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Further improving the Fundamental Plane with SDSS data

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Collaborators

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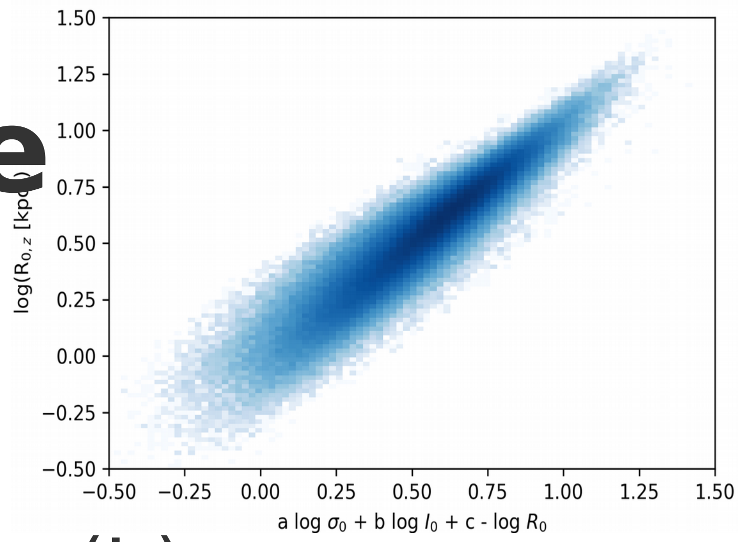
Extragalactic distance indicators

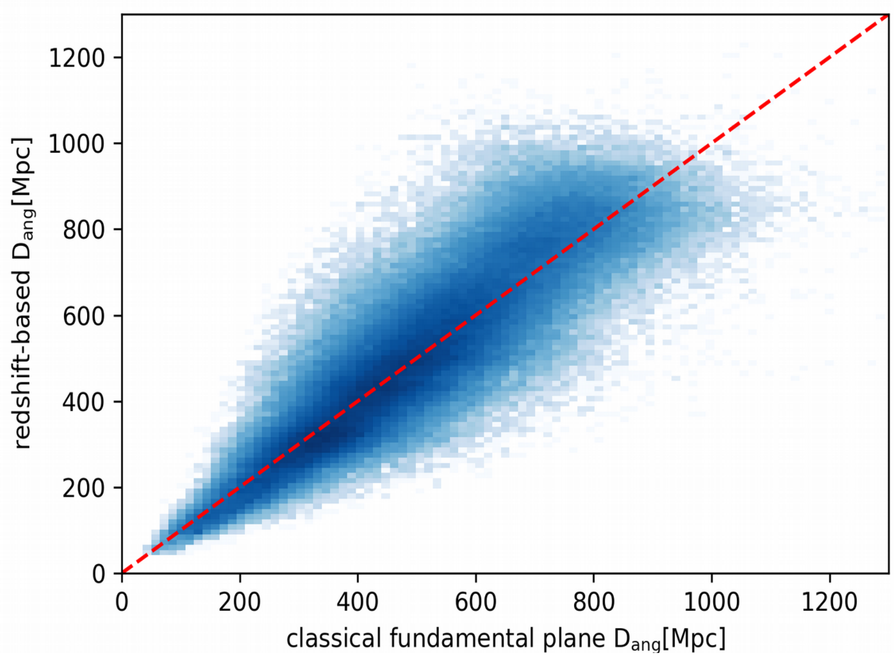
- *Redshift-distance relation*
- Cepheid variables
- Supernovae Type Ia
- Tully-Fisher relation
- **Fundamental plane**
- Brightest Cluster Galaxies
- Surface Brightness Fluctuations
- ...

- **Why redshift independent distances?**
  - **Peculiar motions, cosmology**

The classical fundamental plane



- Empirical relation:
  - physical radius R_0
  - surface brightness $\mu_0 = -2.5 \log(I_0)$
  - central velocity dispersion σ_0
- $\log(R_0) = a \log(\sigma_0) + b \log(I_0) + c$
- Early-type galaxies
- Standard rod
- Redshift-independent ?
- ~20% distance accuracy



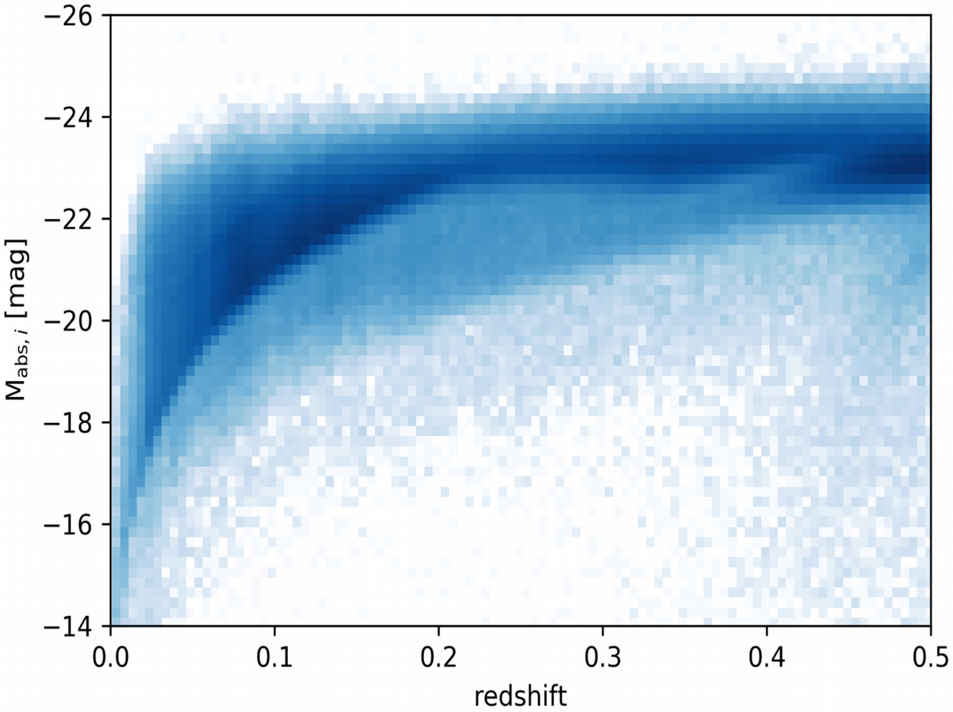
The fundamental plane and SDSS

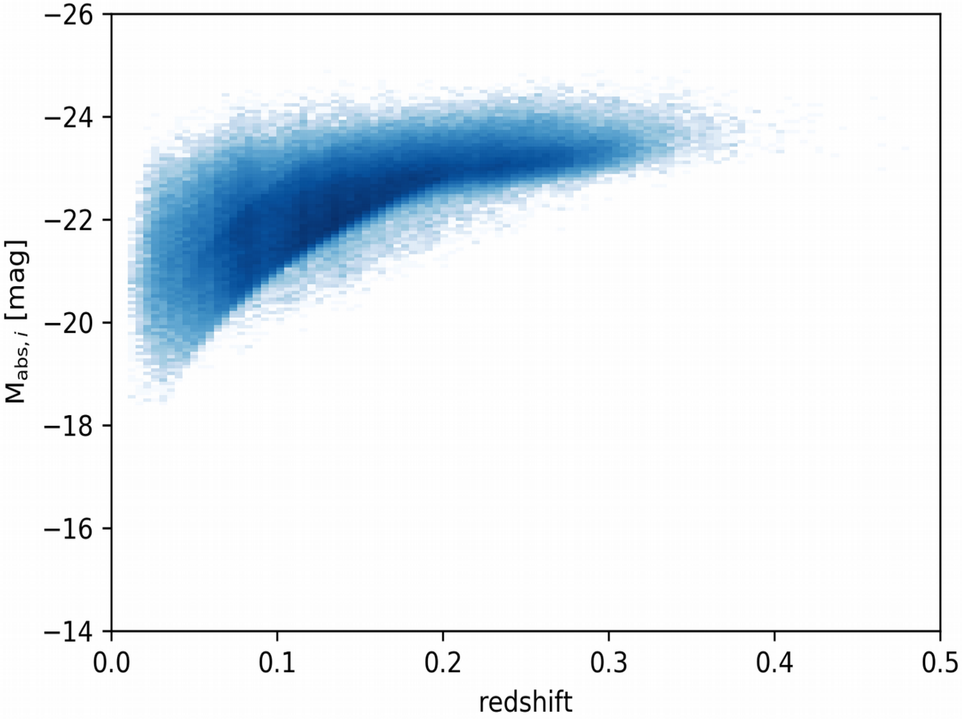
- Bernardi+ 2003 (~9 000 galaxies from the SDSS early-data release)
- Hyde&Bernardi 2009 (~50 000 galaxies from SDSS DR4+DR6)
- Saulder+ 2013 (~93 000 galaxies from SDSS DR8)
- Saulder+ 2015 *(Appendix A)* (~121 000 galaxies from SDSS DR10)

- SDSS is now at DR14
- All fundamental plane work was done with the SDSS main galaxy sample

Our current sample of early-type galaxies in SDSS

- More than 1 250 000 galaxies with redshifts < 0.5
- Colour cuts, axis ratio, and profile fitting quality (deV)
- ~290 000 early-type galaxies from the SDSS main galaxy sample, LRG sample, and BOSS low-z sample.



