Quantum Sensing:

First Steps in Commercialization

September 14th 2016, CWTEC, Cambridge

Trevor Cross, Group CTO, e2v

WE PARTNER WITH OUR CUSTOMERS TO IMPROVE, SAVE AND PROTECT PEOPLE'S LIVES

Outline

- Introduction to e2v
- The UK National Quantum Technology Programme
- Why is e2v interested in Quantum Technologies ?
- Quantum Technologies
- Future plans

e2v and what we do

Scale (FY 2016)

>£230m annual sales

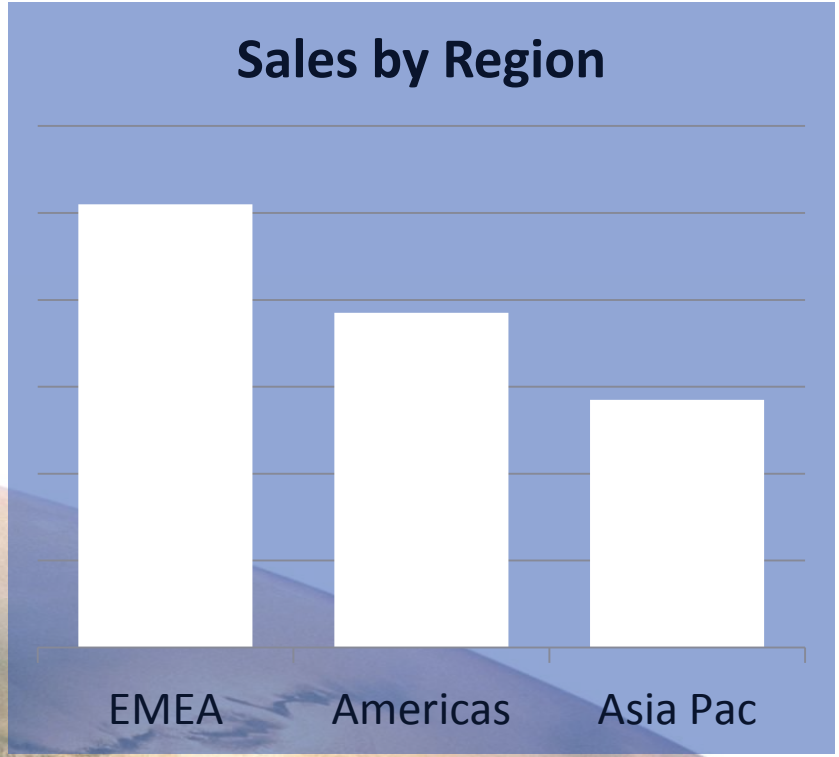
>1750 employees

(of which 1,100 UK based)

>500 engineers & scientists

Operational facilities in

Chelmsford, Lincoln, Grenoble (F), Seville (SP), Milpitas (USA), Linköping (SWE)



Three divisions

RF Power

Two million people are in receipt of life-saving radiotherapy treatments around the world through the use of e2v products

Imaging

Our imaging devices are at the heart of more than 150 space-based instruments including major science observations, planetary exploration missions and Earth observation systems

Semiconductors

Our data converters operate in the harshest of *space environments, powering satellite communication systems* handling 10,000 fully encrypted broadband lines a second

RF Power - Example

Vacuum electronic products for medical particle accelerators - Radiotherapy

Microwave power for radiotherapy systems: the power level, efficiency and high frequency dictate electronic tube technology.

e2v fast tuning magnetrons for medical linacs

- S-band
- up to ~ 7MW peak
- up to ~ 6kW average

e2v compact modulator for medical linacs

- up to ~ 60kV
- up to ~ 200 A
- compact
- operates in any orientation

Photo courtesy of Tomotherapy.

Semiconductors

ADVANCED MICROELECTRONICS – FOR DEMANDING ENVIRONMENTS

- Space / QMLY qualified microprocessors
- Space / QMLV qualified ADC and DAC's
- Design, build, package, life cycle management
- Professional and mil-aerospace markets

