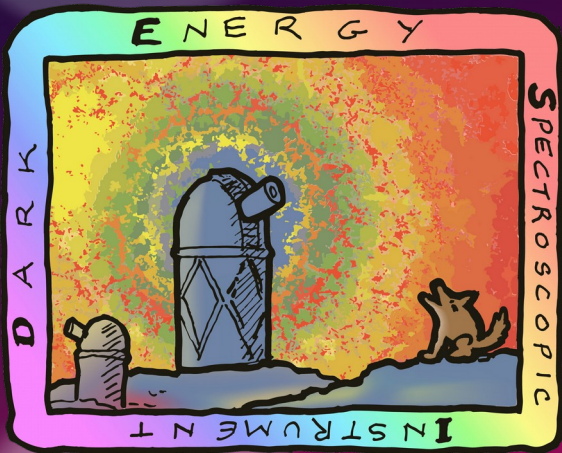
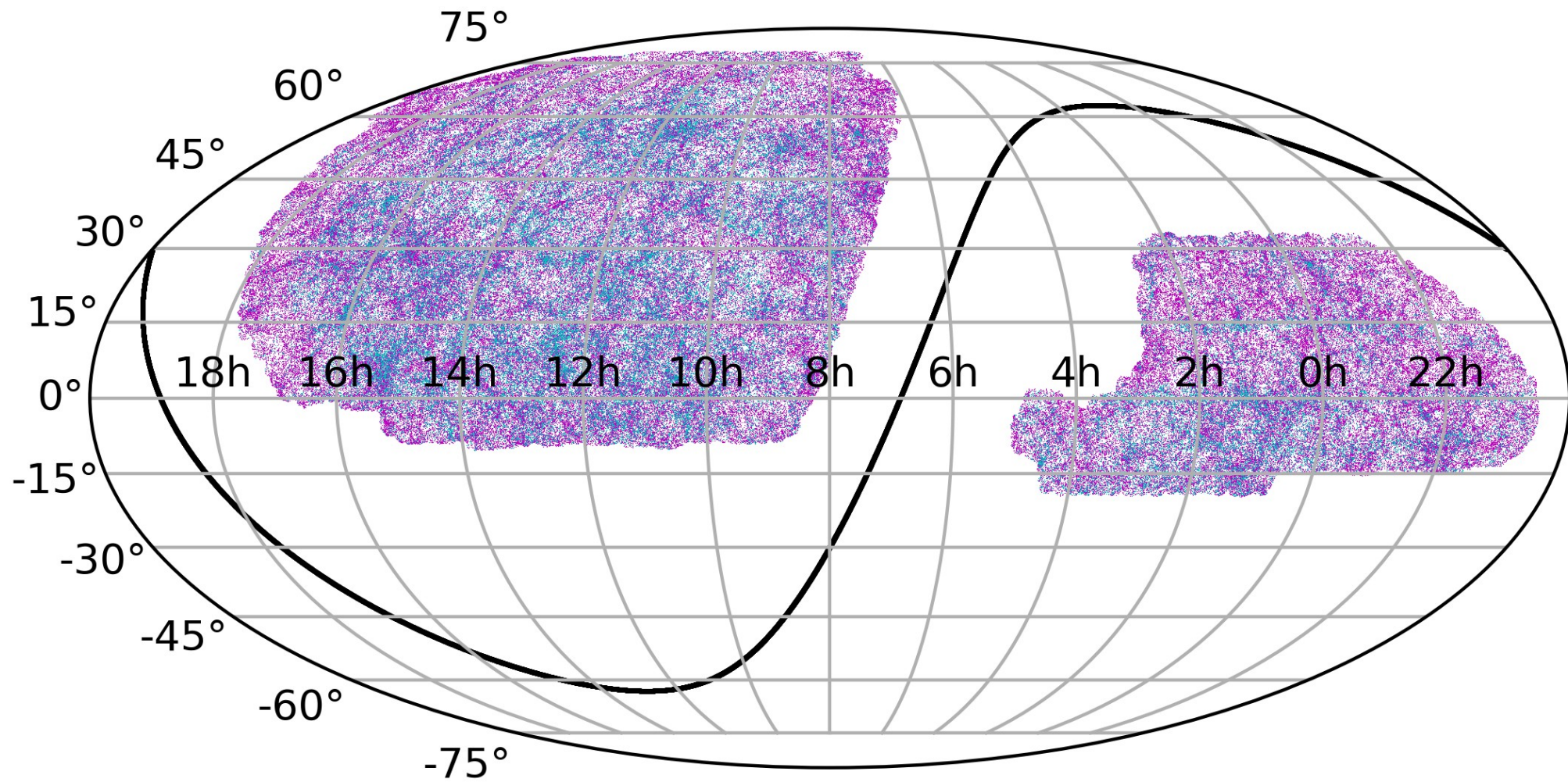


The DESI peculiar velocity survey

from target selection to
the first measurements

by Christoph Saulder (KASI)





Collaborators

- Cullan Howlett (University of Queensland)
- Khaled Said (University of Queensland)
- Kelly Douglass (University of Rochester)
- Alex Kim (LBNL)
- John Moustakas (Siena College)
- Greg Aldering (LBNL)
- Segev BenZvi (University of Rochester)
- Chris Blake (Swinburne University)
- Tamara Davis (University of Queensland)
- Anthony Kremin (LBNL)
- John Lucey (Durham University)
- David Parkinson (KASI)
- Fei Qin (KASI)
- Pauline Zarrouk (LPNHE)
-

Peculiar velocities

- Proper motions of galaxies relative to the Hubble flow
- $(1+z_{\text{obs}}) = (1 + z_{\text{cosmo}}) \cdot (1 + z_{\text{peculiar}})$
- Cosmological redshift: $z_{\text{cosmo}} = a_0/a_z - 1$ (depends on cosmology)
- Peculiar velocities typically only measured in radial direction

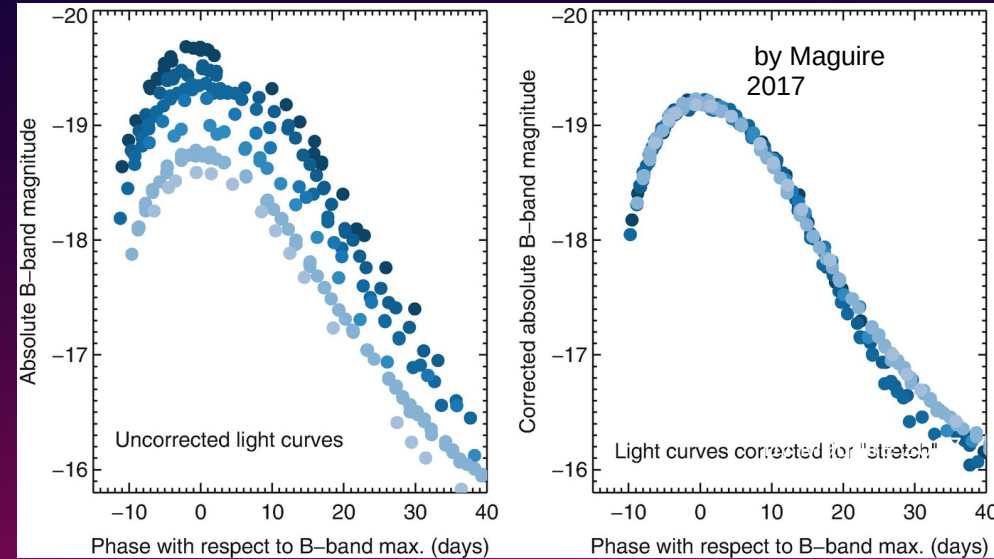
$$1+z_{\text{peculiar}} = \sqrt{\frac{1+v_{\text{peculiar}}/c}{1-v_{\text{peculiar}}/c}}$$

Measuring peculiar velocities

- Redshift + redshift-independent distance indicator (+ a lot of modelling)
- Spectroscopic redshift measurements (nowadays typically done as part of large surveys using fibre spectrographs)
- Redshift-independent distance indicator: requires additional measurements, depending on their type

Redshift-independent distance indicators

- Standard candles:
 - Cepheids
 - Supernovae Type Ia
- Tip-of-the-Red-Giant-Branch
- Surface brightness fluctuations
- Planetary nebulae/globular cluster luminosity functions
- Galaxy scaling relations



Galaxy scaling relations as distance indicators

- Early-type galaxies
 - Faber-Jackson relation
 - D_n - σ relation
 - → unified into the **Fundamental plane**
- Late-type galaxies
 - **Tully-Fisher relation**
- Sk-relation or full kinematic modelling using IFU-data

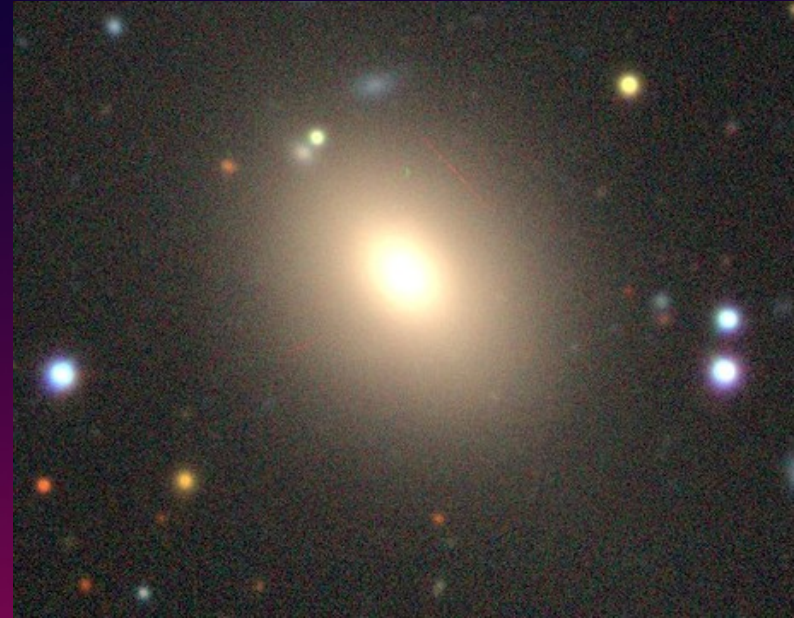
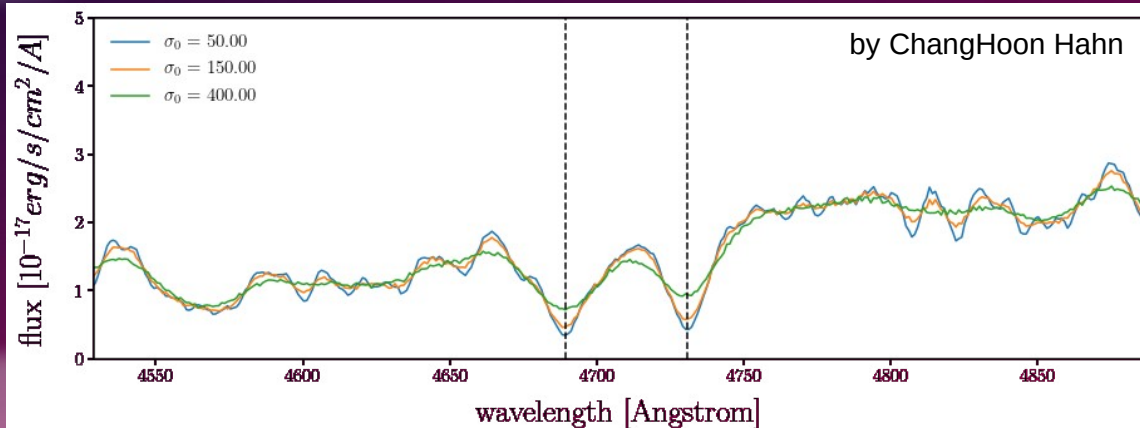


Fundamental plane of early-type galaxies

- Empirical relation:

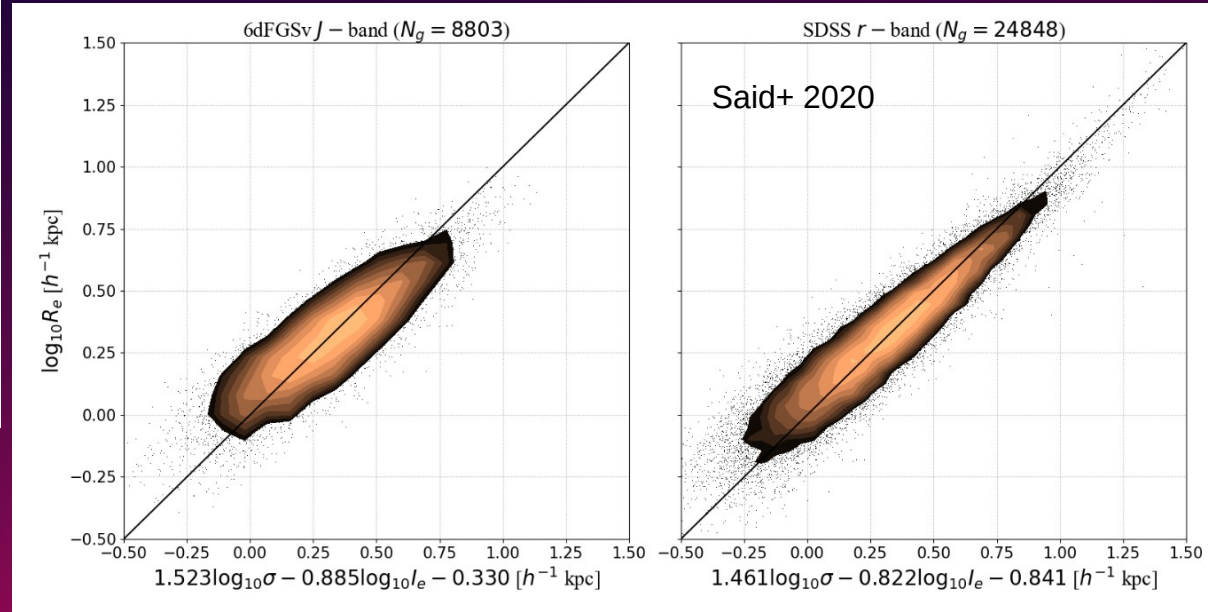
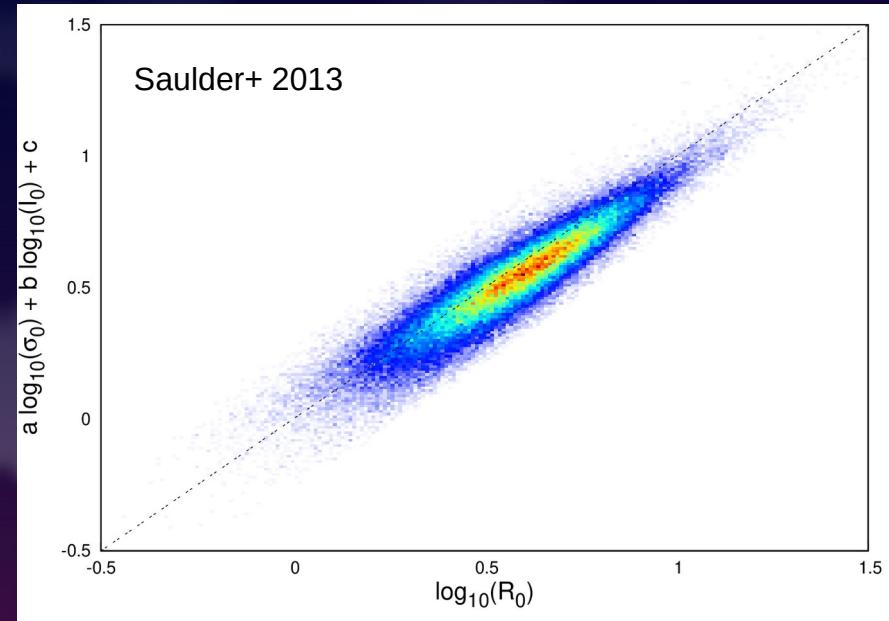
$$\log(R_0) = a \log(\sigma_0) + b \mu_0 + c$$

- Scatter $\sim 20\%$
- Requires good quality spectroscopy to obtain the central velocity dispersion



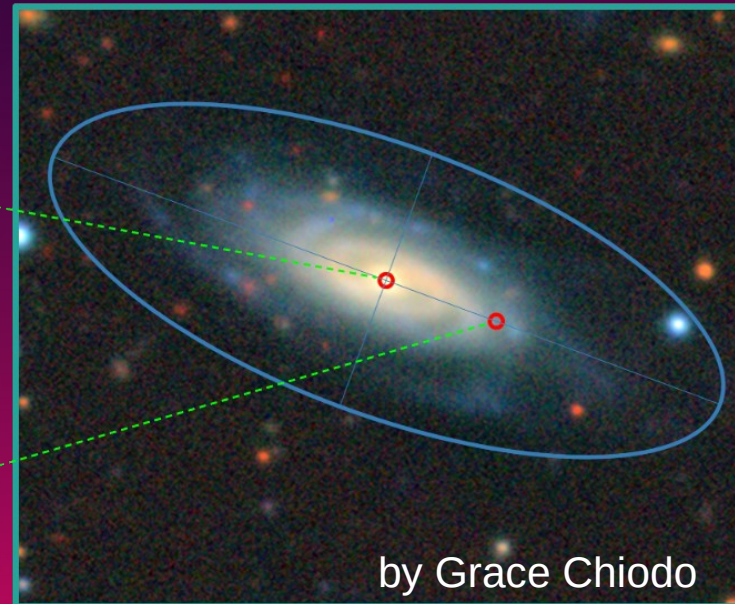
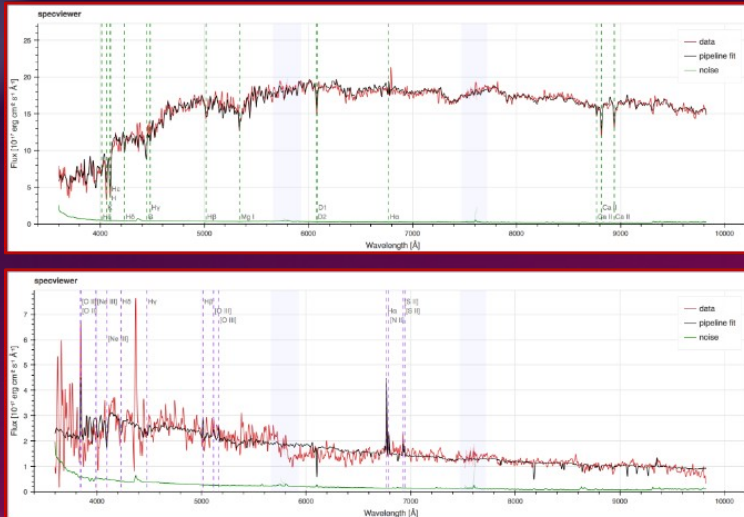
by DESI Legacy Imaging Survey DR9

