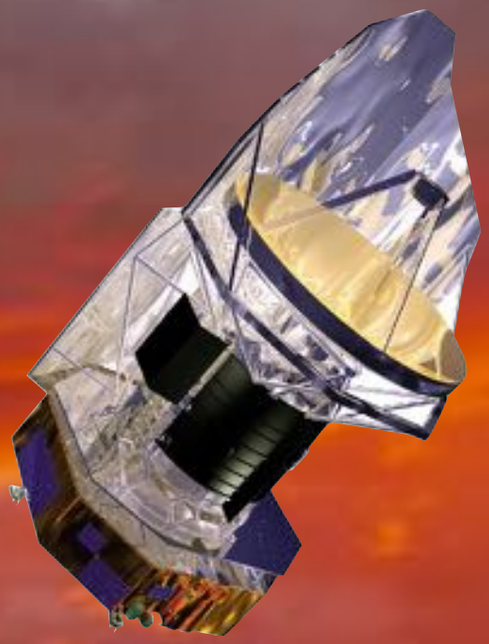
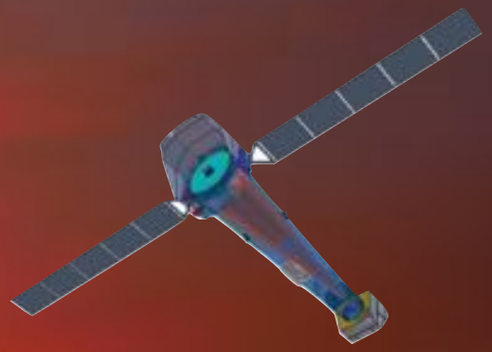




SUB-KELVIN COOLING FOR SPACE AND GROUND-BASED TELESCOPES

FROM RESEARCH TO INDUSTRY

cea

GRENOBLE

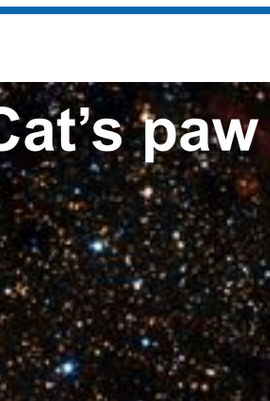
Lionel DUBAND
Univ. Grenoble Alpes, CEA-INAC-SBT, F-38000 Grenoble

What is essential is invisible to the eye …

Cat's paw (or bear claw) nebula (NGC 6334)

Andromeda (M31)

Two things needed
(1) to be able to "see"
(2) to be able to measure



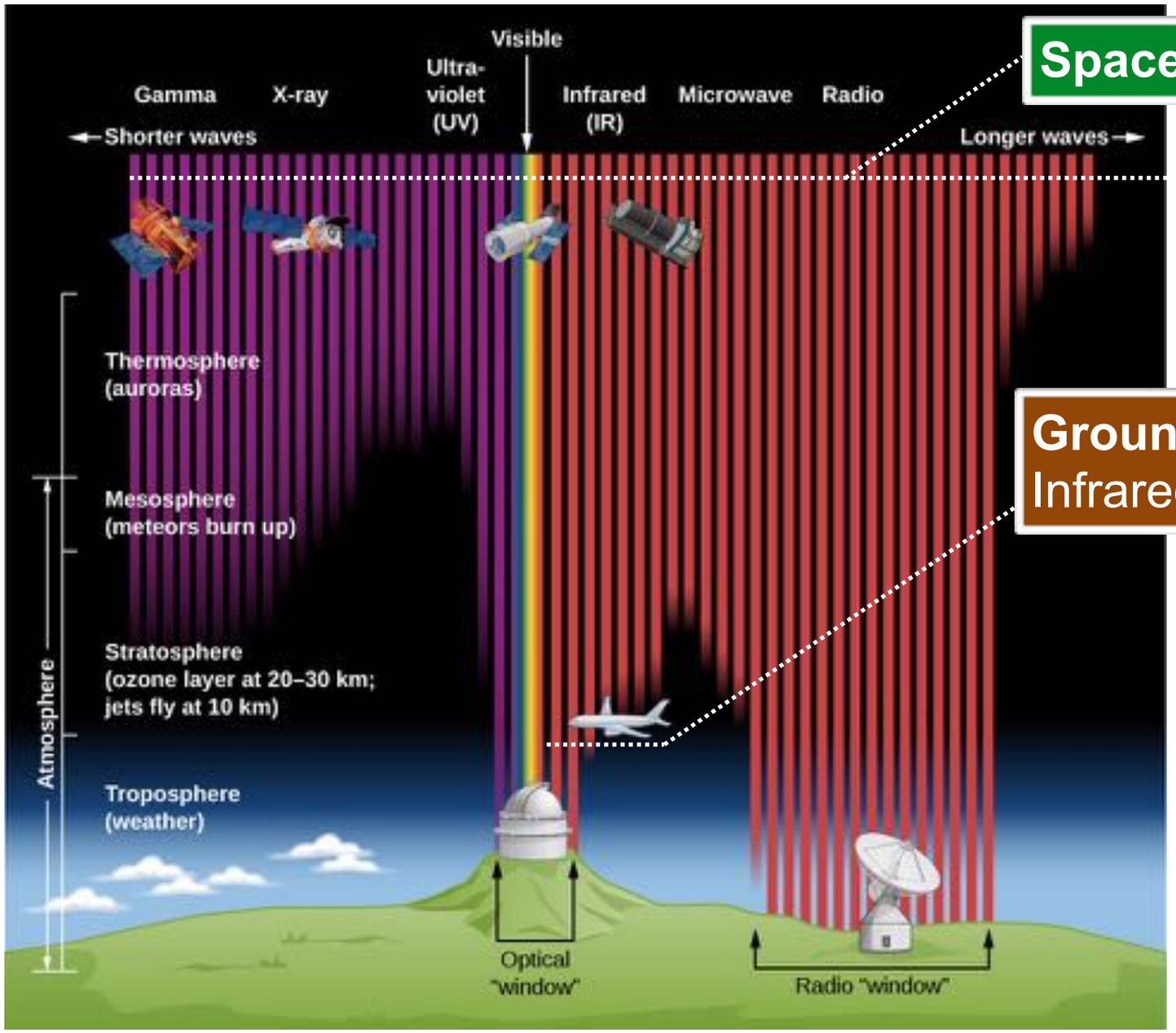
From ground

ArTeMiS APEX + ESO's VISTA telescope

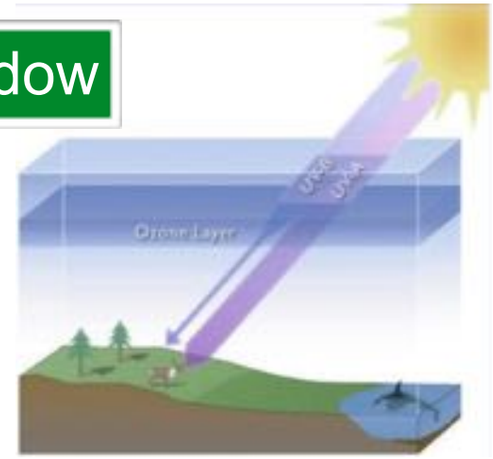
From space

Composite: Visible + XMM Newton + Herschel

Visible to the instruments ?



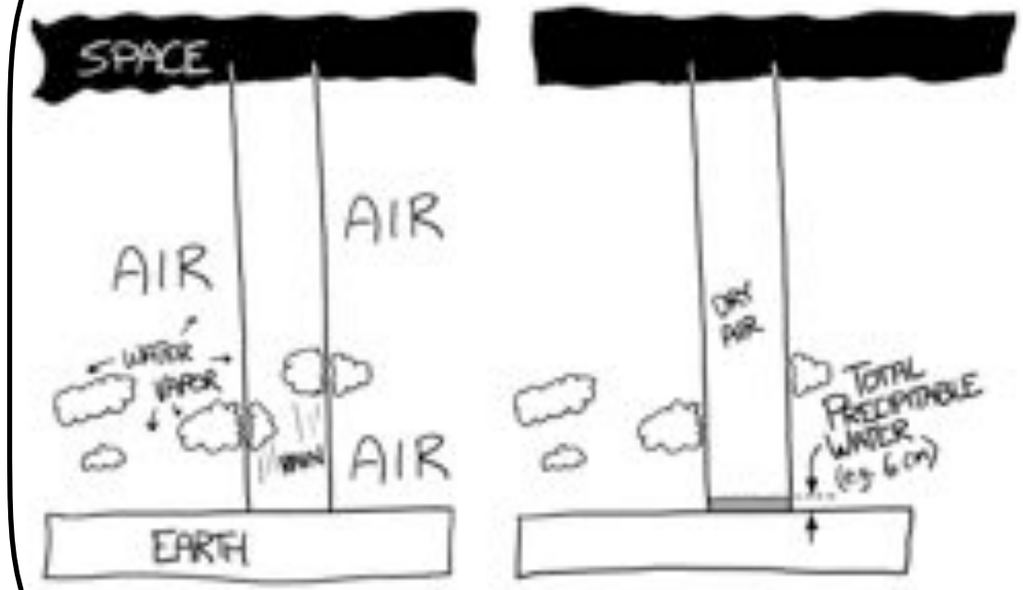
Space opens up the full window



Atmospheric filter
Fortunately for us !

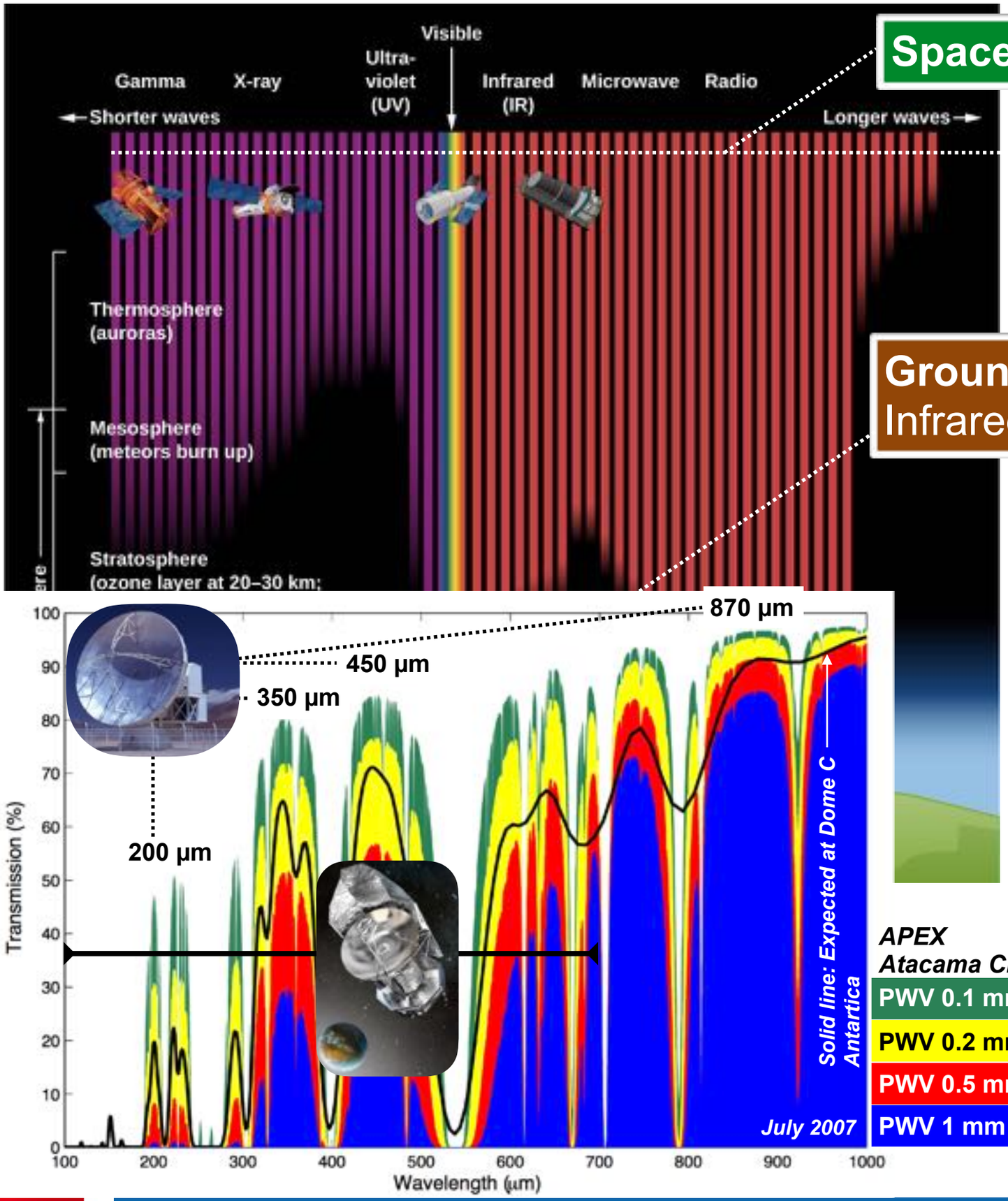
Ground based telescope
Infrared spectrum: few "windows" accessibles

PWV: **P**recipitable **W**ater **V**apor

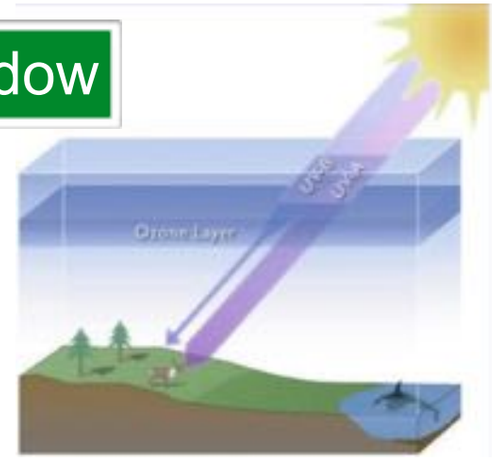


Attenuation of incoming radiation
Increase of noise (thermal emission)
Inhomogeneities in distribution

Visible to the instruments ?



Space opens up the full window



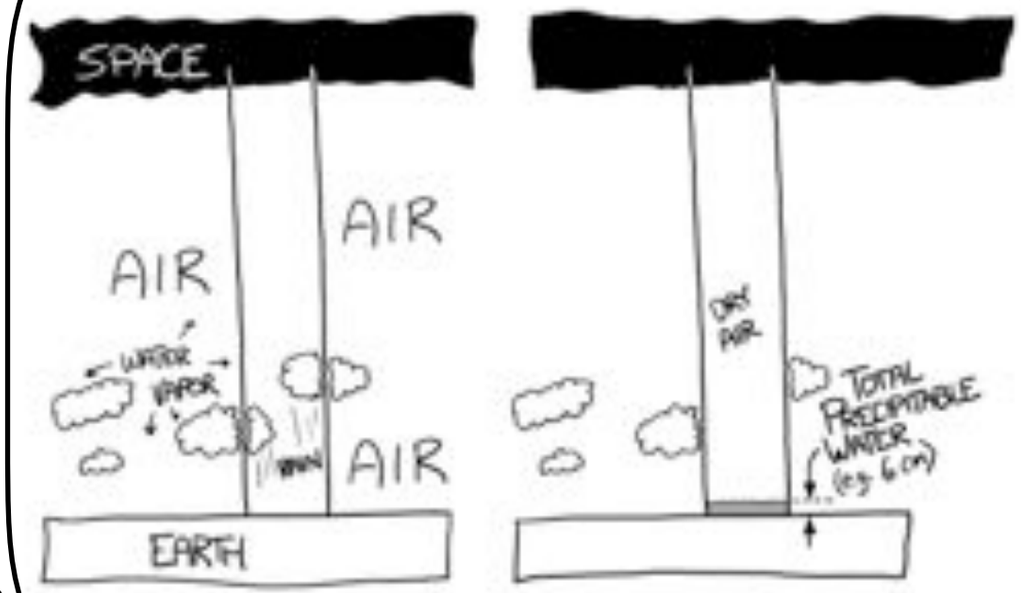
Atmospheric filter
Fortunately for us !

