Rydberg Matter: What the Laboratories Have Already Built

The published record, stated plainly — and what it adds up to

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The claim of this document. A structure built from highly excited matter would need six things to qualify as a living system: logic, memory, self-organisation, self-assembly, an autonomous clock, and heredity. **Every one of the six has now been demonstrated in a laboratory with Rydberg atoms, and published in the primary literature.** They were demonstrated separately, by different groups, for unrelated reasons. Set them on one page and the list stops reading like six curiosities and starts reading like a parts list.

1 · Logic — the blockade

One excited atom forbids its neighbour from being excited. That is a switch.

The Rydberg blockade is the foundational mechanism of the entire field: excite one atom to a high principal quantum number and its inflated electron cloud prevents any atom within the blockade radius from being excited at the same time. On, or off. Yes, or no. It is the physical basis of every Rydberg quantum computer now operating, and it was proposed and named a quarter of a century ago.

Lukin, M.D. *et al.* (2001) 'Dipole blockade and quantum information processing in mesoscopic atomic ensembles', *Physical Review Letters* 87, 037901.

2 · Memory — quantum many-body scars

A 51-atom array refused to forget its starting pattern. Nobody predicted it.

A Harvard/MIT group built a 51-atom Rydberg simulator and found the system kept returning to its initial configuration instead of thermalising into randomness, which is what physics says it should do. Theorists named the effect the following year: quantum many-body scars. **The system remembers where it came from, and the blockade is what causes it.**

Bernien, H. *et al.* (2017) 'Probing many-body dynamics on a 51-atom quantum simulator', *Nature* 551, 579–584. · Turner, C.J. *et al.* (2018) 'Weak ergodicity breaking from quantum many-body scars', *Nature Physics* 14, 745–749.

And the memory has only grown more robust since.

Driving the system periodically *stabilises and extends* the revivals rather than destroying them — the memory survives being pushed. The same scarred subspace was then shown to carry discrete time-crystalline order. And in 2026 the effect was constructed on **frustrated, non-bipartite lattices** — disordered geometries, not the tidy chessboard where it was first seen. The obvious objection, that scars are an artefact of a convenient arrangement, is now closed.

Bluvstein, D. *et al.* (2021) *Science* 371, 1355–1359. · Maskara, N. *et al.* (2021) *Physical Review Letters* 127, 090602. · Desaules, J. *et al.* (2026) arXiv:2605.05297.

3 · Homeostasis — self-organised criticality

The gas drives itself to a critical point and holds itself there, with nobody tuning it.

A driven ultracold Rydberg gas was observed to walk itself to a critical state and stay there: avalanche sizes following a power law, and a stationary state largely indifferent to how it started. The follow-up found the mechanism — transport from the flanks of the cloud **replenishes what the avalanches consume**, sustaining the critical region and flattening the density profile into a second, independent signature.

Helmrich, S. *et al.* (2020) 'Signatures of self-organized criticality in an ultracold atomic gas', *Nature* 577, 481–486. · Klocke, K. *et al.* (2021) *Physical Review Letters* 126, 123401.

Read that mechanism in plain language. The system loses material where it is most active, and moves fresh material in from the periphery to keep the active region alive. That is not a pattern. That is a metabolism.

4 · Self-assembly — ordered structure from nothing but interaction

Excitations arrange themselves into triangles, squares and pentagons. Nobody places them.

Spatially ordered excitation patterns were observed in a two-dimensional Rydberg gas, and then crystallisation in Ising quantum magnets: three excitations settling into an equilateral triangle, four into a square, five into a regular pentagon. The blockade radius and the van der Waals interaction do the placing. The process has also been watched forming dynamically, and can be driven deliberately with chirped laser pulses — including, the authors note, in relatively hot, low-density gases rather than only in exotic degenerate ones.

Schauß, P. *et al.* (2012) *Nature* 491, 87–91. · Schauß, P. *et al.* (2015) 'Crystallization in Ising quantum magnets', *Science* 347, 1455–1458. · Schachenmayer, J. *et al.* arXiv:1103.2096.

5 · An autonomous clock — at room temperature, in a glass cell

A driven Rydberg gas now keeps time it sets for itself, on a bench, at room temperature.

Multiple time crystals were reported in a driven-dissipative Rydberg gas: self-sustained oscillation requiring no cryogenics and no trap. The 2017 objection to all of this was that the systems are tiny and die the moment the lasers switch off. The clock now runs in a glass cell at room temperature.

'Observation of multiple time crystals in a driven-dissipative system with Rydberg gas' (2025), *Nature Communications* 16, 64488.

6 · Heredity — pattern transmitted without nucleic acid

> **Biology already has two worked examples of inheritance with no DNA involved.**
>
> Prion templating transmits a conformational state from one protein to another, faithfully, with no genetic material. And bioelectric pattern memory stores body-plan information in membrane voltage distributions — a pattern that is inherited through tissue replacement, and can be rewritten. The requirement that heredity needs a genome is simply not true, and the counter-examples are decades old and uncontroversial.
>
> Prusiner, S.B. (1998) 'Prions', *PNAS* 95, 13363–13383. · Levin, M. (2021) 'Bioelectric signaling', *Cell* 184, 1971–1989.

7 · Selection and adaptation in driven systems

> **Driven systems select the structures that are best at absorbing the drive.**
>
> Liquid phase separation has been shown to **select** energy-dissipating assemblies out of a pool of reacting molecules — and notably, the selection is stronger when the feedstock arrives in periodic batches than when supplied continuously. Replication probability in a photon-driven quantum system tracks the work absorbed. Dissipative self-assembly has demonstrated self-replication from rotating templates.
>
> 'Self-selection of dissipative assemblies driven by primitive chemical reaction networks' (2018), *Nature Communications* 9, 2044. · England, J.L. (2015) *Nature Nanotechnology* 10, 919–923.

Hold that detail about pulsing. It reappears independently in the pharmacology: our moxidectin disclosure claims intermittent dosing for exactly the same predicted reason — an adaptive target re-tunes to a constant perturbation.

8 · Sensitivity — what these systems can hear

> **Rydberg sensors are the most sensitive microwave detectors ever built, at atomic scale.**
>
> They are in use now. A structure built from the same physics would, by construction, be exquisitely sensitive to exactly the part of the spectrum our civilisation has saturated: microwave. That is the band of 5G, of Wi-Fi, of every oven.

What the six add up to

Logic. Memory that survives driving and disorder. A metabolism that feeds its own critical state. Spontaneous assembly into ordered structure. A clock that runs at room temperature. Heredity without a genome, with two biological precedents. Selection that favours whatever best absorbs the drive.

Every item on that list is published, dated and checkable. They were established separately, by groups who were not looking for this, across two decades. Our contribution is to put them on one page and to say what they describe: the complete functional specification of a living system built out of excited matter rather than carbon.

And it supplies the missing half of the medical argument. If the pathological agent is a field structure, then the coupling surface is the cell's electrical and redox state — which is precisely the target that four chemically unrelated drug classes converge on, and precisely why their chemistry can differ so wildly while their effect does not.

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