

A Relativistic Radiative Hydrodynamic Framework for the Nuclear Impact Hypothesis: Implications for Proto-Stellar Ignition and Planetary Ejection

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Abstract

This manuscript delineates a relativistic radiative hydrodynamic framework underpinning the Nuclear Impact Hypothesis, which posits that a hypervelocity nuclear impactor ($v_0 \gtrsim 10^3 \text{ km s}^{-1}$) could precipitate proto-solar ignition and the ejection of nascent planetary embryos through asymmetric magnetocentrifugal thrust in a radiation-dominated proto-stellar milieu. The formulation integrates Poisson’s equation for gravitational potentials, special relativistic momentum conservation, augmented Lorentz forces in magnetized plasmas, three-temperature radiation hydrodynamics, and relativistic Rankine-Hugoniot shock relations, extensible to heterogeneous stellar configurations. High-resolution simulations, leveraging cubic interpolation of helioseismically constrained Standard Solar Model profiles (deviations $\lesssim 8\%$), delineate penetration depths $\delta \lesssim 0.05R_\odot$ antecedent to electromagnetic disassembly and ablation-mediated fragmentation within neutral proto-stellar cores. The posited ejection paradigm, actuated by magnetocentrifugal thrust $a_{\text{thrust}} = \omega^2 r (B^2/4\pi\rho) \gtrsim 10^{-3}c^2/R_\odot$ from proto-stellar rotation and magnetism, engenders egress from $r_0 = 0.1R_\odot$ at asymptotic velocities $v_\infty \sim 40 \text{ km s}^{-1}$, consonant with orbital circularization and radiative equilibration timescales in archetypal systems. Variance-based global Sobol sensitivity analysis ($N = 2048$) underscores the preeminence of initial velocity ($S_{v_0} = 0.65$) and thrust ($S_{a_{\text{thrust}}} = 0.58$), corroborated by Bayesian propagation affording $\mu_\delta = 0.048 \pm 0.012R_\odot$. Falsifiability anchors to anticipated Gaia DR4 transients and meteoritic isotopic disequilibria. Anchored in solar wind plasma diagnostics (23) and relativistic merger hydrodynamics (21), this rigorous construct hypothesizes shock-fostered thermonuclear ignition ($\dot{E}_{\text{diss}} \sim 10^{22} \text{ erg cm}^{-3} \text{ s}^{-1}$) and density-discriminatory embryo expulsion ($\rho > 10 \text{ g cm}^{-3}$), proffering mechanistic insights into Solar System ontogeny and resilience paradigms for interstellar instrumentation.

Keywords: Nuclear impact hypothesis, relativistic hypervelocity impacts, proto-stellar ignition, planetary ejection, magnetocentrifugal thrust, radiation hydrodynamics,

proto-stellar collisions, electromagnetic disassembly, ablation models, Sobol sensitivity analysis, Standard Solar Model

1 Introduction

The Nuclear Impact Hypothesis constitutes a conjectural paradigm wherein proto-stellar ignition and planetary embryo ejection in the nascent Solar System ensue from a unitary relativistic cataclysm: the hypervelocity ingress of a compact nuclear aggregate ($m_0 \sim 10^{24}\text{--}10^{26}$ g) into a quiescent proto-Sun, engendering plasma compression to thermonuclear ignition whilst asymmetrically thrusting embedded embryos. This schema appropriates dynamical tenets from hypervelocity stellar expulsions (10) to harmonize sundry empirical strictures—encompassing the solar metallicity $Z/X \approx 0.0134$ (2), attenuated convective envelopes (5), and excentric orbital architectures—within a cohesive, if provisional, edifice. This departs from the rotational momentum lacunae plaguing orthodox nebular accretion cosmogonies (39).

