HI galaxies simulations for the SKAO

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20.11.2024

Late-time Cosmology with SKAO

Suggested surveys in the Cosmology SWG Red Book (2018)

- SKA-MID **Wide**, (Band 1)

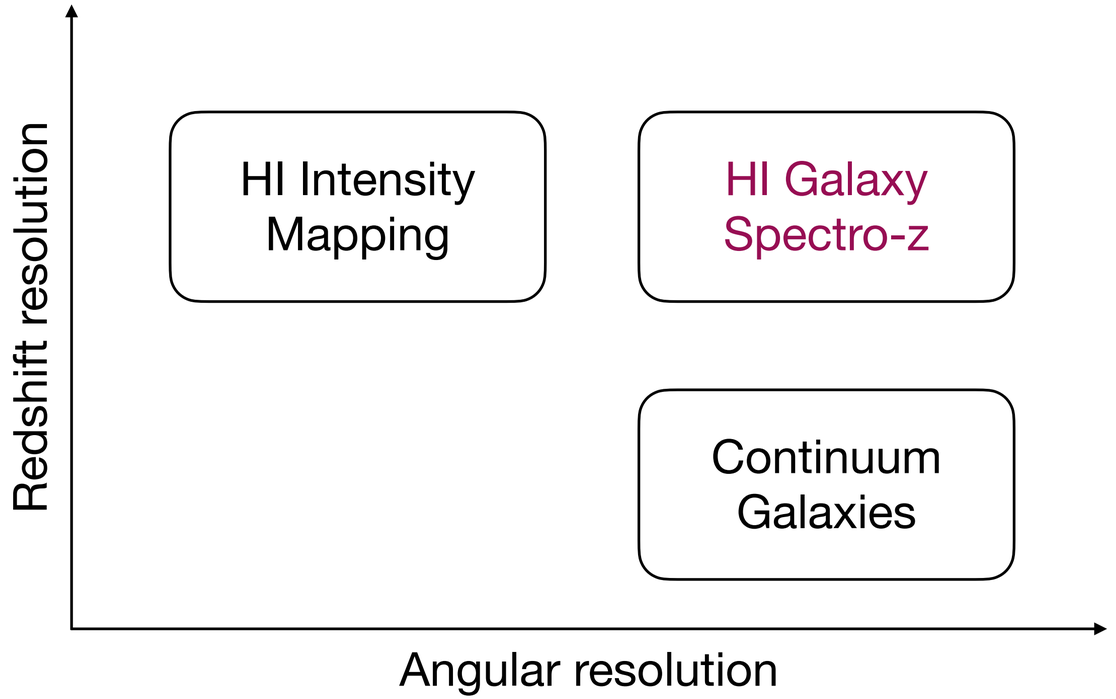
  $z \in [0.35, 3], \quad 20'000\,\mathrm{deg}^2,$

  Goals: Continuum galaxy survey
  & HI intensity mapping survey

- SKA-MID **Medium-Deep**, (Band 2)

  $z \in [0, 0.4], \quad 5000\,\mathrm{deg}^2,$

  Goals: Continuum Weak Lensing survey
  & **HI galaxy redshift survey**



Simulations of HI galaxies

Computational cost, Volume and Mass resolution

Hydro-simulations:

- Explicit gas hydrodynamics
- Follow particle distribution
- sub-grid physics
- Computationally expensive
- Relatively small volumes for cosmology

Semi-Analytical Models (SAM):

- Based on merger tree of N-body DM-only simulations
- Do not follow the particle dynamics
- Same sub-grid physics
- Faster computation
- Can be run on larger volumes

Semi-Analytical Models

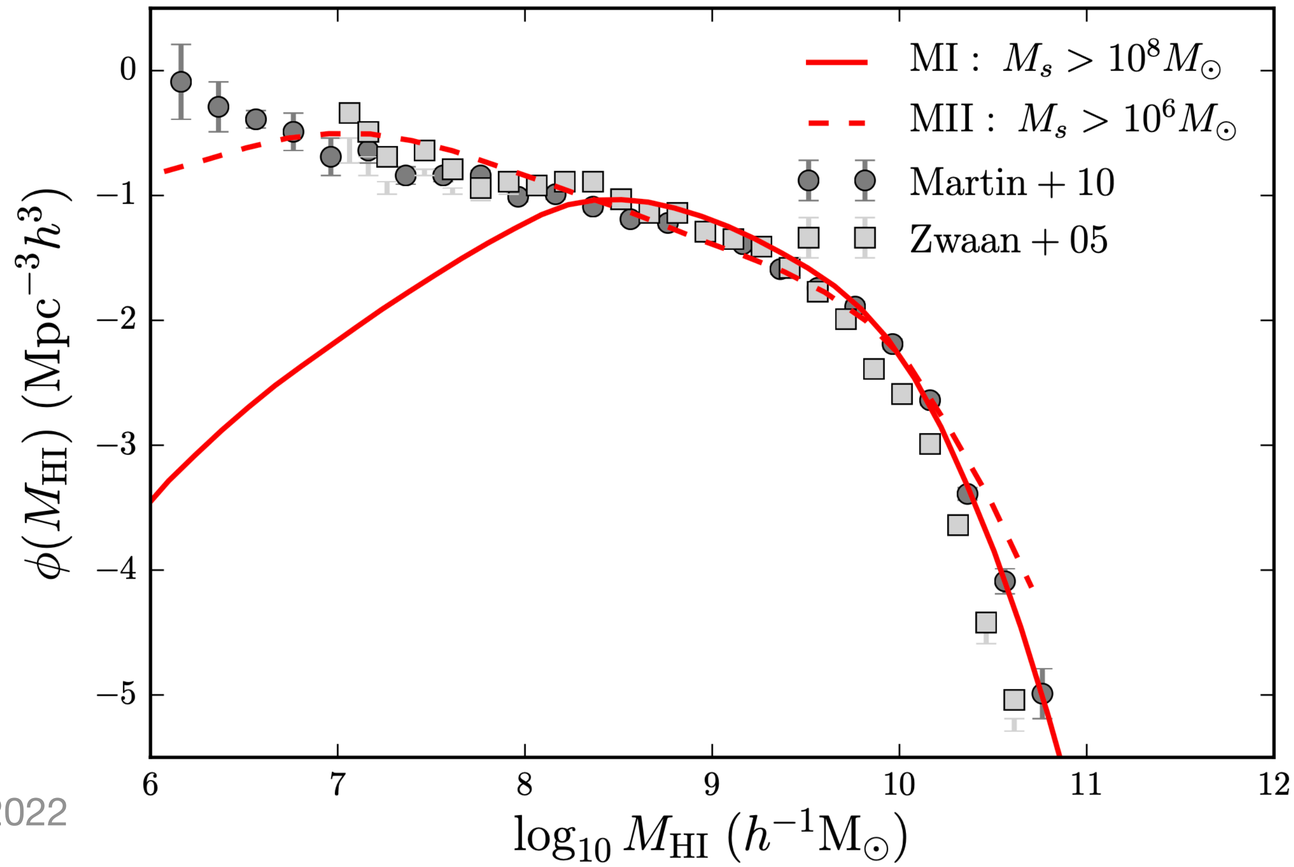
GAlaxy Evolution and Assembly (GAEA) & L-Galaxies

