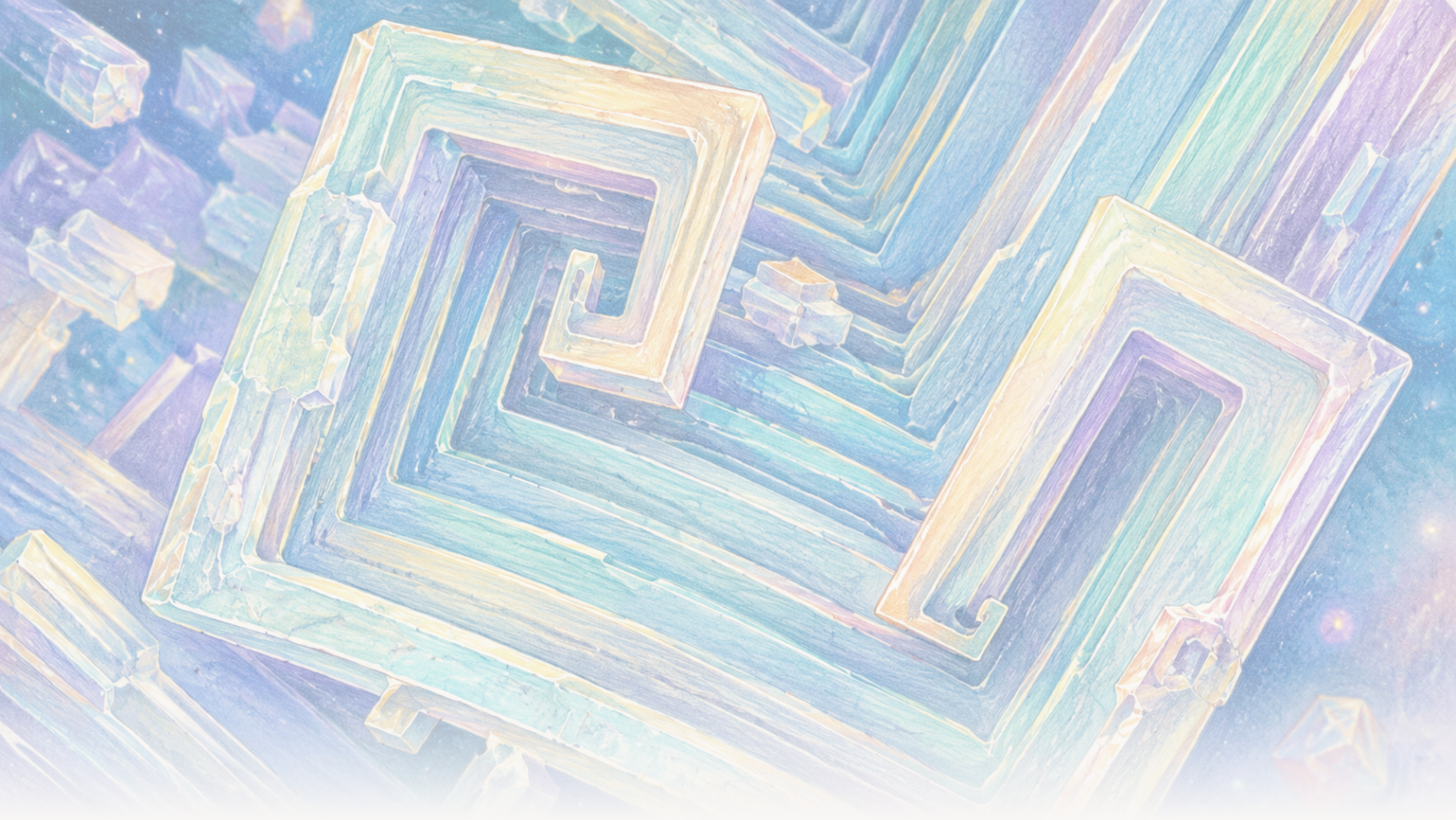

The Clean Paper

WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

A orbit, gishirin tebur ya girma ya zama cubes masu rami. Gravity ta canza brine, ba gishirin ba

