HI galaxy Simulations & HI survey Forecasts

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Late-time Cosmology with SKAO

Suggested surveys in the Cosmology SWG Red Book (2018)

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

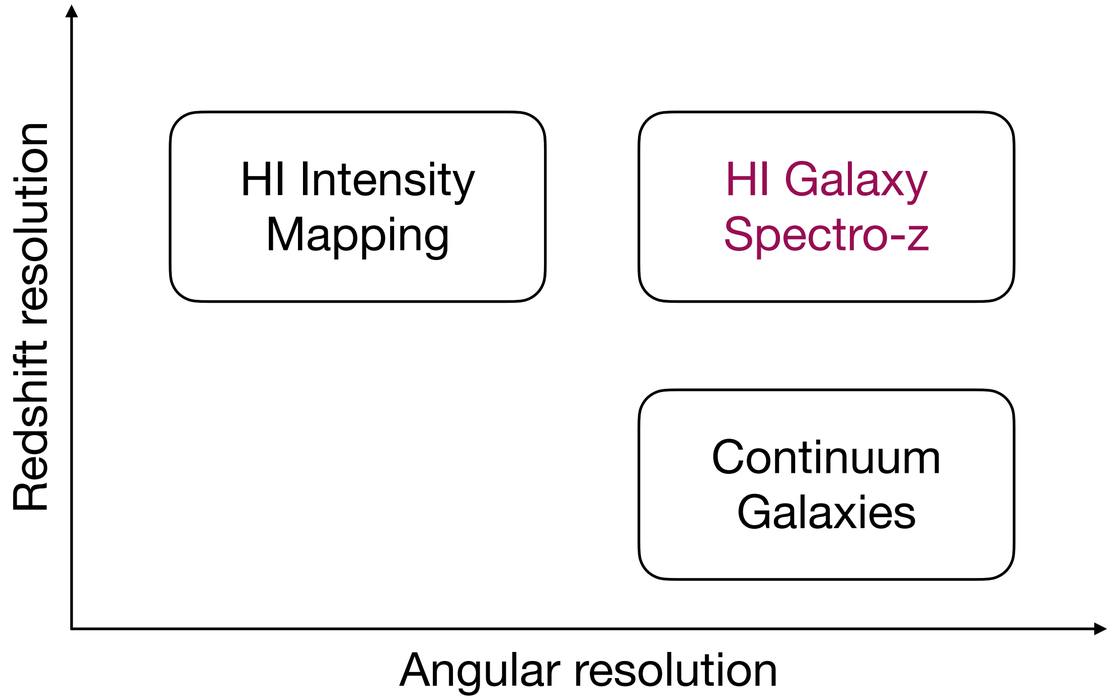
  $z \in [0.35, 3], \quad 20'000\,\mathrm{deg}^2,$

  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

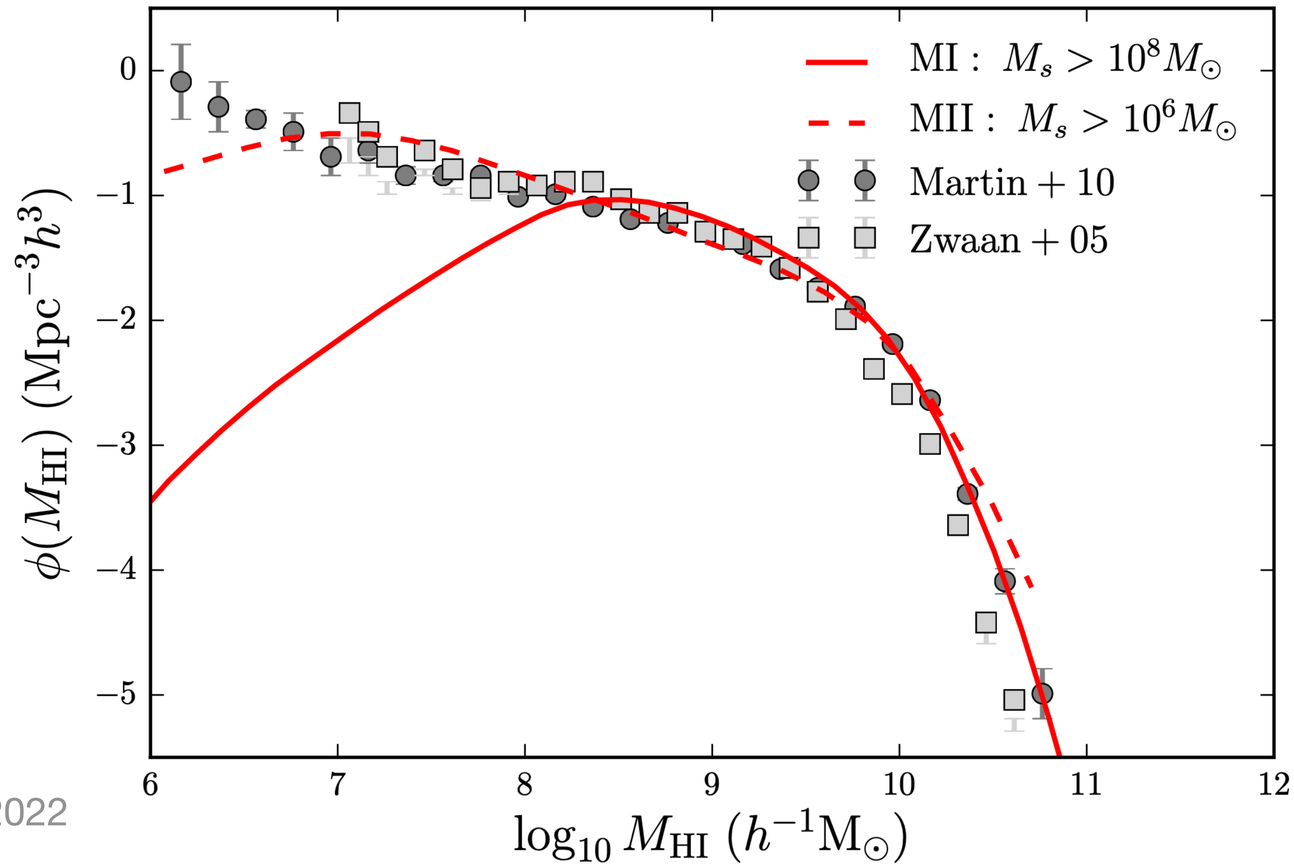
GAlaxy Evolution and Assembly (GAEA) & L-Galaxies

