WFAI (Wide Field Auroral Imager)

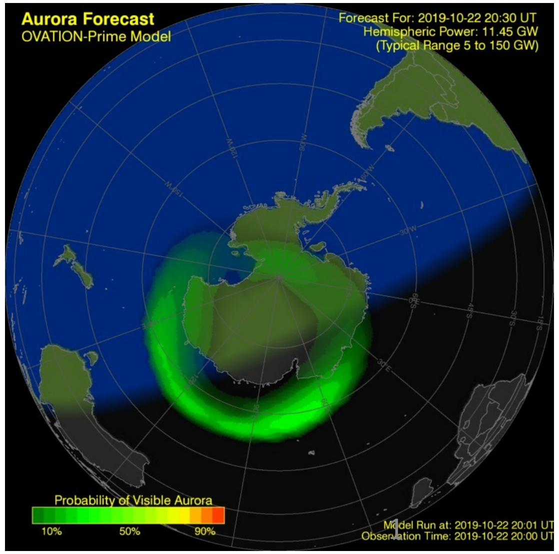
A spectral imager instrument for auroral monitoring

Barthelemy (1) , Le Coarer (1), Ravatin (2), Hugot (3), Rodrigo (1), Prugniaux (1), Dupont (2), Joaquina (3) et al.

(1)CSUG (UGA-GINP)/IPAG (UGA-CNRS)

(2) Pyxalis

(3) LAM



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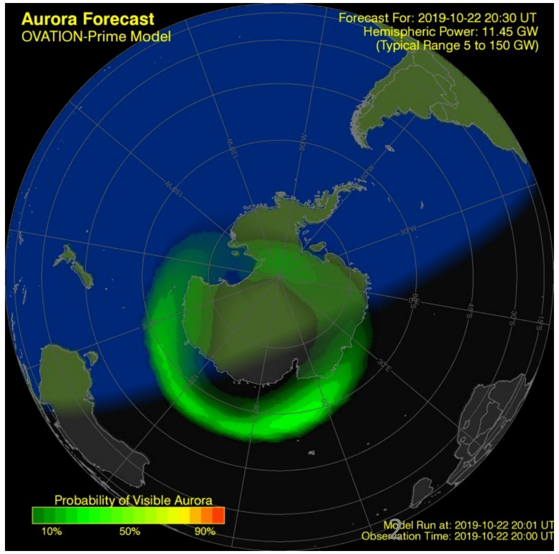
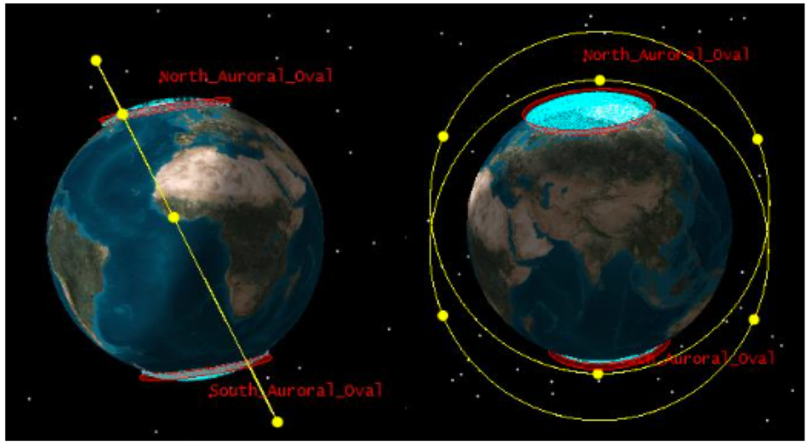
A spectral imager instrument for auroral monitoring

Under pre-development with ESA (2019-2020)



Science case

D3S:
6 satellites
HEO
400 km – 4000 km (or 1800 km)

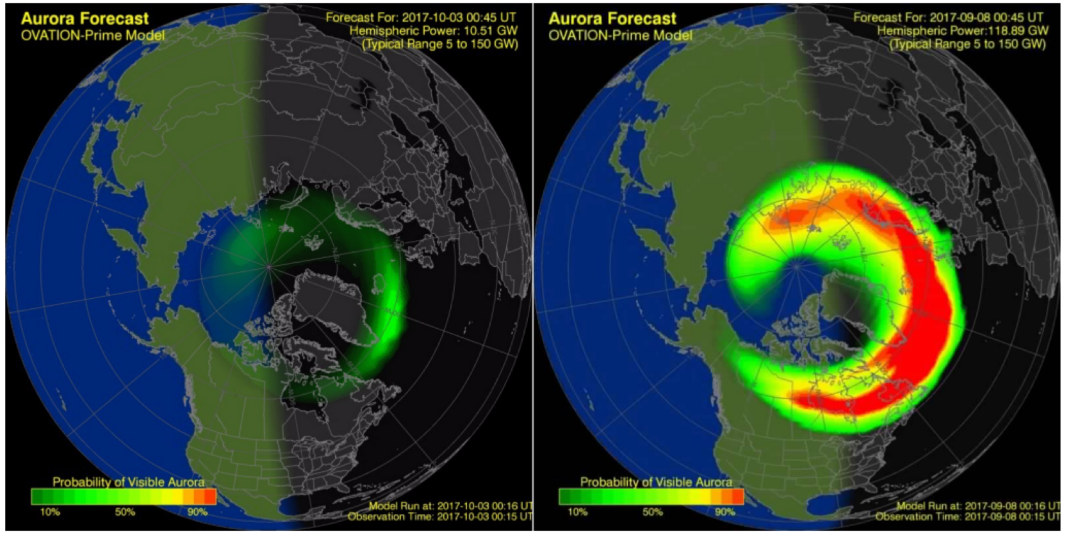


Auroras are a tracer of :

- Particle precipitation from plasma sheet and boundary region (Suprathermal particles, eV and KeV ranges)
  - 2nd most important in term of energy
  - Need for overall coverage
- Observables:
  - Auroral oval location
  - Overall shape and small scale structures
  - Intensities in different lines and bands

- Goal of observations: Global reconstruction of particle precipitations
  - Energies, total flux
  - p^+ and e^-

- **No other way to get global large scale particle precipitation monitoring (quasi continuous)**