Crystals na sodium chloride da aka girma a International Space Station sun haɗa da cubes masu rami da matakai masu faɗin 2 zuwa 8 millimetres. Takardun suna goyon bayan bayanin transport: nutsewar yau da kullum da buoyancy-driven flow sun ragu sosai, yayin da diffusion ya fi rinjaye a farkon girma. Lattice ɗin bai zama sabon nau'in gishiri ba, kuma gwaje-gwajen ba su kafa tsarin masana'antu ba.

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Paper: *Comparison of sodium chloride hopper cubes grown under microgravity and terrestrial conditions*, Donald Pettit and Pietro Fontana, npj Microgravity 5, 25 (2019) · DOI: 10.1038/s41526-019-0085-0

A sararin samaniya, gishirin tebur na yau da kullum ya girma ya zama cubes masu rami da matakai

Crystals ɗin sun yi kama da gine-gine: murabba'ai a cikin murabba'ai, fuskokinsu sun nutse suna yin matakai kamar bene.

An yi su ne da sodium chloride na yau da kullum, sinadari iri ɗaya da gishirin tebur. Abin da ya bambanta ba kayan ba ne. Ruwan gishirin da ke kewaye da su ne.

A Duniya, crystal da ke girma a cikin ruwa mai girman santimita zai iya nutsewa, ya taɓa bango ko wani saman abu, kuma ya taimaka wajen samar da bambancin density da ke jujjuya ruwan. A International Space Station, nutsewar al'ada da kwararar ruwa da buoyancy ke motsawa sun ragu sosai. Wasu crystals na gishiri sun ci gaba da shawagi na dogon lokaci har suka yi girma a hankali kuma cikin daidaito mafi kyau zuwa **hopper cubes** masu gefuna daga 2 zuwa 8 millimetres.

Takardu uku, da aka buga a 2011, 2015 da 2019, sun bayyana waɗannan gwaje-gwaje. Idan aka haɗa su, suna ba da darasi mai kyau a physics na transport: canza yadda sinadarin da ya narke ke isa ga crystal na iya canza siffarsa da ido ke gani ba tare da canza tsarin atoms ɗinsa ba.

Ba su nuna cewa sararin samaniya yana samar da cikakkun crystals ba, ba su kafa wata hanyar masana'antu ba, kuma ba su gano wani sabon nau'in gishiri ba.

Me ke sa cube ya zama hopper

Crystal na sodium chloride na yau da kullum yana da tsarin atoms mai siffar cube. **Hopper crystal** har yanzu cubic ne, amma kusurwoyinsa da gefunansa suna girma da sauri fiye da tsakiyar fuskokinsa. Sakamakon shi ne rami mai matakai a kowace fuska, kamar cube ɗin ya fara gina firam ɗinsa kafin ya cika bangon.

Wani misali na ISS daga baya yana nuna wannan tsarin girma sosai, amma yana ba da yanayin gani ne kawai, ba hujja daga takardun sodium chloride guda uku ba. Hoton Donald Pettit da time-lapse da ke ƙasa suna nuna **potassium chloride**, wani gishiri daban, yana samar da hopper mai matakai da siffofin scroll a microgravity.

