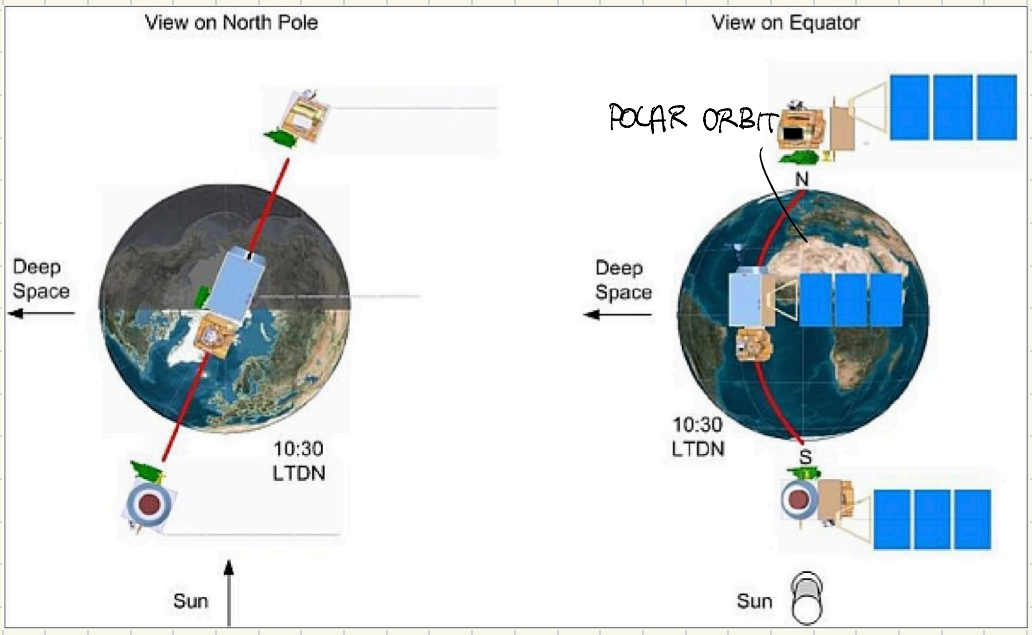
05/05/2025 **EPS**

Sentinel 2

2 crucial aspects → * operations : understand what and when each subs. consume
* case of eclipse / sunlight



solar arrays that always face the sun

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REPORT : how attitude / solar panels face the sun during different operations

Orbit:
- 780 km SSO (LTAN 10:30)
- Period: 101 minutes

EPS:
- **Triple junction cells**
  - Solar arrays area: 7.1 m^2
  - Number of cells: 2016
  - P_{EOL}: 1730 W
  - P_{BOL}: 2300 W
  - 1-axis solar array drive
- **Li-Ion batteries**:
  - Battery electrical charge: 102 Ah
  - Number of cells in series: 8
- **Bus voltage**: 28 (unregulated)

Subsystem / Mode	Science-Sunlight	Eclipse	Telecom	Safe Mode
Payload	266	No payload 0	0	0
OBDH	100	100	100	50
ADCS	150	150	70	20
TT&C	34	34	200	80
Thermal Control	120	160	120	120
EPS	80	80	80	50
Total Consumption	**750**	**524**	**570**	**320**
System Margin (20%)	150	104.8	114	64
Total Required Power	**900**	**634**	**684**	**384**

sizing condition is the most demanding in power POV

observation mission → works in visible and thermal spectrum

SOLAR ARRAY SIZING

① Compute power from solar array

$$P_{SA} = \frac{\frac{P_e T_e}{X_e} + \frac{P_L T_L}{X_L}}{T_L}$$

energy consumed in sunlight

energy consumed in eclipse

controller regulation of the power introduces important losses

P_L = 900 W
T_L = 0.6 T → 60% sunlight, 40% eclipse

P_e = 634 W
T_e = 0.4 T

	X_s	X_e
DET	0.85	0.65
MPPT	0.80	0.60

⇒ P_{SA} = 1830 W

NOTE: during sunlight phase we have to produce enough energy to fed the loads + charge batteries

② Specific power at BOL

$P_{BOL} = P_0 \; \varepsilon \; I_D \cos(\theta)$

- P_0: specific power irradiated by the sun — 1365 W/m²
- ε: cell efficiency in energy conversion
- θ: sun aspect angle: between the normal of our cells and the sun direction
  - the more inclined are the cells the less power is produced: in sentinel case, the solar arrays moves such that θ is always zero

I_D is a loss term → $I_D = 0.8$, generally in range [0.5 - 0.9]

due to: - misalignment
- dust
- current missmatch

$P_{BOL} = 315\ W/m^2$

③ Specific power at EOL

(solar cells degrade a lot in space (radiation + small particles)

$$P_{EOL} = P_{BOL}\left(1 - SPY\right)^{years}$$

(0.03) years of mission

$P_{EOL} = 219\ W/m^2$

④ solar array surface

$$A_{SA} = \frac{P_{SA}}{P_{EOL}} = 8.3\ m^2$$

⑤ number of cells

$$N_{CELL} = ceil\left(\frac{A_{SA}}{A_{cell}}\right) = 2760$$

(area of the single cells (datasheet link on slides)
30.15 mm^2

	COMPUTED	GIVEN
A_{SA}	$8.3\ m^2$	$7.1\ m^2$
P_{EOL}	$219\ W/m^2$ (1818 W)	1730 W
P_{BOL}	$315\ W/m^2$ (2615 W)	2300 W
N_{CELL}	2760	2016

