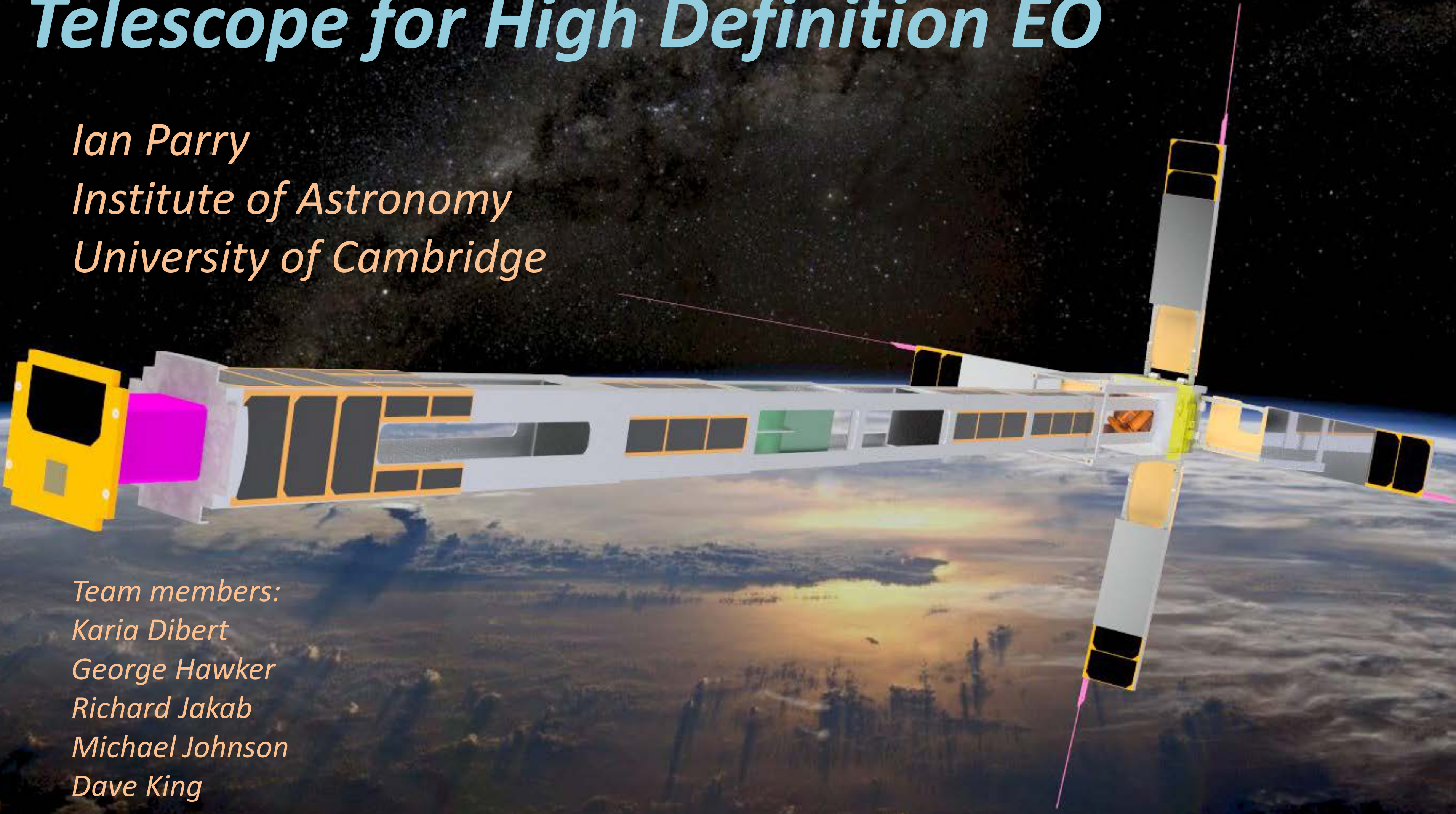
SUPER-SHARP - A Light Weight Unfolding Telescope for High Definition EO

Ian Parry
Institute of Astronomy
University of Cambridge



Team members:
Karia Dibert
George Hawker
Richard Jakab
Michael Johnson
Dave King

CEOI Abingdon May 2019

Image credit: Richard Jakab

Introduction

- Project started as an **astronomical** one: How to build a space telescope with an **optical aperture** that is **24m across** to look for evidence of life on planets in other solar systems.
- This is too big to fit inside even the biggest rocket fairings. This led to the consideration of **unfolding telescope designs**.
- This then led to the realisation that these are potentially very **useful for EO at all telescope size scales because smaller launch packages offer significant cost savings**.
- Once this works nobody will ever build a space telescope the old-fashioned way again!