[figure_pair pending]

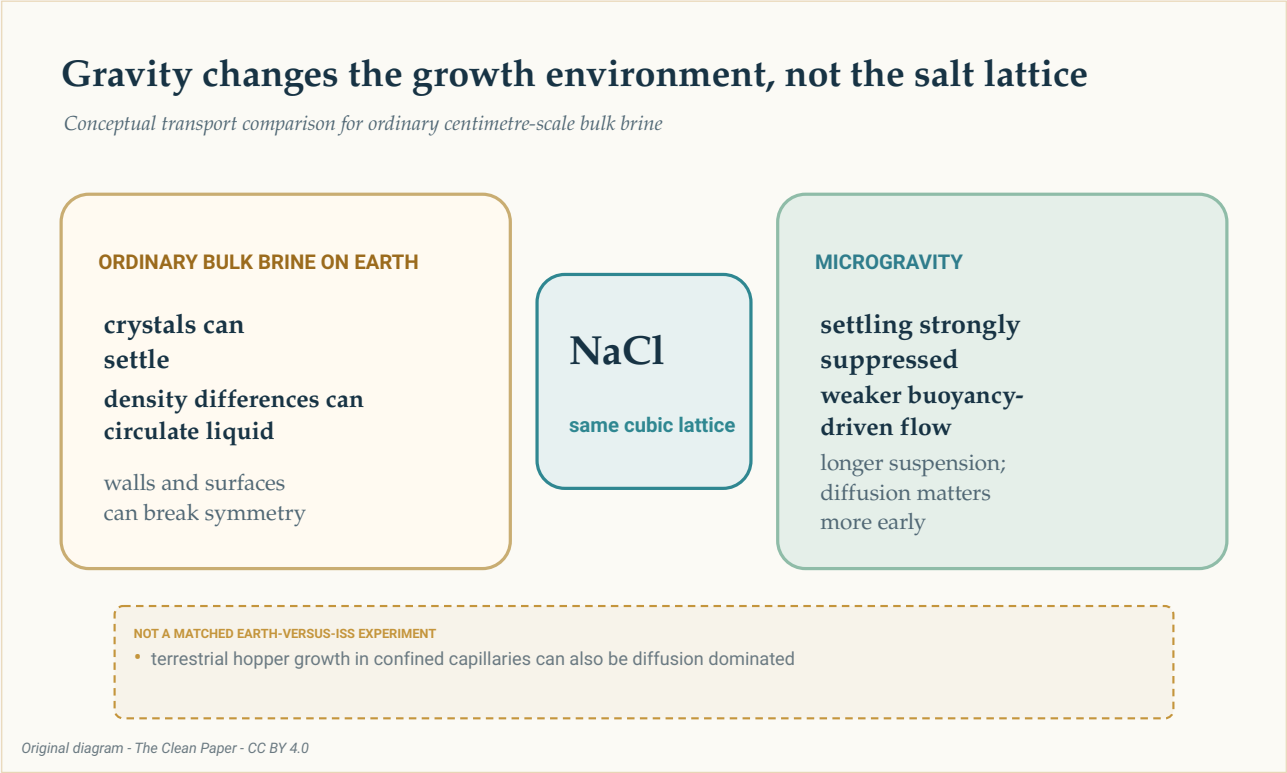
Hotunan scanning electron microscope guda biyu na potassium chloride mai siffar scroll-form hopper crystals da aka girma a ISS. Waɗannan hotuna na baya misalai ne na morphology kawai; ba samfurin sodium chloride ba ne kuma ba aunawa daga binciken 2011, 2015 ko 2019 da wannan labarin ya tattauna ba ne.

[video pending]

Wani time-lapse na baya na girman potassium chloride hopper a cikin siririn fim na ruwa a microgravity. Yana nuna girman gefuna da kusurwoyi, ba gwaje-gwajen sodium chloride ko bayanan da aka nazarta a wannan labarin ba.

Crystals suna girma daga **supersaturated brine**: ruwan gishiri da ya ƙunshi sodium chloride da ya narke fiye da abin da zai iya riƙewa a equilibrium a ƙarƙashin wadannan yanayi. Ions na sodium da chloride dole ne su yi tafiya cikin ruwan su haɗu da saman crystal.

