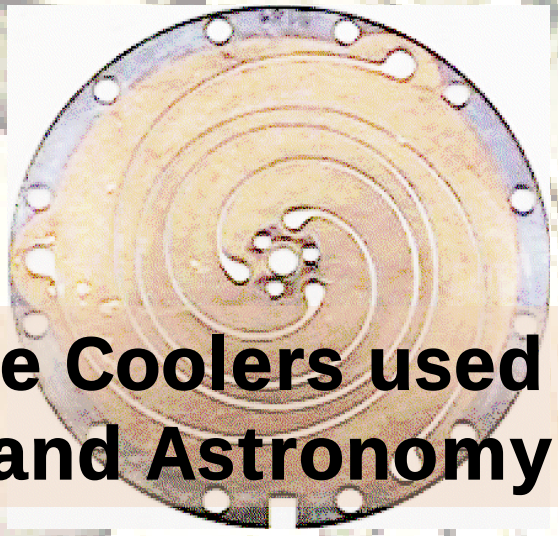
Cryogenics and Magnetics Group



Miniature Closed Cycle Coolers used in Earth Observation and Astronomy

Tom Bradshaw

Martin Crook

Geoff Gilley

Tom Rawlings

Steve Watson

Matt Hills

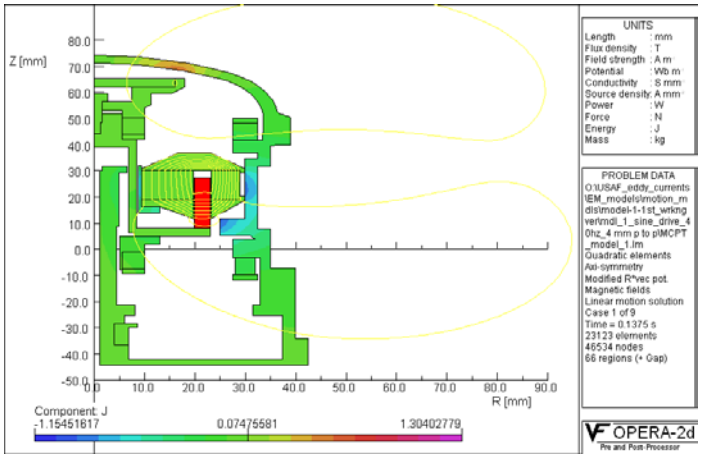
CEOI

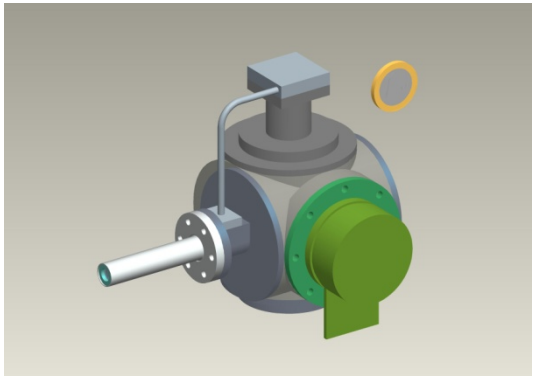
Leicester

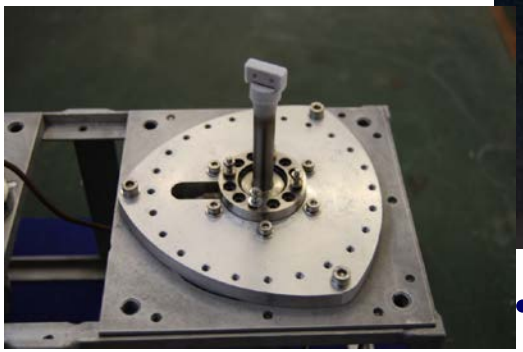
30th April – 1st May 2014

Closed Cycle Refrigerators for Space

- Development at STFC Rutherford Appleton Laboratory has been ongoing for nearly 30 years
- Based on long life diaphragm spring technology – flexure bearings
- Licensed to industry in the UK and the states
  - Technology flown on many missions ATSR series etc.. Used for weather forecasting
- Used to underpin UK involvement in a variety of space missions with RAL Space



