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TAKING THE PULSE OF OUR PLANET FROM SPACE

A MULTI-MODAL SMALL SATELLITE INSTRUMENT FOR MONITORING PHYTOPLANKTON

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24th May 2022

Introduction

- ESA study to develop concepts for future passive sensing optical Earth observation missions using small (<150Kg) satellites – tailored ECSS compliant
- Instrument concept for covariance analysis of SST and chlorophyll, an indicator of phytoplankton population and ocean health
- Team
  - S/C System: SSTL
  - User requirements, simulated instrument assessment & retrieval capability:
  - Bob Brewin University of Exeter, Joshua Van der Hey University of Leicester

SURREY SATELLITE TECHNOLOGY LTD

UNIVERSITY OF EXETER

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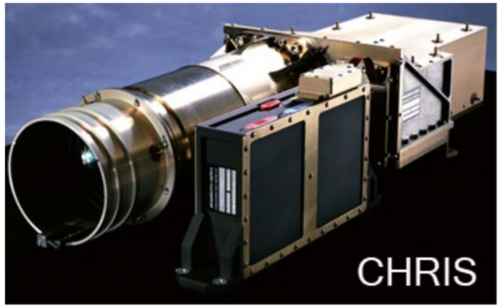
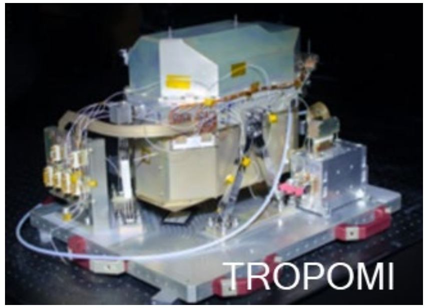
SSTL optical instrument heritage

SSTL Optical Payload Group significant Earth Observation experience:

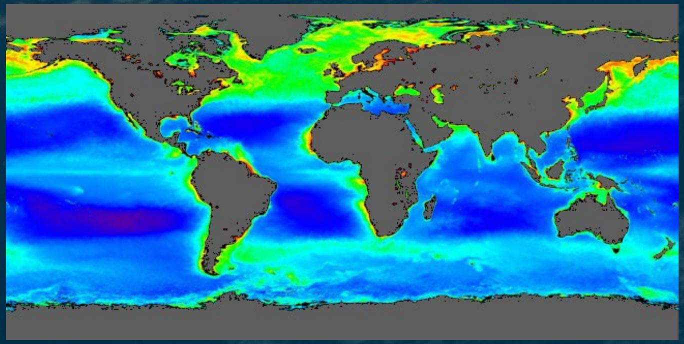
- CHRIS (2001) still operating now on PROBA-1 (SSTL OPG was part of SIRA)
- TROPOMI (2017) on S-5P
- NIRSpec - IFU for JWST (delivered in 2006, launched 2021)
- EarthCARE MSI due for launch 2023

