3D pattern adjustment during directional solidification of a transparent alloy conducted on DECLIC-DSI

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Introduction

- DECLIC-DSI instrument
- Experiments in the DECLIC-DSI

Effect of sub-boundaries on Primary spacing

- Experimental results
- Phase field simulations

Conclusion and perspectives

DECLIC-DSI Device

To study the microstructure formation during directional solidification

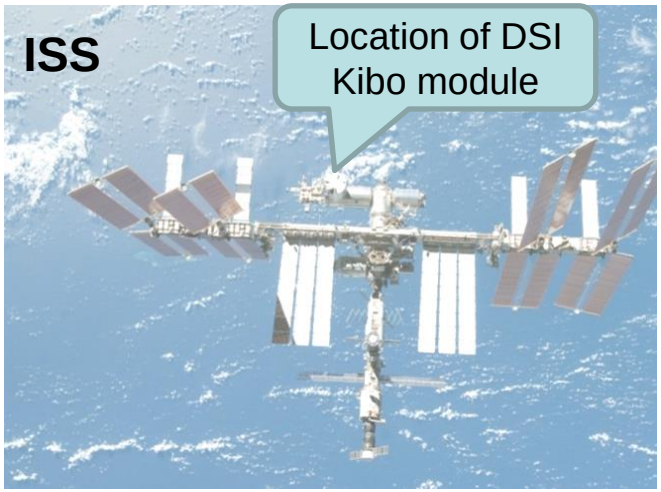
Transparent systems →
In situ and real time observation of interfacial microstructure

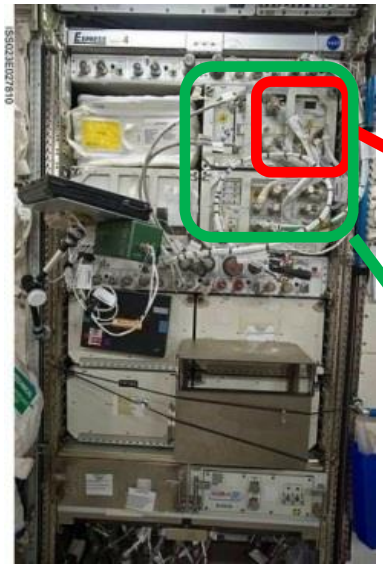
Large cylindrical crucible →
extended patterns

Onboard the ISS from 2009 to 2011 →
microgravity experiments dedicated to cellular regime

Experiments on ground →
understand the effect of convection

Onboard the ISS from 2017 to 2018 →
microgravity experiments dedicated to dendritic regime





DSI
(**D**irectional
Solidification
Insert)

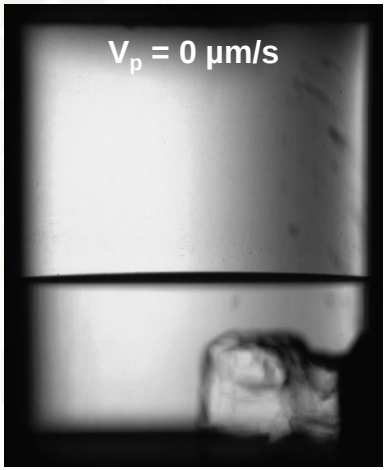
DECLIC

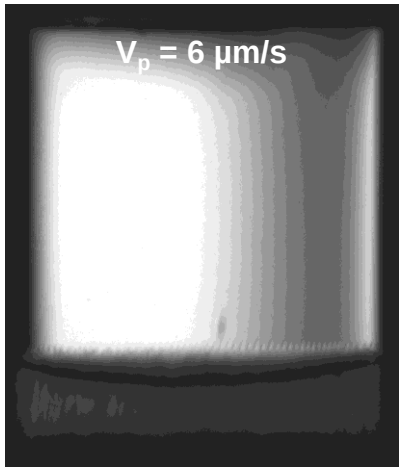
Experiments in the DECLIC-DSI

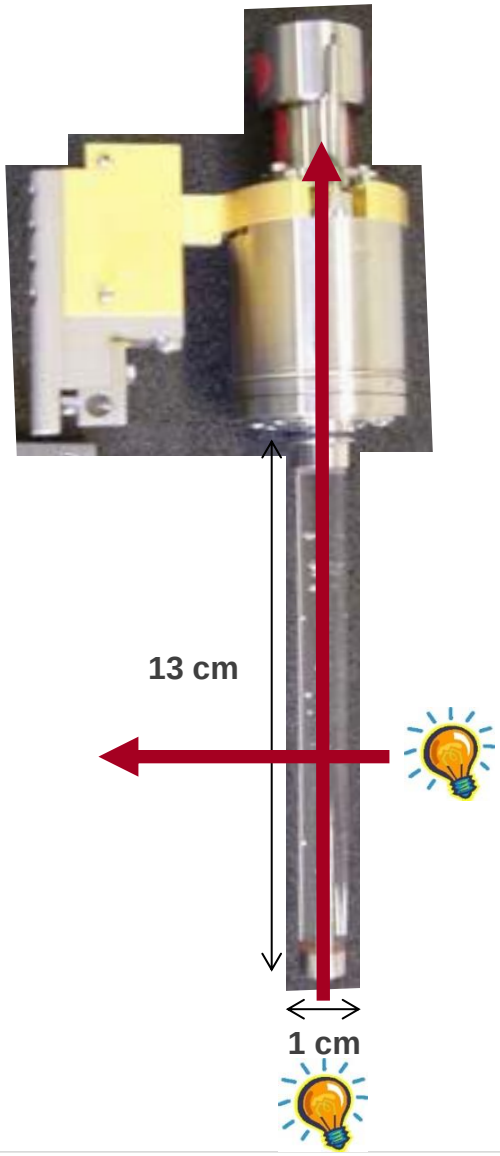
Cylindrical crucible

Diameter: 1 cm
Solidification length: 10 cm
SCN – 0.24 wt% camphor
V: 0.1 – 30 µm/s
G: 12 and 19 K/cm
Solid seed: single crystal of selected orientation; kept during the whole flight campaign