Fundamental plane of early-type galaxies



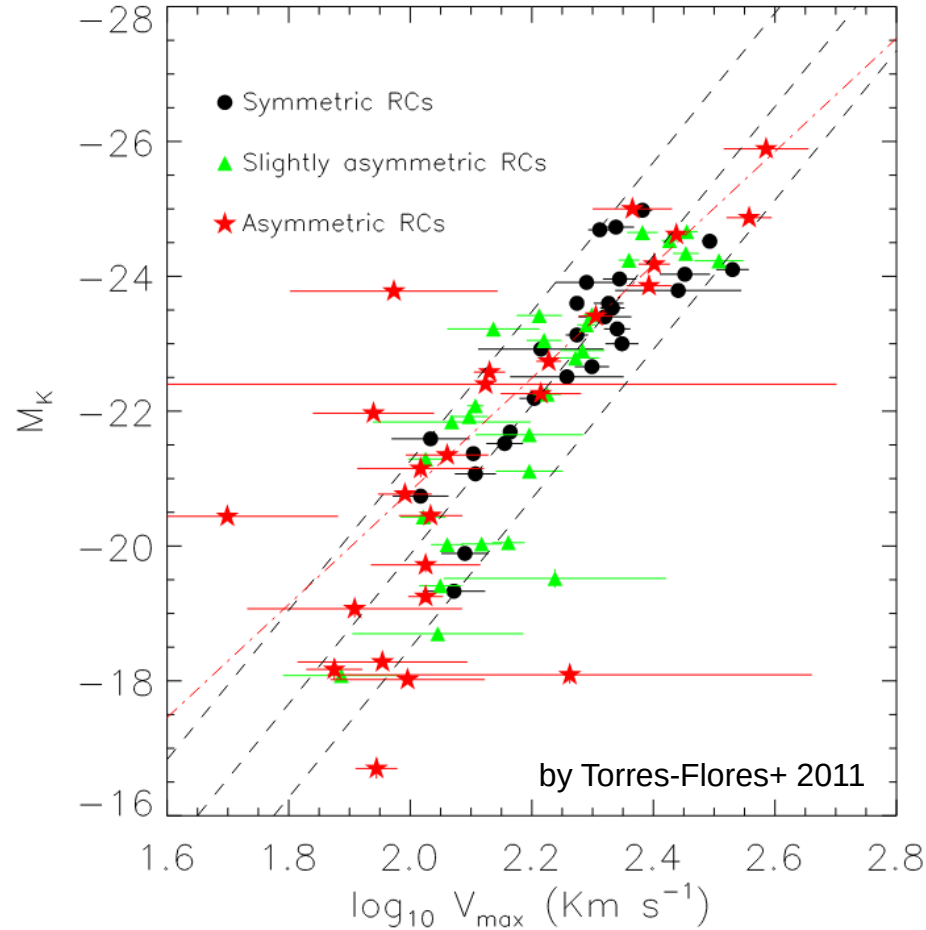
Tully-Fisher relation of late-type galaxies

- $M = b \log (v_{\max}) + c$ with a Scatter $\sim 20\%$
- Measurements of maximal rotational velocity v_{\max}
- Off-centre fibres \rightarrow redshifts relative to the centre



by Grace Chiodo

Tully-Fisher relation of late-type galaxies

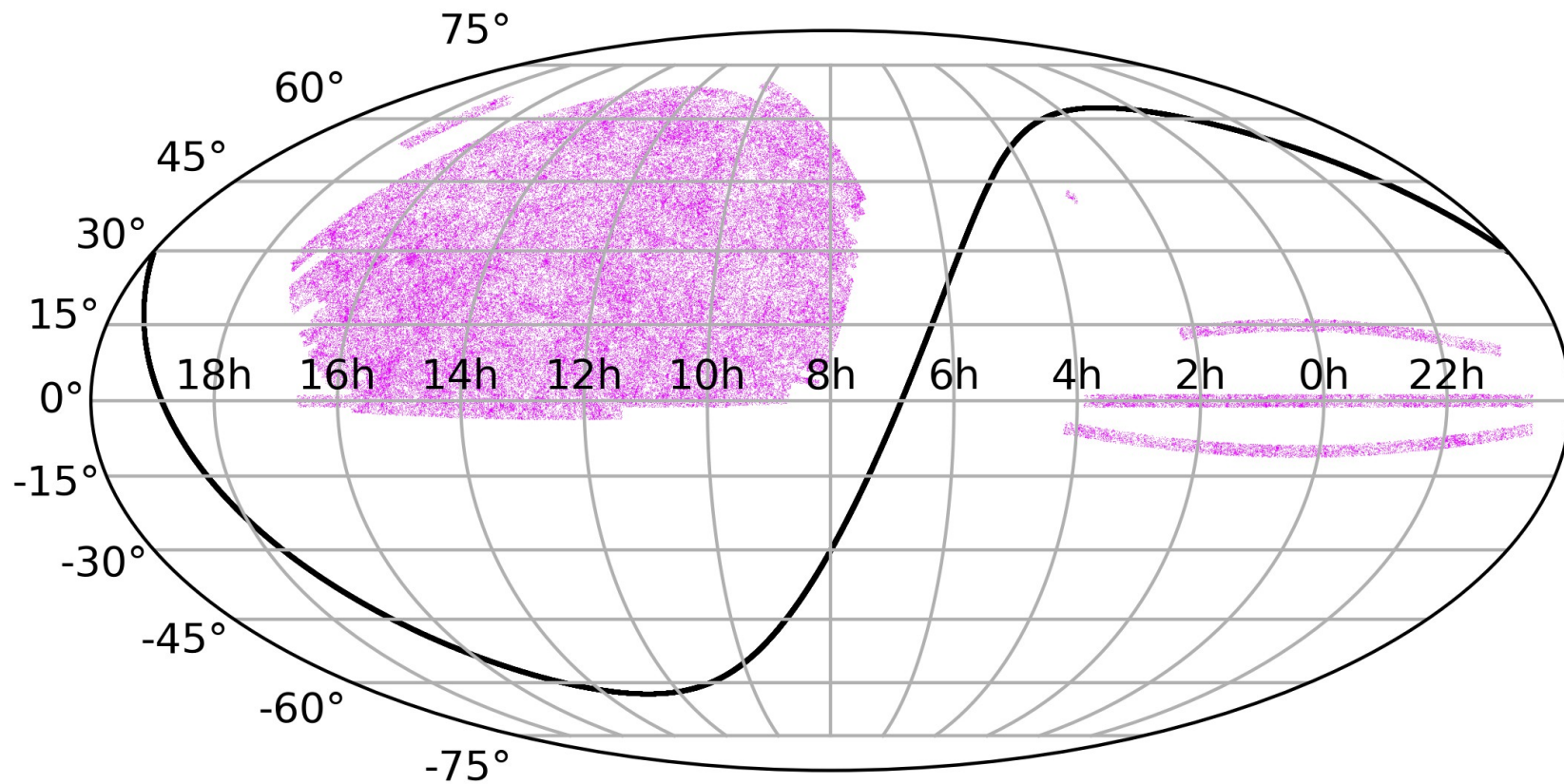


Previous peculiar velocity surveys

- SDSS (mostly DR7) ~100 000 galaxies (using FP)
- 6dFGS: ~10 000 galaxies (using FP)
- SFI++: ~ 5 000 galaxies (using TF)
- 2MTF: ~2 000 galaxies (using TF)
- Taipan survey: cancelled due to technical difficulties (FP)
- CosmicFlows-4: combination of different methods, but mostly TF