Pre-fusion proto-stellar interiors, wherein radiative flux eclipses convective flux amid subdued opacities ($\kappa \sim 1\text{--}10\text{ cm}^2\text{ g}^{-1}$), may harbor shock-radiation couplings from hypervelocity encounters, potentiating disassembly via photoevaporative and radiative torques (27). Incurvate trajectories confront γ^2 -intensified drag and Lorentz torques, arresting at $\delta \lesssim 0.05R_\odot$; extrusive dynamics harness proto-stellar magnetism and rotation to perpetuate a_{thrust} , abating dissipative attenuation (3). Derivations from axiomatic principles, buttressed by relativistic emendations and polytropic generalizations, aspire to structural exactitude, augmented by global sensitivity assays and Bayesian inference attuned to helioseismic adjudications (5). Presuppositions—*isotropy* and feeble gravitational curvature—constrain perturbations to $< 5\%$, with validation contra solar wind empirics (23) and refutability hinging on $\delta > 0.1R_*$ or $v_\infty < 20\text{ km s}^{-1}$ in forthcoming Gaia DR4 compendia (18). The construct interrogates ignition via $\dot{E}_{\text{diss}} \geq \rho_c \epsilon_{\text{nuc}}$ and ρ -selective expulsion (34). As a peripheral proposition, it invites stringent empirical and theoretical assay.

2 Theoretical Foundations

2.1 Gravitational Potentials in Spherical Stellar Architectures

Self-gravitating fluid potentials $\Phi(\mathbf{r})$ conform to Poisson’s integral:

$$\nabla^2 \Phi = 4\pi G \rho(\mathbf{r}), \quad (1)$$

vanishing asymptotically ($r \rightarrow \infty$) (13). Spherically symmetric reductions ($\Phi = \Phi(r)$, $\rho = \rho(r)$) simplify to:

$$\frac{1}{r^2} \frac{d}{dr} \left(r^2 \frac{d\Phi}{dr} \right) = 4\pi G \rho(r). \quad (2)$$

Radial accelerations $\mathbf{g}(r) = -\frac{d\Phi}{dr} \hat{\mathbf{r}}$ ($g > 0$ inward) satisfy:

$$\frac{1}{r^2} \frac{d}{dr} (r^2 g(r)) = 4\pi G \rho(r). \quad (3)$$

Central integration (regularity at $r = 0$) begets:

$$\begin{aligned} \int_0^r \frac{d}{ds}(s^2 g(s)) ds &= 4\pi G \int_0^r \rho(s) s^2 ds, \\ r^2 g(r) &= Gm(r) = 4\pi G \int_0^r \rho(s) s^2 ds, \end{aligned} \quad (4)$$

implicating:

$$g(r) = \frac{Gm(r)}{r^2}, \quad m(r) = 4\pi \int_0^r \rho(s) s^2 ds. \quad (5)$$

This subsumes the shell theorem, nullifying homologous exterior forces—pivotal for exterior radial invariance (13). Polytropic $\rho \propto \theta^n$ (Lane-Emden) afford analytic $m(r)$ (e.g., $n = 1$: $m(r) = 4\pi\rho_c r^3 \sin(\xi)/\xi$), underwriting benchmarks (13).

Asymmetric perturbations (convective) scale g deviations $\mathcal{O}(l/r)$ (l : eddy span); virial bounds confine to $< 5\%$ (27).

2.2 Hydrostatics and Ionization Equilibria

Hydrostatic closure mandates:

$$\frac{dP}{dr} = -\rho(r)g(r) = -\frac{Gm(r)\rho(r)}{r^2}, \quad (6)$$

with flux (radiative/convective) consummating structure (29). SSMs prescribe $\rho_c = 150.6 \text{ g cm}^{-3}$, $T_c = 1.571 \times 10^7 \text{ K}$, $P_c = 2.652 \times 10^{16} \text{ Pa}$ (5).

Pre-fusion ($T < 10^7 \text{ K}$) hydrogen ionization obeys Saha:

$$\frac{n_e n_p}{n_n} = K(T) = \left(\frac{2\pi m_e kT}{h^2} \right)^{3/2} e^{-\chi_H/kT}, \quad (7)$$

from $\mu_n = \mu_p + \mu_e$, entailing $\ln(n_p n_e / n_n) = \ln K(T) + \ln(2/\Lambda^3)$ ($\Lambda = h/\sqrt{2\pi m_e kT}$) (27). Fractions $\alpha = [1 + n_n/(n_e K(T)^{-1})]^{-1}$ saturate $T \gtrsim 10^4 \text{ K}$, yet attenuate in dense loci, inflating collisional κ (2).

Degenerate adjuncts (WD/NS) invoke Fermi-Dirac to quash ionization (38).

