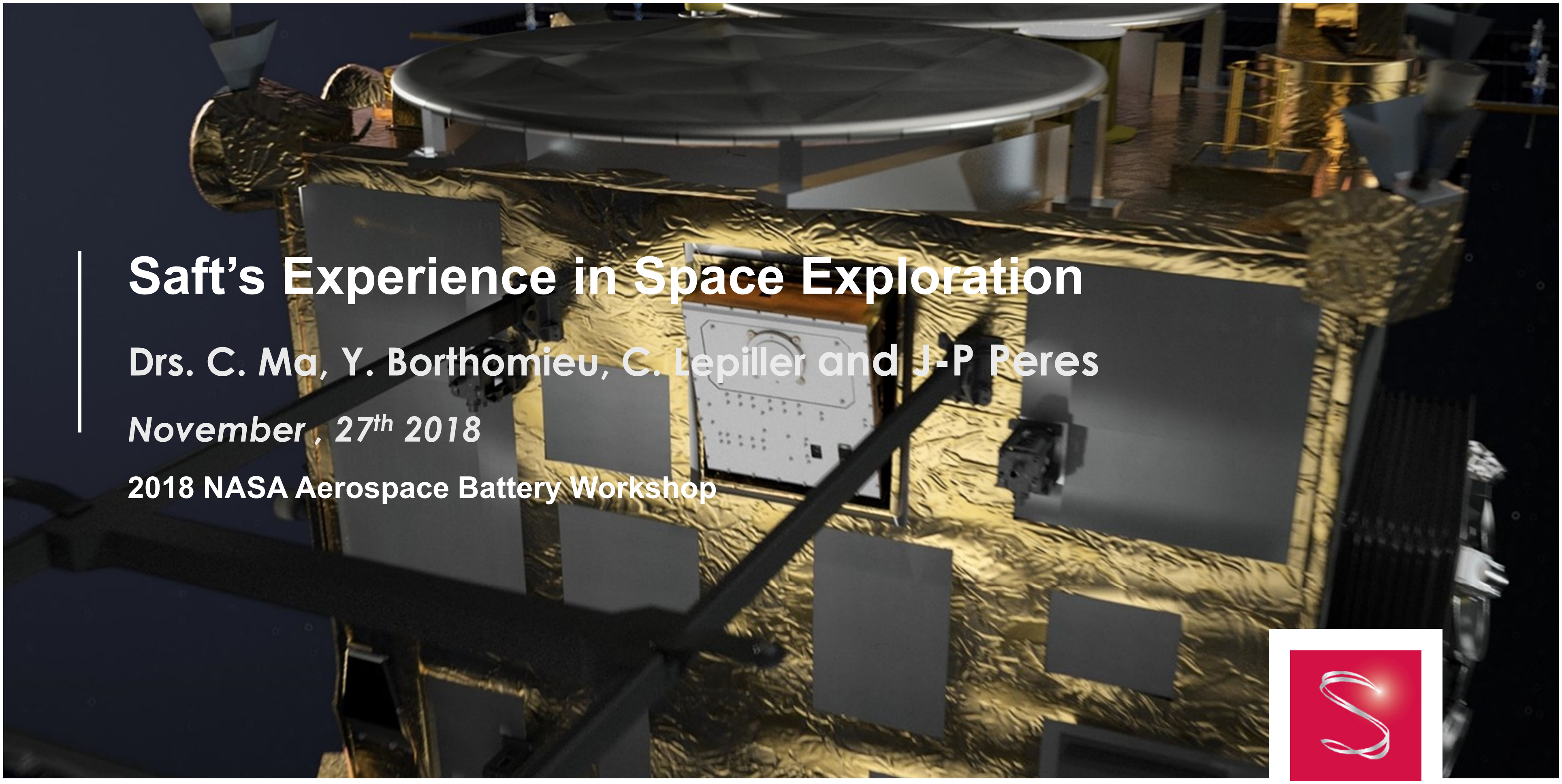


Saft's Experience in Space Exploration

Drs. C. Ma, Y. Borthomieu, C. Lepiller and J-P Peres

November , 27th 2018

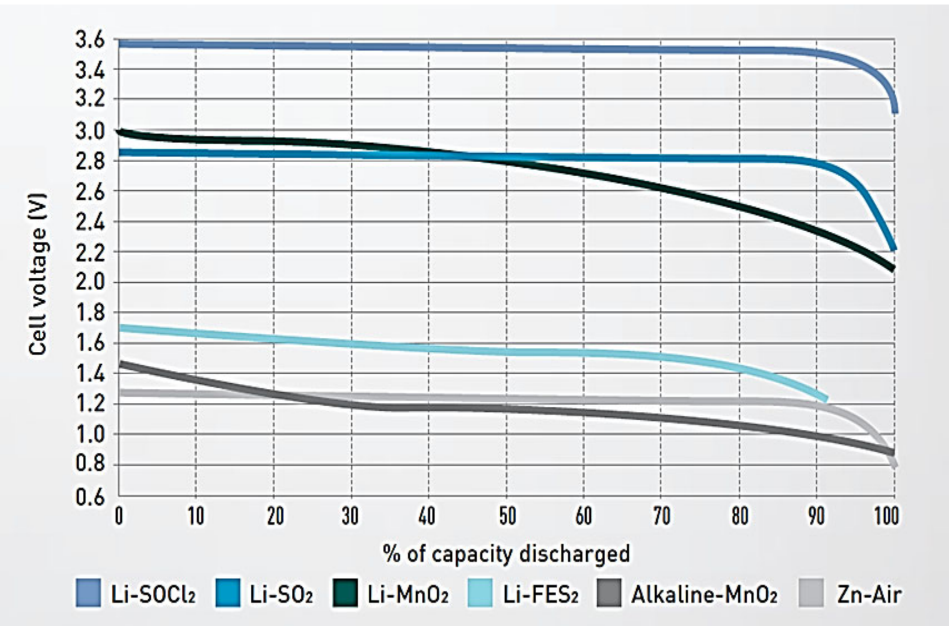
2018 NASA Aerospace Battery Workshop

Agenda

- Primary cell performances
- Mars Pathfinder
- SMART 1
- Philae
- Mascot
- Mars Express

Overview of Lithium primary technologies 1/2

Discharge profiles of primary cells

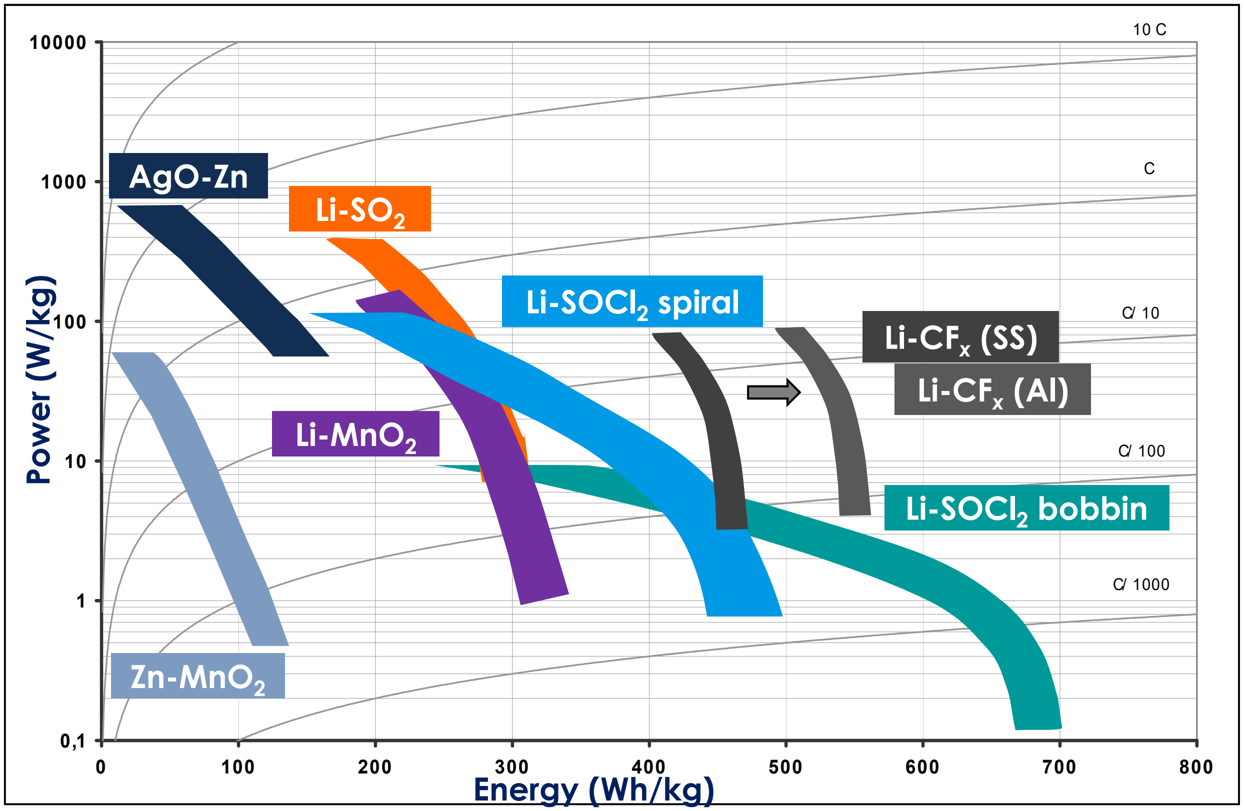


Advantages of Li-$SOCl_2$ batteries

- High energy density
- Low to medium power
- Long operating life
- Extended shelf life
- Wide operating temperature range
- Flat discharge profile

⇨ constant voltage during cell lifetime

Overview of Lithium primary technologies 2/2



2 constructions for Li-SOCl$_2$:

- **Bobbin for high energy up to 700 Wh/kg**
- **Spiral for medium energy up to 450 Wh/kg and power 1-100 W/kg**

2 case materials for Li-CF$_x$:

