Proba-1 CHRIS End of Mission Workshop

18–19 January 2024 | Ghent, Belgium

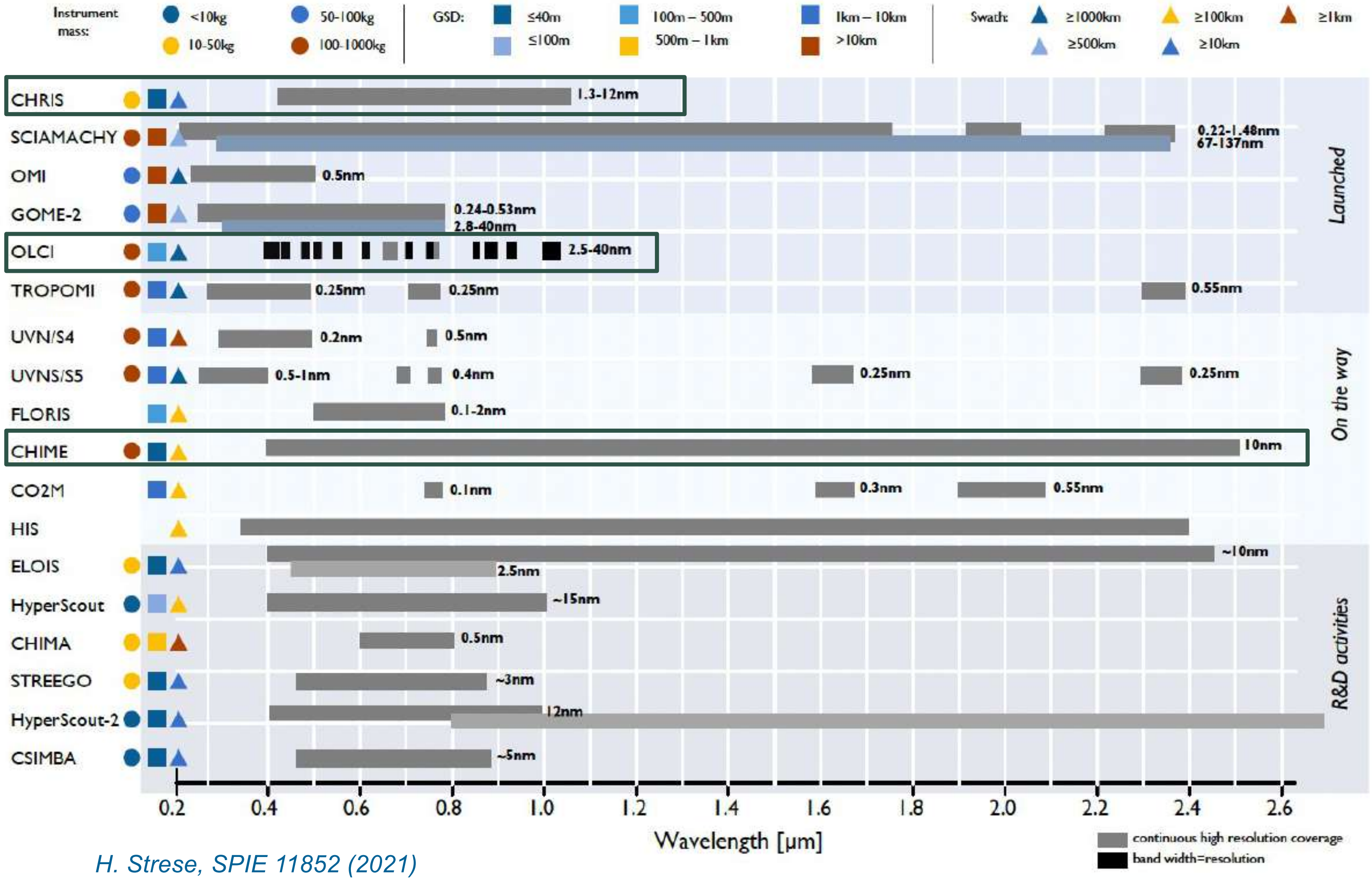
From CHRIS to CHIME: a journey into ESA's imaging spectrometers for EO

J.Nieke, H.Strese, L.Maresi, M.Celesti, S.Lavender and the CHIME Team

ToC

ESA's contribution to Imaging Spectrometers

Imaging spectrometers developed in the frame of ESA contracts are listed.



H. Strese, SPIE 11852 (2021)

Lets focus on “Imaging Spectrometers”

Main driving requirements for Imaging Spectroscopy:

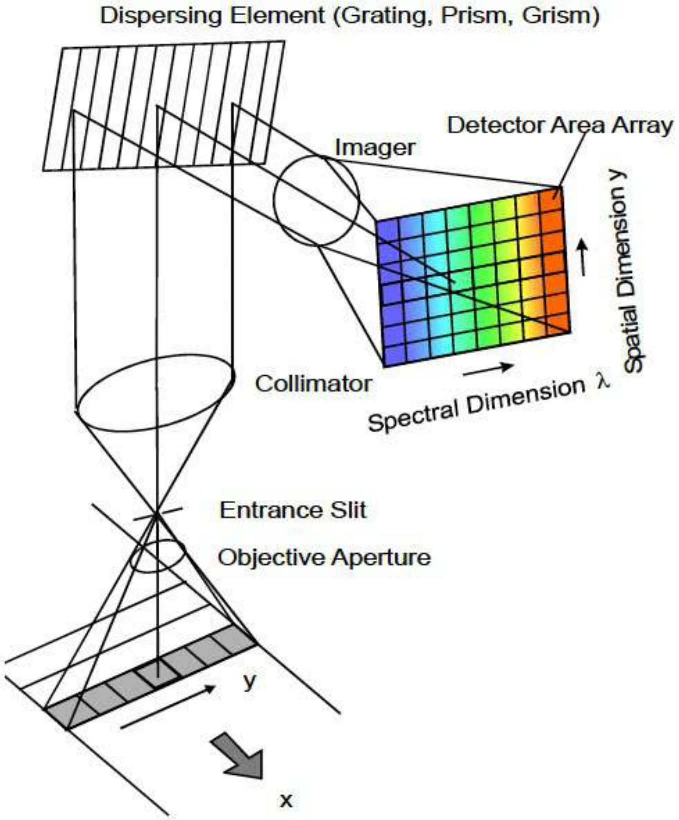
1. **high Signal to Noise Ratio**
2. **high Uniformity**, i.e., low spectral and spatial distortion

Combined with the need to maximize Small GSD & Wide Swath.