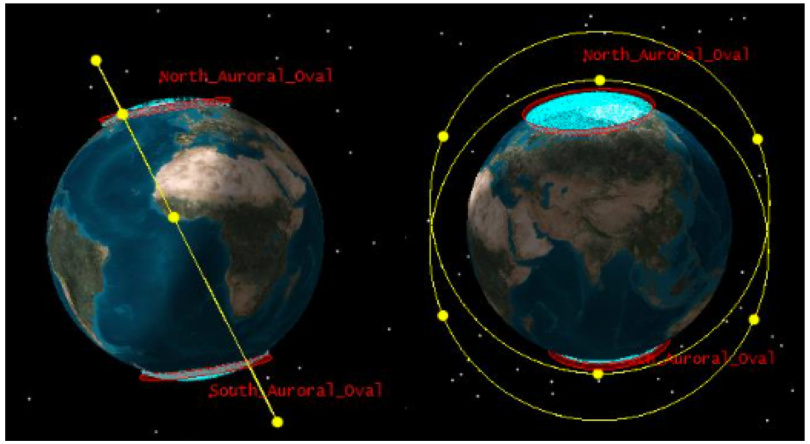


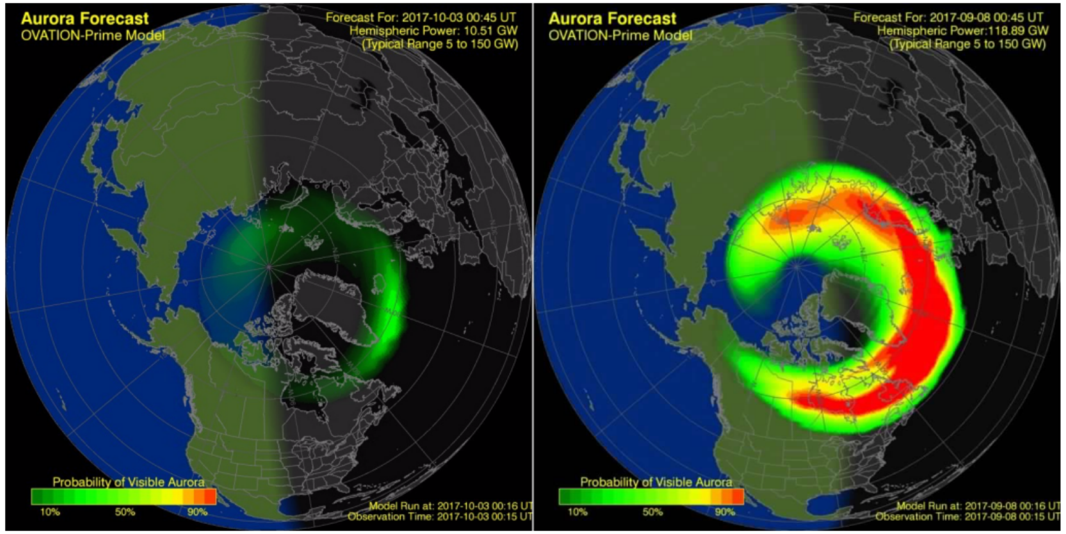
Science case

D3S:
6 satellites
HEO
400 km – 4000 km (or 1800 km)

- Continuous nowcasting of the auroral oval

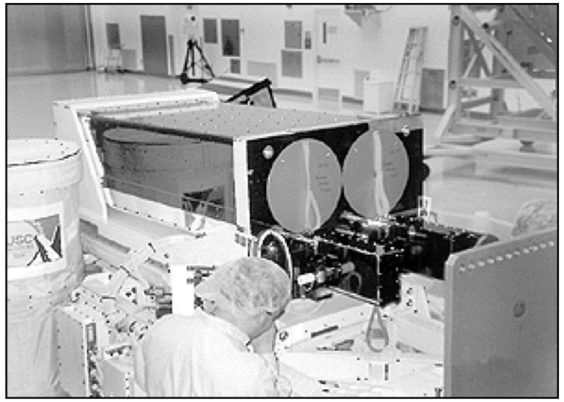
- Coupling with other instruments
  - Ground based
    - Optical, radar, magnetometer
  - Space
    - Particle detectors
    - Magnetospheric satellites



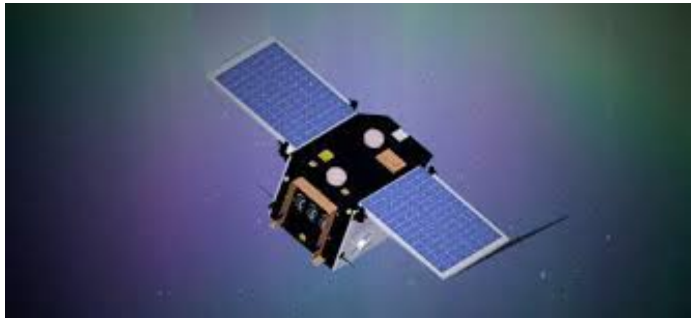


State of the art (Space experiments)

- Airglow
  - GLO (Arizona)
- In the visible
  - Satellite Polar (NASA)
    - Visible imager
  - Satellite REIMEI (JAXA)
    - High speed photometer
    - Several band pass (Green, 427 nm, N2 1st positive band 670 nm)
- No visible spectrometer for the aurora…



Credit Broadfoot



Credit JAXA

State of the art (Space experiments)

- In the UV

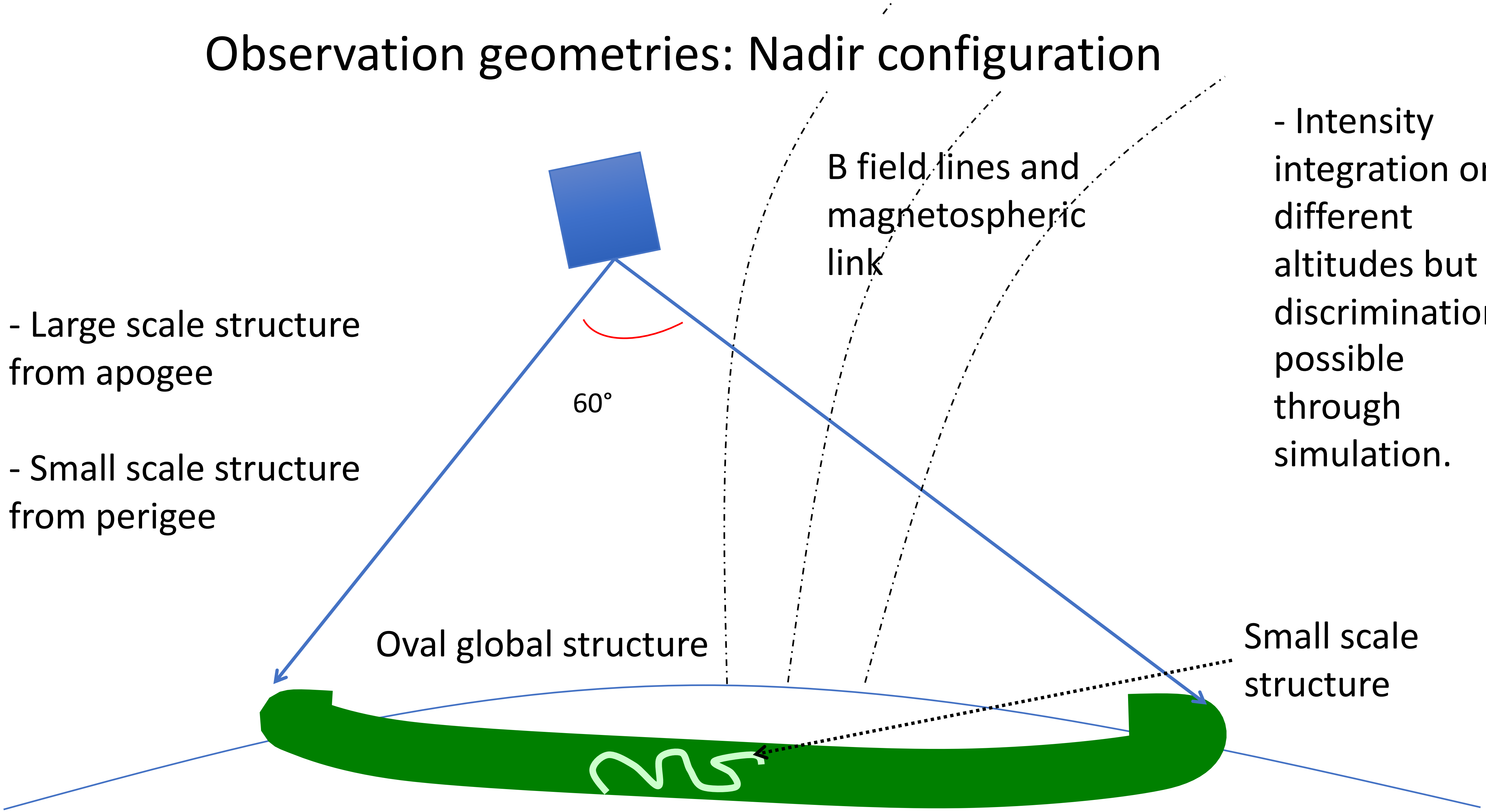
Imager	Angular/Spatial Resolution[a] (deg/km)	Spacecraft altitude	Wavelength (nm)	Image frame rate
WAI/FY-3D	0.8/10	830 km	140–180	2, 100 min
WIC/IMAGE	0.18/120	0.3–7 R_E	140–190	10 s
SI/IMAGE	0.13/100 0.26/200	0.3–7 R_E	135.6 121.6	5 s
UVI/Polar	0.03/30	1–8 R_E	4 filters: 130–190	37 s
GUVI/TIMED	0.8/50	630 km	Spectrometer: 120–180	100 min
SSUSI/DMSP	0.8/50	840 km	Spectrometer: 120–180	100 min
SAI/DE-1	0.32/100	1–4 R_E[b]	Several filters: 121.6–630.0	12 min

From Zhang et al. 2019 Nature.

