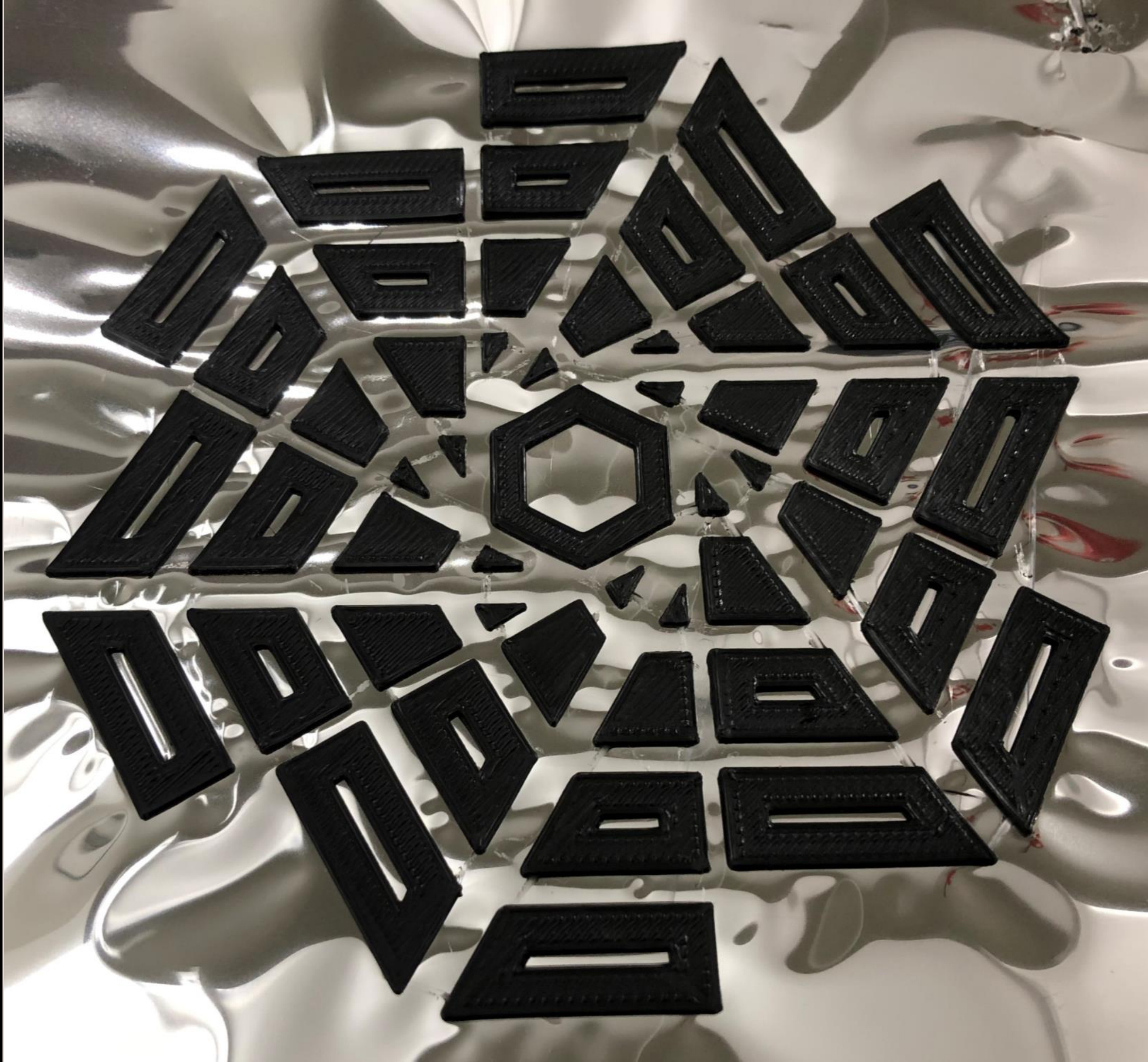
3D-PRINTED ORIGAMI SELF-FOLDING SOLAR SAIL

Space Power Workshop 2021

Stefania Soldini, University of Liverpool

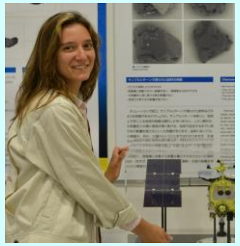
Aloisia Russo and Poalo Paoletti



OUR TEAM

Project Team:

University of Liverpool



Dr Stefania Soldini, PI
(Space Mission Analyst)

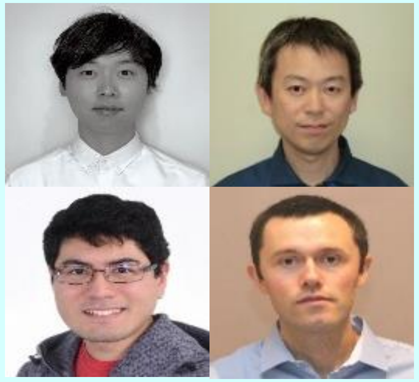
Dr Paolo Paoletti, Co-I
(Robotics & AM)

Ms Aloisia Russo, RA
(Leading Researcher AM)

Oxford Space Systems

Dr Juan Reveles
(Deployable Structures)

Japan Aerospace Exploration Agency



Dr Naoya Ozaki
(CubeSats)

Prof Osamu Mori
(Solar Sails)

Dr Ahmed Sugihara
(Solar Sails)

Dr Stephane Bonardi
(Robotics)

The University of Sheffield

Mentor:

Prof Iain Todd
(EPSRC Future Manufacturing)

SOLAR SAILS STATE OF THE ART

Type of solar sail deployment:

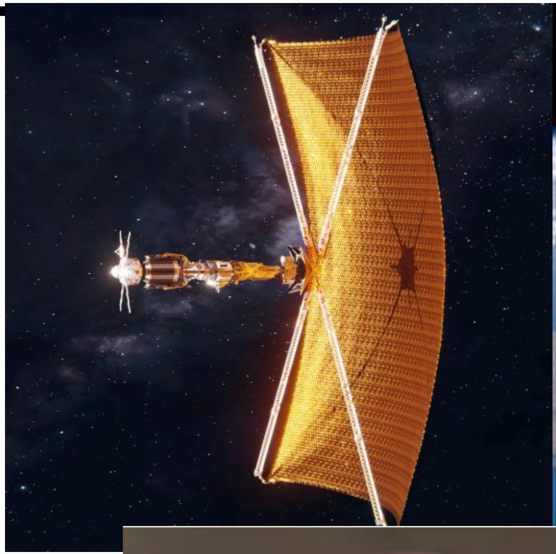
- **Mechanical:** through booms
- **Inflation:** L-Garde solar sail (video on the right)
- **Spinning:** IKAROS
- **Ours:** PDLC + mechanical/thermal/electro-magnetic

