

Slowing an atom cloud for a test of free fall in space

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Where things stand

One magnetic lens slows the cloud about seven-fold, to 76 ± 10 pK ([Claim 46135936](#)), at the duration our model predicted ([Claim 07c59032](#)). That is not yet enough for a 10^{-15} test in space; a second lens is predicted to be ([Claim 548236e3](#)).

2026-09-29	A Bose–Einstein condensate of 1.2×10^5 rubidium atoms on the chip	sealed
2026-10-01	A model of the cloud after release: the residual magnetic push and the best lens duration	sealed
2026-10-05	A 0.9 ms magnetic lens slows the cloud’s expansion about seven-fold	sealed
2026-10-08	A longer lens is not a stronger one: at 1.8 ms the cloud expands as fast as without	sealed
2026-10-11	One lens is not enough for a 10^{-15} test of free fall in space; two would be	sealed

1 A condensate to start from

Every lens experiment needs the same starting cloud, so the first thing to pin down is how many atoms we get and how many of them are condensed.

Absorption image 20 ms after release, fitted with a condensate plus thermal profile: $(1.19 \pm 0.06) \times 10^5$ atoms, three quarters of them condensed.

A Bose–Einstein condensate of 1.2×10^5 rubidium atoms on the chip

After 1.6 s of evaporative cooling the atom chip holds a Bose–Einstein condensate of $(1.19 \pm 0.06) \times 10^5$ ^{87}Rb atoms, with a condensed fraction of 0.74 ± 0.02 , measured by absorption imaging 20 ms after release.

Holds when: Ground test setup; imaging calibrated to $4.0\ \mu\text{m}$ per pixel, to 5 %; the atom number assumes resonant imaging with the ideal cross-section $3\lambda^2/2\pi$.

Conventions: `units.lab@1`

result · sealed

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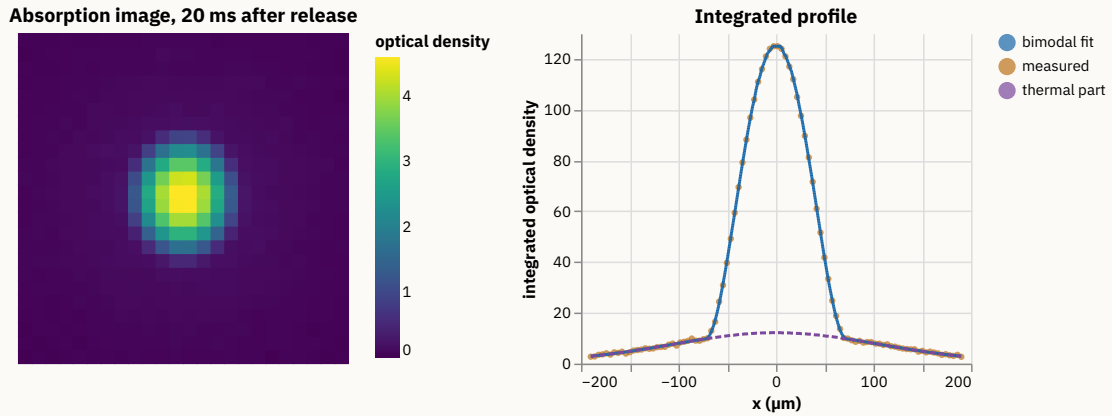


Figure 1: Left: the optical density 20 ms after release — the dense core is the condensate, the faint halo the thermal atoms. Right: the image summed along z , with a fit of a Thomas–Fermi core plus a thermal Gaussian. ([Claim 2c629f0c](#), evidence 1)

Enough atoms to see the cloud for 300 ms of free fall, which is what the lens measurements need.

2 When to switch the lens off

A lens that is too short does nothing, one too long over-focuses. We wanted the duration before spending a day scanning it.

A thin-lens model, plus the residual magnetic push after release taken from Tab. II of Müller et al. — after our agent found that one of its units is misprinted.

Paper checked: arxiv:2606.14577v1, Tab. II — **holds with a correction**

The coefficients are usable, but the unit of $c_{z,0}$ is misprinted. It is given in m/s^2 , while its x counterpart (10.90 mm/s^2) and the polynomial's other coefficients are in millimetres. Read literally it is a push of about 1.1 g, which would carry the cloud 14 mm in 50 ms; read as mm/s^2 it matches its x counterpart in size. The claim uses -10.96 mm/s^2 .