Observation geometries: Nadir configuration

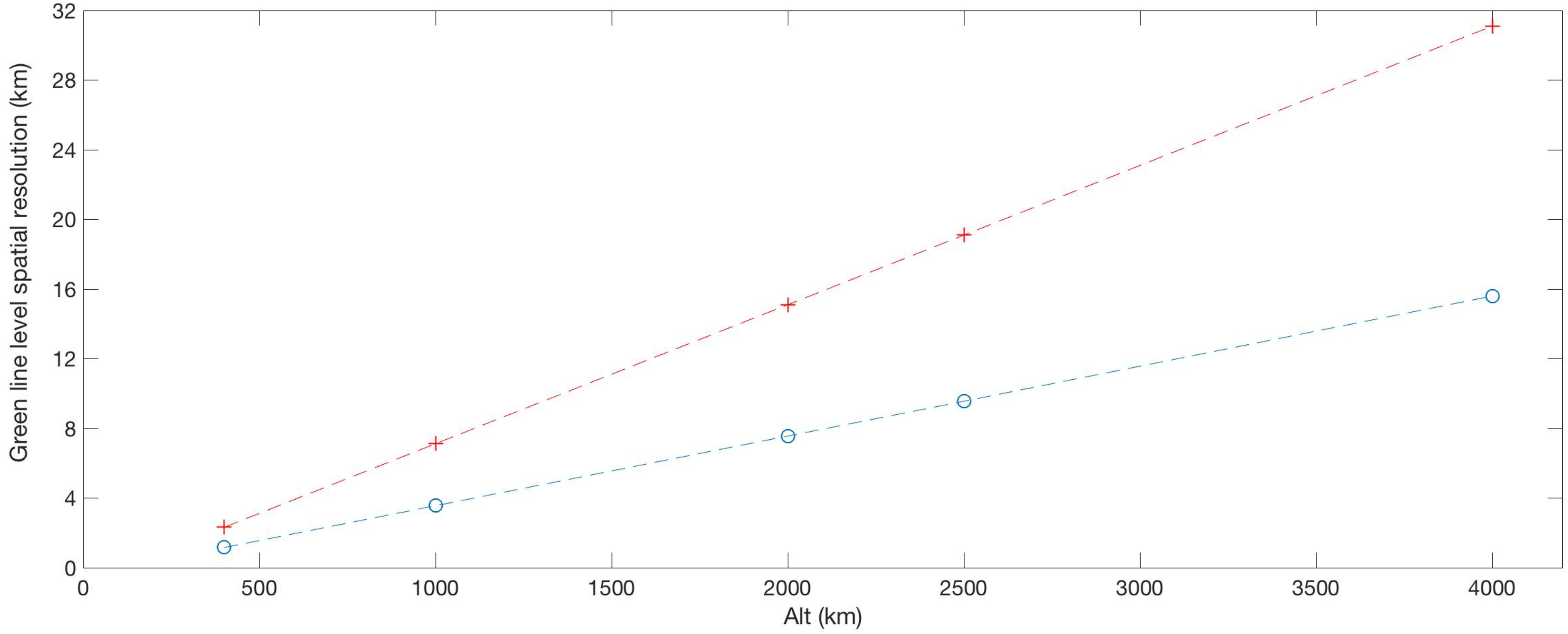
- Large scale structure from apogee

- Small scale structure from perigee



- Intensity integration on different altitudes but discrimination possible through simulation.

Spatial resolution



Spatial resolution at green line level (km/pix)

