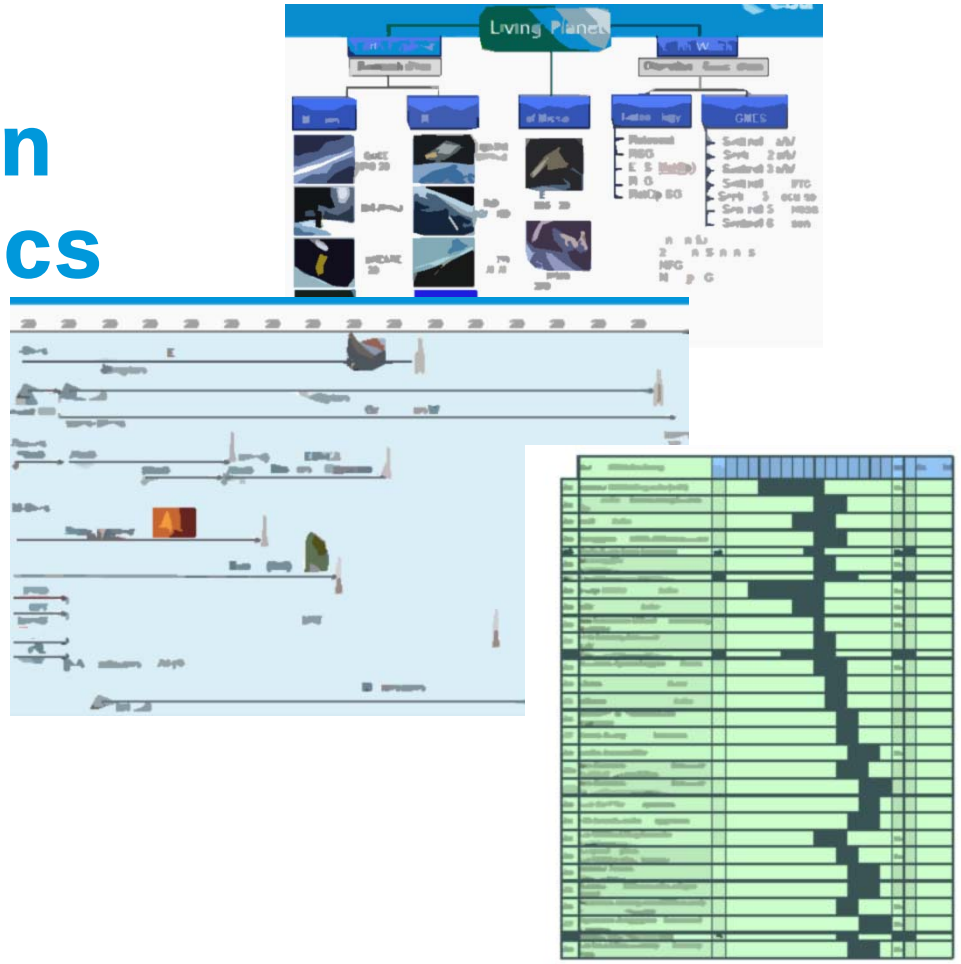
Future Trends in Space Cryogenics



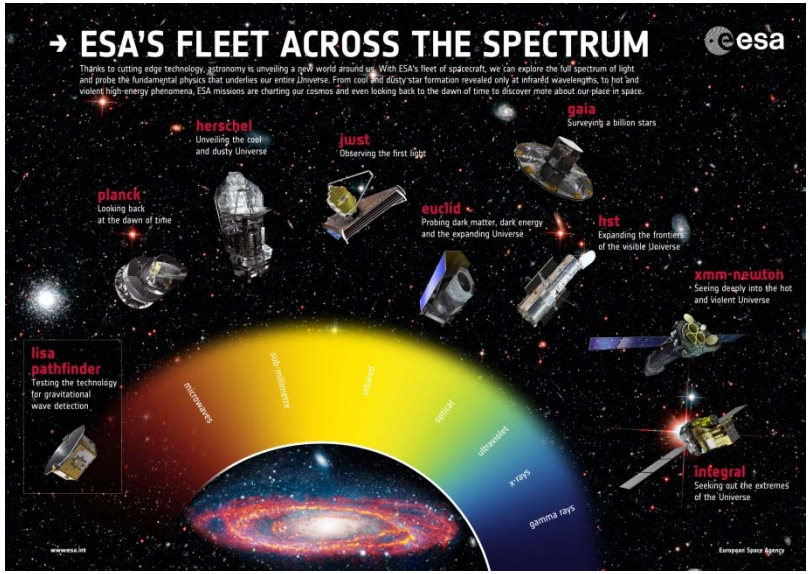
Thierry Tirolien
ESA/ESTEC, Thermal Division

