

A Complete Initial Mass Function For Old Stellar Populations

Program contacts: R. Michael Rich, Bruce Margon
Scientific category: STELLAR POPULATIONS
Instruments: NIR/CAM
Days of observation: 13

Abstract

NGST is capable of reaching the end of the hydrogen burning main sequence in the Galactic bulge, Magellanic Clouds, and the 7 dwarf spheroidals. This permits measurement of the stellar mass function over a range in metallicity of $-2 < [\text{Fe}/\text{H}] < +0.5$. In the Galactic bulge, there is currently a debate as to whether the high rates of microlensing there are due to ordinary low mass stars or brown dwarfs. If the bulge faint-end mass function were identical to that of the local disk, a very large population of brown dwarfs would be required to account for the microlensing events. There continues to be a strong debate on the nature of dark matter that apparently must bind the majority of dwarf spheroidals, and a census of luminous stars would rule out one kind of baryonic matter that could conceivably be responsible. In the case of the Magellanic Clouds, populous young clusters offer a window on the mass function of brown dwarfs formed in a young starsburst, since in populations younger than $\sim 10^7$ yr, they would still be cooling, luminous, and possibly observable.

ASWG DRM Proposal
A Complete Initial Mass Function For Old Stellar Populations

Observing Summary:

Target	RA	Dec	K_{AB}	Configuration/mode	Days
GALACTIC BULGE	18 02	-30 00	H=27	NIR/CAM R10	1
LMC AND CLUSTERS	05 00	-70 00	H=27	NIR/CAM R10	5
7 DWARF	00 00	00 00	H=27	NIR/CAM R10	7
SPHEROIDALS					
Grand total days					13

■ Scientific Objectives

The initial mass function (IMF) is a fundamental physical property of a stellar population and is one of the most crucial ingredients in models of galaxy formation and evolution. It determines the heavy element production, the luminosity evolution over time, and the mass to light ratio of the population. Yet the IMF is usually taken as a free parameter, particularly at the low mass end. Observational constraints on the IMF would therefore be of prime astrophysical importance.

Knowing the lower IMF of spiral bulges and elliptical galaxies is of exceptional importance because these spheroidals contain a large fraction, perhaps a majority, of all the stellar mass of the universe. However, there is no way to determine this IMF except through measuring the luminosity function (LF) of our own bulge (as the only surrogate for the unresolvable population in other galaxies). Although the faint end of the stellar IMF has been determined for the solar neighborhood (Gould et al., 1997), it is only in the Galactic bulge that one can be confident that the stellar population is old, largely coeval, and metal rich (Ortolani et al. 1995; McWilliam & Rich 1993), i.e., the closest we can come in a nearby, resolved stellar population to what prevails in other spiral bulges and elliptical galaxies. Indeed, as mentioned below, the solar neighborhood and the bulge may have very different IMFs. Globular clusters offer another approach towards determining the IMF for $M < \sim M_{\odot}$, and deep HST observations of them are indeed providing important information on their present-day mass functions (PMFs). However, clusters suffer from dynamical evolution and low-mass evaporation so there is no reliable way to infer their IMFs from their PMFs.

The recent discovery of an unexpectedly high rate of microlensing events towards the bulge (Udalski et al. 1994; Alcock et al. 1995) has made the determination of the faint end of the IMF a yet more urgent problem. In brief, if the bulge IMF is close to that of the solar-neighborhood (Gould et al. 1997) then the bulk of the short (~ 10 day) microlensing events remain unexplained (Han 1997). However, an IMF extending to the H-burning limit with a Salpeter law ($dN/d\ln M \propto M^{-1.35}$) can account for both the total mass of the bulge and the frequency of microlensing events (Zhao, Spergel, & Rich 1995). It is tempting to conclude that bulge and solar-neighborhood mass functions are different. However, the interpretation of the microlensing events is sensitive to assumptions about the phase-space distribution of both the lenses and sources, to corrections for binary frequency, and some events may be caused by collapsed stars, brown dwarfs or even non-stellar objects. Therefore, the most reliable way to resolve these ambiguities (and thus maximize the information from microlensing itself) is to obtain a complete stellar inventory of the bulge from star counts and to incorporate this into the microlensing analysis.

The determination of the true luminosity function (hence IMF) in the Galactic bulge faces several potential problems that could degrade the accuracy of any result: differential reddening, disk contamination, and metallicity dispersion. However, from the ground – and to some extent also with HST – the biggest problem is crowding. For example, the Baade’s Window LF obtained with exceptional seeing ($\sim 0''.4$) at the ESO NTT (Ortolani et al.

1995) starts to be severely incomplete just ~ 2 mag below turnoff, at $V \simeq 22$. Similarly, the deepest ground-based, near-IR LF for the bulge (Tiede et al. 1995) is limited by crowding, not by faintness. For this reason we pay special attention to evaluating the crowding effects to be expected with HST observations.

