Meteosat Third Generation (MTG) Lightning Imager (LI) instrument on-ground and in-flight calibration

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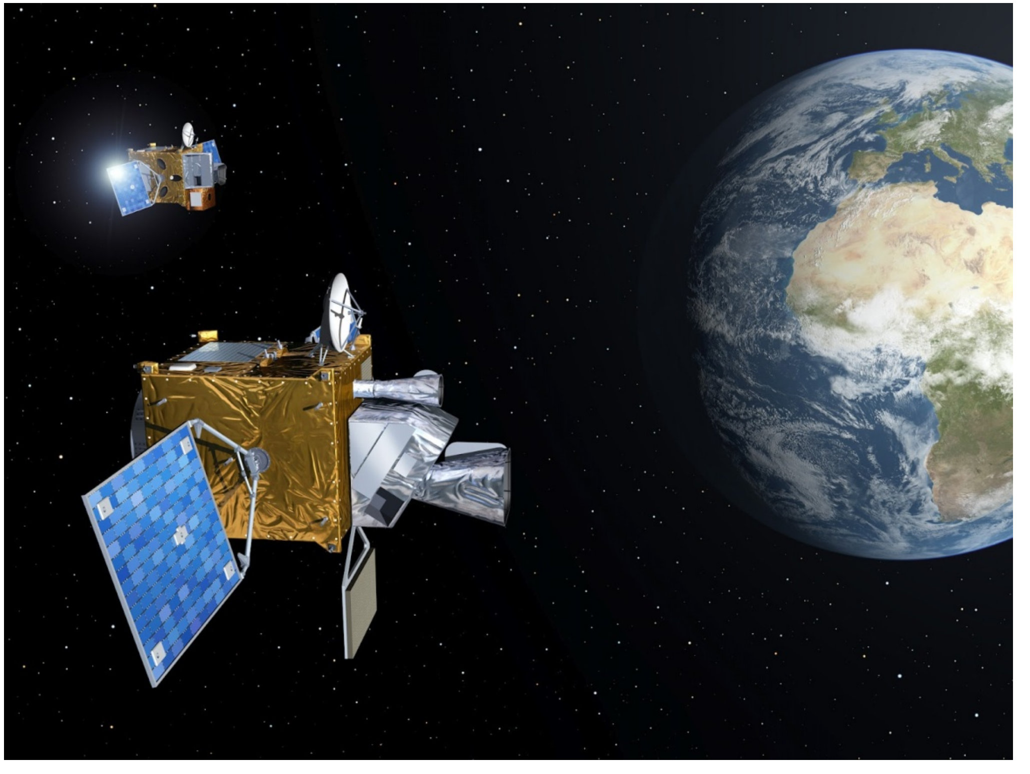
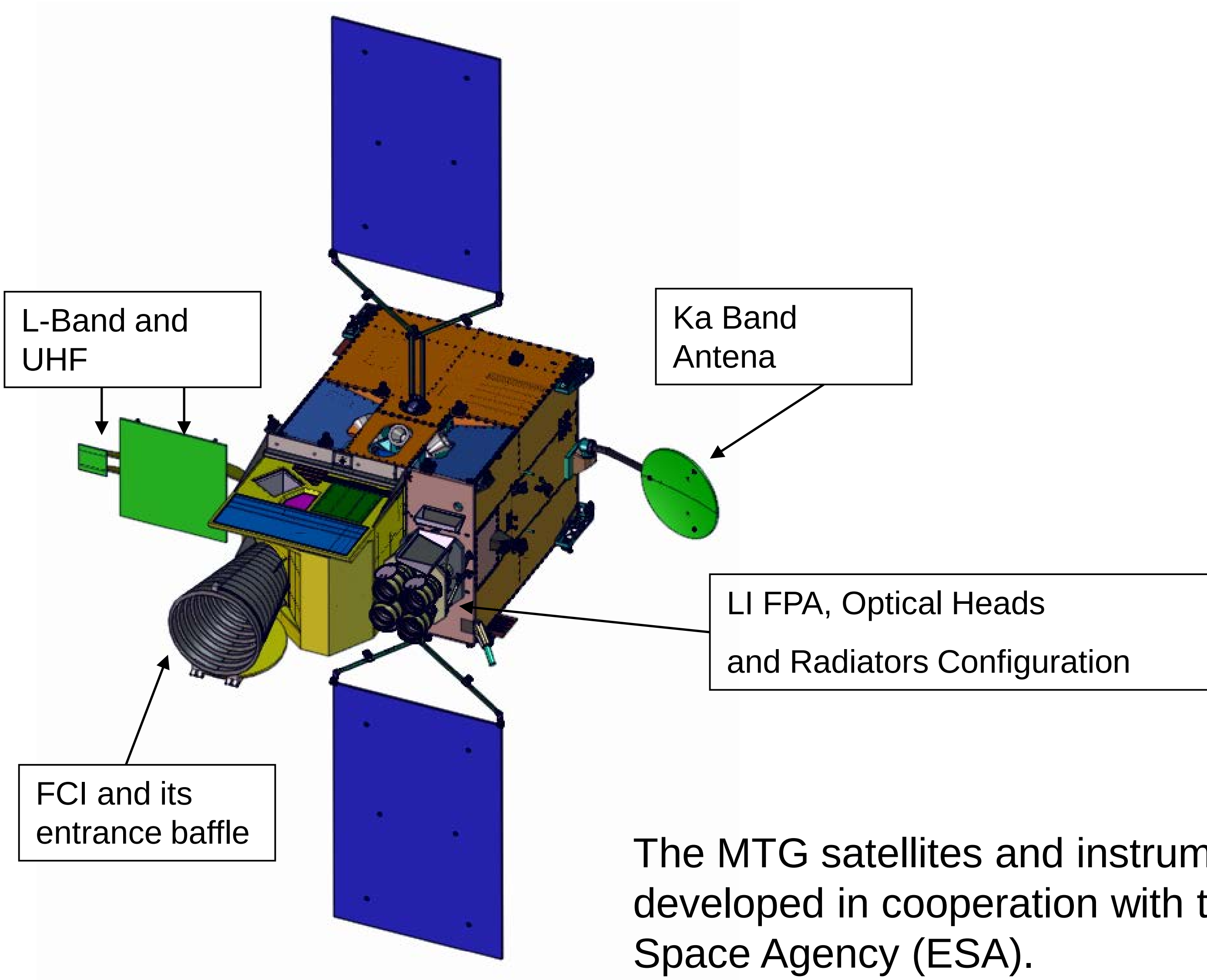
Contents of this presentation

Meteosat Third Generation (MTG) (1/2)

- 4 MTG-I (Imaging) satellites (2021-2041):
  - MTG Lightning Imager (LI).
  - MTG Flexible Combined Imager (FCI), follow-on from MSG-SEVIRI.
- 2 MTG-S (Sounding) satellites (2022-2038):
  - MTG Infrared Sounder (IRS).
  - Copernicus Sentinel-4 UVN.
- MTG-I and MTG-S satellites perform yaw-flips twice per year at equinoxes.

