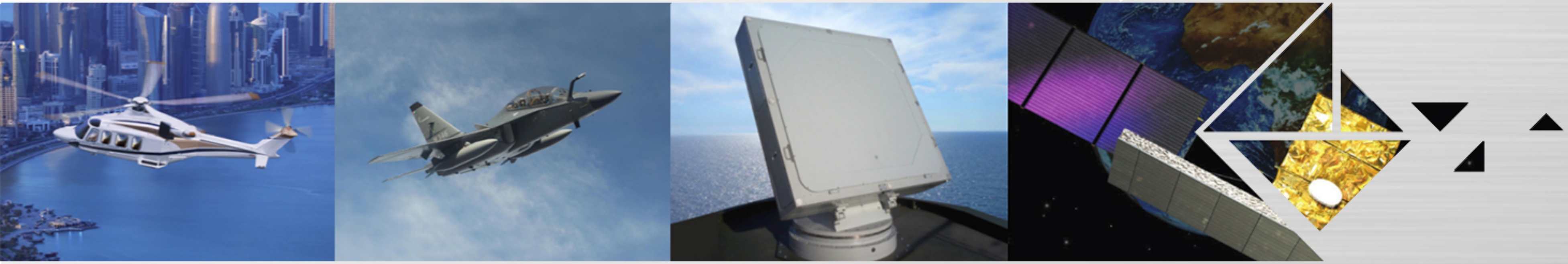
New High Performance Infrared Detectors for Space

CENTRE FOR EARTH OBSERVATION INSTRUMENTATION
EMERGING TECHNOLOGIES WORKSHOP

Keith Barnes – Programme Manager, Science business segment

2ND MAY 2019



LEONARDO

Presentation Outline

- Overview of Leonardo Company
- Infrared Detectors Business and technology
- Space Heritage
- Detector developments for Current flight programmes
- Detector pre-developments
- COTS detectors for space imaging
- Technology developments
- Conclusions

2018 Results (€bn)

A top 10 Global Defence & Aerospace Company

Leonardo is a global high-tech company and one of the key players in Aerospace, Defence and Security worldwide.

Divisions


Helicopters


Aircraft


Aerostructures


Electronics


Cyber Security

Subsidiaries/Joint Ventures

Leonardo DRS
100% Leonardo

Telespazio
67% Leonardo
33% Thales

Thales Alenia Space
67% Thales
33% Leonardo

MBDA
37.5% BAE Systems
37.5% Airbus Group
25% Leonardo

ATR
50% Leonardo
50% Airbus Group

12.4
Revenue

36.1
Order backlog

15.3
New orders

Major UK presence

Edinburgh
Radar, Lasers , Infra-Red Counter Measures, Electro-Optic Targeting

Luton and Lincoln
Defensive Aid Suites, Radar Warning Receivers, Jammers, EW Cyber, EW Training, Mission Systems Integration, Satellite services, Geo-information and ground systems

Bristol
Cyber and Information Assurance, Critical Infrastructure, Training & Simulation

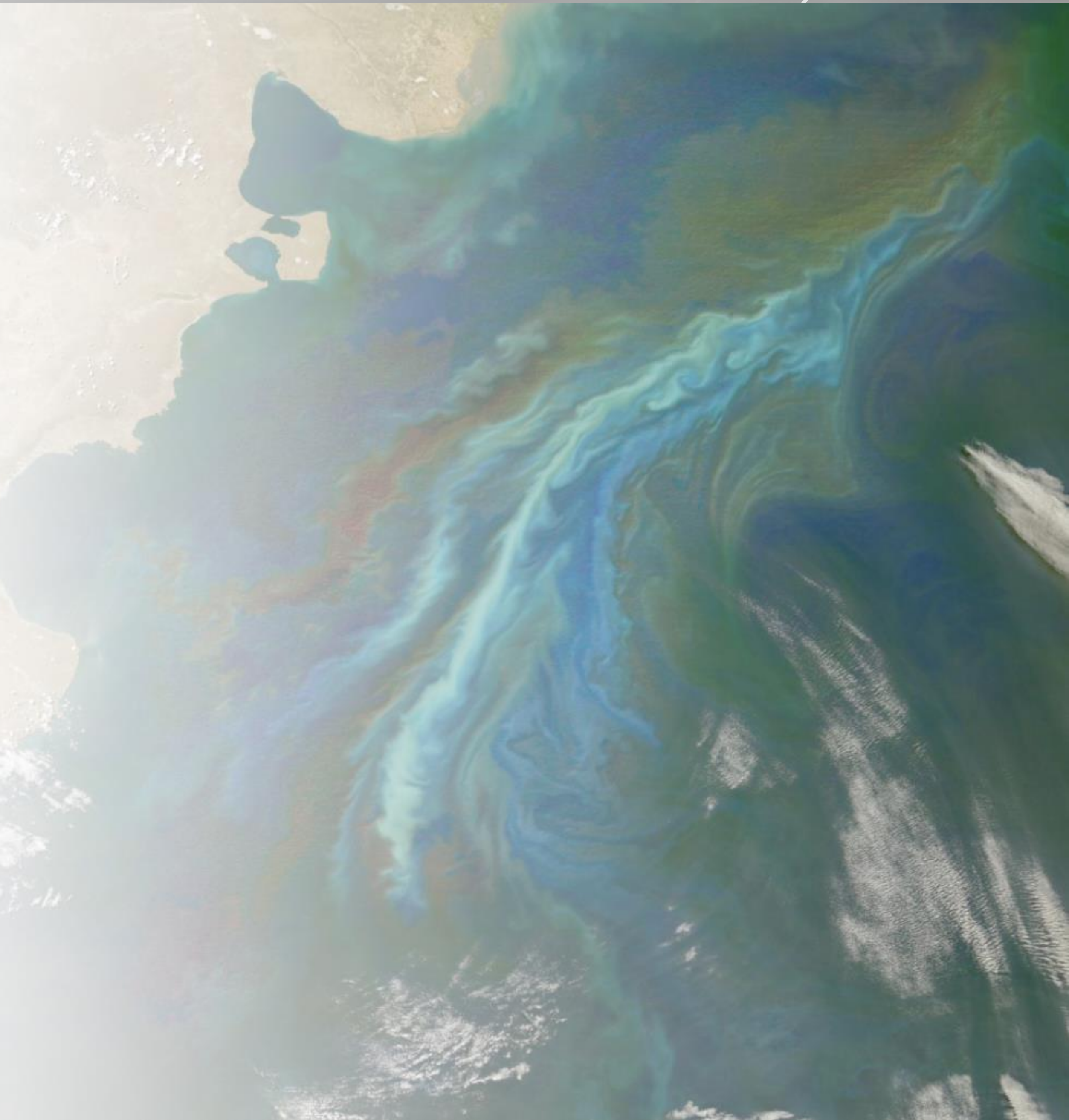
Yeovil
End-to-end helicopter capability

Basildon
Optronics, Defence Communications Systems, Critical National Infrastructure (CNI), Land Systems, Acoustics

Southampton
Infra-Red Detection, Defence Communications Systems, Traffic Control Systems

Presentation Outline

- Overview of Leonardo Company
- Infrared Detectors Business and technology
- Space Heritage
- Detector developments for Current flight programmes
- Detector pre-developments
- COTS detectors for space imaging
- Technology developments
- Conclusions



