Hyper Spectral Imagers for Drones and micro Satellites

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Abstract

The arrival of technologies the last decade such as drones, small optics and 3D printing has opened new opportunities in instrumental and sensor development. Size and weight may now be minimized to achieve high performance airborne Hyper Spectral Imager (HSI) capabilities at extreme low cost. Furthermore, a novel concept called Parallel Internet Prototype Production (PIPP) of a satellite HSI aimed to study ocean color will be presented.

19th International EISCAT Symposium 2019 and
46th Annual European Meeting on Atmospheric Studies by Optical Methods, 19th - 23rd August 2019. Oulu, Finland

Motivation

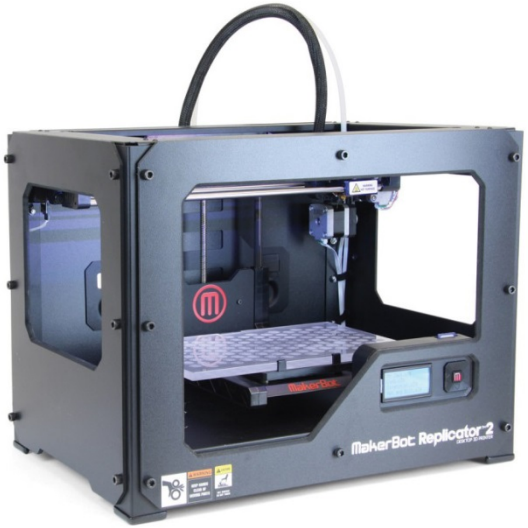
1. It now cost less to buy a drone than hiring a airplane or helicopter for one hour.

2. Low cost camera system with stabilization has been developed for and by the RC community.

3. New high sensitive detectors available (Surveillance, astrophysics, auroral, RC …).

4. 3D printing makes prototyping instruments
- **a)** low cost, ref point 1.
- **b)** low weight / mass.
- **c)** small size.
- **d)** fast …

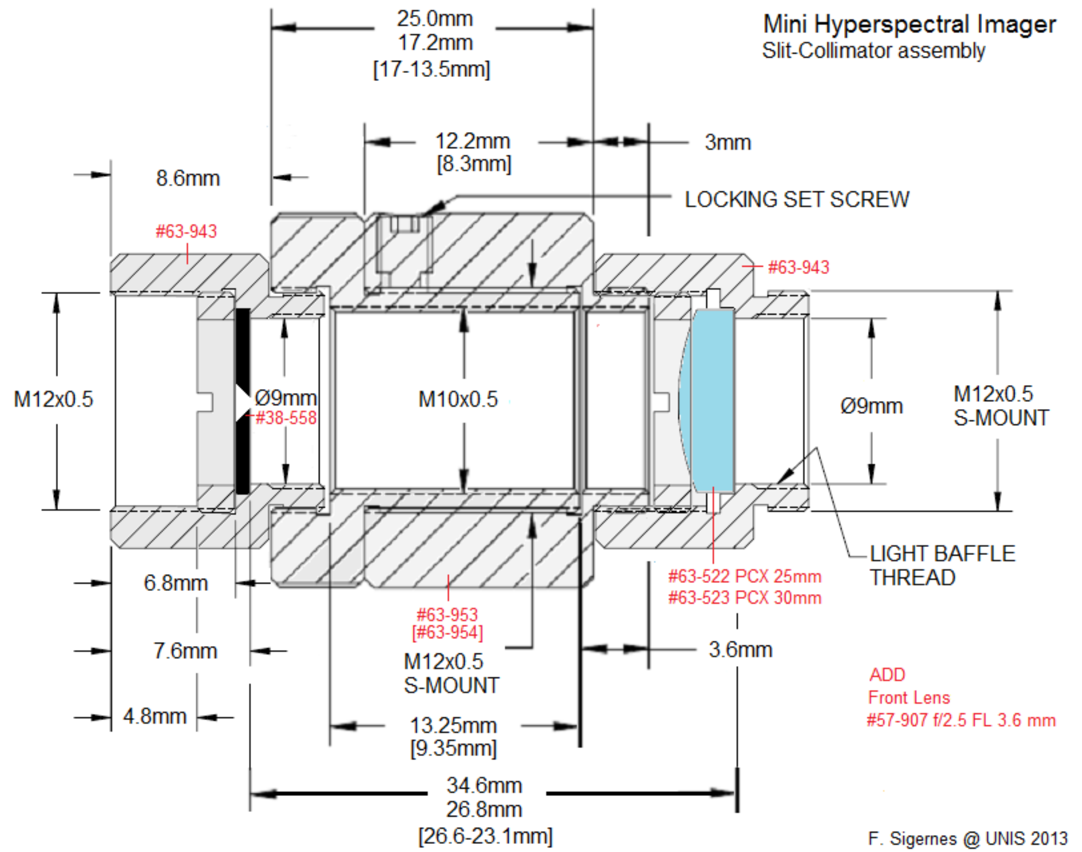
DJI Phantom (2006) and the GoPro (2002)



MakerBot Industries (2009)

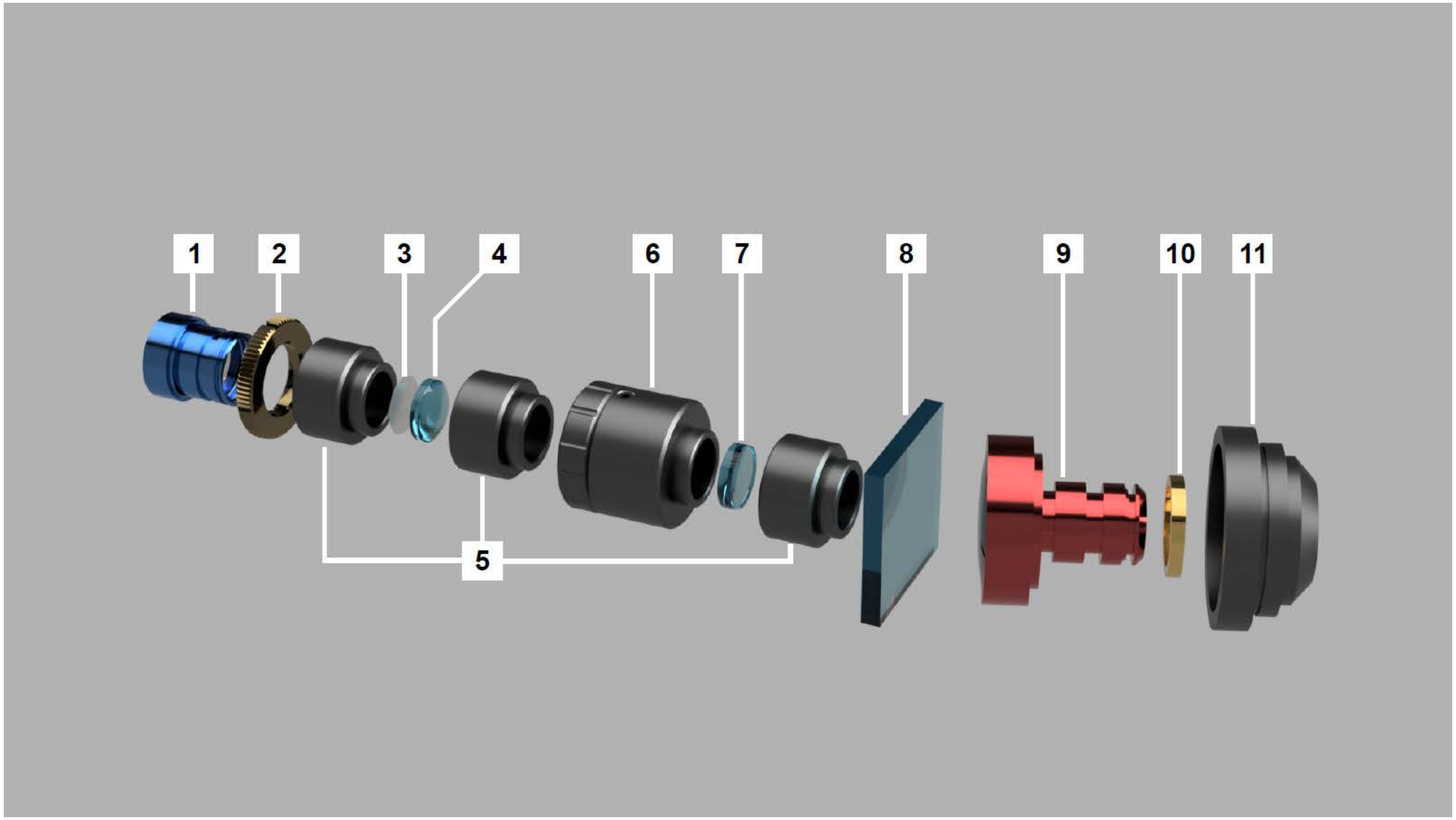
Mix and match assemblies Edmund Optics

Mini spectrograph Slit-Collimator



All parts are from the mix and match assembly from Edmund Optics.

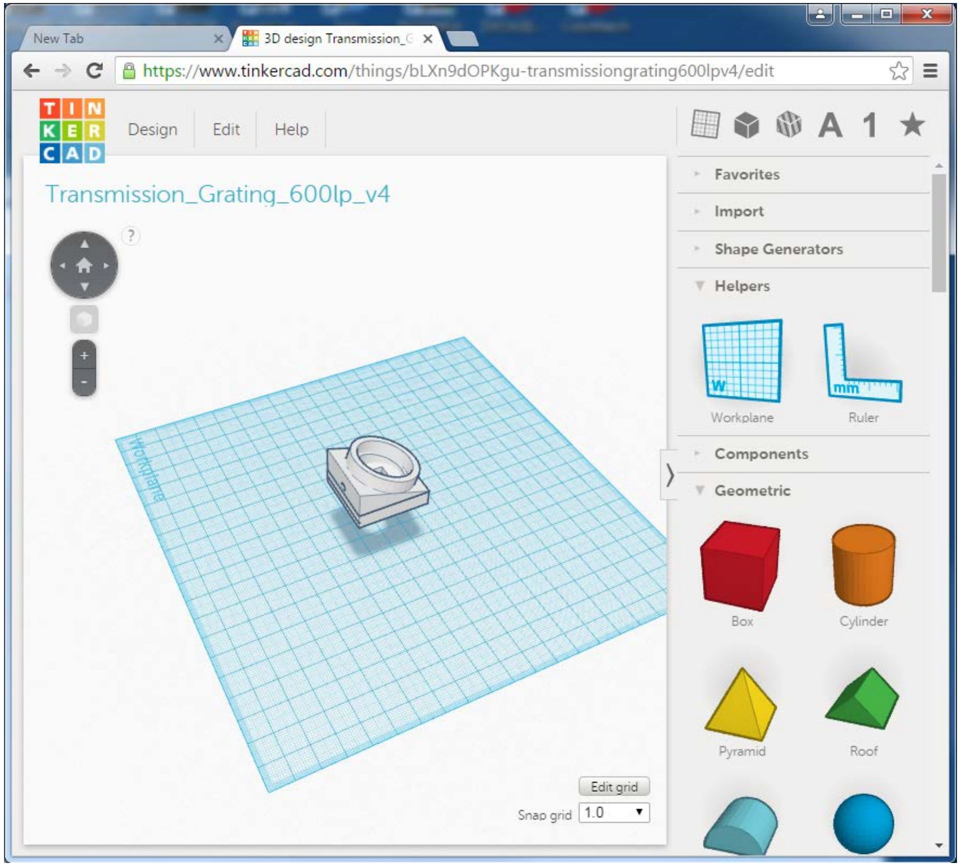
Exploded view of Hyper Spectral Imager (HSI)



