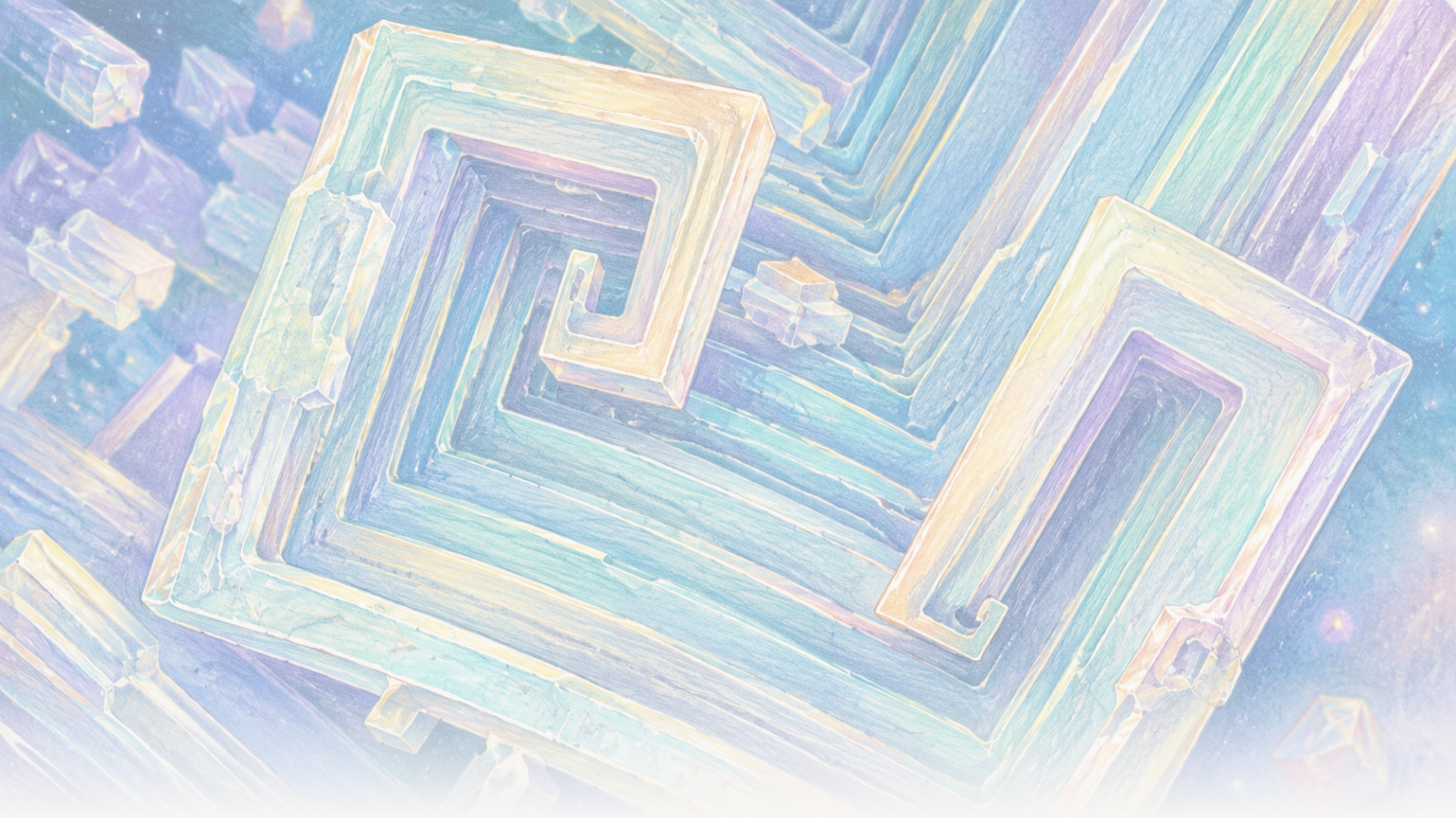

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WHAT THE PAPER SAYS · WHAT IT DOESN'T · WHY IT MATTERS

Orbit keessatti, soogiddi nyaataa cube duwwaa ta'ee guddate. Gravity brine jijjiire, salt miti