Imaging principle allowing to meet those requirements in regional/global scale observation:

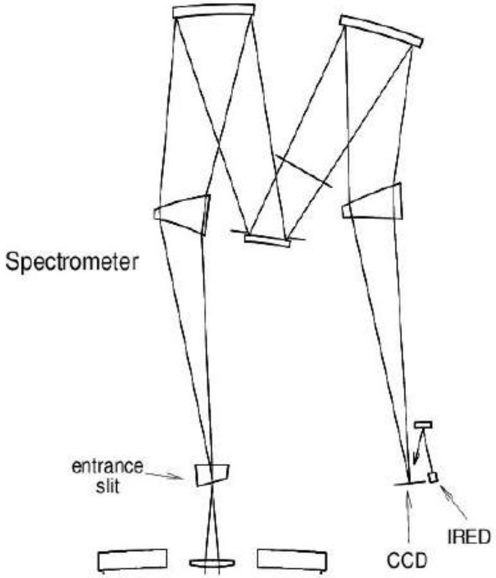
- Instant retrieval of the full spectrum for each spatial pixel along the entire swath the need for uniformity can be achieved (no linear filters, no slew manoeuvres).

- Spectral and Spatial uniformity means: low spatial and spectral misregistration, allowing column-based algorithm retrieval and even sub-pixel target detection.

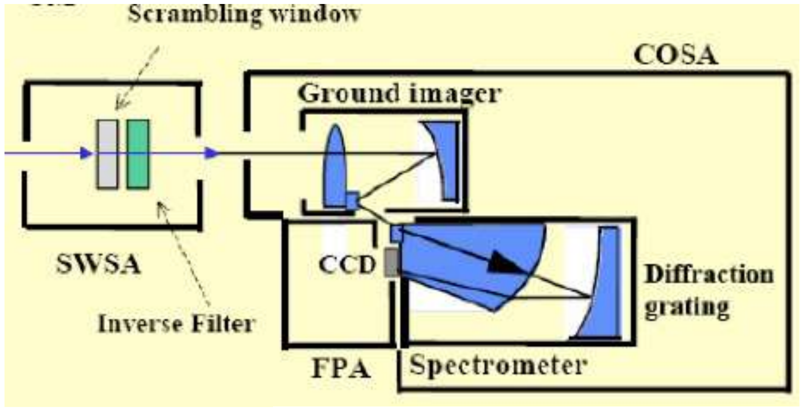


3 examples

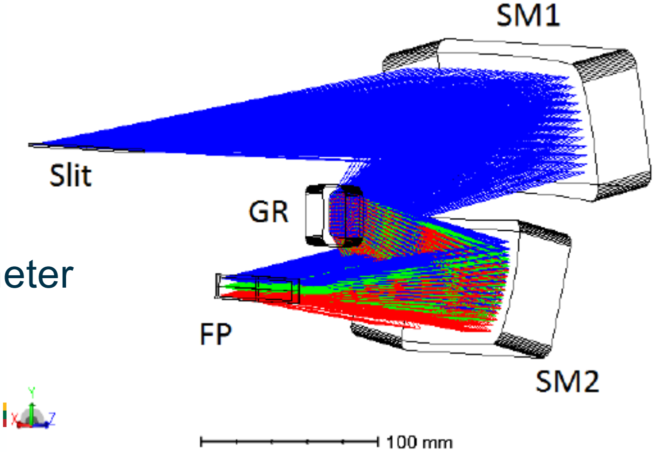
CHRIS: Offner Imaging Spectrometer using refracting curved fused glass prisms with three mirror relay.



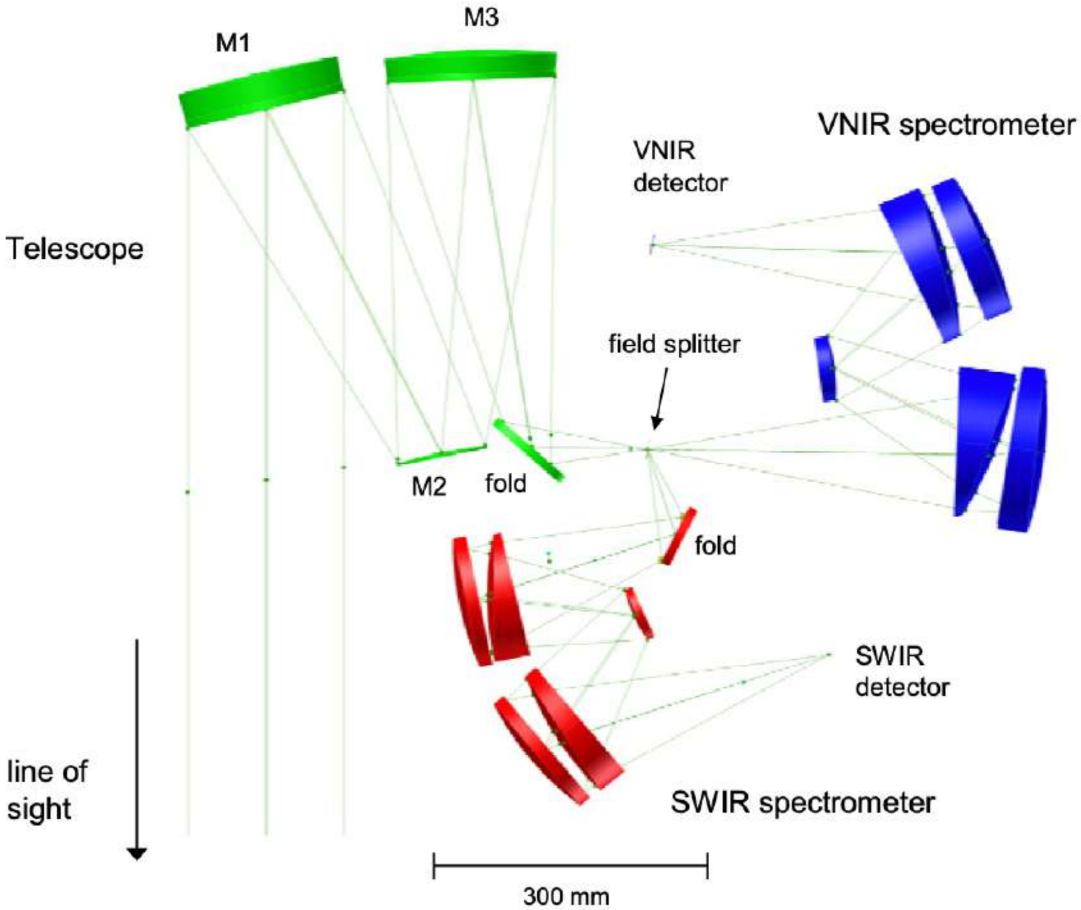
MERIS/OLCI: Dyson Imaging Spectrometer Concave grating, catadioptric design, low F#.



