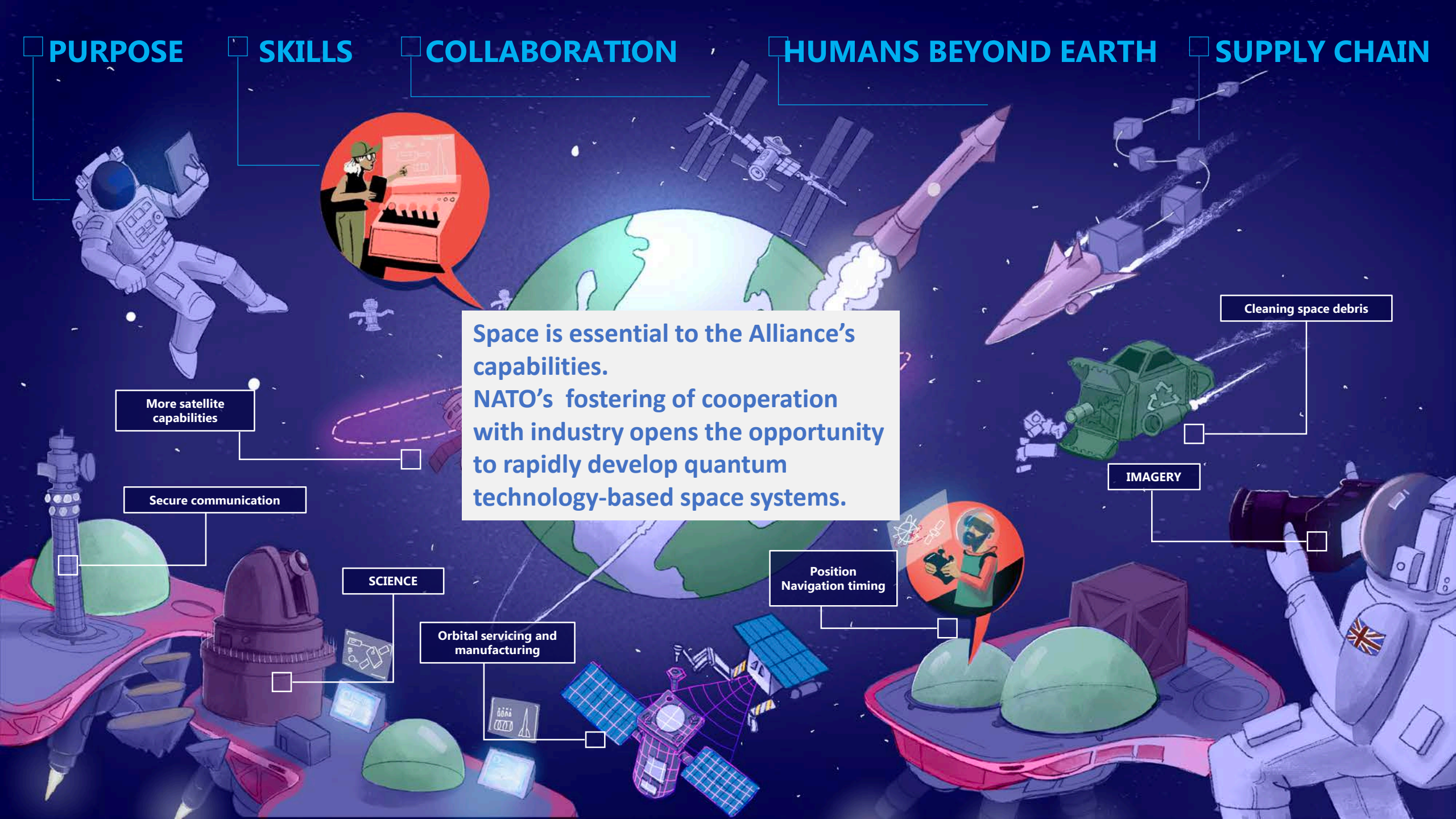
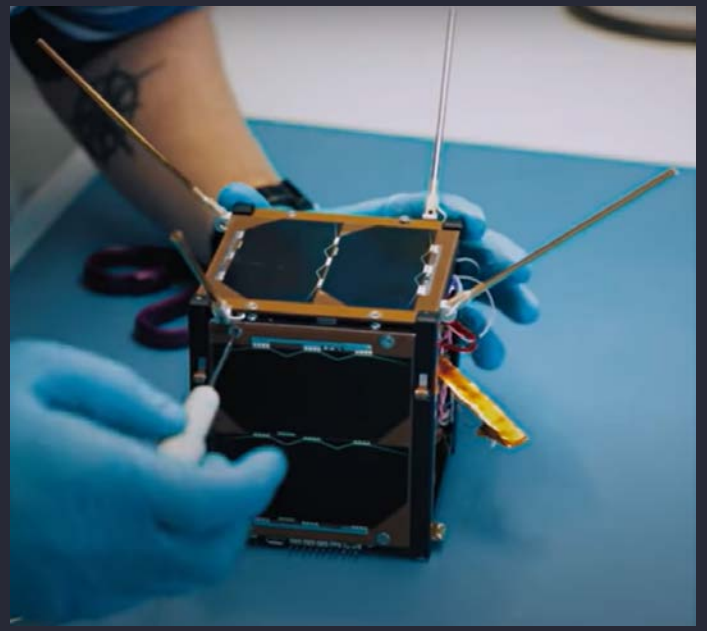
QUANTUM MAGNETOMETERS AS SENSORS IN SMALL SATELLITE MISSIONS

