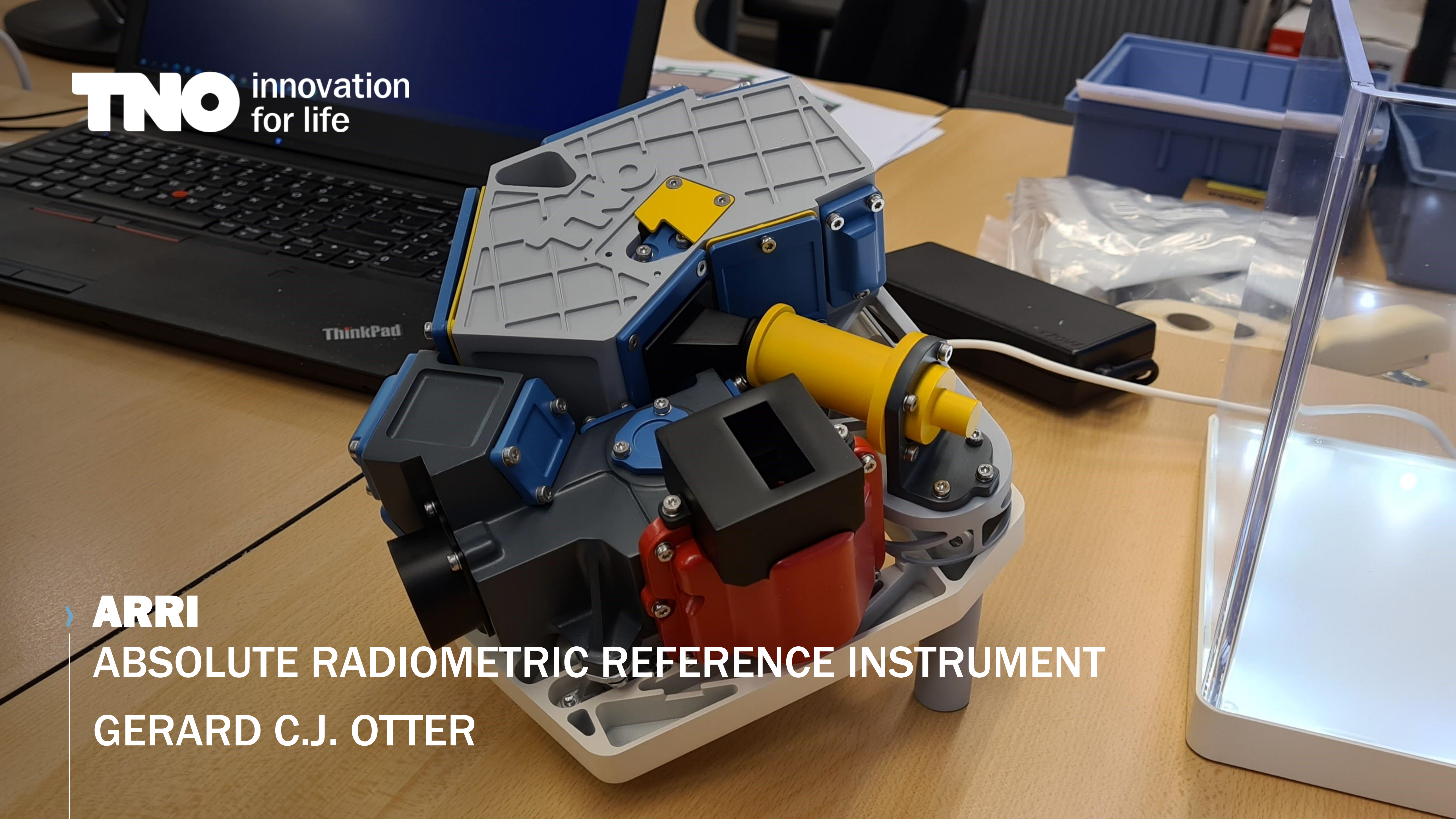
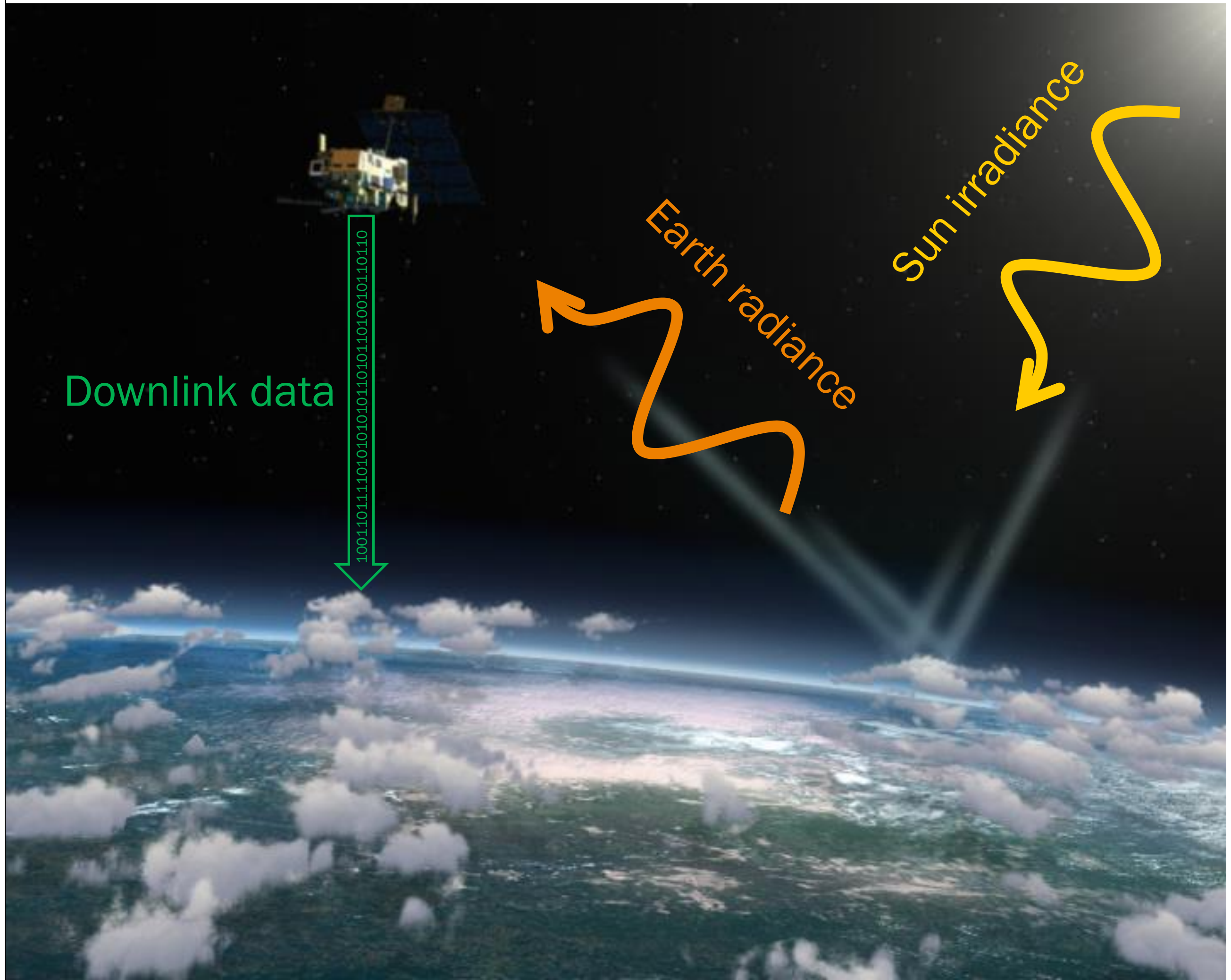