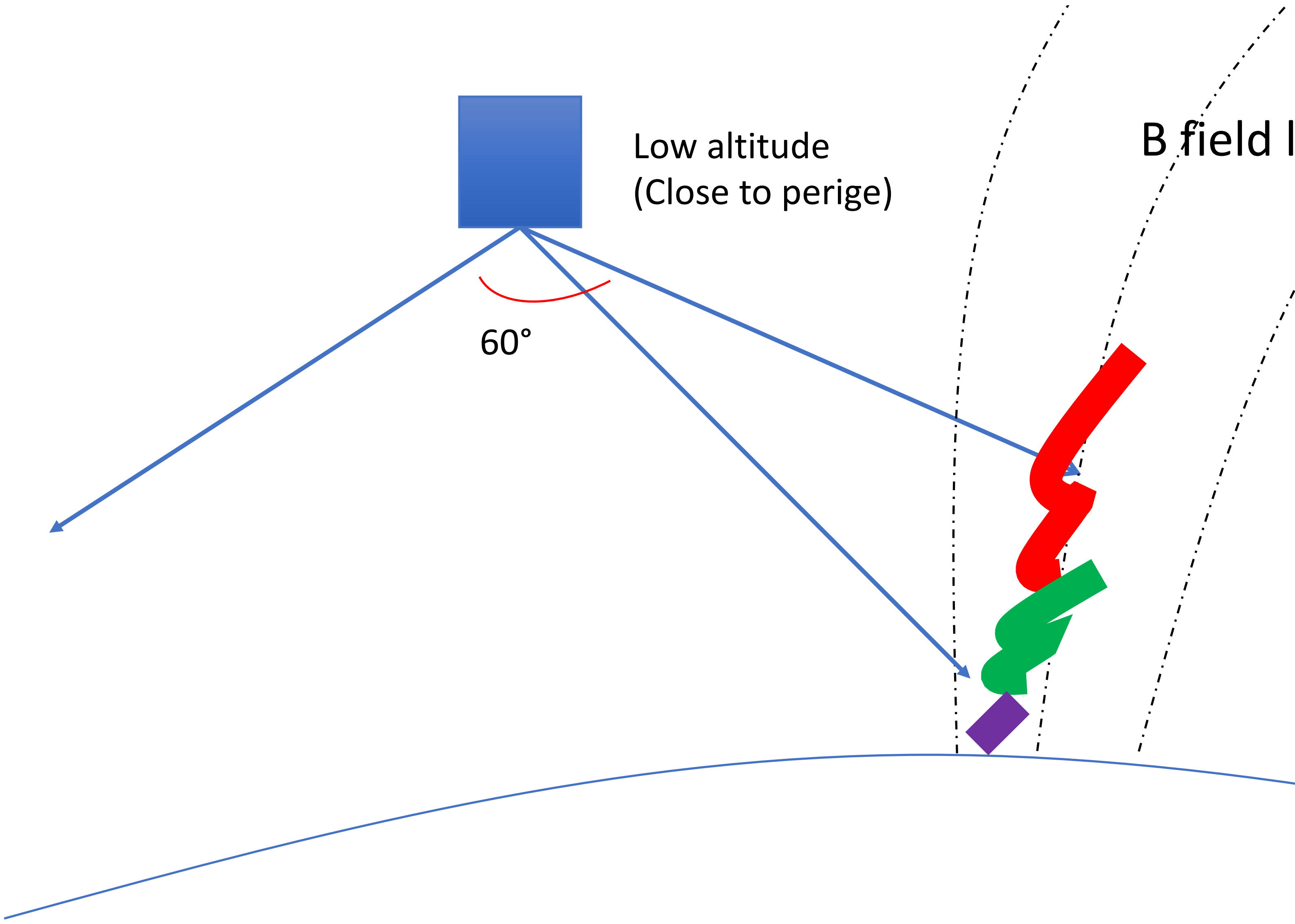
Two options

20 km/pix @2500 km (red) or 8e-3 rad/pix

10 km/pix @ 2500 km (Blue) or 4e-3 rad/pix

<u>Notice: Effective spatial resolution needs to be considered on 2 pixels</u>

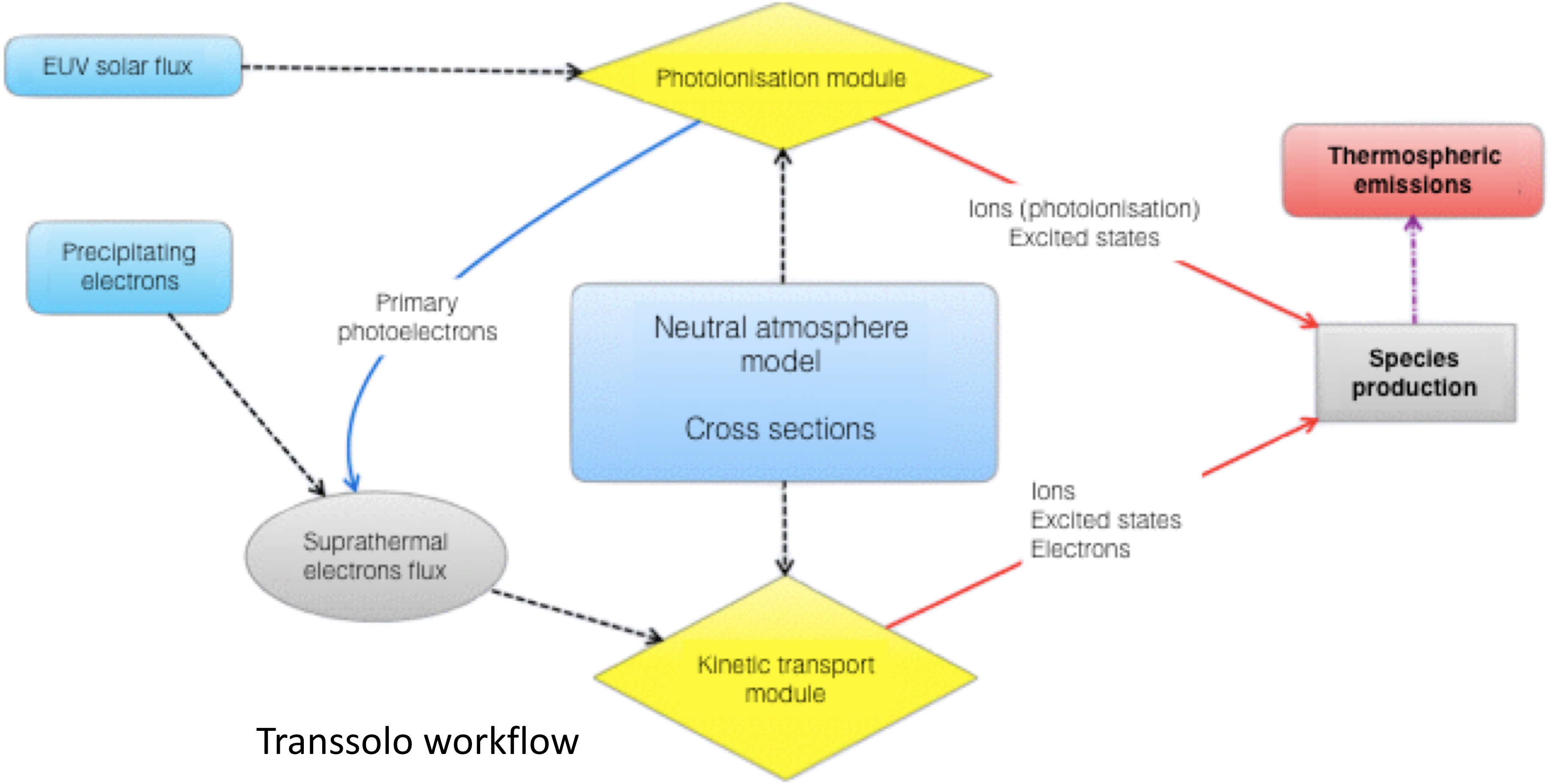
Observation geometries: Limb (pseudo limb) configuration



Altitude discrimination of different emissions.

- Better energetic input reconstruction (Alt profile)
- Energy deposition
- Altitude of the emissions

How to link auroral emissions to particle precipitations?



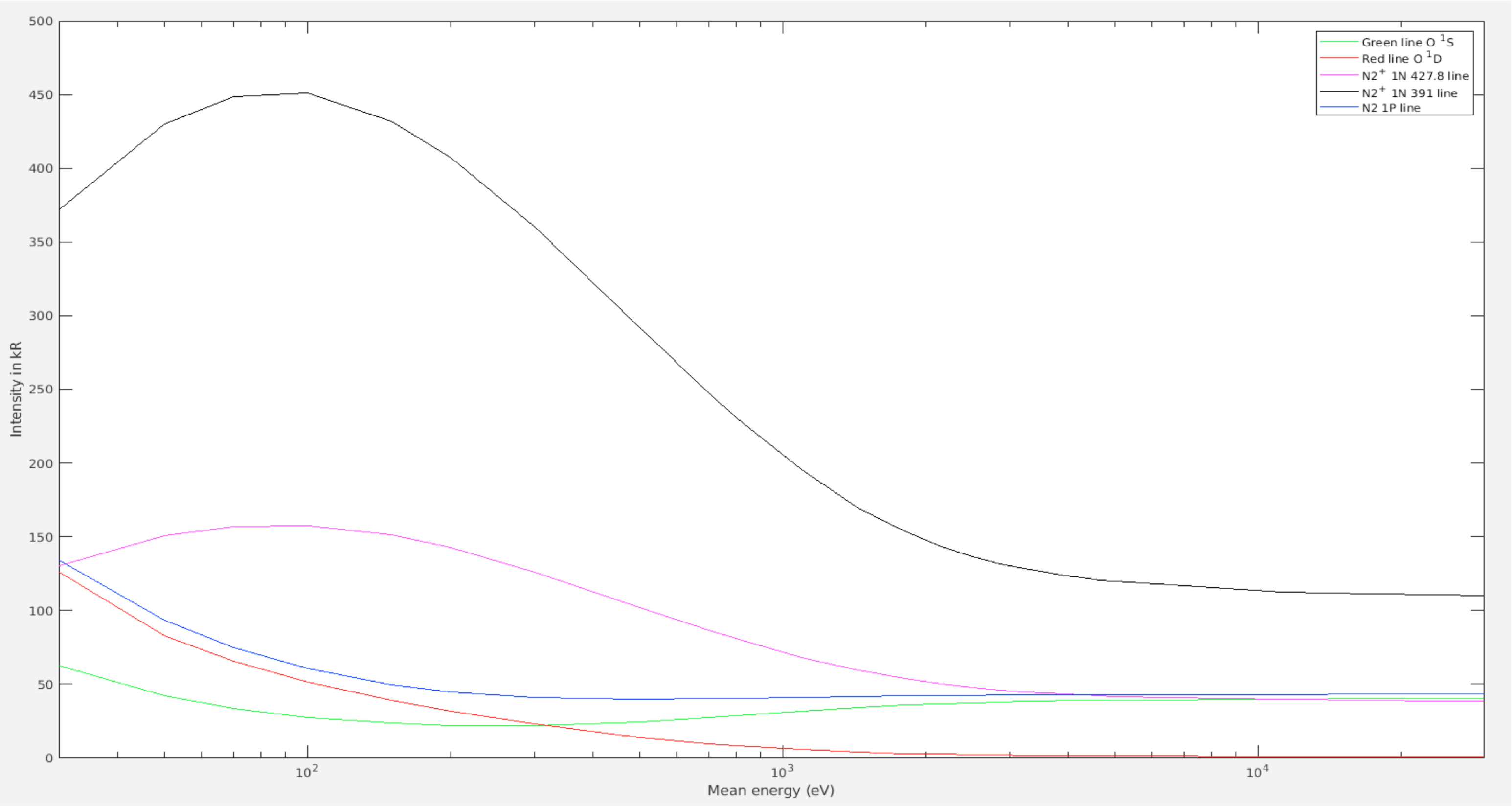
Transsolo workflow

The Transsolo kinetic code

Link between electrons and protons flux and emissions (Vialatte et al. 2017)

Other code for magnetic field propagation (A2000 magnetic field model From MSU)

How to link auroral emissions to particle precipitations?



