QUANTUM TECHNOLOGIES at the EUROPEAN SPACE AGENCY

Bruno Leone

29 March 2017

ESA facts and figures

- Over 50 years of experience
- 22 Member States
- Eight sites/facilities in Europe, about 2300 staff
- 5.75 billion Euro budget (2017)
- Over 80 satellites designed, tested and operated in flight

Purpose of ESA

"To provide for and promote, for exclusively peaceful purposes, cooperation among European states in **space research** and **technology** and their **space applications.**"

Article 2 of ESA Convention

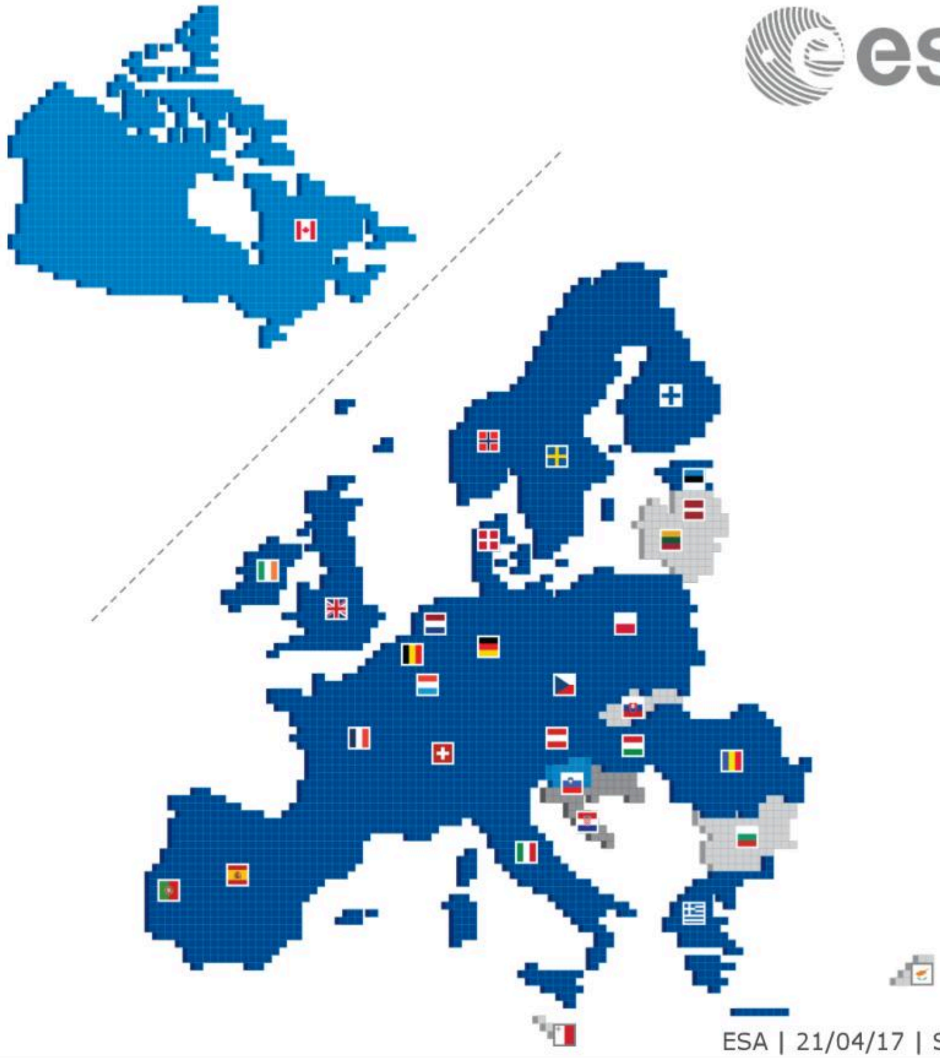
Member States

ESA has 22 Member States: 20 states of the EU (AT, BE, CZ, DE, DK, EE, ES, FI, FR, IT, GR, HU, IE, LU, NL, PT, PL, RO, SE, UK) plus Norway and Switzerland.

Seven other EU states have Cooperation Agreements with ESA: Bulgaria, Cyprus, Latvia, Lithuania, Malta and Slovakia. Discussions are ongoing with Croatia.

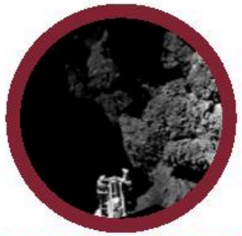
Slovenia is an Associate Member.

Canada takes part in some programmes under a long-standing Cooperation Agreement.



Activities

ESA is one of the few space agencies in the world to combine responsibility in nearly all areas of space activity.


space science


human spaceflight


exploration


earth observation


launchers


navigation


operations


technology


telecommunications

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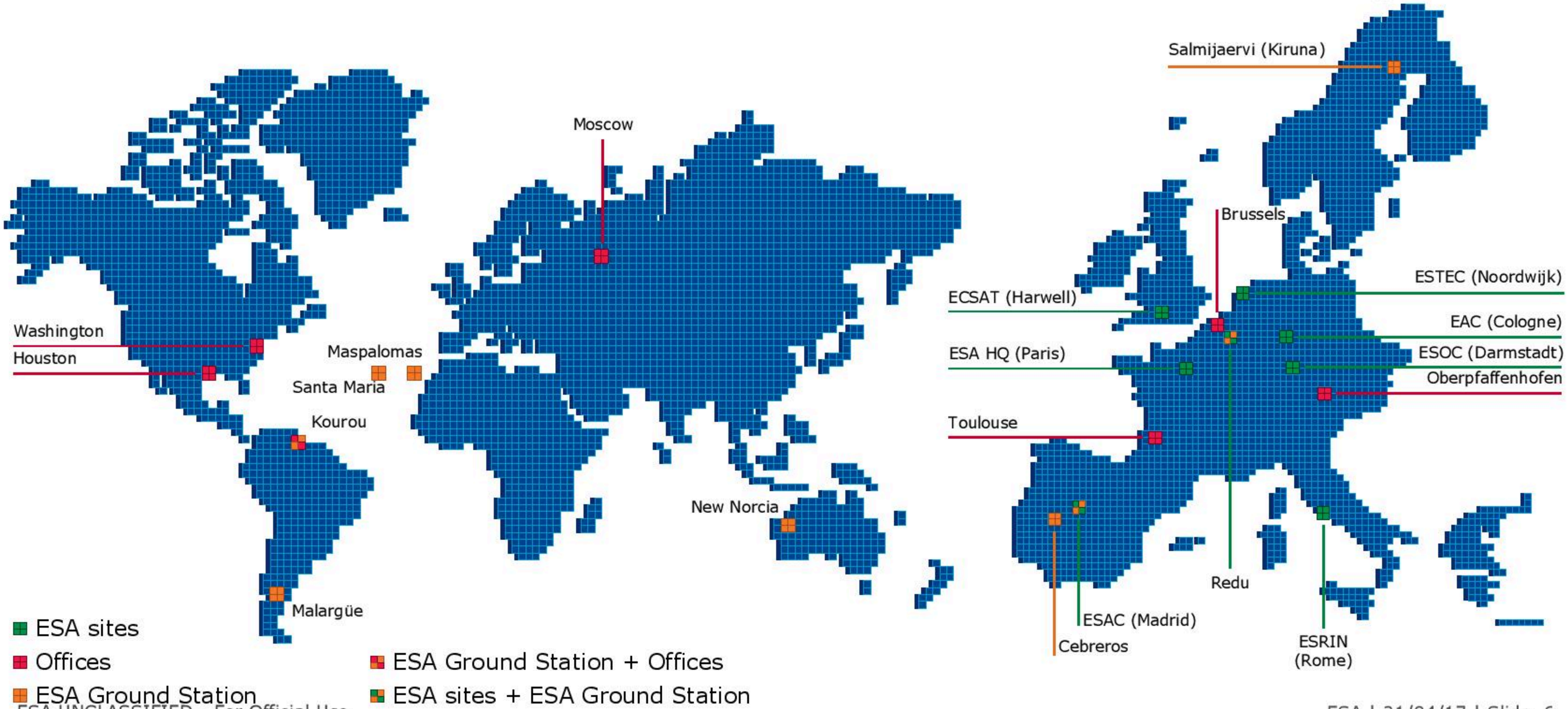
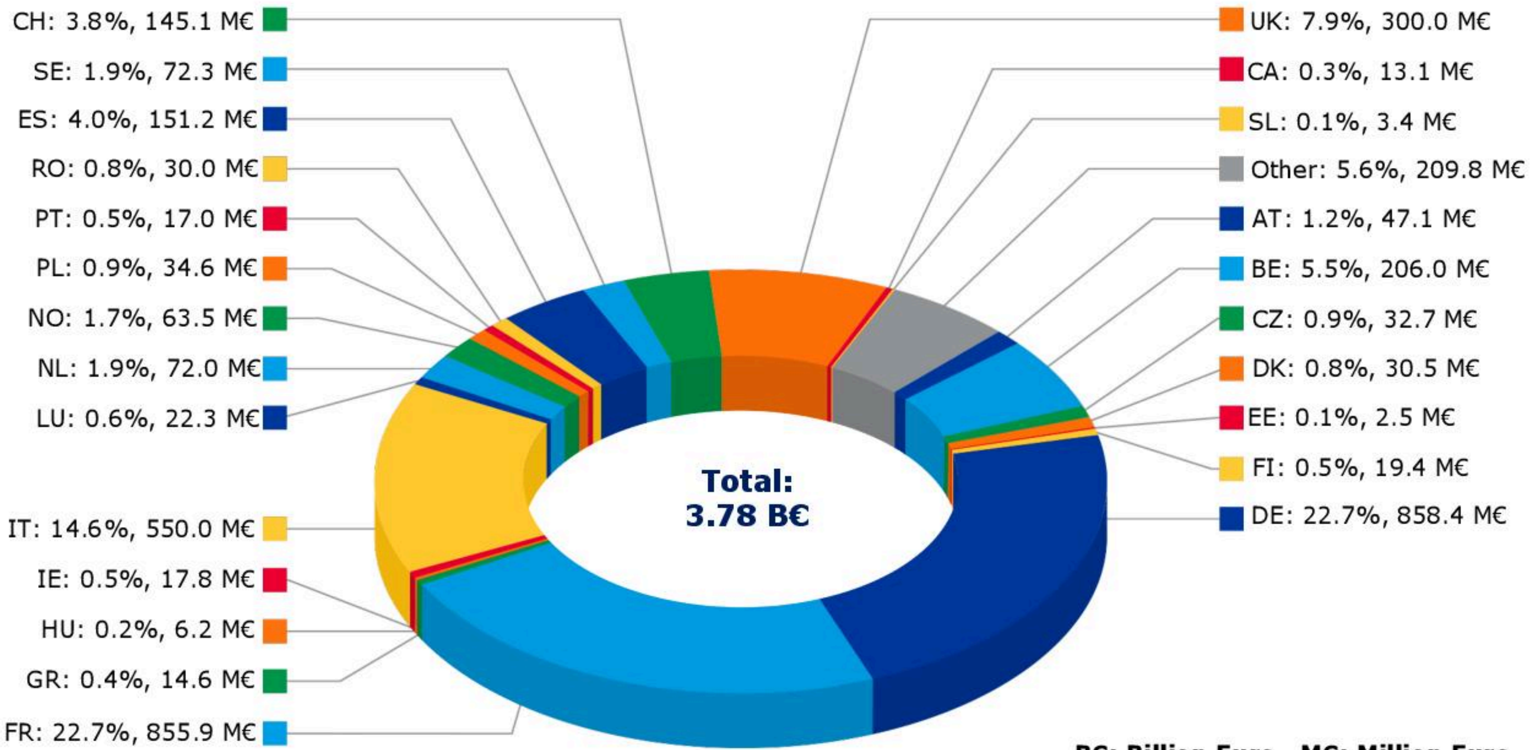
ESA’s locations