General uses of SUPER-SHARP telescopes

- Size matters: The resolution of a telescope (i.e. the level of detail it can see) scales linearly with its diameter: **the bigger the telescope the sharper the images**.
- The SUPER-SHARP idea allows the **launch-size** of a telescope to be **about 7 times smaller than it would otherwise be**. ⇒ more than 7× cheaper.
- SUPER-SHARP is **scalable**. Works from 4.5m diameter large payloads (ARIANE-6 launch) down to CubeSat sizes.
- SUPER-SHARP is potentially a disruptive technology.
- Applications:
  1. Earth Observations (a ~US$3B per year market with rapid growth).
  2. 30cm GSD continuous viewing (via a constellation of nano-Sats).
  3. Higher definition at IR wavelengths.
  4. Surveillance from drones/HAPS/balloons.

Commercial

Scientific

  5. 1m to 30m aperture astronomical missions.
  6. Interplanetary probes within our solar-system.

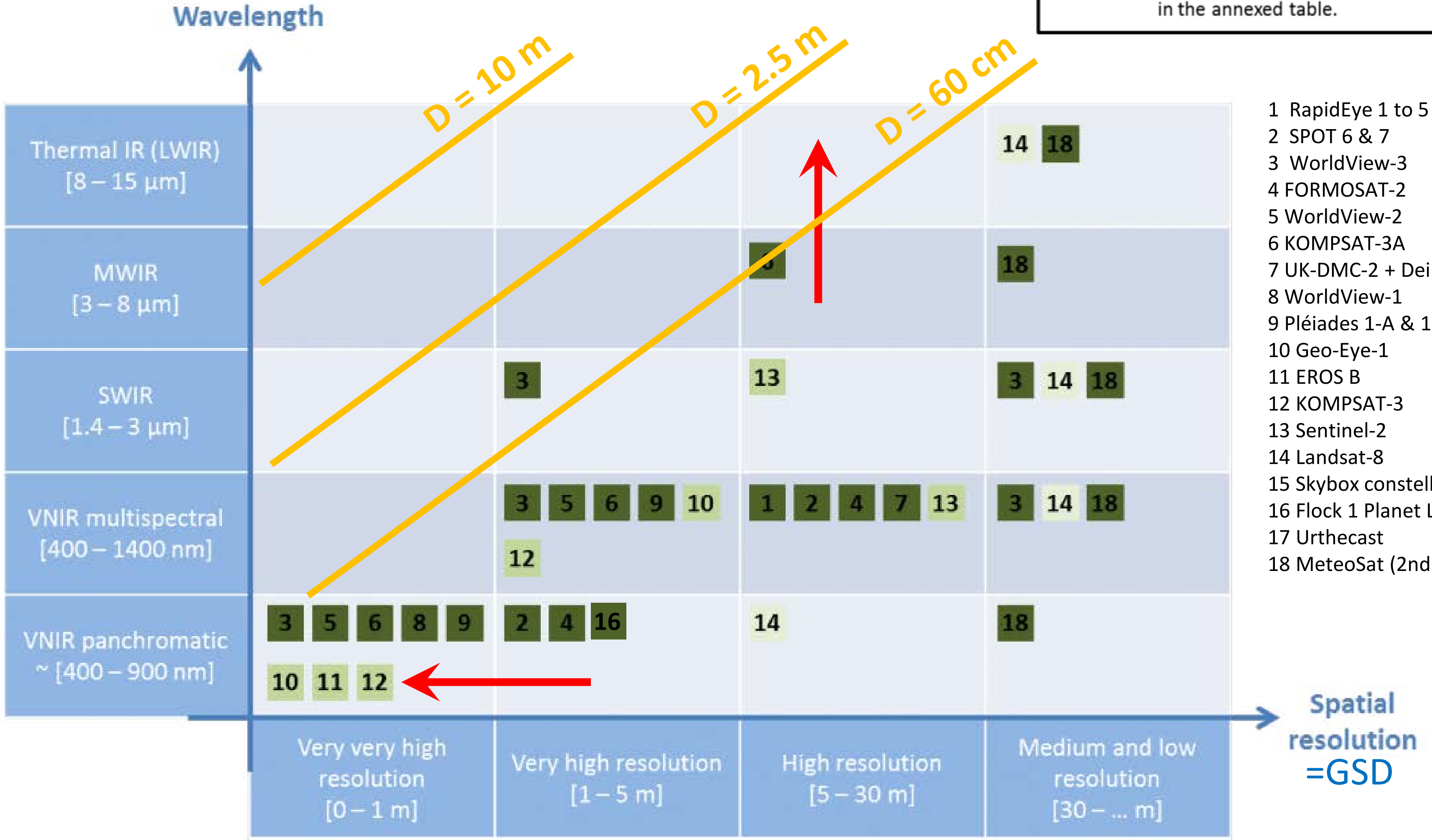
For the same cost SUPER-SHARP offers one of the following:

- Better (smaller) GSD at the same wavelength
- Longer operational wavelength at the same GSD
- Better revisit time (constellation) at the same GSD and wavelength

Legend

High revisit time (> 10 days)
Medium revisit time (2 – 10 days)
Low revisit time (< 2 days)

