Habitats of massive stars across cosmic time

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A Polychromatic Analysis of the Dissolving Stellar Association IRS 6 in the Center of our Galaxy

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Introducing IRS 6 on its Clockwise Orbit around Sgr A*

The IRS 6 region is located about (0.4 ± 0.2) pc northwest of Sgr A* and marked blue in Figure 1. Its derived average velocity dispersion of $\bar{\sigma} = (146 \pm 6)$ km/s suggests a coherent structure moving under the gravitational influence of Sgr A*. Identified via its distinct 343 GHz CO transition emission, observed with ALMA, a catalog of the region lists 419 sources identified in this band and in the infrared H-, K-, L-, and M-bands combined. It includes the known stars IRS 6E, IRS 6W, and IRS 6NW, as well as the IRS 34 sources at the eastern border.

It is one order of magnitude more massive compared to the IRS 13 stellar cluster, located 0.12 pc southwest of Sgr A* (Peißker et al. 2023). Furthermore, its Hill radius of (0.09 ± 0.01) pc corresponds to a theoretical circle drawn around the radio emission between IRS 6E and 6W and is about four times larger than for the tightly bound IRS 13 (Peißker et al. 2023, 2024).

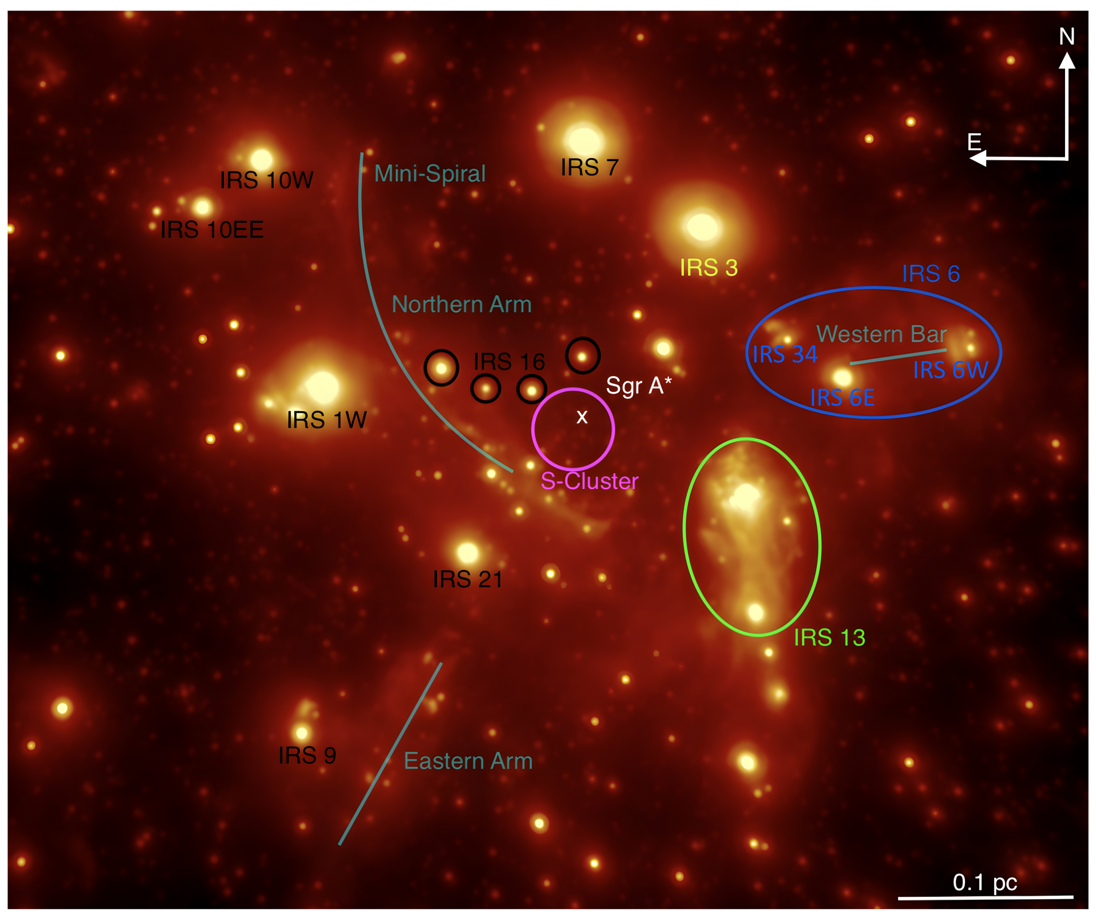

Figure 1: Overview of the inner parsec of the Galactic Center in the infrared L-band (VLT/NACO; self-edited).

A proper motion analysis combined with Keplerian orbit fits puts the sources on a clockwise orbit with the averaged orbital element seen below.