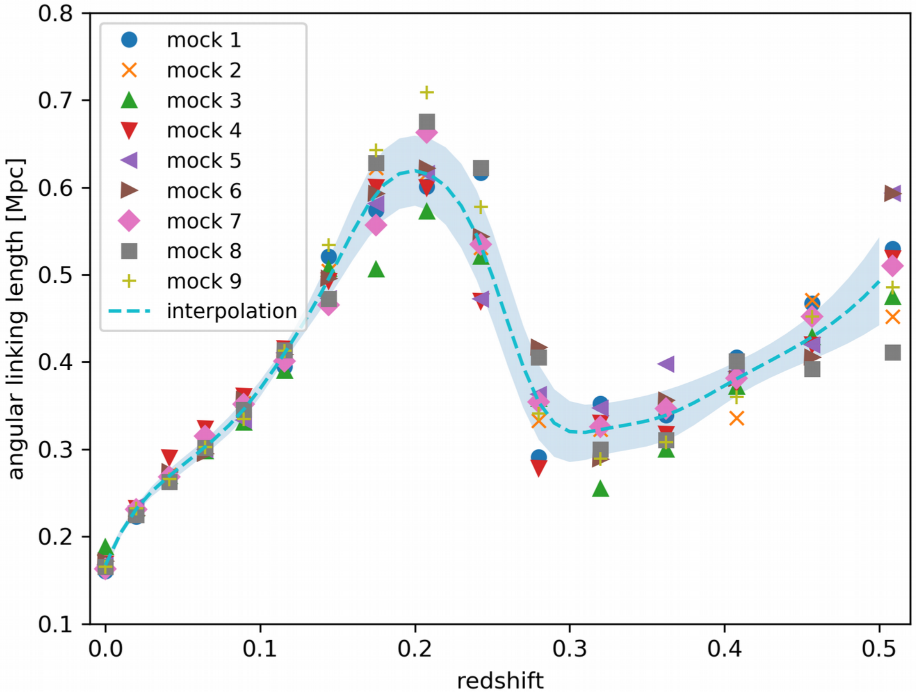


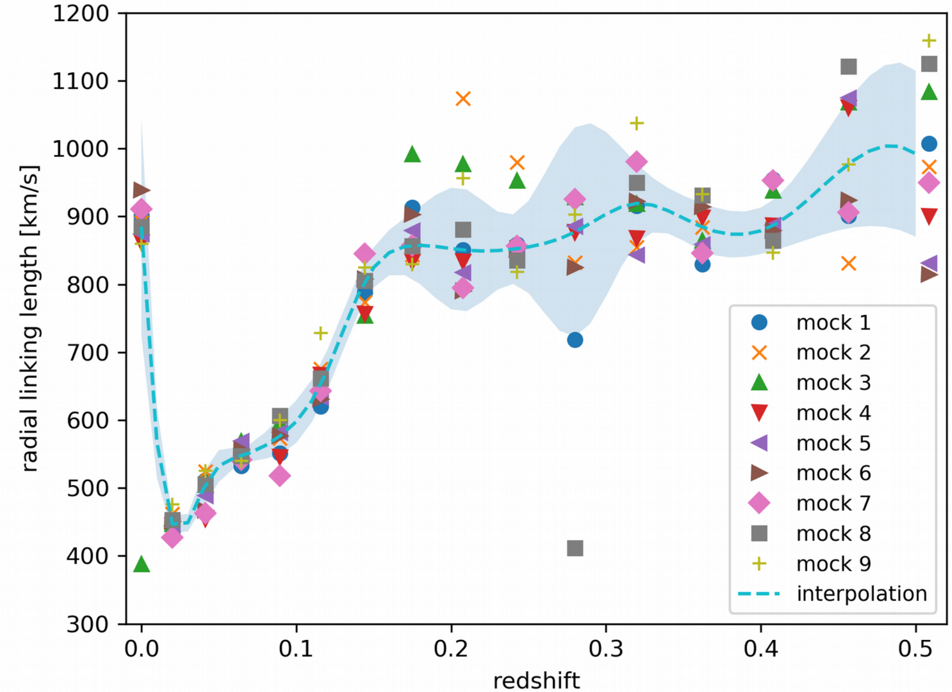
How to improve the fundamental plane distances?

- Using a group finder algorithm to reduce to improve redshift and FP-distances estimates for groups hosting more than one early-type galaxy
  Improvement by ~1% on average
- Re-testing standard corrections and calibrations
  Improvement by ~1%
- Studying the residuals of the classical fundamental plane and correcting for them
- Using full kinematics from integral field spectroscopy (MaNGA)

Group finder

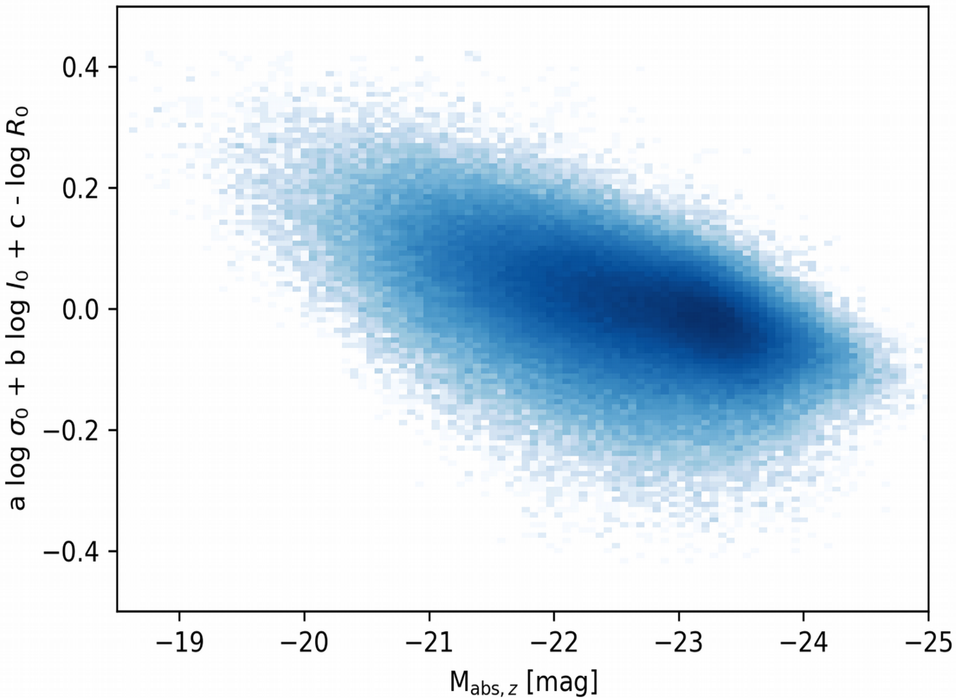
- FoF-group finder (Snaith+ in prep., based on Duarte&Mamon 2014 and Robotham+ 2011)
- Linking lengths calibrated for SDSS/BOSS using mock-catalogues derived from the WMAP7 rerun of the Millennium simulation (Guo+ 2013)