Mark Chang [Capgemini]
Simon Jordan [Cambridge Consultants]
Tony Holt [In-Space Missions]


PURPOSE
SKILLS
COLLABORATION
HUMANS BEYOND EARTH
SUPPLY CHAIN
Space is essential to the Alliance's capabilities.
NATO's fostering of cooperation with industry opens the opportunity to rapidly develop quantum technology-based space systems.
More satellite capabilities
Secure communication
SCIENCE
Orbital servicing and manufacturing
Position Navigation timing
IMAGERY
Cleaning space debris

SMALL SATELLITES FOR DEFENCE

Small satellites are becoming increasingly important in the field of defence. Overall, more than 6,000 small satellites, ranging from a few kilogrammes up to 500 kg have been launched since 2000 for civil, exploratory, and military reasons.



They offer several advantages over terrestrial capabilities e.g., improved situational awareness, enhanced communication capabilities, and increased resilience, usually provided from low Earth orbit, that is up to 2000 km altitude.

They offer

- Shorter Development Time
- Rapid Refresh and Technology Upgrade
- Increased Training Opportunities and Process Improvement
- Lower Cost
- Manufacturing at Scale

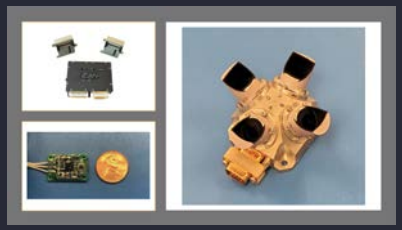
HOW SATELLITE ATTITUDE DETERMINATION WORKS

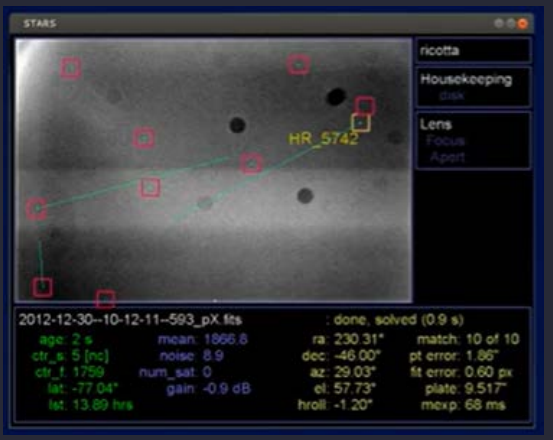
Attitude determination = where am I pointing?

(A) Use two reference points, like stars, the sun, the horizon, etc.

(B) Upload GNSS data from the ground station.

(C) Use the magnetic field + Inertial measurement unit.



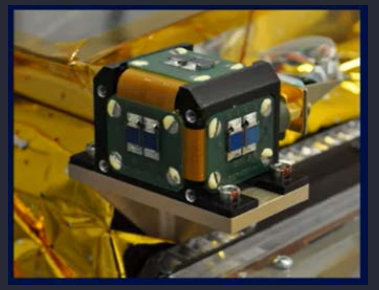


High end solution: star trackers / sun sensors

Heritage solution: Inertial Measurement

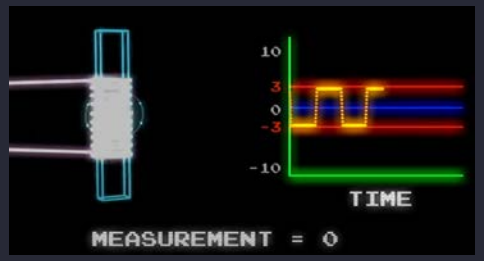
Smallest potential SWaP-C solution:

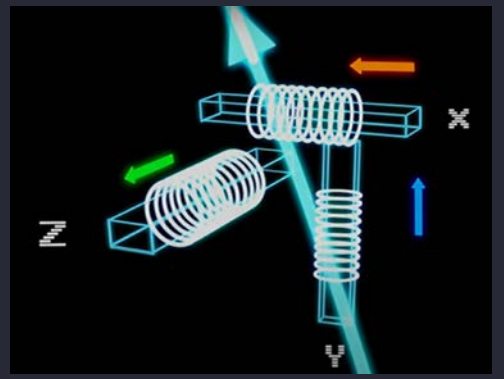
Magnetometer



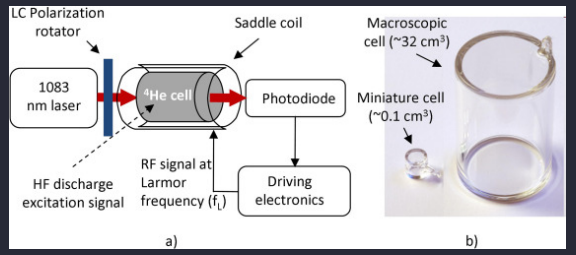
HERITAGE MAGNETOMETERS

Fluxgate Magnetometer

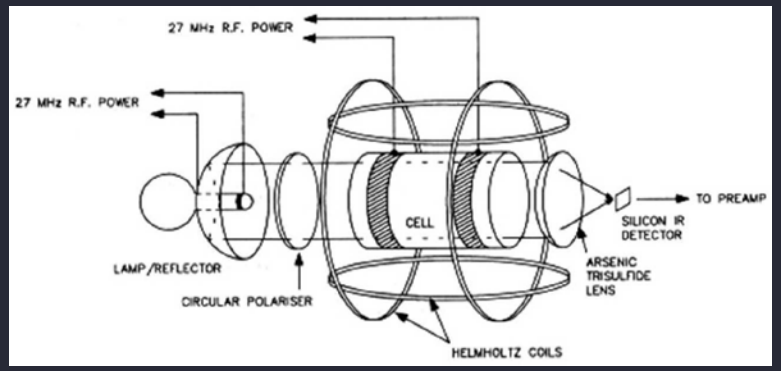




Scalar Helium Magnetometer



Vector Helium Magnetometer



In principle these are all variations on a bar magnet class compass.

QUANTUM MAGNETOMETERS

Atomic vapour cell & Spin Exchange Relaxation Free (SERF) magnetometers

Alkali-vapour magnetometers are extra sensitive magnetic field measurement devices.

An alkali-vapor magnetometer polarises a vapour of alkali-metal atoms, (potassium, rubidium, or caesium) inside a glass cell using a circularly-polarised “pump” laser beam.

Spinning atoms have a magnetic moment, with north and south magnetic poles, so an outside magnetic field will tilt the axis of spin and cause it to precess like a spinning top that’s been pushed off the vertical.

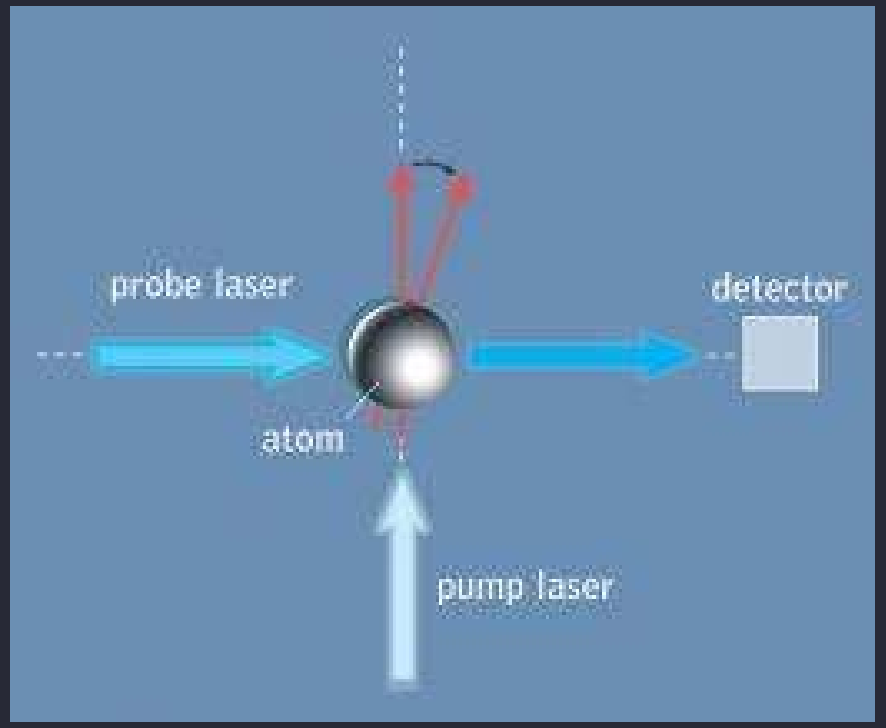
Changes in the outside field’s strength or direction can be detected using a probe laser to repeatedly measure the vapour’s average spin orientation.

The fundamental sensitivity of the measurement depends on:

- the number of atoms in the sample
- the spin relaxation time of the polarised atoms.

Spin relaxation is the loss of polarisation, the return of the population of atoms to random orientations, which happens faster as atoms collide with other atoms, or if the external magnetic field varies.

SERF cells are modified (with buffer gases or coatings) to minimise spin relaxation.



