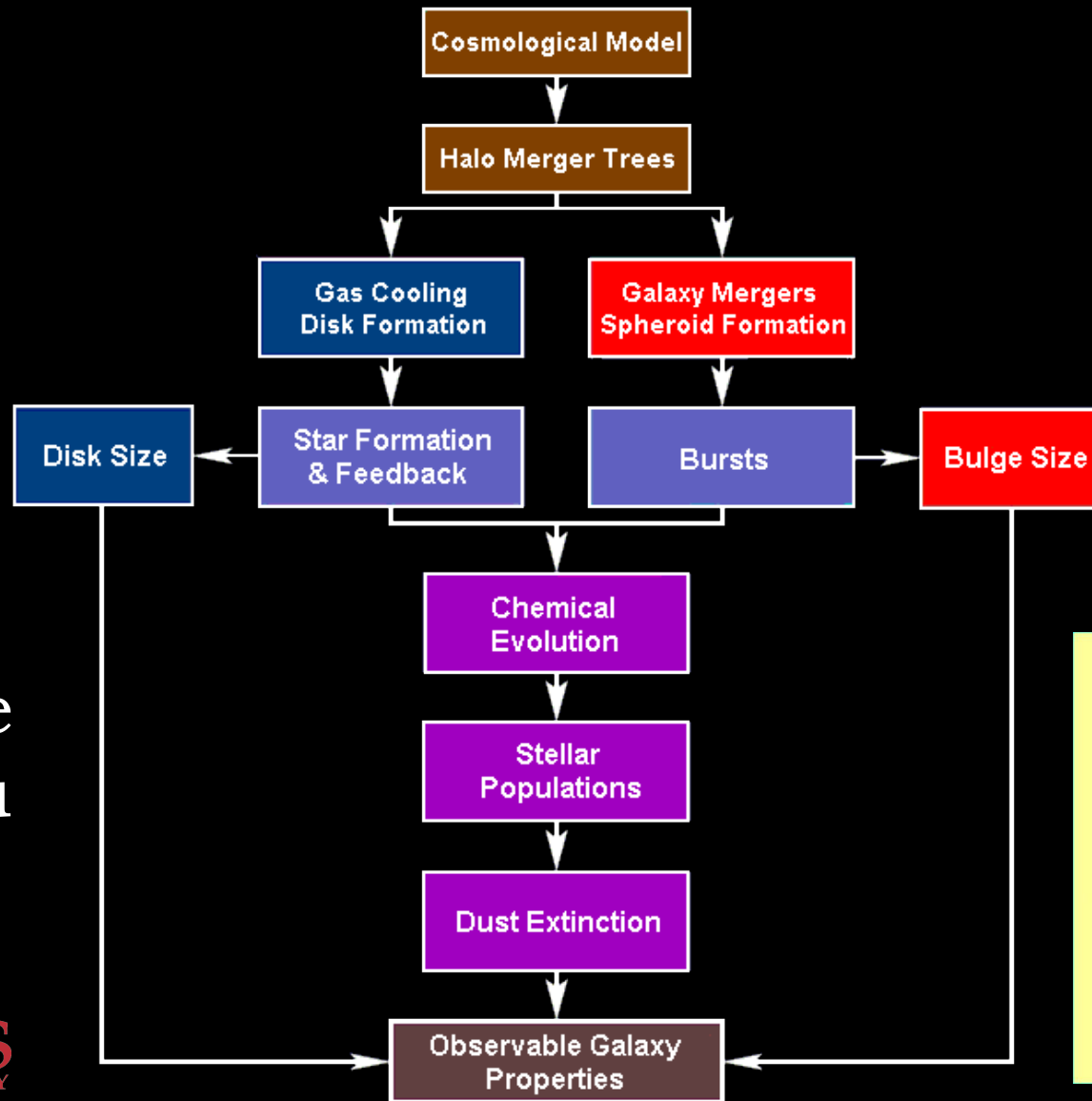


# THE FUTURE OF GALAXY SCALING RELATIONS



Stéphane Courteau



Queen's  
UNIVERSITY



# “Primitive” Galaxy Structural Parameters and Relations

- Size (R), Velocity (V), Luminosity (L), Colour/ Stellar Mass
- Velocity – Luminosity (VL) relation (aka Tully-Fisher Relation, or TFR)
- Size-Luminosity (RL)
- Size-Velocity (RV)
- Luminosity, Velocity/Mass Functions (predicted by  $\Lambda$ CDM)

# Global Galaxy Scaling Relations (based on dynamics)

Tully & Fisher  
(1977)

$$L \sim V^{3.3}$$

for LTGs

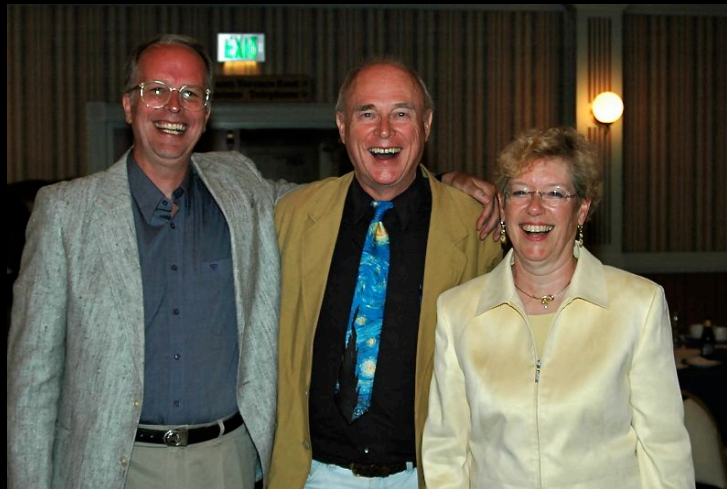


7 Samurai

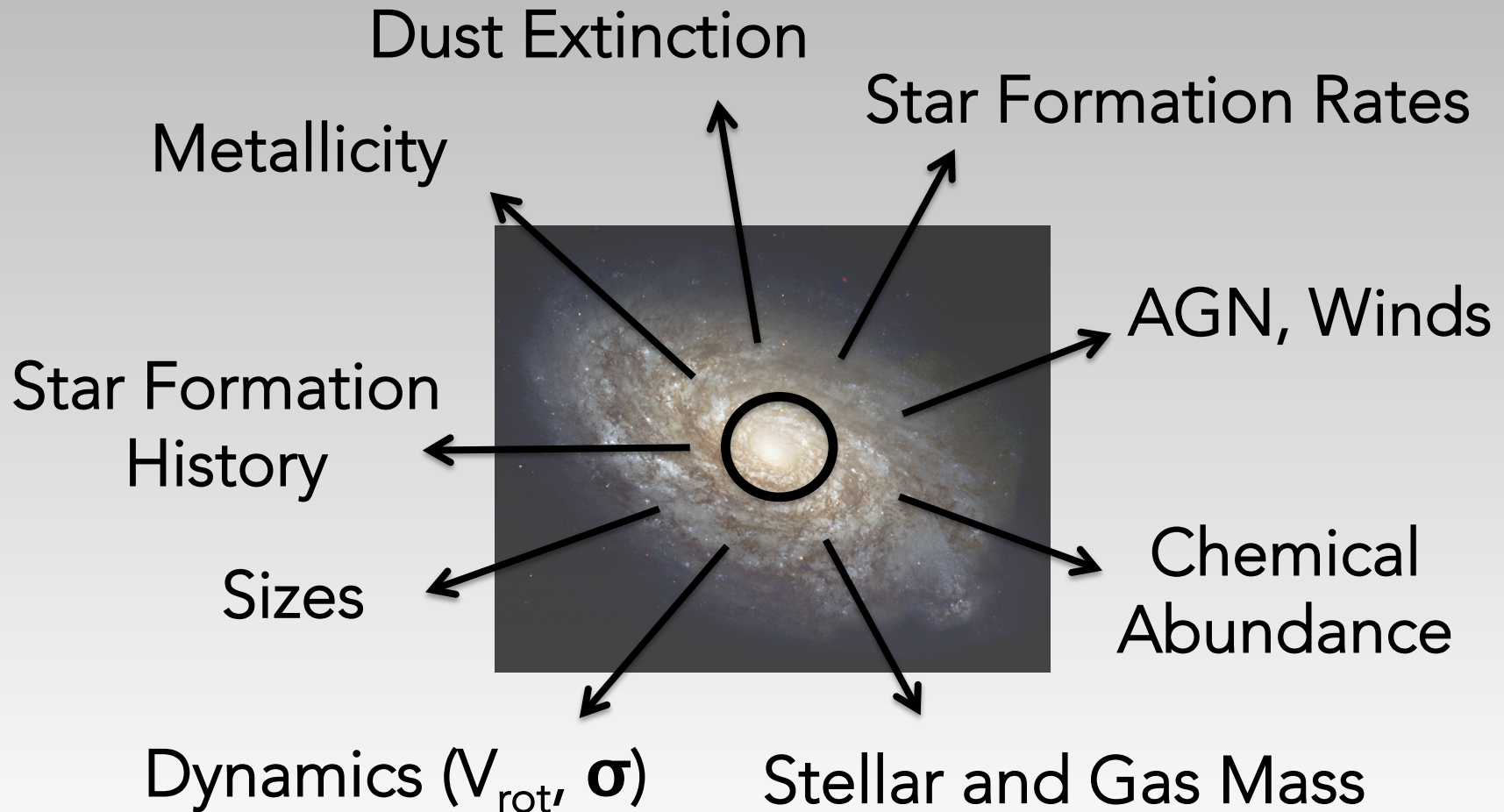
Faber &  
Jackson (1976)

