[dstl] The Science Inside

PHANTOM ECHOES 2:

A Five-Eyes SDA Experiment on GEO Proximity Operations

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Ministry of Defence

Future SDA Challenges

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Novel and Challenging Spacecraft Dynamics

- Novel spacecraft and challenging dynamics (EP, RPO) which traditional models are not well-optimised
- Custody maintenance during frequent manoeuvre and constant-thrust dynamics
- Novel / non-traditional sensors, enhanced software capabilities and federated solutions
- Gaps in (geographical/phenomenological) sensor coverage, target custody challenges
- Manoeuvre detection and processing

Flight Safety of GEO Spacecraft

- Improved tools for custody, threat warning and change detection around HVAs
- GEO slot clearing and "neighbourhood watch" activities
- Behaviour analysis and situation assessment; generation of I&Ws to operators
- Tracking and characterisation of unknown objects
- Pre- / post-event assessment; attribution
- Discrimination ("Combat ID"), tagging and track association

Effective SDA Collaboration & Data-Sharing

- Ability to share data & tools across a coalition
- Need for timely (and reliable) decision-making
- Resource constraints (personnel, architecture) for SSA processing, analysis and execution
- Network architectures, role of automation/AI
- Federated processing & analysis options

Images: *NASA Dawn © NASA/JPL-CalTech; MEV-1 © Northrop Grumman / Space Logistics; GLOBAL SENTINEL 2016 © MOD Crown Copyright*

Future SDA Challenges

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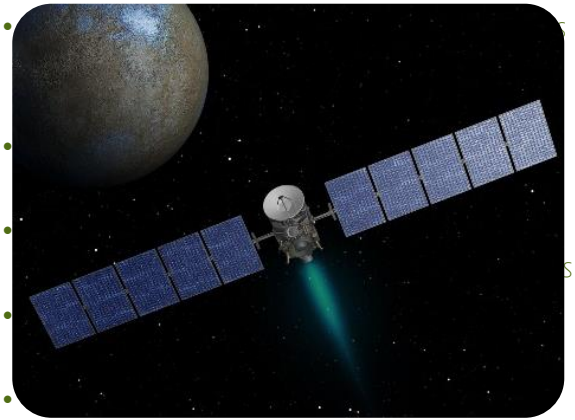
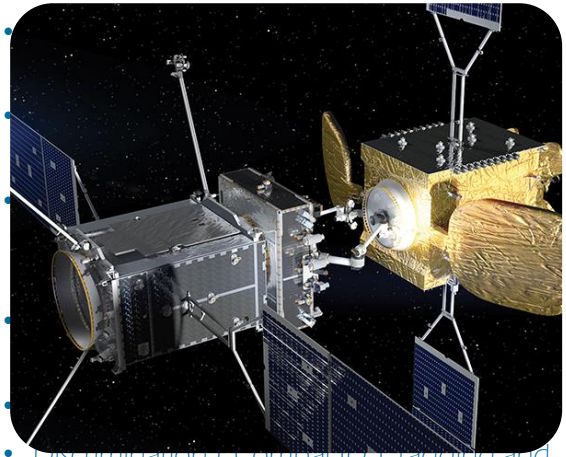
Novel and Challenging Spacecraft Dynamics





- Discrimination (Combat ID), tagging and track association

Flight Safety of GEO Spacecraft

Effective SDA Collaboration & Data-Sharing

PHANTOM ECHOES: **Overview**

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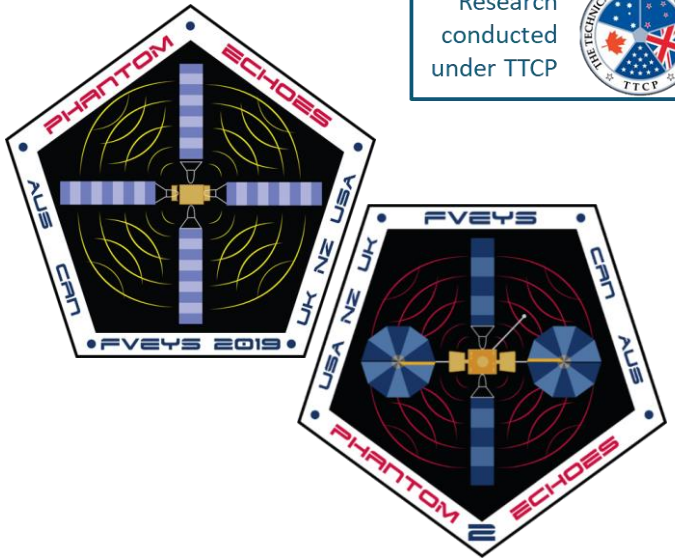
Series of collaborative SSA experiments to understand manoeuvring satellites in proximity in GEO (Geostationary Earth Orbit)