QUANTUM MAGNETOMETERS

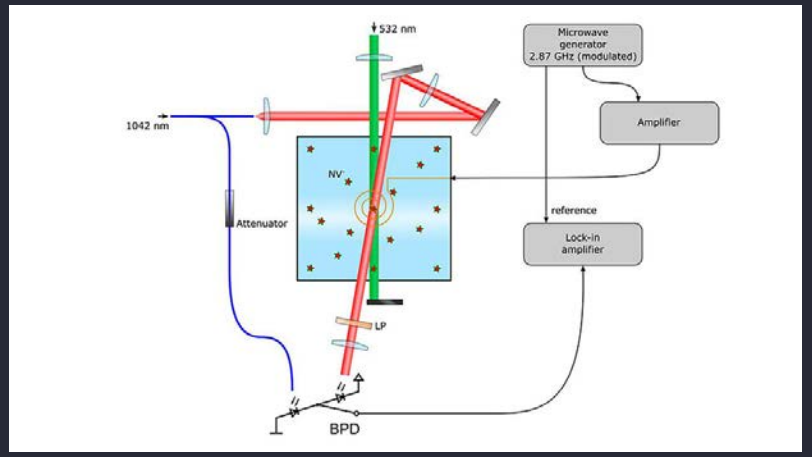
Atomic Defect

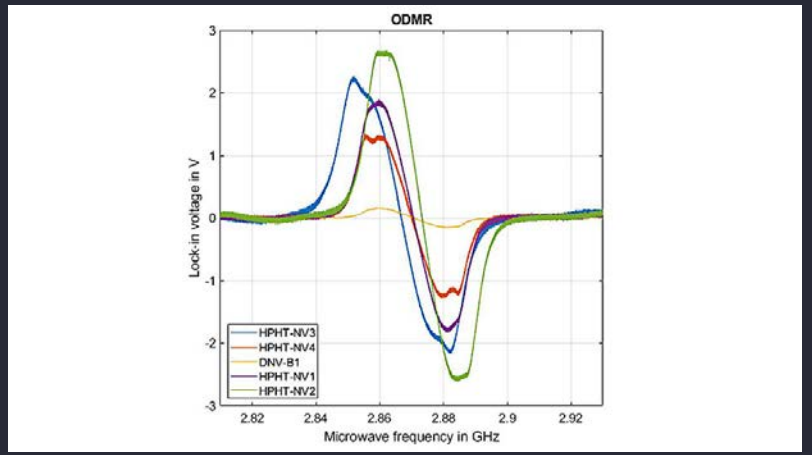
Optical detection of magnetic resonance through the infrared absorption (IR-ODMR) of the Nitrogen-Vacancy centre in diamond (NV centre).

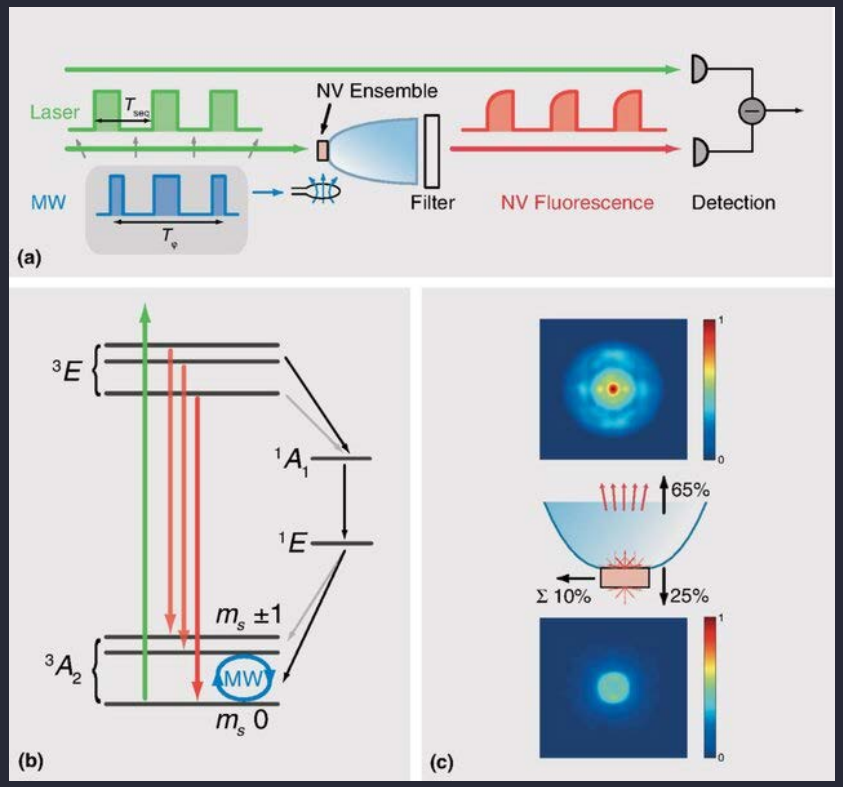
The NV centre is a point defect in the lattice of the diamond which is sensitive to magnetic fields and can be read out optically.

The method is based on excitations of NV centres in a diamond sample using a green laser (532 nm) while a microwave field is applied in parallel. By sweeping the microwave frequency around the vicinity of the zero-field splitting of the ground state of the NV centres, their spectral response can be probed.

At resonance, the absorption of the IR beam at 1042 nm occurs, and the detected laser intensity at the output of the diamond is minimal.





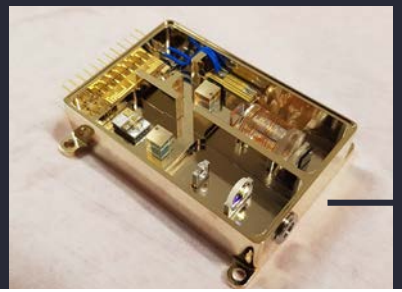


(a) NV ensemble, excited by 532-nm laser pulses. Long-pass-filtered fluorescence is collected with part of the exciting light on a balanced detector. Microwave (MW) pulses are used for NV-spin manipulation.