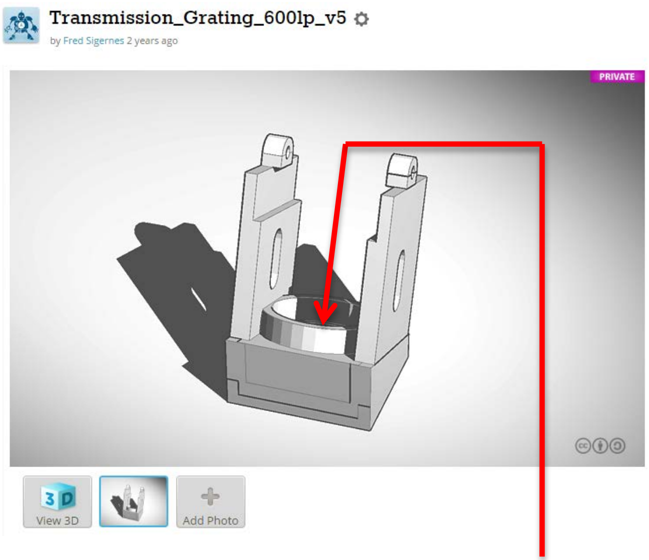
(1) front lens, (2) lock nut, (3) air slit, (4) field lens, (5) three thin lens mounts, (6) focus tube, (7) collimator lens, (8) transmission grating, (9) detector lens, (10) focus spacers, and (11) C-mount lens adapter.

Computer Aided Design (CAD) software

Model 1: Mini spectrograph Grating



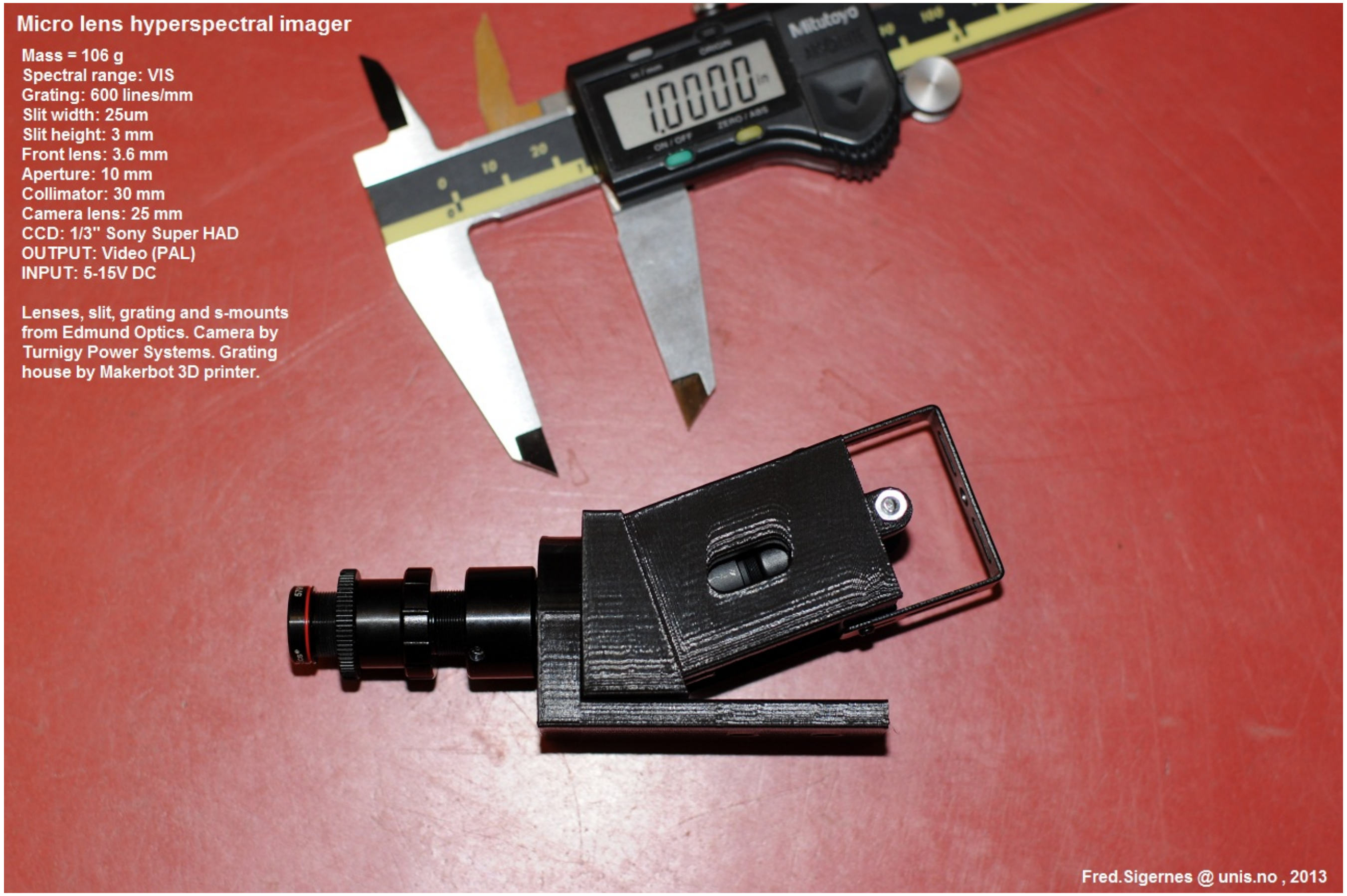
Snapshot TINKERCAD freeware compatible with MakerBot 3D printer. Software is web based!



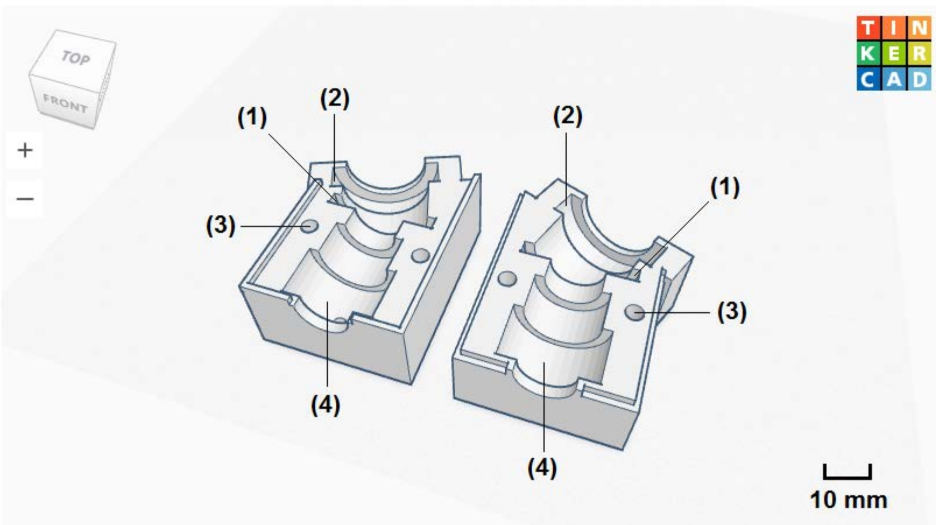
Camera head
Turnigy PAL 700 TVL HobbyKing.com
Sony 1/3-Inch Super HAD CCD

Collector lens
ES 25mm f/2.5

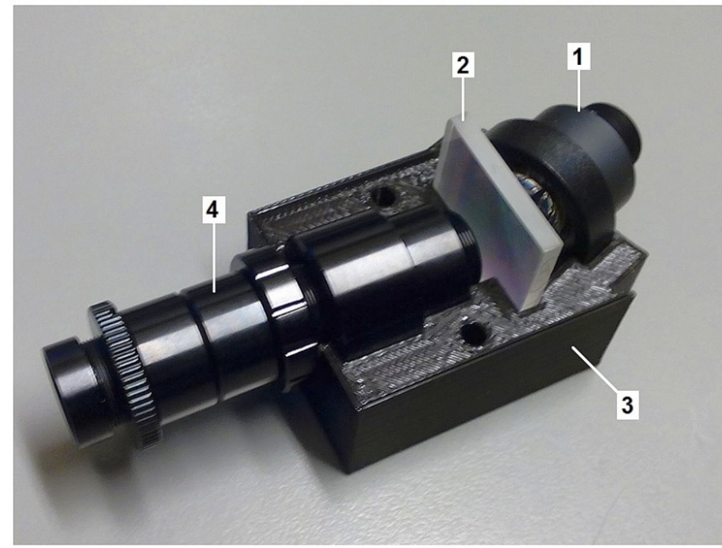
Assembled Hybrid mini pushbroom hyperspectral imager



Model 2: Mini spectrograph Grating - Snap fit design

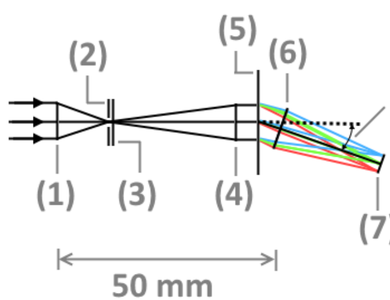


Model 2: (1) 25×25 mm^2 square grating holder, (2) detector lens holder, (3) straight through mount holes, and (4) Collimator-slit-front-optics assembly holder.



Model 2 snap together transmission grating holder: (1) detector lens, (2) 25×25 mm^2 square 600 grooves/mm transmission grating, (3) 3D printed grating holder, and (4) Collimator-slit-front-optics assembly.

