IEEE/CSC SUPERCONDUCTIVITY NEWS FORUM (global edition) July 2014
Presentation given at ICEC25 – ICMC2014, Enschede, July 2014

FROM RESEARCH TO INDUSTRY

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GRENOBLE

SPACE CRYOCOOLER DEVELOPMENTS

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Lionel DUBAND
Univ. Grenoble Alpes, CEA-INAC-SBT, F-38000 Grenoble

FROM RESEARCH TO INDUSTRY
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WHEN IT ALL STARTED

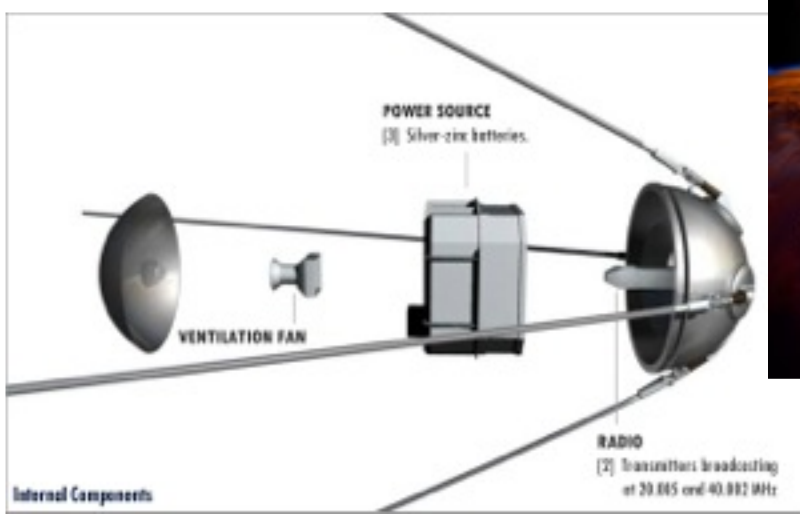
INSTITUT NANOSCIENCES
ET CRYOGÉNIE

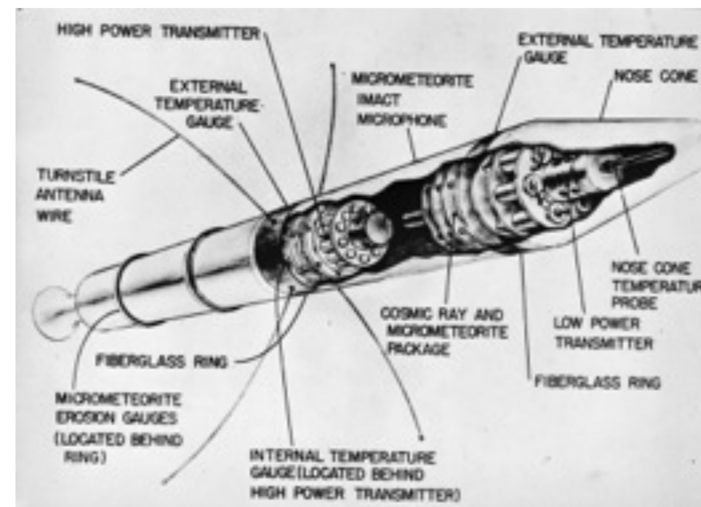
Spoutnik   t0: 1957   Explorer I

October 1957

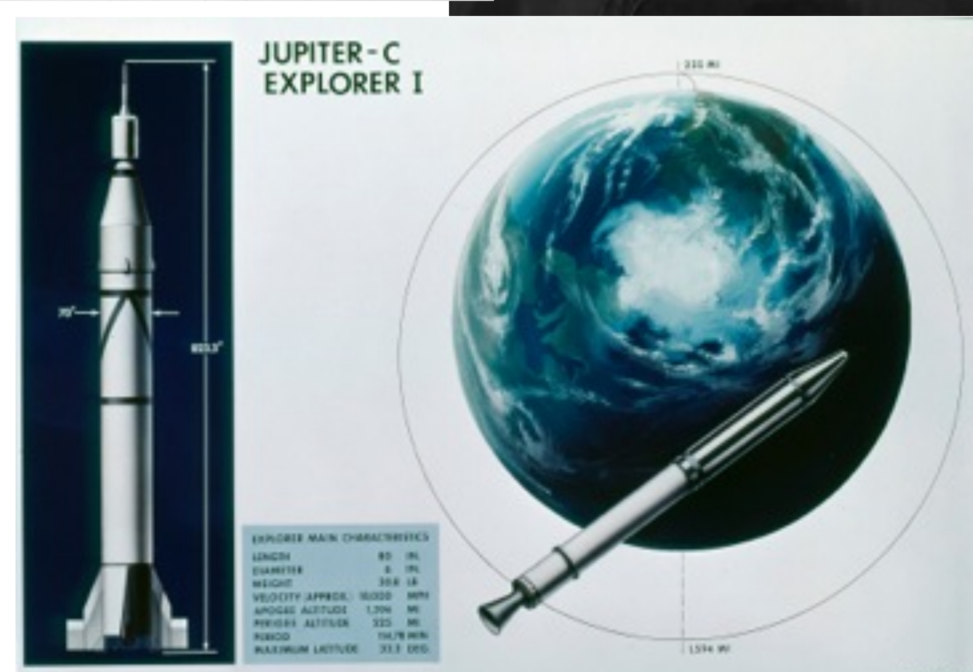

The New York Times.
SOVIET FIRES EARTH SATELLITE INTO SPACE;
IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.;
SPHERE TRACKED IN 4 CROSSINGS OVER U. S.

January 1958

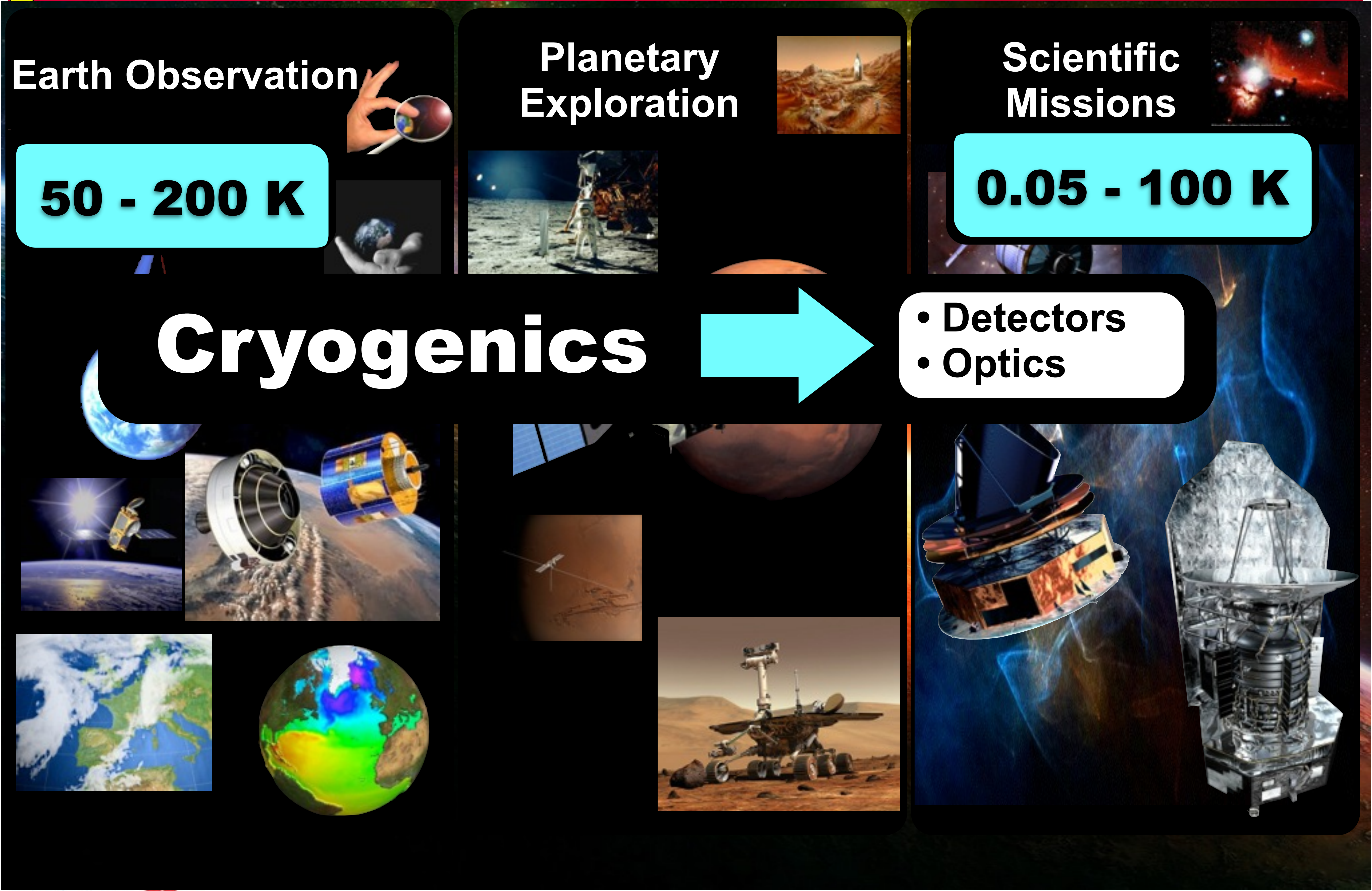





Russians Win Race To Launch Earth Satellite
Man On Threshold Of Space Travel
How To Spot Satellite
U.S. May Speed Up Satellite Program



WHY SPACE ?


Earth Observation
50 - 200 K
Planetary Exploration
Scientific Missions
0.05 - 100 K
Cryogenics
• Detectors
• Optics

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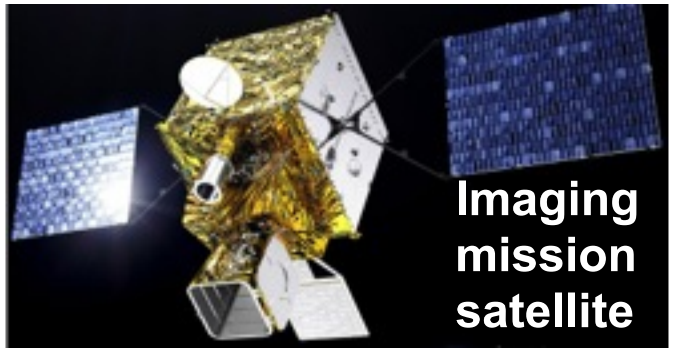
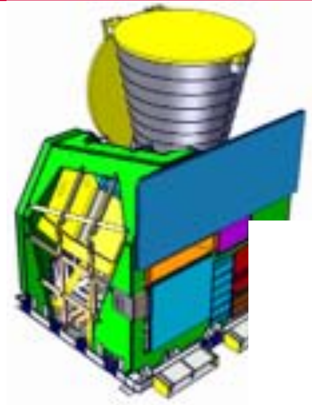
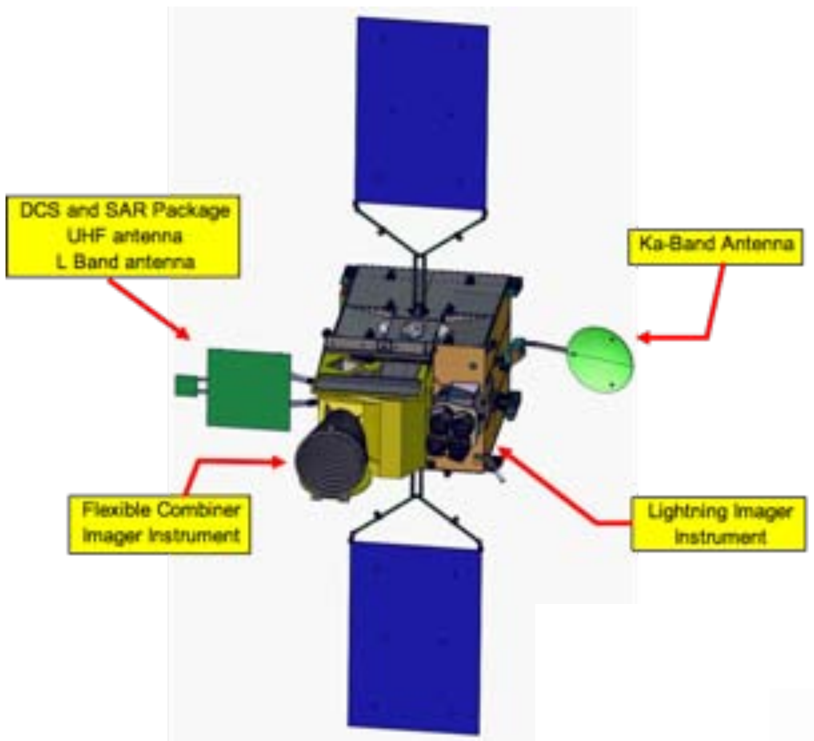
EARTH OBSERVATION: WEATHER SATELLITE MTG

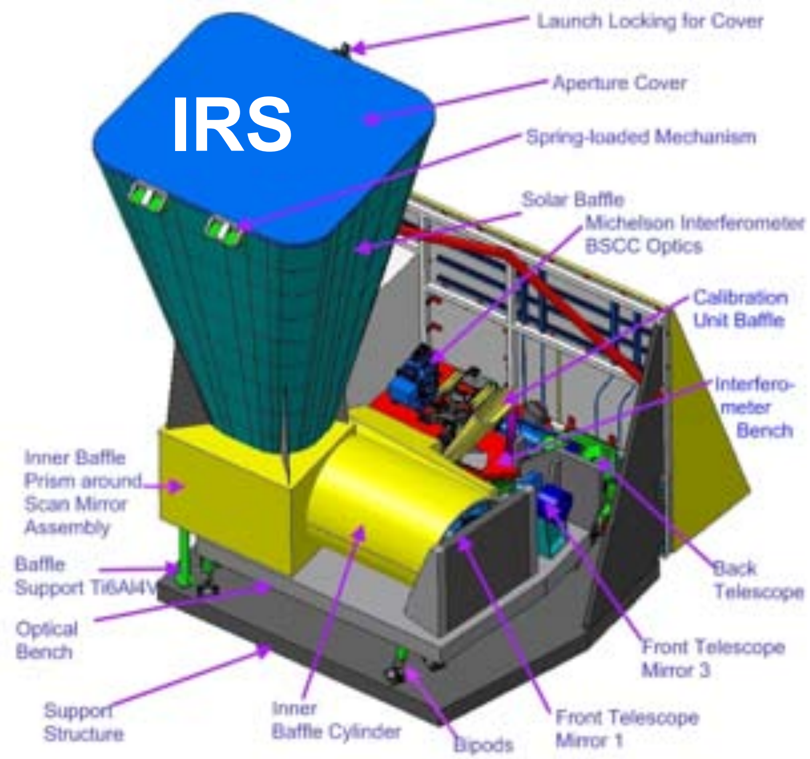


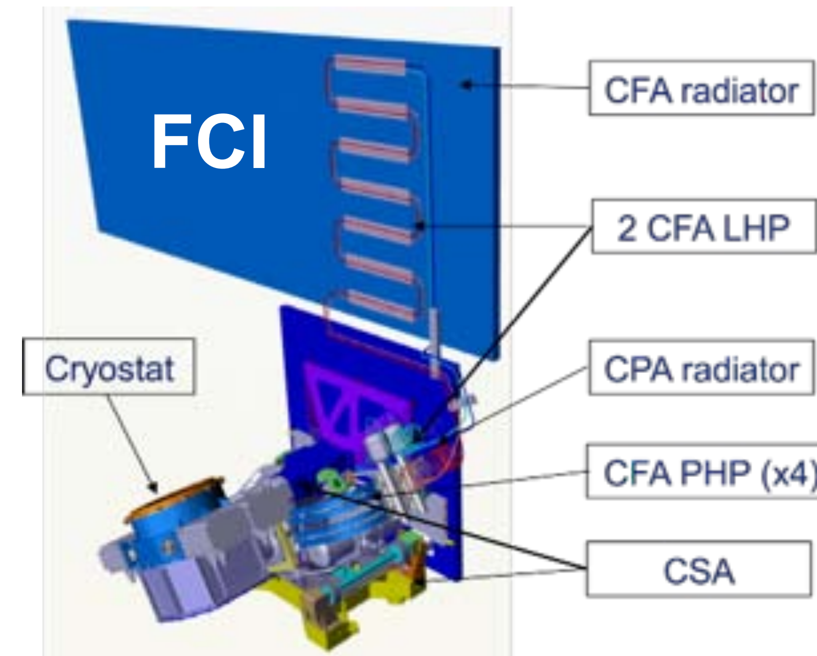


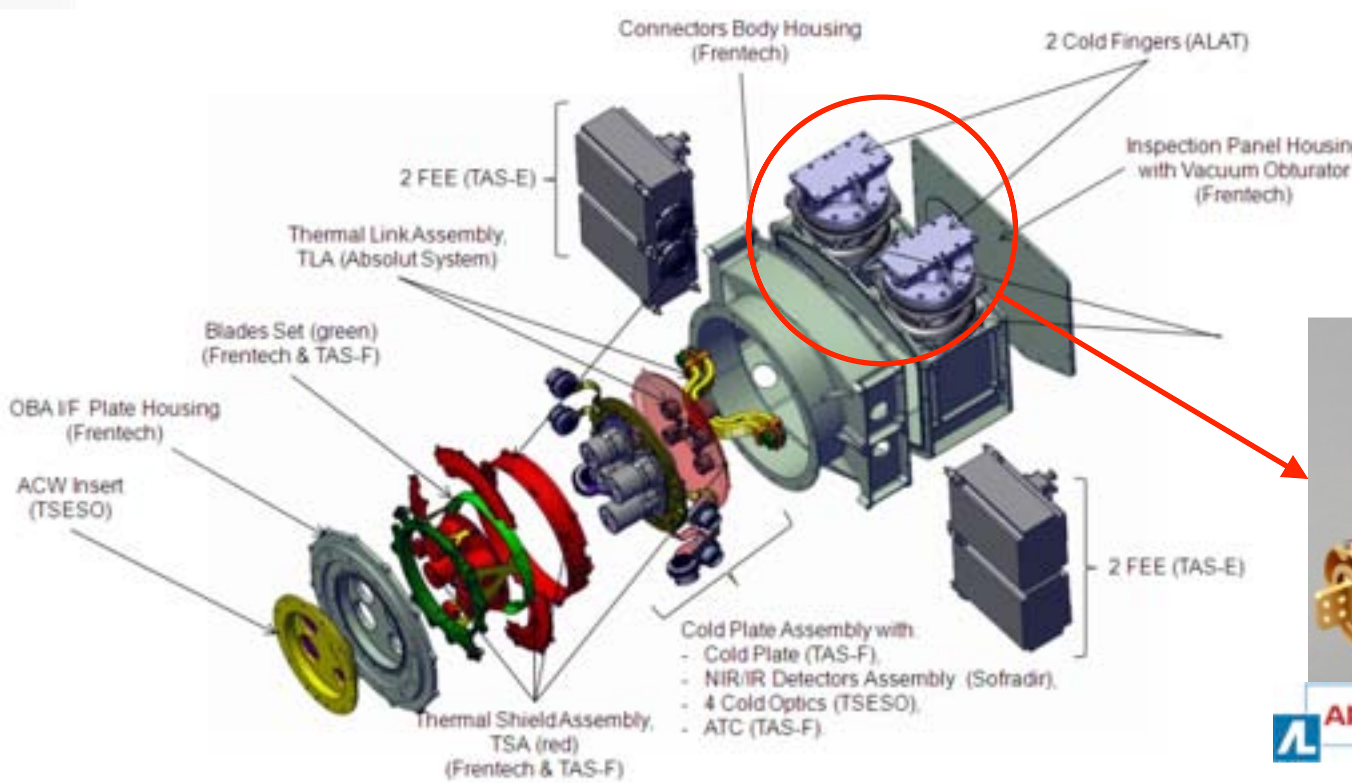
2 instruments
IRS: *Infrared Michelson Interferometer*
FCI: *High spatial and spectral resolution imagery*

55 K and 60 K needed
(photoconductors HgCdTe)









AIR LIQUIDE

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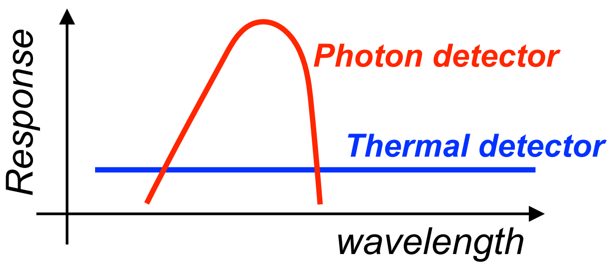
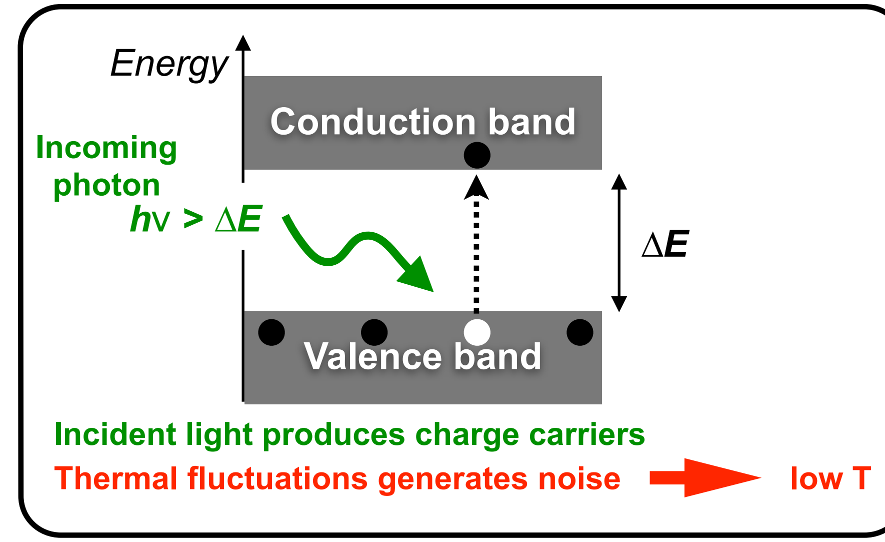
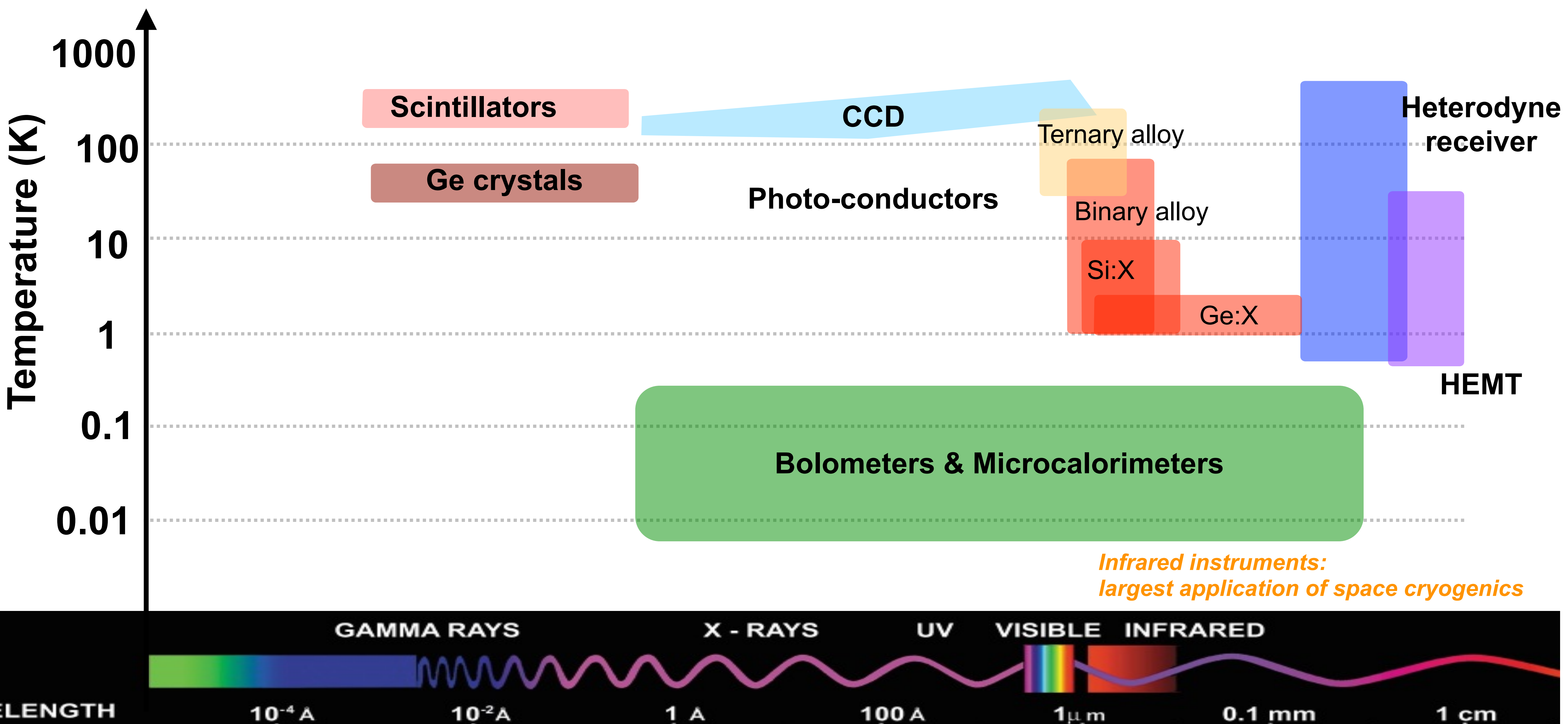
MAIN MOTIVATION: COOLING OF DETECTORS

	Photon detectors	Thermal detectors
Incoming radiation	Interaction with electrons	Temperature change
	wavelength dependent	*≈ wavelength independent*
	E → ΔI, ΔV, ΔR	E → ΔT

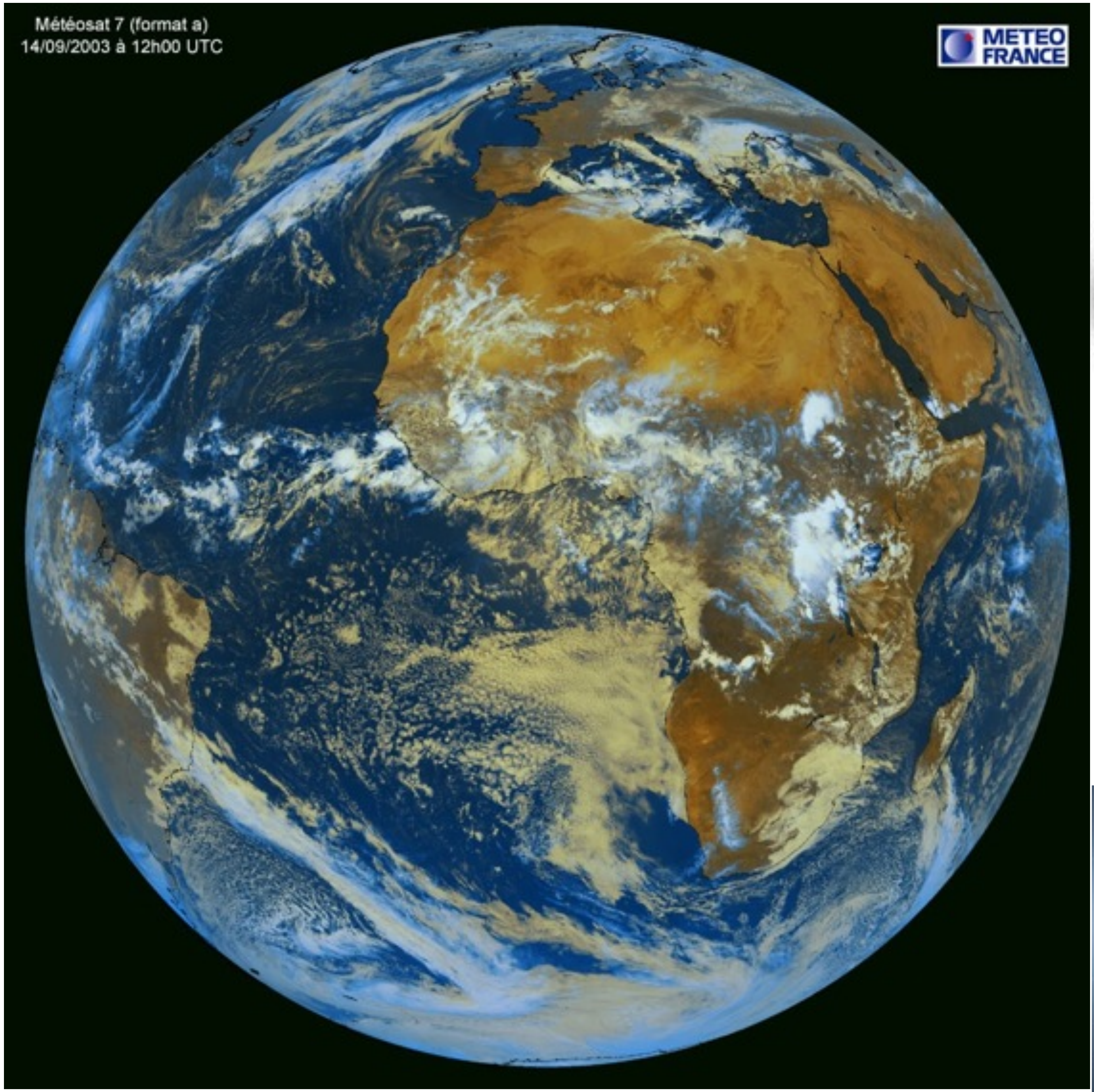




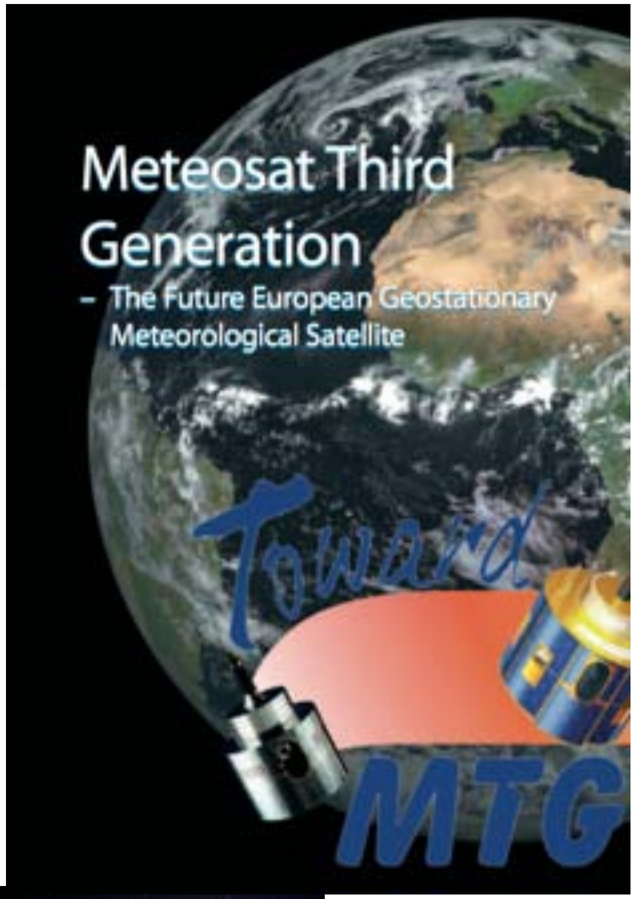


Infrared instruments: largest application of space cryogenics

EARTH OBSERVATION: WEATHER SATELLITE



Meteosat 2G



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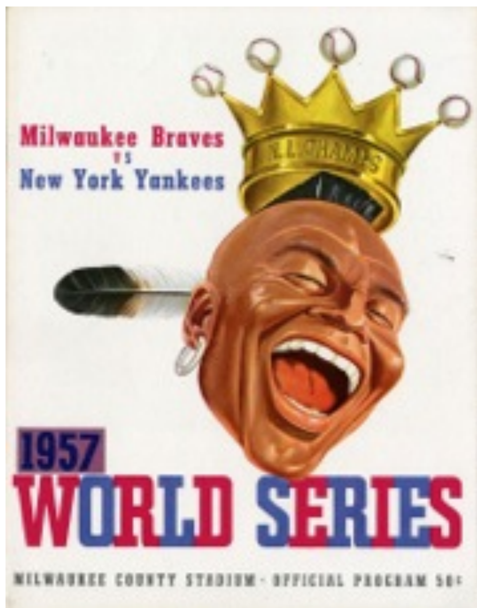
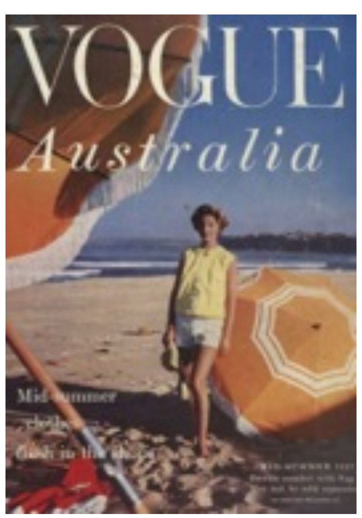
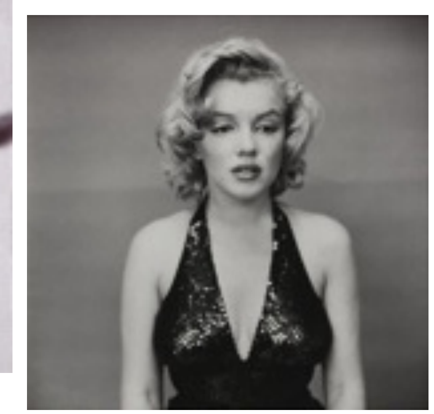
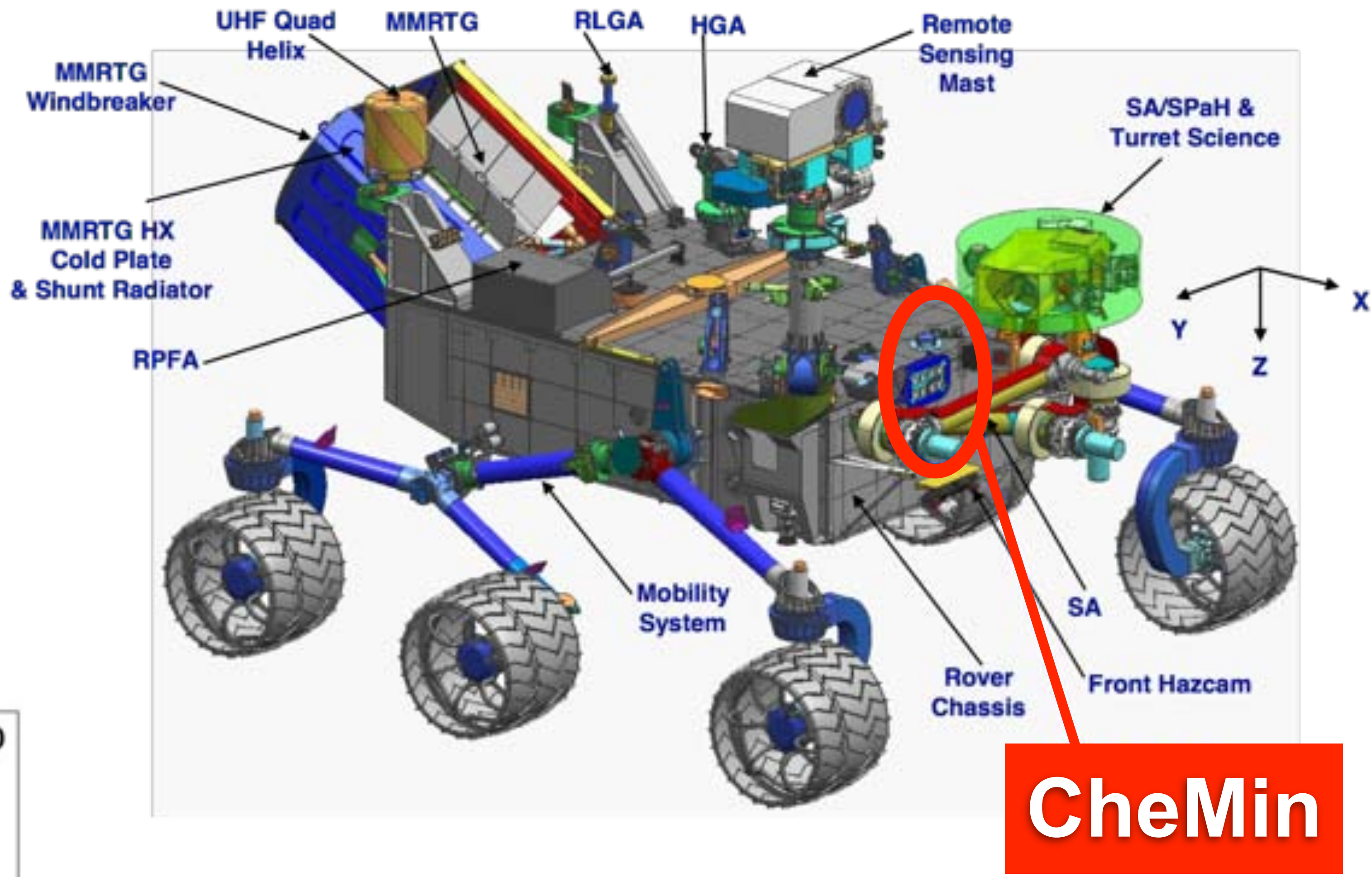
WHEN IT ALL STARTED

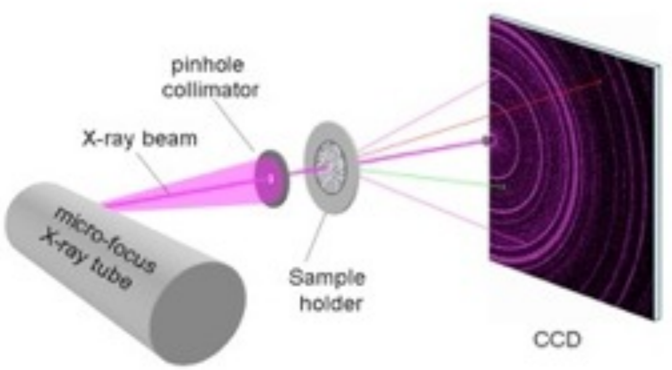


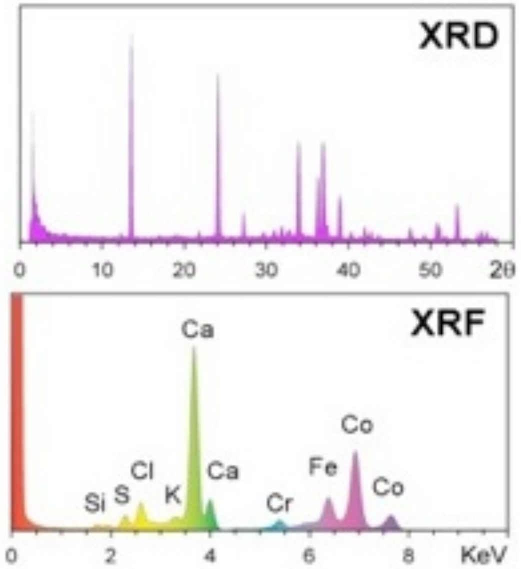




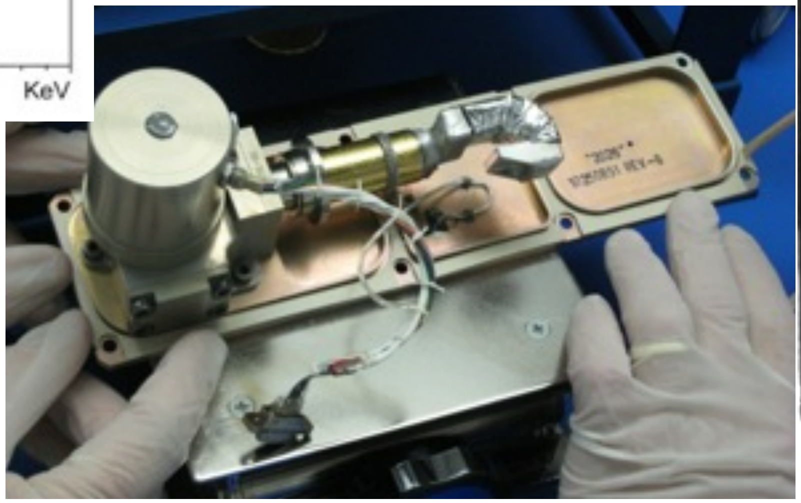
PLANETARY EXPLORATION





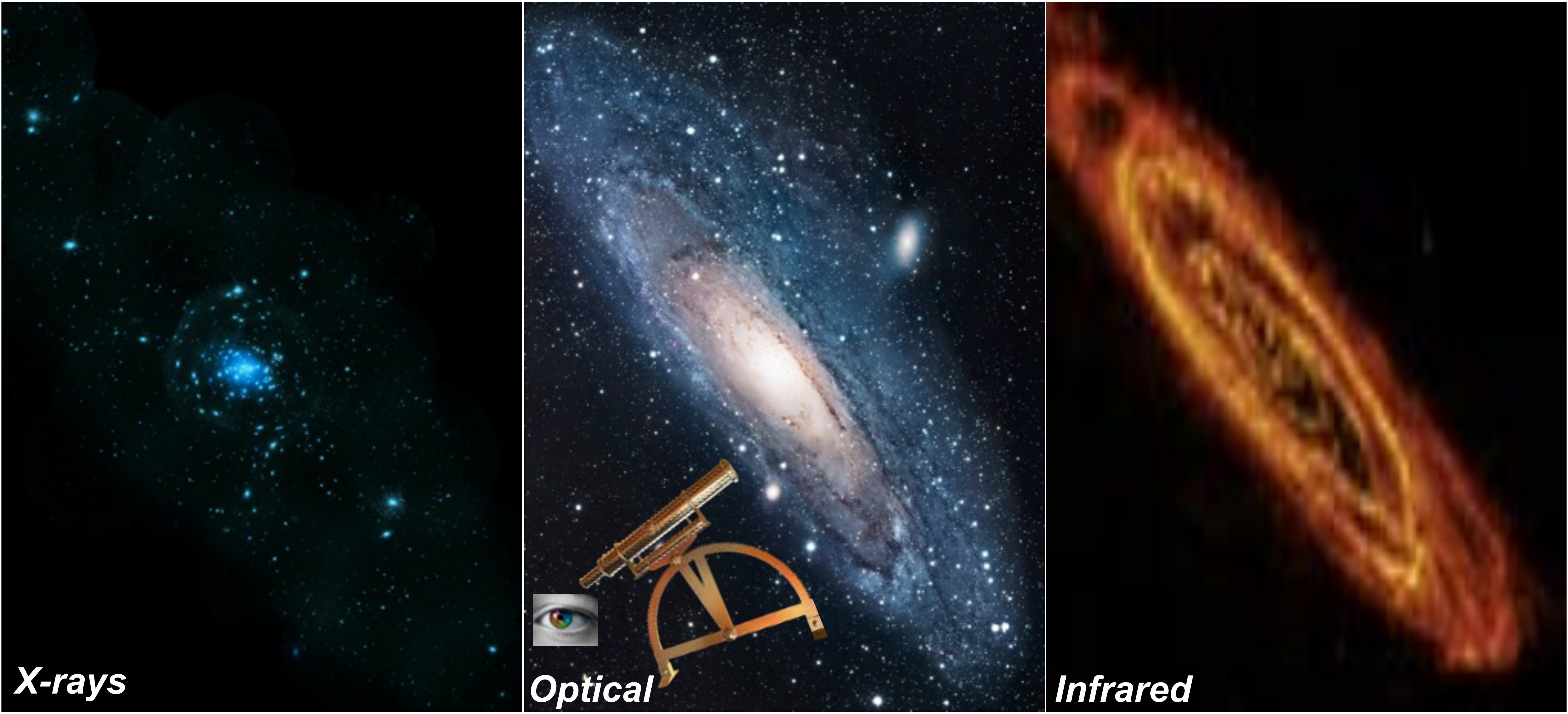


diffraction and fluorescence informations collected by a cooled CCD

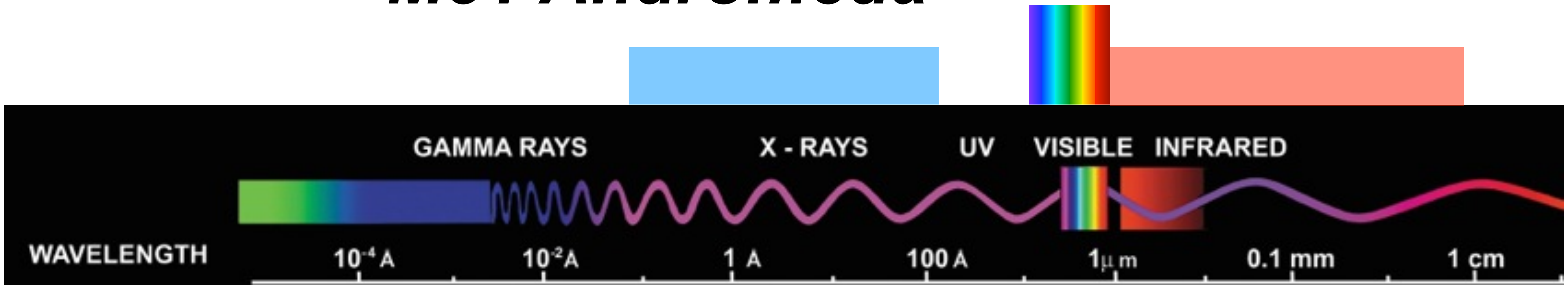


Chemistry and Mineralogy (CheMin): CheMin is a mineralogy instrument, onboard MSL, that identifies and quantifies the minerals present in rocks and soil delivered to it by the Sample Acquisition, Sample Processing and Handling (SA/SPaH) system. The Ricor K508 rotary cooler provides cooling to CCD at ~210K with a lifetime requirement of 1600hrs for surface operations.

SCIENTIFIC MISSIONS



M31 Andromeda



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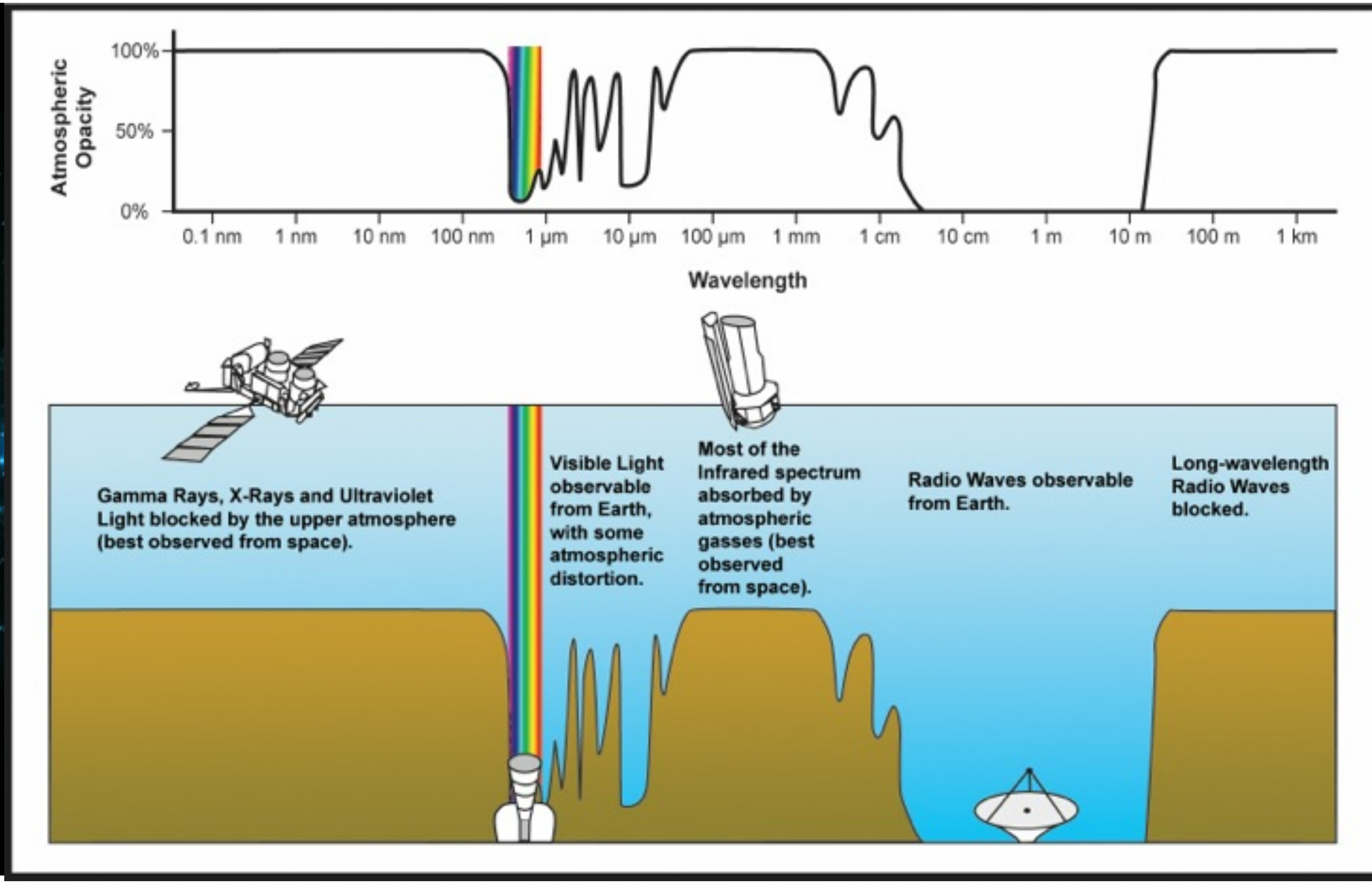
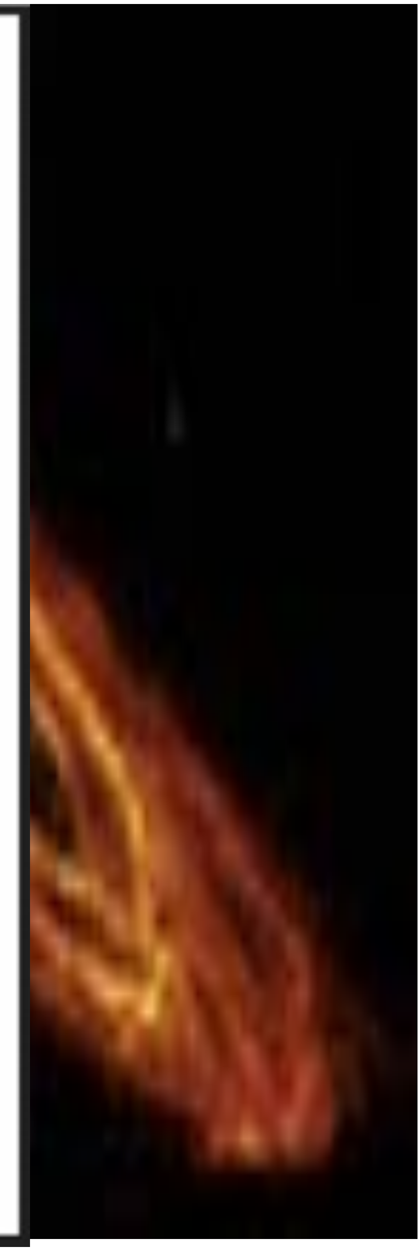
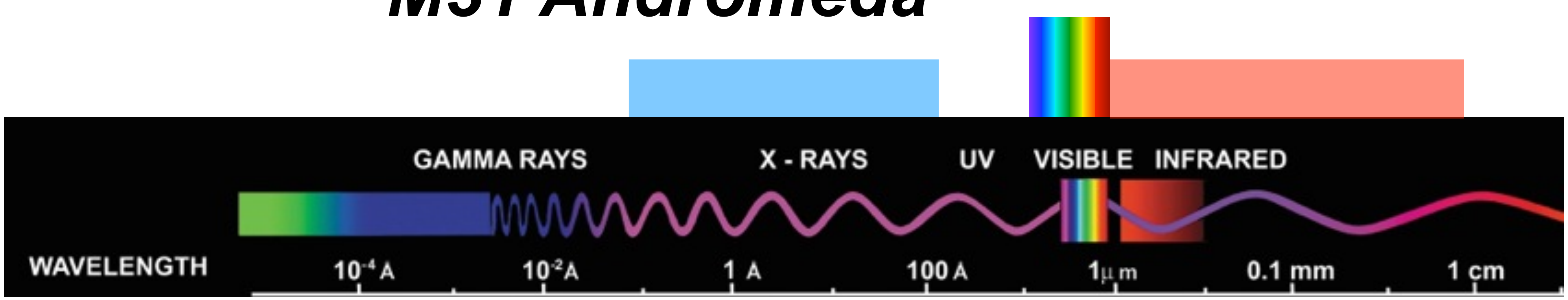
SCIENTIFIC MISSIONS





M31 Andromeda



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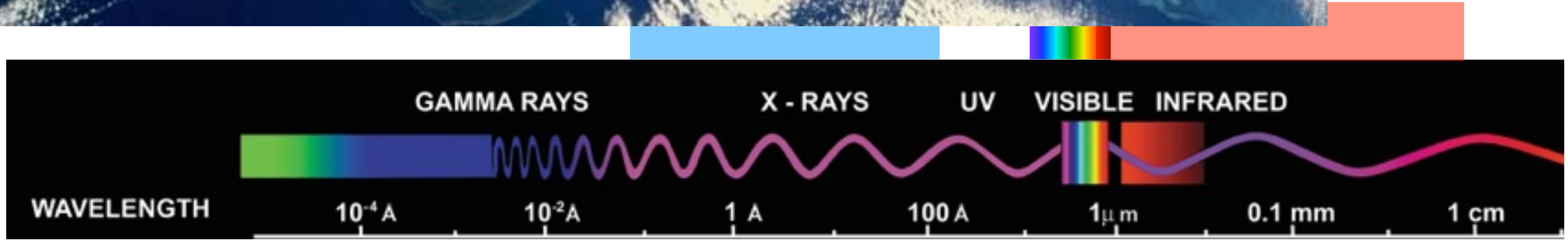
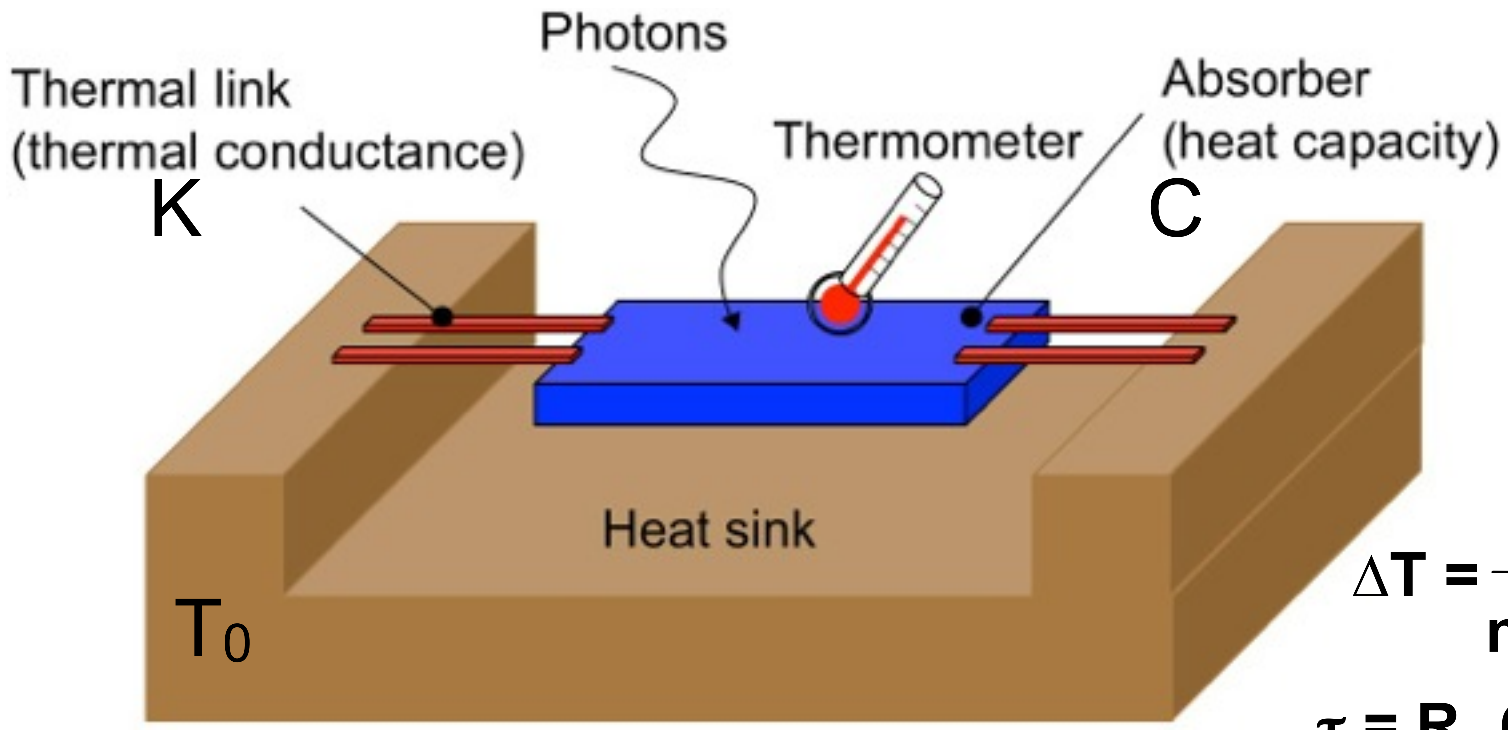
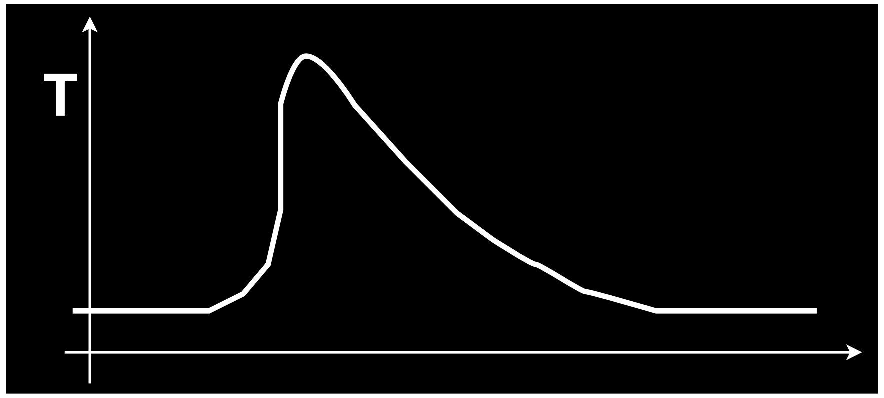
SCIENTIFIC MISSIONS



How to measure those very faint signals ?