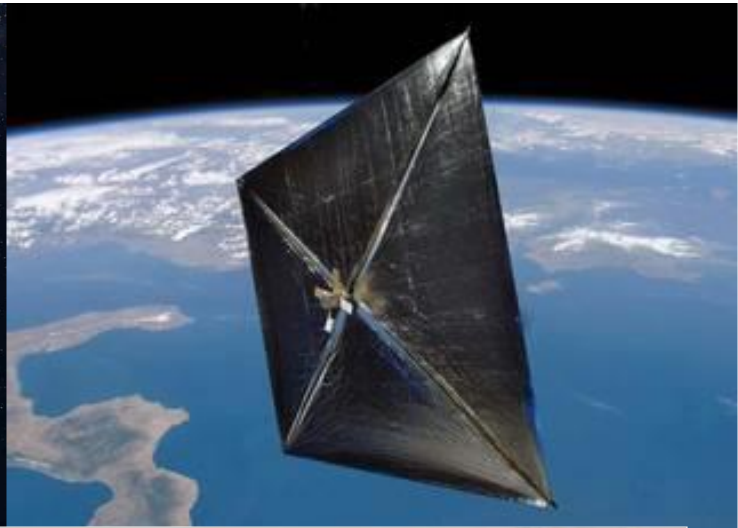
Materials:

- Aluminized membrane (high reflectivity)
- Reflective Control Devices for ACOM
- Flexible and thin solar cells

First Space Experiment:

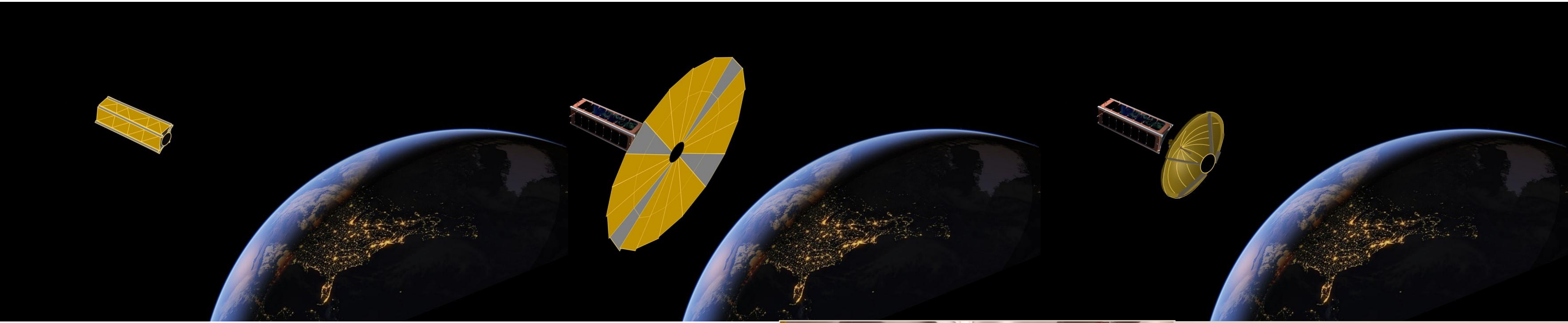
- JAXA's IKAROS Mission (2010)





UNIVERSITY OF LIVERPOOL

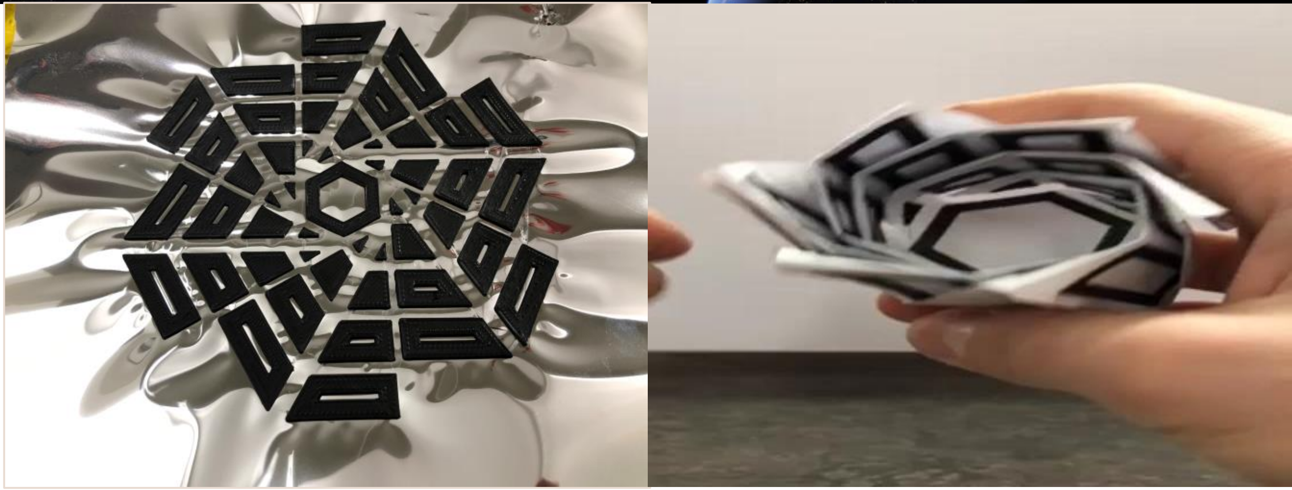
RESEARCH OBJECTIVES



- Explore next generation of solar sails and **AM techniques** for morphing CubeSats capabilities.