Millennium I, “cosmological size”
$V = [500\ \mathrm{Mpc}/h]^3$

Millennium II, “better resolution”
$V = [100\ \mathrm{Mpc}/h]^3$

Explicit treatment of cold gas partition in atomic (HI) and molecular (H2) Hydrogen

Courtesy of M. Spinelli



GAEA:

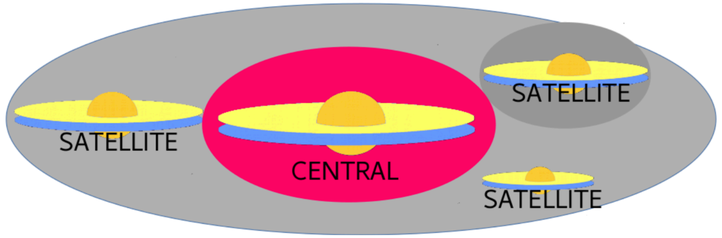
- De Lucia et al. 2014, 2023, 2024
- Hirschmann et al. 2016
- Xie et al. 2017, 2020
- Fontanot et al. 2017, 2018, 2020

L-Galaxies:

- Yates et al. 2021, 2024
- Izquierdo-Villalba et al. 2022
- Ayromlou et al. 2021
- Henriques et al. 2015, 2020

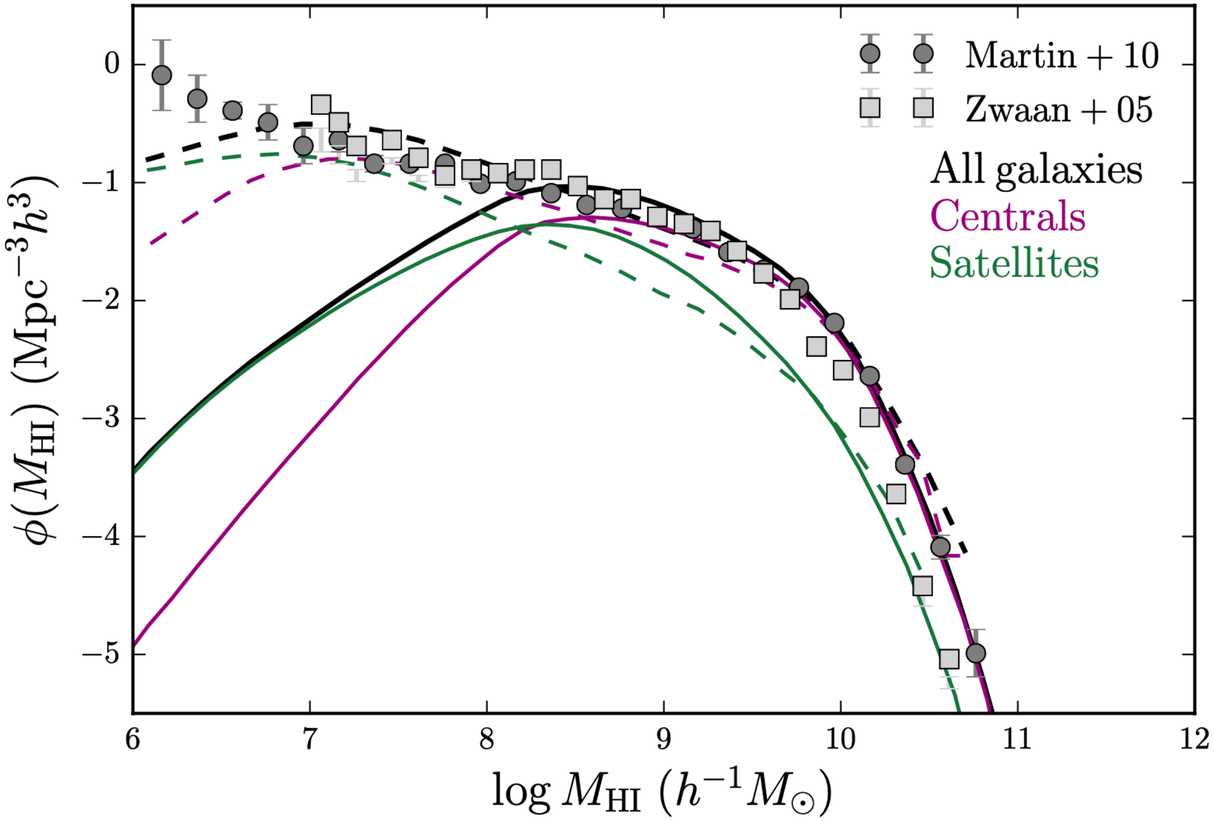
The GAEA SAM

Role of Central and Satellite galaxies



- Centrals dominate from intermediate to high HI mass
- Satellite dominate for low masses
- Orphan satellites “lost their subhalo” i.e. $M_h < 20$ MSI (resp. MSII) particles