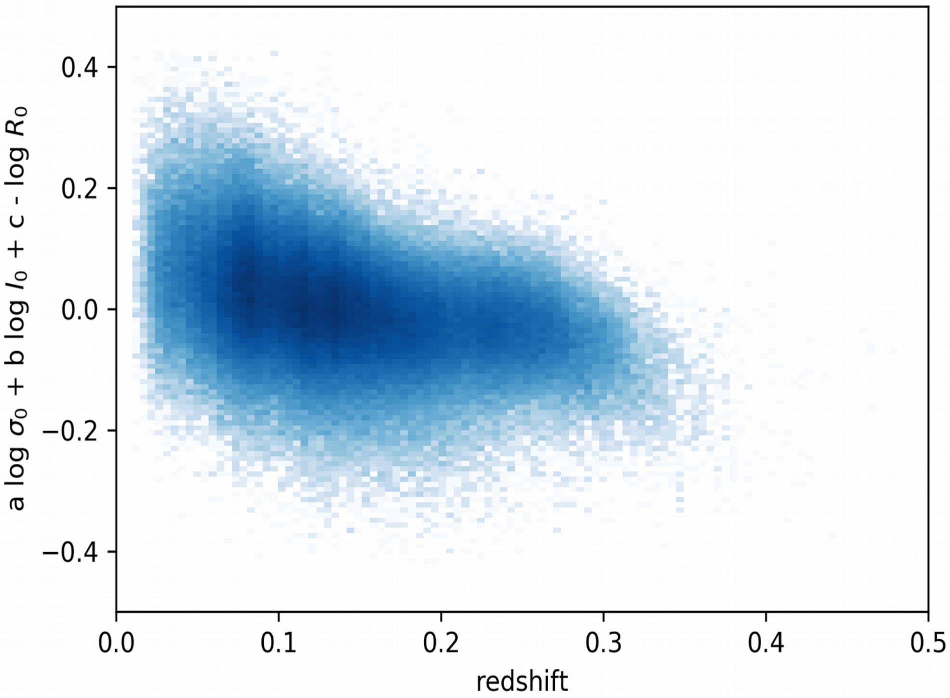




Fundamental plane residuals

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

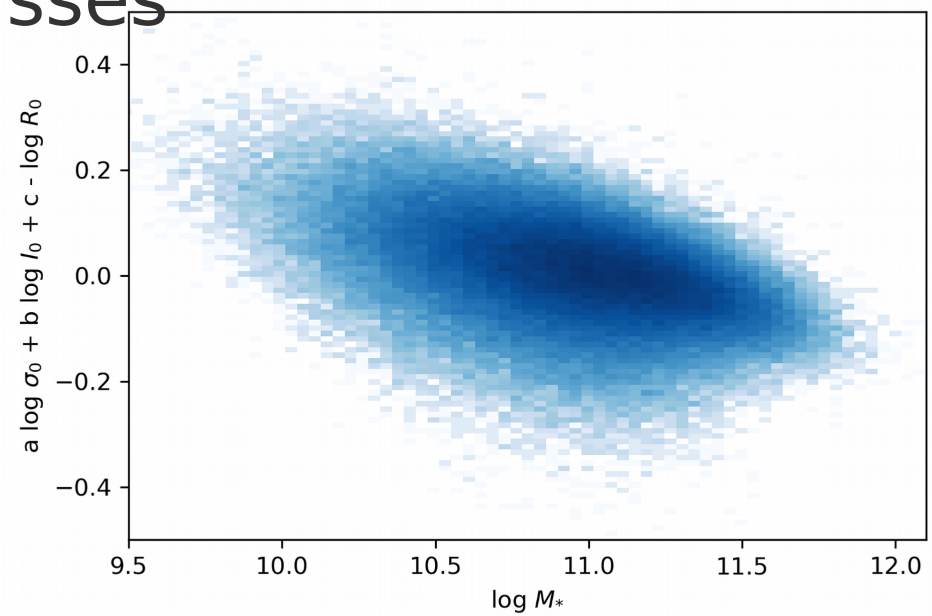


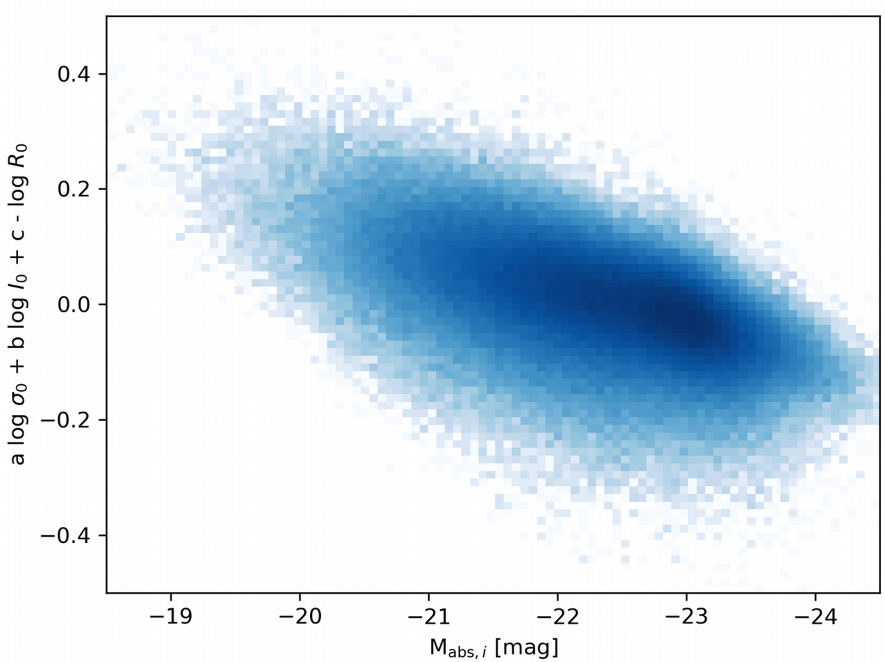


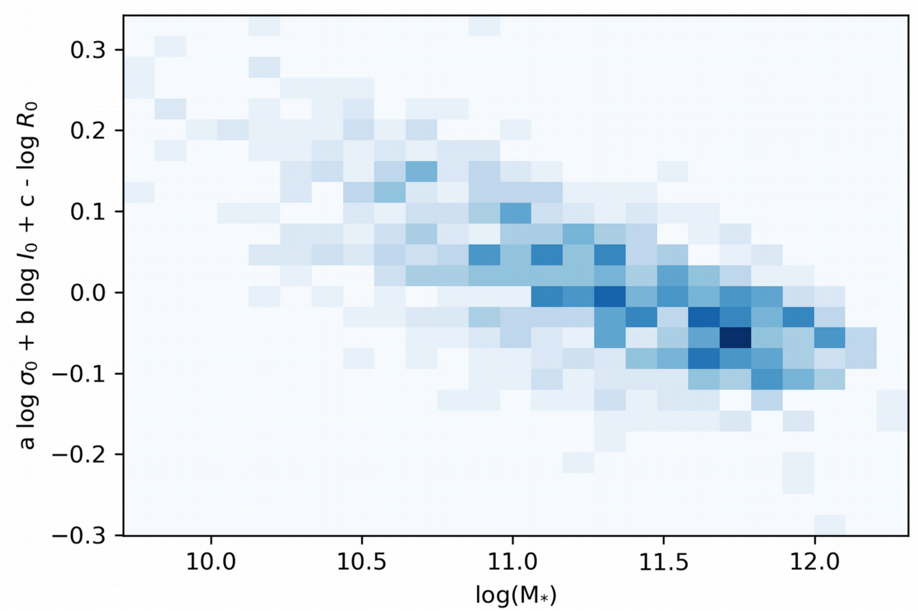
Stellar mass dependence

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

(and colour and redshift)