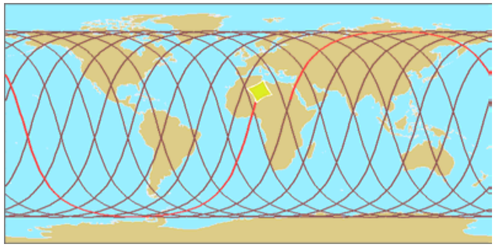


Meteosat Third Generation (MTG) (2/2): MTG-I



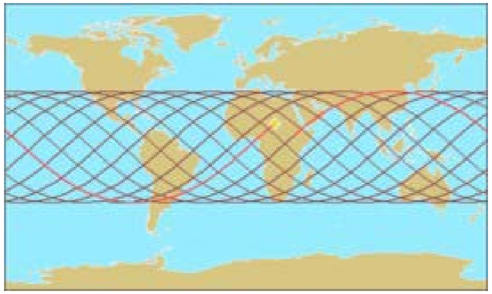
The MTG satellites and instruments are developed in cooperation with the European Space Agency (ESA).

Predecessor / other lightning instruments from space



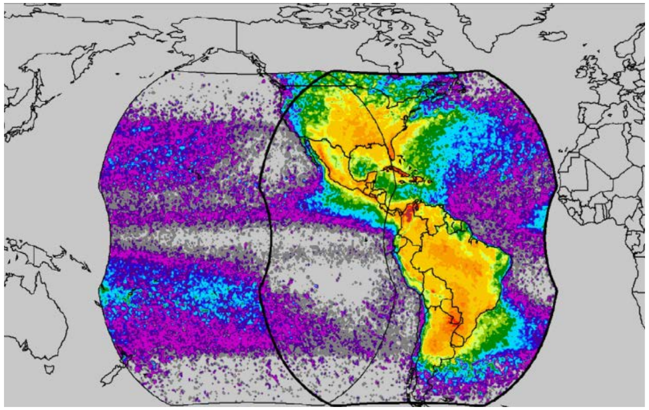
- OTD (1995-2000)

(Optical Transient Detector)
NASA



- TRMM LIS (1997-Present)

(Lightning Imaging Sensor on
NASA Tropical Rainfall Measuring Mission)



- GOES-R/S GLM (2016+)

(Geostationary Lightning Mapper,
NASA / NOAA)

- LIS on ISS (2016+)

(NASA)

- FY-4 GLI (2016+)

(Geostationary Lightning Imager)
China National Space Administration

LI mission objectives (1/2)

Measure lightning from geostationary orbit at subsatellite longitude around 0 degrees, covering (nearly) the complete visible earth disc, for 24 hours per day (day and night) with a certain specified Detection Efficiency.

- Generate “Detected Transients (DTs)”:
  - Real DTs from real lightning.
  - False DTs (from a variety of sources, not from real lightning flashes).

Main challenge for Lightning Imager mission:

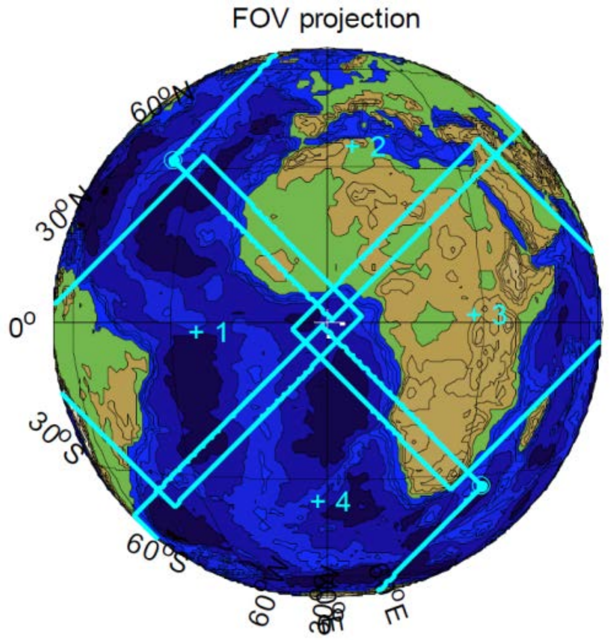
- Maintain a proper balance between filtering (or flagging) false Detected Transients and keeping true Detected Transients from real lightning phenomena (Detection Efficiency).
  - by filtering with a number of algorithms on board of the instrument on the spacecraft.
  - by flagging with a number of algorithms on the ground in the instrument 0-1b data processing software.
  - using instrument and spacecraft properties, as well as lightning properties.

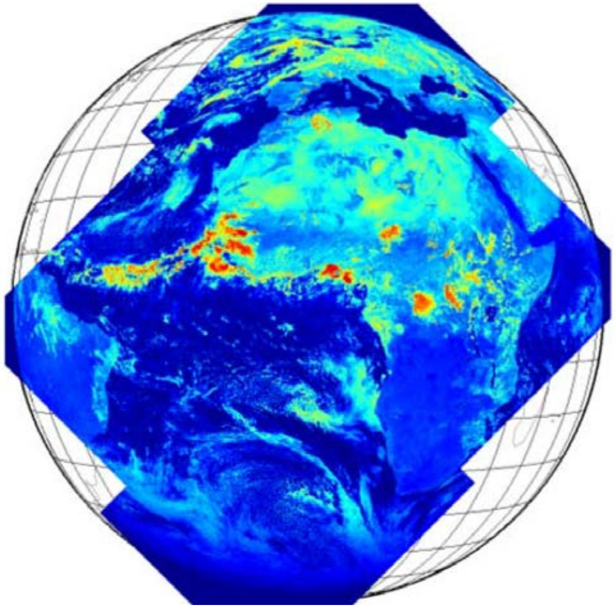
LI mission objectives (2/2)

- Measure at a temporal sampling rate of 1 ms (lightning optical pulse typically lasts 0.6-1.0 ms).
- Measure at a spatial resolution that is capable of resolving lightning with Ø10 km (measured spatial resolution 4.5 km x 4.5 km at subsatellite point).
- Measure neutral oxygen atom triplet at 777.6 nm (strong lightning emission line).
- Background radiance images over geographical coverage area every 30 seconds, for geolocation purposes and for instrument throughput and detector monitoring / calibration.

