AGENIUM SPACE

Geo4i
Geospatial for intelligence

A survey of in-flight radiometric calibration methods and their applicability to Nanosatellites

Rosario Ruiloba (Agenium Space), Emmanuel Hillairet (Geo4I)

Outlines :

Presentation of the companies
Characteristics of some EO VHR sensors (LargeSat & CubeSat)
The radiometric model
Characterization of :
- dark signal
- inter-detector gain
- instrument noise
- absolute radiometric gain

Some clues for Radiometric Calibration of CubeSats

Partnership: Image quality & Calibration

AGENIUM SPACE

Geo4i
Geospatial for intelligence

Agenium Space is part of Agenium Group, a French SME created in 2003

AGENIUM

- AGENIUM IT & SYSTEMS
- AGENIUM SPACE
- AGENIUM INDUSTRIES
- AGENIUM CAMPUS
- AGENIUM 3D LAB
- AGENIUM SCALE
- AGENIUM DRONES SOLUTION
- AGENIUM seity

8.5 M Euros Turnover
FY2019

AGENIUM Space Core Business: **Expertise in EO domain**

Image **Processing**

- Geometry, radiometry, atmospheric corrections, straylight, image quality simulation, information extraction
- Ground Processing Development

Deep **learning**

- General-purpose methodology applied to EO issues
- Ad-hoc comprehensive solutions tailored for specific user needs

Flight **dynamics**

- Extrapolation and orbit restitution, positioning and station-keeping, SCAO
- Expertise shared with AGENIUM group

Geo4i
Geospatial for intelligence

Founded in 2014, Geo4i is a French SME specialized in the processing and operating of geospatial information in the fields of Defense, Security and Safety.

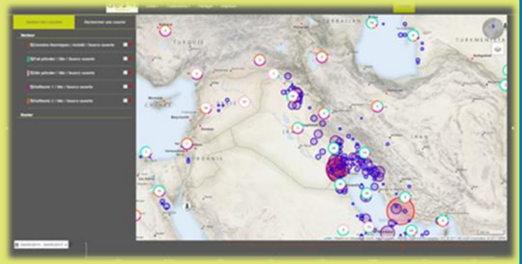
SPACE IMAGERY AND VIDEO PROVIDER

- Optical Multispectral / Radar
- Video
- 3D products
- Image Quality assessment

EUROPEAN SPACE IMAGING
VRICON
SIIS SI Imaging Services
urthecast
planet.
iSi
RESTEC

SOFTWARE DEVELOPMENT

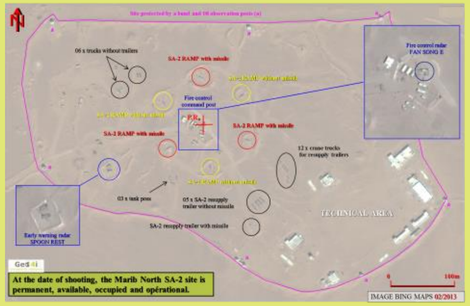
- Images exploitation and analysis
- Automated processing
- Target Identification
- Dedicated tools



GeoSpace Platform

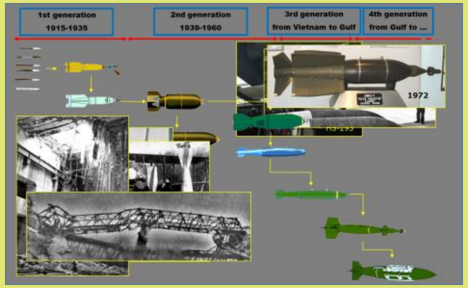
PRODUCTION

- Space Image analysis
- Multi-Source geolocated data analysis
- Value added product generation from radar and multispectral imagery



TRAINING & CONSULTING

- Data Management and open source
- Remote sensing knowledge for Geo-Intelligence
- IMINT Fundamentals
- Military equipment identification



AG Space & Geo4i: User Ground Segment
Definition & Development

Image Quality **Expertise**

Long experience in EO mission

Involved in all the mission steps:

- Sensor and IQ requirements,
- User ground segment definition (ATBDs for L0, L1a,b,c)
- Preparation and participation to in flight commissioning (Calibration, Validation, optimization of algorithms)
- Mission performance control

Software **Development & Optimization**

- Experienced development engineers
- Operational image processing software development
- SW products for vectorization/portability

Deep Learning Use & Expertise

Software development for Image analysis and target identification

Expertise in:

- On board processing,
- Object detection and identification,
- Land cover/land use
- Change and anomalies detection,
- 3D reconstruction
- …

