Unveiling HI galaxy scaling relations at z~0.4 with spectral stacking applied to MeerKAT datacubes

Francesco Sinigaglia

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&

the MIGHTEE collaboration

Science case

Measure HI cosmic density evolution and galaxy
scaling relations linking M_{HI} to M_* and SFR

$\downarrow$

- Observe how HI evolves with time in the Universe
- Understand whether HI directly regulates star formation, or " just" forms H_2
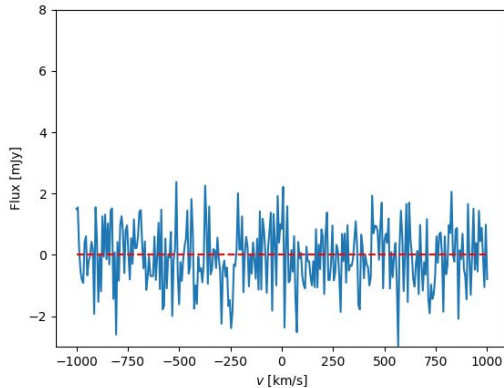
HI galaxy spectral stacking

HI can be observed through the **21-cm emission line**...but the line is **faint**!

At $z<0.1$ direct detection is possible

At $z>0.1$ direct detection not possible: use **spectral stacking**
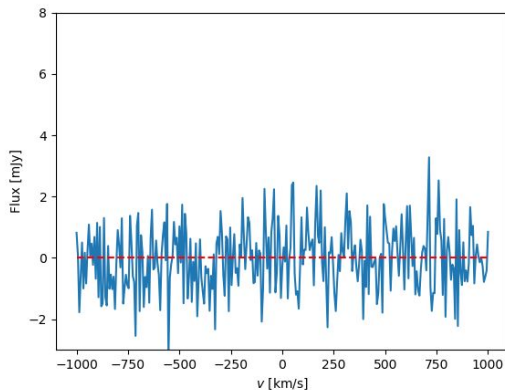
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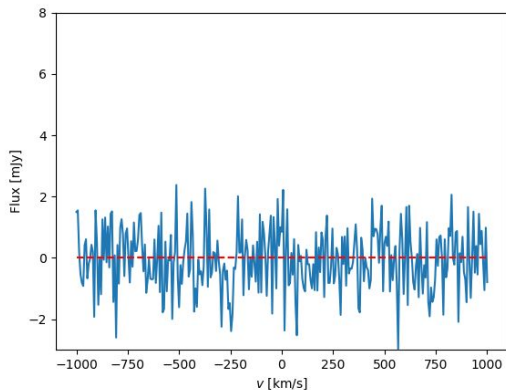
HI galaxy spectral stacking

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$$\text{Signal} \propto N_{spectra}$$
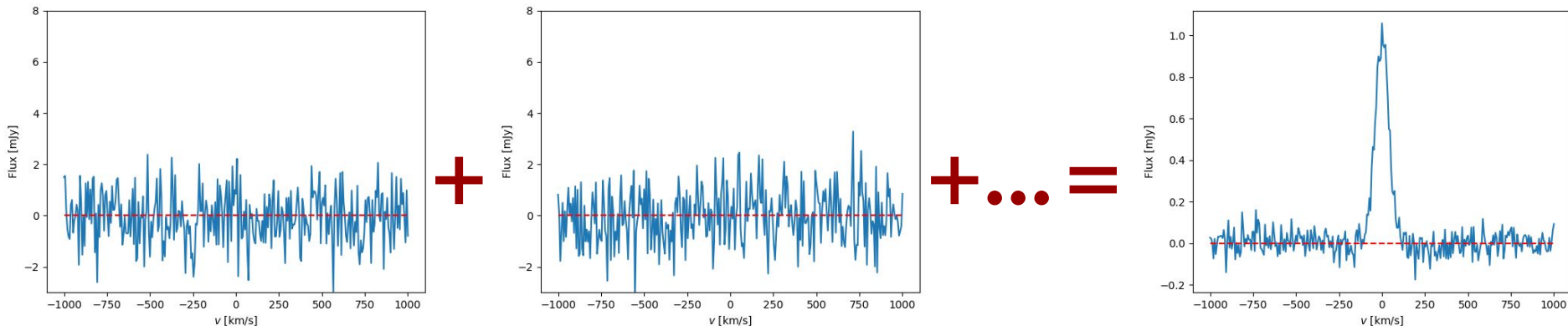$$\text{Noise} \propto \sqrt{N}_{spectra}$$

$$\text{SNR} \propto \sqrt{N}_{spectra}$$

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We have developed our own Python stacking pipeline ULYSSES* and validated it against simulations

*Publicly available soon in my githup repo: https://github.com/francescosinigaglia