Imaging – Space Science
Planet discovery

Kepler – the detection of extra-solar planets

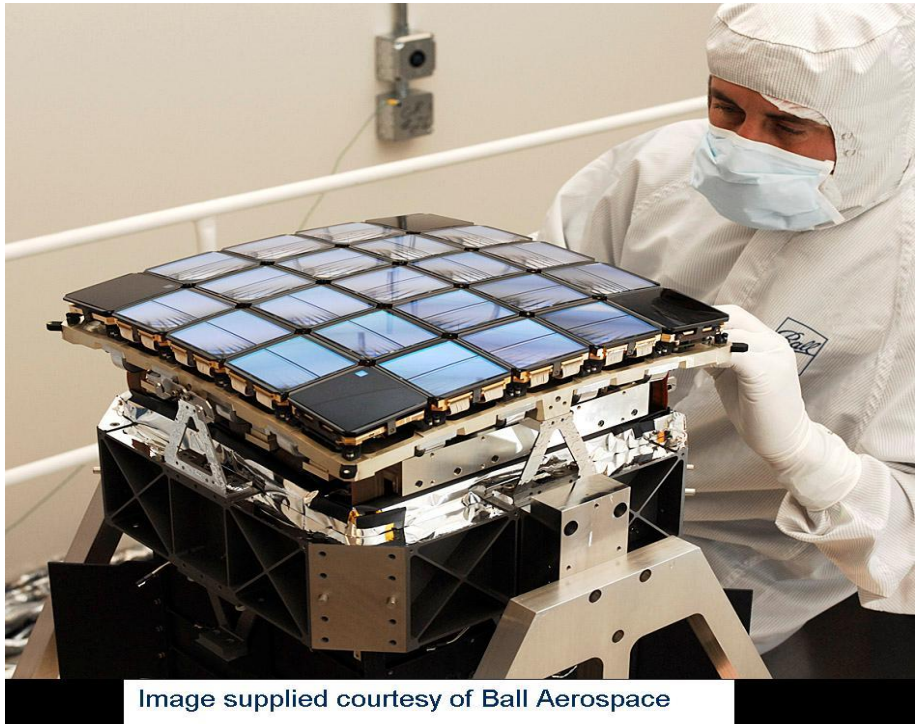


Image supplied courtesy of Ball Aerospace

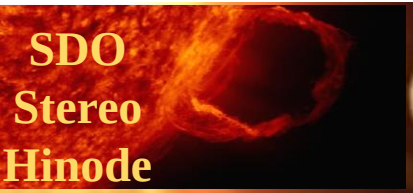
Custom CCDs are used in the Kepler instrument.

This instrument has greatly extending the search for extra-terrestrial planets

Kepler has been a great success – recently announcing the discovery of another 715 new planets taking the known total to 1,700

Every planet…..

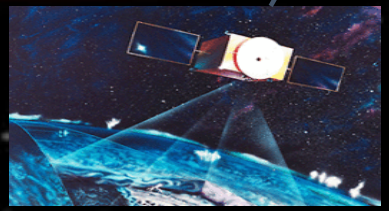
e2v Bringing life to technology



Kepler
PLATO

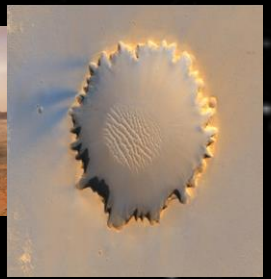
Rosetta

New Horizons



Akatsuki

Curiosity



MRO-HiRise

ESA's Rosetta
every image.....

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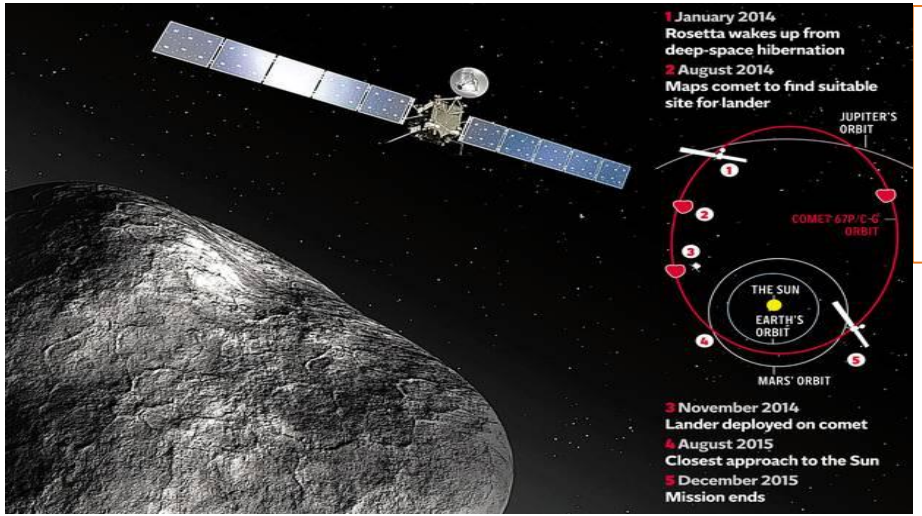
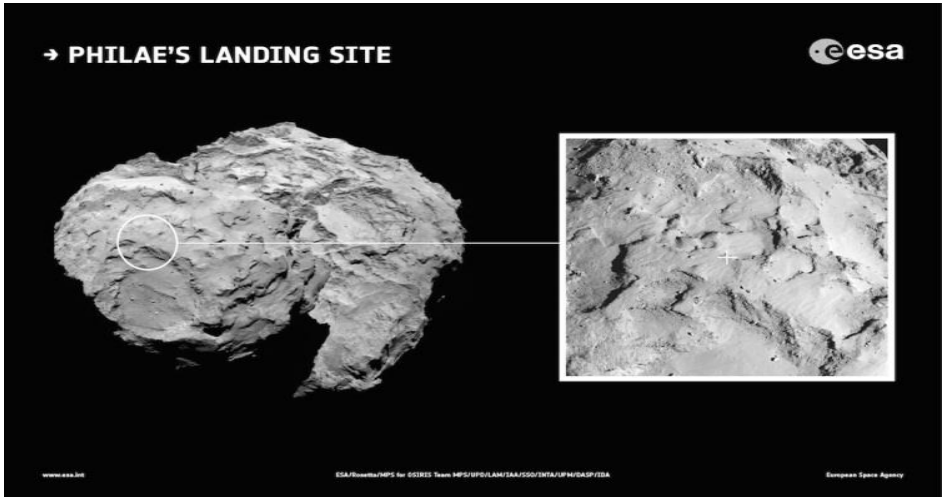


Pictures courtesy ESA

Launched in March 2004 and reached comet 67P/Churyumov–Gerasimenko after 6 billion km in August 2014. Mission life extended to 2016