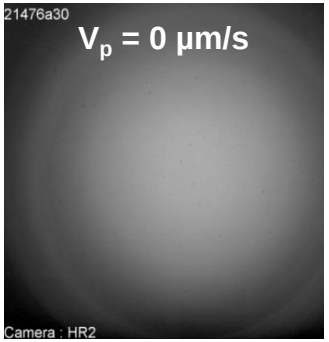
Side view

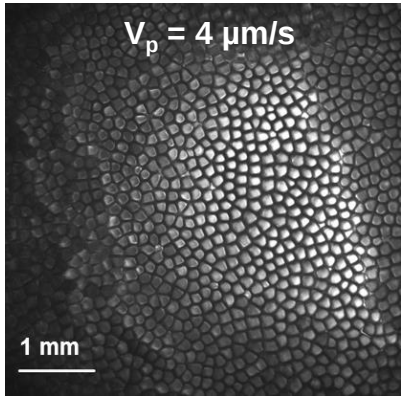


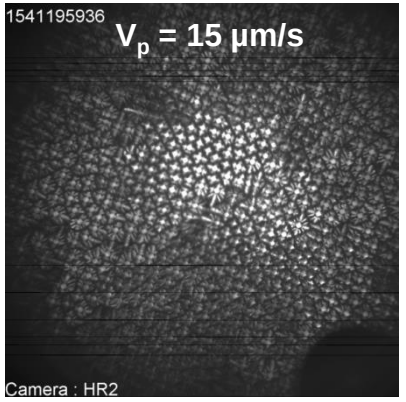




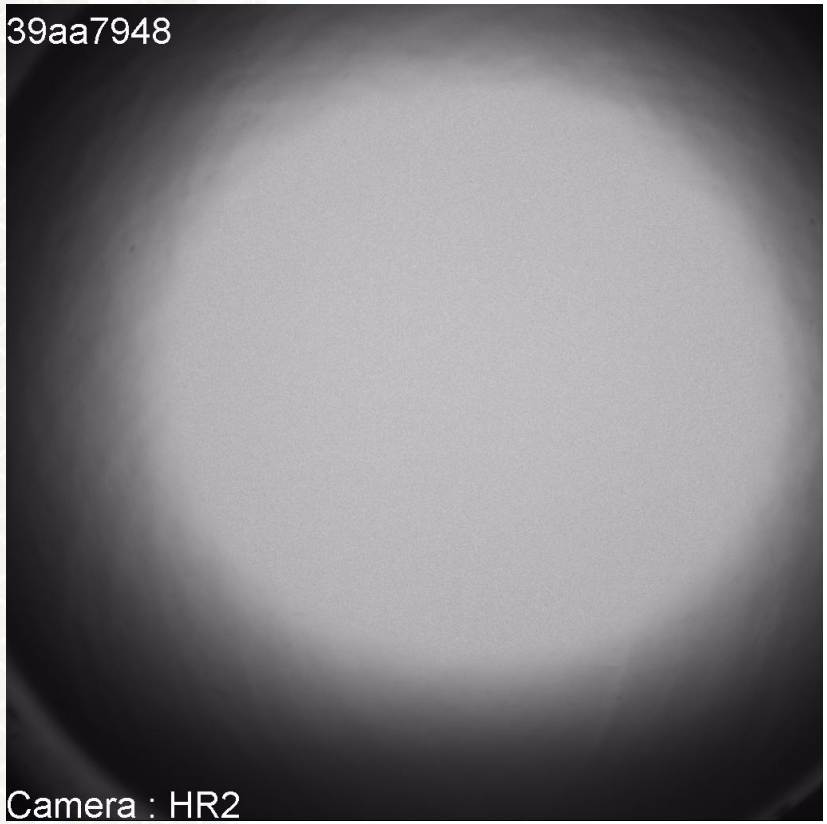
Axial view







Reference experiment



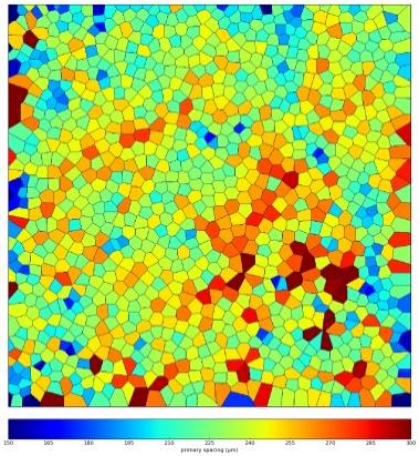
7.37 x 7.37 mm² Real duration: 9h
V_p = 2 µm/s G = 19 K/cm

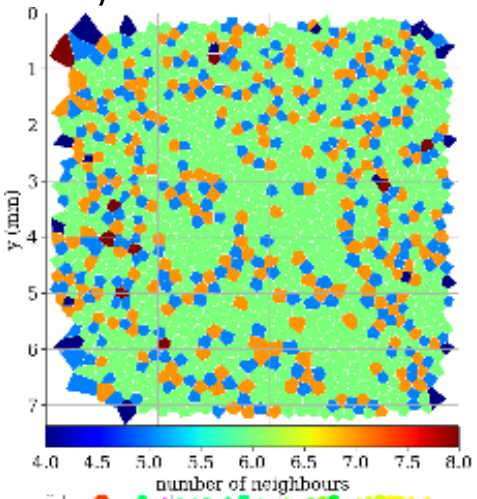
→ Pattern sliding
→ Very few tip-splittings
→ Areas of high elimination

