Image Slicer Technologies for Earth Observation

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The UK Astronomy Technology Centre

- UK's national facility for the design and fabrication of astronomical instruments.
- Ground based
  - VISTA
  - KMOS
- Space based
  - SPIRE (Herschel)
  - MIRI (JWST)
- UV to sub-mm
  - Imagers
  - Spectrographs
  - Hyper-spectral systems
  - Adaptive optics
  - Cryogenic instruments

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Overview

- What is an image slicer & what problem does it solve
- What benefit can an image slicer provide to Earth Observation instrument
  - CEOI Seedcorn #1
- Verification of the design of an image slicing spectrograph for use in space
  - CEOI Seedcorn #2
- What are the next steps for this design
  - ESA ITI project

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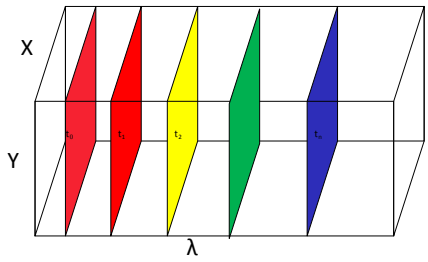
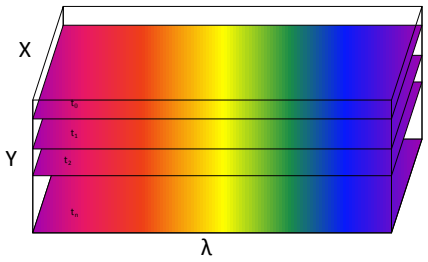
Sampling problem for spectral imaging





- Sample wavelength slices, e.g. Fabry-Pérot,
- Integration time ∝ No. of wavelength slices
- Sparse sampling of the spectral signal

- Sample spatial slices, e.g. long slit (push-broom) spectrograph
- Integration time ∝ No. of spectral slices
- Sparse sampling of the aperture

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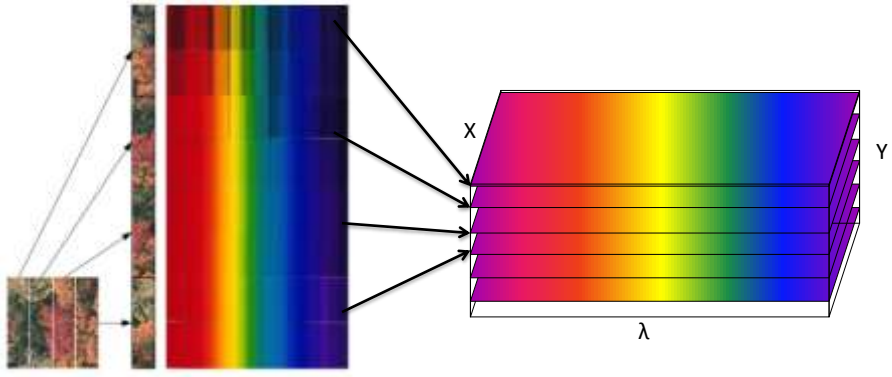
Image slicers solution to the problem



- Split the aperture into strips (optically) then disperse
- Full sampling of the aperture
- Potentially full sampling of the wavelength
- One shot hyper-spectral image of a scene

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Astronomy heritage

- Image slicers have been used for ~20 years: UIST (UKIRT), UVES (ESO), KMOS (ESO)
- Early slicers were fabricated from separate glass elements – typically 5-10 slices
- Current image slicers are machined (from metal) – typically 10-50 slices
- KMOS uses 14 element slicers, 24 in total on patrol arms

