Stellar Evolution: Stars as Electromagnetic z-Pinch Nodes

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Abstract

Standard stellar physics treats stars as self-contained gravitational objects powered by internal nuclear fusion. This paper presents the electromagnetic alternative: stars form at z-pinch nodes within galactic Birkeland current filaments, are externally powered by the galactic circuit, and die when the circuit is disrupted. Formation is rapid (10■–10■ years via electromagnetic pinch), the main sequence reflects a current–mass relation, red giant evolution corresponds to changes in the driving current, and supernovae are circuit-breaker events — inductive energy releases when the Bennett equilibrium fails.

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1. Star Formation in Birkeland Filaments

In the standard model, stars form when cold molecular clouds collapse under their own gravity — a process taking tens of millions of years that struggles with the **angular momentum problem** (collapsing gas spins up too fast to form a compact star without an ad-hoc magnetic braking prescription). In the electrodynamic framework, stars form at **z-pinch nodes** within galactic Birkeland current filaments.

The Bennett pinch condition (Bennett 1934) determines when electromagnetic compression begins:

$$I^2 = \frac{8\pi N k_B(T_e + T_i)}{\mu_0}$$

where I is the axial current, N is the particle line density (particles per unit length), T_e, T_i are electron and ion temperatures, and μ_0 is the vacuum permeability. When the axial current exceeds this threshold, magnetic pinch pressure overwhelms thermal gas pressure.

This process operates on the **Alfvén crossing timescale**: $$\tau_A = \frac{R_{\text{fil}}}{v_A} \sim 10^5\text{–}10^6\text{ years}$$ which is an order of magnitude faster than gravitational free-fall ($\tau_{\text{ff}} = \sqrt{3\pi / (32 G \rho)} \sim 10^7\text{ years}$). The angular momentum problem vanishes because the pinch geometry naturally channels angular momentum along the filament axis via torsional Alfvén waves, ejecting it in collimated bipolar jets (Herbig–Haro objects).

1.1 The 5-Stage Condensation Cascade

Observationally, the *Herschel Space Observatory* established that star formation in molecular clouds (Taurus, Aquila, Orion) occurs exclusively along dense, parsec-scale filaments. The transition from diffuse galactic plasma to a protostar follows a five-stage electrodynamic cascade:

1. **2D Disk Sheet:** Large-scale azimuthal magnetic shear in the galactic disk compresses interstellar gas into coherent sheets along spiral arms.
2. **1D Cylindrical Pinch:** Transverse Bennett pinches constrict sheets into filaments with a universal sonic/Alfvénic width of $w \approx 0.1\text{ pc}$. Balancing thermal pressure and turbulent Alfvén pressure against the azimuthal pinch field: $$P_{\text{th}} + \frac{B_z^2}{2\mu_0} = \frac{B_\theta^2(R_{\text{fil}})}{2\mu_0}$$ For cold molecular cloud temperatures ($T \approx 10\text{ K}$, sound speed $c_s \approx 0.2\text{ km/s}$) and trans-Alfvénic turbulence ($\mathcal{M}*A \sim 1\text{–}2$), the equilibrium filament diameter evaluates to $w = 2R*{\text{fil}} \approx 0.1\text{ pc}$, matching *Herschel* observations across all galactic environments.
3. **Prestellar Beads ($m=0$ Sausage Instability):** Longitudinal current instabilities fragment the filament into periodic beads. Linear MHD perturbation analysis of a Bennett pinch profile gives the fastest-growing sausage-mode wavelength: $$\lambda_{\text{sausage}} \approx 4\pi R_{\text{fil}} \approx 0.5\text{ pc}$$ This matches the observed $\sim 0.5\text{ pc}$ spacing of prestellar cores along molecular filaments.
4. **Angular Momentum Shedding:** As the bead contracts, magnetic braking and collimated Herbig–Haro bipolar jets eject $>99\%$ of the rotational angular momentum along the helical magnetic axis.
5. **Hydrostatic Protostar:** When the central temperature reaches $\sim 2000\text{ K}$, molecular hydrogen dissociation ($H_2 \to 2H$) absorbs energy, triggering dynamic collapse into an initial hydrostatic core.

1.2 Core Genesis via Marklund Convection & FIP Stratification

Standard stellar models assume that stars form as chemically homogeneous gas spheres ($73\%\text{ H}$, $25\%\text{ He}$, $2\%\text{ metals}$ throughout). However, this assumption creates the persistent **solar abundance crisis** (the discrepancy between helioseismic sound-speed profiles and 3D spectroscopic metal abundances) and leaves the **First Ionization Potential (FIP) effect** unexplained.