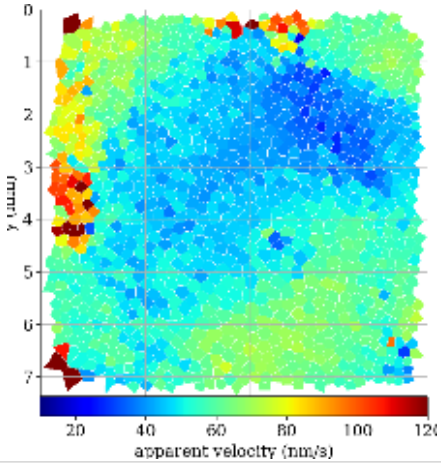
Pattern analysis

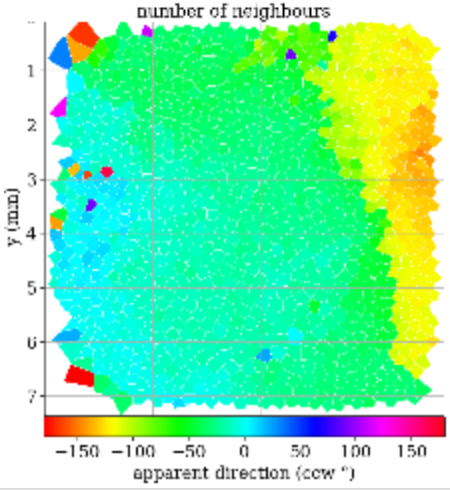
In-house software to follow each cell in time:

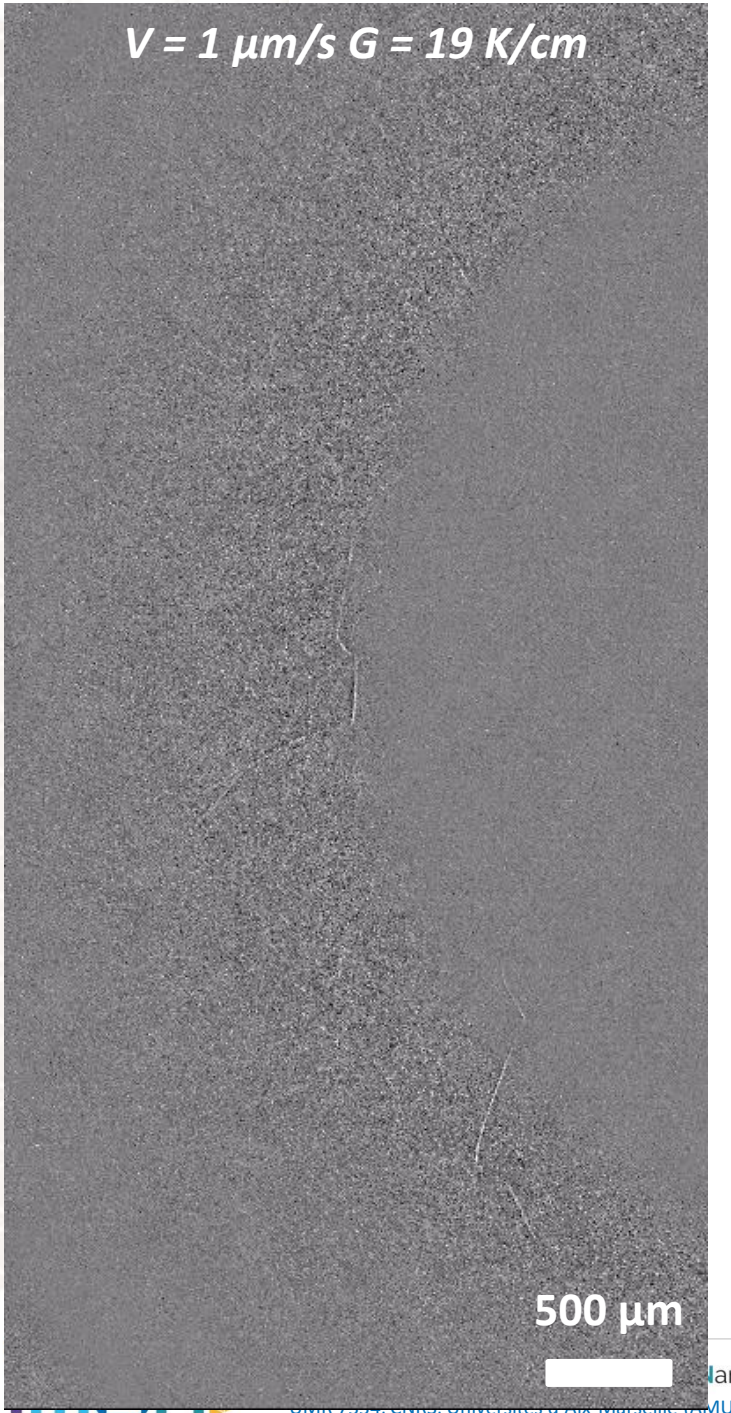
→ Primary spacing
→ Number of 1st neighbors
→ Trajectories (V, direction)











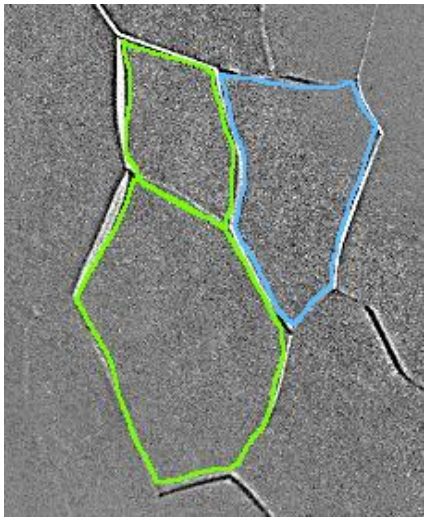
Evidence of Sub-boundaries

→ All boundaries are moving due to non-negligible surface tension anisotropy

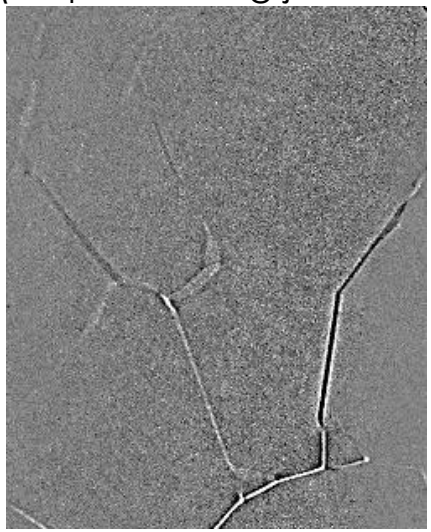
- Confirms the sub-boundary nature
- Even at rest, some SB are moving at very low velocity – SB coarsening