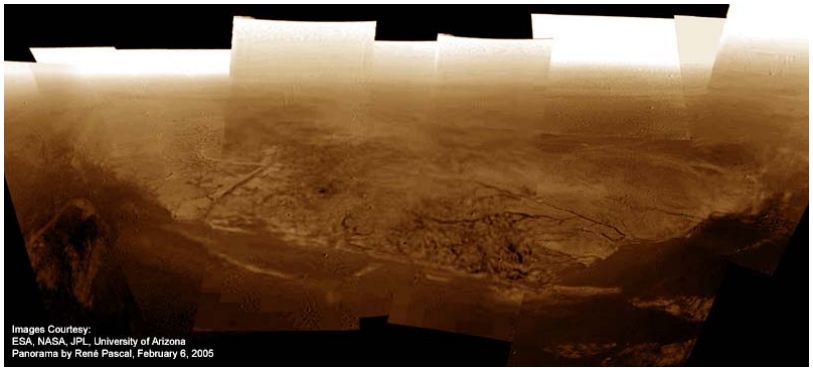
Summary

- Space Cryogenics, a few words
- A glance to the past
- Evolution of the Needs
  - Earth Observation Missions
  - Science Missions
  - Other applications
- Final Words

Space Cryogenics, a few words

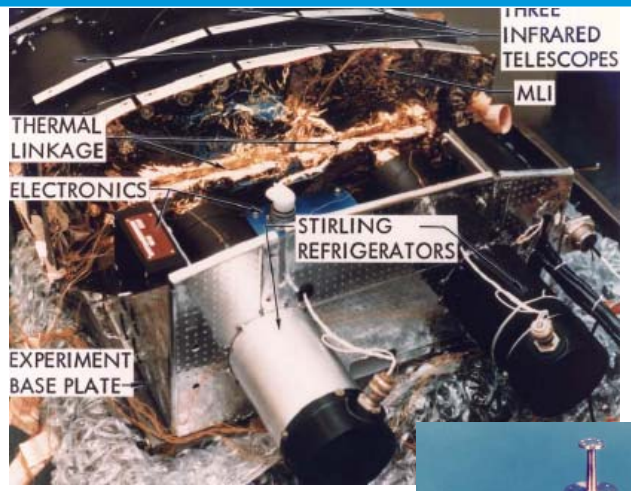
- Cryogenics in Space mainly used for Focal Plane Cooling…
  - Earth Observation
    - Imagery (Civil or Military)
    - Monitoring of lands (fires etc.)
    - Meteorology
    - Atmospheric Chemistry
  - Science
    - Black hole studies
    - Gamma ray studies
    - CMB
    - Chemistry of exoplanets
- But other applications (can) exist:
  - Sample collect and conservation
  - Zero-Boil Off for long cryogenic propulsion missions
  - High Temperature Superconductors
  - Cryogenically cooled Low Noise Amplifiers