Akwai manyan hanyoyi biyu na motsa su. **Diffusion** shi ne motsin bazuwar molecules da ke ɗaukar sinadarin da ya narke daga inda concentration yake da yawa zuwa inda yake ƙasa, ba tare da dukan ruwan yana juyawa ba. **Convection** kuwa motsin ruwan kansa ne. A ƙarƙashin gravity na yau da kullum, ƙananan bambance-bambance a zafi ko concentration na iya canza density su haifar da kwararar buoyancy. Crystals kuma za su iya **sediment**, wato su nutse cikin ruwan.



Kwatancen ra'ayi yana nuna tsarin sodium chloride iri ɗaya a muhallin biyu. A Duniya, babban ruwan gishiri na iya samun nutsewa, zagayawar buoyancy da taba saman abu; microgravity yana rage biyun farko sosai, yana barin crystal ya daɗe yana shawagi kuma diffusion ya fi muhimmanci a farkon girma. Wannan ba gwajin Earth-versus-ISS da aka yi daidai-da-daidai ba ne.

An yi wannan gwajin a International Space Station, dakin gwaje-gwaje mai kewaya Duniya a yanayin microgravity. Kalmar **microgravity** ba tana nufin babu gravity ba. Takardar 2019 ta ruwaito residual acceleration kusan kashi miliyan 1.2 na gravity a saman Duniya, ko 1.2 micro-g, tare da jinkirin motsin ruwa mai maimaituwa. Muhallin ya canza daidaiton transport; bai sa ruwan gishirin ya tsaya cik gaba ɗaya ba.

Hanya mai jinkiri zuwa cubes masu girman millimetre

Binciken 2019 ya mayar da hankali kan hopper cubes da suka girma yayin da ruwa ke ƙafewa daga brine a ISS. Gefunan cubes da aka ruwaito sun kai **2 zuwa 8 millimetres**. Saurin girma ya kai daga **0.34 zuwa 1.0 micrometres a minti** (kimanin **0.49 zuwa 1.44 millimetres a rana**), da matsakaici **0.68 micrometres a minti** da standard deviation 0.23.

A wannan matsakaicin saurin, gefen millimetre 8 zai ɗauki kusan mako guda ya samu. Wannan lissafi kiyasi ne, ba time-lapse ma’auni na kowane mataki na crystal ɗaya ba.

Marubutan sun kiyasta supersaturation ƙasa da **1.002**. Littattafan kwatance na ƙasa da suka kawo sun bayyana hopper growth a supersaturation mafi girma sosai, sama da 1.45, da saurin 10 zuwa 110 micrometres a na biyu na seconds ko mintuna, yawanci suna samar da cubes ƙasa da 250 micrometres.

Wannan kwatancen yana da amfani amma ba matched comparison ba ne. Crystals na ISS da bayanan ƙasa daga littattafai ba su fito daga gwaje-gwajen Earth da orbit da aka yi lokaci guda, da kayan aiki da yanayi iri ɗaya, ƙarƙashin ƙungiya ɗaya ba. Kwantena, interfaces da hanyoyin gwaji daban-daban na iya yin tasiri tare da gravity.

Saboda haka, bambancin da ya fi ƙarfi shi ne bayanin abin da aka gani: a waɗannan lura na ISS, hopper cubes sun girma a hankali, a supersaturation mai ƙasa, tsawon kwanaki zuwa makonni, kuma suka kai girman millimetre.

Diffusion ya fi tasiri a farko; daga baya motsin ruwa har yanzu yana yiwuwa

Takardar 2019 ta yi amfani da **Peclet number** wajen kwatanta transport ta motsin ruwa da transport ta diffusion. Ƙima ƙasa da ɗaya tana nufin diffusion ya fi muhimmanci; ƙima sama da ɗaya tana nufin motsin babban ruwa zai iya fi tasiri.