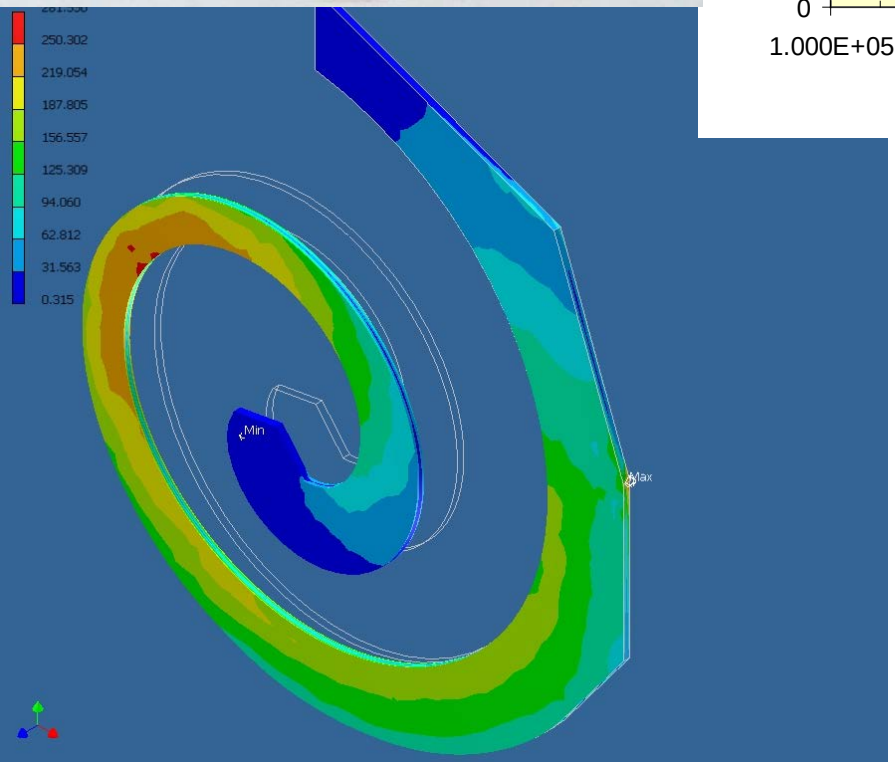


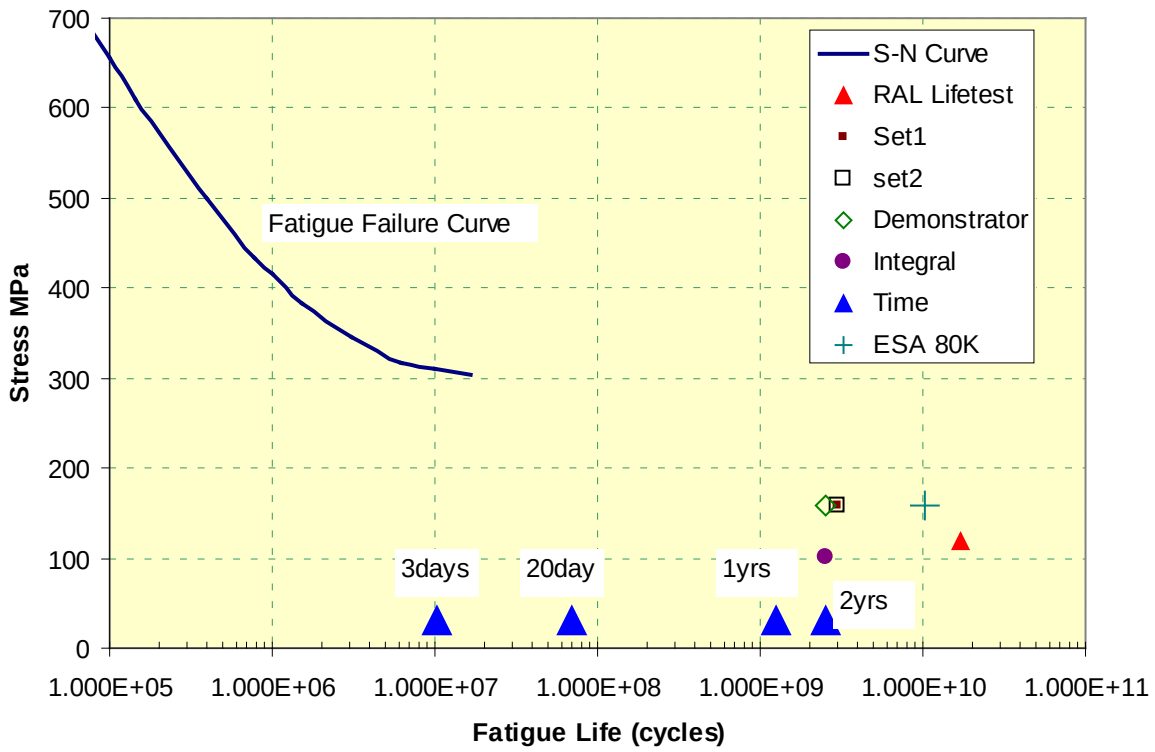


- 80K Single stage
- Has run for 18.6 yrs at 40Hz
- > 2.3×10^{10} cycles

Used on 40 flights and is much copied …

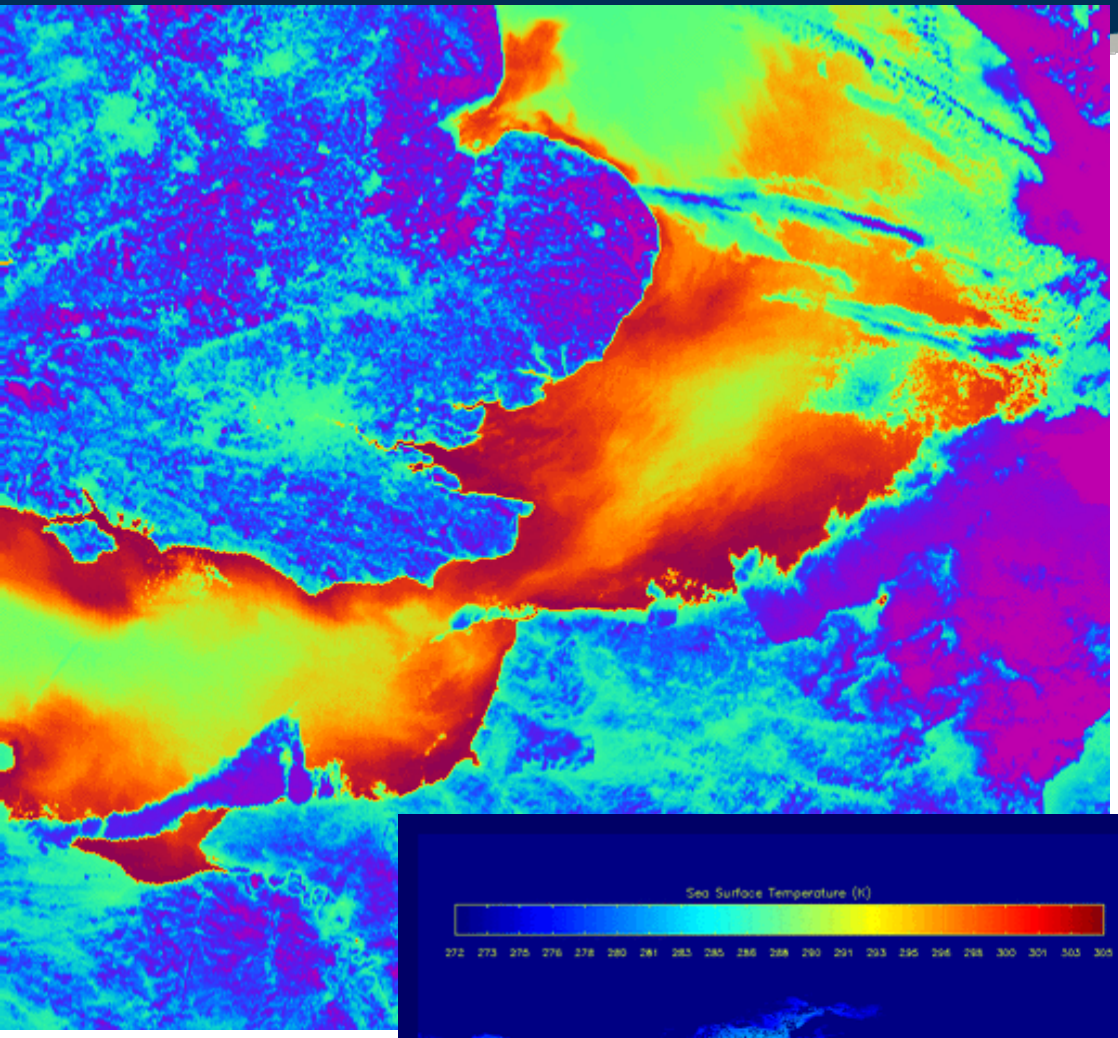
Design features



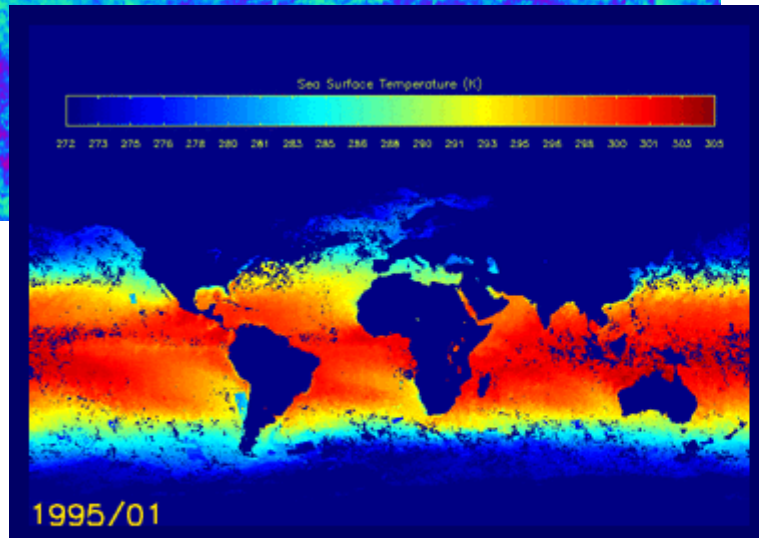


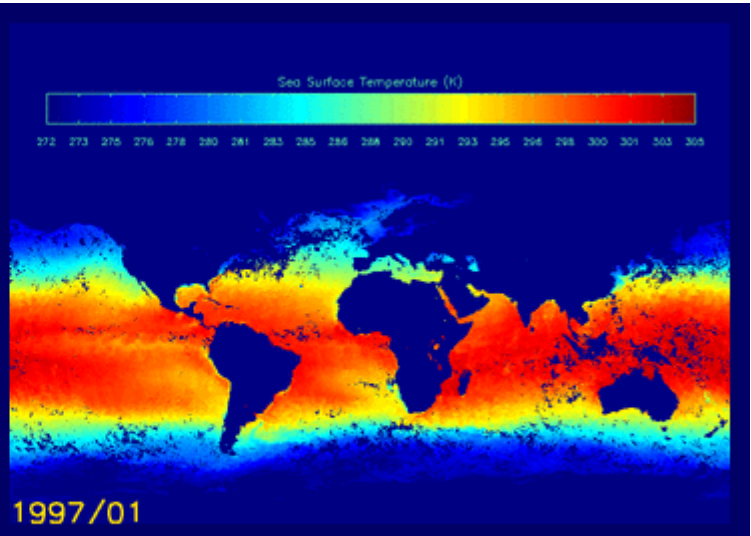
- Flexures are used with clearance seals between pistons and wall
- No rubbing surfaces
- No life limiting features