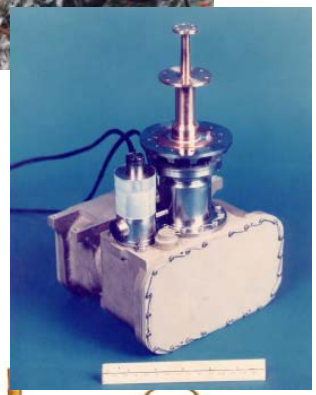


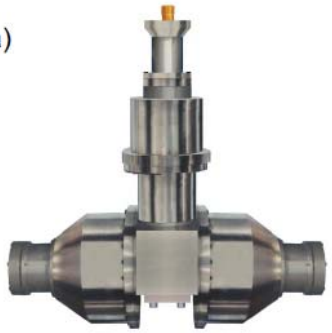


A Glance To The Past

- (some of) The Firsts*:
  - *First Dewars* (1968): LO2 and LH2 Dewars of the Apollo missions
  - *First Cryocooler missions* (1969): Mariner 6 and Mariner 7 open loop N2/H2 Joule-Thomson (Berkeley, US)
  - *First Closed-Cycle mechanical cooler* (1971): Malaker Stirling Cooler (LMSC, US) on-board RM-19 (DoD).
  - *First Multi-Year Cryogenic Mission* (1979): Rhombic Drive Stirling (Philips Lab., NL) on-board a DoD Gamma Ray mission.
  - *First Oxford-Style Coolers in Space* (1991): RAL-version (UK) onboard ERS-1, Oxford-version (UK) onboard UARS.





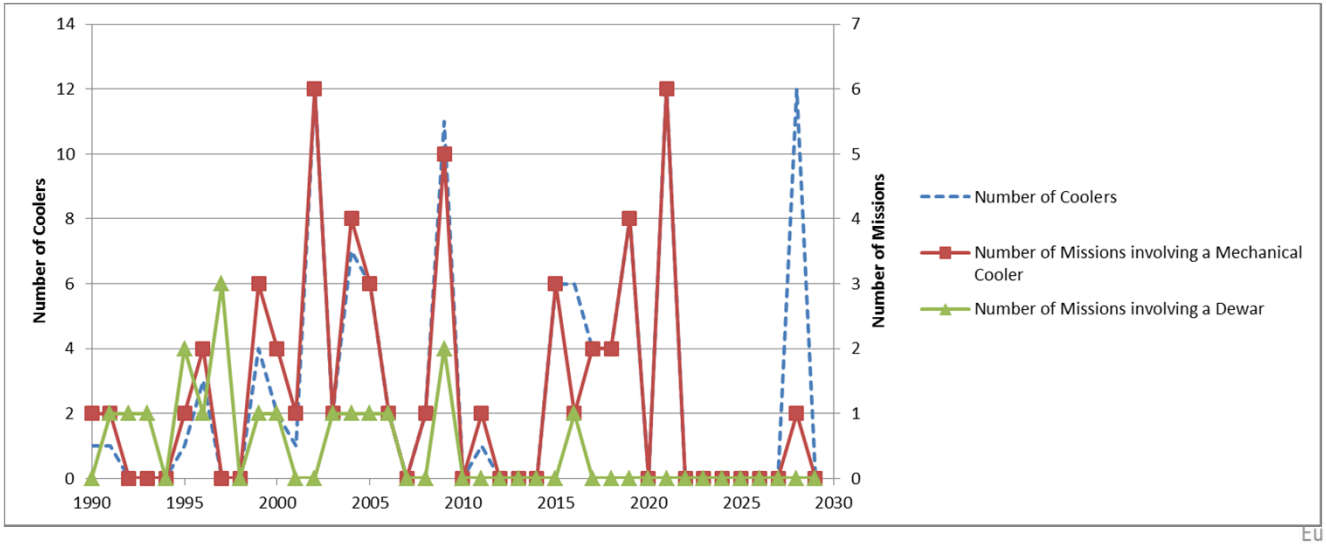


European Space Agency

* Most info come from the excellent R.Ross paper "Aerospace Coolers: a 50-Year Quest for Long-life Cryogenic Cooling in Space"

A Glance To The Past

- Since the 90's and including the missions under development right now ~50 instruments required/are requiring mechanical cryocoolers.
  - It represents a total of ~110 flight coolers worldwide between the early 90's and ~2025.
- In the meanwhile, Liquid or Solid Cryogen dewars which were popular in the 80's and first half of the 90's are not considered anymore.



A Glance To The Past

- The apparition of Oxford-Type coolers in the 90's revolutionized space Cryogenics: the quest for lifetime which drove the developments for decades was achieved.

- What is the next breakthrough that will transform Space Cryogenics?