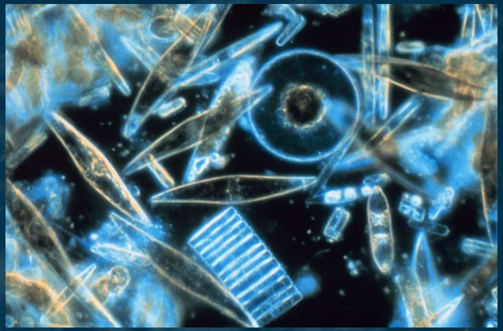


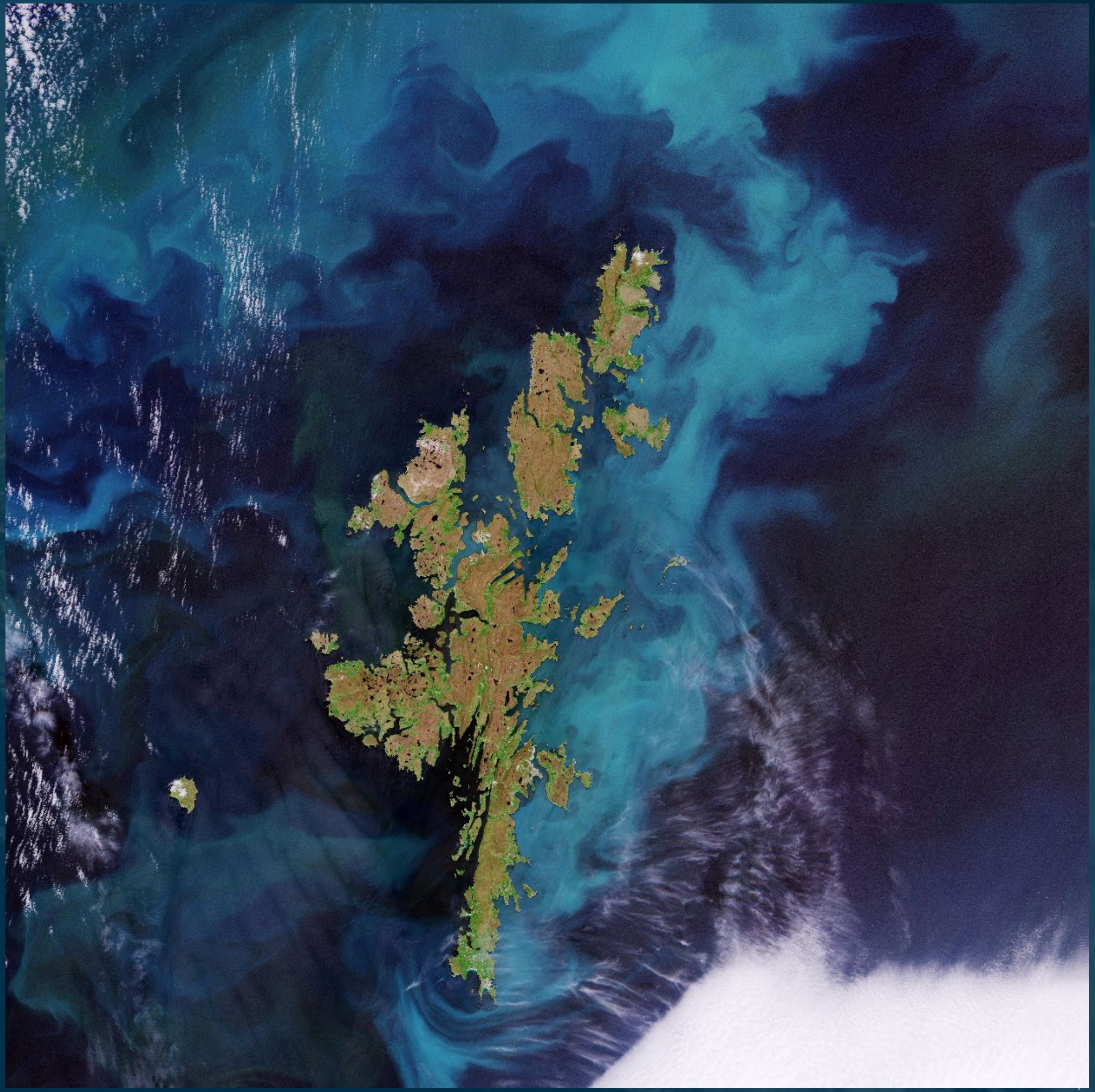


Phytoplankton

- Half of all photosynthesis on the planet, carbon sink
- Represent biomass, and are very crucial as a measure as they drive productivity in the ocean
- Sensitive to temperature changes in seawater
- Satellite imagery + in-situe measurement

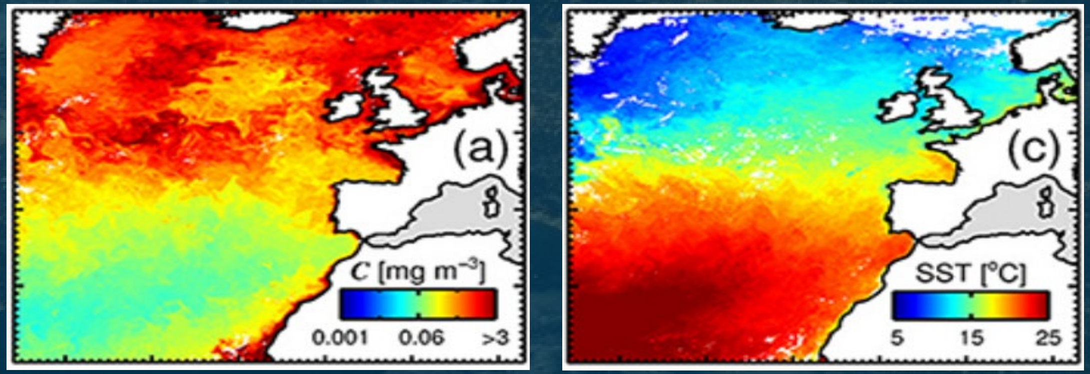






Science case

- Global Climate Observing System (GCOS) recommends (that daily temporal coverage for applications like climate studies is necessary (WMO 2016)
- Covariance analysis of sea temperature and chlorophyll: links phytoplankton population change to rising sea temperatures – direct impact of climate change on ocean health



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  - Phytoplankton are a good indicator of ocean health
- Satellite primary production models (synthesis of organic compounds) require information on phytoplankton biomass from ocean-colour

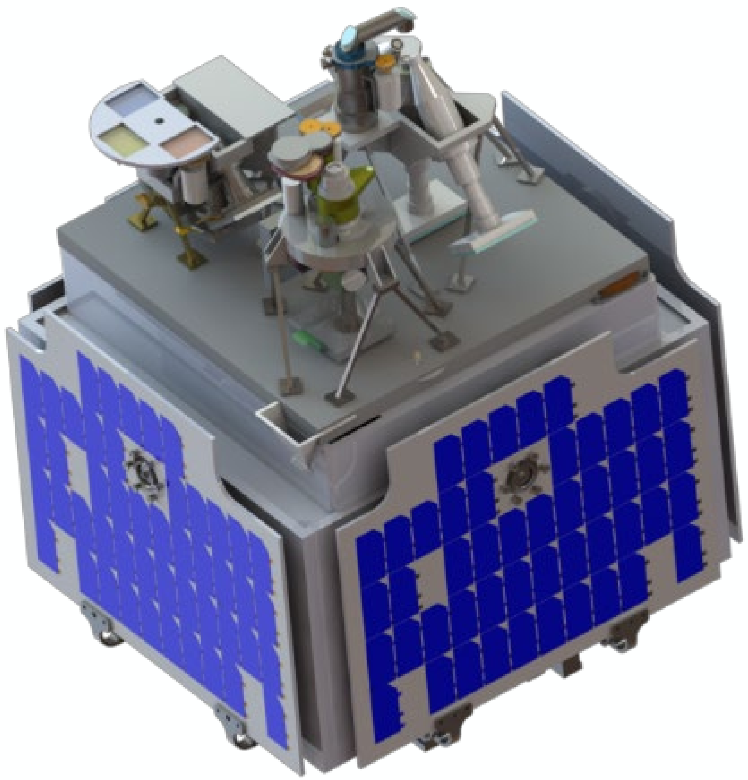
**Brewin et al (2015)

Science case

- Phytoplankton physiology and resources can be inferred from SST
- Combining two data streams can be used to improve retrievals in each
- **Simultaneous** estimates of **Sea Skin Temperature** and **Ocean Colour** helps with retrievals in both data streams:
  - Ocean colour helps improve emissivity estimates in turbid waters
  - SST can improve phytoplankton type retrievals from ocean colour
- **Synergistic** use of **Sea Skin Temperature** and **Ocean Colour** can improve understanding and retrievals of air-gas exchange:
  - SST modulates transfer of gases (e.g. CO_2) between ocean and atmosphere. Ocean colour helps quantify flux of gases between ocean and atmosphere
- Removal of atmospheric effects of aerosols gives better ocean colour products. Multi-angular spectro-polarimeters provide more precise information about absorbing aerosols (**Aerosol Optical Depth**), which are prevalent over large oceanic areas:
  - Better ocean colour product than NIR waveband data used in atmospheric model

Oracle satellite

- SSTL 35 year heritage: COTS design (tailored) ECSS compliant satellite
- Oracle satellite: SSTL-Micro platform (ESA Scout HydroGNSS)
- Orbit: SSO at 561km
- Volume: 0.4m^3
- Data-rate: >160Mbps
- Total wet mass: 77kg
- Mission lifetime: 7 years