Geo4i
Geospatial for intelligence

AGENIUM SPACE

Team experience in Image Quality & Ground Segment

Activities	IQ Expertise	Software Architecture	Software Development	Project Management
Sentinel 2 Pre-Studies and ATBDs authoring (CNES)	X		X[2]	
S2 GPP and IPF (ESTEC and ESRIN)	X	X	X	X
S2 In Flight Commissioning (incl. preparation) (ESTEC and CNES)	X		X[3]	X[1]
Venμs Pre-Studies and ATBDs authoring (CNES)	X		X[2]	
Venμs In Flight Commissioning (incl. preparation) (CNES)	X		X[3]	X[1]
MicroCarb Pre-Studies and ATBDs authoring (L1) (CNES)	X		X[2]	
3MI GPP and IDS (ESTEC and LEONARDO)	X	X	X	X
3MI Ground Calibration (ESTEC and CSL)	X		X	
FLEX L2 Studies (ESTEC)	X	X		X

1 : Management of the team supporting Customer in the flight commissioning
2 : Development of prototypes useful for the studies
3 : Development of IQ and calibration tools useful for commissioning phase

Other Missions: Spot5 / SCARAB (Meghatropiques) / IIR (Calipso) / Taranis / Merlin / …
End customers: CNES, ESA, EUMETSAT

Geo4i Geospatial for intelligence

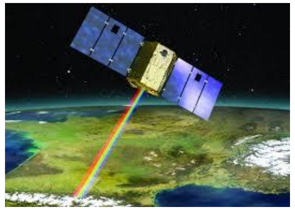
AGENIUM SPACE

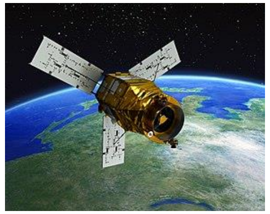
Natural evolution of our core activities

- Image processing : Missions & Ground segments
  - Support to mission specification, image quality & performance assessment
  - Ground segments specifications
  - Ad-hoc Ground Segment development
  - Training for civil and military missions

- Deep learning: On-board processing
  - Objectives:
    - Data reduction -> bottleneck for small satellites
    - Data analysis for intelligent payloads: agility inter-missions, downlink selection, rapid information transmission …
    - Collisions detection/prediction
  - Studies on advanced DNN simplification methods (CNES, ESA)
  - Commercial products and services

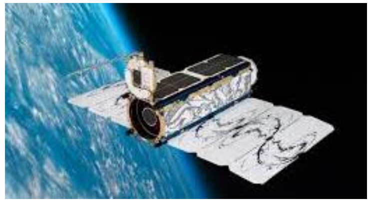
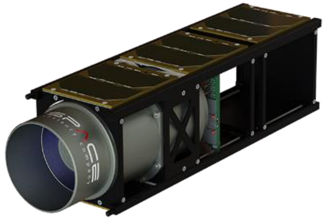
VHR on LargeSats and CubeSats






LargeSats

Mission	Venμs	Pleaides HR	KompSat 3	WorldView 3
Resolution	5.3 m	0.7m (PAN)	0,7m (PAN)	0.31m (PAN)
Swath	27.5 km	20 km	15 km	13.1 km
Spectral bands	12 MS	PAN+4MS	PAN+4MS	PAN+8VNIR+8SWIR
Mass	260kg	940kg	980kg	2800kg


CubeSats

Mission/sensor	DOVE (Planet)	Chameleon (SAC)	KubeKam (SAtlantis)
Resolution	3.7m (@ 475km)	6m (@500km)	2m (@500km)
Swath / Frame	24.6*16.4 km²	49km	13,2 km
Spectral bands	RGB + NIR	PAN+4MS	PAN+4MS
Platform size / status	3U / 120+ on orbit	3U/ On the shelves	12U / On development

Very High Resolution missions are multi-spectral (MS) missions often based on **line-scan technology, with TDI**
Panchromatic (PAN) band is often more resolved than MS bands.

