Supermassive Primordial Stars as the Origin of Galaxies and Heavy Elements: An Alternative Framework for Galaxy Formation

1. Abstract

The formation of galaxies and the origin and distribution of heavy elements in the early universe are fundamental questions in modern astrophysics. While the standard ΛCDM model assumes galaxy formation through the accretion of baryonic matter into dark matter (DM) halos and nucleosynthesis of heavy elements primarily through core-collapse supernovae and neutron star mergers, it faces limitations in explaining the widespread presence of *r*-process elements across vast cosmic scales.
This work proposes an alternative scenario: the existence of supermassive primordial stars (*SMSs*)—with initial masses significantly exceeding the canonical range of Population III stars—as the earliest luminous objects. Their gravitational collapse may have simultaneously triggered the formation of supermassive black holes (SMBHs), initiated galactic structure development, and synthesized heavy elements via *r*-processes occurring in relativistic jets.

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2. Hypothesis: Supermassive Stars as Proto-Galactic Seeds

Conventional models describe Population III stars with masses up to ~300 $M_\odot$. The present hypothesis extends this range to several thousand solar masses. Such stars would be short-lived and dynamically unstable, likely ending in either hyper-energetic supernovae or direct gravitational collapse into black holes.

In this framework, *SMSs* function as proto-galactic cores through the following mechanisms:

- **Jet-induced material distribution**: The collapse leads to the formation of relativistic jets, which eject ionized matter into the surrounding medium. This jet activity resembles quasar-like phenomena but occurs earlier in cosmic history and on smaller spatial scales.
- **Initiation of galactic structure**: The ejected matter—especially when distributed axially—could serve as the template for emerging spiral structures, with angular momentum imparted by the symmetry and rotation of the jets.

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3. Relativistic Jets as *r*-Process Sites and Distributors of Heavy Elements

A persistent challenge in nucleosynthesis theory concerns the origin of heavy *r*-process elements such as Au, U, and Pt. While neutron star mergers are accepted *r*-process sites, their low event rates and localized nature make them insufficient to explain the presence of such elements in extremely metal-poor halo stars and across wide regions of the early universe.

The proposed model posits that *r*-process nucleosynthesis occurred within the jets of collapsing *SMSs*:

- **Favorable conditions for *r*-processes**: Jets produced by the collapse of *SMSs* may attain extreme neutron fluxes, high temperatures, and strong magnetic fields—conditions favorable for rapid neutron capture.

- **Efficient cosmic distribution**: Jets can disseminate newly formed heavy elements into the intergalactic medium, leading to a widespread early enrichment of baryonic matter.
- **Temporal advantage**: These events would occur within the first few hundred million years after the Big Bang, well before the onset of galaxy mergers or neutron star binary evolution.

This early enrichment aligns with spectroscopic observations of ancient stellar populations that show signatures of *r*-process elements despite their early formation epoch.

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4. From Asymmetry to Spiral Structure: Dynamical Evolution of Jet-Enriched Regions

Initially, jet-driven mass ejection from *SMSs* would be highly anisotropic. However, subsequent evolution governed by gravitational instabilities and differential rotation could transform these irregular matter distributions into more organized galactic morphologies:

- **Gravitational anchoring by SMBHs**: The collapsed *SMSs* may directly form SMBHs that serve as the gravitational centers around which baryonic matter accumulates.
- **Angular momentum evolution**: The directionality and rotational dynamics of the jets could define the angular momentum vector of the emerging protogalactic disk.
- **Concordance with observations**: High-redshift observations show irregular galactic morphologies evolving into well-structured spirals—supporting a mechanism involving asymmetric early phases and later dynamical settling.

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5. Comparative Analysis with the Standard Cosmological Framework

Aspect	ΛCDM / Standard Theory	Supermassive Star Hypothesis
Origin of heavy elements	Neutron star mergers, core-collapse supernovae	*r*-processes in jets of collapsing *SMSs*
Galaxy formation	Gas accretion in DM halos, angular momentum from large-scale flows	Jet-induced mass ejection and collapse of *SMSs*
Distribution of heavy elements	Localized enrichment, not easily uniform	Early, widespread distribution via relativistic jets
Early galaxy morphology	Irregular, shaped by hierarchical merging	Asymmetric jet structures evolving into spirals

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6. Early Heavy-Element Enrichment and Cosmic Chemical Evolution

The detection of *r*-process elements in extremely metal-poor stars in the galactic halo indicates that such elements were present at very early times. Given that neutron star mergers require long delay times (>100 Myr), they cannot account for these observations.

This model resolves the issue by proposing that *SMSs*, collapsing within the first few hundred million years post-Big Bang, created *r*-process-enriched jets that chemically seeded the early interstellar medium. Consequences include:

- **Primordial chemical heterogeneity**: Early star-forming regions would inherit *r*-process material, influencing the metallicity and composition of Population II stars.
- **Enhanced planet formation potential**: The early availability of refractory elements (e.g., U, Th, Fe-group) would permit the formation of rocky planets earlier than otherwise expected.
- **Observational testability**: This prediction can be assessed through future high-resolution spectroscopy of extremely high-redshift galaxies and metal-poor stars, as enabled by instruments like the *James Webb Space Telescope* (JWST) and the *Extremely Large Telescope* (ELT).

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7. Conclusion

The supermassive primordial star hypothesis offers a coherent and testable alternative to prevailing models of early cosmic structure and chemical enrichment. Its key advantages include:

- A plausible site for early *r*-process nucleosynthesis, addressing the elemental abundances in ancient stars.
- A mechanism for distributing heavy elements across cosmological distances via directed jets.
- A natural explanation for the correlation between galactic bulge mass and central black hole mass, assuming direct collapse of *SMSs* into SMBHs.

If validated, this theory would represent a paradigm shift in our understanding of the early universe—one in which the first stars were not merely luminous beacons but also the engines of cosmic structure and complexity.

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