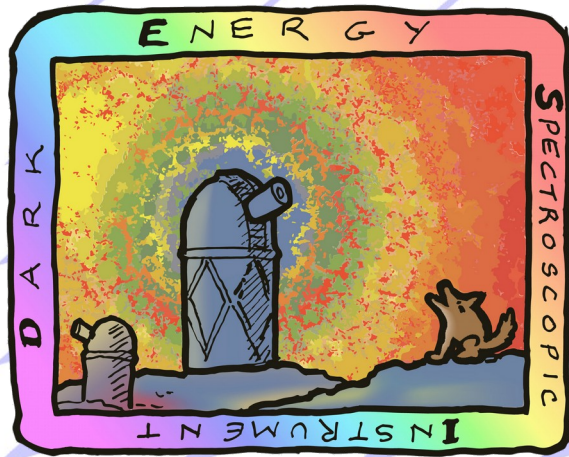


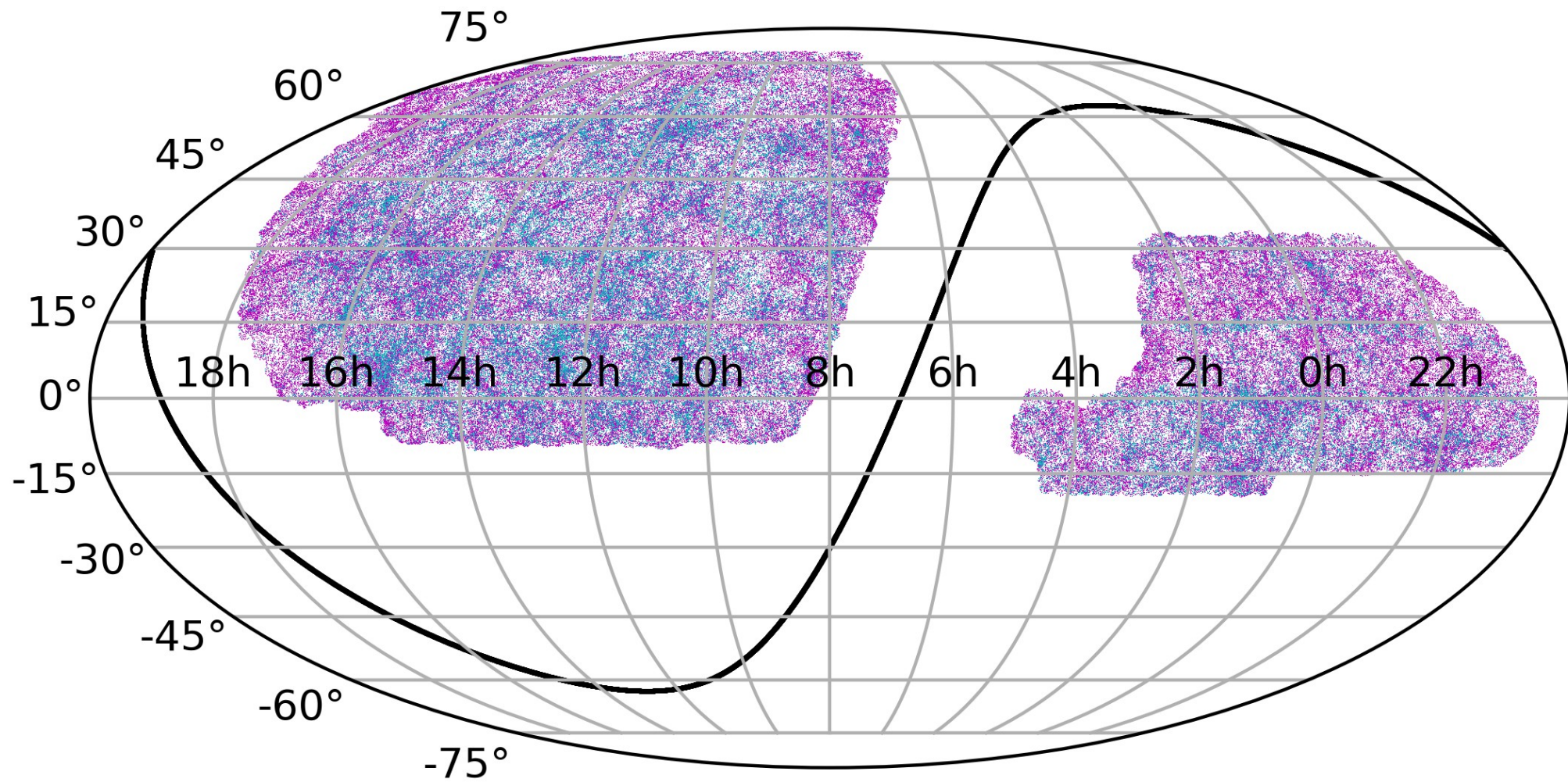
# Designing the DESI peculiar velocity survey

by Christoph Saulder (KASI)



한국천문연구원  
Korea Astronomy & Space Science Institute





# Collaborators

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- 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

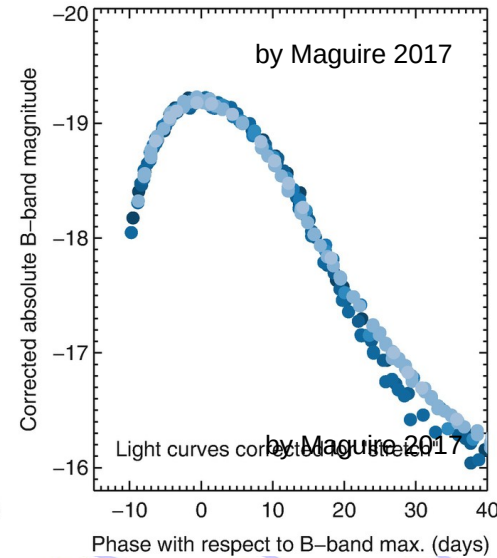
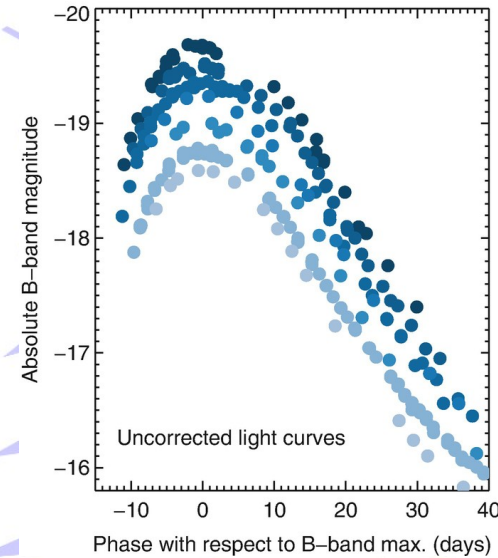


# Measuring peculiar velocities

- **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

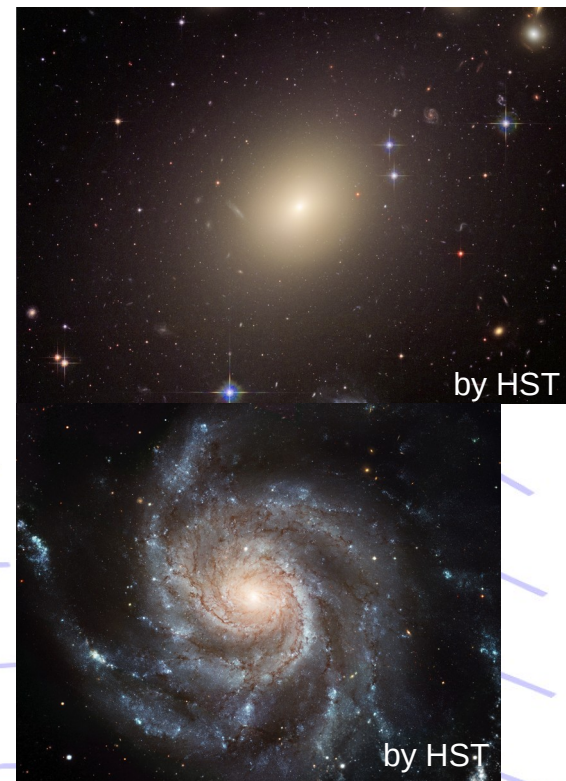
# Redshift-independent distance indicators

- 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

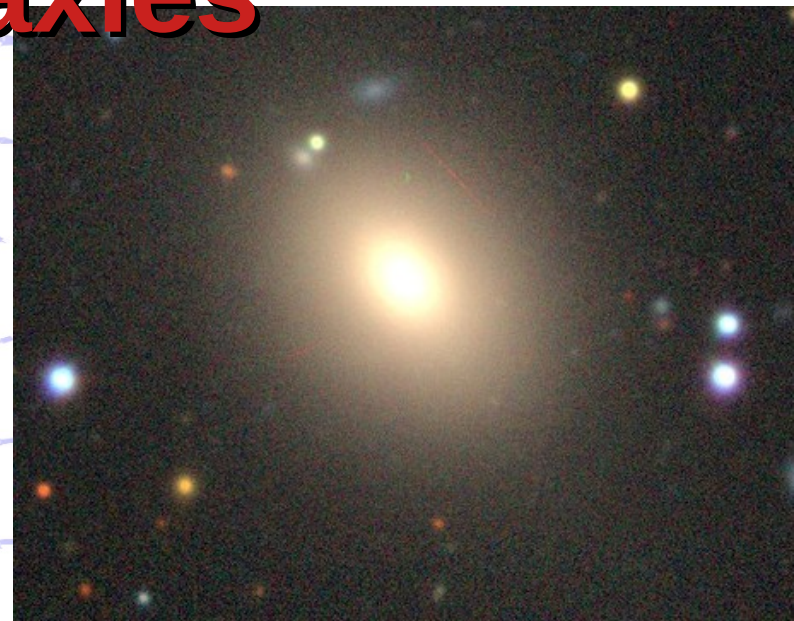
- Early-type galaxies
  - Faber-Jackson relation
  - $D_n$ - $\sigma$  relation
  - → unified into the **Fundamental plane**
- Late-type galaxies
  - **Tully-Fisher relation**
- Sk-relation or full kinematic modelling using IFU-data



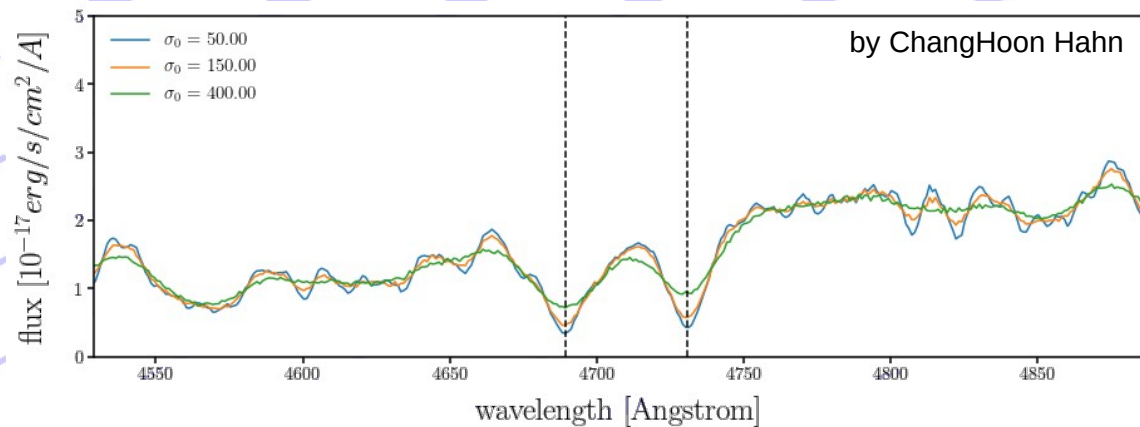


# Fundamental plane of early-type galaxies

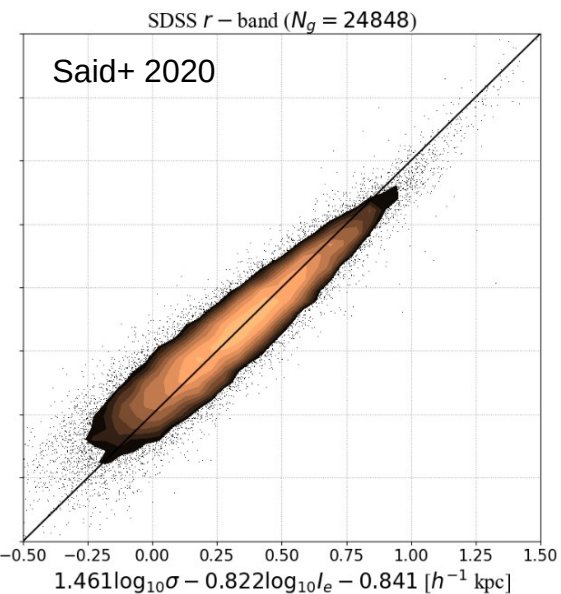
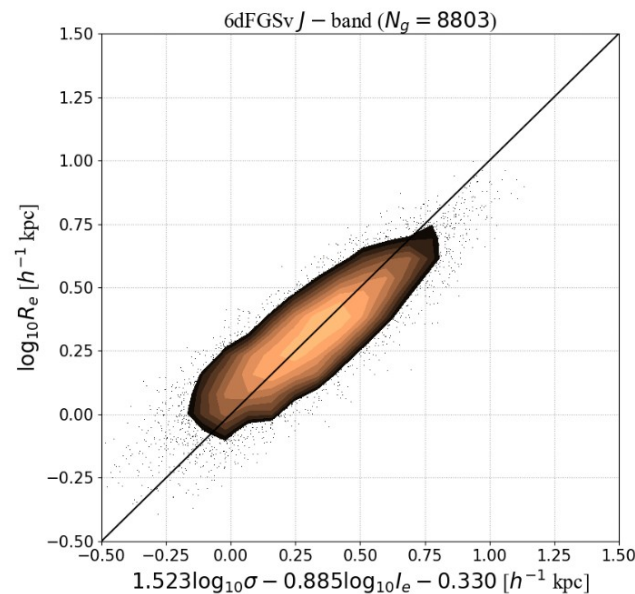
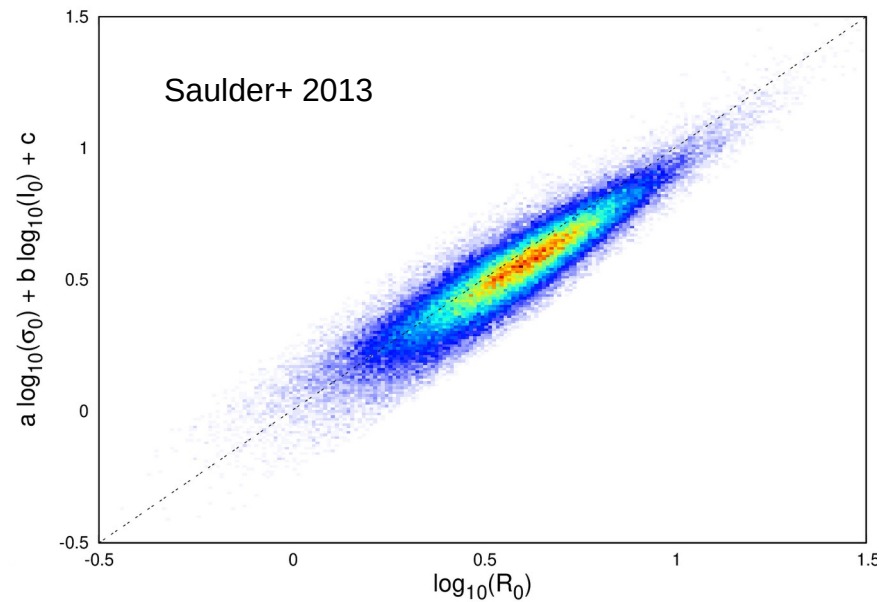
- Empirical relation:  
$$\log(R_0) = a \log(\sigma_0) + b \mu_0 + c$$
  
Scatter  $\sim 20\%$
- Requires good quality spectroscopy to obtain the central velocity dispersions



by DESI Legacy Imaging Survey DR9

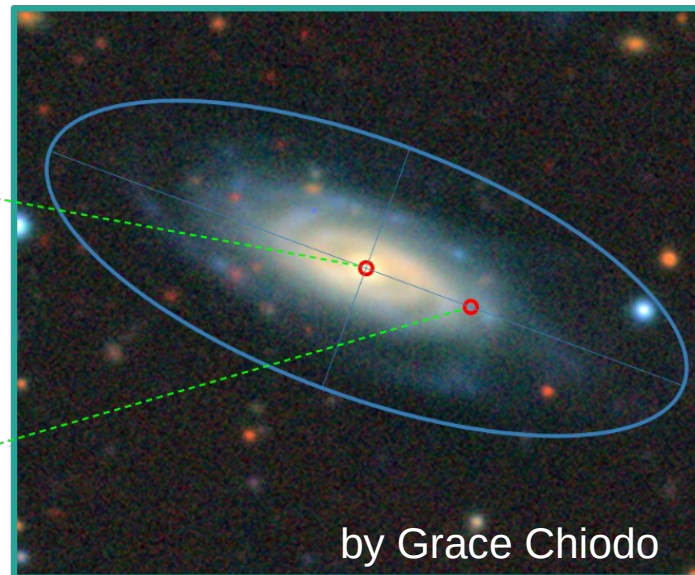
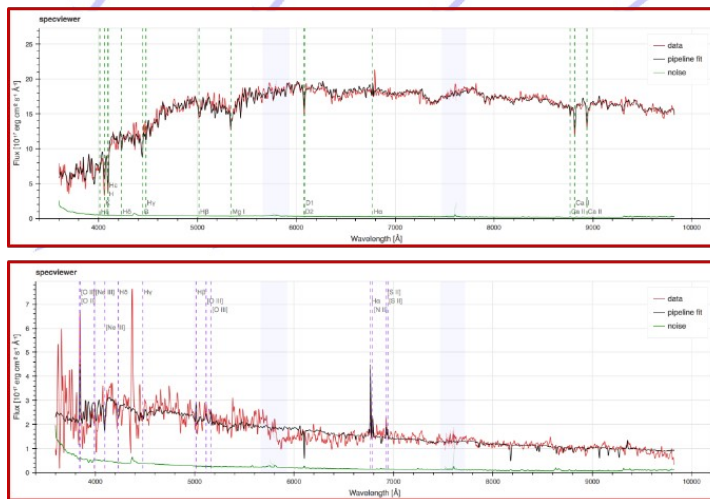