Courtesy of M. Spinelli



Model of the 21cm emission line profile of HI galaxies

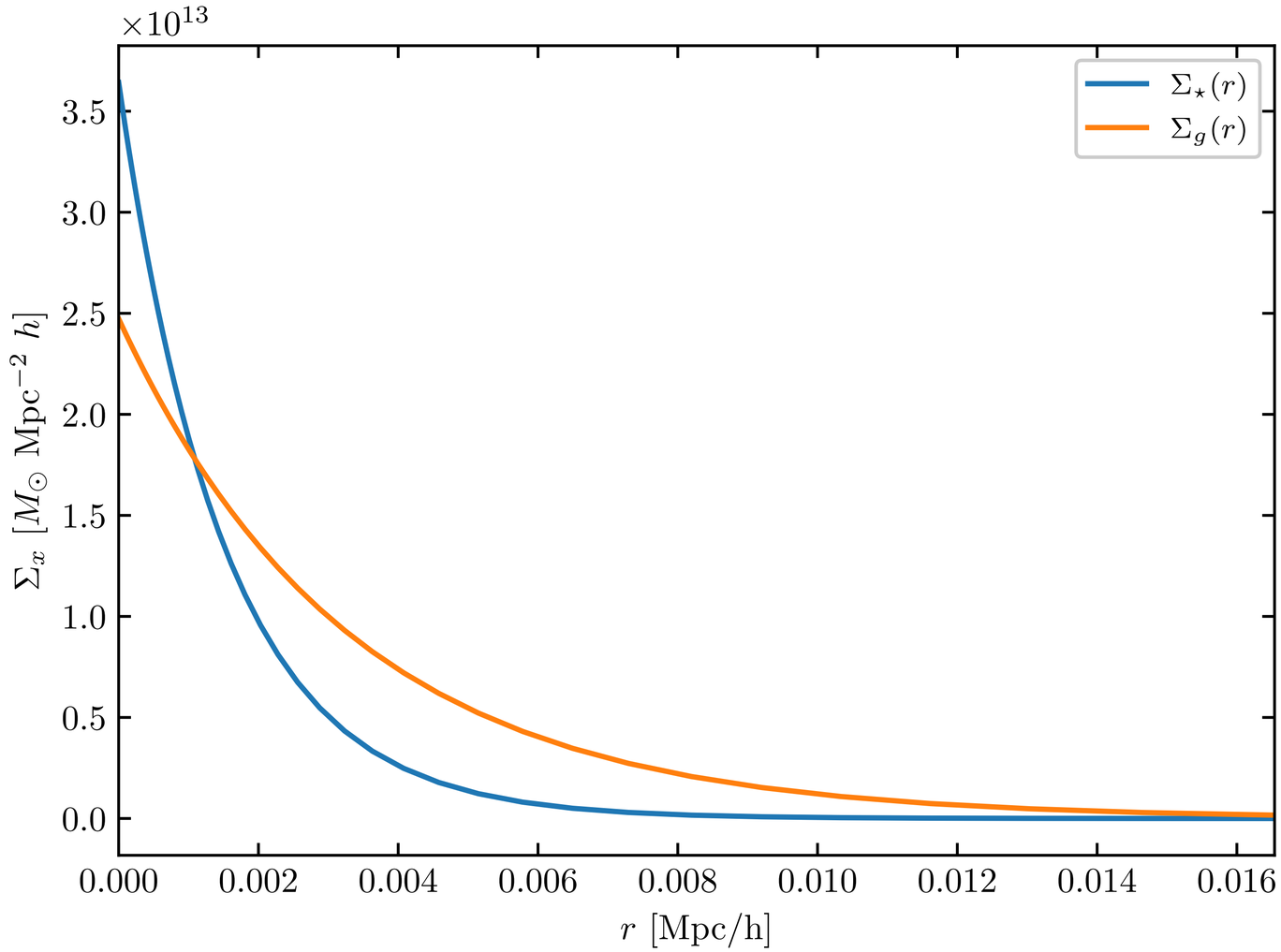
Model Surface Density Profiles

Stellar disk & Cold Gas disk

- Rotationally supported flat disks
- Axially symmetric surface density profiles
- Exponential surface density profiles

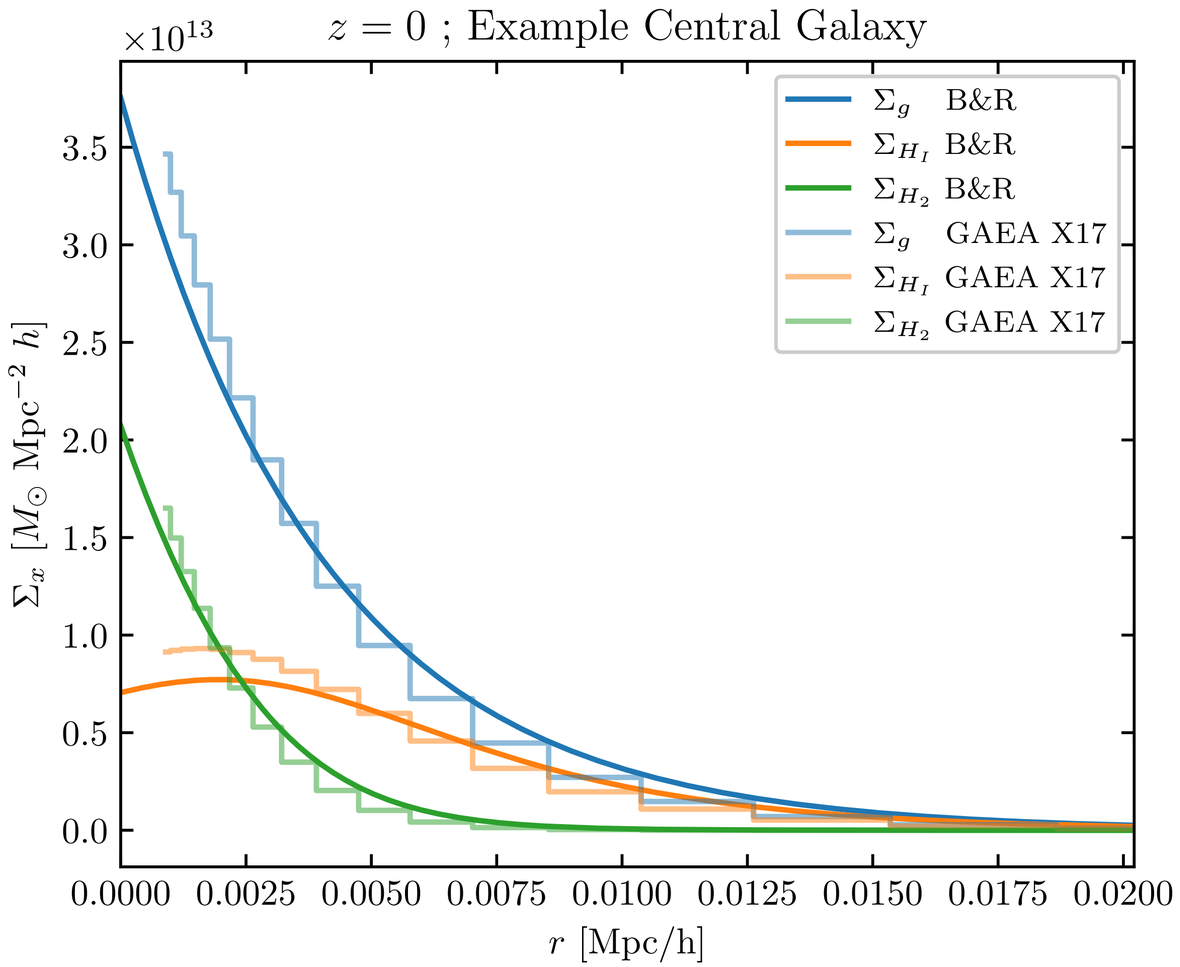
$$\Sigma_\star(r) = \frac{M_\star}{2\pi r_\star} \exp\left[-\frac{r}{r_\star}\right]$$