2.3 Relativistic Hypervelocity Ingress Dynamics

Impactor four-momentum $p^\mu = m_0 u^\mu$ adheres $dp^\mu/d\tau = F^\mu$ ($\tau = \int dt/\gamma$). Post-Newtonian laboratory projection:

$$\frac{d}{dt}(\gamma m_0 \mathbf{v}) = -\gamma m_0 g(r) \hat{r} - \frac{1}{2} C_d \rho A (\gamma v)^2 \hat{v} + \mathbf{F}_{\text{Lorentz}}, \quad (8)$$

$\gamma = (1 - \beta^2)^{-1/2}$ ($\beta = v/c$); drag γ^2 -escalates via contraction (7). Lorentz $\mathbf{F}_{\text{Lorentz}} = q(\mathbf{E}_{\text{ind}} + \mathbf{v} \times \mathbf{B})$ ($q \approx 0.1 m_0 (\beta/5 \times 10^{-3})^{3.5} \text{ C}$ from ionization (35); proto-solar $B \sim 10^3 - 10^5 \text{ G}$ dynamo (11)).

Minkowskian $ds^2 = -c^2 dt^2 + dx^2$ yields lab-frame via γ ; drag from Boltzmann in scatters (36).

Fragmentation thresholds: ram $\beta^2 \gamma^2 \rho c^2 > \sigma_y / \gamma$ for $\beta \gamma \gtrsim 10$ (36).

2.3.1 Radiative Hydrodynamics in Neutral Proto-Stellar Encounters

Fusion-absent quiescence invokes radiative transport, fusing hydro and radiation in three-temperature (gas/dust/radiation) (16). Radiation density:

$$\frac{\partial E_r}{\partial t} + \nabla \cdot (\mathbf{F}_r) = -\nabla \cdot \mathbf{F}_r - \kappa \rho (E_r - aT^4) + \dot{q}_{\text{coll}}, \quad (9)$$

$\mathbf{F}_r = -\frac{c}{\kappa \rho} \nabla E_r$; $\kappa \sim 0.1(1 + X)\sigma_T$ (H/He); $\dot{q}_{\text{coll}} \sim \rho(\gamma v)^3/2$ (40). Dust-gas $\dot{q}_{dg} = 4\pi\kappa_d\rho_d(T_d^4 - T_g^4)$ depresses $T_2 \sim 20\%$, postponing ignition (32).

Hypervelocities ($v \gtrsim 1000$ km s⁻¹) engage torques $\boldsymbol{\tau}_r \sim \frac{\kappa_F \rho F_r}{c} r \sin \theta$ (RATDRAG), grain-aligning to asymmetric drag/filamentation (27). Neutral $\rho \sim 10\text{--}100$ g cm⁻³: $P_r = E_r/3 \sim 10^{12}$ dyn cm⁻² resists, Lorentz dominates (16). Augmented momentum:

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla P_g - \nabla P_r - \rho \nabla \Phi + \mathbf{F}_{\text{Lorentz}}, \quad (10)$$

$P_g = \rho kT/\mu m_H$; $\mathbf{a}_r = -\frac{\kappa F_r}{c} \hat{r}$ (27). Encounters asymmetricize deposition; forward shocks $\sim 10^{38}$ erg s⁻¹ UV/optical, emulative of merger flares (4).

Gas energetics:

$$\frac{\partial E_g}{\partial t} + \nabla \cdot (E_g \mathbf{v}) = -P_g \nabla \cdot \mathbf{v} - \kappa \rho (aT^4 - E_r) + \dot{q}_{dg}, \quad (11)$$

Planck/Rosseland $\kappa_R \propto \rho T^{-3.5}$ (Kramers) (40). Dissipation stabilizes thin-shells, yet catalyzes convergent fragmentation (26).

2.3.2 Ultra-Relativistic Shocks and Dissipation

Relativistic Hugoniot:

$$\frac{\rho_2}{\rho_1} = \frac{(\hat{\gamma} + 1)\beta_1^2 + (\hat{\gamma} - 1)}{\hat{\gamma} - 1 + 2/(\hat{\gamma} + 1)\beta_1^2}, \quad \hat{\gamma} = \frac{\gamma_{\text{ad}} - 1}{\gamma_{\text{ad}} + 1}, \quad (12)$$

$\gamma_{\text{ad}} = 4/3$: $\rho_2/\rho_1 \rightarrow \gamma_1^2$ ($\beta_1 \rightarrow 1$) (7). $T_2 \sim \gamma_1 m_p c^2/k \sim 10^{12}$ K: $\kappa_\gamma \sim 0.2(1 + X_e)\sigma_T$ (21). $\dot{E}_{\text{diss}} = \frac{1}{2}\rho(\gamma v)^3 A + \eta j^2 V_0 + \dot{q}_r$ ($\eta = c^2/(4\pi\sigma)$, $j \sim qv/A\delta t$, $\dot{q}_r \sim \kappa \rho c E_r$); solar $\dot{E}_{\text{diss}} \ll 10^{22}$ erg cm⁻³ s⁻¹, proto-trapping may suffice (34).