# Fundamental plane of early-type galaxies



# Tully-Fisher relation of late-type galaxies

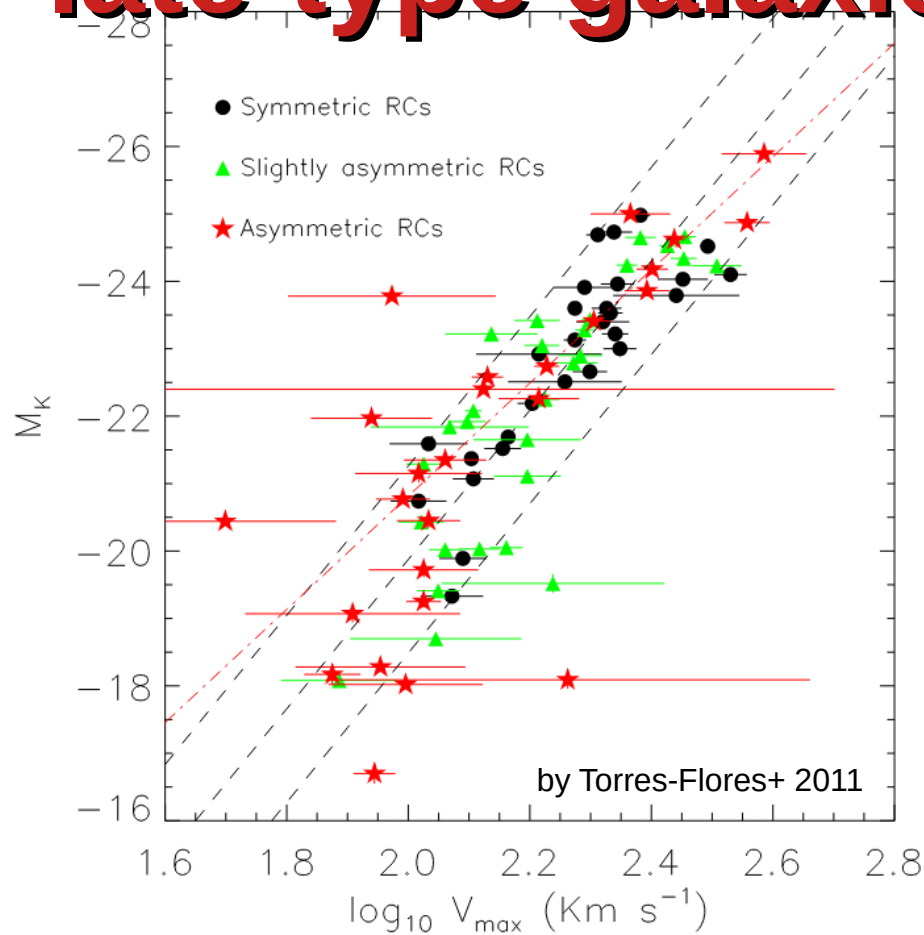
- $M = b \log (v_{\max}) + c$  with a Scatter  $\sim 20\%$
- Measurements of maximal rotational velocity  $v_{\max}$
- Off-centre fibres  $\rightarrow$  redshifts relative to the centre



by Grace Chiodo



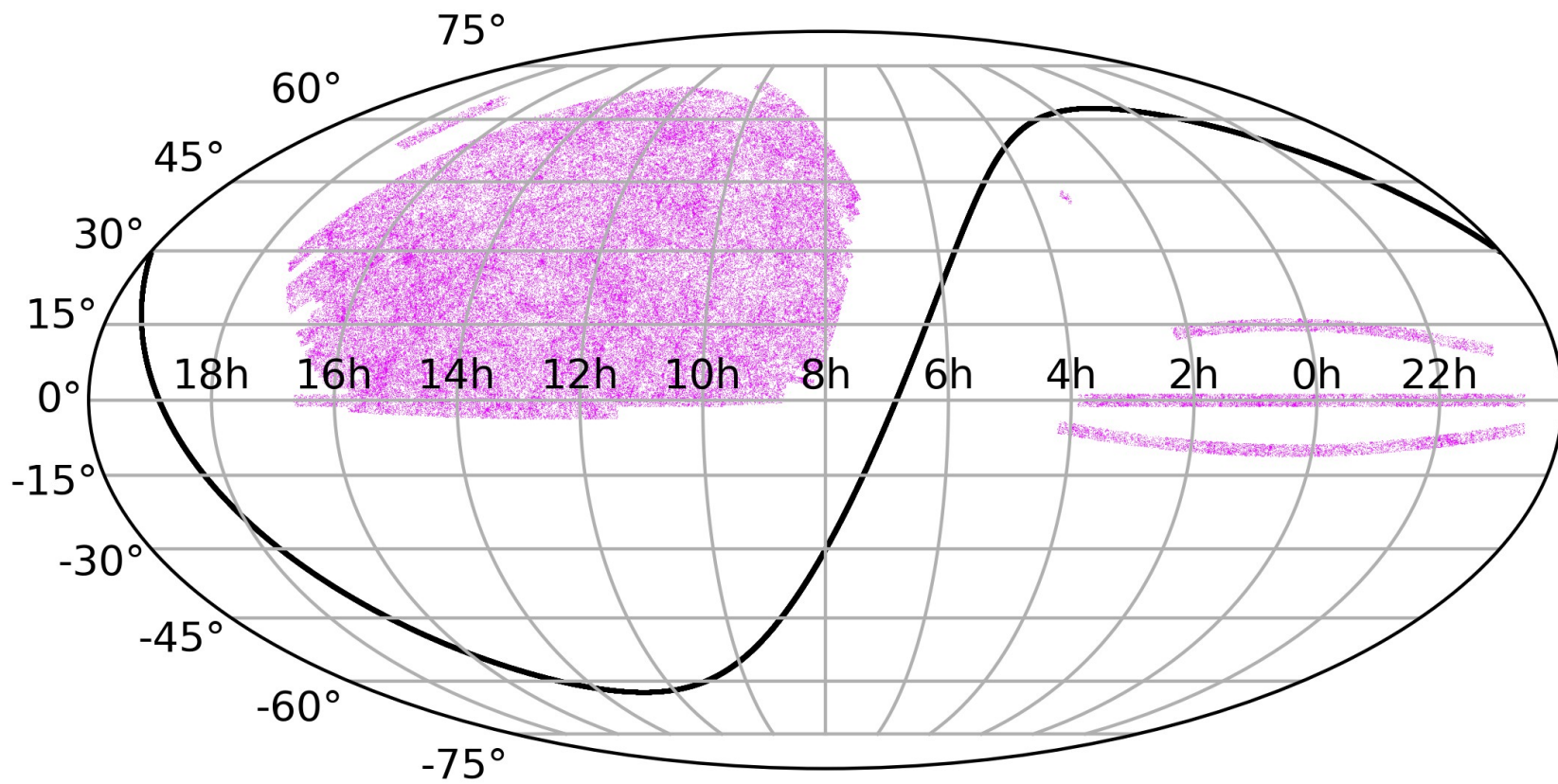
# Tully-Fisher relation of late-type galaxies