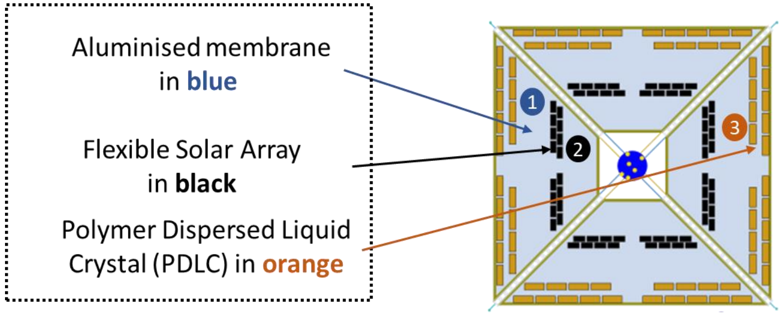
- To look at AM techniques for the design of **folding mechanism** applied to solar sail membranes

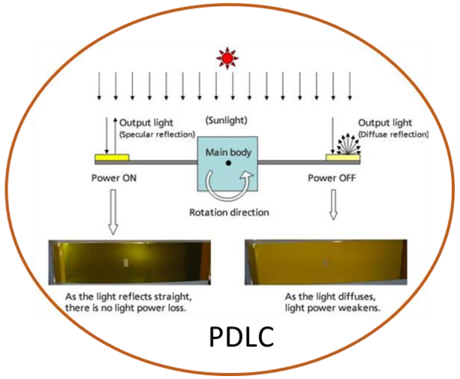
    - Can AM facilitate a cost-effective manufacturing of origami's crease patterns for self-foldable morphing solar sail membranes?
    - Which AM techniques and materials can enable the manufacturing of embedded devices for regulating the thermal-optical properties of the sail membrane?



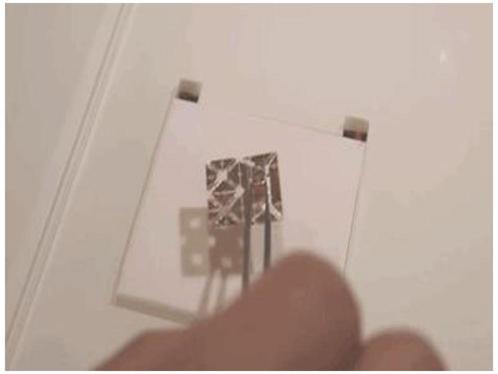
Proof of concept

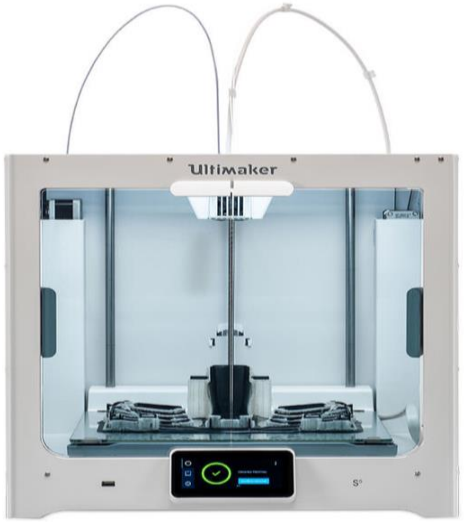
SYSTEM CONSTRAINTS





- Prototype dimensions
- Ultimaker materials compatibility: NO Peek
- Material suitable for space applications or with high TRL
- Triangle based pattern
- 1G tests
- Thermal constraints due to the space environment
- PDLC devices constraints



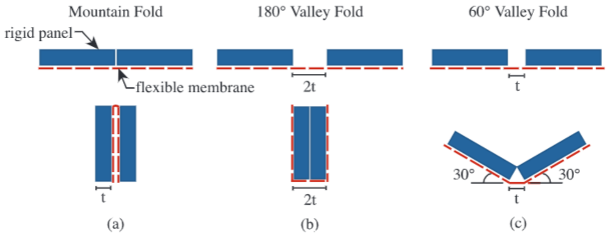


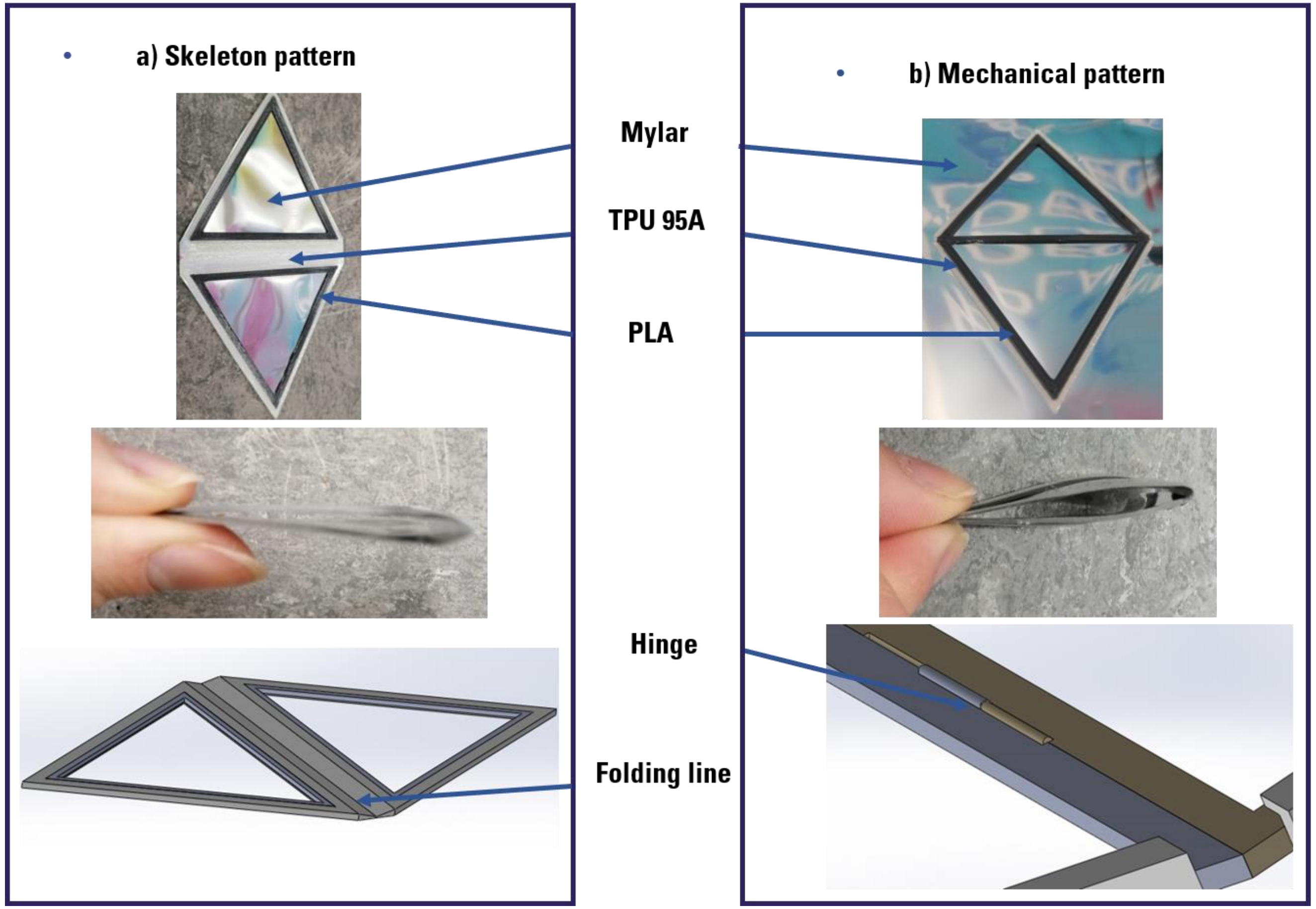
- 2015 IEEE International Conference on Robotics and Automation (ICRA) Washington State Convention Center Seattle, Washington, May 26-30, 2015