Geo4i
Geospatial for intelligence

AGENIUM SPACE

The Radiometric model

Optical model : From radiance outside the instrument to photon flux observed by one-pixel detector

$$\phi_{(photons/m^2s)} = Sa_{(sr)} \cdot \int_\lambda SRF(\lambda) .\ K^{-1}_{(J/photon)}(\lambda).R_{(W/m^2.sr.\mu m)}(\lambda).d\lambda \quad + Noise$$

SRF : Spectral Response Function
K : Energy of one Photon at a given wavelength

Sa : Solid angle of the detector
R : Radiance as input of instrument

Detector model : from photon flux to output digital count.

$$X_{(DC)} = Int\ [\ ((\phi_{(photons/m^2.s)} \cdot A_{(m^2)} .\ Qe_{(e-/photon)} + Dark_{(e-/s)}) \cdot Ti_{(s)} .\ G_{(V/e-)} + Offset_{(V)}).\ Qf_{(DC/V)} + Noise\ ]$$

A : Area of the detector
Qe : Quantum efficiency
Dark : Dark current
Ti : integration Time

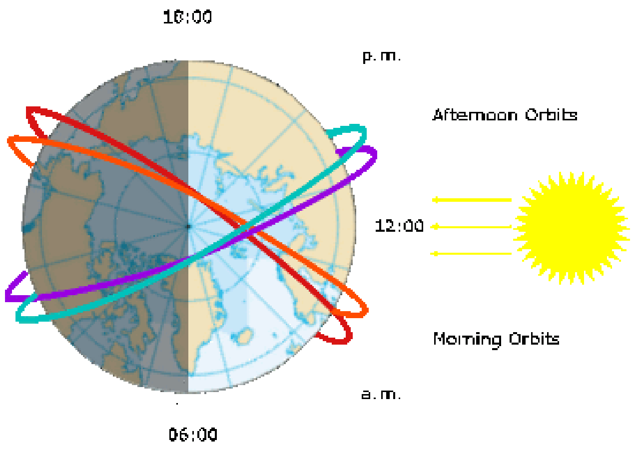
G : electronic Gain
Offset : electronic Offset
Qf : Quantization factor

Simplified model for linescan multispectral sensor :

$$X_{i,j} = (A_{k,tdi} . g_{j,tdi} . R_{i,j} + Dark_{j,tdi})$$

average$_j$ $(g_j)=1$ for R_{ref} g_j : linear, polynomial, piece-wise linear

Estimation of Dark signal



Long acquisition (to reduce instrument noise) :

- over Ocean by night (without Moonlight).
- with Telescope shutter closed

Dark dependence on temperature :

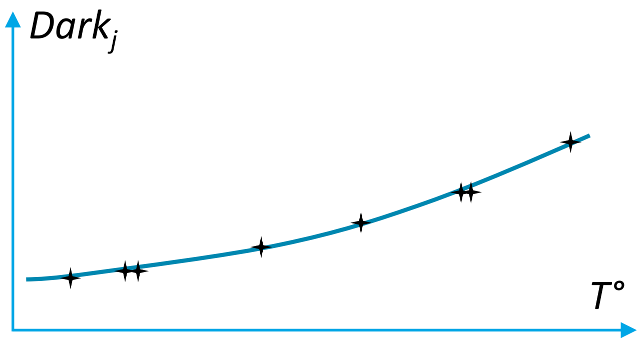
- Not an issue when focal plane is thermally regulated.
- Else, need to know dark currents function of temperature (=> cubesats)

⇒ [Tmin,Tmax]$_{science}$ C [Tmin, Tmax]$_{calibration}$?

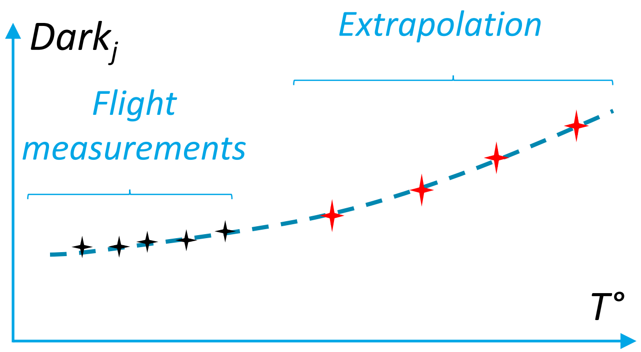
Not obvious when calibration acquired on eclipse side and science acquired on sun side of the orbit

One solution :

- On ground calibration : define the shape of thermal laws.
- In flight calibration : using the ground law to extrapolate new values at higher temperatures.



