An Iceberg Scenario for Late-Type Spiral Galaxy Bulges

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Abstract. Fitting exponential profiles to the bulges of the early-type spiral galaxies from de Jong & van der Kruit (1994) under-estimates their sizes at the 2 – 3 $\sigma$ significance level. Allowing for the range of structural shapes which these bulges possess – through fitting an $r^{1/n}$ profile – the mean effective bulge radius to disk scale-length ratio, $r_e/h$, is larger for the early-type spirals than the late-type spirals at the 1.5 – 2 $\sigma$ level in the optical passbands, and only the 1$\sigma$ level in the K-band. The bulge-to-disk size ratio is therefore not a useful parameter for determining morphological type in spirals. However, the central galaxy (bulge+disk) surface brightness minus the central disk surface brightness is significantly (> 3 $\sigma$) brighter for the early-type spirals than the late-type spirals. Similarly, the ‘normalised’ radius at which the bulge and disk light contribute equally is significantly larger for the early-type spirals, and we propose these parameters to help quantify the Hubble sequence for spirals.

If the mean bulge-to-disk size ratio is indeed the same for early- and late-type spirals, it implies that the bulges of late-type spirals must be relatively submerged in the disk when compared to the bulges of early-type spirals.

The surface photometry data from a volume-limited sample of 86 low-inclination disk galaxies (de Jong & van der Kruit 1994) has been re-analysed to explore the presence and implications of varying bulge profile shapes. A seeing convolved Sersic $r^{1/n}$ model was fitted to the bulge while a seeing convolved exponential profile was simultaneously fitted to the disk of each galaxy.

The light profiles from the bulges of the early-type spiral galaxies (Sa, Sb) are not exponential, but have shape parameters $n > 1$. Use of the exponential model was found to significantly under-estimate the effective radius of these bulges. Consequently, for the early-type spiral galaxies, allowing for the observed range of structural profile shapes results in a mean ratio for the bulge effective radius ($r_e$) to disk scale-length ($h$) that is significantly (2 – 3 $\sigma$) larger than the ratio obtained by fitting exponential bulge profile models. Subsequently, this affects estimates of the difference between the mean $r_e/h$ ratio for the early- and late-type spiral galaxies, and estimates of this ratio along the Hubble sequence of spiral galaxies. For example, forcing an exponential bulge model to the K-band data resulted in a mean $r_e/h$ ratio for the early-type spirals that was statistically smaller(!) (at the 98% significance level) than the mean $r_e/h$ ratio for the late-type spirals (Graham & Prieto 1999). Similarly, in the optical passbands this ratio was shown to be smaller for the early-type spiral galaxies than the late-type spiral galaxies – a result which appears to contradict the classical picture from the Hubble sequence for spirals. However, allowing for the structural inhomology
of the bulges – through fitting an $r^{1/n}$ bulge model – the mean $r_e/h$ ratio for the early-type spirals is found to be larger than that of the late-type spirals. Although, the difference is not as significant as one may have thought, at the 1.5 – 2 $\sigma$ level in the $B$, $R$ and $I$ bands and only the 1 $\sigma$ level in the $K$-band.

Despite this, the radius at which the bulge and disk light contribute equally (after accounting for intrinsically different galaxy sizes), and the difference between the total central surface brightness of the galaxy and the central disk surface brightness is significantly ($> 3 \sigma$ in all bands) larger in the early-type spirals than in the late-type spirals. Such parameters also provide a quantitative measure to the Hubble sequence which was founded on qualitative criteria. Taken together, the above results imply that the bulges of late-type spiral galaxies are somewhat 'submerged' in comparison to the bulges of the early-type spirals. That is, the relative bulge-to-disk stellar density in late-type spirals must be lower than that in early-type spirals, while the relative size of the bulge is roughly the same. This gives rise to what we tentatively refer to as an 'iceberg-like' scenario for the bulges of late-type spirals (see Fig. 1).

References