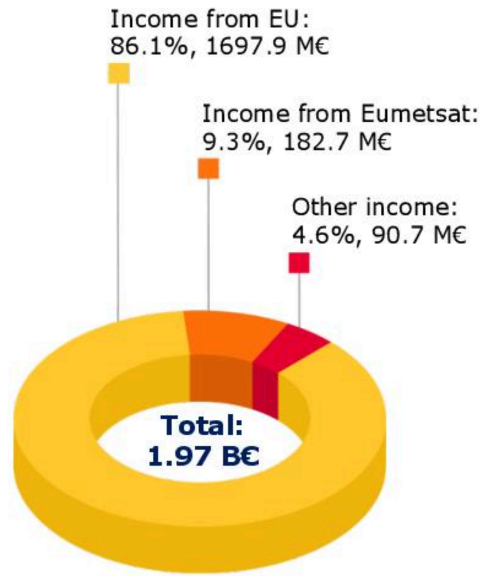


ESA budget for 2017: 5.75 B€

ESA Activities and Programmes

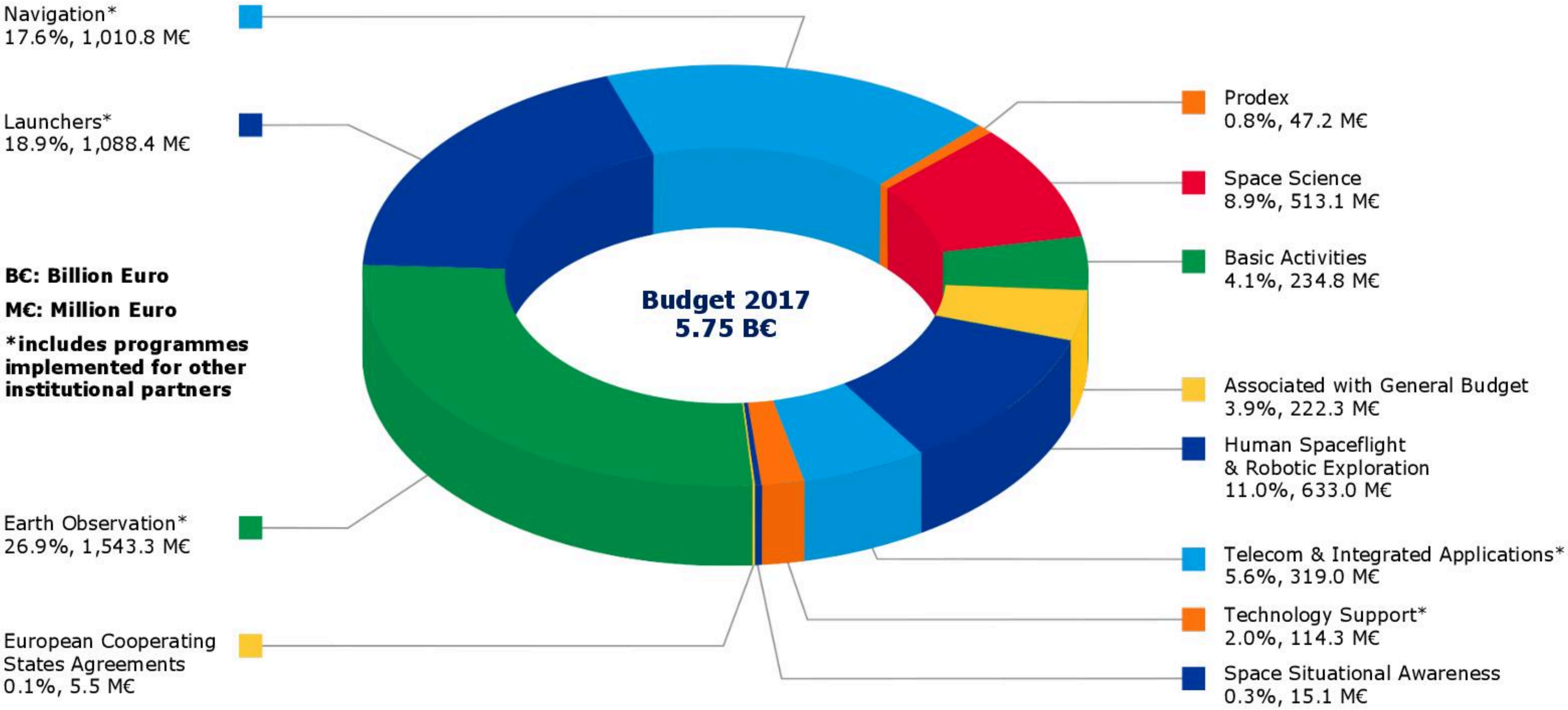


Programmes implemented for other institutional partners



B€: Billion Euro   M€: Million Euro

ESA budget for 2017: by domain

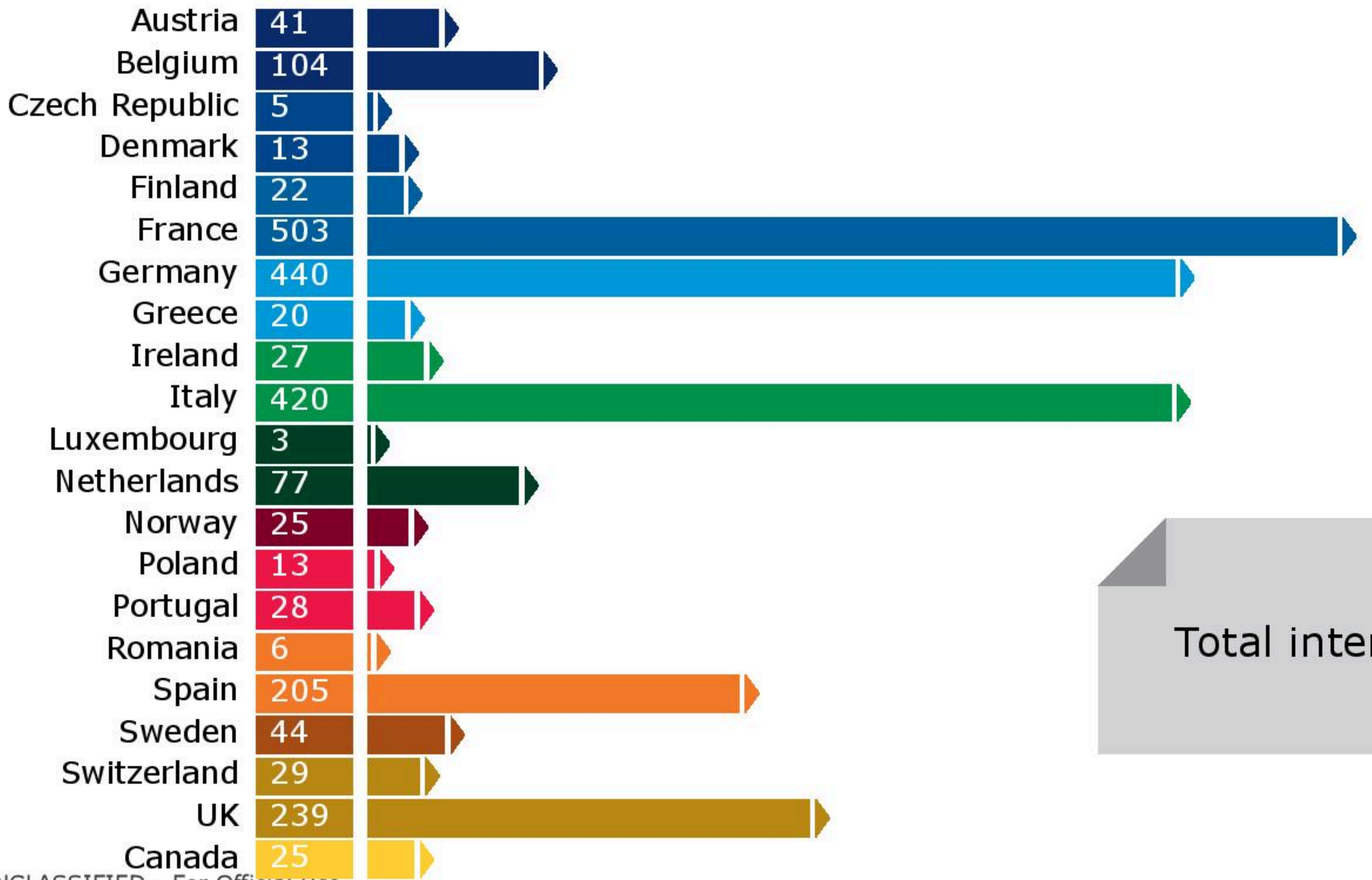


B€: Billion Euro

M€: Million Euro

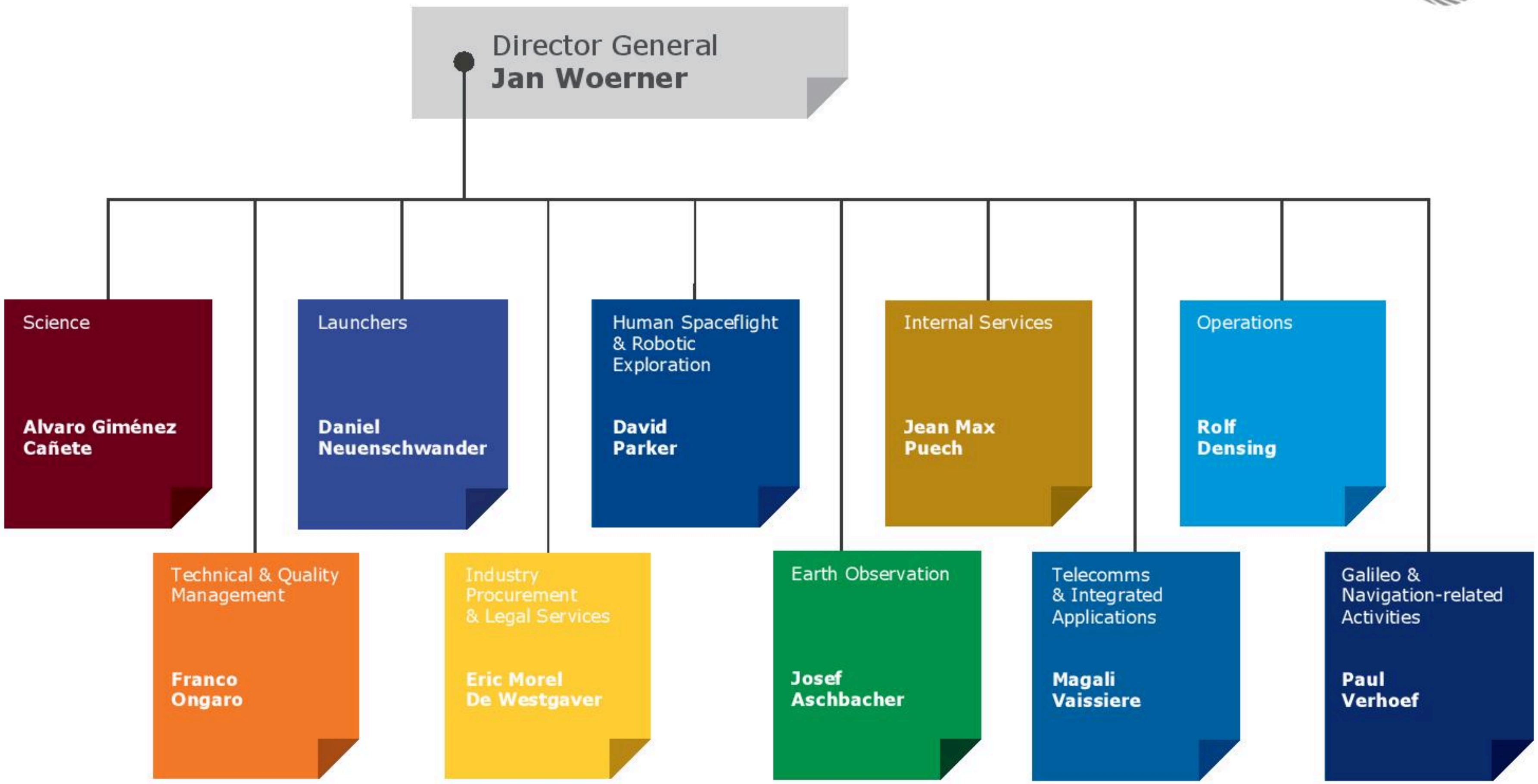
***includes programmes implemented for other institutional partners**

Staff by nationality in 2016



Total international staff: 2289

ESA directors



ESA and the European space sector

ESA Member States finance 50% of the total public space spending in Europe. Because of the cooperation between ESA, EC and the national space agencies:

- The European space industry sustains around 35 000 jobs;
- Europe is successful in the commercial arena, with a market share of telecom and launch services higher than the fraction of Europe's public spending worldwide;
- European scientific communities are world-class and attract international cooperation;
- Research and innovation centres are recognised worldwide;
- European space operators (Arianespace, Eumetsat, Eutelsat, SES Global, etc.) are the most successful in the world.

ESA’s industrial policy

About 85% of ESA’s budget is spent on contracts with European industry.

ESA’s industrial policy:

- Ensures that Member States get a fair return on their investment;
- Improves competitiveness of European industry;
- Maintains and develops space technology;
- Exploits the advantages of free competitive bidding, except where incompatible with objectives of the industrial policy.

Birth of commercial operators

ESA's 'catalyst' role

ESA is responsible for R&D of space projects. On completion of qualification, they are handed to outside entities for production and exploitation. Most of these entities emanated from ESA.

Meteorology: Eumetsat

Launch services: Arianespace

Telecoms: Eutelsat and Inmarsat

ESA Council

The Council is the governing body of ESA.

It provides the basic policy guidelines for ESA's activities. Each Member State is represented on the Council and has one vote.

Every two to three years, Council meets at ministerial level ('Ministerial Council') to take key decisions on new and continuing programmes and financial commitment.

The ESA Council at ministerial level also meets together with the EU Council to form the European 'Space Council'.

Ministerial Council 2016, Lucerne

Ministers declared support for the ESA Director General's vision for Europe in space and the role and development of ESA: now the Space 4.0i era can start with ESA committing to **inform**, **innovate**, **interact** and **inspire**. The next Council at ministerial level is scheduled for the end of 2019 in Spain.

Four Resolutions were adopted:

- **Towards Space 4.0** for a 'United Space in Europe';
- **Level of Resources** for the Agency's Mandatory Activities 2017–21;
- **Guiana Space Centre,** 2017–21;
- **ESA Programmes.**

Space 4.0: a new era of space

Space 4.0 represents the evolution of the space sector into a new era:

- From being the preserve of the governments of a few spacefaring nations, to an increased number of diverse space actors around the world;
- With the emergence of private companies, participation with academia, industry and citizens, digitalisation and global interaction;
- Analogous to, and is intertwined with, Industry 4.0, which is considered as the unfolding fourth industrial revolution of manufacturing and services.

Space 4.0i

Space 4.0 is adapted to an ESA-specific derivative, **'Space 4.0i'**, which describes the way ESA will play its role as a space agency for Europe.

Space 4.0i combines the described global situation of space developments with the 'i' standing for an ESA-specific interpretation of the tasks:

- **ESA innovates** – through more disruptive and risk-taking technologies;
- **ESA informs** – through the reinforcement of the link with large public and user communities;
- **ESA inspires** – through the launch of new initiatives and programmes, both current and future generations;
- **ESA interacts** – through enhanced partnerships with Member States, European institutions, international players and industrial partners.

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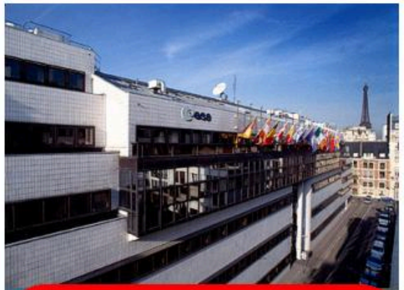
ESA Establishments and Centres in Europe



ESA-Headquarters (HQ)
Paris

European Space Research & Technical Centre (ESTEC)
Noordwijk

European Space Operation Centre (ESOC)
Darmstadt

European Space Research Institute (ESRIN)
Rome

European Astronauts Centre (EAC)
Cologne

ESA-Redu Centre
Redu

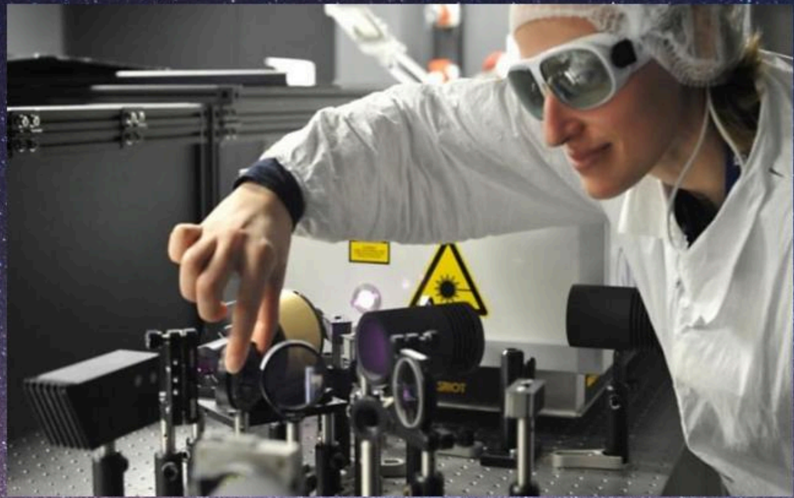
European Space Astronomy Centre (ESAC)
Madrid

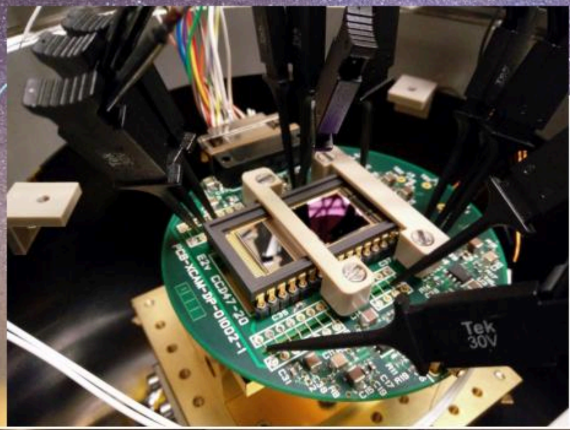
NEW site: European Centre for Space Applications and Telecommunications (ECSAT)
Harwell

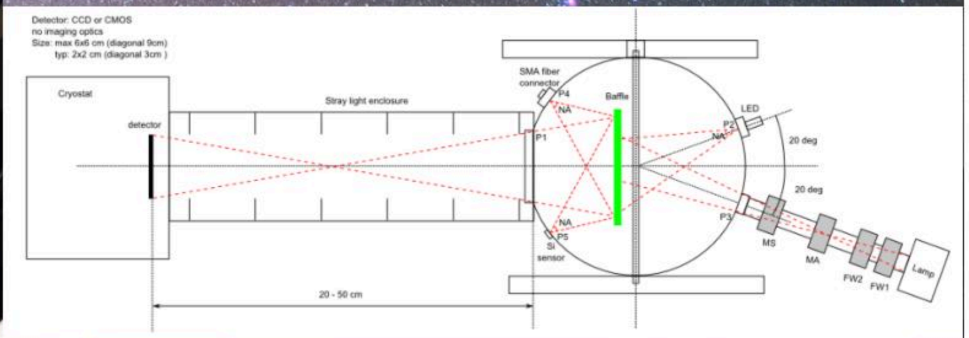
ESA Optoelectronics Section

1. Laser developments – provide support to:
   - Lidar missions: Aeolus, EarthCare
   - Lasers for quantum technologies:
     - Atomic clocks
     - Cold atom inteferometry
   - Future Gravity mapping and gravitational wave detection
2. Detector developments
   - CCD and CMOS
   - MCT
   - X-ray, Far-IR, THz
3. Photonics
   - Fibres and sensors
   - Optical telecoms
   - Microphotonics
4. Optoelectronics Test-Facilities
   - Optical Ground Station (Tenerife)
   - Laser diode testing
   - LIC and LIDT testing
   - Mobile Lidar
   - Detector Characterisation

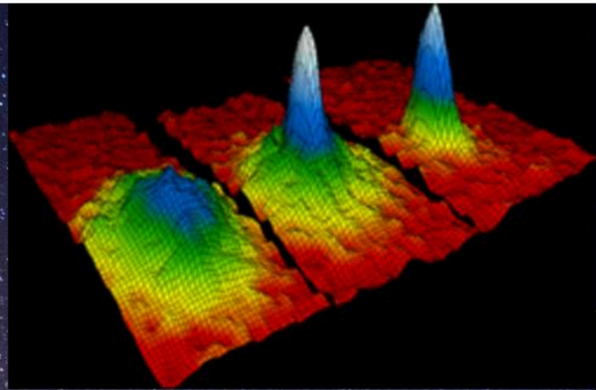
Optoelectronics Test Facilities

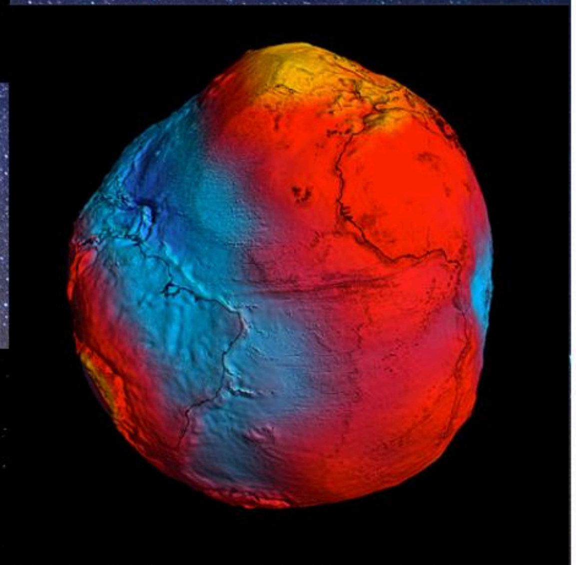






Quantum Technologies





Quantum Sensors

- Cold Atom Interferometry
  - Fundamental Physics
  - Gravity Mapping

Quantum Optics

- Entangled states in gravity gradient
- Quantum Encryption

QT – Implementations for Space

- Workshop at ESA-ESTEC, Nov. 2016

Cold Atom Physics

Why cold atoms?