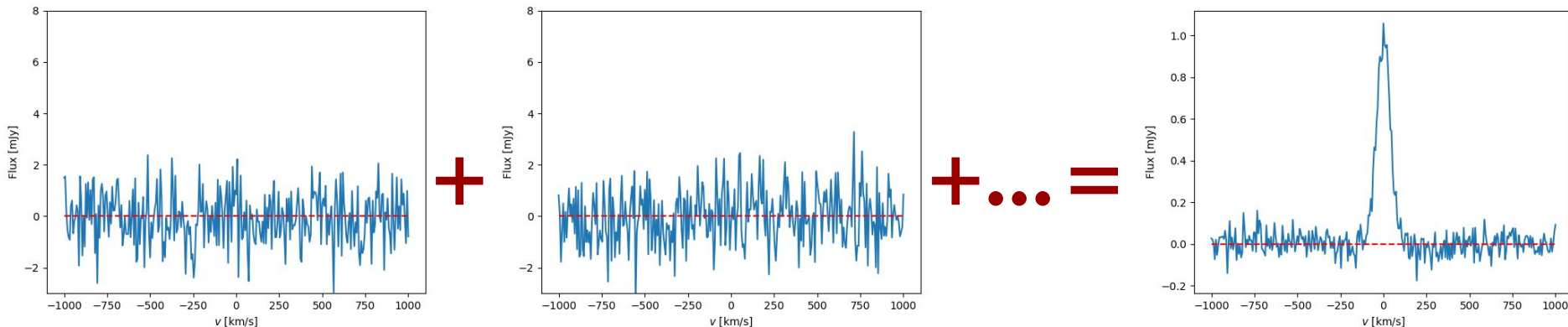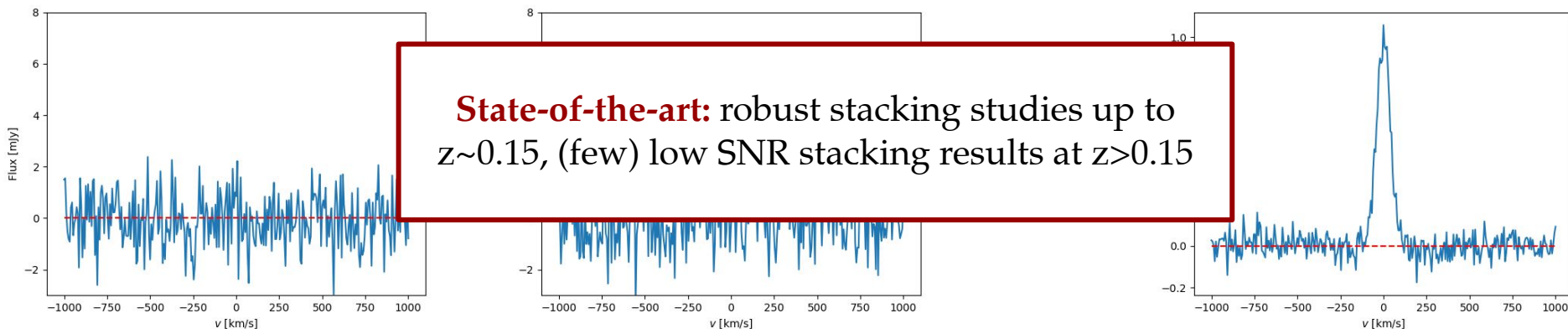# HI galaxy spectral stacking

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State-of-the-art: robust stacking studies up to z~0.15, (few) low SNR stacking results at z>0.15

We have developed our own Python stacking pipeline ULYSSES* and validated it against simulations

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Francesco Sinigaglia, *Unveiling HI scaling relation at z~0.4 with MeerKAT data*

The MIGHTEE survey

- **MeerKAT: 64 dishes (13.5m diameter) located in the Karoo Desert (S. Africa)**
- **Bandwidth: $0.90 < \nu < 1.67$ GHz   (HI emission: $\nu \sim 1.42$ GHz)**
- **Redshift range: $0 < z < 0.5$**
- **Field: ~ 20 deg^2 (including COSMOS and XMM-LSS)**
- **Early Science data: XMM-LSS at $z<0.084$, COSMOS at $z<0.49$ (no data at $0.09<z<0.23$ due to bad RFI)**

Real MeerKAT picture
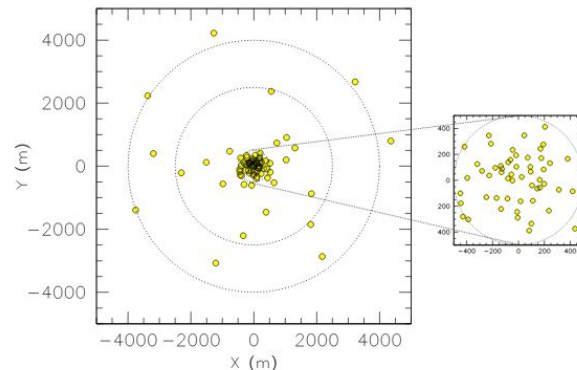
Location of dishes in the Karoo

Stacking galaxies within a large field-of-view

PB correction

$$S(v) = \Sigma_i \, p_i \, S_i(v) / \Sigma_i \, p_i^2$$

Weighting schemes

$$S(v) = \Sigma_i \, p_i \, w_i S_i(v) / \Sigma_i \, (p_i^2 \, w_i)$$

Lah+07: $w_i = 1/\sigma_{rms}$

Fabello+11: $w_i = 1/\sigma^2_{rms}$

Delhaize+13: $w_i = 1/(\sigma^2_{rms} d_L^4)$

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$\longrightarrow$ $\propto$ inverse of noise level $\times$ distance

Stacking galaxies in a large field-of-view

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⟶ $\propto$ inverse of noise level × distance

No systematic checks of accuracy in literature!

Distribution of mock galaxies within the footprint
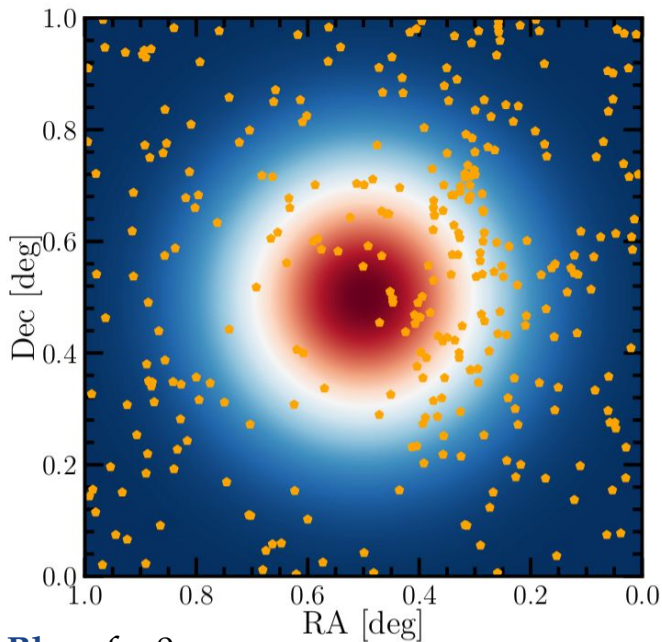
Blue: $f = 0$
Red: $f = 1$