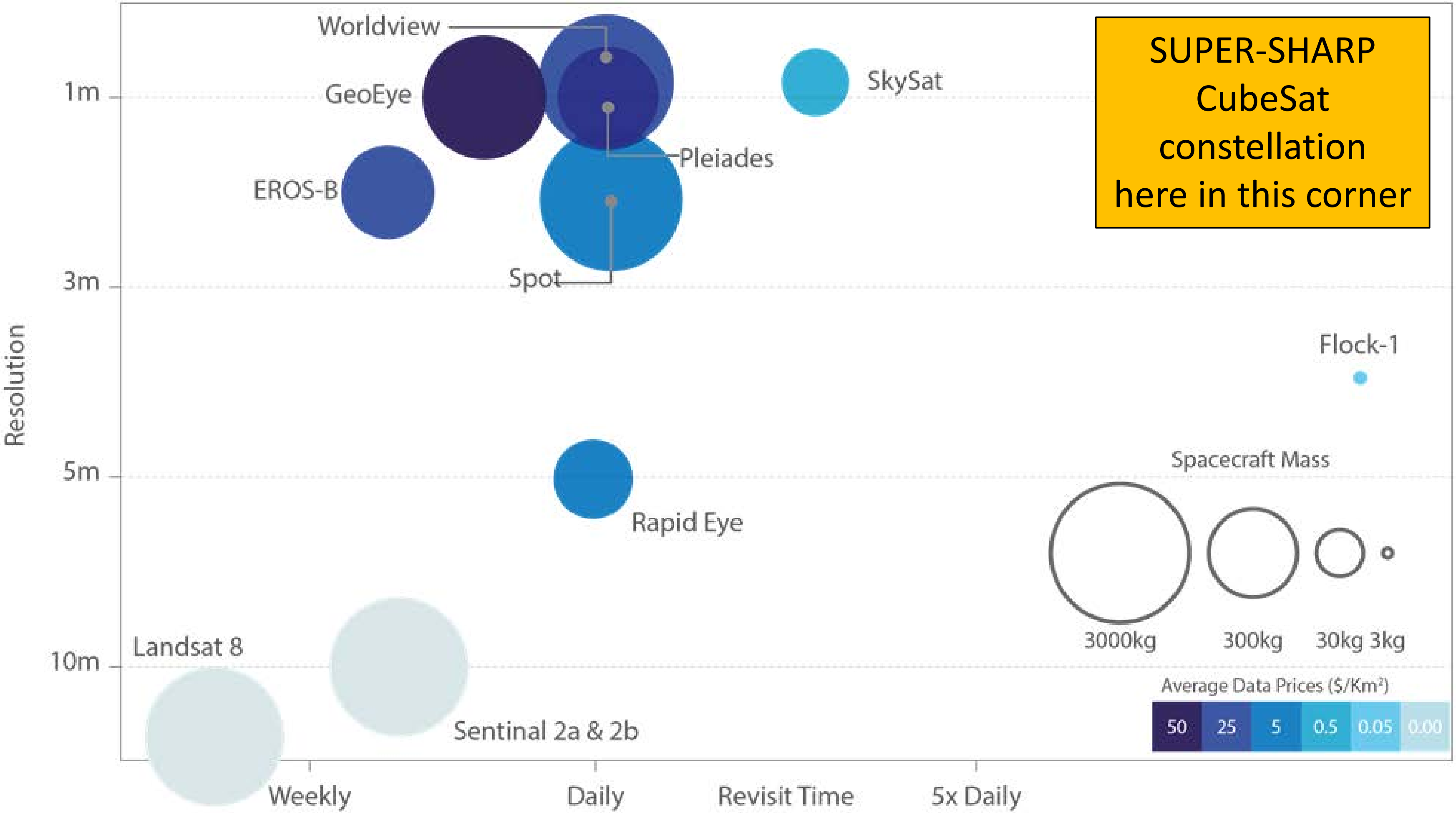
Numbers are referring to the satellites listed in the annexed table.



	Very very high resolution [0 – 1 m]	Very high resolution [1 – 5 m]	High resolution [5 – 30 m]	Medium and low resolution [30 – ... m]
Thermal IR (LWIR) [8 – 15 µm]				14 18
MWIR [3 – 8 µm]			6	18
SWIR [1.4 – 3 µm]		3	13	3 14 18
VNIR multispectral [400 – 1400 nm]		3 5 6 9 10 12	1 2 4 7 13	3 14 18
VNIR panchromatic ~ [400 – 900 nm]	3 5 6 8 9 10 11 12	2 4 16	14	18

1 RapidEye 1 to 5
2 SPOT 6 & 7
3 WorldView-3
4 FORMOSAT-2
5 WorldView-2
6 KOMPSAT-3A
7 UK-DMC-2 + Deimos-1
8 WorldView-1
9 Pléiades 1-A & 1-B
10 Geo-Eye-1
11 EROS B
12 KOMPSAT-3
13 Sentinel-2
14 Landsat-8
15 Skybox constellation
16 Flock 1 Planet Labs
17 Urthecast
18 MeteoSat (2nd Gen)

