Benefits of Freeform surfaces for Space Optical Systems

Cyril Bourgenot

CEOI - Emerging Technologies Workshop

Session Advanced Optics & Deployables - Virtual meeting

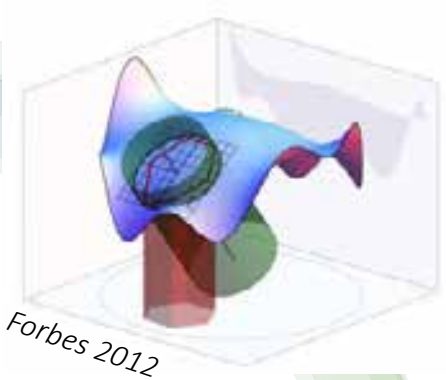
21st April 2021

CfAI
Centre for Advanced Instrumentation

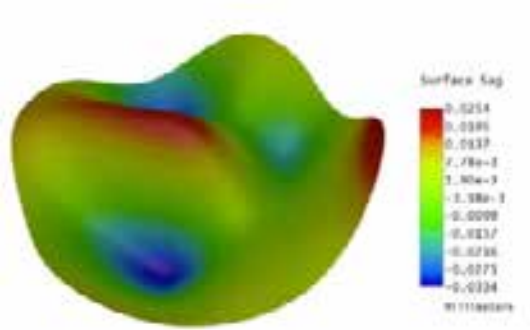
Durham University

An emerging technology

- The increased use of freeform optical surfaces is the result of developments in :
  - THEORY : the theory of aberrations,
  - COMPUTATION METHOD : techniques in optical system optimization,
  - TECHNOLOGY : computation speed,
  - MACHINING : precision fabrication of surfaces without symmetry,
  - METROLOGY : Extensions to the range of the surface slopes allowed in optical testing



Forbes 2012



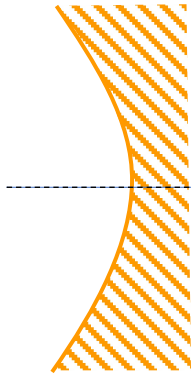
Zemax – TrueFreeForm

Credit : microdevices.jpl.nasa.gov/

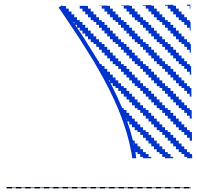
Kevin P. Thompson and Jannick P. Rolland, "Freeform Optical Surfaces: A Revolution in Imaging Optical Design," Optics & Photonics News 23(6), 30-35 (2012)

Freeform surface – definition(s)

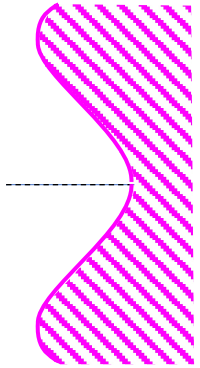
Sphere
- Constant radius
- Rotationally symmetric



Asphere
- Varying radius
- Rotationally symmetric
- Apex on surface



Off axis Asphere
- Varying radius
- Axis of rotational symmetric outside aperture
- Apex off the surface



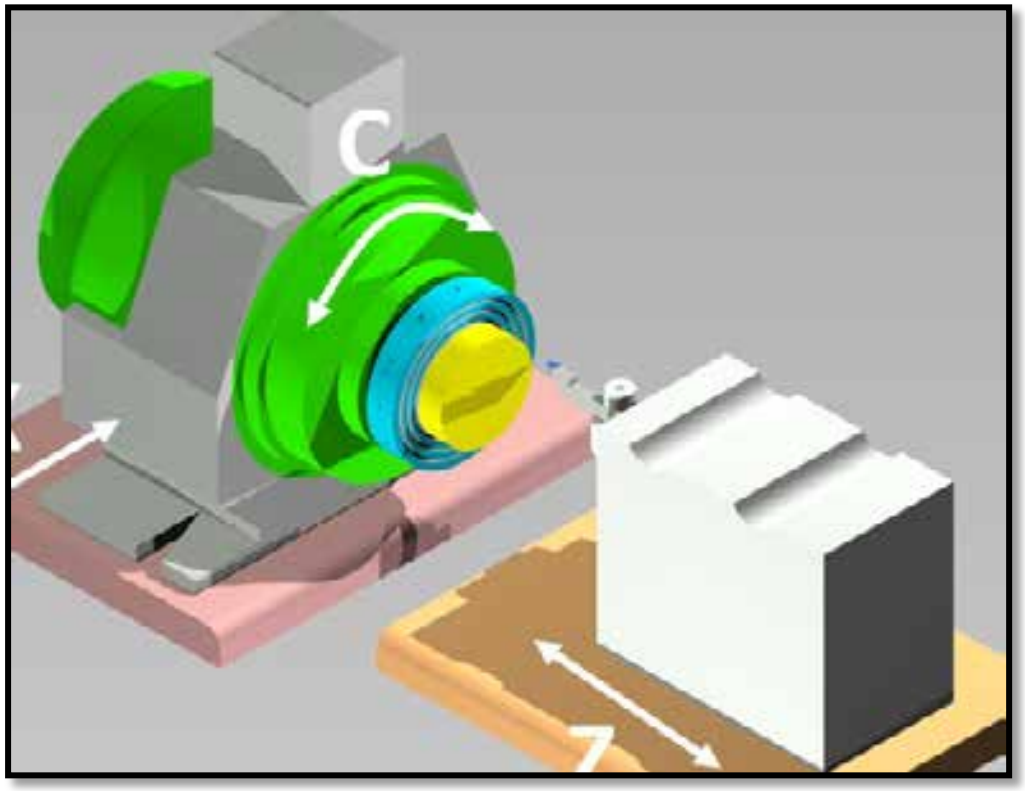
Strong Asphere
- Varying radius
- Rotationally symmetric
- Non monotonic

Freeform
- No symmetry

Degrees of freedom → design

Freeform surface – definition(s)

Freeform Optical Surface, Modern Definition (post-2000) :
An optical surface that leverages a third independent axis (C-axis in diamond turning terminology) during the creation process to create an optical surface with as-designed nonsymmetric features.



Kevin P. Thompson and Jannick P. Rolland, "Freeform Optical Surfaces: A Revolution in Imaging Optical Design," Optics & Photonics News 23(6), 30-35 (2012)

Benefits of freeform surfaces

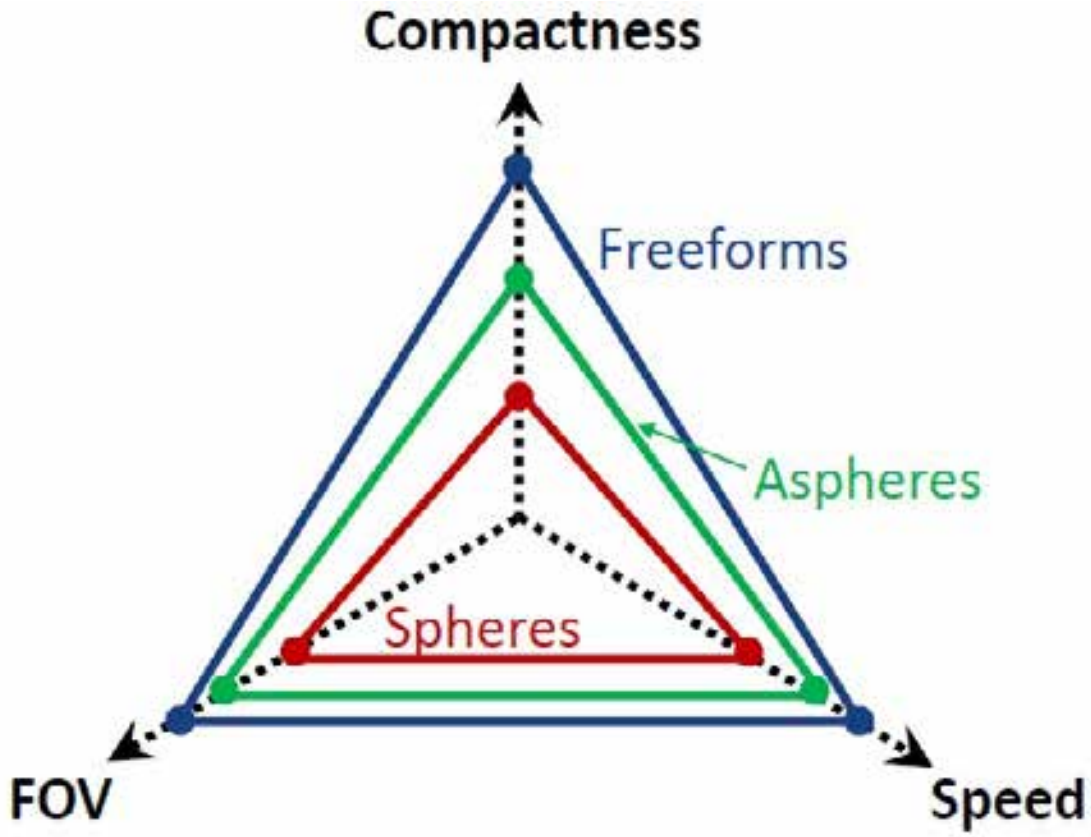
Compactness	X
Field of View	X
Speed	X

Goals from industrial development

- Reduce number of components
- Increase functionality
- Cheaper system
- Improved performance

