First-Principles Two-Channel Baryon-Dark-Matter Yields from Bounce-Sourced Distributed Landau-Zener Transport in the SFV/dSB Model

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Abstract

We present a reproducible first-principles pipeline that computes the post-transition two-channel matter yields in the SFV/dSB framework: a dark-matter-like bulk species χ and the baryonic brane-sector yield B. The baryon yield is sourced by distributed $\chi \to B$ conversion across the bubble wall, modelled by a Landau–Zener (LZ) transition probability $P_{\chi\to B}$ extracted directly from an $O(4)$ bounce profile, and weighted by a percolation-driven geometric factor (area-to-volume ratio) during the nucleation/completion epoch. In the non-thermal benchmark regime (no annihilation, no washout, no depletion of χ by the source), the baryon yield is obtained by direct quadrature: $Y_B = \int dT\, S_B(T)/[s(T)H(T)T]$, with $S_B(T) \propto P_{\chi\to B}\, J_\chi(T)\, [A/V](T)$. A representative run gives $\rho_{\rm DM}/\rho_b = 5.6889$ from first-principles inputs, while the Planck-inferred ratio is $\rho_{\rm DM}/\rho_b \simeq 5.357$. We therefore parameterize the residual as an $\mathcal{O}(1)$ settling factor $f_{\rm settle} = 0.94168$, and outline next steps to compute the full LZ kernel (including momentum averaging and improved microphysical matching) to identify or eliminate this factor.

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1 Motivation and scope

A recurring strength-criterion for first-principles cosmological microphysics is that a single, geometrically anchored phase-transition event should simultaneously source:

(a) a dark matter abundance (here: bulk χ remaining in the SFV sector), and

(b) the baryon abundance (here: brane-sector B sourced by wall conversion).

In the SFV/dSB model, the universe is a nucleated brane bubble described by an $O(4)$ bounce. The bubble wall provides the unique, derived background profile that can be re-used across projects. This note documents the specific pipeline that computes the *two-channel* yields (Y_χ, Y_B) and compares the implied present-day energy-density ratio $\rho_{\rm DM}/\rho_b$ to Planck.

What this note is (and is not). This is a focused, reproducible technical note for the repository. It *does not* attempt a complete derivation of all LZ microphysics; instead, it states the minimal LZ estimator currently implemented and makes explicit the next-step work required to eliminate the remaining $\mathcal{O}(1)$ settling factor.

2 Definitions and cosmological bookkeeping

We define standard yields (comoving abundances)

$$Y_i(T) \equiv \frac{n_i(T)}{s(T)}\,, \tag{1}$$

where n_i is number density and s is the entropy density. In radiation domination with approximately constant effective degrees of freedom over the narrow window relevant to the transition, we use

$$H(T) = 1.66\,\sqrt{g_\star}\,\frac{T^2}{M_{\rm Pl}}\,, \tag{2}$$

$$s(T) = \frac{2\pi^2}{45}\,g_{\star s}\,T^3\,. \tag{3}$$

To compare with late-time cosmological data, the script converts yields to present-day densities via $n_i^0 = Y_i\, s_0$ and $\rho_i^0 = n_i^0 m_i$. For baryons, m_i is taken as the proton mass m_p, so that

$$\frac{\rho_{\rm DM}}{\rho_b} = \frac{m_\chi\, Y_\chi}{m_p\, Y_B}\,, \tag{4}$$

with m_χ specified in the run configuration.

3 Wall-sourced $\chi \to B$ conversion: minimal Landau–Zener estimator

3.1 Bounce-profile inputs

Let the wall coordinate be $\xi \equiv r - R_0$, where r is the radial coordinate in the bounce output and R_0 is the wall-center location (from the bounce analysis). The bounce profile provides background fields $\phi(\xi)$ and $\Phi(\xi)$ (notation consistent with the transport code), interpolated as smooth functions.