Research conducted under TTCP



- **Aims:**
  - **Collect data** on real-world satellite docking events
  - Explore use of **"non-traditional" sensors** for GEO RPO monitoring
  - Prototype methods to enhance ability to **resolve & characterise** closely-spaced objects in GEO
  - **Understand behaviour** of these types of satellites in order to recognise similar behaviour in future

[dstl] dia DRDC RDDC Australian Government Department of Defence Defence Science and Technology Group AFRL THE AIR FORCE RESEARCH LABORATORY

Experiment Lead: **UK** (Dstl)

Images: *Logos courtesy of their respective owners; flag images from Flagipedia.NET*

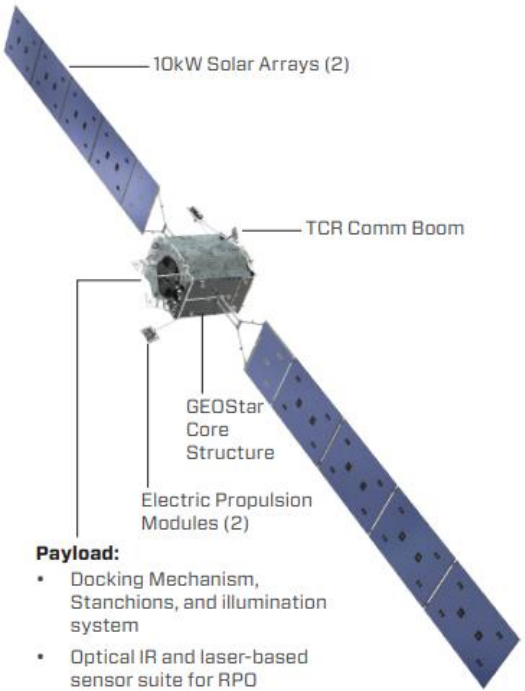
Mission Extension Vehicle-1 and -2:

Commercial on-orbit servicing vehicle for life extension of GEO comms satellite(s):

- Provision of propulsion capability on behalf of client satellite
- Capability to dock to client without pre-designed interface
- Docking undertaken without interruption to client service

Mission features of interest:

- EP orbit-raising (GTO → GEO), frequent manoeuvring
- Rendezvous & Proximity Operations



- Spacecraft manufactured and operated by Northrop Grumman / Space Logistics LLC

Image: *Mission Extension Vehicle © Northrop-Grumman*

PHANTOM ECHOES: **Timeline**

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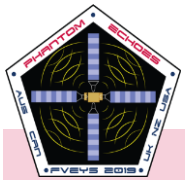
***KEY**: Real-World Data Collection Campaign:*

- Initial experiment to gather preliminary data and understand problem
- Development of processing architecture and data-sharing methodology (VerSSA)
- Ad-hoc tracking and observation of MEV-1/Intelsat-901



PHASE I

09 Oct 2019
Launch

MEV-1 / Intelsat-901

25 Feb 2020
Docking

Launch
15 Aug 2020

MEV-2 / Intelsat 10-02

Docking
12 Apr 2021

ANALYSIS

PHASE II

Undertaken:

- Tracking & OD custody campaign
- RPO campaign

MEV Mission Segment:

- Launch / LEOP
- EP Orbit-Raising
- Approach
- Docking / RPO
- Resumption of Service