Southampton History

60 year heritage in cooled and uncooled IR Detectors

1950 Work began on infrared detectors at Mullard Research Laboratories (Philips)

1993 Business purchased by GEC-Marconi

1999 GEC-Marconi defence interests purchased by British Aerospace to form BAE Systems Plc

2005 JV between Italian company Finmeccanica and BAE Systems to create Selex S&AS

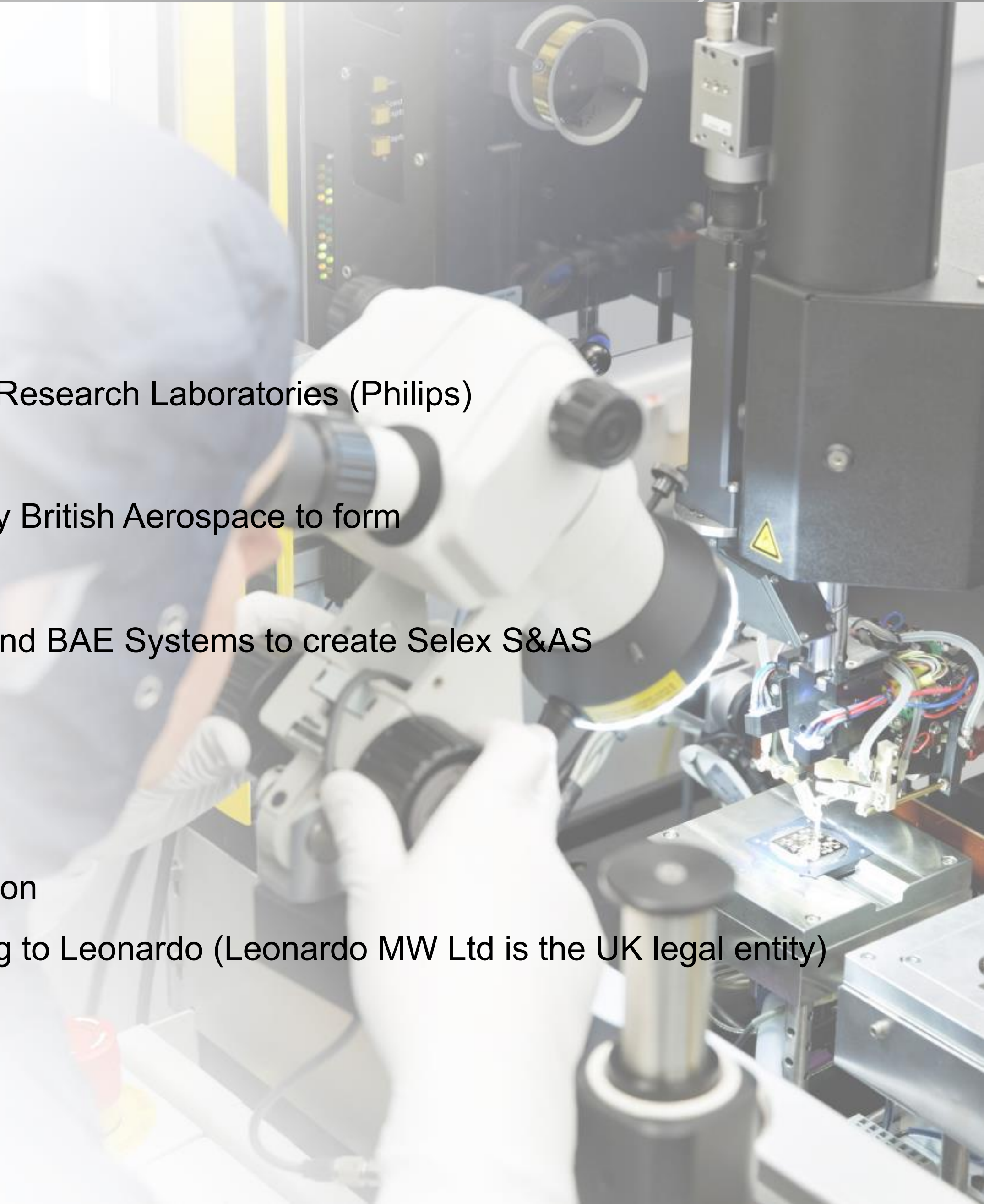
2007 Finmeccanica buy BAE Systems stake

2010 Selex Galileo re-branding

2013 Company re-organisation to form Selex ES

2014 Integration of 3 Selex ES sites at Southampton

2016 Creation of a single company and re-branding to Leonardo (Leonardo MW Ltd is the UK legal entity)



Infrared Detectors
Southampton UK

World leader in the design, development and manufacture of IR detectors

180 people (>70 degree or above)

9500m2 facility, 3000m2 clean rooms

LRQA Quality Assurance ISO 9001:2008 | AS9100 Rev D | ISO14001:2004

Markets include:

- Infrared spectroscopy
- Space & Astronomy instruments
- Thermal Imaging for Land-based, Naval & Airborne systems
- Missile Guidance

IR Material Technologies:

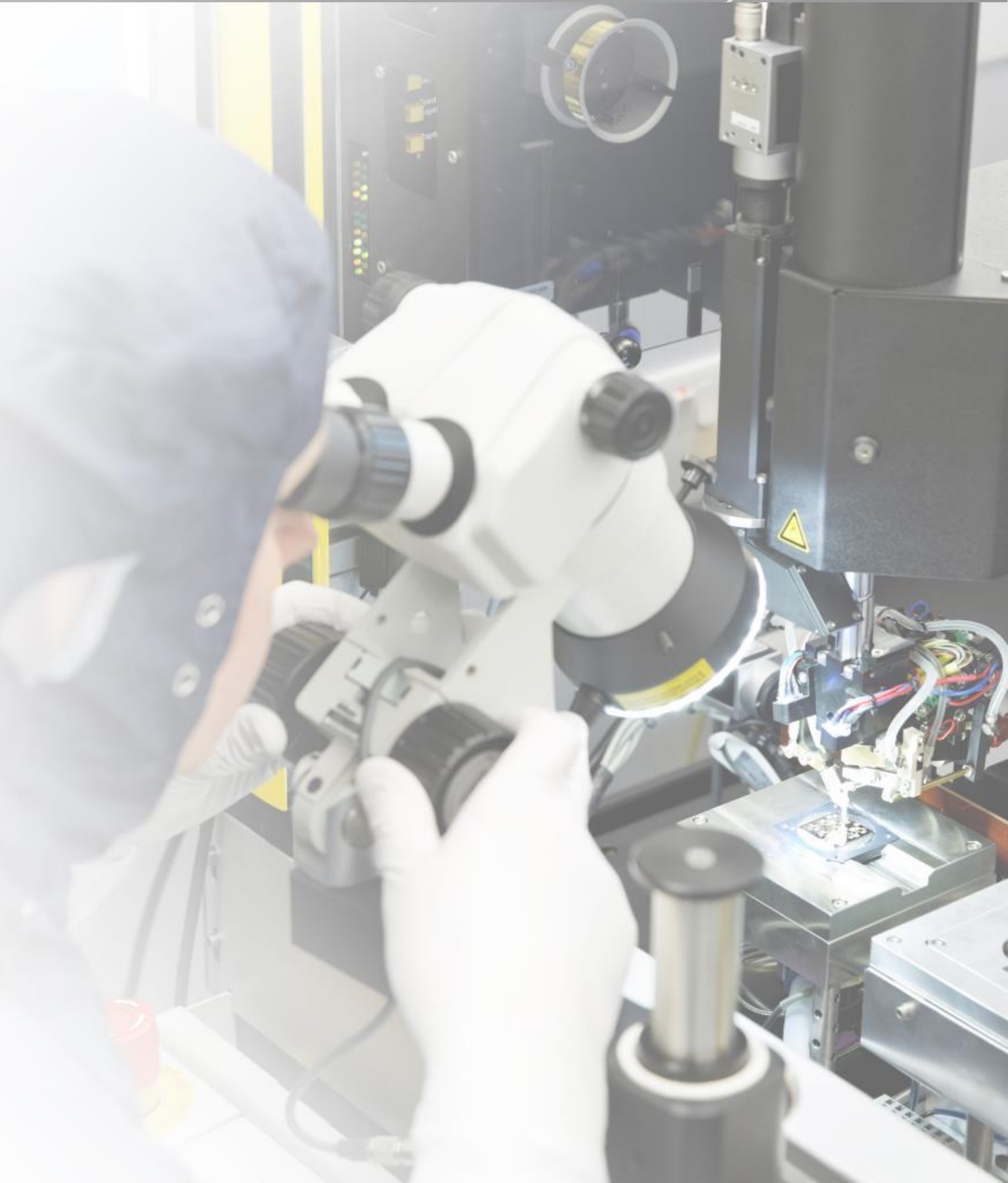
DLATGS

Single element room temp pyroelectric detectors, broad spectral response

Mercury Cadmium Telluride (MCT)

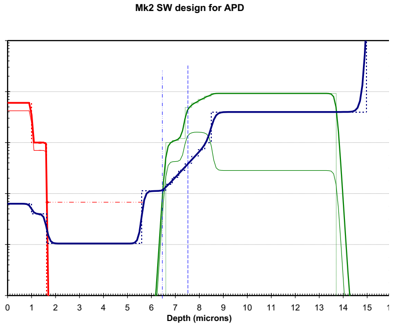
High performance SW (0.8 – 3) MW (3-5), LW (8-11.5um) and broadband 2-D FPA detectors, Dual Colour and HD

LW and VLW PC detectors



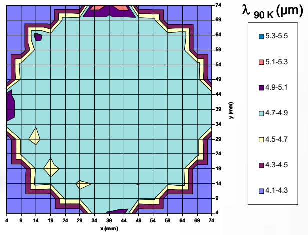
Technology – MCT hybrid photovoltaic arrays