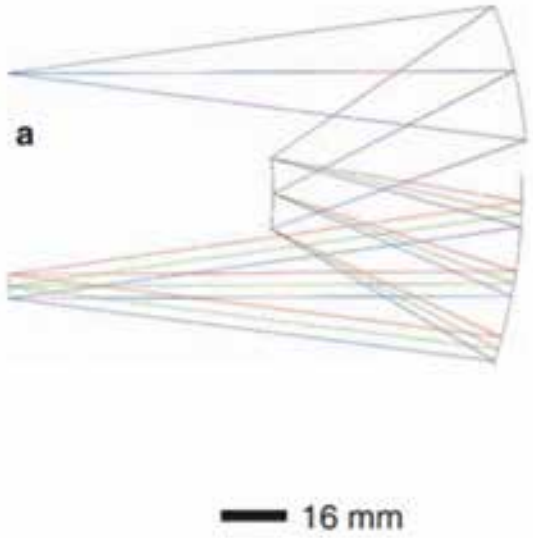
Desired critical properties

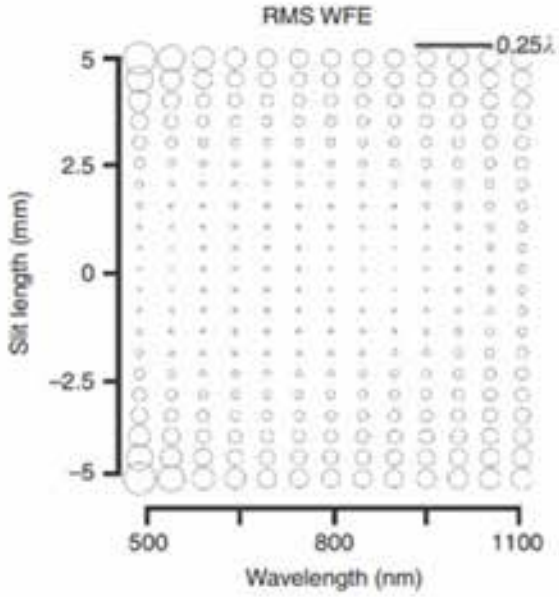
- Size/volume/weight
- Field of view
- F-number/aperture/SNR



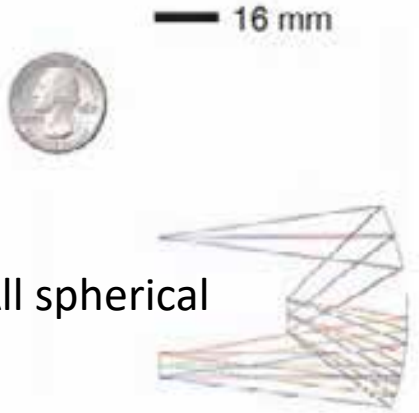
An example : Spectrograph

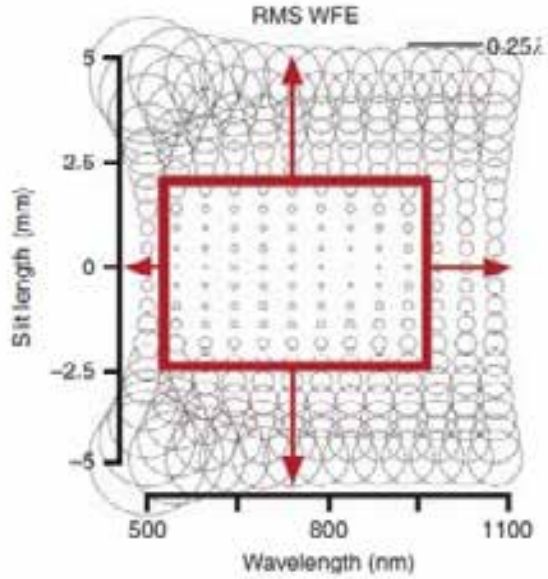
Compactness	**X**
Field of View	
Speed	



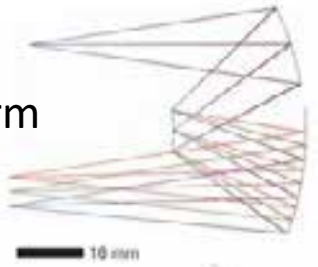


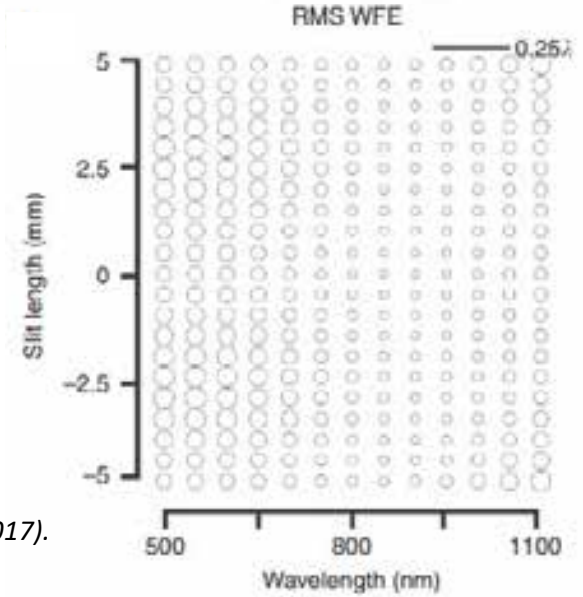
All spherical





Freeform





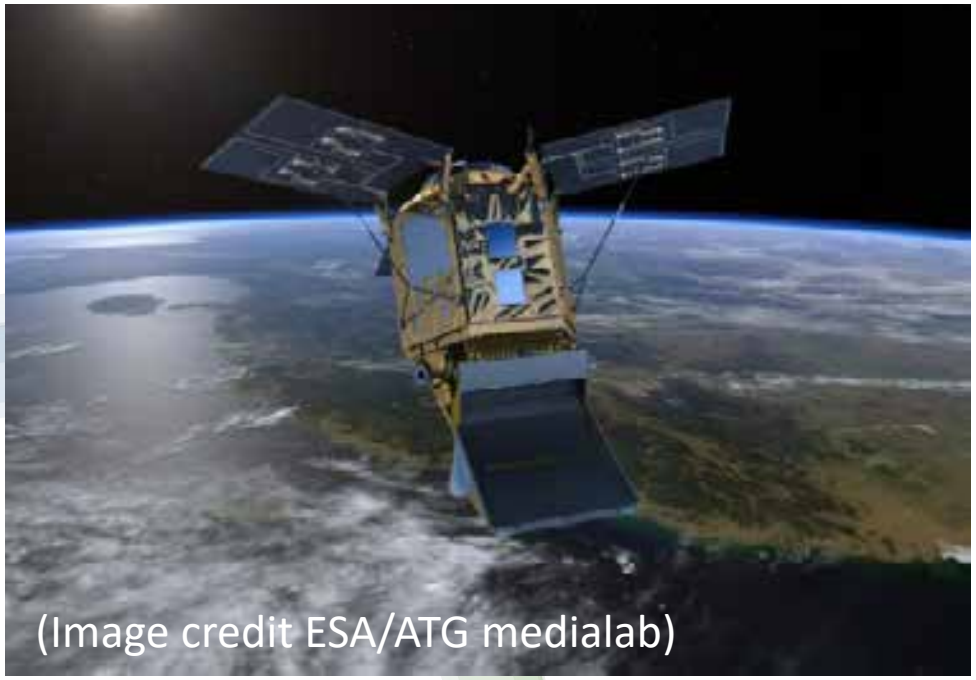
J. Reimers, A. Bauer, K. P. Thompson, and J. P. Rolland, "Freeform spectrometer enabling increased compactness," Light. Sci. & Appl. 6, e17026–e17026 (2017).

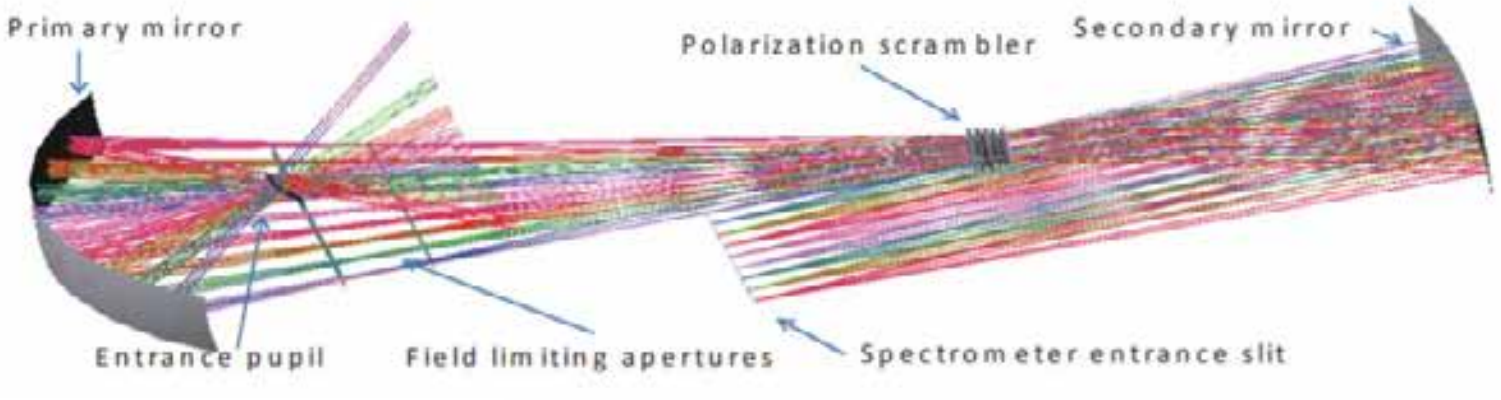
Freeform in space : TROPOMI (sentinel 5P)

