Why are classical bulges more common in S0 galaxies than in spiral galaxies?

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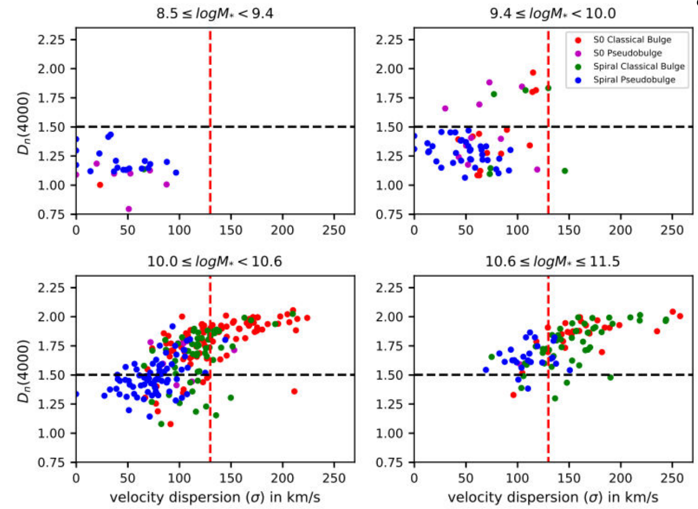
ABSTRACT

In this paper, we try to understand why the classical bulge fraction observed in S0 galaxies is significantly higher than that in spiral galaxies. We carry out a comparative study of the bulge and global properties of a sample of spiral and S0 galaxies in a fixed environment. Our sample is flux limited and contains 262 spiral and 155 S0 galaxies drawn from the Sloan Digital Sky Survey. We have classified bulges into classical and pseudo-bulge categories based on their position on the Kormendy diagram. Dividing our sample into bins of galaxy stellar mass, we find that the fraction of S0 galaxies hosting a classical bulge is significantly higher than the classical bulge fraction seen in spirals even at fixed stellar mass. We have compared the bulge and the global properties of spirals and S0 galaxies in our sample and find indications that spiral galaxies which host a classical bulge, preferentially get converted into S0 population as compared to pseudo-bulge hosting spirals. By studying the star formation properties of our galaxies in the *NUV−r* colour–mass diagram, we find that the pseudo-bulge hosting spirals are mostly star forming while the majority of classical bulge host spirals are in the green valley or in the passive sequence. We suggest that some internal process, such as AGN feedback or morphological quenching due to the massive bulge, quenches these classical bulge hosting spirals and transforms them into S0 galaxies, thus resulting in the observed predominance of the classical bulge in S0 galaxies.



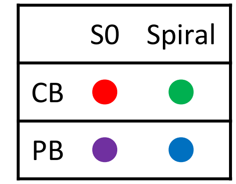


Figure 2. Plots showing the position of classical and pseudo-bulge hosting spiral and S0 galaxies on the $D_n(4000)$-central velocity dispersion (σ) plane. The stellar mass range of galaxies in each panel is stated on the top of each panel in units of log($M_\odot$). The black dashed line $D_n(4000) = 1.5$ separates bulges into young (with $D_n(4000) < 1.5$) and old ($D_n(4000) \geq 1.5$) population. The red line at σ = 130 km s^{-1} has been put for reliability check of pseudo-bulge classification. Pseudo-bulges falling to the right to this line are unreliable. The plot shows that higher mass galaxies have older and kinematically hot bulges. While the population of classical and pseudo-bulges is expectedly different in their properties, the classical bulges hosted by spirals and S0 have sufficient overlap in the $D_n(4000)-\sigma$ space pointing to a similarity in properties.

Fig2. 速度分散 vs Dn4000
- どのMs binにおいても、σ(CB) > σ(PB)
- CB S0 と CB Spiral の分布（力学、星種族）は似ている。

<u>Classical bulge を持つS0銀河はどのように形成されるのか？</u>

- SDSSデータを用いて
  - 同じ数密度環境(field~group)で切ってSpiralとS0銀河を抽出 。
  - 銀河bulge部の表面輝度と有効半径の相関（Kormendy relation）でclassical (CB) と pseudo-bulge (PB) に分類。

Table 1. Number of classical and pseudo-bulge hosting spirals and S0 in different stellar mass bins.

