Structural Decompositions in Large Galaxy Surveys

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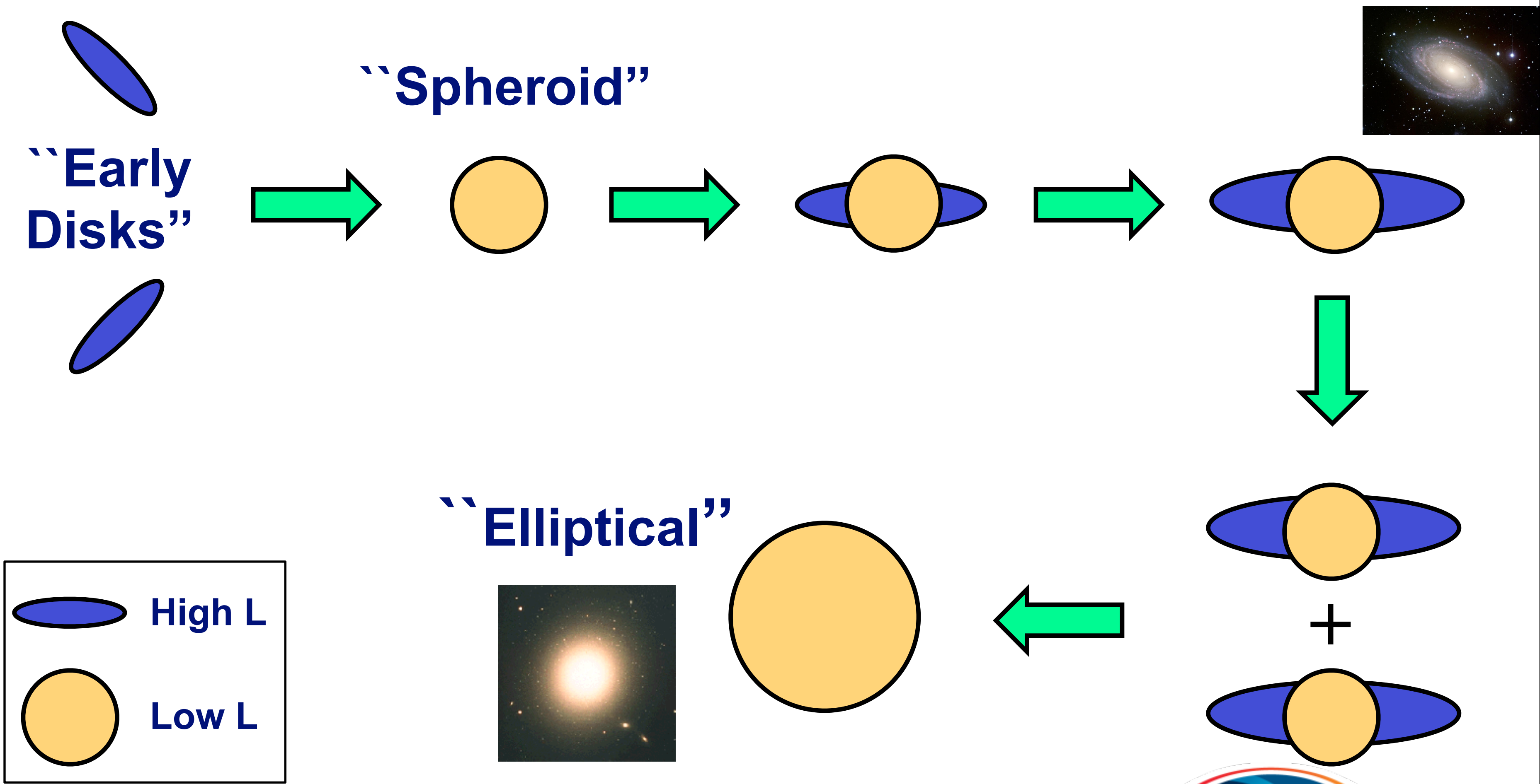
“Deconstructing Galaxies: Structure and Morphology in the Era of Large Surveys”
Santiago, Chile, November 18-22, 2013

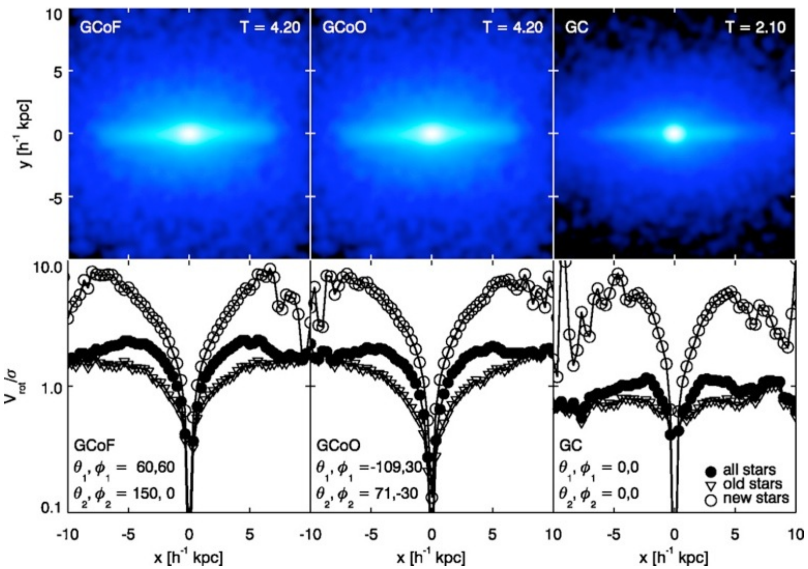
Outline

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

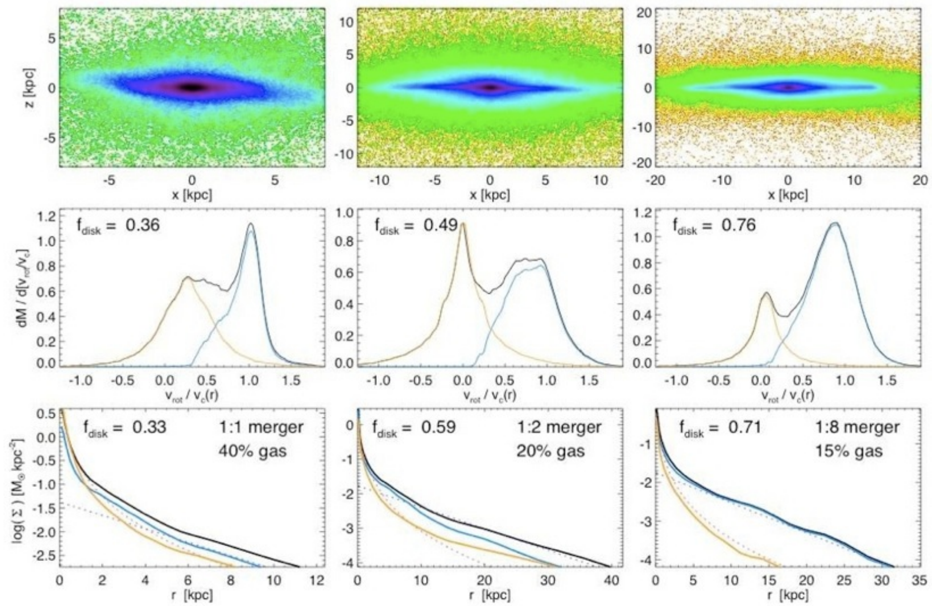
Galaxy Morphology Through Hierarchical Mass Assembly