PHANTOM ECHOES: **Timeline**

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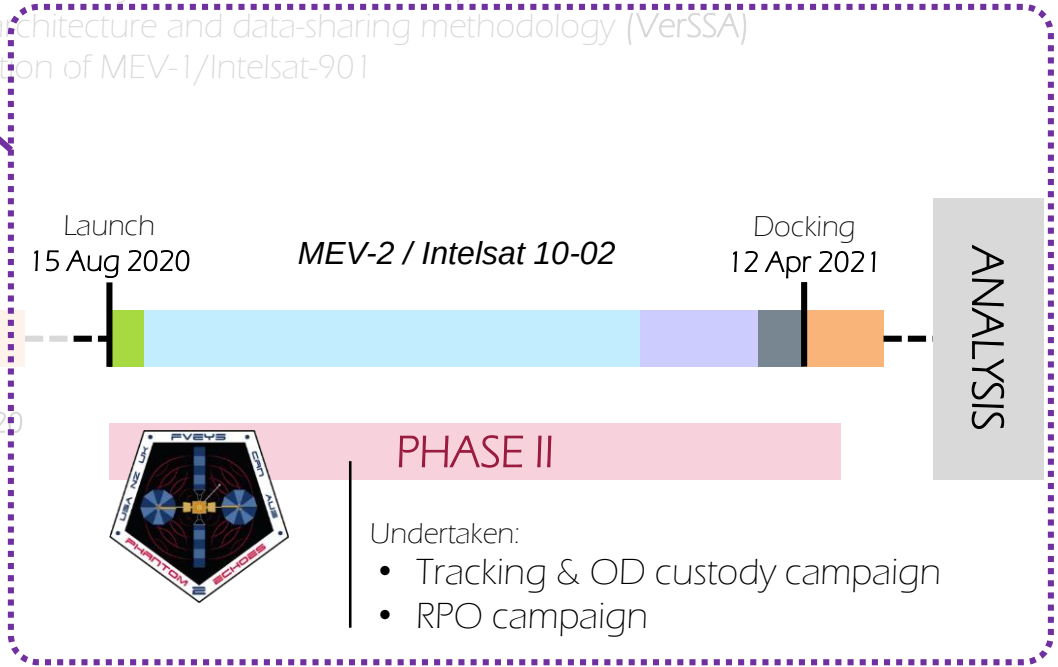
***KEY**: Real-World Data Collection Campaign:*

The "PHANTOM ECHOES 2" Experiment



MEV Mission Segment:

- Launch / LEOP
- EP Orbit-Raising
- Approach
- Docking / RPO
- Resumption of Service

- **Real-world data-collection campaign on MEV-2 / IS10-02:**
  - **Custody & OD during MEV-2 orbit raising:**
    - Sensor cueing & handover principles across FVEYs network
    - Custody maintenance, manoeuvre estimation and orbit determination

Electric Propulsion Orbit-Raising (*EPOR*) tracking campaign:
→ *October 2020* and *November 2020*

  - **Observation during MEV-2 rendezvous activities:**
    - Photometric & spectral analysis of client/servicer signatures
    - Discrimination and custody of servicer during GEO approach
    - Use of novel / academic sensors for proximity sensing and warning

Rendezvous & Proximity Operations (*RPO*) campaign:
→ *January 2021* to *April 2021*

Slide Bookmarks:

EPOR

RPO

PHANTOM ECHOES 2: **Participants**

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DRDC
RDDC

AFRL
THE AIR FORCE RESEARCH LABORATORY
LEAD | DISCOVER | DEVELOP | DELIVER

[dstl]

Australian Government
Department of Defence
Defence Science and Technology Group

dta
Defence Technology Agency

NORTHROP GRUMMAN

iTelescope

GOONHILLY

BAS
Basingstoke Astronomical Society

THE UNIVERSITY OF ARIZONA

SAFRAN

WARWICK
THE UNIVERSITY OF WARWICK

TEXAS
The University of Texas at Austin
+ ISON

TAMWORTH REGIONAL ASTRONOMY CLUB INC

numerica

NERC
SCIENCE OF THE ENVIRONMENT

deimos
elecnor group

UNIVERSITY OF LIVERPOOL
+ CUBICA

University of Kent

SPACE OPERATIONS CENTRE
UNITED KINGDOM

UK OFFICIAL

Images: *Logos courtesy of their respective owners; flag images from Flagipedia.NET*