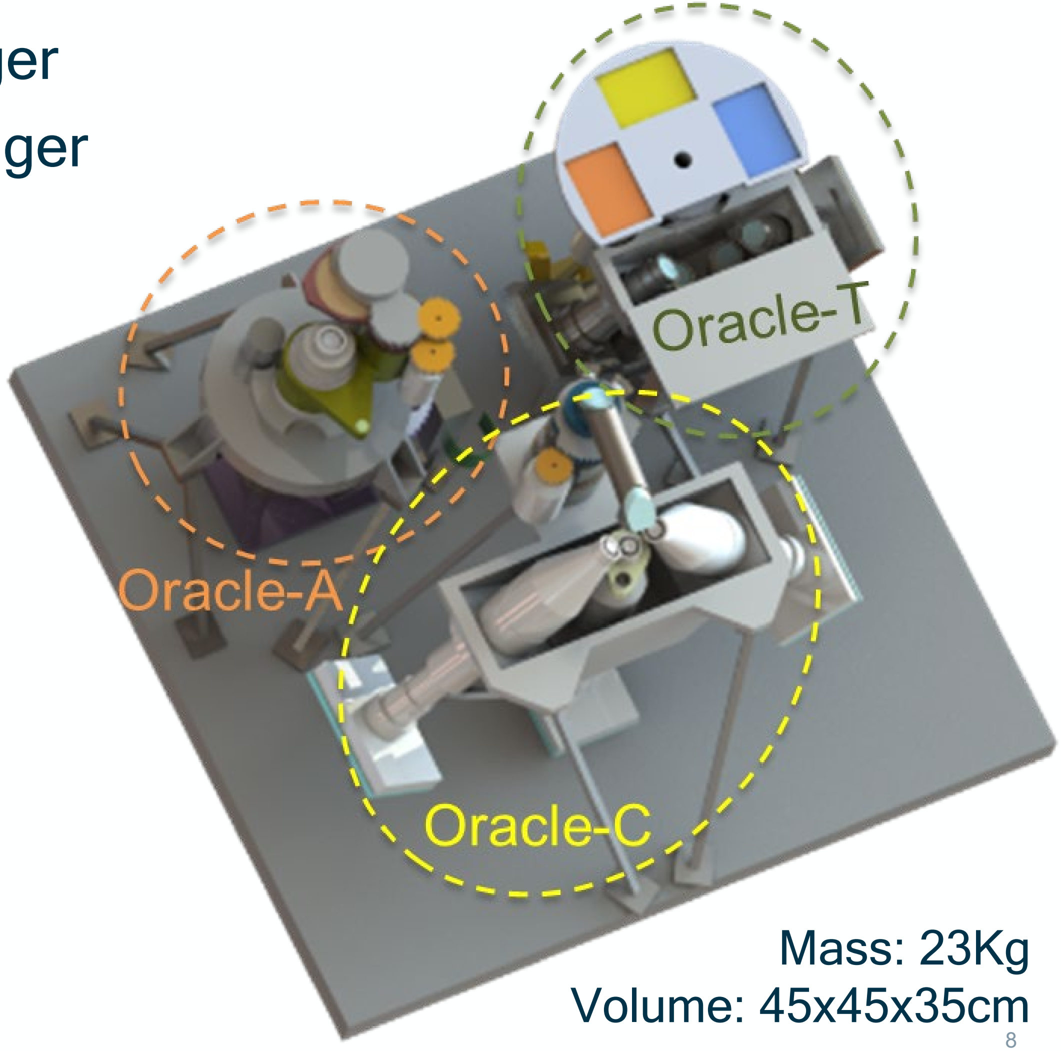


Oracle payload

- Oracle payload consists of three instruments:
  - Oracle-C: multi-spectral pushbroom colour imager
  - Oracle-T: multi-spectral pushbroom thermal imager
  - Oracle-A: multi-spectral polarimetric imager
- Simultaneous imaging with same swath
- First time on a small satellite

Parameter	Oracle-C	Oracle-T	Oracle-A
Focal length (mm)	30.8	31.7	6.2
F-number	3.3	2.0	5.1
ACT pixels	11520	3840	1280
GSD (m)	100	300	900
Swath (km)	1152	1152	1152
Multispectral bands	8	3	11*
Mass (Kg)	8.0	7.8	5.7
Viewing angles	-	-	7