$$L \sim \sigma^4$$

for ETGs



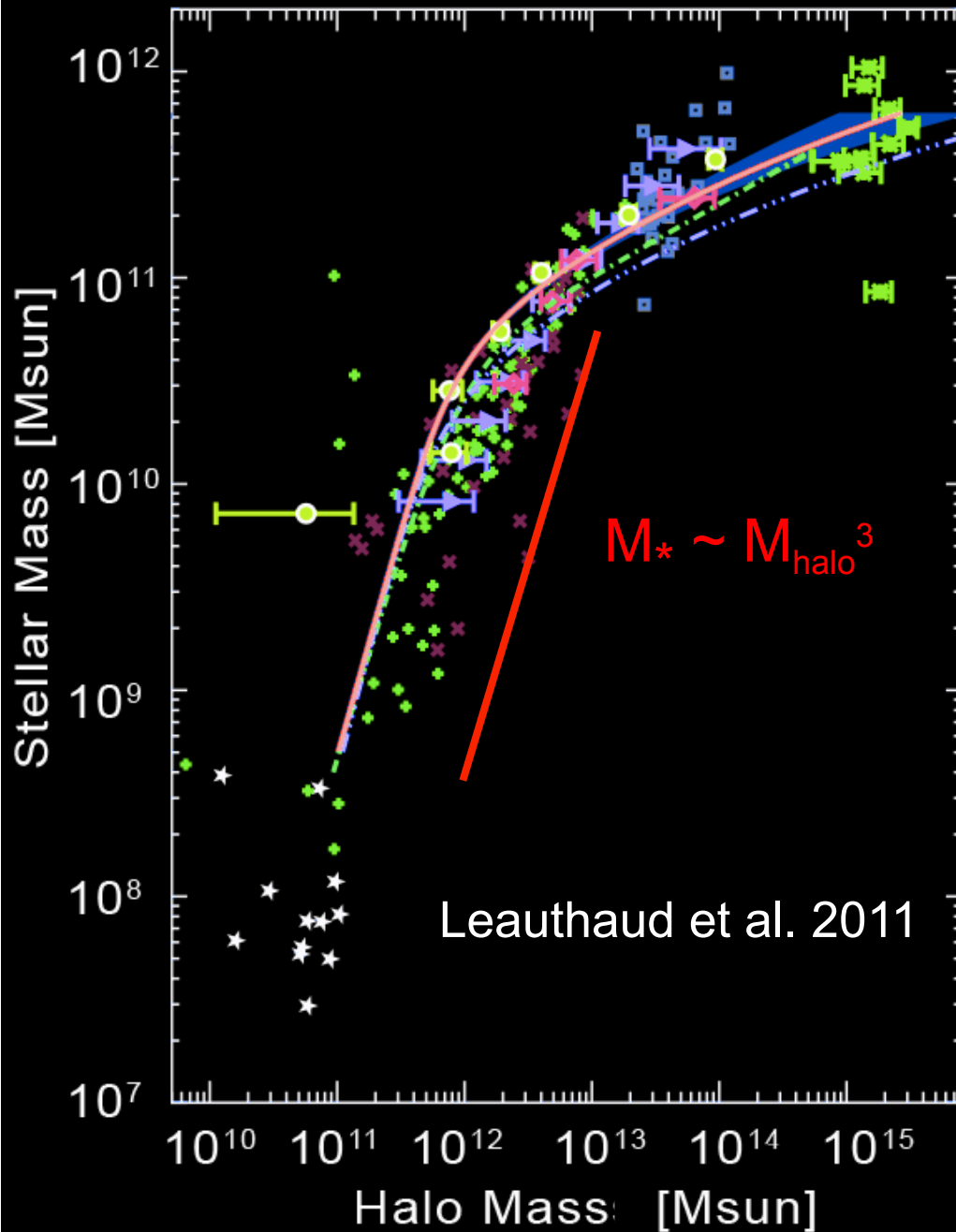
# Modern (SDSS) Structural Parameters and Relations



# Use of (Disk) Scaling Relations

- Originally, TFRs used to determine galaxy distance for cosmic flow studies [Marseille '13]  
e.g. Tully-Fisher 1977; Courteau+93; Strauss & Willick 1995; Giovanelli+97; Masters+06; Springob+09
- TFRs assembled over broad range of types  
e.g. Courteau+03[bars]; Vogt+04[env.]; Courteau+07; Pizagno+07  
for testing galaxy formation models e.g. Dalcanton+97; MMW99; Navarro & Steinmetz+00; Dutton+07; Gnedin+07
- Connecting ET and LT galaxies with their haloes through dynamics / velocity function  
e.g. Dutton+11; Trujillo-Gomez+11; Papastergis+11; Reyes+12
- Evolution of Scaling Relations with time  
[Oxford July'14] Ziegler+02; Barden04; Kassin+07; Miller+13

# Stellar Mass-Halo Mass



4 Methods: consistent results

Halo Matching - rank order  
halos from simulations and  
stellar masses from surveys