# 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



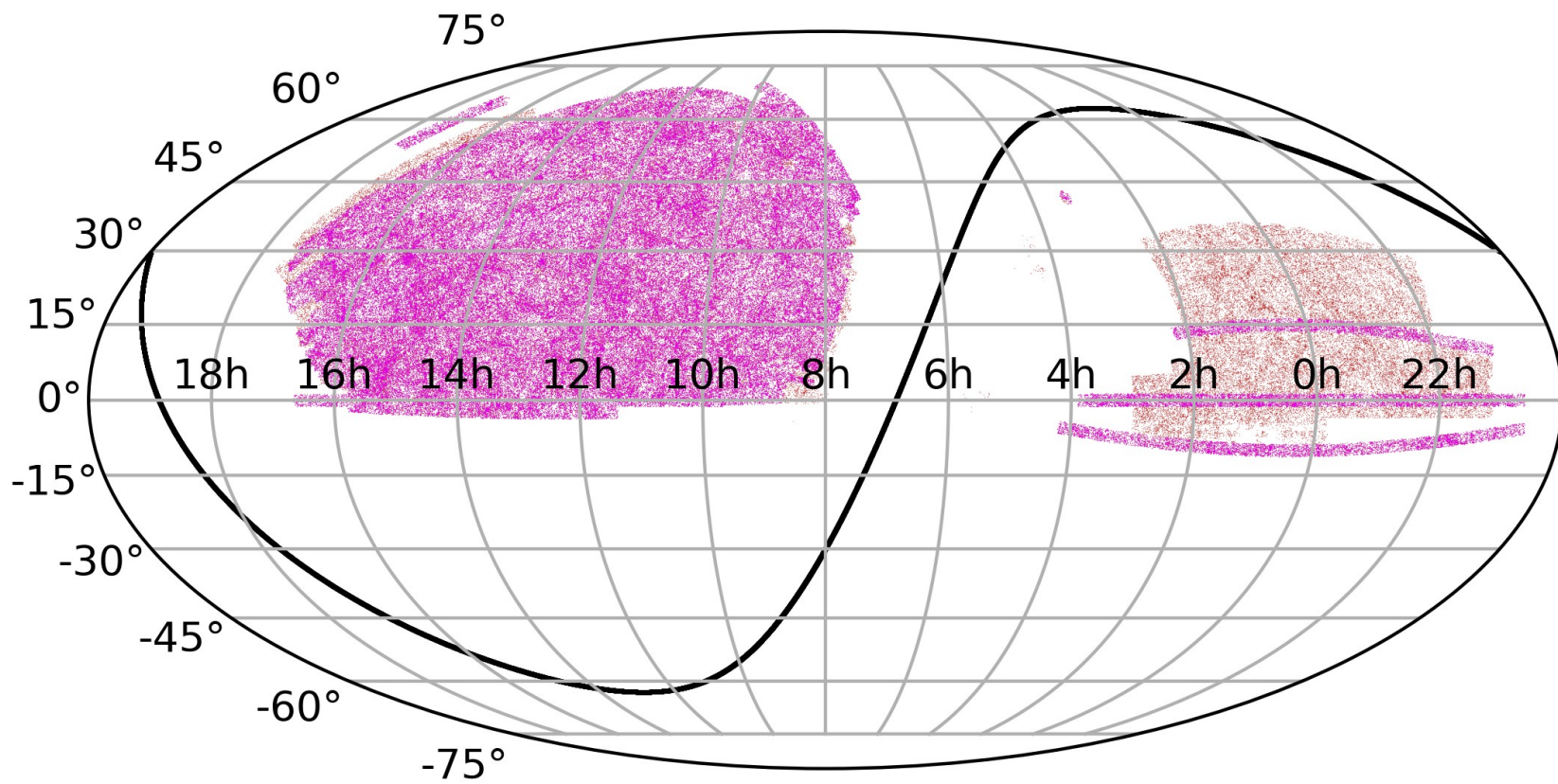


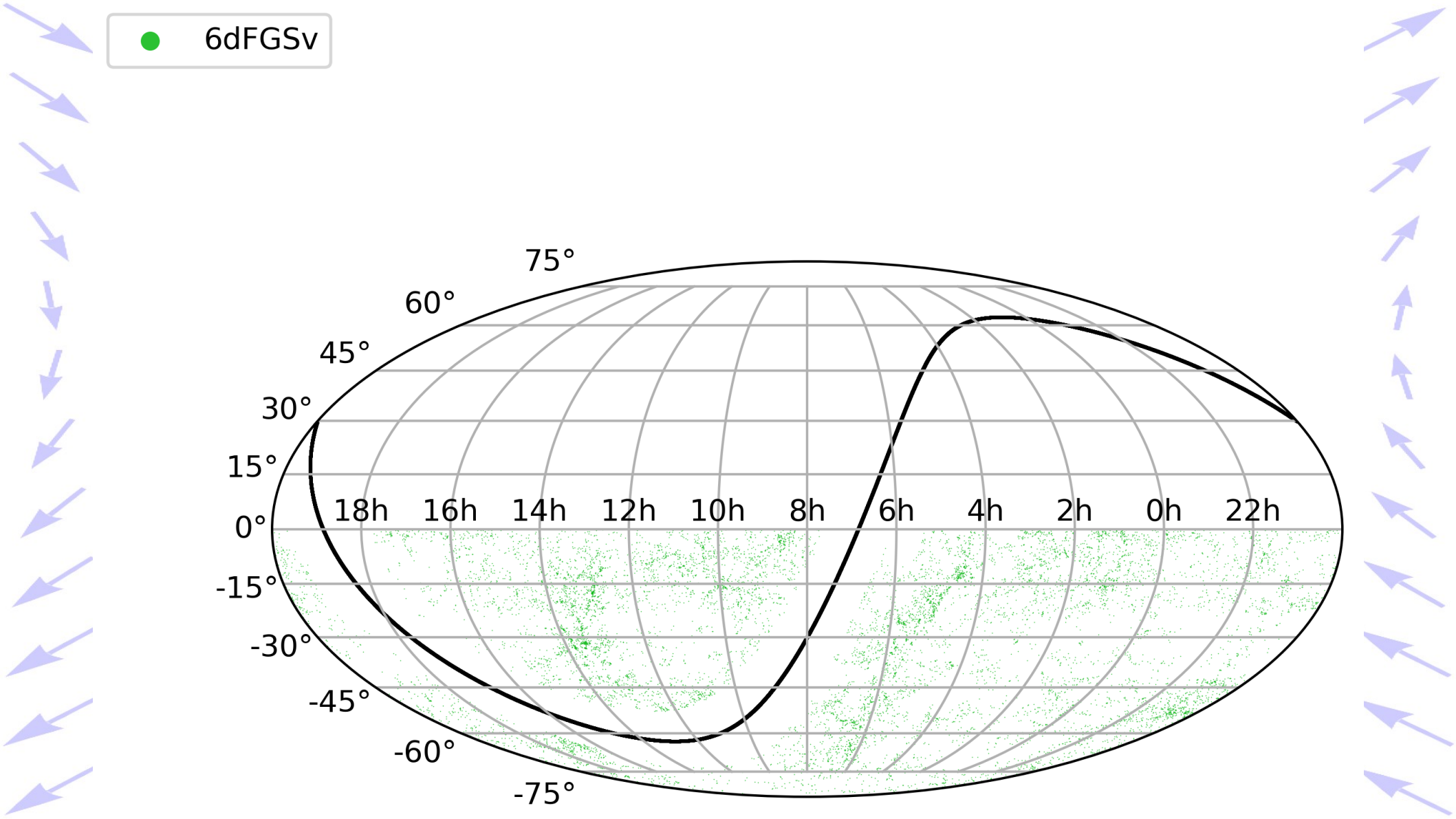


SDSS DR17



SDSS DR7







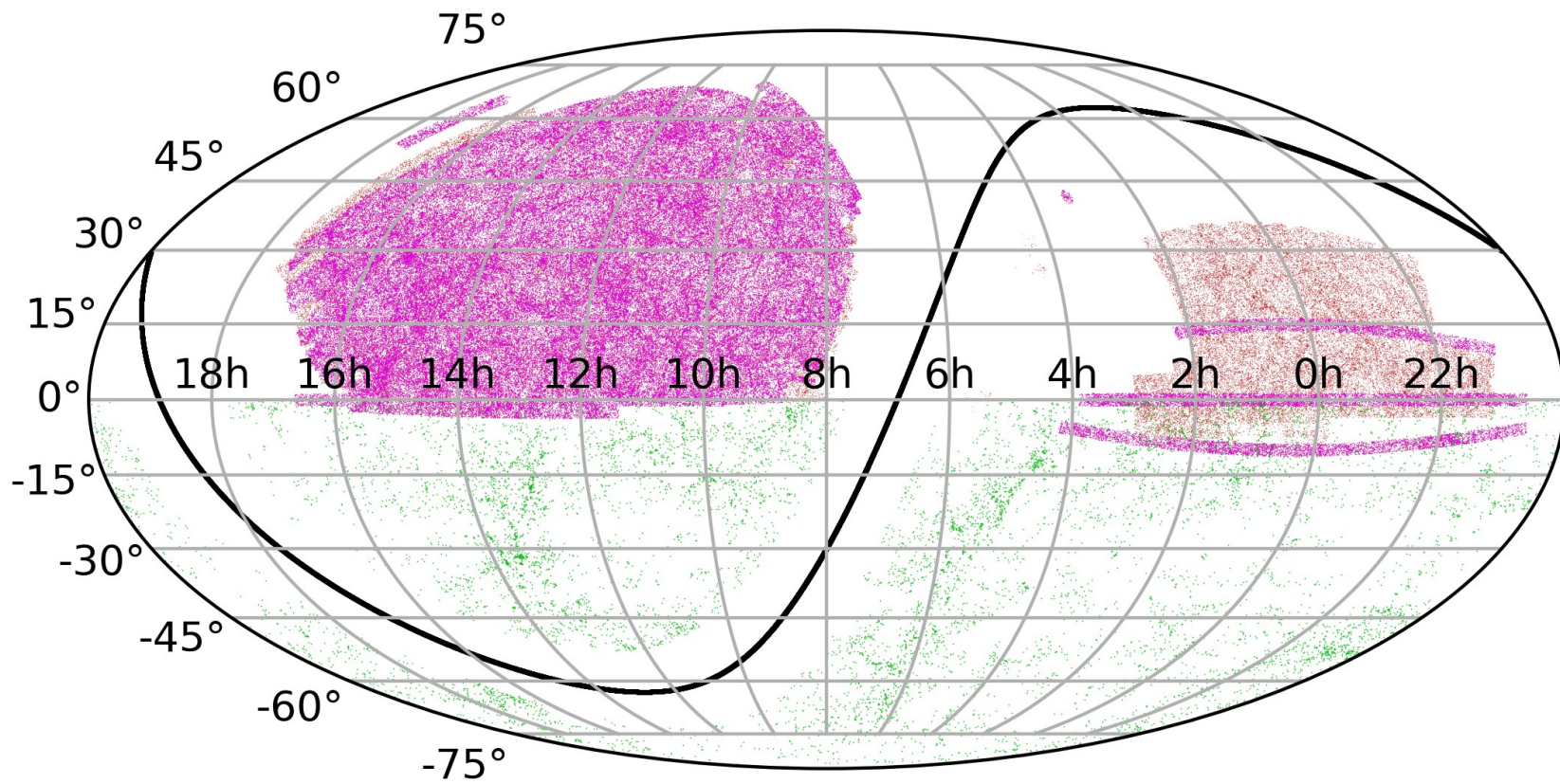
SDSS DR17



SDSS DR7

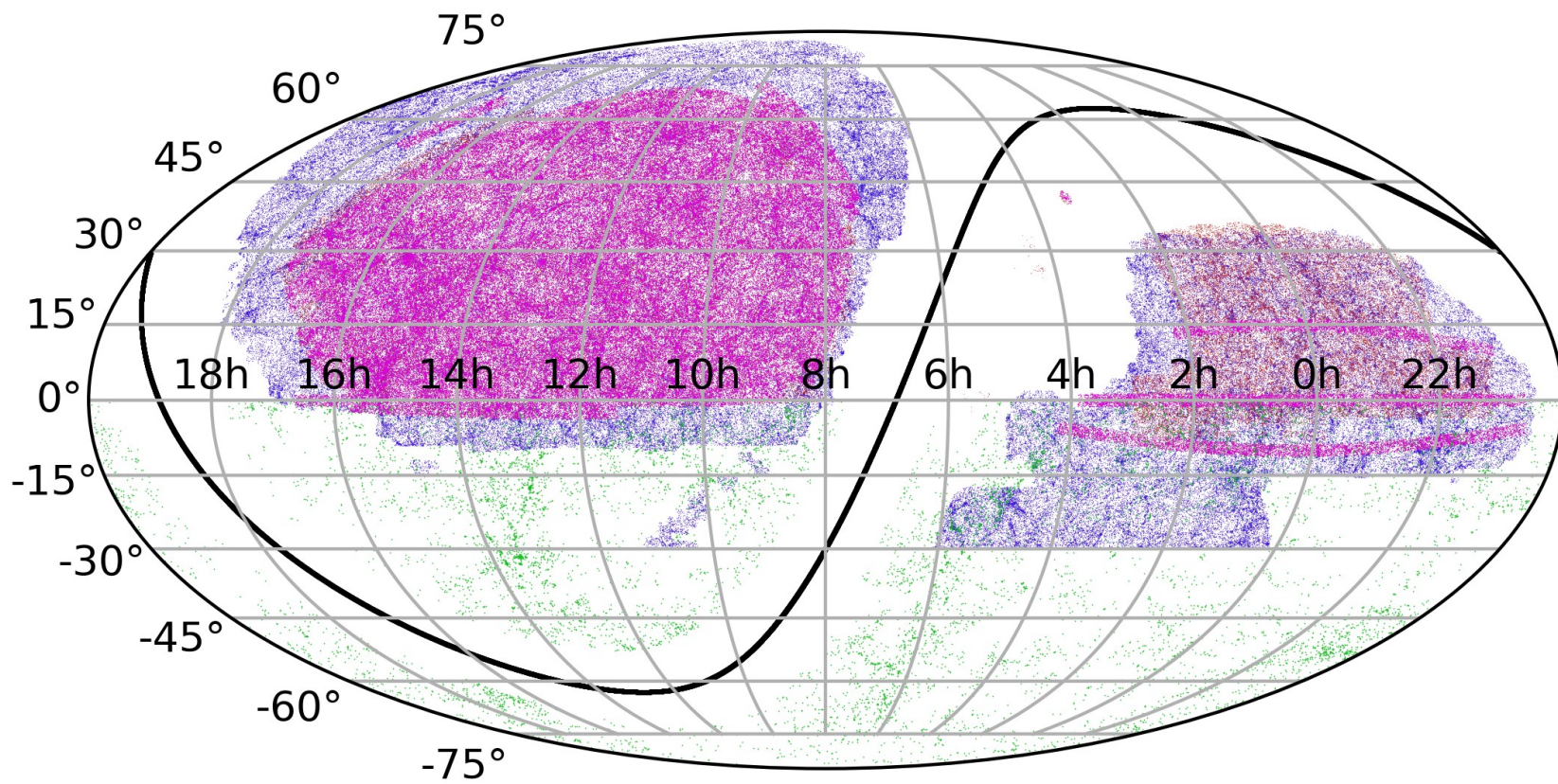


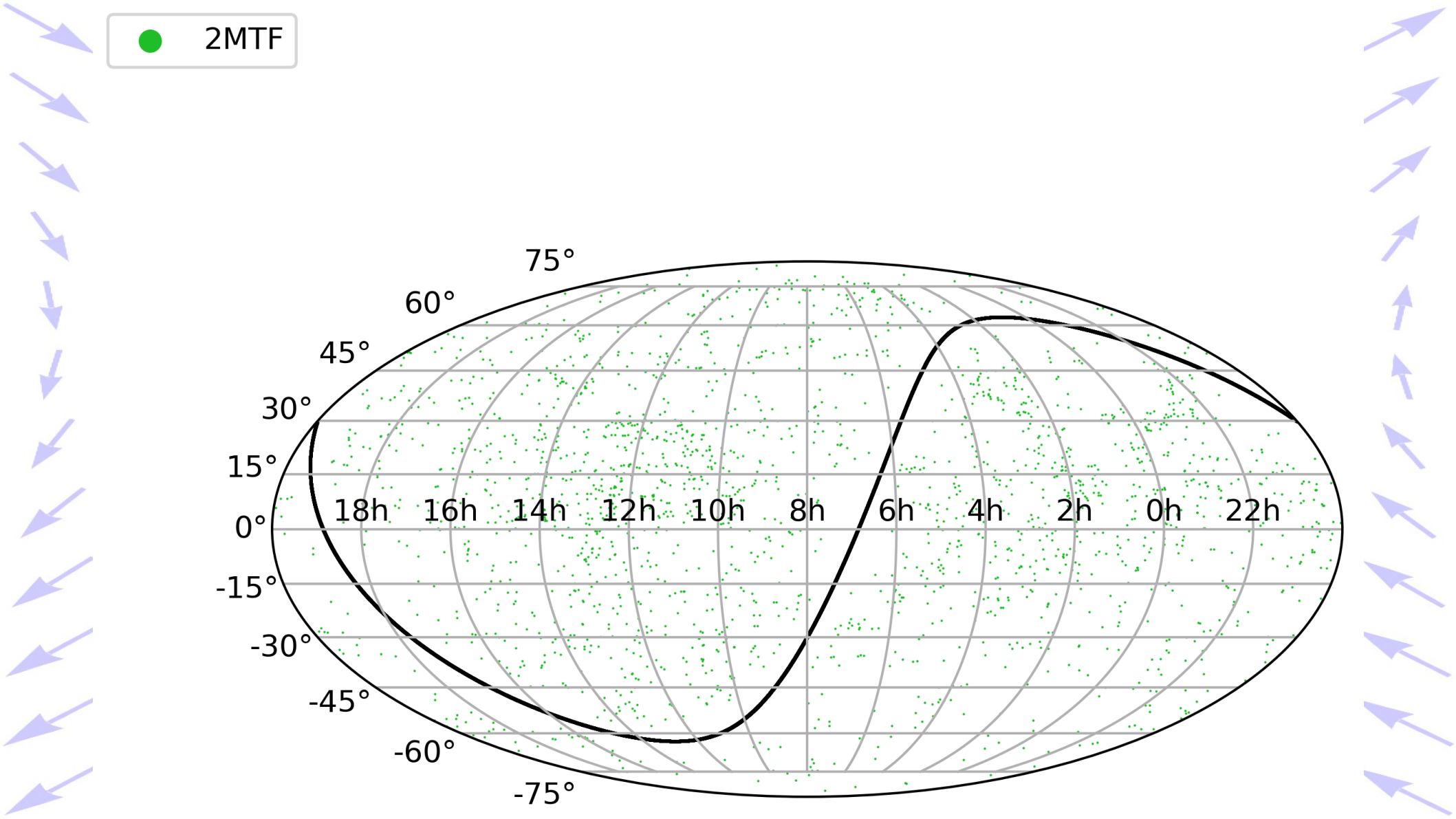
6dFGSv

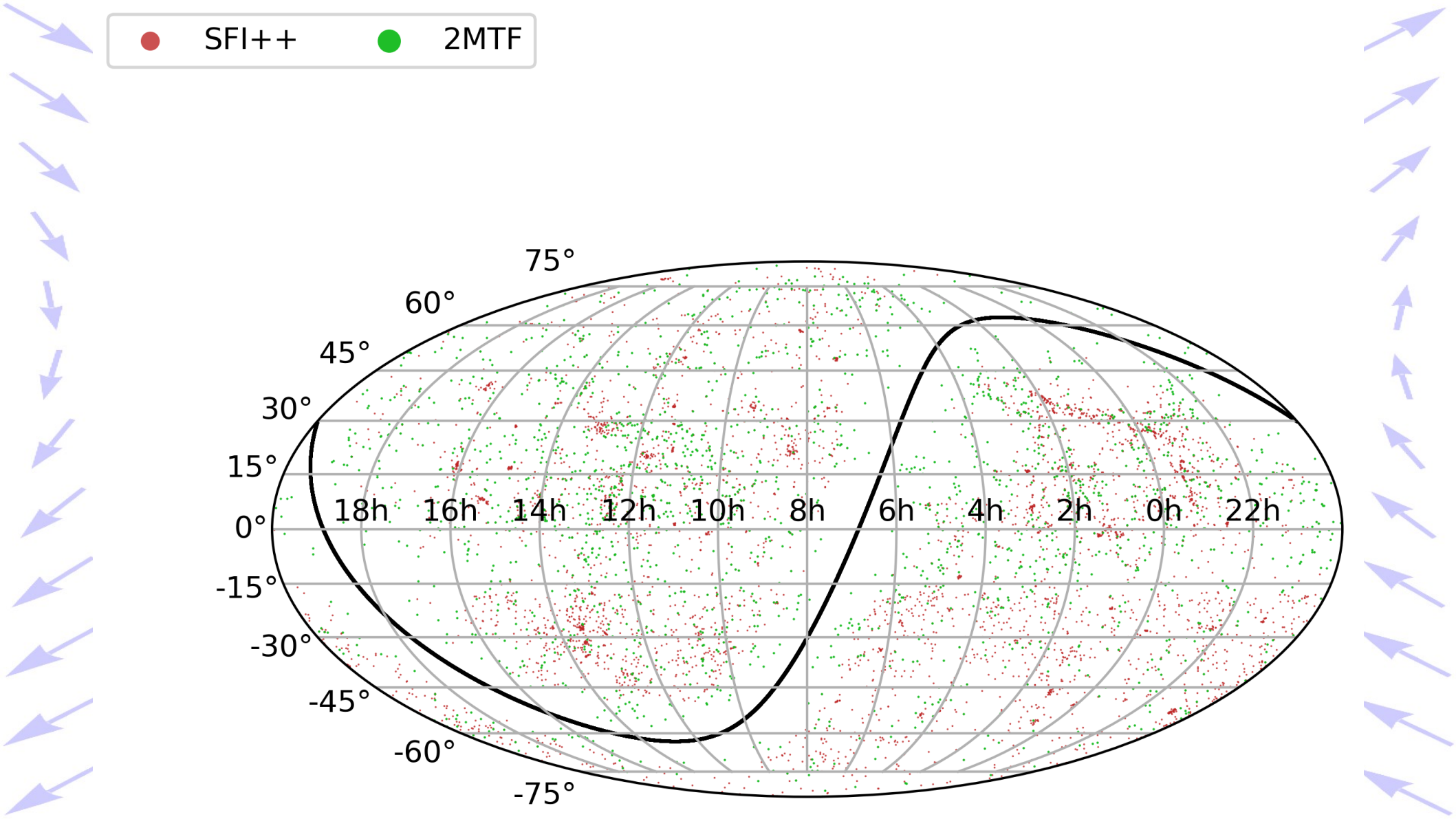




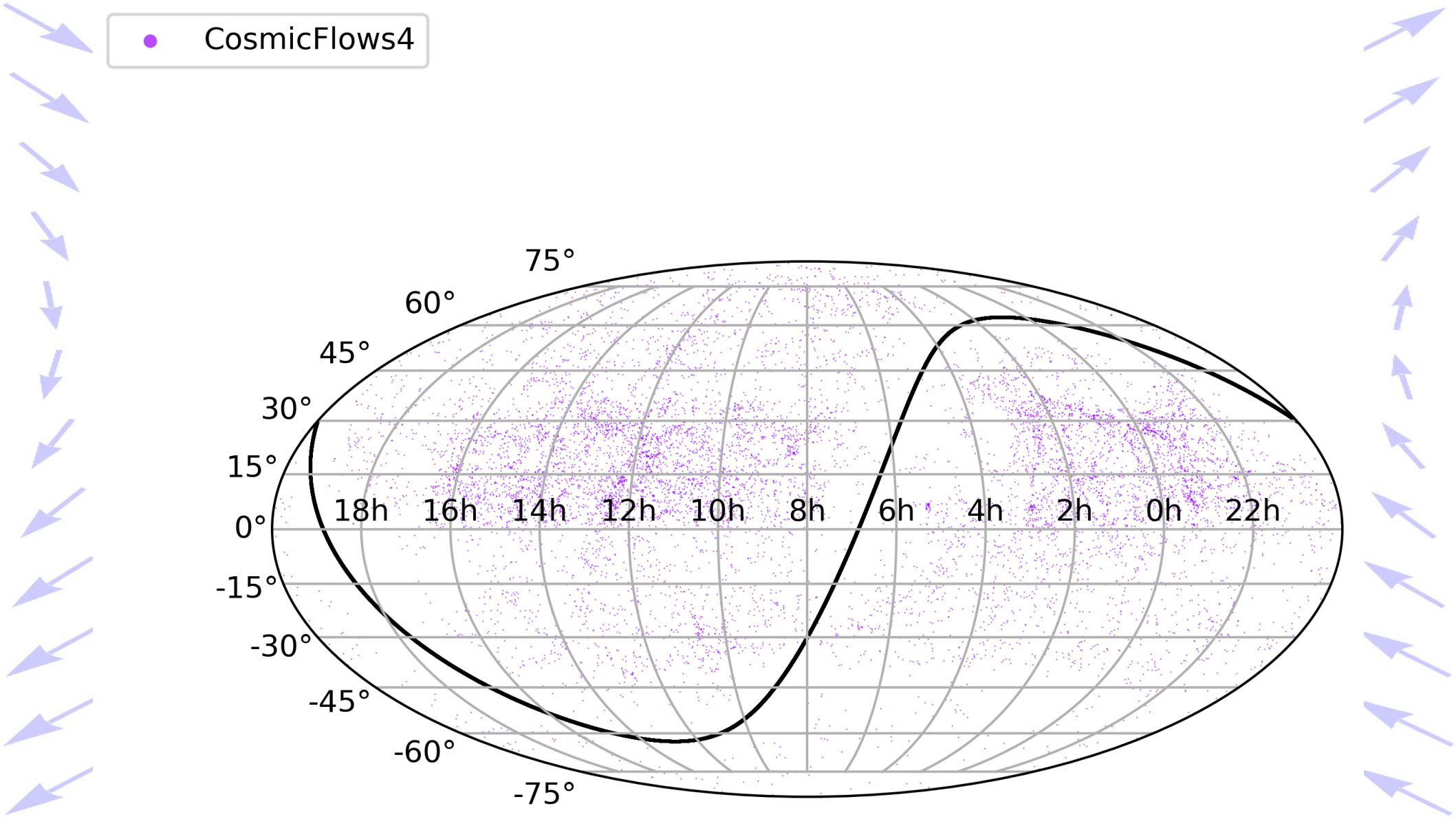
● DESI PV    ● SDSS DR17    ● SDSS DR7    ● 6dFGSv













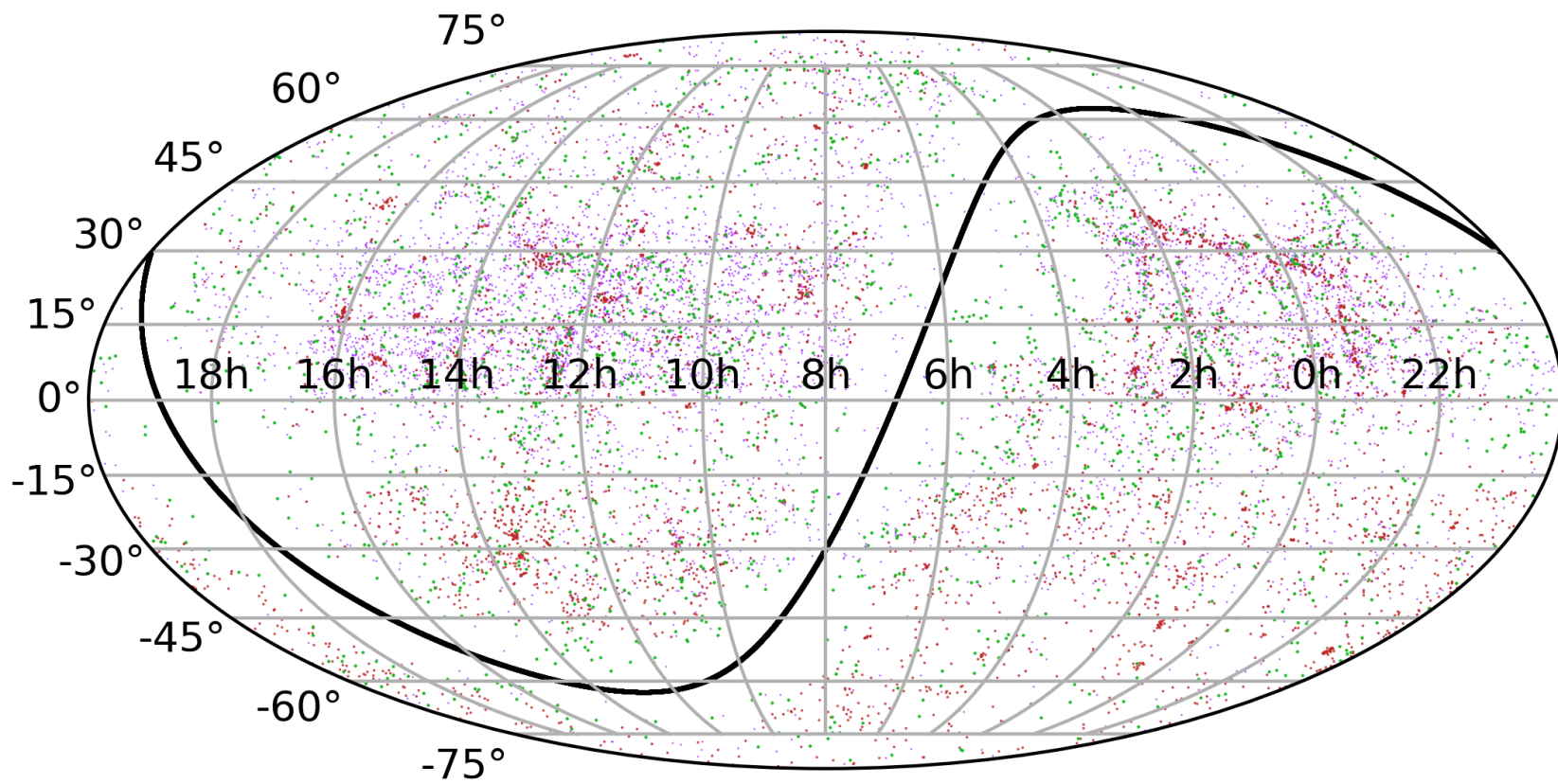
CosmicFlows4

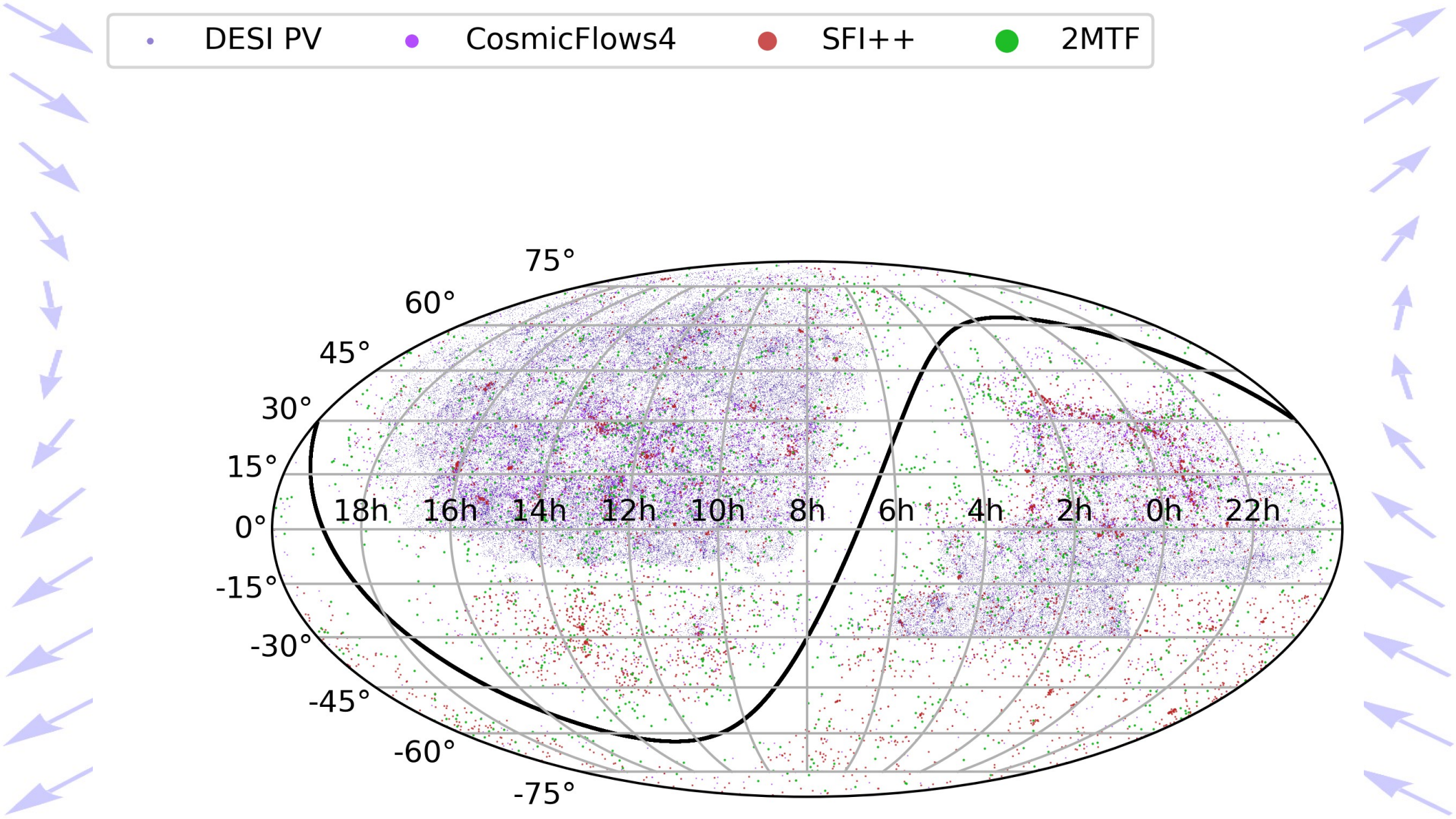


SFI++



2MTF

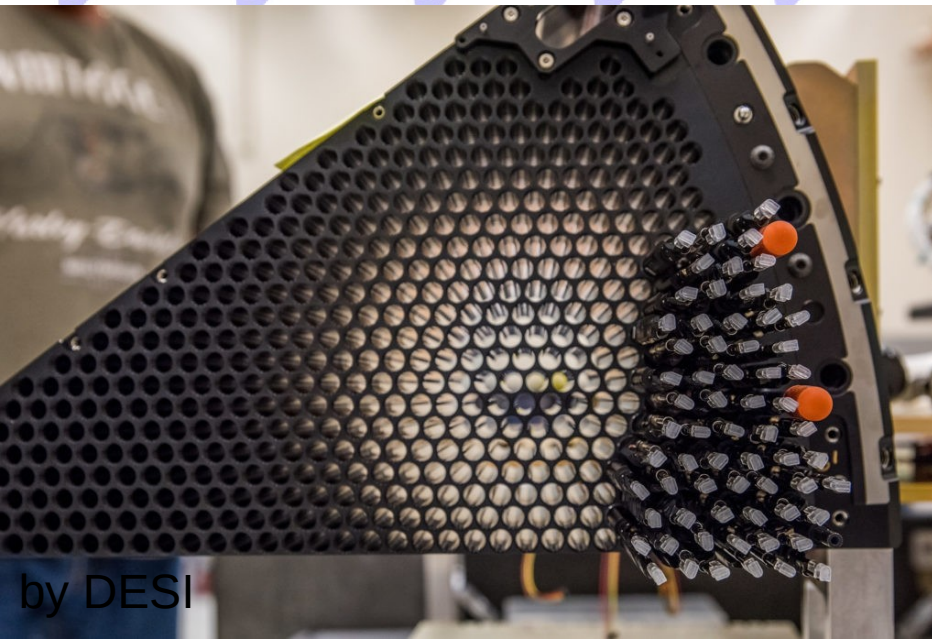






# The Dark Energy Spectroscopic Instrument

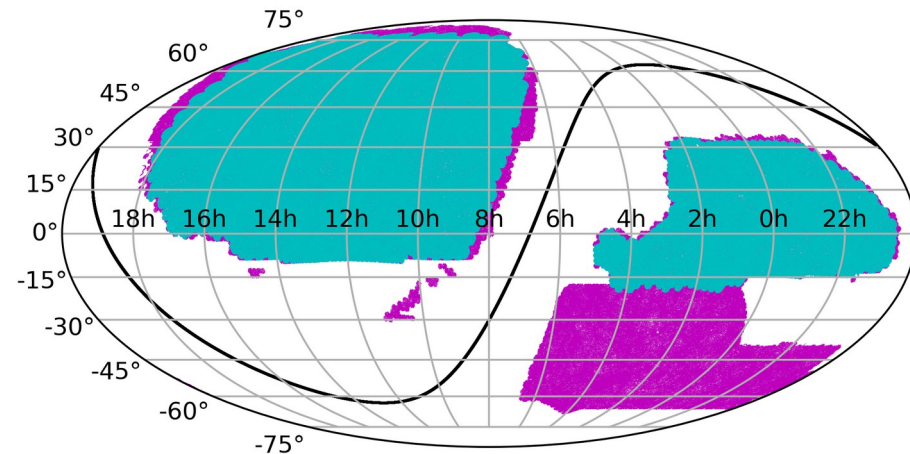
- 4-meter Mayall Telescope at Kitt Peak National Observatory
- 5000 robotic fibres in 10 petals with 500 each