Credit: Figure adapted from https://business.esa.int/newcomers-earth-observation-guide



SUPER-SHARP CubeSat constellation here in this corner

Credit: Figure adapted from https://business.esa.int/newcomers-earth-observation-guide

Ground Sampling Distance, (i.e. resolution) with low-cost small-sats and nano-sats

$$\text{GSD (cm)} = \boxed{37}\left(\frac{H}{550km}\right)\left(\frac{\lambda}{400nm}\right)\left(\frac{60cm}{D}\right)$$

3U in LEO
Launch cost US$300k

$$= \boxed{22}\left(\frac{H}{550km}\right)\left(\frac{\lambda}{400nm}\right)\left(\frac{1.0m}{D}\right)$$

12U in LEO
Launch cost US$999k

$$= \boxed{9}\left(\frac{H}{550km}\right)\left(\frac{\lambda}{400nm}\right)\left(\frac{2.5m}{D}\right)$$

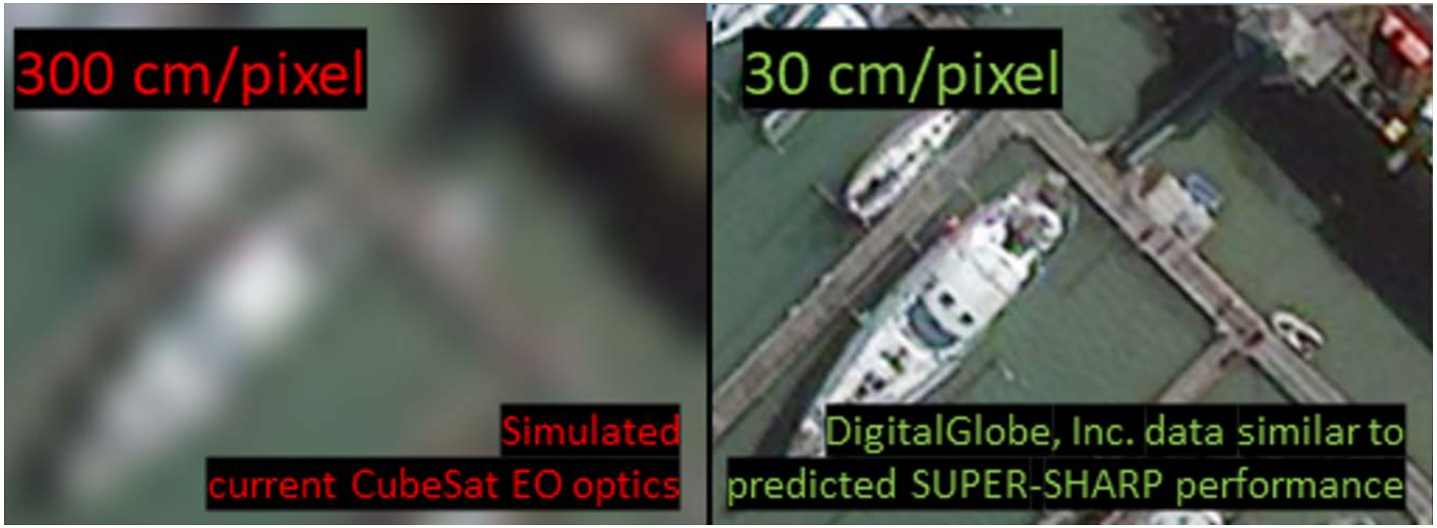
50kg satellite in LEO
Launch cost US$1.7M

H = orbital height

λ = wavelength

D = telescope aperture width

Credit: George Hawker and Michael Johnson



Development plan

- Milestone 1 is a **lab-based proof of concept demonstrator** for the unfolding and self-aligning technologies (in progress).
- Milestone 2 is a **TRL7 space-telescope subsystem.**
- Milestone 3 is a **cubesat in-orbit demonstrator.** This needs ~£1.5M for the 3U version or ~£2.5M for the 12U version.
- Milestone 4: Many commercial and scientific projects.