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:

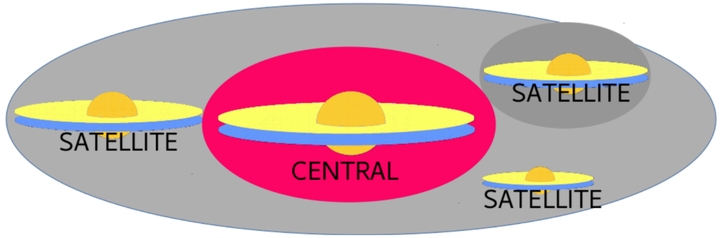
- De Lucia et al. 2014, 2023, 2024
- Hirschmann et al. 2016
- Xie et al. 2017, 2020
- Fontanot et al. 2017, 2018, 2020

L-Galaxies:

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

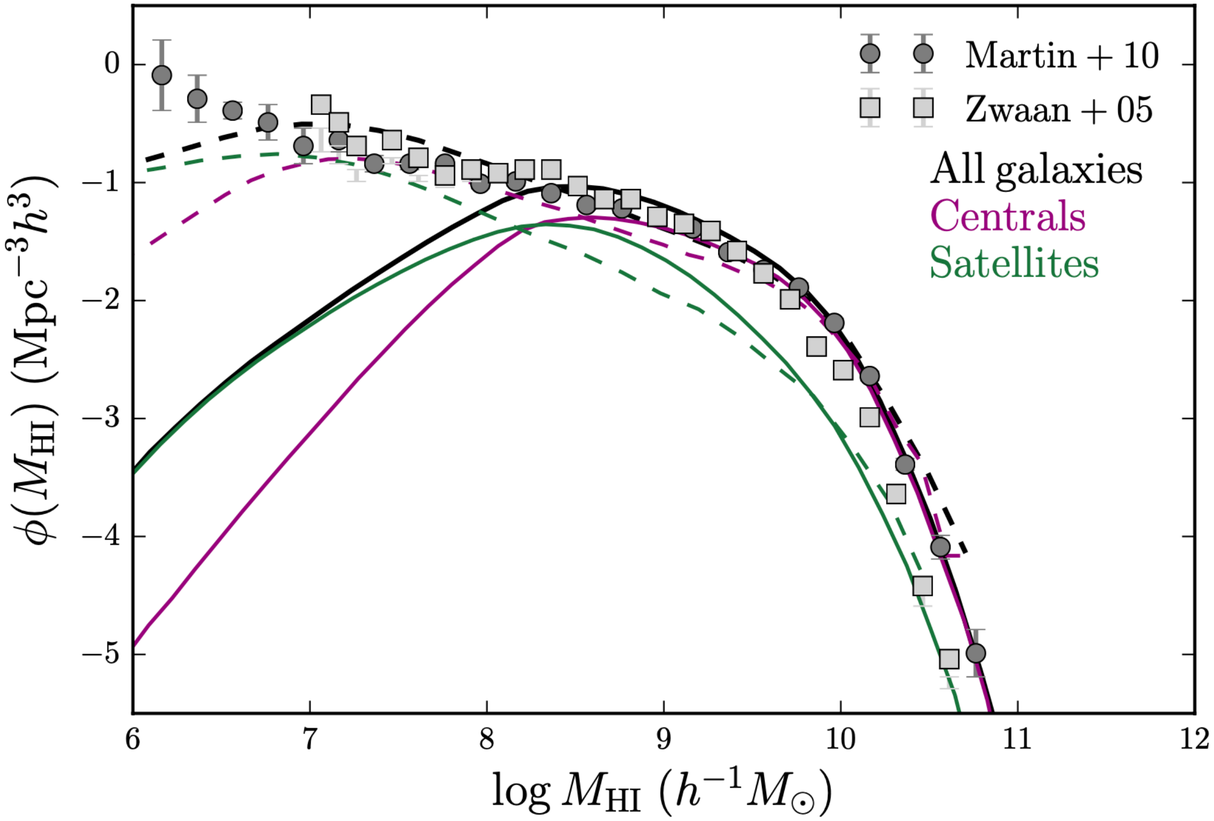
Semi-Analytical Models

Role of Central and Satellite galaxies



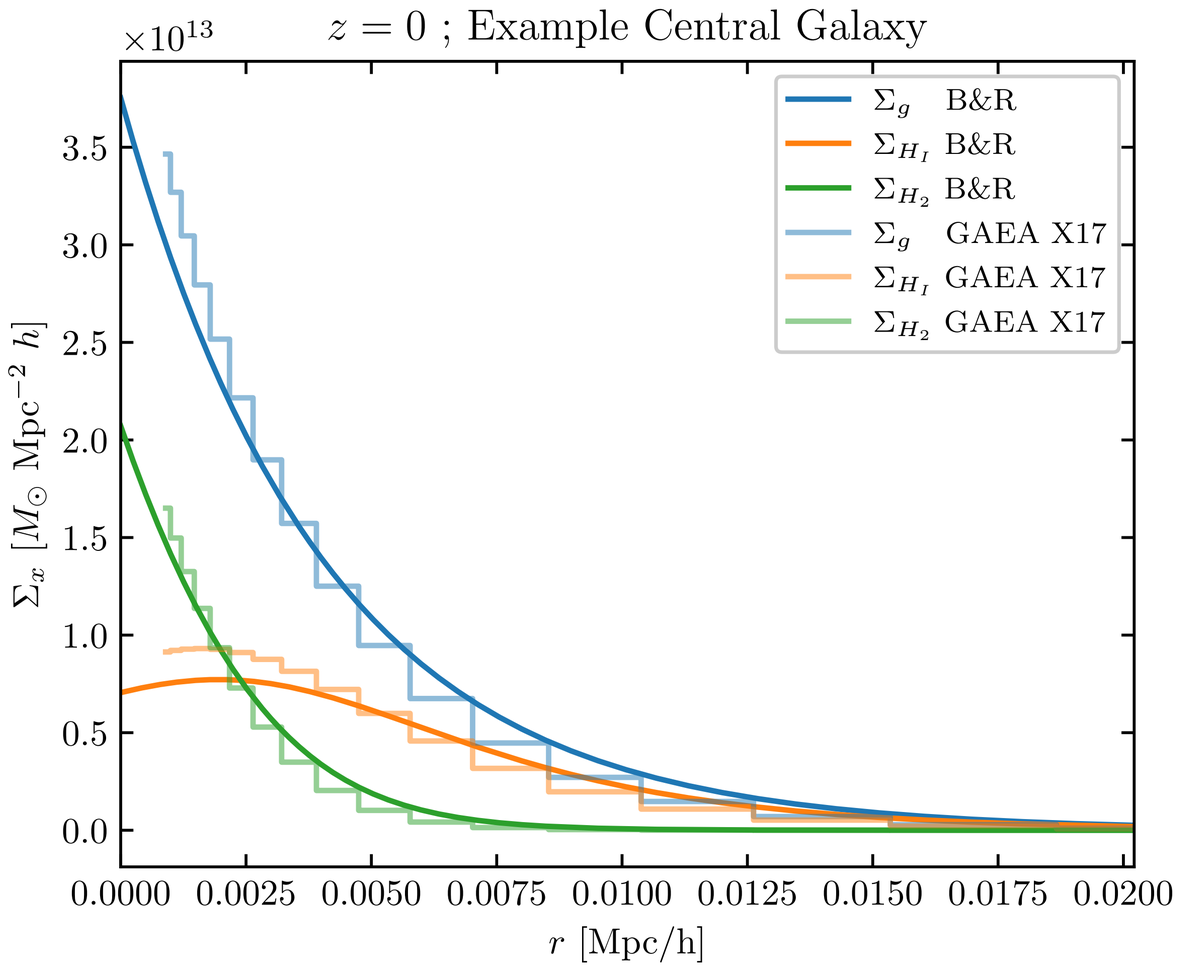
- Centrals dominate from intermediate to high HI mass
- Satellite dominate for low masses
- Orphan satellites “lost their subhalo” i.e. $M_h < 20$ MSI (resp. MSII) particles