A Changing Theoretical Picture: Disks in Merger Remnants



Robertson et al. 2006, ApJ, 645, 986



Hopkins et al. 2009, ApJ, 691, 1168

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

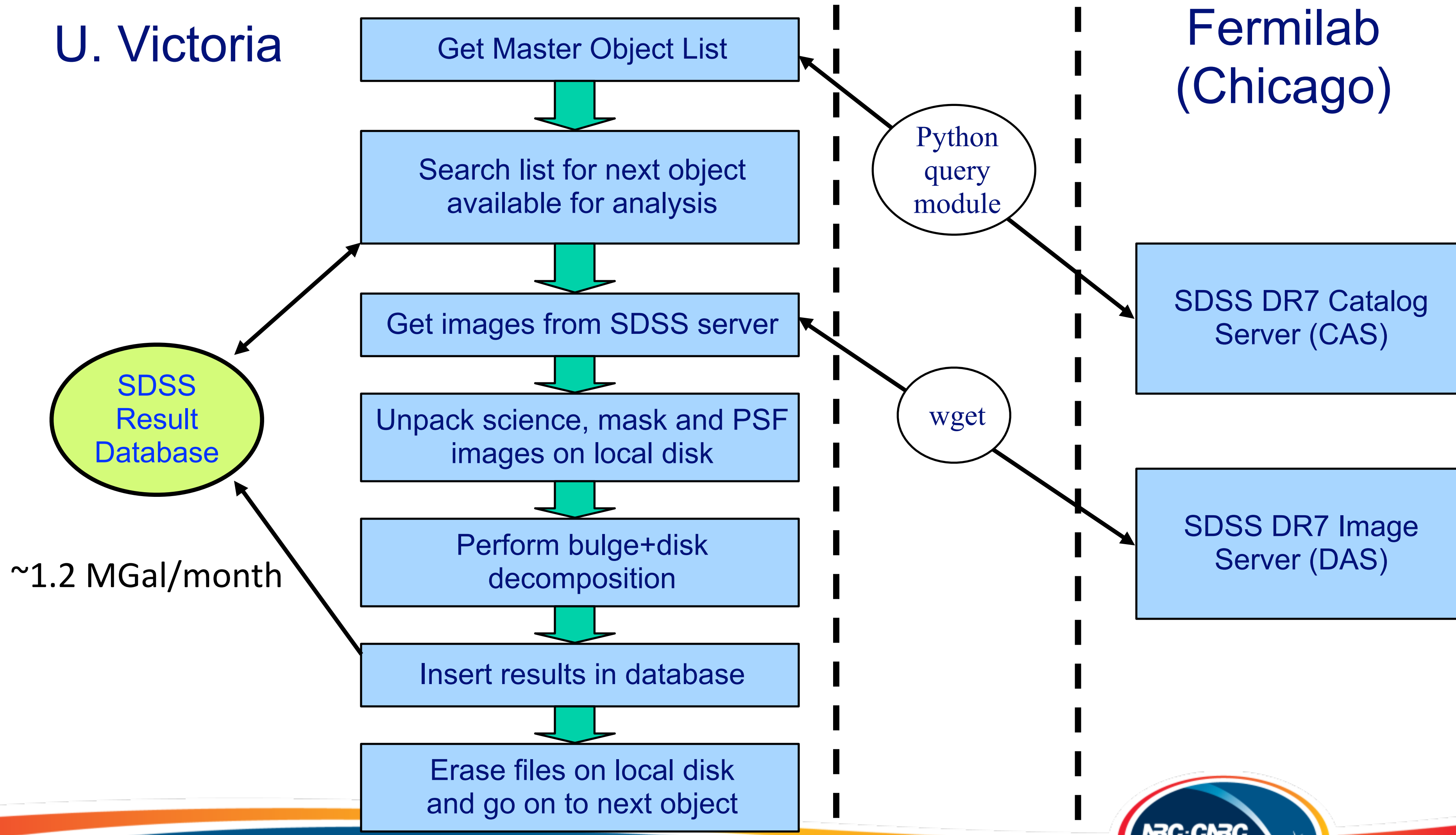
- Kelvin et al. 2013 - GAMA - 167,600 galaxies - ugrizYJHK
- Lackner and Gunn 2012, 2013 - SDSS - 71,285 galaxies - gri
- Meert et al. 2013, Bernardi et al. 2013 - SDSS - 260,000 galaxies - r-band
- Vika et al. 2013 - SDSS (w/ MEGAMORPH) - 4026 galaxies - ugriz

Sloan Digital Sky Survey Galaxy Sample

- Data Release 7 (DR7)
- $14 < r_{p,\ corr} < 17.77$ ($z \approx 0.1$)
- 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:

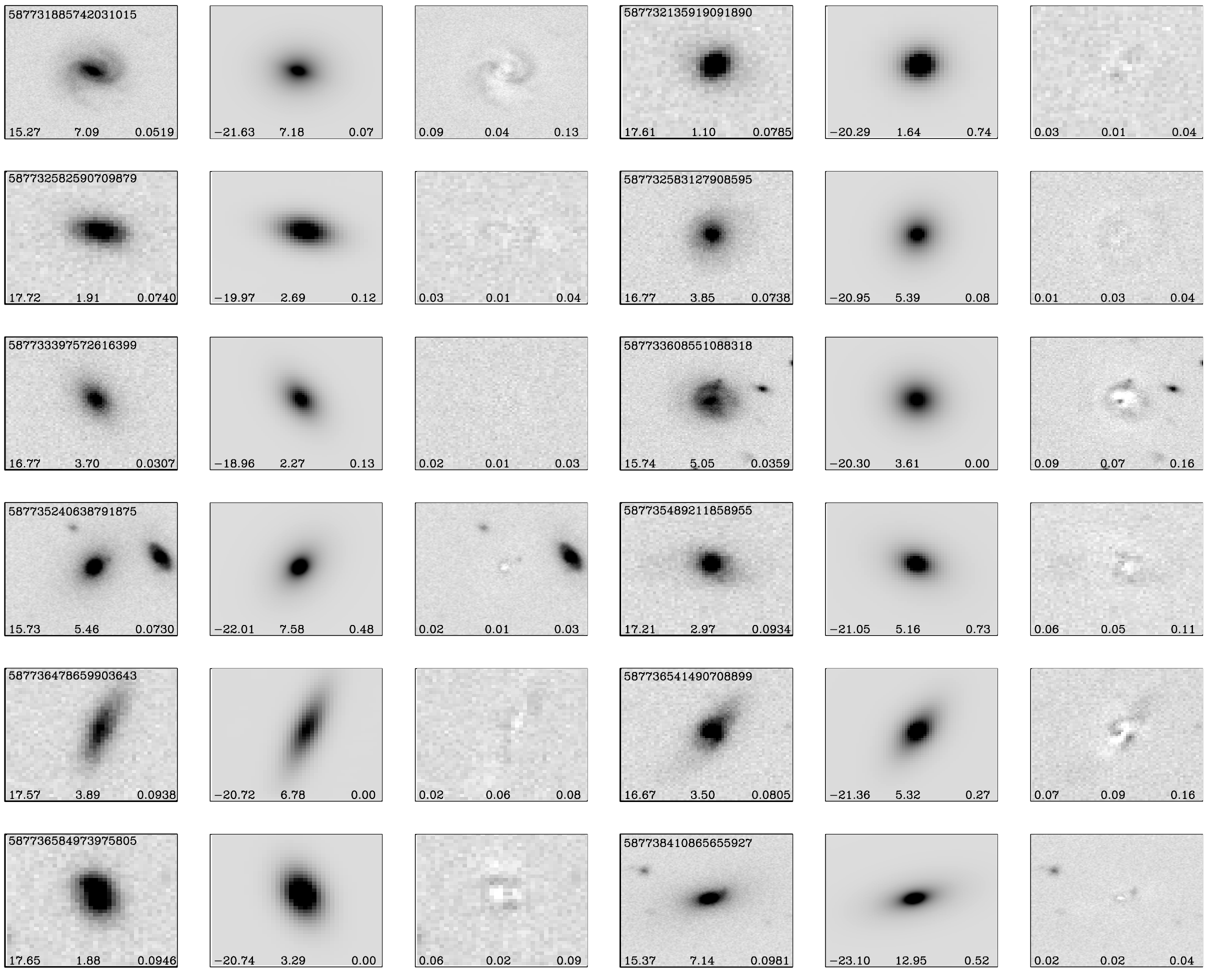
$$\Sigma_{obs}(r,\theta) = (\Sigma_{bulge}(r,\theta) + \Sigma_{disk}(r,\theta)) * PSF(r,\theta)$$

Fitting parameters include:

- Total fluxes and bulge fractions
- Bulge effective radius r_e, ellipticity e and position angle ϕ_b
- Disk scale length r_d, inclination i and position ϕ_d
- Bulge Sérsic index n_b

→ Robust, non-linear optimization performed using Metropolis Algorithm (1953)