SDSS DR7

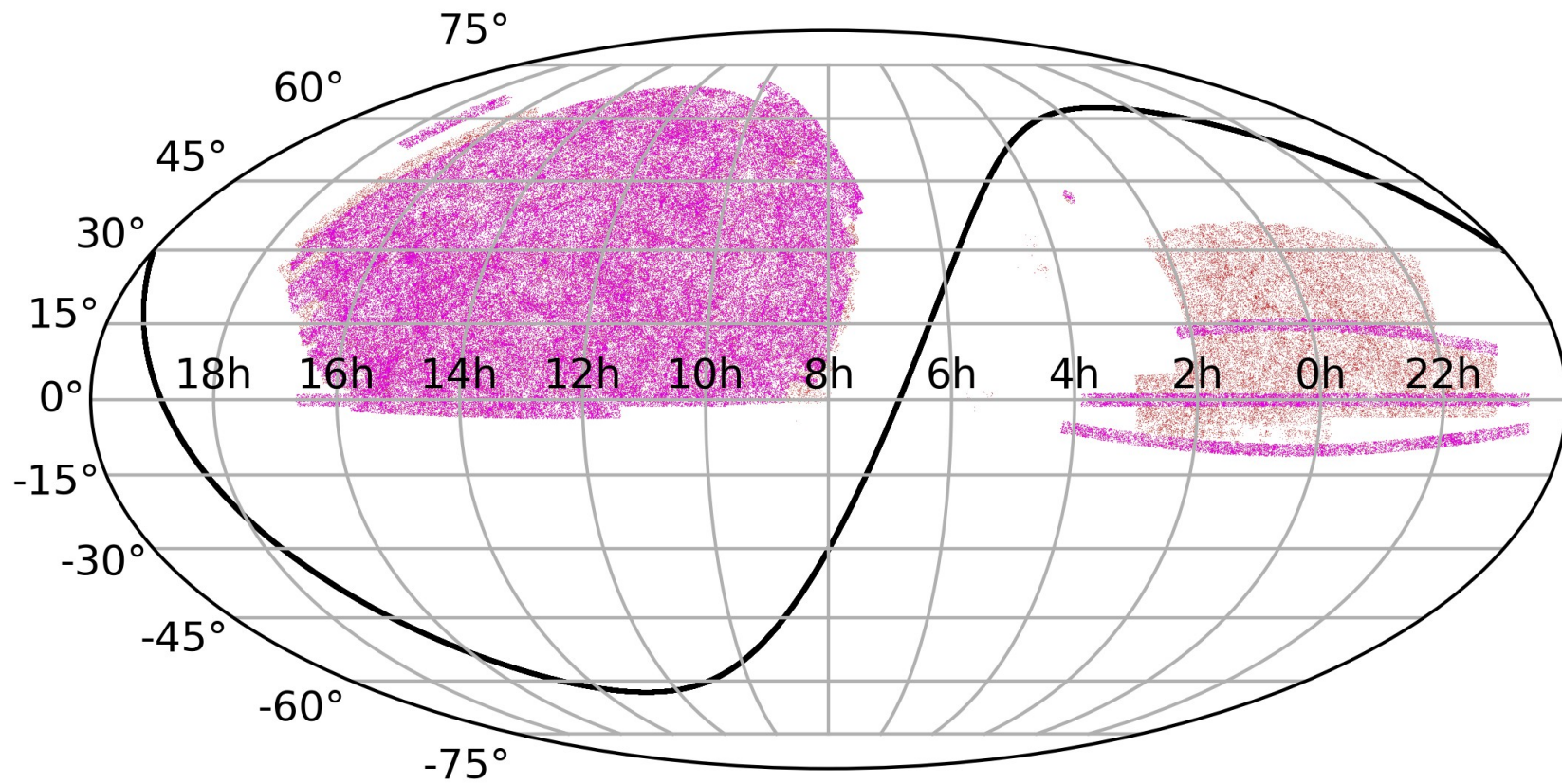




SDSS DR17

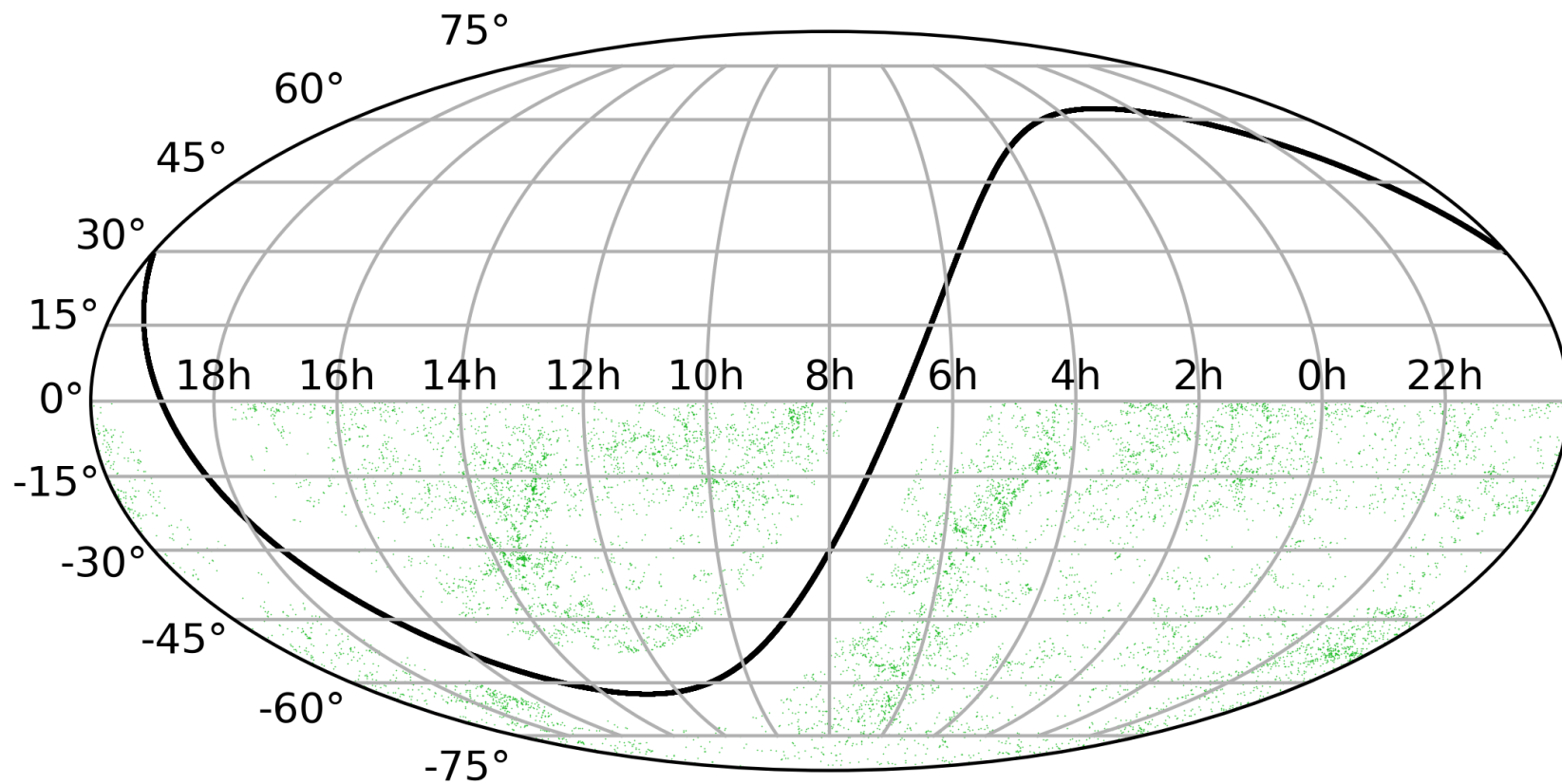


SDSS DR7





6dFGSv





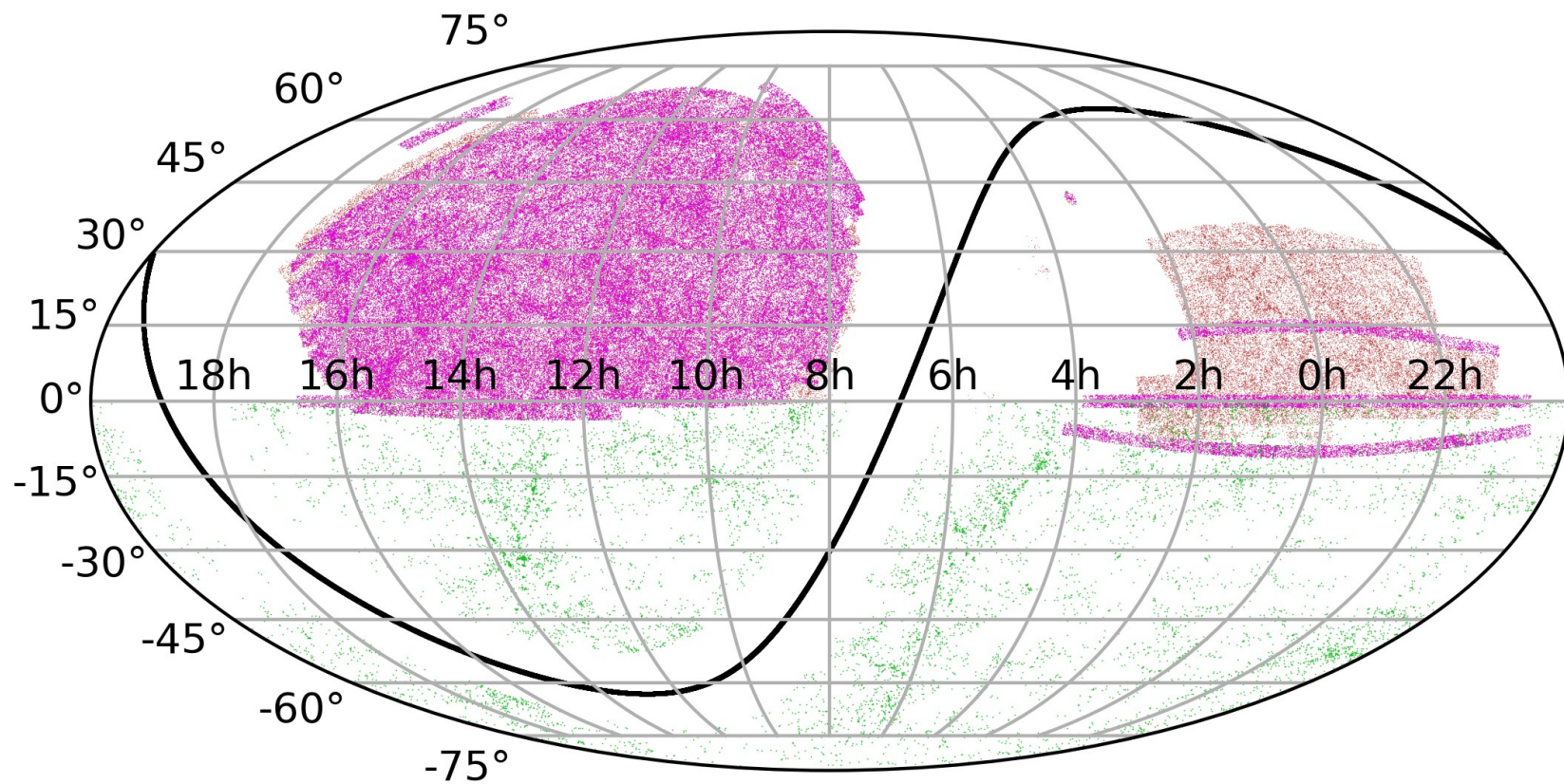
SDSS DR17



SDSS DR7



6dFGSv





DESI PV



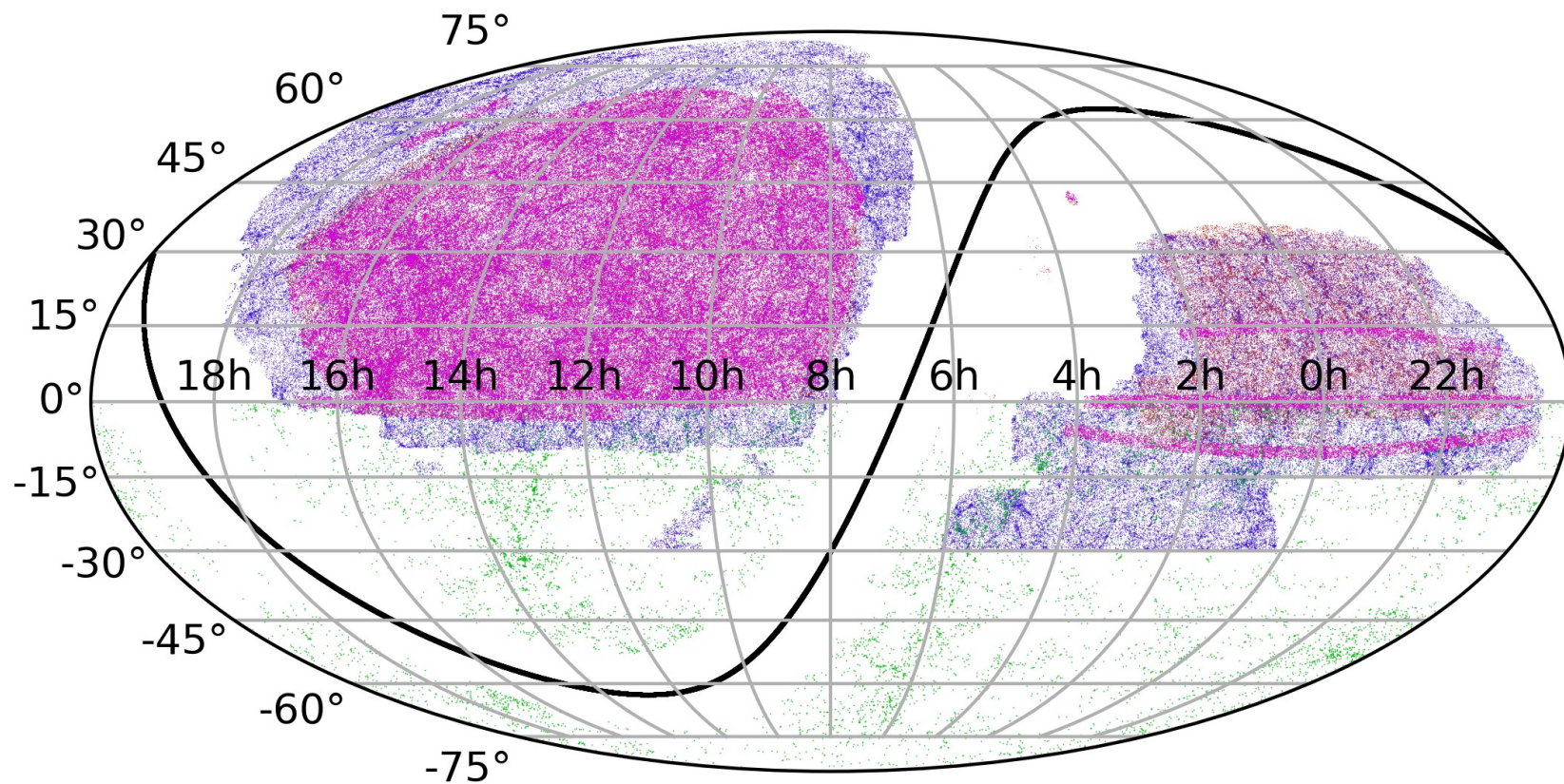
SDSS DR17



SDSS DR7

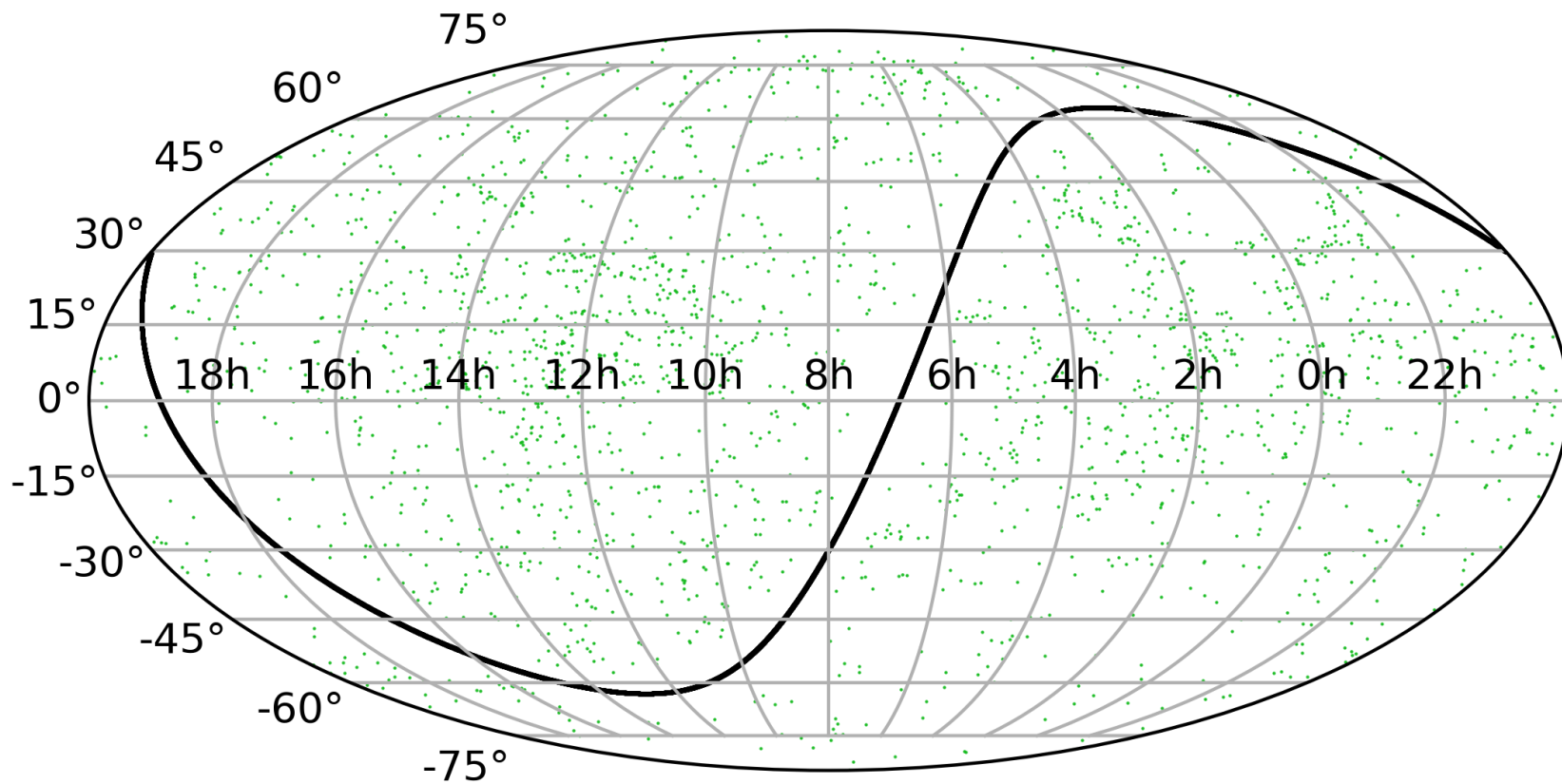


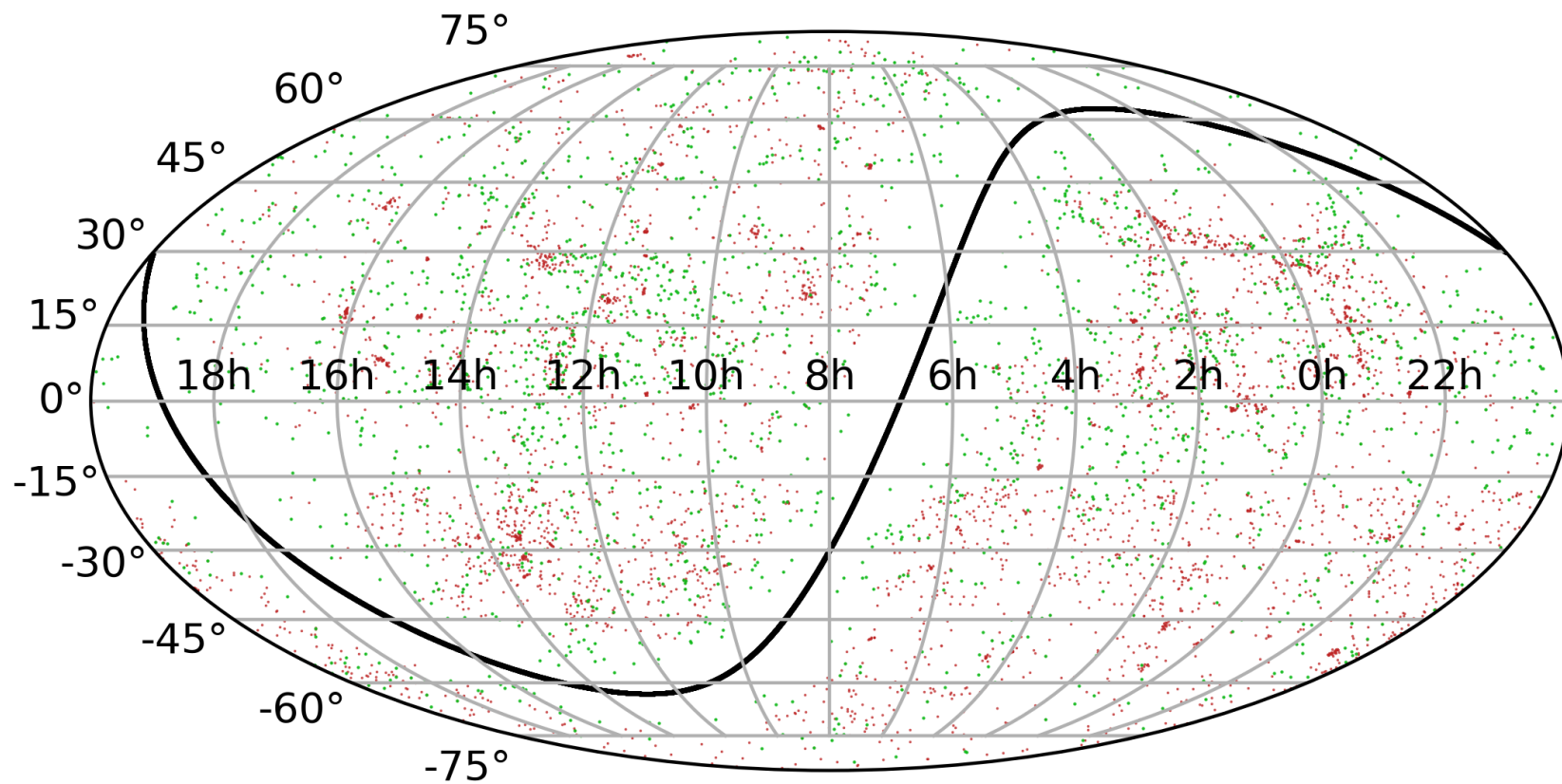
6dFGSv





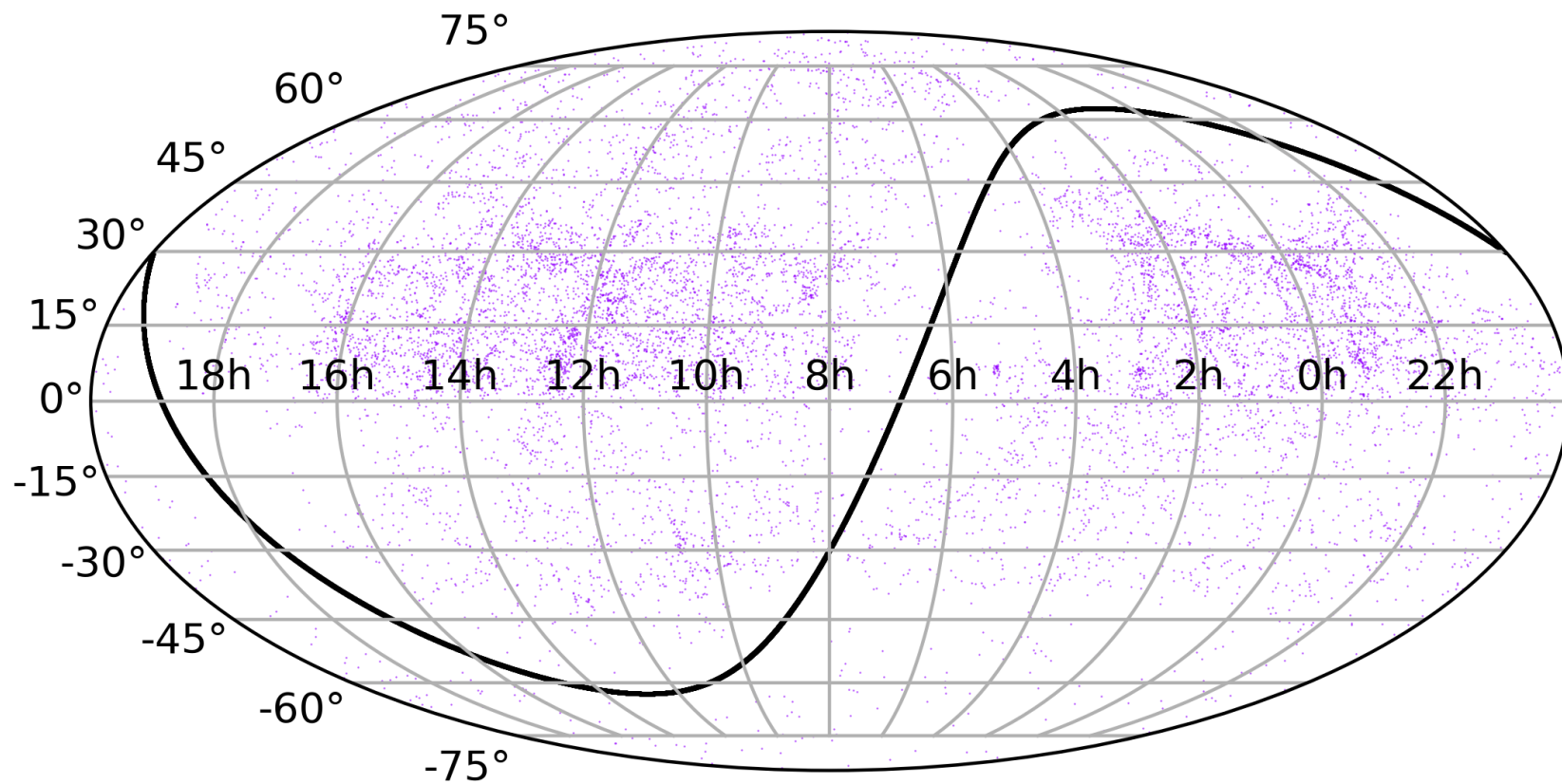
2MTF







CosmicFlows4





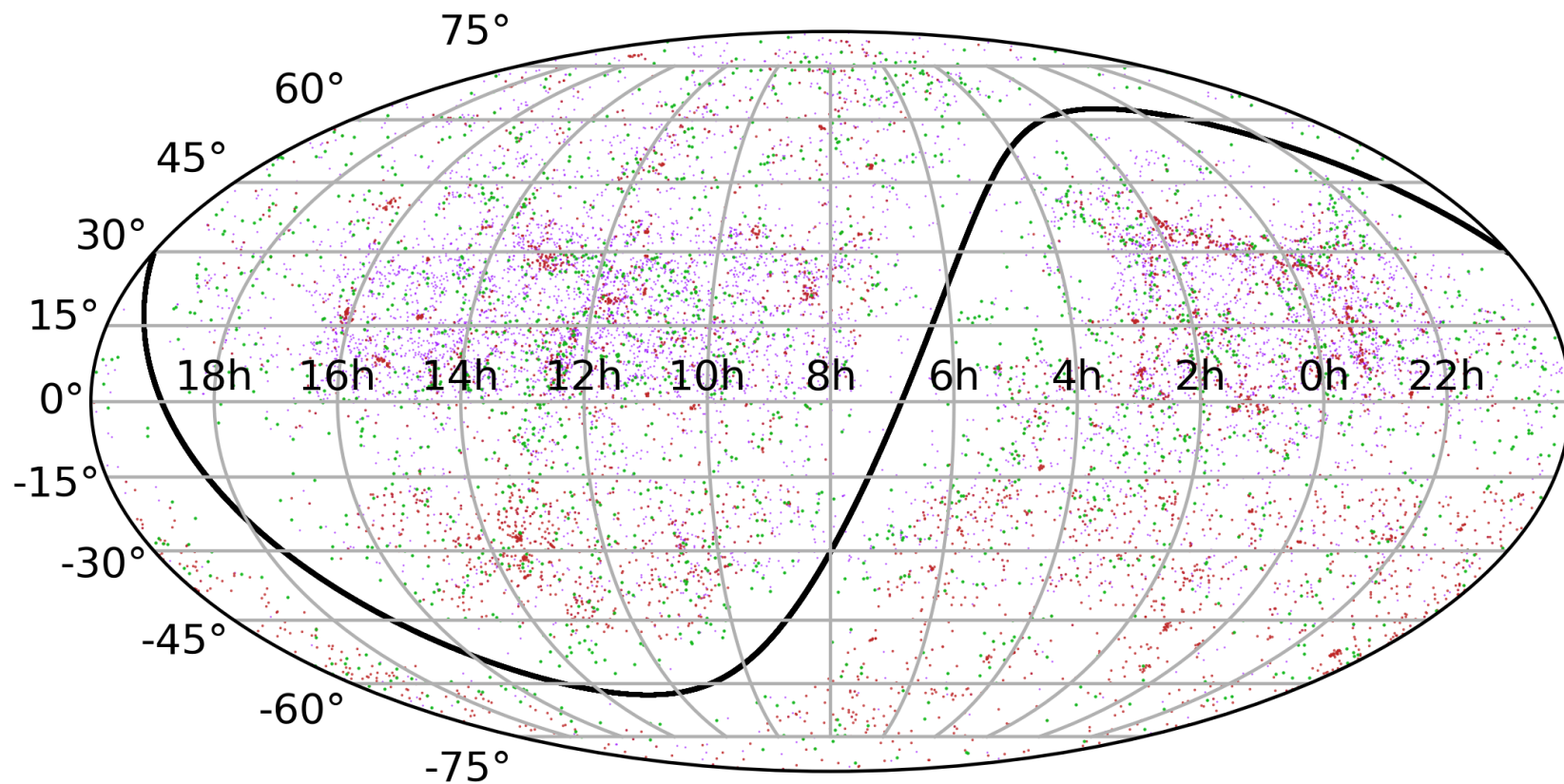
CosmicFlows4



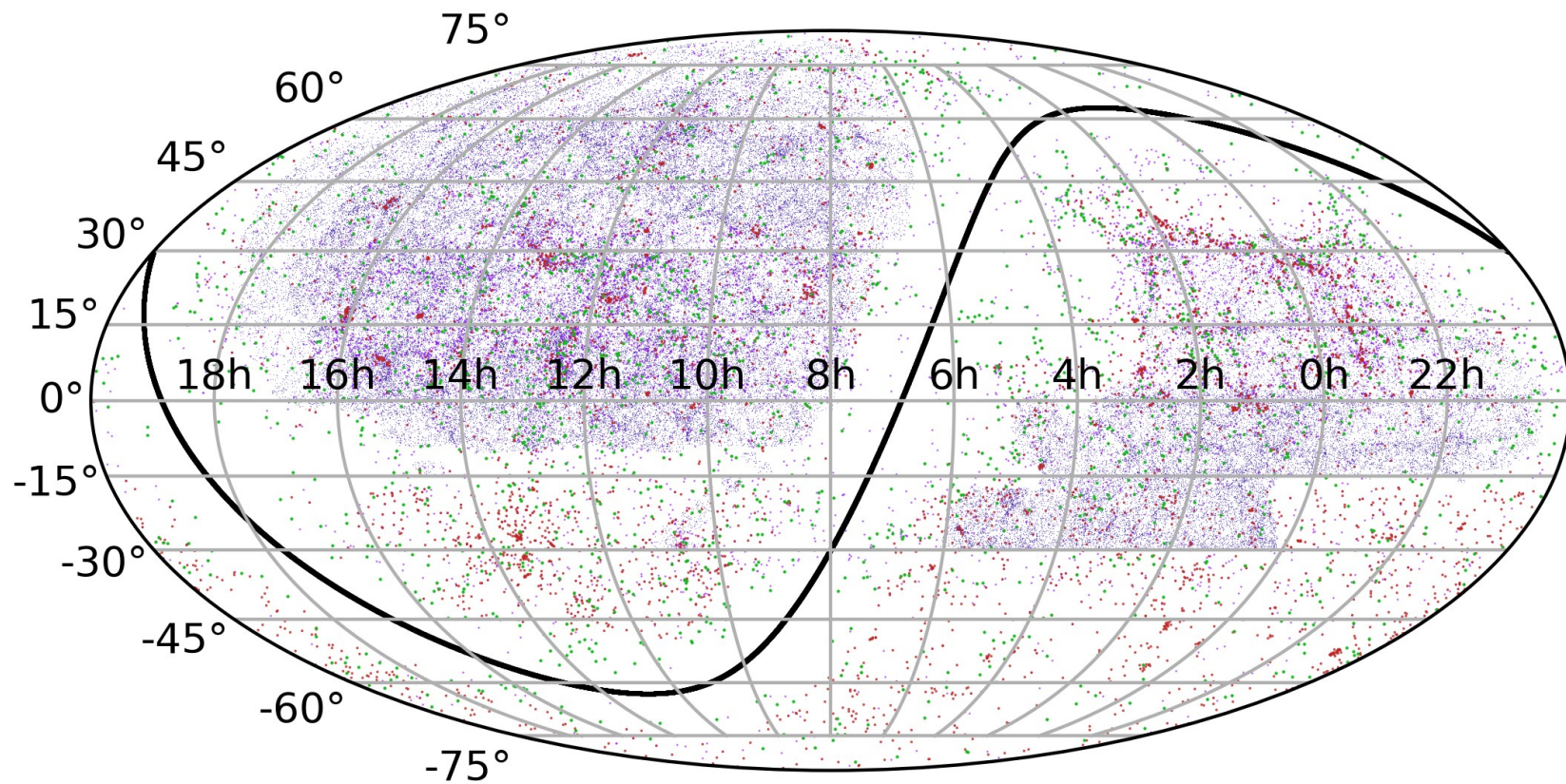
SFI++



2MTF

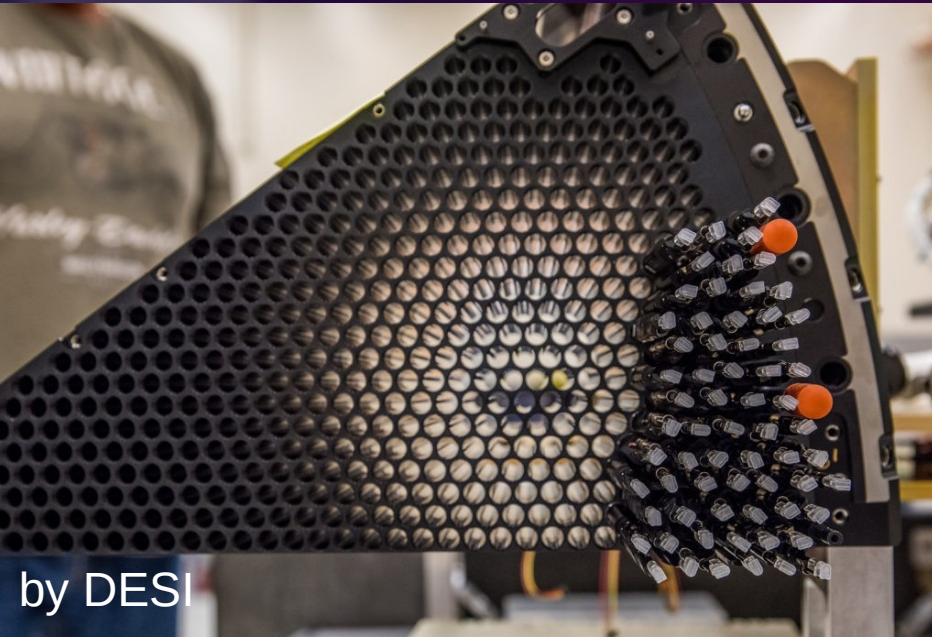


• DESI PV • CosmicFlows4 • SFI++ • 2MTF



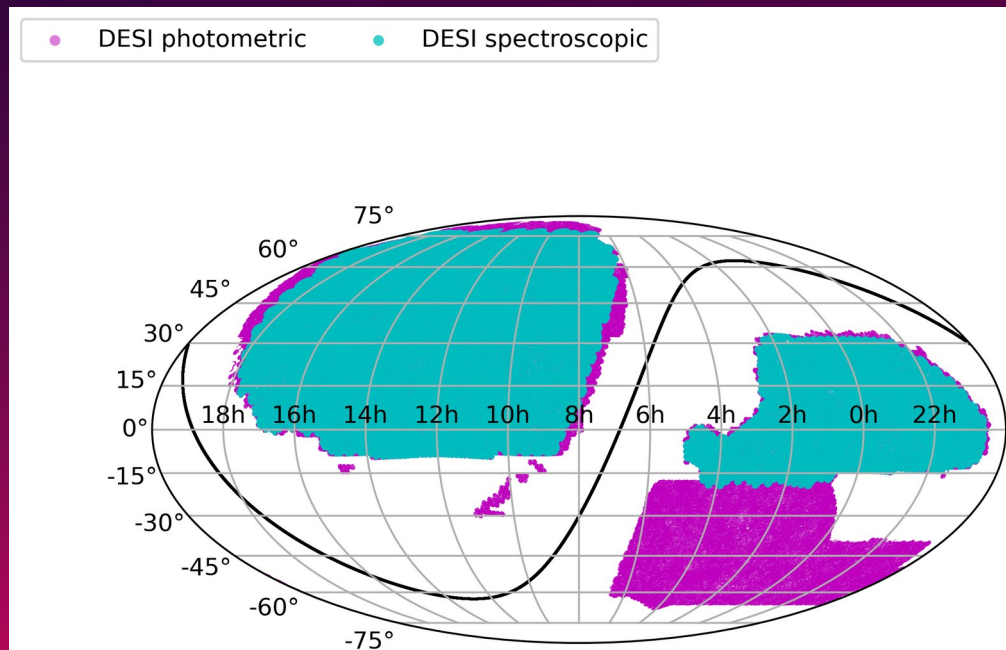
The Dark Energy Spectroscopic Instrument

- 4-meter Mayall Telescope at Kitt Peak National Observatory
- 5000 robotic fibres
in 10 petals with 500 each



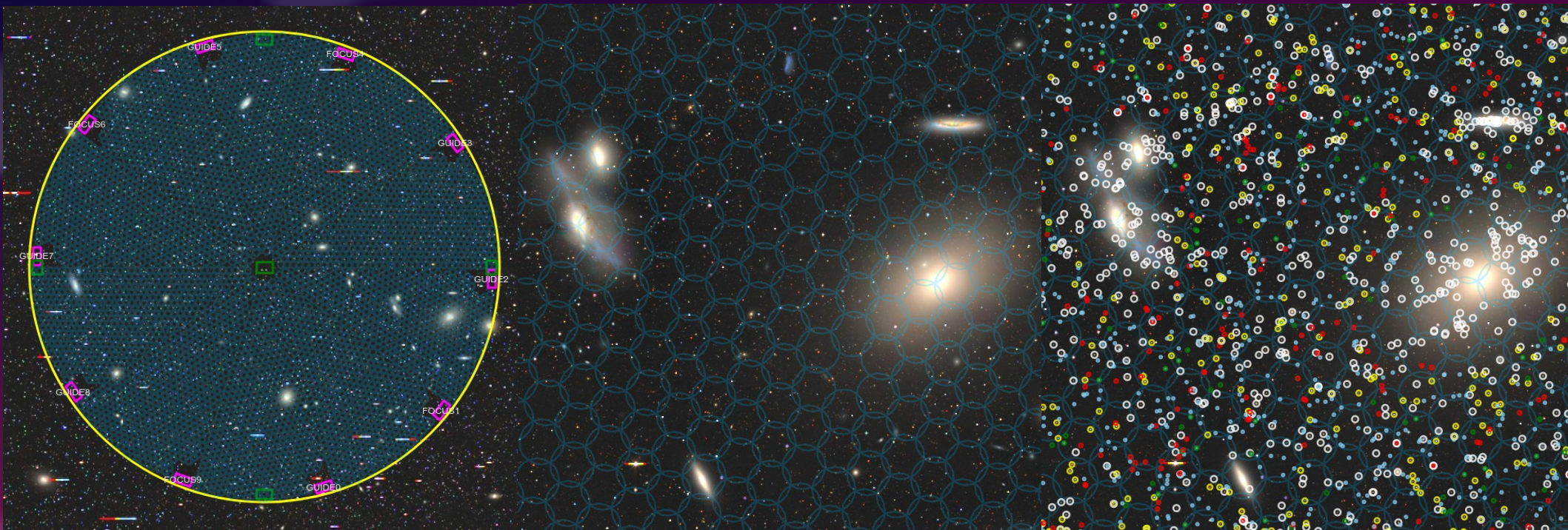
Photometric and spectroscopic survey

- DESI Legacy Imaging Survey DR9
 - grz photometry for target selections (supplemented with WISE data)
- DESI survey
 - 3 arms (360 – 980 nm, R: 2k-5k)
 - Main target classes for BAO
BGS, LRG, ELG, QSO
 - Milky Way science targets
 - **Spare fibres for secondary targeting programmes**



