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[Mandeep Singh](#)*

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Concept Paper

Quantum Stellar Batteries (QSBs): A Theoretical Framework for Stellar-Scale

Mandeep Singh

Independent Researcher — Originator of the Quantum Stellar Battery (QSB) Concept, India;
mandeepsingh10122k@gmail.com

Abstract

We introduce the concept of Quantum Stellar Batteries (QSBs): hypothetical quantum-material-based devices capable of storing energy at stellar scales. Building on ideas from quantum thermodynamics, entanglement-enhanced charging, and exotic condensed-matter phases, QSBs are proposed as ultra-dense repositories that could buffer and regulate power harvested by stellar megastructures (e.g., Dyson swarms). We outline an initial theoretical framework, discuss feasibility constraints, sketch prospective applications and risks, and position QSBs within the trajectory of civilizations progressing along the Kardashev scale. The proposal is intentionally speculative but aims to be falsifiable at subscales through laboratory realizations of quantum batteries and extreme energy-density materials. Quantum Stellar Batteries (QSBs) are a proposed class of quantum-material-based energy storage devices capable of capturing, storing, and releasing stellar-scale energy. This paper introduces the theoretical framework for QSBs, their potential role in advancing civilizations along the Kardashev scale, and their possible applications in sustainable energy, planetary defense, and interstellar exploration. A speculative but noteworthy extension of this concept is the “Star Bomb (Controlled Stellar Discharge, CSD),” an extreme application where a QSB could be deliberately discharged in a catastrophic manner, rivaling astrophysical events. While highly theoretical, this work highlights both the immense promise and the profound risks of QSB technology.

Keywords: Quantum Stellar Batteries (QSBs); stellar energy storage; kardashev scale; quantum materials; cosmology; star bomb; Controlled Stellar Discharge (CSD)

I. Introduction

The total luminosity of the Sun is $P_{\odot} \approx 3.8 \times 10^{26}$ W. For a civilization aspiring to Type II status on the Kardashev scale, capturing a significant fraction of stellar output is necessary but insufficient: *storage* and *regulation* at comparable scales are also required. Existing technologies (chemical batteries, flywheels, SMES, hydro, and fission/fusion fuel cycles) operate many orders of magnitude below the energy densities implied by *one second* of solar emission, $E_{1s} = P_{\odot} \times 1 \text{ s} \sim 3.8 \times 10^{26}$ J.

We propose *Quantum Stellar Batteries* (QSBs): compact (relative to megastructures) storage media based on strongly correlated and topological quantum matter, designed to absorb, confine, and release enormous amounts of energy via collective quantum degrees of freedom. This article states the concept, delineates theoretical ingredients, and articulates testable subproblems.

II. Theoretical Background

A. Quantum Thermodynamics and Many-Body Charging

Recent theory indicates that ensembles of N coupled quantum units can exhibit charging advantages over independent cells, with power scaling that can surpass classical limits via entanglement-assisted protocols [3,4]. Let $H = H_0 + V(t)$ with H_0 the internal Hamiltonian of the storage medium and $V(t)$ its coupling to a charging field. The *ergotropy* W —the maximum extractable work—is bounded by the state's passive rearrangement. Protocols that drive the system along non-passive trajectories

can, in principle, increase charging power while preserving reversibility bounds set by the second law.

B. Target Energy Scales

A reference table situates orders of magnitude:

System	Specific energy [J/kg]
Li-ion battery (state-of-art)	$\sim 10^6$
Fission fuel (effective)	$\sim 10^{14}$
Matter–antimatter (theoretical)	$\sim 9 \times 10^{16}$
Hypothetical QSB target window $\gtrsim 10^{20}$	

The QSB window is aspirational and presumes collective storage in metastable quantum phases with macroscopic coherence lengths.

C. Coupling to Stellar Collectors

Let a Dyson swarm deliver irradiance $I(t)$ onto a QSB aperture of area A . The instantaneous charging power is $P_{in}(t) = \eta_{abs} I(t) A$, with η_{abs} an absorption efficiency that may be frequency-selective. A spectral matched filter, realized by photonic/phononic band engineering, can improve η_{abs} under realistic stellar spectra.

III. Concept of Quantum Stellar Batteries

A. Working Principles (Hypothesized)

We consider a lattice of strongly interacting degrees of freedom (e.g., spins, excitons, Cooper pairs) engineered to realize a deep energy landscape with long-lived, high-energy metastable states. Charging corresponds to coherently steering the system into such states; discharging corresponds to a controlled transition back to lower-energy manifolds while delivering work to an external load. Two guiding design motifs are:

1. **Entanglement-enhanced charging:** transient multipartite entanglement increases charging power beyond the sum of local rates. [4]
2. **Topologically protected storage:** non-local order suppresses relaxation pathways, extending storage lifetimes against local perturbations.