- Study/observe internal structure of free atoms (≠ solid state physics)
- Atom waves potentially more interesting than electron or neutron waves (neutral + rich internal structure)
- Interaction with external electric fields and gravity

BUT: RT atom speeds ~ 300 m/s

- Atom beams have low coherence ➔ difficult to handle as waves
- Limited observation time (few ms) on a table-top experiment

Low temperature physics

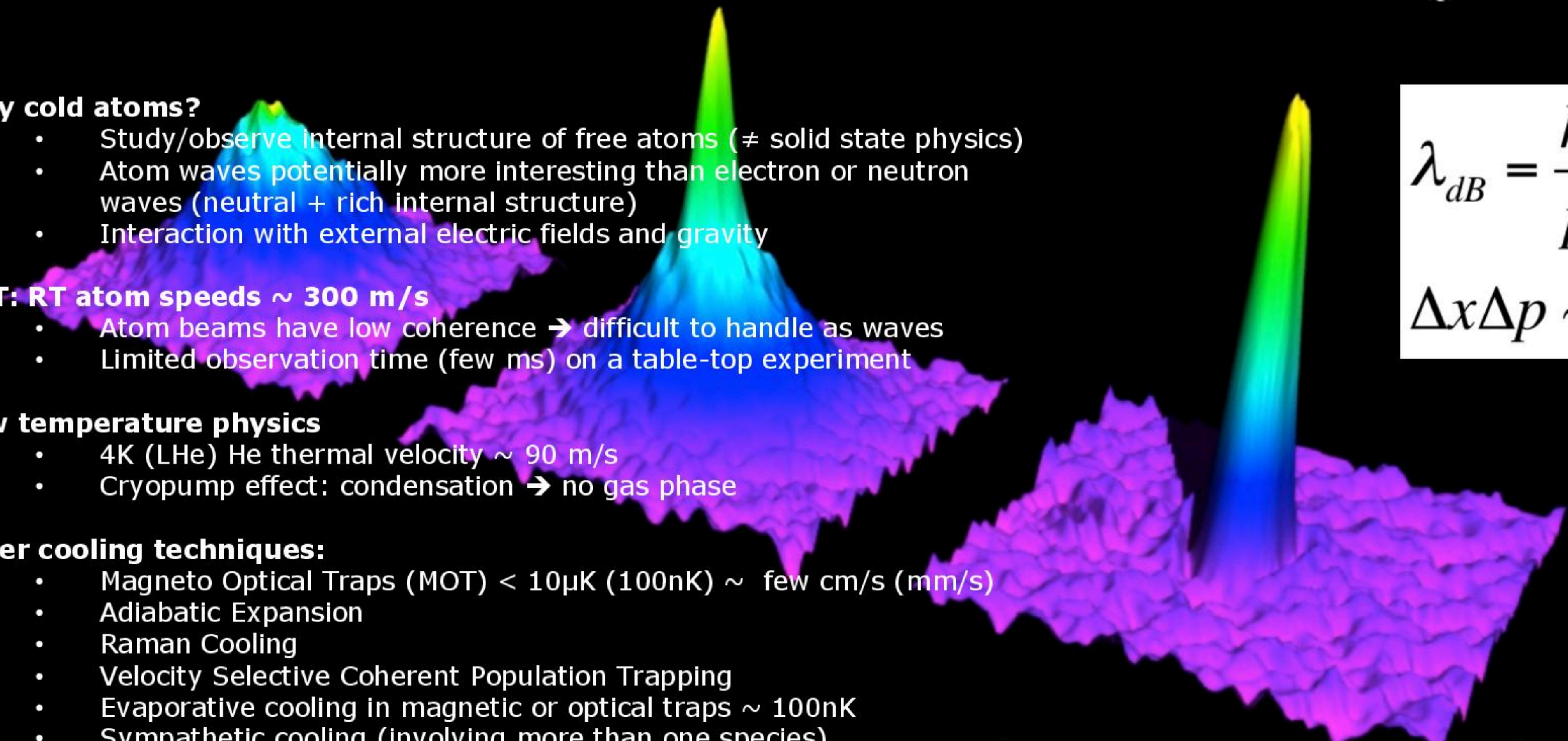
- 4K (LHe) He thermal velocity ~ 90 m/s
- Cryopump effect: condensation ➔ no gas phase

Laser cooling techniques:

- Magneto Optical Traps (MOT) < 10μK (100nK) ~ few cm/s (mm/s)
- Adiabatic Expansion
- Raman Cooling
- Velocity Selective Coherent Population Trapping
- Evaporative cooling in magnetic or optical traps ~ 100nK
- Sympathetic cooling (involving more than one species)

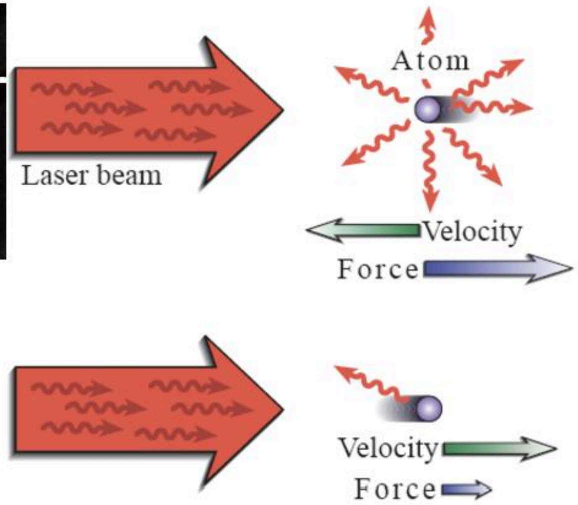
$$\lambda_{dB} = \frac{h}{p}$$

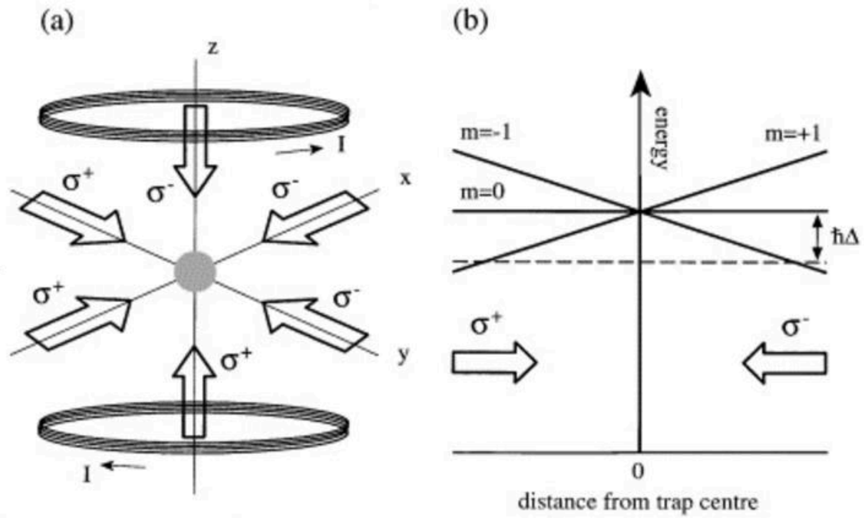
$$\Delta x \Delta p \sim \hbar$$

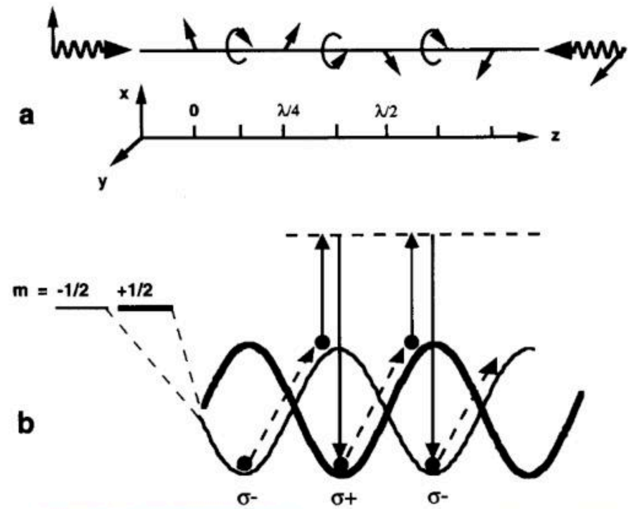


Phase Transition to a Bose-Einstein Condensate

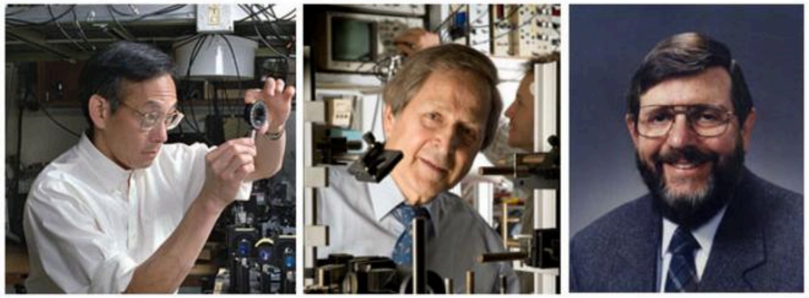
Magneto Optical Tr



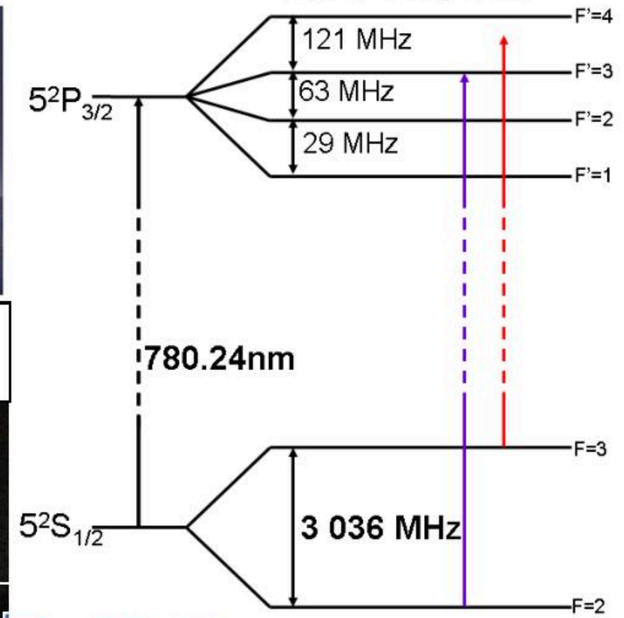




(a) Interfering, counter-propagating beams having orthogonal, linear polarizations create a polarization gradient. (b) The different Zeeman sublevels are shifted differently in light fields with different polarizations; optical pumping tends to put atomic population on the lowest energy level, but non-adiabatic motion results in "Sisyphus" cooling.



1997 Nobel Prize in Physics — Stephen Chu, Claude Cohen-Tannoudji, and Wiliam D. Phillips

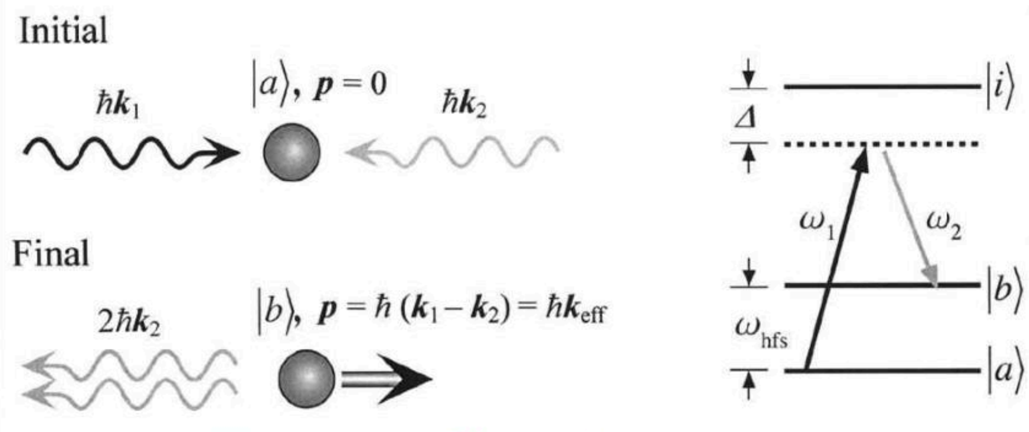


Credit: RAL Space

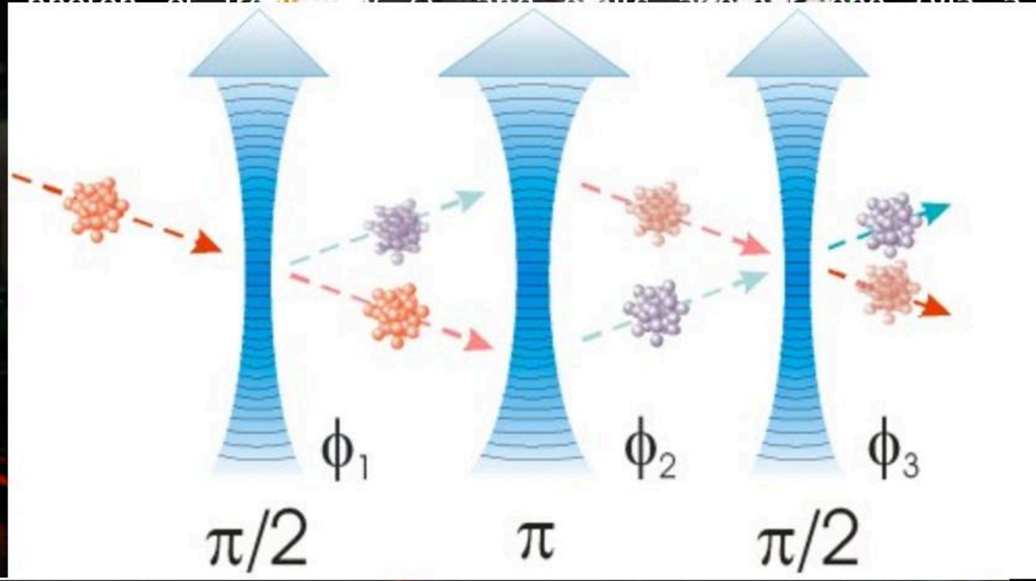
Atom Optics

- What is needed:
  - Coherent mechanism providing the equivalent of mirrors, beam splitters and lenses for cold atoms beams

- Stimulated Raman transitions
  - Two counter-propagating laser beams stimulate Raman transitions between hyperfine ground states
  - Provides a recoil from the two photons (absorbed + emitted)
  - Large detuning, Δ, reduces probability of excited state $|i>$ becoming populated
  - Depending on how long they are applied, stimulated Raman transitions act as mirrors (π pulse) or beam splitters (π/2 pulse)



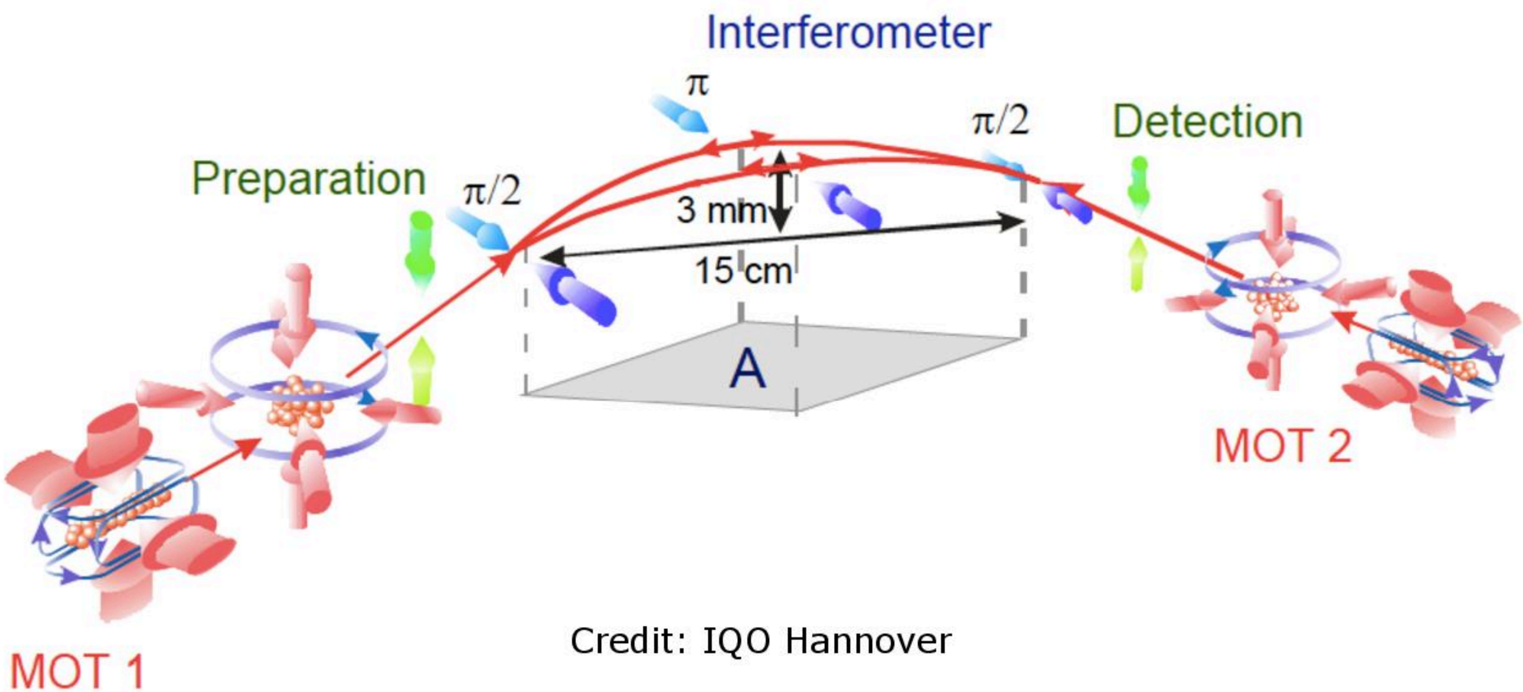
An atom undergoes a stimulated Raman transition, absorbs a



Cold Atom Interferometry (CAI)

- 2D MOT loads 3D MOT with high flux ~ 10^9 atoms/s
- 3D MOT cools atom clouds ~ 10^8 ^{87}Rb atoms <10μK
- Atomic state preparation for atom optics sequence
- Raman π/2—π—π/2 sequence
- Detection by fluorescence

10^{11} improvement!

