Spiral Galaxy Formation based on Detailed Spectroscopic Studies

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Galaxy Formation, Durham, UK - July 18-22, 2011
Why Study Spiral Bulges?

![Diagram showing the composition of the universe with a focus on dark energy, dark matter, normal matter, and specific components like gas, stars, dust, and supermassive black holes.](http://www.eso.org/~jiske/mgc/)

- **Dark Energy**: 72%
- **Dark Matter**: 24%
- **Normal Matter**: 4%
  - **Gas**: 91.7%
  - **Stars**: 8.3%
  - **Dust**: 0.008%
  - **Supermassive Black Holes**: 0.01%

*(Graham et al. 2007)*

- **Stars in Discs**: 60%
- **Stars in Bulges**: 27%
- **Stars in Ellipticals**: 10%
- **Stars in Blue Spheroids**: 3%

*(Driver et al. 2007abc)*
**Fundamental Question:** Can the hierarchical $\Lambda$CDM and secular formation scenarios be combined into a single, coherent view of galaxy and bulge formation?
UGC 2124 (Sba)  NGC 7490 (Sbc)  NGC 173 (Sc)  NGC 628 (Sc)

NGC 7495 (SABc)  NGC 7741 (SBcd)  NGC 7610 (Scd)  IC 239 (SABcd)
Radial Spectra: M74 (NGC 628)


\[ r_e = 11.3'' \quad r_d = 70.6'' \]

$r_e = 4.8''$  
$r_d = 18.4''$
Beyond Single Age/Z Estimates: Full Spectral Synthesis

- bound-constrained optimization: best-fit linear non-zero combination of spectral templates

\[ \log_{10}(L_{\lambda}/L_{\odot}) \]

library consists of 70 templates from Bruzual & Charlot 2003 models with full range of age and metallicity

Fit based on bound constrained optimization of a non-zero linear combination of SSP model spectra.

Data

Regions masked from fit


\(<A> = 7.14 \text{ Gyr} \quad <Z> = 0.0110 \quad \chi^2 = 2.47 \quad \lambda(\AA) = 1.0 \quad N7495\)
Population Synthesis Fits for R=0 spectra

Age/Z vs. "mass" for Bulges

Light-Weighted values

Mass-Weighted values

Age/Z vs. "mass" for Spheroids

Ellipticals from Thomas et al. 2005: SSP

Bulges from Morelli et al. 2008: SSP

Bulges from Ganda et al. 2008: SSP

Bulges from Ganda et al. 2008: SFH

Bulges from MacArthur et al. 2009: SFH
Star Formation History as a fn. of Radius

Light-Weighted

Mass-Weighted

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**Comparison With Simulations ($\Lambda$CDM+SPH)**

**morphology:**
- Sérsic $n \sim 1.5$
- $r_e/r_h \sim 0.1$

**kinematics:**
- $\sigma_0 \sim 150$ km/s, decreasing profile

**SFHs:**
- bulges $\rightarrow$ old
- disks $\rightarrow$ extended SFH

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Scannapieco, White, Springel, & Tissera, 2011, MNRAS

Age/Z Gradients
MacArthur etal. 2009
Resolving Milky Way Outlier Conundrum

Predicting NIR Colours from Synthesis Fits

With moderate spectral resolution, good $\lambda$ coverage, and high S/N/Å (>50), measurement of light- and mass-weighted ages, metallicities, & dust for late-type galaxies is feasible with full spectrum fitting.

Details are critical: calibration (flux & $\lambda$), resolution, velocity dispersion, & rotation must be treated self-consistently (within data & models).

Bulges follow similar trends to ellipticals in age/Z at a given mass (also true at $0.1 < z < 1$; see MacArthur et al. 2008, ApJ 680, 70).

All bulges are dominated by OLD stellar pops (>~80% by mass).

Secular contribution increases in weight with decreasing $\sigma_0$.

Spheroid formation dominated by processes common to all spheroids, whether or not they currently reside in disks.

Dominant formation mechanism occurred on shorter timescales for more massive spheroids.

Spectroscopic vs. broadband information can help constrain SPS models and evaluate simulation (N-body+SPH) results.