

Fabrication & integration of Pk devices on PCB for flight experiment

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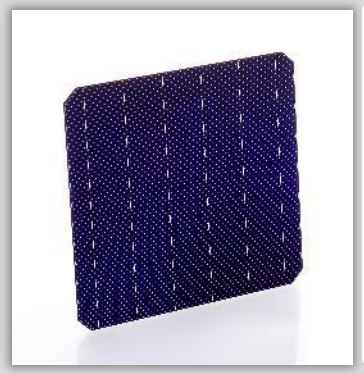
CEA @ INES : RESEARCH INSTITUTE FOR SOLAR ENERGY

PV PREMIUM ▶ HIGH EFFICIENCY, LOW CARBON

Example of best-in-class PV technologies developed by **CEA at INES**

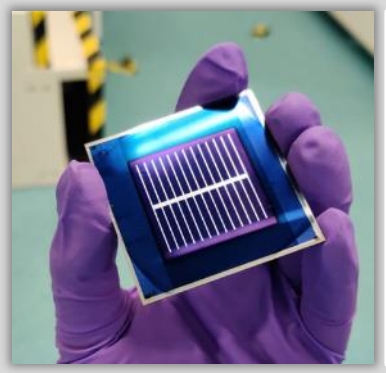


High maturity

- Industrialisation towards Gigafactories
- Bring Silicon to limits
- Sustainability : Indium, Silver…

Silicon heterojunction

25% efficiency ▶ to industry



Low maturity

- Efficiency
- Best architecture
- Stability
- Processes

TANDEM Si/Perovskite

▶ 30 % target on large format



High maturity

- Cell-to-module modelling
- Shingling, paving
- Interconnection
- Ecodesign : new materials

Advanced moduling

▶ Increase W/m²



AGENDA

A. Lastest Pk records at CEA-INES

B. Perovskites in Space: opportunities & challenges

C. Fabrication of Pk devices & integration on PCB

D. BOL characterisations & flight program

E. Conclusions & perspectives



LATEST PK RECORDS AT CEA-INES

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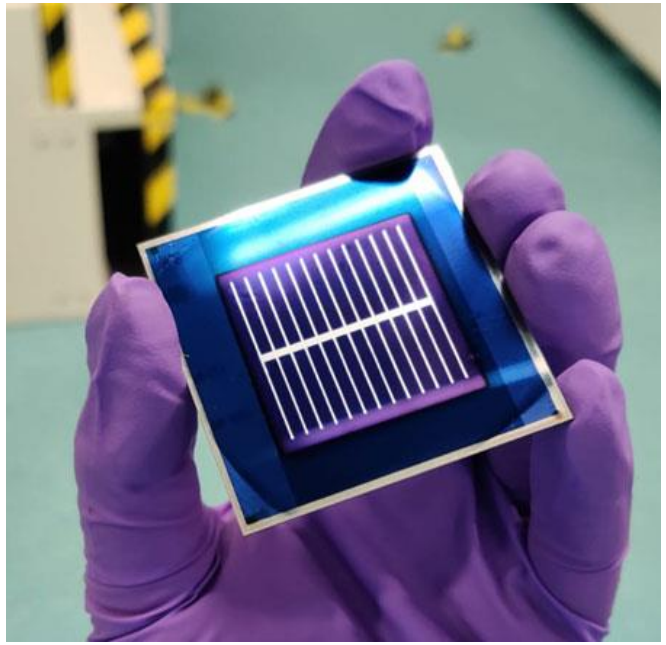
LAST RECORDS

March 2022 – Single junction PSC

- PCE = 20.3% and FF >93%
- Active area of 11.2cm²
- 8 cells in series, module combining coating deposition techniques and laser patterning



Picture of a 9cm² tandem cell © CEA

March 2023 – Tandem Pk - Si

- PCE = 26.5%
- Active area of 9cm²
- Integration of a large bangap perovskite on a heterojunction silicon cell

https://www.ines-solaire.org/news/nouveau-record-pour-la-technologie-des-modules-perovskites/
https://www.ines-solaire.org/news/enel-green-power-et-le-cea-sont-de-retour-avec-un-record-de-rendement-de-26.5-sur-9-cm/



