EVIDENCE AGAINST FORMATION OF THE STELLAR BULGE BY MERGERS TAKING PLACE OVER A HUBBLE TIME

R.M. RICH
Department of Astronomy
Columbia University
New York, NY 10027

ABSTRACT. Data on abundances and ages of stars in the nuclear bulge of the Galaxy are in conflict with a scenario in which the bulge has been slowly accumulated by mergers of Magellanic Cloud-like systems taking place over a Hubble Time.

I review the abundance distribution of 88 K Giant stars in Baade's window, and show that the distribution is fit by the simple model of chemical evolution unmodified by gas infall. The metal rich stars in the bulge could not have formed in small galaxies of $\approx 10^{10}$ solar masses, which do not retain their metal-enriched gas.

Two large surveys of luminous evolved stars in the bulge–the M giant surveys of Blanco, and the carbon star surveys of Azzopardi, Lequeux, and Rebeirot, find no luminous carbon stars or M supergiants which would signify the presence of an intermediate-age population. I present infrared photometry of 33 bulge carbon stars which shows that they are intrinsically faint, confirming the lack of an intermediate age population.

The lack of young turnoff stars in the color-magnitude diagrams of bulge fields by Terndrup and Rich further strengthens the case against a substantial bulge population younger than 5 Gyr.

1. Introduction

While the structure of the cluster at the center of our Galaxy has been observable in the infrared, only recently, as reported in this volume, has it become possible to study individual stars, such as OH/IR stars, with radio and infrared techniques. Therefore, studies of individual stars in the central thousand parsecs, the stellar bulge, still are a useful guide as we seek to understand the physical properties of the central star cluster.

The notion that merger activity has played an important role in the formation of galactic nuclei and bulges is not a new idea. Tremaine, Ostriker, and Spitzer (1975) first suggested that the nucleus of M31 was formed from multiple mergers of globular clusters, decelerated by dynamical friction. Recently, Schweizer and Seitzer (1988) have observed apparent merger signatures–tails and ripples–in some disk galaxies, and they propose that many, if not all bulges are the products of mergers. Such merger events could involve the infall of several dwarf galaxy sized, $10^9 M_\odot$ sized objects taking place over a Hubble time. Certain bulge features, such as cross or box-shaped isophotes, are best explained by infall of a cold disk, as Hernquist and Quinn (1988) point out. Given this revival of an old idea, it is well

M. Morris (ed.), The Center of the Galaxy, 63–69.

worth looking for evidence that the stellar bulge of our Galaxy has been built by mergers. After all, infall of several cold disks could provide fuel for the activity at the very center.

Continuing merger activity affects the distribution of stellar abundances and ages; its most dominant signature would be a substantial intermediate age stellar population. I propose that such a population is not present in the stellar bulge, though it is probably present in the tens of parsecs near the nucleus.