→ Motion associated to numerous phenomena → **dynamical reorganization**

Elimination of SG



Nucleation of a new SG (on pre-existing junctions)

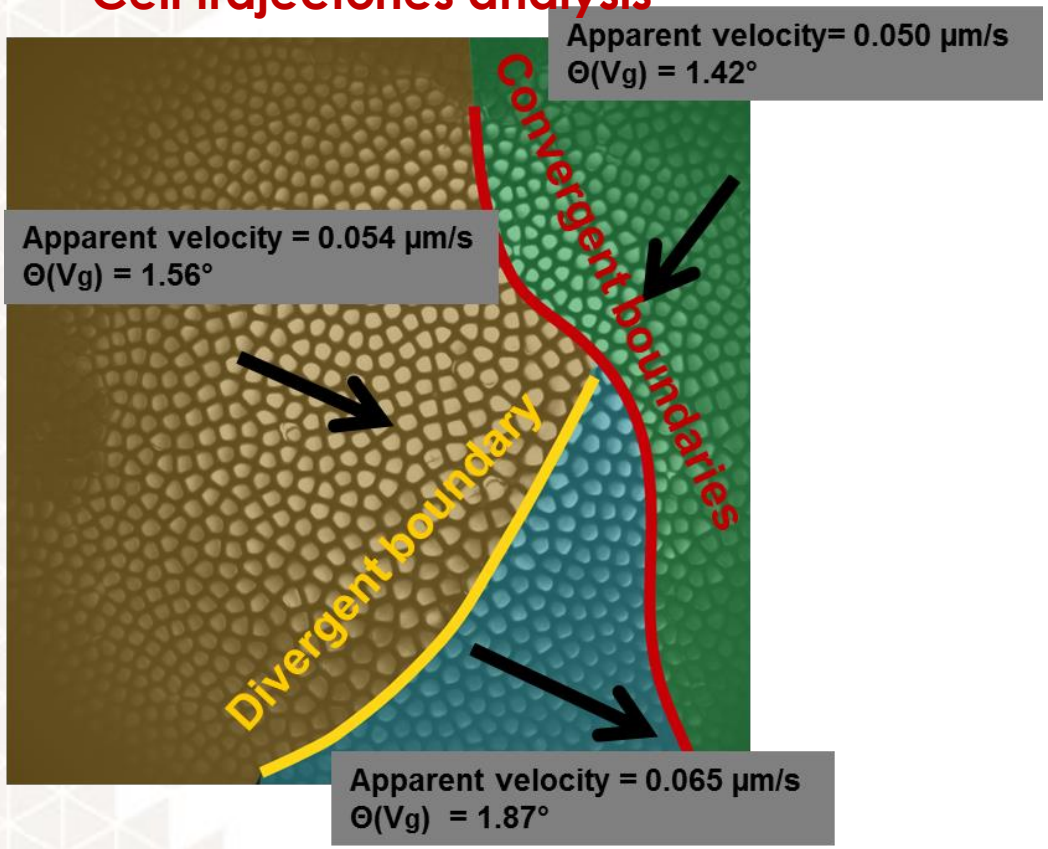


→ **All the Sub-grain boundaries are fixed when morphological instability triggers**

S. Bottin-Rousseau et al. PRB 66 (2012) 4102
G. Faivre et al. CR Phys 14 (2013) 149

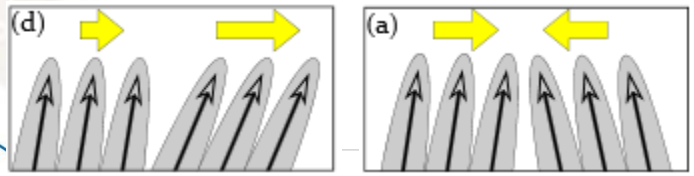
Effect of sub-grain on the dynamics of primary spacing

