Low Cost Hyperspectral Imaging for Drones

F. Sigernes

University Centre in Svalbard (UNIS) /

Kjell Henriksen Observatory (KHO)

Lecture: Summer Schools Arctic Earth Observation techniques, Norwegian Centre for Space-related Education (NAROM), Andøya Space Centre,8-12 August, 2016.

OUTLINE

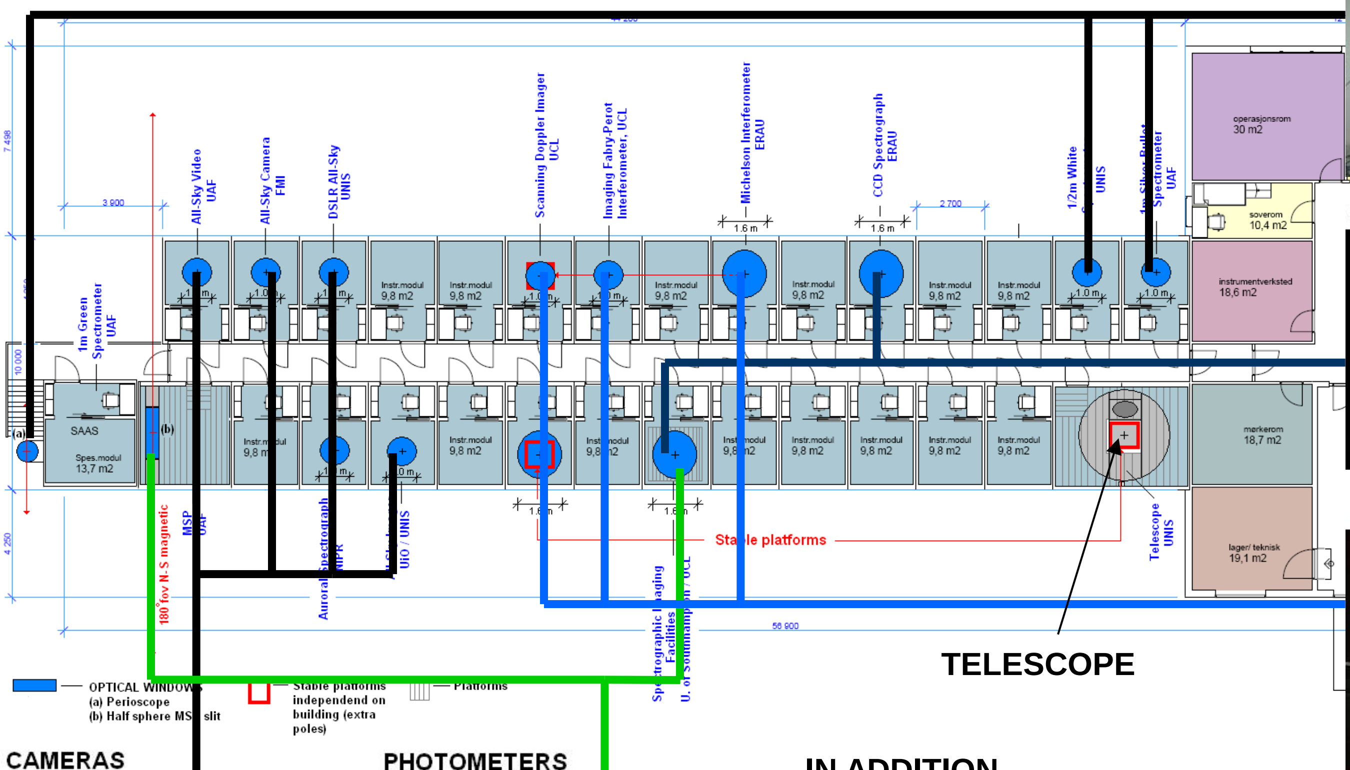
1. Introduction - where to I come from?
2. Basic Spectroscopy – a repetition!
3. Hyperspectral – what is it?
4. Sample data from Svalbard – what has been done?
5. Instrumental development – how to we make one?
6. What will we do?

Lecture slides and extended syllabus on hyperspectral imaging
Can be downloaded from http://kho.unis.no
[under link Documents points 40) and 41)].

http://kho.unis.no

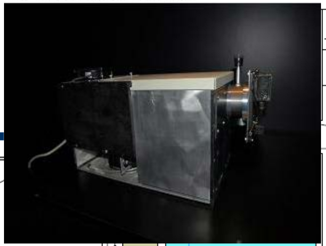
21 different institutions from 10 nations are present (2016).

Instruments @ KHO



SPECTROMETERS

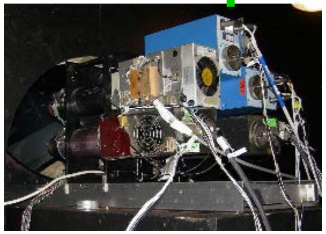
SPECTROGRAPHS



Interferometers

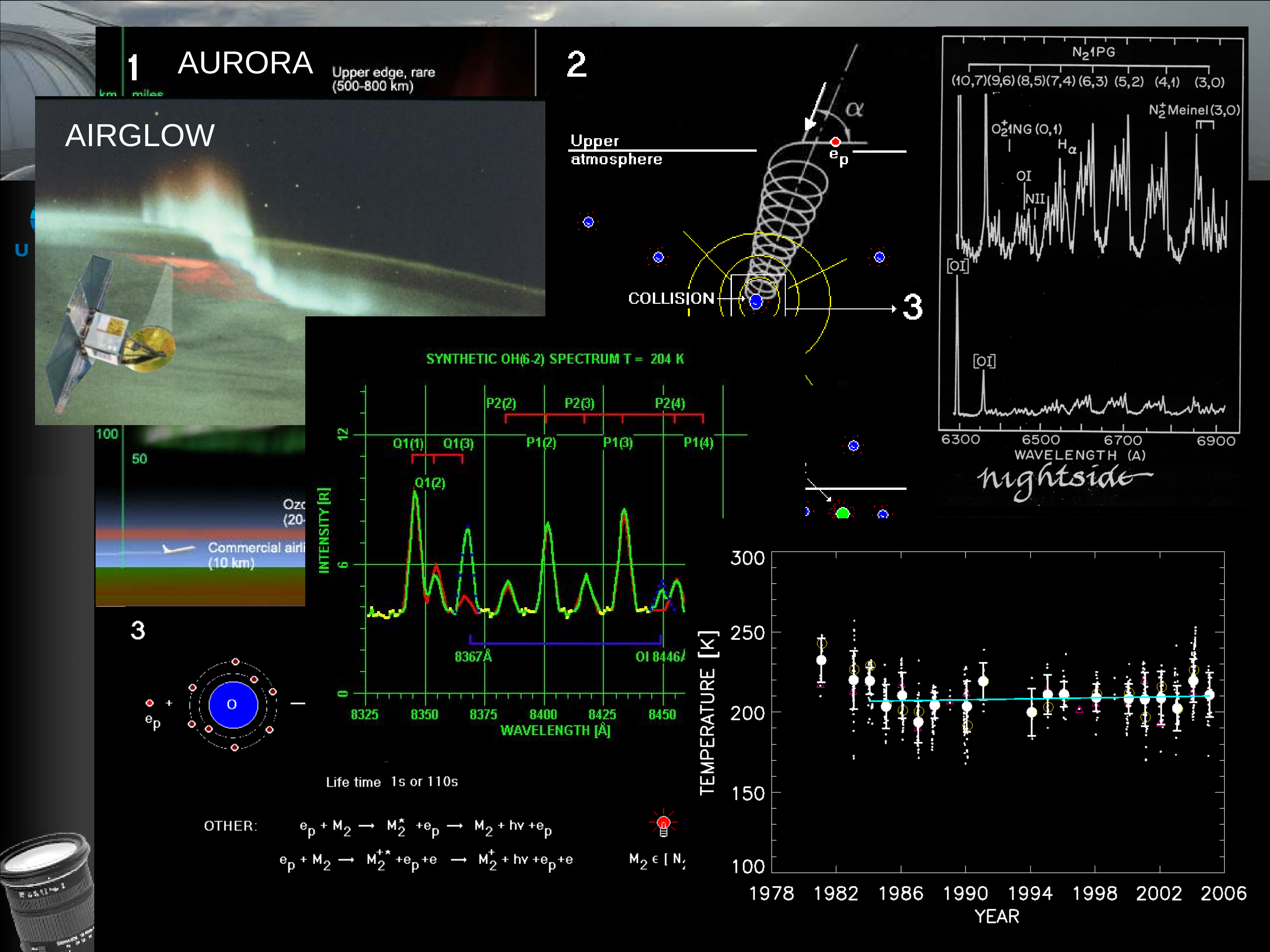
CAMERAS

PHOTOMETERS



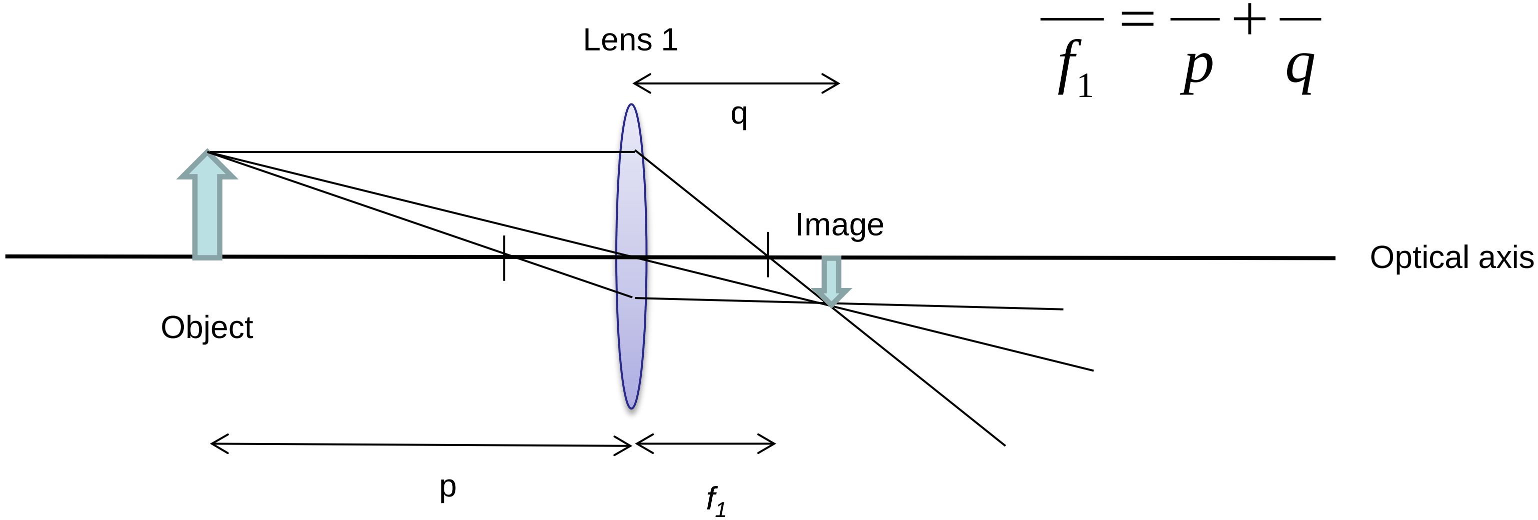
IN ADDITION

a) Magnetometers
b) Scintillation receivers (GPS)
c) Riometer
d) Weather station
e) Web cameras

