ELECTRICAL POWER SUB-SYSTEM

PRESENTED BY : NICOLAS CHAPUIS

SLIDES ORIGINALLY WRITTEN BY: VINCENT LEMPEREUR

Date: 16/11/2022
Ref: SY-0071-01-00-Formation_EPS.pptx
Template: 83230347-DOC-TAS-EN-006

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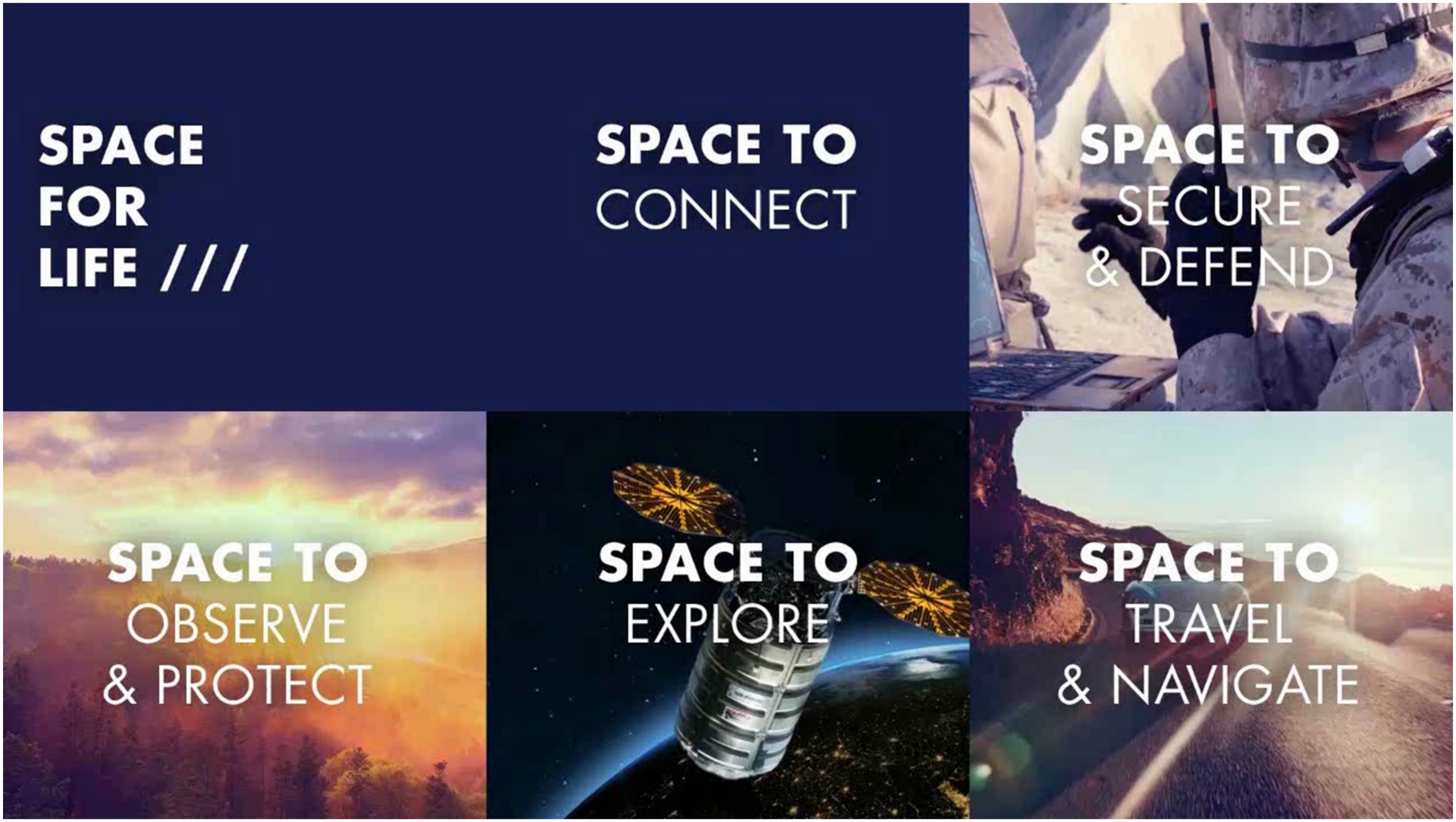
ThalesAlenia Space


SPACE FOR LIFE ///
SPACE TO CONNECT
SPACE TO SECURE & DEFEND
SPACE TO OBSERVE & PROTECT
SPACE TO EXPLORE
SPACE TO TRAVEL & NAVIGATE

THALES ALENIA SPACE IN 2021

2,15
BN € SALES

8,900
EMPLOYEES

18 SITES
WORLDWIDE

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ThalesAlenia Space


ARTEMIS
HUMANITY'S RETURN TO THE MOON
EUROPE'S EARTH OBSERVATION PROGRAMME, LOOKING AT OUR PLANET & ITS ENVIRONMENT
Copernicus
Europe's eyes on Earth
SWOT
SURFACE WATER & OCEAN TOPOGRAPHY
GLOBAL MEASUREMENT OF SURFACE WATER HEIGHT FOR LAKES, RIVERS AND FLOOD ZONES, AS WELL AS DEEP AND COASTAL OCEANS
BLACKSKY
THE FIRST GLOBAL INTELLIGENCE PLATFORM DELIVERING RELEVANT INFORMATION IN REAL TIME


SPACE
FOR LIFE
ThalesAlenia
a Thales / Leonardo company
Space

THALES ALENIA SPACE IN BELGIUM

A world leader in power electronics for satellites and launchers

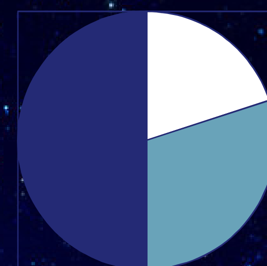
More than 750

3 sites

Charleroi
Leuven
Hasselt

Belgian leader in the space sector

>60 years of experience in Space



~250 units / year

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NEW SPACE IN THALES ALENIA SPACE IN BELGIUM

Software-defined **Long term sustainability**

Electrical propulsion leader

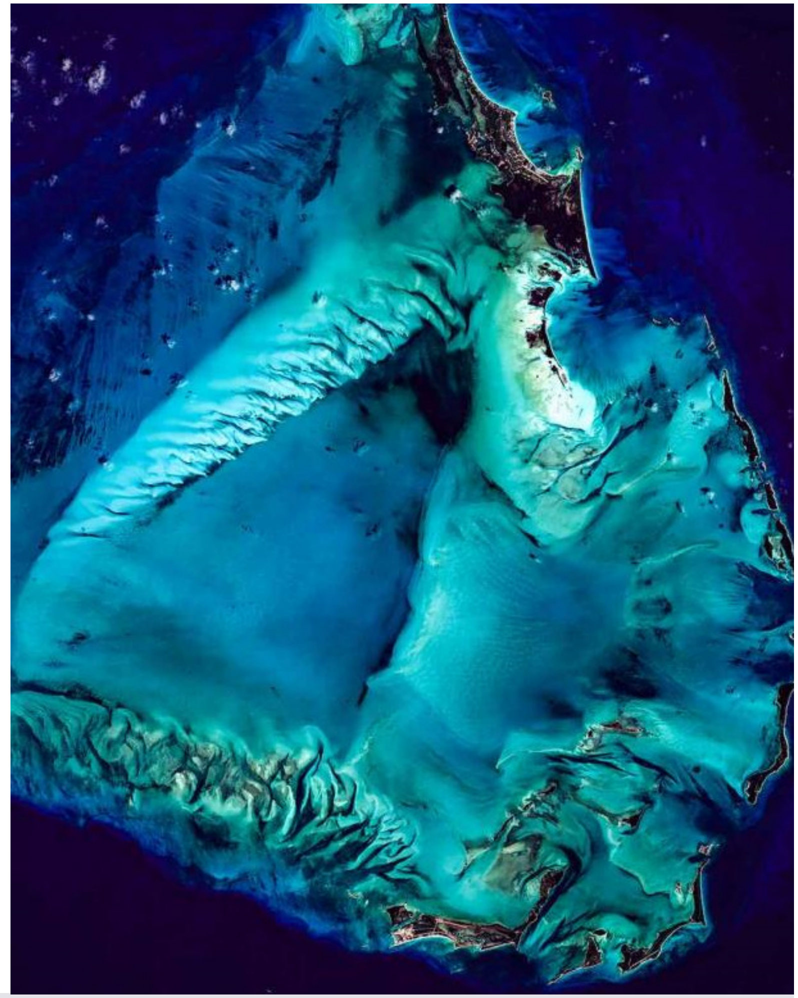
Federate High power/High voltage integration

Automotive components **Micro-solutions**

Agile Techno-push **New ways of working**

System approach Automatised manufacturing **Partnership**

Open-innovation Explore



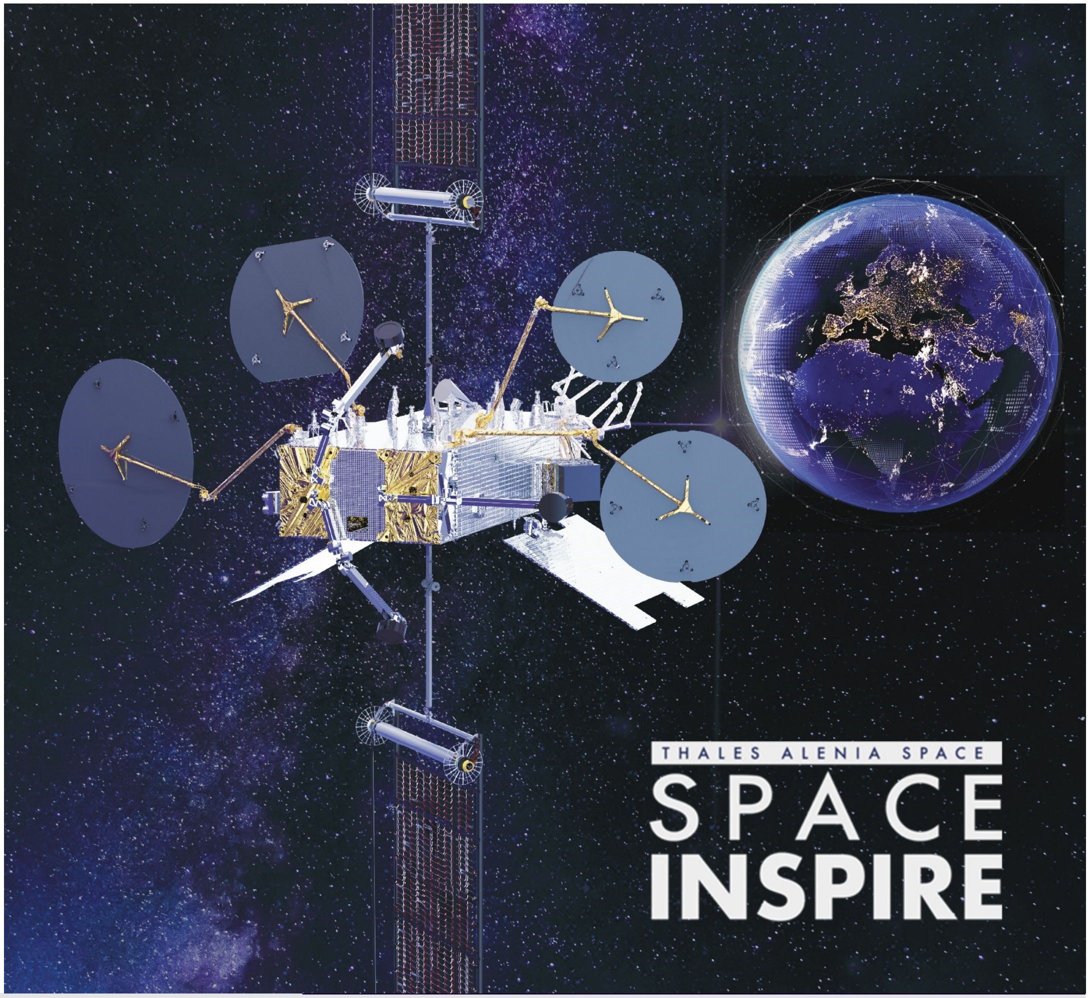
A Fully Flexible Software-Defined Satellite