- **Stainless steel 450 Wh/kg**
- **Aluminium 550 Wh/kg**

Li-CF$_x$ is the best technology to achieve high energies with a spiral construction

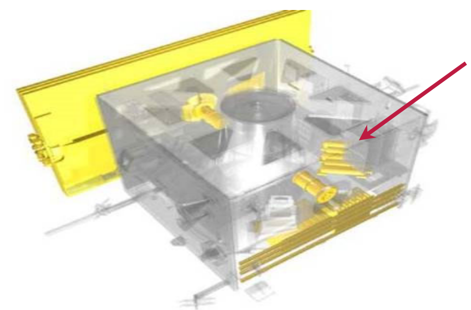
Pathfinder and Sojourner – first landing on Mars Planet using Li-SO_2 battery from Saft Cockeysville

Mars Mission and Critical Flight Termination Battery

- Have delivered 15 flight batteries and over 3000 cells
- Battery configuration: 12S1P
  - LO26SX Cells supplied by Saft plant in Valdese, NC
  - Nominal Capacity: 7.75 Ah
  - Voltage: 26 V – 36 V
- Assembly completed by Saft Cockeysville
  - Cell bussing welded via standard practice
  - PWA with fuses and 38999 connectors integrated in battery
  - Cells potted in place with epoxy
- Acceptance testing includes
  - Battery acceptance test: thermal cycling and vibration with pulse testing
  - Cell lot age surveillance: thermal cycling & vibration with pulse tests, capacity and impedance
- Powered Pathfinder and Soujourner Martian rovers in 1997.

SMART 1 : first EPS and first Li-Ion on Moon

- SMART-1was the first of the Small Missions for Advanced Research and technology (SMART), element of ESA's Horizons 2000 plan for scientific projects testing key technologies for future missions.
- The mission of SMART-1 was the flight demonstration of Electric Primary propulsion for a scientific lunar orbiting spacecraft delivered in a standard geostationary transfer orbit. It included the Launch and early orbit phase, the Earth escape phase, the Moon capture phase, and the Lunar observation phase.
- SMART1 **was powered with 5 Saft VES140 Li-Ion battery** which was used for the thruster engine electric supply



SMART 1 mission

Incredible journey

- SMART-1 launched 27th September 2003.

- 14 months elliptic route toward Moon…using PPS1350
- 15 novembre 2004 : First Moon Orbit.
- 3 september 2006 : The probe crashed on Moon
- and 54 kg of Xenon were used.

- More than 100 000 electrical cycles
- And the battery behaved perfectly well until the Moon crash in 2006

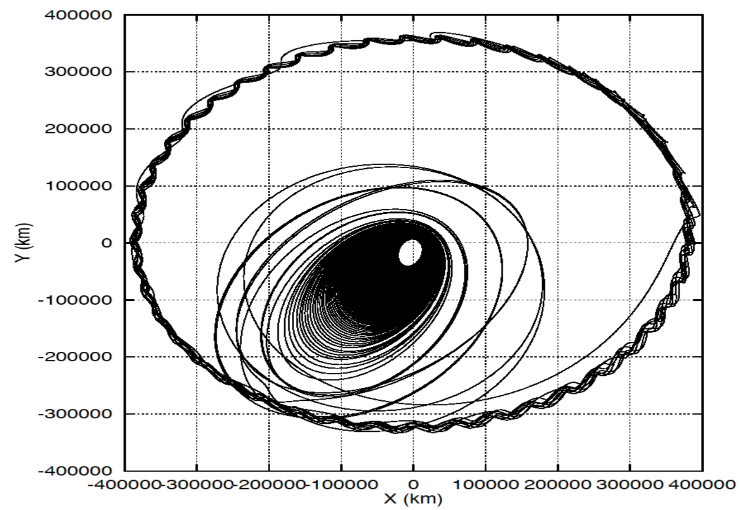


Figure 3.9: SMART-1 reference trajectory: from GTO to end of mission (equator projection)

SMART 1 mission

Small Mission for Advanced Research in Technology-1 (SMART-1) crashed in 2006 after the probe had orbited the moon for three years, recording images.

The Lunar Reconnaissance Orbiter, which is currently orbiting the moon, managed to take photos of the probe's crash site. P. Stooke / B. Foing et al. 2017 / NASA / GSFC / Arizona State University

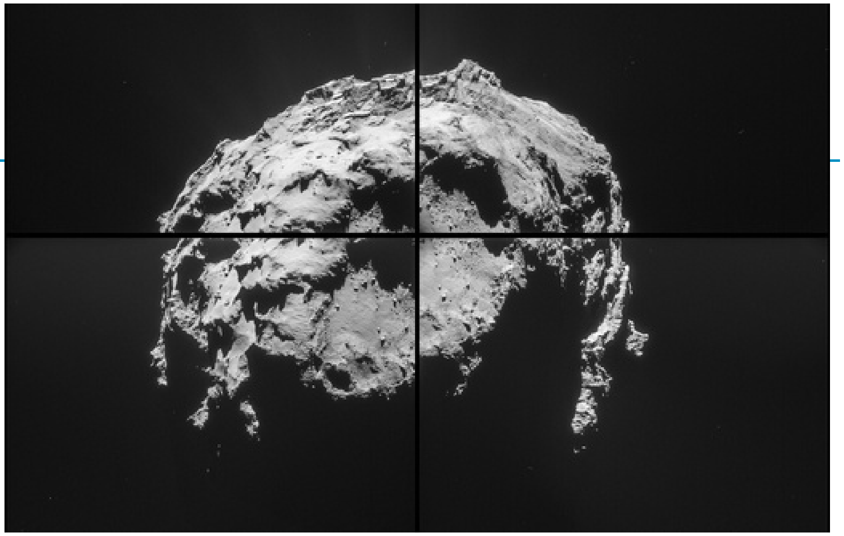
Philae : first landing on a comet (Tchuryomov-Gerasimenko)