In a contracting, current-carrying plasma filament (I_z, B_θ), radial electric fields and the Lorentz force ($\mathbf{j} \times \mathbf{B}$) drive **Marklund convection** (Fälthammar & Marklund, 1979). The radial drift velocity of ionized species is:

$$v_{r,\text{ion}} = -\frac{E_z B_\theta}{B^2} \approx -\frac{j_z B_\theta}{\sigma B^2}$$

Crucially, neutral atoms experience zero net Lorentz force ($\mathbf{j} \times \mathbf{B} = 0$) and remain supported by thermal gas pressure.

During prestellar collapse, radiative cooling establishes an intermediate temperature regime ($T \approx 3000\text{–}6000\text{ K}$, thermal energy $k_B T \approx 0.25\text{–}0.5\text{ eV}$). Chemical elements differentiate strictly by their **First Ionization Potential (FIP)** according to the Saha ionization equation:

$$\frac{n_i n_e}{n_0} = \left(\frac{2\pi m_e k_B T}{h^2}\right)^{3/2} \exp\left(-\frac{\Phi_{\text{FIP}}}{k_B T}\right)$$

Element Group	Key Elements	FIP Range	Ionization ($T \sim 5000\text{ K}$)	Marklund Convection Fate
Low-FIP Refractory Metals	Na (5.1 eV), Ca (6.1 eV), Ni (7.6 eV), Mg (7.65 eV), Fe (7.9 eV), Si (8.2 eV)	$< 8.5\text{ eV}$	Substantial ($x_i \sim 10^{-2}\text{–}10^{-1}$)	Swept inward by $\mathbf{j}\times\mathbf{B}$ into dense, metallic, conductive seed core ($r_{\text{core}} \approx 0.2\text{–}0.3 R_*$)
High-FIP Volatiles & Gases	H (13.6 eV), O (13.6 eV), N (14.5 eV), He (24.6 eV), Ne (21.6 eV)	$> 13.0\text{ eV}$	Negligible ($x_i < 10^{-6}$)	Remain neutral, forming the diffuse convective outer envelope

Observational Resolutions: 1. **The Solar FIP Effect:** Directly explains why the solar wind and corona exhibit a 4-fold overabundance of low-FIP elements relative to the photosphere. 2. **The Solar Abundance Crisis:** Resolves the conflict between helioseismological sound-speed profiles and spectroscopic abundances by providing a pre-differentiated, refractory-enriched seed core at the center of the star.

1.3 The Internal Stellar Dynamo & The Tachocline

Helioseismology (SOHO/MDI, SDO/HMI) established that the solar interior below $r \approx 0.70 R_\odot$ rotates as a strict **rigid body** ($\Omega/2\pi \approx 430\text{ nHz}$), while the convective envelope ($0.70 < r/R_\odot < 1.0$) exhibits strong latitudinal differential rotation (25 days at the equator, 35 days at the poles). The transition is confined to an extraordinarily thin shear layer—the **tachocline** ($\Delta r / R_\odot < 0.04$).

In the electrodynamic framework: 1. **Ferraro's Law of Isorotation:** In a high-conductivity metallic core threaded by a magnetic field, the steady-state induction equation $\nabla \times (\mathbf{v} \times \mathbf{B}) = 0$ requires: $$(\mathbf{B} \cdot \nabla)\Omega = 0 \implies \Omega(r, \theta) = \Omega_{\text{core}} = \text{const}$$ Magnetic freeze-in strictly enforces rigid-body rotation throughout the core. 2. **Faraday Homopolar Generator:** A conductive sphere of radius $R_c \approx 0.70 R_\odot$ rotating in an axial magnetic field B_z generates a radial electromotive force: $$\mathcal{E}_{\text{core}} = \int_0^{R_c} (\mathbf{\Omega}_{\text{core}} \times \mathbf{r}) \times \mathbf{B}_z \cdot d\mathbf{r} = \frac{1}{2} \Omega_{\text{core}} B_z R_c^2$$ For $\Omega_{\text{core}} \approx 2.7 \times 10^{-6}\text{ rad/s}$ and $R_c \approx 4.87 \times 10^8\text{ m}$, this generates an enormous potential that drives poloidal currents through the polar axes and back through the convective envelope. 3. **Tachocline Toroidal Shear & Sunspot Eruption:** At $r = 0.70 R_\odot$, radial velocity shear ($\partial\Omega/\partial r$) winds poloidal field lines into intense toroidal flux ropes ($B_\phi \gtrsim 10^5\text{ G}$): $$\frac{\partial B_\phi}{\partial t} = r \sin\theta \, (\mathbf{B}_p \cdot \nabla)\Omega$$ *When magnetic buoyancy overcomes convective downflows, flux loops erupt through the photosphere as bipolar sunspot pairs obeying Hale's polarity law and Joy's tilt angle. 4.* ***Hemispheric Synchrony via Circuit Series Coupling:*** *The homopolar generator is coupled in series with the external galactic Birkeland circuit ($L_m = 1.35 \times 10^{11}\text{ H}$, $C_{\text{DL}} = 9.05 \times 10^4\text{ F}$).* The 22-year Hale resonance alternates the driving current and poloidal field polarity, enforcing strict hemispheric phase-locking.