Full Reconfiguration in Orbit

Unrivaled Mission Performances

Extensive Hosting Capacity

Smart Operations



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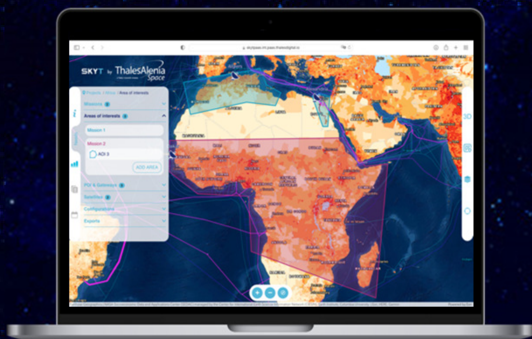
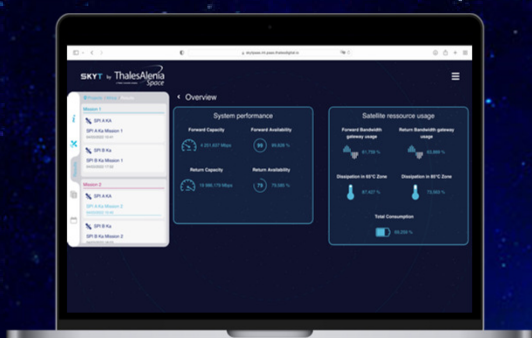


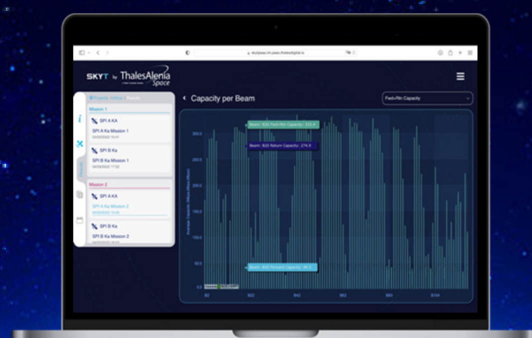
Create Areas of Interests

Configure your satellite

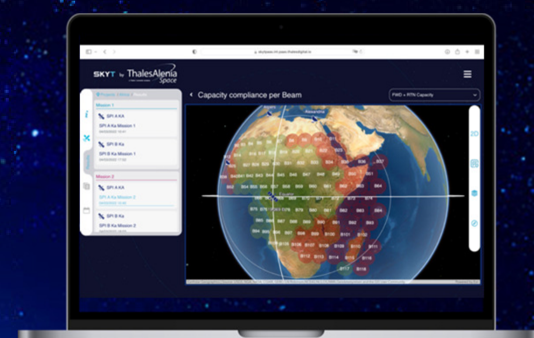
Configure your coverage



Visualise the system budget



Visualise results with barcharts

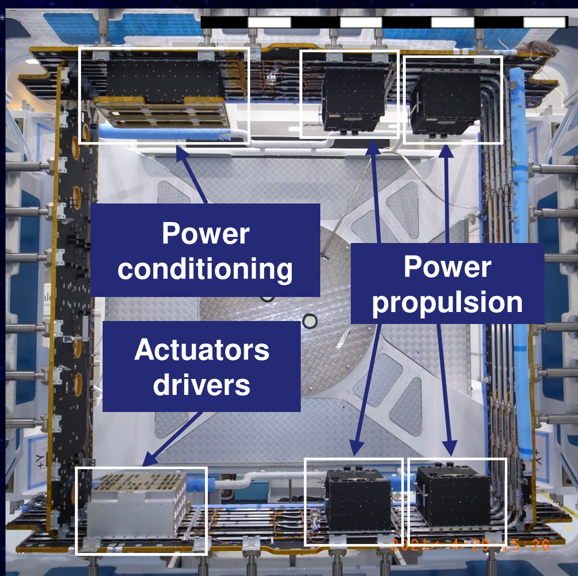


Visualise results in 2D/3D Maps

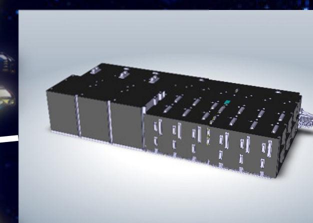
OUR SOLUTIONS IN BELGIUM

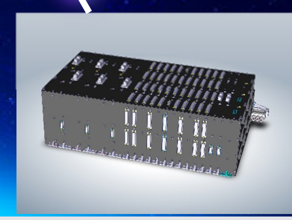
A COMPLETE NEW GENERATION FOR **AVIONICS SUBSYSTEM**

2020 Satellite



Space Inspire





same scale

- More power
- More interfaces
- More functions
- More flexible
- Less mass
- Automotive components
- **Much** more faster to build
- **Cost** efficiency

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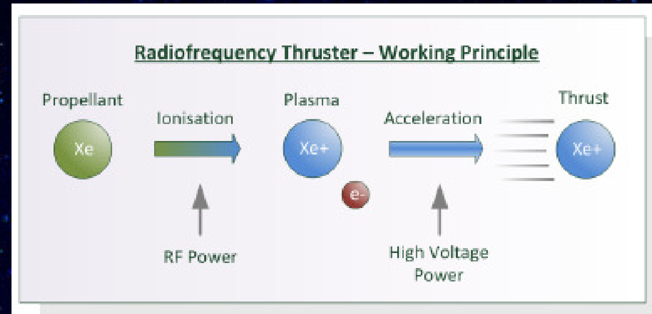
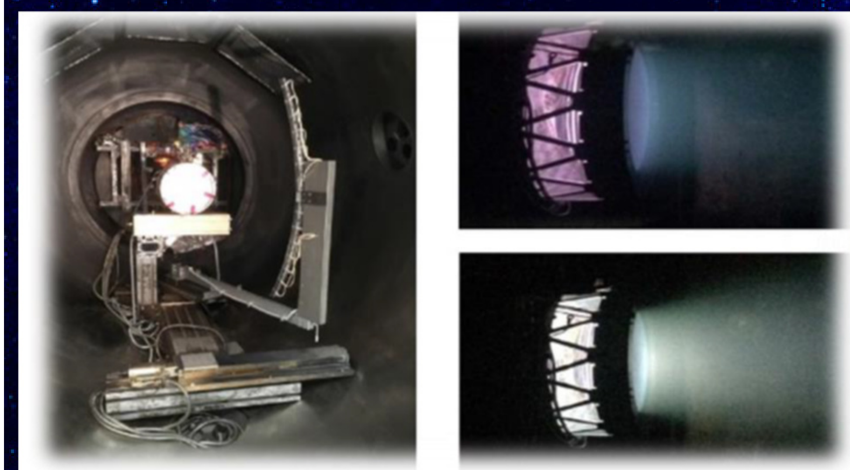
LEADER IN ELECTRICAL PROPULSION

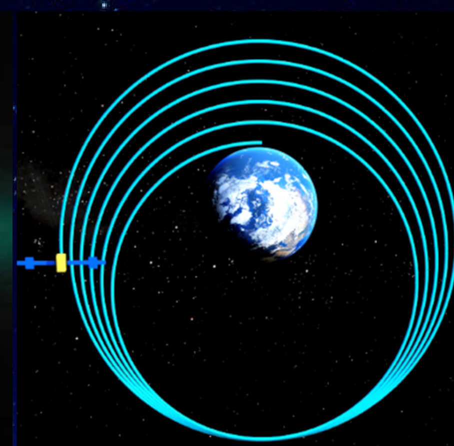
From **Chemical** propulsion to full **Electrical** propulsion
with **G**rid **I**on **E**ngine technology

We provide **power for thrusters**

Orbit raising | Station keeping





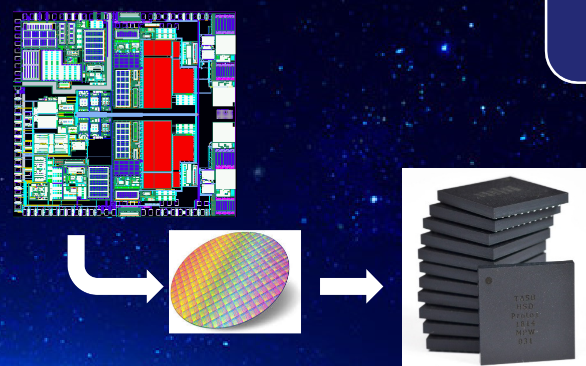


SOFTWARE INSIDE & MICRO-SOLUTION

Proprietary micro-controllers
in all products
with **adapted software solutions**

Software defined solutions – Flexibility – Live Reconfiguration

Strong **partnerships** with leading-edge companies



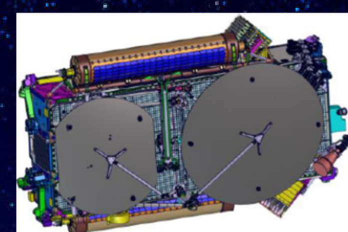
Proprietary GaN driver
for all power switches

High performance – High integration

OUR SOLUTION
A COMPLETE NEW GENERATION FOR **SOLAR GENERATOR**

Flexible Solar Array

Smaller footprint in launcher
for **bigger solar cells surface**



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AND OTHER NEW TECHNOLOGIES FOR HIGH VOLTAGE AND HIGH POWER SOLUTIONS…

- Break-through technologies developed since 5 to 10 years, becoming mature now
- Matured in fruitful partnerships with Belgian and European SMEs, in other industries
- Successfully combining « open innovation » in a « fierce competition » environment

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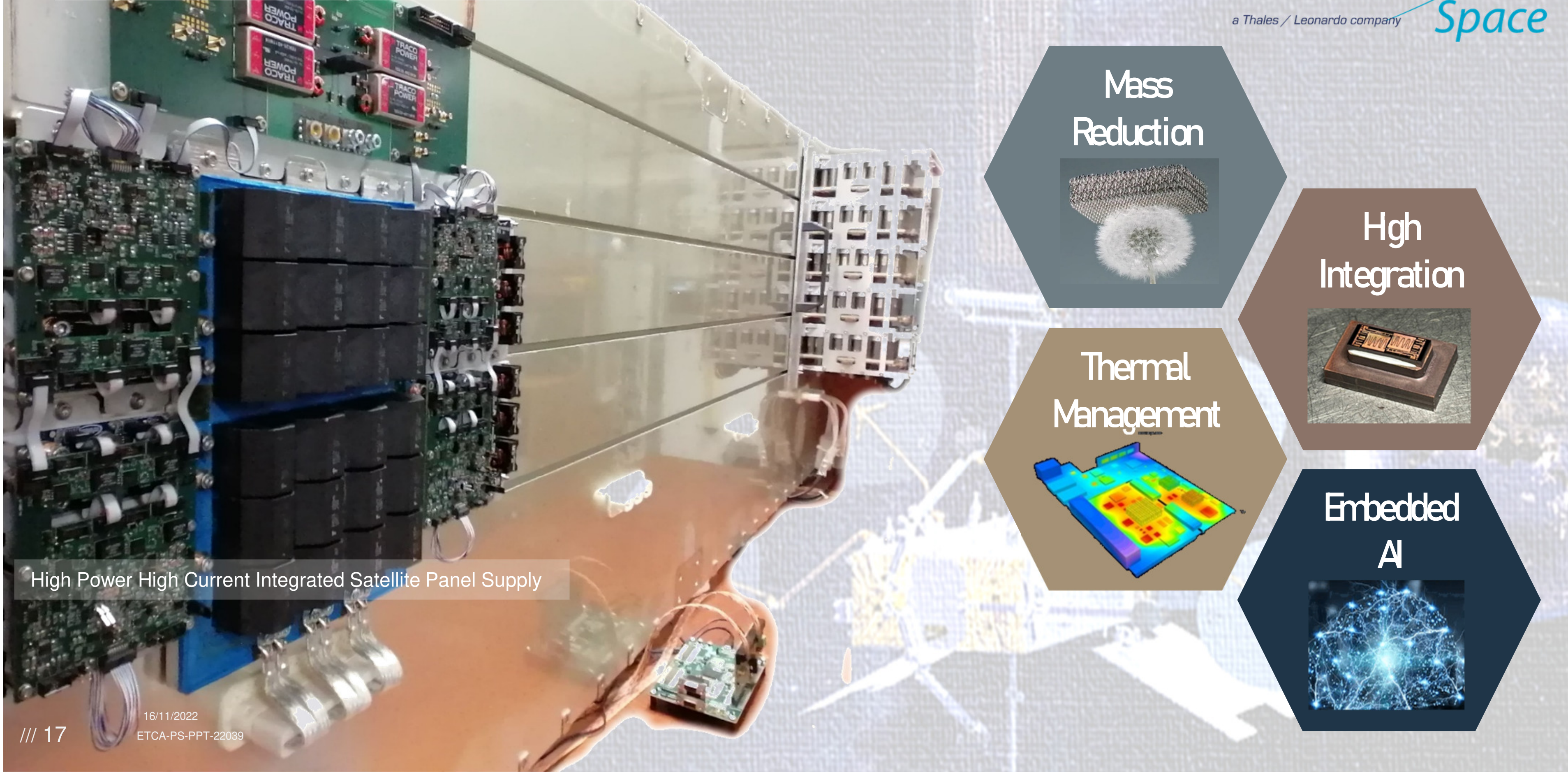
Current Innovation Main Challenges