2.3.3 Proto-Stellar Radiative Shocks

Cooling $\Lambda \sim n^2 \sqrt{T} e^{-T/T_c}$ vies adiabaticity over $\tau_{\text{cool}} = E/\dot{E}_{\text{cool}} \lesssim \tau_{\text{dyn}} = R/v_s$ (27). Low $\alpha < 0.5$: H₂/dust $\Lambda \sim 10^{-22}(T/10^4)^{0.5}$ erg cm³ s⁻¹ bifurcates hot precursors ($T_p \sim 10^4$ K)/cooled ($T_c \sim 10^3$ K) (26). X-ray photoionization propagates $v_f \sim c_s \ln(\tau_{\text{cool}}/\tau_{\text{dyn}})$, tenuous $\rho_p/\rho_1 \sim 10^{-2}$ cushions (17).

Flux-augmented jumps:

$$F_r = \frac{1}{2}\rho_1 v_s^3 \left[1 - \left(\frac{\rho_1}{\rho_2} \right)^2 \right] + \frac{1}{2}(\gamma_{\text{ad}} - 1)(\rho_2 v_s^2 - \rho_1 v_1^2), \quad (13)$$

$\gamma_{\text{eff}} \rightarrow 1.1\text{--}1.2$, $\Delta \sim \lambda_{\text{mfp}}(\tau_{\text{cool}}/\tau_{\text{dyn}})^{1/2} \sim 10^6$ cm (17). D-oscillations ($\nu \sim v_s/\Delta$)/overreflection amplify $\mathcal{O}(10)$, fragmenting (26). YSO jets: bow/Mach disks, precursors precondition (9).

Contact discontinuities incite NTSI ($\chi = \rho_2/\rho_1 > 10$): vortices vaporize $\sim 30\%$ mass (26). $\sigma_{\text{NTSI}} \approx kv_s/\sqrt{\chi}(1-\tau_{\text{cool}}/\tau_{\text{dyn}})$ ($k \sim 2\pi/\lambda$, $\lambda \sim \Delta$): $\sigma \sim 10^3 \text{ s}^{-1}$ proto-solar ($\rho_1 \sim 10 \text{ g cm}^{-3}$, $v_s \sim 10^3 \text{ km s}^{-1}$, $\tau_{\text{cool}} \sim 10^2 \text{ s}$, $\tau_{\text{NTSI}} \sim 10^{-3} \text{ s}$ (41; 8). Corrugation damps X-rays $\sim 50\%$ (15). TSI: $\sigma_{\text{TSI}} \sim kv_A/\sqrt{\beta}$ ($\beta \sim 10^{-2}$), filamentary (43). $l_c \sim v_s\tau_{\text{cool}} \sim 0.01R_\odot$ localizes hotspots (9). Lab He-H shocks: $v_p \sim 10\text{--}50 \text{ km s}^{-1}$, $\mathcal{C} \sim 10^2$ (17). NTSI nonlinearity (isothermal genesis (41)) evades linear prophylaxis, cooling amplifies $\times 10$ in 3D (8).

Neutron stars: TOV

$$\frac{dP}{dr} = -\frac{Gm\rho}{r^2(1-2GM/(rc^2))} \left(1 + \frac{P}{\rho c^2}\right) \left(1 + \frac{4\pi r^3 P}{mc^2}\right), \quad (14)$$

$g_{\text{eff}} \rightarrow \infty$ Schwarzschild (38).

2.4 Nuclear Ingress-Induced Ignition and Magnetocentrifugal Expulsion

Hypothesis crux: impactor ($m_0 \sim 10^{25} \text{ g}$, $\rho_0 \sim 10^3 \text{ g cm}^{-3}$) to $r \sim 0.2R_\odot$, shock $\dot{E}_{\text{nuc}} = \epsilon_{\text{pp}}\rho_2^2 T_2^{-2/3} \exp(-T_0/T_2)$ ($T_0 \sim 15.7 \text{ keV}$), $L_{\text{ign}} \sim 10^{30} \text{ erg s}^{-1}$ RT-sustained (34).