Sodium chloride crystals International Space Station irratti guddatan hollow, stepped cubes 2 hanga 8 millimetres across dabalatan. Papers transport explanation deeggaru: ordinary settling fi buoyancy-driven flow baay'ee suppress godhaman, early growth keessatti diffusion dominate godhe. Lattice salt gosa haaraa hin taane, experiments industrial process hin establish godhan.

Written by Matteo · Cross-checked by Vera Rubin · Edited by Michele Renda · Figures by Matteo and Nova Vela · AI-assisted, human-reviewed

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

Orbit keessatti, soogiddi nyaataa idileen cube duwwaa, sadarkaa sadarkaan ijaarame ta'ee guddate

Kiristaalota sun ijaarsa architecture fakkaatu turan: frame iskuweerii tokko keessaa frame iskuweerii biraa, fuulawwan isaanii stairs fakkaatanii keessaa duwwaa ta'anii.

Isaan sodium chloride idilee irraa ijaaraman, compound soogidda nyaataa keessa jiru sanuma. Wanti adda ta'e maateriyaalii miti. Brine isa marsu ture.

Lafa irratti, kiristaala volume liquid centimetre-scale keessatti guddatu gadi lixuu, wall ykn fuula tuquu, fi density garaagarummaa furmaata circulate godhan uumuuf gargaaraa ta'uu danda'a. International Space Station irratti, idilee settling fi buoyancy-driven flow baay'ee suppressed turan. Salt kiristaalota muraasni yeroo gahaa suspended ta'anii, suuta fi symmetry caalaadhaan **hopper cubes** edges 2 hanga 8 millimetres qaban ta'anii guddatan.

Barruulee sadii, bara 2011, 2015 fi 2019 maxxanfaman, yaaliiwwan kana ibsu. Waliin, transport fiiziksii irratti barnoota qulqulluu tokko kennu: dissolved maateriyaalii akkamitti kiristaala bira ga'u jijjiiruun atomic caasaa isaa osoo hin jijjiirin mul'ataa boca isaa jijjiiruu danda'a.

Space perfect kiristaalota uuma hin agarsiisan, industrial adeemsa hin mirkaneessu, salt gosa haaraa hin mul'isan.

Cube tokko hopper akkamitti ta'a

Normal sodium chloride kiristaala cubic atomic arrangement qaba. **Hopper kiristaala** ammallee cubic dha, garuu corners fi edges isaa centers fuulota dura guddatu. Bu'aan isaa fuula tokko tokko irratti hollow stepped depression, akka cube frame isaa dura ijaaree wall booda guutuuf yaalu fakkaata.

Boodaa ISS fakkeenya tokko growth akkaataa kana mul'isa, garuu barruulee sodium-chloride sadii keessaa ragaa miti; haala dha. Suuraa fi time-lapse Donald Pettit armaan gadi **potassium chloride**, salt adda ta'e, microgravity keessatti stepped hopper fi scroll morphologies uumu agarsiisu.

[figure_pair pending]

