

The fundamental plane and peculiar motions in the local universe

Christoph Saulder

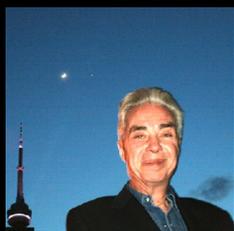
(Korea Institute for Advanced Study)

Alpine Cosmology Workshop
July 2 2019, La Berarde, France

Collaborators



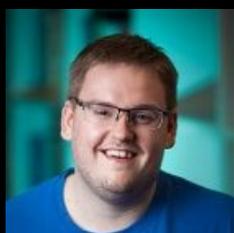
Christoph Saulder (KIAS)



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Owain Snaith (Paris Observatory)



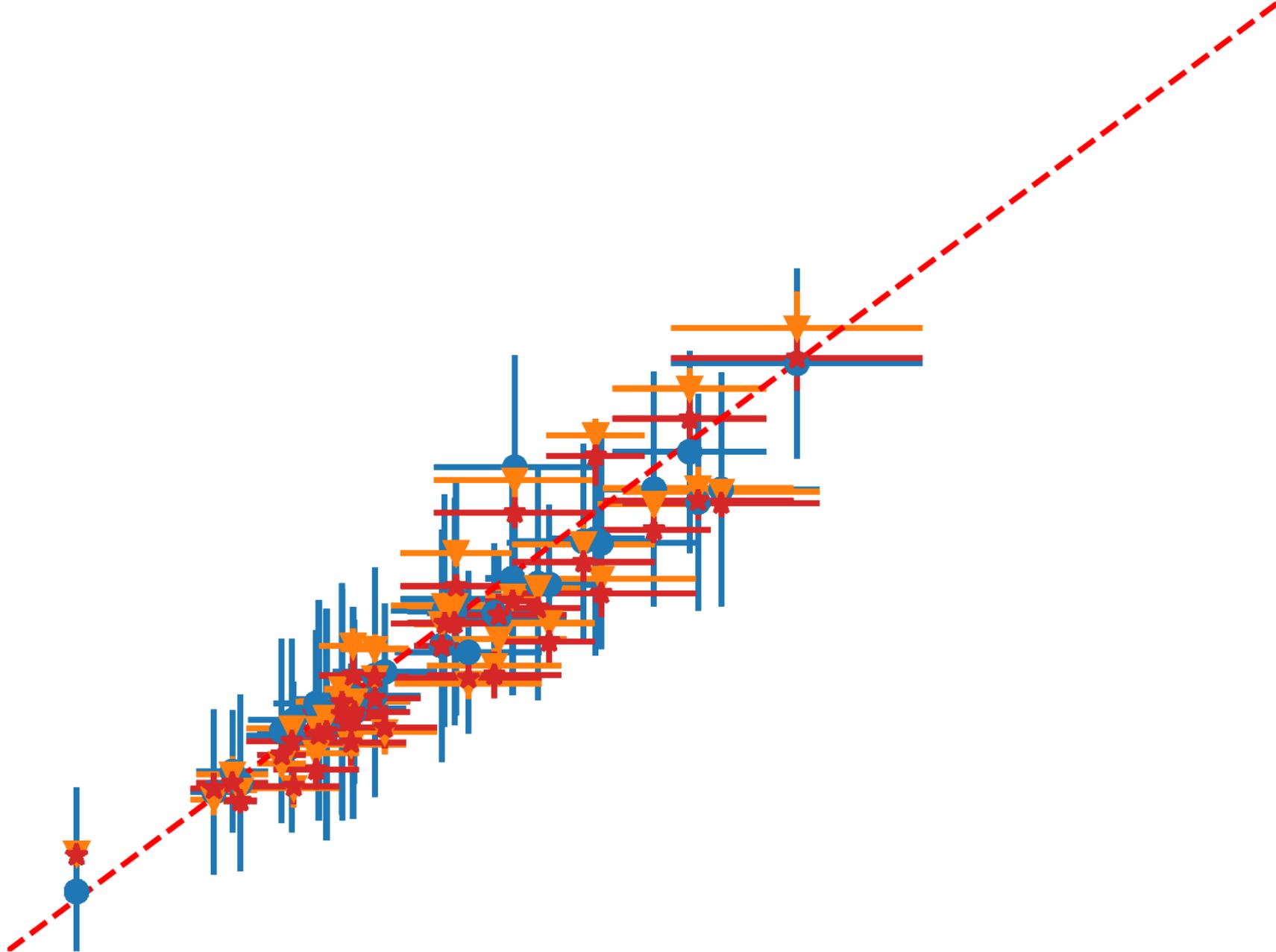
Cullan Howlett (University of Queensland)



Changbom Park (KIAS)

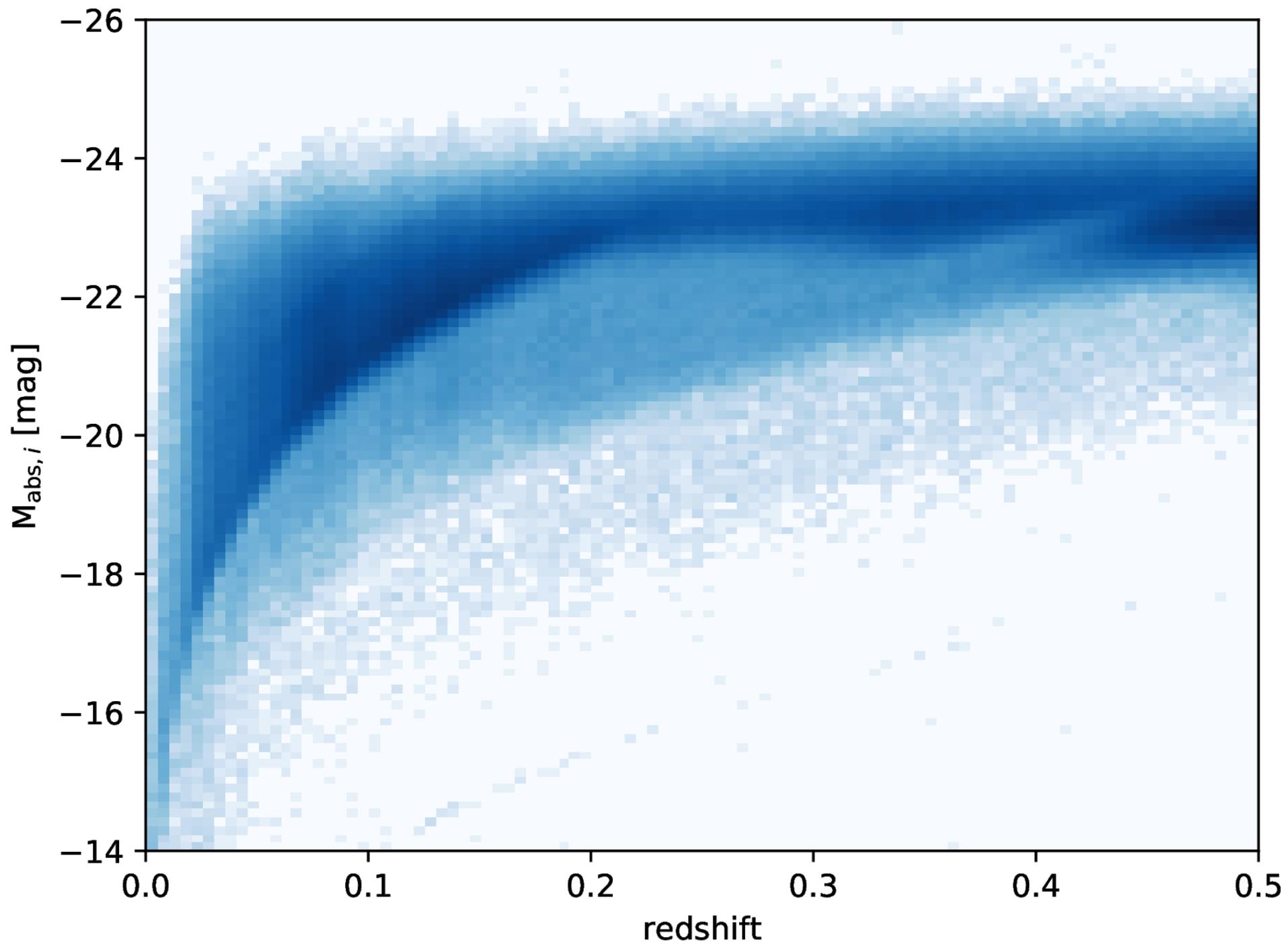


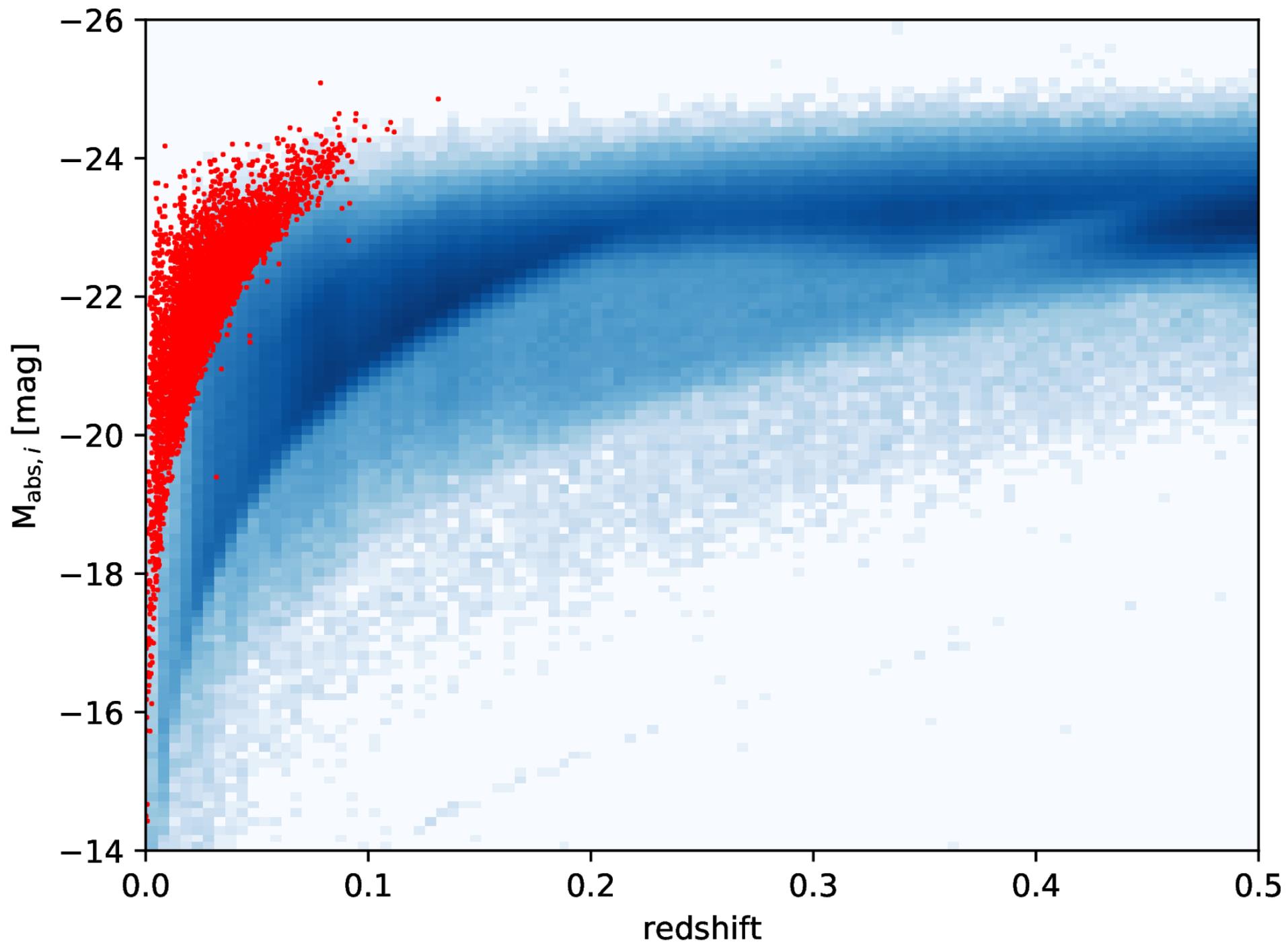
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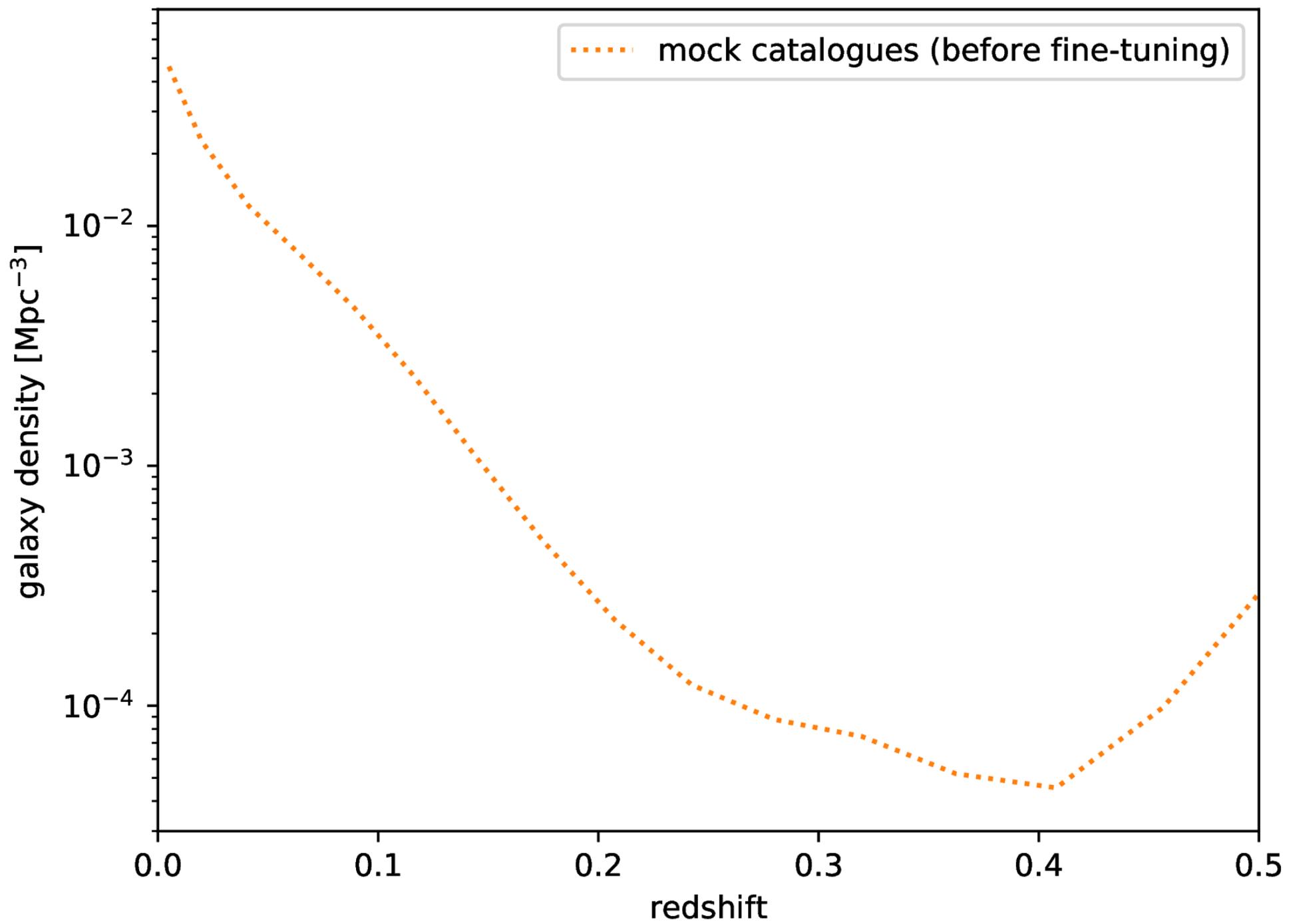