- Mission-critical primary lithium battery supplied to the CNES (Centre National d'Etudes Spatiales) for the Philae lander, the key payload of the Rosetta mission under European Space Agency (ESA) responsibility.
- Saft's LSH20 primary lithium battery is part of the 100 kg Philae Lander craft, a key part of the Rosetta mission, ensuring that maximum power is available for the mission-critical operations even after the **10-year journey from Earth performed at -60°C.**
- 3-days successful mission to the 67P/Tchourioumov-Gerasimenko comet providing power for scientific experiments (9 pieces of equipment and comms to ground).

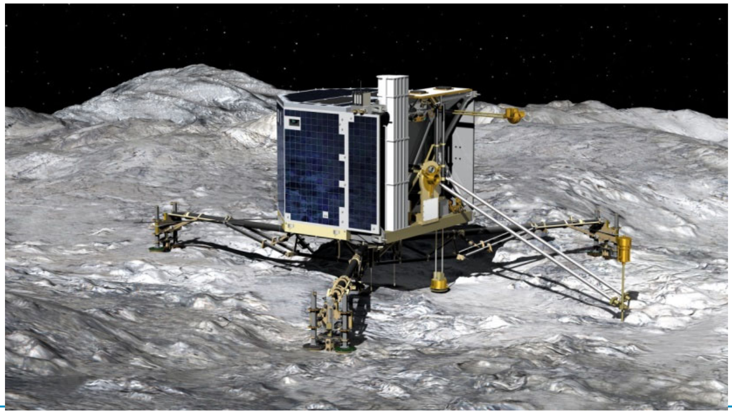
Philae mission

10 Years journey to reach the 67P comet

- ***Rosetta/Philae*** was a space probe built by the European Space Agency
- The mission was launched on 2 March 2004, on a 10-year journey towards comet 67P/Chourioumov-Gerasimenko.
- On 20 January 2014, it 'woke up' and prepared for arrival at the comet in August that year.
- On 12 November, the mission deployed its Philae probe to the comet, the first time in history that such an extraordinary feat was achieved.
- During the next phase of the mission, Rosetta accompanied the comet through perihelion (13 August 2015) until the end of the mission.



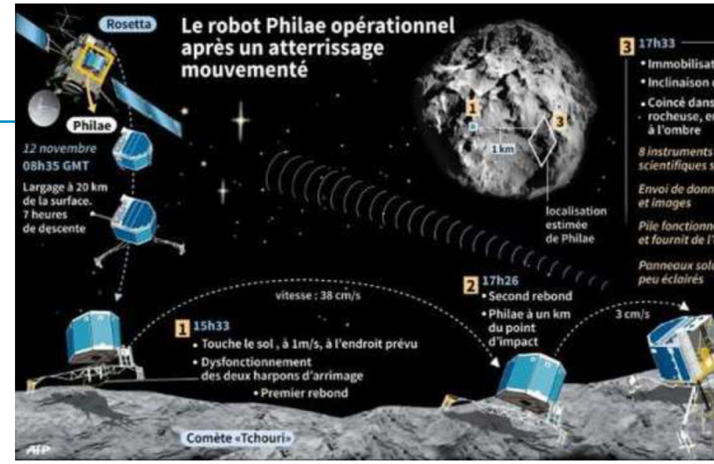
67P/Chourioumov-Gerasimenko, ESA Credits



