

FROM RESEARCH TO INDUSTRY

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GRENOBLE



www.cea.fr

CRYOGENICS FOR SPACE

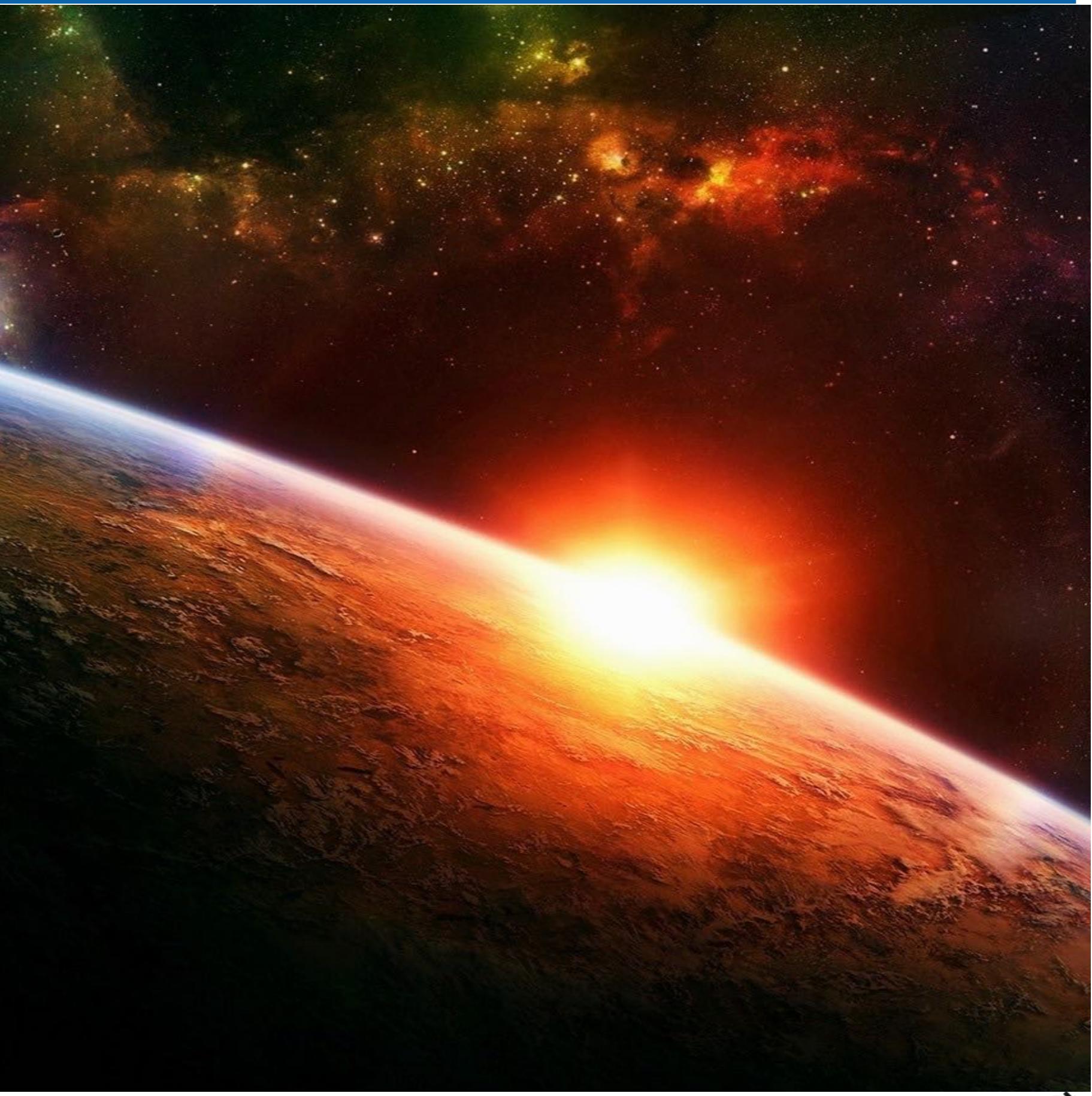
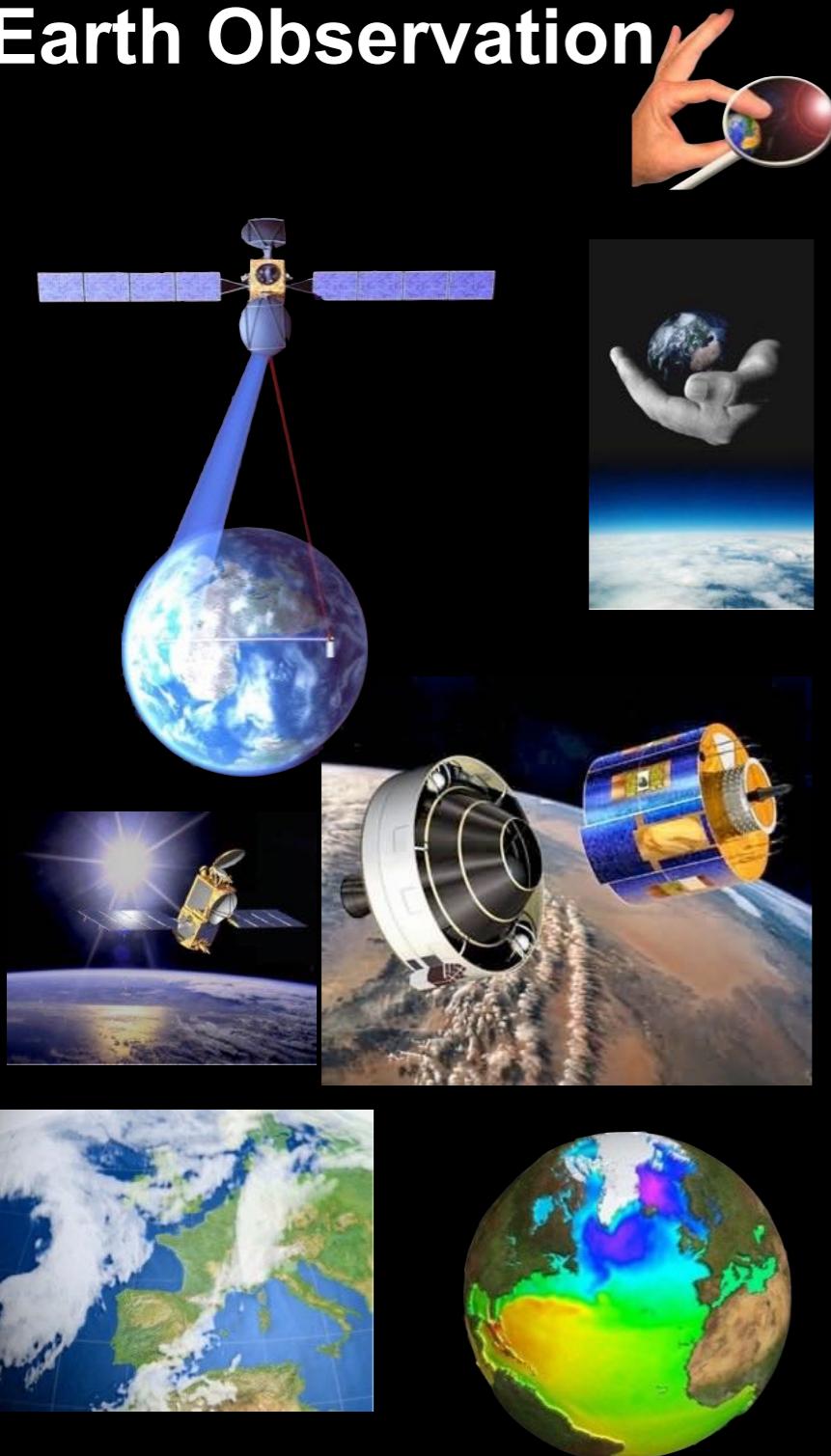
a modest
introduction



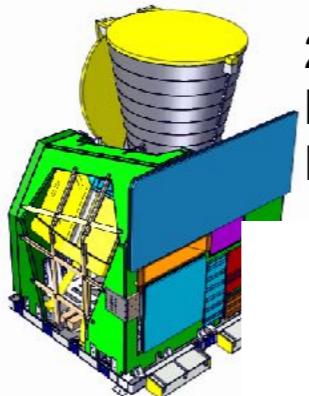
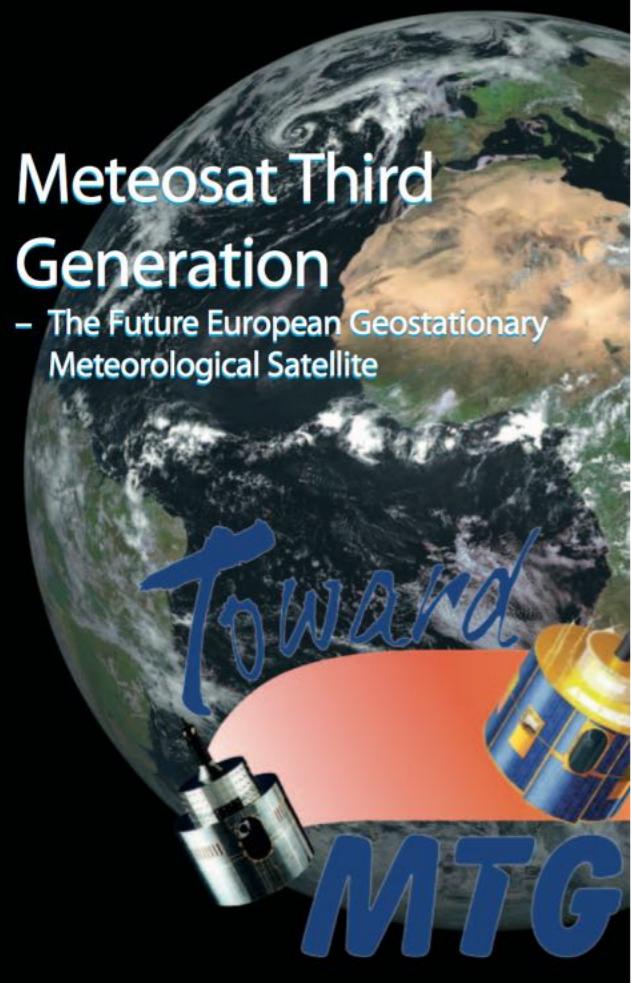
Lionel DUBAND
Univ. Grenoble Alpes, CEA-IRIG-DSBT, F-38000 Grenoble

Why Space ?

Earth Observation



Earth observation: Weather satellite MTG

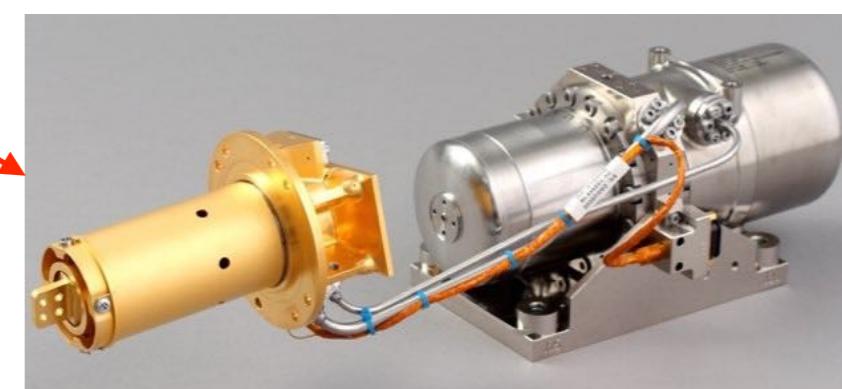
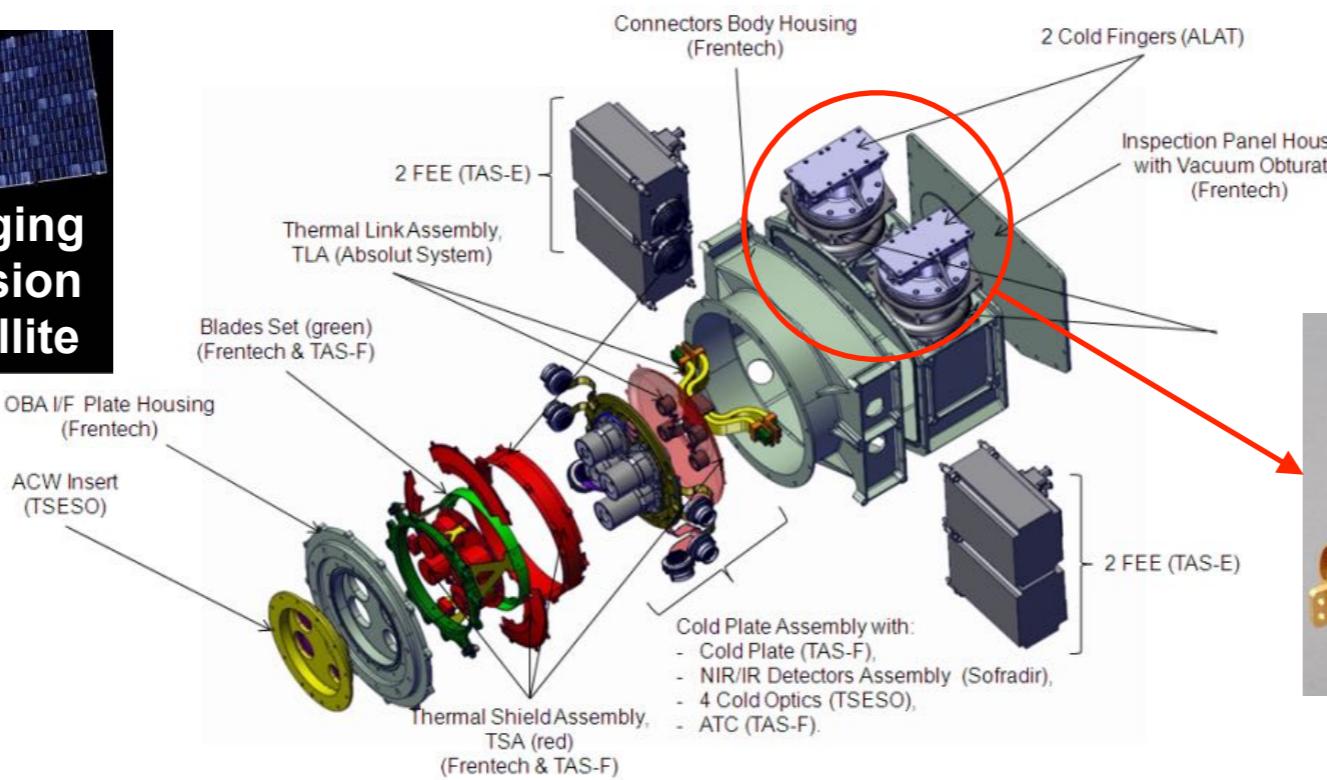
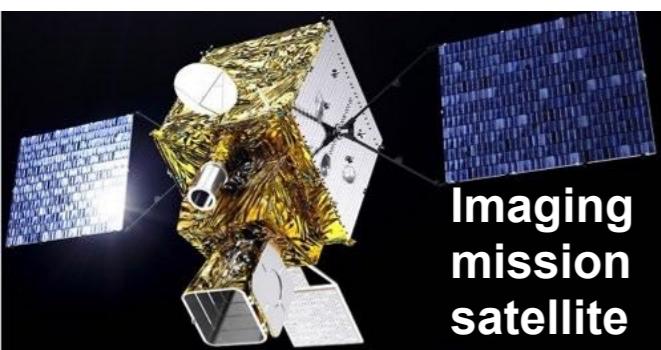
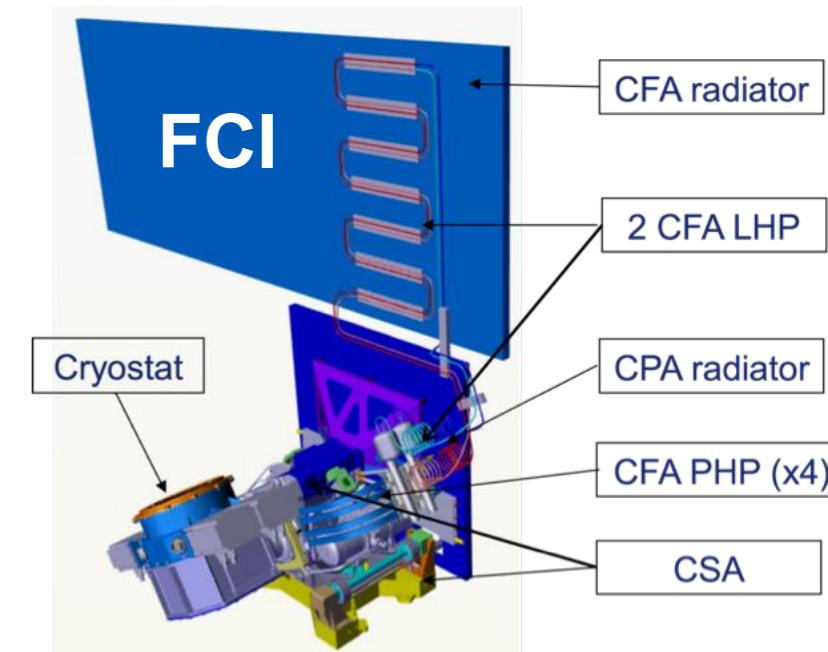
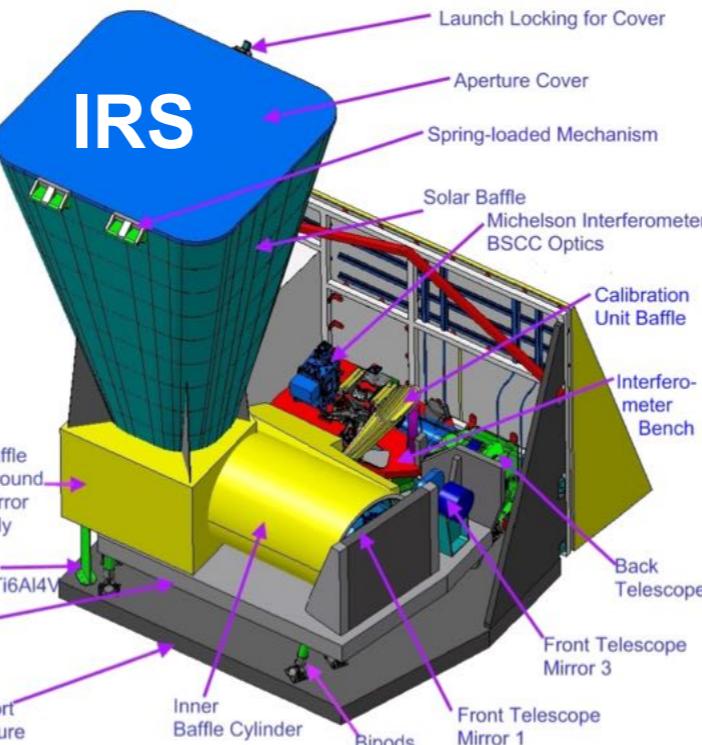


2 instruments

IRS: Infrared Michelson Interferometer

FCI: High spatial and spectral resolution imagery

55 K and 60 K needed
(photoconductors HgCdTe)

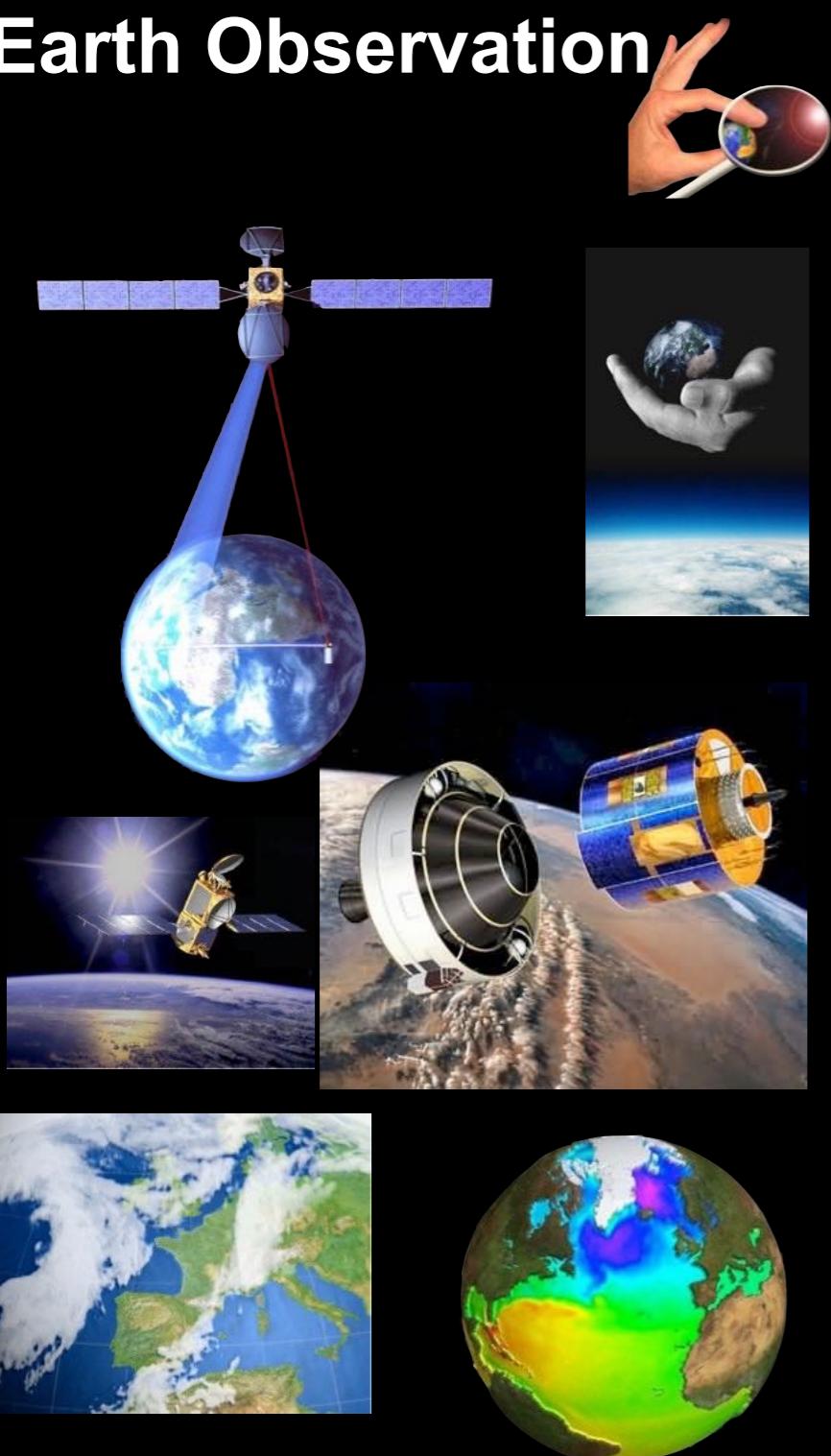


See Thierry Wiertz
presentation

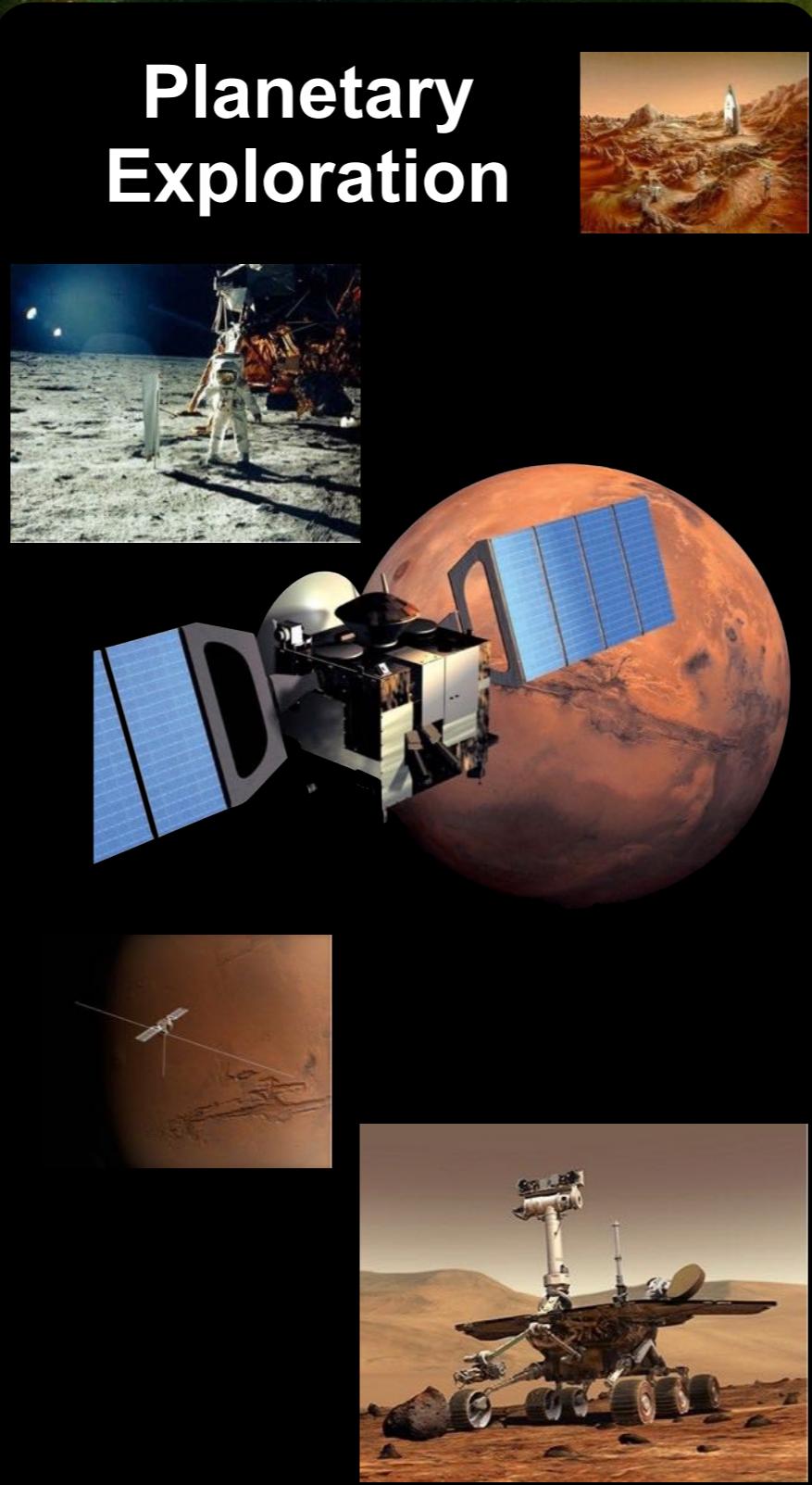


Why Space ?