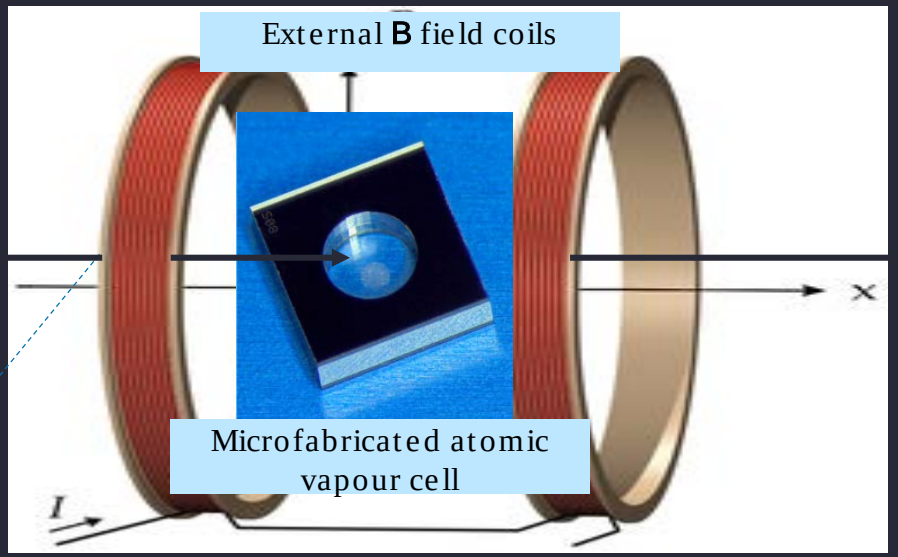
(b) NV-energy-level scheme: Manipulation of electron spin in a triplet ground state. Spin-state-dependent fluorescence allows readout of the spin state.

(c) Fluorescence collection with parabolic collector (simulation results).

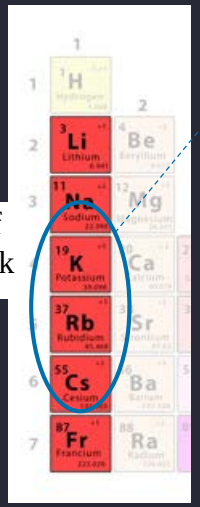
LABORATORY *COTS* QUANTUM MAGNETOMETER



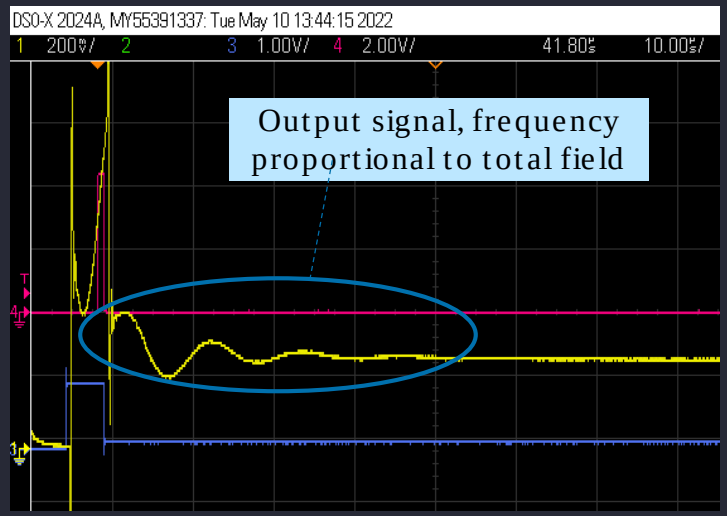
Frequency stabilised laser – 780nm
(same wavelength as CD burner)



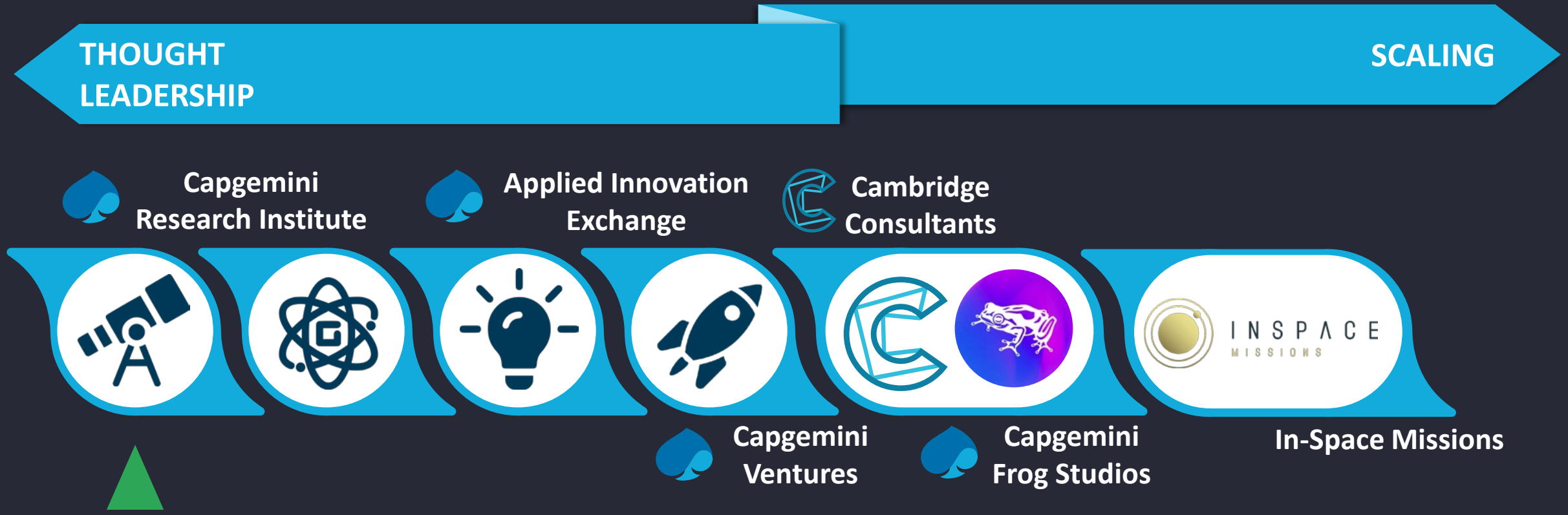
Cell contains tiny amount of Rb metal – Cs and K also work