ARRI

ABSOLUTE RADIOMETRIC REFERENCE INSTRUMENT

GERARD C.J. OTTER

INTRODUCING ARRI
EARTH OBSERVATION



Raw data

↓

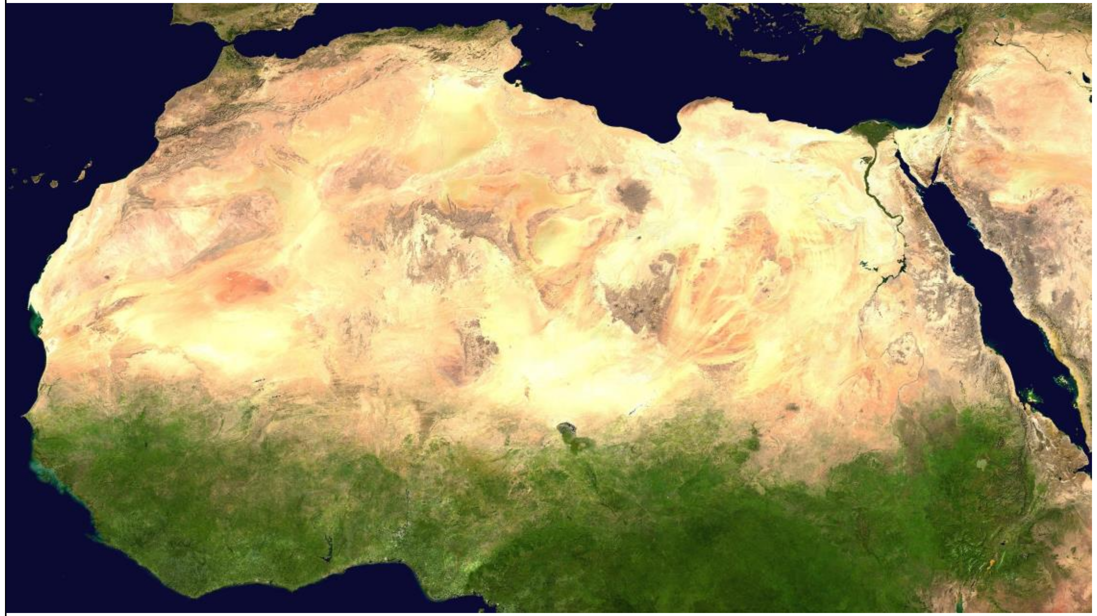
Calibration

↓

$$\text{Earth reflectance} = \frac{\text{Earth radiance}}{\text{Sun irradiance}}$$

INTRODUCING ARRI

CALIBRATION, MONITORING INSTRUMENT CHANGES DURING LIFETIME



Vicarious calibration using stable known scenes

- Requires no on board hardware
- Knowledge and stability is limited

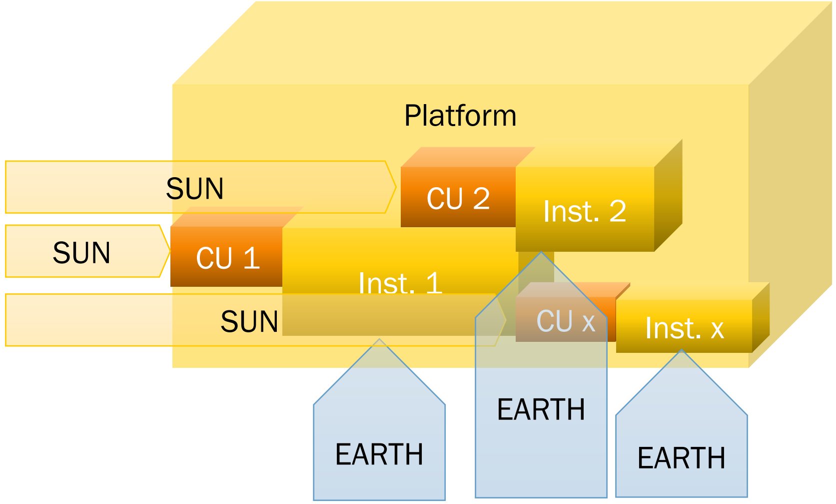
Solar calibration using on board diffuser

- More accurate
- Requires on board diffuser and diffuser monitoring (for highest accuracy)

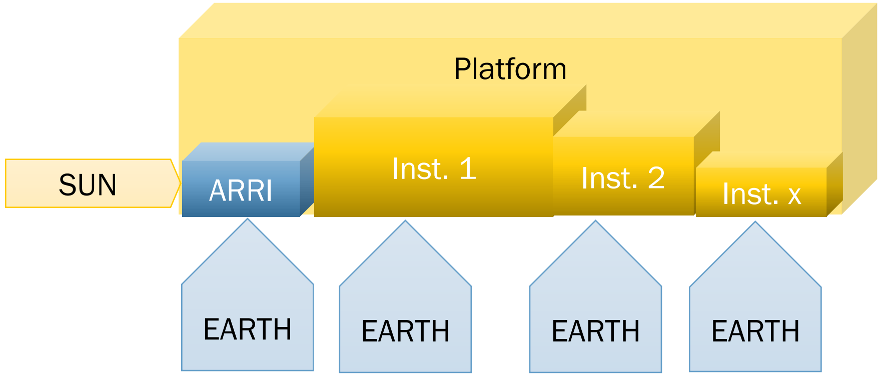
INTRODUCING ARRI

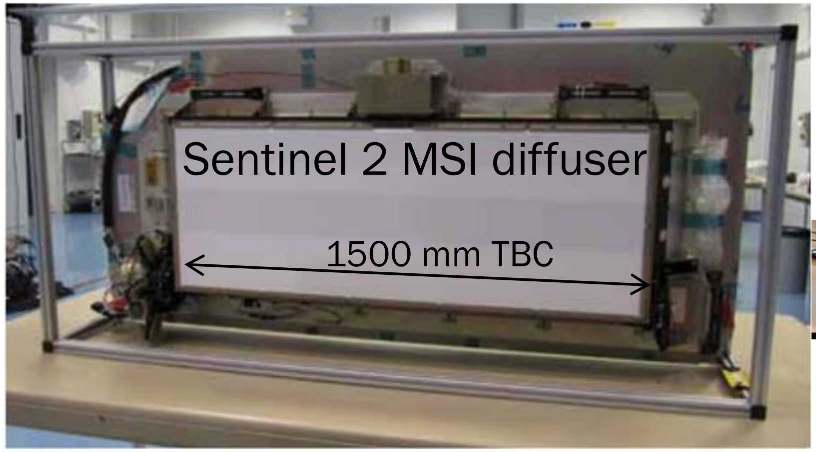
REDUCING ON-BOARD CALIBRATION HARDWARE

Each instrument with sun calibration unit



One instrument (ARRI) calibrated with respect to the sun providing reference reflectance to all instruments