GAIA

ESA's 1 billion star mapping mission – 1bn pixels

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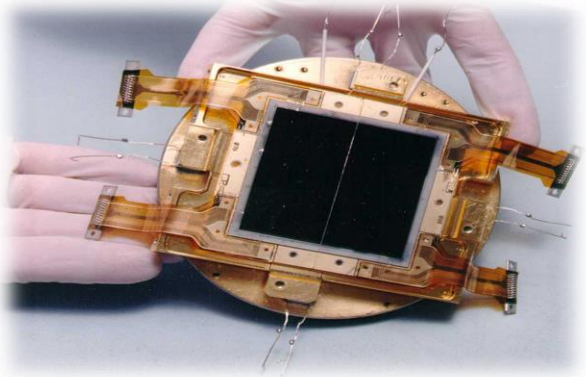
GAIA mosaic 106 large area CCD91-72 image sensors, designed, manufactured by e2v. Launched 19.12.13

e2v business today includes….
Custom CCDs - Ultra High performance



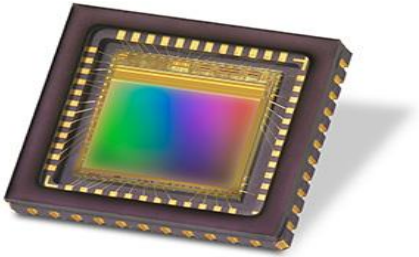
Pictures courtesy ESA

Pictures courtesy of NASA

CCD43 for Wide Field Camera 3

Several $m

….and High volume CMOS sensors



Sapphire 1.3M – EV76C560

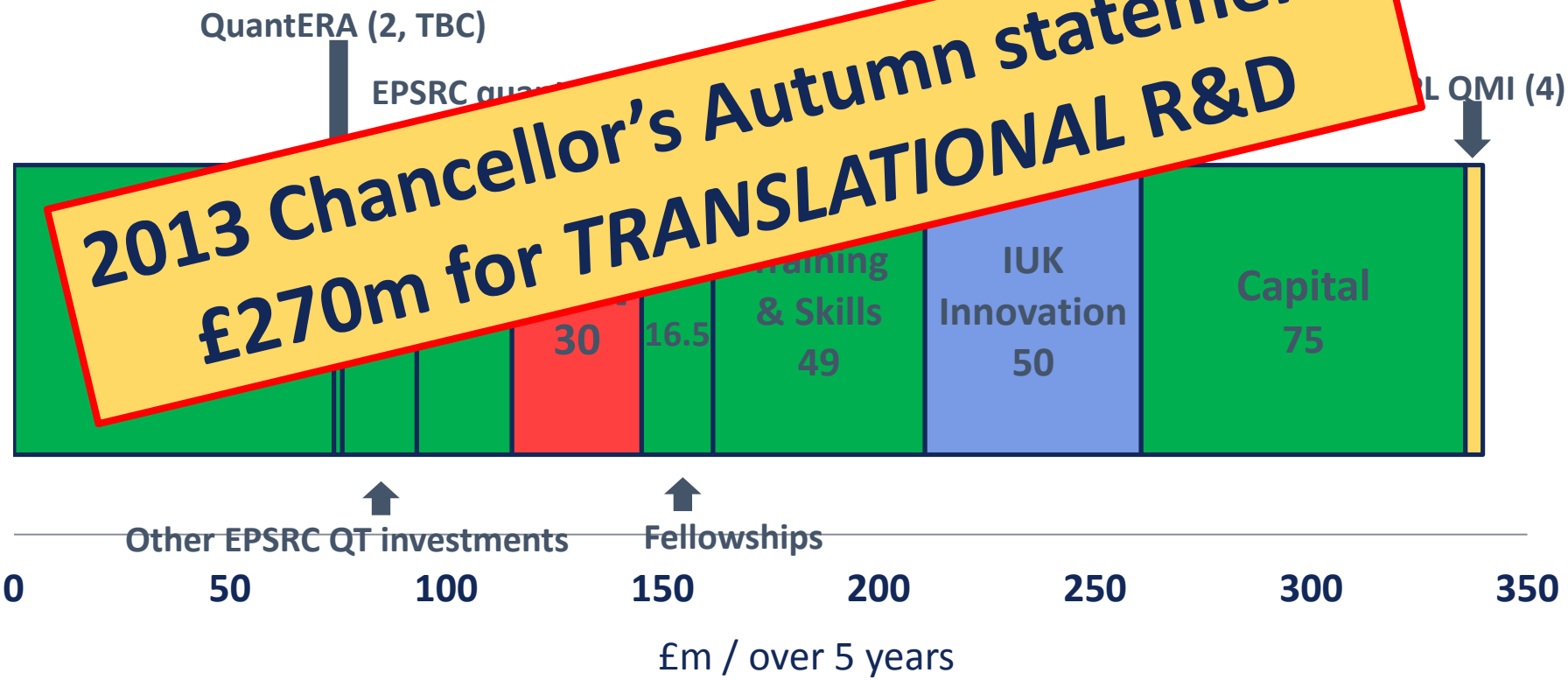
c.2,000,000 units supplied

c.$10 / piece

UK National Quantum Technologies Program

UK National Program – 1st 5 years

Dec 2014 – Nov 2019



2013 Chancellor's Autumn statement: £270m for TRANSLATIONAL R&D

Slide courtesy of EPSRC-Dec 15

National Programme – 4 QT Hubs

e2v Bringing life to technology

UK National Quantum Technology Hub in Sensors and Metrology

QUANTIC

UK NATIONAL QUANTUM TECHNOLOGIES PROGRAMME

NQIT Networked Quantum Information Technologies

QUANTUM COMMUNICATIONS HUB

Quantum Technologies and e2v

What is *Quantum Technologies* to us ?