Optical diagram: (1) front lens, (2) entrance slit, (3) field lens, (4) collimator lens, (5) 600 lines/mm transmission grating, (6) detector lens, (7) exit focus plane.



$$\lambda = \left(\frac{a}{k}\right) \cdot sin\beta$$

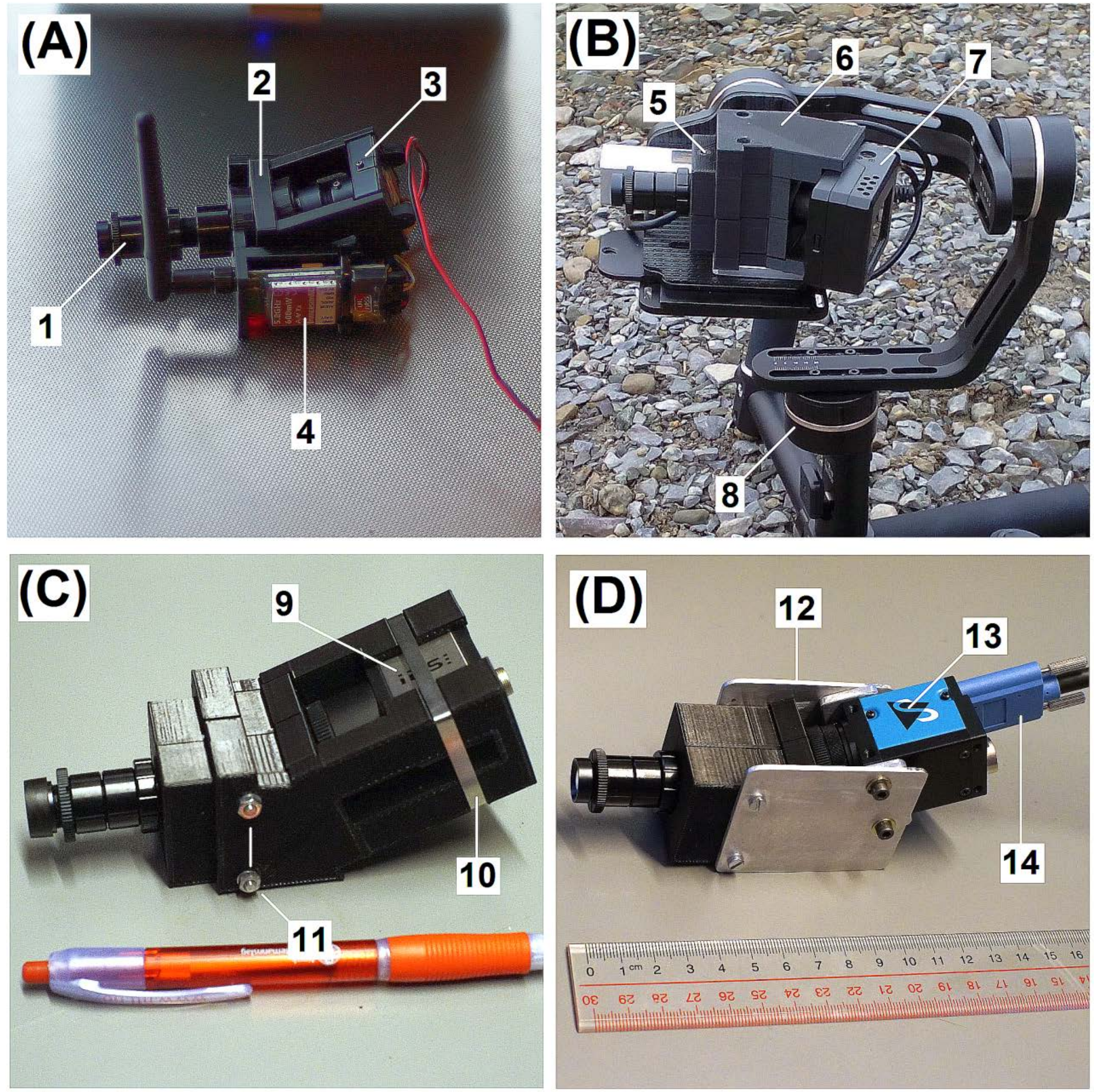
β = 19.36° for wavelength λ = 552.5 nm k = 1

Optical and mechanical parts cost

Item	Description	Part number (EO)	~Cost [US$]
1	Front lens f/4 Focal Length (FL) 16 mm	#83-107	50
2	M12 lock nut for m-video lenses	#64-102	10
3	Precision air slit 25mm x 3mm	#38-558	101
4	Field lens FL = 10 mm	#63-519	38
5	3 x S-Mount thin lens mounts	#63-943	81
6	S-mount focus tube	#63-953	49
7	Collimator lens FL = 30 mm	#63-523	37
8	600 grooves/mm transmission grating $25\times25\ mm^2$	#49-580	105
9	Detector lens f/2.5 FL=25 mm	#56-776	60
10	S-Mount brass spacer rings	#54-461	70
11	C-mount to m-video lens adapter	#53-675	25
			626

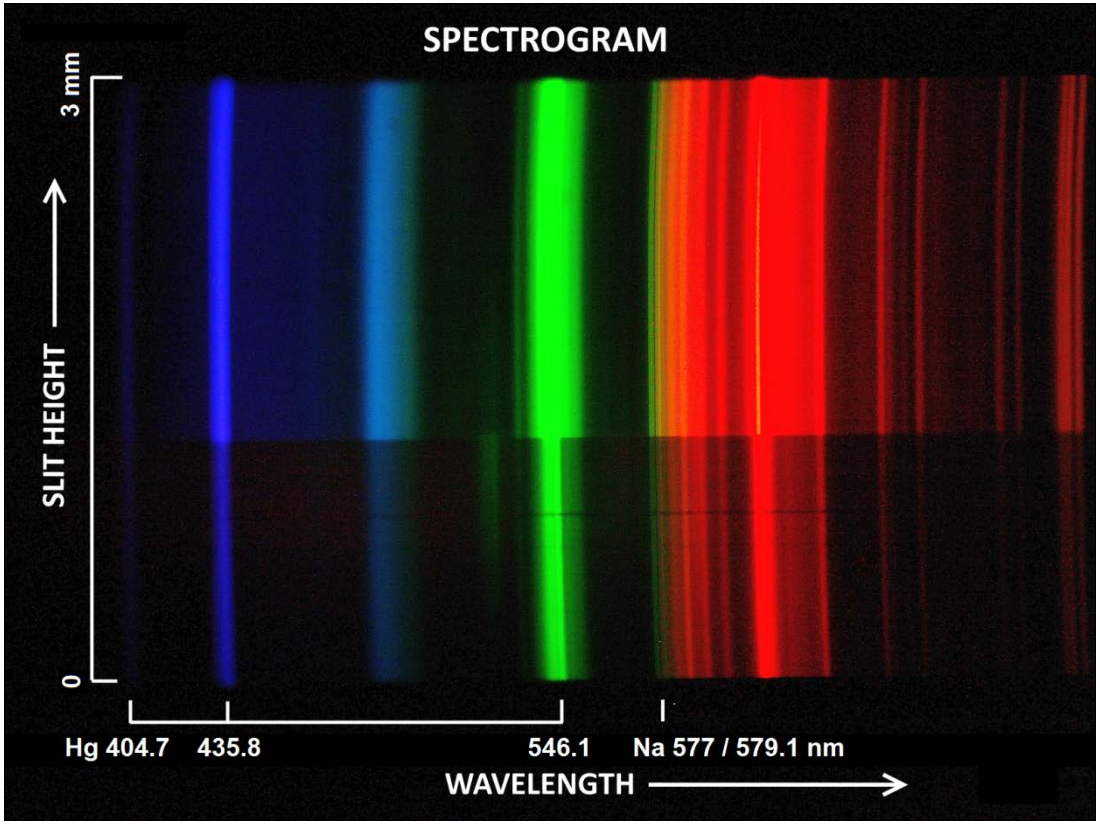
Detectors

4 x prototypes



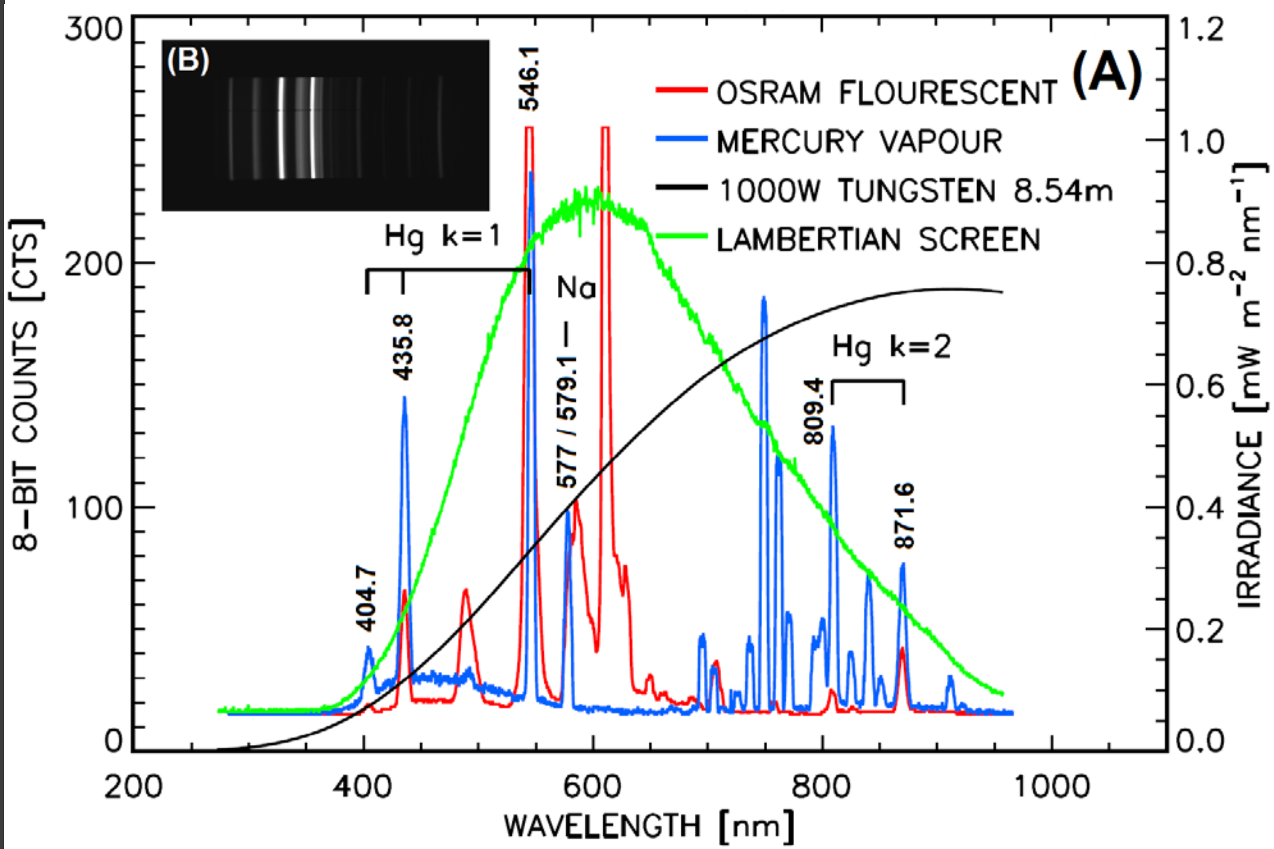
	Sensor type	Sensor size [mm²]	Spectral range [nm]	FWHM [nm]	Mass [g]	Cost [US$]
A	Sony Super HAD Color CCD	4.800 × 3.600	435.8 – 733.6	1.4	106	34
B	5M pixel Color CMOS	4.300 × 3.200	434.8 – 701.3	1.4	128	280
C	Monochrome CMOS	11.264 × 5.986	297.5 – 1005.5	1.4	152	1300
D	Monochrome CMOS	11.251 × 7.032	281.8 – 966.1	5.0	168	920

Performance



The doublet at ~580 nm is Sodium (Na). The upper part of the spectrogram is the white paper, and the lower part is a light gray colored surface (office bench).

