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# Nuclear Star Clusters in Bulgeless Galaxies

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**Abstract**

Centers of spiral galaxy bulges are very special in terms of their dynamics and star formation history. We investigate whether the centers of bulge-less galaxies are as unique in their structure and stellar populations. Our HST imaging survey of very late-type, bulge-less (Sd) galaxies has revealed unusually bright, nuclear star clusters at their photometric center in 75% of the cases. We have obtained high-resolution spectra with UVES at the VLT for 10 of those objects. We find that the majority of the clusters are younger than 1 Gyr. The masses of the clusters as determined from the velocity dispersion range between $10^6$ and $10^8$ $M_\odot$ and are typically one order of magnitude higher than would be expected from stellar synthesis models. We interpret this as an underlying population of older generations of stars that have already faded with time and thus do not show up in the spectrum. Consequently nuclear cluster formation is a repetitive event in very late type galaxies, which can contribute to the build-up of bulges.

## 1.1 Introduction

The centers of spiral galaxy bulges are very special in terms of their dynamics and star formation history. Not only do they often contain weak AGN (Ho et al. 1997) but they also often host nuclear gas disks and regions of star formation (Carollo et al. 1997). It is now commonly believed that all bulges contain a SMBH (Kormendy & Gebhardt 2001). The centers of bulge-less Sd galaxies are less well defined. Gravity hardly provides a vector pointing to the center in their shallow harmonic potentials as can be seen in the image of NGC428 (Fig 1.1, taken from Böker et al. 2002a). Nonetheless images of the central parts of spiral galaxies of all Hubble types, obtained in the last decade with the unique resolution of HST, have revealed that they frequently harbor a luminous, compact stellar cluster in their dynamical center (e.g. Carollo et al. 1997; Böker et al. 2002a).

Those few nuclear clusters studied spectroscopically so far tend to be young. Our Galaxy has two nuclear clusters younger than $5 \cdot 10^6$ years (Figer et al. 1999). IC 342 has a nuclear cluster younger than 60 Myr (Böker et al. 1999), while NGC 4449 has a cluster age between 6 and 10 Myr (Böker et al. 2001; Gelatt et al. 2001). Considering the shallow potentials mentioned above, the nature of the nuclear clusters becomes even more interesting.

However a bias to younger, hence more luminous clusters is well possible, as only those are bright enough to stand out against the background bulge. This contrast problem is less pronounced in very late type, bulge-less spirals. We have therefore undertaken a spectro-