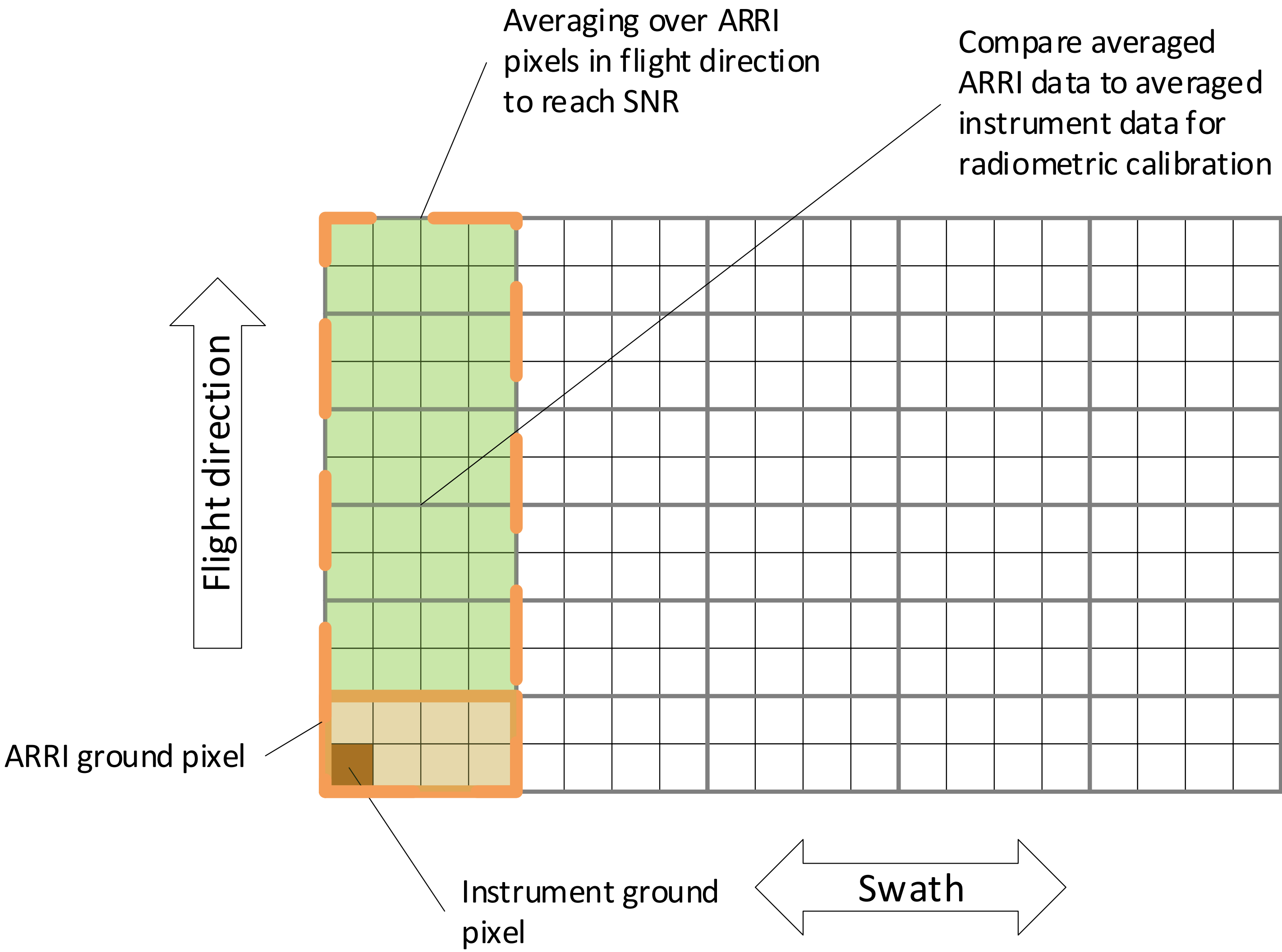




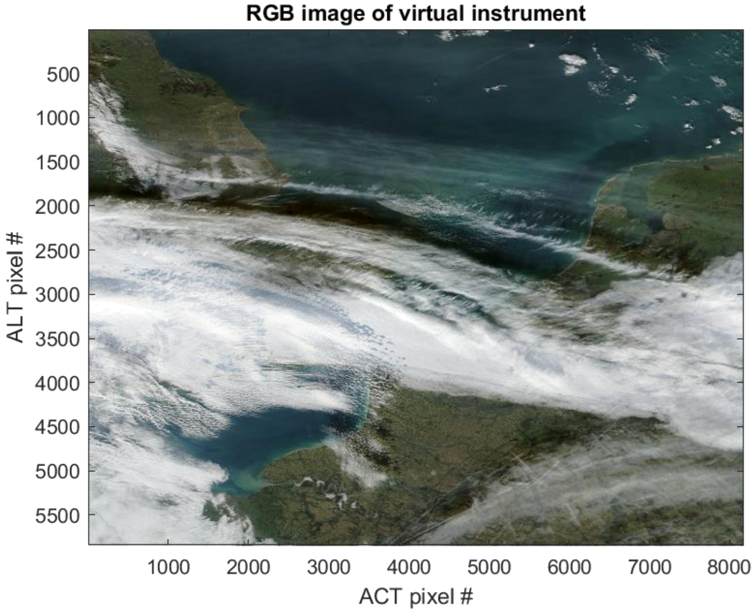
ARRI 1:1 model

200 mm

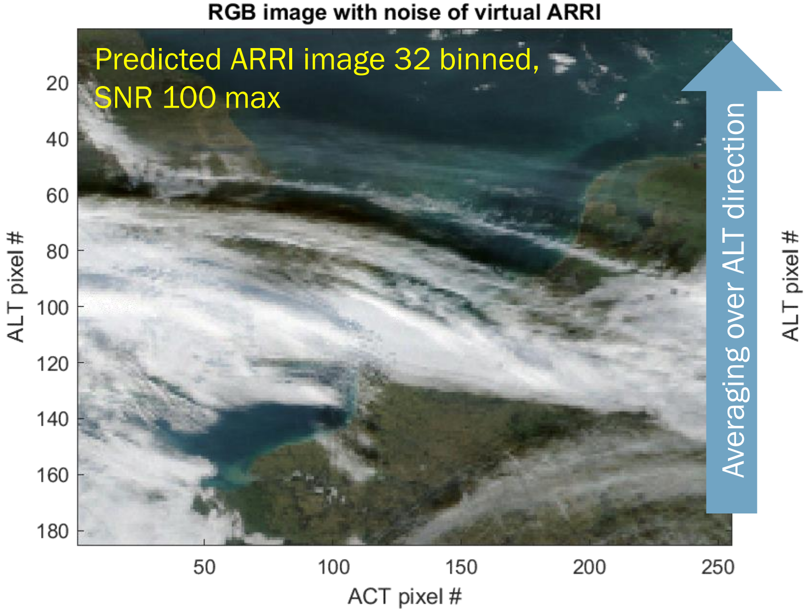
ARRI WORKING PRINCIPLE

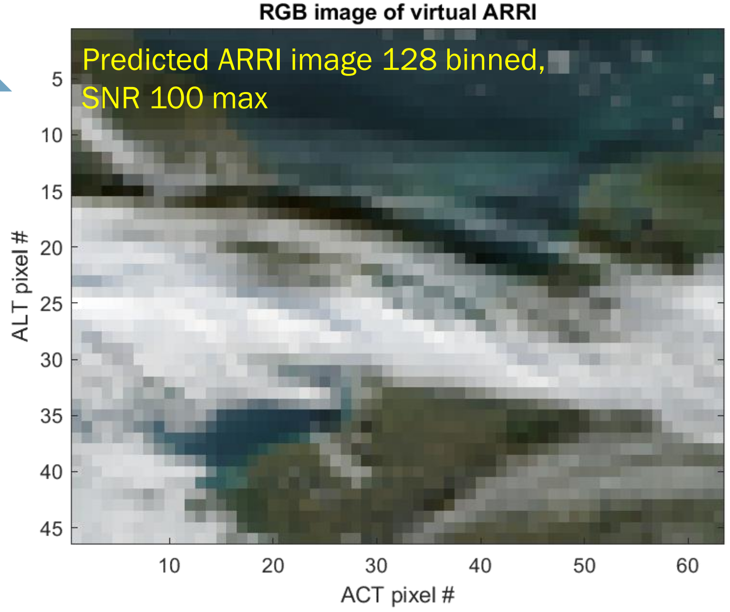


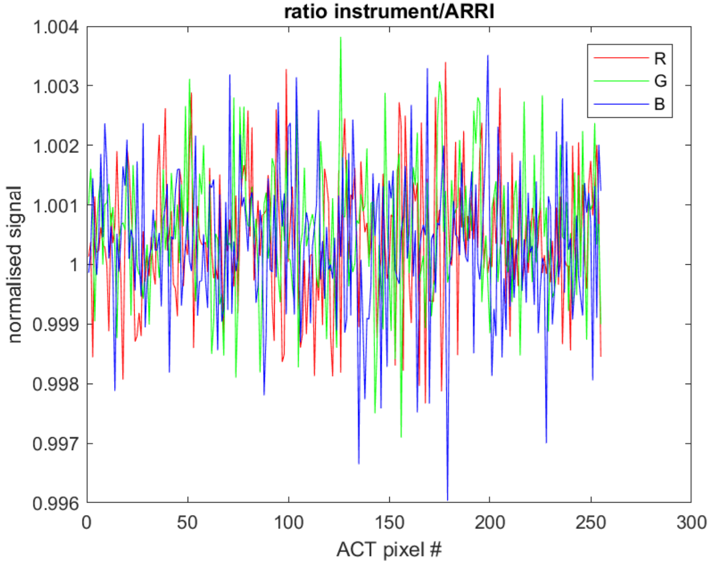
ARRI WORKING PRINCIPLE

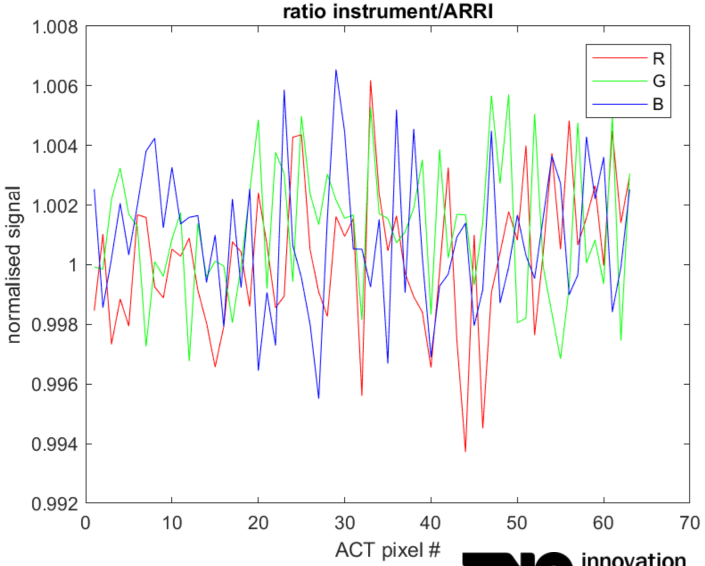


Original image (125 m sampling)







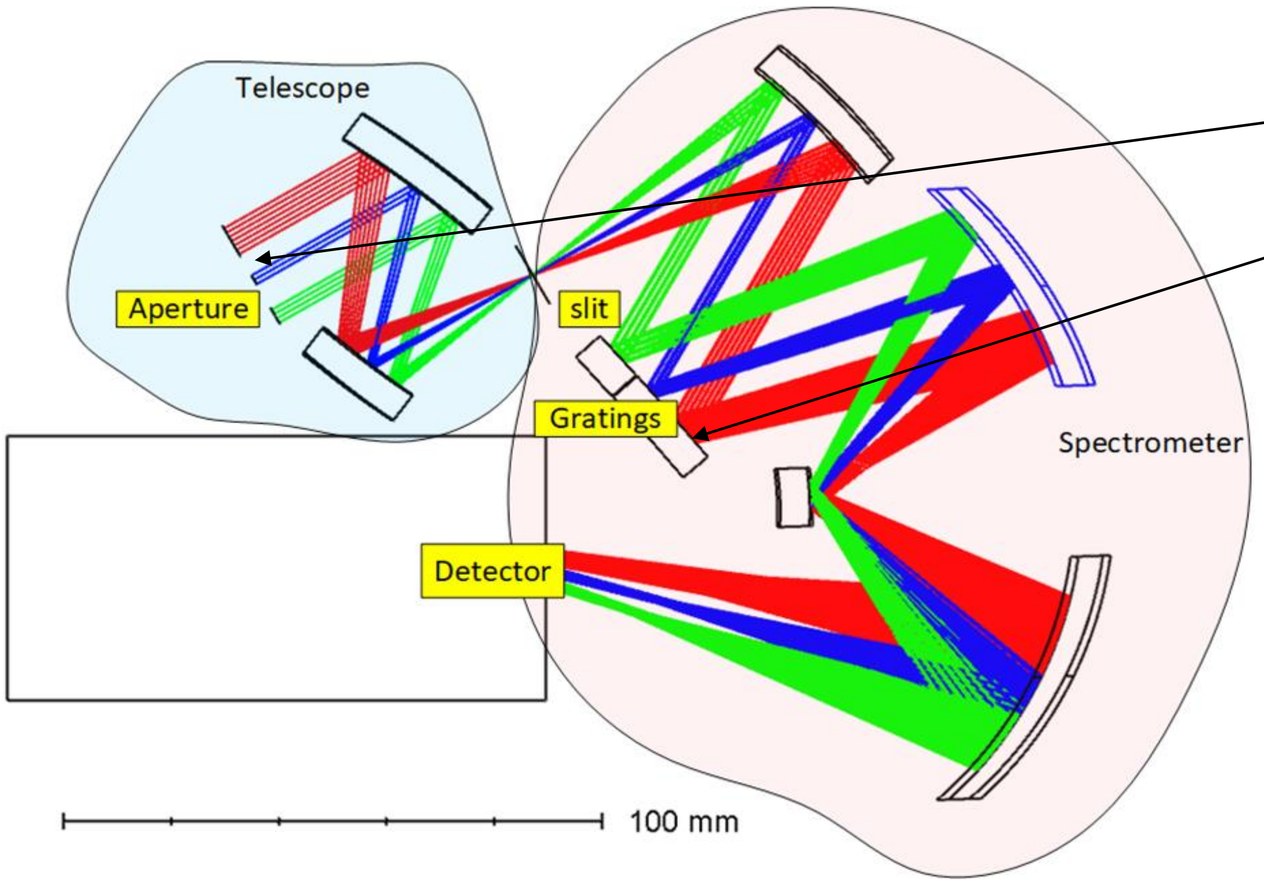


ARRI DESIGN
ASSUMPTIONS AND SPECIFICATIONS

- Low earth orbit.
- The main instruments use a pushbroom strategy.
- The radiometric degradation of the main instrument is not strongly spectrally or spatially dependent. (no high frequent behaviour)

Parameter	Unit	Value	Justification
Altitude	km	800	Similar altitude to Sentinel 5, CO2M, CHIME
Swath	km	150	150 science pixels as a representative case
ACT GSD at nadir	km	1.0	
ALT GSD at nadir	km	35	Maximum temporal misregistration of 5 seconds
Min. wavelength	nm	400	Cover visible band up to shortwave infrared. In this wavelength range the sun is used as reference.
Max. wavelength	nm	2500	
Max. spectral resolution	nm	10-20	Increase towards longer wavelengths.
Min. spectral oversampling	-	1	The value is a compromise to cover the spectral range on a single detector. An oversampling of 2 would have been preferred. For radiometric calibration however it is deemed less important.
Min. spatial oversampling	-	2.0	To enable flexible co-registration
Max. acquisition time	min	30	Well within 1 orbit. This will be composed of multiple time samples.
SNR	-	1000	Within a single orbit. This allows for accurate trend analysis