> **Rabo ne, ba maɓallin kashewa da kunnawa ba**
>
> Peclet number kwatance ne tsakanin saurin transport guda biyu. Ba ya raba duniya zuwa ruwa da ya tsaya cik gaba ɗaya a ƙasa da ɗaya da pure convection a sama da ɗaya. A nan ƙimar ta canza da girman crystal da kuma kiyasin velocity da aka yi wa brine da ke kewaye. Ƙananan crystals sun kasance a fili cikin yanayin da diffusion ya fi rinjaye; crystal mafi girma a babban vessel na iya shiga yanayin da jinkirin motsin ruwa ya fara muhimmanci.

A cikin ƙananan drops masu kusan 0.8 centimetres, ƙididdigar Peclet ta tashi daga kusan **0.0004** kusa da nucleation zuwa kusan **0.03** a girman ƙarshe da aka auna. Diffusion ya ci gaba da rinjaye.

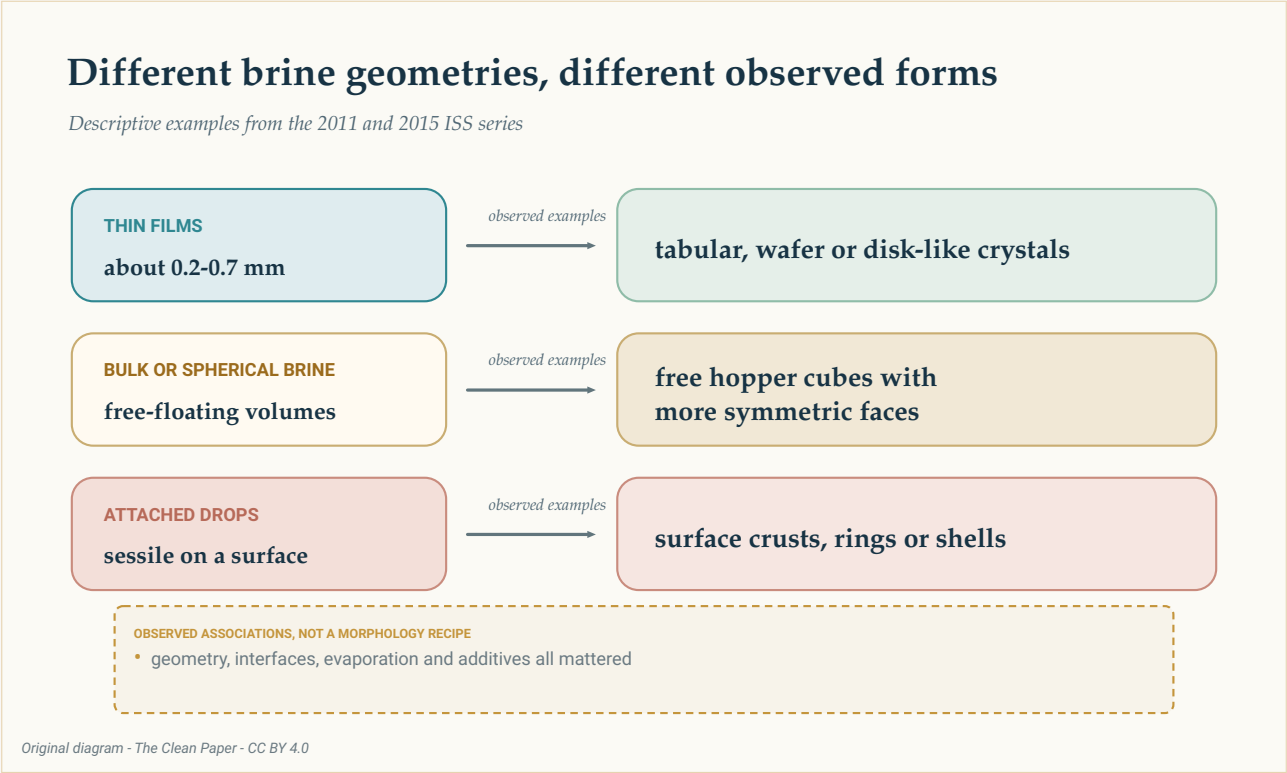
A crystallizers masu 2 zuwa 3 centimetres, kiyasin ya tashi daga kusan **0.05** ga nucleus mai 50 micrometres zuwa kusan **4** ga gefe mai 4 millimetres. Farkon girma har yanzu diffusion ne ya fi rinjaye, amma jinkirin motsi mai maimaituwa na iya taimakawa daga baya.