# 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**

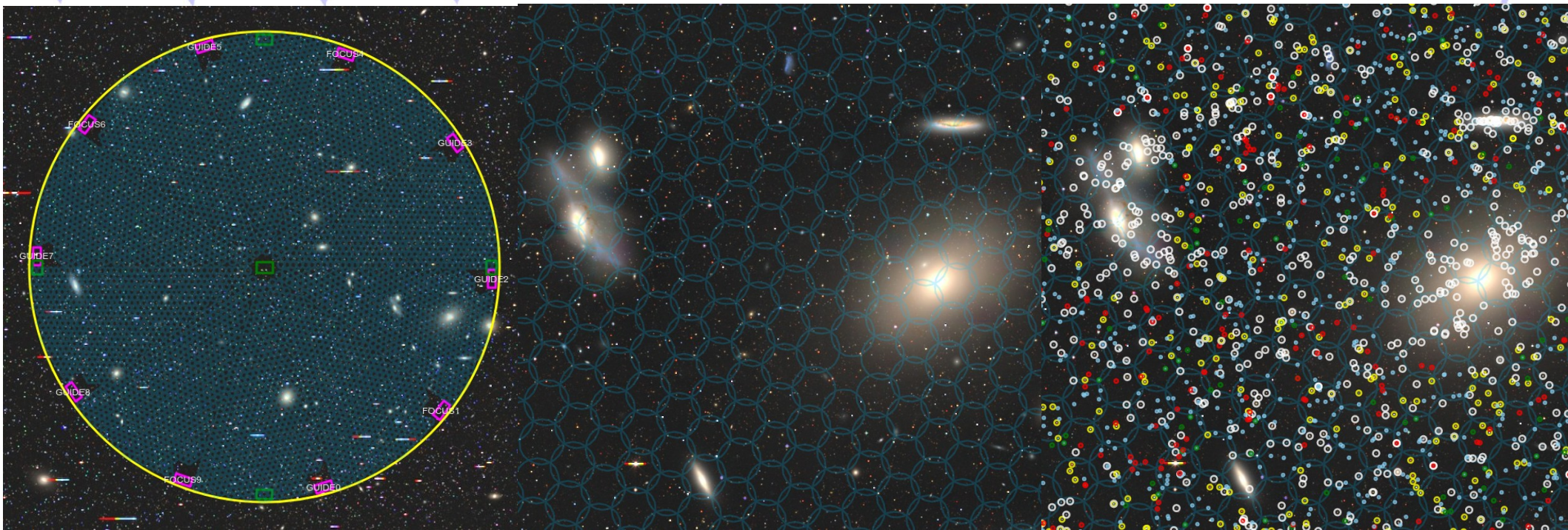
• DESI photometric • DESI spectroscopic





# 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

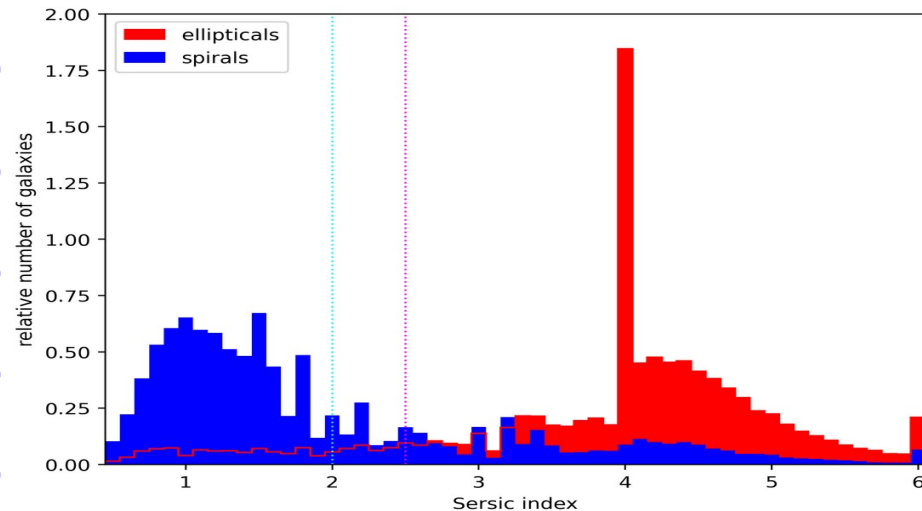
- Main targets (BGS, LRG, ELG, QSO, MWS) have always priority
- Spare fibres:
  - Bright galaxies (SGA) are masked for dark time targets (ELG, LRG, QSO):  
If no other target within patrol radius of fibre positioner
  - After multiple passes: all main targets within patrol radius observed
  - Some big 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)