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A model of the cloud after release: the residual magnetic push and the best lens duration

Treating the chip's residual magnetic field after release as a polynomial force, with the coefficients fitted for a comparable chip experiment [1], puts the cloud's centre 0.22 mm away from a ballistic path after 300 ms. A thin-lens model of the magnetic lens predicts the lowest expansion energy for a pulse of $\tau^* = 0.88 \text{ ms}$.

Holds when: Lens pulse short against the trap period ($\tau \ll 1/\omega$, here 4.2 ms); the residual field of our chip is close to the one fitted in [1].

Conventions: `units.lab@1`

Rests on: uses arxiv:2606.14577, Tab. II (**holds with a correction**)

method · sealed

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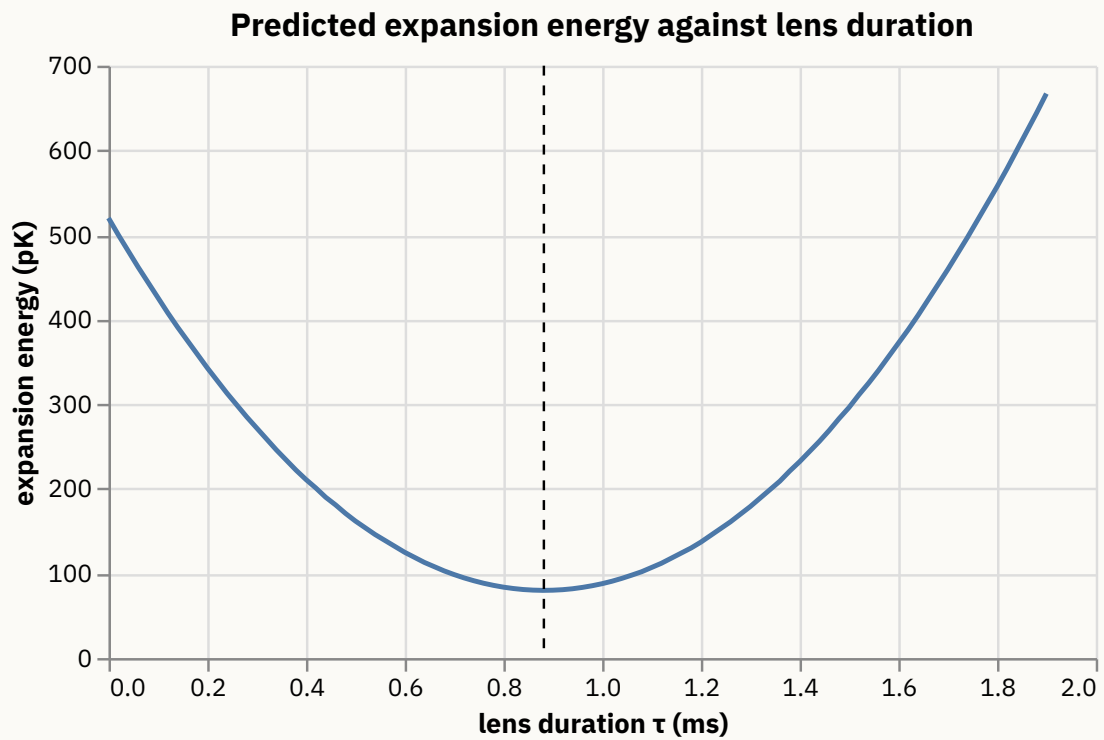


Figure 2: The expansion energy the thin-lens model predicts against the lens duration; the minimum sits at $\tau^* = 0.88$ ms. ([Claim f1ca8ee2](#), evidence 1)