Mass range (log($M_*/M_\odot$))	8.2–8.8	8.8–9.4	9.4–10.0	10.0–10.6	10.6–11.2	11.2–11.8
No. of spiral galaxies	2	19	42	127	68	4
Pseudo-bulge host spirals	2	18	36	71	25	1
Classical bulge host spirals	0	1	6	56	43	3
Spiral classical bulge fraction (per cent)	0	5.3	14.3	44.1	63.2	75
No. of S0 galaxies	2	6	23	97	25	2
Pseudo-bulge host S0s	2	5	10	8	1	0
Classical bulge host S0s	0	1	13	89	24	2
S0 classical bulge fraction (per cent)	0	16.7	56.5	91.7	96.0	100

どのMs binにおいても、CB S0 >> CB Spiral。その差はどこから来るのか？
- PB Spiral → CB S0 ?
  - x Merging説：頻度が低い。CB S0以外も形成される。サイズが大きくなる（Fig3）。
- CB Spiral → CB S0 ?
  - x Tidal interaction説：可能だが本サンプルの数密度環境ではあまり効かない。
  - ○ Internal process説：SN/AGN feedback, morphological quenching等によるdisk SF quenching。

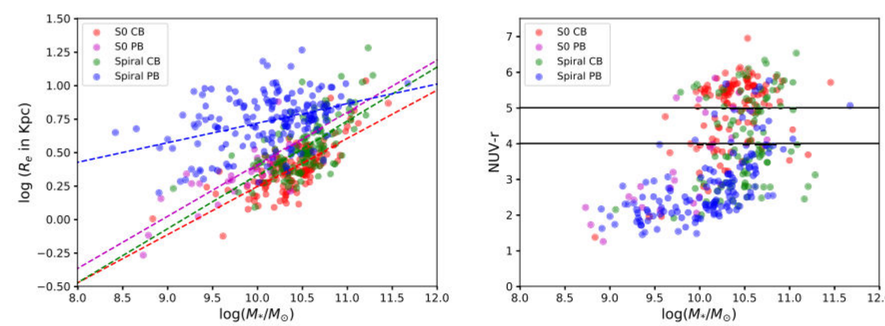


Figure 3. The global properties of classical and pseudo-bulge hosting spirals and S0 galaxies. **Left** : The size stellar mass relation for the classical and pseudo-bulge hosting spirals and S0 galaxies. The galaxy size has been taken as the logarithm of the galaxy semimajor axis effective radius (R_e). The coloured lines are the best-fit lines passing through the different population of objects as denoted by the legend in the plot. The plot shows that, at similar stellar mass, the pseudo-bulge hosting spirals are bigger in size as compared to classical bulge host spirals. The classical bulge hosting S0 galaxies have a similar mass–size relation as the classical bulge hosting spirals. **Right**: The NUV−r colour–stellar mass diagram for the spirals and S0s in our sample. The two horizontal lines at NUV = 5 and NUV = 4 mark the boundary of the green valley region (Salim 2014) which separates passive red sequence lying above the green valley from the star-forming galaxy sequence which lies below this region. The plot shows that pseudo-bulge hosting spirals are mainly star forming. Classical bulge hosting spirals mainly populate the passive sequence and green valley region just like the classical bulge hosting S0 galaxies. The distribution of galaxies on both panels suggests that classical bulge hosting spirals are the progenitors of classical bulge hosting S0 galaxies.

Fig3. Ms vs re, Ms vs color
- PB SpiralはCB Spiralより大きい
- PB Spiralは青い（星形成中）がCB Spiralは中間～赤い（沈静中）。
- CB S0 と CB Spiral の分布は似ている。
- → CB Spiralのdisk SFが沈静化してCB S0が生まれる？