*Galaxy Evolution across the Hubble Time*
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# Formation and Evolution of Nucleated Galaxies

**Kenji Bekki**

School of Physics, University of New South Wales, Sydney 2052, Australia
email: bekki@phys.unsw.edu.au

**Abstract.** We discuss how stellar galactic nuclei (SGN) form and evolve during galaxy formation and evolution based on chemodynamical simulations on the central regions (1-1000 pc) of galaxies. Our simulations demonstrate that dissipative formation of SGN through rapid transfer of gas into the central 10 pc of galaxies is more consistent with recent observations of SGN than dissipationless formation of SGN through merging of globular clusters (GCs). Nuclear structures in the remnants of major galaxy mergers between low-mass, nucleated spirals are found to depend strongly on the mass-ratio of massive black holes (MBHs) to SGN in spirals in the sense that the remnants have more distinct SGN in the mergers with the smaller MBH-to-SGN-mass-ratios. During the destruction of low-mass, nucleated galaxies by strong tidal fields of giant galaxies, SGN can remain intact. The stripped SGN can be observed as bright GCs around the giant galaxies. The color-magnitude relation of metal-poor GCs (referred to as "the blue tilt") recently discovered for bright galaxies is similar to that of SGN, which suggests that the origin of the blue tilt is closely associated with the formation processes of SGN of gas-rich, low-mass dwarfs in the high redshift universe.

**Keywords.** galaxies: formation, galaxies: evolution, galaxies: star clusters, galaxies: nuclei

## 1. Dissipationless or dissipative formation ?

Recent observational studies of stellar galactic nuclei (SGN) for early-type galaxies in the HST ACS Virgo Cluster Survey (e.g., Côte *et al.* 2006) have provided vital clues to the question as to whether stellar galactic nuclei (SGN) were formed through dissipationless merging of GCs (e.g., Tremaine *et al.* 1975) or through dissipative transfer of gas to nuclear regions of galaxies (e.g., Bekki *et al.* 2006). By comparing these observations with numerical simulations of SGN formation, our studies (Bekki *et al.* 2004; Bekki *et al.* 2006) suggest that (1) the observed luminosity-size relation of SGN (Côte *et al.* 2006) is consistent with the GC merging model, (2) the possible evidences for the presence of multiple stellar populations with different ages and metallicities (Walcher *et al.* 2005) are consistent with the dissipative model, and (3) the observed color-magnitude relation of SGN can not be simply explained by the GC merging model (Côte *et al.* 2006).

## 2. Nuclear structures of merger remnants

We have investigated final nuclear structures of the remnants of major mergers between low-mass spirals with SGN and massive black holes (MBHs) in the centers of SGN and without massive bulges based on GRAPE simulations with multiple softening lengths and individual time steps for different collisionless components. Figure 1 shows that the merger remnant has a distinct SGN (i.e., the density profile characterized by the remarkable central excess of stellar density) for the model with the MBH-to-SGN-mass-ratio of 0.01. The merger remnant in the model with the MBH-to-SGN-mass-ratio of 1 shows no distinct SGN yet has a flat nuclear core, because binary MBHs can destroy the



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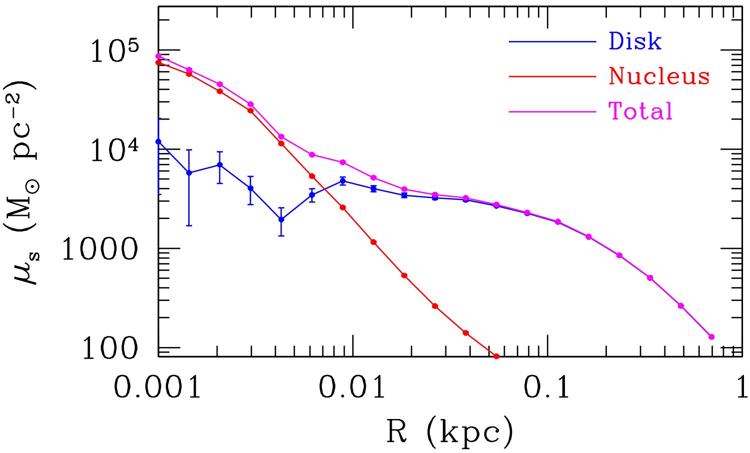


**Figure 1.** The projected surface stellar density profile of stars in the merger remnant of nucleated, bulge-less spirals with the MBH-to-SGN-mass-ratio of 0.01. The magenta line represents the profile of all stars whereas the blue and the red ones represent the contribution from disk stars (i.e., stars that are initially within progenitor disks) and from nuclear ones, respectively. The binary MBHs are trapped in the center of the merged SGN (i.e., no destruction by dynamical heating of MBHs) so that the remnant can be nucleated.

initial SGN of merger progenitor spirals. These results suggest that the MBH-to-SGN-mass-ratio of a merger is a key parameter that determines the final nuclear structure of the remnant.

## 3. Properties of stripped SGN

Low-mass galaxies with SGN are susceptible to strong tidal force of giant galaxies and thus can be transformed into "naked SGN" owing to tidal destruction processes (Bekki *et al.* 2003). These naked SGN, which can be observed as bright GCs around giant galaxies, should have properties similar to those of the present SGN. The observed mass-metallicity relation (referred to as "the blue tilt"; Strader *et al.* 2005) of $Z \propto M^{0.55}$ in metal-poor GCs (derived from the color-magnitude relation) for bright galaxies (Harris *et al.* 2006) is quite similar to that of $Z \propto M^{0.43}$ in SGN (Côte *et al.* 2006). This similarity implies that a significant fraction of metal-poor GCs originate from SGN formed in low-mass dwarfs at the high redshift universe.

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**Discussion**

JEAN BRODIE: Just a couple of comments about the blue tilt in globular cluster systems. The blue tilt extends continuously down to faint magnitudes and it was simultaneously discovered by Strader *et al.* and Harris *et al.*

KENJI BEKKI: Yes, I understand that.

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