Weak Lensing

Satellite Kinematics

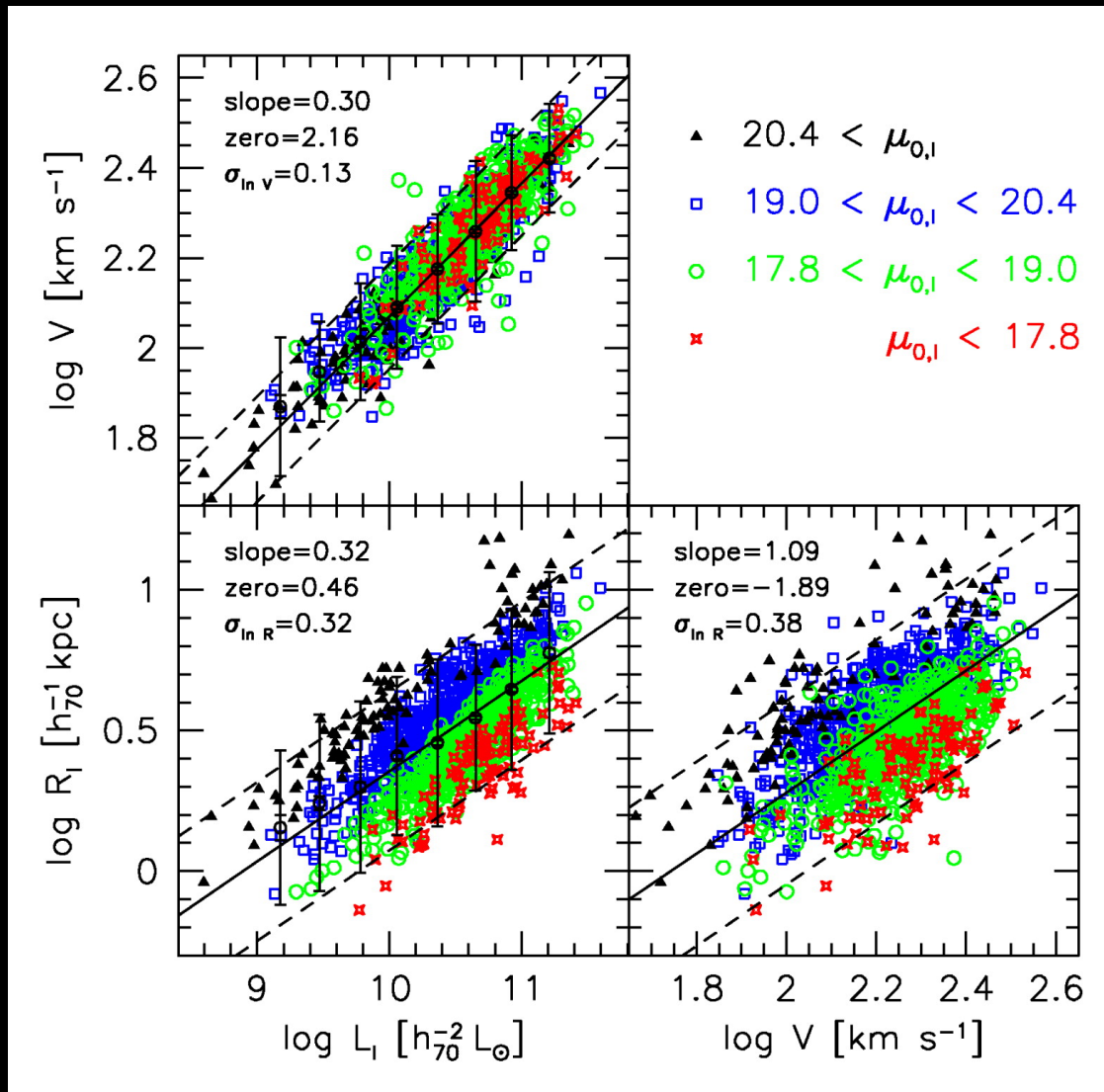
Tully-Fisher (caveats)

- WL, COSMOS this paper,  $z=0.37$
- WL, Mandelbaum *et al.* 2006,  $z=0.1$
- WL, Leauthaud *et al.* 2010,  $z=0.3$
- \* WL, Hoekstra *et al.* 2007,  $z \sim 0.2$
- .-.- AM, Moster *et al.* 2010,  $z=0.1$
- .-.- AM, Behroozi *et al.* 2010,  $z=0.1$
- ◇ SK, Conroy *et al.* 2007,  $z \sim 0.06$
- △ SK, More *et al.* 2010,  $z \sim 0.05$
- ★ TF, Geha *et al.* 2006,  $z=0$
- × TF, Pizagno *et al.* 2006,  $z=0$
- + TF, Springob *et al.* 2005,  $z=0$

# Global Disk Galaxy Scaling Relations

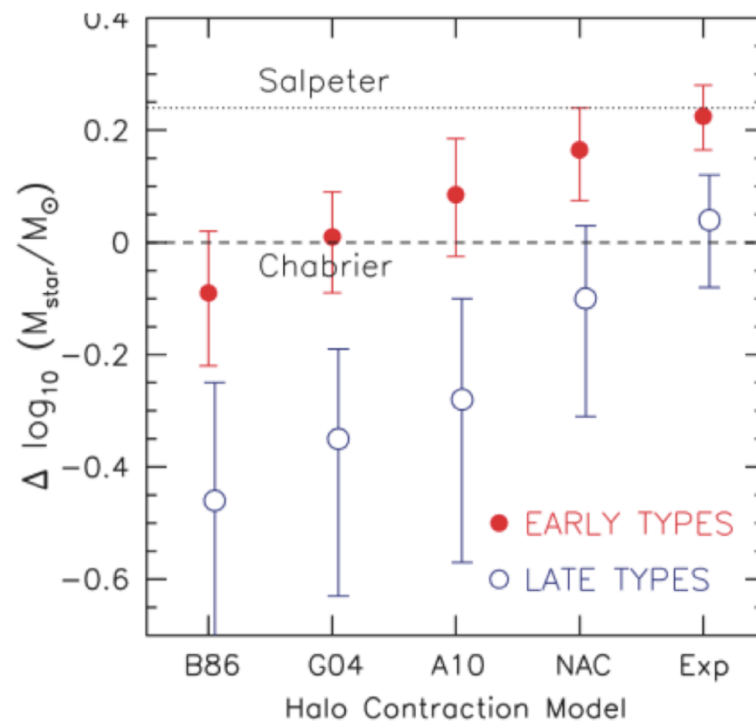
Tully &  
Fisher (1977)

