NYX : a Night-time Optical Imaging Mission

ESA Contract : 4000104172/11/NL/AF

Final Presentation

March 14th, 2013

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Document Reference : EF.PS.JJA.13.000052

Agenda

1. Description of NYX study
2. Product Requirements
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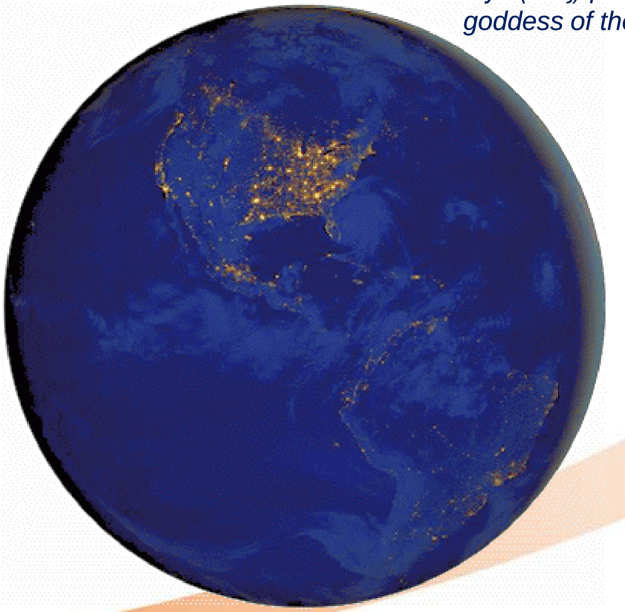
   - Applications review
   - Summary of scientist consultation
3. Instrument and mission trade-off cases
   - GEO step and stare concept
   - LEO push-broom concept
     - LEO step and stare concept
4. Baseline : LEO Step and Stare instrument
   - Description
   - Performances
   - Development of key technologies
5. Conclusion

Nyx (Νύξ) primordial goddess of the night.

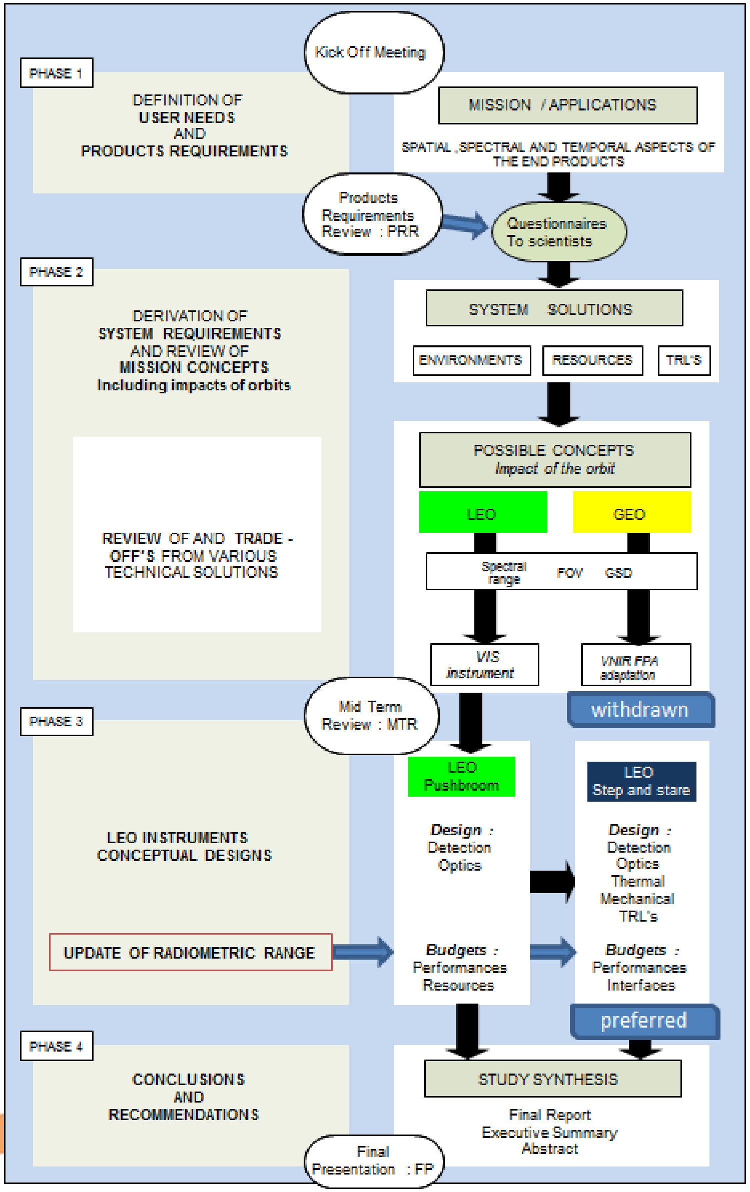


NYX Instrument Final Presentation

1. Description of the Study

Description of the study

- ESA ITT : AO/1-6598/10/NL/AF
- Astrium proposal : January 2011
- Team :
  - Astrium SAS
  - Austrian Institude of Technology (AIT)
- Support of scientists (Questionnaire)
  - Universities, NOAA
- Main steps :
  - KO : June 2011
  - PRR :
  - Delta PRR
  - Mid-term review (MTR) : July 19th, 2012
  - Delta MTR
  - Final review : March 14th, 2013



Documentation issued during the study

	Title	Reference
TN1	Product Requirement Review Report	EF.RP.JJA.11.00239 Iss 04
TN2G	TN2G : GEO NYX System requirements report	EF.NT.JJA.12.00118 Iss 01
TN2L	LEO NYX System requirements report	EF.TN.JJA.12.00117 Iss 01
TN3G	Candidate GEO NYX Mission Concepts Report	EF.TN.JJA.12.00120 Iss 01
TN3L	LEO NYX Mission Concepts Report	EF.NT.JJA.12.00119 Iss 03
TN3LS	A step and stare instrument for NYX mission in LEO	EF.NT.PL.12.00232 Iss 02
TN4	NYX Study Final Report	EF.NT.PL.13.00039 Iss 01
	Instrument Radiometric Model	EF.NT.FK.13.00043 Iss01
	NYX Study Abstract	EF.NT.PL.13.00038 Iss 01
	NYX Study Executive Summary	EF.NT.PL.13.00040 Iss 01

NYX Instrument Final Review

2. Product Requirements Review

Product Requirements Review

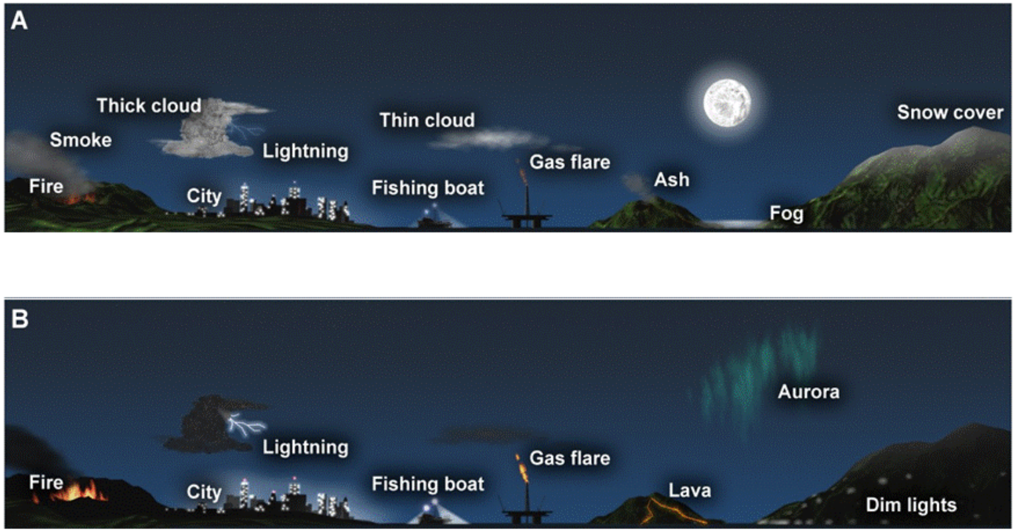
1. EXISTING AND/OR PLANNED MISSIONS
2. APPLICATIONS REVIEW
3. SUMMARY OF SCIENTIST CONSULTATION

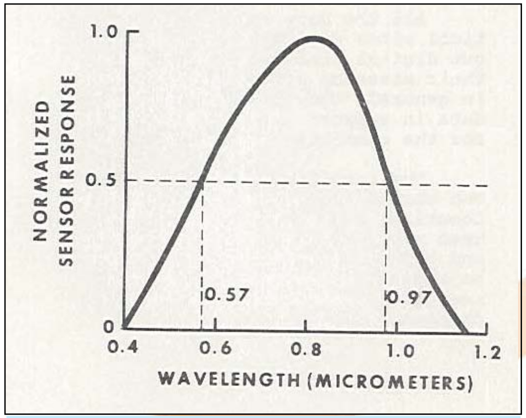
DMSP-OLS

- Defense Meteorological Satellite Program / Operational Linescan System
  - Originated in the mid 1960s, data available to the public since declassification in 1972, the system then called Data Acquisition and Processing Program (DAPP), superseded by DMSP. Upgraded over time
  - Objectives
    - Collecting global (visual and infrared) cloud cover on a daily basis
    - Provide real time direct readout of local area environmental data to mobile receiving terminals at key locations throughout the world
    - Continue the advancement of environmental satellite technology to meet DoD requirements
  - Operational Linescan System (OLS) (>1976)
    - LEO SSO at ~830km, with nighttime overpass typically between 19:00 and 21:00
    - Broad field of view of 3,000km swath width
    - Nominal resolution of 0.56km in **fine mode**, smoothed on board into 5x5 pixel blocks to 2.8km (**smooth mode**) –
    - Onboard calibration during each scan (adjustment of instrumental gain values every 0.4 milliseconds) to account for varying conditions of solar and lunar illumination

EXISTING AND/OR PLANNED MISSIONS

- Defense Meteorological Satellite Program
  - 2 broadband sensors + photomultiplier tube (PMT)
    - **Visible band** [0.58 - 0.91] µm FWHM, sensitive to radiation in the radiometric range 0.1 → 10 $W/m^2/sr$
    - **Infrared band** [10.3 - 12.9] µm FWHM, sensitive to radiation at black body temperature in the range 190 → 310 Kelvin
    - **PMT**, band [0.51 - 0.86] µm FWHM , sensitive to radiation in the radiometric range 10^{-5} → 0.1 $W/m^2/sr$





DMSP visible band spectral interval and normalized response curve(1974)

NPOESS/JPSS - VIIRS

- Visible/Infrared Imager Radiometer Suite
  - onboard the NPOESS Preparatory Project (NPP) , bridge mission from NASA's Earth Observing System (EOS) of satellites to the next-generation Joint Polar Satellite System (JPSS), previously called the National Polar-orbiting Operational Environmental Satellite System (NPOESS)

- Visible/Infrared Imager Radiometer Suite
  - 22 channels derived primarily from three legacy instruments
    - the National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR)
    - the NASA Moderate Resolution Imaging Spectroradiometer (MODIS)
    - the DMSP-OLS

    - OLS with its low-light nighttime visible sensing capability is the only sensor providing heritage for the VIIRS Day/Night Band (DNB)

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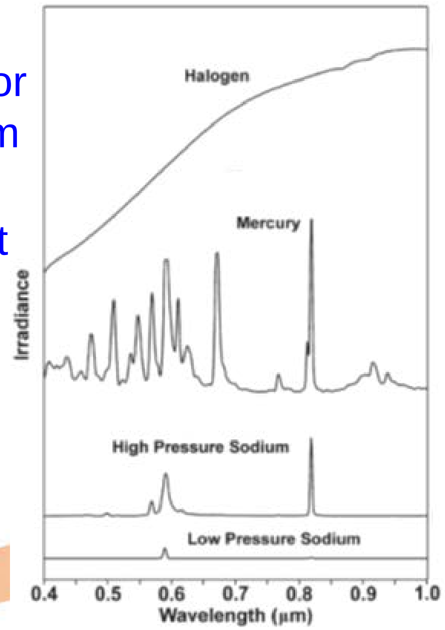
  - the NASA Moderate Resolution Imaging Spectroradiometer (MODIS)
  - the DMSP-OLS
  - OLS with its low-light nighttime visible sensing capability is the only sensor providing heritage for the VIIRS Day/Night Band (DNB)

- Launched october 28th 2011 on a polar SSO at 824 km (14 orbit/day)

The NightSat Program / Concept

- First plan for a dedicated nighttime visible imagery mission (NOAA/NASA consortium…)
  - “Mapping the human footprint”
    - NightSat is a concept for a satellite program capable of global observation of the location, extent and brightness of night-time lights at a spatial resolution suitable for the delineation of the primary features laying within human settlements
- Establishing main requirements
  - **High-resolution field spectra** for different types of outdoor lighting (e.g., mercury vapor, high and low pressure sodium vapor, and light-emitting diode)
  - **Moderate resolution color photography** of cities at night from the **International Space Station** (ISS) – GSD 60m
- To date, no go-ahead from NASA
  - New proposal submitted in September 2011 to NASA’s Earth Venture-2 call, within the Earth System Science Pathfinder Program
  - 2013 sequestration on NASA and NOAA programs



The NightSat Program / Concept

- Primary findings
  - NightSat should collect data from a near-synchronous orbit in the early evening with 50 to 100m spatial resolution and have detection limits of 2.5E^{-4} W/m^2/sr/µm or better (factor 10)
  - Multispectral low-light imaging data would provide valuable information on the type or character of lighting
    - Potentially stronger predictors of variables, such as ambient population density and economic activity; and
    - Valuable information to predict response of other species to artificial night lighting (e.g. ecological cons. of light pollution)
  - One or more thermal bands for detecting cloud-free areas and contamination by fires (300-500m GSD) would be useful
    - US: If potentially flown on NPOESS/JPSS → VIIRS
    - Europe: If potentially flown on MetOp → METimage

The NightSat Program / Concept

- Primary findings

Number of bands	Band 1	Band 2	Band 3	Band 4	Band 5
One	0.5–0.9 um				
Two	Not recommended				
Three	Scotopic band 0.454 to 0.549 μm	Photopic band 0.51 to 0.61 μm	Red to NIR band 0.61 to 0.9 μm		
Four	Scotopic band 0.454 to 0.549 μm	Photopic band 0.51 to 0.61 μm	Red band 0.61 to 0.7 μm	NIR band 0.7 to 0.9 μm	
Five	Scotopic band 0.454 to 0.549 μm	Photopic band 0.51 to 0.61 μm	Red band 0.61 to 0.7 μm	NIR band A 0.7 to 0.8 μm	NIR band B 0.8 to 0.9 μm

	Low-light band(s)	Thermal band(s)
Ground sample distance (m)	50–100	300–500
GIFOV (m)	70–150	400–600
Swath (km)	~200	~200
Revisit time (days)	~20	~20
Geolocation error (RMS in m)	50	100
Min. radiance or temperature (Watts $cm^{-2} sr^{-1} \mu m^{-1}$ or degrees K)	Good: $2.5E^{-8}$ (human settlements) Better: $2.5E^{-9}$ (terrain lit by shielded lighting and sparsely lit development) Best: $5E^{-10}$ (artificial sky brightness)	240 K
Max. radiance or temperature (Watts $cm^{-2} sr^{-1} \mu m^{-1}$ or degrees K)	$2.5E^{-2}$ (sunlit terrain)	400 K
Duty cycle	40%	40%

GEO NightSat ?

- Nighttime lighting detection from a geostationary platform
  - Potential advantages
    - Track diurnal patterns of lighting;
    - Ability to observe the same scene at various local time;
    - Greater opportunity to obtain cloud-free observation/night;
    - Increase the sensor duty cycle beyond the confines of daylight;
    - Thorough observation of fluctuating gas flares and biomass burning (e.g. direct view of Africa and Middle East/Russian fields)
  - Main drawbacks
    - Sun Aspect Angle durng observation

      Observation time not possible at midnight
    - High distortion at European latitude
    - Three satelittes for a full Earth coverage

Other systems

- MetOp-SG / LLI Imaging System
  - Low Light Imager with PAN imaging at 500 m GSD
  - Goal is to measure the visible and very near infrared light (below 0.9µm) reflected by clouds, emitted by fires and produced by cities
- MetOp-SG / METimage
  - Aimed at being the European successor of the AVHRR instrument flown on the former meteorological low orbit satellites
  - Objective is to measure sunlight reflected or scattered back by the Earth's surface, the atmosphere, and the clouds in several spectral bands ranging from visible light to thermal infrared (good spatial resolution is key requirement)

Analysis of the LEO scenario

- Synthetic review of existing and future system concepts

Instrument	Spectral Bands	SSD (m)	Mass (kg)	Power (W)
DMSP / OLS	2 bands (VIS and LWIR)	500 (MR VIS) / 2700 (LRVIS & LWIR)	No figure available	No figure available
NPOESS / VIIRS	22 bands (VIS to LWIR)	300 to 700 (from VIS to LWIR)	275	240
Nightsat LEO	4 or 5 bands (VIS to LWIR)	25 to 100 (from VIS toLWIR)	No figure available	No figure available
Nightsat LEO	4 bands (VIS)	50 (VIS)	30	110
MetOp-SG/ METimage	15 to 41 bands **(*)** (VIS to VLWIR)	500 to 1000 (from VIS toVLWIR)	240	200
MetOp-SG / LLI	1 band (VIS)	700 (VIS)	54	60
NYX LEO	4 or 5 bands (VIS to LWIR)	25 to 100 (from VIS to NIR)	40	40

(*) 15 bands with Priority 1 (VIS to LWIR) / 41 bands with Priority up to 4 (VIS to VLWIR)

Anticipated coverage of the main NYX mission aspects

Application		Sensors				
		DMSP / OLS	NPOESS / VIIRS	Nightsat	MetOp-SG / LLI	NYX
1	**Human settlements**					
1.1	Global urban extent	X	X	X	X	X
1.2	Detailed mapping of urban areas			X		X
2	**Population**					
2.1	Estimating the density of constructed surfaces			X		X
2.2	Estimating population			X		X
3	**Human activity**					
3.1	Mapping electric power access	X / pan	X / pan	X / µspe	X / pan	X / µspe
3.2	Estimating gas flaring Parts			X		X
3.3	Economic activity	X	X	X	X	X
3.4	Tracking night-time fisheries	X	X	X	X	X
3.5	Tracking night maritime activity	X	X	X	X	X
4	**Hazards and Disaster management**					
4.1	Fire detection	X	X	X	X	X
4.2	Biomass burning	X	X	X	X	X

Legend: (green) *HR only* (red) *Night only* (blue) *HR & Night*

4 Hazards and Disaster management

Anticipated coverage of the main NYX mission aspects

Application		Sensors				
		DMSP / OLS	NPOESS / VIIRS	Nightsat	MetOp-SG / LLI	NYX
4	**Hazards and Disaster management (cont'd)**					
4.3	Power outage detection			X		X
4.4	Tracking disaster recovery			X		X
4.5	Volcanoes lava flows		X	X		X
4.6	Volcanoes dust clouds	X	X	X	moonlight	X
5	**Light pollution**					
5.1	Artificial light sky seen brightness			X		X
5.2	Ecological and Zoological effect					
5.3	Health effects on human beings					
6	**Meteorology**					
6.1	Urban heat islands			X		X
6.2	Cloud coverage	X	X	X	moonlight	X
6.3	Snow cover mapping	X	X	X	moonlight	X
6.4	Dust storm	X	X	X	moonlight	X
6.5	Lightning detection / auroras	X	X	X	X	X

Legend: *HR only* (green) — *Night only* (red) — *HR & Night* (blue)

Preliminary conclusion

- **NYX**, as **NightSat**, are first aimed at the best application / products harvest anticipated by the research community
  - Both projects surpass the already implemented NPP/JPSS-VIIRS mission through the "spatial resolution" (GSD) and "multi-spectral" critical aspects
  - Implementing 25~50 meters GSD and multi-spectral imaging should allow to fill the gap between projected optimum use and technical feasibility

- **NYX** could make a breakthrough and obtain large support from scientist community if NighSat program is not granted due to 2013 sequestration impacts on NASA and NOAA budgets.

Washington and District of Columbia, USA

Product Requirements Review

1. EXISTING AND/OR PLANNED MISSIONS
2. APPLICATIONS REVIEW
3. SUMMARY OF SCIENTIST CONSULTATION

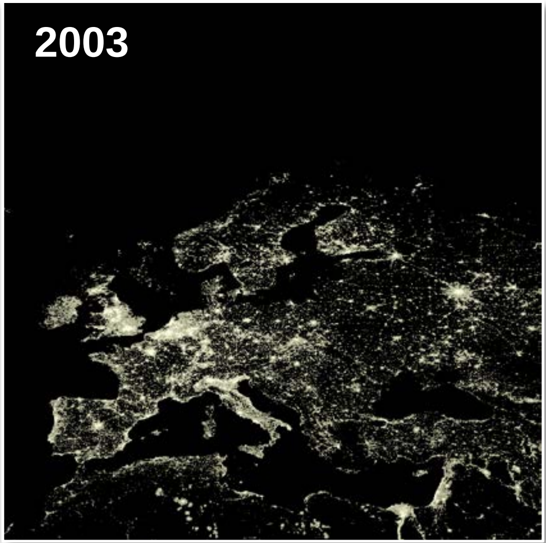
Synthesis of Applications and Derived Requirements

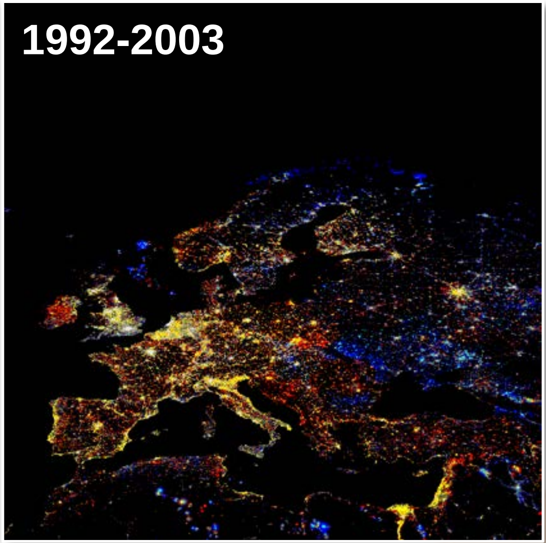
- **Human settlements**
  - Global urban extent of urban areas
  - Detailed mapping of urban areas
- **Human activity**
  - Mapping electric power access
  - Estimating gas flaring volumes
  - Economic activity
- **Hazards and Disaster management**
  - Fire detection and biomass burning
  - Power outage detection and tracking disaster recovery
  - Volcanoes / lava and fumes

Synthesis of Applications and Derived Requirements

- **Population**
  - Estimating the density of constructed surfaces
  - Population estimated from nighttime imagery
- **Light pollution**
  - Artificial night sky brightness
  - Fisheries and maritime activity
  - Ecological effects
  - Health effects on humans
- **Meteorology**
  - Urban heat islands
  - Cloud coverage
  - Snow cover mapping
  - Dust storm
  - Lightning detection and auroras imaging

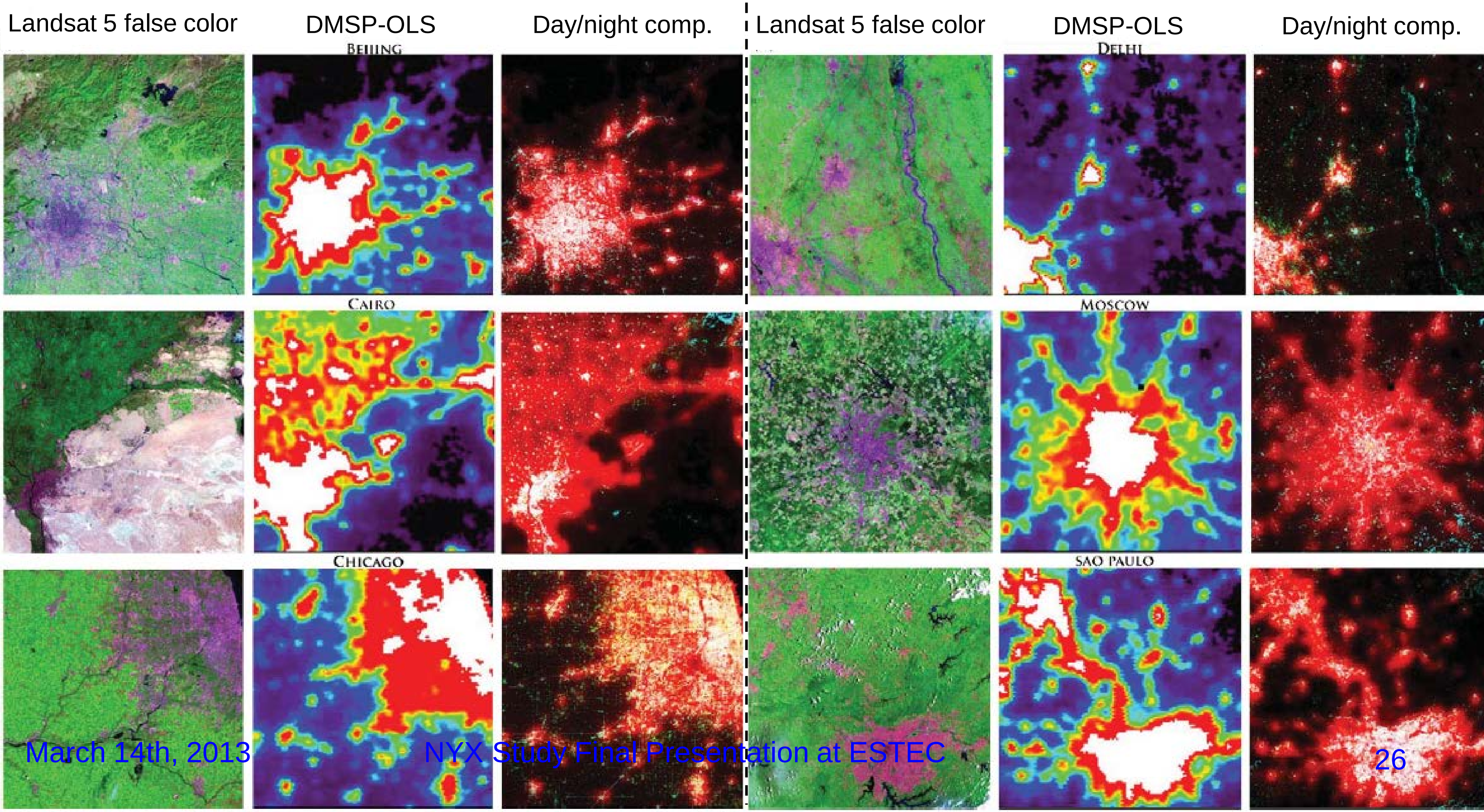
Artificial night lighting as seen from space