Laser is tuned to D-line of alkali metal (shown here for sodium). This excites the atom into a magnetically sensitive state. The magnetic field makes it oscillate (Larmor precession), we detect this optically. This frequency is proportional to the total magnetic field with extreme precision. This allows measurement of tiny (0.0001nT) magnetic fields

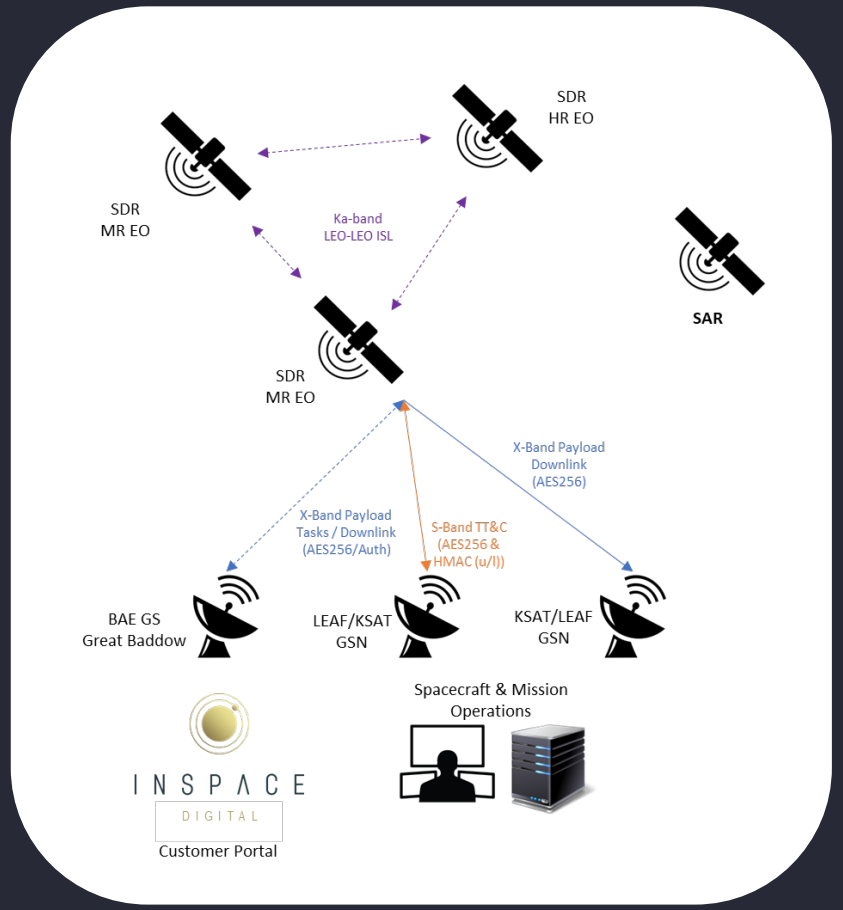


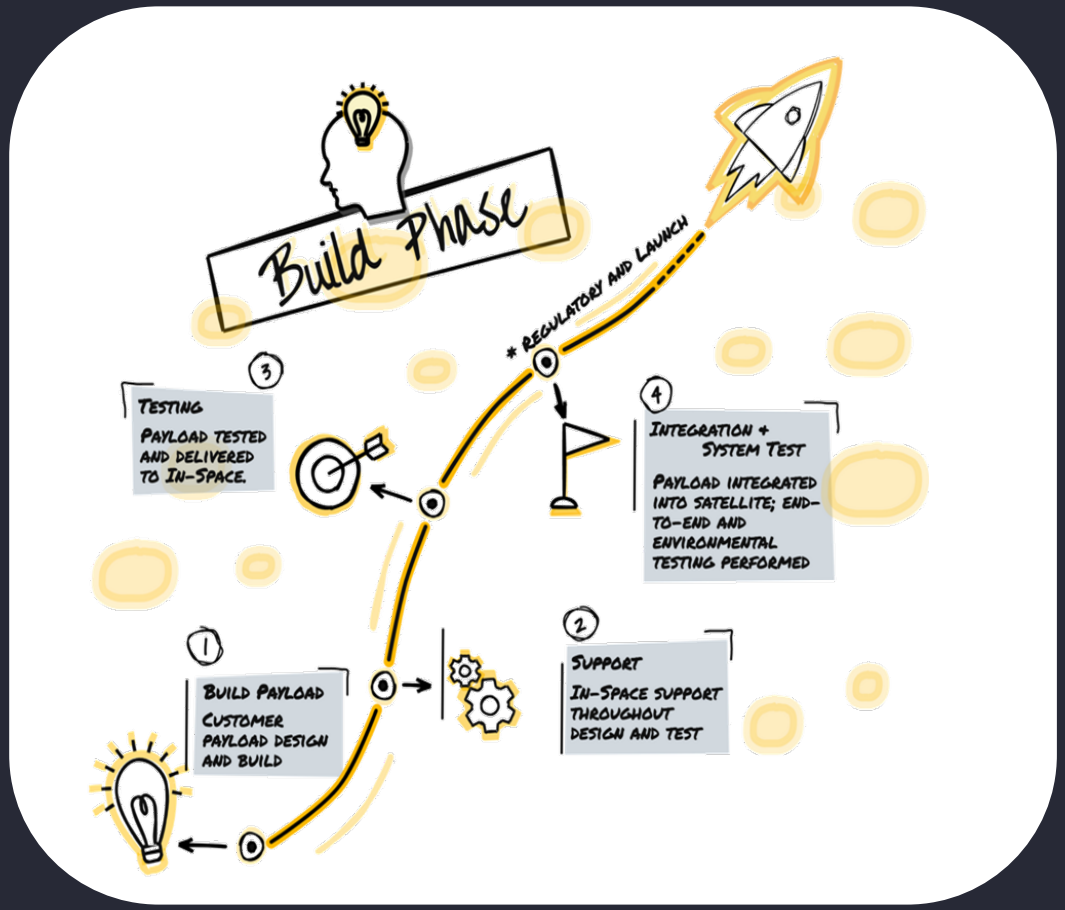
OUR ONE-STOP-SHOP COLLABORATION



WHAT IN-SPACE MISSIONS IS PROUD TO DO

What we have &what we can do (hosted payloads or dedicated satellite)





IN-SPACE MISSIONS DIGITAL OFFERING

INSPACE MISSIONS

INFORMATION

Exploit our rich archive of geometric & radiometric corrected EO, SAR and RF data, or utilise our tailored analytics products that are continually updated with data from our In-Space Digital Live system.

SIMULATION

Develop your applications in a simulated environment that is fully representative of the operational In-Space Digital Live system configuration.

DATA

Task the In-Space Digital Live system to deliver timely geolocated raw or processed EO, SAR and RF data to further your application development

ORBIT

Validate, upload and execute your application on the live In-Space Digital Live system with the full support of our service delivery team