$$L \sim V^3$$



*Courteau+07;  
also Hall+12*

# Dark halo response and the stellar IMF in early-type and late-type galaxies

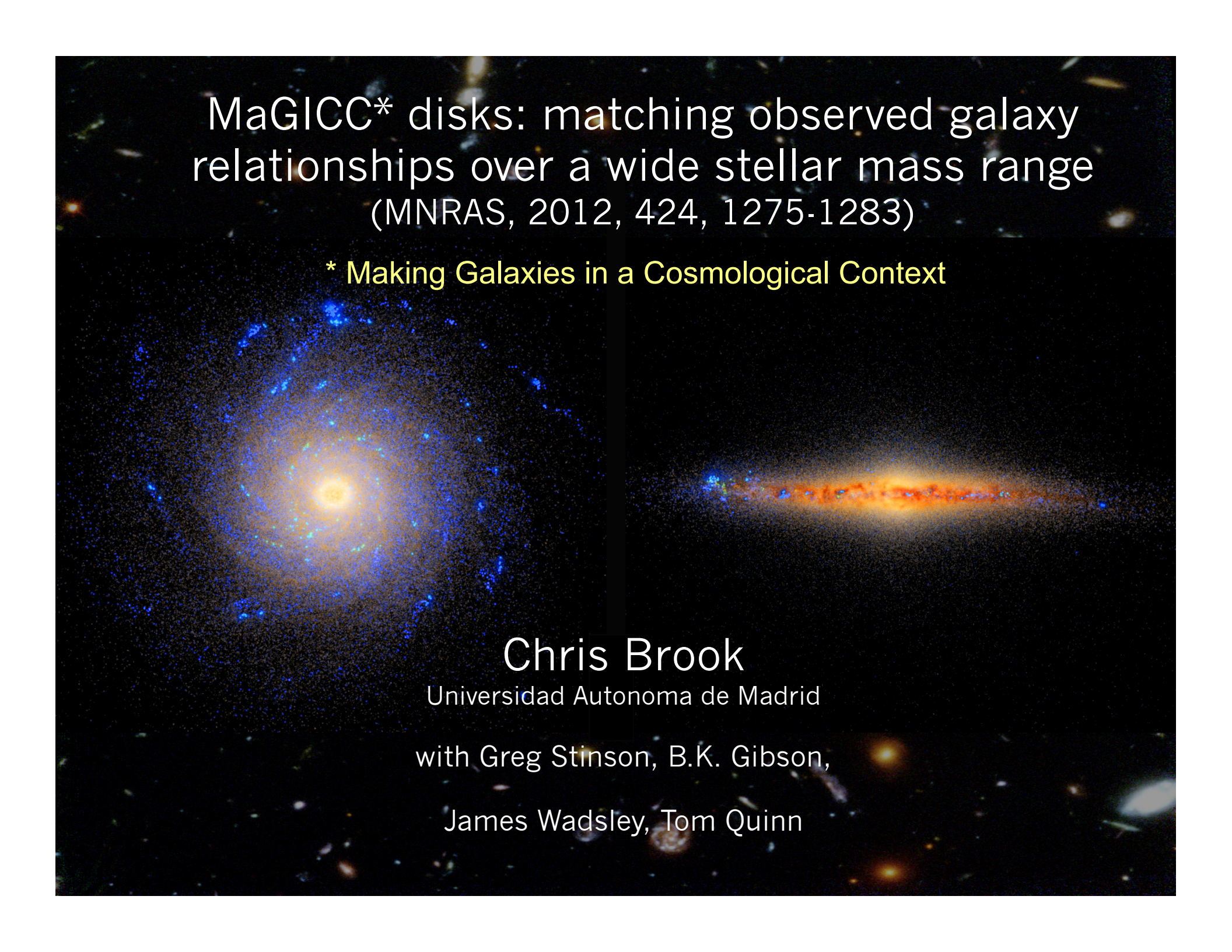


**Figure 17.** Offset in stellar masses required to match the zero-point of the VM relations as a function of halo response model, calculated at  $\log_{10}(V_{\text{opt}}/\text{km s}^{-1}) = 2.30$ , for early-type (red filled symbols) and late-type (blue open symbols) galaxies. The models correspond to the following: B86 – Blumenthal et al. (1986); G04 – Gnedin et al. (2004); A10 – Abadi et al. (2010); NAC – no halo contraction; Exp – halo expansion with  $\nu = -0.5$  in equation (17). The error bars show the effects of  $2\sigma$  systematic errors on the zero-points of the VM and  $M_{200}-M_{\text{star}}$  relations. For fixed IMF (i.e. horizontal lines) early-type galaxies require stronger contraction than late-type galaxies, while for fixed halo response (vertical direction) early-type galaxies require heavier IMFs than late-type galaxies.

$V=1.54 \sigma$  for ETGs;  
Courteau+07b;  
Catinella+12;  
Courteau+13

Dutton+11; see also  
Trujillo-Gomez+11



The background of the slide is a dark, starry field filled with numerous small, distant galaxies. Two prominent simulated galaxies are shown in the foreground. On the left is a bright, yellowish-white elliptical galaxy with a dense central core and a diffuse, blue-tinted outer disk. On the right is a long, thin, edge-on galaxy with a bright orange-red central region and a blue-tinted outer disk. The text is overlaid on the top half of the image.

MaGICC\* disks: matching observed galaxy  
relationships over a wide stellar mass range  
(MNRAS, 2012, 424, 1275-1283)

\* Making Galaxies in a Cosmological Context

Chris Brook

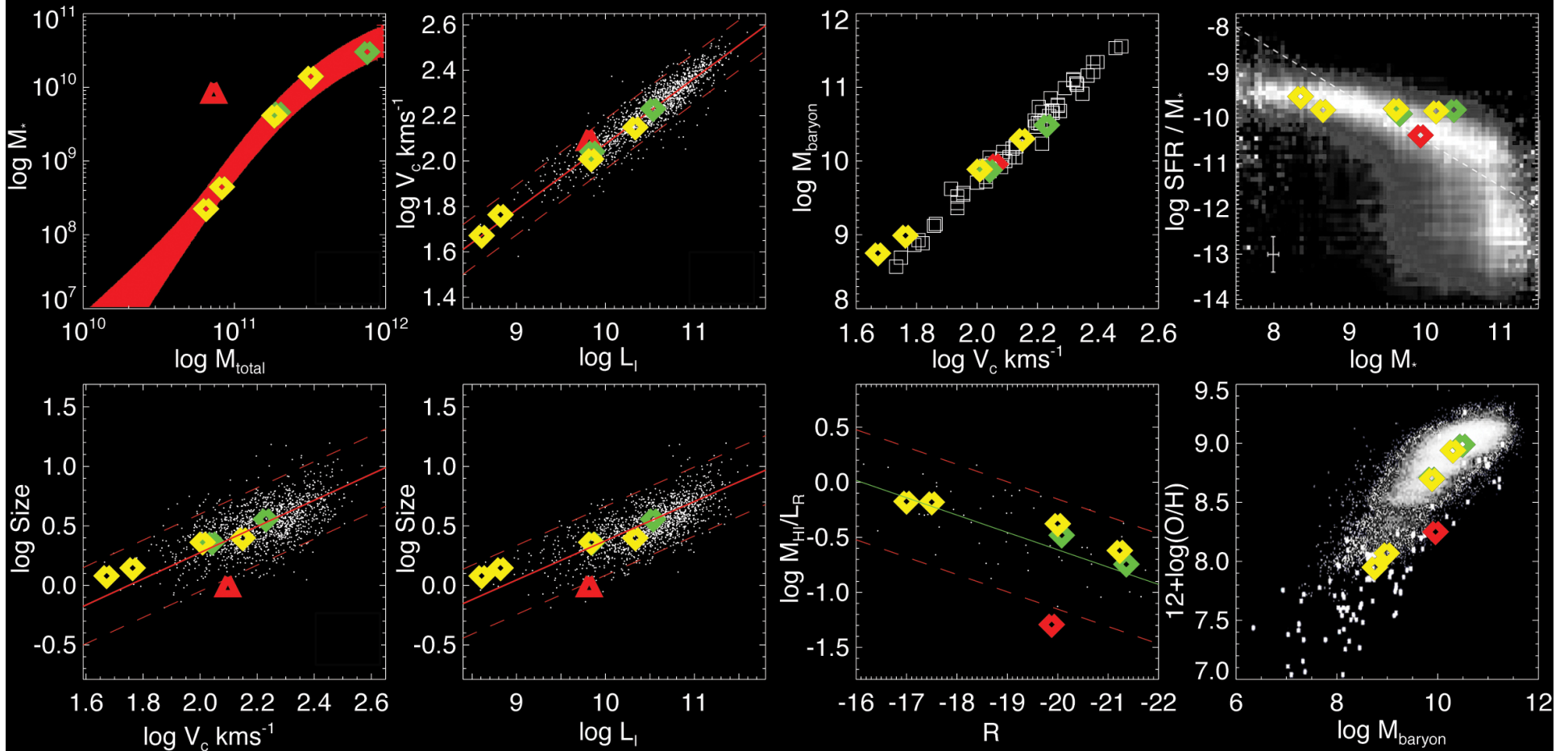
Universidad Autonoma de Madrid


with Greg Stinson, B.K. Gibson,


James Wadsley, Tom Quinn


# Stellar-Mass, Halo-Mass

Size (S), Rotation Velocity ( $V_c$ ), Luminosity ( $L$ ),  $M_{\text{HI}}$ , Specific SFR, Colour, Mbarryons, Metallicity ( $\log O/H$ )




**same resolution**  
**same physics**  
**same feedback**


**low resolution**  
**same physics**  
**same feedback**  
 **$C_*$  adjusted**


**old feedback**  
**Stinson et al 2010**  
**Scannapieco et al. 2012**

**Data from**  
**Courteau+07**  
**McGaugh+05**

# Key Science Questions

1. How was angular momentum distributed among baryonic and non-baryonic components as the galaxy formed?
2. How do various mass components assemble and influence one another?
3. How does gas accretion drive the growth of galaxies?
4. What are the relative roles of stellar accretion, minor and major mergers, and instabilities in forming galactic bulges and ellipticals?
5. What quenches star formation? What external forces affect star formation in groups and clusters?



# On the choice of scaling parameters

Hall et al (2012, MNRAS, 425, 2741)

“An Investigation of Sloan Digital Sky Survey imaging data and multiband scaling relations of (3041) spiral galaxies”

Compare SDSS DR7 Petrosian R and L with similar values from isophotal fits to the SDSS galaxy images.