Spectrogram from instrument (B). Target is white paper edge illuminated by fluorescent tube (OSRAM FQ 54W/830 HO). The emissions lines of mercury (Hg) at wavelengths 404.7, 435.8 and 546.1 nm are marked.

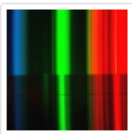


Each mercury emission line is marked according to wavelength and spectral order k. The green spectrum is a 30 second exposure of a Lambertian screen (Labsphere SRT-99-180) illuminated by a 1000W Tungsten lamp (ORIEL SN7-1275) located 8.54 m away from the screen. Black colored spectrum is the irradiance of the screen in absolute units of mW m^{-2} nm^{-1}. Panel (B): The spectrogram of the fluorescent tube.

Wavelength and sensitivity calibration of 3D printed Hyper Spectral Imager (HSI) - instrument (D). Panel (A): The spectra are sampled from the center horizontal row of the detector. The gain was set to zero. The blue spectrum is from a Mercury (Hg) vapour tube supplied by Edmund Optics Ltd. (SN K60-908). The red curve represents the spectrum of a fluorescent tube (OSRAM FQ 54W/830 HO)

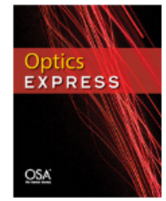

440 nm
A
B
S
RGB

UNIS



Do it yourself hyperspectral imager for handheld to airborne operations

Fred Sigernes, Mikko Syrjäsuo, Rune Storvold, João Fortuna, Mariusz Eivind Grøtte, and Tor Arne Johansen



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Abstract

This study describes rapid prototype construction of small and lightweight push broom Hyper Spectral Imagers (HSI). The dispersive element housings are printed by a thermoplastic 3D printer combined with S-mount optical components and commercial off-the-shelf camera heads. Four models with a mass less than 200 g are presented with a spectral range in the visible to the near-infrared part of the electromagnetic spectrum. The bandpass is in the range from 1.4 - 5 nm. Three test experiments with motorized gimbals to stabilize attitude show that the instruments are capable of push broom spectral imaging from various platforms, including airborne drone to handheld operations.

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Rated as the most read paper in Optics Express February 2018.

Among the 10 top most read papers for 6 months!

Mass production!

Together with NTNU AMOS and Moon Labs we are proud to announce that our first serial produced Hyper Spectral Imager (HSI) no. v4J arrived in the mail today! (November 2018).

Customers:

1. **Lamont-Doherty Earth Observatory, Columbia University, USA.**
2. **Biological and Satellite Oceanography Laboratory, University of California Santa Cruz, USA.**
3. **IDLEtechs AS, Trondheim, Norway.**
4. **DNV GL (Det Norske Veritas Germanischer Lloyd)**
5. **Scout Drone Inspection, Trondheim, Norway.**
6. **Brandon Sackmann, Integral Consulting Inc., US.***

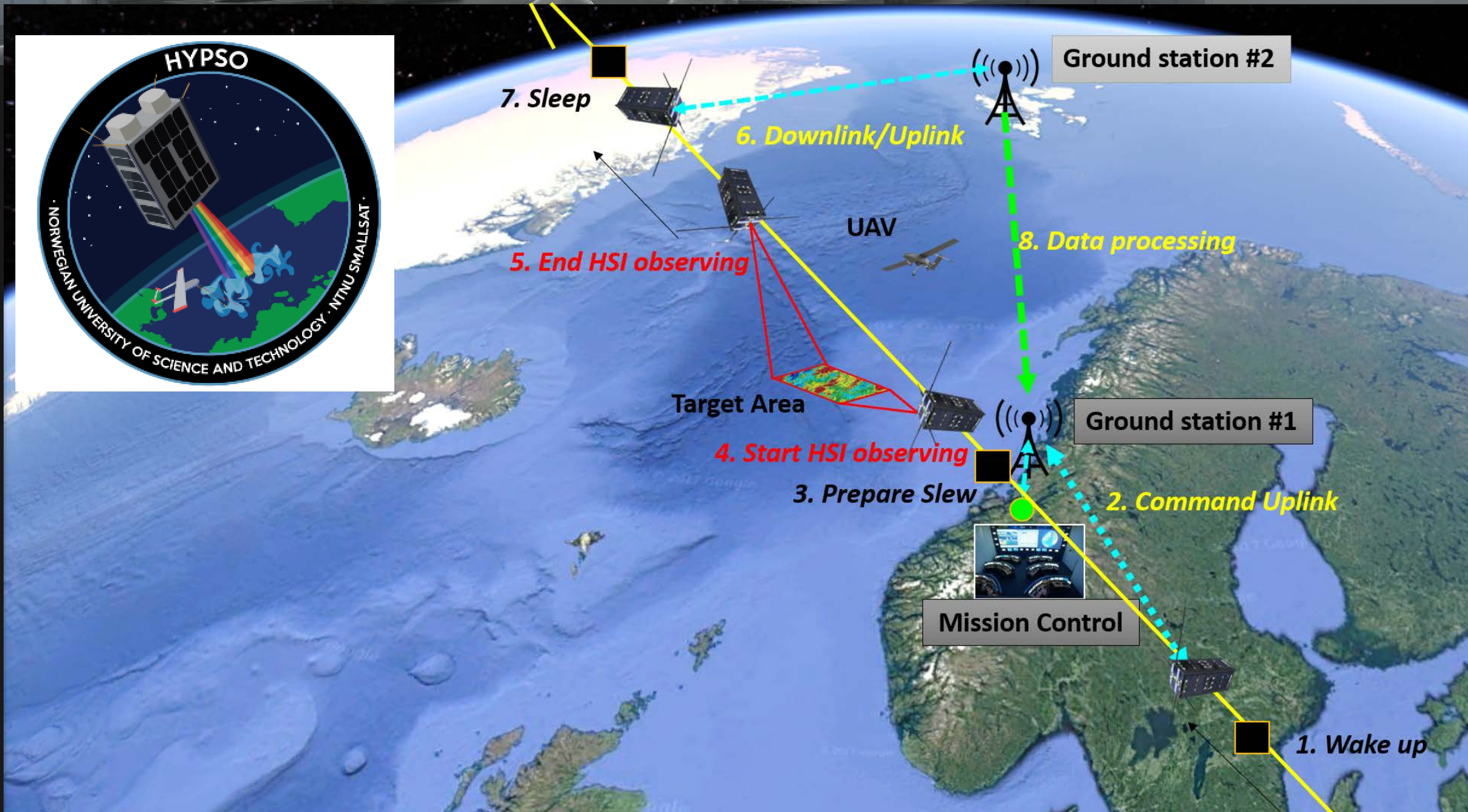
*** HSI V4 PIPP**

CENTRE OF EXCELLENCE

NTNU AMOS - Centre for Autonomous Marine Operations and Systems

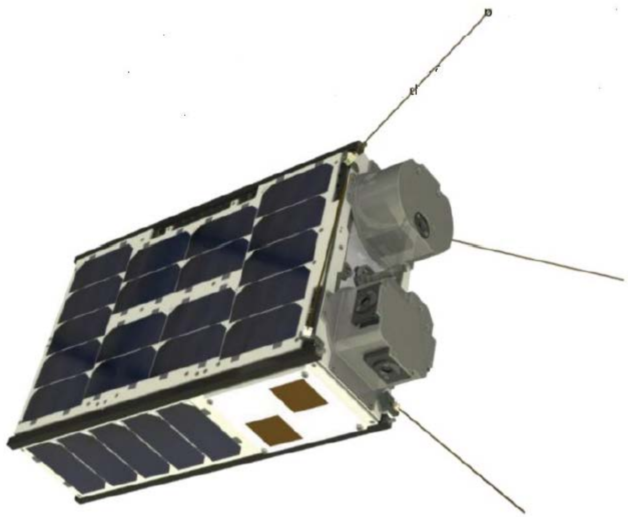
NTNU AMOS research areas (from the left): Mapping and monitoring, intelligent ships and operations, intelligent marine structures and operations and robotic platforms.

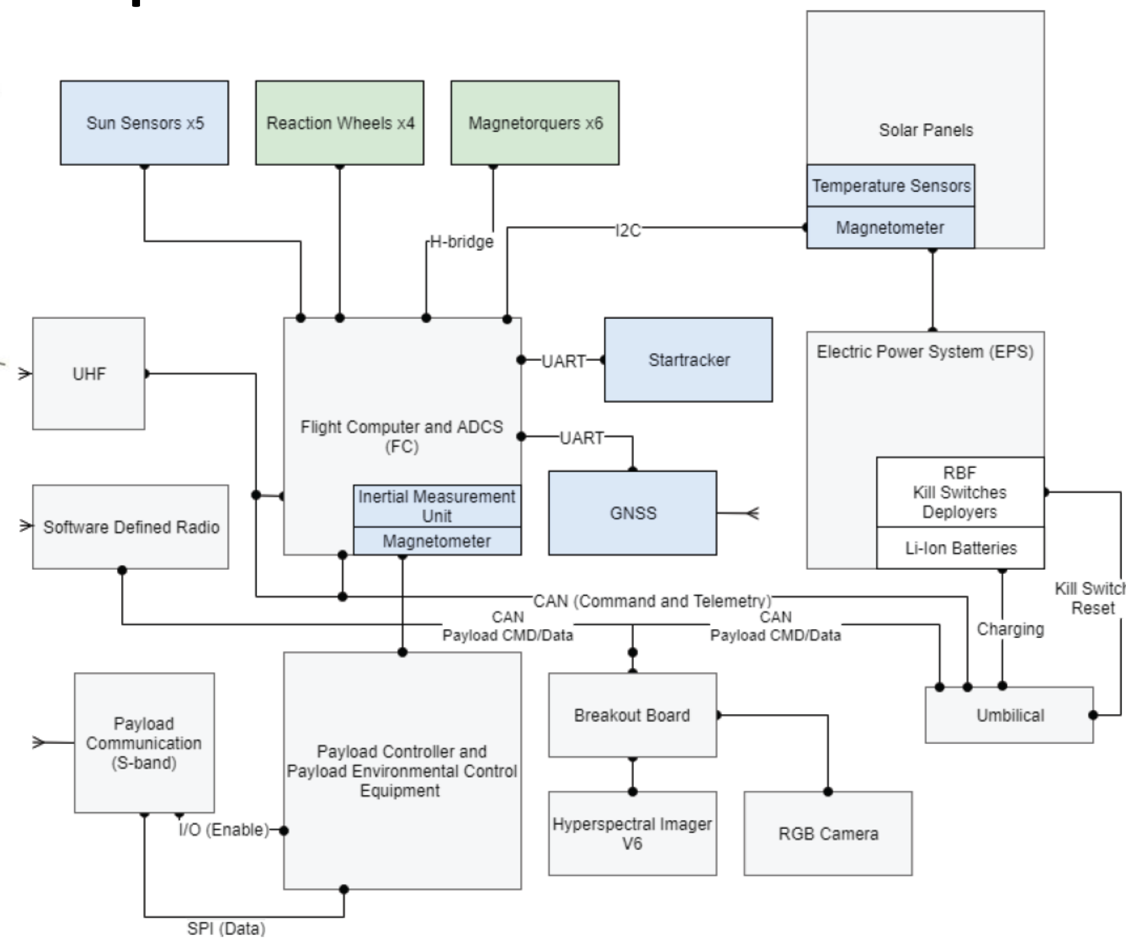
HYPSO (HYPER-SPECTRAL SMALLSAT FOR OCEAN OBSERVATION)