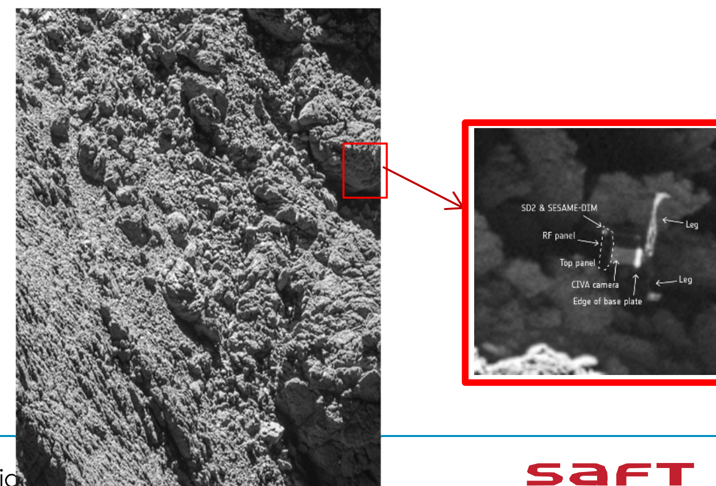
Philae, CNES Credits

Philae: first landing on a comet

- The 12th November, Rosetta dropped Philae probe at 20 km altitude
- 1- After 7 hours descent, first touch down at 1 m/s
- 2- 2nd Rebound at 1km from the first contact
- 3-Stabilization with inclined position in rocky area (solar panels inefficient)
- **A Li-$SOCl_2$ battery provided power to Philae for 65 h**
  - Telecommands
  - Telecommunication, data collection, images
  - 9 equipments for scientific experiments
- On September 5th, 2016, less than a month before the end of the mission, Rosetta's high-resolution camera revealed Philae lander wedged into a dark crack



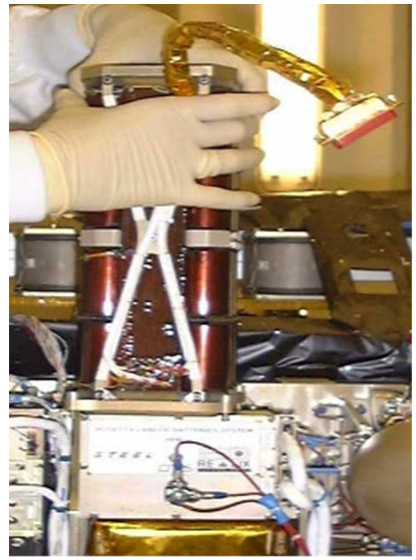
Philae landing, CNES Credits



Space Probe: Philae/Rosetta

Li-$SOCl_2$ attery for Philae: 8S4P based on LSH20 cells:

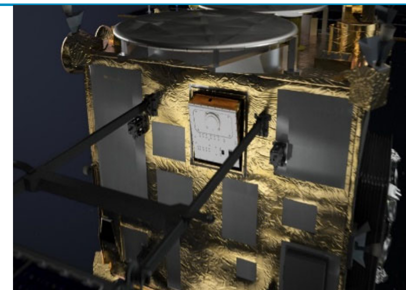
- 10 model batteries tested in parallel to the mission + 1 flight battery
- Characteristics:
  - Weight: 3 kg
  - Volume: l = 110, L = 150, H = 215
  - Capacity: 21 Ah at 5 A discharge
  - Voltage: 32.8 V

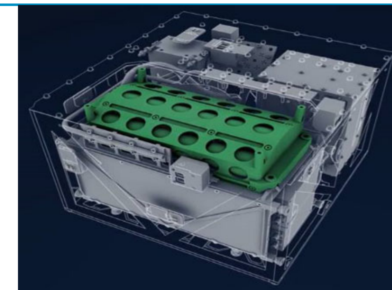


Assembly into lander (July 2003)

Mascot : first landing on an asteroid Ryugu

- ***Hayabusa2*** ("Peregrine falcon-2") is an asteroid sample-return mission operated by the Japanese space agency, JAXA.
- *Hayabusa2* was launched on 3 December 2014 and rendezvoused with near-Earth asteroid 162173 Ryugu on 27 June 2018. It is in the process of surveying the asteroid for a year and a half, departing in December 2019, and returning to Earth in December 2020.
- Hayabusa2 carries multiple science payloads for remote sensing, sampling, and four small rovers that will investigate the asteroid surface to inform the environmental context of the samples collected.
- MASCOT (Mobile Asteroid Surface Scout), is one of the asteroid landers designed to research the origins of the solar system, which relied on a Saft battery system as its power source

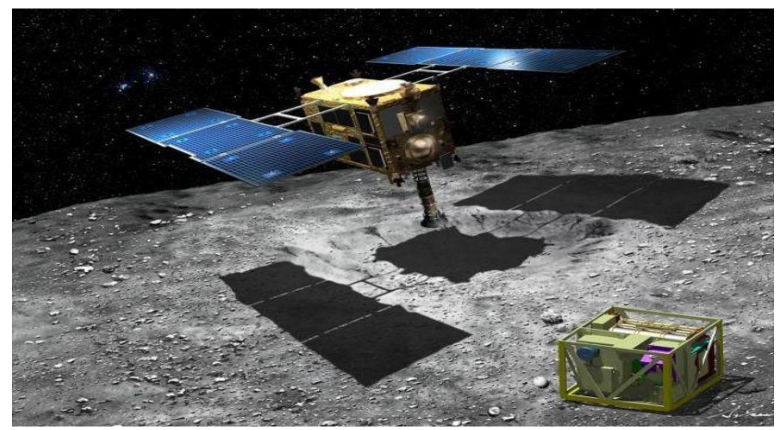




Mascot : first landing on an asteroid Ryugu

Mascot probe is the little brother of Philae and has just finished successfully its mission on Ryugu Asteroid