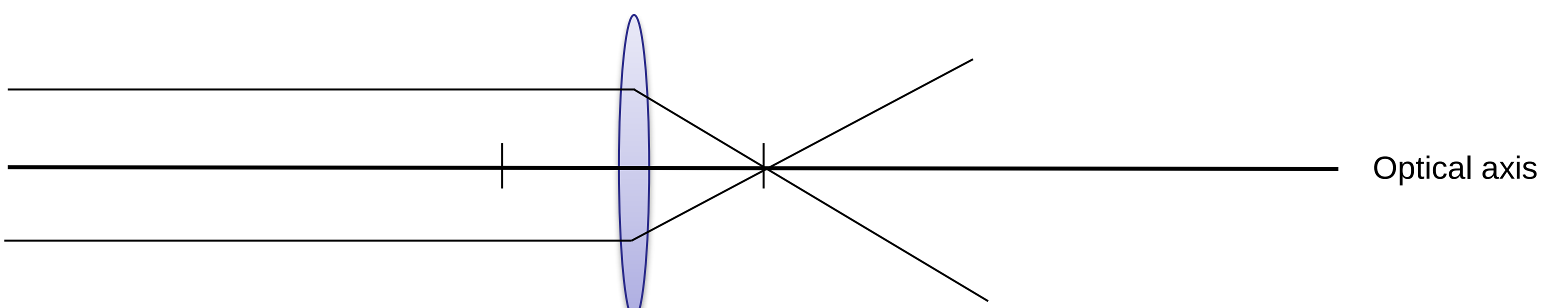

1
AURORA
Upper edge, rare
(500-800 km)
km
miles
AIRGLOW
100
50
Ozo
(20-
Commercial airli
(10 km)
2
Upper
atmosphere
α
ep
COLLISION
3
N2 1PG
(10,7)(9,6) (8,5)(7,4) (6,3) (5,2) (4,1) (3,0)
N2+ Meinel (3,0)
O2+ 1NG (0,1)
Hα
OI
NII
[OI]
[OI]
6300
6500
6700
6900
WAVELENGTH (A)
nightside
SYNTHETIC OH(6-2) SPECTRUM T = 204 K
P2(2)
P2(3)
P2(4)
Q1(1)
Q1(3)
P1(2)
P1(3)
P1(4)
Q1(2)
INTENSITY [R]
12
6
0
8367Å
OI 8446Å
8325
8350
8375
8400
8425
8450
WAVELENGTH [Å]
3
ep +
O
Life time 1s or 110s
OTHER:
$e_p + M_2 \rightarrow M_2^* + e_p \rightarrow M_2 + h\nu + e_p$
$e_p + M_2 \rightarrow M_2^{+*} + e_p + e \rightarrow M_2^+ + h\nu + e_p + e$
$M_2 \in [N_2$
TEMPERATURE [K]
300
250
200
150
100
1978
1982
1986
1990
1994
1998
2002
2006
YEAR

Basic optics (2D)

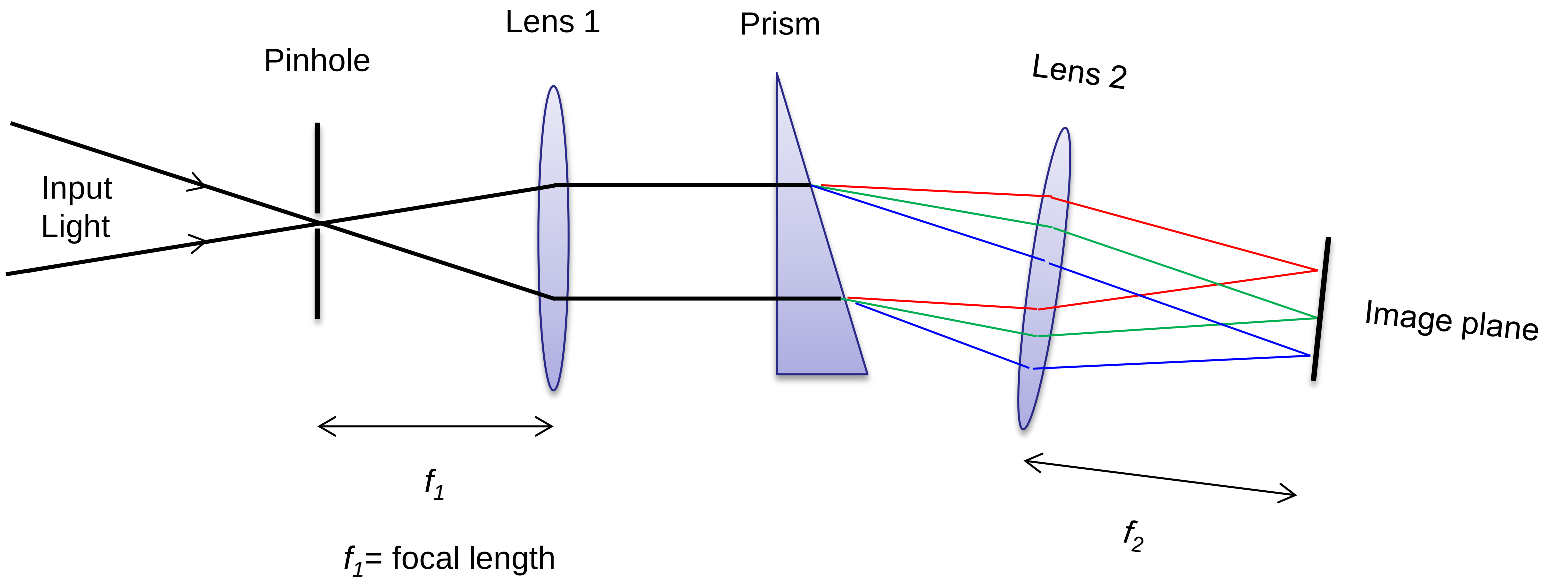
$$\frac{1}{f_1} = \frac{1}{p} + \frac{1}{q}$$



f_1= focal length



Basic spectroscopy (2D)



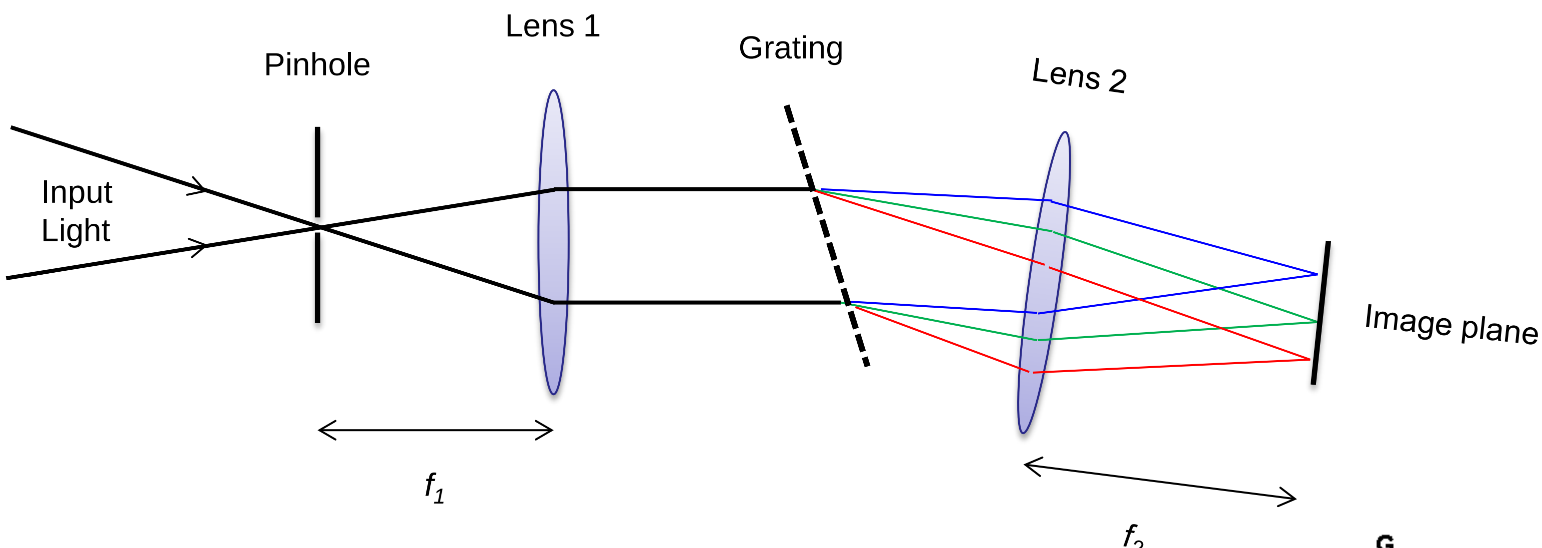
The result is a prism spectrograph.

$$n_p \sin\omega = \sin\alpha$$

We could call it a pinhole color separator.
It images the pinhole as a function of wavelength (color).