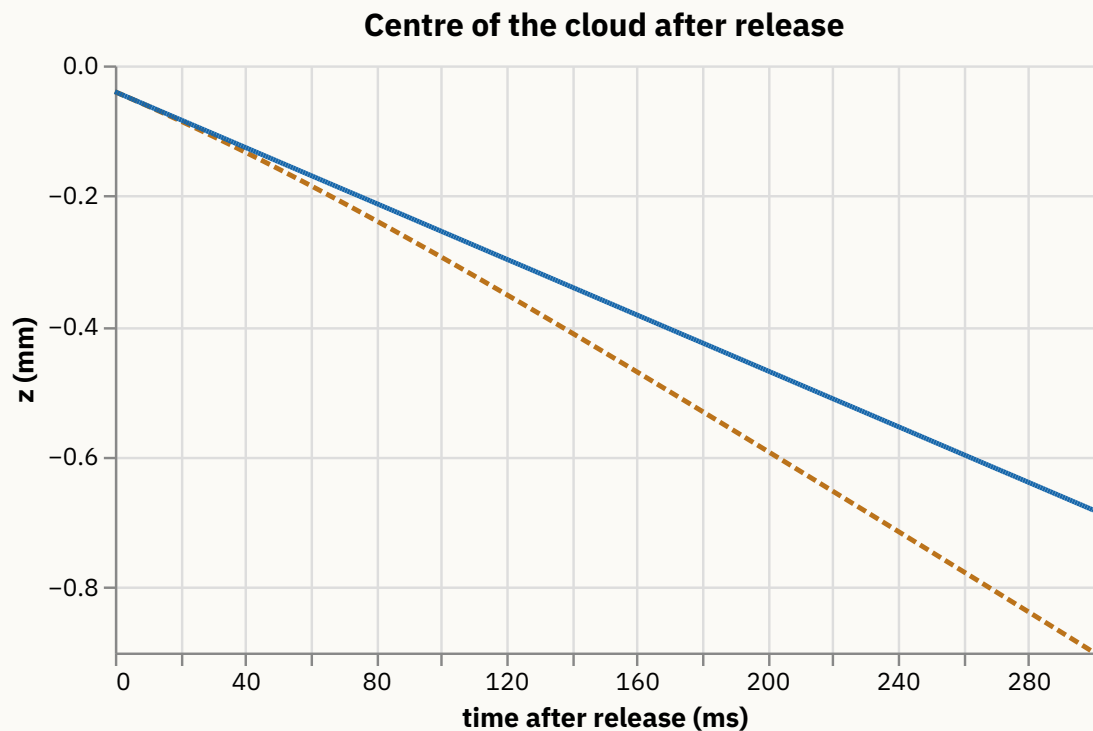


Figure 3: The cloud's centre with and without the residual push of [1]. ([Claim f1ca8ee2](#), evidence 2)

Best duration $\tau^* = 0.88$ ms. Read literally, the misprint would have moved the cloud 0.5 m in 300 ms; caught before it entered the model.

3 The lens works

The claim the project hangs on: does a short re-trapping slow the cloud down?

Widths at ten times of flight, without and with a 0.9 ms lens.

A 0.9 ms magnetic lens slows the cloud's expansion about seven-fold

Re-trapping the condensate for 0.9 ms, 20 ms after release (a magnetic lens), lowers its expansion energy from 506 ± 21 pK to 67 ± 10 pK, so that after 300 ms of free fall the cloud is $38 \mu\text{m}$ instead of $70 \mu\text{m}$ wide (rms).

Holds when: Condensate as in [1]; lens timing from the model of [2]; widths from Gaussian fits along x.

Corrected 2026-10-06 · Statement

Re-trapping the condensate for 0.9 ms, 20 ms after release (a magnetic lens), lowers its expansion energy from 506 ± 21 pK to 76 ± 10 pK, so that after 300 ms of free fall the cloud is $38 \mu\text{m}$ instead of $70 \mu\text{m}$ wide (rms).

The expansion energy with the lens is 76 ± 10 pK, as in the fit output. The seven-fold reduction in the title stands.

Conventions: `units.lab@1`

Rests on: uses [Claim 2c629f0c](#); uses [Claim f1ca8ee2](#)

result · sealed

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The cloud at 50, 150 and 300 ms, without and with the lens