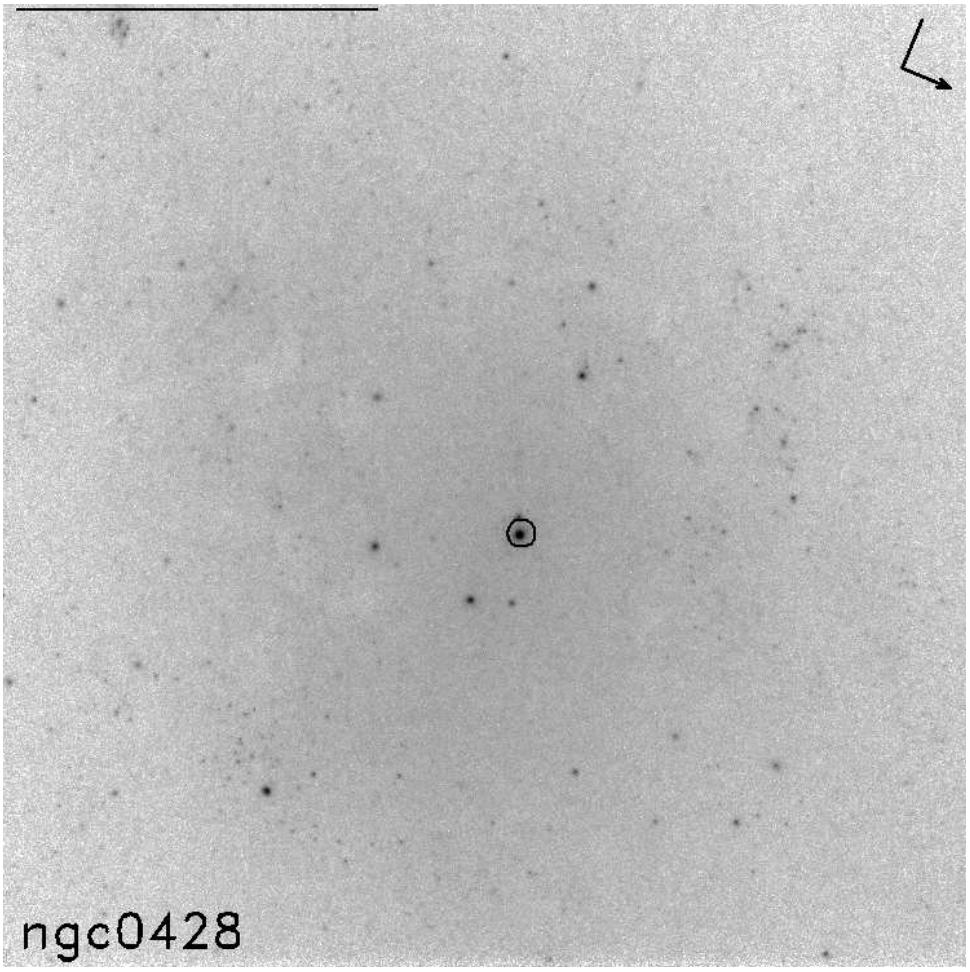


Fig. 1.1. HST image of the bulge-less galaxy NGC 428. The nuclear cluster is encircled for easier identification.

scopic study of objects from the Böker survey to elucidate the nature of those nuclear clusters. Preliminary results from STIS spectroscopy have already been reported in Böker et al. (2002b). There we find that of the 6 studied objects, 5 are younger than 1 Gyr. We now present further ground-based spectroscopy of 10 more objects.

## 1.2 Data

The spectra were taken with the high resolution spectrograph UVES at the VLT in December 2001. The observed objects together with their distances and absolute magnitudes are listed in Table 1.1. The spectra cover a wavelength range between 3500 and 9900 AA at a resolution of 40000 and are therefore suited for age determinations as well as velocity dispersion measurements. Exposure times ranged from 1h to 6h. We also observed templates stars to be used in the determination of the velocity dispersion. The echelle spectra where reduced with the UVES pipeline in the automatic mode. No continuum correction was applied.