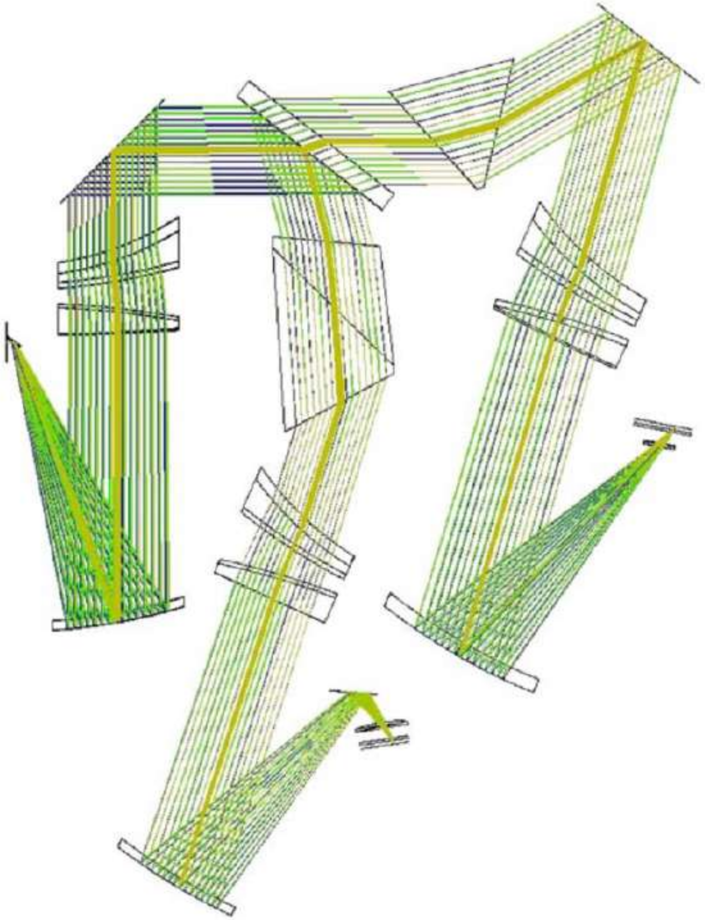
CHIME: Offner Imaging Spectrometer



EnMAP(DLR) and PRISMA(ASI) using Prisms



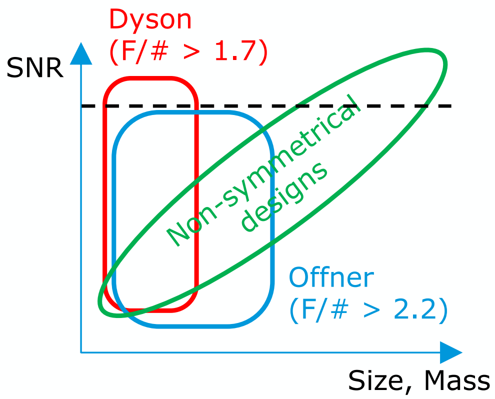
ENMAP optical system, *Sang 2008*



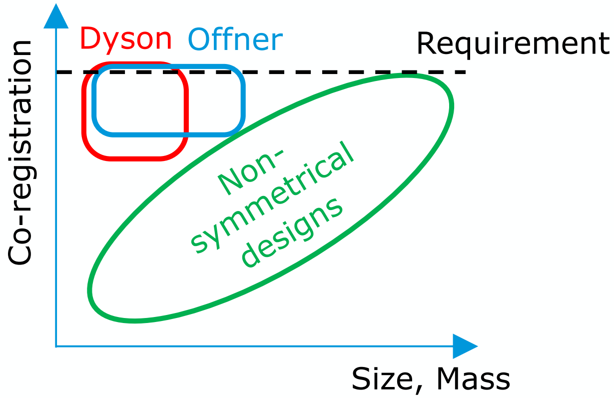
PRISMA NIR/SWIR spectrometer layout (without telescope) *Labate 2009*

IS Design Considerations

High SNR → low F/#
→ high transmittance
→ min. number of optical surfaces



Low distortion: Spatial and spectral co-registration
→ symmetric designs (inherently low aberrations)
→ reflective designs preferable (dispersion!)
→ min. number of spectral bands (preferably one band)



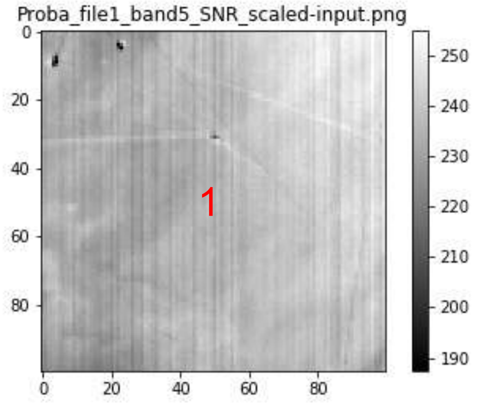
	f-number (*f*/#)	Focal lengths L [mm]	Aperture D [mm]
CHRIS	6	746	120
MERIS/OLCI	~2	67.3	20x32
ENMAP	3	522	174
PRISMA	3	620	210
CHIME	Telescope 5 Instrument 3	Tele 1329 (0.6 magnification)	260

Windpassinger 2018

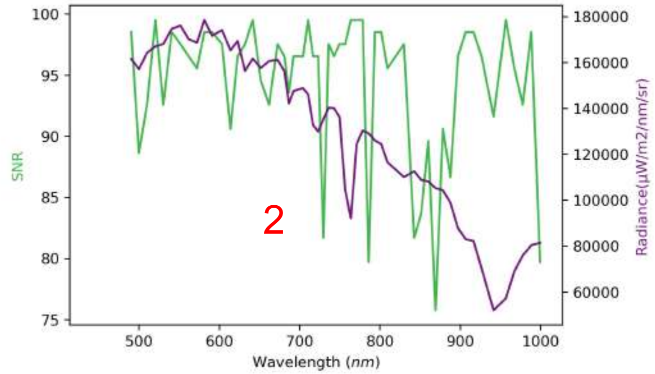
Compare CHRIS vs CHIME SNR

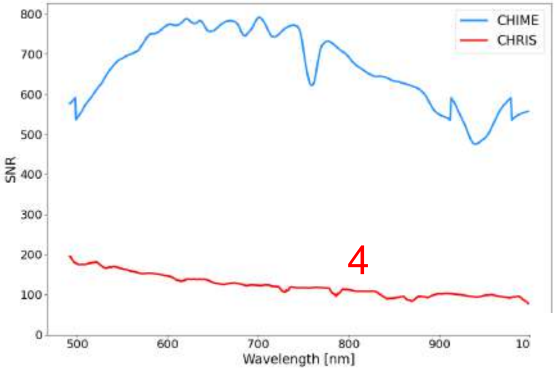
1. CHRIS data in Mode 1 Band (62 spectral channels in native spectral resolution i.e., 1.25nm at 415nm, increasing to 11.25nm at 1050nm)
2. TOA radiance and SNR in native spectral resolution
3. Native resolution SNR and 10nm scaled using Barnsley 2004 under the assumption that the signal is photon noise limited
4. Comparison of scaled CHRIS SNR with CHIME SNR for same TOA radiance