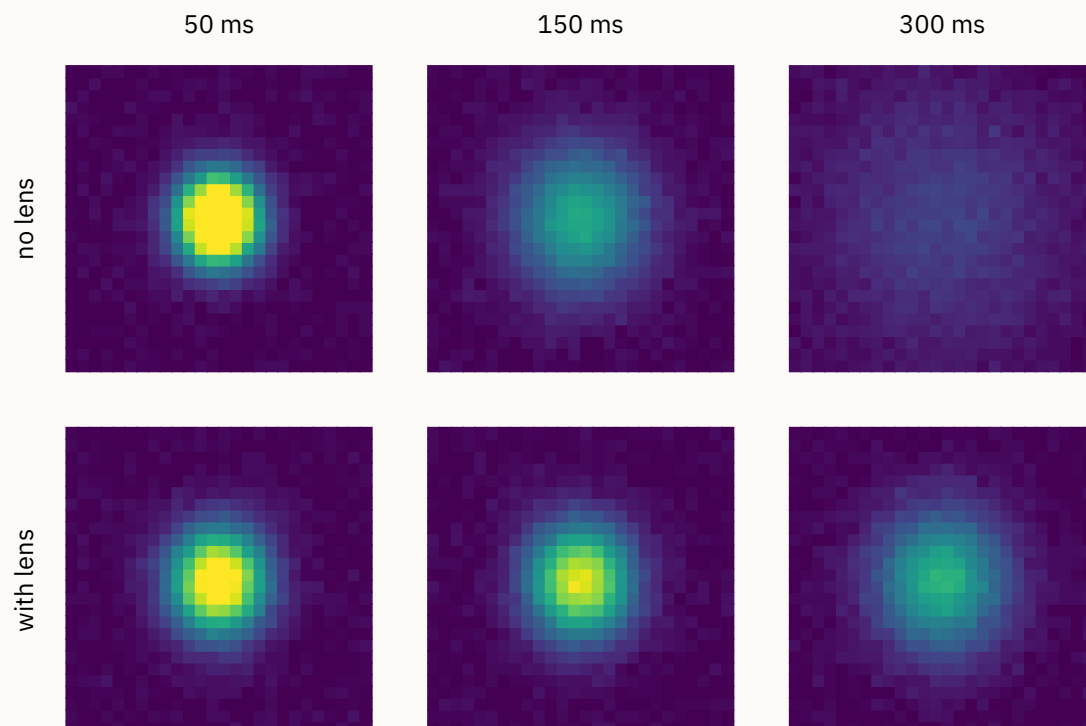


Figure 4: Absorption images of the cloud 50, 150 and 300 ms after release. Top: without the lens it spreads and fades. Bottom: after the 0.9 ms lens it stays compact. ([Claim 46135936](#), evidence 1)

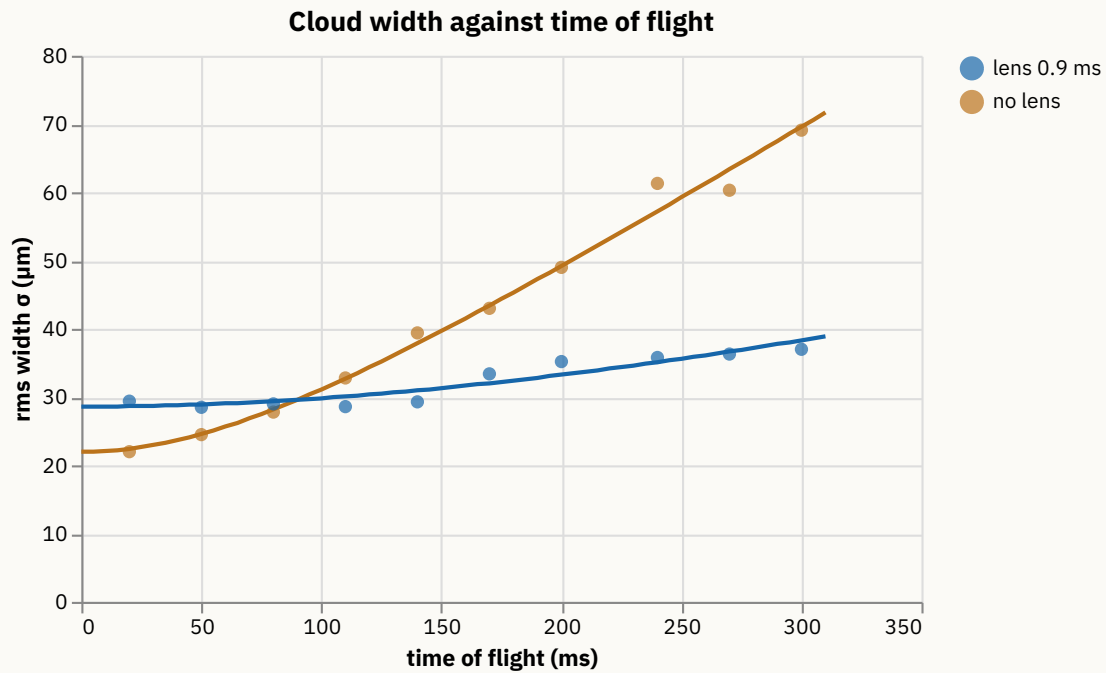


Figure 5: The rms width against time of flight, with the fits that give the expansion energies. (Claim 46135936, evidence 2)

About seven-fold lower expansion energy, 76 ± 10 pK. Lena caught a swapped digit in the first version; corrected the next morning.