$$n_p = A_1 + \frac{B_1}{\lambda^2}$$

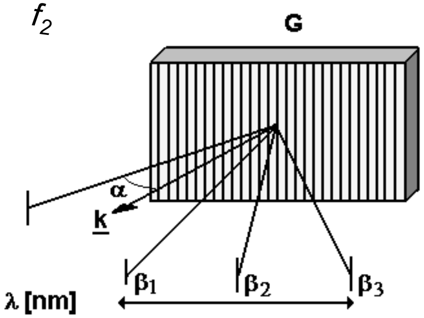
Basic spectroscopy (2D)



f_1= focal length

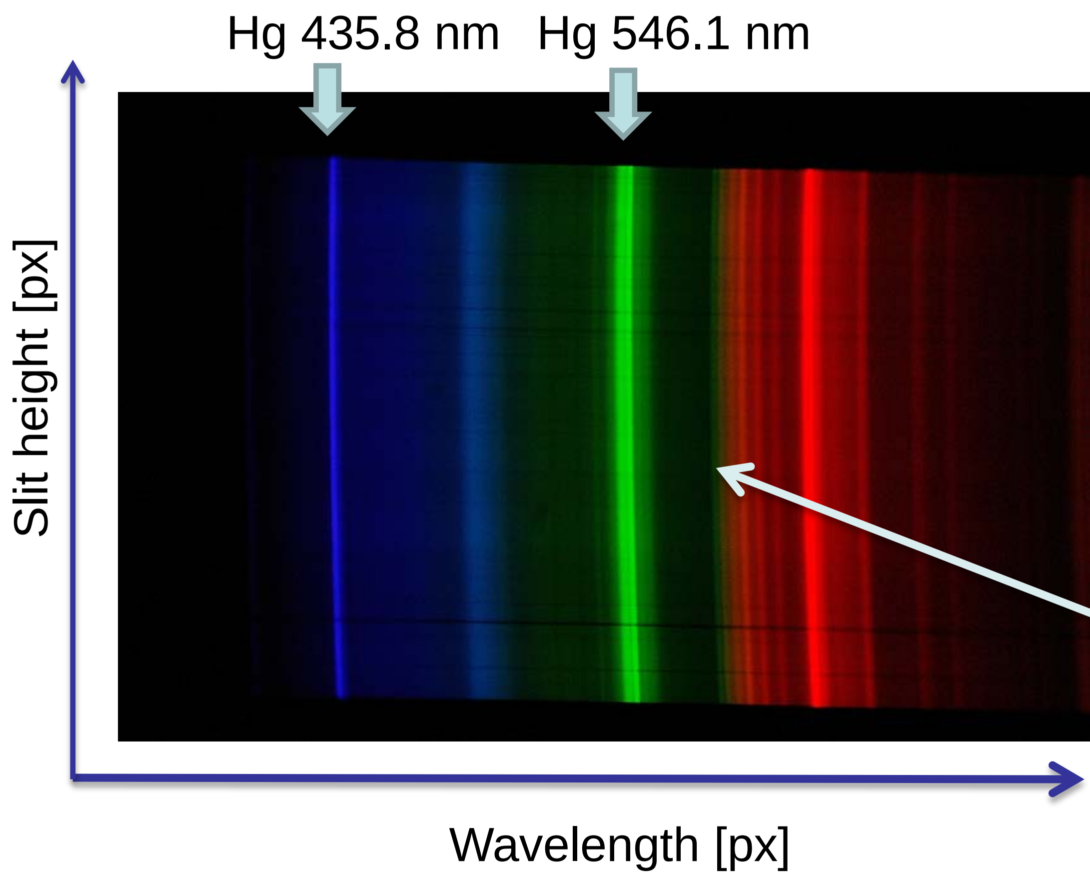
The result is a Grating spectrograph.
It diffracts opposite in color compared to the prism spectrograph.

$$n\lambda = a(\sin\alpha + \sin\beta)$$



λ [nm]			
n=1	200	400	600
2	100	200	300
3	66.6	133.3	200
4	50	100	150

Basic spectroscopy – We use a slit instead of pinhole (3D)

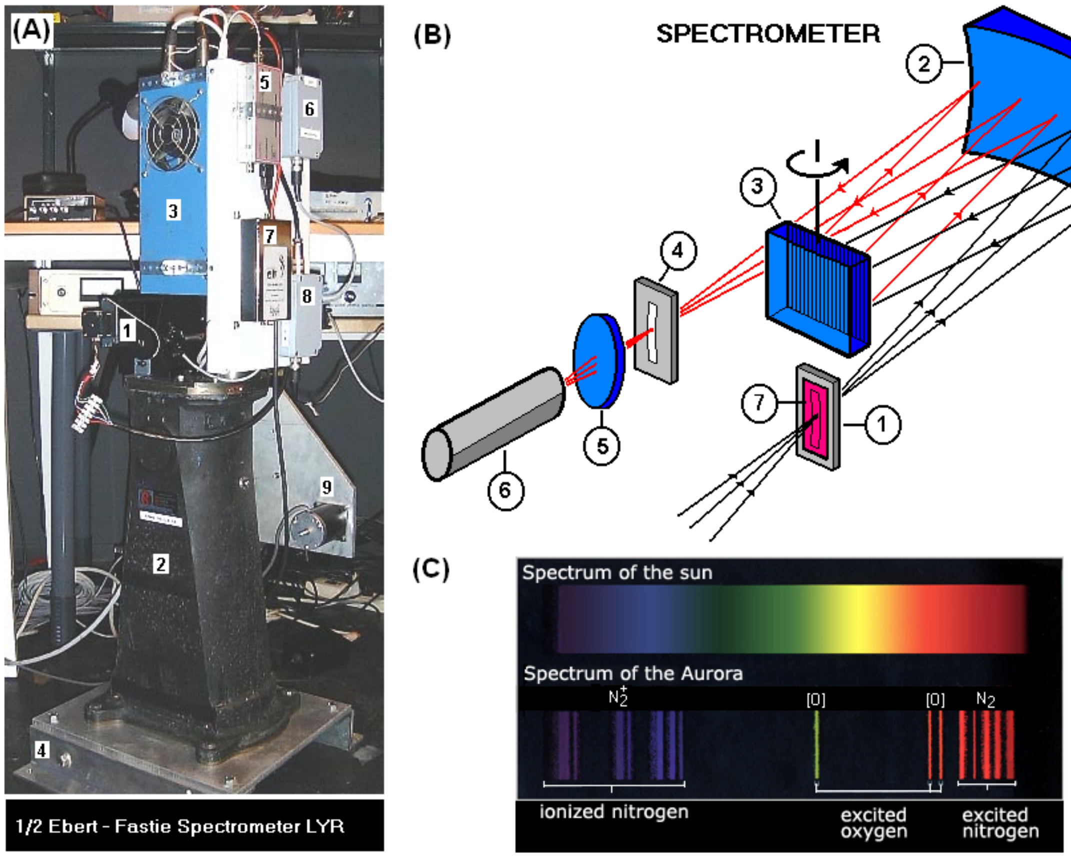


SOURCE:
White paper illuminated by regular OSRAM low pressure gas discharge tube (office lamp).

Sodium Doublet
Na 589/589.6 nm.
Bandpass ~ 1nm

$\lambda \approx a \times px + b$ ⟹ Range = [355 – 720 nm]

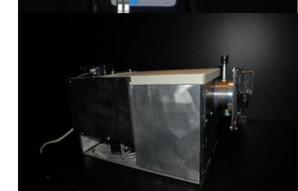
Spectrometers - Spectrographs @ KHO



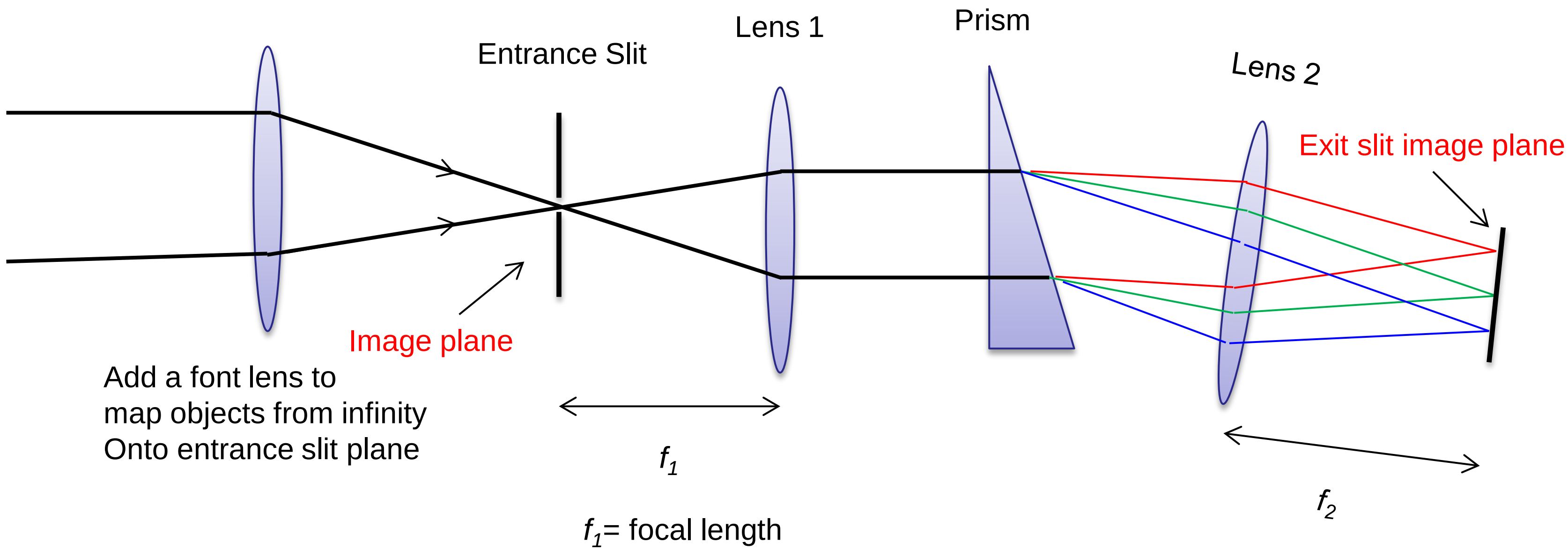
Custom made instruments (MNOK)







Hyperspectral imaging (2D)



We now have an image in the entrance slit plane of the spectrograph. But only a slice of this image is allowed to enter. This slit image slice is now seen as a function of color in the exit plane. This will create structure in the spectrogram in the parallel direction of the slit.

Hyperspectral imaging (3D)