PE2 EPOR Campaign: Overview

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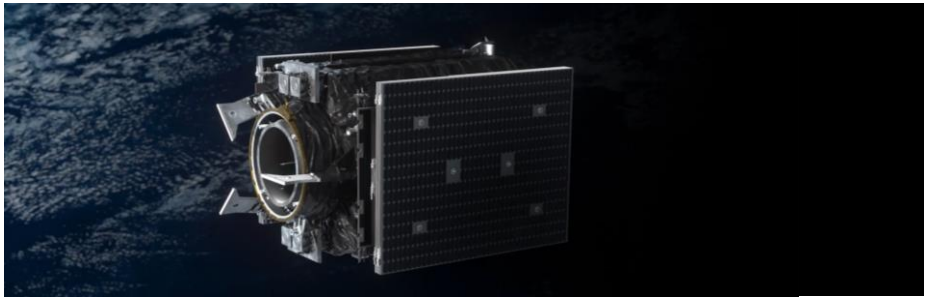
EPOR



- **28th September** to **11th October 2020**
  - Two-week “mini-experiment”: tracking & custody
- **5th November** to **11th November 2020**
  - Repeat of MEV-2 custody “mini-experiment”
  - Sequenced alongside SACT 20-3 exercise

Objectives:

- Trial MEV-2 custody processes using VerSSA + FVEY optical network:
  - Observe, process data and form orbit cues to allow re-acquisition of target by next observatory
  - Augment with commercial SDA data (Numerica and UDL)
- Examine novel / other methods of orbit estimation and “forecasting”
- Assess utility of “non-traditional” sensors and other capabilities for GTO tracking

* Electric Propulsion Orbit-Raising mission segment

Image: *MEV-2 mission © Northrop Grumman*

PHANTOM ECHOES 2: **Sensors**

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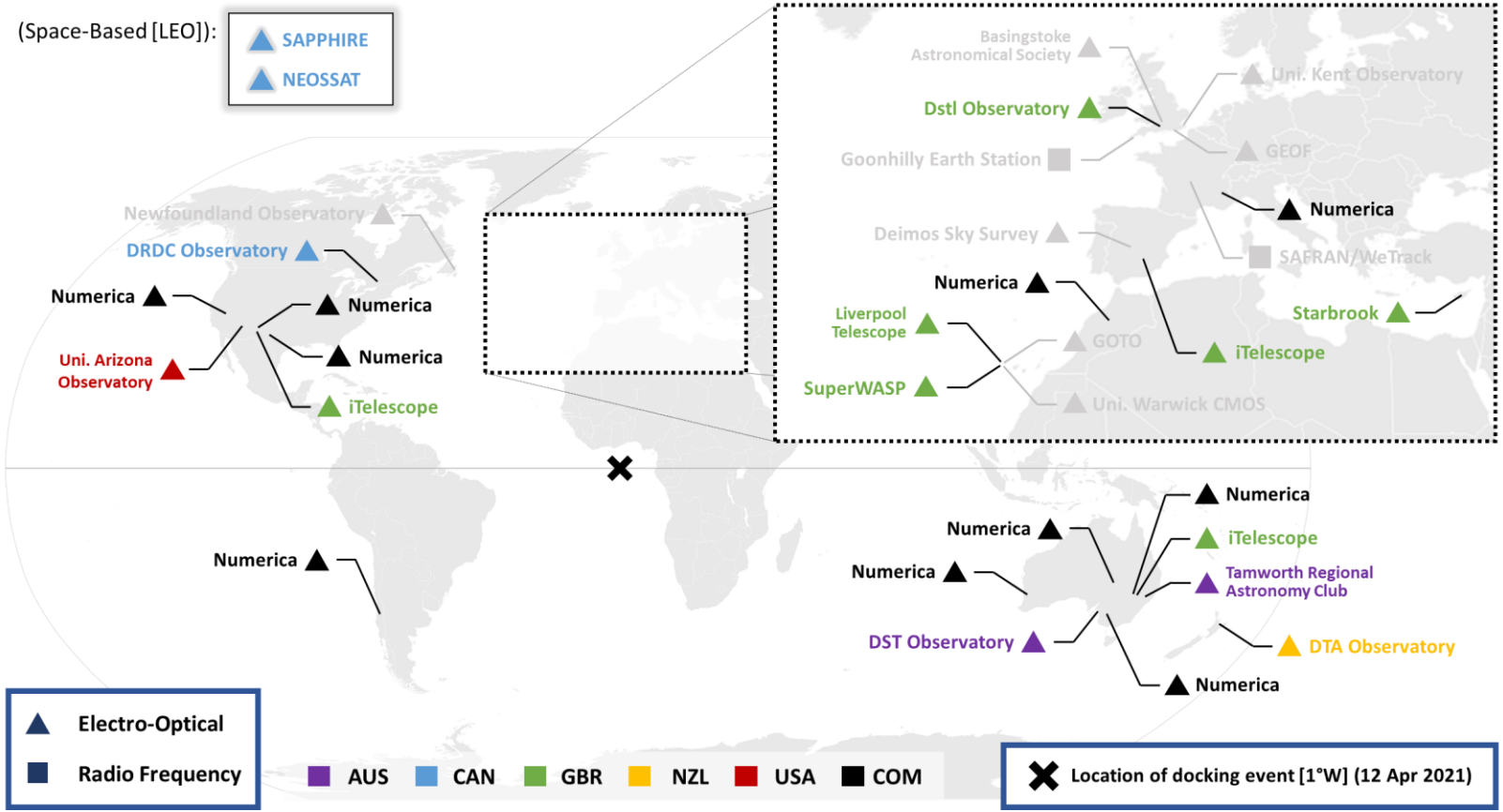
EPOR