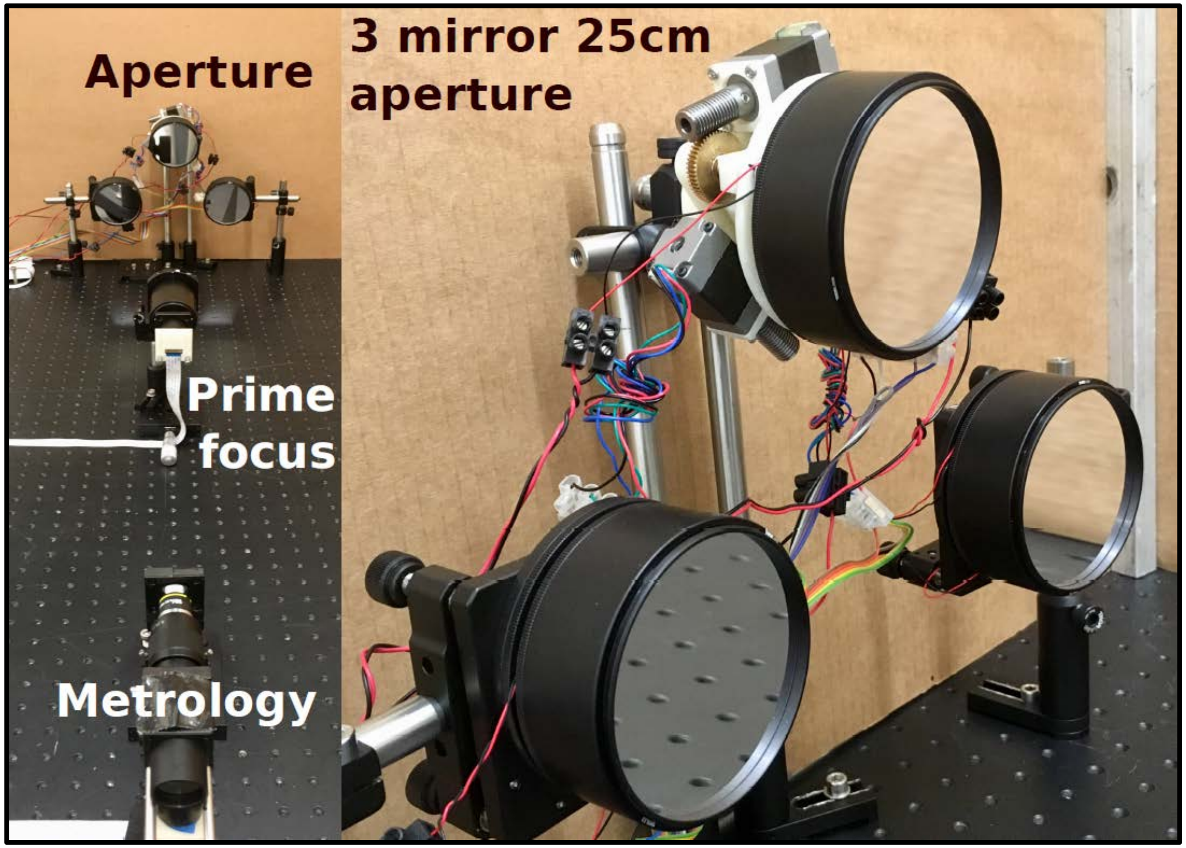
Technical Challenges

- Unfolding telescopes are actually an old idea – has not been done before because it is technically challenging.
- Need an innovative and reliable **unfolding scheme** which places the telescope's optical elements with an accuracy of about D/300.
- Need to put the deployed optics in to **precise alignment** (accuracy of a fraction of a λ for the primary mirror segments) and then continuously maintain that alignment.
- This also therefore requires:
    1. a very **precise metrology system** to measure where the optics are.
    2. a set of **high accuracy actuators** to move them to where they are supposed to be.
    3. a **sophisticated control system** to close the loop.
- It's this continuous self-alignment part that's the new idea.

Development work – current status

- Have built and operated a precise **metrology system.**
- Have built and operated precise **actuated mirror modules**.
- Currently developing the **software control system** to close the loop.
- Currently building an **unfolding scheme** CubeSat prototype which places the telescope's mirror segments with an accuracy of about 2-3mm.
- Building CubeSat compatible **primary mirror segments** complete with nano-positioning actuators.
- Have developed several **CubeSat** unfolding CAD **designs**.

Our three mirror lab prototype.