*polarised radiance



Mass: 23Kg
Volume: 45x45x35cm

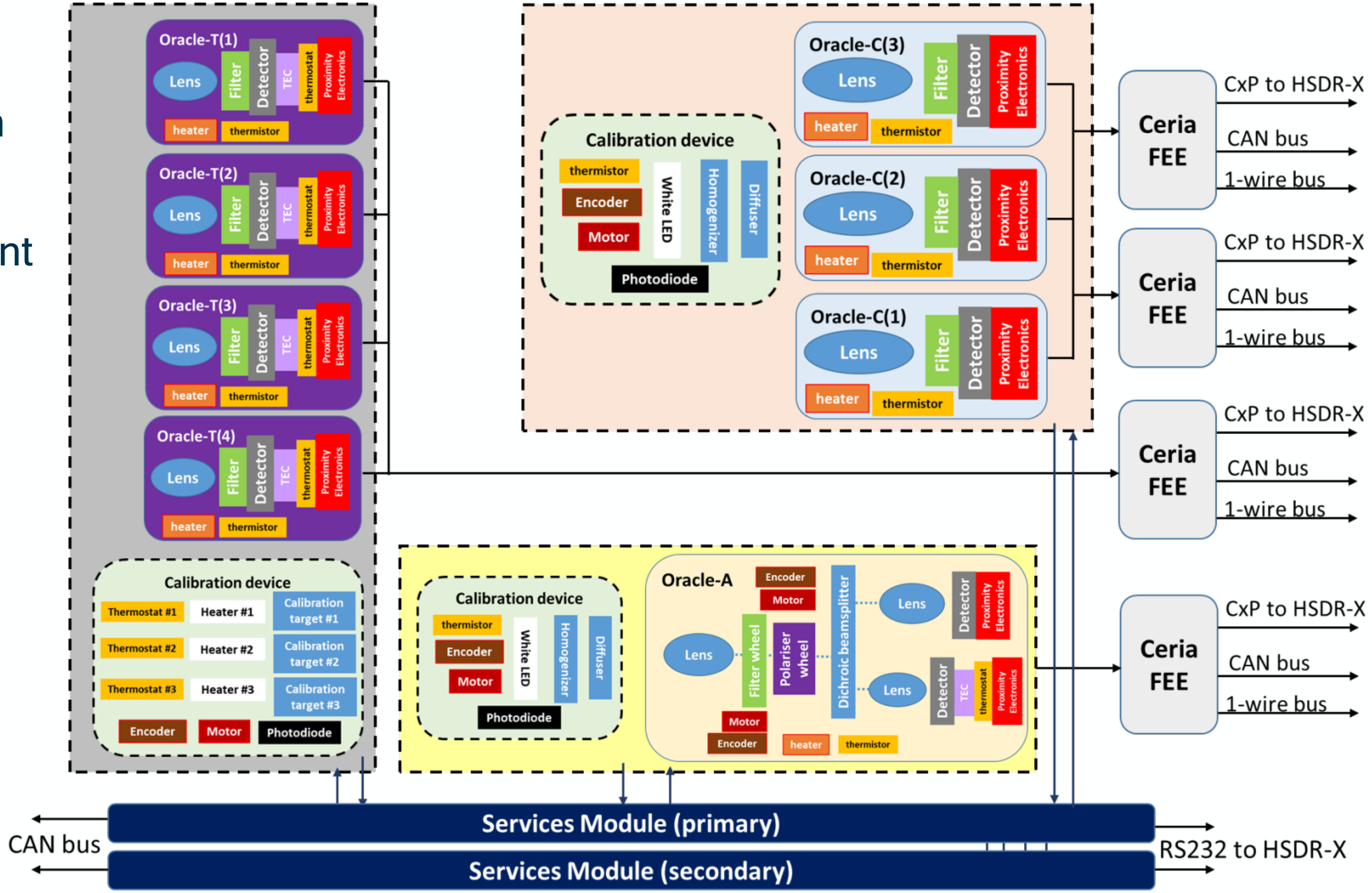
Oracle instrument architecture

esa

All imagers use:

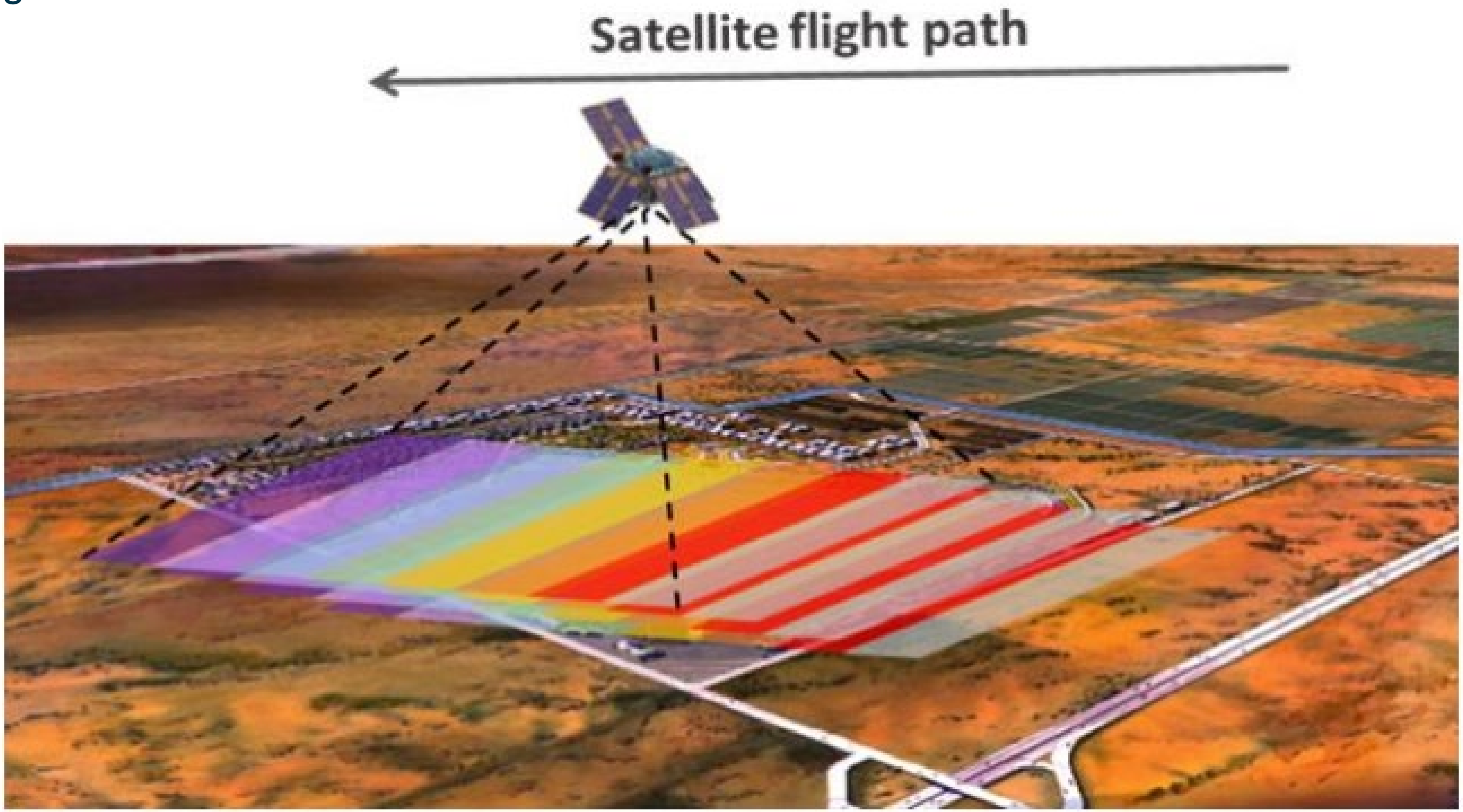
- Common, dual redundant SSTL Ceria Front-End Electronics (FEE)
- SSTL Services Module, dual redundant
- Individual internal calibration