- CNES /DLR/ Jaxa Program
- Launched in 2014, the probe has landed the asteroid 1999 JU3 (Ryugu) the 3rd of October 2018
- Mascot probe analyze the asteroid ground composition
- Mascot used Saft primary battery system as its power source
- The battery technology is LSH20 in 3S3P configuration with one flight battery
- The battery ensured that the mission was a great achievement as it provided 16 hours of data to asteroid researchers, a duration that was previously inconceivable for a craft with such sophisticated onboard systems



Space Probe: 4M Probe from LuxSpace

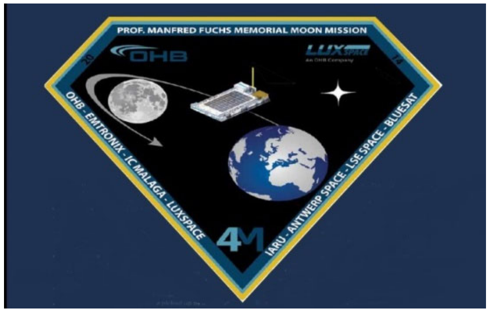
– Lunar probe mission Chang 5T1 launched in 2014 with Long Marche

– 28 LSH20 HTS in series for 6 Weeks long duration mission in cold conditions

– 1 Flight model delivered

– C/50 discharge

– Mission a success with more than 438 hours of functioning at -20°C



EXOMARS Rover

- The 2020 mission will land a Russian platform and a European rover on Mars.
- Saft batteries will power the platform and the rover
- The platform will carry Russian and European instruments that will acquire measurements of the planet's environment for one Mars year (687 Earth days),
- the 310-kg rover will have 9 scientific instruments to study the soil and subsoil.
- Able to drill down to a depth of 2 metres, this rover will collect and analyse samples that have not been exposed to the radiation and oxidizers that would otherwise destroy organic materials.

© Thales Alenia Space/Master Image Programmes.

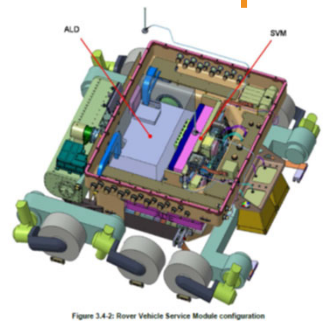
MP-Xtd long life & robustness …

Under qualification for 2020 Exomars Rover mission

AIRBUS DEFENCE & SPACE

esa

Extreme temperatures mission



MP-Xtd under qualification for Exomars 2020

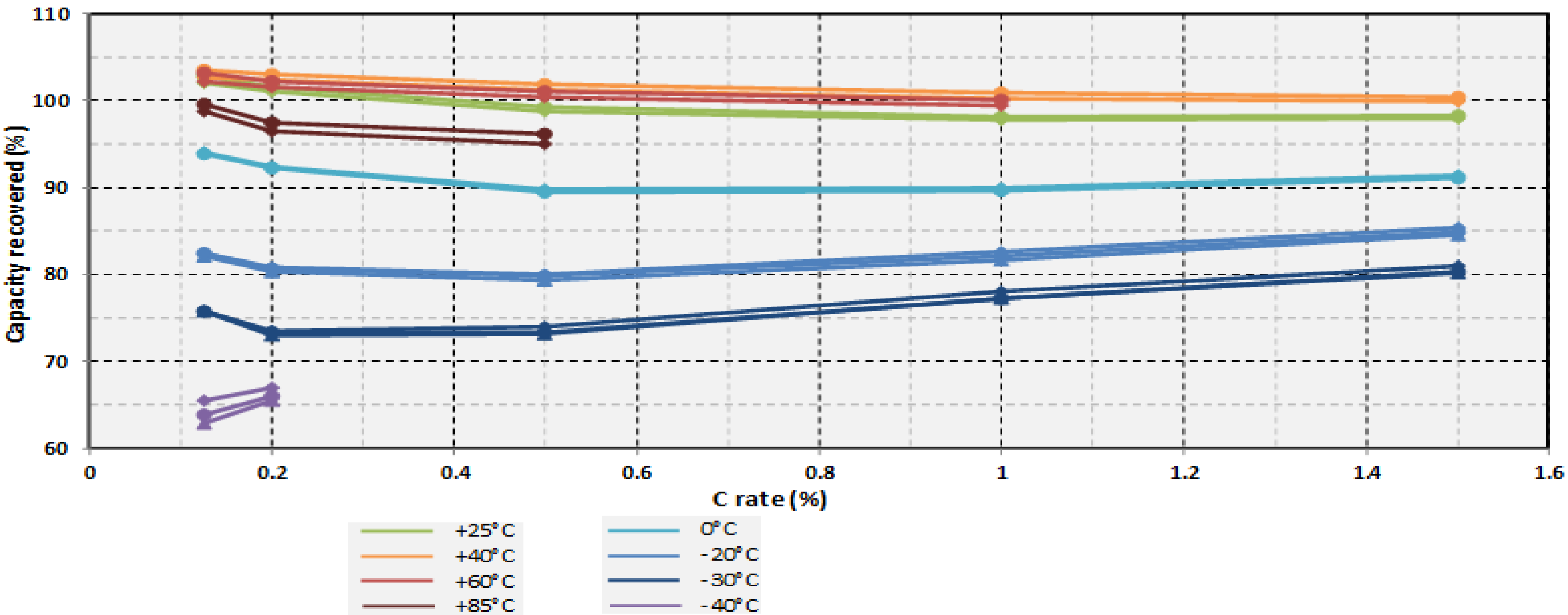
→ EXOMARS mission :
1/ 15 months at +20°C
2/ 9 months at +50°C
3/ Cruise : 9 months (+20°C/+40°C)
4/ Mission : 2 years 220 cycles at -20°C