We generated mock datacubes with same features as real MIGHTEE data
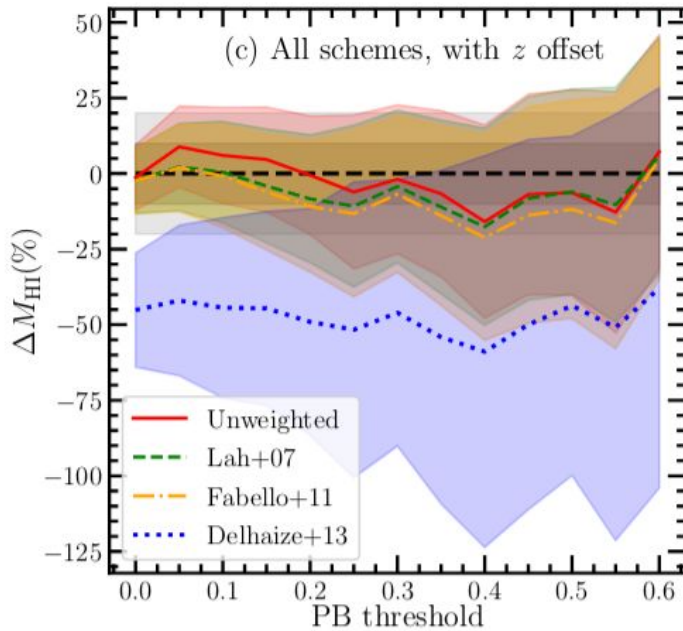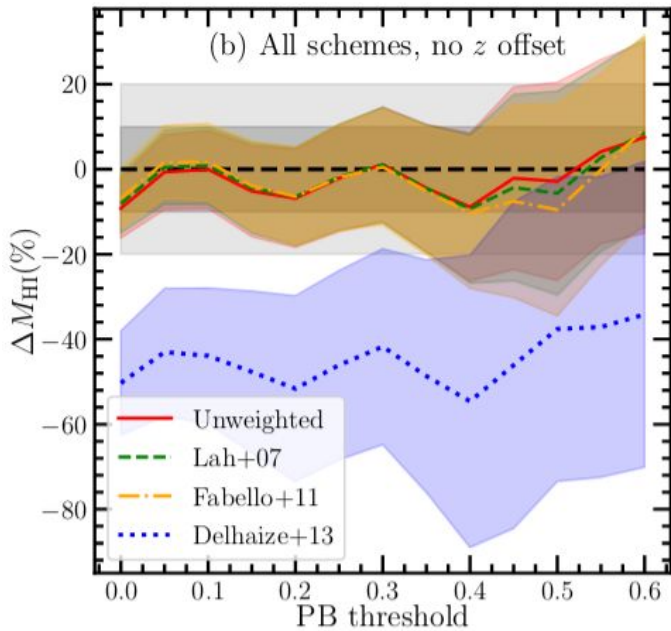Most of the galaxies are in regions with low f
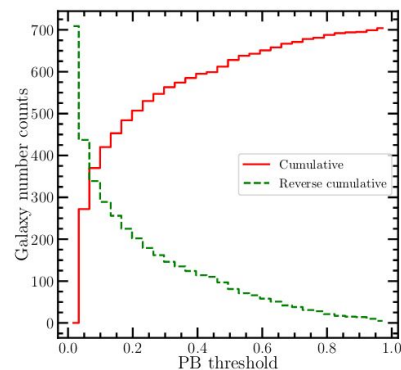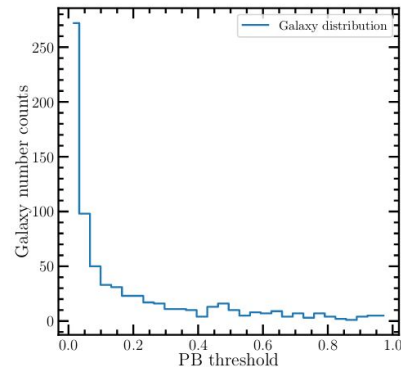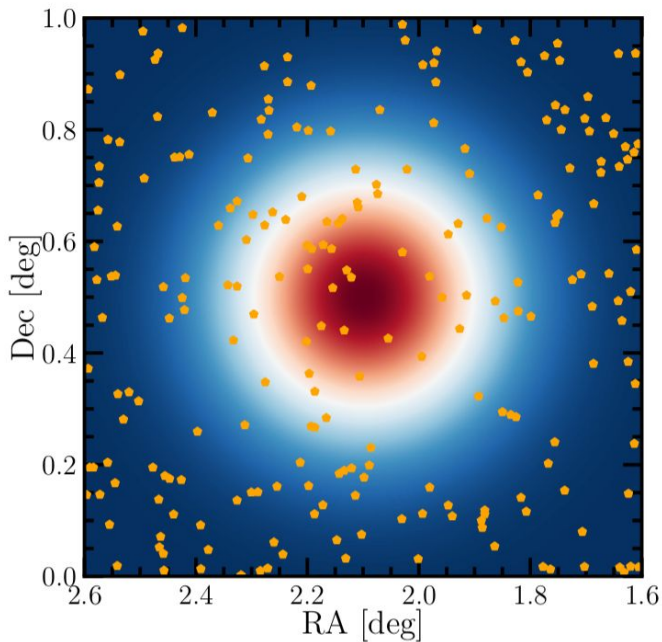
Sinigaglia, Elson, Rodighiero et al. (in prep. 1) (with MIGHTEE-HI collaboration)

Francesco Sinigaglia, *Unveiling HI scaling relation at z~0.4 with MeerKAT data*

Bias in m_HI estimate with stacking

(b) All schemes, no z offset

(c) All schemes, with z offset

Legend (both plots):
- Unweighted
- Lah+07
- Fabello+11
- Delhaize+13

Axes: $\Delta M_{HI}(\%)$ vs PB threshold

We generated mock datacubes with same features as real MIGHTEE data
Test of accuracy of PB correction and weighting schemes