Understanding the DESI fibre assignment

- Fibres can move in patrol radius, many competing targets
- Multiple passes (up to 7), observations in dark time and bright time

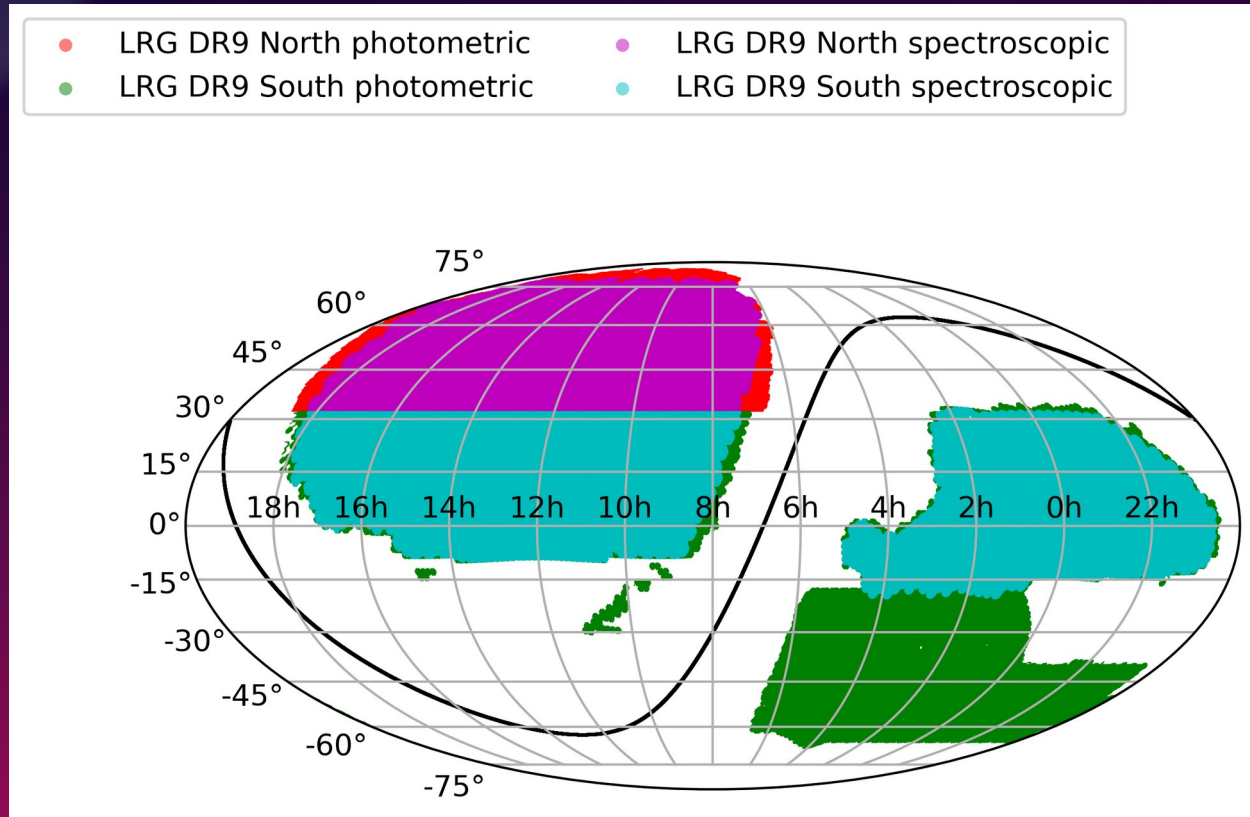


Using the spare fibres

- Main targets (BGS, LRG, ELG, QSO, MWS) have always priority
- Spare fibres:
 - Bright galaxies (SGA) are masked for dark time targets (ELG, LRG, QSO):
If no other target within patrol radius of fibre positioner
 - After multiple passes: all main targets within patrol radius observed
 - Some big galaxies (from SGA) cover several patrol radii
 - no other targets by chance (very rare)
- Spare fibres are used for several secondary targeting programmes
- Allow for additional observations in dark time with high SNR (FP)
- Over time: additional measurements of off-centre redshifts (TF)

DESI Legacy Imaging Survey DR9

- grz photometry for target selections (supplemented with WISE data)

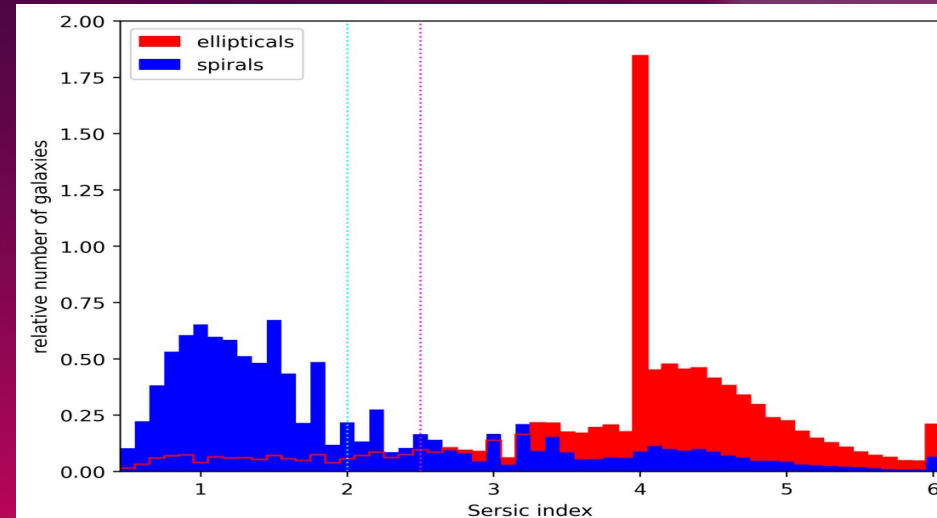


Target selection

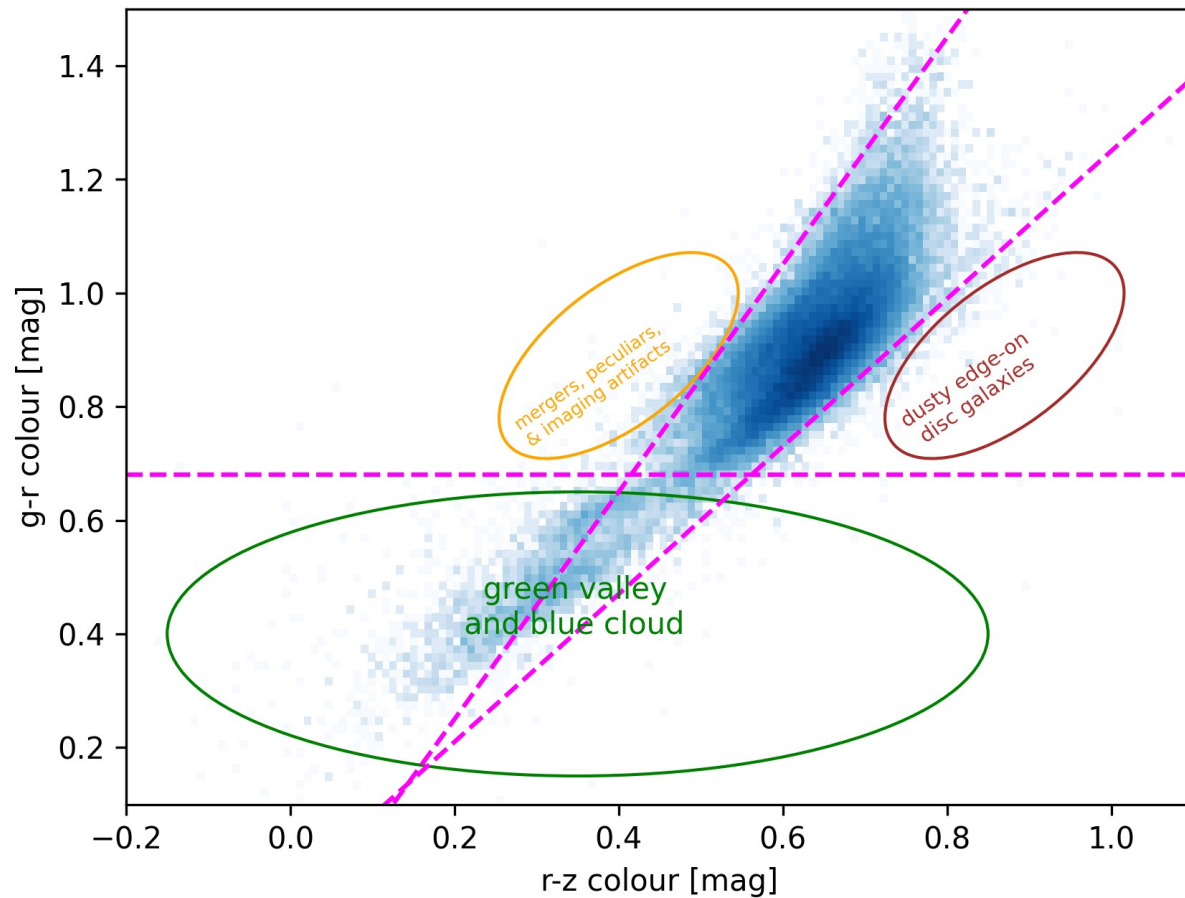
- Had to be done before start of spectroscopic observations
- Using DESI Legacy Imaging Survey DR9
- ETGs for FP
- LTGs for TF-relation
- Truth catalogues from the Siena Galaxy Atlas and GalaxyZoo