Thermal detector: Bolometer





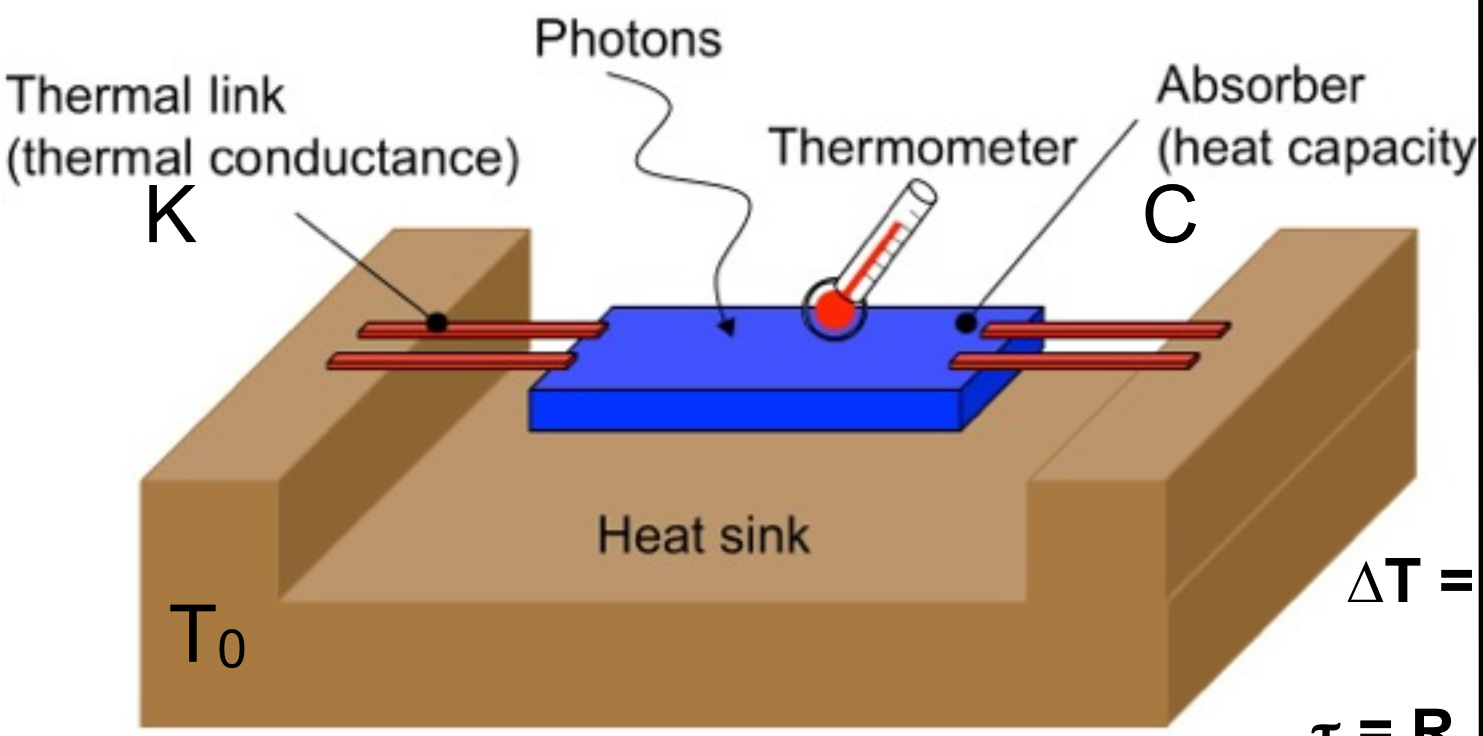
$$\Delta T = \frac{E}{mC}$$

$$\tau = R_{th}C = \frac{C}{K}$$

Measurable ΔT ? → Minimize C → Low Temperature

How to measure those very faint signals ?

Thermal detector: Bolometer

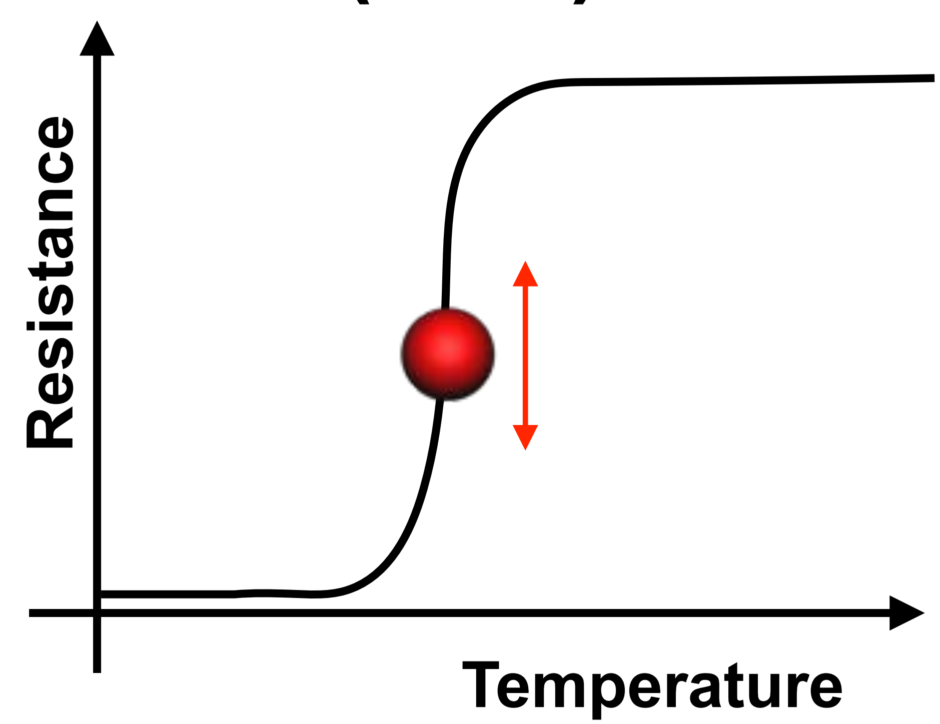


ΔT =

τ = R_{th}

Measurable ΔT ? → Minimize

Transition Edge Sensor (TES)



small change in T

↓

big change in R

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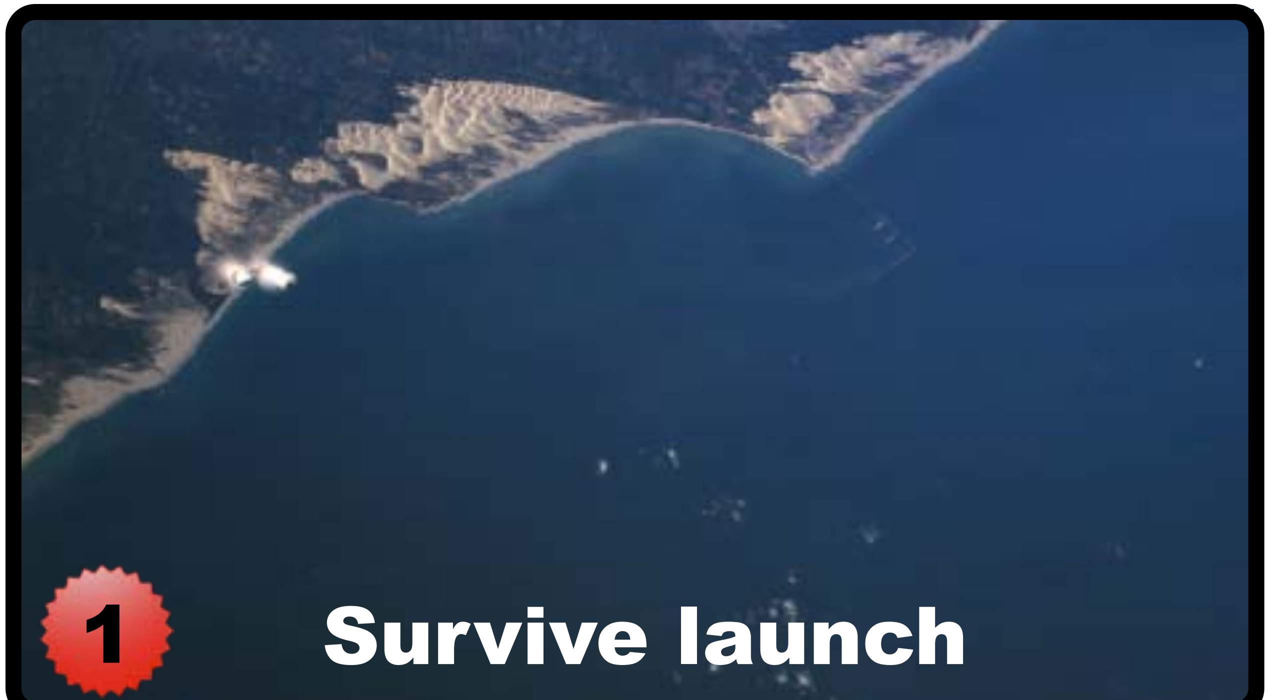
SPACE ENVIRONMENT: CONSTRAINTS



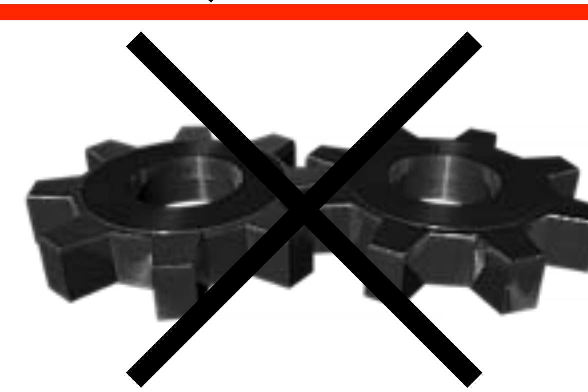
1 Survive launch

4 Reliability → 1500 000 km

5 Lifetime (> 5 ans)

2 Mass, power to be minimized

3 Operation in free fall



No moving parts or absence of any friction

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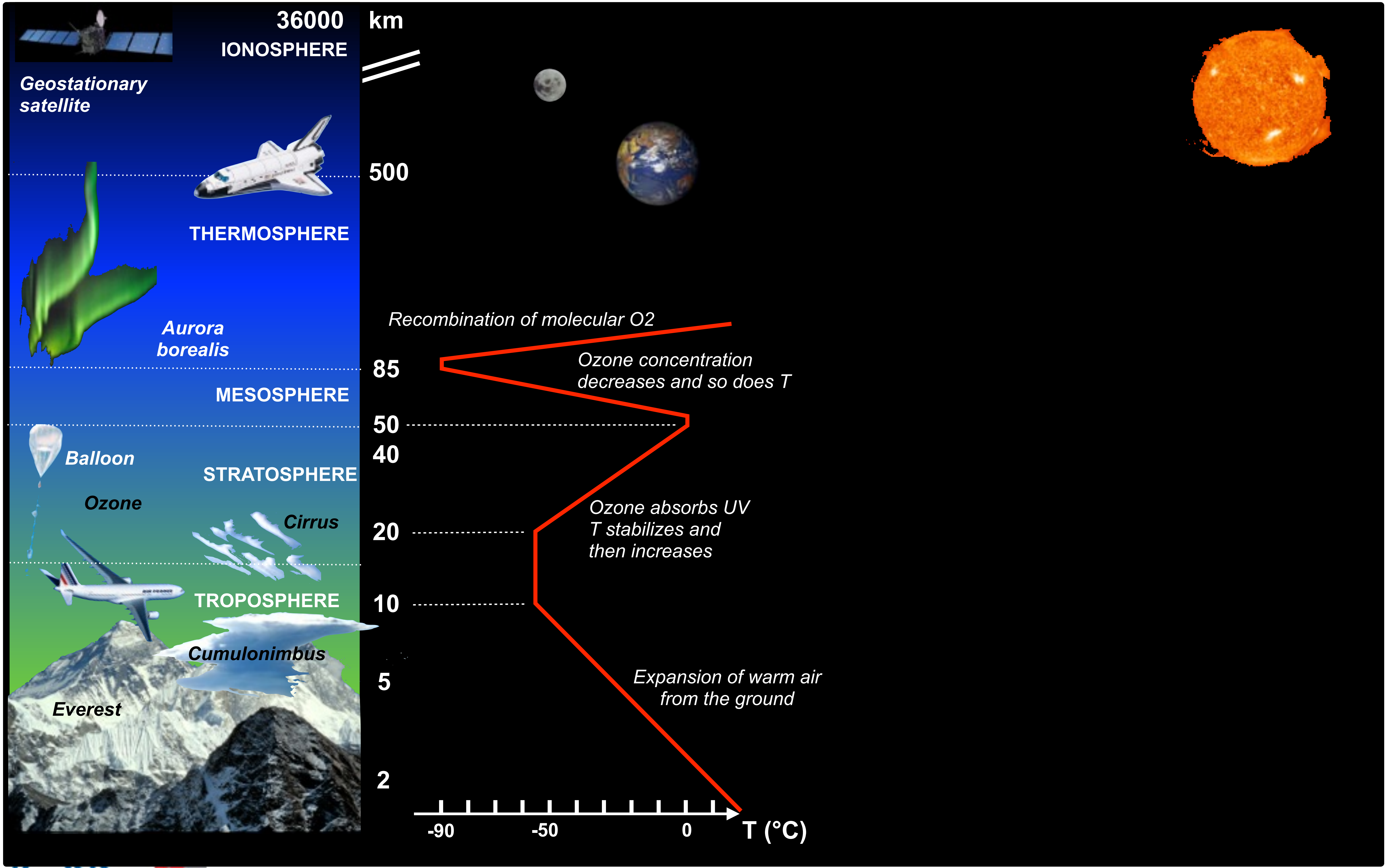
IS IT COLD OUT THERE ?



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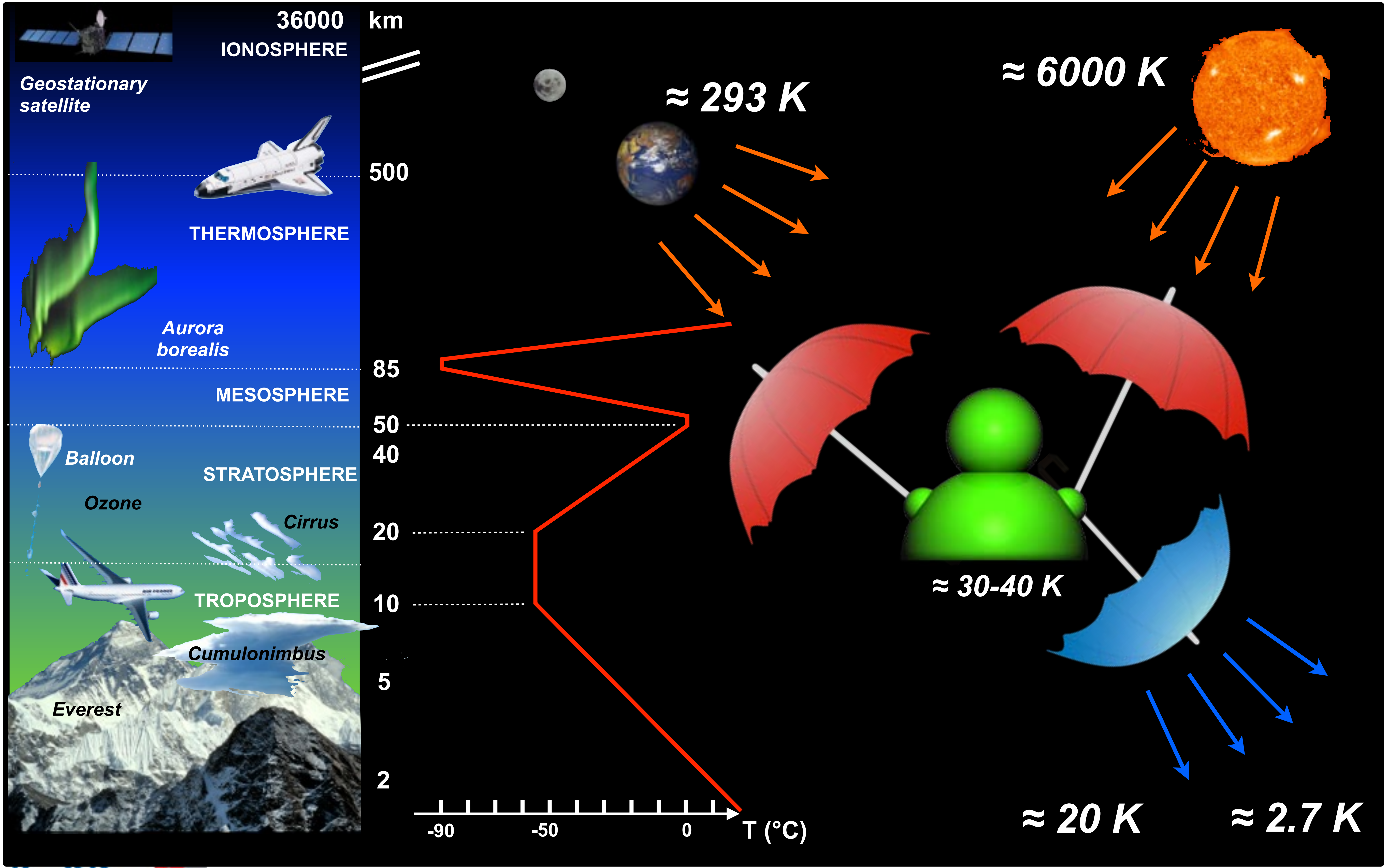

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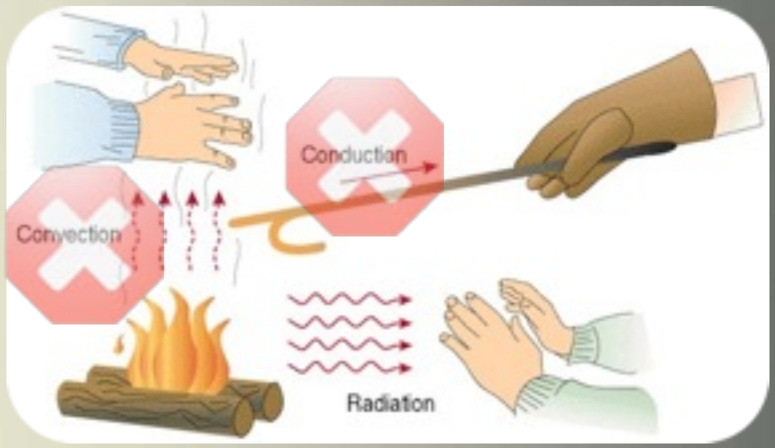
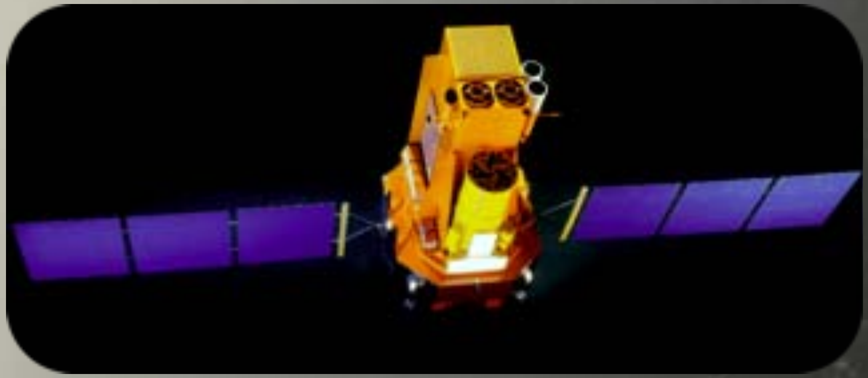
SPACE: NATURAL RESOURCES

≈ High Vacuum



Radiative heat transfert (deep space @ 2.7 K)



Solar photons

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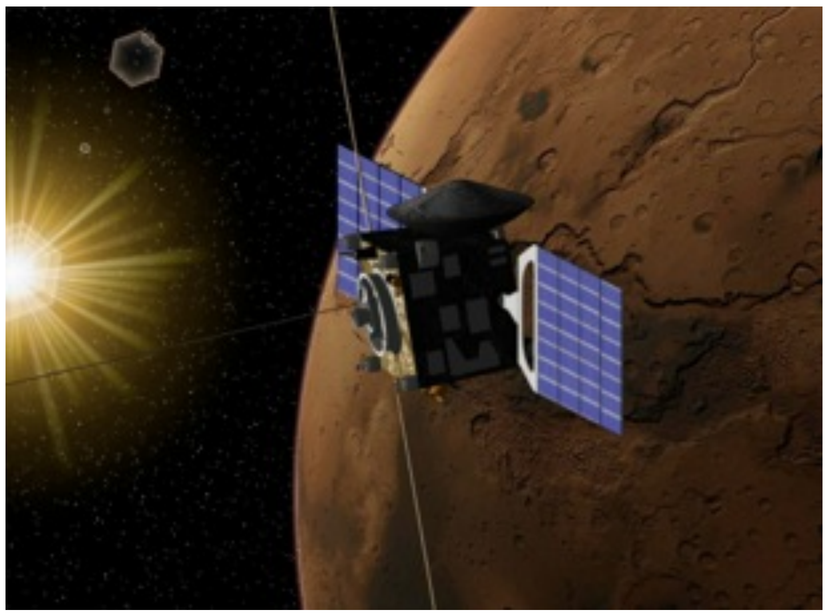
SPACE COOLING CHAINS

0.01 K | 0.1 K | 1 K | 10 K | 100 K | 300 K



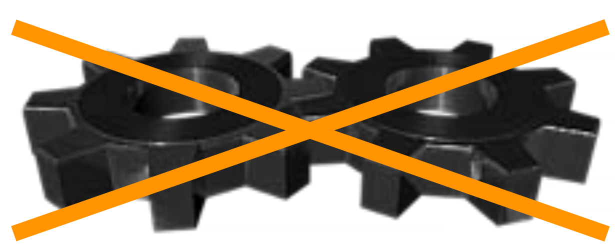
Passive Radiators

Stored cryogen (Cryostat)

Active "mechanical" coolers

"Ultra" low T coolers
(3 technologies: sorption, magnetic, dilution)

Reliability



No moving parts or absence of friction

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SPACE CRYOGENICS - CURRENT GENERAL TENDENCY

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I CANNOT BE EXHAUSTIVE - SORRY

FCT activespace technologies
UCL MSSL
EADS astrium
Honeywell
Science & Technology Facilities Council Rutherford Appleton Laboratory
University of Twente The Netherlands
THALES Cryogenics
AIR LIQUIDE
cea
NÉEL Institut
AIM

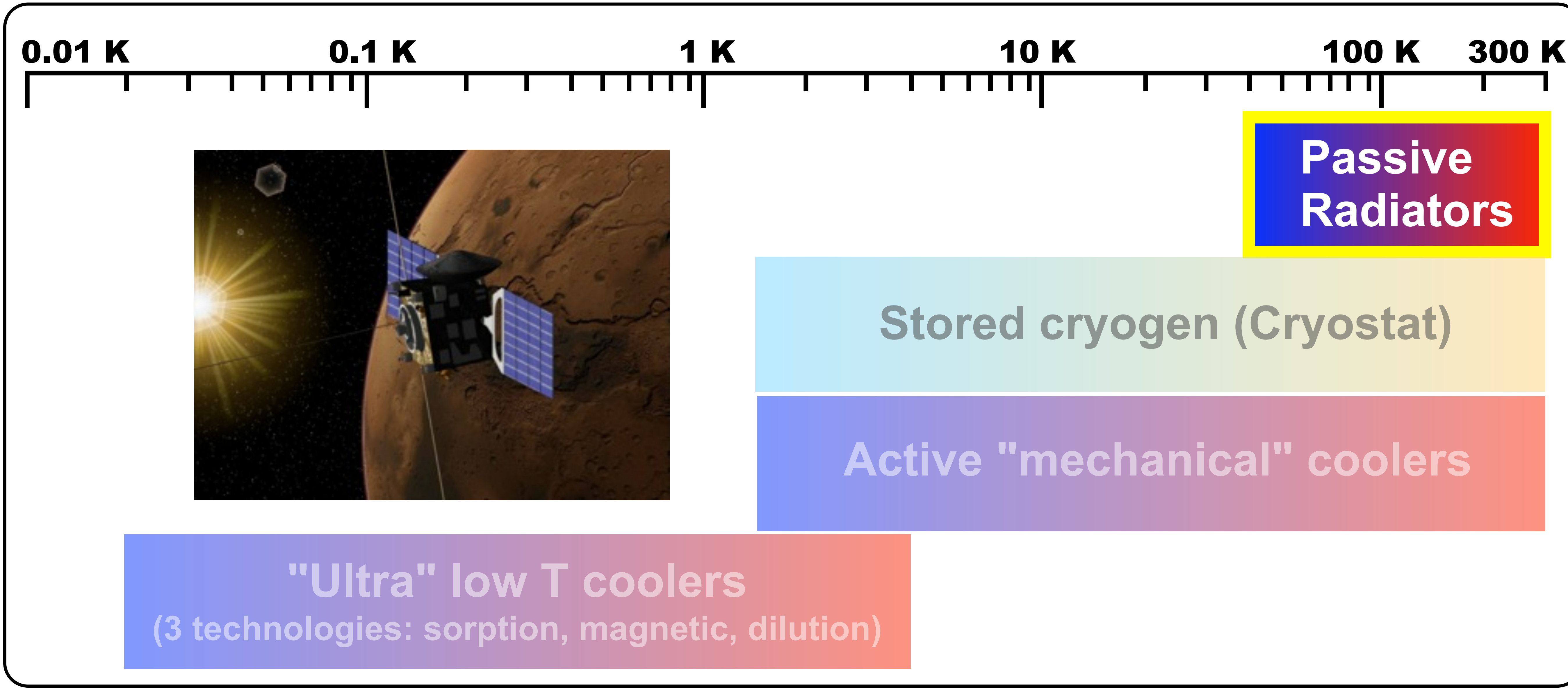
SUNPOWER
NASA
JPL
Creare
LOCKHEED MARTIN
Ball
Raytheon
NORTHROP GRUMMAN

中国航天
IPC
SITP
Sumitomo Heavy Industries, Ltd.
JAXA

RICOR

SPACE CRYOGENICS

SPACE COOLING CHAINS



- Efficient
- Simple
- Reliable
- Vibration free

- Limited performance @ low T
- Orbit / orientation dependent

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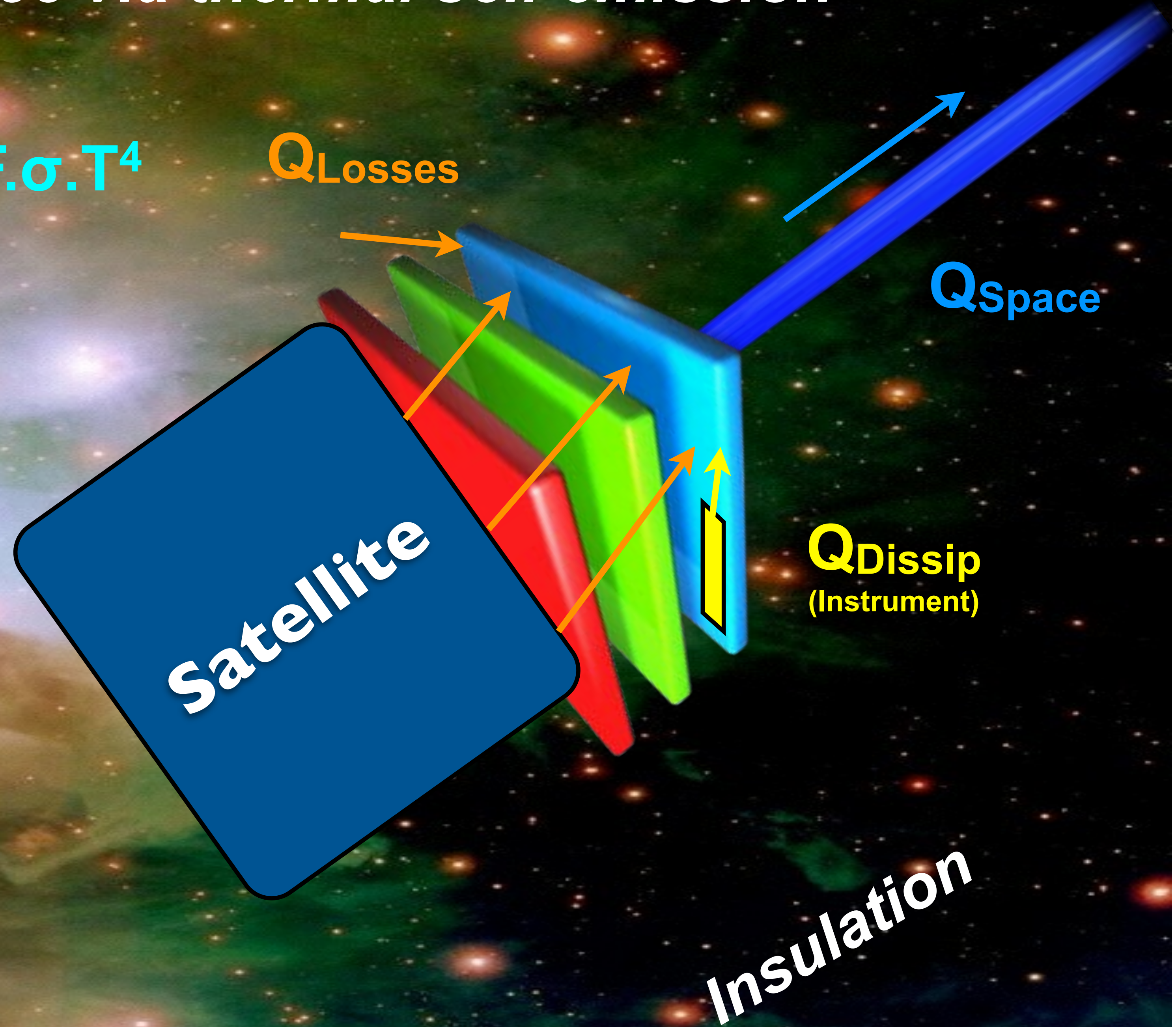
RADIATIVE COOLING

Direct coupling to deep space via thermal self emission

$$Q_{Space} = Q_{Dissip} + Q_{Losses}$$

$$Q_{Space} = \varepsilon.A.F.\sigma.(T^4 - T_s^4) \approx \varepsilon.A.F.\sigma.T^4$$

$\sigma = 5.67\ 10^{-8}\ W.m^{-2}.K^{-4}$
$F \approx 1$ (form factor)
$\varepsilon \approx 0.9$ to 1 (black paint, open honey comb)



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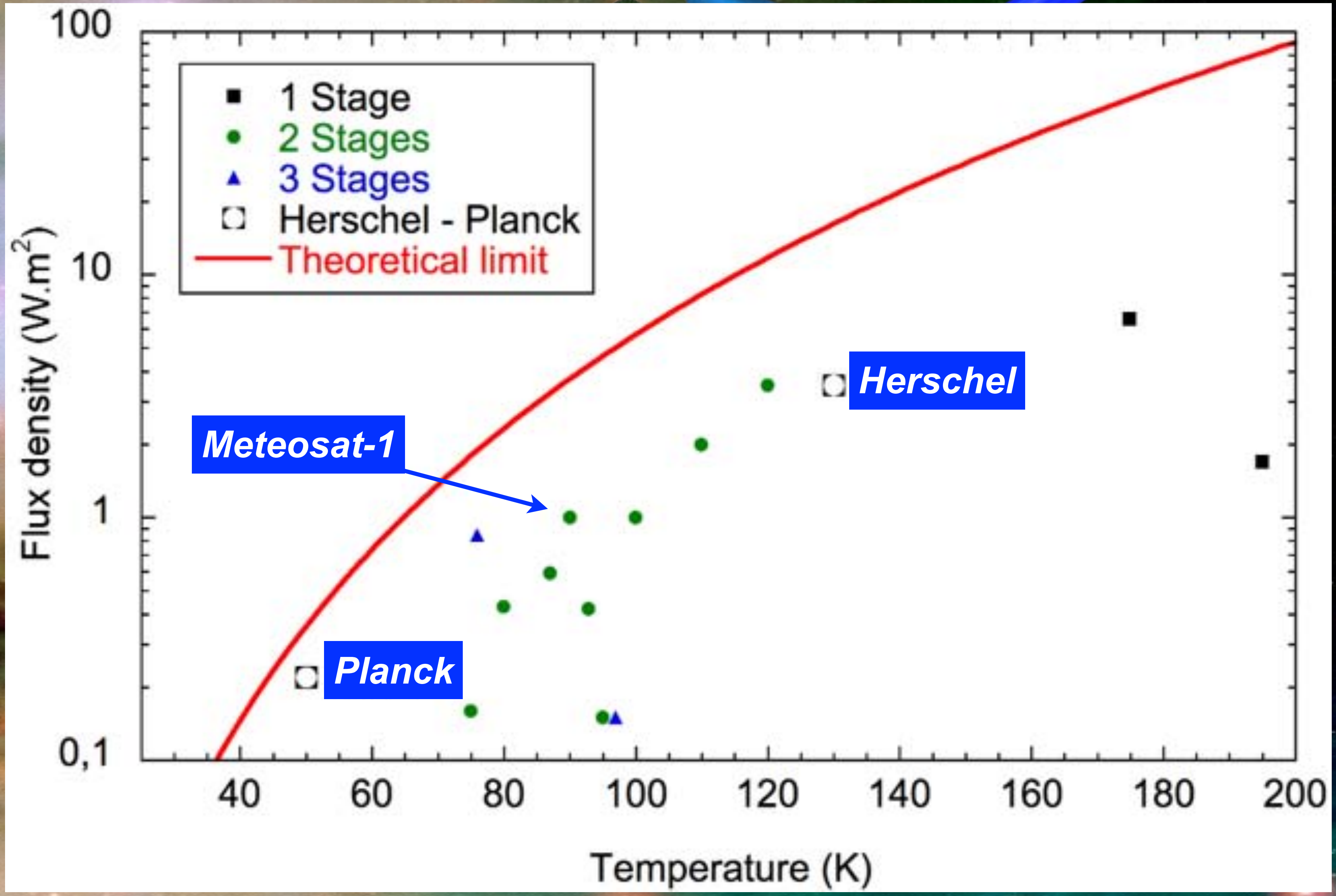
$Q_{Space} = \varepsilon.A.F.\sigma.(T^4 - T_s^4) \approx \varepsilon.A.F.\sigma.T^4$

Q_{Losses}

σ = 5.67 10^{-8} $W.m^{-2}.K^{-4}$
F ≈ 1 (form factor)
ε ≈ 0.9 to 1 (black paint, open honey comb)



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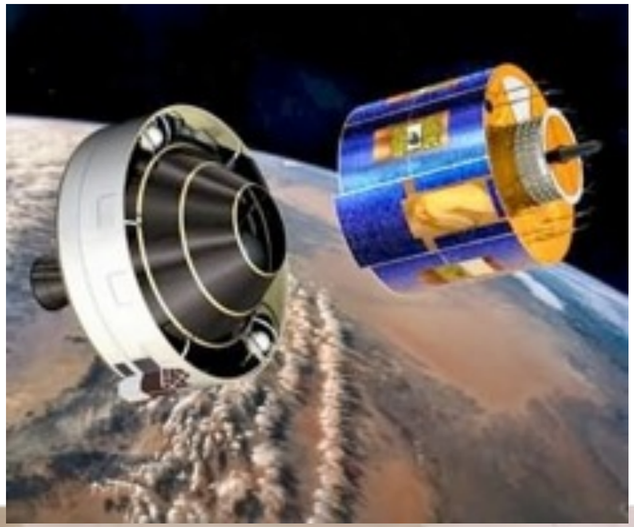
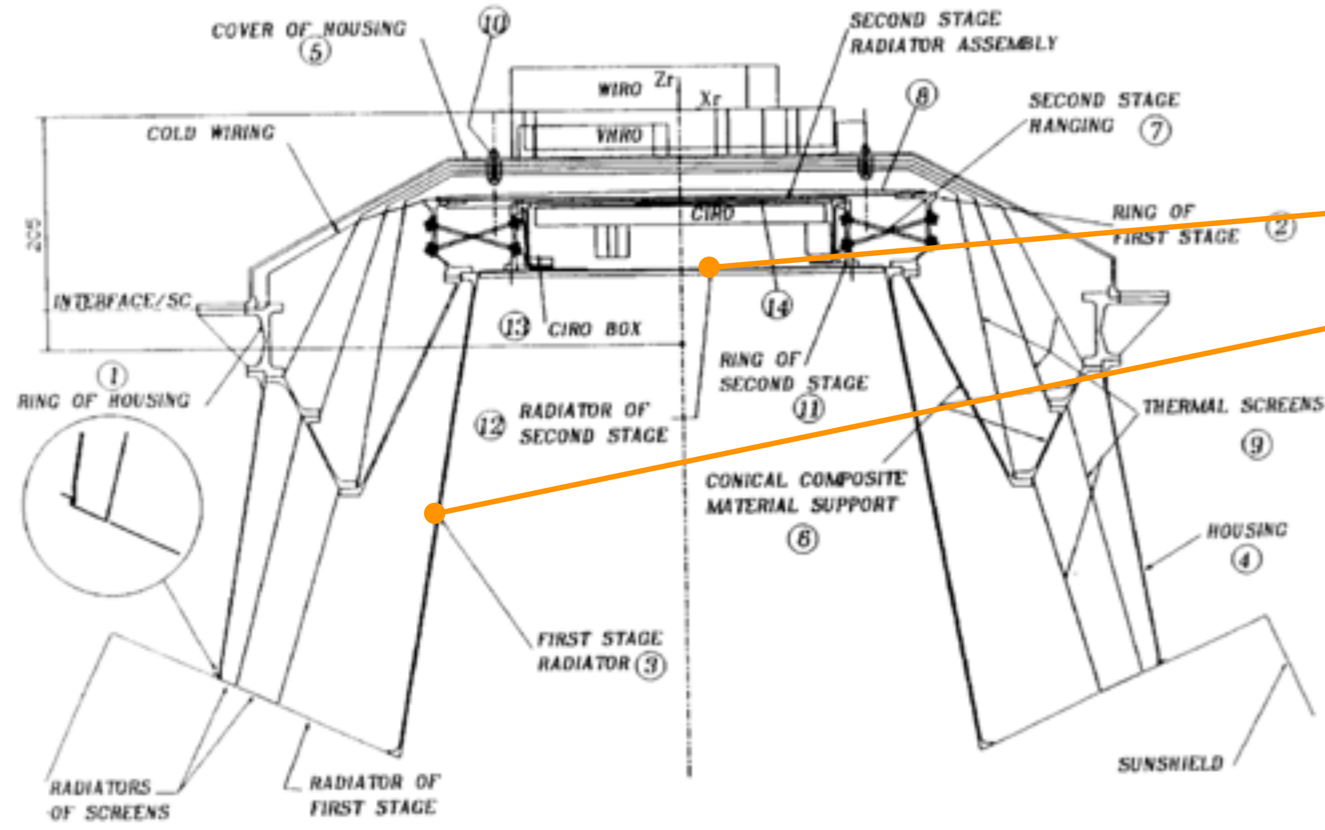
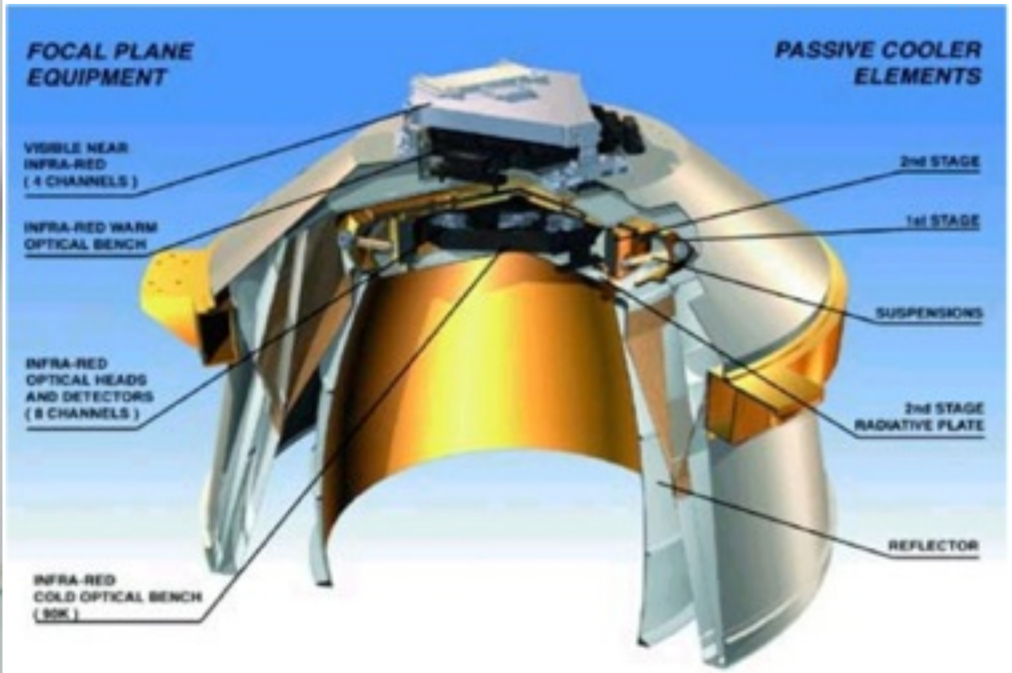
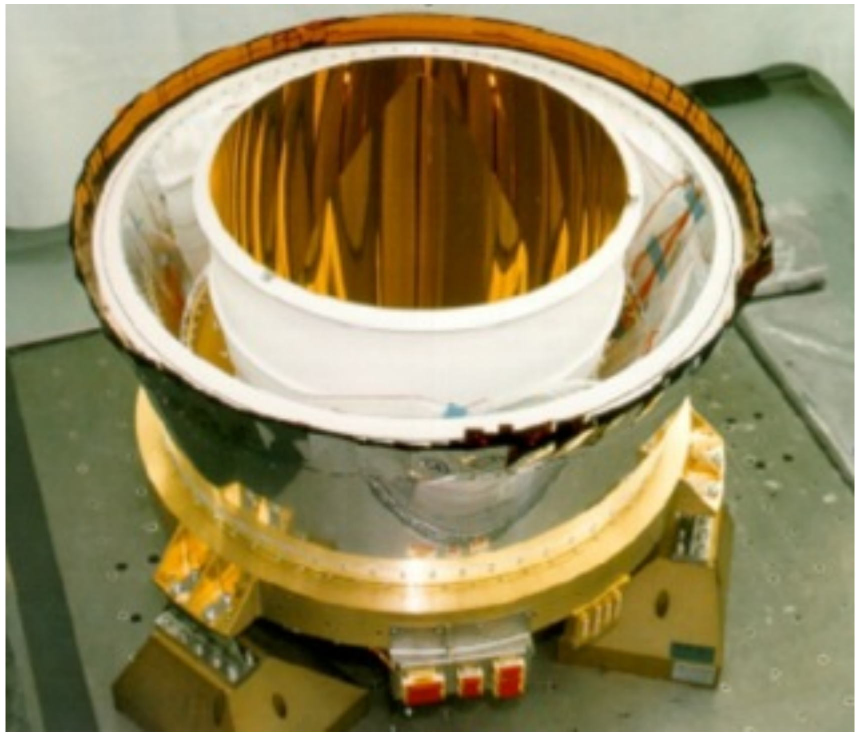
EXAMPLE METEOSAT 2 GENERATION





Two stages
85 K - 95 K
≈ 120 K





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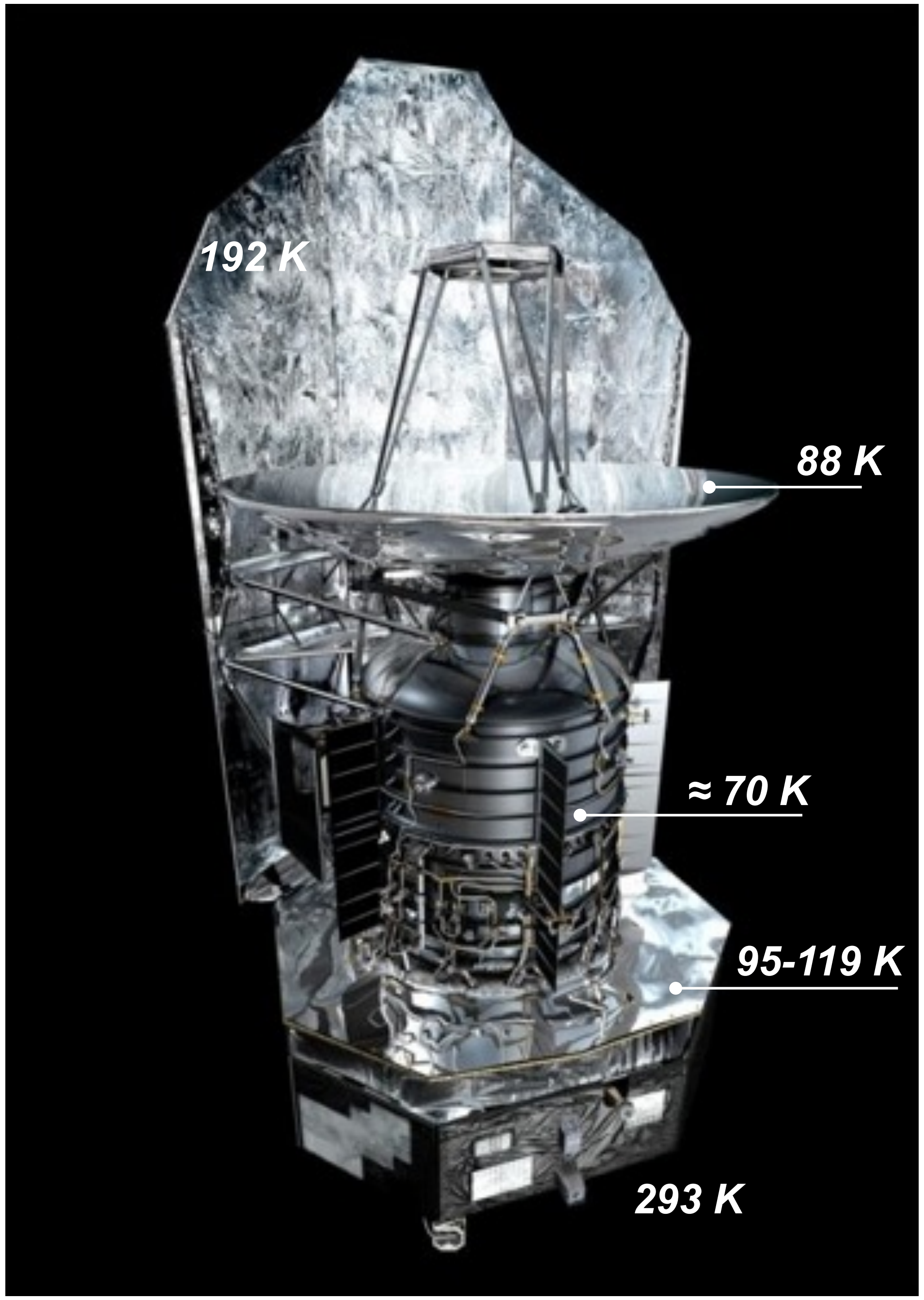
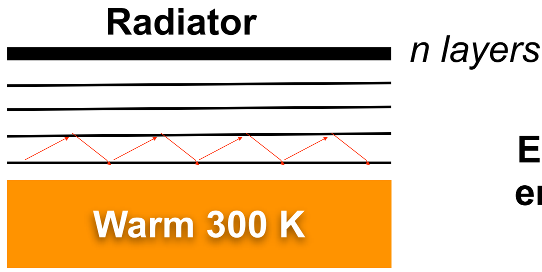
MLI / V-GROOVES - HERSCHEL / PLANCK