Ground calibration



Flight calibration

Geo4i
Geospatial for intelligence

AGENIUM SPACE

Estimation of gj (flat-fied)

<u>Acquisitions with uniform targets covering the whole swath:</u>

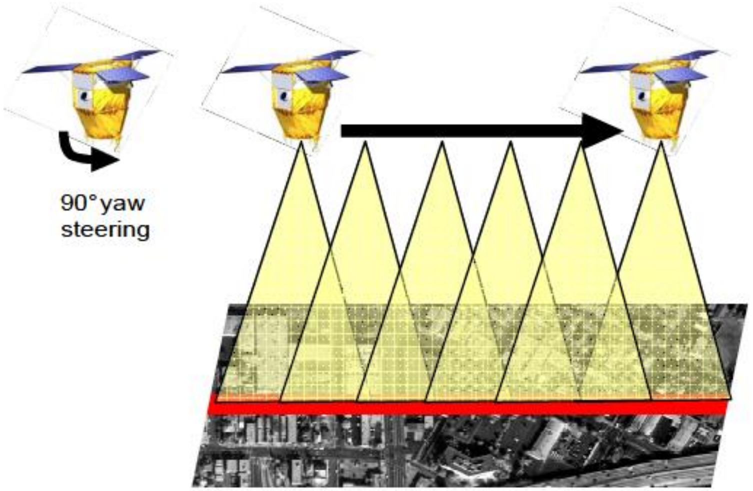
1/ Deployable sun diffuser (Sentinel 2) => Complex to develop on a cubeSat.

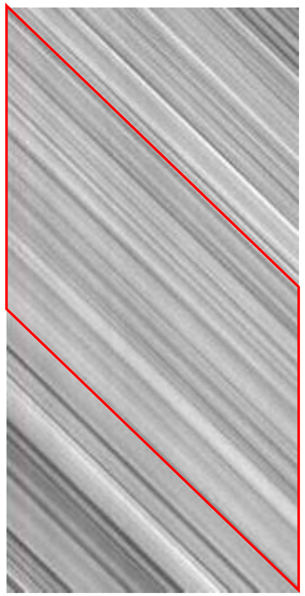
2/ AMETHIST : On any landscape with 90° yaw steering (Pleiades HR)

⇒ Need an accurate steering : scan-line parallel to the ground velocity => Complex for a CubeSat

⇒ Each pixel of the scan-line is acquiring the same landscape.

⇒ A histogram matching method allows to reach the inter-detector gains (including non-linearity)





AMETHIST acquisition principle and corresponding acquired image (Courtesy of CNES)

Geo4i
Geospatial for intelligence

AGENIUM SPACE

Estimation of gj (flat field)

3/ Classical method : Uniform natural landscapes (0° yaw steering)

(Spot5, Venµs)

⇒ Identify the areas where landscape is uniform.

⇒ Correct from Dark and sun angles.

⇒ Compute mean-line to reduce impact of instrument and landscape noises

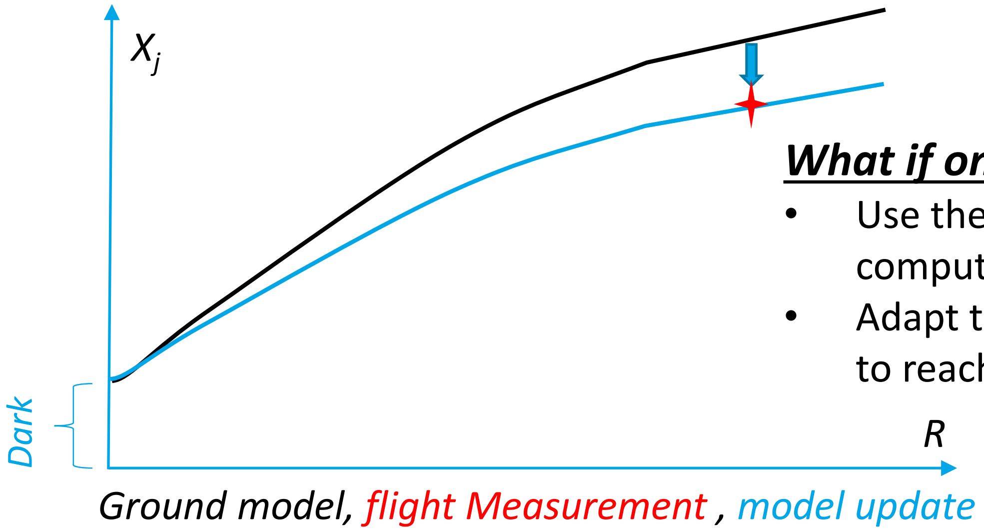
⇒ Method usable for CubeSats : compatible with small swath and bad agility

4/ Uniform natural landscapes +90° yaw steering

⇒ Limits the impact of landscape non uniformity across track.