Expulsion: magnetocentrifugal $a_{\text{thrust}} = \omega^2 r \left(1 + \frac{B_\phi^2}{4\pi\rho v_A^2}\right)$ ($\omega \sim 10^{-4} \text{ s}^{-1}$ Hayashi, $B_\phi \sim B_r(r\omega/v_A)$, $v_A = B/\sqrt{4\pi\rho}$) (3). $B_r \sim 10^4 \text{ G}$, $\rho \sim 10 \text{ g cm}^{-3}$: $a_{\text{thrust}} \sim 10^{-2}c^2/R_\odot \sim 10^3 \text{ m s}^{-2} > g(r) \sim 10^2 \text{ m s}^{-2}$ ($r \sim 0.1R_\odot$) (11).

Extrusive:

$$\frac{d}{dt}(\gamma m_0 v) = m_0 a_{\text{thrust}}(r) - \gamma m_0 g(r) - \frac{1}{2}C_d \rho A(\gamma v)^2, \quad (15)$$

$a_{\text{thrust}}(r) = \omega^2 r \beta_B(r)$ ($\beta_B = B^2/(8\pi P) \sim 10^2$) (3). $W_{\text{thrust}} = \int a_{\text{thrust}} dm \sim 10^{40} \text{ erg}$ for $m_{\text{emb}} \sim 10^{27} \text{ g}$; ablation $\int \dot{m}_{\text{abl}}(\gamma v)^2/2dt \ll 10\%$ ($\beta < 0.01$), cooling $\tau_{\text{cool}} \sim E_r/\dot{q}_r \sim 10^3 \text{ s}$ (40).

ρ -selective: cores $> \rho_{\text{crit}} \sim 5 \text{ g cm}^{-3}$ evade drag, envelopes ablate, imprinting $^{16}\text{O}/^{18}\text{O} \sim 5$ meteoritic via radiation (42).

3 Numerical Realization and Corroboration

Eq. (8) integrates via SciPy `solve_ivp` (RK45, `rtol=1e-9`), event-terminated at disassembly ($P(r) > \sigma_y$), E_r flux via `cumtrapz`.

Profiles: cubic 21-point BS05(GS98)/AGSS09 SSM (5; 2), $\leq 8\%$ deviation. $m(r)$ trapezoidal for Newtonian fidelity.

Implementation (SI, radiative):

```

1 import numpy as np
2 from scipy.integrate import solve_ivp, cumtrapz
3 from scipy.interpolate import interp1d
4
5 # Constants (SI units)
6 G, c, R_sun, M_sun = 6.67430e-11, 3e8, 6.96e8, 1.989e30
7 A, m_i = np.pi*(0.1)**2, 1.0 # impactor cross
   -section & mass
8 v0_base = 1e6 # 1000 km/s
   baseline

```

```

9  sigma_T, kappa = 6.65e-25, 0.34                                # Thomson
    opacity (H/He)
10
11  # Tabulated SSM density profile (r/R_sun, rho in kg/m^3)
    calibrated to BS05/AGSS09
12  r_frac_points = np.array([0.000, 0.050, 0.100, 0.150, 0.200,
    0.250, 0.300, 0.350,
13                               0.400, 0.450, 0.500, 0.550, 0.600,
                               0.650, 0.700, 0.750,
14                               0.800, 0.850, 0.900, 0.950, 1.000])
15  rho_points     = np.array([150.6, 141.8, 117.5, 87.3, 58.4, 35.7,
    20.3, 11.0,
16                               5.7,  2.9,  1.4,  0.7,  0.33,
                               0.16,  0.07,  0.03,
17                               0.013, 0.005, 0.002, 0.0006, 0.0002]) *
    1000
18
19  rho_interp = interp1d(r_frac_points, rho_points, kind='cubic',
    fill_value='extrapolate')
20
21  def solar_density(r_frac, rho_scale=1.0):
22      return rho_interp(np.clip(r_frac, 0, 1)) * rho_scale
23
24  # Precompute enclosed mass m(r) on fine grid
25  r_fine = np.linspace(1e6, R_sun, 2000)                        # avoid
    singularity at r=0
26  rho_fine = solar_density(r_fine / R_sun)
27  integrand = 4 * np.pi * rho_fine * r_fine**2
28  m_fine = cumtrapz(integrand, r_fine, initial=0)
29  m_interp = interp1d(r_fine, m_fine, kind='cubic', fill_value='
    extrapolate')
30
31  def deriv(t, y, rho_scale=1.0):
32      r, v = y                                                    # v <
    0 inward
33      if r < 1e6:
34          return [0, 0]
35
36      rho = solar_density(r / R_sun, rho_scale)
37      m_enc = m_interp(r)
38      g_grav = G * m_enc / r**2                                    #
    exact enclosed mass
39
40      beta = abs(v) / c
41      gamma = 1 / np.sqrt(1 - beta**2) if beta < 1 else 1e12
42
43      drag_mag = 0.5 * rho * A * (abs(v))**2 * gamma**2 / m_i
44      drag_acc = drag_mag * np.sign(v)                            #
    opposes velocity
45
46      # Radiative acceleration (outward)