PEROVSKITES IN SPACE: OPPORTUNITIES & CHALLENGES

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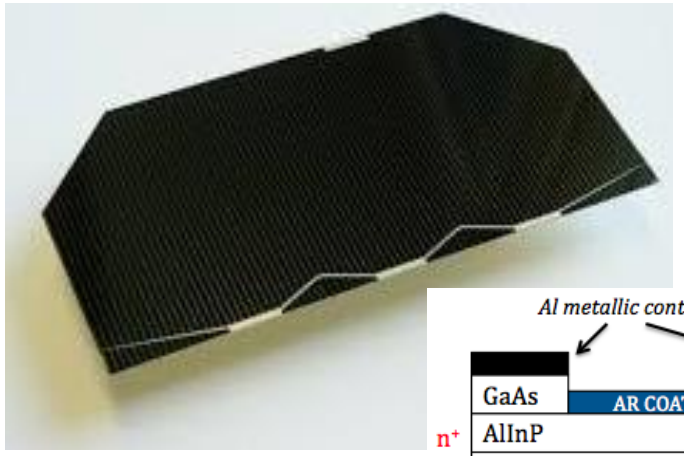
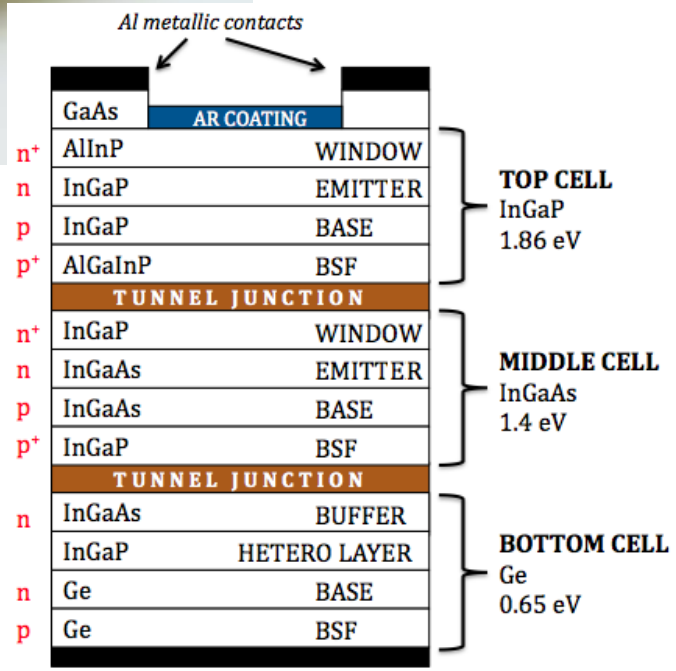
III-V & PEROVSKITES SOLAR CELLS

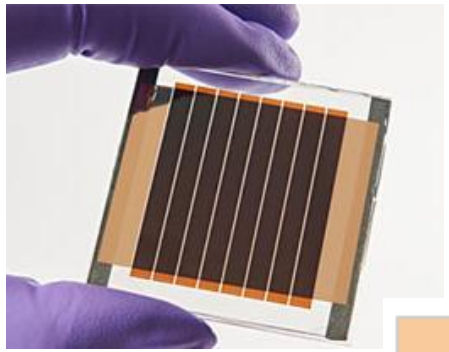
Space standard solar cells:
III-V/Ge space multi-junction