Results



- This type of cooler has been flown on many types of mission





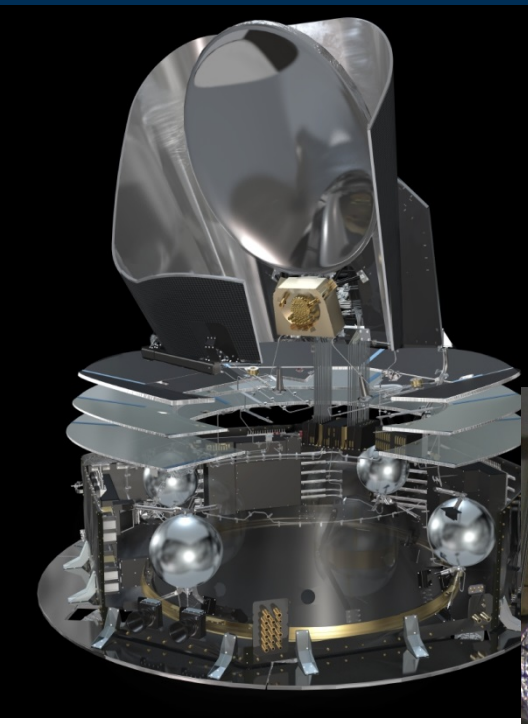
Credits:
ESA/CCLRC/RAL/NERC/
BNSC

Astrium/RAL Coolers in Space

Summary of UK Cryocoolers produced for Flight and Qualification Programmes										09/05/2010
UK Cooler Type	Instrument/ Satellite or Customer	Launch Date	Switch on date	End Service	Op. years per Cooler	Accum. years for all coolers	#FM coolers	# Other Coolers	Use of other coolers/ Instrument/Model	Current Status
Oxford/RAL 80K	ISAMS/UARS	Sep-91		Jul-92	1.8	3.6	1	1	FM spare	Decommissioned 2005
Oxford/RAL 80K	Lifetest	N/A		Restarted (+)	18.6	18.6		1	Lifetest	Lifetime exceeded
RAL 80K - head to head	ATSR-1/ERS-1	Jul-91		Mar-00	8.6	8.6	1			Mission complete
Astrium(BAe) 80K*	Qual&LifeTest/ESA	N/A			8.1	8.1		1	QM	Lifetime exceeded
Astrium(BAe) 80K	HTSSE-I/NRL	Nov-93		Nov-93	0.2	0.2	1	1	EM	Orbit not achieved
RAL 80K - head to head	ATSR-2/ERS-2	Apr-95		Feb-08	12.8	12.8	1			Decommissioned Feb 2008
Astrium(BAe) 80K	IMG/Adeos	Aug-96		Jun-97	0.9	1.8	1	1	EM	Satellite failed
"	HTSSE-II/NRL-Argos	Feb-99		Aug-00	1.5	1.5	1	1	EM	Mission completed
"	JPL, TRW, ESA, Fujitsu, GSFC, Rockwell, Hughes				1.1	13.8		13	Evaluation	Nominal operation (latest reports) - average operational years/cooler
"	MOPITT/CSA		Jan-92		0.2	0.4		2	EQM	Testing complete, now in use at CSA for pulse tube testing
Astrium 50-80K Stirling*	MOPITT/Terra	Dec-99	02-Mar-00	Ongoing	10.1	20.1	2	1	FM spare	Mission extended (2011), system failure affected 1 displacer
"	Qual&Life Test/ESA	N/A		Restarted	6.9	6.9		1	QM	Lifetime exceeded
"	SMR/ODIN	Feb-01	24-Feb-01	Ongoing	9.2	9.2	1			Mission extended (Dec.2009)
"	MIPAS/ENVISAT	Mar-02	09-Mar-02	Ongoing	8.0	16.0	2	2	EQM	Mission extended (2011 possibly to 2014))
"	AATSR/ENVISAT	Mar-02	11-Mar-02	Ongoing	8.2	16.5	2	1	FM spare	Mission extended (2011)
Batch 2	SPI/INTEGRAL	Nov-02	14-Oct-02	Ongoing	7.3	29.2	4	2	FM spare	Mission extended (Dec.2010)
Batch 3a	Military – A /CNES	Jun-05		Ongoing	5.4	10.7	2	2	EM	Last report nominal
Batch 3b	Military – B /CNES	Dec-09		Ongoing	0.1	0.1	2		QFM	Launched successfully
Batch 4a	SLSTR/S3A	TBD		Pre-CDR			2	2	EM	EM/PFM build in progress
Batch 4b	SLSTR/S3B	TBD		Pre-CDR			2		FM	
RAL/Astrium 4K J-T	Planck	May-09	21-May-09	Ongoing	1.0	1.2	2	2	FM Spare	Commissioned 21-May-09, Cooldown achieved 02-Jul09
Astrium 20-50K	Qual&LifeTest/ESA	N/A		Rebuild	0.5	1.2		2	QM, DM	After restarting programme, lifetesting now scheduled to start mid 2010
High Power 50-80K (ESA Adv.50-80K)	N/A	N/A		CDR						ESA approval of CDR expected shortly
TOTALS	= 124 flight quality mechanisms					113.1	183.5	27	36	= 63 flight quality systems

Courtesy of Andrew Gibson (slightly out of date)