Railroad Valley Playa site



Modified from Lavender et al IGARSS 2022





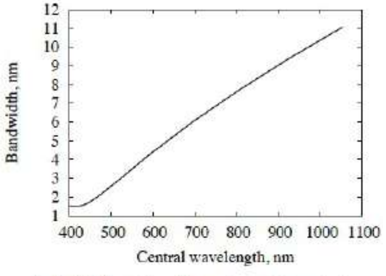
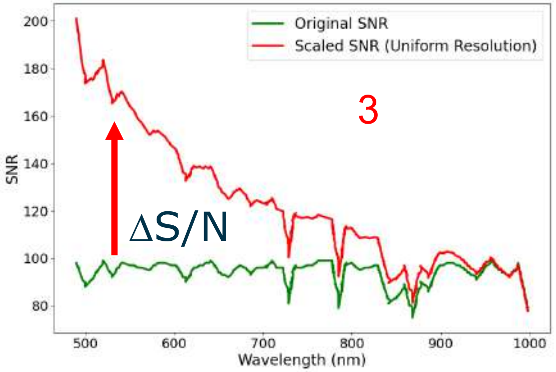


Fig. 2. CHRIS spectral resolution against central wavelength.

Barnsley 2004



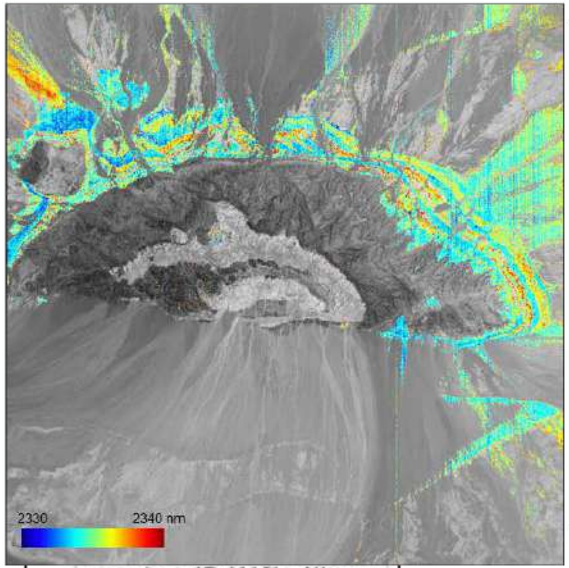
Scaling estimate:

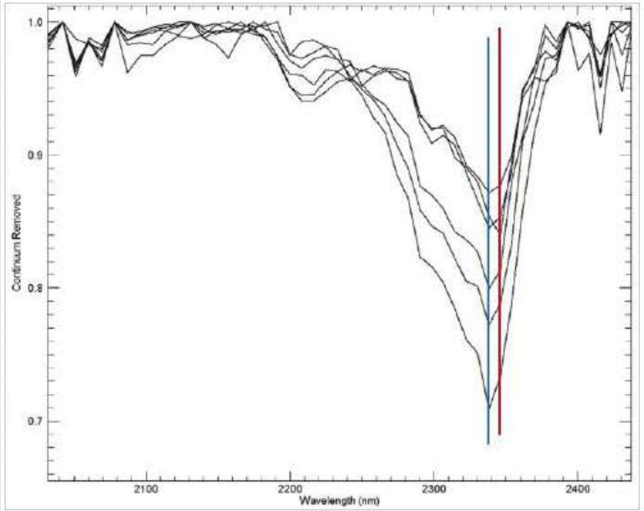
$$\Delta S/N = d\lambda\, N_e / (d\lambda\, N_e)^{1/2} = (d\lambda\, N_e)^{1/2}$$

No compromise on SNR, and here is why:

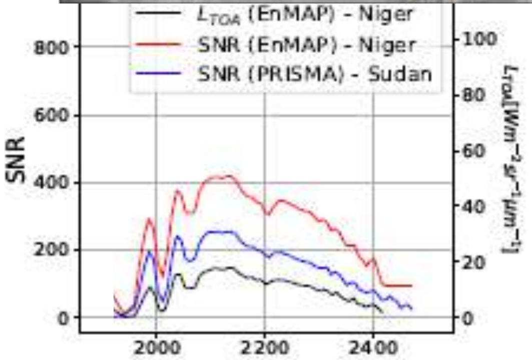
Siah-Kuh: Carbonate mapping

EnMAP data can depict <10 nm shifts in the minimum wavelength of carbonate minerals.





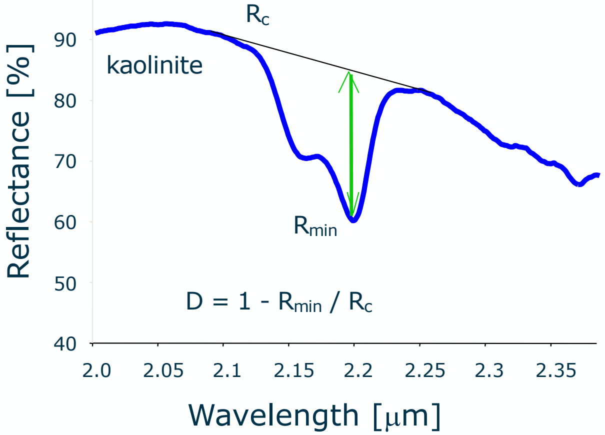
Asadzadeh and Chabrillat (2023)



TOA radiance (black) and SNR (red) spectra of an EnMAP dataset from a Niger area and a SNR spectrum of a PRISMA dataset from a Sudan area (blue).