Ground based telescope
Infrared spectrum: few "windows" accessibles

APEX
Atacama Chile

- PWV 0.1 mm
- PWV 0.2 mm
- PWV 0.5 mm
- PWV 1 mm

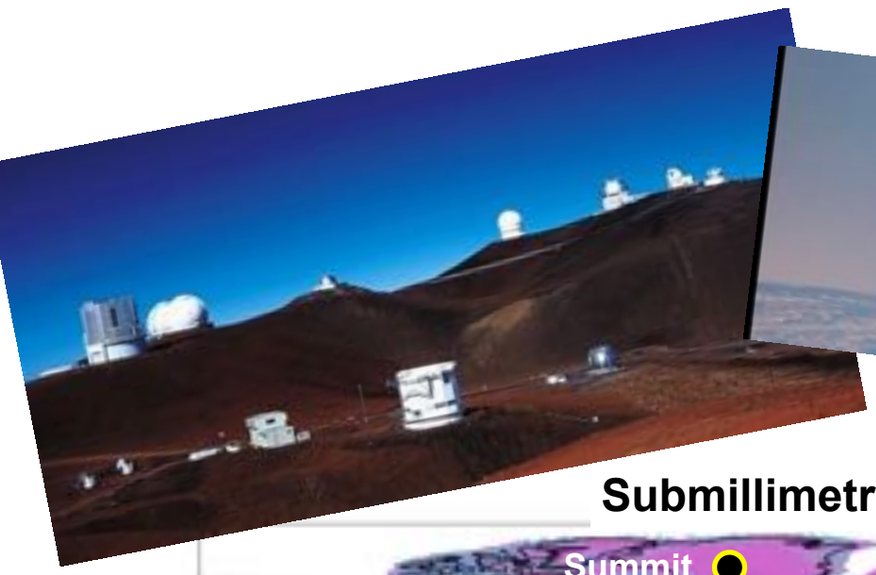
PWV: **P**recipitable **W**ater **V**apor



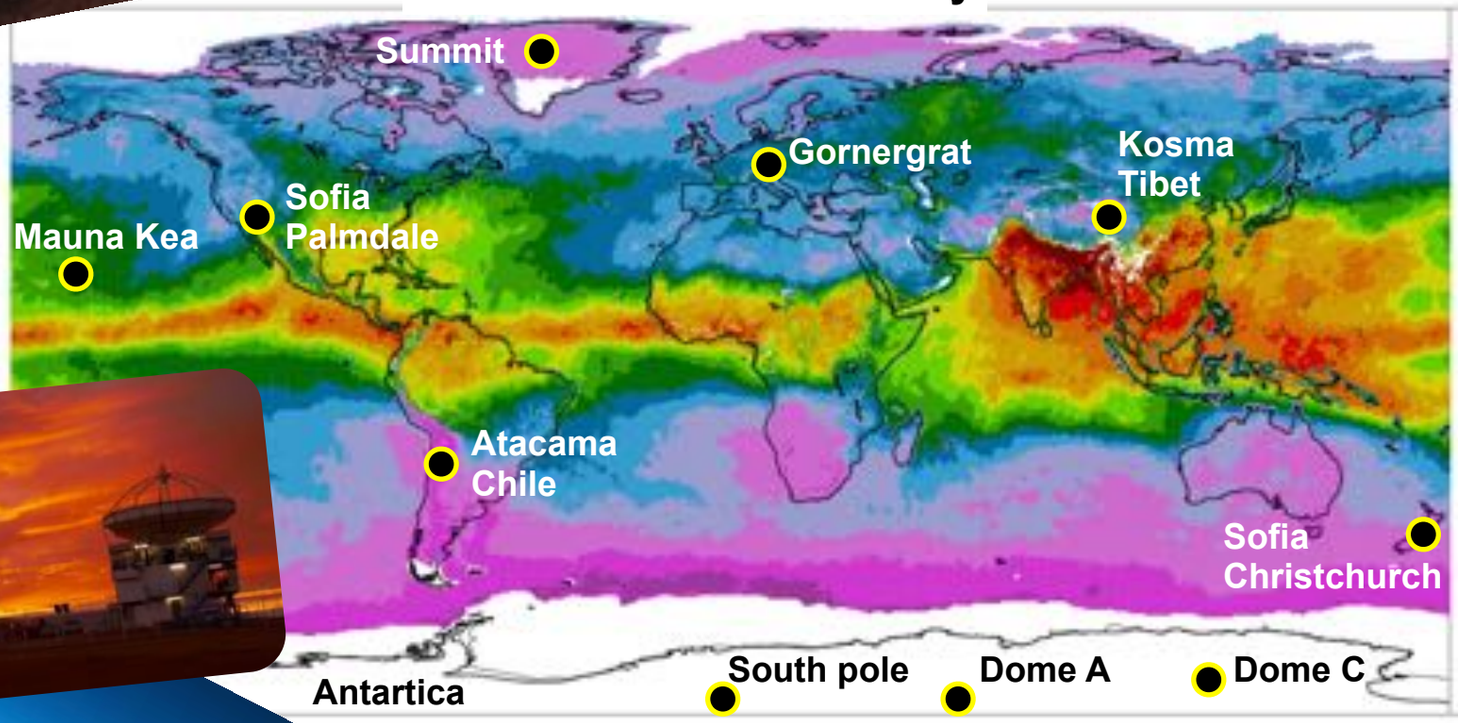
Attenuation of incoming radiation
Increase of noise (thermal emission)
Inhomogeneities in distribution

Reasonable transmission ➡ **Very low PWV**

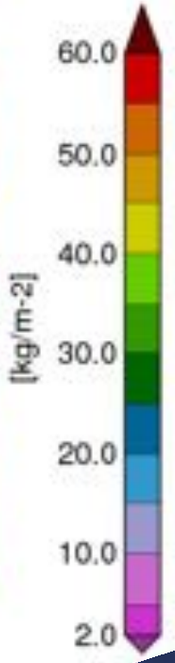
To be able to see: harsh environment or space



Submillimetric Astronomy

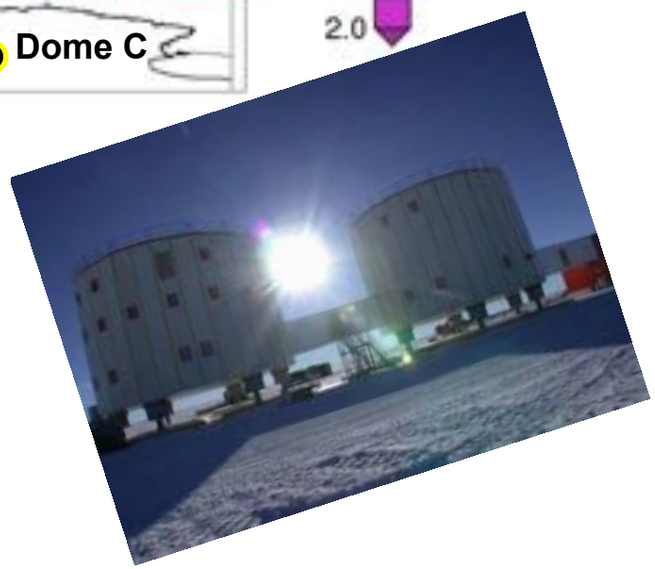


PWV: 1mm = 1 kg.m^{-2}



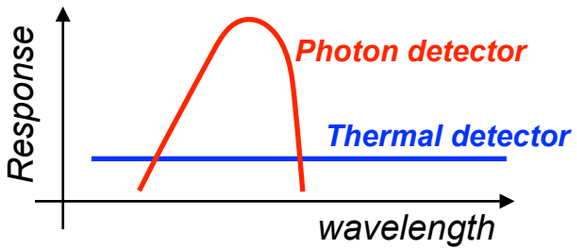
- ☑ Remote location
- ☑ High altitude and/or cold
- ☑ Complicated logistic

Could be tough to get there !



To be able to measure: Shh ! faint signals coming in

	Photon detectors	Thermal detectors
Incoming radiation	**Interaction with electrons**	**Temperature change**