CAPGEMINI’S CREDENTIALS

OUR QUANTUM TECHNOLOGY AREAS OF EXPERTISE

QUANTUM COMPUTING

- Material science, Drug discovery
- Risk modeling & Operational optimization
- Machine learning
- IBM-Q Hub and Broad Capgemini analytics expertise

QUANTUM-SAFE COMMUNICATION

- World-class quantum communication labs in Portugal and Cambridge, UK
- Post-quantum security
- Quantum key distribution
- Quantum internet applications for confidentiality, access control, and consensus protocols

QUANTUM SENSING

- Positioning, timing & navigation
- Radar technologies
- Earth observation
- Strong engineering expertise and laboratory at Cambridge Consultants

CAPGEMINI'S QUANTUM LAB – THE VALUE ADD

Domain experts (Space services, Life sciences, …)

Technological experts (Engineering, optimization, simulation, machine learning …)

- **Partnerships** (IBM, growing partner/consortium ecosystem and universities …)

Facilities in **Cambridge & Portugal**

30+ engineers from across Capgemini footprint

OUR USP

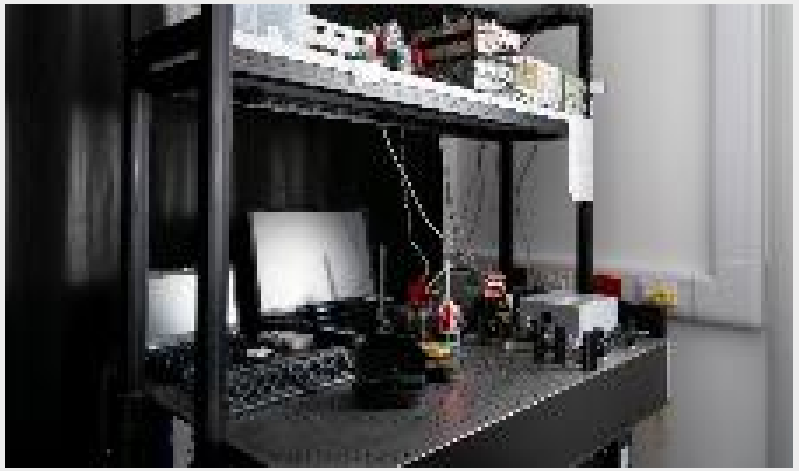
- End to end implementation
- Turning theory into business - bridging the gap between research and use cases
- One stop shop for all quantum
- Flexibility in exploration
- Ability to scale