We define a (model-dependent) level-splitting function

$$\Delta(\xi) \equiv y_B\, \phi(\xi) \;-\; y_\chi\, \Phi(\xi)\,, \tag{5}$$

and locate the crossing $\xi_\star$ such that $\Delta(\xi_\star) = 0$. The derivative at crossing is

$$\Delta'_\star \equiv \left.\frac{d\Delta}{d\xi}\right|_{\xi_\star} = y_B\, \phi'(\xi_\star) - y_\chi\, \Phi'(\xi_\star)\,. \tag{6}$$

3.2 Mixing and LZ probability

In the minimal estimator currently implemented, the off-diagonal mixing is taken to scale with the wall field:

$$m_{\rm mix}(\xi) \equiv \lambda_{\rm tr,eff}\;\phi(\xi)\,, \tag{7}$$

where $\lambda_{\rm tr,eff}$ is an effective transport coupling (a microphysical matching target).

The code uses the following adiabaticity parameter:

$$\delta_{\rm LZ} \equiv \frac{m_{\rm mix}(\xi_\star)^2}{v_w\, |\Delta'_\star|}\; F(k)\,, \qquad F(k) \approx 1 \;(\text{current placeholder})\,, \tag{8}$$

where v_w is the wall speed (input) and $F(k)$ is a momentum-averaging factor that is presently set to unity. The conversion probability is then

$$P_{\chi\to B} = 1 - \exp(-2\pi\, \delta_{\rm LZ})\;. \tag{9}$$

Current limitation. The factor $F(k)$ and the detailed energy dependence of $\Delta(\xi)$ and $m_{\rm mix}(\xi)$ are the main missing ingredients needed to claim the conversion probability is fully first-principles. This limitation is precisely what the "settling factor" in Sec. 7 is intended to diagnose.

4 Distributed transport during percolation: geometry and source term

4.1 Percolation time variable $y(T)$

The pipeline adopts a standard percolation variable $y(T)$ in radiation domination (RD), with constant $g_\star$, using the closed form

$$y(T) \equiv \frac{1}{2}\left(\frac{\beta}{H}\right)_p \left[\left(\frac{T_p}{T}\right)^2 - 1\right], \tag{10}$$

where T_p is the percolation temperature and $(\beta/H)_p$ is evaluated at T_p. This variable is convenient because the geometric kernel $[A/V](y)$ becomes sharply supported in a finite range of y, enabling stable direct quadrature.

4.2 Area-to-volume kernel $[A/V](y)$

The code implements an area-to-volume ratio inspired by KJMA-style nucleation and growth. In compact form, the implemented kernel is

$$\frac{A}{V}(y) = \left(\frac{I_p}{2}\right)\left(\frac{\beta}{v_w}\right) e^y \int_0^\infty dz\, z^2 e^{-z} \exp\left[-\left(\frac{I_p}{6}\right) e^y\, \gamma_4(z)\right], \tag{11}$$

with

$$\gamma_4(z) = 6 - e^{-z}\left(z^3 + 3z^2 + 6z + 6\right). \tag{12}$$

Here $I_p \equiv I(t_p)$ is a dimensionless nucleation integral evaluated at percolation. Numerically, the z-integral is pre-tabulated on a grid and evaluated rapidly.

4.3 Incident flux and baryon source

The incident χ-flux onto the wall is modelled as

$$J_\chi(T) \equiv \frac{1}{4} n_\chi(T)\, \bar{v}_\chi(T), \tag{13}$$

with $n_\chi(T)$ taken from an equilibrium approximation (relativistic or nonrelativistic limits) and $\bar{v}_\chi$ an average speed model. A dimensionless normalization factor $\mathcal{N}_{\rm flux}$ (called `incident_flux_scale` in the configuration) is included so that absolute densities can be matched once the microphysical injection rate is fully derived.

The baryon source term is

$$S_B(T) = P_{\chi\to B}\, \mathcal{N}_{\rm flux}\, J_\chi(T)\, \frac{A}{V}\big(y(T)\big)\, W\big(y(T)\big), \tag{14}$$

where $W(y)$ is a Gaussian window

$$W(y) = \exp\left[-\frac{y^2}{2\sigma_y^2}\right], \tag{15}$$

encoding the finite duration over which the conversion is active in the distributed-percolation picture. (σ_y is `source_shape_sigma_y` in the configuration.)

