Eliminating the Apparent $\mathcal{O}(1)$ "Settling Factor" in Two-Channel Baryon–Dark-Matter Transport: Correct Target Observable and an Effective-Mixing Roadmap in the SFV/dSB Model

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Abstract

We document and clarify a first-principles transport calculation in the SFV/dSB framework in which a bulk-sector species χ (dark-matter-like) partially converts to a baryonic brane-sector yield B during bubble-wall passage following nucleation. Earlier pipeline notes reported a near-unity "settling factor" $f_{\rm settle} \simeq 0.94$ required to match the observed $\rho_{\rm DM}/\rho_b$ ratio. Here we show that this factor primarily arose from targeting the *wrong observable*: Planck reports an *energy-density* ratio $\rho_{\rm DM}/\rho_b$, while the wall-transport code outputs a *number* ratio $n_\chi/n_B = (1-P)/P$. Once the correct number-ratio target is used—including the dark-matter mass inferred from the updated SFV sound-speed calibration ($m_\chi \simeq 2.0\,\text{GeV}$)—the apparent $\mathcal{O}(1)$ settling factor disappears. A representative bounce-sourced run yields $\delta_{\rm LZ} = 0.053271$, $P_{\chi\to B} = 0.284456$, and $n_\chi/n_B = 2.51548$, which implies $\rho_{\rm DM}/\rho_b \simeq 5.36$ for $m_\chi \simeq 2.0\,\text{GeV}$. The remaining open problem is not an $\mathcal{O}(1)$ late-time correction, but the derivation of the *effective mixing strength* entering the local Landau–Zener estimator from first principles (microphysical overlap, momentum averaging, and unit-consistent wall kernels).

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1 Context and the "settling factor" that motivated this note

In the SFV/dSB model, the post-nucleation universe contains a wall-mediated two-channel transport process: a bulk species χ can convert to a brane-sector baryonic yield B as the bubble wall sweeps through. The simplest diagnostic output of the wall-conversion step is the *number ratio*

$$\frac{n_\chi}{n_B} = \frac{1 - P_{\chi\to B}}{P_{\chi\to B}}, \tag{1}$$

where $P_{\chi\to B} \equiv P(\chi \to B)$.

In an earlier pipeline note, an $\mathcal{O}(1)$ factor $f_{\rm settle} \simeq 0.94$ was introduced to bring a *predicted ratio* into agreement with the observational target. This note explains that the dominant origin of that factor was an incorrect target: the observational quantity commonly quoted from Planck is the *energy-density* ratio $\rho_{\rm DM}/\rho_b \approx \Omega_c/\Omega_b$, not the number ratio n_χ/n_B. When $m_\chi \neq m_p$, these are not equal, and confusing them produces an apparent residual $\mathcal{O}(1)$ discrepancy.

2 Correct target observable: energy ratio vs number ratio

2.1 Planck target as an energy-density ratio

Planck (base ΛCDM) constrains the present-day density parameters Ω_c (cold dark matter) and Ω_b (baryons), and the commonly cited ratio is

$$\left(\frac{\rho_{\rm DM}}{\rho_b}\right)_{\rm obs} \simeq \frac{\Omega_c}{\Omega_b} \approx 5.36, \tag{2}$$

where the numerical value corresponds to representative Planck best-fit parameters.[1]

2.2 Number-ratio target depends on the dark-matter mass

The wall-transport code naturally predicts a *number* ratio, but the observable is the *energy* ratio:

$$\frac{\rho_{\rm DM}}{\rho_b} = \frac{m_\chi n_\chi}{m_p\, n_B} = \left(\frac{m_\chi}{m_p}\right)\left(\frac{n_\chi}{n_B}\right). \tag{3}$$

Therefore the *correct number-ratio target* is

$$\left(\frac{n_\chi}{n_B}\right)_{\rm tgt} = \left(\frac{\rho_{\rm DM}}{\rho_b}\right)_{\rm obs}\left(\frac{m_p}{m_\chi}\right). \tag{4}$$

[1]The precise central value depends slightly on the dataset combination (TT/TE/EE+lensing, BAO, etc.). For this project we use the conventional Planck-era benchmark $\rho_{\rm DM}/\rho_b \simeq 5.36$, consistent with $\Omega_c h^2 \simeq 0.12$ and $\Omega_b h^2 \simeq 0.0224$.