$\bar{a}$ [as]	$\bar{e}$	$\bar{i}$ [°]	$\bar{\omega}$ [°]	$\bar{\Omega}$ [°]	$\bar{t}_{closest}$ [yr]
13 ± 2	0.5 ± 0.1	21 ± 12	31 ± 21	71 ± 16	2307 ± 206

Its eccentricity and longitude of the ascending node are in agreement with the clockwise disk (Genzel et al. 2003), although the averaged semi-major axis is too large (von Fellenberg et al. 2022) and the inclination is too small (Jia et al. 2023). Singhal et al. (2024) showed that approximately 2/3 of orbits maintain their disc-like configuration characterized by similar values of both the inclination and the longitude of the ascending node throughout their entire course of evolution. Thus, IRS 6's non-randomized orbital elements indicate a common origin.

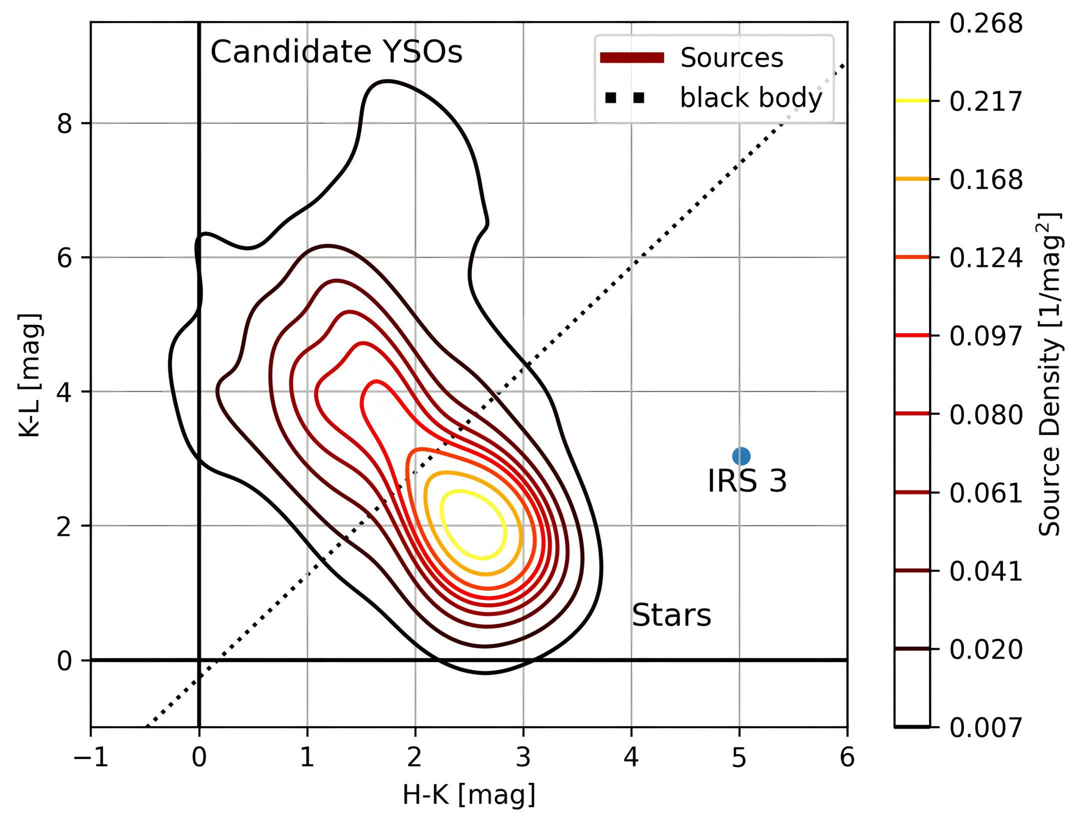

Figure 2: Color-color diagram of all sources visible in the H-, K-, and L-bands in the IRS 6 region as a kernel density estimation plot. The black dotted line describes a black body and separates the YSO candidates, main-sequence, and evolved stars.

Color-Color Diagram and Source Classification

A color-color diagram of the region, seen in Figure 2, allowed a source classification that included main-sequence stars as well as candidate young stellar objects (YSOs). Other dusty red objects suggest evolved stars that lost their outer hydrogen layers. An example of such is IRS 6E, which was classified as a late-type WC9 Wolf-Rayet star (Krabbe et al. 1991; Clénet et al. 2001).

Choosing six random YSO candidates from the upper left corner of the color-color diagram, which also had their orbital elements fitted to, for Spectral Energy Distribution (SED) fits resulted in Class I YSOs. This classification was taken from Lada (1987)'s description of protostars. The calculated H-K colors (Berrilli et al. 1992), fitted masses of $4 - 6\,M_\odot$, and luminosities reaching $1.6 \times 10^3\,L_\odot$ indicate medium-mass YSOs, potential Herbig Ae/Be stars, similar to those found in IRS13 (Peißker et al. 2024). The best-fit SEDs of IRS 6E and IRS 34SW resulted in luminosity and radii estimates comparable to Wolf-Rayet stars. Thus, they agree with their earlier classifications based on spectral analysis. For IRS 6E, a spectral analysis based on ERIS data showed signs of CNO-cycle products, hinting at a stellar nature of the potentially unresolved source.