Proprietary MOVPE semiconductor growth technology and indium bump bond flip chip hybridisation

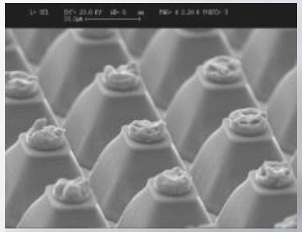


MCT Design and Modelling

3rd generation MCT growth on low cost 3” and 4’’ GaAs substrates



λ Mapping

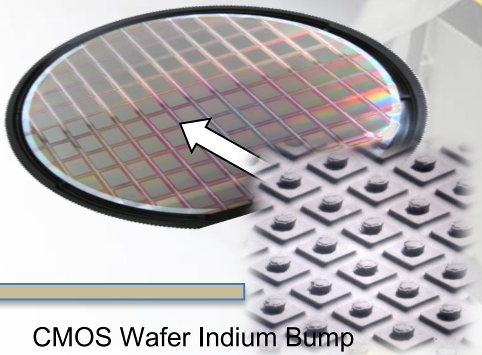


Wafer scale MCT processing into mesa diode arrays with Indium bump interconnect to ROIC

Space test cleanroom

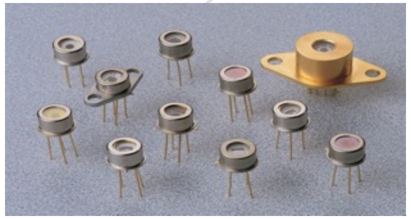
Dedicated space assembly cleanroom

Flip Chip bump bonder

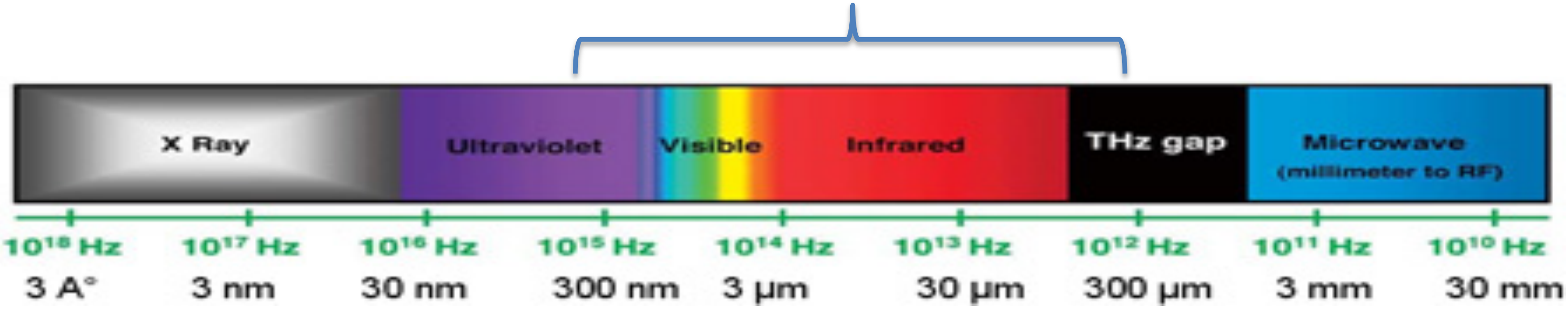


CMOS Wafer Indium Bump Deposition & Probe Testing

Technology – DLATGS pyroelectric detectors



- Broad spectral capability of DLATGS extends from 0.2µm to >100µm
- Deuteration increases the Curie Temperature from 49° C to 60° C
- Alanine doping enables material to repole after exposure to temperatures above it's Curie point
- Industry standard packages available include TO5, TO66 and TO37
- Standard window materials include KBr, CsI, ARC ZnSe, CaF_2, KRS-5, Polythene, Diamond
- Additional environmental protection including parylene coating and hermetic window sealing
- TO66 and TO37 packages include a single stage peltier cooler (TEC) to enable temperature stabilisation element



Applications – DLATGS pyroelectric detectors

Lab based FT-IR Spectrometer

Portable

Hand-held

IR Microscope

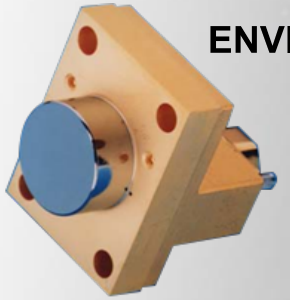
Thermal emission spectrometer on Mars Rover

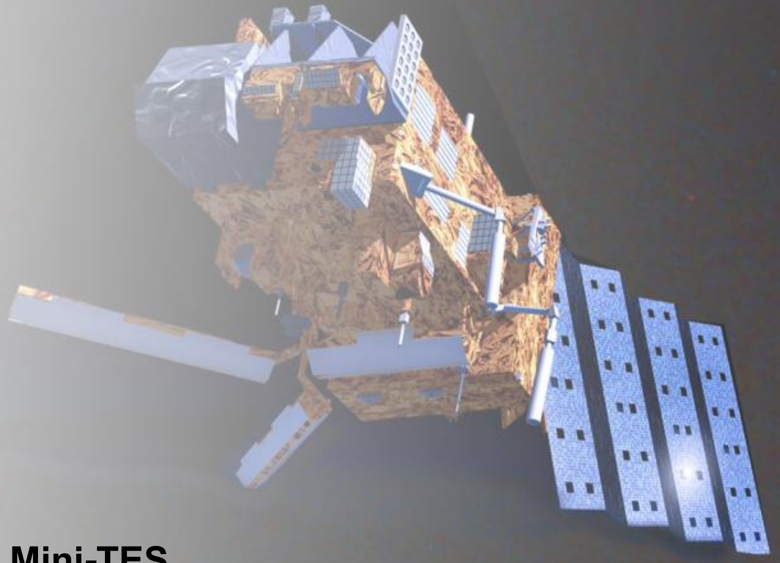
Presentation Outline

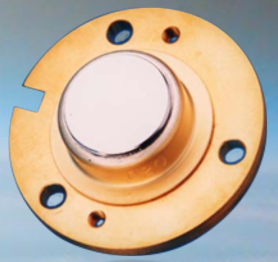
- Overview of Leonardo Company
- Infrared Detectors Business and technology
- Space Heritage
- Detector developments for Current flight programmes
- Detector pre-developments
- COTS detectors for space imaging
- Technology developments
- Conclusions

Infrared Detectors – Space Flight Heritage

1972 Selective chopper radiometer
Nimbus 5 for NASA in collaboration with University of Oxford
1974 Horizon sensor – X4 Miranda Earth Satellite UK/USA
1975 IR spin scan radiometer
Synchronous meteorological satellite for Hughes Corporation
1977 Meteosat 1st generation
1991 ATSR (Along track scanning radiometer) – UARS for RAL
1998 PMIRR (Pressure modulated infra red radiometer)
Mars Mariner for University of Oxford
2000 STRV2 – 2 colour PV array for DERA/BMDO
2001 BIRD (bispectral integrated detector cooler assembly) for DLR
2002 **MIPAS (Michelson interferometer for passive atmospheric sounding)**
Envisat for ESA
2003 Raytheon Mini TES on NASA's Mars Spirit and Opportunity Rovers
2004 **SEVIRI (Spinning Enhanced Visible and InfraRed Imager)**
Meteosat 2nd generation (MSG)
2016 OSIRIS-REx thermal emission spectrometer (OTES)
NASA asteroid sample return mission
2018 GOSAT 2 - Greenhouse Gas Observing Satellite-2 FTIR – JAXA mission
2020 UAE Planetary Science Mission – Study of climate and atmosphere
2020 ISEM (Infrared Spectrometer for ExoMars) for ESA



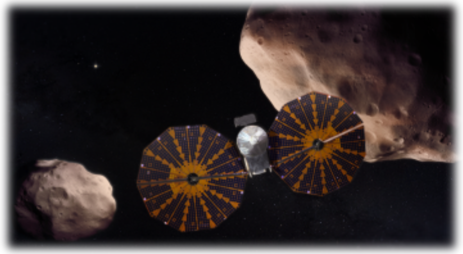




Presentation Outline

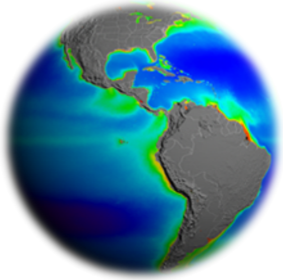
- Overview of Leonardo Company
- Infrared Detectors Business and technology
- Space Heritage
- Detector developments for Current flight programmes
- Detector pre-developments
- COTS detectors for space imaging
- Technology developments
- Conclusions

Infrared Detector – Current Space Flight Programmes



2021 NASA LUCY mission to Jupiter’s Trojan asteroids

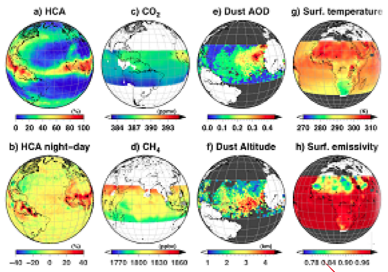
TGS The first space mission to study Jupiter's swarms of Trojan asteroids mission will revolutionize knowledge of planetary origins and the formation of the solar system.