Updated SFV calibration and m_χ. A key input is the dark-matter-like mass m_χ implied by the SFV microphysical calibration. An older draft used $c_s \simeq 100\,\mathrm{m/s}$ and obtained $m_\chi \simeq 5.94\,\mathrm{GeV}$. With the updated sound speed $c_s \simeq 297\,\mathrm{m/s}$, holding the same healing-length calibration ($\xi \propto 1/(mc_s)$) implies

$$m_\chi \;\propto\; \frac{1}{c_s} \qquad \Rightarrow \qquad m_\chi^{(\mathrm{new})} \simeq m_\chi^{(\mathrm{old})} \frac{c_s^{(\mathrm{old})}}{c_s^{(\mathrm{new})}} \simeq 5.94\,\frac{100}{297} \simeq 2.0\,\mathrm{GeV}. \tag{5}$$

With $m_\chi \simeq 2.0\,\mathrm{GeV}$ and $m_p \simeq 0.938\,\mathrm{GeV}$, Eq. (4) gives

$$\left(\frac{n_\chi}{n_B}\right)_{\mathrm{tgt}} \approx 5.36 \times \frac{0.938}{2.0} \approx 2.51. \tag{6}$$

This is the correct target for the transport code output n_χ/n_B.

3 Bounce-sourced wall conversion: local Landau–Zener estimator

3.1 Crossing condition from the bounce profile

The wall profile is extracted from an $O(4)$ bounce solution and expressed in a wall coordinate $\xi \equiv r - R_0$, where R_0 is the wall center (peak location used in the scripts). Two background fields are read from the bounce CSV: $\phi(\xi)$ and $\Phi(\xi)$. A level-splitting function is defined (script convention)

$$\Delta(\xi) \;\equiv\; y_B\,\phi(\xi) \;-\; y_\chi\,\Phi(\xi), \tag{7}$$

and the crossing $\xi_\star$ is the root $\Delta(\xi_\star) = 0$. The slope at crossing is

$$\Delta'_\star \;\equiv\; \left.\frac{d\Delta}{d\xi}\right|_{\xi_\star}. \tag{8}$$

3.2 Local mixing and adiabaticity parameter

In the simplest local model used by `transport_from_profile.py`, the off-diagonal mixing is taken to be

$$m_{\mathrm{mix}}(\xi) \equiv \lambda_{\mathrm{tr,eff}}\;\phi(\xi), \tag{9}$$

where $\lambda_{\mathrm{tr,eff}}$ is an *effective* transport mixing strength. The LZ adiabaticity parameter is then

$$\delta_{\mathrm{LZ}} \;\equiv\; \frac{m_{\mathrm{mix}}(\xi_\star)^2}{v_w\,|\Delta'_\star|} \;=\; \frac{\lambda^2_{\mathrm{tr,eff}}\,\phi_\star^2}{v_w\,|\Delta'_\star|}, \qquad \phi_\star \equiv \phi(\xi_\star), \tag{10}$$

and the conversion probability is

$$P_{\chi\to B} \;=\; 1 - \exp(-2\pi\,\delta_{\mathrm{LZ}})\,. \tag{11}$$

Finally, the number ratio follows from Eq. (1).

Important: what $\lambda_{\mathrm{tr,eff}}$ represents. Equation (10) is *not* a complete microphysical derivation. The entire content of momentum/angle averaging, wall-profile overlap suppression, and unit-consistent mapping from the bounce coordinate ξ into a physical scattering problem is, at present, encapsulated into the single effective constant $\lambda_{\mathrm{tr,eff}}$. This note clarifies how using the correct target observable eliminates the earlier $\mathcal{O}(1)$ factor, and then defines the remaining first-principles task: deriving $\lambda_{\mathrm{tr,eff}}$ without tuning.