PE2 EPOR Campaign: Results

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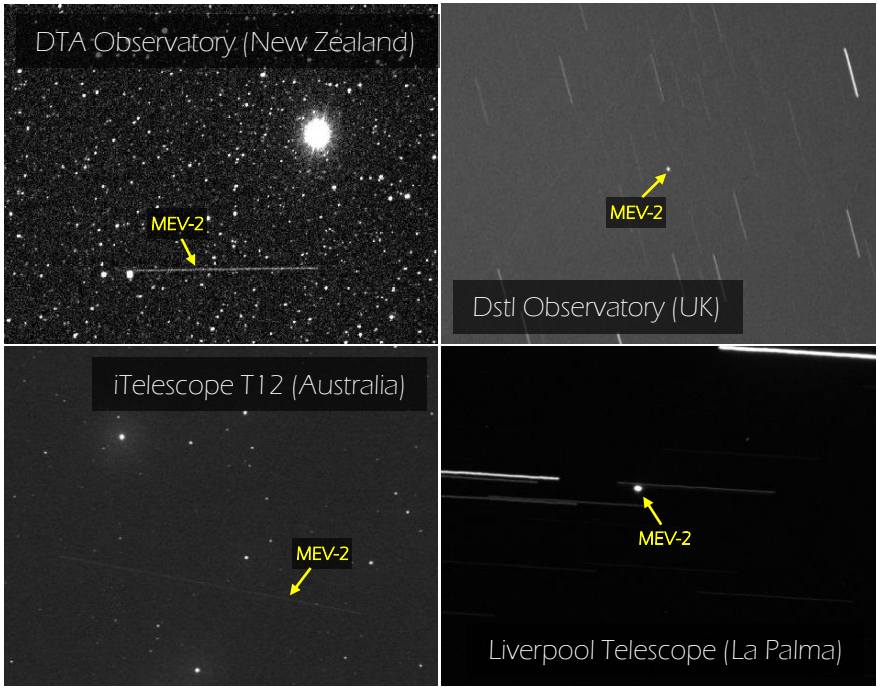
EPOR



- **Optical Tracking of MEV-2 by sensors:**
  - Dstl (UK)
  - Defence Technology Agency (NZ)
  - DST Group (AUS)
  - Defence R&D Canada (CAN)
  - Uni. Arizona (US)
  - Uni. Warwick (La Palma)
  - Uni. Liverpool (La Palma)
  - Numerica (multiple sites)
  - iTelescope (multiple sites)

Data exchanged via VerSSA + UDL:

CYVERSE

Unified Data Library

- Automated processing of data using VerSSA:
  - Stepwise generation of new GP/SP orbit solutions; circulate updated ELSETs to rest of network
  - **Maintenance of MEV-2 tracking despite outages in public Space-Track.org TLE data**

Images: *DTA, Dstl, iTelescope.NET, Uni. Liverpool / Cubica Technology Ltd. / Liverpool John Moores Uni.*