7S8P MP176065 XTD

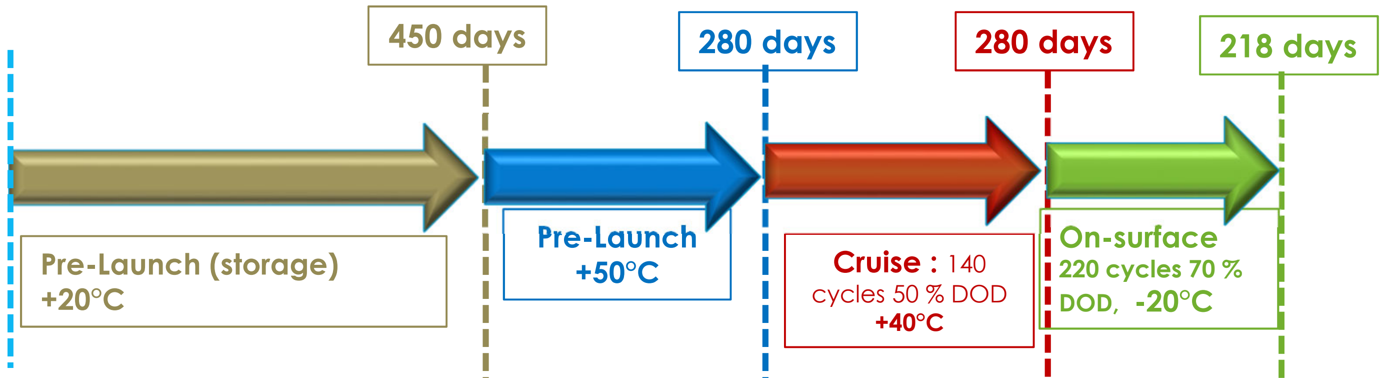
saft

MP Xtd Performances :

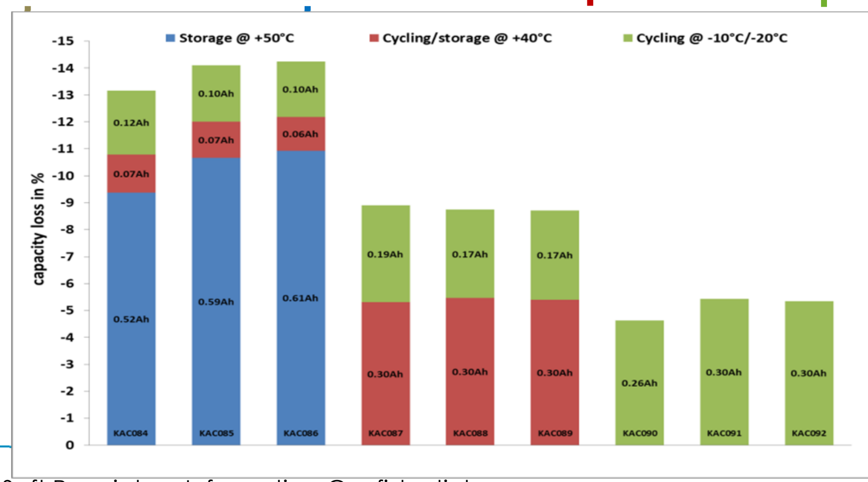
Capacity at different rates and temperatures



Exomars mission phases



– **Cell Energy Evolution**



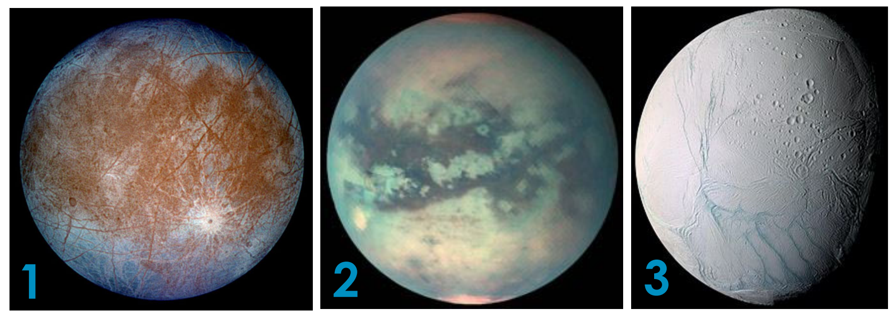
What's next for deep space exploration?