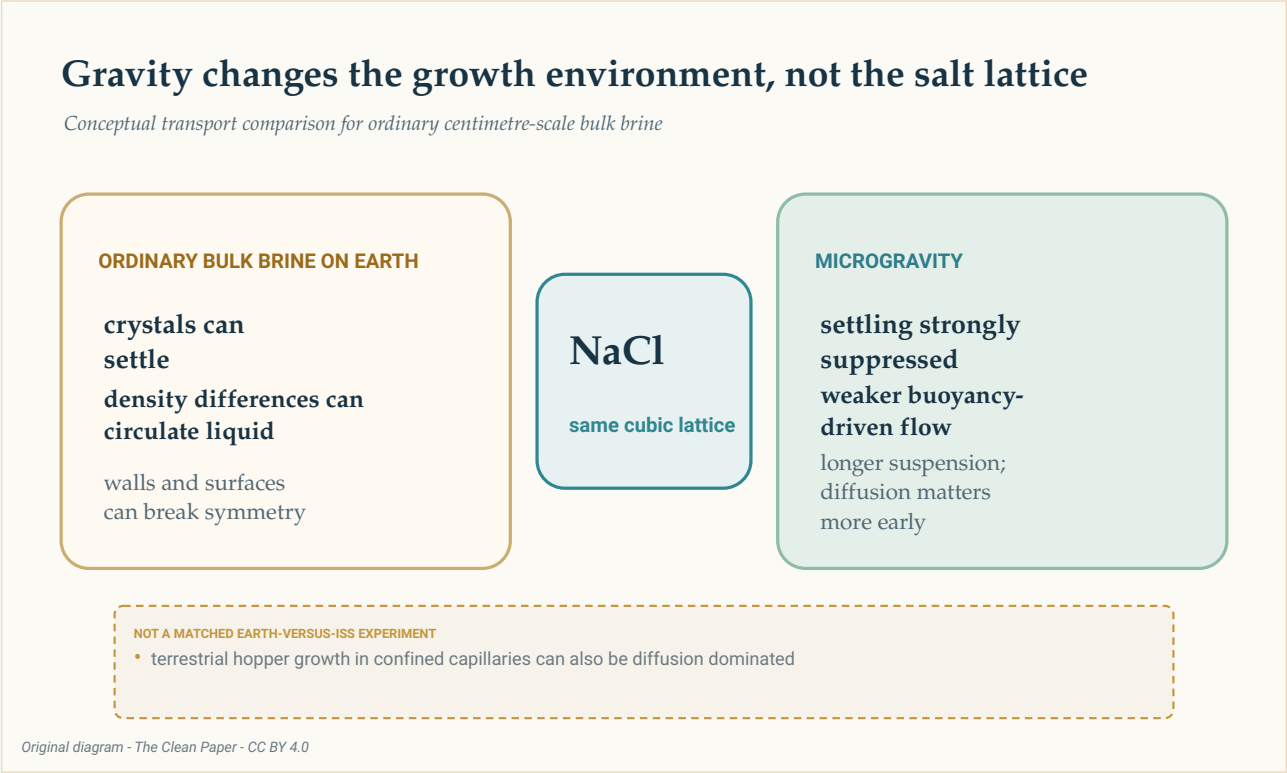
Scanning elektiroonii micrographs lama potassium chloride scroll-form hopper kiristaalota ISS irratti guddatan. Suuraaleen boodaa kun morphology'f contextual fakkeenyonni qofa; sodium-chloride saamudawwan ykn safartuuwwan qorannoowwan 2011, 2015 ykn 2019 article kana keessatti irratti dubbannu miti.

[video pending]

Boodaa time-lapse potassium chloride hopper growth water film haphii keessa microgravity keessatti. Edge-and-corner growth agarsiisa; sodium-chloride yaaliiwwan ykn daataa article kana keessatti analysed miti.

Kiristaalota **supersaturated brine** irraa guddatu: salt water, haalawwan sana keessatti madaallii tasgabbaa'aa irratti baay'ina sodium chloride qabachuu danda'u caalaa dissolved qabu. Sodium fi chloride ions liquid keessa deemanii kiristaala fuula irratti makamu qabu.

Karaa gurguddaa lama isaan sochoosuu jira. **Diffusion** tasaa molekiyuulii motion, dissolved maateriyaalii concentration garaagarummaa irraa gara gadiitti bulk liquid circulation malee geessu dha. **Convection** liquid mataa isaa socho'uu dha. Idilee gravity jalatti, ho'a ykn concentration garaagarummaa xixiqqoon density jijjiiranii buoyancy circulation sochii gochuu danda'u. Kiristaalota illee **sediment**, jechuun liquid keessa gadi setiluu danda'u.