PE2 RPO Campaign: Overview

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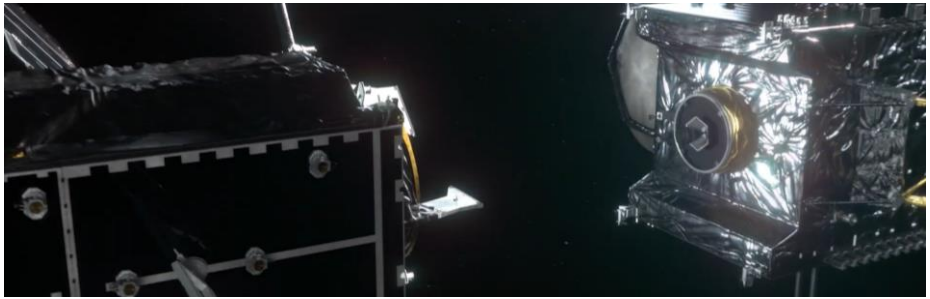
RPO



- **25th January** to **25th April 2021**
  - Observation and tracking of MEV-2 rendezvous and docking with INTELSAT 10-02 (1°W)
  - Collaboration with GLOBAL SENTINEL RWE#4
  - Enormous archive of collected data
  - Still underway: data analysis and exploitation

- **Objectives:**
  - Collection of data from multiple sensors & sites:
    - Electro-Optical (astrometry, photometry)
    - Spectral (colour photometry)
    - RF (Passive RF, TDOA/FDOA)
    - Space-based vs. ground-based
  - *Areas of Interest:*
    - Resolvability of individual objects
    - Discrimination & object tagging/ID
    - Change detection before/after docking
    - Modelling of dynamics & manoeuvres

* Rendezvous & Proximity Operations mission segment

Image: *MEV-2 mission © Northrop Grumman*

PHANTOM ECHOES 2: **Sensors**

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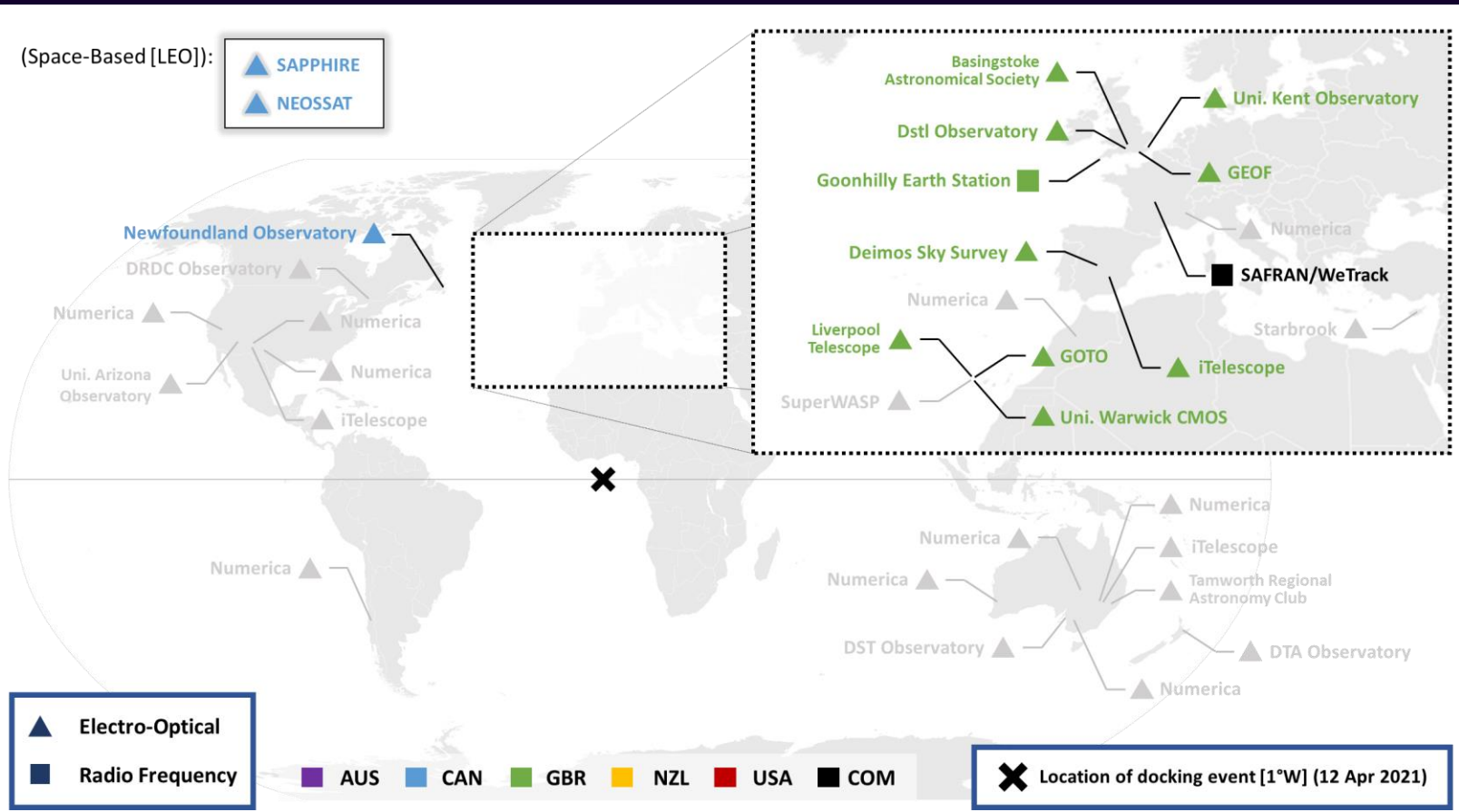
RPO