PB correction:

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Bias in m_{HI} estimate with stacking

(b) All schemes, ... offset

(c) All ... with z offset

If mass is **not uniform** with z ...
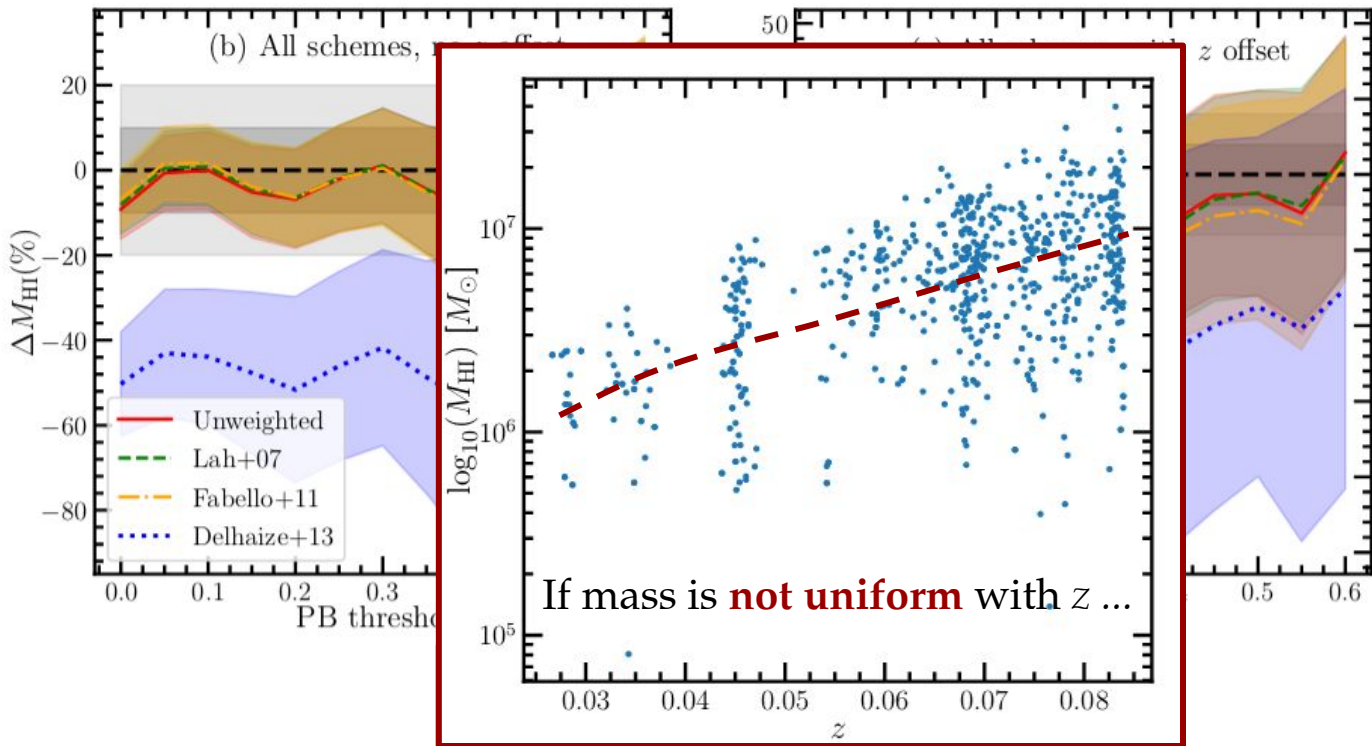
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...it is not a good idea to weight by **distance**!

Sinigaglia, Elson, Rodighiero et al. (in prep. 1) (with MIGHTEE-HI collaboration)

COSMOS galaxies sample at *z*>0.23
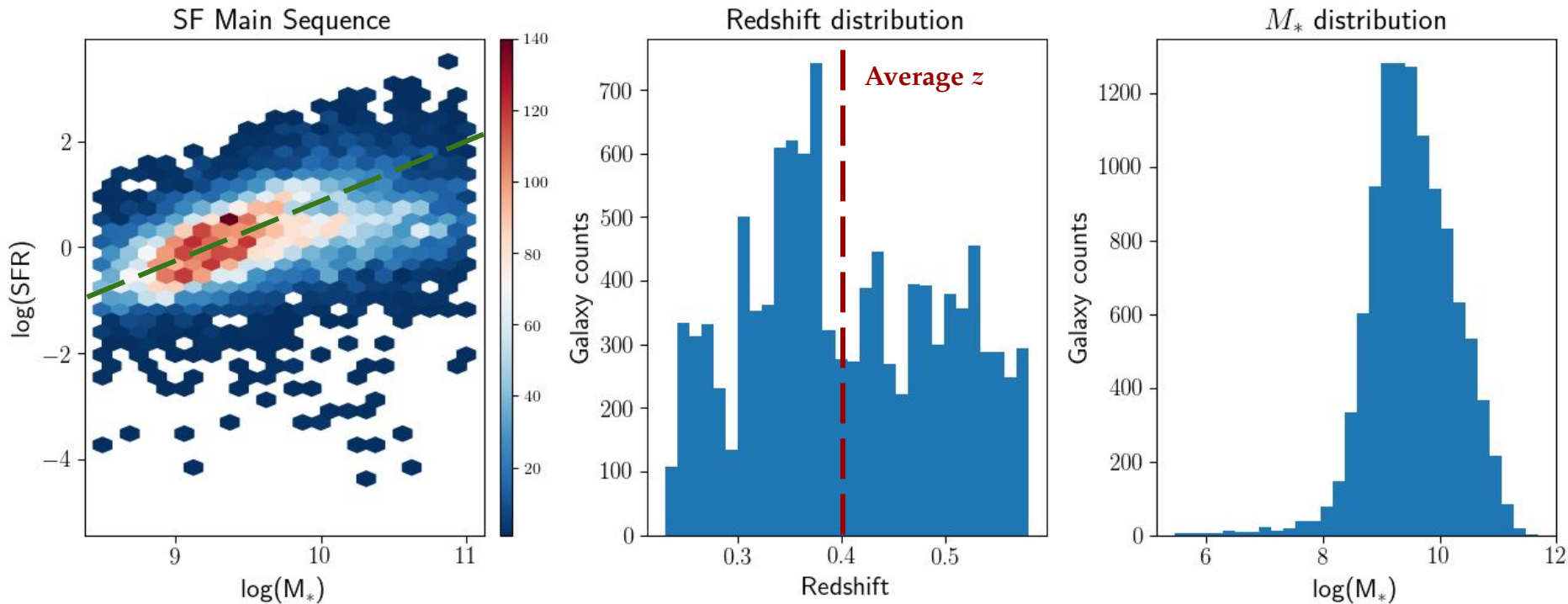
~12000 COSMOS galaxies with *M** and SFR available through (CIGALE) SED fitting (in progress)