Shi ya sa cewa “microgravity ta kawar da convection” ba daidai ba ne. Zagayawar ruwa da buoyancy ke motsawa

da nutsewa na yau da kullum sun ragu sosai. Amma residual acceleration da motsin da za a iya auna sun ci gaba da kasancewa.

Siffar ruwan ma ta yi tasiri

Takardar 2011 da takardar 2015 sun faɗaɗa hoton. Sun ruwaito samuwar crystals na gishiri a thin films, layers na ruwa masu kauri, kusan spherical brine volumes da drops da suka manne da wani surface.



Layuka uku suna taƙaita misalan da aka lura a cikin wannan dossier: thin films da tabular ko disk-like forms, bulk ko spherical brine da free hopper cubes, da attached drops masu crusts, rings ko shells. Waɗannan alaka ne da aka lura, ba girke-girke ko tabbaci ba.

A binciken 2011, thin films masu kauri kusan 0.2 zuwa 0.7 millimetres sun samar da siraran wafers da tabular crystals. Brine volumes masu shawagi cikin ’yanci sun ba lateral faces damar yin daidaito mafi kyau da kuma samar da hopper cubes.

Lura na 2015 sun haɗa da thin sheets masu kauri 0.2 zuwa 0.7 millimetres, layers masu kauri kusan 4 zuwa 6 millimetres da attached hemispherical drops masu faɗi kusan 20 zuwa 32 millimetres. Siffofin da aka ruwaito sun haɗa da tabular hoppers, cubes, disk-like crystals, dendrites, rings da shells. K’ara polyethylene glycol ya rage hopper growth a wani saitin lura.

Marubutan sun bayyana aikin 2015 a matsayin lura da aka yi da kayan da ba a inventory ba a lokacin hutun crew, ba tsayayyen shirin bincike ba. Misalan suna nuna cewa geometry na ruwa, interfaces, evaporation da additives

duk sun yi tasiri. Ba su kafa deterministic recipe inda siffar container guda take tabbatar da siffar crystal guda ba.

Tsarin crystal bai koma sabon nau’in gishiri ba

Bambanci tsakanin **crystal structure** da **morphology** yana da muhimmanci.

Structure shi ne tsarin atoms da ke maimaituwa. Morphology ita ce siffar waje da ido ke gani. Neutron diffraction a takardar 2011 bai gano canjin tsarin sodium chloride ko canjin lattice-cell parameters idan aka kwatanta da samfurin ƙasa ba. Samfurin orbit kuma sun ƙunshi **brine inclusions**, ƙananan aljihunan solution da suka makale a cikin crystal.

Saboda haka, girma da daidaitaccen kamannin ba hujja ba ne cewa kayan sun fi tsafta ko ba su da defects. Babu wata takarda a cikin dossier da ta ruwaito higher chemical purity, better mechanical performance ko dacewa da wani takamaiman na’ura.

Gravity ta yi tasiri ne kai tsaye ba a kan bonds ba. Ta canza nutsewa, zagayawar ruwa, orientation da taɓa surfaces. Ba ta canza ƙarfan sodium-chloride bonds ba kuma ba ta samar da sabon atomic phase ba.

