The Arches cluster out to its tidal radius: dynamical mass segregation & the effect of the extinction law on the mass function

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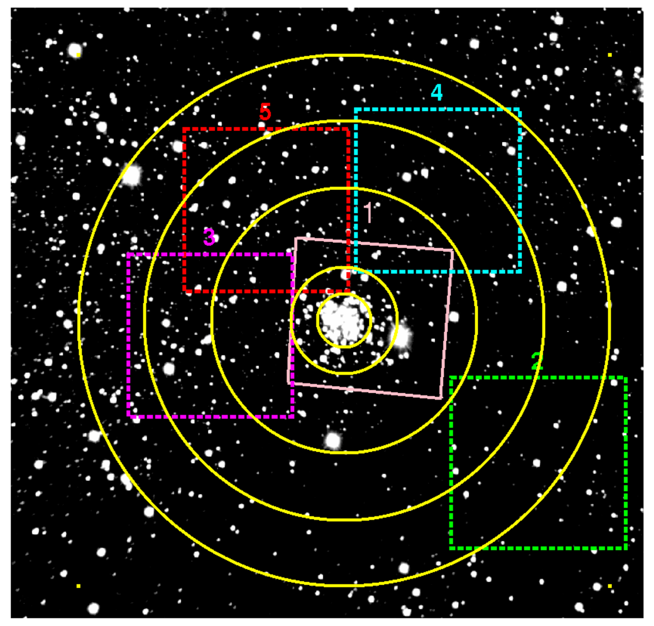
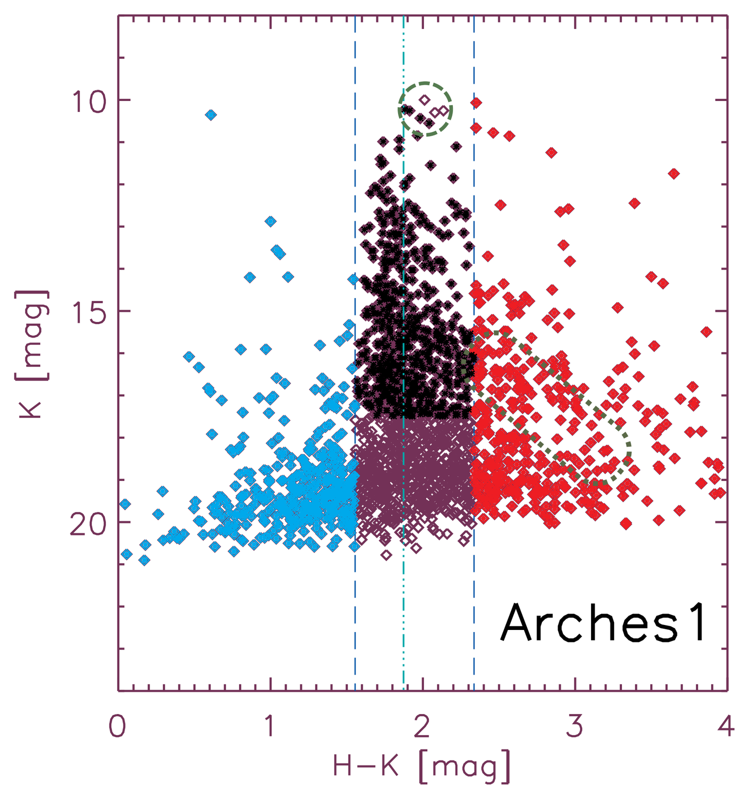
Summary

The Galactic Center is the most active site of star formation in the Milky Way Galaxy, where particularly high-mass stars have formed very recently and are still forming today. However, since we are looking at the Galactic Center through the galactic disk , knowledge of extinction is crucial to study the region. The Arches cluster is a young, massive starburst cluster, near the Galactic Center. We observed the Arches cluster out to its tidal radius using K_s band imaging obtained with NAOS/CONICA at the VLT combined with Subaro/Cisco *J*-band data to gain a full understanding of the cluster mass distribution. We show that the determination of the mass of the most massive star in the Arches cluster, which had been used in previous studies to establish an upper-mass limit for the star formation process in the Milky Way, strongly depends on the assumed slope of the extinction law. Assuming the two regimes of widely used infrared extinction laws we show that the difference can reach up to 30% in extracted initial mass and ~ 1 magnitude in acquired K_s-band extinction while the present mass function slope changes by ~ 0.17 dex. The present-day mass function slopes derived assuming the Nishiyama et al. (2009) extinction law are increasing from a flat slope of $\alpha_{Nishi} = -1.50 \pm 0.35$ in the core ($r < 0.2$ pc) to $\alpha_{Nishi} = -2.21 \pm 0.27$ in the intermediate annulus $0.2 < r < 0.4$ and become depleted of high mass stars, $\alpha_{Nishi} = -3.21 \pm 0.30$, in the outer annulus ($0.4 < r < 1.5$ pc) . This picture is consistent with mass segregation due to the dynamical evolution of the cluster.