2. The Stellar Abundance Distribution in Baade's Window

The interest in studying the bulge is, of course, motivated by the possibility that it is a stellar population representative of many other galaxies. Whitford (1978) illustrates this by showing that, like other spiral bulges and elliptical galaxies, the patch of bulge known as Baade's Window $\ell = 1°$, $b = -4°$) has strong stellar absorption lines of Fe, Mg, and Na, and lacks the Balmer series. To first order then, the bulge's integrated light is that of a K giant, and lacks the blue light that signals the presence of a young stellar population. From the evolved stellar content, we can infer that the bulge has a wide range in abundance, as it contains RR Lyrae variables, whose progenitors are metal poor, and M giants, whose progenitors are metal rich. An unbiased study of the abundance distribution function must sample K giants, as all stars evolve through that phase, regardless of metallicity. Whitford and Rich (1983) obtained spectra of 21 K giants and showed that the bulge has a wide range of abundances, including some stars which are apparently the most metal rich known. Figure 1 illustrates this range in abundance, as well as the remarkably strong-lined character of some bulge K giants. Figure 2 shows the spectrum of a very late M giant, which may have once been a metal rich K giant. Using the abundance distribution to learn about the bulge's formation requires that we fit it to models of chemical evolution, which in turn requires a larger unbiased sample. Rich (1988) determines [Fe/H] for 88 K giants in Baade's Window, and fits their abundance distribution to the simple model of chemical evolution, as Figure 3 illustrates. If the bulge's chemical evolution were dominated by inflow of material, the abundance distribution would be skewed toward the metal rich end, as Mould (1984) points out. In fact, the bulge's abundance distribution is very similar to that of a $10^{12} M_\odot$ model of Yoshii and Arimoto (1986) with no infall or outflow, and complete processing of the gas into stars. I sound a cautionary note, though, in that the entire stellar population of the central bulge has not been sampled, and the metal rich stars could, as a whole, dominate those of lesser abundance. Larson's (1974) models of galaxy formation predict that, in contrast to the bulge *all* of the stars near the nucleus of a galaxy are metal rich. With current technology we are now just capable of testing Larson's theory. Nonetheless, for the bulge to have an inflow-dominated abundance distribution, the character of the stellar abundance distribution must change radically in the inner 500 pc. We also note that dwarf galaxies, such as the Magellanic clouds, lack stars of greater than solar abundance. This is expected on theoretical grounds; as Yoshii and Arimoto (1987) point out, supernova-driven winds can expel metal rich gas before it turns into stars, particularly in galaxies below $10^{10} M_\odot$. The most metal rich stars found in Baade's window could not have formed in dwarf galaxies.

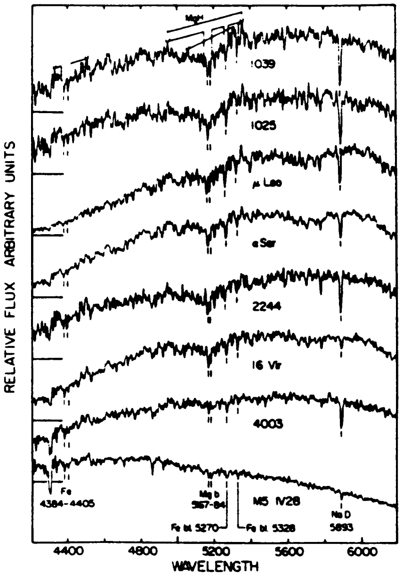

Figure 1. These spectra illustrate both the wide range of abundances and strong-lined character of bulge K giants in Baade's Window. All stars illustrated have approximately the same (J−K) color. Stars 1039, 1025, 2244, and 4003 are bulge K giants (see Arp, 1965 for identifications). Note how strong-lined bulge giants 1025 and 1039 are compared to μ Leo, the most metal rich solar neighborhood star, which has 5 times the solar metal abundance.

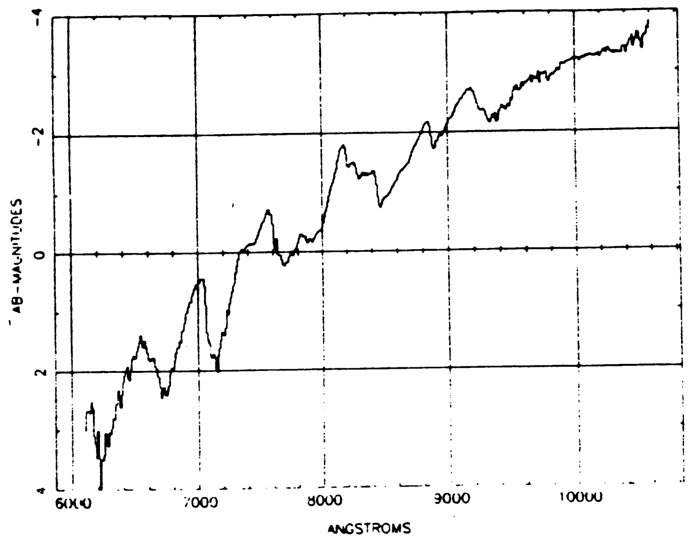

Figure 2. An example of a bulge M giant. Blanco 289 is classified M9III by Blanco, McCarthy, and Blanco (1984). All of the strong features are due to TiO. Bulge M Giants have very blue (J−K) color for their TiO band strengths. Spectrum obtained with the Palomar 5m Hale Telescope courtesy J. Biretta and J. Gunn.