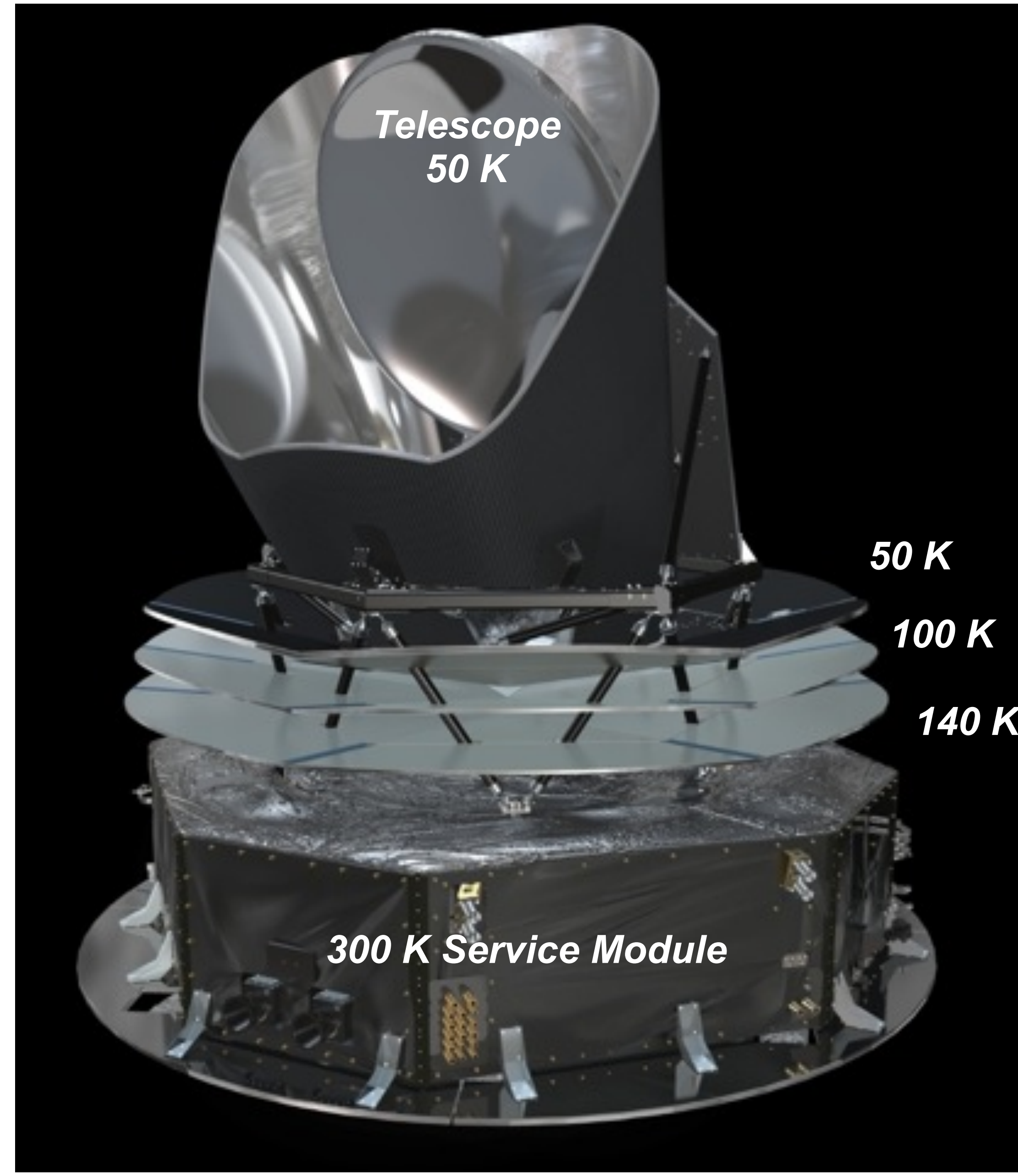


“Classical”

MLI: radiation trapped between layers

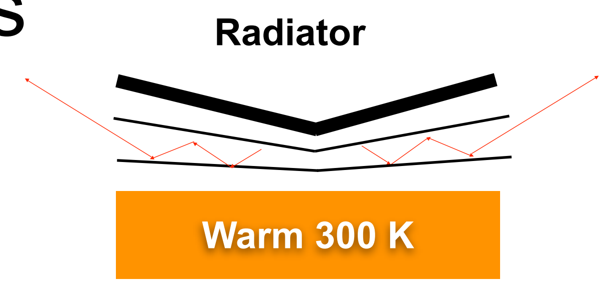


Equivalent emissivity: ε/n



“V-Grooves”

Radiation rejected to space



Equivalent emissivity: ε^n

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SPACE COOLING CHAINS

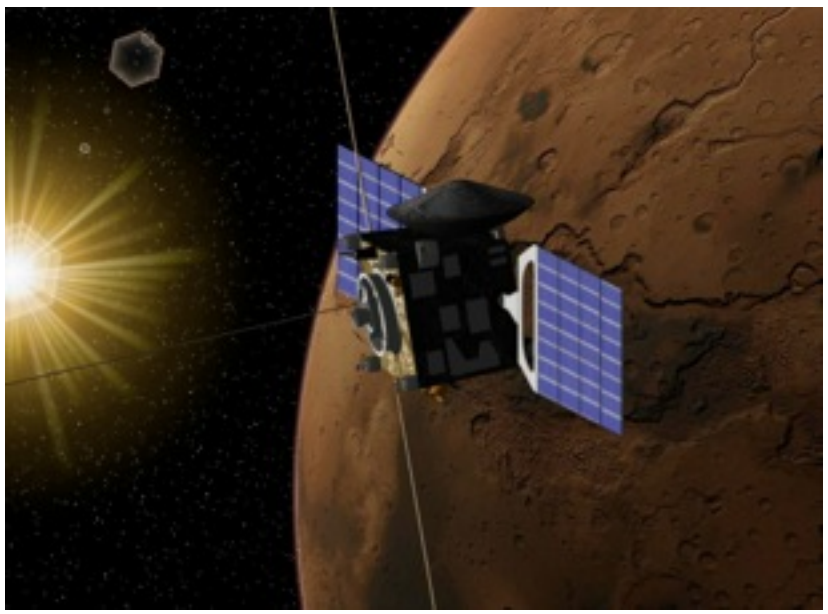
0.01 K | 0.1 K | 1 K | 10 K | 100 K | 300 K

Passive Radiators

Stored cryogen (Cryostat)

Active "mechanical" coolers

"Ultra" low T coolers
(3 technologies: sorption, magnetic, dilution)



- Efficient
- Simple
- Reliable
- Cold vapor

- Limited mission duration
- only selected T available
- Volume & Mass
- On ground management

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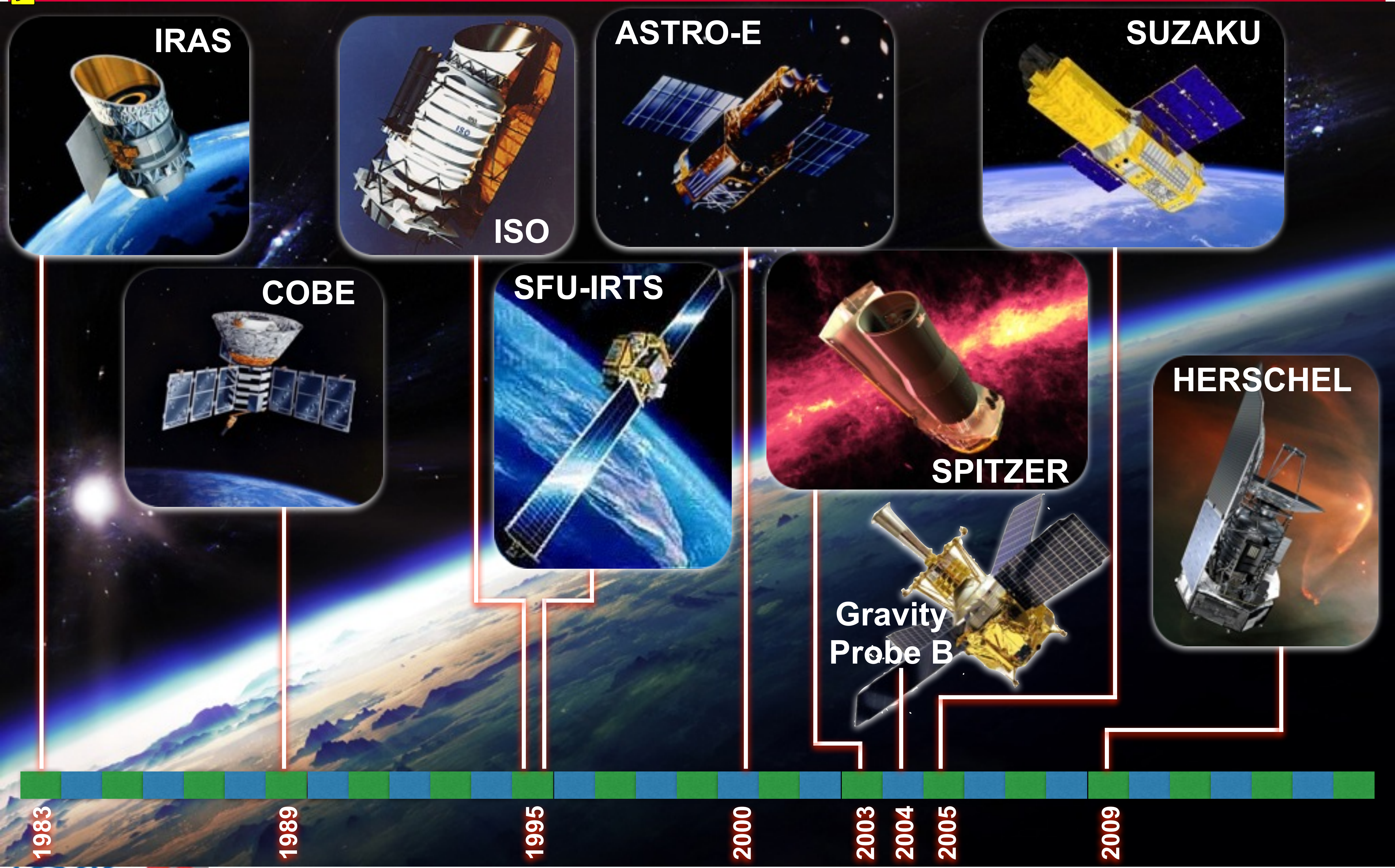
LOW TEMPERATURE MISSIONS WITH STORED CRYOGENS (4K OR LESS)



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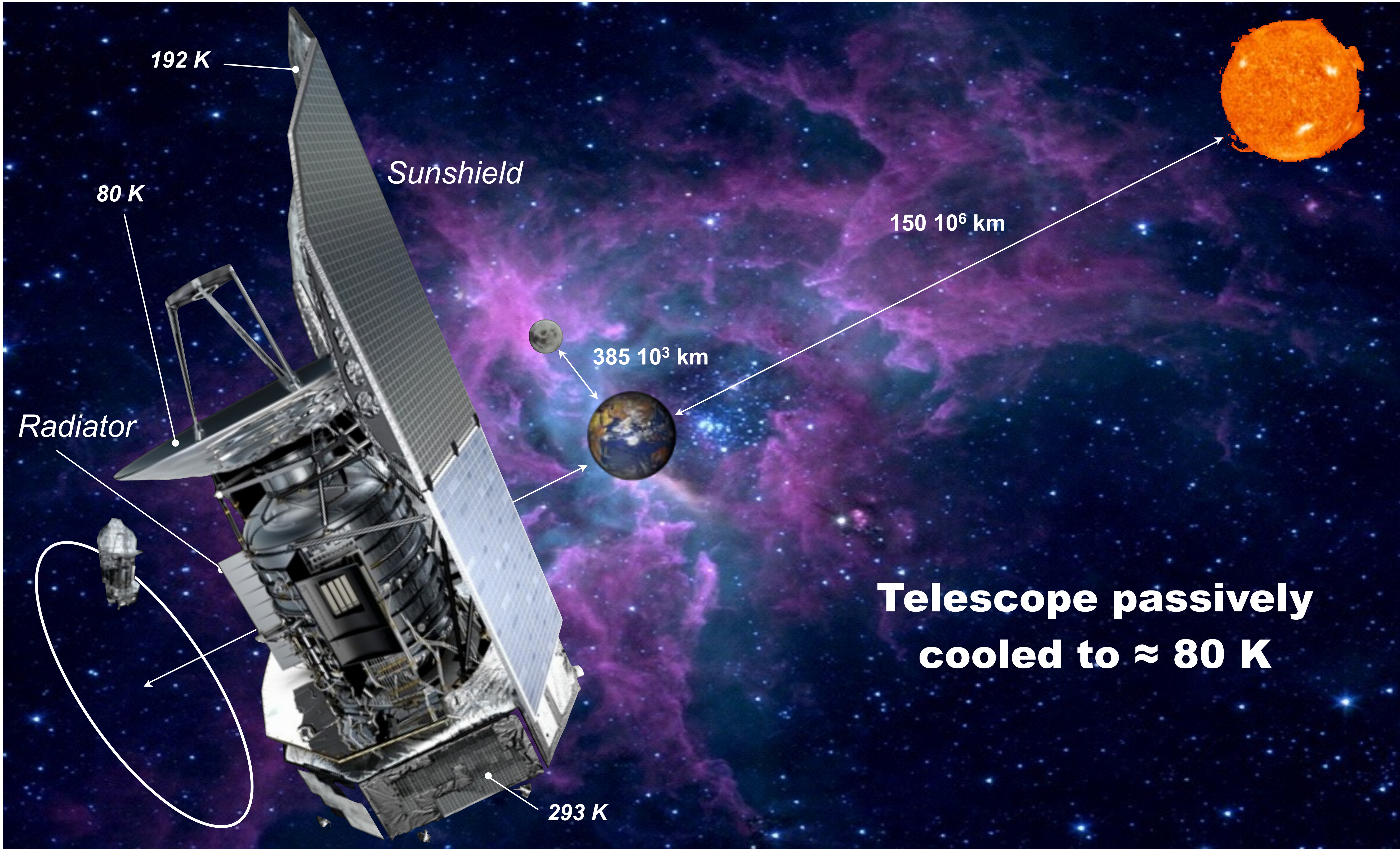
HERSCHEL CRYOGENIC CHAIN - 1



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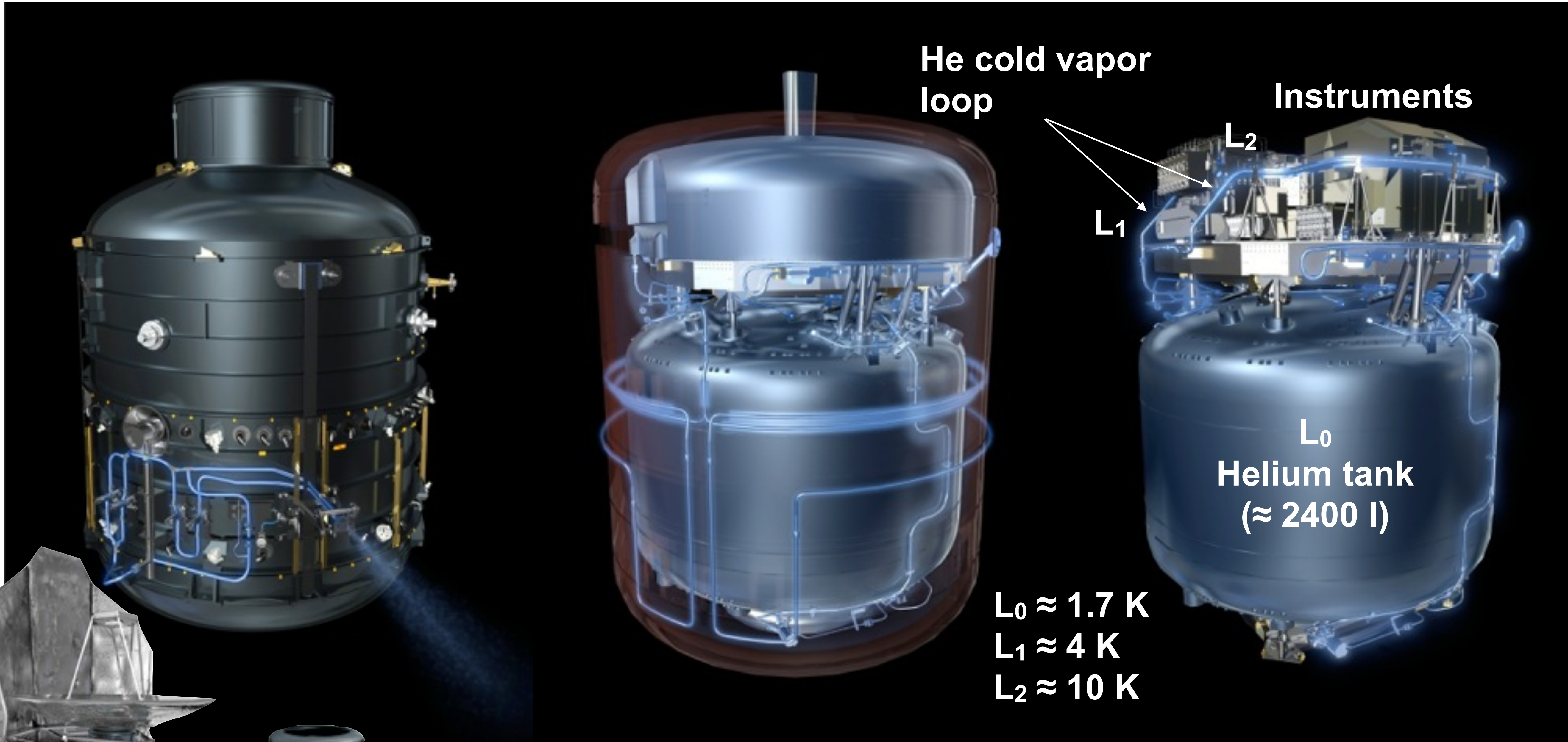
HERSCHEL CRYOGENIC CHAIN - 2



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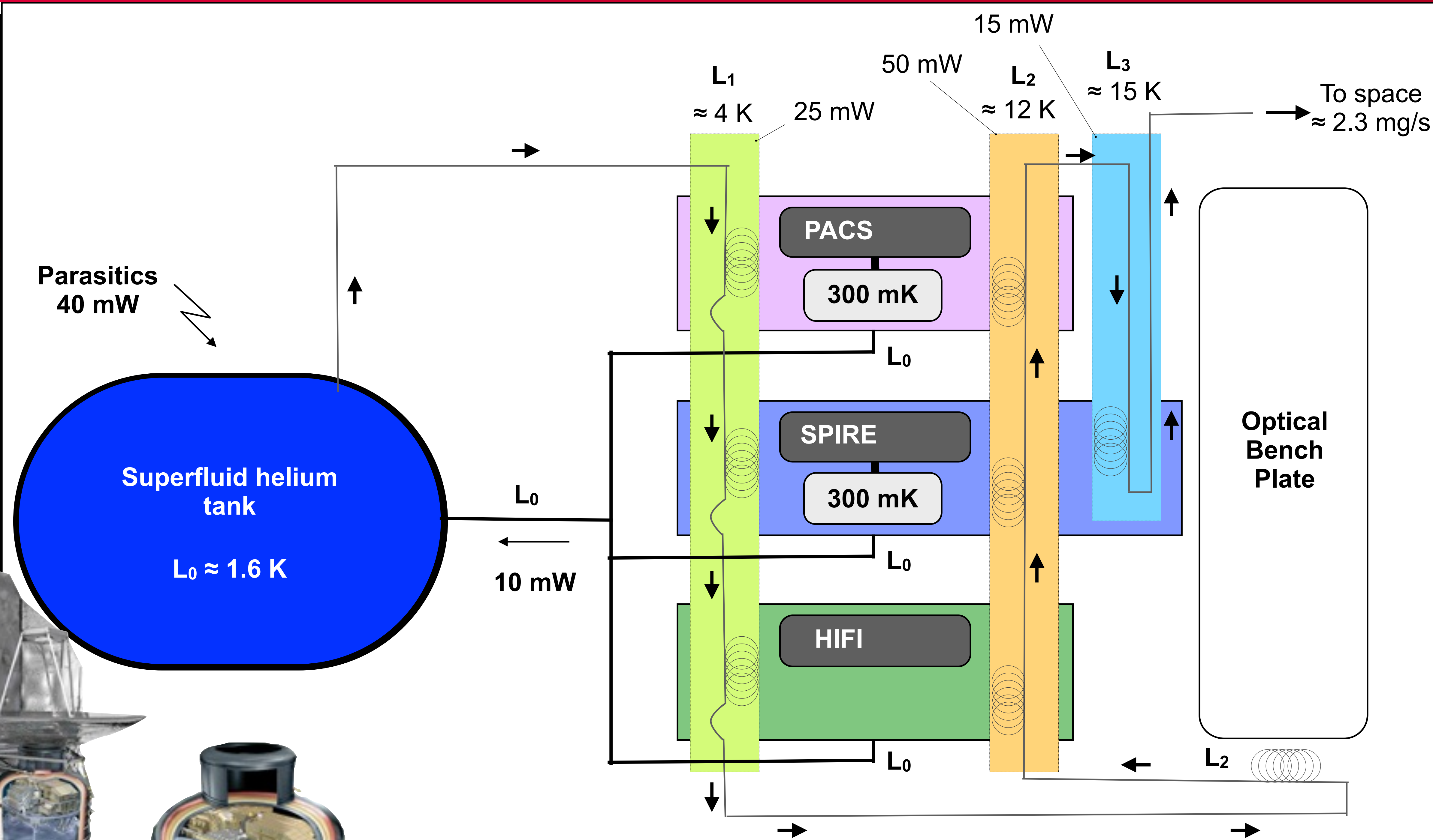
HERSCHEL CRYOGENIC CHAIN - 2



SPACE COOLING CHAINS

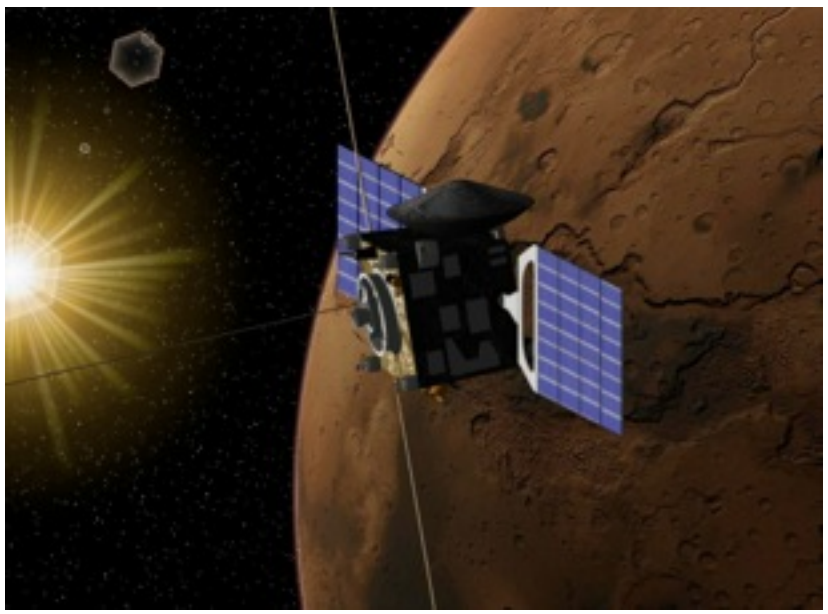
0.01 K | 0.1 K | 1 K | 10 K | 100 K | 300 K

Passive Radiators

Stored cryogen (Cryostat)

Active "mechanical" coolers

"Ultra" low T coolers
(3 technologies: sorption, magnetic, dilution)



- Lifetime
- Warm launch
- Ground tests

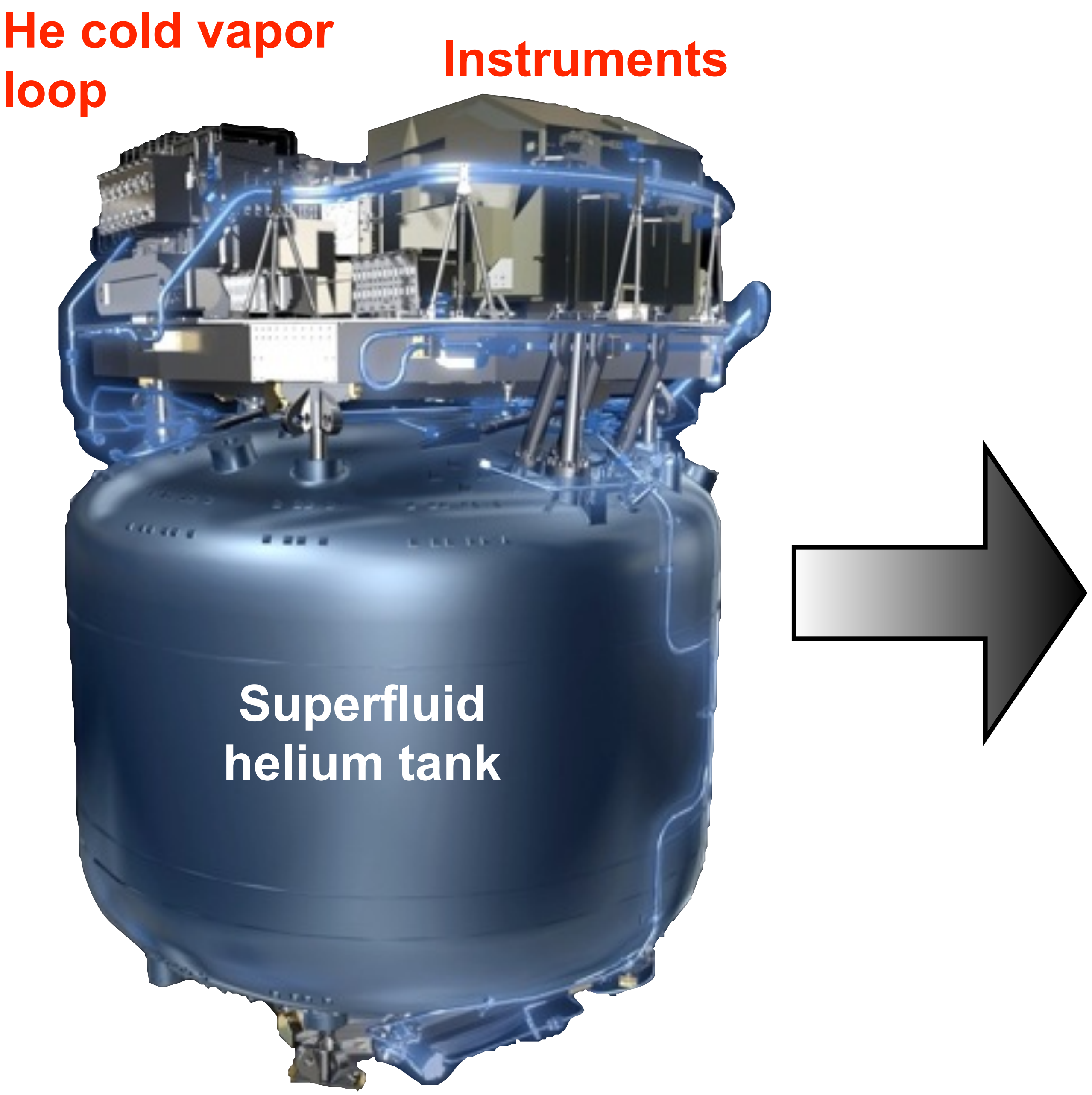
- Peak power
- Thermal interfaces
- Vibration

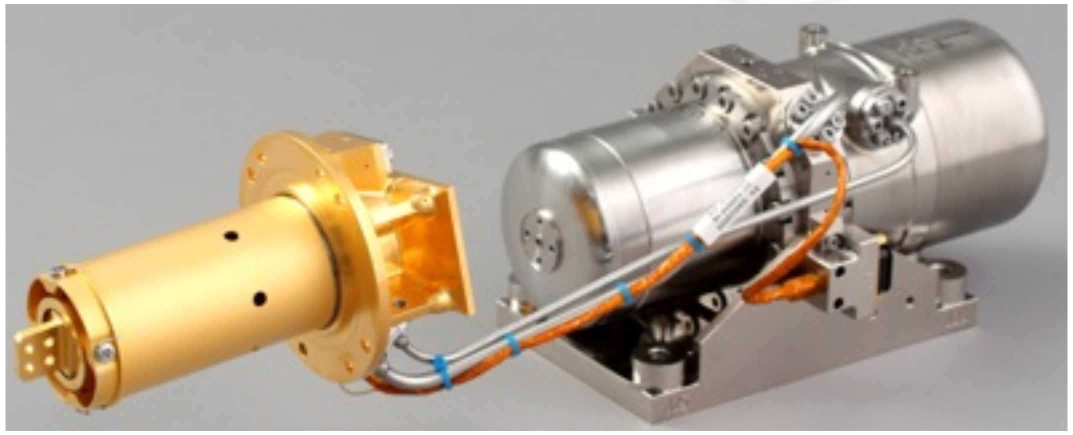
SPACE CRYOGENICS: CURRENT TENDENCY

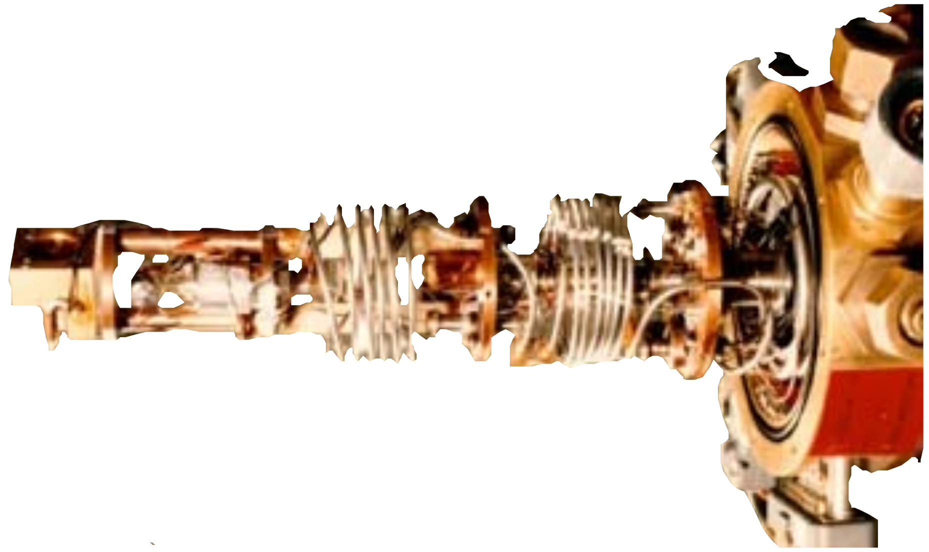
- Thermal interface
- Peak Power
- Distribution (vapor)
- Vibration free
- Passive (once in space)

- Limited lifetime
- Volume
- Mass
- On ground management
  - Vacuum shell needed

SPACE CRYOGENICS: CURRENT TENDENCY

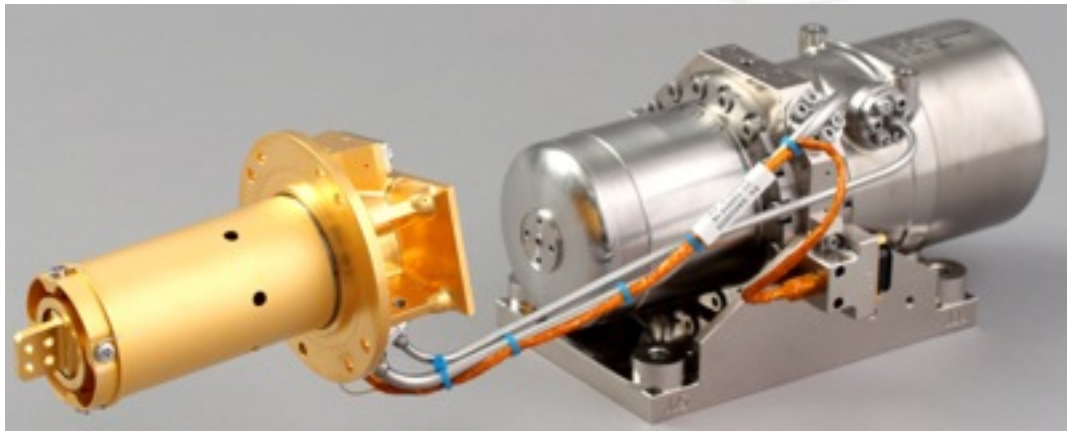




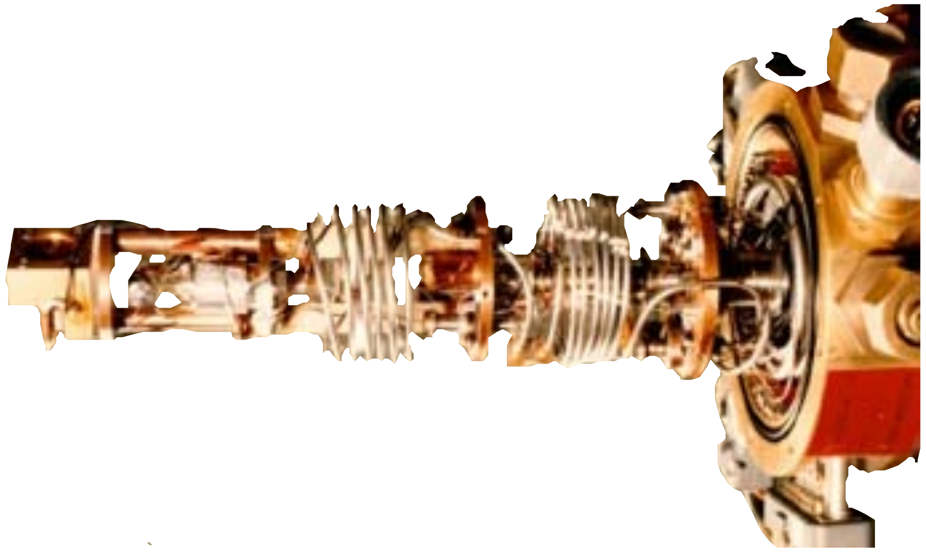


SPACE CRYOGENICS: CURRENT TENDENCY

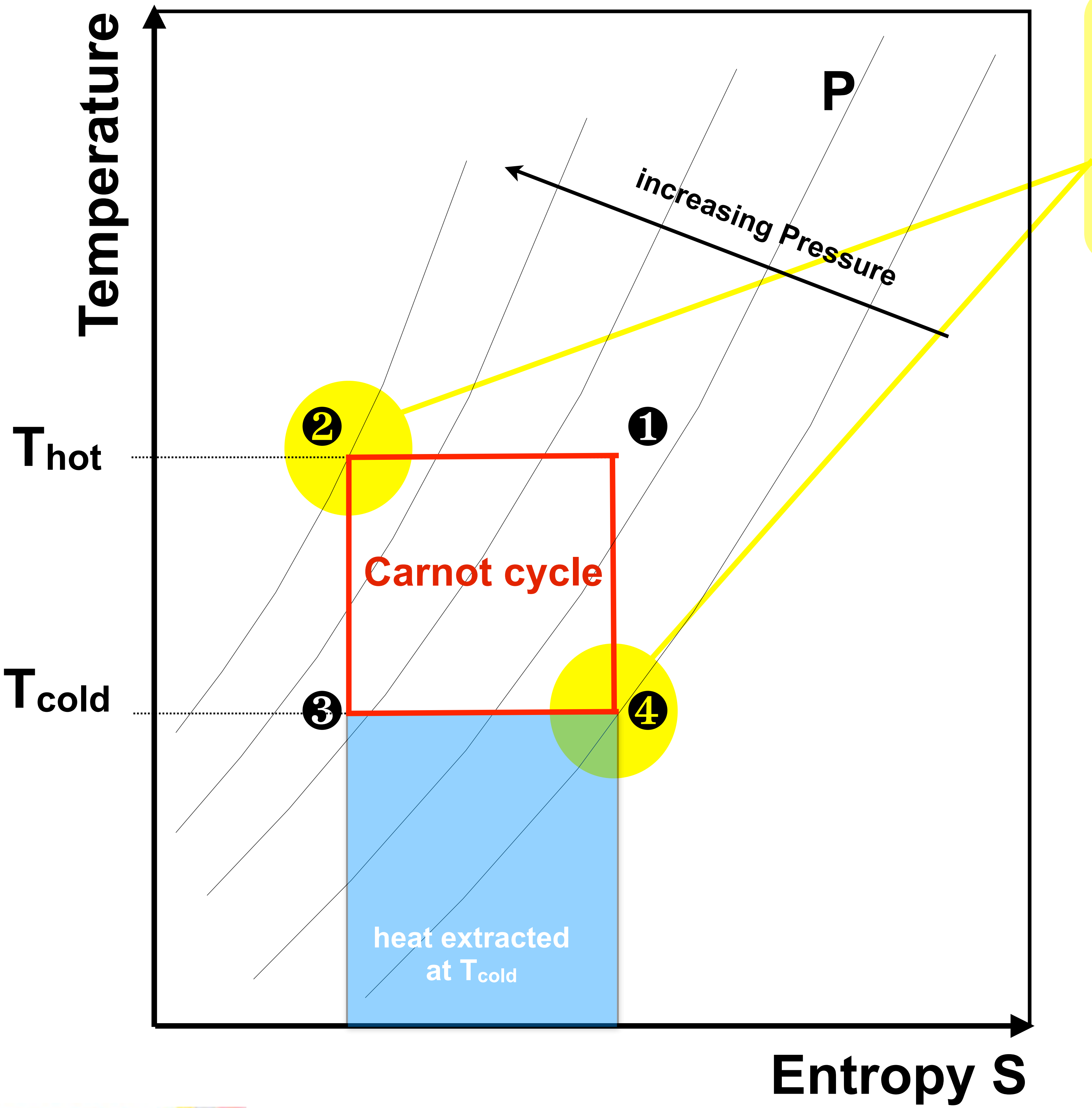
- Lifetime
- Volume
- Ground tests
- Warm launch



- Heat distribution
- Interface
- Vibration
- Thermal peak power



ONLY THE BEST: MYTHICAL CARNOT CYCLE



Example
300 K - 60 K cooler

Carnot cycle
pressure ratio ❷/❹ ≈ 120 !!

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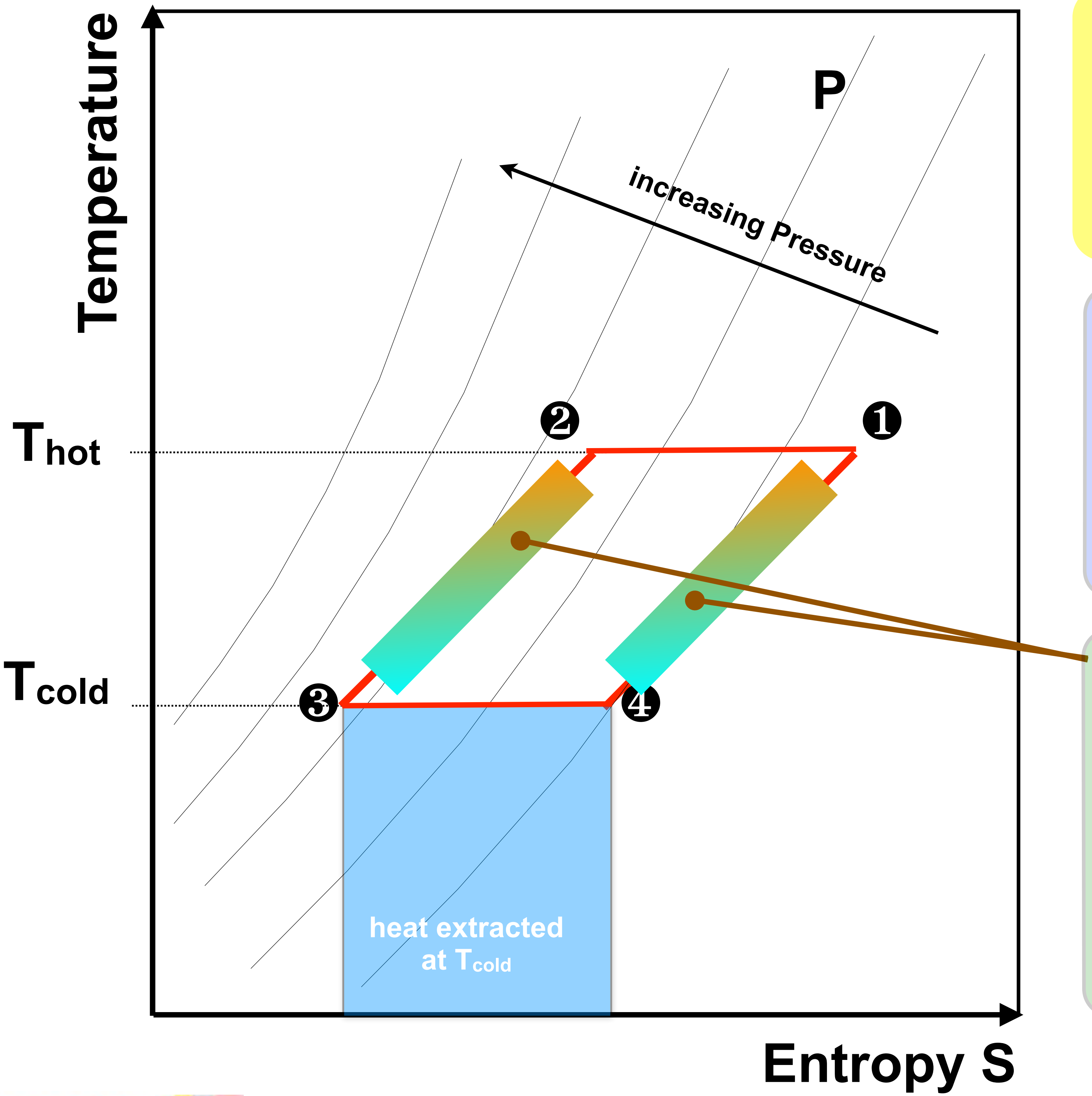
ONLY THE BEST: MYTHICAL CARNOT CYCLE



Example
300 K - 60 K cooler

Carnot cycle
pressure ratio ❷/❹ ≈ 120 !!

Isentropic evolution

Isochoric (Stirling)

Isobaric (Ericsson, GM)

In theory, COP ≈ Carnot

heat transfer at variable T

Regenerator (thermal sponge) or counter flow heat exchanger

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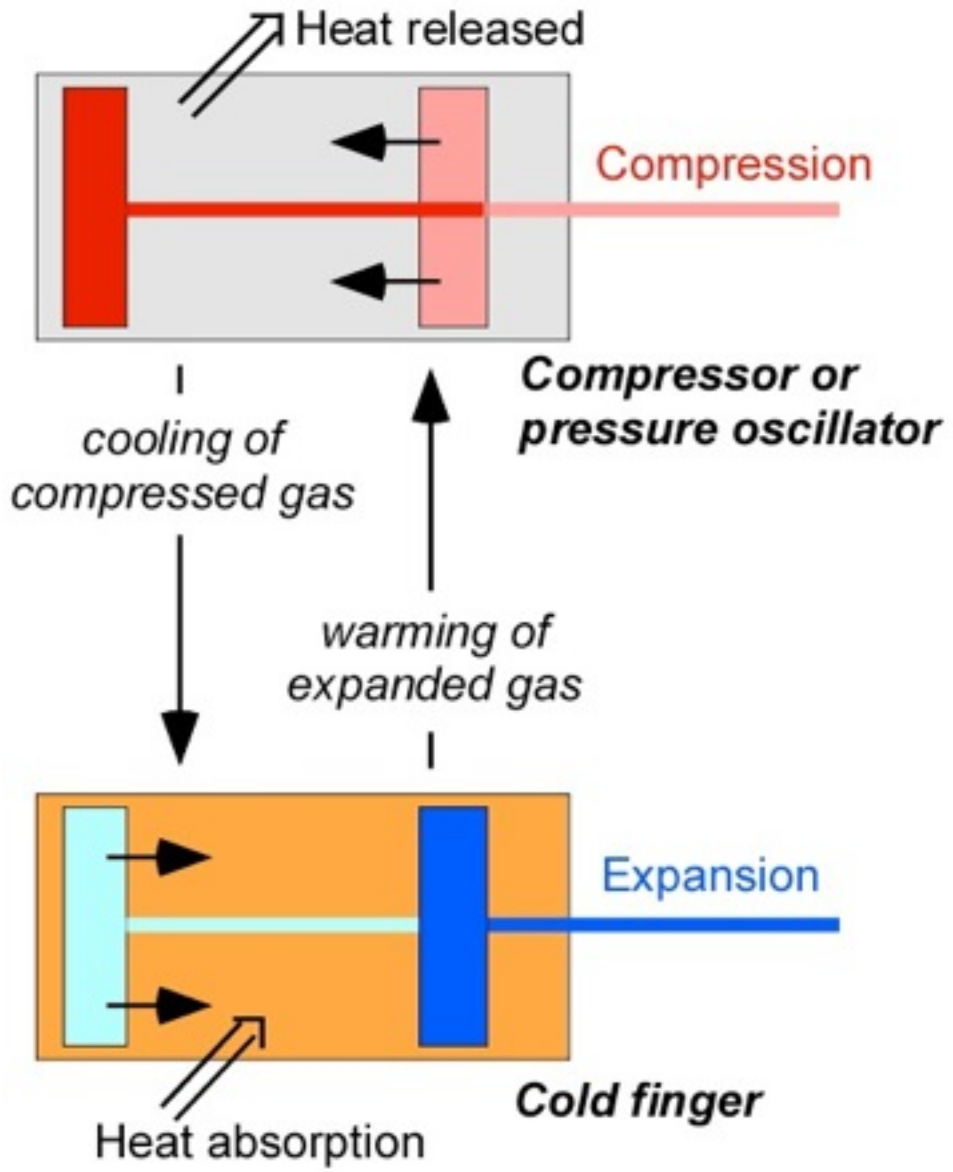
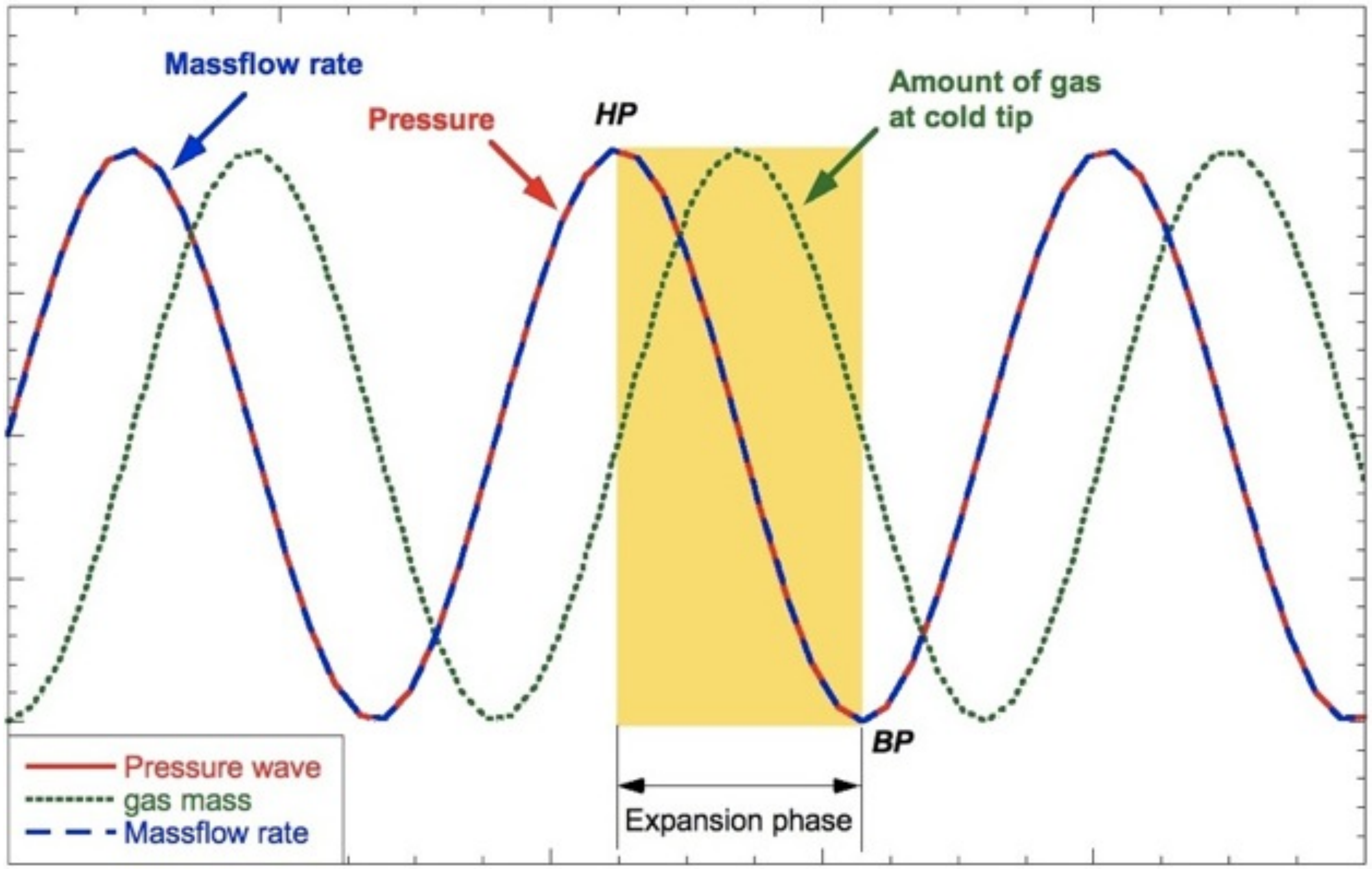
(MOST) MECHANICAL CRYOCOOLERS





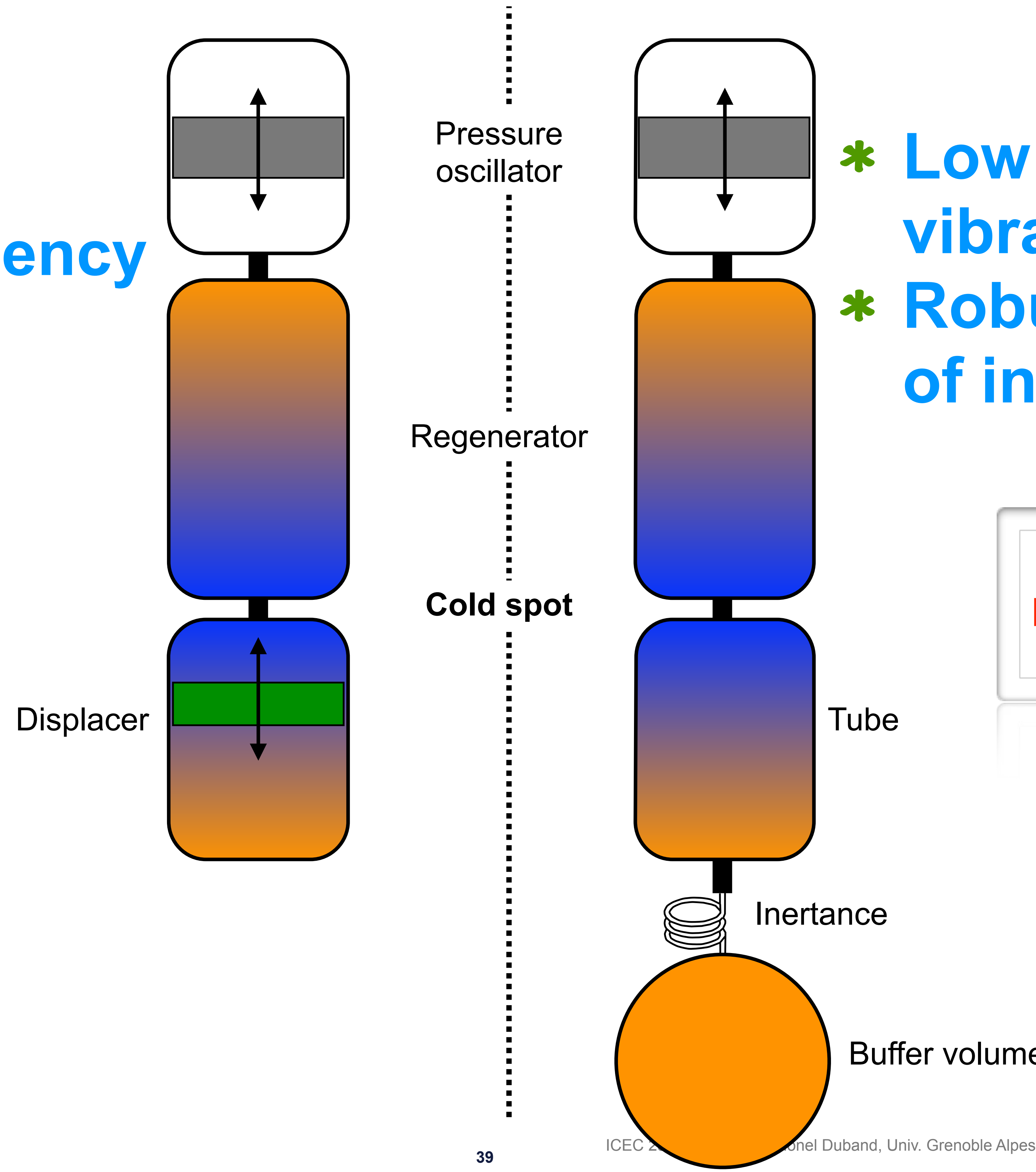
Expansion of maximum amount of gas at the right place and right time