ARRI DESIGN
OPTICAL DESIGN

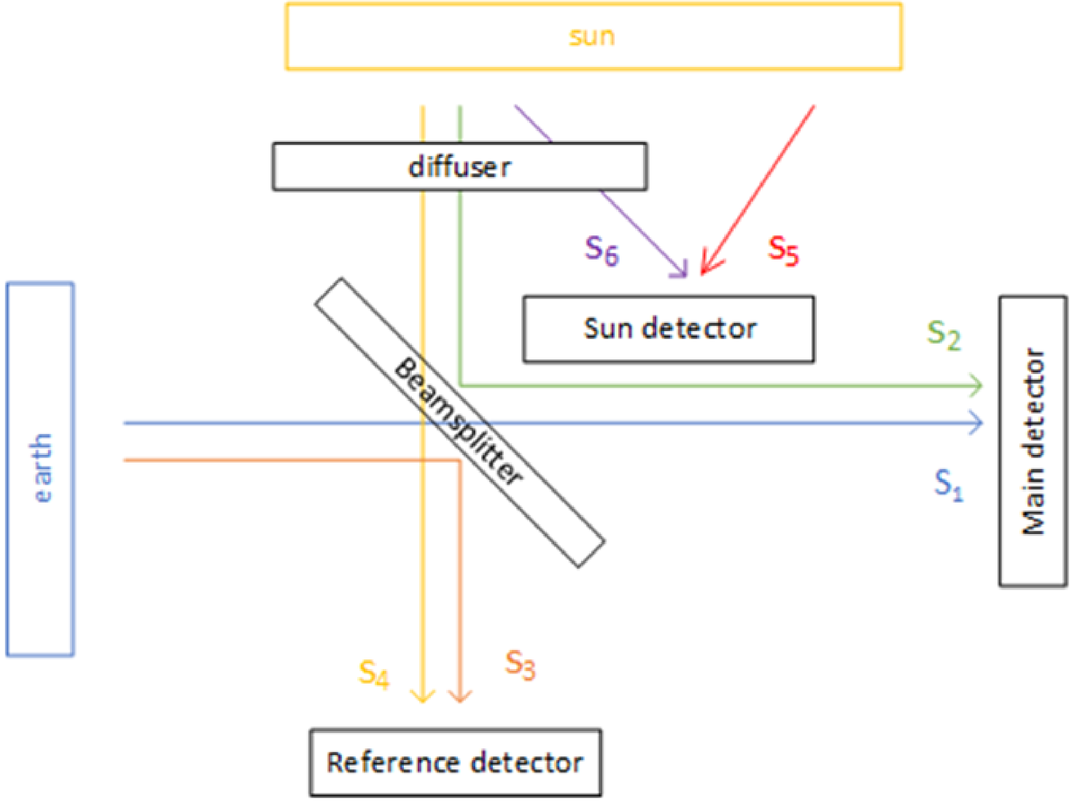


Three apertures for three spectral bands

Three gratings for three spectral bands

Band filters to be implemented

ARRI DESIGN
ON BOARD CALIBRATION APPROACH (PATENT PENDING)



Main detector
S_1 Earth radiance signal
S_2 Sun irradiance (via diffuser) signal

Reference detector
S_3 Earth radiance signal
S_4 Sun irradiance (via diffuser) signal

Sun detector
S_5 Sun irradiance signal
S_6 Sun irradiance (via diffuser) signal

ARRI DESIGN

BIT OF MATH

Sun observation

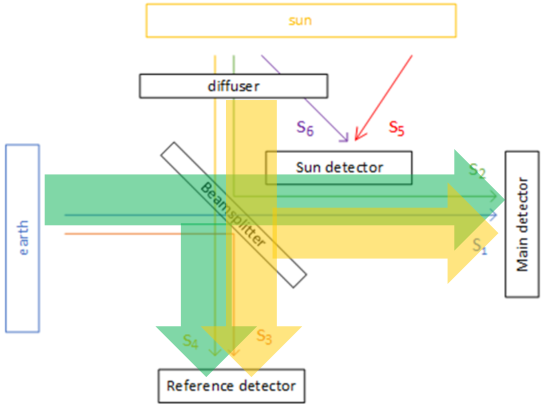
$$S_2(\theta,\lambda) = e_{sun}(\lambda)\, BSDF(\theta,\lambda)\, R(\theta,\lambda)\ \ H_s(\theta,\lambda)$$
$$S_4(\theta,\lambda) = e_{sun}(\lambda)\, BSDF(\theta,\lambda)\, T(\theta,\lambda)\ \ H_r(\theta,\lambda)$$

$$S_1(\theta,\lambda) = L_{earth}(\theta,\lambda)\, T(\theta,\lambda)\, H_s(\theta,\lambda)$$
$$S_3(\theta,\lambda) = L_{earth}(\theta,\lambda)\, R(\theta,\lambda)\, H_r(\theta,\lambda)$$

Earth observation

$$\frac{L_{earth}(\theta,\lambda)}{e_{sun}(\lambda)} = \frac{S_1(\theta,\lambda)}{S_2(\theta,\lambda)} \frac{BSDF(\theta,\lambda)\, R(\theta,\lambda)}{T(\theta,\lambda)}$$

$$\frac{L_{earth}(\theta,\lambda)}{e_{sun}(\lambda)} = \frac{S_3(\theta,\lambda)}{S_4(\theta,\lambda)} \frac{BSDF(\theta,\lambda)\, T(\theta,\lambda)}{R(\theta,\lambda)}$$



$$RT(\theta,\lambda) = \frac{R(\theta,\lambda)}{T(\theta,\lambda)} = \sqrt{\frac{S_3(\theta,\lambda)\, S_2(\theta,\lambda)}{S_4(\theta,\lambda)\, S_1(\theta,\lambda)}}$$

ARRI DESIGN

BIT OF MATH

Sun observation

$$S_5(\lambda) = e_{sun}(\lambda)\ \cos(\phi_5)\, H_{sr}(\lambda)$$

$$S_6(\lambda) = e_{sun}(\lambda)\ \cos(\phi_6)\, BSDF(\theta,\lambda)\ \ G\, H_{sr}(\lambda)$$

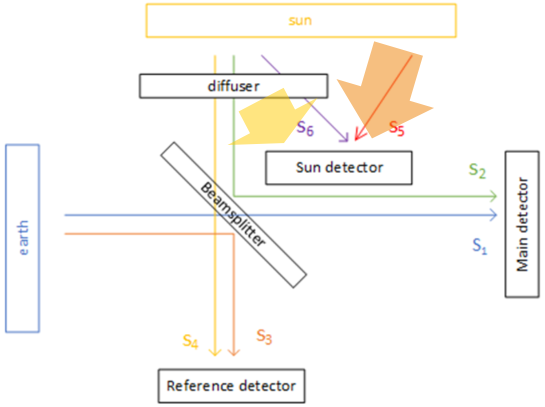
Direct sun illumination
(can be anywhere during earth observation)

$$BSDF(\theta,\lambda) = \frac{S_6(\lambda)\cos(\phi_5)}{S_5(\lambda)\cos(\phi_6)} G(\theta)$$