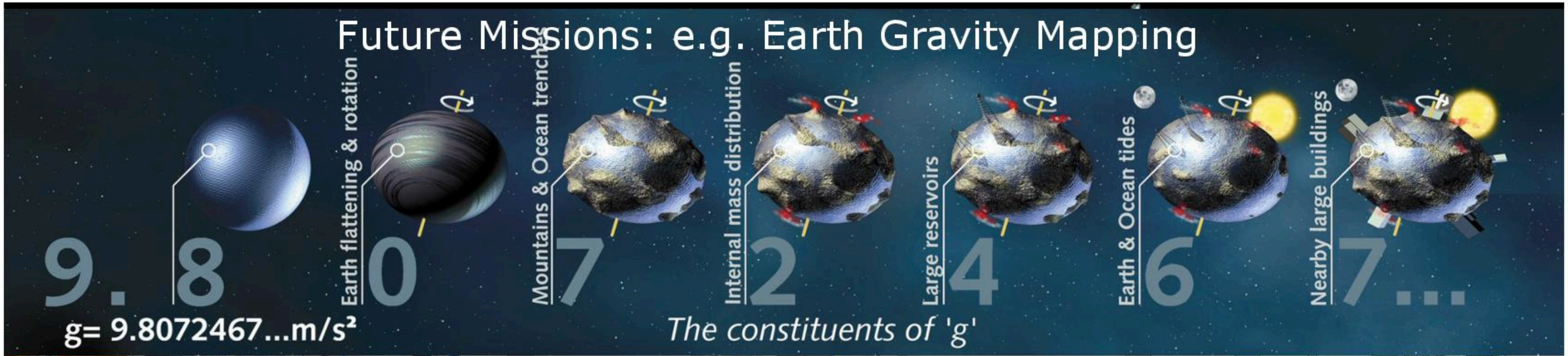


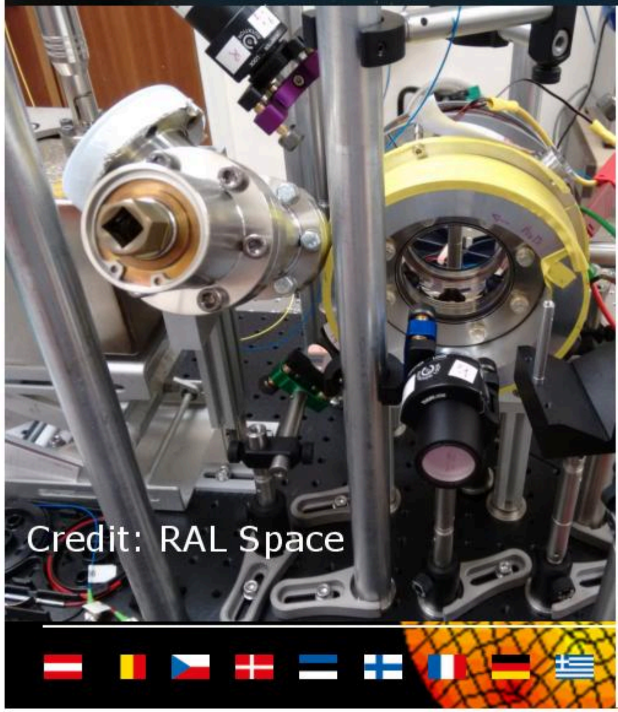
Credit: IQO Hannover

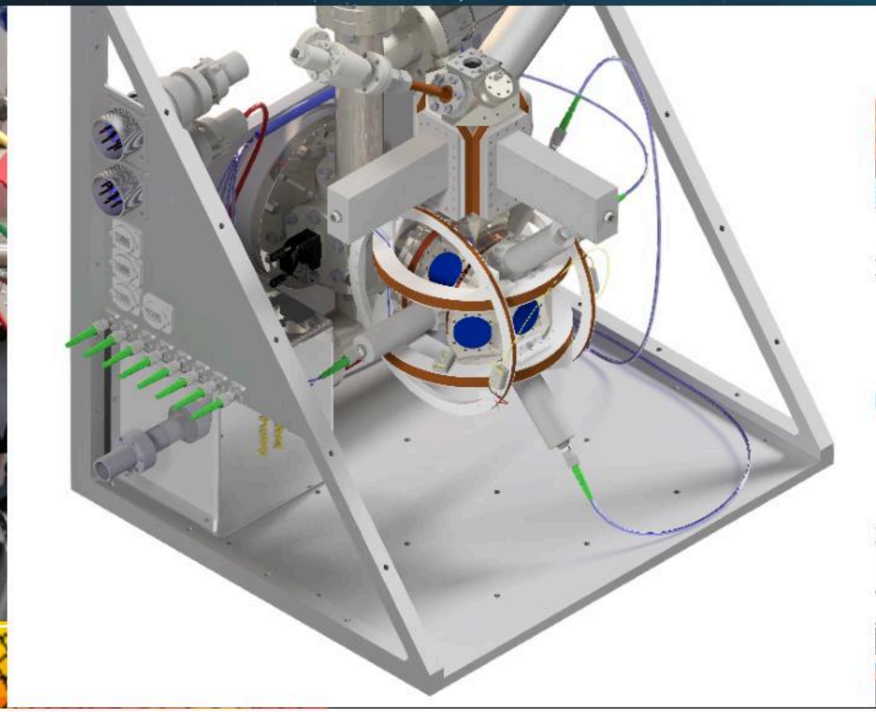
$$\Delta\varphi_{light} = \frac{4\pi}{\lambda c}\vec{\Omega}\cdot\vec{A}$$

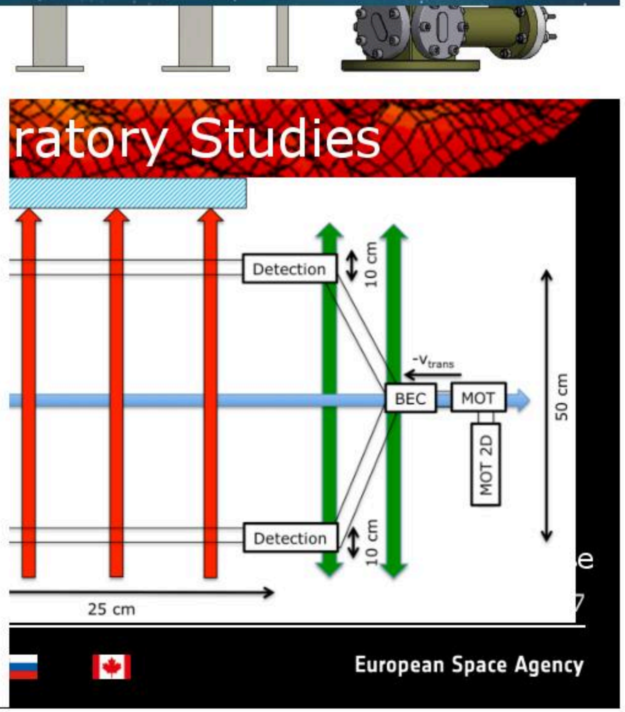
$$\Delta\varphi_{atom} = \frac{4\pi}{\lambda_{dB} v}\vec{\Omega}\cdot\vec{A}$$

$$\Delta\varphi_{atom} = \frac{mc^2}{\hbar\omega}\Delta\varphi_{light}$$


Future Missions: e.g. Earth Gravity Mapping
9. 8
Earth flattening & rotation
0
Mountains & Ocean trenches
7
Internal mass distribution
2
Large reservoirs
4
Earth & Ocean tides
6
Nearby large buildings
7...
g= 9.8072467...m/s²
The constituents of 'g'


Credit: RAL Space

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Detection
10 cm
-v_trans
BEC
MOT
MOT 2D
50 cm
Detection
10 cm
25 cm
European Space Agency

CAI Applications

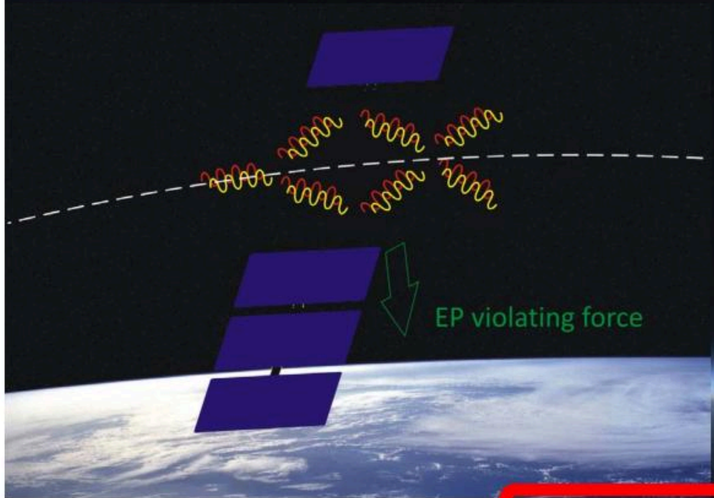
Gravity Mapping

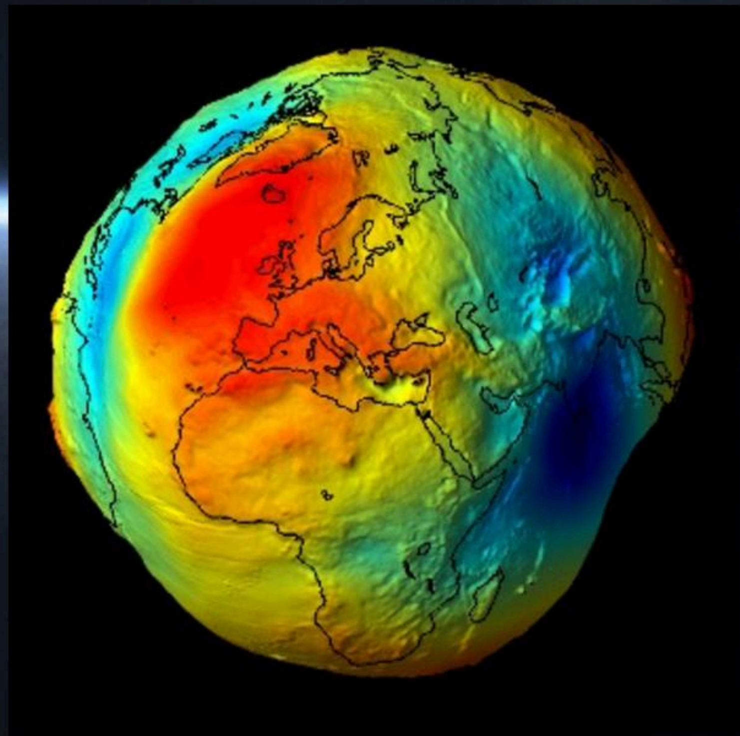
Inertial Navigation

Attitude Monitoring

Accelerometers for Drag-Free Systems

Deep Space Accelerometers





Fundamental Physics:

- Testing General Relativity
- Short-Range Forces
- Atom-Surface Interactions
- Fundamental Constants
- Electron Electric Dipole Moment
- Spin-Gravity Coupling
- Quantum Fluctuations
- Decoherence

Activities

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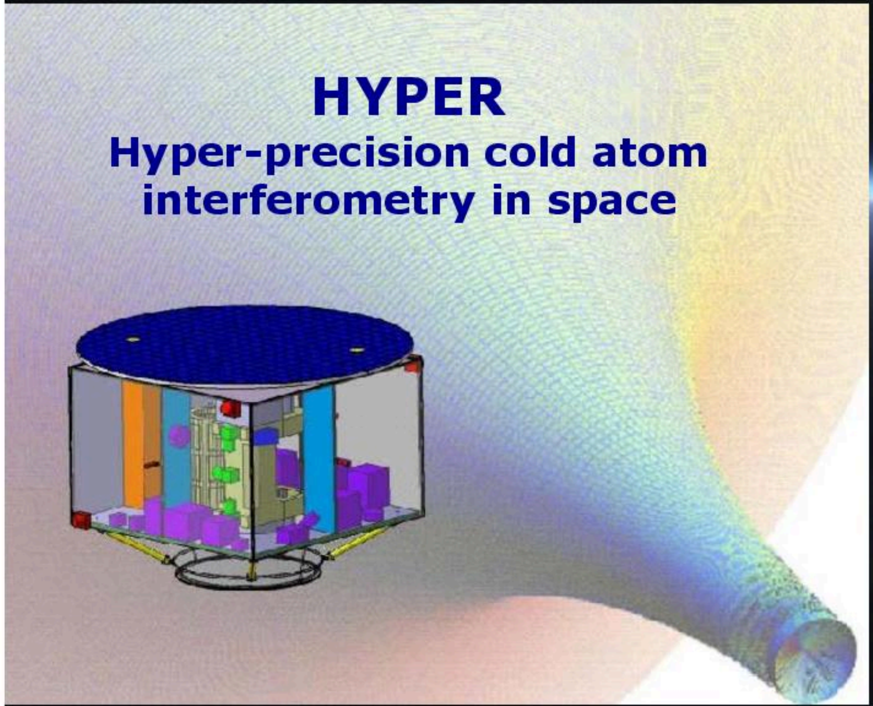
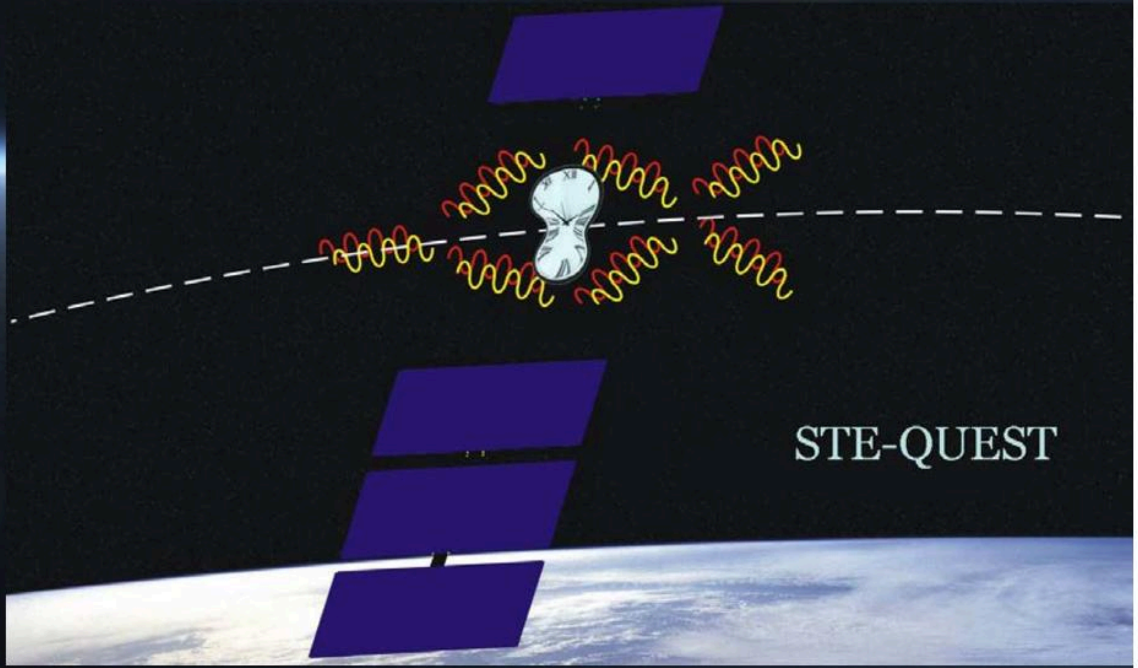
Science mission studies

HYPER Industrial Feasibility – 2003
Credit: EADS Astrium GmbH



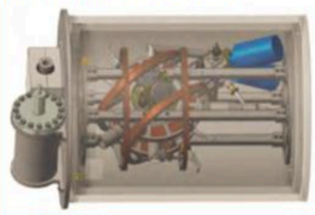
Space-Time Explorer and Quantum Equivalence Principle Space Test

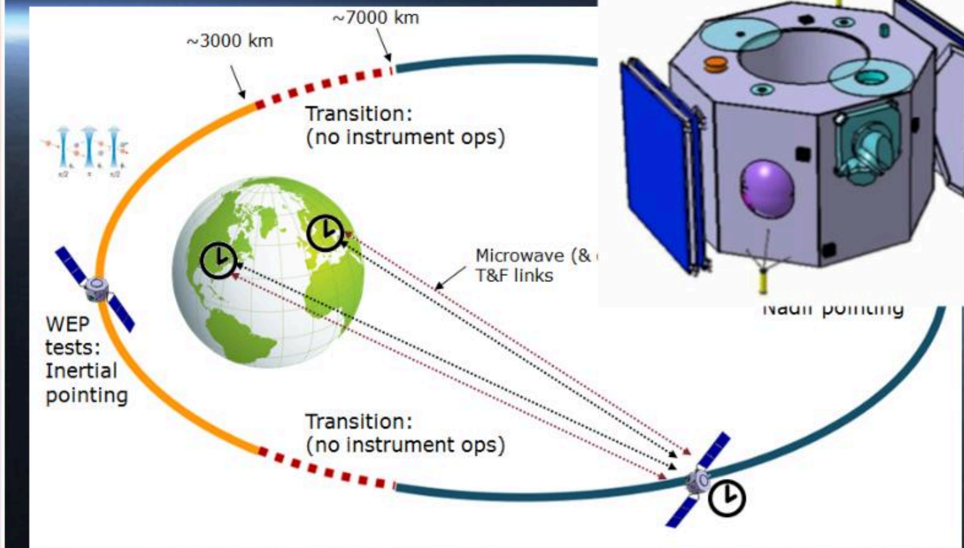
- ESA Cosmic Vision proposal – 2011
- Feasible? Yes
- Outstanding Science? Yes
- Payload TRL challenges? Yes

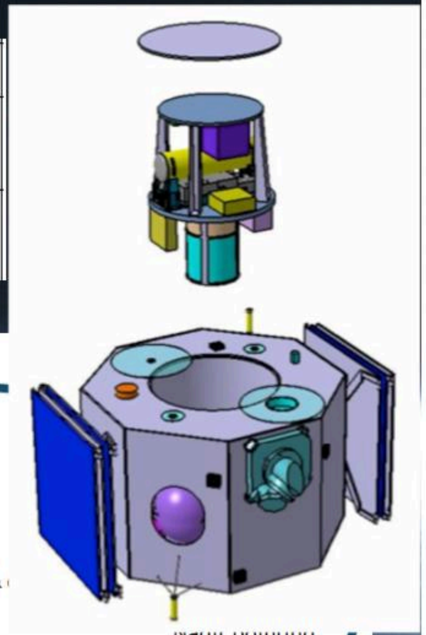


M3 Candidate STE-QUEST

Theme	What are the fundamental physical laws of the Universe?
Primary Goal	To test the Einstein's Equivalence Principle to high precision and search for new fundamental constituents and interactions in the Universe.
Observables	• Differential acceleration measurements of freely falling atoms; • Clock redshift measurements.