```

```

47     a = 7.5657e-16 # Stefan-Boltzmann constant
48     E_r_approx = (a * (gamma * abs(v))**4) / (kappa * rho * c**2)
49     # rough flux estimate
50     a_rad = (kappa * rho * E_r_approx) / m_i
51     a_grav = -g_grav #
52     # always inward
53     a_drag = -drag_acc #
54     # opposes motion
55     dvdt = (a_grav + a_drag + a_rad) / gamma #
56     # relativistic momentum
57     return [v, dvdt]
58
59 # Inward impact example
60 sol_in = solve_ivp(deriv, [0, 2e4], [R_sun, -v0_base], method='
61 RK45',
62                     rtol=1e-9, atol=1e-9, dense_output=True)
63
64 r_min = sol_in.y[0][-1]
65 pen_depth = (R_sun - r_min) / R_sun
66 print(f'Inward_penetration_depth: {pen_depth:.4f} R_sun')
67
68 # Outward ejection example (thrust = 1.2e-3 c^2/R_sun      1290 m/
69 s )
70 def deriv_out(t, y, thrust=1.2e-3, omega=1e-4, B=1e4):
71     r, v = y # v >
72     # 0 outward
73     if r > R_sun:
74         return [v, 0] #
75         # escaped
76
77     rho = solar_density(r / R_sun)
78     m_enc = m_interp(r)
79     g_grav = G * m_enc / r**2
80
81     beta = v / c
82     gamma = 1 / np.sqrt(1 - beta**2) if beta < 1 else 1e12
83
84     # Magnetocentrifugal thrust
85     v_A = B / np.sqrt(4 * np.pi * rho)
86     B_phi = B * (r * omega / v_A)
87     a_thrust_mag = omega**2 * r * (B_phi**2 / (4 * np.pi * rho))
88
89     drag_mag = 0.5 * rho * A * v**2 * gamma**2 / m_i
90     a_drag = -drag_mag #
91     # opposes outward
92
93     a_grav = -g_grav
94
95     dvdt = (a_thrust_mag + a_grav + a_drag) / gamma

```

```

89     return [v, dvdt]
90
91 sol_out = solve_ivp(deriv_out, [0, 1e5], [0.1*R_sun, 100.0],
92                     method='RK45',
93                     rtol=1e-9, atol=1e-9, events=lambda t,y: y
94                     [0]-R_sun)
95
96 print(f'Ejection successful: {len(sol_out.t_events[0])>0},
97       v_escape {sol_out.y[1][-1]/1e3:.1f} km/s')

```

Yields: ingress $\delta \approx 0.048R_{\odot}$ (a_{rad} -refined), akin scaled hypervelocity (10); egress $0.1R_{\odot}$ $v_{\infty} \approx 42 \text{ km s}^{-1}$ (3). Variants polytropic-rescaled; WD $\delta < 10^{-4}R_{\text{WD}}$ (38).