New frontiers in Solar system are moons of outer planets called the « Ocean worlds »

(1) Europa, moon of Jupiter

(2) Titan and (3) Enceladus, moons of Saturn

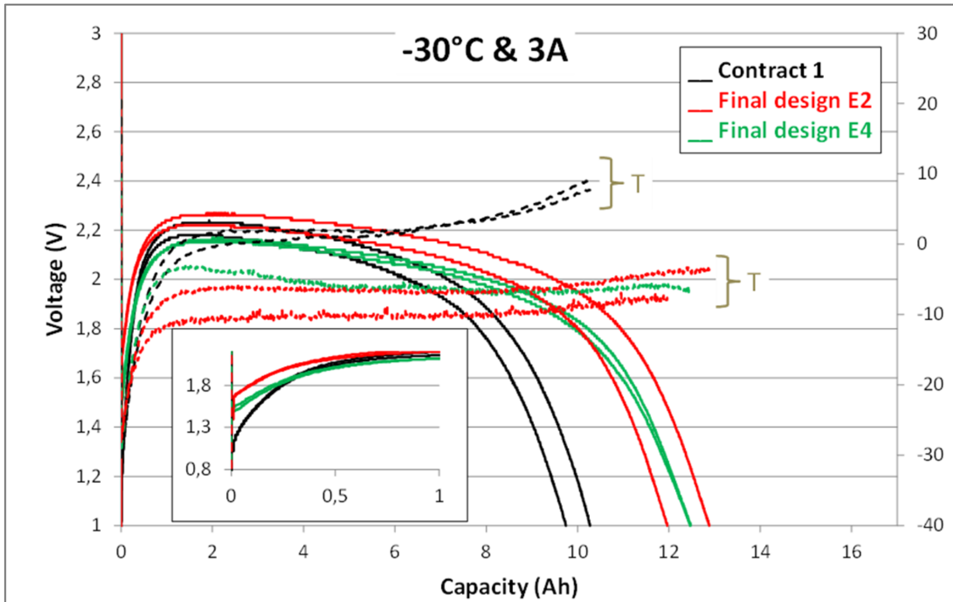
For a surface mission to assess habitablity, bio-signatures and even life, main constraint lies in high energy levels required to power the lander for several weeks at moderate to low temperatures down to -40°C after a long journey from Earth ⇨ **Primary source of > 700 Wh/kg**

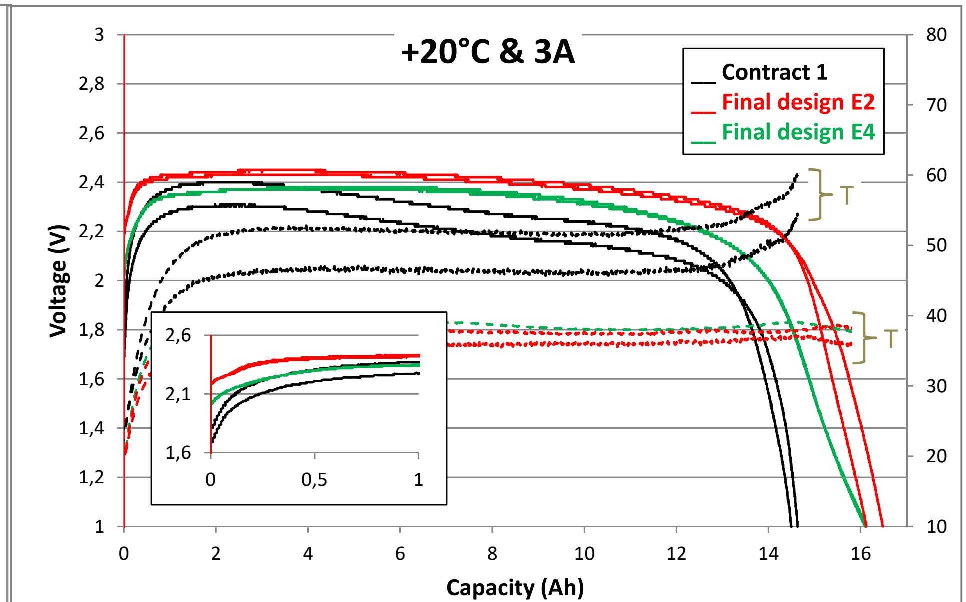


– **Li-CF_x takes advantage of existing Li primary and Li-ion technological features:**
- Long and thin ink-coated cathode like Li-ion based on Cf_x material/conductive carbon/polymeric binder
- Long lithium metal anode with metal current collector like spiral Li-$SOCl_2$ but thinner
- Electrolyte based on organic solvents like Li-ion
- Robust mechanical housing like Li-ion and Li-$SOCl_2$
- Very low self-discharge rate like Li-$SOCl_2$ with no passivation in storage due to stable SEI like Li-ion

Development of high energy/high power Li-CF_x cells at Saft

D-size / SS mechanical housing / Several iterations of internal design





- Great improvements have been achieved on capacity/power at low T°, cell self-heating and initial low voltage
- Next step would be to optimize aluminium-based hard case to increase energy level further


Merci
Vielen Dank
Dekuji
תודה, תודה לך!
Thank you
谢谢
Tack