Courtesy of M. Spinelli



Model Surface Density Profiles

Partition of the cold gas



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

- Blitz & Rosolowsky 2006:

  Empirical relation between ratio of atomic gas and hydrostatic pressure

- Krumholz et al. 2008:

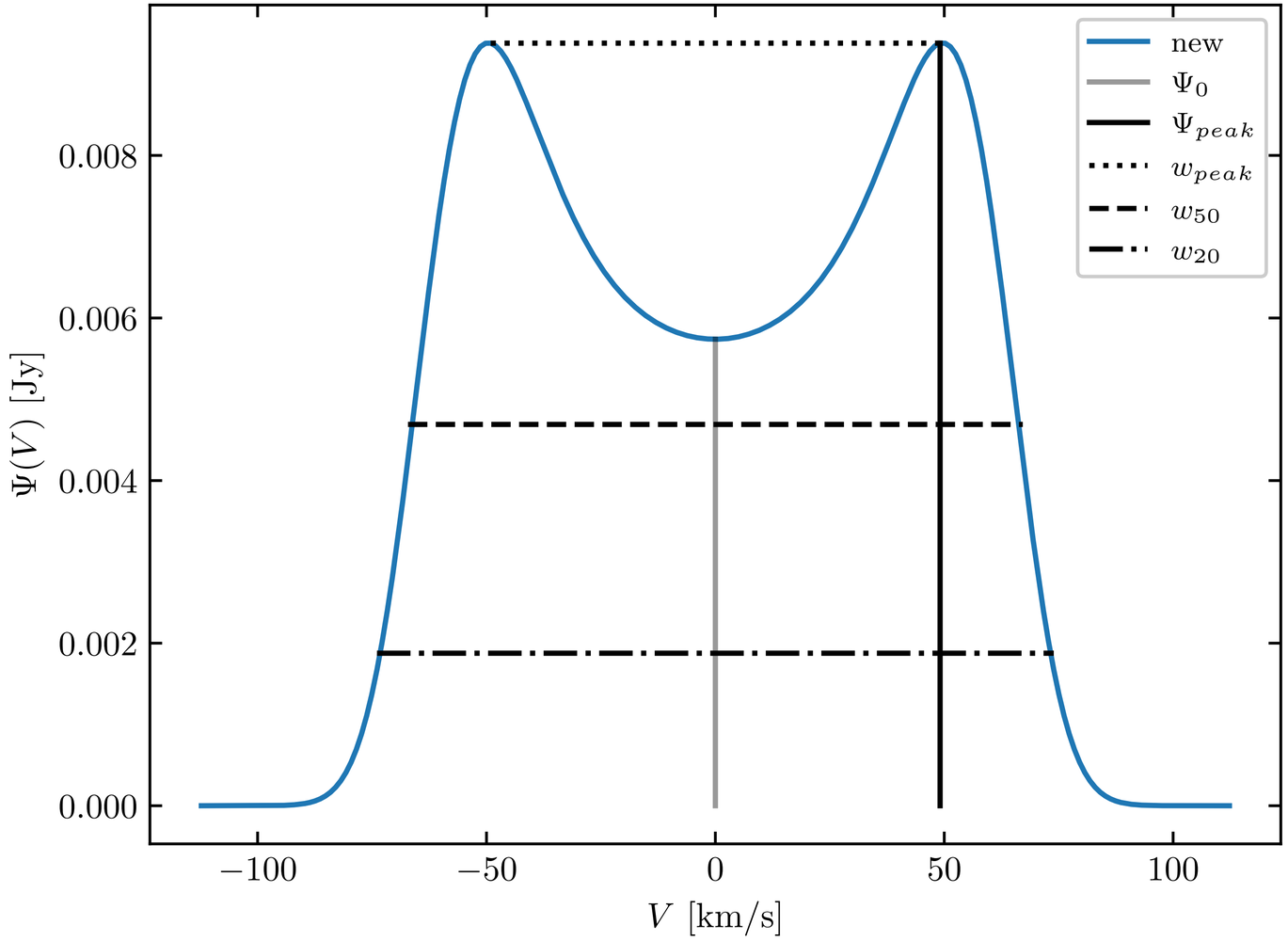
  Empirical relation between ratio of atomic gas and gas phase metallicity