COSMOS cubes: noise RMS trend
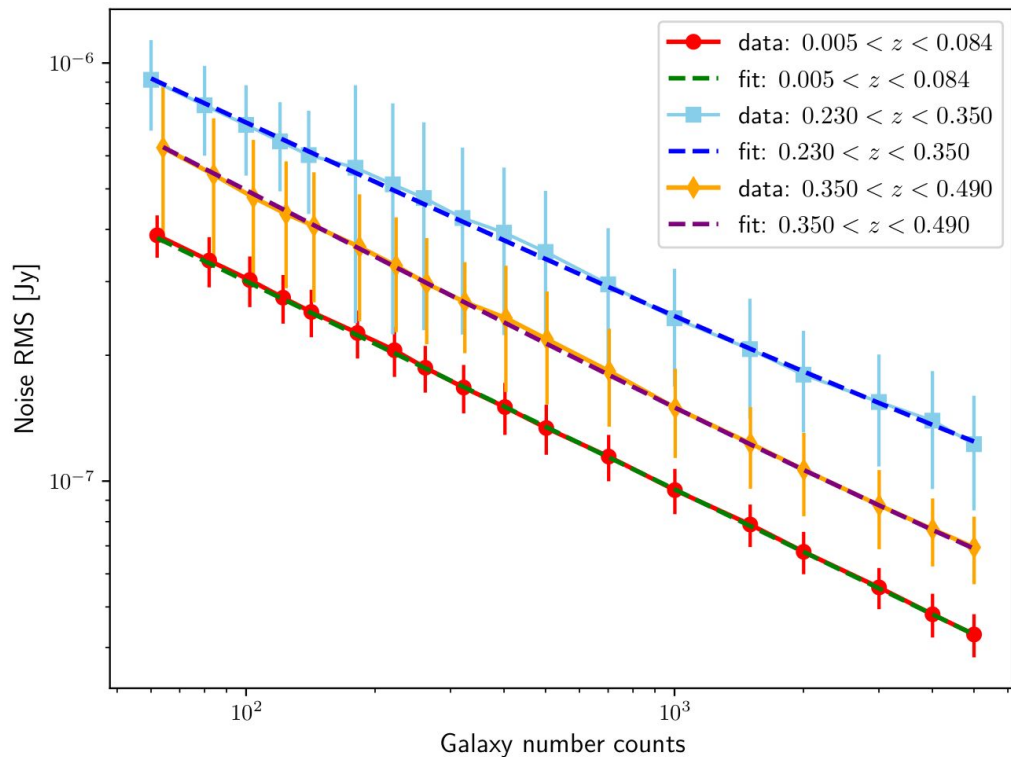
Noise RMS $\propto 1/\sqrt{N}$

N = number of stacked galaxies
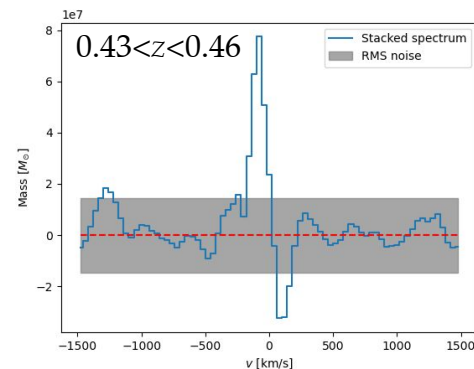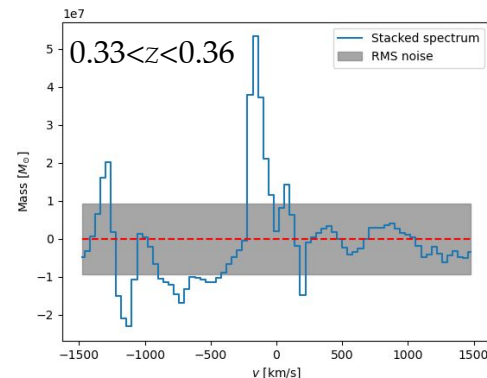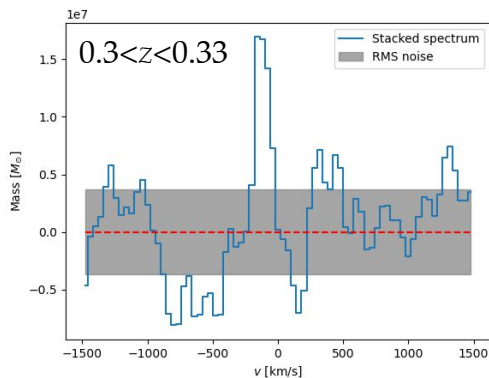
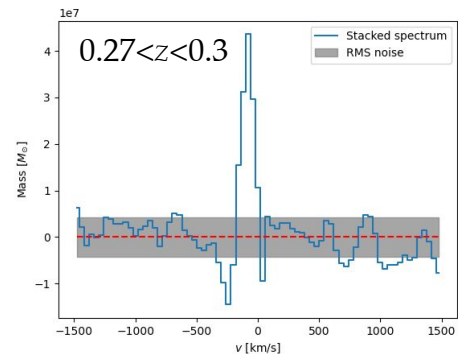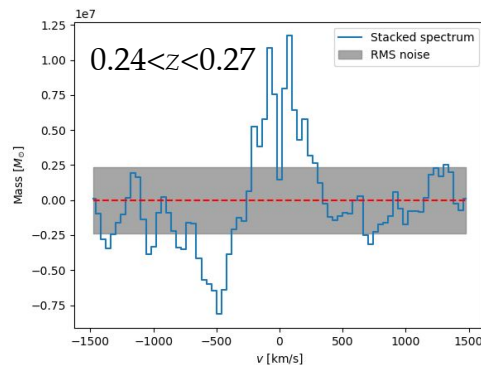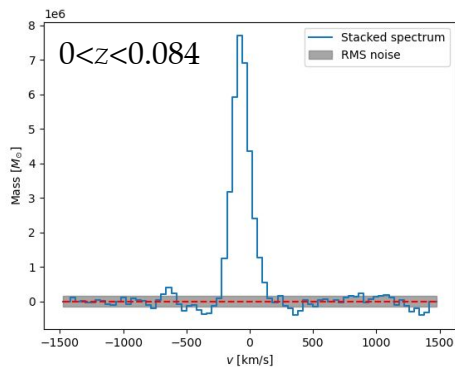The trend holds over all the probed redshift range