NTNU team: 20 students, 6 PhDs and 2 Post. Docs.
F. Sigernes hired as Prof. II to assist HSI prototyping payload.
Teaching: TTK20 Hyperspectral remote sensing, autumn 2018.
Trailer: http://kho.unis.no/Media/NTNU_FINAL_v1.mp4

Baseline Spacecraft Description





6U Satellite bus from NanoAvionics

Launch: 2019-2020

HYPSO Architecture

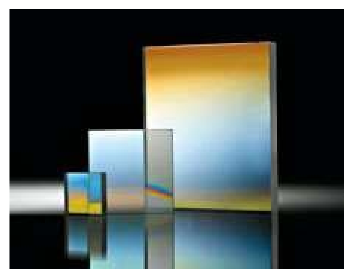
Parallel Rapid Internet Prototype Development

Mix and match assembly of optomechanical parts from Thorlabs and optics from Edmund.

THORLABS

Edmund optics | worldwide

30 mm Cage plate system



Lens objectives and grating

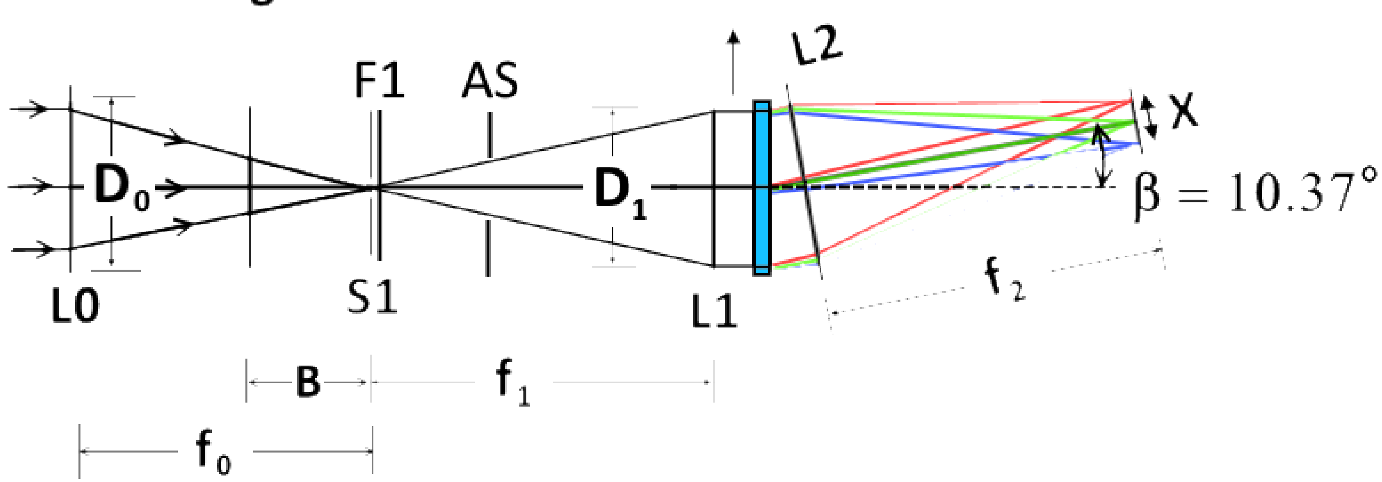
2x Form 2 Desktop 3D printers

Optical diagram HSI v6

EO Grating (G) #49-579 25mm Sq.

300 grooves/mm

Blaze angle: 17.5°



D_1 = 18 mm

f_1 = 50mm

f_2 = 50mm

L2 f/2.0

L1 f/2.8

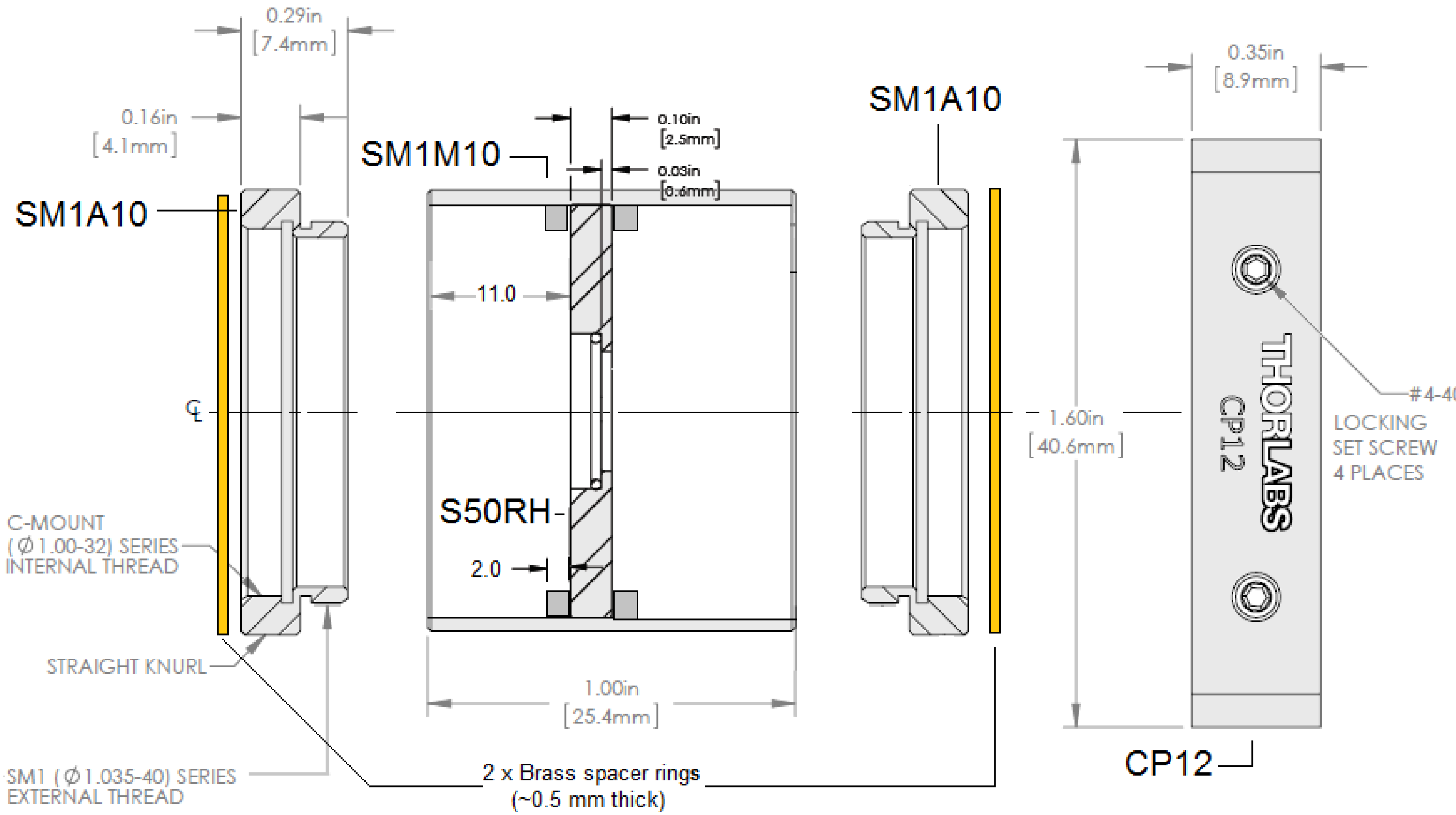
B = 17.5 mm

Range 400 - 800 nm

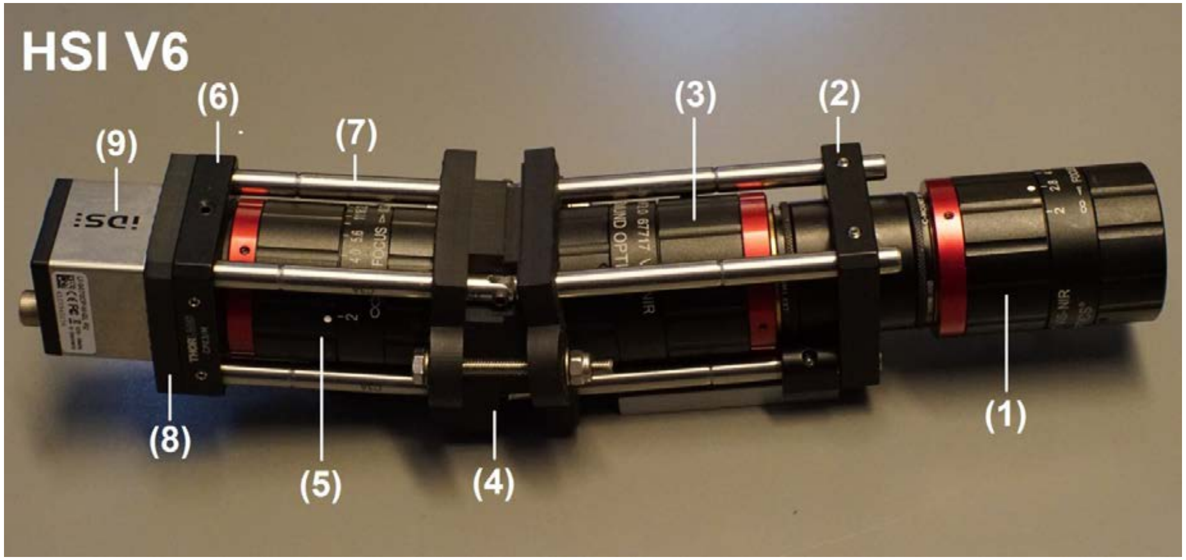
X = 6.11 mm

f_0 = 50 mm and up

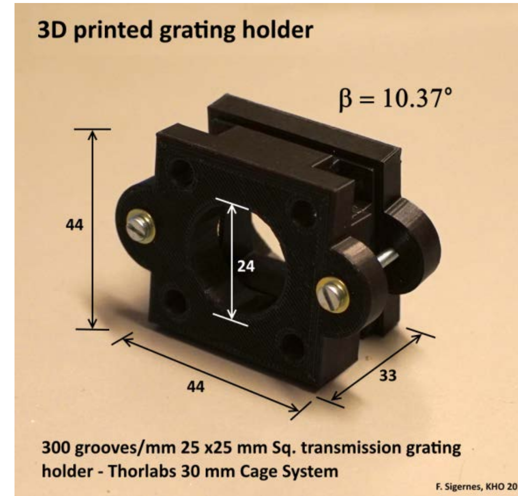
Optomechanical parts Front-slit-collimator HSI v6