Mass flow rate & pressure oscillation in phase

STIRLING VERSUS PULSE TUBE

* High efficiency

Phase shift mechanically controlled



* Low induced vibration
* Robust / Ease of integration

Phase shift pneumatically controlled

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STIRLING VERSUS PULSE TUBE

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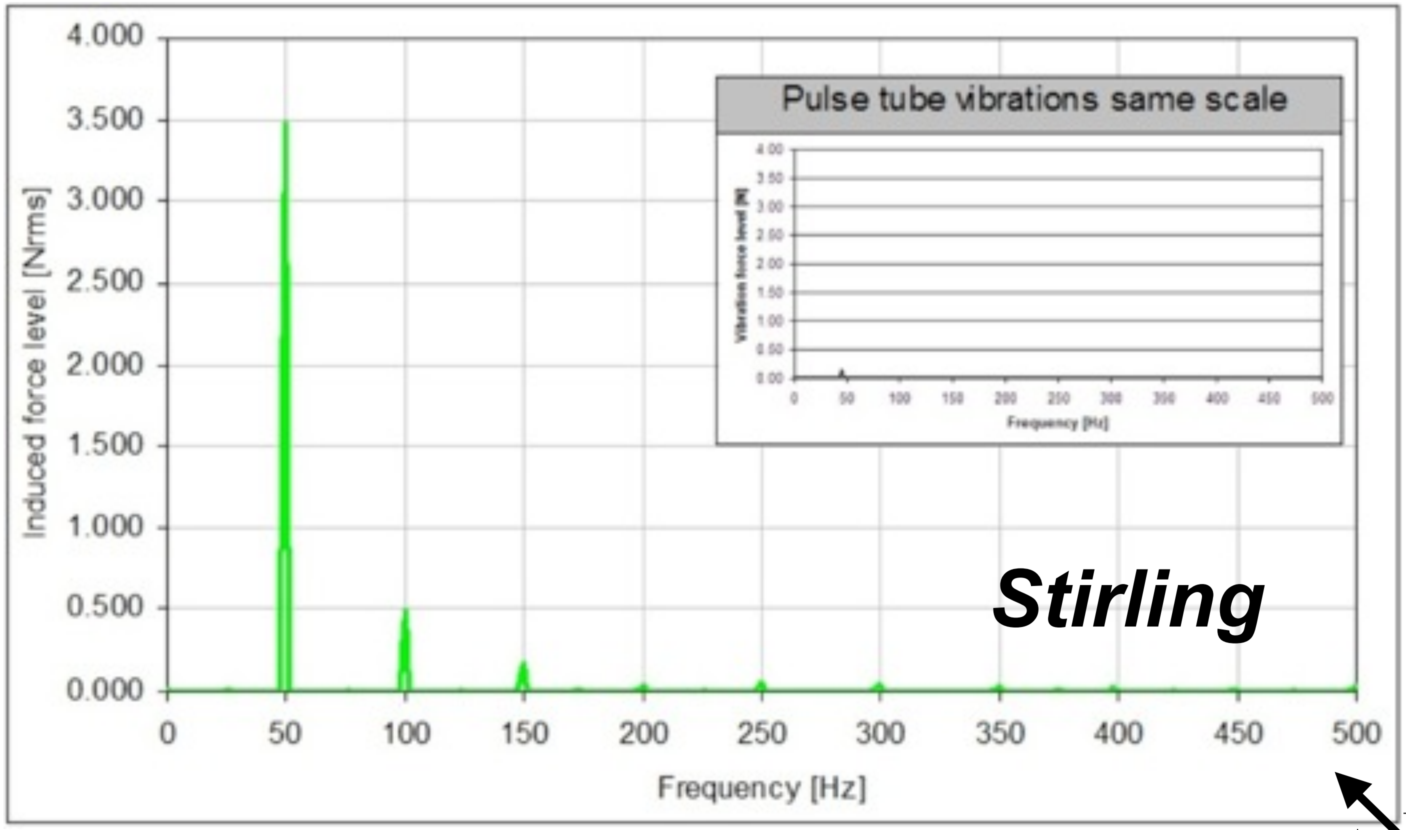
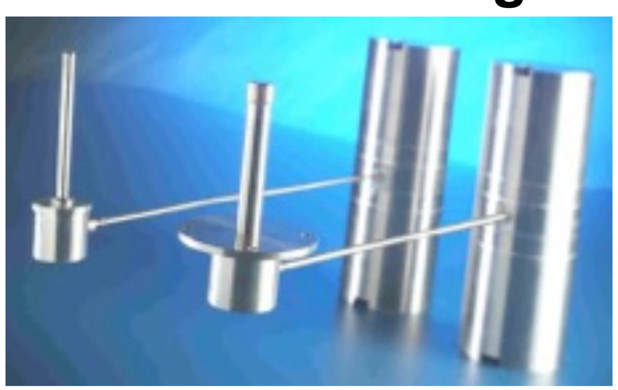
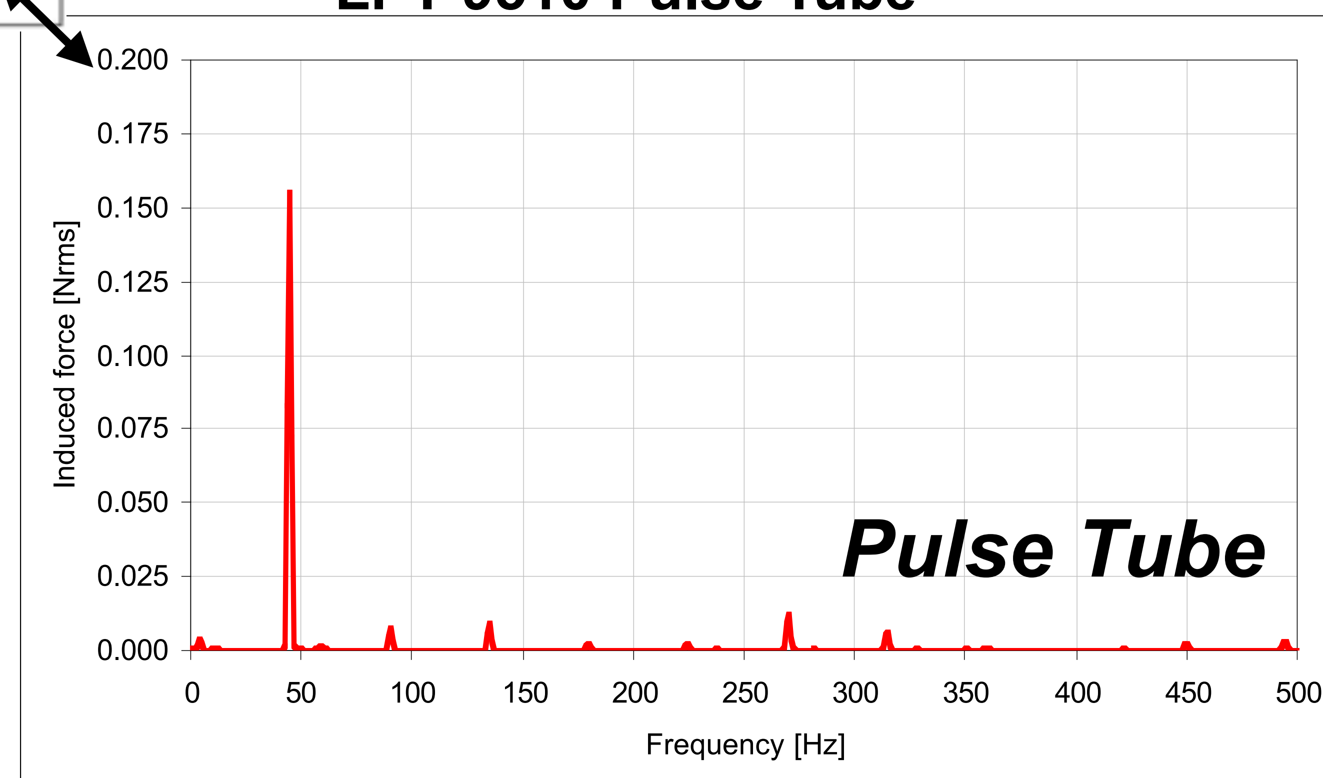
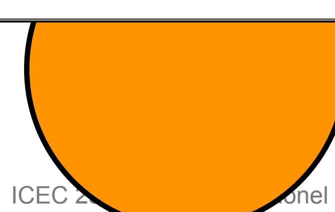


LSF 9589 Stirling



LPT 9510 Pulse Tube





Buffer volume

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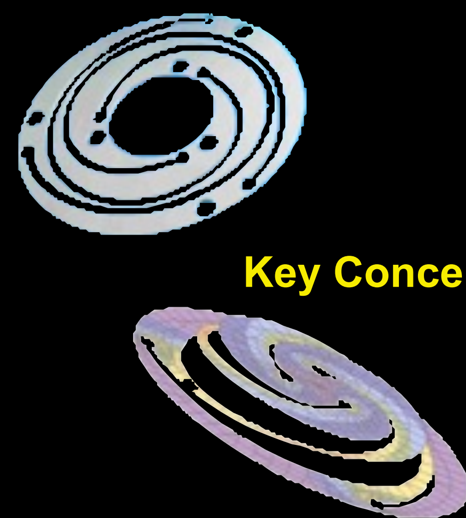
COOLER DNA (PRESSURE OSCILLATOR)

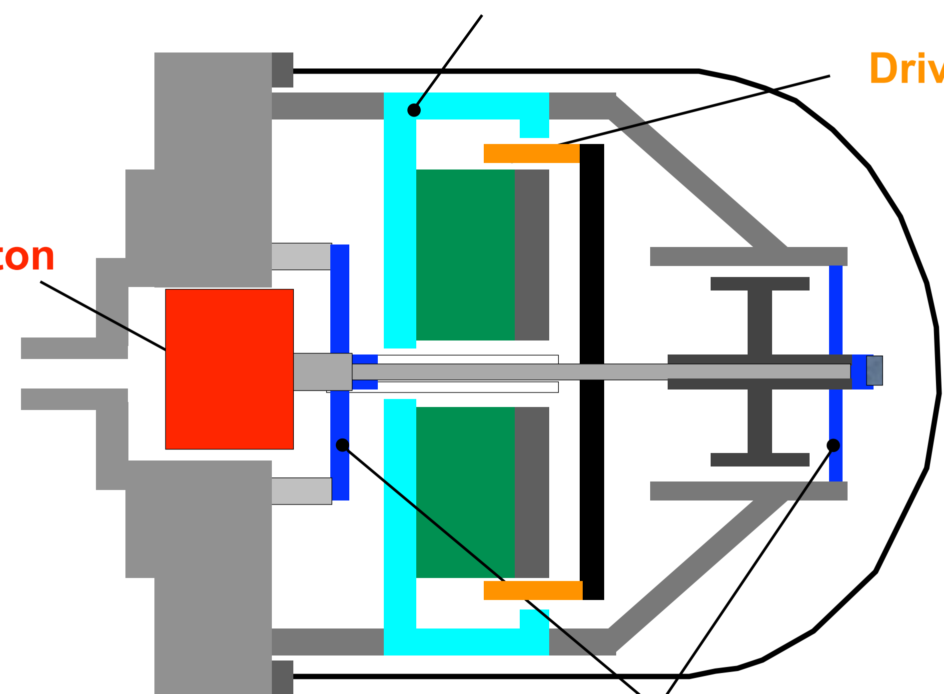
High Frequency (≈ > 30 Hz)

Motion without friction (≈)



Key Concept

No Maintenance



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Science & Technology Facilities Council

The precursor
80K Single Stage Stirling

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Overall:

- ☑ **Mature technology**
- ☑ **High Technical Readiness Level (TRL)**
- ☑ **several thousands of hours in operation in orbit**

  Original BAe 50-80 K cooler: currently 23 in orbit, 177 years accumulated in orbit,

  AIRS PT: over 12 years of operation
- ☑ **On going: Multi stage, low T system, Miniature cooler, high frequency**

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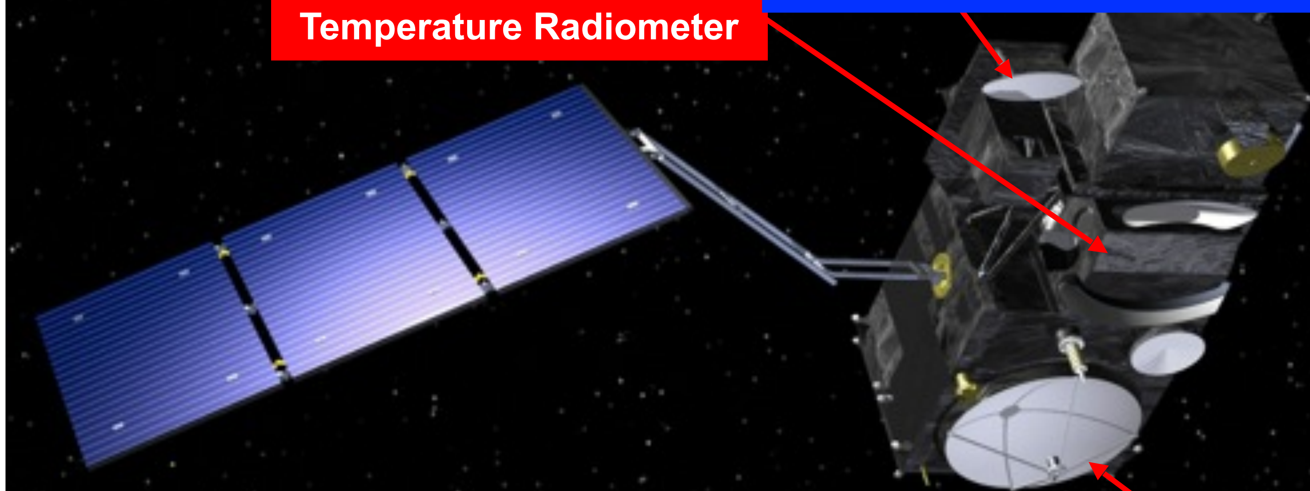
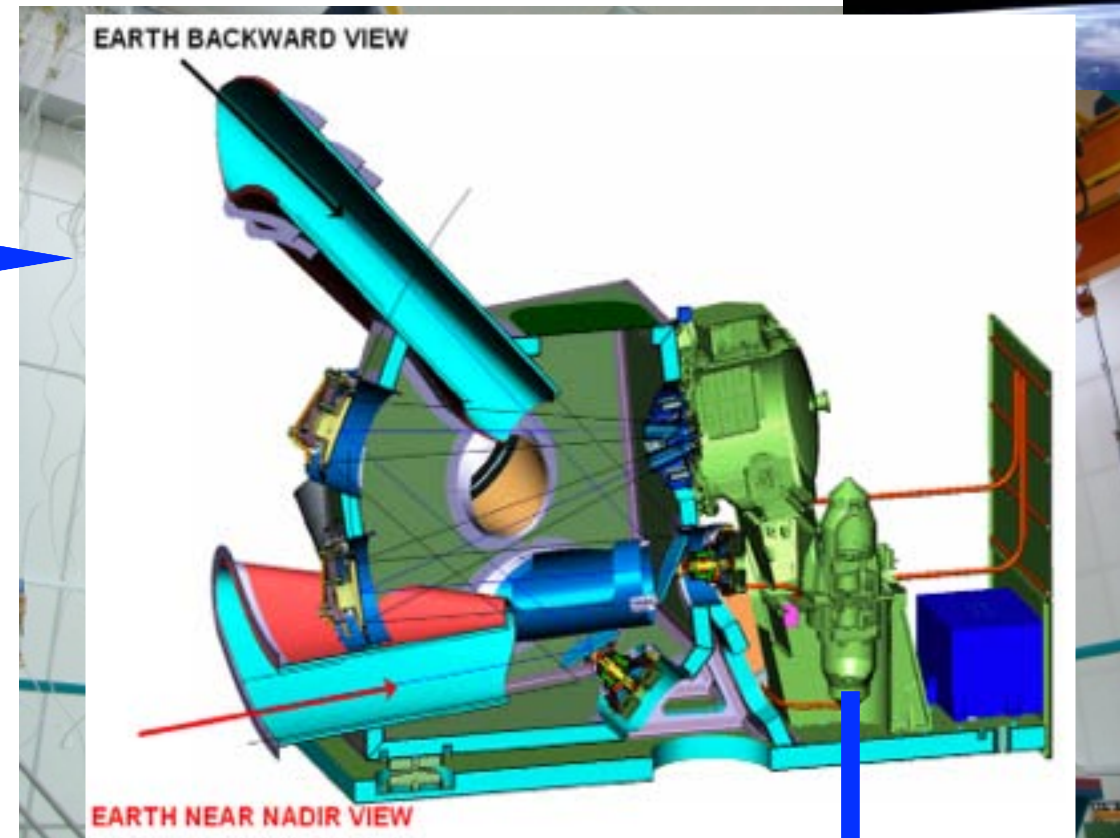
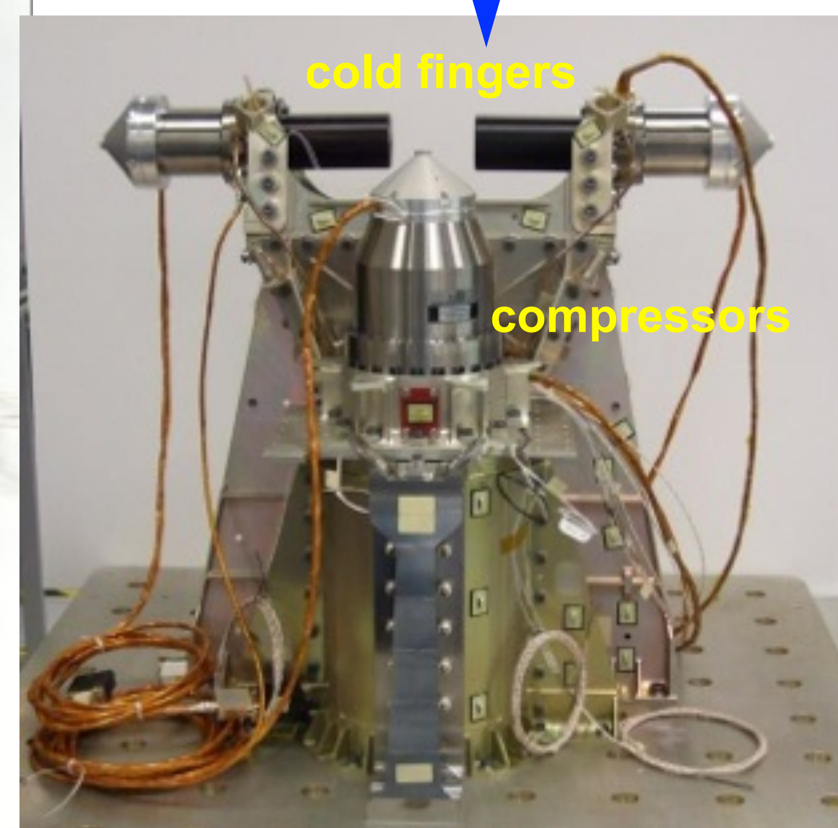
SENTINEL 3: OCEAN & GLOBAL LAND MONITORING

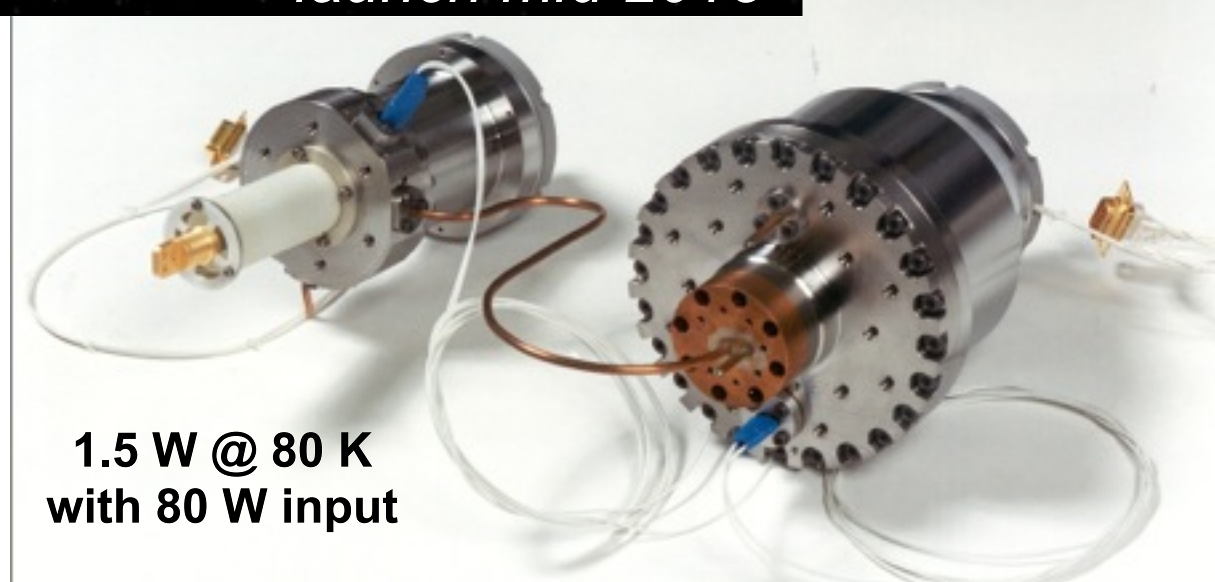




Main satellite characteristics
- 1250 kg maximal mass
- 3.89 m x 2.202 m x 2.207 m
- Average power consumption of 1100 W
- 7.5 years lifetime (fuel for 5 add. years)

Scheduled to launch mid 2015





1.5 W @ 80 K
with 80 W input

AIRBUS DEFENCE & SPACE

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METEOSAT 3G

50 K Single Stage

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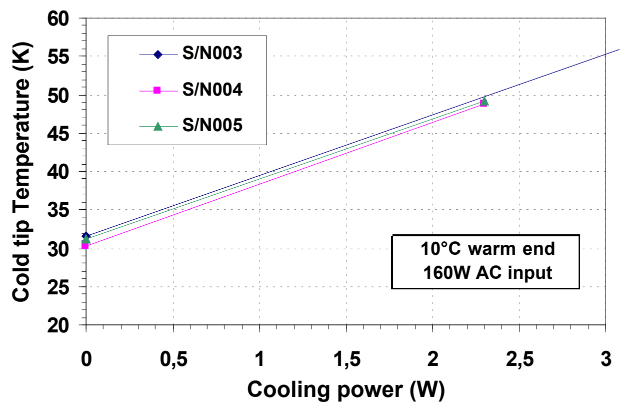
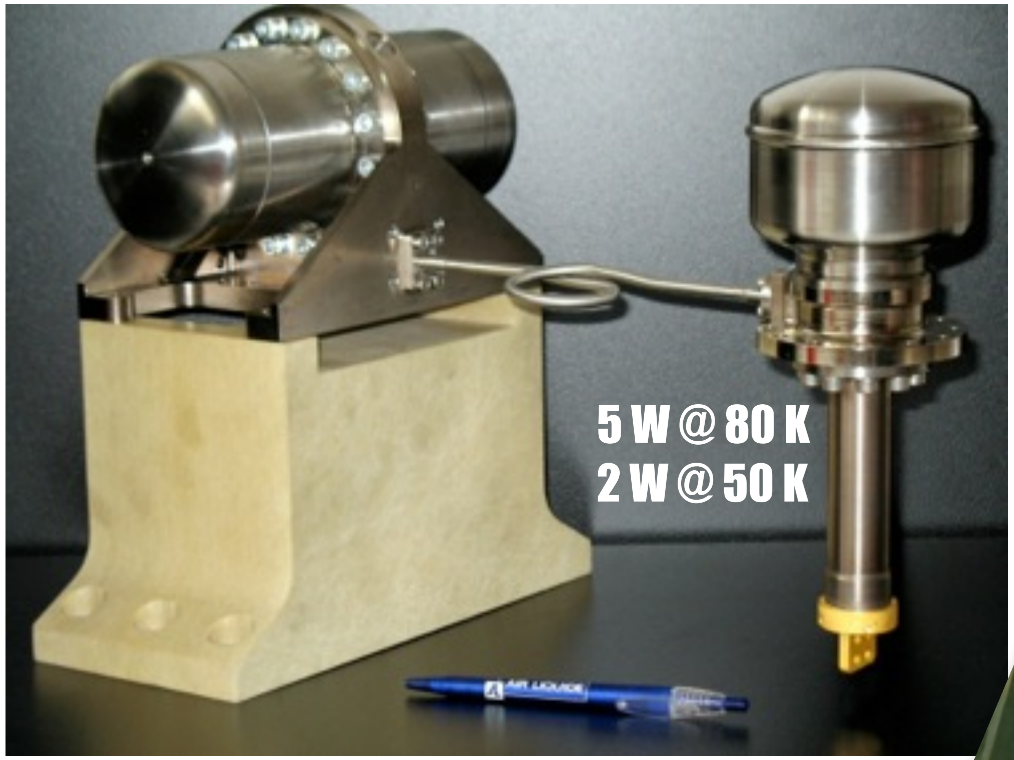
2.3 W @ 50 K
160 W input
5.1 Kg





LPTC

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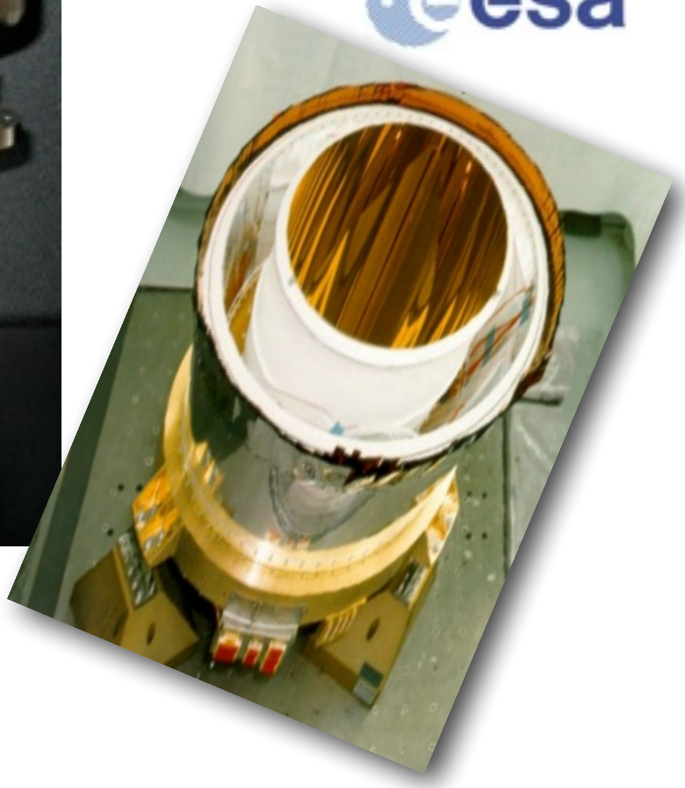

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AIR LIQUIDE

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ALTERNATIVE APPROACH: COOLER OF THE SHELF (COTS)

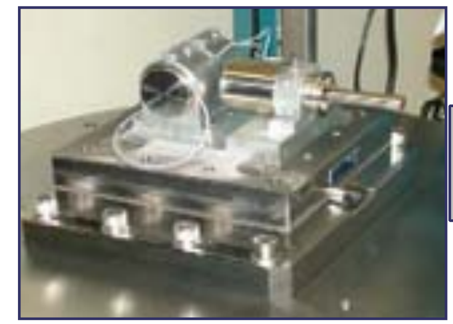
"High costs": Full space qualification, Maximum performance.

- In line with ESA standards, adherence to ESA/NASA guidelines

LPT 9310 in test configuration

"Low costs": Reliability is important, High price level not affordable.

- Products based on normal definition and production standards
- Special but limited screening of parts / products
- Extra burn-in to avoid infant mortality



LPT 9510 on JPL test bench

Cost effective solution: Reliability is key, No extreme performance.

- Design based on existing / proven definitions
- Extra but limited effort on parts and processes (based on risk assessment)
- Extensive screening of subassemblies / final products

THALES Split Stirling LSF 9599

ORS 1 Satellite (launched 2011)

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THALES

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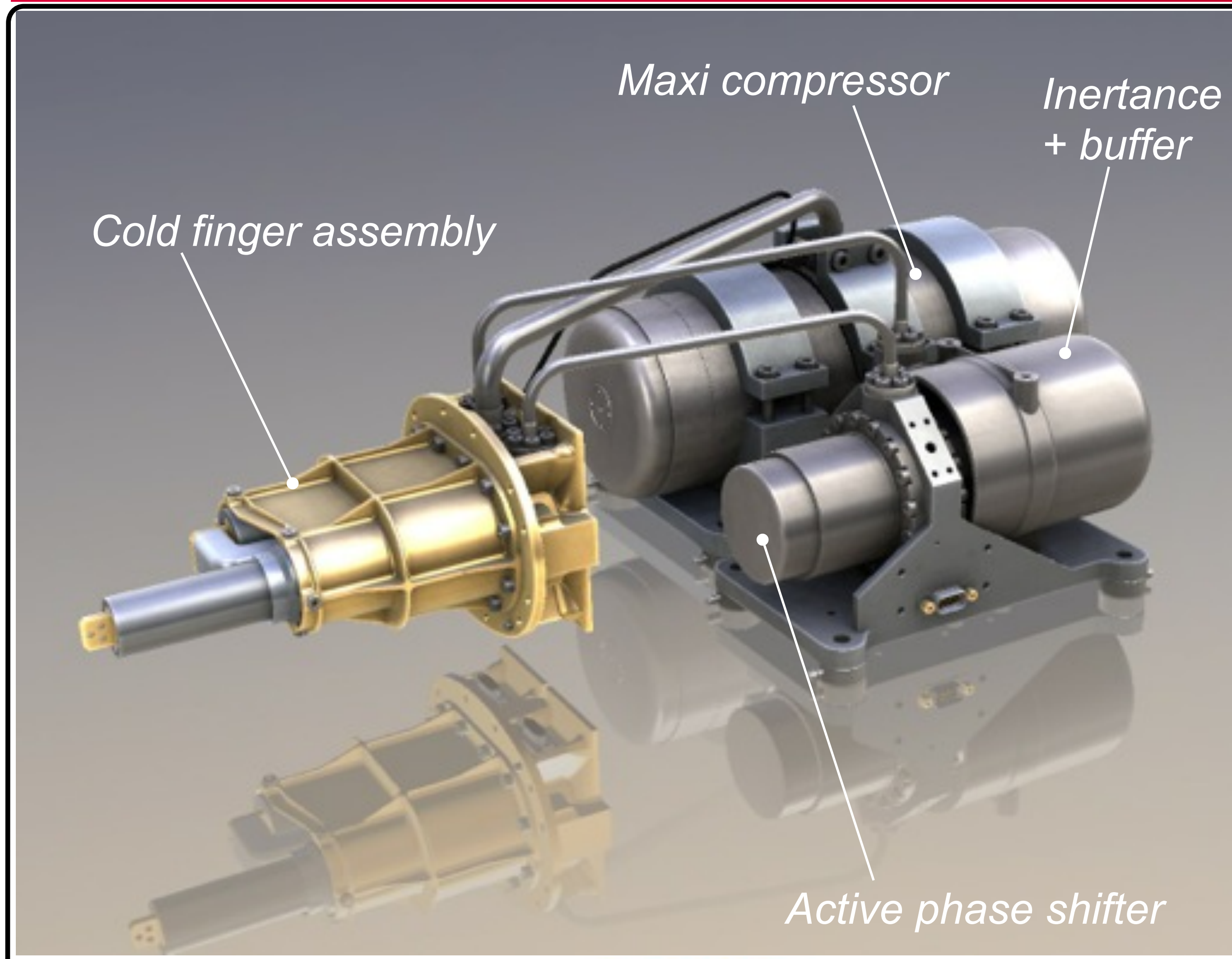
LOW TEMPERATURE MULTISTAGE PULSE TUBE



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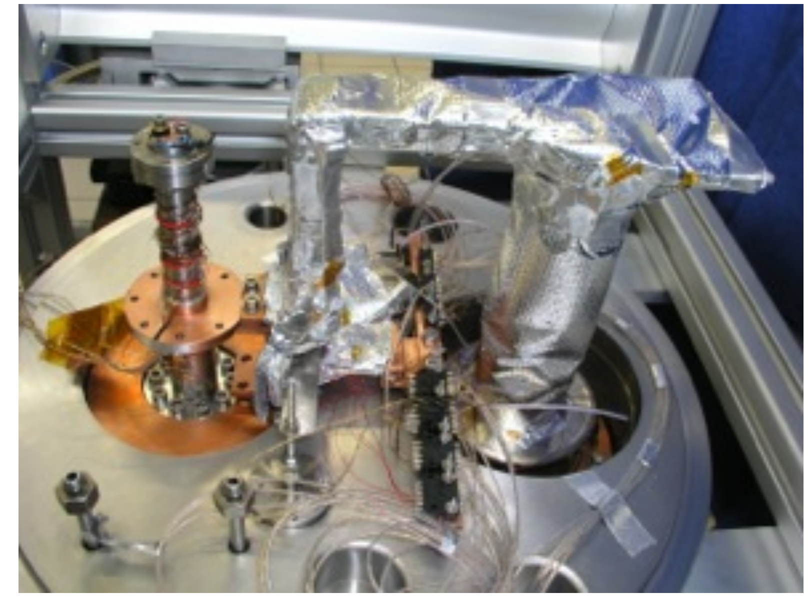
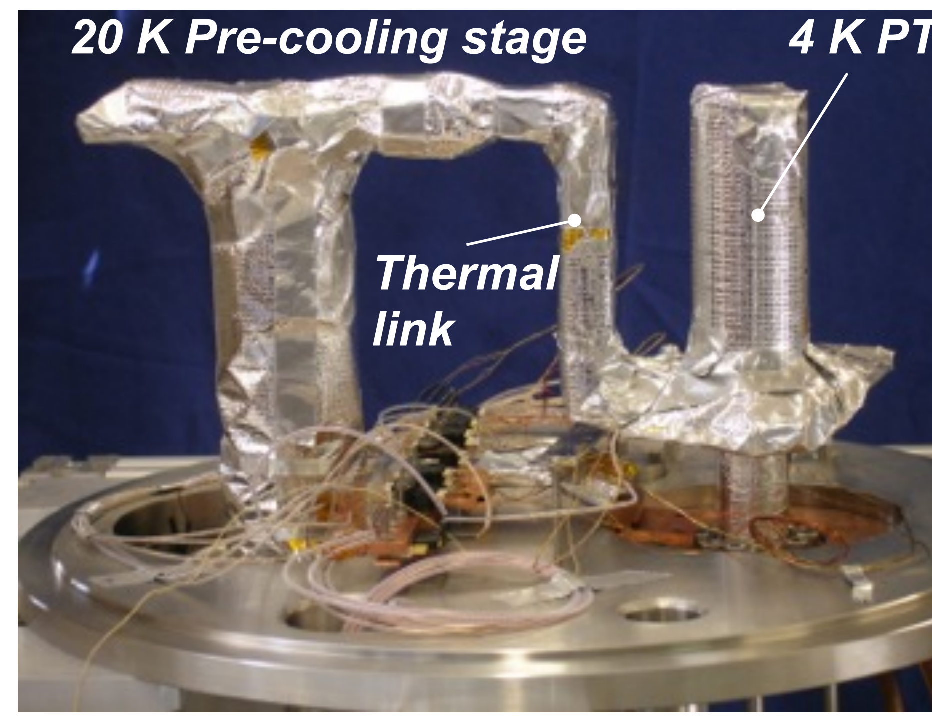
300 mW @ 15 K

4 K Pulse Tube





3.86 K reached June 2014 !
15 mW @ 4.5 K

Possible application

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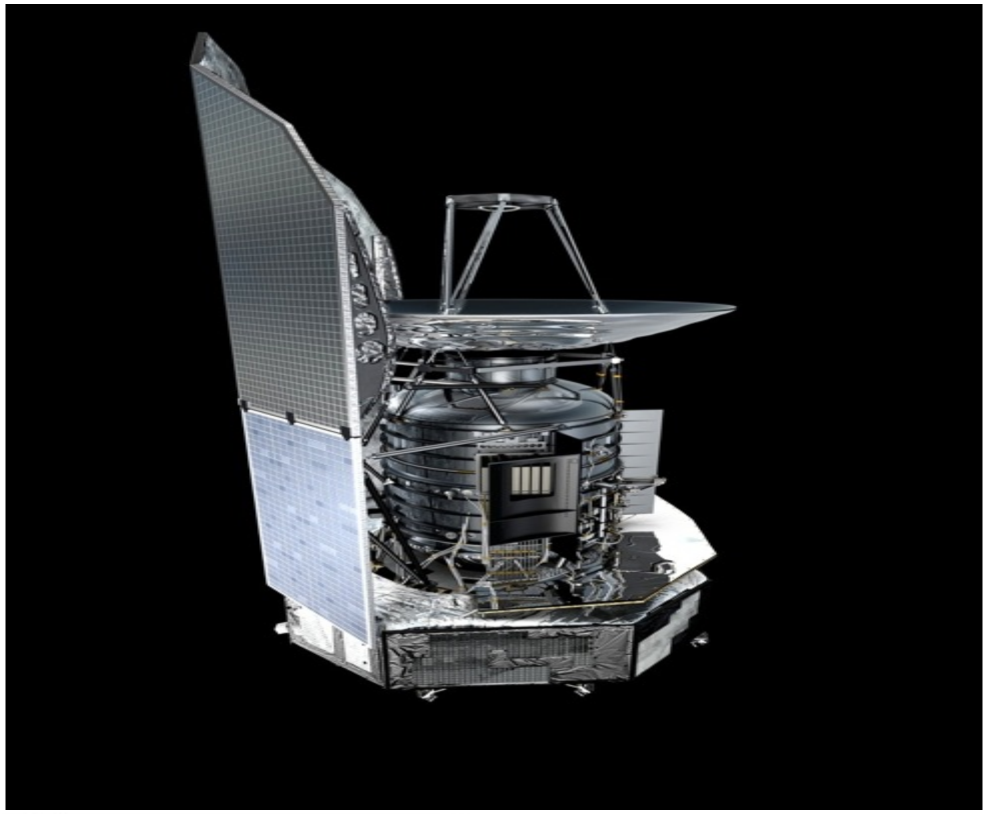
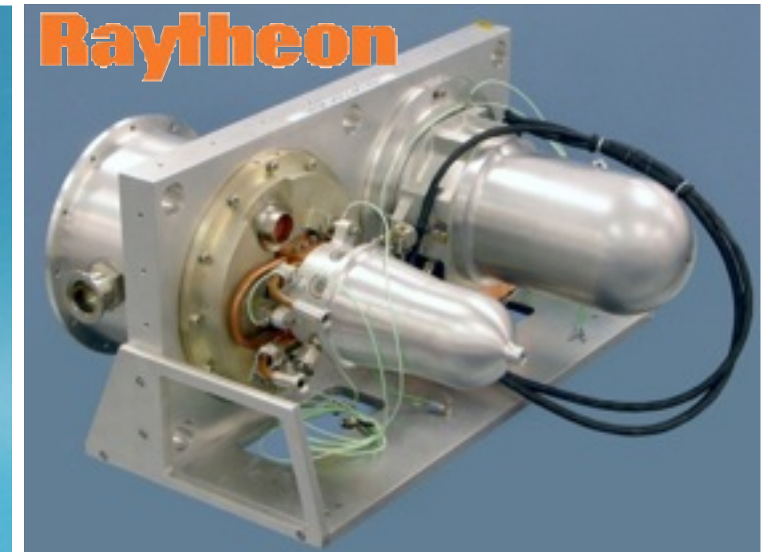
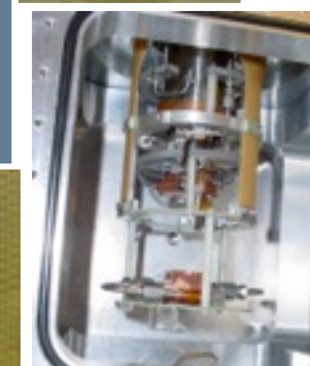
CAN'T BE EXHAUSTIVE - MANY SUPPLIERS !

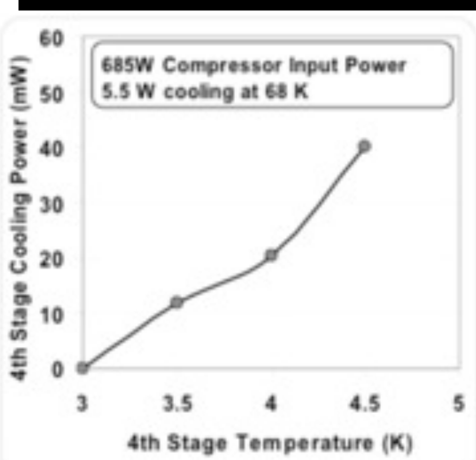
LOCKHEED MARTIN



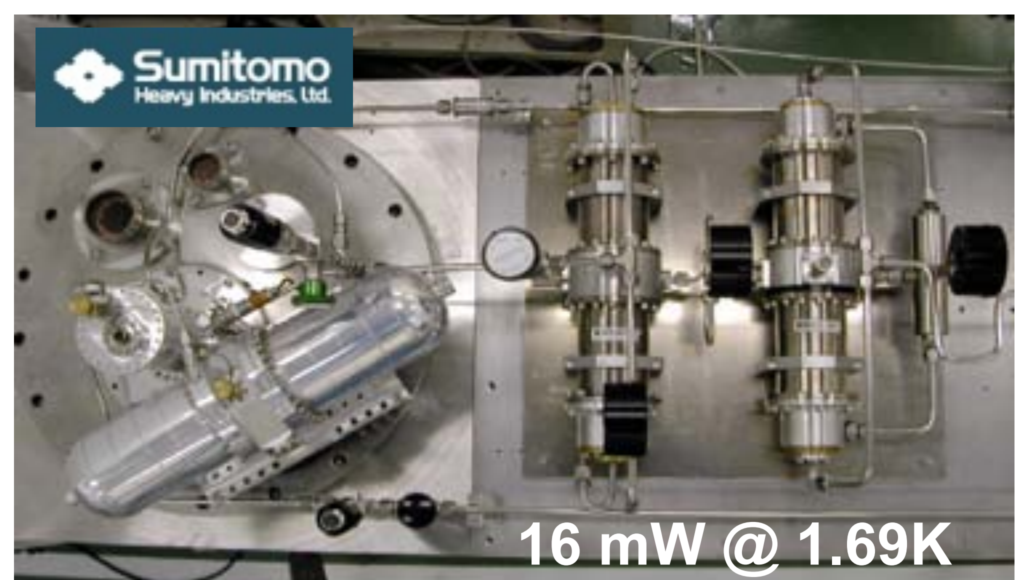




Ball



Creare



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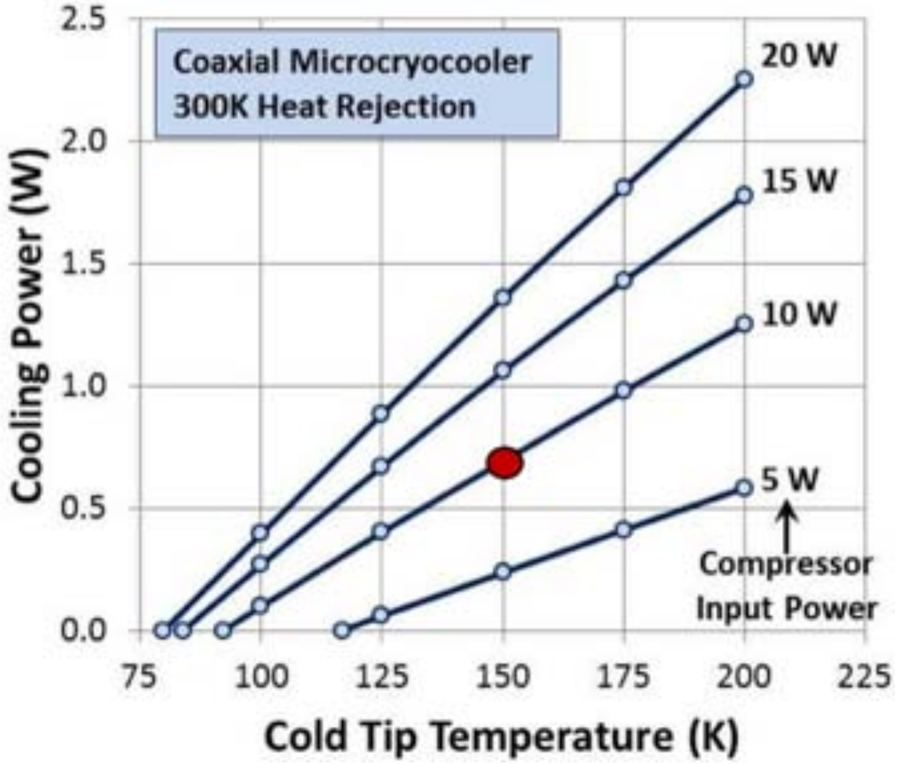
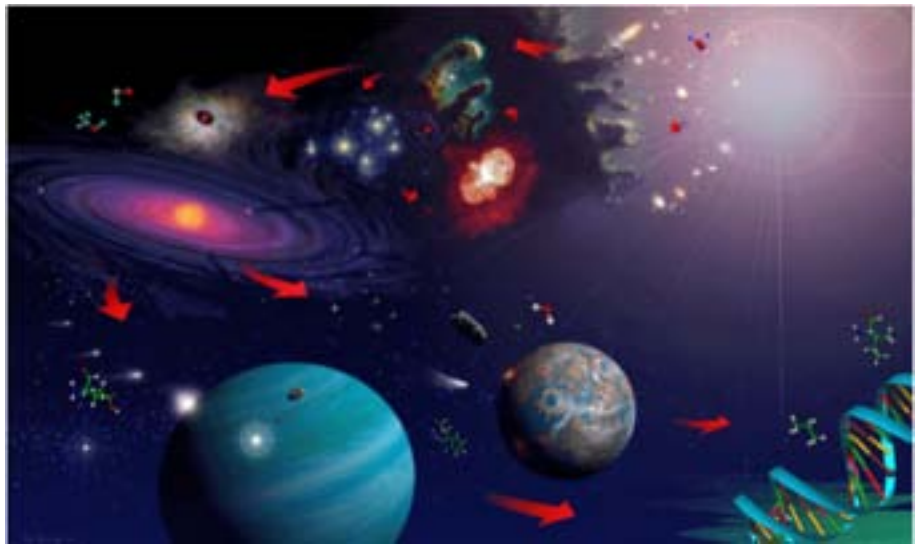
PULSE TUBE MICROCRYOCOOLER

Low SWaP (Size, Weight and Power)

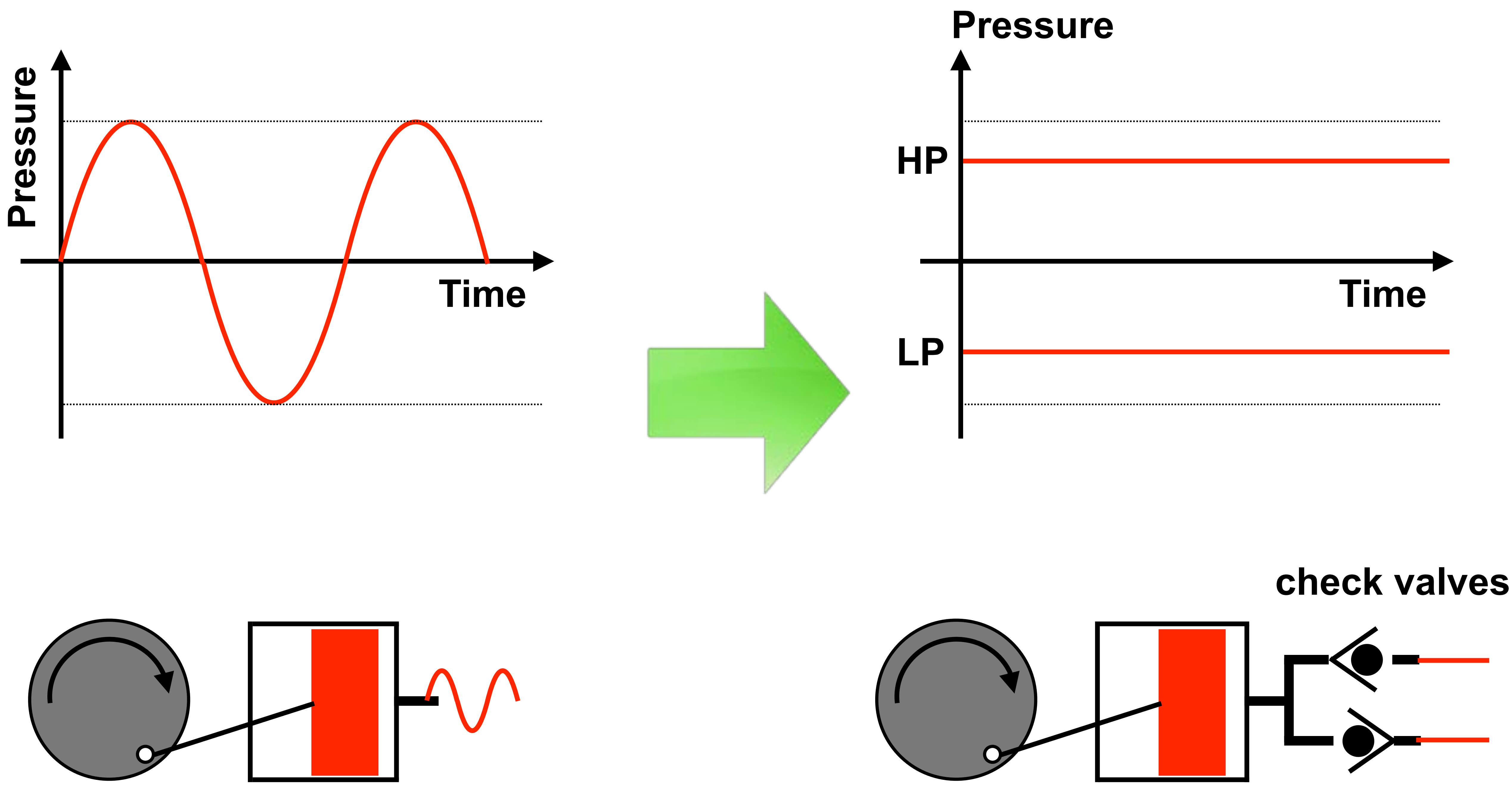


690 mW @ 150 K
10 W input
100 Hz
compressor Ø32 x 90 mm
Cold finger Ø42 x 110 mm
Mass: 328 gr (comp. 210, CF 118)



Could be used in the NASA MatISSE program
(Maturation of Instruments for Solar System Exploration)

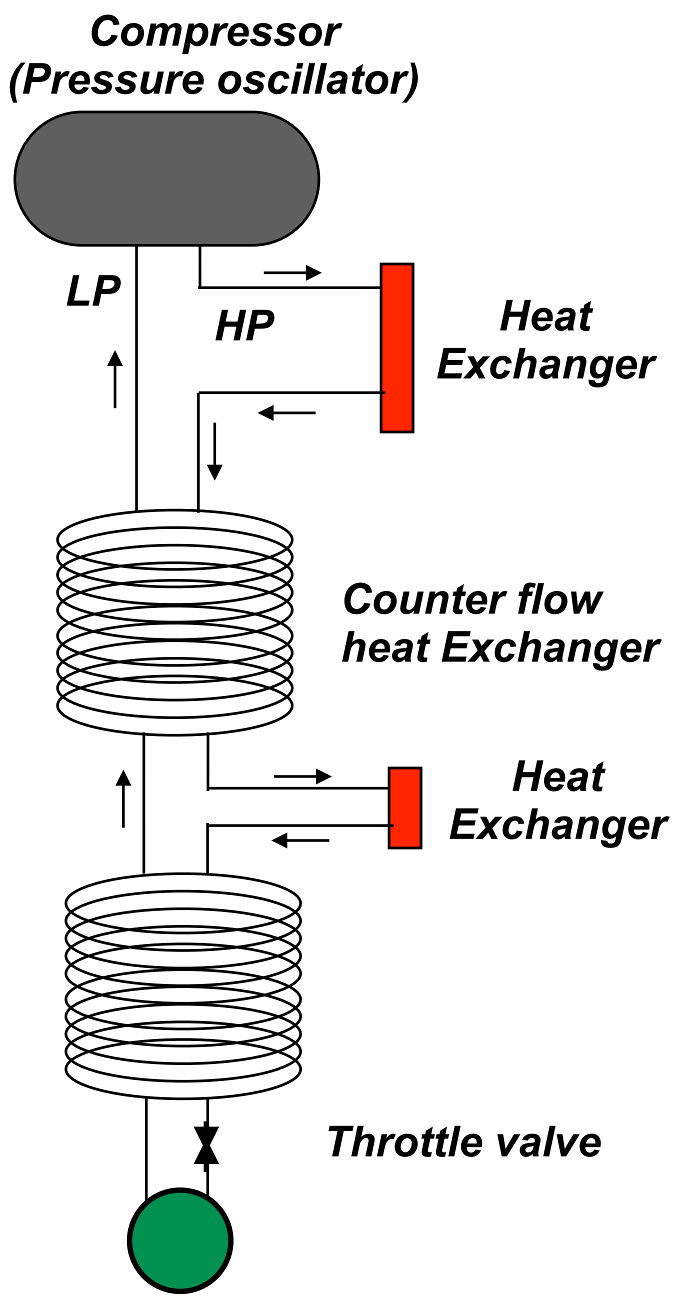
LOWER TEMPERATURE OR VIBRATION LESS: JOULE THOMSON SYSTEM