Conversion from an LF to an MF requires a mass-luminosity relation. While this relation is highly uncertain for some populations, it is empirically well established for stars of solar metallicity from observations of nearby visual and eclipsing binaries (Henry & McCarthy 1993). Thus, the major technical problems are in the construction of the LF itself, namely how to take account of foreground disk contamination, and especially at the faint end, photometric errors and blended images. We are well equipped to properly simulate all these effect, including running programs with artificial stars. The correction for binaries (almost all of which will be unresolved) is also a problem. While some statistical information about binarity can be extracted from the width of the main sequence and/or the optical/infrared colors of the detected stars, the binary fraction will probably remain as the largest single source of uncertainty in the construction of the bulge IMF.

1 Deep Luminosity Functions in the Dwarf Spheroidal Populations

A decade of improved radial velocity measurements in dwarf spheroidals appears to confirm that some kind of dark matter is required to bind these systems. The discovery of the Sgr dwarf galaxy has actually strengthened this conclusion, since one way out of dark is the possibility that all dwarf spheroidals are actually tidally disintegrating. Sgr actually is, and its properties agree with theoretical predictions for this process. For the other 7 dwarf spheroidals, the dark matter problem continues.

One possibility is that faint hydrogen burning stars account for presently unobserved baryonic matter; a steeper faint end mass function could conceivably be the cause. In a limiting exposure to $H = 32$, NGST is capable of reaching the hydrogen burning limit in *all* of the Milky Way dwarf spheroidal satellites. While it is unlikely that large numbers of faint hydrogen burning stars can account for the dark matter in these systems, such a study potentially gives much insight into the star formation process over a wide range of metallicity, early in the Galaxy's history.

2 Initial Mass Function of the Magellanic Clouds and their Populous Young Clusters

At a modulus of 18.6, the hydrogen burning limit is found at $H = 28.6$ in the LMC. The rich range of ages in the field and clusters will provide an ideal testbed to explore what parameters affect the IMF. The clusters themselves rang in luminosity from open cluster to true globular cluster, and there are numbers of young populous clusters present. For the youngest clusters, such as R136A or NGC 2004, and likely to clusters as old as 1 Gyr, NGST can detect cooling brown dwarfs. The mass function of brown dwarfs formed in the normal formation process of massive globular clusters is a complete unknown. However, the mass

fraction locked in brown dwarfs is a vital and interesting question since that mass will never be recycled into new generations of massive stars and is permanently out of the chemical evolution process. Complete luminosity functions as faint as NGST can image will be of great interest in these populous young clusters.

3 NGST requirements

This program could fail due to 2 problems: (1) photometric crowding and (2) a high background caused by bright stars, which overwhelms the faintest, most interesting stars.

High spatial resolution – diffraction limited imaging at H – could solve the first problem. The second problem could be solved by using wide-field apodization to suppress wide angle diffracted light. Because the faint end of the main sequence is cool, this program would be expected to go extremely well with the near-IR imager.

4 References

- Alcock, C. et al. 1995, ApJ, 445, 133
De Marchi, G. & Paresce, F. 1995, A&A, 304, 211
Frogel, J. A., Terndrup, D. M., Blanco, V. M., & Whitford, A. E. 1990, ApJ, 353, 494
Gould, A., Bahcall, J., & Flynn, C. 1997, ApJ 482, 913
Han, C. 1997, ApJ, 484, 555
Henry, T. J. & McCarthy, D. W. 1993, AJ 106, 773
McWilliam, A., & Rich, R. M. 1994, ApJS, 91, 749
Ortolani, S. et al. 1996, Nature, 377, 701
Renzini, A. 1994, in Galaxy Formation, ed. J. Silk & N. Vittorio (Amsterdam: North Holland), p. 303
Tiede, G. P., Frogel, J. A., & Terndrup, D. M. 1995, AJ, 110, 2788
Terndrup, D. M., 1988 AJ, 96, 884
Udalski, A. et al. 1994, Acta Astron., 44,165
Zhao, H.S., Spergel, D., & Rich, R.M. 1995, ApJL, 440, L13

■ NGST Uniqueness/Relationship to Other Facilities

I have attempted to use HST with WFPC2 and NICMOS to reach the end of the H-burning sequence in the bulge. WFPC2 fails by 5 magnitudes. We also have been unable to reach the hydrogen burning limit in a 14 orbit integration with nicmos. For the more distant systems (LMC, dwarf spheroidals) no instrument can challenge NGST.

It is possible that 8m telescopes with adaptive optics and OH suppression filters may be able to reach the $H = +26$ limit for point sources.

■ Observing Strategy

Deep images of the fields using the near-IR camera in two widely separated infrared bands, probably J and K . The density of stars in the Bulge *nicmos* field appears high enough that the main sequence is clearly defined, and therefore we expect that it will not be necessary to clean the CMD's using proper motions.

In both the bulge and LMC, we contemplate measuring the IMF in several different fields in order to exploit gradients in age and metallicity.

■ Special Requirements

Maximum FWHM: $100'$ at $1.0 \mu\text{m}$

Minimum FOV: $1.0'$ at $1.0 \mu\text{m}$

■ Precursor/Supporting Observations

Some parts of the problem will be worked on with HST. Clearly, the bright end of the IMF should already be well defined by the time these data are taken.