Instrument	**Acronym**	**High Level Description**
Atomic Clock 	ATC	Cold atom microwave clock with optical oscillator for short term performance.
Atom Interferometer 	ATI	Dual-species Rb85, Rb87 cold atom interferometer for differential acceleration measurements.

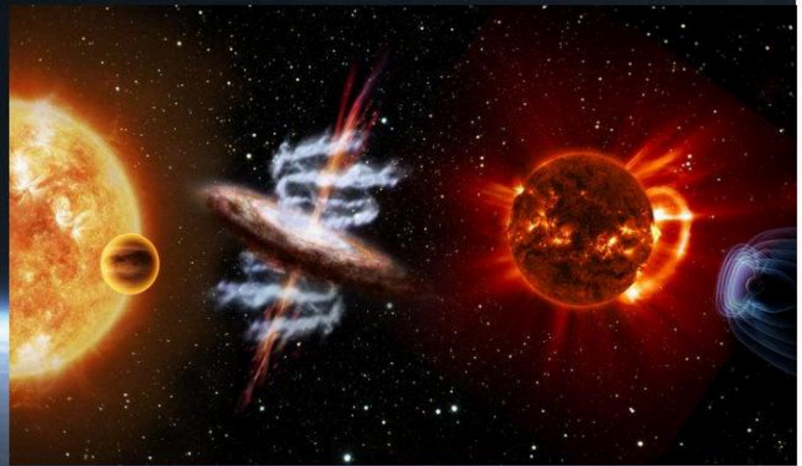




Science missions selection and implemenatation

Missions are selected through open Calls

- 2007: Call for M1/M2 and L1 mission
- 2010: Call for M3 mission
- 2012: Call for S1 mission
- 2013: Call for L2/L3 missions science themes
- 2014: Call for L2 mission, Call for M4 mission
- 2015: Call for ESA/CAS S2 mission
- 2016: Call for M5 mission, Call for New Science Ideas, Call for L3 mission



Four type of missions considered today: L, M, S and O missions

LARGE-Missions: ~ 2 ESA Science Programme yearly budget (1B€ cost to ESA excluding payload), possibly with international partner(s), typically 6-7 years preparation, then 7-8 years development (Phase B2/C/D)
L1 = JUICE, L2 = Athena, L3 = "The Gravitational Universe"

MEDIUM-Missions: ~ 1 ESA Science Programme yearly budget (500 M€ cost to ESA excluding payload), ~ 4 year preparation (Phase 0, A, B1 studies and technology activities), then 6-7 years development (Phase B2/C/D)
M1 = Solar Orbiter, M2 = Euclid, M3 = PLATO, M4 = ARIEL/THOR/XIPE

SMALL-Missions: Member State led (50 M€ cost to ESA), use of COTS technology, fast cycle ~ 4-5 years phase A-D.
S1 = CHEOPS, S2 = SMILE (jointly with China)

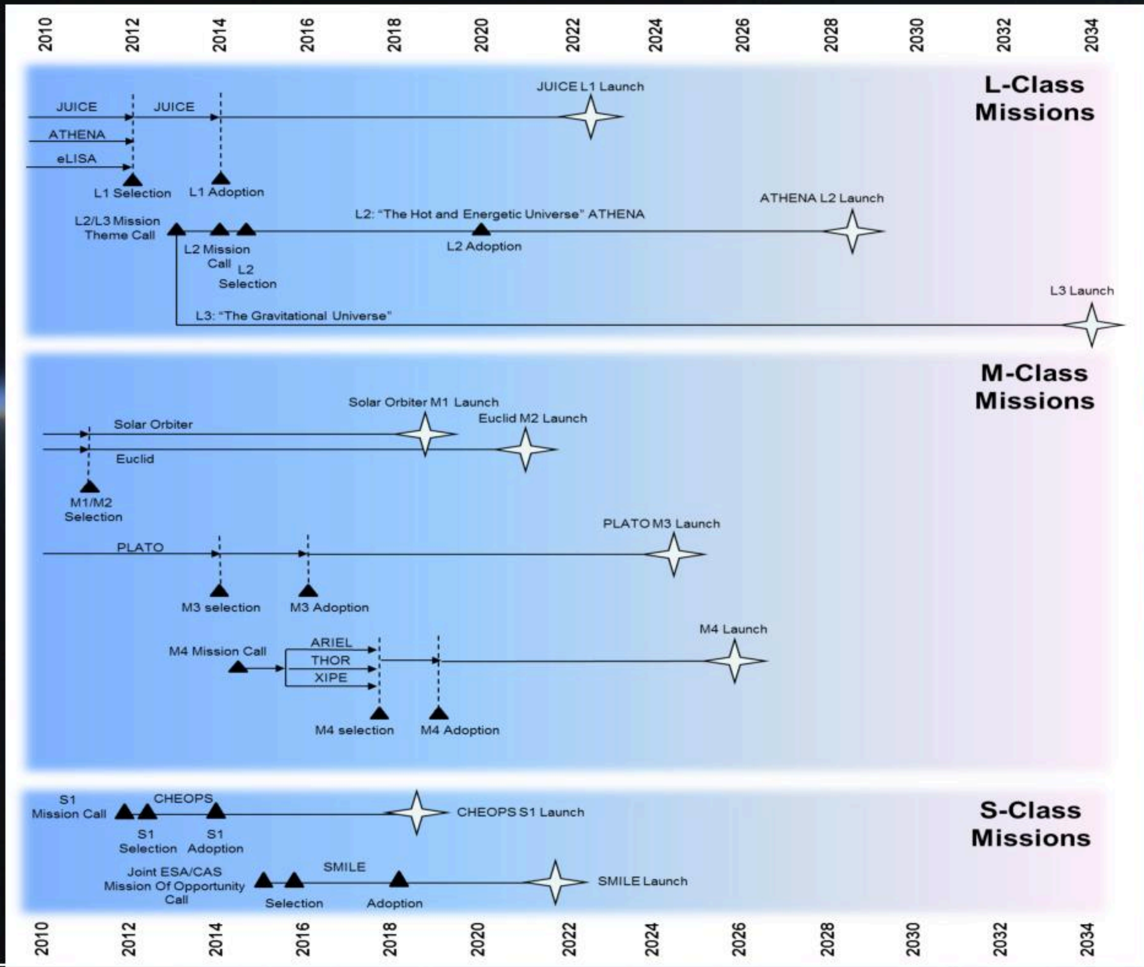
OPPORTUNITY-Missions: Other Agency led, ESA contribution on case by case basis

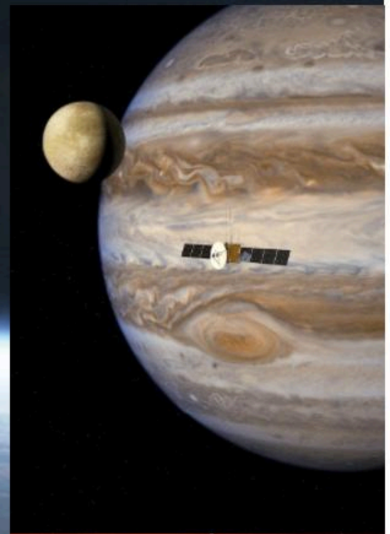
Science Programme Timeline

Large Mission
Observatory Class
Major advance in a field
ESA cost: 1000M€

Medium Mission
Ambitious Science
ESA cost: 500M€

Small Mission
Targeted science
ESA/member state
ESA cost: 50M€





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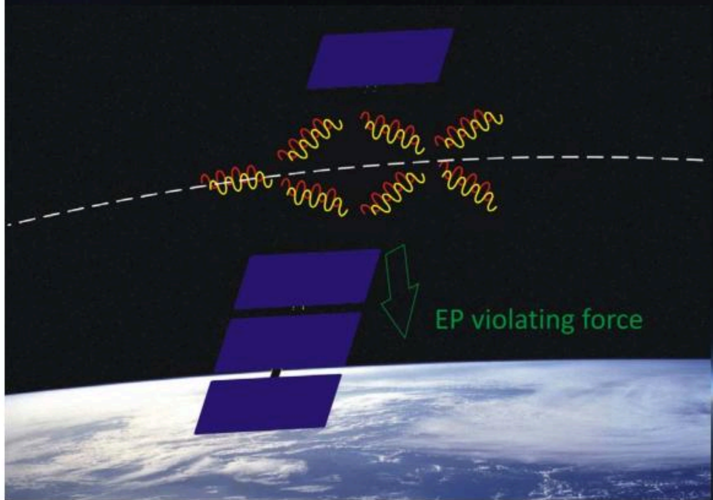

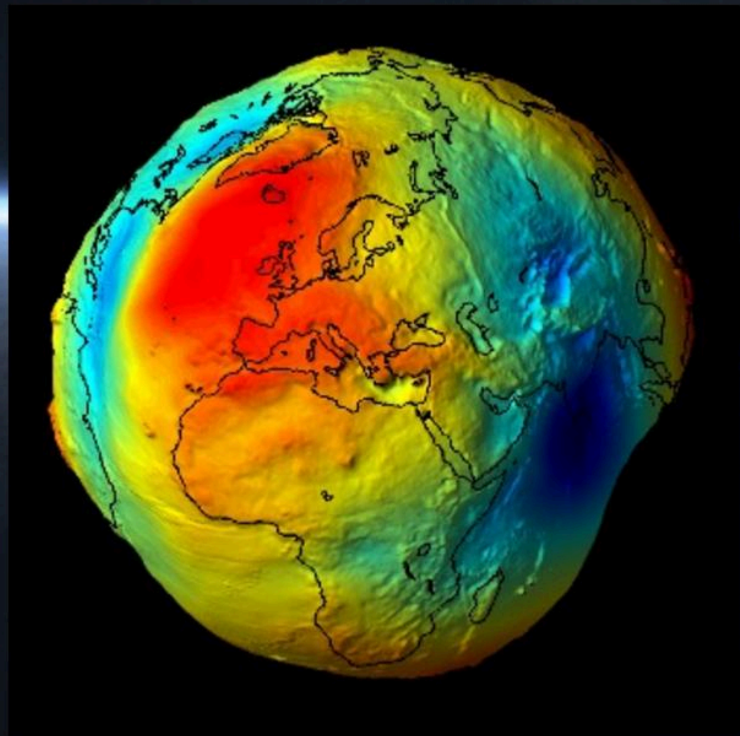

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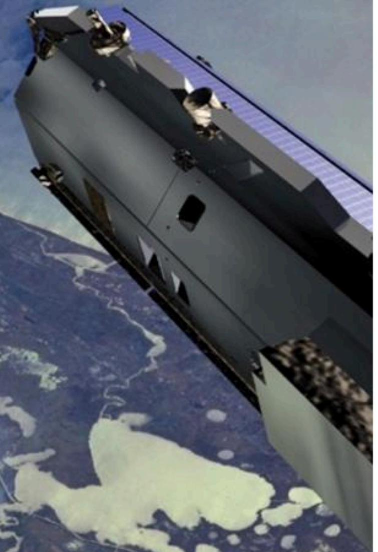
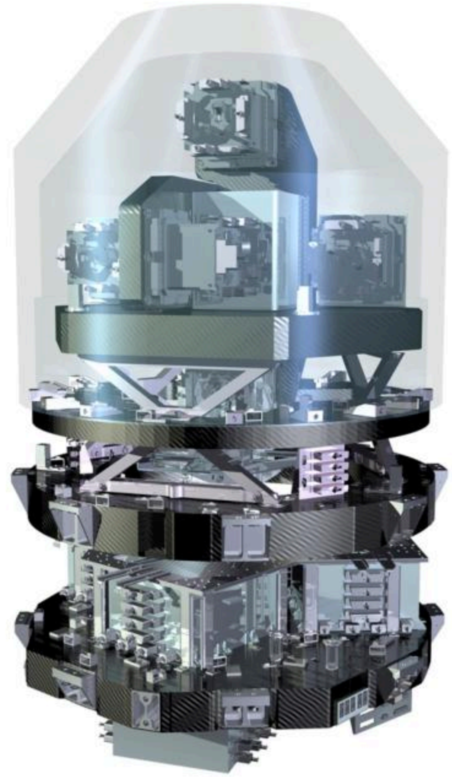
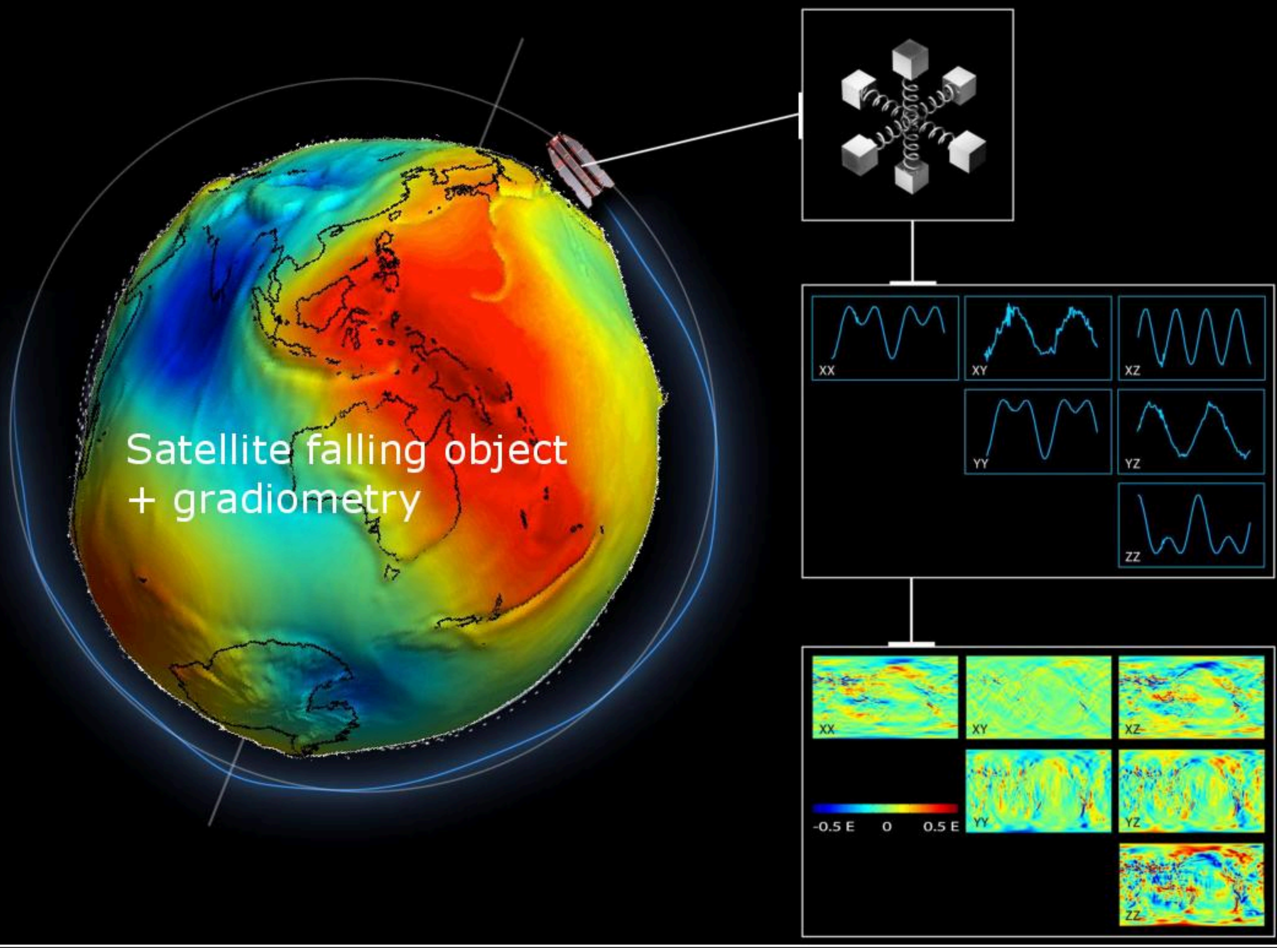
GOCE