2022 NASA PACE OCI SWIR detectors

MCT Plankton, Aerosol and Cloud Ecosystems (PACE) on Ocean Colour Instrument (OCI)

Monitoring global phytoplankton distribution and abundance with unprecedented detail, the OCI will help us to better understand the complex systems that drive ocean ecology.



2022 CNES IASI-NG to be launched on MetOp SG A

MCT Infrared Atmospheric Sounding Interferometer – New Generation

Measurement of the temperature and water vapour profiles of the Earth’s atmosphere for Meteorology, and huge potential to measure greenhouse gases, clouds, aerosols, ozone and trace gases.

IASI NG Infrared Detector Requirements

These are realised as Mercury Cadmium Telluride (MCT) infrared sensing arrays in 4 detectors

- Detection unit stored at a cryogenic temperature (of around -200 ºC)
- Coverage of the infrared band of 3.6 to 15.5 microns
- Designed for optimum signal-to-noise ratio
- Common 4 x 4 array format of 1.3 mm square macropixel to match IASI-NG instrument optics
- Band 1 uses 1st generation MCT growth technology to give best performance for longwave material
- Bands 2, 3 and 4 use Leonardo proprietary 3rd generation MCT growth technology hybridized to custom silicon readout IC

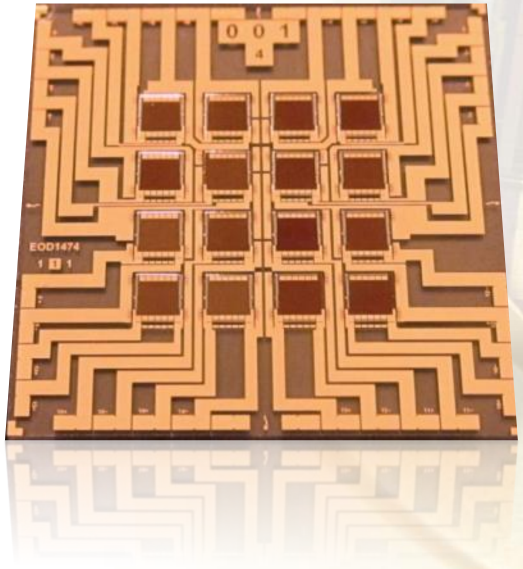
4	3	2	1	BAND
3.6-4.4	4.4-5.1	5.1-8.7	8.7–15.5	µm
3rd GENERATION PHOTOVOLTAIC			**1st GENERATION PHOTOCONDUCTIVE**	TYPE

IASI-NG Band 1 MCT Photoconductive Array

1st generation technology

Heritage from other space programmes such as Meteosat second generation SEVIRI instrument

- Referred to as 1st generation infrared growth technology which became mature in the 1970s.
- Ideal for very long wave detectors, up to 17 microns, where they are superior to photodiodes in S/N and detectivity
- 4 x 4 macropixel array to match IASI-NG instrument optics
- New, optimized design, developed to give best performance for IASI-NG - each macropixel comprises 12 strip labyrinth device



IASI-NG Bands 2, 3 and 4 Photovoltaic Arrays

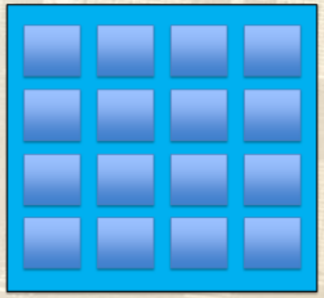
3rd generation technology

IASI-NG detectors are the first detectors developed, qualified and manufactured for space using Leonardo's 3rd generation MCT technology

They share the heritage, reliability, and manufacturability of Leonardo's conventional MCT arrays in production in Southampton

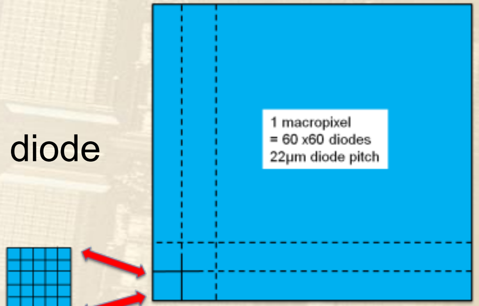
MCT DIODE ARRAY

- MCT chips are approximately 1cm square
- 4 x 4 macropixel array, each macropixel 1.3mm square
- Formed of a continuous matrix of photodiodes on 22 micron pitch



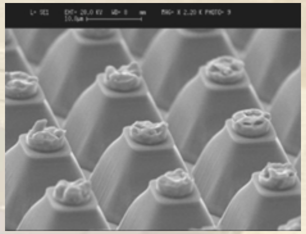
CUSTOM SILICON READOUT INTEGRATED CIRCUIT (ROIC)

- Designed for IASI-NG to provide required functionality in a radiation hard design
- Integrated 5 x 5 diode memory cell within the silicon readout IC allow for diode selection/deselection to achieve highest performance

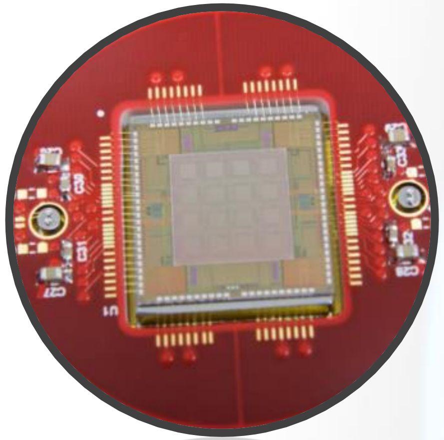


INDIUM BUMP BOND HYBRIDISATION

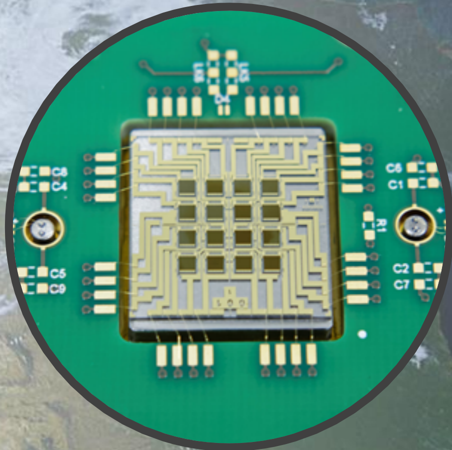
- All MCT photodiodes are individually electrically connected to metallization pads on the Silicon chip