Nice Gaussian statistics!

Frank et al. (in prep.) (with MIGHTEE-HI collaboration, incl. FS)

Francesco Sinigaglia, *Unveiling HI scaling relation at z~0.4 with MeerKAT data*

Preliminary stacking results

Sinigaglia, Rodighiero, Elson et al. (in prep. 2) (with MIGHTEE-HI collaboration)

Francesco Sinigaglia, *Unveiling HI scaling relation at z~0.4 with MeerKAT data*

Preliminary stacking results

Robust detections up to z~0.5!
Assessment of HI cosmic evolution in progress
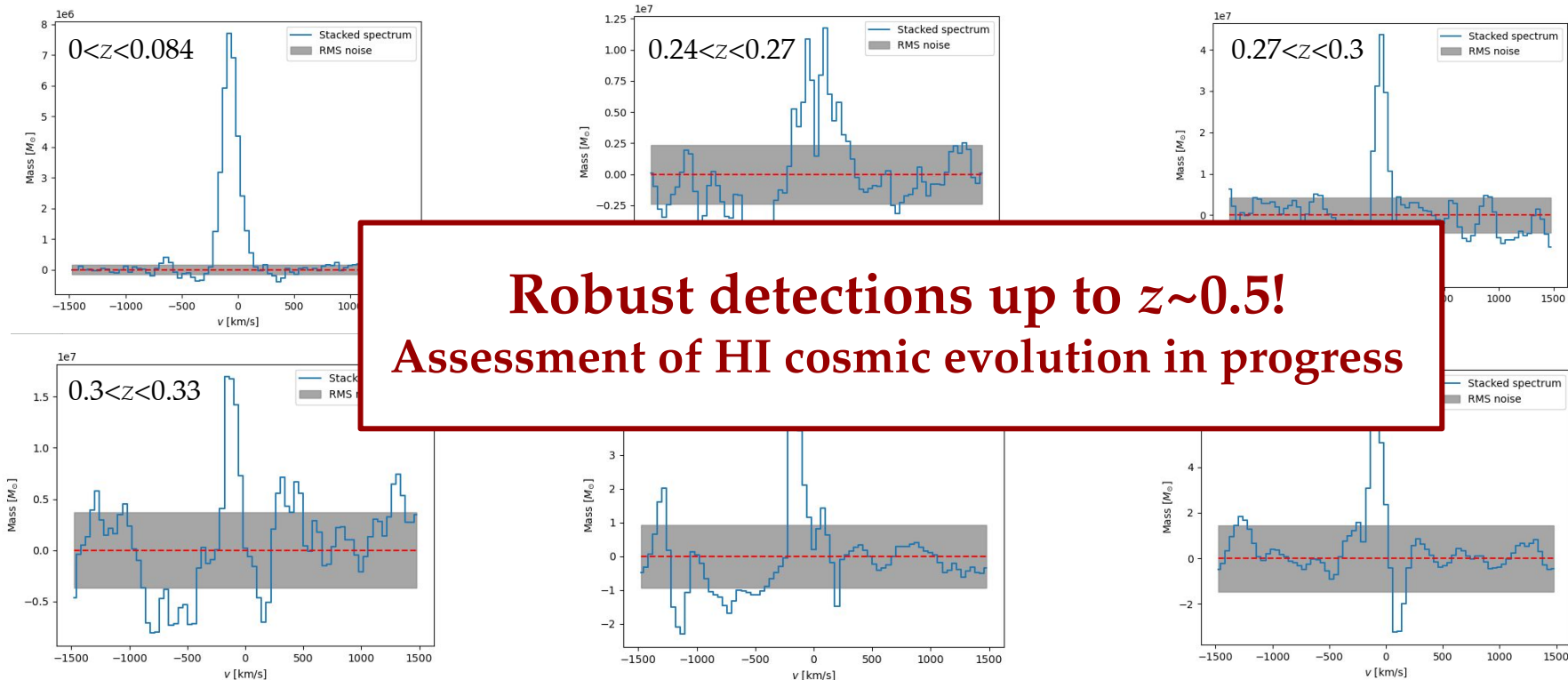
Sinigaglia, Rodighiero, Elson et al. (in prep. 2) (with MIGHTEE-HI collaboration)