**Scatter degradation VL by ~8% and RV by ~30% with SDSS Petrosian parameters.**

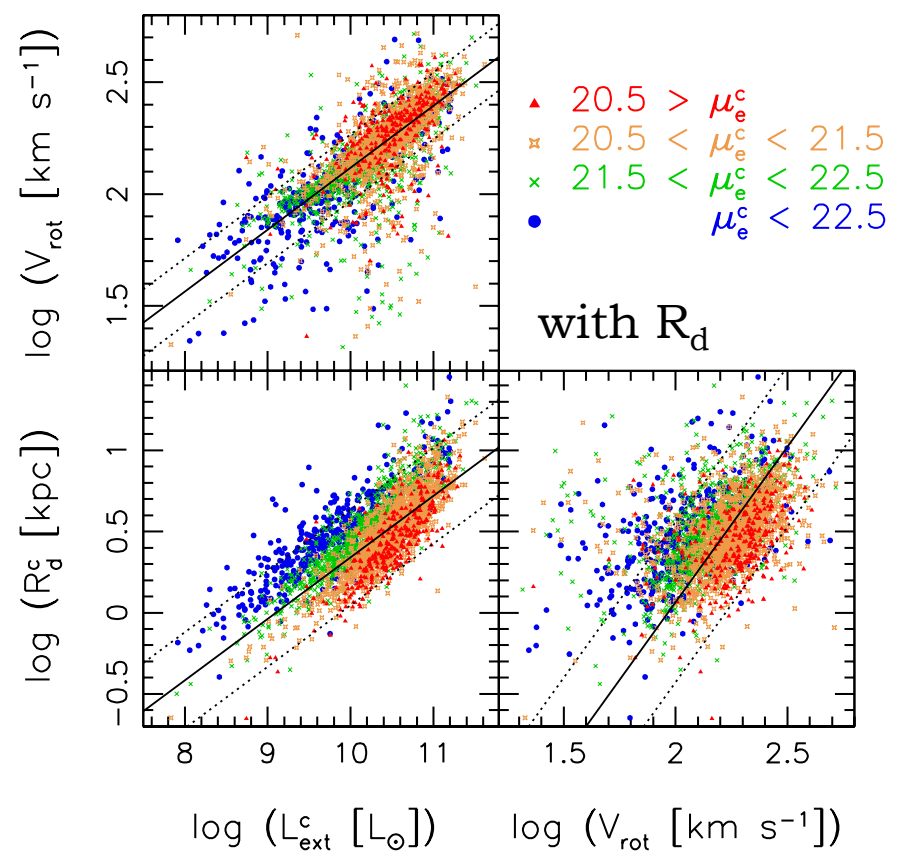
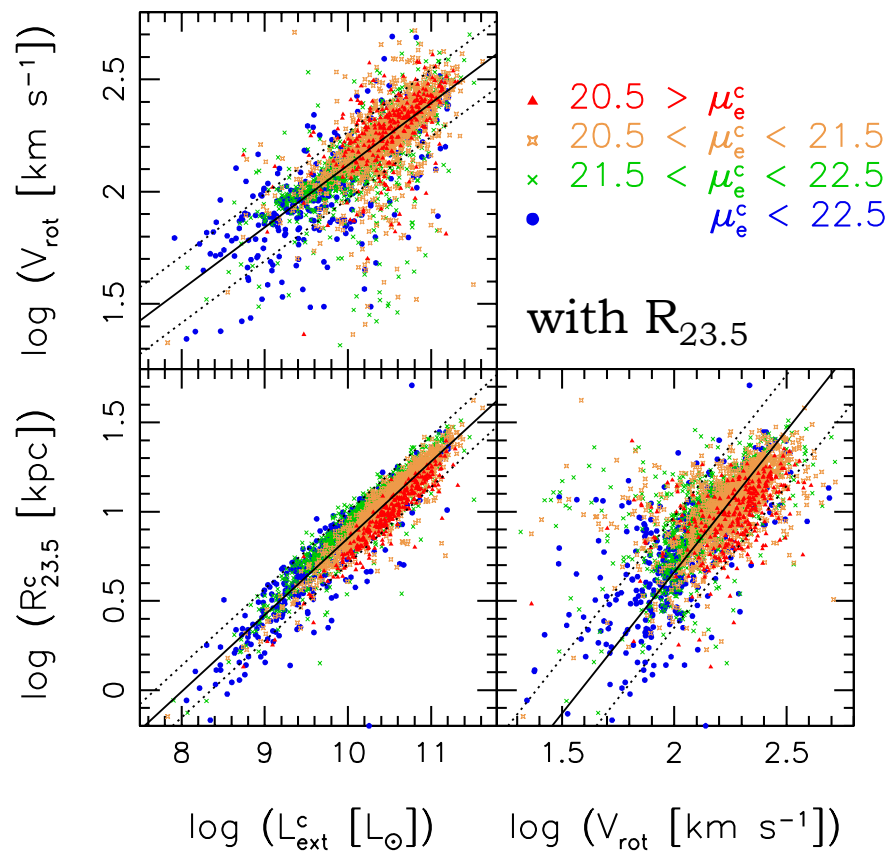
**Largest (Baryonic) TFR to date: Hall et al (2012)**



Melanie Hall

Ask me for the data.  
Web site coming soon!

# Careful about catalog (SDSS) data and choice of scaling parameters!



Hall et al (2012); see also Saintonge & Spekkens (2011)

# Modern Studies

- Courteau et al (2007), Dutton et al (2007):

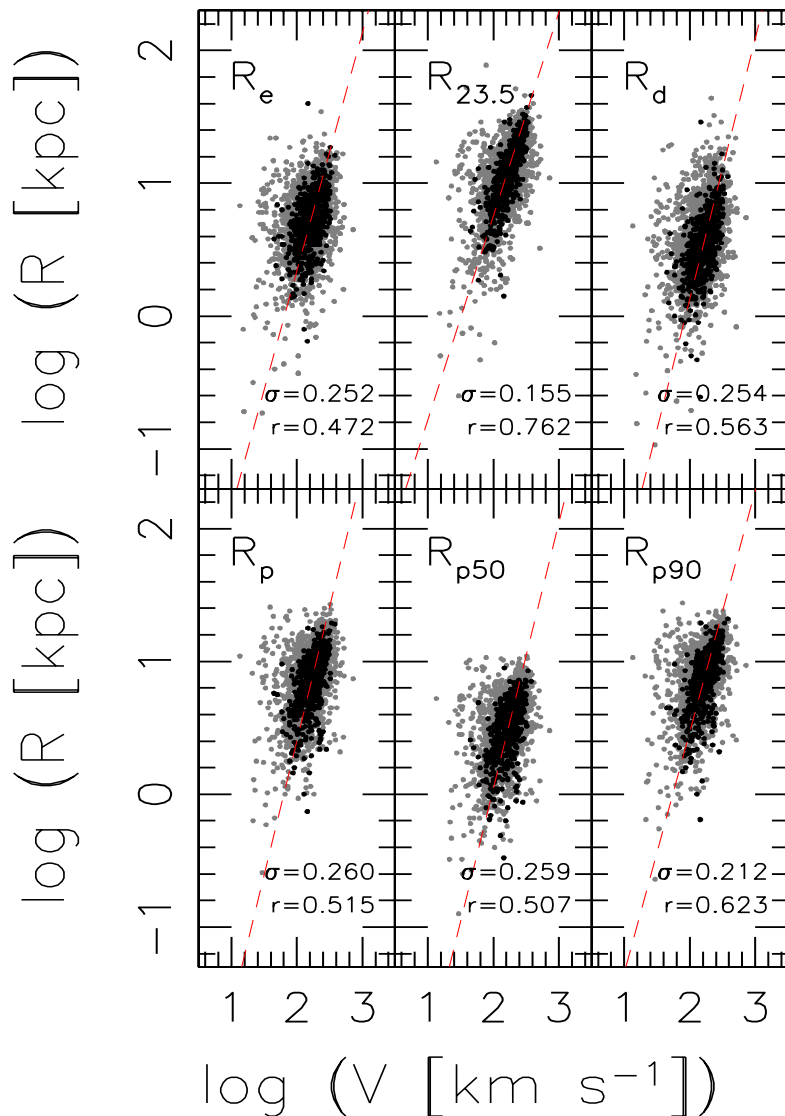
$$V_{obs} \propto L_{ext}^{0.29} \quad R_d \propto L_{ext}^{0.32} \quad R_d \propto V_{obs}^{1.1}$$

- Hall et al (2012):

$$V_{obs} \propto L_{23.5}^{0.26} \quad R_{23.5} \propto L_{23.5}^{0.4} \quad R_{23.5} \propto V_{obs}^{1.5}$$

Hall+12 based on 3041 spiral galaxies with SDSS imaging and HI line widths. Performed our own *isophotal fitting* and *sky subtraction*

# SDSS Study



The best radial measure:

$R_{23.5}$

-- not all radii created equal.

