Insights on the Sun birth environment in the context of star-cluster formation in hub-filament systems

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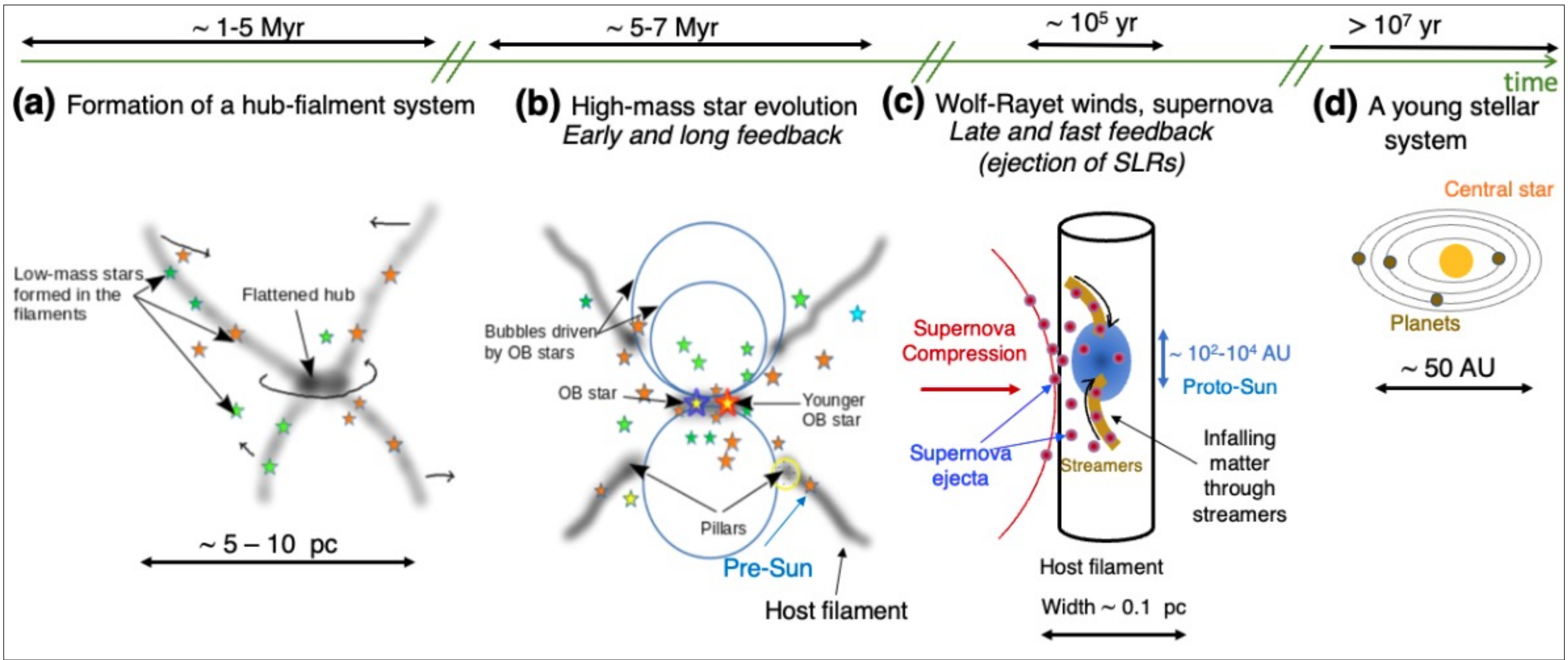
ABSTRACT

Molecular filaments are observed to be the main sites of Sun-like star formation, while **massive stars form in dense hubs**, at the junction of multiple filaments. The role of hub-filament configurations has not been discussed yet in relation to the birth environment of the solar system and to infer the origin of isotopic ratios of **Short-Lived Radionuclides** (**SLR**, such as ^{26}Al) of **Calcium-Aluminum-rich Inclusions** (**CAI**s) observed in meteorites. In this work, we present simple analytical estimates of the impact of stellar feedback on the young solar system forming along a filament of a hub-filament system. We suggest that the host filament can shield the young solar system from the stellar feedback, both during the formation and evolution of stars (stellar outflow, wind, and radiation) and at the end of their life (supernovae). We show that the young solar system formed along a dense filament can be enriched with supernovae ejecta (e.g., ^{26}Al) during the formation timescale of CAIs. We also propose that the **streamers** recently observed around protostars may be channeling the SLR-rich material onto the young solar system. We conclude that considering hub-filament configurations as the birth environment of the Sun is important when deriving theoretical models explaining the observed properties of the solar system.