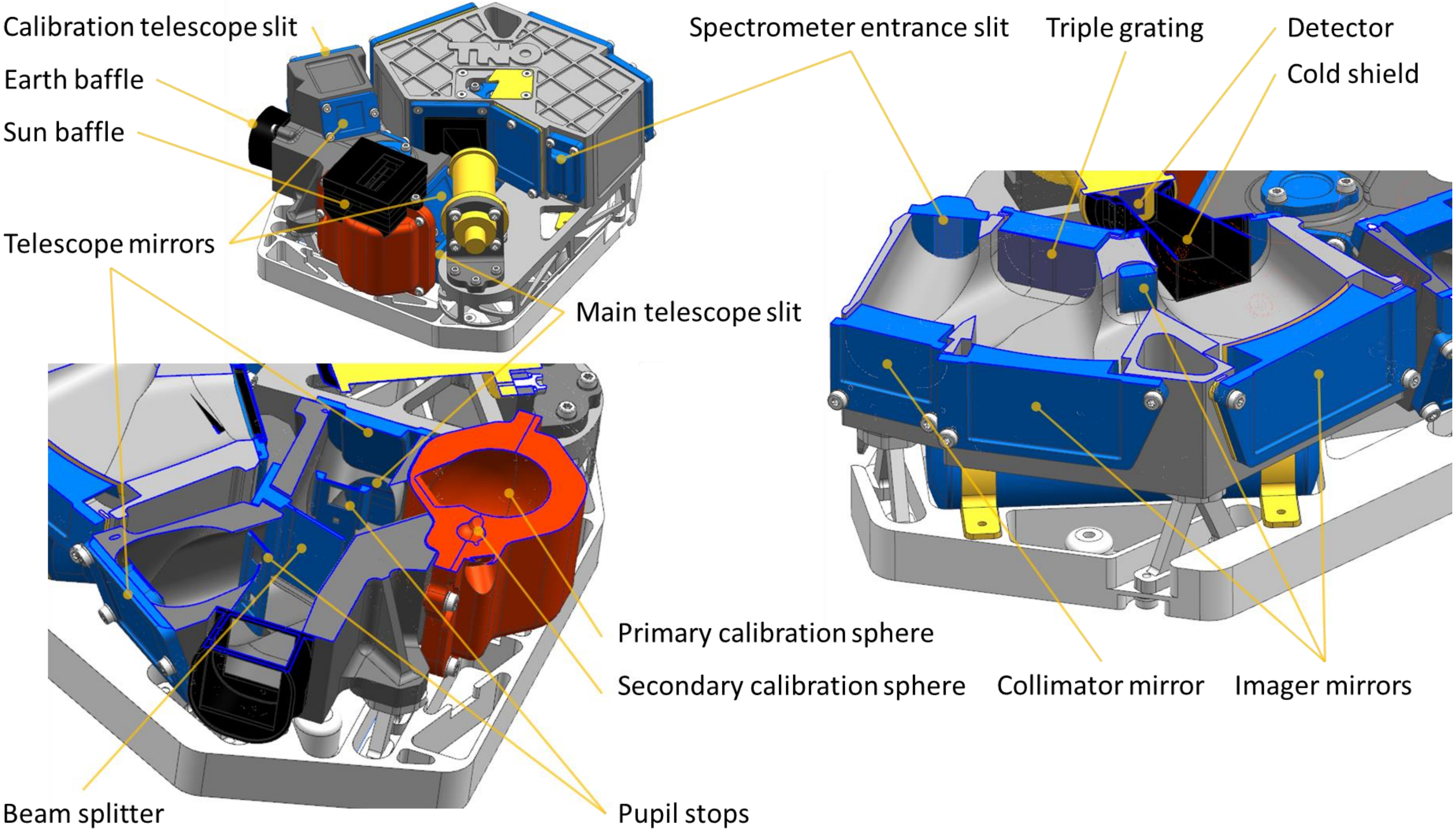
Geometrical factors

$$\frac{L_{earth}(\theta,\lambda)}{e_{sun}(\lambda)} = \frac{S_1(\theta,\lambda)}{S_2(\theta,\lambda)}\sqrt{\frac{S_3(\theta,\lambda)\,S_2(\theta,\lambda)}{S_4(\theta,\lambda)\,S_1(\theta,\lambda)}}\,BSDF(\theta,\lambda)$$

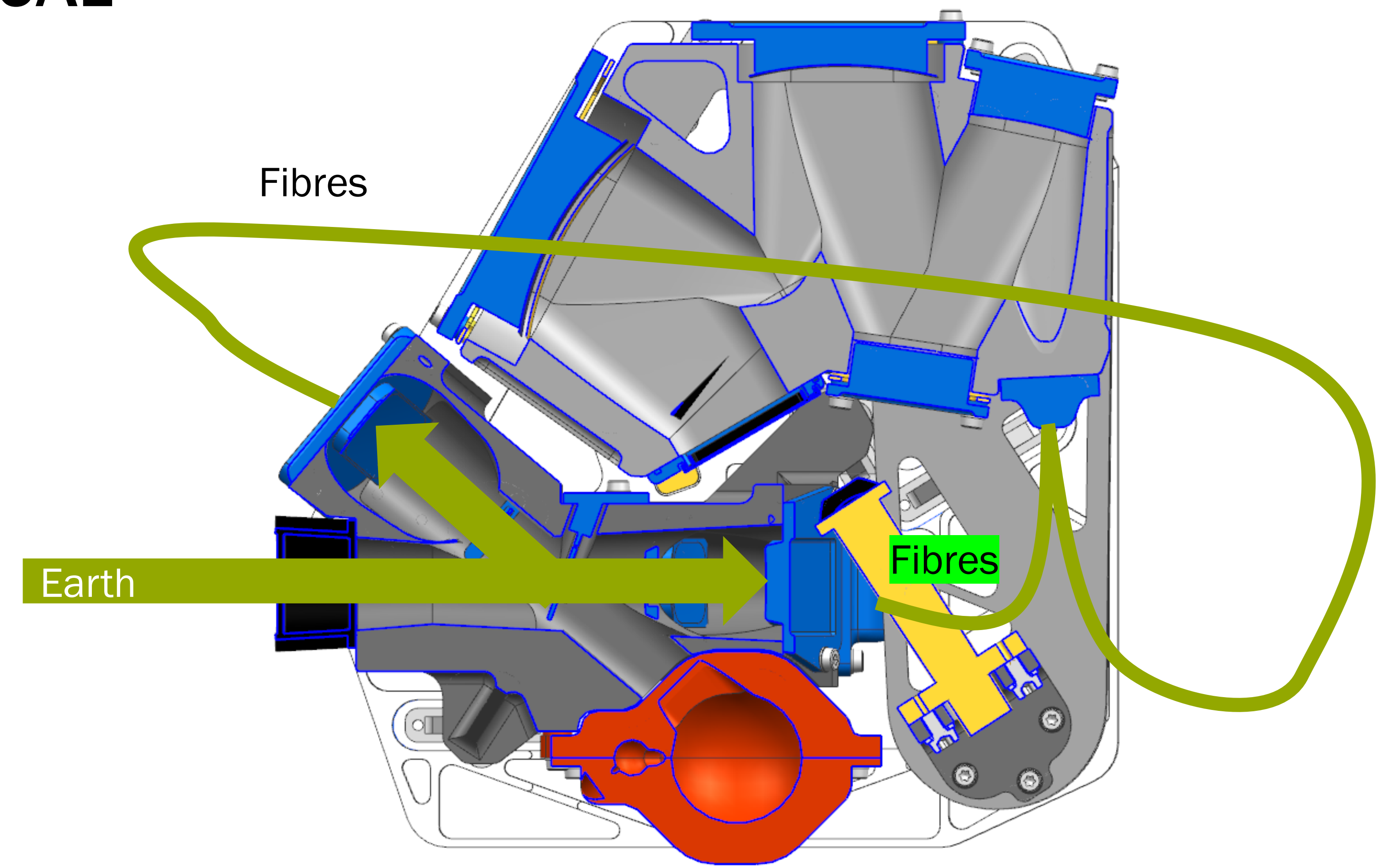
$$\frac{L_{earth}(\theta,\lambda)}{e_{sun}(\lambda)} = \sqrt{\frac{S_3(\theta,\lambda)\,S_1(\theta,\lambda)}{S_4(\theta,\lambda)\,S_2(\theta,\lambda)}\frac{S_6(\lambda)\cos(\phi_5)}{S_5(\lambda)\cos(\phi_6)}}\,G(\theta)$$