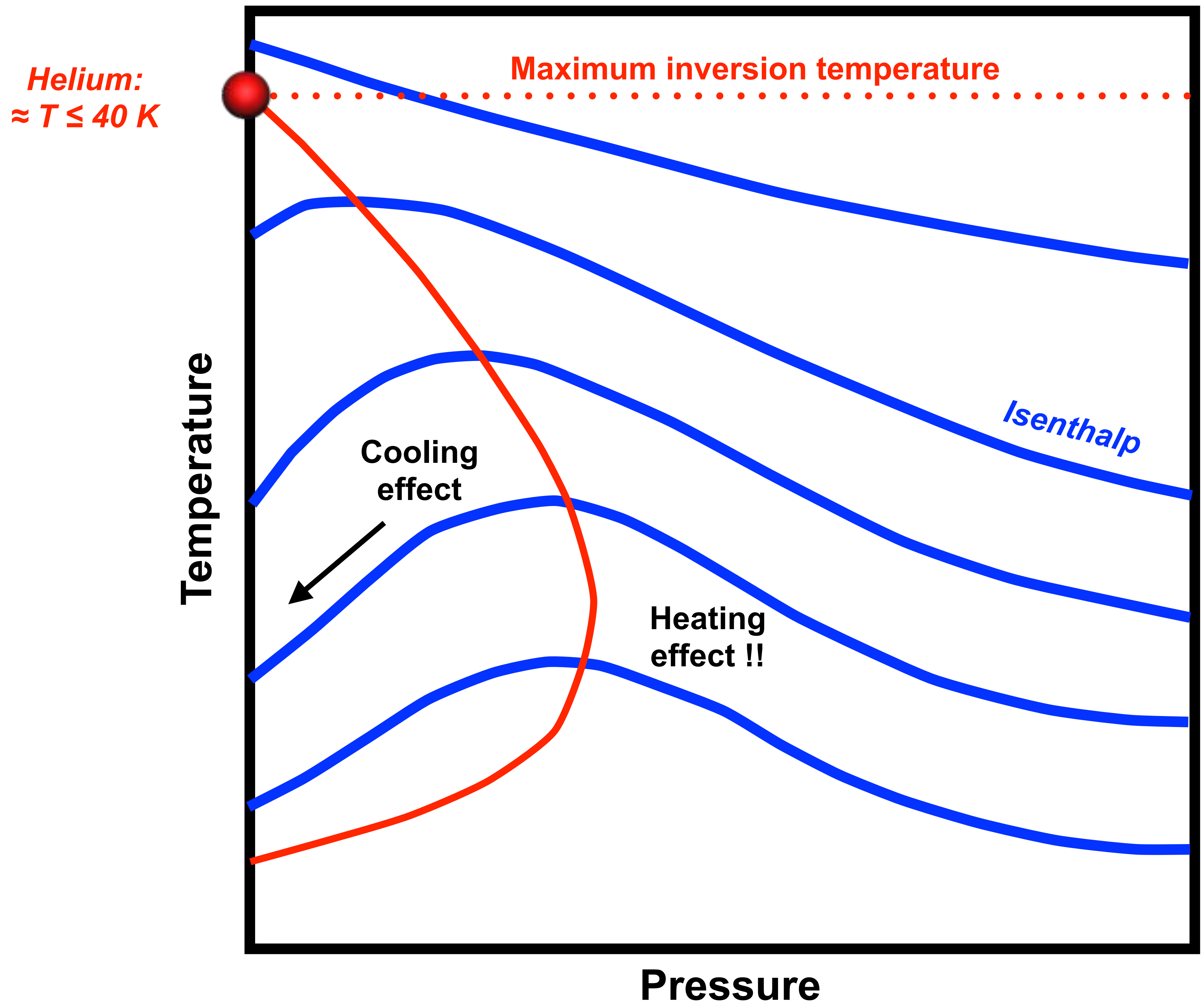


Direct benefit from heritage (flexure spring)

JOULE THOMSON LOOP

ISENTHALPIC EXPANSION





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4K JT SYSTEM - PLANCK

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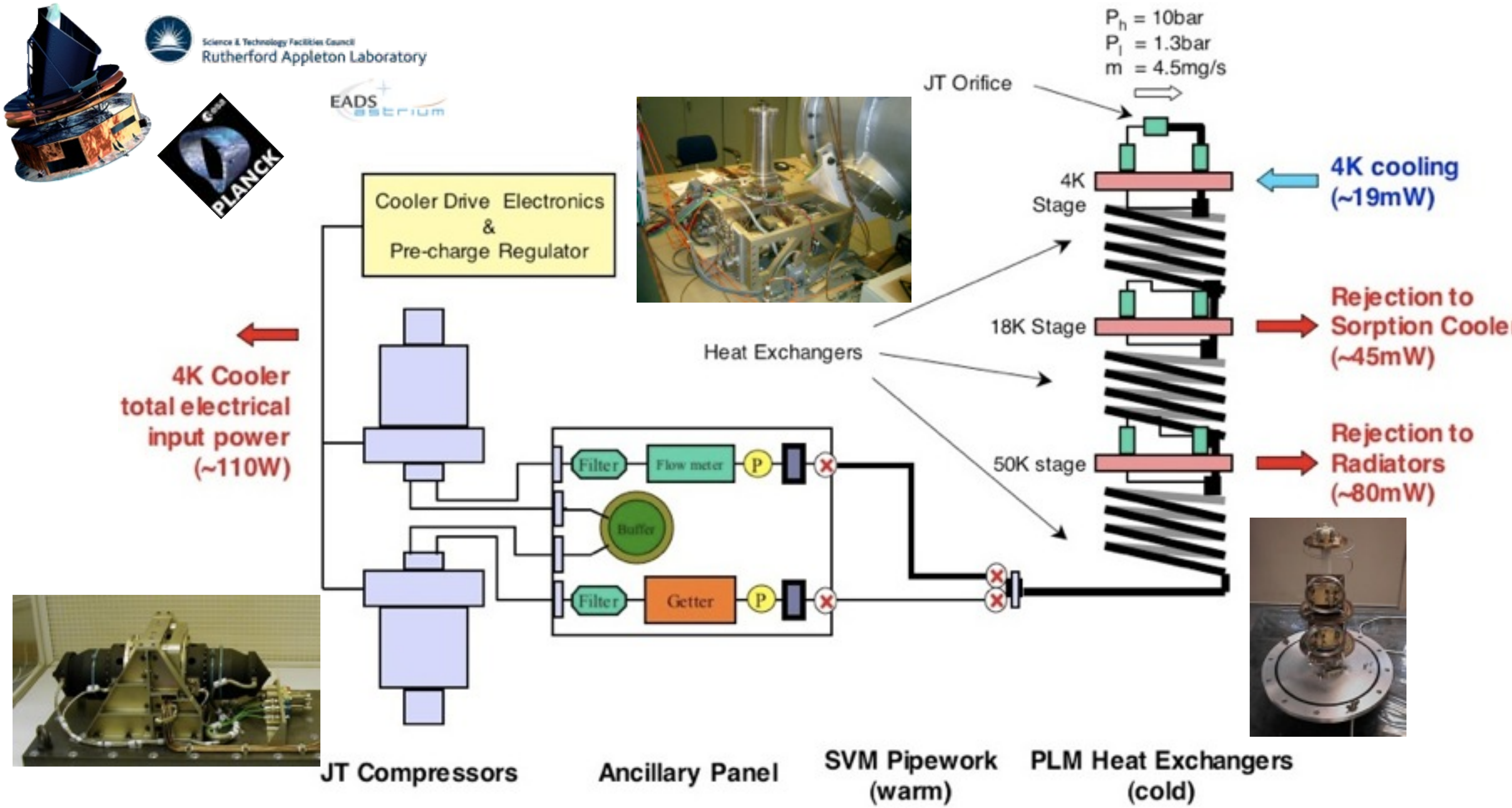
EADS astrium



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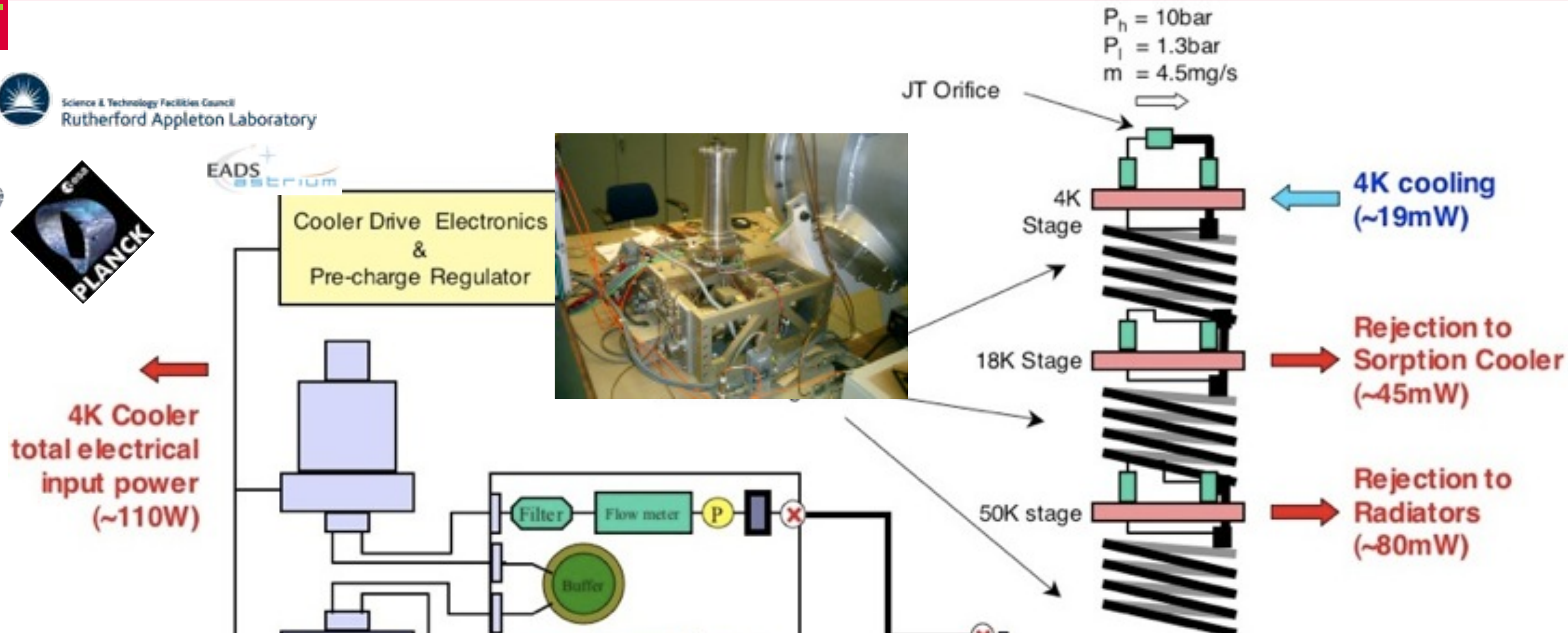
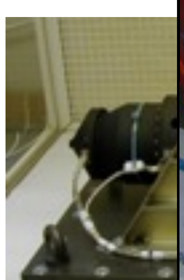
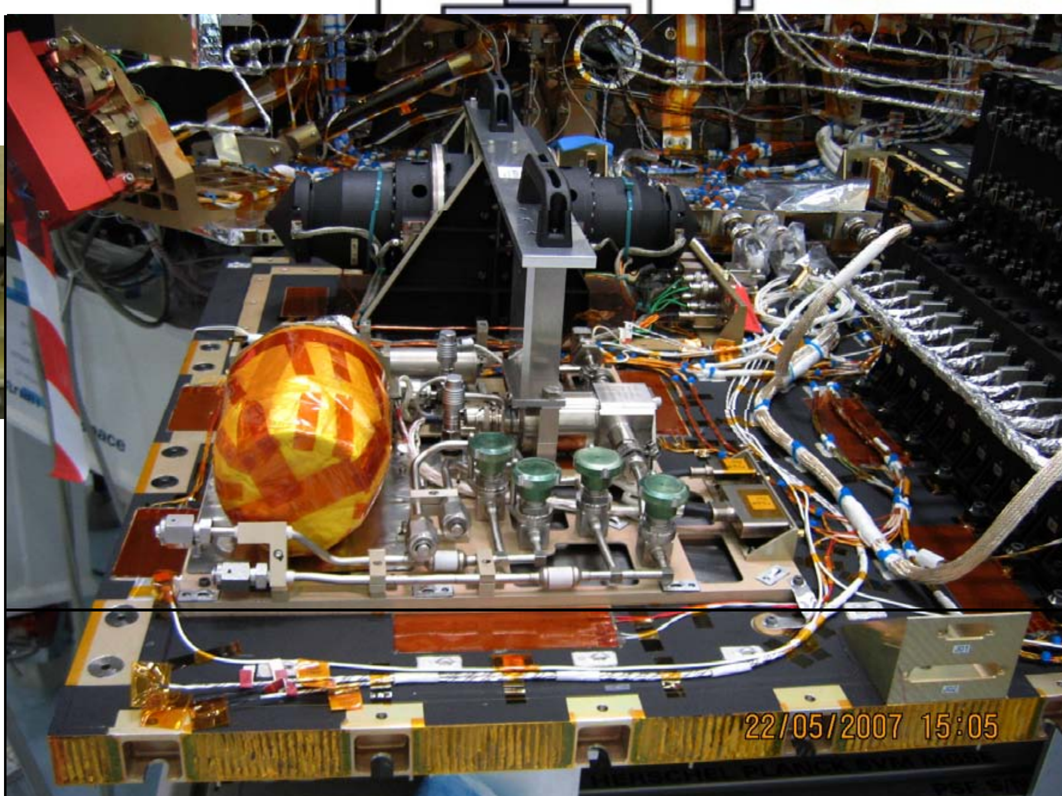
4K JT SYSTEM - PLANCK

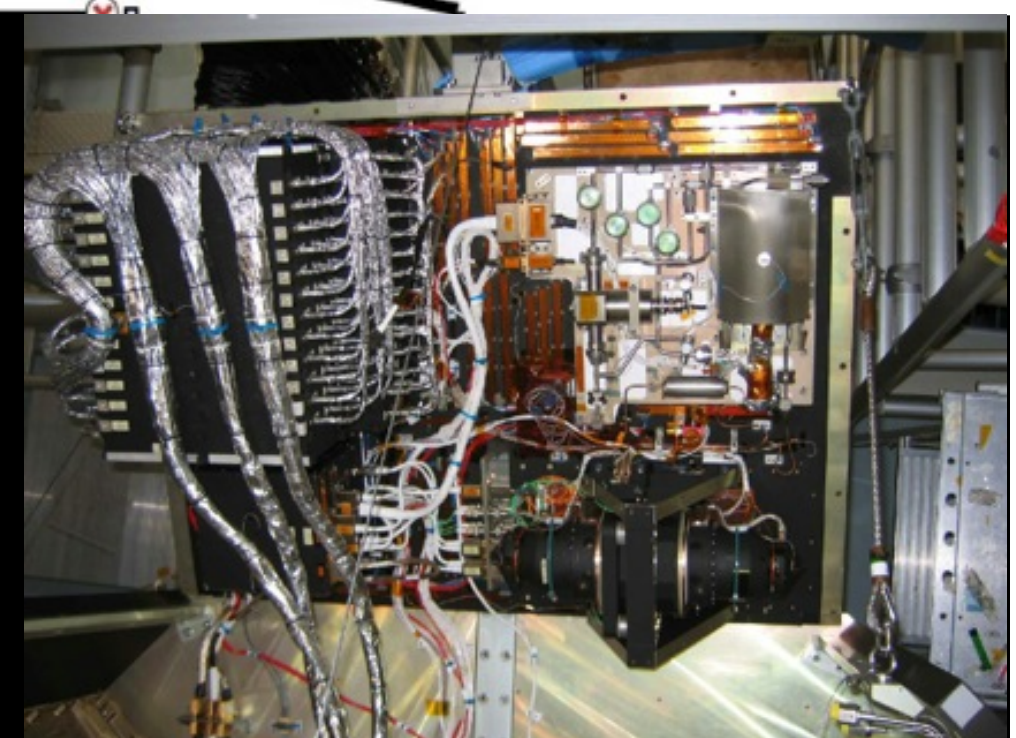
Science & Technology Facilities Council
Rutherford Appleton Laboratory

EADS astrium









RAL - Astrium 4K JT Loop onboard PLANCK (HFI Instrument)

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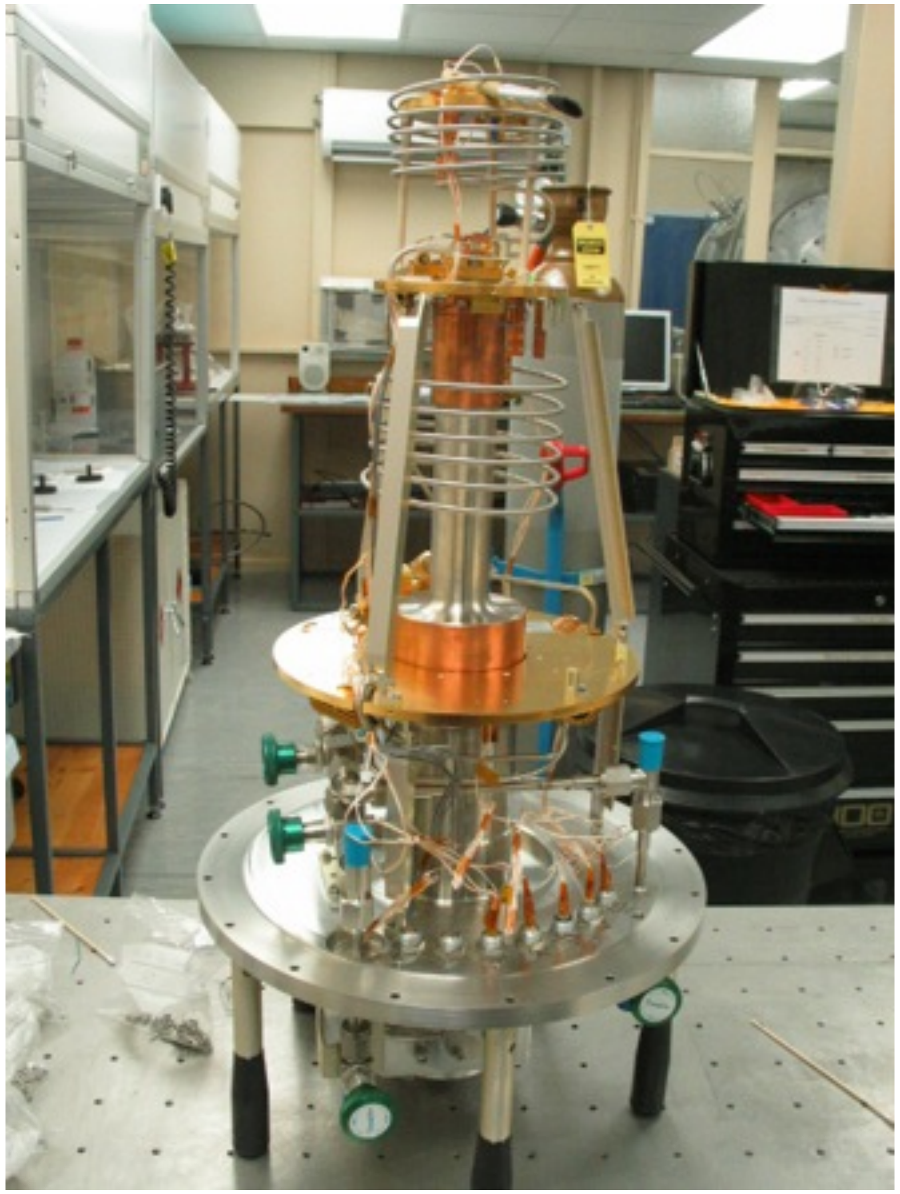
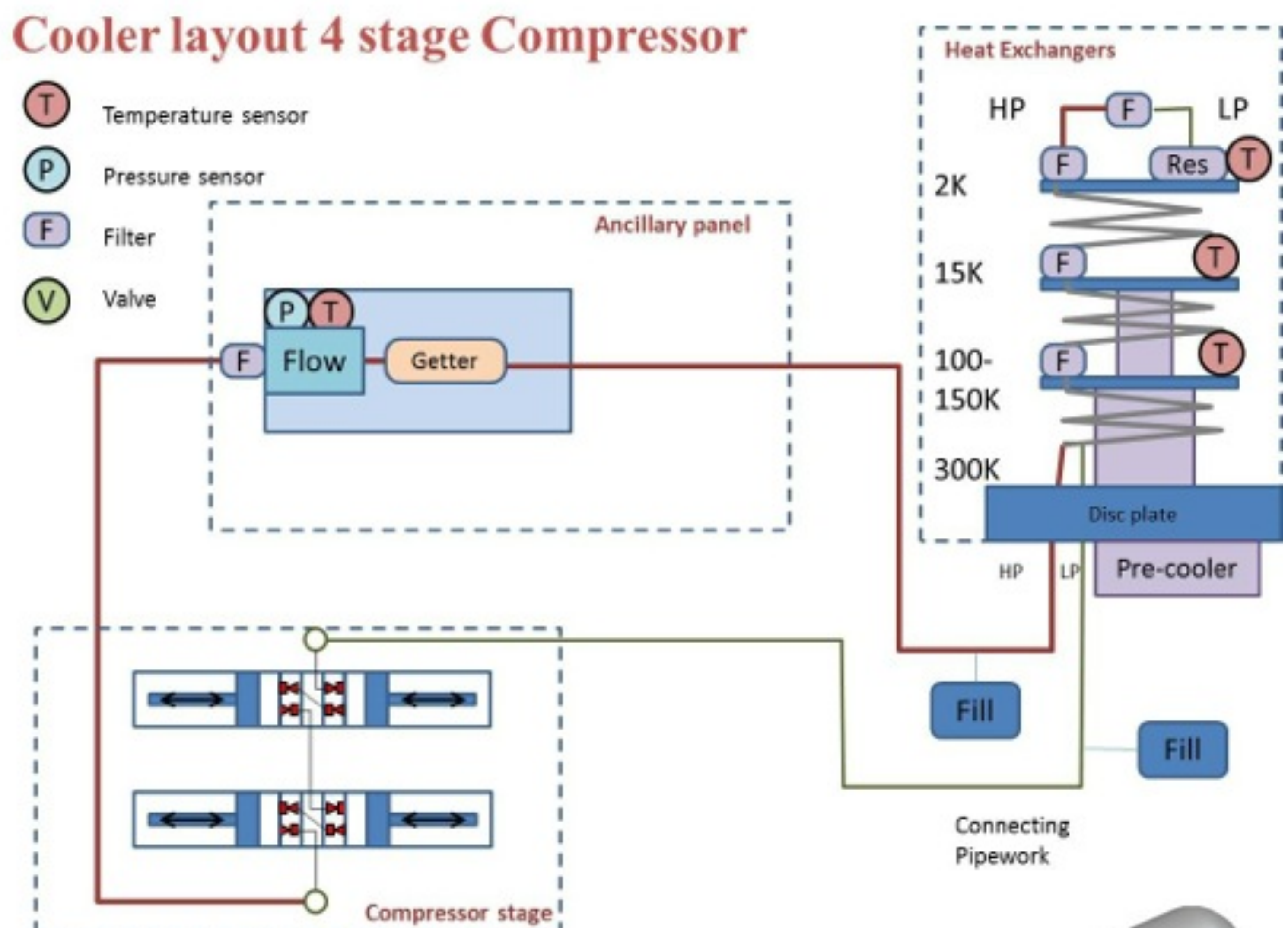
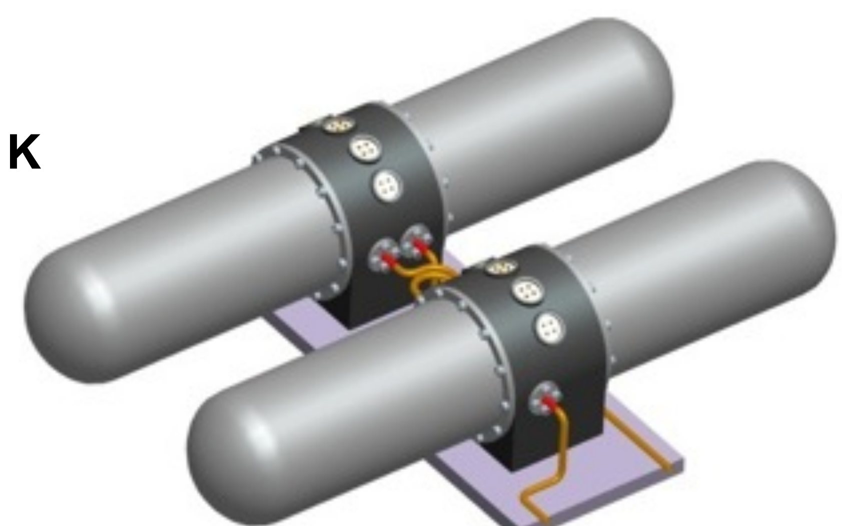
ADVANCED 2 K COOLER PROGRAM





Objective of 20 mW @ 2 K



Possible application

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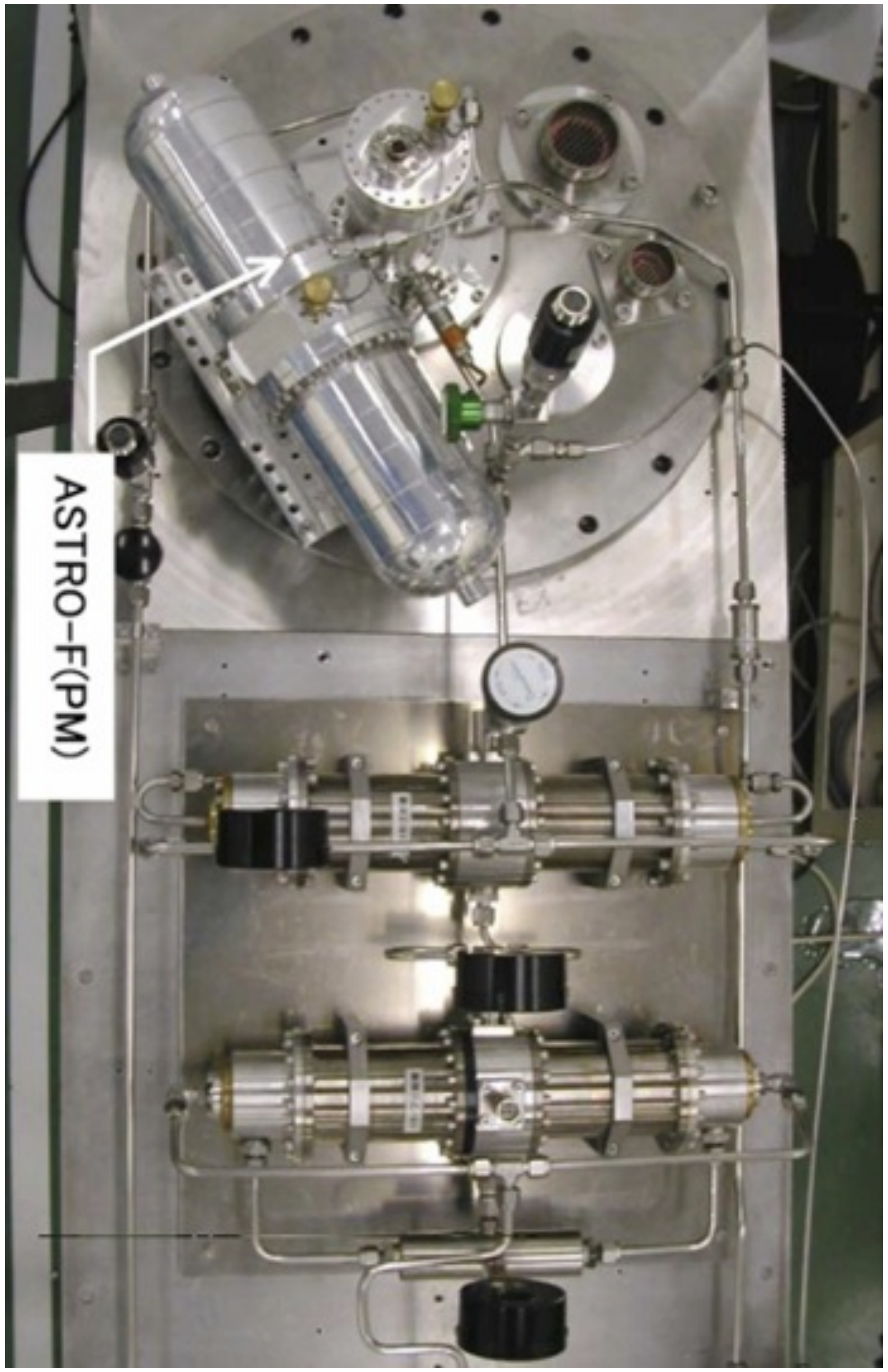
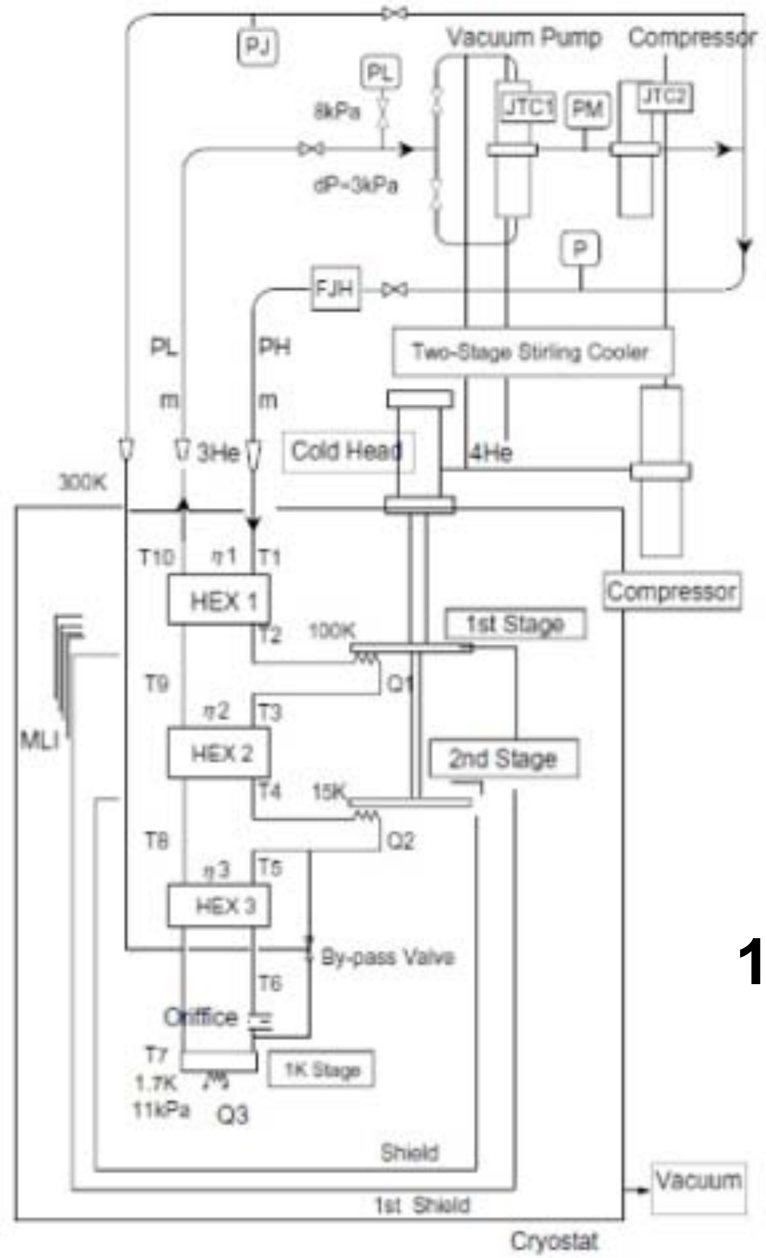
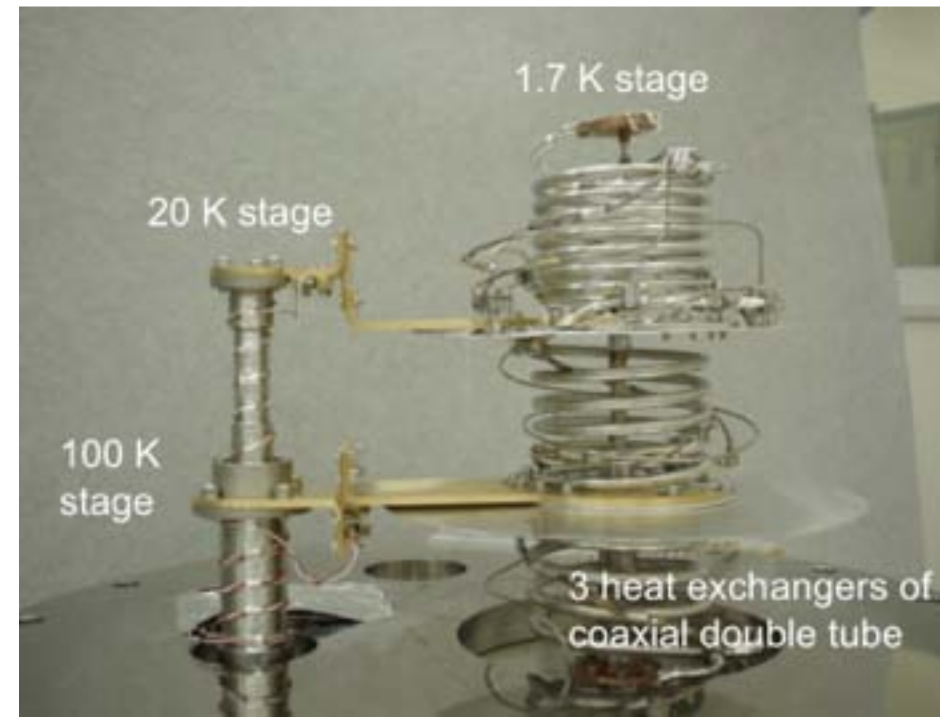
JT SYSTEM - JAXA (ASTRO-F, SPICA, ...)



JT compressors
(4 stages: 8 kPa to 0.7 MPa)
(ratio 87)



Prototype cooler



16 mW @ 1.7 K with 160 W input

EM unit (with 4 compressors) under fabrication (SPICA/SAFARI mission)

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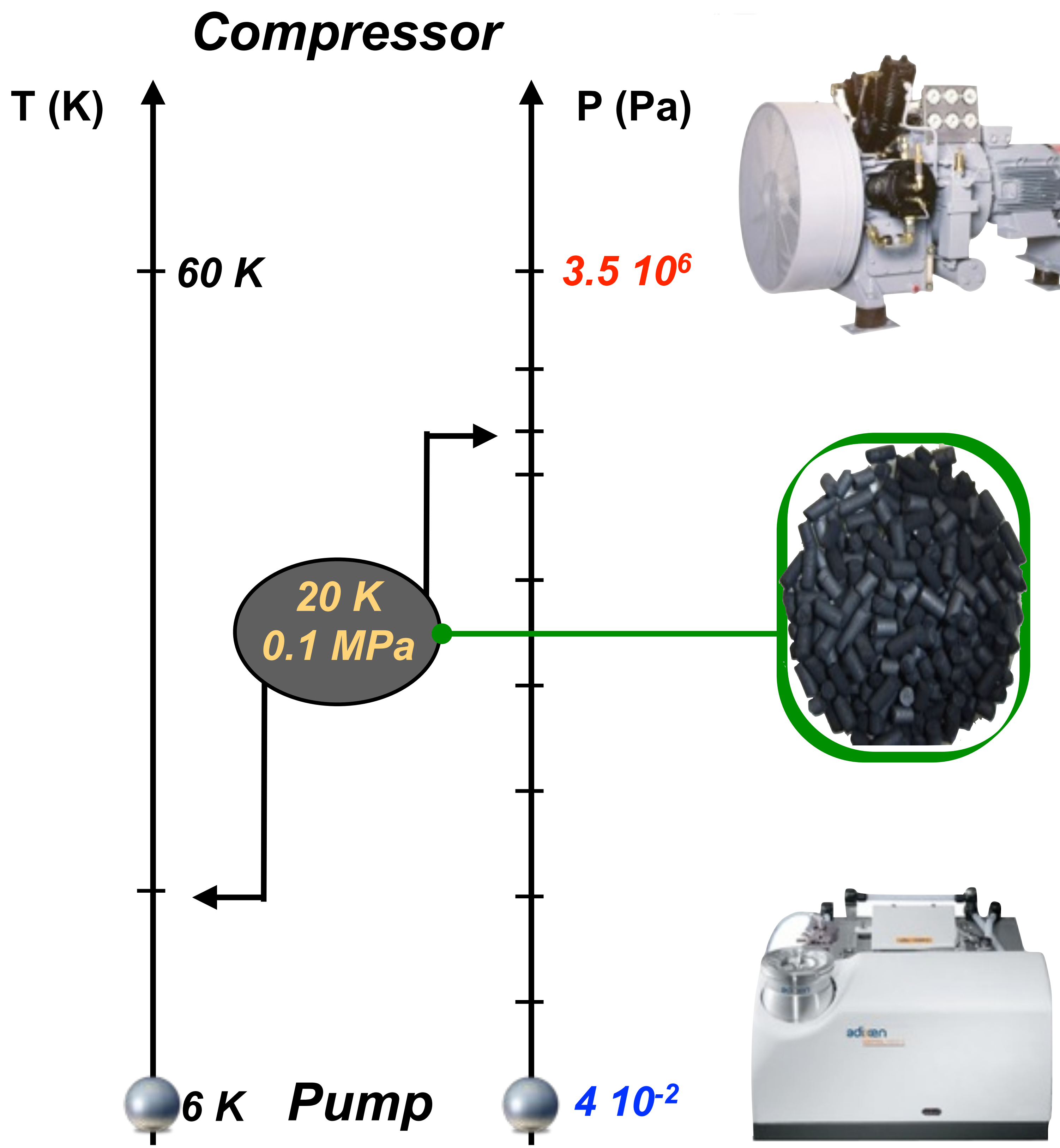
VIBRATIONLESS ? ALTERNATIVE COMPRESSOR



1 order of magnitude in T

8 orders of magnitude in P

No mechanical equivalent (in 1 stage)

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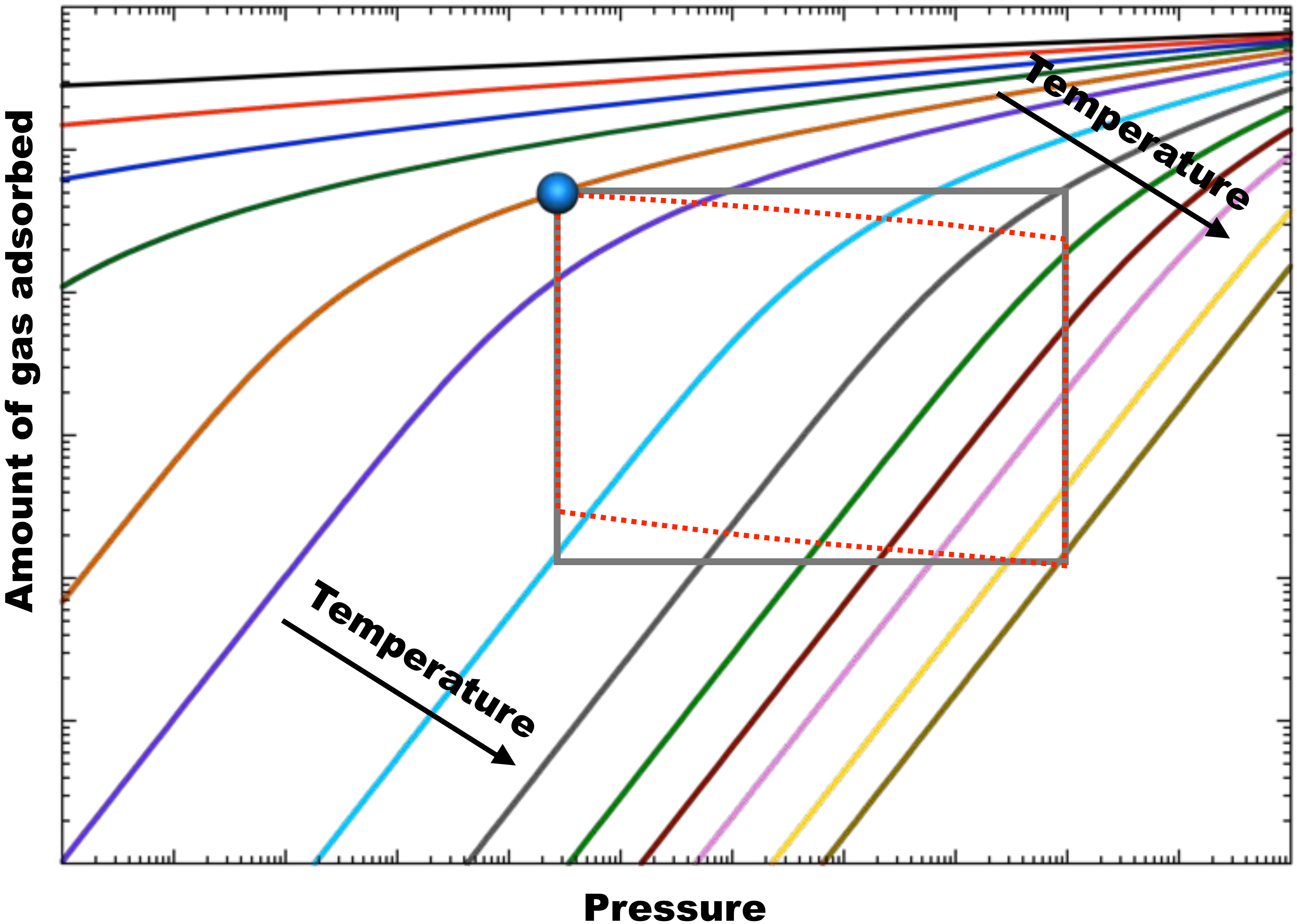
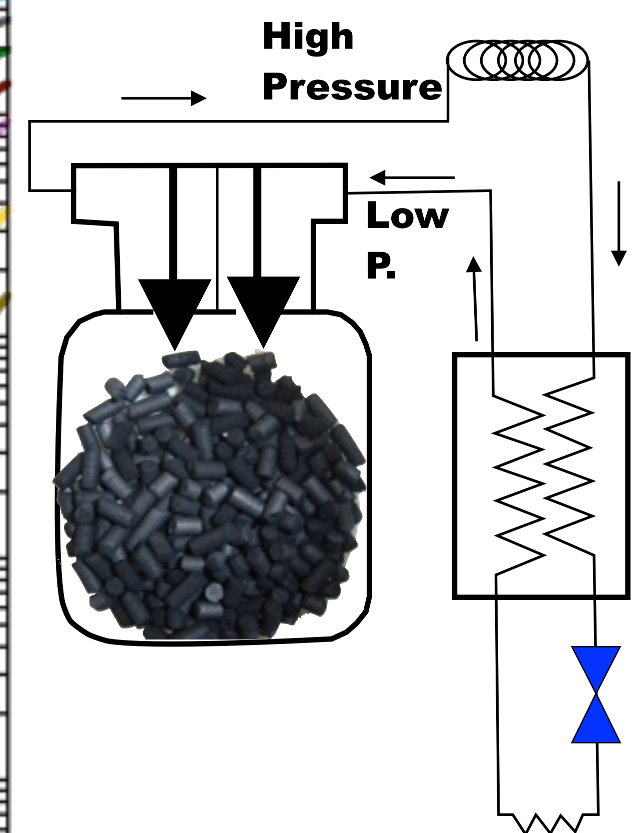
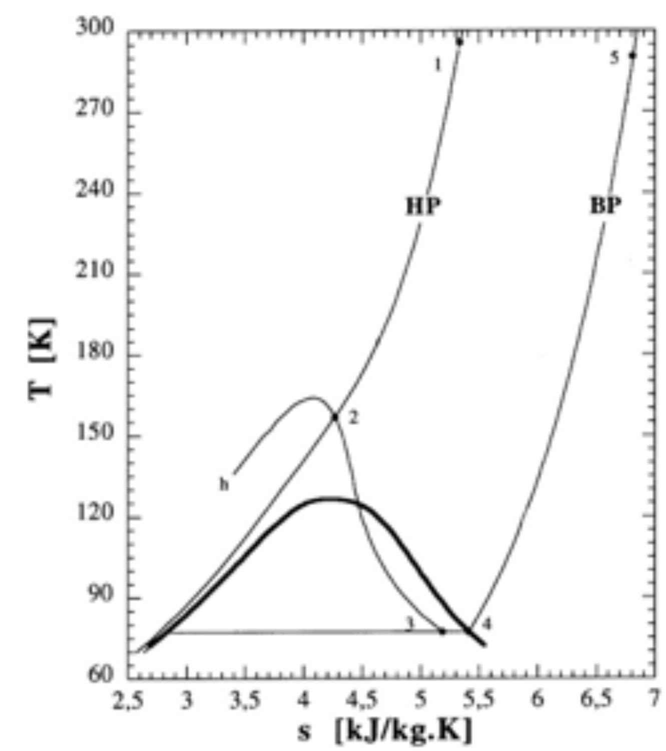
IEEE/CSC SUPERCONDUCTIVITY NEWS FORUM (global edition) July 2014
Presentation given at ICEC25 – ICMC2014, Enschede, July 2014

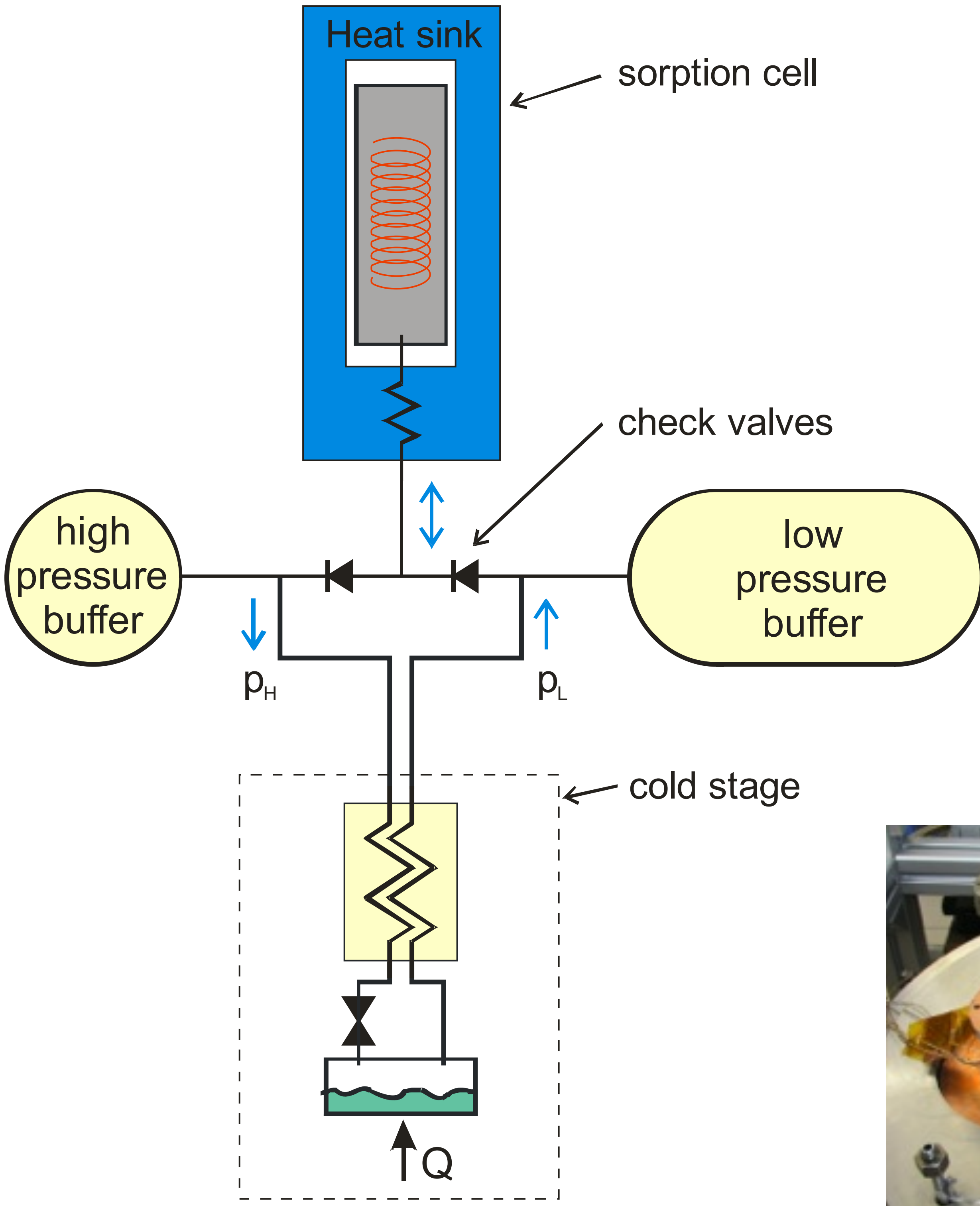
JOULE THOMSON WITH SORPTION COMPRESSOR

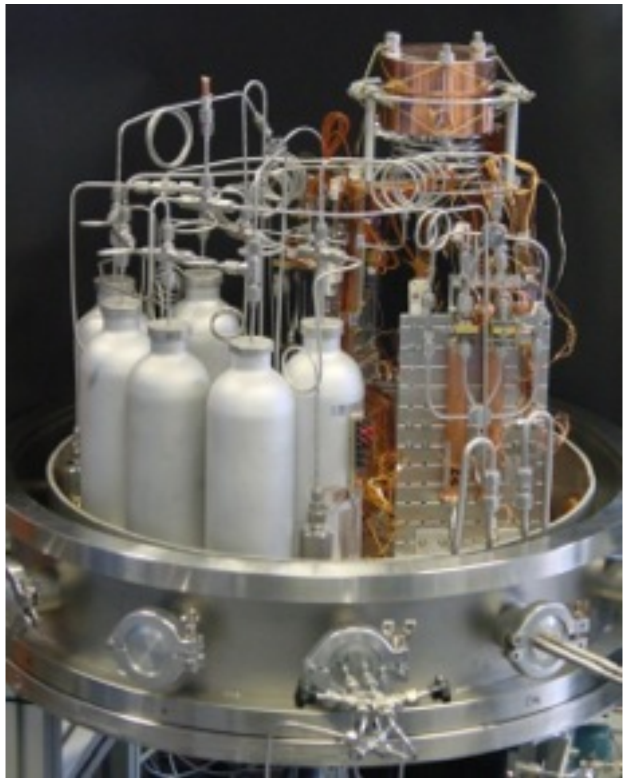




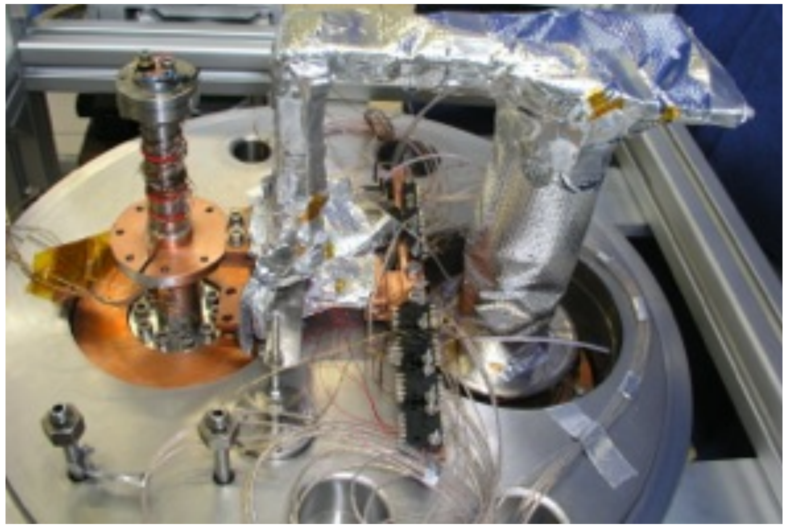


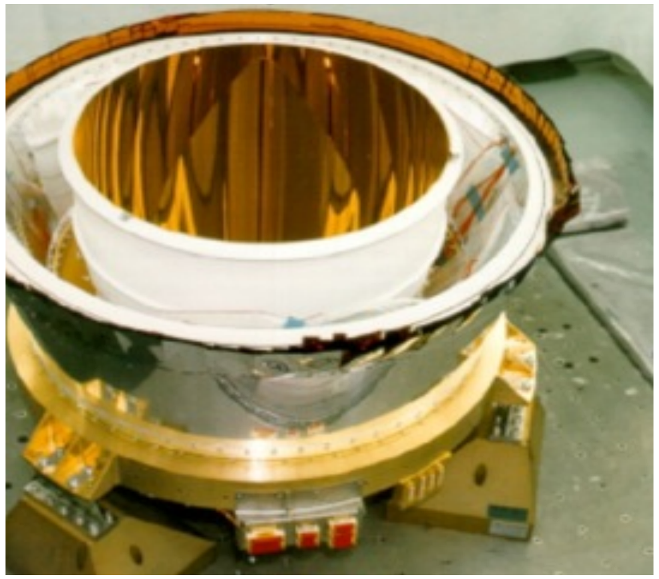
HELIUM & HYDROGEN JT COOLER - VIBRATION FREE