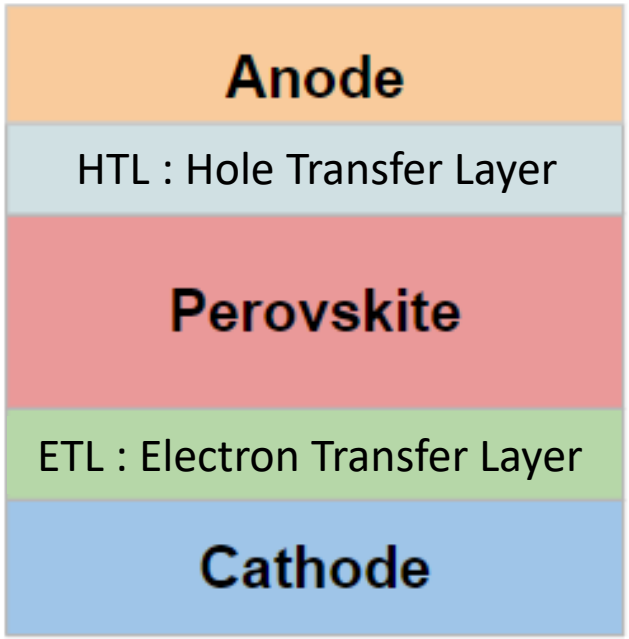


Industrial cell

Alternative cell candidate for space ?
Single junction Perovskite Solar Cells (PSC)



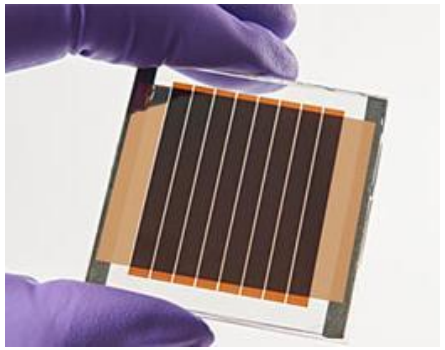
R&D cell



III-V & PEROVSKITES SOLAR CELLS

	III-V: Industrial	Perovskite: R&D
Record efficiency (AM1.5g)	39.5%	25.7%
Active layer thickness	~15µm	<1µm
Specific power	~3W/g	~30W/g
Manufacturing	Complex High temp. >600°C	Simpler (?) Soft chemistry <100°C
Cost	€€€€	€ (?)
Temperature & vac. stability	✓	?
UV resistance	✓	?
Radiation hardness (e-, p+)	✓	✓
Solar array integration	✓	?





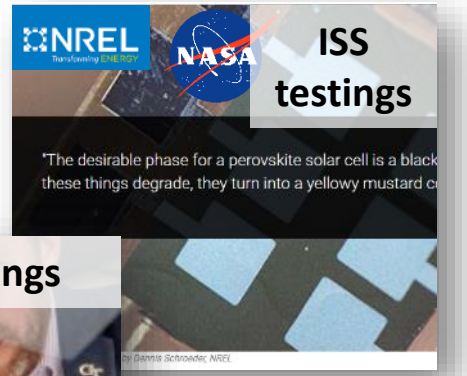
France RM et al.,
DOI: 10.1016/j.joule.2022.04.024
Cardwell D. et al.,
DOI: 10.1109/PVSC.2017.8366552

Green MA et al.,
DOI: 10.1002/pip.3595
Hu Y. et al.,
DOI: 10.1021/acsenergylett.1c01193

FLIGHT EXPERIEMENTS & PERSPECTIVES

- Many tests ongoing for Pk cells in space

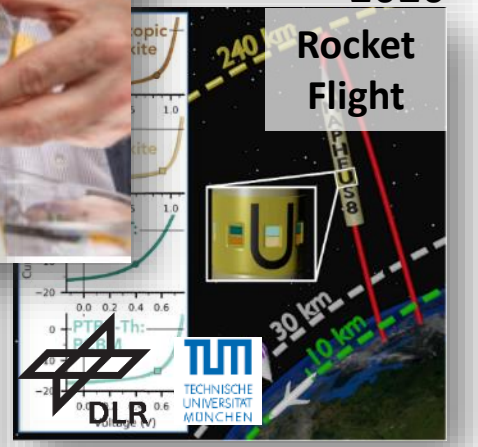
2021/2022



2019



2020



2018



- Interest for Moon/Mars exploration





- Target power ~ 1 MW → Only 12 kg Pk needed
- With 3500$ lauching cost → 0.1 $/W (15% eff.)