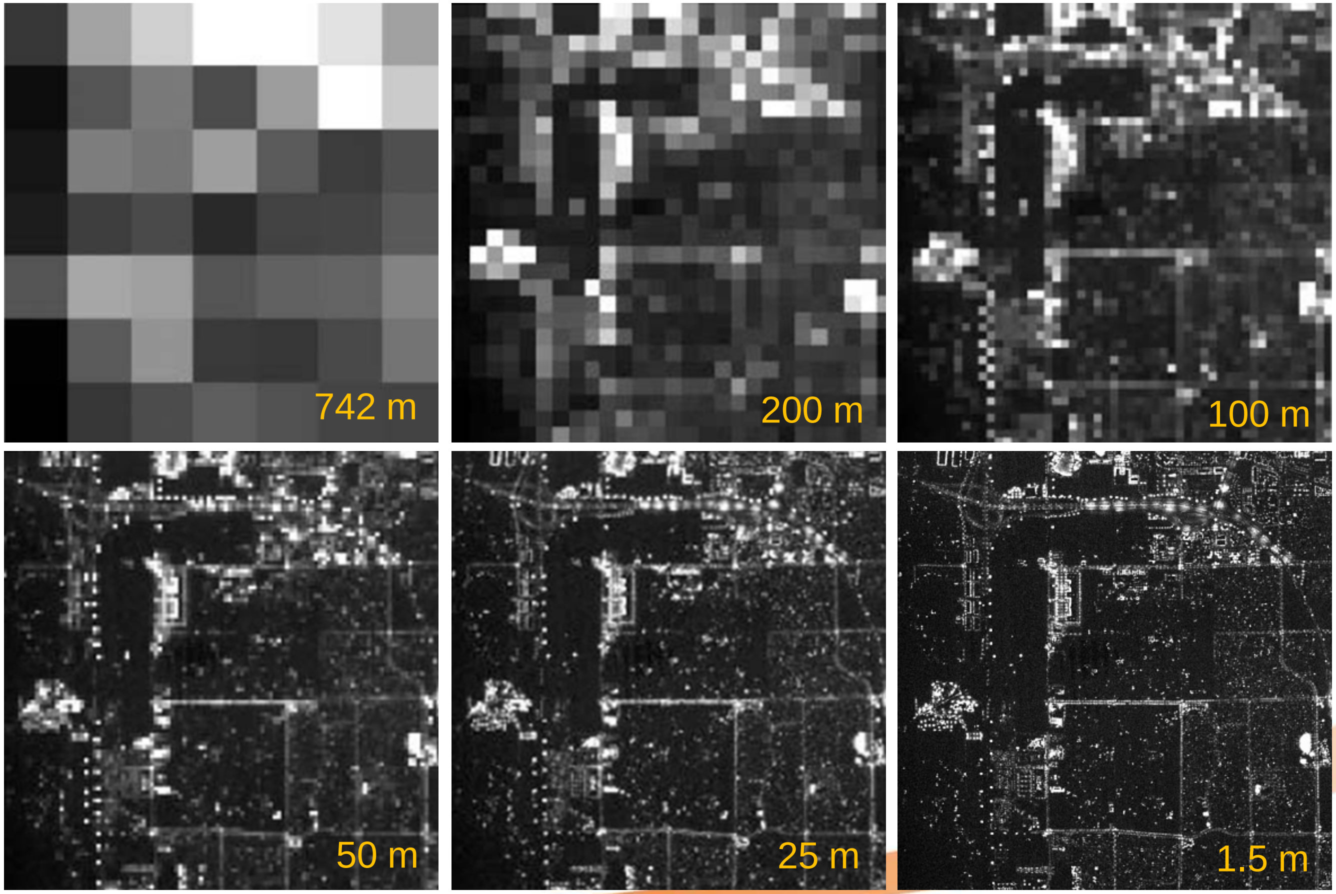
Human settlements

- Global urban extent (urban-rural LC gradients)

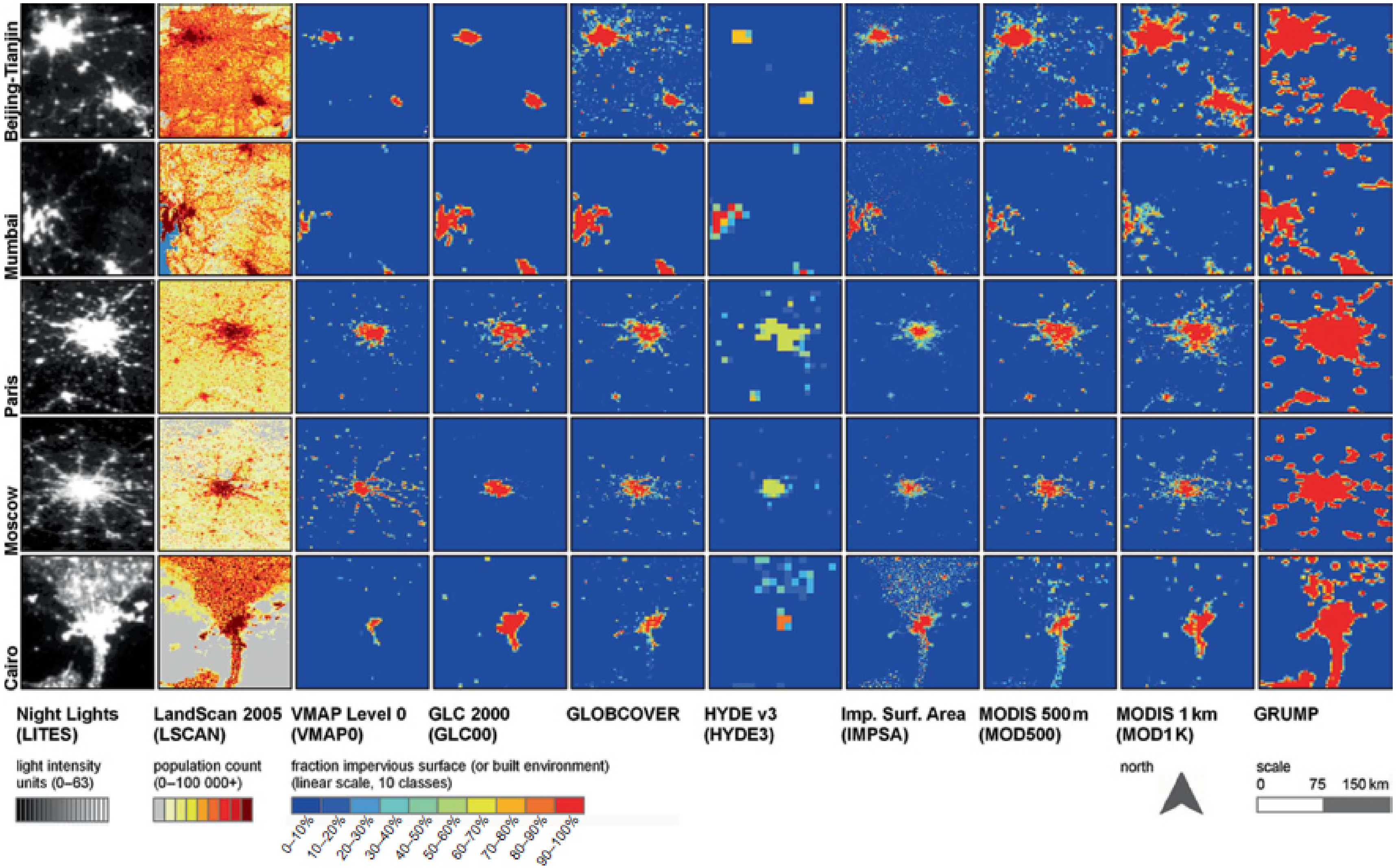


Human settlements

- Detailed mapping of urban areas (simulation / Las Vegas)

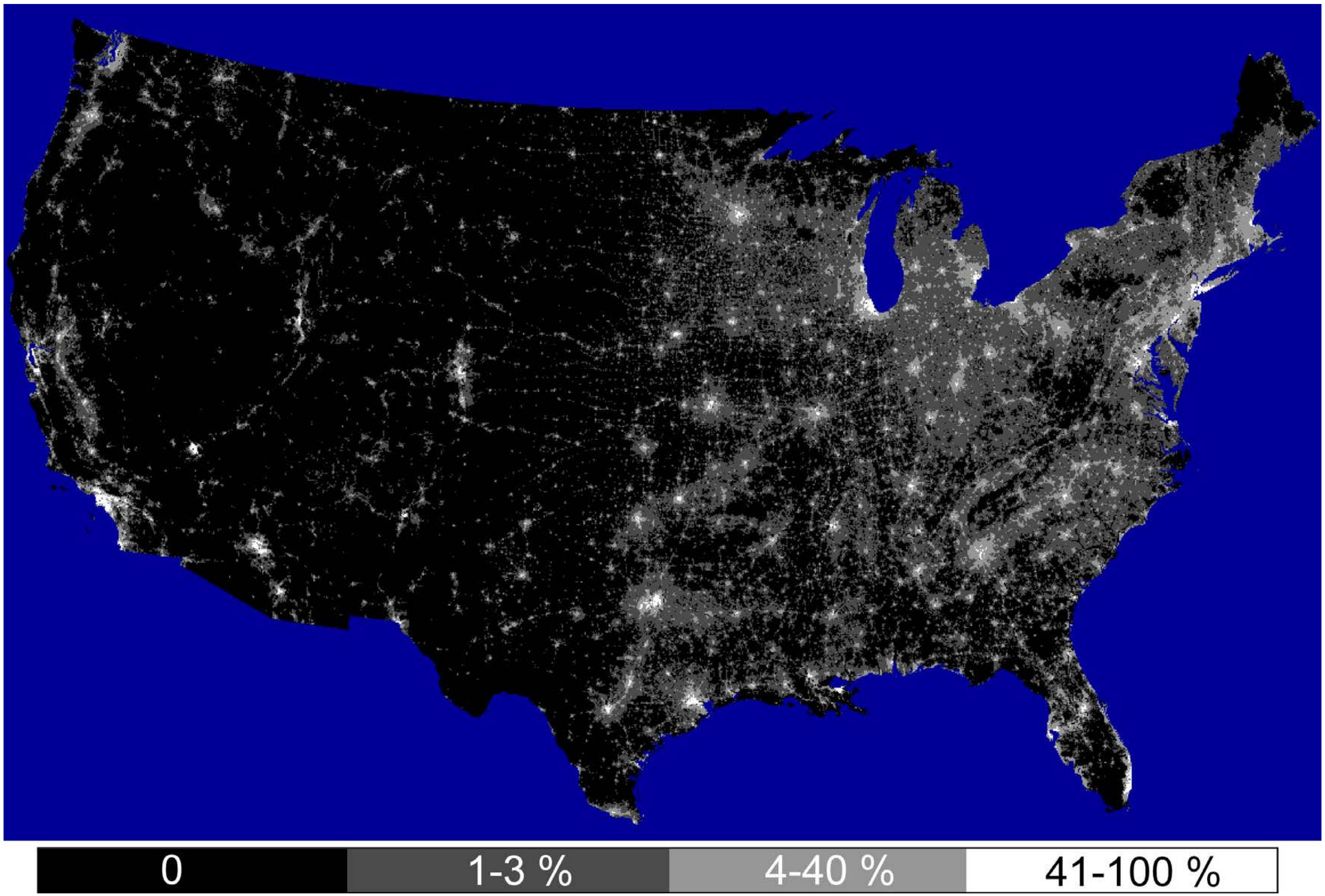


Human population



Human population

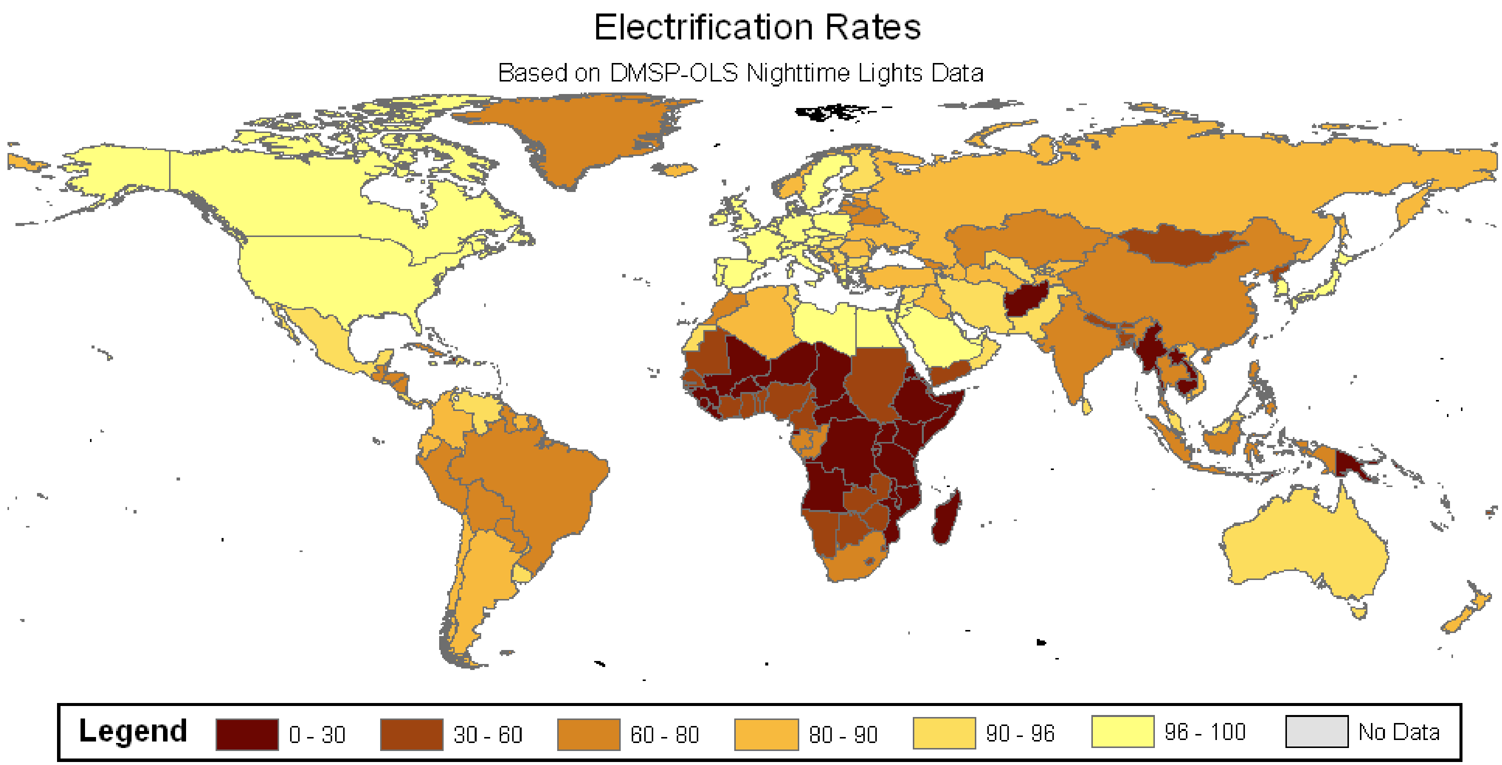
- Estimating the density of constructed surfaces



Human activity

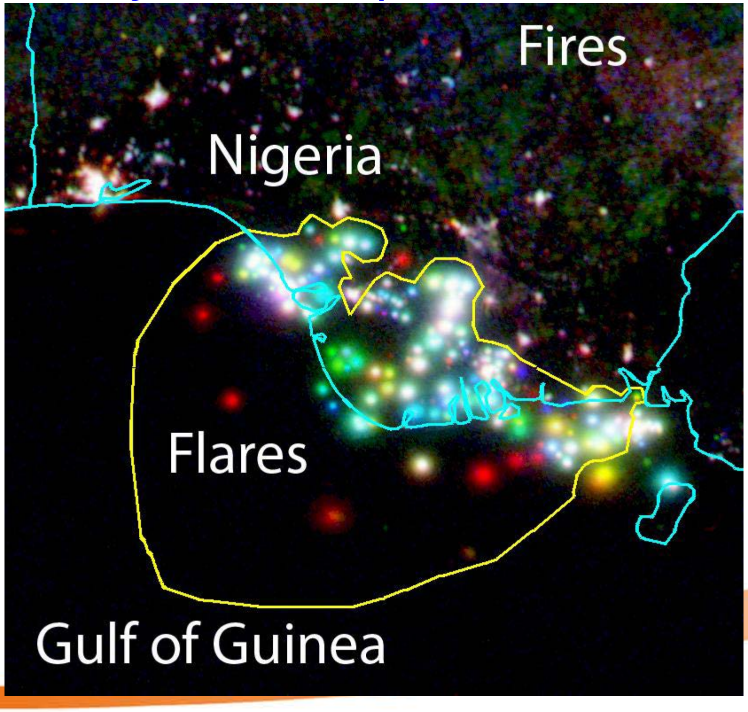
Human activity

- Mapping electric power access



Human activity

- Estimating gas flaring volumes
  - Gas flaring occurs at petroleum production and processing facilities, where the gas-byproduct is safely burnt off or rather where there is insufficient infrastructure for the utilization of the gas (primarily methane)



1994

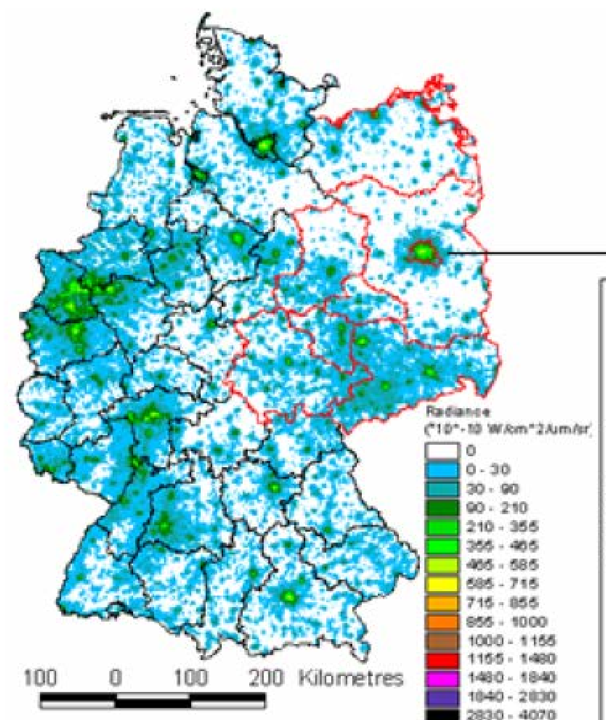
2000

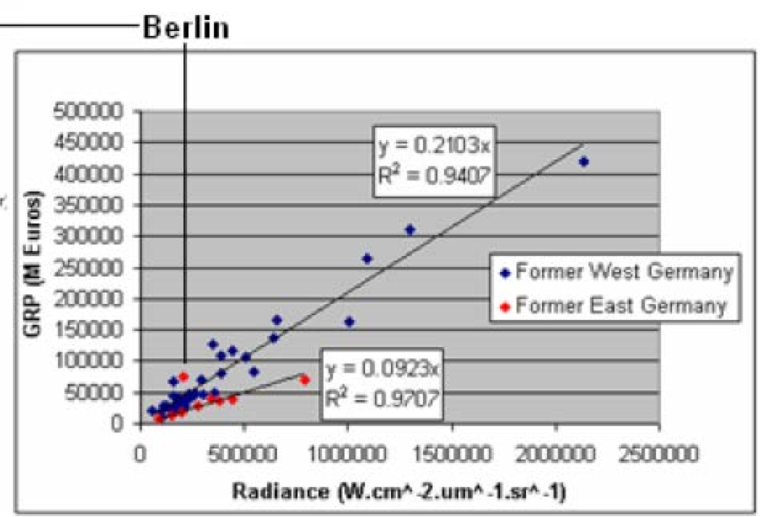
2008

Human activity

- Economic activity
  - Relationship provided only a moderately strong regression factor → using <u>sub-national</u> data

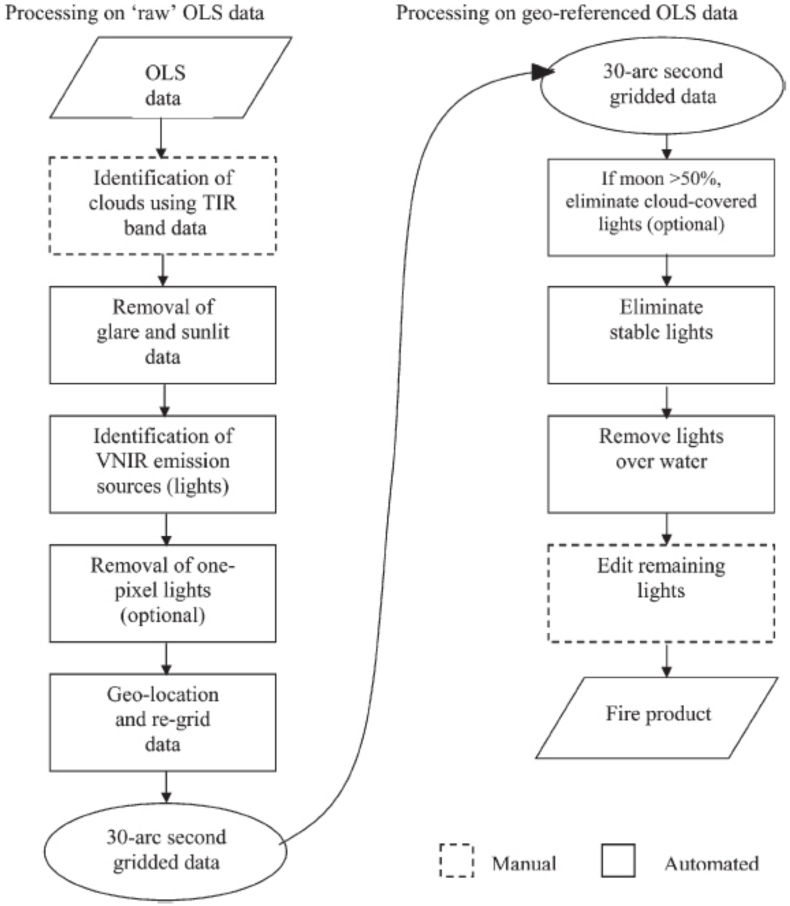
Points in the former Eastern Germany (in **red**) have a different relationship to those in Western Germany (in **blue**).





Hazards and disaster management

- Fire detection (referring to DMSP-OLS studies)
  - Time series analysis of night-time DMSP-OLS observations
    - Definition of a reference data sets of <u>"stable" lights</u>
    - Consistently present in the same location
  - Fires
    - Visible near-infrared emission sources
    - On land, outside the stable lights reference set → <u>ephemeral/temporal features</u>
    - Not associated with lightning



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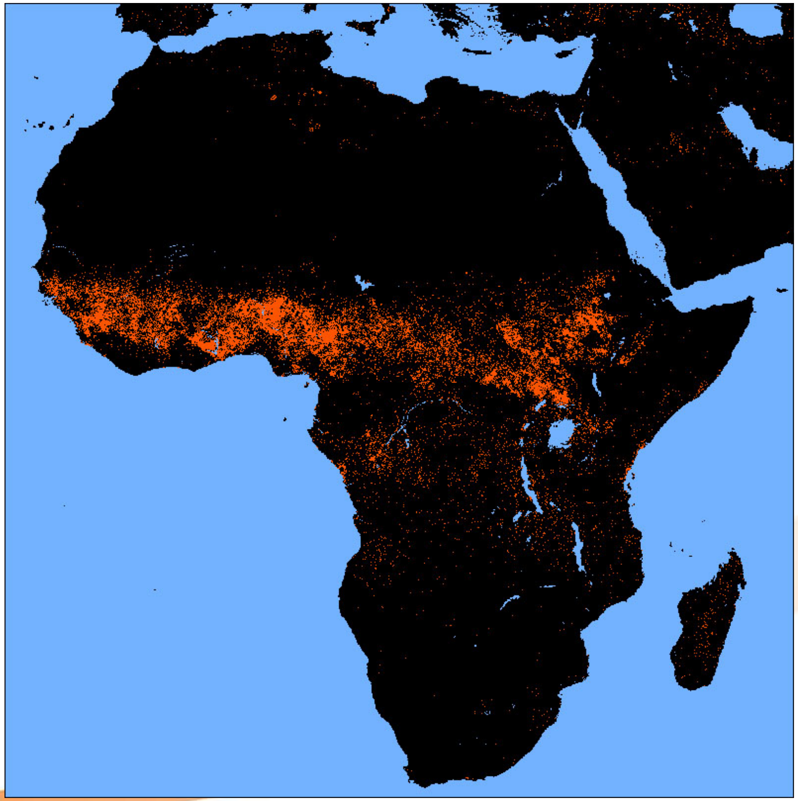
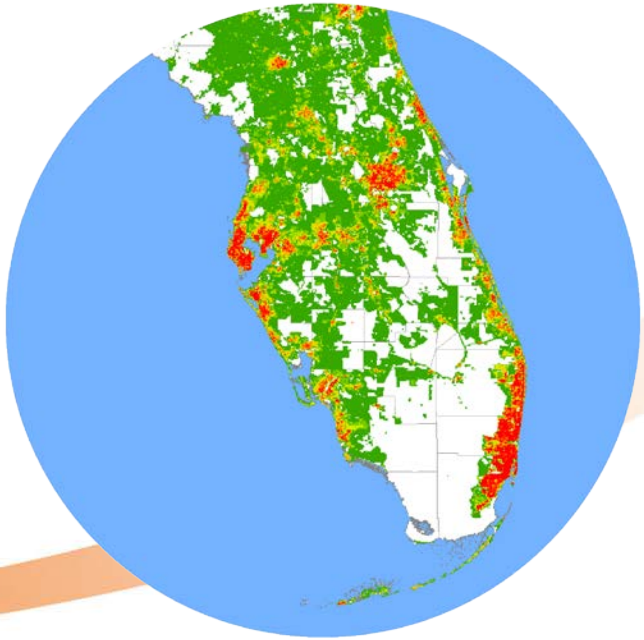
DMSP-OLS annual fire product 2009



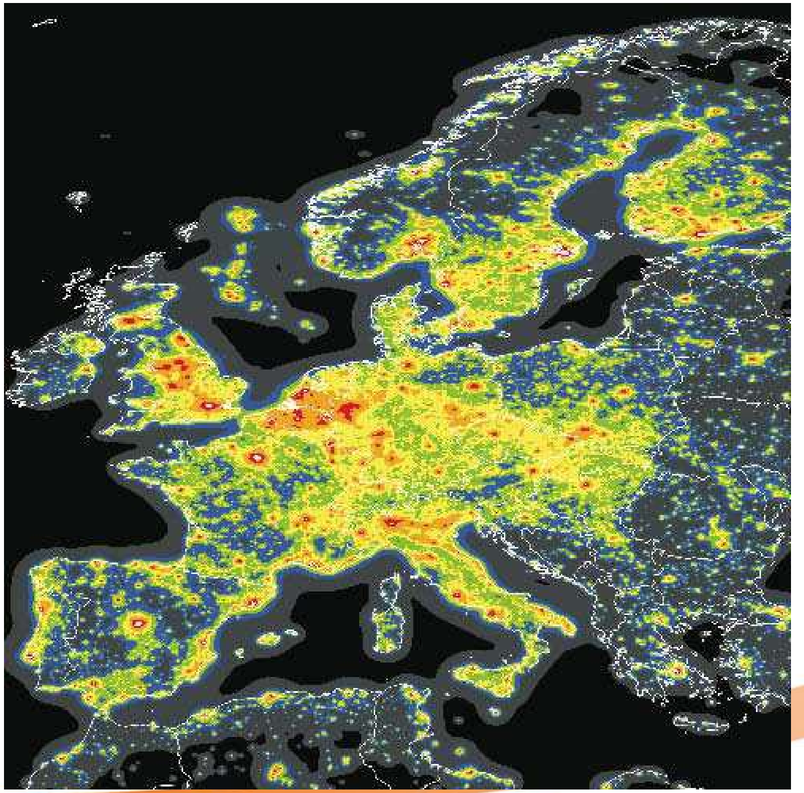
Hazards and disaster management

- Power outage detection and disaster recovery
  - According to official statements of Florida Power & Light (FPL) more than 3.2 m customers were without electric service
  - That is equivalent to approximately 6,000,000 people
  - Delineation of affected area through satellite based power outage detection
  - Overlay with spatial population data, such as U.S. Census Grids, GRUMP, GPW, Landscan …
  - The resulting number of people identified of being without power in Florida the night after Wilma passed is 6,869,244