- GOCE: Gravity Field and Steady-State Ocean Circulation Explorer
- Main instrument: Electrostatic Gravity Gradiometer (EGG) – a set of six 3-axis accelerometers mounted in a diamond configuration in an ultra-stable structure
- Each accelerometer pair forms a 50 cm long gradiometer arm
- Three arms are mounted orthogonally: along-track, cross-track and vertically
- Onboard GPS receiver used as a Satellite-to-Satellite Tracking Instrument (SSTI) supplemented the gradiometer measurements



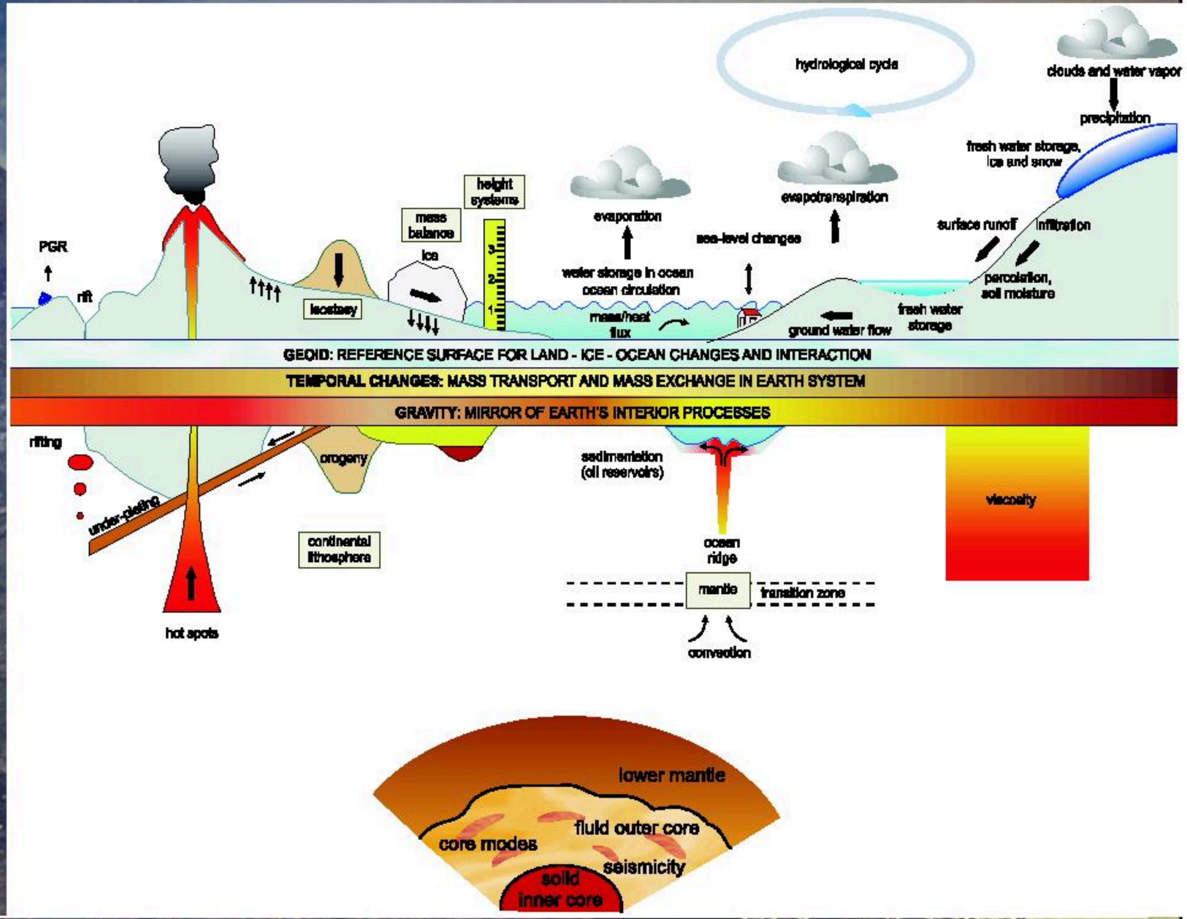


Measurement Concept

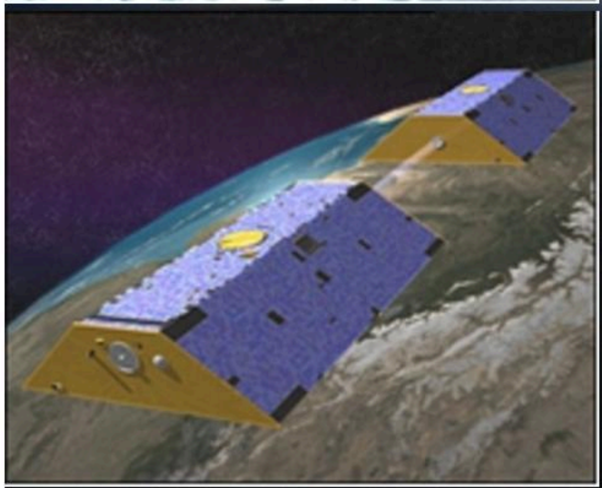


Earth Gravity - Applications

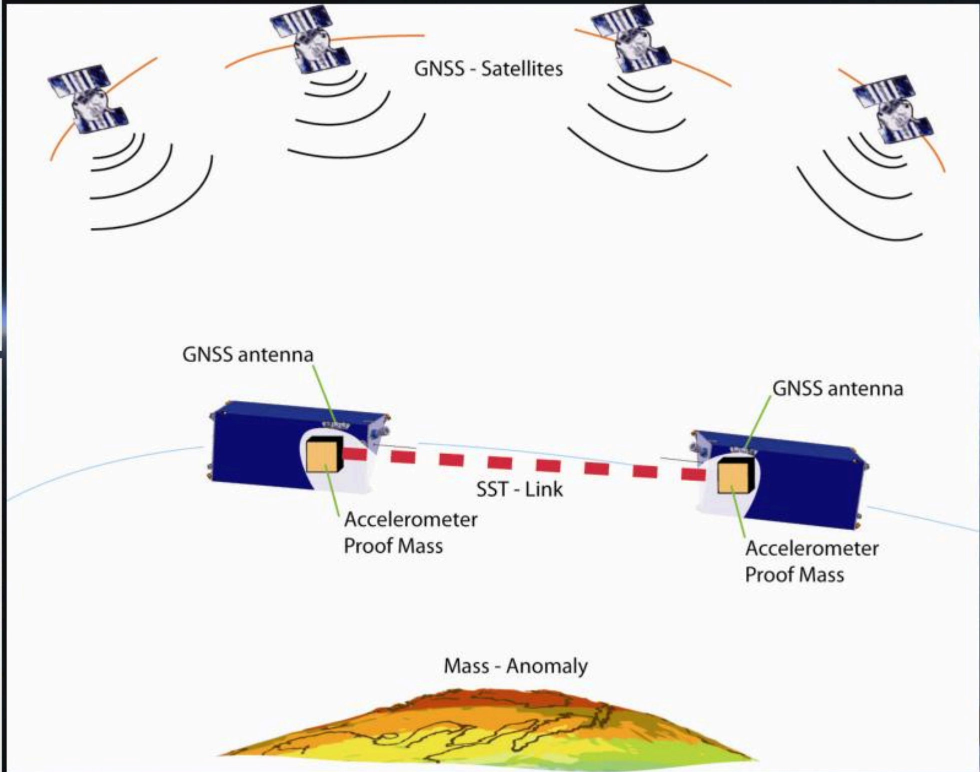
- Use satellite and ground data + modelling
- Solid Earth
- Geophysics
- Geodesy
- Hydrology
- Oceanography
- Ice sheets
- Glaciers
- Sea level
- Atmosphere
- Applications:
  - Civil engineering, prospecting, etc.
  - CCI (ice sheets, ocean transport, seasonal effects)



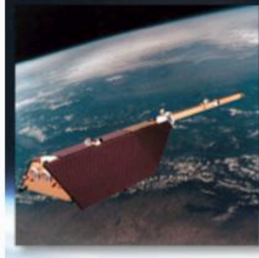
CHAMP and GRACE

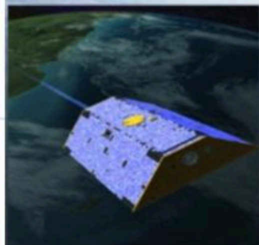


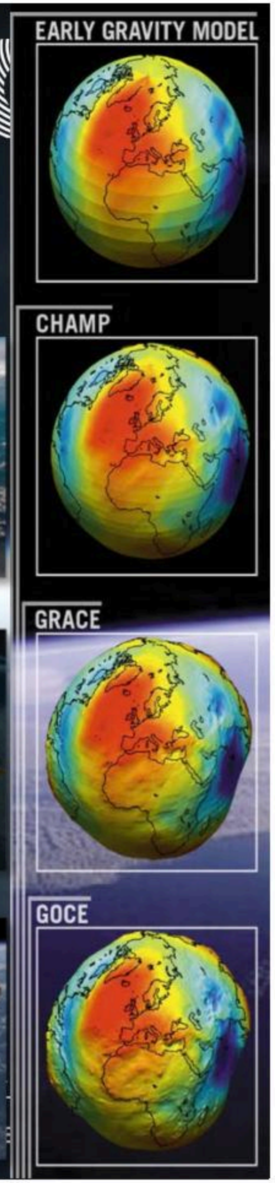
LOW-LOW SST



Credit: Airbus DS







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Science & Environment

Goce gravity boost to geothermal hunt

By Jonathan Amos
BBC Science Correspondent, Vienna

16 April 2015 | Science & Environment

Iceland is famous for its geothermal power stations, but the resource globally is under-developed

The hunt for sources of geothermal energy is getting a boost from new observations of the Earth made from space.

rds at
trail
nto

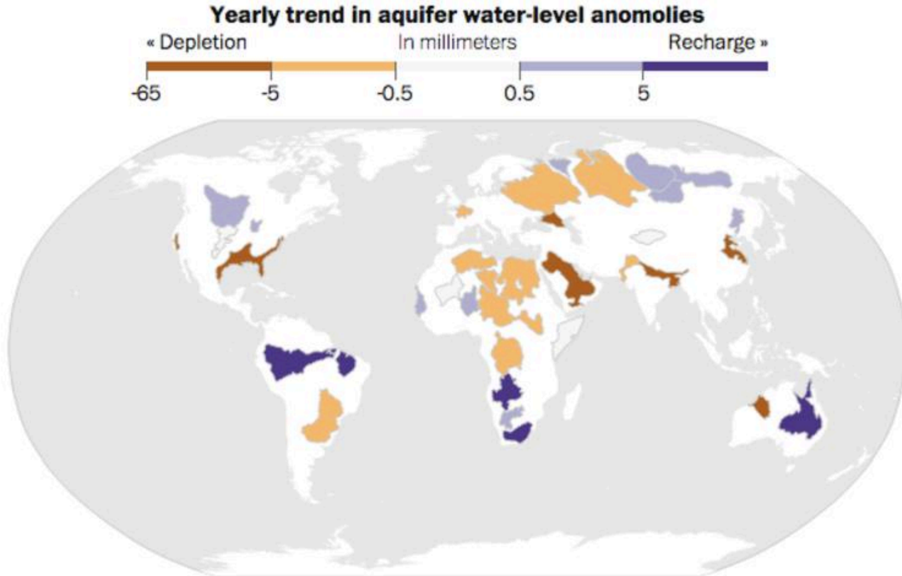
Photo taker

The Washington Post
Democracy Dies in Darkness

By Todd C. Frankel June 16, 2015

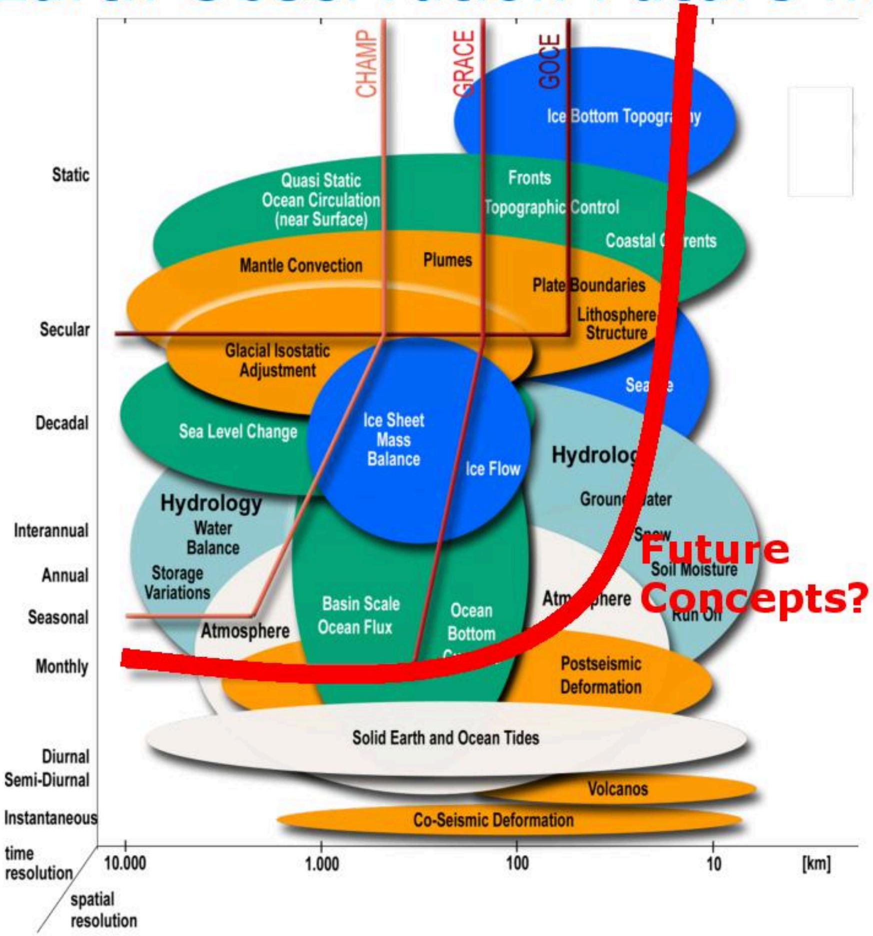
Satellite system flags stressed aquifers

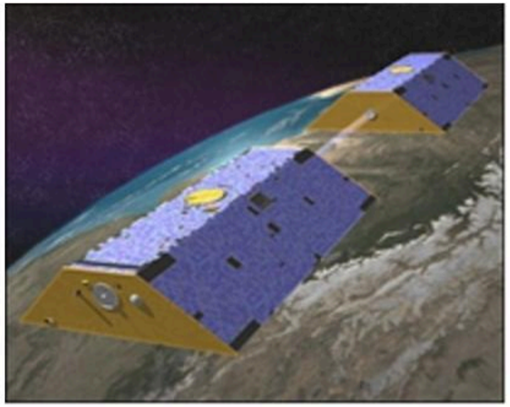
More than half of Earth's 37 largest aquifers are being depleted, according to gravitational data from the GRACE satellite system.