### 1.3 First Key: The Age

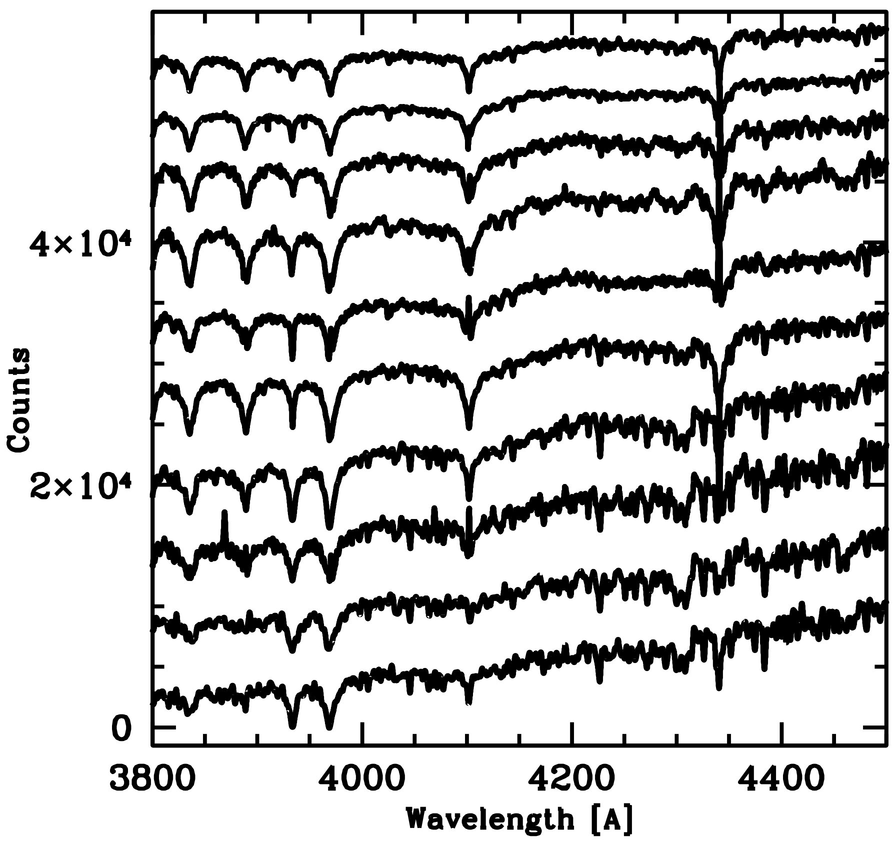


Fig. 1.2. Blue spectra of 10 nuclear clusters as taken with UVES at the VLT. The spectra are in an age sequence and in the same order as the galaxies in Table 1.1.

Figure 1.2 shows the smoothed blue parts of the UVES spectra. Their age has been estimated by fitting single-age, solar metallicity Bruzual & Charlot templates with a Salpeter IMF. The age spacing was logarithmic: 1, 3, 6, 10, ..., 10000 Myr. As is described in Böker et al. (2002b) this is only a rough age estimator. Significantly better fits are obtained by mixing different ages also with our data. This hints towards the presence of different generations of stars. The ages presented here therefore only give the last star formation episode, as M/L increases with age. A more thorough analysis of this problem will be done in a forthcoming

Table 1.1. *Age of the best fitting single age population for each nuclear cluster. ([a] is an object from Carollo et al. 1997)*

| Galaxy | type | Distance [Mpc] | $M_I$ (cluster) | Age [yr] | $M/L_I$ |
|---|---|---|---|---|---|
| NGC1493 | SBcd | 11.4 | -11.43 | $10^7$ | 0.04 |
| NGC2139 | SABcd | 23.6 | -12.65 | $10^7$ | 0.04 |
| NGC7424 | SABcd | 10.9 | -11.41 | $10^7$ | 0.04 |
| NGC1385[a] | Sb | 24 | -12.89 | $10^7$ | 0.04 |
| NGC7418 | SABcd | 18.4 | -16.23 | $10^7$ | 0.04 |
| NGC7793 | SAd | 3.3 | -13.64 | $2 \cdot 10^8$ | 0.46 |
| NGC 300 | SAd | 2.2 | -11.43 | $5 \cdot 10^8$ | 0.73 |
| NGC1042 | SABcd | 18.2 | -12.95 | $10^9$ | 1.03 |
| NGC3423 | SAcd | 14.6 | -11.84 | $10^9$ | 1.03 |
| NGC 428 | SABm | 16.1 | -13.15 | $10^9$ | 1.03 |

paper. The Bruzual & Charlot models also give a mass to light ratio (M/L) corresponding to each age. The determined ages and M/Ls in the I band are listed in Table 1.1.

The histogram in absolute magnitudes (Figure 1.3) shows that we are still biased to higher luminosities. But although the total observed sample (dotted green) covers only the brighter two thirds of the total Böker sample (full blue), the three clusters older than 1 Gyr (dashed red) are not fainter than the rest. At the moment there is not indication that older means fainter. If we take the observed sample to be a representative subsample of the brighter part of the luminosity function of nuclear clusters, we can give the following lower limits: more than 46% of the detected nuclear clusters are younger than 1 Gyr and more than 35% of very late type galaxies harbor such a young nuclear cluster. We conclude that the duty cycle of star formation in nuclear clusters must be much shorter than a Hubble time.