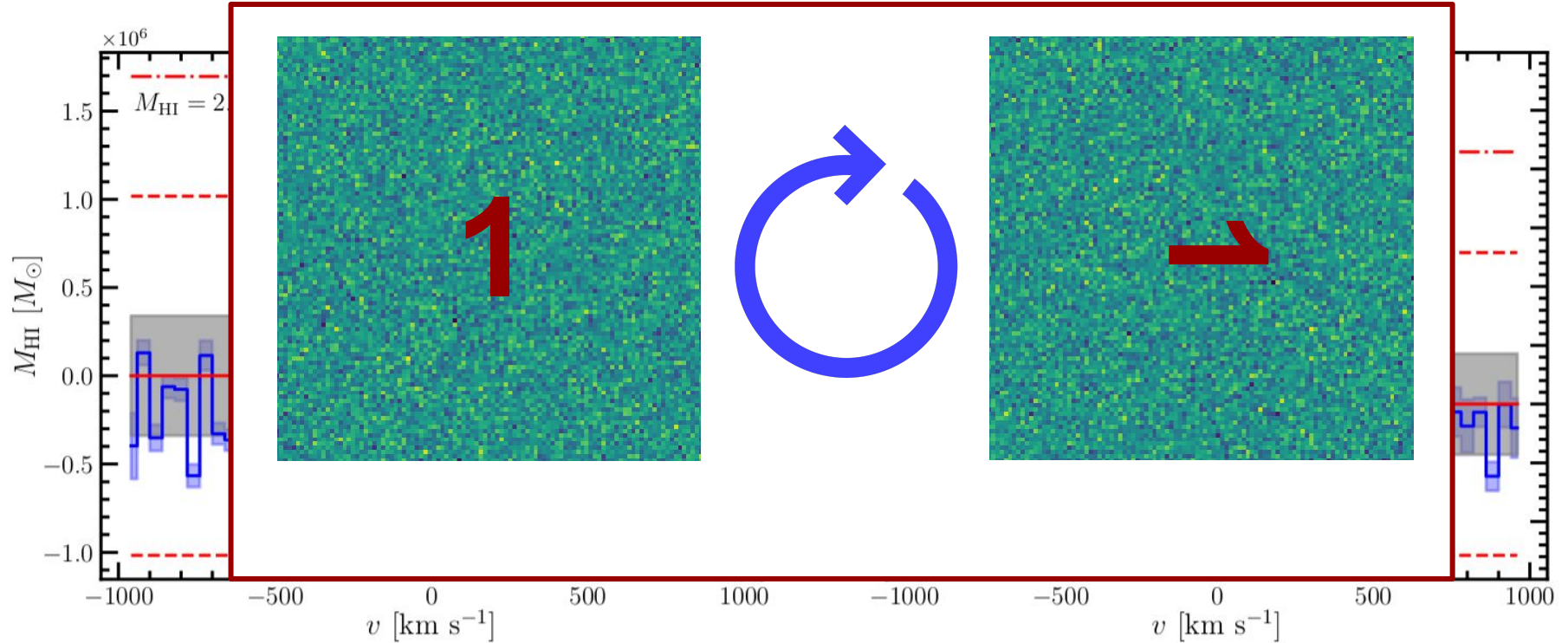Francesco Sinigaglia, *Unveiling HI scaling relation at z~0.4 with MeerKAT data*

Summary and take-home messages

- New stacking pipeline in place and soon publicly available

- MIGHTEE-HI data available up to z~0.5 (private data at the moment, but soon public)

- Generated mock datacubes to assess the accuracy of technical operations performed in stacking

- Primary beam correction induces small deviations, weighting by distance is not a good option

- Preliminary stacking experiments are successful: robust assessment of cosmic HI evolution

- Exciting science regarding scaling relations to come in the near future

- Two papers in preparation!
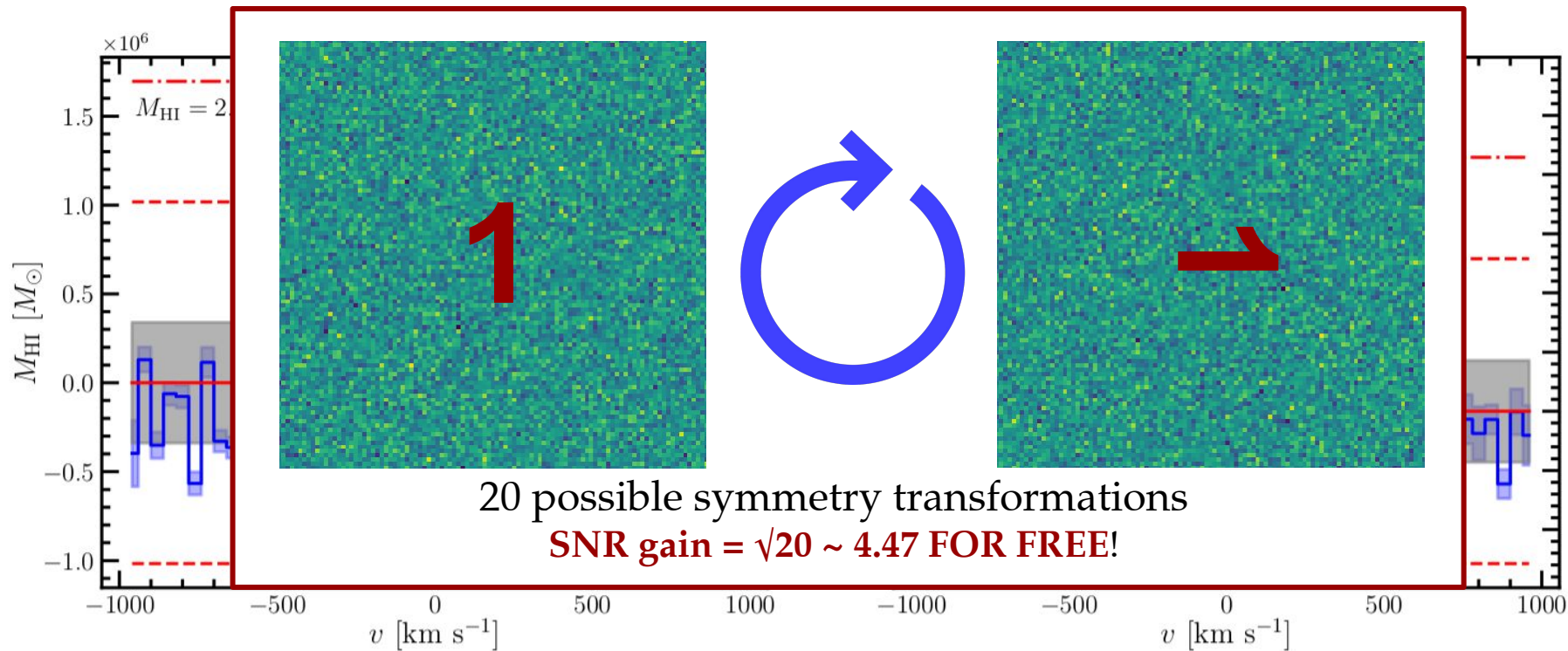
Exploiting cubelet symmetry