Light pollution

- Artificial night sky brightness
  - First World Atlas of the artificial night sky brightness (Cinzano et al. 2001)

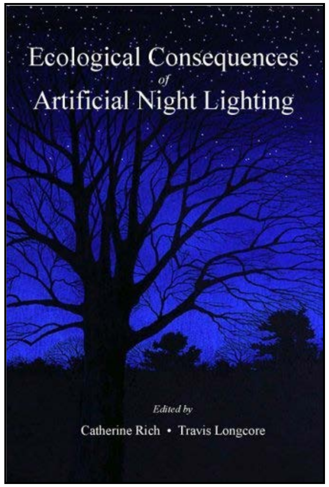


Light pollution

- Ecological effects of artificial night lighting
  - Ecological Consequences of Artificial Night Lighting (Rich & Longcore 2006)

    Selected chapters:
    - Effects of artificial night lighting on migrating birds
      [Gauthreaux Jr. and Belser]
    - Threatened sea turtle nesting sites
      [Salmon]
    - Fish response to artificial night lighting
      [Nightingale, Longcore, and Simenstad]
    - …
  - Global assessment of light pollution impact on protected areas (Aubrecht et al. 2010)

    Initiated in the framework of the IUCN/WCPA on Cities and Protected Areas and its [*Dark Skies Advisory Group*] *(since early 2009)*

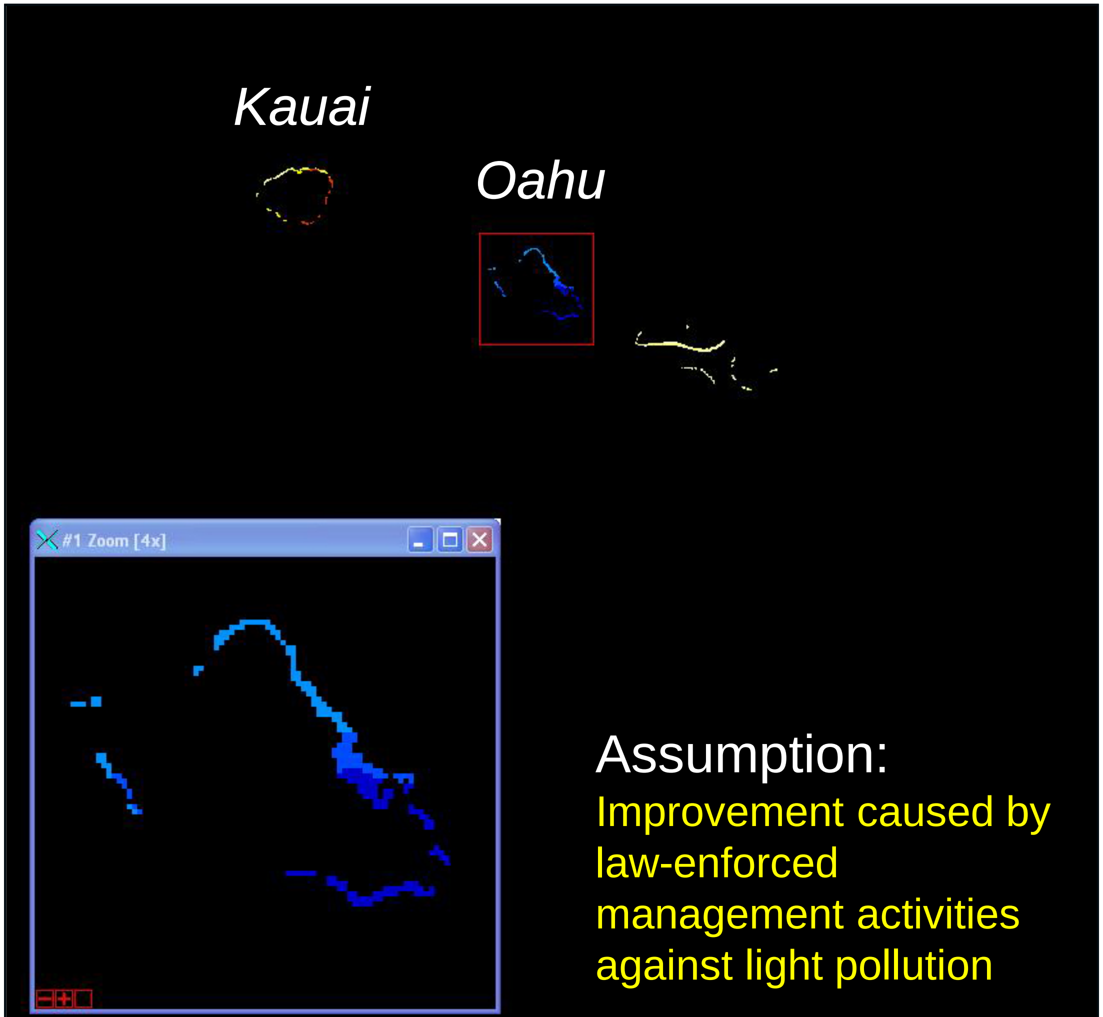


Light pollution

- Ecological effects – Coral reefs
  - NOAA has a global program to monitor SST (sea surface temperature) anomalies – heat stress
  - To date there has only been one single global survey of anthropogenic stress on coral reefs → '*Reefs at risk*'
  - The new research objective was to create a globally consistent assessment of the proximity of specific anthropogenic stressors to coral reefs using DMSP nighttime lights
    - Development
    - Gas flaring
    - Heavily lit fishing boats

Light pollution

- Ecological effects – Coral reefs



Visualization of temporal trends (1992-2003) in potential stress to coral reefs

Red → Decline

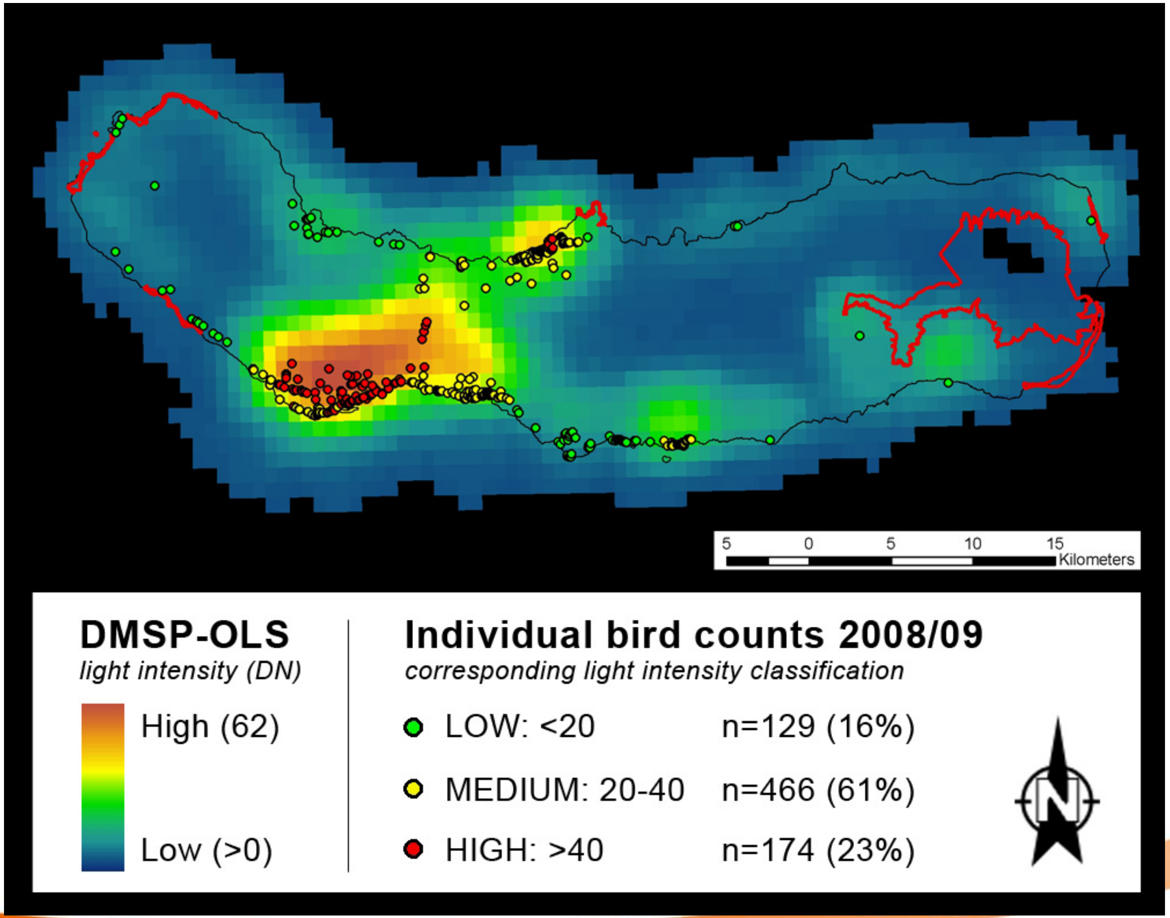
Blue → Improvement

Cities LPI_temp

Hawaii

Light pollution

- Ecological effects – Sea birds

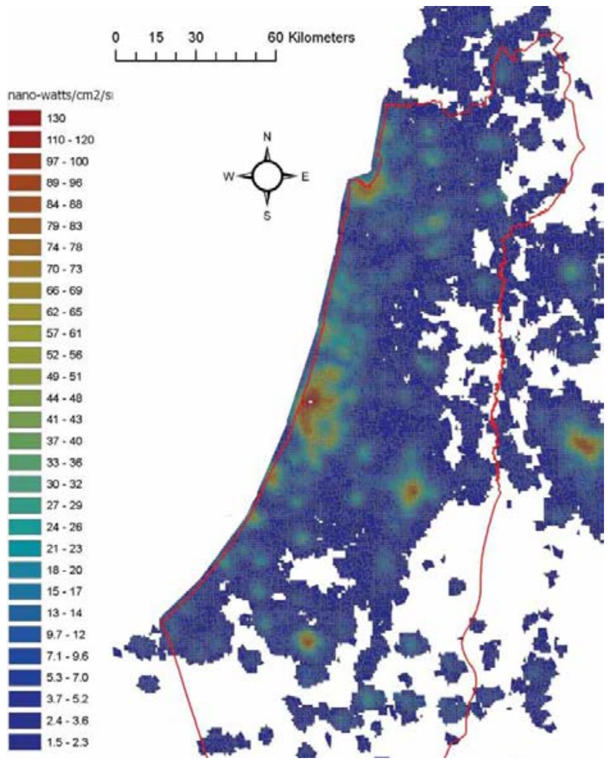


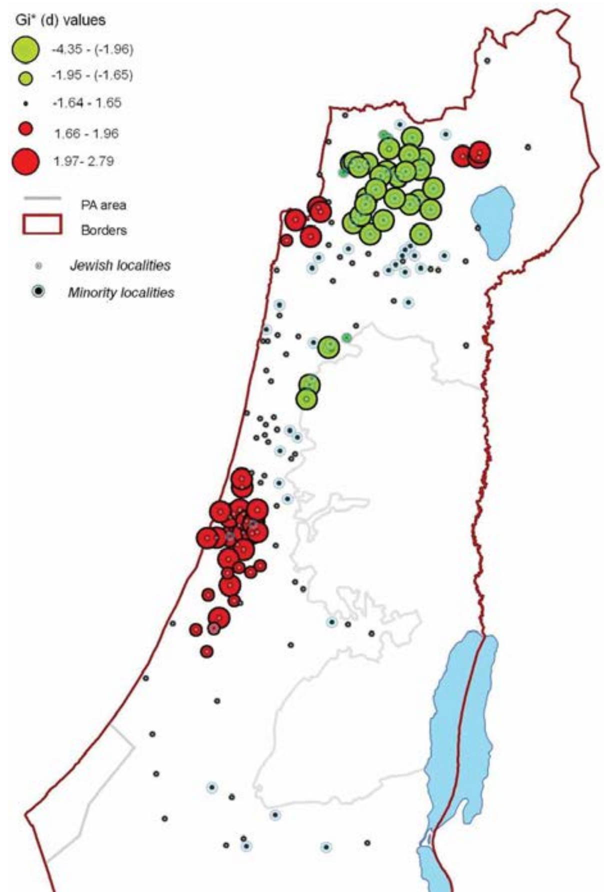
NYX

a Night-time Optical Imaging Mission

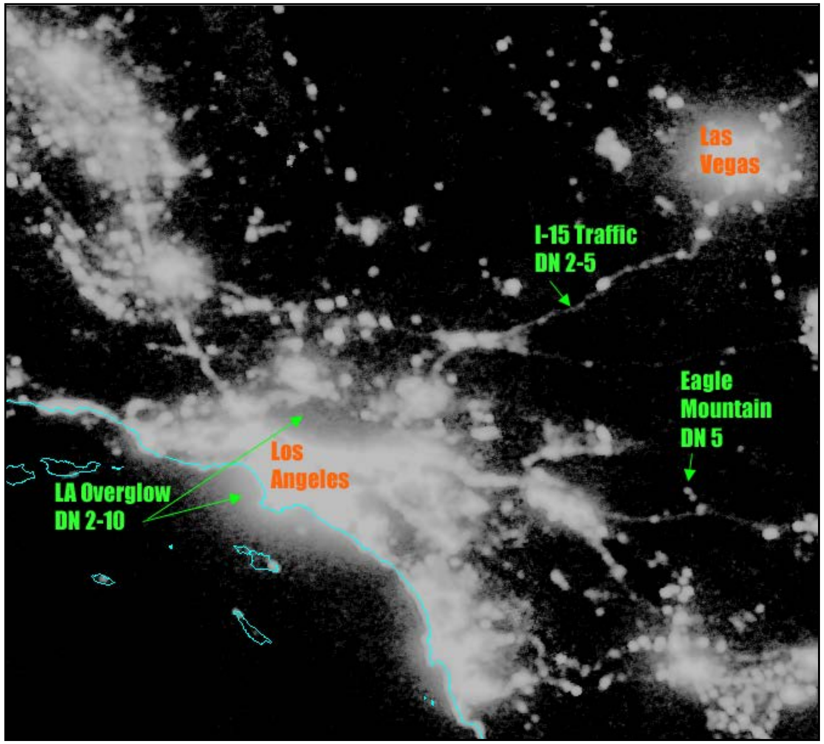
Light pollution

- Health effects on humans
  - Israel case studies





Shortcomings of DMSP nighttime lights



- Coarse spatial resolution
  - 2.5 km GSD
- OLS lights are larger than sources on the ground → 'Overglow' surrounds bright sources
- No visible band calibration
- 6 bit quantification
- Urban centers saturate in operational data
- No spectral information on the type of the lighting or changes in lighting type

VIIRS

NightSat | NYX

Meteorology

- Urban heat islands
- Cloud coverage
  - Moonlit clouds detected by DMSP-OLS (PMT)
- Dust storms
  - Under sufficient moonlight
- Snow cover mapping
  - Reflected moon light visible images can fill the existing gap potentially existing with the current observation systems (IR, MW)
- Lightning detection / auroras imaging
  - High imaging frequency needed
  - Compare occurrence records with other operational systems

Experts survey

- Baddiley, C. (Royal Astronomical Society, UK)
- Elvidge, C. (NOAA/NGDC, USA)
- Falchi, F. (Light Pollution Science & Technology Institute, Italy)
- Hollan, J. (Nicholas Copernicus Observatory and Planetarium Brno, Czech Republic)
- Kyba, C., Hölker, F., and colleagues (Freie Universität Berlin, Institute for Space Sciences, Germany)
- Lolkema, D. (National Institute for Public Health and the Environment RIVM, the Netherlands)
- Longcore, T. (University of Southern California, Urban Wildlands Group, USA)
- Matsuno, Y. (University of Tokyo, Japan)
- Rodriguez, A. (Estación Biológica de Doñana CSIC, Department of Evolutionary Ecology, Spain)
- Small, C. (LDEO, Columbia University, NASA SEDAC, USA)
- *Pending*: Sutton, P. (U. Denver, USA); Doll, C. (UNU, Japan)

Product Requirements Review

1. EXISTING AND/OR PLANNED MISSIONS

2. APPLICATIONS REVIEW

3. DEFINITION OF INSTRUMENT CLASSES

Classes of instrument requirements

	Application	Light source	Product	Typology					Night only
				Coverage	Resolution	VIS / IR	Initiation	Duration	
1	**Human settlements**								
1.1	Global urban extent	Man-made lighting	Images (cloud free)	Regional to global	1 km	VIS	Slow variations	Week(s) to years	N
1.2	Detailed mapping of urban areas	Man-made lighting	Images (cloud free)	Regional	10-50 m	VIS	Slow variations	Week(s) to years	N
2	**Human population**								
2.1	Estimating the density of constructed surfaces	Man-made lighting	Images (cloud free)	Regional to global	25-50 m	VIS	Population detection limit	Week(s) to years	N
2.2	Population estimated from nighttime imagery	Man-made lighting	Images (cloud free)	Regional to global	25-50 m	VIS	Population detection limit	Week(s) to years	N
3	**Human activity**								
3.1	Mapping electric power access	Man-made lighting	Images (cloud free)	Regional to global	1 km	VIS / multispe	Slow variations	Week(s) to years	Y
3.2	Estimating gas flaring	Flare	Images (cloud free) with detected "hot spots"	Regional	50-100 m	VIS	Slow variations	Week(s) to years	Y
3.3	Economic activity	Man-made lighting	Images (cloud free)	Regional to global	1 km	VIS	Slow variations	Week(s) to years	Y
3.4	Tracking night-time heavy lit fisheries	Fish boat / Man-made lighting	Images (cloud free) with detected "hot spots"	Regional	100 m	VIS	Sudden, not predictable	Hours to days	Y
3.5	Tracking night-time maritime activity	Any boat / Man-made lighting	Images (cloud free) with detected "hot spots"	Regional to global	100 m	VIS	Sudden, not predictable	Hours to days	Y
4	**Hazards and Disaster management**								
4.1	Fire detection	Fire	Images (cloud free) with detected "hot spots"	Regional to global	50 m	VIS / IR	Sudden, not predictable	Hours to days	N
4.2	Biomass burning	Fire	Images (cloud free) with detected "hot spots"	Regional to global	1 km	VIS / IR	Slow variations	Hours to days	N
4.3	Power outage detection	Man-made lighting	Images (cloud free)	Regional	25-50 m	VIS / multispe	Sudden, not predictable	Few days	Y
4.4	Tracking disaster recovery	Man-made lighting	Images (cloud free)	Regional	25-50 m	VIS	Sudden, not predictable	Week(s) to years	N
4.5	Volcanoes lava flows	Lava flow	Images (cloud free) with detected "hot spots	Regional	25-50 m	VIS / IR	Sudden, not predictable	Week(s) to years	N
0.6	Volcanoes dust clouds	Moon (lunar reflection)	Images	Regional to global	25 to 100 m for VIS image rectification	VIS	Sudden, not predictable	Week(s) to years	N
5	**Light pollution**								
5.1	Artificial night sky brightness	Man-made lighting	Images (cloud free)	Regional	100 m	VIS	Slow variations	Week(s) to years	Y
5.2	Tracking night-time heavy lit fisheries	Fish boat / Man-made lighting	Images (cloud free) with detected "hot spots"	Regional	100 m	VIS	Sudden, not predictable	Hours to days	Y
5.3	Ecological and zoological effects	Man-made lighting	Images (cloud free)	Regional	100 m	VIS	Slow variations	Week(s) to years	Y
5.4	Health effects on humans	Man-made lighting	Images (cloud free)	Regional	25-50 m	VIS	Slow variations	Week(s) to years	Y
6	**Meteorology**								
6.1	Urban heat islands	Man-made lighting	Images (cloud free)	Regional	1 km	VIS / IR	Slow variations		Y
6.2	Cloud coverage	Moon (lunar reflection)	Images	Regional to global	25 to 100 m for VIS image rectification	VIS / IR	Sudden, not predictable	Night (day through Météo images)	N
6.3	Snow cover mapping	Moon (lunar reflection)	Images (cloud free)	Regional to global	1 km	VIS / IR	Sudden	Night (day through Météo images)	N
6.4	Dust storm	Moon (lunar reflection)	Images (cloud free)	Regional	25 to 100 m for VIS image rectification	VIS / IR	Sudden, not predictable	Night (day through Météo images)	N
6.5	Lightning detection / auroras imaging	Lightning	Images with detected "hot spots"	Regional to global	1 km	VIS	Sudden, not predictable	Night (day through Météo images)	N

3 classes of instruments

	#1	#2	#3	Units
Spatial Sampling (GSD): Goal value	25	100	1 000	m
Spatial resolution : PSF 80% encircled energy	30	120	1 200	m
Swath width	300	700	2 000	km
Minimum Image Extent:	300*300	700*700	2 000*2 000	km
Spectral range and resolution **(*)**	PAN [0.4-0.9] Blue [0.4-0.5] Green [0.5-0.6] Na [0.56-0.61] NIR [0.8-0.9]	PAN [0.4-0.9] Blue [0.4-0.5] Green [0.5-0.6] Na [0.56-0.61] NIR [0.8-0.9]	PAN [0.4-0.9] Blue [0.4-0.5] Green [0.5-0.6] Na [0.56-0.61] NIR [0.8-0.9]	µm
Spectral response homogeneity	5%	5%	5%	
Radiance detection: R_1 Goal value :R_{min}	100 10	30 -100 3- 10	10 1	µW/m²/sr/µm
Max. Radiance	100	100	100	W/m²/sr/µm
SNR	3 @R_{min} 10 @R_1	3 @R_{min} 10 @R_1	3 @R_{min} 10 @R_1	
Inflight radiometric calibration	YES	YES	YES	
Effective revisit time: Goal value	1 to 3	1 to 3	1 to 3	day
Geo-Location Raw image without GCP	35	150	200	m
Geo-Location with GCP and image processing	15 / 200	50 / 200	NA	m
Orbit	LEO/GEO	LEO/GEO	LEO/GEO	

NYX Instrument Final Presentation

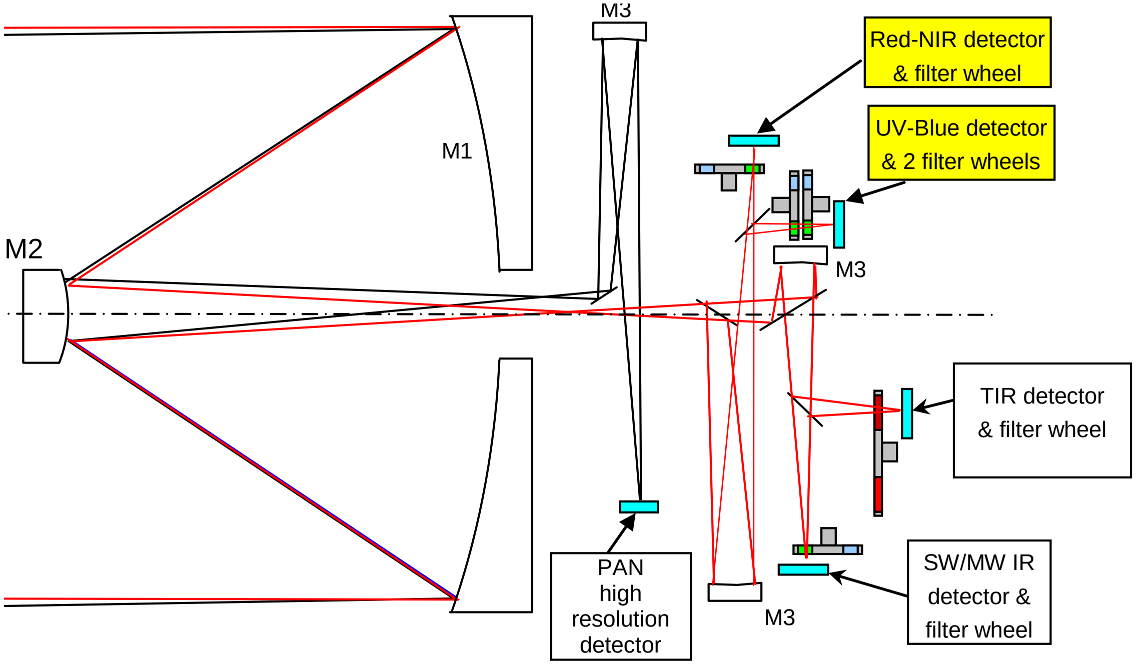
3. Instrument and mission trade-off

Instrument and mission trade-off

1. **GEO STEP AND STARE CONCEPT**
2. **LEO PUSHBROOM CONCEPT**
3. **LEO STEP AND STARE CONCEPT**

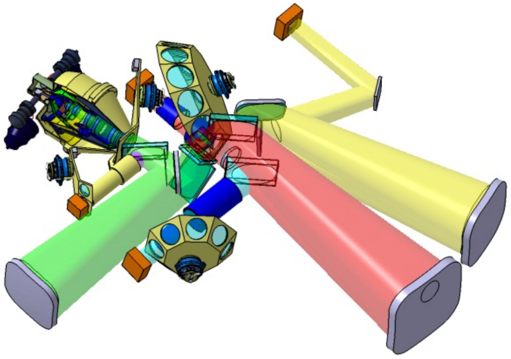
GEO INSTRUMENT CONCEPT

- NYX Instrument onboard GEO-OCULUS
  - Best solution is to share telescope FPA but increases Geo-Oculus complexity which is already high



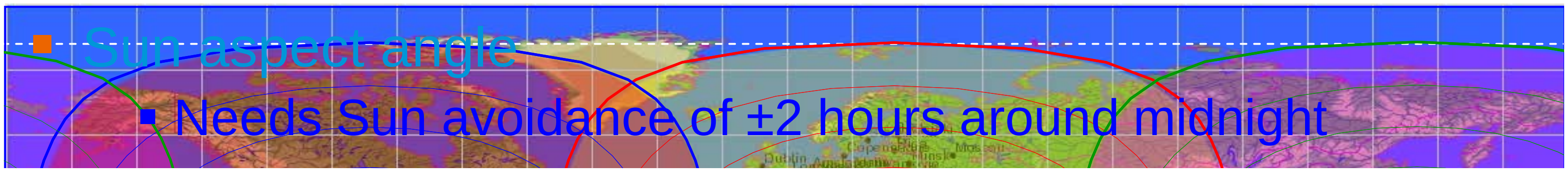
Preliminary optical architecture Geo-oculus + integrated NYX channels

Band	Wheel 1	Wheel 2
UV1	P1	Clear
UV2	P2	Clear
VNIR1	P3	Clear
VNIR2	P4	Clear
VNIR3	P5	Clear
VNIR4	P6	Clear
VNIR5	P7	Clear
VNIR6	P8	Clear
VNIR8	Clear	P1
VNIR9	Clear	P2
VNIR10	Clear	P3
VIS1	Clear	P4
VIS2	Clear	P5
VIS3	Clear	P6
Narrow PAN	Clear	P7
Dark	Clear	Closed
FlatField	Clear	Clear

