From Nucleation to Galaxies

From: Joe Maxwell from Joe Maxwell
joesystemica@substack.com

To: joseph.maxwell02@proton.me
joseph.maxwell02@proton.me

On: Sunday, 24 May 2026 at 22:21:31

From Nucleation to Galaxies

A materials-informed view of early cosmic structure

JOE MAXWELL
MAY 24

This is not a replacement cosmology.

It does not propose new forces, new constants, new particles, or a new explanation for the early universe.

It is a modelling note from a materials engineering viewpoint.

The question is narrower:

when systems undergo extreme, non-equilibrium transitions, do ordered structures emerge through local thresholds, path-dependent growth, and inherited constraints?

And if they do, can that lens help us ask better questions about early cosmic structure?

That is the frame.

Not "galaxies are grains."

Not "space is a material."

Not "JWST proves a new universe."

Just this:

materials science spends a lot of time studying how structure forms under constraint.

Nucleation. Growth. Phase transitions. Defects. Boundaries. Non-equilibrium ordering. History-dependent structure.

Cosmology, at the largest scale imaginable, is also concerned with structure formation.

So the careful question is not whether the universe is literally a material.

It is whether some of the structural habits materials scientists use to read formation history might help us think more clearly about the early cosmos.

Snapshots are not stories

A telescope image is not just a picture of things.

It is evidence of a formation process.

The same is true in materials science.

If you look at a polished and etched metal sample under a microscope, you may see grains, boundaries, inclusions, defects, deformation lines, and phase contrast. But the image alone does not tell you the full story.

You have to ask what process could have produced that structure.

Was the material cooled quickly?

Was it heat treated?

Was it mechanically worked?

Did one phase nucleate before another?

Did boundaries form because growth fronts collided?

Did a defect cause local ordering earlier than the rest of the material?

A microstructure is not only an object.

It is a memory.

It records the conditions under which it formed.

That is the lens I want to use here.

Not to force cosmology into metallurgy.

But to ask whether early cosmic structure can be read, cautiously, as formation history.

What JWST actually changed

When the James Webb Space Telescope began producing deep observations of the early universe, some of the first public reactions were dramatic.

“Too big, too early.”

“Cosmology is broken.”

“The universe should not look like this.”

That language was always too strong.

Some early galaxies that appeared surprisingly massive may have been overestimated because actively accreting black holes can make galaxies appear brighter, which can lead to inflated stellar-mass estimates. NASA and University of Texas researchers reported this as one reason some early galaxies were “not too big for their britches after all.”

So the serious version is not:

JWST broke cosmology.

The serious version is:

JWST sharpened the question of how rapidly, efficiently, and unevenly early structure formed.

That question has not gone away. JWST continues to reveal early galaxies that appear massive, dusty, efficient at forming stars, or structurally mature in ways that challenge simple public narratives of slow, smooth build-up. The “Red Monsters” study, for example, reported three massive dusty galaxies in the first billion years whose star formation appeared nearly twice as efficient as lower-mass galaxies from the same epoch or ordinary galaxies at later times.

That does not mean the standard cosmological framework collapses.

It means the early universe may have been better at building structure than our simplest intuitions expected.

And that is where the materials lens becomes useful.

Nucleation before uniform growth

In materials, structure rarely appears everywhere at once.

It begins locally.

A small region crosses a threshold.

A new phase becomes stable there before it becomes stable everywhere.

That region acts as a nucleus.

Then growth follows.

The surrounding material may still be disordered, metastable, or lagging behind, but the nucleated region has already changed the future of the system.

This is basic materials thinking.

Uniform starting conditions do not guarantee uniform final structure once symmetry breaks.

A material under rapid cooling, high stress, strong gradients, or non-equilibrium forcing will not politely organise everywhere at the same time. Local variations matter. Impurities matter. Surfaces matter. Strain matters. Timing matters.

The final structure inherits those local beginnings.

A grain structure is not just what the material is.

It is where ordering began, how fast it grew, where growth fronts collided, and what constraints were present during formation.

So here is the cautious cosmological analogy:

could some early cosmic structure reflect thresholded, spatially uneven ordering rather than smooth global growth?

Not as a replacement for current galaxy-formation modelling.

As a structural question.

If the early universe had regions where local conditions crossed formation thresholds earlier, then maturity would not need to arrive everywhere at once.

Some regions would appear ahead.

Some would lag.

Some would seed later growth.

Some would become boundaries, corridors, or void-like absences in the later large-scale structure.

That is not an answer.

It is a better kind of question.

The boundary of the analogy

This is the part that matters.

Galaxies are not grains.

Space is not a grain boundary.

Dark matter halos are not precipitates.

The universe is not a metal sample.

If the analogy depends on those literal identities, it fails immediately.

The transferable structure is more abstract:

Materials language

Safer cosmological question

Overclaim to avoid

Nucleation

Did some regions begin ordering earlier?

Galaxies are literal nuclei

Growth

Did early local structure bias later assembly?

Galaxy formation follows metallurgical laws

Grain boundaries

Do later large-scale structures preserve inherited separations?

Space is literally a grain boundary

Defects

Do persistent anomalies encode formation history?

Every anomaly is meaningful

Quench

Did rapid transition preserve incomplete relaxation?

The CMB is literally a frozen material

Phase transition

Did governing behaviour change across regimes?