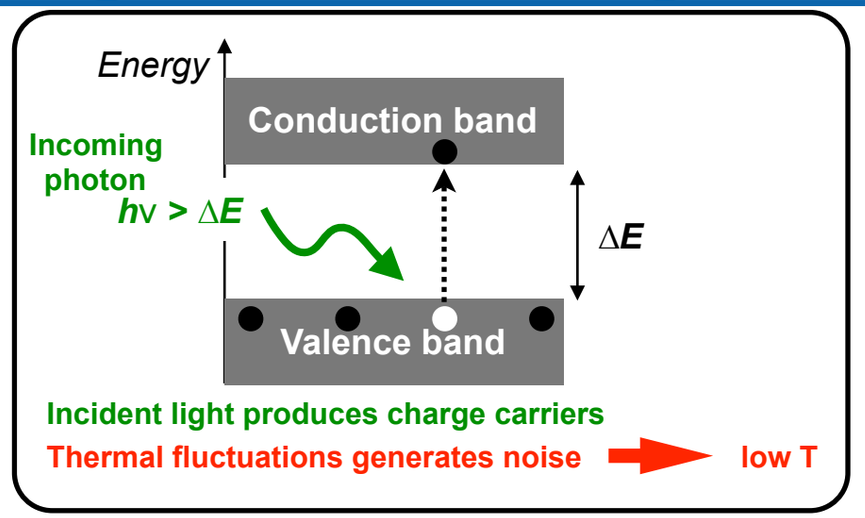


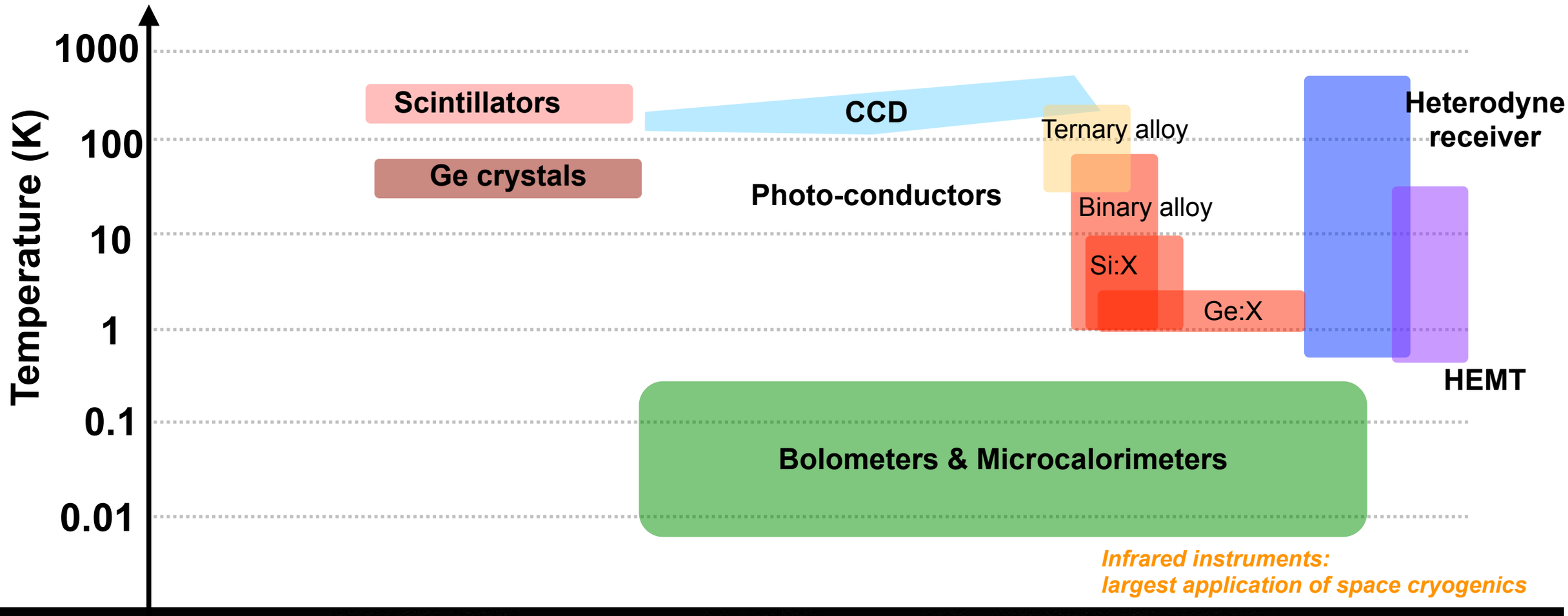
wavelength dependent

E → ΔI, ΔV, ΔR

≈ wavelength independent

E → ΔT

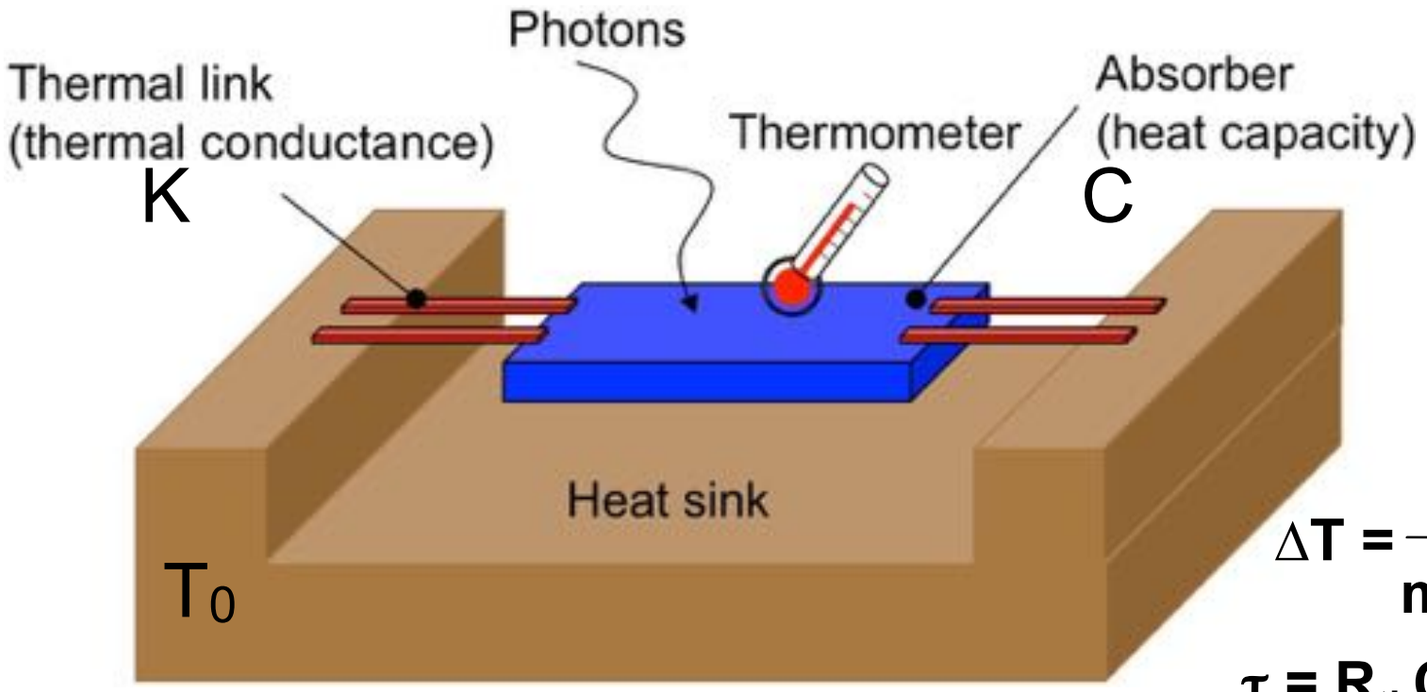


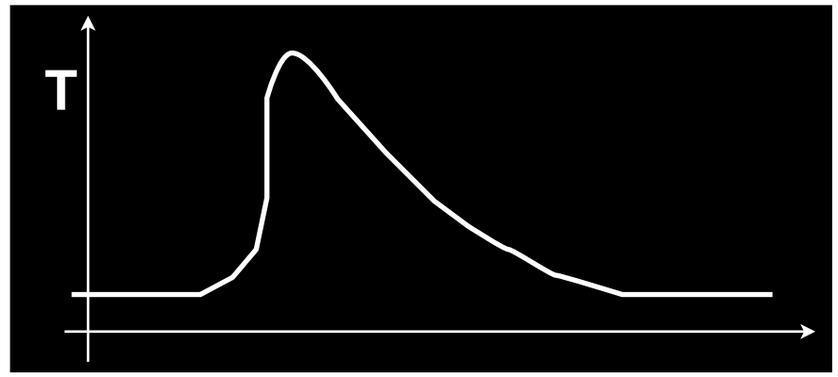


To be able to measure: Shh ! faint signals coming in

Cryogenics

Thermal detector: Bolometer





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

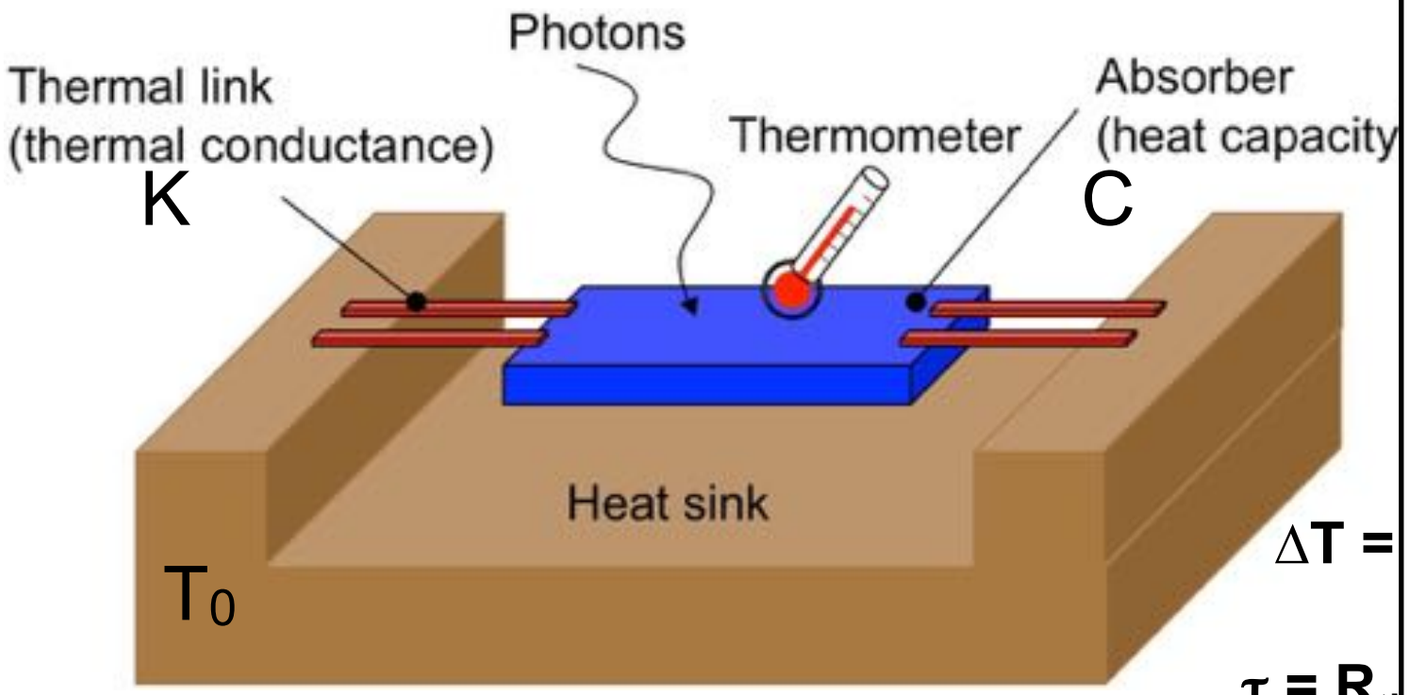
$$\tau = R_{th}C = \frac{C}{K}$$

Measurable ΔT ? → Minimize C → Low Temperature

To be able to measure: Shh ! faint signals coming in

Cryogenics

Thermal detector: Bolometer

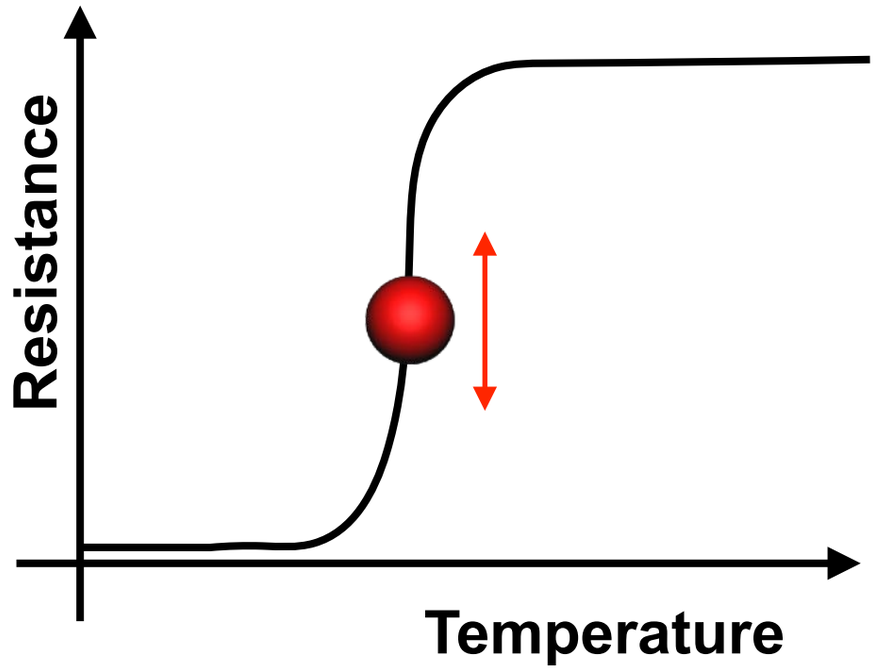


$\Delta T =$

$\tau = R_{th}$

Measurable ΔT ? → **Minimize**

Transition Edge Sensor (TES)



small change in T

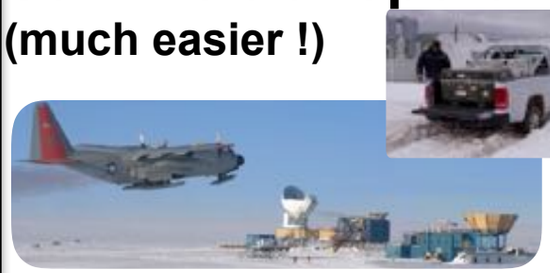
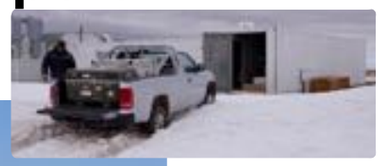
↓

big change in R

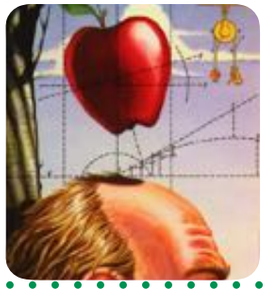
Drivers for the cryogenic chain

Ground based *harsh environment*

Survive transport
(much easier !)

Gravity



Can be used to move things !

Mass

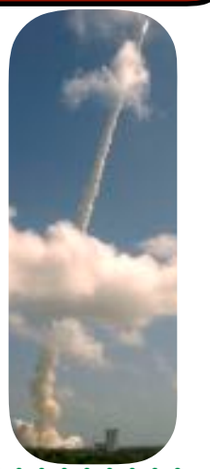

Maintenance *limited if possible*


Preferably no consumable
(electricity only - cryogen free)

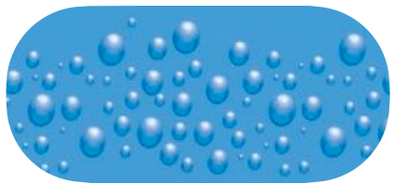

Space borne

Survive launch
(and transport)





Microgravity



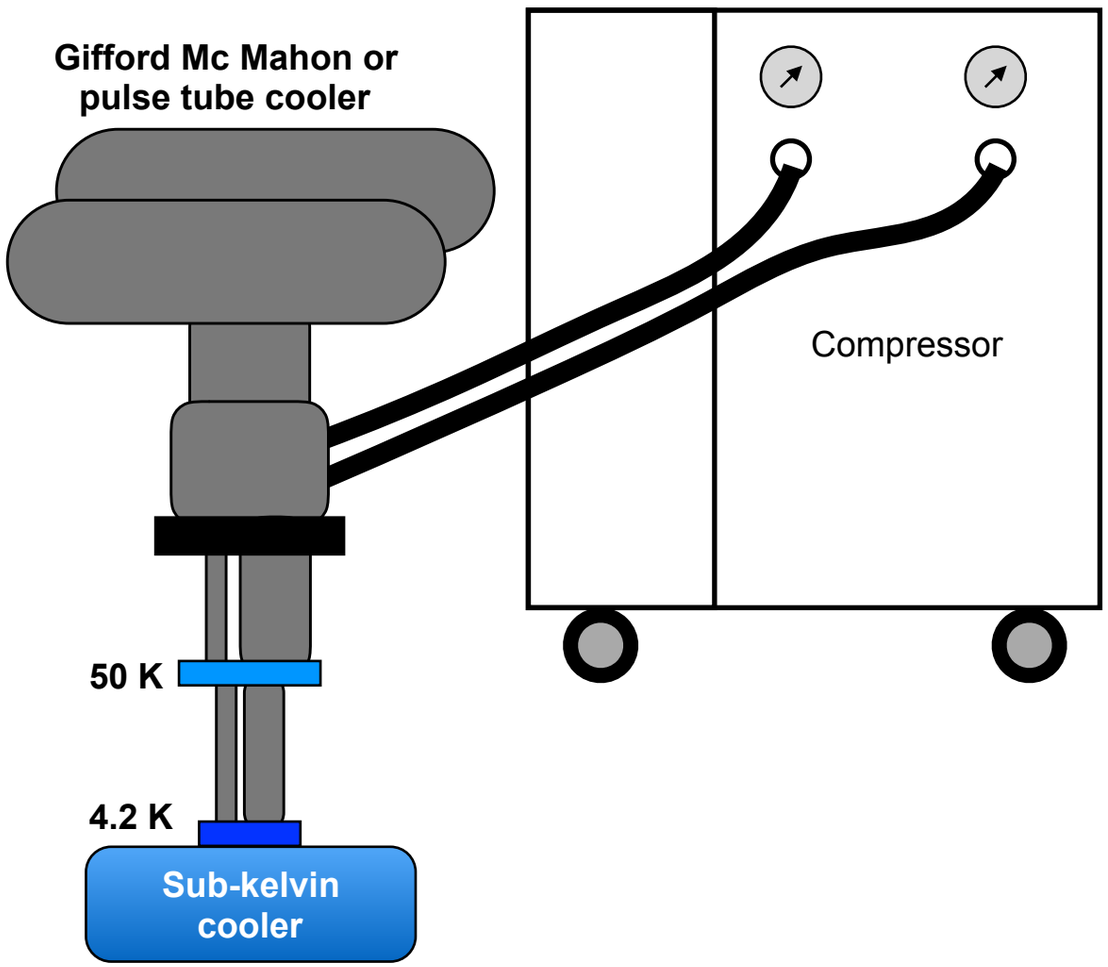
Liquid ?
Tricks needed

~~**Maintenance**~~


Typical cryogenic chain

Ground based

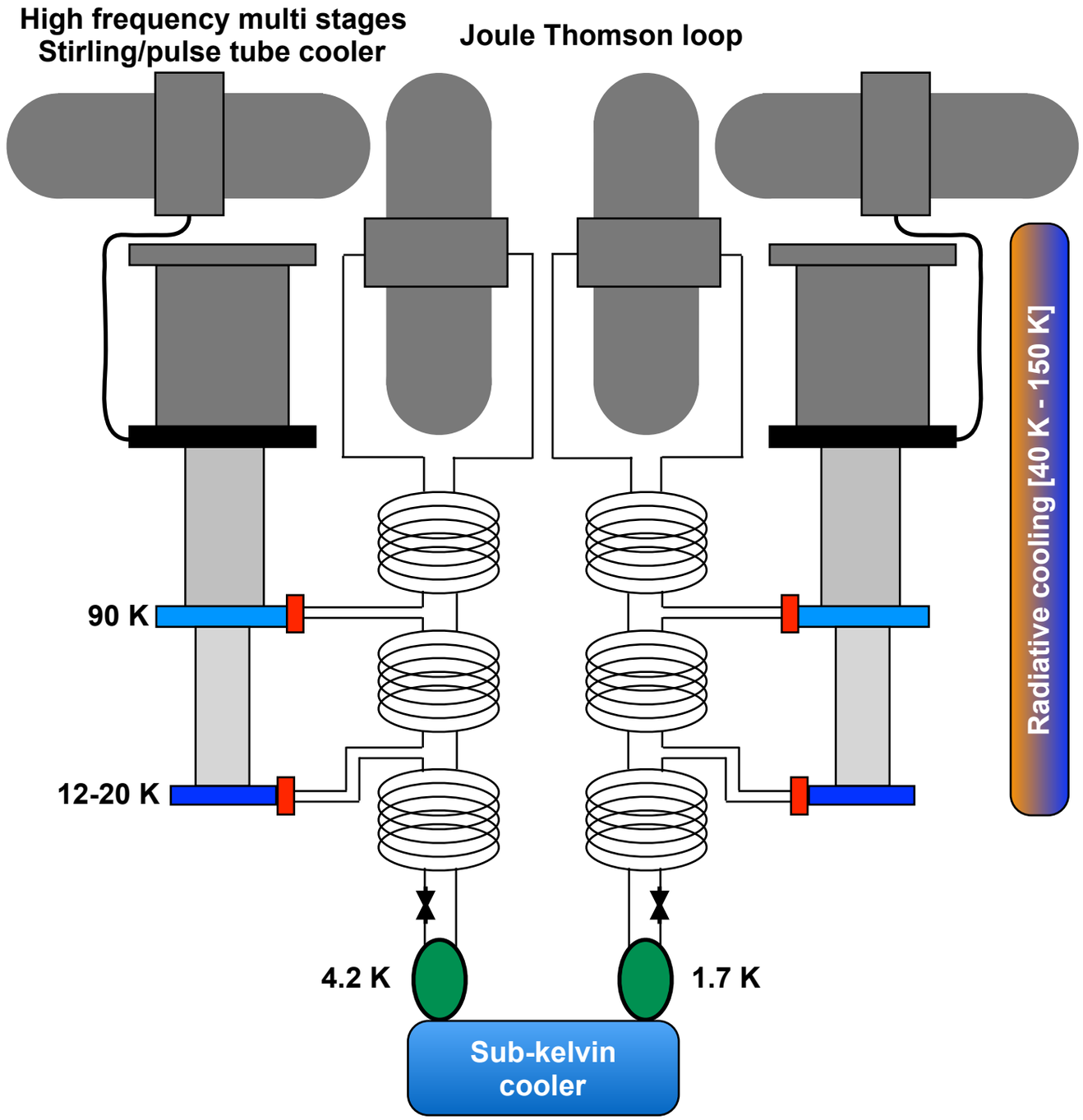
harsh environment



Input power ≈ several kW

Not to scale

Space borne



Input power ≈ several hundreds of W

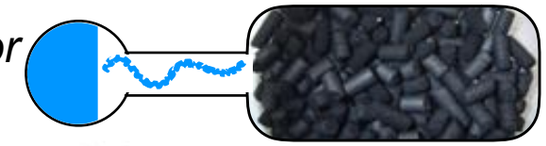
Sub-kelvin: 3 proven and extensively used techniques

Can be combined together

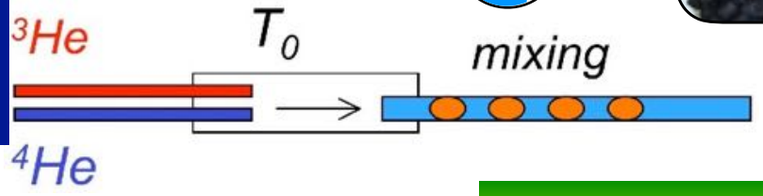
0.01 K | 0.1 K | 1 K | 10 K

Max interface temperature

Magnetic (ADR) — ≈ No

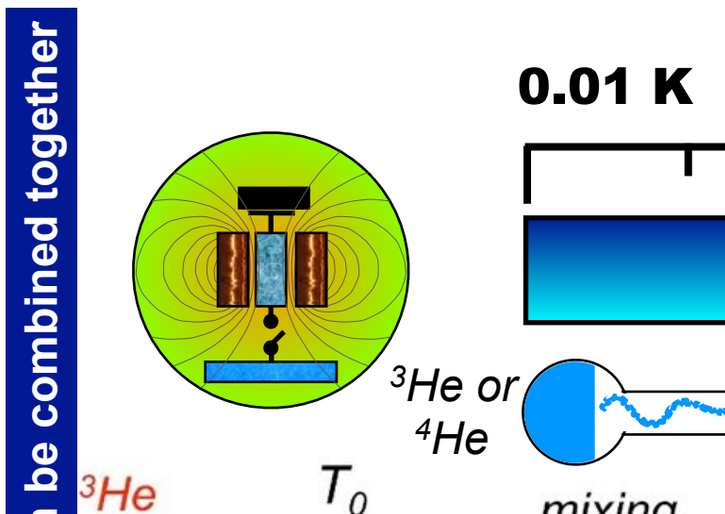


Evaporative (sorption) — < 5.2 K

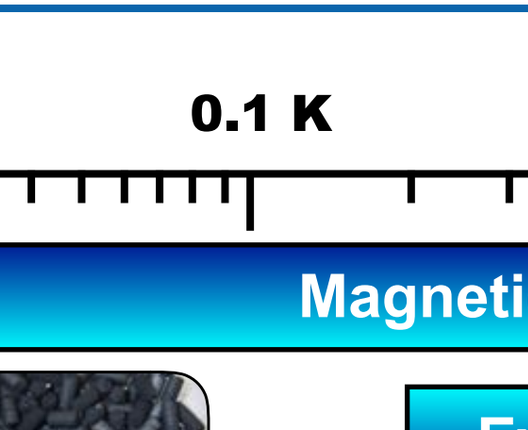


Dilution — < 1.7 K

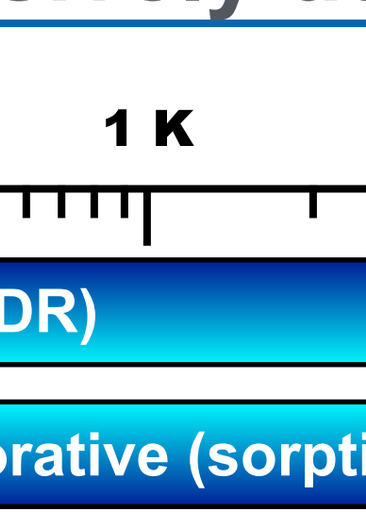
All space compatible and flown in the last 10 years



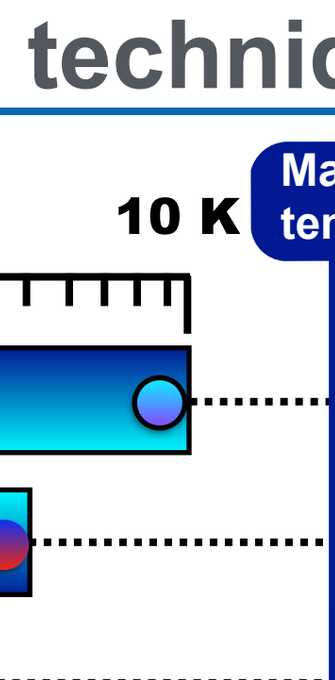
2016 — *0.8 µW @ 50 mK*



2005 — **ASTRO E2 (SUZAKU)** — *0.3 µW @ 60 mK*



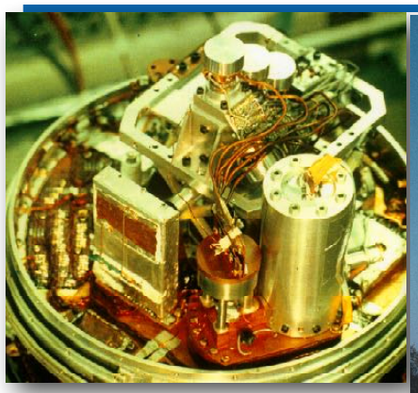
2009-2012 — **PLANCK** — *0.2 µW @ 100 mK*