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KMOS focal plane

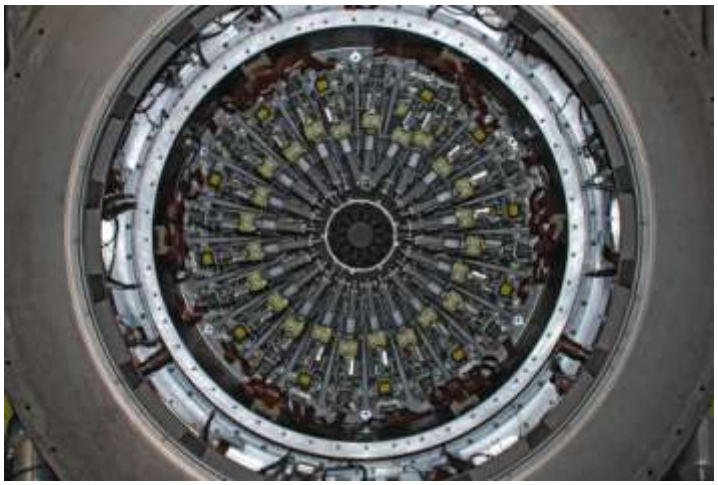

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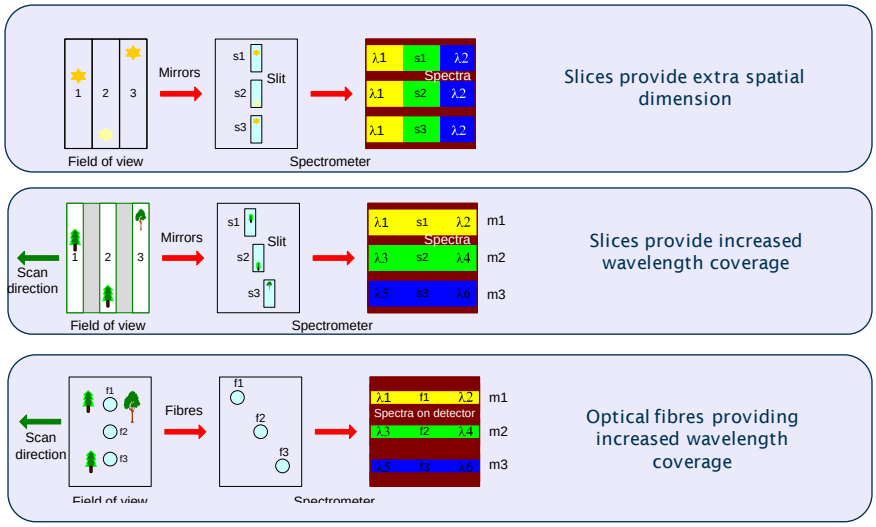
Image slicers – sampling strategies



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First CEOI Seed corn project

UK-ATC and Edinburgh University design study using the OCO specifications as a baseline. Objective was to improve SNR and/or decrease size of the design

Scientific	Technical
Swath width: 10 km Sampling 1.3 km by 2.2 km	Slit length: 50 arc-minutes Slit width: 1 arc-minute
Three pass-bands : O_2, Weak CO_2, Strong CO_2	Wavelengths: 0.765 µm, 1.6065 µm, 2.062 µm
Spectral Resolution: 24,000	Sampling at detector: 2 – 3 pixels
Signal to Noise Ratio: >300 for CO_2 >240 for O_2	Detector: 1024 × 1024 px 18 µm pitch
(Observe both polarisation states)	

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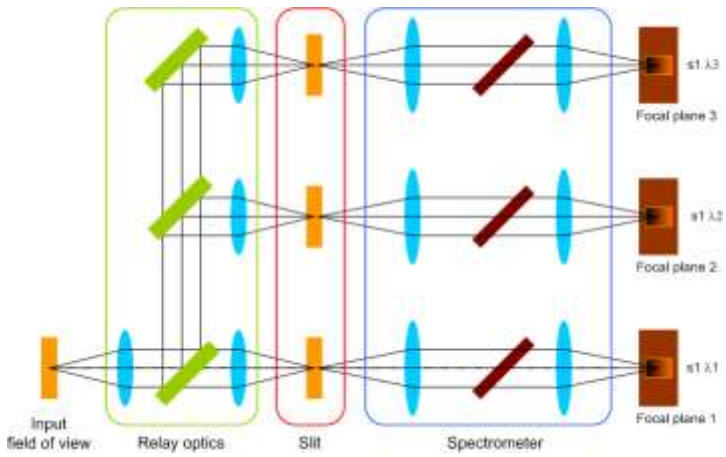
OCO block diagram