HI 21cm emission line model

Vectorized & Parallelized modular python package

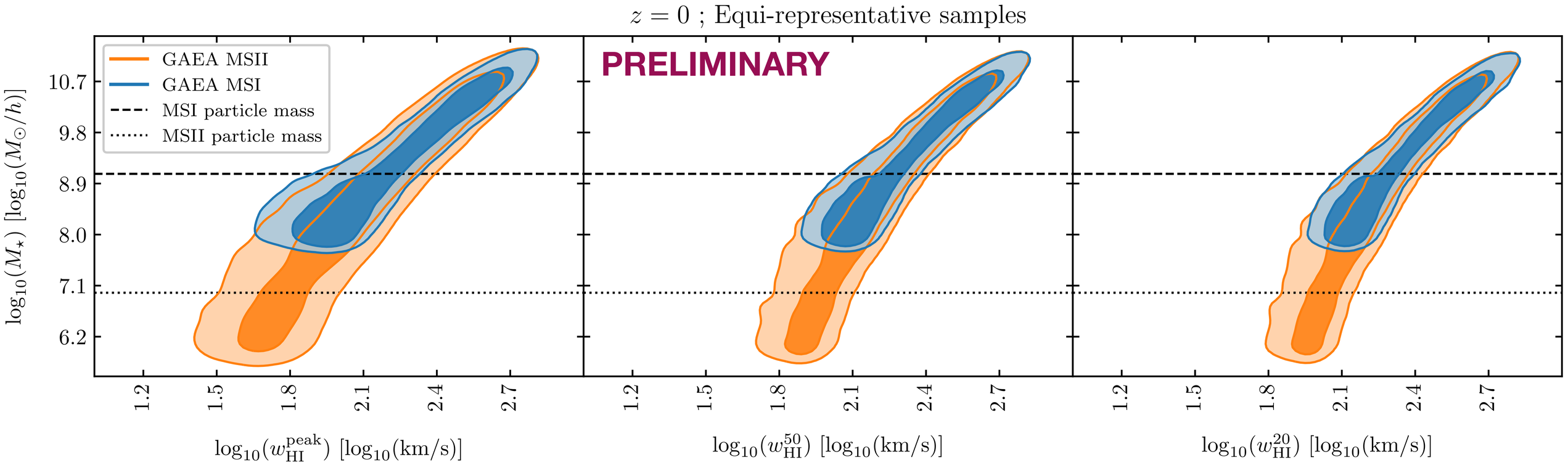
Consistency checks:

- N-body Resolution effects: MSI vs MSII
- SAM model choice: GAEA vs L-Galaxies
- Comparison with available observational data, modelling effects of: Inclination, gas dispersion, noise, resolution, redshift, etc.