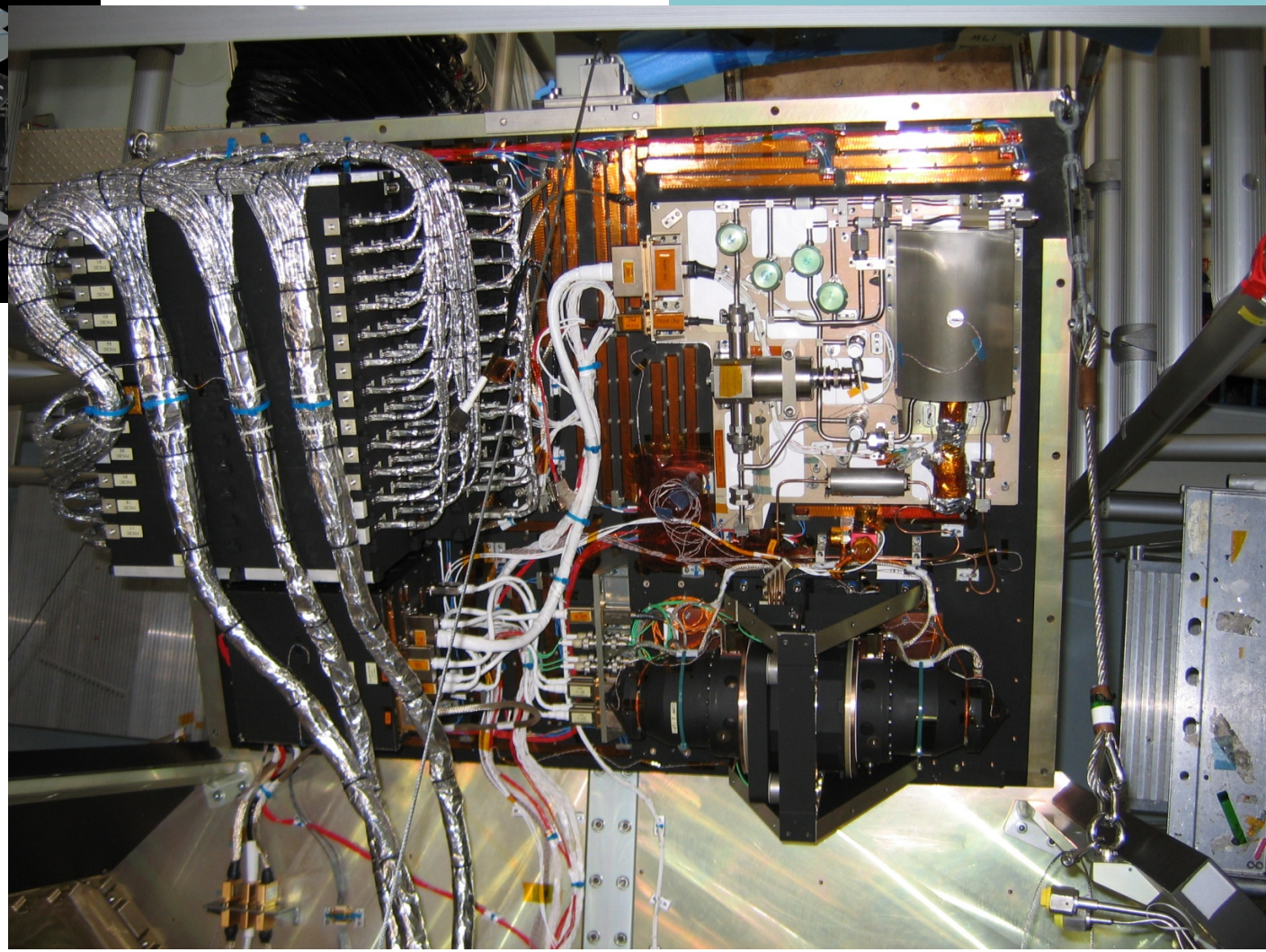
The Planck Spacecraft



Picture: ESA/AOES Medialab

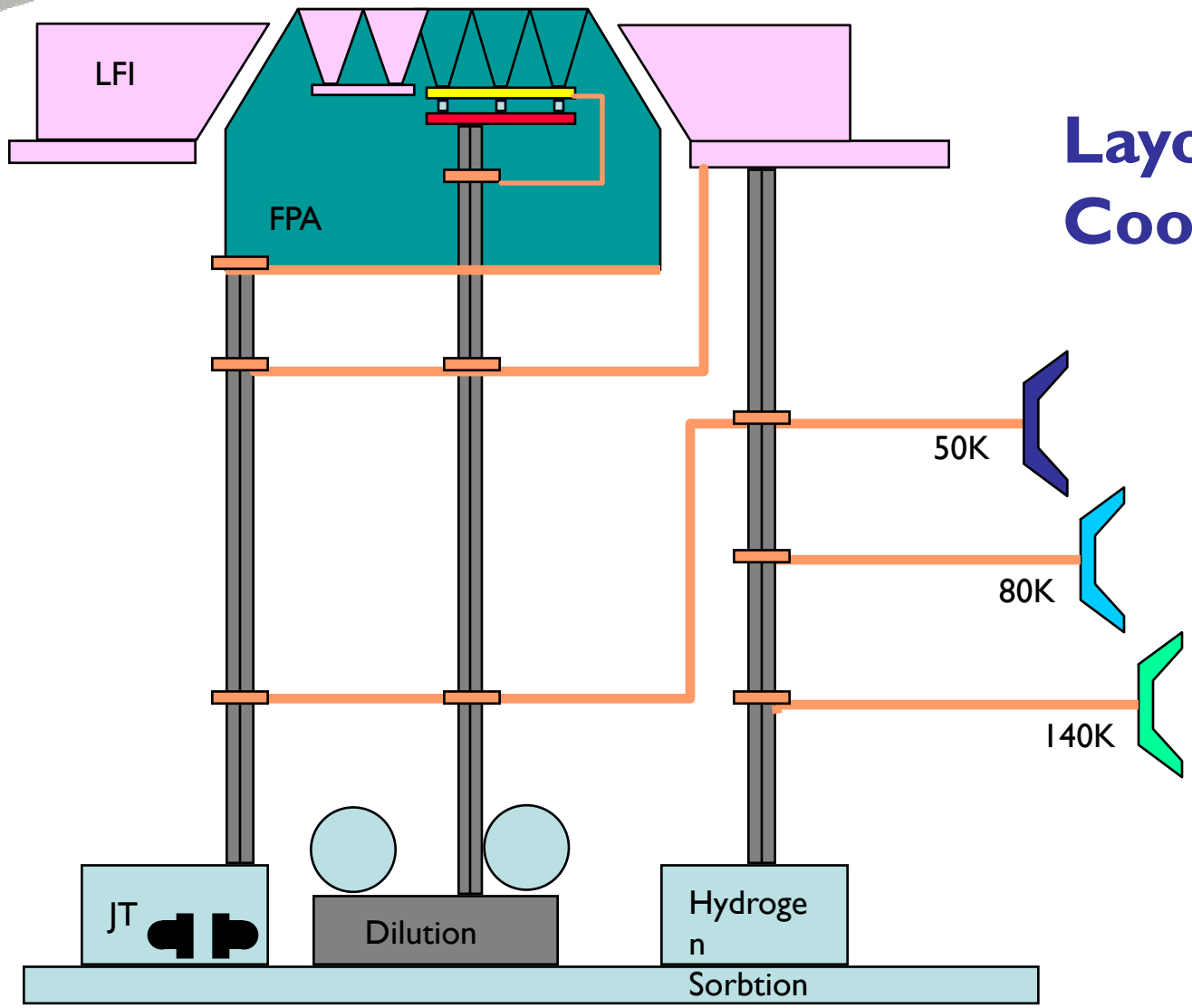
Cosmic Microwave Background measurements

RAL supplied the 4K cooler



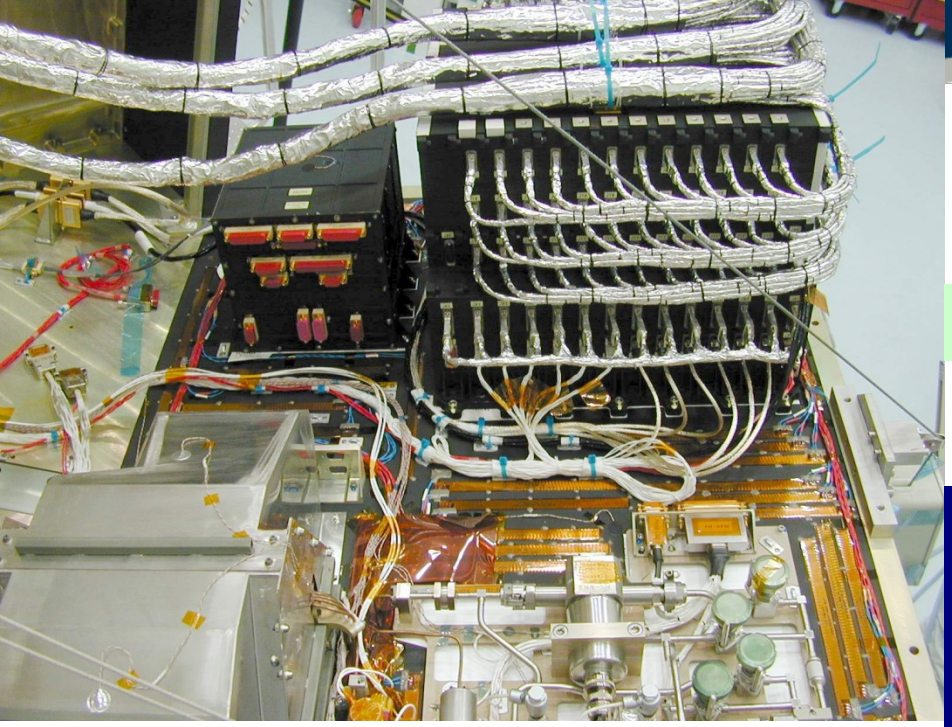
The Planck Spacecraft

Layout of the Planck Cooling System



100mK
1.6K
4K
20K
50K
80K
140K
280K
Thermal link

The Planck Spacecraft



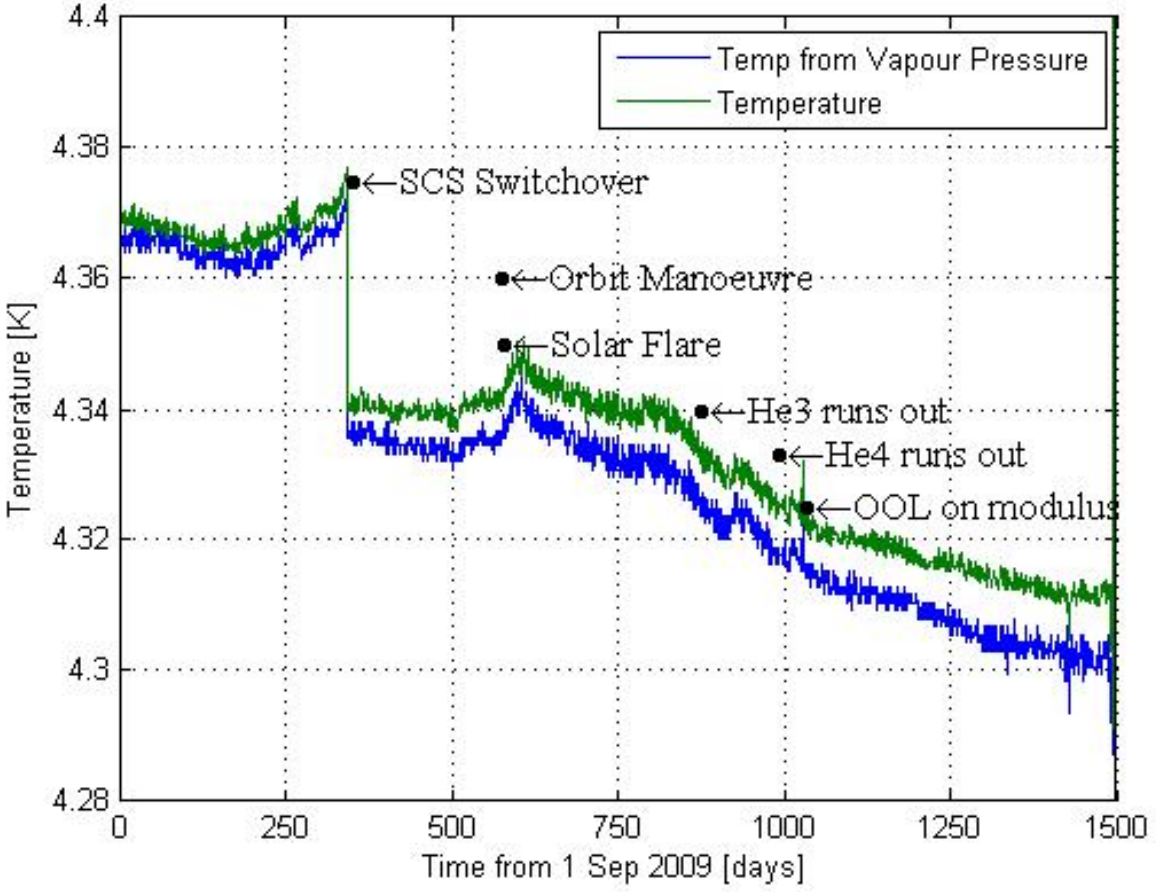
Compressors (inside magnetic shielding on the left), Gas cleaning panel (lower right) and electronics (upper left) on the satellite panel