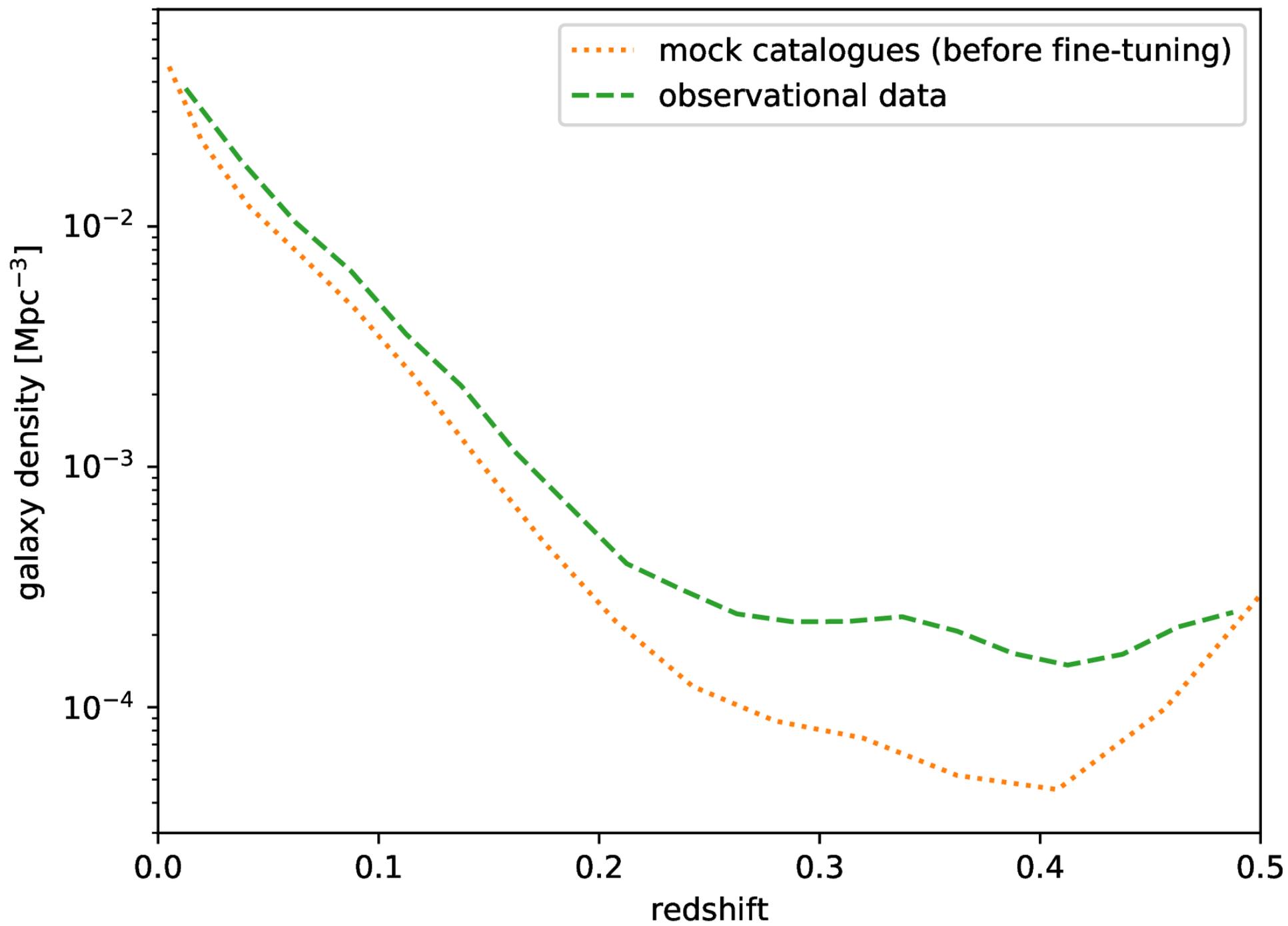
Group catalogue

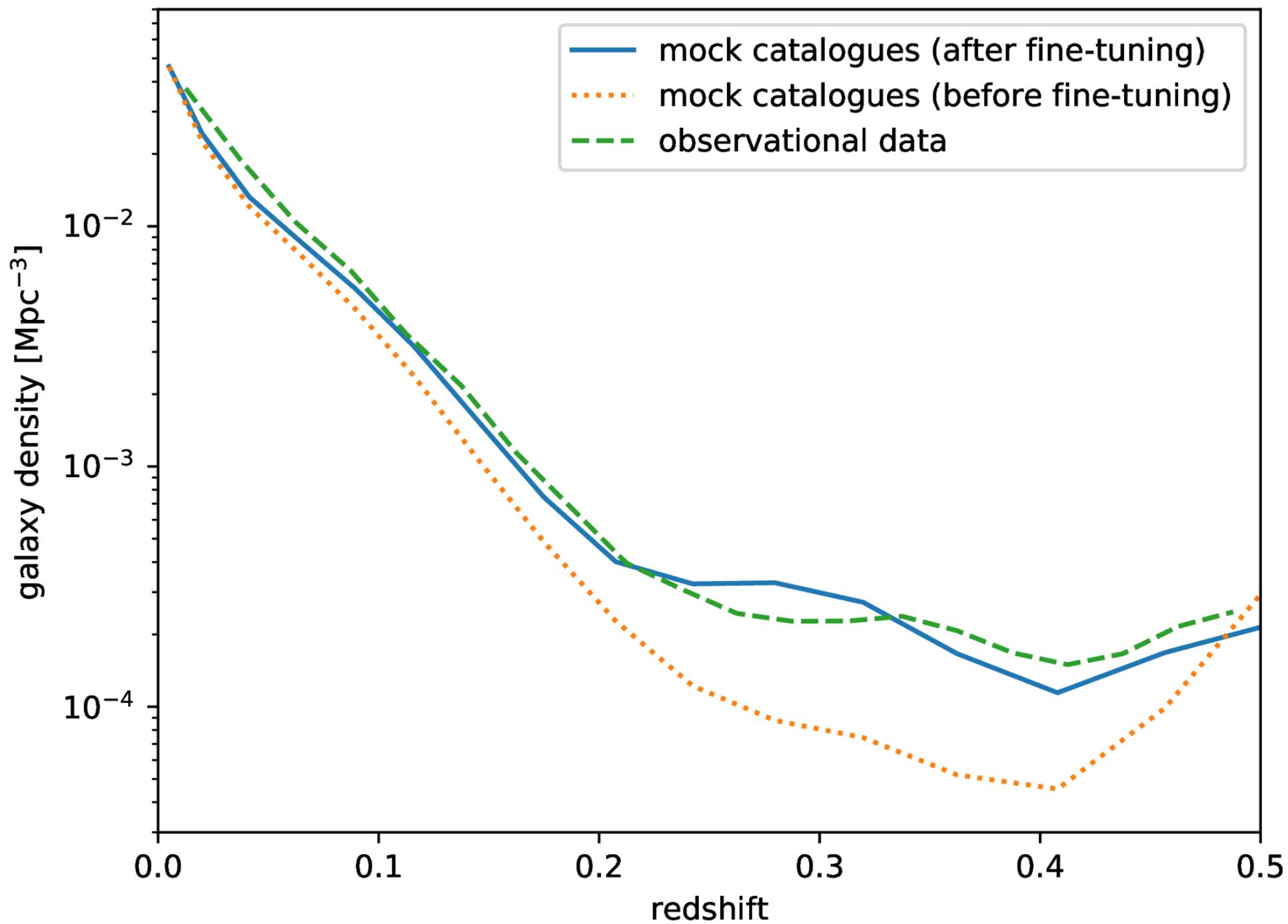
- Improving our special purpose group catalogue from Saulder+2016 and expanding it beyond $z=0.1$
- SDSS DR15
 - SDSS spectroscopic footprint (9 376 square degree)
 - Redshift up to $z=0.5$
- 2MRS (2MASS Redshift Survey)
 - Within the SDSS coverage
 - Compensate for the saturation bias of the SDSS main galaxy sample
- Linking length optimized using mock catalogues derived from the Millennium simulation (WMAP7 rerun by Guo+2011)

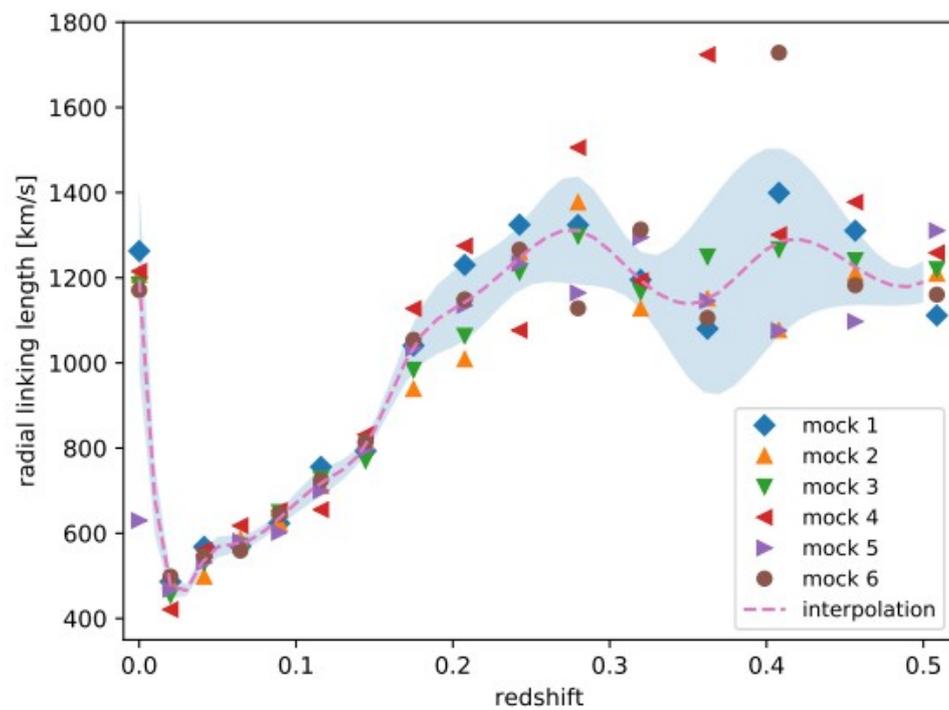
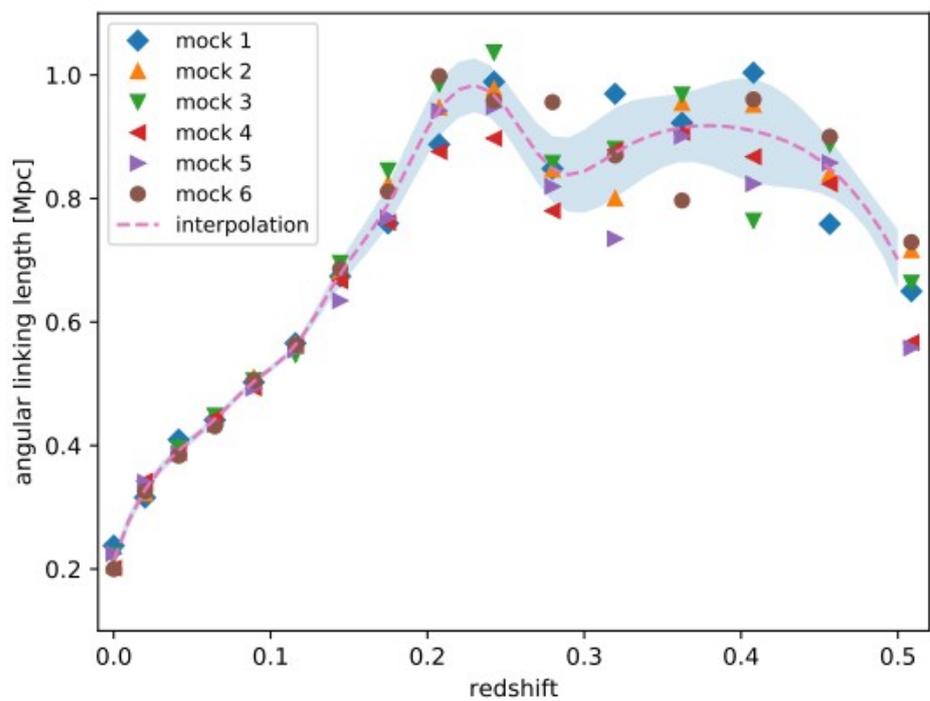
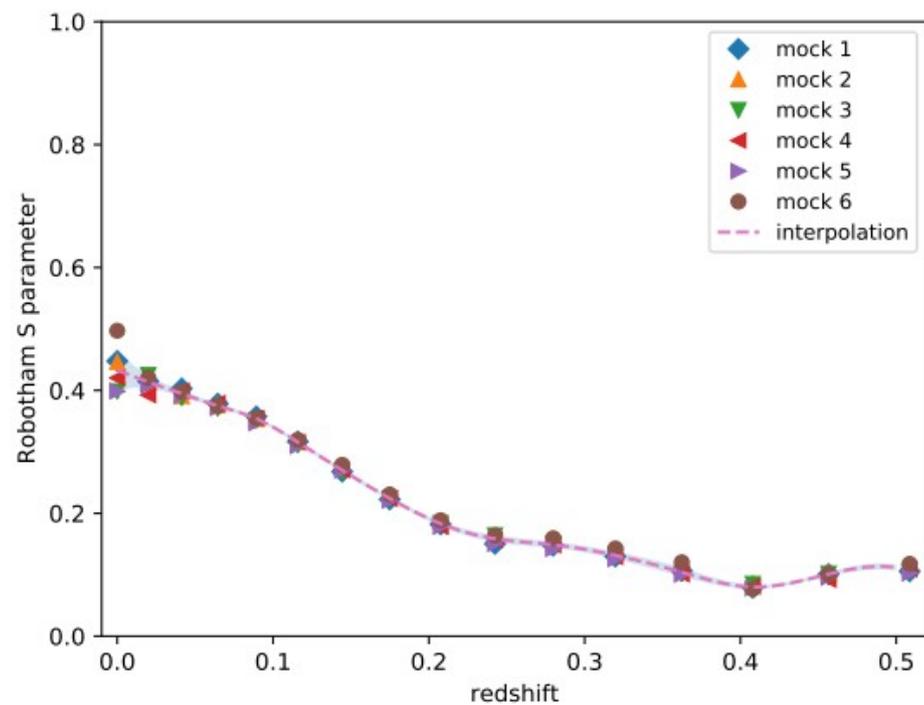
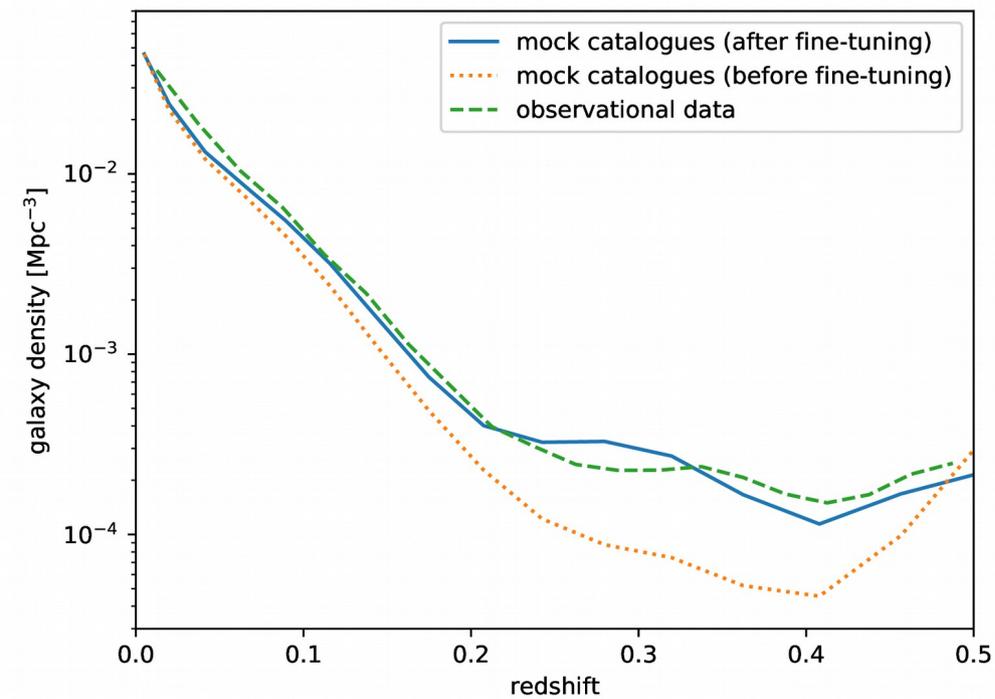






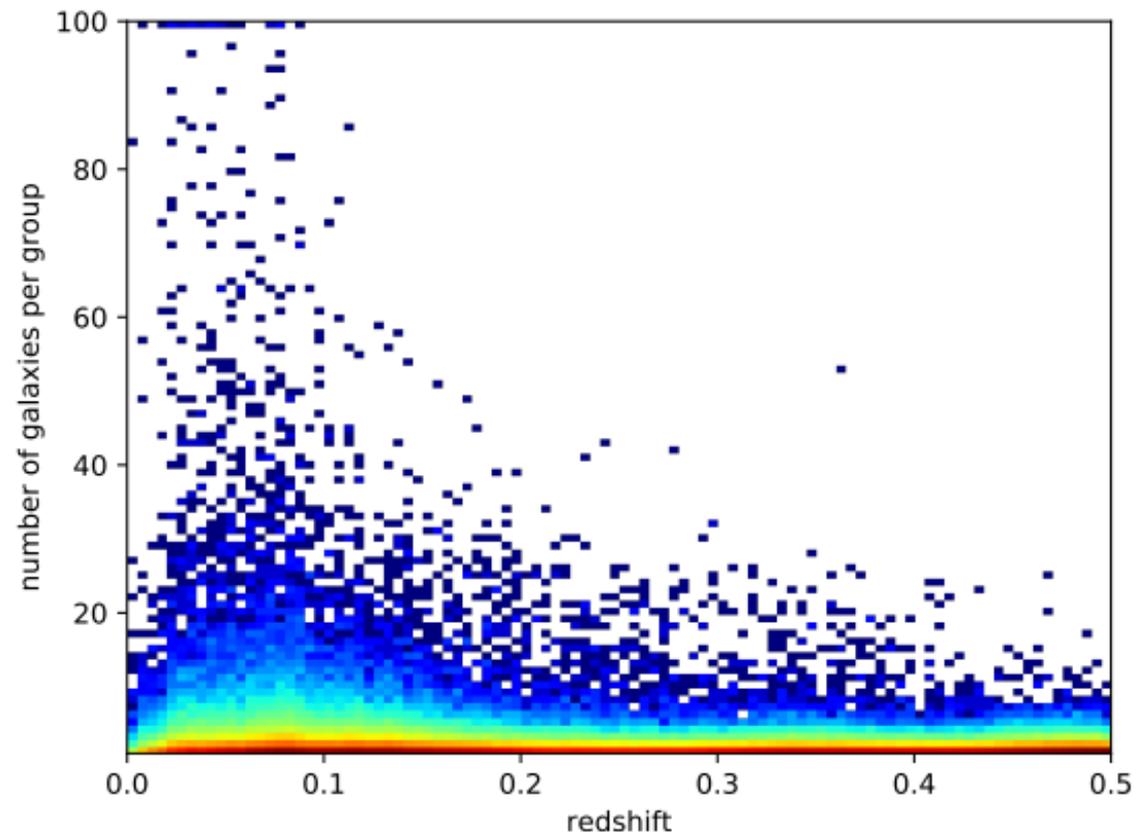






Statistics

- 1 480 600 galaxies in our group catalogue
- 997 161 individual galaxies (or groups with only one detectable member)
- 165 132 groups
- 3 467 clusters with $N \geq 10$
- 25 clusters with $N \geq 100$