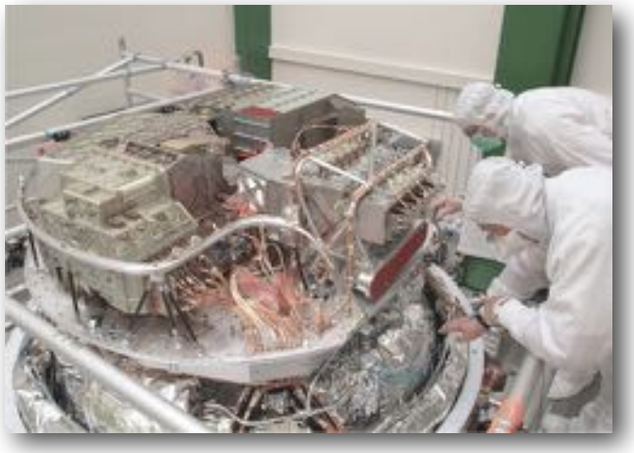


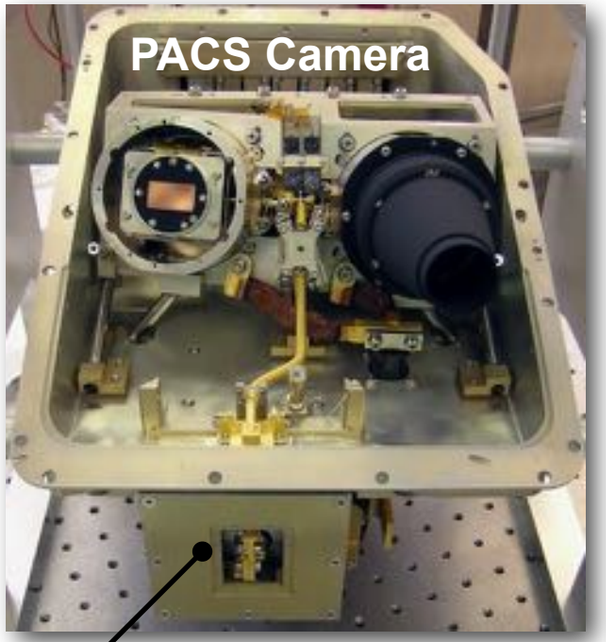
2009-2013 — **HERSCHEL** — *10 µW @ 290 mK*

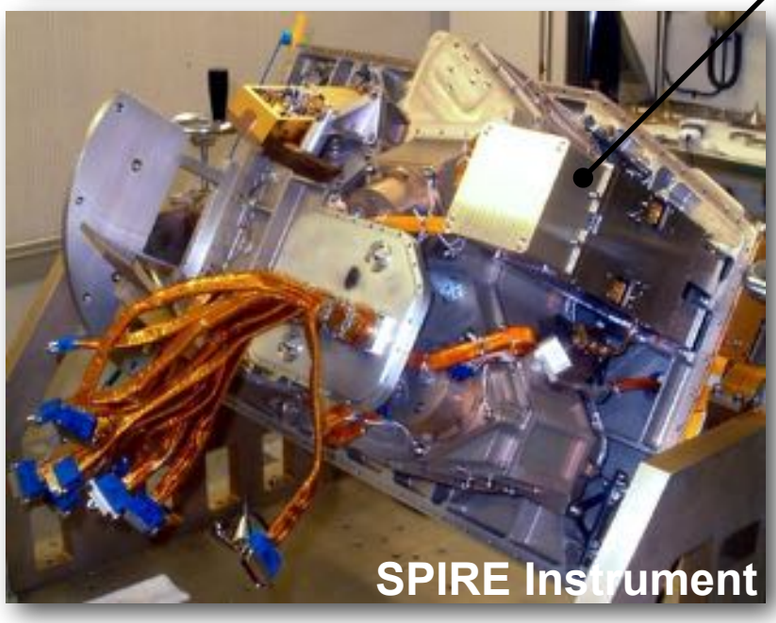
10 mK | **100 mK** | **1 K**

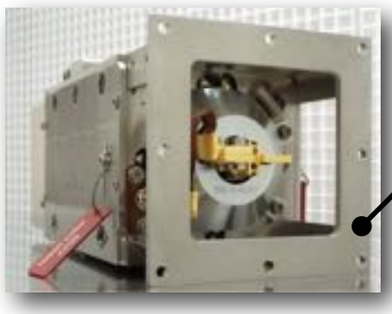
Evaporative cooling: from rockets to satellite



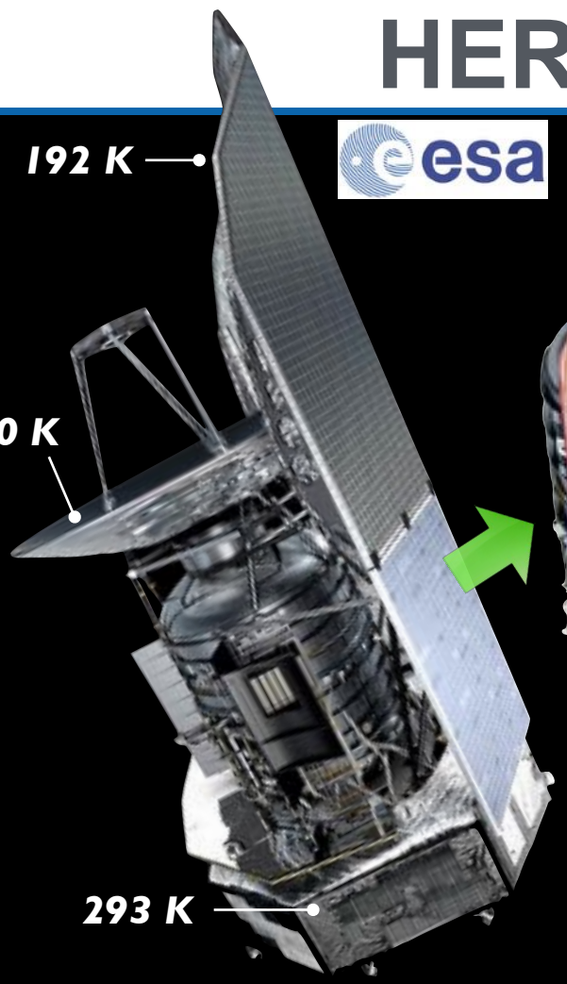




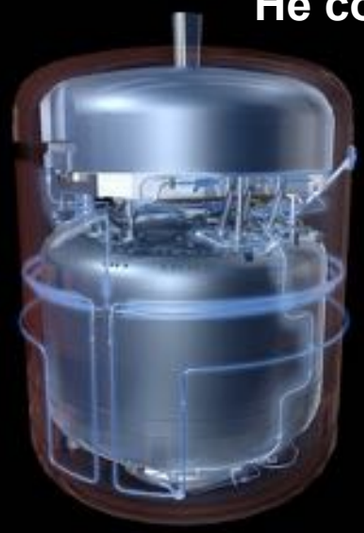




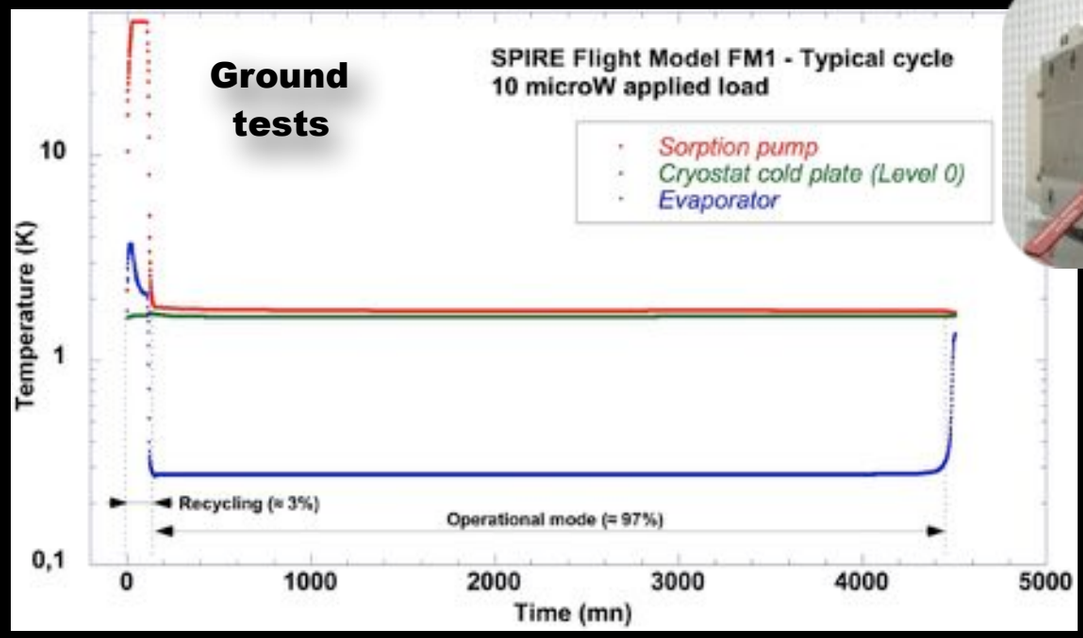
HERSCHEL Cryogenic chain - In flight

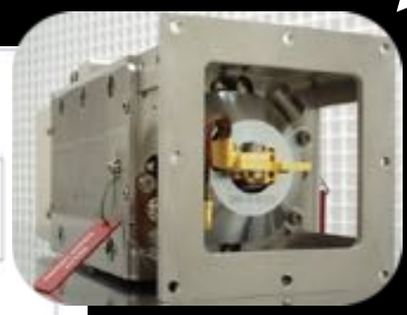


80 K passive cooling
+ 1.7 K He superfluid tank
+ 300 mK He sorption cooler



$L_0 \approx 1.7$ K
$L_1 \approx 4$ K
$L_2 \approx 10$ K



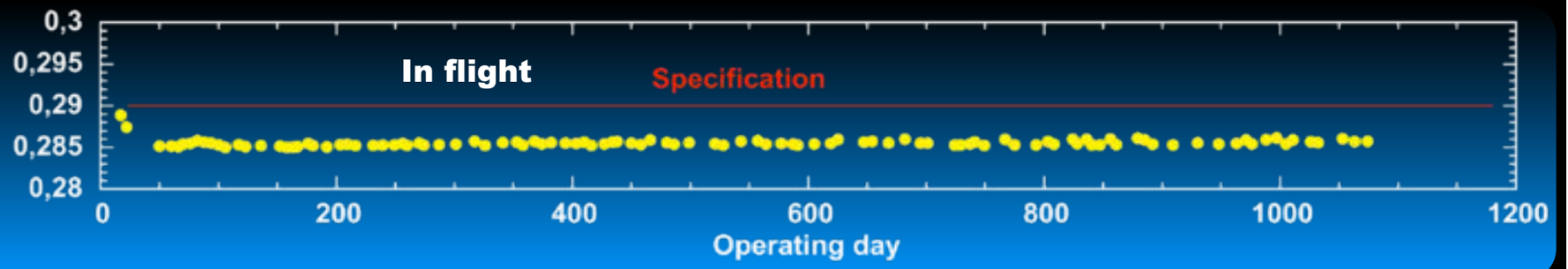


300 mK Helium sorption cooler

10 µW @ 290 mK
≈ 2 days autonomy
"Unlimited" lifetime
Vibration free

HERSCHEL

SPIRE Sorption unit

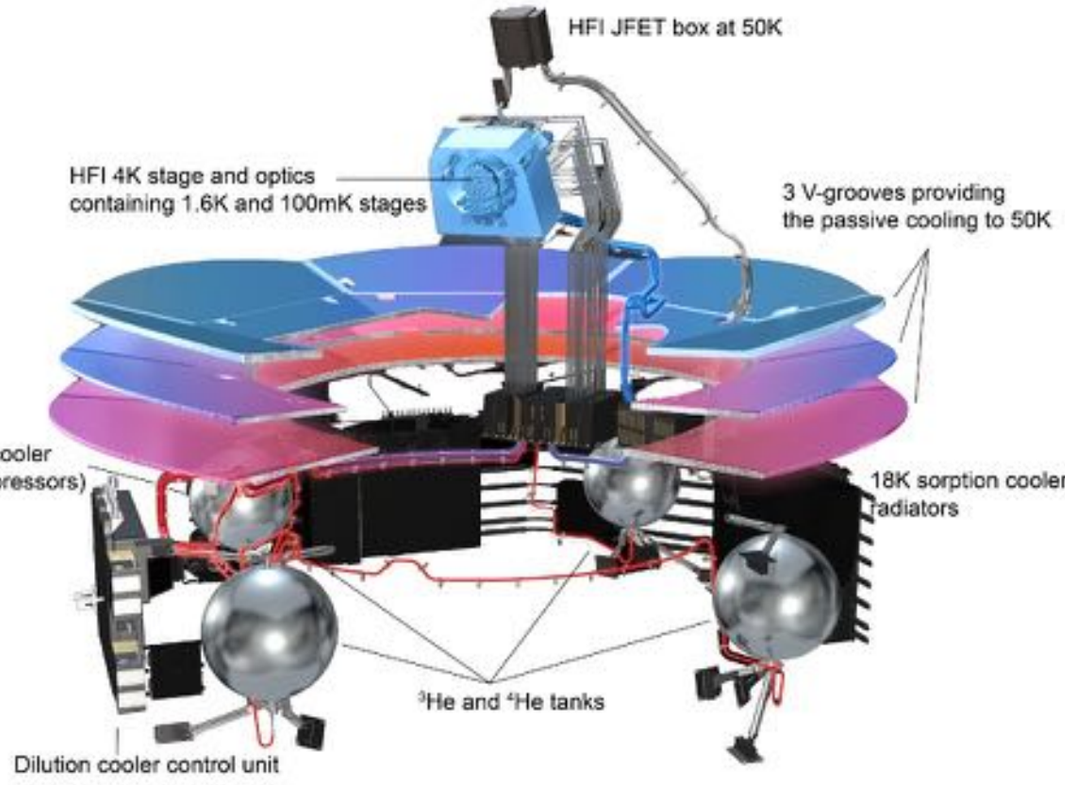


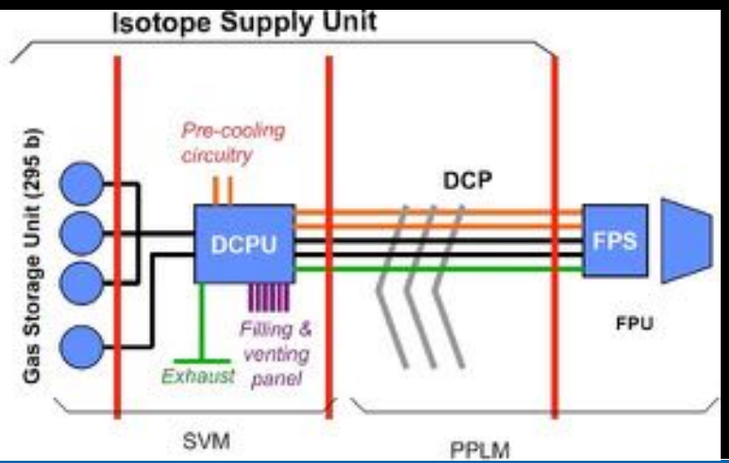
PLANCK Cryogenic chain - In flight

Combination of passive cooling
+ 18 K H2 sorption cooler
+ 4K JT loop
+ dilution (incl. 1.6 K JT loop)

100 mK
dilution cooler

200 nW @ 100 mK continuous cooling from 1.6 K (≈ 8 µW)
Open cycle: Lifetime limited
≈ 2 years mission