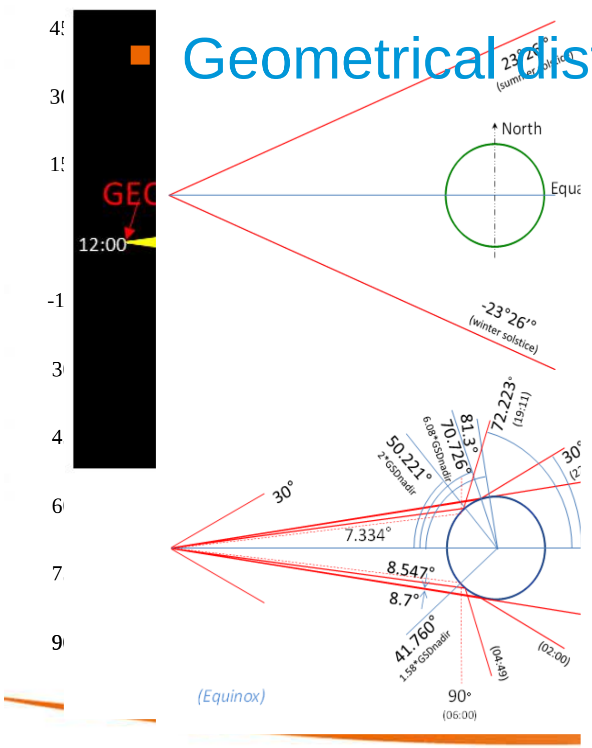


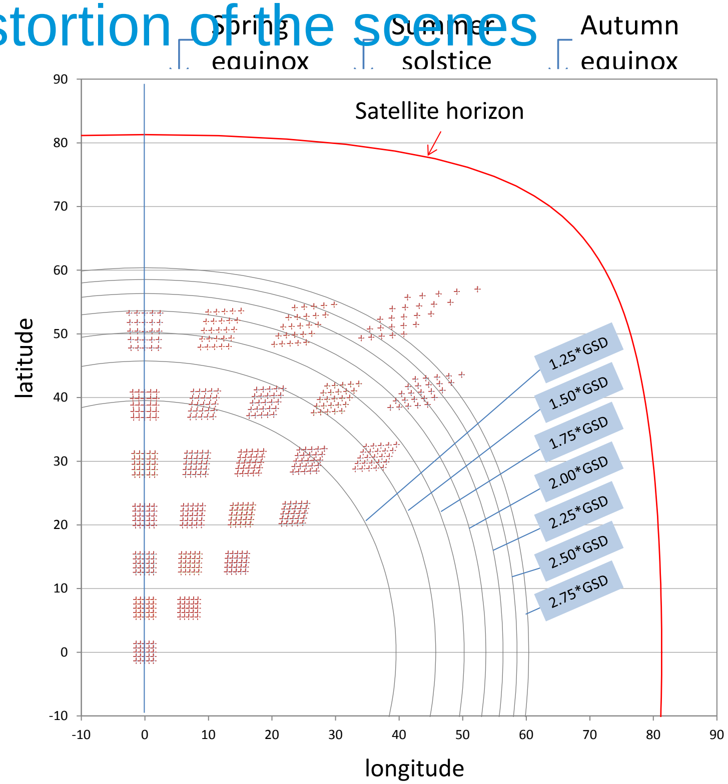
Impact of GEO orbit

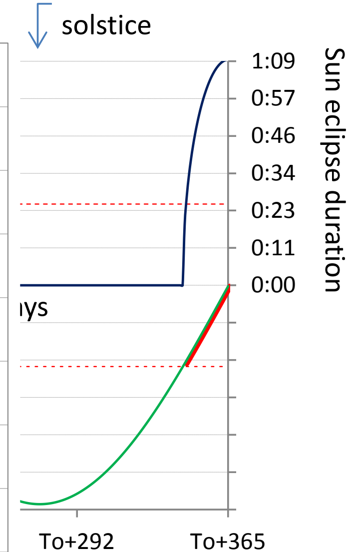
- 3 satellites to a full Earth coverage



- Sun aspect angle
  - Needs Sun avoidance of ±2 hours around midnight
- Geometrical distortion of the scenes

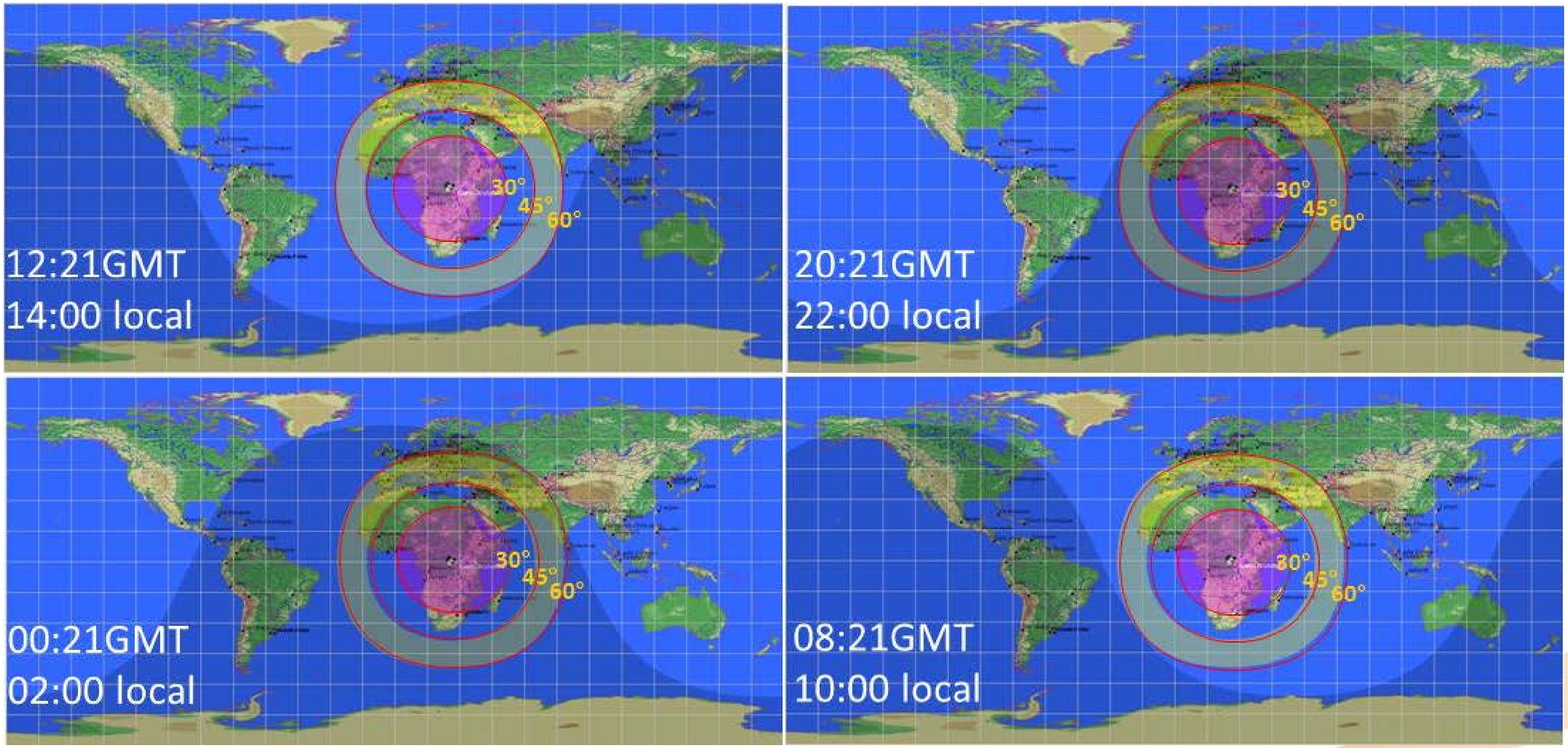






Observation time

- Case of GEO

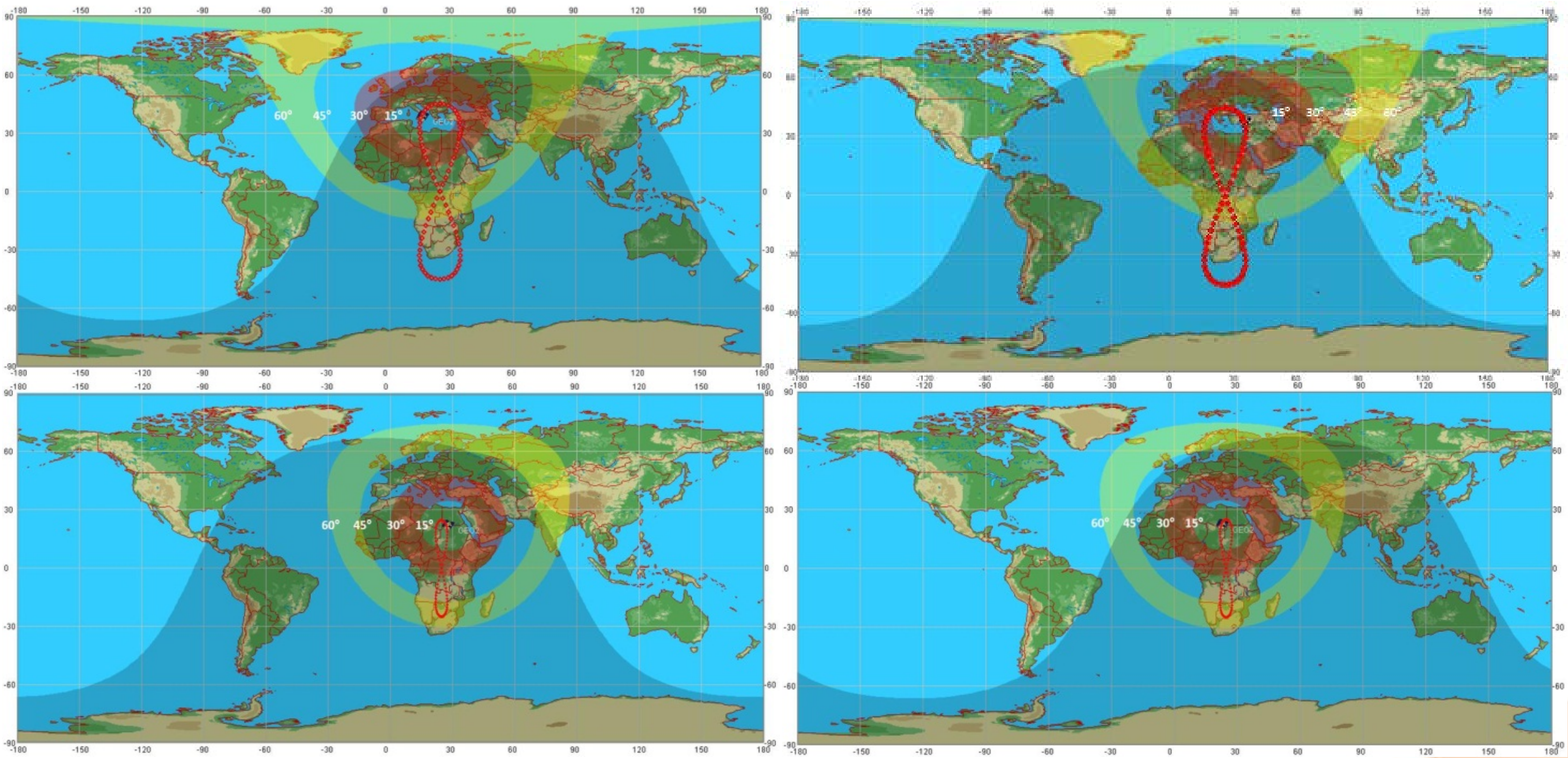


Possible observation time (example of the summer solstice)

Figure 3-30 : Position of the satellite Nadir at beginning and end of the Sun avoidance manoeuvre (±30°)

Observation time

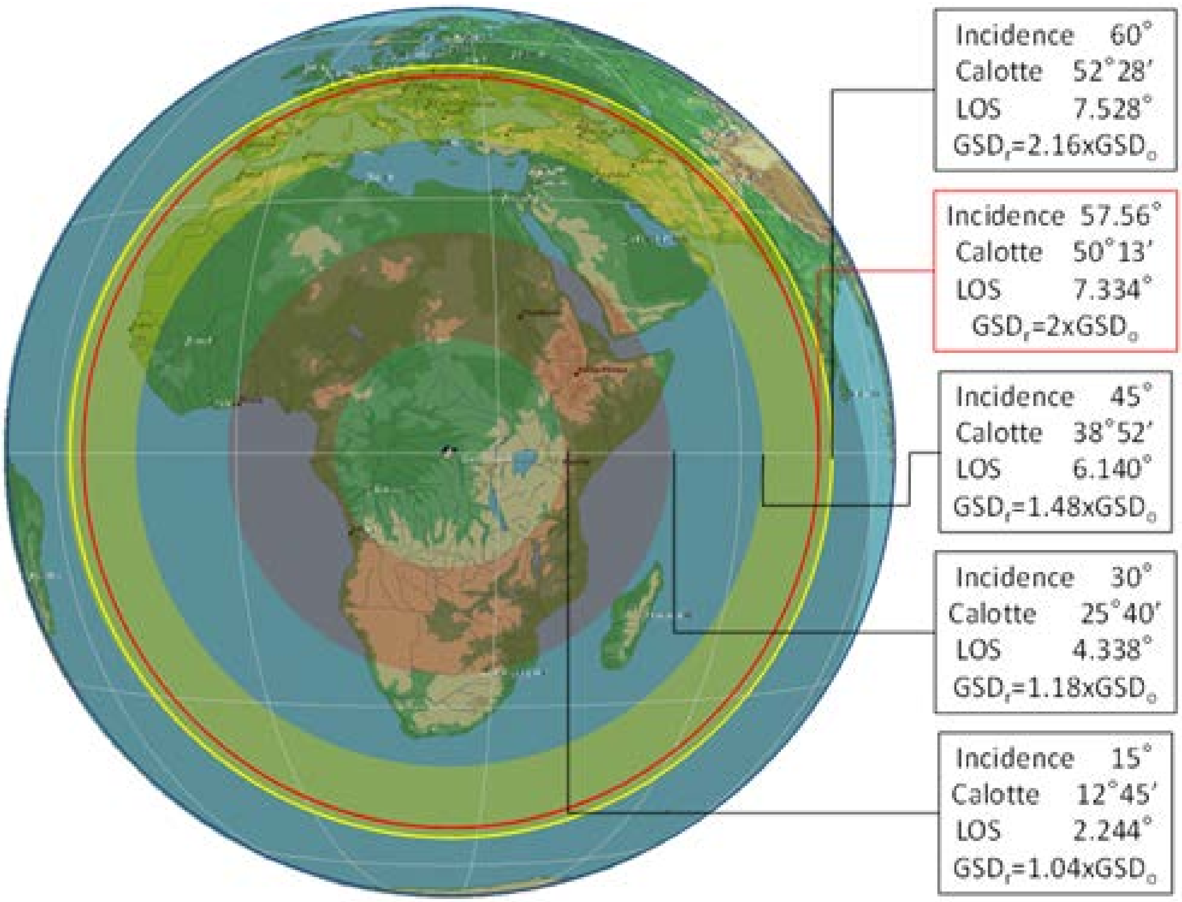
- Case of the GSO with 45° or 25° inclination



Position of the satellite Nadir at beginning and end of the Sun avoidance manoeuvre (±30°)

GSD and Incidence

- GEO

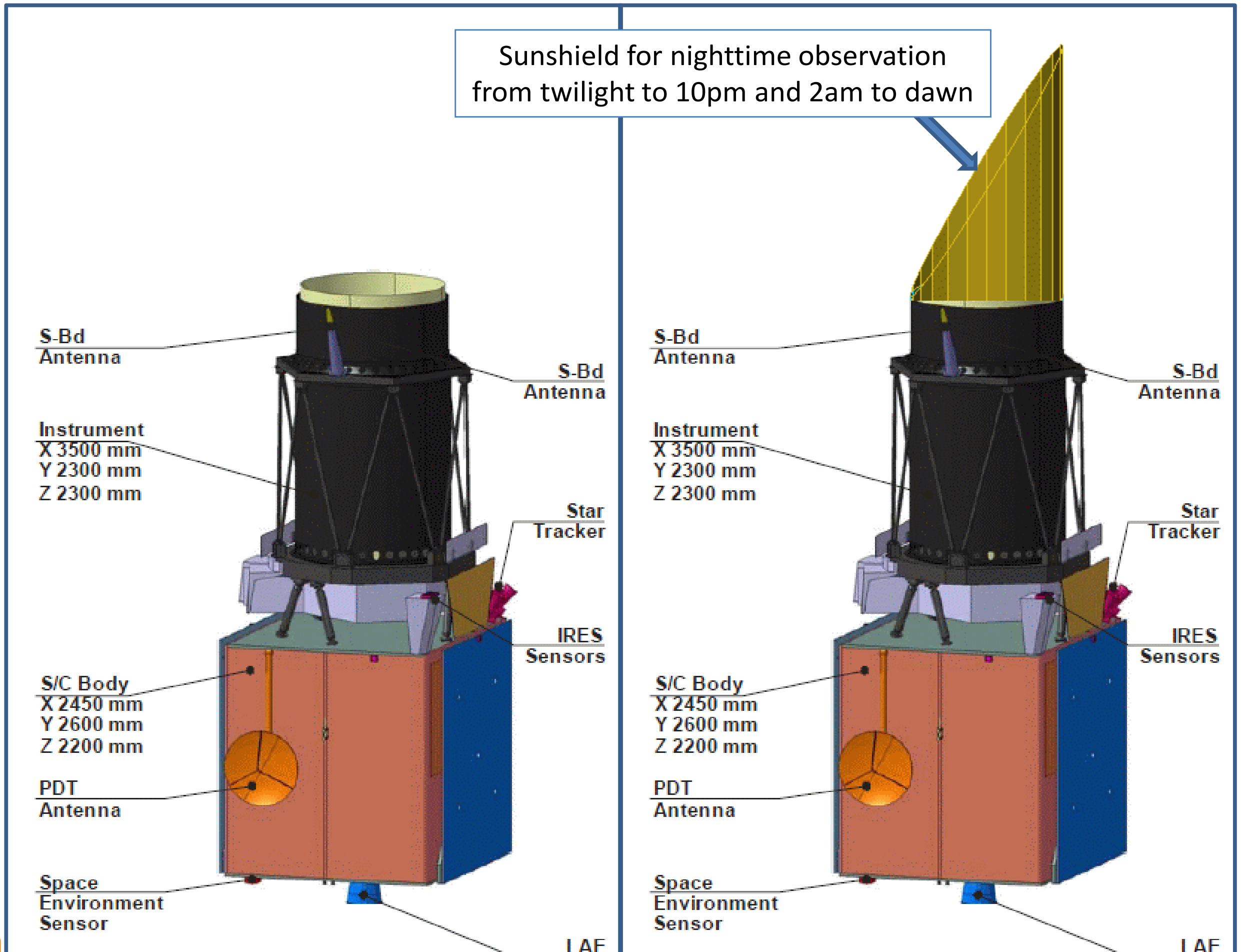


GEO Instrument concept : performances

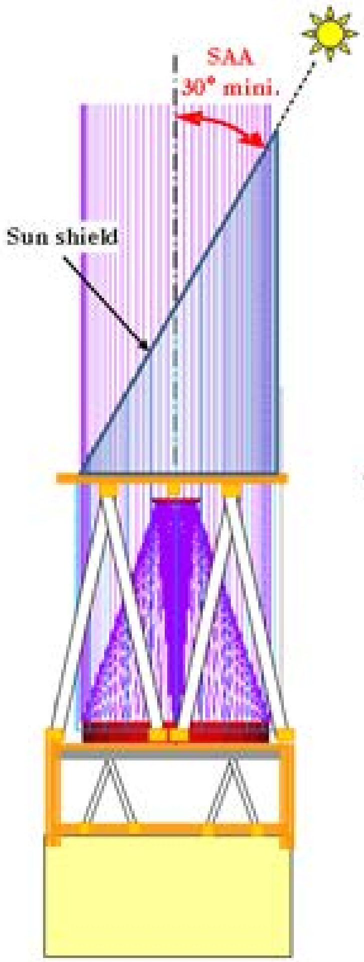
1µrad stability	1/ Resolution = 1000m					2/ Resolution = 80m / 120m					3/ Resolution = 80m					4/ Resolution = 80m					5/ Resolution 100m / 50m				
		UV-VIS			NIR		UV-VIS			NIR		UV-VIS			NIR		UV-VIS			NIR					
channel	*VIS1*	*VIS2*	*VIS3*	*PAN*	*NIR*	*VIS1*	*VIS2*	*VIS3*	*PAN*	*NIR*	*VIS1*	*VIS2*	*VIS3*	*PAN*	*NIR*	*VIS1*	*VIS2*	*VIS3*	*PAN*	*NIR*	*VIS1*	*VIS2*	*VIS3*	*NIR*	*PAN*
EW elementary pixel GSD (m)	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	50	50	50	50	50
EW pixel binning factor	25	25	25	25	25	3	4	3	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1
EW binned pixel GSD (m)	1000	1000	1000	1000	1000	120	160	120	80	80	80	80	80	80	80	80	80	80	80	80	50	50	50	50	50
R1 (W/m2/sr/µm)	1,0E-5	1,0E-5	1,0E-5	1,0E-5	1,0E-5	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4	1,0E-4
lamda0 (µm)	0,5	0,56	0,655	0,55	0,8	0,5	0,56	0,655	0,55	0,8	0,5	0,56	0,655	0,55	0,8	0,5	0,56	0,655	0,55	0,8	0,5	0,56	0,655	0,8	0,65
delta_lambda (µm)	0,1	0,1	0,1	0,3	0,2	0,1	0,1	0,1	0,3	0,2	0,1	0,1	0,1	0,3	0,2	0,1	0,1	0,1	0,3	0,2	0,1	0,1	0,1	0,2	0,5
pixel type	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	3T	4T	4T	4T	4T	4T
pixel dark signal (e-/sec)	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,7	1,3	1,3	1,3	1,3	1,3
pixel QE at lambda0	0,9	0,9	0,9	0,9	0,7	0,9	0,9	0,9	0,9	0,7	0,9	0,9	0,9	0,9	0,7	0,9	0,9	0,9	0,9	0,7	0,9	0,9	0,9	0,7	0,7
pixel signal (e-/sec)	2	2	2	5	4	15	17	20	51	38	15	17	20	51	38	15	17	20	51	38	24	27	31	60	121
integration time (sec)	7,30	6,50	5,55	2,20	2,95	6,25	4,15	4,75	2,85	3,80	3,32	2,98	2,55	1,00	1,32	3,32	2,97	2,55	1,00	1,32	2,30	2,30	0,52	0,93	0,45
Signal per pixel(e-)	11	11	11	11	11	96	71	95	144	145	51	51	51	51	50	51	51	51	51	50	55	62	16	55	55
DarkSignal(e-)	13	11	10	4	5	11	7	8	5	7	6	5	4	2	2	6	5	4	2	2	3	3	1	1	1
total ReadOutNoise (e-)	39	39	39	39	39	39	39	39	39	39	11	11	11	11	11	11	11	11	11	11	2	2	2	2	2
12 bits quantization noise (e-)	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	1	1	1	1	1
PhotonicSignalNoise(e-)	3	3	3	3	3	10	8	10	12	12	7	7	7	7	7	7	7	7	7	7	7	8	4	7	7
DarkNoise(e-)	4	3	3	2	2	3	3	3	2	3	2	2	2	1	2	2	2	2	1	2	2	2	1	1	1
Noise per pixel(e-)	39	39	39	39	39	40	40	40	41	41	14	14	14	14	14	14	14	14	14	14	8	8	5	8	8
SNR binned pixel 1 image	10,06	10,03	10,03	10,03	10,14	10,07	10,07	10,03	9,97	10,02	10,01	10,07	10,09	10,05	10,00	10,01	10,04	10,09	10,05	10,00	9,88	10,52	5,01	10,05	10,07
Diffraction MTF	0,99	0,99	0,99	0,99	0,99	0,94	0,95	0,92	0,90	0,85	0,91	0,89	0,88	0,90	0,85	0,91	0,89	0,88	0,90	0,85	0,85	0,83	0,80	0,76	0,80
Aberration MTF	0,99	0,99	0,99	0,99	0,99	0,89	0,93	0,92	0,86	0,91	0,85	0,86	0,88	0,86	0,91	0,85	0,86	0,88	0,86	0,91	0,77	0,80	0,83	0,86	0,83
Smearing MTF	0,97	0,98	0,98	1,00	1,00	0,09	0,69	0,36	0,45	0,17	0,31	0,43	0,56	0,92	0,86	0,31	0,42	0,56	0,92	0,86	0,18	0,31	0,31	0,83	0,96
Detector Nyquist MTF	0,35	0,37	0,40	0,36	0,38	0,35	0,37	0,40	0,36	0,38	0,35	0,37	0,40	0,36	0,38	0,35	0,37	0,40	0,36	0,38	0,35	0,37	0,40	0,38	0,36
Total MTF	0,33	0,35	0,39	0,35	0,37	0,03	0,22	0,12	0,12	0,05	0,08	0,12	0,17	0,26	0,25	0,08	0,12	0,17	0,26	0,25	0,04	0,08	0,08	0,21	0,23
RSB*MTF	3,35	3,55	3,86	3,53	3,76	0,25	2,25	1,22	1,24	0,51	0,84	1,22	1,74	2,57	2,52	0,84	1,21	1,74	2,57	2,52	0,40	0,80	0,42	2,09	2,30

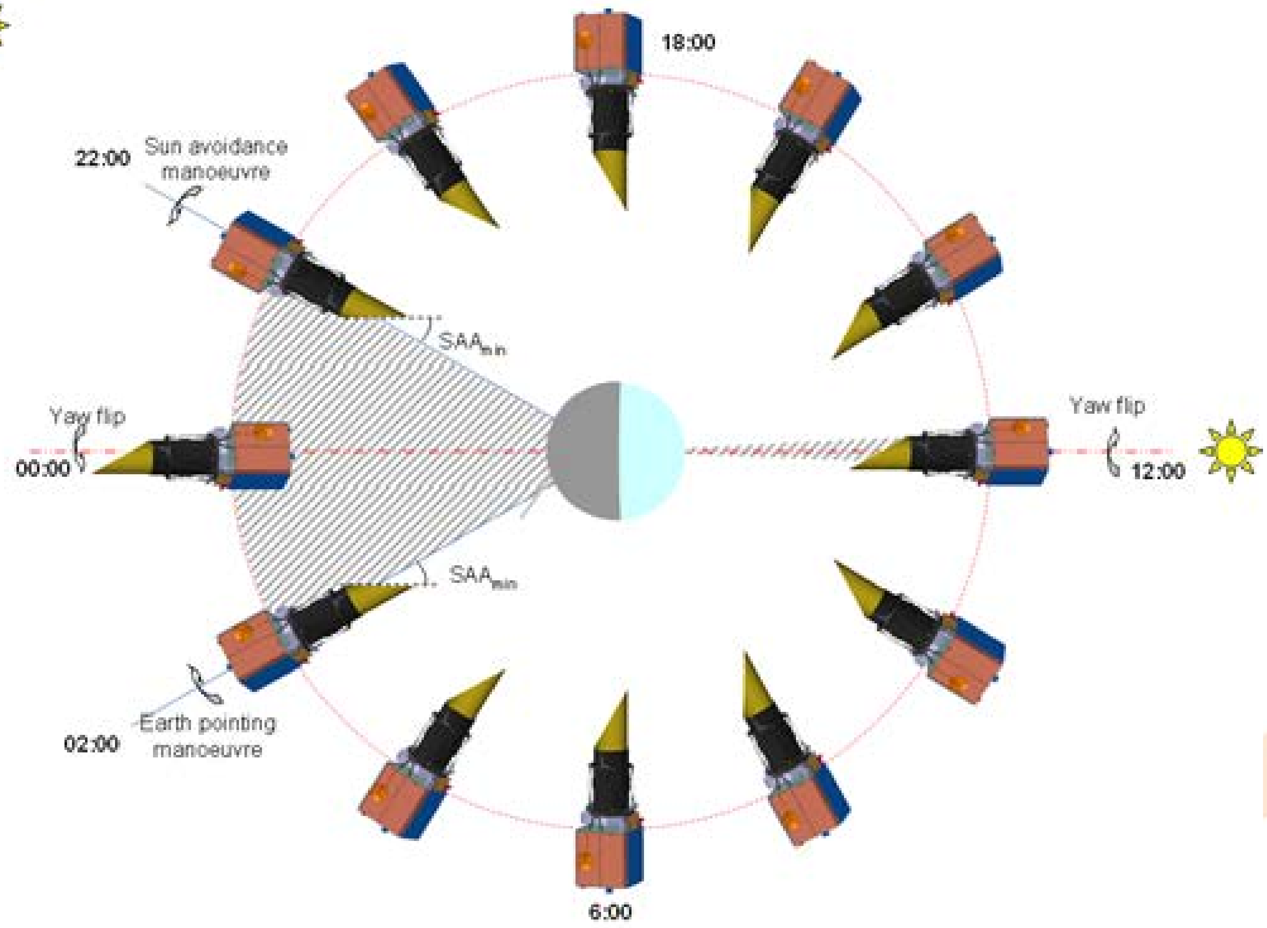
Impact of Sun Aspect Angle

- Need of an additional Sun Shield at 30° (max) +2.78m height



Sun avoidance maneuvers





CONCLUSION GEO INSTRUMENT CONCEPT

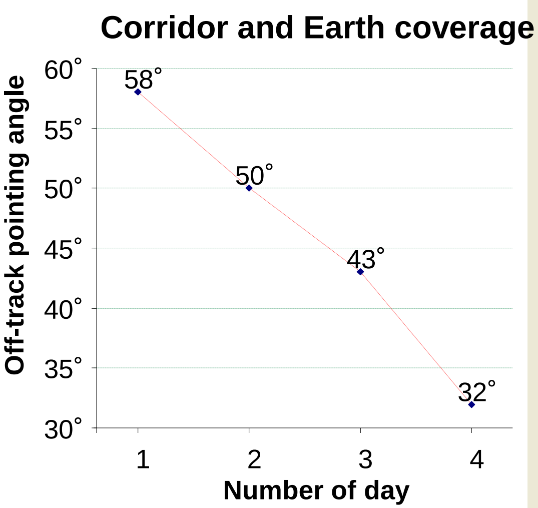
- Use of Geo Oculus instrument with minor Focal Plane modifications
- SNR of 10 :
  - 1000 m resolution, at 10^{-5} W/m²/sr/µm (binning on board)
  - 250 m resolution, at 10^{-4} W/m²/sr/µm (binning on board)
- To meet resolution better than 100m with the same minimum SNR of 10
  - Decrease 3T detector noise by Digital Correlated Double Sampling
  - Consider scenes with flux of 10^{-3} W/m²/sr/µm
  - Consider platform with better pointing stability of 1µrad/Sec
  - On Board Image processing allowing optimizing the binning strategy versus integration time and pointing stability / pointing knowledge to keep resolution below 100m for low flux.
- All these results are provided, assuming **no** straylight at instrument level
  - Dedicated Sunshield,
  - Earth Night images outside 22:00-02:00 time slot. + additional 35 mn avoidance when aiming closer to limb
  - The satellite shall be also rotated by 180° around yaw axis every day
- Combining the limit on the operational availability due to Sun avoidance manoeuvre each night, and rotation of the satellite about yaw axis every day, with the necessity to add a tall sunshield, the GEO orbit can not be considered as a good choice for Earth imaging during nighttime in the visible.