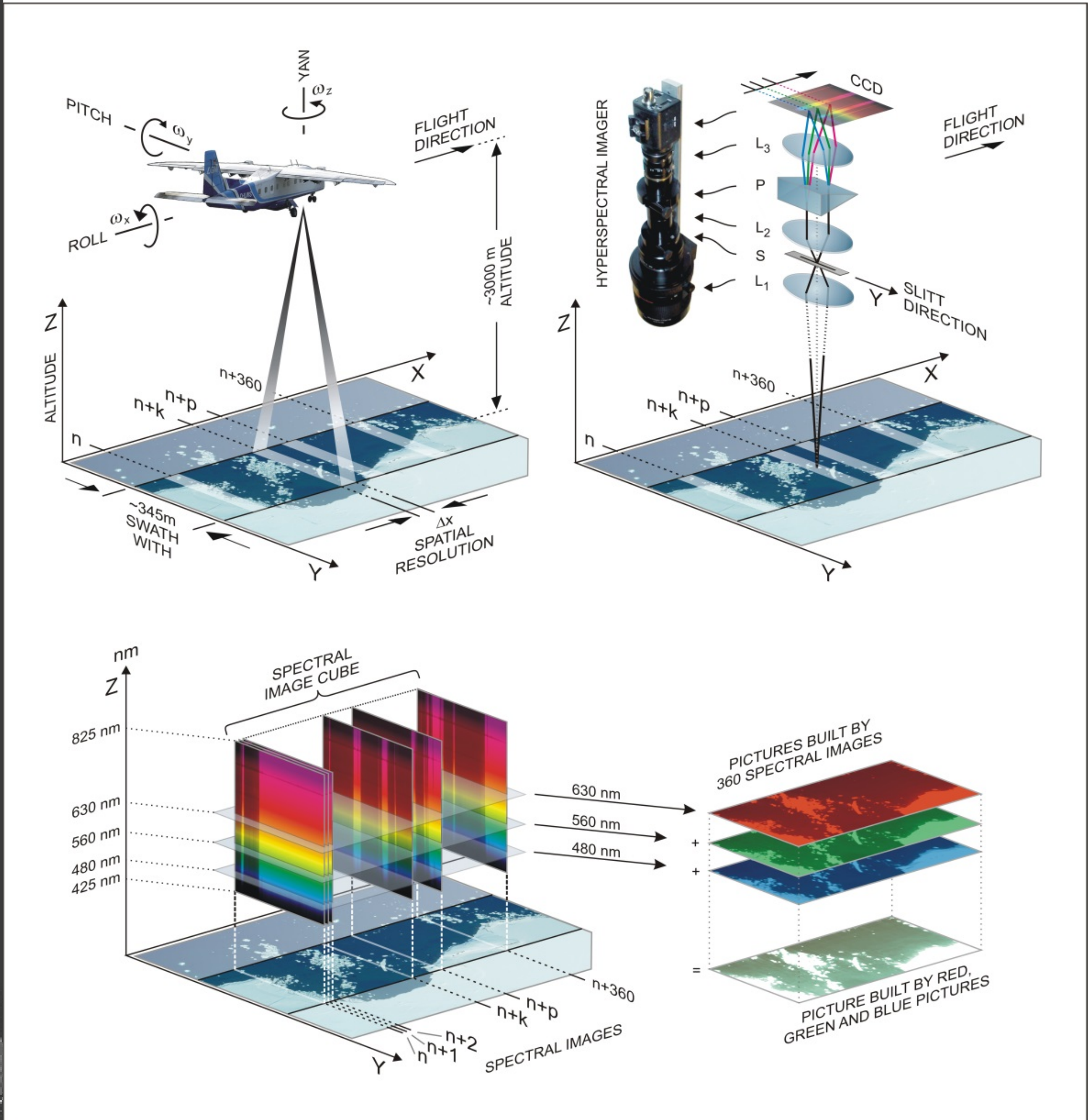


Image technique

In order to sample the whole Target object, we need to rotate the instrument or fly over it.

Or the slit entrance image needs to sweep across the entrance slit plane (rotating mirror).

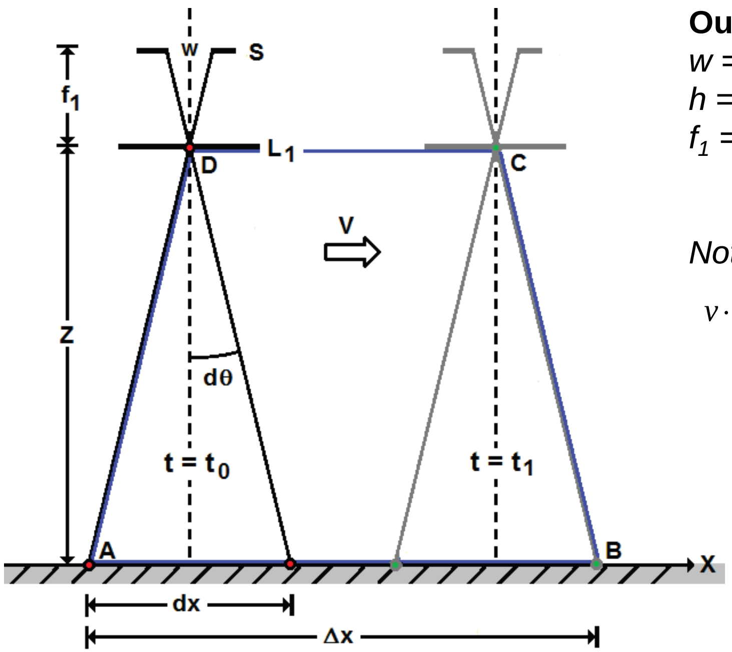
This is known as the **pushbroom** technique.

The net result is a spectral cube or **spectral movie.**

We can now generate images as a function of wavelength.

It is **hyper**!

Pushbroom basics – Spatial resolution



DC: $v \cdot (t_1 - t_0) = v \cdot \Delta t$

AB: $\Delta x = dx + v \cdot \Delta t$

$$dx = \frac{z \times w}{f_1}$$

$$\Delta y = \frac{z \times h}{f_1 \times N}$$

Our instruments:
w = 0.025 mm
h = 3 mm
f_1 = 16 mm

Note that

$$v \cdot \tau \le dx$$

$$d\theta = \arctan(\frac{w}{2 f_1}) = 0.045^o$$

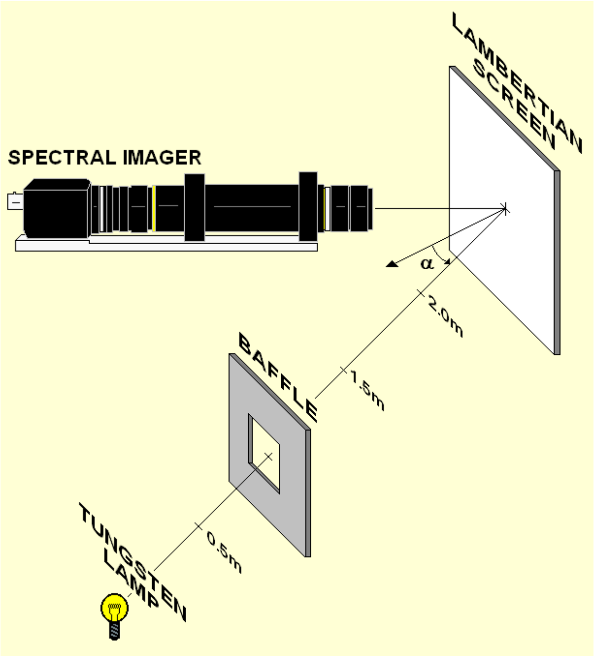
$$\Omega = 2 \times \arctan(\frac{h}{2 f_1}) = 10.7^o$$

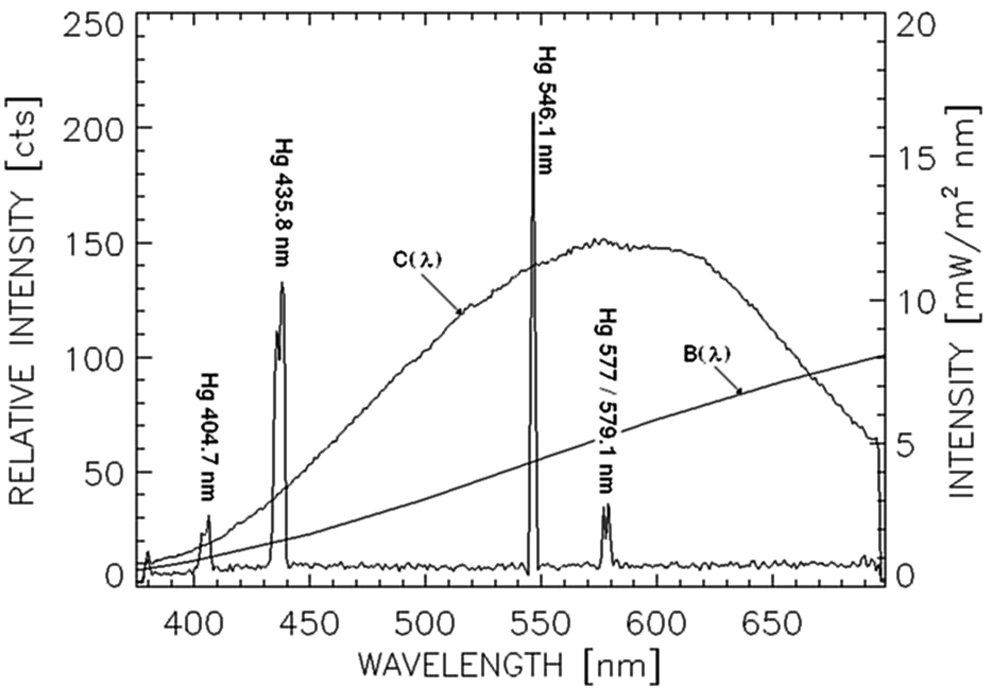
$$SW = 2z \times \tan(\frac{\Omega}{2})$$

Z	dx	Δx	SW
100	0.16	0.36	18.75
300	0.47	0.67	56.25
500	0.78	0.98	93.75
1000	1.56	1.80	187.5

Table 1. Example calculations.
Parameters: Δt = 20 ms (1/50) s., 25 frames per second, read out time τ = 20 ms and speed v = 10 m/s (36 km/t). All numbers in meters.

CALIBRATION-CALIBRATION-CALIBRATION

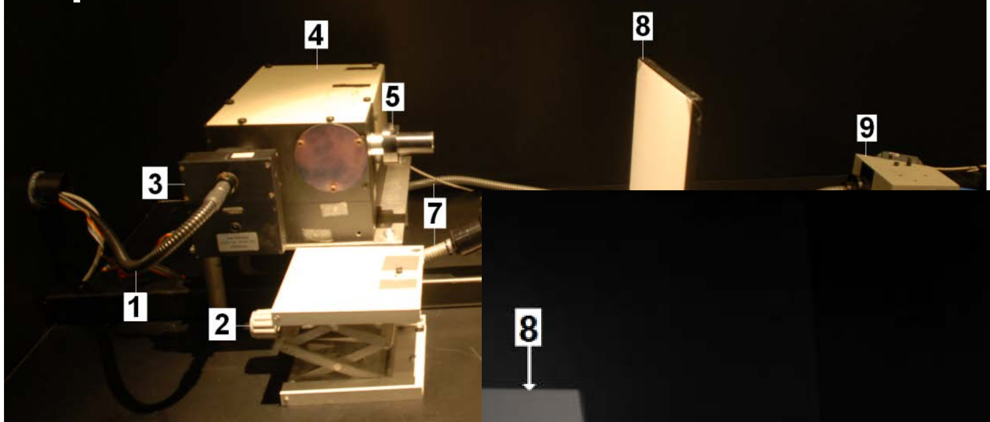


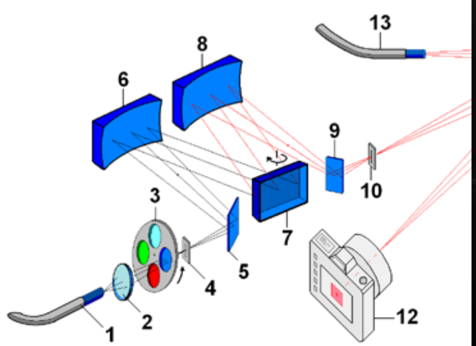


$$B_\lambda = \frac{M_{o\lambda}}{\pi} \rho_\lambda \left(\frac{z_o}{z} \right)^2 \times \cos\alpha$$