Cell trajectories analysis

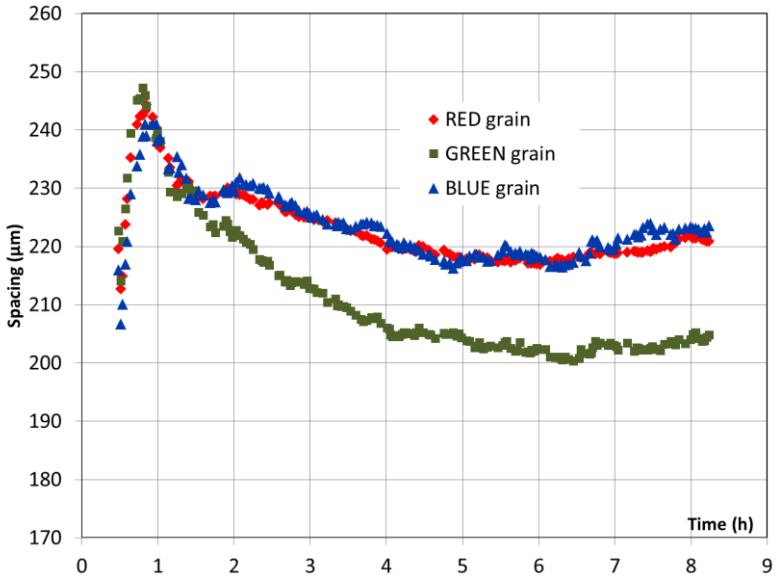


→ 3 areas of ≠ Vg and ≠ θ ⇒ **3 sub-grains**

→ **Divergent and convergent GB**



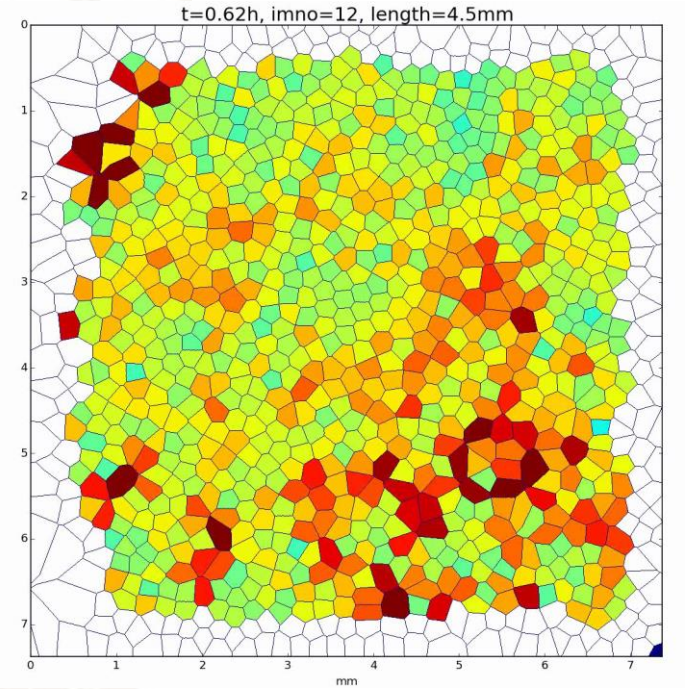
Primary spacing evolution by sub-grain



→ Noticeable differences of λ evolution depending on sub-grain

→ **Cannot be attributed to differences of misorientation (1.4° < θ(Vg) < 1.9°)**

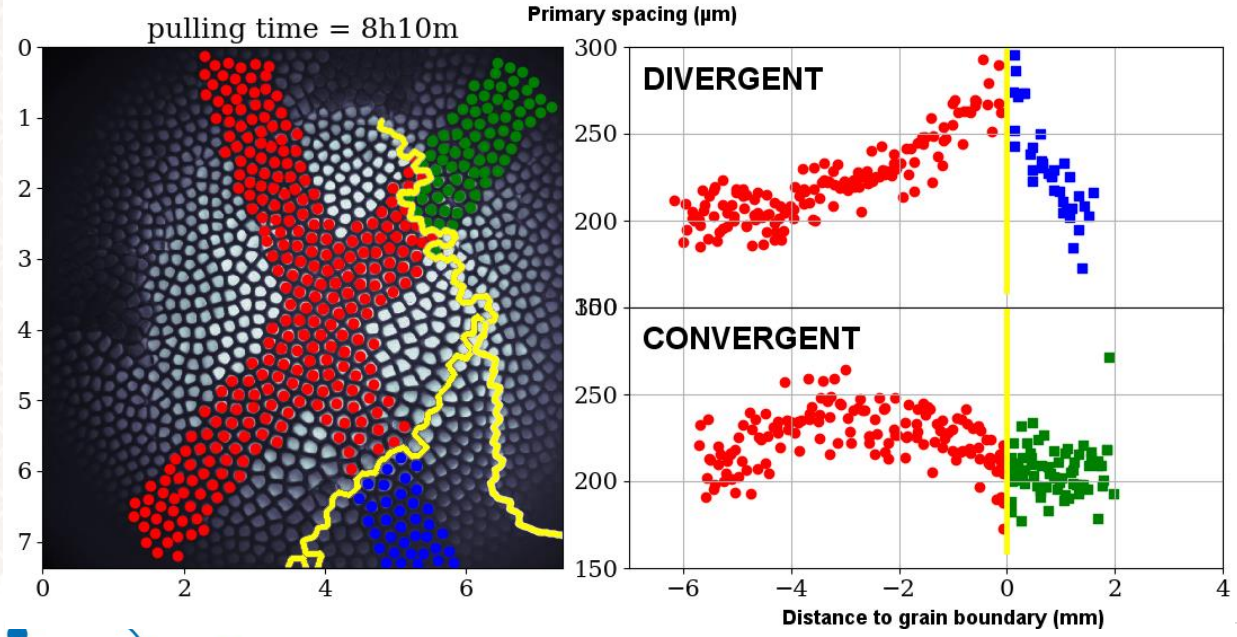
Boundaries configuration



→ **Initially:** large distribution of λ, homogeneously distributed

→ **With time:** global decrease of λ except around the divergent GB

Primary spacing map
Duration: 6.5 h



→ **The evolution of primary spacing strongly depends on the distance to the divergent GB (effect ≈ 20 cells)**

→ **The effect of convergent GB is of shorter distance (≈ 5 cells)**

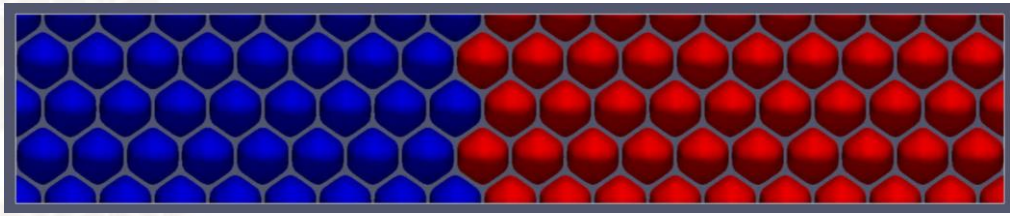
Critical role of boundaries

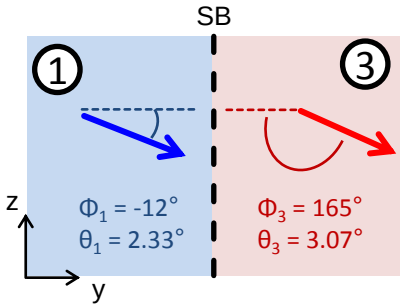
Divergent SB: comparison experiment and PF