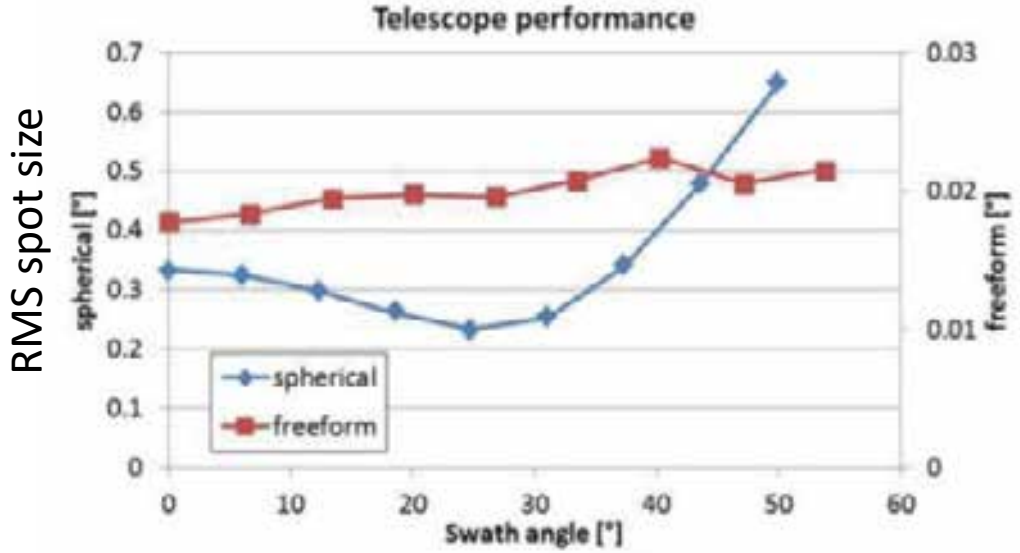
Compactness	
Field of View	**X**
Speed	

The TROPOspheric Monitoring Instrument (**TROPOMI**) is the satellite instrument on board the Copernicus Sentinel-5 Precursor satellite.

TNO innovation for life



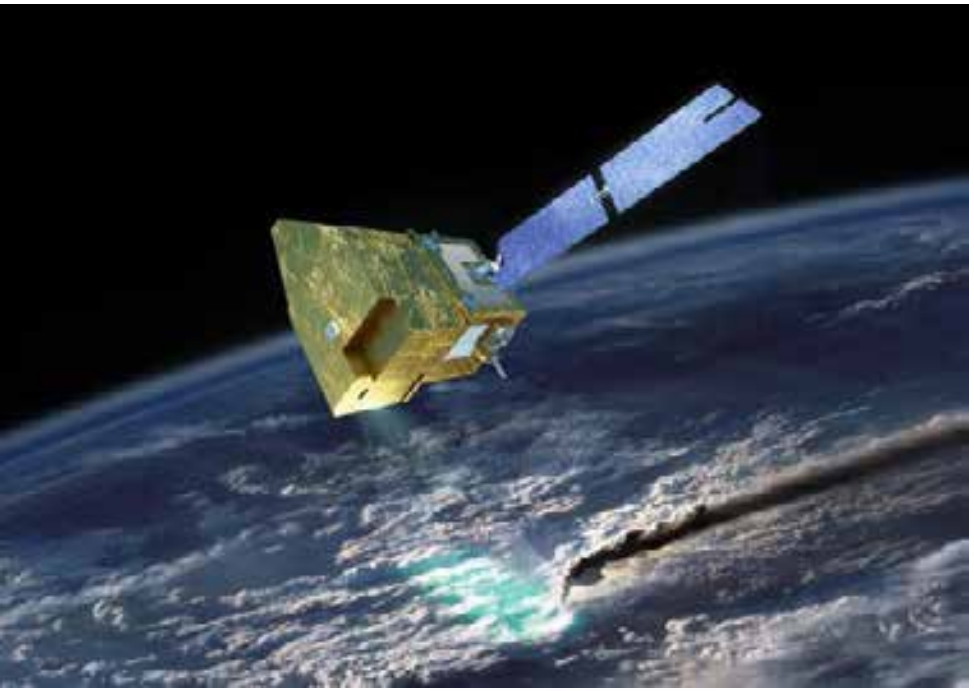




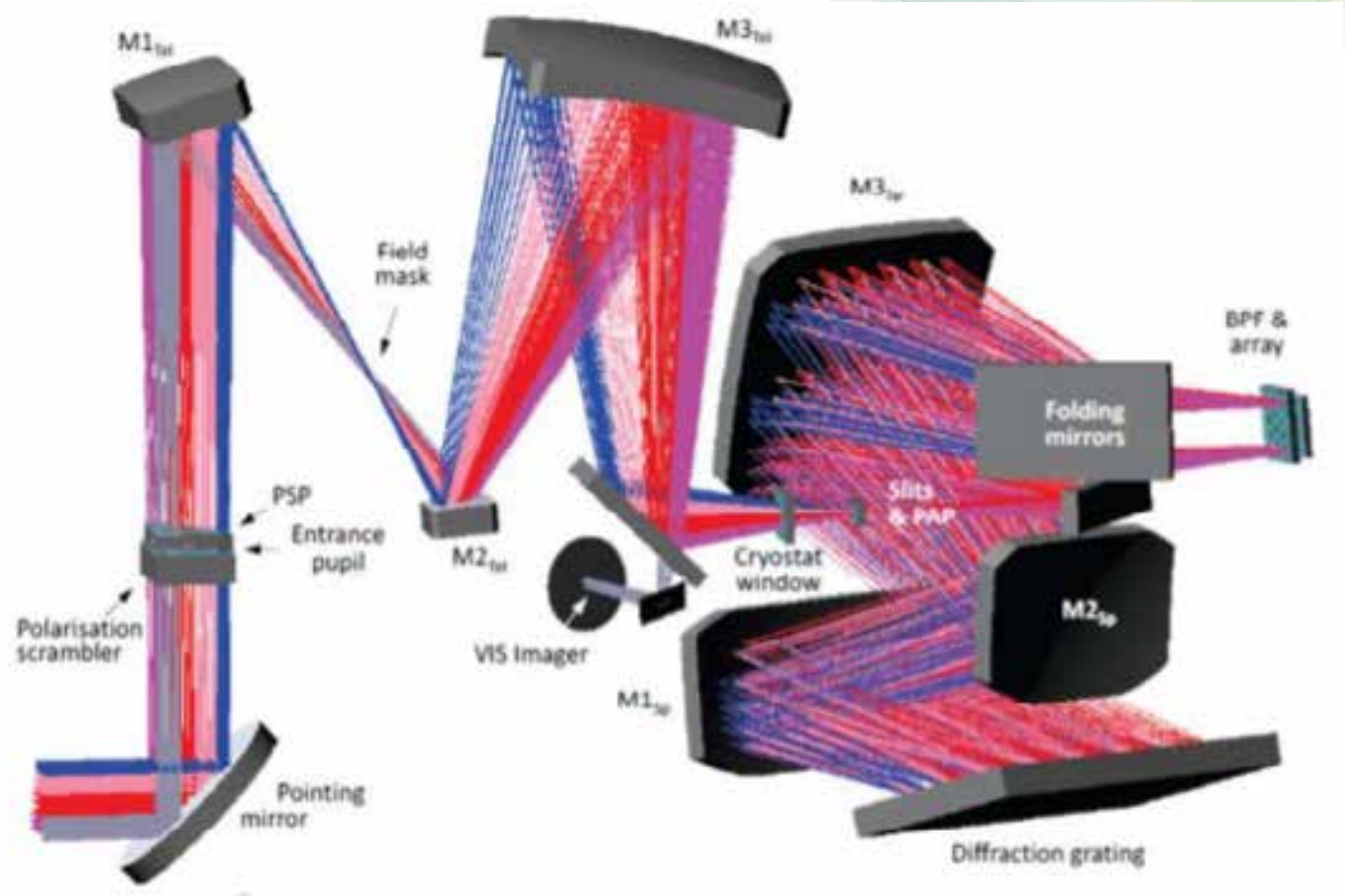
very large field of view of 2600 km with a 7 km resolution
Freeform makes it a factor of 10 to 30 better and remains much more constant over the field

Freeform in space : Microcarb (2021)