# 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

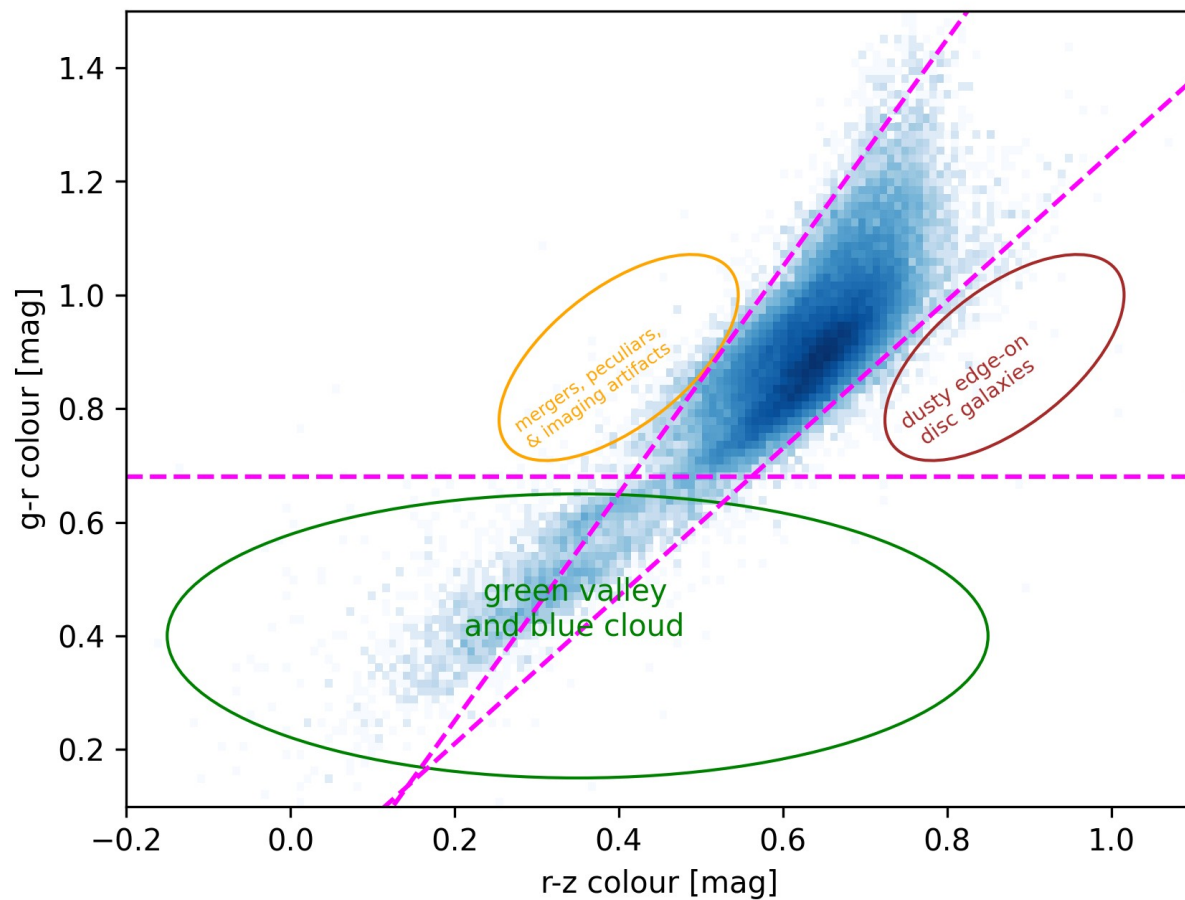
# Fundamental plane targets

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

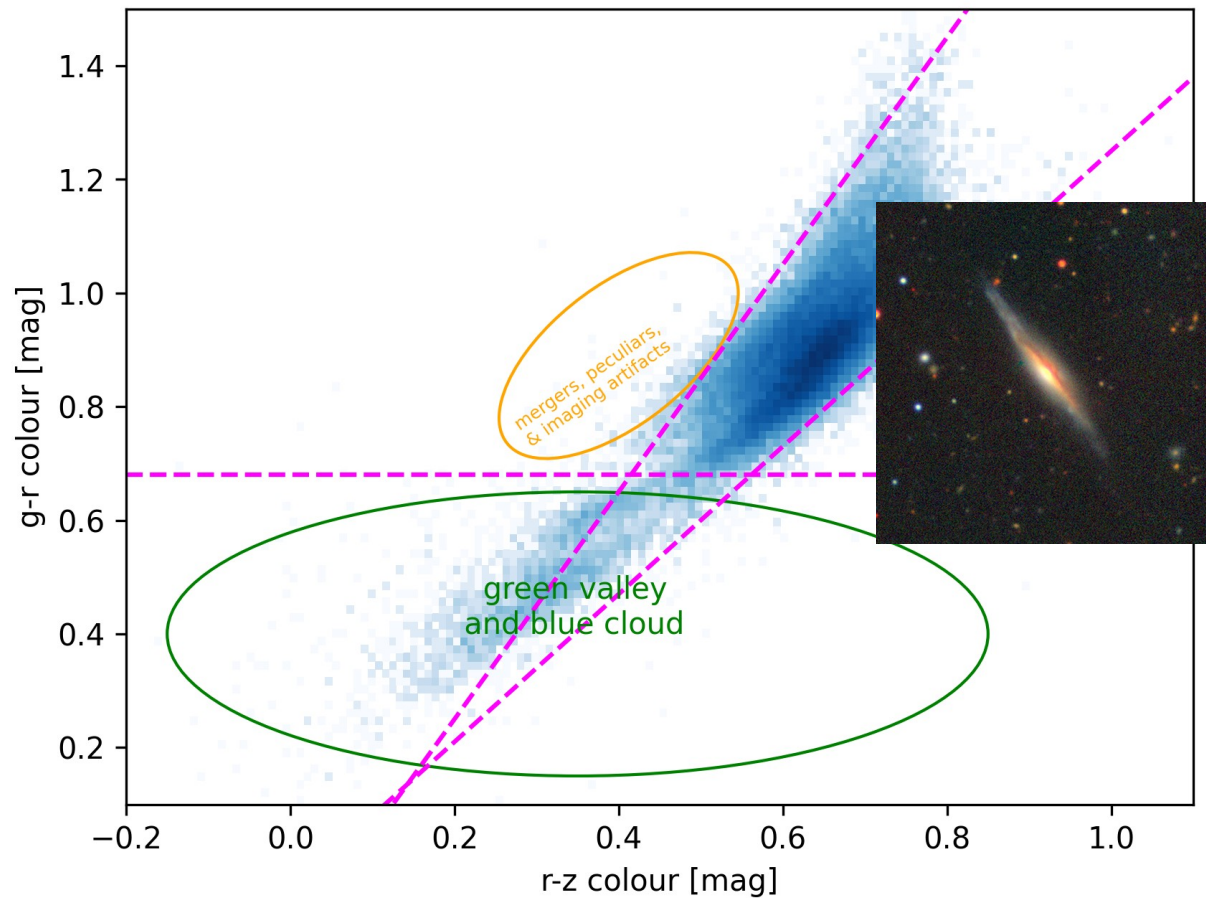




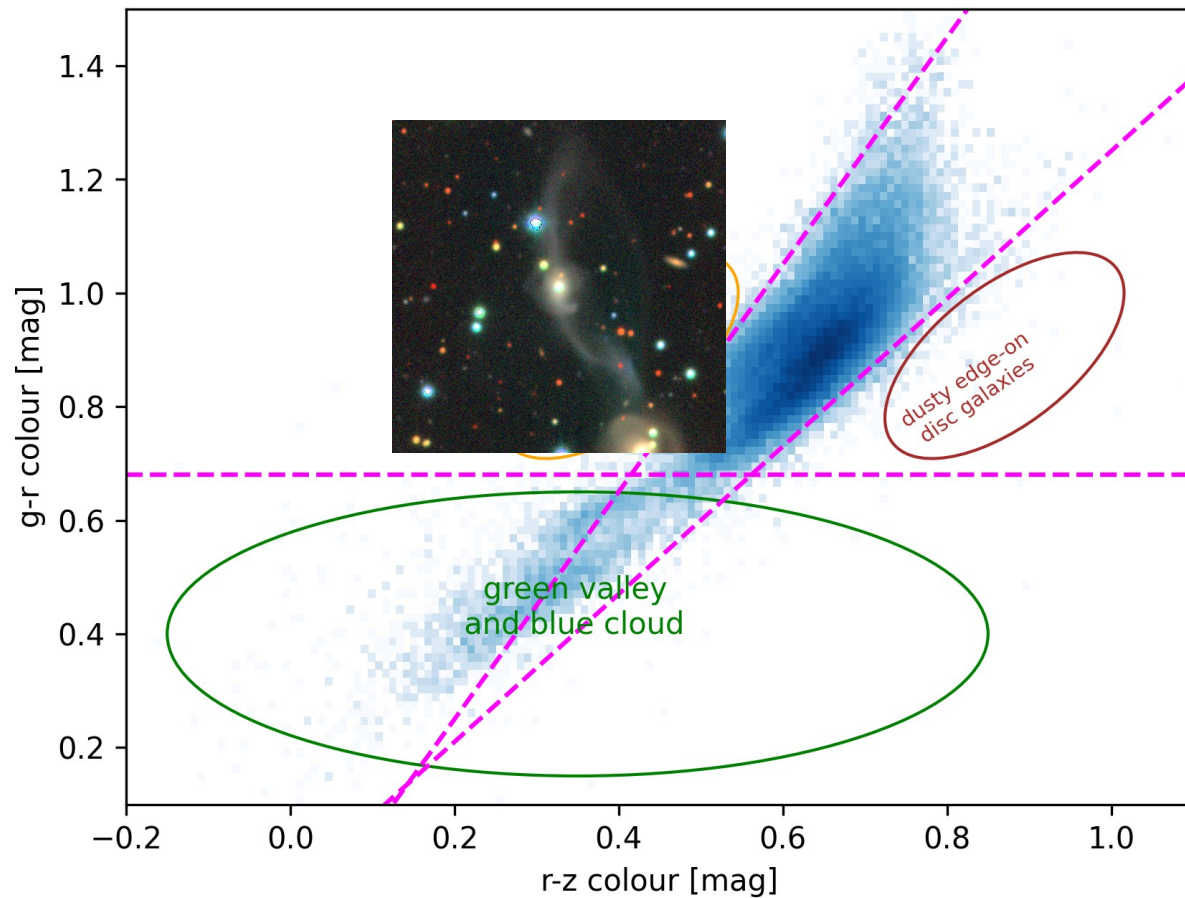
# Colour cuts



# Colour cuts

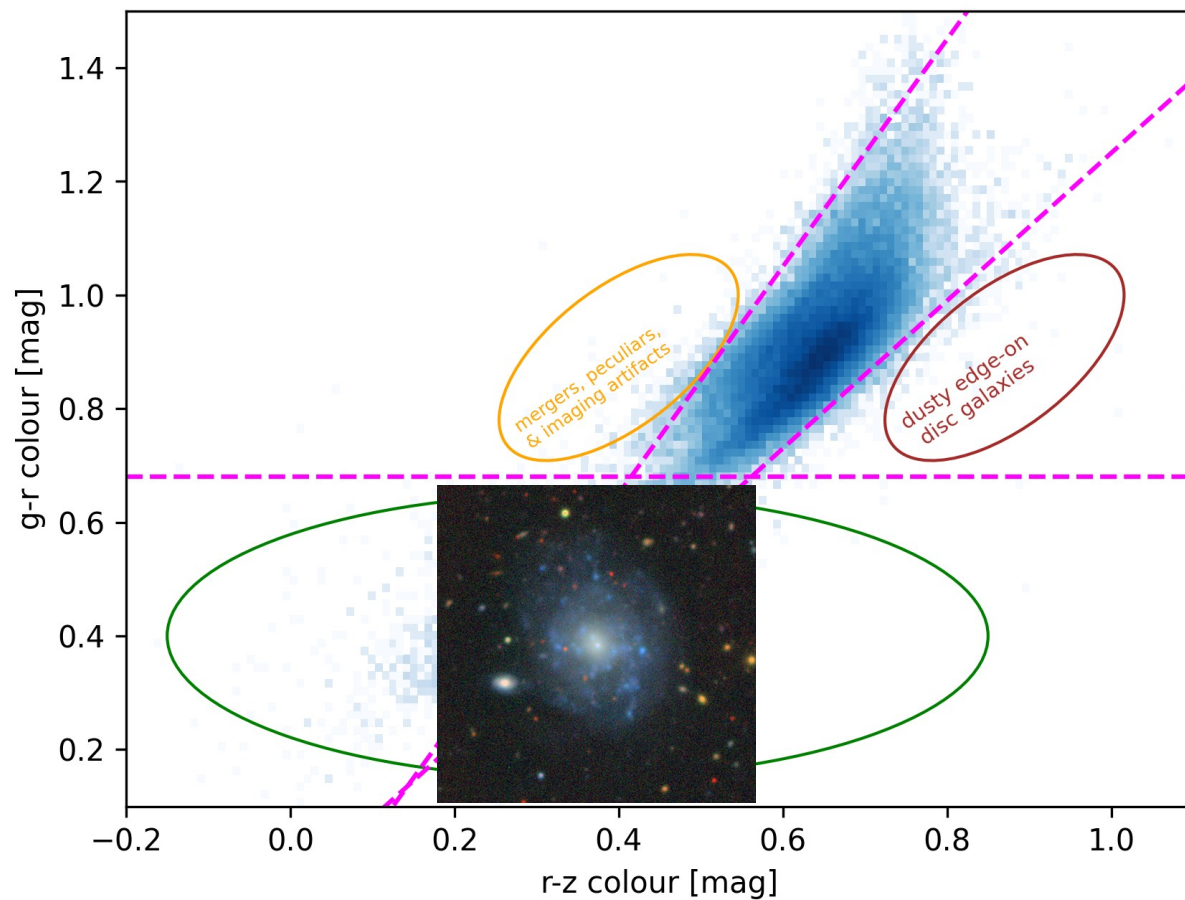


# Colour cuts

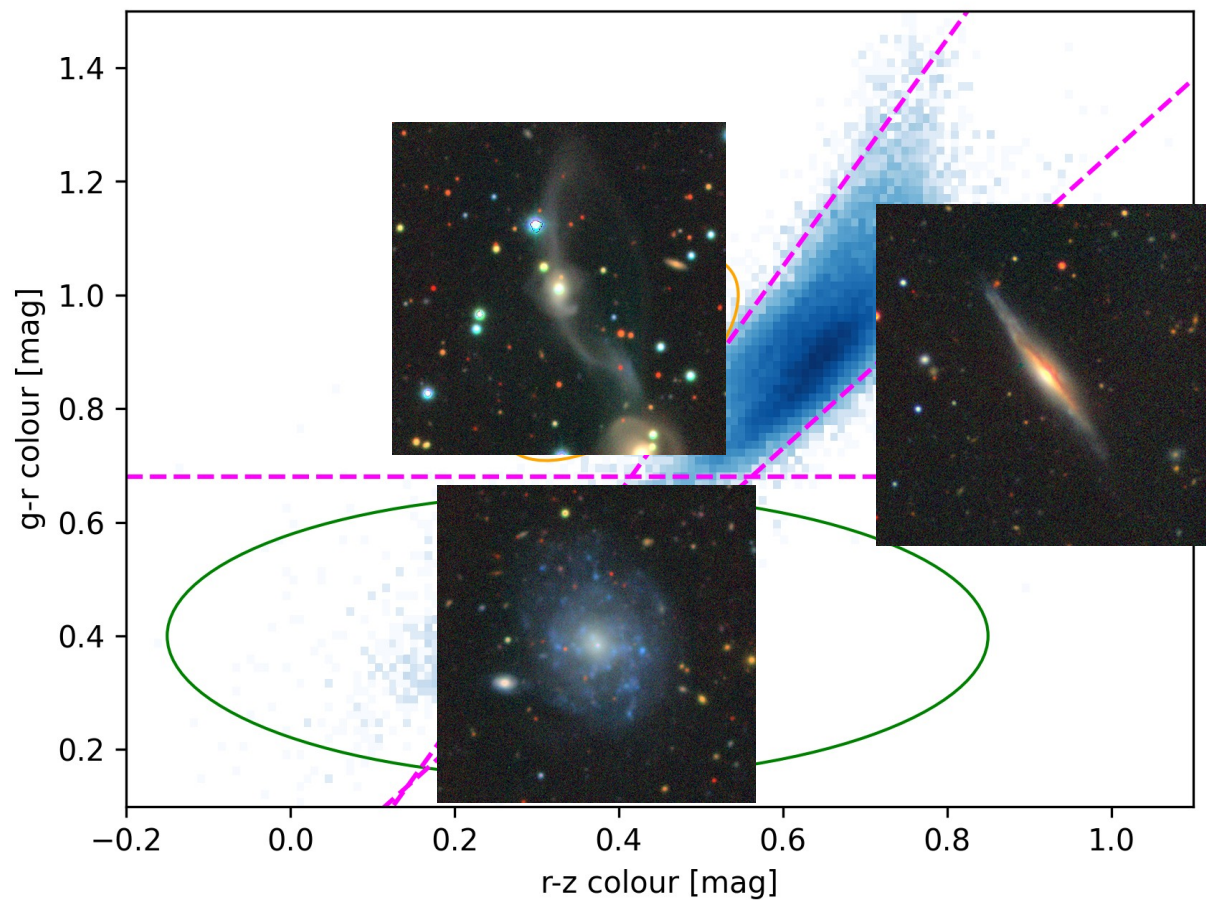




# Colour cuts



# 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

NGC7832

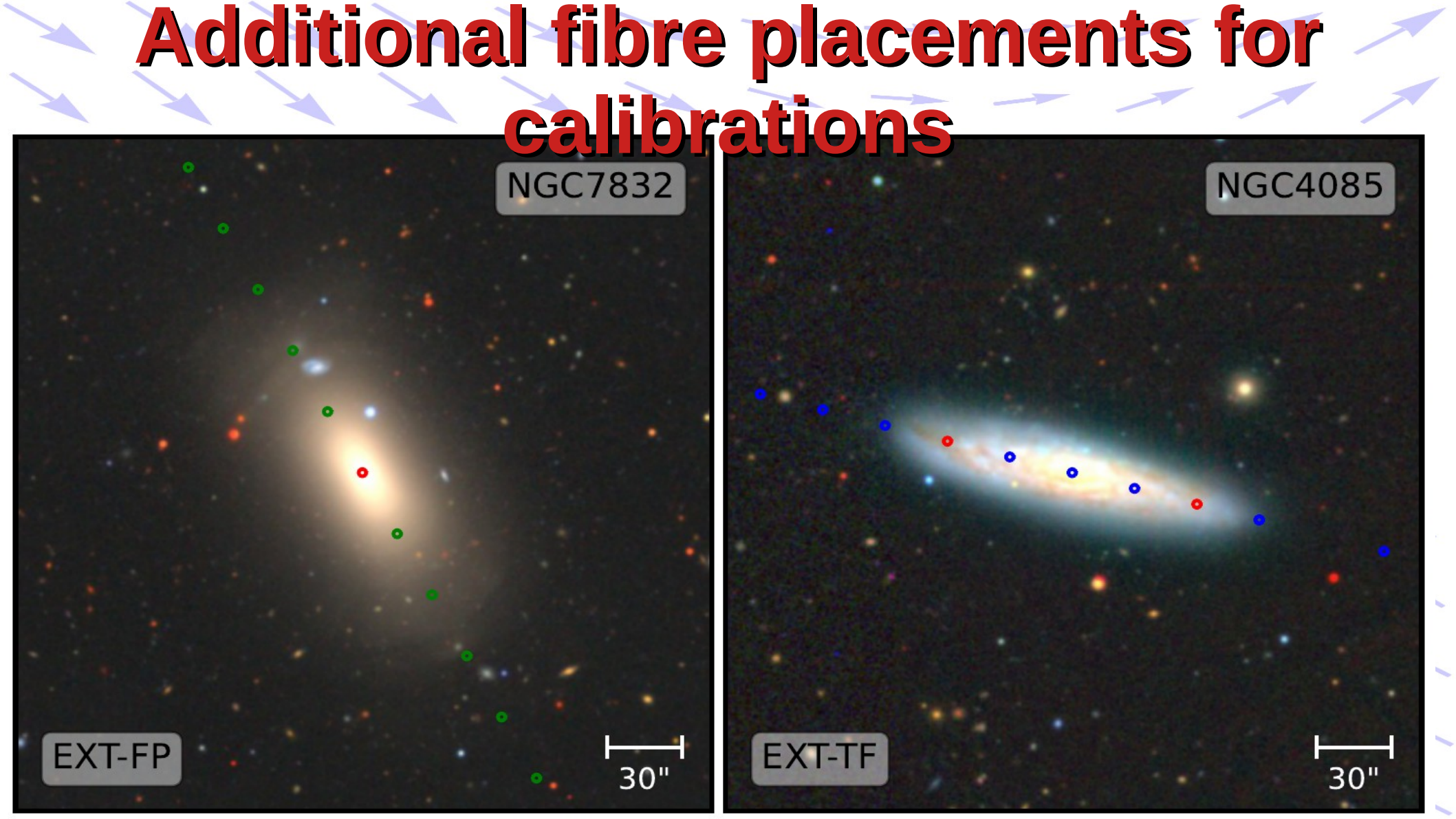
EXT-FP

30"

NGC4085

EXT-TF

30"



# Low resolution integral field spectroscopy

PGC028718

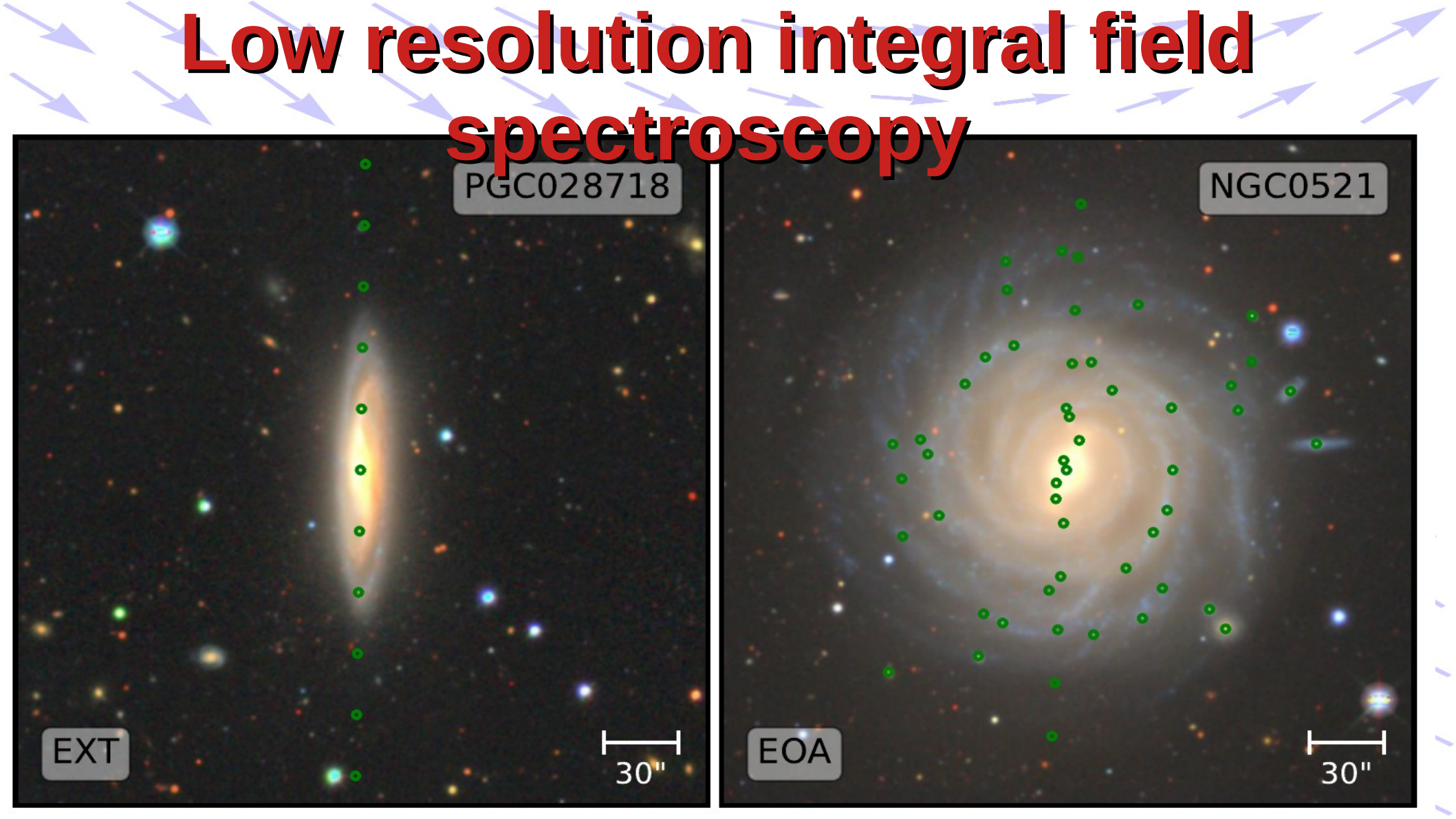
NGC0521

EXT

30''

EOA

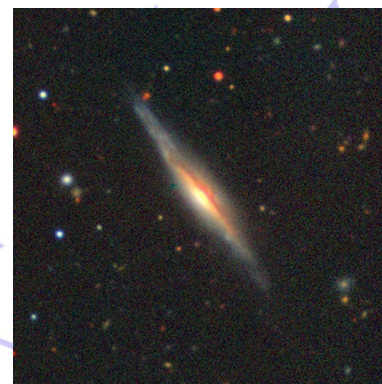
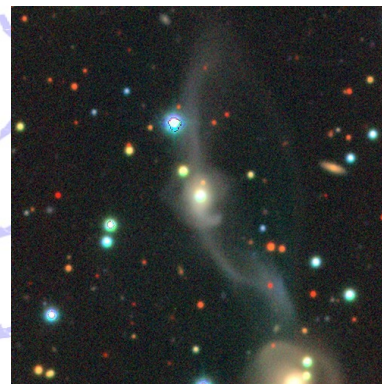
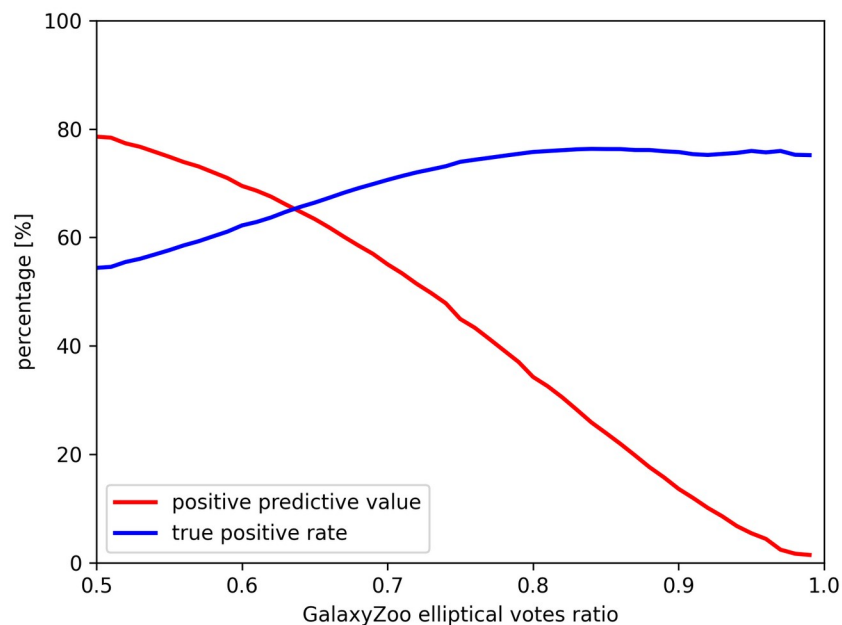
30''





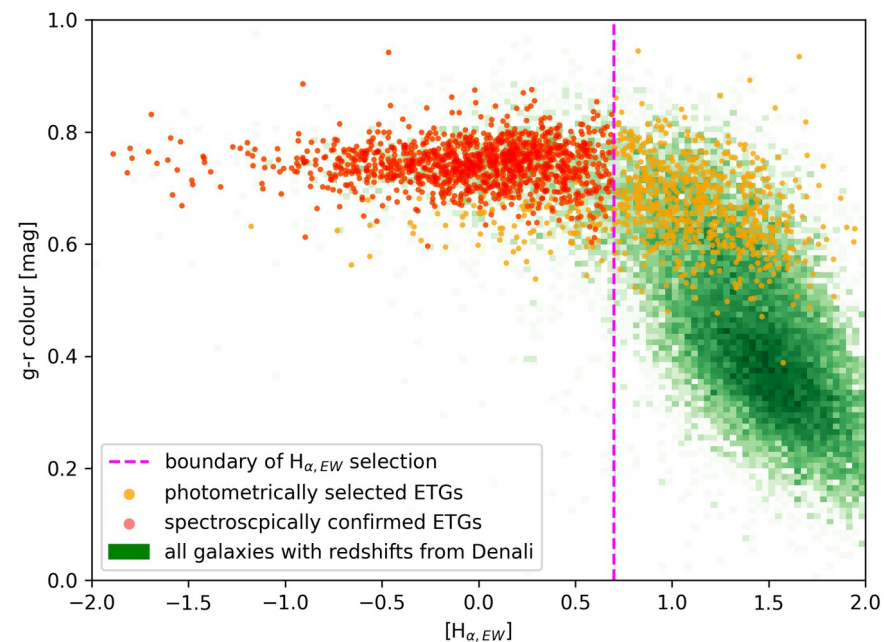
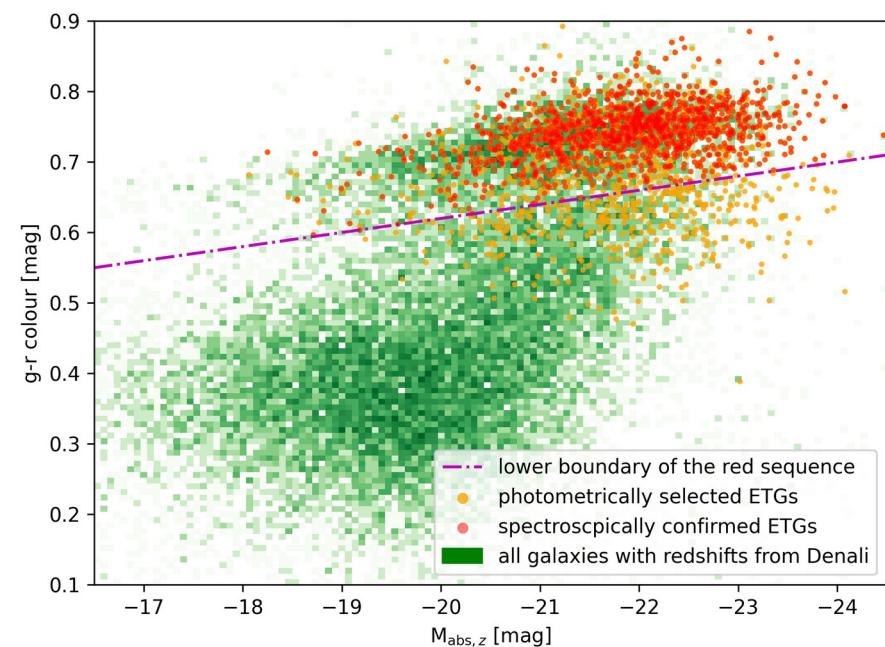
# Verification of our target selection

- 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

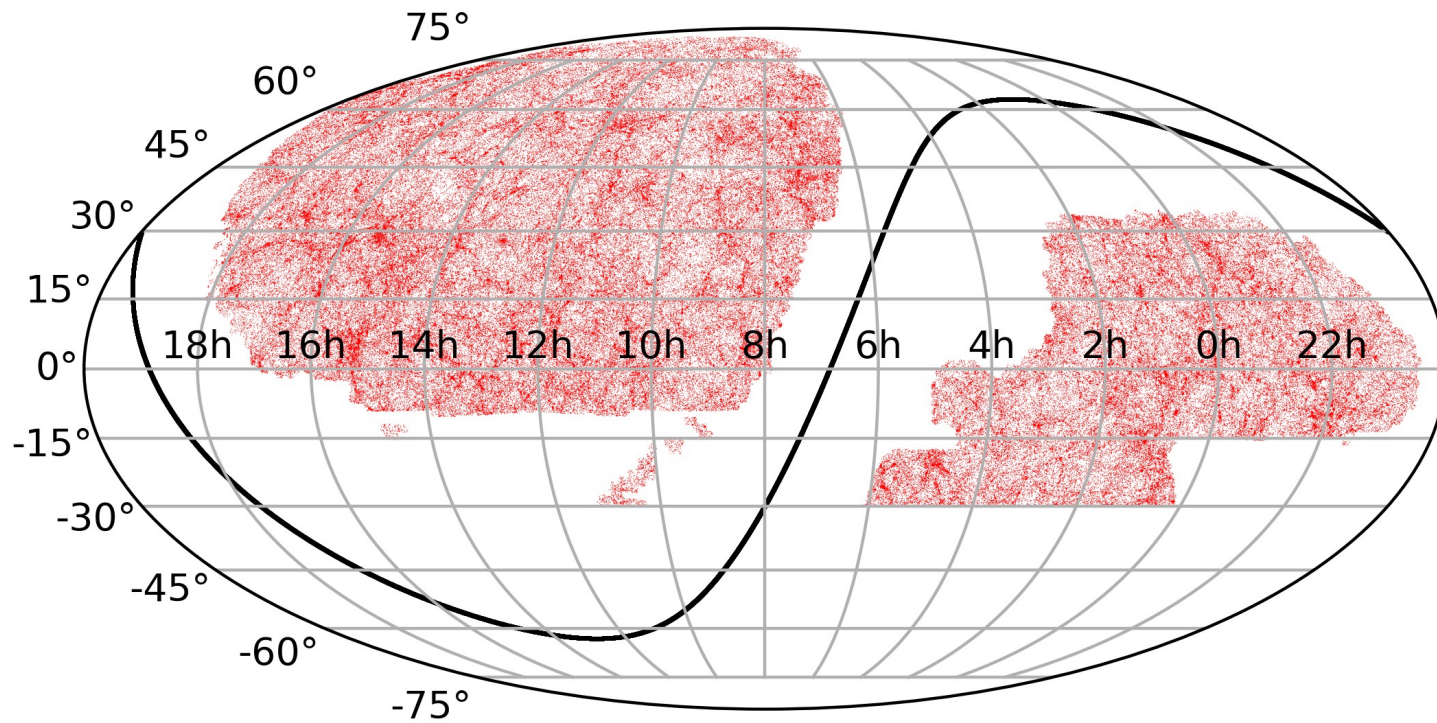
- Using the science verification data (observation before the main survey) to test our criteria and refine them further
- Using fastspec data to further clean the sample (~75% remain)