## 1.4 Second Key: The Mass

Velocity dispersions are measured from the calcium triplet. We use the Rix & White (1992) code that matches simultaneously a combination of template stars of different spectral type (between F1 and K2) and a gaussian broadening. As shown in Figure 1.4, which shows a typical fit, we can thus account for young populations by determining their influence on the width of the Ca-triplet from the Paschen lines. Measured velocity dispersions range between $13-42 \pm 1$ km/s. The HST I-band light profile is then used to derive the potential under the assumption of spherical symmetry. Plugging the light profile and the potential into Jeans' equation yields the velocity dispersion profile. As the velocity dispersion scales with $\sqrt{M/L}$, the measured velocity dispersion can then be used to derive M/L. Integrating over the light profile also yields the mass (see Häring et al. 2003, in preparation). NGC 1385 had to be excluded from this step as we did not have a light profile yet.

As can be seen from Figure 1.5 the $M/L_I$ ratios derived from the dynamical analysis are consistently higher than the ones estimated from the fitting of population synthesis models. Uncertainties from the dynamical modeling are about 50%. The derived M/L values for the last star formation episode are rather upper limits as Balmer emission tends to fill up the absorption in some cases. We are therefore forced to introduce some kind of non-luminous

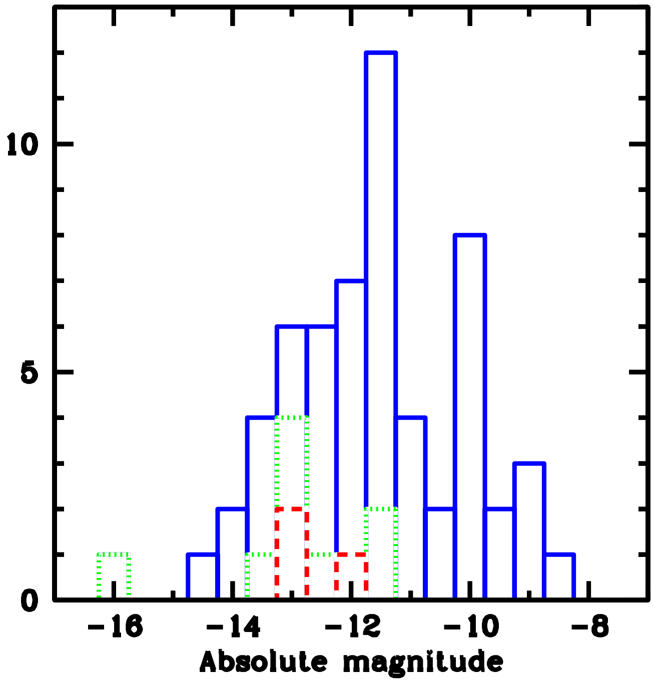


Fig. 1.3. Histogram showing all detected nuclear clusters in the Böker et al. (2002a) sample (full blue), our subsample (dotted green) and those that we determine to be older than 1 Gyr (dashed red).

matter. The most conservative assumption is that earlier generations of stars are present in the nuclear cluster. Stellar populations fade with time, so they do not show up in the spectrum. Yet their gravitational influence is apparent in the dynamics of the clusters.

## 1.5 Conclusions

The generally young ages of the clusters point to a duty cycle for the formation of nuclear clusters that is much shorter than a Hubble time. We would thus expect the nuclear clusters to be composed of different generations of stars. Older generations of stars will be fainter due to fading. They should thus show up in a dynamical analysis where their mass can be felt, but the spectrum should be dominated by the last star formation episode. This is exactly what we measure with the velocity dispersions in the nuclear clusters. We thus conclude that nuclear cluster formation is a recurring event in the centers of very late type galaxies. This could contribute significantly to the build-up of bulges. Indeed pseudobulges are thought to form through secular evolution and gas inflow in disks (see, e.g., Kormendy & Gebhardt 2001 and references therein). The nuclear clusters in very late type Sd galaxies are thus candidates for pseudobulges in their infancy.