Pipework inside the satellite

In Flight Results – Press. & Temp. stability

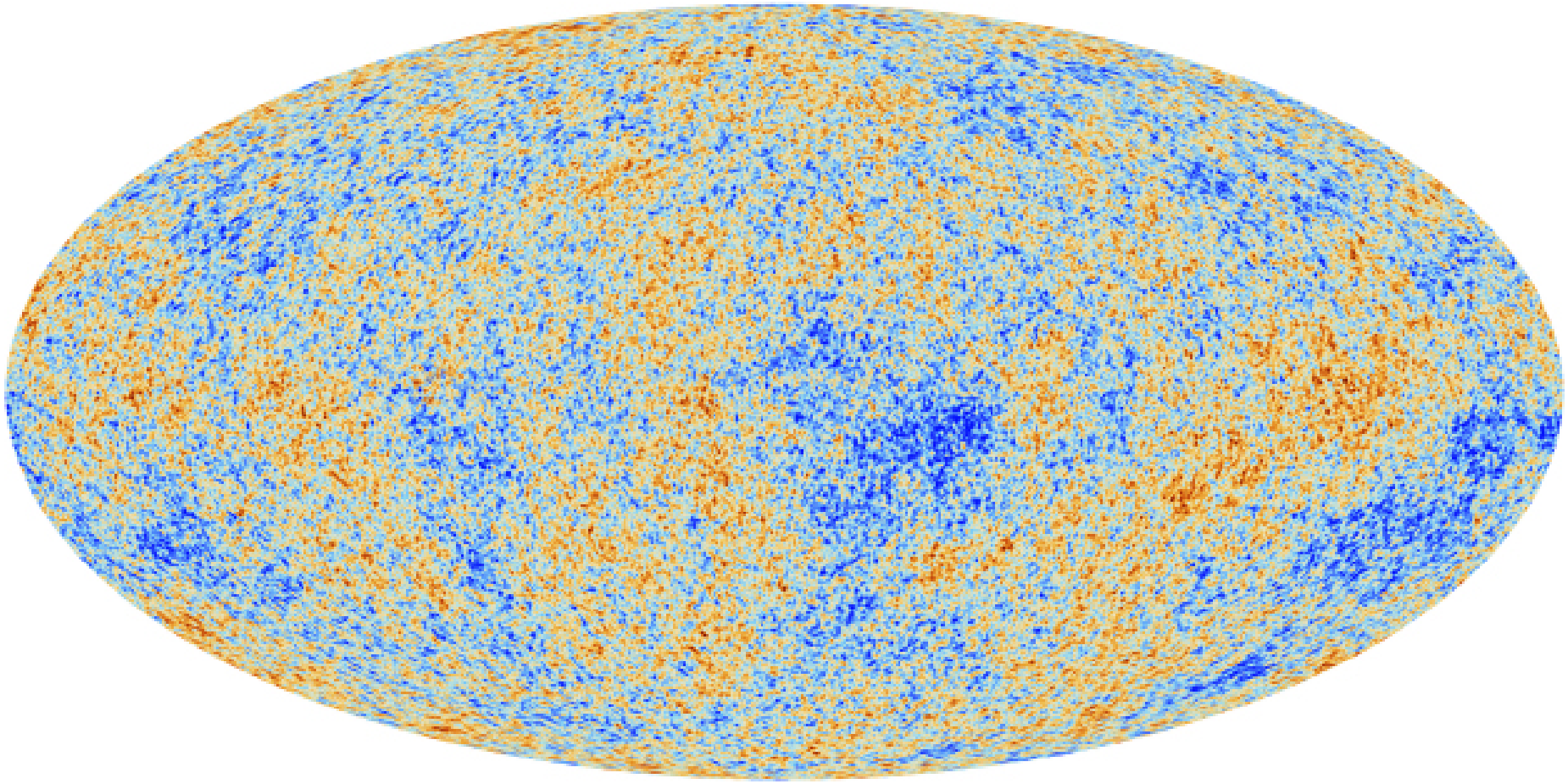
- Low pressure side of the JT expansion measured at ambient
- With no pressure drop the temperature inferred from this should match the temperature measured at the cold end

- Pressure drop down low pressure side ~ 0.013 bar calculated ~12mK
- Not sure why difference is greater after SCS switchover
- Increased heat load after dilution finishes?

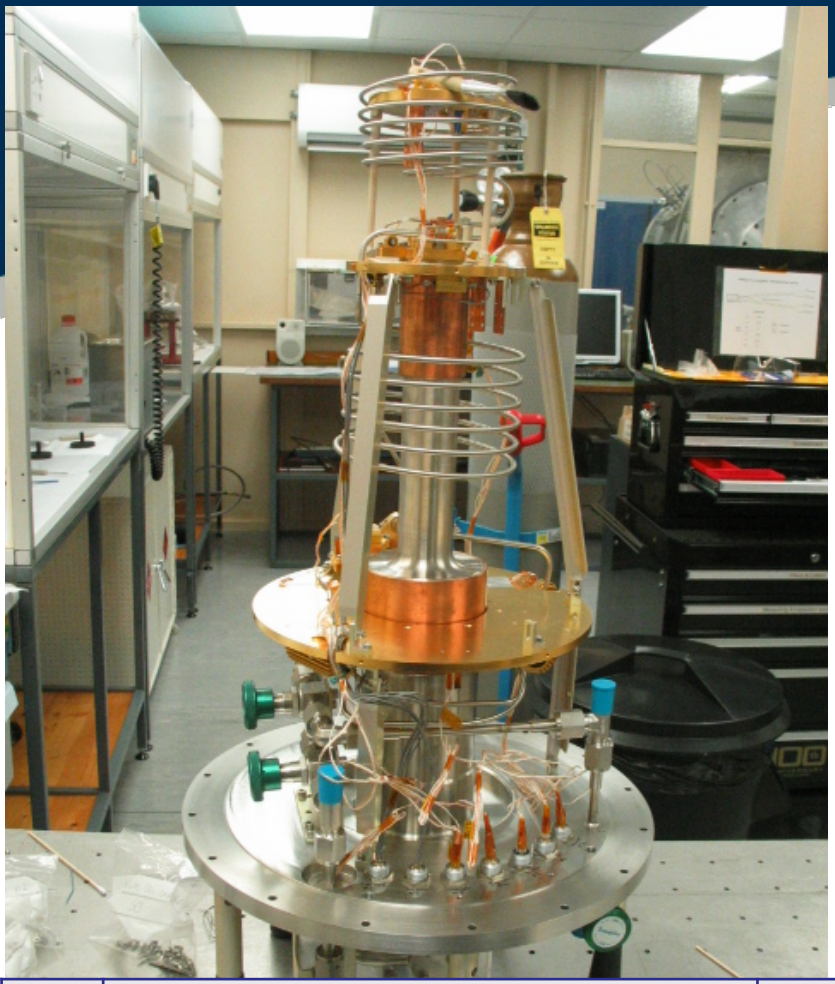


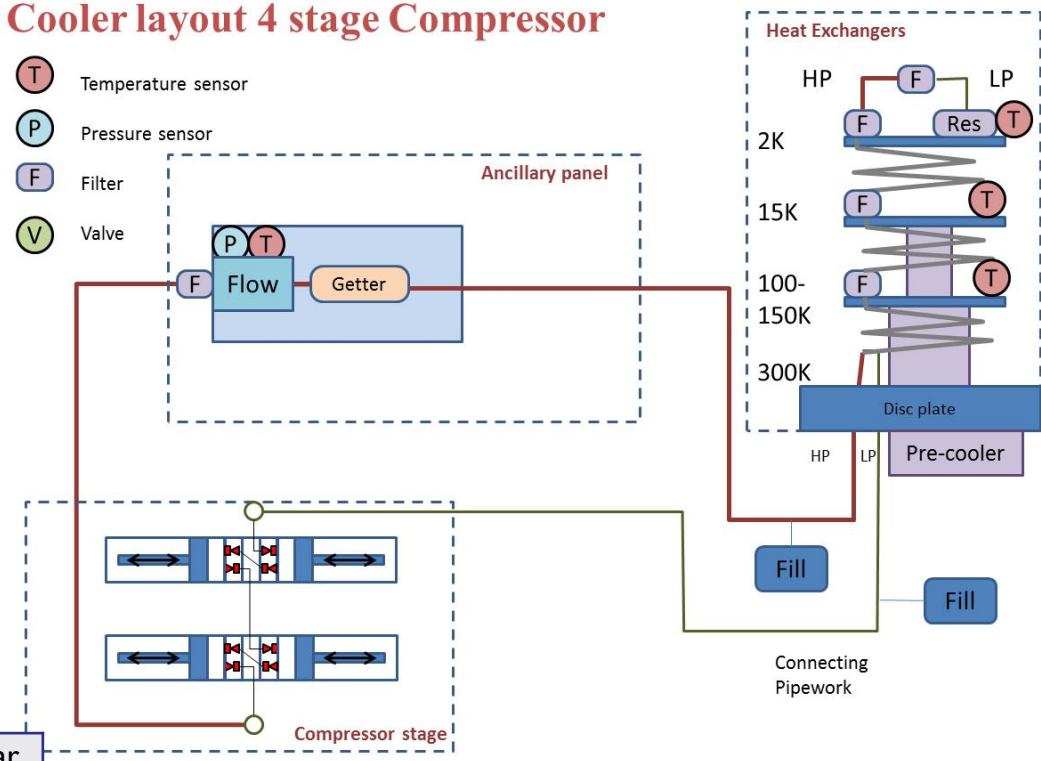
Day 676 (565 on graph) orbit manoeuvre
Day 677 (566 on graph) Solar flare
Day 975 (864 on graph) He3 on dilution runs out
Day 1092 (981 on graph) He4 on dilution starts to run out
Day 1135 (1024 on graph) OOL on 4K modulus of imbalance