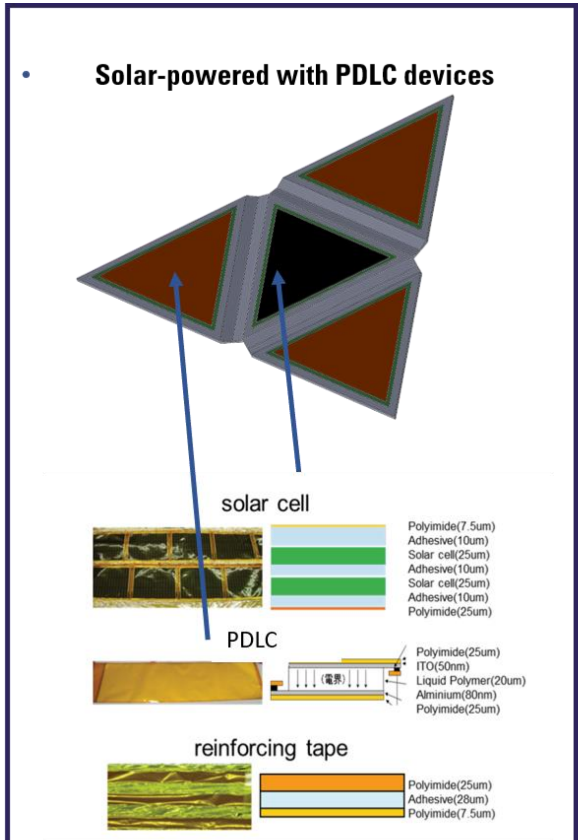
TRADE-OFF ANALYSIS

Three different origami patterns
- Mechanical
- Skeleton
- MIT robot origami

Suitable material to be printed direct on Mylar and Kapton
Suitable way to set the high reflective material on the printer plate







(Image Credit JAXA)