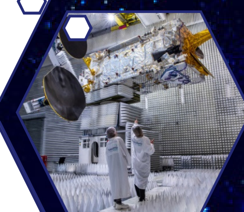


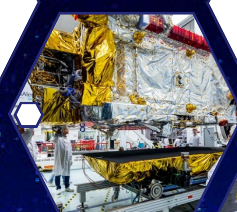
High Power High Current Integrated Satellite Panel Supply

WE ARE HIRING ! JOIN US, APPLY NOW !

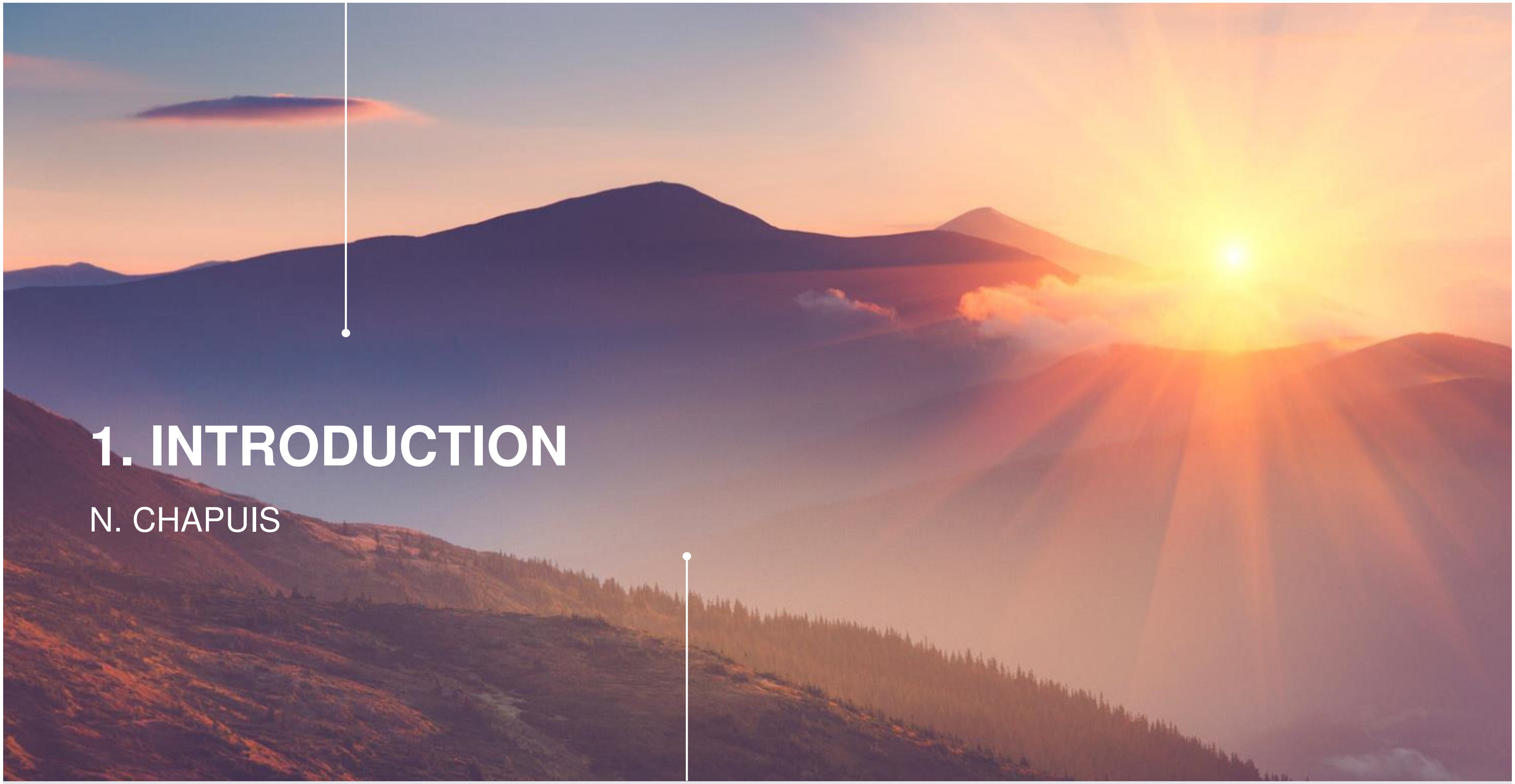
>60 open positions in Belgium

- Electronics engineering-satellite-launcher-aerospace
- Planner
- Technical managers-power & analogue electronics
- Electronic design engineers
- IVVQ engineers
- Projet managers
- Test engineers for production equipments
- Technicians in electronics for IVVQ





Check Now - https://emploi.thalesgroup.com/



1. INTRODUCTION

N. CHAPUIS

INTRODUCTION

/// Training

/ GRADUATED AS ELECTRONICS ENGINEER FROM ECAM IN BRUSSELS

/// Professional career in TAS-Belgium at Charleroi

- Specialized in hardware design in Electronics for satellite platform equipments

/ ELECTRONIC DESIGNER

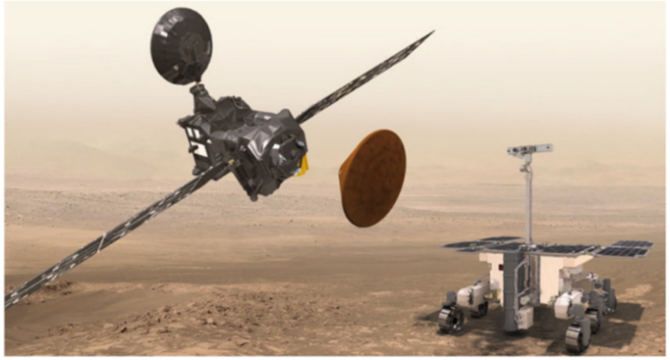
- Power conditioning and distribution (PCU/PCDU/SDIU) for low and medium power satellites (1kW to 6kW).

/ TECHNICAL MANAGER

- PCDU : during all V-cycle developments for scientific satellites (e.g. ESA Mars exploration Exomars carrier module).

/ ENGINEERING HW DESIGN TEAM MANAGER

- Electrical Power Subsystem: PCU/PCDU/SDIU
- Propulsion sub-system: power supplies for Hall Effect Thrusters (PPU).
- Launchers Ariane-6: power supplies for nozzles orientation



Source: Le Temps

INTRODUCTION / EPS GENERAL INFORMATION

///A satellite is made of…

/// P/F (Platform)

- **MECHANICAL & THERMAL STRUCTURE**
- **ELECTRICAL SYSTEM, AVIONIC, PROPULSION**
- **ON-BOARD COMPUTER, SOFTWARE, REMOTE CONTROL**
- **ENERGY SOURCES: SOLAR, BATTERIES, FUEL**

/// P/L (Payload)

- **ANTENNAS, TWTA, …**
- **CAMERA, ALTIMETER, RADAR, DETECTORS, …**
- **CLOCK, SCIENTIFIC INSTRUMENTS,…**

INTRODUCTION / EPS GENERAL INFORMATION

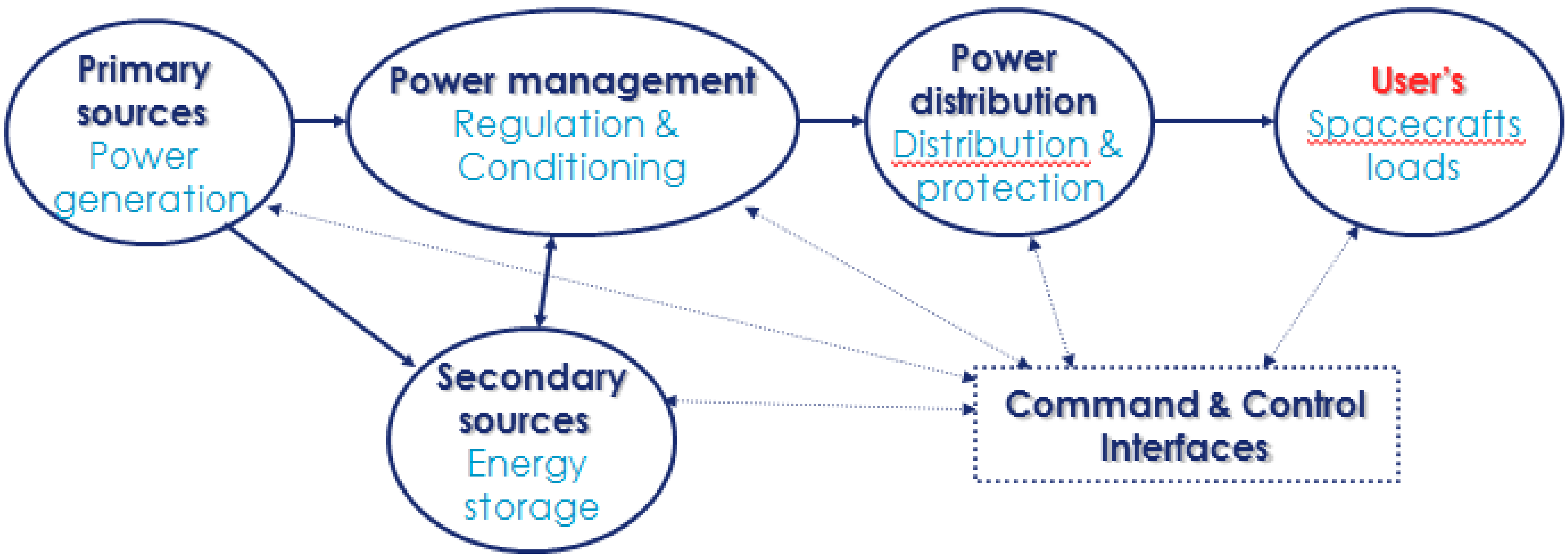
/// Satellite Electrical Power Subsystem (EPS) shall