Compactness	**X**
Field of View	
Speed	



Mission to monitor carbon in the atmosphere



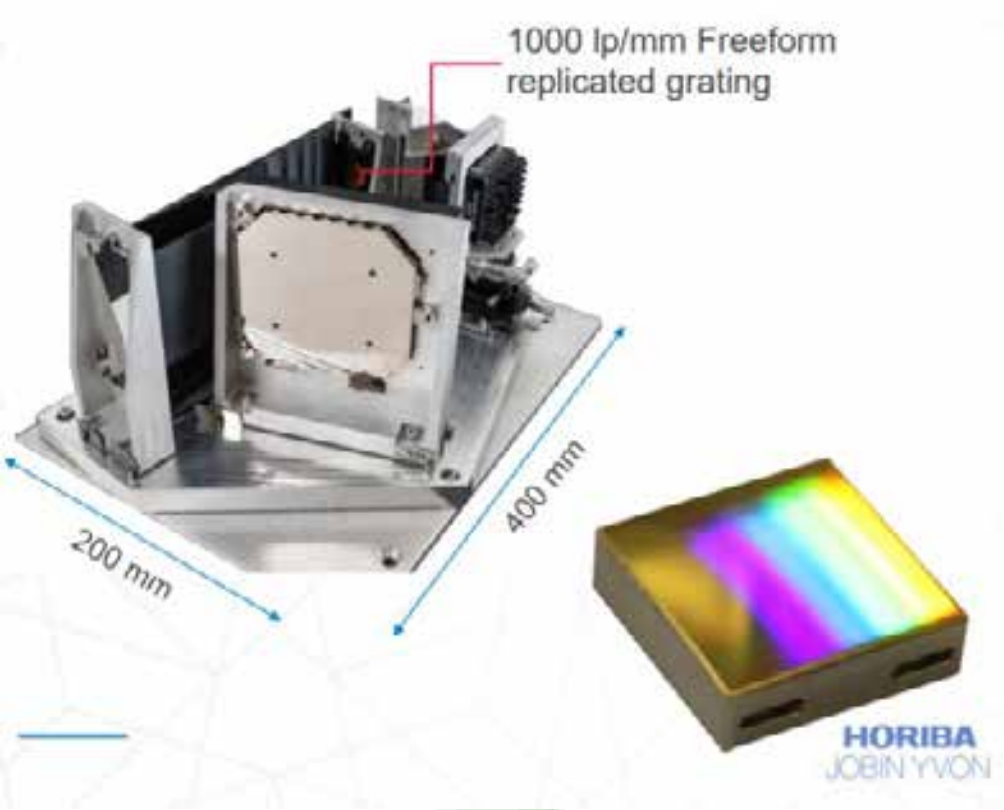
low profile / low cost Myriade platform

R. Geyl, E. Ruch, H. Leplan, F. Riguet, S. Lopez, "Precision space freeform optics for Microcarb: final report," Proc. SPIE 11487, Optical Manufacturing and Testing XIII, 114870X (20 August 2020)

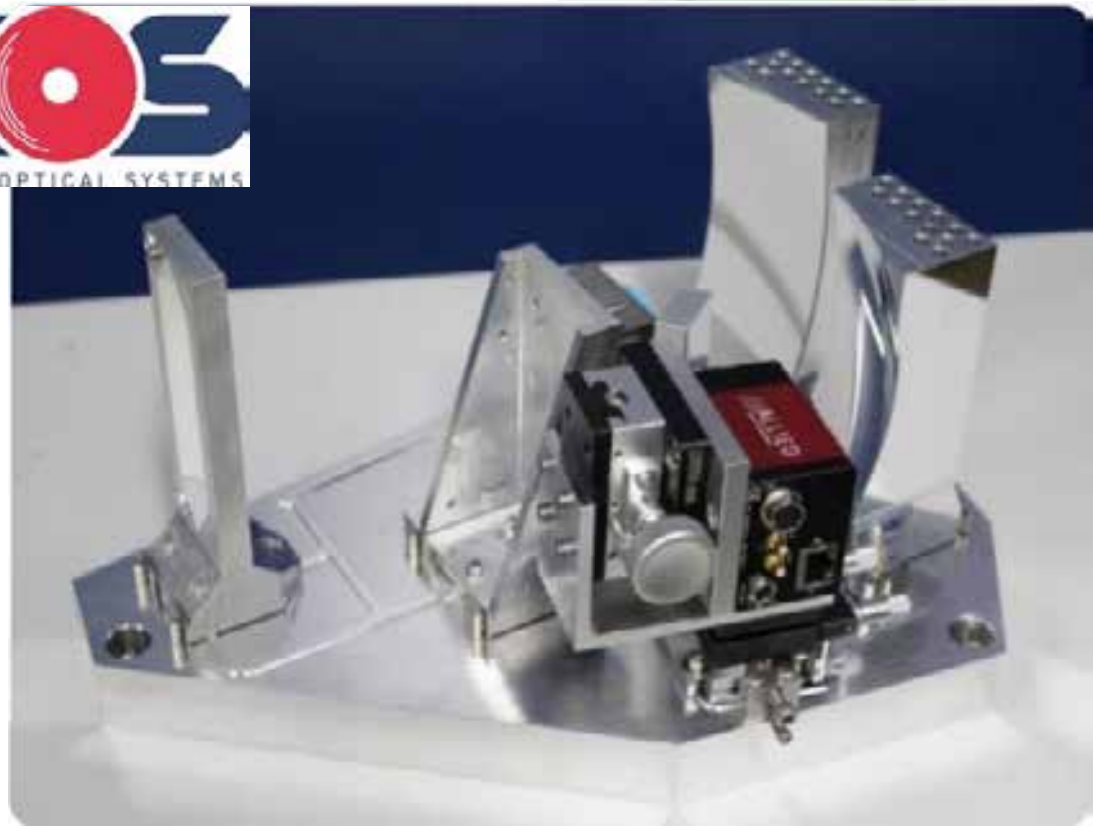
Freeform in space spectrograph smallsat

Compactness	**X**
Field of View	
Speed	

CHIMA – Compact Hyperspectral Imager for Monitoring of Atmosphere

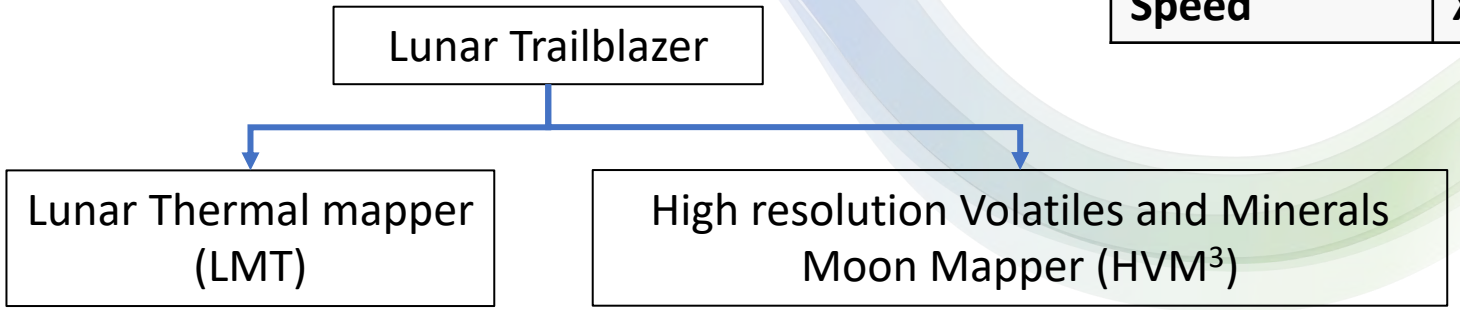


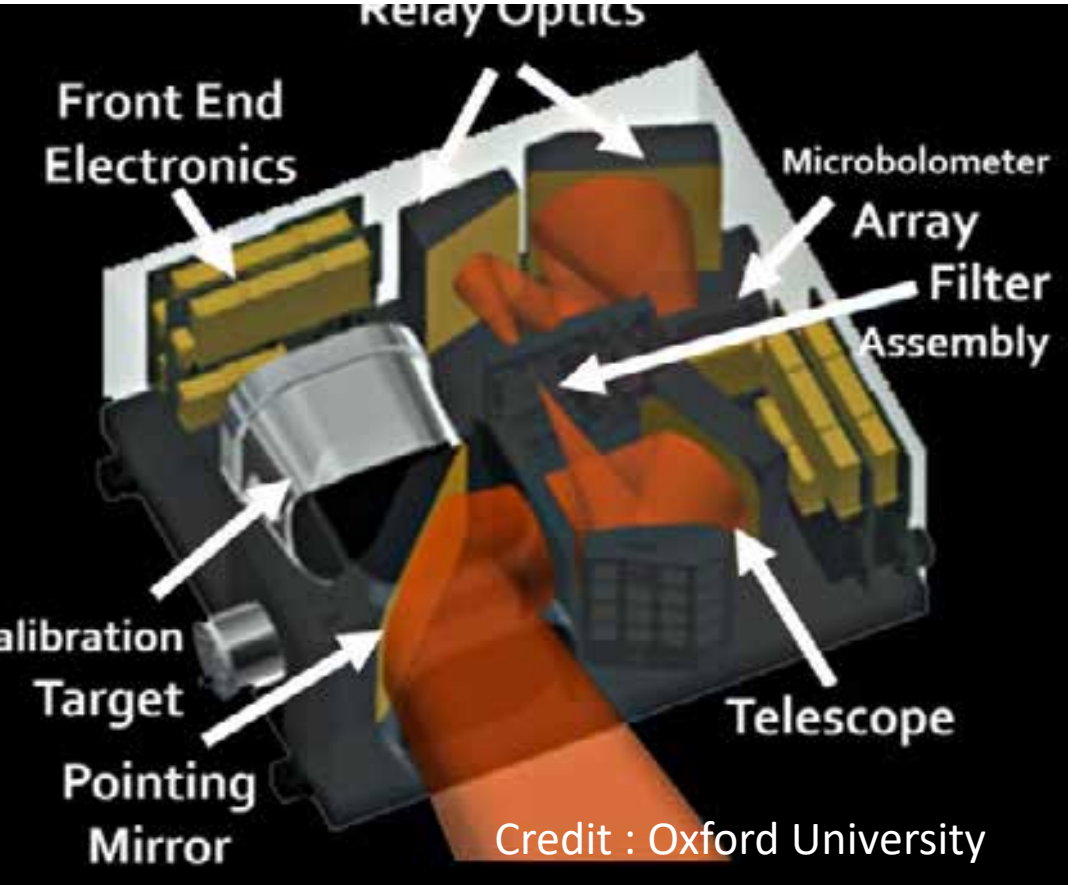
ELOIS - Enhanced Light Offner Imaging Spectrometer



