

## **Structural Decompositions in Large Galaxy Surveys**

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"Deconstructing Galaxies: Structure and Morphology in the Era of Large Surveys" Santiago, Chile, November 18-22, 2013







- Bulges and disks in hierarchical galaxy formation
- Rationale for quantitative morphology
- Performing decompositions in large surveys
- Results
- Future Work



## Galaxy Morphology Through Hierarchical Mass Assembly



# A Changing Theoretical Picture: Disks in Merger Remnants





### **Rationale for Quantitative Morphology**

#### **Pros:**

- Can be automated for large surveys
- Reproducible in its successes and its failures
- Can be linked to numerical simulations

#### **Caveats:**

- Analysis tools should not be treated as black boxes
- Systematics dominate (sky, sky, and sky)
- Catalogs should not be "over-interpreted"



## **Application to Large Surveys**

- Large statistical samples are required for comparison with stochastic, hierarchical galaxy assembly models
- Well-characterized errors and completeness limits
- Control samples can be defined
- The local and distant Universes can be compared
- Unique subsamples can be selected for follow-up studies



## Decompositions (=Parametric Modelling) in Large (Local) Surveys

- Kelvin et al. 2013 GAMA 167,600 galaxies ugrizYJHK
- Lackner and Gunn 2012, 2013 SDSS 71,285 galaxies gri
- Meert et al. 2013, Bernardi et al. 2013 SDSS 260,000 galaxies - r-band
- Vika et al. 2013 SDSS (w/ MEGAMORPH) 4026 galaxies - ugriz



## Sloan Digital Sky Survey Galaxy Sample



- Data Release 7 (DR7)
- 14 < r<sub>p, corr</sub> < 17.77 (z ≈ 0.1)
- N = 1,123,718 galaxies
- Full 2D, PSF-convolved, bulge+disk decompositions in *u*, *g*, *r*, *i* and *z*

(Simard et al. 2011, ApJS, 196, 11; Mendel et al. 2013, ApJS, in press)



## **SDSS Remote Data Mining**



## **SDSS Bulge+Disk Decompositions**

The 2D bulge+disk model is:

 $\Sigma_{obs}(r,\theta) = (\Sigma_{bulge}(r,\theta) + \Sigma_{disk}(r,\theta)) * PSF(r,\theta)$ 

Fitting parameters include:

- Total fluxes and bulge fractions
- Bulge effective radius  $r_e$ , ellipticity e and position angle  $\phi_b$
- Disk scale length  $r_d$ , inclination *i* and position  $\phi_d$
- Bulge Sérsic index *n*<sup>b</sup>



<u>Robust</u>, non-linear optimization performed using Metropolis Algorithm (1953)

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#### **SDSS Bulge+Disk Decompositions**



## **Object Segmentation - SDSS vs SExtractor**





SExtractor (d=0.00005 and not default value of 0.005!)





SDSS

(Simard et al. 2011, ApJS, 196, 11)

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#### **Object Segmentation - Crowding Errors**



press.)

#### **"False" Structural Components**



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## **SDSS Artificial Galaxy Error Maps**

 $Median(\Delta(B/T)_r)$ 



 $\sigma(\Delta(B/T)_r)$ 

0.14 0 0.15 0 0.15 0 0.16 0 2280 2 0.16 0 0.14 0 0.14 0 0.14 0 0.14 0 0.14 0 0.14 0 0.14 0 0.15 0 0.14 0 0.15 0 0.14 0 0.15 0 0.14 0 0.14 0 0.15 0 0.14 0 0.12 0	15         0.17         0.18           31         0.18         179           18         0.16         179           18         0.16         189           19         0.16         306           16         0.16         199           19         0.16         309           19         0.16         119           19         0.16         119           19         0.16         119           19         0.16         119           19         0.16         119           19         0.16         119           19         0.16         119           19         0.16         119           19         0.16         119           19         0.16         119           19         0.16         119           19         0.15         119	0.16 C 1 103 C	0.18           1.18           0.18           0.18           0.18           0.19           0.115           0.115           0.116           0.116           0.116	0.17 113 0.18 198 0.19 301 0.19 301 0.17 421 0.17 499 0.17 472 0.16 0.18 0.17 0.17 472	0.18 41 0.20 95 0.19 134 0.20 162 0.19 178 0.19 175 0.18 192
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m<sub>gal,r,in</sub>