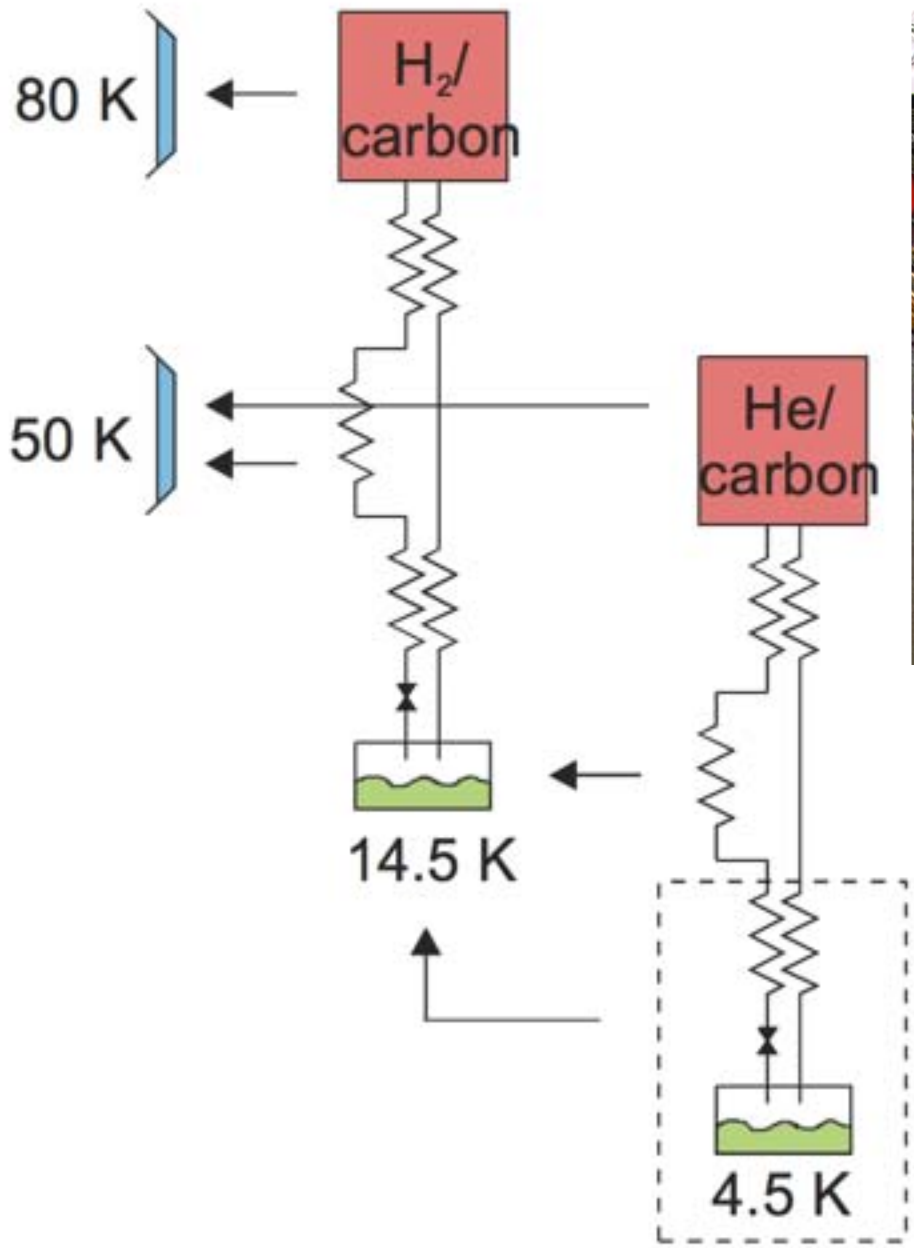


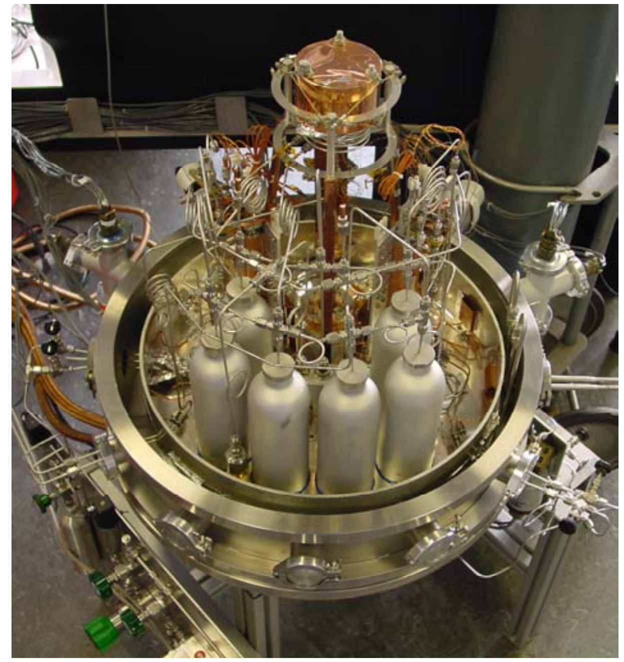
4.5 K helium cooler (ICC14, 2006)

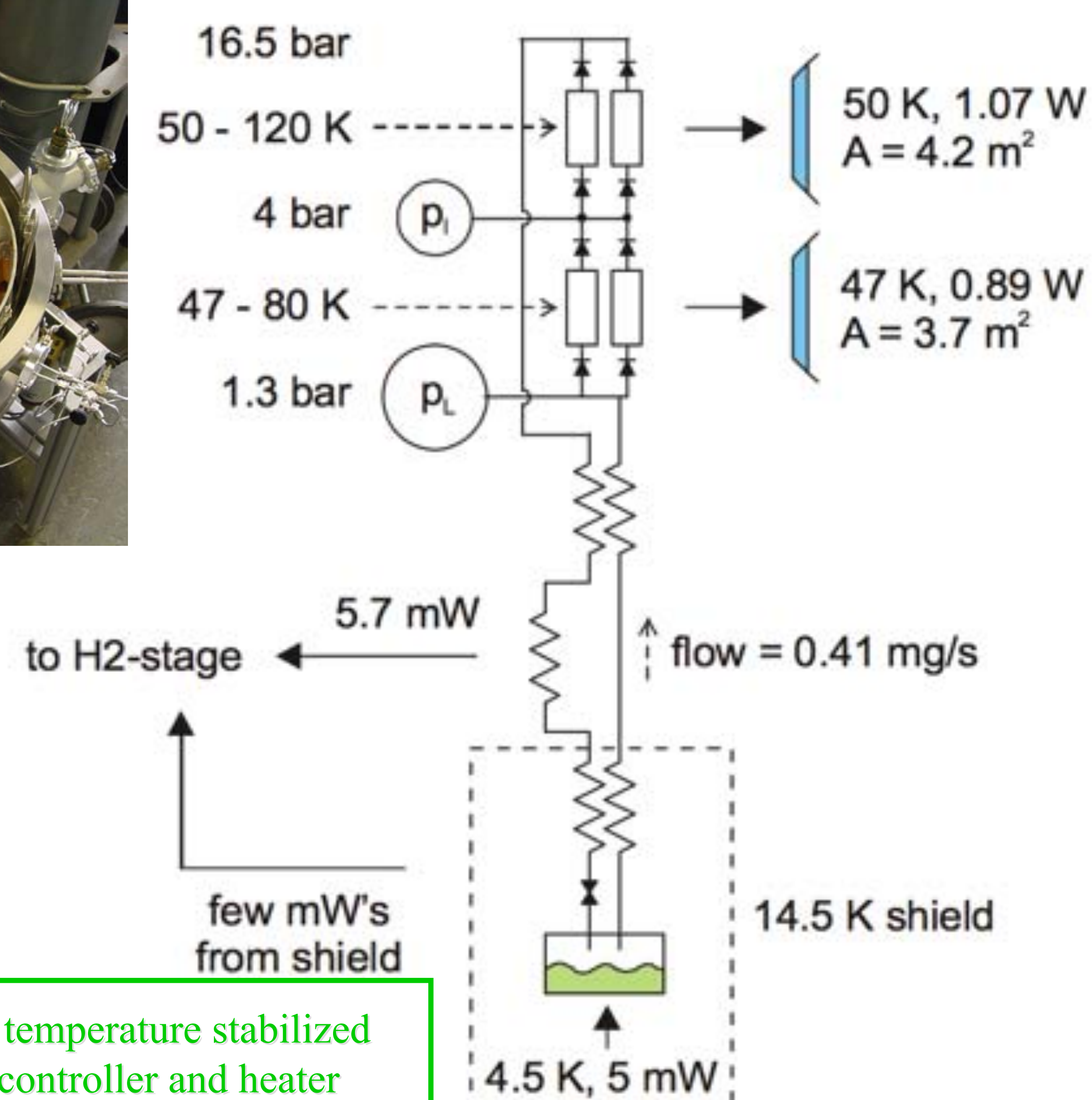




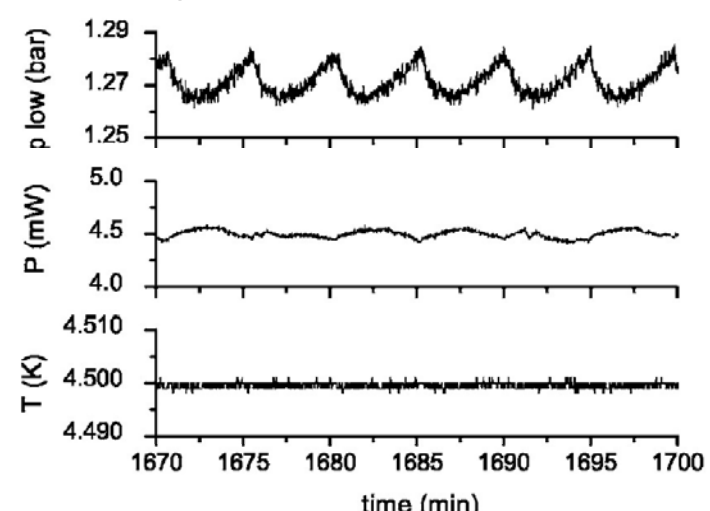
14.5 K hydrogen cooler (ICC17, 2012)







cold tip temperature stabilized by PID controller and heater



Typical results (Lab prototype)

4.5 mW @ 4.5 K
Tstability ≈ 1 mK

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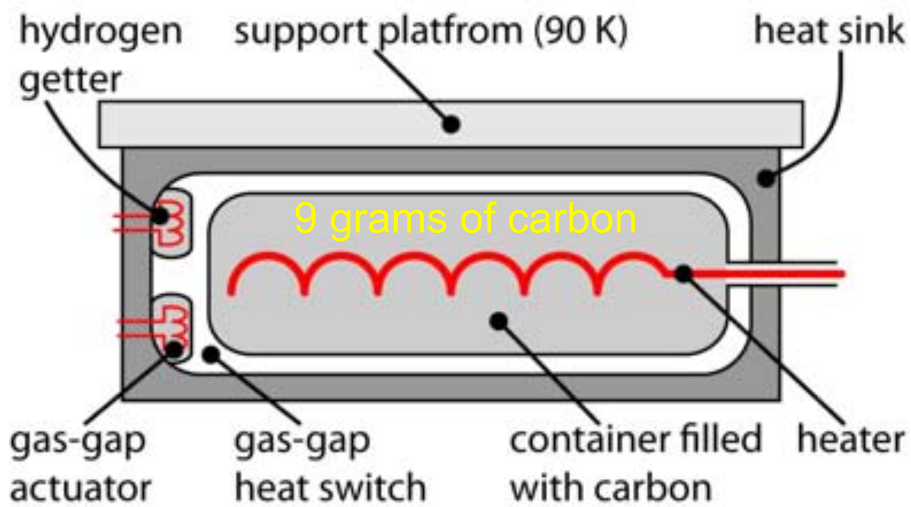
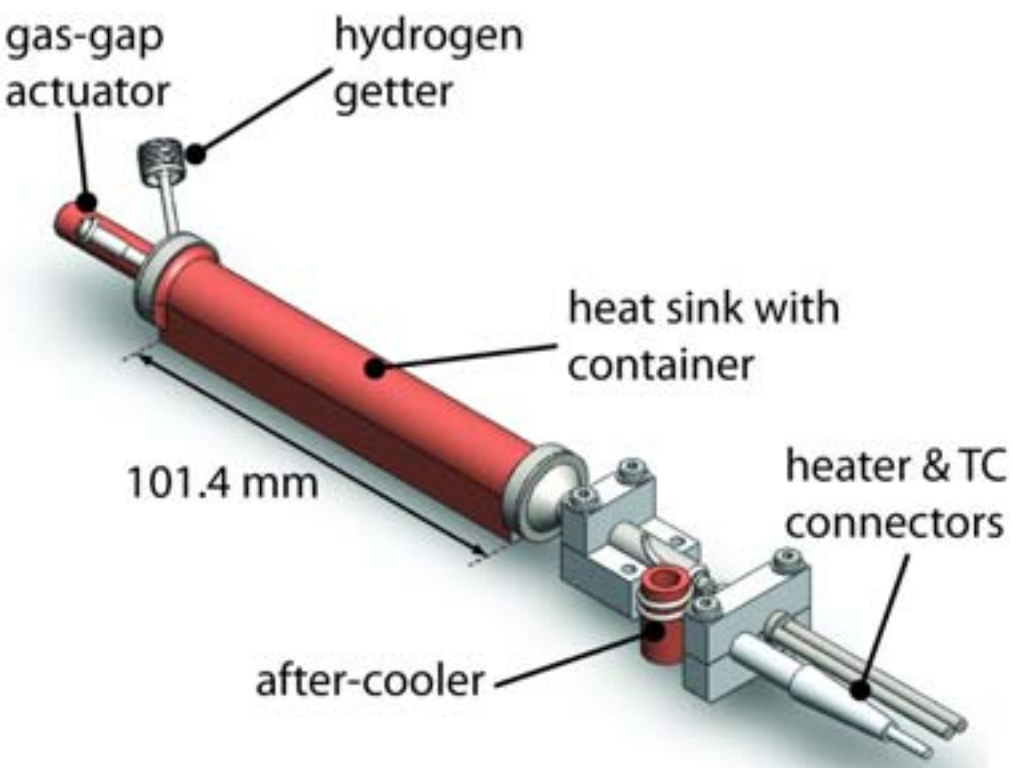
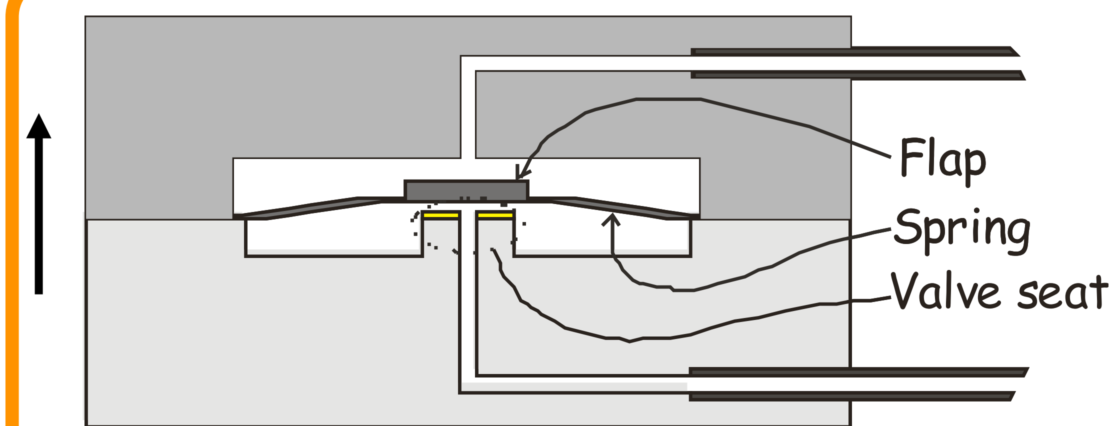
SMALL IS BEAUTIFUL



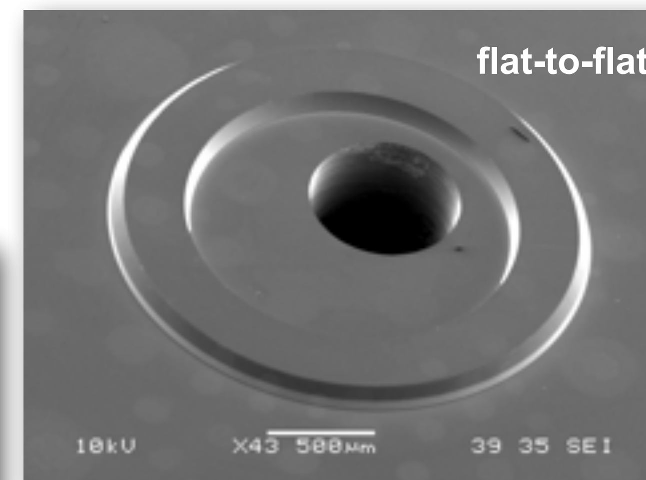


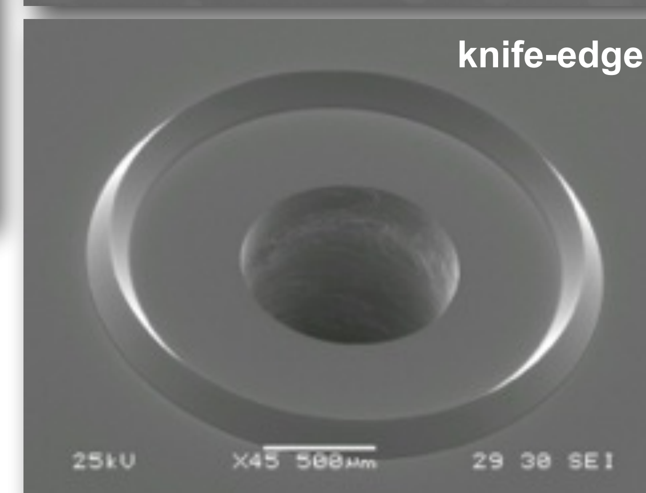


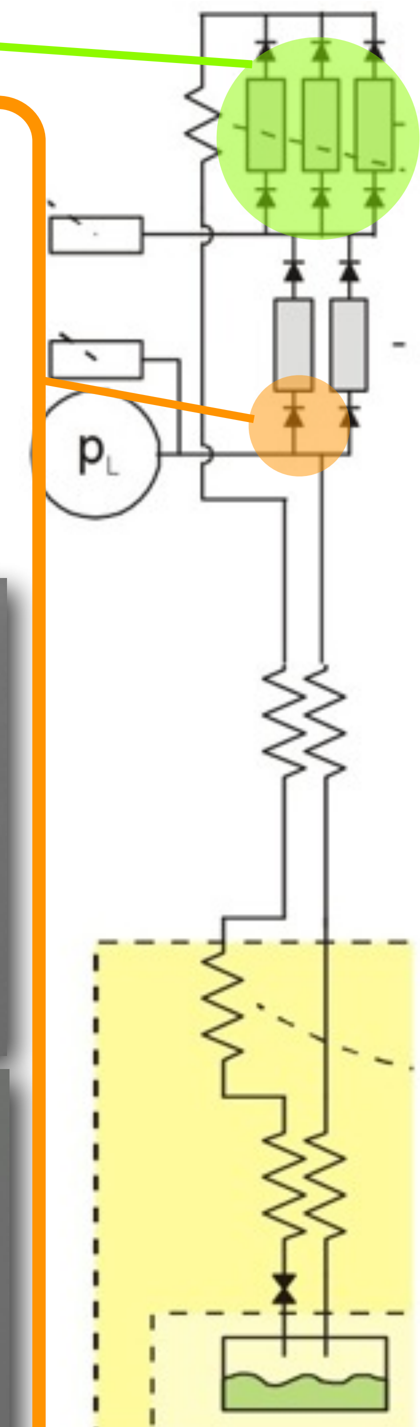
flat-to-flat seal
3 bar to 0.1 bar

flap: Au layer 10 μm

knife-edge seal
50 bar to 3 bar







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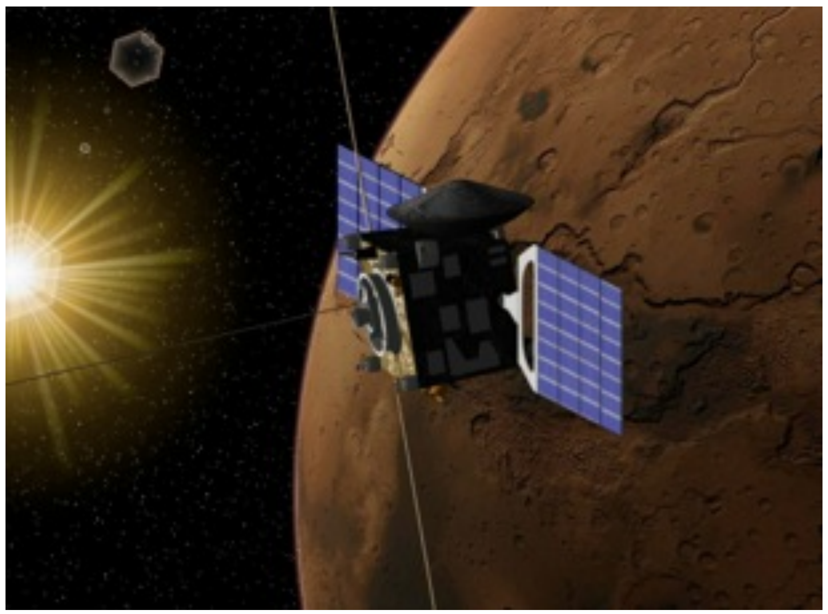
SPACE COOLING CHAINS

0.01 K 0.1 K 1 K 10 K 100 K 300 K



Passive Radiators

Stored cryogen (Cryostat)

Active "mechanical" coolers

"Ultra" low T coolers

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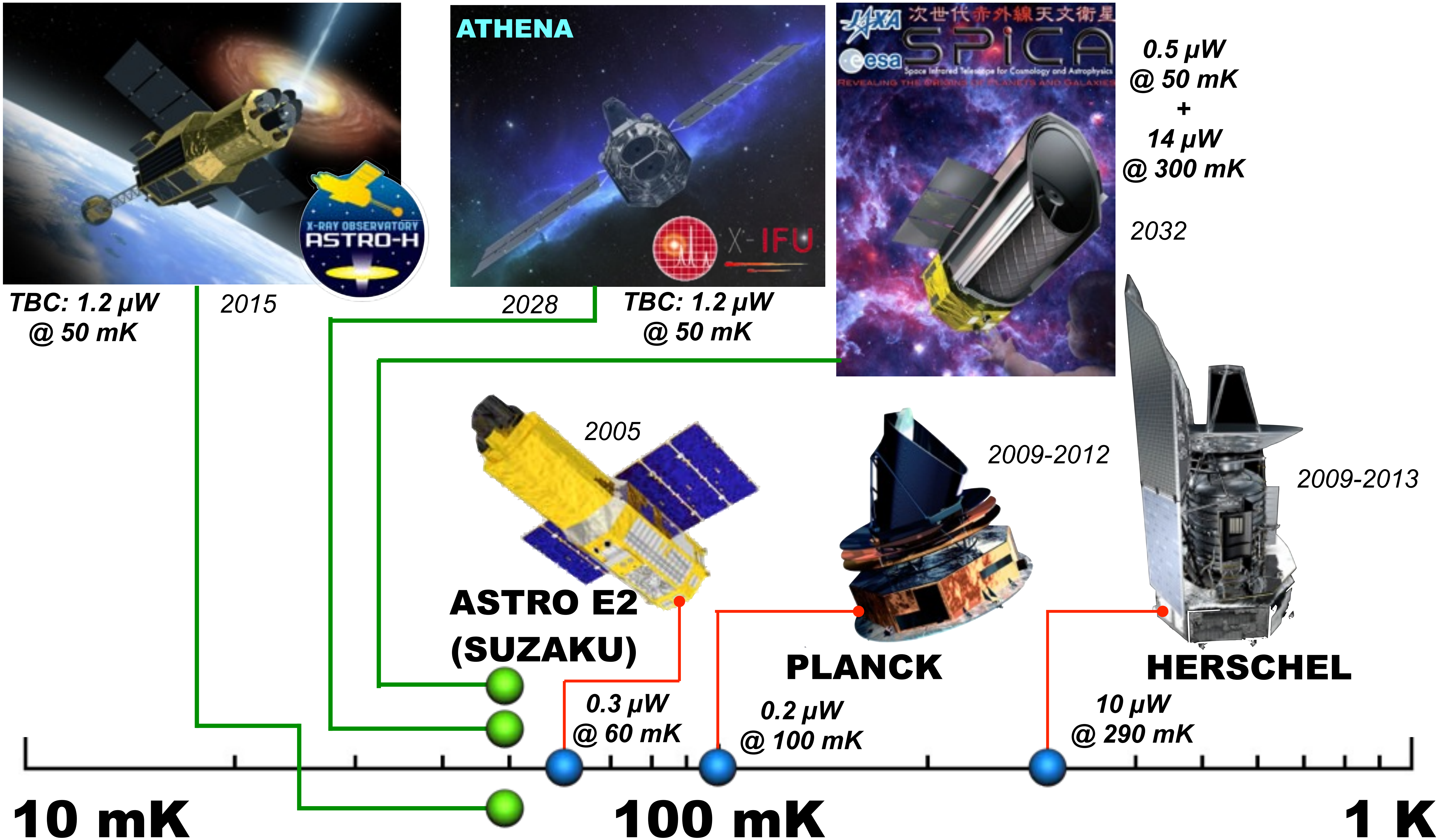
PAST (LAST DECADE) & FUTURE SUBKELVIN MISSIONS



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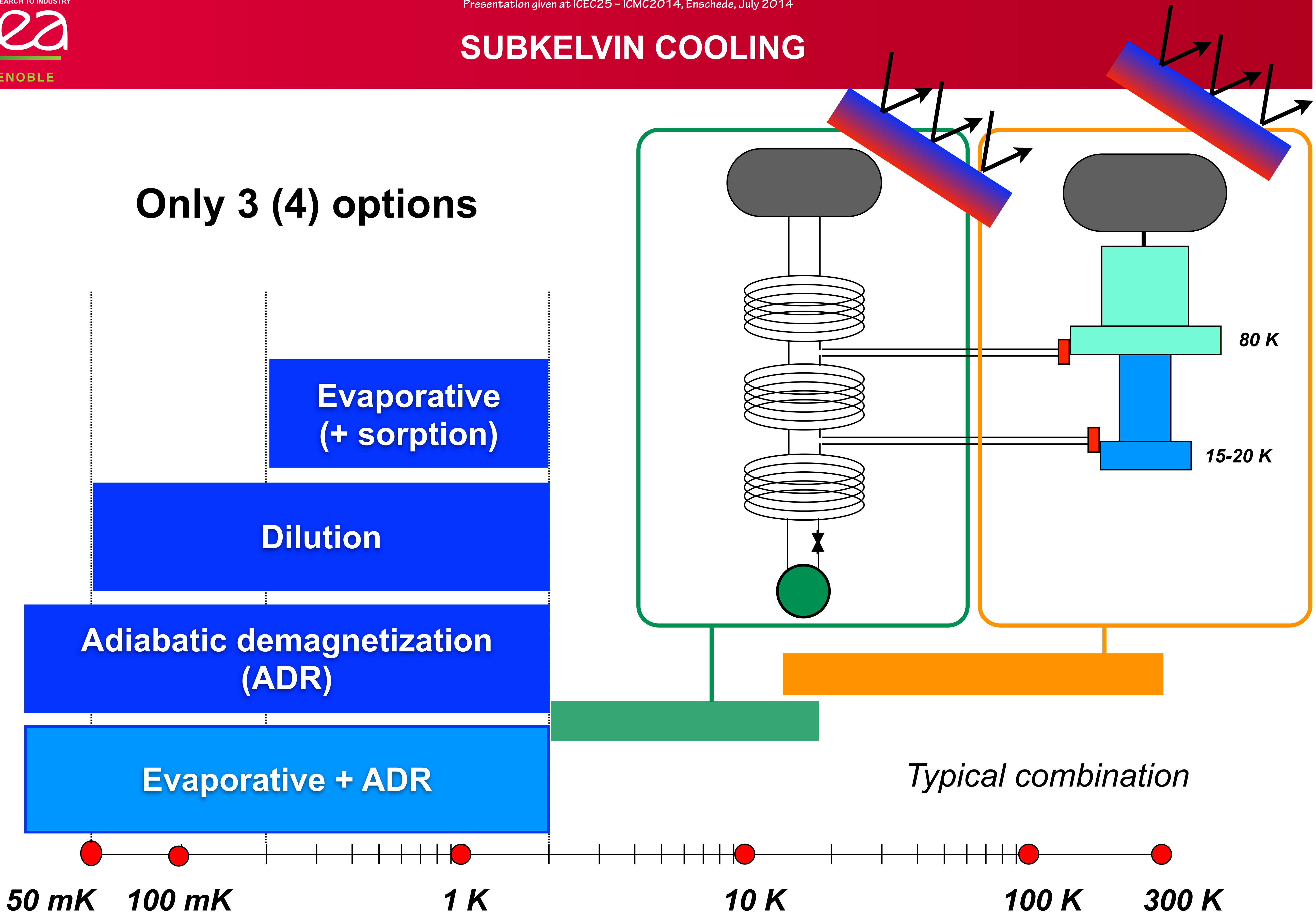
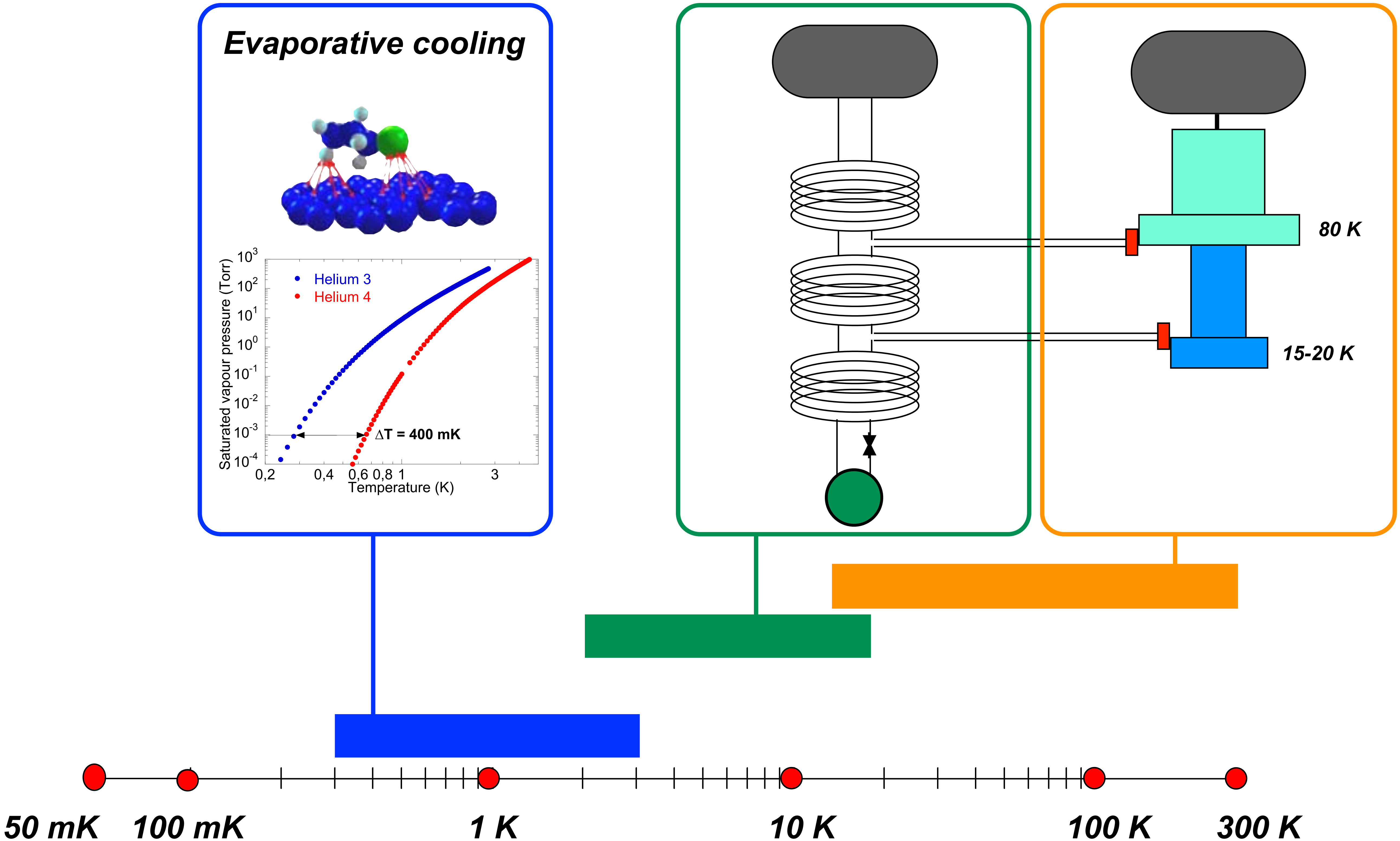
SUBKELVIN COOLING

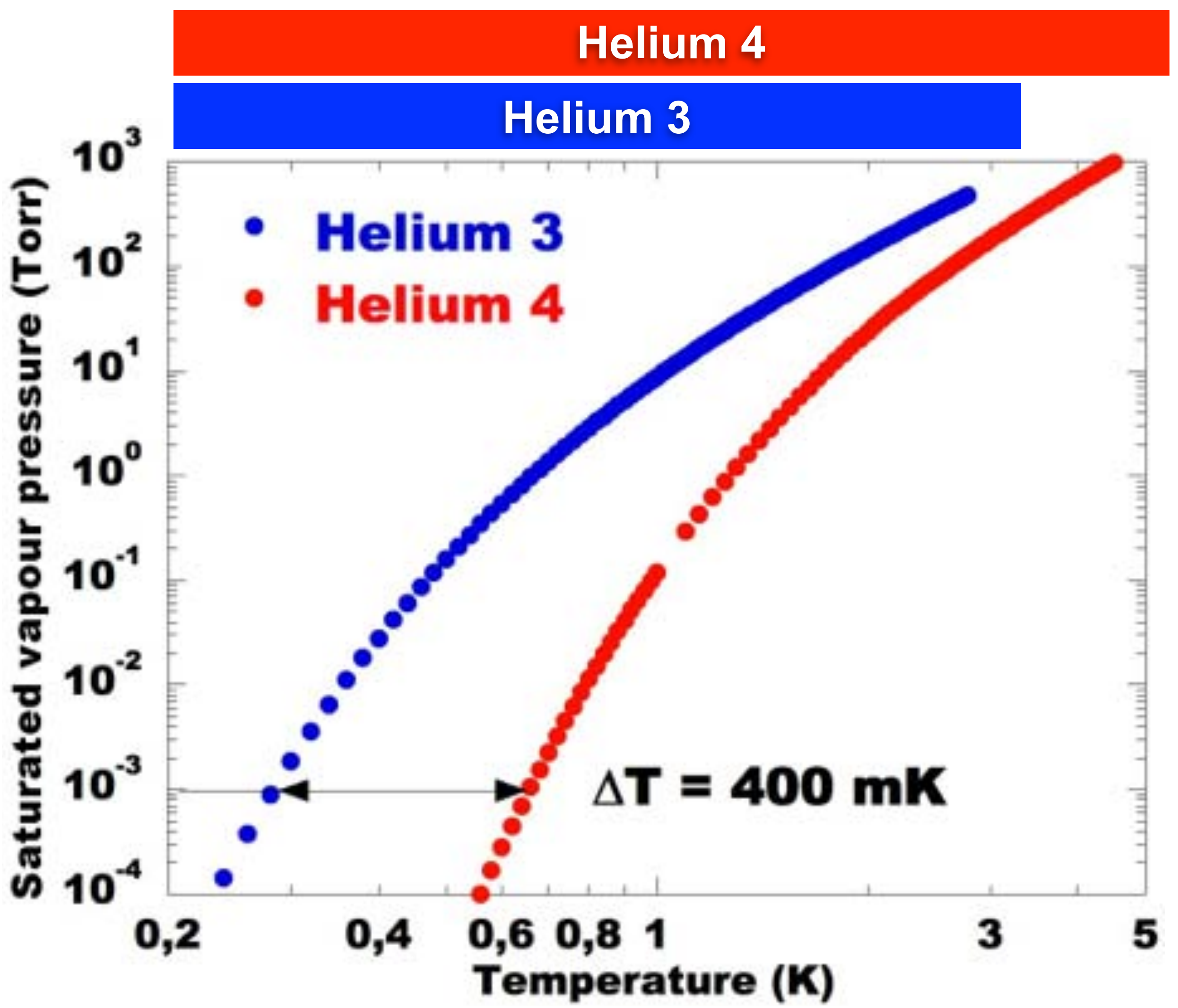
Only 3 (4) options

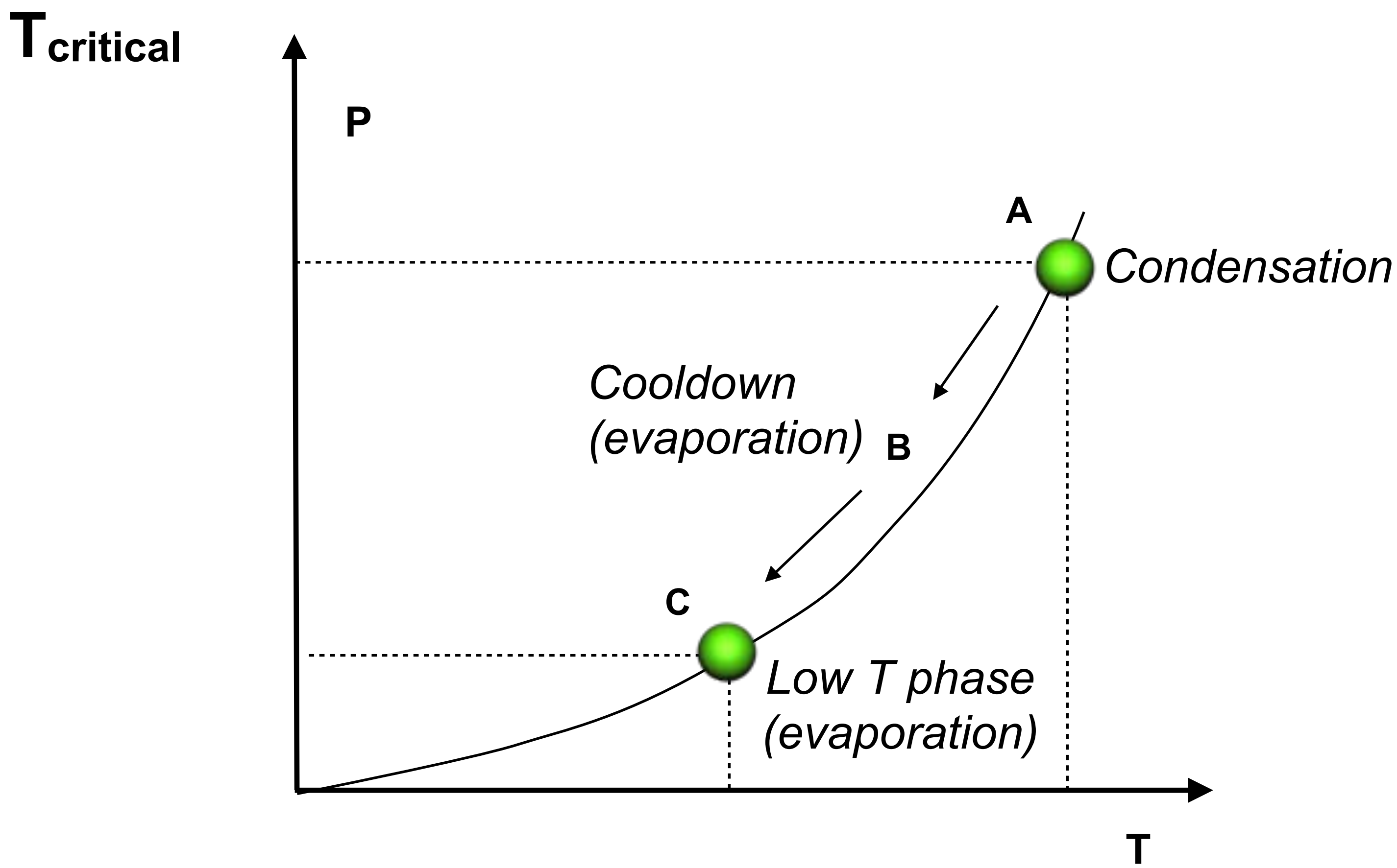


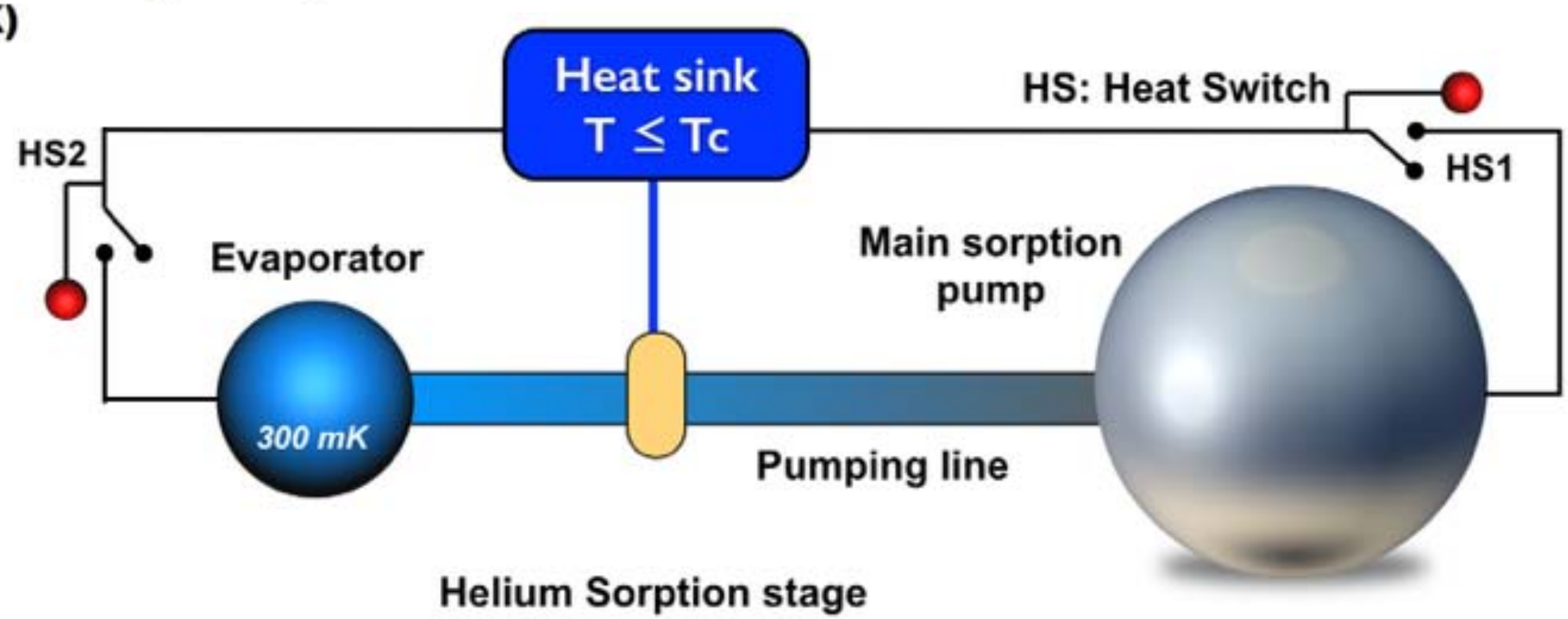
^{3}HE EVAPORATIVE COOLING



HELIUM EVAPORATIVE COOLING







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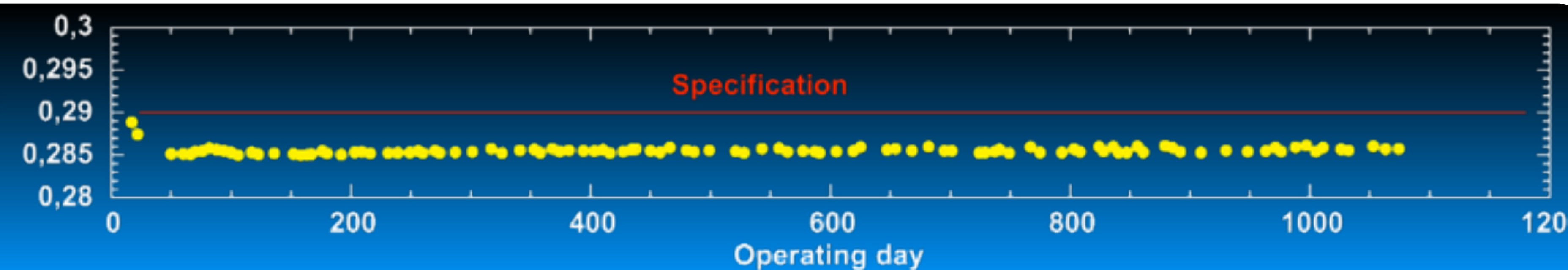
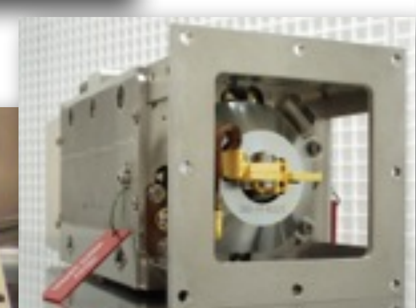
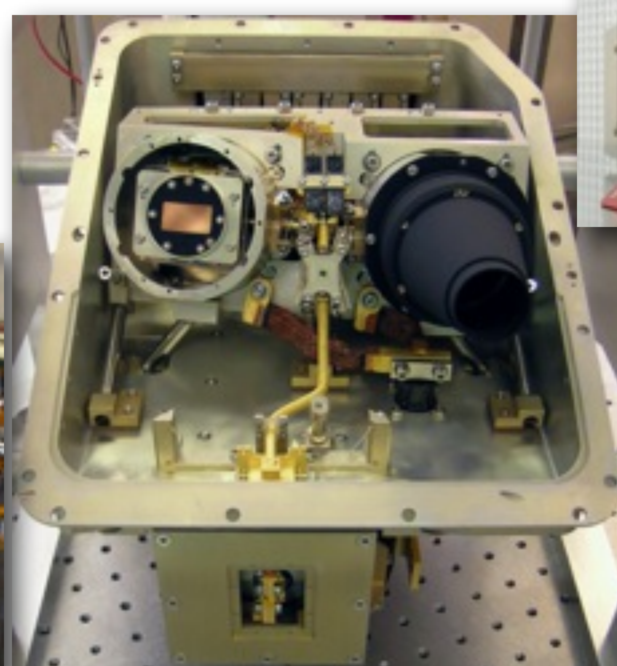
HERSCHEL

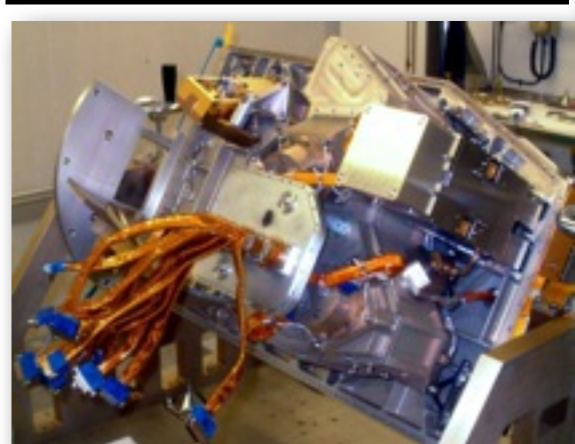
HERSCHEL

SPIRE Sorption unit









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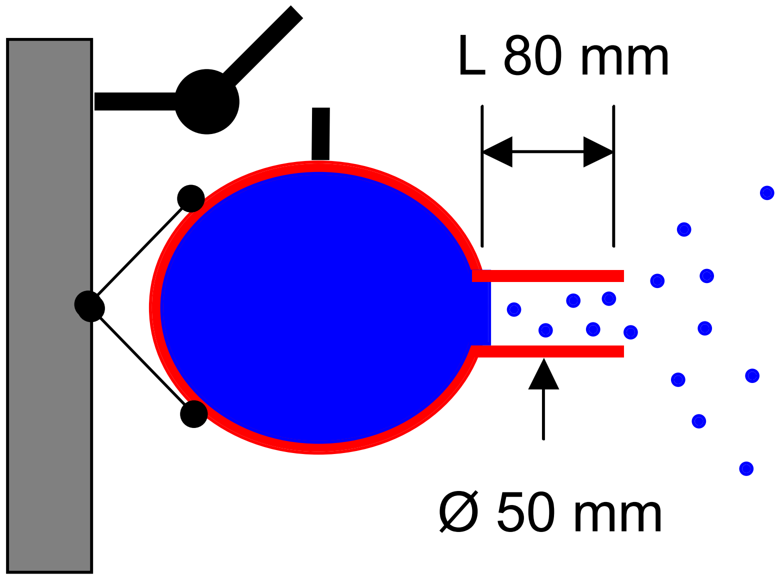
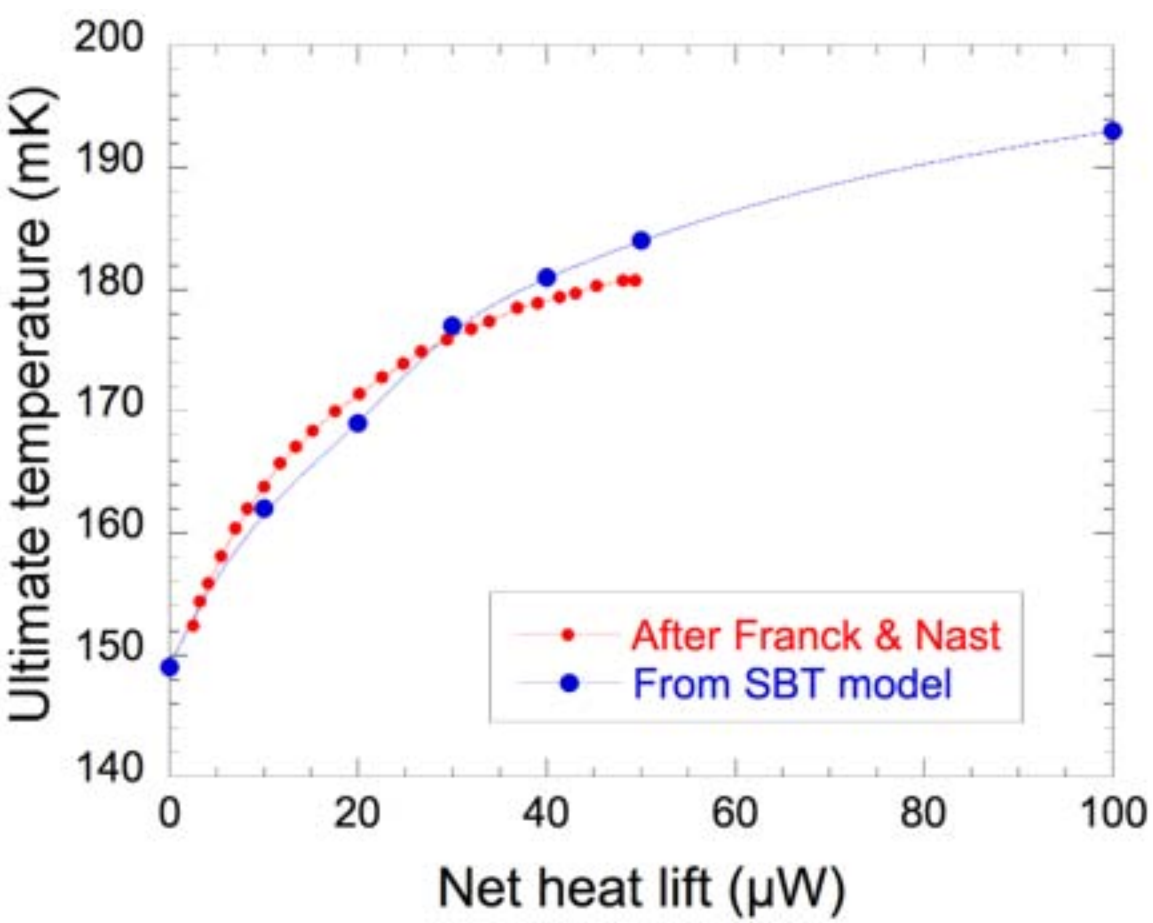
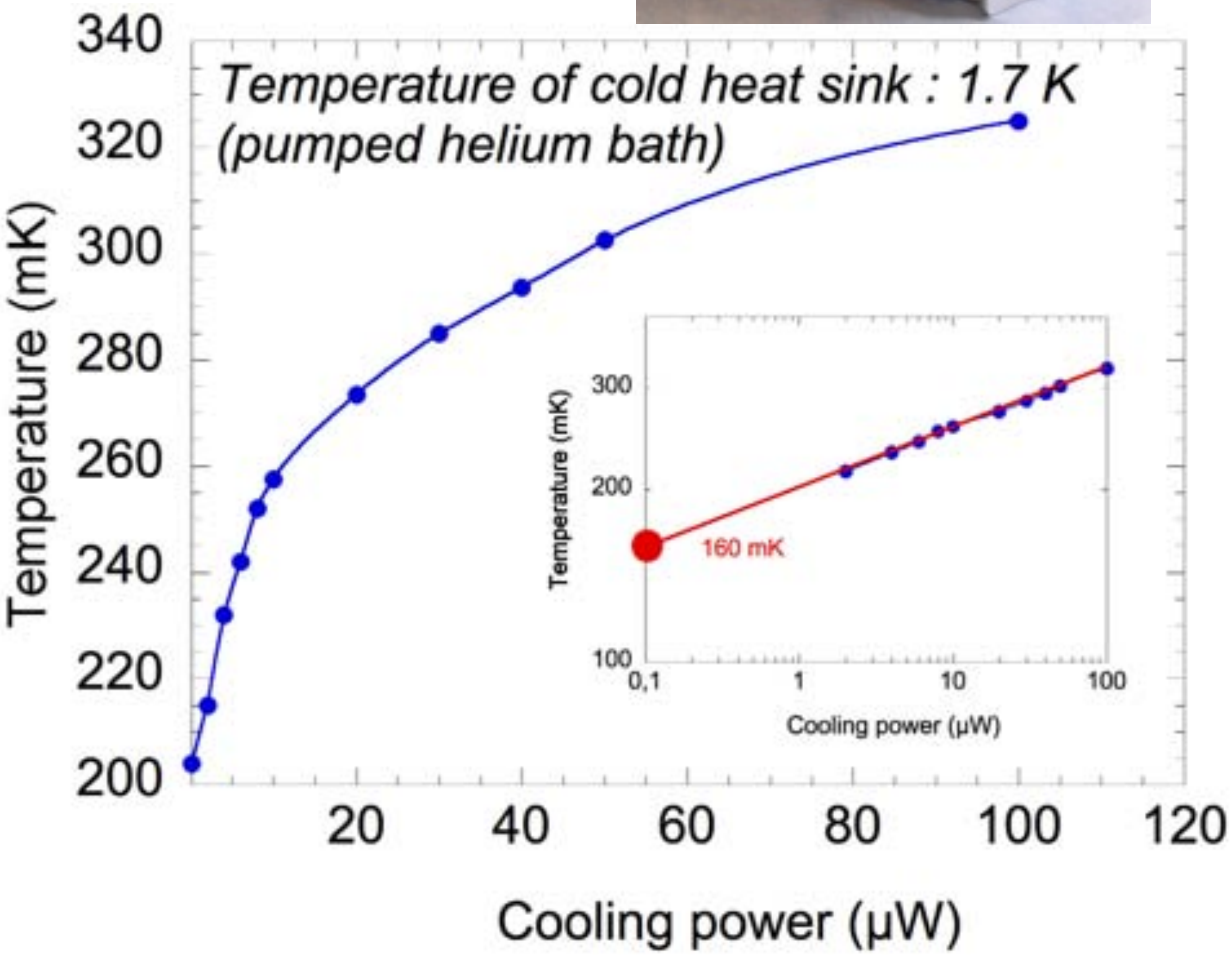
3HE SORPTION COOLER: ULTIMATE T ?