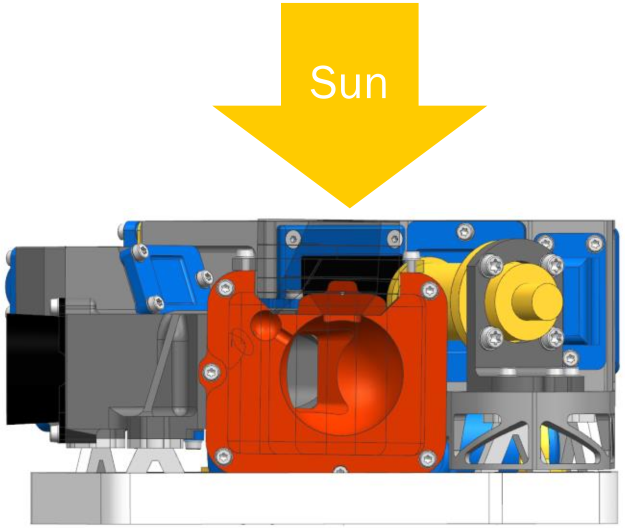
ARRI DESIGN
MECHANICAL

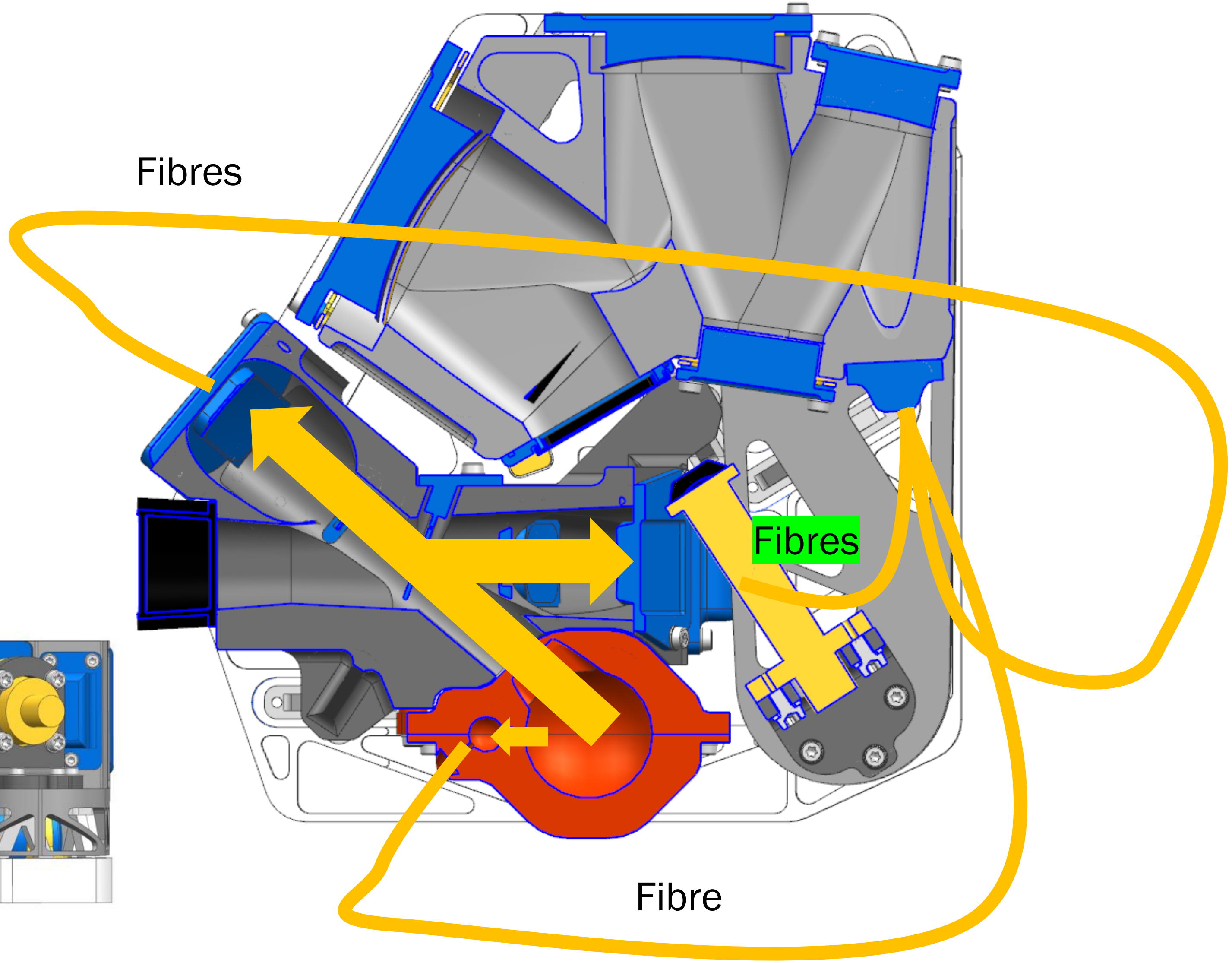


ARRI DESIGN
MECHANICAL

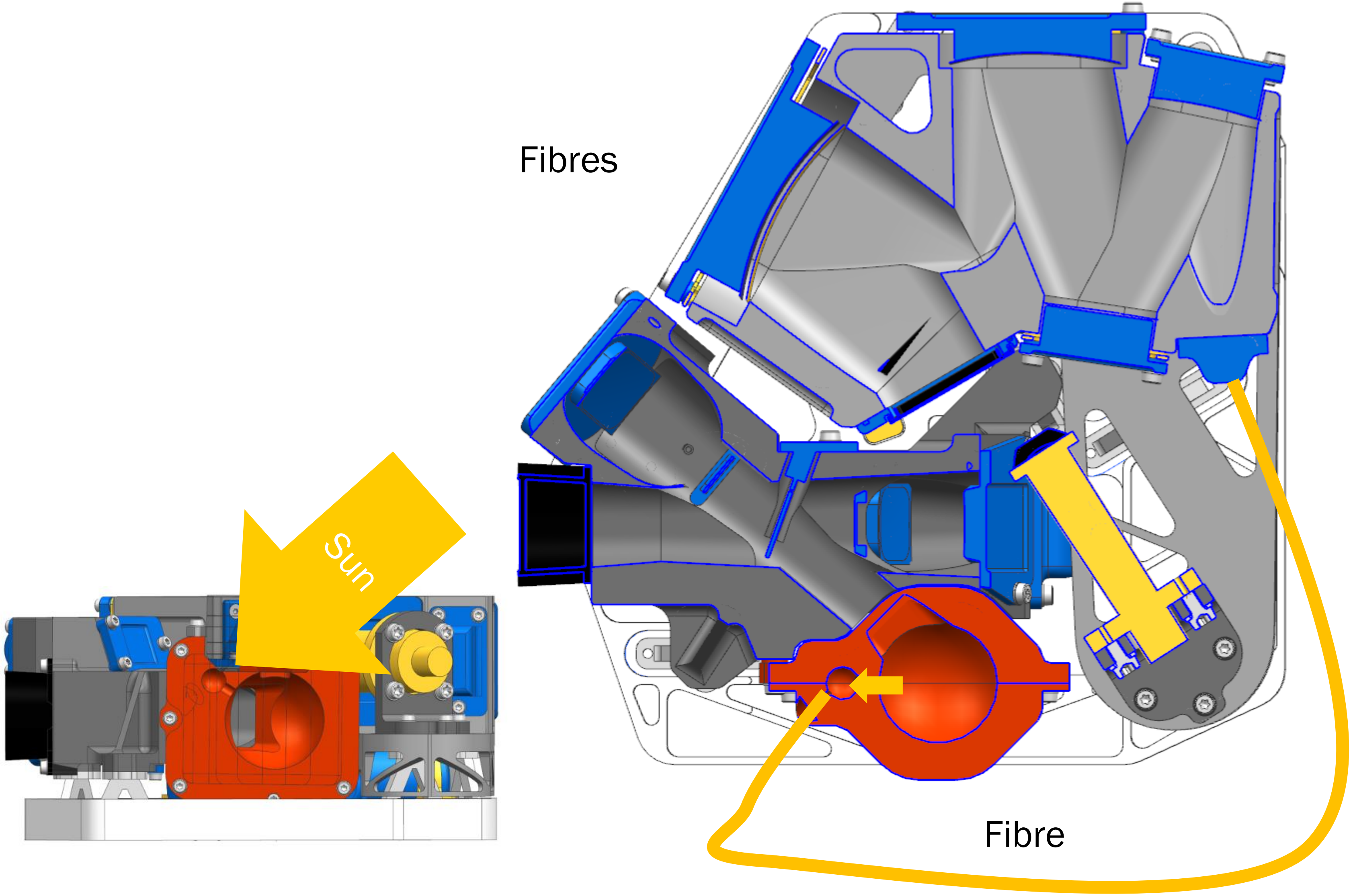


ARRI DESIGN
MECHANICAL





ARRI DESIGN
MECHANICAL

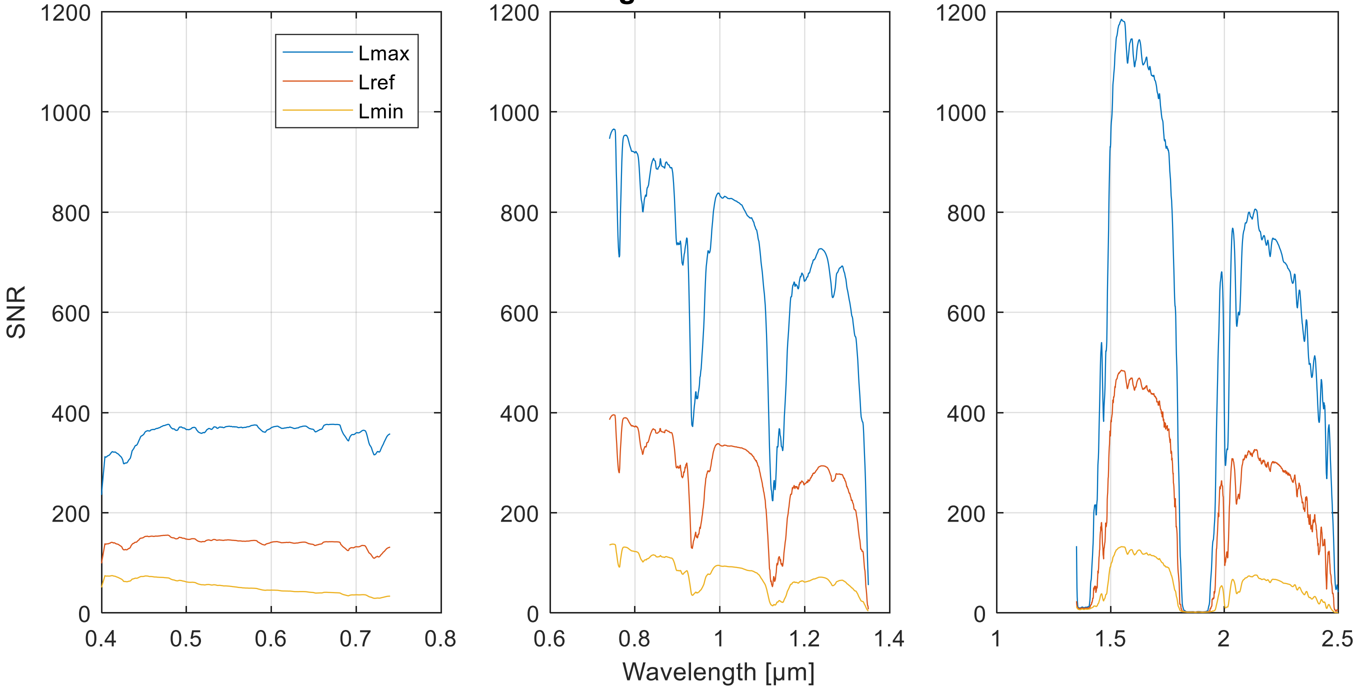


ARRI PERFORMANCE
SNR AND RADIOMETRIC UNCERTAINTY

$$\frac{L_{earth}(\theta,\lambda)}{e_{sun}(\lambda)} = \sqrt{\frac{S_3(\theta,\lambda)\, S_1(\theta,\lambda)}{S_4(\theta,\lambda)\, S_2(\theta,\lambda)}}\, \frac{S_6(\lambda)}{S_5(\lambda)}\, \frac{\cos(\phi_5)}{\cos(\phi_6)}\, G(\theta)$$