Intensity of auroral lines for different input mean energy

Fitted parameters:

E_{moy}

E_{tot}

(<u>PhD of Elisa Robert</u>)

Note that several energies can give a, identical emission for some lines:

<u>**Multi line studies are thus mandatory**</u>

<u>**Better sensitivity for electrons with less than 3 keV**</u>

FUV versus visible (or both)

- FUV visible on both night and day sides
  - However
    - O 130 nm optically thick and resonant with the sun
    - O 135 nm resonant with the sun
  - LBH of strong interest but concerns only N_2 excitations

- Visible
  - Not observable at the nadir on the dayside (Auroral mapping)
  - Observable at the limb
  - Perturbated by moonlight
  - A larger panel of information (N2, O I, H alpha, …)

Both FUV and Visible are needed for auroral particle monitoring

Needs

- Visible and FUV auroral monitoring (From FUV to 1µm)
- Wide field (60°x60°)
    - Full oval monitoring
- Spatial resolution (10 to 20 km)
    - Small scale structures
- Spectral resolution (1 to 10 nm for vibrational bands)
    - Molecular and atomic lines monitoring for better discrimination of energies and total flux

A wide field auroral spectral imager,

added to a FUV photometer (135 and 138 nm)

WFAI-AOSI (Visible instrument)

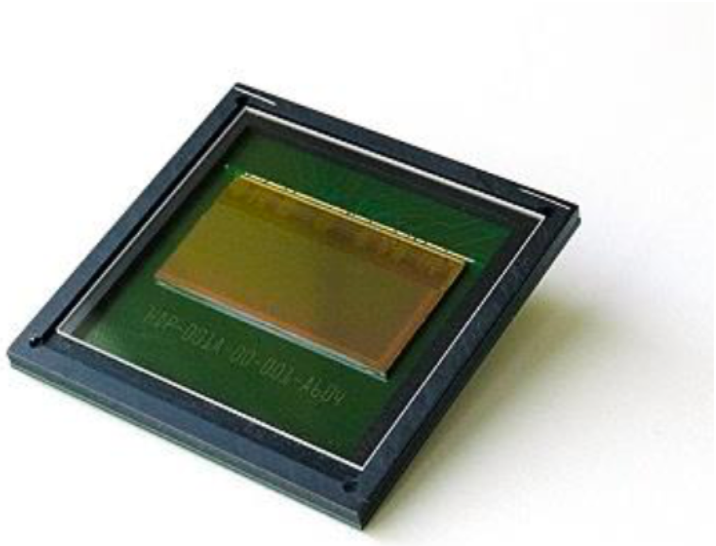
- Performances
  - Depending of the available power and volume
- Spatial resolution from 10 km to 20 km/pix
- Spectral resolution: 120 cm^{-1} (1 to 12 nm)
  - Vibrational bands accessible
- Sensitivity
  - Depending of the auroral intensity
    - Full spectra of the ovals within 10 s to 30 s
- Self calibration on the moon (Photometry) and on the known wavelength of the main lines (Green, N_2^+ 427 nm for example)

- Targeted lines:
  - O I 557 nm
  - O I 630 nm
  - N_2^+ 391 nm
  - N_2^+ 427 nm
  - N_2 1st positive band (Several vibrational bands)
  - Other fainter lines for strong auroras

- Night side (Possible with moonlight) with degraded sensitivity

- Need to be able to switch off the part of instrument aiming in the dayside
  - Need for several units

WFAI AOSI

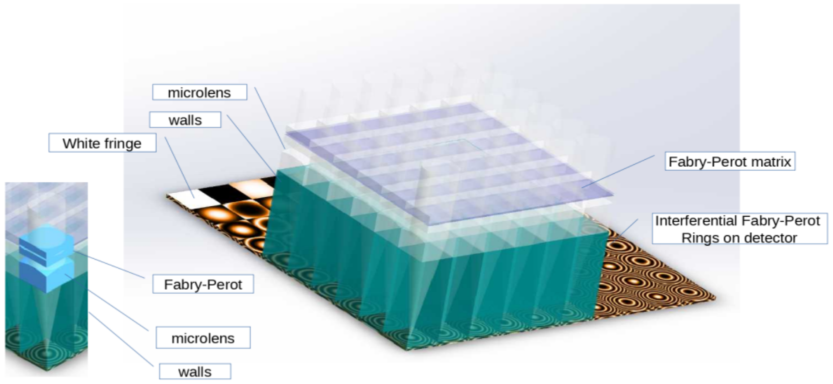


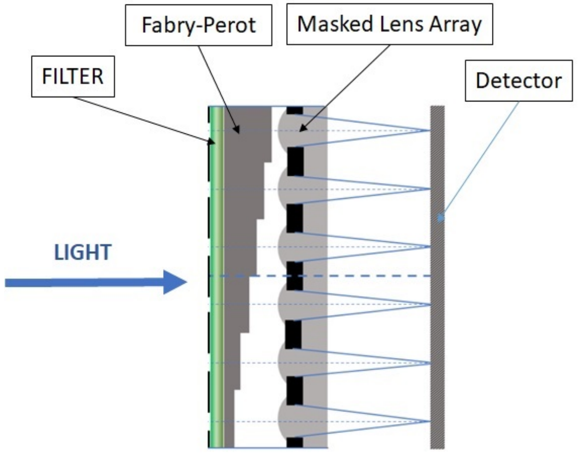
- Optical design: detectors
  - Based on HDPYX from Pyxalis
    - CMOS, 2.5e noise, 100ke FWC
    - Dyn 120 dB (HDR mode)
    - 10 µm pitch
    - 2808x1096
    - BSI in development

- 4 to 16 units for full FoV (Trade off with spatial resolution and sensitivity)
    - Advantage: allow to switch off units looking to the dayside.