Lunar Trailblazer (2024) – Lunar Thermal mapper

Compactness	**X**
Field of View	**X**
Speed	**X**





Credit : Oxford University

- SIMPLEx (Small Innovative Missions for Planetary Exploration)
- Lunar Trailblazer will directly detect and map water on the lunar surface to determine the form (OH, H2O or ice), abundance, and distribution as a function of latitude, soil maturity and composition
- Optical design by Rory Evans FOV : 9x9˚, F/1.5, 100 m/pixel, 6-100 µm

UNIVERSITY OF OXFORD

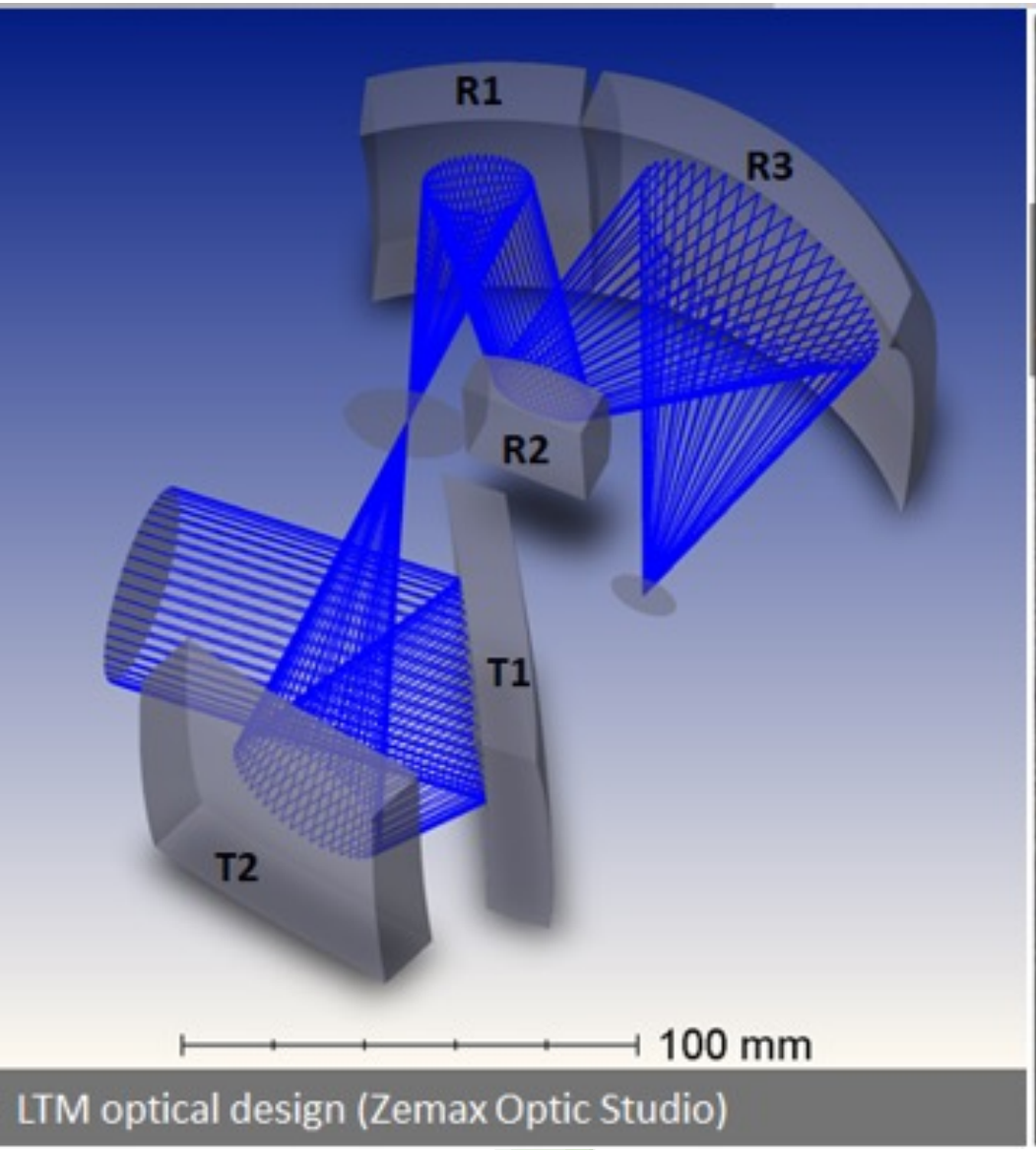
Durham University

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

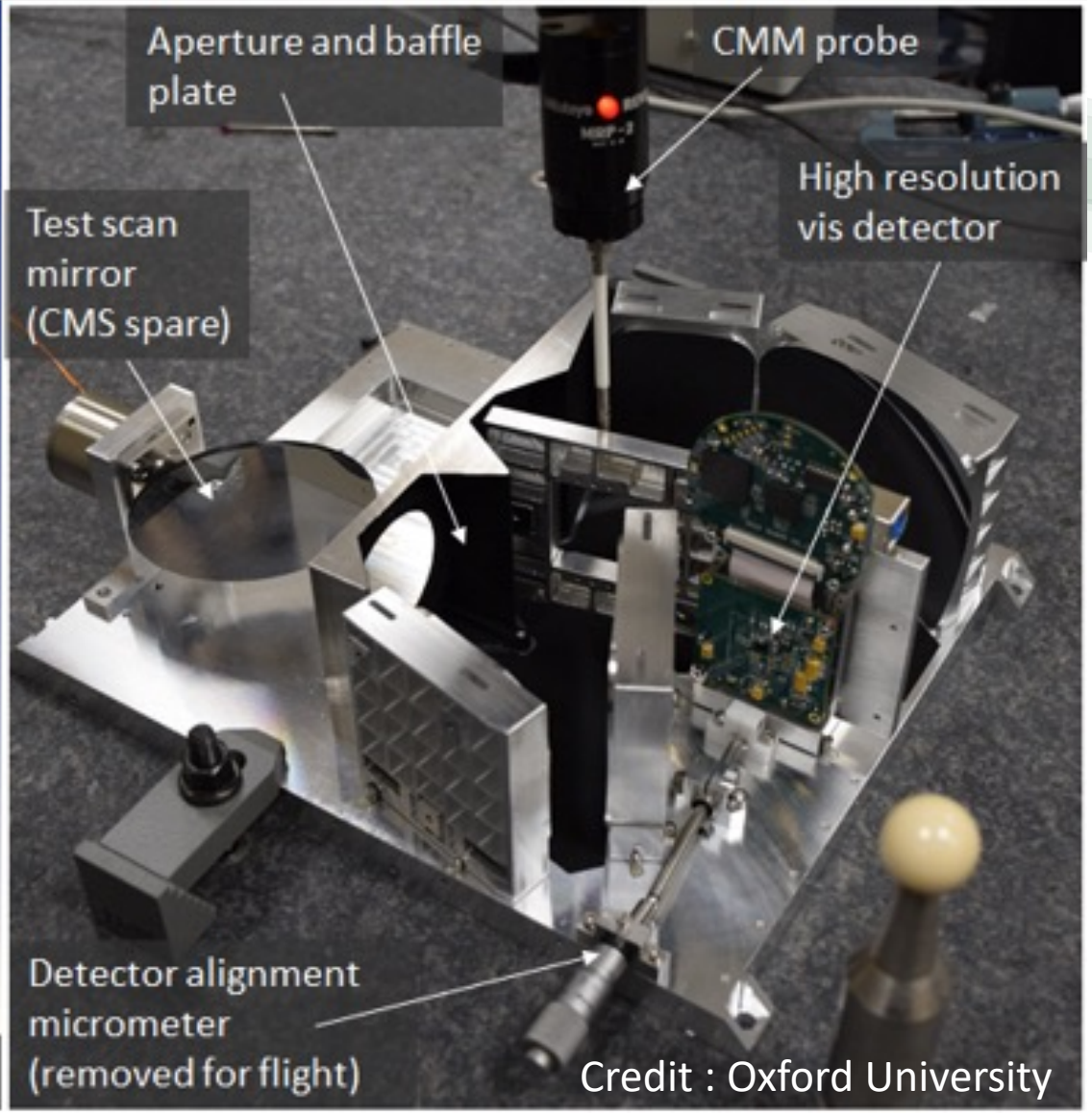
RAL Space

Lunar Trailblazer (2024) – Prototype (2020)