SDSS Bulge+Disk Decompositions

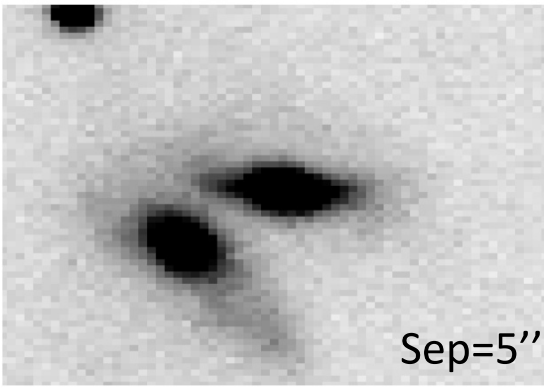


Performed simultaneously in g- and r-band filters

Wealth of residual structures

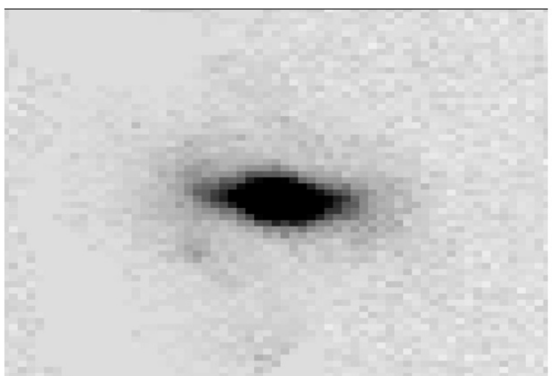
(Simard et al. 2011, ApJS, 196, 11)

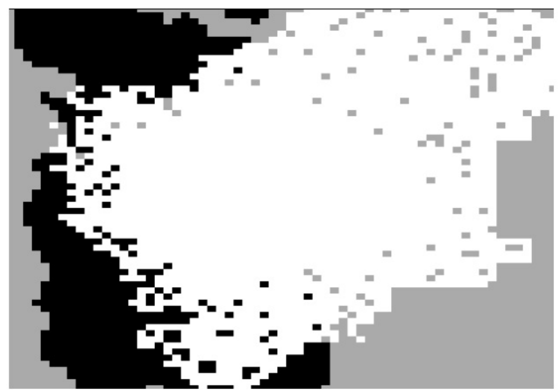
Object Segmentation - SDSS vs SExtractor



SExtractor

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

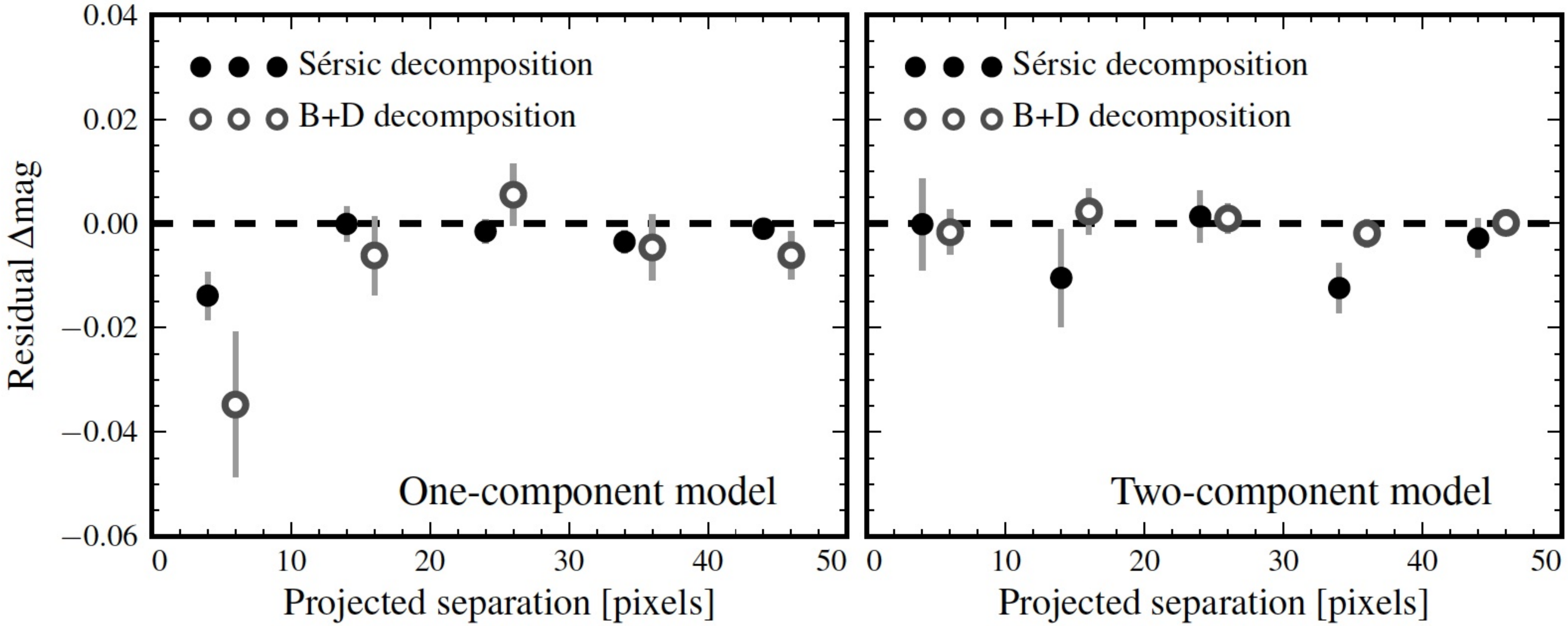




SDSS

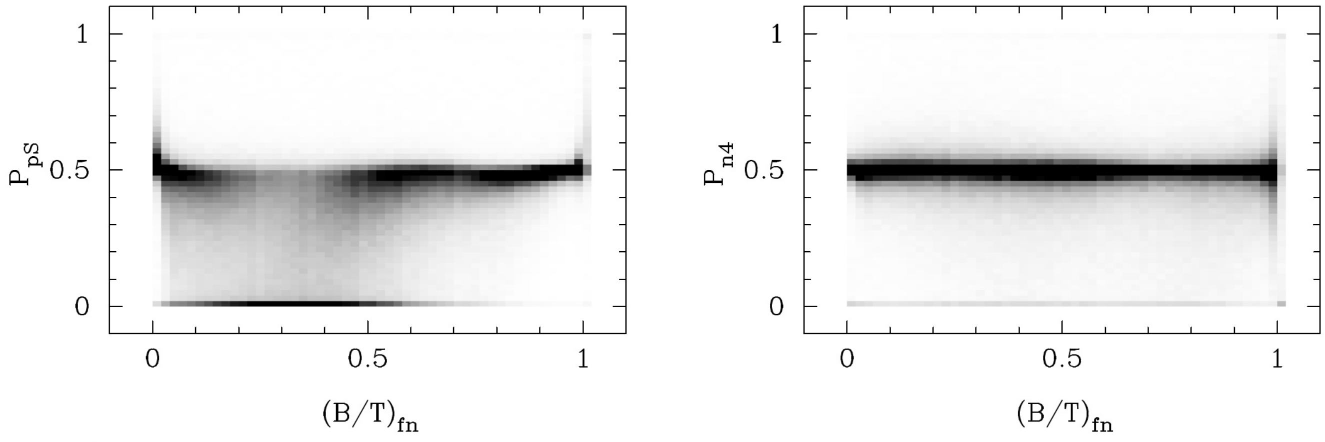
(Simard et al. 2011, ApJS, 196, 11)

Object Segmentation - Crowding Errors



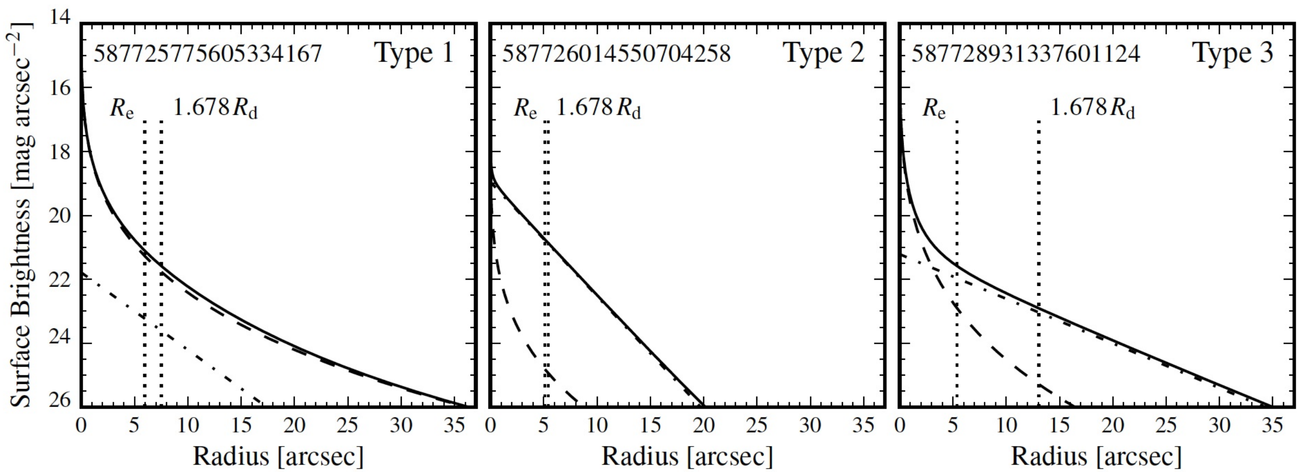
(Mendel et al. 2013, ApJS, in press.)