Total power consumption: <61W



Oracle-C Imaging Mode

Pushbroom, fixed bands



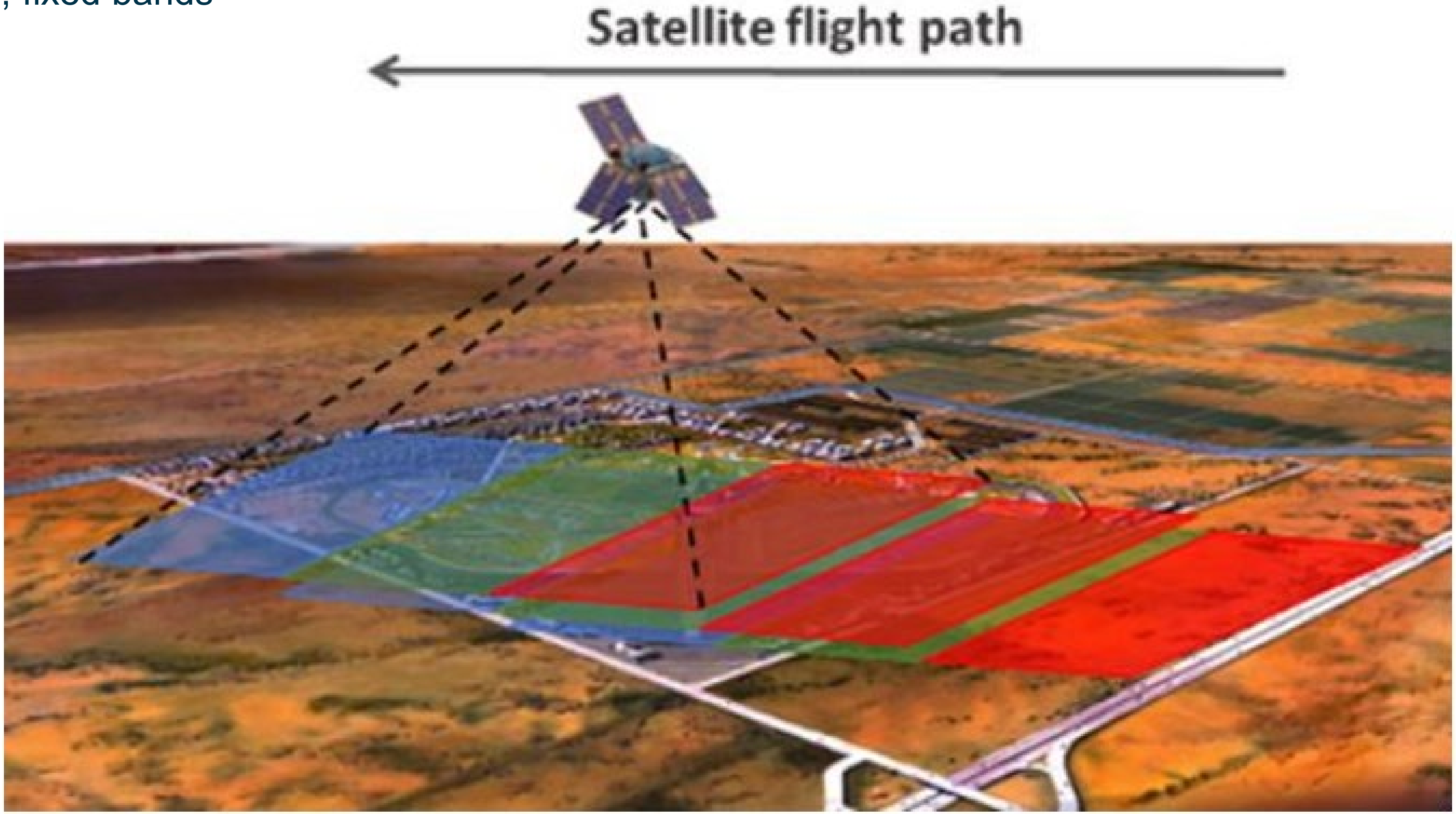
Oracle-C

- 3 self-contained sub-imagers mounted across track for increased swath
- COTS detectors format size limit
- Pushbroom imaging requires off-chip TDI with 123 along track pixels
- Internal calibration device used simultaneously by all 3 sub-imagers and moved in/out of field of view

Parameter	Value
Focal length	30.8mm
F-number	3.3
ACT pixels	11520
GSD	100m
Swath (at 561km)	1152km
Multispectral bands	8
Frame rate	76Hz

