THE STELLAR INITIAL MASS FUNCTION
IN THE GALACTIC CENTER

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Abstract
Massive stars define the upper limits of the star formation process, dominate the energetics of their local environs, and significantly affect the chemical evolution of galaxies. Their role in starburst galaxies and the early Universe is likely to be important, but we still do not know the maximum mass that a star can possess, i.e. “the upper mass cutoff.” I will discuss results from a program to measure the upper mass cutoff and IMF slope in the Galactic Center. The results suggest that the IMF in the Galactic center may deviate significantly from the Salpeter value, and that there may be an upper mass cutoff to the initial mass function of ~150 Msun.

1. Motivating Questions

Two simple, yet still unanswered, questions motivate this paper. First, is the stellar initial mass function (IMF) universal? Second, what is the most massive star that can form? These questions are related, as they concern primary output products of the star formation process. The IMF is observed to be roughly constant, within errors, although outliers to the value of the slope do exist. The data at the high mass end are woefully incomplete for determining the upper limit for which the IMF essentially becomes zero, i.e. an upper mass cutoff.

There are several properties of stellar clusters that are required for estimating the high mass IMF slope and, in particular, an upper mass cutoff:

1. the associated star formation event must produce a large amount of mass in stars, at least \(10^4 M_\odot\),

2. the resultant cluster must be young enough, certainly no older than 3 Myr, so that its most massive members are pre-supernovae,
3 the cluster must be old enough for its stars to have emerged from their natal cocoons,

4 the cluster must be close enough to be resolved into individual stars, and

5 the stellar surface number density must be low enough to allow one to separate light from individual stars.

Given this rather long list of requirements, it is perhaps not surprising that, as of yet, an upper mass cutoff has not been identified; although, recent work might have identified a cutoff in R136, a starburst cluster in the LMC (Weidner & Kroupa 2004). There is only one cluster in the Galaxy that can satisfy these requirements, the Arches cluster near the Galactic center. There are two other clusters massive enough, the Quintuplet and Central clusters, also both in the Galactic center, but those clusters are both too old, \( \sim 4 \text{ Myr} \), and their most massive members have dimmed as WR stars or compact objects.

2. The Galactic center environment and its young clusters

The Galactic center occupies a very small volume, \( \sim 0.04\% \) of the Galaxy, yet it contains 10\% of all Galactic molecular material and a similar proportion of newly formed stars. The extreme tidal forces in the center shred molecular clouds having densities less than about \( 10^4 \text{ cm}^{-3} \); therefore, the clouds in the region necessarily have relatively high densities compared to those in the disk. The cloud temperatures are also about a factor of three higher, and the magnetic field strength may be as much as 1 mG. This environment may favor the formation of massive stars (Morris 1993). See Morris & Serabyn (1996) for a review.

There are three massive young clusters within a projected radius of 30 pc of the Galactic center: the Arches, the Quintuplet, and the Central cluster. Their properties have been reviewed (Figer et al. 1999a; Figer et al. 1999c; Figer et al. 2002; Figer 2003). In brief, all three have about equal mass, \( \sim 10^4 \text{ } M_\odot \); but the first is only 2-2.5 Myr old, or about half the age of the other two. These older clusters are too old for an accurate determination of their initial mass functions using photometry alone, as their most massive members have likely progressed to the supernovae stage, or, at the least, have dimmed substantially and are lost amongst the background population of red giants. Even when they are distinguished from the background, as Wolf-Rayet stars, it is impossible to infer their original masses.
3. The Arches cluster and the IMF in the Galactic center

The Arches cluster is located just 30 pc, in projection, from the Galactic center (Cotera et al. 1992; Nagata et al. 1995; Figer 1995; Cotera 1995; Cotera et al. 1996; Blum et al. 2001). It contains 160 O-stars, and is the most massive young cluster in the Galaxy (Serabyn, Shupe, & Figer 1998; Figer et al. 1999a). Given its youth, its members have not yet advanced to their end states, and they still follow a linear relationship between mass and magnitude (Figer et al. 2002). The brightest members have masses \( \sim 120 \, M_\odot \), and are enriched in helium and nitrogen (Najarro, Figer, Hillier, & Kudritzki 2004). They are commensurately luminous, up to \( 10^{6.3} \, L_\odot \), and have prodigious winds that carry a significant amount of mass, up to \( 10^{-5} \, M_\odot \, yr^{-1} \). Some of these winds have been individually identified through radio observations of their free-free emission (Lang, Goss, & Rodríguez 2001), and there are several point-like and diffuse x-ray emission sources centered on the cluster (Yusef-Zadeh et al. 2002).