"False" Structural Components



F-test

(Simard et al. 2011)

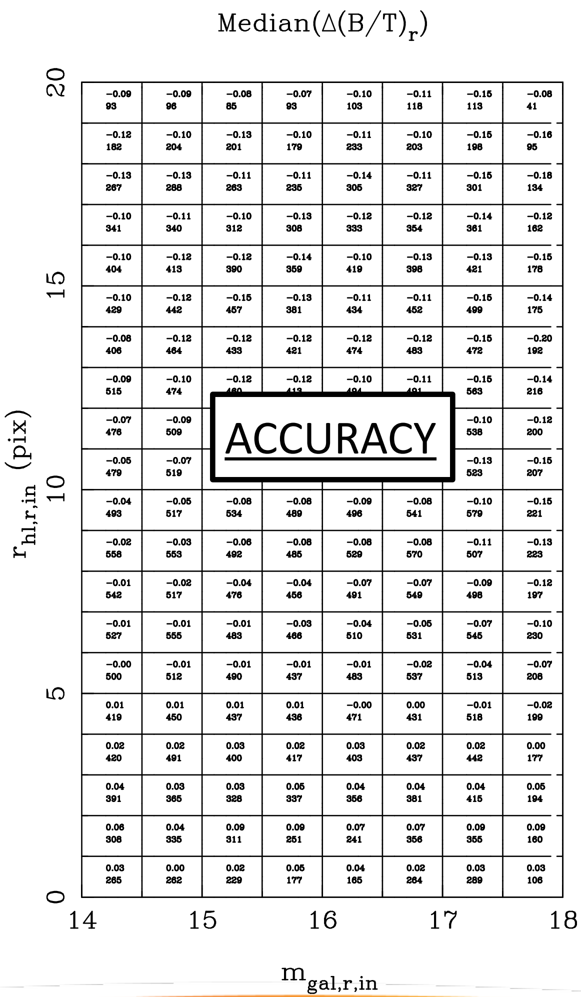


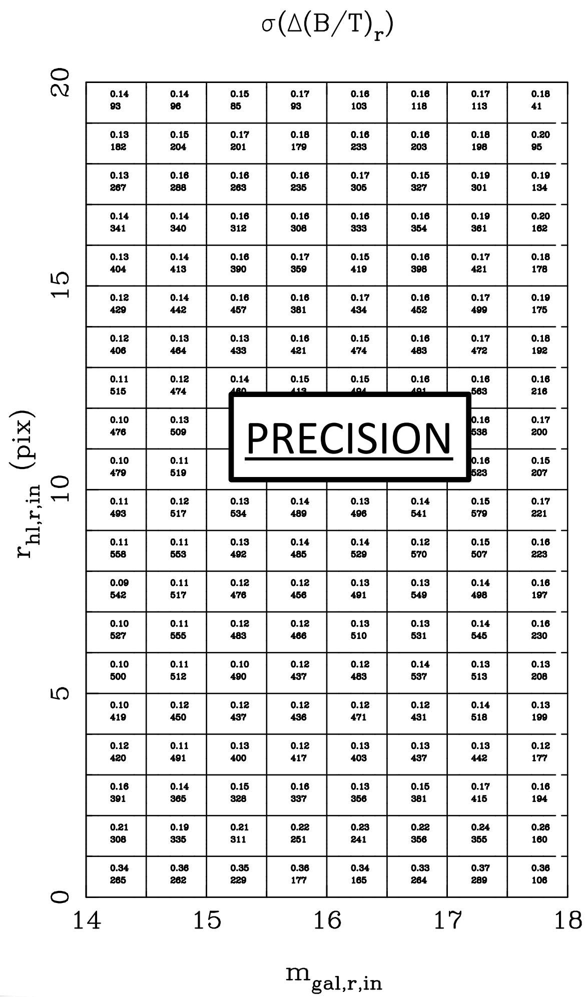
Profile Type

(Mendel et al. 2013;

also Allen et al. 2006 and Kent 1985!)

SDSS Artificial Galaxy Error Maps



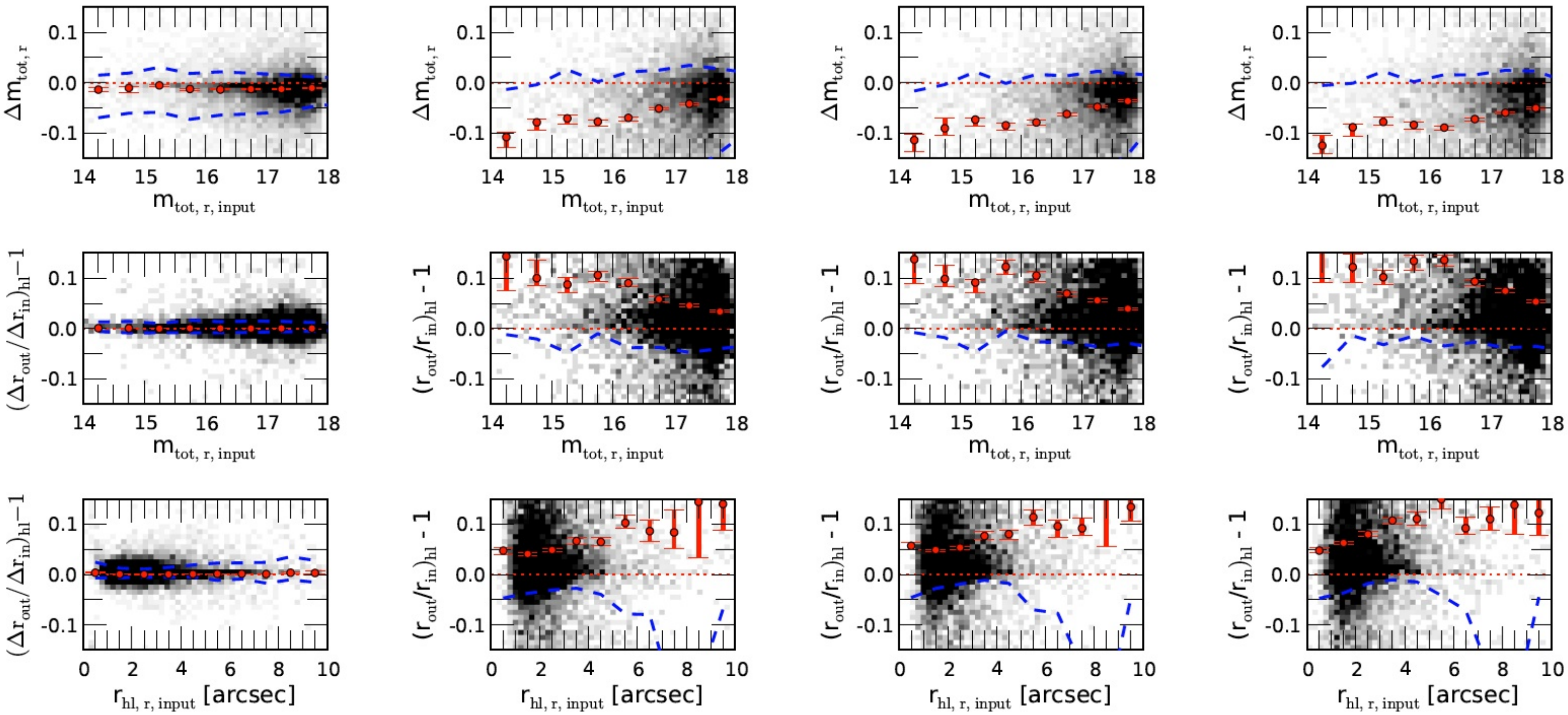


Detailed mapping of systematic and random errors as a function of input galaxy parameters *and* fitting models