# Spectroscopic targets

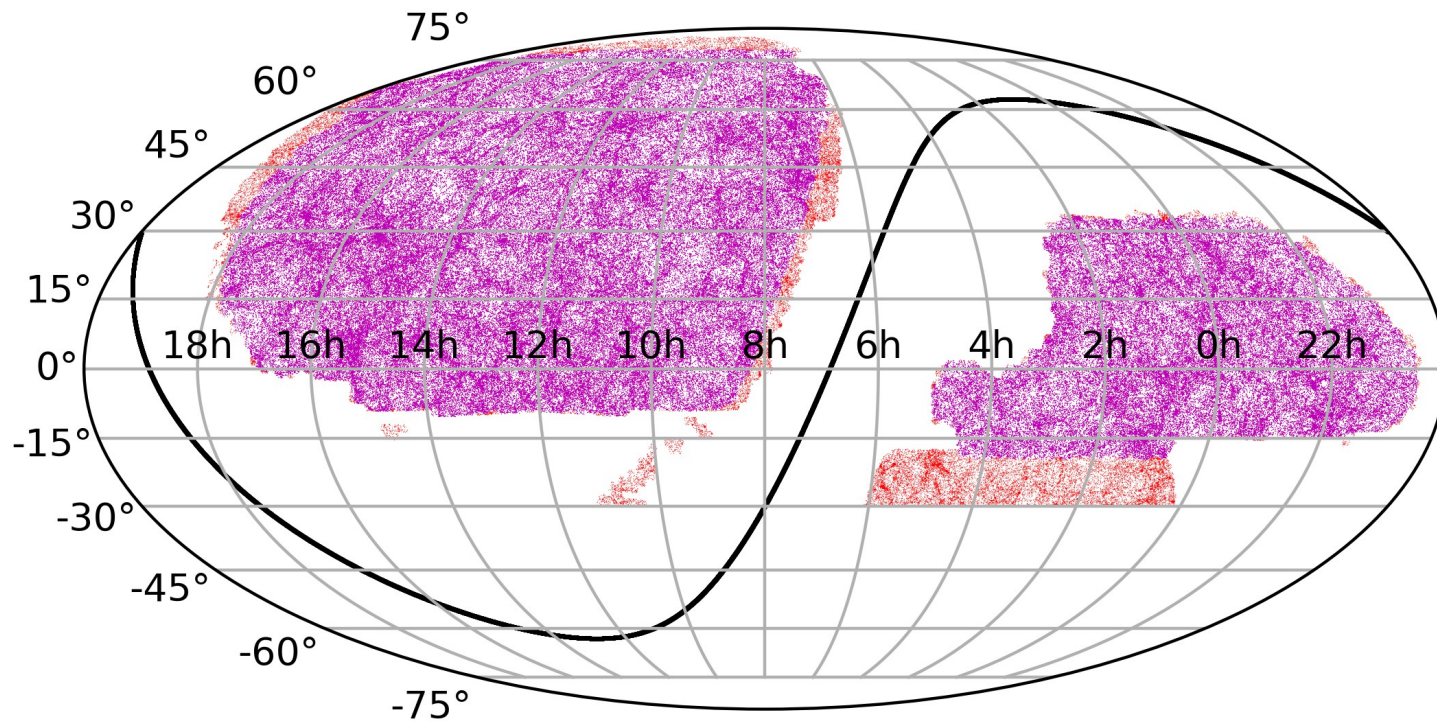
• FP targets





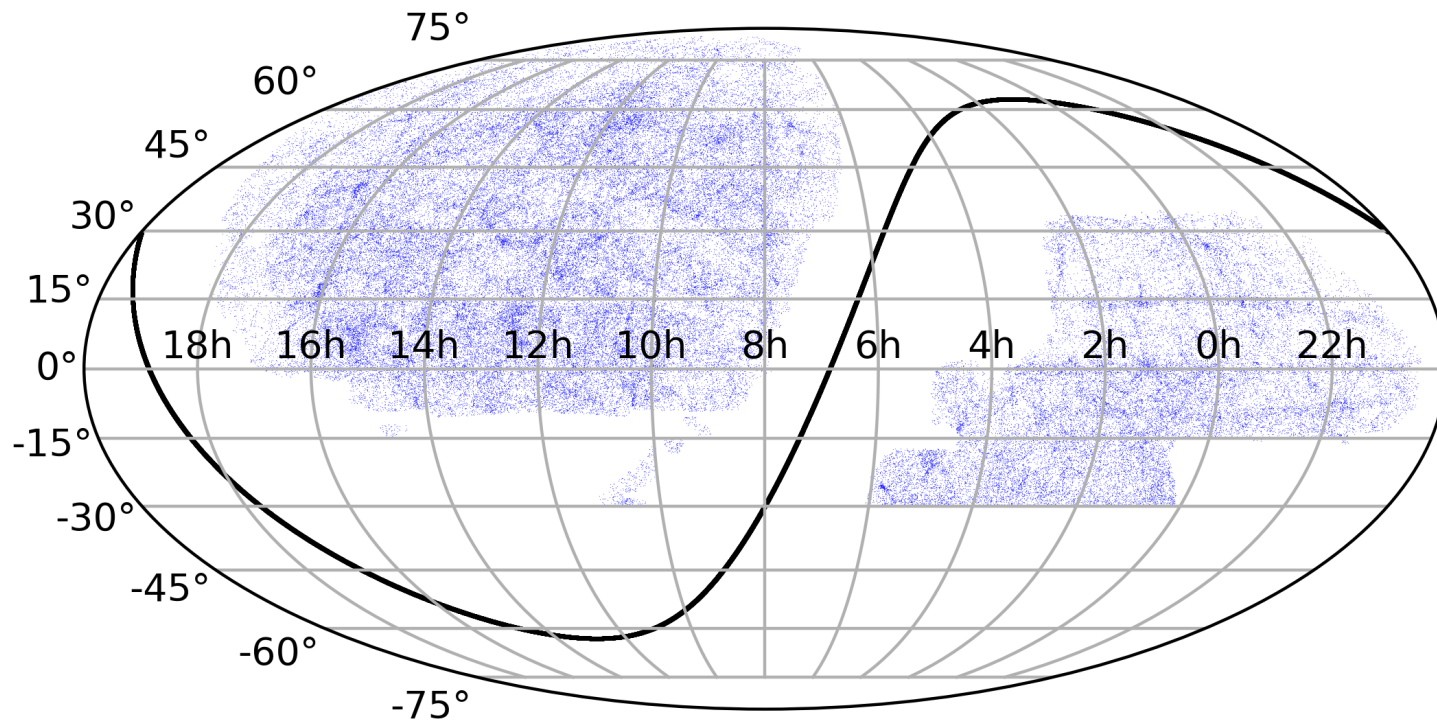
# Spectroscopic targets

• FP targets      • FP in spec



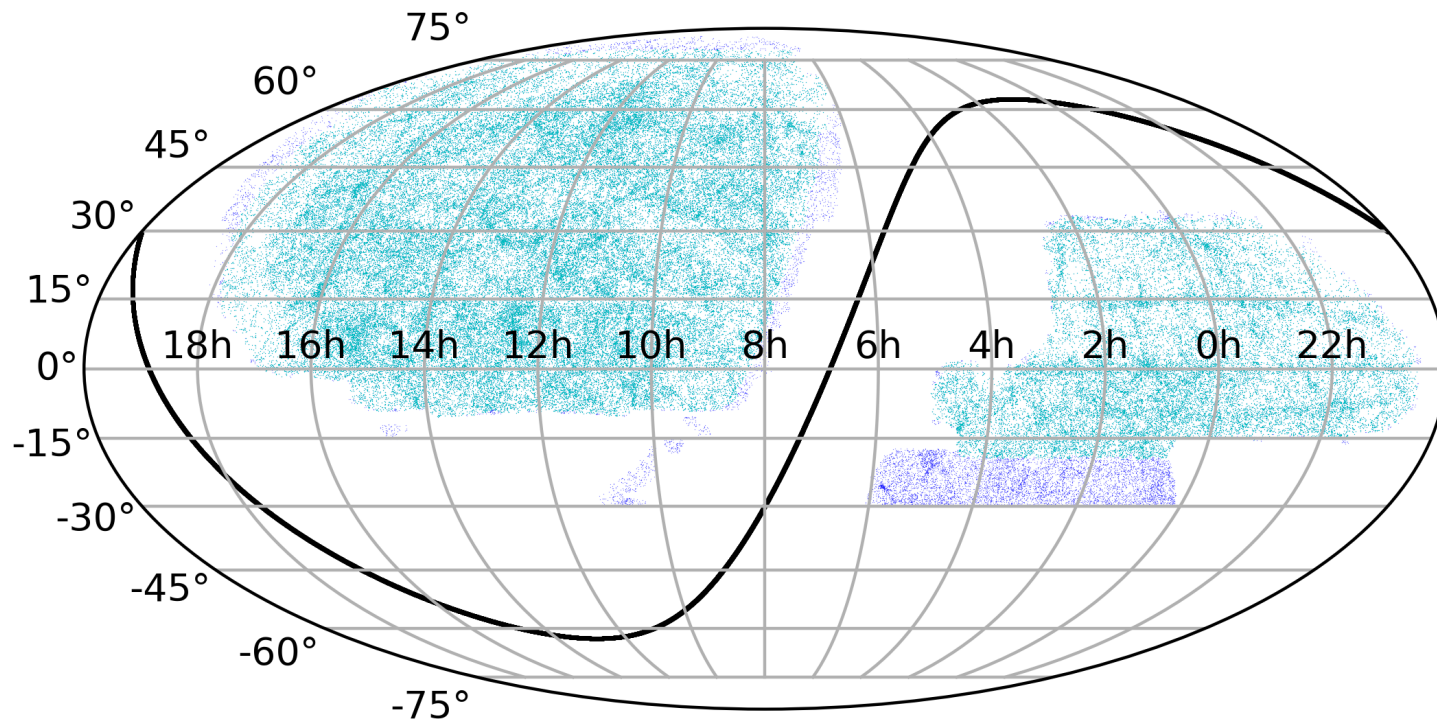
# Spectroscopic targets

• TF targets



# Spectroscopic targets

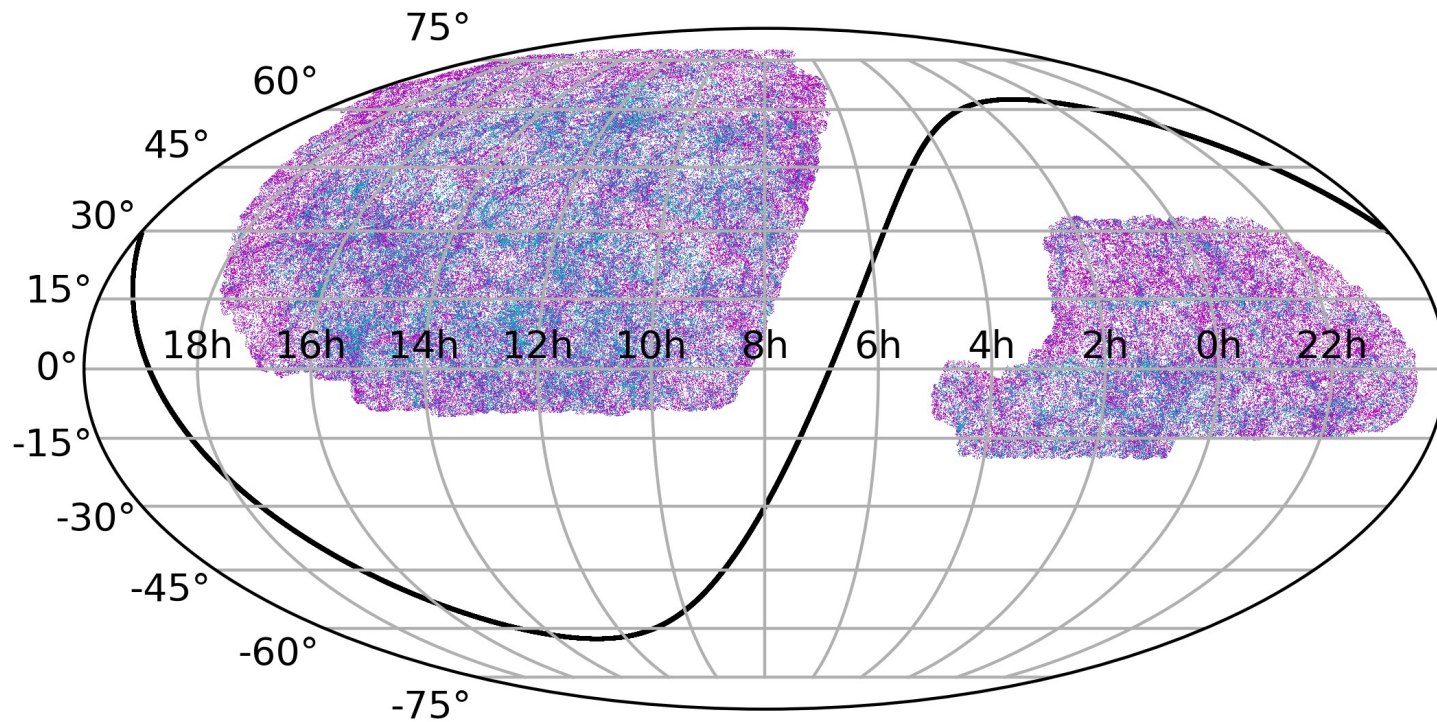
• TF targets      • TF in spec





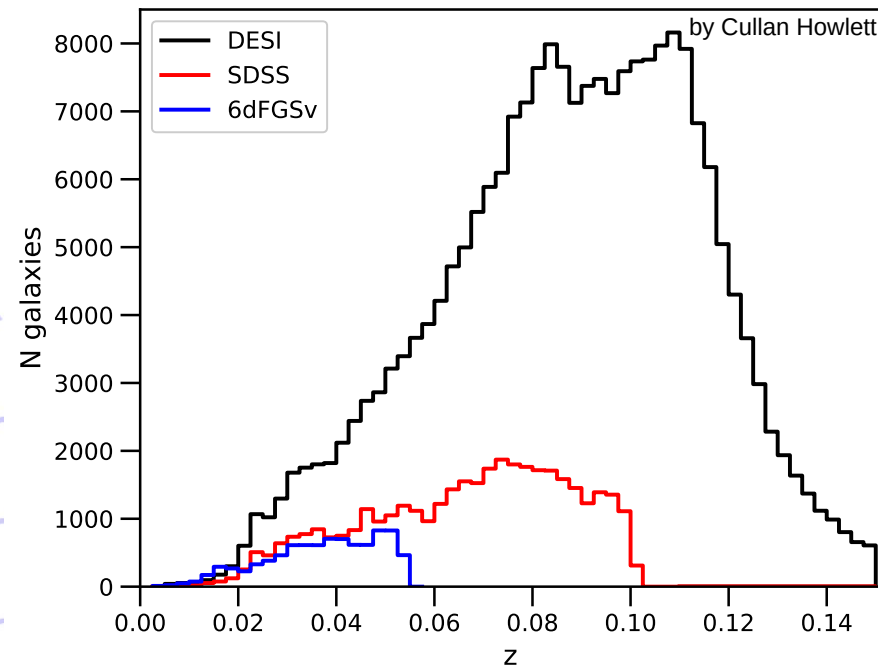
# Spectroscopic targets

• FP in spec      • TF in spec



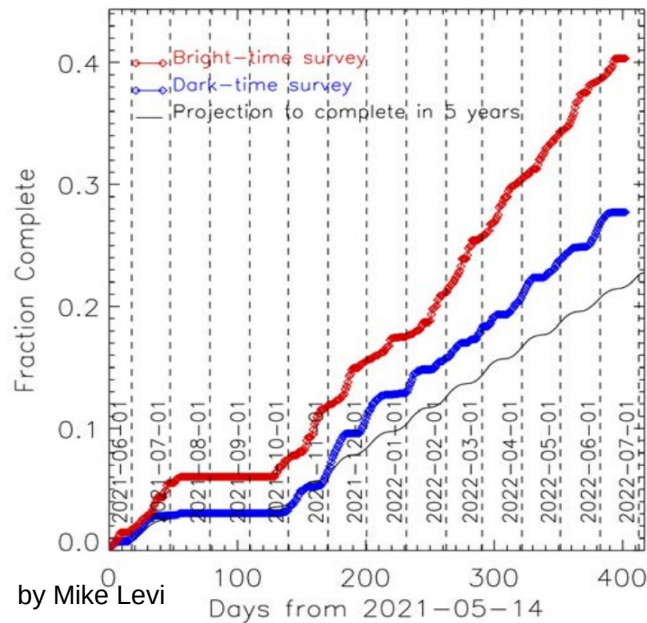
# DESI PV sample size

- 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 (maybe 17 000)
- Most true low redshift velocity dispersion measurements successful
- ~ 60% of the targets will be used



# Current status of DESI

- Main survey started in May 2021
- After 1 Year (out of 5):
  - Bright time almost 40% complete
  - Dark time over  $\frac{1}{4}$  complete
- Initially width first, now depths first
- Internal: unblinded data until July 2021 for tests



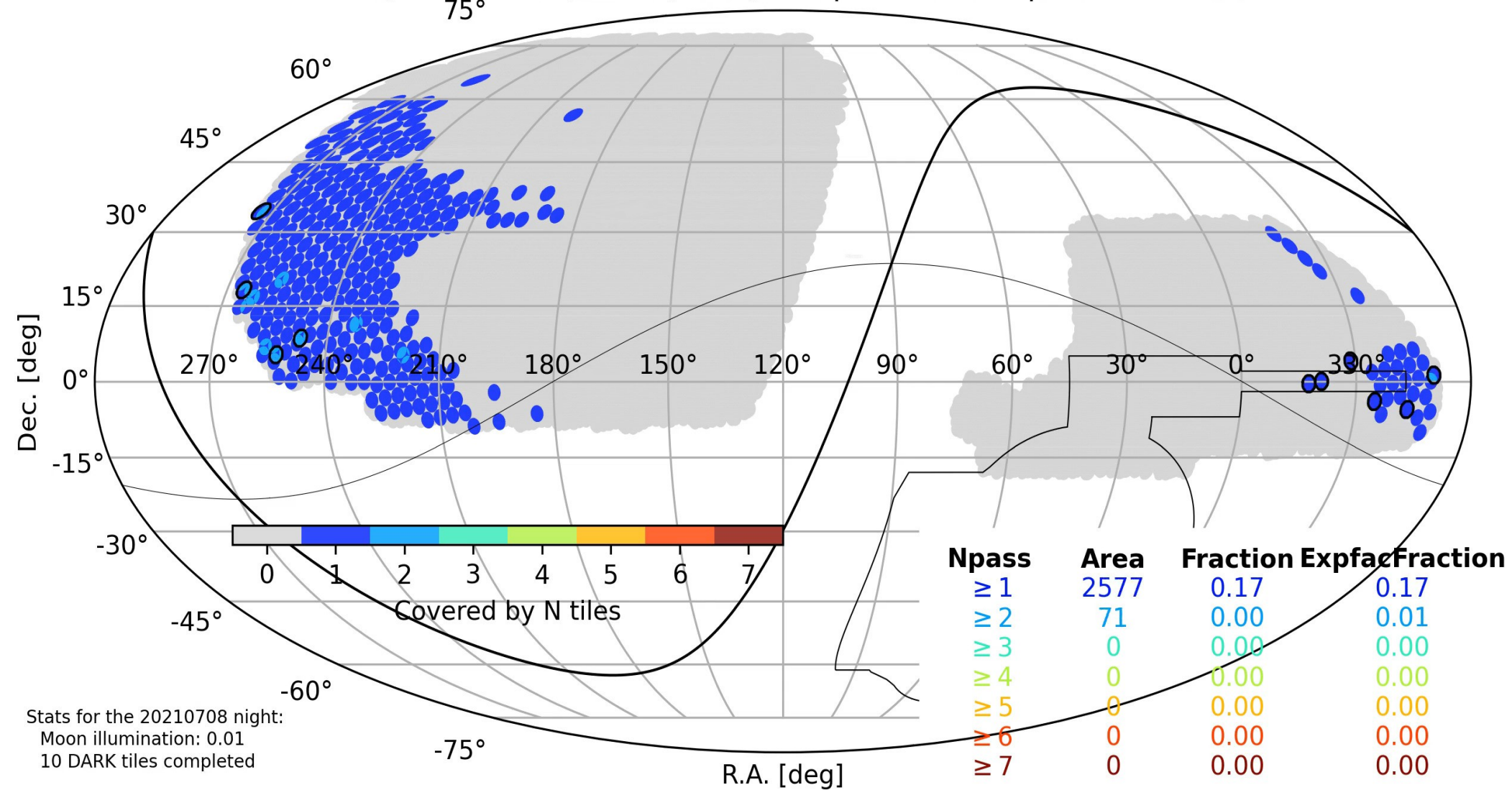


# Contreras Fire



No fire damage, possible smoke damages  
are currently being assessed

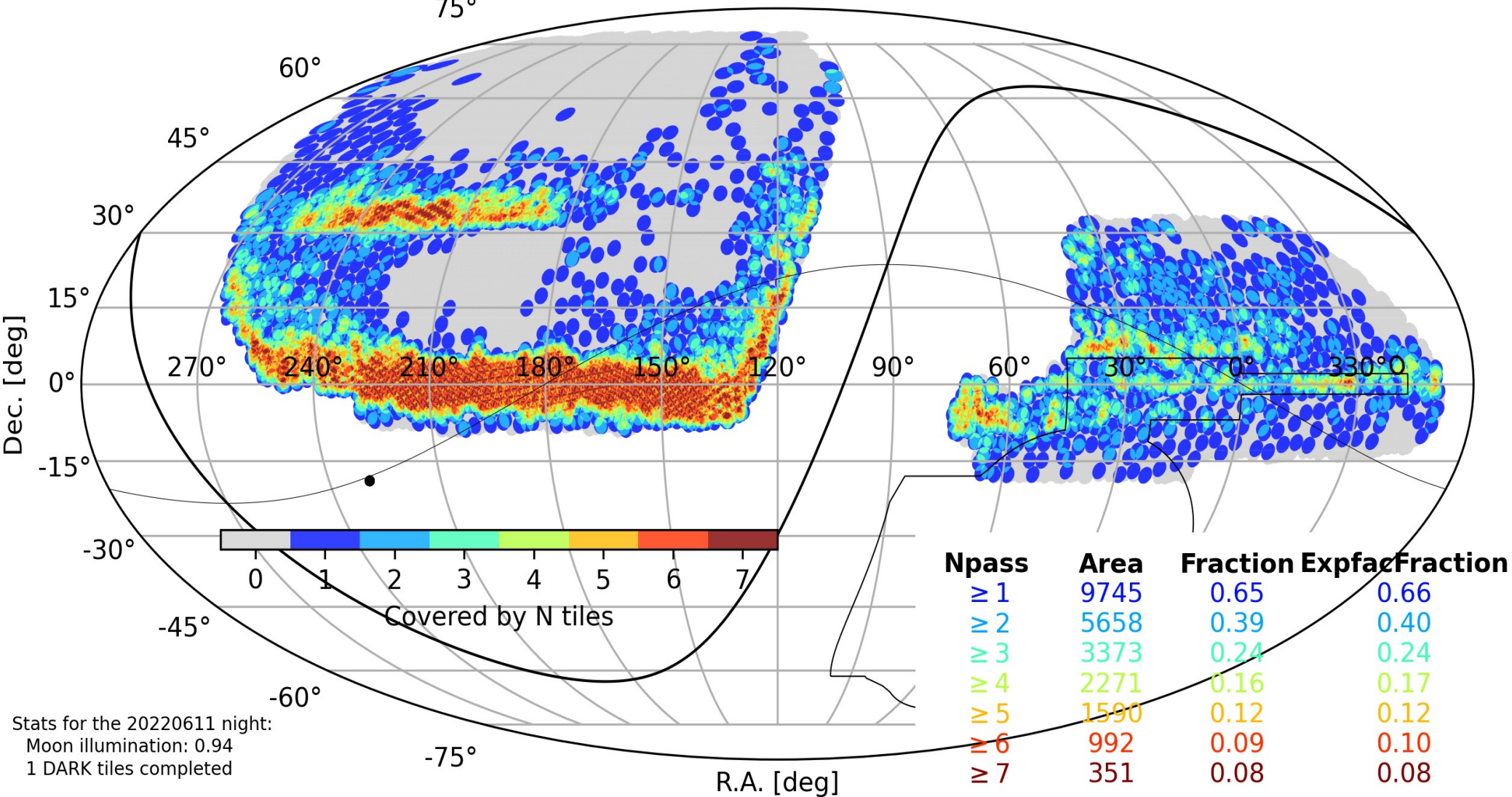
Main/DARK : 304/9929 (=3%) completed tiles up to 20210708