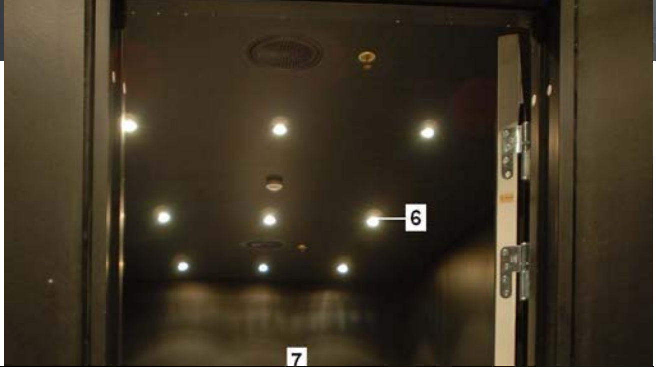
CALIBRATION

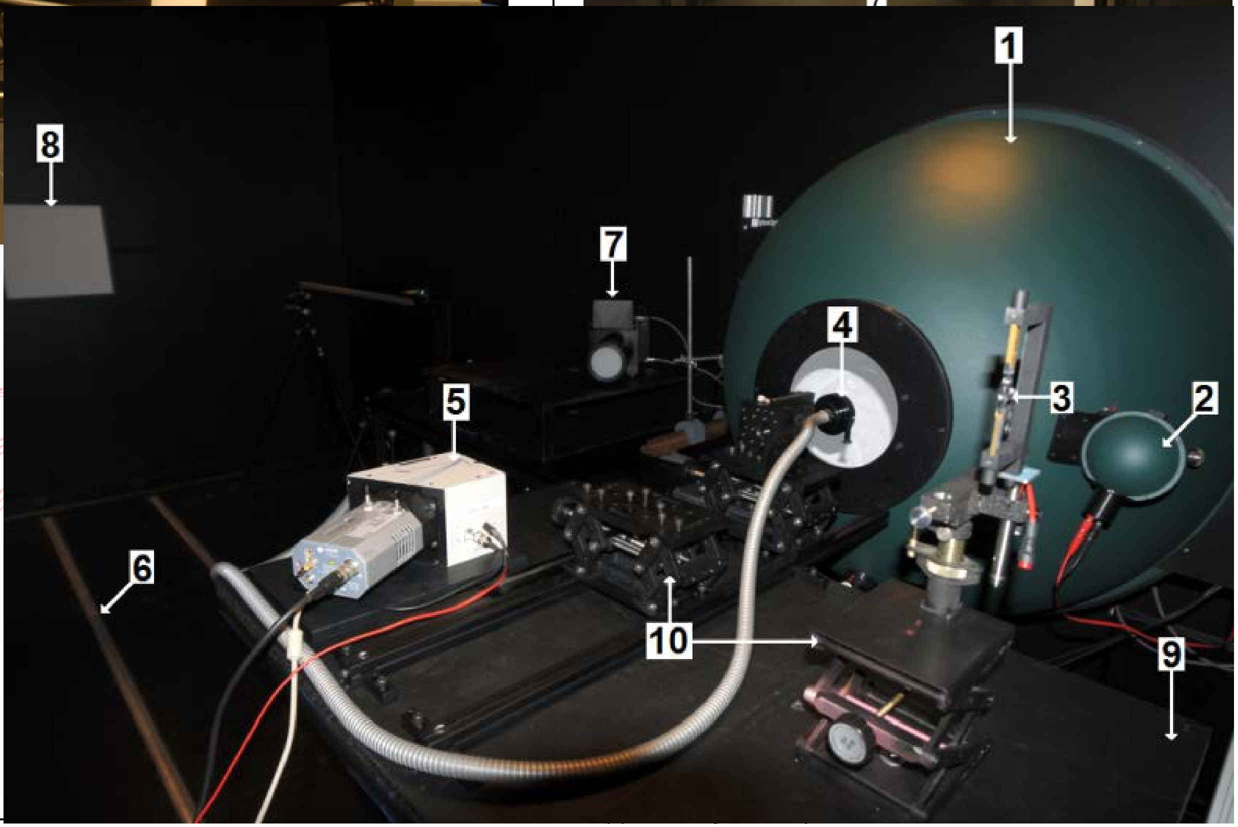
Spectral camera calibration





Narrow field of view spectral calibration





SCENARIO

1. SVALSAT is well established.
2. All polar satellites in field of view.
3. Longyearbyen airport.
4. Local airborne carriers.
5. AGF-207, AGF-331 & AGF-218
6. Logistics
7. CryoWing UAV w/ NORUT IT

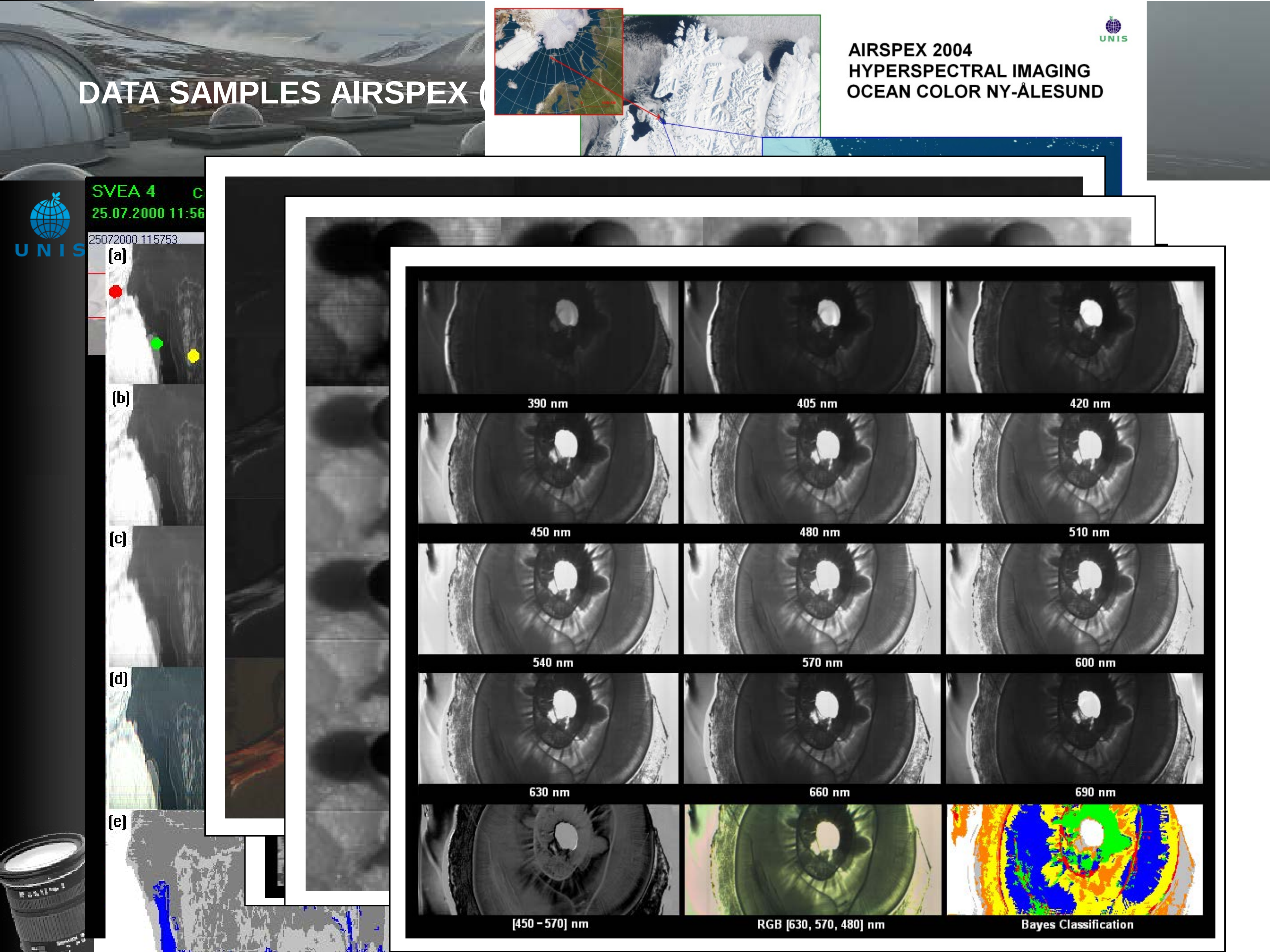
= REMOTE SENSING

AGF-331
Remote Sensing and Spectroscopy (15 ECTS)

Hyperspectral Students 2000 - 2007

AIRSPEX2007

DATA SAMPLES AIRSPEX (



AIRSPEX 2006

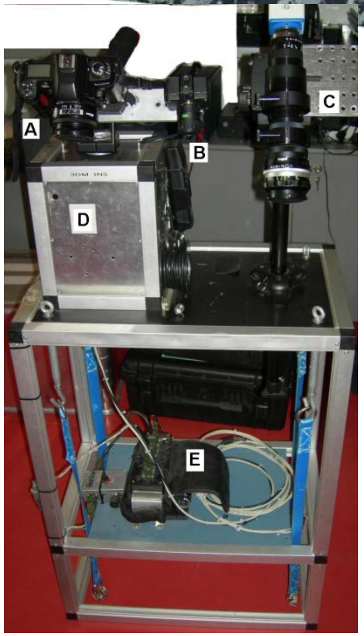
S2Pro DSLR

RGB 625, 550, 475 nm Longyearbyen, May 3, 2006 1500m

NIR 800, 625, 550 nm

Classification

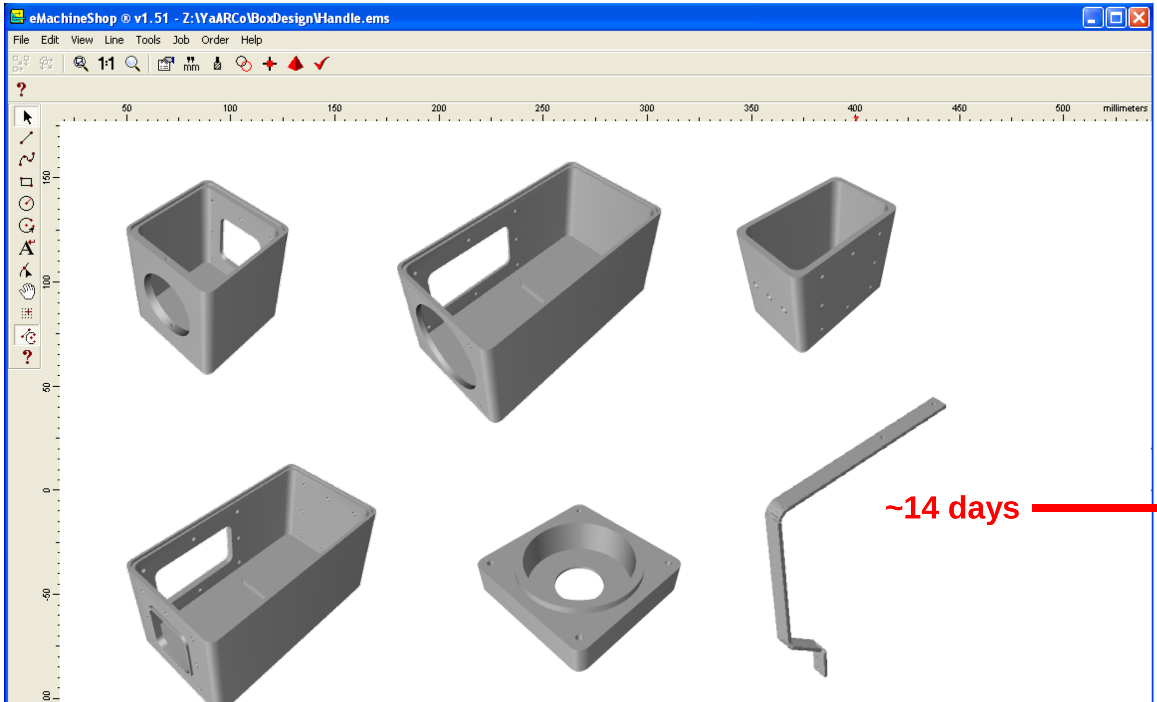
Vegitation1	rock, vegitated	reflection	Belt wagons	Gravel1	snow, wet	Road
Vegitation2	UNIS	Fjord	Roof, gray	Roof, nir	Gravel2	Shadow
vegitation,wet	Roof, red	Rock, spars. veg.	Roof, brown	Gravel, dark	Snow	Snow, dirty
Road3	Melt Water					