Use these maps to “observe” theoretical catalogs

Impact of Fitting Model

No noise | Fiducial | Noise 4x | Res 2x

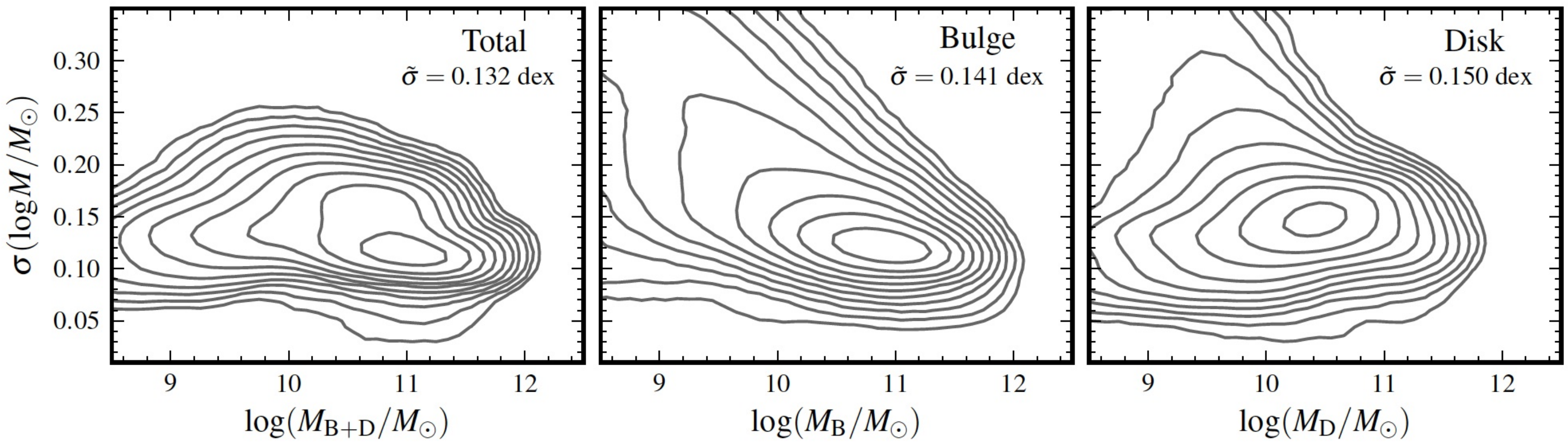


SDSS - Input: SerExp - Model: Ser

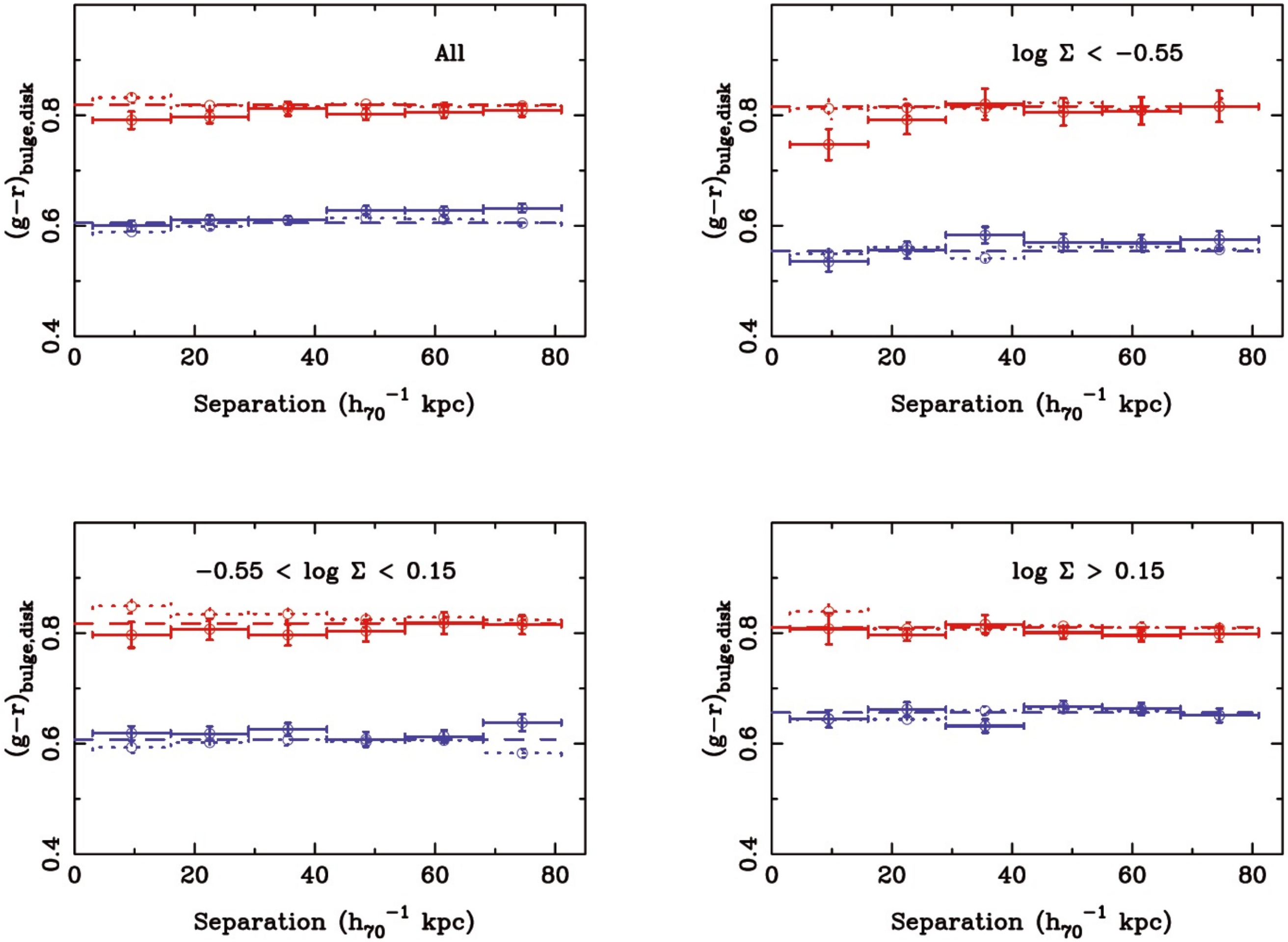
(Meert et al. 2013, MNRAS, 433, 1344)

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:

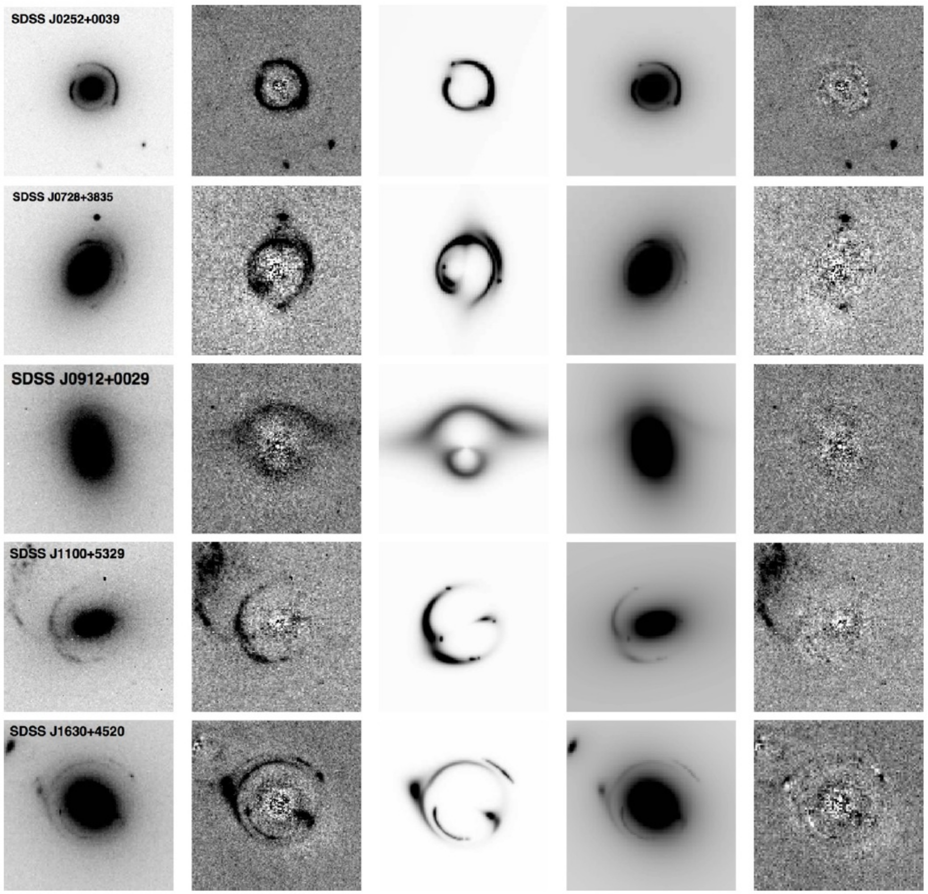
$r_p < 80\ h_{70}^{-1}$ kpc

$\Delta v < 200$ 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 galaxy-galaxy interactions

