Description of Additional Supplementary Files

File Name: Supplementary Movie 1
Description: an experimental video showing in situ observations during microgravity directional solidification of a succinonitrile (SCN)-0.24wt% camphor alloy at a velocity $V = 1.5 \mu m/s$ within a temperature gradient $G = 19 K/cm$, from $t = 0$ to 11 h (Fig. 1 in the Letter). These optical images were recorded from a camera with an immersed lens in the liquid directly facing the solidification front main growth direction.

File Name: Supplementary Movie 2
Description: an experimental video showing the emergence and drifting of a solitary cell (SC), corresponding to Fig. 1d-h in the Letter, from $t = 3.5$ to 11 h (SCN-0.24wt% camphor alloy, $V = 1.5 \mu m/s$, $G = 19 K/cm$). The SC drifts within the neighbor host grain and ultimately is eliminated by being squeezed between two cells from two different grains.

File Name: Supplementary Movie 3
Description: an experimental video showing the emergence and progression of a solitary cell (SC) during microgravity directional solidification of a SCN-0.24wt% camphor alloy at $V = 1.5 \mu m/s$ and $G = 19 K/cm$ within a foreign host grain from $t = 3.5$ to 11 h (Fig. 2a of the Letter).

File Name: Supplementary Movie 4
Description: an experimental video showing the early stages of planar interface destabilization, followed by the emergence and drifting of a SC during directional solidification of a SCN-0.24wt% camphor alloy with $V = 2.0 \mu m/s$ and $G = 19 K/cm$ from $t = 0$ to 8.2 h (Supplementary Fig. 1).

File Name: Supplementary Movie 5
Description: shows the threedimensional locations of cell tips post-processed from the experiment of Fig. 2 in the Letter (SCN-0.24wt% camphor alloy, $V = 1.5 \mu m/s$, $G = 19 K/cm$, from $t = 3.5$ to 11 h). Blue and red colors correspond to left and right grains, respectively, in Fig. 2a. The video highlights the roughening and branching of the GB, and the subsequent formation of a tubular GB defect.

File Name: Supplementary Movie 6
Description: shows phase-field simulation results of the microstructure evolution at $V = 1.5 \mu m/s$ and $G = 19 K/cm$ of a SCN0.24wt% camphor alloy from $t = 0$ h to $t = 12$ h. The horizontal and vertical domain sizes are $L_x = 1912 \mu m$ and $L_z = 633 \mu m$, respectively. This simulation uses crystal angles, $(\theta_1, \phi_1) = (6°, -56°)$ for the left (blue) grain and $(\theta_2, \phi_2) = (3°, 84°)$ for the right (red) grain, similar to those measured in experiments. A SC emerges at $t = t_0 = 2.6$ h (Fig. 3a in the Letter) and drifts within the red host grain, with a drifting direction dictated by its original grain orientation independently of the drifting direction of the host grain. Periodic boundary conditions apply along the top and bottom boundaries.
File Name: Supplementary Movie 7
Description: shows the three-dimensional trajectories of cells (in blue and red lines for the left and right grains) and the resulting GB morphology (cyan surface) in the phase-field simulation of Supplementary Movie 6 and Fig. 3 of the Letter (SCN-0.24wt% camphor alloy, $V = 1.5 \ \mu m/s, \ G = 19 \ K/cm$, from $t = 2.6$ to $12 \ h$). It highlights the roughening and branching of the GB, and the subsequent formation of a tubular GB defect.

File Name: Supplementary Movie 8
Description: shows phase-field simulation results of the evolutions of bicrystalline microstructures with different crystal orientations, corresponding to Fig. 4c-f in the Letter, namely GB stability (0 s to 8 s), grain interpenetration (8 s to 16 s), one-side grain penetration (16 s to 25 s), and SC emergence (25 s to 33 s).