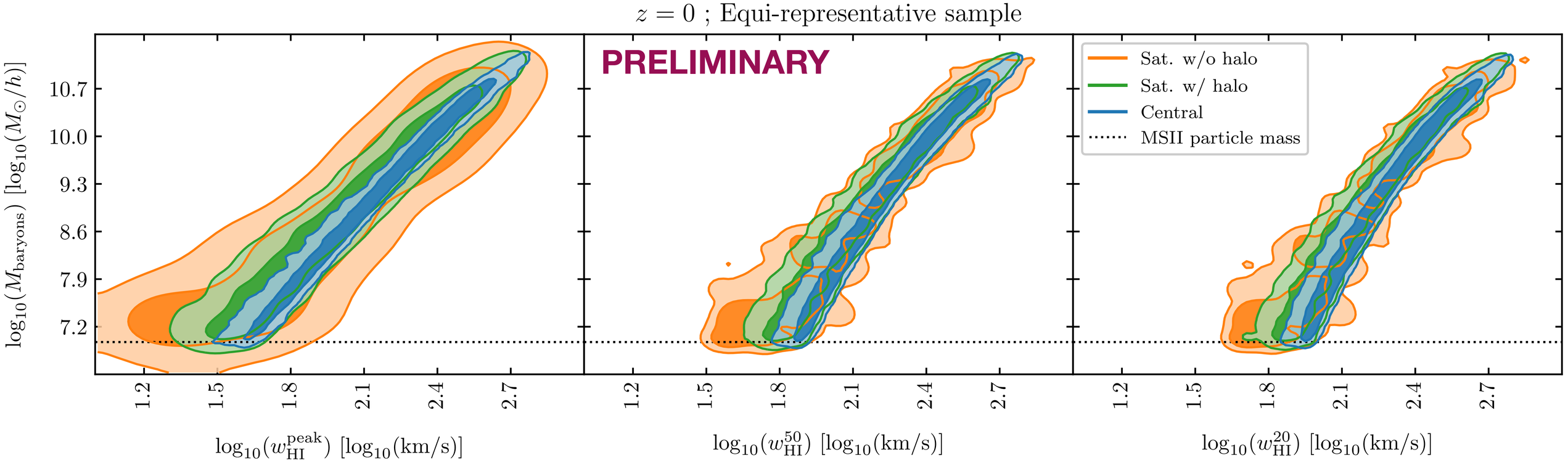
Scaling relations

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



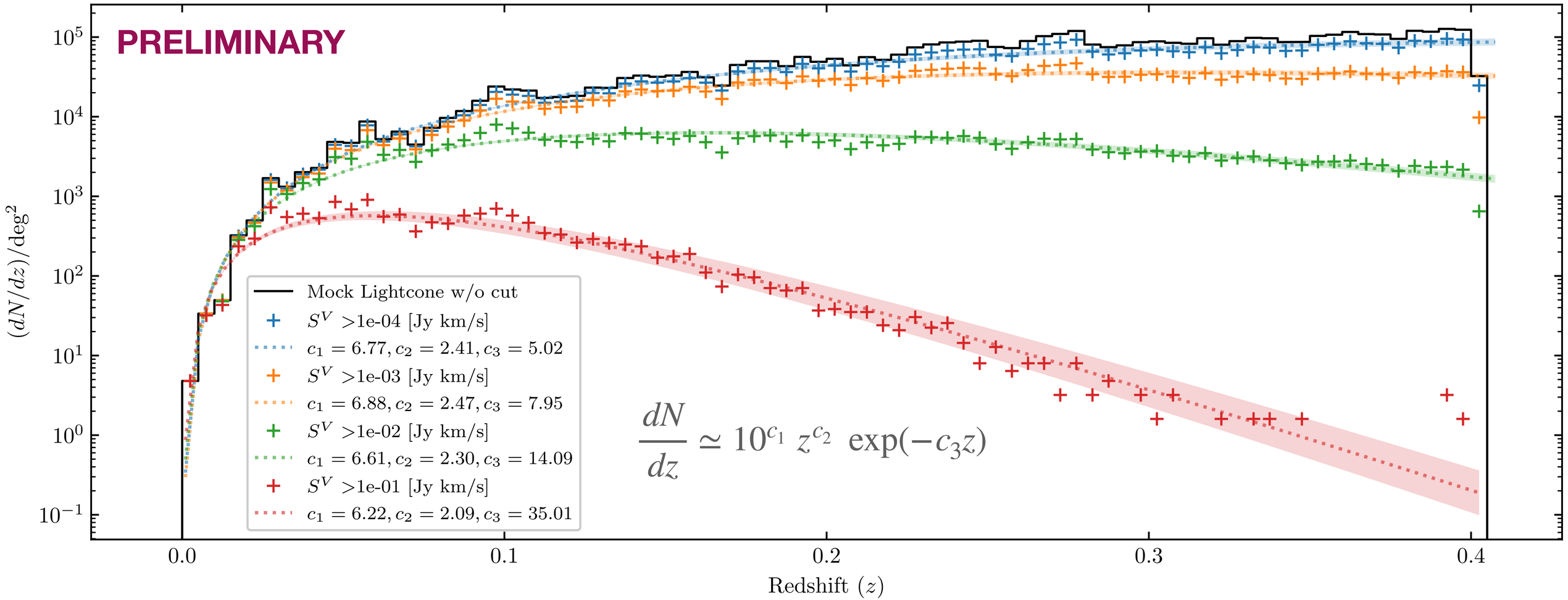
Scaling relations

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



Mock HI Survey: Number counts

For different integrated flux thresholds



Suggested contributions/chapter updates

Update of chapter: HI galaxy simulations for the SKA: number counts and bias

- Updated simulations using the state-of-the-art SAMs (GAEA and L-Galaxies)
- dN/dz and $b(z)$ for integrated/peak flux density limited mock surveys, for AA* / AA4 configs.

But also of interest:

- Additional line feature (e.g. double peak) detection number counts (e.g. for a Tully-Fisher PV survey)

Suggested contributions/chapter updates

Update of chapter: Cosmology from HI galaxy surveys with the SKA

- Use updated dN/dz and $b(z)$ from simulations
- Unified MCMC forecasting framework:
  - BAO, RSD, P(k)
  - Direct Peculiar Velocities measurements (Tully-Fisher)
  - Other obs. in the redbook: Voids, Doppler mag., etc.
- ΛCDM + Extended models

Suggested contributions/chapter updates

New chapter: Cosmology with direct peculiar velocities measurements

- Simulation-based model for the Tully-Fisher relation
- Refinement of dN/dz and $b(z)$ with line feature detection thresholds
- Integrated in the MCMC forecast framework
- Synergy with the Dipole(s) science case