Evolution of the Needs – Earth Observation Missions

Living Planet

Earth Explorer

Research driven

Core Missions

GOCE
2009-2013

ADM-Aeolus
2016

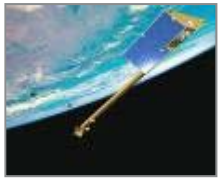
EarthCARE
2018

Biomass
2020

Opportunity Missions

CryoSat-2
08/04/10

SMOS
02/11/09



Swarm
22/11/13

CarbonSat or FLEX

EE8
2022

Continuity of Missions

ERS-2
1995 – 2011

Envisat
2002 - 2012

Earth Watch

Operational Service driven

Operational Meteorology

- Meteosat
- MSG
- EPS (MetOp)
- MTG (2 s/c x 3)
- MetOp SG (2 s/c x 3)

Copernicus (ex GMES)

- Sentinel 1 a/b/c/d
- Sentinel 2 a/b/c/d
- Sentinel 3 a/b/c/d
- Sentinel 4 (on MTG)
- Sentinel 5 precursor
- Sentinel 5 (on MOSG)
- Sentinel 6 (Jason)

and in future:
2nd gen. Sentinels
MFG
MetOp TG
..

Evolution of the Needs – Earth Observation Missions

- Mainly 2 types of Missions:
  - Operational Service Driven (MTG, MOSG, Sent 3)
  - Research Driven (e.g. CarbonSat (still in competition))
- Operational Service Driven missions:
  - Usually "ambitious" (= with significant resources) but constraining.
  - In Europe, we are today right now at the end of a Cycle (major missions launch in the next 5 years).
  - Next Meteorological missions Cycle (M4G, MOTG) due for the late 2030s
  - Second Generation Copernicus Mission: in the Mid-30's.

→ No "Big" operational TIR EO mission in the next 20 years

Evolution of the Needs – Earth Observation Missions

- Operational Service Driven missions – sketch of the future needs:
  - Cut-Off Wavelength comparable with current missions (13 - 15µm)
    - Current technology of MCT can be suited with minimum temperature ~40K
  - Might be a need to increase the size of the detector matrix (2Kx2K) to cope with missions such as high spatial resolution in GEO, but most probably not at very long wave length/low temperature.
  - Microvibrations will be a driver. More than ever.
  - Possible need of High Resolution TIR mission but will probably need cooling @ 77K.