Earth Observation



Planetary Exploration



Planetary exploration

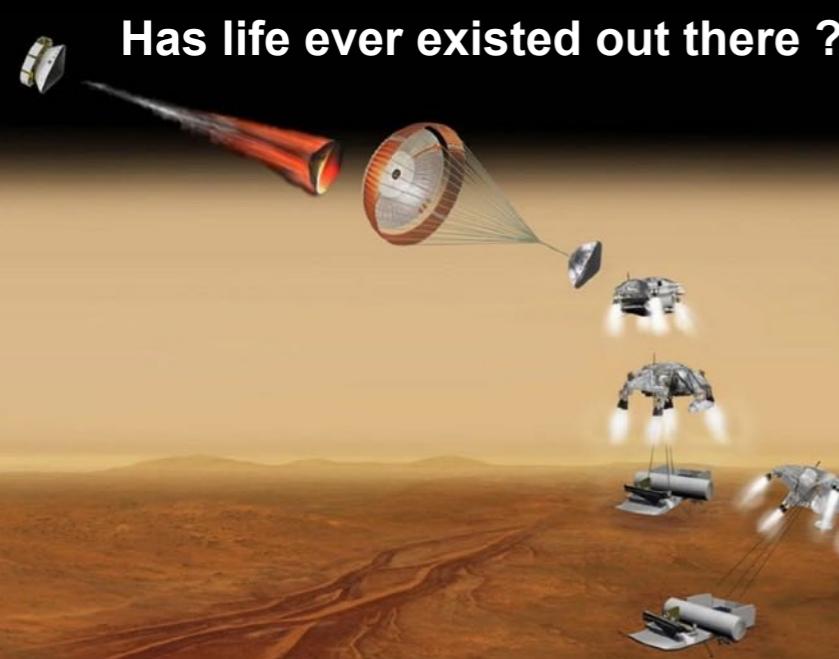
MARS SCIENCE LABORATORY (MSL)

Launched Nov. 2011

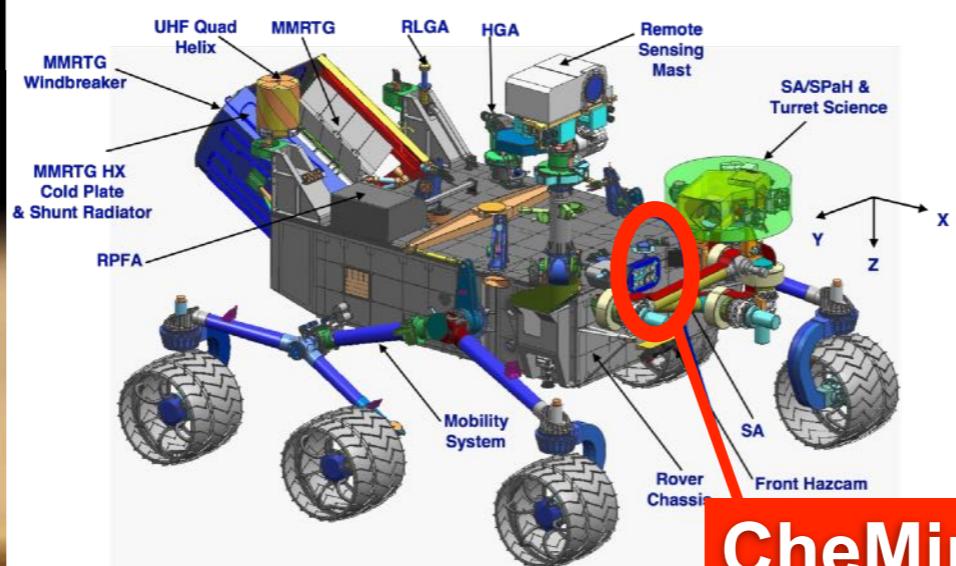
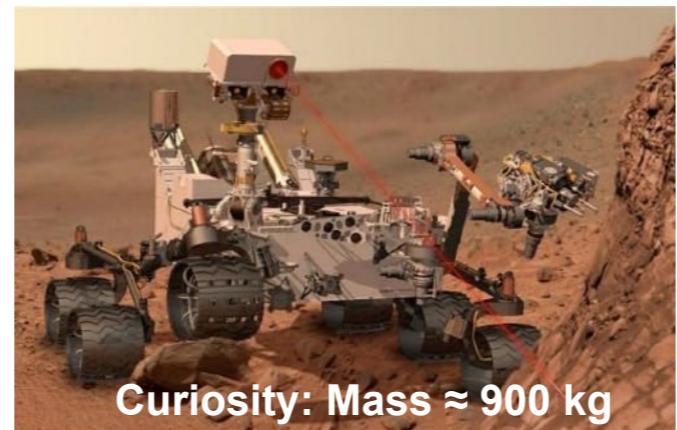
Trip: 8 months ($570 \cdot 10^6$ km)

Landed Aug. 2012

Lifetime: 22 months



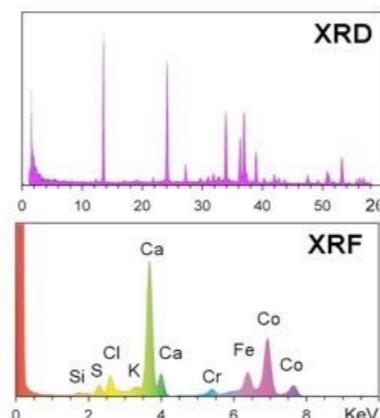
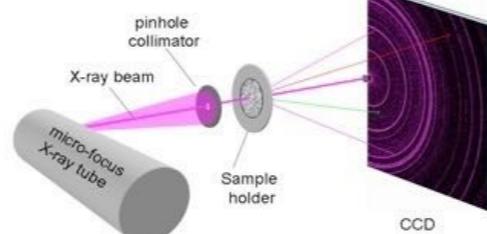
Has life ever existed out there ?



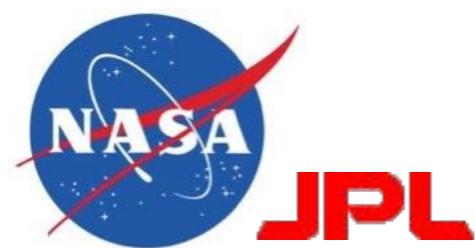
CheMin



RICOR
CRYOGENIC & VACUUM SYSTEMS



diffraction and fluorescence
informations collected by a
cooled CCD



Why Space ?

Earth Observation

50 - 200 K



Planetary Exploration

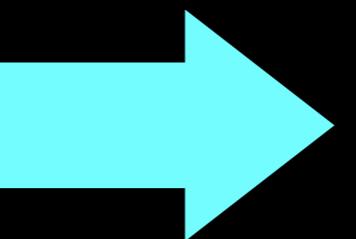


Scientific Missions

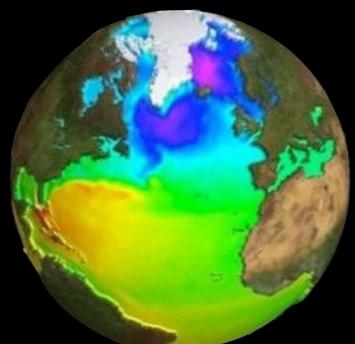
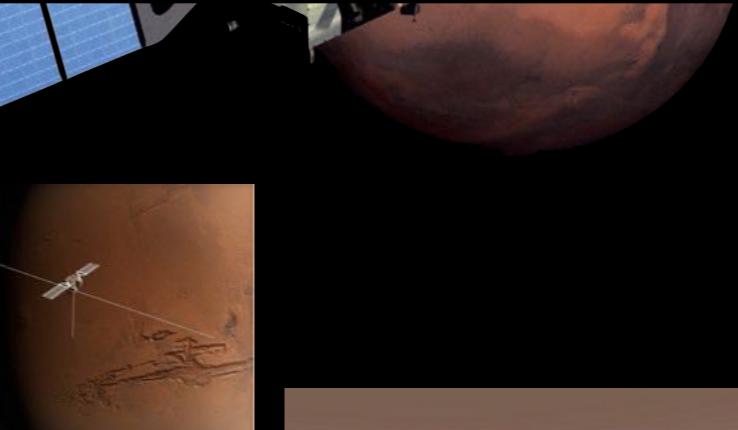
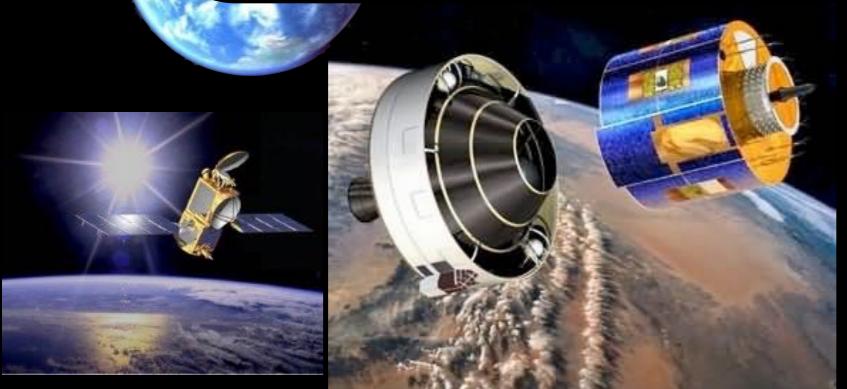
0.05 - 100 K



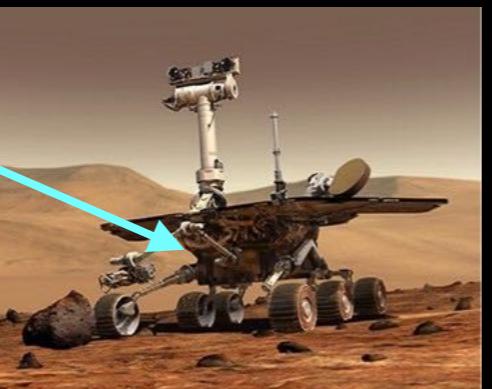
Cryogenics



- Detectors
- Optics



Any T.
210 K here



What is essential is invisible to the eye ...



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



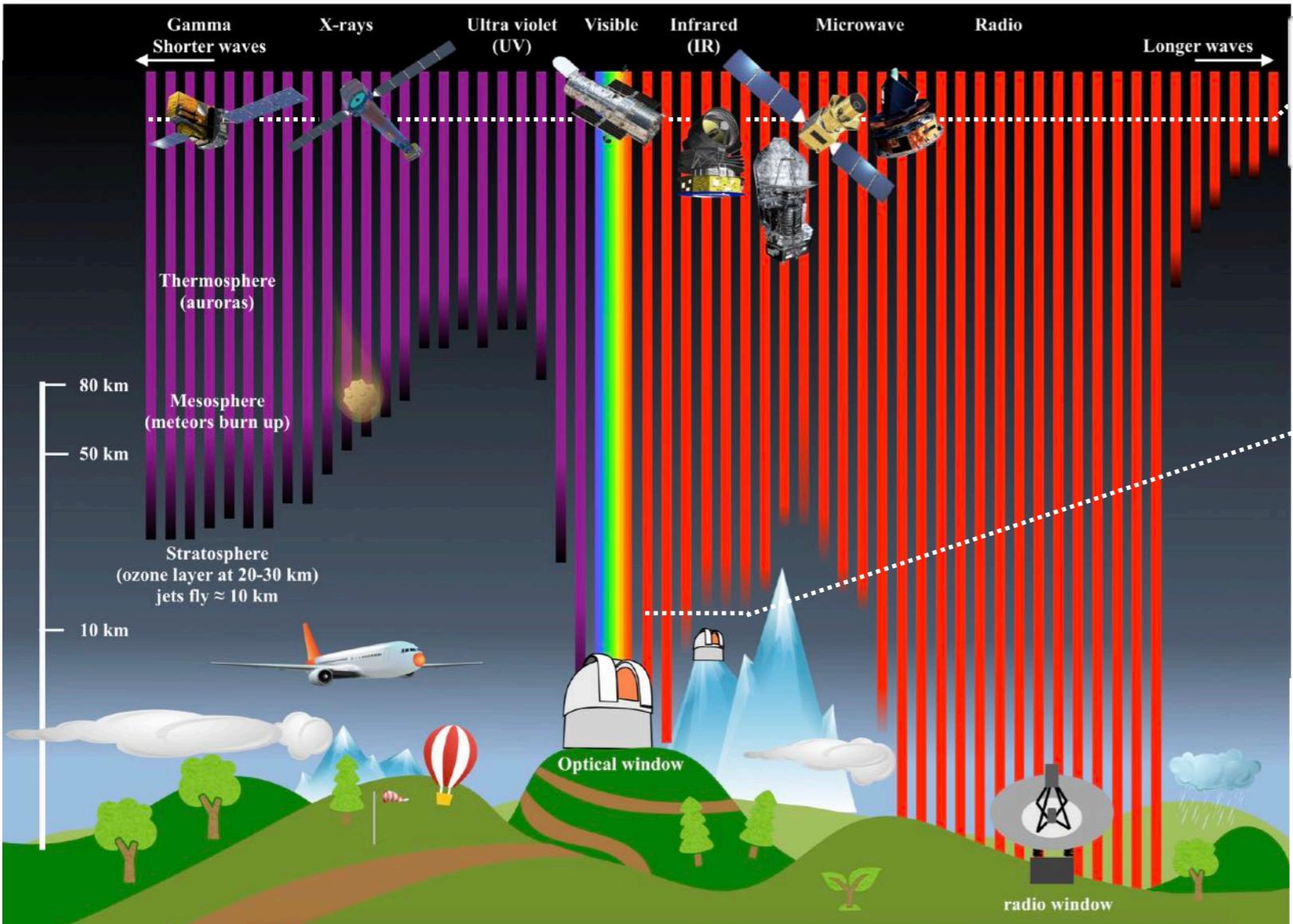
From ground

ArTeMiS APEX + ESO's VISTA telescope

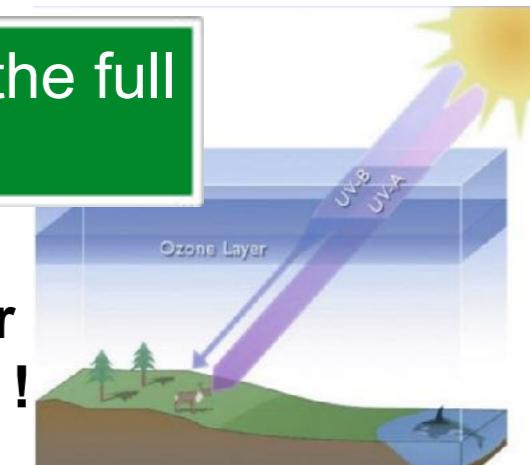


Composite: Visible + XMM Newton + Herschel

Visible to the instruments ?



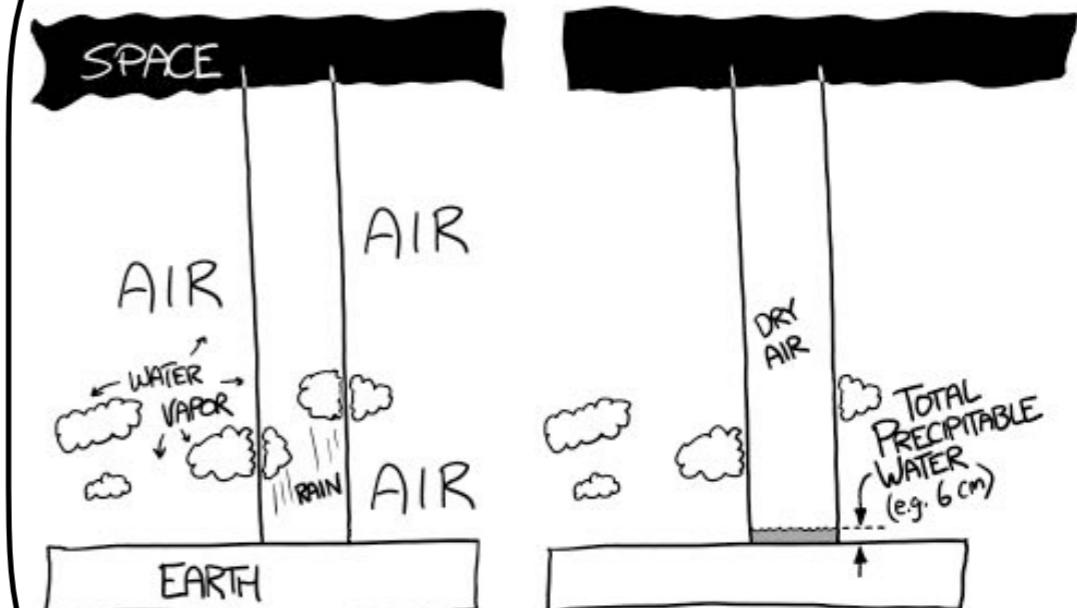
Space opens up the full window



Atmospheric filter
Fortunately for us !

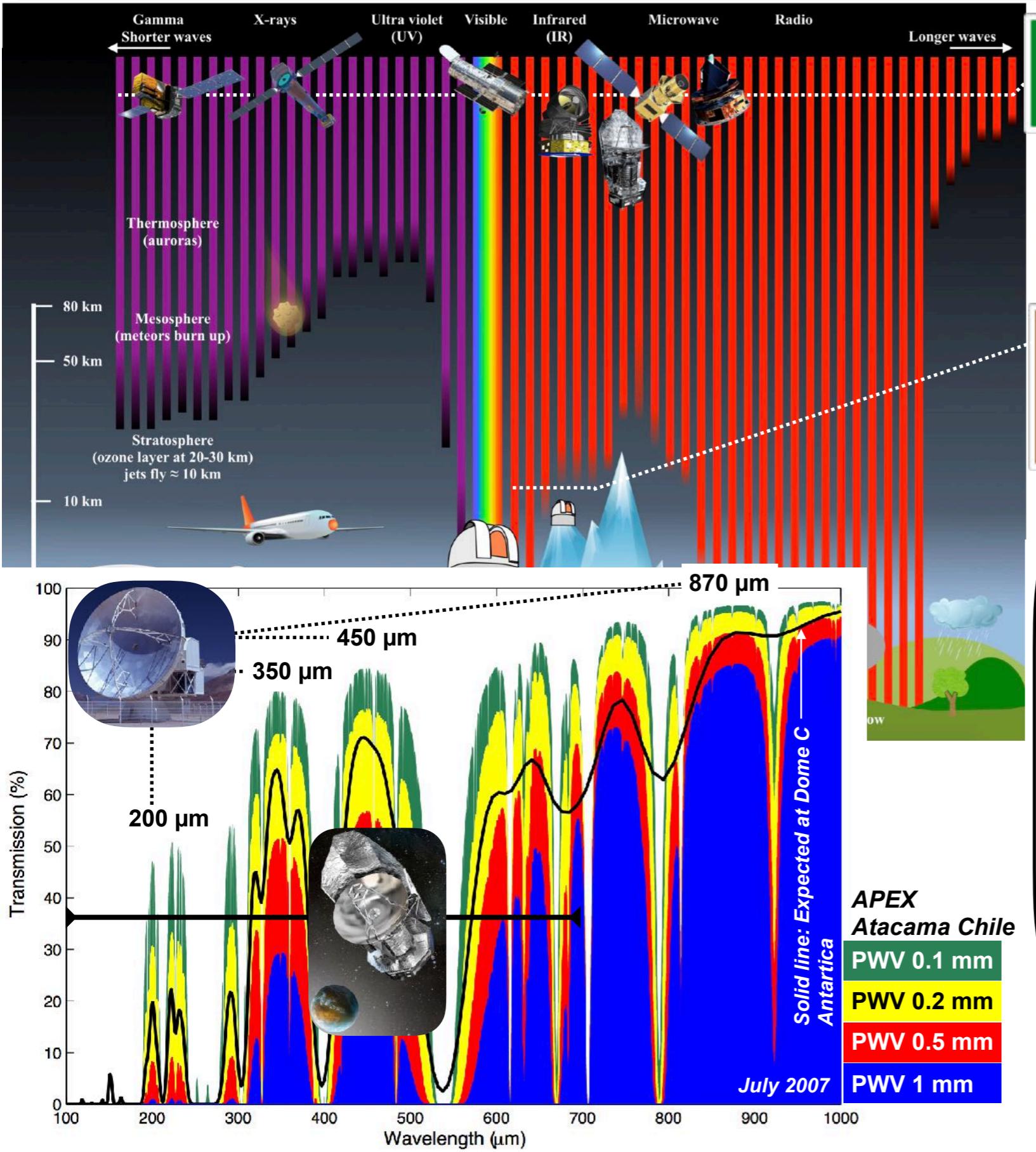
Ground based telescope
Infrared spectrum: few "windows" accessibles

PWV: Precipitable Water Vapor



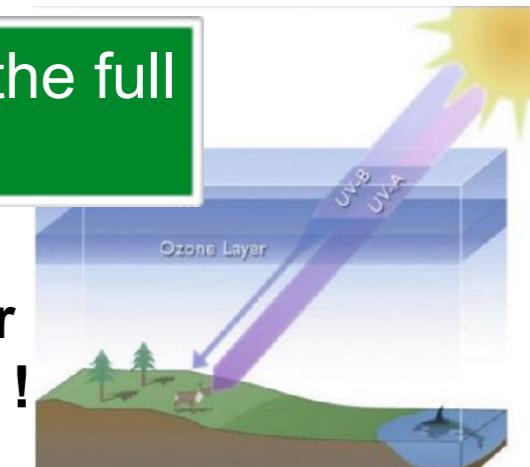
Attenuation of incoming radiation
Increase of noise (thermal emission)
Inhomogeneities in distribution

Visible to the instruments ?