WFAI AOSI

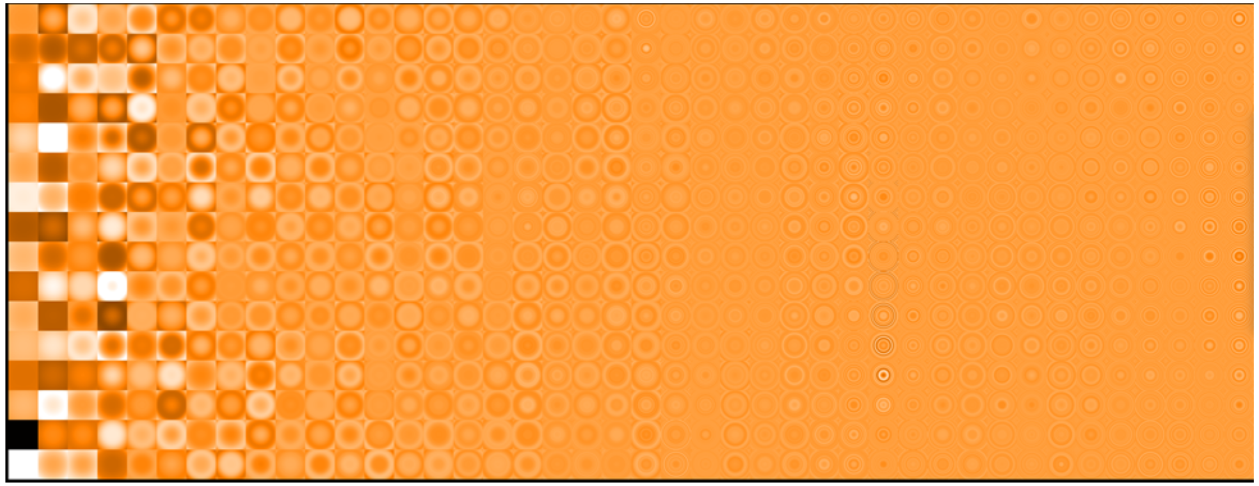
- Optical design:
  - 1 to 2 mm focal length
  - 66x66 (or 33x33) images
  - Fabry Perot interferometers with fixed OPD
  - Micro holes sets to isolate each OPD
  - Several units (Each covering 15°x15° or 30°x30°) to reach 60°x60°
    - Trade off with the spatial resolution (In discussion)

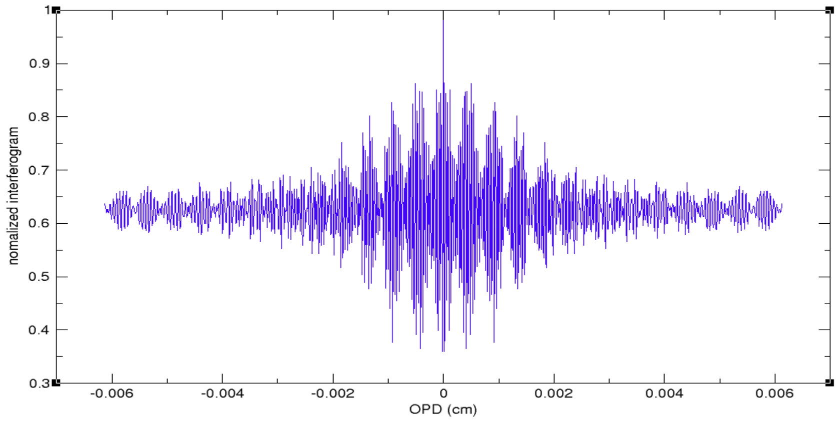




WFAI AOSI

- Data processing



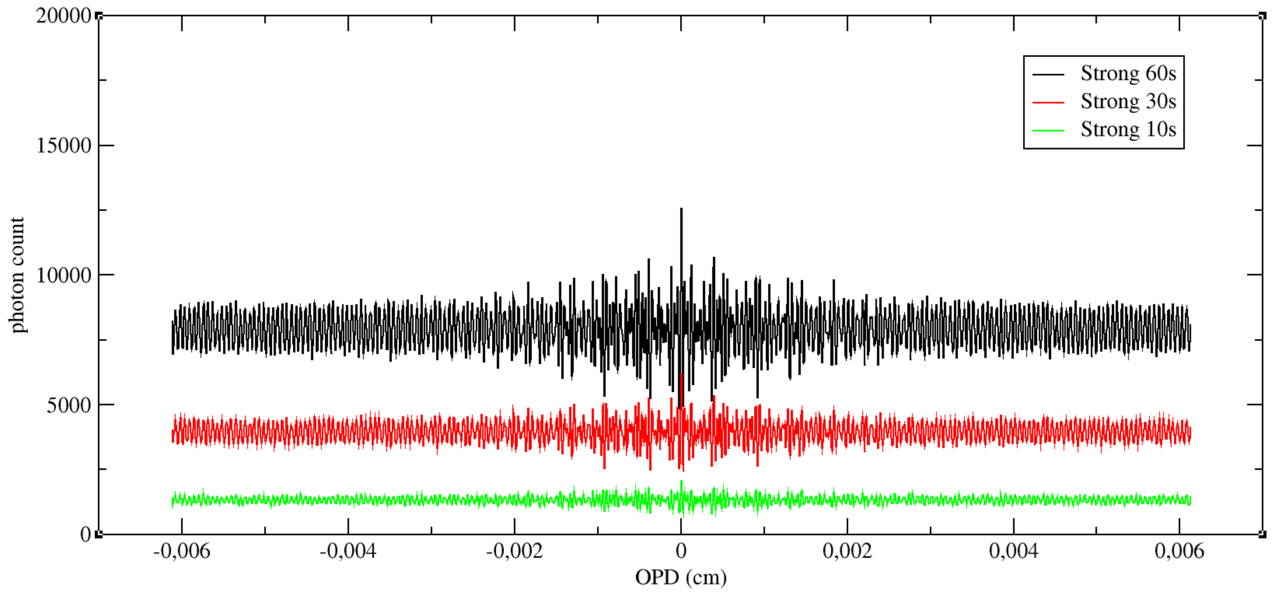


Images on the detector

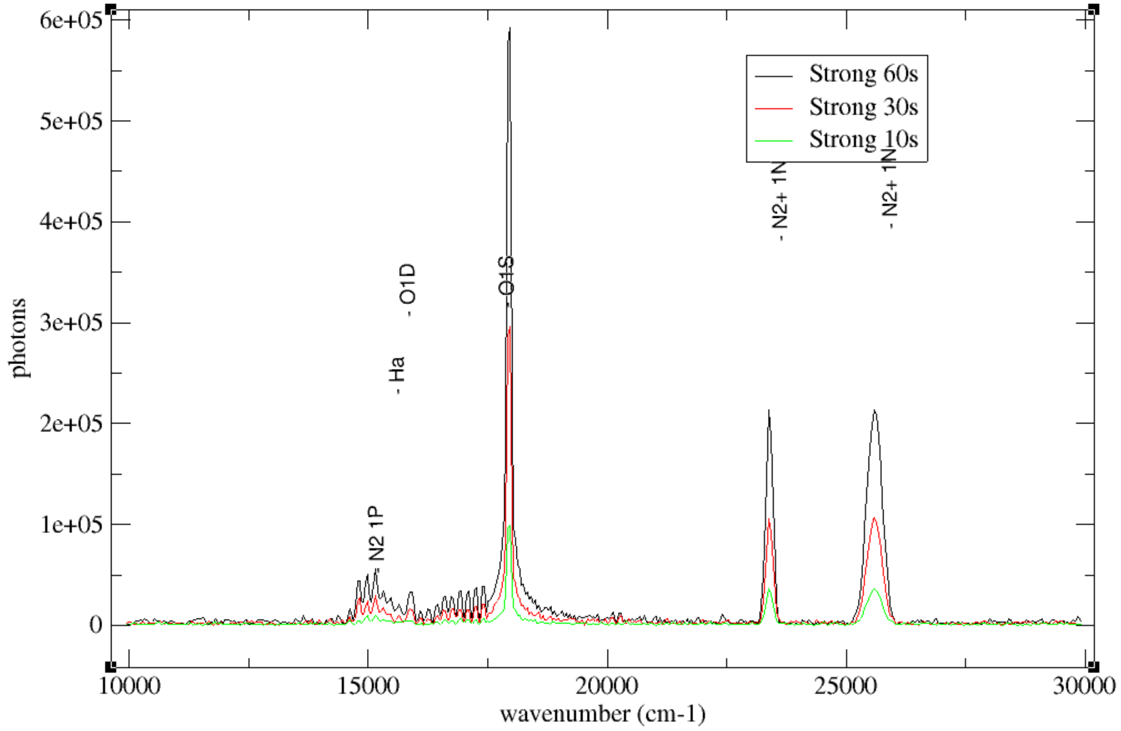
Each small image represents a full FoV with a specific OPD.