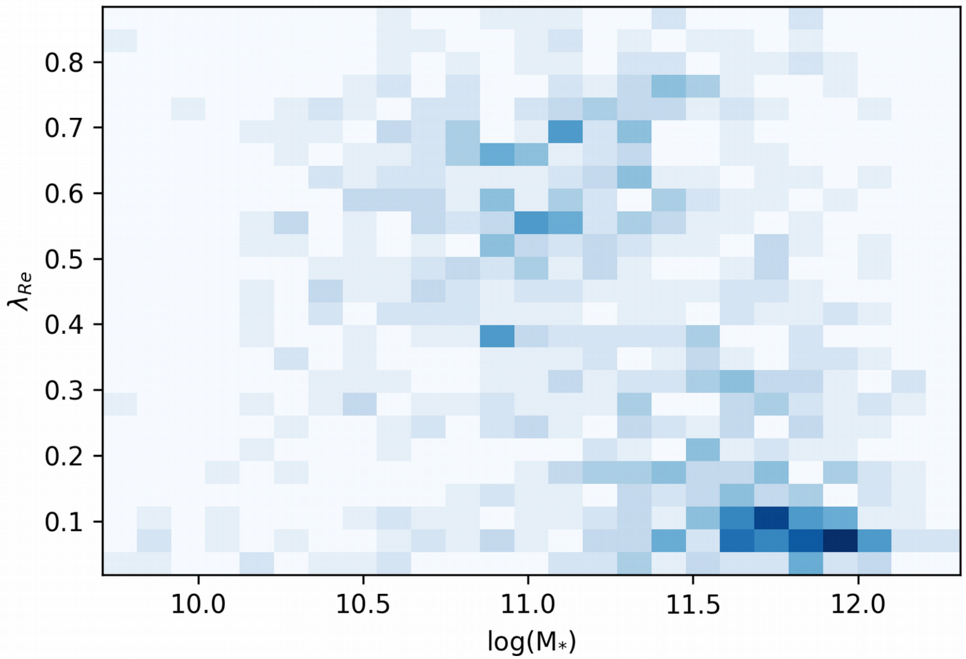


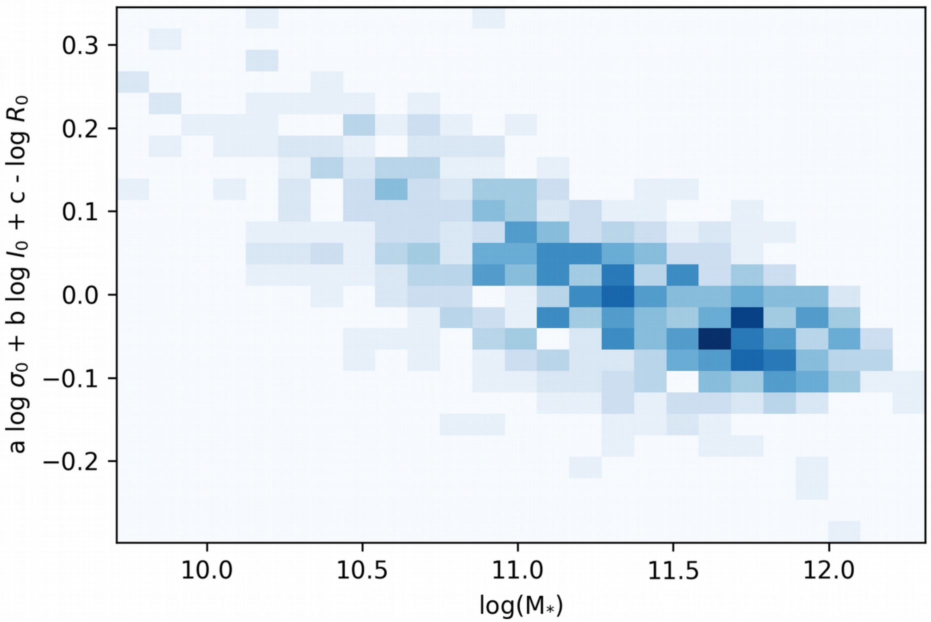


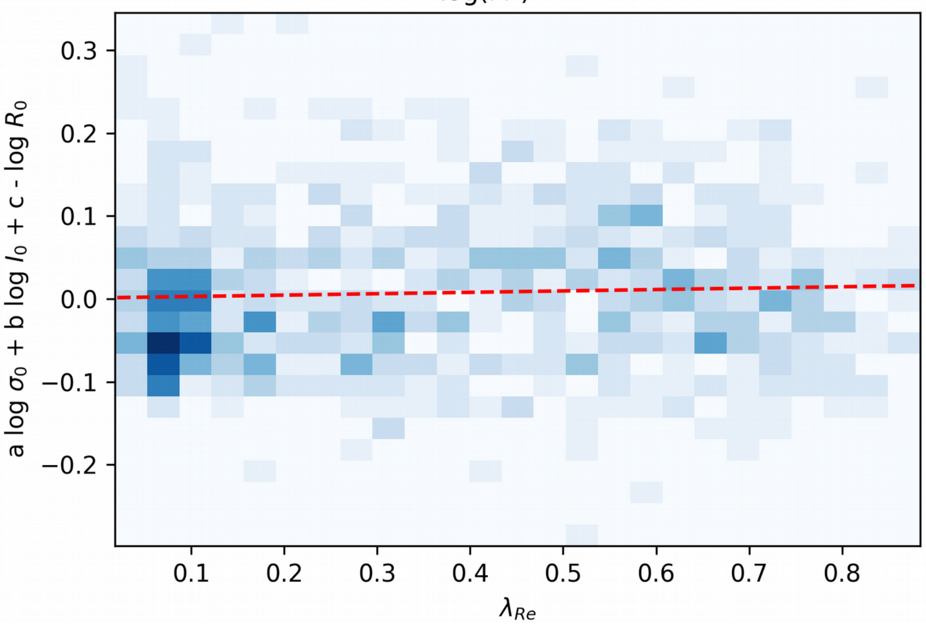


MaNGA comparison

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



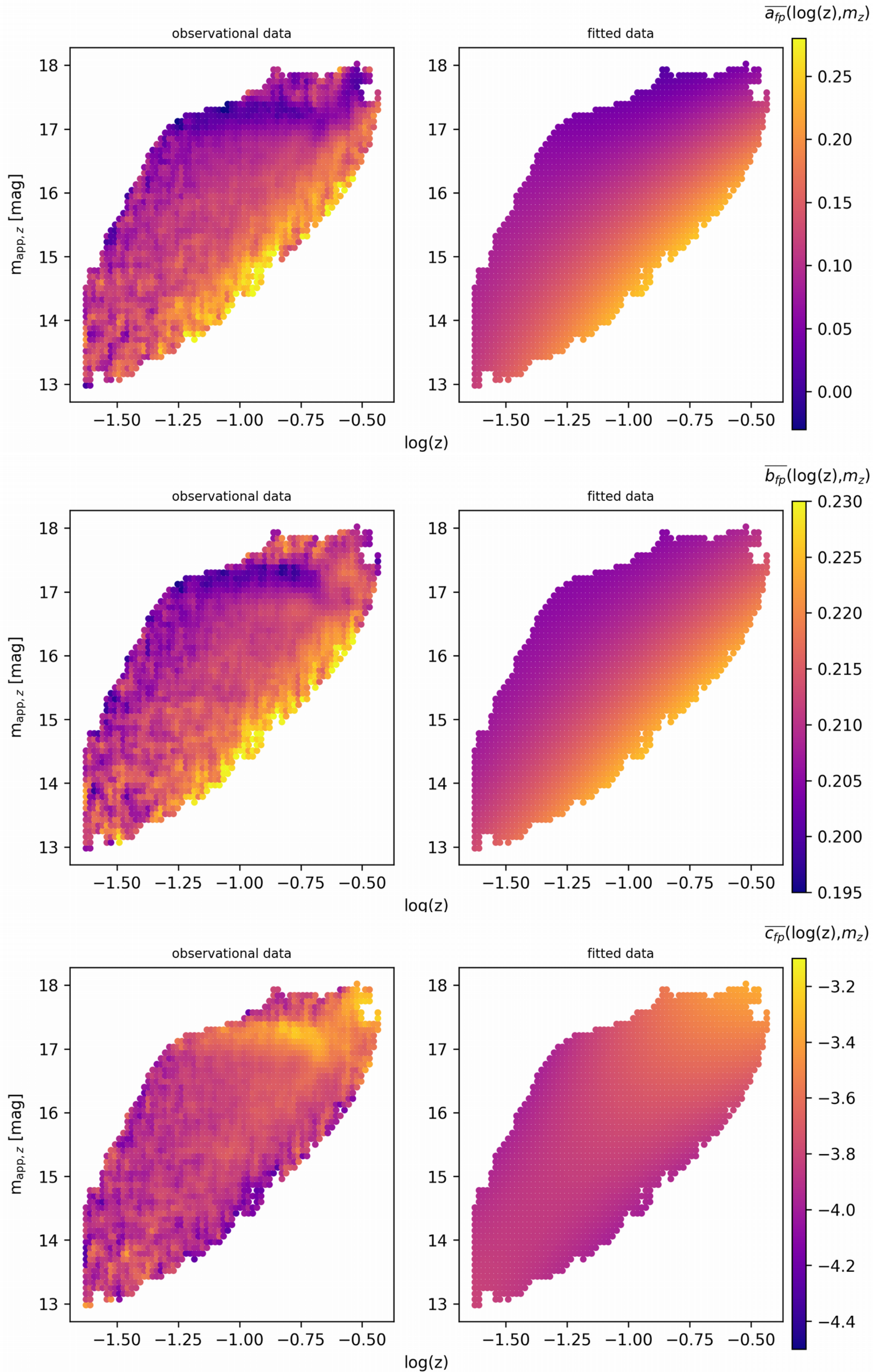


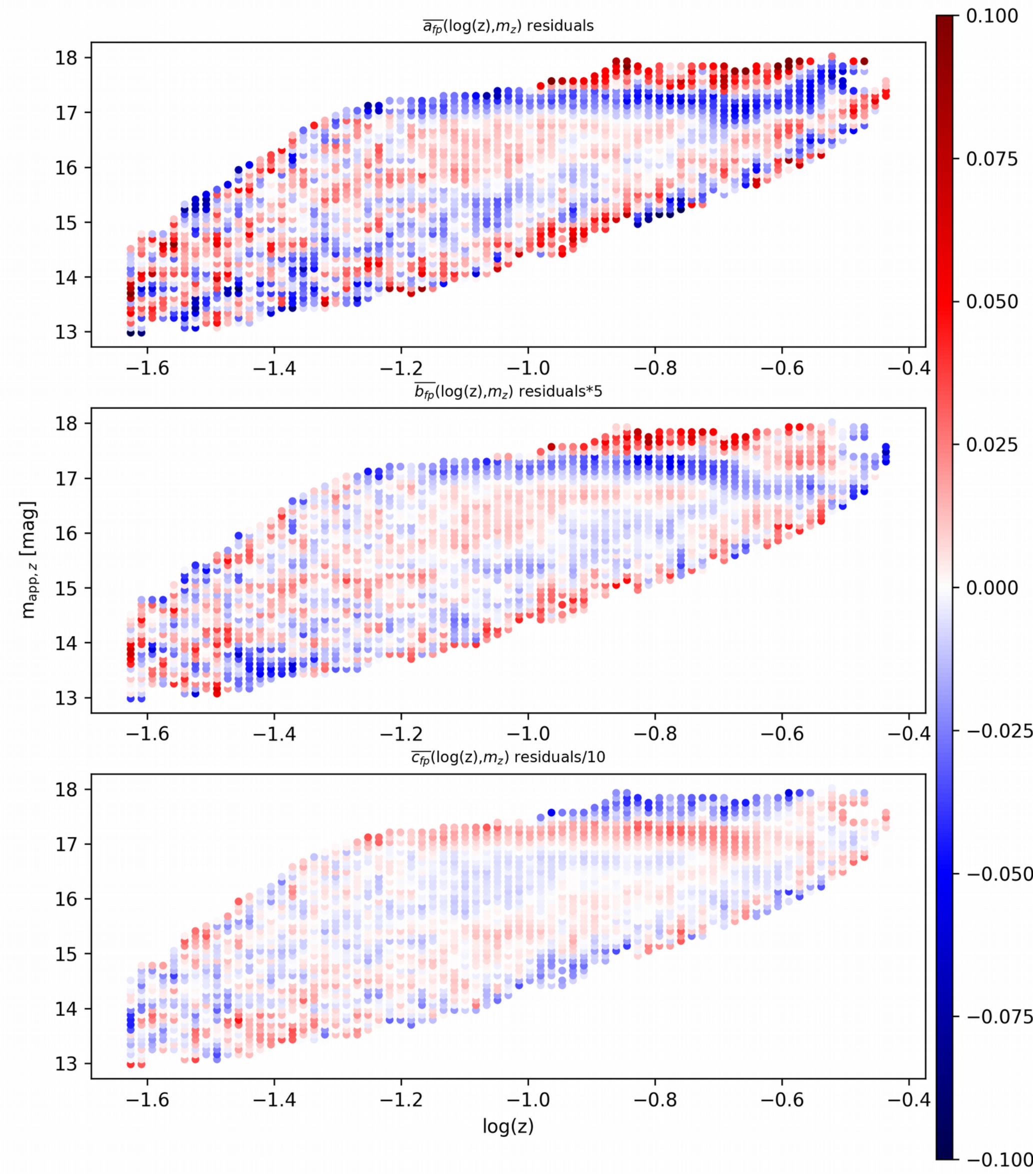


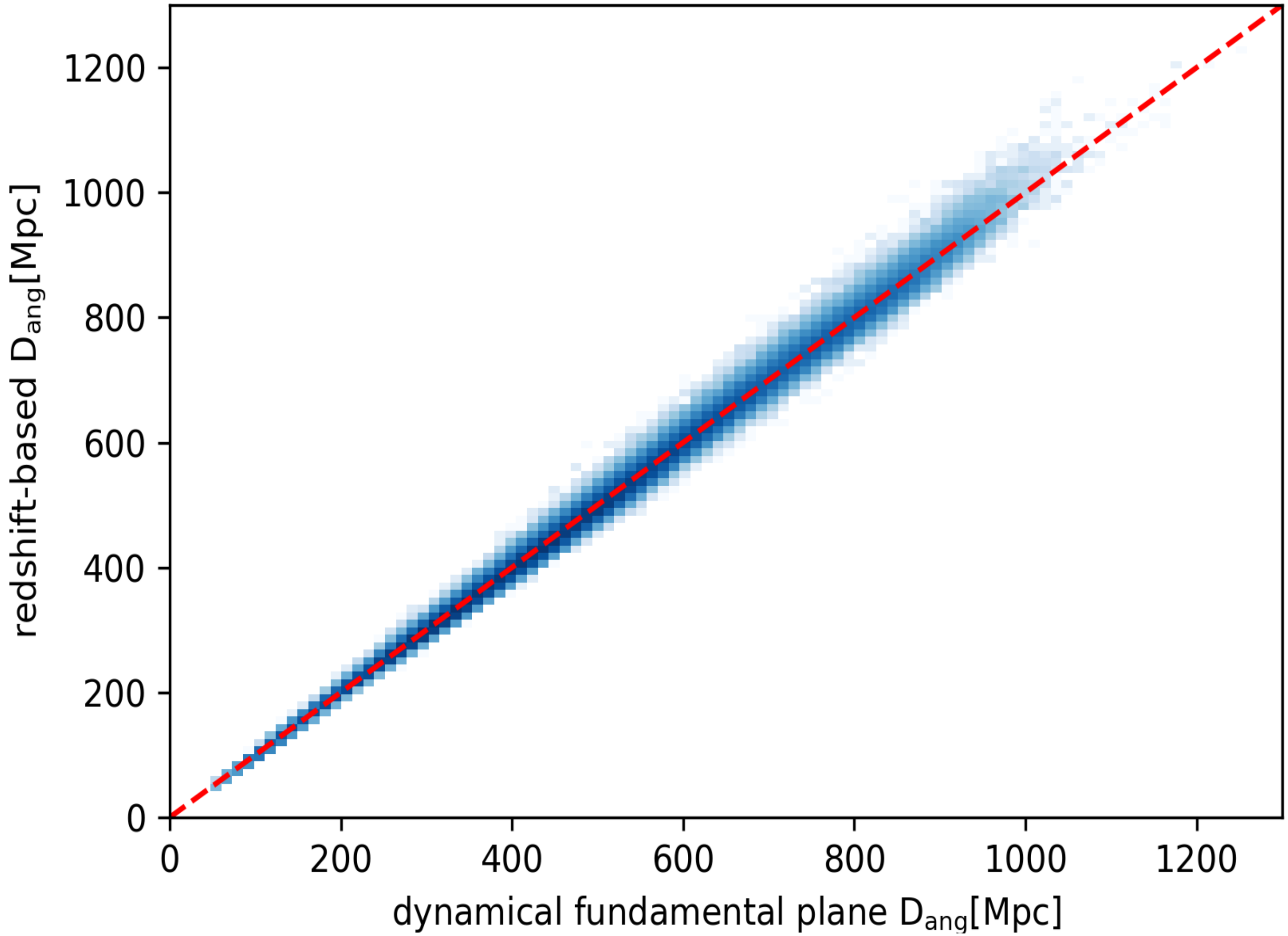
The dynamical fundamental plane

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

Value ranges of coefficients are different due to slightly limited range of FP-parameters