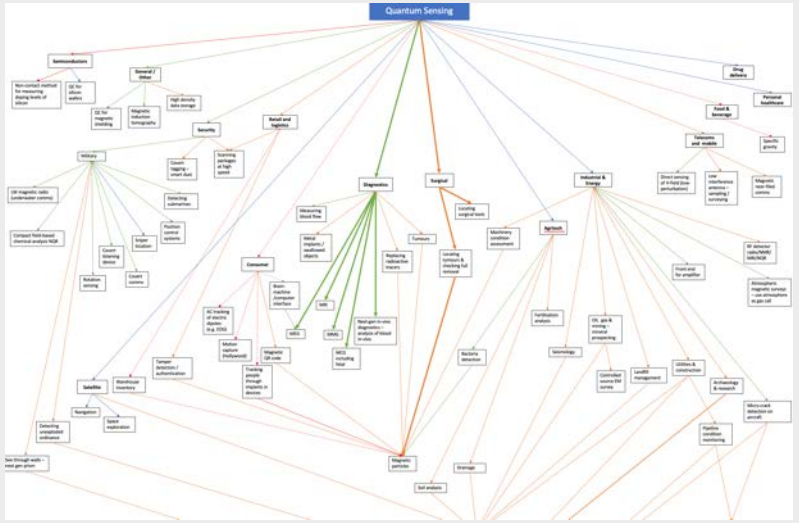
CAPGEMINI'S QUANTUM LAB

RESEARCH INTO MAGNETOMETRY

NEXT-GENERATION QUANTUM-ENABLED MAGNETIC SENSING

WITH THE UNIVERSITY OF STRATHCLYDE





Challenges

To create a magnetometer that detects the magnetic field using optical rotation of the plane of polarization of a laser in a rubidium vapor

Key elements

- Experimental setup of quantum sensor based on a rubidium vapor
- Control of laser frequency
- Control of background magnetic field
- Signal processing, and filtering out noise

Success

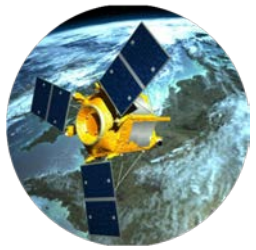
- around x100 sensitivity improvement over a conventional sensor
- Identified use cases for medical imaging and navigation
- Market opportunity identification

CAPGEMINI'S SPACE HERITAGE

WE'VE GOT OVER 35 YEARS OF INTERNATIONAL EXPERIENCE WORKING WITH INDUSTRY TO DELIVER SUCCESSFUL SPACE MISSIONS

EGNOS | ISS Planning
Envisat

1990s



ExoMars | CSO |
SARGS Curiosity

2010s

Copernicus S2 Data
Production

2020s

1980s

COSPAS | SPOT

2000s

PLEIADES | Spot 6 & 7

2015s

FalconEye Misseo | CFOSAT
MTG
BEPI-COLOMBO
BIOMASS
Copernicus

esa European Space Agency
arianeGROUP
AIRBUS DEFENCE & SPACE
cnes CENTRE NATIONAL D'ETUDES SPATIALES
OneWeb
EUMETSAT
EUSPA European Union Agency for the Space Programme

WE COVER THE WHOLE VALUE STREAM FOR SPACE

Upstream; commercial satellites, launch market, institutional budget lines

Midstream; Spacecraft ops & in-orbit management

Downstream; spacecraft-derived data, applications & services, consumer equipment

End users; B2B/B2C

Digital manufacturing
- IoT / Connectivity
- Digital twin
- M-AIT expertise & tools dev
- PLM

Digital Platform
- Data exploitation platform
- Scientific office expertise
- Thematic & verticalized services
- Data fusion & analytics

Verticalized services
- Space intelligence
- Connected territories

Critical & Complex Segment
- Control centre
- Mission centre
- Expertise centre
- Data storage & processing platform
- Critical GS element (HW/SW)
- Application management

Digital Service
- Customer experience & digital marketing
- Go to market support
- Search & Rescue service

Space segment
- MBSE
- AR/VR
- System simulation and modelling
- Physical Design & studies: Mechanical, Thermal, Electrical
- On-board processing

Common Digital services
- CRM
- Billing
- ERP projects & services

Advanced manufacturing & operational analytics (AI / ML / Deep Learning)

Cloud computing & managed services

Cybersecurity

Capgemini

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Capgemini is a global leader in partnering with companies to transform and manage their business by harnessing the power of technology. The Group is guided everyday by its purpose of unleashing human energy through technology for an inclusive and sustainable future. It is a responsible and diverse organization of 325,000 team members in more than 50 countries. With its strong 55-year heritage and deep industry expertise, Capgemini is trusted by its clients to address the entire breadth of their business needs, from strategy and design to operations, fuelled by the fast evolving and innovative world of cloud, data, AI, connectivity, software, digital engineering and platforms. The Group reported in 2021 global revenues of €18 billion.

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