WFAI AOSI

- Data processing



Interferograms for different exposure time (10-30-60 s)



Synthetic auroral spectra

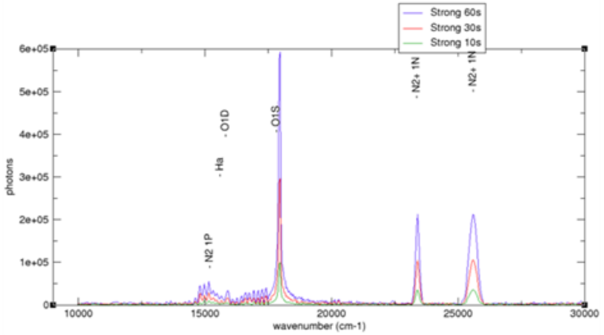
WFAI AOSI

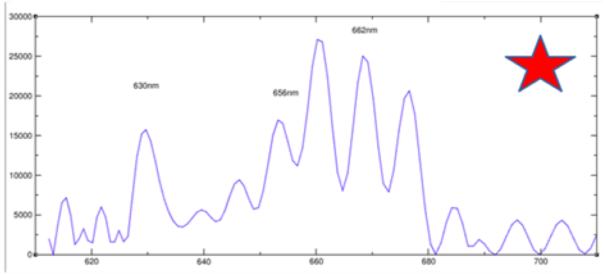
- Data processing

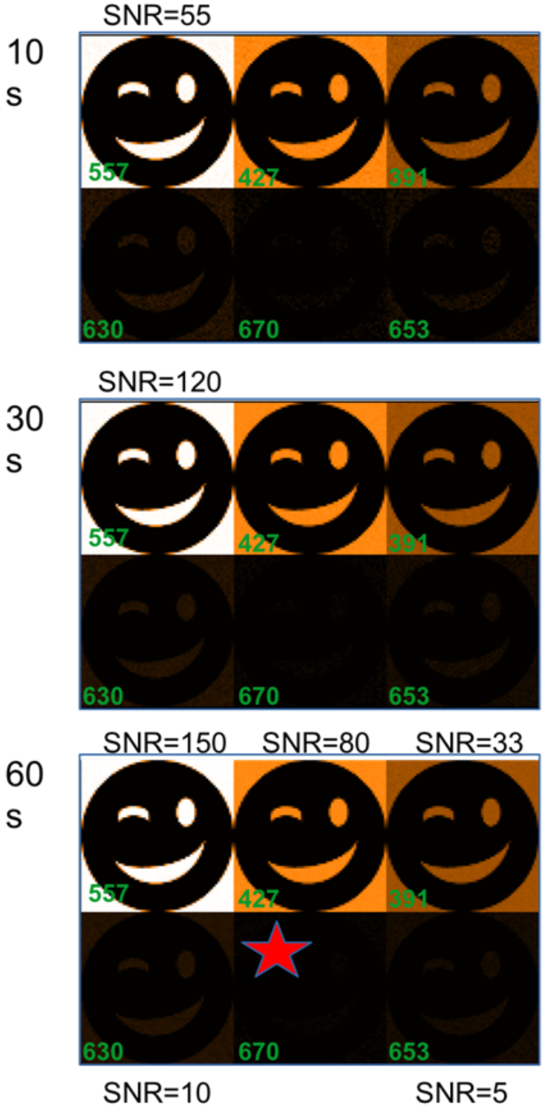
- Images in different bands

(Oval with a smiley shape in black)

Strong without Moon







WFAI AOSI

- Data processing
  - Detection of the oval shape possible with faint aurora with moon (60 s exp time)
    - Oval with smiley shape (White)

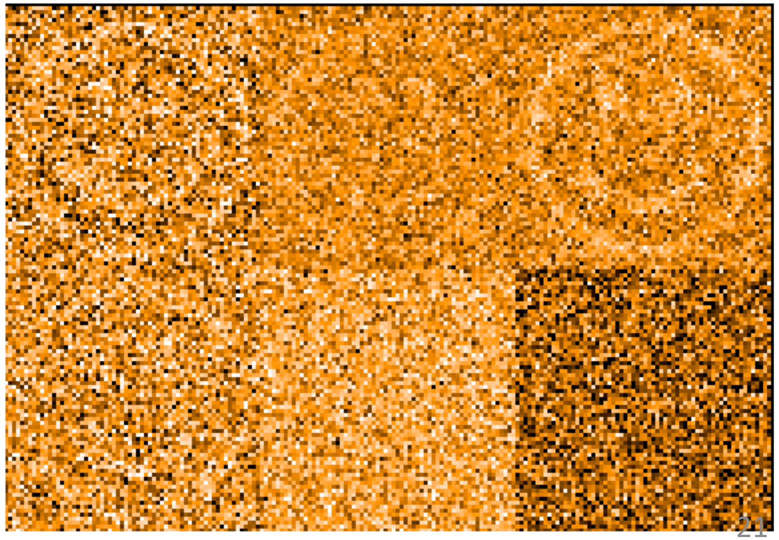
557 nm 427 nm 391 nm

Without moon

630 nm 670 nm 656 nm

557 nm 427 nm 391 nm

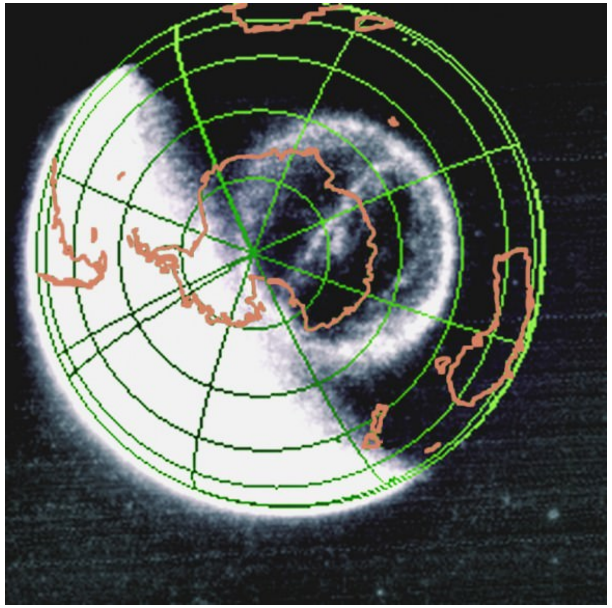
With moon



630 nm 670 nm 656 nm

WFAI-AUI

Less than ½ U



FUV auroral oval (120-190 nm)
(NASA, SWRI, Satellite IMAGE)

- 2 or 3 spectral bands
  - O I 130 nm
  - O I 135 nm
  - N2 LBH 138 nm
- Narrow band filters to avoid daylight blinding
  - Different strategy compared to WAI (Fengyun-3D satellite with wide bands)
- Wide field 60°x60°
- Same exp time as AOSI
- Focal length: 8 mm
- Aperture : 2.8 mm

3 axis of development:
- Work on UV materials : glasses and coatings (for narrow & wide band)
- Optical design : **transmissive** wide field imaging system in the UV
- Sensor : development and test of **Curved UV sensors**