→ Target condition: V_p = 2 μm/s, G = 19 K/cm

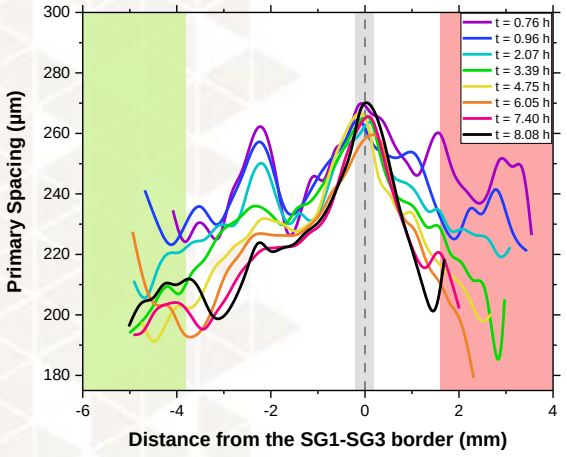
→ Regular hexagonal array (λ = 220 μm)

→ Simulation box: 3960.74 × 760.14 μm²

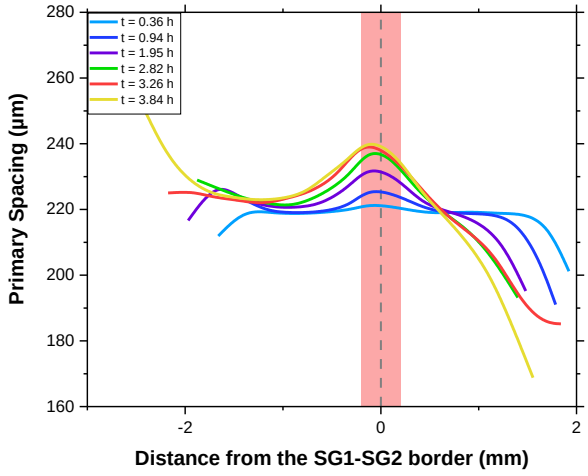




EXPERIMENT



3D SIMULATION



→ The **plateau λ on the left** is decreasing in experiment, while increasing in the 3D PF simulation

- **Exp:** the source produces cells with smaller λ
- **PF:** the source produces cells with larger λ

→ The **shape of the λ peak** extends in simulation while becomes narrower in experiment

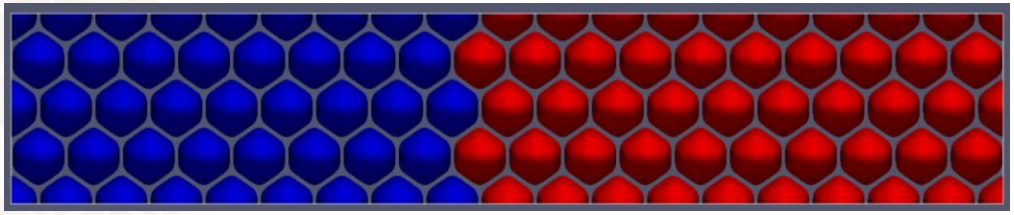
Long distance effect of sources?

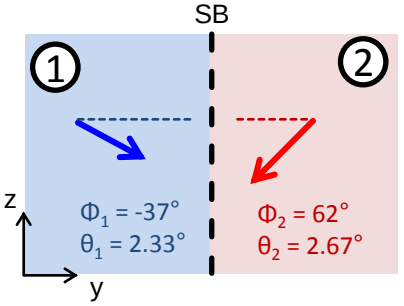
Convergent SB: comparison experiment and PF

→ Target condition: V_p = 2 μm/s, G = 19 K/cm

→ Regular hexagonal array (λ = 220 μm)

→ Simulation box: 3960.74 × 760.14 μm²



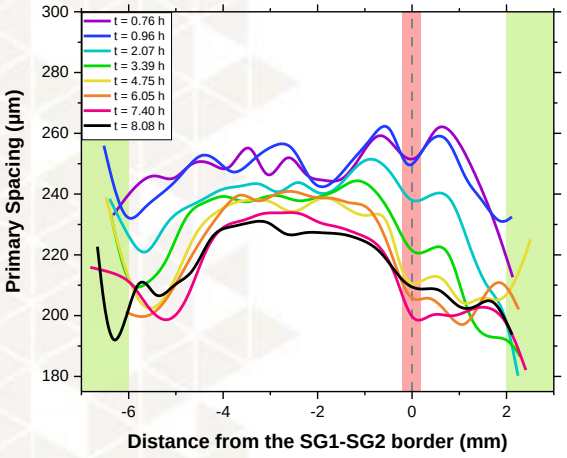


→ **Mechanisms along SB**

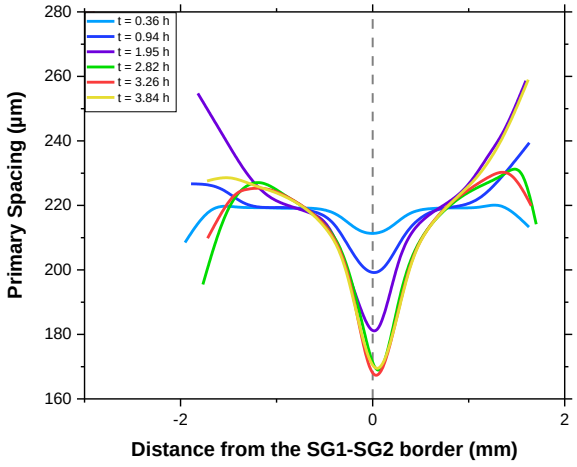
- **Exp:** SB ≈ stable, numerous eliminations
- **PF:** incursions

→ The **λ at the SB** keeps decreasing until reaches the lowest point

EXPERIMENT



3D SIMULATION



→ The **plateau λ on the right side of SB** is decreasing in experiment, while increasing in the 3D PF simulation

- **Exp:** the source produces cells with smaller λ
- **PF:** the source produces cells with larger λ

Long distance effect of sources?