Results



Advanced 2K Cooler Programme





a	Pressure drop down the total heat exchanger system	< 50mbar
b	Load on the first stage	< 300mW
c	Load on the second stage	< 150mW
d	JT cooling power	> 20mW
e	Temperature of cold stage	<2K

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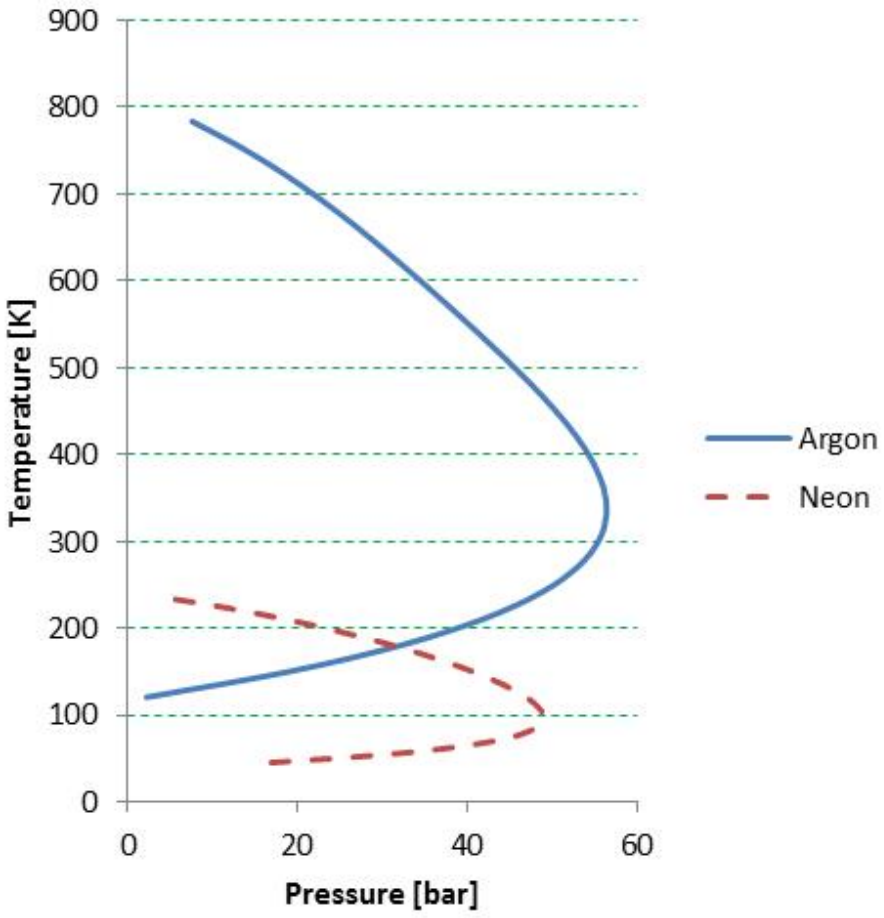
ECHO Study on a Neon JT Cooler



- Neon has been suggested as a refrigerant in a Joule-Thomson system on EChO – MPt 24.56, BPt 27.1K
- The inversion curve is a locus of maximum cooling on expansion of the gas
- For Neon some pre-cooling is required
- To achieve a temperature of ~27K requires a return pressure ~1bar
- As a baseline feasibility study we looked at the use of an existing two stage compressor design that would provide a moderate inlet pressure of ~12bar

ECHO Study on a Neon JT Cooler

	Bottom HX	Middle HX	JT HX	JT effect	Cond	Total
293	-1018.9				-6.7	-1025.6
100	1078.1	-436.1			6.7	648.7
45		593.1	-48.7		0.8	545.1
28				-203.5	0.1	-203.4

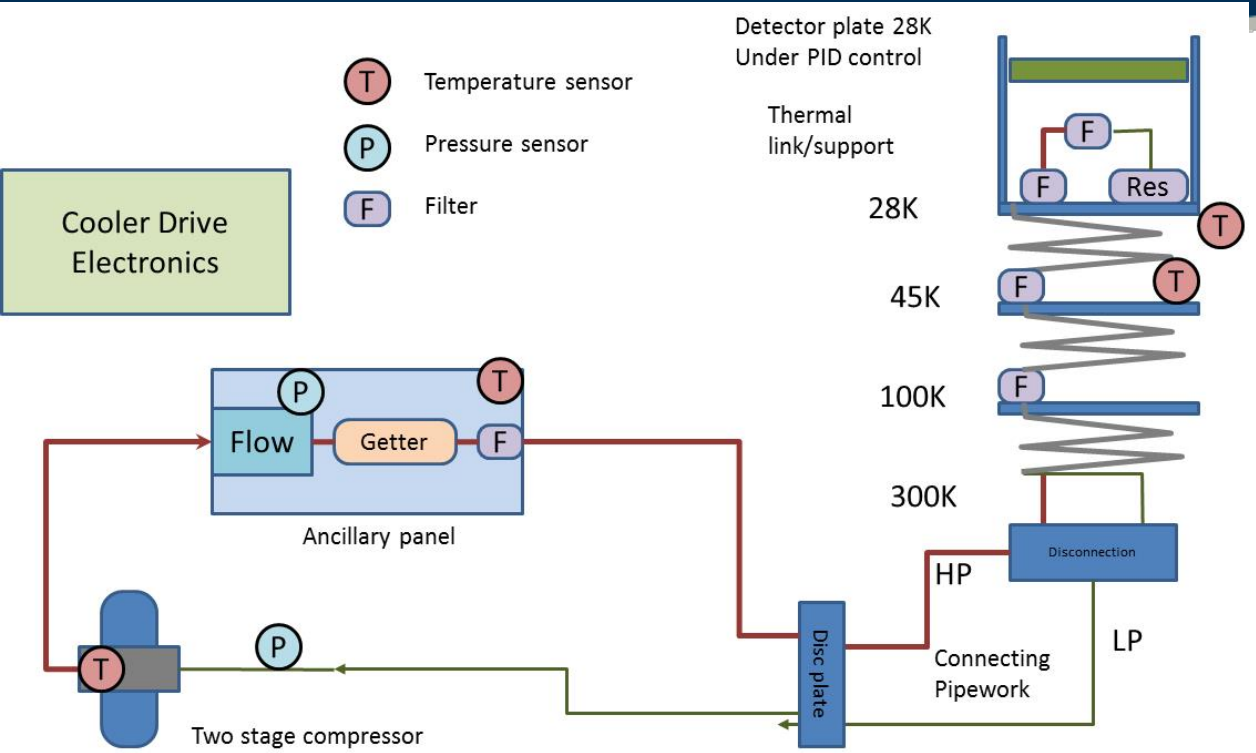
All power quoted in the table are mW, -ve figures indicate cooling

Parameter	Value
frequency	40Hz
fill pressure	4.5bar
stroke	5.5mm (max=7mm)
total input power	95W
P high	12bar
P low	0.9bar
mass flow	35mg/s
piston sizes	1st stage 24mm, 2nd stage 14mm
spring rate	2-3N/mm

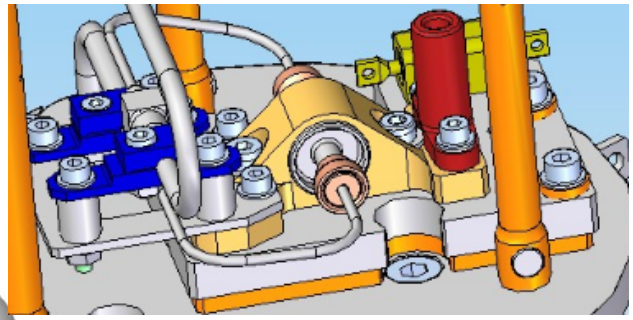
- Assume pre-cooling is available at 100 and 45K
- A flow of 35mg/s is required for 200mW of cooling at 27K
- The mass flow rate of 35mg/s implies a volumetric flow of 38 x 10^{-6} m^3/s at 1.1 bar and 293K.
- The required operating parameters are well within the capabilities of the two stage design. Going to a four stage compressor set could give benefits.