- PROVIDE TO EACH S/C PLATFORM AND PAYLOAD EQUIPMENT THE REQUIRED POWER OVER THE WHOLE MISSION
- HAVE ENERGY CAPACITY TO POWER EQUIPMENTS IN CASE OF ORBITAL NIGHT PHASES, TRANSIENT PHASES AND PEAK POWER DEMAND
- AUTONOMOUSLY MANAGE THE AVAILABLE POWER IN ORDER TO PROVIDE THE EQUIPMENT'S POWER AND TO CHARGE THE BATTERY
- FULFILL SOME DISTRIBUTION REQUIREMENTS PROVIDING ON/OFF PROTECTED POWER LINES, HEATER SUPPLY (FOR S/C THERMAL CONTROL NEEDS) AND COMMANDING PYRO LINES (E.G. SA AND ANTENNA DEPLOYMENT)

NOTE: POWER SYSTEM FAILURE MEANS THE LOSS OF MISSION

INTRODUCTION / EPS GENERAL INFORMATION

/// General functional block diagram



INTRODUCTION / EPS GENERAL INFORMATION

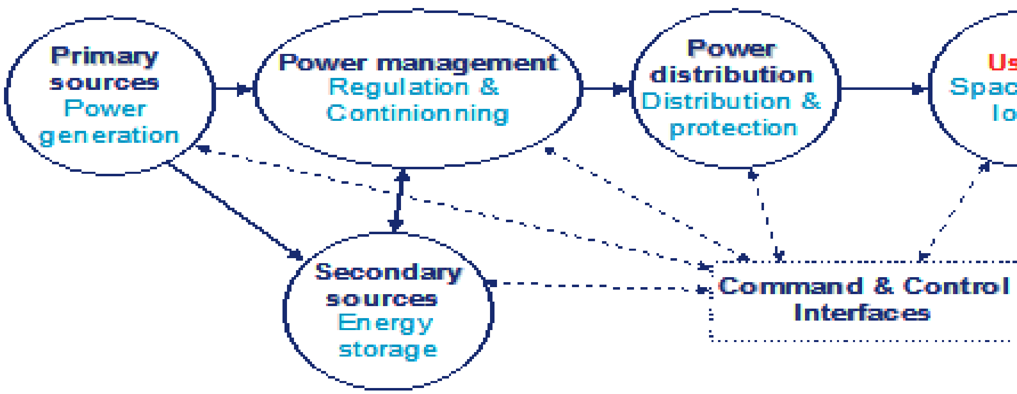
/// Functions (1)

/ POWER GENERATION

- The power is generated from different sources (`fuel') or combination of them: the Solar radiant energy (solar cells via photovoltaic effect), Chemical (piles – fuel cells), nuclear (RTG), mechanical (reaction wheels), …
- Primary sources convert `fuel' into electrical power

/ ENERGY STORAGE

- The energy is generally stored under an electro-mechanical form and retrieved under an electrical form
- The storage of the energy is done by a secondary source, when the primary system's energy is not available or insufficient



INTRODUCTION / EPS GENERAL INFORMATION

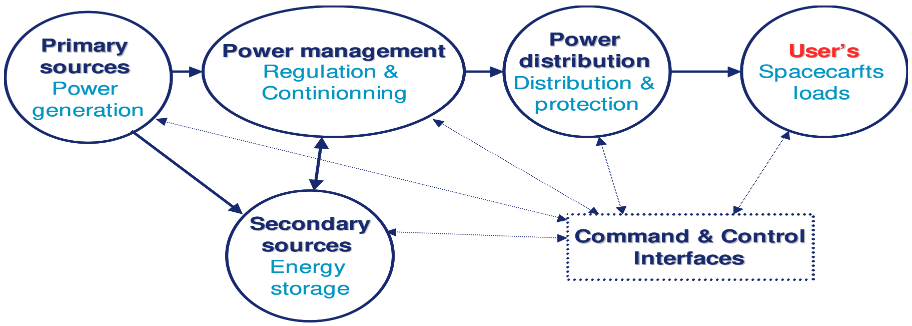
/// Functions (2)

/ CONDITIONING AND REGULATION

- This function covers everything which is required to adapt the primary sources to the need of users `equipment'
- Regulators
  - To maintain a constant voltage or current
  - Regulation of battery charge and discharge, regulation of the commutation of solar generator sections

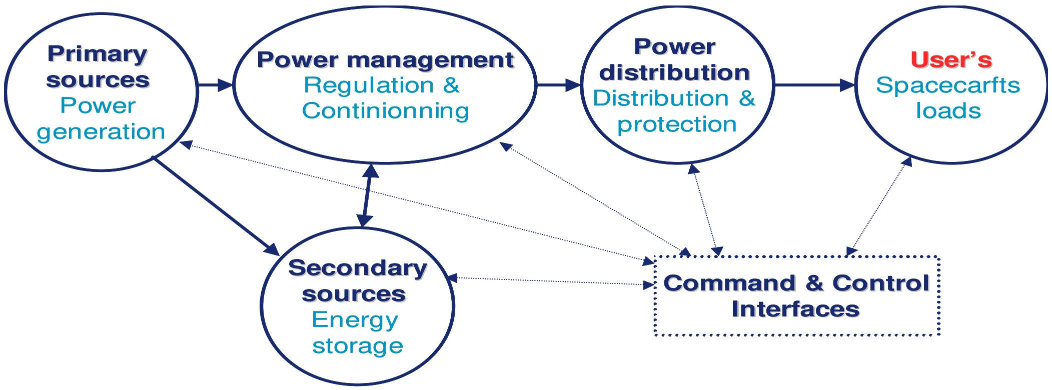
/ DISTRIBUTION

- To distribute the conditioned power to users
- DC/DC voltage converters
- ON/OFF switches
- Does not include the harness



INTRODUCTION / EPS GENERAL INFORMATION

/// Functions (3)



/ PROTECTION
- To avoid a propagation of failures or any Single Point Failure
- Protections against short-circuits
  - Fuses
  - Circuit breakers

/ CONTROL
- Observing parameters
  - Current, voltages, temperatures, status, …
- Information are transmitted to the Ground by telemetry for mid-term and long-term monitoring
- Information are transmitted to the On-Board Computer for real-time monitoring

/ COMMAND
- Configuration setting (nominal, safety, recovery, …)
- Parameters
- ON/OFF

INTRODUCTION / EPS GENERAL INFORMATION
SYSTEM DRIVERS / SYNTHESIS

/// The orbit

- **LOW EARTH ORBIT (LEO), GEOSTATIONARY (GEO), MEAN EARTH ORBIT (MEO), SUN SYNCHRONOUS ORBIT (SSO), SUN CENTRIC (INTERPLANETARY), …**

/// The mission

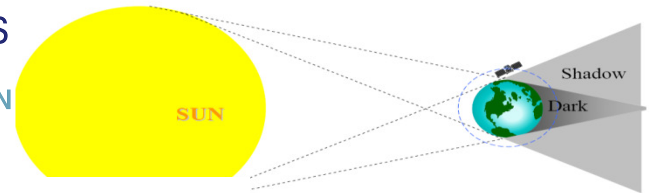
- **(Life) duration**
- **Energy budget**
  - Mission profiles
  - Payload needs
  - Max and Mean power
  - Orientation (attitude) of the satellite
- **Reliability requirements**

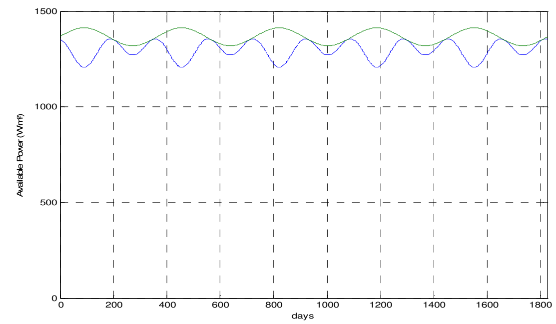
INTRODUCTION / EPS GENERAL INFORMATION
SYSTEM DRIVERS / ORBITS

///LEO (Low Earth Orbit) / Scientific applications

- **ORBIT**
  - Altitude: between 350 and 1000 km
  - Duration:~2 hours
  - Low sensitivity to radiations
- **ECLIPSES**
  - High variability versus the orbit selection
  - Up to 40 % of eclipse duration
  - Thousands of cycles along mission duration

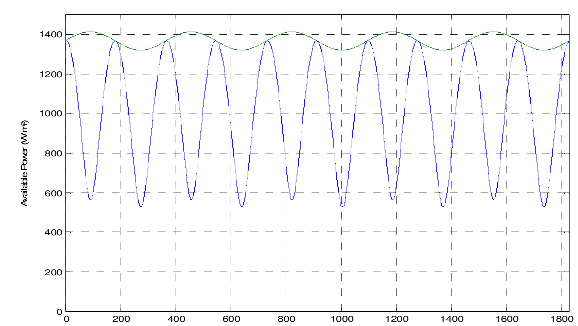
Ø SUN

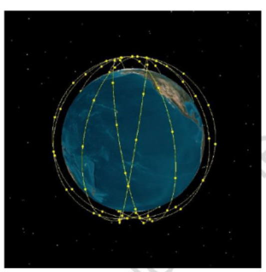




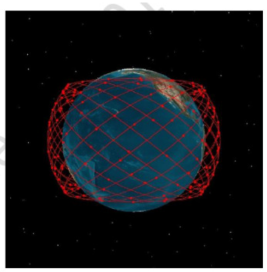
SA flux (sun-synchronous orbit)
- > Min SA flux = 1220 W

SA flux (polar orbit)
- > Min SA flux = 520 W

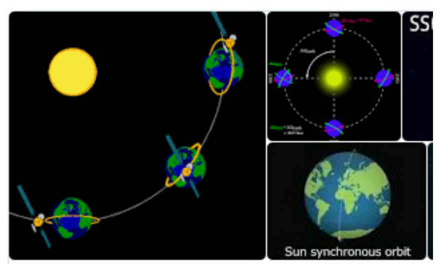




Polar Orbit



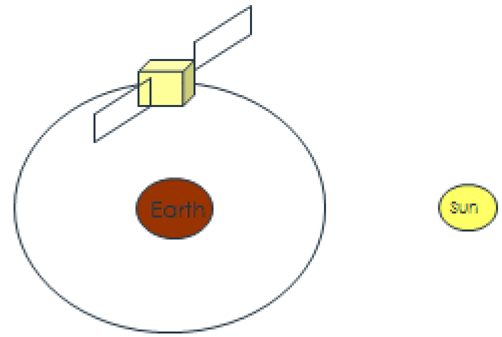
Inclined Orbit



Sun-synchronous orbit

Source: Wikipedia

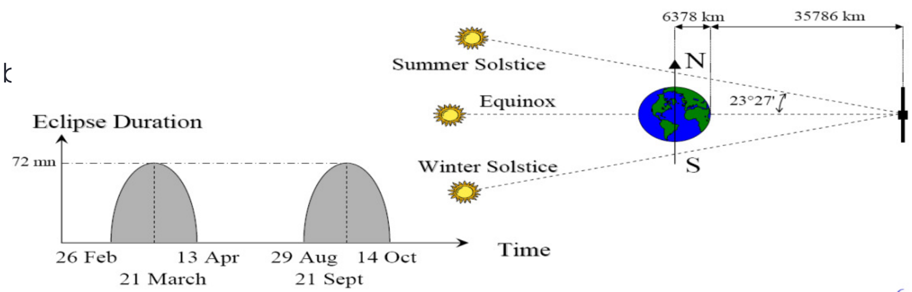
INTRODUCTION / EPS GENERAL INFORMATION
SYSTEM DRIVERS / ORBITS
///GEO (Geostationary Orbit): Telecom application



- **ORBIT**
  - Type: Circular
  - Altitude: 35786 km
  - Duration: 24 hours
  - Medium sensitivity to radiations
- **ECLIPSES**
  - Less than 1% of mission duration
  - Only during equinoctial periods
  - From few to 72 minutes max