Conceptual walbira qabuu environment lamaan keessatti sodium chloride lattice sanuma agarsiisa. Idilee bulk brine Lafa irratti settling, buoyancy circulation fi fuula contact qabaachuu danda'a; microgravity jalqaba keessaa lamaan dura baay'ee suppress godha, longer suspension hayyama fi jalqabaa growth keessatti diffusion caalaatti barbaachisaa godha. Kun matched Earth-versus-ISS yaalii miti.

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Yaalii kun International Space Station, orbiting microgravity laaboraatoorii keessatti godhame. Jechi **microgravity** gravity homaa hin jiru jechuu miti. Barruu 2019 residual acceleration naannoo 1.2 millionths Lafa's fuula gravity, ykn 1.2 micro-g, fi slow cyclic liquid motion gabaase. Environment transport balance jijjiire; brine perfect amma iyyuu hin godhne.

Karaa suuta millimetre-scale cubes ga'u

Qorannoo 2019 hopper cubes water ISS brine keessaa evaporate ta'aa yeroo guddatan irratti xiyyeeffate. Gabaafame cube edges **2 hanga 8 millimetres** turan. Growth saffisoota **0.34 hanga 1.0 micrometres tokkoon tokkoon minute** (naannoo **0.49 hanga 1.44 millimetres tokkoon tokkoon day**) turan; giddugaleessa **0.68 micrometres tokkoon tokkoon minute** fi istaandaardii deviation 0.23.

giddugaleessa saffisa sana irratti, edge 8-millimetre tokko guddachuuf tilmaamaan torban tokko fudhata. Shallaggii kun tilmaama dha; stage kiristaala tokko hunda time-lapse'n safarame miti.

Barreessitoonni supersaturation **1.002** gadi tilmaaman. Terrestrial walbira qabuu literature isaanii hopper growth supersaturation baay'ee ol, 1.45 ol, saffisoota 10 hanga 110 micrometres tokkoon tokkoon lammaffaa irratti sekondii ykn minutes keessatti, yeroo baay'ee cubes 250 micrometres gadi uumu, ibsa.

Walbira qabuu kun informative dha, garuu matched miti. ISS kiristaalota fi terrestrial literature simultaneous, identical Lafa fi orbit arms team sanumaatiin raawwataman irraa miti. Containers, interfaces fi malleen adda addaa gravity waliin barbaachisaa gochuu danda'u.

Kanaaf contrast strongest descriptive dha: ilaalchawwan ISS kana keessatti, hopper cubes gadi-aanaa supersaturation irratti suuta, days hanga weeks keessatti guddatan, millimetre safartuu ga'an.

Jalqaba diffusion ol-aanaa ture; booda flow ammallee danda'ama ture

Barruu 2019 **Peclet lakkoofsa** fayyadamee transport liquid motion fi diffusion walbira qaba. Gatiin tokko gadi diffusion caalaatti barbaachisaa ta'uu agarsiisa; tokko ol bulk motion dominate gochuu danda'a.

> **Reeshiyoo dha, switch miti**
>
> Peclet lakkoofsa transport saffisoota lama walbira qaba. Gatii tokko gadi liquid perfect amma iyyuu, tokko ol pure convection jechuun addaan hin qoodu. As gatiin kiristaala hammamtaa fi velocity tilmaama surrounding brine irratti hundaa'uun jijjiirame. Isa xiqqaa kiristaalota diffusion-dominated haala keessatti ifa turan; isa guddaa kiristaala guddaa caalaa vessel keessatti haala slow liquid motion barbaachisaa godhu keessa seenuu danda'a ture.

Drops xixiqqoo naannoo 0.8-centimetre keessatti, tilmaamame Peclet gatiiwwan nucleation bira naannoo **0.0004** irraa hanga dhumaa safarame hammamtaa irratti **0.03** ta'utti ol ka'an. Diffusion dominant ta'ee hafe.