In practice
Multistage system
(^4He, ^3He, ^3He)
Ground based



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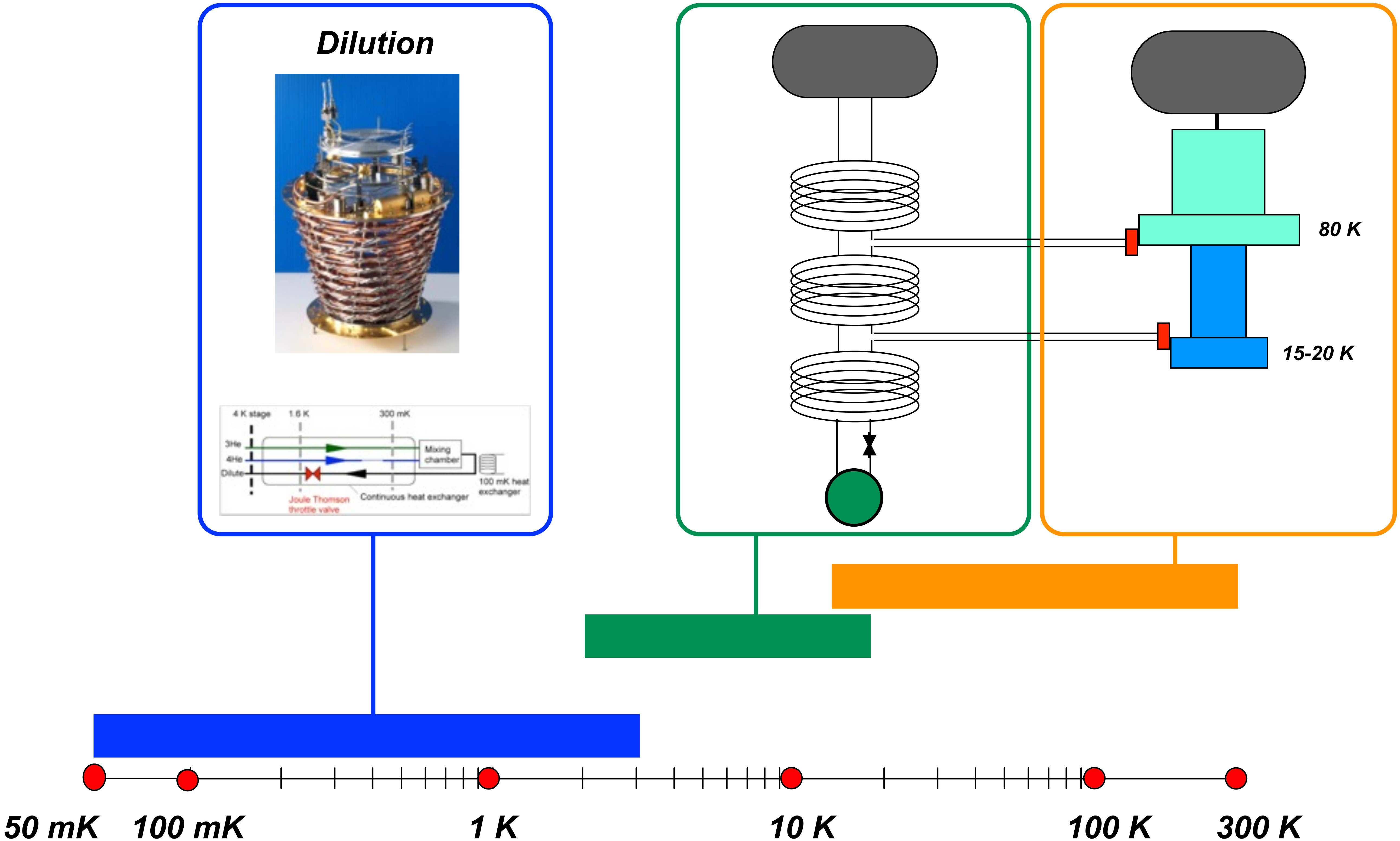
DILUTION COOLER



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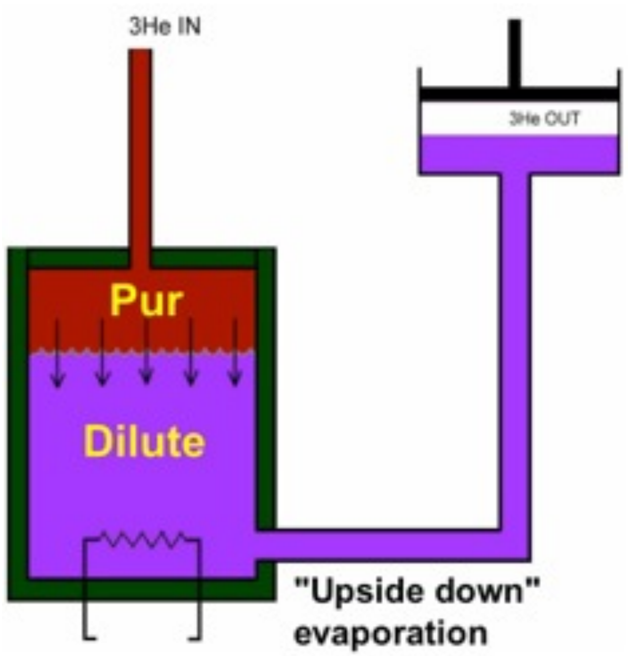
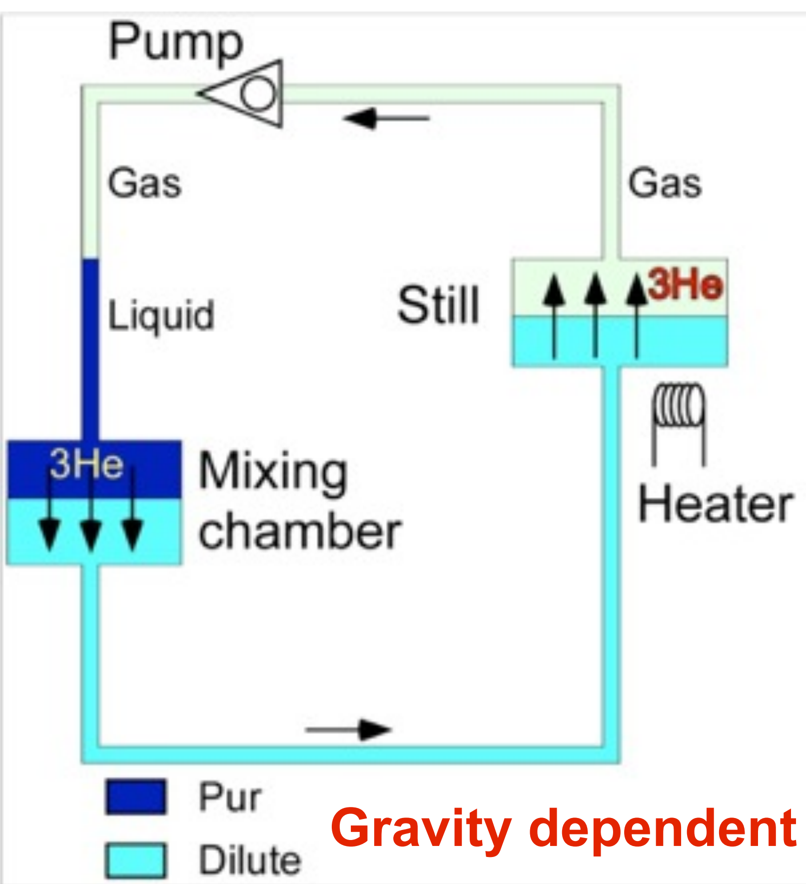
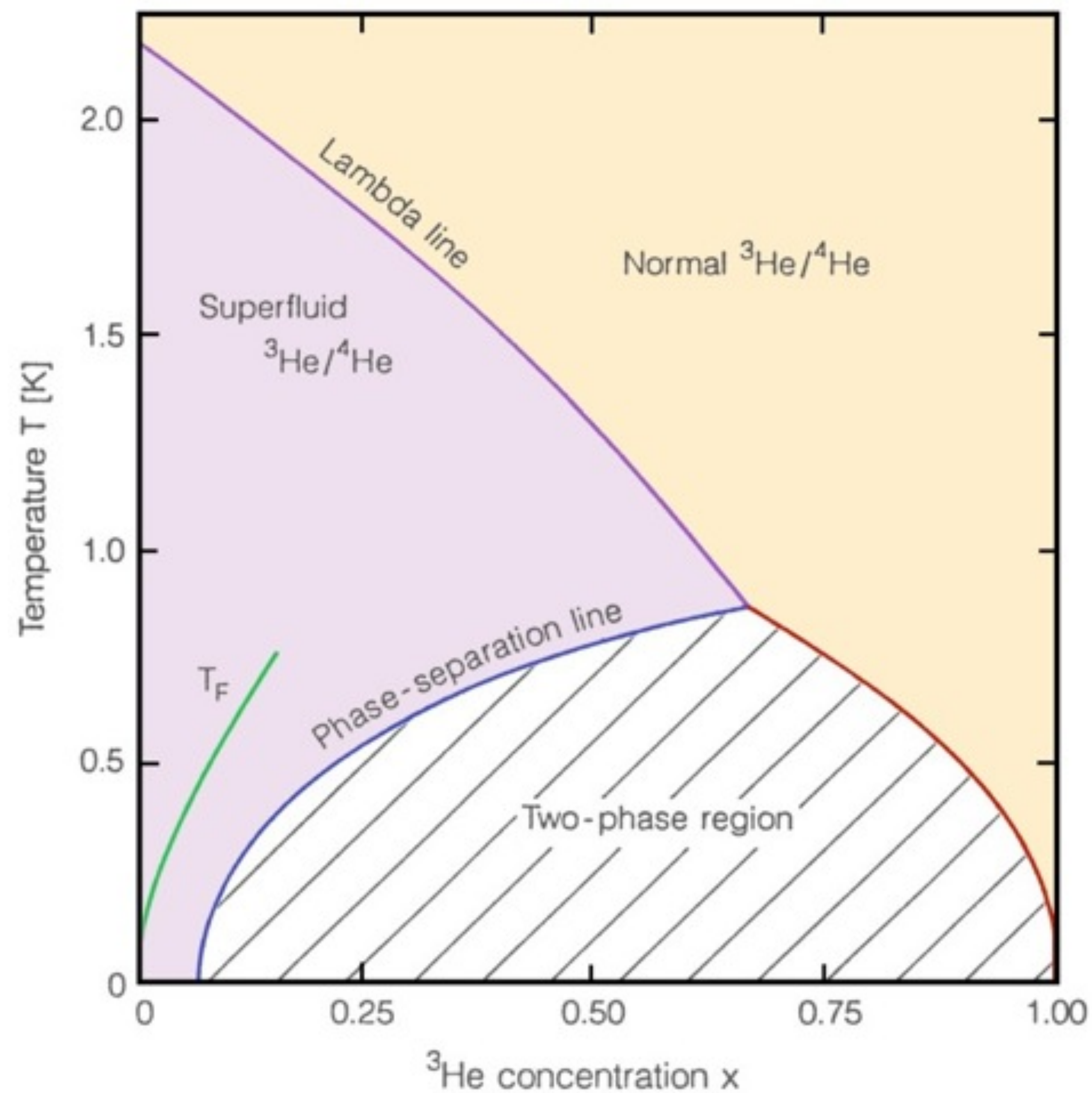
DILUTION


3He IN
3He OUT
Pur
Dilute
"Upside down"
evaporation


Pump
Gas
Gas
Liquid
Still
3He
3He
Mixing
chamber
Heater
Pur
Dilute
Gravity dependent


Temperature T [K]
2.0
1.5
1.0
0.5
0
Lambda line
Normal $^3He/^4He$
Superfluid
$^3He/^4He$
T_F
Phase-separation line
Two-phase region
0
0.25
0.50
0.75
1.00
^3He concentration x

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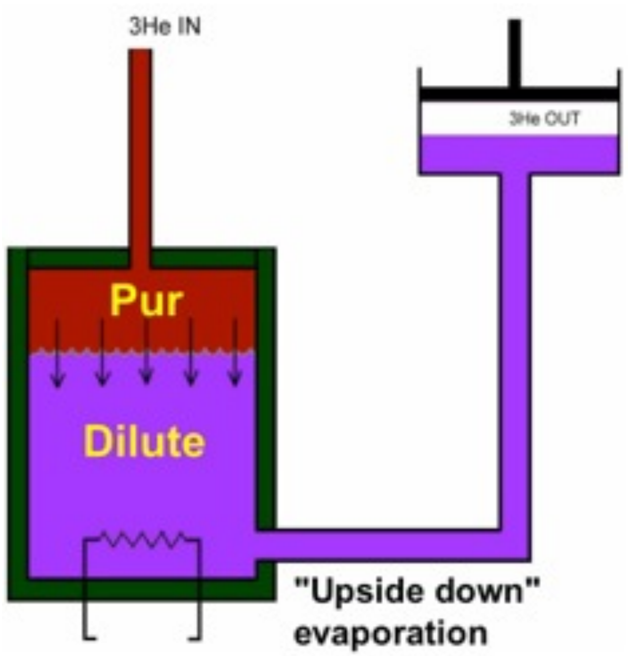
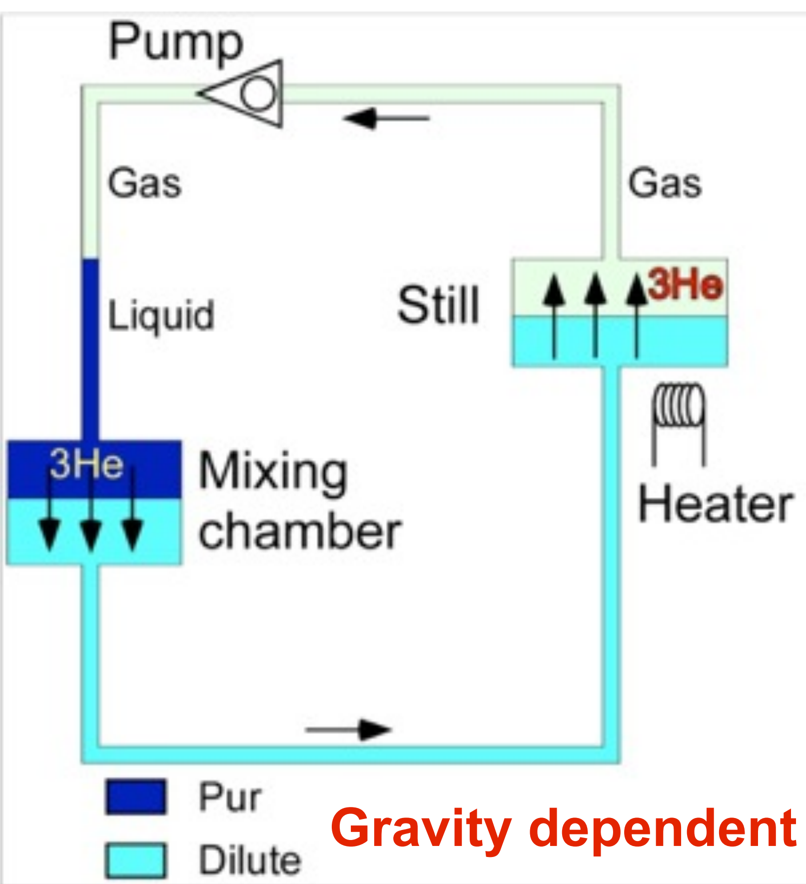
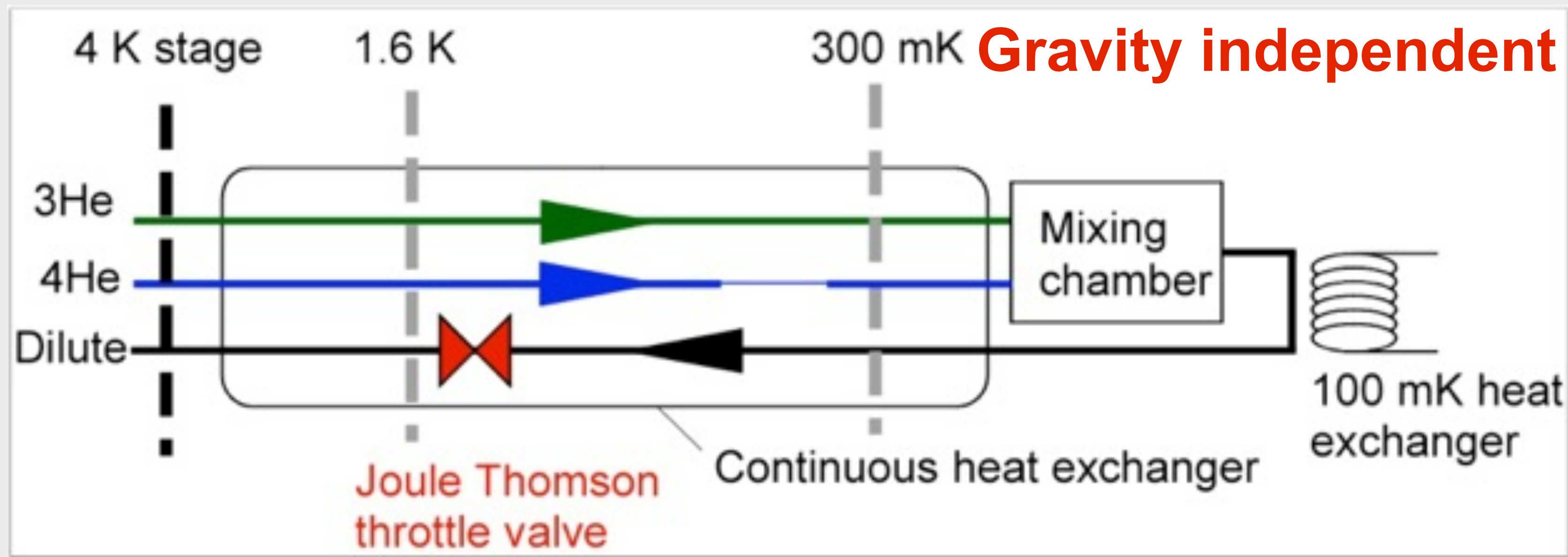
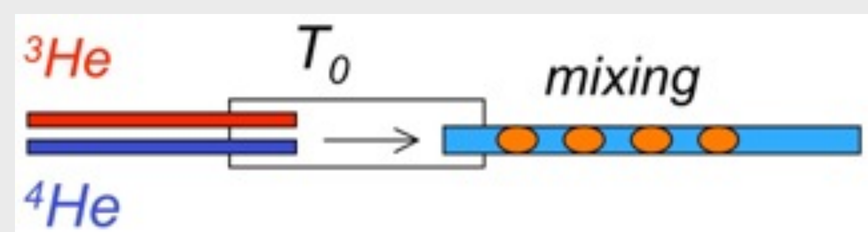
DILUTION









- Can be operated from a 4 K heat sink
- Cooling P @ T ultimate
+
available cooling continuously from 4K down to T ultim.

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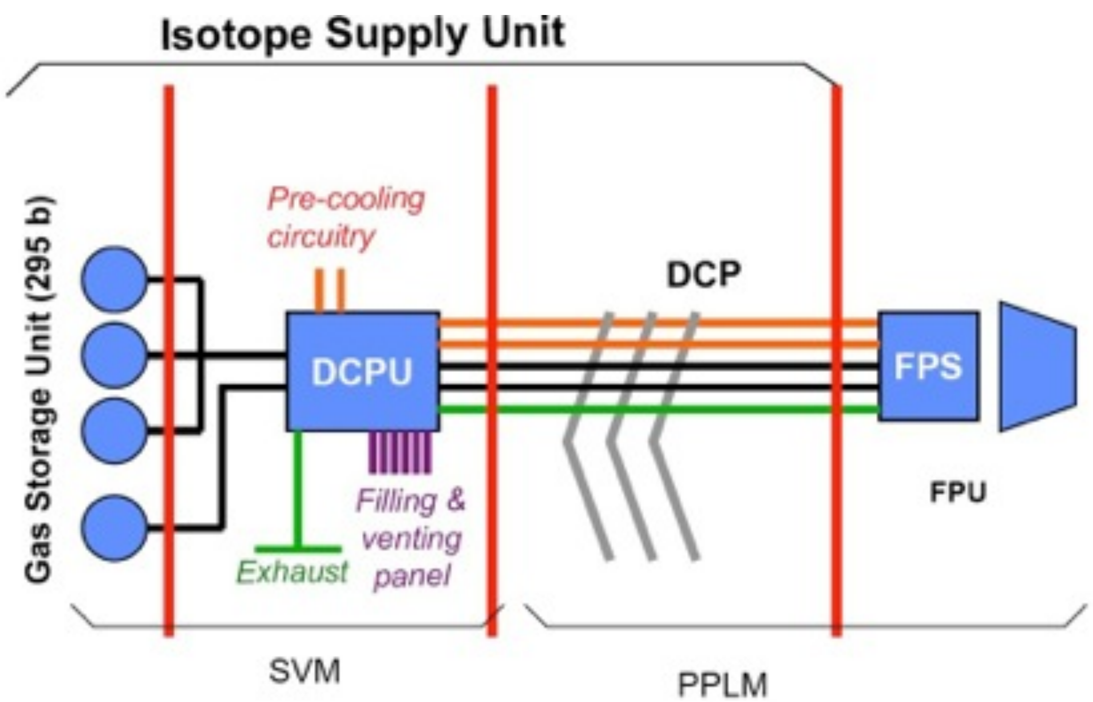
PLANCK DILUTION COOLER

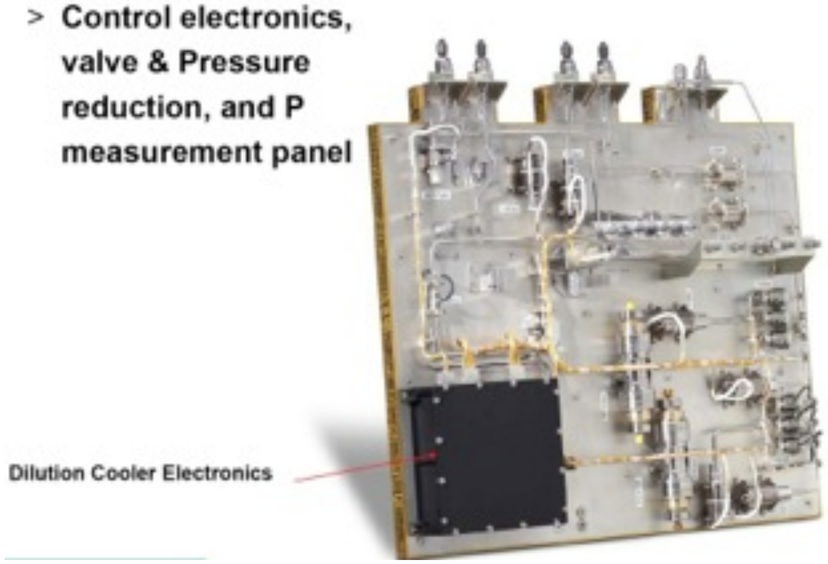


200 nW @ 100 mK

continuous cooling from 1.6 K (≈ 8 µW)

Open cycle: Lifetime limited ≈ 2 years mission

- Control electronics, valve & Pressure reduction, and P measurement panel



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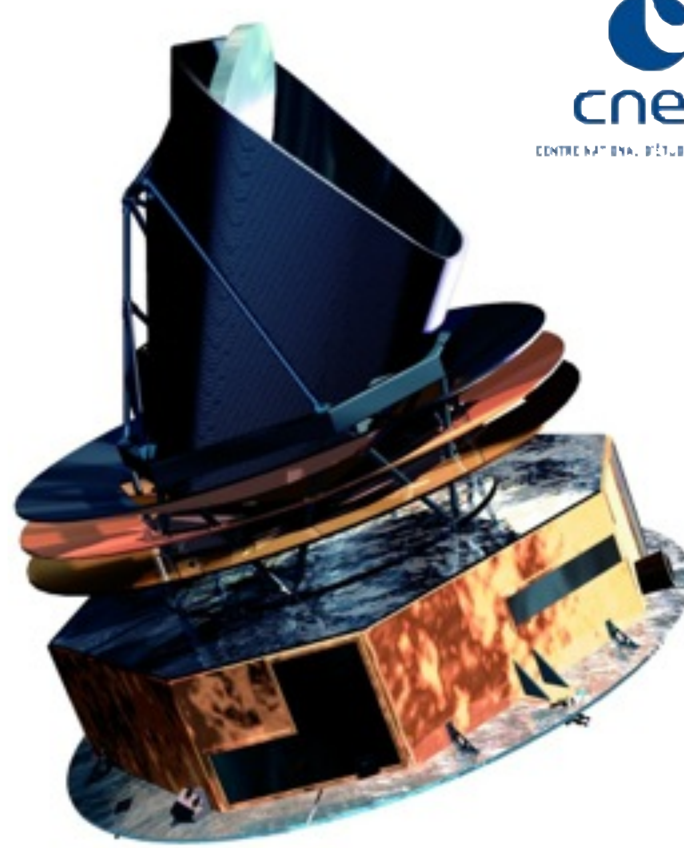

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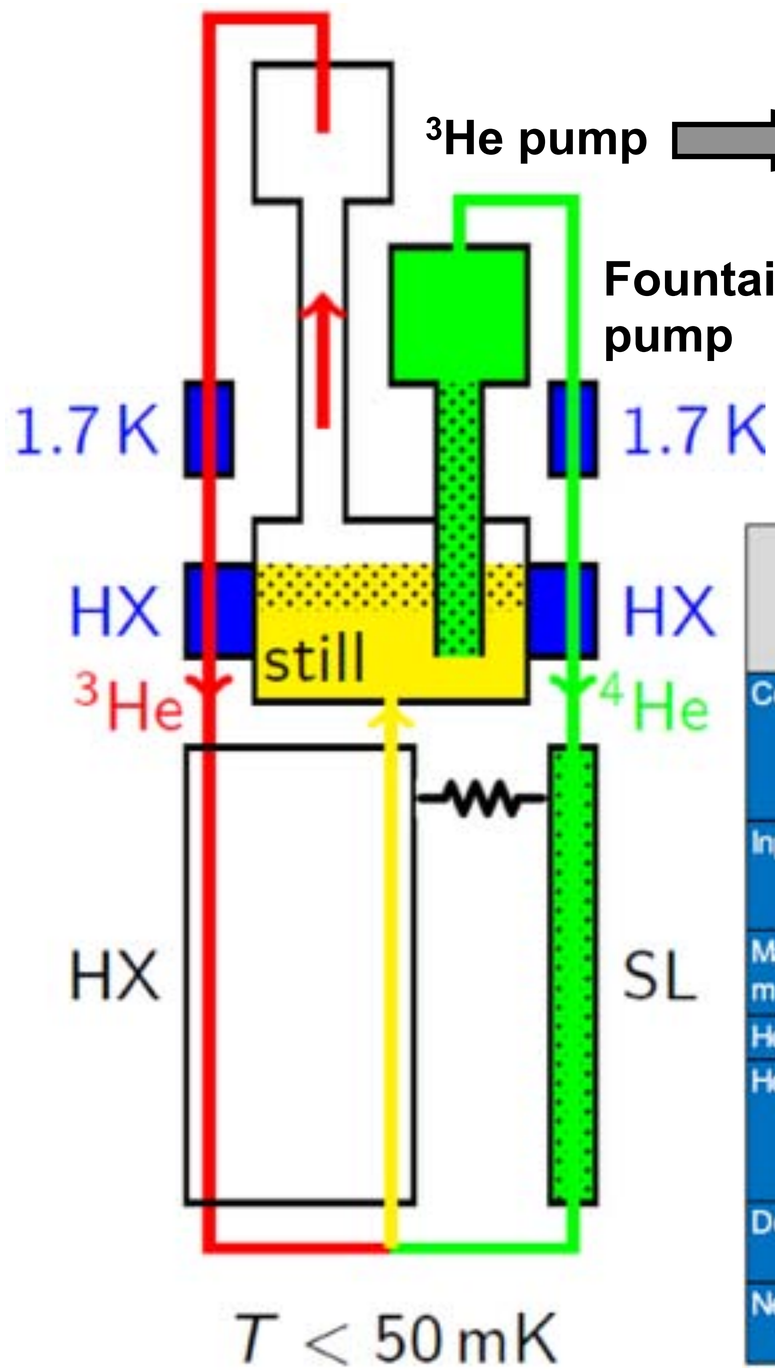
CONTINUOUS DILUTION COOLER



Circulate the ^{3}He

Parameter	Linear Compressor (JAXA + SHI)	Sorption Compressor (COOL + U.Twente)	Holweck Compressor (CNRS + AL)
Compression ratio	5.4mb/140mb (@17µmol/s) demonstrated	5mb/200mb (@20µmol/s) expected	5mb/200mb (@20µmol/s) demonstrated
Input Power (no margin)	<80W	~10W@300K (estimated)	~100W@300K (estimated)
Mass (without electronics & margin)	~20kg	~2.2kg	~2kg
Heat lift below 300K	None	~80mW@15K	None
Heritage	Based on 1K-Class JT Cooler EM compressors	Based on the 4K JT Sorption Cooler EM for Darwin	No space heritage except for gas bearings (MELFI)
Dev. Status	BBM under assembly	Check valves demonstrated	Compression ratio demonstrated
Next development steps	BBM evaluation	15K demonstrator	Demonstrate gas bearings

Latest result:
1 µW @ 51 mK (liquid T !)

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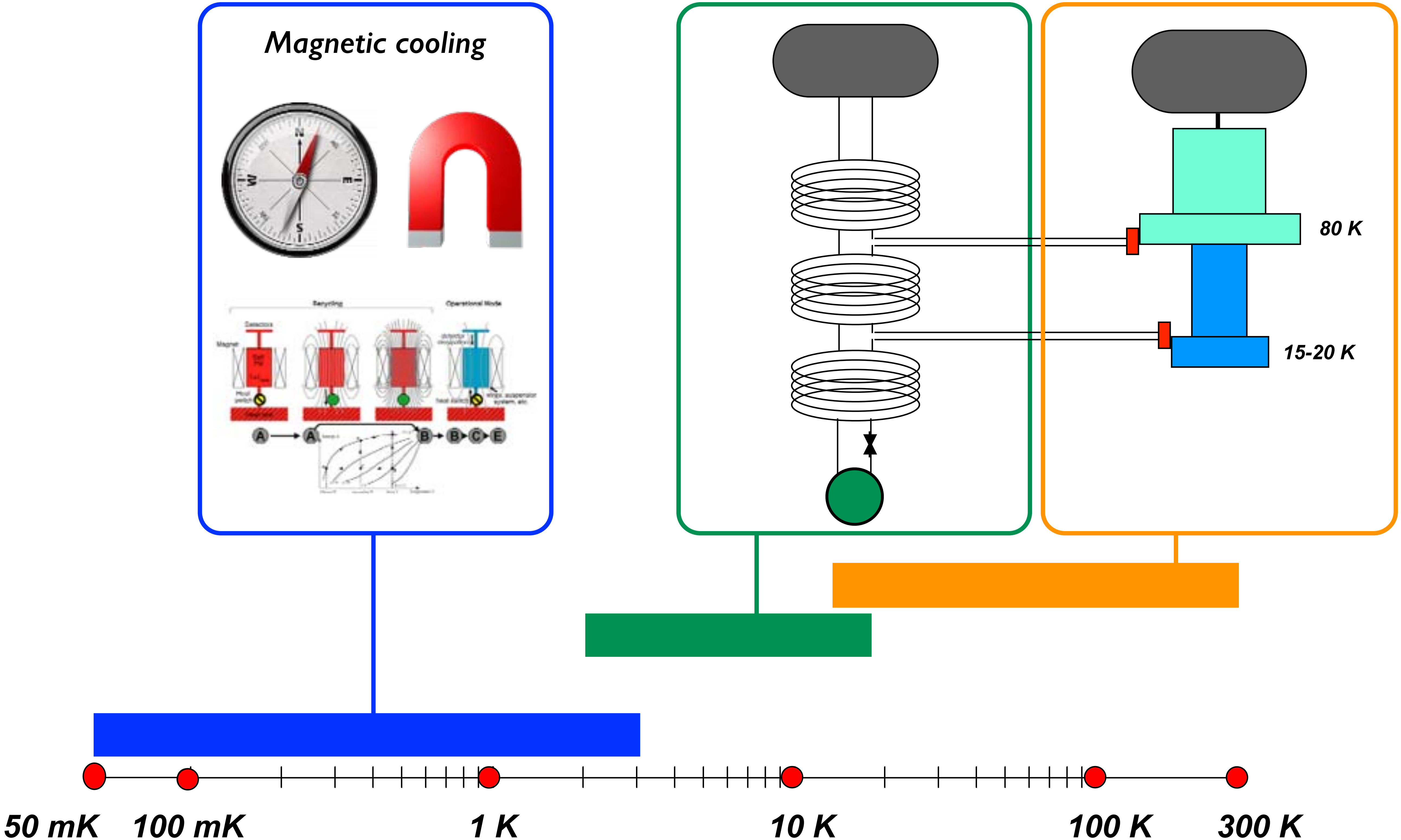
ADIABATIC DEMAGNETIZATION



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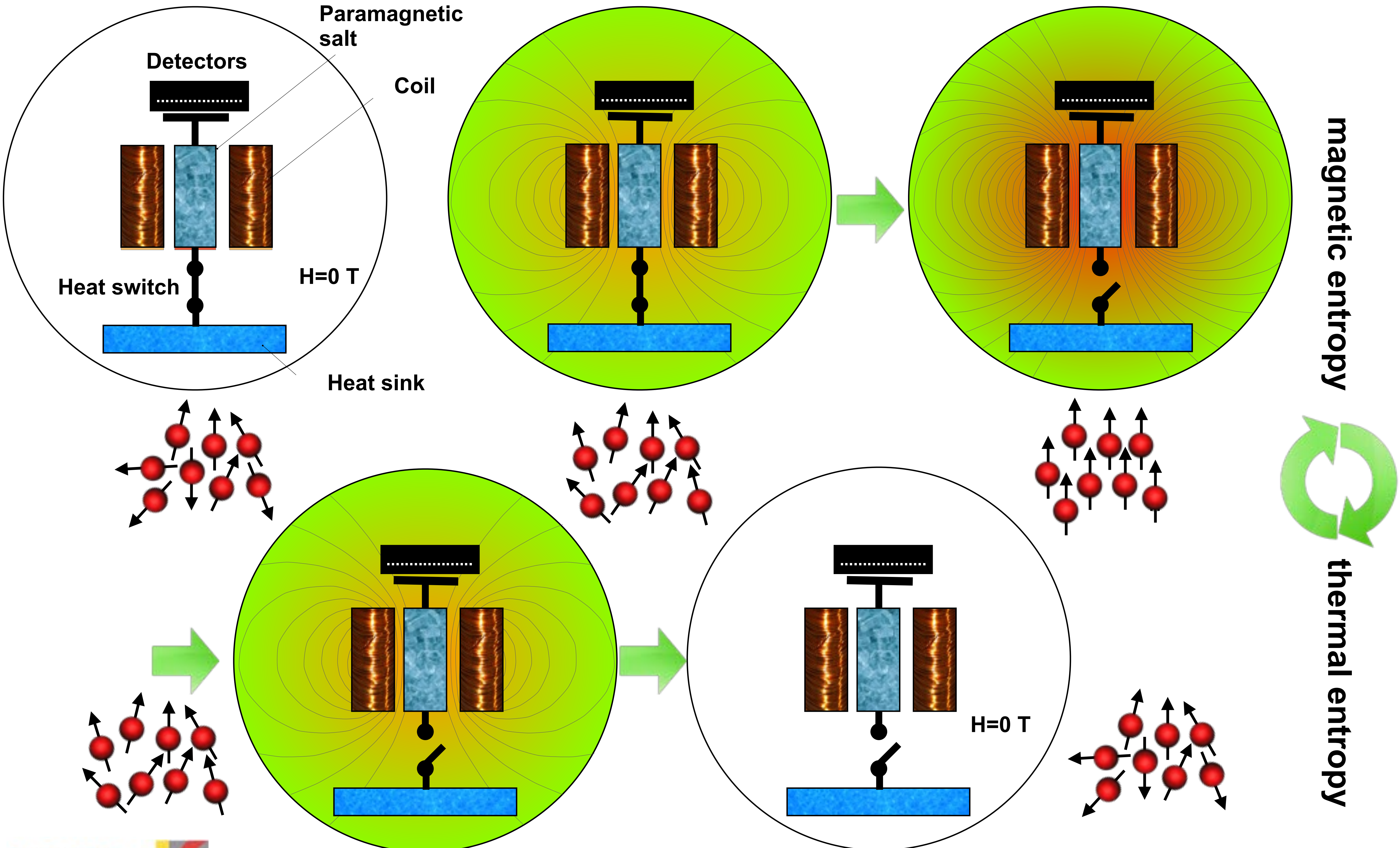
ADIABATIC DEMAGNETIZATION



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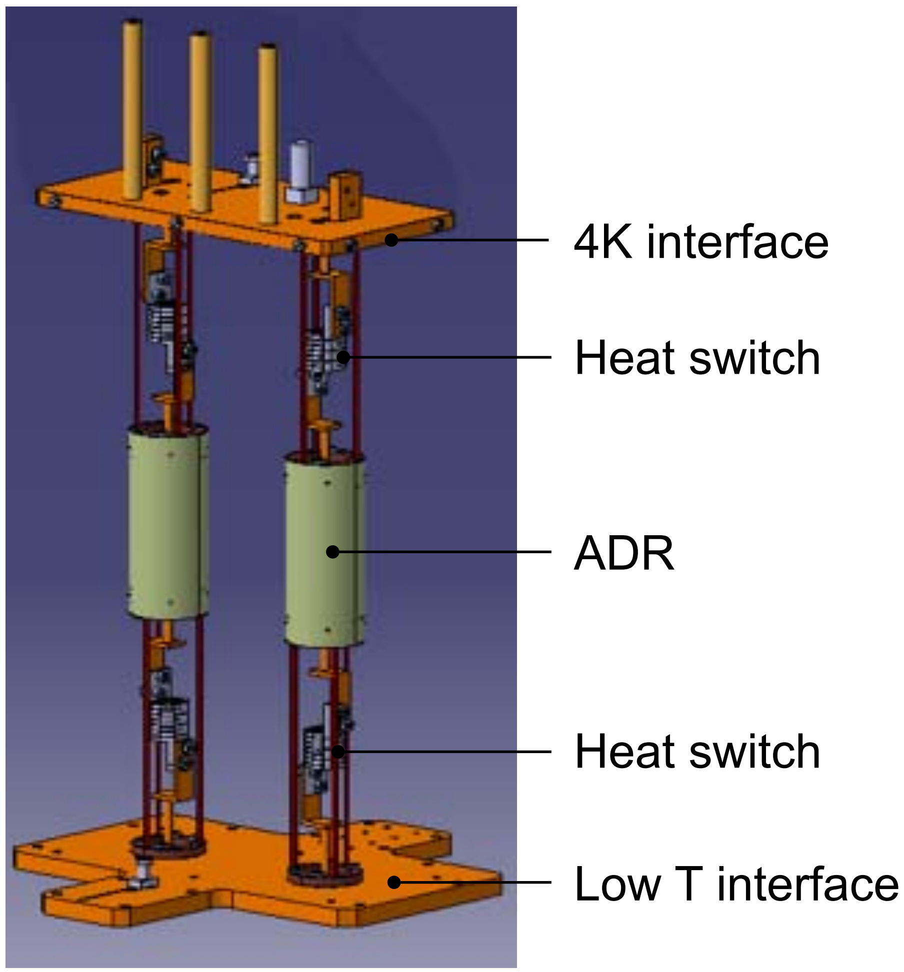
RAPID RECYCLING TANDEM ADR (CONTINUOUS)

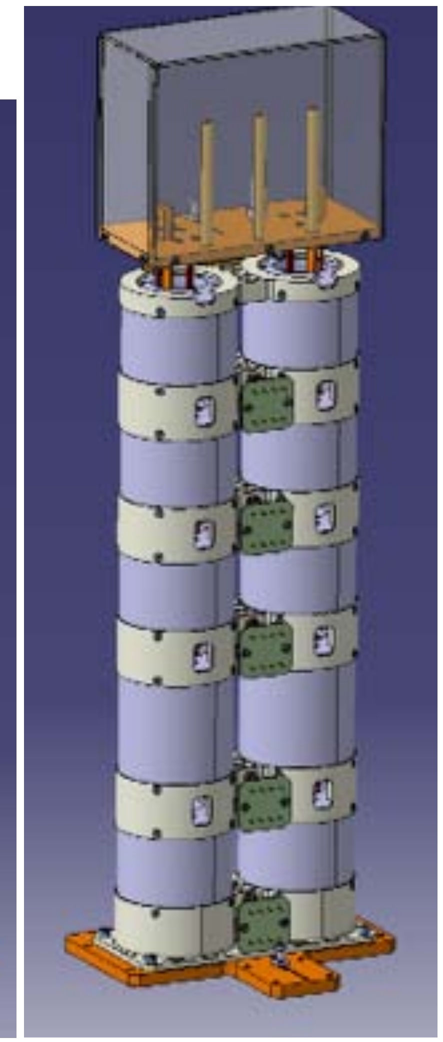
- **Tandem magnetic refrigerators**
- **Utilizes two magnetic cooling chains**
- **Provides continuous cooling**
- **Magnets are shielded**
- **Single thermal interface (4 K or lower)**

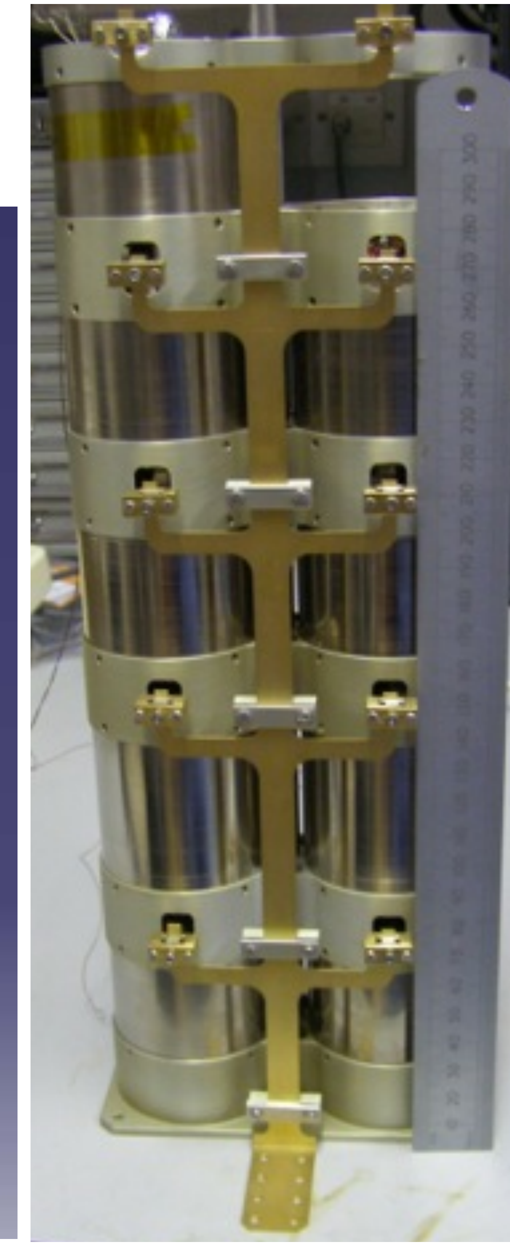
Preliminary results on single stage



200 mK - 4 K:
Recycling time ≈ 2.5 minutes
(4K to 170 mK in 30 sec.)

Next step





Estimated base operating T:

80 mK from 4 K

50 mK when operated from 2 K

H 355 x W 120 x D 56 mm
8.3 kg

Predicted cooling powers based on hold time of 10 minutes and operated from 4 K:
- 1 μW at 80 mK
- 5 μW at 100 mK
- 41 μW at 300 mK

UCL MSSL

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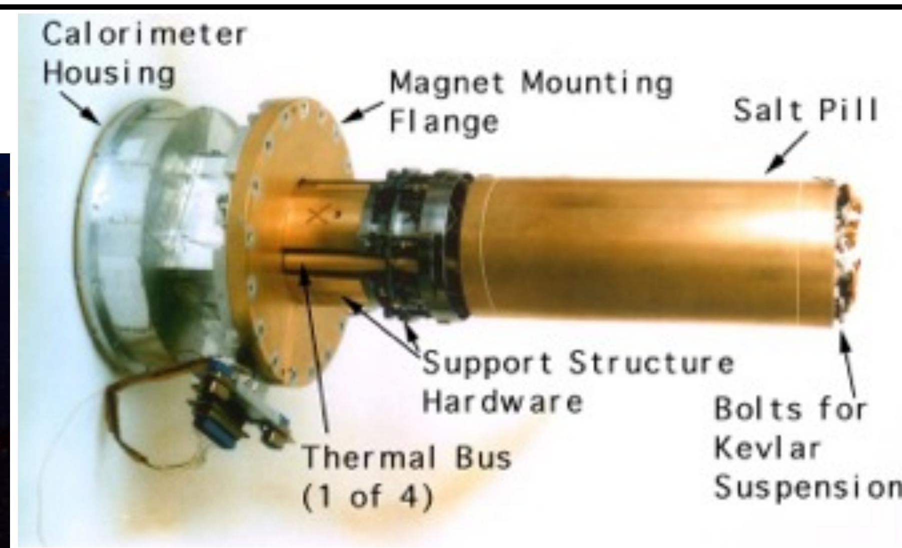
ASTRO E2 (SUZAKU) ADR & CADR



60 mK reached on orbit !
Lowest T of (known) universe

cnrs
NÉEL institut
NASA
CODE 552 CRYOGENICS & FLUIDS
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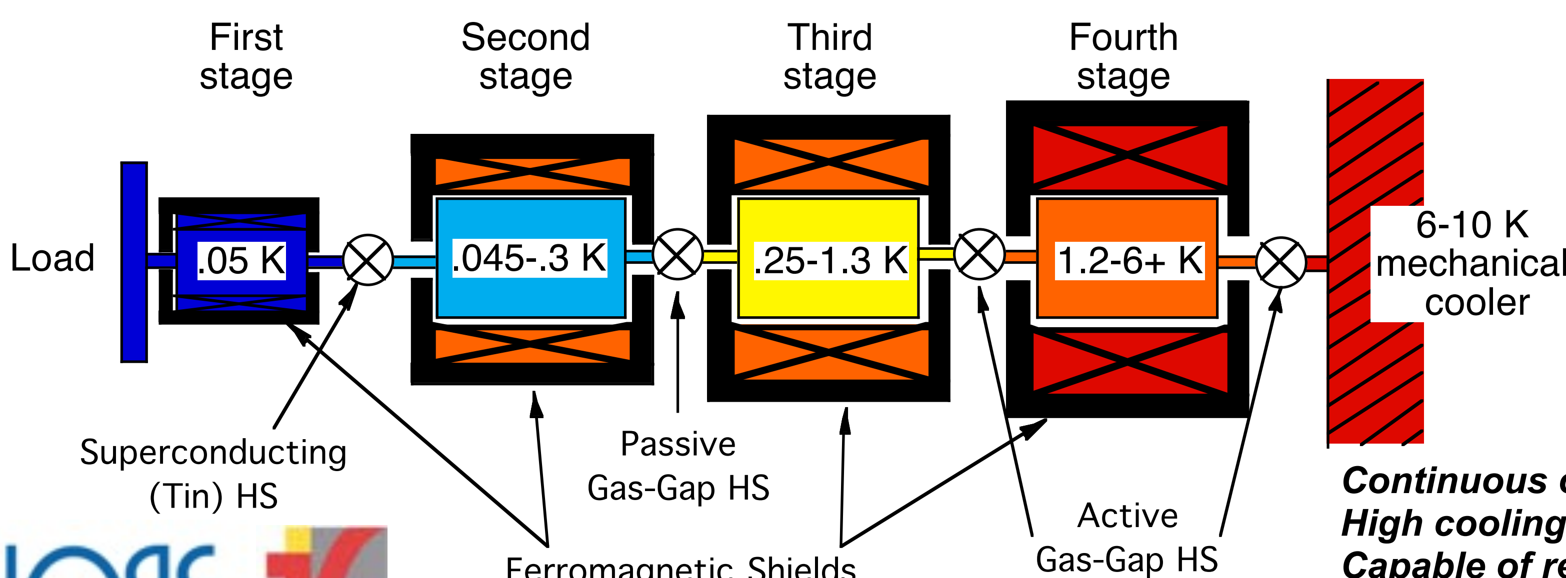
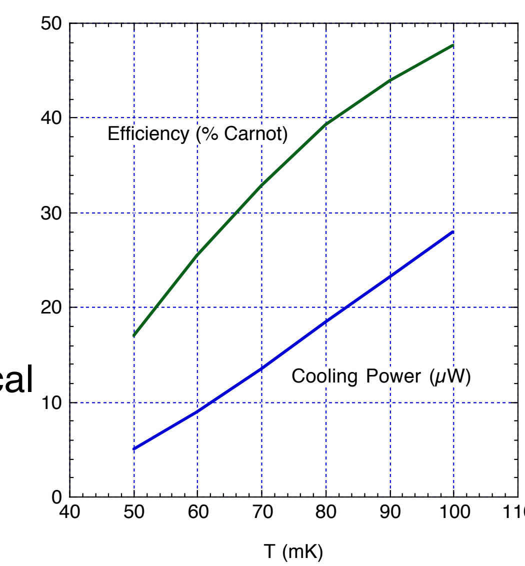
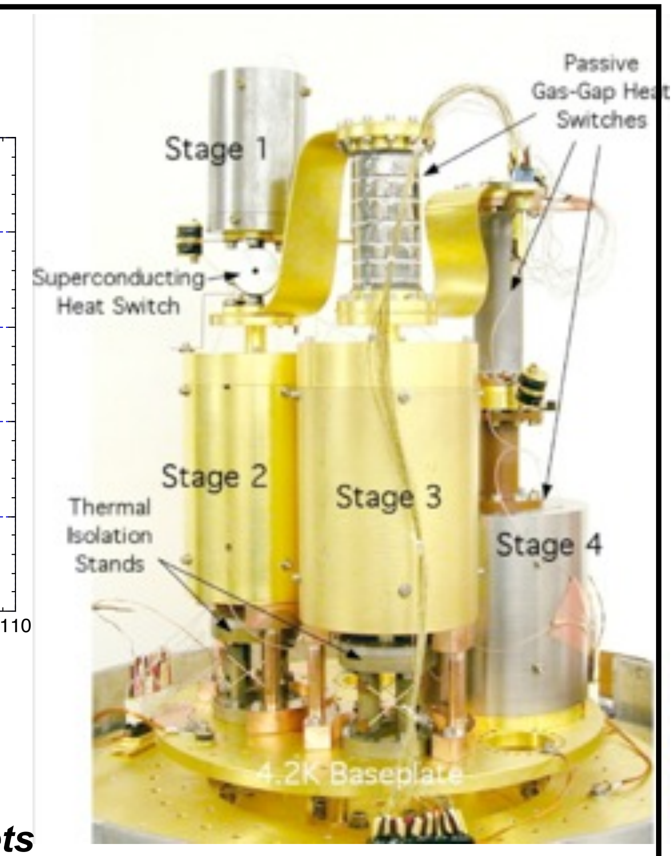
100 mK
290 mK

Continuous ADR

Load is directly cooled by one stage
Upper stages cascade heat to the heat sink







Continuous operation
High cooling power
Capable of rejecting heat at 6+ K
Requires development of Nb_3Sn magnets