Detailed mapping of systematic and random errors as a function of input galaxy parameters *and* fitting models

Use these maps to "observe" theoretical catalogs



## Impact of Fitting Model

0.1

0.0

0.1

0.0 -0.1

0.0

-0.1

0

14

14

15

15



Fiducial

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 $m_{\rm tot,\,r,\,input}$ 

16

 $m_{\rm tot,\,r,\,input}$ 

 $r_{hl, r, input}$  [arcsec]

17

17

8 10

18

18

Noise 4x

0.1

0.0

0.1

-0.1

0.0

0

14

14

15

15

8 10

r<sub>hl, r, input</sub> [arcsec]

 $\Delta m_{\rm tot,\,r}$ 

 $(r_{out}/r_{in})_{hl}$  - 1

 $(r_{out}/r_{in})_{hl}$  - 1

Res 2x

18

18



0.1

0.0



SDSS - Input: SerExp - Model: Ser

(Meert et al. 2013, MNRAS, 433, 1344)



#### **New SDSS Stellar Masses**

- Mendel et al. 2013, ApJS, in press (arXiv:1310.8304)
- Galaxy, bulge and disk stellar masses for 660,000 galaxies
- Typical statistical errors of ~0.15 dex
- Systematic uncertainty of 60% from choice of synthesis models, extinction law, IMF and stellar evolution details



### **Using Control Samples**



(Ellison et al. 2010, MNRAS, 407, 1514)

5780 SDSS DR4 galaxy pairs with:

 $r_p < 80 \ h_{70}^{-1} \ \text{kpc}$  $\Delta v < 200 \ \text{km/s}$ 

Control sample matched in redshift, stellar mass and local density - four control galaxies per pair galaxy

Bluer bulges at low local density -> higher gas content -> greater response to galaxygalaxy interactions





(Bandara et al. 2013, ApJ, 777, 1)

62 strongly lensed galaxies from Sloan Lens ACS (SLACS) survey

 $0.20 \le z \le 1.20$  (median z = 0.6)

Lens image modelling done with LENSFIT (Peng et al. 2006)





(Bandara et al. 2013, ApJ, 777, 1)

Image reconstructions in the source plane:

- single galaxies
- pairs
- even groups!





(Bandara et al. 2013, ApJ, 777, 1)

Blue points are from GEMS survey (Barden et al. 2005)

Galaxy sizeluminosity relation can be probed at fainter levels than previous surveys using gravitational lensing

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 $n \leq 2.5, 0.4 \leq z < 0.75$ 

 $n \le 2.5, 0.75 \le z \le 1.2$ 



<sup>(</sup>Bandara et al. 2013, ApJ, 777, 1)

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Blue and red arrows are size-luminosity evolution vectors to z = 0 for a bright, massive disk galaxy and a faint, compact disk galaxy respectively (Brooks et al. 2011)

Greyscale is the volume-corrected number density of 660,000 SDSS galaxies

Large SDSS sample puts high-redshift measurements in context to show differential evolution in the data in agreement with the theoretical results

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## Bulges are not spheroids wrapped in disks



Careful, quantitative definition of bulge and spheroid subsamples

171,243 spheroids 70,612 bulges

 $R_{e,pS}\simeq~1.4~R_{e,B}$ 

(also Gadotti 2009)

(Berg et al. 2013, MNRAS, submitted)



#### **Disk Mass-Size versus B/D Ratio**



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#### **Disk Central Density versus B/D Ratio**



# Effect of Environment on Disks and Bulges



(Lackner & Gunn 2013, MNRAS, 428, 2141)

12,500 SDSS galaxies with a classical (n=4) bulge

 $\Delta$ (g-r)<sub>disk</sub> $\sim$ 0.05 in poor groups



#### **Future Work**

- Realistic galaxy images are now being (or will be) produced from the latest numerical simulations, e.g., ILLUSTRIS, EAGLE, FIRE
- These images should be inserted (repeatedly) in real survey data and analyzed *exactly* like real galaxies
- They would thus be subjected to the same random and systematic errors (resolution, sky, segmentation) as a function of local density