The IMF in the Galactic center has been measured in one location, the Arches cluster (Figer et al. 1999a; Stolte, Grebel, Brandner, & Figer 2002), and it is somewhat shallow compared to the Salpeter value (Salpeter 1955). Figure 1 shows the mass function, as observed using HST/NICMOS. It was constructed by converting magnitudes into masses using the Geneva stellar evolution models (Schaller, Schaerer, Meynet, & Maeder 1992). The counts have been corrected for contamination by the background population. The slope appears to be shallow with respect to the Salpeter value. Such a cluster is likely to have experienced significant dynamical evolution in the strong tidal field of the Galactic center; however, Kim et al. (2000) find that this effect is unlikely to have produced such a flat slope.

4. An upper mass cutoff

The Arches cluster appears to have an upper mass cutoff (Figer 2003; Figer 2004; Figer et al. 2005). Figure 2 shows the mass function extended to very high masses and computed out to a radius of 12 arcseconds from the center of the Arches cluster. In this plot, we see that one might expect massive stars up to 500\( -1,000 \, M_\odot \), yet none are seen beyond \( \sim 120 \, M_\odot \). Taking account of errors, and the unreliable mass-magnitude relation at the highest masses, one can safely estimate an upper mass cutoff of \( \sim 150 \, M_\odot \). The most important caveat to this result relates to the youth of the cluster. An age \( > 3 \, Myr \) would mean that the most massive stars have progressed to their end states and would
Figure 1. Present-day mass function of the Arches cluster in the F205W NICMOS filter (bold). Incompleteness corrected data are shown with a dashed line. The dotted line shows concurrence with earlier observations using Keck for the highest mass stars. The average IMF slope is $-0.7$, although Stolte et al. (2002) found a slightly steeper slope of $-0.9$ after correcting for differential extinction.

not be observed. Several analyses suggest an age of 2-2.5 Myr (Figer et al. 1999a; Blum et al. 2001; Figer et al. 2002; Najarro, Figer, Hillier, & Kudritzki 2004). Note that an age <1 Myr would give a deficit of roughly twice that shown in the figure and a predicted maximum stellar mass of 600–1,700 $M_\odot$. A similar analysis was done for R136 in the LMC that also found a cutoff of 150 $M_\odot$ (Weidner & Kroupa 2004).

5. **Supermassive stars in violation of the cutoff?**

There are several stars in apparent violation of the cutoff estimated in the Arches cluster. The Pistol star, in the Quintuplet cluster, has an estimated initial mass of 150–200 $M_\odot$ (Figer et al. 1998; Figer et al. 1999b). Star #362 in the Quintuplet cluster is a near-twin to the Pistol star (Figer et al. 1999c; Geballe, Najarro, & Figer 2000), so it likely had a similar initial mass. Both stars are roughly equally bright, although they are also both variable (Glass, Matsumoto, Carter, & Sekiguchi 2001). It is interesting to note that these two stars, if as massive as we think, should only live for $\sim$3 Myr, yet they reside in a cluster that is at least 4 Myr old. LBV1806–20 is another high mass star that may violate the
limit, but it is likely binary (Figer, Najarro, & Kudritzki 2004). η Car, with a system mass that may be higher than the limit, is also a likely binary (Damineli et al. 2000). A promising resolution to the apparent paradox of a limit and systems with higher masses could be that all such systems are either binary or have been built through recent mergers (Figer & Kim 2002).

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Figure 2. Present-day mass function of the Arches cluster in the F205W NICMOS filter with lines overplotted for the inferred mass function and the Salpter mass function. The hatched regions demonstrate that one would expect there to be many very massive stars in the cluster (Figer 2005).
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