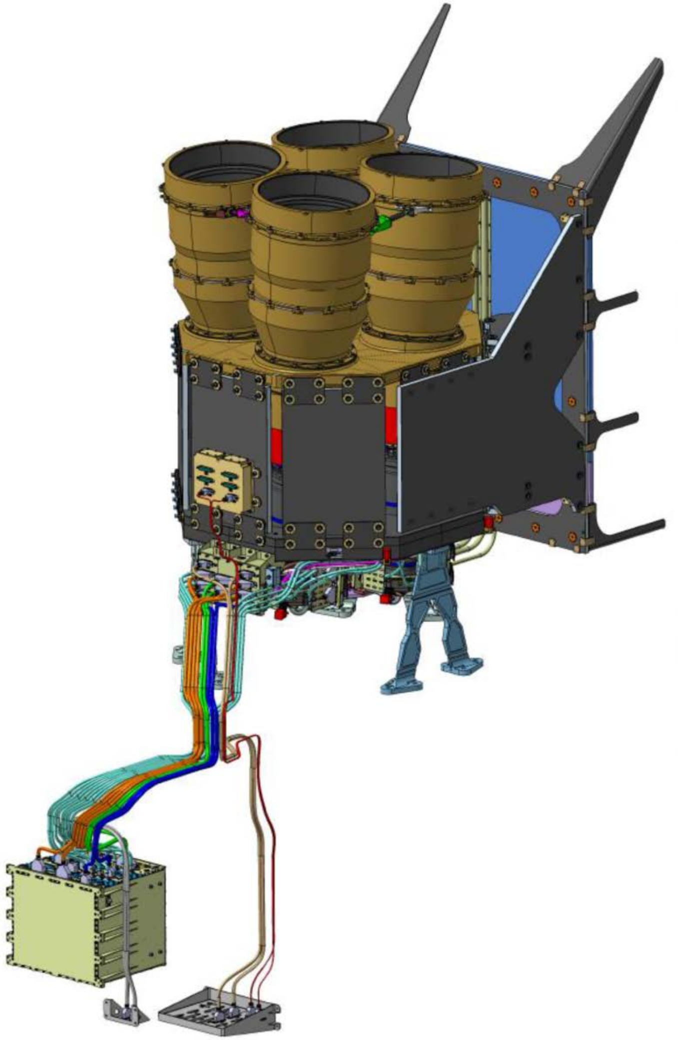
LI instrument (1/3)

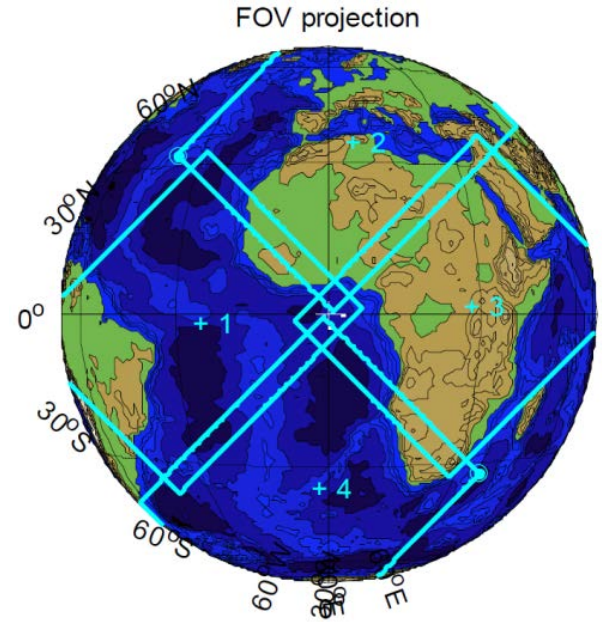
- 4 optical cameras to cope with the relatively large geographical coverage area (including Northern Europe), each one equipped with:
  - CMOS detector, operated around 293 K, 1170x1000 pixels.
  - Solar rejection filter.
  - Spectral band pass filter at 777.6 nm (atomic O emission line).
  - Optical system with F# 1.73, 110 mm entrance pupil diameter and 191 mm effective focal length, Field Of View 5.1 degrees.





LI instrument (2/3)



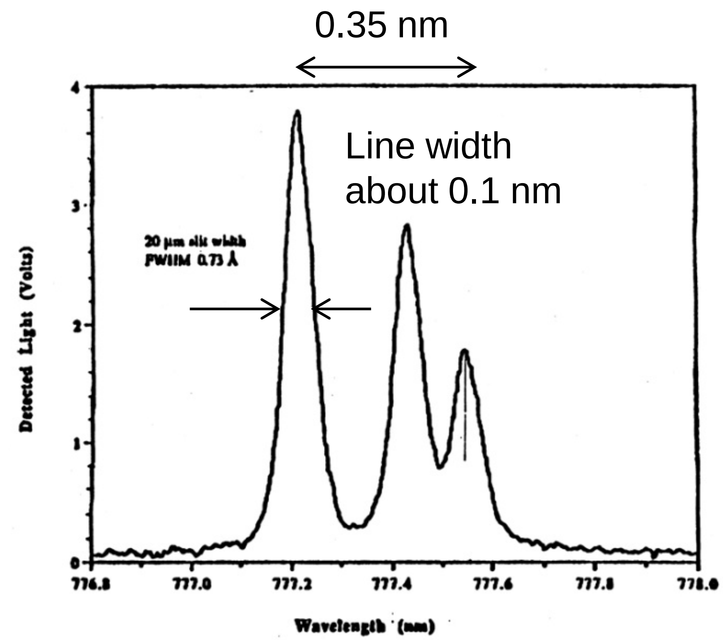


Lightning Imager (LI) characteristics:

- Mass about 110 kg (incl. 10% contingency).
- Power consumption about 300 W.
- Data rate to ground 30 Mbps.

LI instrument (3/3)

How to discriminate between a bright cloud (background) and a lightning phenomenon?



1. Spectrally:
Oxygen atom triplet at 777.6 nm, spectral band pass filter with diameter 11 cm and spectral width 1.9 nm.
vs
“White” cloud.

2. Spatially: Ground sampling distance subsatellite point 4.5 km x 4.5 km with (near) full earth disc viewing: 4.7 million pixels (!). Typical lightning size 10 km diameter.

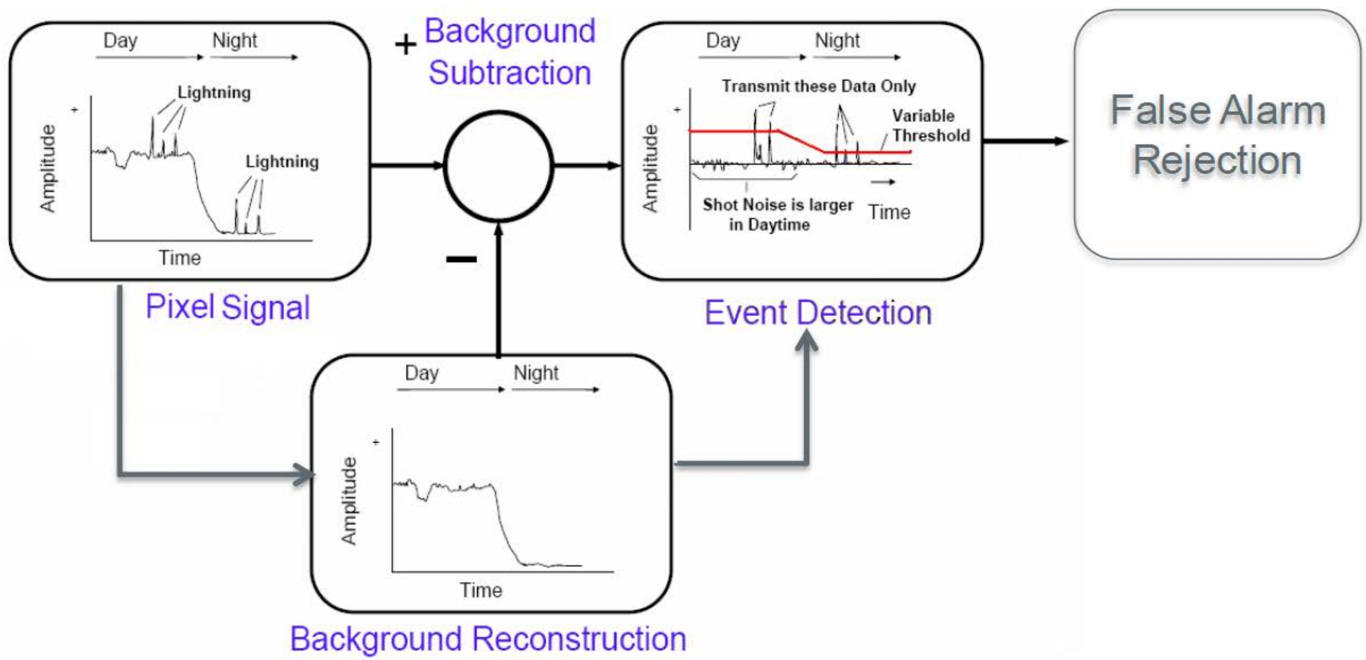
3. Temporally: Lightning optical pulse has a typical duration of 0.6 msec, hence use a frame refresh time of 1 msec. Compare each frame with “background frame”.