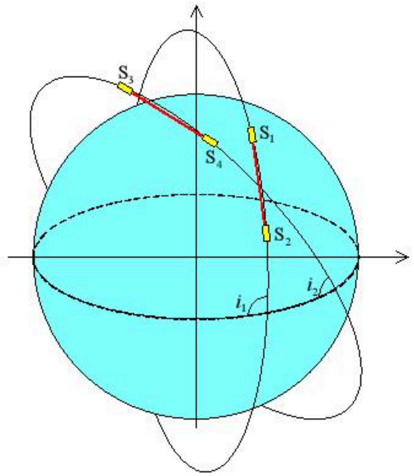
Source: Water Resources Research

Earth Observation Future needs

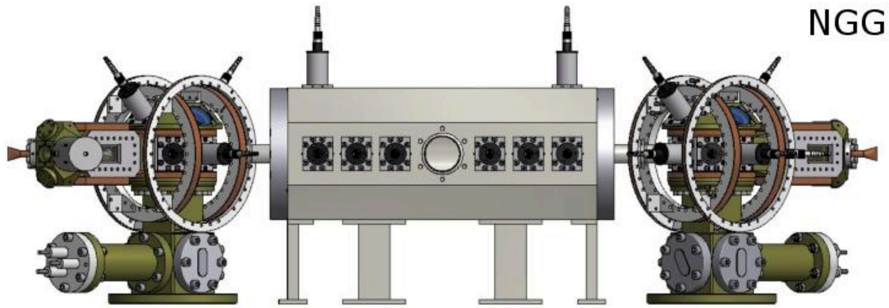




GRACE FO



NGGM



CAI

Activities

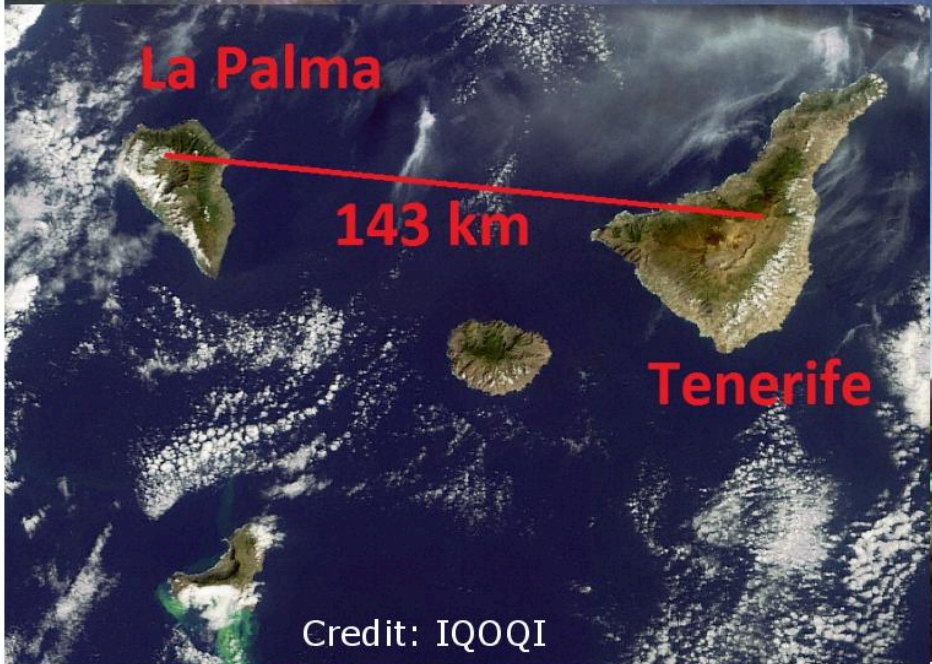
ESA is one of the few space agencies in the world to combine responsibility in nearly all areas of space activity.

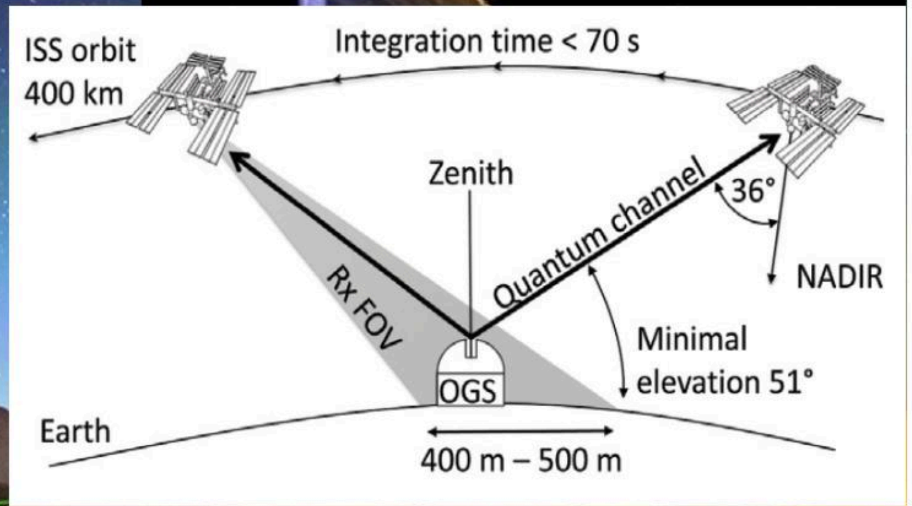
* Space science is a Mandatory programme, all Member States contribute to it according to GNP. All other programmes are Optional, funded 'a la carte' by Participating States.

Quantum Optics - Science

Interaction between gravity and quantum entanglement:

- The interaction between an entangled quantum state propagating through a gravity gradient (eg. away from earth) is unknown. Experiments using the ISS or other
- space platforms are proposed by the science community and studied at ESA.



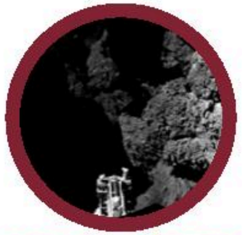


Creation and study of long distance entanglement:

- Past: 143 km links between Tenerife and La Palma demonstrating entanglement (2007) and quantum teleportation (2013)
- Future: extending to > 500 km requires space (ISS, GEO, moon or others)

Activities

ESA is one of the few space agencies in the world to combine responsibility in nearly all areas of space activity.



space science

human spaceflight

exploration

earth observation

launchers

navigation

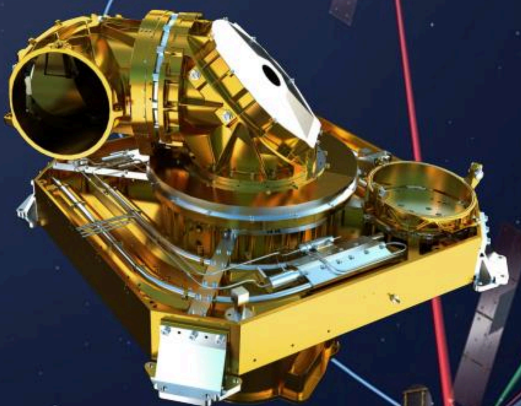
operations

technology

telecommunications

* Space science is a Mandatory programme, all Member States contribute to it according to GNP. All other programmes are Optional, funded 'a la carte' by Participating States.

Quantum Optics – Secure Communication



Credit: TESAT

Utilisation of quantum cryptography for laser communication links:

- Classical laser communication links are now used for operational systems (eg. TESAT laser terminal).
- Adding a quantum link (ie. a transceiver for entangled photons) would allow quantum secure key distributions between:
  - ground <-> space
  - ground <-> ground (intercontinental)
- ESA is developing the transceiver technology and analysing different application scenarios and business cases.
- Strong benefits from ESA's classical laser communication developments

scylight

UK National Quantum Technologies Programme

5 year, £300 million UK programme to expedite the commercialisation of Quantum 2.0

UK National Quantum Technology Hub in Sensors and Metrology

Quantum Communications Hub

UK National Quantum Technologies Programme

NQIT Networked Quantum Information Technologies

QUANTIC

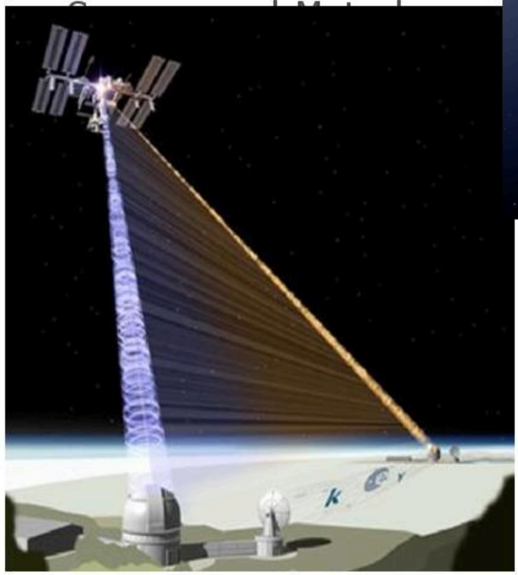
Quantum Technologies for Space

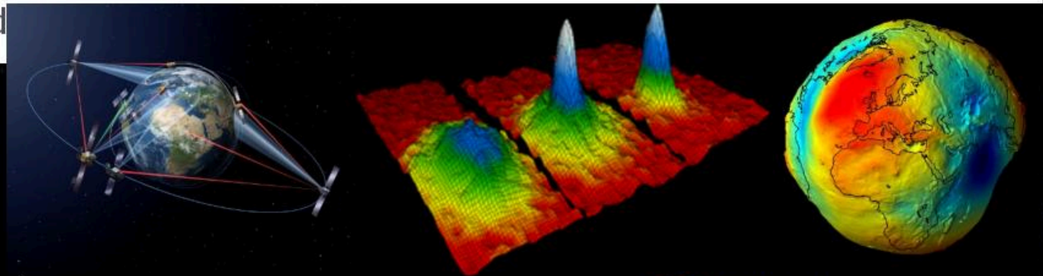
Cold Atom Interferometry

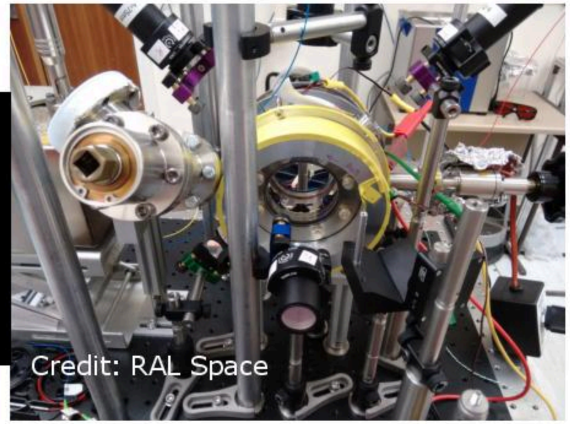
Applications: Inertial sensing and Navigation, Gravity mapping, Fundamental physics

Missions: Future satellite gravity gradiometry, Fundamental physics

Activities: Technology d







Credit: RAL Space

Quantum Cryptography

Applications: Emerging markets in long-distance secure quantum communications

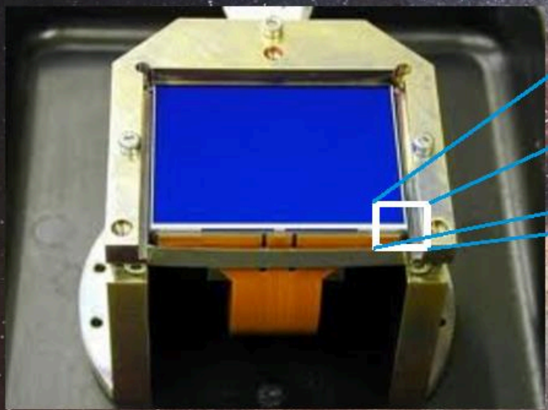
Missions: Future quantum communications missions development supported by ScyLight Element of ARTES programme

Interest: UK Quantum Communications Hub and industry partner BT to participate as major player in European collaboration efforts

GAIA CCD Array

At FPA level – 1 billion pixels comp

An example of CCD extrem



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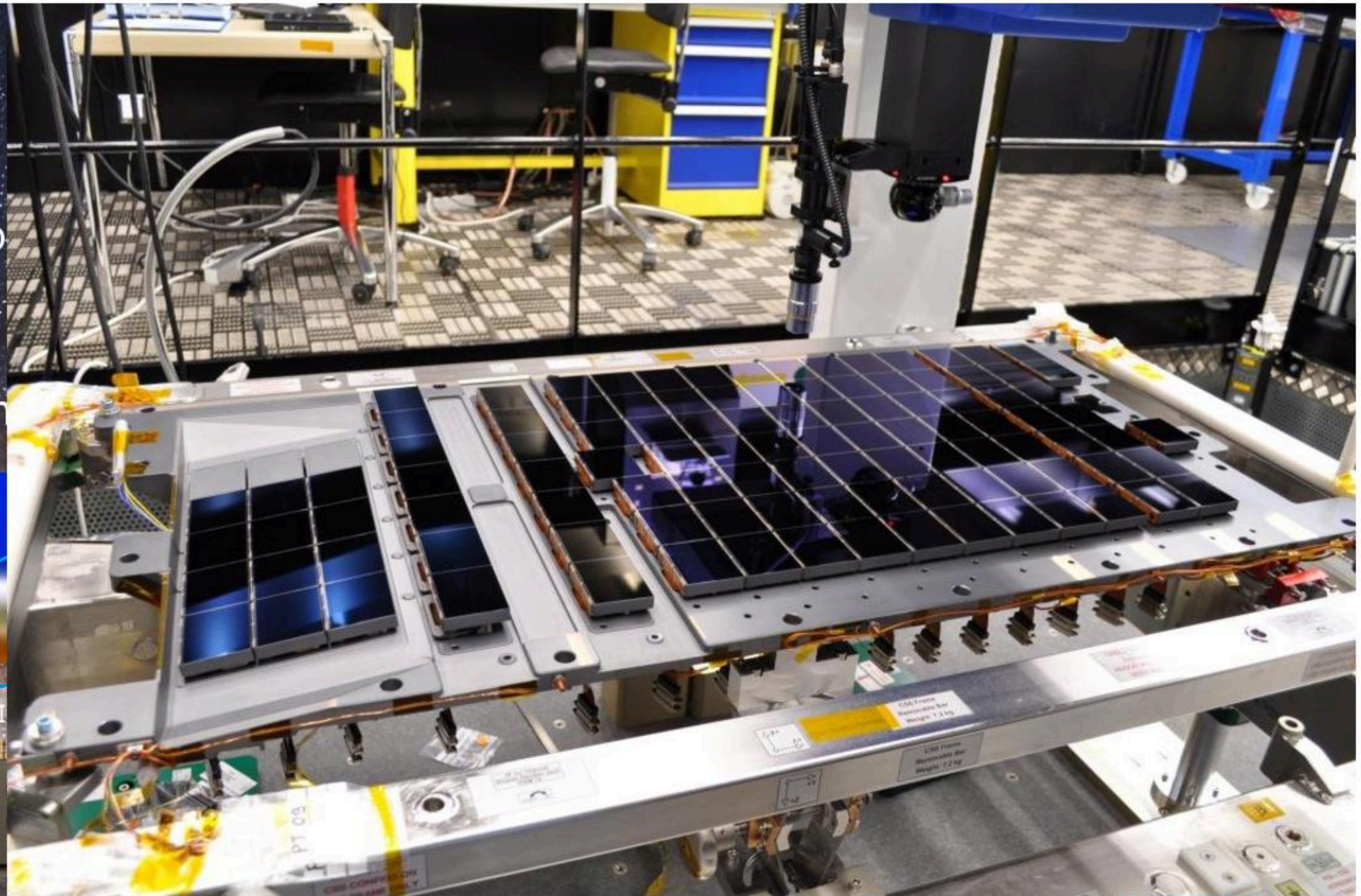
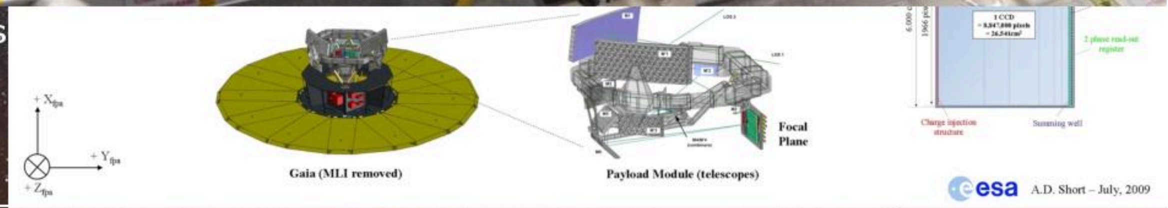


At detector level - 9 million pixels compared to 48 pixels



Why Quantum Technologies in space?

Unique feature of space:

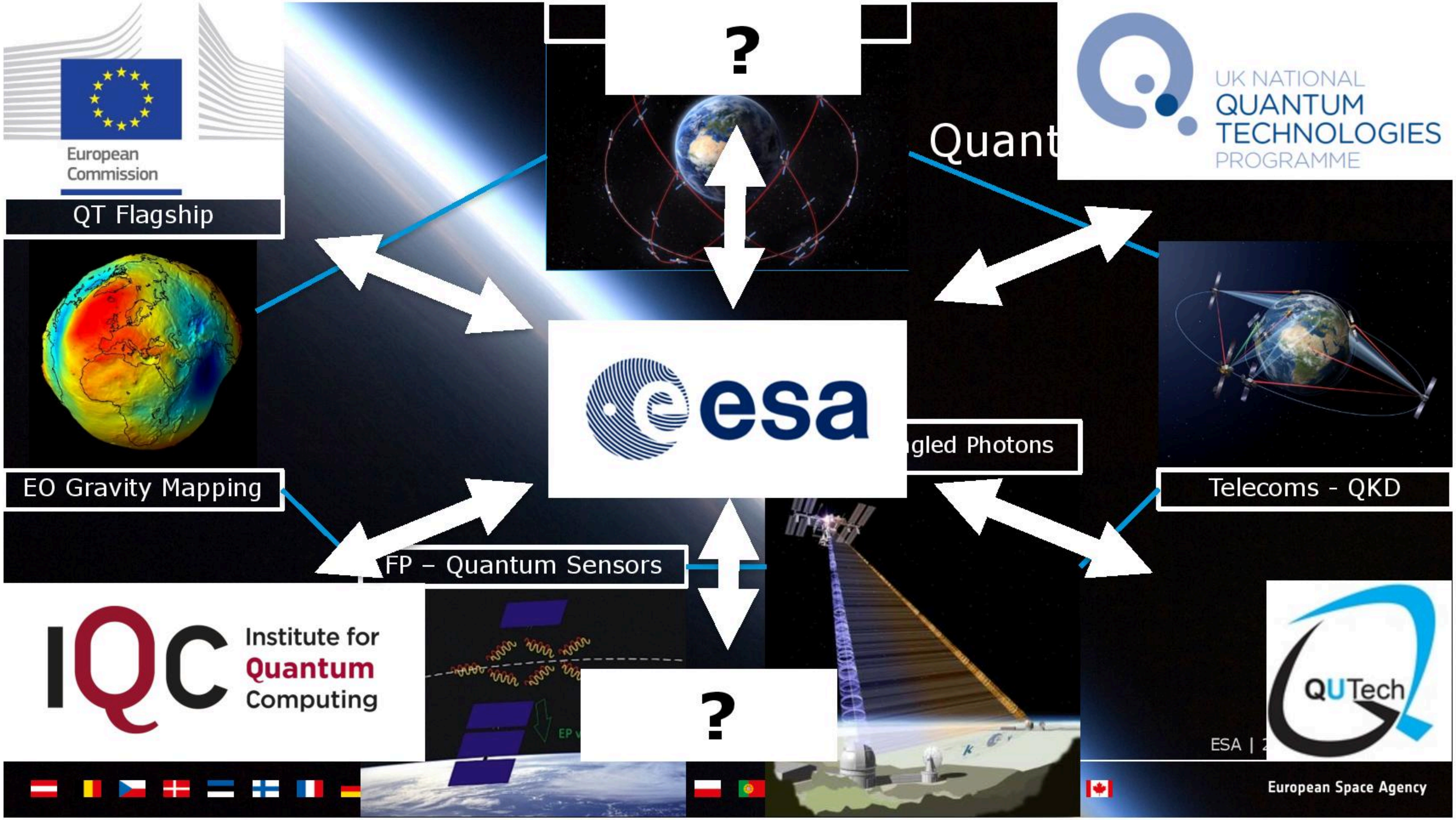
- Infinitely long "free fall"
- Large gravitational potential variations (many altitudes possible)
- Large velocity variations
- Quiet gravitational environment
- Long interaction times
- Large free-propagation distances

Additional reasons

- Space industry is an early adopter
- Stakes are raised by ESA's exacting requirements for space hardware

What's in it for ESA?