Traditional fundamental plane

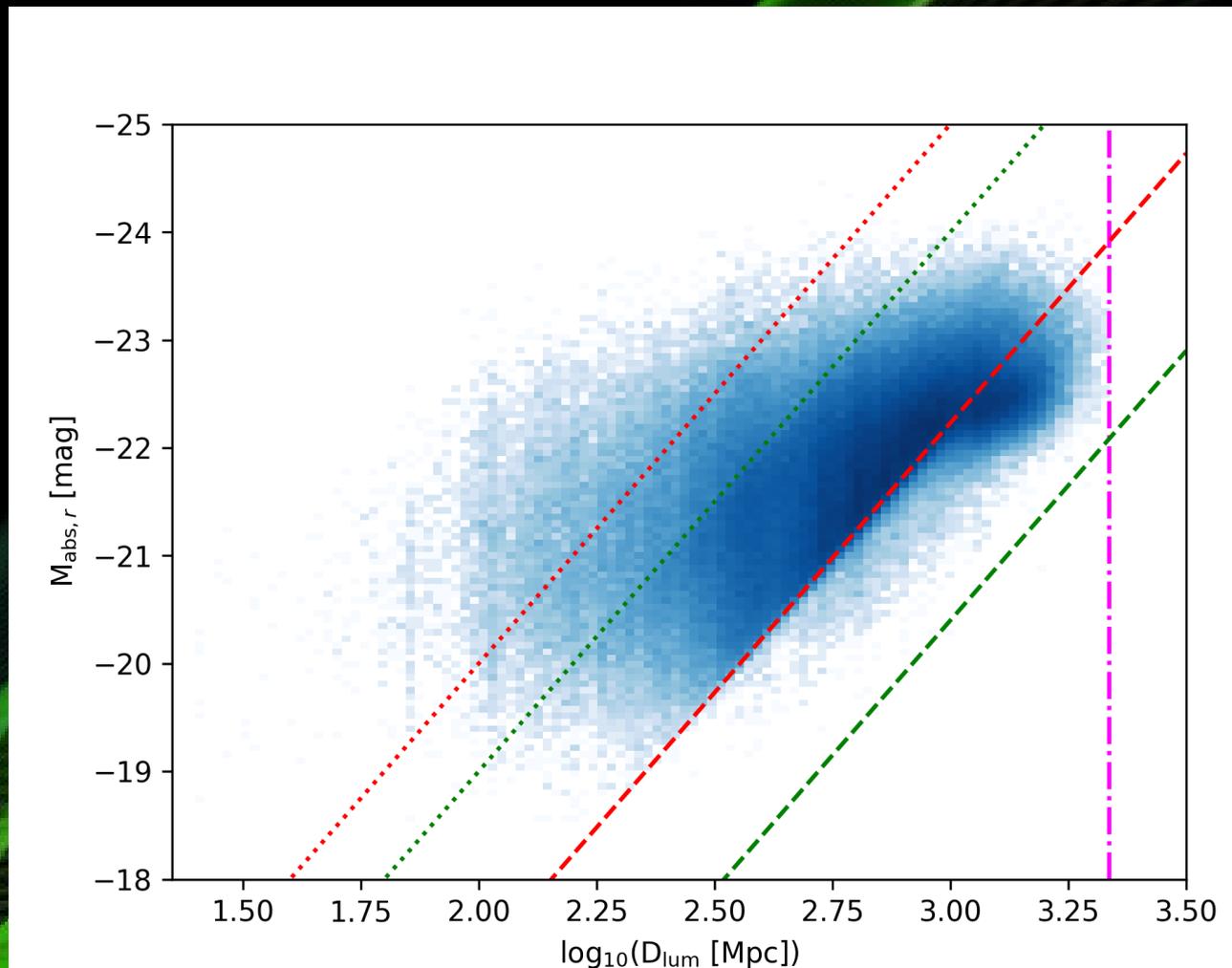
- Empirical relation between two redshift-independent observables and one distance dependent quantity (Dressler+ 1987, Djorgovski&Davis 1987)

$$\log_{10}(R_e) = a \cdot \log_{10}(\sigma_0) + b \cdot \mu_e + c$$

- Standard rod for early-type galaxies
 - comparing observed sizes with predicted sizes
 - angular diameter distances
- 320 309 suitable early-type galaxies in SDSS DR15
largest dataset every used for the fundamental plane

Sample selection

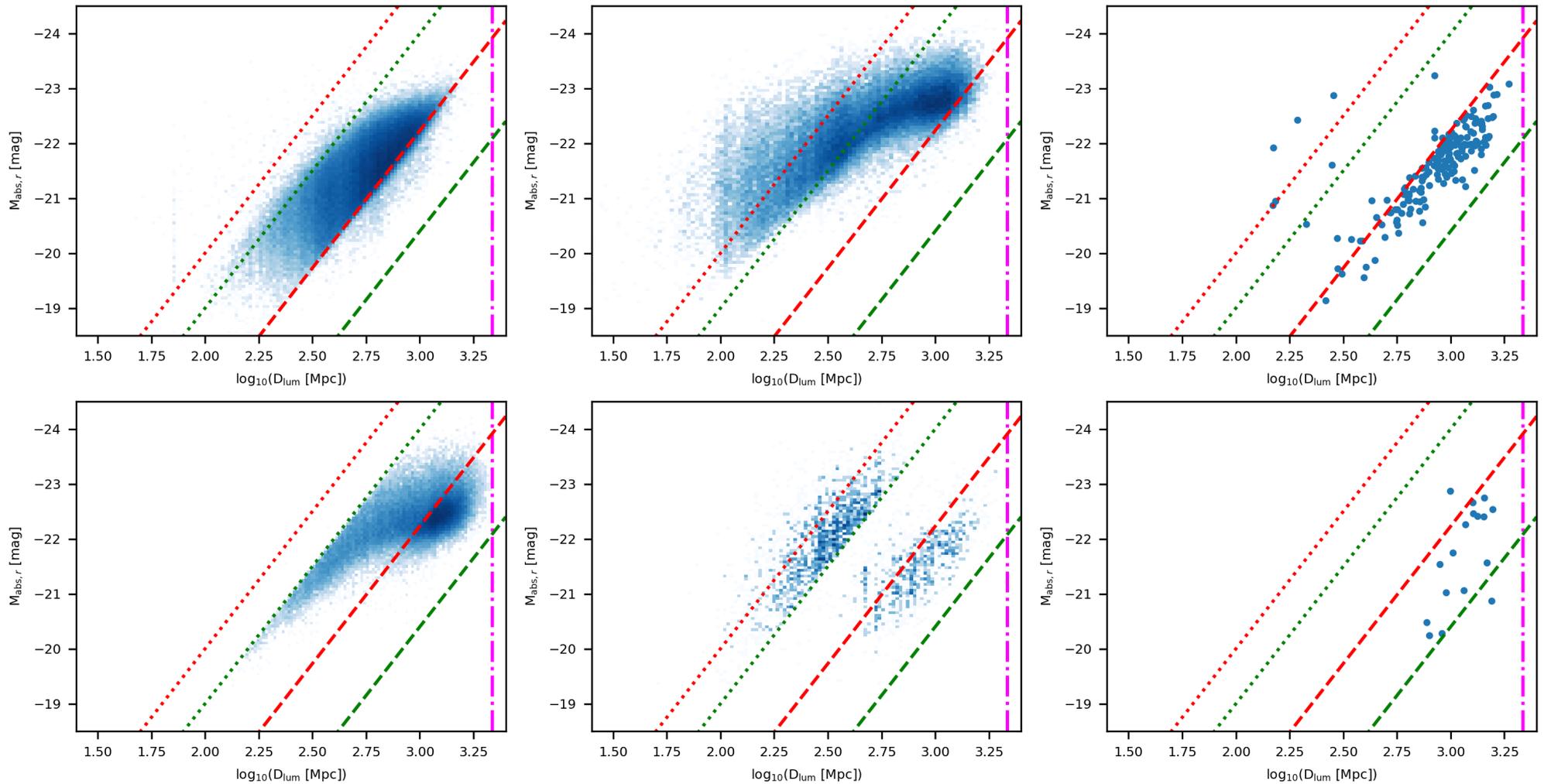
- Higher likelihood for de Vaucouleurs profile than exponential profile
- Colour cuts
- $\sigma > 100\text{km/s}$
- Quality controls
- Outlier removal
- 320 309 ETGs in SDSS/BOSS



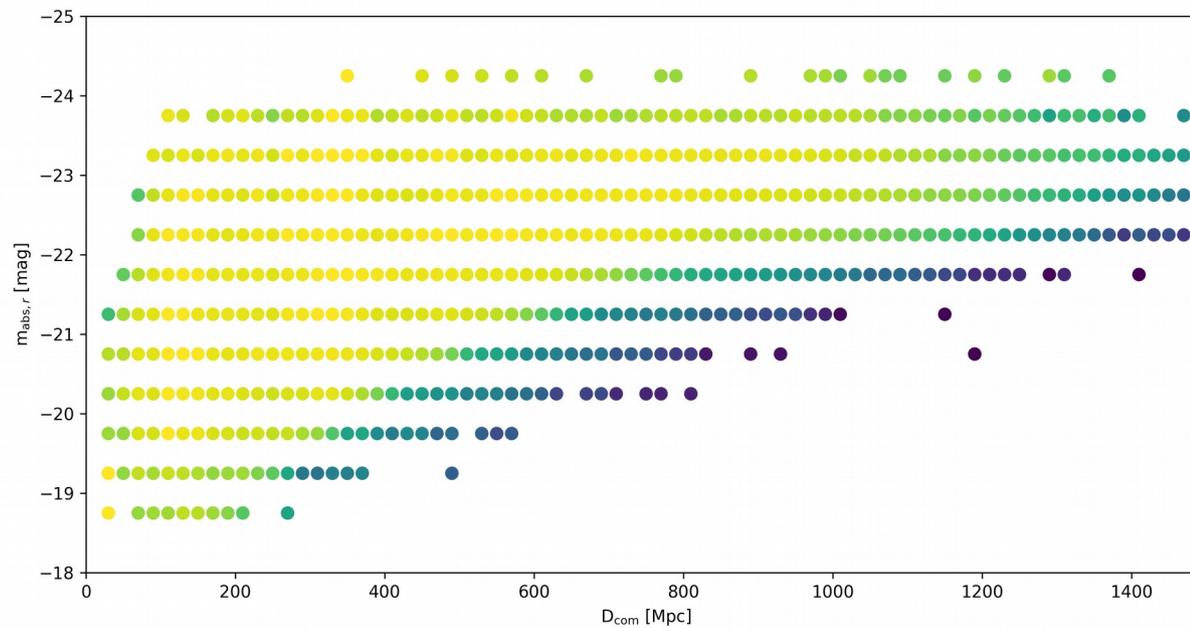
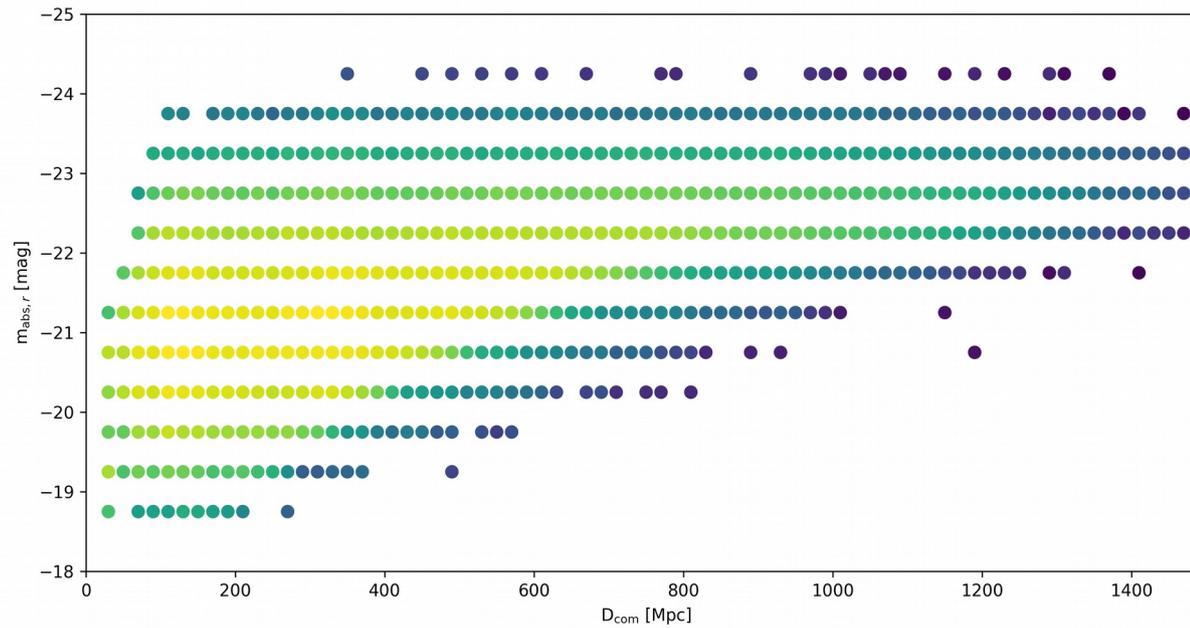
Preparing for the fundamental plane

- Applying basic calibrations and corrections to all the data retrieved from SDSS:
- Corrections for galactic extinction (Schlegel+ 1998)
- K-corrections (Chilingarian+ 2010)
- Evolution corrections for magnitudes (our own based on Bernardi+ 2003), sizes and velocity dispersions (Beifiori+ 2014)
- Corrections for fixed fibre sizes (Jorgensen+ 1995, Wegner+ 1999)
- Calculating the fundamental plane parameters:
- R_e , σ_0 , and μ_e

Subsets of our ETG sample



Density and completeness

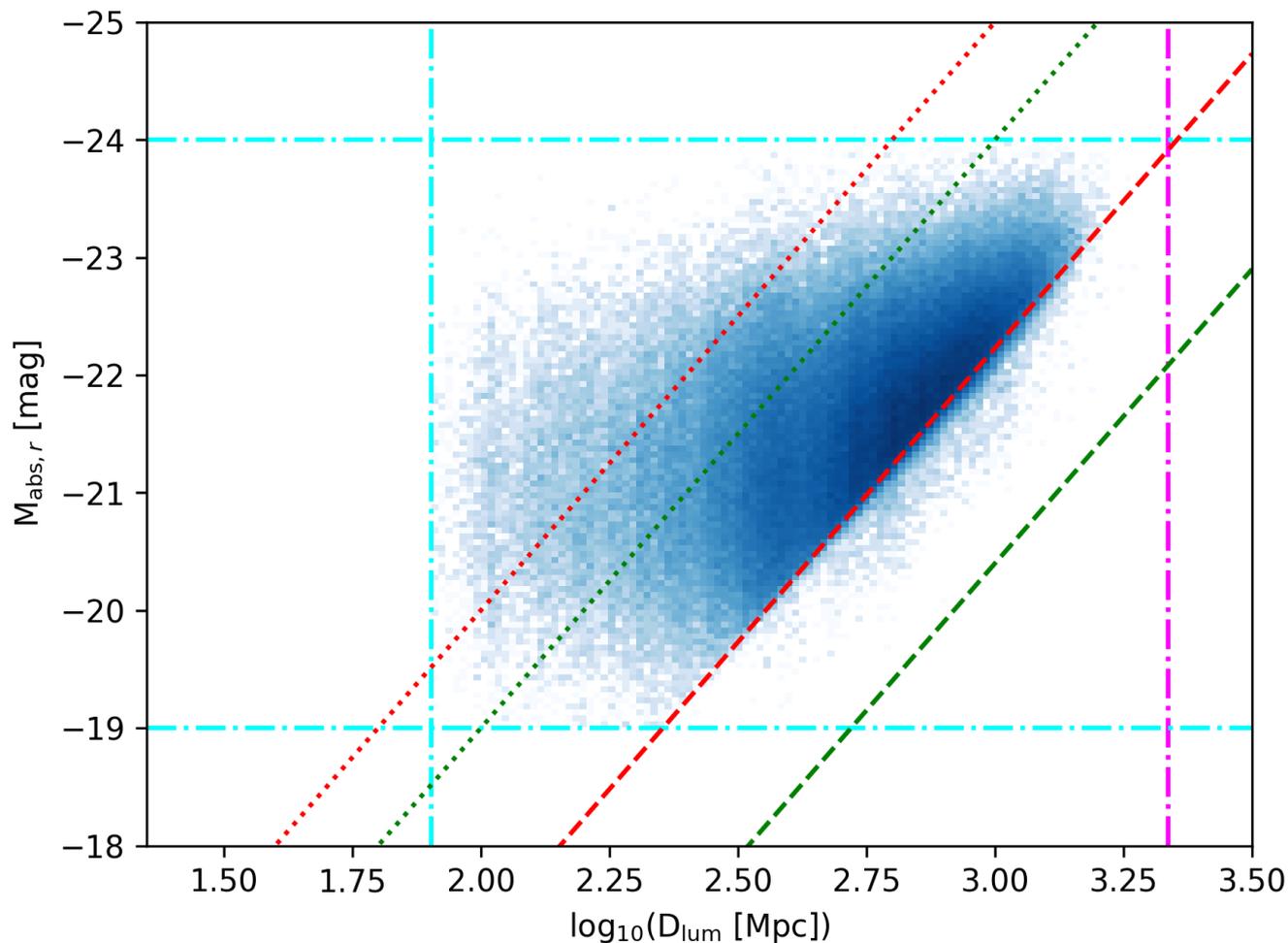


Calibration sample

- Well-defined subsample based on the SDSS main galaxy sample with additional cuts