4 Eliminating the apparent $f_{\rm settle} \simeq 0.94$: corrected target and updated mass

4.1 Where $f_{\rm settle}$ came from

Earlier work compared a predicted *number* ratio to the Planck *energy* ratio. If one incorrectly equates $\frac{n_\chi}{n_B} \overset{?}{\approx} \frac{\rho_{\rm DM}}{\rho_b}$, then any $m_\chi \neq m_p$ will manifest as a spurious correction factor. From Eq. (3), the mismatch factor is

$$\frac{(n_\chi/n_B)}{(\rho_{\rm DM}/\rho_b)} \;=\; \frac{m_p}{m_\chi}. \tag{12}$$

For m_χ near a GeV, this is an $\mathcal{O}(1)$ number—precisely the magnitude of the previously introduced $f_{\rm settle} \sim 0.94$ when m_χ was taken near $\sim 0.95\,\mathrm{GeV}$. Thus $f_{\rm settle}$ was largely bookkeeping: the wrong target observable was used.

4.2 Corrected target for $m_\chi \simeq 2.0\,\mathrm{GeV}$

With the updated SFV calibration implying $m_\chi \simeq 2.0\,\mathrm{GeV}$ (Eq. (5)), the correct number target is ~ 2.51 (Eq. (6)), which corresponds to a target probability

$$P^{(\rm tgt)}_{\chi\to B} \;=\; \frac{1}{1+(n_\chi/n_B)_{\rm tgt}} \;\approx\; \frac{1}{1+2.51} \;\approx\; 0.285. \tag{13}$$

5 Numerical benchmark: bounce-sourced run and recovered Planck ratio

A representative run of `transport_from_profile.py` on the bounce profile `background_profile.csv` produced the following diagnostic values (verbatim from the run output):

$$\xi_\star = -0.1512028724, \tag{14}$$
$$\phi_\star = 0.3729827675, \tag{15}$$
$$\Delta'_\star = 0.7873385809, \tag{16}$$
$$\delta_{\rm LZ} = 0.05327108935, \tag{17}$$
$$P_{\chi\to B} = 0.28445595669, \tag{18}$$
$$\frac{n_\chi}{n_B} = 2.5154827188. \tag{19}$$

Using Eq. (3) with $m_\chi = 2.0\,\mathrm{GeV}$ and $m_p \simeq 0.938\,\mathrm{GeV}$, the implied energy-density ratio is

$$\frac{\rho_{\rm DM}}{\rho_b} \;=\; \left(\frac{m_\chi}{m_p}\right)\left(\frac{n_\chi}{n_B}\right) \;\approx\; \left(\frac{2.0}{0.938}\right) \times 2.51548 \;\approx\; 5.36, \tag{20}$$

which matches the Planck-era benchmark in Eq. (2) without introducing any additional $\mathcal{O}(1)$ settling factor.

Conclusion of this step. The prior $f_{\rm settle} \simeq 0.94$ does not represent an additional late-time physical process in this benchmark; it was a consequence of comparing the wrong kind of ratio (number vs energy) under a mass mismatch.

6 What remains: deriving $\lambda_{\mathrm{tr,eff}}$ from first principles

While the corrected target removes the spurious $\mathcal{O}(1)$ mismatch, the present implementation still requires specifying an *effective* mixing strength $\lambda_{\mathrm{tr,eff}}$ that controls δ_{LZ} via Eq. (10). The key "no tuning" goal is to compute this quantity from microphysics anchored to the same bounce wall.

6.1 Distributed-overlap to local-equivalent mapping

The script `extended_LZ_lambda_v2.py` implements a distributed-overlap model in which mixing is suppressed away from the crossing by a finite-energy overlap kernel $f(\xi, E)$, typically of WKB form $f(\xi, E) \sim \exp[-I(\xi, E)]$, with I an integral of an effective barrier momentum $\kappa(\xi, E)$. The distributed model naturally produces an integral of the schematic form

$$I_2 \equiv \int d\xi \, \phi(\xi)^2 \, \left\langle f(\xi, E)^2 \right\rangle_E , \tag{21}$$

where $\langle \cdot \rangle_E$ denotes an energy average under an assumed distribution. The same script outputs a *local-equivalent* constant $\lambda_{\mathrm{eff,eq}}$ that reproduces the distributed result when inserted into the local LZ formula:

$$\lambda_{\mathrm{eff,eq}} \equiv g_{\mathrm{portal}} \frac{\sqrt{I_2}}{\phi_\star}, \tag{22}$$

so that $\lambda_{\mathrm{tr,eff}}$ in Eq. (10) is identified with $\lambda_{\mathrm{eff,eq}}$ for comparison to `transport_from_profile.py`.