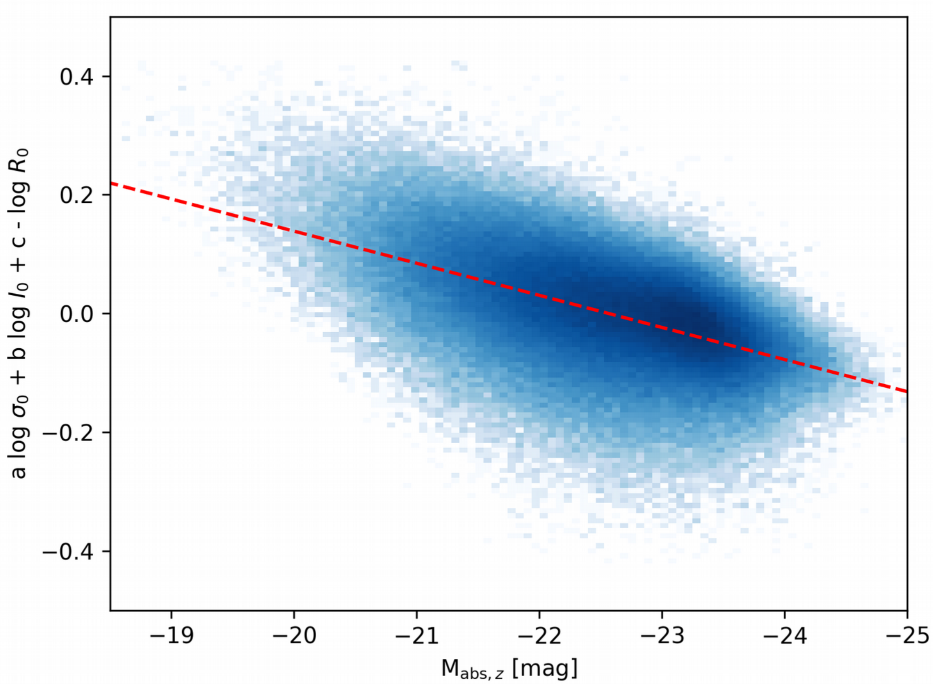


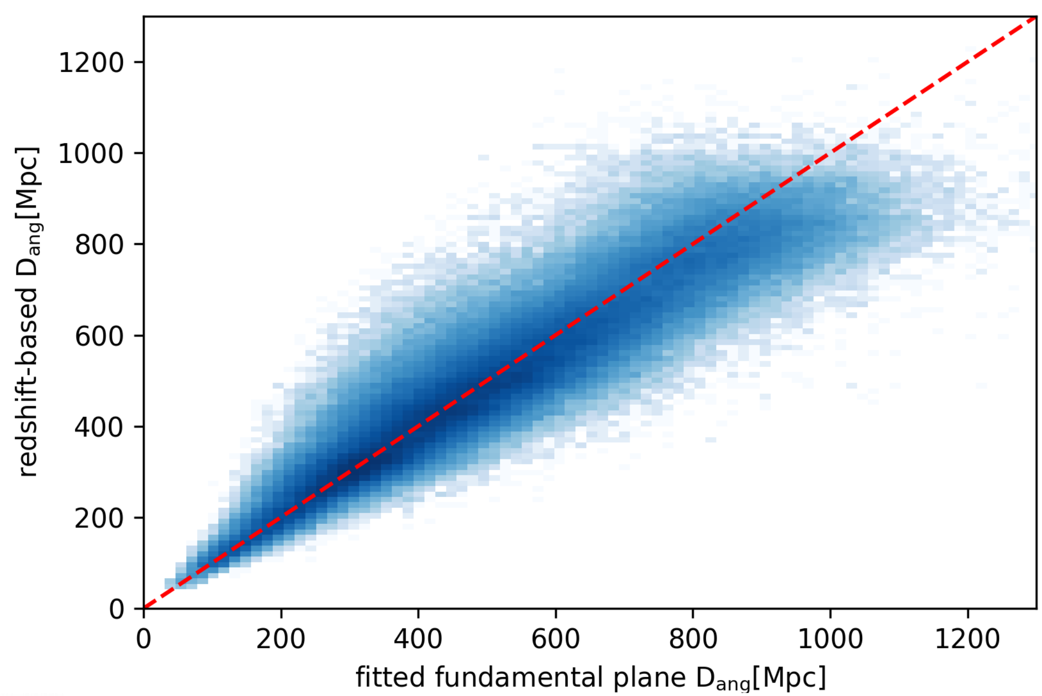


- 290 000 (redshift-independent ?) distances with 5% accuracy (including systematics) compared to redshift-distances
- ~9%, if compared to SN Type Ia and Tully-Fisher

Alternative: direct correction for absolute magnitude bias

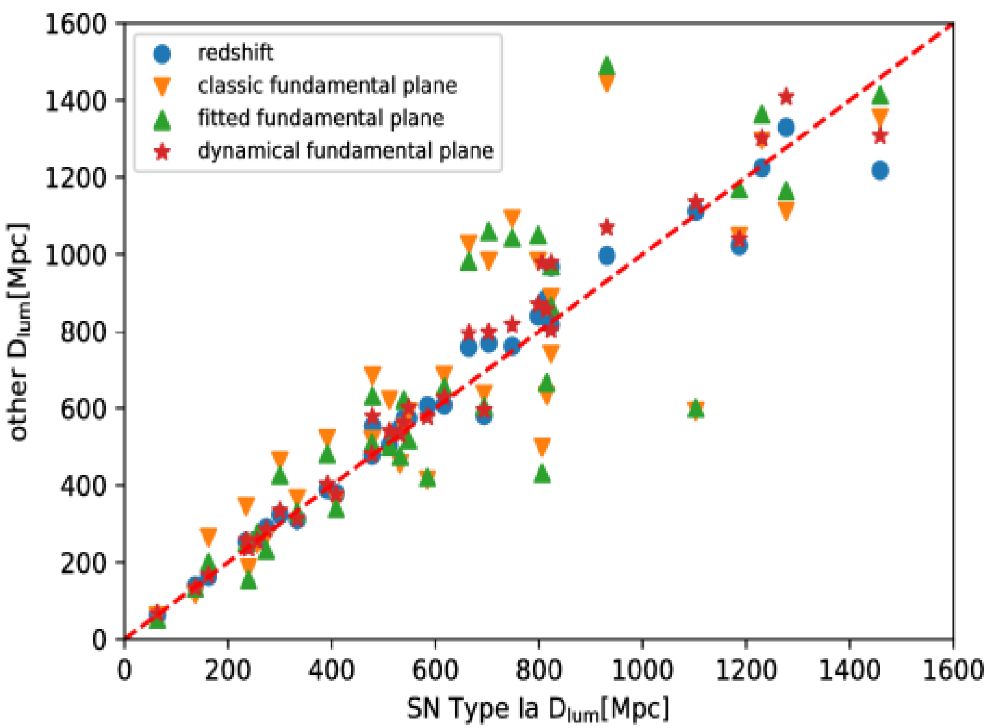
- Using a fit on the absolute magnitude systematic bias to correct for it
- Room for improvement, maybe use stellar masses
- Distance error down to 15%