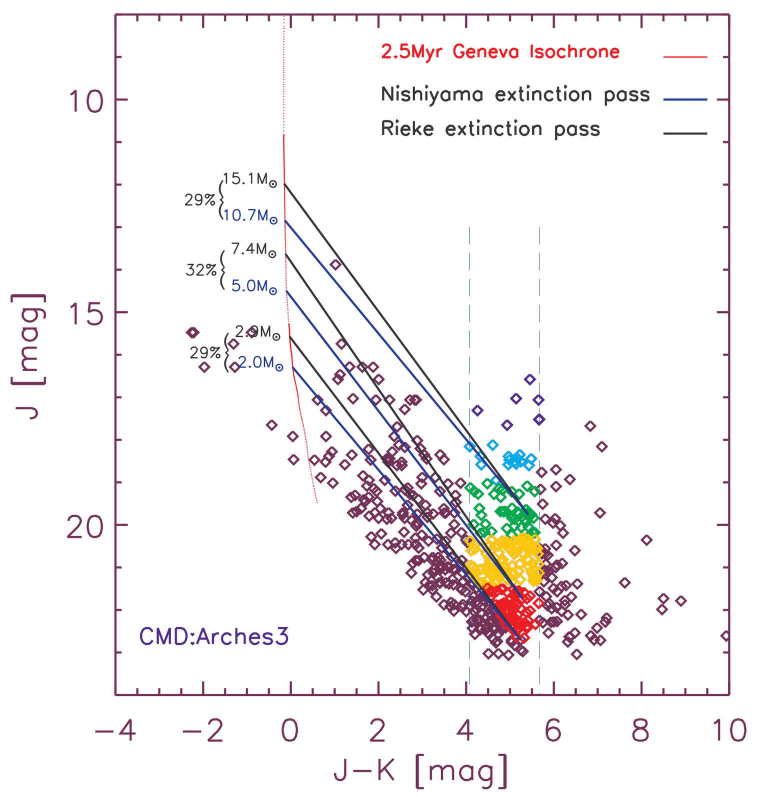
Observation and method



The Arches cluster is the youngest among the three massive clusters in the Galactic center(GC) providing a collection of high-mass stars and a very dense core ($\rho_{core} \sim 10^5\, M_\odot/\mathrm{pc}^3$) which makes it an excellent site to address questions about massive star formation, the stellar mass function and the dynamical evolution of massive clusters in the GC. We analyzed high-resolution near-infrared adaptive optics data (H& K_s band) in combination with seeing-limited J-band observations of the Arches cluster to derive the stellar mass function up to the cluster's tidal radius for the First time. The locations of the NACO fields (K_s-band observation) are shown overlaid on the SUBARU *J*-band image of the Arches cluster. Circles illustrate distances of 0.2, 0.4, 1, 1.5 and 2 pc from the center of the cluster.