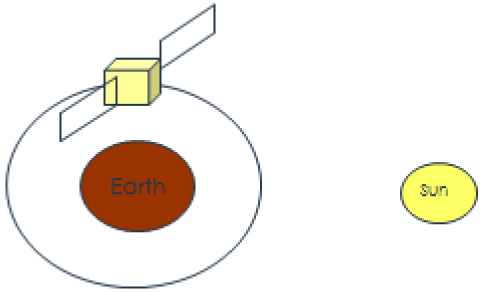
… DURING LIFETIME … BUT UP TO 6 MONTHS ELECTRICAL ORBIT RAISING WITH ELECTRICAL PROPULSION DRASTICALLY MODIFY THE SITUATION

- Increased number of longer eclipses
  - Thermal cycling more severe
  - Ratio charge / discharge impacted
  - Higher battery DoD (especially if thrust has to k
- More stringent radiative environment

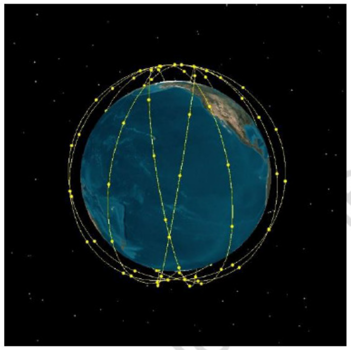


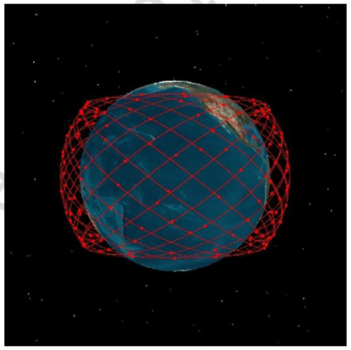
- **MISSION DURATION**
  - 15 years
- **EXAMPLE(S): SPACEBUS BASED SATELLITES, …**

///MEO (Medium Earth Orbit): GPS / TELECOM applications



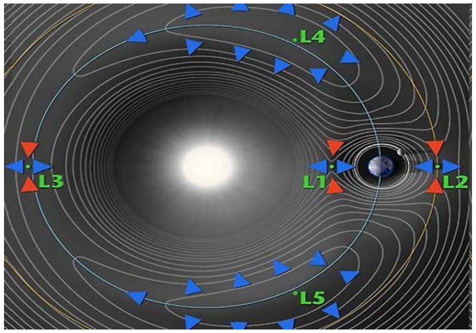
- **ORBIT**
  - Type: Circular
  - Altitude: 1000 to 20000 km
  - Duration: 12 hours
  - Medium to high sensitivity to radiations (according to orbit height)
- **ECLIPSES**
  - Duration: up to 1 hour
- **MISSION DURATION**
  - Up to 15 years
- **EXAMPLE(S): GLOBALSTAR, GALILEO, O3B …**


Polar Orbit


Inclined Orbit

INTRODUCTION / EPS GENERAL INFORMATION
SYSTEM DRIVERS / ORBITS

/// Lagrange Point: Scientific applications - ESA



- **POINTS WHERE THE COMBINED GRAVITATIONAL PULL OF TWO LARGE MASSES PRECISELY COMPENSATE THE CENTRIPETAL FORCE REQUIRED TO ROTATE WITH THEM (ANALOGY WITH THE GEOSTATIONARY ORBIT)**
  - Distance from earth for L1,L2: 1.5*10^6 km
- **ECLIPSES**
  - None
- **MISSION DURATION**
  - 3 years
- **EXAMPLE(S): HERSCHEL (L2), PLANCK(L2), GAIA(L2),…**

/// Interplanetary

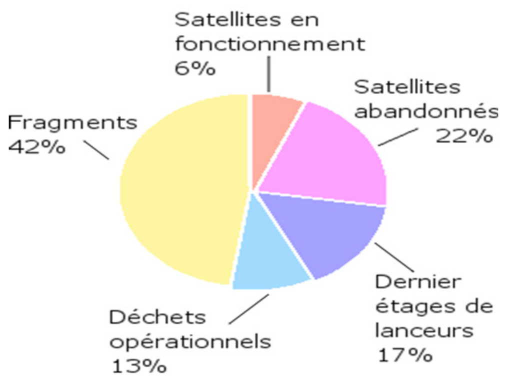
- **CHALLENGE : MANAGEMENT OF SOLAR FLUX, WHICH DECREASES WITH THE SQUARE OF THE DISTANCE TO THE SUN**

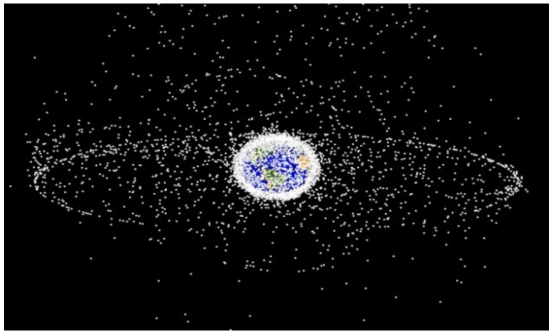
	Distance (AU)	Solar flux (W/m^2)
Mercury	0.39	$9.3\ 10^3$
Earth	1.0	$1.36\ 10^3$
Mars	1.5	582
Jupiter	5.2	48.7
Saturn	9.5	13.5

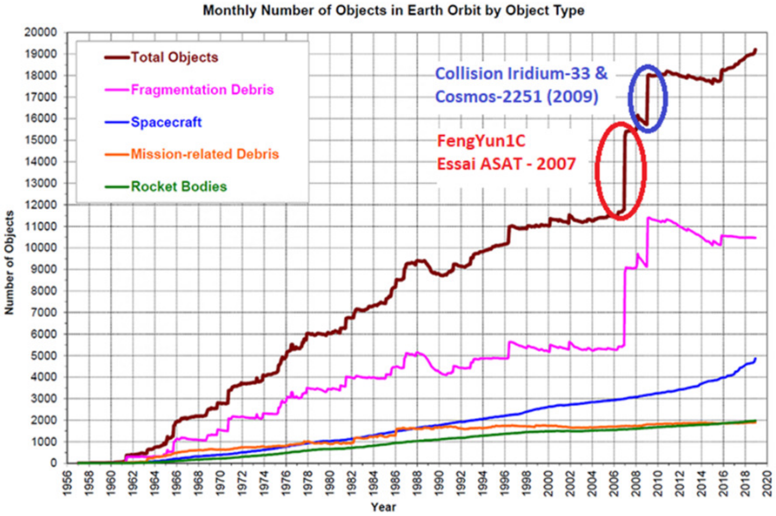
INTRODUCTION / EPS GENERAL INFORMATION SYSTEM DRIVERS / ORBITS

///System drivers / Orbits

M-METEORITE & DEBRIS







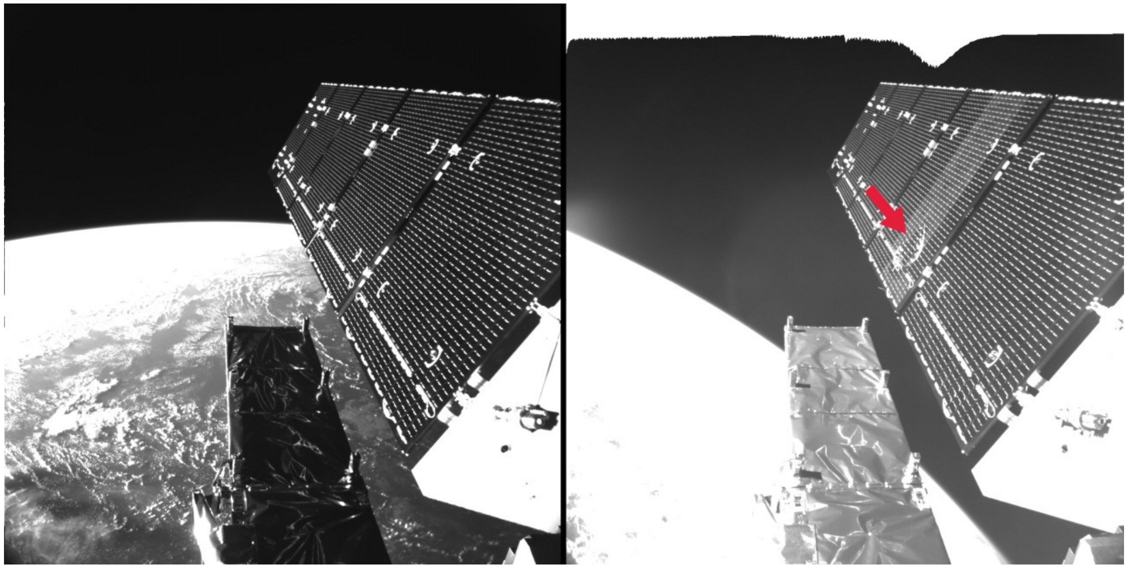
- 15 000 parts > 10cm
- 300 000 parts < 10 cm
- Large concentration between 700 & 1000 km

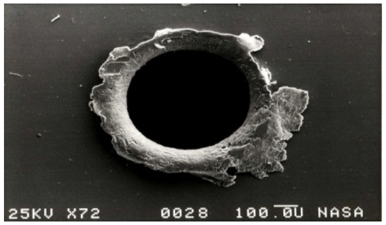
INTRODUCTION / EPS GENERAL INFORMATION

///System drivers / Orbits

ESA RULE TO AVOID GENERATION OF NEW DEBRIS

- Controlled de-orbitation or
- Parking in specific orbit with complete (propulsion and electronic) passivation (25 years in LEO, 100 years in GEO)



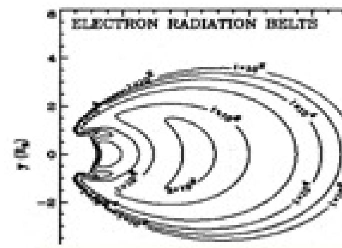


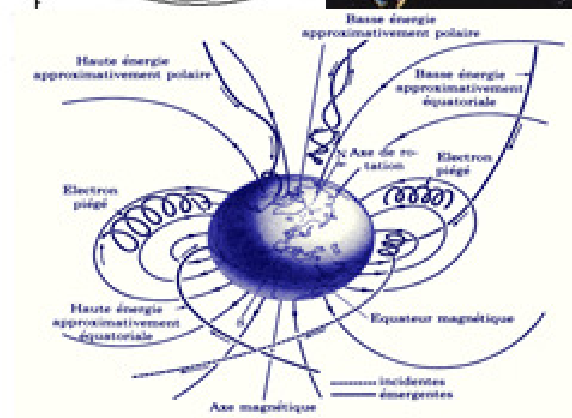
INTRODUCTION / EPS GENERAL INFORMATION

///System drivers / Orbits

RADIATION SOURCES

- Trapped electrons
  Van Allen belts
- Trapped protons
  Van Allen belts
- Sun protons
  Sun eruptions
- Space heavy ions
  Cosmic rays