4. Background subtraction per detector pixel (in on-board electronics, differential technique), thresholding and Detected Transient (DT) detection.

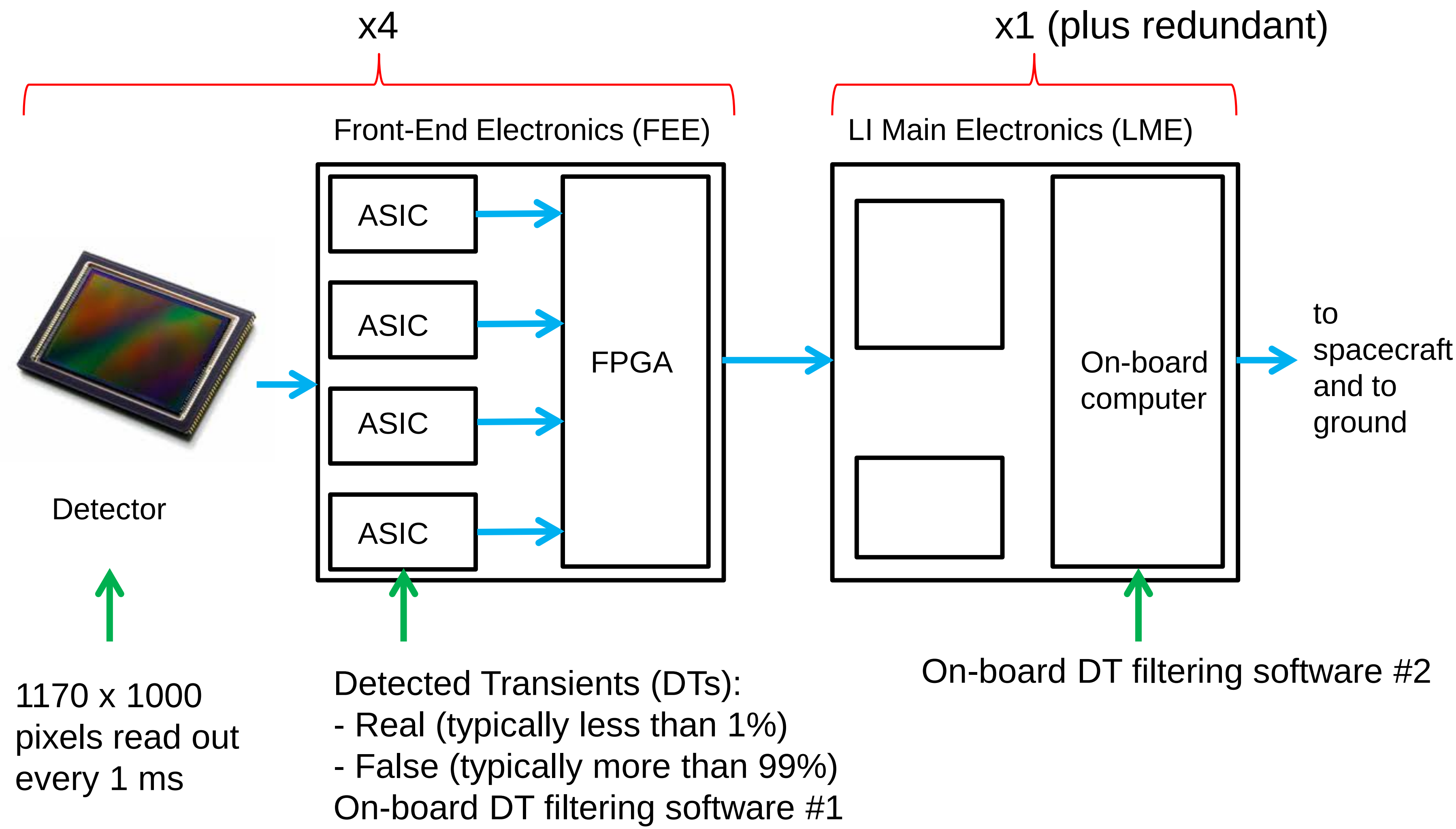
LI instrument detection principle (1/5)

- Each optical camera has its own Front-End Electronics (FEE) that processes the data from the detector:
  - Real time reference background signal estimation for all detector pixels.
  - Subtract the reference background from the detector pixel and frame in question to obtain the net illumination level per frame.
  - Thresholding per detector pixel of differential signal.

    Thresholds depend on the background signal (higher signal equals higher noise, which equals a higher threshold).
  - Samples exceeding the threshold are the ***Detected Transients (DTs)***.
  - Distinction between real and false events on board: discard as many false DTs as possible whilst maintaining the real DTs.



LI detection principle (2/5)



LI detection principle (3/5)

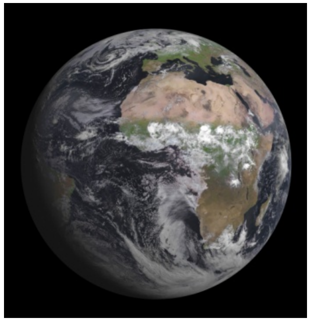
- LI basic data products as measured (Level-0):
  - Detected Transients (DTs) ***on board*** for every 1 ms frame:
    - DT radiance signal, plus signals of 8 surrounding detector pixels.
    - Measured background radiance signals 3x3 matrix at time of DT detection.
    - Used threshold at time of detection.
  - ***On the ground:*** Measured global background radiance images for all detector pixels and all 4 optical cameras, every 30 seconds.

rad	rad	rad
rad	rad DT	rad
rad	rad	rad

+

bck	bck	bck
bck	bck	bck
bck	bck	bck

and



LI detection principle (4/5): data flow and DT filtering / flagging

1. Real-Time Pixel Processor (RTPP): DT detection

2. Single-Detected-Transient Filter

3. Microvibration / Jitter Filter (MVF)

On-board Detected Transient (DT) **Filtering** software:
- Remove false DTs
- Retain true DTs

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4. On-ground Microvibration / Jitter Filter / flagging