(A) S2Pro DSLR, (B) Webcam,
(C) Hyperspectral imager,
(D) Gyro / INS & (E) Battery pack

NEW TYPE OF INSTRUMENT DEVELOPMENT

EXAMPLE 1: HYPERSPECTRAL IMAGER



~14 days →

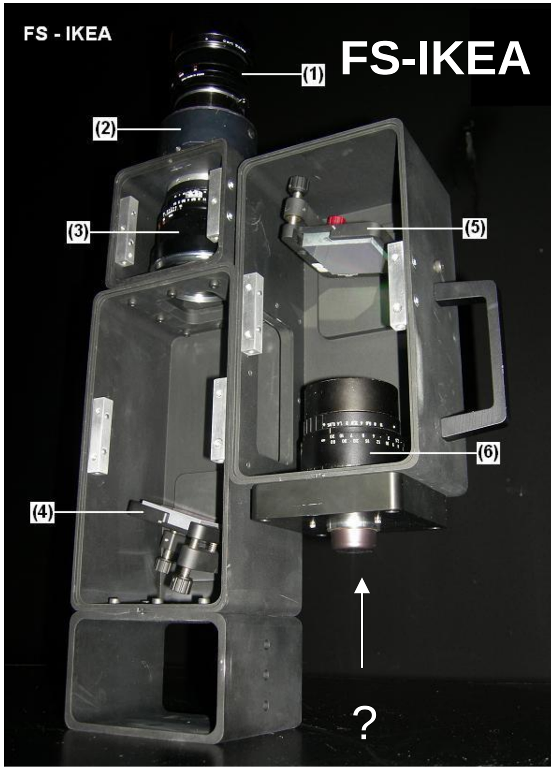
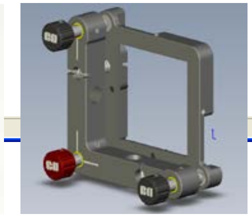
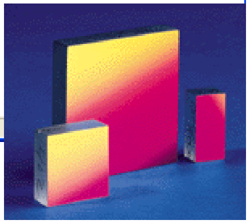


Figure Caption: The FS - IKEA. (1) front lens, (2) slit house, (3) collimator lens, (4) flat surface mirror, (5) blazed grating, and (6) camera / detector lens.

Electronic Machine Shops



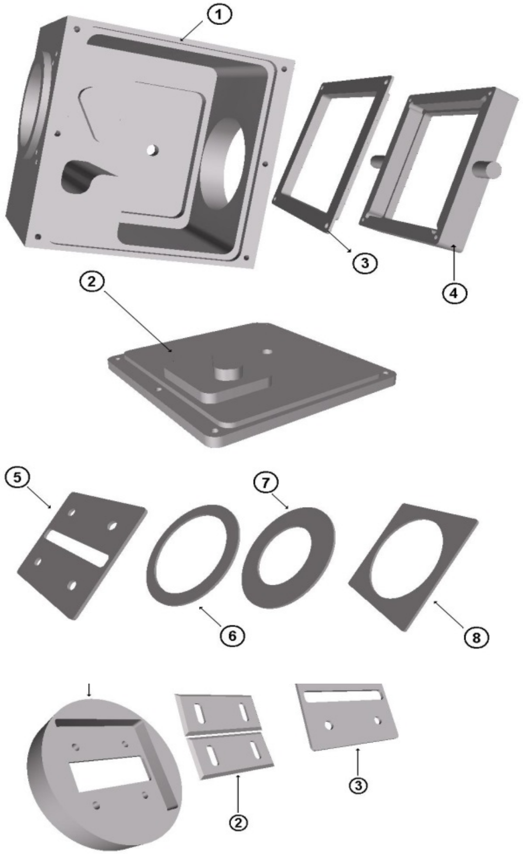


Purchase optics and mounts

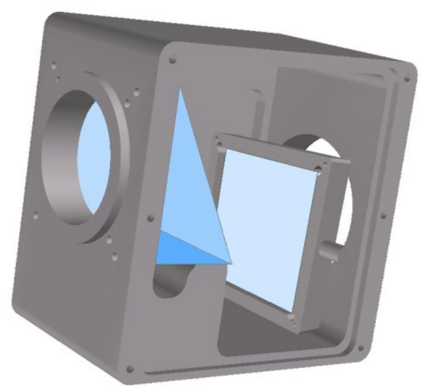
EMCCD Andor Luca R

NEW TYPE OF INSTRUMENT DEVELOPMENT

EXAMPLE 2: no. 1 Meridian Imaging Svalbard Spectrograph (noMISS)



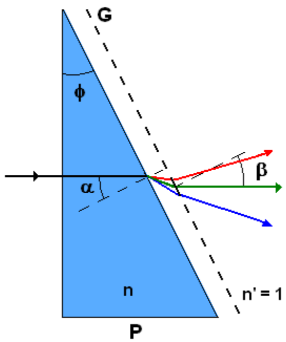
eMachineShop Parts



Tunable GRISM

Assemble optics and mounts (Thorlabs). Detector ATIK 314L+

KEY OPTICAL ELEMENT



The grating equation is modified by using Snell's law

$$m\,\lambda = a\left(n\sin\alpha + \sin\beta\right)$$

where *m* is the spectral order, λ is the wavelength, *a* the groove spacing, α the incident angle and β the diffracted angle. *n* is the refractive index of the prism given by the formula of *Cauchy*

$$n = A + \frac{B}{\lambda^2}$$

A and *B* are constants according to substance of the glass material used.

Wavelength λ [nm]	Refractive index n	Diffracted angle β [deg.]
300	1.61829	38.9872
400	1.58942	33.6908
500	1.57606	29.2111
600	1.56880	25.1126
700	1.56442	21.2360
800	1.56158	17.5051
900	1.55963	13.8757

Diffracted angles for a GRISM with $\phi = \alpha = 30^{o}$, grating groove spacing a = 1666.667 nm (a 600 lines / mm) and spectral order m = 1.

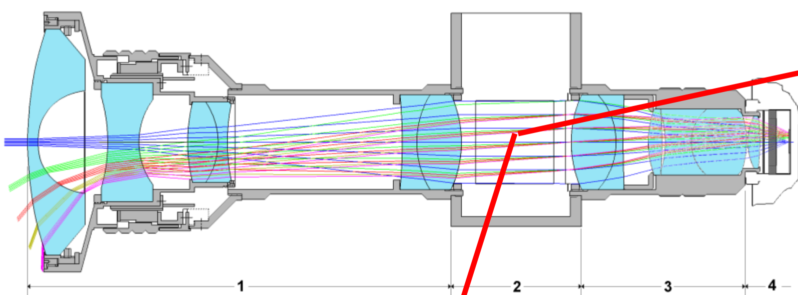
Cauchy's index of refraction constants are *A* = 1.5523 and B = 5939.39 nm for Borate flint glass.

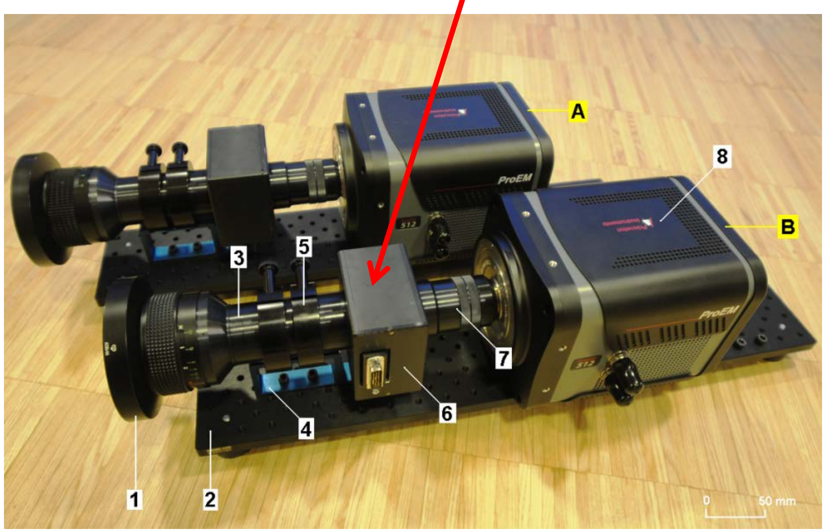
The total spread in the diffracted angles of the spectrum is also less than using a grating alone. The latter is due to the fact that a prism disperses blue light more than red, whereas the grating diffracts red light more than blue.

UNIS

NEW TYPE OF INSTRUMENTS

EXAMPLE 3: no. 1 NORUSCA





Liquid Crystal Tunable Filters (LCTFs).

Based on the Lyot filter (stack of birefringent plates).