Fundamental plane targets

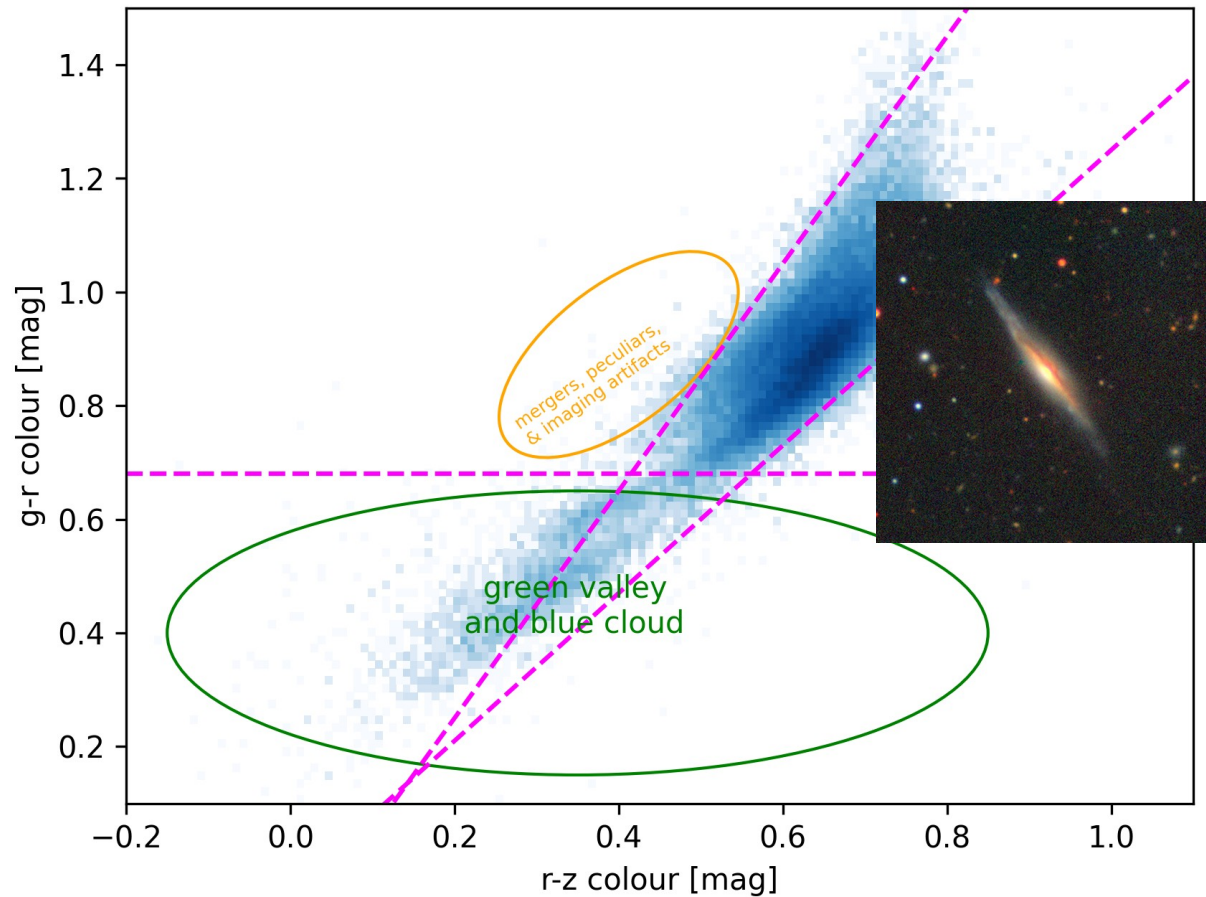
- Early-type galaxies that lie (nicely) on the fundamental plane
- (old) BGS target selection as the first step (nearby bright galaxies)
- Ellipticity < 0.7
- photoz < 0.15
- Sersic index > 2.5
- Magnitude limit ($r < 18\text{mag}$)
- Colour cuts



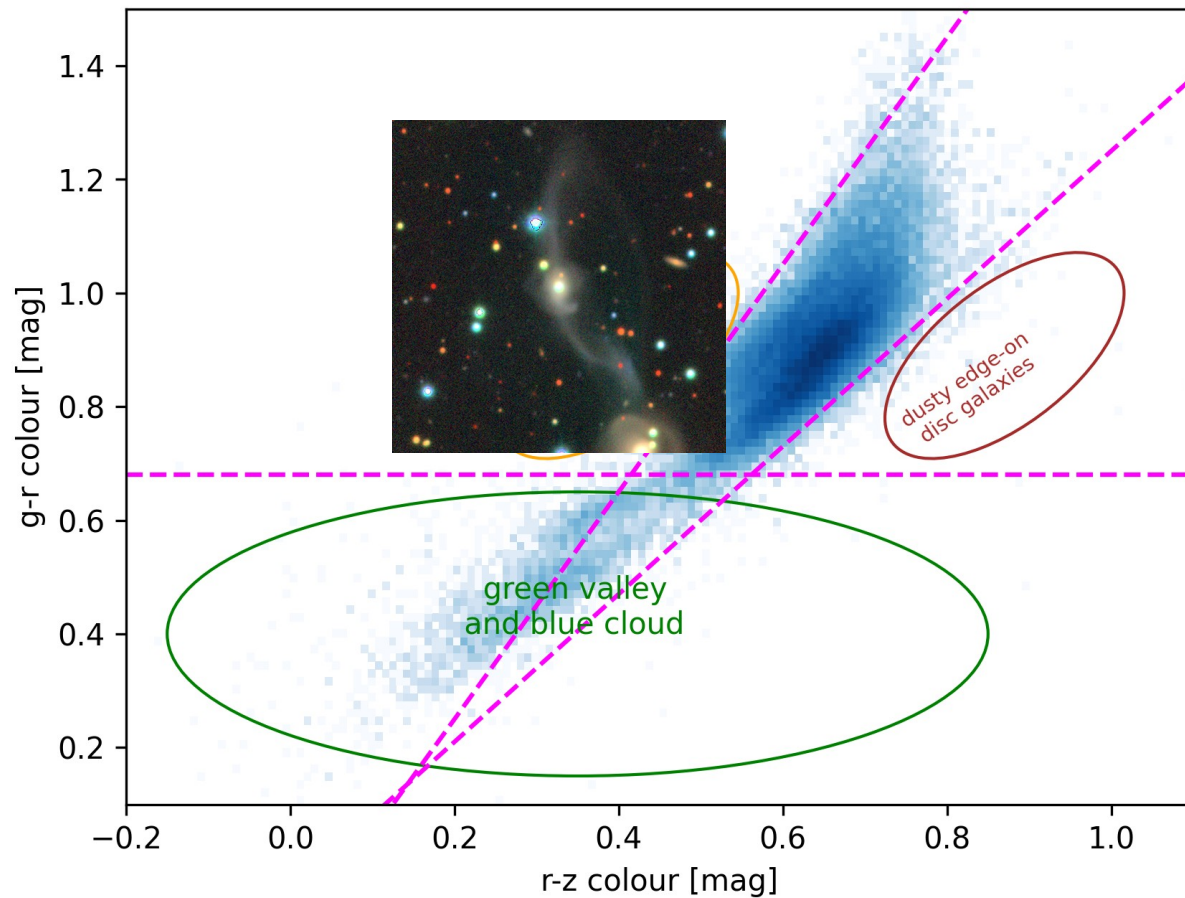
Colour cuts



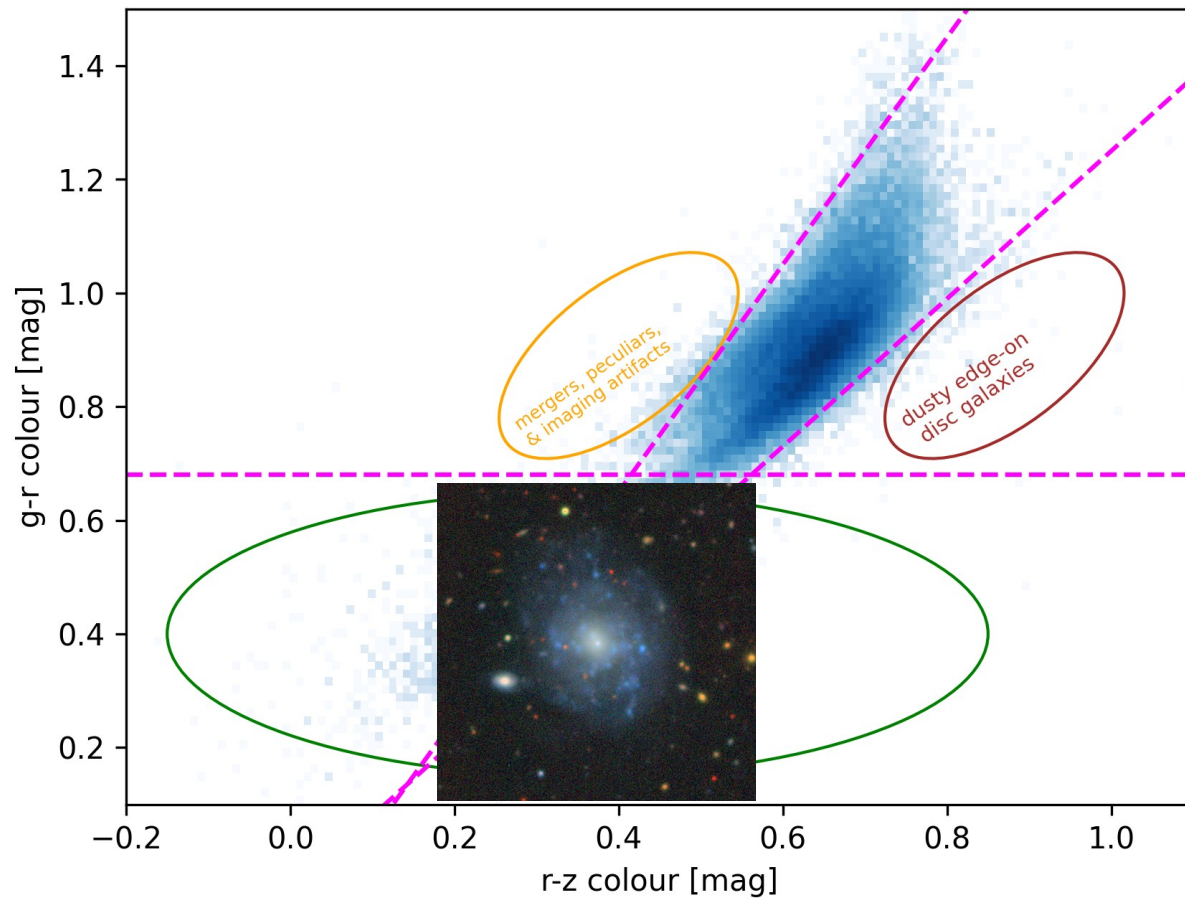
Colour cuts



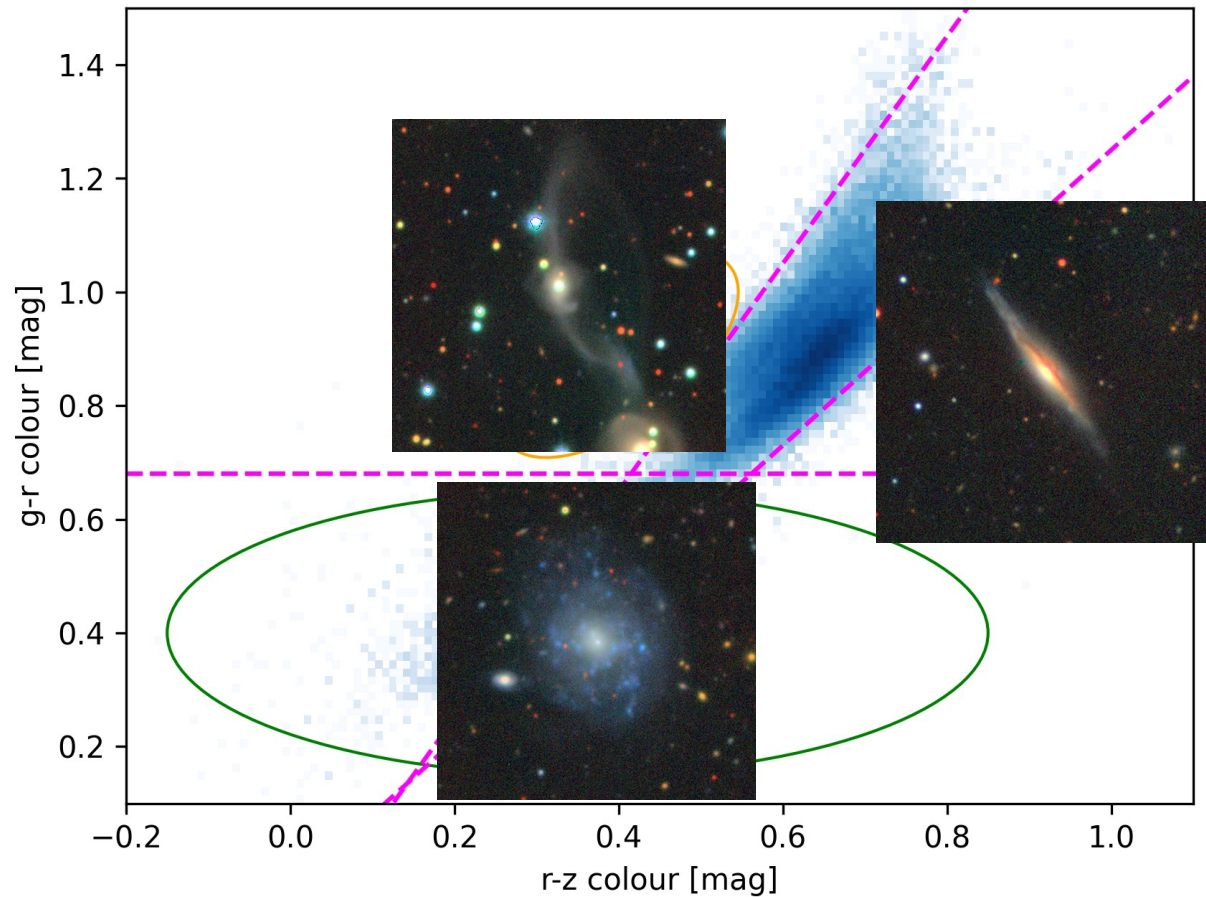
Colour cuts



Colour cuts



Colour cuts



Tully-Fisher relation targets

- Late-type galaxies for which we can get off-axis measurements of their rotation velocity
- Only objects from the Siena Galaxy Atlas (large galaxies)
- Inclination of at least 25 degree
- Sersic index < 2
- $D26 > 20''$