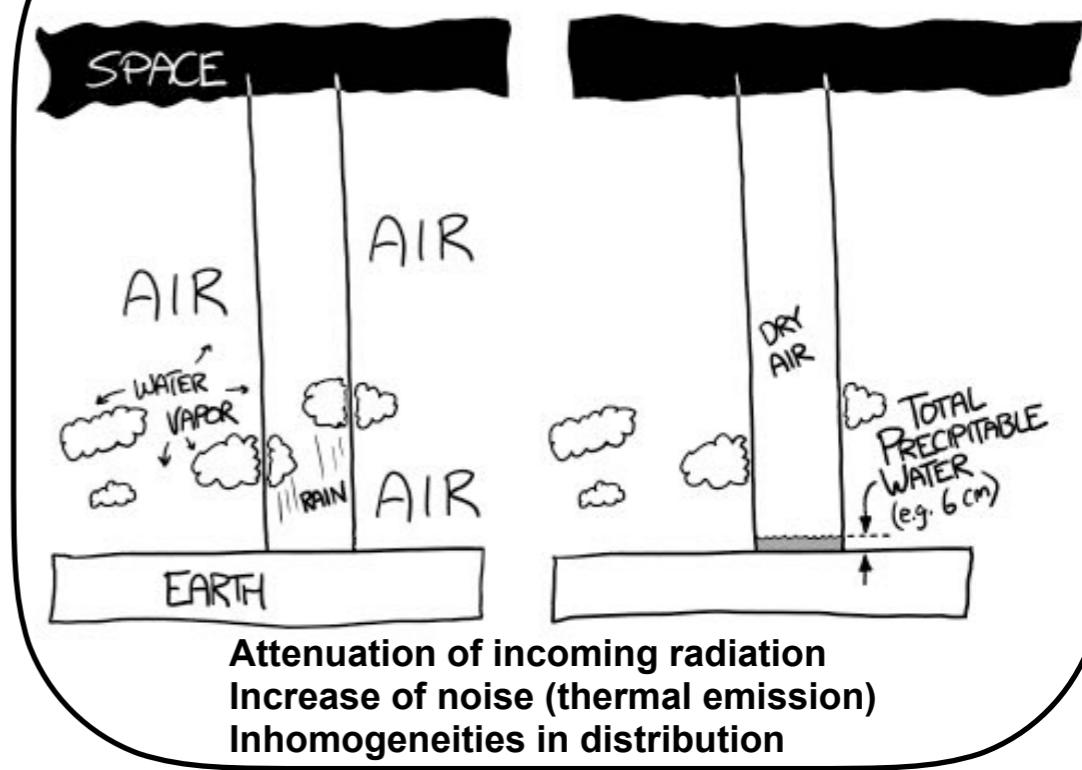
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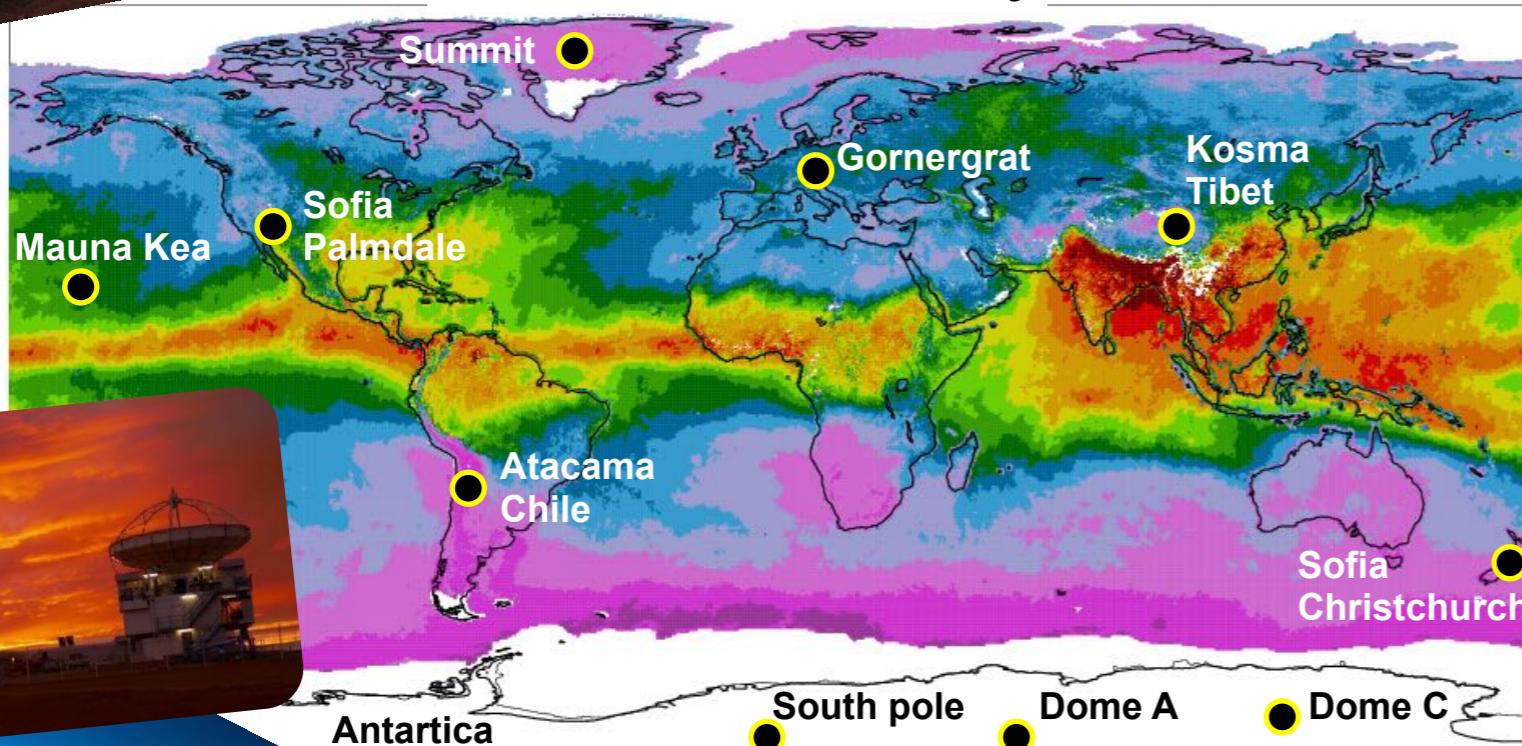


Reasonable transmission → Very low PWV

To be able to see: harsh environment or space



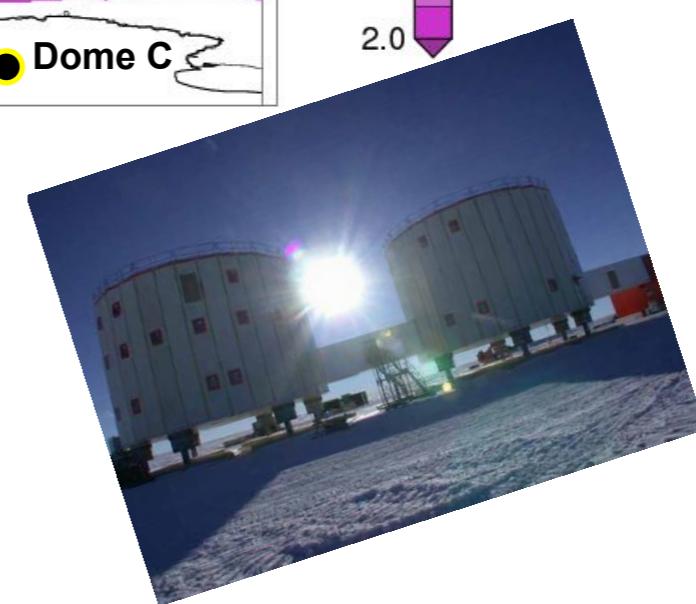
Submillimetric Astronomy



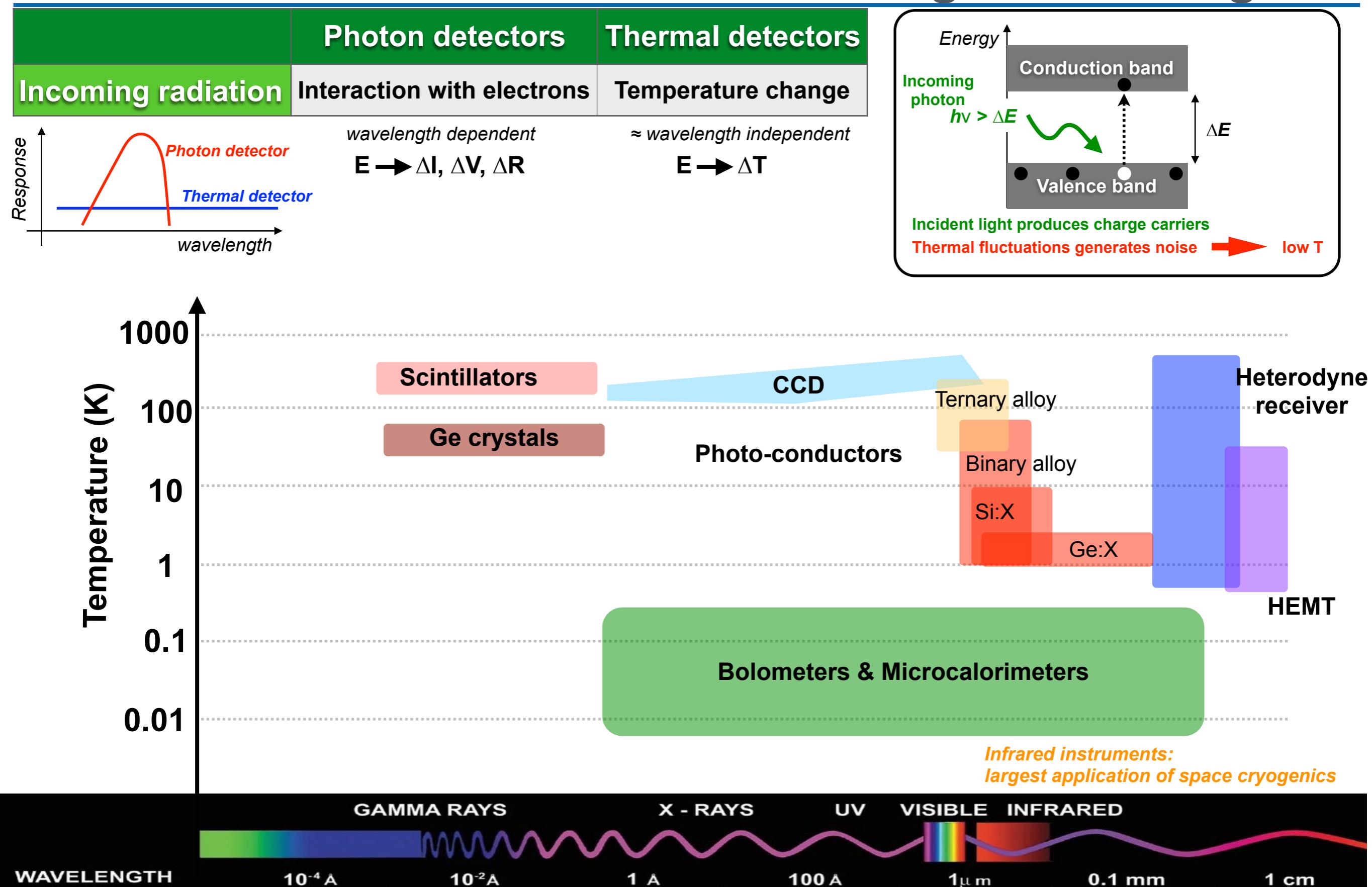
$$\text{PWV: } 1\text{mm} = 1 \text{kg.m}^{-2}$$

- 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

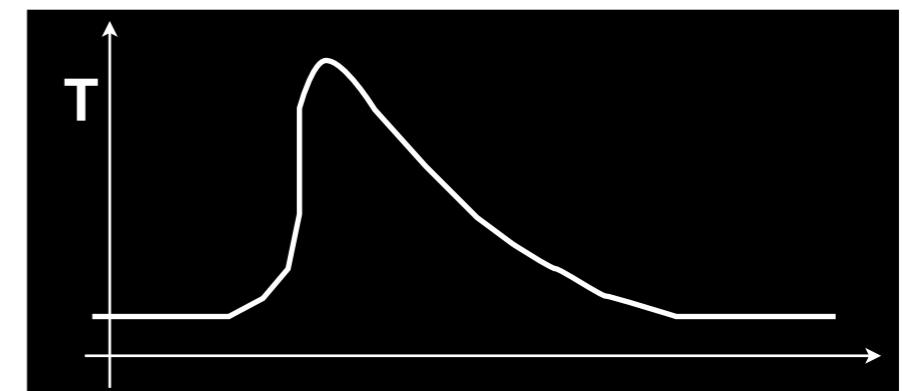
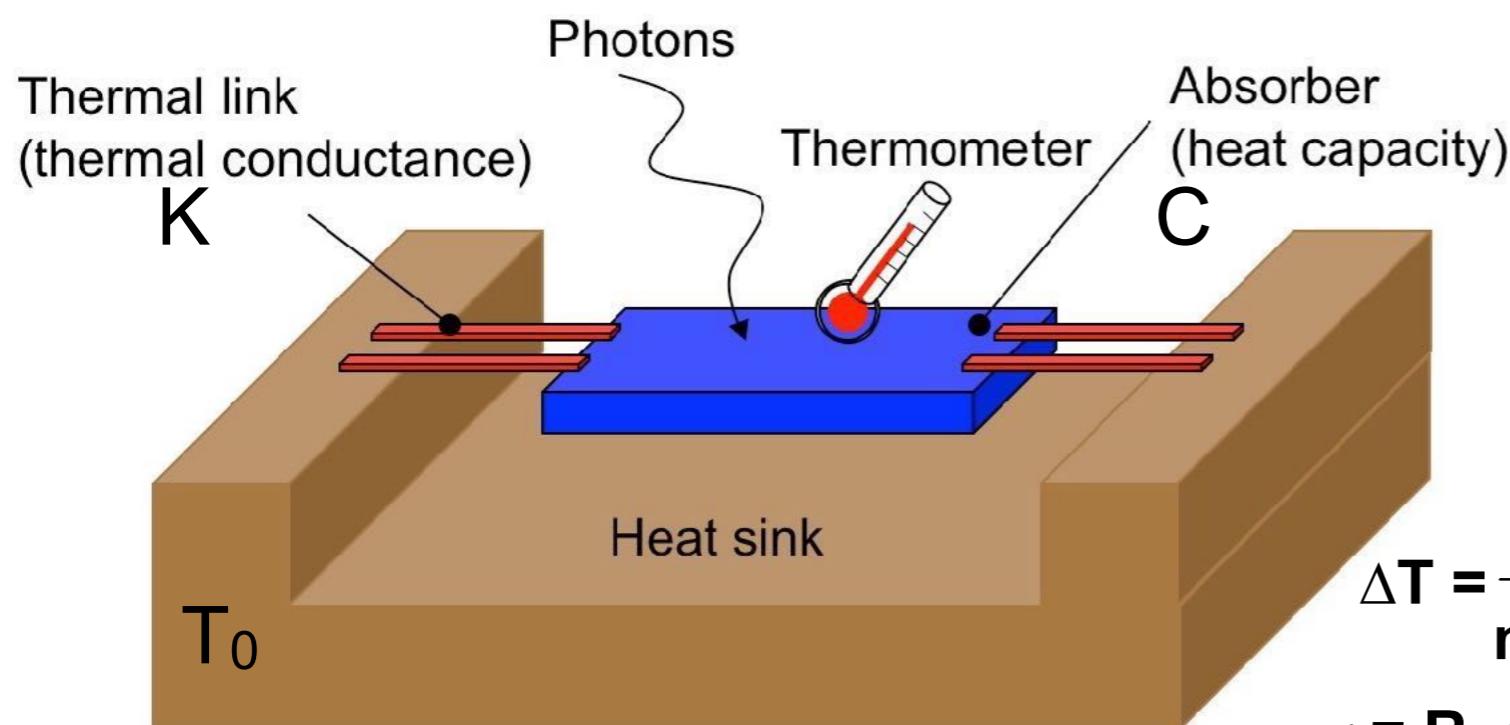


To be able to measure: Shh ! faint signals coming in

Cryogenics



Thermal detector: Bolometer



$$\Delta T = \frac{E}{mC}$$
$$\tau = R_{th}C = \frac{C}{K}$$

Measurable ΔT ? → Minimize C → Low Temperature

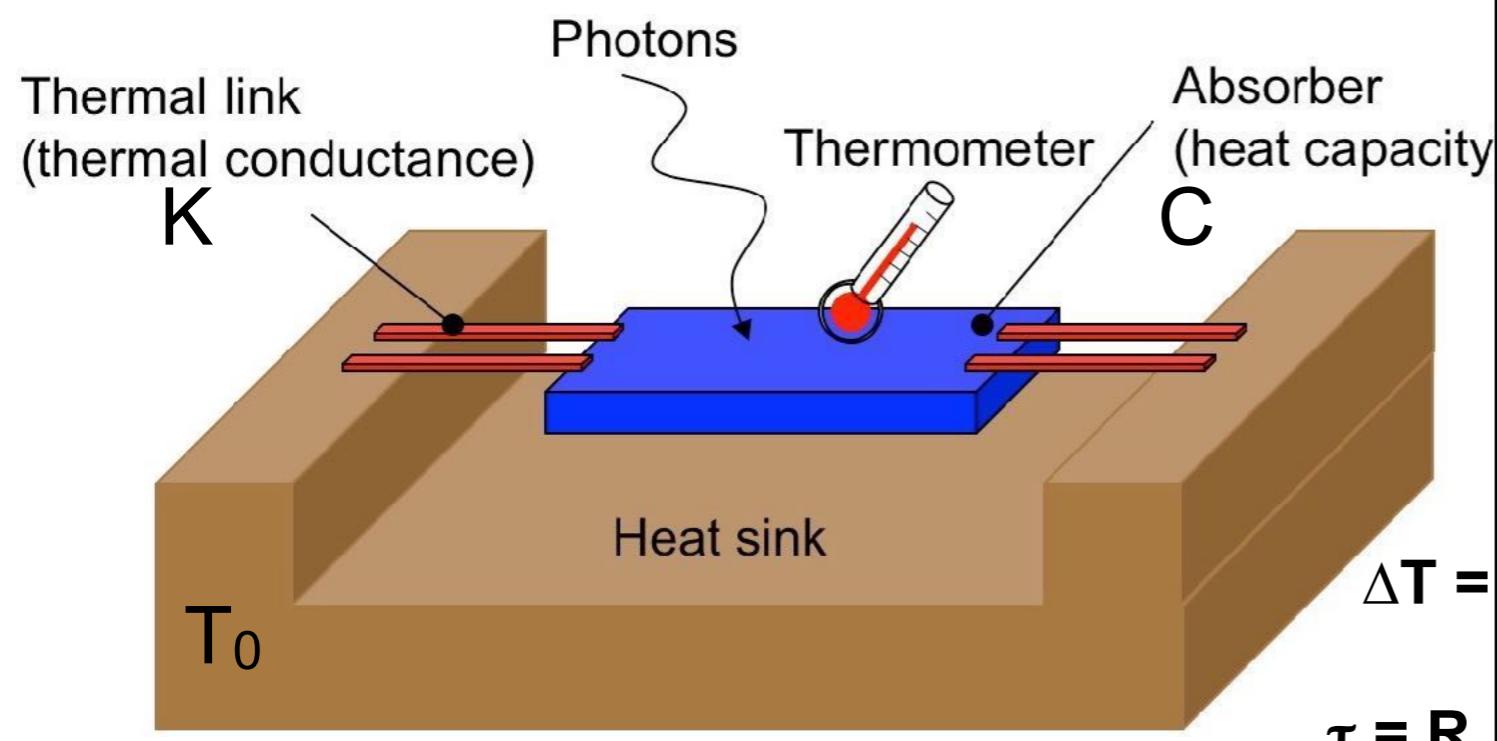
To be able to measure: Shh ! faint signals coming in



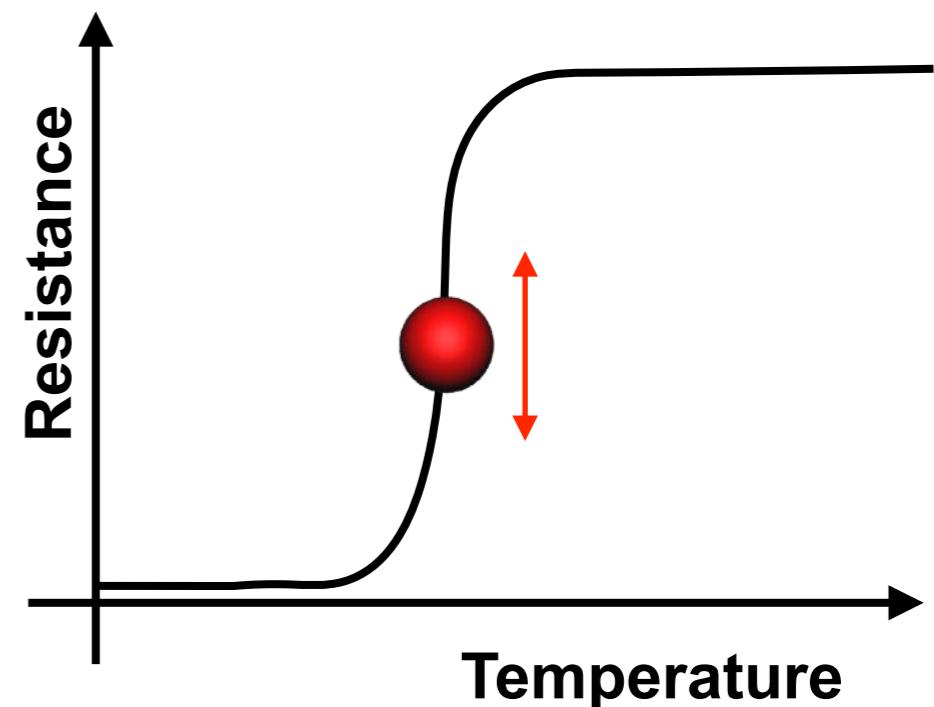
Cryogenics



Thermal detector: Bolometer



Transition Edge Sensor (TES)



small change in T



big change in R

Measurable ΔT ? Minimize

Drivers for the cryogenic chain

Ground based *harsh environment*

Survive transport
(much easier !)