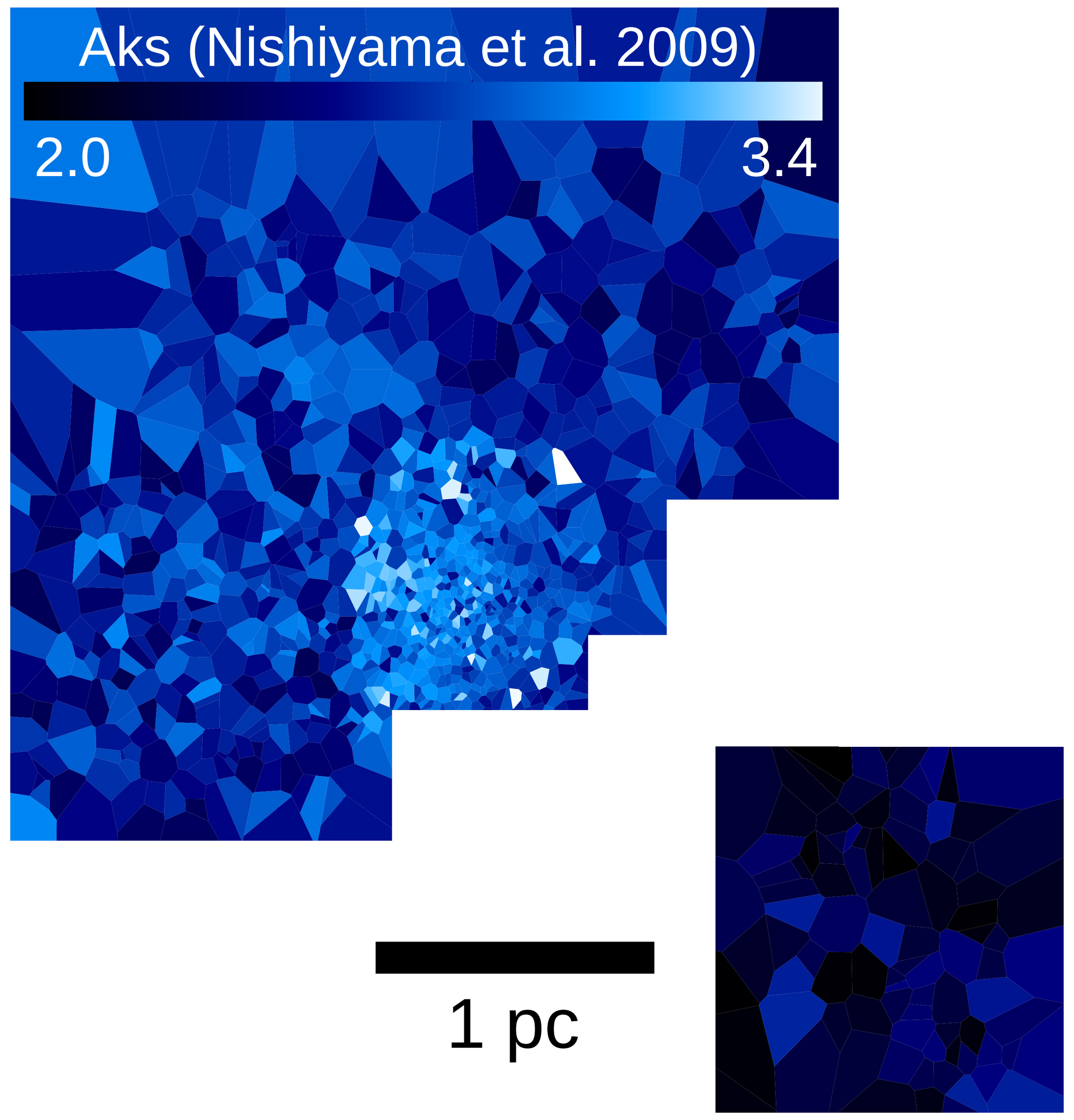


Color-magnitude diagram of the center of the Arches cluster. Vertical dashed lines show the color-cut used to discard contaminating background and foreground sources. Less extincted foreground sources, mostly associated with the spiral arms, are shown by blue diamonds whereas intrinsically red objects like red giants or red clump stars (the latter marked with an enclosed dotted line) are illustrated with red diamonds. The black diamonds represent likely cluster members.