WEIGHT COMPARISON

- PLA,TPU and Mylar

- PLA,TPU and Kapton

- ABS/CC,TPU and Kapton

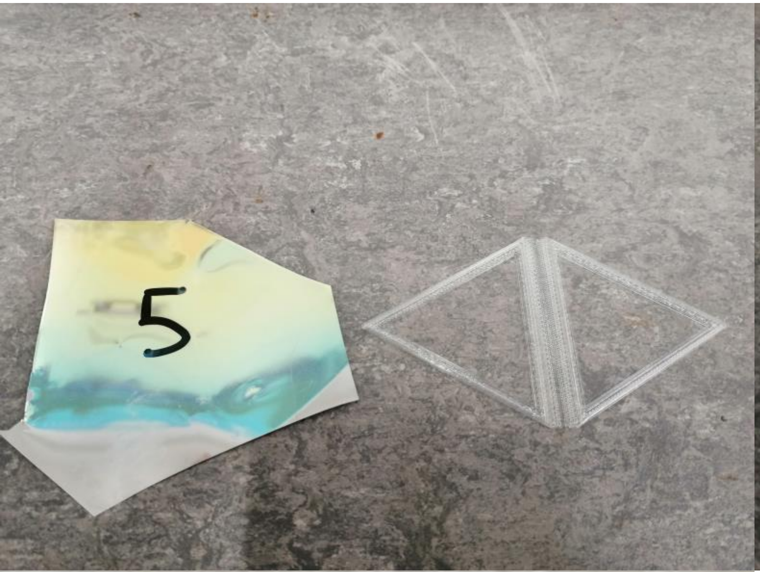
- ABS/CC,TPU and Mylar

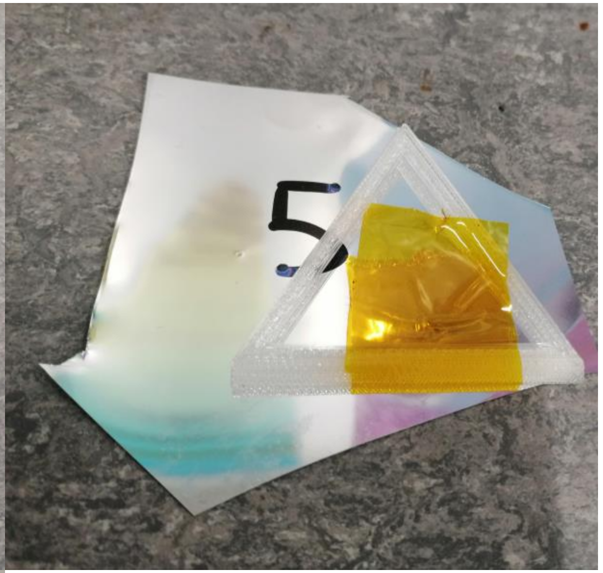
- Nylon/CC, TPU and Mylar

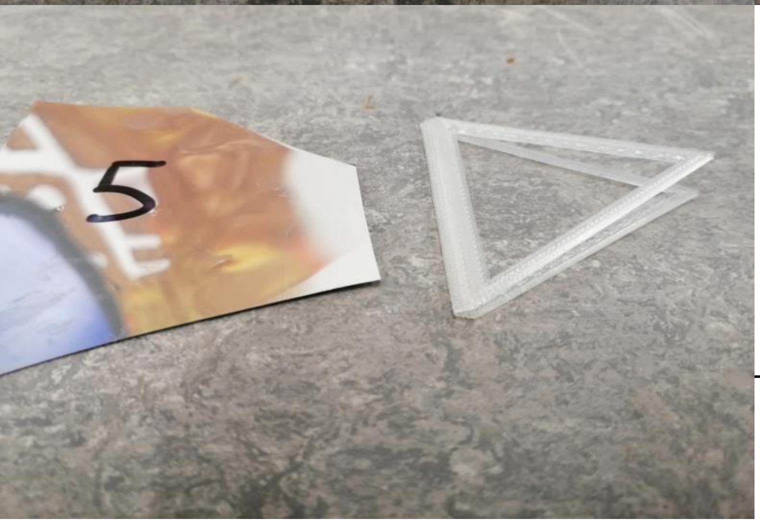
- Nylon/CC, TPU and Kapton

THE POWER OF THE 4D-PRINTING

- Test 5: new 4D filament used
- In the oven for 3 minutes at 75°C
- Deformed with 7° of inclination







- Test 5: water at 60°C

CAD DESIGN OF THE FINAL SHAPE

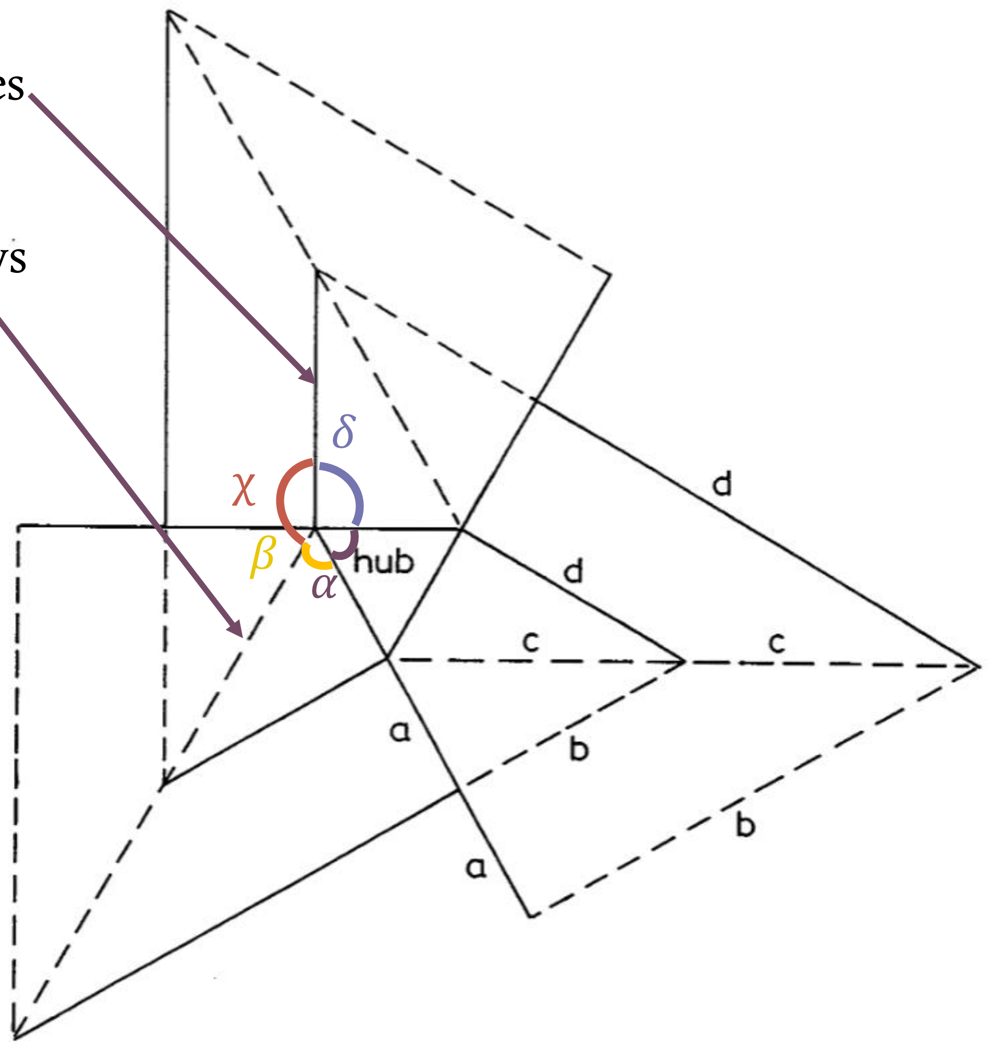
- *Major folds* n=3
  folding lines from central figure edges
  They are mounts
- *Intermediate folds*
  dashed folding lines which are valleys
- *Hub angle* $\alpha = (1 - \frac{2}{n})\pi$

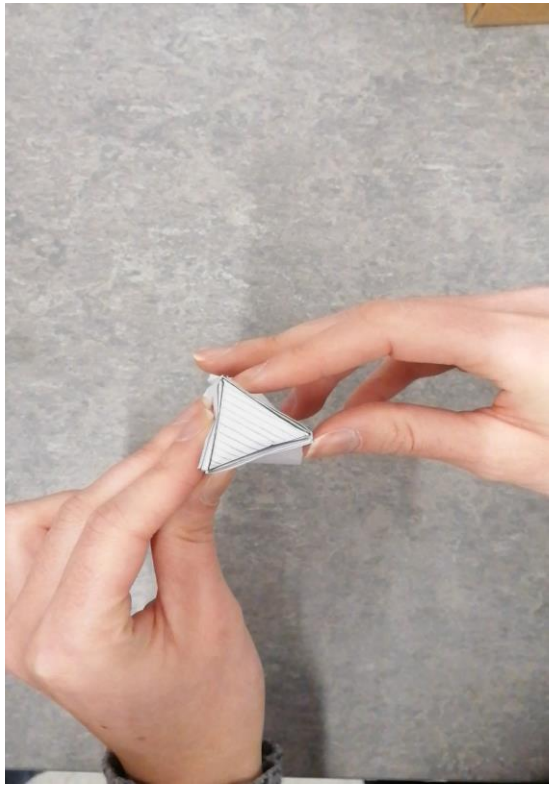
$$\alpha + \beta + \delta + \chi = 2\pi$$

$$\beta = \frac{\pi}{n}, \chi = \left(\frac{1}{2} + \frac{1}{n}\right)\pi$$

$$\alpha = \frac{\pi}{3}, \beta = \frac{\pi}{3}, \delta = \frac{\pi}{2}, \chi = \frac{5}{6}\pi$$