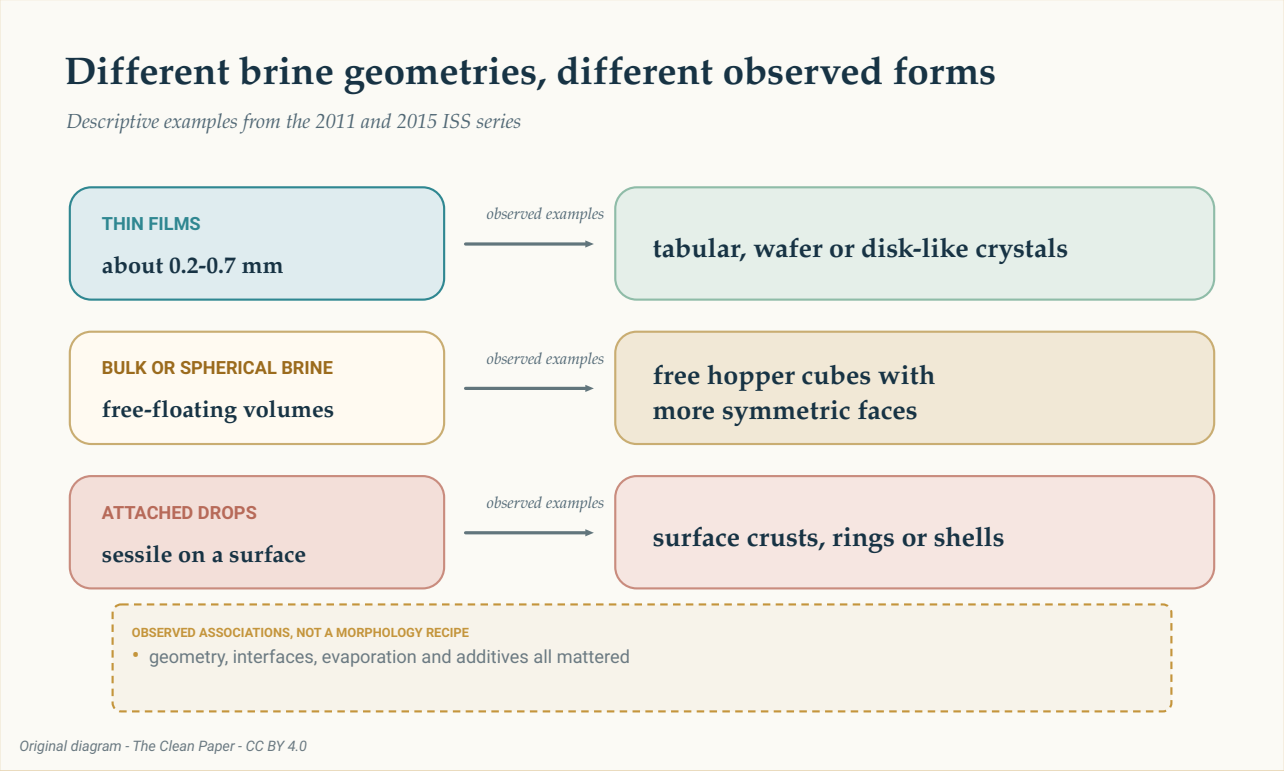
Crystallizers 2- hanga 3-centimetre keessatti, tilmaama nucleus 50-micrometre tokkoof naannoo **0.05** irraa edge 4-millimetre tokkoof naannoo **4** ta'utti ol ka'e. Jalqabaa growth diffusion dominated ture,

garuu slow cyclic motion booda contribution gochuu danda'a ture.

Kanaaf "microgravity convection balleesse" jechuun dogoggora. Idilee buoyancy-driven circulation fi settling baay'ee reduced turan. Residual acceleration fi measurable motion hafe.