A health warning must be applied to these figures!: The heat exchangers are not optimised; We need to look at the effect of increasing the high pressure with more compression stages (currently using 12 bar); etc... This is a first cut indication that the use of Neon is feasible

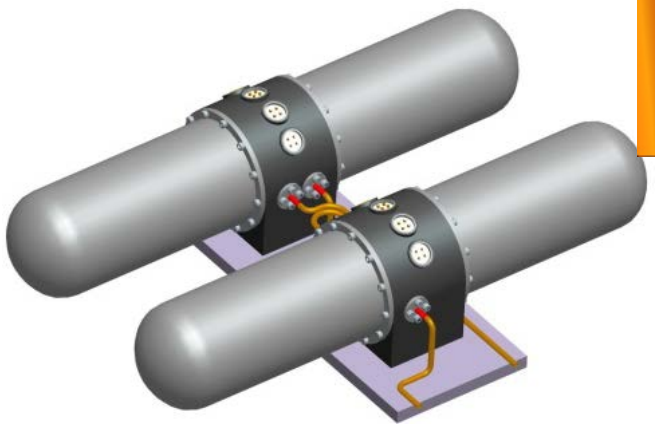
ECHO Study on a Neon JT Cooler



Cold end of system incorporating liquid reservoirs – note that we could have more than one of these for distributed cooling



We have a well defined system for achieving gas purity. No blockages on Planck (a 4K system) since launch (2009-2013)
Shown are stage filters for gas purity



Four stage compressors being designed for ESA 2K cooler programme – EChO would use half of these (or all four if more stages are desirable)

A Small Scale Cooler for use at 80K

ESA contract 4000102281/10/NL/SFe

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T Tirolien
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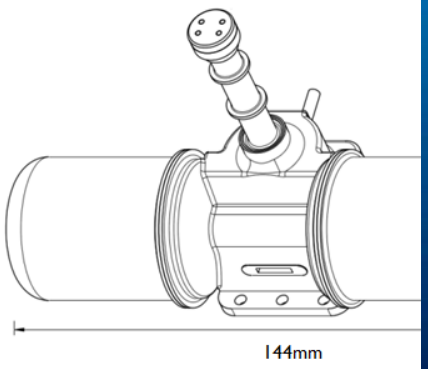
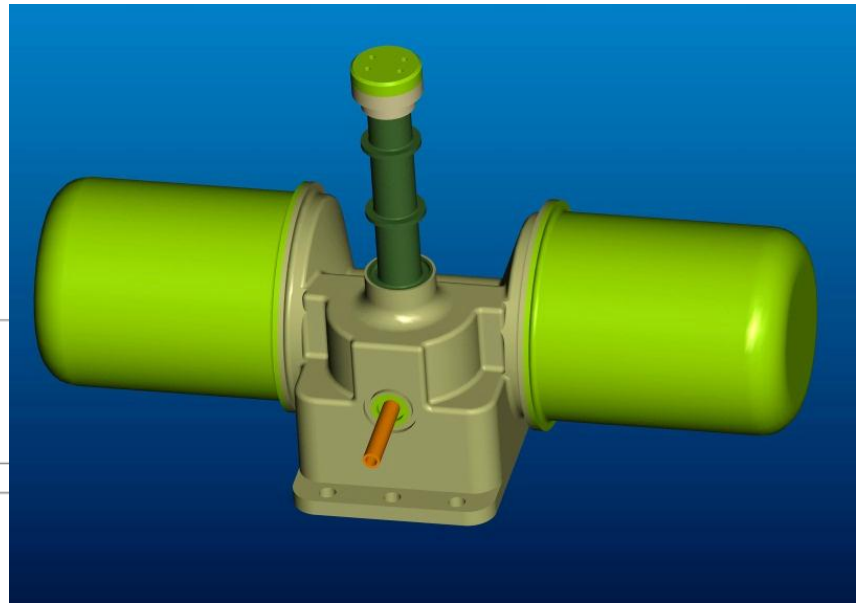
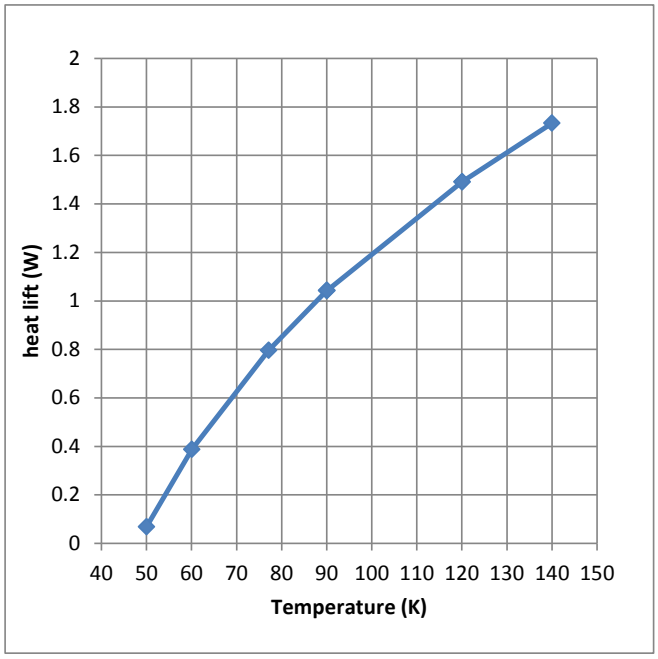
Space Cryogenics Workshop,
ESTEC 2013







SMALL SCALE COOLER PRODUCT SPECIFICATION	
Mass (excluding CDE)	580g
Size Envelope (excluding DCE)	144 x 61 x 93mm
Input power (750mW@77K, +20°C rejection)	15W
Input power (750mW@77K, -20°C rejection)	10W
Operating environment range	-30°C to +50°C
Lifetime	>50 000hrs

DISCLAIMER – there are margins on these figures, however experience dictates that modelled performance is not always a good indicator of actual performance!

A NEW CLOSED CYCLE COOLER FOR SPACE APPLICATIONS

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STFC, Rutherford Appleton Laboratory, Harwell Oxford, OX11 0QX, UK.

C. Cheuk, P.Iredale, J. Moore
Honeywell Hymatic, Burnt Meadow Road, Redditch, B98 9HJ, UK.

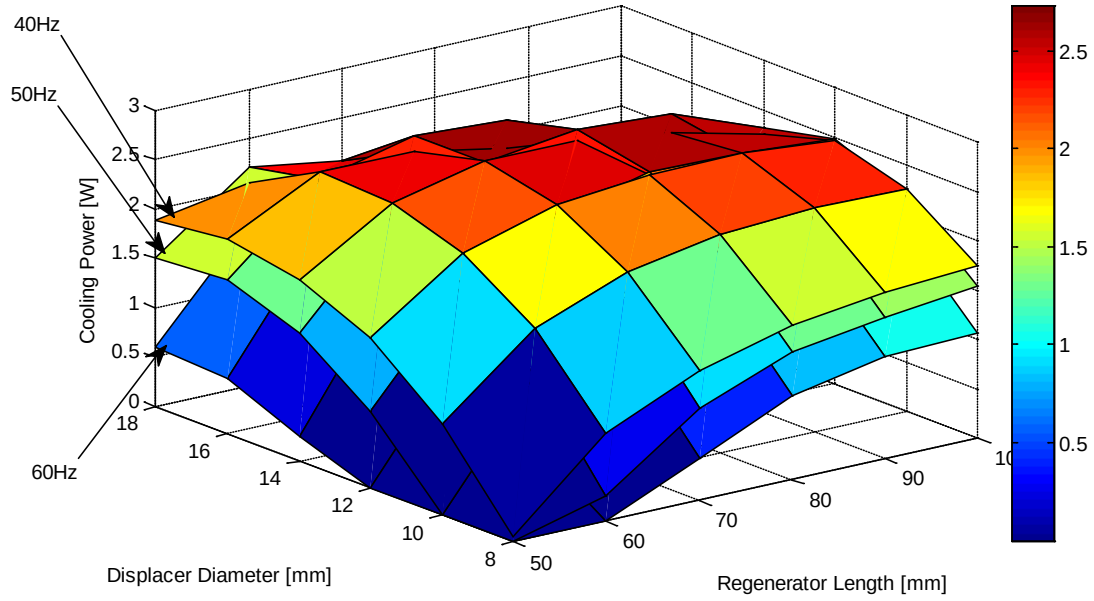
S. Mitchell, B.Olivier and M. Townend
Systems Engineering & Assessment Ltd, Building 660, Bristol Business Park, Coldharbour Lane, Bristol, BS16 1EJ, UK.

