Image credit: NASA, ESA, and The Hubble Heritage Team

## **Peculiar motions in observations & simulations**

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### **Distance Indicators**

- Redshift-distance relation
- Cepheid variables
- Supernovae Type Ia
- Tully-Fisher relation
- Fundamental plane
- Brightest Cluster Galaxies
- Surface Brightness Fluctuations

### Peculiar motions: redshifts + distance indicator

# The classical fundamental plane

- Empirical relation:
  - physical radius R<sub>0</sub>
  - surface brightness  $\mu_0 = -2.5 \log(I_0)$
  - central velocity dispersion  $\sigma_0$
- $\log(R_0) = a \log(\sigma_0) + b \log(I_0) + c$
- Early-type galaxies
- Standard rod
- Redshift-independent ?
- ~19% distance accuracy





## **Group finder**

- FoF-group finder (Snaith+ in prep., based on Duarte&Mamon 2014 and Robotham+ 2011)
- Linking lengths calibrated for SDSS/BOSS using mock-catalogues derived from the WMAP7 rerun of the Millennium simulation (Guo+ 2013)



## Fundamental plane residuals

- Dominant contributions from redshift and absolute magnitudes
- Size-evolution
- Brighter (more massive) galaxies are different
- Ideas similar to stellar mass FP (Hyde&Bernardi 2009)



# The dynamical fundamental plane

- Binning sample galaxies in the log(z)-apparent magnitude plane (only observable parameters)
- Calculate the fundamental plane coefficients for each bin
- Remove bins with fewer than 100 galaxies
- Fit 2D-functions to the FP coefficients in the bins
- Use these fits instead of the static coefficients to derive the dynamical fundamental plane:

• 
$$\log(R_0) = a_{dyn}(m,z) \log(\sigma_0) + b_{dyn}(m,z) \mu_0 + c_{dyn}(m,z)$$

#### Parameter spaces of coefficients are different due to prior





-3.6

-3.8

-4.0

-4.2

-4.4

-1.50 -1.25 -1.00 -0.75 -0.50



18

17

16

15

14

18

17

16

15

14

m<sub>app, i</sub> [mag]

m<sub>app, i</sub> [mag]



- 280 000 (redshift-independent ?) distances with 5% accuracy (including systematics) compared to redshift-distances
- ~9%, if compared to SN Type Ia and Tully-Fisher

# **Comparison to other distance indicators**

- SN Type Ia (Betoule+ 2014) ... if in one of our ETG
- Tully-Fisher relation: from NED, if cluster has more than 1 early-type and more than 1 late-type galaxy
- BCG is work in progress



### **Peculiar motions in numerical simulations**

- Future goal: measure the  $\beta = \Omega_{_{m}}/b$  parameter (Park 2000)
- Mock catalogues based on the Horizon Run 4
- Difficulty: include all scatters, selection effects, and systematics correctly in the simulated data



 Cosmological comparison using the MultiVerse simulations

## **ANY QUESTIONS?**



## ADDITIONAL SLIDES for possible questions

# Using classical FP-distances in stead of redshifts

- Dynamical Fundamental Plane has explicitly redshift dependent coefficients
- Use classical FP-distances as a "prior" instead
- Only a 2% improvement compared to classical FP-distances and redshifts
- Systematics might even be trickier
- Work in progress



## MaNGA comparison

- Strong correlation of classical FP residuals and stellar mass, but not with the kinematic parameter  $\lambda_{\rm Re}$
- Data from Graham+ 2018







### **Data for Group Catalogue**

- Almost all SDSS galaxies below a redshift of 0.5
- More than 1 250 000 galaxies



### **ETG sample selection**

- Colour cuts, axis ratio, and profile fitting quality
- ~280 000 early-type galaxies



### **Environmental dependence of the fundamental plane**



### **Bin sizes**

#### • 0.5 mag x 0.4 in log(z)



### Classical fundamental plane redshift dependences

- Tolman effect: surface brightness dimming according to General Relativity (1+z)<sup>4</sup>
- K-correction: spectral energy distribution is redshifted (our corrections: Chilingarian+ 2010)
- Size-correction: the apparent size of galaxies depends on the wave-length, which is redshifted.
- Evolutionary correction: (Q · z ... Bernardi+ 2003)
- Malmquist bias correction: corrections for selection effects in magnitude limited surveys

### **Stellar mass dependence**

- Mendel+ 2014 stellar masses
- Dominant source of FP residuals
- Well parametrised by absolute magnitudes