Default fibre placements

PGC087458



FP



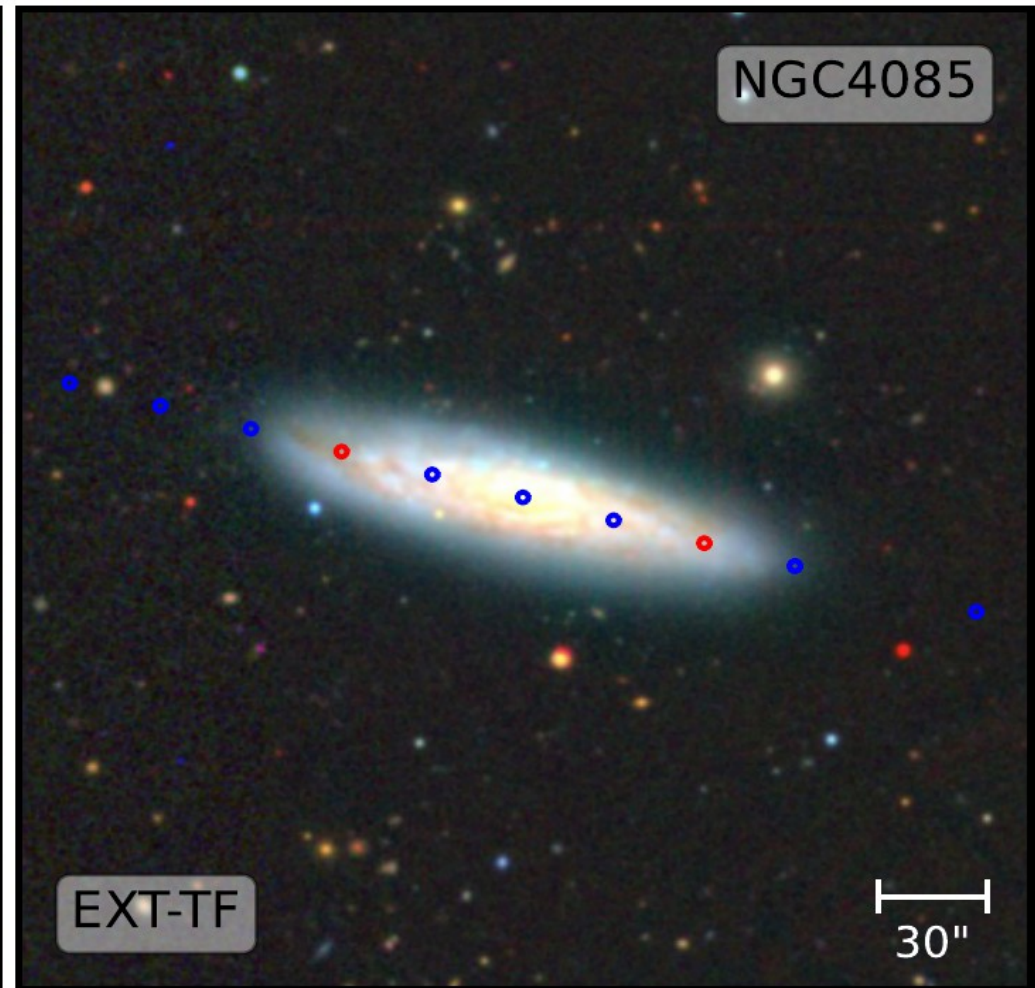
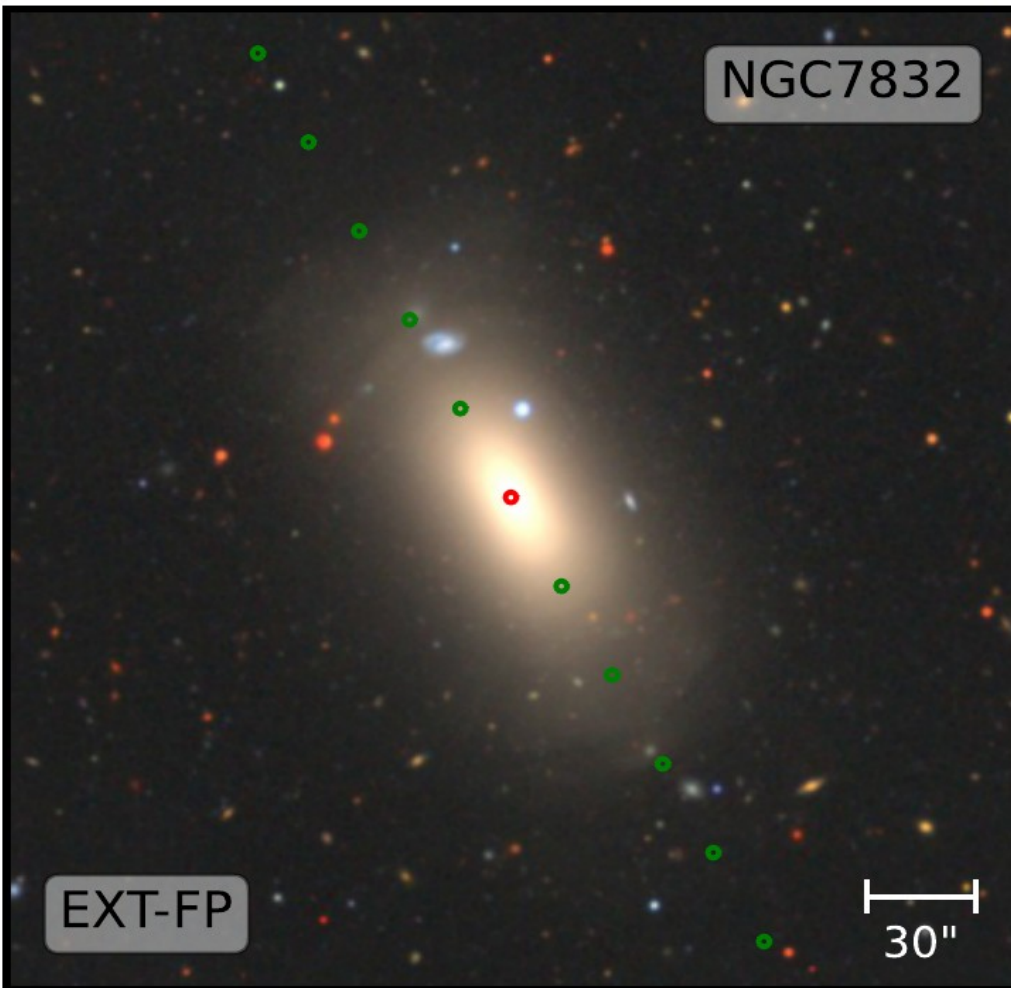
UGC12903



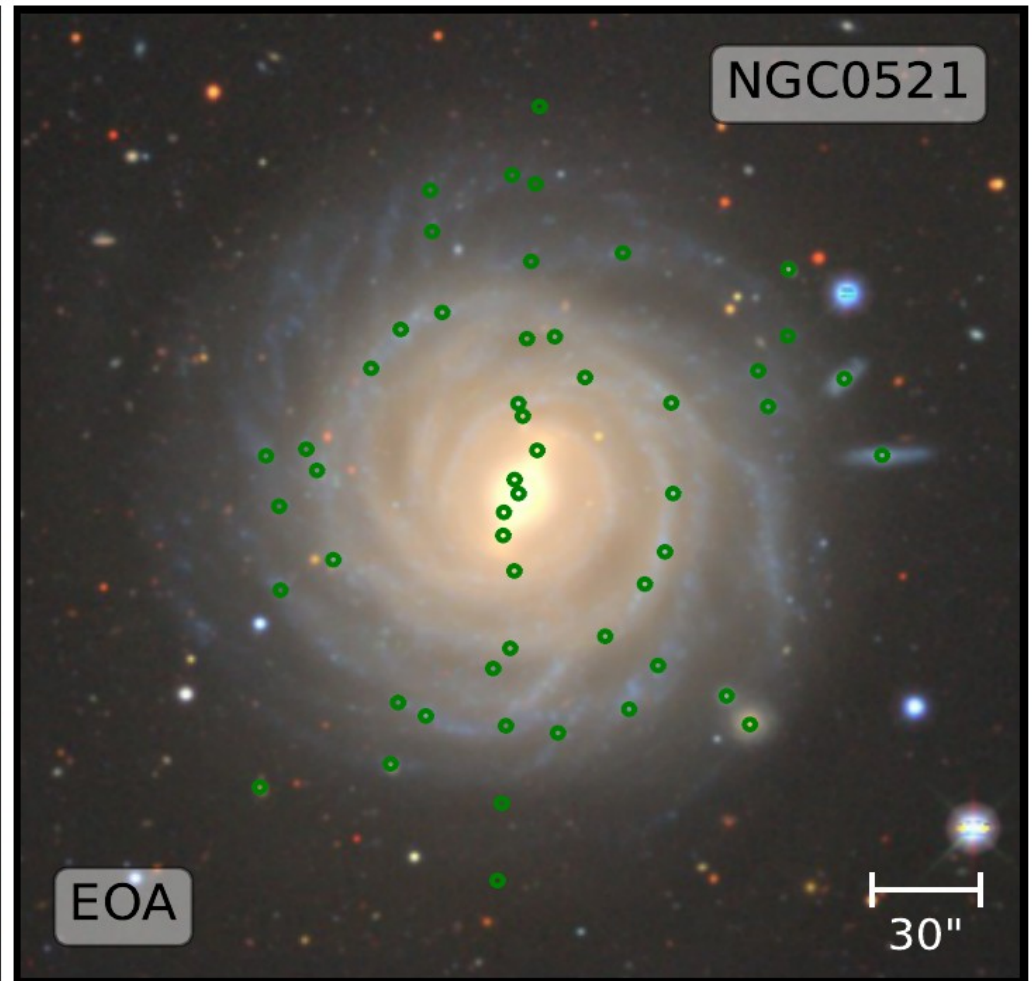
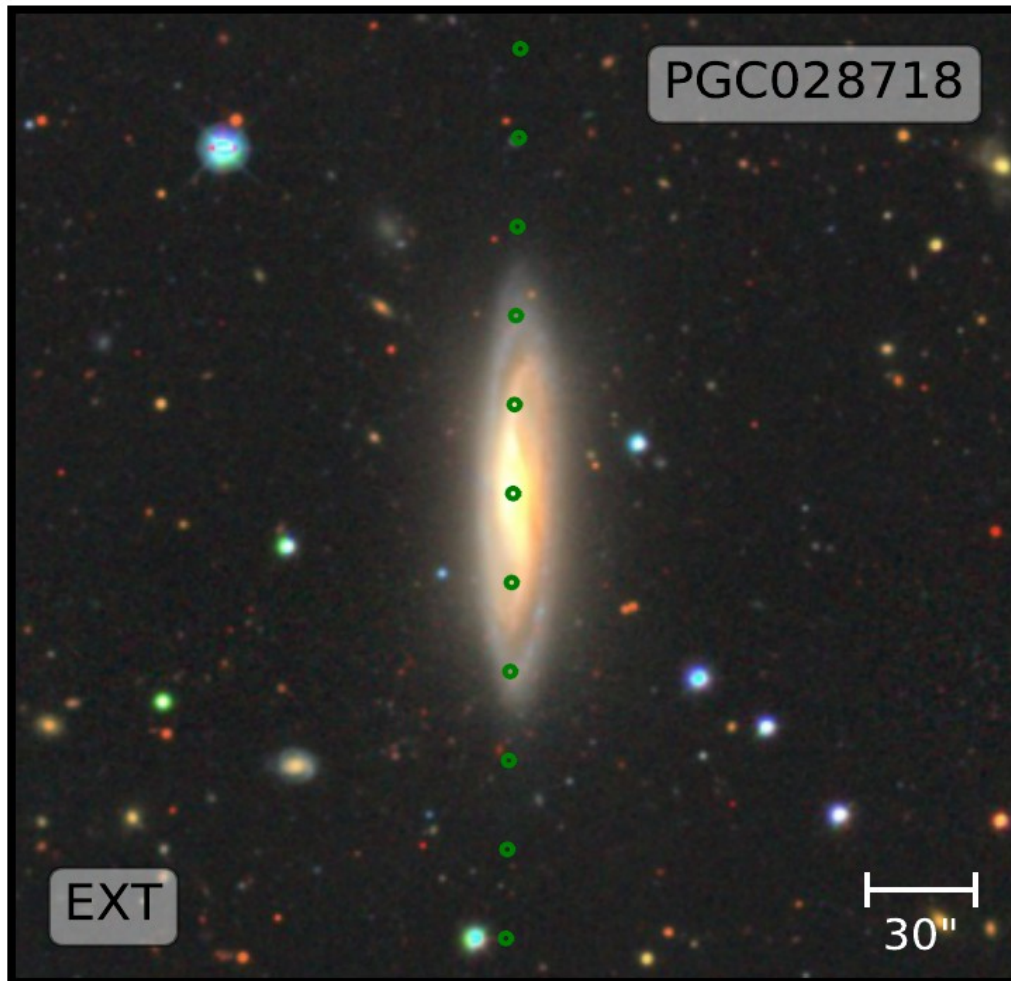
TF



Additional fibre placements for calibrations

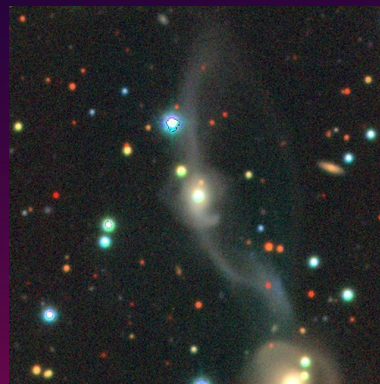
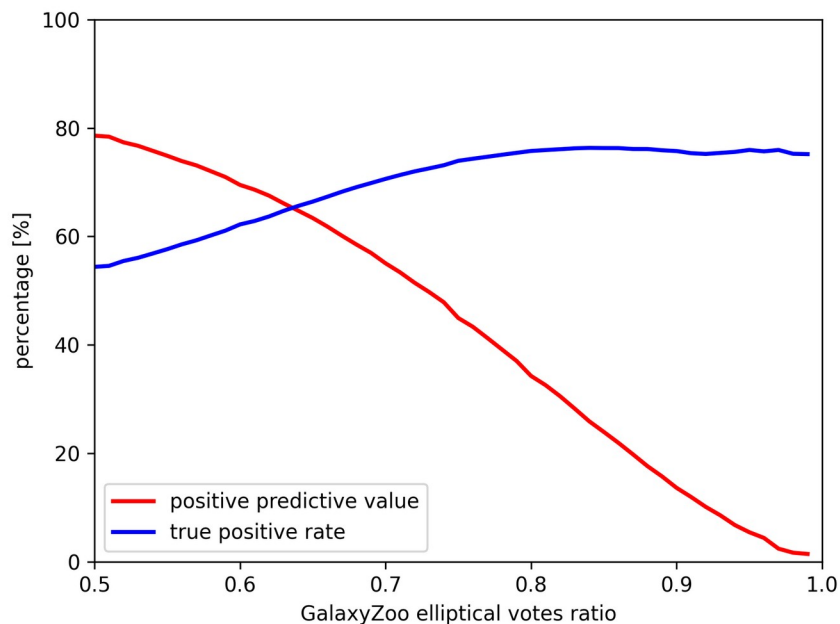


Low resolution integral field spectroscopy



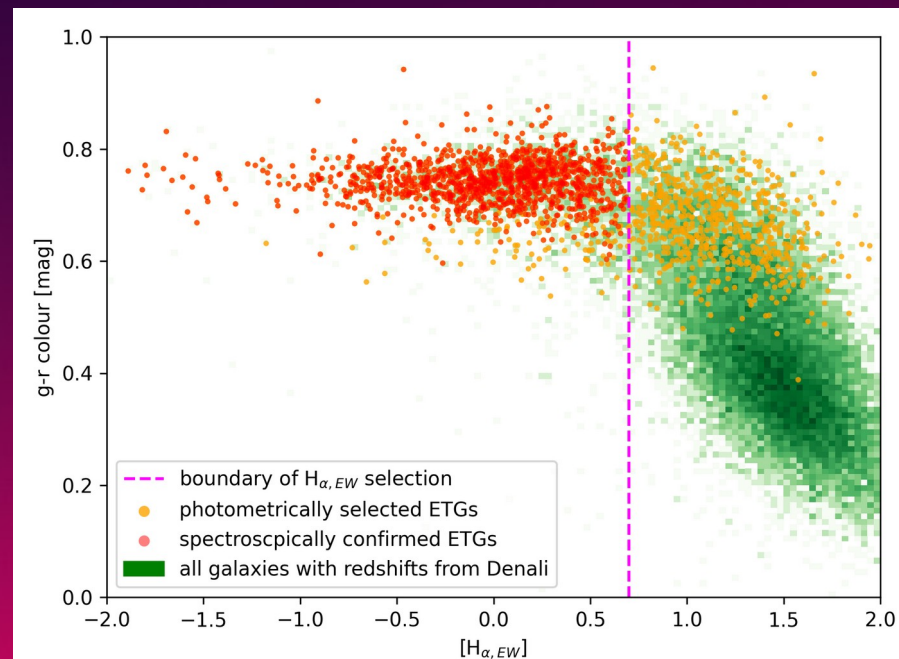
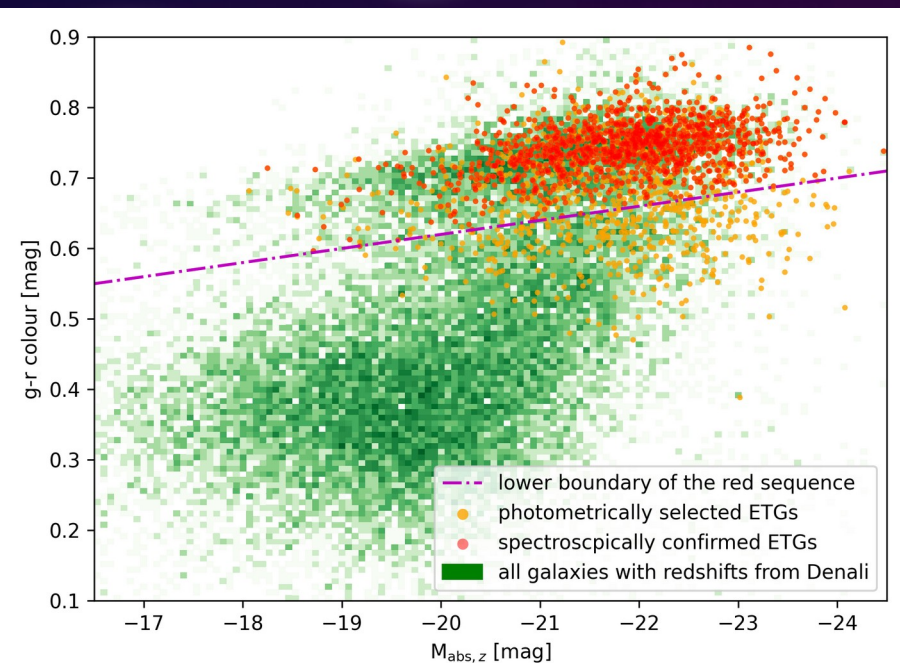
Verification of our target selection

- Tests with existing morphological catalogues (GalaxyZoo and Siena Galaxy Atlas) within the SDSS DR7 footprint
- Visual inspection to find outliers



