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Star-formation histories, metallicity distributions and luminosity functions

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Abstract. A selection of topics was discussed, but given the limits of space, I discuss here only the IMF in any depth, with only a brief supplementary comment on the bulge.

1. The Stellar Initial Mass Function

The stellar Initial Mass Function is a fundamental aspect of star formation. Variations in the IMF are predicted in many theories, particularly those that invoke the Jeans mass, and associated dependences on cooling rates and pressure. The environment of the Galactic Center is rather different from the solar neighbourhood, and the dense, massive, young star clusters there provide an interesting test of the variation, or not, of the massive-star IMF. Indeed, early star-count observations had suggested a flatter IMF in the Arches star cluster, some 25 pc in projection from the Galactic Center and with age $\lesssim 3$ Myr, than in the solar neighbourhood (Figer *et al.* 1999). However, the most recent data, obtained with the NACO Adaptive Optics imager on the VLT, are entirely consistent with a standard, Salpeter (1955), slope to the IMF above $10\,M_\odot$ (Espinoza, Selman & Melnick 2009), *modulo* a level of mass segregation in the inner regions.

The level of variation in generations of massive stars that have since exploded as core-collapse supernovae can be constrained through analysis of the elemental abundances in low-mass stars that they pre-enriched. In general, if the massive-star IMF is biased towards more massive stars, the predicted ratio of alpha-elements to iron will be higher, due to the dependence of the nucleosynthetic yields on progenitor mass, within the range of core-collapse progenitors, $\sim 10\,M_\odot$ to $\sim 50\,M_\odot$ (e.g. Kobayashi *et al.* 2006). Stars formed early in the history of self-enrichment of a system will show signatures of only core-collapse supernovae, and when these stars can be identified, they show remarkably little scatter in most elemental abundance ratios, even down to very low levels of [Fe/H] (e.g. Cayrel *et al.* 2004). This constancy, within estimated errors, implies not only an invariant massive-star IMF, but also efficient mixing so that IMF-averaged yields are achieved (e.g. Wyse & Gilmore 1992; François *et al.* 2004). It should be noted that the conclusion of the invariance of the IMF from the lack of scatter is not dependent on the details of the supernova models, nor on a chemical evolution model, but is a robust conclusion. Of course, determination of what the IMF is from the value of the elemental ratios would be sensitive to models.

These conclusions hold for stars in diverse environments such as the old, metal-rich bulge (e.g. Fulbright, McWilliam & Rich 2007) and metal-poor halo. Even in the metal-poor dwarf spheroidals, where the bulk of the member stars show lower values of [α/Fe] (e.g. Venn *et al.* 2004), consistent with their broad internal spread of ages and likely self-enrichment by Type Ia supernovae (see Unavane, Wyse & Gilmore 1996), the most metal-poor – and presumably oldest – stars show the same enhanced ratio as in the field halo (e.g. Koch *et al.* 2008).

Extending this analysis to larger samples of extremely metal-poor stars is possible through exploitation of the database from the RAVE moderate-resolution spectroscopic survey of bright stars ($I < 12$; see Steinmetz *et al.* 2006 for an introduction to the survey), for which 4–8m-class telescopes suffice for follow-up high-resolution data. Preliminary results (Fulbright, Wyse, Grebel *et al.*, in prep) are very encouraging. Extremely metal poor stars, with [Fe/H] < -3 dex, have also been identified in dwarf spheroidal galaxies (e.g. Kirby *et al.* 2008; Norris *et al.* 2008), predominantly in the 'ultra-faint' systems discovered by analysis of the imaging data of the Sloan Digital Sky Survey (e.g. Belokurov *et al.* 2006, 2007).

As noted below, the ages of the bulge and halo stars are equal to look-back times corresponding to redshifts of 2 and above, implying constancy of the massive star IMF back to these early stages of the Universe, in a wide range of physical conditions.

The low-mass luminosity function can be determined in most systems by straightforward star counts, and again the constancy or otherwise of the IMF can be tested in systems that probe a wide range of physical parameters: the high-metallicity, old, dense stellar bulge; the low-metallicity, old, diffuse, dark-matter dominated dwarf spheroidals; the low-metallicity, old, dense Globular star clusters; and lastly the young disk star and open clusters. Again, all is consistent with an invariant low-mass IMF (e.g. Wyse 2005).

In terms of modelling the Galaxy, the IMF should be held fixed.

2. The Bulge

The conclusion that the bulge consists of exclusively old stars – at least those regions probed by low-reddening windows – is not new, but has been given considerably more weight by a recent HST-based analysis by Clarkson *et al.* (2008) in the Sgr low-extinction window. These authors used multi-epoch observations to identify foreground disk stars, through their proper motions. After removal of these younger stars, the colour-magnitude diagram remaining is that of an old, metal-rich population. However, much more data are required to map the stellar population in the bulge, and understand how it connects to the stellar halo, and to the inner thin and thick disks.

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