PLANCK Cryogenic chain - In flight

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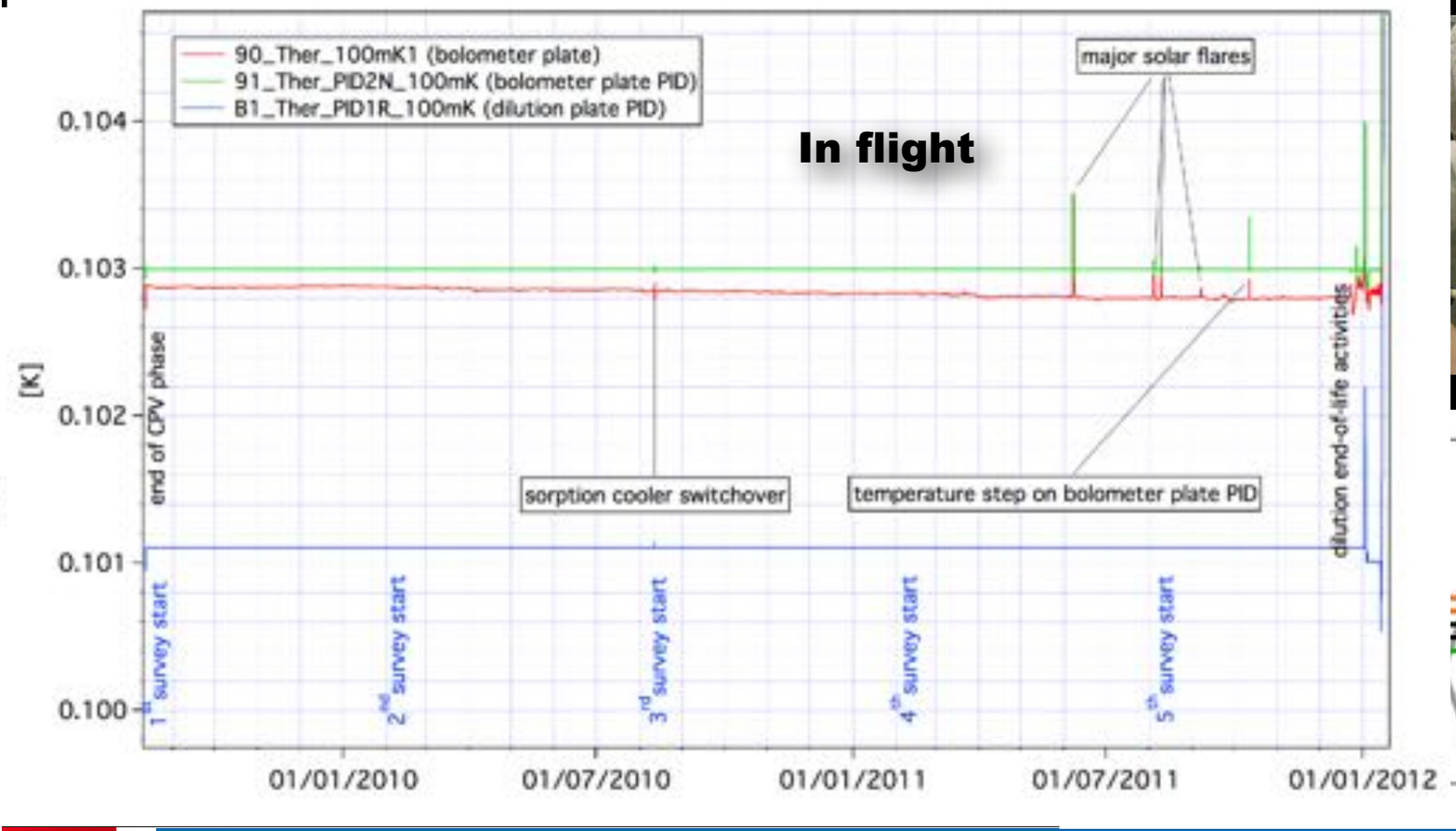
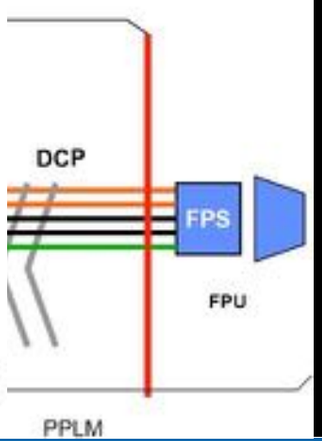
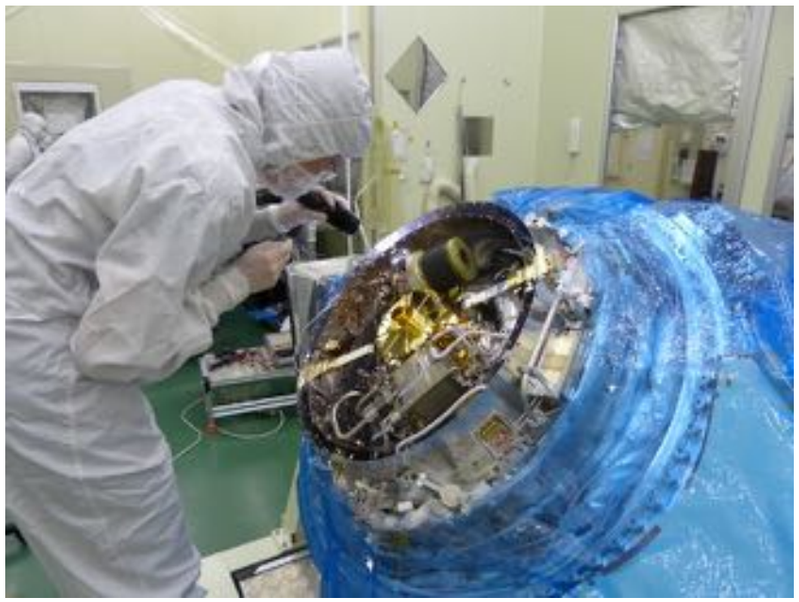
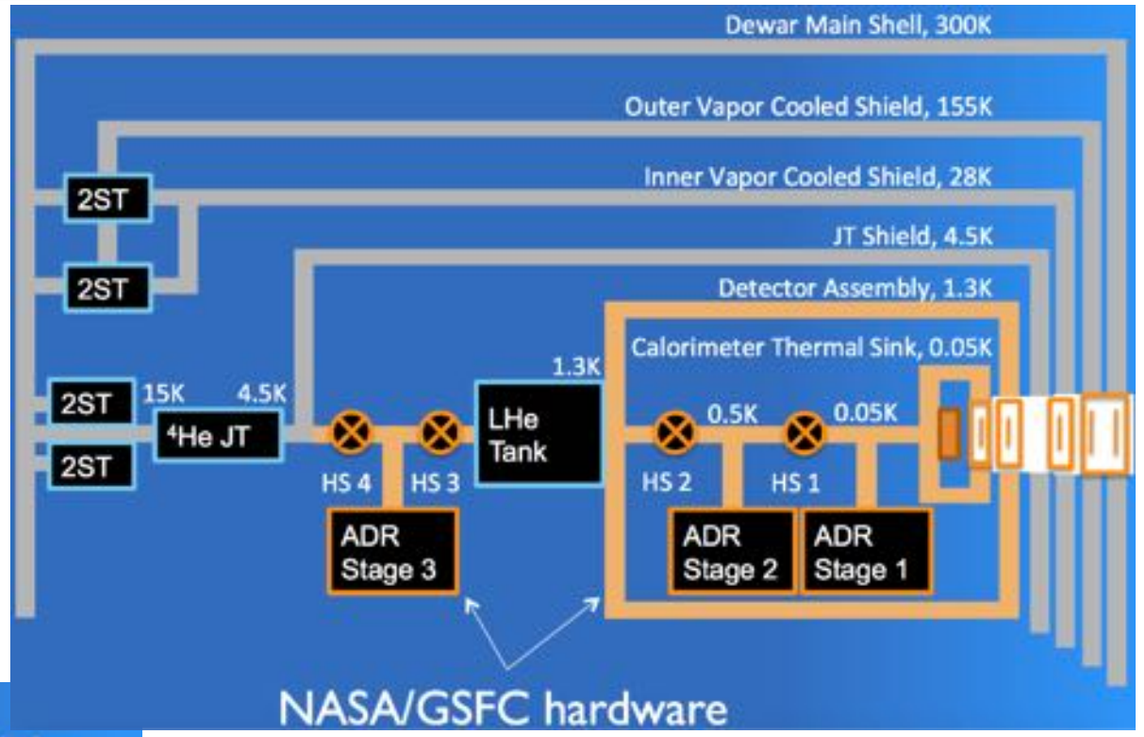
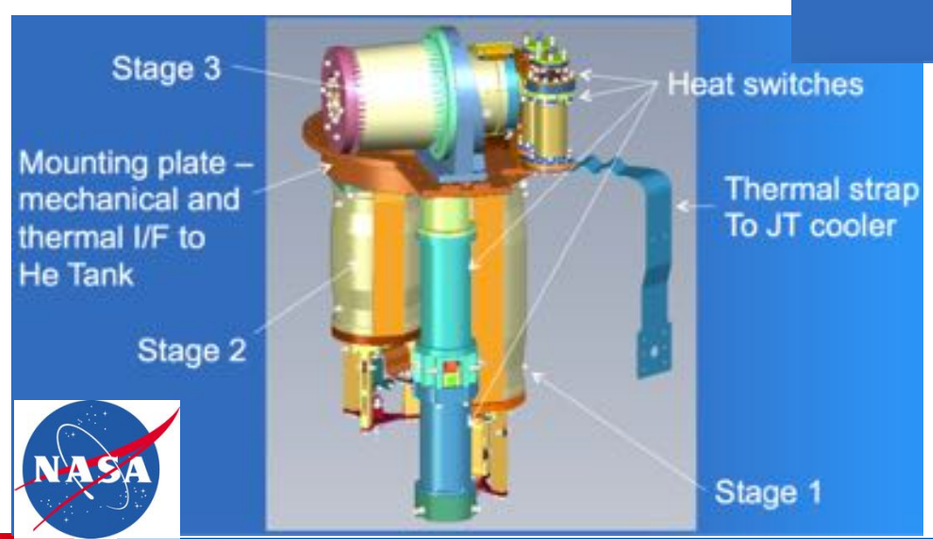




HITOMI (ASTRO-H) Cryogenic chain

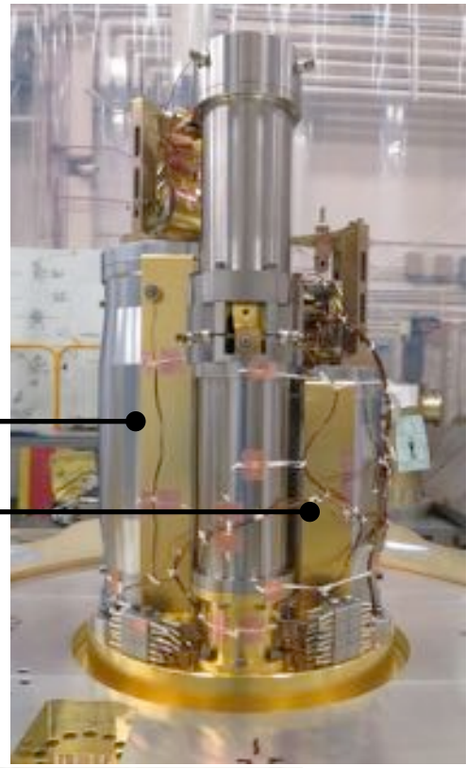


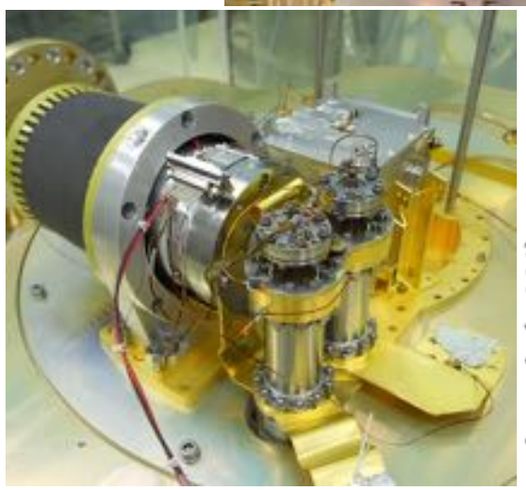




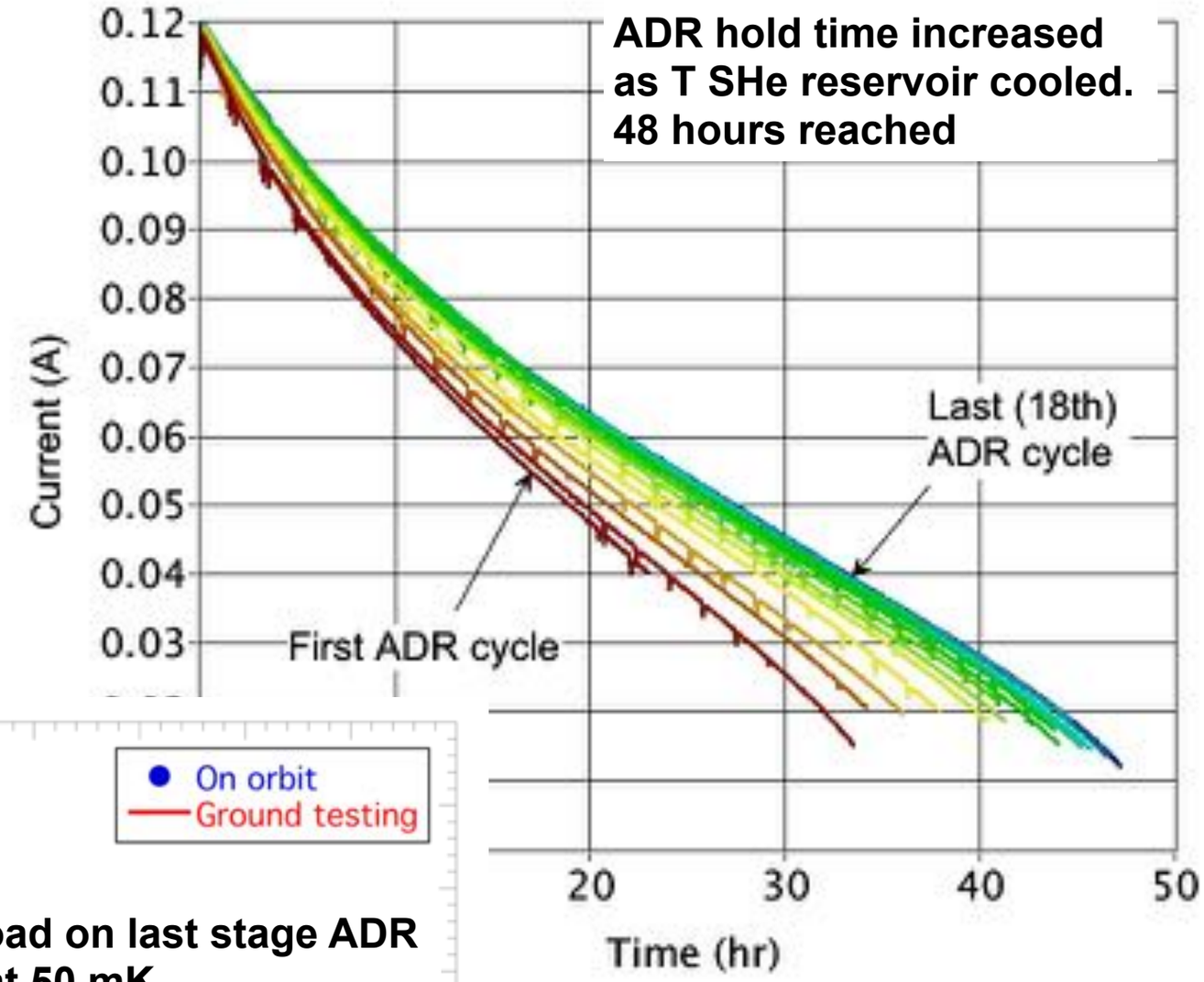
Combination of passive cooling
+ Multistage stirling coolers
+ 4K JT loop
+ 1.3 K He Superfluid reservoir
+ 3 stages ADR (2 stages used with SHe, 3 stages when reservoir out of helium)