Compactness	X
Field of View	X
Speed	X

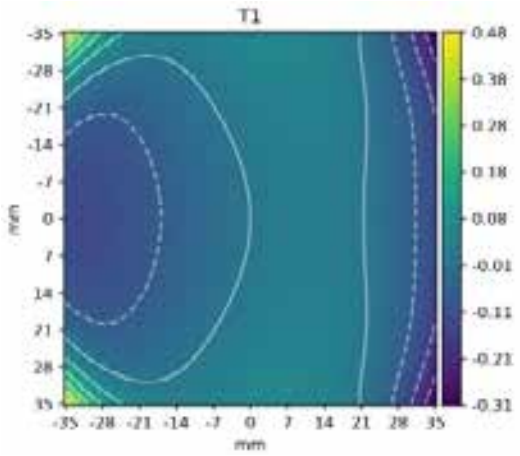


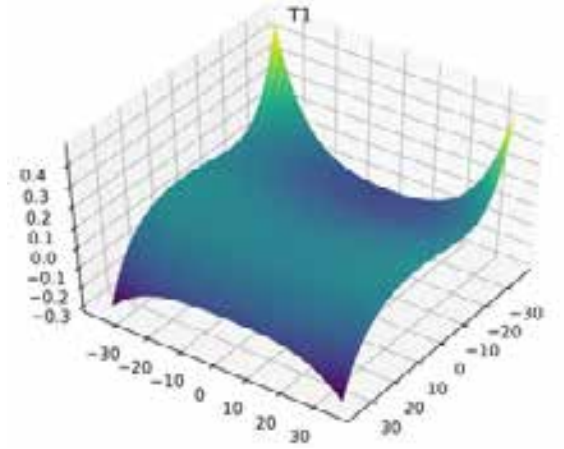
LTM optical design (Zemax Optic Studio)

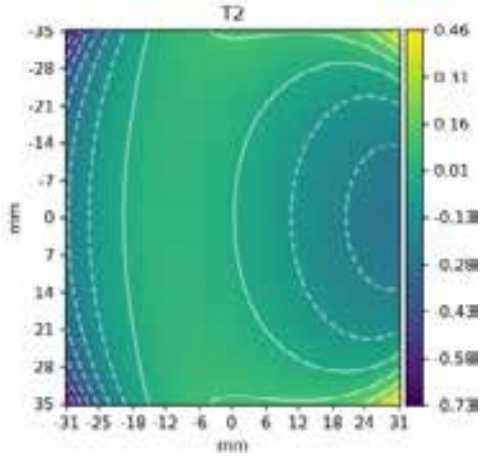


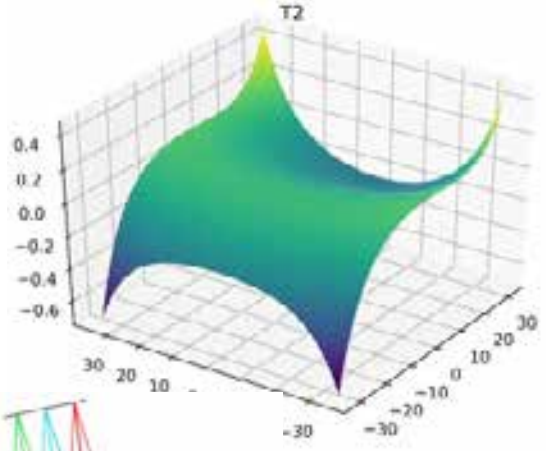
Credit : Oxford University

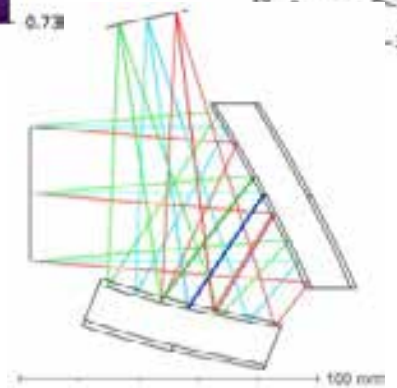
Lunar Trailblazer – Lunar Thermal mapper

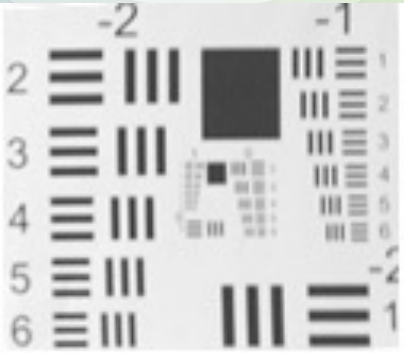










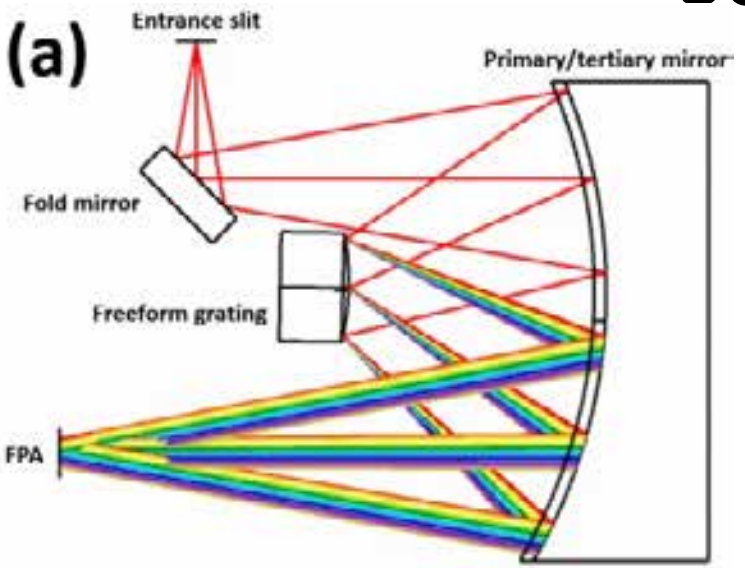


T1 : Mass : 108g
0.8mm deviation from BFS

T2 : Mass : 101g
1.2mm deviation from BFS

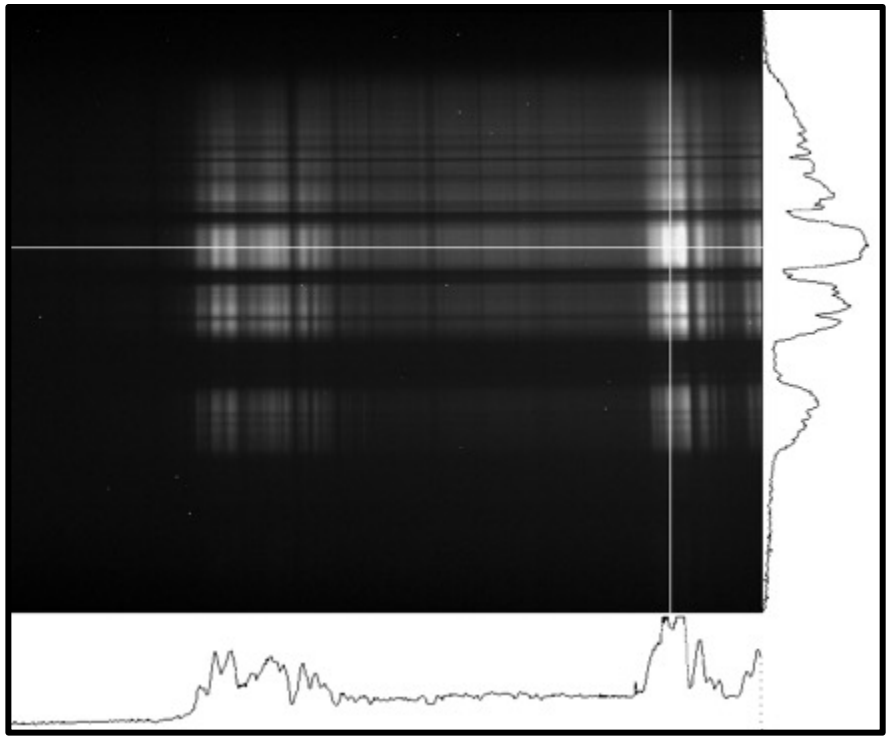
Freeform based hYperspectral imager for MOisture Sensing (FYMOS)

Compactness	X
Field of View	
Speed	X

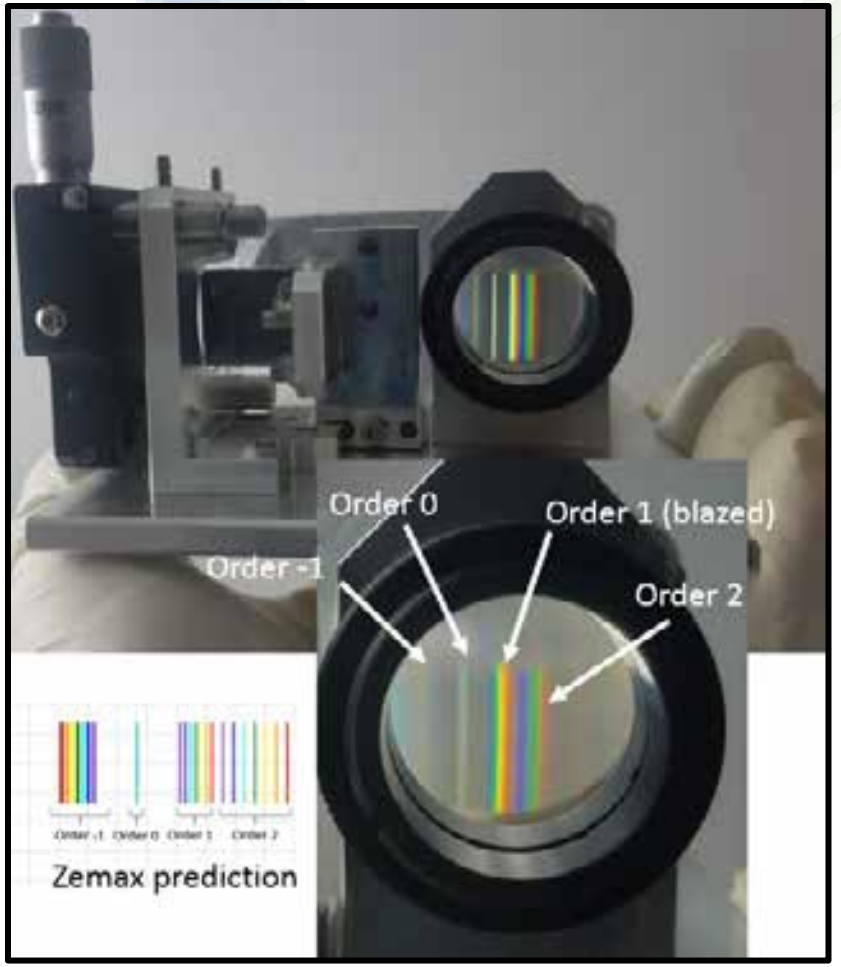


F/#	2.8
Wavelength	[0.7-1.7µm]
Spectral resolution	8 nm
Slit Size	6 mm
Sensor Size	6x4 mm