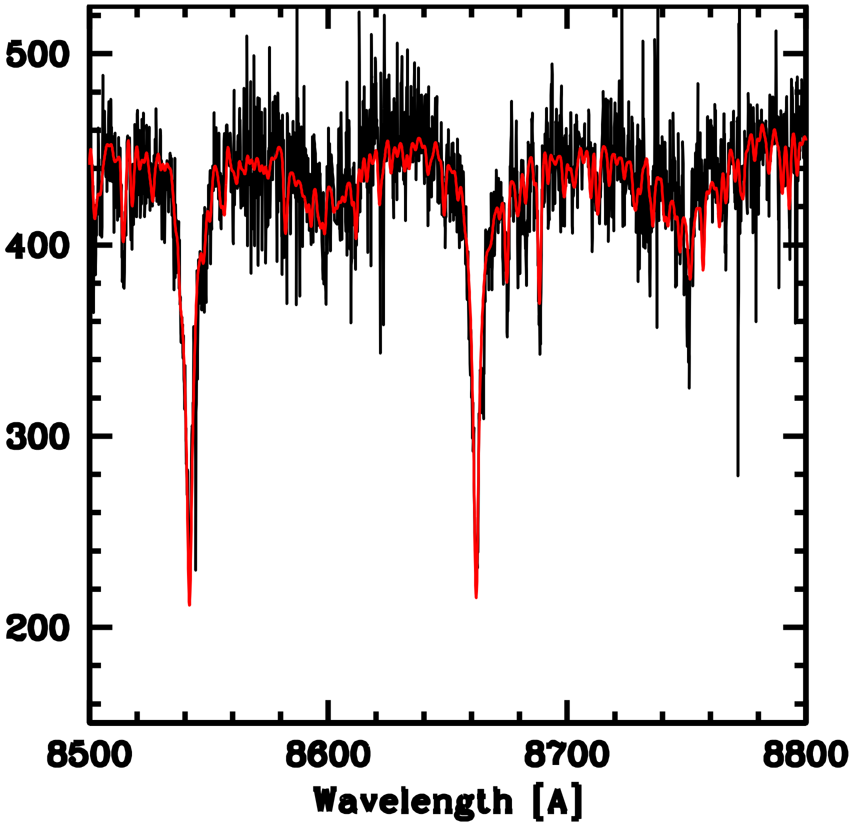


Fig. 1.4. Fit (red) to a UVES spectrum (black) to determine the velocity dispersion.

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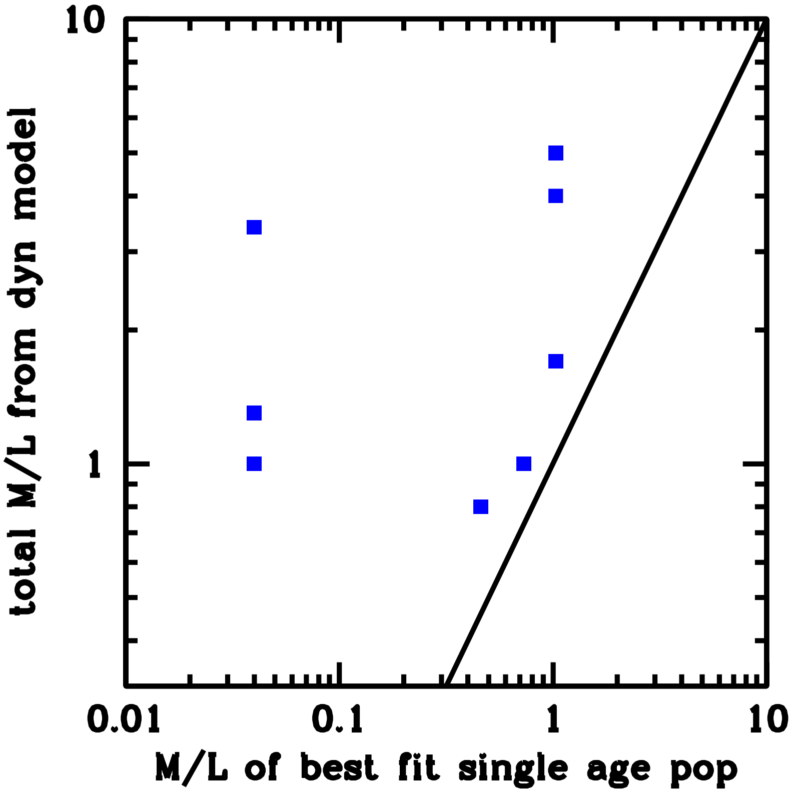


Fig. 1.5. Comparison of dynamical and stellar synthesis M/Ls.