WFAI Budgets and requirements

Requirements	AOSI	AUI
Spectral resolution	nm range (1-12 nm depending of the wavelength)	
FoV	60° (Possible in one frame with 40 km resolution @2500km)	60°
Wavelengths	350 nm – 750 nm	130, 135 & 138nm
Spatial resolution	10 km@ 2500 km altitude (TBC) 20 to 40 km @2500 km depending of chosen options	25 km@ 2500 km altitude
Mass	$\leq$ 3 Kg	$\leq$ 2 Kg
Power Consumption	$\leq$ 20 W (goal 10W)	$\leq$ 10 W
Data rate	$\leq$ 230 kbps/image	$\leq$ 30 kbps/image
Dimensions	Instrument 100 x 100 x 200 mm^3 TBC Electronic Box 150 x 70 x 200 mm^3 TBC	Instrument 100 x 250 x 250 mm^3 TBC Electronic Box 100 x 100 x 200 mm^3 TBC

Trade off in yellow

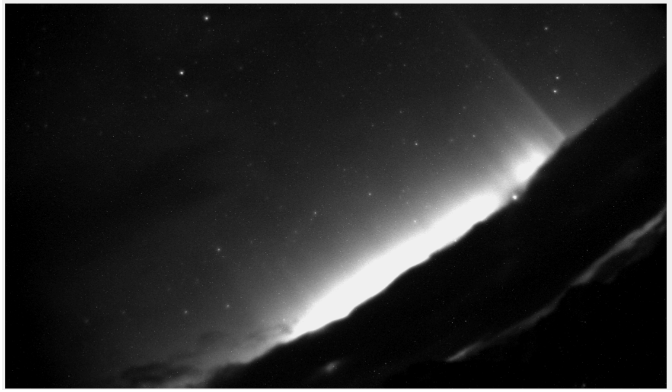
A strong heritage in auroral monitoring and instrumentation

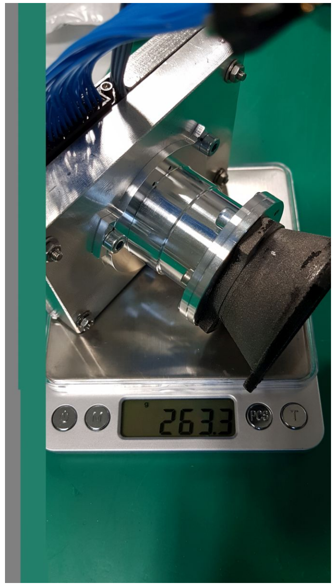
- Ground based instrument
  - Spectropolarimeter 1er Cru

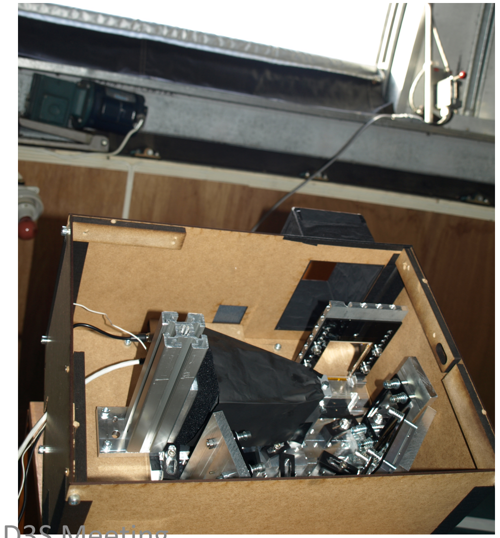
- Space instruments
  - AMICal Sat
    Launch planned Q1 2020
    Imager 42° FoV (Diagonal)
    Very sensitive

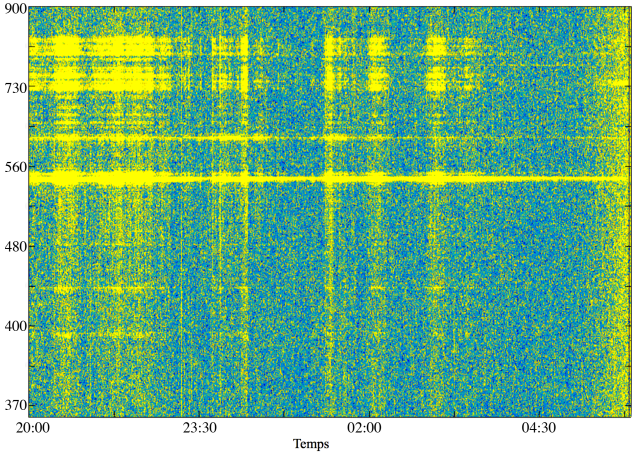
  - ATISE
    - Launch 2022
    - Spectrometer narrow FoV (6x 1° x1.5°), 6 line of sight
      - Extremely sensitive (5R for 1 s exp time)
      - 27 cm-1 spectral resolution
      - 350-900 nm

- Among a large set of instruments or subsystems developed in Grenoble (Rosetta, Planck, AMS2,…)







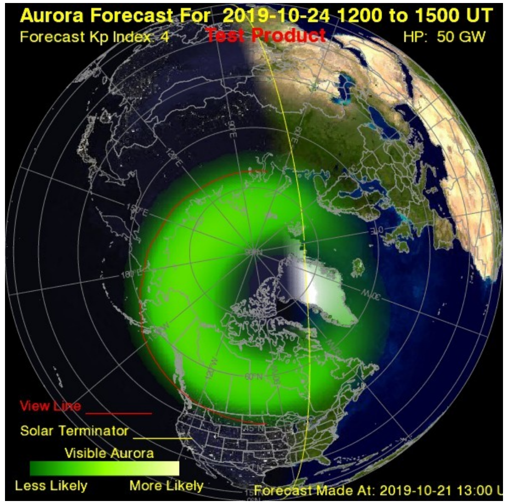


Available facilities

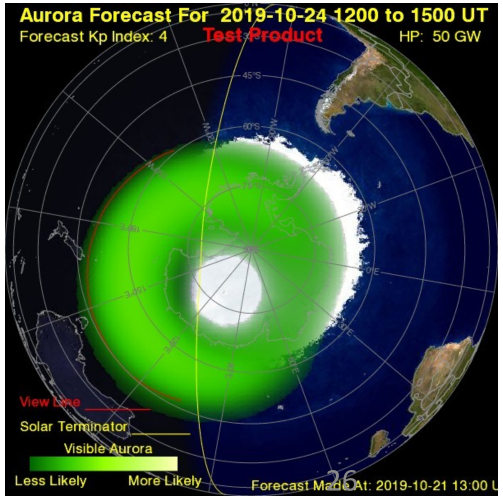
- CSUG:
  - Link with IPAG (Optical labs, white rooms, integration hall)
  - Grenoble university facilities (White rooms, workshops)
  - Human resources of both CSUG and IPAG
  - Collaboration with the SERAS (Mechanical and thermical design and realisation workshop of the Neel institute)
- LAM
  - Spatial AIT platform
- Pyxalis
  - Design and validation center close to Grenoble
  - Strong experience in sensor design for space application

Conclusion

- **<u>Space weather missions need optic auroral monitoring</u>**
  - Full spatial coverage particle precipitation monitoring
  - Energy deposition



- **<u>We propose an spectral imager instrument in the visible coupled to a FUV instrument</u>**
  - Large scale monitoring in both dayside and nightside
  - Including moon period
    - **<u>Quasi continuous monitoring</u>**
- **For a service**
  - Global precipitation fluxes (e- and p+) with high spatial resolution.



Conclusion

- **Space weather missions need optic auroral monitoring**
  - Full spatial coverage particle precipitation monitoring
  - Energy deposition

- **We propose an hyperspectral instrument in the visible coupled to a FUV instrument**
  - Large scale monitoring in both dayside and nightsi
  - Including moon period
    - **Quasi continuous monitoring**
- **For a service**
  - Global precipitatio d p+) with high spatial resolution

Representative laboratory breadboard ready for Q4 2020