For the run corresponding to Sec. 5, `extended_LZ_lambda_v2.py` reported

$$\lambda_{0,\mathrm{required}} \approx 0.0472243, \qquad \lambda_{\mathrm{eff,eq}} \approx 0.300745, \tag{23}$$

where $\lambda_{0,\mathrm{required}}$ is the bare coefficient required in the distributed kernel and $\lambda_{\mathrm{eff,eq}}$ is the corresponding effective constant used by the local estimator. In other words, the *elimination* of the spurious f_{settle} reveals the next target: computing the overlap/averaging physics that yields $\lambda_{\mathrm{eff,eq}}$ from first principles.

6.2 Why this is the correct "next-step" tuning target

In the current pipeline, the observational match is controlled primarily by $P_{\chi\to B}$, and for small-to-moderate δ_{LZ} one has $P_{\chi\to B} \sim 2\pi\delta_{\mathrm{LZ}}$ so that $P_{\chi\to B} \propto \lambda^2_{\mathrm{tr,eff}}$. Thus a physically derived overlap suppression and momentum averaging are precisely the ingredients needed to make the match parameter-free at this stage.

7 Next steps (actionable first-principles upgrades)

To remove residual effective inputs and complete the first-principles story, the following upgrades are planned:

1) **Unit-consistent wall-to-transport mapping.** Ensure the ξ coordinate used in overlap integrals and $\kappa(\xi, E)$ has a physically consistent conversion (including any rescalings between solver units and physical units). This directly impacts I_2 and therefore $\lambda_{\mathrm{eff,eq}}$.

2) **Momentum/angle averaging with the correct phase-space measure.** Replace the current simple energy-weighting proxy with a physically justified distribution and measure appropriate to the reheating/transport environment (e.g., 3D phase-space weighting rather than 1D MB).

3) **Derive the barrier function $\kappa(\xi, E)$ from microphysics.** Express κ in terms of the wall-dependent masses and potentials inferred from the bounce (or from the SFV/dSB matching), rather than using simplified placeholders.

4) **Automated side selection and asymptotic plateau detection.** The overlap integral should terminate where the relevant mass profile reaches its asymptotic plateau (e.g., 99% of its asymptotic value), rather than at a fixed ξ-multiple, to prevent accidental bias.

5) **End-to-end closure test.** Use the resulting first-principles $\lambda_{\mathrm{tr,eff}}$ to predict $P_{\chi\to B}$ and n_χ/n_B with no manual insertion of $\lambda_{\mathrm{eff,eq}}$, and verify that the implied $\rho_{\mathrm{DM}}/\rho_b$ matches Eq. (2).

A Reproducibility checklist (repository)

Key scripts

- `transport_from_profile.py` (local LZ from bounce crossing)
- `extended_LZ_lambda_v2.py` (distributed overlap → local-equivalent mixing)
- `xi_overlap_finiteE_v2.py` (finite-energy overlap diagnostics)

Recommended run order

```
python extended_LZ_lambda_v2.py --params extended_LZ_lambda_params.json
# copy lambda_eff_equiv into transport_params.json as couplings.lambda_tr_eff
python transport_from_profile.py --params transport_params.json
```

Core outputs to record

- $\xi_\star, \phi_\star, \Delta'_\star$
- $\delta_{\mathrm{LZ}}, P_{\chi\to B}, n_\chi/n_B$
- m_χ used for converting to $\rho_{\mathrm{DM}}/\rho_b$
- $\lambda_{0,\mathrm{required}}$ and $\lambda_{\mathrm{eff,eq}}$ from the extended script

References

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[3] Planck Collaboration, "Planck 2018 results. VI. Cosmological parameters," *Astron. Astrophys.* **641** (2020) A6.

[4] Particle Data Group, "Review of Particle Physics," *Prog. Theor. Exp. Phys.* (updated biennially).