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

Suggested Chapter Updates:

- HI galaxies simulations: dN/dz & $b(z)$
- HI redshift survey (MCMC) forecasts

Suggested New Contribution:

- Cosmology with a SKAO Tully-Fisher peculiar velocity survey

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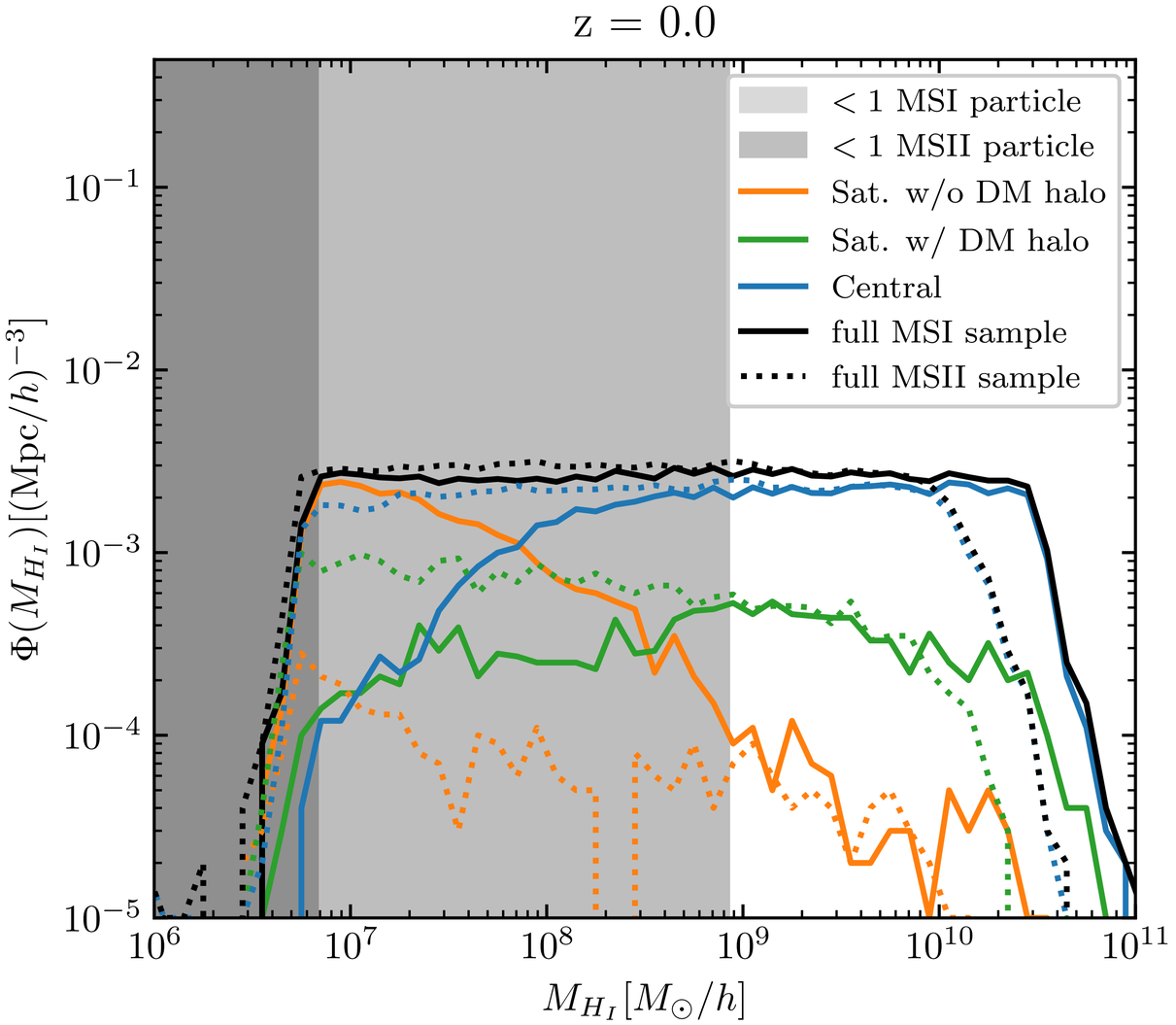
Backup