$$\Sigma_g(r) = \frac{M_g}{2\pi r_g} \exp\left[-\frac{r}{r_g}\right]$$



Model Surface Density Profiles

Partition of Hydrogen



$$\Sigma_{H_2}(r) = f_{\mathrm{mol}}(r) \cdot \Sigma_H(r)$$
$$\Sigma_{HI}(r) = \left(1 - f_{\mathrm{mol}}(r)\right) \cdot \Sigma_H(r)$$

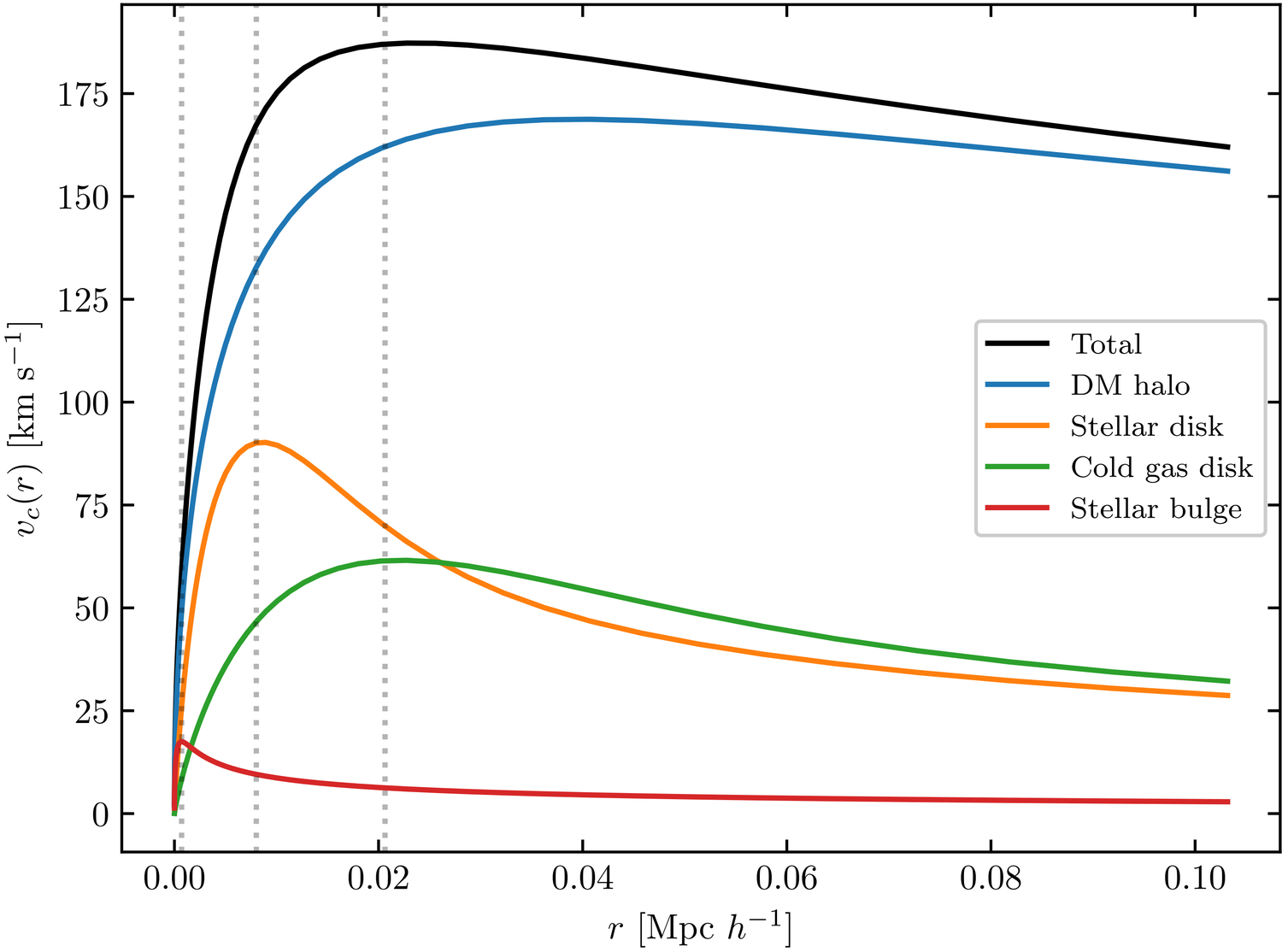
- Blitz & Rosolowsky (2006):

  Empirical relation between ratio of atomic gas and hydrostatic pressure

- Krumholz et al. (2008):