3 spectrometers, 20% utilisation of detectors

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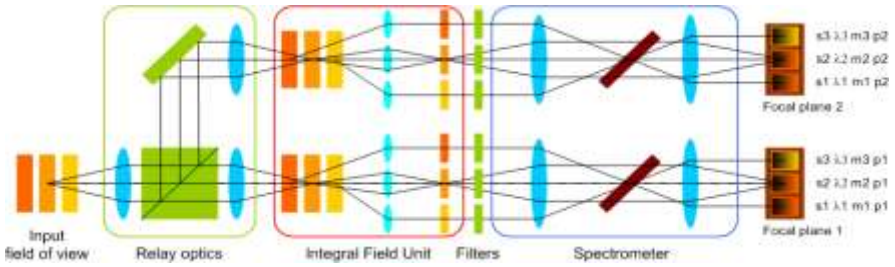
Concept system



- Relay optics split the two polarisations – observing both polarisations improves efficiency and avoids needing to match slit orientation to the source polarisation.
- Mutliple-order spectrograph design to provide 3 wavelength channels from one spectrograph

Comparison to existing system

OCO layout

Image slicing spectrometer layout

Performance comparison

Concept	Orbiting Carbon Observatory	CEOI integral field spectrometer concept
Number of spectrometers	3	2
Number of detectors	3	2
Number of slits	1	3
Transmittance	1	1.5
Number of polarisations	1	2
Signal to noise ratio	1	1.22
Instrument Volume/Mass estimate	1	0.7
Power estimate	1	0.7
Cost estimate	1	0.8
Redundancy	1	2

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Second CEOI Seed corn project PERSIST

- PERSIST: Prototype Earth obseRving System using Image Slicer Technology
- Aim was to prove the design by building a bench mounted prototype image slicer spectrometer with a SWIR detector system.
- The system would simultaneously capture three wavelength ranges (via three slices) on one detector.
- Needed to demonstrate the feasibility of the technology for use in an Earth Observation instrument to measure atmospheric CO_2;
  - Show three clear spectra on one detector
  - Measure cross talk and stray light
- Increase TRL of multiple-order spectrometer

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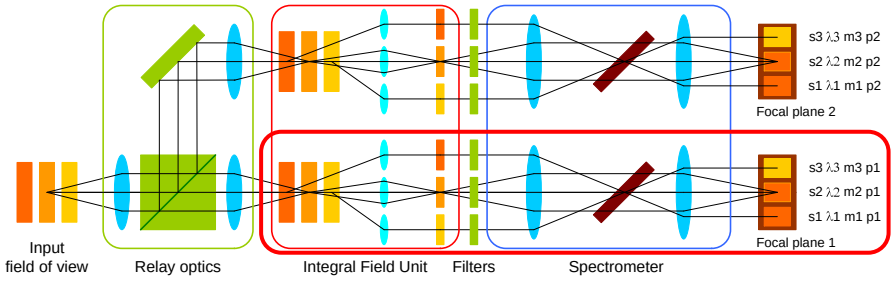
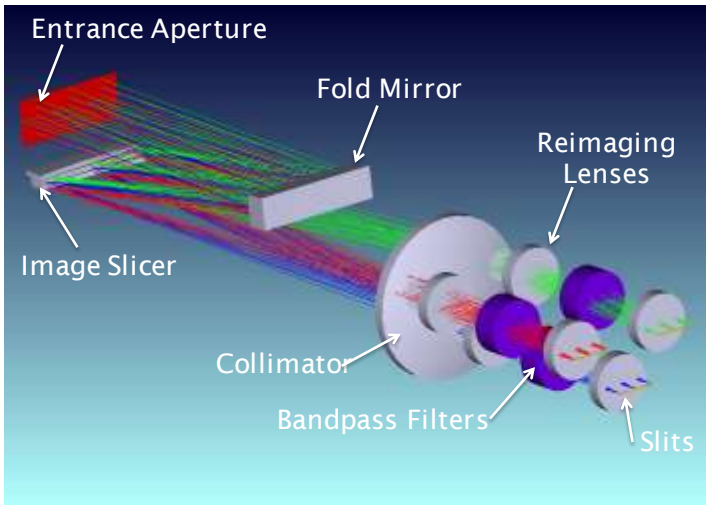


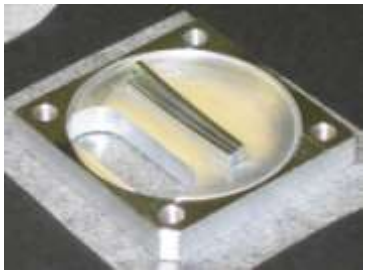
- Telescope simulator built from COTS components.
- Image slicer sub-system was custom made – assembly made portable for display purposes.
- Bench spectrometer with COTS lenses and COTS Echelle diffraction grating.
- Light source and SWIR detector are existing UK ATC systems.