5. Hybrid (2+3) algorithm Flagging

6. Other Filters / Flagging: Spatio-temporal Flash algorithm, detector specific noise, glints, cosmic particles, etc.

On-ground Flagging software in 0-1b data processing software

To Level-1b data products

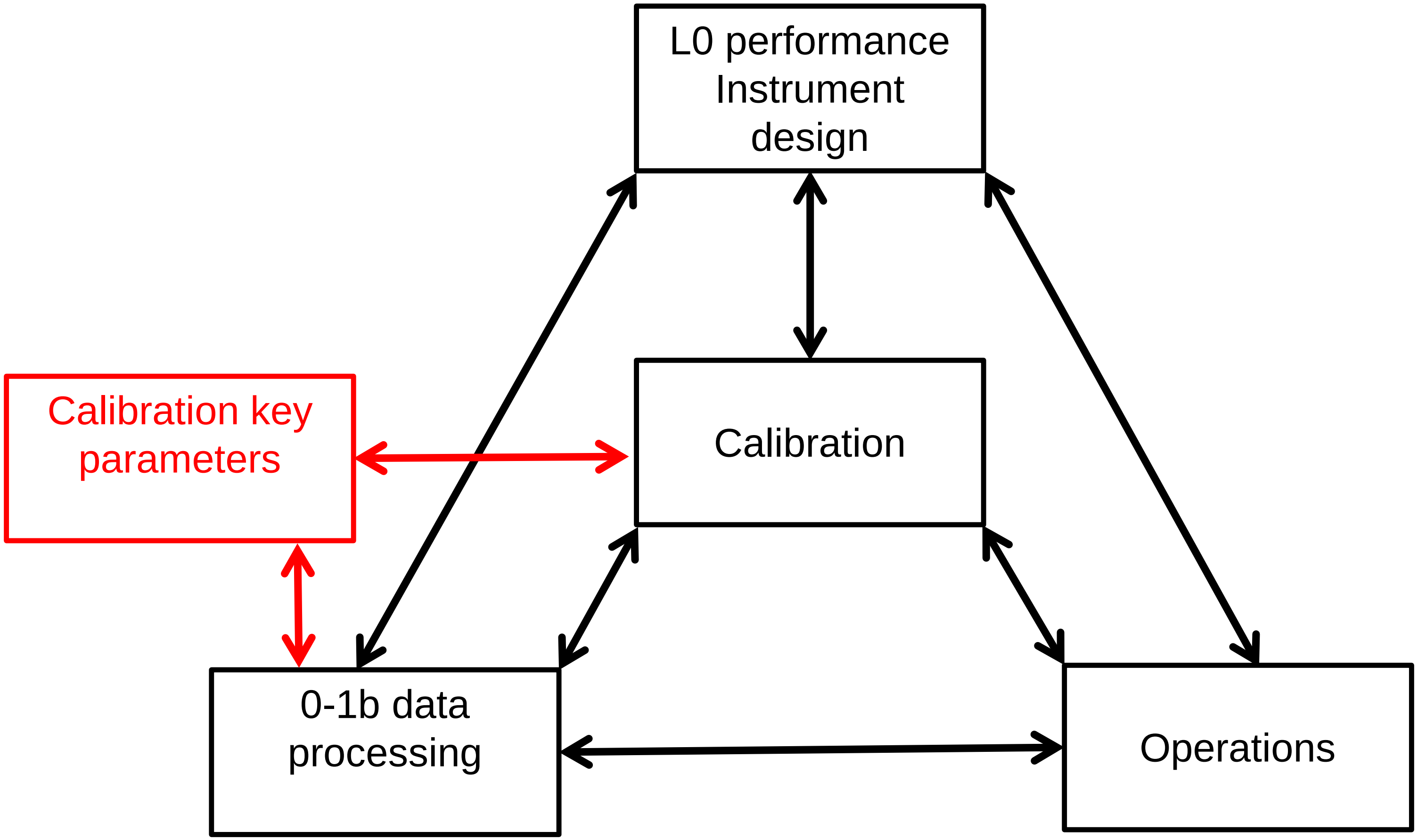
LI instrument detection principle (5/5)

- A Detected Transient (DT) (from real lightning or false) is any sample that exceeds the threshold.
- False DTs can originate from:
  - Noise.
  - Microvibrations in combination with scene contrast.
  - Cosmic particles hitting the detectors.
  - Solar glint on open water, lakes or rivers.
  - Etc.

- All DTs that pass the on-board filtering are transmitted to the ground along with housekeeping:
  - The DT signal.
  - the spatial coordinates (detector row and column).
  - time information uniquely identifying the sequence of DT occurrence.
  - the background radiance signal of the related spatial sample.
  - the trigger threshold.
  - the signals of the adjacent spatial samples + their background radiance signals.

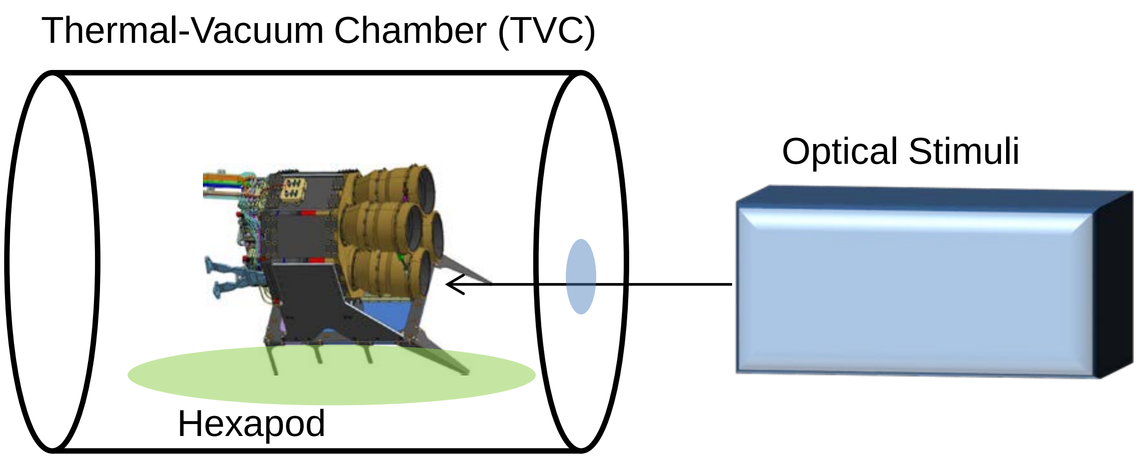
- On the ground DTs, background radiance image measurements and calibration measurement data are further processed by the 0-1b data processing software.