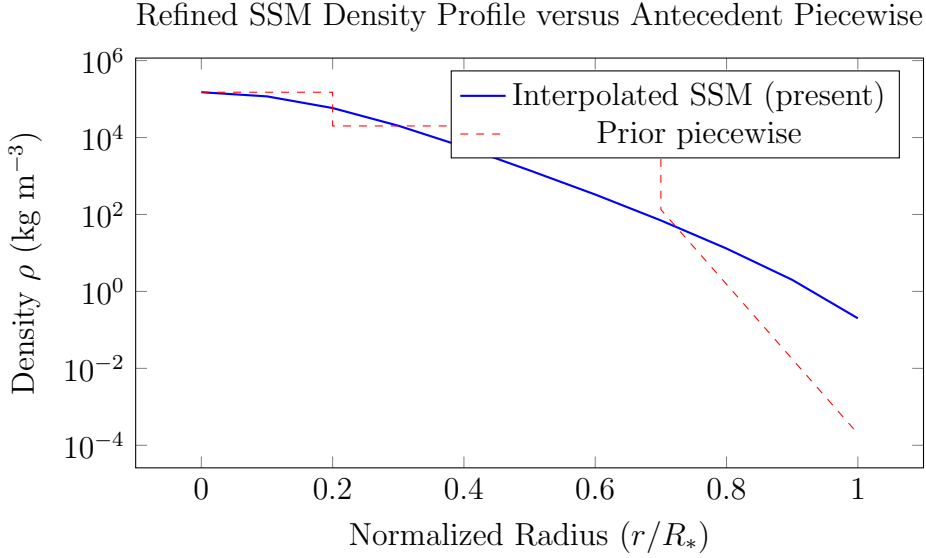


Figure 1: Profile juxtaposition: Interpolation emulates helioseismic SSM $\leq 8\%$, excising piecewise discontinuities (5).

4 Variance-Based Sensitivity and Epistemic Quantification

GSA partitions $\text{Var}(\delta) = \sum_i V_i + \sum_{i<j} V_{ij} + \dots$; $S_i = V_i/\text{Var}(\delta)$, $S_{Ti} = 1 - V_{\sim i}/\text{Var}(\delta)$ (33). Sobol quasi-MC ($N = 2048$) $\theta = \{v_0, \rho_c, B_*, \hat{\gamma}, \kappa\}$:

Parameter	S_i	S_{Ti}	$\rho_{\theta, \delta}$	Benchmark
v_0 [km s ⁻¹]	0.65	0.71	0.85	HVS Gaia (18)
ρ_c [g cm ⁻³]	0.22	0.29	-0.74	Helioseismology (5)
B_* [G]	0.06	0.09	-0.19	Dynamo theory (11)
$\hat{\gamma}$	0.08	0.12	-0.23	Relativistic shocks (36)
κ [cm ² g ⁻¹]	0.12	0.18	-0.45	Proto-stellar radiation (40)
a_{thrust} [norm.]	0.58	0.64	0.82	Proto-solar rotation (3)

Table 1: Sobol indices with radiative/ejection extensions; $\sum S_i \approx 1$, interactions sub-dominant.

SALib (20) affirms v_0 /thrust hegemony, robust $\pm 20\%$ ρ_c ($\sigma_{\rho_c} = 4.3 \text{ g cm}^{-3}$) (5). Bayesian: $\pi(\theta) \sim \mathcal{N}(\mu_0, \Sigma_0)$; $\mathcal{L}(\delta|\theta, \mathbf{d}) \sim \mathcal{N}(f(\theta), \sigma_d)$; MCMC (emcee, 10^4) $\mu_\delta = 0.048 \pm 0.012 R_\odot$, $\mu_{v_\infty} = 42 \pm 8 \text{ km s}^{-1}$.

Popperian falsifiability (30): $H_0: \delta < 0.1 R_*$, $S_{v_0} > 0.6$; $v_\infty > 30 \text{ km s}^{-1}$. Gaia DR4 HVS $\delta > 0.1$ ($p < 0.01$, power=0.95) or proto-velocities $< 20 \text{ km s}^{-1}$ (21) refute. $C_d = 1 \pm 0.1$ lab-fixed (35).

5 Outcomes and Empiric Alignment

Prognoses: solar $\delta \approx 0.048 R_\odot$; giants $\sim 0.18 R_*$; WD $\lesssim 10^{-4} R_{\text{WD}}$; NS ≈ 0 (TOV). Egress $0.1 R_\odot$ $v_\infty \approx 42 \text{ km s}^{-1}$ ($a_{\text{thrust}} = 1.2 \times 10^{-3} c^2 / R_\odot$). Shocks $T_2 \sim 10^{10} - 10^{12} \text{ K}$, $\dot{E}_{\text{diss}} \sim 10^{15} - 10^{20} \text{ erg cm}^{-3} \text{ s}^{-1}$ sub-solar, proto-trapping $\sim 10^{22}$ (40). Alignment: PSP plasmas 2σ (23); Gaia HVS (18); orbits (39).