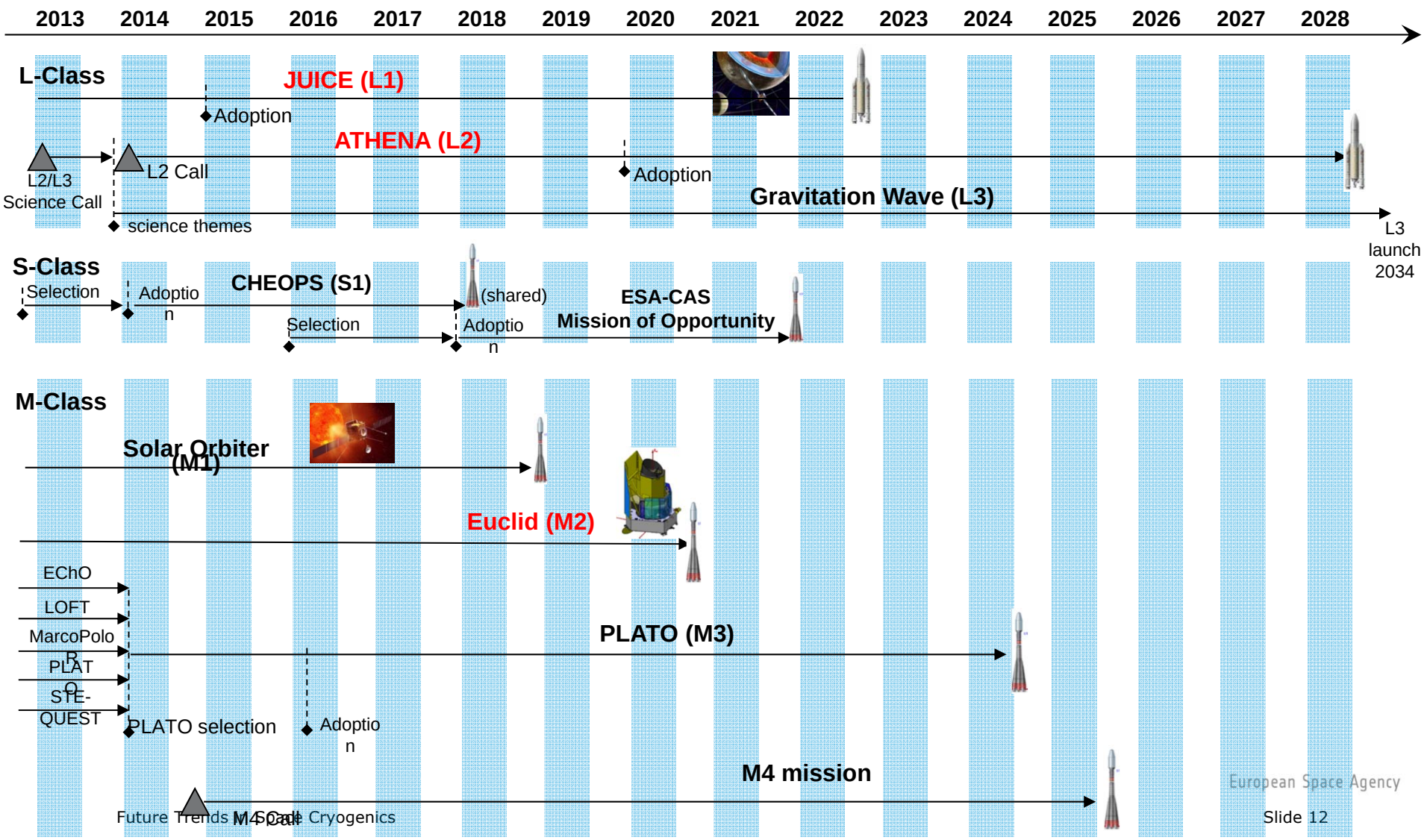
Evolution of the Needs – Earth Observation Missions

- Research Driven missions:
  - 'Big' missions like ADM-Aeolus or Earthcare are less likely to happen → the tendency is to go toward smaller missions.
  - Next call for ideas in 2016.
- Research Driven missions – sketch of the future needs:
  - Missions will avoid T<80K (adds complexity)
  - The SWIR/MWIR wavelengths are and will stay of interest (CO_2 is a popular topic).
    - Cooling at 120-170K will be required
  - As the missions will be smaller (of opportunity) Mechanical Cryocoolers will be avoided if possible (especially in the 120 – 170K region – competition with the radiators) unless they are:
    - Small,
    - Efficient,
    - Cheap,
    - Reliable
    - And don't disturb the instrument.

Evolution of the Needs – Earth Observation Missions

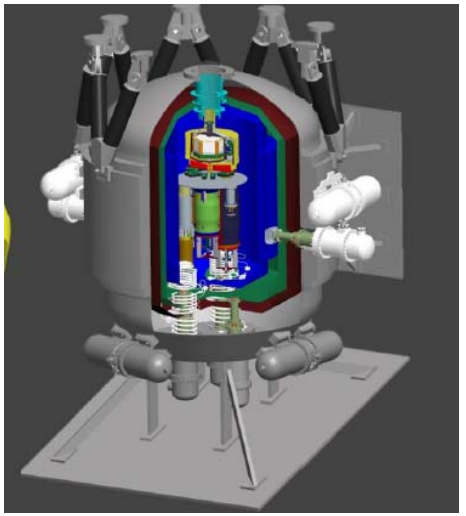
- Summary:
  - Cooling below 77K:
    - No big mission before 2030 (but potential peak of demand around that time).
    - Target temperature will decrease, but not significantly (40K).
    - Microvibrations will be the main concern.
  - Cooling above 77K:
    - Tendency to go toward cheaper miniaturized coolers (but reliability will always be a concern):
      - Ground-based coolers made more reliable?
      - Or long-life miniaturized coolers made cheaper?
    - 120 – 150K temperature range of special interest:
      - Optimization in that temperature range.
      - Thermal Stability will be a stringent requirement
      - Alternative cooling solution or architecture in that temperature range shall be investigated.