Putting High Redshift Universe in Context: Size-Luminosity Relation with Gravitational Lensing



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

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

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

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

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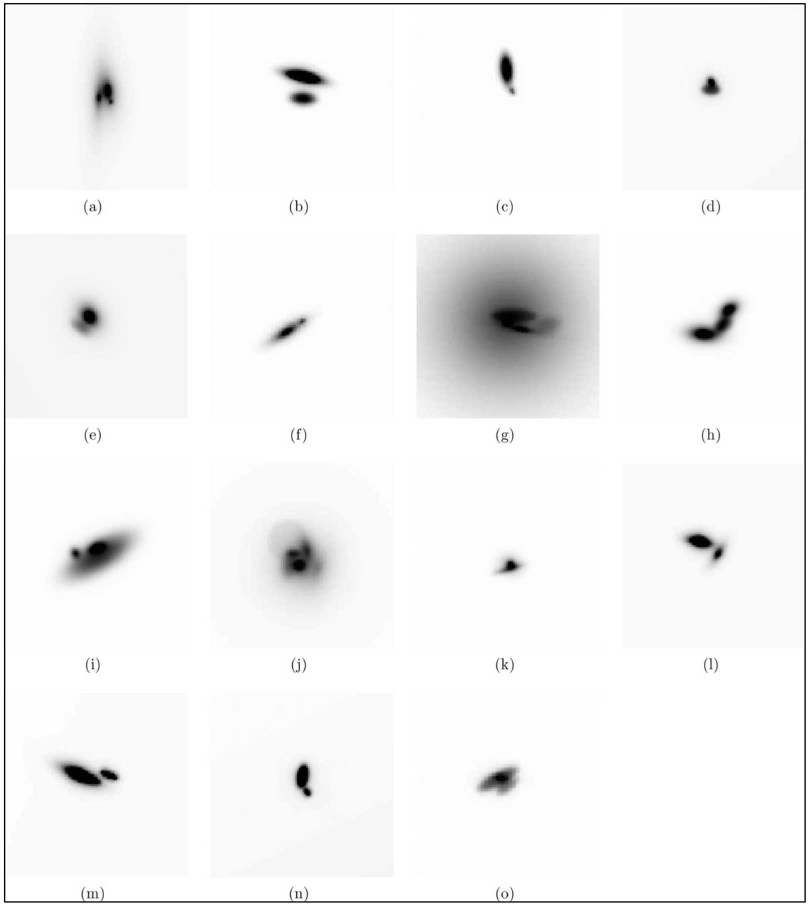

(Bandara et al. 2013, ApJ, 777, 1)

Image reconstructions in the source plane:

- single galaxies
- pairs
- even groups!

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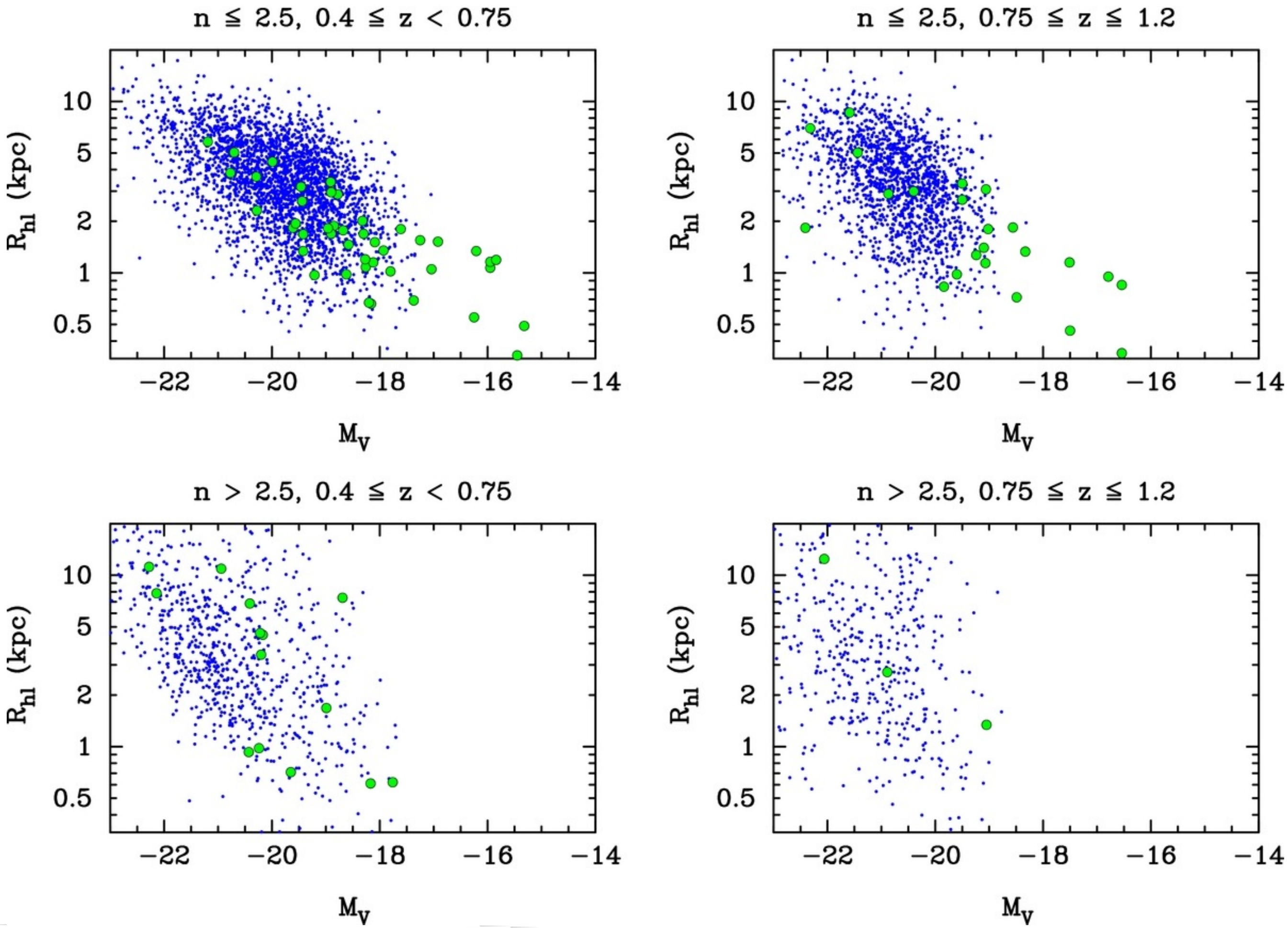
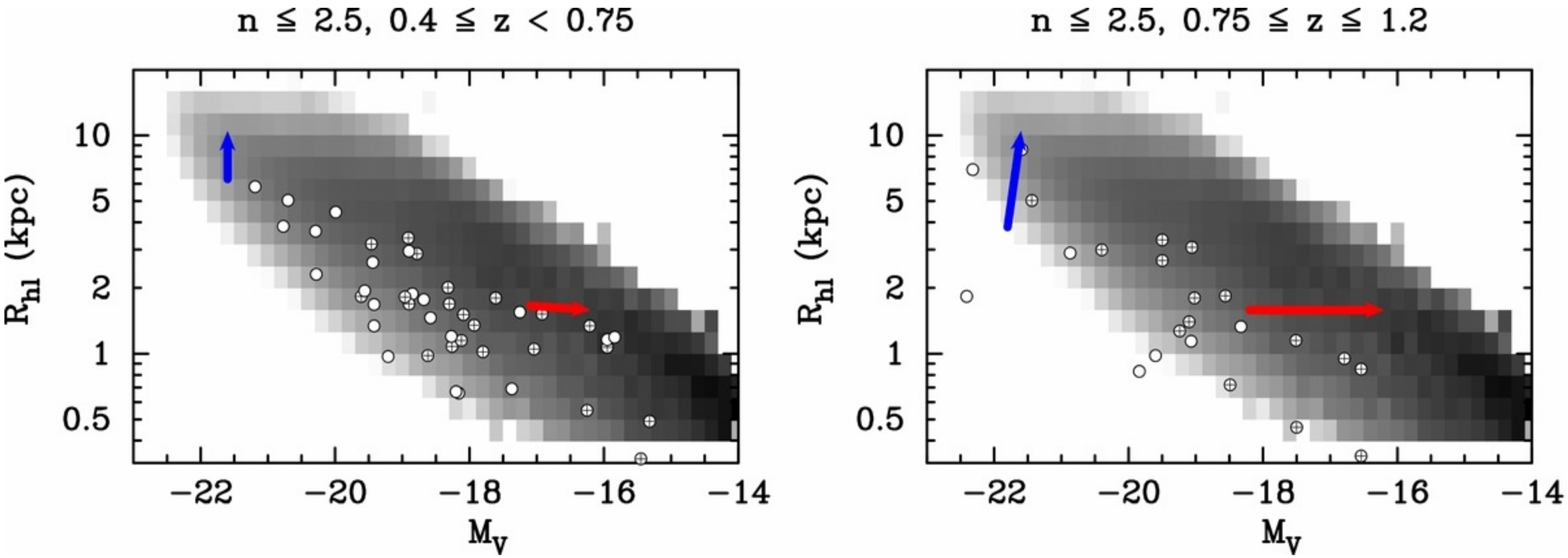