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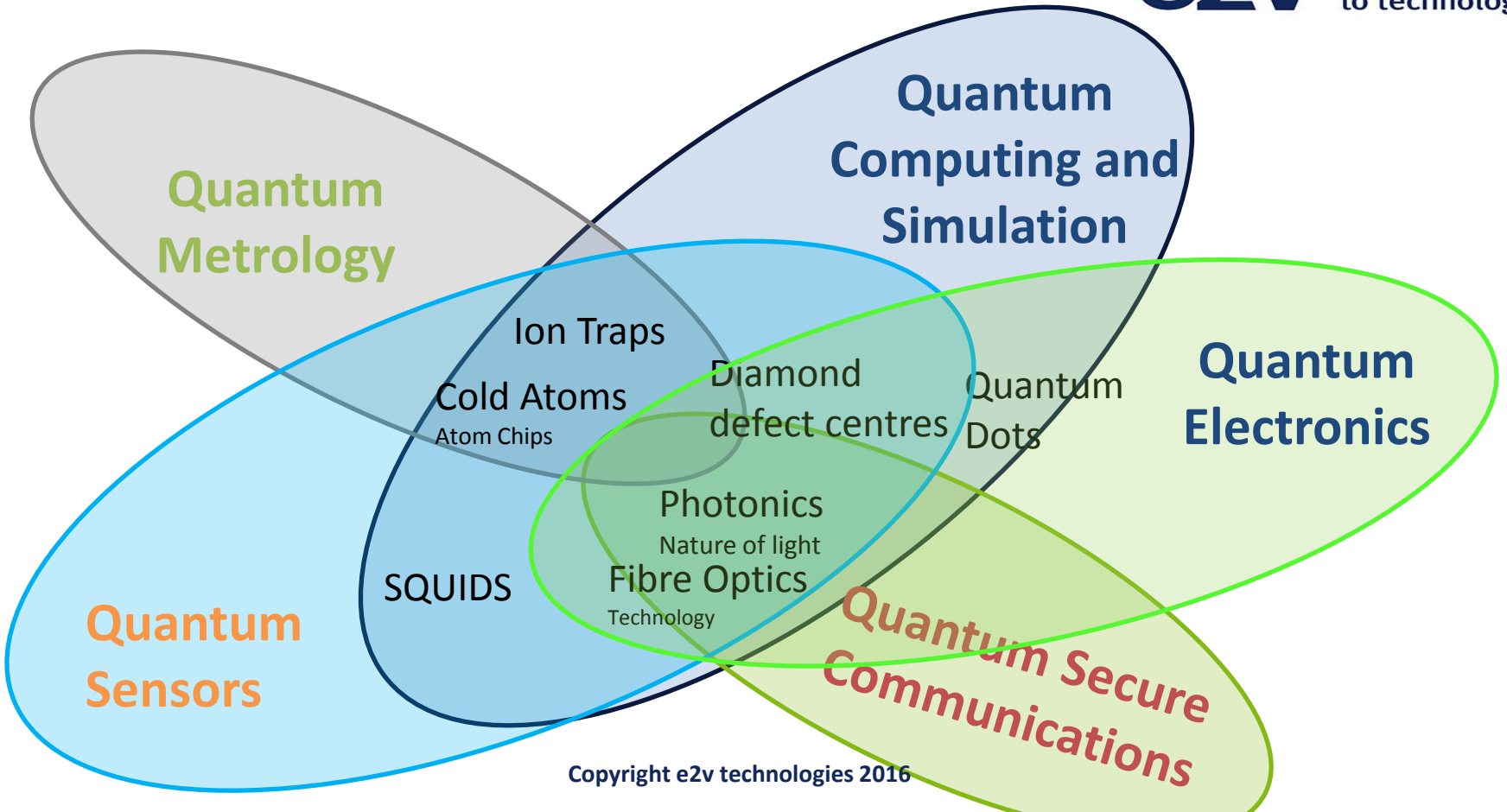
Quite simply *Quantum Technologies* is a new platform technology that will be increasingly pervasive in all walks of life.

Over the next 5-10 years it will mature to an extent that the landscape for the supply chain and wealth generation will start to be defined: this could be a major opportunity for e2v.

Quantum Technologies



Where could e2v be involved?

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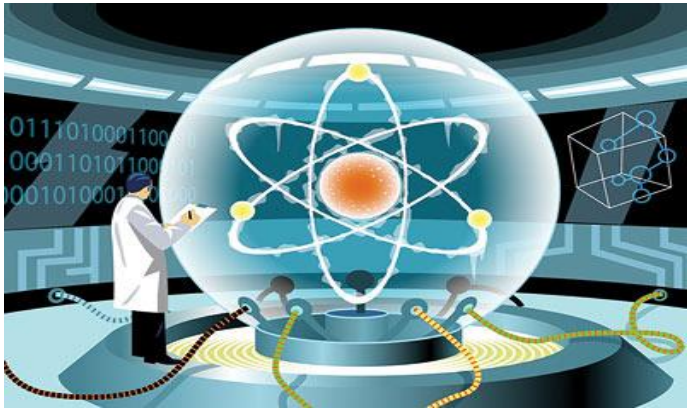
Many areas of QT are still mostly theoretical / very low TRL