Bifni liquid illee barbaachisaa ture

Barruu 2011 fi barruu 2015 suuraa bal'isan. Salt crystallization haphii films, thicker liquid layers, gara spherical brine volumes fi drops fuula irratti attached keessatti gabaasan.



Rows sadii fakkeenyonni dossier keessaa mul'ate cuunfu: haphii films tabular ykn disk-like bocawwan waliin, bulk ykn spherical brine free hopper cubes waliin, fi attached drops crusts, rings ykn shells waliin. Kun descriptive associations dha; recipe ykn guarantee miti.

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Qorannoo 2011 keessatti, haphii films thickness tilmaamaan 0.2 hanga 0.7 millimetres ta'an haphii wafers fi tabular kiristaalota uuman. Free-floating brine volumes caalaa symmetric lateral fuulota fi hopper cubes hayyaman.

Ilaalchawwan 2015 haphii sheets 0.2 hanga 0.7 millimetres, thicker layers naannoo 4 hanga 6 millimetres, fi attached hemispherical drops keessatti naannoo 20 hanga 32 millimetres dabalatan. Bocawwan gabaafaman tabular hoppers, cubes, disk-like kiristaalota, dendrites, rings fi shells turan. Polyethylene glycol dabaluu set ilaalchawwan tokko keessatti hopper growth suppress godhe.

Barreessitoonni 2015 hojii ilaalchawwan non-inventoried supplies fayyadamuun crew off-duty yeroo keessatti godhaman jechuun ibsan; rigorous programmatic investigation miti. Fakkeenyonni liquid ji'oometirii, interfaces, evaporation fi additives hundi barbaachisaa akka godhan agarsiisu. Deterministic recipe container shape tokko kiristaala shape tokko guarantee godhu hin define godhan.

Lattice'n salt gosa haaraa hin taane

Garaagarummaan **kiristaala caasaa** fi **morphology** gidduu murteessaa dha.

Caasaa repeating atomic arrangement dha. Morphology mul'ataa alaa boca dha. Neutron diffraction barruu 2011 keessatti sodium chloride caasaa jijjiirame ykn lattice-cell paaraameetiroota terrestrial saamudawwan irraa jijjiiraman hin identify godhne. Orbiitii saamudawwan illee **brine inclusions**, pockets furmaata xixiqqoo kiristaala keessa qabaman, qabu turan.

Kanaaf guddaa, symmetric appearance purity ol-aanaa ykn defect-free maateriyaalii'f ragaa miti. Barruulee dossier keessaa tokko iyyuu ol-aanaa chemical purity, caalaatti gaarii mechanical raawwii ykn suitability device addaa tokkoof hin gabaasa godhu.

Gravity indirectly hojjete. Settling, liquid circulation, orientation fi contact fuulota waliin jijjiire. Strength sodium-chloride bonds hin jijjiirre, atomic sadarkaa haaraa hin uumne.

Yaaliiwwan kun maal nu barsiisuu danda'u fi maal hin dandeenye

Barruulee transport explanation deeggaru: idilee settling fi buoyancy-driven flow baay'ee suppress gochuun kiristaalota muraasa suspended akka hafu, slow fi symmetric haalawwan caalaa keessatti akka guddatu hayyame. Safarame sizes, saffisoota fi bocawwan kallattii ilaalchawwan dha; supersaturation, growth seenaa fi Peclet gatiiwwan tilmaamota dabalatu; Lafa waliin walbira qabuu gariin maxxanfame yaaliiwwan biroo irratti hunda'a.

Dossier kanaaf denominator ifaa tokko hin jiru. nama dhuunfaa kiristaalota, crystallizers fi selected fakkeenyonni barruulee sadii keessatti walitti makata. Isaan total tokko keessatti ida'uun uniform yaalii hin jirre fakkeessa.