Conclusion

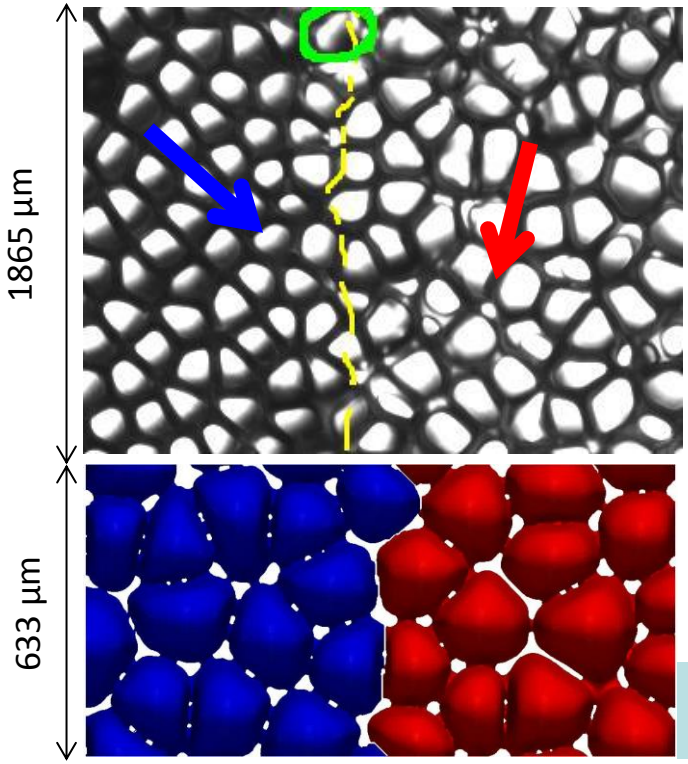
⇒ **Success of µg experiments:** extended 2D patterns of cells

→ **Benchmark data in diffusive transport mode**

⇒ **Critical role of sub-boundaries configuration on primary spacing evolution**

→ *3D phase simulations in progress…*

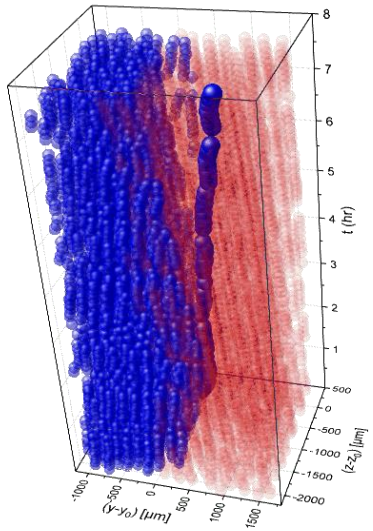
⇒ **1st observation of solitary cells:** 3D phase field simulations