Instrument system engineering aspects



LI on-ground calibration (1/4): overall

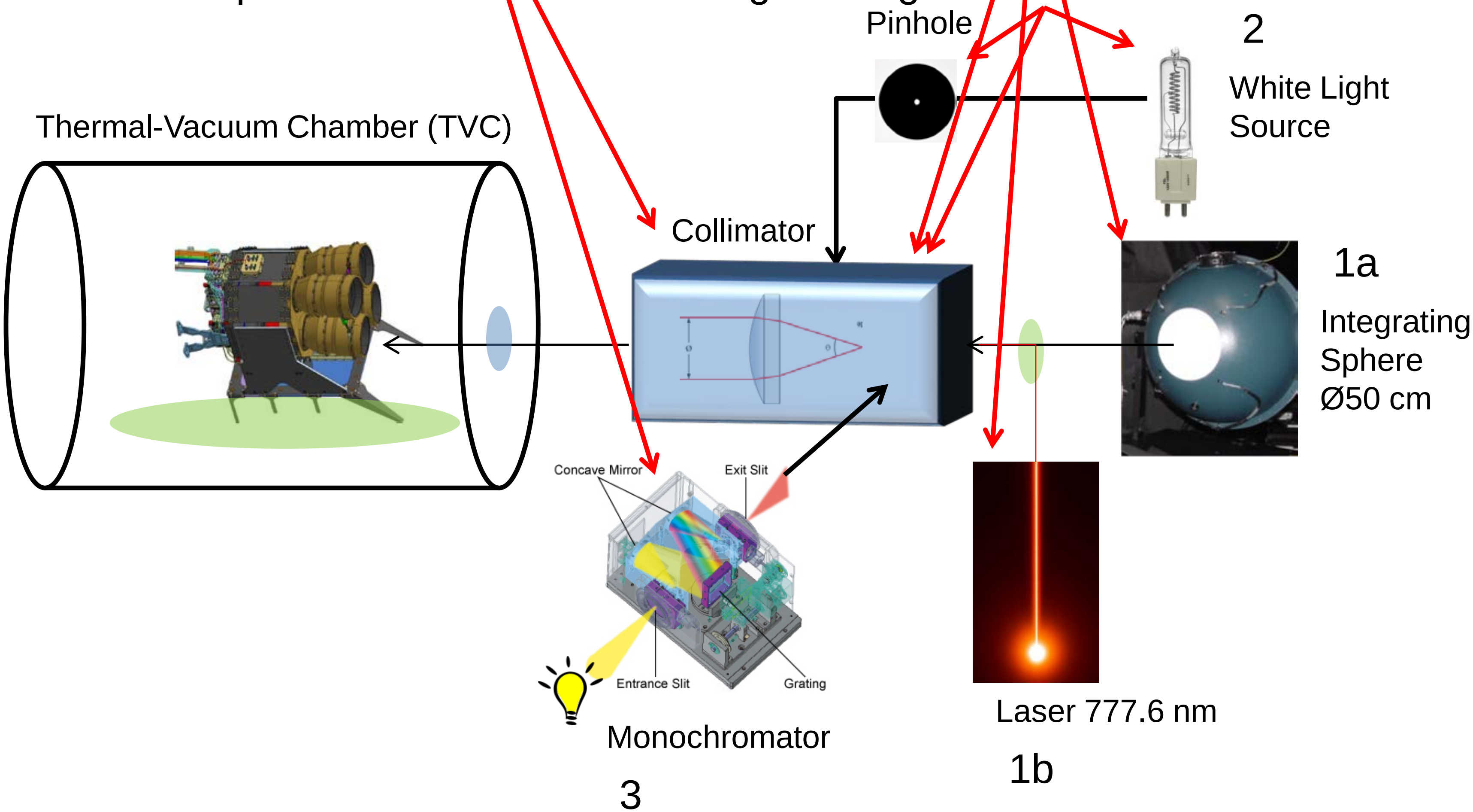
- Calibration performed at Optical Head level (all 4 optical cameras integrated) inside Thermal-Vacuum Chamber (TVC).
- Hexapod inside the TVC to position each Optical Camera in front of the optical stimuli.
- All optical stimuli outside the TVC.



LI on-ground calibration (2/4): Optical Stimuli

Detection Probability.

- for optical camera relative boresight coregistration.



LI on-ground calibration (3/4): Measurements

Calibration and 0-1b data processing:

- Detected Transient flagging (distinguish between real and false DTs).
  - Characterisation / calibration of potential spatial ghosts.

- Radiometric calibration (for both DTs and Background Radiance, i.e. transients and ‘constant’ in time, overall accuracy requirement better than 10%):
  - Detector and electronics.
    - Pixel Response Non-Uniformity (PRNU).
    - Pixel-dependent offset.
    - Pixel-dependent dark current (+ temperature dependence).
    - Relative electronic gain ratios.
  - Absolute radiometric calibration.
  - Polarisation characterisation.
  - Earth and sun stray light calibration / characterisation (in field / out-of-field).

LI on-ground calibration (4/4): Measurements

Calibration and 0-1b data processing (continued):

- Geolocation / geometric (accuracy requirement better than 4 km, during day and night):
  - Pixel Line Of Sight (LOS).
  - Pixel Field Of View (FOV) / Point Spread Function (2-dimensional) (PSF).
  - Line Of Sight calibration between the 4 optical cameras.

- Spectral calibration:
  - Narrow band pass spectral transmission calibration (per detector pixel).

LI in-orbit calibration

Options available for calibration and instrument performance monitoring in orbit, frequency to be decided, typically once per week:

- No on-board calibration (light) sources.
- Routinely obtained background radiance images over geographical coverage area every 30 seconds:
  - Detector performance monitoring / calibration.
  - Optical throughput performance monitoring / calibration.
- Dedicated dark measurements with varying detector exposure times from 40 microseconds to 5 seconds.
  - Pixel-dependent dark current and electronic offset calibration. Update the on-board pixel-dependent offset parameters.
  - Pixel-dependent non-linearity.
  - These measurements affect lightning detection capability / availability.

LI in-orbit Verification / Validation

Verification / validation of lightning detection capabilities:

- Against other satellite equipment:
  - GLM (GOES)
  - LIS-ISS
  - etc.
- Against ground-based lightning detection networks:
  - LINET (D)
  - Meteorage (F)
  - ATDNet (UK)
  - NordLis (Scandinavia)
  - etc.
- Complicated:
  - by the fact that satellite-based systems and ground-based systems typically observe different phenomena / frequencies associated with the lightning flashes.
  - by different sensitivities of the ground-based networks.
- Using two LI instruments in orbit (from 2024 onwards).

Conclusions

- Meteosat Third Generation (MTG) Lightning Imager (LI) system development progresses as planned for launch in 2021:
  - Instrument and detection techniques.
  - On-ground and in-orbit calibration under development.
  - 0-1 data processing.
  - 1-2 data processing (lightning flashes).
  - Instrument operations.