Qorannoowwan manufacturing himannaa'f ragaa barbaachisu illee hin gabaasan. Throughput, production cost, anniisaa fayyadama, yield, amanamummaa ykn faayidaa qabu maateriyaalii raawwii hin safaran. Series 2015 exploratory ture. Terrestrial walbira qabuwwan matched controls hin turre. Guddaa ykn visually striking ta'uun fayyadama tokkoof caalaatti gaarii ta'uu waliin walqixa miti.

Natural salt deposits hopper cubes centimetres keessatti safaraman qabaachuu danda'u, yeroo tokko tokko brine-soaked mud keessatti suspended. Barruu 2019 slow, diffusion-dominated growth waliin danda'amaa analogy dhiyeessa. Kun walbira qabuu nama hawwatu dha; natural fi orbiitii hoppers

adeemsa hojii tokko qofa waliin share godhu mirkaneessu miti.

Cuunfaa gabaabaa

Salt kiristaalota evaporating brine irraa International Space Station irratti guddatan hollow, stepped hopper cubes 2 hanga 8 millimetres keessatti dabalatan. Barruulee transport irratti hundaa'e explanation deeggaru: microgravity idilee settling fi buoyancy-driven flow baay'ee suppress godhe, slow growth fi longer suspension hayyame, jalqabaa stage diffusion dominate godhe. Liquid ji'oometirii, interfaces, evaporation fi additives illee morphology irratti dhiibbaa godhan. Neutron diffraction sodium chloride caasaa haaraa hin agarsiifne; brine inclusions illee hafe. Hojichi bounded materials-science haala qorannoo dha; space perfect kiristaalota uuma ykn industrial adeemsa dandeessisa jedhuuf ragaa miti.

Sakatta'a ifaa

Wanti barruulee agarsiisan: Millimetre-scale sodium chloride hopper cubes fi morphologies biroo ISS brine geometries hedduu keessatti guddatan. Hopper cubes 2019 gadi-aanaa tilmaamame supersaturation irratti suuta guddatan; jalqabaa growth keessatti diffusion dominant ture.

Wanti hiikame: Settling fi buoyancy-driven flow baay'ee reduced ta'uun longer suspension fi caalaa symmetric growth hayyame. Guddaa caalaa crystallizer keessatti slow liquid motion late stage irratti barbaachisaa gochuu danda'a ture.

Wanti isaan hin agarsiifne: Atomic boca salt haaraa, kiristaalota purer ykn defect-free, matched Earth-versus-ISS yaalii, universal advantage microgravity, ykn commercial manufacturing route.

Daangaawwan ijoo: Qorannoowwan sadii adda adda, geometries fi selected fakkeenyonni adda adda waliin; cross-qorannoo terrestrial walbira qabuwwan; tilmaamame transport hangawwan; dossier keessaa exploratory, non-programmatic kutaalee; adeemsa economics ykn raawwii qormaatawwan hin jiru.

Dubbisaan waliigalaa hammam amantaa qabaachuu qaba? Gabaafame orbiitii morphologies fi slow growth dhugaa ta'uu irratti amantaa guddaa. Ilaalchawwan guutuu keessatti transport explanation account gaarii ta'uu irratti amantaa giddu-galeessaa. Salt yaaliiwwan kana waliigalaa promise space manufacturing godhanii hiikuu irratti amantaa baay'ee gadi-aanaa.

Maddoota

Pettit and Fontana, Comparison of sodium chloride hopper cubes grown under microgravity and terrestrial conditions, npj Microgravity 5, 25 (2019)
https://doi.org/10.1038/s41526-019-0085-0

Fontana, Schefer and Pettit, Characterization of sodium chloride crystals grown in microgravity, Journal of Crystal Growth 324, 207-211 (2011)
https://doi.org/10.1016/j.jcrysgro.2011.04.001

Fontana, Pettit and Cristoforetti, Sodium chloride crystallization from thin liquid sheets, thick layers, and sessile drops in microgravity, Journal of Crystal Growth 428, 80-85 (2015)
https://doi.org/10.1016/j.jcrysgro.2015.07.026