Gravity



Can be used to move things !

Mass



HEAVY OK



Maintenance *limited if possible*



~~Maintenance~~

Reliability



Preferably no consumable
(electricity only - cryogen free)

Space borne

Survive launch
(and transport)



Microgravity



Liquid ?
Tricks needed

Light required



Space: natural resources

Solar photons



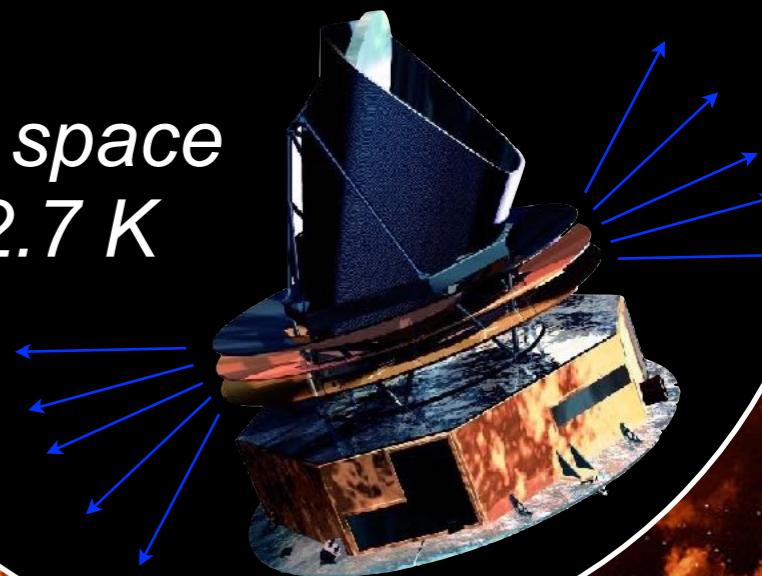
High vacuum



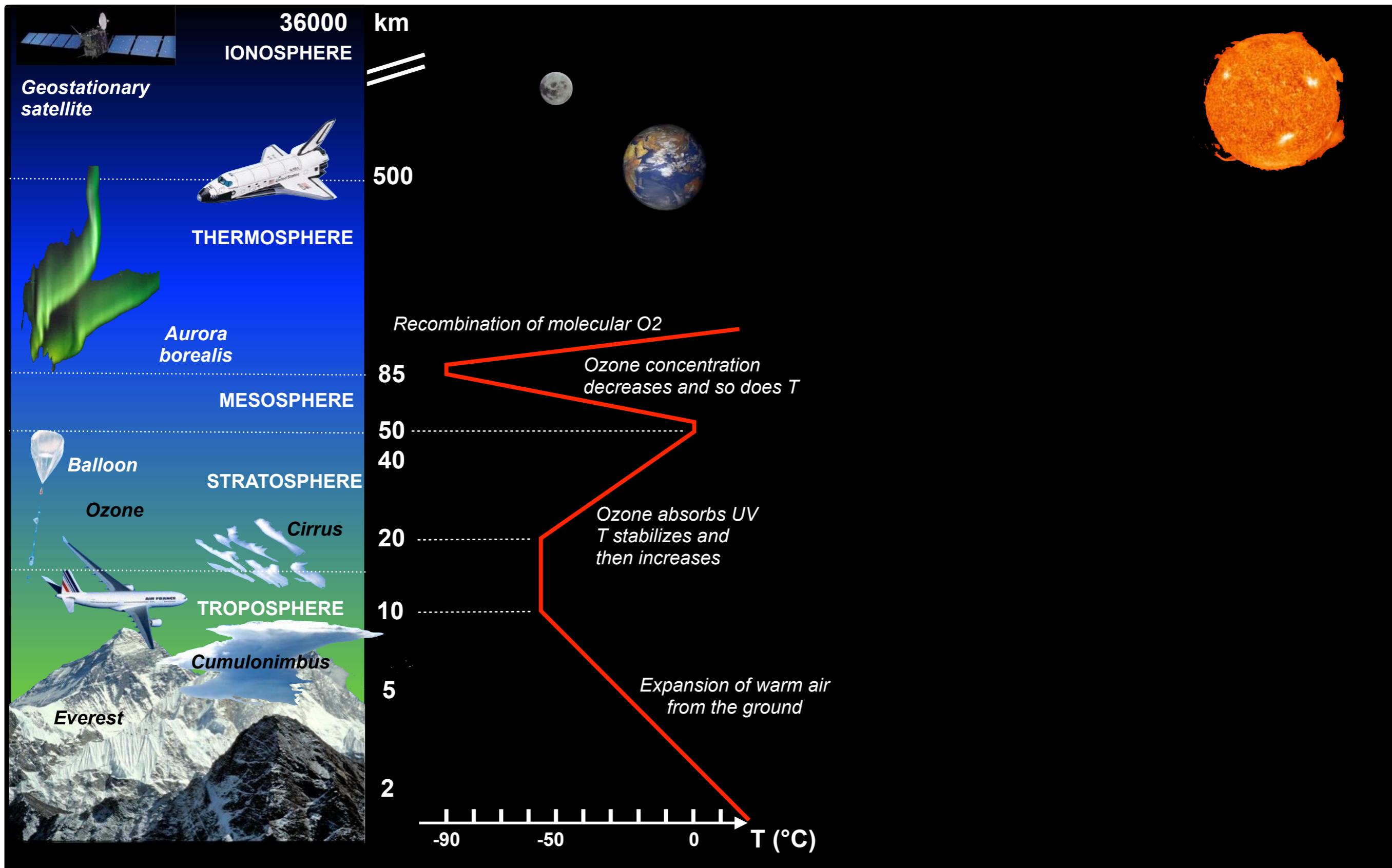
Heat transfer

- ~~Convective~~
- ~~Conductive~~
- Radiative

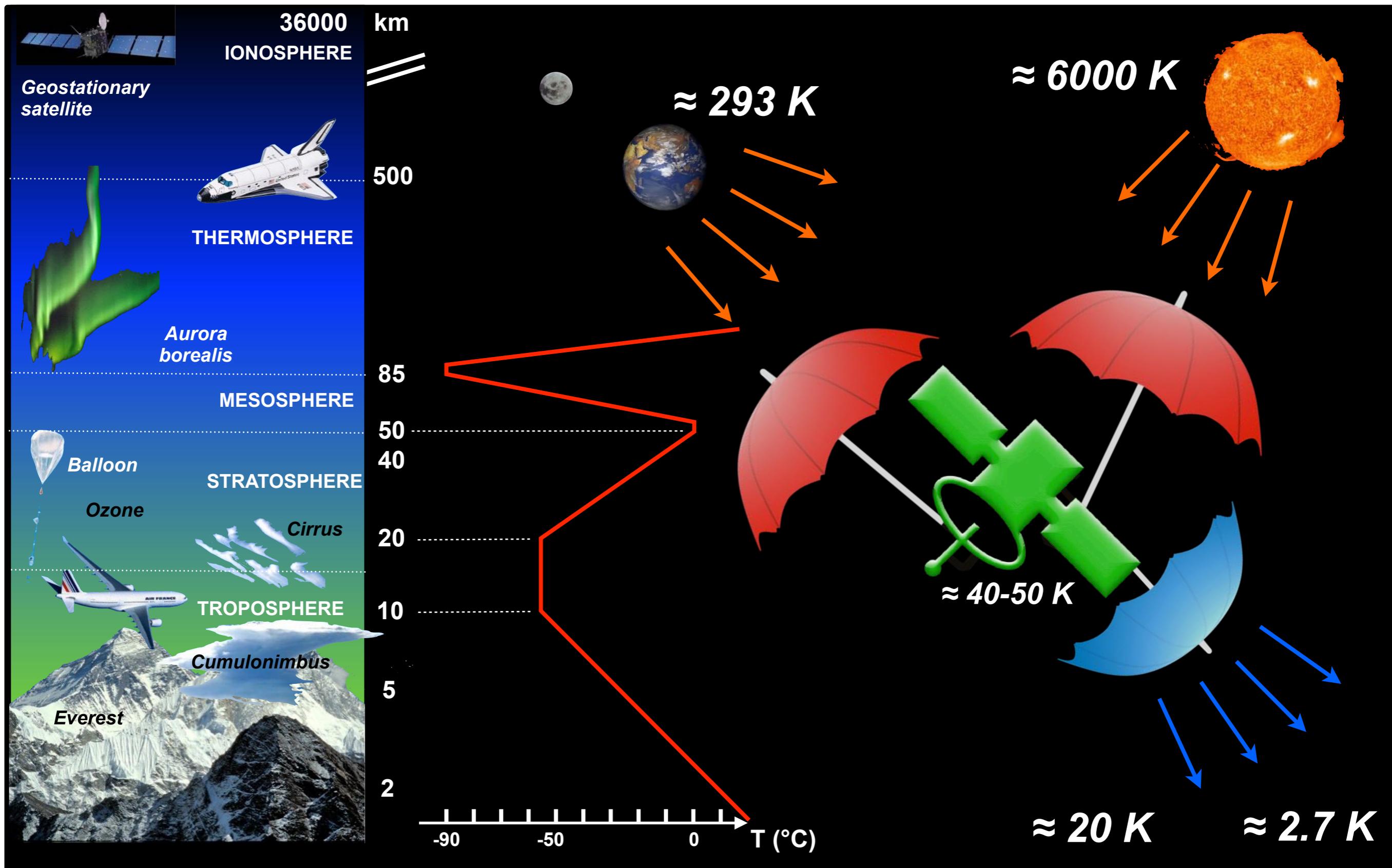
Deep space
@ 2.7 K



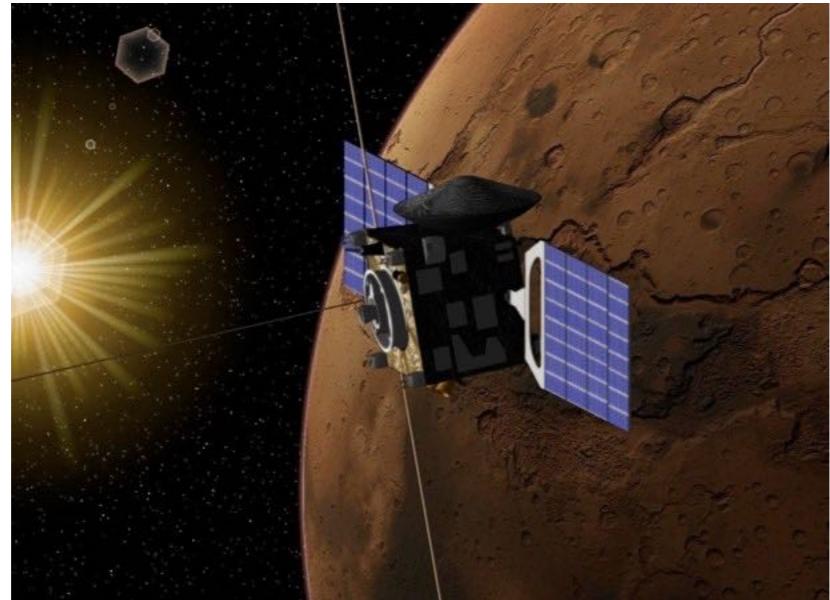
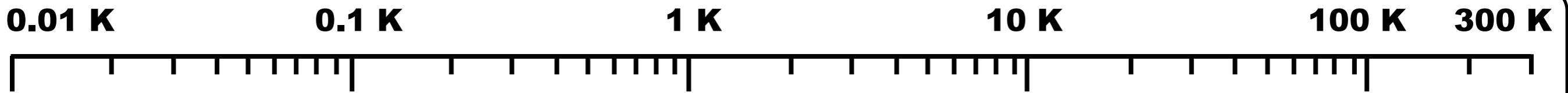
Is it cold out there ?



Is it cold out there ?



Space cooling chains



Passive Radiators

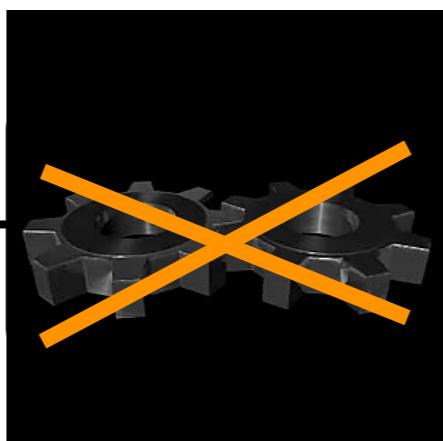
Stored cryogen (Cryostat)

Active "mechanical" coolers

"Ultra" low T coolers

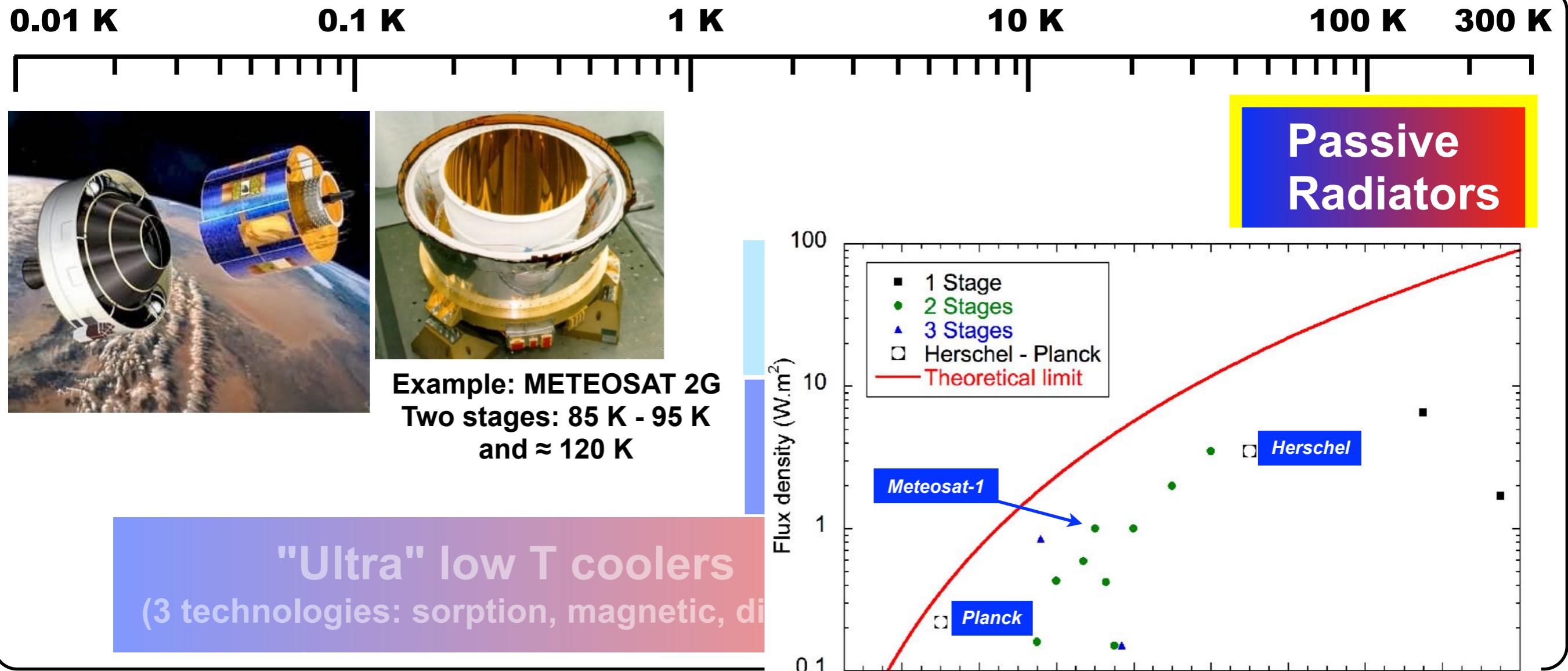
(3 technologies: sorption, magnetic, dilution)

Reliability



No moving parts or absence of friction

Space cooling chains

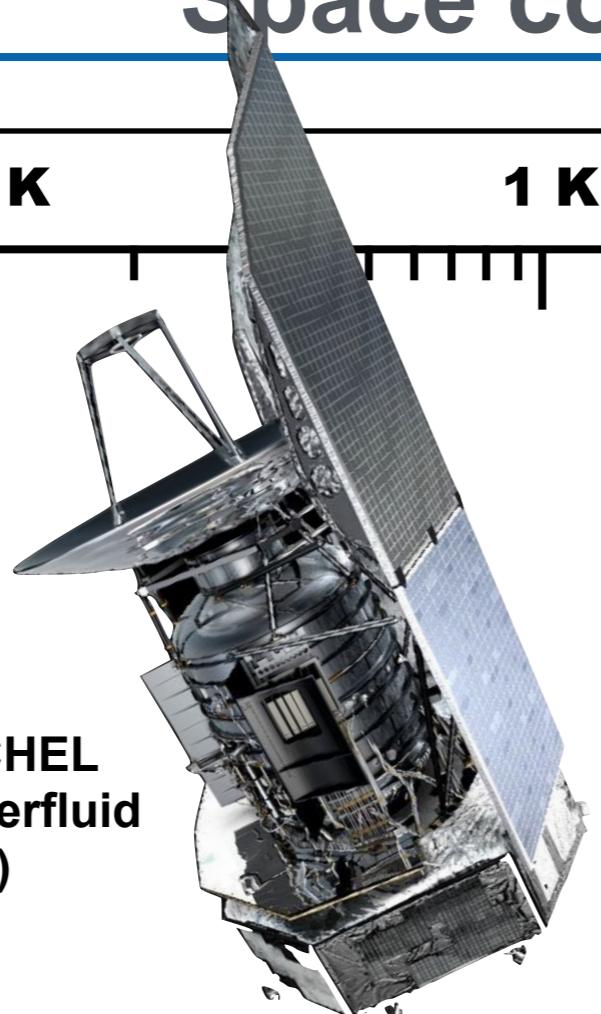
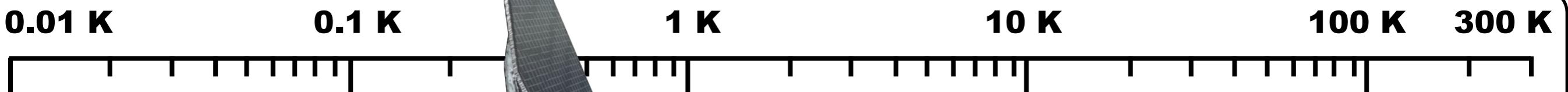


- * Efficient
- * Simple
- * Reliable
- * Vibration free



- * Limited performance @ low T
- * Orbit / orientation dependent

Space cooling chains



Example: HERSCHEL
≈ 2360 liters of superfluid helium (1.7 K)

Stored cryogen (Cryostat)

Active "mechanical" coolers

"Ultra" low T coolers

(3 technologies: sorption, magnetic, dilution)

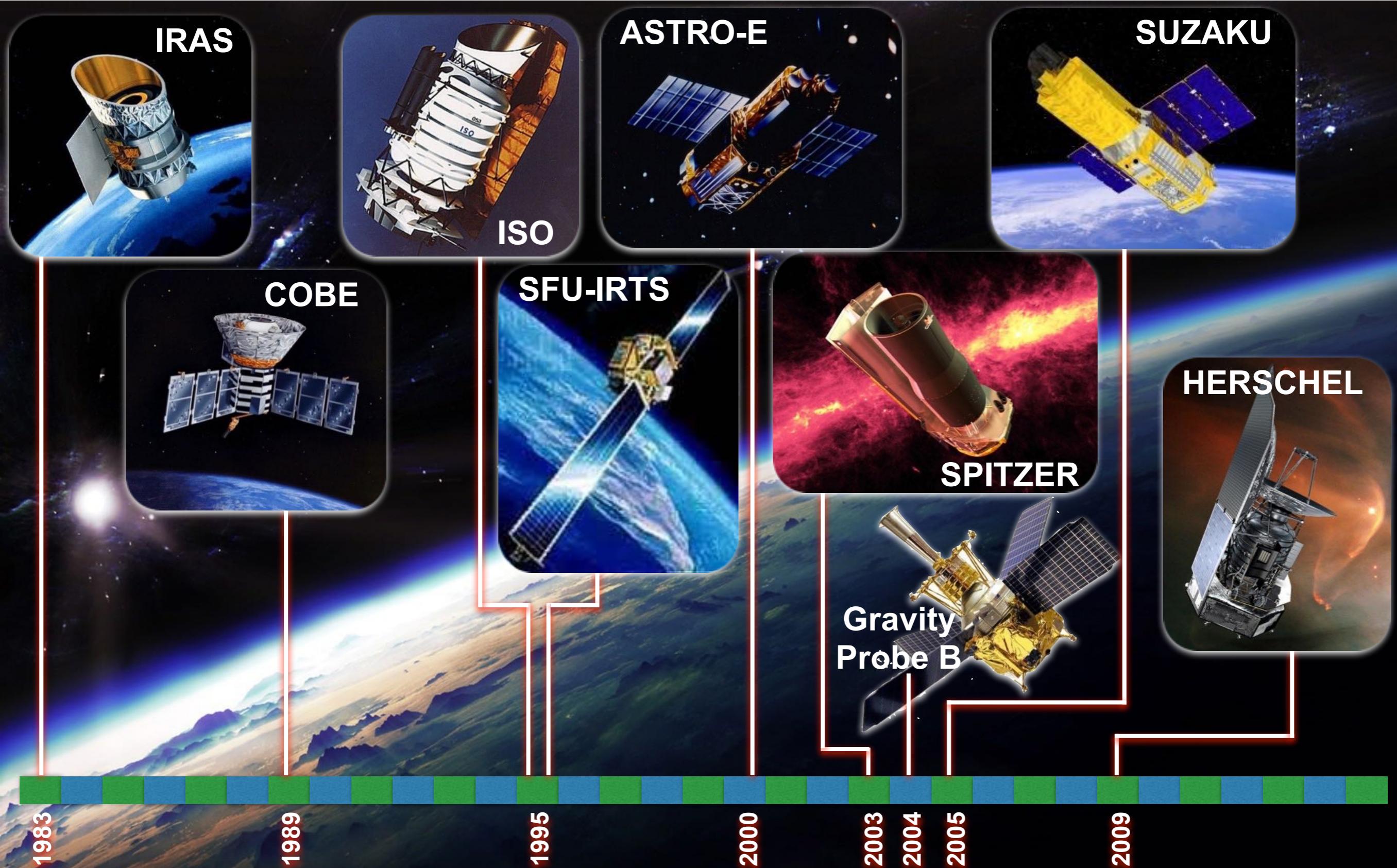


- * Efficient
- * Simple
- * Reliable
- * Cold vapor

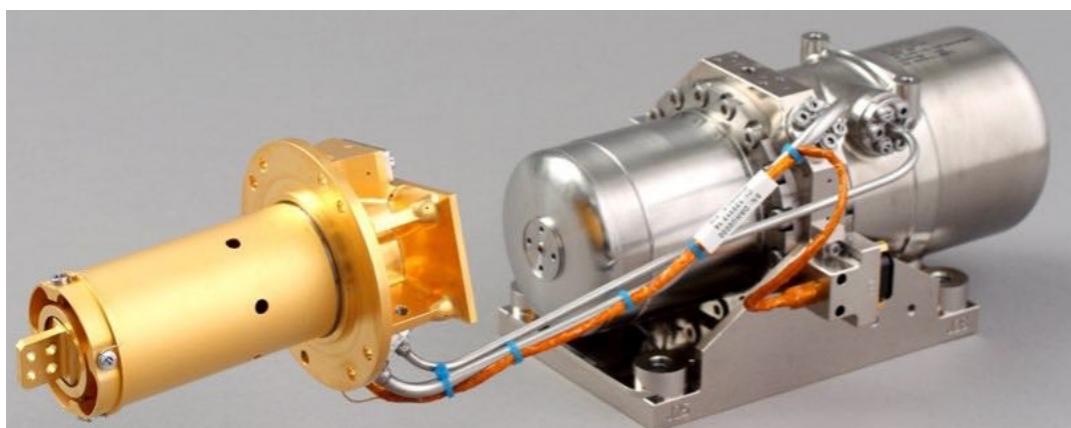
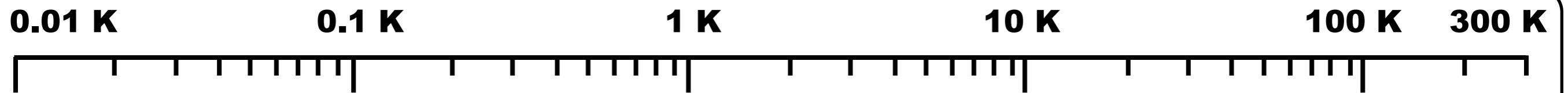