Pushbroom hyperspectral imager



Atmospheric spectrum



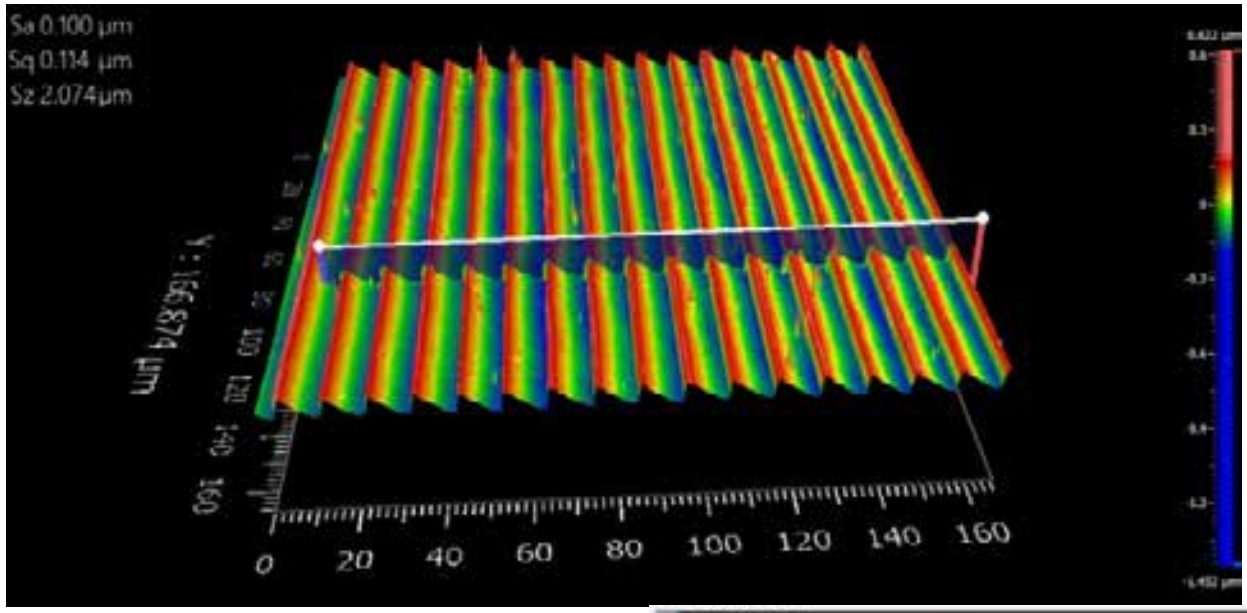
Engineering and Physical Sciences Research Council

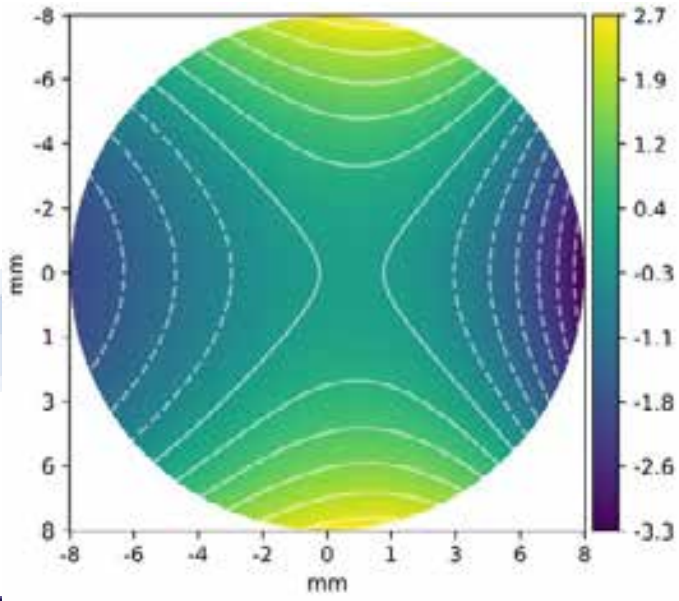
EP/S001727/1

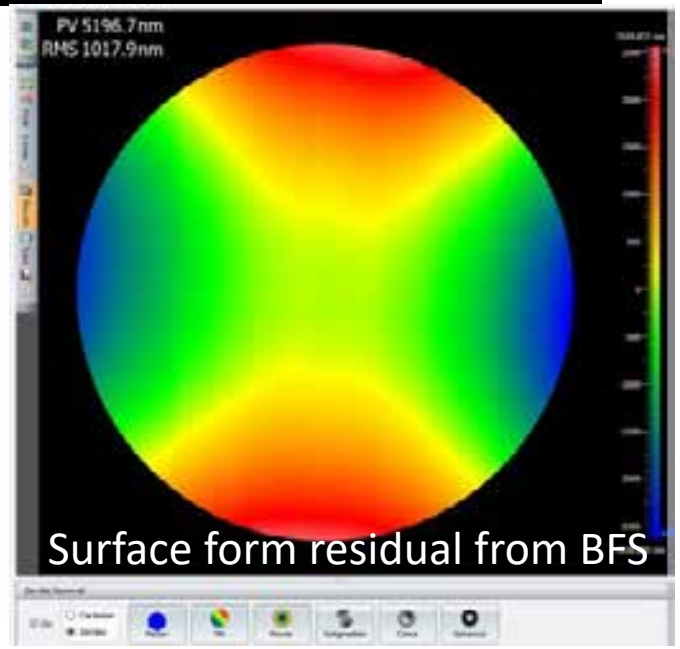
Project blog : https://ukremotesensingtechnologycentre.wordpress.com/blog/

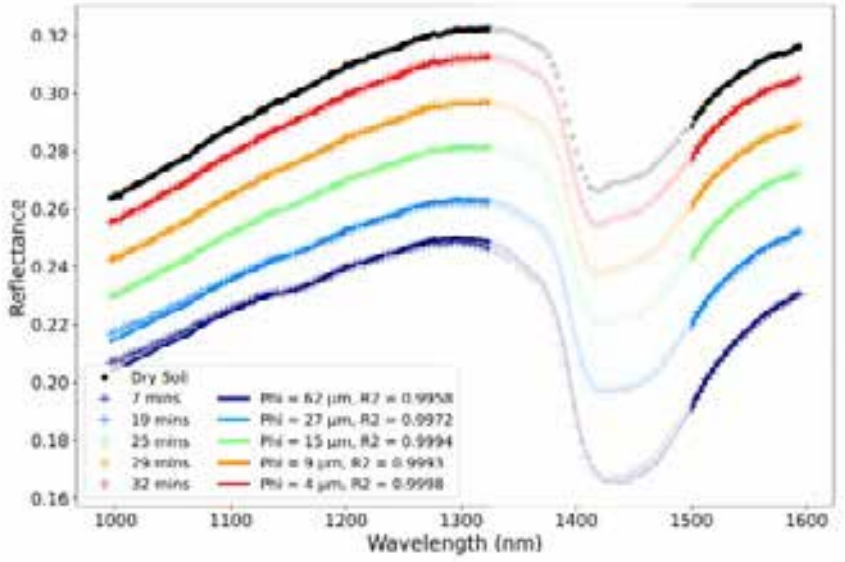
Freeform based hYperspectral imager for MOisture Sensing (FYMOS)

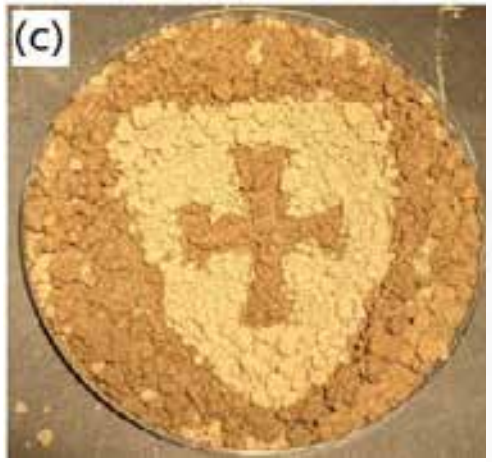
Compactness	**X**
Field of View	
Speed	**X**