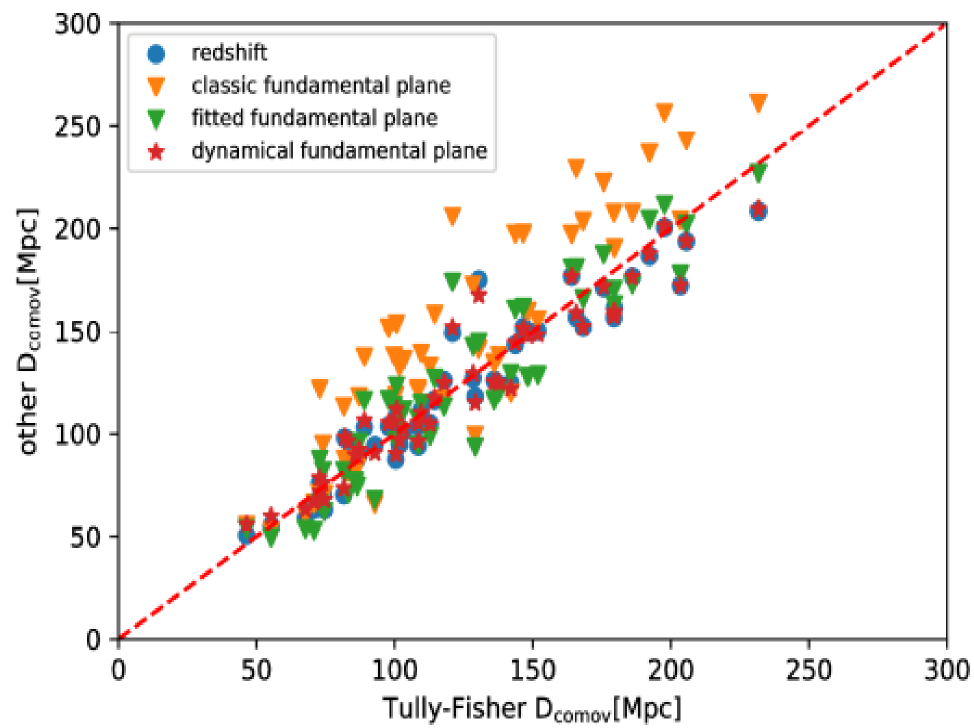




Comparison to other distance indicators

- 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
- Improved FP calibrations generally agree well with TF



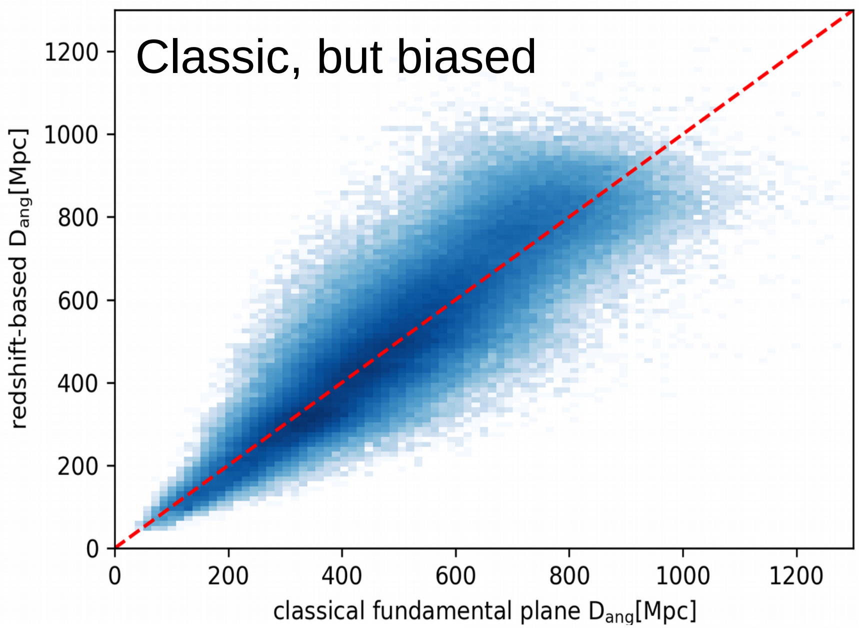


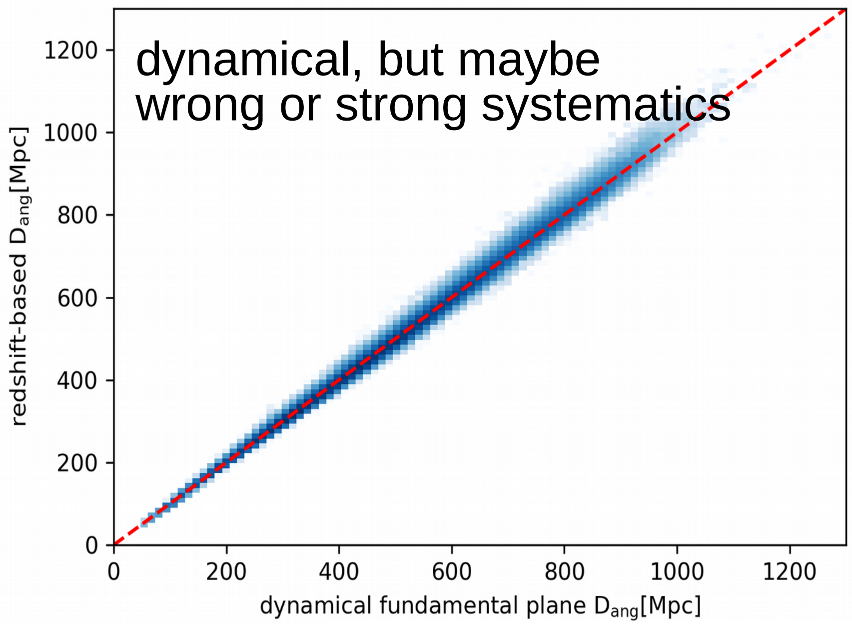
Summary

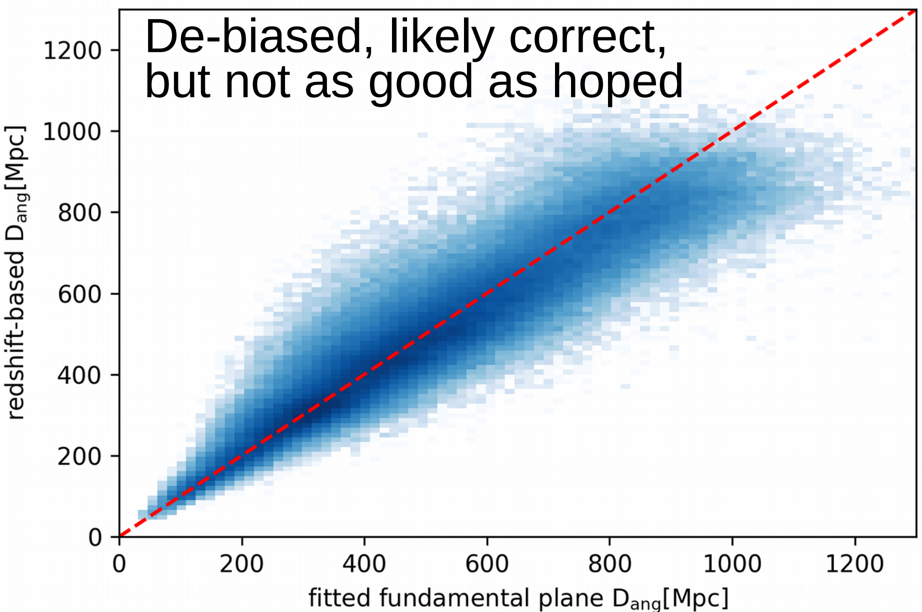
- Magnitude limited surveys are naturally biased
- Classic fundamental plane is biased
- Different ways to improve upon it, but methods yet untested
- Unidentified systematic biases
- But interesting agreement with Tully-Fisher data
- Different Fundamental planes based on how they are fitted … what do you want to do with it?

- **Choose your application, pay the bias**

ANY QUESTIONS?