For luminosity:  $L_{23.5}$

Hall+12; uses  $V$  from Springob+05/07

# On the choice of scaling parameters

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“An Investigation of Sloan Digital Sky Survey imaging data and multiband scaling relations of (3041) spiral galaxies”

Compare SDSS DR7 Petrosian R and L with similar values from isophotal fits to the SDSS galaxy images.

Scatter degradation VL by ~8% and RV by ~30% with SDSS Petrosian parameters.

Largest (Baryonic) TFR to date: Hall et al (2012)



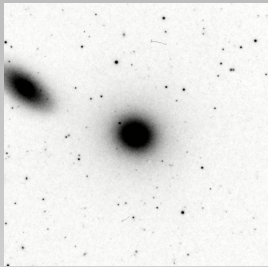
Melanie Hall

**Ask me for the data.  
Web site coming soon!**



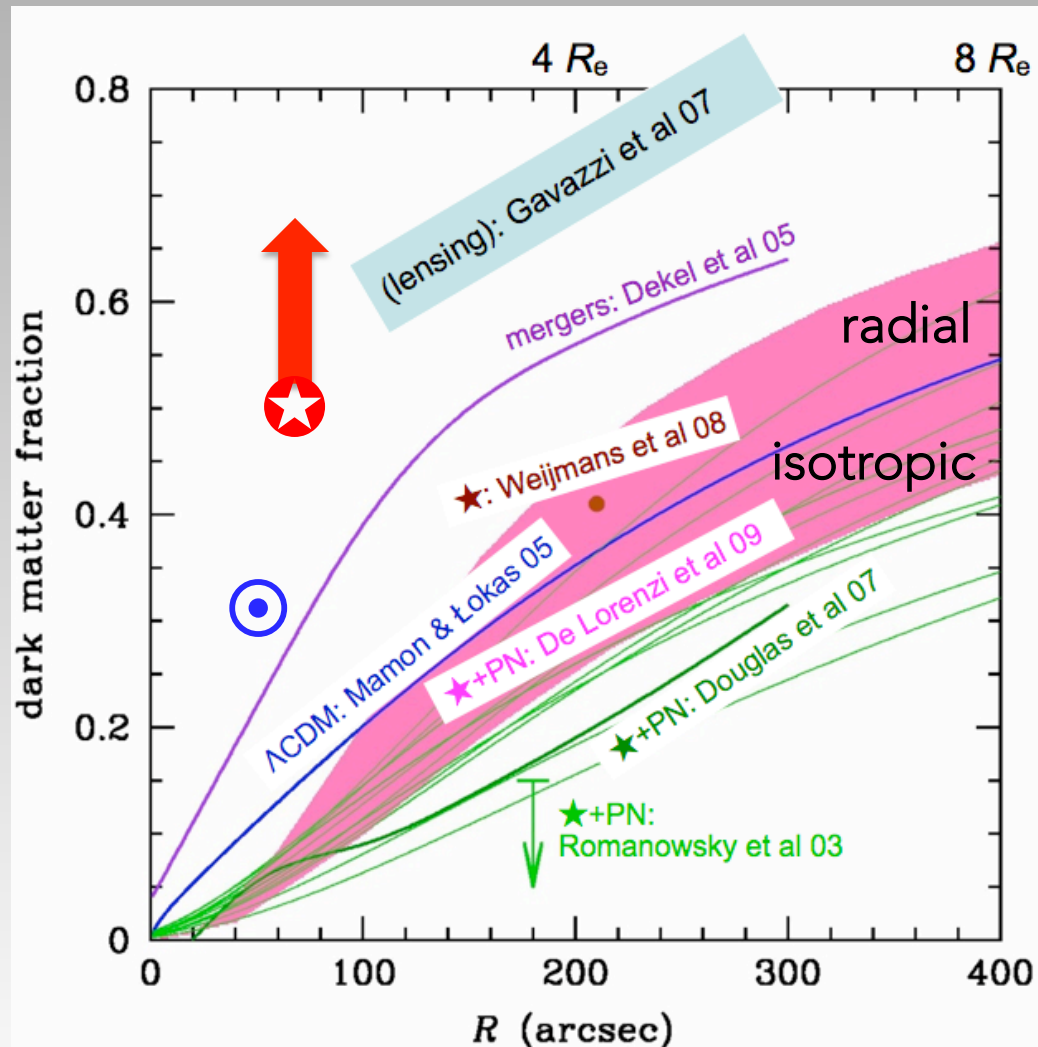
# Dark Matter Fractions: Deep, homogeneous sampling needed

M105; E1



- ⊙ Cappellari
- ★ Spirals

Courteau et al+13  
Reviews of Modern  
Physics



Dark matter content @ 1,2,3,4...  $R_e$  still uncertain!



Joel Roediger

# The SHIVir Survey

























## Spectroscopy and *H*-band Imaging of the *Virgo* cluster survey



Nathalie Ouellette

(w/ McDonald, Roediger, Ouellette, Holtzman, Dalcanton)

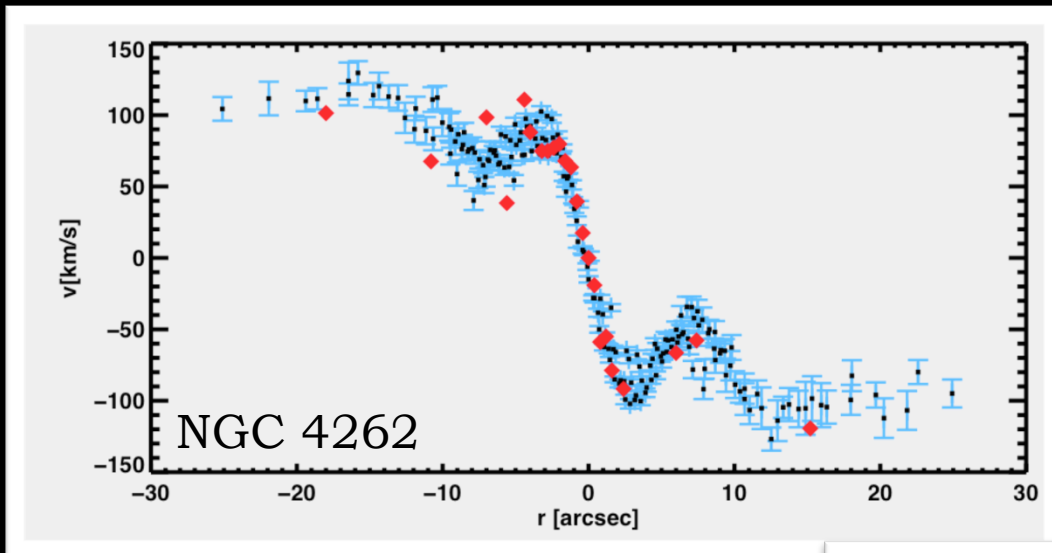
- *g,r,i,z* (SDSS DR7) and NIR *H*-band imaging (CFHT) of 300+ *Virgo* cluster galaxies: SB profiles, isophotal masses and radii, stellar masses, scale lengths, etc.
- Optical spectroscopy from Palomar, KPNO, and APO for ~200 SHIVir galaxies
- *Carried out by:*  
Mike McDonald (MIT)  
Joel Roediger (Queen's/UCSC)  
Nathalie Ouellette (Queen's)