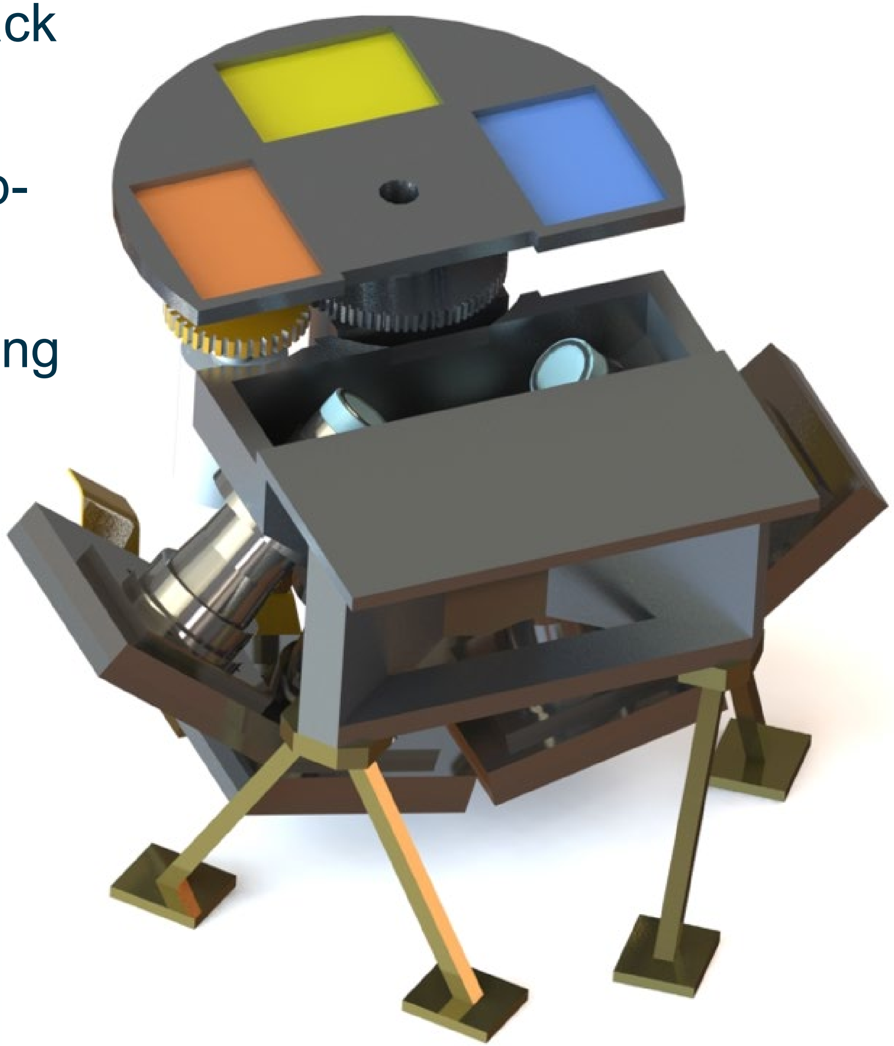
Oracle-T Imaging Mode

Pushbroom, fixed bands



Oracle-T

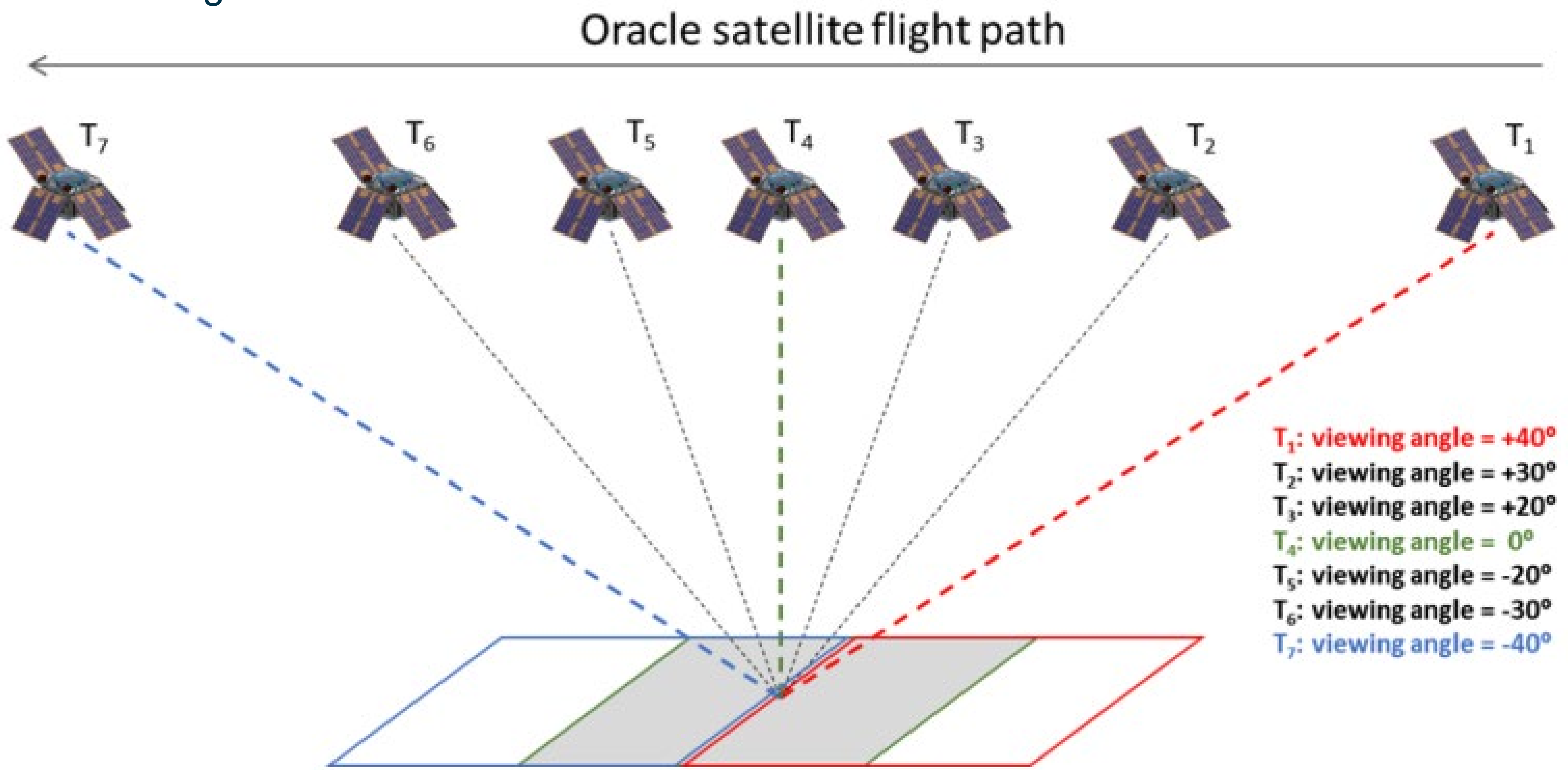
- Consists of 4 self-contained sub-imagers mounted across track for increased swath
- Internal calibration device is used simultaneously by all 4 sub-imagers, moved in/out of field of view, to counteract drift
- Pushbroom imaging requires off-chip TDI with 60 stages (along track pixels)



Parameter	Value
Focal length (mm)	31.7
F-number	2.0
ACT pixels	3840
GSD (m)	300
Swath (km)	1152
Multispectral bands	3
Frame rate (Hz)	25