⇒ Compared to AMETHIST :

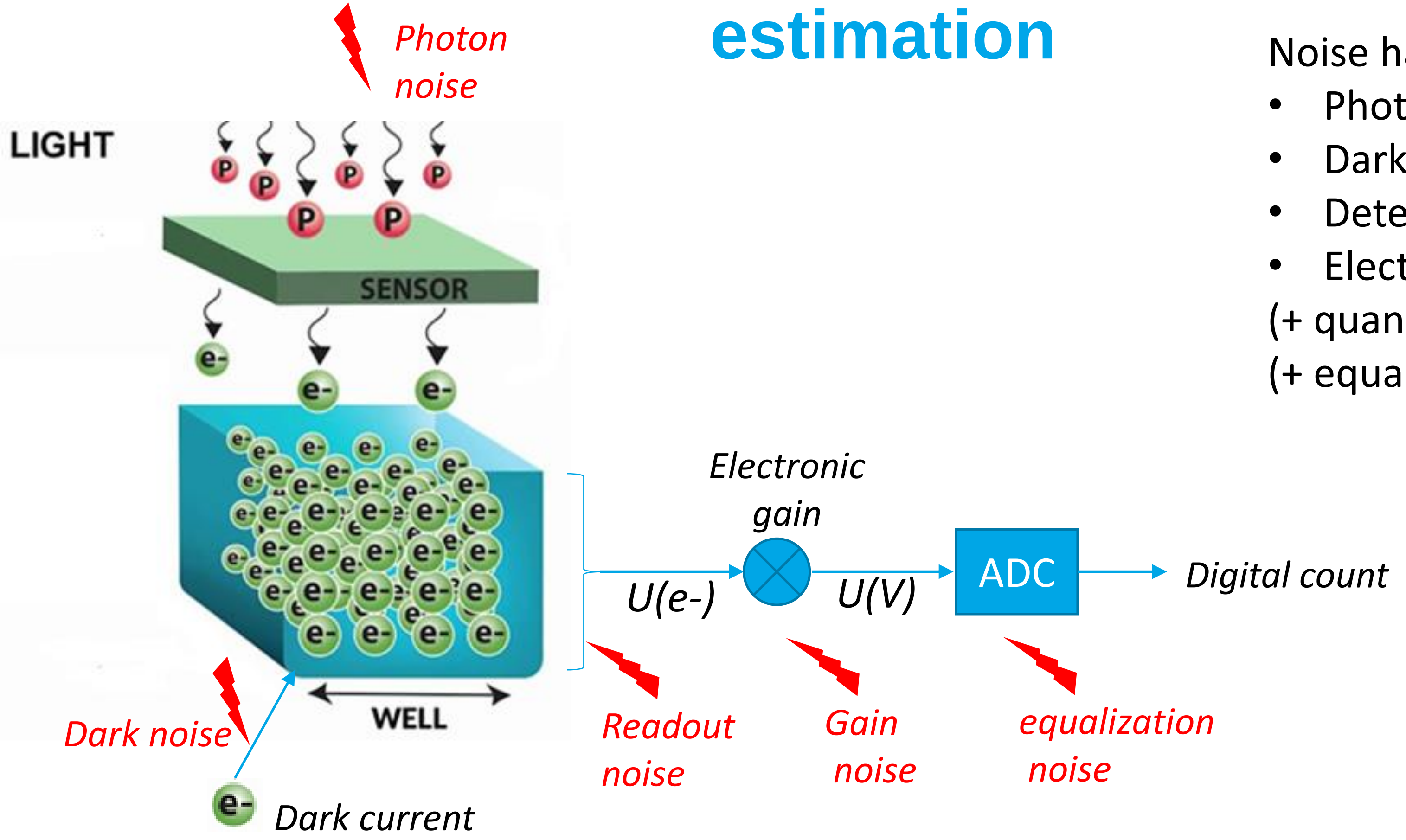
- ⇒ Allows less accuracy in yaw steering (landscape is quasi uniform)
- ⇒ no direct access to non-linearity.



What if only one radiance level available ?

- Use the non-linearity shape computed during ground calibration.
- Adapt the shape with a **scale factor** to reach right value for the measurement.