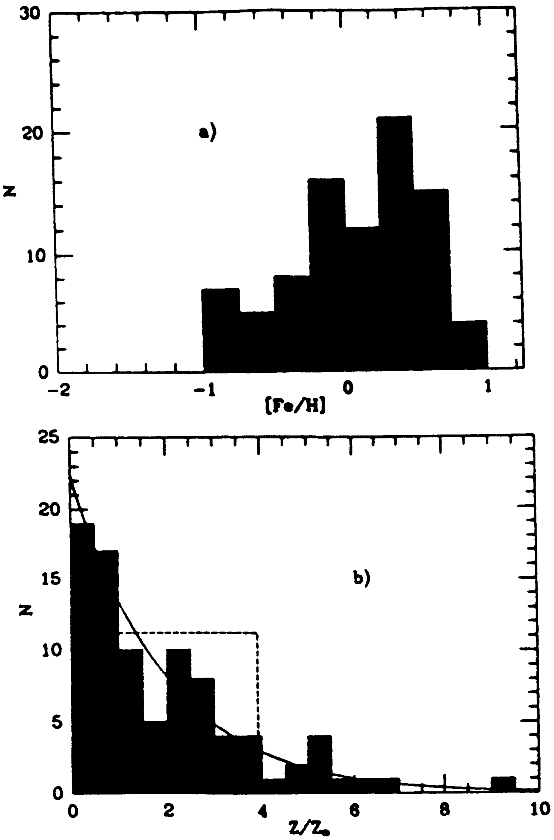

Figure 3. (a) Abundance distribution of bulge K giants in Baade's Window at $\ell = 1°$, $b = -4°$. Note the range over 2 orders of magnitude (Rich, 1988) (b) Differential abundance distribution of bulge giants in (a) converted to units of $Z/Z_{\odot}$, and compared to two limiting cases of the simple model of chemical evolution. Solid line: simple "closed box" model with complete gas consumption; $\langle z \rangle = 2Z/Z_{\odot}$. Dashed line: Simple model, in the limiting case where a small fraction of the initial volume of gas is converted to stars, the remainder being expelled from the system.

3. Lack of a Young or Intermediate-Age Population

3.1 THE ASYMPTOTIC GIANT BRANCH

If the bulge has been gradually built over a Hubble time, or even if a single merger event involving some $10^9 M_{\odot}$ of material has taken place within the last 8 Gyr, the stellar population would contain many luminous AGB stars. In the Magellanic Clouds, Mould and Aaronson (1986) show that intermediate age clusters, particularly those 1-5 Gyr old, signal their presence with C stars with luminosities greater than $M_{\rm bol} = -4.3$, the He core flash luminosity.

https://doi.org/10.1017/S0074180900186346 Published online by Cambridge University Press

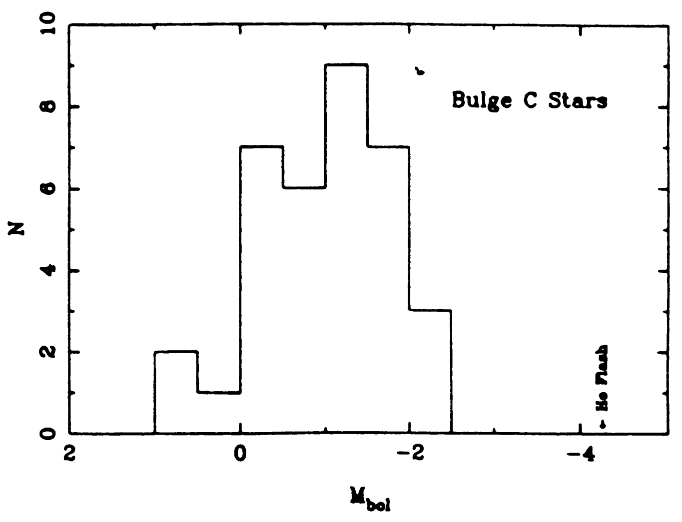

Figure 5. Luminosity function of 33 bulge carbon stars from a preliminary study by Rich, Azzopardi, Lequeux, and Rebeirot. These stars were identified in 8 galactic bulge fields ranging from $b = -2.4°$ to $b = -10°$. These stars are among the faintest C stars known, considerably fainter than the He flash luminosity at $M_{bol} = -4.3$; they clearly have not evolved from a young population.