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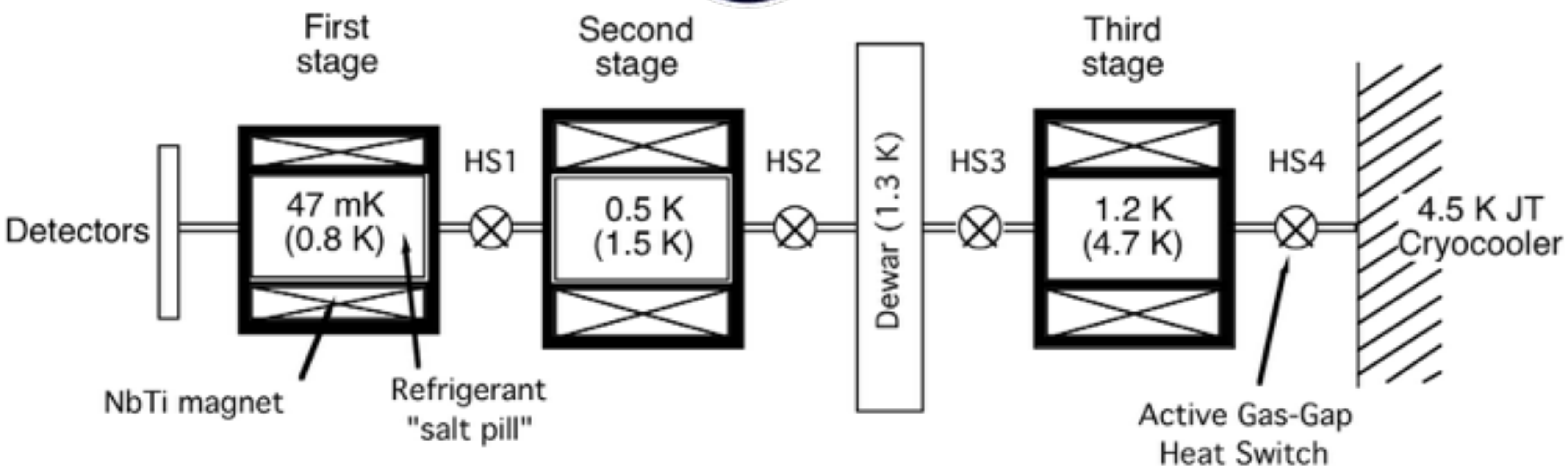
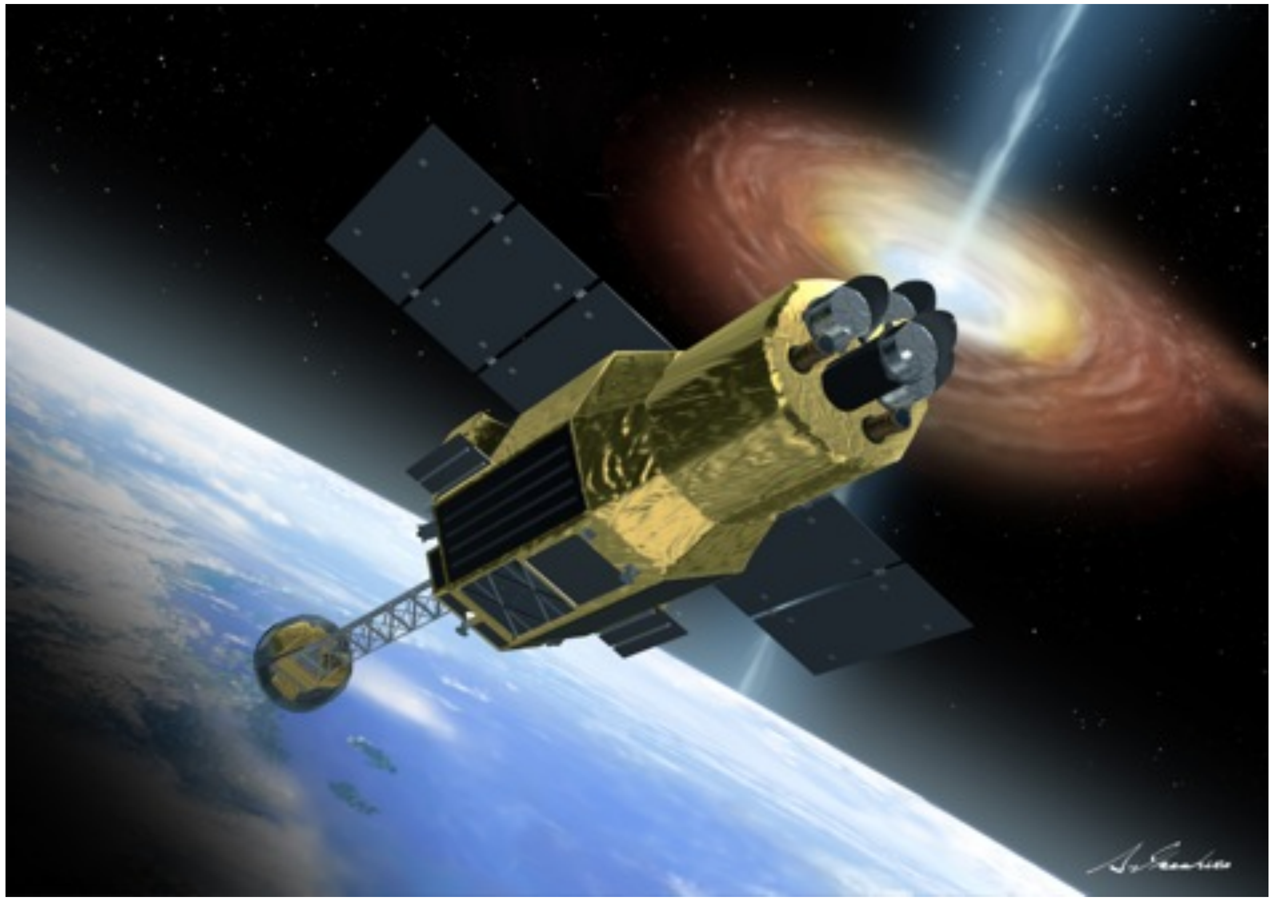
IEEE/CSC SUPERCONDUCTIVITY NEWS FORUM (global edition) July 2014
Presentation given at ICEC25 – ICMC2014, Enschede, July 2014

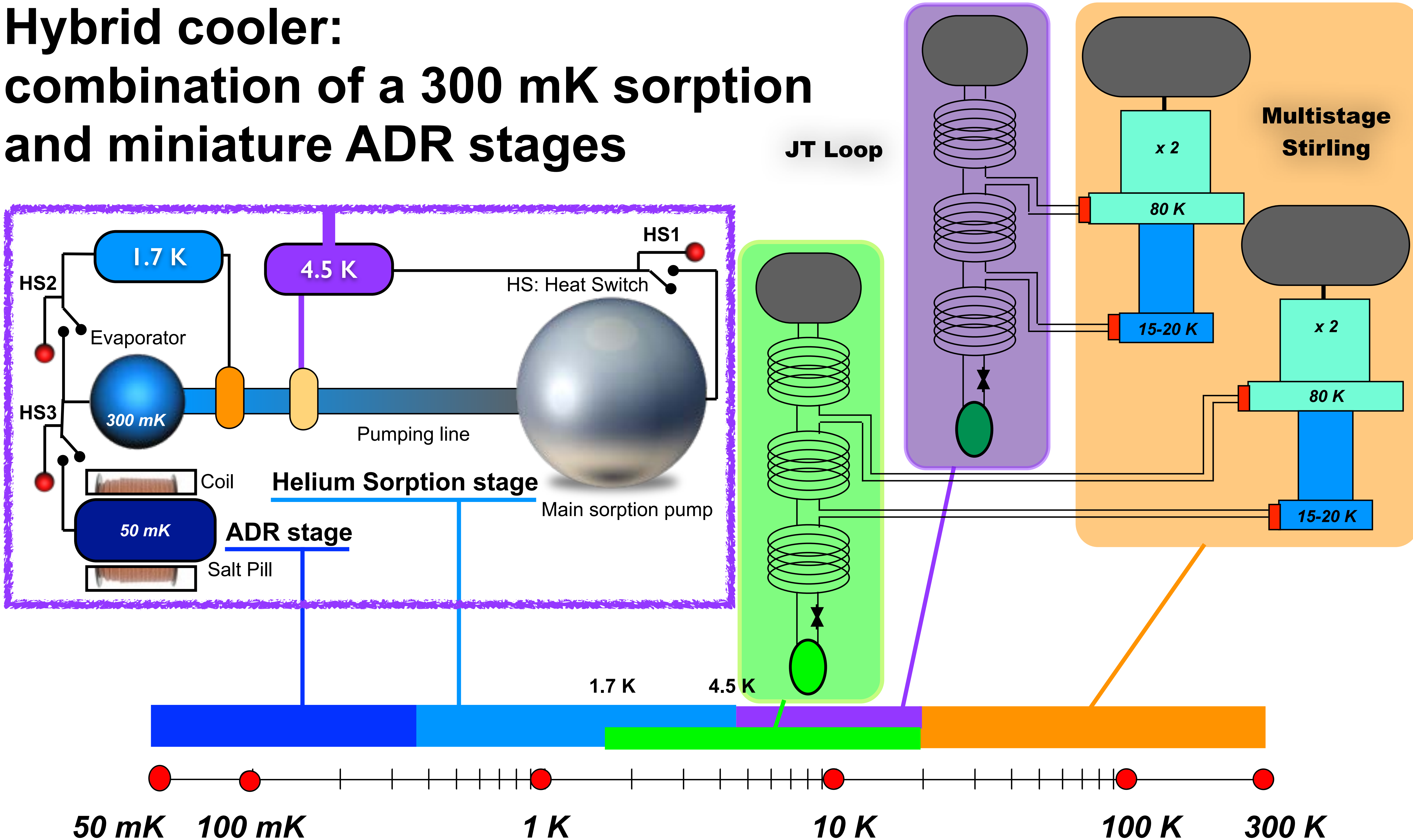
ASTRO-H: 3 STAGES ADR





50 mK COOLER HYBRID CONCEPT

Hybrid cooler: combination of a 300 mK sorption and miniature ADR stages



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TWO EM MODEL DEVELOPED

123 x 185 x 300 mm

5846 gr

1 µW @ 50 mK
(34 hours)

10 µW @ 300 mK
(37 hours)

Mission being re-optimized
(M4 selection)

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TWO EM MODEL DEVELOPED

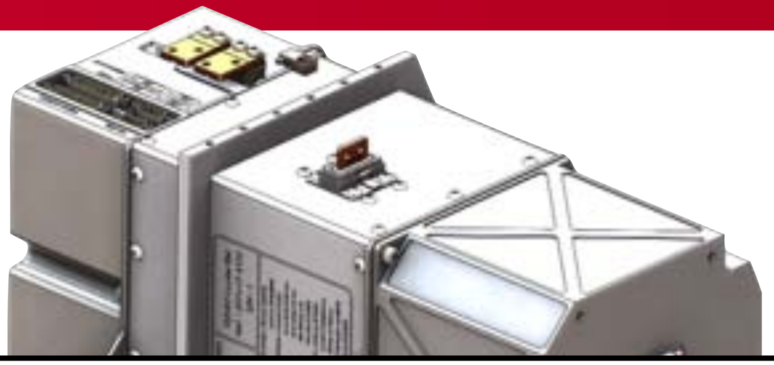
ESA TRP (IXO/ATHENA)
To specifications

123 x 185 x 300 mm

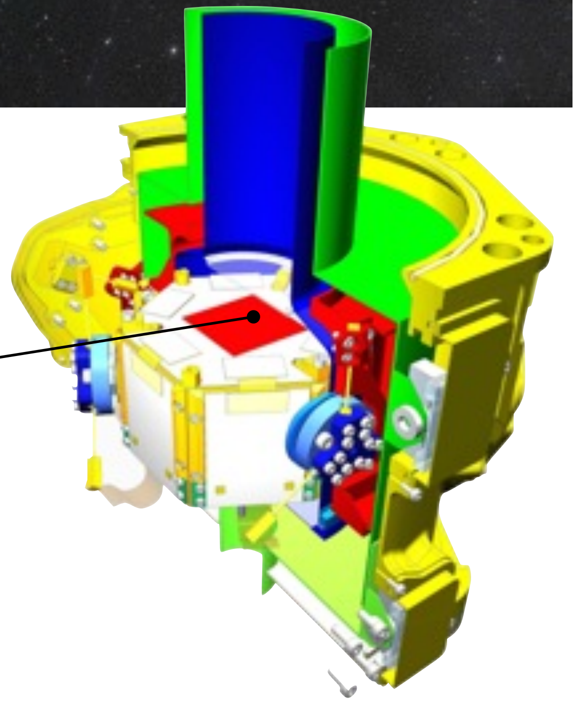
5846 gr

10 µW @ 300 mK (37 hours)

1 µW @ 50 mK (34 hours)

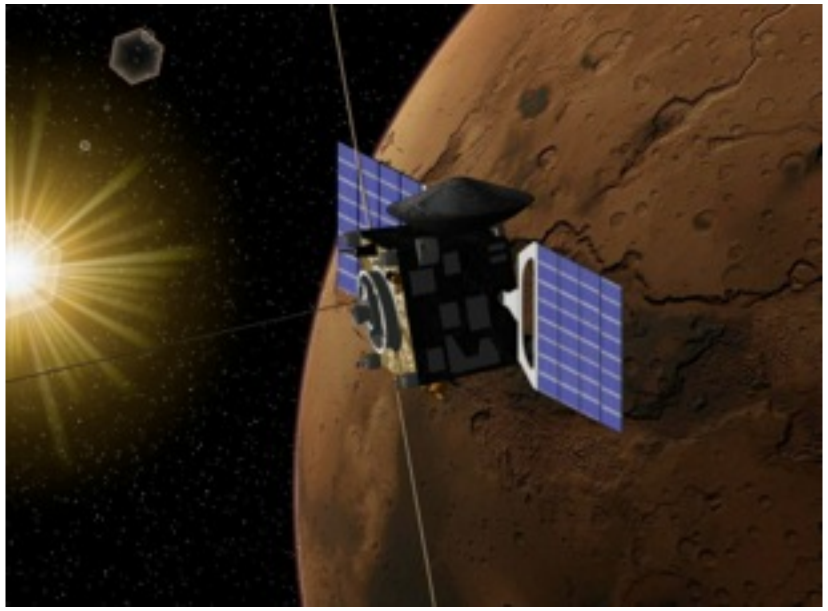


X-IFU Instrument
Focal Plane Assembly



THE MISSING LINKS

0.01 K | 0.1 K | 1 K | 10 K | 100 K | 300 K



Passive Radiators

Stored cryogen (Cryostat)

Active "mechanical" coolers

"Ultra" low T coolers
(3 technologies: sorption, magnetic, dilution)

- **Distance to detectors could be meters**
- **Temperature stability**
- **Induced vibrations**
- **Absorption of peak powers**
- **Temperature gradient**
- **On ground management (time constant)**

FLEXIBLE LINKS

SDL/11-224

FLEXIBLE THERMAL LINKS

Space Dynamics Laboratory (SDL) has the facilities and experience to meet the most stringent link requirements. SDL thermal links have been selected for NASA's JWST program. Full support services include thermal and dynamic testing and certification at cryogenic temperatures.

SDL's Flexible Thermal Links

Eliminate : Joining materials including solder
Internal contact resistance
Wicking into braid/foil
Outgassing

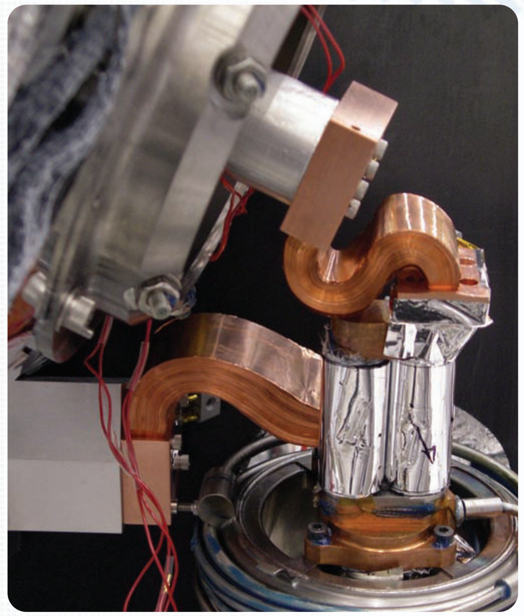
Maximize : Thermal conductance
Dynamic/mechanical flexibility

Provide : High Performance
Affordable Solutions

Appropriate material types and configurations are available based on customer-specific thermal and mechanical requirements for conductance, mass, and flexibility

SPECIFICATIONS

CONDUCTANCE :	0.01 - 10W/K
STIFFNESS : (flexibility)	Typically < 1 N/mm all axes
MASS :	5g - 10kg
MATERIAL :	Copper, Aluminum, etc.
TYPE :	Foil or Braid
TRANSFER LENGTHS :	2mm - 2m



SDL flexible thermal links attach the focal plane assembly to the cryo-coolers on the GIFTS Instrument

The SDL flexible thermal links are configurable to almost any desired shape and end-block configuration.

Space Dynamics LABORATORY
Utah State University Research Foundation

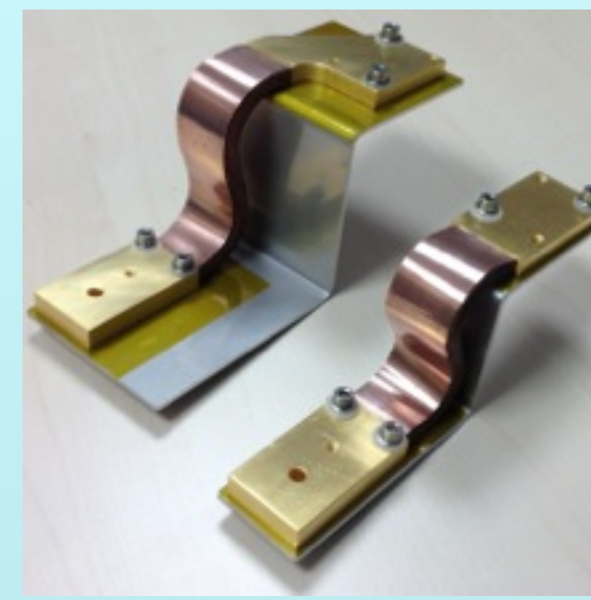
1695 North Research Park Way • North Logan, Utah 84341 • Phone 435.713.3400 • www.spacedynamics.org

≈ Simple but not easy to make

On-going activities in the frame of CSO and MTG

CSO: 2 sets of FMs delivered
MTG: 6 sets delivered

99.999% AL
High flexibility in all direction (< 5N/mm)
High K: >1W/K @ 80K
Mass < 100g for complete thermal link



99.99% OFHC
High flexibility in all direction (< 0.5N/mm)
High K: >0.5W/K @ 300K
Mass < 350g for complete thermal link

INNOVATIVE SOLUTIONS
ABSOLUT SYSTEM

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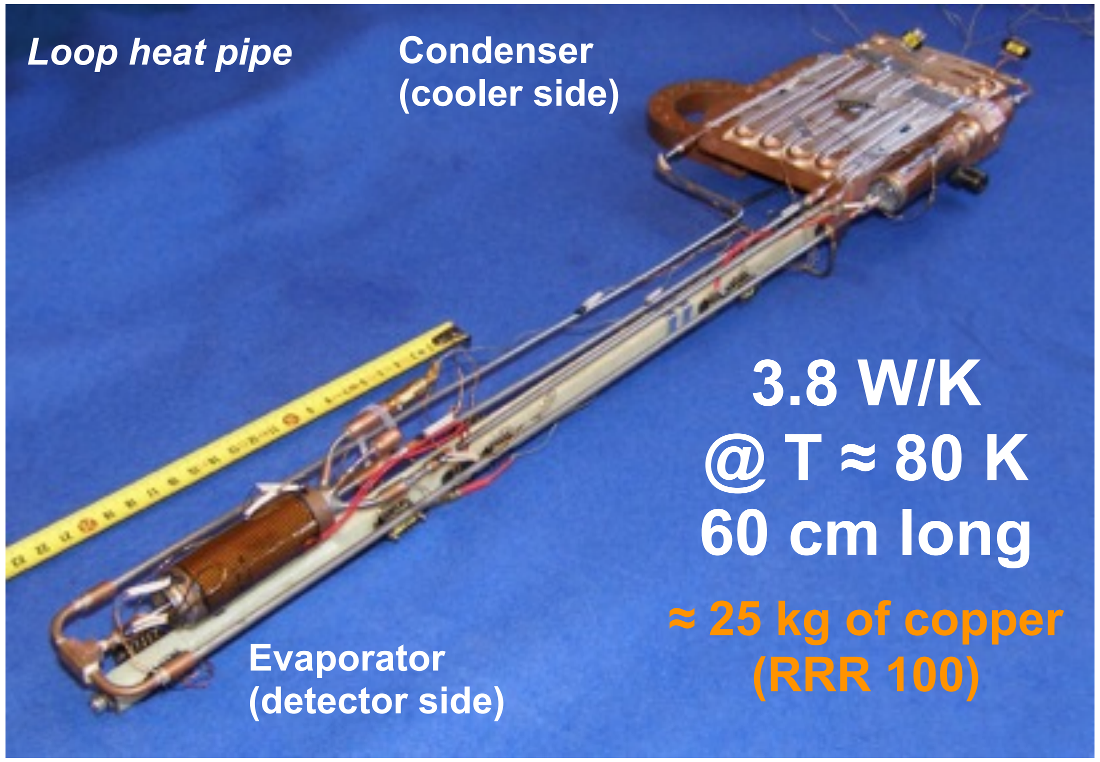
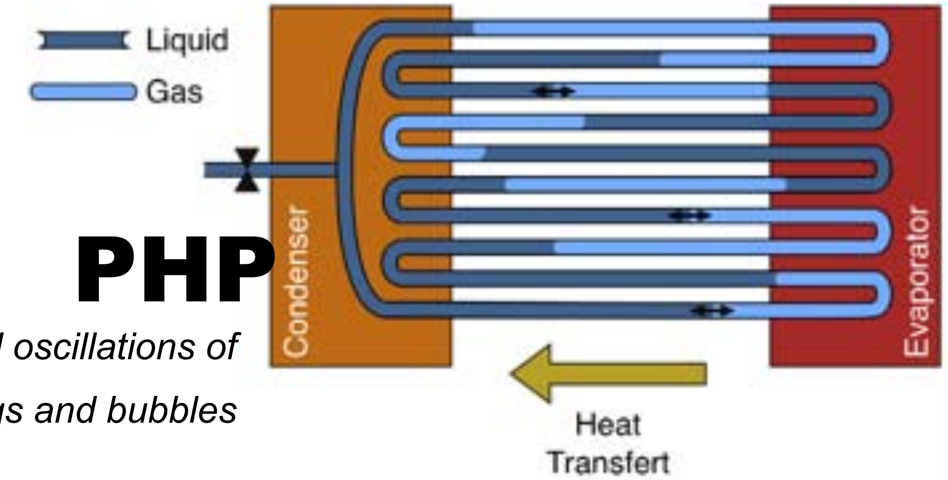
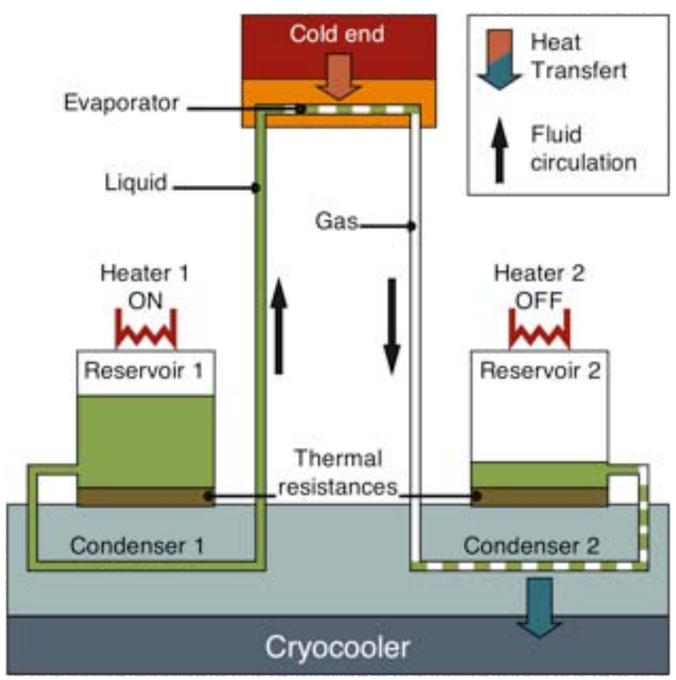
HEAT PIPE & PHP

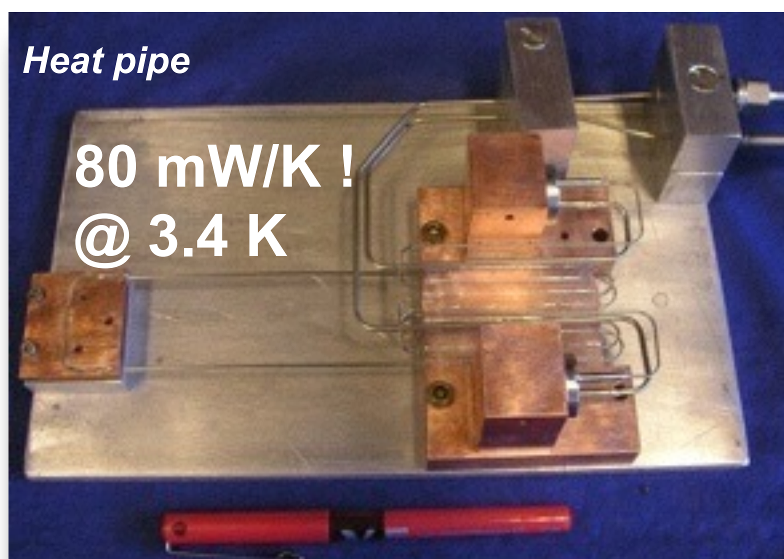


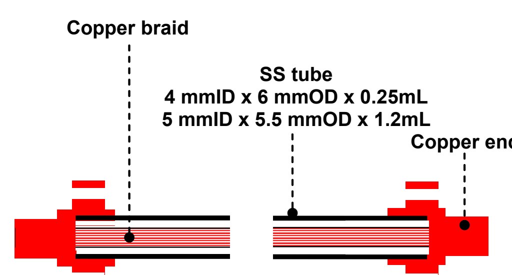
PHP

Sustained oscillations of liquid plugs and bubbles





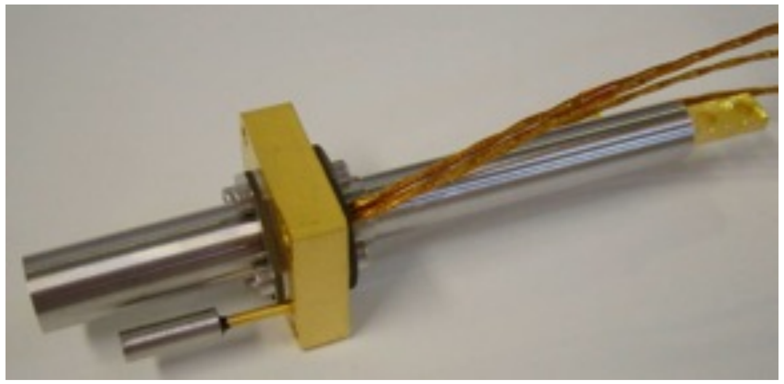


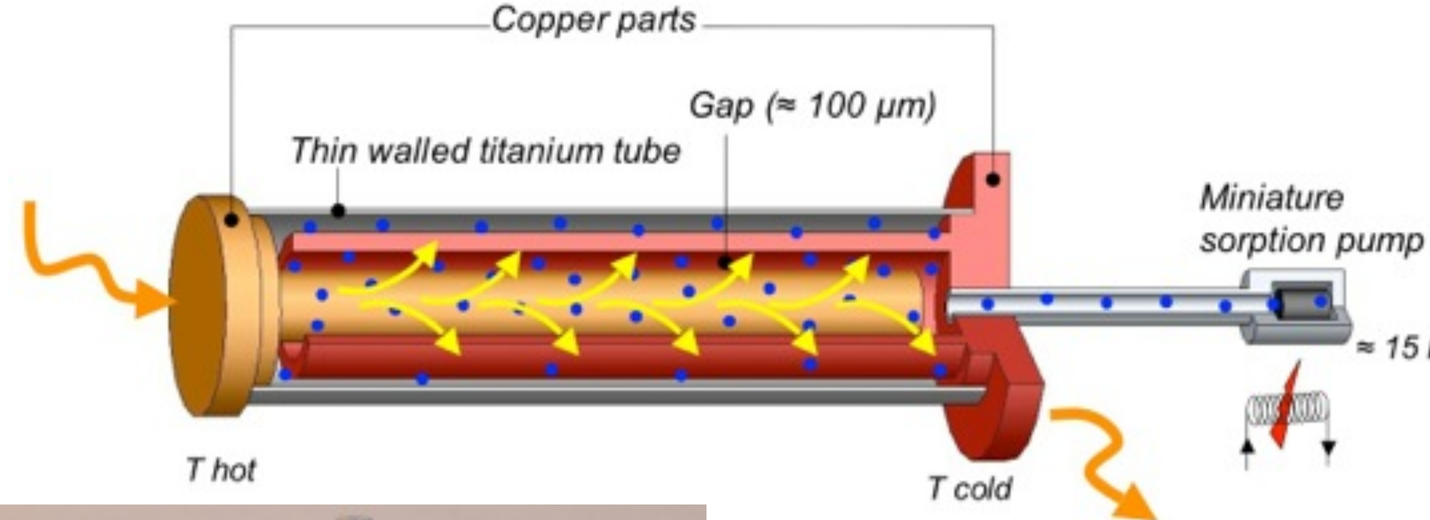


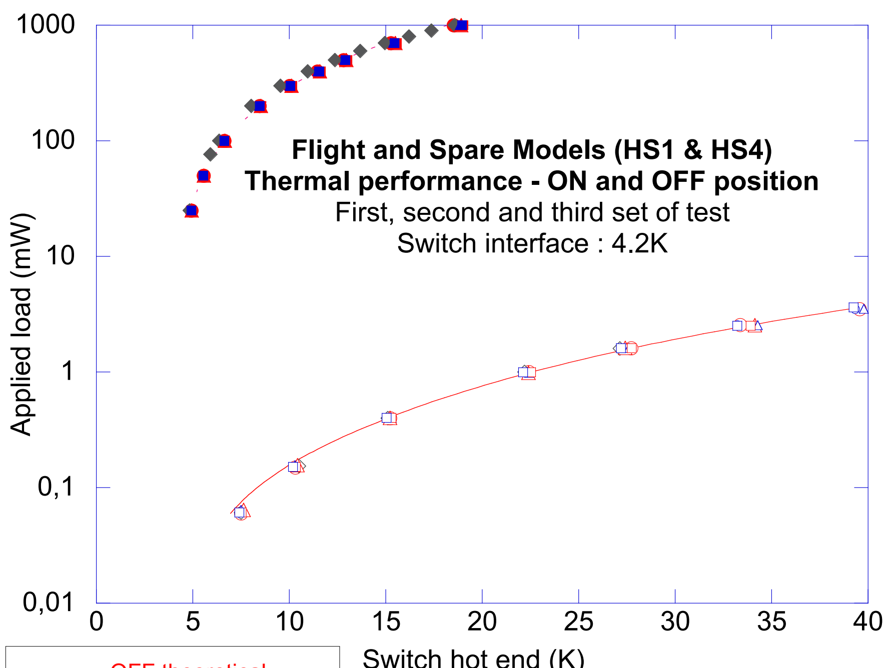
ANCILLARY EQUIPMENT: HEAT SWITCH

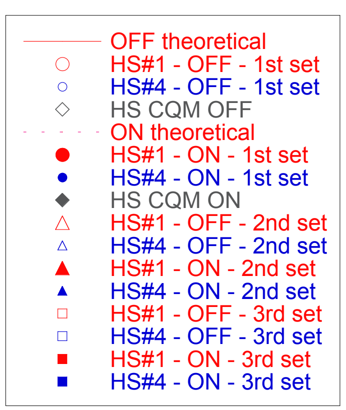
Most commonly used: Gas Gap Heat Switch

PLANCK Helium gas gap heat switch

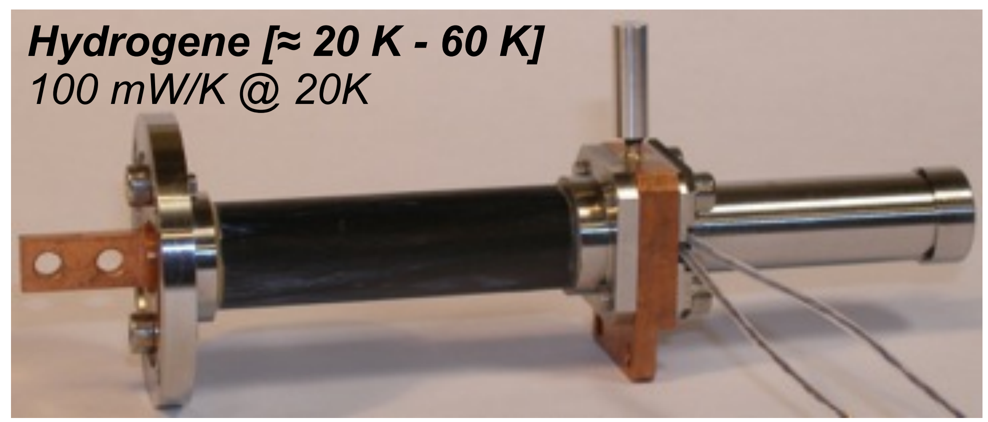




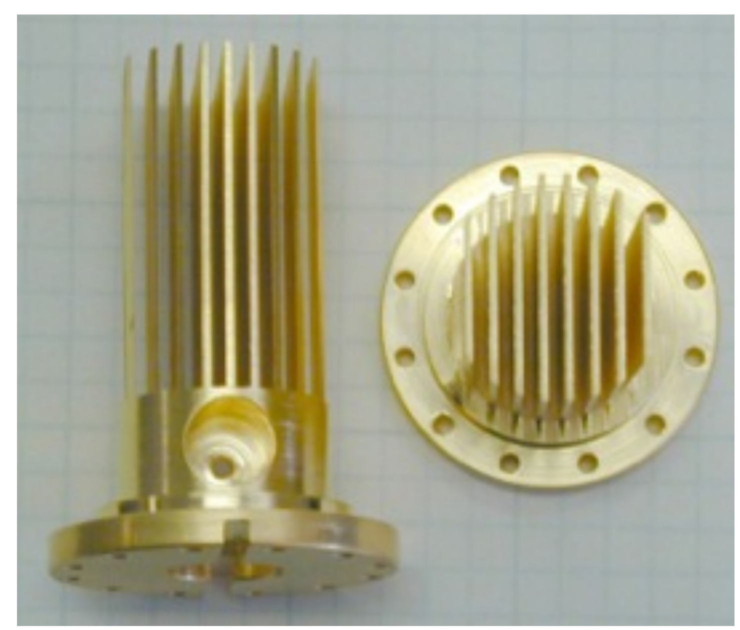




- *Test #1 : first set of thermal test*
- *Test #2 : second set performed after 24h 60°C bake out*
- *Test #3 : third set performed after the vibrations tests*



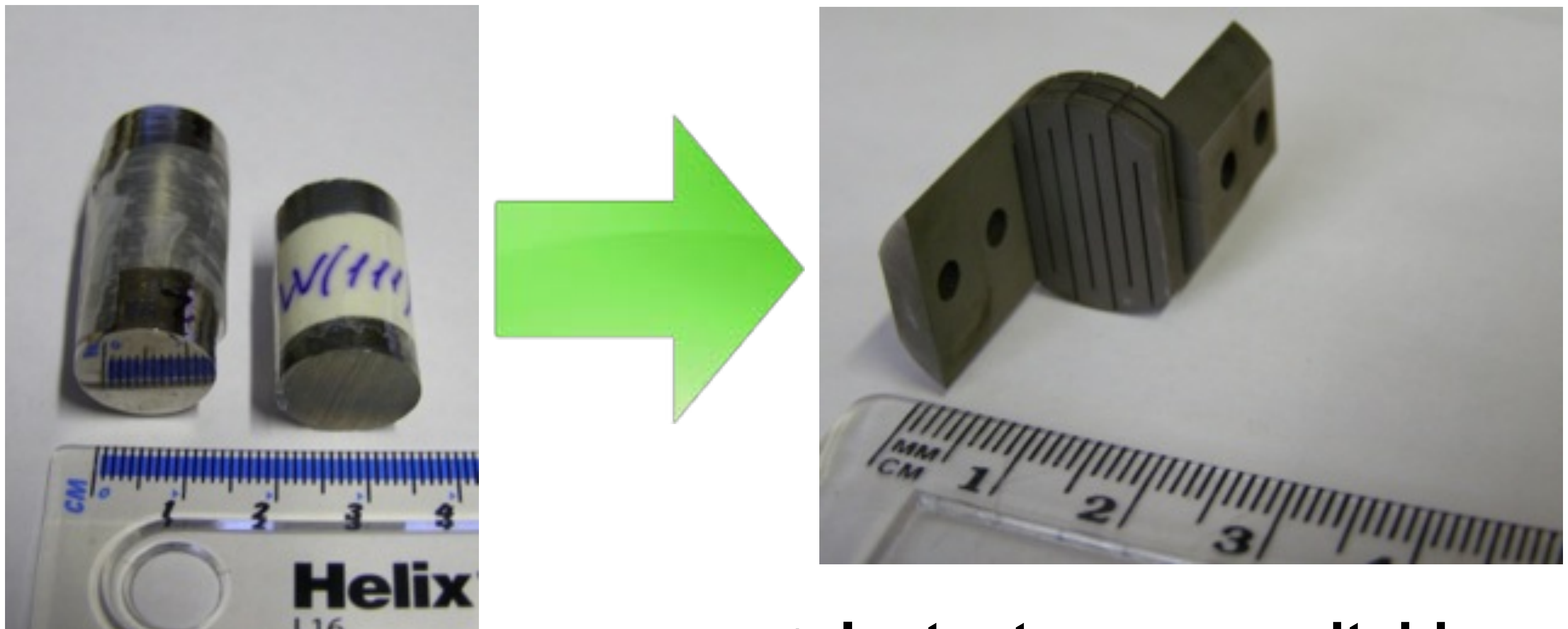
Other geometry (NASA Goddard)

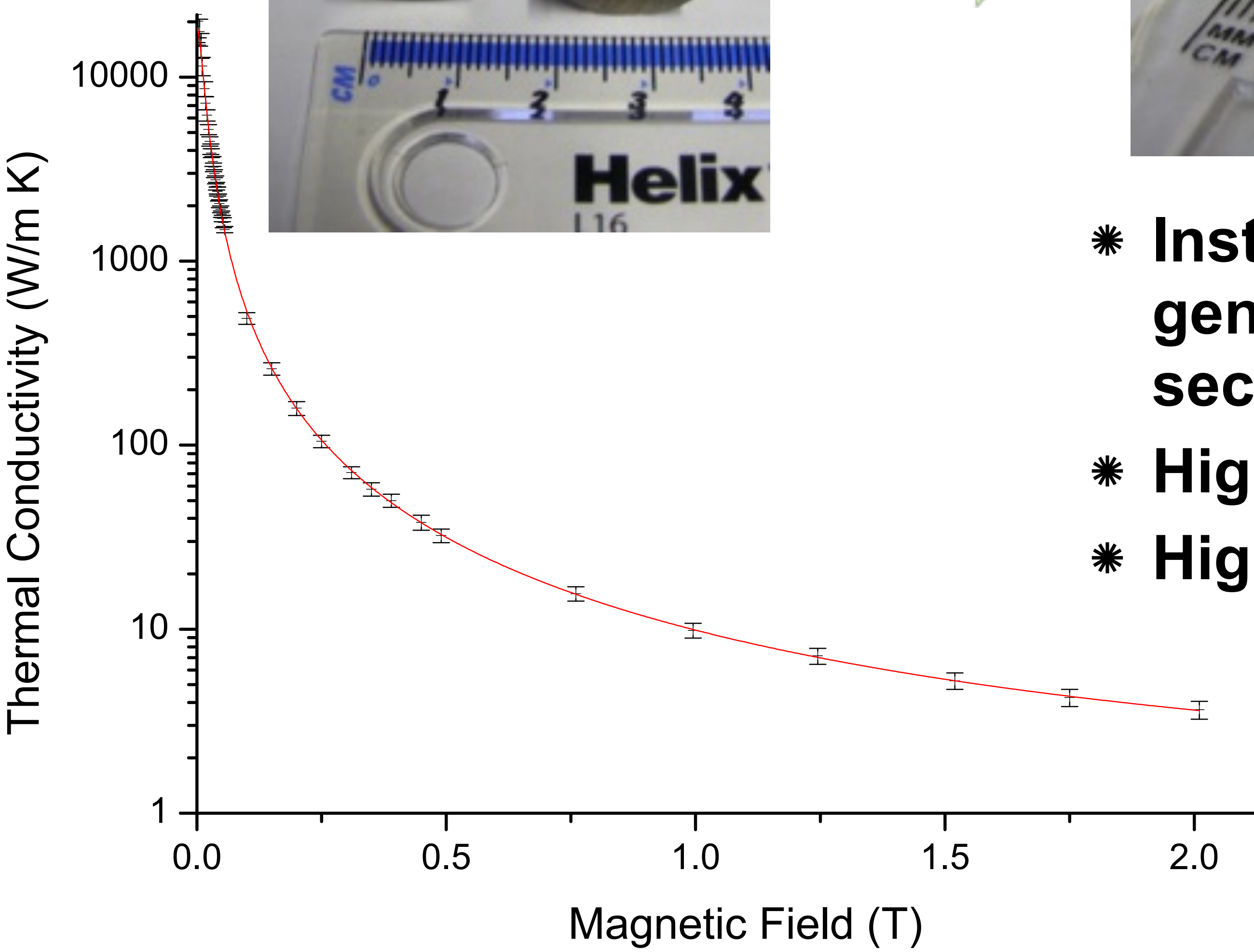


MAGNETORESISTIVE HEAT SWITCH

Magnetoresistive heat switch made from tungsten

Works by the slowing down of electrons in a metal due to a tangential magnetic field





- **Instantaneous switching – limited by speed of generating the magnetic field, currently 30 seconds to go from 0 to 2 Tesla**
- **High thermal conductivity 200 W/cm/K**
- **High switching ratio ~10^4** (related to the magnetic field)

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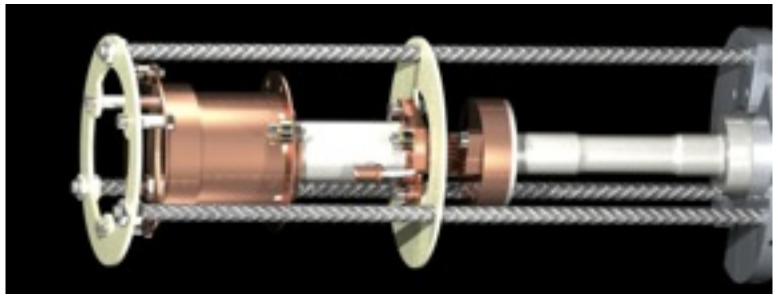
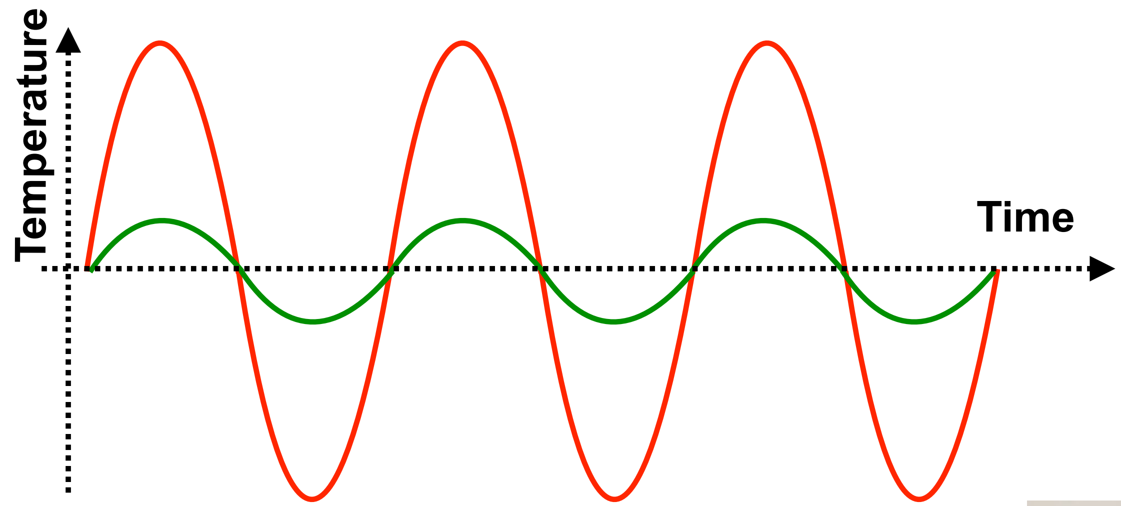
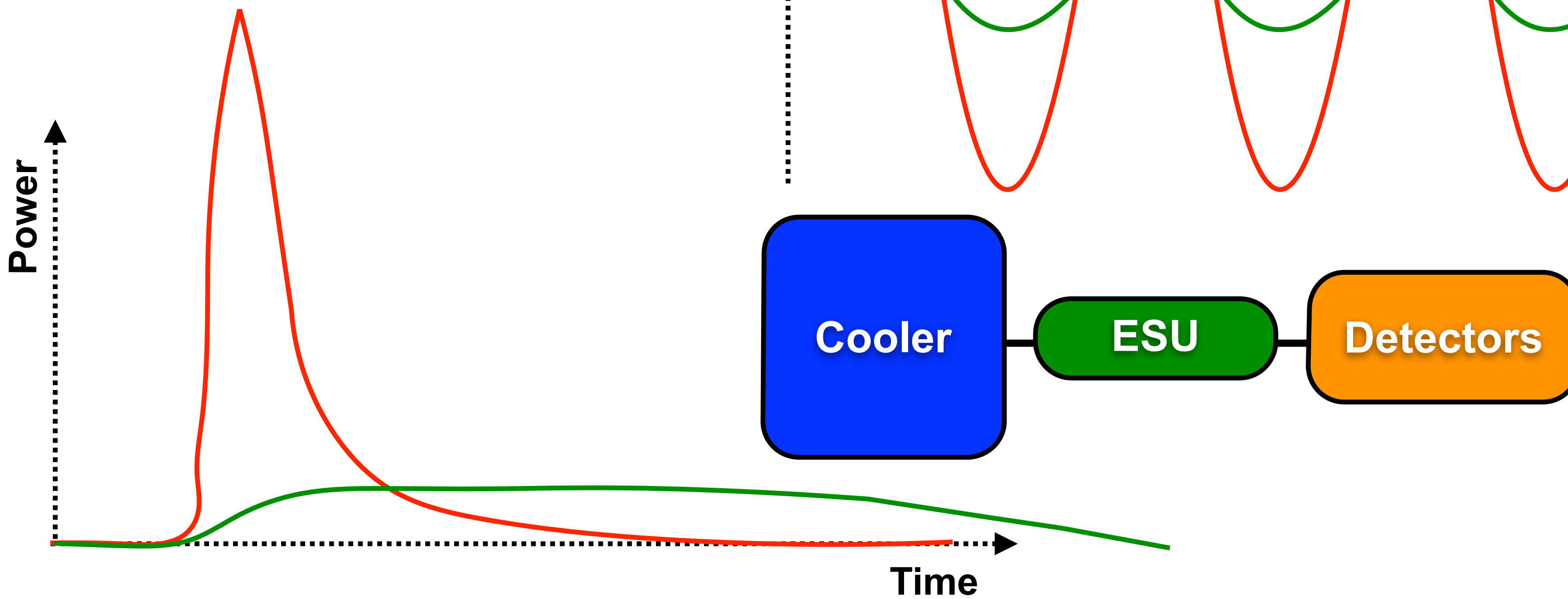
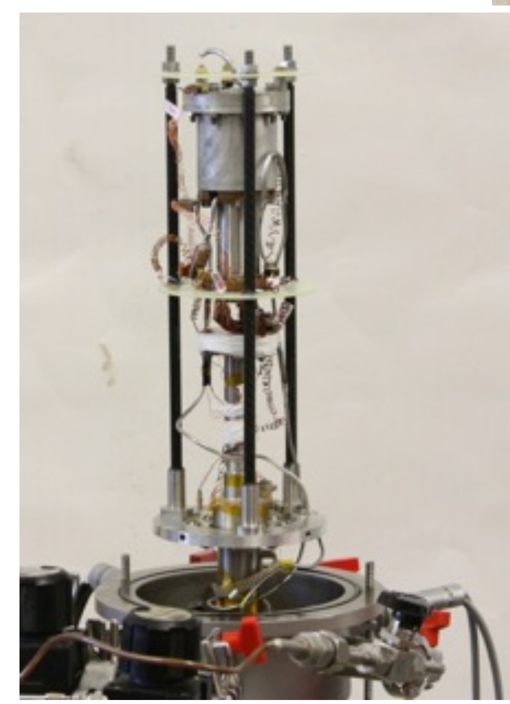
ENERGY STORAGE UNIT









Several applications

- Attenuate temperature oscillations
- Absorbs peak power (then energy dumped over longer period)
- cooler turned OFF: provides stable operation for a limited time

Example of Thermal Buffers:

Liquid-Gas Hydrogen
400 J between 15 and 16 K
V ≈ 20 cm3

Liquid-Gas Neon
1000 J at 40 K +/- 50 mK
2000 J between 38 and 40 K
35 cm3

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activespace technologies

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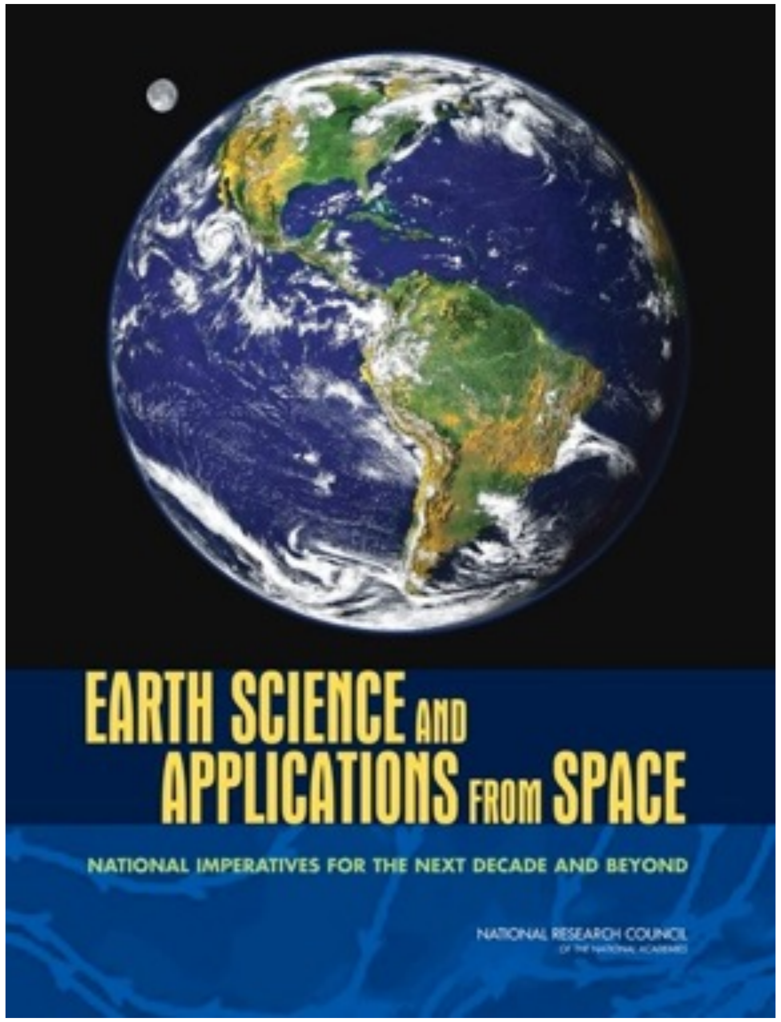
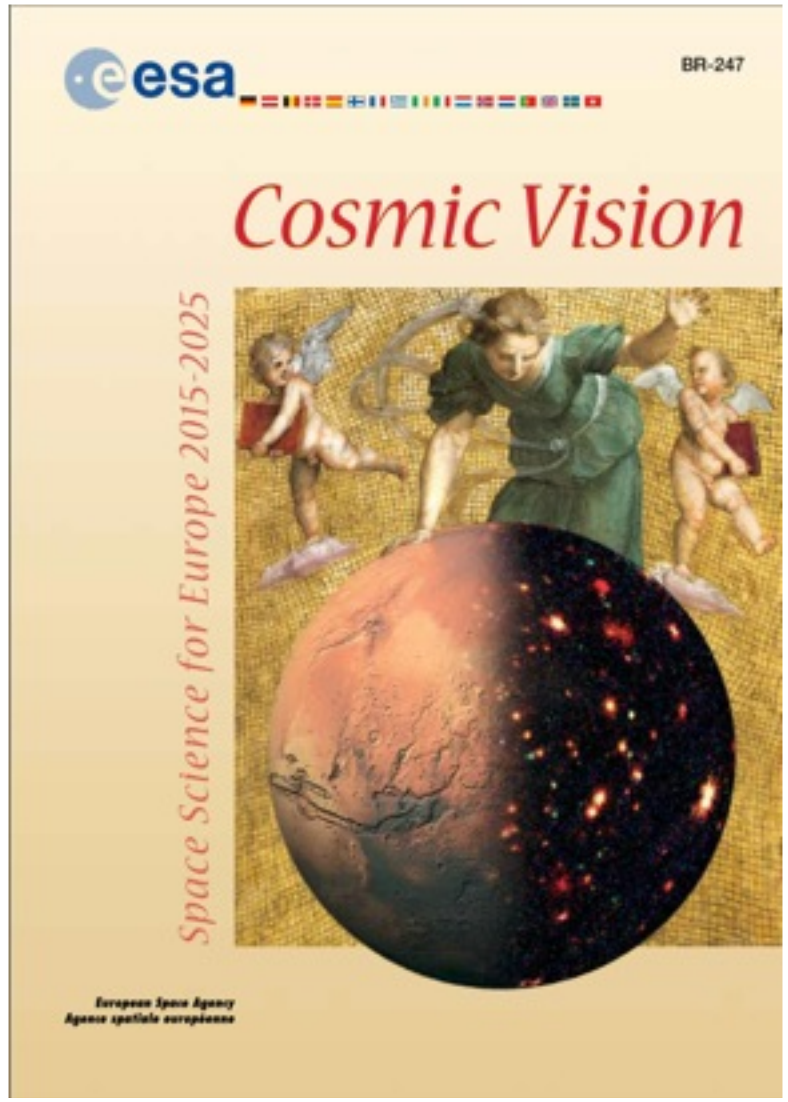
TO ETERNITY AND BEYOND





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Thierry Tirolien
Marcel Ter Brake
David Valentini
Stuart Watson

Peter Shirron - Cold facts Feb. 2014

These systems will deliver what the community needs: better access to cold in space. But you know what will happen. Scientists will develop better detectors, and demand lower temperature, longer mission lifetimes, lower cost, mass, size, etc. We should hope for no less. That's what will keep space cryogenics as exciting and relevant into the next 50 years as it has been over the last.

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