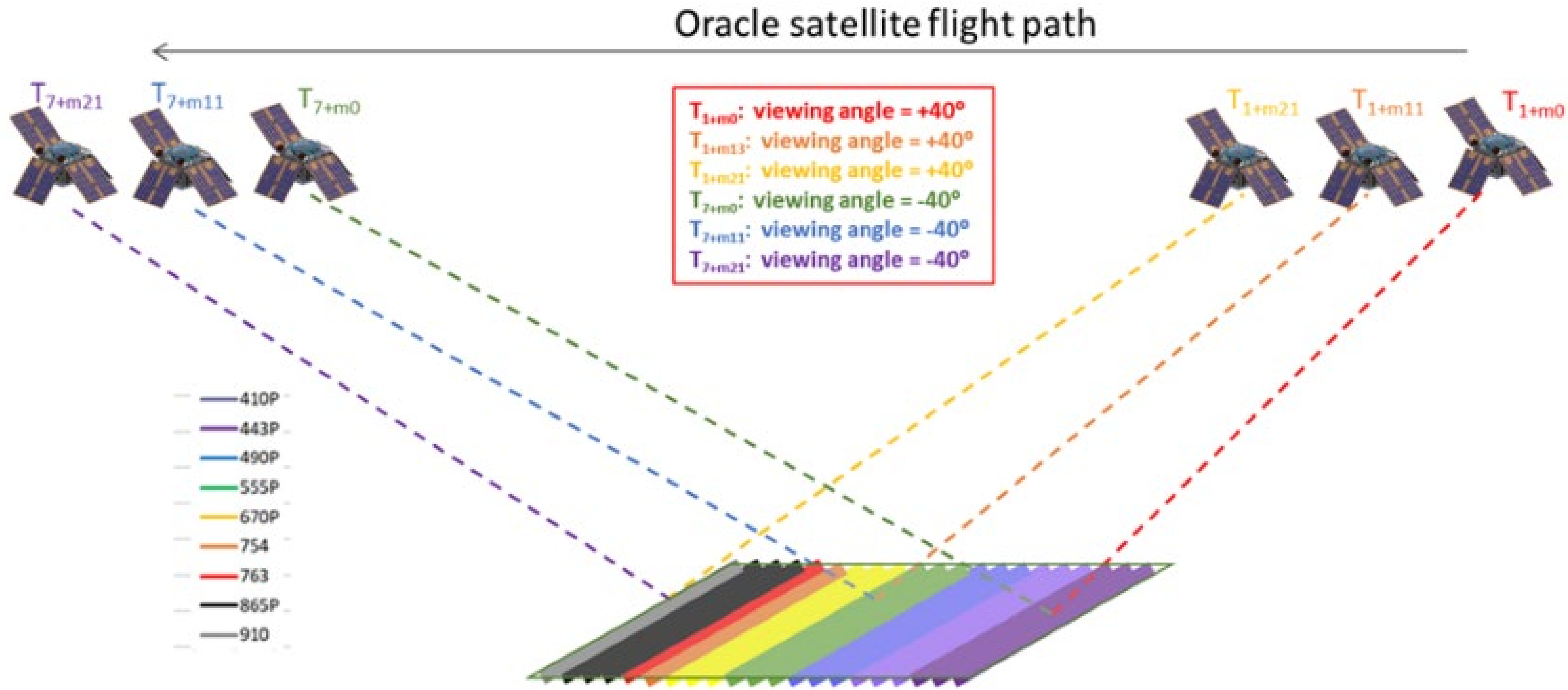
Oracle-A Imaging Mode

Seven observation angles



Oracle-A 8 Bands

8 Fixed Spectral Bands



Oracle-A

- Calibration device moves in/out of field of view prior to retrieval session
- Operation is same as POLDER/3MI (Adeos 1/2 / Parasol) – rotating filters

Parameter	VNIR	SWIR
Focal length (mm)	6.8	6.2
F-number	5.6	5.1
ACT pixels	1280 (2x binned)	1280
GSD (m)	900	900
Swath (km)	1152	1152
Multispectral bands**	9*	3*
Frame rate (Hz)	9	9

*910nm is in both bands to allow cross-correlation
**some bands are polarised same as 3MI

Viewing angles	-40º, -30º, -20º, nadir, +20º, +30º, +40º
Polarisation angles	-45º, 0º, +45º
Polarisation sensitivity	0.976

Oracle performance summary

- SNR for Ocean colour optical bands of >417 is sufficient, Oracle A atmospheric
- Radiometric accuracy <5% sufficient, after calibration device 'pre-devs'
- Fits into SSTL-42: mass, size, data Tx and power consumption

  4000km imaging per orbit (600s)

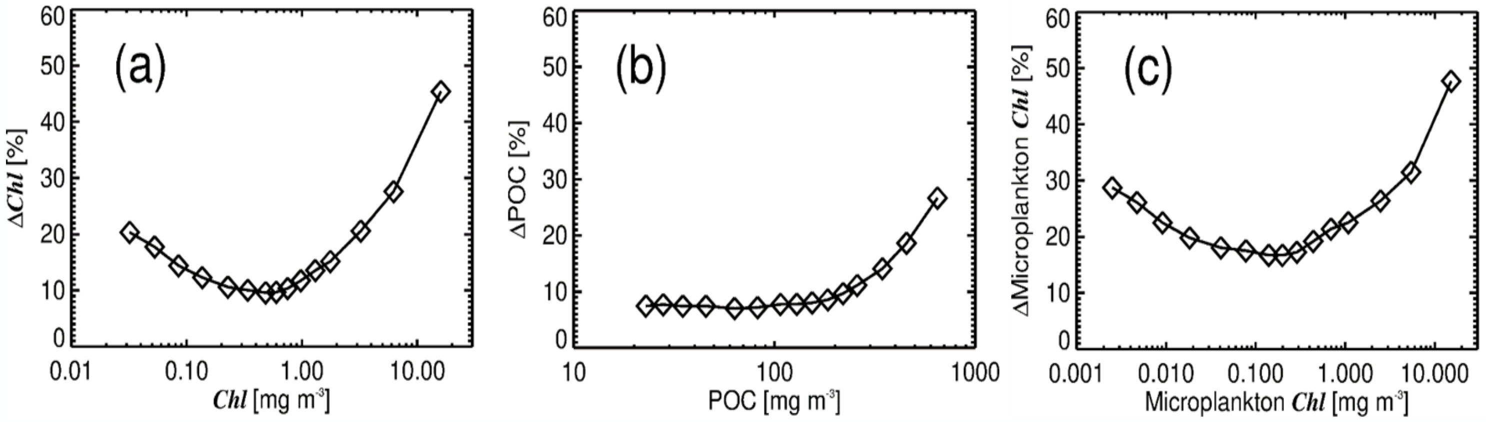
Parameter	Oracle-C		Oracle-T		Oracle-A	
	Requirement	Modelled	Requirement	Modelled	Requirement	Modelled
GSD (at 561km SSO)	100m	100m	300m	300m	900m	900m
Multispectral bands	8	8	3	3	11	11
Min. MTF at Nyquist	0.1	0.17	0.1	0.12	0.1	0.31
Min. SNR	400	417*	-	-	200	261**
Max. NETD @ 300K	-	-	0.5K	0.5K	-	-
Polarisation sensitivity	-	<0.07	-	-	>0.95	0.97
Radiometric accuracy	5%	13%	5%	10%	5%	15%

*OLCI Lref
**3MI Lref

User assessment

- Chlorophyl (Chl) concentration, Particulate Organic Carbon (POC) concentration and microplankton Chl estimated using the ocean colour models to asses expected changes in ocean colour product uncertainty
  - OC3 (SeaWiFS) algorithm
  - Brewin Microplankton Chl algorithm
  - Stramski POC algorithm
- Model parameters varied by producing a Gaussian probability distribution and assumed 5% uncertainty in model parameters,
- Ocean colour products are good, i.e. relatively small uncertainty for most of the range in all three