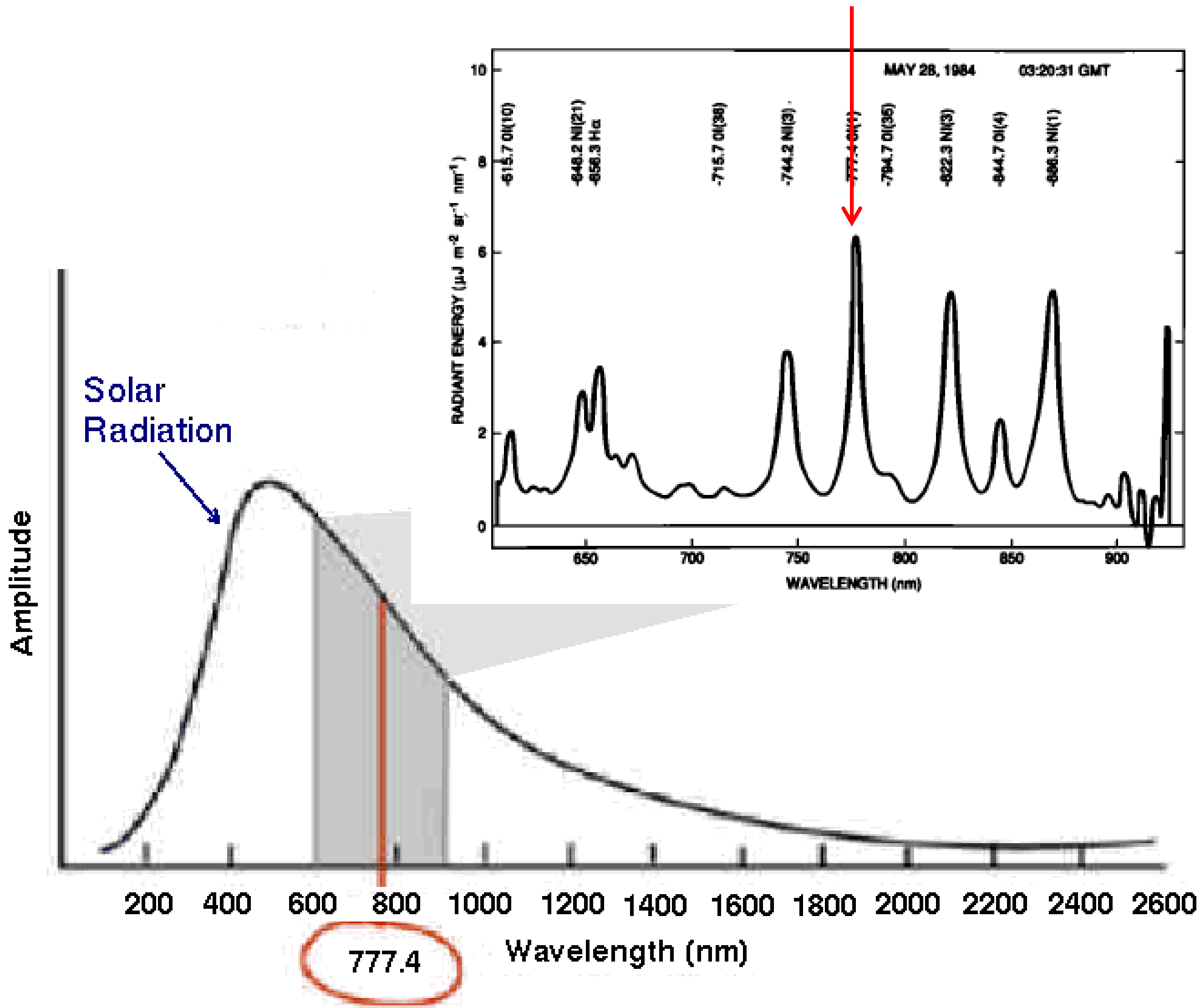
- Complex instrument due to large geographical coverage area and high lightning detection efficiency requirements.

- Maintain a close link between instrument performance, on-ground data processing, calibration and instrument operations.

- In-orbit verification of lightning detection efficiency at level-1b and at level-2 (lightning flashes) will be a major challenge.

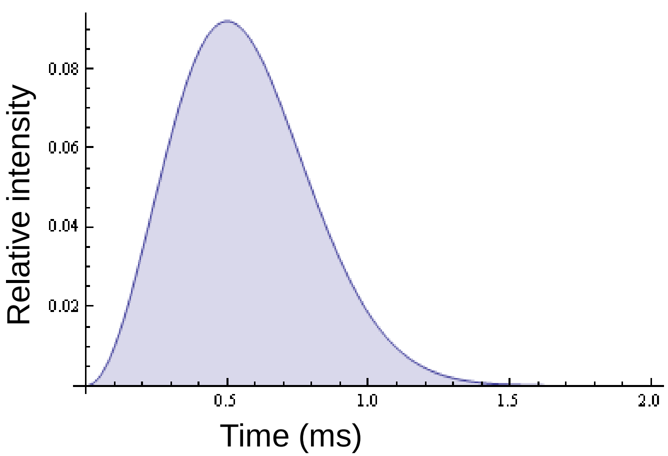
BACKUP SLIDES

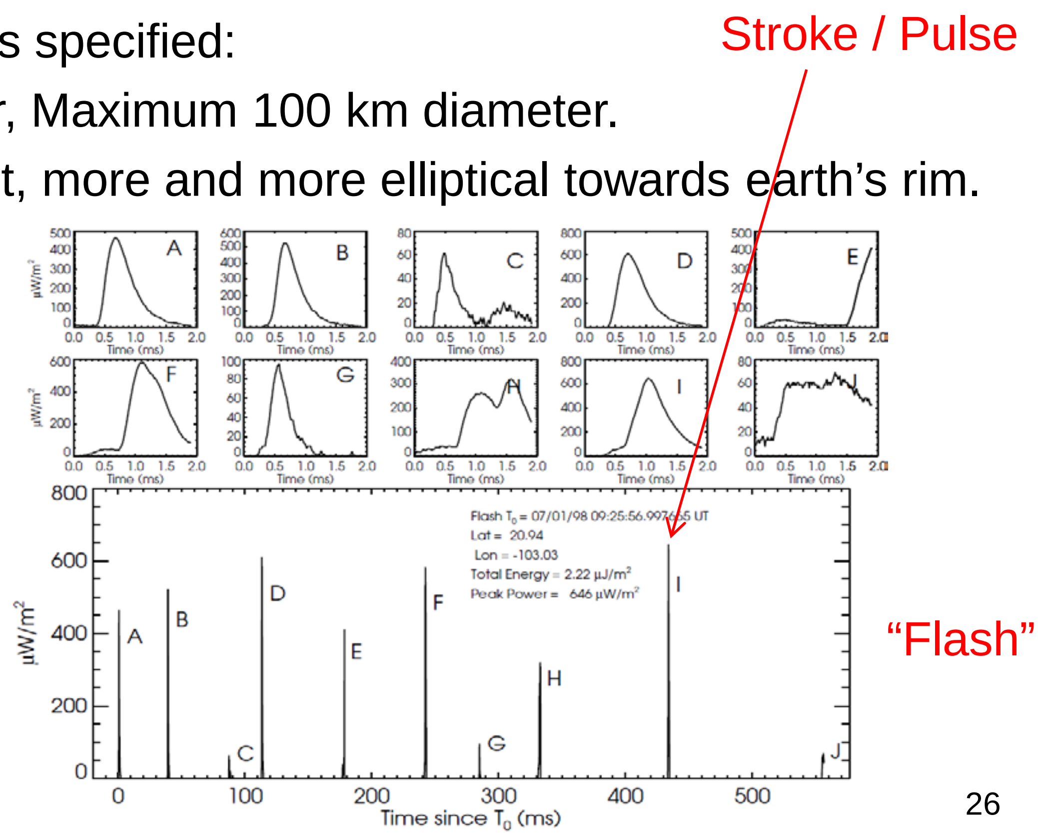
Lightning Imager (LI): Instrument



Lightning characteristics

- A lightning flash lasts typically between 1 and 1.5 seconds and consists of 1..several (e.g. 15) lightning strokes (optical pulses).
- A lightning stroke, as observed from space through the clouds after multiple scattering, has a temporal duration of typically 0.6 ms.
- Lightning optical pulse energy as specified:
  - Minimum 10 $\mu Jm^{-2}sr^{-1}$ (4 $\mu Jm^{-2}sr^{-1}$ during the night).
  - Maximum 400 $\mu Jm^{-2}sr^{-1}$.
- Lightning optical pulse size as specified:
  - Minimum 10 km diameter, Maximum 100 km diameter.
  - Circle at subsatellite point, more and more elliptical towards earth's rim.