- * Limited mission duration
- * only selected T available
- * Volume & Mass
- * On ground management

Low temp. missions with stored cryogens (4K or less)



Space cooling chains



Example: METEOSAT 3G
Large pulse tube cooler:
 $\approx 3 \text{ W} @ 50 \text{ K}$

Passive Radiators

Stored cryogen (Cryostat)

Active "mechanical" coolers

"Ultra" low T coolers

(3 technologies: sorption, magnetic, dilution)



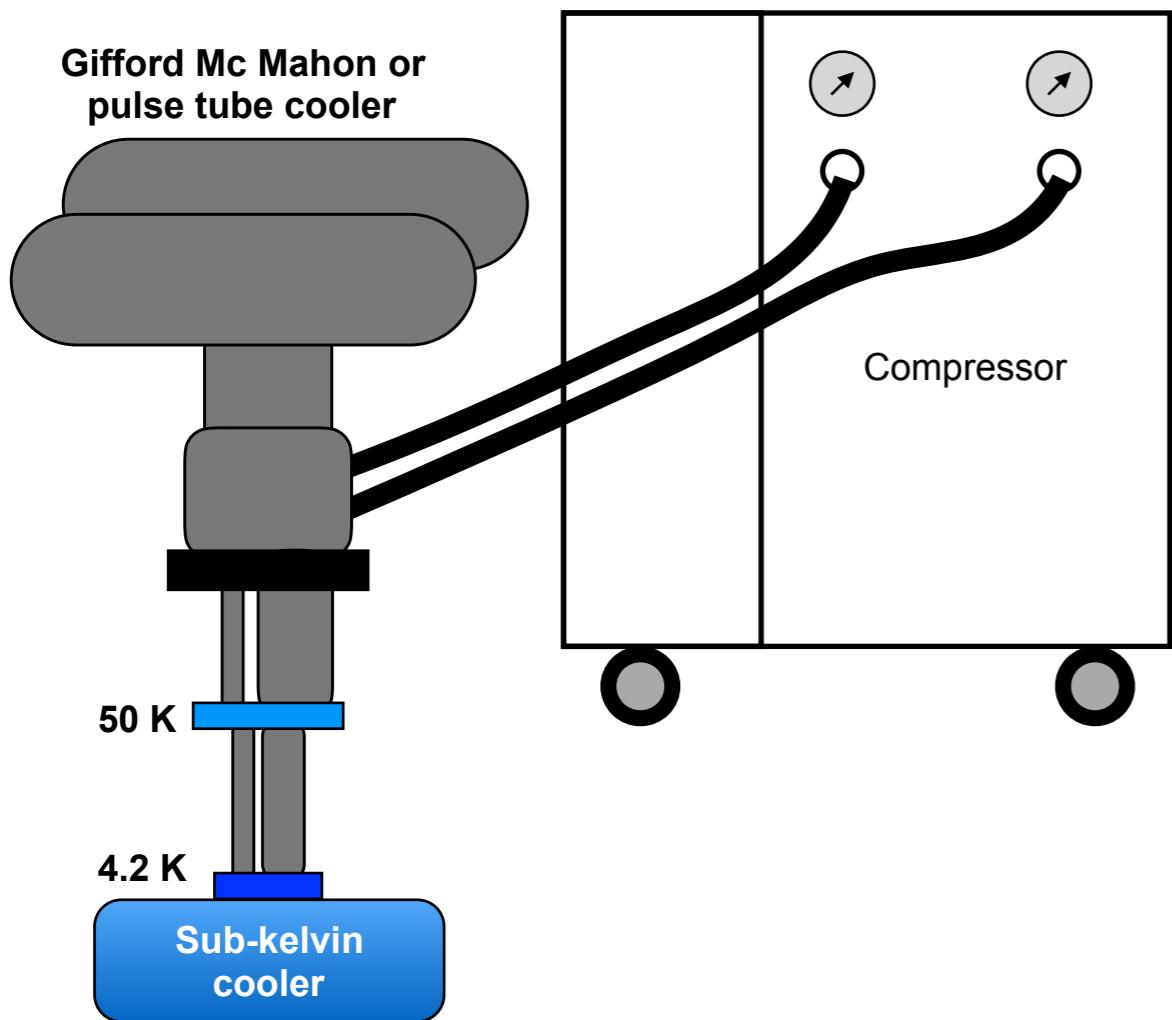
- * Lifetime
- * Warm launch
- * Ground tests



- * Peak power
- * Thermal interfaces
- * Vibration

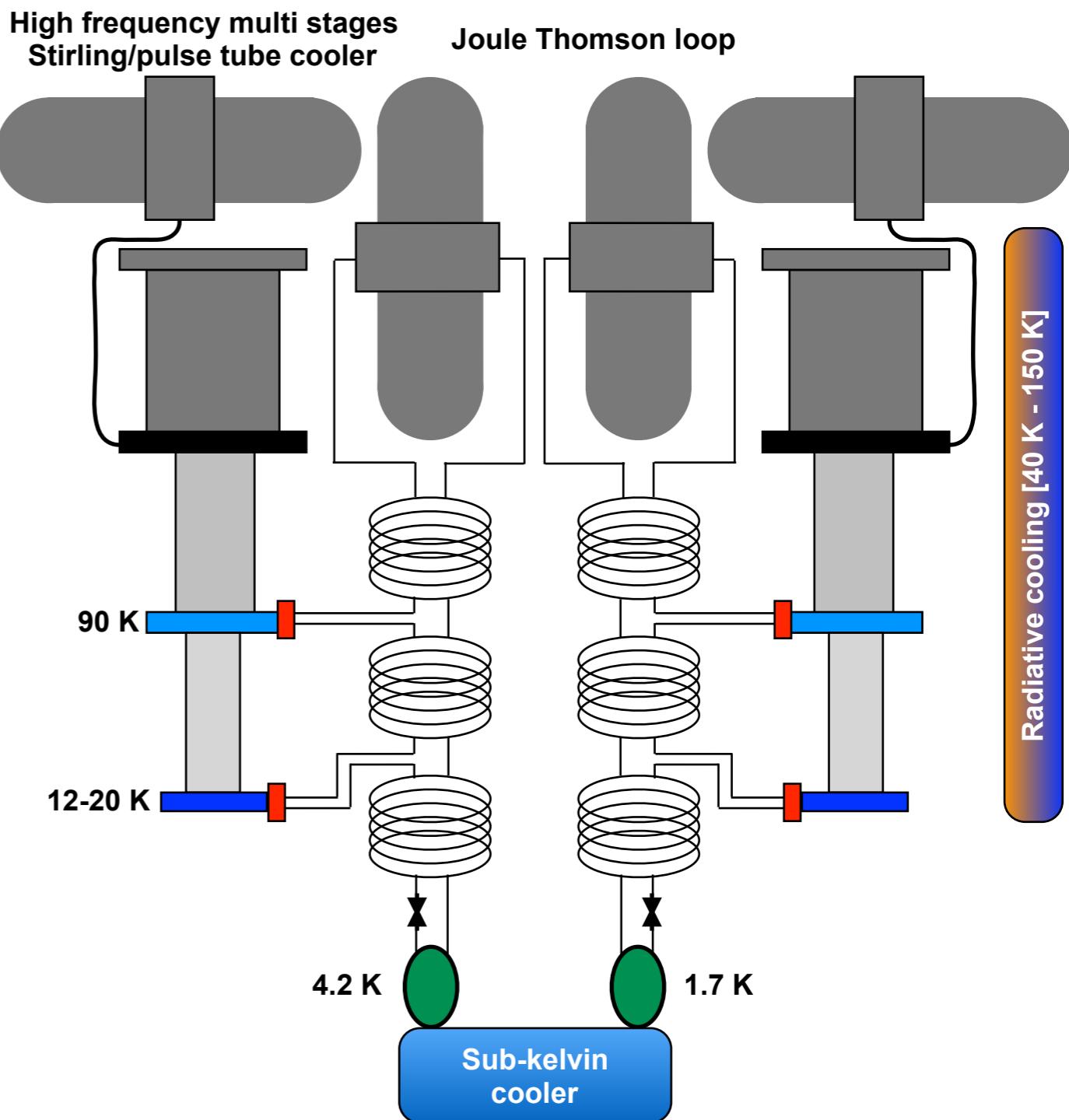
Typical cryogenic chain

Ground based harsh environment



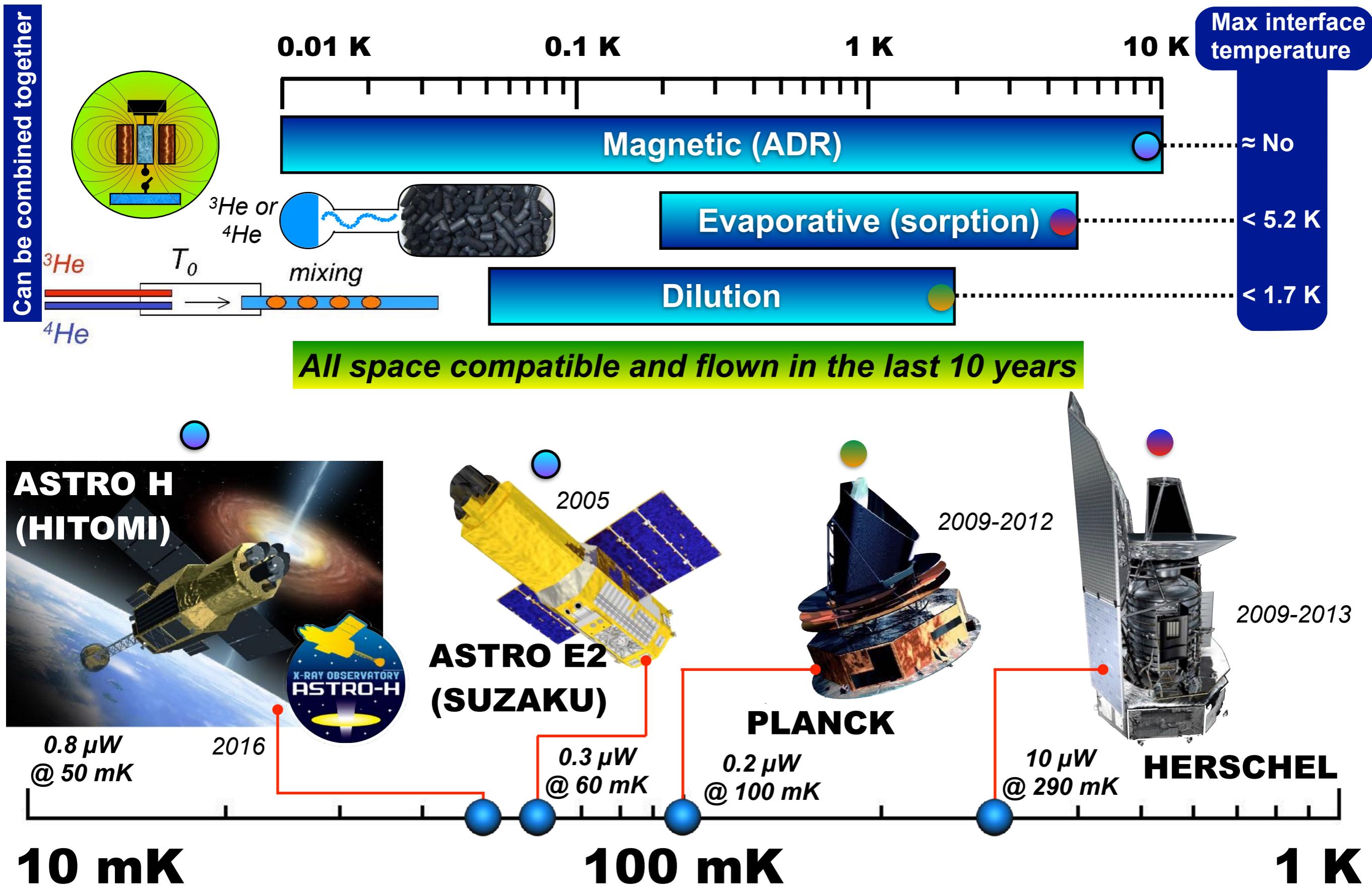
Input power \approx several kW

Space borne



Input power \approx several hundreds of W

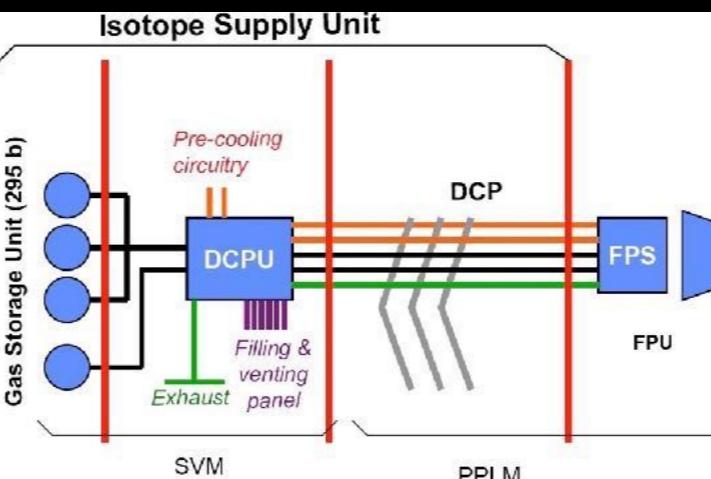
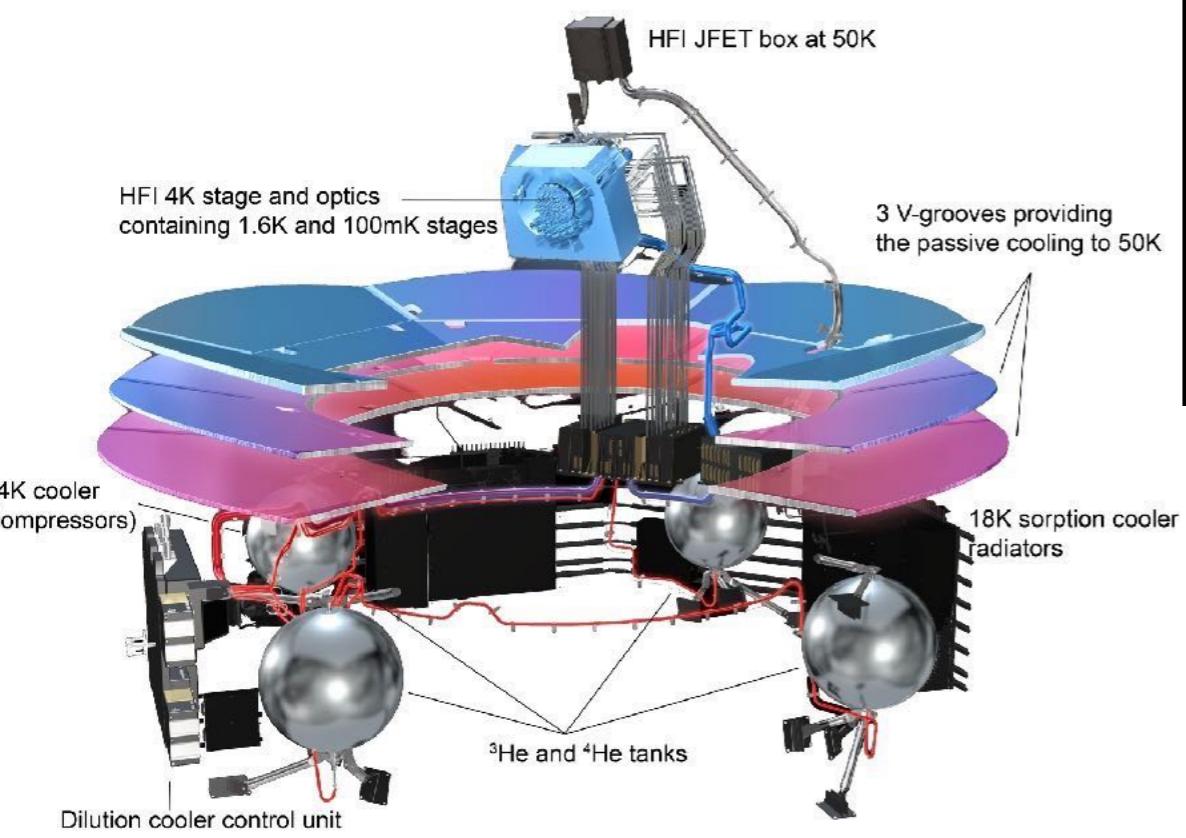
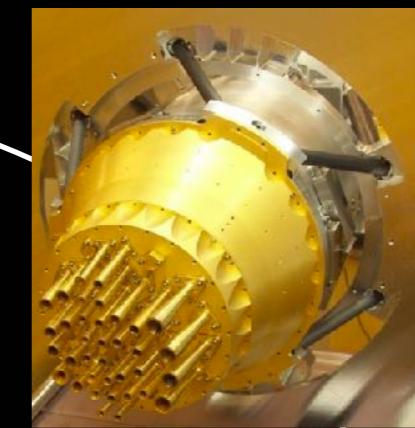
Sub-kelvin: 3 proven and extensively used techniques



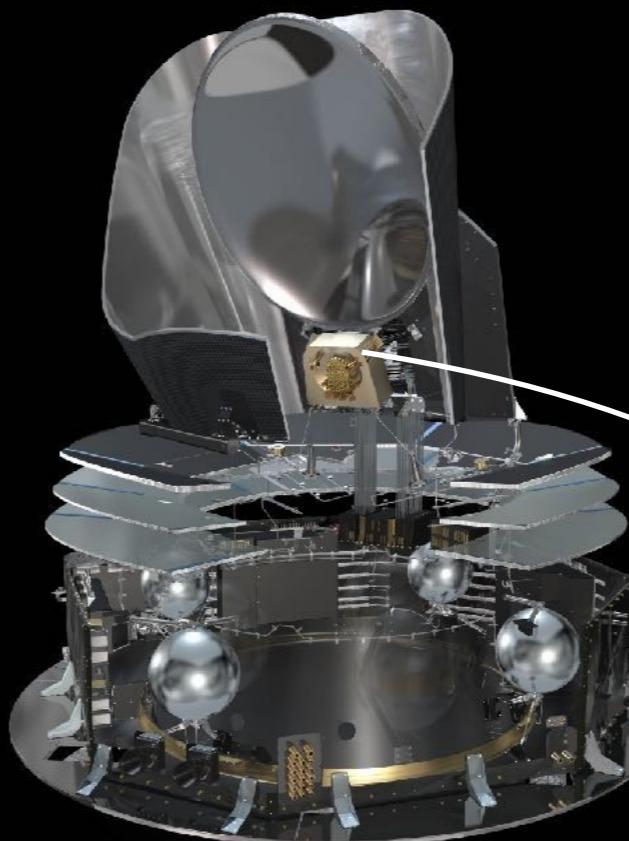
PLANCK Cryogenic chain - In flight



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



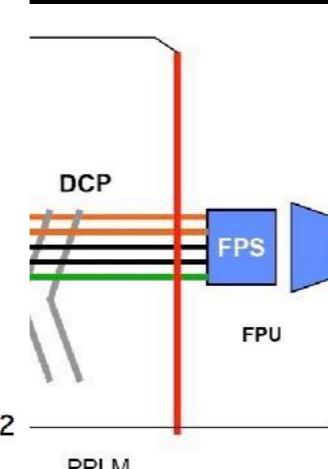
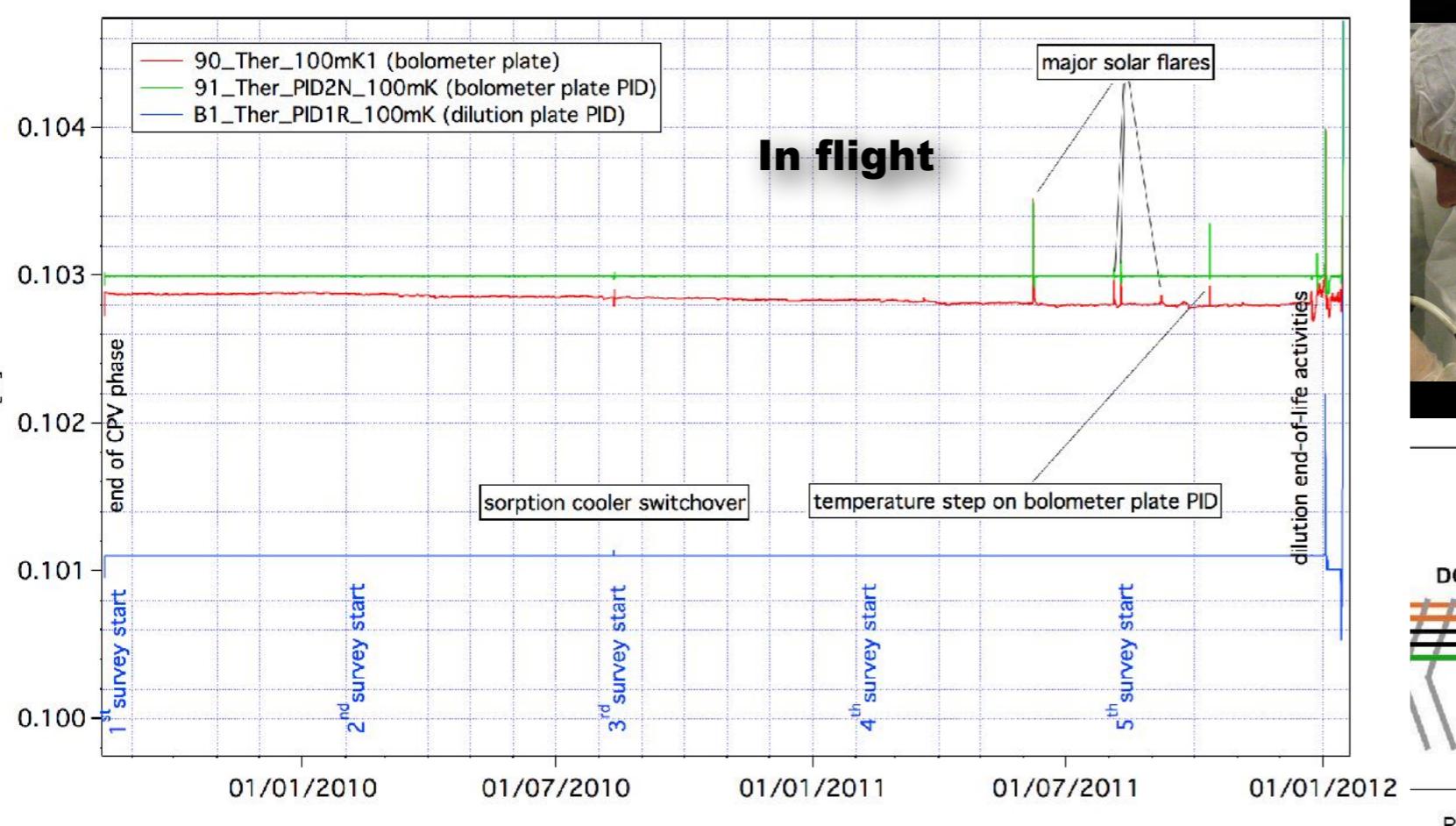
PLANCK Cryogenic chain - In flight