$a = 3$ cm, b =5.2 cm, c = 6 cm





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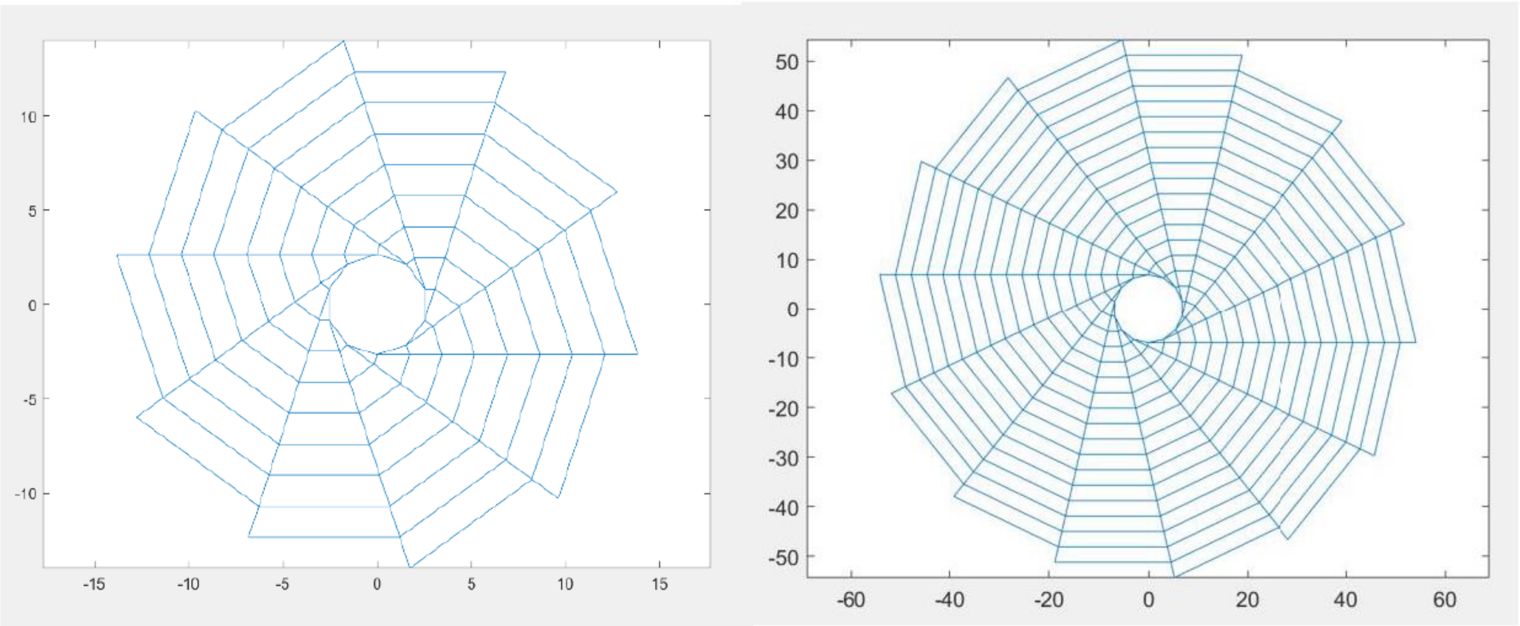
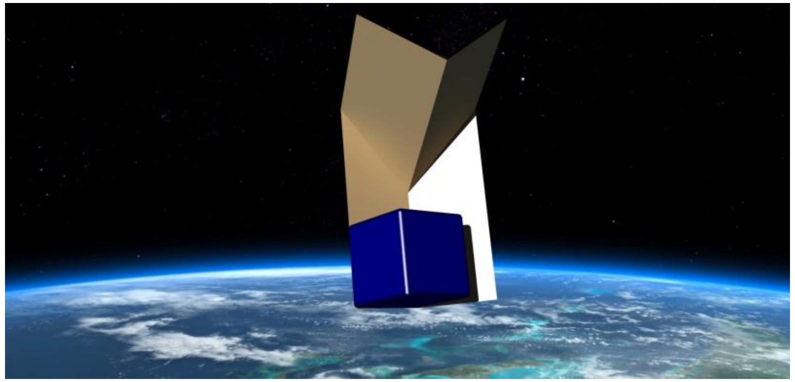
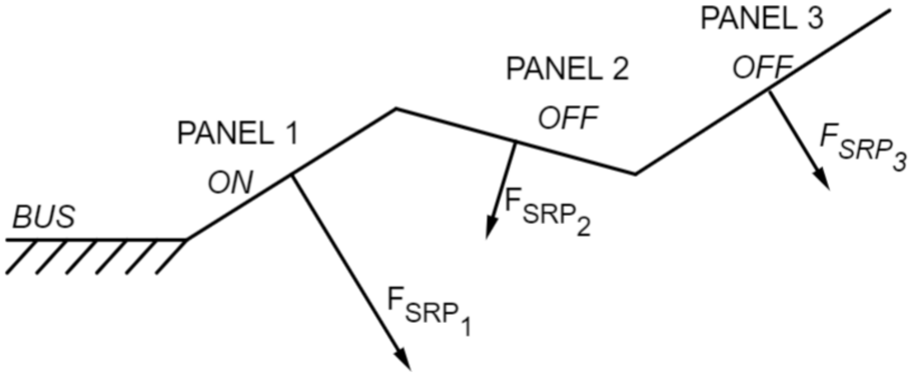
Algorithm based from Guest & Pellegrino, 1992