- 242 269

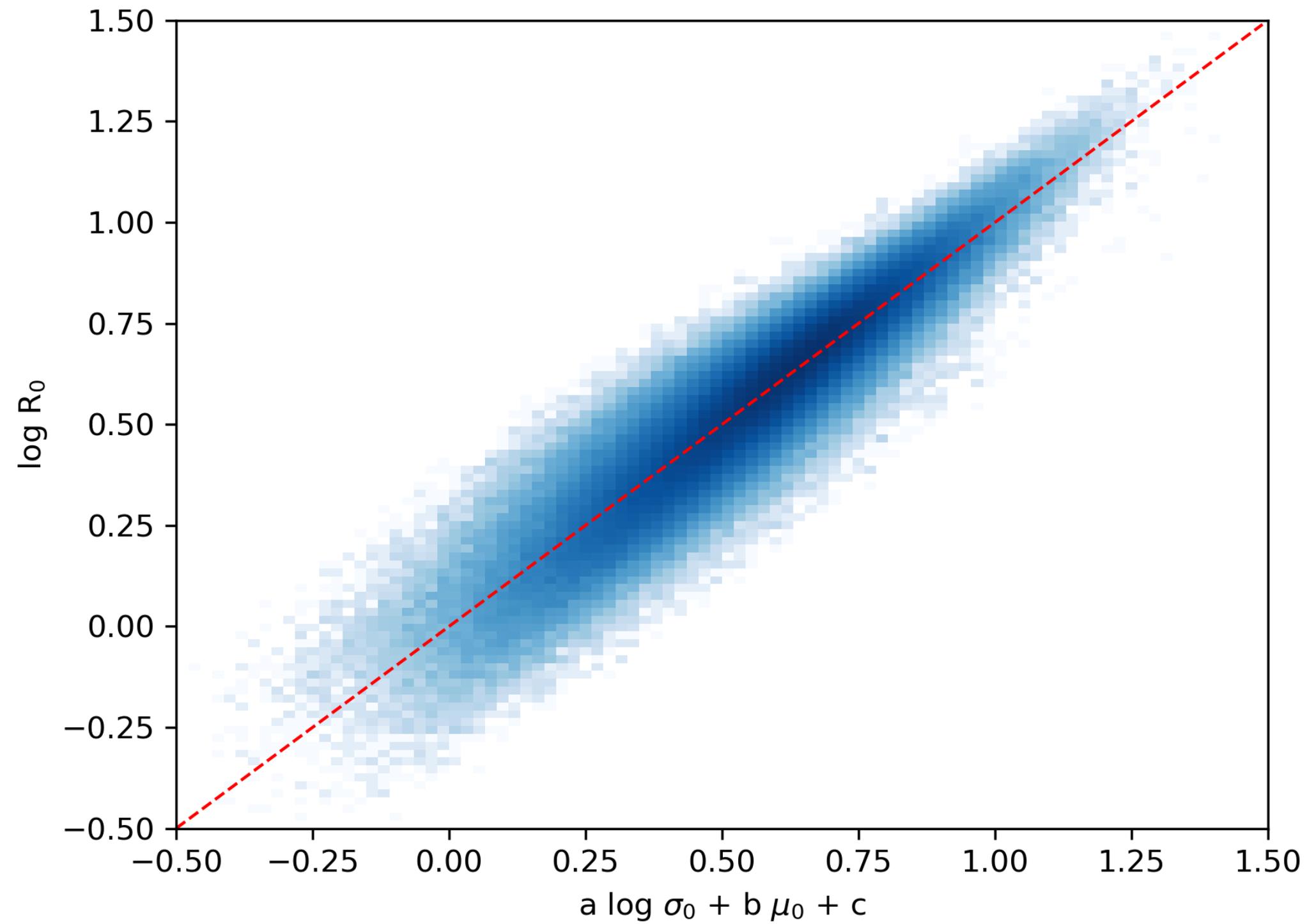
ETGs



- Using the best method for distance calibrations:
- Direct fit (minimizing the scatter in radii (Sheth&Bernardi 2013)) using least squares
- Volume-weights to adjust for the Malmquist bias
- → fundamental plane coefficients

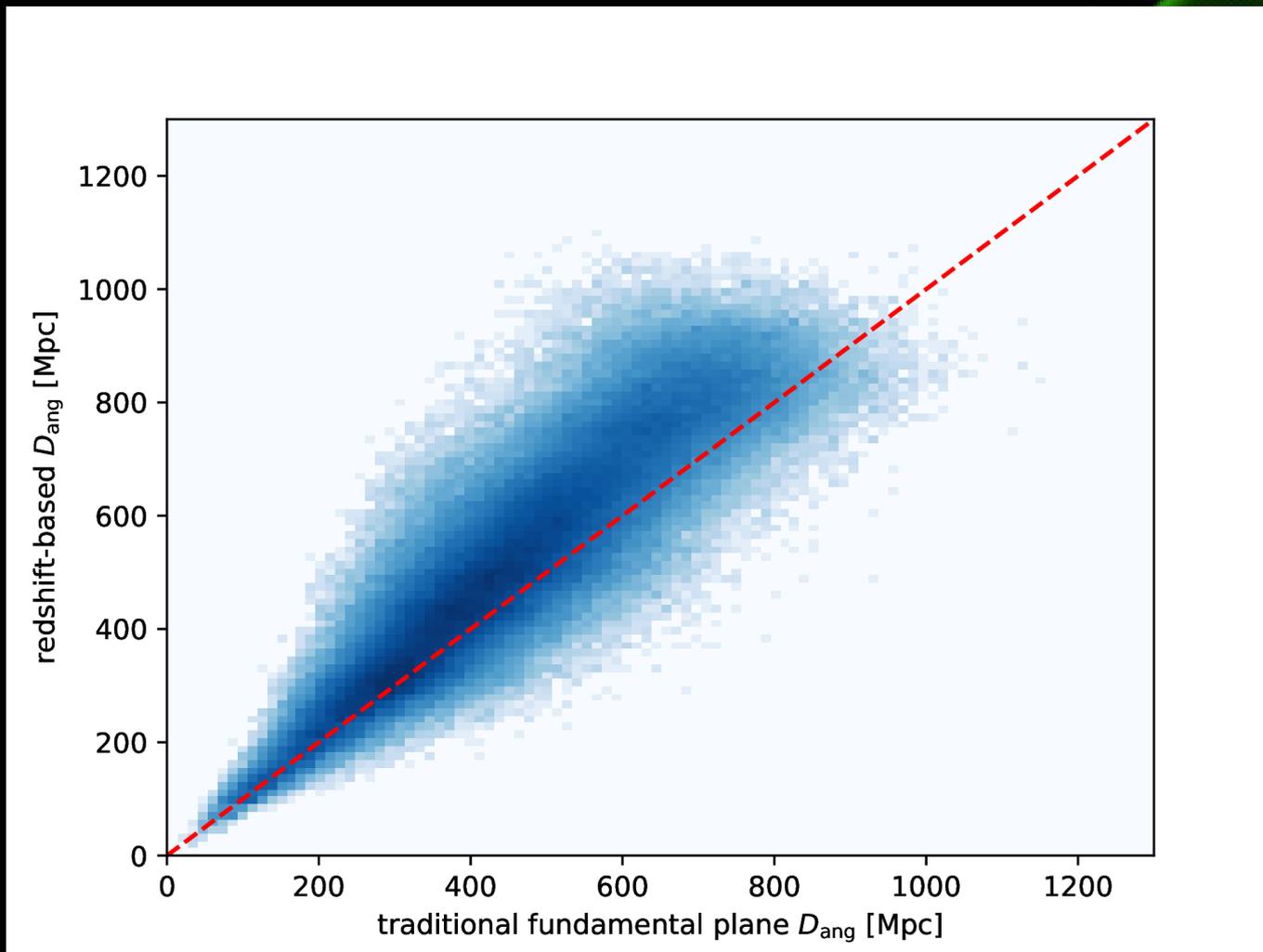
- Applying the coefficients for the entire sample

- Distance accuracy: 20%
- Group catalogue improves it to 18.7%
- 0.2% of it is systematic redshift-dependent bias



Fundamental plane distances

- Scatter of 20.0% without the group catalogue
- Scatter of 18.7% with the group catalogue



Expanded fundamental planes

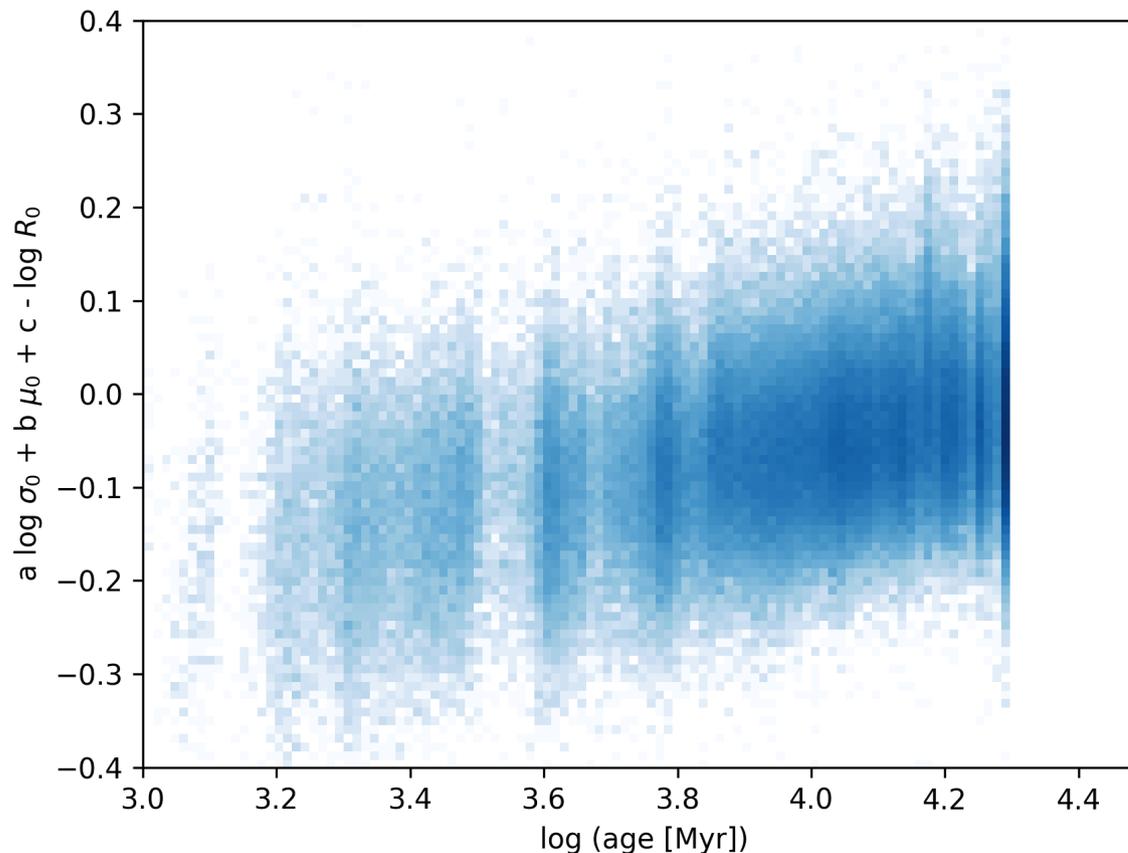
- Additional parameters may contribute to the scatter of the fundamental plane
- Independent parameters are hard to find
- Stellar age the most promising candidate (motivation from both observations (VandeSande+ 2018) and simulations (Lu+ 2019))
- Using the stellar age t_* obtained from simple stellar population models by Chiligarian+ 2016

$$\log_{10}(R_0) = a_{\text{exp}} \log_{10}(\sigma_0) + b_{\text{exp}} \mu_0 + d_{\text{exp}} \log_{10}(t_*) + c_{\text{exp}}$$

- Subsample of 184 203 galaxies (182 913 of them used for the calibrations)

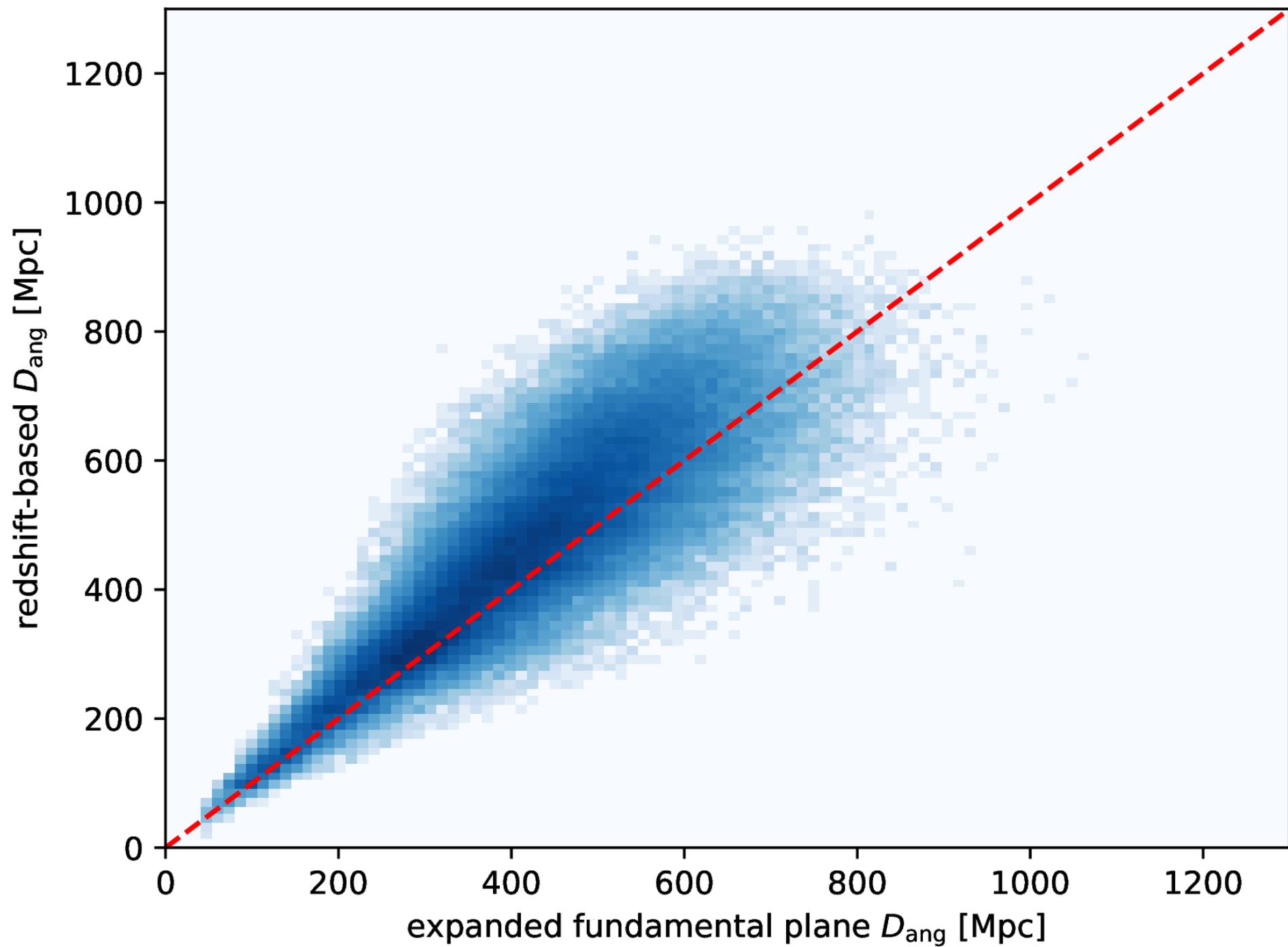
Age dependence

- Clear trends
- Stellar populations contribute to the scatter of the fundamental plane



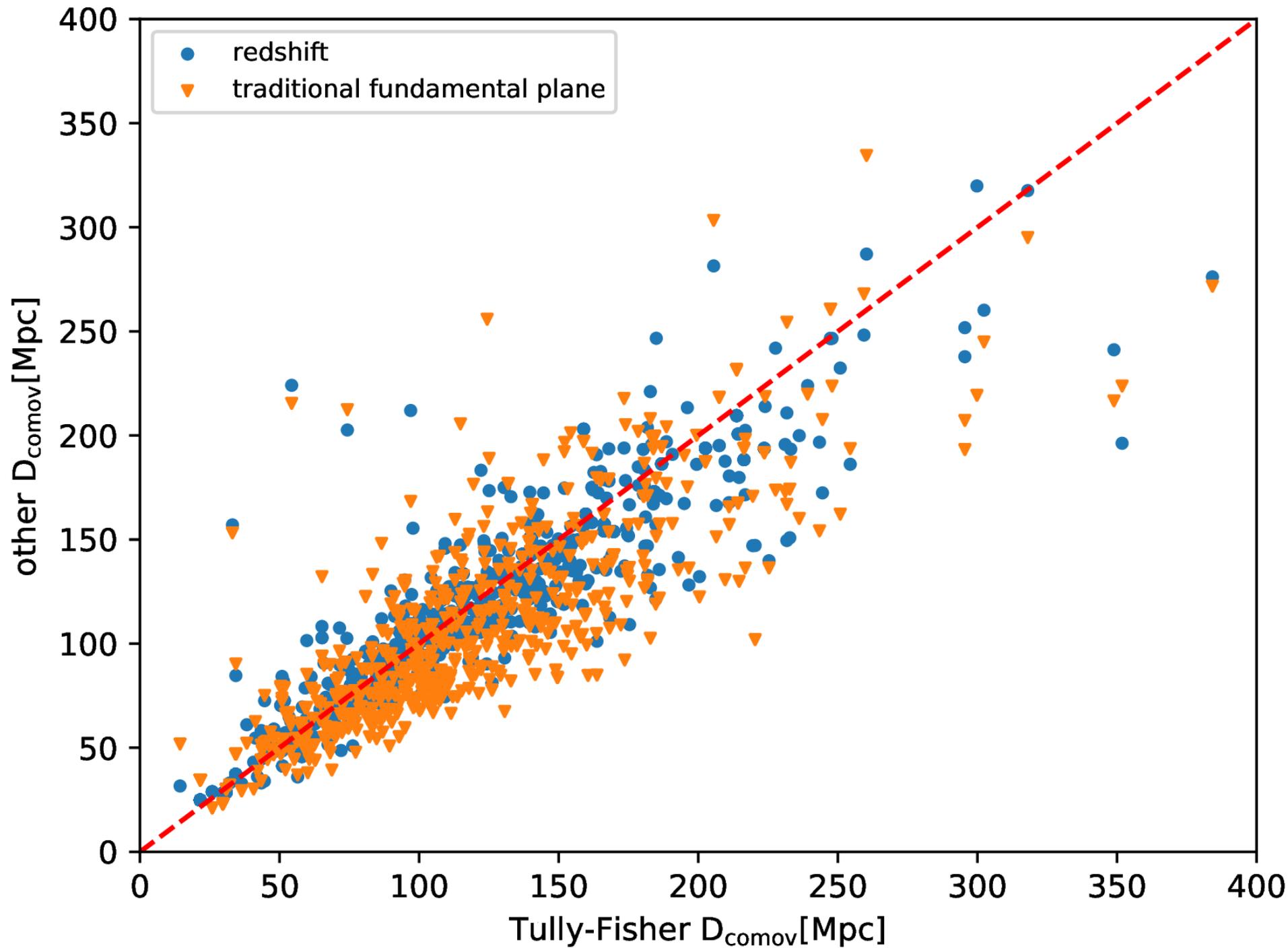
Does it improve the distance estimates?