PE2 RPO Campaign: Sensors

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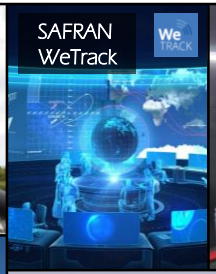
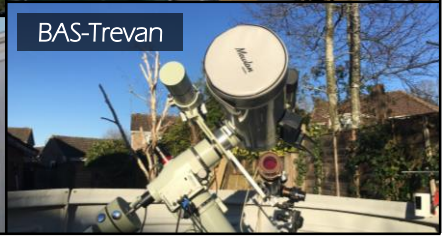
RPO





PE2 RPO Campaign: Results

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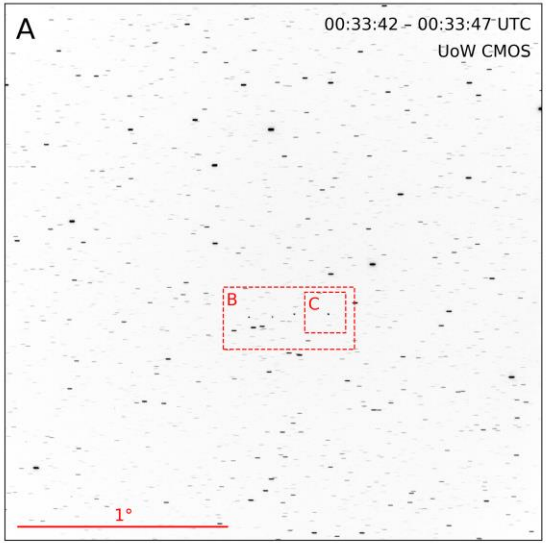
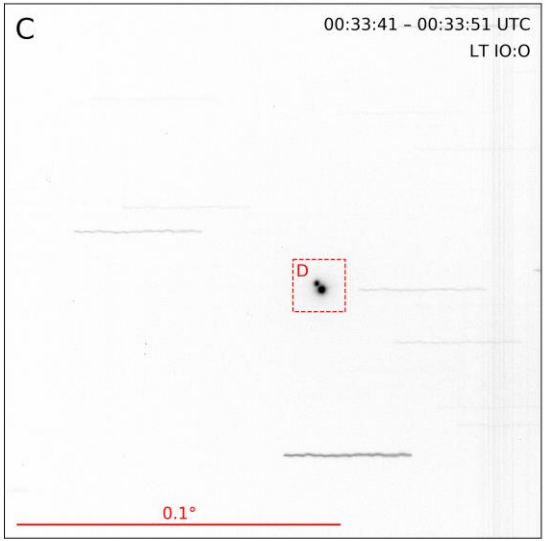
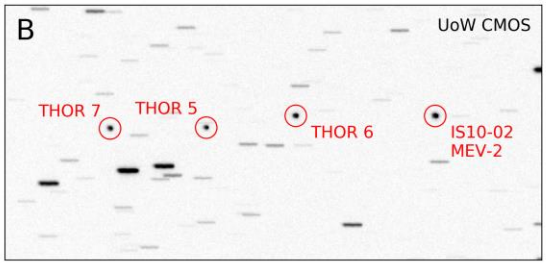
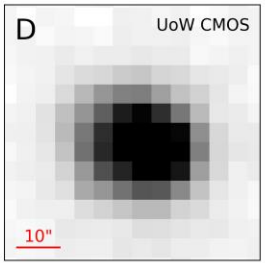
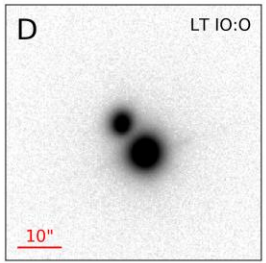
RPO