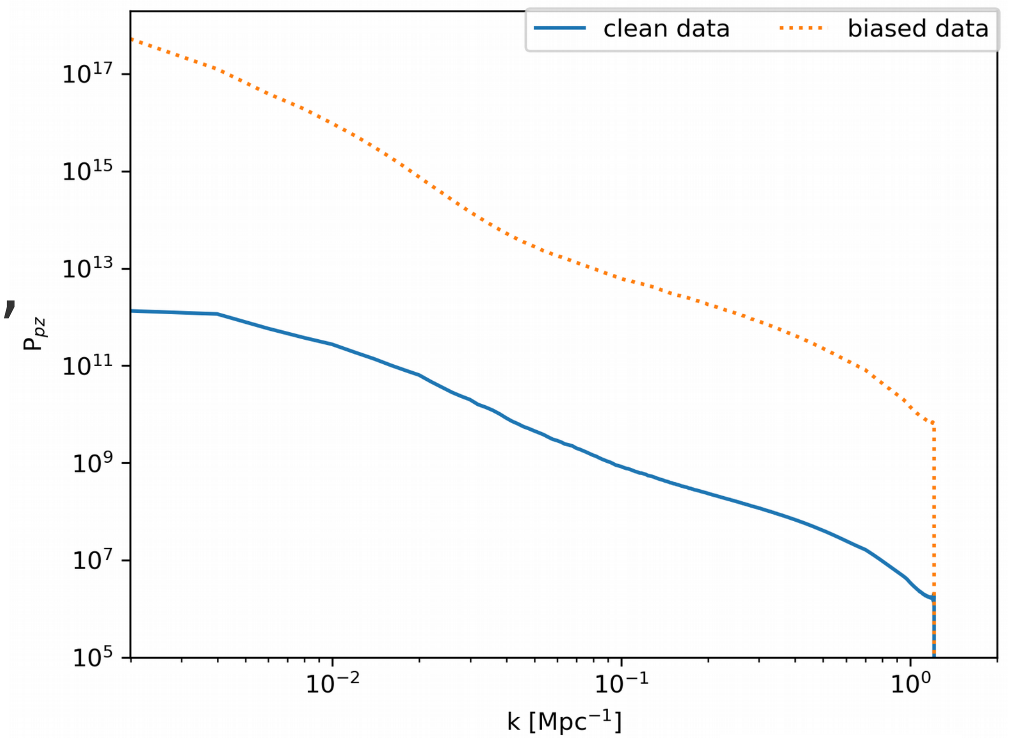


ADDITIONAL SLIDES

for possible questions

Peculiar motions in numerical simulations

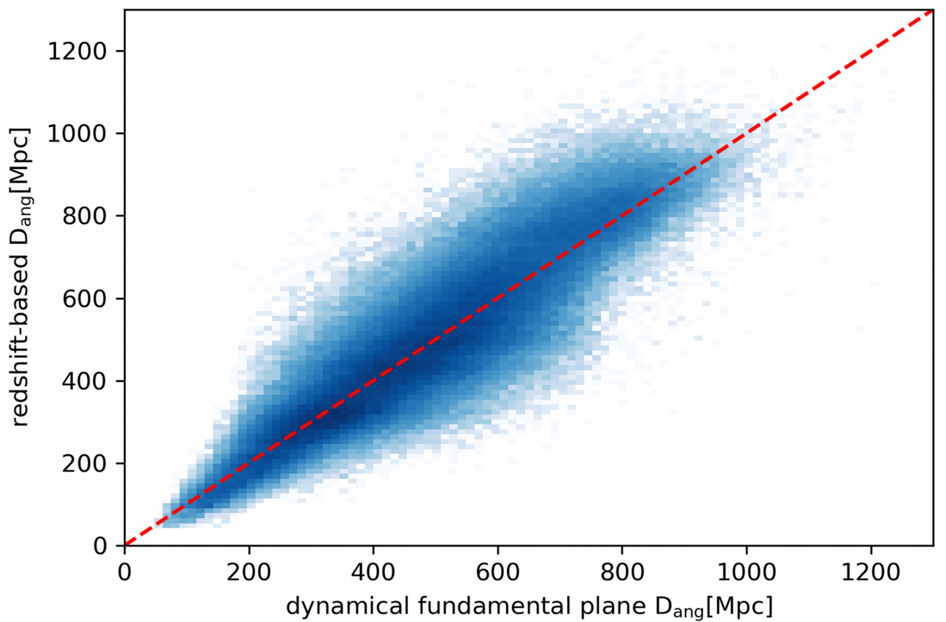
- Future goal: measure the $\beta = \Omega_m/b$ parameter (Park 2000)
- Mock catalogues based on the Horizon Run 4



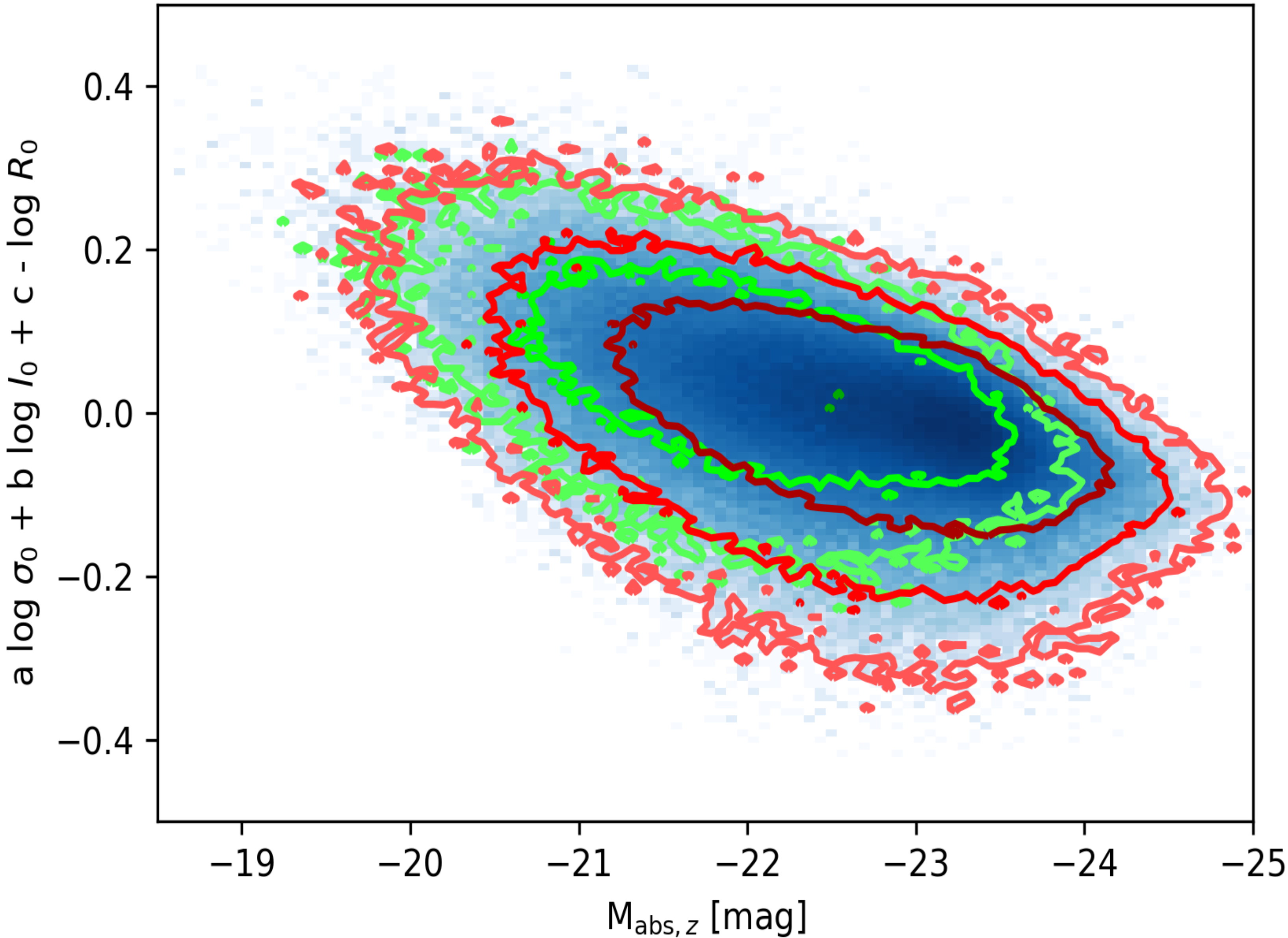
- Difficulty: include all scatters, selection effects, and systematics correctly in the simulated data
- Cosmological comparison using the MultiVerse simulations

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,
  but things do not
  look too good.