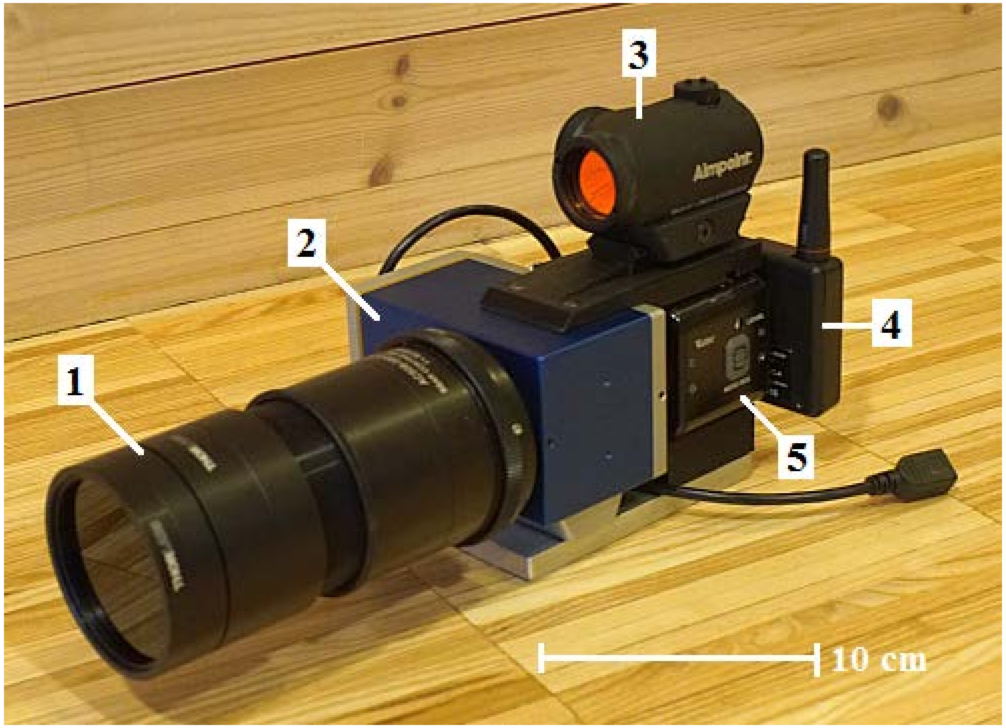
“The ability to electronically tune the band pass wavelength of these filters throughout the visible electromagnetic spectrum makes them an ideal candidate for hyperspectral imaging”

Cost: 1 MNOK

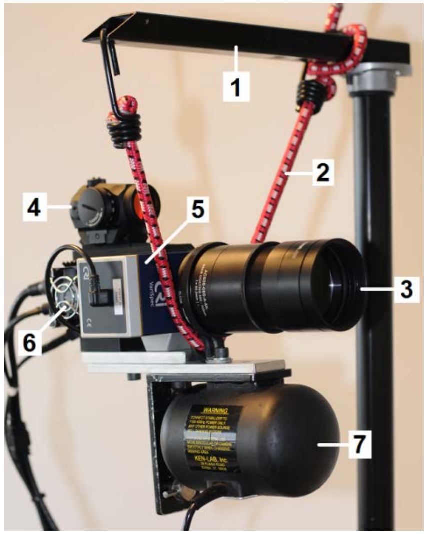
NEW TYPE OF INSTRUMENTS

Snapshot of moon at 650 nm

EXAMPLE 4: Narrow field of view Hyperspectral LCTF camera



Prototype hyperspectral camera: (1) lens, (2) Liquid Crystal Tunable Filter (LCTF)- Varipsec, (3) aimpoint, (4) radio controller of camera head, and (5) Astrovid camera head.



Gyro rig: (1) mount arm, (2) elastic rope, (3) lens, (4) aimpoint, (5) Varispec filter, (6) camera head, and (7) hand held gyro stabilizer.

Note that stabilization did not work airborne!

LOW COST DEVELOPMENT < 50 kNOK

Motivation

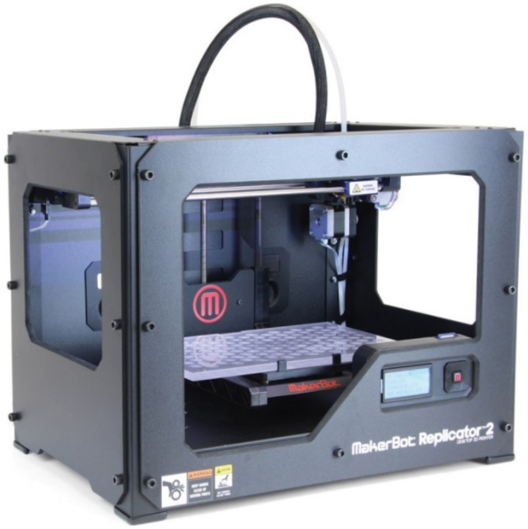
1. It now cost less to buy a drone than hiring a airplane or helicopter for one hour.

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)

LOW COST DEVELOPMENT < 50 kNOK

Mini spectrograph basic equations

Quadrocopter Hyperspectral Imager

$k\lambda = a(\sin\alpha + \sin\beta)$

$\alpha = 0 \quad k = 1 \quad \omega = 17.45°$

$a = 16\,666.7$ Å; 600 lines/mm

$\lambda_B \approx 5000$ Å

$\beta = \sin^{-1}\left(\frac{k\lambda}{a}\right)$

$\lambda_0 = 4000$ Å $\quad \lambda_1 = 5525$ Å $\quad \lambda_2 = 7000$ Å

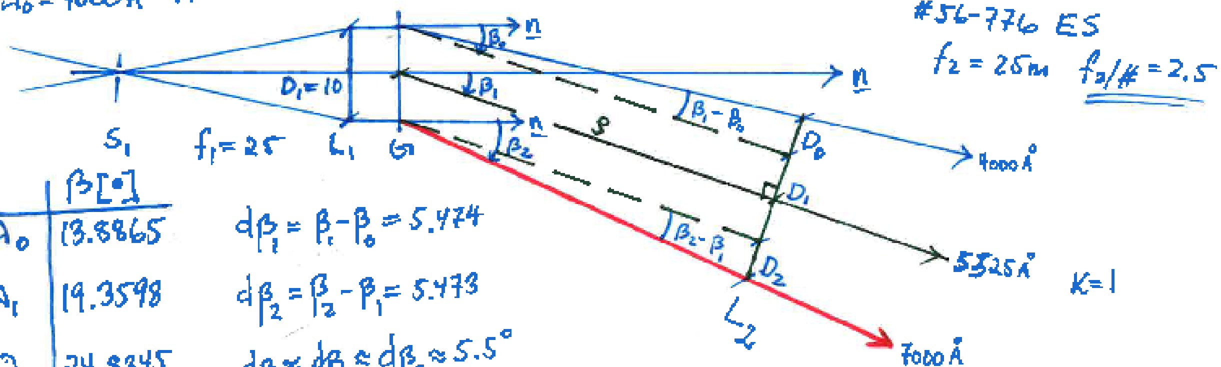
$f_1/\# = \frac{f_1}{D_1} = 2.5$

$f_2/\# = \frac{f_2}{D_0 + D_1 + D_2} = \frac{f_2}{D_1 + 2D_0} = \frac{f_2}{D_1 + 2\rho\tan d\beta} \approx \frac{f_2}{D_1 + 0.2\rho}$

ex: $\rho = 5$ mm $\Rightarrow f_2/\# \approx \frac{f_2}{10}$

#56-776 ES

$f_2 = 25$ mm $\quad f_2/\# = 2.5$



	β [°]
λ_0	13.8865
λ_1	19.3598
λ_2	24.8345

$d\beta_1 = \beta_1 - \beta_0 = 5.474$

$d\beta_2 = \beta_2 - \beta_1 = 5.473$

$d\beta \approx d\beta_1 \approx d\beta_2 \approx 5.5°$

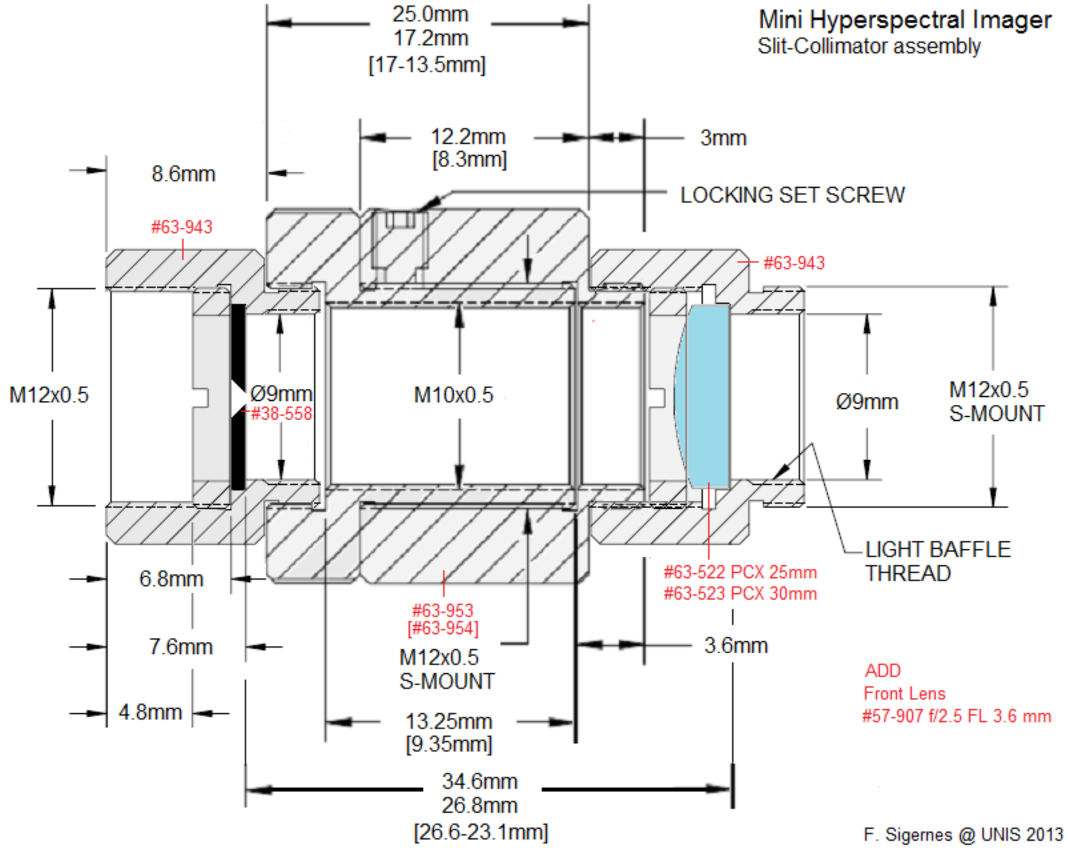
$D_0 = D_2 \Rightarrow \tan d\beta = D_0/\rho$