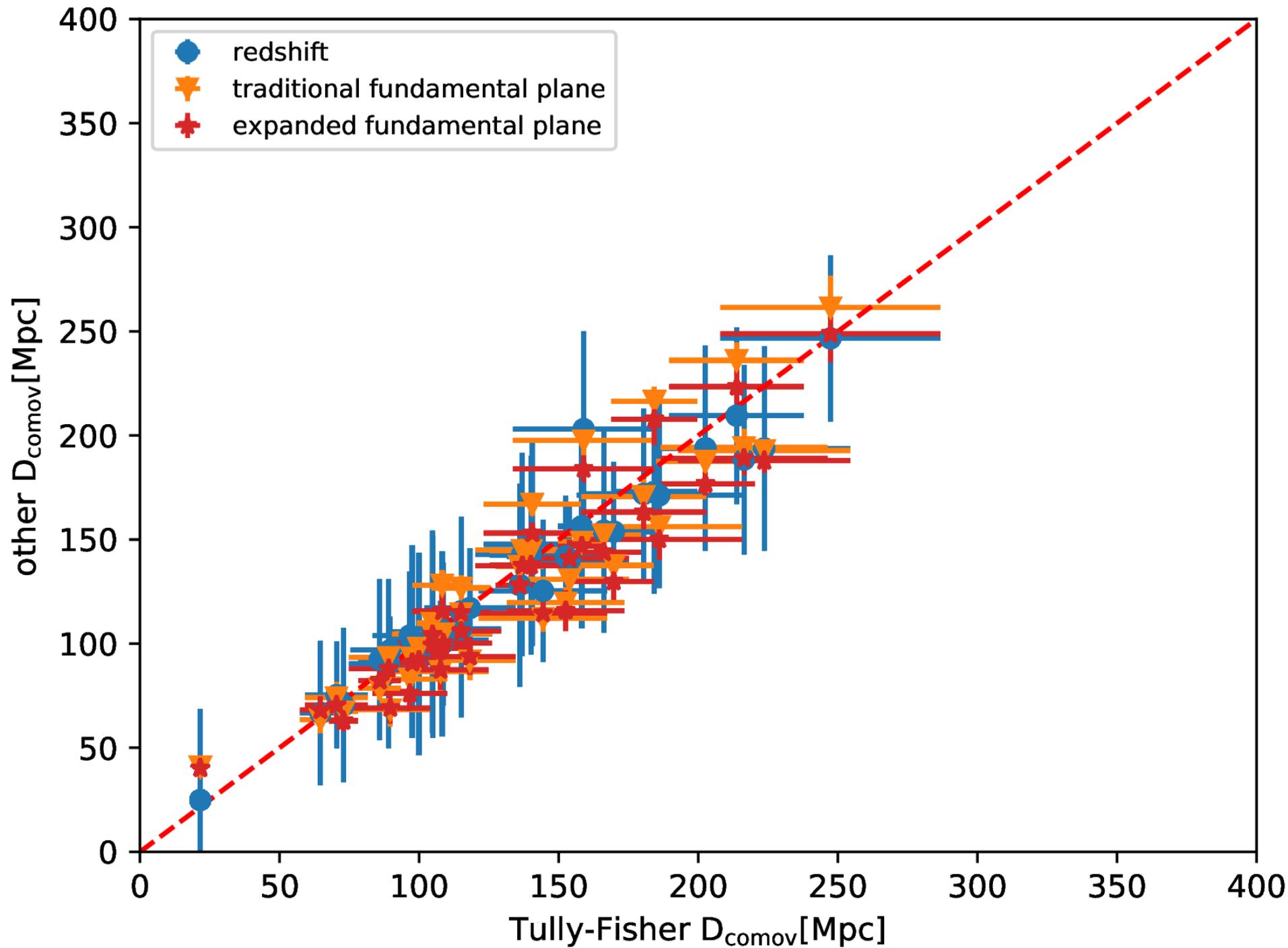
- Comparison only with the subsample (184 203 galaxies) for which we had stellar ages
- 20.2%/18.9% for the traditional fundamental plane
- 18.8%/17.5% for the expanded fundamental plane
- Marginal improvement, but we still have to test how it effects the biases
- For fair comparison: recalibrate the traditional fundamental plane for the same dataset and only use those galaxies.

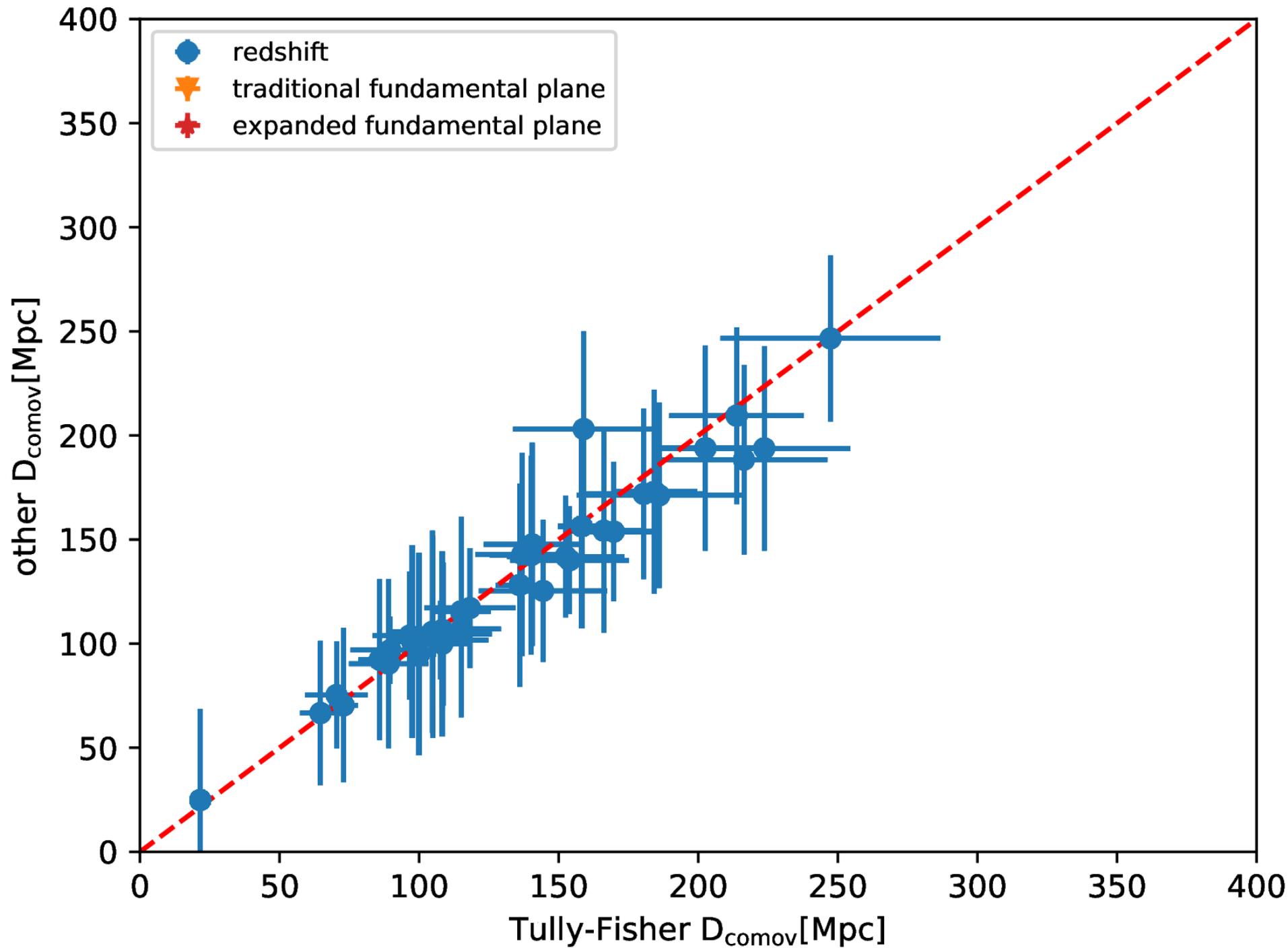


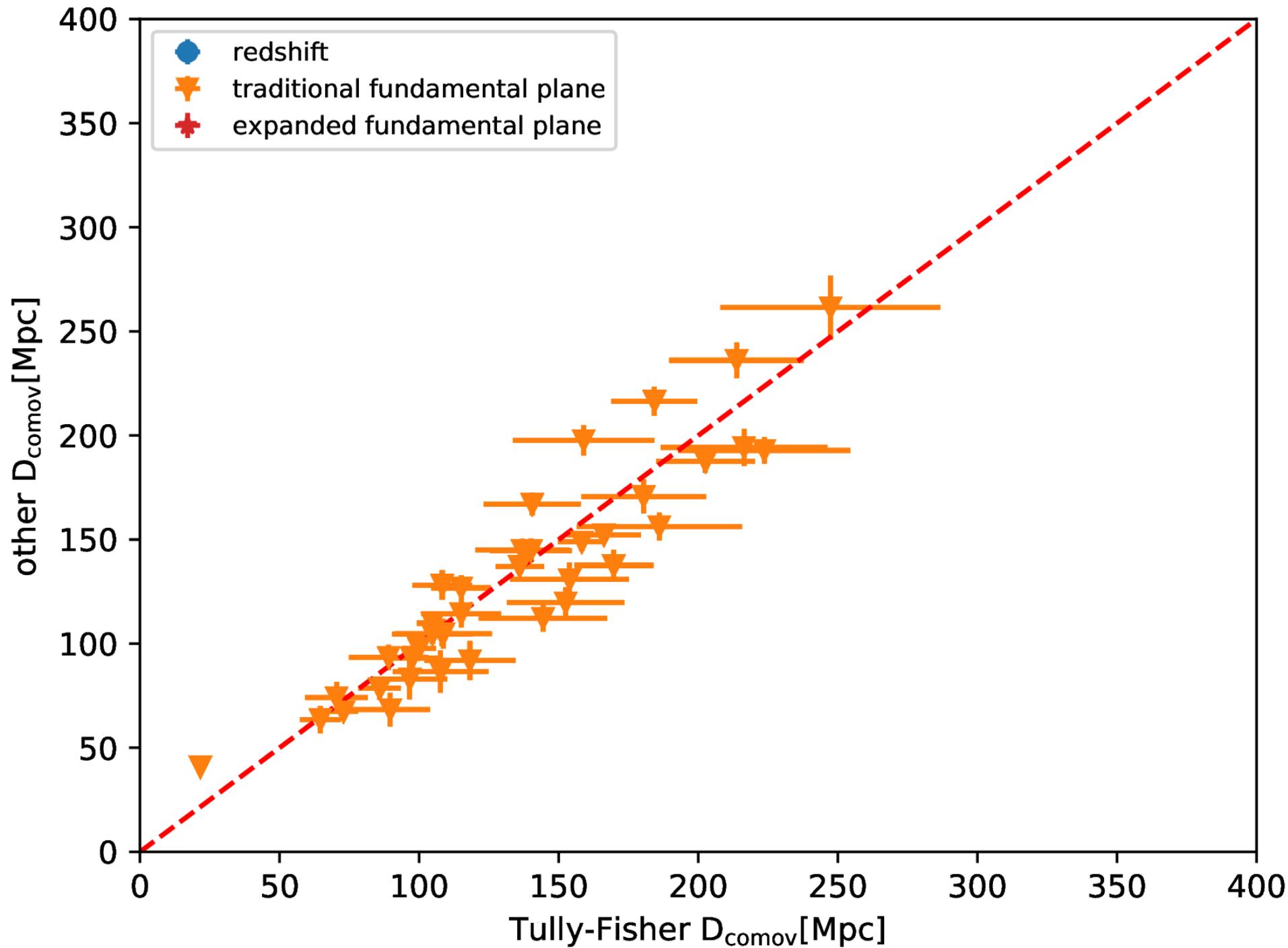
Comparison to the Tully-Fisher relation

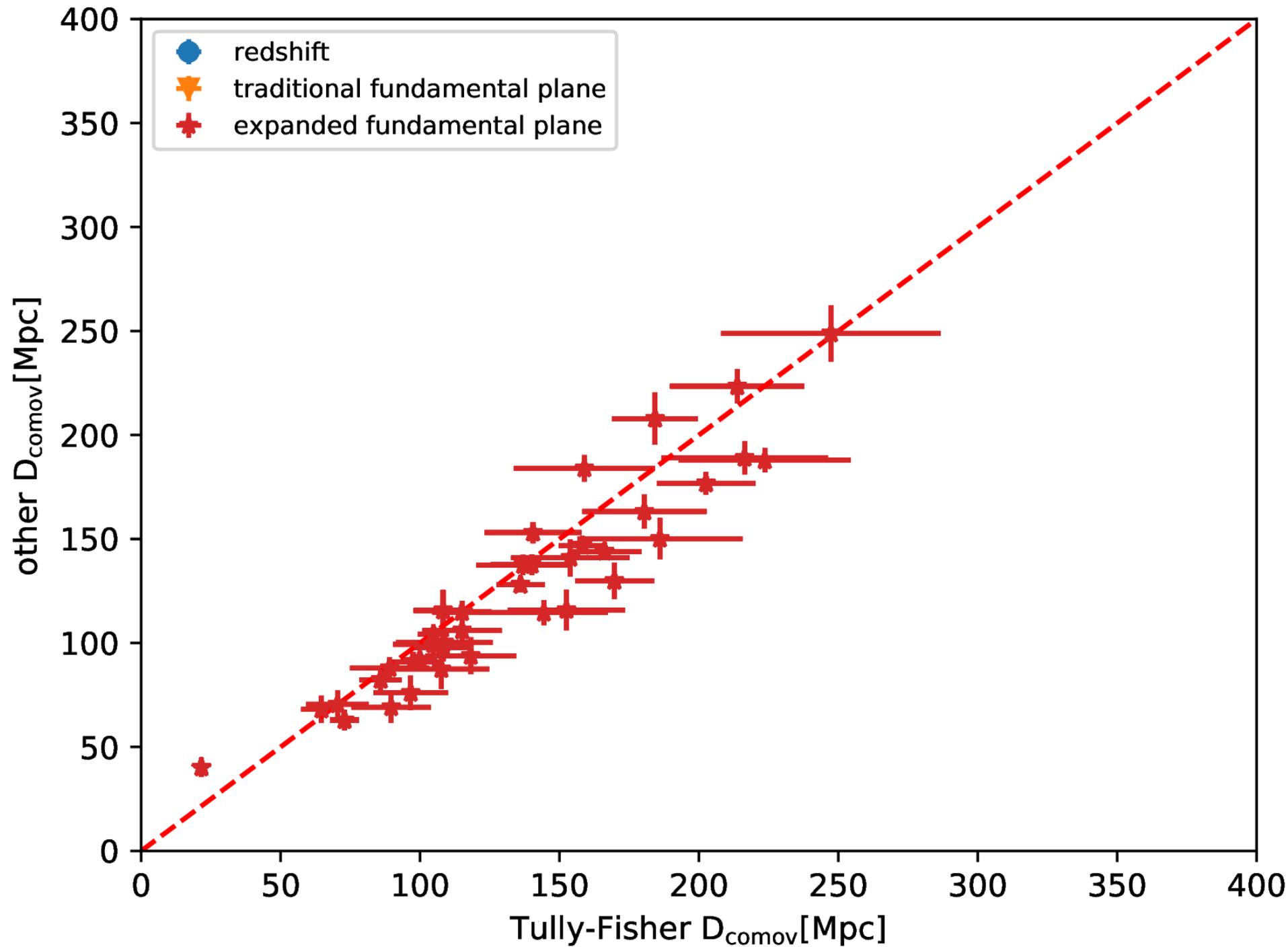
- NASA/IPAC Extragalactic Database (NED)
- 20 900 Tully-Fisher relation based distance measurements to 4 481 unique galaxies
- Error weighted average for galaxies that have more than one measurement
- Intrinsic scatter of 23.5%
- Using our group catalogue to compare them