 VCC0355 (184.8773,14.8776) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0389 (185.0137,14.9615) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0437 (185.2033,17.4872) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0459 (185.2970,17.6386) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>
 VCC0483 (185.3865,14.6061) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0490 (185.4115,15.7451) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0497 (185.4269,14.5983) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0510 (185.4737,15.6458) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>
 VCC0522 (185.5150,12.7409) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0523 (185.5171,12.7874) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0543 (185.5813,14.7607) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0545 (185.5816,15.7335) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>
 VCC0559 (185.6306,15.5376) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0570 (185.6606,11.8009) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0583 (185.687526,15.502170) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0596 (185.7288,15.8222) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>
 VCC0608 (185.7572,15.9055) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0620 (185.7899,11.7259) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0630 (185.8218, 11.3679) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0634 (185.8334,15.8203) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>
 VCC0654 (185.8970,16.7223) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0655 (185.9060,17.5408) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0664 (185.9352,12.4783) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>	 VCC0679 (185.9777,11.4905) Profiles: <a href="#">g</a> , <a href="#">r</a> , <a href="#">i</a> , <a href="#">z</a> , <a href="#">H</a> <a href="#">ALL</a>

<http://www.astro.queensu.ca/virgo>

# The SHIVr Survey: Comparisons

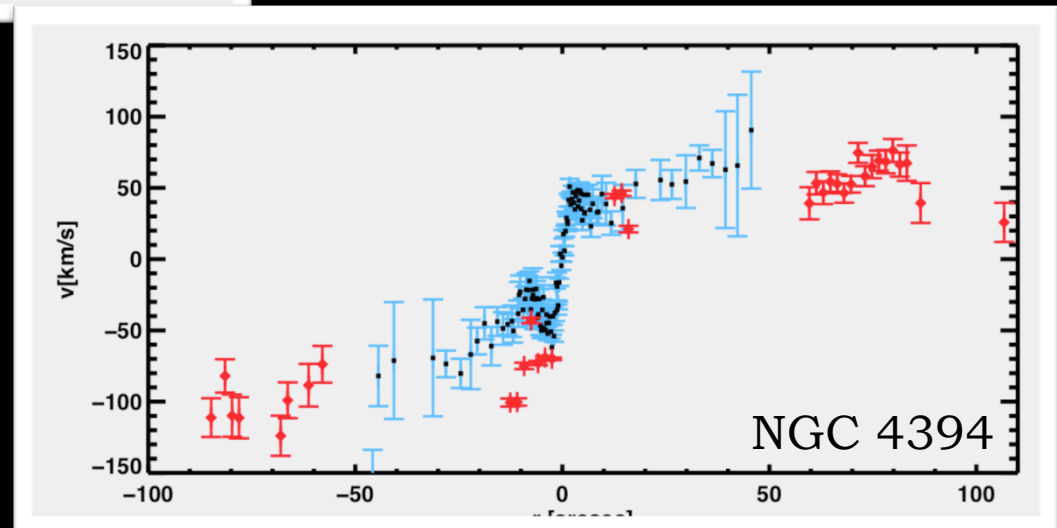
SAURON/CALIFA (thanks to J. Falcon-Barroso/M.Seidel)



CALIFA versus SHIVr

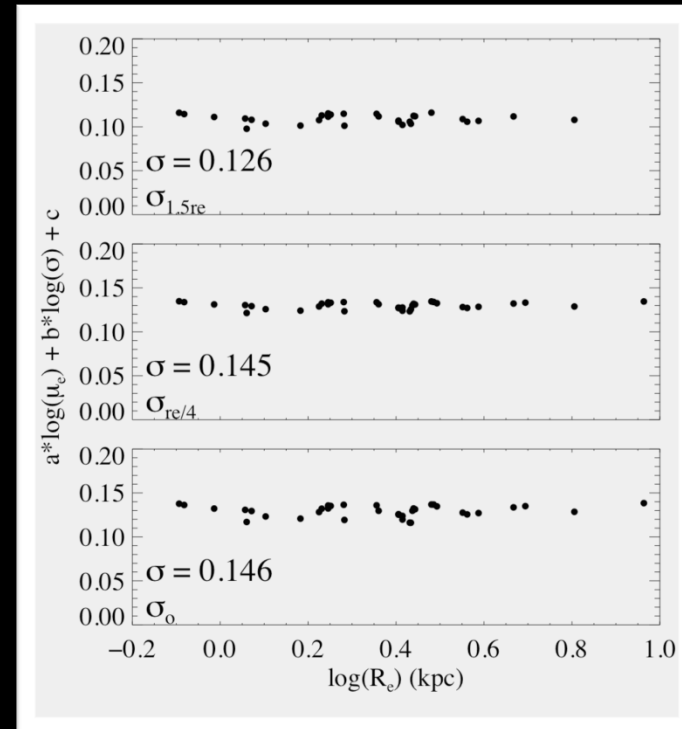
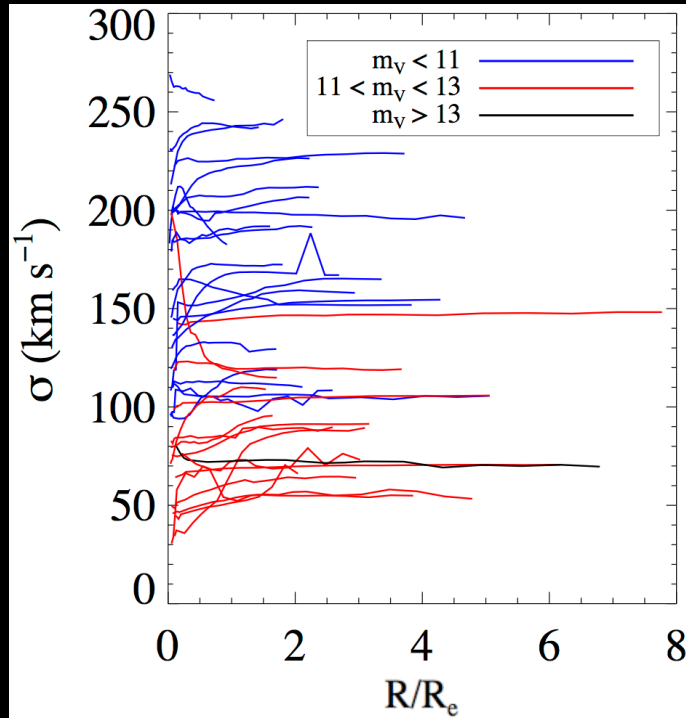
Excellent inner sampling with SAURON; SHIVr reaches deeper

Excellent match for sigmas between SHIVr and ACSVCS and SAURON; i.e. 1D and 2D sigmas comparable



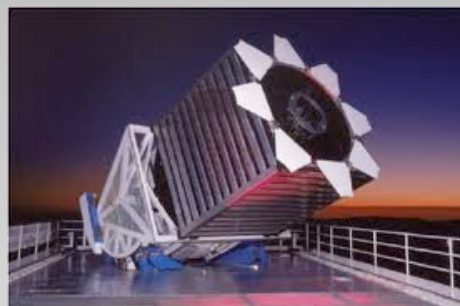
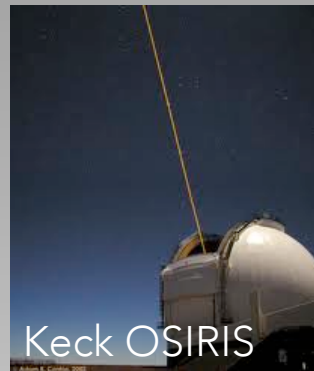
# The SHIVr Survey: Prelim. results

- Deep optical RCs for 34 LTGs and 31 ETGs
- V-dispersion profiles for 33 ETGs
- Get TFR, FJ, and FP scaling relations