Quantum Computers

Magnetometer

Gravimeter

Rotational

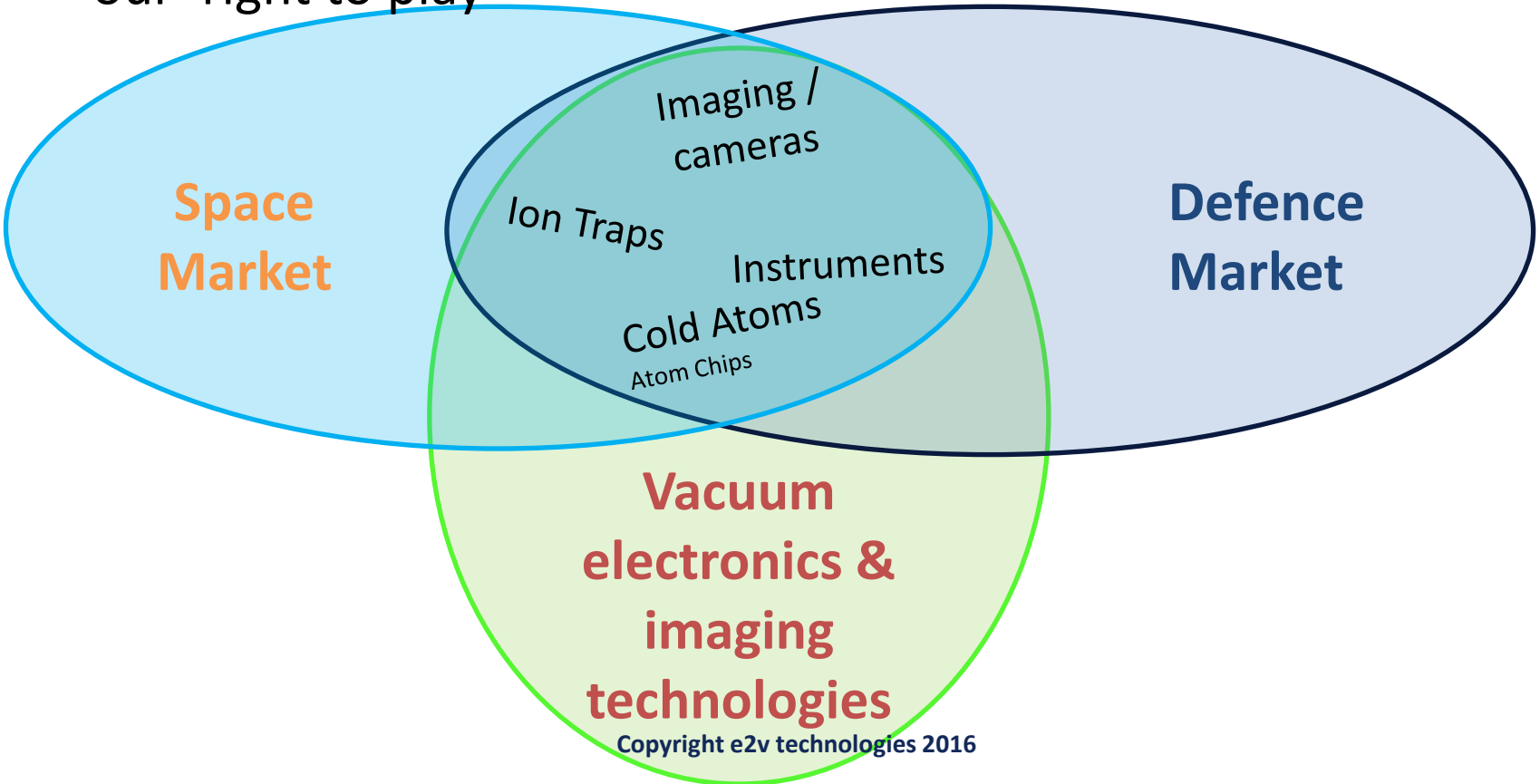
Accelerometer

Accelerometers have a clear and ready application in **Inertial Navigation Systems**

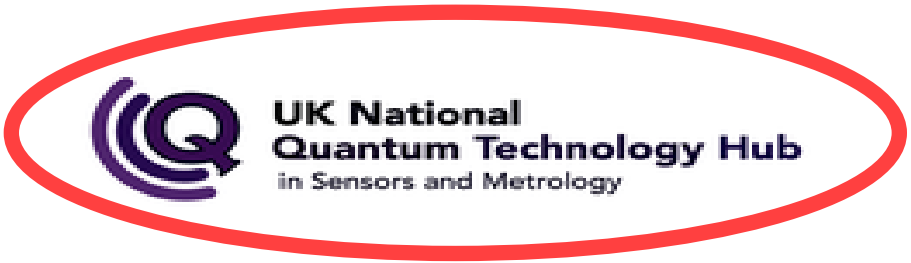
Quantum sensors are coming to fruition and will soon be used outside of the lab.

e2v Markets and Technologies

- our ‘right to play’



National Programme – 4 QT Hubs

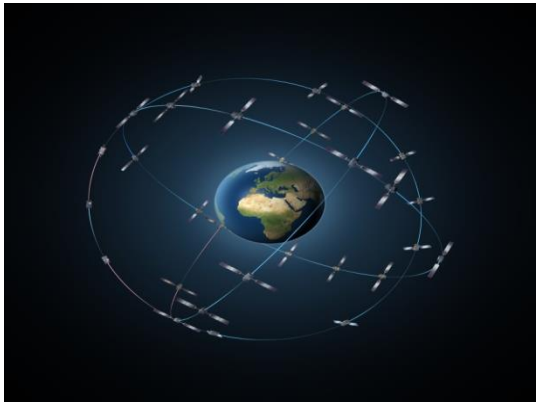


So what ??