Evolution of the Needs – Scientific Missions



Evolution of the Needs – Scientific Missions

- In the Current Cosmic Vision Plan:
  - 3 selected missions need Cryogenics.
  - 2 missions to be selected.



- With Athena and the X-IFU, an ambitious Scientific Cryogenic Mission will keep busy the community for the next cycle (covered yesterday).

- What else?
  - Potential Themes that might come up in the future:
    - Cooled Mirror below 10K
    - Post Planck mission with continuous 50mK cooling

Evolution of the Needs – Scientific Missions

- Some Characteristics of Cryogenics for Scientific missions:
  - Possibility to go to L2 that allows efficient passive cooling.
    - The temperature range [60, 180K] that can be challenging in EO is less critical (cf. Euclid – FPA@94K)
  - Specific Cooling Needs – very mission dependent e.g.:
    - Cryogenic Chains to 50mK (e.g. SPICA, ATHENA)
    - Vibration Free Cooling down to 6K (e.g. Darwin).
    - Remote Deployable Cooling (e.g. JWST)
- What about the potential subjects that might come up:
  - Cooled Mirror below 10K:
    - 6-10K Cooler?
    - Distributed Cooling?
    - Heat Transportation below 10K?
  - Continuous 50mK cooling:
    - Closed Cycle Dilution refrigerator?
    - 50mK Heat Switch?

Evolution of the Needs – Scientific Missions

- Summary:
  - Athena needs are already identified:
    - Cryochain to 50mK (with associated electronics and Cryostat technology) for X-IFU.
    - Potential needs of ~200 - 250K Temperature HP or LHP for WFI.
  - Potential future needs from Cosmic Vision:
    - Cooling large Mirror below 10K
    - Continuous 50mK Cooler

Evolution of the Needs – Other applications

- Exploration:
  - Miniaturized, power limited, and (usually) lifetime limited experiments will look for efficient, not expensive, light coolers. Typically Rotary Type Stirling cooler → this need will remain.
  - For Lunar missions, sample acquisition or conservation at temperatures ~120K are foreseen: miniaturized (and lifetime limited) coolers could be used, as well as Energy Storage Units.
  - Zero Boil Off architecture for ambitious Human Exploration Missions: needs to be prepared, even though there is no mission identified before 2035.

Evolution of the Needs – Other applications

- Telecom:
  - Despite potential advantages identified of using HTS in telecom architectures, no evolution in this domain in the last years.
  - Cryogenically Cooled LNAs could be used for some application (Small Terminal Business) but not in the main broadcasting market.
  - For this application to break through, the emphasis would be on:
    - Temperature > 77K
    - **Lifetime guaranteed of 15 years.**
    - Miniaturized and integrated.

Courtesy of Callisto

Final Words

- Future Trends of Space Cryogenics?
  - Earth Observation
    - There will always be a need for optimized coolers at 40-50K for the big TIR Missions (but one batch every 20 years). For those missions, the next breakthrough will concern exported microvibrations.
    - In the medium term, miniaturized, cheap coolers optimized for 77K to 120K could find a market.
    - The convergence Space/Ground Based long lifetime coolers will accelerate (missions are already using such coolers to satisfy specific needs).
  - Science
    - Needs in this domain are not trends but dictated by specific missions. Potential upcoming missions: Cold Mirror and Continuous 50mK.
  - Exploration
    - Miniaturized 77K – 120K coolers will always be needed (detector cooling or sample conservation). Lifetime is not such a driver, but price and Product Assurance is.
  - Telecom
    - Difficult market to break through. Will require miniaturized, efficient and extremely reliable coolers.

Self-Promotion

- If you are interested in Space Cryogenics, do not hesitate to **sign-up for the 6th European Space Cryogenics Workshop!**
- It will take place from the **30/11/15 to the 02/12/15 in ESTEC (Noordwijk, NL)**