we learnt from the two earlier prototypes to build an unfolding, self-aligning TIR space telescope as a **12U payload** (UCAM/S4)
2. Include viewing angle and large area coverage to create highly realistic **emulated TIR space data** from drone data (UCAM/S4)
3. Continue our **stakeholder engagement** program (UCAM/S4)
4. Develop tools to **robustly evaluate the energy output** of any building on the planet (UCAM)
5. Prototype a system to enable **TIR strip-mapping** (S4)
6. Develop test modules on an existing data distribution platform allowing TIR infrared imagery to be **easily overlaid** with visible imagery (Open Cosmos Ltd)
7. Develop **diamond-turned free-form optics** specifically for the patented self-aligning telescope (Durham Precision Optics – new partner).

# The End