Each material on the Earth‘s surface has a unique spectral characteristic

Pigments, Minerals, Man Made Objects



Identification / Quantification => Diagnosis

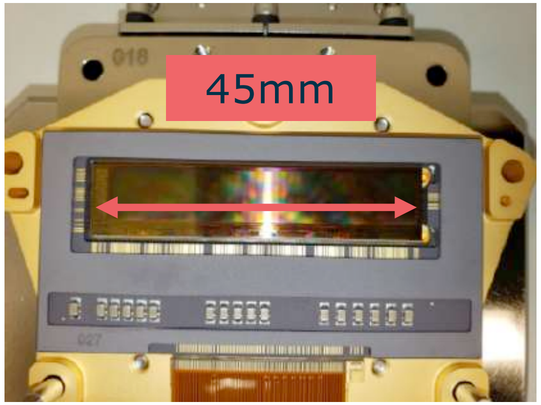
Shape
Position
→ Identification

Depth → Quantification

Three technologies advancements paved the way to move to Global IS observatory

Nieke et al SPIE 12729 (2023)

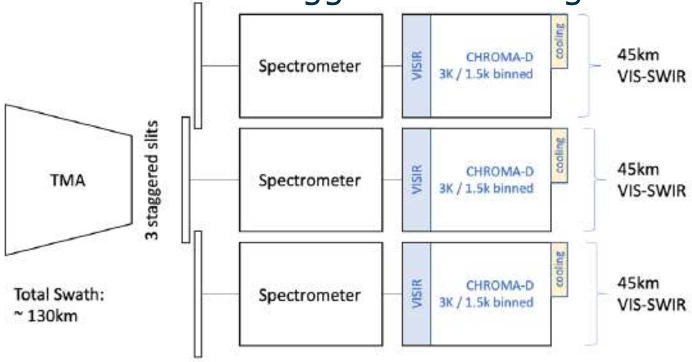
1. A **large detector** with high sensitivities over a wide spectral range (VIS-SWIR).
2. A **compact imaging spectrometer** with common TMA to accommodate three spectrometers in its focal plane and **Dual blaze grating** to cover the full spectrum.
3. **On-board data processing** using new artificial intelligence functions.



Detector VM 3072x512 pixels
Swindells et al. SPIE 12777

Wijata et al. IEEE GRSM (2023)
Vitulli et al 4S Symp (2022)

Telescope and spectrometers for the staggered slit design



Buschkamp et al SPIE 12777,
Borguet et al SPIE 12777 (2023)

1) Large detector with high sensitivities over a wide spectral range (VIS-SWIR)

Need: A fast large detector with on chip amplifiers, low noise and sensitivitie
a wide spectral range (VIS-SWIR) allows to retrieve the entire spectrum of a ground pixel at once using a single spectrometer.

Solution: Teledyne e2v detector and package (3Kx512 CHROMA-D VIS-SWIR)
- CHROMA-D18 ROIC is an 18 micron pixel digital readout integrated circuit
- stitch blocks enable detector sizes in formats that scale in blocks of 1024 columns by 512 rows allowed to move to 3k.
- each block has 2 primary high speed outputs, running at 1.6 Gbps.

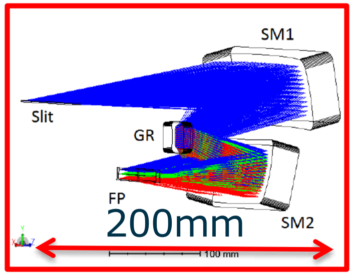
A large swath of 130km with 30m resolution requires approximately 4500 pixels. Detector pixels are binned to achieve the full well necessary to reach the high SNR.

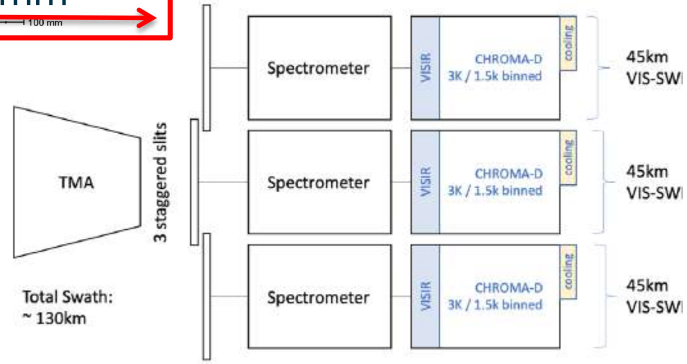
Swindells et al. "Infrared detector developments at Teledyne e2v for current and future missions," SPIE 12777, International Conference on Space Optics — ICSO (2023)

2) Compact imaging spectrometer with Dual blaze grating

Need: Continuous pushbroom operations (no motion compensation to increase the integration time) and high SNR.

Solution: Imaging Spectrometer with a low F# (F#/3.3 or lower to satisfy the SNR). Using a modified Offner with a demagnification of 0.6 was designed. The demagnification allowed to increase the F# of the telescope to 5.5, making the telescope easier to manufacture. A TMA will be able to accommodate three spectrometers in its focal plane.



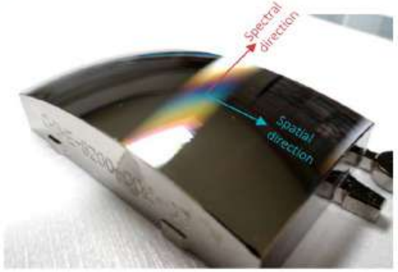


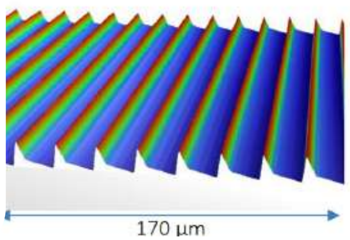
Buschkamp et al SPIE 12777,
Borguet et al SPIE 12777 (2023)

Need: High optical efficiency and low straylight

Solution: Offner Design with only 7 reflective optical elements (TMA, folding mirrors and an Offner modified spectrometer with two mirrors and the grating).

- A Grating is in general the largest straylight contributor. But recent advances of Single Point Diamond turning allows roughness and groves depth being controlled within a few nanometres.