V_p = 1.5 µm/s
G = 19 K/cm

→ **Behavior maps = f(orientation angles)**

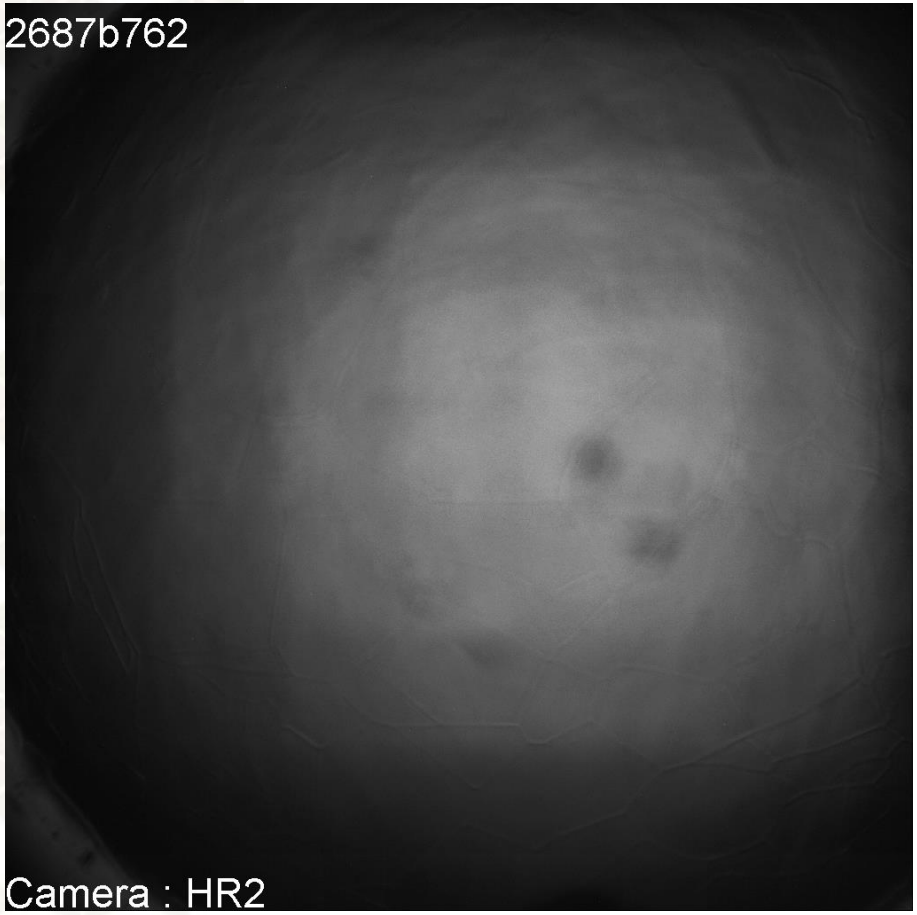
Orientation defect



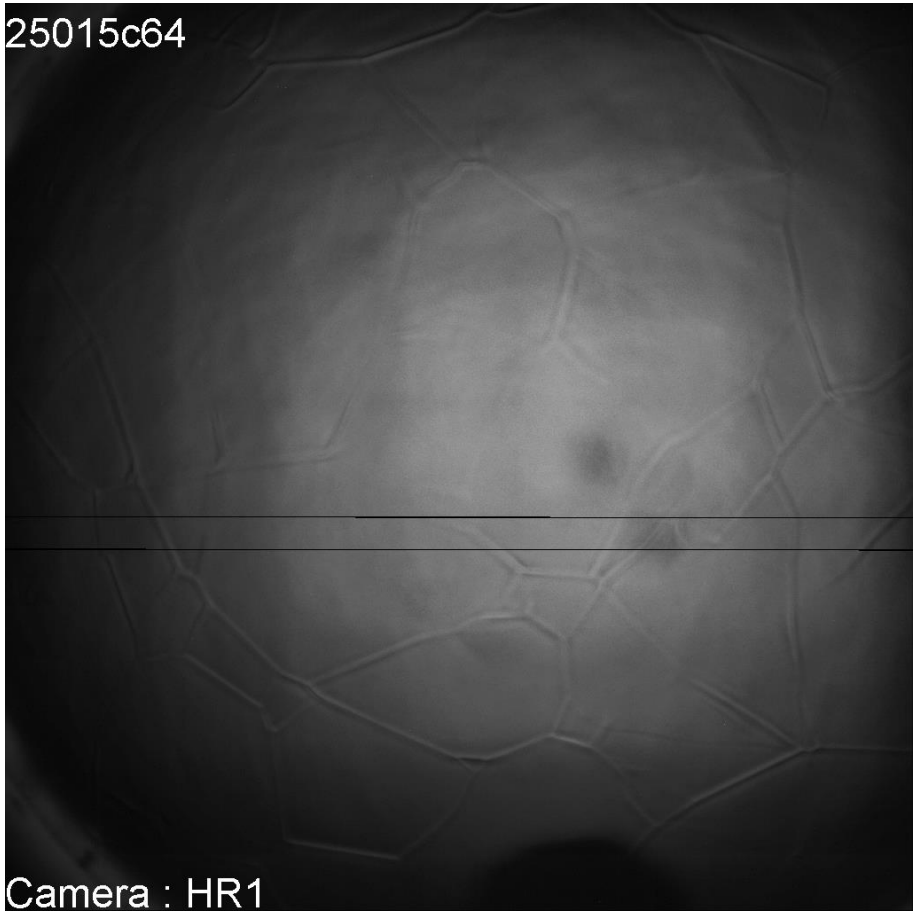
DSI-R: dedicated to the dendritic regime

→ Increase of concentration ⇒ **Dendrites at lower pulling rates**

→ Study of **the formation of well-developed dendritic array structures**



V_1 = 12 V_2 = 3 µm/s, G = 12 K/cm, *3h28min*



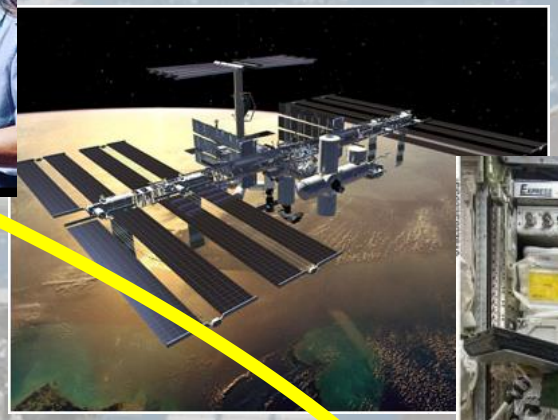
V_1 = 1.5 V_2 = 12 µm/s, G = 12 K/cm, *6h15min*

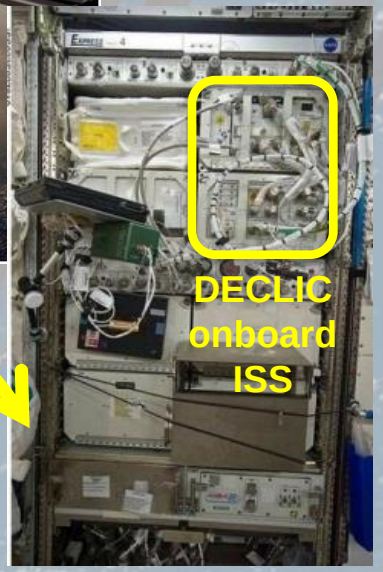
Image IM2NP

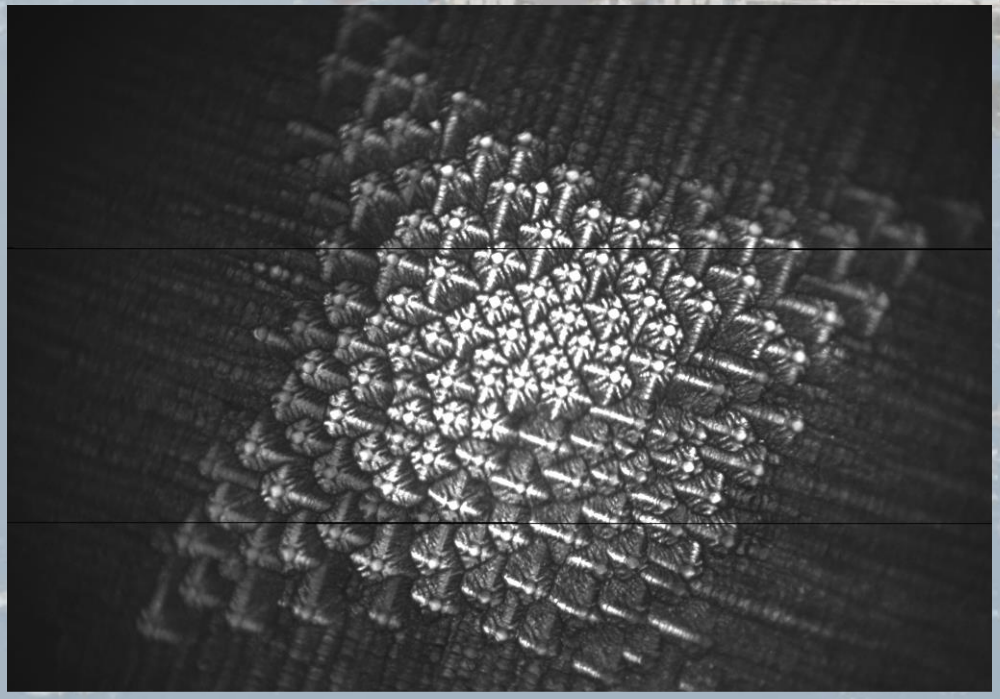
Image CADMOS-CNES/Sébastien Rouquette

Deepest thanks to

CNES and NASA







Thank you for your attention

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