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+ 18 K H₂ sorption cooler
+ 4K JT loop
+ dilution (incl. 1.6 K JT loop)



100 mK
dilution cooler



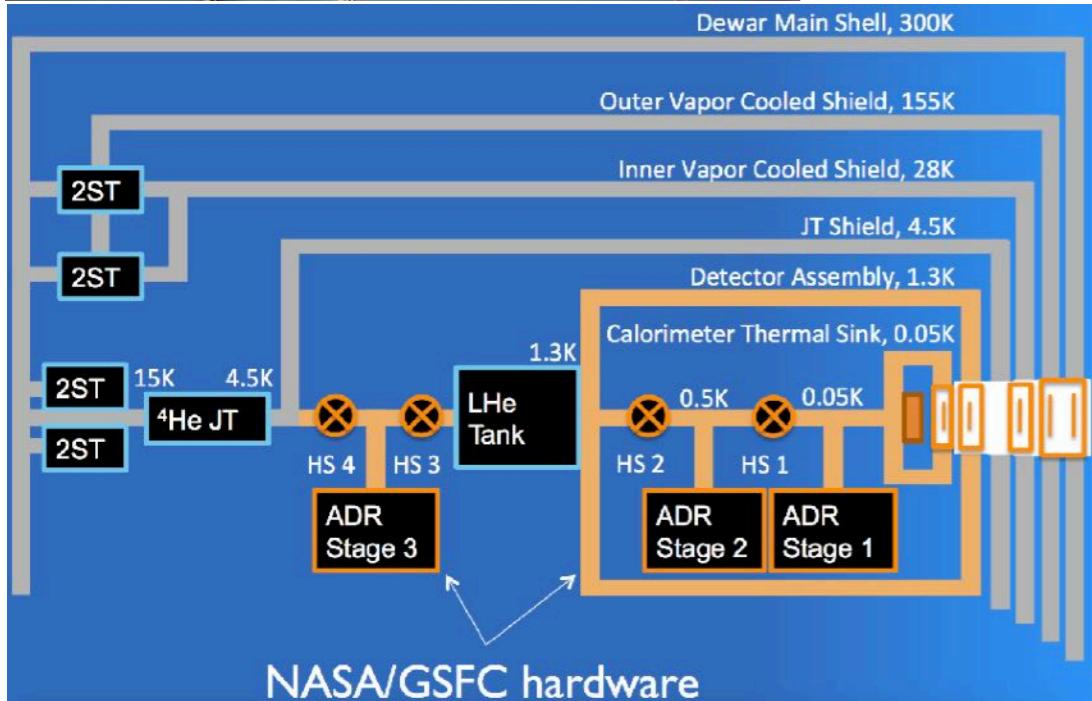
200 nW @ 100 mK continuous cooling
from 1.6 K (\approx 8 μ W)
Open cycle: Lifetime limited
 \approx 2 years mission

HITOMI (ASTRO-H) Cryogenic chain



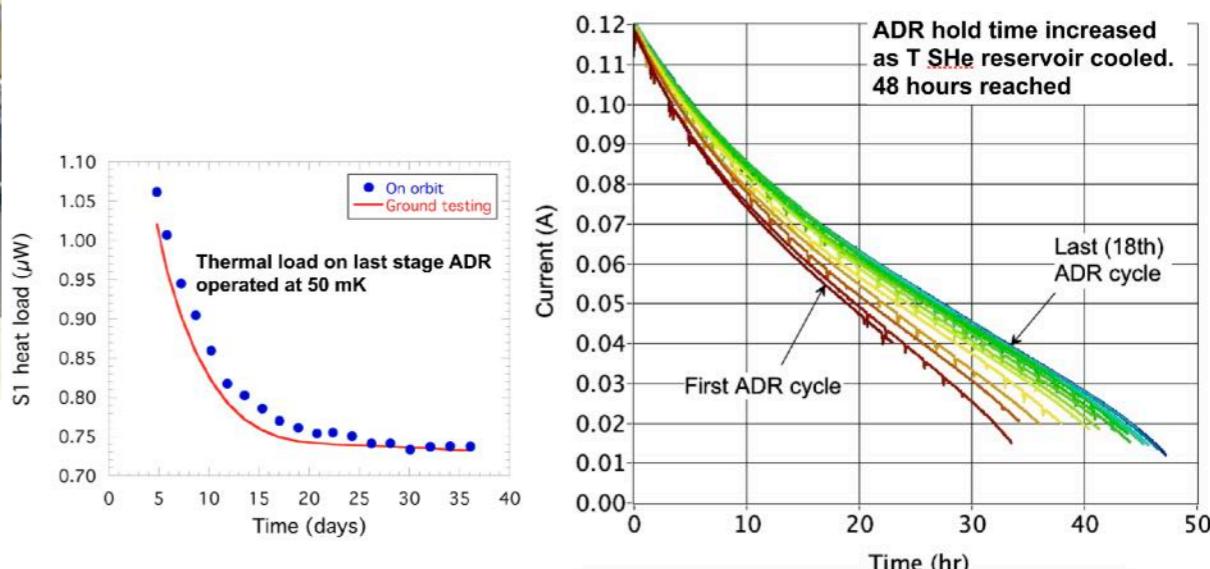
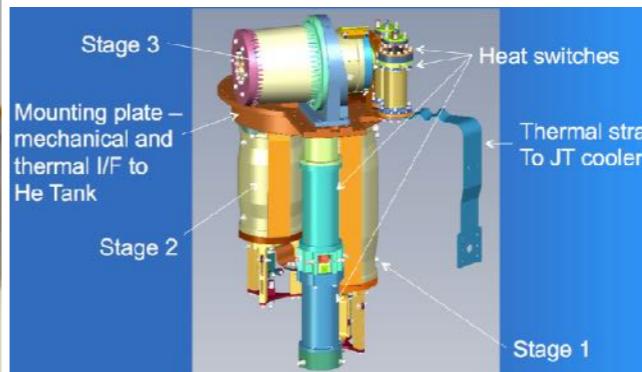
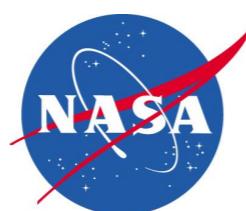
Feb. 17th 2016

JAXA
Japan Aerospace
Exploration Agency



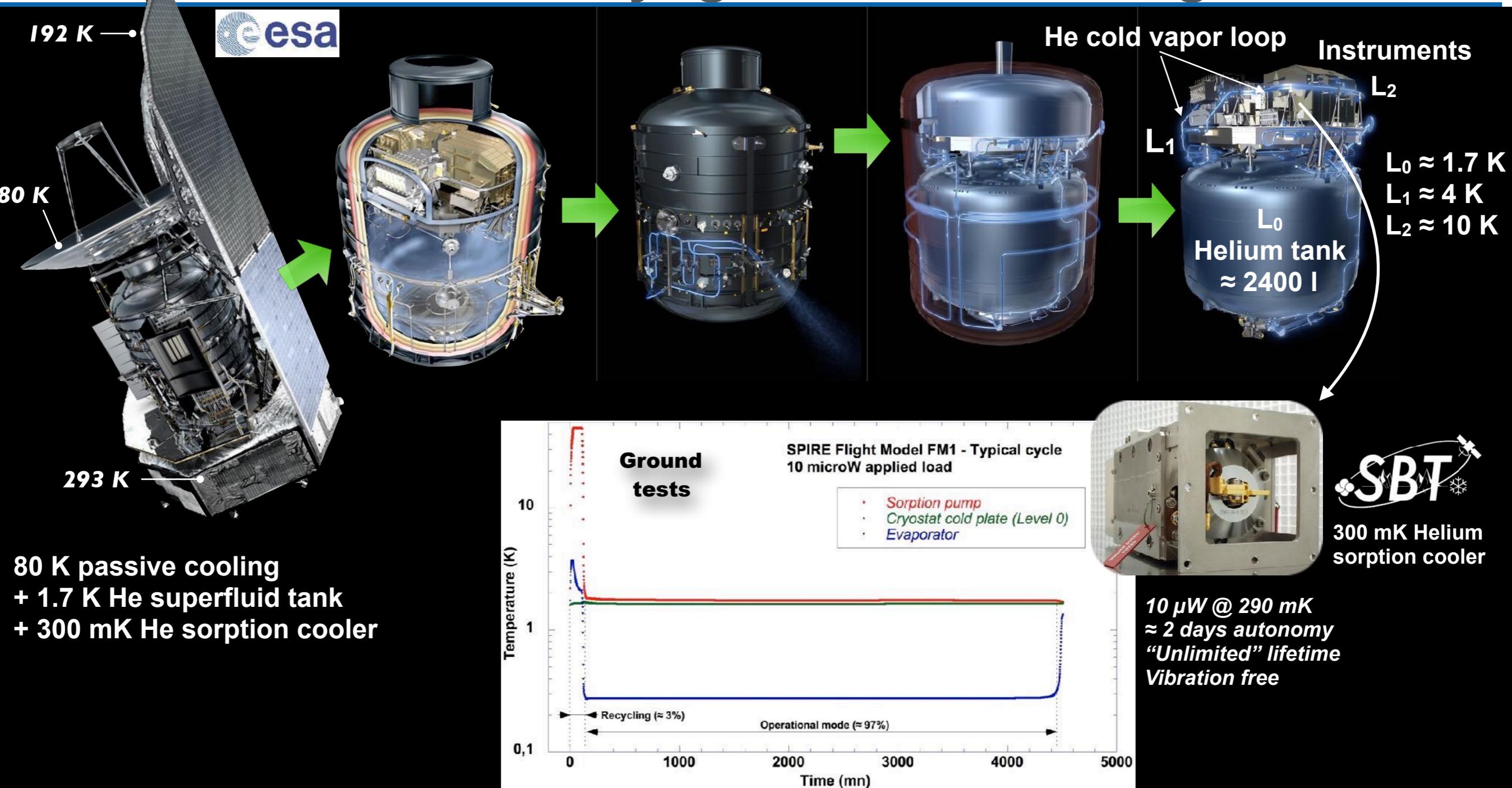
Combination of passive cooling

- + 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)

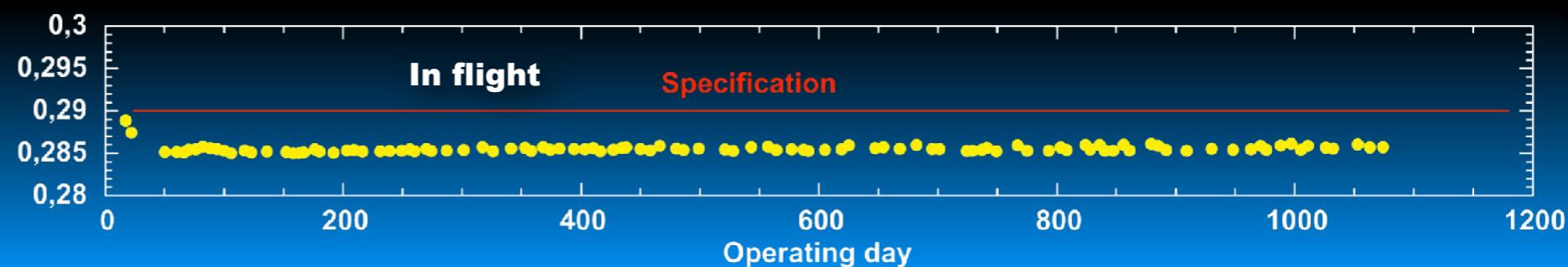


Cryogenics performed as expected but mission failed due to attitude control anomaly resulting in uncontrolled spin of spacecraft

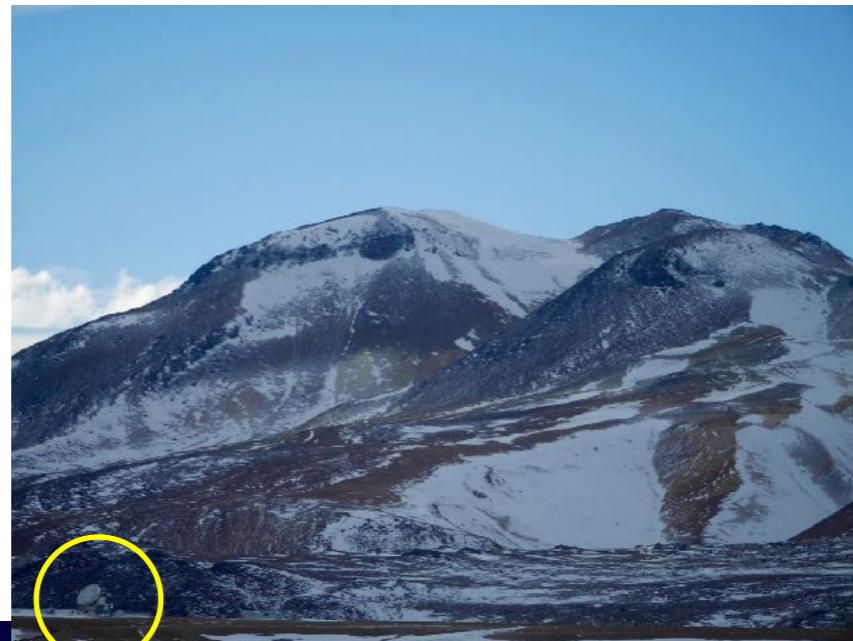
HERSCHEL Cryogenic chain - In flight



HERSCHEL SPIRE Sorption unit



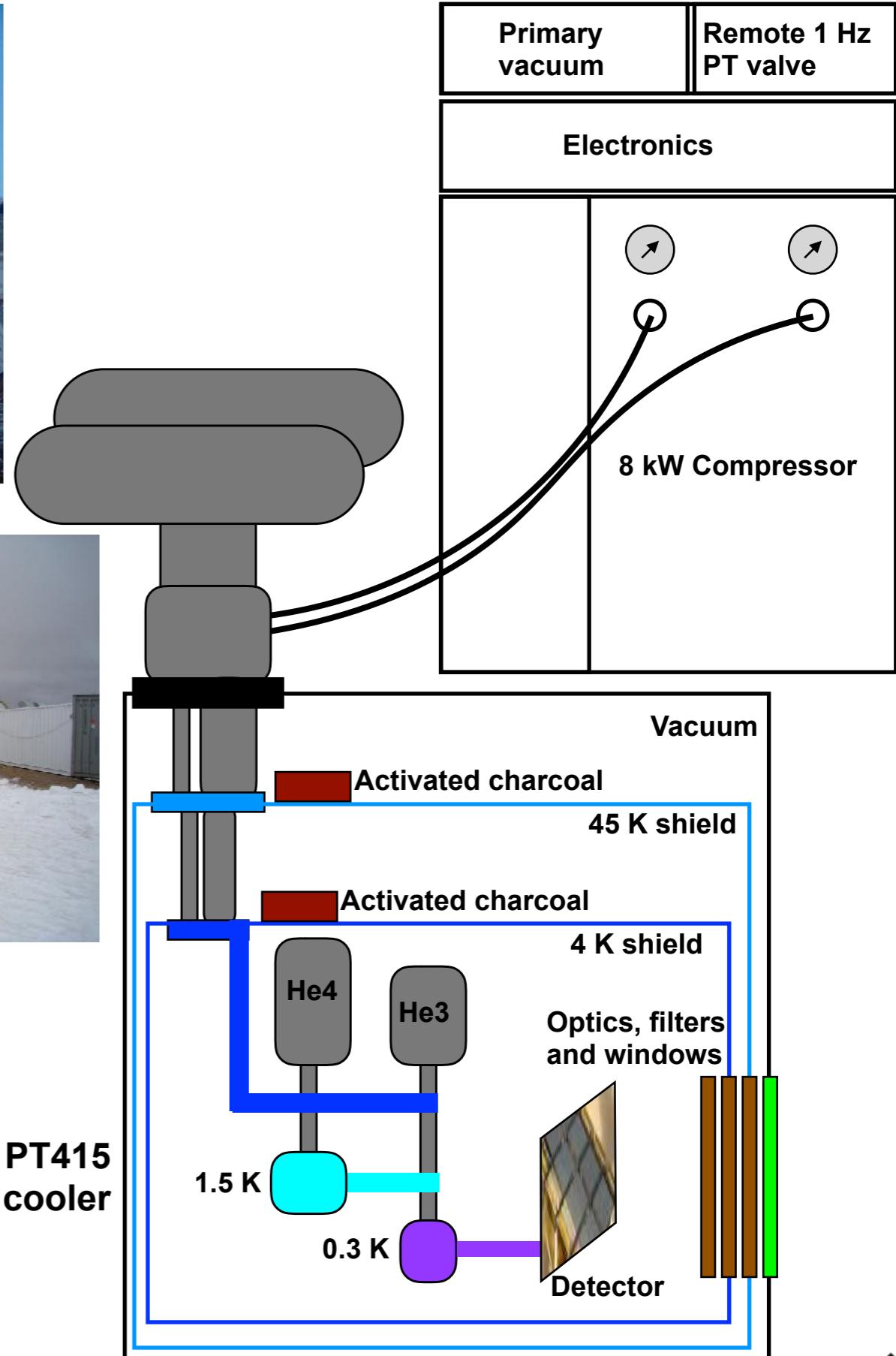
Ground based telescopes - ARTEMIS APEX



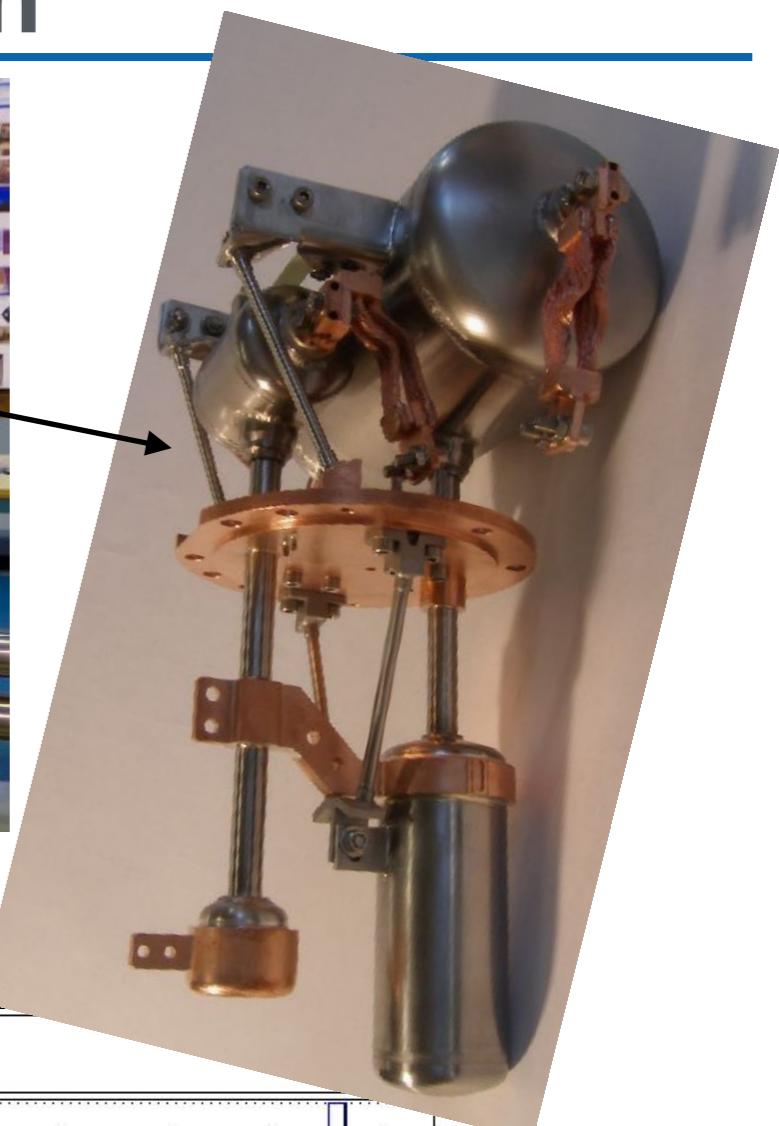
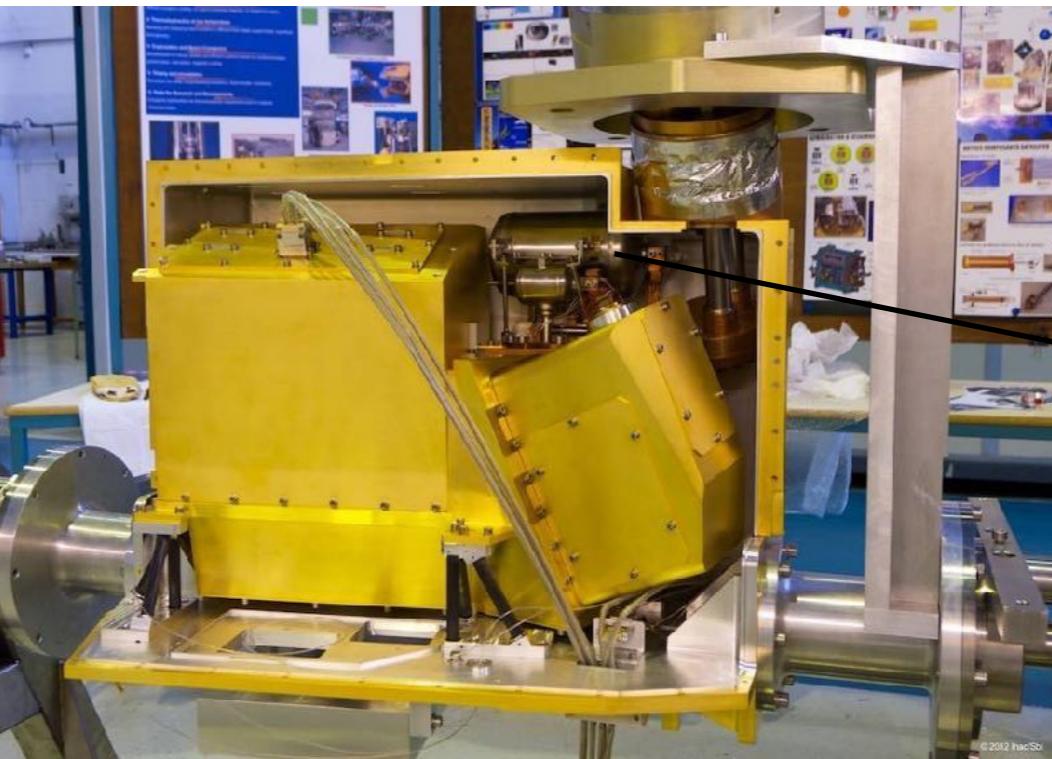
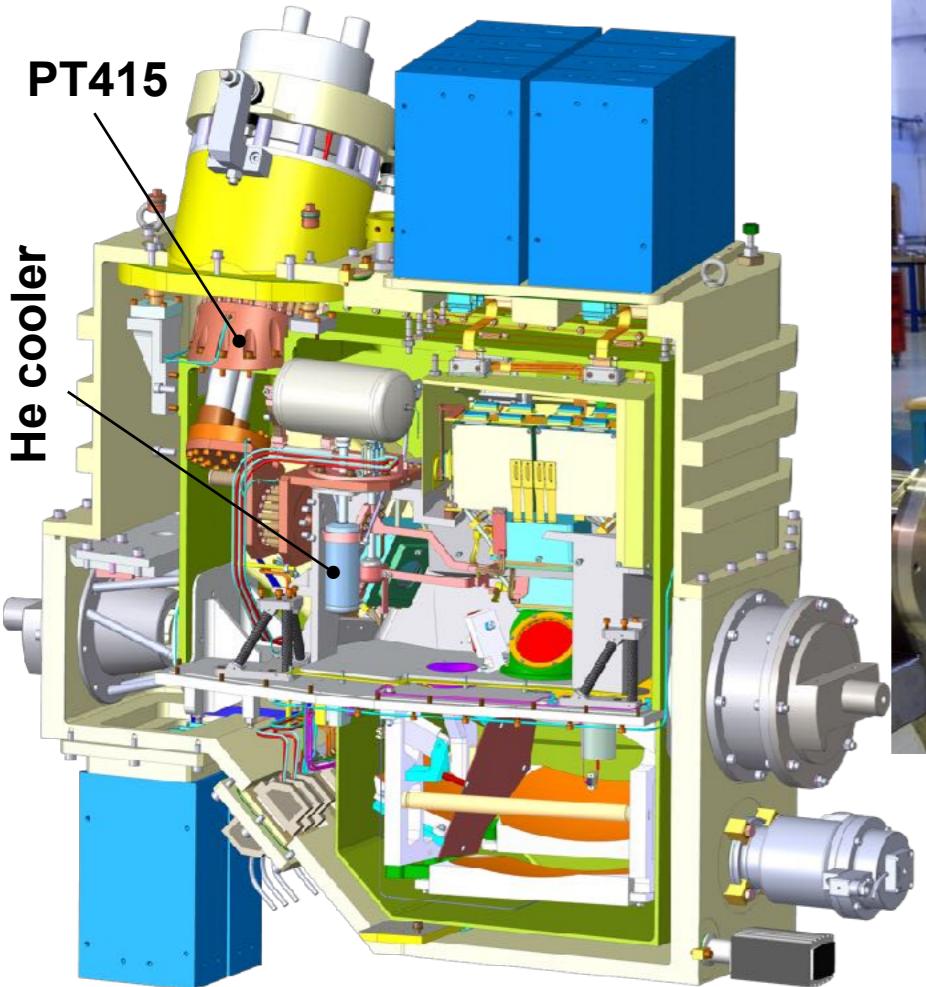
Altitude 5100m