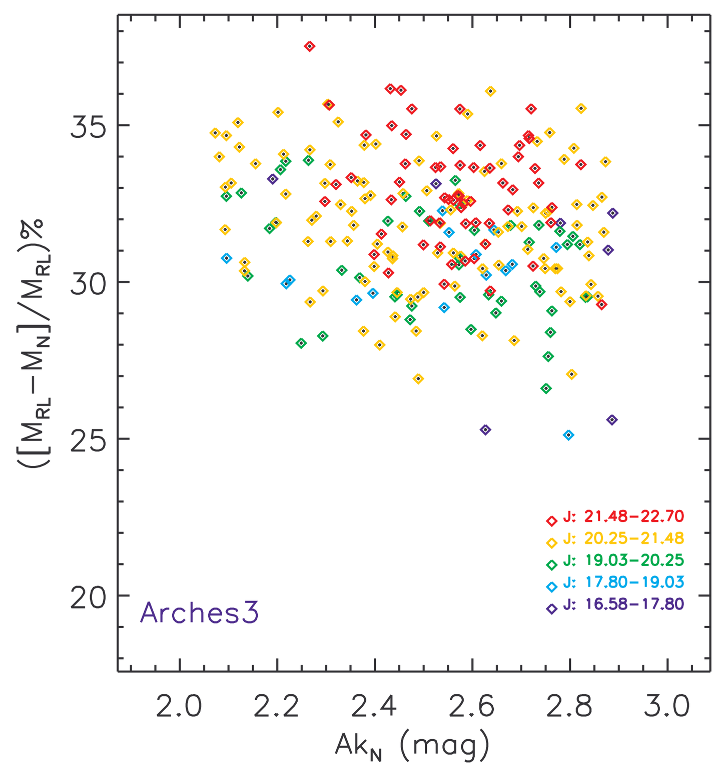


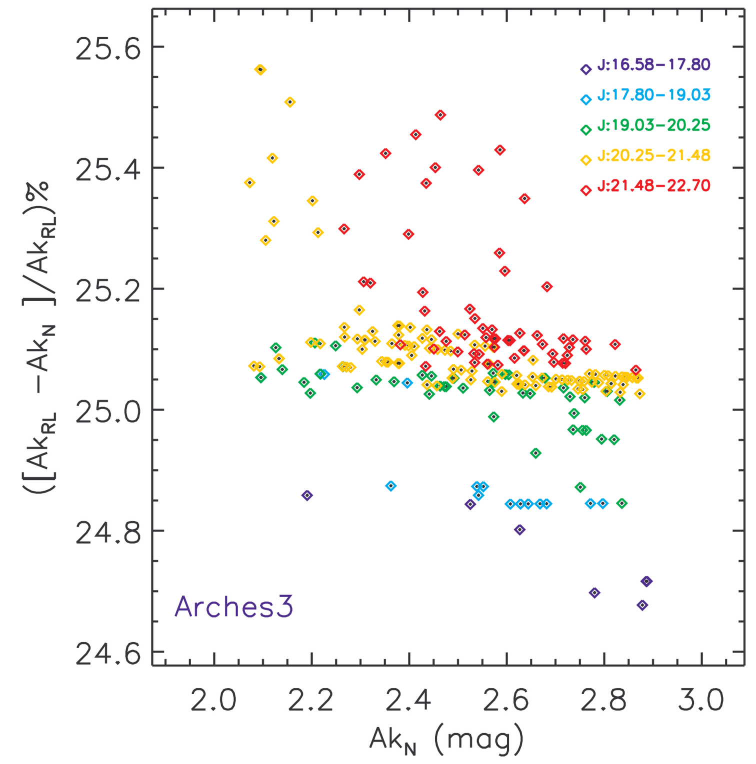
Extinction causes stars to be reddened with respect to their intrinsic color. We slide back the cluster members along each extinction path toward the non-extincted theoretical isochrone. The brightness, color and mass of a star at the intersection point of the non-reddened isochrone with the extinction vector are assumed to be the intrinsic brightness, color and mass of the star. Assuming different extinction laws will change the derived extinction and consequently the intrinsic properties of the stars. Black lines represent the extinction path assuming the Rieke & Lebofsky extinction law (1985) while blue lines are extinction paths based on the Nishiyama et al. (2009) extinction law. The difference of derived masses using the two laws are written for sample sources close to the isochrone in percentage.