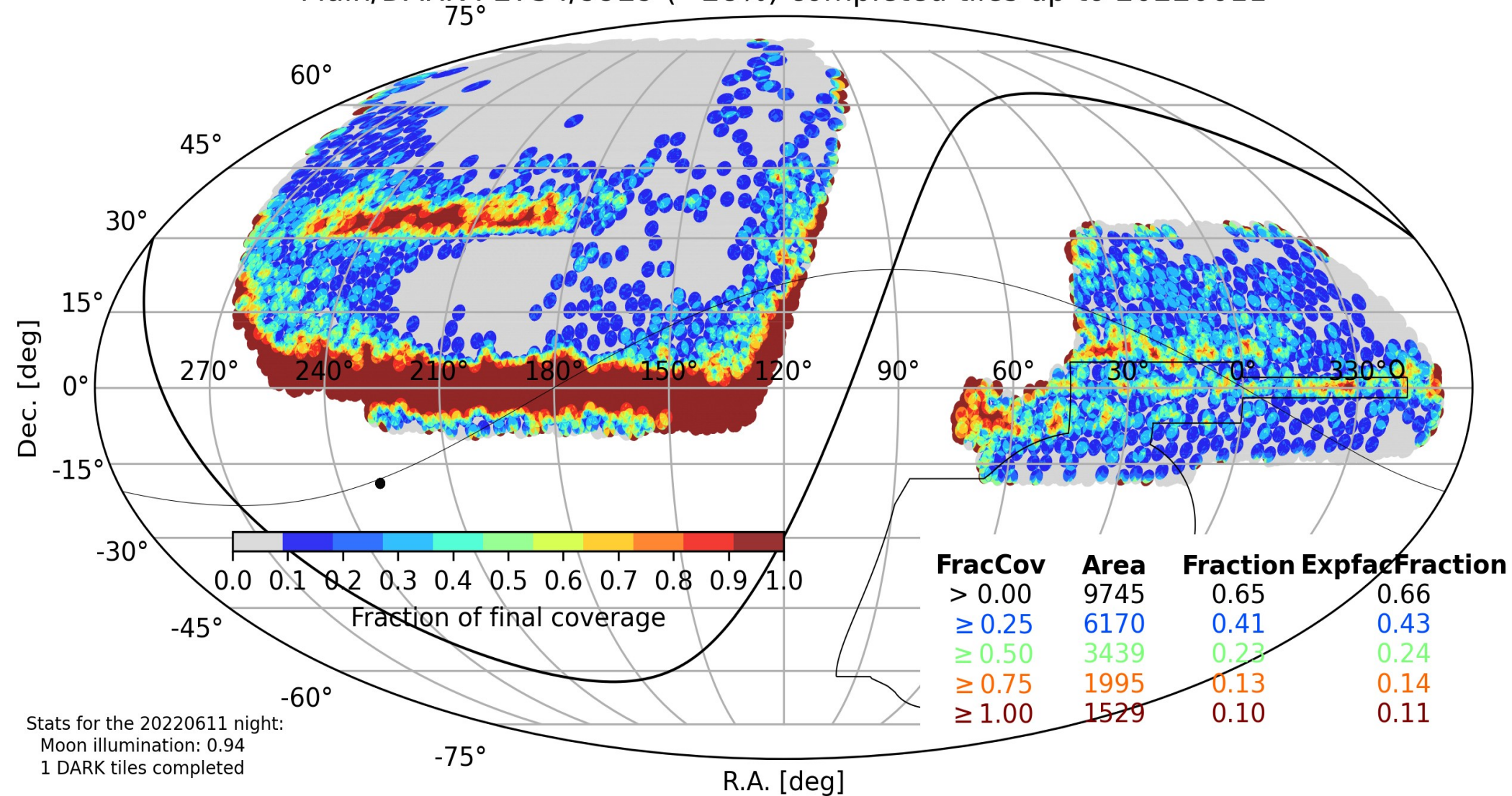
Main/DARK : 2754/9929 (=28%) completed tiles up to 20220611

Dec. [deg]





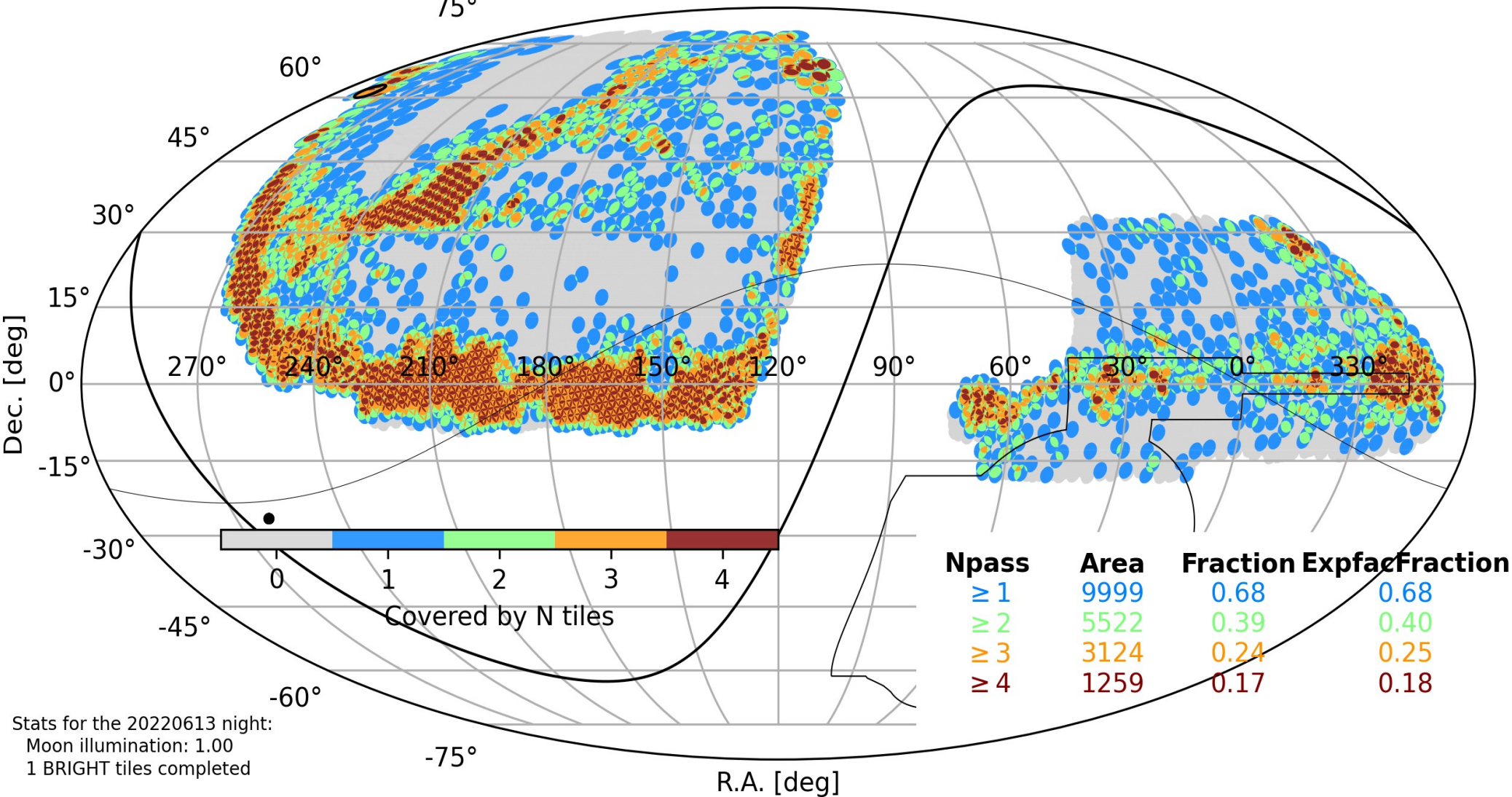
Main/DARK : 2754/9929 (=28%) completed tiles up to 20220611



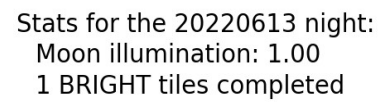
Stats for the 20220611 night:  
Moon illumination: 0.94  
1 DARK tiles completed

Main/BRIGHT : 2285/5676 (=40%) completed tiles up to 20220613

Dec. [deg]



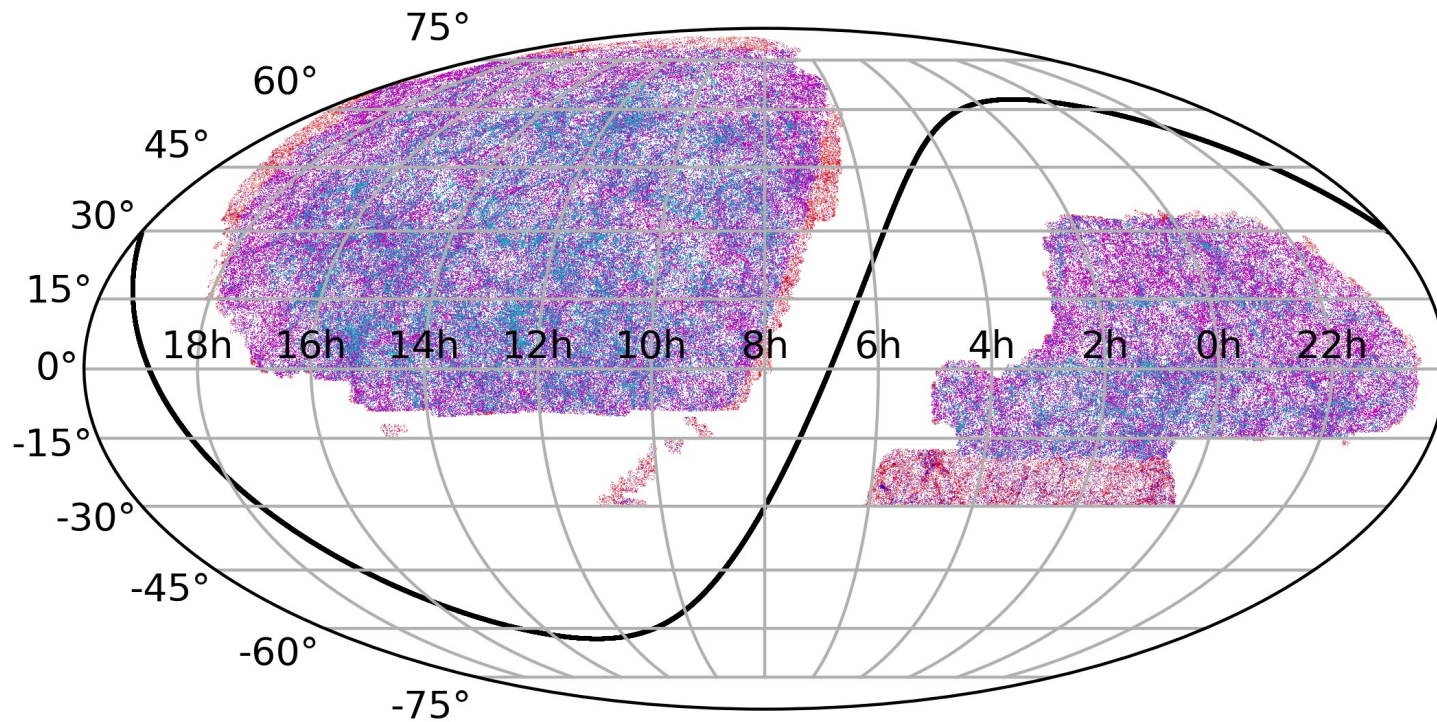


$75^\circ$ 



# Spectroscopic targets

• FP targets    • TF targets    • FP in spec    • TF in spec

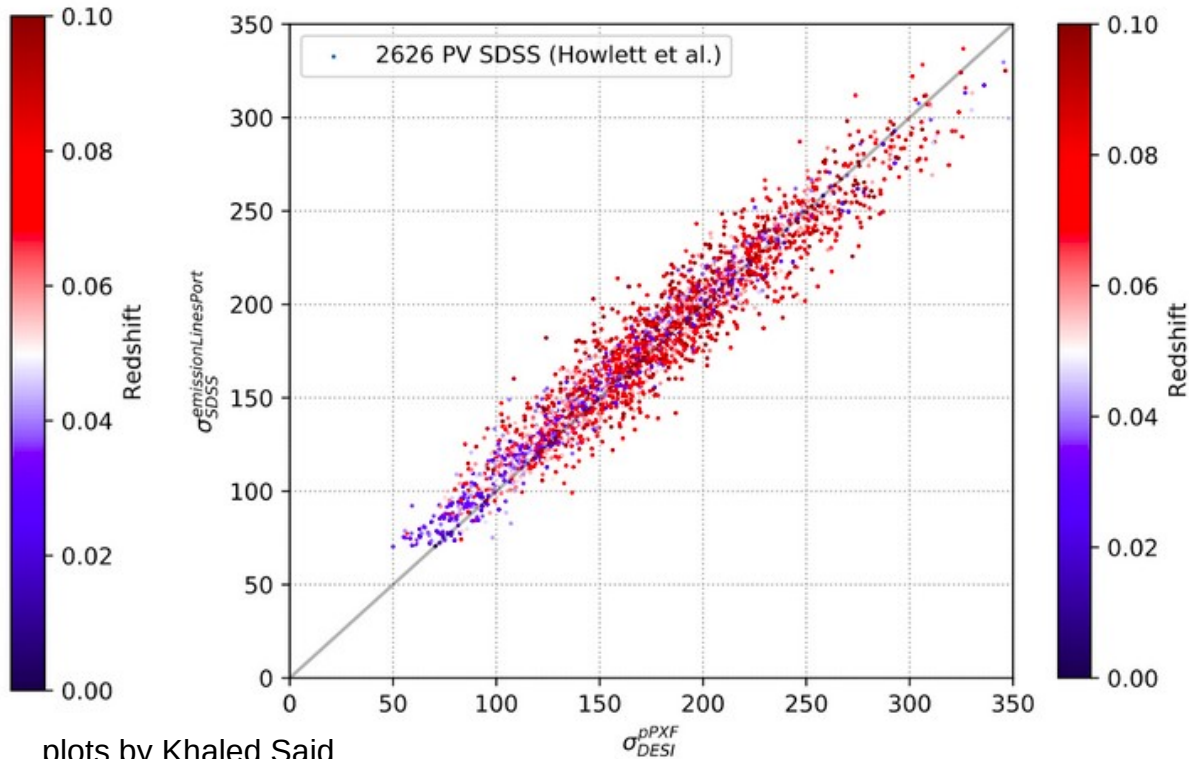
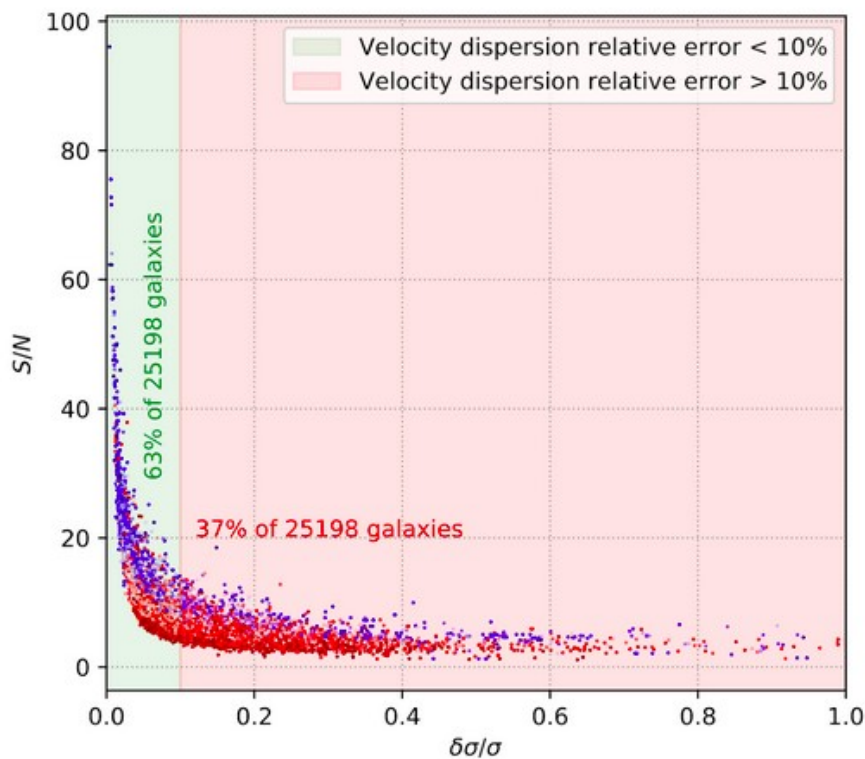


# Current status of the observations fundamental plane

- 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  $\delta\sigma/\sigma < 10\%$

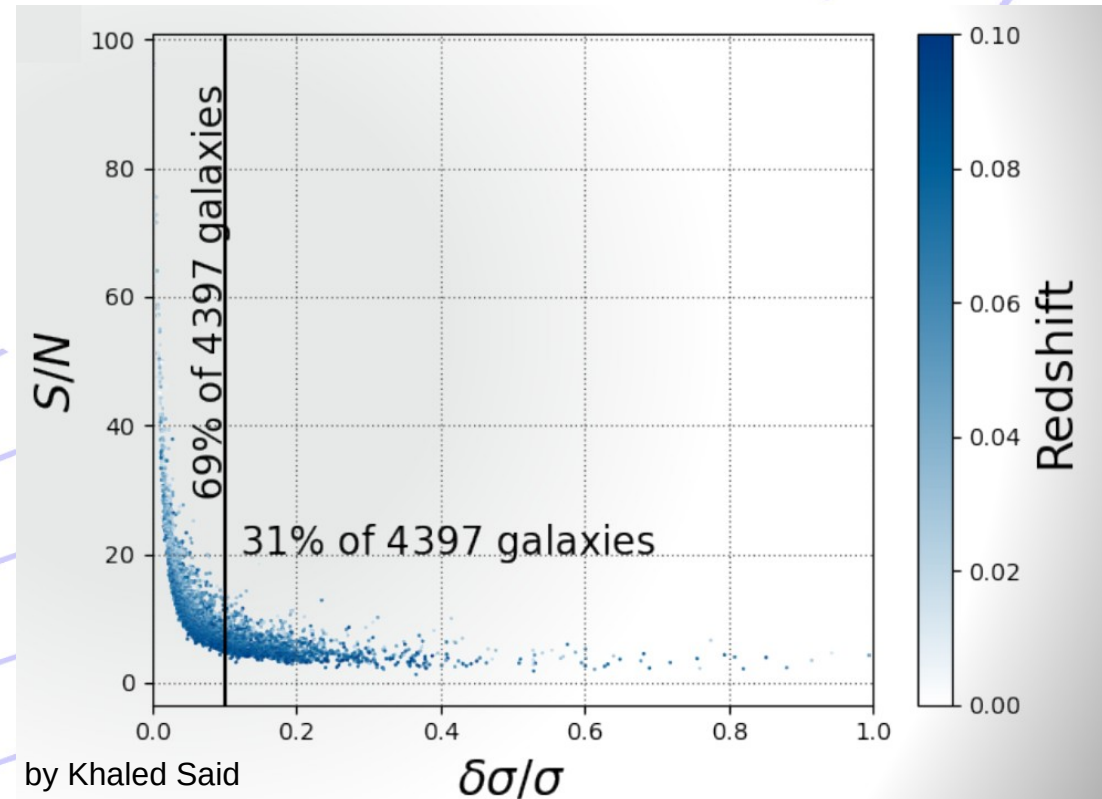


plots by Khaled Said

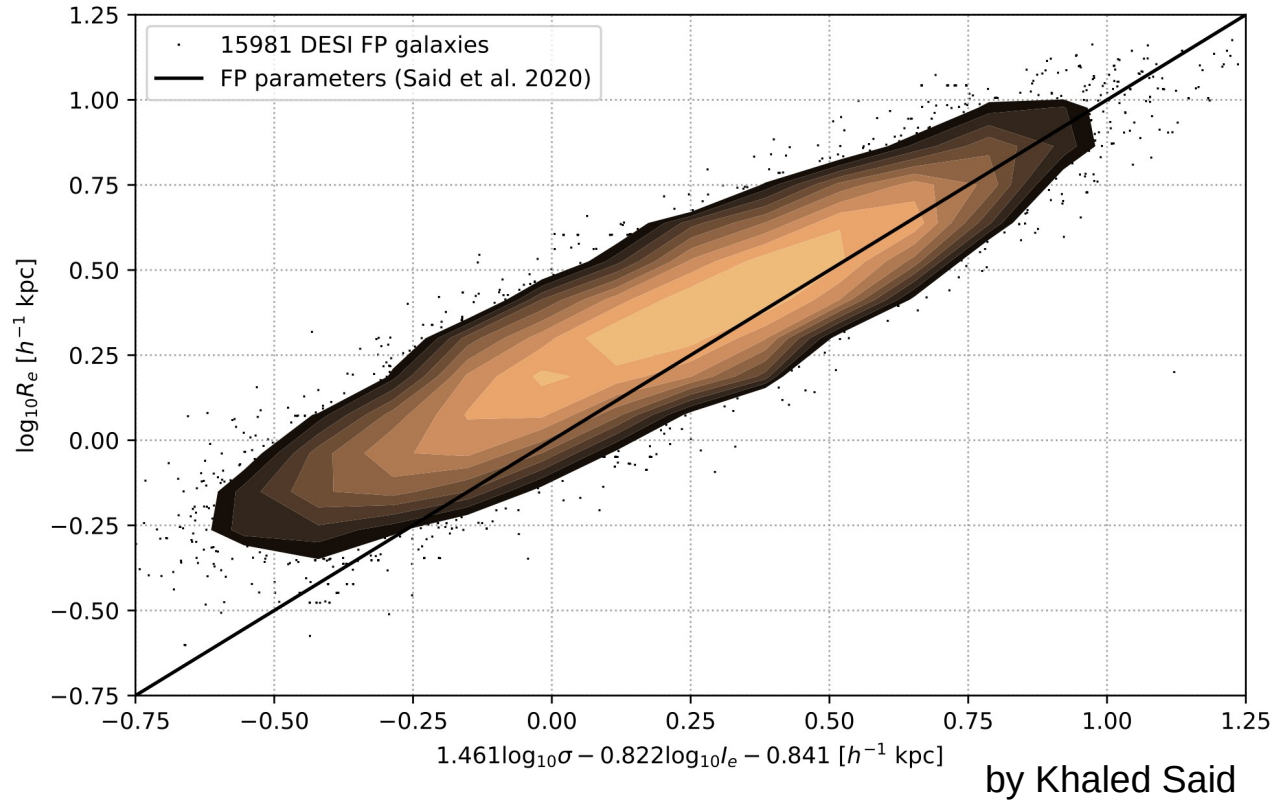


# Success rate of velocity dispersion measurements

- Only with SV3 (1% survey data)
- Even better success
- 20% scatter with this data
- Further improvements in cleaning the data will follow