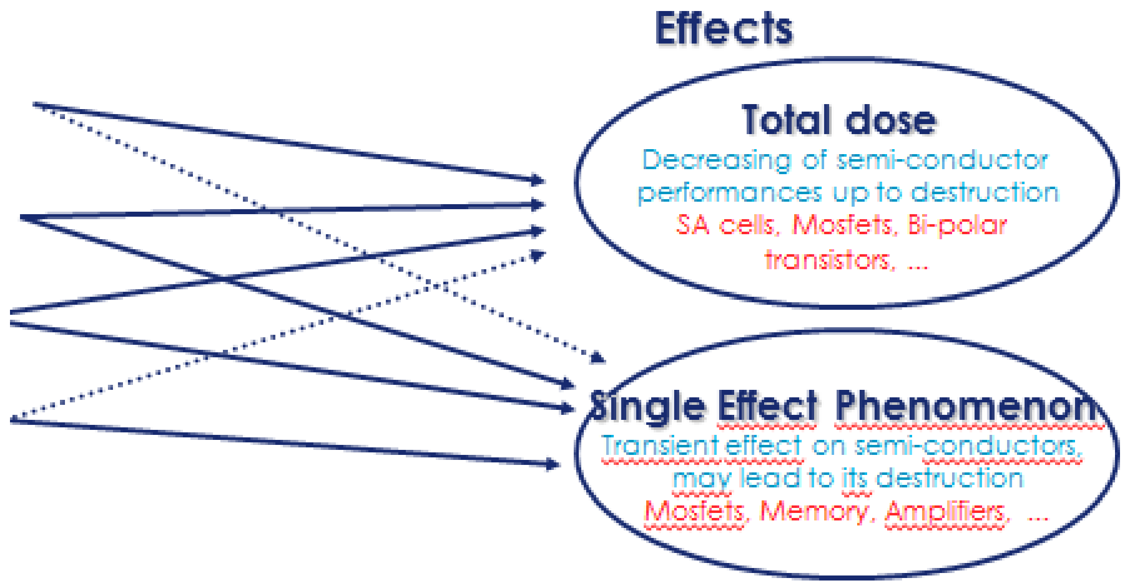


INTRODUCTION / EPS GENERAL INFORMATION

/// System drivers / Orbits

/ RADIATION SOURCES

- Trapped electrons
  Van Allen belts
- Trapped protons
  Van Allen belts
- Sun protons
  Sun eruptions
- Space heavy ions
  Cosmic rays



-> The radiation environment has a direct impact on the definition & sizing of EPS

INTRODUCTION / EPS GENERAL INFORMATION

/// System drivers / Missions

/ (LIFE) DURATION

- From few minutes (launchers) to 15 years (GEO satellites)
- Ageing drifts shall be assessed on each EPS constituent / Even some manufacturers may not be qualified for long term missions (e.g. ABSL batteries)
- Impact on total radiation dose & nb of thermal cycles

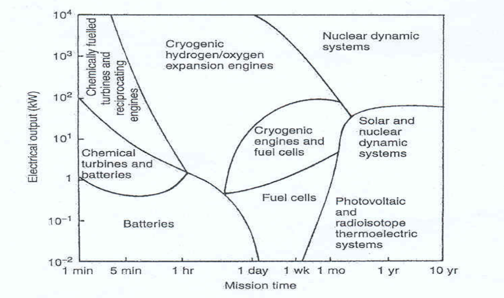


Figure 10.1 Power outputs: mission duration relationship between energy source and appropriate operational scenario [2] (From Angrist, S. W. (1982) *Direct Energy Conversion*, 4th edn, Copyright Allyn and Bacon, New York)

/// Reliability requirements

/ EPS MAY BE REQUESTED TO BE

- SPF (single point failure) free

- No single failure may lead to the loss of mission
- Note: for human mission, no combination of two failures may lead to the loss of mission

- Not reliable

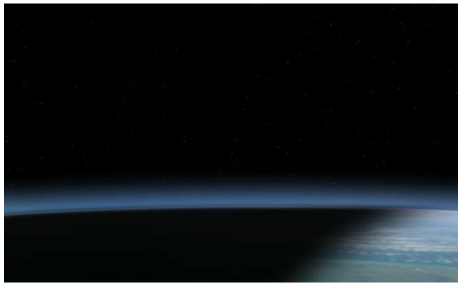
- E.g.: in µSAT, any failure may lead to the loss of mission
- -> Important impact on system architecture (definition of redundancy) and on system cost

INTRODUCTION / EPS GENERAL INFORMATION

///System drivers / Missions

ENERGY BUDGET

- Mission profiles
- Payload needs
  - TV broadcasting points a zone of the Earth
  - Science satellites may point any zone of the sky
  - Military satellites may point any zone of the earth and shall be very agile
- Max and Mean power (in sunlight and in eclipse)
- Orientation (attitude) of the satellite. The attitude constraints directly drive the sizing of the primary and secondary sources: impacts on
  - Eclipse duration
  - SA flux
  - Payload power available (in sunlight and in eclipse)
  - Definition of recovery / safety attitudes of the S/C
  - …



INTRODUCTION / EPS GENERAL INFORMATION

/// EPS equipments glossary

Equipment	
Battery Charge Regulator	BCR
Battery Discharge Regulator	BDR
Begin Of Life	BoL
Converter	CV
Depth Of Discharge	DoD
End of Charge	EoC
End of Discharge	EoD
End Of Life	EoL
Electrical Power Subsystem	EPS
Fold-back Current Limiter	FCL
Latching Current Limiter	LCL

Equipment	
Launch and Early Orbit Phase	LEOP
Maximum Peak Power Tracking	MPPT
Power Conditioning Unit	PCU
Power Conditioning & Distribution Unit	PCDU
Power Sub-System	PSS
Regulated bus	RB
Sequential Switching / Shunt Regulator	S3R
Solar Array	SA
Solar Array Drive Mechanism	SADM
State of Charge	SoC
Unregulated Bus	URB

INTRODUCTION / EPS GENERAL INFORMATION

/// EPS in practice (2)

JASON 1 (2001) Mini satellite

Oceanographic Observation satellite – P = 500 W

Jason 1	Mass (kg)	Satellite mass ratio
Satellite dry mass	472	100 %
Power Conditioning System (incl. SADM)	10	2 %
Distribution	29	6 %
Battery NiCd	45	10 %
Solar Array	42	9 %
Power TOTAL	**126**	**27 %**

INTRODUCTION / EPS GENERAL INFORMATION

/// EPS in practice (3)

DEMETER (2004) Micro Satellite

Science (Geodesy) satellite – P = 110 W

DEMETER	Mass (kg)	Satellite mass ratio
Satellite dry mass	110	100 %
Power Conditioning System (incl. SADM)	6.5	6 %
Battery Li-Ion	4	4 %
Solar Array	6.5	6 %
Power TOTAL	**17**	**16 %**

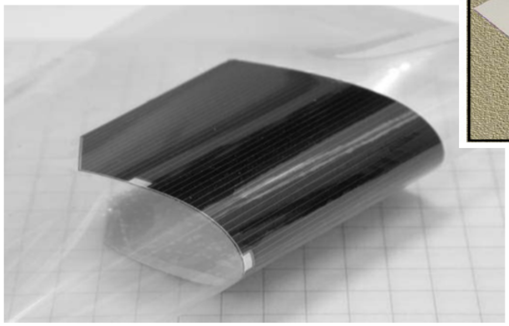
2. PRIMARY POWER SOURCES

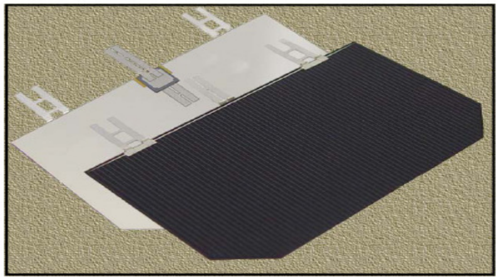
- SOLAR CELLS & SOLAR ARRAYS
- FUEL CELLS
- RTG
- OTHERS

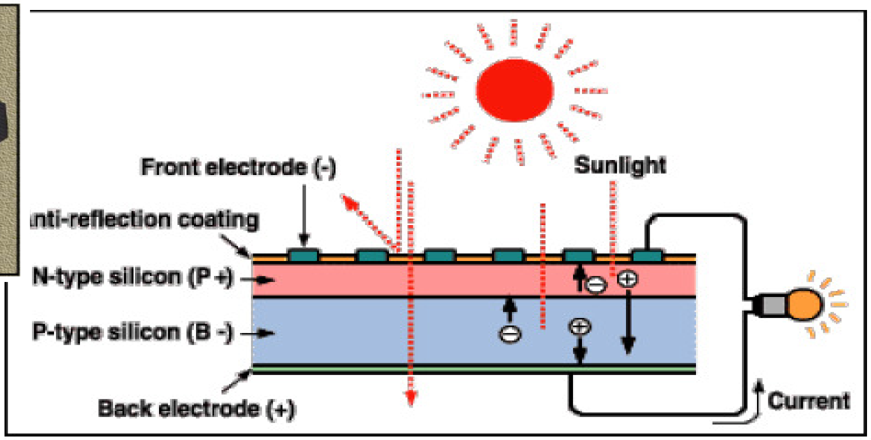
PRIMARY POWER SOURCES/ SOLAR CELLS & ARRAYS

/// SA cells

- **A SOLAR CELL IS COMPOSED OF A SEMI-CONDUCTOR MATERIAL AND CONVERTS PHOTONS TO ELECTRONS**
- **PHOTO-VOLTAÏC EFFECT**
  - The solar flux is reflected, absorbed by the solar cell or crosses it
  - Every absorbed photon whose energy is greater than semi-conductor gap is going to release an electron and to create a positive « hole » (lack of electron). This electron is part of the crystalline network
  - Photons with excessive energy dissipate it as heat in the cell, leading to reduced efficiency
  - An electrical field is introduced in the cell in order to separate this pair of opposite charges





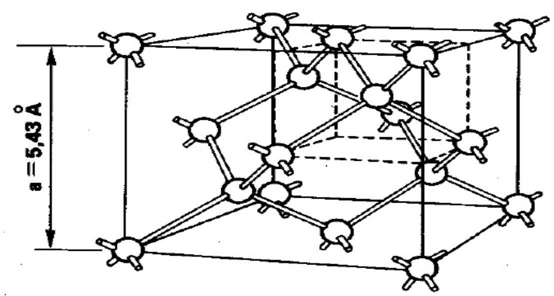


PRIMARY POWER SOURCES/ SOLAR CELLS & ARRAYS

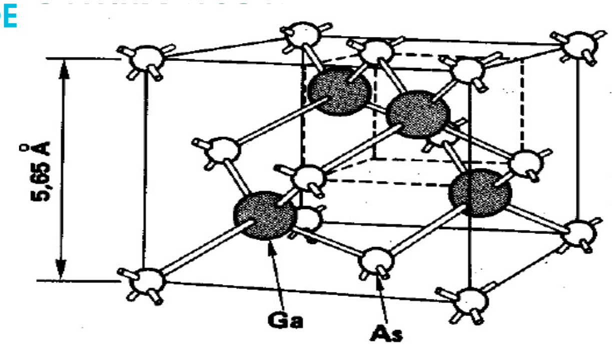
/// Semi-conductors properties

/ MOST COMMON SEMI-CONDUCTORS: SILICIUM AND ARSENIDE

- Cubic crystalline structures

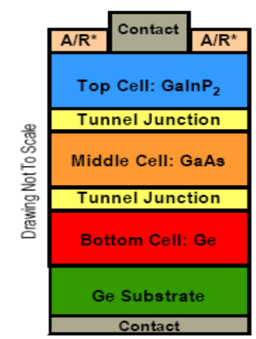


Silicium



Arsenide Gallium

- Method of GaAs Growth: Metal Organic Vapor Phase Epitaxy
- N-type contact (upper surface of the cell): multi-finger arrangement
  - Efficient current collection
  - Good optical transparency
  - Connected at a bar along one edge of the cell