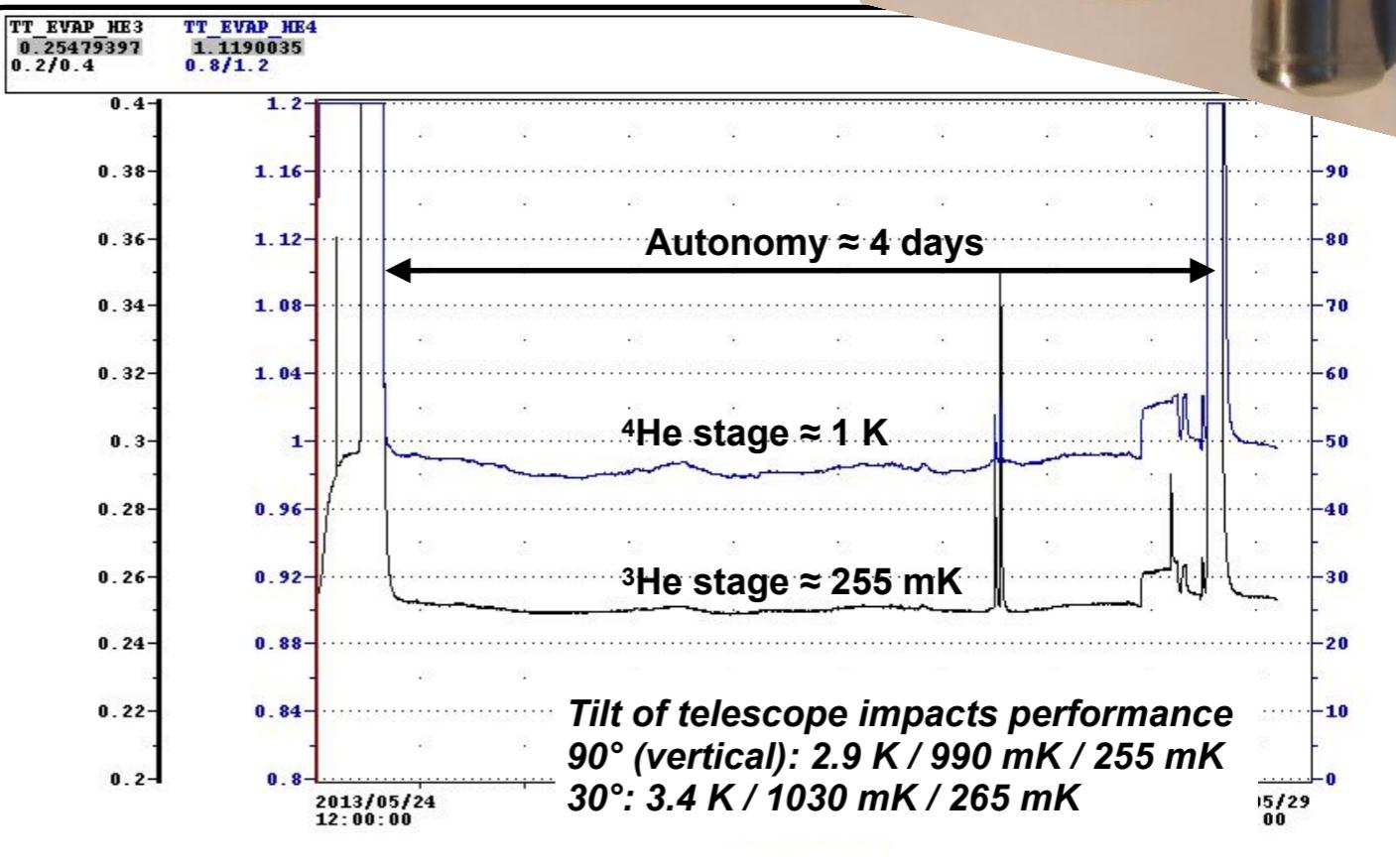
CryoMech PT415
+ 2 stages He sorption cooler



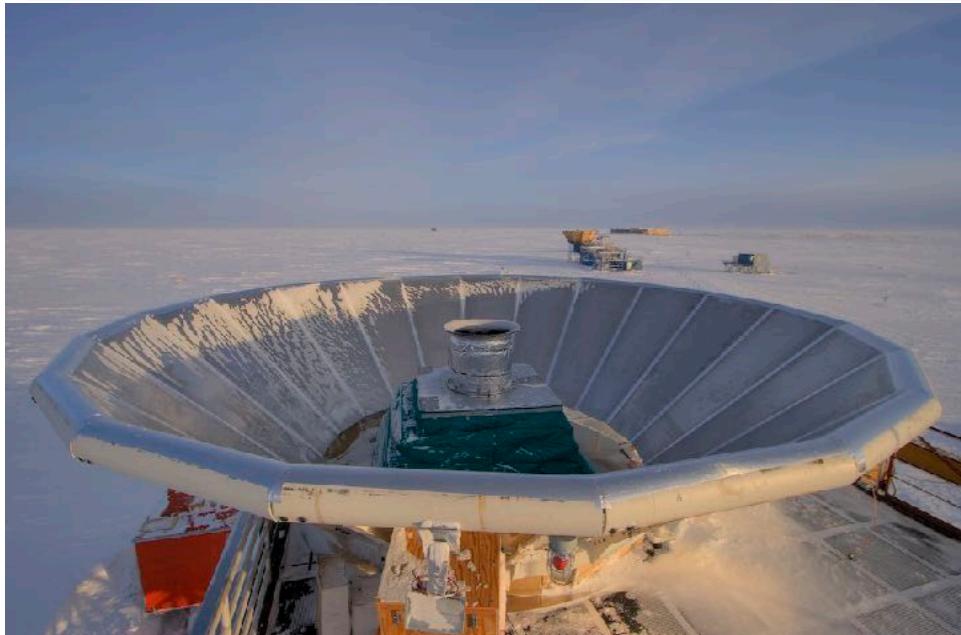
ARTEMIS cryogenic chain



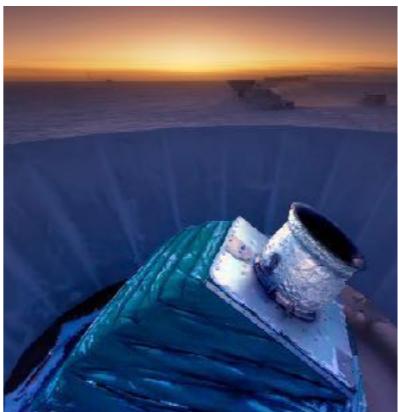
Irfu • SBT Double stage helium sorption cooler



Gravitational waves ... cryogenics needed



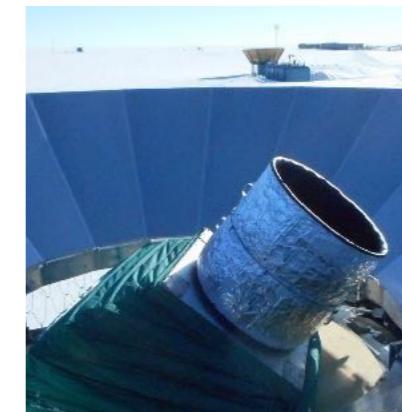
BICEP2
(2010-2012)



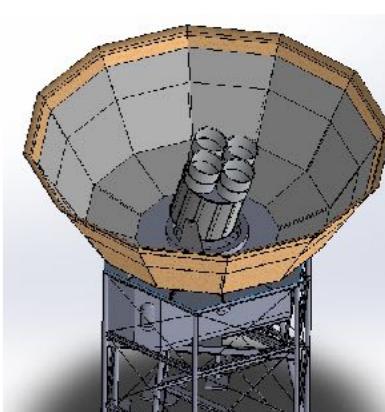
Keck Array
(2012-2017)



BICEP3
(2015-)



BICEP Array
(2018-)



If you are a night owl, the South pole is for you !
6 months long ...

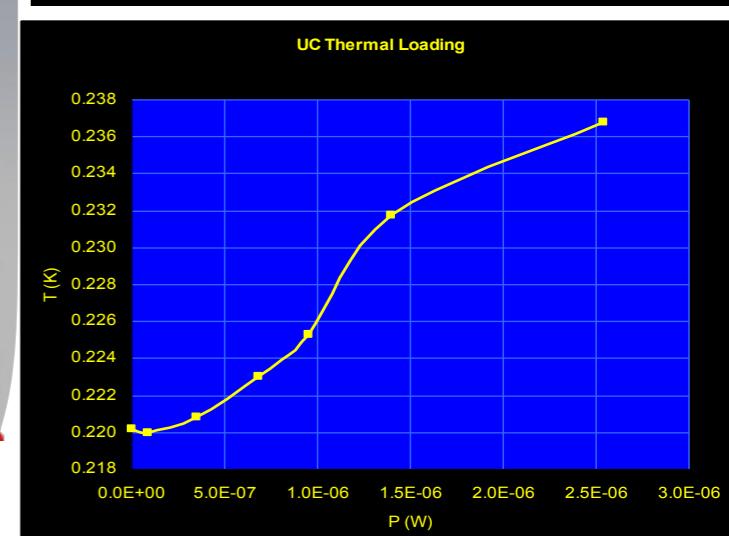
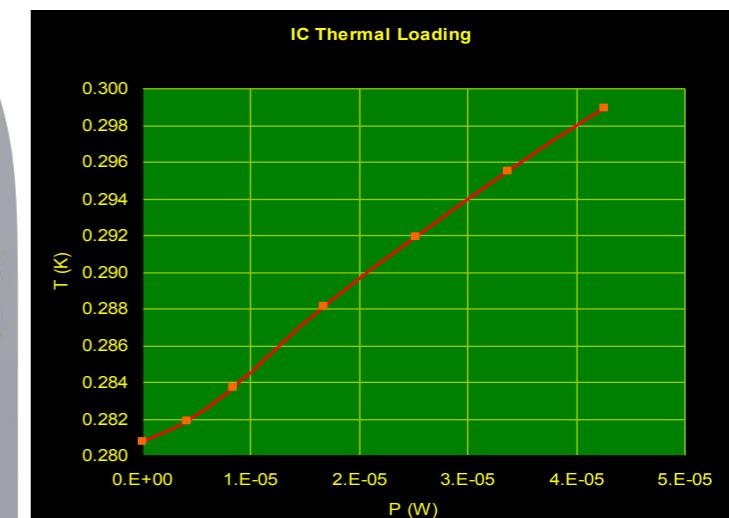
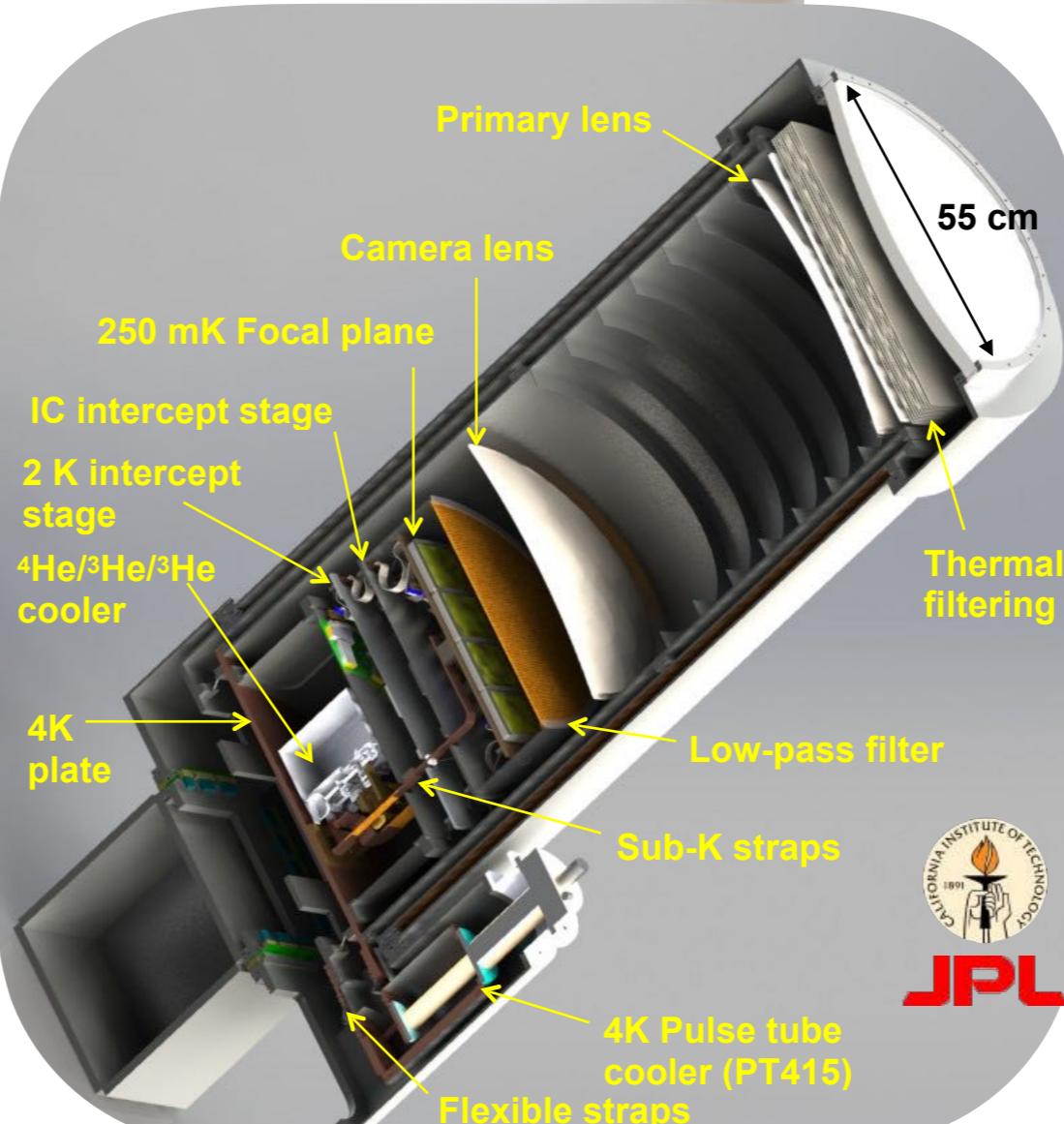
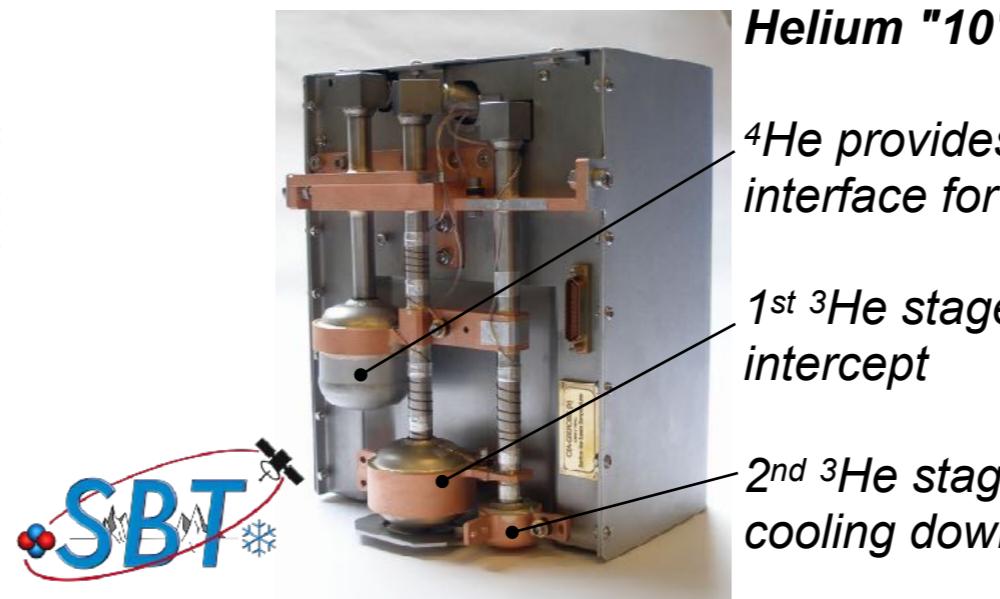
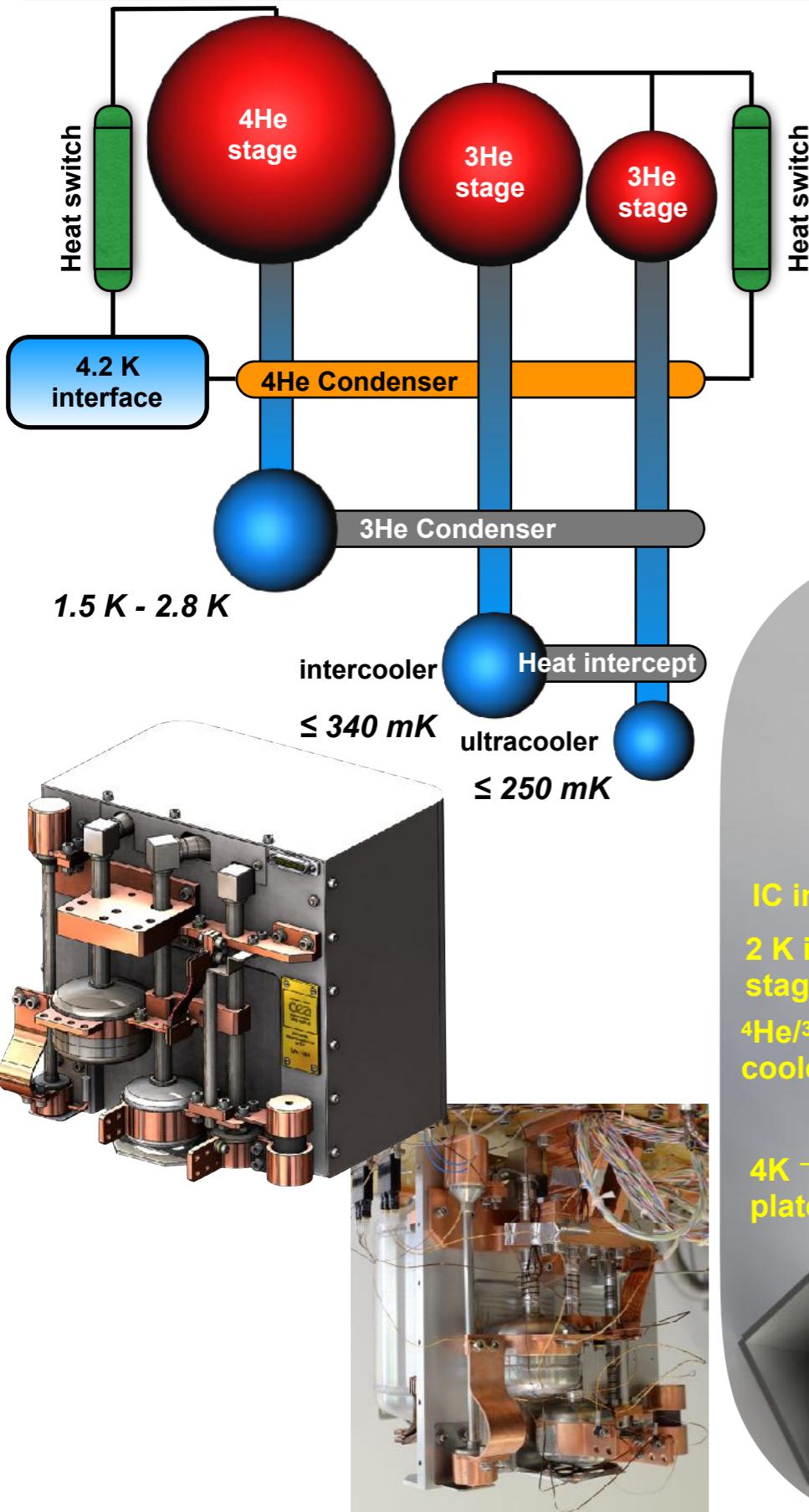
Altitude: 2850 m
Average temperature: -50°C
Lowest T: -82°C
Highest T: -12°C