Ultra Cold Atoms based sensors

Versatile devices to measure gravity, acceleration, time, …

Current quantum devices equally good or better than classical sensors

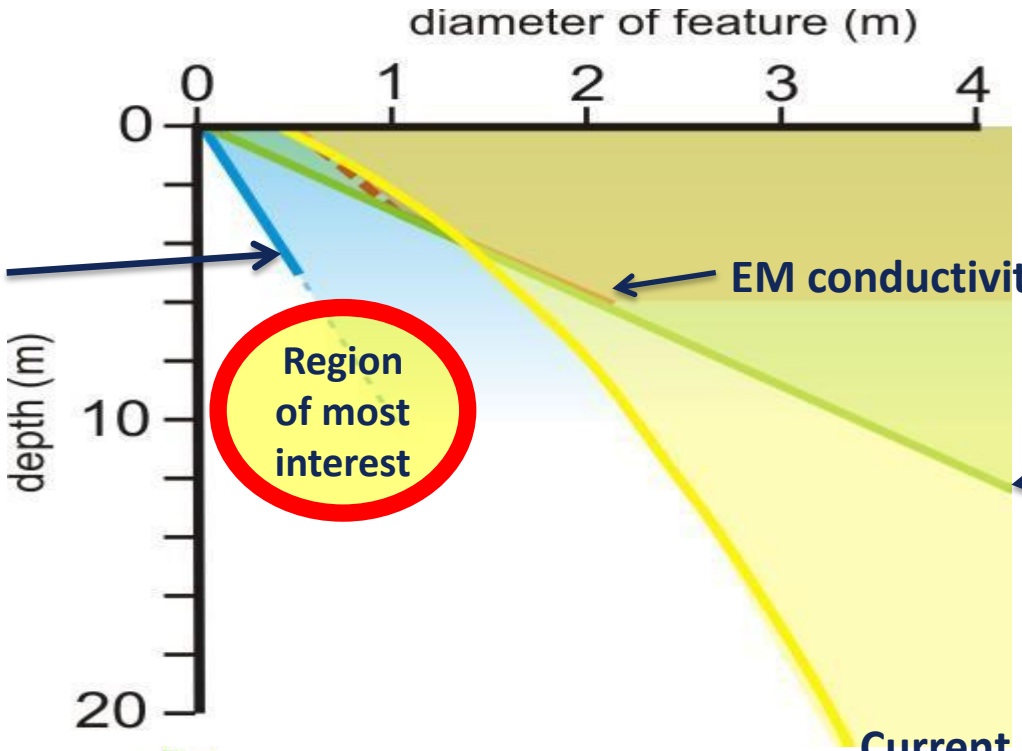


1. **Gravity-Sensors:**
   - Find pipes underground
   - See tunnels
   - Archaeology
   - Volcanic activity
2. **Acceleration-Sensors:**
   - Inertial navigation
3. **Atomic-Clocks:**
   - Next generation GPS/Galileo
   - GPS resilience
   - Transaction timestamping

The identification of hazardous voids

- Construction industry – brownfield sites
- Sink holes, mine workings
- Infrastructure projects (e.g. HS2)
- Defence applications

Detectable Feature size vs. depth



Ground Penetrating Radar ('GPR')

Region of most interest

EM conductivity

Electrical resistivity

Current micro-gravity

Diagram based on figure credit RSK / Birmingham University

Potential advantages of QT gravity instrumentation

- **Identification of smaller features at greater depths**
- **Works in all conditions**
  - Not affected by moisture levels in the ground (c.f. GPR)
  - No known method to screen, hide.
- **Potentially faster**
  - Hours not weeks
- **Absolute and not requiring calibrations / drift compensation**

Detectable Feature size vs. depth

Cold atom gravity gradiometer

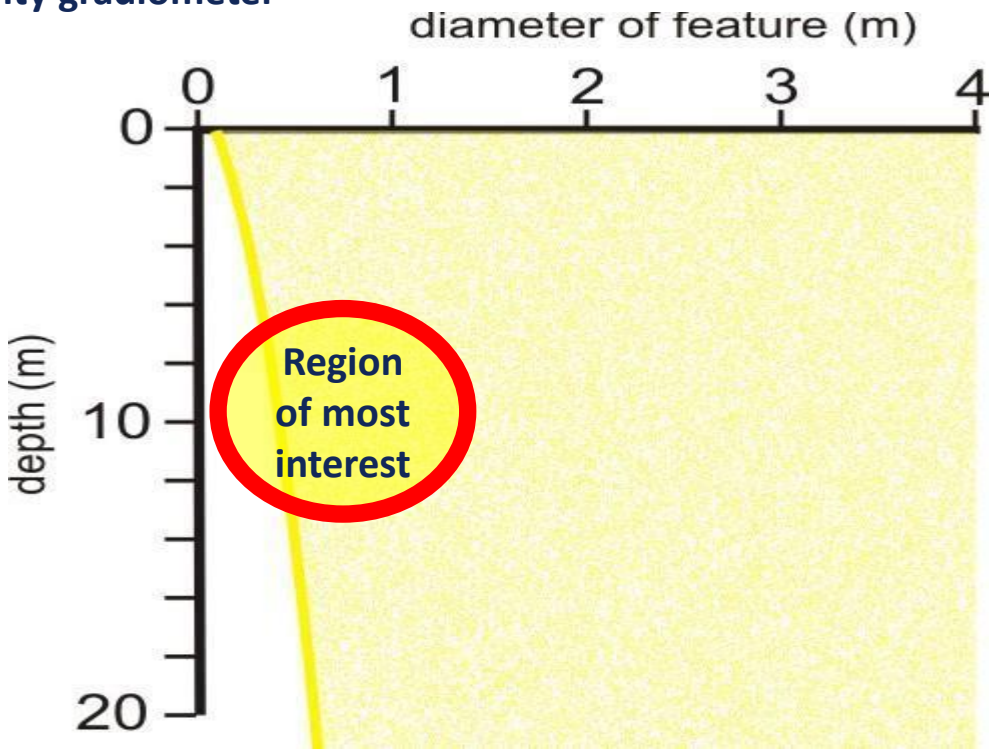


Diagram based on figure credit RSK / Birmingham University

Current Activity

But first….an innovation timeline - imaging technology case study

45cm

1952 – Image Isocon
TV Camera image sensor used for the live televising of QEII coronation ceremony

Note: Base technology originally licenced from RCA in USA

A parallel - the evolution of imaging technology ??