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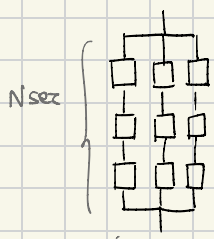
oversized

⑥ refined sizing



— define how many cells are in series or in parallel: based on the voltage of the solar arrays that has to match the system voltage

- voltage sum in series
- current sum in parallel

IMPORTANT FROM DATASHEET → - Area
- short circuit current (Isc)
- open circuit voltage (Voc)
- maximum power voltage (Vm)

$V_m = V_{cell} = 2.33\ V$

$$N_{series} = ceil\left(\frac{V_{SYS}}{V_{cell}}\right) = 13 \qquad V_{SYS} = 28\ V$$

$$N_{parallel} = ceil\left(\frac{N_{cell}}{N_{series}}\right) + 1 = 214$$

$N_{cells} = N_{parallel}\, N_{series} = 2782$ ⇒ A_{SA} is updated

$A_{SA} = N_{cells}\, A_{cell} = 8.38\ m^2$

so $P_{EOL,SA} = A_{SA} P_0 \epsilon I_d (1-SPY)^{years} = 1846\ W$ } ② 1AU because we're on Earth (always specify it)
$P_{BOL,SA} = 2782\ W$ } (relevant scenario

BATTERY SIZING

(give power during eclipse

the battery capacity $E = \frac{P_e T_e}{\frac{x_e}{DoD\ \eta\ N}} = 1682\ Wh$

(x_e: EOL efficiency of battery 80%; N: number of battery [2-5] (NOT cells))

DoD: "Depth of Discharge" = 30%

batteries degrade over time mainly because of: - temperature
- cycle depth)

how much available energy of the cells we consume in each cycle: it is better to do small cycles instead of a big cycle of discharge to save the battery

⇒ DoD in the span [30% - 50%] or lower to have on EOL efficiency of 80%

(the DoD could be higher if the batteries have small number of cycles [60% - 70%]

Another reason to have low DoD is for when we go out of eclipse: if we remain with only 20% and we have a failure, we lose the control

(small DoD also increase reliability of the system

① identify series and parallel connections of the cells

$N_{ser} = ceil\left(\frac{V_{sys}}{V_{cell}}\right) = 8$

(V_{cell}: 3.6 V)

DATASHEET OF BATTERY → - voltage

$N_{parallel} = ceil\left(\frac{E}{E_{string}}\right) + 1 = 23$

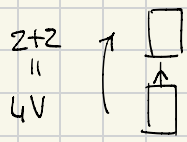
(E_{string}: capacity of the string)

$E_{string} = \mu\ C_{cell} (V_{cell} N_{serie}) = 69.12\ Wh$

(C_{cell}: electrical charge of the cell 3AH; μ: efficiency factor 0.8; $V_{cell} N_{serie}$: voltage of the string)

1 AH
2 V
→ 2 VAH = 2 WH

(ex) 2 batteries in series



$N_{cell} = 8 \cdot 23 = 184$
$E_{cell} = 1589\ Wh$ → $E_{string} \cdot N_{parallel}$
$C_{cell} = 56.77\ AH$

$$mass = \frac{E_{req}}{\text{specific energy}} = 10.6 \text{ kg per pack}$$

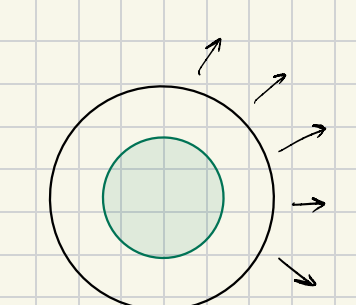
(on slides (Li-ion)

$$volume = \frac{E_{req}}{\text{energy density}} = 6.35 \ell \text{ per pack}$$

HINTS:

NO ECLIPSES

- contingency → how much time in safe mode?
- detumbling

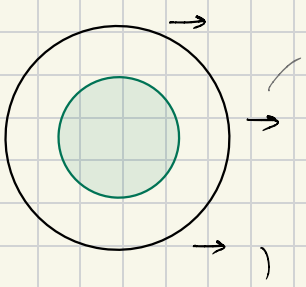


no power production because solar arrays are tilted in a way that doesn't allow energy production

(case treated as eclipse

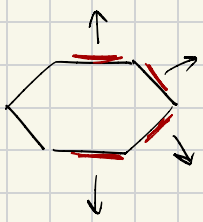
$$P_{SA} = \frac{P_E T_E}{\frac{x_E}{T_L}} + \frac{P_L T_L}{\frac{x_L}{T_L}}$$

ATTENTION to which value we put in the formula



panels always face the sun
(sentinel case)

solar array → sometimes cells are on the body of s/c so distributed in many faces



in this case we could consider different sun aspect angle

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different ways to compute this case:

* consider an average of angles, it is like we're considering an equivalent face
* consider flat faces and then say that they are distributed in different ways

DATA FROM HERMES MISSION

Safe Mode → after detumbling (usually all s/c do that)

EPS → a lot of data about it (60%), it is the most important subsystem because it tells something about healthy