Mr Robert Ariss, BEng Student, Liverpool

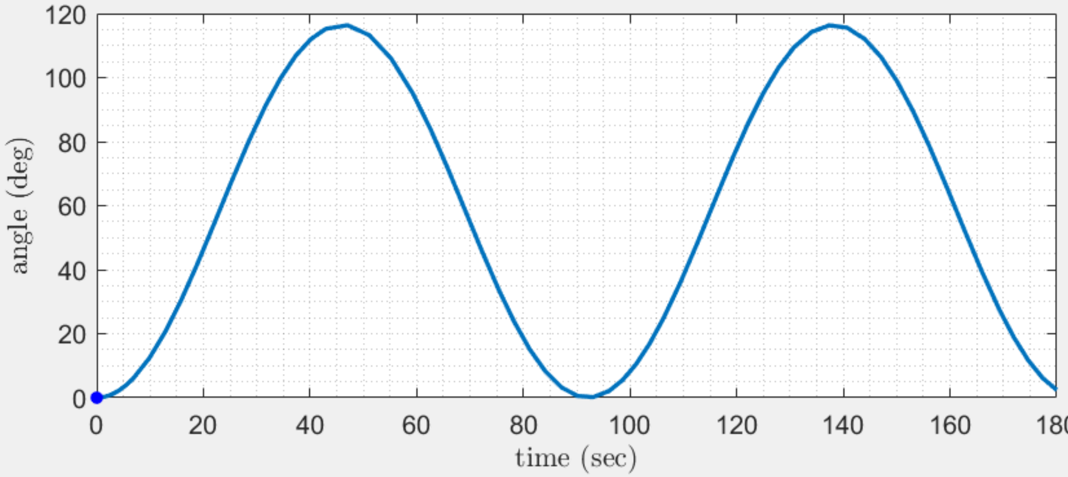
ONE LINK SIMULATION RESULTS

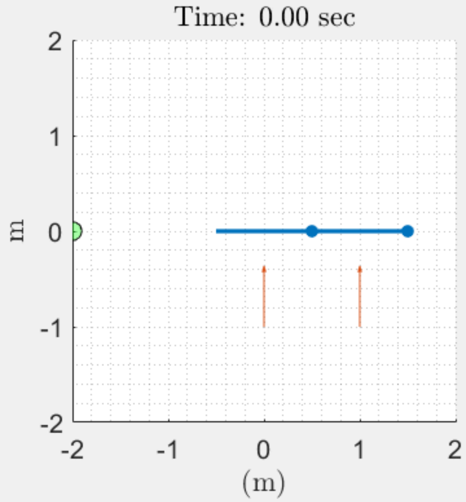




Mr Aleksander Fiuk, MEng TU Delft

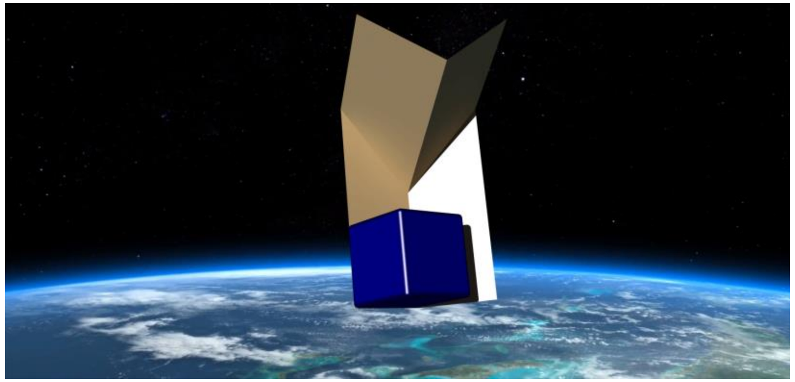
Multi-body origami simulation in collaboration with Prof. Colin McInnes

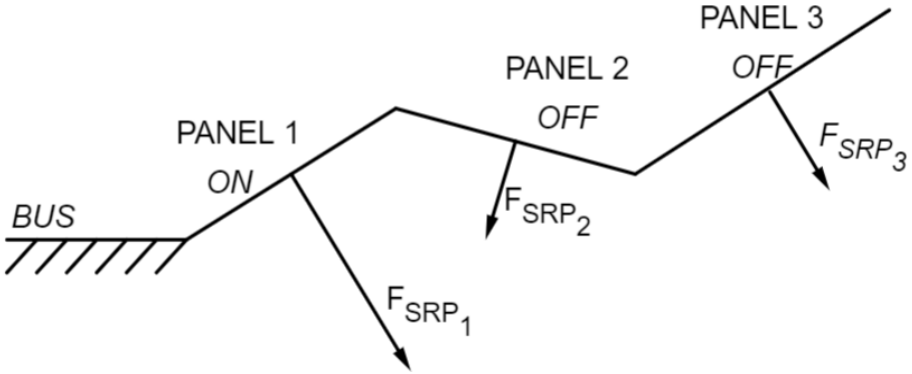




Ms Aloisia Russo, Research Assistant, Liverpool

TWO LINK AND BUS





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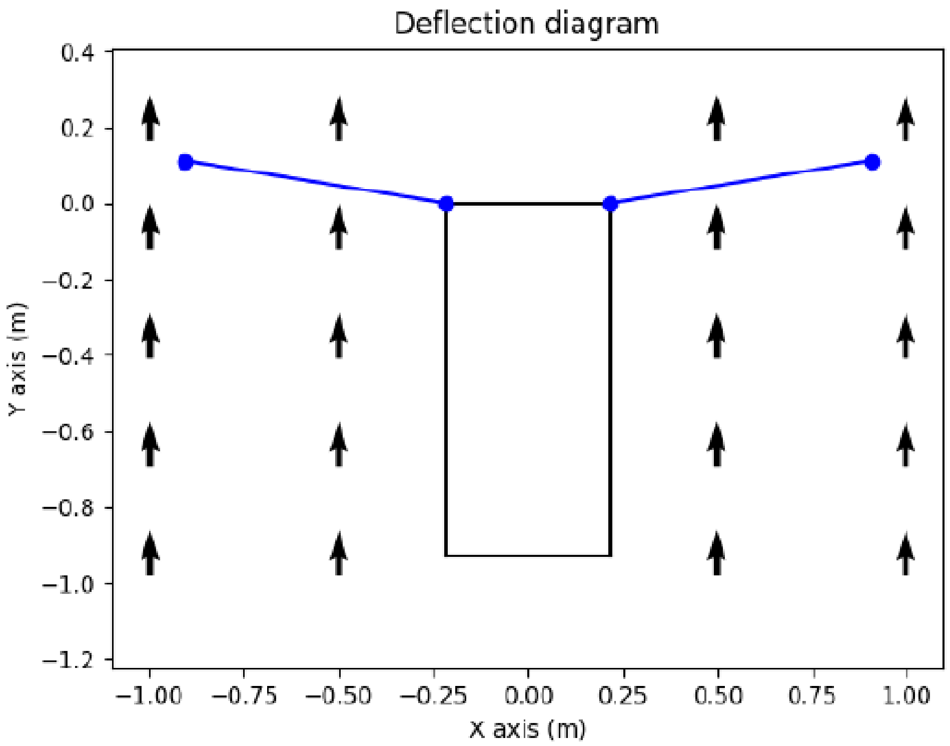