Noise estimation



Noise has different contributors:

- Photon noise
- Dark noise
- Detector readout noise
- Electronic Gain noise

(+ quantization noise)
(+ equalization residual noise)

Some contributors are depending only on incoming flux, some are depending on digital count.
Classical formula : $\sigma^2 = A + B.R$ (R : Observed radiance)

Geo4i Geospatial for intelligence

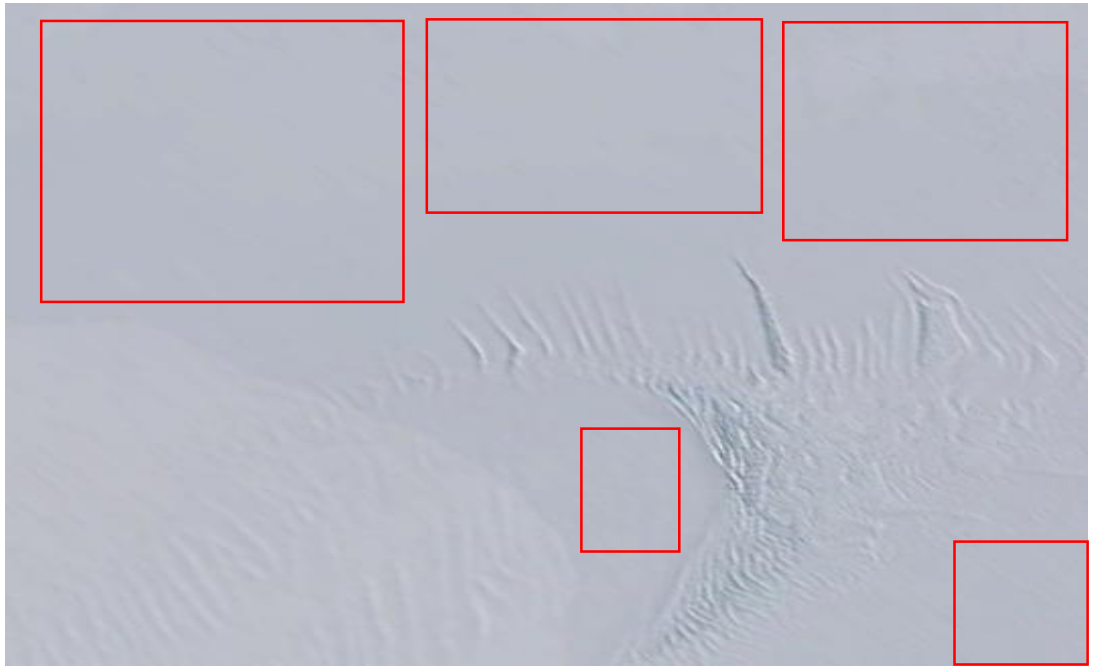
AGENIUM SPACE

Noise estimation

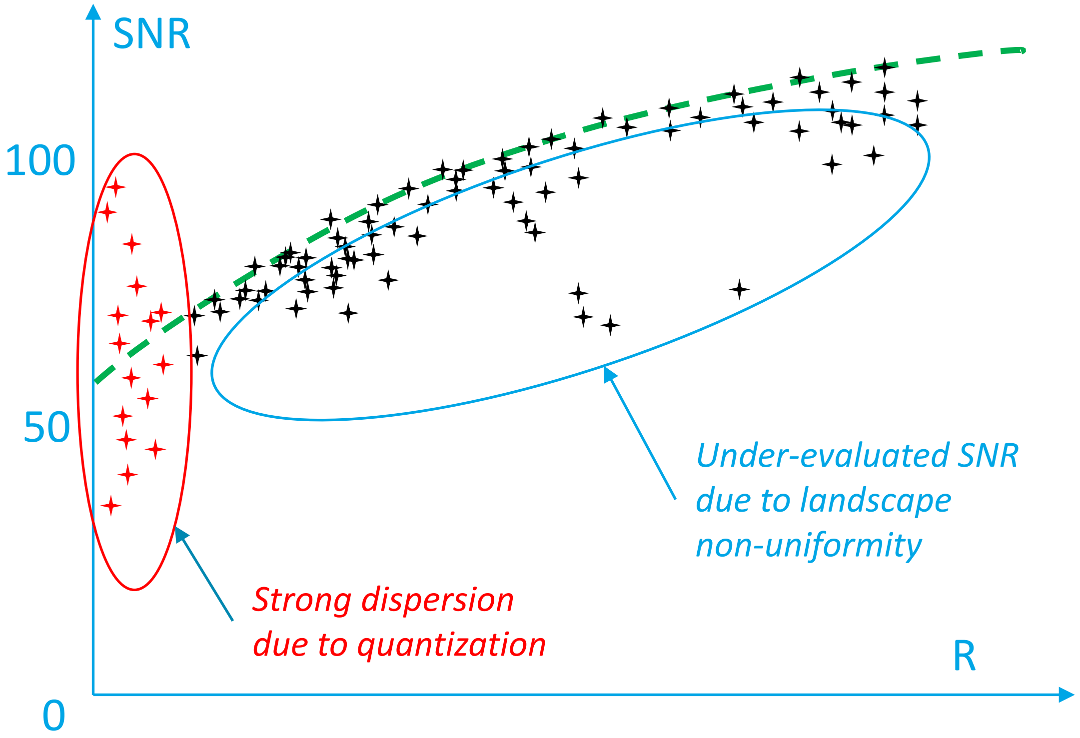
$$\sigma^2 = A + B.R$$
$$SNR = R/\sqrt{A + B.R}$$