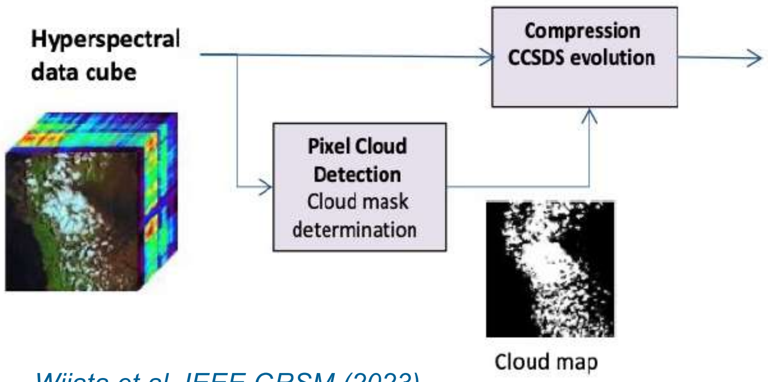


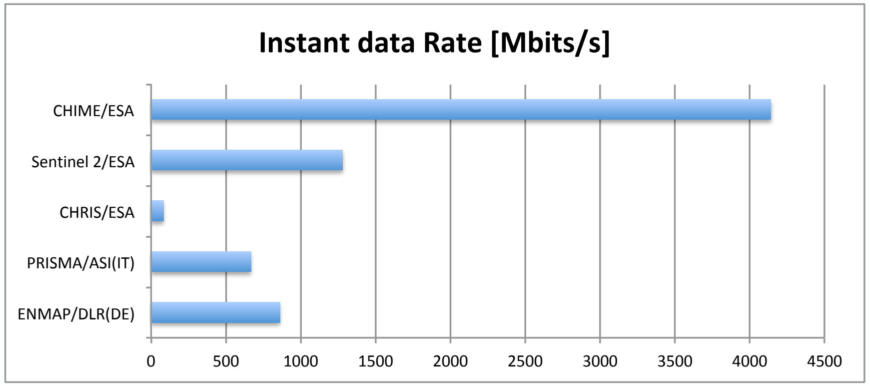


3) On-board data processing using new artificial intelligence functions

Need: Global acquisition asks for continuous data throughput close to 5 Gb/s acquired over land and coastal areas; the CHIME payload will deliver about 1 Tb of data per orbit. Downloads are foreseen within 6–12-min visibility time slots over Ground Stations with a Ka-band link, which offers up to a 3.6-Gb/ s download data rate.

Solution: The CHIME Data Processing Unit (DPU) performs on-board image selective compression for ground and cloud pixels. The implemented solution consist of a classifier (based on artificial intelligence techniques, i.e. Support Vector Machine), whose output mask is used to drive the selective compression.





Wijata et al. IEEE GRSM (2023)
Vitulli et al 4S Symp (2022)

Space Segment

Prime Contractor: **Thales Alenia Space France** (TAS-F)

Status:

KO: 2020, Currently in Phase C, CDR: 2024/25, QAR of PFM: 2028

Instrument Prime: **OHB (DE)** with

- LEONARDO (IT) for Focal Planes & E2E Calibration
- AMOS (BE) for 3 x spectrometer, gratings and slits
- Teledyne E2V (UK) for the Detection Unit

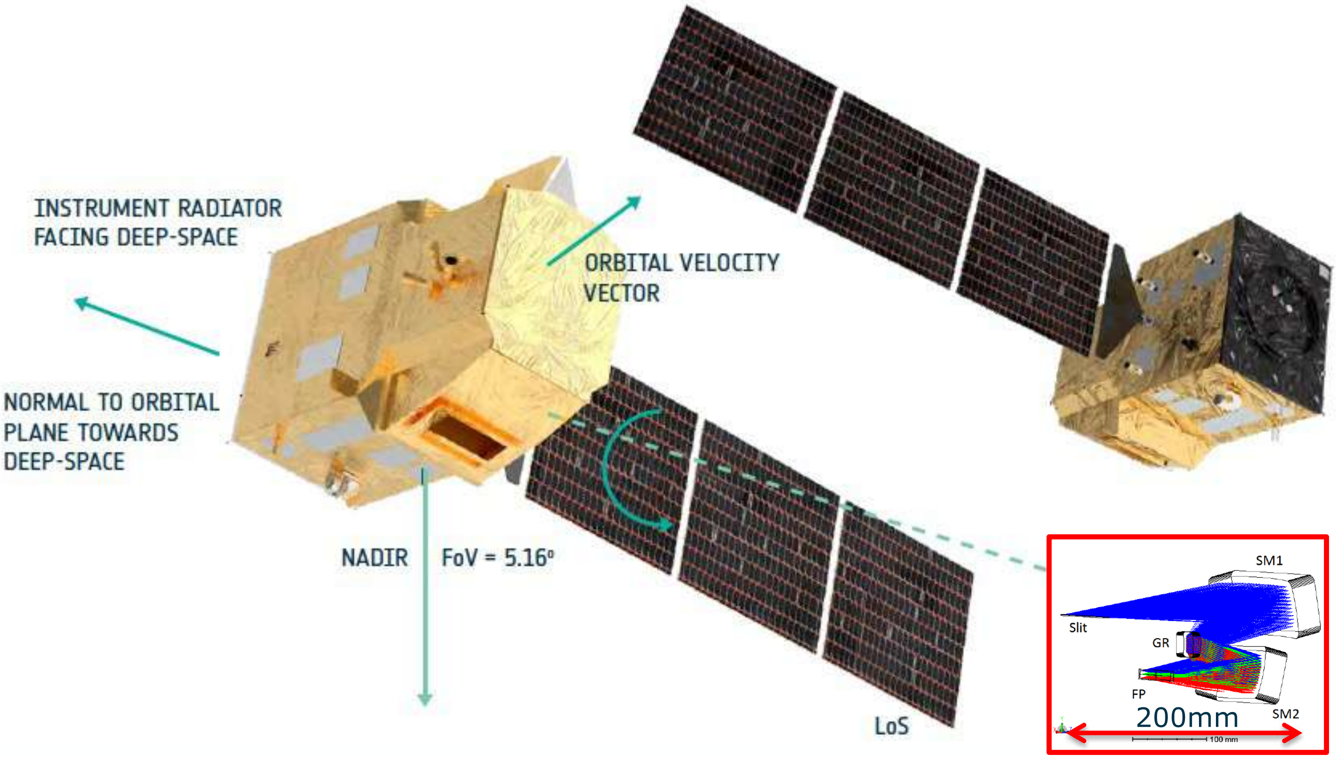
CHIME ORBIT and PLATFORM

Orbit

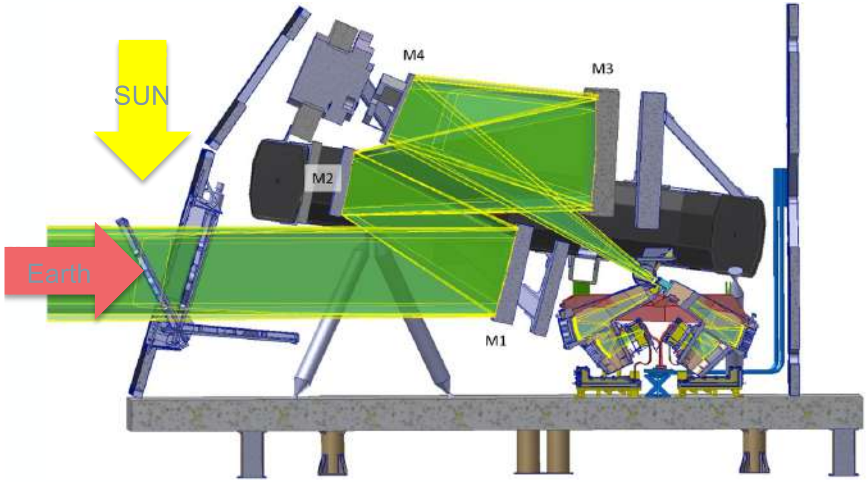
- 632 km mean altitude
- 22 days repeat cycle (1 S/C)
- 10:45 AM local time at descending node