FABRICATION OF PK DEVICES & INTEGRATION ON PCB

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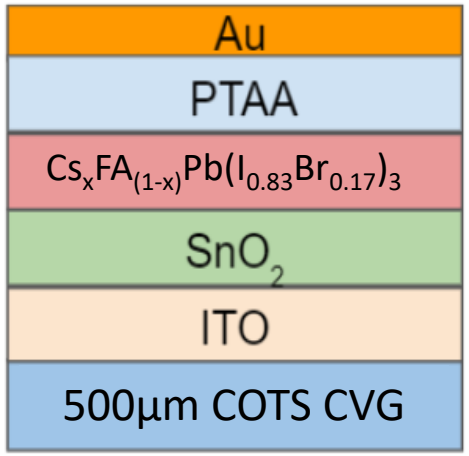
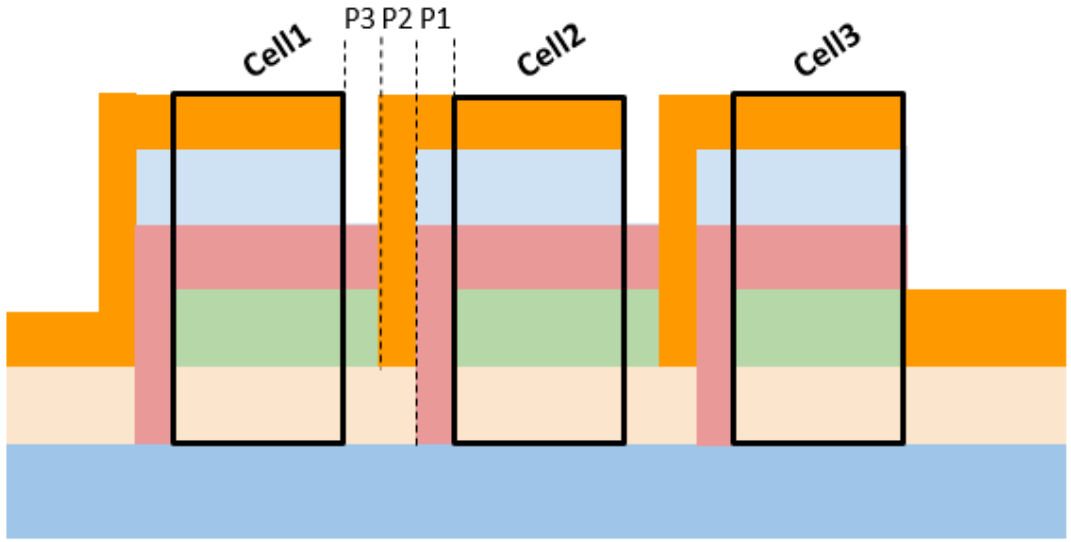
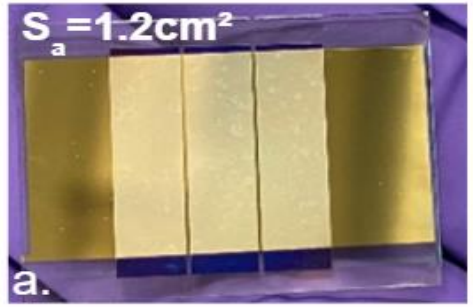
PK SOLAR ARRAYS ON COVERGLASS