- **Optical Tracking by:**
  - Dstl (UK)
  - Defence R&D Canada (CAN)
  - Basingstoke Astronomical Society (UK)
  - Deimos Sky Survey (Spain)
  - iTelescope (Spain)
  - UK Space Geodesy Facility (UK)
  - Uni. Kent (UK)
  - Uni. Liverpool (La Palma)
  - Uni. Warwick (La Palma)

Example: Uni. Warwick CMOS test telescope + Liverpool Telescope (both on La Palma)

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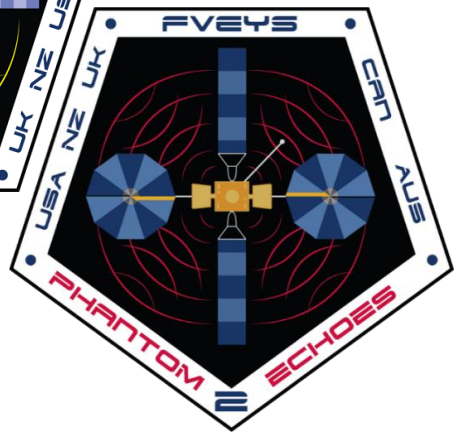
Images: *Uni. Warwick; Uni. Liverpool, Cubica Technology Ltd., Liverpool John Moores University*

Summary

- **Expert scientific team created across UK Gov't, R&D, academia and industry:**
  - International experiment under UK/US/CAN/ AUS/NZ research agreement

- **Real-world observation of surrogate targets relevant to GEO RPO problem:**
  - *MEV-1* and *Intelsat-901* [2019-2020]
  - *MEV-2* and *Intelsat 10-02* [2020-2021]



Research conducted under TTCP

Understanding of future (novel) sensing capabilities relevant to protection of assets in GEO

Summary

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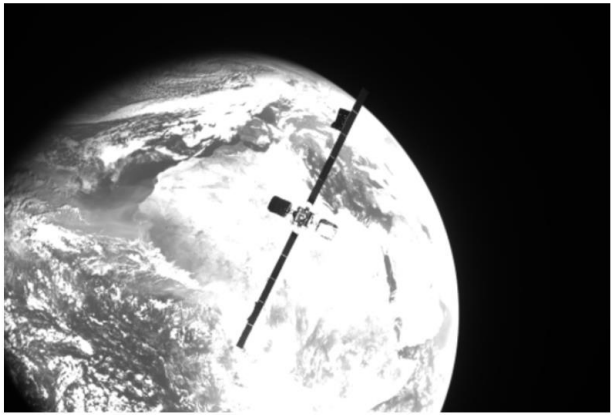

21 April 2021 — Press release

Dstl leads successful experiment to observe satellites docking

Data captured during the Phantom Echoes 2 project, headed by an international group of defence space scientists, will help improve performance and space safety.

- GOV.UK article published on **21st April 2021**

https://bit.ly/PHANTOM-ECHOES-2

Dstl
22 April at 11:00 ·

Our space scientists have led a successful experiment to observe satellites docking.

Data captured during the collaborative Phantom Echoes 2 project will help improve performance and space safety.

Read more ---> bit.ly/3na1xUc Image: Northrop Grumman Corporation

University of Warwick Liverpool Telescope Basingstoke Astronomical Society Air Force Research Laboratory - AFRL University of Liverpool The University of Arizona Airbus Space Airbus Defence University of Kent Bluestaq

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Summary

Acknowledgments:

Co-authors listed in ***bold italics***

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Thanks also to*: the Gravitational-wave Optical Transient Observer (GOTO) project collaboration, Liverpool John Moores University, the National Science Foundation (CyVerse), the UK Science and Technology Facilities Council and all of the organisations listed on the 'PHANTOM ECHOES 2: Participants' slide.*

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