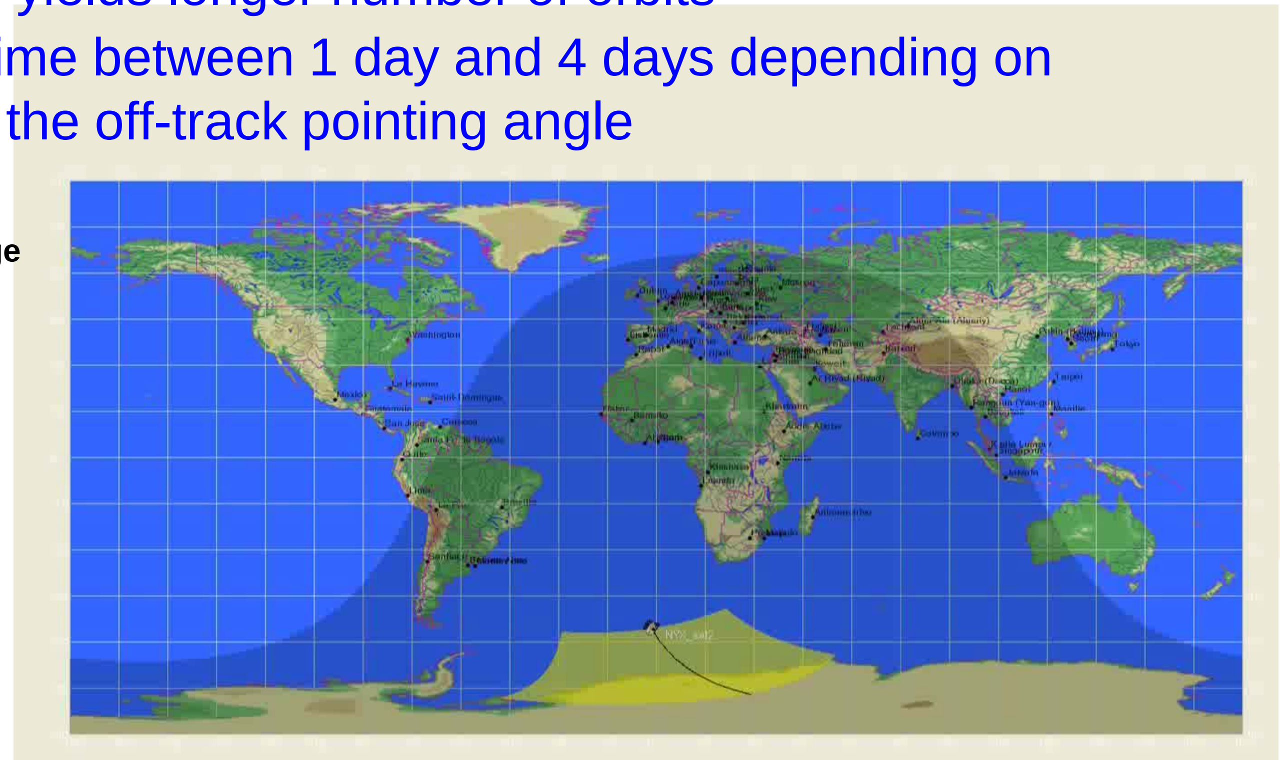
Instrument and mission trade-off cases

1. GEO STEP AND STARE CONCEPT
2. LEO PUSHBROOM CONCEPT
3. LEO STEP AND STARE CONCEPT

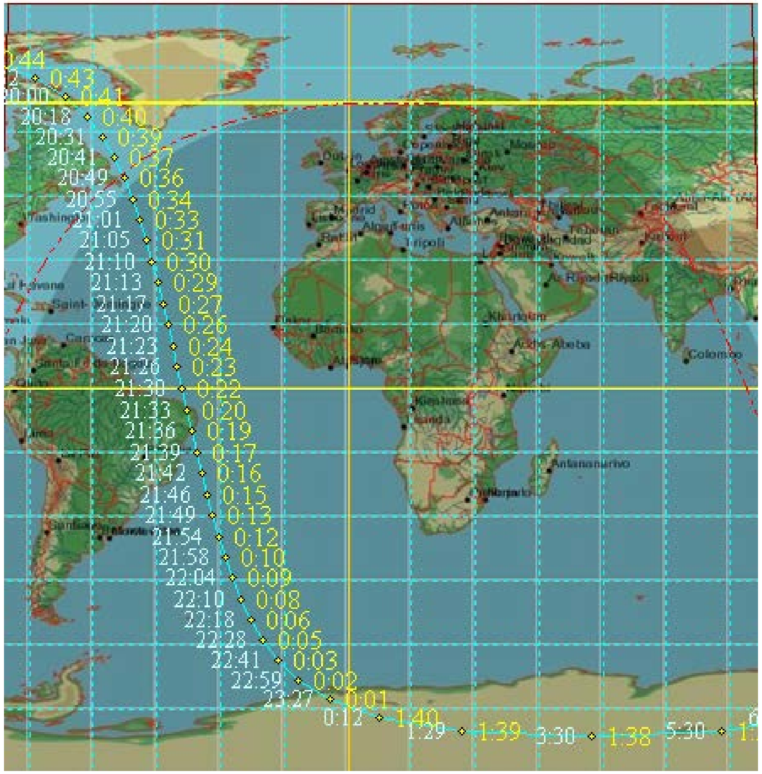
IMPACT OF METOP-SG LEO ORBIT

- Full Earth coverage vs Off-track angle
  - All points of the Earth during night time can be accessed in 1 day with off track pointing angle of ±58°.
  - Smaller angle yields longer number of orbits
  - Mean revisit time between 1 day and 4 days depending on the value of the off-track pointing angle

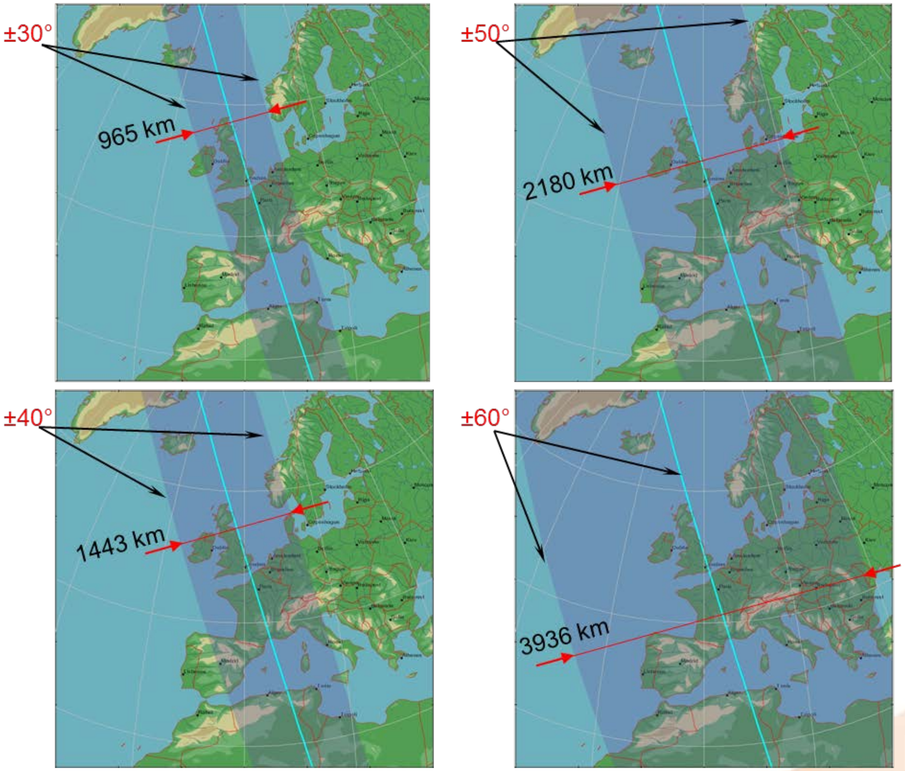




System requirements



orbit and local time



access corridor and off track pointing over Europe

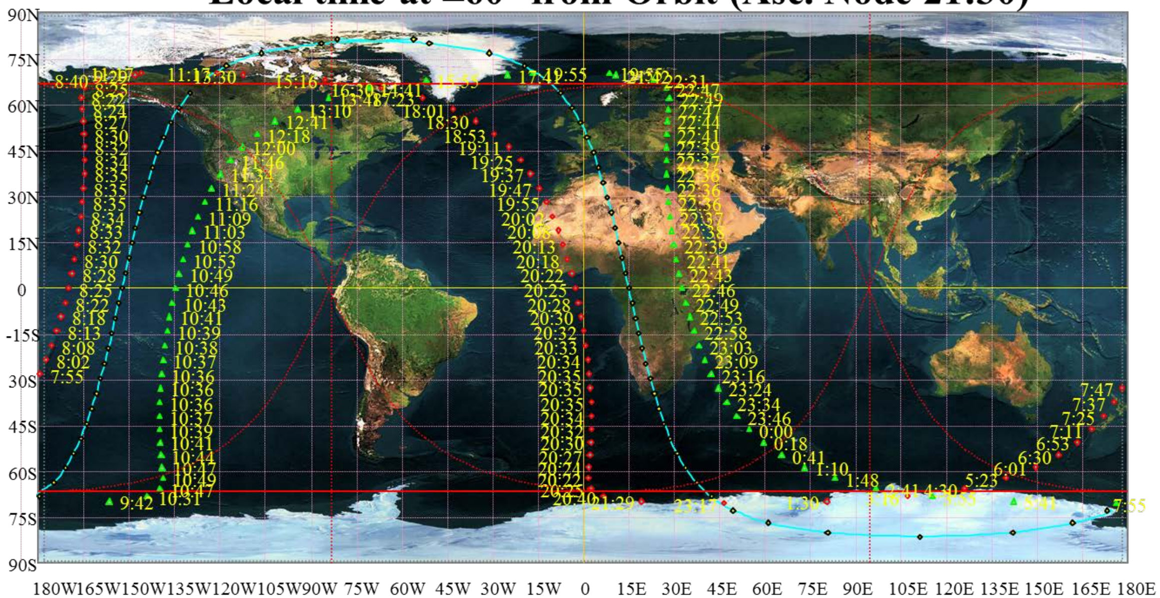
NYX

a Night-time Optical Imaging Mission

GSD, Revisit and off-track angle

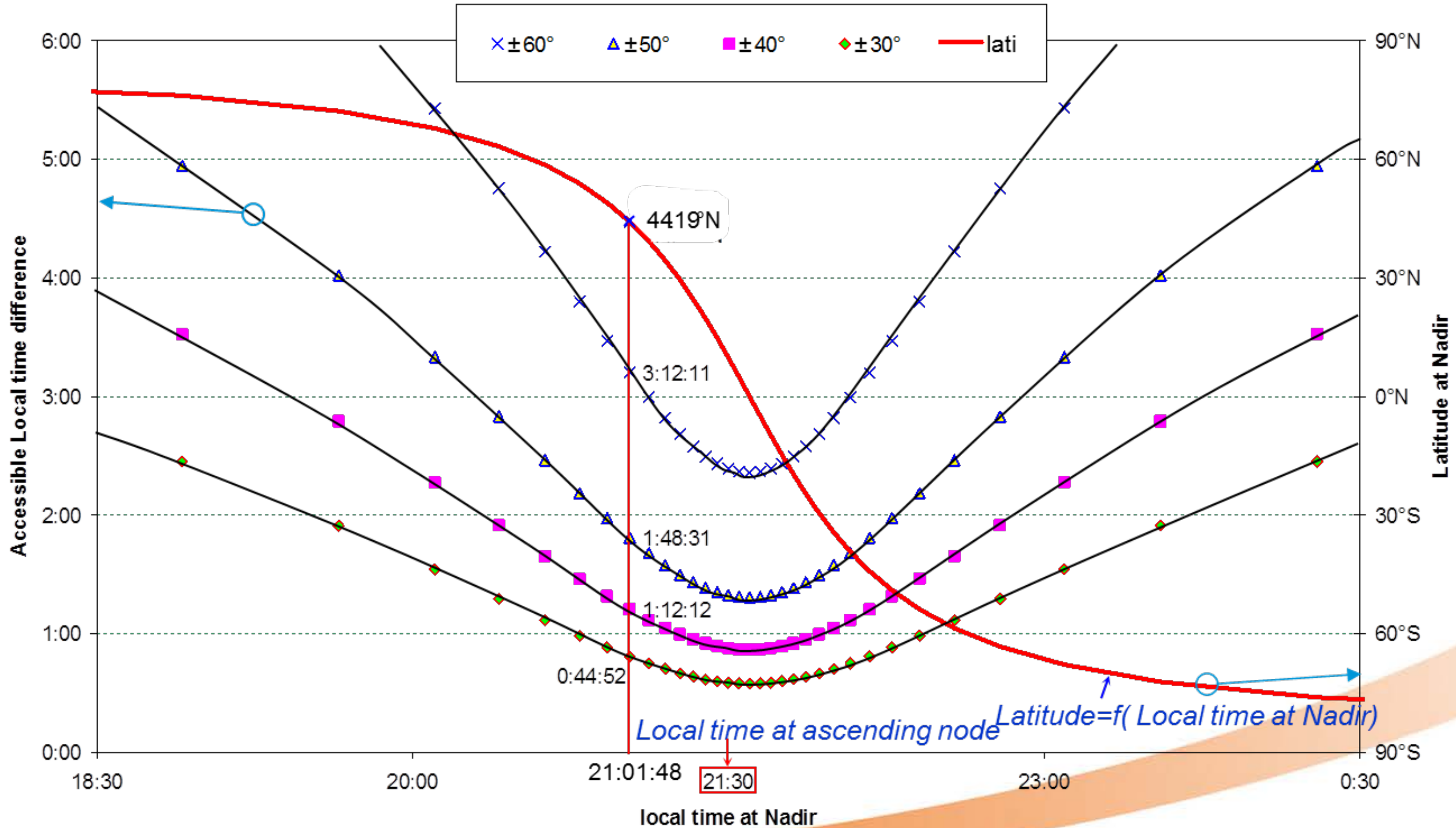
	FOV edge	ACT	ALT	Off Track angle at the edge of the image line			
revisit	incidence	GSD/GSDo	GSD/GSDo	swath 97.5 km	swath 300 km	swath 350 km	Swath 700 km
1 day	67.87°	8.58	2.43	54.82°	47.85°	46.18°	35.30°
2 days	60.63°	5.18	2.03	51.19°	44.22°	42.55°	31.67°
3 days	50.87°	3.12	1.66	45.17°	38.21°	36.54°	25.66°
>3 days	46.63°	**2.00**	1.37	36.70°	29.74°	28.07°	17.19°
4 days	37.29°	1.88	1.34	35.18°	28.21°	26.54°	15.66°
5 days	18.67°	1.21	1.09	19.02°	12.06°	10.38°	0°

Local time at ±60° from Orbit (Asc. Node 21:30)



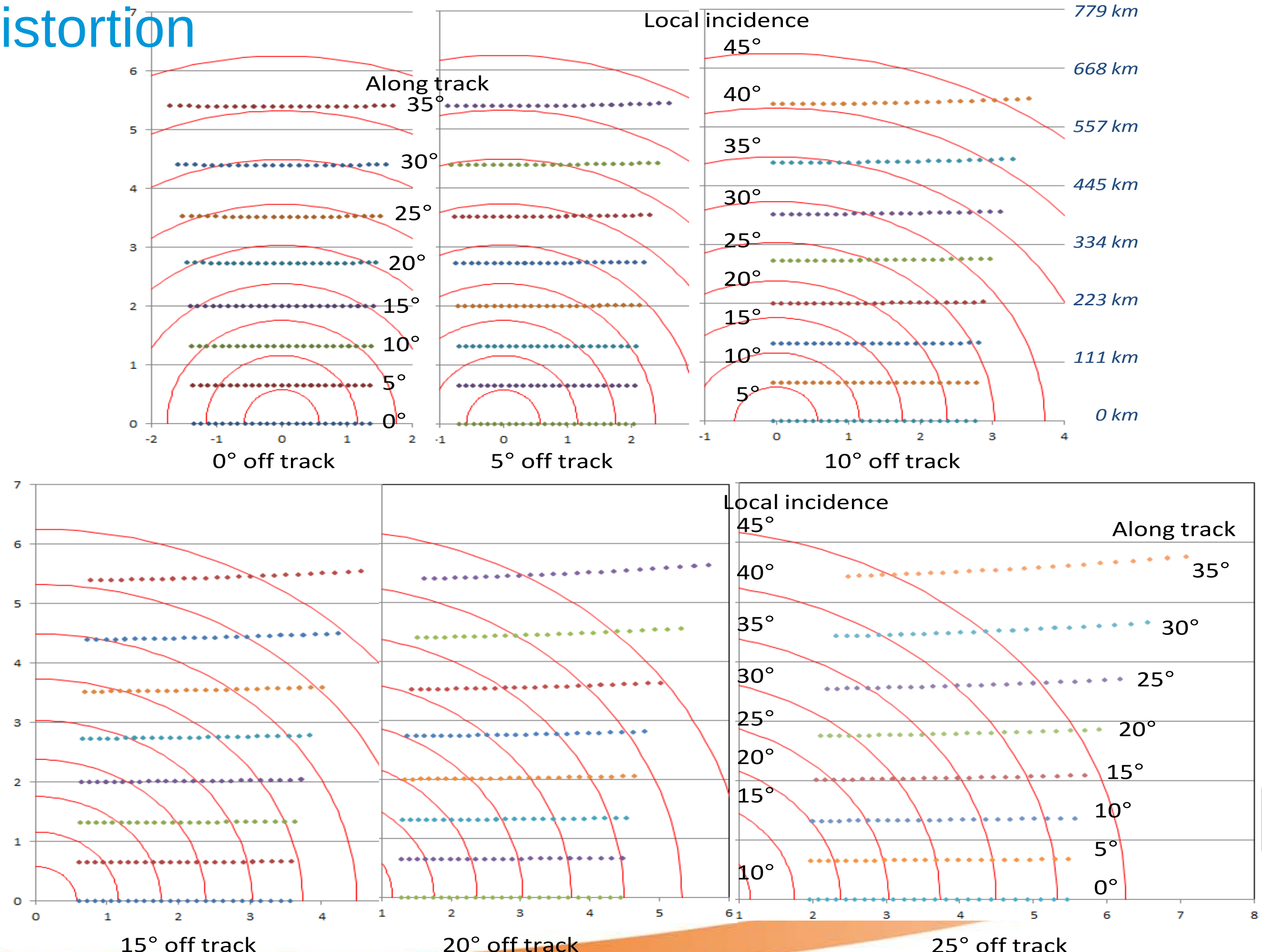
Constraints on observation

- Off-track pointing angle and local time



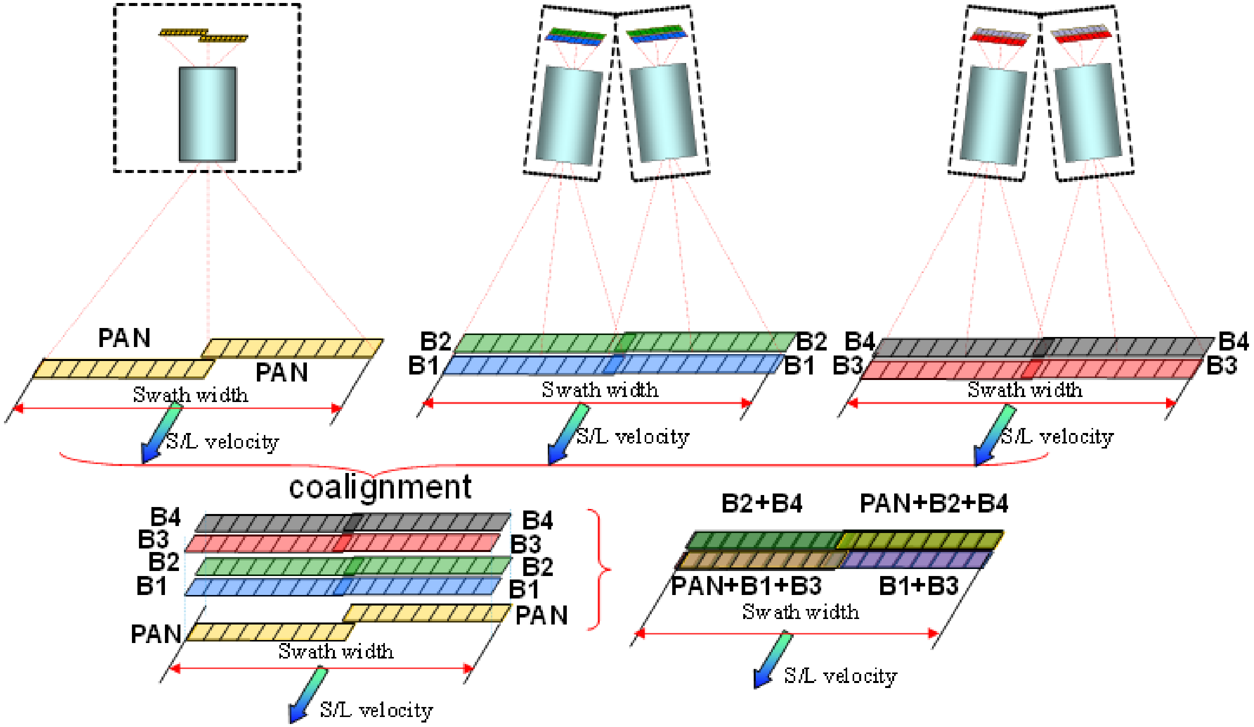
Constraints on observation

- Distortion



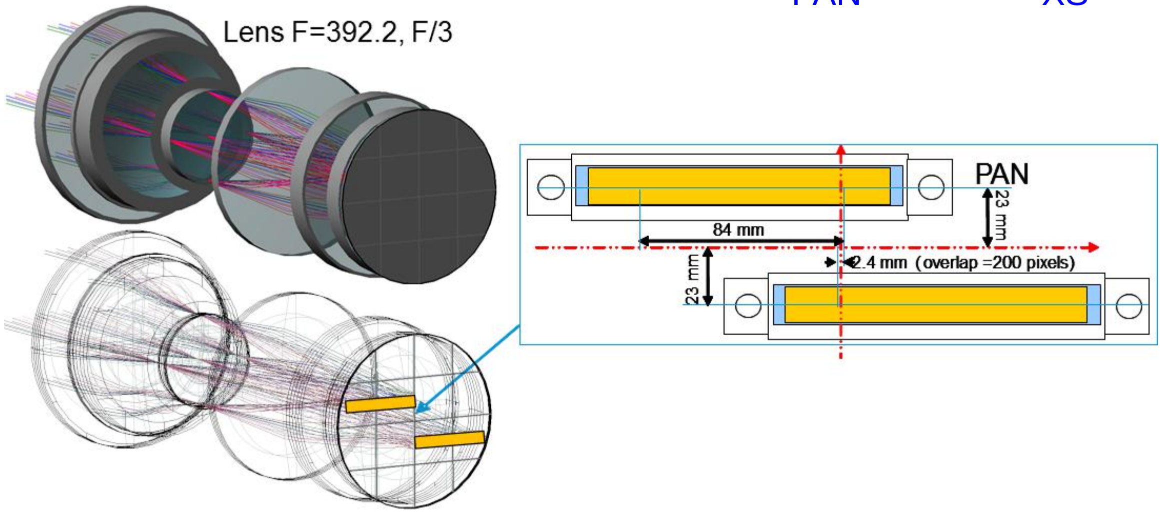
Spatial coverage and Swath size

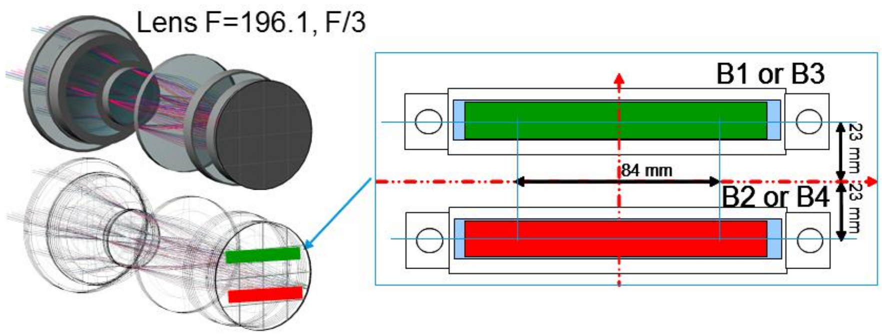
- Configuration with full dynamic on one single detector
  - Swath 300 km
  - GSD 25 m at Nadir, pitch 12 µm in PAN, same optics