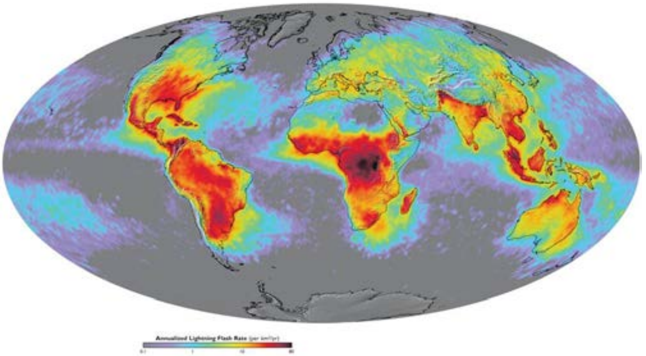
Lightning characteristics: Detected Transients (DTs), Groups and Flashes

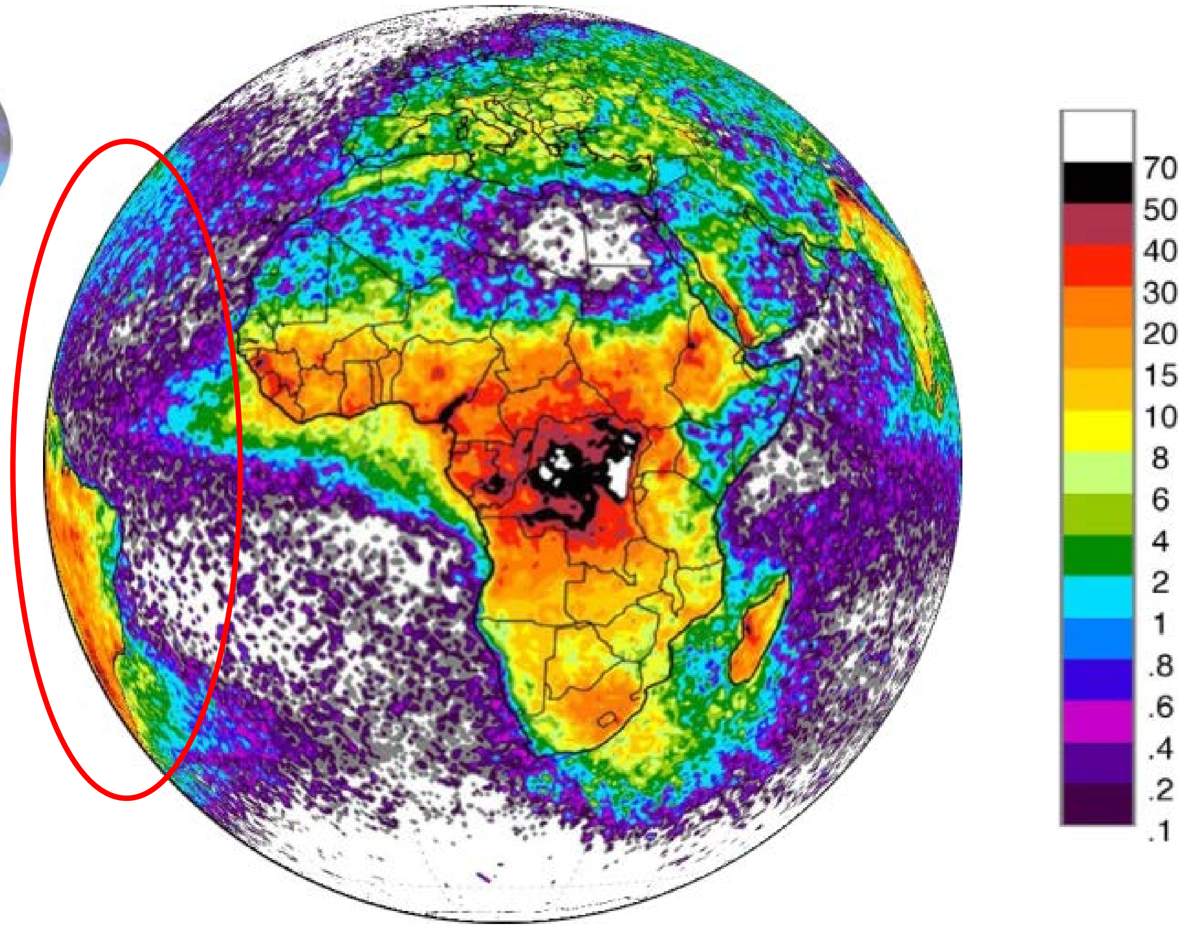
Lightning Flash =

(time) sequence of various lightning optical pulses, each two spaced by no more than e.g. 300 ms, occurring at approximately the same location (e.g. within 50 km).

Physical phenomenon	Measured by instrument	Data level
-	DT (detector pixel)	Level-0 / Level-1b
Lightning Stroke / Lightning Optical Pulse	Group (of detector pixels)	Level-2
Lightning Flash	-	Level-2

Lightning characteristics





Overlap with U.S. GOES-R Geostationary Lightning Mapper (GLM)

Annual flash rate (in flashes / km² / year) over the Earth (MTG view), as derived from U.S. LIS (low-earth orbit) observations at 0.5° resolution

Lightning Imager (LI) requirements (1/2)

- Detection efficiency for optical pulses:
  - 70% at 45 degrees north latitude, subsatellite longitude.
  - Lower towards the rim of the earth.
  - For optical pulse energy of 10 $\mu Jm^{-2}sr^{-1}$ and diameter 10 km.

- False alarm rate at Level-0 < 35000 false events per second (< 35 false events per frame).
- False alarm rate at Level-1b < 350 false events per second after on-ground data processing.

- Radiometric accuracy 10%.

- Geolocation accuracy at subsatellite point: 4 km.

- Geographical coverage: 84% of the visible earth disc, including Europe.

Lightning Imager (LI) requirements (2/2)

Main challenge for Lightning Imager instrument / system:

Maintain proper balance between False Detected Transients (DTs) and Real (lightning) DTs and Lightning Detection Efficiency:

- Large data reduction required before data are sent to ground, removing as many false DTs as possible.
  - but real lightning DTs need to be kept as much as possible.
- DT filtering on board and filtering/flagging on ground in 0-1b and 1-2 data processing software.

Lightning Imager(LI): ground data processing

Raw DTs (real + false)
+
Raw background radiance images

Geophysically calibrated DTs (real + false)
+
Background radiance images

Flashes
Groups
Accumulated products (groups and flashes)

Level-0 data → Level-1b data → Level-2 data

Less false DTs, maintain as much as possible real DTs