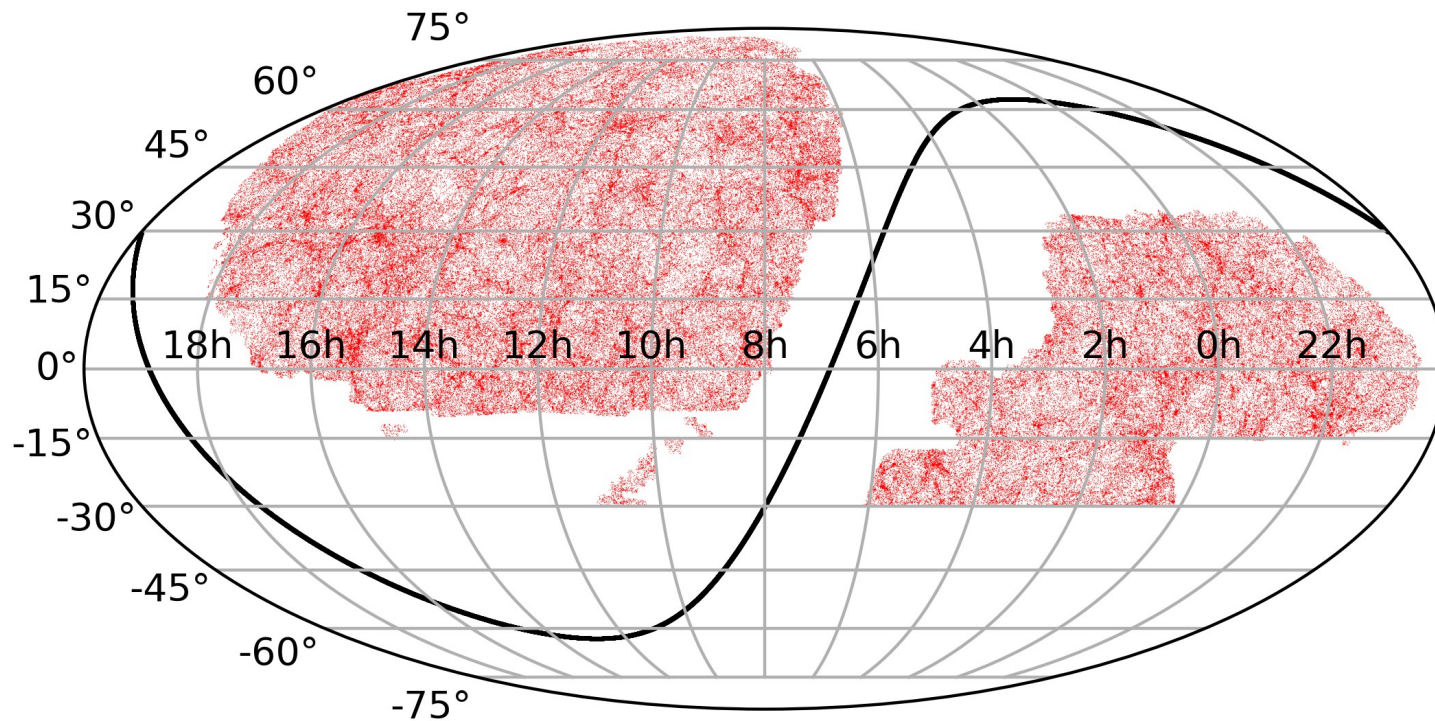
Verification of our target selection

- Using the science verification data (observation before the main survey) to test our criteria and refine them further
- Using fastspec data to further clean the sample ($\sim 75\%$ remain)



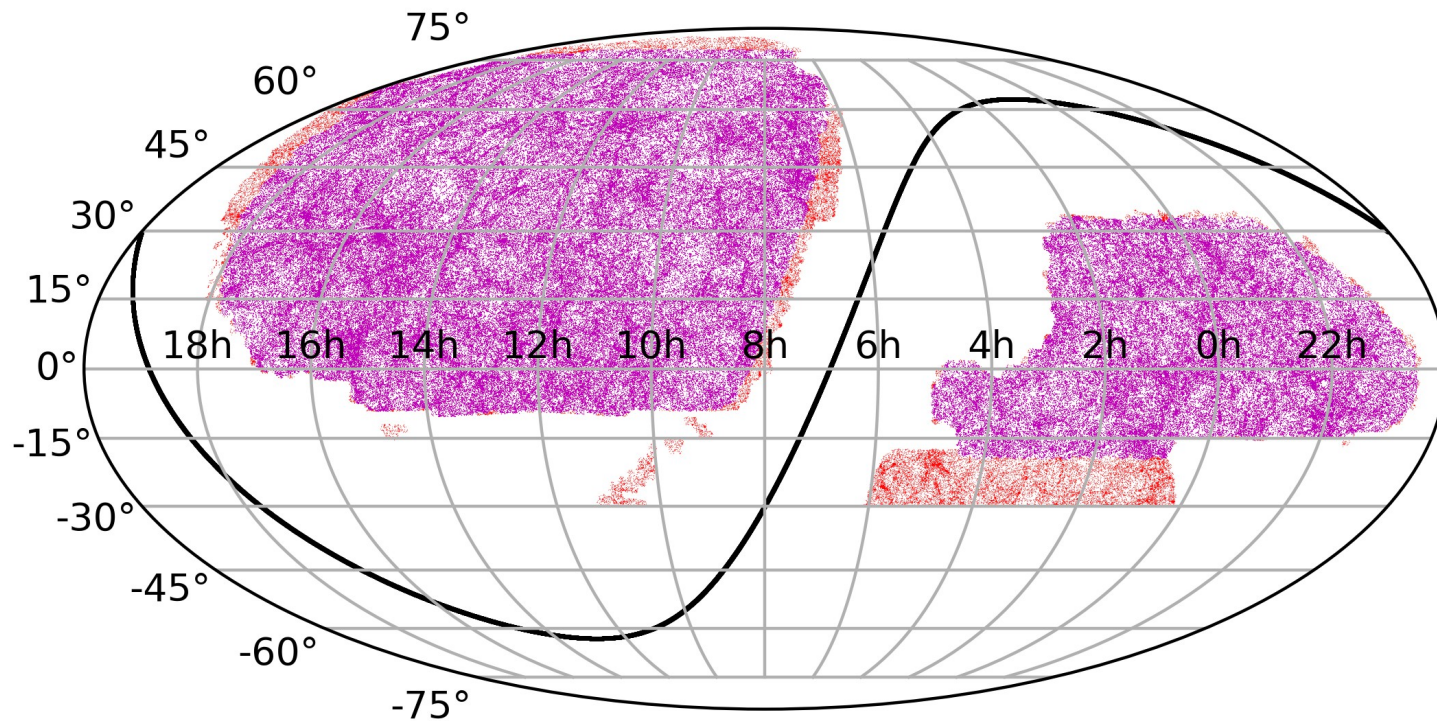
Spectroscopic targets

• FP targets



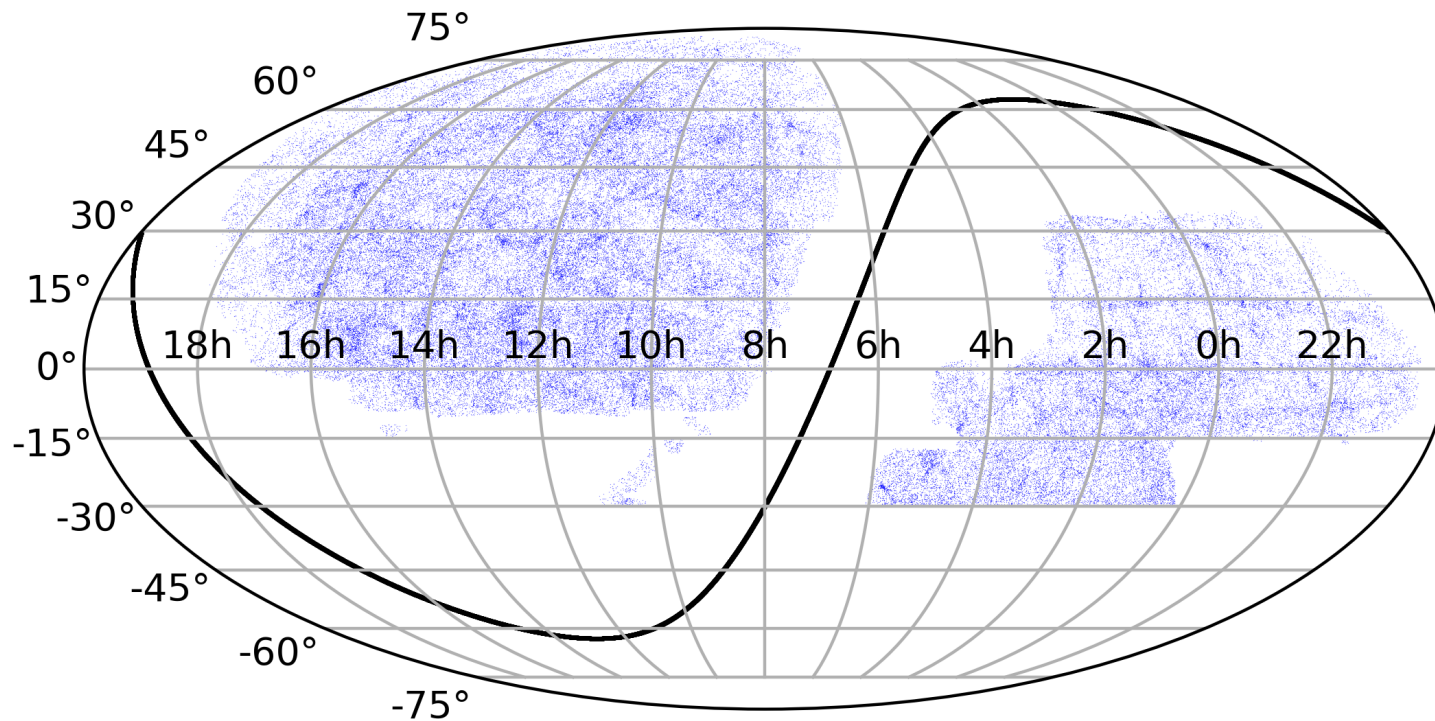
Spectroscopic targets

• FP targets • FP in spec



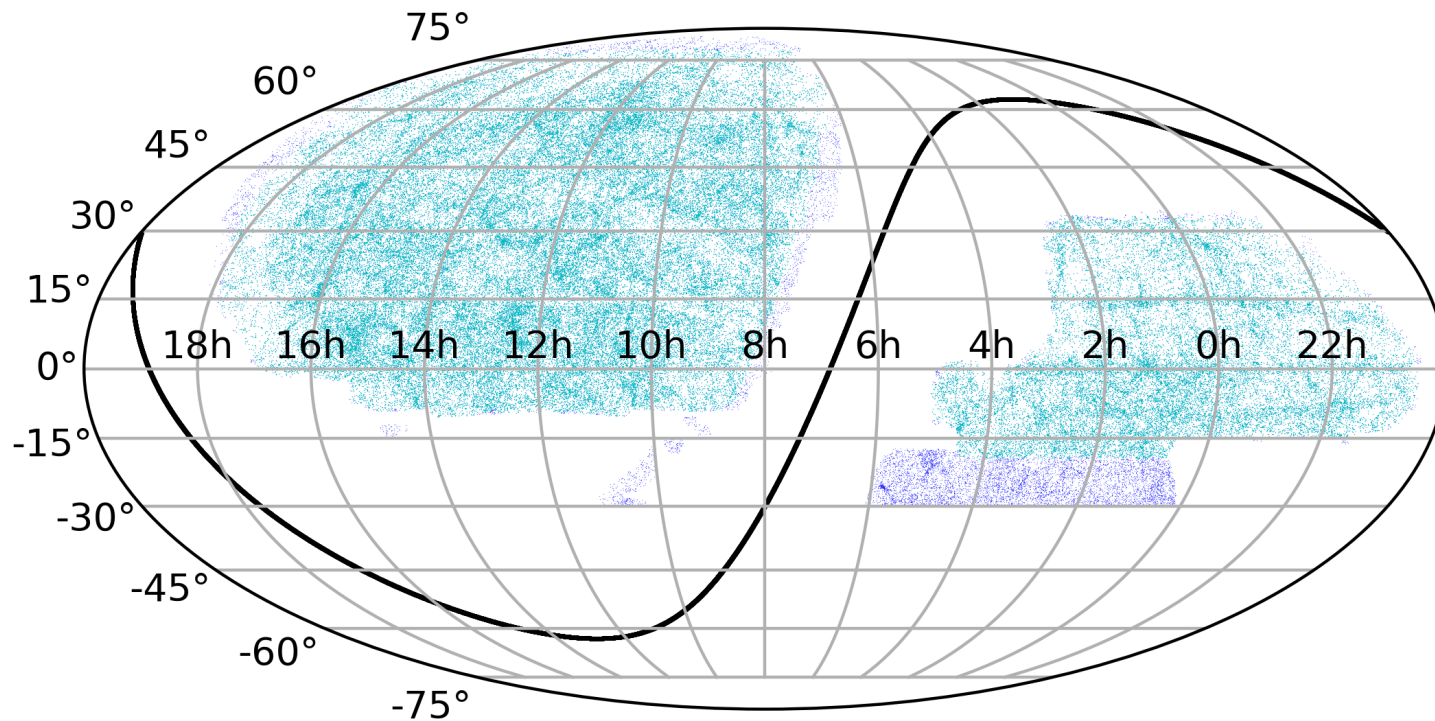
Spectroscopic targets

• TF targets



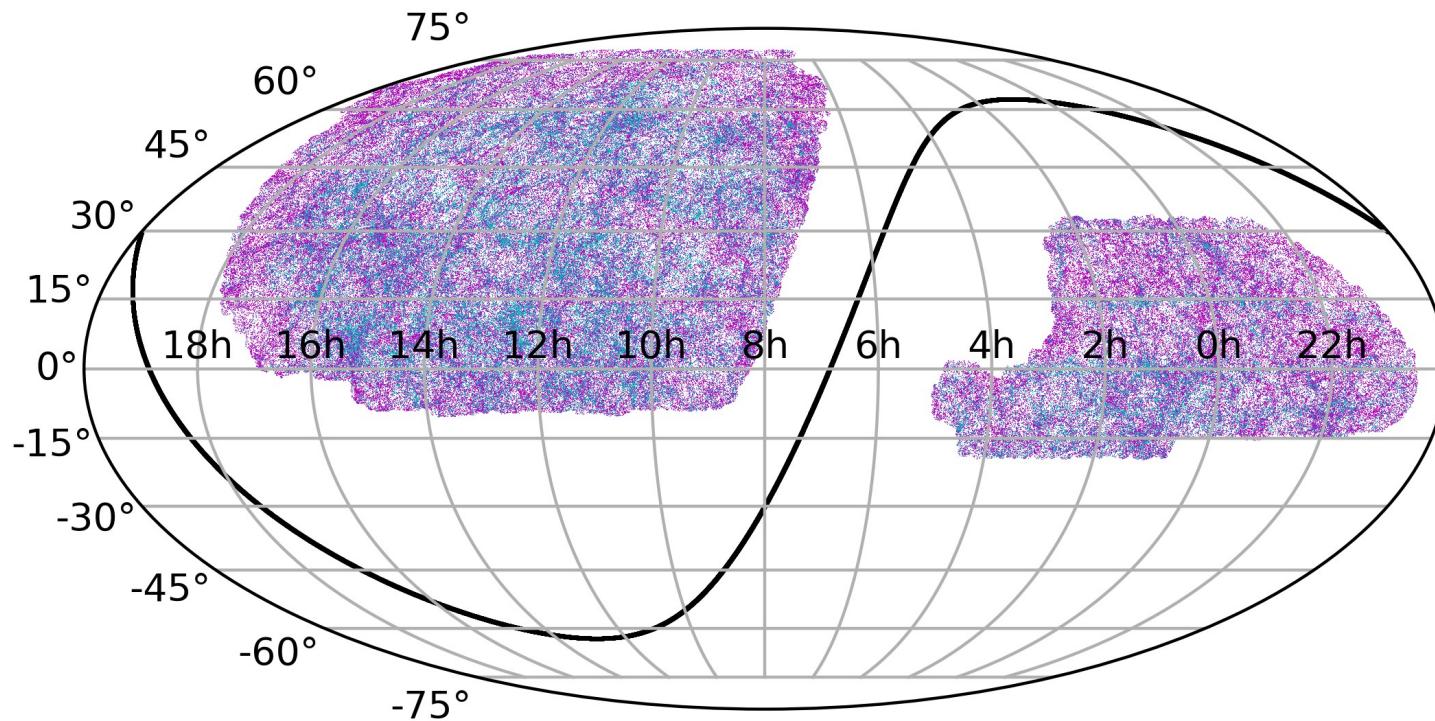
Spectroscopic targets

• TF targets • TF in spec



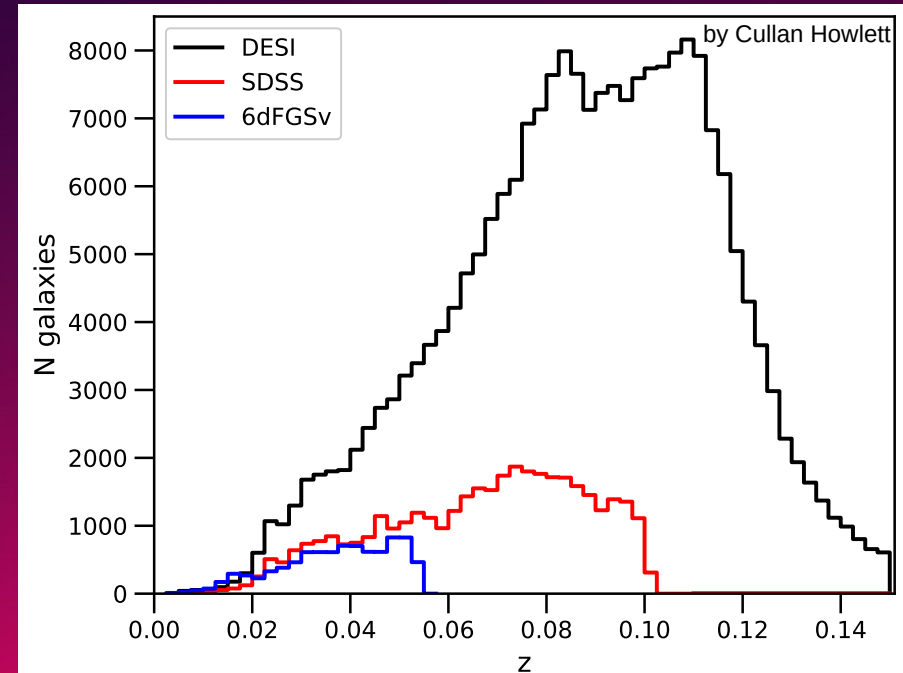
Spectroscopic targets

• FP in spec • TF in spec



DESI PV sample size

- Largest fundamental plane (target) sample so far: 373 533 galaxies
- Largest Tully-Fisher relation (target) sample so far: 118 637 galaxies
- 14 000 square degree
- Most true low redshift velocity dispersion measurements successful
- ~ 50% of the targets will be used