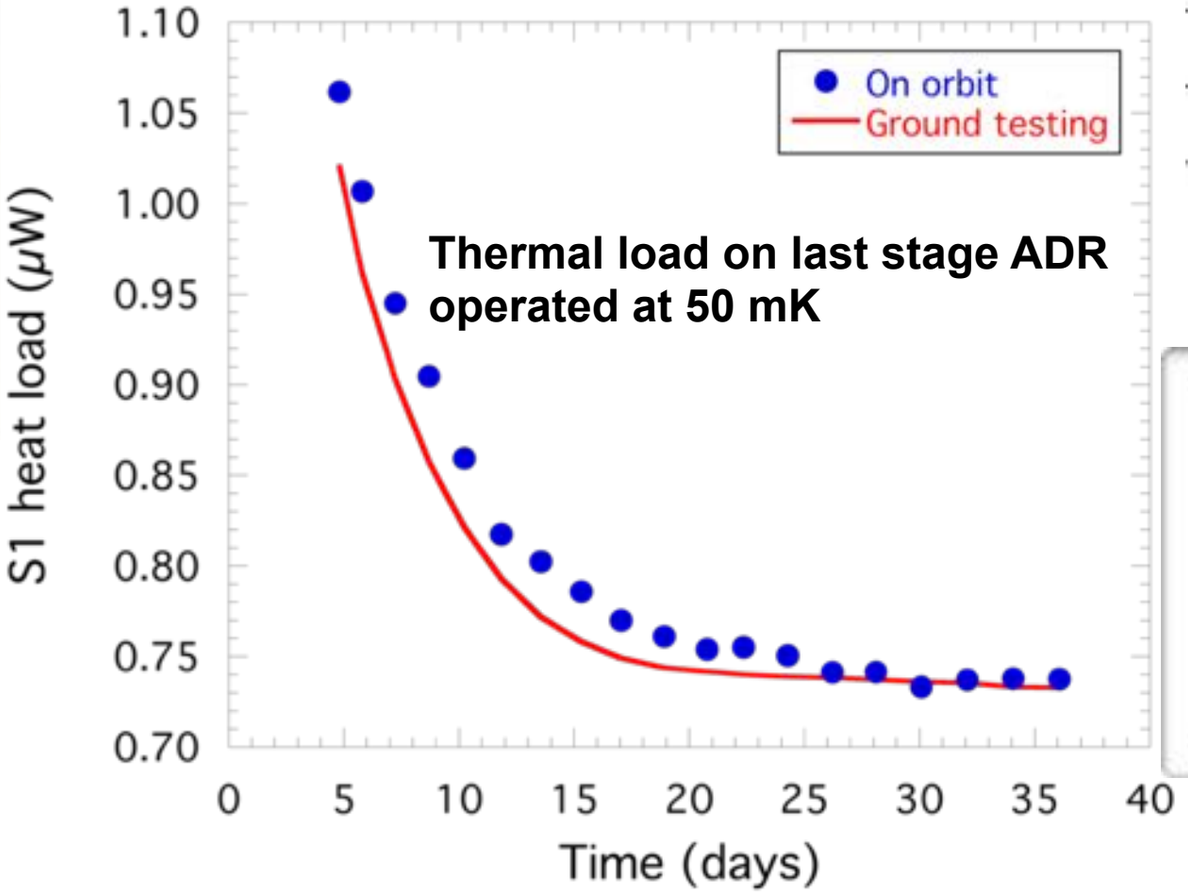
HITOMI (ASTRO-H) - In flight





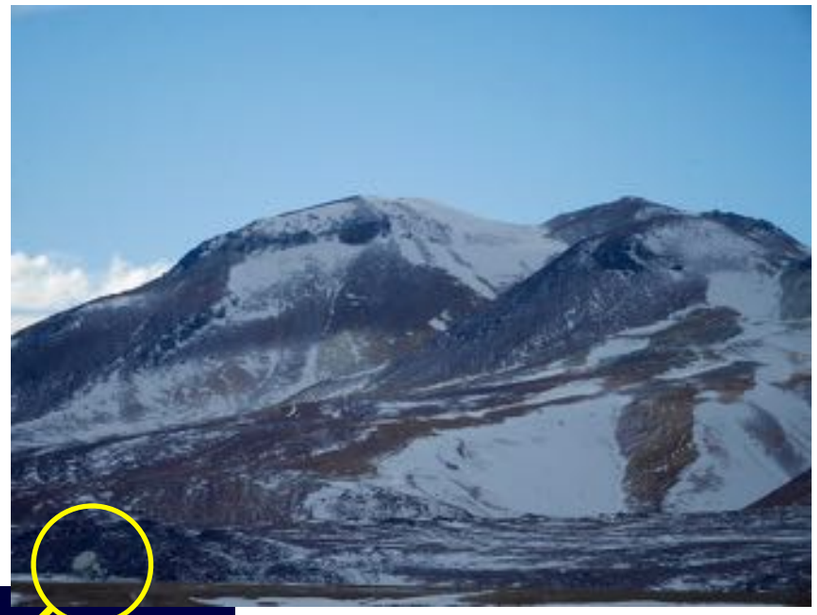
Stage 3



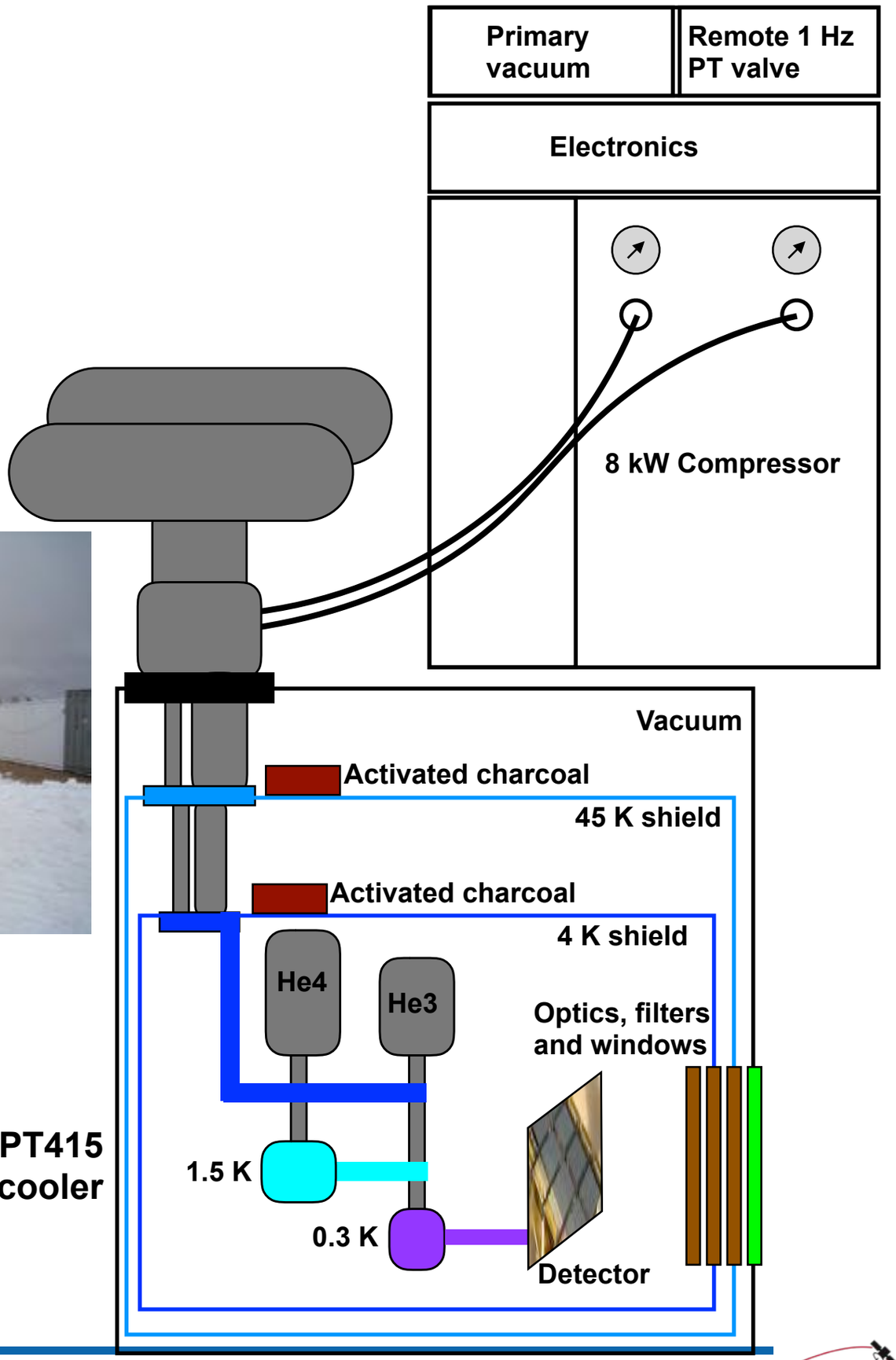


Cryogenics performed as expected but mission failed due to attitude control anomaly resulting in uncontrolled spin of spacecraft

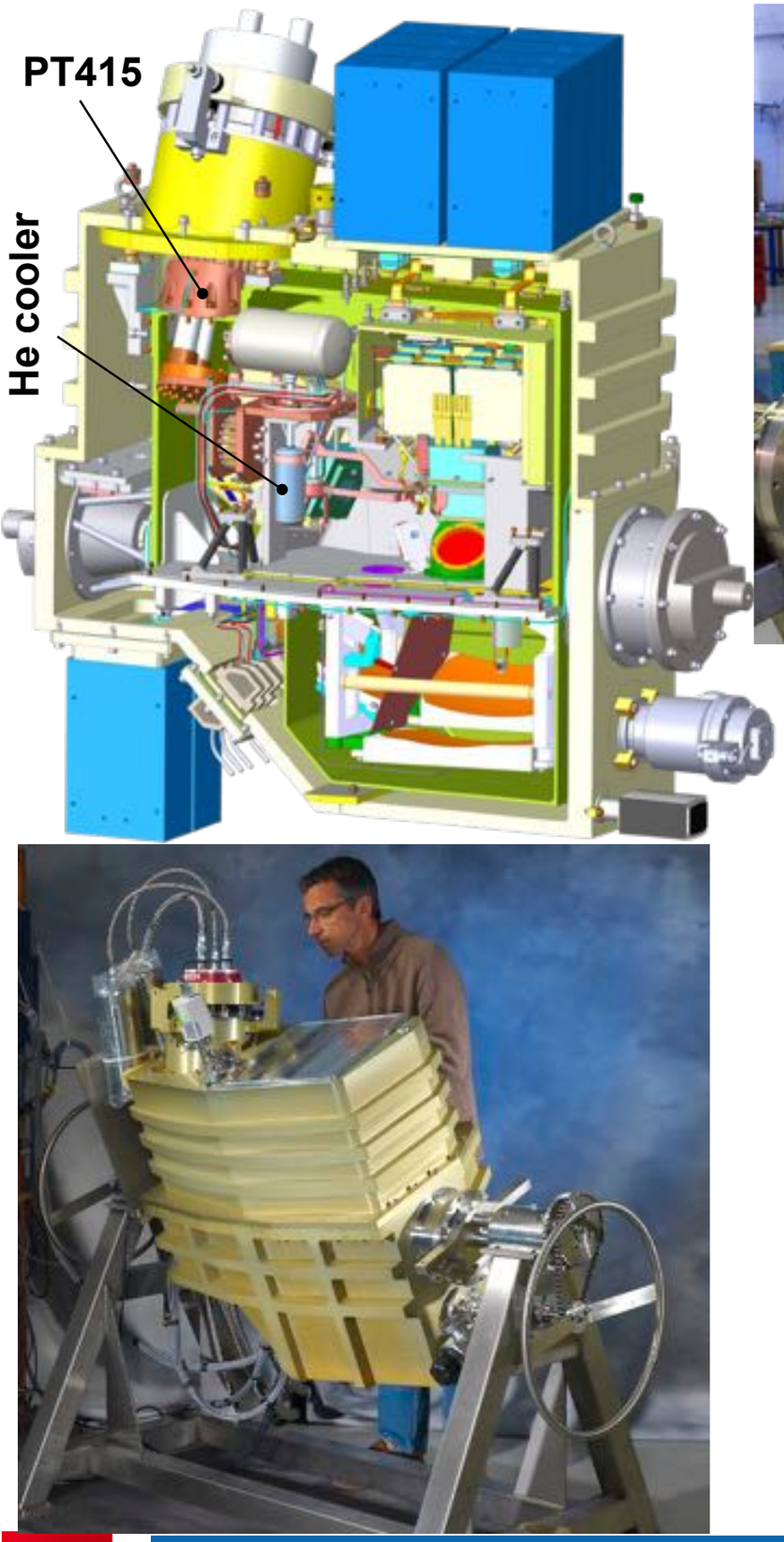
Ground based telescopes - ARTEMIS APEX

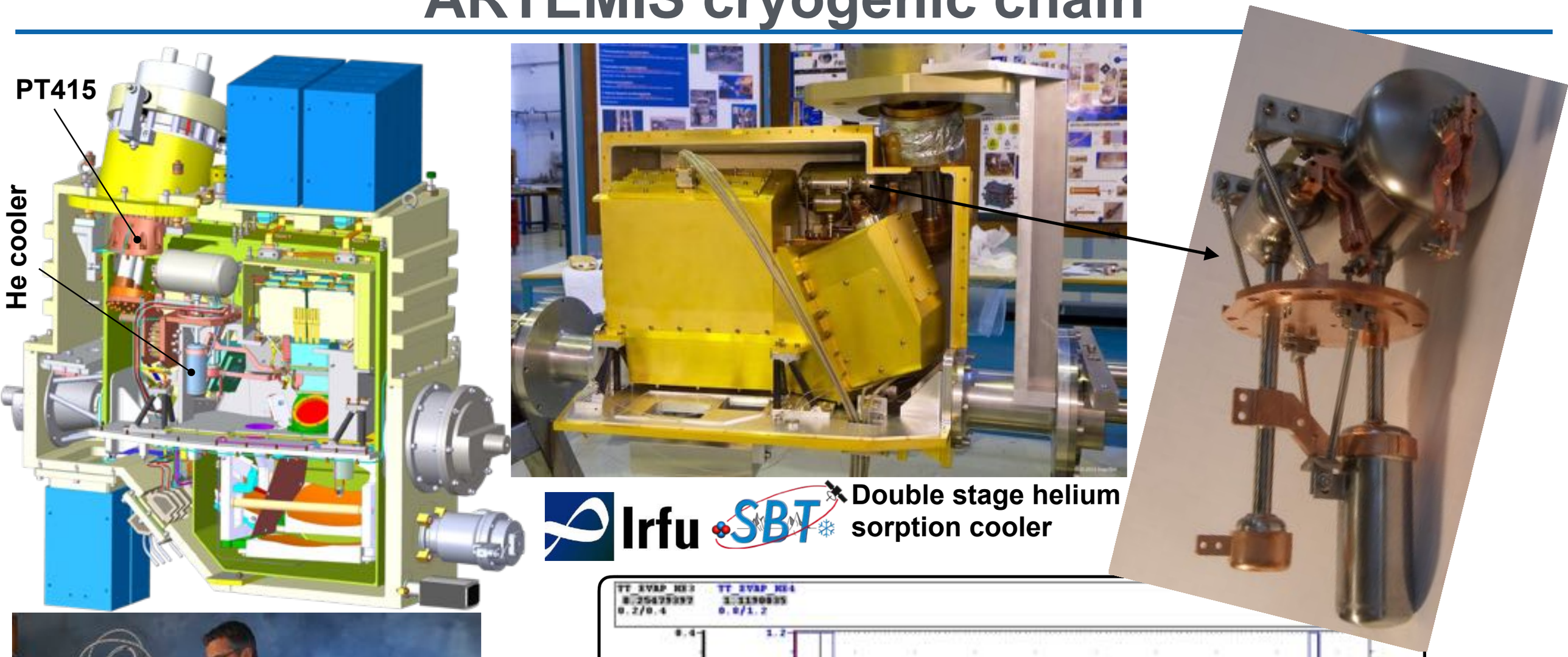


CryoMech PT415
+ 2 stages He sorption cooler



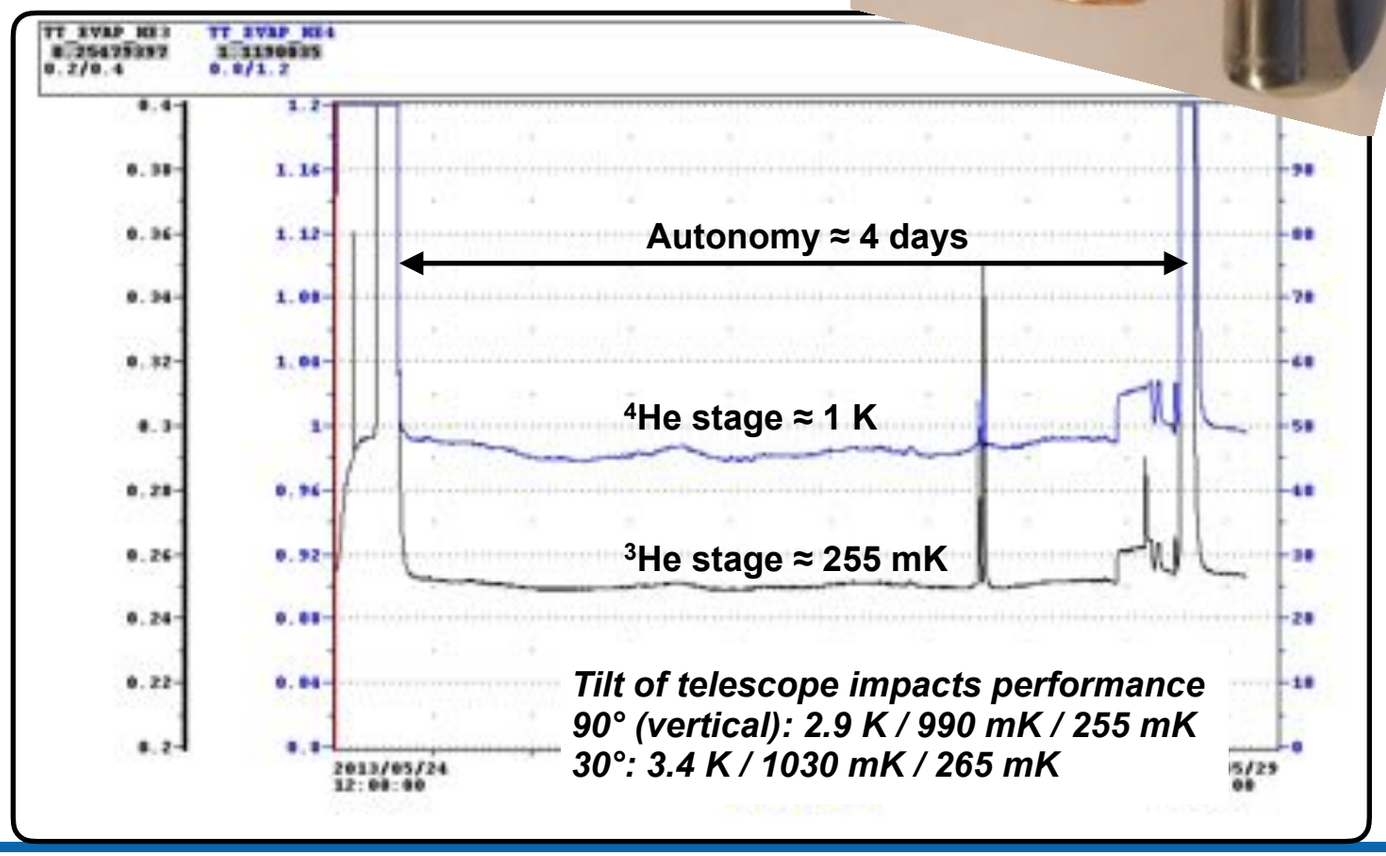
ARTEMIS cryogenic chain



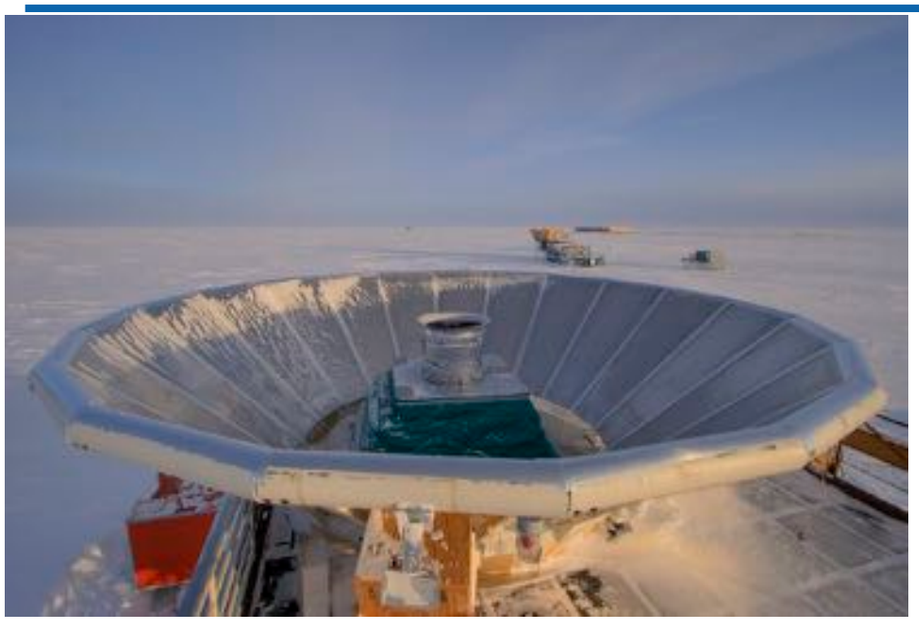


Irfu SBT

Double stage helium sorption cooler



Gravitational waves … cryogenics needed

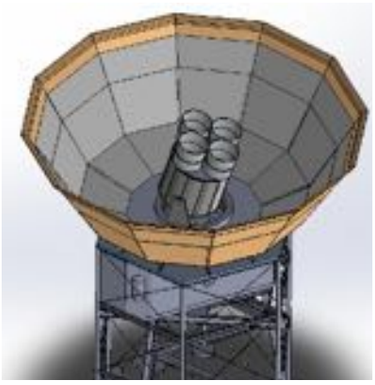


BICEP2
(2010-2012)