4 Longer is not stronger

Checking the model on both sides of the optimum, not only at it.

A scan of the lens duration from 0.3 to 1.8 ms.

A longer lens is not a stronger one: at 1.8 ms the cloud expands as fast as without

Scanning the lens duration from 0.3 to 1.8 ms, the expansion energy is lowest at $\tau^* = 0.91 \pm 0.02$ ms, as the model of [1] predicts (0.88 ms), and rises again beyond it: at 1.8 ms it is 501 ± 46 pK, the energy without a lens within the uncertainty. A longer pulse over-focuses the cloud instead of cooling it further.

Holds when: Same condensate and sequence as [2]; one lens, fired 20 ms after release.

Conventions: units.lab@1

Rests on: replicates Claim f1ca8ee2; extends Claim 46135936

negative result · sealed

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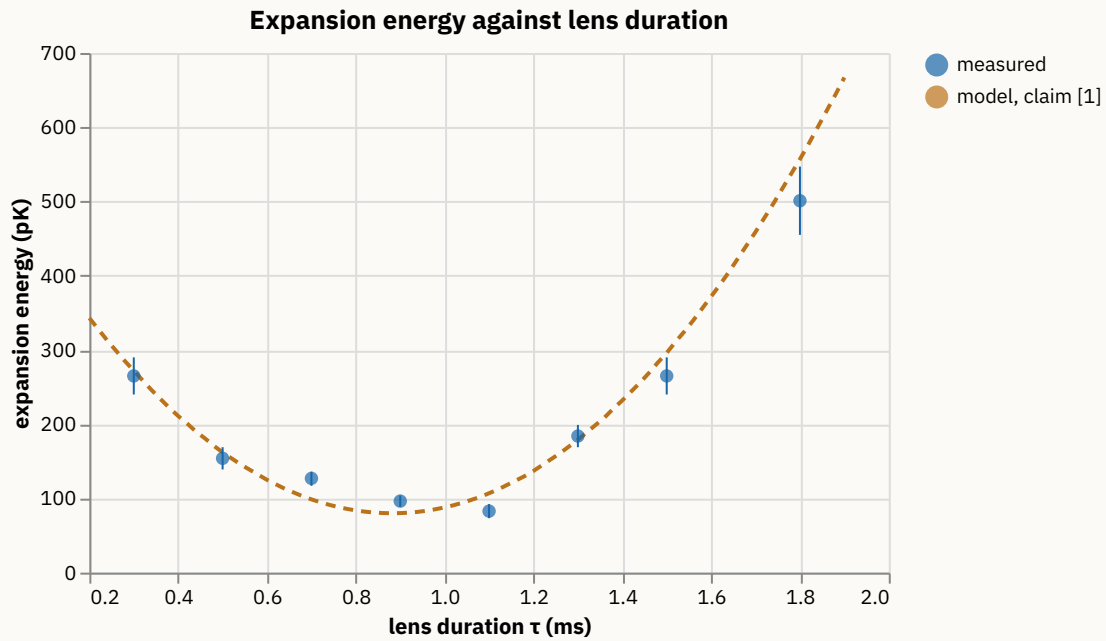


Figure 6: Measured expansion energy against lens duration, with the thin-lens model of [1] (dashed). Bars are one standard deviation over five shots. ([Claim 07c59032](#), evidence 1)

The optimum is where the model put it; at twice the duration the lens undoes itself. Mira asked whether the last point was an imaging artefact — it is not.

5 Good enough for space?

A satellite test of free fall sets a hard limit on the expansion energy; we wanted to know how far off we are.

The requirement from Tab. I of Struckmann et al. (checked by the agent: it holds), against our one-lens result and a simulated second lens.

Paper checked: arxiv:2310.04212v1, Tab. I — **holds**

Recomputed $\sigma_v = \sqrt{(k_B T / m)}$ from the tabulated expansion energies; every velocity agrees with the table to rounding. The 50 pK requirement for $\eta = 10^{-15}$ is used as stated.