Science & Technology Facilities Council
Rutherford Appleton Laboratory

Honeywell

sea
a Cohort plc company

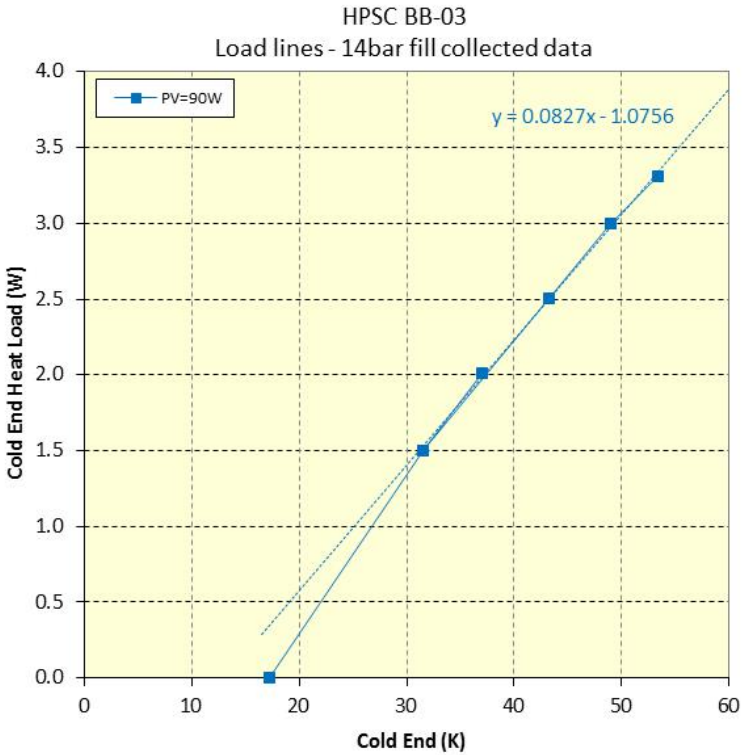
Space Cryogenics Workshop ESTEC
December 2013

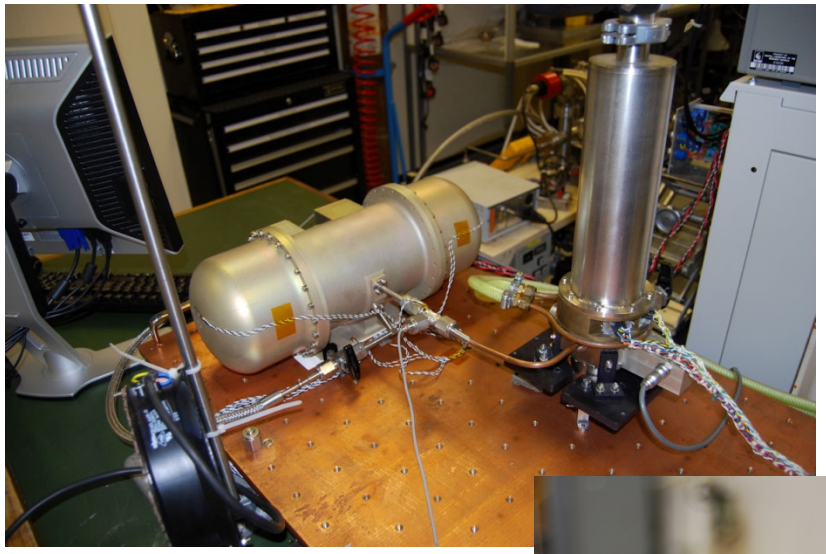


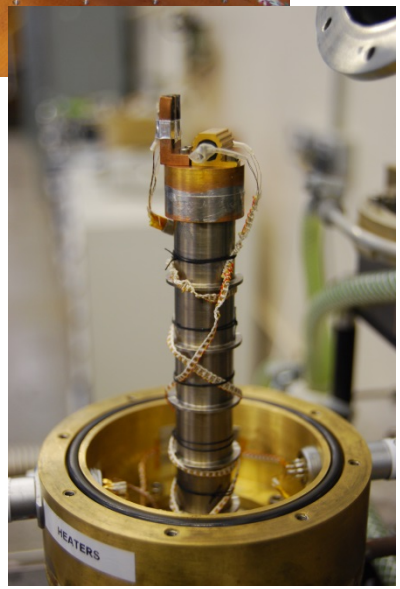
- 50K with 2.4W cooling
- Active Temperature Control (±2mk over 10s, ±25mk over 10 min)
- Vibration minimisation for all harmonics below 500Hz
- Efficiency (minimise system power consumption)
- Reliability (redundant configuration)
- Power Conditioning (Bus emissions)
  (to reduce Conducted Emissions to acceptable levels)
- Being industrialised at the moment

LOCUS – Low Cost Upper atmosphere Sounder

Demonstrator Limb sounding multi-channel radiometer mission in THz region (see Brian Ellison talk)







Requirement is for ~3W at 50K with a stability of +/-50mK – can achieve this with ~ 115W total input power

First steps will be to use an existing cooler

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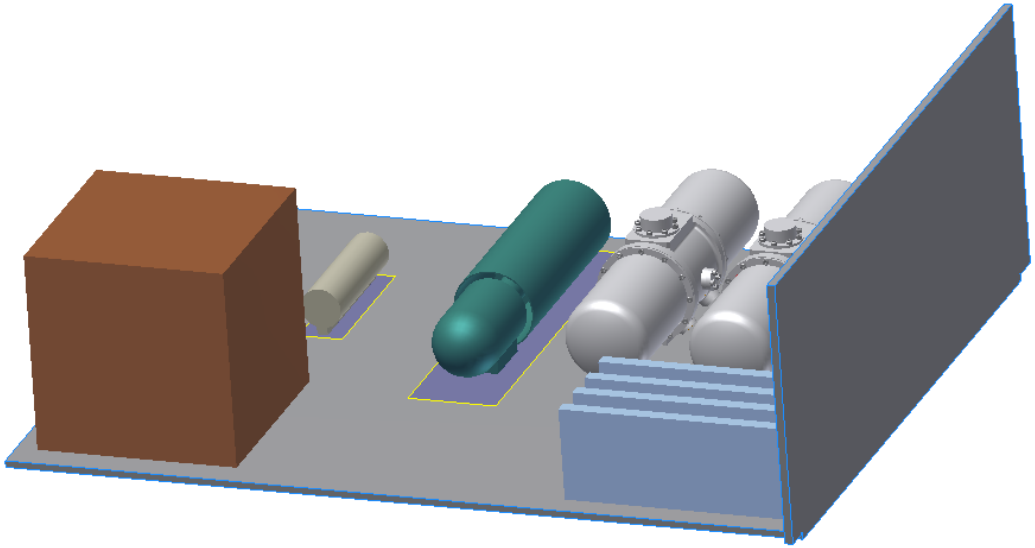
Technology

Quantum Devices

Standard rack with height ~200mm



Components required:

- Balanced JT stage compressors
- Balanced Stirling compressors
- Displacer/JT unit with space for quantum devices
- Control electronics
- Power Supply Unit
- Gas cleaning system

- Requirement for a compact, rack mounted 4K cooler although could configure for 3K or ~2K
- Uses are for superconducting devices for single photon counting and quantum cryptography
- Potentially a large market for these devices
- Taking the cost out of space developed hardware
- Bid into EPSRC as part of Quantum Hub development
- Suitable for use on an aircraft

ATSR2 picture
of the UK+

Future Opportunities in Earth Observation

Host of other instruments making measurements ….

- Future satellites are in the ESA GMES Global Monitoring for Environment Security campaign
- Sentinel 1-6 – some are payloads on other satellites
- Meteosat Third Generation

…..All use Cryogenics !

Science & Technology Facilities Council
Technology

THE END

BRITISH CRYOGENIC CLUSTER

The Most Powerful Concentration of Cryogenic Expertise on Earth

British Cryogenics Council