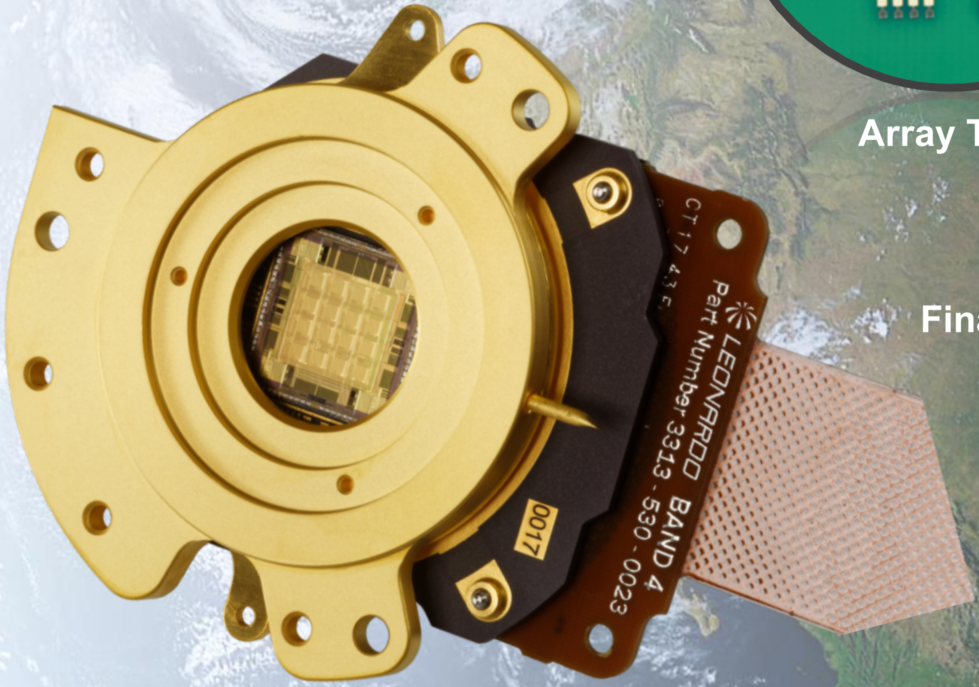
IASI-NG detector assembly and test



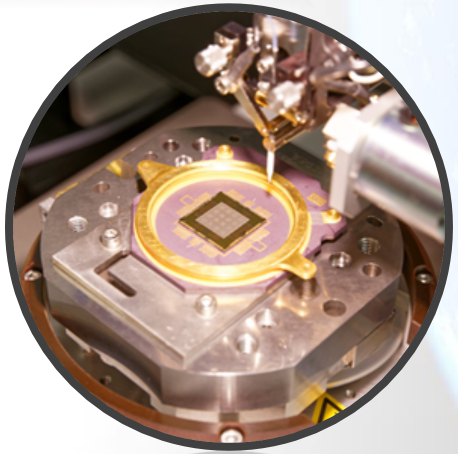
Custom silicon readout IC test



Array Test



Final Assembly



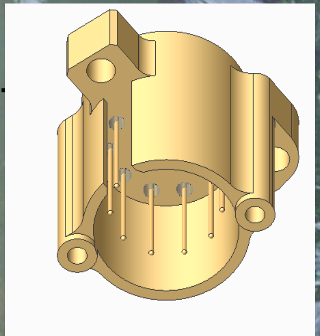
Wirebond

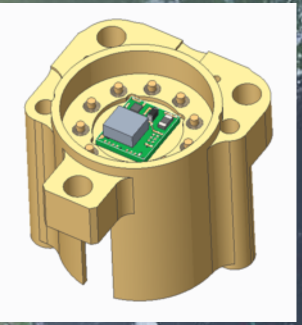
Custom metal package with electrical flex assembly

PACE for NASA

SWIR MCT large area diode co-packaged with discrete electronic components

- PACE = Plankton, Aerosol and Cloud Ecosystems on Ocean Colour Instrument (OCI) planned launch 2022.
- Supply of engineering and flight sub-assemblies consisting of large area MCT diodes and other components.
- Wavebands from 1.5 to 2.5μm.
- 350μm diameter diode produced by shorting together 24μm pitch mesas.
  - Bump bonded to GaAs lead-out on which discrete electronic chip components are also mounted
- Low capacitance design
  - Small junction area compared to optical area.
- MCT with n-absorber and p-common (n on p)
  - Illumination through common
  - Common transmits radiation > 1.4 μm
  - Absorption starts at junction giving high internal QE and good linearity
- Gold plated Kovar non-hermetic package

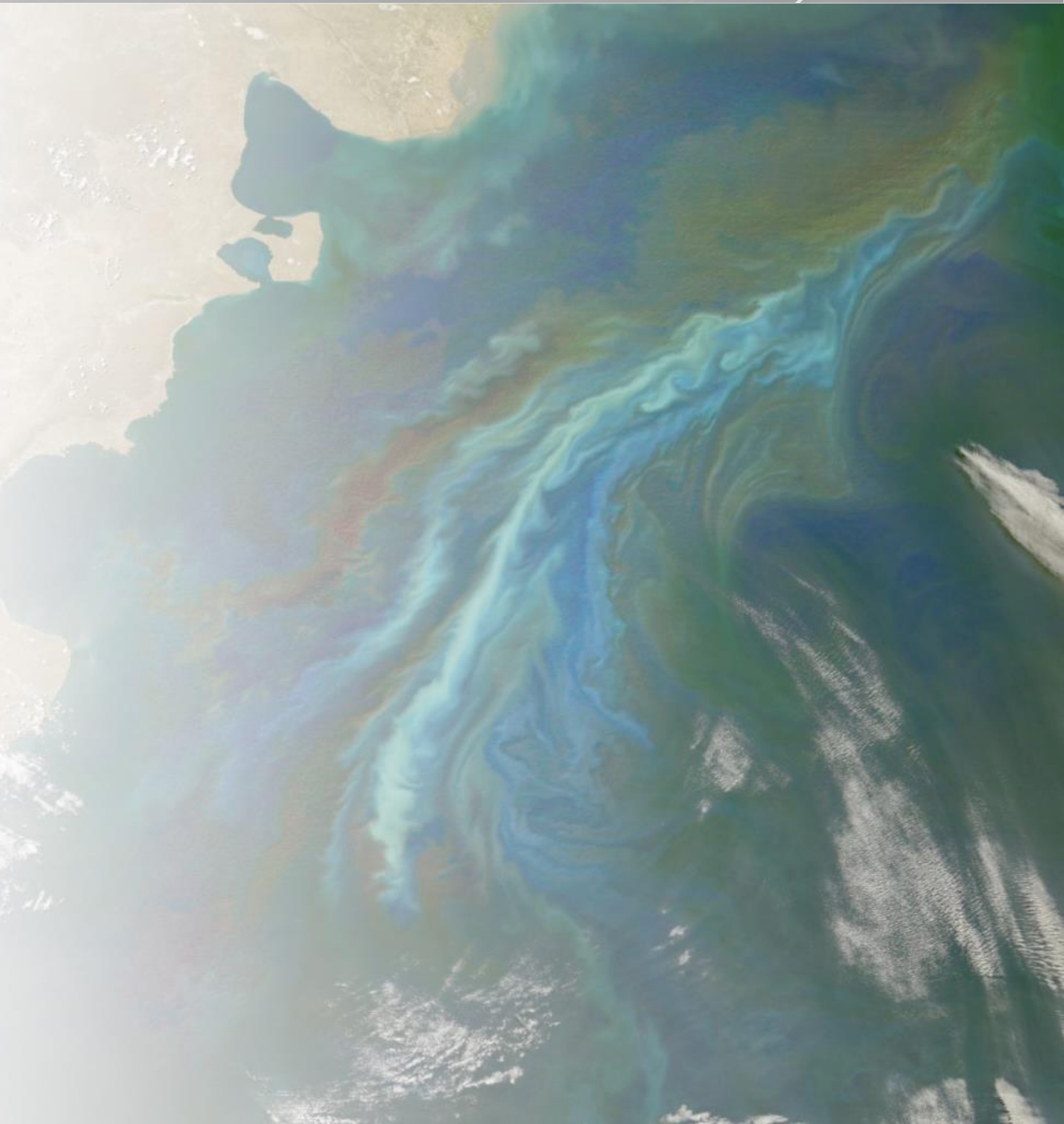




LEONARDO

Presentation Outline

- Overview of Leonardo Company
- Infrared Detectors Business and technology
- Space Heritage
- Detector developments for Current flight programmes
- Detector pre-developments
- COTS detectors for space imaging
- Technology developments
- Conclusions



MCT detector pre-developments for Space Applications

ESA

Large area avalanche photodiodes – DIAL ESA APD

LFNIR 1k x 1k near infrared array

***Visible hybrid CMOS (with e2v) using LFNIR ROIC**

***2k x 2k SWIR array including current CCN**

Very long wave low dark current

SAPHIRA SWIR MCT APD gamma and proton testing

CEOI / UK Space

SWIR MCT APD life testing

Heavy ion radiation testing of ESA LFNIR

Extended (0.8 – 2.5 µm) response (SAPHIRA)

2k x 2k SWIR APD array

Proton testing LFNIR

***CEOI/ANU SWIR 1k x 1k space environmental testing hyperspectral**

NASA

PACE SWIR large area (ocean survey)

***1k x 1k NIR LFA APD array (UH – NASA)**

***Current projects**

ROICs customised for Space & Astronomy Applications

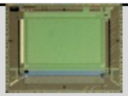
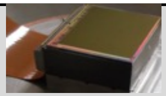
All ROICs are APD compatible

ME1000 SAPHIRA - Shortwave Avalanche PHotodiode for Infra-Red Applications

ME930 LFNIR - Large Format Near Infra-Red

ME950 SWIR - Short Wave Infra-Red

ME1070 SWIR - 1k x 1k NASA funded

	ME1000 Saphira 	ME930 LFNIR 	ME950 SWIR 	ME1070 1kx1k
Array Format	320 x 256	1280 x 1032	2056 x 2048	1024 x 1024
Pixel Pitch	24µm	15µm	17µm	15µm
CMOS Technology	0.6µm	0.35µm	0.35µm	0.35µm
Pixel Design	Source Follower	Source Follower	Source Follower	Source Follower
Number of Video Outputs	4 / 8 / 16 / 32	4 / 8 / 16 / 32	16	16
Max. Frame Rate	4kHz	5Hz	40Hz	15Hz

MCT SWIR Avalanche photodiode arrays

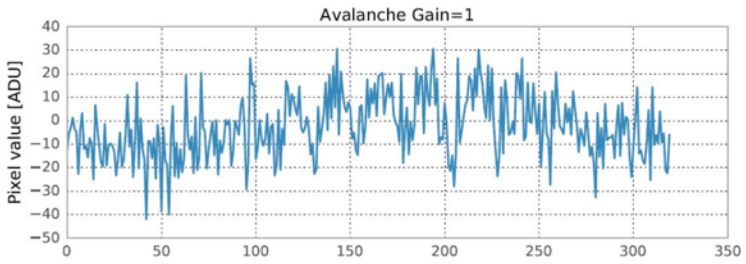
Leonardo's SAPHIRA MCT arrays have recently been subjected to radiation testing under an ESA contract.