A Br-γ line map of IRS 6 shows hot, ionized gas in the same region as the cold dust seen in the 343 GHz CO transition. This alludes to a complex dust morphology, heated by stars with prominent winds, e.g., Wolf-Rayet stars. These results suggest at least two stellar generations formed during two separate events. The first stellar generation may have formed during an initial inspiral to the distance of the Circum Nuclear Disk (CND).

AMUSE Simulation of an Inspiraling Molecular Cloud

This inspiraling theory was tested with an Astrophysical Multipurpose Software Environment (AMUSE) simulation. We initialized a $78{,}000\,M_\odot$ cloud at 10 pc from Sgr A* with sub-Keplerian velocity. As seen in Figure 3, the cloud shows fragmentation and elongation while inspiraling, creating overdensities that gravitationally collapse. Taking the initial mass function with Kroupa/Salpeter values (Kroupa 2001), 4529 main-sequence stars and 7063 candidate YSOs in five stellar clusters were formed over the whole simulation time of 5 Myr.

After losing more angular momentum at the CND's distance, an additional inspiraling process could have triggered the second star formation event, as shown in earlier simulations, e.g., by Bonnell and Rice (2008) or Jalali et al. (2014).

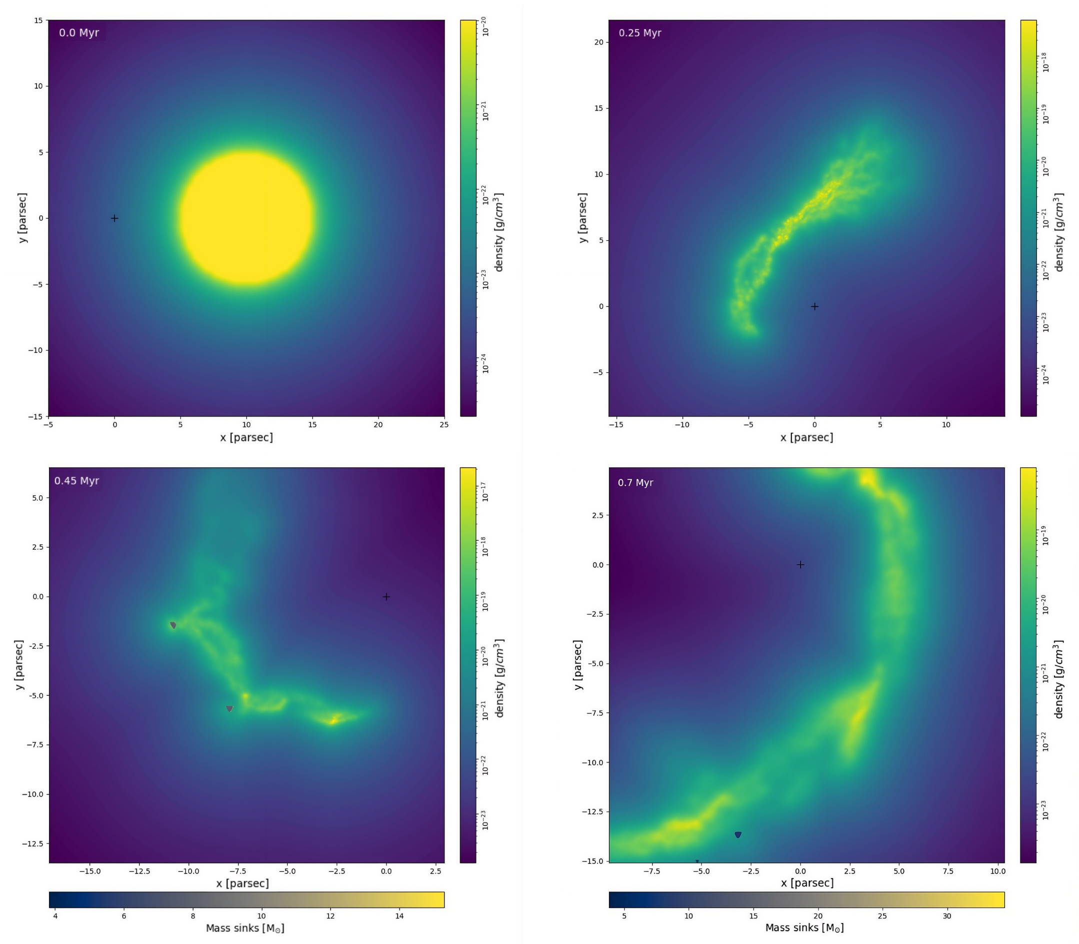

Figure 3: Evolution of an inspiraling molecular cloud visualized over the course of 0.7 Myr. The black cross marks the position of Sgr A* and the triangles cluster candidates.

Conclusion

IRS 6 could be the remnant of a massive molecular cloud that spiraled into the inner parsec and underwent at least two star formation events. Overall, we find strong indications of IRS 6 being a stellar association that gravitationally interacts with Sgr A* and shows signs of evaporation.

References

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