Characterization of A and B : use of uniform areas at different radiances:

- Uniform areas from diffuser acquisitions, or from natural landscapes
- Compute statistics **only along the columns** (to avoid perturbations due to equalization residues)
- Compute **HF standard deviation** (to avoid perturbations due to LF landscape variations)



Selection of quasi-uniform areas on Snow landscape acquisition over Antarctica



SNR measurements, and SNR law function of radiance

Estimation of Ak (absolute radiometric calibration)

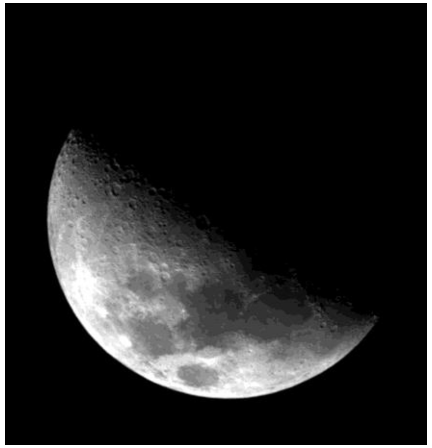
Sentinel2 sun diffuser (ESA, Sener, CSL)

<u>Acquisitions on reference targets:</u>

1. Sun diffuser or other internal references
   - Possible ageing issues
   - Complex for CubeSats
2. PICS (Sahara and Arabia sites)
   - BRDF + Atmosphere information available
   - Need to process its own radiative transfer
   - Targets are large scale sites (100*100km²)
3. Using RadCalNet
   - Easy to use, good accuracy
   - Only quasi Nadir observations on small targets.
4. On Moon
   - No atmosphere, nor ageing issues
   - ROLO/POLO models
   - Need strong de-pointing capabilities (CubeSats ?)
5. Simultaneous Nadir Overpasses (SNO) with other sensors :
   - Comparison between sensors
   - Useful for a constellation of same satellites (different orbits)
   - Use of LargeSat images as "Gold Reference"

<u>Other methods :</u>

- Rayleigh over ocean (blue bands)
- Deep Convective Clouds, Sunglint (interband calibration)



Moon Seen by Venµs (Courtesy CNES)