Standard physics is wrong

The analogy is only useful if it carries relationships, not objects.

Local threshold crossing.

Path-dependent growth.

Formation memory.

Inherited constraint.

Boundary formation.

Non-uniform maturation.

Those are the transferable pieces.

Everything else stays behind.

Early maturity without extra time

One of the useful things materials thinking gives us is a way to separate two ideas people often mix together:

old-looking structure does not always require old age.

In materials, a structure can look “mature” because the system was driven hard.

Rapid cooling can preserve non-equilibrium structure.

High gradients can accelerate local ordering.

Strong constraints can force a system to choose a configuration earlier than it would under gentle conditions.

A material is not violating physics when it forms unexpected microstructure.

It is revealing that the formation conditions were not the simple ones you imagined.

That is the lens I want to apply to early galaxies.

If a galaxy appears mature early, one possible question is not only:

how did it have enough time?

but also:

what local conditions made that formation pathway unusually efficient?

That question already exists inside astrophysics through discussions of dark matter halo assembly, gas cooling, feedback, metallicity, star-formation efficiency, dust, black hole activity, and selection effects.

The materials lens does not replace those.

It organises attention around threshold, growth, and inherited structure.

The point is not to say “materials science explains JWST.”

The point is to ask:

what would early structure formation look like if we treated it less like smooth global assembly and more like non-equilibrium ordering under constraint?

Structure as history

Materials preserve history through structure.

A grain boundary tells you something happened there.

A defect is not merely an error. It may be the point where history concentrated.

A phase distribution tells you something about cooling, chemistry, kinetics, and constraint.

The same attitude can be useful in cosmology.

A galaxy is not only an object at a redshift.

It is an outcome of prior conditions.

A filament is not only a present-day arrangement.

It is a growth pathway.

A void is not only empty space.

It may be a region where a different formation history unfolded.

Again, this does not mean every pattern is meaningful.

Some things are noise.

Some things are selection effects.

Some things are modelling artefacts.

Some things disappear with better data.

But the principle remains:

structure should be read as a trace of process before it is treated as a static object.

That is true in a metal sample.

It is also a useful discipline when looking at the early universe.

What this lens would ask us to look for

If a nucleation-like, non-equilibrium growth lens is useful, it should not just produce nice metaphors.

It should produce questions.

For example:

Do early "mature" galaxies cluster more strongly than expected?

Do massive or dusty early galaxies preferentially occupy overdense regions or proto-filamentary environments?

Do early luminous objects show spatial correlations that survive correction for selection effects?

Do chemically evolved early systems appear randomly distributed, or do they trace regions of earlier threshold crossing?

Can standard simulations reproduce the same apparent early maturity through local efficiency, environment, and feedback without changing background cosmology?

What observational signature would distinguish local non-uniform growth from simple detection bias?

These are the kinds of questions the materials lens should lead to.

Not "believe the analogy."

Test the pattern.

What would make the lens fail

This matters.

A serious modelling lens should know how to die.

The materials-informed reading weakens if improved mass estimates continue to reduce the early-maturity tension.

It weakens if black hole contamination, dust modelling, stellar-population assumptions, and selection effects account for most of the surprising structure.

It weakens if early massive or mature-looking galaxies turn out to be distributed in ways that add no new information beyond existing models.

It weakens if “nucleation” becomes only a poetic relabelling of known galaxy formation.

And it fails completely if it stops producing testable questions.

That is the boundary.

The lens is useful only if it helps us ask cleaner questions about structure formation.

If it only sounds good, throw it away.

Where this sits in Cosmologia

This piece is the wedge.

The safe entry point.

The materials-engineering doorway into a wider question.

Cosmologia is the larger programme behind it, but the larger programme has to stay disciplined.

Cosmologia is not a replacement theory of physics. In the recap document, it is defined as a bounded modelling programme that applies a constraint-first, state-space grammar to cosmology without asserting new physical laws or replacing existing theories.

That distinction matters.

The JWST/materials note asks a narrow question:

can a materials-informed language of nucleation, growth, thresholds and inherited structure help us think better about early cosmic structure?

Cosmologia asks a broader one:

how do physical descriptions change across regimes, and what gets preserved when one description gives way to another?

The technical back-end of Cosmologia goes further. It treats regime transitions through coarse-graining, loss accounting, capture thresholds, hysteresis, and emergent metric-like structure. One formal appendix explicitly says its purpose is only to show that the regime-transition logic can be made mathematically well-defined, internally consistent and falsifiable, without claiming physical completeness, uniqueness, necessity or cosmological truth.

That is later work.

This piece stays at the first bridge.

Materials to cosmos.

Nucleation to galaxies.

Structure as history.

Closing

JWST has not handed us a finished crisis.

It has handed us better evidence that the early universe was structurally interesting.

Maybe some tensions soften.

Maybe some disappear.

Maybe some survive.

But the deeper lesson remains useful either way:

early structure should not be treated only as a collection of objects.

It should be treated as a record of formation.

A material remembers how it cooled.

A fracture remembers how stress moved.

A grain structure remembers where order began.

The universe may not be a material.

But structure still remembers.

And if we want to understand the early cosmos, one of the best questions we can ask is not only:

what do we see?

but:

what kind of process could leave a structure like this behind?

That is where this lens begins.

Not as an answer.

As a better question.

SHARE

LIKE COMMENT RESTACK