Mr Raymond Minarro, BEng Student, Liverpool

CEII/NETWORK+ EPSRC GRANT

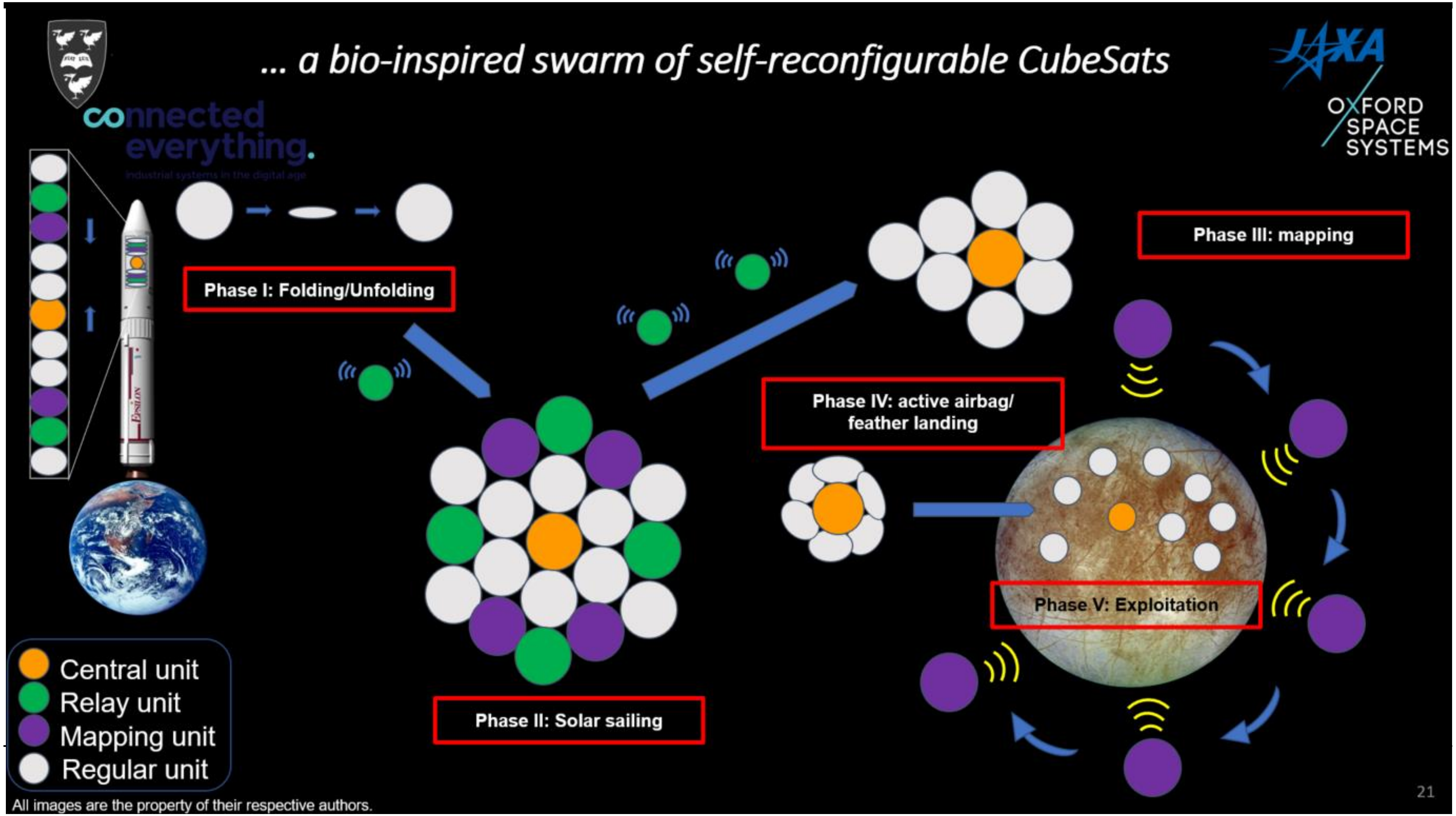
Imagine a bio-inspired approach towards space exploration…

Exploration

Coordination

Reconfiguration

OUR VISION



... a bio-inspired swarm of self-reconfigurable CubeSats
connected everything.
JAXA
OXFORD SPACE SYSTEMS
Phase I: Folding/Unfolding
Phase II: Solar sailing
Phase III: mapping
Phase IV: active airbag/ feather landing
Phase V: Exploitation
Central unit
Relay unit
Mapping unit
Regular unit
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connected everything.

Connected Everything: Accelerating Digital Manufacturing Research Collaboration and Innovation

Feasibility studies	• Funding novel ideas including exploratory interdisciplinary projects • connectedeverything.ac.uk/feasibility-studies/ • Next call in Autumn 2020
Thematic areas	• Our 9 themes cut across all our activities. New themes are Regulation, Socio-technical data rich systems, Creativity & Design • connectedeverything.ac.uk/activities/thematic-areas/
Strategic agenda setting	• We work with industry to identify partners for future research and opportunities for investment in new technologies • Digital World 2050 report will be written in year 3 (2021/22)
People movement and skills	• We offer ECR placements to go into industry and workshops to increase industry engagement • We will support summer schools and workshops
Conferences and networking	• Supporting leadership development and access to the best ideas within digital manufacturing • We deliver an annual conference, offer networking opportunities within and across other related networks
Dissemination and impact	• We share everything we do connectedeverything.ac.uk

UKRI Engineering and Physical Sciences Research Council

THANKS FOR THE ATTENTION

Questions?