Platform

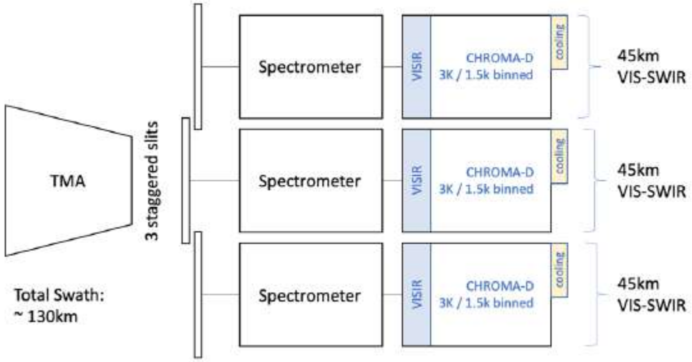
- 7.5 years lifetime
- Consumables for 5 yrs mission extension
- Gyroless
- 16 Tbit mass memory
- Ka-band downlink at 3.7 Gbps
- Controlled de-orbiting
- 1852 kg wet mass
- Onboard data processing (AI-based cloud-detection and compression) Data Processing Unit (DPU)



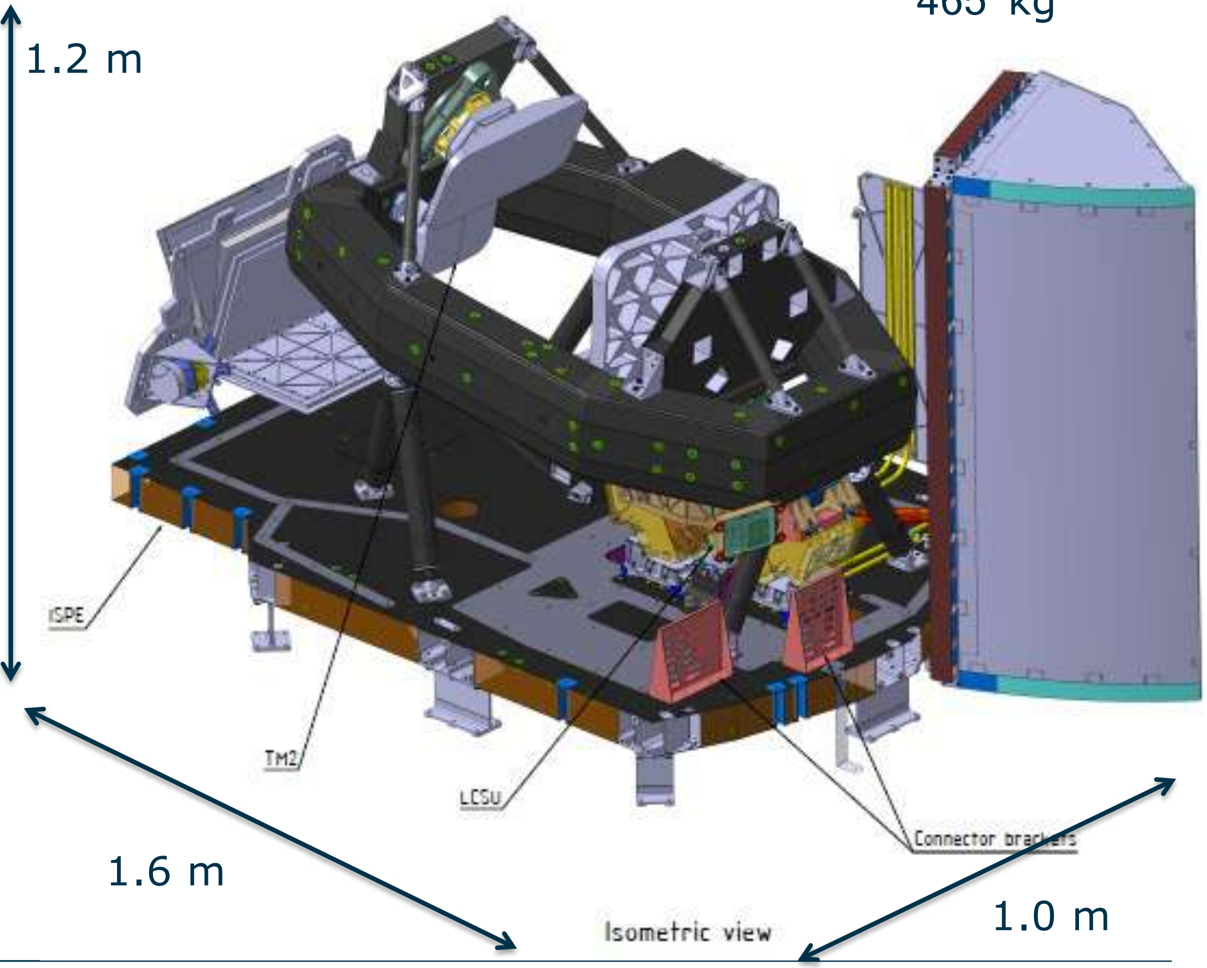
HyperSpectral Imager HSI



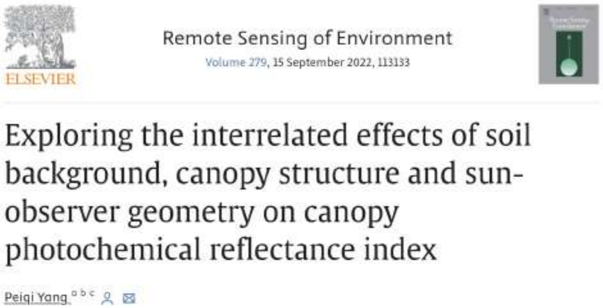
Conceptual design for the optical accommodation of telescope and spectrometers for the staggered slit design