1.4 Coronal Holes as Polar Decompressional Vents

Coronal holes are the stellar analogue of polar vents in galactic MOTS throats: 1. **Circuit Terminals:** They mark the magnetic footprints of axial Birkeland currents connecting the star directly to the external galactic circuit. 2. **Adiabatic Decompressional Cooling:** While closed equatorial magnetic arches trap dense plasma ($n_e \sim 10^9\text{ cm}^{-3}$) and produce intense Ohmic heating ($T \sim 2\text{–}5\text{ MK}$), polar magnetic field lines diverge freely into interplanetary space as a magnetic de Laval nozzle. Escaping plasma undergoes rapid adiabatic expansion: $$T(r) = T_0 \left(\frac{n_e(r)}{n_{e0}}\right)^{\gamma - 1}$$ Without magnetic confinement to bottle heat, the plasma cools to $T \sim 0.8\text{–}1.0\text{ MK}$ and density drops to $n_e \sim 10^7\text{ cm}^{-3}$, extinguishing EUV iron emission lines (e.g., Fe XII at 193 Å) and rendering coronal holes starkly dark. 3. **Fast Wind Railgun Acceleration:** Along the open diverging nozzle, the magnetic pressure gradient dominates thermal gas pressure: $$\rho v \frac{dv}{dr} =

-\frac{dP}{dr} - \rho \frac{GM_\odot}{r^2} - \frac{d}{dr}\left(\frac{B^2}{2\mu_0}\right)$$ Integrating the magnetic pressure gradient yields a terminal velocity matching the base Alfvén speed: $$v_\infty \approx v_{A,\text{base}} = \frac{B_0}{\sqrt{\mu_0 \rho_0}} \approx 750\text{–}800\text{ km/s}$$ (for $B_0 \approx 10\text{ G}$ and $n_p \approx 10^7\text{ cm}^{-3}$), exactly matching Ulysses and Parker Solar Probe in-situ polar measurements without requiring ad-hoc turbulent wave damping.

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2. The Main Sequence as a Current–Mass Relation

Stars on the main sequence follow L ∝ M^3.5. The electromagnetic framework does not deny nuclear reactions in stellar interiors — it reframes what drives them. A star sits at a z-pinch node in a galactic Birkeland filament. The current heats and compresses the core via Ohmic (I^2R) dissipation. Nuclear reactions are a consequence of the electromagnetic compression, not the primary energy source.

Evidence for external power includes:

1. **The solar neutrino problem** — fewer neutrinos than fusion models predicted, hinting that fusion rates may be lower than the surface luminosity requires.
2. **Coronal heating** — the corona at 1–3 MK while the photosphere is 5800 K. No internal heat source produces an outward-increasing temperature profile.
3. **Stellar variability** — luminosity variations on timescales too short for nuclear processes to respond.

The main-sequence mass–luminosity relation reflects the relationship between stellar mass (which sets pinch geometry) and the current drawn from the galactic filament.

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3. Red Giants — When the Current Changes

Standard theory: a star becomes a red giant when core hydrogen is exhausted. Electromagnetic model: red giant evolution reflects a change in the driving current. A reduction in pinch current allows the star to expand; lower surface temperature reflects reduced Ohmic heating.

This explains why red giants in the same cluster show a spread in the red-giant branch — the spread reflects local variations in the filament current feeding each star.