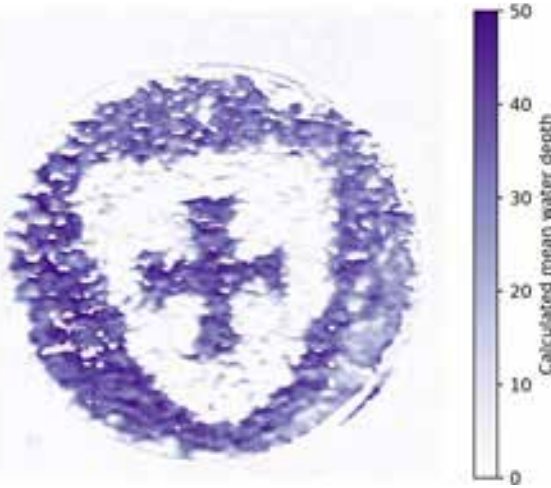






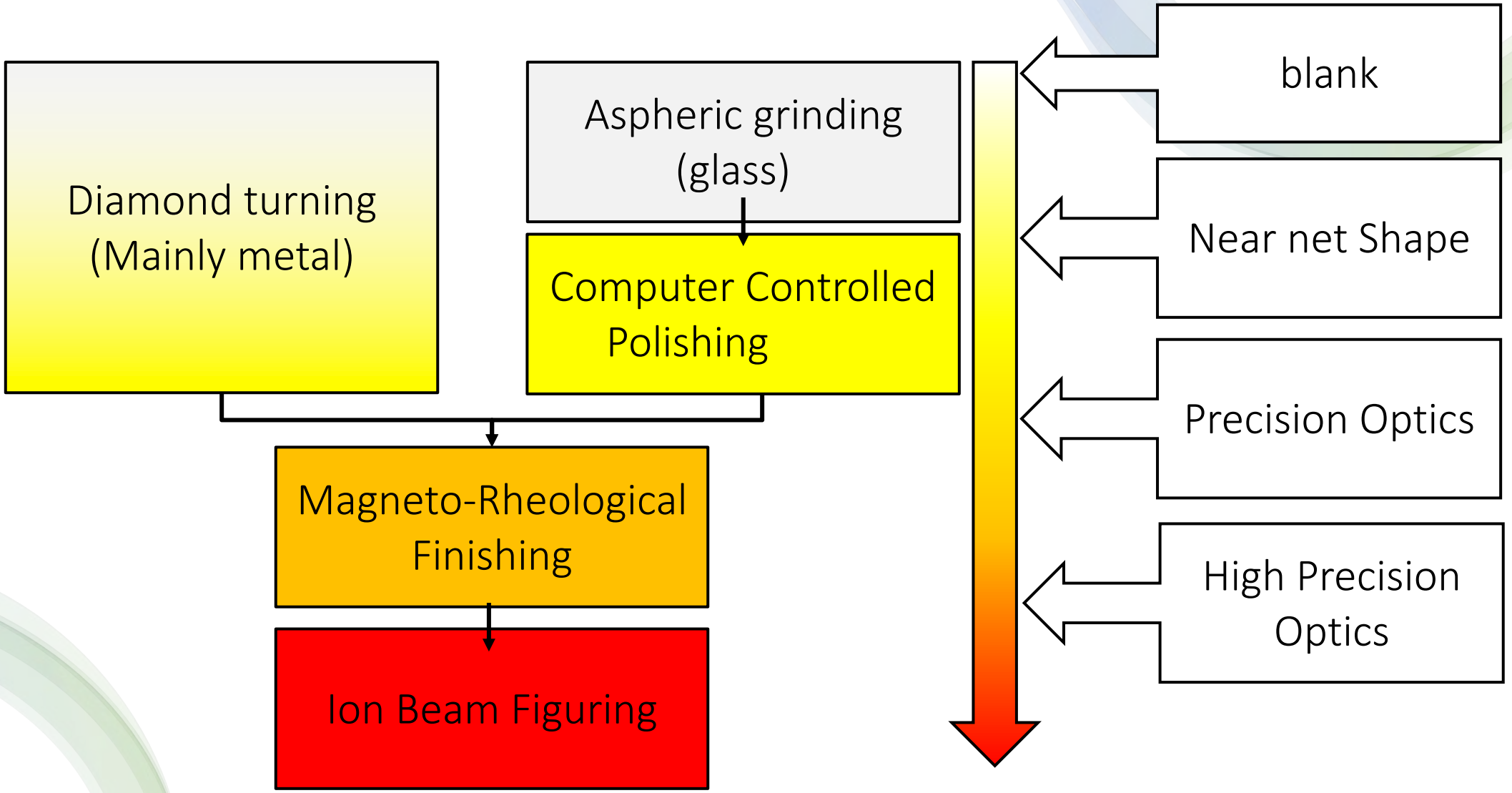






UKRI- EPSRC Grant Reference : EP/S001727/1

Freeform manufacturing



Freeform metrology

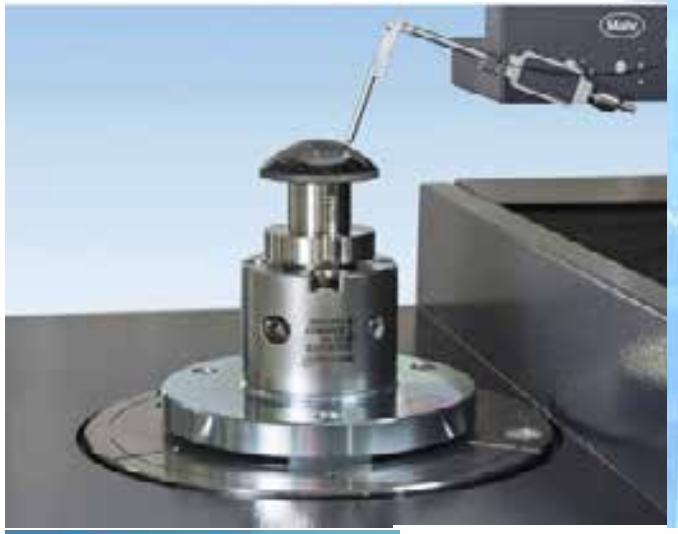
contact 3D profilometry

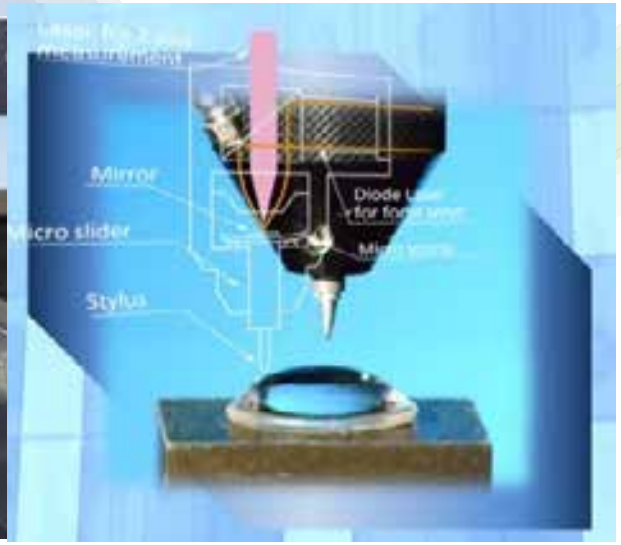
- Marh Optics - MFU 200 Aspheric 3D
- Panasonic UA3P

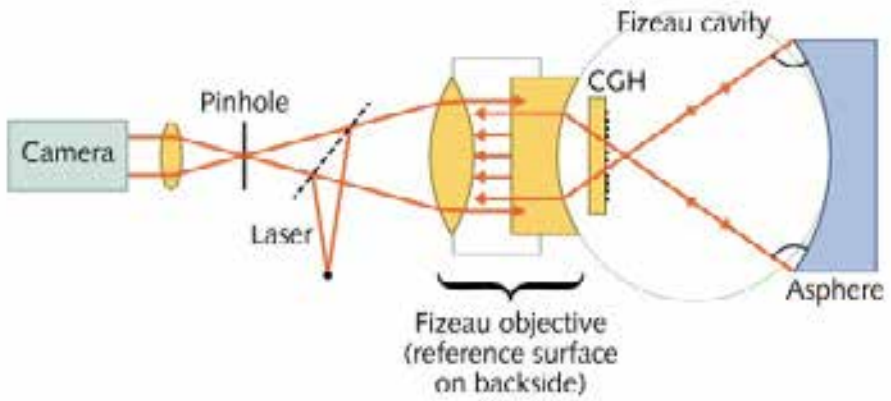
Non contact 3D profilometry

- Luphoscan (Taylor-hobson)

CGH (computer generated hologram)







What next?

Space Optics TEchnology Centre (SOTEC)

National Infrastructure in Support of Space Enterprise

- To facilitate and promote cooperation, collaboration, and coordination between space optics actors in Academia, Research, and Industry.
- To initiate and facilitate novel and innovative research challenges and accelerate impact.
- To develop a strategic plan to scale up space optics manufacturing capability across the country.
- To provide a forum for the community to speak collectively to funding bodies and standard agencies.
- To promote the wider importance of optical design and manufacture capabilities in the UK.
- To build a strategy for renewing the UK optical engineering capability through appropriate academic training and industry placement schemes.

Durham University

University of HUDDERSFIELD
Inspiring tomorrow's professionals