(Bandara et al. 2013, ApJ, 777, 1)

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

Galaxy size-luminosity relation can be probed at fainter levels than previous surveys using gravitational lensing

Putting High Redshift Universe in Context: Size-Luminosity Relation with Gravitational Lensing



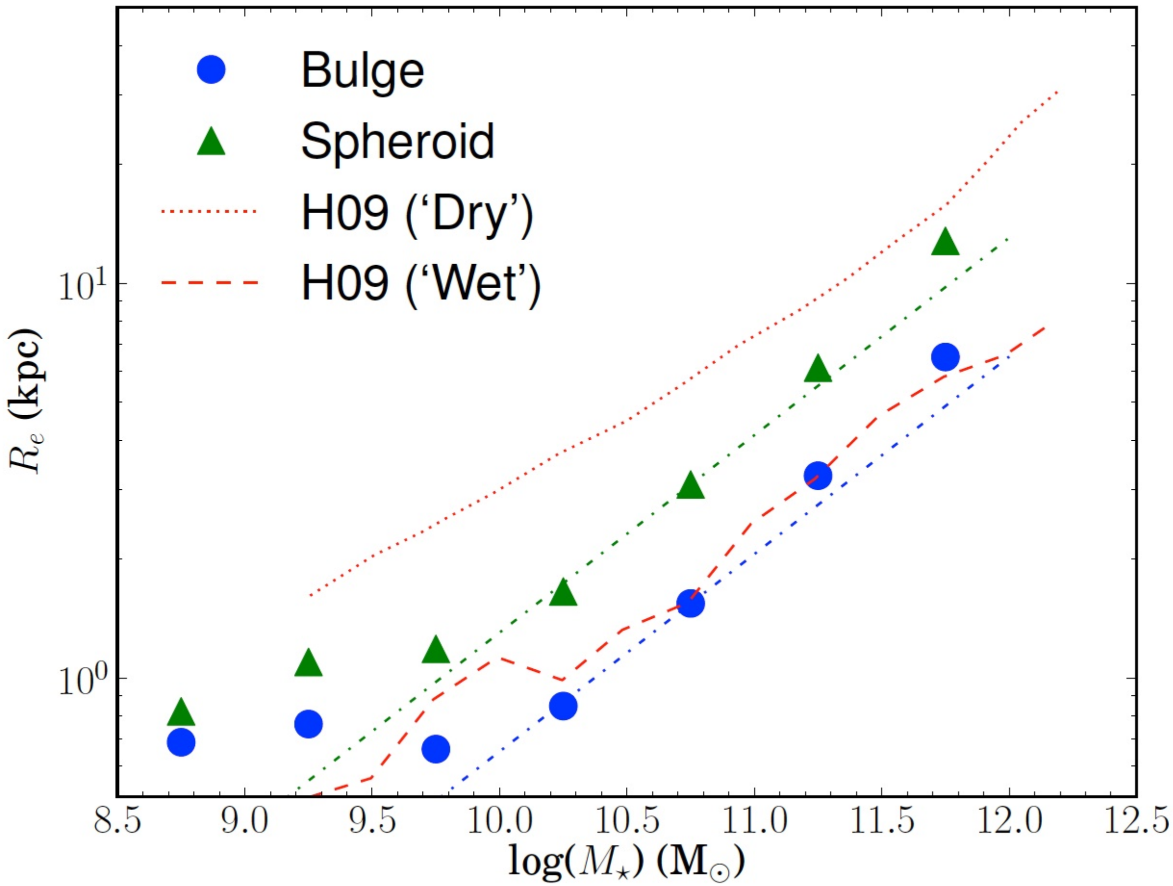
(Bandara et al. 2013, ApJ, 777, 1)

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

Bulges are not spheroids wrapped in disks



Careful, quantitative definition of bulge and spheroid subsamples

171,243 spheroids

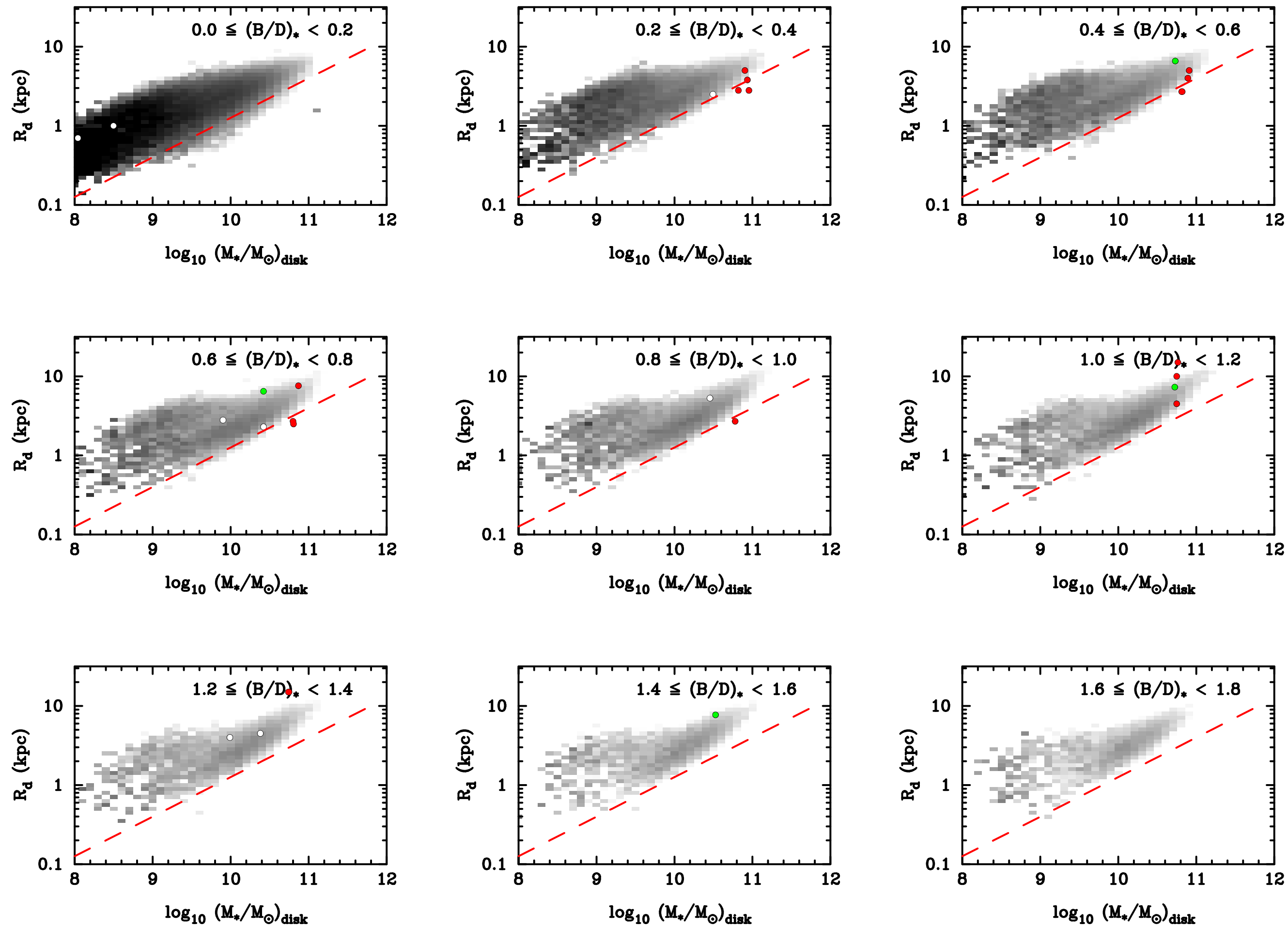
70,612 bulges

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

(also Gadotti 2009)