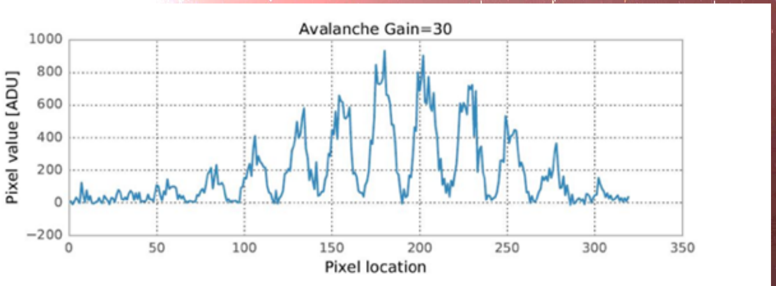
They are already enabling new science on ESO's ground based GRAVITY astronomy instrument

Jan 2016	First Light For Future Black Hole Probe
June 2016	Successful First Observations of Galactic Centre with GRAVITY
July 2018	First Successful Test of Einstein's General Relativity Near Supermassive Black Hole
Oct 2018	Most Detailed Observations of Material Orbiting close to a Black Hole
Mar 2019	GRAVITY instrument breaks new ground in exoplanet imaging

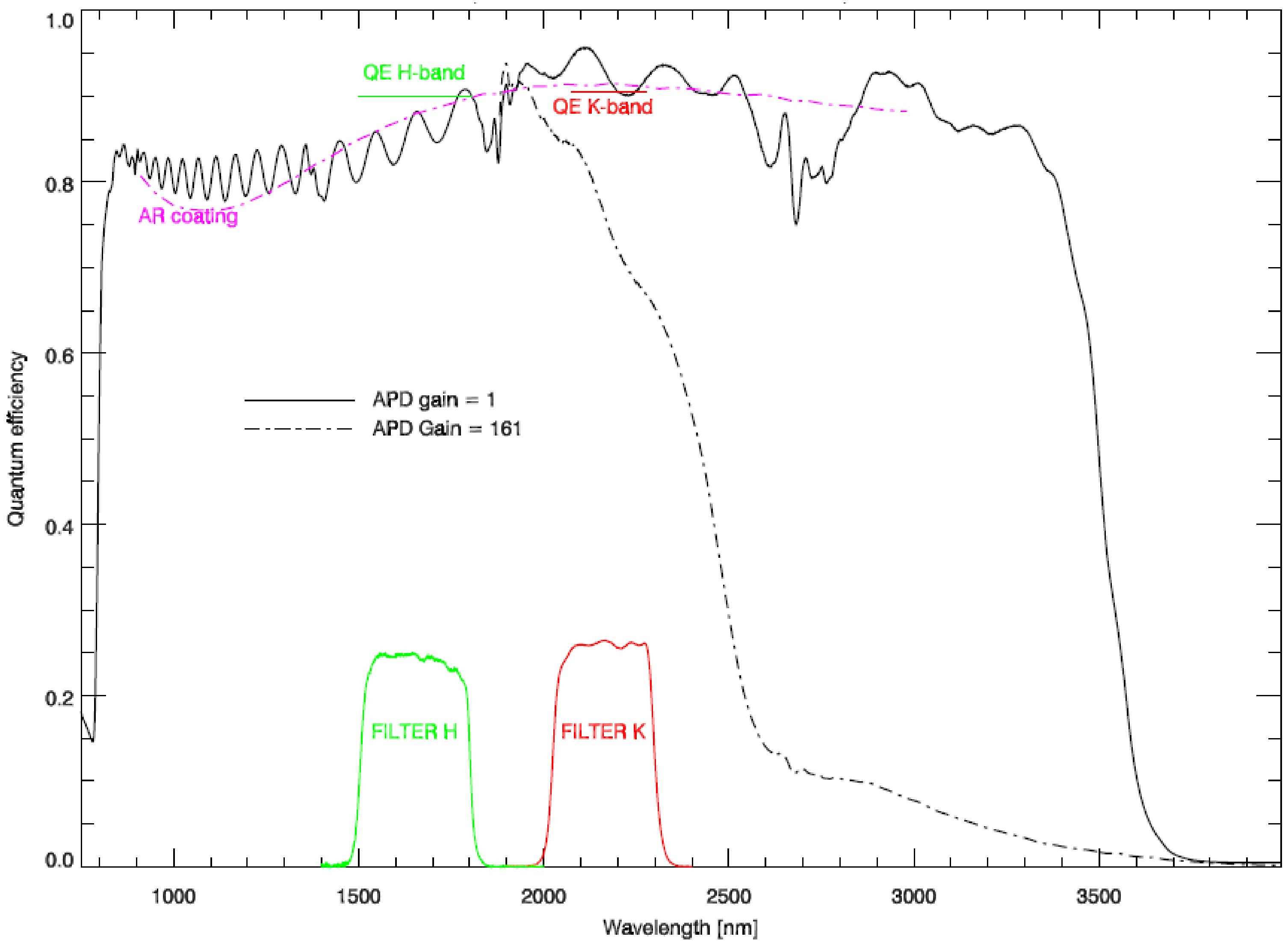
Each telescope has one SAPHIRA acting as **wavefront sensors**, observing the same star and controlling atmospheric distortion and a fifth SAPHIRA acting as a **fringe tracker** to lock the four telescopes together to a few nanometers.