Extinction map & comparing derived parameters using the two extinction laws



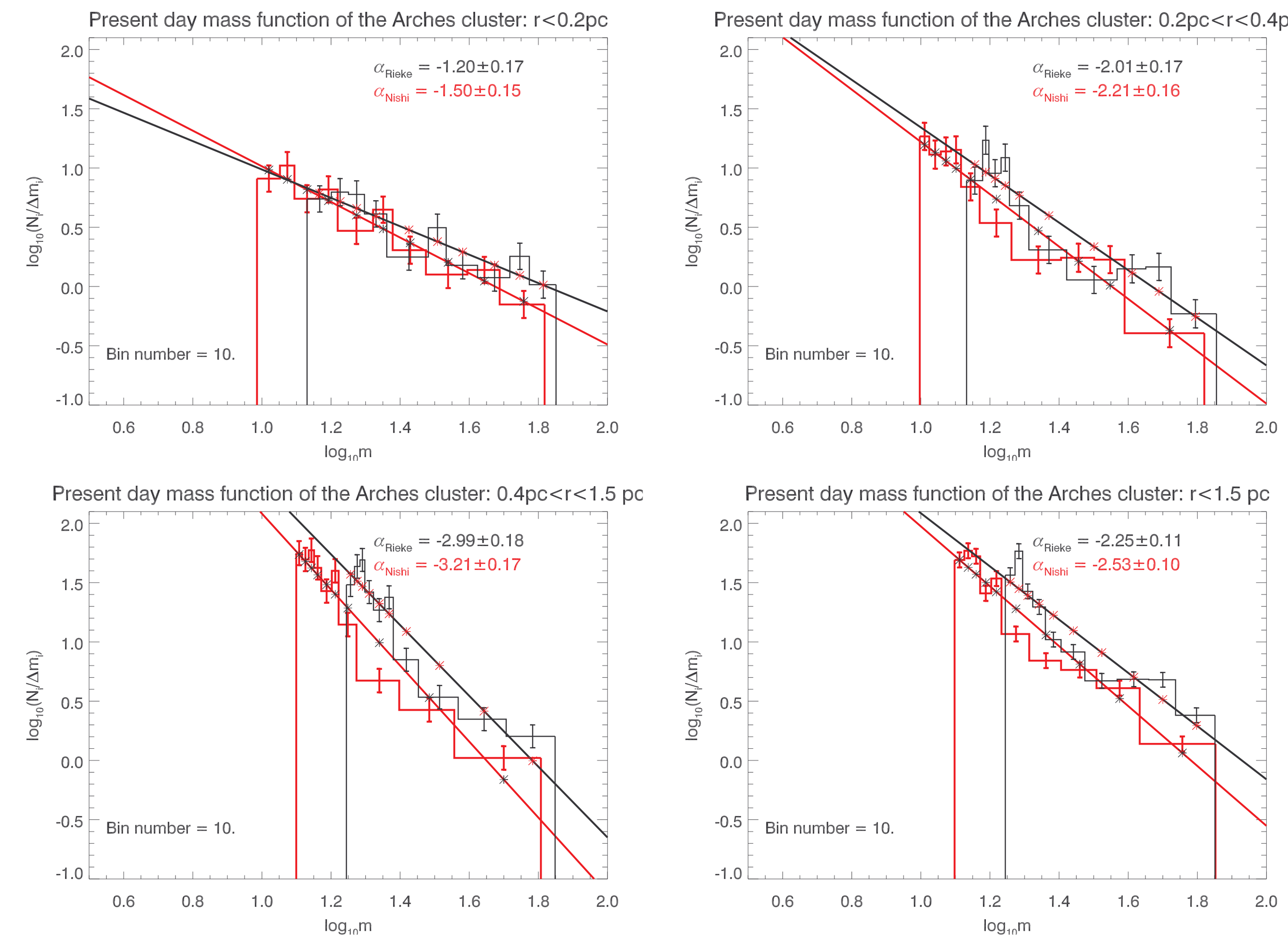
The extinction map of the Arches cluster using Voronoi diagrams: each star is associated with one and only one cell the color of which is determined by the measured extinction value at the star. A region of lower extinction is present in the center of the cluster while stripes of larger extinction are present in the south west and partly north west of the cluster. The extinction is high and vary up to ~ 2 mag across the cluster. The extinction values derived based on the Rieke & Lebofsky 1985 extinction law vary between $2.7 < A_{K_s} < 4.5$ mag while utilizing the Nishiyama et al. 2009 extinction law yields an extinction range of $2 < A_{K_s} < 3.4$ mag. The structure of the two extinction maps based on the two different extinction laws is only marginally different. North is up and East is to the left.