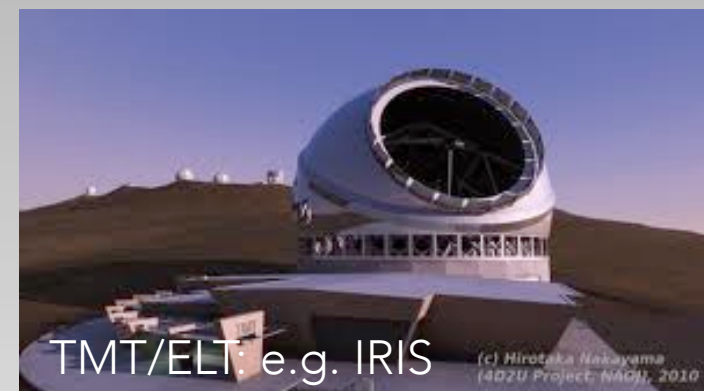


- Future: (4-5m exhausted) Gemini/GMOS program

high-z  
landscape:  
era of high-z  
IFUs



**We need a  $z=0$   
baseline  
for spectroscopy**



## Current & Planned IFU Surveys

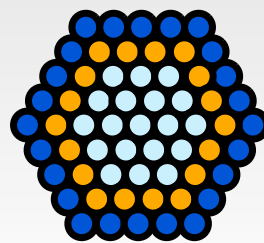
- DiskMass (PMAS/PPaK/Calar Alto / 2.7" fiber /FOV=74"x64"): 140 face-on LTGs
- SAURON/Atlas3D (FOV=33"x41"): ~330 mostly ETGs
- CALIFA (Calar Alto: uses PPak): ~600 galaxies (highest resolution / FOV)
- SAMI at AAO (13 IFUs over 1 deg FOV / 14.9" per IFU): ~3400 galaxies

**MaNGA will provide such a baseline for 10,000 galaxies**

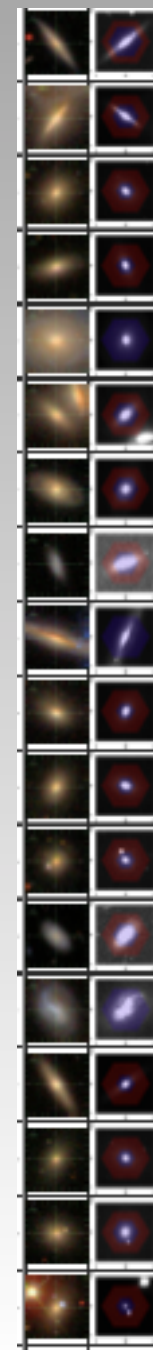


# MaNGA Basic Facts

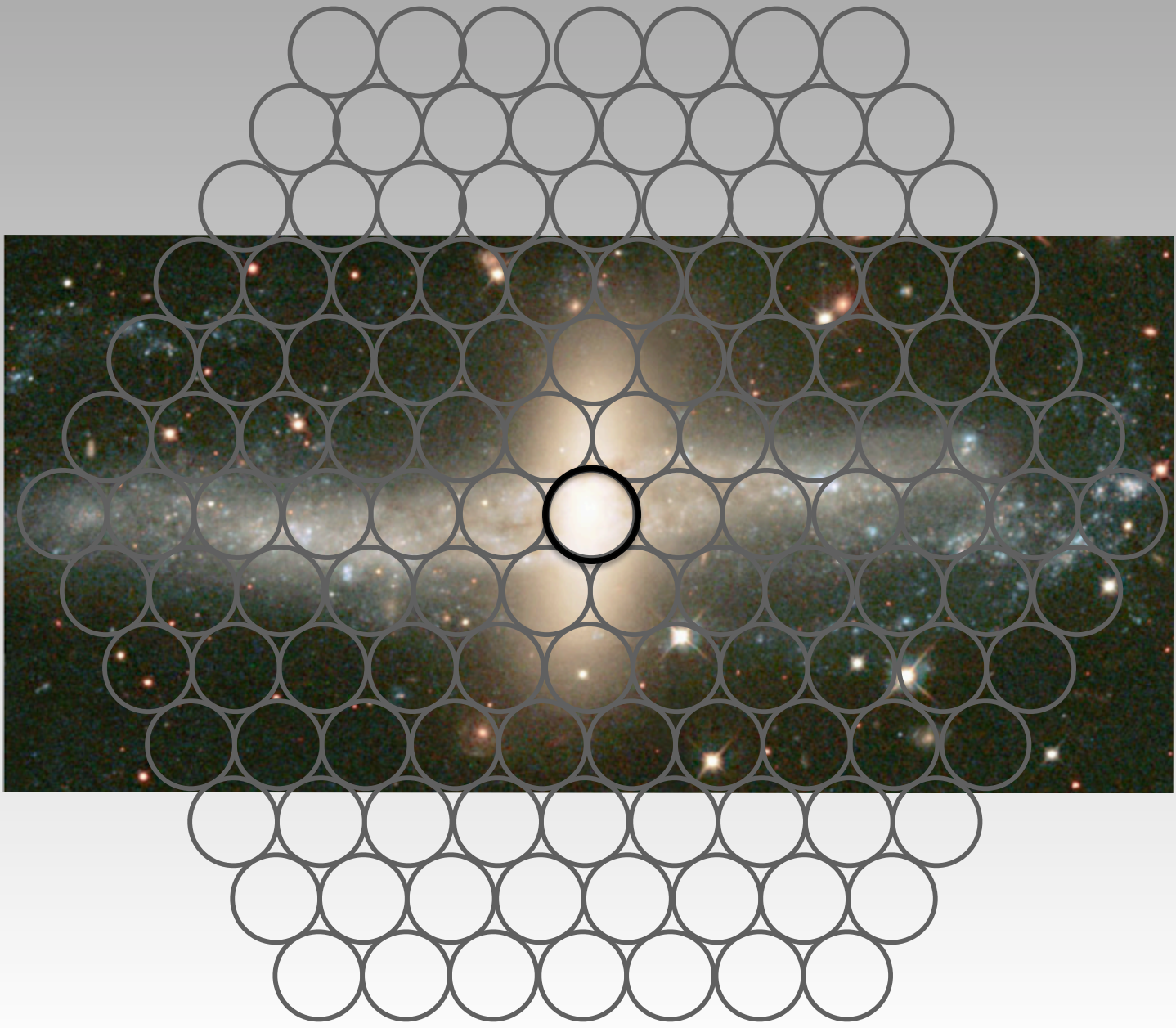
- 10,000 galaxies at  $z > 0.03$  with 2D spectra (SFRs, SFHs,  $V$ ,  $\sigma$ , dust, metallicity, stellar masses, ...)
- Dynamics and stellar pop with  $S/N=5-10$  at  $1.5R_e$
- ~3 hour integrations with BOSS
- Spectral coverage: 360-1000 nm
- Spectral resolution (sigma): 50-70 km/s
- 80% of the targets will be resolved by at least 19 spatial elements out to  $1.5R_e$
- ~6 year project (2014-2020)
- Science verification: Fall 2014
- First press release: Jan 2015
- DR13: July 16



Actual MaNGA targets



# MaNGA Basic Facts



# Wish list (Obs.)

- **General:** must determine biases and applicability of structural parameters ( $V_{\text{rot}}$ ,  $\sigma$ ,  $R_{23.5}$ , accurate  $D$ , ...) Measure  $V(r)$  and  $\sigma(r)$  as deeply and homogeneously as possible.
- **BTF/FP analysis for tens of thousands of LTGs and ETGs:** need *deep* dynamics ( $V$ ,  $\sigma$ ), PNe, GCs, lensing, X-ray maps, multi-wavelength imaging, gas fractions  
E.g. SAURON, Atlas3D, ALFALFA, CALIFA, MaNGA, SLACS, *SHIVir*, ... (bias on dynamics)
- **VL/RL/LF analysis for LTGs/ETGs:** must constrain stellar population models, IMF and AC. *Slope, zero-point and scatter of scaling relations must be matched.*



Dutton+11; Trujillo-Gomez+11; Papastergis+11; Reyes+12