This gives similar resolution to a space-based telescope of 130m diameter



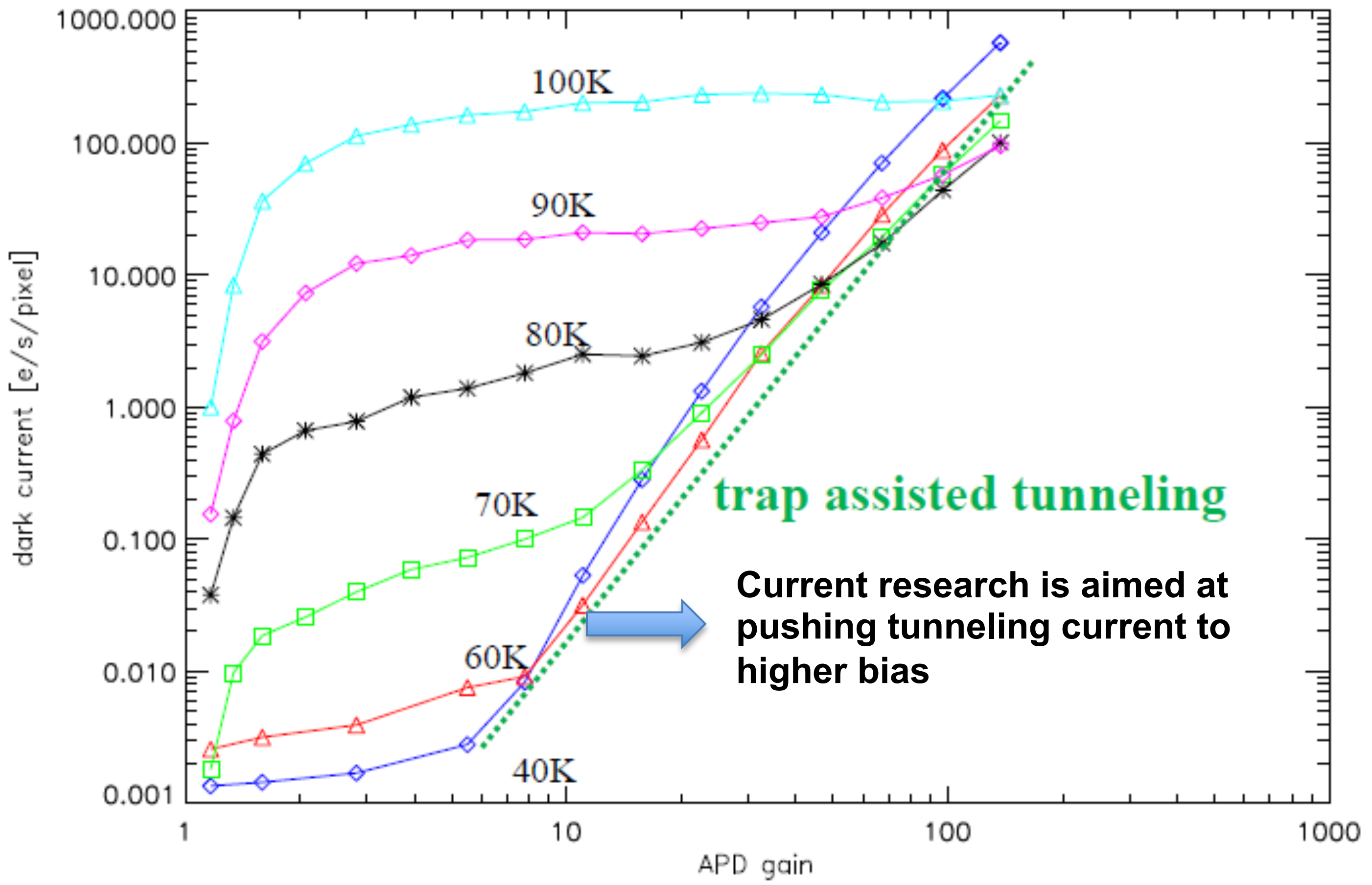


SWIR APD Characterisation ESO measurement (QE)



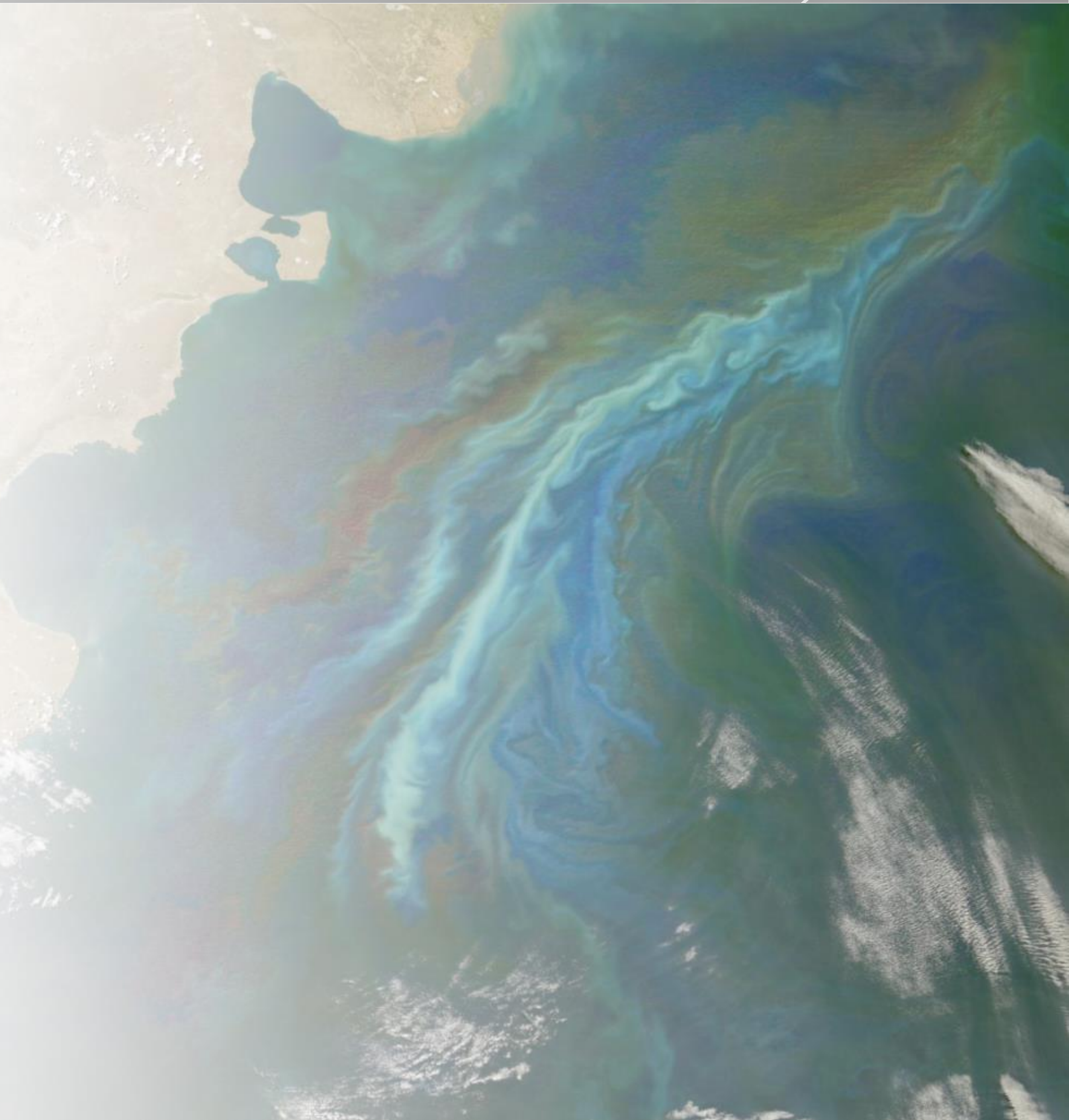
Dark current in Mark 13/14 arrays

(Combination of Leonardo, ESO and UH results)