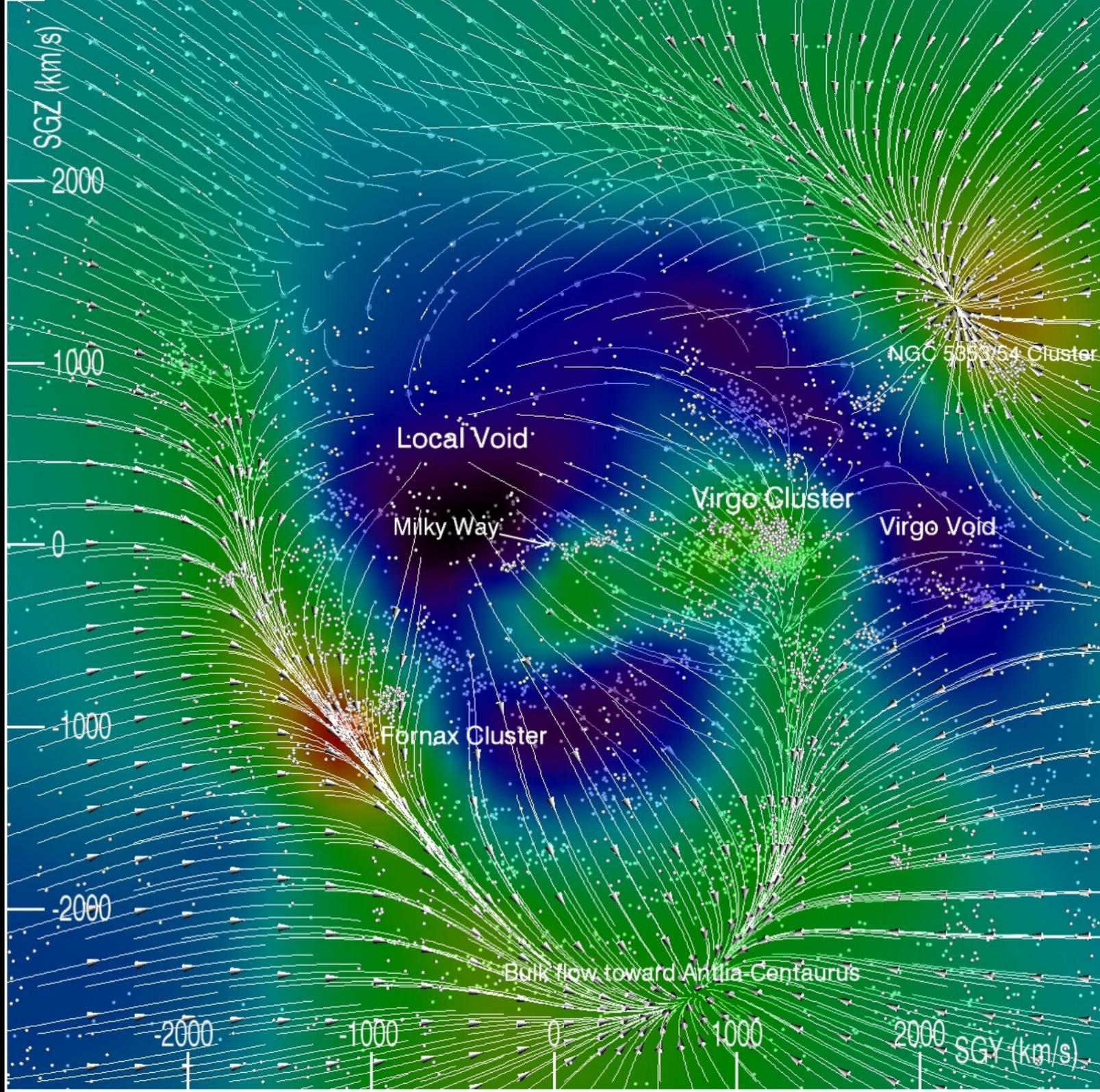


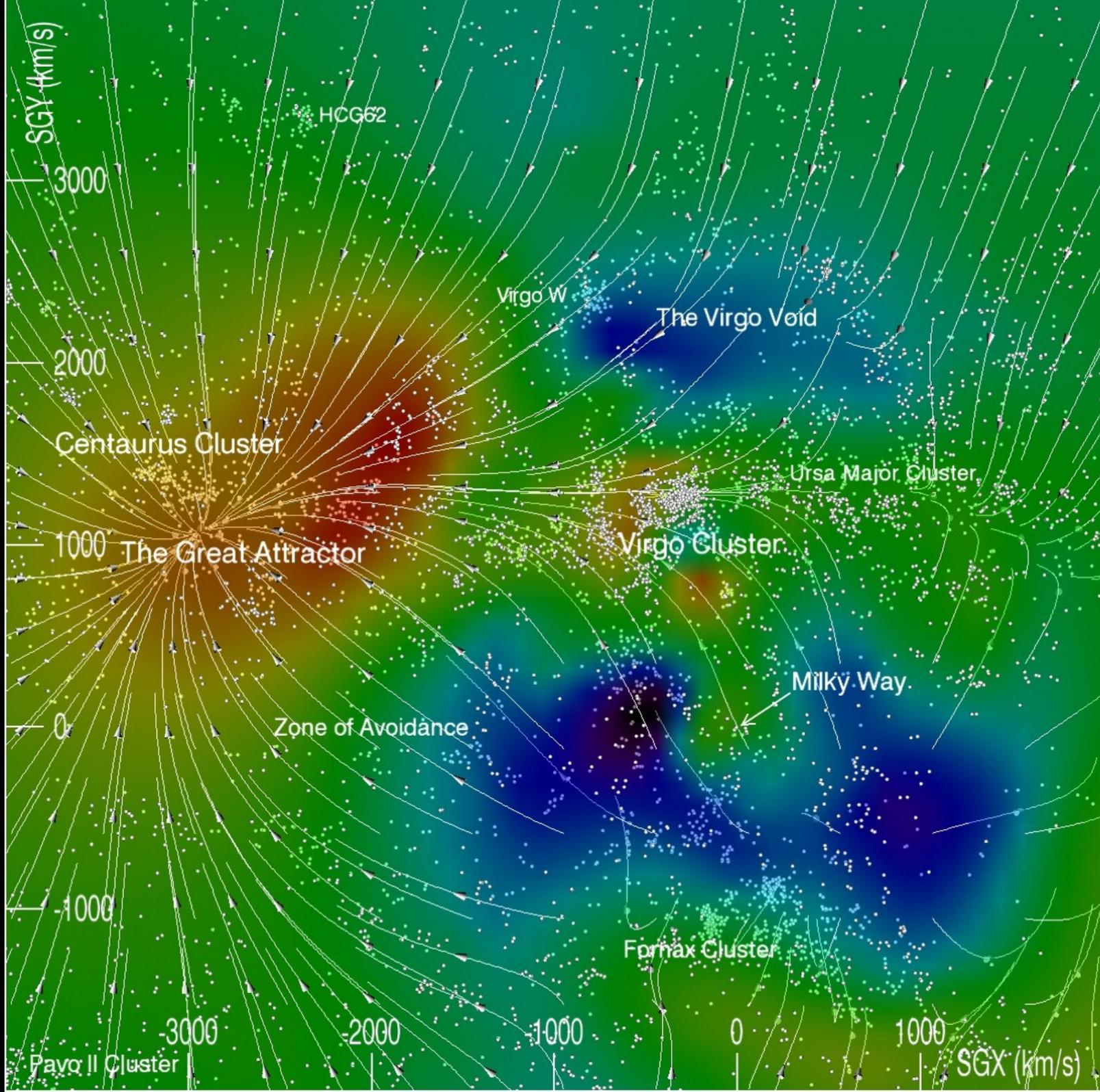




CosmicFlows-3 sample

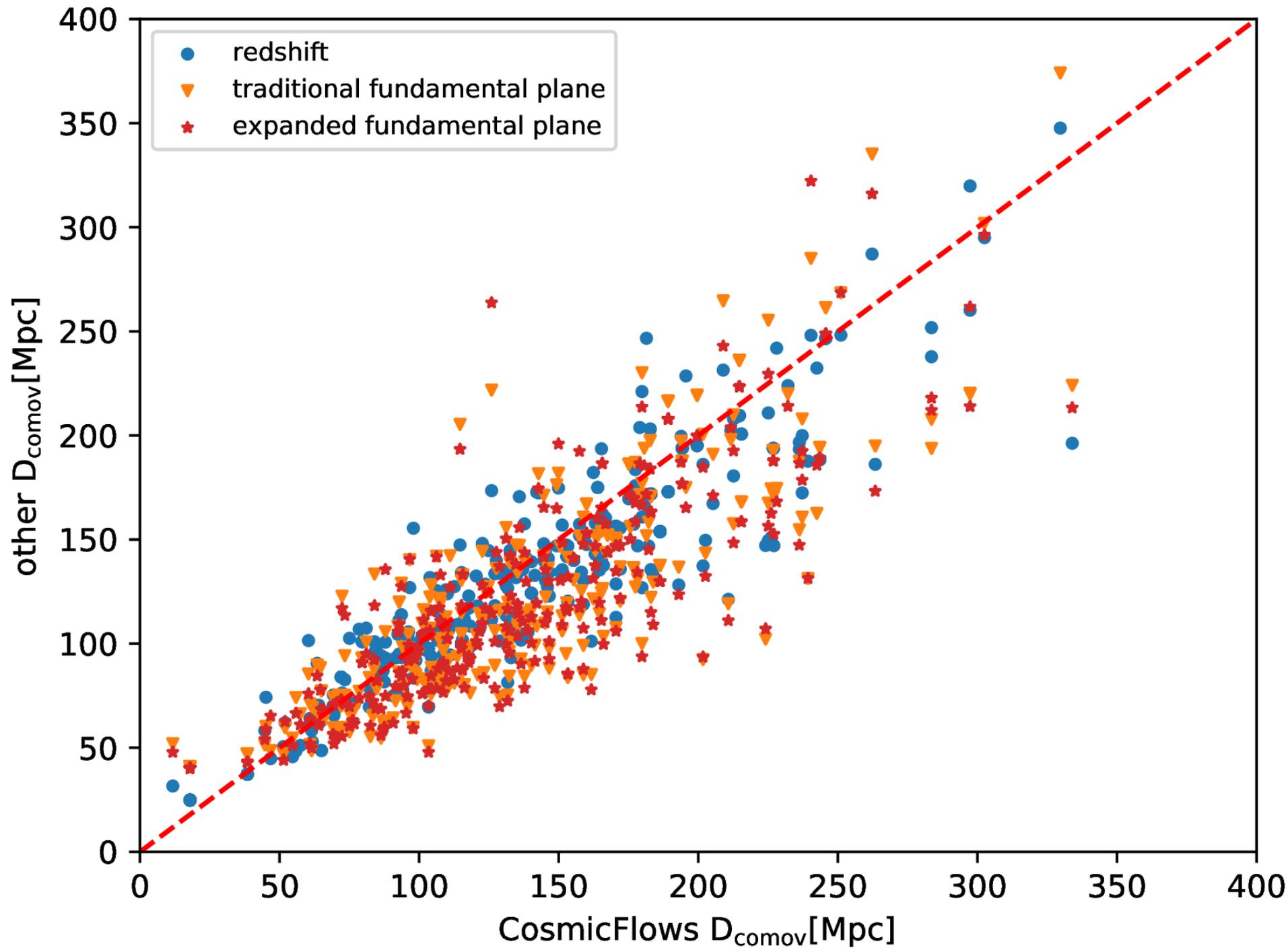
- A well-calibrated sample of distances to 17 669 galaxies in the local universe (Tully+2016)
- Uses a large range of different distance indicators:
 - Tully-Fisher relation
 - surface brightness fluctuations
 - fundamental plane
 - tip of the red giant branch
 - ...
- Fancy visualisations