Keck Array
(2012-2017)

BICEP3
(2015-)

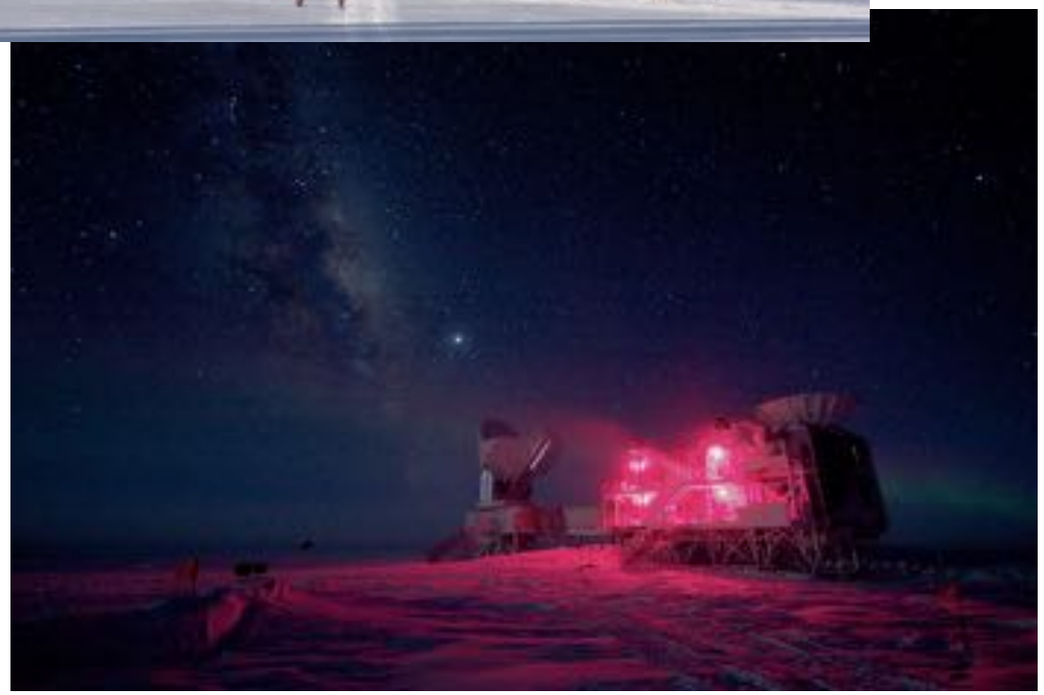
BICEP Array
(2018-)



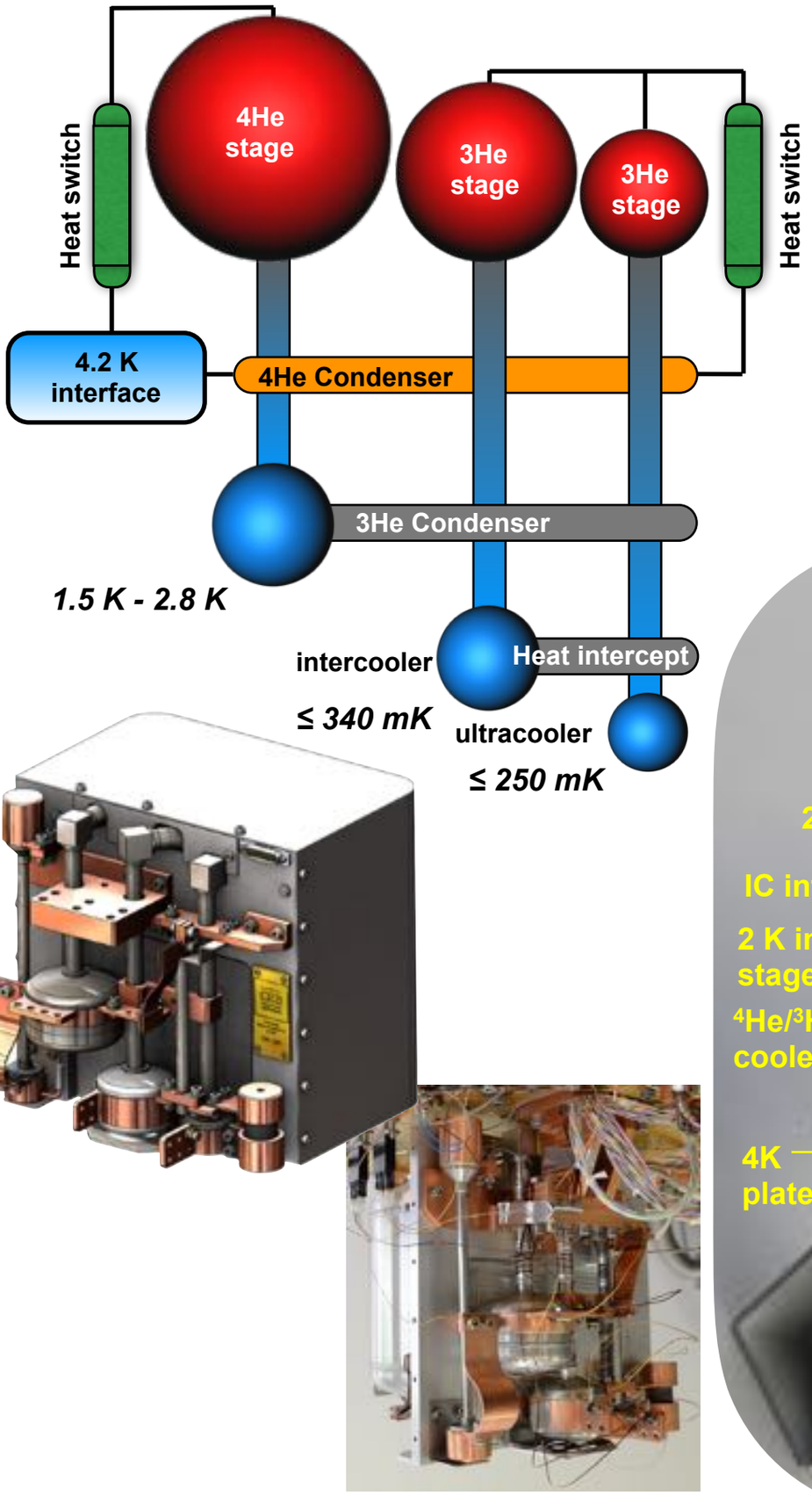
If you are a night owl, the South pole is for you !

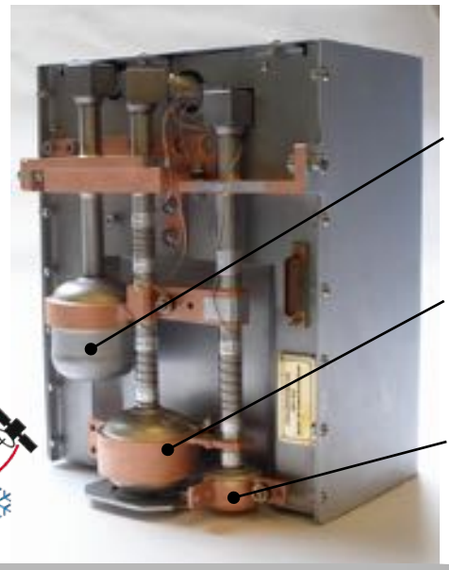
6 months long …

Altitude: 2850 m
Average temperature: -50°C
Lowest T: -82°C
Highest T: -12°C



BICEP series: 3 stages He sorption coolers (He10)





Helium "10" cooler:

^{4}He provides condensation interface for ^{3}He stages **4**

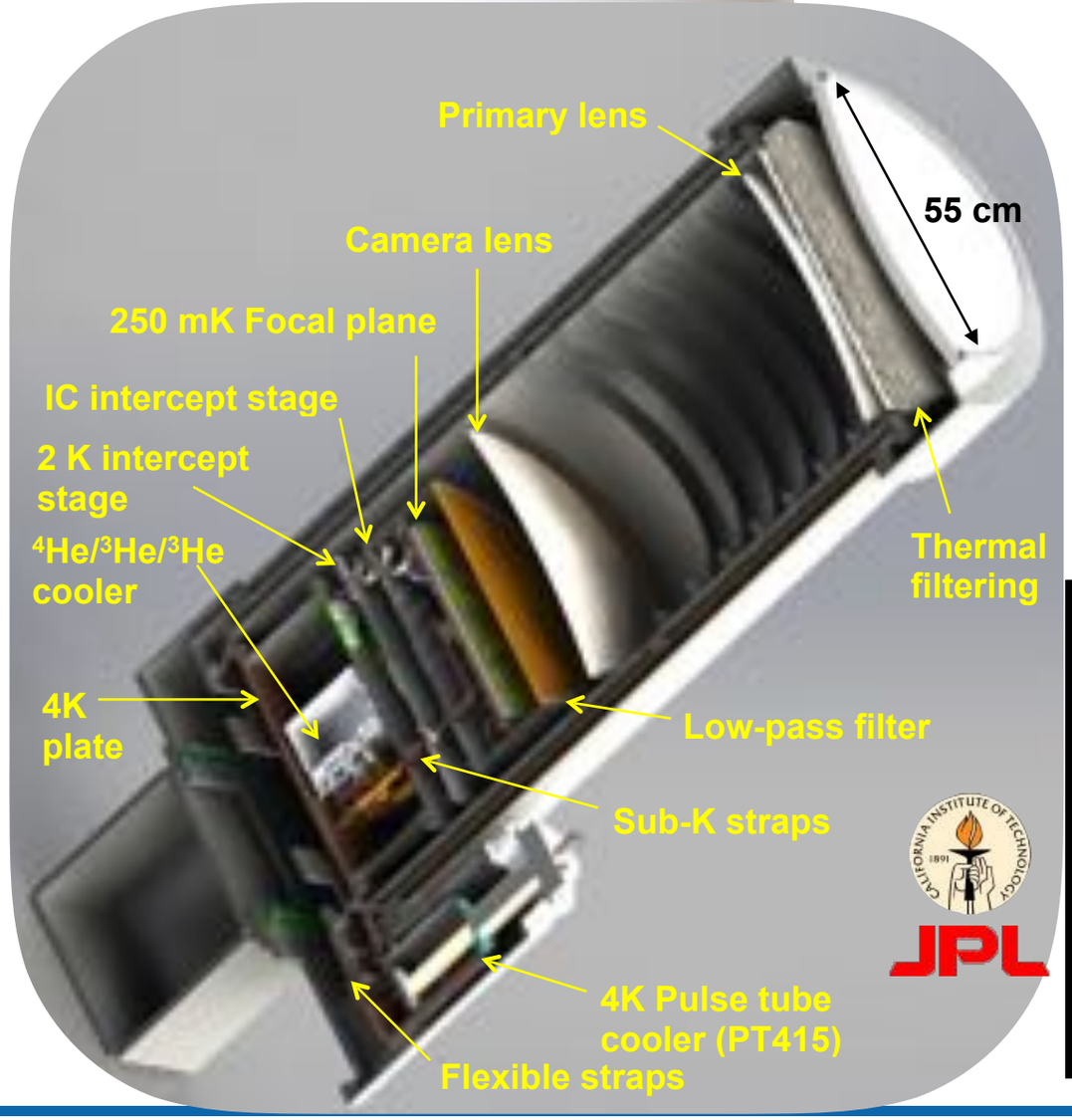
+

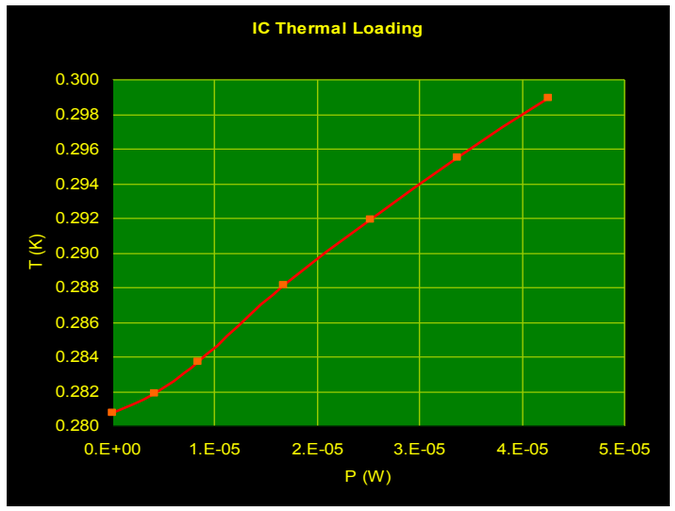
1st ^{3}He stage acts as an intercept **3**

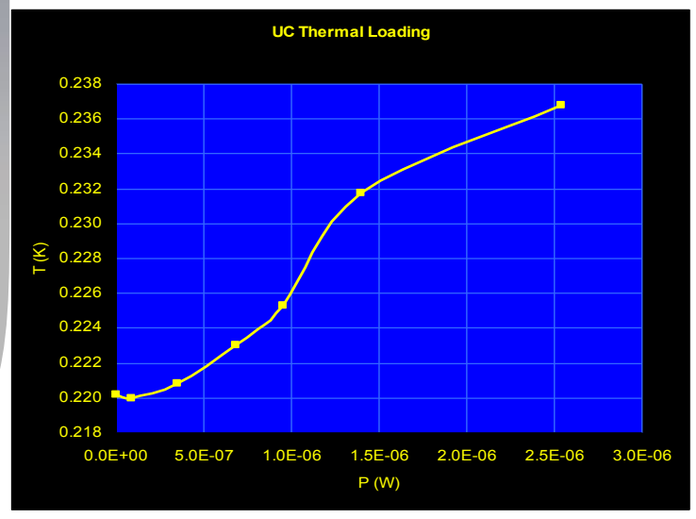
+

2nd ^{3}He stage provides cooling down to 220 mK **3**

= 10







Sub-kelvin missions: what's coming up

2028

2032

2025

Only 3 (4) options

Evaporative (+ sorption)

Dilution

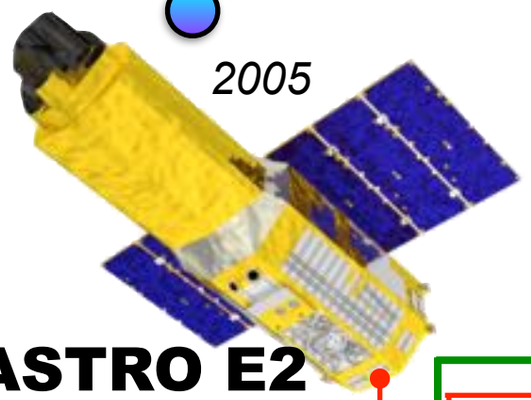
Adiabatic demagnetization (ADR)

Evaporative + ADR

50 mK 100 mK 1 K

0.8 μW @ 50 mK

2016



2005

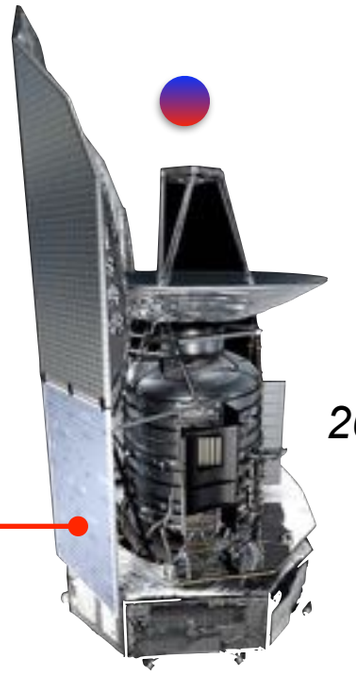
ASTRO E2 (SUZAKU)