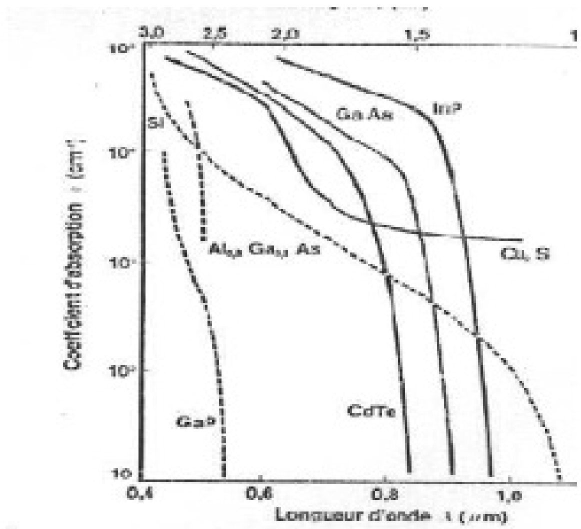


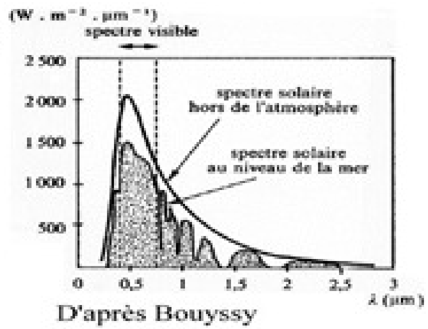
*A/R: Anti-Reflective Coating

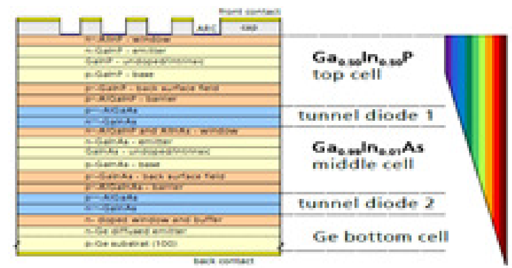
PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

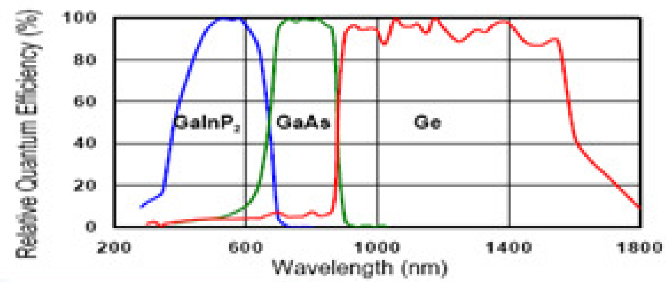
/// Solar flux

SEMI-CONDUCTOR GAP IS CHOSEN TO FIT WITH SPACE LIGHT WAVELENGTH







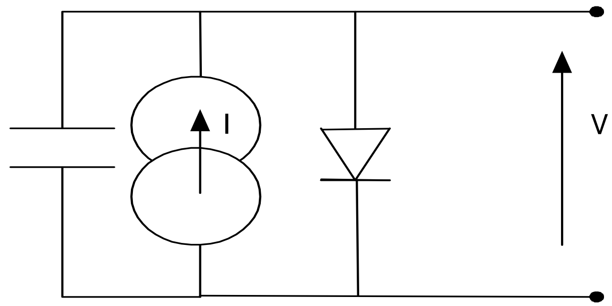


PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

/// Equivalent circuit diagram

/ EACH SOLAR CELL IS EQUIVALENT TO

- a current source in parallel with
- a capacitor (variable) and
- a diode



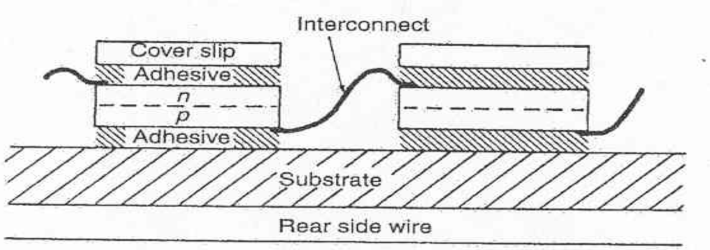
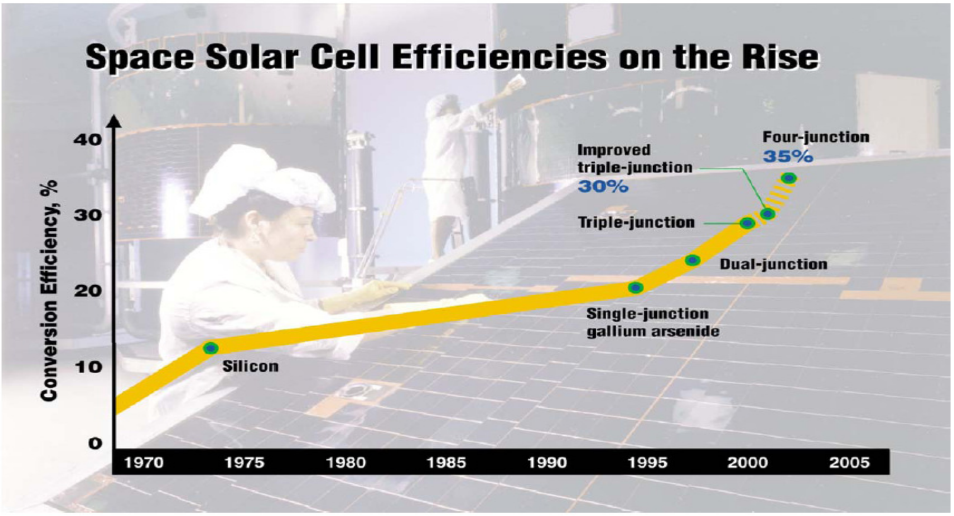
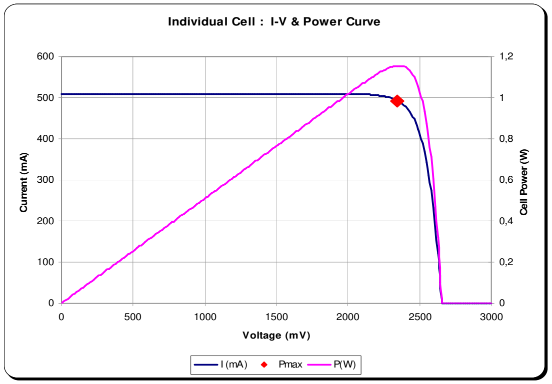


Figure 10.3 Schematic of a typical solar cell assembly

PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

/// SA cell efficiency & characteristics

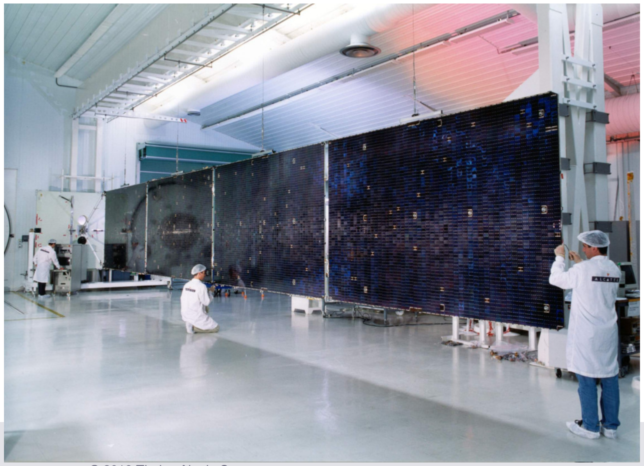


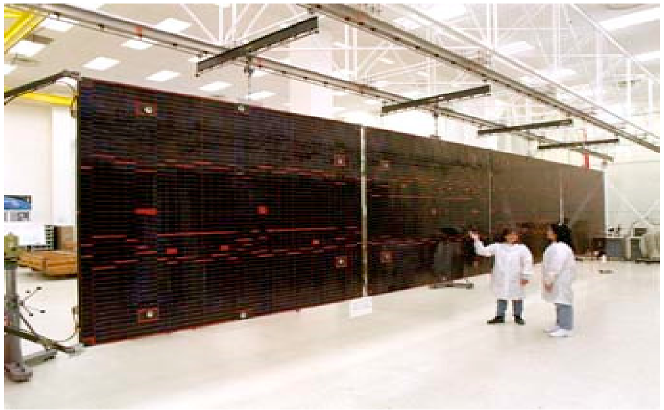


PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

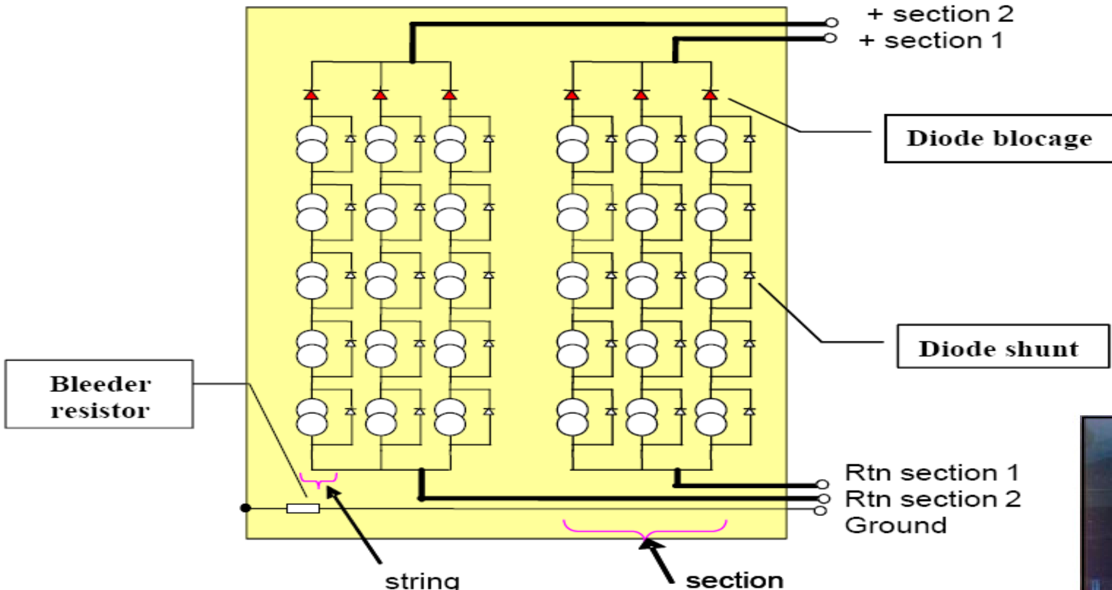
///Solar arrays

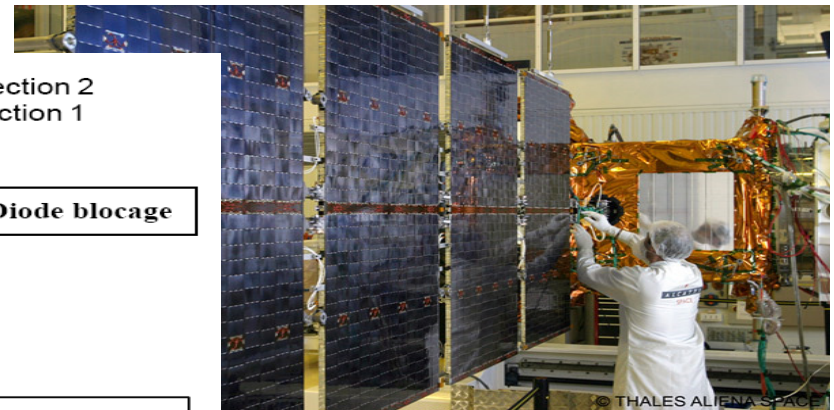
- A SOLAR CELL PRODUCES SOME HUNDREDS OF MILLIWATTS
- A SOLAR ARRAY (SA) IS COMPOSED OF THOUSANDS CELLS ASSEMBLED IN SERIES AND IN PARALLEL
  - The network = cells + interconnections + cabling + diodes
  - A string = assembling of cells in series to obtain the desired voltage
  - A section = strings in parallel to obtain the desired current
- SECTIONS ARE INDEPENDENT