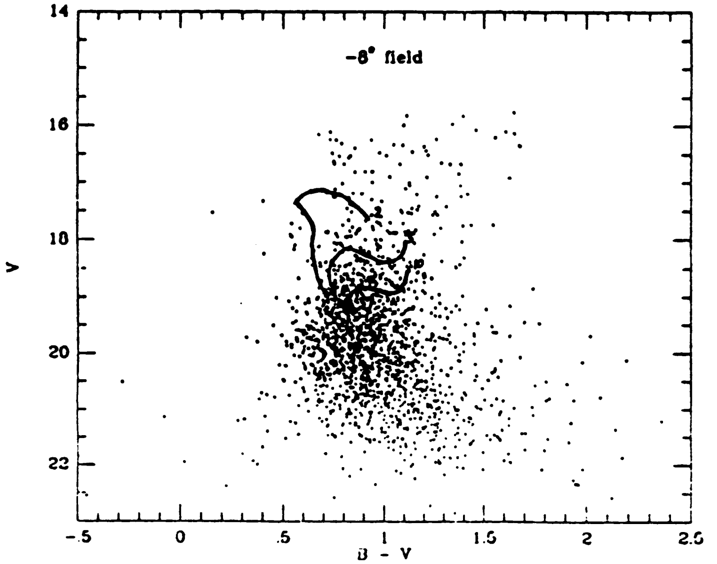

Figure 6. Color-magnitude diagram of a bulge field at −8° from Rich (1985) Isochrones are for 2, 5, and 10 Gyr. The number of young stars predicted from possible evolved AGB stars is 2 orders of magnitude greater than the numbers observed. Terndrup (1988) confirms this in a comprehensive study of several bulge fields.

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As Rich *et al.* (1987) report, the survey of Azzopardi, Lequeux, and Rebeirot does indeed yield spectroscopically confirmed carbon stars, but they are not luminous (Figure 5). In fact, they are among the least luminous C stars known. C stars in the Magellanic Clouds and solar neighborhood exceed the He core flash luminosity by 1 magnitude. It may be argued that the high metallicity prevents the formation of C stars, but recall (Figure 3) that the bulge population covers a wide range of metallicity. Even the solar neighborhood has numerous luminous C stars, and Claussen *et al.* (1987) estimate that 10% of all F stars ($1.2 - 1.6 M_{\odot}$) become C stars at some point in their lifetime. If a Magellanic type system, containing $\sim 10^4$ C stars (Blanco and McCarthy, 1983) had merged with the bulge, we would expect a number of luminous C stars to be present. Because of their low luminosities, the bulge C stars are interesting oddities of stellar evolution, but do not signal the presence of an intermediate age population.

3.2 THE COLOR-MAGNITUDE DIAGRAM

The most obvious place to look for a young population is in the turnoff portion of the color-magnitude diagram. Unfortunately, crowding in the bulge makes this observation impossible at Baade's Window (Terndrup, 1988), but it is possible in a field at $-8°$ (Rich, 1985). As Figure 6, from Rich (1985) illustrates, a turnoff at 2-8 Gyr is not obviously present. If we keep in mind that giants live for $\sim 10^6$ yr and dwarfs for $\sim 10^9$ yr, even if only the Lloyd Evans Miras are young, the 10^3 turnoff stars per Mira are not present (the case in the $-4°$ field; Rich, 1985). Terndrup's (1988) beautiful series of color-magnitude diagrams forcefully establishes the large age of the stellar bulge population, particularly in fields at $-8°$ and $-10°$.

4. Conclusions

Three independent lines of study: stellar abundances, the luminosities of evolved giants, and the color magnitude diagram, jointly rule out the formation of the bulge by a series of merger events taking place over a Hubble time. However, they do not rule out mergers within the first few Gyr of the Galaxy's existence. Future studies involving more color-magnitude diagrams from the ground and space, and large samples of stellar radial velocities, will place stronger constraints on the age and formation history of the bulge.

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