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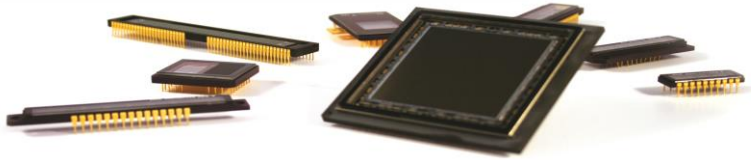
1953

c. £10,000

1980



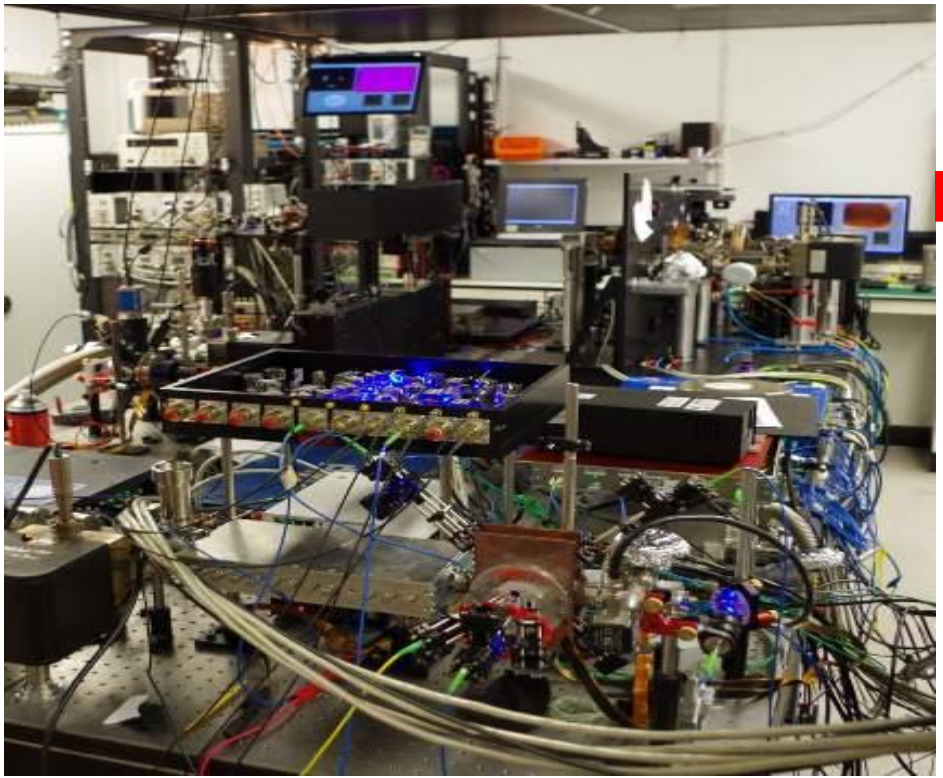
2015

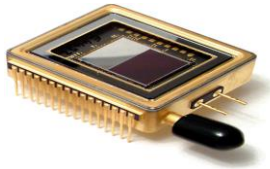
£4.95, including toolkit to fit !

Suspend your disbelief……

….the unimaginable can happen!

Development into usable products





Transition to all ‘solid state’ 0.02 litres – consumer products

Gravity Imaging – On track

Some achievements over the last 12months

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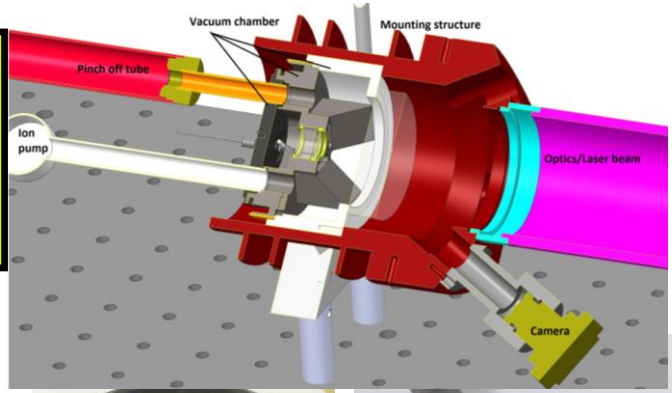
Nov 15: e2v portable atom trap concept

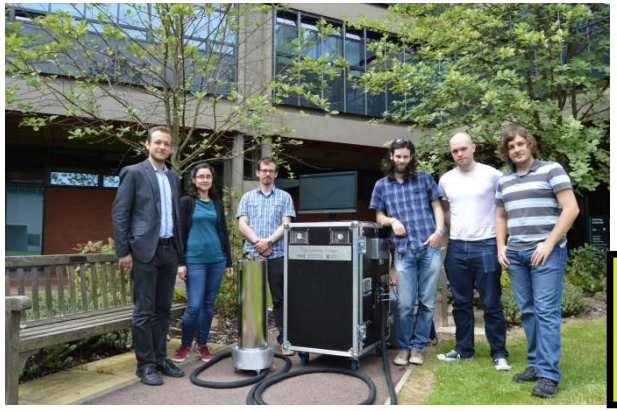
August 16: Planned SWAP-C reduction taking shape: e2v designed and built components made, integration and test due September on schedule.