  Empirical relation between ratio of atomic gas and gas phase metallicity

Circular velocity profiles

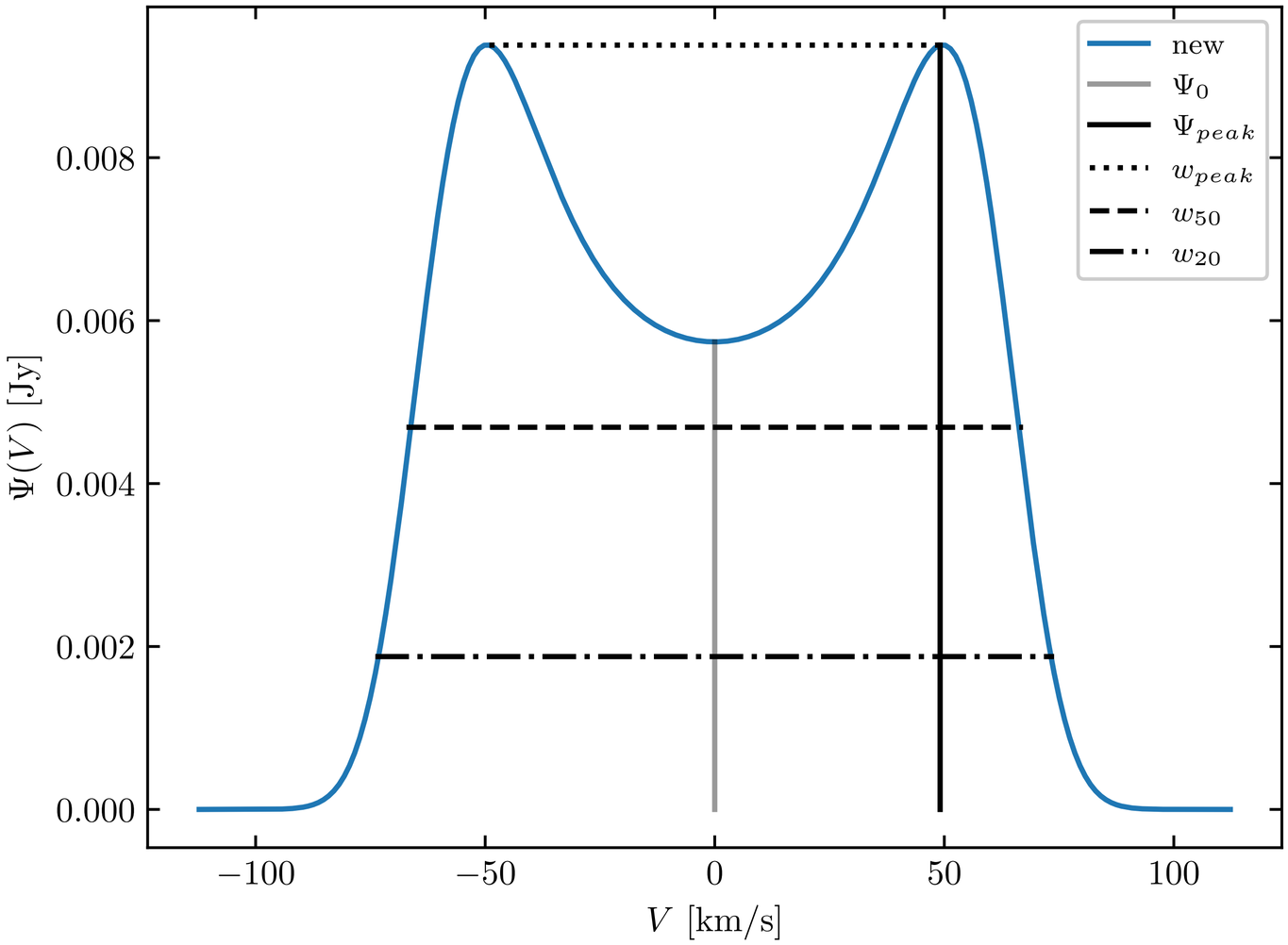


HI 21cm emission line model

Vectorized & Parallelized modular python package

Consistency checks:

- N-body Resolution effects: MSI vs MSII
- SAM choice: GAEA vs L-Galaxies
- Role of Central / Satellite galaxies