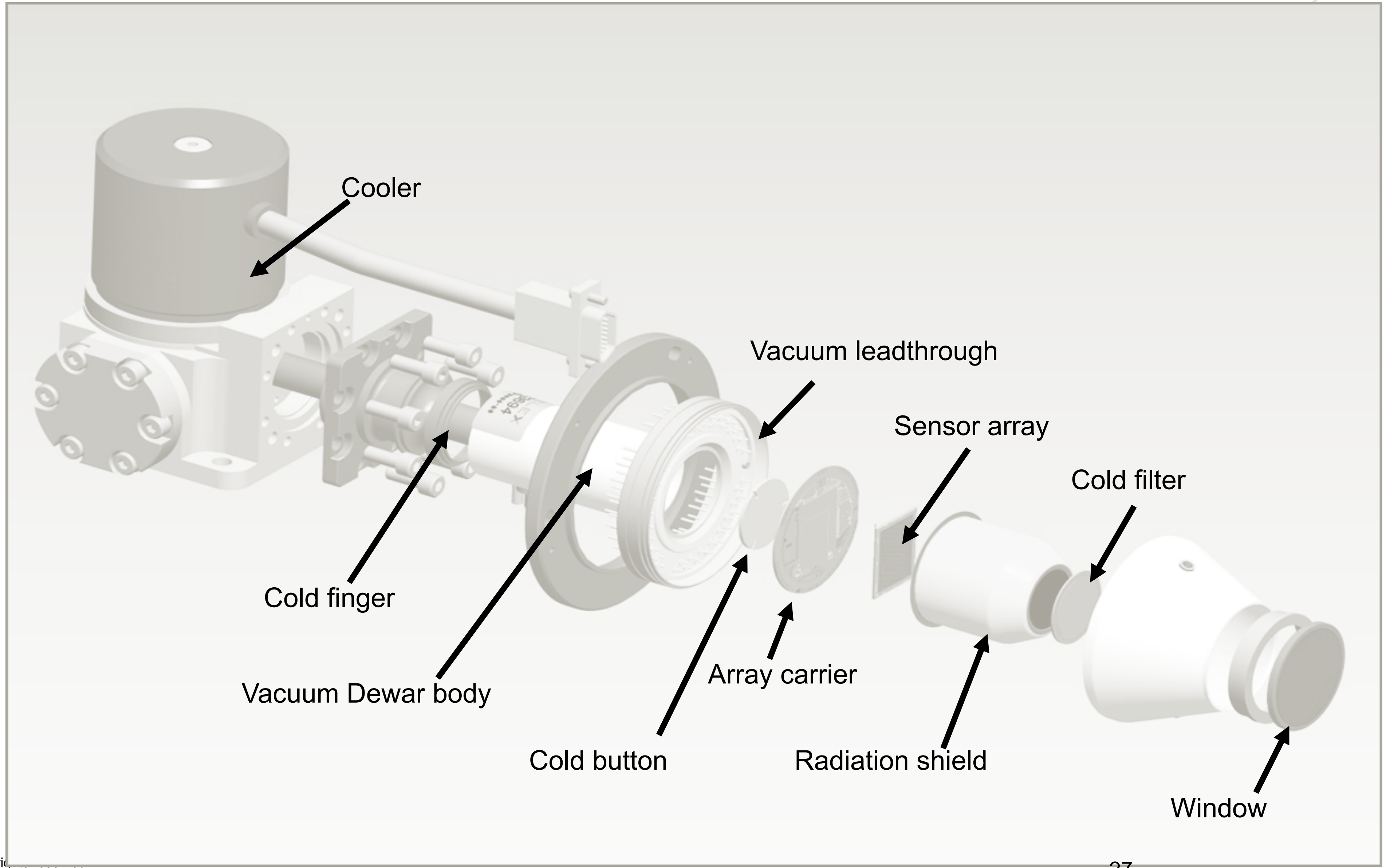


Presentation Outline

- Overview of Leonardo Company
- Infrared Detectors Business and technology
- Space Heritage
- Detector developments for Current flight programmes
- Detector pre-developments
- COTS detectors for space imaging
- Technology developments
- Conclusions



Generic Infra-red detector assembly

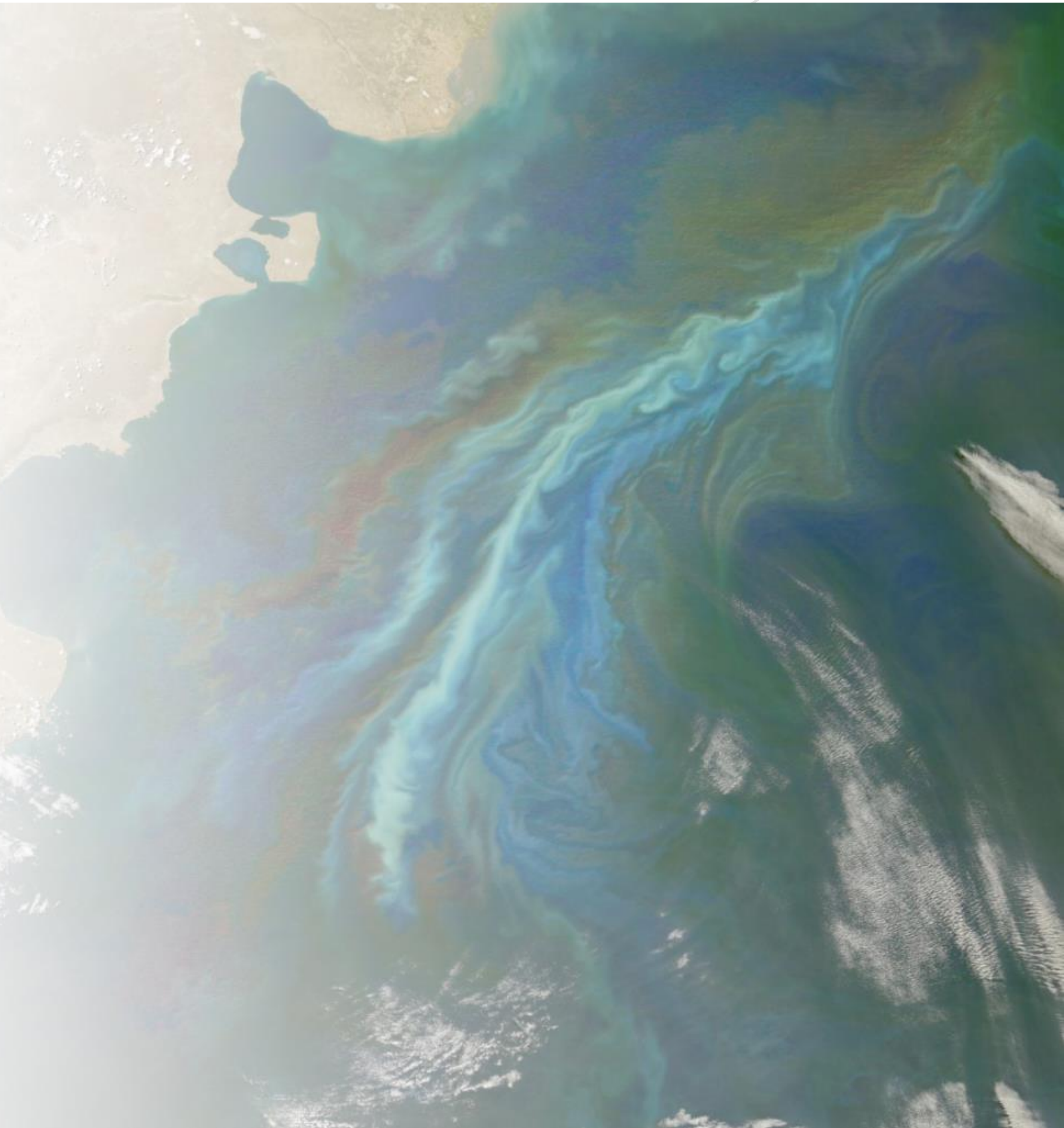


27

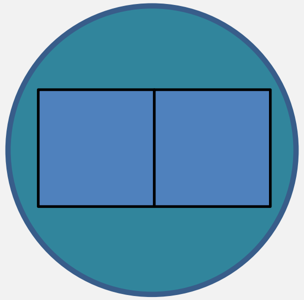
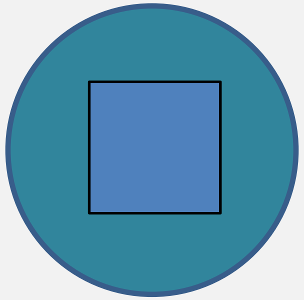
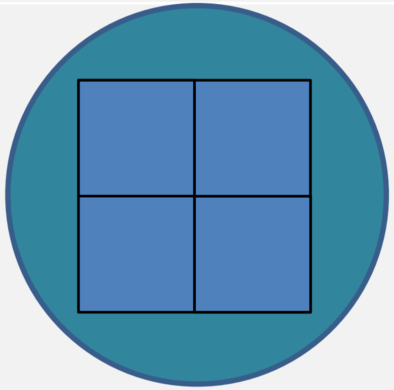
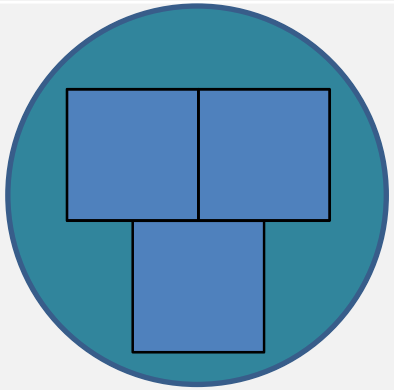
COTS MCT detector for space - SuperHawk 1280 x 1024 / 8µm pitch

Presentation Outline

- Overview of Leonardo Company
- Infrared Detectors Business and technology
- Space Heritage
- Detector developments for Current flight programmes
- Detector pre-developments
- COTS detectors for space imaging
- Technology developments
- Conclusions



LARGE FORMAT ARRAYS : 4” vs 3” substrate

	Example of a 2kx2k array on 15µm pitch, inclusive of dummy pixels = 32mm x 32mm	Example of a 2kx2k array on 17µm pitch, inclusive of dummy pixels = 35mm x 35mm
3’’		
4’’		

Presentation Outline

- Overview of Leonardo Company
- Infrared Detectors Business and technology
- Space Heritage
- Detector developments for Current flight programmes
- Detector pre-developments
- COTS detectors for space imaging
- Technology developments
- Conclusions

LEONARDO

CONCLUSIONS

All of these activities contribute to the competitiveness of Leonardo infrared detectors

IASI-NG	Maintains our 1st generation MCT PC technology capability Provides flight heritage for 3rd generation MCT PV technology Demonstrates capability to deliver a highly demanding detector development for space Developed skills across engineering, production and product assurance
PACE	Establishes working relationship and credibility with NASA Develops assembly techniques for space electronics
CEOI	Demonstrate suitability of new technology for space applications De-risks technology by increasing TRL and gather data for the next proposals
SCIENCE	Improved accuracy and confidence in instrument data Demonstrate fundamental laws of physics
COMMERCIAL	Exploits latest manufacturing and product technology for space Develops technology and skills to the benefit of the whole detector business Increases the profile of the company and the Leonardo detector business

THANK **YOU** FOR YOUR ATTENTION