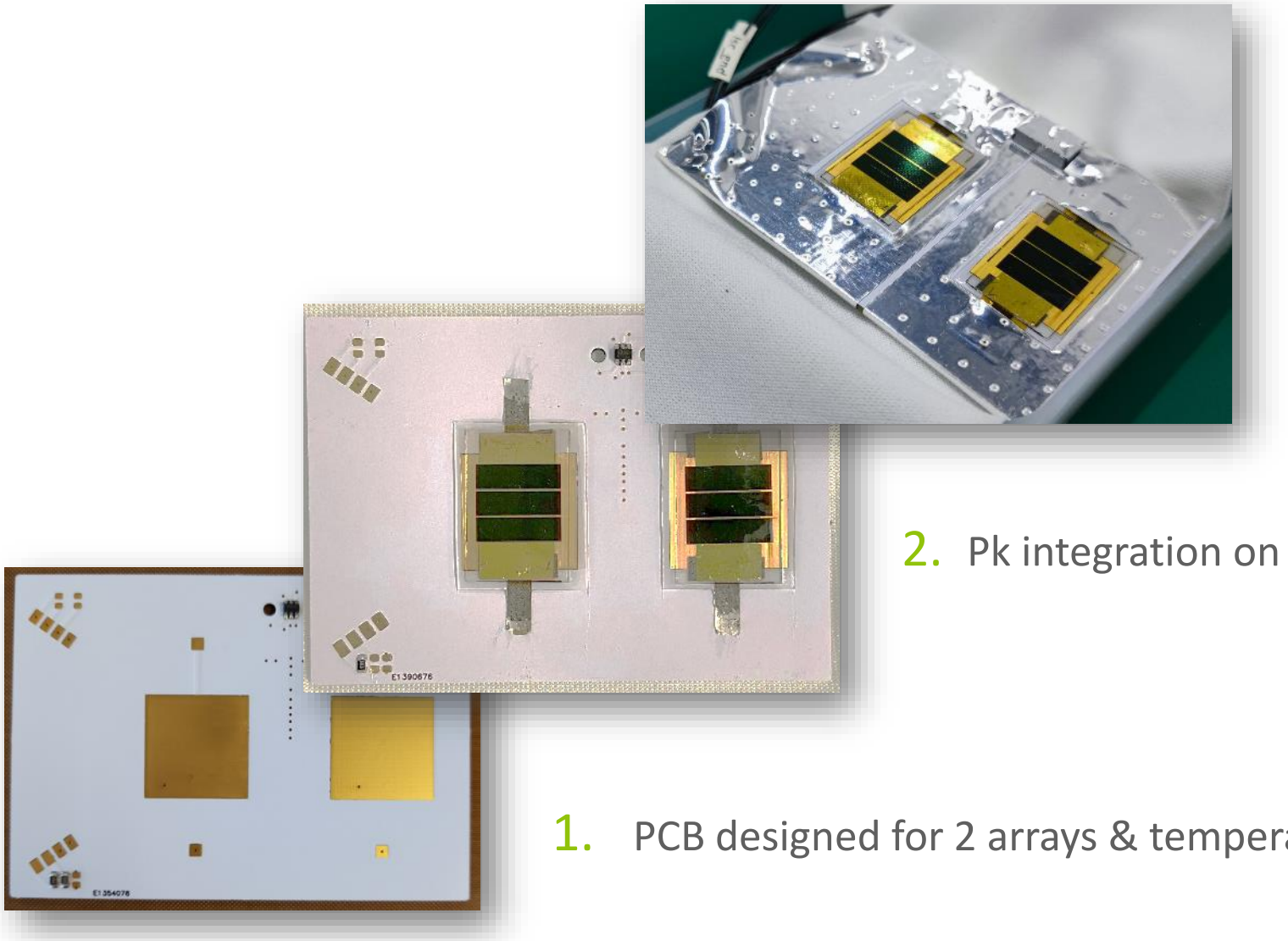






- Double-cation mixed halides deposition on CVG: spin-coating + antisolvent quenching
- Series connection via laser scribing: active cell width few mm, interconnection width few 100µm
- Final array design: 3 series connected cell with total active area 1.2 cm^2