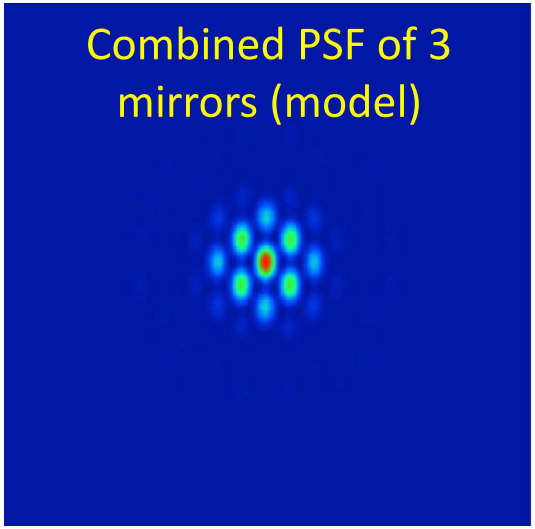


Current status

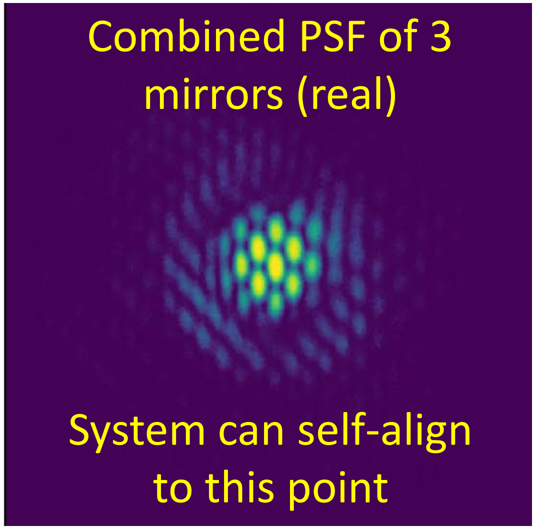
Tip/tilt accuracy is ~50nm

Piston accuracy is about ~5 microns.

Credit: Karia Dibert, George Hawker and Michael Johnson

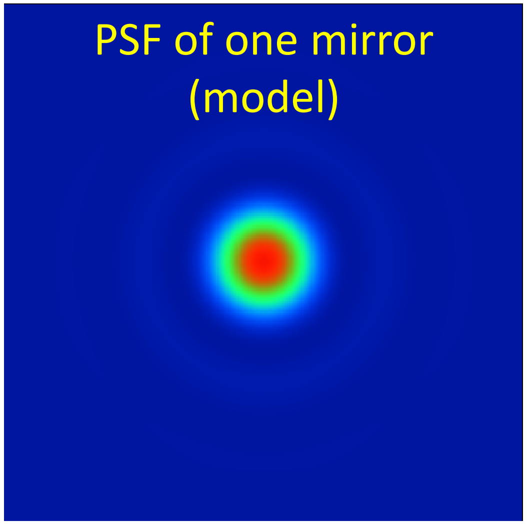


Combined PSF of 3 mirrors (model)

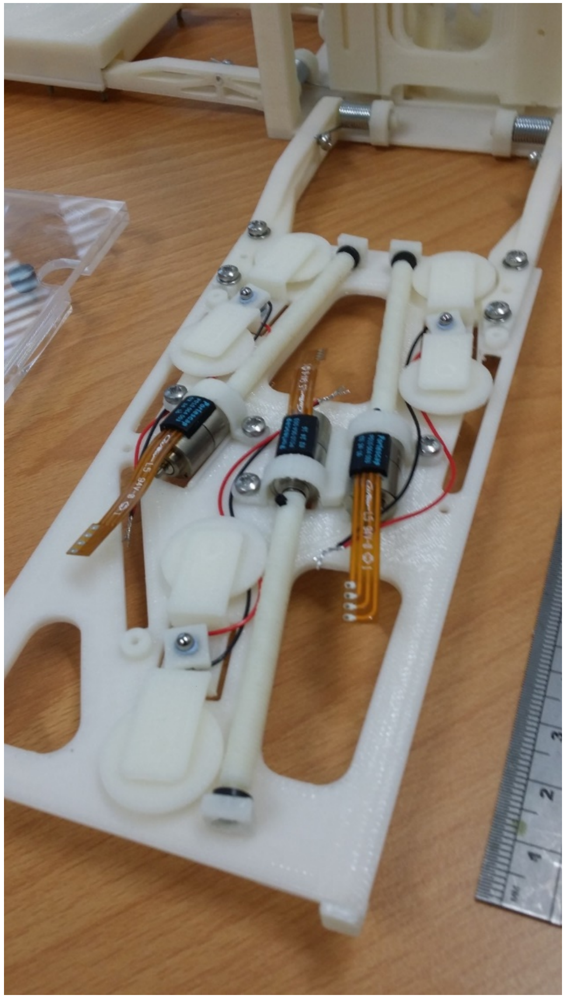


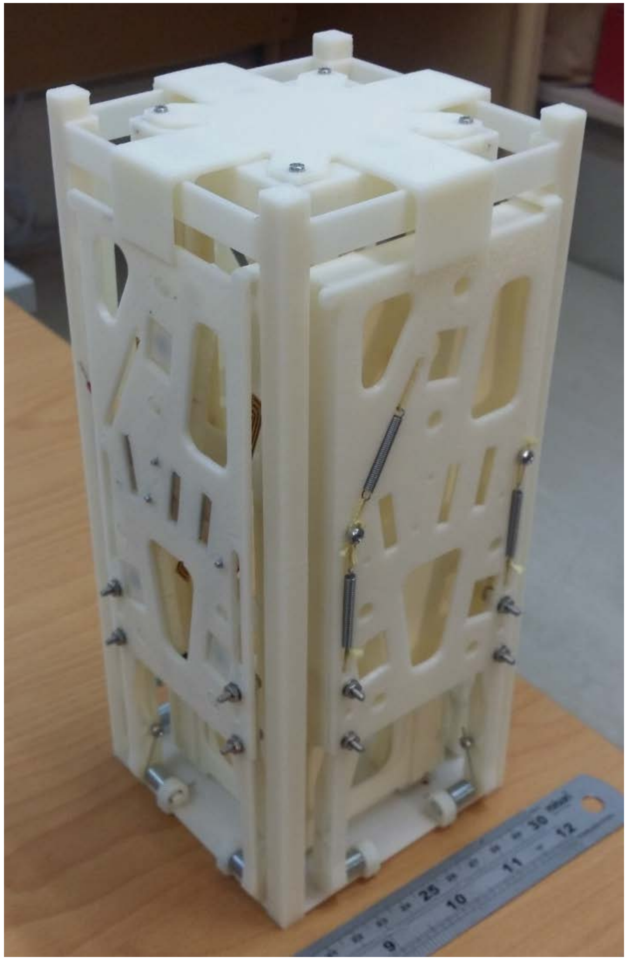
Combined PSF of 3 mirrors (real)