B. Minimal Phenomenology

Let $E(t)$ be stored energy, with effective loss rate $\gamma(E)$ and controlled output $P_{out}(t)$. A coarse model reads

$$\dot{E}(t) = P_{in}(t) - P_{out}(t) - \gamma(E) E(t). \quad (1)$$

Engineering goals are to (i) maximize integrated ergotropy $\int P_{out} dt$ subject to constraints, and (ii) minimize $\gamma(E)$ across operating regimes (including high E).

IV. Applications and Civilizational Roles

- **Buffering stellar variability:** smoothing solar/stellar intermittency and protecting Dyson infrastructures from flares/CMEs.
- **Interstellar propulsion:** supplying pulsed power for beamed sails or fusion/annihilation drives.
- **Planetary defense:** powering directed-energy systems for asteroid deflection and radiation shielding.
- **Climate and grid stabilization:** planetary-scale load balancing and terraforming support.

- **Medical & Bioenergy:** QSBs could provide extreme miniaturized and long-lasting energy sources for medical implants, bio-sensors, and advanced prosthetics, eliminating the need for frequent replacements or external charging.
- **Quantum Computing Integration:** Such devices may serve as dual-purpose devices, storing both energy and quantum information for autonomous quantum systems.

V. QSBs and Cosmological Implications

One of the most profound implications of studying Quantum Stellar Batteries (QSBs) is their potential to shed light on the fundamental question of how energy existed prior to the expansion of the universe. According to the conservation of energy, energy cannot be created or destroyed; it can only be transformed. Thus, the total energy observed in the present-day universe must have been contained, in some form, before the event commonly referred to as the Big Bang.

The QSB concept provides a useful theoretical analogy for this state. By proposing that stellar-scale energy can be compactly stored in quantum materials, such devices mimic the possible quantum conditions of the primordial universe. Just as a QSB contains enormous energy within a confined and stable structure, the pre-Big Bang singularity may have represented a cosmic-scale “battery,” storing all the energy of the universe before its rapid expansion.

Furthermore, the study of quantum-scale energy storage and release mechanisms could help physicists construct new models of early-universe cosmology. By investigating how QSBs compress and discharge energy under extreme densities, parallels may be drawn to how the universe transitioned from a highly compressed quantum vacuum state into the expanding cosmos. This line of inquiry might also bridge gaps between quantum physics, cosmology, and general relativity, offering a pathway toward a more unified physical framework.

In essence, QSB research not only holds technological promise but also offers a unique conceptual framework for exploring the origins of cosmic energy and the nature of the universe before expansion.

VI. Future Research Directions

Further exploration of QSBs could focus on quantum stability, scalable material synthesis, and controlled high-density energy release. Simulations of stellar-scale energy dynamics, integration with nanotechnology, and coupling with quantum information systems represent key avenues for theoretical investigation. Future work should also address safety protocols to mitigate catastrophic failure modes.

VII. Civilizational Implications

If realized, QSBs could accelerate the transition to higher Kardashev civilizations. For a Type I society, they may provide global clean energy. For Type II, they could store stellar output on massive scales, reducing reliance on Dyson spheres. For Type III, they may underpin galaxy-scale infrastructures and novel defense systems such as controlled “Star Bombs.” Theoretical studies of QSBs thus extend beyond physics into long-term civilizational evolution.

VIII. Risks and Safety (“Star Bomb” Hypothesis)

A QSB contains energy densities that, if catastrophically released, would surpass the energy release of any known weapon class. Safety requires multi-layered confinement (geometric, topological, magnetic), negative-feedback discharge controllers, and geofencing (locating QSB arrays off-world). Ethical governance is essential to avoid weaponization.

IX. Feasibility and Timelines (Speculative)

Near-term (to ~100 years): laboratory quantum batteries with mesoscopic capacities and demonstrable entanglement-enhanced charging. Mid-term (102–103 years): macroscopic quantum materials with engineered relaxation spectra and partial QSB prototypes. Far-term (> 103 years): Type II civilizations deploying QSBs networks with stellar collectors. Plausibility rises with material advances; we estimate rough realization probabilities of approximately 5% within the next century, 20–30% (half-millennium), and 60%+ (beyond a millennium), conditional on civilizational continuity.

X. Case Studies and Extensions

A. Solar Flares and Dyson Infrastructures

Distributed swarms are resilient to local damage, where as rigid shells are not. QSB buffers can absorb and redistribute flare surges, reducing peak loads and protecting sensitive elements.

B. Alternative Energy Sources

Beyond solar photons: pulsar beams, accretion-disk radiation, black-hole spin extraction (Penrose process), and advanced fusion plants are candidate inputs. Frequency-selective couplings and robust converters are required.

XI. Conclusion

QSBs provide a theoretical scaffold connecting quantum many-body physics with stellar engineering and long-horizon energy strategy. While speculative, the framework yields concrete subproblems suitable for present-day inquiry. The concept of the Quantum Stellar Battery (QSB) was originally proposed by Mandeep Singh (2025), and is presented here as an independent theoretical contribution.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

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