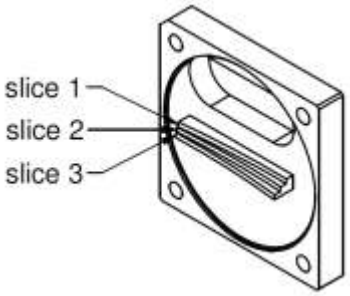
Optical layout of PERSIST IFU



PERSIST Image Slicer

- Diamond machined aluminium.
- Off-axis spherical slices.
- Component includes input aperture.
- Area surrounding slice will have a black mask.





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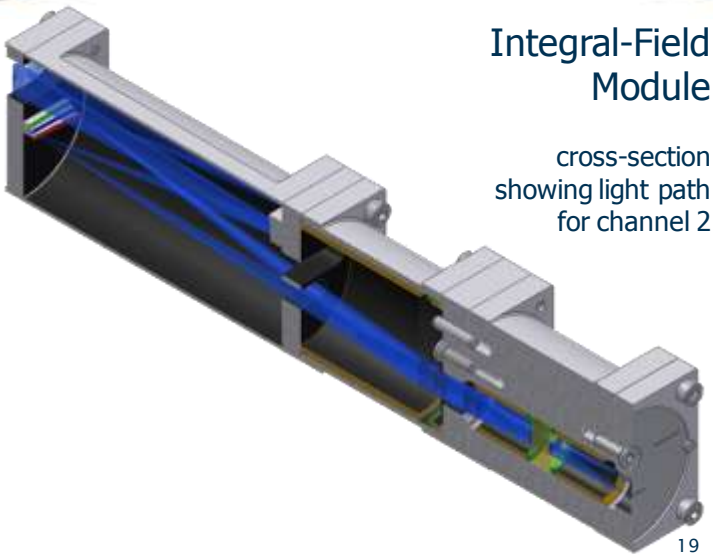
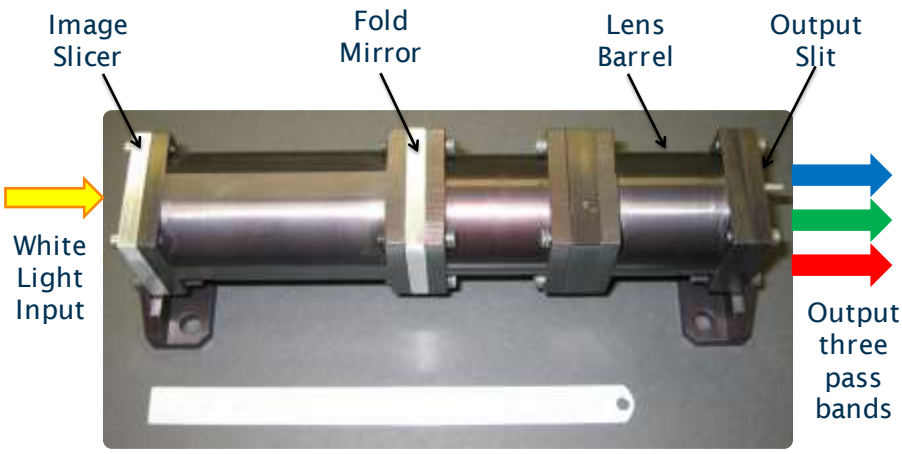
Integral-Field Module