INTEGRATION OF PK ARRAY ON PCB



3. PCB cabling & thermal protection

2. Pk integration on PCB using welding & lamination process

1. PCB designed for 2 arrays & temperature monitoring



BOL CHARACTERISATIONS & FLIGHT PROGRAM

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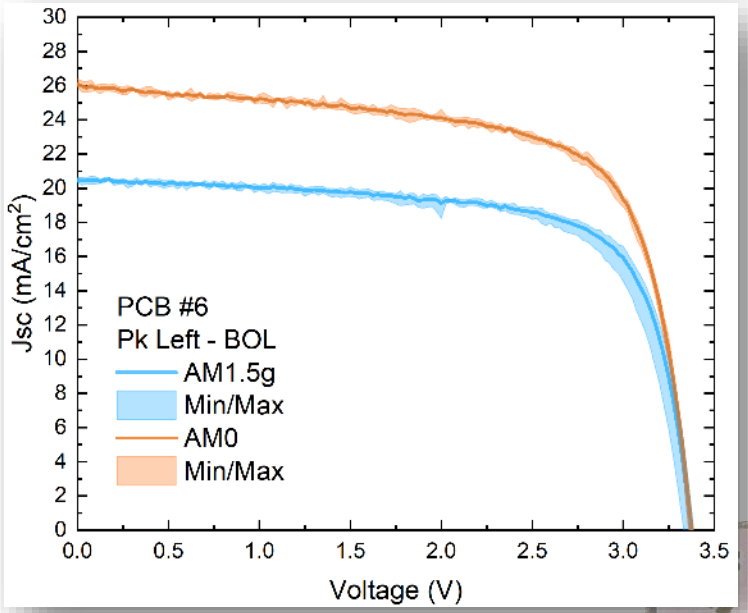
IV PERFORMANCES

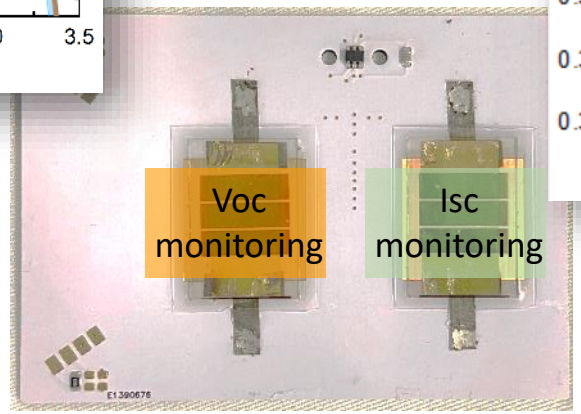
- Pk arrays description

<u>Pk Left:</u>
- 3 series-connected cells
- Tot. area 1.2 cm^2

<u>Pk right:</u>
- 3 series-connected cells
- Tot. area. 1.2 cm^2
- Shunted by 47Ω resistor







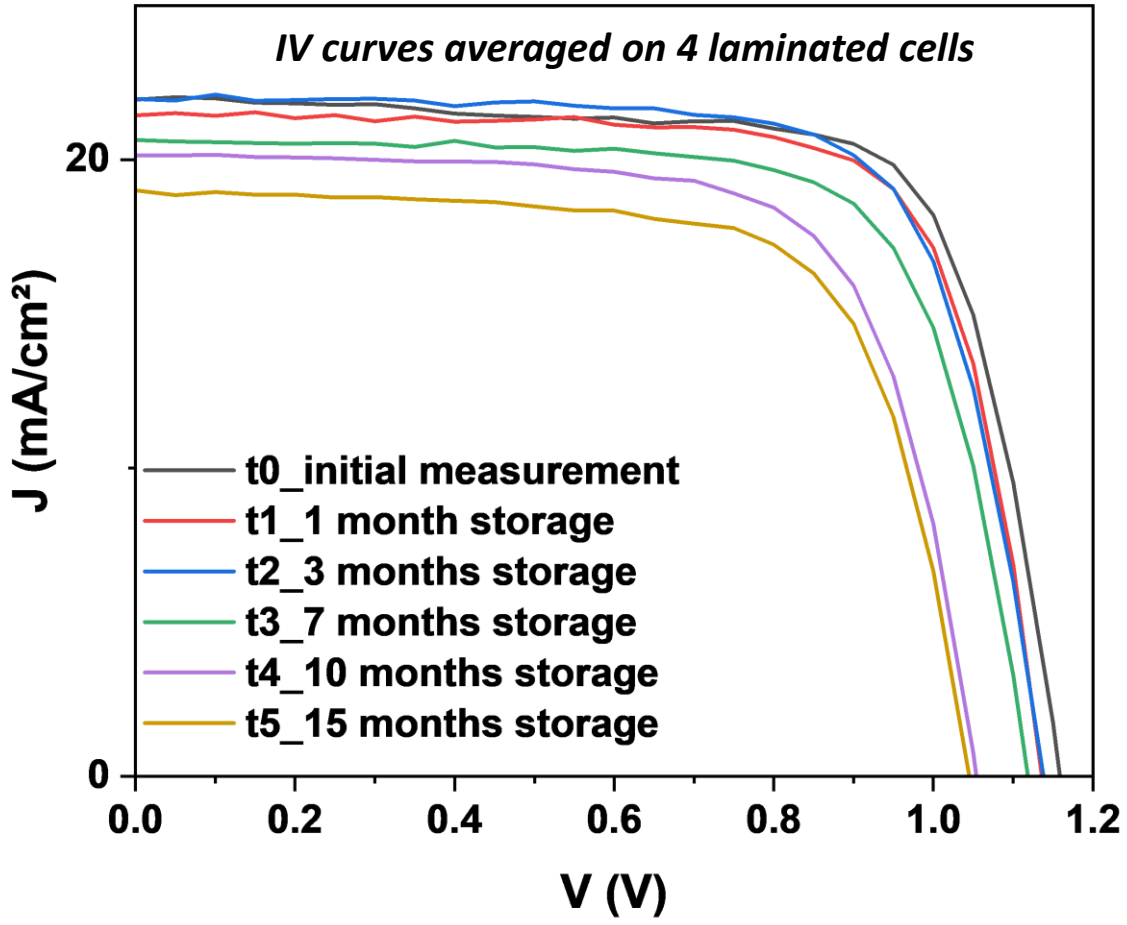
		Voc (V)	Jsc (mA/cm2)	Isc (mA)	FF	PCE (%)
AM1.5g	Pk Left	**3.371**	**20.5**	**8.2**	**0.714**	**16.5**
	Pk Right	**0.404**	**21.5**	**8.6**		
		Voc (V)	Jsc (mA/cm2)	Isc (mA)	FF	PCE (%)
AM0	Pk Left	**3.360**	**26.0**	**10.4**	**0.687**	**14.6**
	Pk Right	**0.515**	**27.4**	**11.0**		