0.3 μW @ 60 mK

2009-2012

PLANCK

0.2 μW @ 100 mK



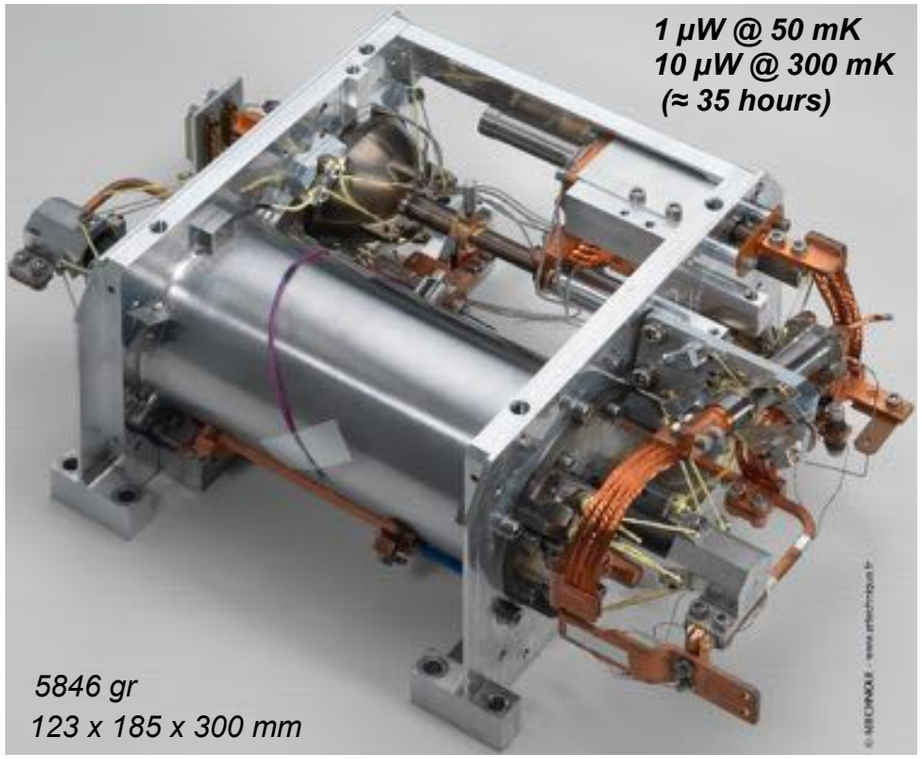
2009-2013

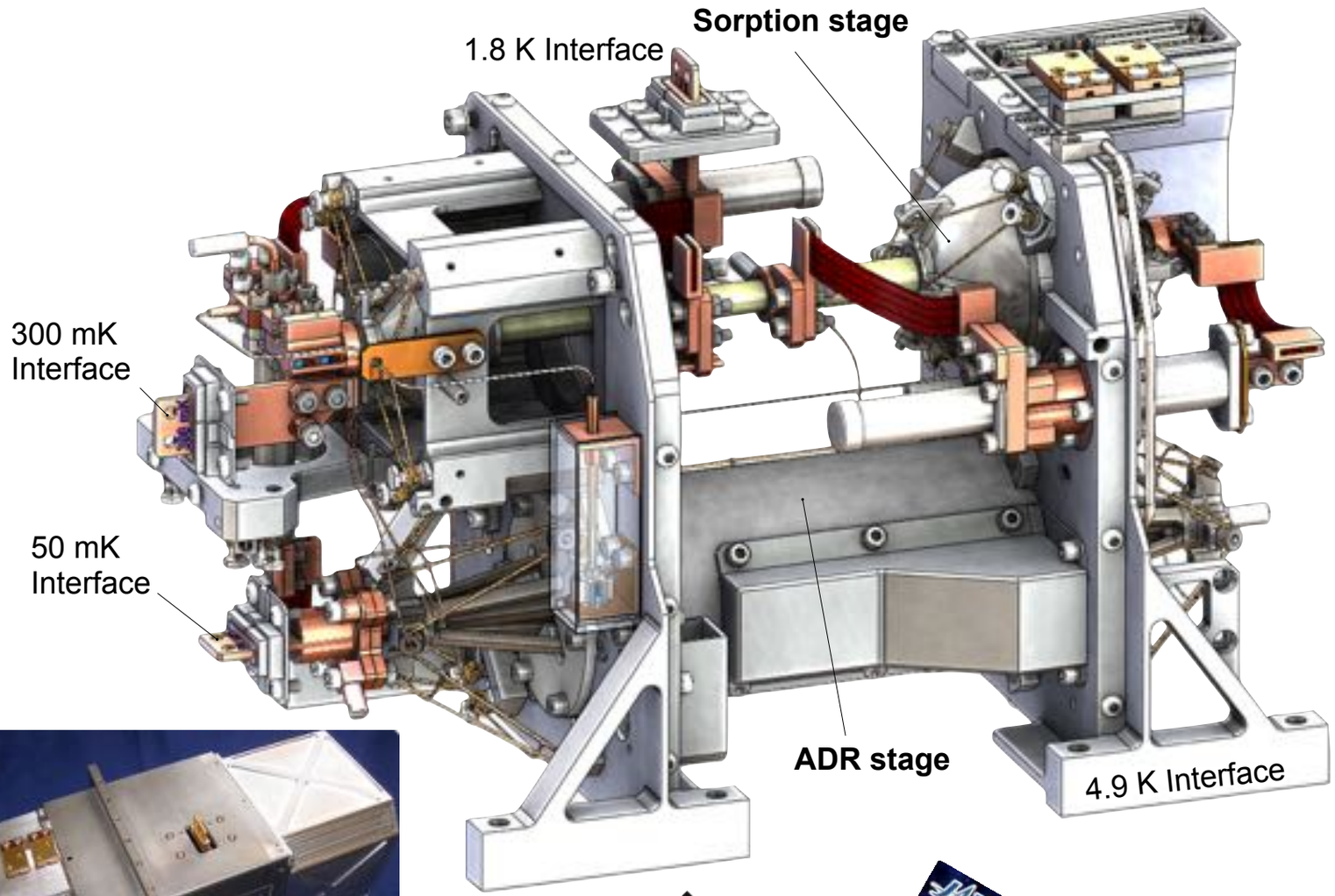
10 μW @ 290 mK

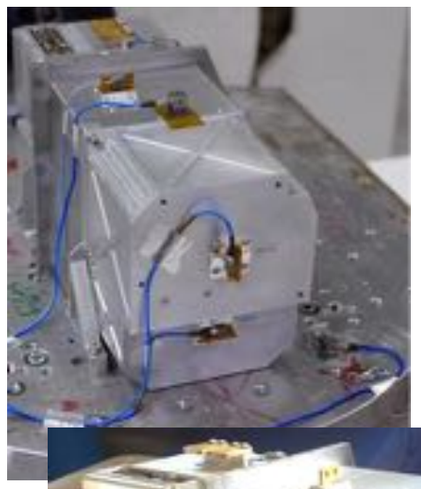
HERSCHEL

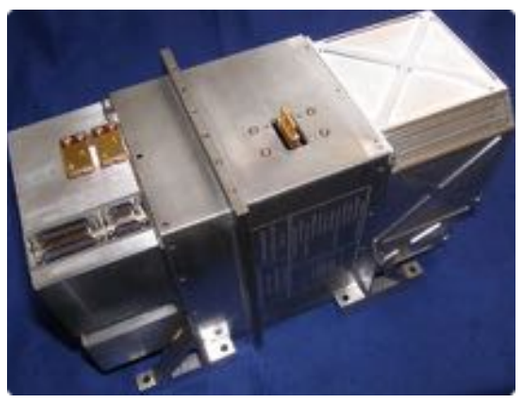
10 mK 100 mK 1 K

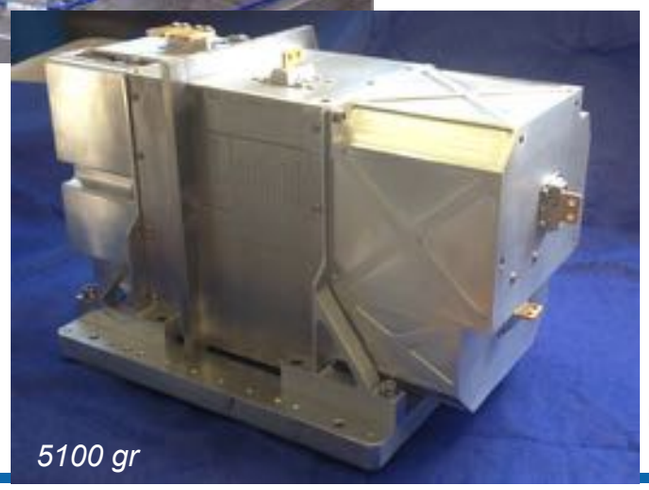
50 mK hybrid cooler: combination He sorption + ADR

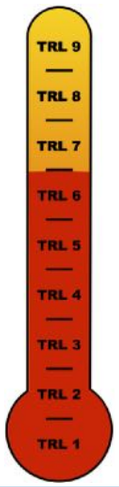


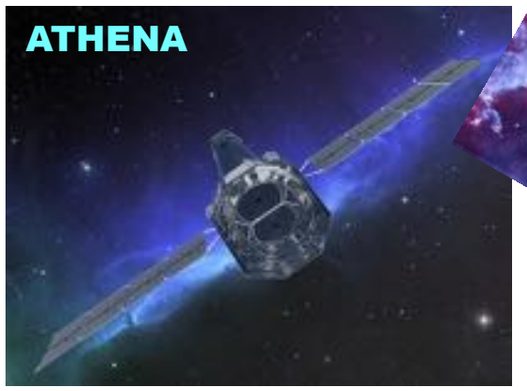








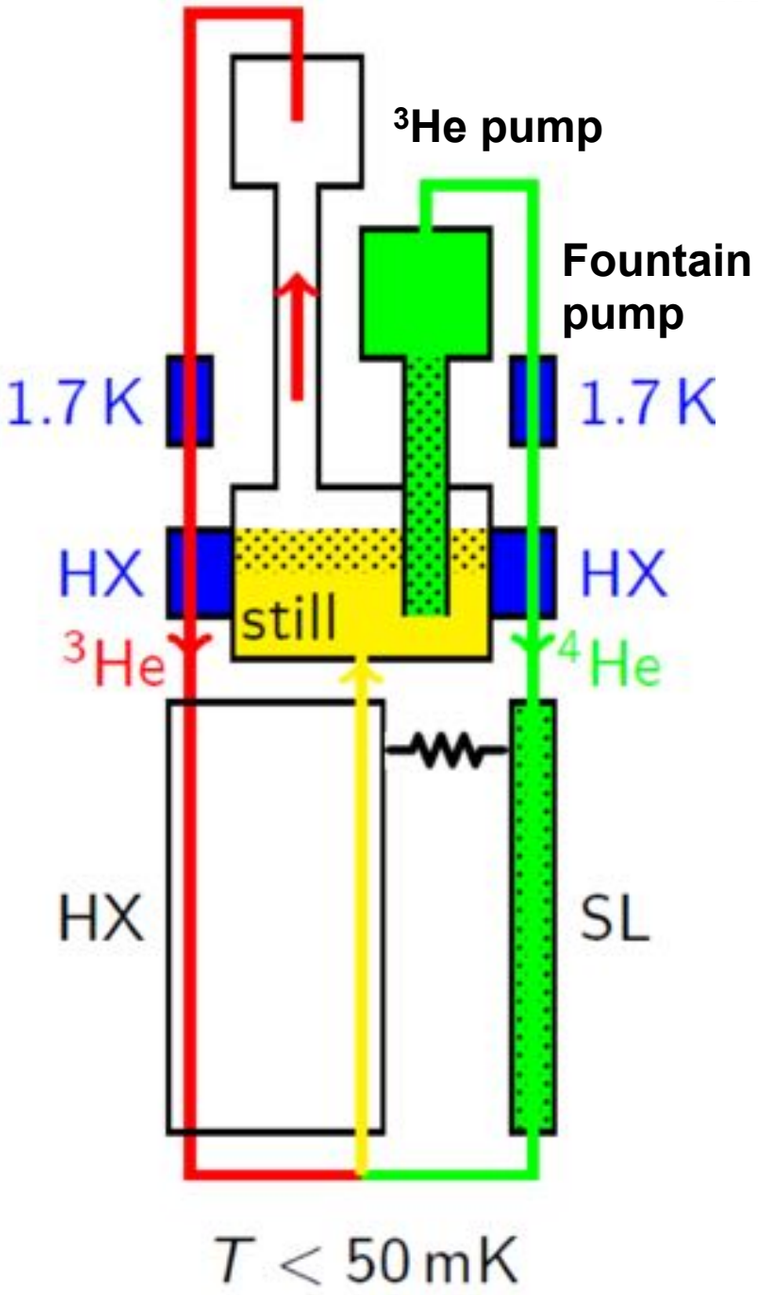




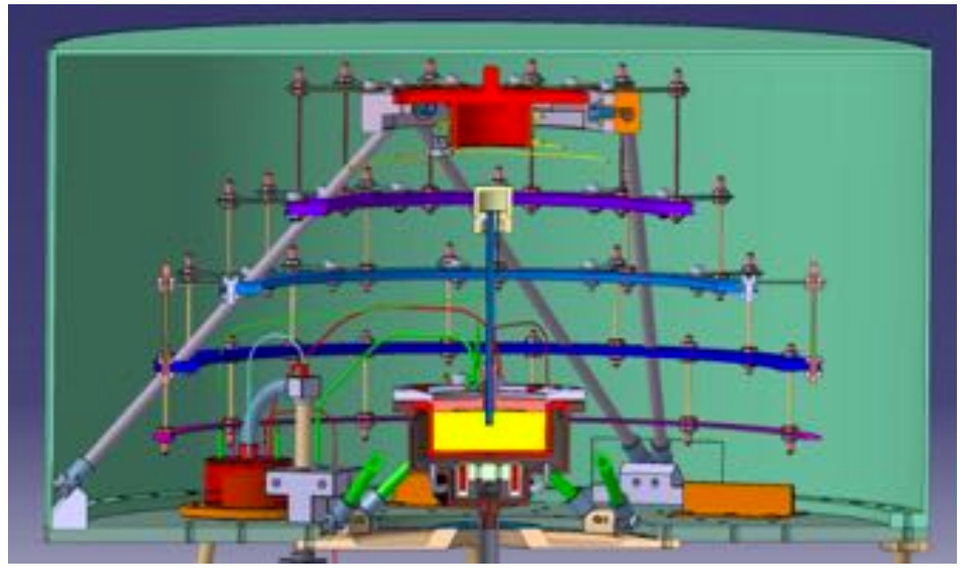
Continuous Dilution cooler

^{3}He-^{4}He mixture: distillate the ^{3}He, extract the ^{4}He with a fountain pump

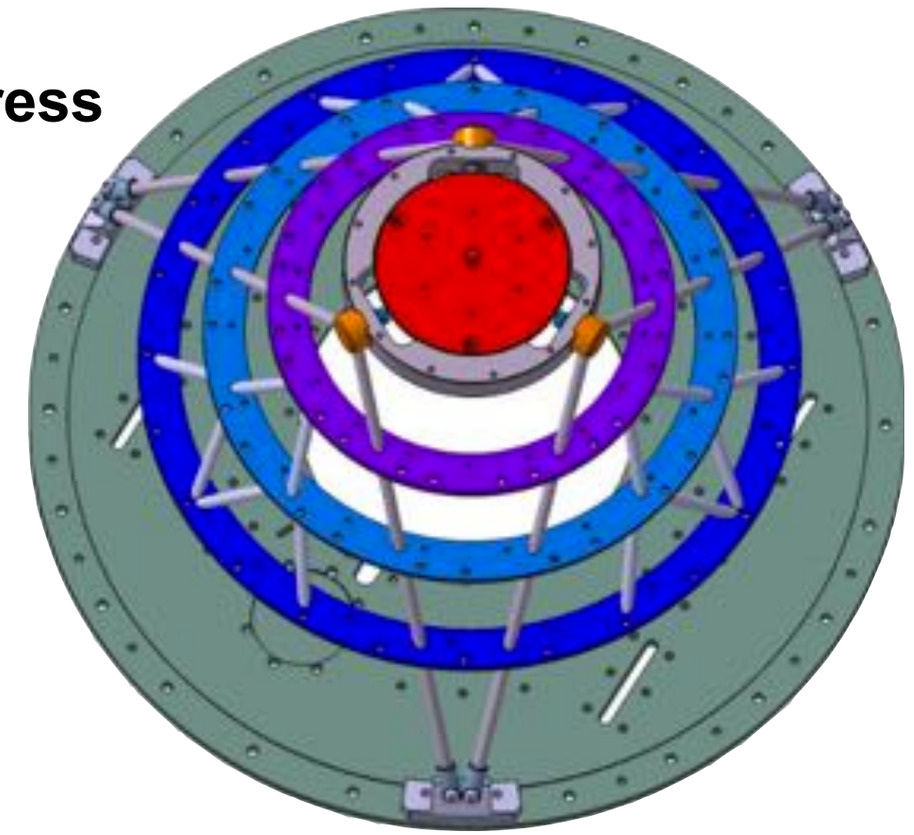
Mix again → Cooling effect



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



Work in progress



Thank you for your attention

Whether in the lab,
in harsh environment
or far away in space,
cryogenics is cool