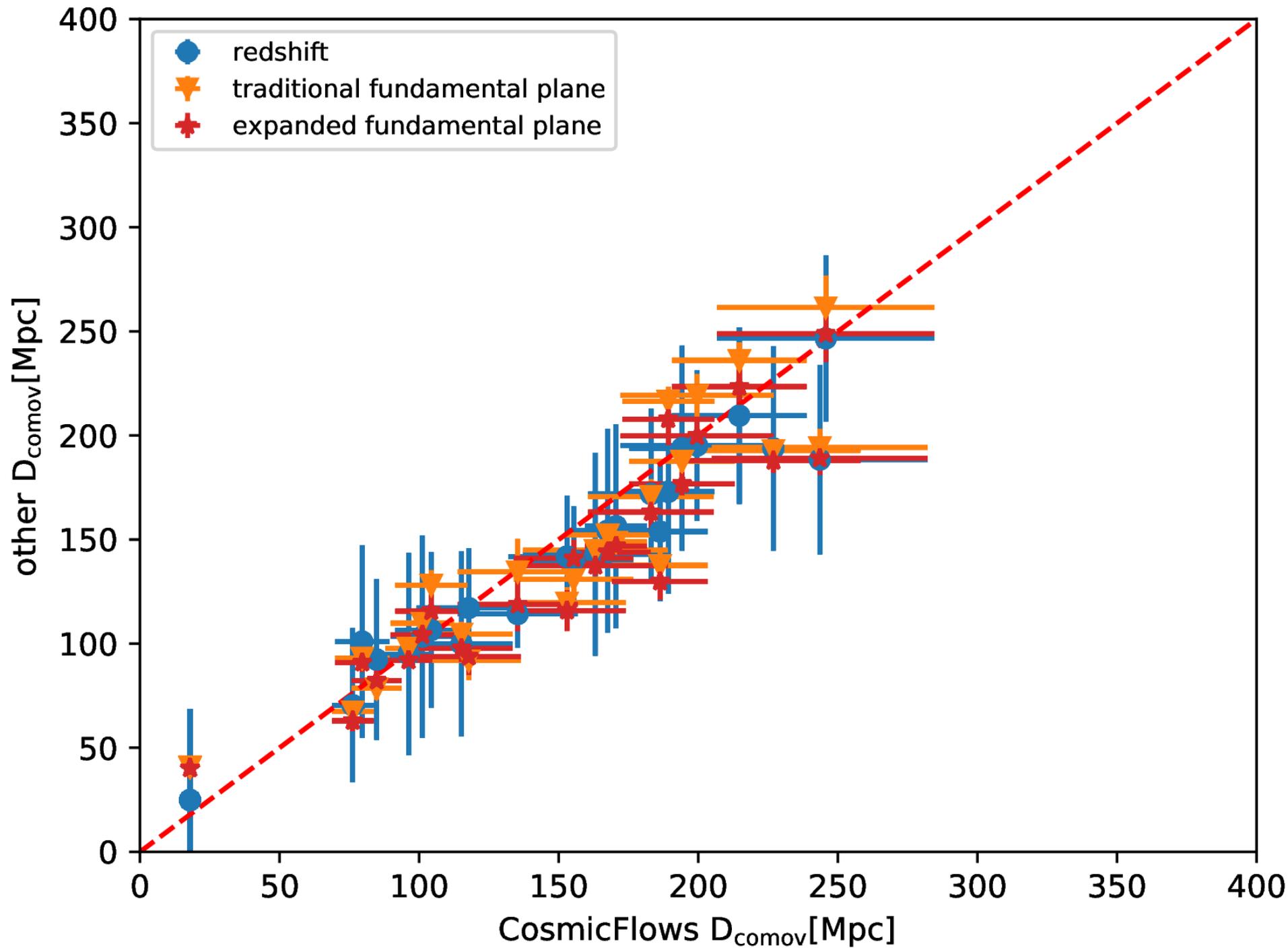


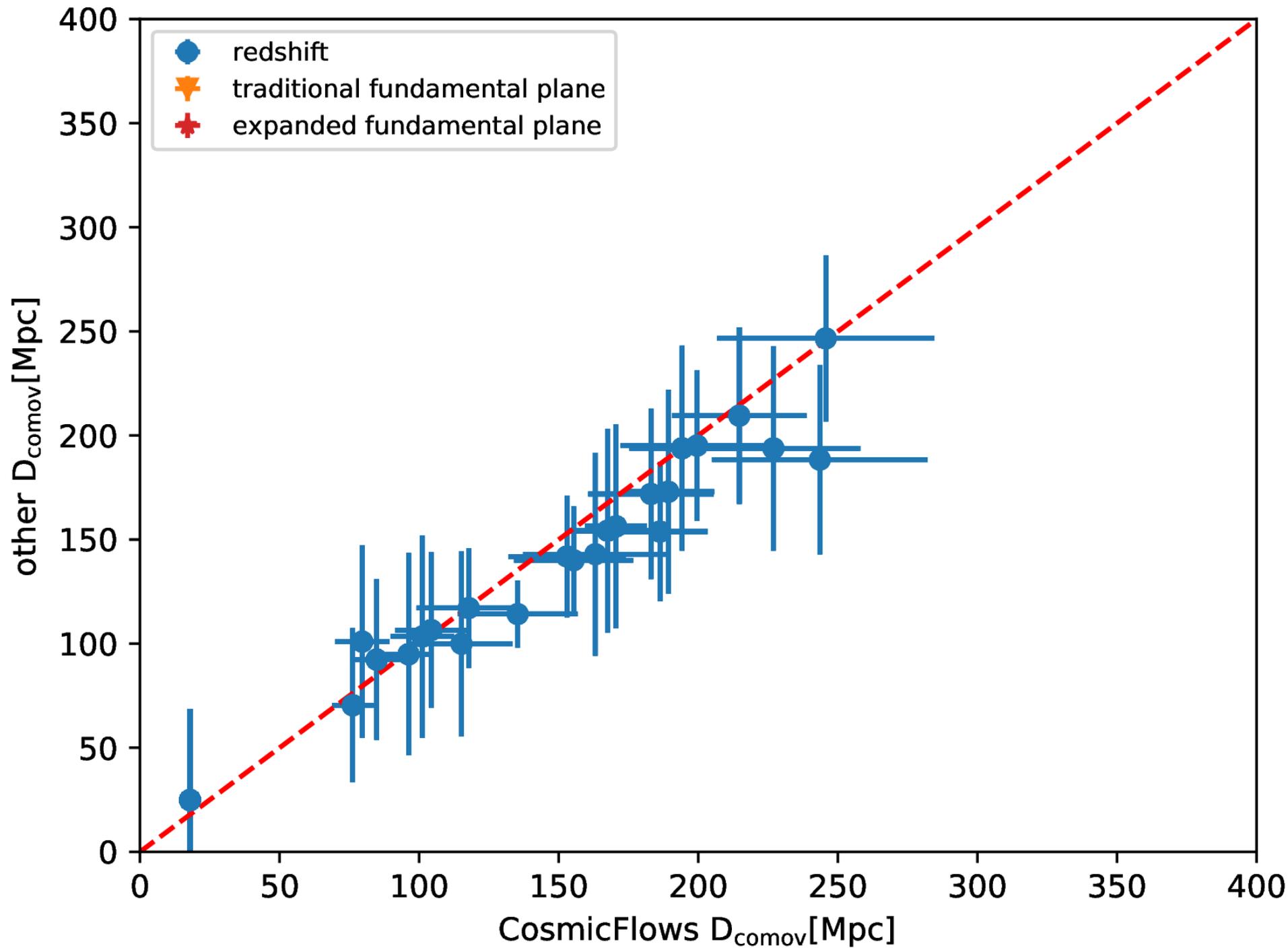


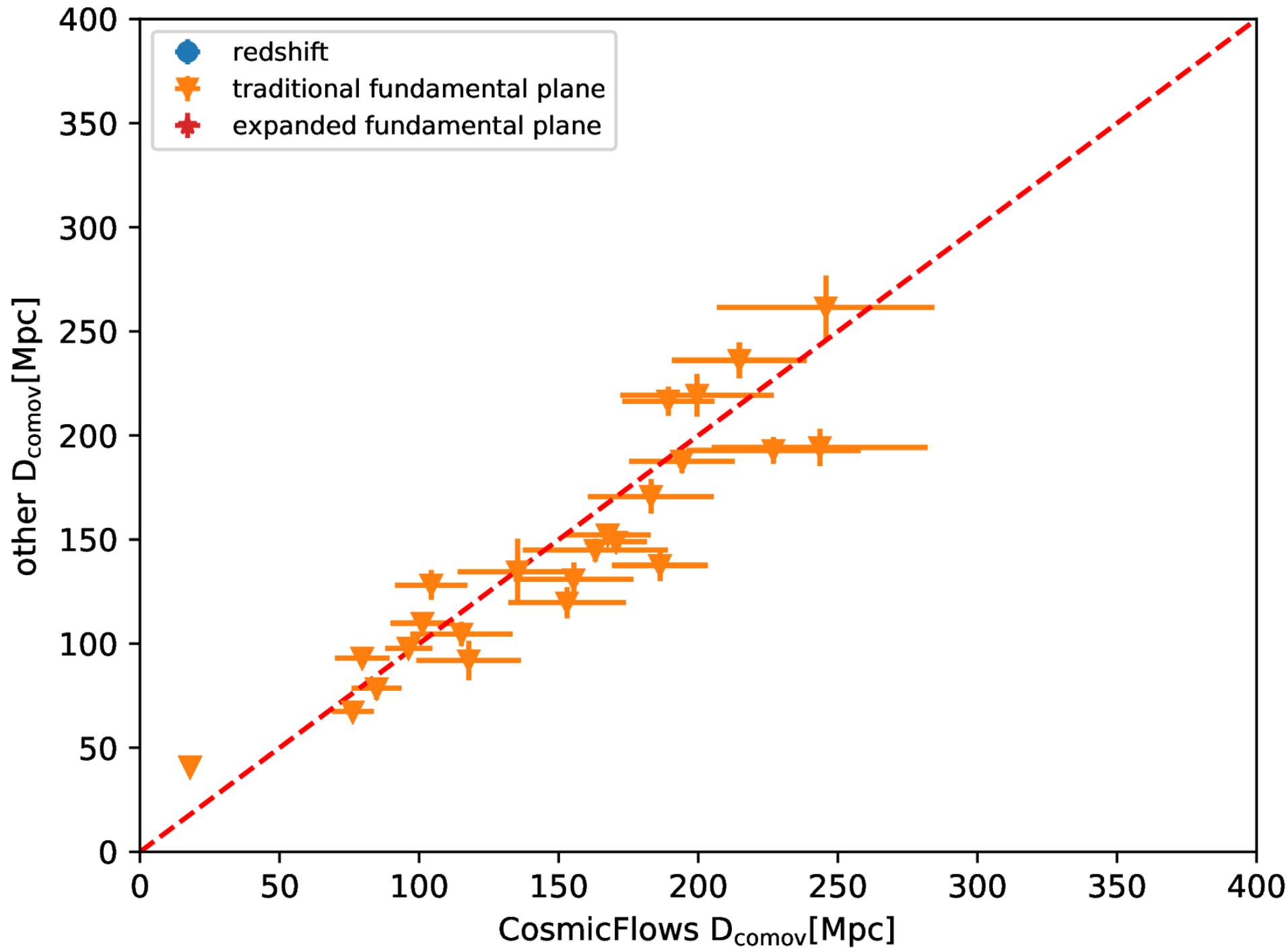
Comparison to the CosmicFlows-3 sample

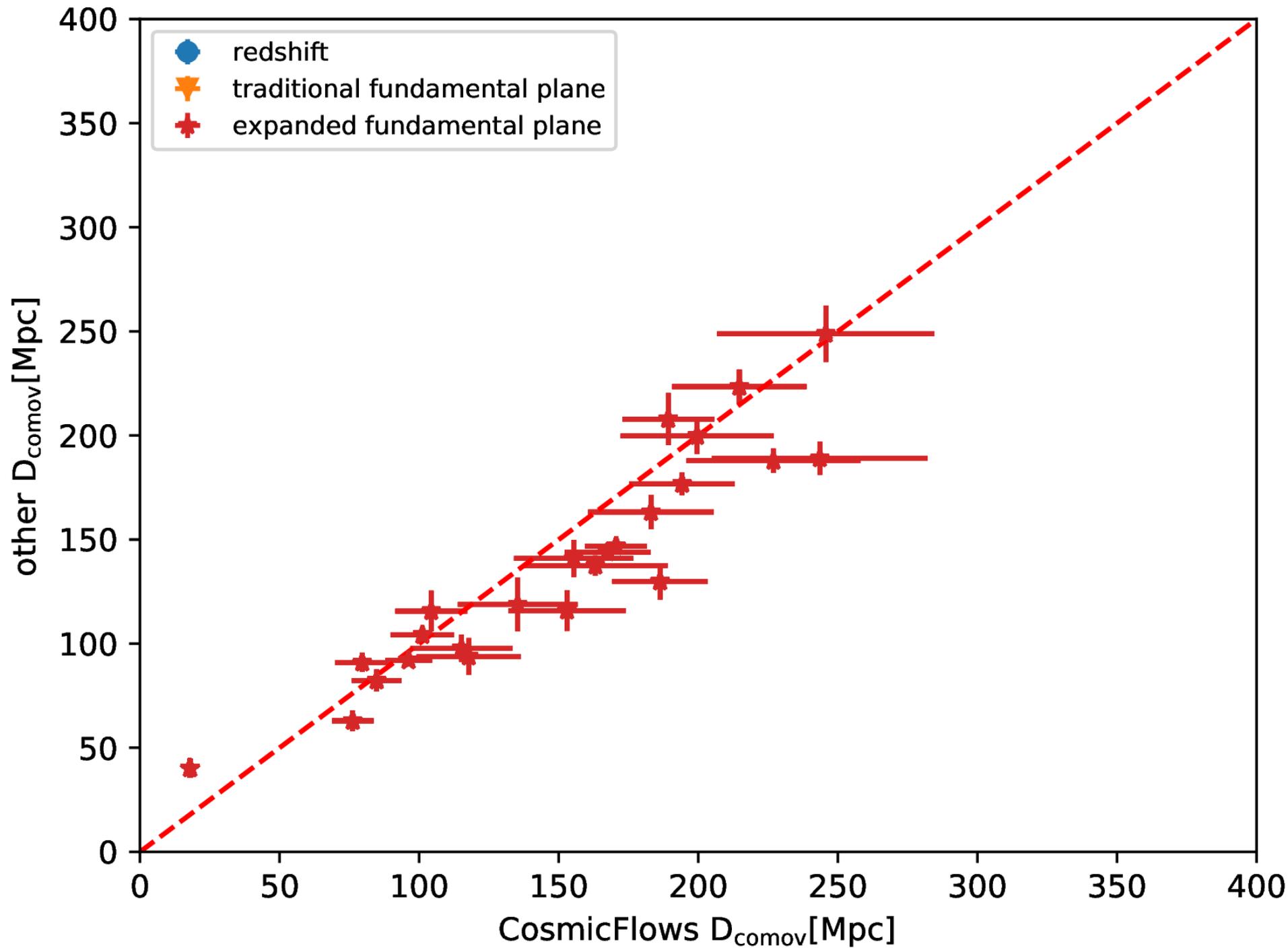
- We exclude their fundamental plane data
- Using our group catalogue to compare the samples
- Rescaling their cosmology to fit the one assumed by our calibrations
- Notable issue: they used the LG rest frame, we used the CMB rest frame