(Berg et al. 2013, MNRAS, submitted)

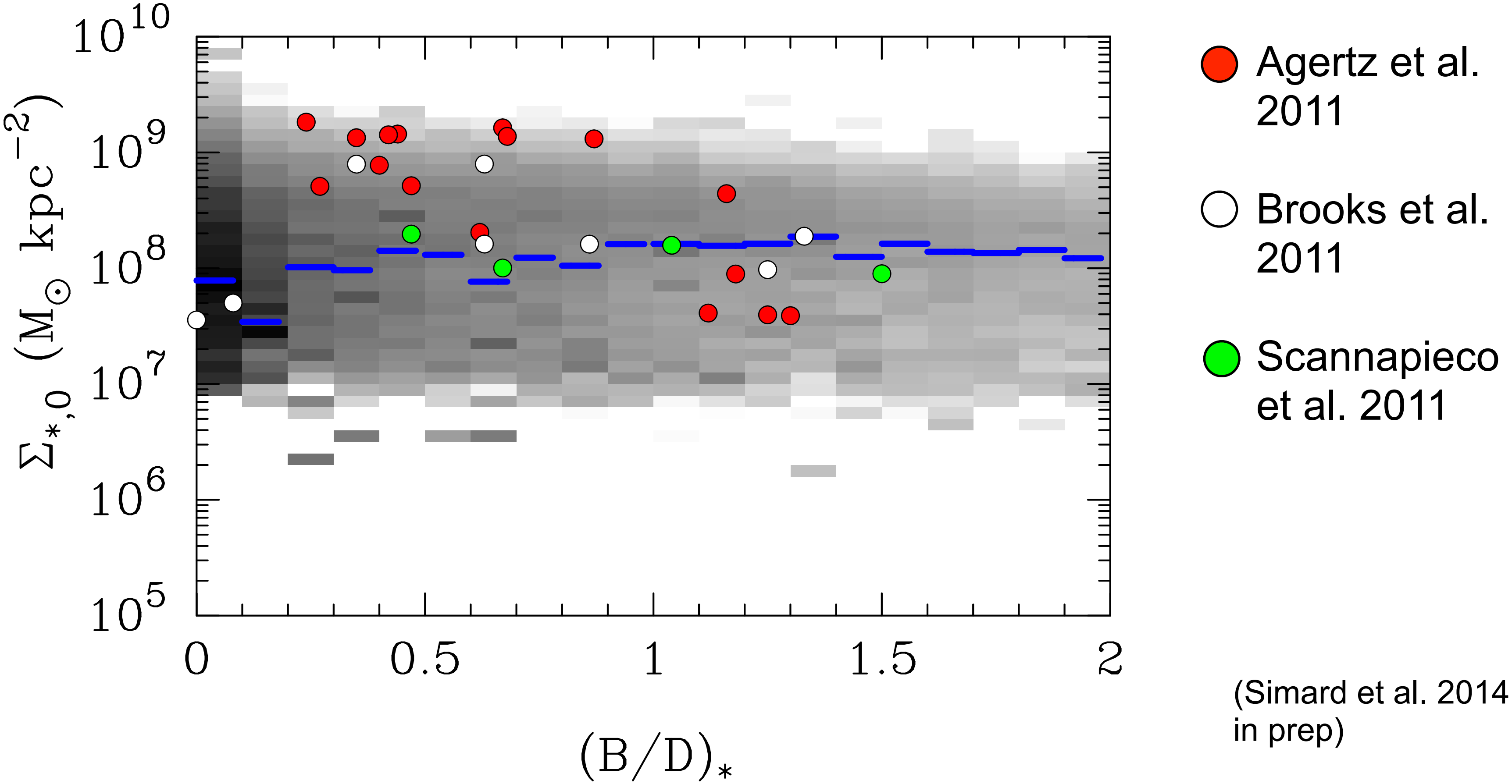
Disk Mass-Size versus B/D Ratio



$10^9\ M_\odot\ kpc^{-2}$

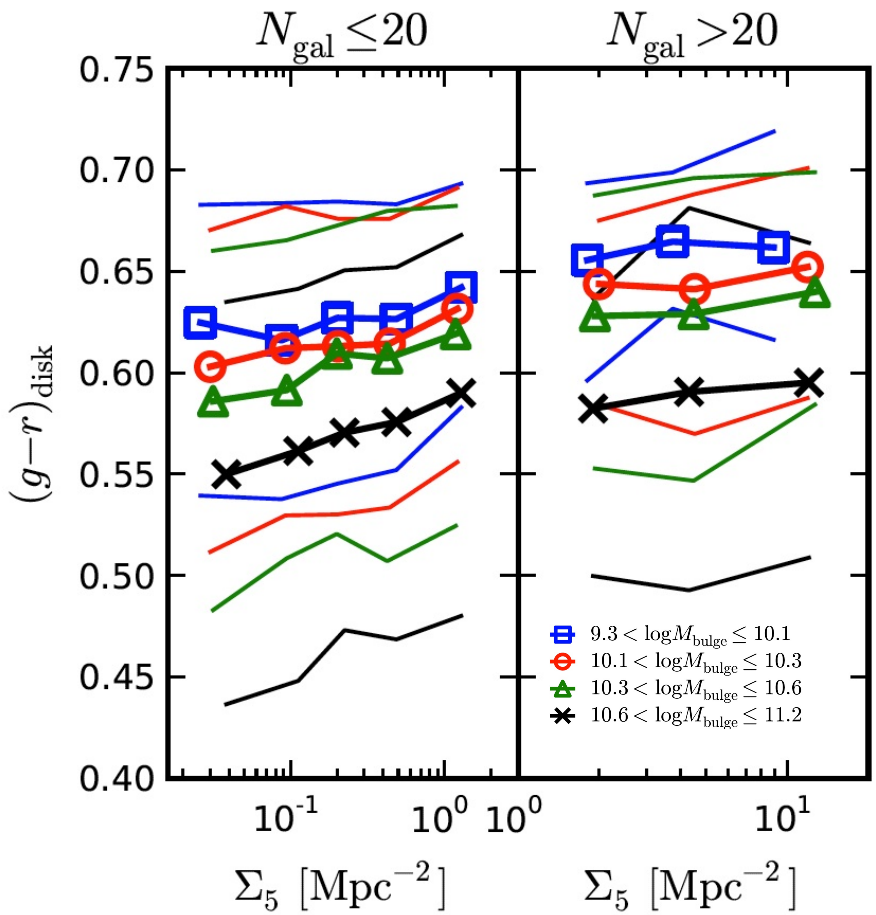
(Simard et al. 2014, in prep)

Disk Central Density versus B/D Ratio



(Simard et al. 2014, in prep)

Effect of Environment on Disks and Bulges



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

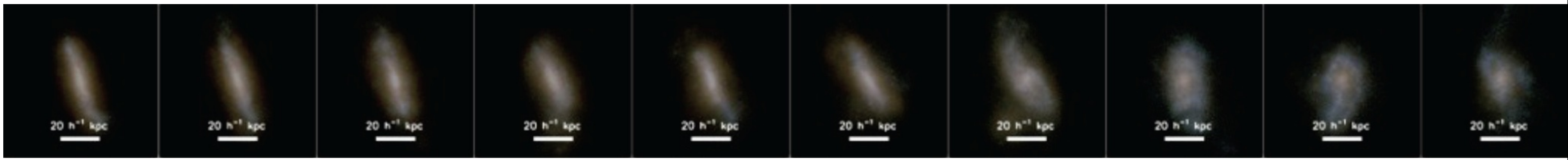
12,500 SDSS galaxies with a classical (n=4) bulge

$\Delta(g\text{-}r)_{disk} \sim 0.05$ 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

z = 0 z = 2



ILLUSTRIS - Torrey P. 2013, “Feeding, Feeding and Fireworks” Conference