Hub-filament systems and the impact of stellar feedback on the formation of planetary systems

(a) Low- to intermediate-mass stars form along dense molecular filaments, which merge to form a hub-filament system with a dense hub at the junction of multiple filaments. These hubs provide the large mass and the high density required for the formation of high-mass stars (e.g., Kumar et al. 2020, 2022) .

(b) High-mass stars form in the dense hub. The feedback from massive stars during their formation and evolution (outflow and wind) compresses the dense filaments and flow away into the ISM through the inter-filamentary diffuse medium forming bipolar shaped HII regions. At an advance evolutionary stage the HII regions erode the tip of the filaments close to the hub detaching the filaments from the hub. These dense filaments, hosting pre- and proto-Suns, are not destroyed but compressed by the expanding bubble (e.g., Zavagno et al. 2020) .

(c) At the end of its life, the massive star formed in the hub, after a Wolf-Rayet wind phase explodes in a supernova (SN). A Sun-like star forming filament may survive the SN shock for > 0.3 Myr and be enriched by the ejecta containing SLRs such as ^{26}Al. The SN ejecta is channeled onto the young solar system enriching the CAIs forming in the disk with SLRs within 0.1 Myr. These SLR-enriched gas and dust may be channeled along the filament from distances larger than the core size and the protoplanetary disk size along streamers.

(d) Streamers may provide SLRs during the entire evolution of the protostellar system and the formation of planetary systems.

Properties of a filament that may form solar type stars

- Resemblance between the core mass function (CMF) and the initial mass function (André et al. 2014) → The mass of a star is determined at the prestellar core stage
- Mass transfer efficiency of ~ 30% → A 1 $M_\odot$ star will from out of a 3 $M_\odot$ prestellar core
- The CMF of individual filaments peaks at the filament effective Jeans mass (André et al. 2019) → Higher mass cores form along higher line mass (denser) filaments
- Filaments are observed to be in virial balance (Arzoumanian et al. 2013) with a 0.1pc width (Arzoumanian et al. 2019) → A 3 $M_\odot$ prestellar core forms from the fragmentation of a filament with a line mass of 90 $M_\odot$/pc (density ~ 10^5 cm^{-3})

$$M_{\rm line}^{\rm fil-Sun} \sim 90\,{\rm M_\odot\,pc^{-1}} \left(\frac{\rm M_{pre}}{3\,{\rm M_\odot}}\right)\left(\frac{\rm W_{fil}}{0.1\,{\rm pc}}\right)^{-1}$$

Destruction timescale from a supernova shock

$$t_{\rm dest,fil} \sim 0.3\,{\rm Myr}\left(\frac{\chi}{10^4}\right)^{1/2}\left(\frac{R_{\rm fil}}{0.05\,{\rm pc}}\right)\left(\frac{v_{\rm b}}{200\,{\rm km\,s^{-1}}}\right)^{-1}$$

Density ratio (filament/ambiant) — Filament radius — SN Blast velocity

(Klein et al. 1994, Nakamura et al. 2006)

Conclusion and implication

We suggest that a proto-Sun forming in a filament next to a hub hosting massive stars can survive both the early HII region feedback and the later violent feedback from a SN, which will provide the required amount of ^{26}Al to explain the observations. This scenario may have multiple important implications in our understanding of the formation, evolution, and properties of stellar systems. For example, the host filament may shield the young solar system from the far-ultraviolet radiation from OB stars that would photoevaporate the protostellar disk affecting its final size, which would have a direct impact on planet formation within the disk (Adams et al. 2004).

References

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