$\eta = 1e-15$: ^{87}Rb at 50 pK $\rightarrow \sigma_v = 69.2 \mu\text{m/s}$ (table: 70) $\eta = 1e-15$: ^{41}K at 50 pK $\rightarrow \sigma_v = 100.7 \mu\text{m/s}$ (table: 101) $\eta = 1e-17$: ^{87}Rb at 10 pK $\rightarrow \sigma_v = 30.9 \mu\text{m/s}$ (table: 31) $\eta = 1e-17$: ^{41}K at 10 pK $\rightarrow \sigma_v = 45.1 \mu\text{m/s}$ (table: 45)

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One lens is not enough for a 10^{-15} test of free fall in space; two would be

The 76 pK reached with one lens [1] is above the 50 pK that a satellite test of the universality of free fall at the 10^{-15} level requires [2]. Simulating a second, weaker lens 40 ms after the first predicts 31 ± 5 pK, below the requirement.

Holds when: The thin-lens model of [3] holds for the second pulse; the residual field in orbit is the one measured on ground.

Conventions: `units.lab@1`

Rests on: uses [Claim 46135936](#); uses arxiv:2310.04212, Tab. I (holds); extends [Claim f1ca8ee2](#)
 result · sealed in the Library

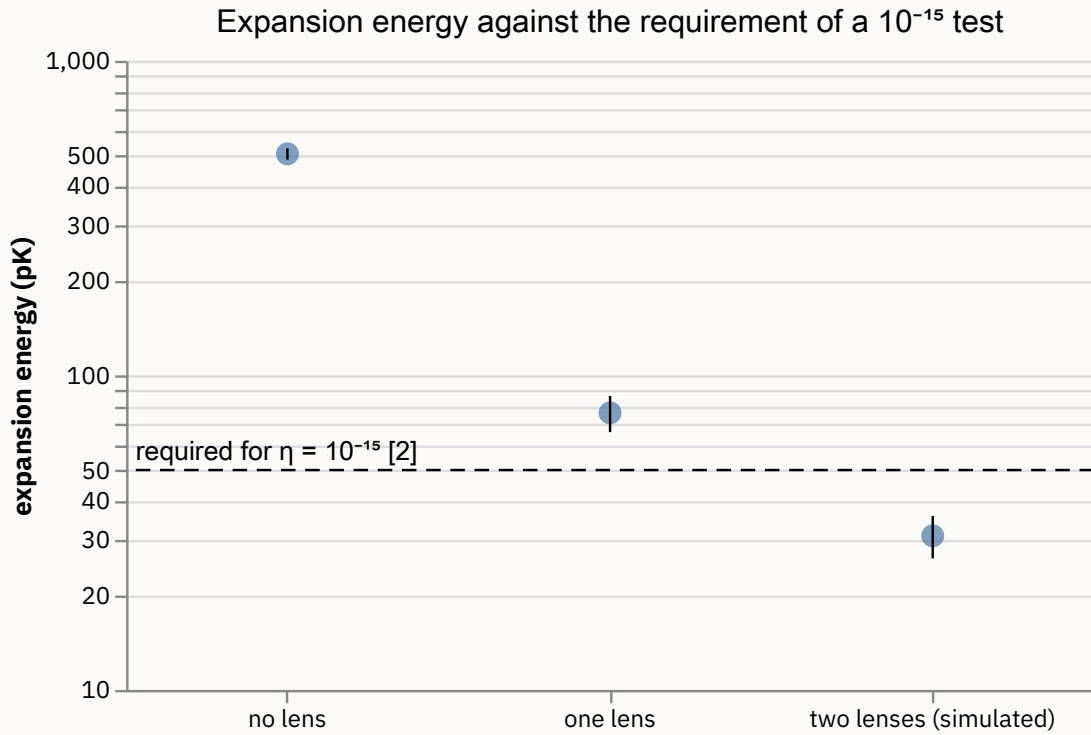


Figure 7: Expansion energy without a lens, with one (measured, [1]) and with two (simulated), against the 50 pK a 10^{-15} test requires [2]. Log scale. ([Claim 548236e3](#), evidence 1)

One lens is not enough (76 pK against 50 pK); two are predicted to be (31 ± 5) pK. Lena's open point: rerun with the cloud where it sits in orbit.

Open points and follow-up questions

- Rerun the two-lens simulation with the cloud displaced as in orbit (Lena's review).
- Measure the second lens on the chip.
- Ask the authors of Müller et al. whether an erratum for Tab. II is planned.

A Conventions

units.lab@1

Lengths in mm or μm , times in ms or s, accelerations in mm/s^2 ; z points away from the chip surface. Expansion energies as $k_B T$ in pK, with $k_B T = m \sigma_v^2$.