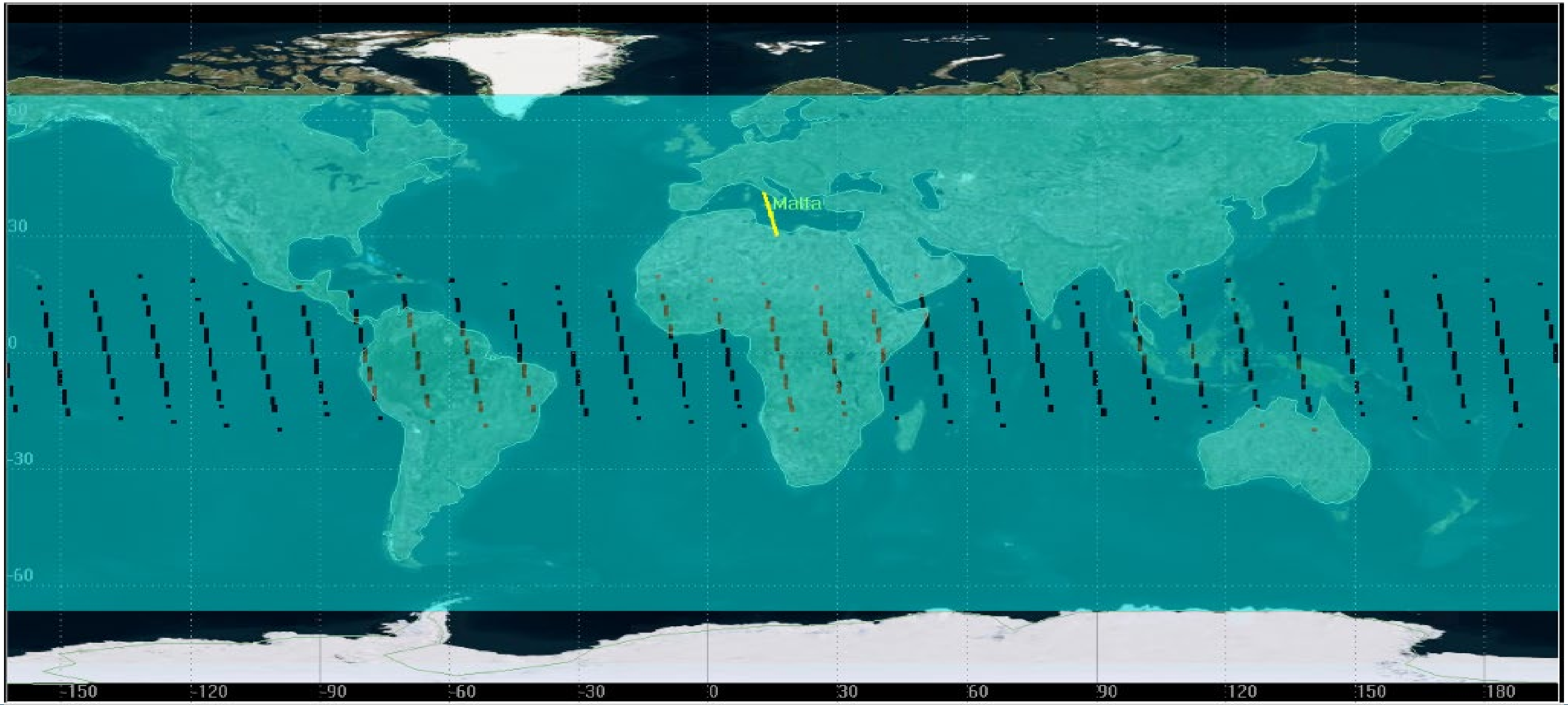
Product Uncertainty (%)



Chl, POC, microplankton concentrations

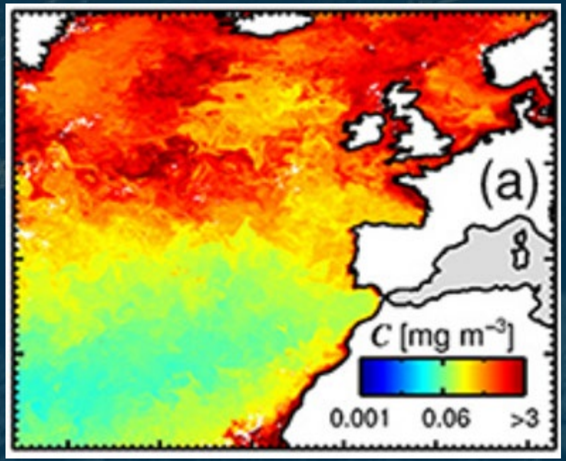
Oracle orbit and coverage

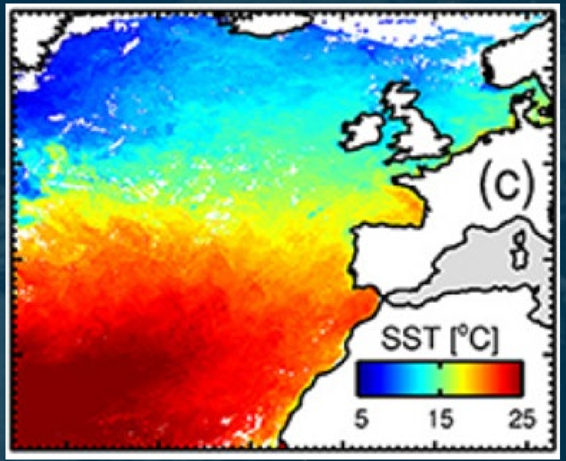
- Global coverage requires 16-satellite constellation at 561km SSO for 8 evenly spaced sub-daily accesses

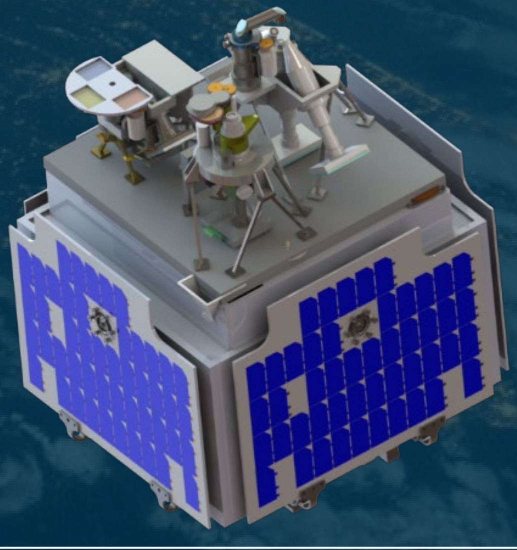


Conclusions

- GCOS high temporal resolution achieved by 16-satellite constellation allows 8 regular daily accesses globally, provides sub daily datasets
- Quality requirements met: ocean colour SNR >400, TOA brightness uncertainty <0.5k
- Affordable constellation could provide complimentary datasets with temporal coverage
- Better understanding of ocean health via examination of phytoplankton populations
- Next steps: expand work to derisk calibration approach and algorithms for L2 products, validate system design and progress with partners







Thank you

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