Next generation HSI V6



Assembled instrument using a standard USB 3.0 iDS camera head. (1) front lens, (2) CP12 cage plate, (3) collimator lens, (4) 3D printed grating holder, (5) camera lens, (6) CP03/M cage plate, (7) steel rods, (8) 3D printed camera mount insert and (9) iDS CMOS camera head.



Item	Parts / links	Description	Qty	Cost $
1	EO #67-717	50 mm VIS-NIR lens (Front, Collimator and Detector lenses)	3	1650.00
2	EO #49-579	25mm Sq. 17.5deg. Blazed Trans. grating (300 lines/mm)	1	105.00
3	Thorlabs SM1A10	Adapter ring SM1 – C-mount internal	2	39.16
4	Thorlabs SM1M10	SM1 lens tube 1 inch long with internal threads.	1	13.87
5	Thorlabs CP12	30 mm Cage plate - SM1 tubes	1	20.81
6	Thorlabs S50RD	Fixed high precision mounted slit	1	95.75
7	Thorlabs CP13/M	C-mount 30 mm cage plate (NTNU sensor board)	1	30.90
8	Thorlabs CP03/M	30 mm Cage plate – 35 mm aperture (iDS-mount)	1	18.77
9	Thorlabs ER1.5-P4	4 x Steel rods 1.5 inch long	1	22.22
10	Thorlabs ER1 –P4	4 x Steel rods 1.0 inch long	1	19.19
11	Thorlabs C3A	4 x Rod End Swivels	1	58.97
12	Detector	iDS IMX174 camera head	1	1000
13	Thorlabs Spacer Rings	C-mount 0.25 – 2 mm space ring kit (2 each)	1	98.94
		Total	16	3173.58

Experimental setup: Computer with USB3, square mount frame and rotary tablet (Syrp Genie Mini) 60s - 30° range - 30 frames / s.

HYPSO-RP-006	HSIv6 Assembly, Fred's Design HYPSO Mission	Date 08.04.2019

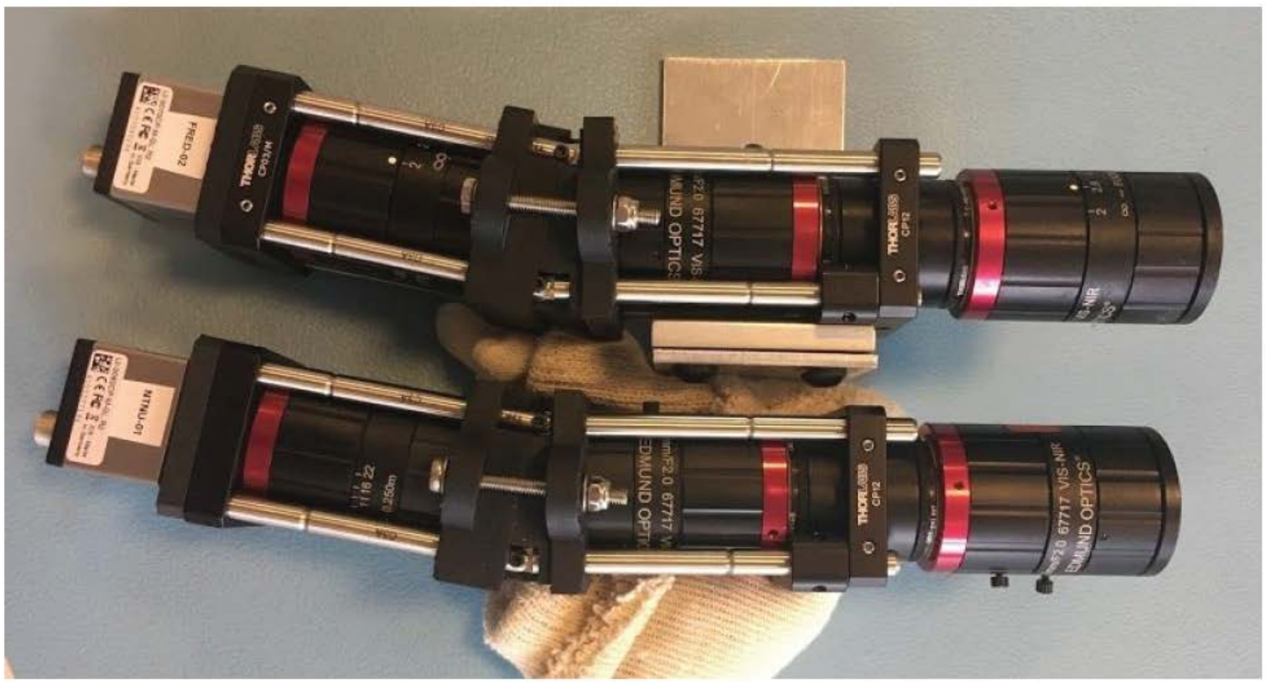
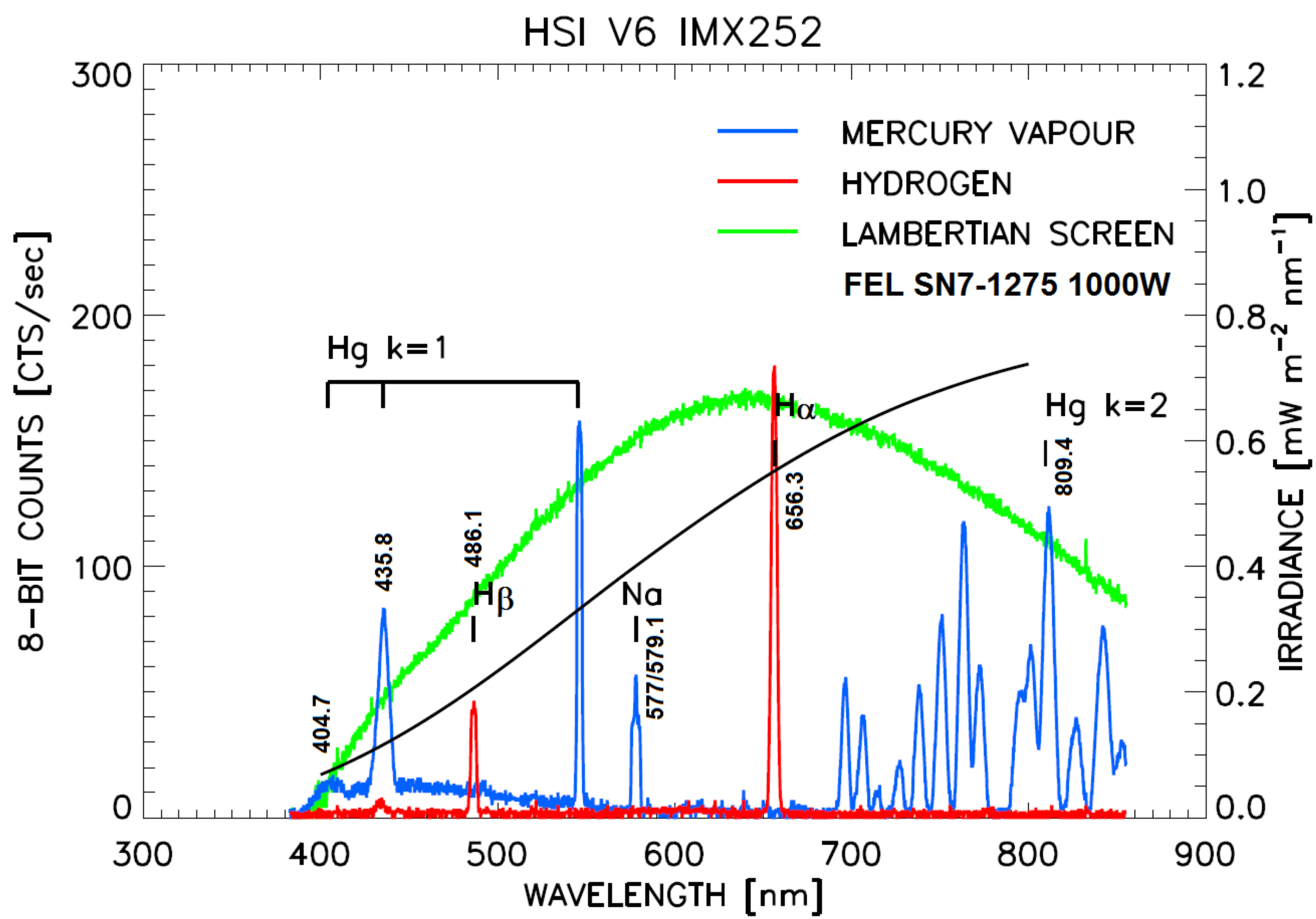