Sinigaglia, Elson, Rodighiero et al. (in prep. 1) (with MIGHTEE-HI collaboration)

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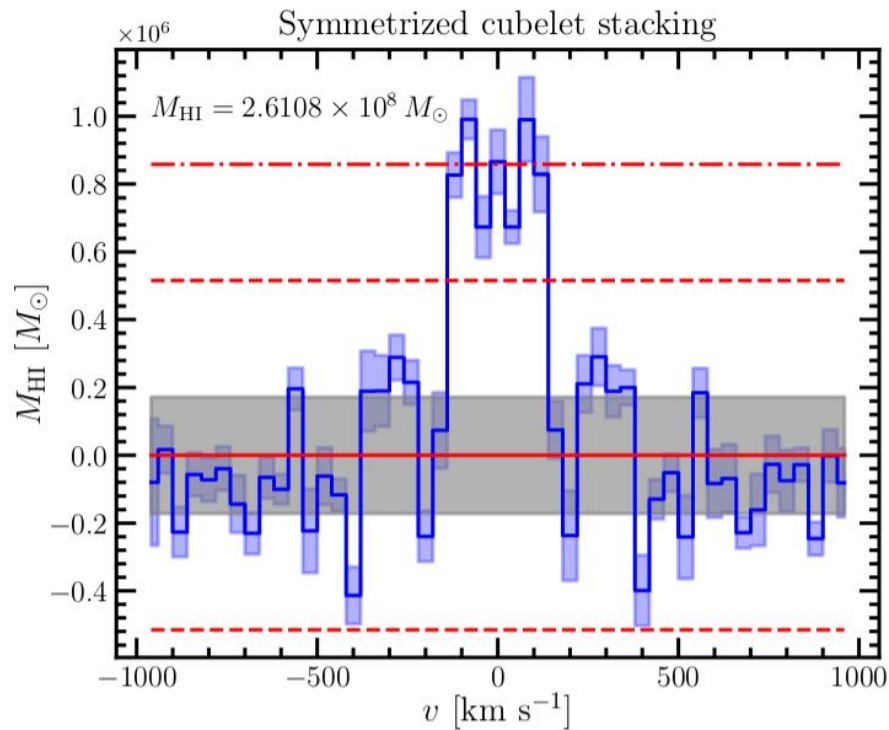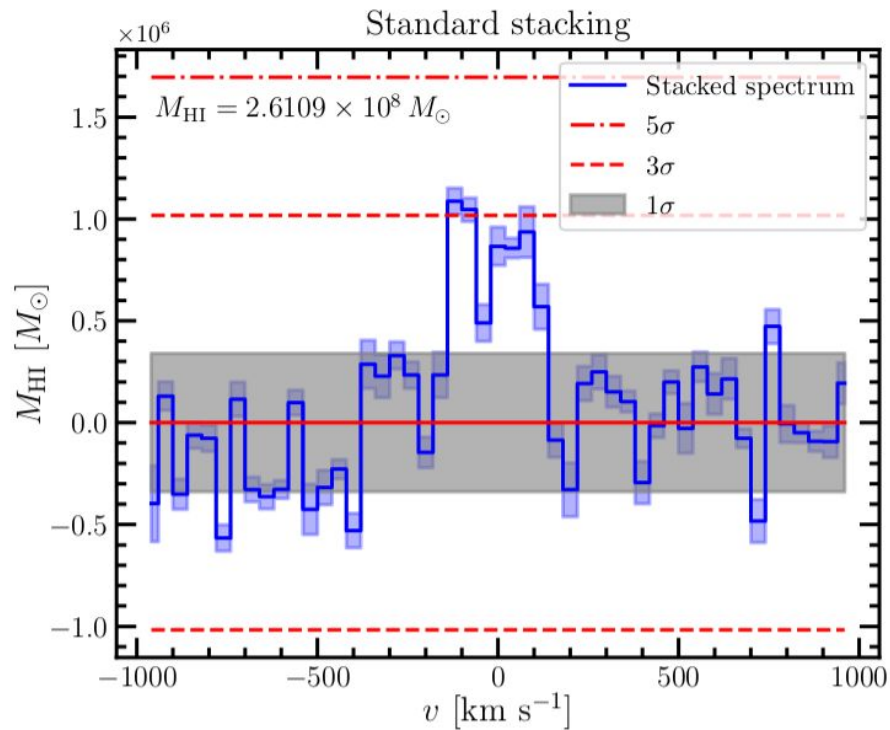20 possible symmetry transformations
SNR gain = √20 ~ 4.47 FOR FREE!

Sinigaglia, Elson, Rodighiero et al. (in prep. 1) (with MIGHTEE-HI collaboration)

Francesco Sinigaglia, *Unveiling HI scaling relation at z~0.4 with MeerKAT data*

Exploiting cubelet symmetry

Standard stacking — $M_{HI} = 2.6109 \times 10^8 \, M_\odot$
Symmetrized cubelet stacking — $M_{HI} = 2.6108 \times 10^8 \, M_\odot$

Legend: Stacked spectrum, 5σ, 3σ, 1σ

Sinigaglia, Elson, Rodighiero et al. (in prep. 1) (with MIGHTEE-HI collaboration)

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