UNIVERSITY OF BIRMINGHAM

[dstl]

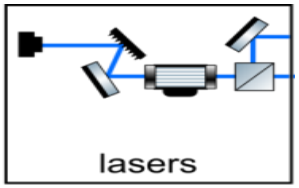
Innovate UK



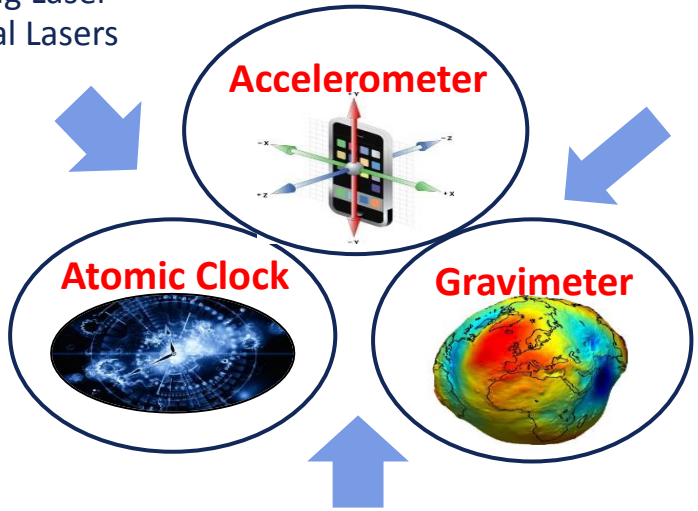
June 16: Birmingham Built Gravity System successful outside demonstration.

Future plans

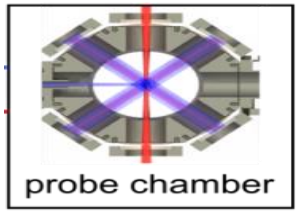
Cold Atom Sensors – issues for space



Cooling Laser
Special Lasers
Raman
Clock
Lattice



Laser Control
Sequence Controller
Special Electronics
Oscillators
Current sources
RF

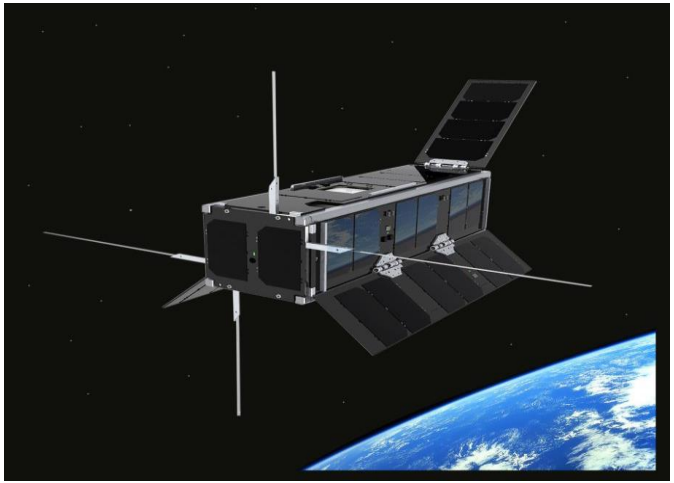


Vacuum Chamber
MOT
Shielding
Fast loading
Magnetic Field Control
Optics

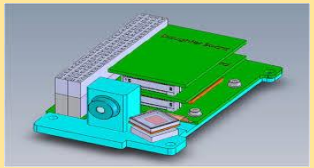
IUK / Catapult Cubesat opportunity

e2v Bringing life to technology

- Mature critical subsystems
- Capitalize on UK translational programme
- Achieve leadership in UK for Space
- Re-use Ukube-1 technology / experience



- Help build supply chain & spin offs (*)



(*) e.g. Open University / X-cam (an SME) C3D imager on Ukube-1 (e2v sensor!) has achieved 4 follow on sales to date

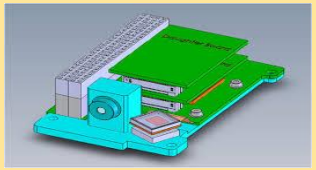
IUK ault Cubesat opportunity

e2v Bringing life to technology

- Mature cri ms
- Capitalize on UK tra ogramme
- Achieve leadership in UK for
- Re-use Ukube-1 technology / experien

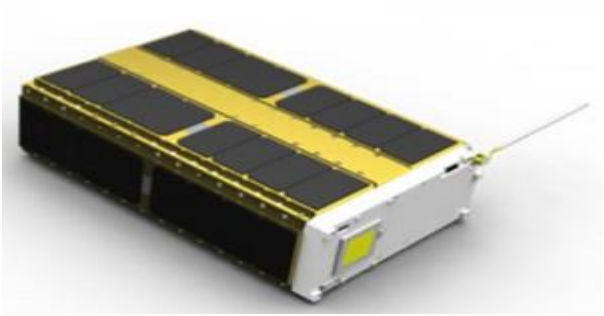
Too small, not enough power!

- Help build supply chain & spin offs (*)



(*) e ity
/ X-cam
imager on
sensor!) has a
follow on sales to

What it might look like…..



Conclusions

Suspend your disbelief……

….the unimaginable can happen!

Thank you