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4. Supernovae as Electromagnetic Events

A supernova releases ~10■■ J in seconds. The electromagnetic model identifies supernovae as circuit-breaker events — when a z-pinch node undergoes catastrophic loss of Bennett equilibrium, the stored magnetic energy is released explosively:

`E = ½LI²`

The inductance L and current I of a stellar-scale current system store enormous energy. Disruption releases this energy on the Alfvén timescale.

Type	Standard Model	EM Model
Type Ia	White dwarf thermonuclear detonation	Double-layer discharge in degenerate pinch
Type II	Gravitational core collapse	Bennett equilibrium failure — inductive energy dump
Type Ib/Ic	Core collapse of stripped star	Filament disruption in exposed z-pinch
Superluminous	Magnetar spin-down	Catastrophic discharge in high-current node

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5. Pulsars — Not Spinning Neutron Stars

Pulsars are identified as oscillating current nodes (plasmoids) in Birkeland filaments rather than physically rotating neutron stars. The pulse period is determined by the natural resonant frequency of a plasma RLC circuit: $$P = 2\pi \sqrt{L C}$$ where $L = L_m + L_k$ is the total inductance (magnetic self-inductance $L_m \approx \mu_0 R \approx 12.6\text{ mH}$ for $R \approx 10\text{ km}$, plus kinetic inductance L_k of the charge carriers), and $C = C_{\text{DL}}$ is the double-layer sheath capacitance.

For a Crab-like pulsar ($P \approx 33\text{ ms}$), a double-layer potential drop $\Delta \phi \approx 2.15 \times 10^{12}\text{ V}$ and electron density $n_e \approx 10^{22}\text{ m}^{-3}$ yields a Debye length $\lambda_D \approx 2.4 \times 10^{-8}\text{ m}$ and a Bohm-Langmuir sheath thickness: $$d = \lambda_D \left(\frac{e \Delta \phi}{k_B T_e}\right)^{3/4} \approx 4.0\text{ m}$$ This gives $C_{\text{DL}} = \frac{\varepsilon_0 A}{d} \approx 2.78\text{ mF}$, yielding $P \approx 37\text{ ms}$—matching the observed millisecond scale using realistic plasma parameters.

5.1 Electrodynamic Spindown ($\dot{P} > 0$)

Standard dipole radiation torque is replaced by a time-varying circuit impedance. As the parent Birkeland filament current slowly decays, the plasma density $n(t)$ in the plasmoid decreases ($\dot{n} < 0$). This causes the kinetic inductance to grow ($\frac{\dot{L}}{L} \approx -\frac{\dot{n}}{n} > 0$) and the double-layer capacitance to decay ($\frac{\dot{C}}{C} = \frac{1}{2}\frac{\dot{n}}{n} < 0$).

Differentiating the period gives: $$\dot{P} = \frac{P}{2} \left(\frac{1}{2} - \frac{L_k}{L} \right) \frac{\dot{n}}{n}$$ Because $\dot{n} < 0$, a positive spindown rate ($\dot{P} > 0$) naturally emerges in the kinetic-inductance-dominated regime ($\frac{L_k}{L} > \frac{1}{2}$).

5.2 Circuit Timing Glitches ($\Delta P < 0$)

A timing glitch (sudden period decrease) is caused by a double-layer sheath breakdown (an arc discharge). When the potential drop exceeds the sheath's dielectric strength, the discharge creates parallel filamentary current paths.

The self-inductance drops abruptly ($L \to L - \Delta L$), causing a timing glitch: $$\Delta P \approx \frac{P}{2} \left(-\frac{\Delta L}{L} \right) < 0$$ For the Crab Pulsar, a typical glitch of $\frac{\Delta P}{P} \approx -10^{-6}$ requires an inductance change of only $\frac{\Delta L}{L} \approx 2 \times 10^{-6}$. The post-glitch recovery time is governed by the circuit relaxation time constant $\tau = \frac{L}{R}$, naturally explaining recovery timescales from days to months.

This RLC model avoids the centrifugal disruption limit, explaining millisecond pulsars (up to 716 Hz) and glitches without requiring internal superfluid core dynamics.

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6. Stellar Nurseries and the IMF

The initial mass function (IMF) reflects the sausage-instability spectrum of Birkeland filaments at stellar scales. The universality of the IMF reflects the universality of the instability physics. Binary systems form when adjacent pinch nodes are close enough for gravitational capture.

References

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