Based on CHIME phase A/B1 spectra

Assuming Max IT = 0.9 seconds



4xSNR 1000 -> 0.2%

2xSNR 1000 -> 0.14%

Geometrical knowledge
Negligible error

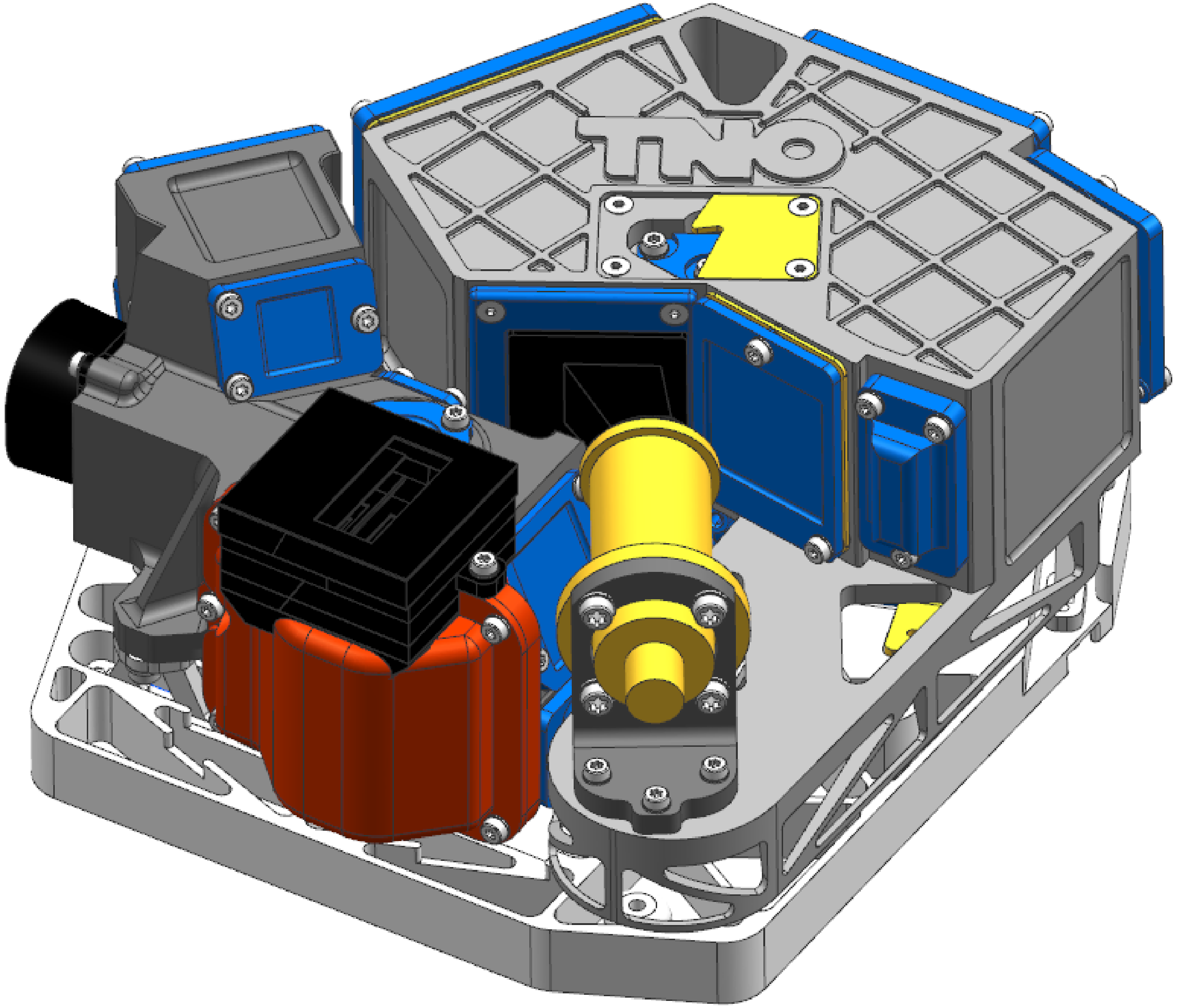
Based on on-ground characterisation
0.8%

Inter instrument comparison 0.2%

Radiometric uncertainty main instrument 0.86%

CONCLUSION

- It is possible to have a small instrument (4 U) providing a radiometric reference.
- Uncertainty of less than 1% seems feasible
- In orbit strategies can still be further improved



THANK YOU FOR YOUR TIME

TNO innovation for life