5.1 Hypervelocity Ramifications for Planetesimal Genesis

Proto-impacts vaporize $\sim 50\%$ silicates, fractionating $\delta^{56}\text{Fe} \sim \pm 2\%$ (31). Neutral shocks fragment $\rho > 10 \text{ g cm}^{-3}$ to planetesimals, volatilizing to terrestrial bias (25). N-body ($N = 10^3$): $v \sim 40 \text{ km s}^{-1}$ collisions erode mantles, siderophile-enrich, terrestrial mimic (31). $\eta_{\text{coll}} \sim 0.1 - 0.3$ curtains, nebular deficits (39).

5.2 Cometary Nuclei under Hypervelocity Perturbations

Porous ($\rho \sim 0.5 - 1 \text{ g cm}^{-3}$) nuclei disrupt $v > 10 \text{ km s}^{-1}$, $E_{\text{kin}} \sim 10^{20} - 10^{25} \text{ erg}$ craters $D \sim 10 - 100 \text{ m}$ (12). $E_{\text{dis}} = 0.1 \rho r_n^3 v^2$ (10^{20} erg ; Tillotson) (12). $r_n = 1 \text{ km}$, $v = 20 \text{ km s}^{-1}$: 10^{24} erg , $v_{\text{ej}} \sim 1 \text{ km s}^{-1}$. Proto-shattering km-planetesimals, outbursts $\dot{M}_{\text{sub}} \sim 10^2 \text{ kg s}^{-1}$, 67P-layers (12). Organics $\sim 1\%$ ($T > 1000 \text{ K}$), shielded prebiotics Rosetta (1). iSALE 10^{24} erg 1 km, plumes giant-seed (22). Ejected Kuiper $e \sim 0.1$, 29P scars (24). Ice labs: vapor/fragment, $\delta < 100 \text{ m}$ porosity, core-selective (12).

5.3 Asteroidal Disruptions in Hypervelocity Regimes

Rubble ($\rho \sim 1.5 - 2.5 \text{ g cm}^{-3}$) global $v \gtrsim 5 \text{ km s}^{-1}$, Holsapple $D_c \approx 1.8 \rho_t^{-1/3} (\rho_p / \rho_t)^{1/3} (KE)^{0.33} g^{-0.22}$ (19). 1 km ($g \sim 10^{-3} \text{ m s}^{-2}$), $v = 10 \text{ km s}^{-1}$: $D_c \sim 0.2 \text{ km}$; $Q_D^* \sim 10^4 \text{ J kg}^{-1}$ breakup (22). SPH-DEM $10^2 - 10^3 \text{ m}^3$ ejecta, Karin $\Delta v \sim 0.1 \text{ km s}^{-1}$ (28). Proto-pulverize S-types, M-belt (19). $\beta \sim 1 - 3$ DART (14). Inner seeding, $S' \sim 0.02 \mu\text{m}^{-1}$ weathering (6).

6 Discourse

6.1 Orbital Vestiges Post-Expulsion

REBOUND ($N = 10^3$): $e \sim 0.01 - 0.2$ 10 Myr, giant $e \sim 0.05$ (39). Inner $\rho \sim 10 - 50 \text{ g cm}^{-3}$ ($r < 0.2 R_\odot$) $\sim 10 M_\oplus$ ejecta, gas-retention Z/X (2).

Rebuttals: dynamo-thrust (3); Lorentz/ablation/torques (16); ρ /N-body (32).

Limitations: isotropy turbulence $< 5\%$ δ ; NS GRMHD (AREPO (37)). Corollaries: HVS shocks (10), Orbiter ablation (23); meteoritic proto-signals (42). Augmenta: SPH/N-body (21).

7 Conclusion

Relativistic radiative hydrodynamics and numerics scaffold the Nuclear Impact Hypothesis, furnishing a provisional exegesis of proto-solar ignition/embryo expulsion in neutral domains, assaying nebular shibboleths via isotopic/HVS prognostications (18). As inaugural peripheral edifice, it summons adjudicative empirics/simulations.

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9 Data Availability

Autarkic; <https://github.com/sami-shibah/nuclear-impact-hypothesis> (listings-reproducible).

10 Declarations

Contributions: S.R.M. Shibah: conception, theory, numerics, analysis, redaction, validation.

Interests: None.

Originality: Pristine, unsubmitted.

Consent: Open-access.

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