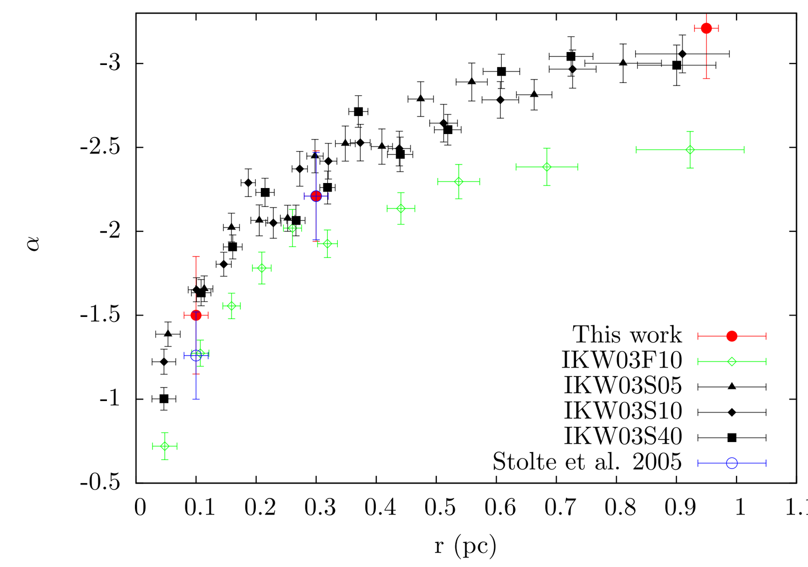


Assuming different extinction laws will change the derived extinction and consequently the intrinsic properties of the stars. Left: **Derived masses using the RL-EL are 30% higher than derived masses assuming the N-EL across the Arches cluster.This is crucial as the Arches cluster is not expected to have had any supernova at its present age. As the cluster is believed to cover the full mass range, it was used to derive a possible upper-mass limit of $M = 150 M_\odot$ for the star formation process in the Milky Way (Figer et al. 2005).** Such an upper mass limit has severe implications on our understanding of the stellar evolution and the formation of the highest mass stars. While the most massive initial mass in our sample is $104 M_\odot$ when de-reddening with a Rieke & Lebofsky 1985, the highest initial mass is only 80 when the Nishiyama et al. 2009 extinction law is used. Right:The average AKs difference in the cluster is 24%. The AKs difference in percentage (right) and absolute value (left) for one of the outer fields is shown.

Mass functions



The present-day mass function of the Arches cluster. Red lines correspond to the mass distribution derived based on the N-EL while black lines represent the mass function assuming the RL-EL. Both mass functions are fitted with a power-law like function with reported slopes of α shown in the respective color. The present-day mass functions are plotted in three regions: (a) the inner core of $r < 0.2$ pc, (b) the intermediate annulus of $0.2 < r < 0.4$ pc and, (c) the cluster outskirts of $0.4 < r < 1.5$ pc. The present-day mass function steepens as we move outward from the cluster center. While in the core of the cluster the number of massive stars compared to lower mass stars are high relative to the normal Salpeter mass function ($\alpha = -2.35$, 1955), the intermediate annulus has a Salpeter like distribution and the outskirts are depleted of high-mass stars. (d) The complete present-day mass distribution of the cluster within $r < 1.5$ pc which is consistent within the uncertainties with a Salpeter IMF.



It was argued before that the IMF might be top-heavy in the GC due to increased could temperatures and magnetic fields (Morris 1993, Dib et al. 2007). The figure is adopted from Harfst et al. 2010 and compares the mass function slopes from the best fitting models of N-body simulations of the Arches cluster to the observed values. The black filled symbols represent the models with Salpeter IMF with different lower mass limits while green open symbols correspond to a model with flat IMF. The three Salpeter and the one flat IMF models deviate primarily at larger radii ($r > 0.4$ pc). The derived slope from a model starting with a Salpeter IMF at birth in the radius of 1 pc is $\alpha \sim -3$ which is in good agreement with our finding of $\alpha_{Nishi} \sim -3.21 \pm 0.30$ in the outskirts of the Arches cluster. **Therefore, we conclude that the observed slopes are consistent with dynamical evolution of a cluster which formed with a normal Salpeter IMF.**

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I am a PhD student at the Argelander Institute for Astronomy at the University of Bonn, where I am a member of the the Emmy Noether group on The formation and evolution of Milky Way starburst clusters led by Dr. Andrea Stolte.

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