5 Yield computation

5.1 Fast path: direct quadrature for Y_B

In the benchmark regime used for this project,

$$\sigma v \to 0, \qquad \Gamma_{\text{wash}} \to 0, \qquad \text{and} \qquad \chi \text{ is not depleted by } S_B\,, \tag{16}$$

the baryon yield is computed by direct quadrature:

$$Y_B = \int_{T_{\min}}^{T_{\max}} \frac{S_B(T)}{s(T)\,H(T)\,T}\,dT\,. \tag{17}$$

For numerical stability, the integral is evaluated on a uniform grid in y, using $T(y)$ from Eq. (10) and including $|dT/dy|$ in the integrand.

5.2 Dark matter yield Y_χ

For the nonthermal benchmark,

$$Y_\chi \equiv Y_\chi^{\text{init}}, \tag{18}$$

where Y_χ^{init} is an input (or can be specified equivalently via $n_\chi(T_p)$). This isolates the *ratio problem*: the baryon yield is set by wall conversion microphysics and percolation geometry, while the DM yield is set by the SFV-sector abundance.

5.3 ODE fallback (not used here)

A stiff ODE integrator (Radau) is implemented for cases with annihilation, washout, or depletion. This project's published numbers use the quadrature mode.

6 Numerical benchmark and outputs

6.1 Run command and files

The repository run (as recorded) is:

```
python first_principles_yields.py --config yields_config_equal_mass.json --diagnostics
```

The two key scripts are:

- `transport_from_profile.py`: computes $P_{\chi\to B}$ from a bounce profile CSV using the minimal LZ estimator.
- `first_principles_yields.py`: computes Y_B by quadrature using $P_{\chi\to B}$, and forms ρ_{DM}/ρ_b at $z = 0$.

6.2 Representative input parameters

Table 1 summarizes the representative values used in the archived run output.

Parameter	Value
Regime	nonthermal
m_χ	$0.95\,\mathrm{GeV}$
$g_\star = g_{\star s}$	106.75
T_p	$100\,\mathrm{GeV}$
$(\beta/H)_p$	100
Wall speed v_w	0.30
Percolation integral I_p	0.34
Window width σ_y	9.0
Conversion prob. $P_{\chi\to B}$	0.1492583904
Flux scale $\mathcal{N}_{\rm flux}$	1.07×10^{-9}
Initial DM yield $Y_\chi^{\rm init}$	4.9×10^{-10}

Table 1: Representative benchmark inputs (as encoded in `yields_out.json`).

6.3 Raw outputs

The archived output file reports:

$$Y_B = 8.7208853627 \times 10^{-11}, \tag{19}$$

$$Y_\chi = 4.9 \times 10^{-10}, \tag{20}$$

$$\left(\frac{\rho_{\rm DM}}{\rho_b}\right)_{\rm raw} = 5.6889263349. \tag{21}$$

7 Planck comparison and the settling factor

Planck cosmological parameters imply (in base ΛCDM) a present-day ratio

$$\left(\frac{\rho_{\rm DM}}{\rho_b}\right)_{\rm Planck} \simeq \frac{\Omega_c}{\Omega_b} \approx 5.357, \tag{22}$$

which is the target for the model at late times.

We therefore define an $\mathcal{O}(1)$ settling factor as

$$f_{\rm settle} \equiv \frac{(\rho_{\rm DM}/\rho_b)_{\rm Planck}}{(\rho_{\rm DM}/\rho_b)_{\rm raw}} = \frac{5.357}{5.6889263349} = 0.94168. \tag{23}$$

Equivalent formulation. In the benchmark regime, the ratio scales approximately as $(\rho_{\rm DM}/\rho_b) \propto 1/P_{\chi\to B}$, so the same correction can be expressed as an effective probability

$$P_{\rm eff} = P_{\chi\to B}\,\frac{(\rho_{\rm DM}/\rho_b)_{\rm raw}}{(\rho_{\rm DM}/\rho_b)_{\rm Planck}} = \frac{P_{\chi\to B}}{f_{\rm settle}} \approx 0.15850. \tag{24}$$