Pk arrays integrated on PCB validated
14.6% AM0 Efficiency measured

STABILITY OF PK ARRAYS

- Pk cells lamination with space grade silicone
  - Same adhesive used for PCB encapsulation
- Performance monitoring during several months of cleanroom storage (air, dark)

AM1.5G	Jsc (mA/cm²)	Voc (V)	FF (%)	PCE (%)
t0 initial measurement	**22.0** +/- 0.2	**1.155** +/- 0.005	**74** +/- 3	**18.9** +/- 1.3
t3 7 months storage	**20.6** +/- 0.2	**1.116** +/- 0.005	**73** +/- 1	**16.7** +/- 0.2
t5 15 months storage	**19.0** +/- 0.4	**1.094** +/- 0.009	**71** +/- 1	**14.8** +/- 0.4



Sufficient stability to study in-orbit performances as demonstrated by 15 months Earth storage of reference encapsulated Pk cells

FLIGHT PROGRAM & LAUNCH

- PCB designed for integration on side of a 3U nanosat



- Thermal excursion in the range [-50; +60°C]
- Data monitoring for > 1 year @ 530 km
  - Isc, Voc, temperature
  - Sun direction & altitude
- Solar irradiance will be estimated with 0.5% precision
- January 3, 2023 from Cape Canaveral Space Force Station → First European launch of PSCs
  - SpaceX Falcon 9 rocket with 114 nano-satellites
  - Launching : https://www.space.com/spacex-transporter-6-mission-launch-success
  - Press release from QOSMOSYS : https://qosmosys.com/zeus-1-launch-makes-airbus-the-first-european-company-to-test-perovskite-solar-cells-in-space/
- Activation & first Pk array flight data expected begin of May