Consistency checks

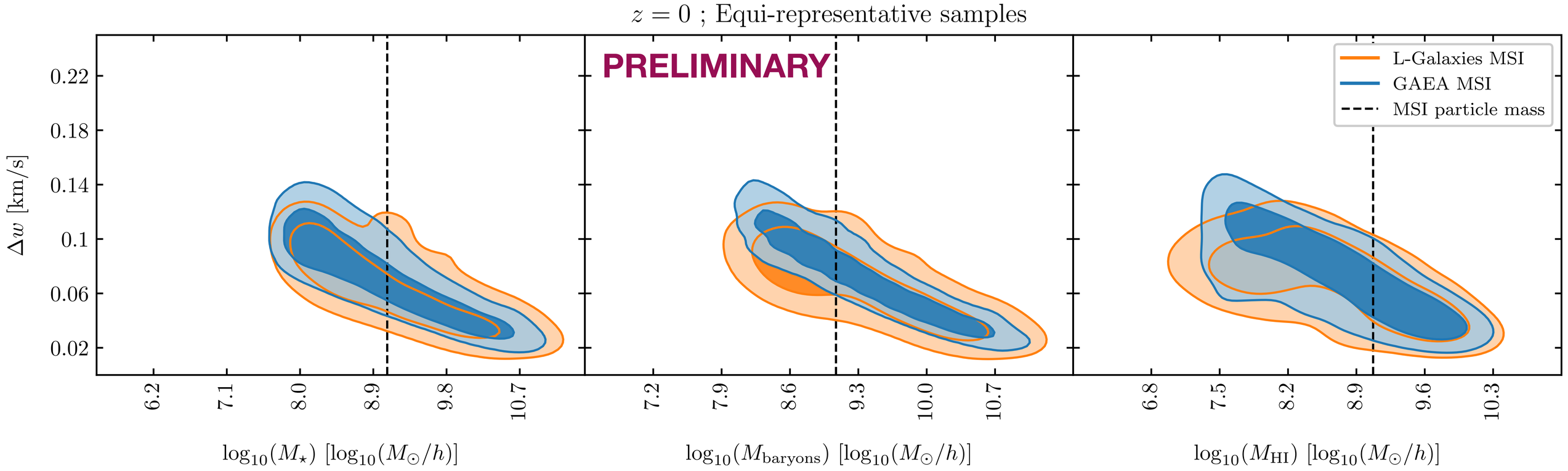
Equi-representative random sample



Scaling relations

HI line widths differences <—> Masses

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

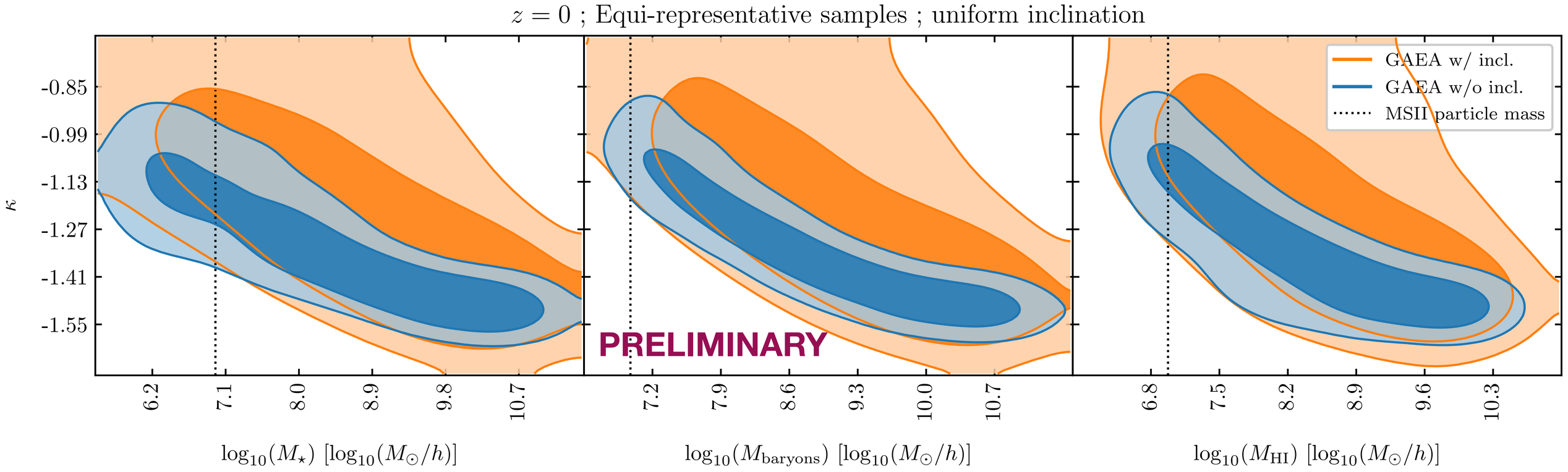


Scaling relations

HI line kurtosis <—> Masses

$$\kappa = \frac{\mu_4}{\mu_2^2} - 3$$

$$\mu_n = \frac{\int_{-\infty}^{\infty} \Psi_{HI}(V)(V - \bar{V})^n dV}{\int_{-\infty}^{\infty} \Psi_{HI}(V) dV}$$



Scaling relations

Neutral Hydrogen Mass - HI line widths