Abin da waɗannan gwaje-gwajen za su iya koya mana — da abin da ba za su iya ba

Takardun suna goyon bayan bayani na transport: rage nutsewar yau da kullum da buoyancy-driven flow sosai ya bar wasu crystals suna shawagi na dogon lokaci suna girma a hankali cikin yanayi mai daidaito. Girman, rates da siffofin da aka auna lura ne kai tsaye; supersaturation, growth history da Peclet ƙimomi sun ƙunshi estimates; kwatancen da Duniya kuma ya dogara wani ɓangare ga wasu gwaje-gwajen da aka buga.

Babu denominator guda mai tsabta ga wannan dossier. Yana haɗa crystals guda-guda, crystallizers da zaɓaɓɓun misalai daga takardu uku. Tara su cikin total guda zai sa a yi tunanin uniform gwaji ne, alhali babu shi.

Binciken kuma bai ruwaito hujjar da ake buƙata don yin ikirari na manufacturing ba. Ba su auna throughput, production cost, energy use, yield, reliability ko useful material performance ba. Jerin 2015 exploratory ne. Kwatancen ƙasa ba matched controls ba ne. Kuma kasancewa babba ko mai jan hankali ga ido ba yana nufin ya fi kyau ga application ba.

Natural salt deposits na iya ƙunsar hopper cubes masu girman centimetres, wani lokaci suna shawagi a laka da brine ya jiƙa. Takardar 2019 ta ba da shawarar yiwuwar kamanceceniya da slow, diffusion-dominated growth. Kwatance ne mai ban sha’awa, ba hujjar cewa natural da orbital hoppers suna da mechanism guda ba.

Taƙaitaccen bayani

Crystals na gishiri da suka girma daga brine mai ƙafewa a International Space Station sun haɗa da hopper cubes masu rami da matakai masu faɗin 2 zuwa 8 millimetres. Takardun suna goyon bayan bayani na transport: microgravity ta rage nutsewar yau da kullum da buoyancy-driven flow sosai, ta bar girma mai jinkiri da shawagi na dogon lokaci yayin da diffusion ya fi rinjaye a farko. Geometry na ruwa, interfaces, evaporation da additives ma sun shafi morphology. Neutron diffraction bai nuna sabon tsarin sodium chloride ba, kuma brine inclusions sun kasance. Aikin ƙayyadadden case bincike ne na materials science, ba hujjar cewa sararin samaniya yana yin cikakkun crystals ko yana samar da tsarin masana'antu ba.

Binciken ba tare da ƙarin gishiri ba

Abin da takardun suka nuna: Millimetre-scale sodium chloride hopper cubes da wasu morphologies sun girma a geometries daban-daban na brine a ISS. Hopper cubes na 2019 sun girma a hankali a ƙaramin supersaturation da aka kiyasta, tare da diffusion ya fi rinjaye a farko.

Abin da aka fassara daga bayanan: Rage nutsewa da buoyancy-driven flow sosai ya ba da damar dogon shawagi da girma mai daidaito. Jinkirin motsin ruwa na iya yin tasiri a ƙarshen girma a babban crystallizer.

Abin da ba su nuna ba: Sabon atomic form na gishiri, crystals mafi tsafta ko marasa defects, matched Earth-versus-ISS gwaji, fa'idar microgravity ta ko'ina, ko hanyar commercial manufacturing.

Manyan iyakoki: Bincike uku daban-daban da geometries da zaɓaɓɓun misalai daban; kwatancen ƙasa daga bincike daban; transport quantities da aka kiyasta; sassan dossier masu exploratory, ba programmatic ba; da rashin process economics ko performance tests.

Yaya yawan amincewar da mai karatu na gama-gari ya kamata ya yi? Babban amincewa cewa morphologies da slow growth da aka ruwaito a orbit gaskiya ne. Matsakaicin amincewa cewa transport explanation shi ne mafi kyawun bayanin abubuwan da aka lura. Ƙaramin amincewa sosai ga duk wani ikirari da zai mayar da waɗannan gwaje-gwajen gishiri zuwa alkawari na gaba ɗaya game da space manufacturing.

Majiyoyi

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