CONCLUSIONS & PERSPECTIVES

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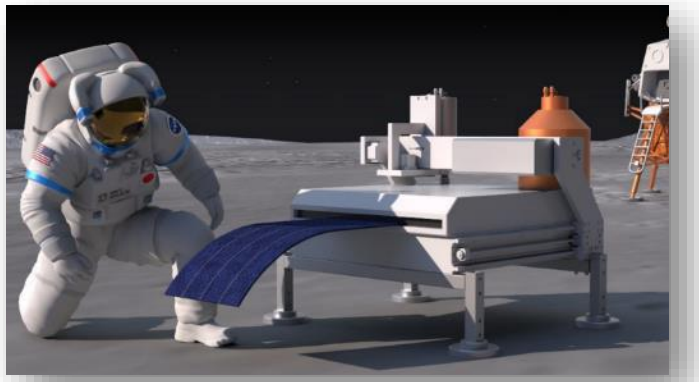
CONCLUSIONS & PERSPECTIVES

PSC advantages & challenges

- **Lots of research focusing on compatibility of Pk PV for space:**
  - High specific power (W/kg) potential, low cost, radiation hardness
  - Perspectives markets in for LEO orbits & exploration
  - Flight tests are key for Pk: integration & combined constraints challenges

- **Perspectives: lightweight Gen II Pk flexible arrays**



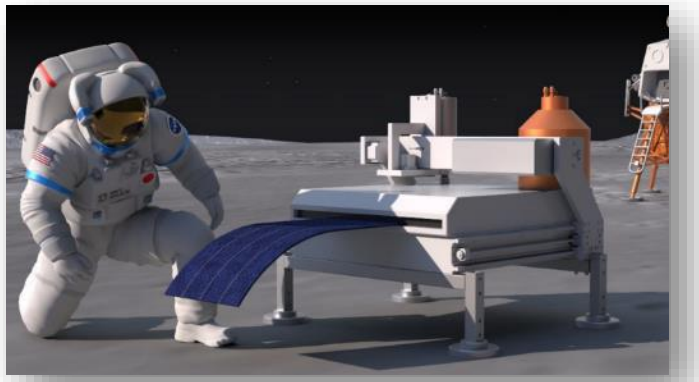
CONCLUSIONS & PERSPECTIVES

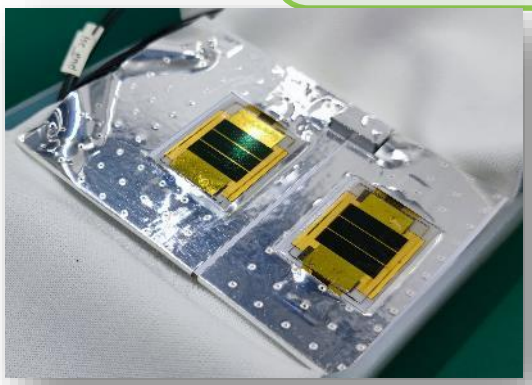
PSC advantages & challenges

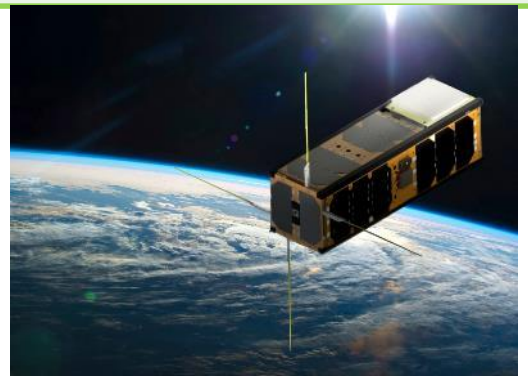
- **Lots of research focusing on compatibility of Pk PV for space:**
  - High specific power (W/kg) potential, low cost, radiation hardness
  - Perspectives markets in for LEO orbits & exploration
  - Flight tests are key for Pk: integration & combined constraints challenges
- **Perspectives: lightweight Gen II Pk flexible arrays**

Flight program expectations

- **Pk arrays successfully manufactured & integrated on PCB for nanosat**
  - Arrays: 3 series connected cells on CVG
  - Integration on PCB with welding and lamination
  - Performance achieved: AM0 14.6% Efficiency
  - Stability > 15 months demonstrated for ground storage
  - First European launch of PSC with in-situ monotoring
- **Successful launch January 3rd 2023**
- **Data from 530 km orbit expected in May 2023**









Thank you for your attention

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Oumaima Mhibik[1], Sophie Duzellier[2], Thierry Nuns[2], Romain Cariou[1]

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