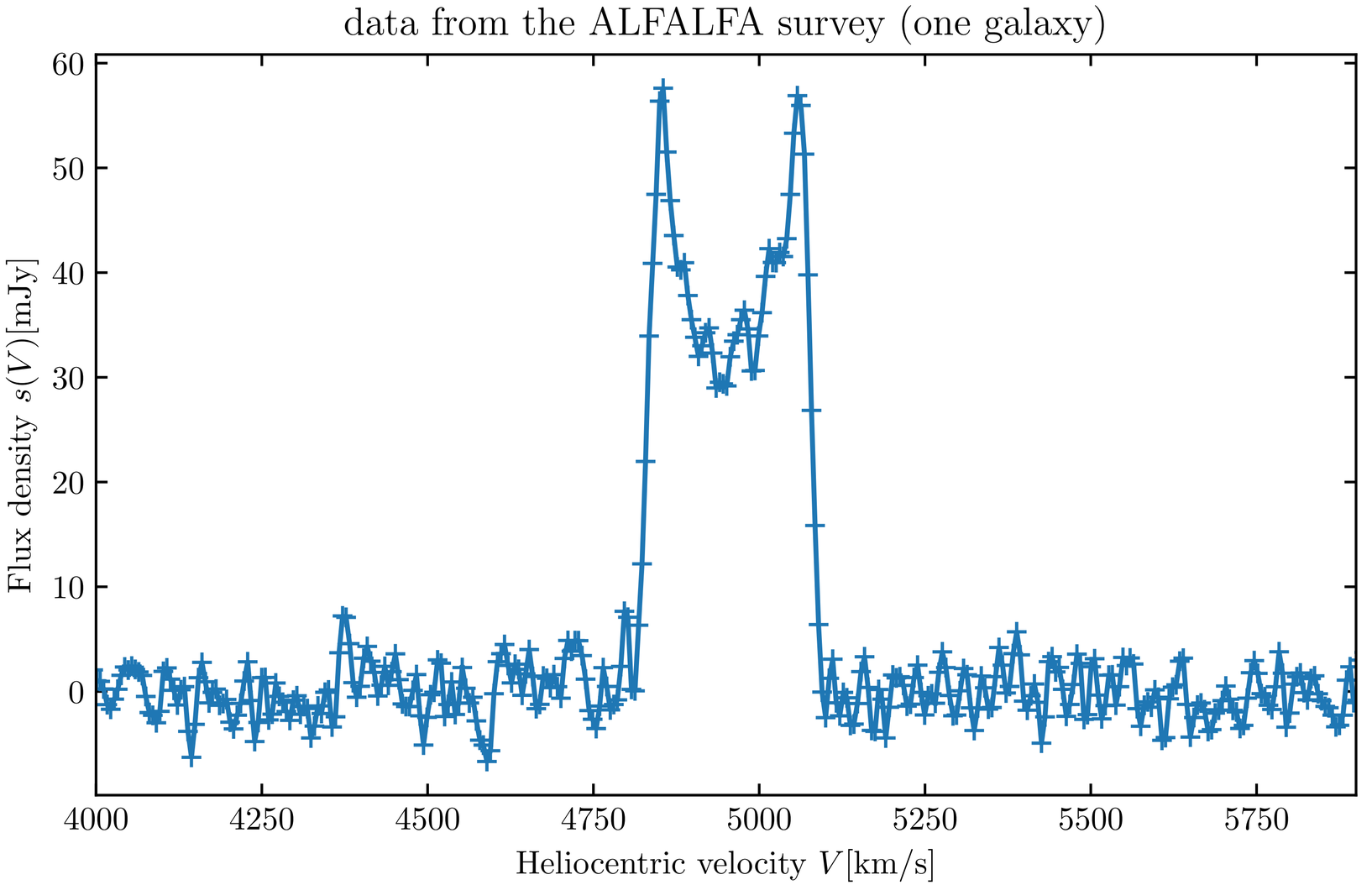


Consistency checks

Comparison with available observational data

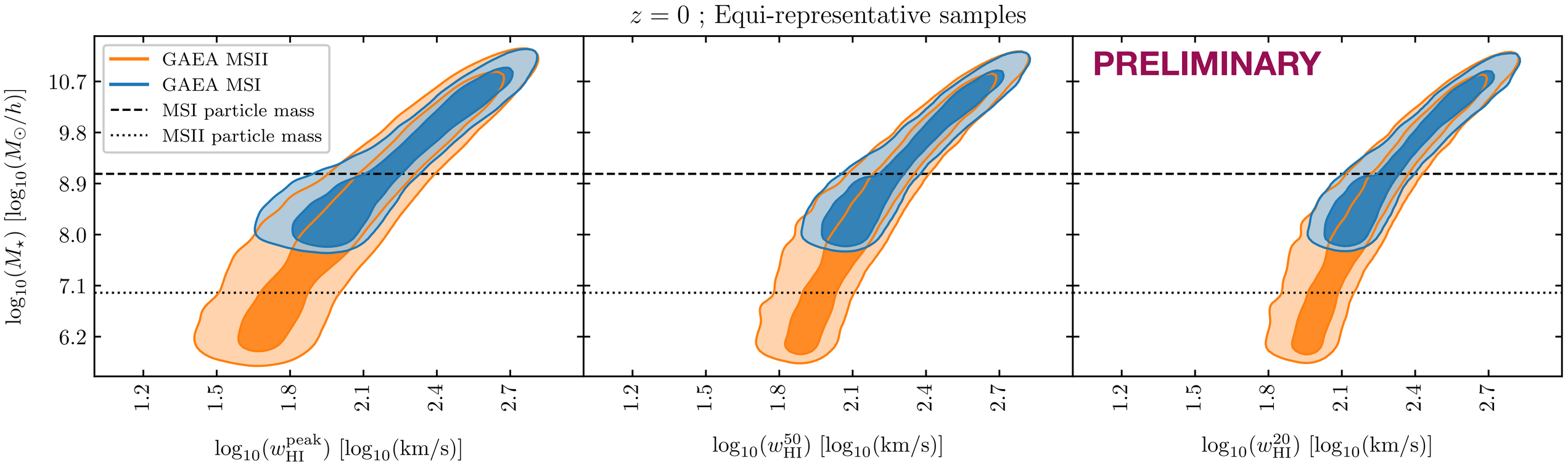
Modelling effects of:

- Inclination
- Gas dispersion
- Noise
- Spectral resolution
- Redshift



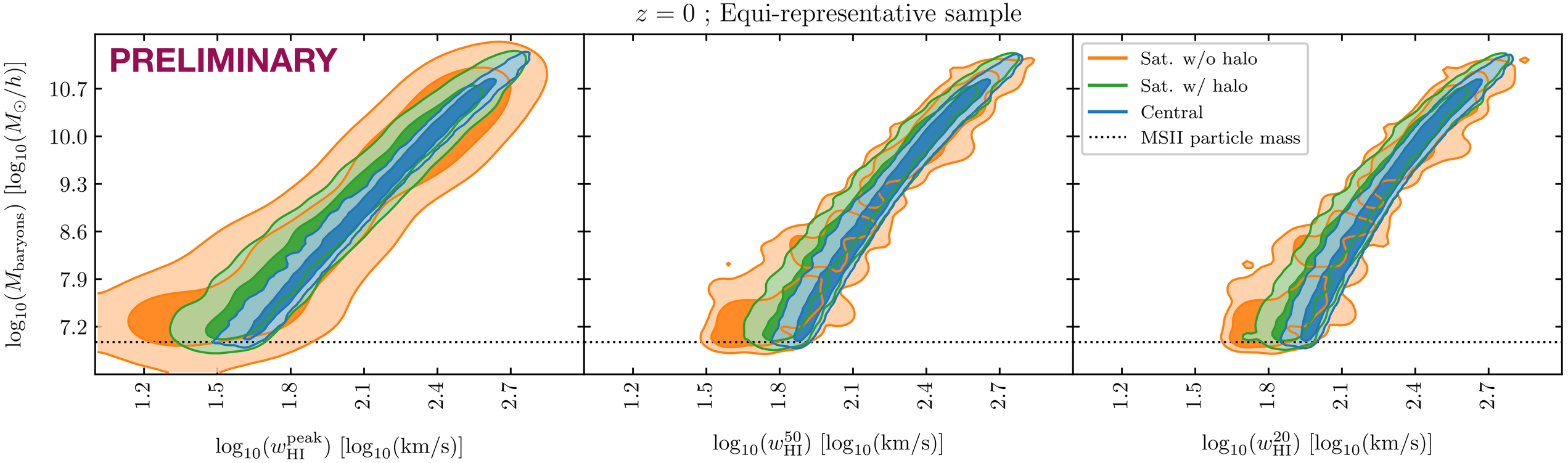
Scaling relations

Tully-Fisher (TF) relation: Stellar Mass <—> HI line widths



Scaling relations

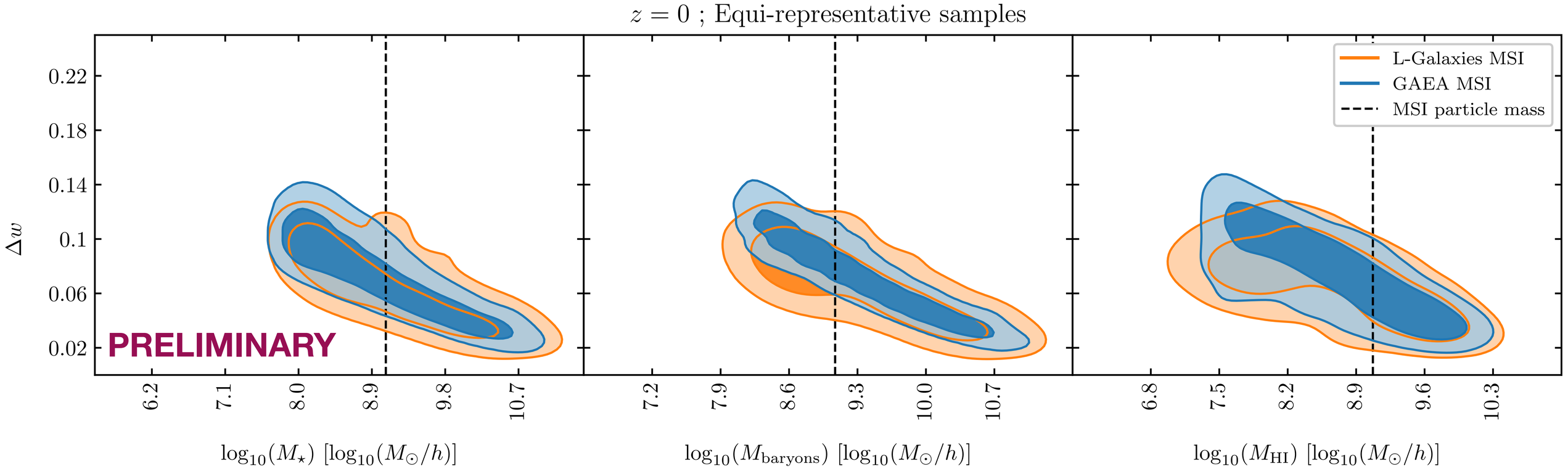
Baryonic Tully-Fisher (BTF) relation: Baryonic Mass <—> HI line widths



Scaling relations

HI line widths differences <—> Masses

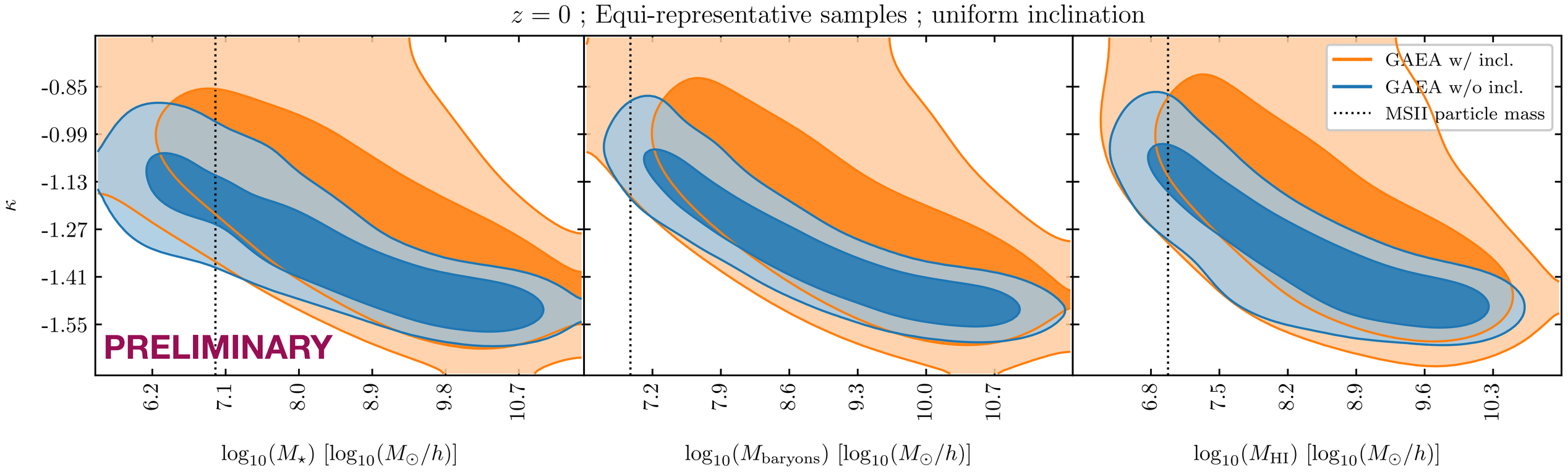
$$\Delta w = \frac{w_{20} - w_{50}}{w_{20}}$$