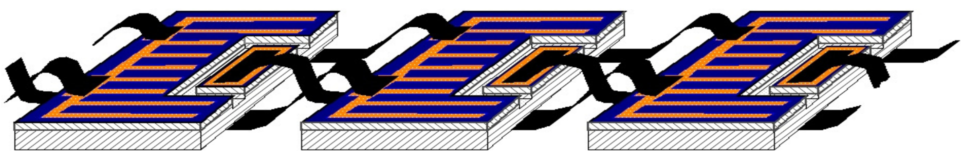




PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

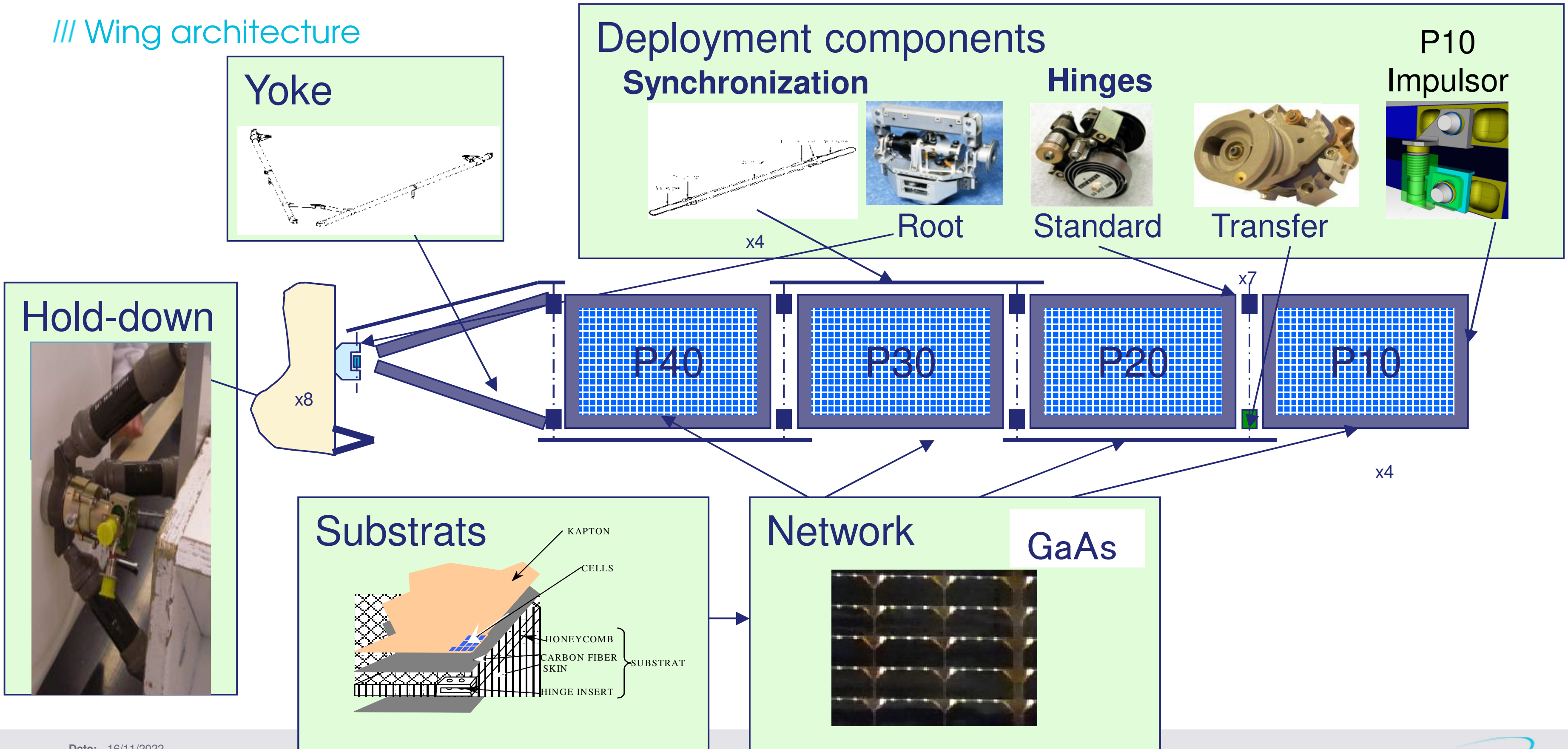






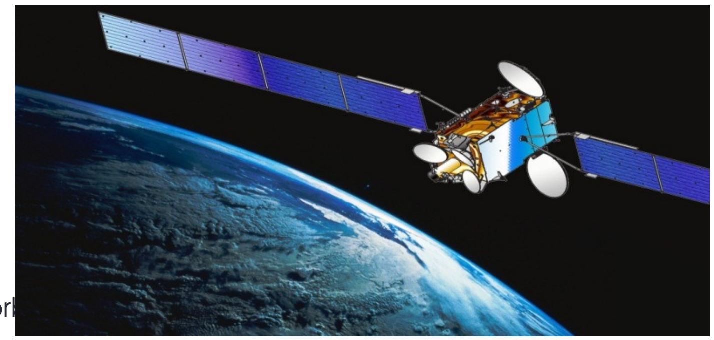
PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

/// Wing architecture



PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

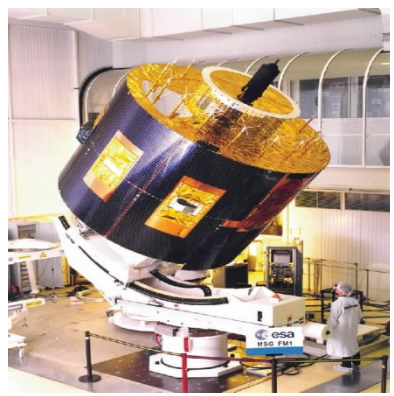
/// Solar arrays – Types



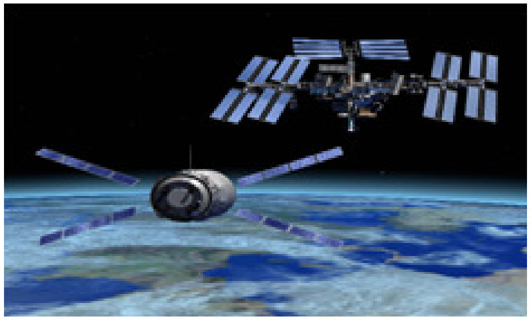
FIXED
- Solar cells are glued on the structure of the satellite
- The power is limited by the surface of the satellite

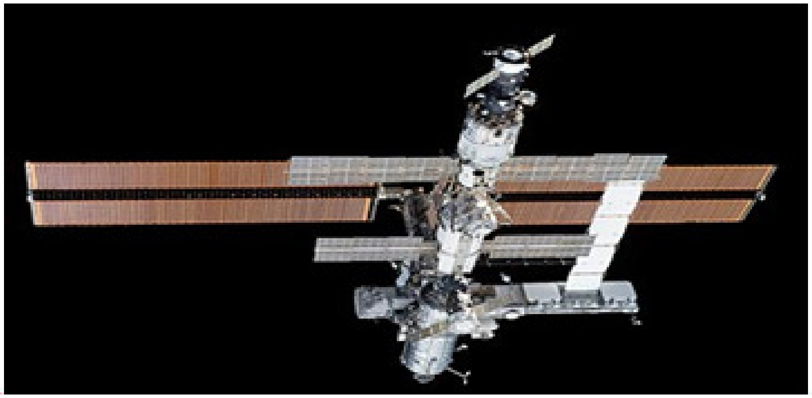
DEPLOYABLE (FIXED)
- Solar cells are glued on flaps (folded at launch and deployed in or
- Difficult to manage the attitude constraints

DEPLOYABLE AND MOBILE
- 1-degree of freedom



PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS





PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

/// Panel, glue, coverglass, …

/ SUBSTRATE

- Kapton with glass – or carbon- reinforcement

/ GLUE, ADHESIVE

- Fix SA cell on SA panel
- Fix the coverglass on the cell
- Ensure electrical & thermal conductivity

/ PANEL (HONEYCOMB)

- Support SA cells
- Transfer heat to bottom side
- Face high thermal gradient
- Be compatible with deployment and orientation mechanisms

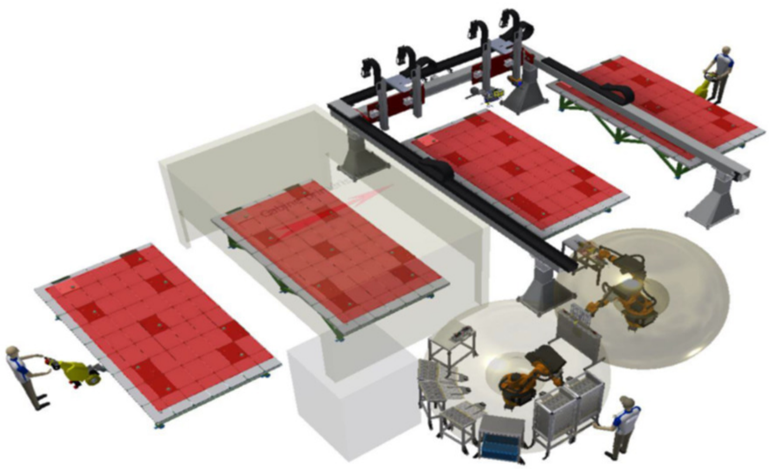
/ COVERGLASS

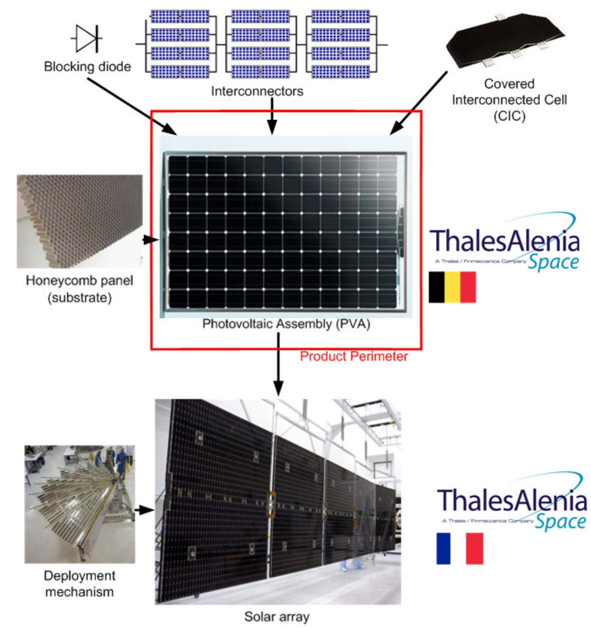
- Protect SA cell against ATOX
- Protect SA cell against radiation
- Limit the UV flux to the adhesive layer and to the cell by allowing suitable wavelength selection, via a good optical coupling (between free-space and glass & between glass and adhesive)

PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

/// TAS-B - PVA Factory4.0: our current challenges

- **AUTOMATION OF CRITICAL PROCESSES: GLUE DISPENSE, LAY-DOWN, WELDING**
  - In-line testing, control and traceability
- **AIDING STATIONS FOR HARNESSING LEVERAGING 4.0 TECHNOLOGIES**
  - « Augmented » operator focus on manufacturing operations
- **AUTOMATION OF ACCEPTANCE TEST EXECUTION**





PRIMARY POWER SOURCES / SOLAR CELLS & ARRAYS

/// Efficiency degradation factors

- **CELLS MISTMATCH & CALIBRATION**
- **MISSION LIFETIME**
  - Loss of power: 1% to 2% every year (depends of the orbit)
- **RADIATION EFFECTS**

Radiation Degradation
(Fluence 1MeV Electrons/cm^2)

Parameters	$1x10^{14}$	$5x10^{14}$	$1x10^{15}$
Imp/Imp_0	0.99	0.98	0.96
Vmp/Vmp_0	0.94	0.91	0.89
Pmp/Pmp_0	0.93	0.89	0.86

Illustration SPECTROLAB

- **UV**
- **METEORITE IMPACT**
- **ATOX DENSITY**
  - Aggressive and corrosive environment (tied to the LEO) on cover glass protection and on exposed interconnection (oxidation of silver and then increase of resistivity)