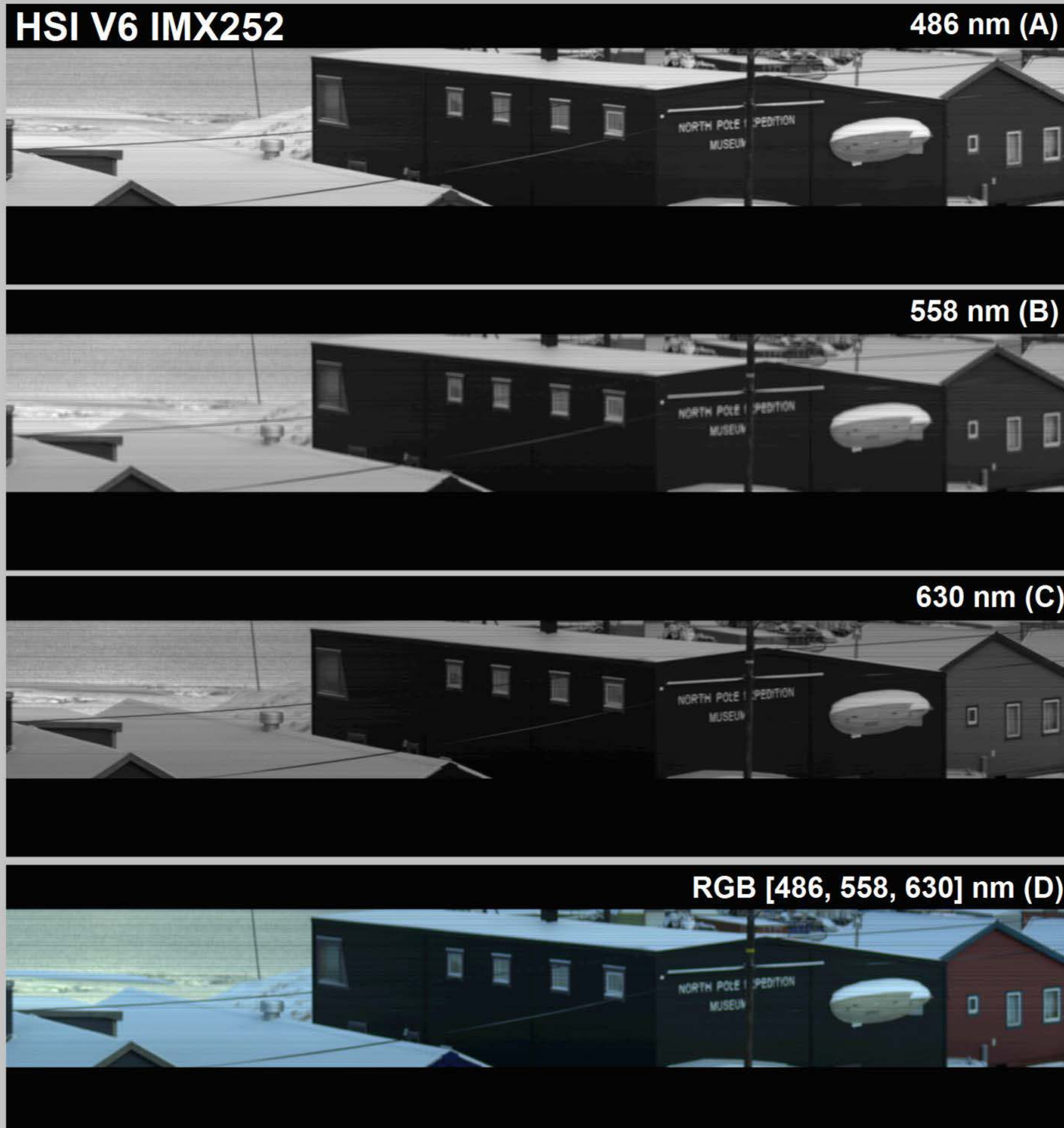
Fig.1. The new HSIv6, NTNU-01, and its sibling, FRED-02.

Above image from student report: HSIv6 NTNU-01 Assembly HYPSO-RP-006



HSI V6 IMX252
8-BIT COUNTS [CTS/sec]
IRRADIANCE [mW m^{-2} nm^{-1}]
WAVELENGTH [nm]
MERCURY VAPOUR
HYDROGEN
LAMBERTIAN SCREEN
FEL SN7-1275 1000W
Hg k=1
Hg k=2
404.7
435.8
486.1
Hβ
Na
577/579.1
Hα
656.3
809.4
300
200
100
0
1.2
1.0
0.8
0.6
0.4
0.2
0.0
300
400
500
600
700
800
900


HSI V6 IMX252
RGB [486, 558, 630] nm
(A)
F/2.8
RGB [486, 558, 630] nm
(B)
F/4.0
RGB [480, 550, 800] nm
(C)
F/4.0



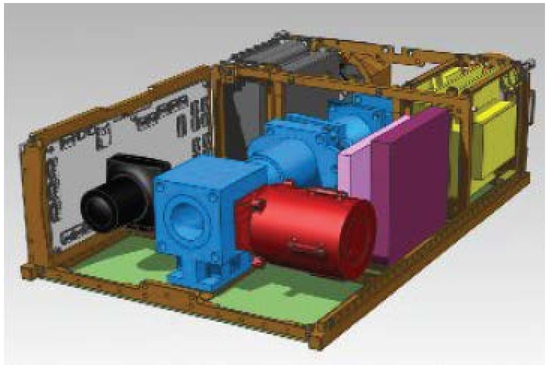
Images by HSI V6 using the iDS IMX252 sensor. Target is out my office windows at UNIS in Longyearbyen on 08.10.2018 in Solar twilight conditions and new snow. The lower RGB composite in Panel (D) is constructed by combining images at center wavelengths 486 *nm* (blue) panel (A), 558 *nm* (green) panel (B) and 630 *nm* (red) panel (C). The individual images have a bandpass of 3.3 *nm*. The front lens is at F/value 2.8. The sweep range and period were set to 30 degrees and 60 seconds, respectively. The framerate was 30 frames per second. The gain of the sensor was zero.

Images by HSI V6 using the iDS IMX252 sensor. Target is out my office windows at UNIS in Longyearbyen on 10.10.2018 with the Sun only 1 degree above the horizon and new snow. The lower RGB composite in Panel (D) is constructed by combining images at center wavelengths 486 *nm* (blue) panel (A), 578 *nm* (green) panel (B) and 630 *nm* (red) panel (C). The individual images have a bandpass of 10 *nm*. The front lens is at F/value 2.8. The sweep range and period were set to 30 degrees and 60 seconds, respectively. The framerate was 30 frames per second. The gain of the sensor was set to 30.

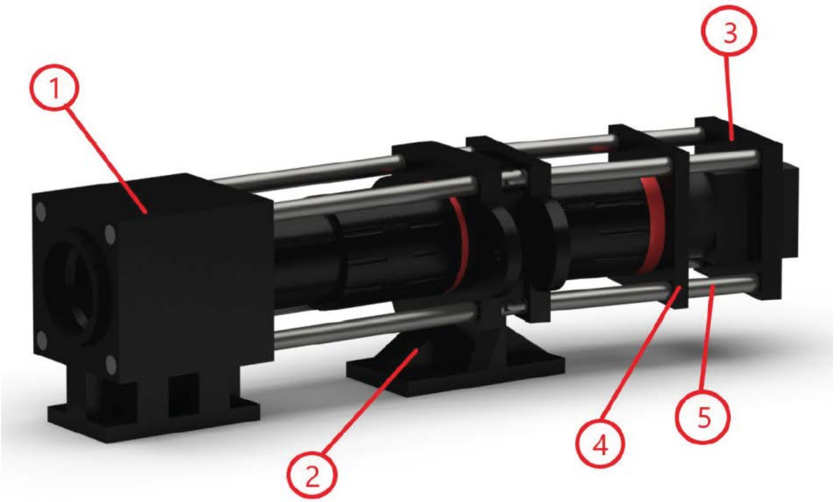
Stress testing and ruggedization

1. Reduction of parts - simplification of design
2. Make 3D printed parts in metal.
3. Thermal, radiation, vibrational and shock tests.

HSI Camera
RGB Camera
SDR (TOTEM)
OPU (Picozed)
Star tracker
RW/ Magneto Torque unit
Battery pack unit
Payload Interface Board
Solar panels
6U Bus frame structure

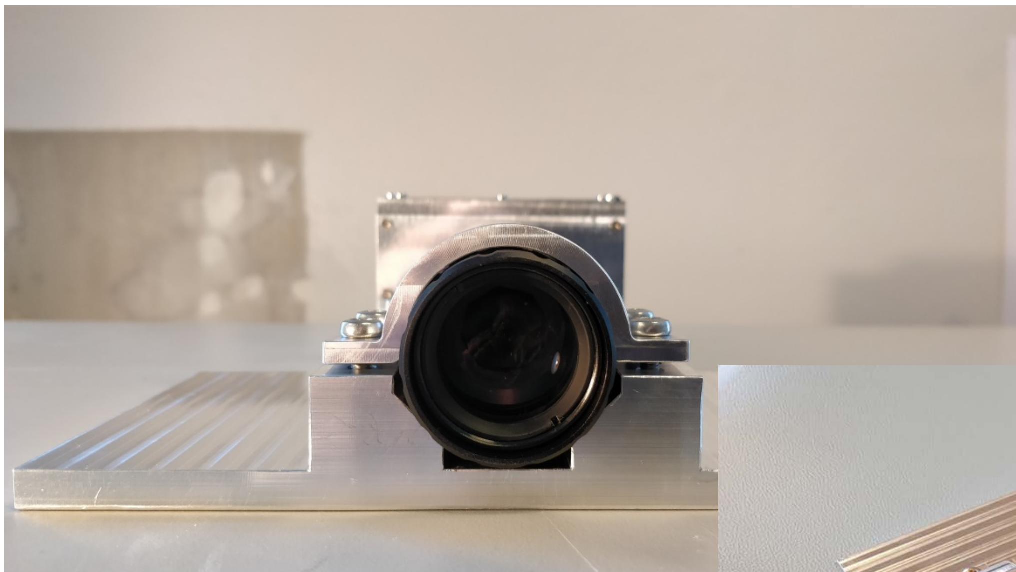


Cubsat architecture



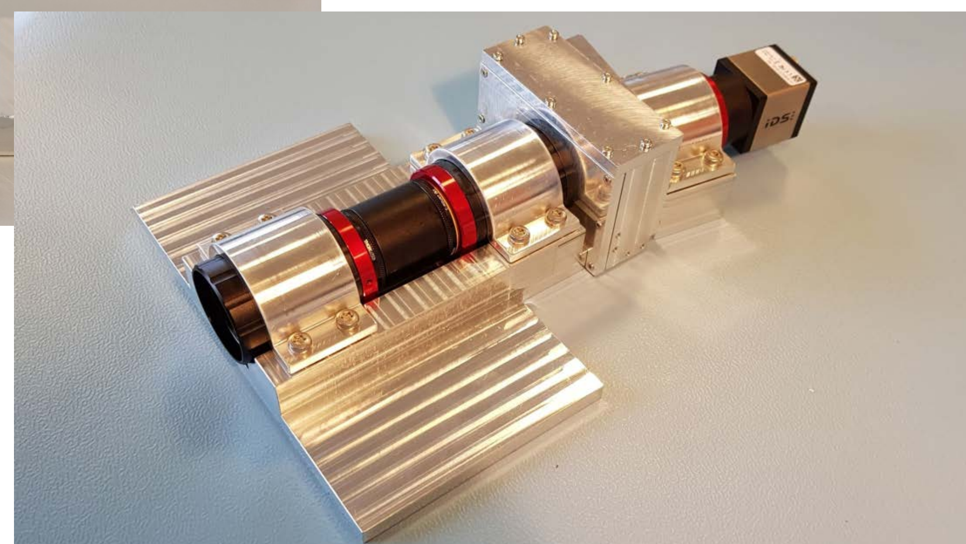
Metal design of HSI v6:
(1) Larger cage plates (50x50 mm), (2) added mount frame structure interfaces, (3) new plate for camera head, (4) camera lens cage plate, and (5) longer steel rods.