Scaling relations

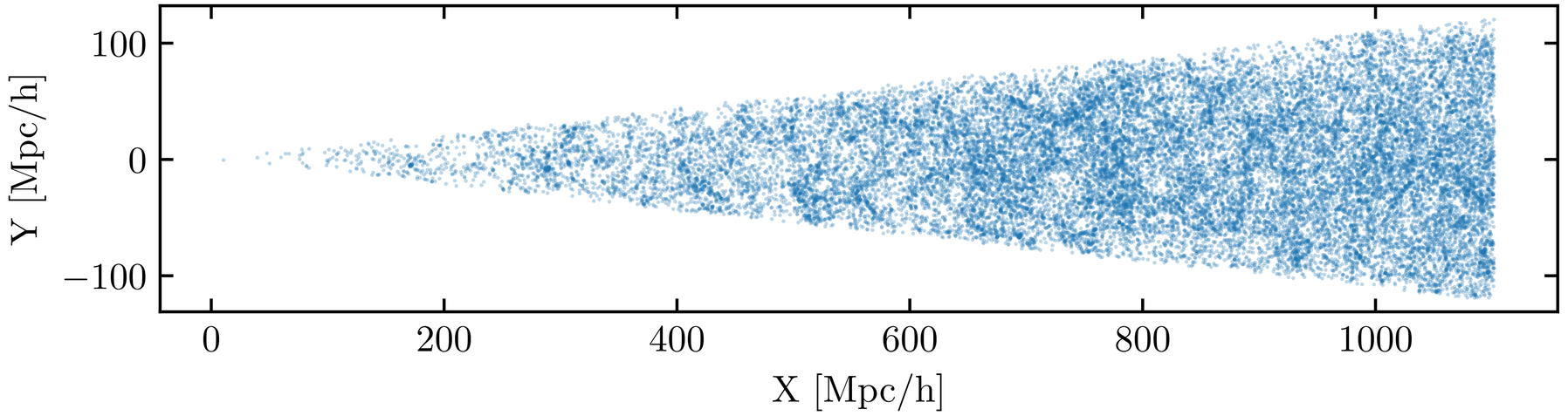
HI line kurtosis <—> Masses

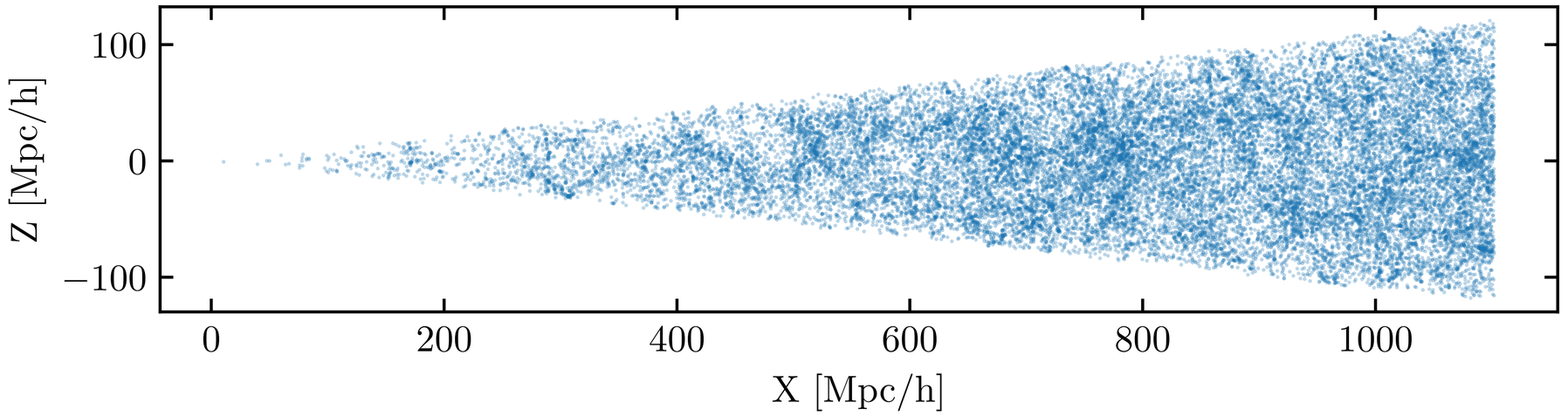
$$\kappa = \frac{\mu_4}{\mu_2^2} - 3 \qquad \mu_n = \frac{\int_{-\infty}^{\infty} S_{HI}(V)\ (V - \bar{V})^n dV}{\int_{-\infty}^{\infty} S_{HI}(V) dV}$$



Mock Light Cone

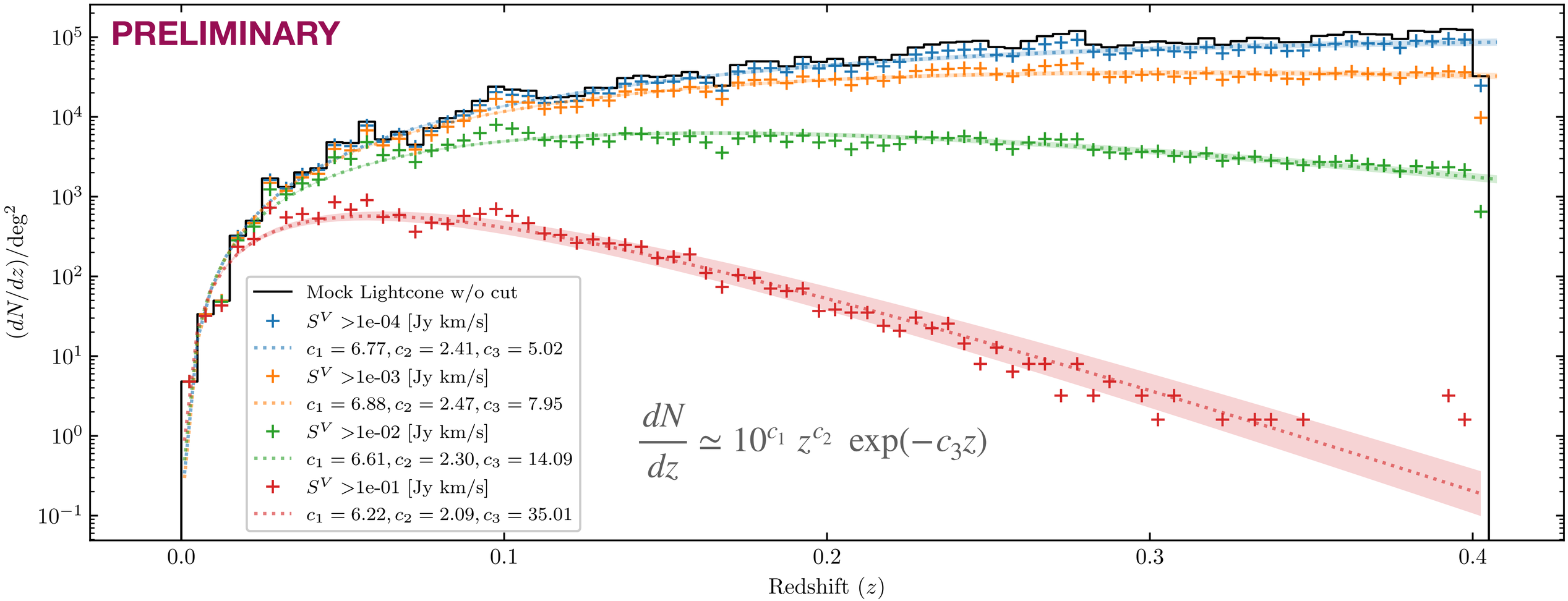
$\Omega \simeq 520\ \mathrm{deg}^2, 0 < z < 0.4$





Mock SKAO HI Survey: Number counts

For different integrated flux thresholds



Summary

Ready Tools:

- SAMs – adapted to simulate cosmology sized volumes
- New (fast) code to compute HI 21cm emission line profiles
- Mock HI survey lightcones with arbitrary flux thresholds

Ongoing efforts to produce **realistic mock catalogues** for SKAO HI galaxy redshift surveys:

SKAO *“Cosmology - HI Galaxy”* Focus Group (synergy between the two eponymous SWG) led by G. De Lucia and A. Ponomareva

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