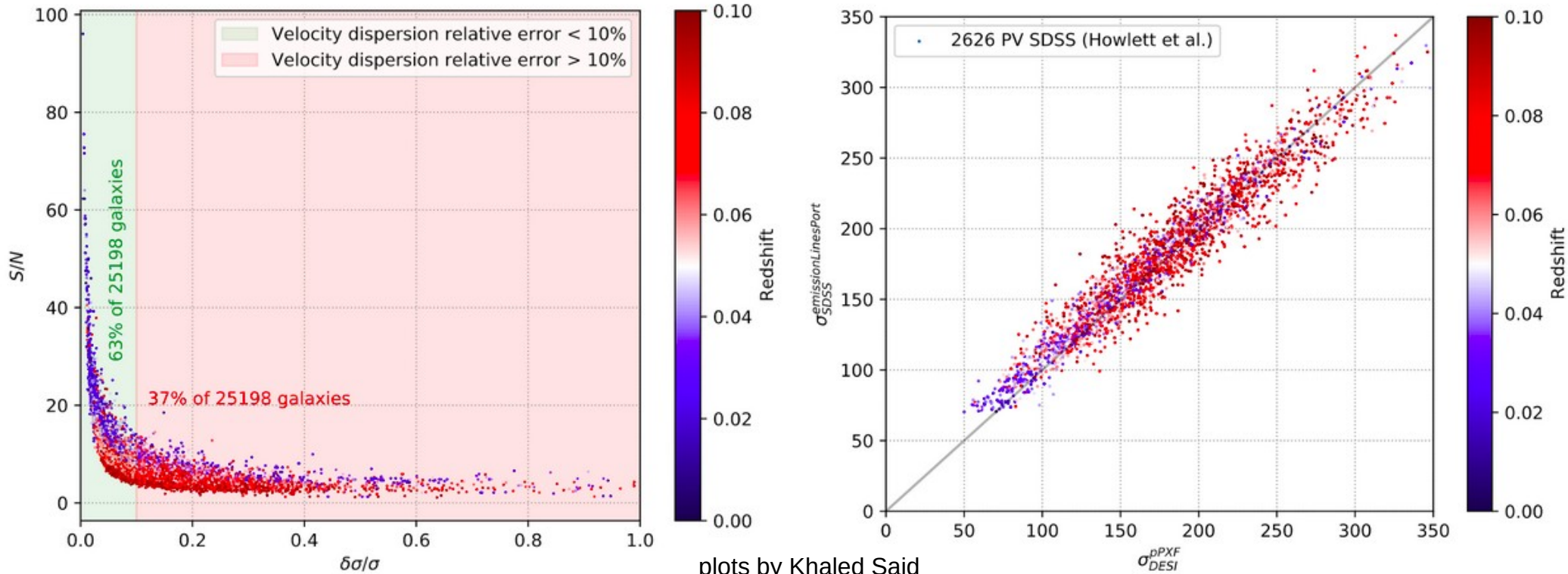


Current status of the observations fundamental plane

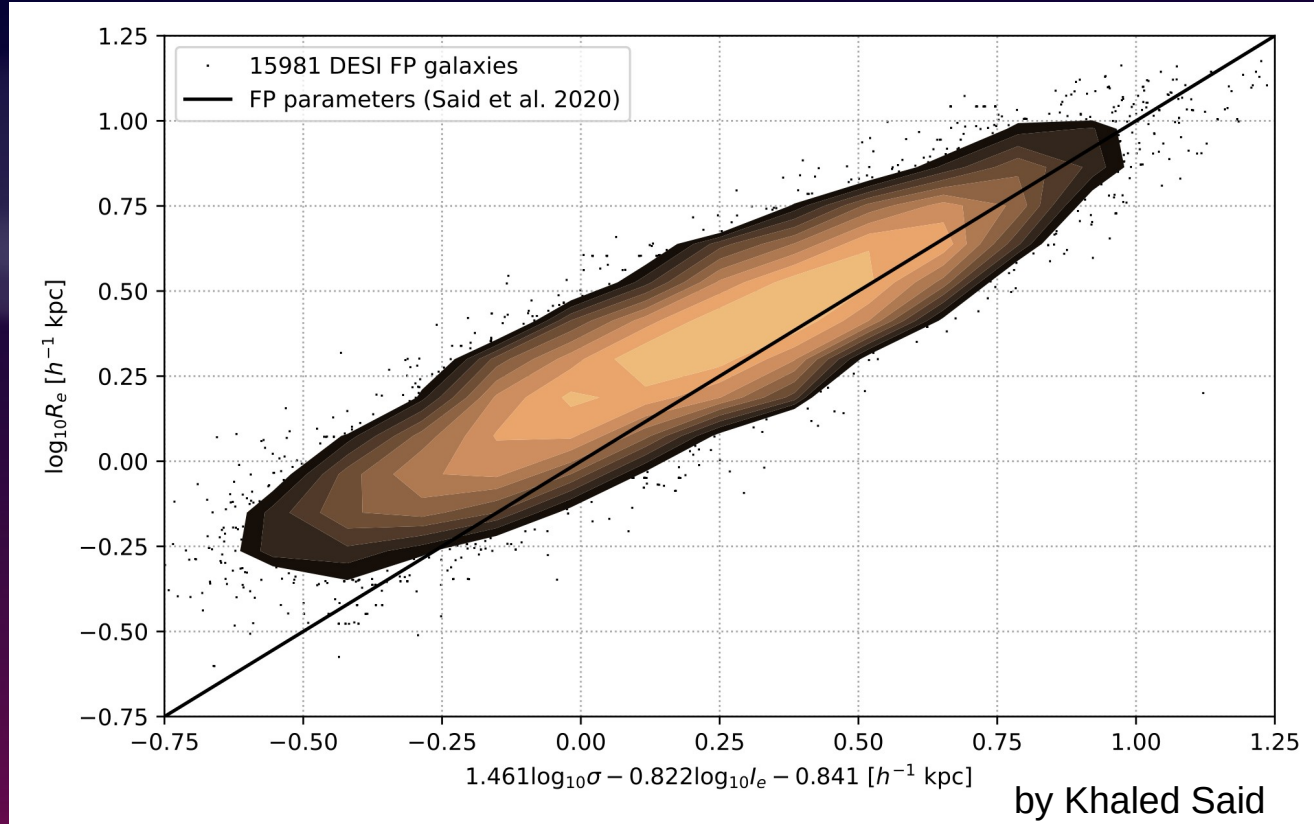
- 29 983 of our photometrically selected ETGs targets (22 519, if spectroscopic selection is considered as well) have already been observed by DESI before summer (Everest/Fuji releases)
- 15 981 have spectra with a $\text{SNR} > 7.5$ (despite many in bright time ... dark time observation in the future after a bug fix)
- Already a larger sample than the 6dFGS FP catalogue
- Fitting is work in progress, but data already agrees well with previous fundamental plane calibrations (Said+ 2020)

Success rate of velocity dispersion measurements

- Require $S/N > 7.5$ and $\delta\sigma/\sigma < 10\%$



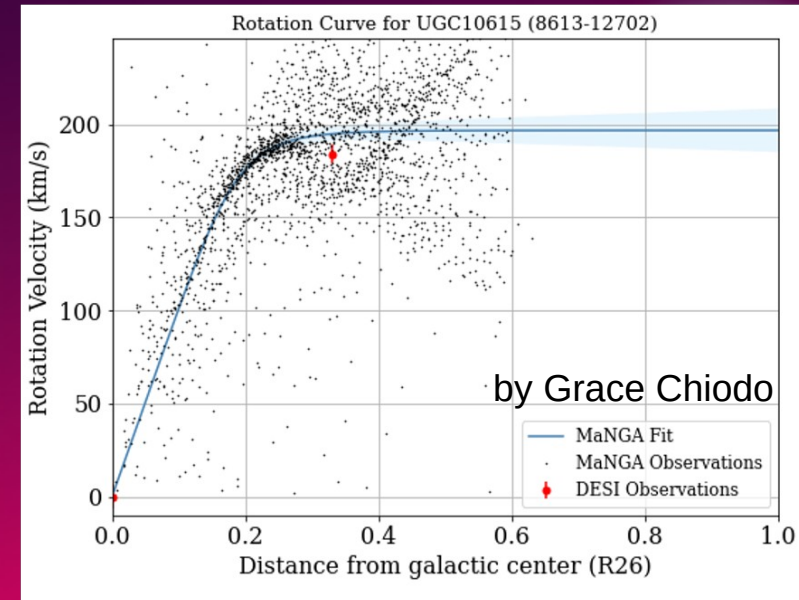
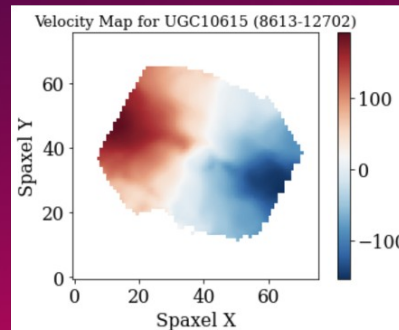
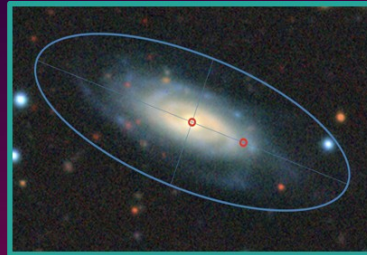
Fundamental plane fits using Everest



- Ongoing discussions about spectroscopic selection criteria of the fundamental plane galaxies

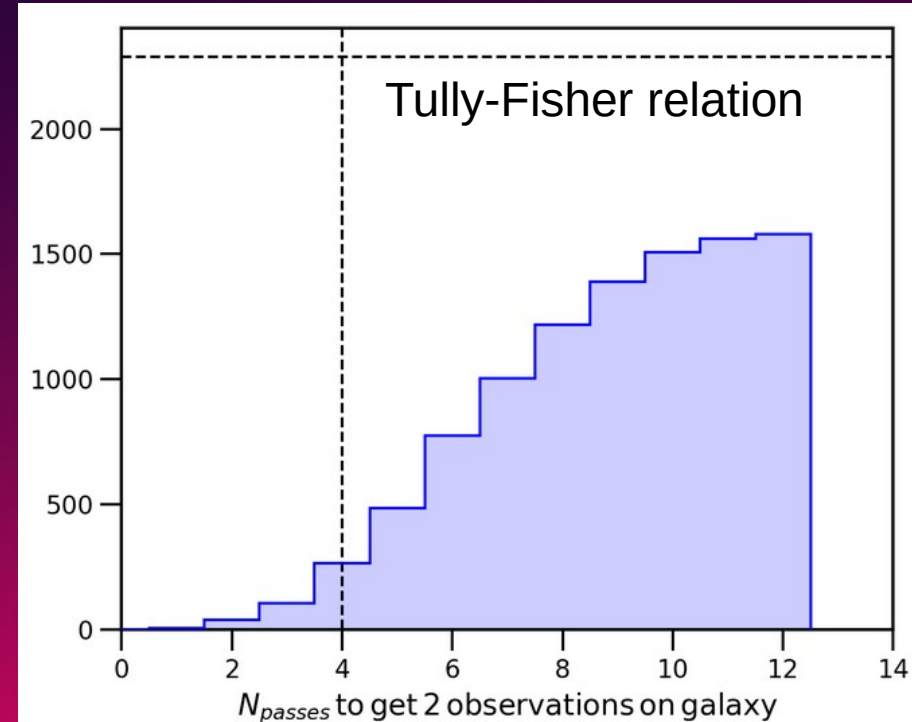
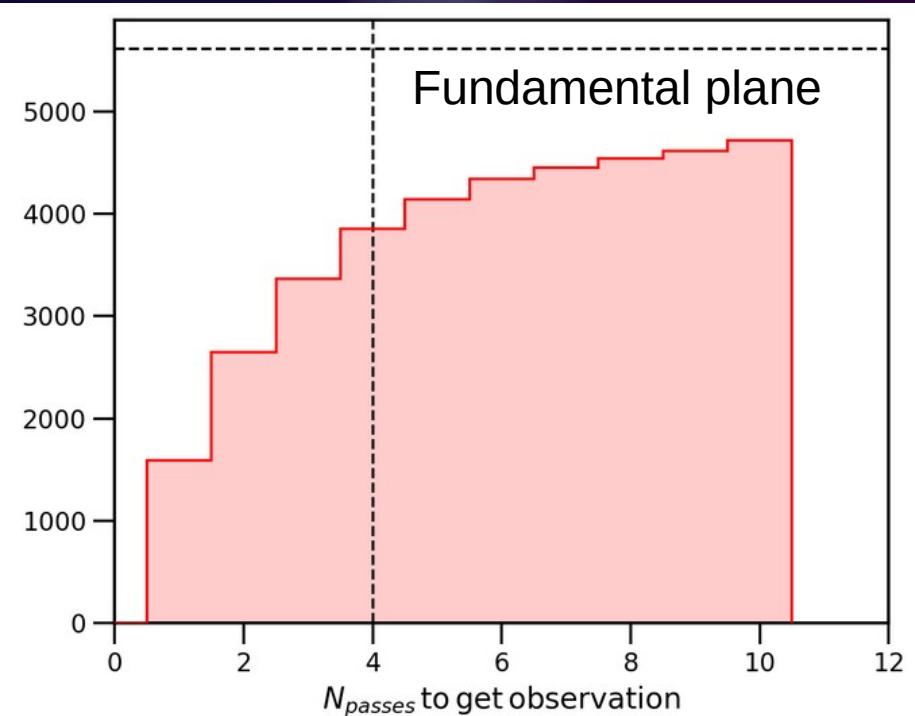
Status of the observations – Tully-Fisher relation

- Tully-Fisher relation targets are slower going
- At least two observations on the same galaxy required
- In the Guadalupe (DA0.2) data mostly one pass
 - need multiple passes to get spare fibres for all our target
- Mostly tests with MANGA
- Fibres get enough light to get redshifts



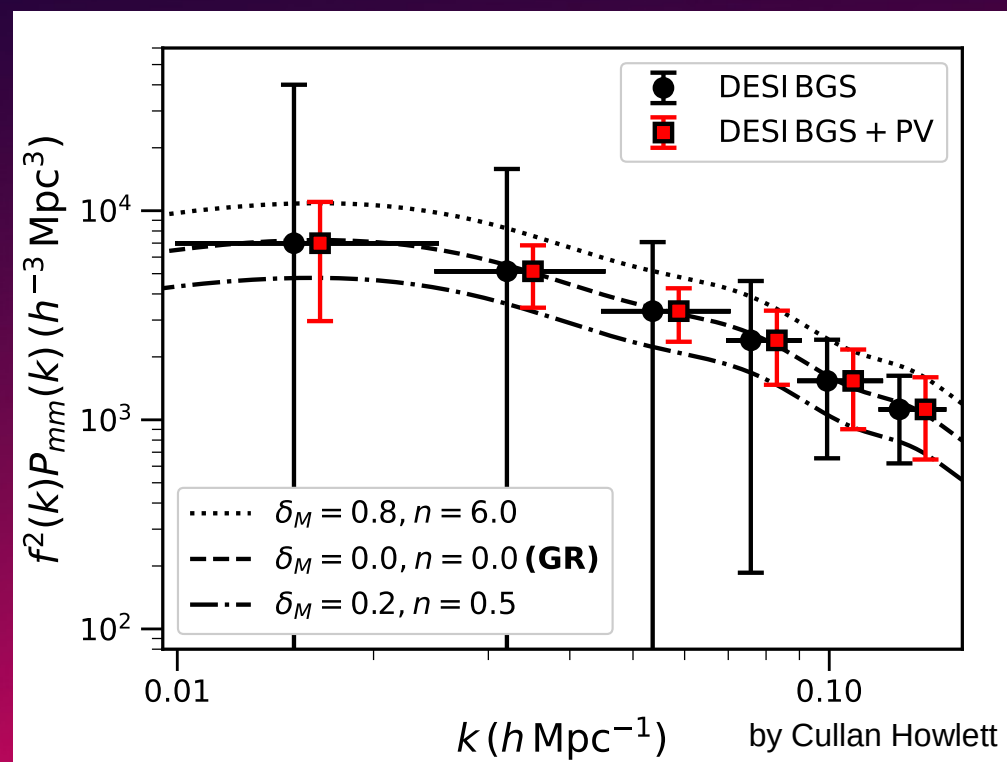
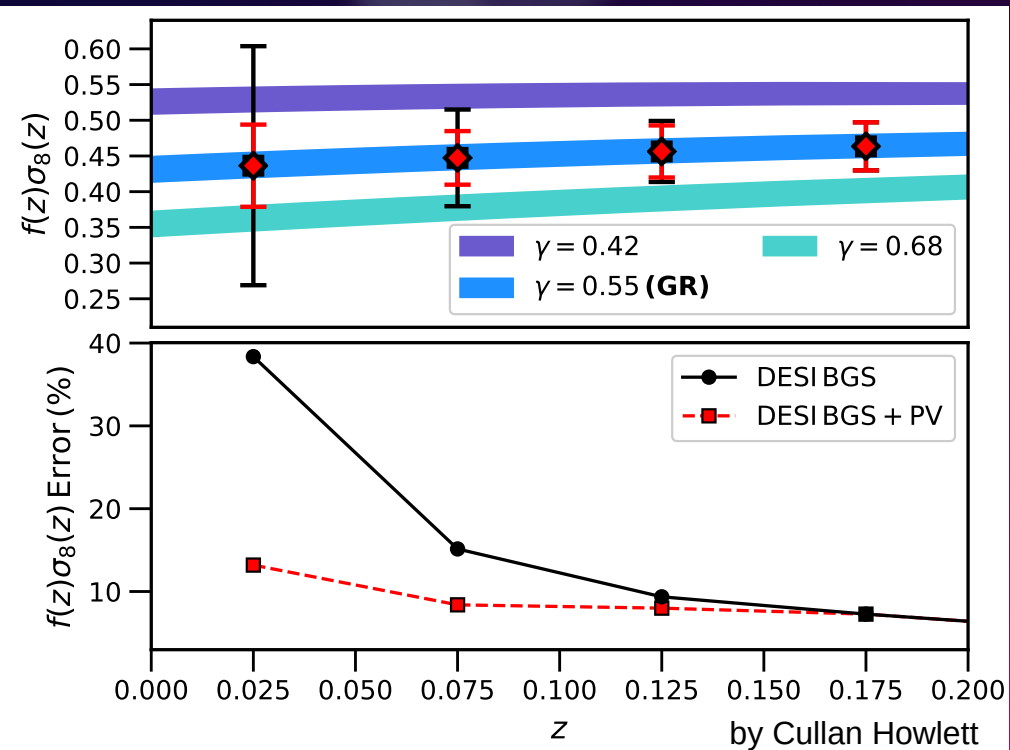
Data collection based on SV3

- TF had 7 targets (for testing) in SV3 (it will only be 3 in main)
→ 12% success, but not really representative
- FP had about 2/3 of the targets with observations after 4 passes



Improving cosmological measurements

- Growth rate: $f\sigma_8$, improving constraints from DESI BGS for the evolution and scale-dependence



Conclusions and Outlook

- Tully-Fisher relation and fundamental plane distances collected with the same survey
- Success rate measured, but needs update with Y1 data → important for mocks
- Three papers currently in the works (target selection, fundamental plane calibration, Tully-Fisher relation calibrations)
- Up to 200 000 FP distances and maybe 100 000 TF distances over 14 000 deg² → largest peculiar velocity survey so far
- Notable improvements in the measurements of $f\sigma_8$ at low redshifts

Any questions?