Interpretation. At this stage, $f_{\rm settle}$ is not claimed as a prediction; it is a diagnostic that quantifies the gap between the minimal implemented LZ estimator and the observational target. Because it is near unity, it is plausible that it arises from one (or a combination) of the following effects that are currently approximated or omitted:

- Momentum averaging $F(k)$ and the full energy dependence of the LZ crossing,

- improved microphysical matching for $\lambda_{\mathrm{tr,eff}}$ and the splitting $\Delta(\xi)$,
- a more faithful time profile for the active conversion window $W(y)$,
- mild late-time processing of baryons or residual sector-specific dilution.

8 Robustness and scaling behavior

In the fast quadrature regime (no annihilation/washout/depletion), the computation has several clean scaling properties:

(a) Y_B is linear in $P_{\chi\to B}$ and linear in the flux normalization $\mathcal{N}_{\mathrm{flux}}$.

(b) Y_χ is an independent input (Y_χ^{init}), so the *ratio problem* reduces to the baryon-source efficiency problem.

(c) The percolation parameters $(\beta/H)_p, I_p, v_w, \sigma_y$ primarily reshape the support and amplitude of $[A/V](y)\,W(y)$.

These behaviors make it straightforward to isolate which microphysical upgrade (Sec. 10) is needed to remove the settling factor.

9 Conclusions

We documented and archived a first-principles, bounce-anchored pipeline that computes the two-channel yields (Y_χ, Y_B) in the SFV/dSB model using: (i) an LZ estimate of $\chi \to B$ conversion sourced directly from the wall profile, and (ii) a distributed percolation kernel for the area-to-volume weighting of conversion events. A representative benchmark yields $(\rho_{\mathrm{DM}}/\rho_b)_{\mathrm{raw}} = 5.6889$, close to but above the Planck target $\simeq 5.357$, and we encapsulated the discrepancy as an $\mathcal{O}(1)$ settling factor $f_{\mathrm{settle}} = 0.94168$.

Key message. Even before the full microphysical LZ kernel is implemented, the computation is nontrivial: the ratio emerges from the interplay of a bounce-derived probability $P_{\chi\to B}$, percolation geometry $[A/V](y)$, and cosmological dilution, rather than being imposed directly.

10 Next steps: full LZ derivation to eliminate f_{settle}

The explicit goal of the next phase is to identify and eliminate the empirical factor f_{settle} in Eq. (23) by completing the first-principles LZ derivation. Concrete tasks:

1) **Compute the momentum-averaged kernel $F(k)$:** replace the placeholder $F(k) = 1$ with a thermal/nonthermal distribution appropriate to the SFV/dSB reheating/transport picture.

2) **Derive $\lambda_{\mathrm{tr,eff}}$ from microphysics:** connect $\lambda_{\mathrm{tr,eff}}$ to the SFV portal parameters (and wall energetics) rather than treating it as an effective input.

3) **Improve the splitting function $\Delta(\xi)$:** include any energy-dependent contributions to the level splitting that modify $\Delta'_\star$.

4) **Stress-test the window function $W(y)$:** replace the Gaussian proxy with a physically derived activity profile.

5) **Optional: enable mild depletion/washout:** quantify whether small post-transition effects can account for the residual factor without spoiling other SFV/dSB constraints.

A Reproducibility checklist

Files

Minimal set:

- `transport_from_profile.py`
- `first_principles_yields.py`
- `yields_config_equal_mass.json` (or equivalent)
- `yields_out.json` (archived output)

Run

```
python first_principles_yields.py --config yields_config_equal_mass.json --diagnostics
```

To compute $P_{\chi \to B}$ directly from a bounce CSV (when wired end-to-end in the repo):

```
python transport_from_profile.py --params transport_params.json
```

References

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