System can self-align to this point



PSF of one mirror (model)





Construction of a working unfolding CubeSat telescope subsystem and a CubeSat compatible mirror module.

A 3U SUPER-SHARP technology demonstrator

Folded

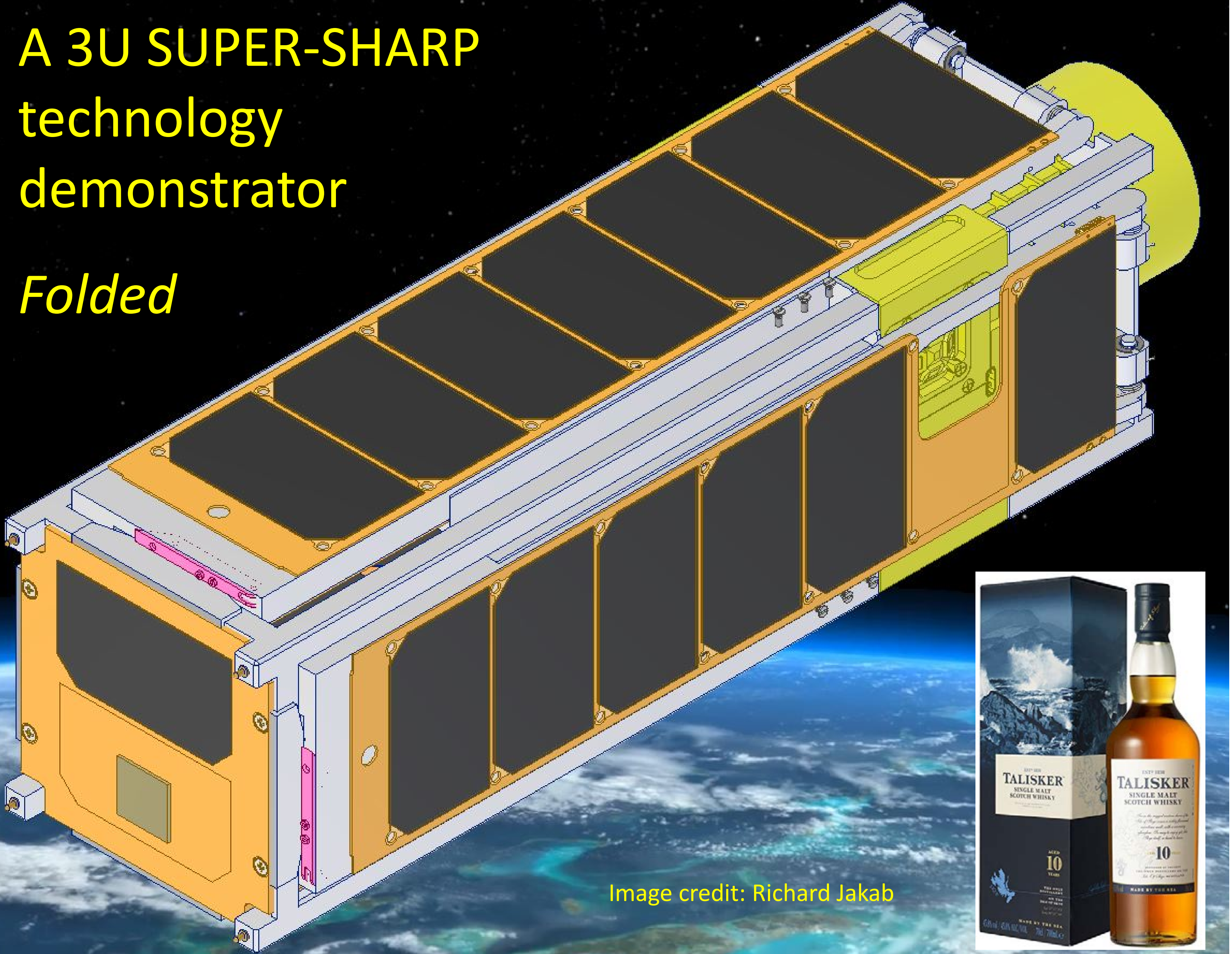


Image credit: Richard Jakab

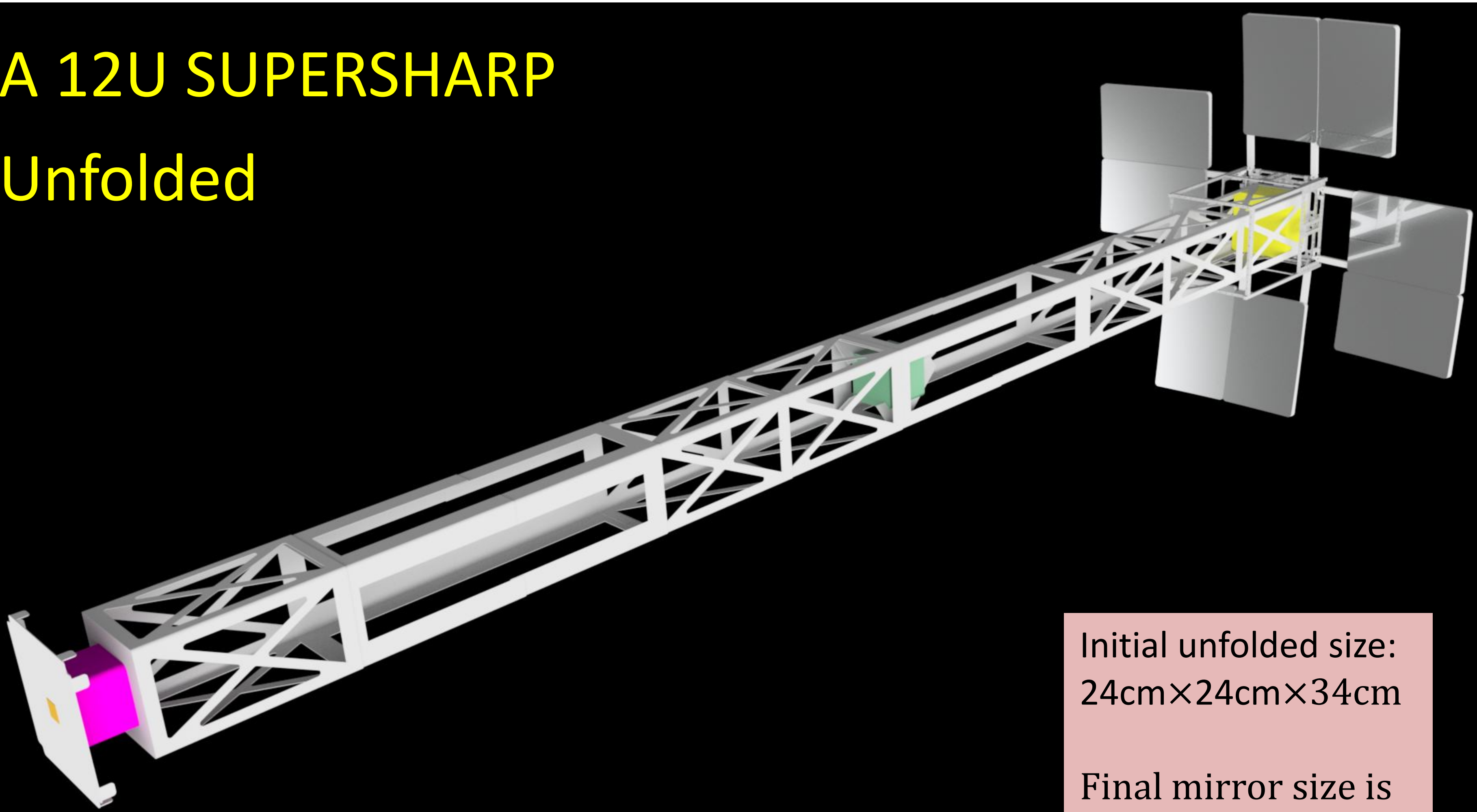
A 3U SUPERSHARP technology demonstrator

Unfolded

Includes all required sub-systems: coms, attitude control, power and computing.

Image credit: Richard Jakab

A 12U SUPERSHARP
Unfolded



Initial unfolded size:
24cm×24cm×34cm

Final mirror size is
~90cm AF

Image credit: Richard Jakab

Summary

- A problem in astronomy led to work on unfolding space telescopes.
- Fast and affordable unfolding space telescopes on all scales (CubeSats to the largest launchers) can potentially provide high resolution optical/IR imaging for EO.
- To move forward, this idea needs technology development (lab and CubeSat prototypes). This started in Cambridge about 18 months ago.
- Current lab performance is adequate for a LWIR version.
- We are confident that we can improve performance to MWIR then SWIR then optical wavelengths.
- Aiming to have a TRL7 version in 18-24 months.
- Aiming to have an in-orbit demonstration in 3 – 4 years.
- Aiming to have a profitable business in 5 years.

The End