Spatial coverage and Swath size

- Configuration with full dynamic on one single detector
  - Swath 300 km
  - GSD 25m PAN and 100m XS; $EFL_{PAN}=2*EFL_{XS}$; XS binning





INITIAL DYNAMIC RANGE

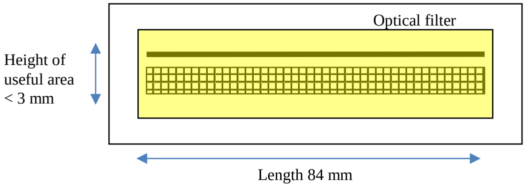
- principle for the acquisition of the full dynamic range (here Rmax/R1 = 10^6) by 3 detectors

Band	PAN	B1	B2	B3	B4
GSD	25 m	50 m	50 m	50 m	50 m
Swath	300 km	300 km	300 km	300 km	300 km
Pupil diameter	197 mm	99 mm	99 mm	99 mm	99 mm
Radiance detection	1E-04 W/m²/sr/µm	1E-04 W/m²/sr/µm	1E-04 W/m²/sr/µm	1E-04 W/m²/sr/µm	1E-04 W/m²/sr/µm
Max radiance	1E+02 W/m²/sr/µm	1E+02 W/m²/sr/µm	1E+02 W/m²/sr/µm	1E+02 W/m²/sr/µm	1E+02 W/m²/sr/µm
Noise limit (allocation)	14 e-	18 e-	20 e-	17 e-	15 e-
NTDI sized by SNR(R1)	19	63	89	47	24
Radiometric section number required with SNR for overlap of 20	3	3	3	3	3
Lmax section 1	9E-02 W/m²/sr/µm	8E-02 W/m²/sr/µm	8E-02 W/m²/sr/µm	9E-02 W/m²/sr/µm	1E-01 W/m²/sr/µm
Lmax section 2	1E+01 W/m²/sr/µm	1E+01 W/m²/sr/µm	1E+01 W/m²/sr/µm	1E+01 W/m²/sr/µm	1E+01 W/m²/sr/µm
Readout frequency section 1	403 kHz	403 kHz	403 kHz	403 kHz	403 kHz
Readout frequency section 2	1613 kHz	807 kHz	807 kHz	807 kHz	807 kHz
Readout frequency section 3	1613 kHz	807 kHz	807 kHz	807 kHz	807 kHz
Number of detector	2	1	1	1	1
Number of video output per detector	6	4	4	4	4
Pixel per line per detector	6000	6000	6000	6000	6000
Pixel pitch	12,0 µm	12,0 µm	12,0 µm	12,0 µm	12,0 µm
binning	No	No	No	No	No

- Performance where fulfilled only with very fast optics at F/2
- Proposition to change the minimum and maximum Radiance

Radiometic performance

- With reduced radiometric range

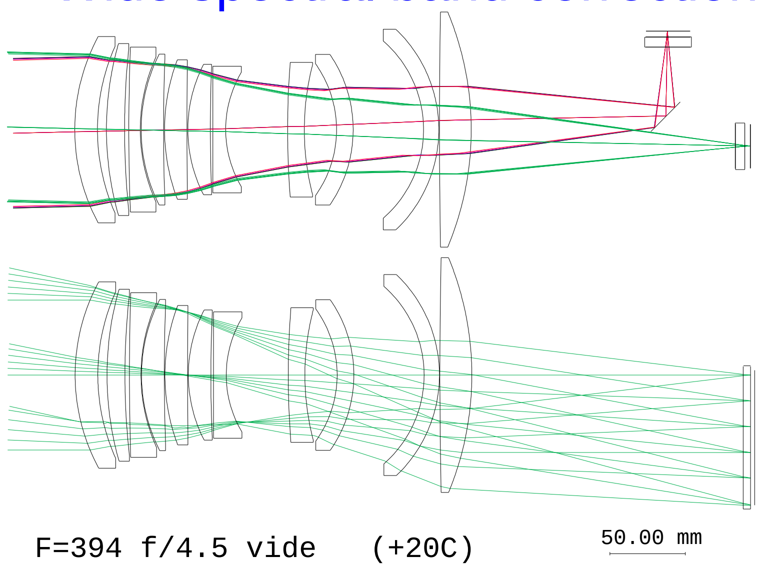


Band	PAN	B1	B2	B3	B4
GSD	25 m	100 m	100 m	100 m	100 m
Swath	300 km	300 km	300 km	300 km	300 km
Pupil diameter	88 mm	44 mm	44 mm	44 mm	44 mm
F-Number	F/4.50	F/4.50	F/4.50	F/4.50	F/4.50
Radiance detection	0.0005 W/m²/sr/µm	0.0005 W/m²/sr/µm	0.0005 W/m²/sr/µm	0.0005 W/m²/sr/µm	0.0005 W/m²/sr/µm
Max radiance	20 W/m²/sr/µm	20 W/m²/sr/µm	20 W/m²/sr/µm	20 W/m²/sr/µm	20 W/m²/sr/µm
Noise limit (allocation)	14 e-	13 e-	15 e-	12 e-	10 e-
NTDI sized by SNR(R1)	19	13	19	10	5
Radiometric section number required with SNR for overlap of 20	2	2	2	2	2
Rmax section 1	0.453 W/m²/sr/µm	0.528 W/m²/sr/µm	0.481 W/m²/sr/µm	0.556 W/m²/sr/µm	0.618 W/m²/sr/µm
Rmax section 2	66.9 W/m²/sr/µm	78.0 W/m²/sr/µm	70.9 W/m²/sr/µm	82.0 W/m²/sr/µm	91.2 W/m²/sr/µm
Readout frequency section 1	403 kHz	50 kHz	50 kHz	50 kHz	50 kHz
Readout frequency section 2	1613 kHz	101 kHz	101 kHz	101 kHz	101 kHz
Readout frequency section 3	1613 kHz	101 kHz	101 kHz	101 kHz	101 kHz
Number of detector	2	1	1	1	1
Number of video output per detector	6	6	6	6	6
Pixel per line per detector	6000	6000	6000	6000	6000
Pixel pitch	12.0 µm	12.0 µm	12.0 µm	12.0 µm	12.0 µm
binning	No	Yes	Yes	Yes	Yes
N bining	1	2	2	2	2
Operating temperature	-30 °C	-30 °C	-30 °C	-30 °C	-30 °C
Tint	3.79E-03 s	1.52E-02 s	1.52E-02 s	1.52E-02 s	1.52E-02 s
Qsat	200	200	200	200	200

two detectors sharing the focal plane.

Optimized optical lens F/4.5

- Preliminary design
  - Athermal optical design is possible thanks to the two front surfaces made of Schott SF11 (similar design on HRS and THEOS TOP-MS)
  - Wide spectral band correction



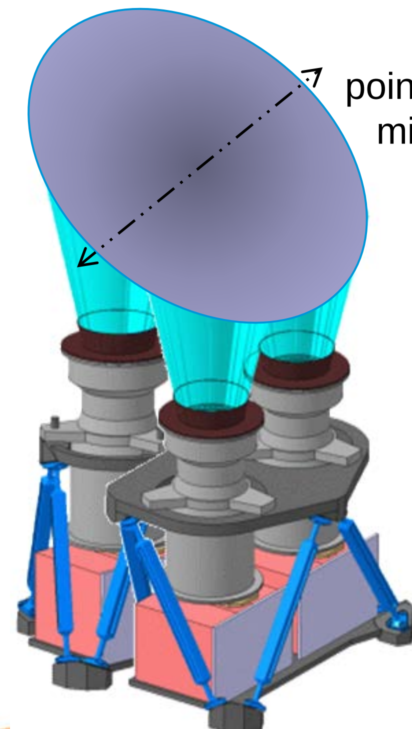


Figure 3.2-2: Dioptirc lens at F/4.5 with two detectors (left) /
Lens arrangement without the scan/steering mirror, mechanism and structure.(right)

Preliminary Mass budget

- Change in radiance limits made the mass lower, but still far above the requirment of 40 kg !

Mass budget / Pushbroom		
Lens Number	3	5
Lens glasses	10.0	25.0
lens barrels and housing	6.2	15.6
Structure	22.2	55.6
Detector and proximity electronic	5.0	8.3
Thermal H/W	4.8	11.9
Harness	3.0	5.0
ICU	18.8	32.5
Scan mirror	4.5	9.0
mechanism	5.0	10.0
control unit	13.5	22.5
Calibration	2	3.5
total omu	62.7 kg	144.0 kg
total icu	32.3 kg	55.0 kg
grand total	93.0 kg	195.5 kg
mass+contingencies	102.4 kg	215.0 kg

Main results of NYX study at end of phase 2

- Pushbroom concept
  - The pushbroom configuration faces a lot of challenges:
    - a large swath > 20°
    - a low radiance level → large pupil diameter (0,2 m) and high F/N (2)
    - a large dynamic range and five spectral bands

      → either five bands per detector and dynamic segmentation ensured by separated detectors

      → either one detector per band and dynamic segmentation inside each detector

      → need for 3 or 5 lenses
  - Main conclusion :
    - The pushbroom configurations yields to design solutions which are out of specification in term of mass and power

➢ A new concept is proposed with a **step and stare** imagery

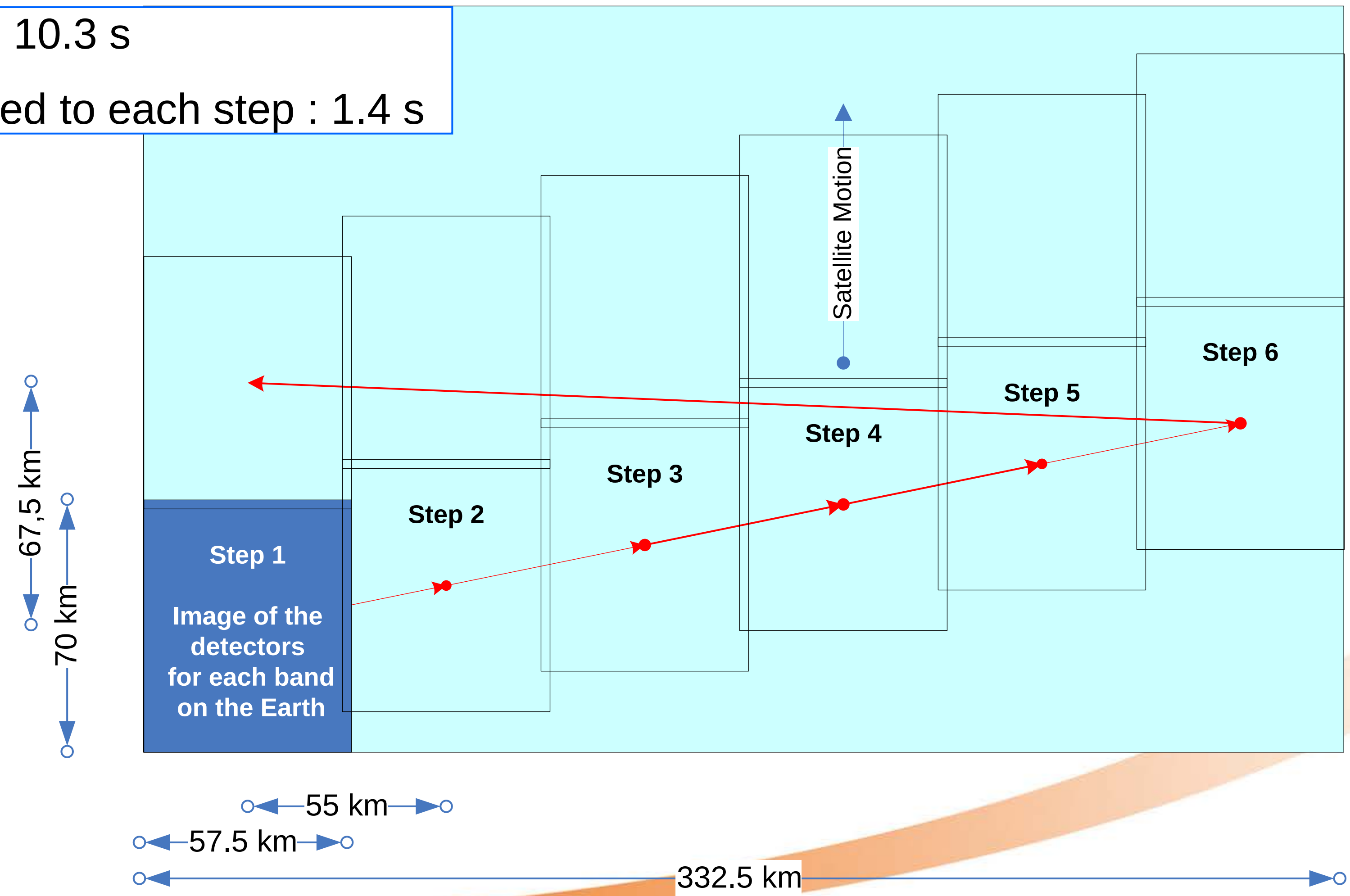
Instrument and mission trade-off cases

1. GEO STEP AND STARE CONCEPT
2. LEO PUSHBROOM CONCEPT
3. LEO STEP AND STARE CONCEPT

LEO Step and Stare concept

Scan cycle : 10.3 s

Time allocated to each step : 1.4 s



NYX Instrument Final Presentation

4. The Step & Stare Instrument : recommended baseline

All the space you need

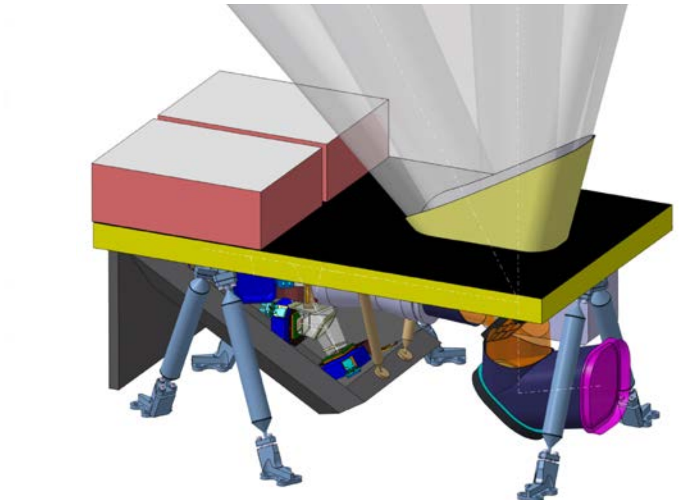
Mission Requirements

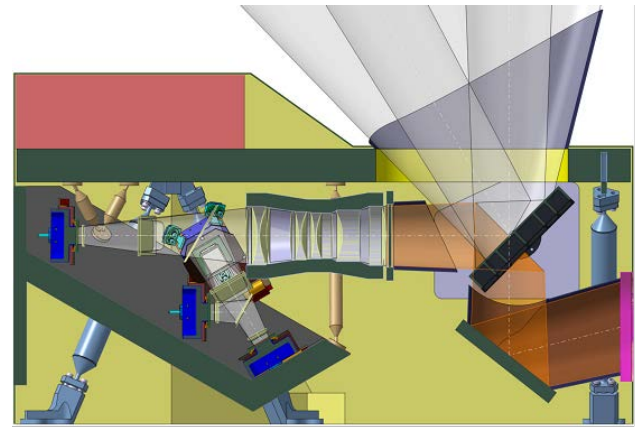
Orbit type	Sun synchronous				
altitude	835 km				
LAN	21h30 +/- 15 mn				
Spectral Bands	PAN	VIS 1	VIS 2	VIS 3	NIR
lambda min (µm)	0.4	0.4	0.5	0.56	0.8
lambda max (µm)	0.9	0.5	0.6	0.61	0.9
GSD Nadir- Baseline	25 m	100 m	100 m	100 m	100 m
GSD Nadir - Option	25 m	50 m	50 m	50 m	50 m
Swath width @ Nadir	≥ 300 km				
R1 radiance	5.10^{-4} $W.m^{-2}.sr^{-1}µm^{-1}$				
SNR @ R1	≥ 10				
R min radiance	5.10^{-5} $W.m^{-2}.sr^{-1}µm^{-1}$				
SNR @ Rmin	≥ 3				
Rmax	20 $W.m^{-2}.sr^{-1}µm^{-1}$				

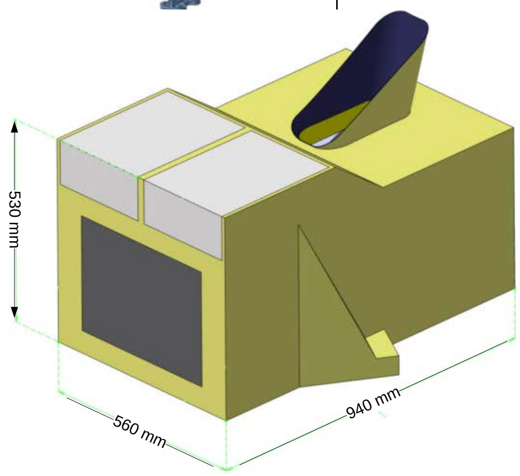
Step & Stare instrument main characteristics

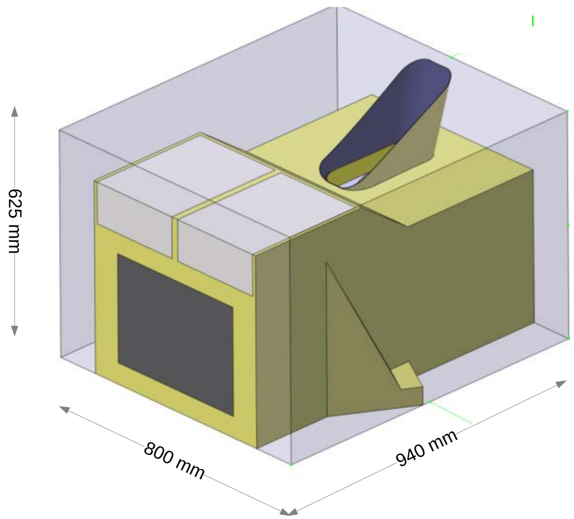
Mission Characteristics		
Spectral bands	PAN	MS
GSD (m)	25	50 or 100
Swath width @ Nadir (km)	332.5	332.5
Scanning Characteristics		
Scan cycle	10.269 s	
Number of steps ACT	6	
Time allocated to each step	1.445 s	
Optical Assembly		
Focal length	334 mm	
Pupil diameter	90 mm	F/D = 3.71
Field of view	3.9 x 4.8°	
Focal Plane Assembly		
5 Detectors : CMOS Matrix @ 220 K	2800 pixels ALT	2300 pixels ACT
Pixel pitch	10 µm ACT	10 µm ACT
3 different exposure times inside each step.	150 ms , 10 ms, 0.1 ms	
Budgets		
Volume	Overall dimensions : 625 x 800 x 940 mm^3 Wo local appendices : 530 x 560 x 940 mm^3	
Mass	60 kg	
Power	90 W	

A compact instrument



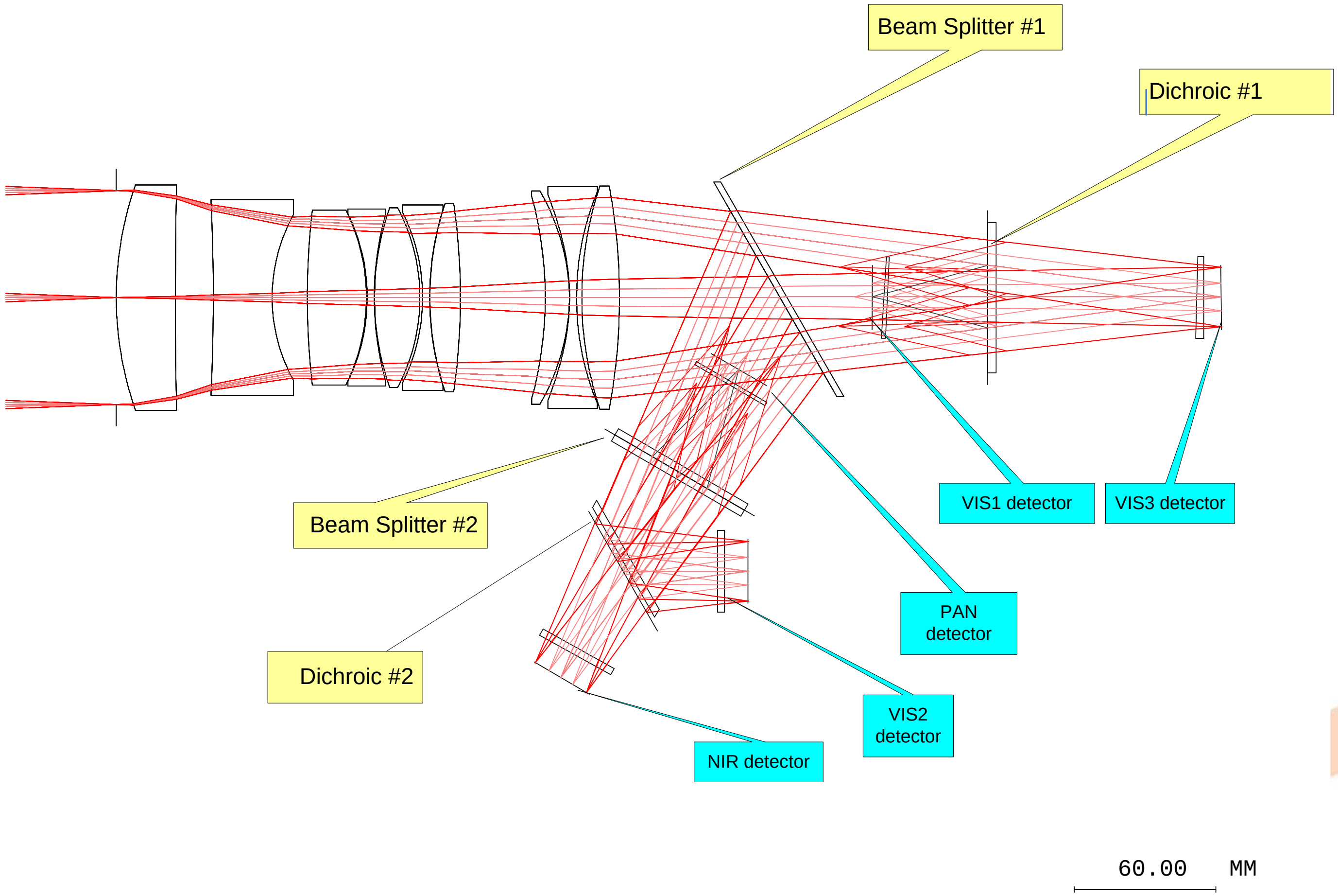




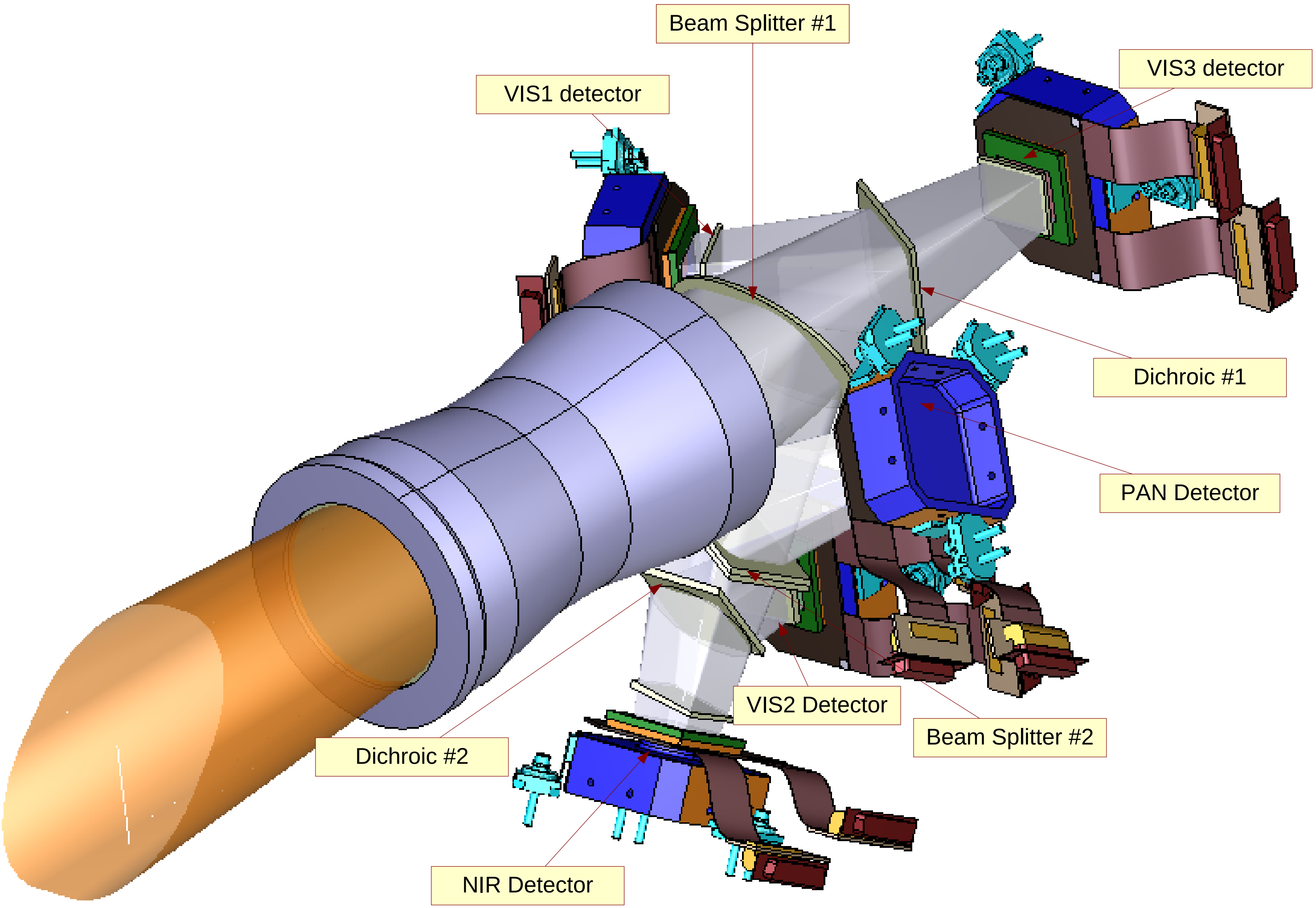


a Night-time Optical Imaging Mission

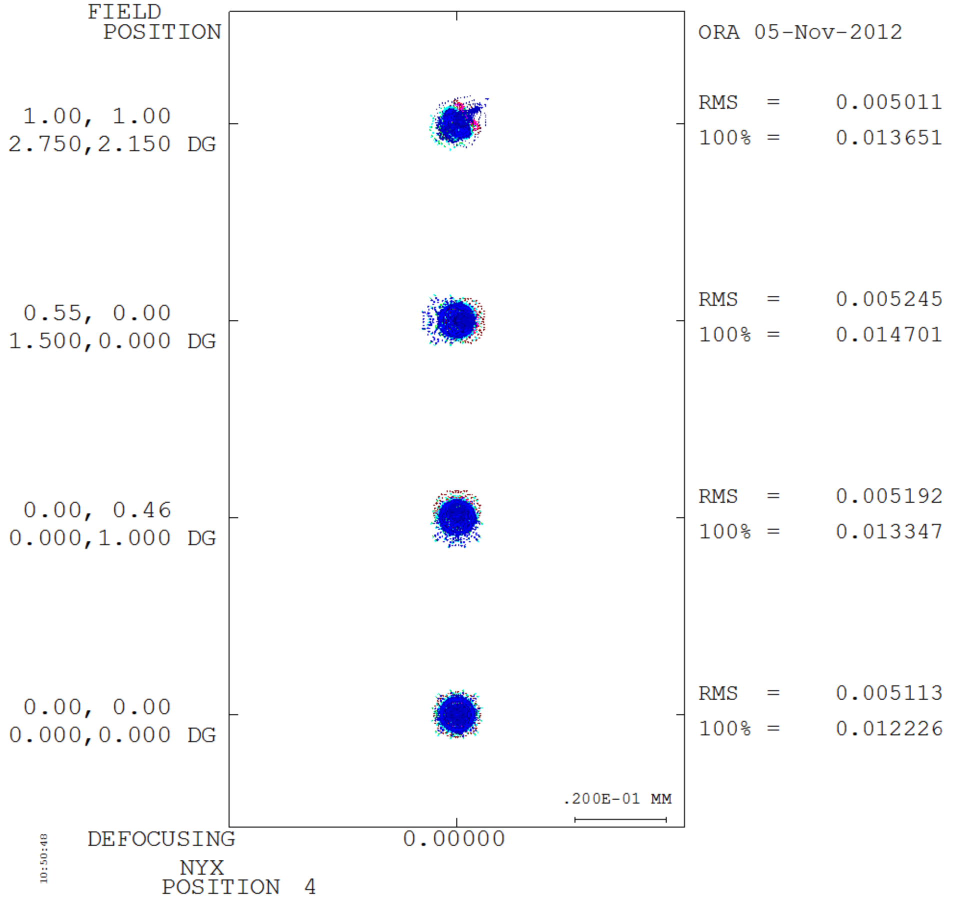
Optical Architecture : One refractive telescope accommodating the five spectral bands