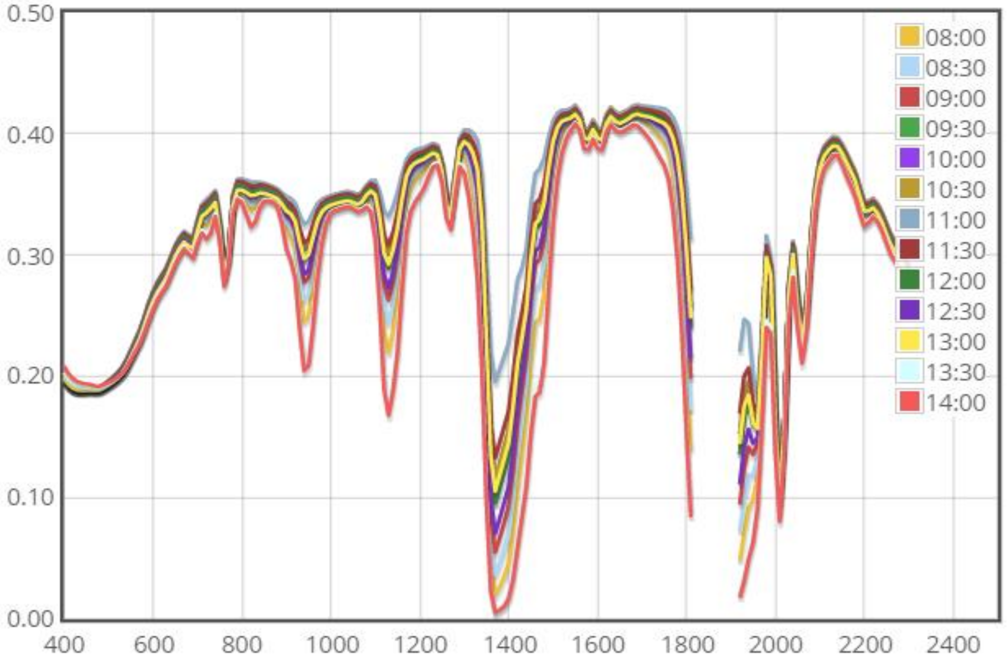
Geo4i
Geospatial for intelligence

AGENIUM SPACE

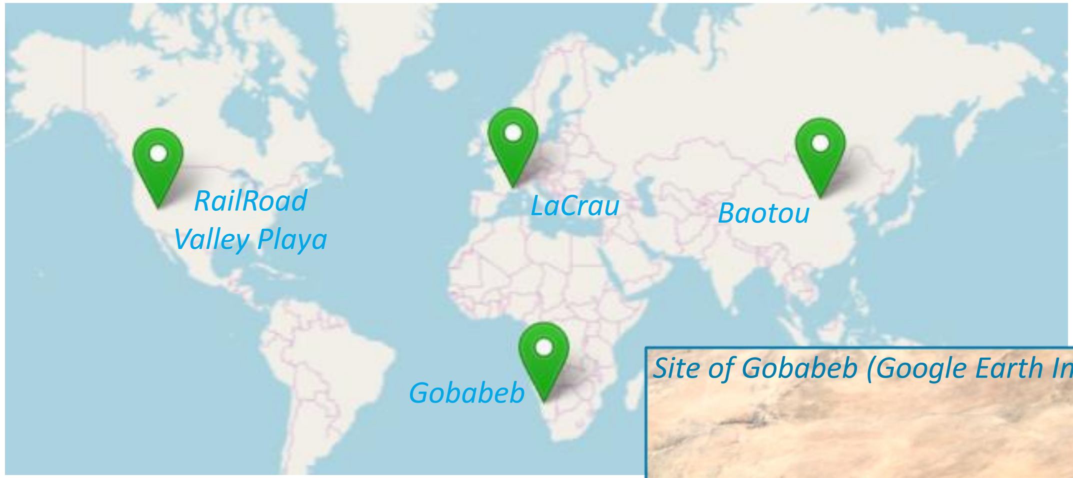
Estimation of Ak : RadCalNet

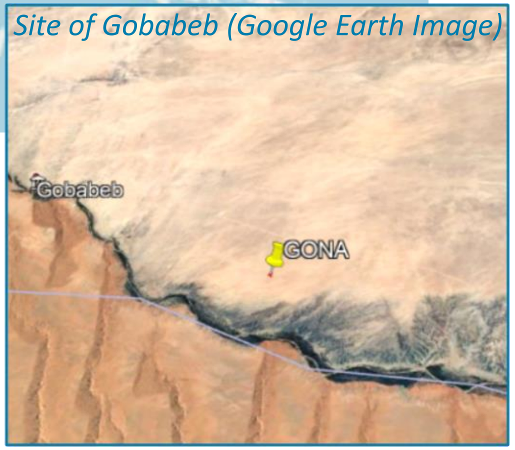
<u>RadCalNet provides :</u>

- TOA reflectance spectra of 4 sites + associated uncertainties
- Corresponding to nadir observations
- Every 30min (9H-15H local time) when not cloudy
- Representative of ground surface of min 50*50m²



Gobabeb TOA reflectance spectra on 30th of September 2019





<u>Ready to use :</u>

- Integrate RADCALNET spectrum on Instrument SRF
- Compare with instrument observations

<u>Constraint :</u>

- Works for quasi Nadir observations

  => Constraints on orbits

Geo4i Geospatial for intelligence

AGENIUM SPACE

Some clues for CubeSat radiometric calibration

Cost of solutions is a strong argument :

For sensor, platform, launch…
… even for calibration, and User Ground Segment (costs can be factorized in case of large constellation)

Calibration methods :

- Ak : RadCalNet if reachable by the mission orbit.
- g_j : classical method, Uniform areas reachable due to the small swath of the sensor.

Some specific issues to be tackled :

- Low SNR (even if compensation using TDI) : Importance to assess noise level :
  Noise computed on uniform landscape => method to discriminate landscape vs instrument noise.

- Stability of the sensor vs temperature : to take into account in the radiometric model
  Importance to have a good ground calibration on a large set of temperatures.

Geo4i Geospatial for intelligence

AGENIUM SPACE

A survey of in-flight radiometric calibration methods and their applicability to Nanosatellites

Rosario Ruiloba (Agenium Space), Emmanuel Hillairet (Geo4I)

THANK YOU FOR YOUR ATTENTION

VH RODA Workshop 2019, Frascati