# First fundamental plane fits



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

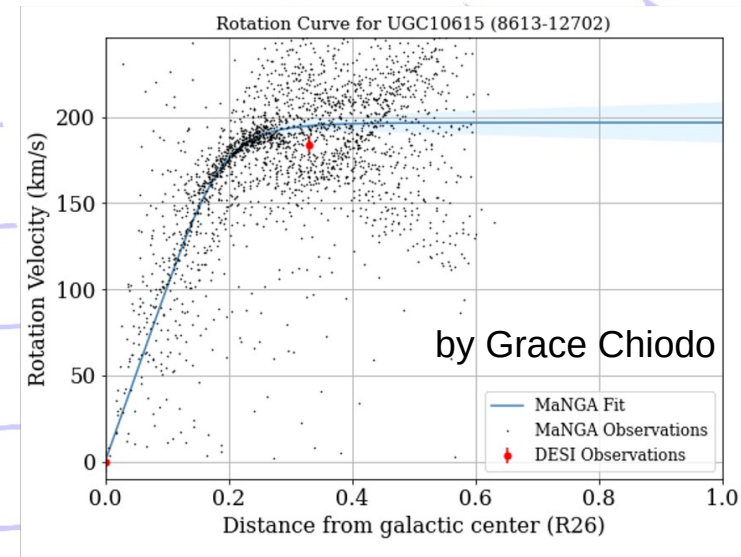
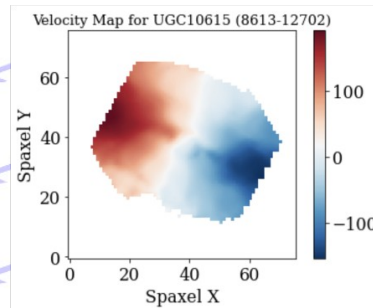
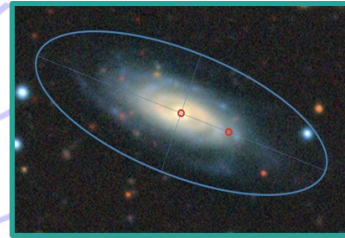
# Status of the observations

## – 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 targets

- Mostly tests with MANGA
- Fibres get enough light to get redshifts



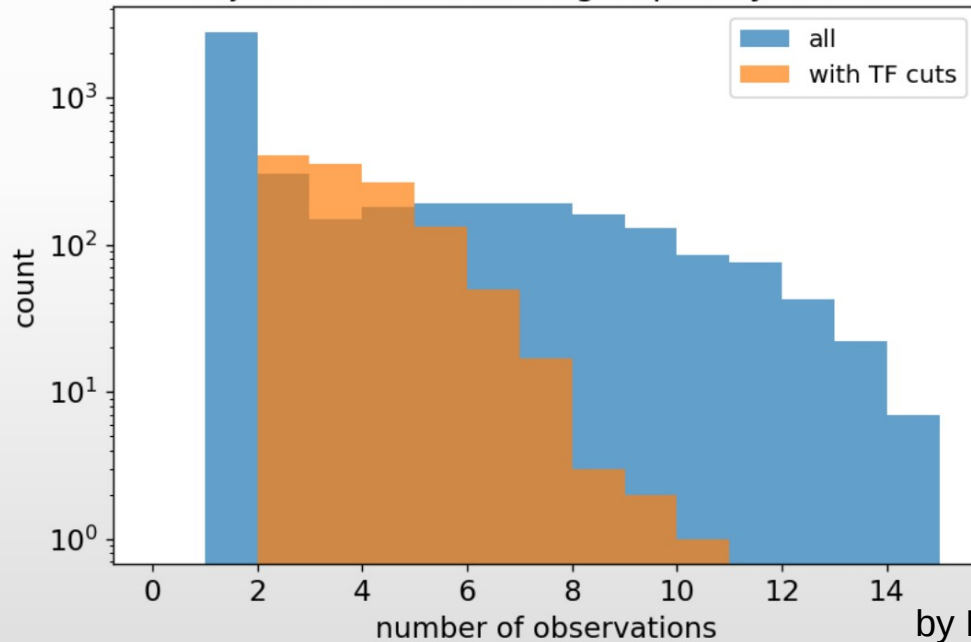


# Status of the observations

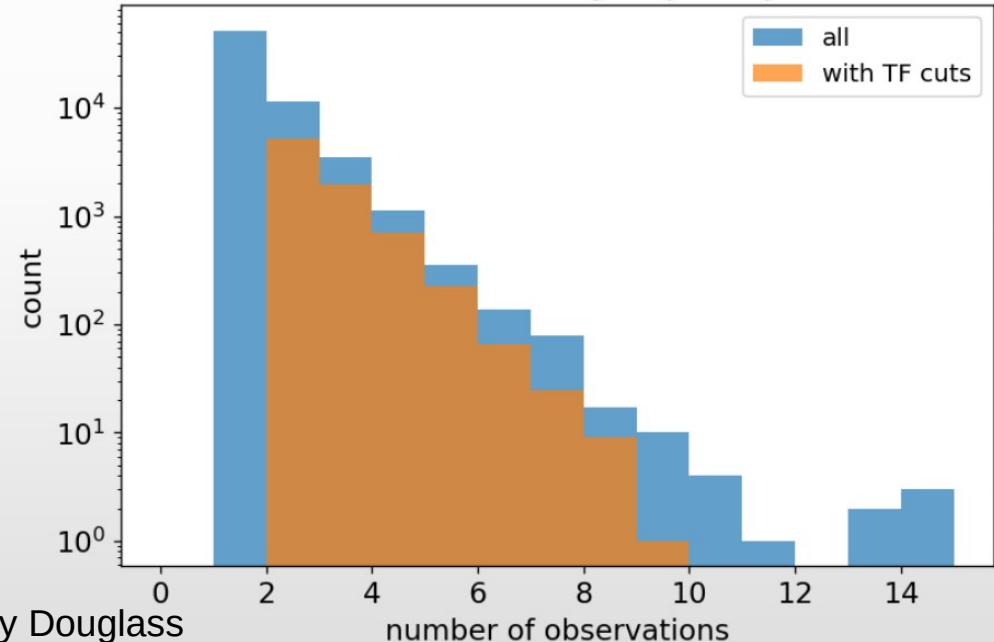
## – Tully-Fisher relation

- Changes in success rate due to improved targetting strategy between SV and main survey

Fuji (SV) observations grouped by SGA ID



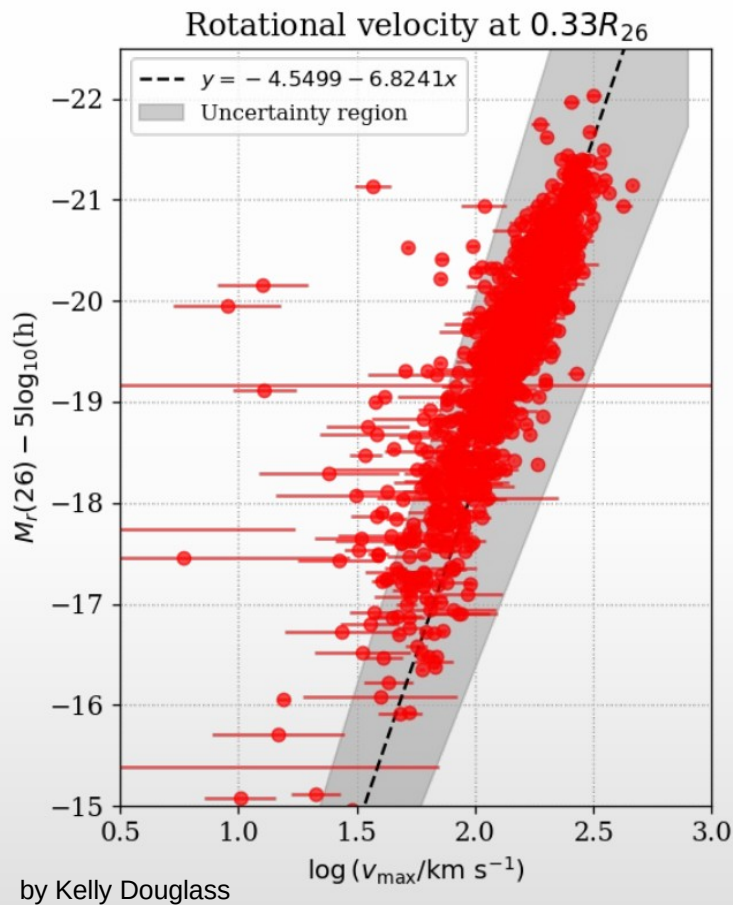
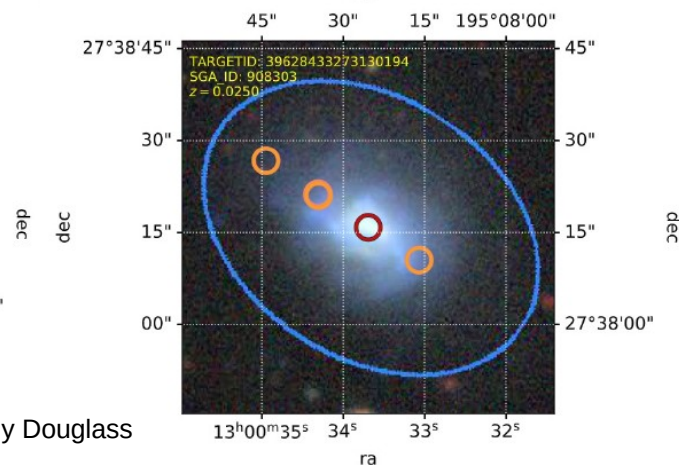
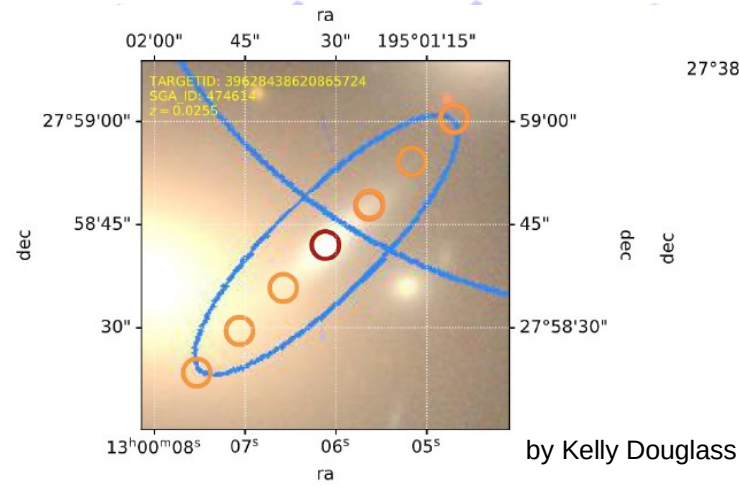
MAIN Y1 observations grouped by SGA ID



by Kelly Douglass

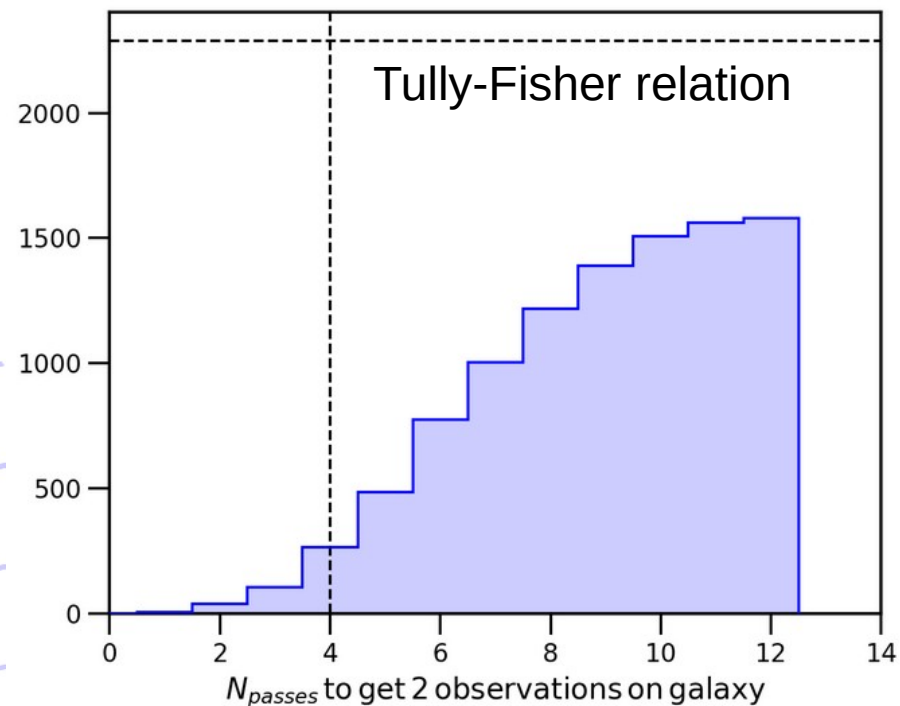
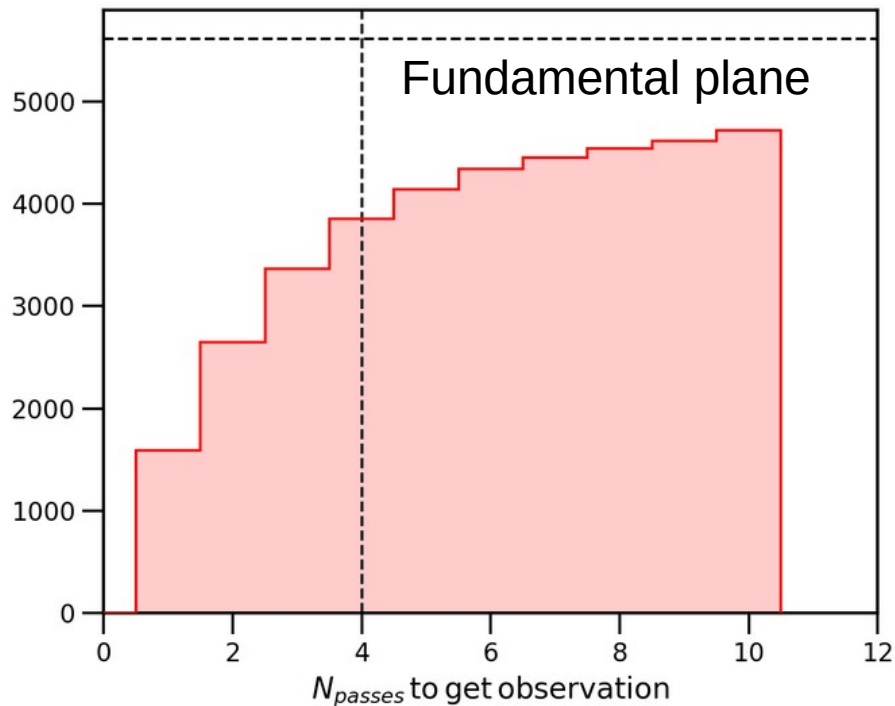
# First Tully-Fisher relation fit

- Some cleaning using visual inspection is still necessary
- Coma cluster for calibration
- TF measurements for 934 spirals in early DESI data



# Data collection based on SV3

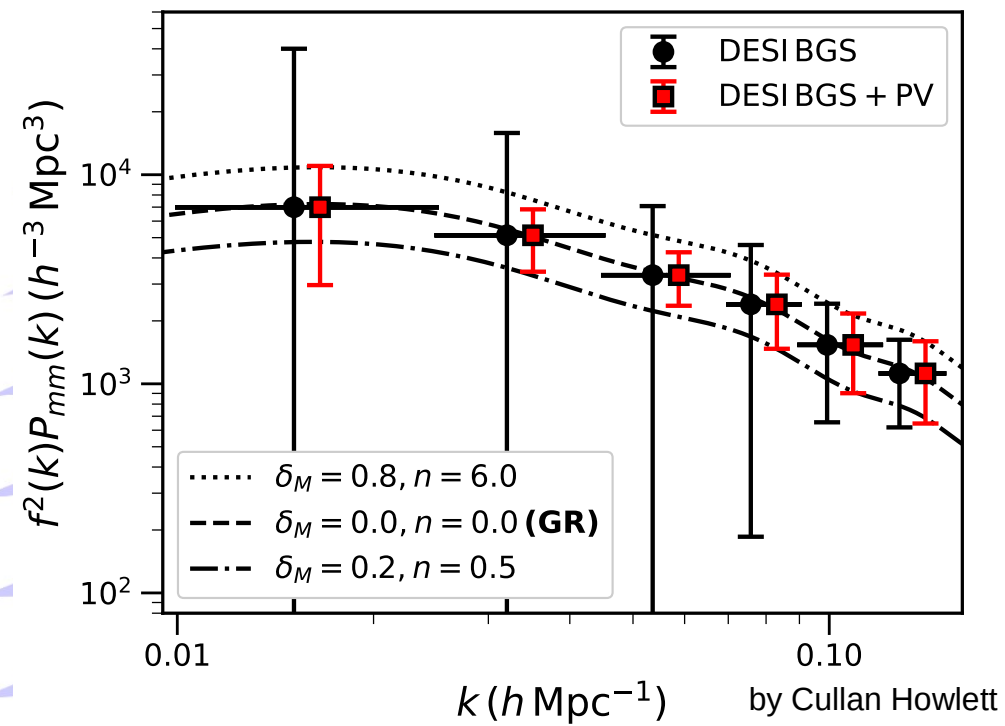
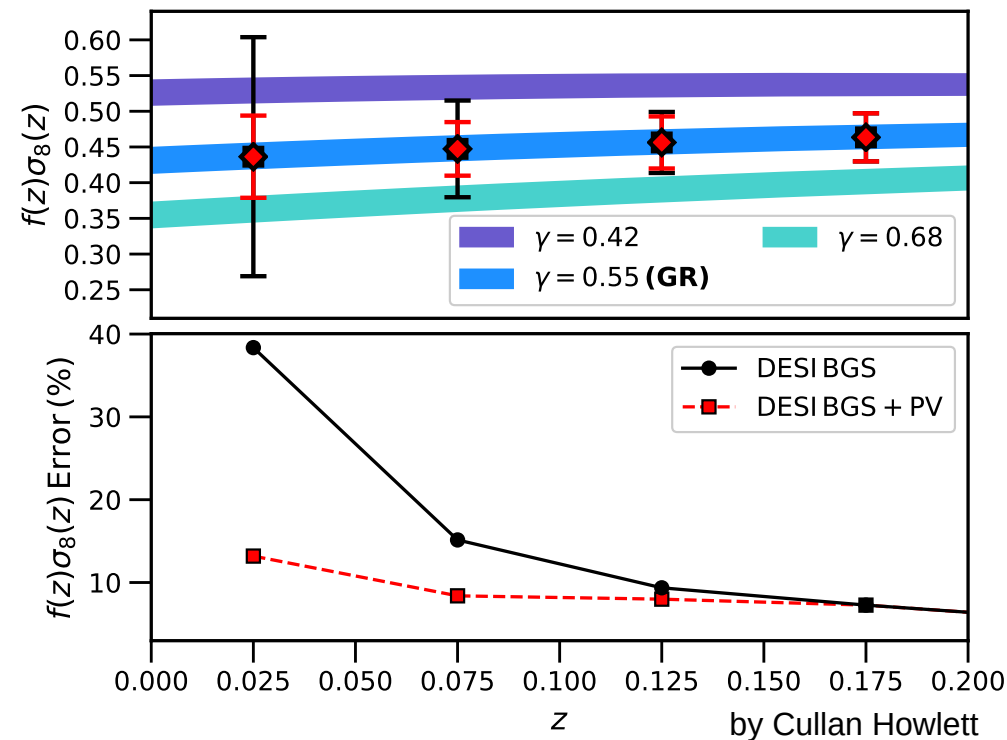
- TF had 7 targets (for testing) in SV3 (it will only be 3 in main)  
→ 12% success, but not really representative
- FP had about 2/3 of the targets with observations after 4 passes





# 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 60 000 TF distances over 14 000 deg<sup>2</sup> (maybe more) → largest peculiar velocity survey so far
- Notable improvements in the measurements of  $f\sigma_8$  at low redshifts

# Any questions?

• FP targets    • TF targets    • FP in spec    • TF in spec