Spectral bands are separated with two beam splitters and two dichroics



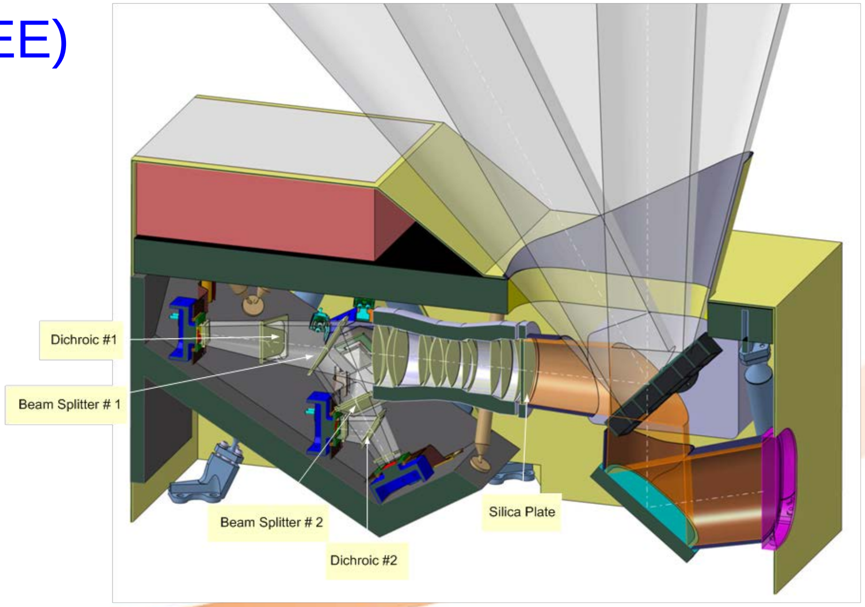
The optical design has been optimized for all spectral bands



PAN channel

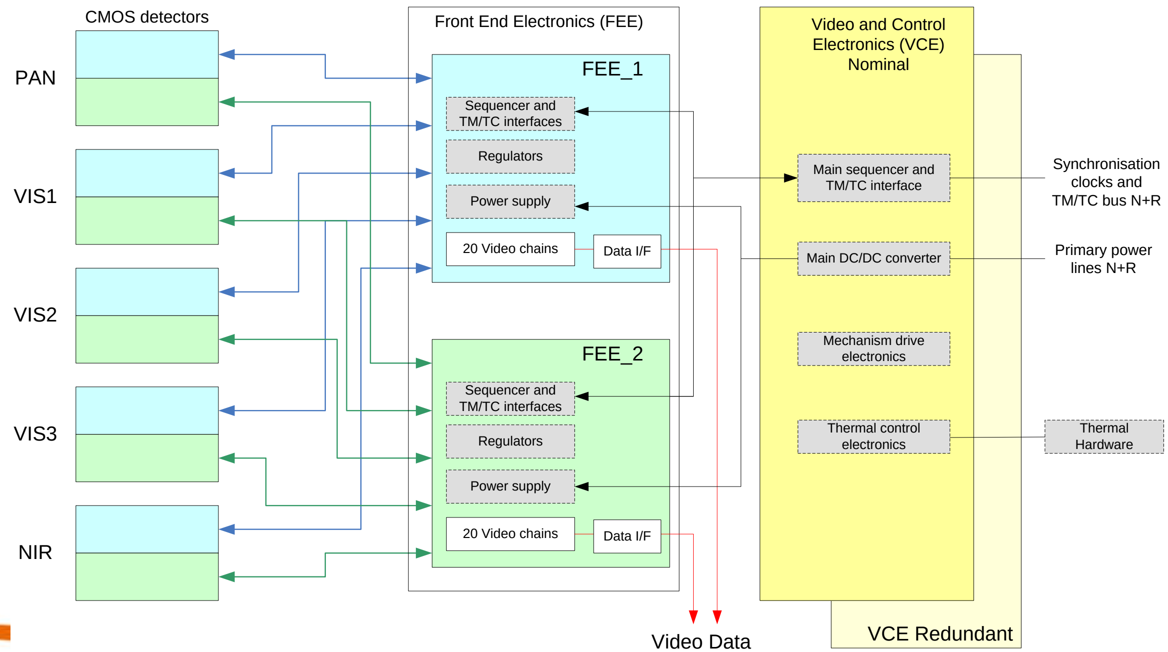
NYX instrument consists of two main sub-assemblies

- The imager assembly including :
  - the two-axis scan assembly
  - the lenses
  - the focal plane = the optics (beam splitters, dichroics, filters) and the five detectors
  - the two front-end electronics (FEE)
- The main electronics (VCE)
  - main sequencer
  - TM TC interface
  - main DC/DC converter
  - mechanism drive electronics
  - thermal control



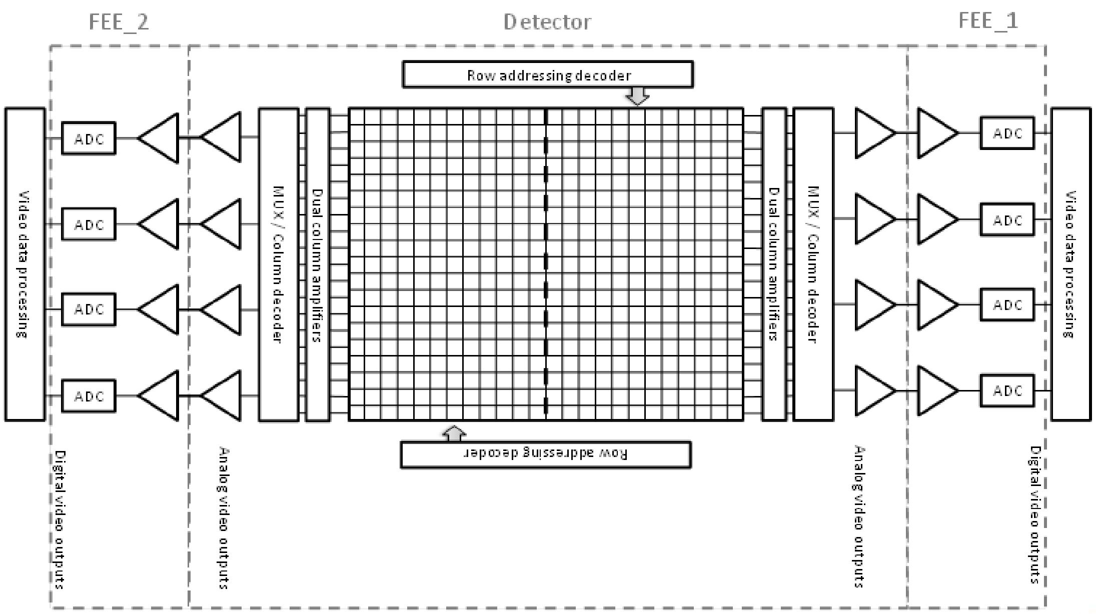
NYX detection chain overview (1/2)

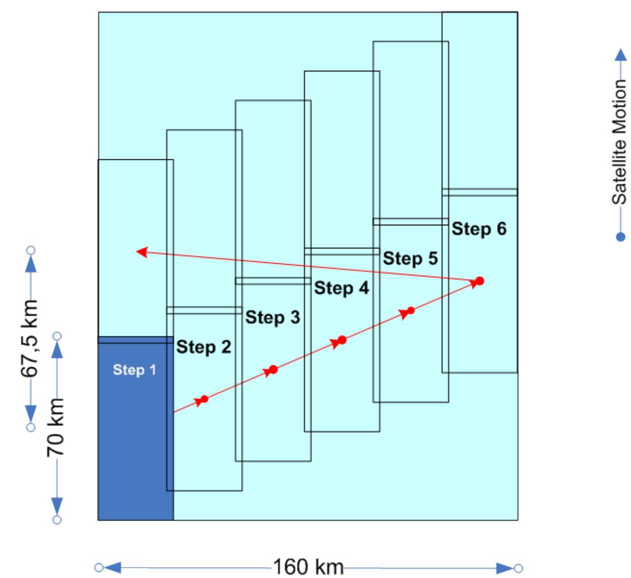
- The NYX detection chain: 5 CMOS matrices, 2 identical and interchangeable FEEs and 1 VCE (cold redunded)
- Each CMOS matrix addresses a dedicated spectral band
- FEE functions: pre-amplification and digitization of the signal
- VCE functions: main sequencer, TM/TC interfaces, DC/DC converters, thermal control and mechanism drive electronics



NYX detection chain overview (2/2)

- Reliable detection chain design: a single failure does not result in the loss of a complete spectral band (half of the nominal swath)
  - CMOS detector: 2 ROICs addressing each half of the pixels matrix
  - Each FEE interfaces with half of each CMOS detector
  - The VCE is cold redunded



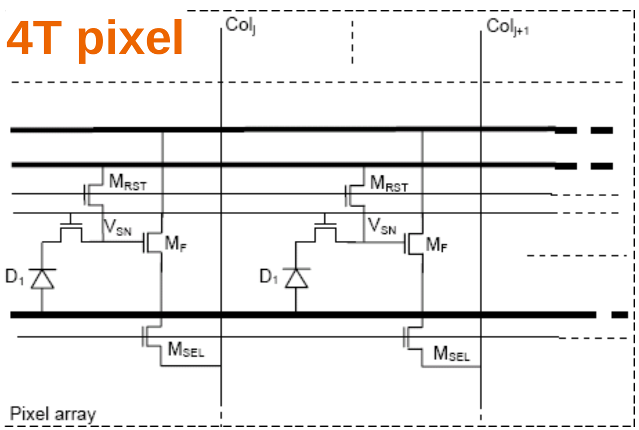


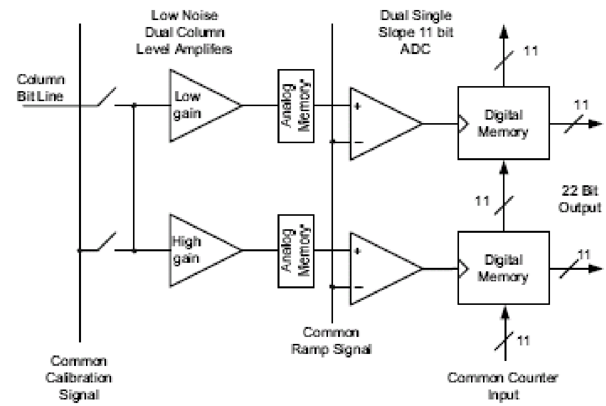
Half swath at Nadir in degraded mode

NYX CMOS detector technology (1/2)

- Challenging SNR requirement at Rmin calls for QE maximisation and very low noise pixel technology
  - ➔ Optimized epi layer and substrate resistivity + BIL
  - ➔ Low noise 4T (pinned photodiode) pixel technology
- Wide radiance dynamic: gain adaptation required not to saturate the pixels
  - ➔ Dual column level amplifiers

4T pixel



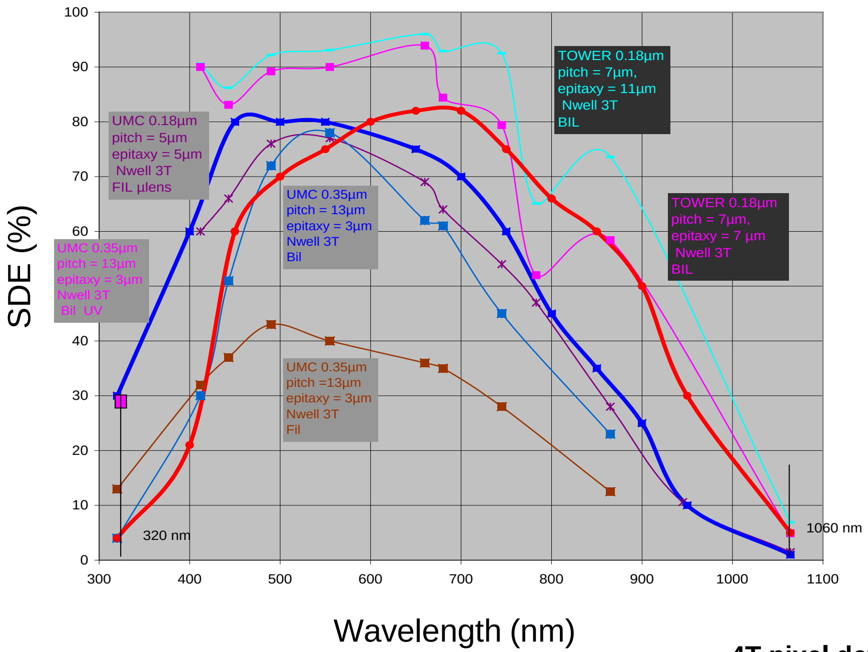


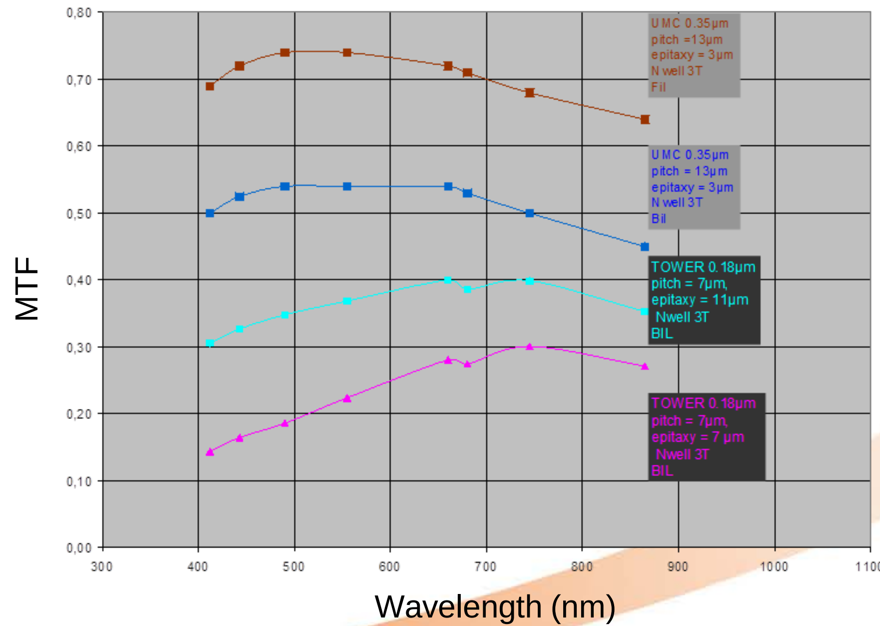
Wide Dynamic Range Low Light Level CMOS Image Sensor

Boyd Fowler, Chiao Liu, Steve Mims, Janusz Balicki, Wang Li, Hung Do, and Paul Vu

NYX CMOS detector technology (2/2)

- Astrium has experience on
  - Fine tuned CIS process for QE maximisation
  - 4T pixel technology
  - Readout circuit with column amplification

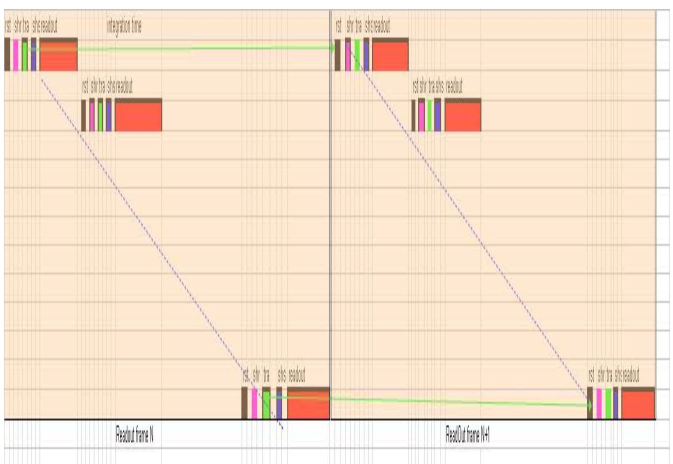




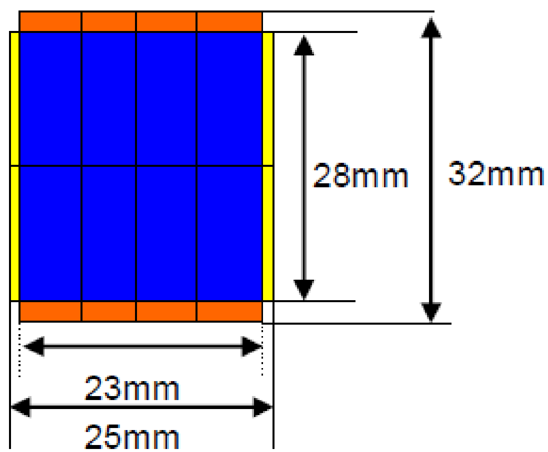
4T pixel detector characteristics

NYX CMOS detector design

CIS technology	CIS 0.18 µm with 10 µm epi and high resistive substrate, operated in BIL
Detector size	28 x 32 mm²
Pixels array size	23 x 28 mm²
Pixel pitch	10 µm
Pixel architecture	Low noise 4T pixel
Binning	Pixel binning (4x4 binning factor) to meet the GSD_XS of 100 m
Readout circuit	Dual column amplifiers with fixed gain (low/high radiance) 2 independent readout circuits each addressing half of the CMOS matrix
Operating mode	Rolling shutter mode



Rolling shutter mode



NYX CMOS matrix

COMS/GOCI CMOS detector with 2 readout circuits and flex

NYX CMOS detector operating conditions

- Detector Operating temperature: 220 K
- 4x2 outputs / detector operated at 5 Mpix/s (Tframe = 175 ms)
- 3 images with decreasing integration times to cover the full dynamic without saturation: 150 ms, 10 ms, 0.1 ms.
- Total sequence duration for 3 images (~685 msec) well within the allocated time per ACT step (1,245 sec). The remaining time can be used for:
  - Increasing the horizontal swath (additional ACT steps)
  - Improving the image quality at Rmin (additional image)
  - Improving margins allocation:
    - Better LOS stability at platform and/or mechanism level
    - Improved XS GSD (50m)
    - Relaxing some design parameters (e.g. stabilization time)

NYX CMOS detection chain sizing

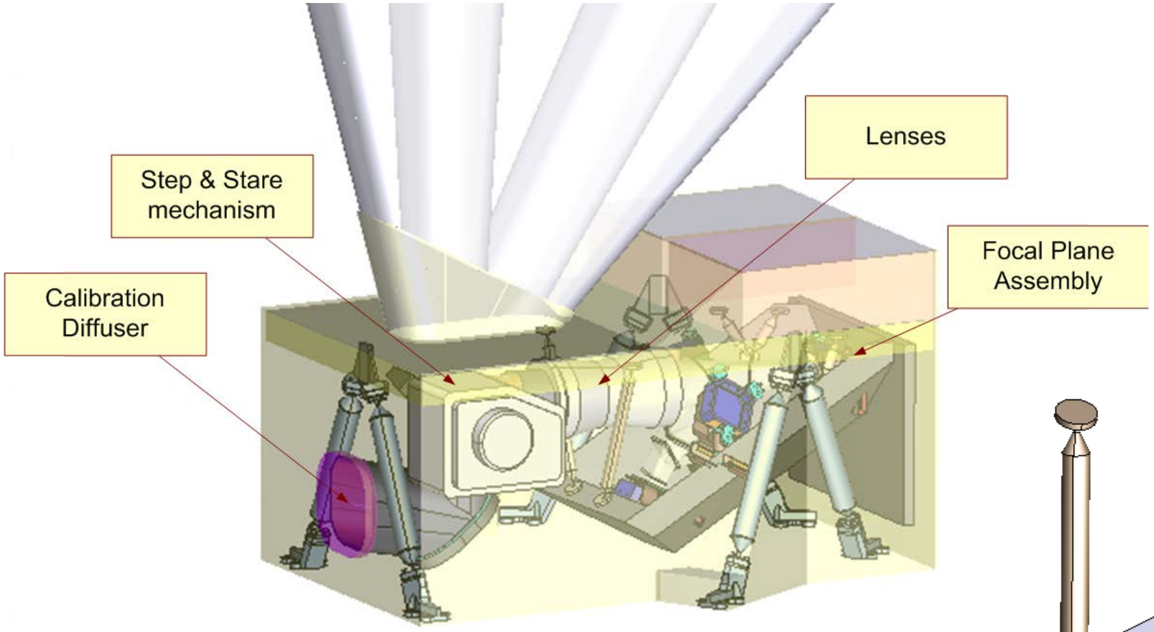
- Very low detection chain noise required to meet SNR of 3 at Rmin
- Detector on-chip column amplification simplifies the video chain sizing
- Column amplifier gain set to 8 for image @ Rmin and 0.8 for others
- Detection chain figures based on GMES Sentinel-2 MSI VNIR detection chain:
  - FEE amplification noise: 150 µV rms
  - FEE gain: 2.8
  - 14 bits ADC (e.g. 9240LP from Maxwell Technologies)
- Noise margin added (200 µV rms at ADC input)

Mechanical and thermal architecture

The opto-mechanical concept relies on :

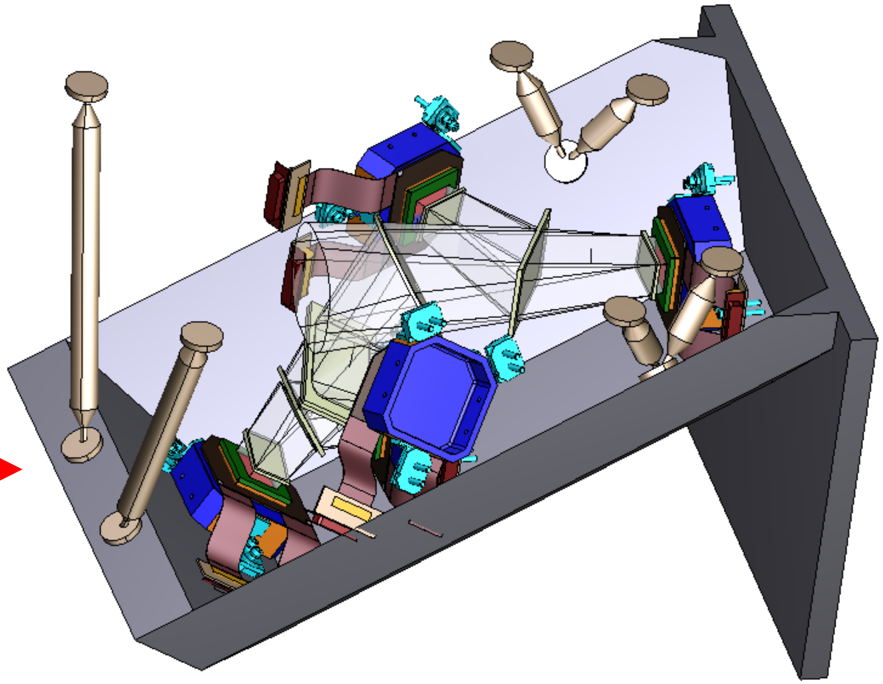
- A main structure including iso-static fixations
- An entrance baffle
- A step and stare mechanism assembly.
- A refractive telescope of 90 mm diameter
- A cold temperature focal plane assemby (Image sensors and associated optics) and its radiator
- The two Front End Electronics (FEE)
- The calibration assembly consists of a folding mirror and a calibration window which are fixed on the main structure.

Mechanical and thermal architecture



The focal plane optical bench (SiC)

is derived from MSI Sentinel 2 concept



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NYX

a Night-time Optical Imaging Mission

A two-axis step and stare mechanism

- The NYX step and stare mechanism is based on the mechanism studied in the frame of IASI NG instrument and benefits from MTG scan mechanism breadboarding activities (SVC/ALT design & performance aspects).