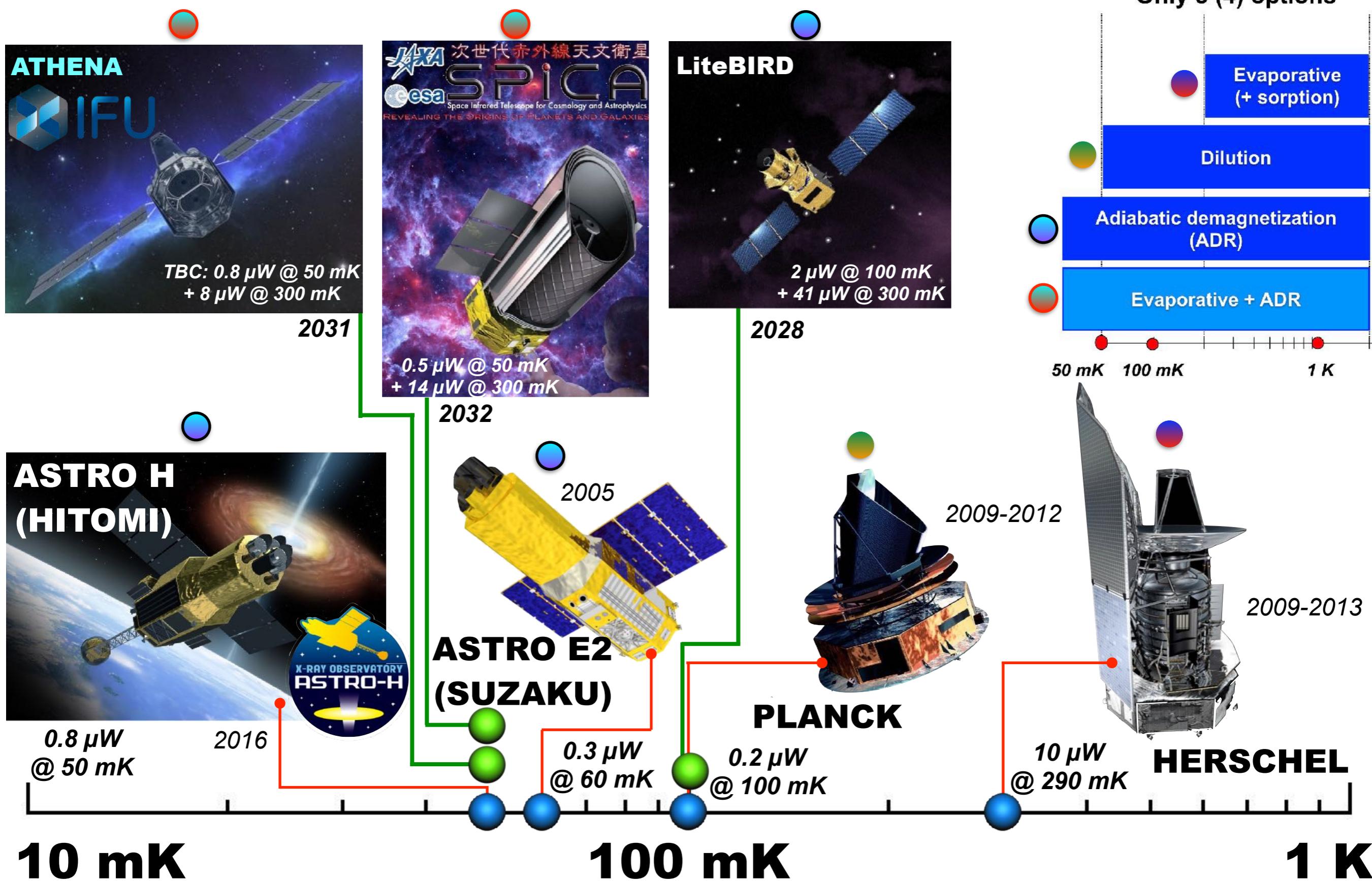
JPL



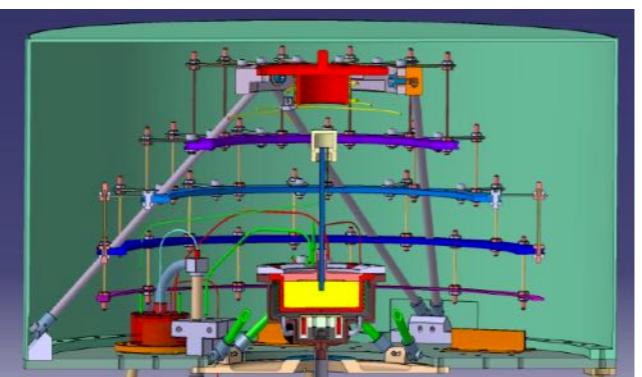
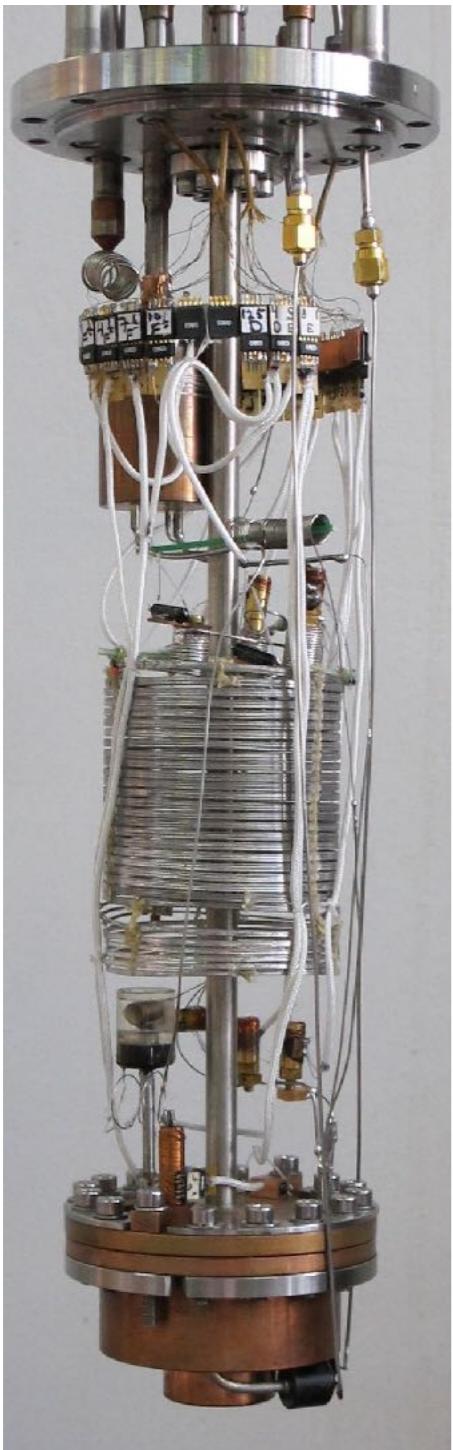
BICEP series: 3 stages He sorption coolers (He10)



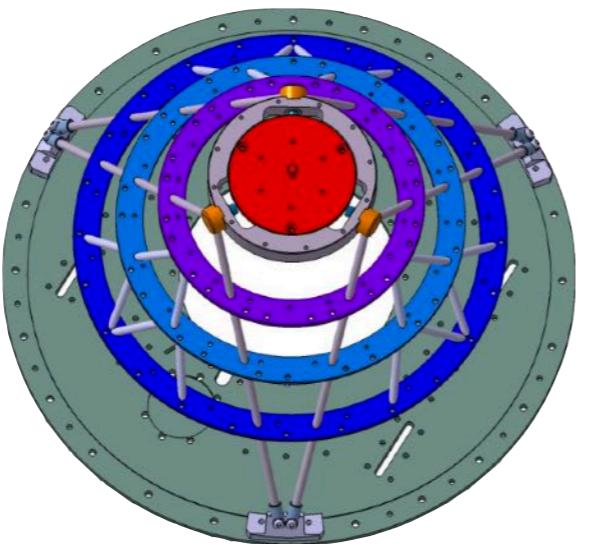
Sub-kelvin missions: what's coming up



Multistage ADR & Continuous Dilution cooler



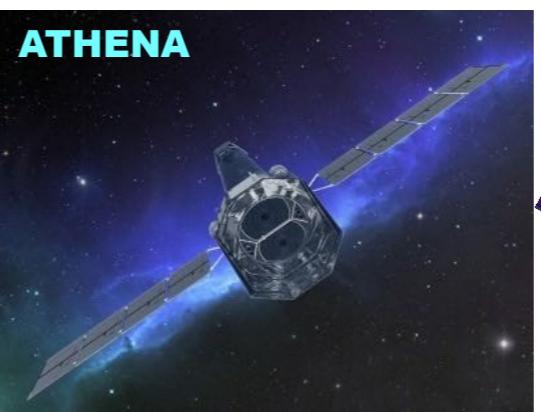
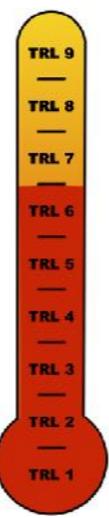
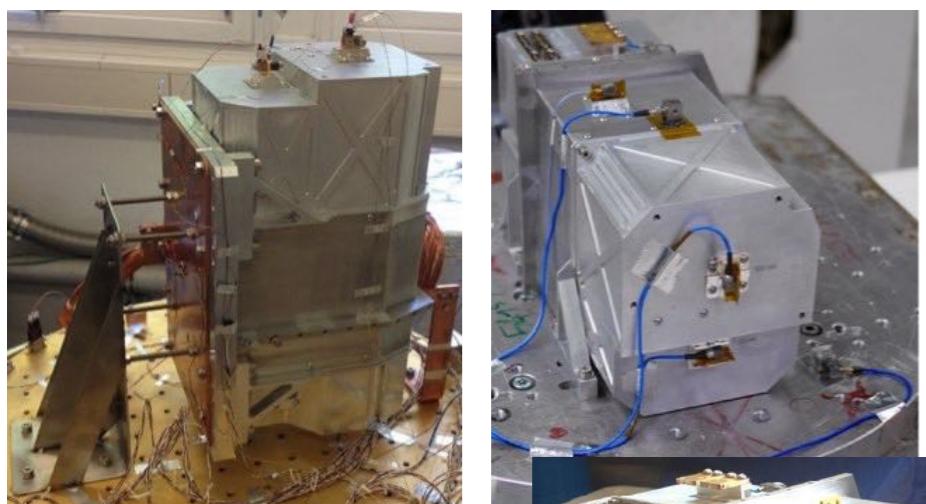
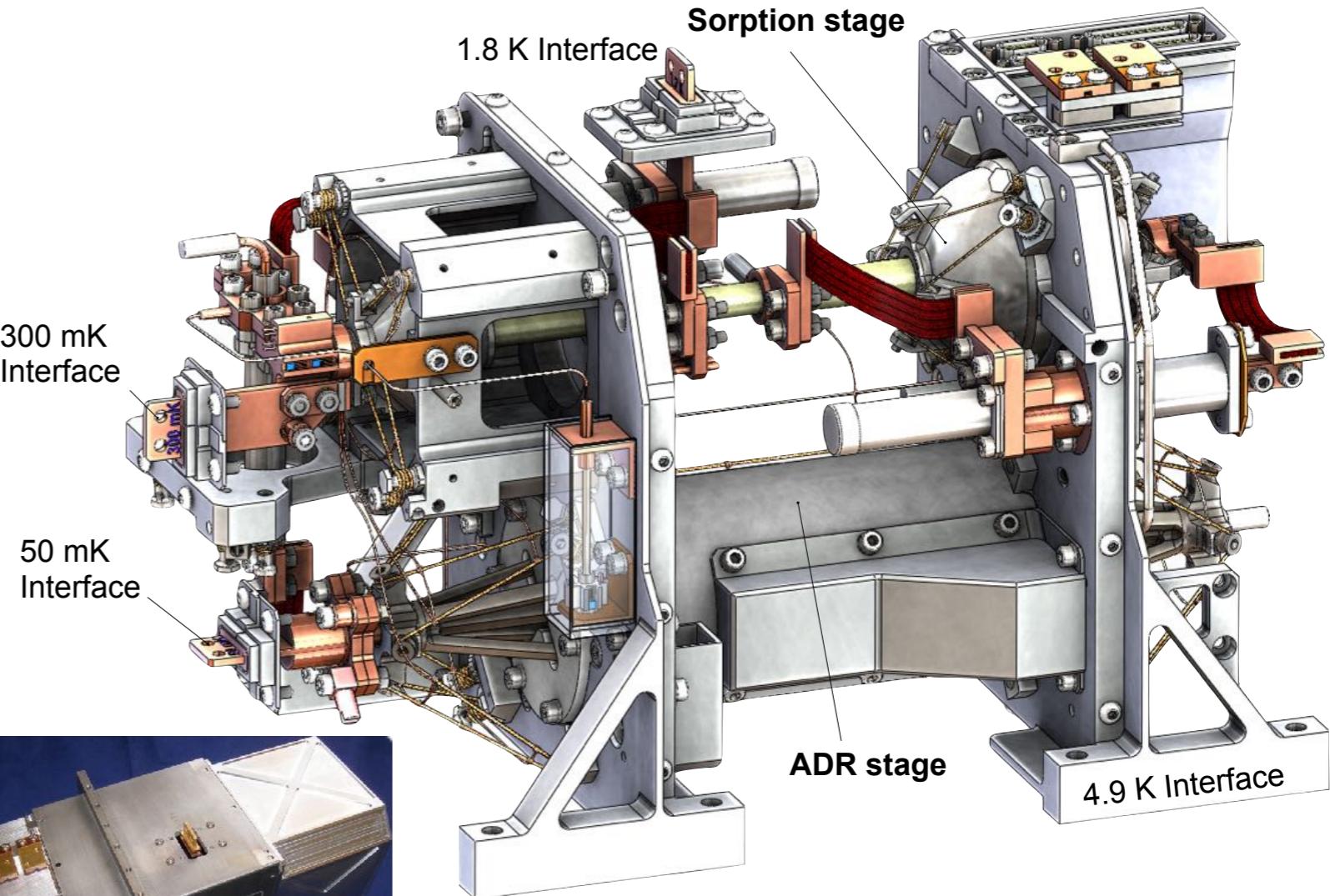
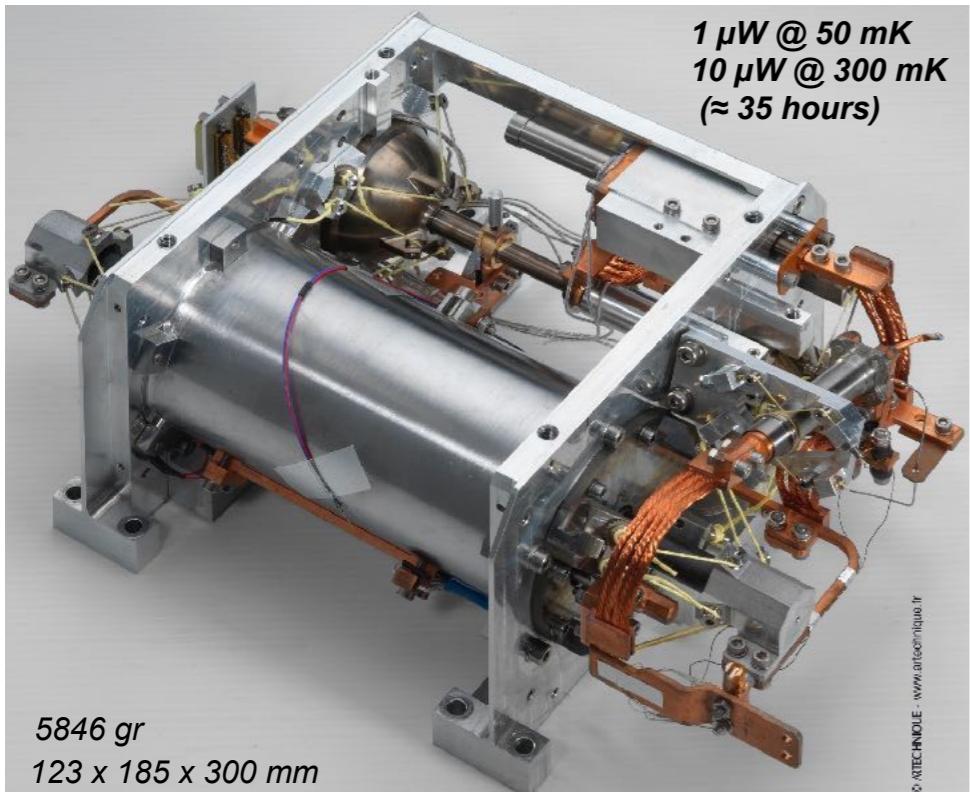
See Gérard Vermeulen
presentation



See Jean Marc Duval
presentation



50 mK hybrid cooler: combination He sorption + ADR



The missing links: not to be forgotten

0.01 K

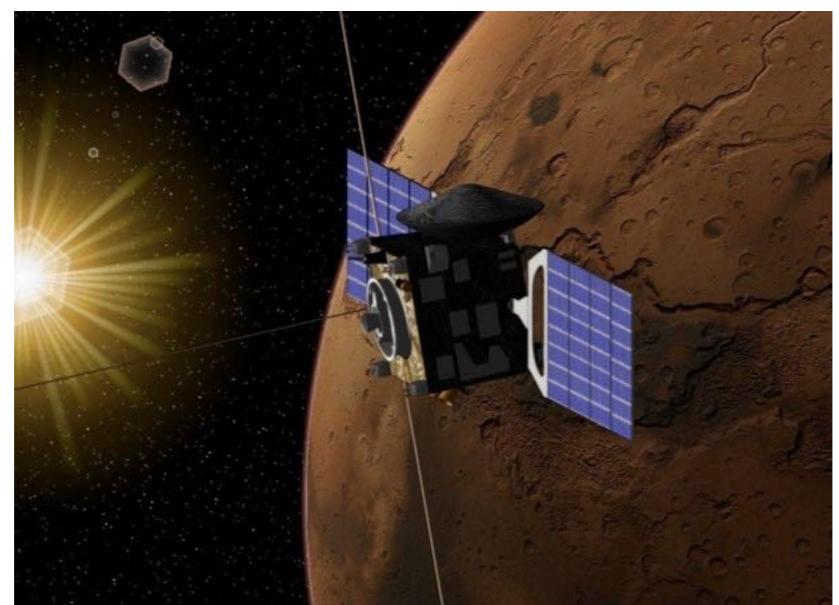
0.1 K

1 K

10 K

100 K

300 K



Passive Radiators

Stored cryogen (Cryostat)

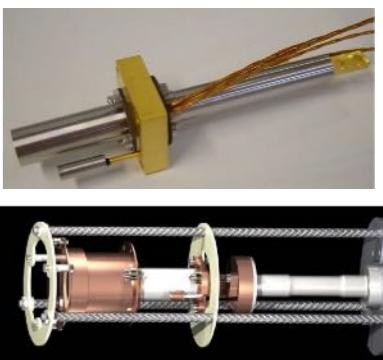
Active "mechanical" coolers

"Ultra" low T coolers

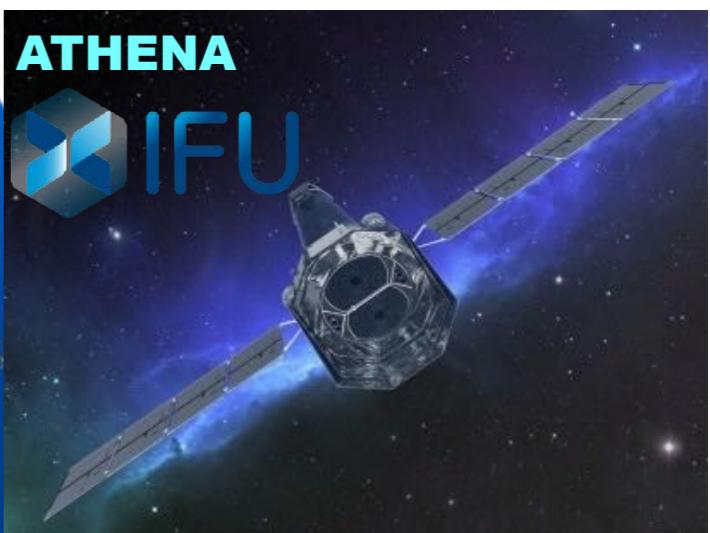
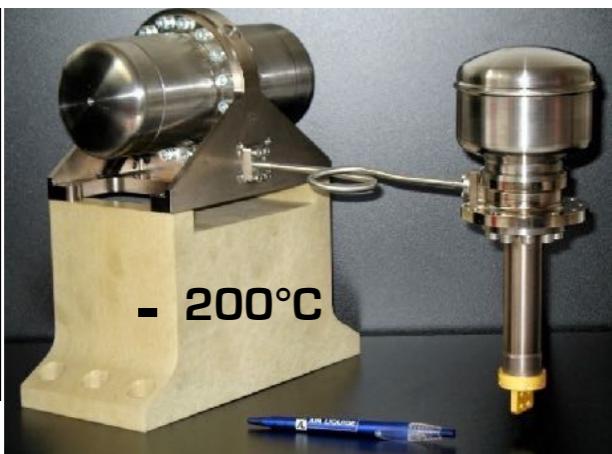
(technologies: sorption, magnetic, dilution)

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

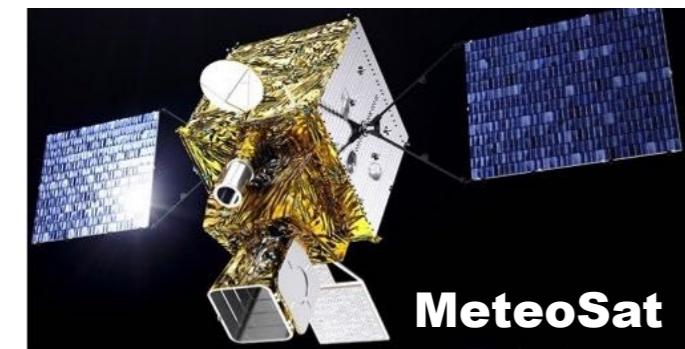
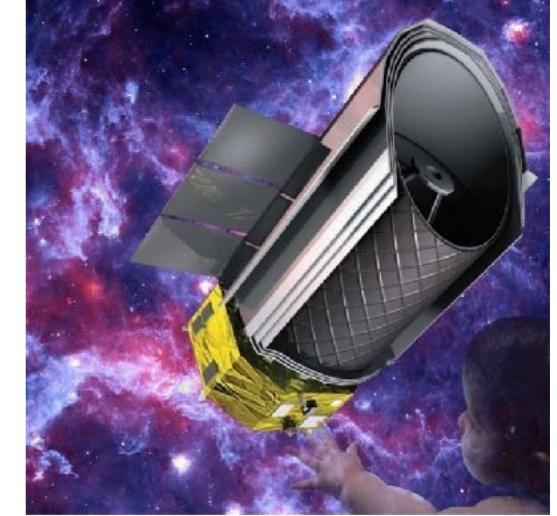
Flexible links, heat pipes, heat switches, energy storage unit, etc...



Grenoble: Space cryogenic hub ?



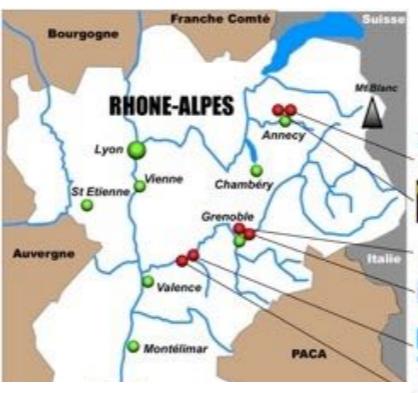
JAXA 次世代赤外線天文衛星
esa SPICA
Space Infrared Telescope for Cosmology and Astrophysics
REVEALING THE ORIGINS OF PLANETS AND GALAXIES



MeteoSat

- 223°C

- Physicists and Engineers
- Highly rated institutes (HCERES)
- International collaborations
- Strong links with industry
- Technology transfers
- ≈ 600 persons
- 600 000 l of LHe₄ produced
- Space cryogenic: positioning unique in the world



Competitive local economic



LiteBIRD

Thank you for your attention