465 kg



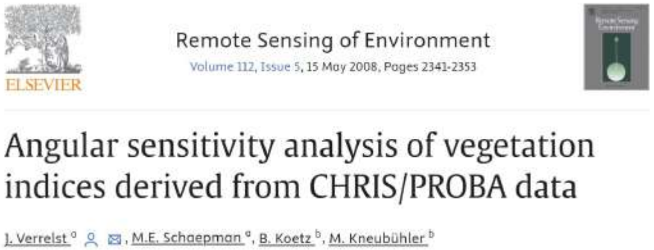
CHRIS: The leap forward for Imaging Spectroscopy


Remote Sensing of Environment
Volume 279, 15 September 2022, 113133

Exploring the interrelated effects of soil background, canopy structure and sun-observer geometry on canopy photochemical reflectance index

Peiqi Yang [a b c]

… accounting for viewing geometry


Remote Sensing of Environment
Volume 112, Issue 5, 15 May 2008, Pages 2341-2353

Angular sensitivity analysis of vegetation indices derived from CHRIS/PROBA data

J. Verrelst [a], M.E. Schaepman [a], B. Koetz [b], M. Kneubühler [b]

Building Capacity especially for
1) BoA BRDF corrections
2) Development of new retrieval algorithms
3) Input for essential time series

… developing new products

… exploring hyperspectral time series

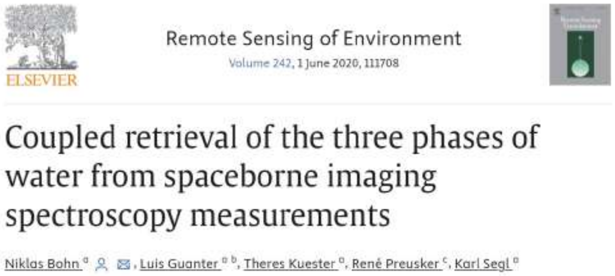

remote sensing

MDPI

Article

Functional Phenology of a Texas Post Oak Savanna from a CHRIS PROBA Time Series

Michael J. Hill [1,2,*], Andrew Millington [2], Rebecca Lemons [1] and Cherie New [1]


Remote Sensing of Environment
Volume 242, 1 June 2020, 111708

Coupled retrieval of the three phases of water from spaceborne imaging spectroscopy measurements

Niklas Bohn [a], Luis Guanter [a b], Theres Kuester [a], René Preusker [c], Karl Segl [a]

Lessons From CHRIS (Lobb & Cutter (2004)):

DESIGN OF THE COMPACT HIGH-RESOLUTION IMAGING SPECTROMETER (CHRIS), AND FUTURE DEVELOPMENTS

Mike Cutter, Dan Lobb

Sira Technology Ltd, South Hill, Chislehurst, Kent, BR7 5EH, UK.

Mike.Cutter@sira.co.uk, Dan.Lobb@sira.co.uk

1) Spectrometer Design
…using curved prisms …is a strong candidate for extension for more demanding requirements, such as those of SPECTRA.

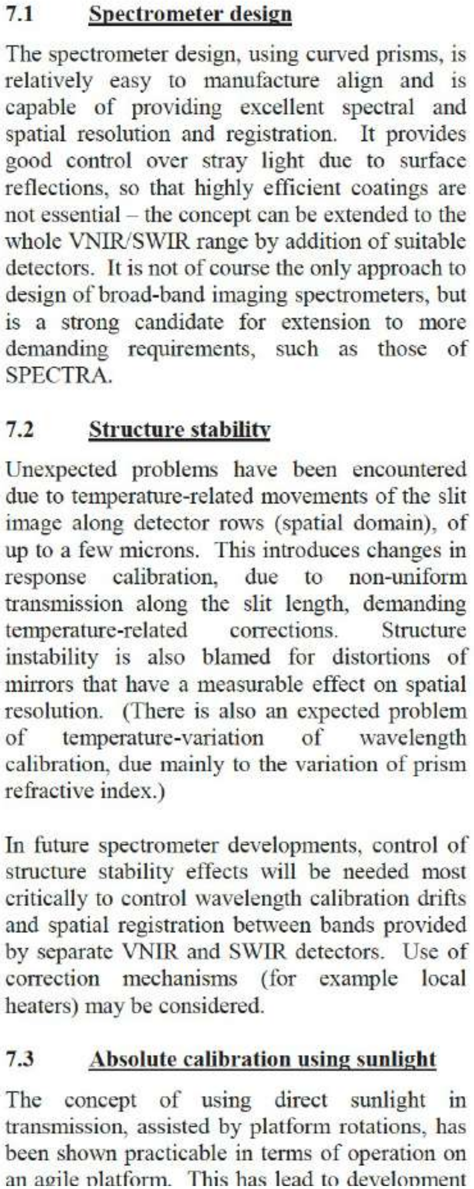
☑

2) Structure Stability
…control of structure stabilty effects ...needed to control wavelengths drifts and spatial registration between VNIR and SWIR detectors

☑

3) Abolute calibration using sunlight
…direct sunlight in transmission … has shown practible in terms of operations on an agile platform.

☑



7.1 Spectrometer design

The spectrometer design, using curved prisms, is relatively easy to manufacture align and is capable of providing excellent spectral and spatial resolution and registration. It provides good control over stray light due to surface reflections, so that highly efficient coatings are not essential – the concept can be extended to the whole VNIR/SWIR range by addition of suitable detectors. It is not of course the only approach to design of broad-band imaging spectrometers, but is a strong candidate for extension to more demanding requirements, such as those of SPECTRA.

7.2 Structure stability

Unexpected problems have been encountered due to temperature-related movements of the slit image along detector rows (spatial domain), of up to a few microns. This introduces changes in response calibration, due to non-uniform transmission along the slit length, demanding temperature-related corrections. Structure instability is also blamed for distortions of mirrors that have a measurable effect on spatial resolution. (There is also an expected problem of temperature-variation of wavelength calibration, due mainly to the variation of prism refractive index.)

In future spectrometer developments, control of structure stability effects will be needed most critically to control wavelength calibration drifts and spatial registration between bands provided by separate VNIR and SWIR detectors. Use of correction mechanisms (for example local heaters) may be considered.

7.3 Absolute calibration using sunlight

The concept of using direct sunlight in transmission, assisted by platform rotations, has been shown practicable in terms of operation on an agile platform. This has lead to development

PROGRAMME OF THE
EUROPEAN UNION

Thank you for your attention!

CHIME

Copernicus Hyperspectral Imaging
Mission for the Environment

Jens Nieke

CHIME Project Manager