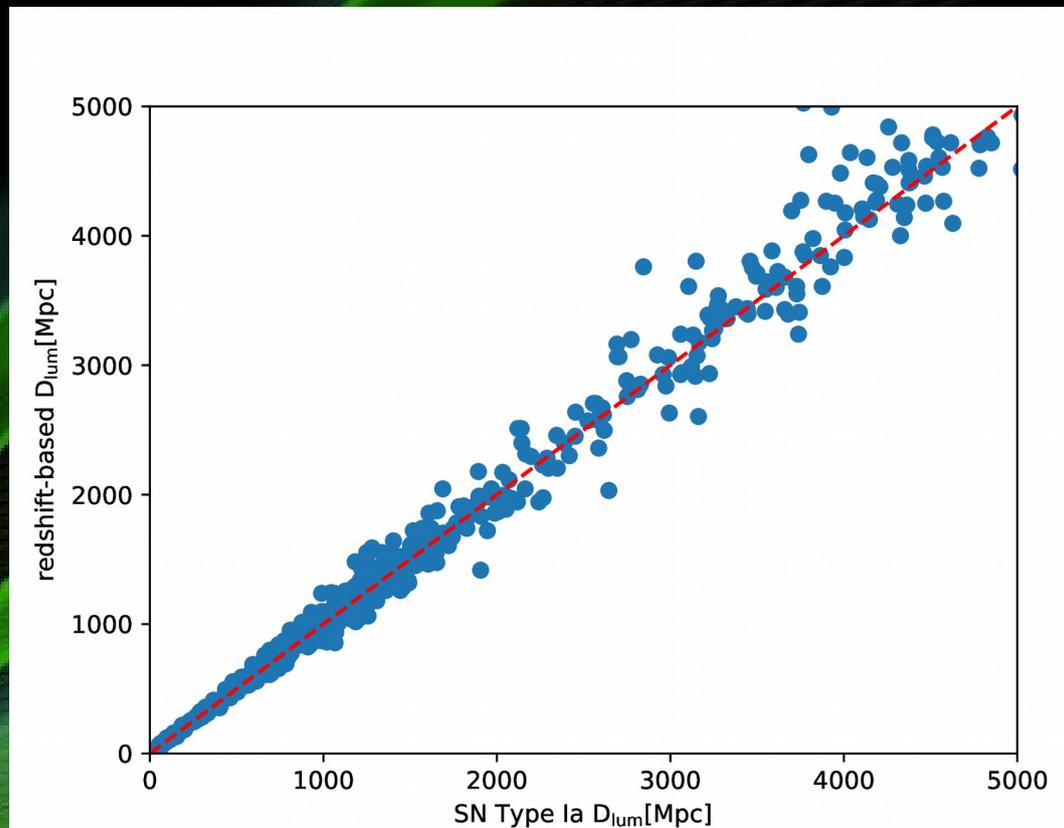


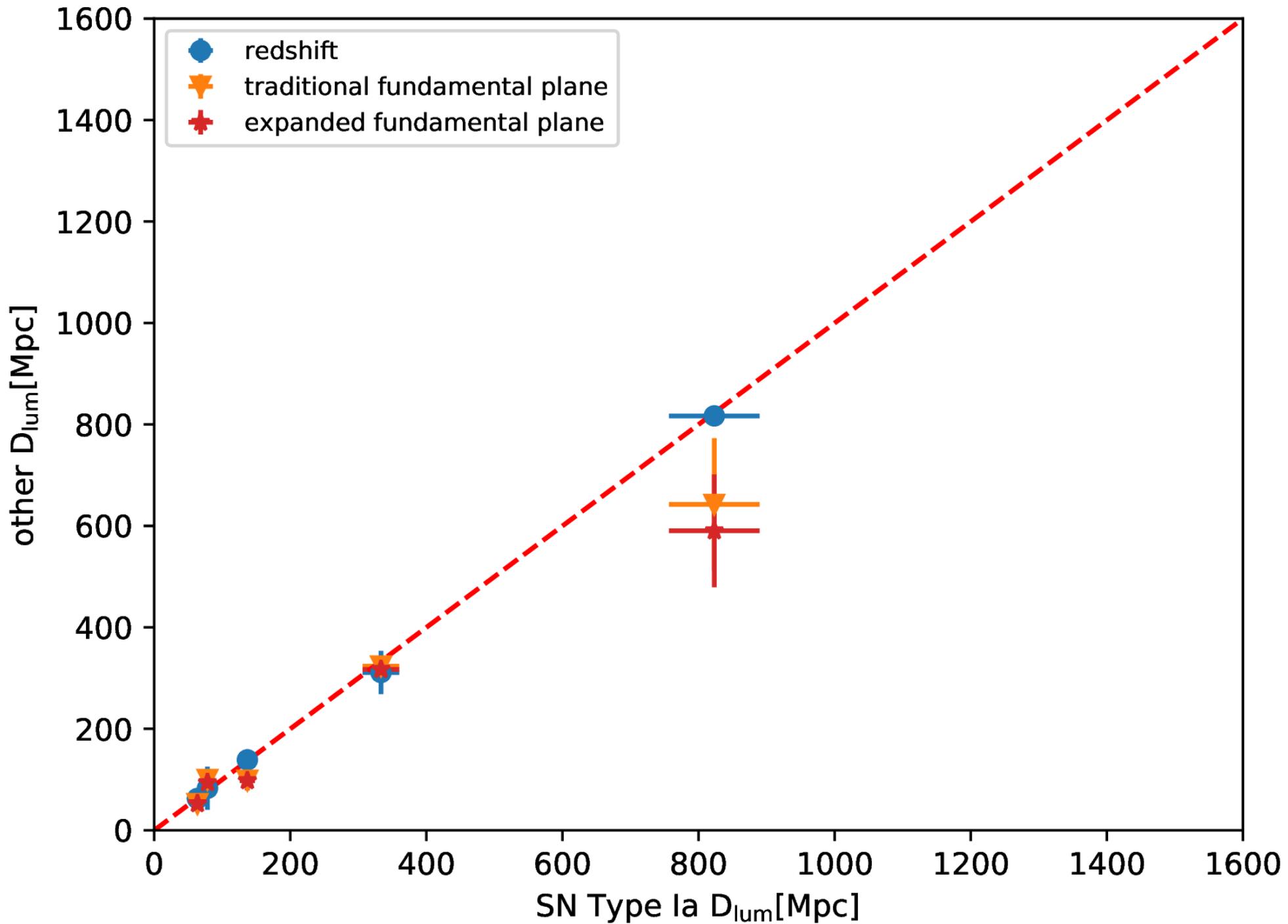


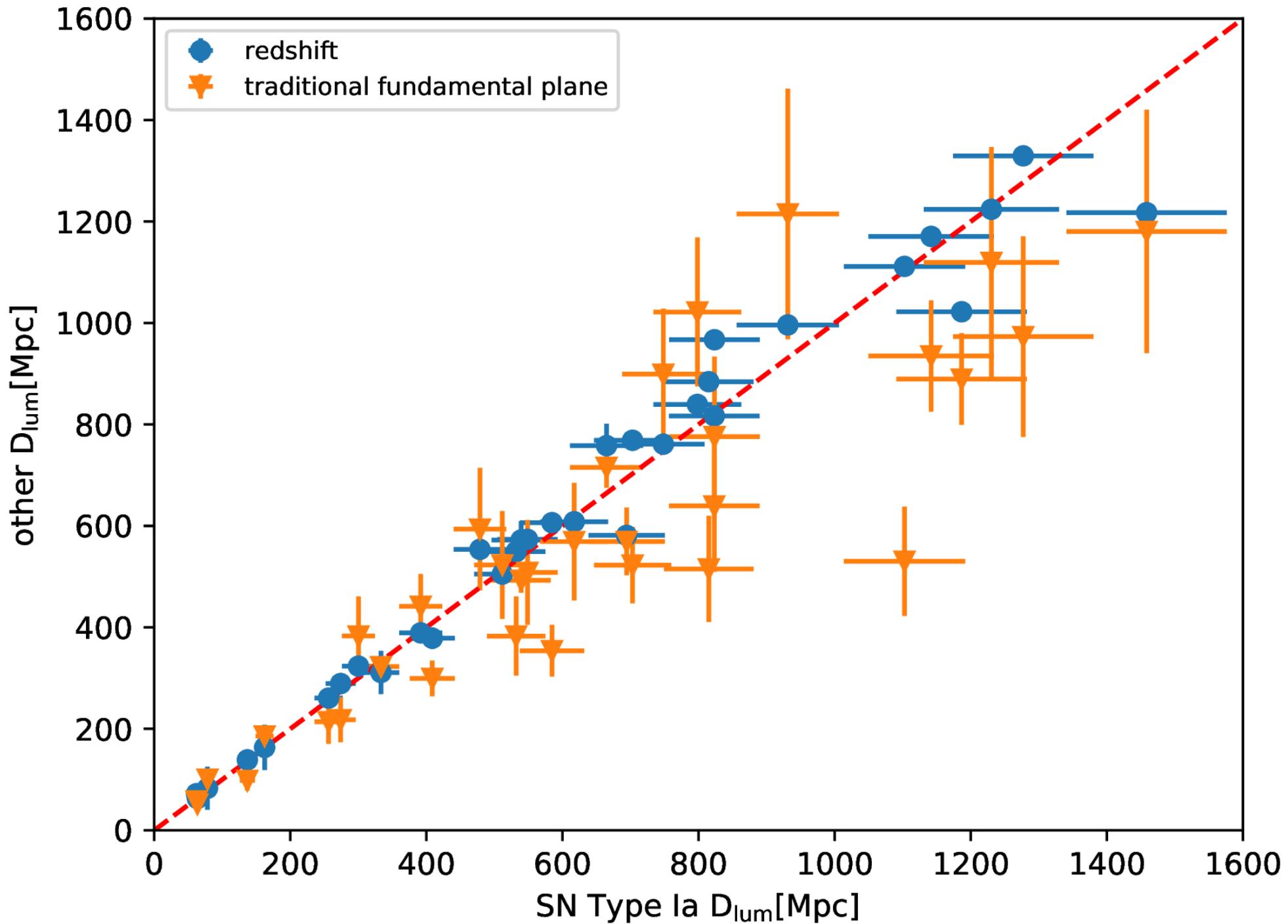


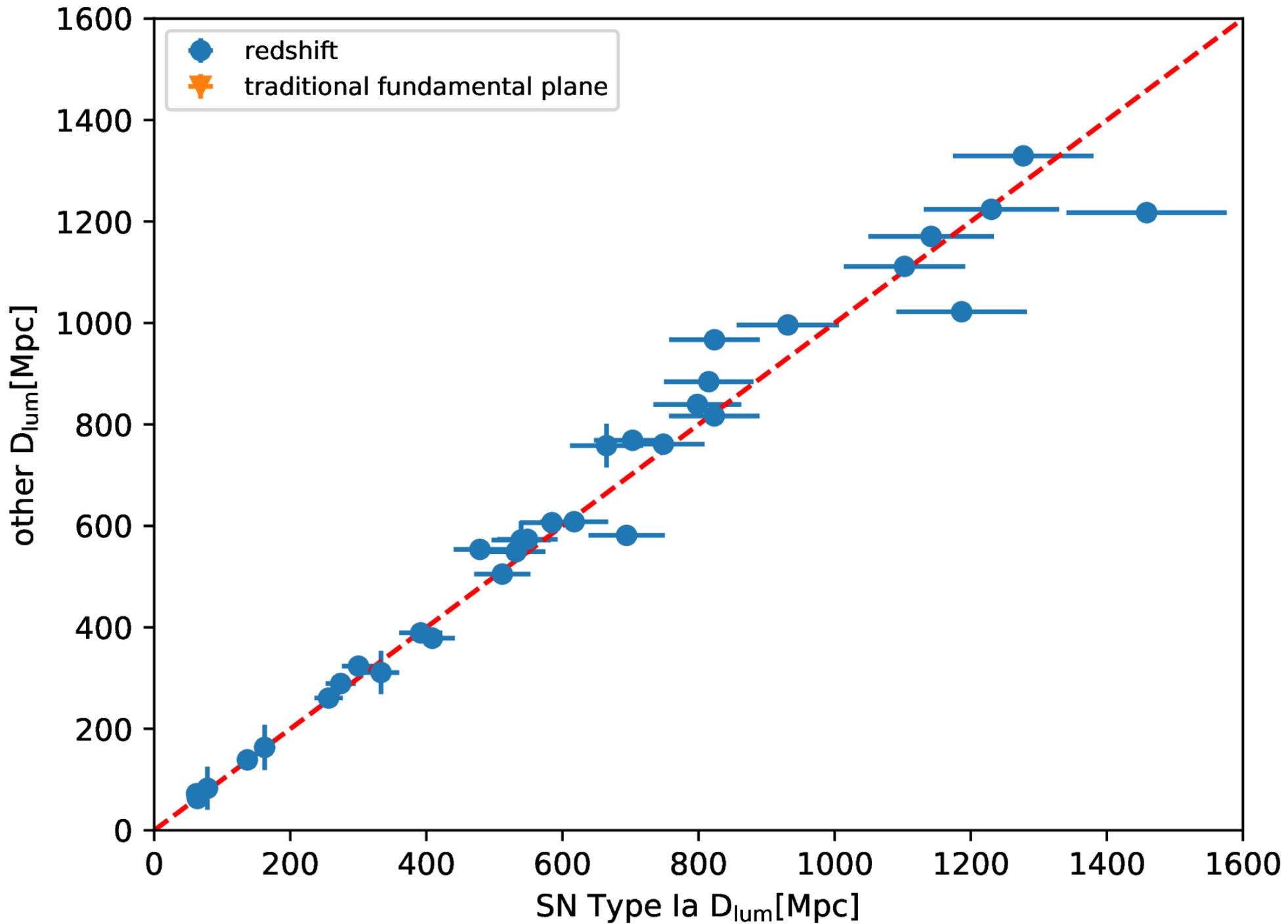
Comparison to supernovae Type Ia

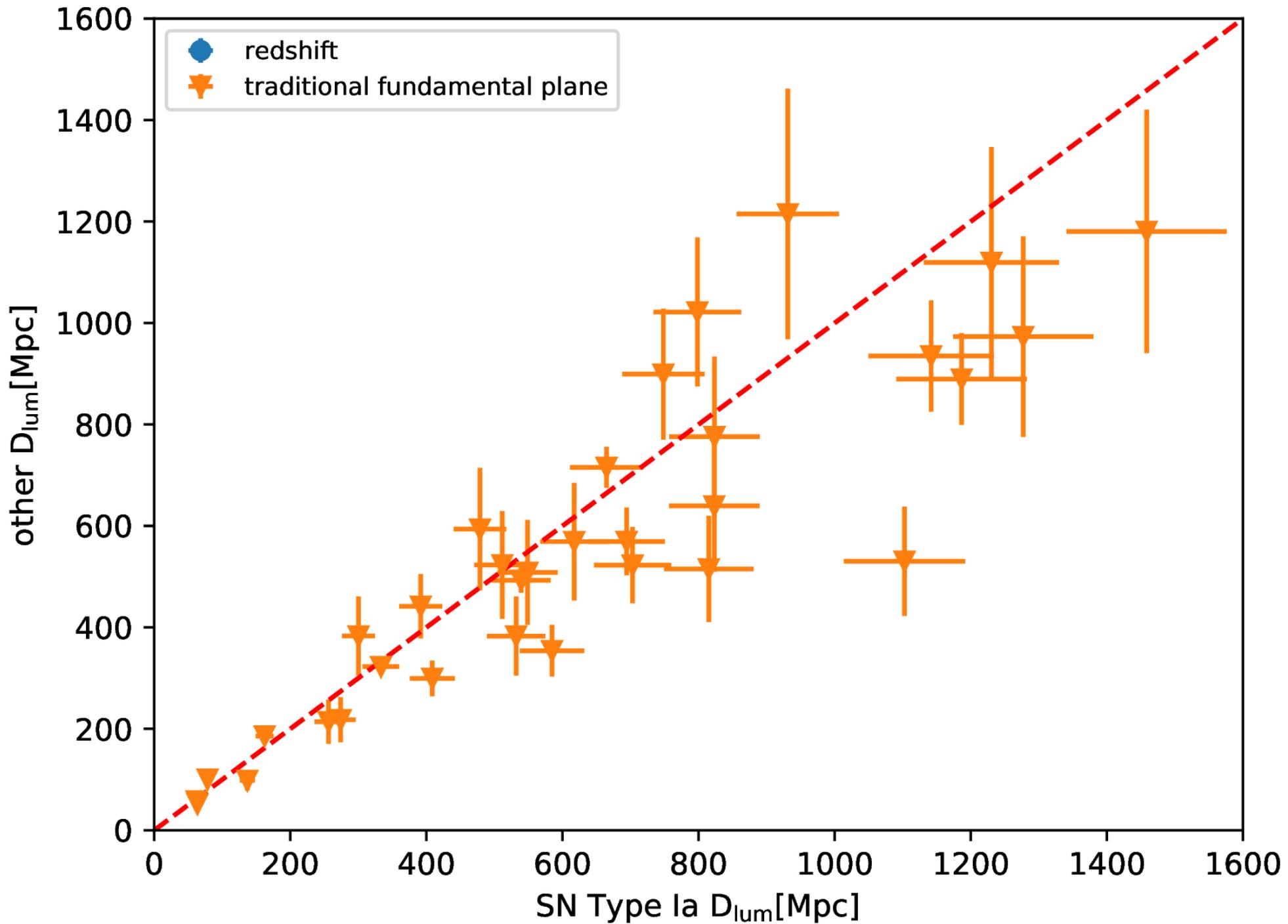
- Sample of Betoule+ 2014 containing 740 SN Type Ia (consistently calibrated)
- 33 of these supernovae in our ETGs
- Scatter of supernova distances about $\sim 8\%$

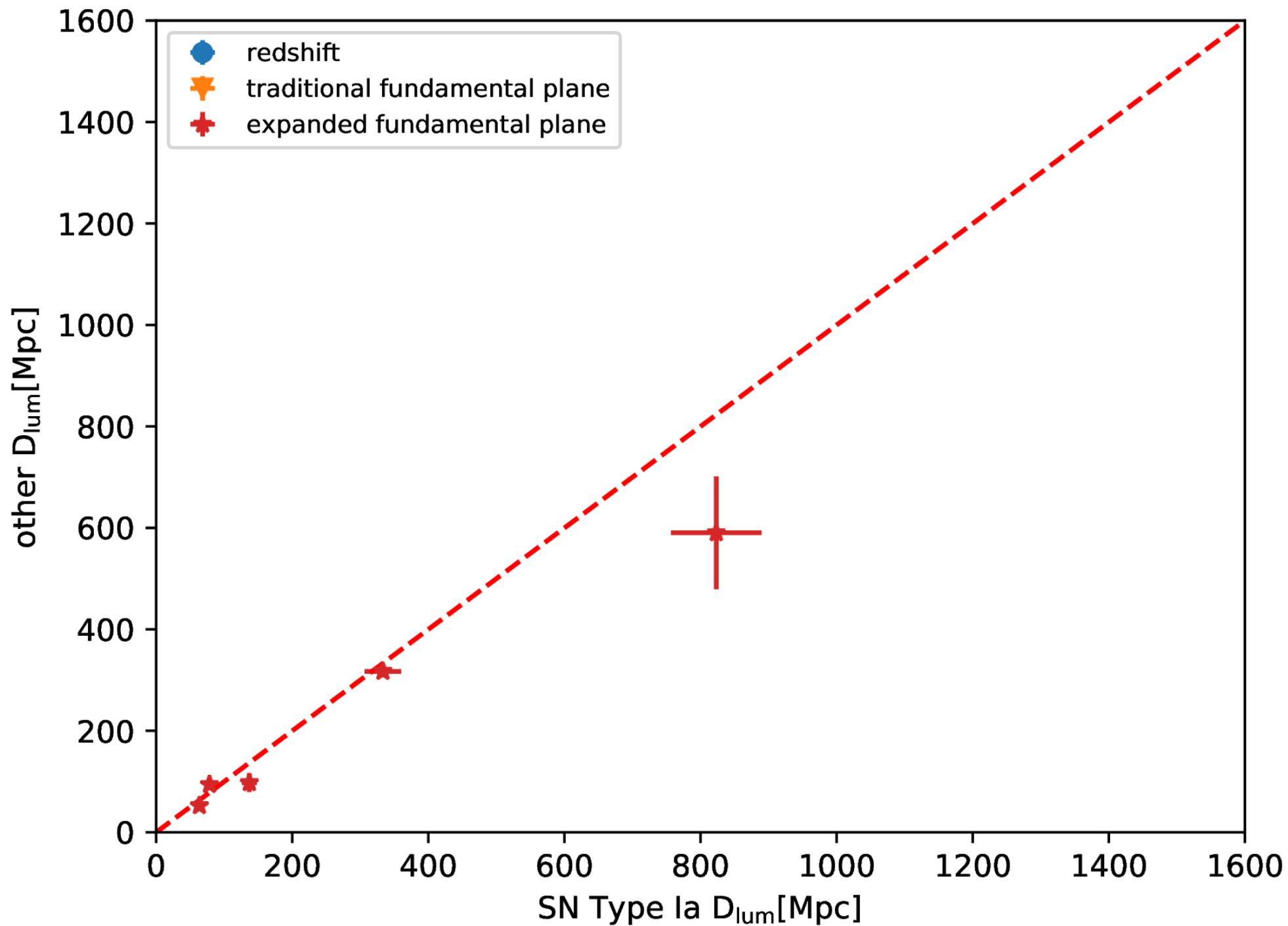










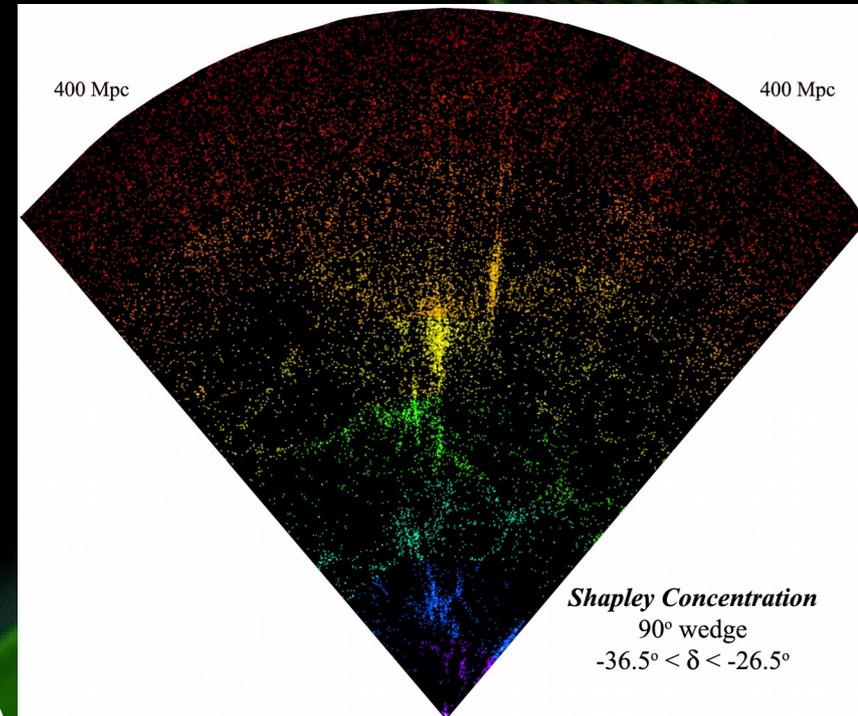


Statistics

- Tully-Fisher comparison:
 - Redshifts: 32.1%, 8.0% (rich groups)
 - Traditional fundamental plane: 30.7%, 15.8%
 - For the subsample: 37.5%, 19.2%
 - Expanded fundamental plane: 35.6%, 18.2%
- CosmicFlows-3 comparison:
 - Redshifts: 20.2%, 13.1%
 - Traditional fundamental plane: 30.7%, 23.2%
 - For the subsample: 32.5%, 29.6%
 - Expanded fundamental plane: 30.9%, 28.9%
- Supernovae Type Ia comparison:
 - Redshifts: 8.4%
 - Traditional fundamental plane: 22.9%

Peculiar Motions

- Galaxies are not sitting still
- Motion induced by gravity of other galaxies/clusters/...
- Redshift space distortions:
- Finger of God effect (random motion inside clusters)
- Kaiser effect (coherent infall into clusters)
- Scatter around the homogeneous Hubble flow



by Thomas Jarrett (IPAC/Caltech)

Measuring peculiar motions

- Observed redshift = cosmological redshift + redshift caused by peculiar motions + gravitational redshift (usually negligible)
- Cosmological redshift predicted by the expansion of the universe (Hubble flow)
- Compare observed redshift at a certain distance to the predicted one
- Requires a redshift-independent distance indicator and redshift measurements
- Lots of systematic biases need to be considered

Peculiar motion studies

- At the moment:
- CosmicFlows-3 (Tully+ 2016)
 - Uses primarily Tully-Fisher relation data
 - Collects data from various sources (and methods)
 - All sky
- 6dFGSv (Springob+ 2014)
 - Uses the fundamental plane
 - Only Southern hemisphere (6dFGS follow-up)
 - Recently reworked data: Howlett+ 2017, Qin+ 2018, Howlett+ 2019

Our goal

- Providing an extended self-consistent peculiar velocity model for the Northern hemisphere
- Complementary to the 6dFGSv
- Using the methods of Howlett+ 2019 on our data to supplement their catalogue.
- Help to reduce directional issues with their data
- Study the momentum power spectrum (with Park C.)
- Correlations with clusters from LOFAR data (with Schwarz D.)

Summary

- Group catalogue covering ~1 500 000 galaxies
- ~320 000 traditional fundamental plane distances
- ~184 000 expanded fundamental plane distances
- Largest self-consistent set of redshift-independent distances ever produced

- Comparison to Tully-Fisher relation, CosmicFlows-3, and Supernova Type Ia distances
- Peculiar motion data is work in progress