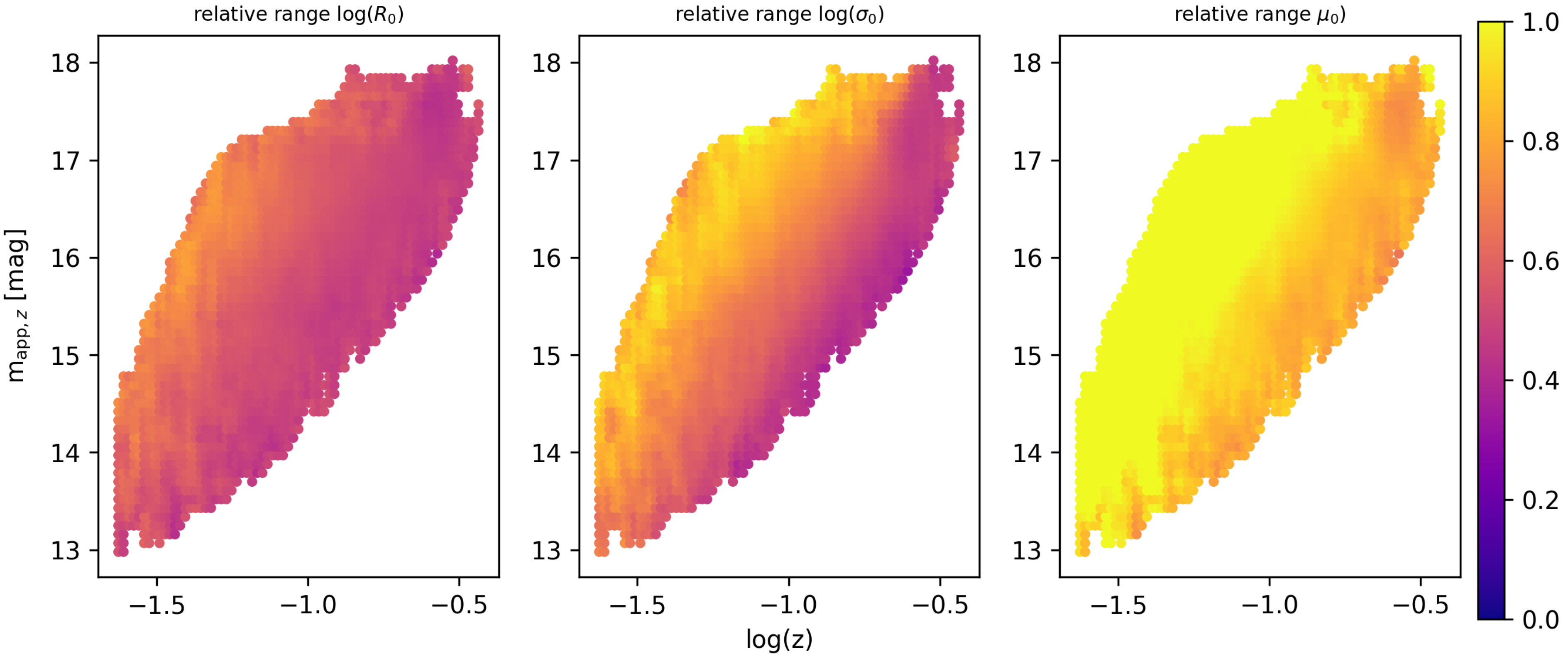


Environmental dependence of the fundamental plane



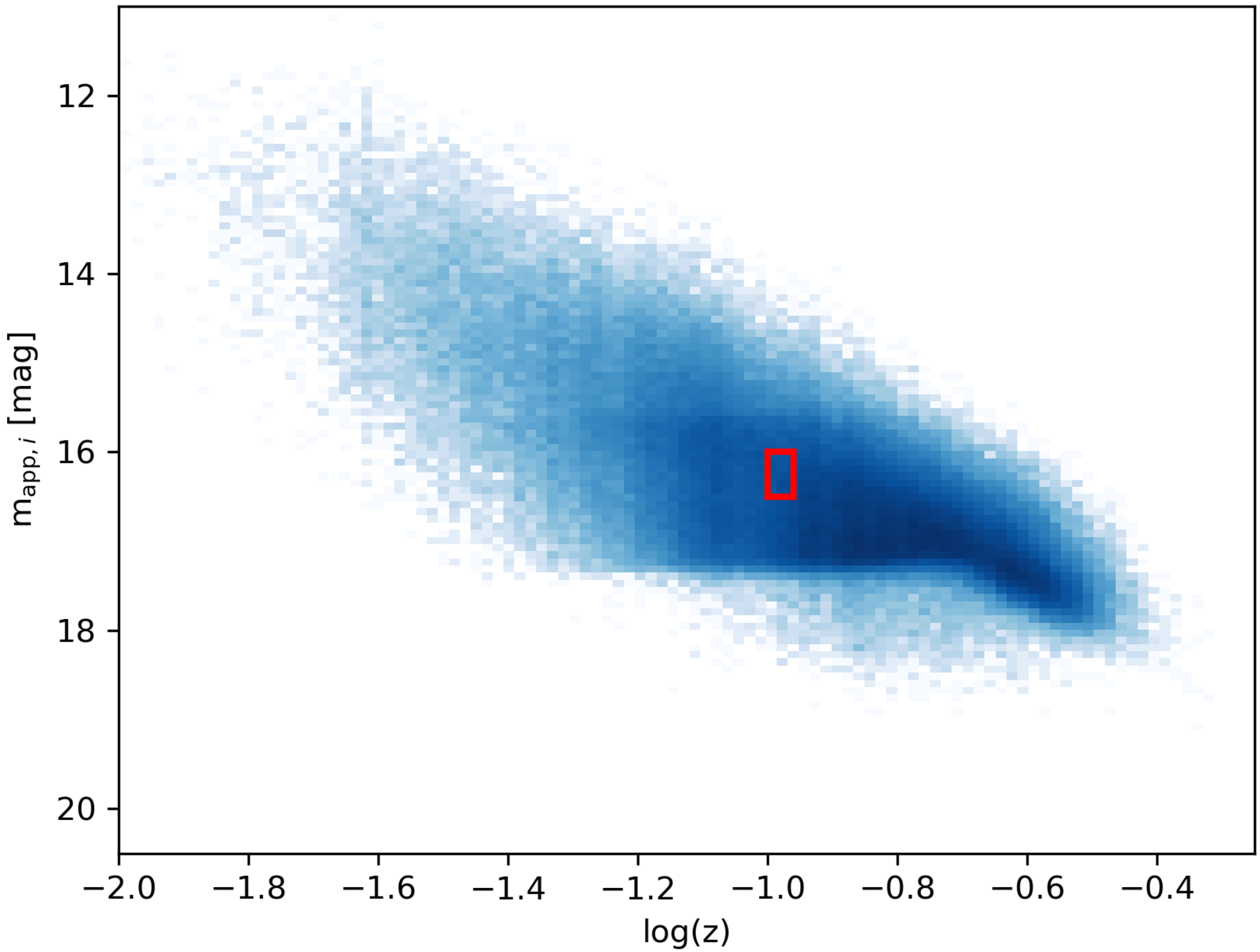
Limitations in parameters due to the dynamical fundamental plane binning

- Reduces the range of sizes by about 50%, while surface brightnesses are barely affected.



Bin sizes

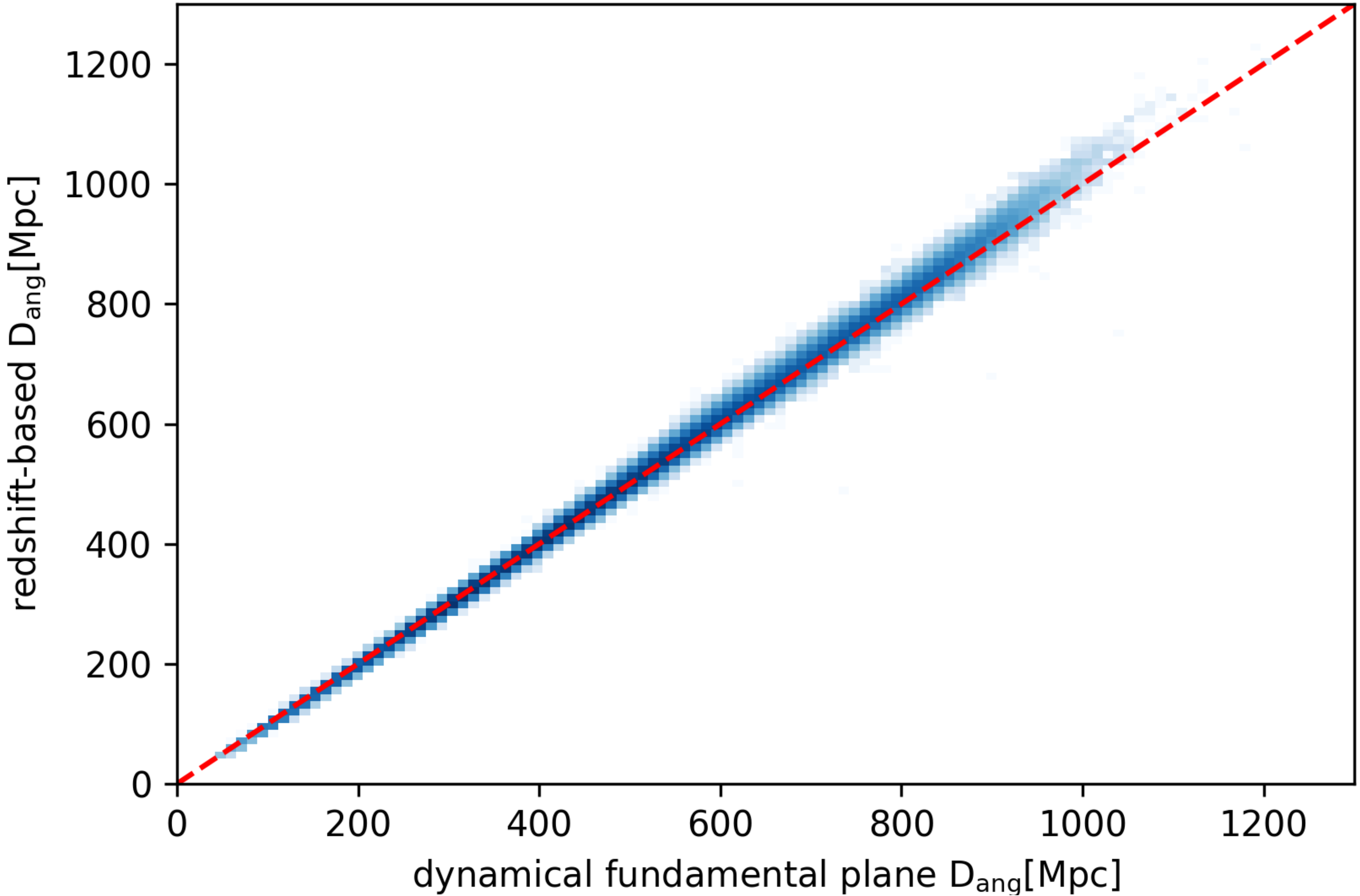
- 0.5 mag x 0.4 in log(z)



Classical fundamental plane redshift dependences

- Tolman effect: surface brightness dimming according to General Relativity $(1+z)^4$
- 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: ($Q \cdot z$ … Bernardi+ 2003)
- Malmquist bias correction: corrections for selection effects in magnitude limited surveys

Stellar mass (absolute magnitude, colour) dynamical fundamental plane



Generally similar to our other approach … not sure what is better