cross-section showing light path for channel 2



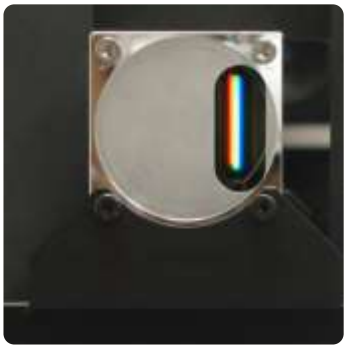
Fully Assembled IFU module



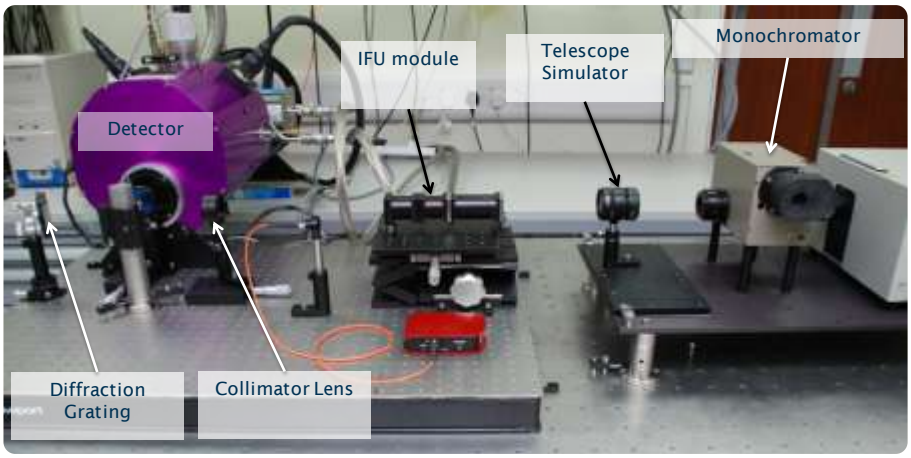
Layout of output slit

Picture of IFU output slit showing the three wavelength channels

Reverse illumination to demonstrate field of view



PERSIST – Fully Assembled



Simultaneous Capture of Three Spectral Bands

Illumination with a Filament Lamp

Uniform Illumination

1600 nm

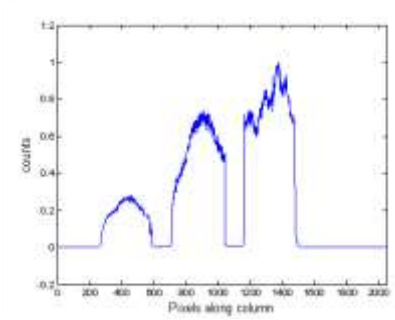
1020 nm

2000 nm

Measurement of Scattered Light

Contrast enhanced image showing scattered light between spectra

Plot of intensity along a column, scattered light level is < 2 % of peak intensity



Summary of Test Results

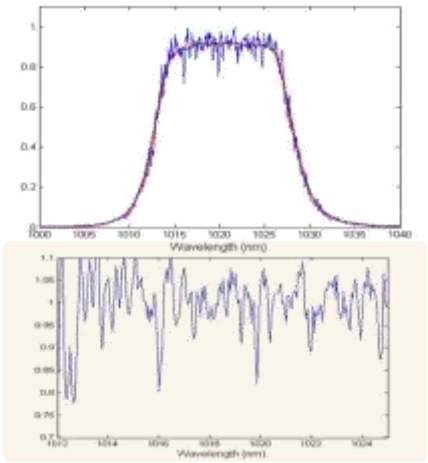
Test	Results
Wavelength scan 0.8-2.5 μm to check for light leaks	No light leaks found at a level ~10^{-4}
Ghost images	Seventh order ghost for central slit, can be moved out of field of view by adjusting grating angle
Scattered Light	1 – 2 % measured between spectra – consistent with scattered light modelling of un-coated lenses and filter. Sufficient gap to avoid cross talk.
Image quality	Full system degrades image by 2-3 pixels FWHM – consistent with use of simplified optical design
Spectral Resolution	Measured to be ~2,700

Example atmospheric spectrum

Test set-up

- Small telescope located outside lab
- Telescope pointed directly at sun
- Optical fibre feed to PERSIST
- Spectrum formed shown below

Plot of 1020 nm spectrum



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Current status and next steps

- Report on design for trace gas analysis (SWIR) shows size/cost/efficiency beneifts
- Lab tests prove image quality and throughput efficiency
- ESA ITI offer to raise TRL level of design
- Multi-order spectrometer design re-used in GHOST instrument for NASA Global Hawk (to fly in 2015)
- Expanding science uses;
  - Shorter wavelengths — Greater multiplex
  - Smaller instruments — Faster instruments
- Industrial involvement

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