- QT promises:
  - better sensor performance
  - better measurement accuracy
  - faster computation
- Could do all these things in a fundamentally different way
- Key to innovation


?
European Commission
QT Flagship
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Quantum Technologies Workshop Highlights

- Collaboration is possible and indeed welcome
- Collaboration interface need to be clarified and improved:
  - Need for multidisciplinarity
  - Create a pan-European synergy / quantum space lab?
- Interest in space:
  - Rugged, miniaturised devices
  - Long-distance entanglement
- Tasks ahead:
  - Increase TRL (sensors)
  - Establish business case (QKD)
- Interest in QT:
  - Unprecedented performance
  - Disruptive innovation
  - Security
- Mismatch between disruptive technologies and current space programmes
- Need for In-Orbit Demonstration missions
- Europe should not miss the QKD boat a second time

Quantum Space Lab

- Required features:
  - Combine:
    - ESA expertise
    - Space (optical) payload AIV proven track record
    - Academia
    - Hands-on experience in setting up and running QT experiments
  - Space technology development rigour
  - Stable manpower: so that knowledge and know-how is not lost with departing PhD
- Nice to have:
  - Co-location of ESA, payload integrator, and academia

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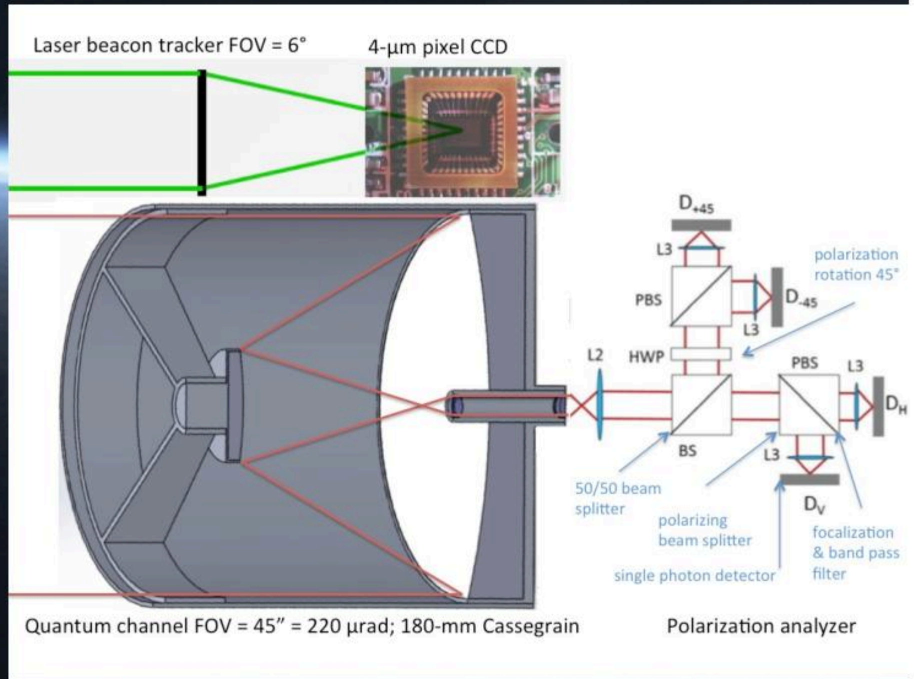
Cubesats projects

NanoBOB (QKD demonstrator)

- Not yet funded
- Grenoble University Space Center (CSUG)
- Vienna IQOQI



Cold Atom Space PAyload (CASPA)

- Innovate UK phase 0 study funded
- e2v main lead
- UoB university lead

IOD Funding Routes - ScyLight

ScyLight:
SeCure and Laser communication Technology

- New ARTES Framework called ScyLight (pronounce “skylight”) was launched at ESA Council at Ministerial level (Dec. 2016)
- Three themes
  - Optical Communication Terminal Technology
  - Intra-Satellite Photonics / Optical Payloads
  - Quantum Cryptography Technologies
- Four lines:
  - Common System and Technologies Activities (up to 75% funded)
  - Optical Communication Terminals and components (up to 75% funded)
  - Intra-Satellite Photonics / Optical Payloads (up to 75% funded)
  - Quantum Cryptography Technologies (up to 100% funded)
- All of the above also cover in-orbit/service demonstrations

General Support Technology Programme (GSTP)

ELEMENT 1

Develop

Work plan driven envelope programme for techno development (fully funded and exceptionally co-funded)

ELEMENT 2

Make

Industry initiated, co-funded direct negotiation envelope programme for technology maturation leading to products

ELEMENT 3

Fly (Small Missions)

Envelope which hosts sub elements such as Proba 3, (AIM, e-deorbit B2), cubesats, ISS payloads (GEROS), techno flight opportunities

Element 3 / Fly (Small Missions Initiative)

Small missions will exist in most ESA programmes, subject to the Programme constraints.

Multi-disciplinary missions (spanning more than a single programme's objectives), with strong risk and new technology, are normally less likely to be supported in competition with dedicated missions fully in line with Programme objectives, and are therefore more likely to be pursued in GSTP.

The small missions managed by TEC have traditionally a large share of SME participation from several under-returned MS.

Element 3 / Fly (Small Missions Initiative)

We see three main classes of small missions:

a) Technology flight opportunities, including cubesats;

b) Missions fully developed under GSTP, like the Proba series, where however the exploitation of the mission beyond the technical demonstration, has proven of interest for other programmes (EOP, SCI, SSA)

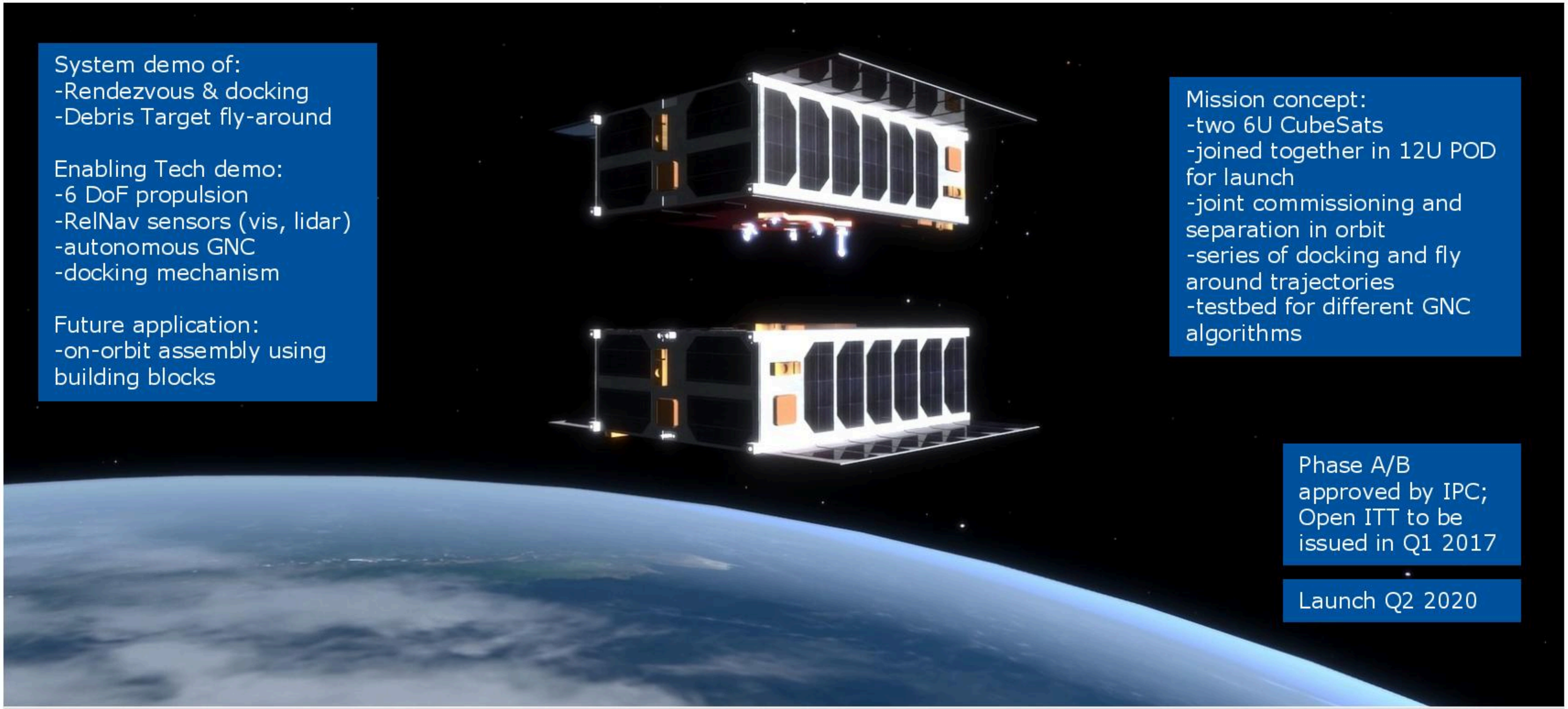
c) Partnership missions, where mission support is shared between GSTP and another ESA programme or partner (MS or international)

Element 3 / Fly (Small Missions Initiative)

Missions will be proposed by:

THE EXECUTIVE	MS FOR IMPLEMENTATION IN THE PROGRAMME
Either to be fully implemented in the "Fly" Element, e.g.: PROBA 3, OPSSAT, etc., or with programmatic implementation in another programme (e.g. SAOCOM, IMDB)	Either fully (HET demo, Hun) or shared with a national initiative (e.g. Altius), and with other participants if desired;

Rendezvous Autonomous CubeSat Experiment



System demo of:
-Rendezvous & docking
-Debris Target fly-around

Enabling Tech demo:
-6 DoF propulsion
-RelNav sensors (vis, lidar)
-autonomous GNC
-docking mechanism

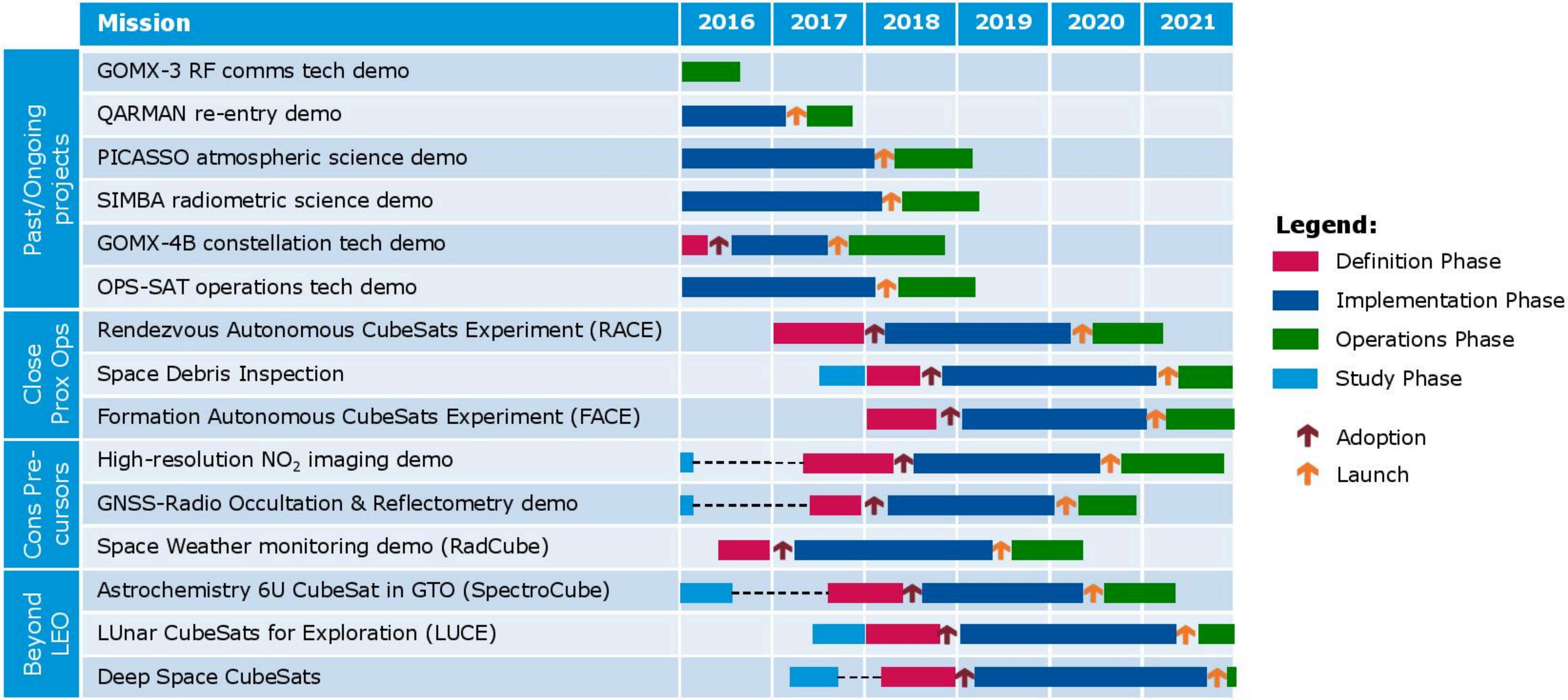
Future application:
-on-orbit assembly using building blocks

Mission concept:
-two 6U CubeSats
-joined together in 12U POD for launch
-joint commissioning and separation in orbit
-series of docking and fly around trajectories
-testbed for different GNC algorithms

Phase A/B approved by IPC; Open ITT to be issued in Q1 2017

Launch Q2 2020

ESA IOD CubeSat/Nano-sat Missions Roadmap



IOD missions/TDAs planned for KO in 2017

Element	Domain	Title	Budget (kEuros)	Status
Fly	IOD Missions	Framework activity "“High performance CubeSats/nanosats development and IOD”	10,000	Activity in prep
		Rendezvous Autonomous Cubesats Experiment (RACE) Mission Phase A/B	400	ITT in prep*
		High-resolution NO2 imager nano-sat misssion Phase A/B	400	Activity in prep
		SpectroCube mission Phase A/B	400	Activity TBD
		URSA-1 and 2 IOD missions	4000	Activity TBC
Make	Power	Miniaturised Solar Array Drive Assembly for 6U/12U cubesats	400	ITT in prep*
	Propulsion	6 DoF Micro-propulsion System Development for Nanosats	800	RFQ in prep*
		Propulsion system for Orbit Control of Micro-satellites	1200	ITT in prep*
		Miniaturised bi-propellant propulsion system for CubeSats/nanosats	375	Activity defined
		Miniaturised high specific impulse electric propulsion system for nano-sats	1700	Activity in prep
	Data handling	Highly integrated rad hard COTS avionics for CubeSats/nanosats	600	Activity in prep
	Communications	Miniaturised deep space transponder for CubeSats/nanosats	1000	Activity TBD
		Reflectarray HGA for high performance CubeSat communications	500	Activity TBD
	Ground segment	CubeSat/nanosat mobile ground segment development and deployment	800	Activity in prep
	System AIT	Automated AIT processes and systems for CubeSats/nanosats constellations	200	Activity in prep

* Already approved by IPC

ESA Quantum Technology Workshop

Quantum Technology –Implementations for Space Workshop
9 November 2016
ESA/ESTEC, The Netherlands

2nd Quantum Technology –Implementations for Space Workshop
14-15 November 2017
ESA/ESTEC, The Netherlands

PLEASE SAVE THE DATE !

Acknowledgements

ESA

Optoelectronics Section

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Brian Shortt (Head)

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