HSI v6 metal prototype NTNU



Front view

Photos by Henrik Galtung, Department of Engineering Design and Materials, NTNU, **15 May 2019**.



Top side view

Metal prototype of HSI v6:
(1) Large mount plate
(2) Ring clamp holders for lenses
(3) Square grating house
(4) 10.37^{o} wedge

Hyperspectral All-Sky Cameras (NORUSCAII)

Owner

University Centre in Svalbard (UNIS)

Scientific objectives
Instruments are designed to do low light all-sky hyperspectral imaging. Auroral morphology, airglow or any object visible on the night sky is the target for these instruments.

Triangulation is conducted by a twin instrument located in Barentsburg, 50 km in distance from KHO.

Contact
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Address: UNIS, P.O. Box 156,
N-9171 Longyearbyen, Norway
E-mail: fred@unis.no
Phone/Fax: +47 79023335/01

Instrument specifications
Camera: NORUSCA II x2
Spatial coverage: All-Sky
Exposure time: > 1 second/channel
Detector head: EMCCD
Resolution: 512 x 512
F-value: 1.0
Filter: Liguid Crystal Tunable Filter (LCTF)
Bandpass: ~7nm

Example Channels (15x):

[CH1] 470.9 nm N_2^+ 1N(0-2)
[CH2] 557.7 nm [OI]
[CH3] 630.0 nm [OI]
[CH4] 427.8 nm N_2^+ 1N(0-1)
[CH5] 450.0 nm BCK
[CH6] 486.1 nm H_β
[CH7] 500.2 nm NII
[CH8] 568.0 nm NII
[CH9] 589.0 nm NaI
[CH10] 636.4 nm [OI]
[CH11] 656.3 nm H_α
[CH12] 662.4 nm N_2 1P(6-3)
[CH13] 670.5 nm N_2 1P(5-2)
[CH14] 676.4 nm N_2 1P(11-9)
[CH15] 700.0 nm BCK

Hyperspectral tracker (Fs-Ikea)

Owner

University Centre in Svalbard (UNIS)

Scientific objectives
The instrument is a narrow field of view hyperspectral pushbroom imager. A front optical mirror system enables it to track any objects on the night sky as a function of wavelength throughout the visible spectrum.

Instrument specifications
(A) Spectrograph: FS-IKEA
Spectral range: 420-700nm
Bandpass: ~1nm
Collimator lens: 250mm
Entrance Slit-width: 0.250mm
Grating: 600 lines/mm
Camera lens: 50mm
Detector head: Andor Luca R (EMCCD)
Resolution: 1004 x 1002
Exposure time: ~1s per spectrogram
Front lens: Zeiss Planar F/1.4 85mm ZF.

(B) All-Sky scanner:
Type: 2xfirst surface mirrors
Azimuth range: 360°
Zenith angle: ą90°
Aperture: ~10 inch.
Resolution: 0.0003°
Accuracy: ą0.05°

Contact
PI: Fred Sigernes
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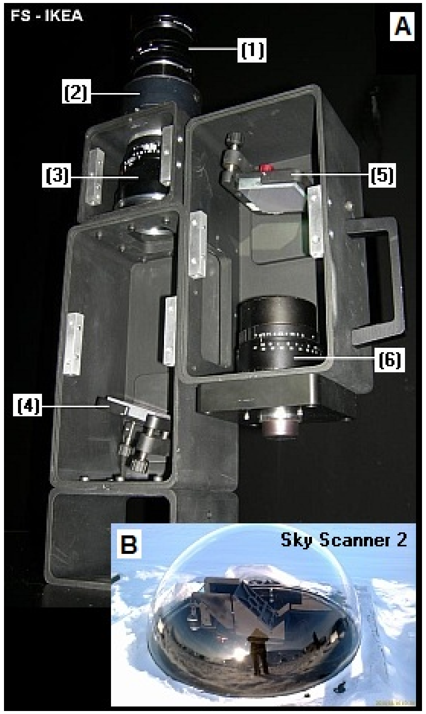
N-9171 Longyearbyen, Norway
E-mail: fred@unis.no
Phone/Fax: +47 79023335/01

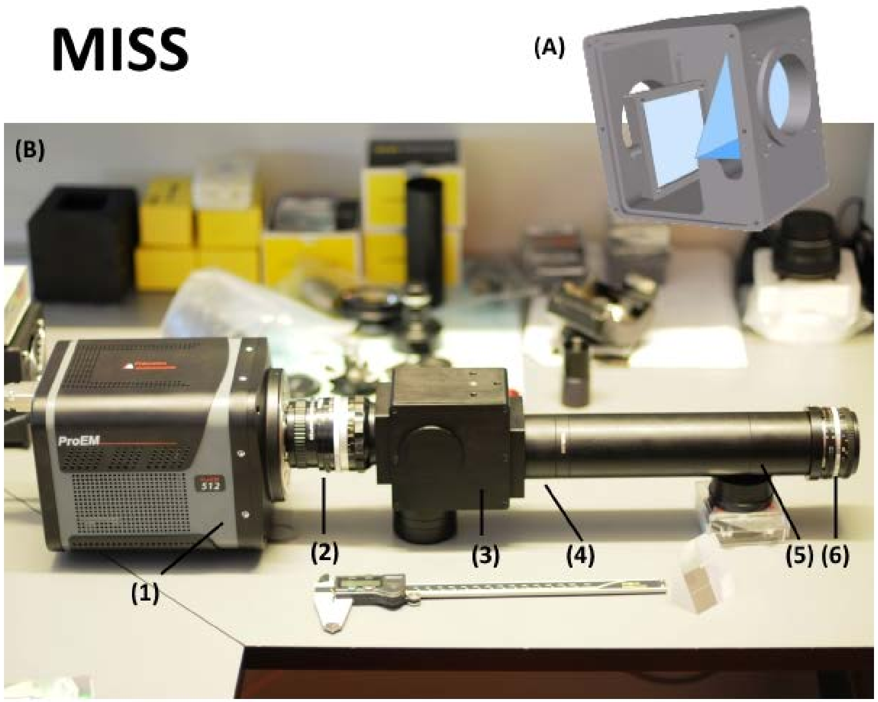


The Fs-Ikea spectrograph-protective covers off. Panel (A): (1) Front lens, (2) Slit housing, (3) Collimator, (4) Flat surface mirror, (5) Reflective grating, and (6) Camera lens. Panel (B): All-Sky scanner

The Meridian Imaging Svalbard Spectrograph (MISS)

Owner

University Centre in Svalbard (UNIS)



The Meridian Imaging Svalbard Spectrograph (MISS) under construction. Panel (A): Air spaced tunable transmission grating and prism (TGRISM). Panel(B): MISS main parts are (1) detector,(2) camera lens, (3) TGRISM, (4) collimator, (5) slit, and (6) front optics.

Scientific objectives
The instrument is a wide field of view hyperspectral pushbroom imager. Its main aim is to measure the night sky spectrum from North to South in the geomagnetic meridian plane to track the aurora. There are no moving mechanical parts in the design. It is a future replacement candidate of the Meridian Scanning Photometers (MSP).

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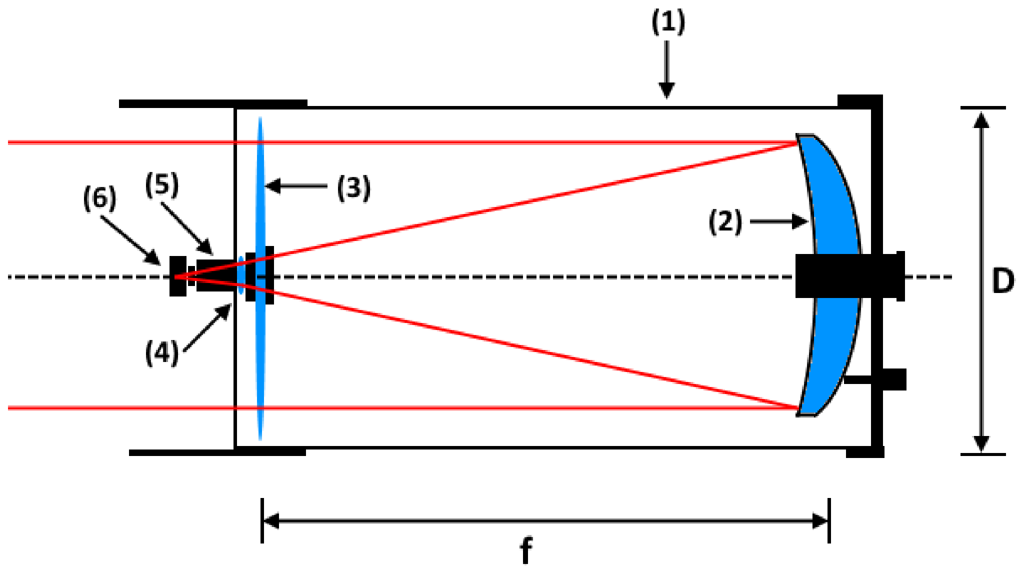
Instrument specifications
Detector: Atik 414EX
Lens: Peleng F-mount F/3.5 (180 degree circular)
Spatial coverage: All sky
Angular resolution: 1 degree
Time resolution: 4 frames / minute
Spectral resolution: ~1 nm

One example of next generation designs?

HyperStar Hyper Spectral Imager (HHSI)



(1) Schmidt Cassegrain telescope (Celestron 6" / 14" SCT or Edge HD)
(2) Primary mirror
(3) Front window
(4) Hyperstar replacement for secondary mirror (HS-14, HS-C14HD or HS3-C6)
(5) Backfocal spacer adapter
(6) Thin film Hyper Spectral Imager
(BaySpec OCI-1000B150)

F. Sigernes Reproduction of HyperStar Starizona.com (2019)

Conclusion

Parallel internet HSI prototype construction with 3D printing and off-the-shelf optical components

1. Low cost < 700$
2. Mass < 200g
3. RC, Action cameras and Industrial CMOS heads may be used.
4. Commercial gyro stabilized gimbals may be used.
5. Self-contained motorized gyro gimbals and internal camera head recording reduce auxiliary device support requirements and complexity of field operations.
6. V4 is tested successfully on drones.
7. V6 medium cost, larger optics and ready for larger drones.
8. V6 metal version will be space borne!
9. The push broom hyperspectral imaging technique is revitalized.