Galaxies in 3D across the Universe
Proceedings IAU Symposium No. 309, 2014
B. L. Ziegler, F. Combes, H. Dannerbauer, M. Verdugo, eds.

doi:10.1017/S1743921314010503

Using 3D Spectroscopy to Probe the Orbital Structure of Composite Bulges

Peter Erwin[1,2], Roberto Saglia, Jens Thomas[1,2], Maximilian Fabricius[1,2], Ralf Bender[1,2], Stephanie Rusli[1,2], Nina Nowak[3], John E. Beckman[4] and Juan Carlos Vega Beltrán[4]

[1]Max-Planck-Insitut für extraterrestrische Physik, Giessenbachstr., 85748 Garching, Germany
[2]Universitäts-Sternwarte München, Scheinerstrasse 1, 81679 München, Germany
[3]Stockholm University, Department of Astronomy, Oskar Klein Centre, SE-10691 Stockholm, Sweden
[4]Instituto de Astrofísica de Canarias, C/ Via Láctea s/n, 38200 La Laguna, Tenerife, Spain

Abstract. Detailed imaging and spectroscopic analysis of the centers of nearby S0 and spiral galaxies shows the existence of "composite bulges", where both classical bulges and disky pseudobulges coexist in the same galaxy. As part of a search for supermassive black holes in nearby galaxy nuclei, we obtained VLT-SINFONI observations in adaptive-optics mode of several of these galaxies. Schwarzschild dynamical modeling enables us to disentangle the stellar orbital structure of the different central components, and to distinguish the differing contributions of kinematically hot (classical bulge) and kinematically cool (pseudobulge) components in the same galaxy.

Keywords. galaxies: elliptical and lenticular, cD - galaxies: evolution - galaxies: formation

1. Introduction

Although the standard picture of the stellar structure of disk galaxies combines a disk and a central bulge, recent studies have suggested a dichotomy between galaxies which host *classical* bulges – round, kinematically hot, and presumed to originate from violent mergers at high redshift – and those with *pseudobulges*, where the central excess stellar light is from a flattened, kinematically cool structure, presumed to originate from some long-term, internal ("secular") processes.

We have recently found evidence that some disk galaxies can harbor both a classical bulge *and* a disky pseuduobulge (we use the term "disky pseudobulges" to distinguish them from bar-derived box/peanut structures, which are sometimes also called pseudobulges). Evidence for this includes a combination of highly flattened isophotes, disky substructures (spirals, nuclear rings, nuclear bars), and stellar kinematics dominated by rotation in the disky pseudobulge, and rounder isophotes and stellar kinematics dominated by velocity dispersion in the classical-bulge region; see Nowak *et al.* (2010) and Erwin *et al.* (2014) for details.

As part of our SINFONI Search for Supermassive Black Holes (S^3BH), we observed approximately 30 disk and elliptical galaxies with the SINFONI IFU on the VLT, using natural- or laser-guide-star adaptive optics to obtain 3D K-band spectroscopy of the galaxy centers; our sample includes three well-defined examples of composite-bulge galaxies. We combine the high-resolution stellar kinematics derived from this data with larger-scale, ground-based spectroscopy and *HST* and ground-based imaging to measure SMBH masses via Schwarzschild dynamical modeling (e.g., Nowak *et al.* 2007, 2008, 2010; Rusli *et al.* 2011, 2013).

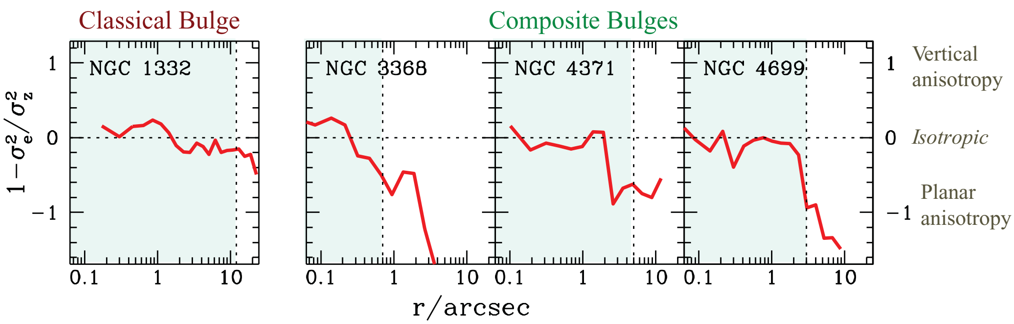

Figure 1. Results of Schwarzschild modeling for classical-bulge S0 galaxy NGC 1332 (Rusli *et al.* 2011, left) and three composite-bulge galaxies, based on VLT-SINFONI AO data. The plots, based on mass-weighted averages of stellar orbits within ±23° of the equatorial plane for each galaxy, show equatorial-vs-vertical stellar anisotropy as a function of radius; the equatorial term combines radial and tangential dispersions: $\sigma_e^2 = (\sigma_R^2 + \sigma_\phi^2)/2$. Vertical dashed lines mark the approximate photometric transition between the classical bulge and the disk (for NGC 1332) or between the classical bulge and the disky pseudobulge (other three galaxies), with the shading indicating the classical-bulge region. For all four galaxies, the classical bulge is dominated by isotropic velocity dispersion, while the disk or disky pseudobulge regions show planar-dominant anisotropy.

As part of the Schwarzschild modeling process, we obtain weighted libraries of stellar orbits for the central galaxy regions; these can be used to explore the relative contributions of ordered (rotational) and random stellar motions within classical and disky pseudobulge regions. Fig. 1 shows part of this analysis, plotting the planar/vertical anisotropy of 3D stellar orbits as a function of radius for an S0 with a purely classical bulge (NGC 1332) and for three composite-bulge galaxies. The anisotropy term measures the relative amounts of "equatorial" dispersion (that is, radial and azimuthal dispersions added in quadrature) versus vertical dispersion (with respect to the equatorial plane). In all four galaxies, the dispersion is approximately isotropic within the classical-bulge region, and shifts to an equatorial-dominant state in the disk outside (for NGC 1332) or in the disky pseudobulge region (for the composite-bulge galaxies). This is additional evidence supporting the argument that what we identify as "classical bulges" in the composite-bulge systems are isotropic, pressure-supported components similar to low-luminosity ellipticals, while the disky pseudobulges have stellar kinematics similar to those of large-scale disks.

Full details of this study are presented in Erwin *et al.* (2014).

References

Erwin, P., Saglia, R. P., Fabricius, M., Thomas, J., Nowak, N., Rusli, S., Bender, R., Vega Beltrán, J. C., & Beckman, J. E., 2014, *MNRAS*, submitted

Nowak, N., Saglia, R. P., Thomas, J., Bender, R., Pannella, M., Gebhardt, K., & Davies, R. I., 2007, *MNRAS*, 379, 909

Nowak, N., Saglia, R. P., Thomas, J., Bender, R., Davies, R. I., & Gebhardt, K., R. I., 2008, *MNRAS*, 391, 1629

Nowak, N., Thomas, J., Erwin, P., Saglia, R. P., Bender, R., & Davies, R. I., 2010, *MNRAS*, 403, 646

Rusli, S. P., Thomas, J., Erwin, P., Saglia, R. P., Nowak, N., & Bender, R., 2011, *MNRAS*, 410, 1223

Rusli, S. P., Thomas, J., Saglia, R. P., Fabricius, M., Erwin, P., Bender, R., Nowak, N., Lee, C. H., Riffeser, A., & Sharp, R., 2013, *AJ*, 146, 45

https://doi.org/10.1017/S1743921314010503 Published online by Cambridge University Press