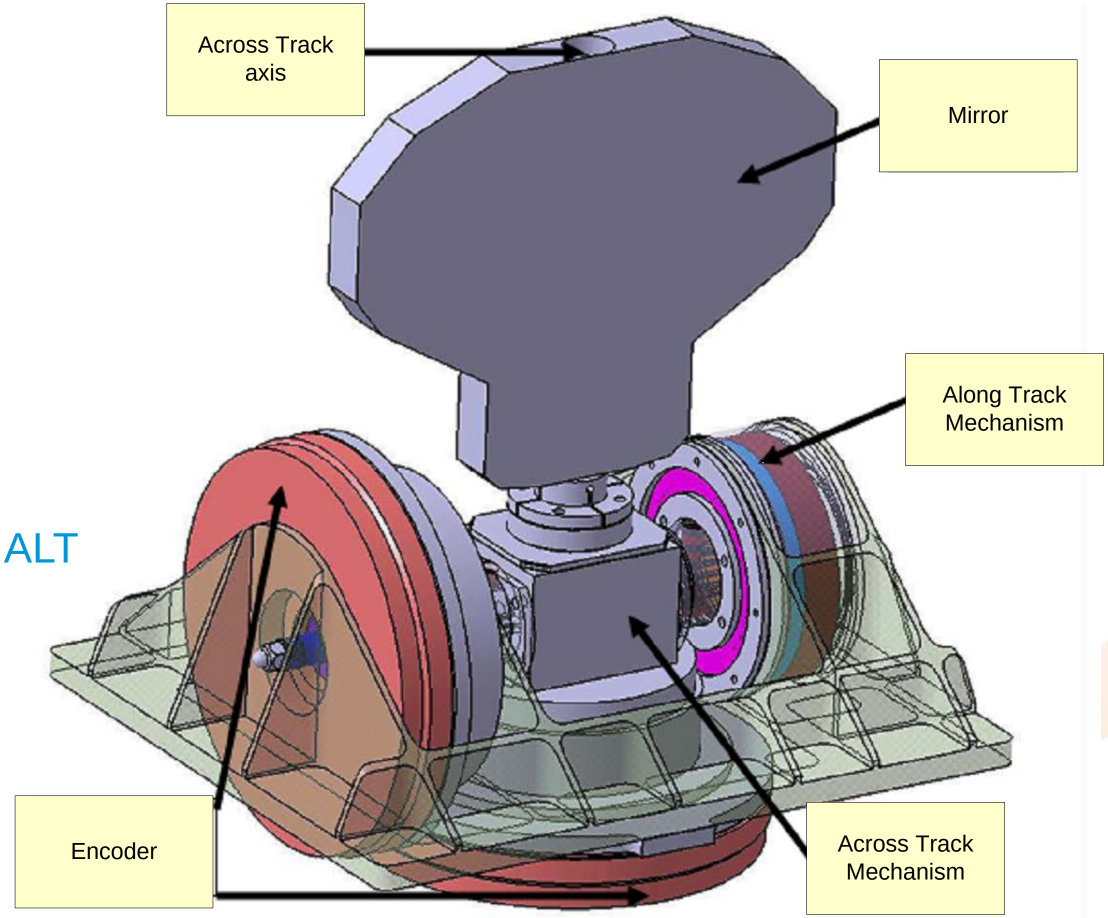
	ALT Satellite Velocity Compensation	ACT Scanning
Guidance	Flexural pivots	Ball bearings
Motor	LAT (Limited Angle Torquer)	DC brushless torque motor
Optical Encoder	Codechamp 24 bits	Codechamp 24 bits
Pointing accuracy	+/- 200 µrad (*)	+/- 200 µrad
Pointing stability	**ΔLOS < 3,2 µrad @ 1 σ (*)**	**ΔLOS < 3 µrad @ 1 σ (**)**
	Compatible with a 20 µrad ΔLOS PtP allocation on each axis	
Range Angle (at mechanism level)	+/- 0,2 °	> 90 ° ('infinite' by principle)

(*) Demonstrated on MTG BB
MTG scan mechanism predevelopment : design & performance. J Vinals, T Blais and Al.
14th European Space Mechanisms & Tribology Symposium - ESMATS 2011 Constance, Germany 28-30 Sept 2011
(**) Stabilization time : 0,3 s.

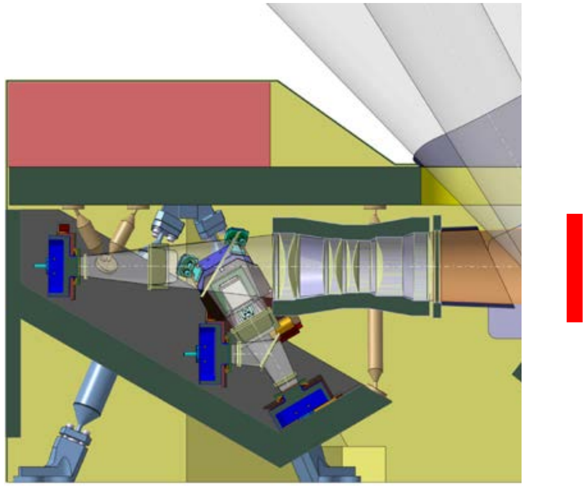
The scan mechanism assembly benefits from Astrium heritage on several missions

It includes:

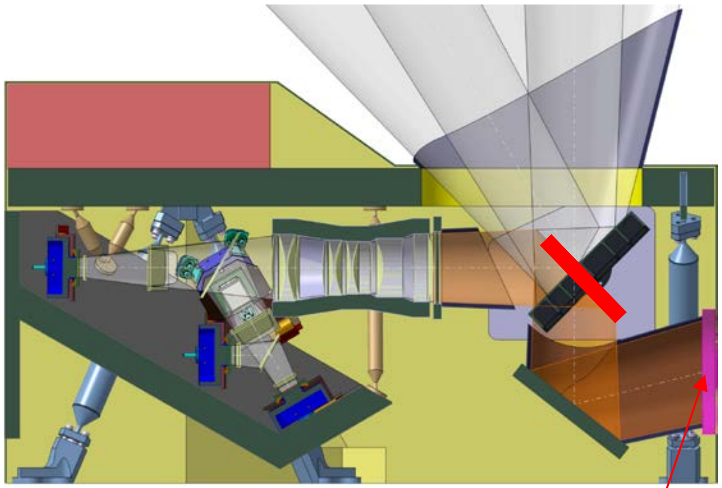
- a SiC mirror
- ball bearings ACT
- flexural pivots ALT
- 2 motors
    - LAT ACT
    - DC Brushless torque motor ALT
- 2 optical encoders (ACT & ALT)



Sun Calibration is performed with a diffuser illuminated by the Sun



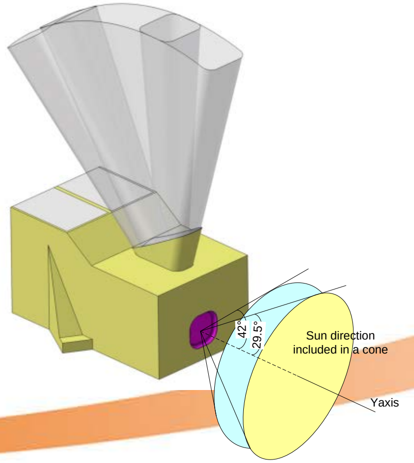
Scan mirror position for darkness calibration



Scan mirror position for Sun calibration

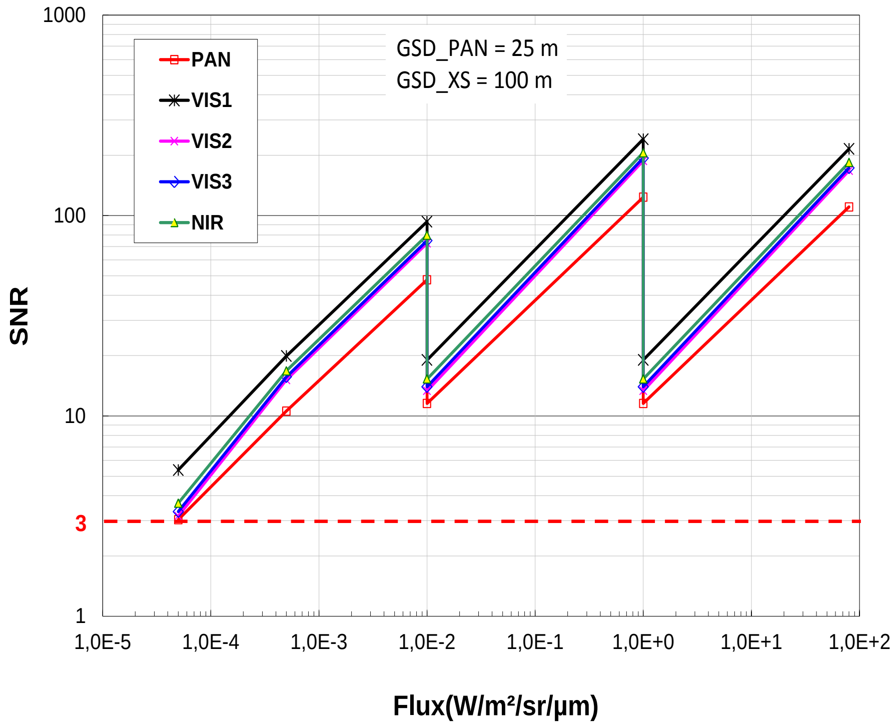
Diffuser

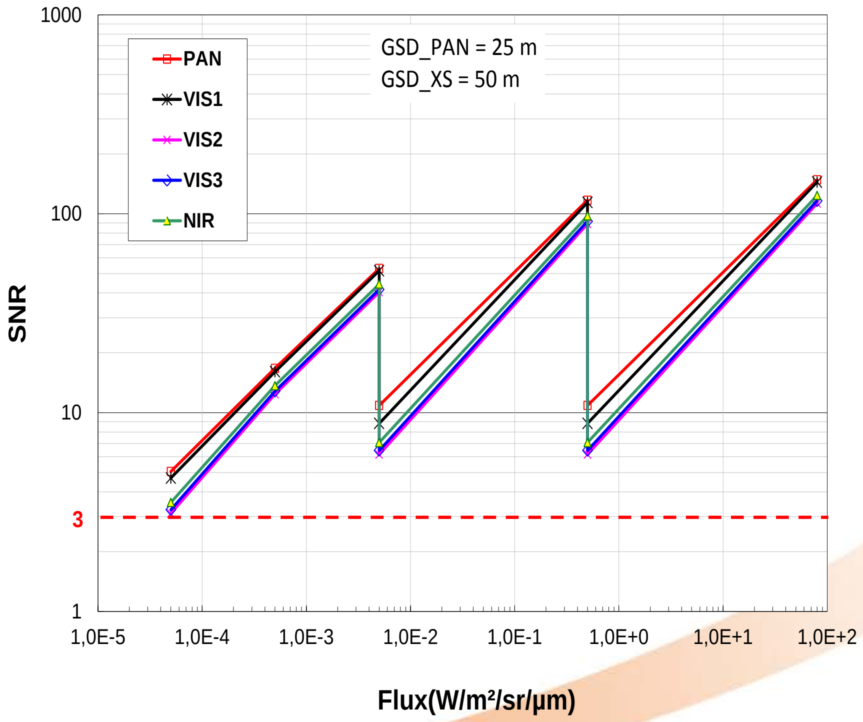
- Similar calibration concept as for GOCI instrument flying on COMS satellite
- Calibration can be done for several integration times (several levels of signal)
- No straylight issue due to the diffuser which is not illuminated by Sun during nighttime imaging.



NYX radiometric performances

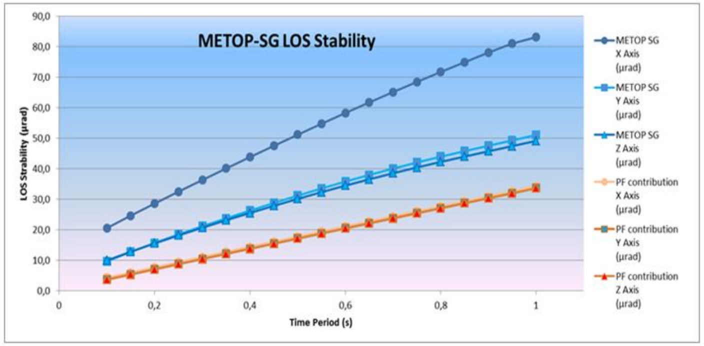
- All the SNR performances are met over the wide dynamic range and for the five spectral bands





NYX MTF performance

The LOS stability (platform stability and step and stare mechanism performances) are driving the integration time that can be allocated to the instrument to achieve MTF performance around 0.1



- METOP SG satellite.
  - Stability figure is > 80 µrad/s (X axis)
  - Main contributors are :
    - AOCS, SADM (Solar Arrays), APM (Antennas) for the Platform
    - MWS (X axis), MET IMAGE, IASI-NG for the Instruments.
  - The integration time is limited to 0,150 s for PAN channel, and MTF performance is :
    - 0,09 along X axis
    - 0,16 along Y axis
- Considering a high resolution satellite platform (stability figure < 50 µrad/s)
  - MTF performance is improved to 0,16 for both axis
  - Or the integration time can be increased up to 0,3 s to improve SNR performances

MTF and SNR performances are met with METOP SG platform. Better figures can be achieved with higher resolution platforms

Mass and power budget

Optical Assembly	7,9
Step and stare mechanism	9
Structure	19
Calibration	1
Detectors	0,8
FEE	6
Radiators	2
Optical Assembly	**45,7**
Video & Control Electronics : VCE (N & R)	**10,0**
Harness	**4**
NYX instrument - Mass budget (kg)	**60**

FEE units		40
VCE (N & R)	Sequencer	2
	TM TC	2
	Thermal Control (monitoring)	3
	Instrument Thermal Control	10
	CV	12
	Step & Stare Mechanism (including Drive Electronics)	21
NYX instrument - Power Budget (W)		**90**

Mass and power budgets are compliant with NYX allocations

Data rate

- Baseline case

		PAN	XS	PAN + XS
GSD	m	25	100	
Number of pixels ALT for each elementary image		2800	700	
Number of pixels ACT for each elementary image		2300	575	
Number of elementary images		6	6	
Number of bits		12	12	
Number of spectral bands		1	4	
Number of images for each scene		3	3	
Cycle period	s	10,269	10,269	
Mean Data rate wo compression	Mbit/s	135	34	169
Compression ratio		3	3	
Mean Data rate with compression	Mbit/s	**45**	**11**	**56**
Mean Data rate with compression and fusion (1 single image - 14 bits)	Mbit/s	**18**	**4**	**22**

- Option case

		PAN	XS	PAN + XS
GSD	m	25	50	
Number of pixels ALT for each elementary image		2800	1400	
Number of pixels ACT for each elementary image		2300	1150	
Number of elementary images		6	6	
Number of bits		12	12	
Number of spectral bands		1	4	
Number of images for each scene		3	3	
Cycle period	s	10,269	10,269	
Mean Data rate wo compression	Mbit/s	135	135	271
Compression ratio		3	3	
Mean Data rate with compression	Mbit/s	**45**	**45**	**90**
Mean Data rate with compression and fusion (1 single image - 14 bits)	Mbit/s	**18**	**18**	**35**

Comparison of Pushbroom and Step and stare concepts

	Pushbroom concept	Step and stare concept
	Three cameras : PAN camera + Two XS Cameras PAN Camera : Φ88 mm PAN F/4,5 FOV 20° Two PAN CCD pixel pitch = 12 µm XS Camera : Φ 44 mm – Two XS CCD per camera 36 video outputs Development of a new CCD detector including PAN and XS lines Detector operated @ 240 K	One single instrument Φ 90 mm F/3,7 FOV : 4° 5 CMOS matrix pixel pitch : 10µm 20 video outputs @ 5 Mpix/s CMOS matrix to be developed Same design for all bands Detector operated @ 220 K
+	Less sensitive to LOS unstabilities (Ti : 3,8 ms x 19 TDI stages = 72 ms)	**One single instrument** **Compliant with volume and mass allocations** **Mission Flexibility : accessible width and number of images per step** **Design flexibility : exposure time selection** **Reliability: no SPF in the detection chains**
-	CCD (PAN + XS) detector to be developed Large FOV for the optics **Mass budget exceeding the allocation** 1 axis Scanning mechanism to be implemented for out of track viewing and for calibration purpose Need for a large mirror for scan and calibration covering the pupil of the 3 cameras **Dimensions**	Beam splitter and dichroic accommodation More sensitive to LOS unstabilities (Ti > 150 ms) CMOS matrix to be developed 2 axis Step and stare mechanism to be implemented

TRL levels

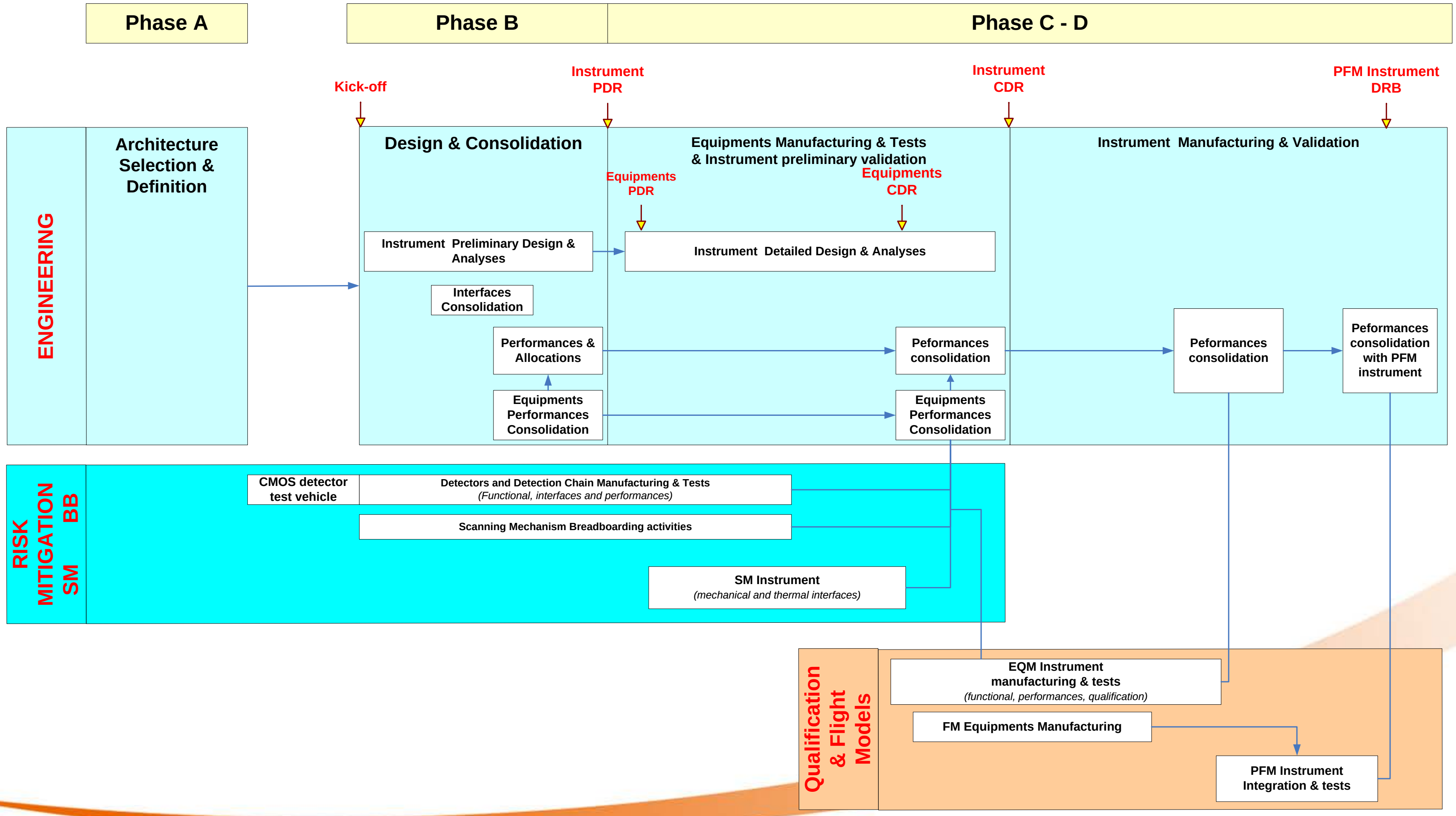
- CMOS detectors : TRL 4

CMOS Imaging Sensor technology	TRL	Comments
3T pixel, FIL/BIL, UMC 0.35 µm	9	GOCI CMOS detector
3T pixel, FIL/BIL, UMC 0.18 µm	7	Prototypes with environmental testing (e.g. radiation tests)
3T pixel, FIL/BIL, TowerJazz 0.18 µm	7	Prototypes: electro-optical characterization and environmental testing (e.g. radiation tests)
4T pixel, FIL/BIL, TowerJazz 0.18 µm	4	Prototypes: electro-optical characterization

- Step and stare mechanism : TRL > 6
  - Motor from space qualified SOTEREM family - CMG (TRL 9)
  - Pivots derived from MTG BB submitted to vibrations and life test (TRL 7)
  - Optical encoders are used on several projects (i.e. Pléiades)
- Optics technology : TRL 9

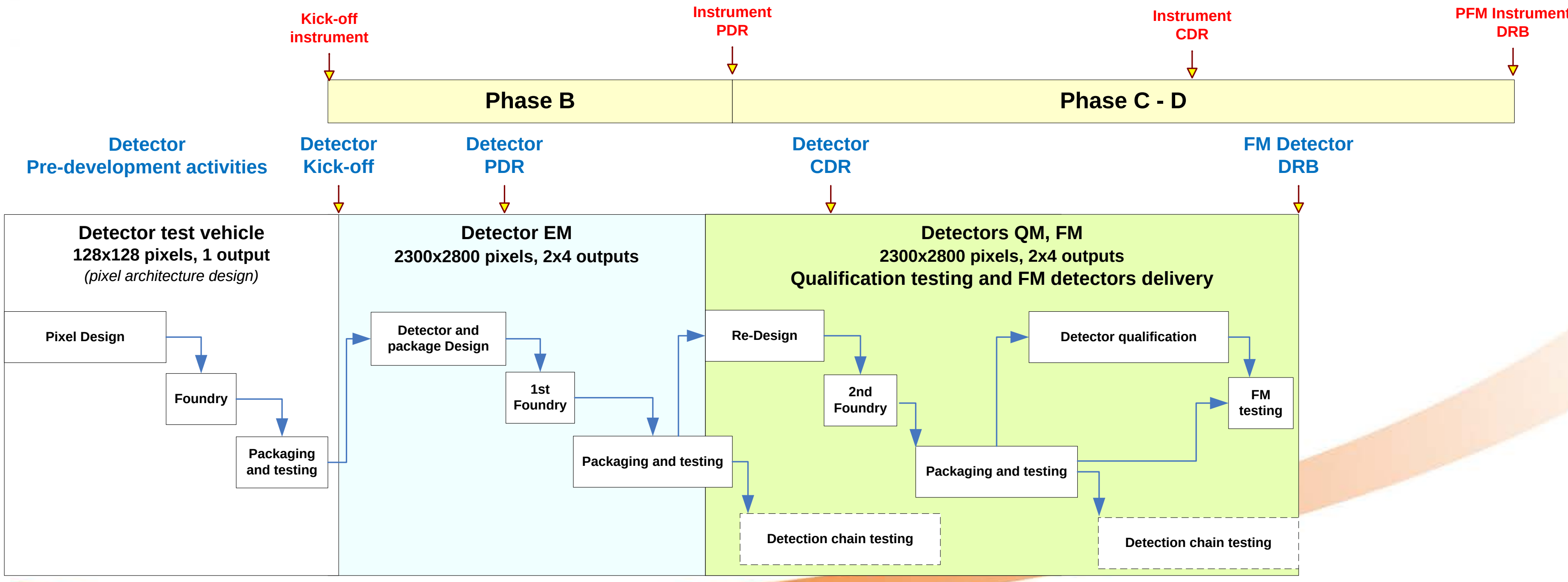
Development overview

- Main development efforts to be concentrated on the detectors

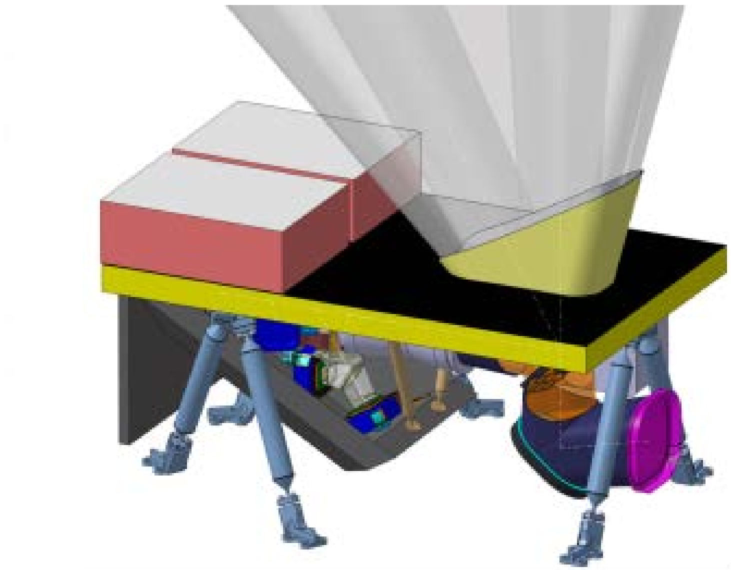


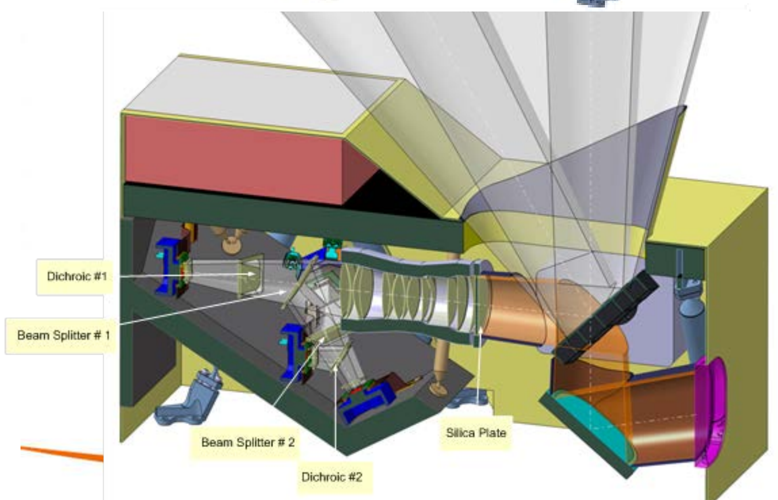
Detector development programme

- The proposed development plan is similar to the successful GMES Sentinel-2 MSI VNIR detector development programme.
- It includes pre-development activities prior to Phase B as well as design upgrade capability between the first manufacturing detectors batch and the flight model one.
- Total duration of the detector development programme is about 48 months.



The step and stare instrument is answering NYX mission





Mission Characteristics			
Spectral bands	PAN		XS
GSD	25 m		50 m or 100 m
Swath width @ Nadir	332.5 km		332.5 km
Scanning Characteristics			
Time cycle	10.269 s		
Number of steps ACT	6 steps		
Transition from step N to step N+1	0.1 s + 0.3 s (stab.)		3.77 degrees
Transition from Step 6 to Step 1	0.5 s + 0.3 s (stab.)		18.85 degrees
Time allocated to each step	1.245 s		
Space Velocity Compensation angular amplitude	0.652 degrees (Line of sight)		
Optical Assembly			
Focal length	334 mm		
Pupil diameter	90 mm		F/D = 3.71
Field of view	3.94° x 4.8°		
Focal plane assembly			
5 Detectors : CMOS Matrix operated @ 220 K	2800 pixels ALT		2300 pixels ACT
	Pitch ALT : 10 µm		Pitch ACT : 10 µm
3 different exposure times inside each step	150 – 300 ms	10 ms	0.1 ms
Read out time for each exposure	175 ms	175 ms	175 ms
Budgets			
Volume (VCE not included)	o Overall dimensions : 625 x 800 x 940 mm^3 o Wo local appendices : 530 x 560 x 940 mm^3		
Mass	60 kg		
Power	90 W		

NYX Instrument Final Presentation

Conclusions

CONCLUSIONS

- NYX mission and system requirements are consolidated
  - a PAN GSD of 25 m and XS GSD 100 m (option for 50 m)
  - 1 PAN +4 XS spectral bands
  - Swath width ≥ 300 km
- GEO
  - Due to Sun Aspect Angle during nighttime, no imagery can be done around midnight (22:00 - 02:00) with a constraint on daytime operation (180° yaw rotation about noon)
- LEO
  - Pushbroom concept doesn't meet mass and volume requirements
  - All performances are met with the Step and Stare concept, which is our prefered and recommended baseline concept.