G – Transmission grating 12.7×12.7 mm^2
ES #

I. Sigernes, October 2013

LOW COST DEVELOPMENT < 50 kNOK

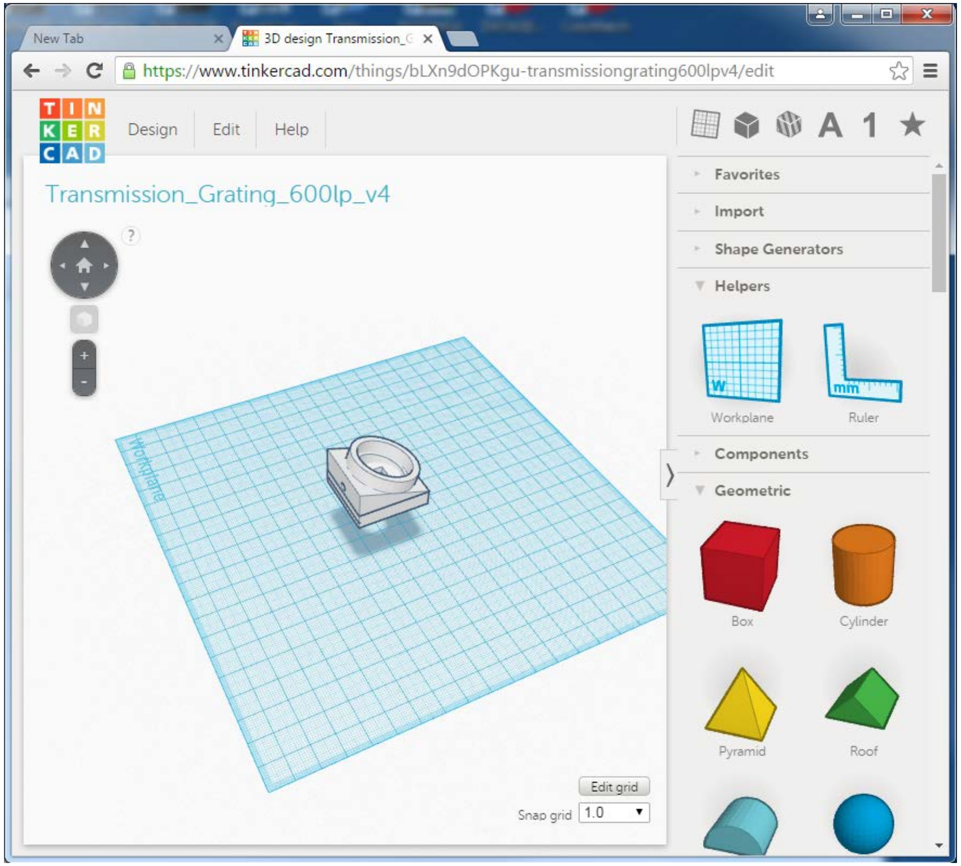
Mini spectrograph Slit-Collimator assembly



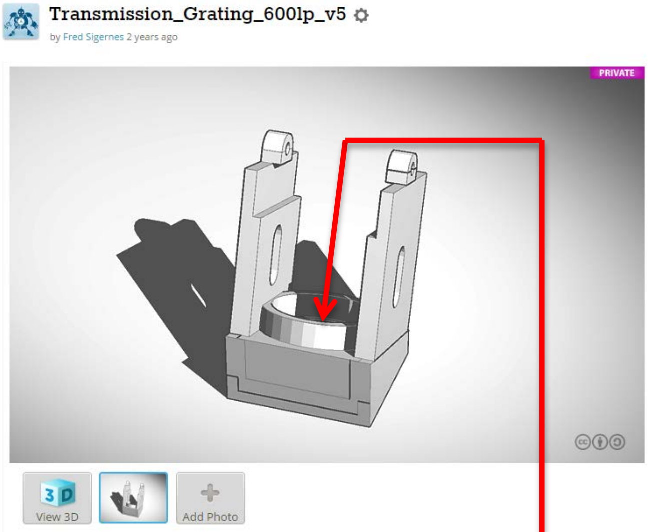
All parts are from the mix and match assembly from Edmund Optics.

LOW COST DEVELOPMENT < 50 kNOK

Mini spectrograph Grating holder / Detector / Camera Clip on mount



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

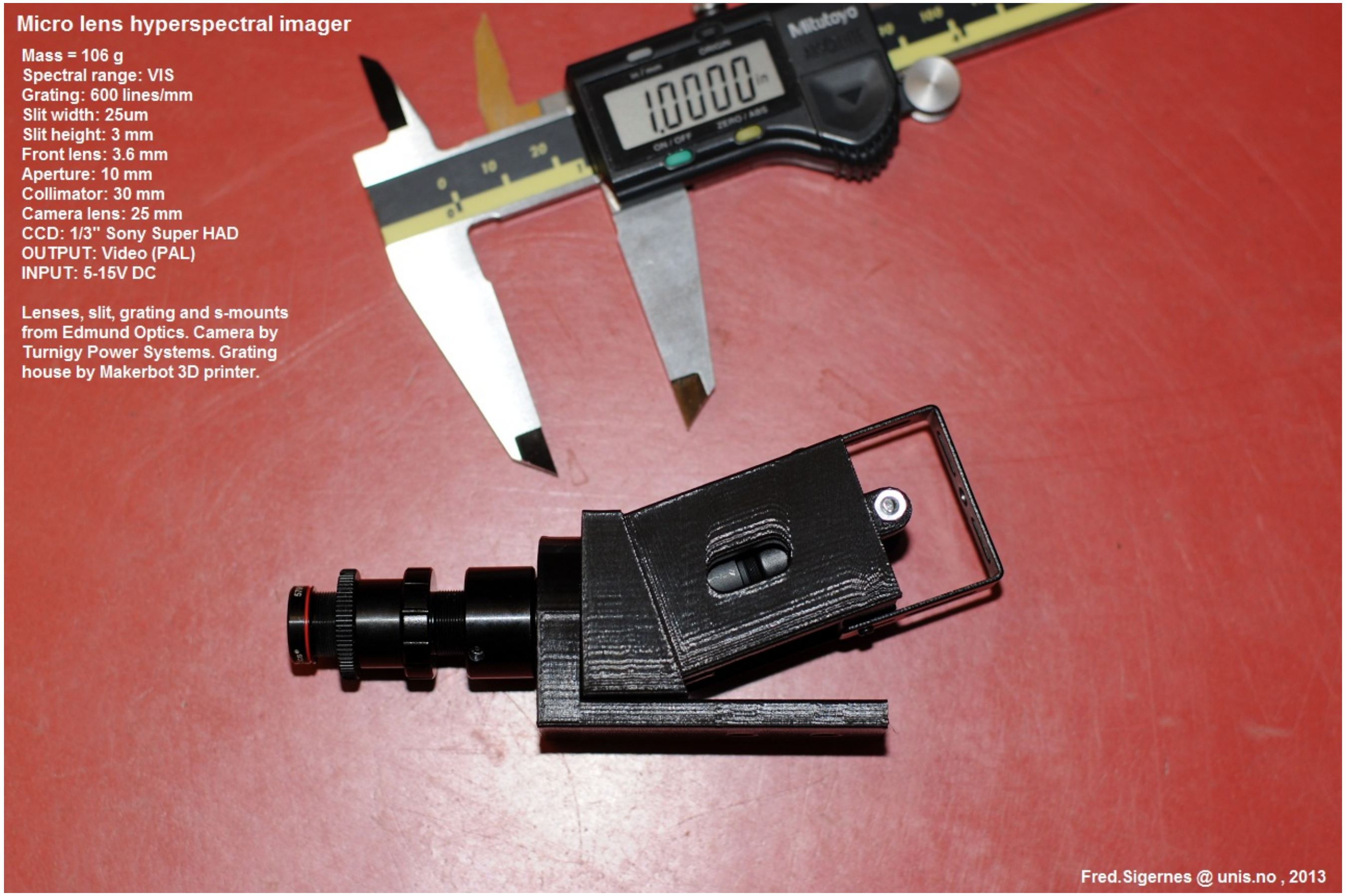


Camera head
Turnigy PAL 700 TVL HobbyKing.com
Sony 1/3-Inch Super HAD CCD

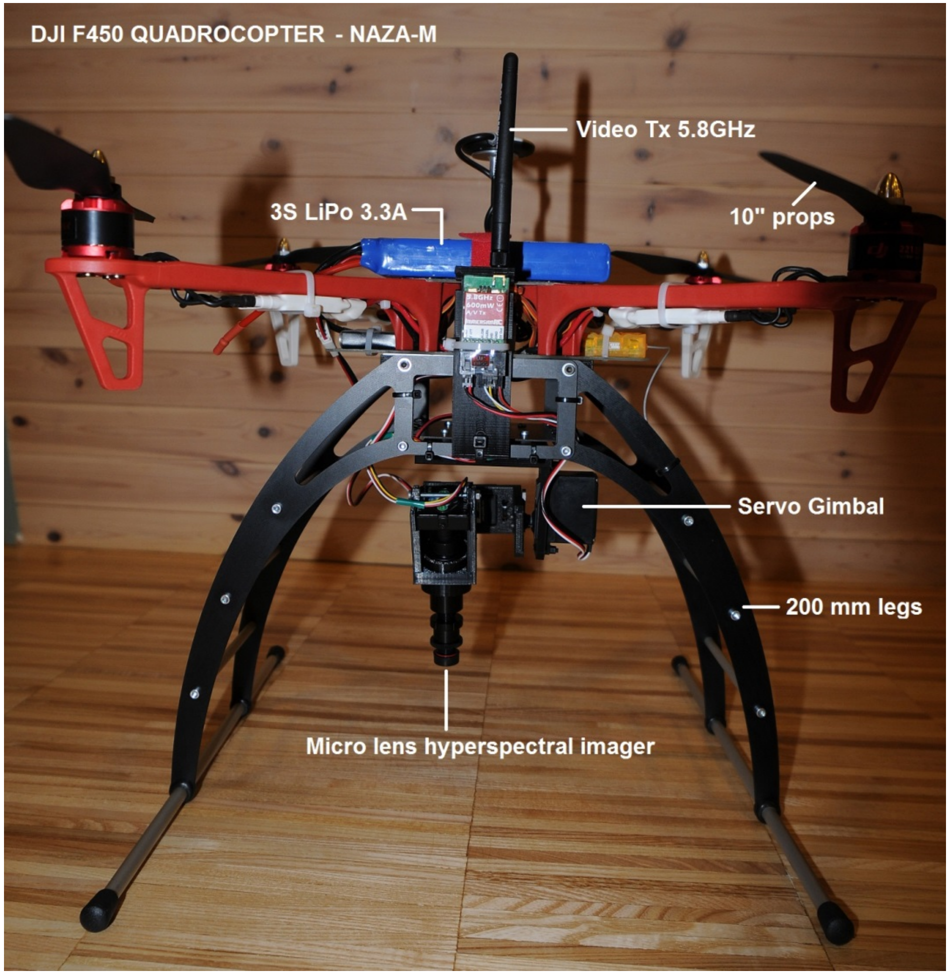
Collector lens
ES 25mm f/2.5

LOW COST DEVELOPMENT < 50 kNOK

Assembled Hybrid mini pushbroom hyperspectral imager



Drone Experiment



Instrument mounted to a DJI F450 Quadrocopter.

Note that the Gimbal here is brush type servos connected to the NASA-M flight controller.

The experiment was not successful due to vibrations and slow response of the gimbal.

We will do the same with hopefully a better brushless gimbal and carrier.