THE HI MASS FUNCTION AS A PROBE OF PHOTOIONISATION FEEDBACK ON LOW MASS GALAXY FORMATION

PROBING PHOTOIONISATION FEEDBACK

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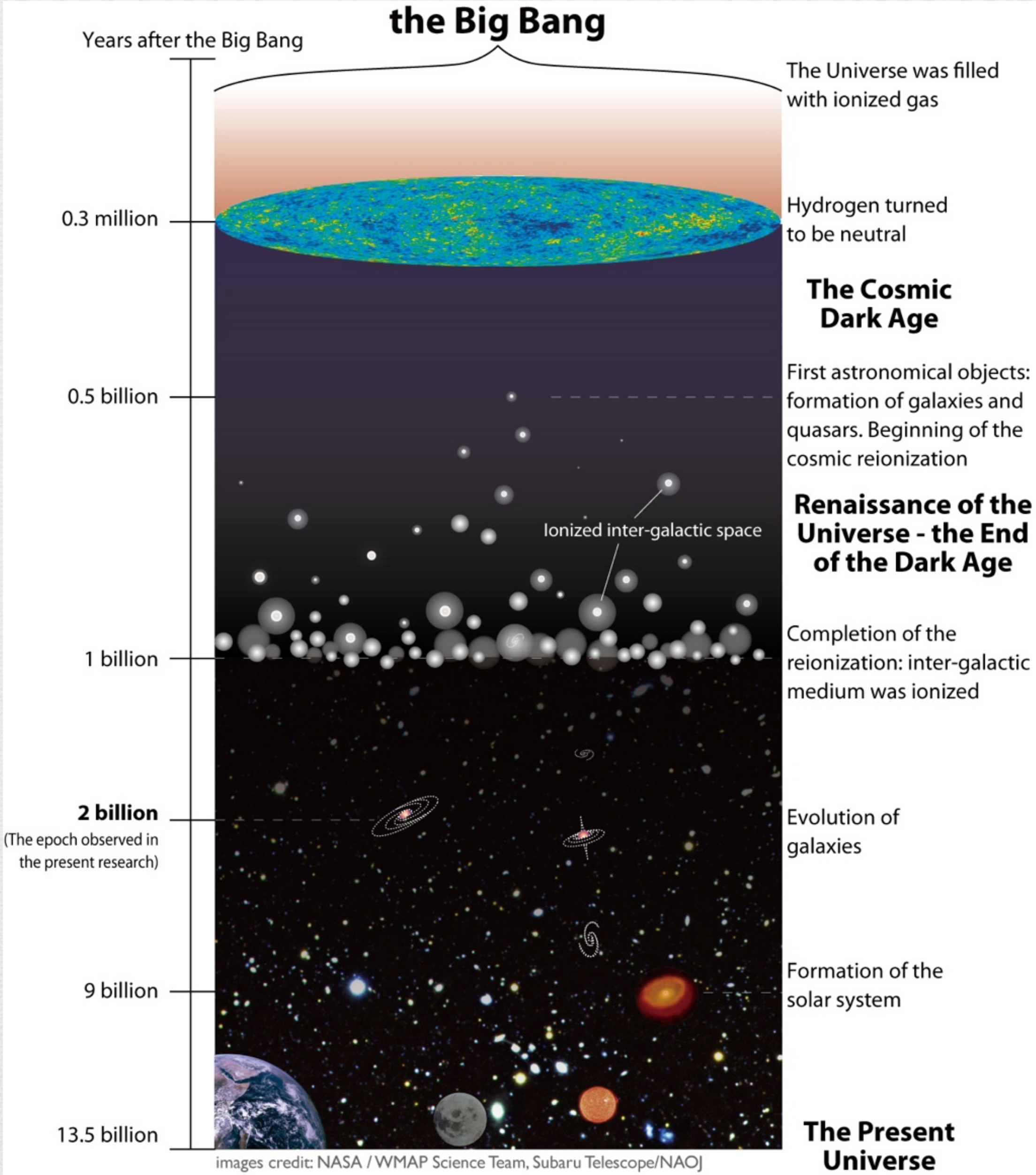
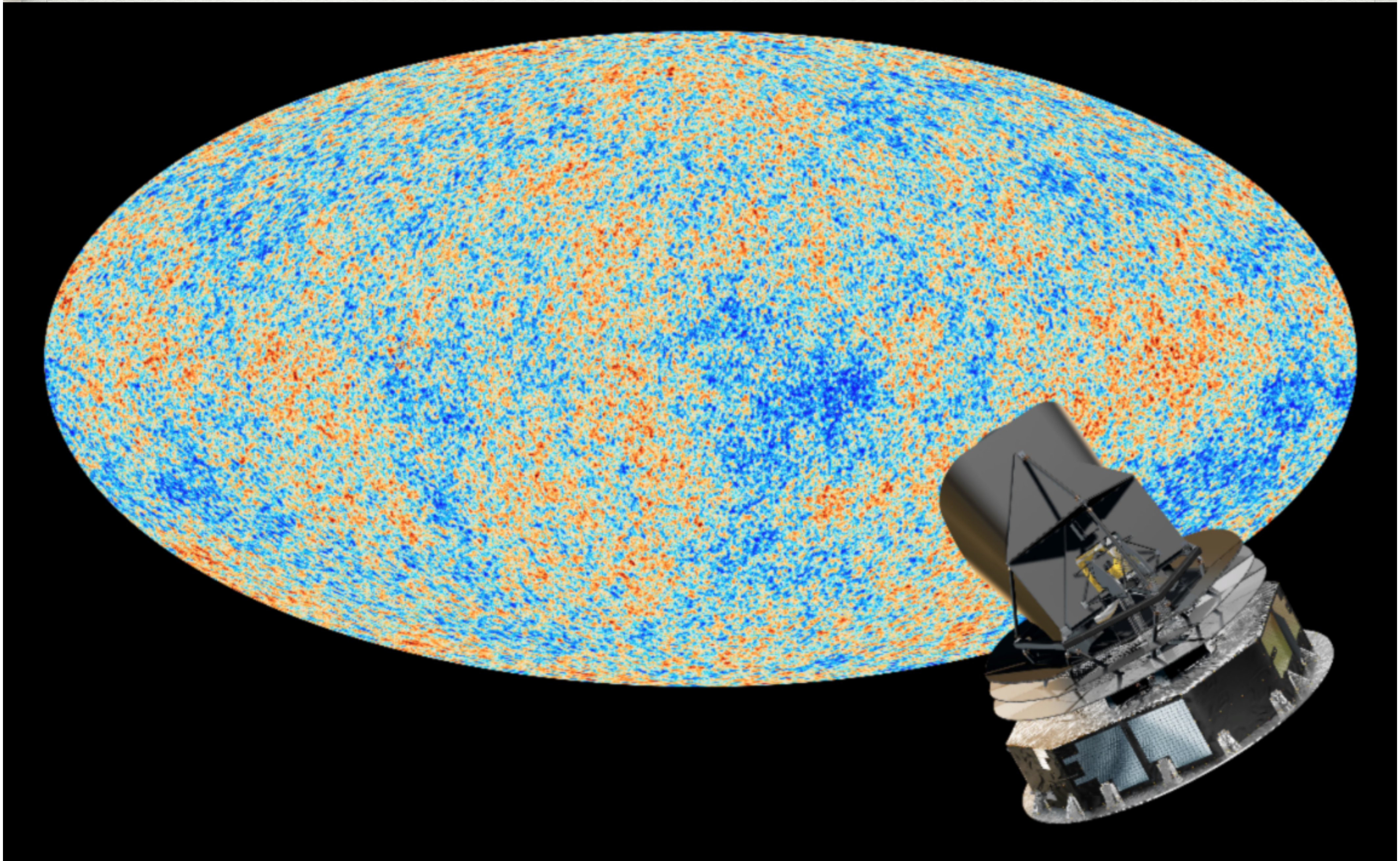
Summary

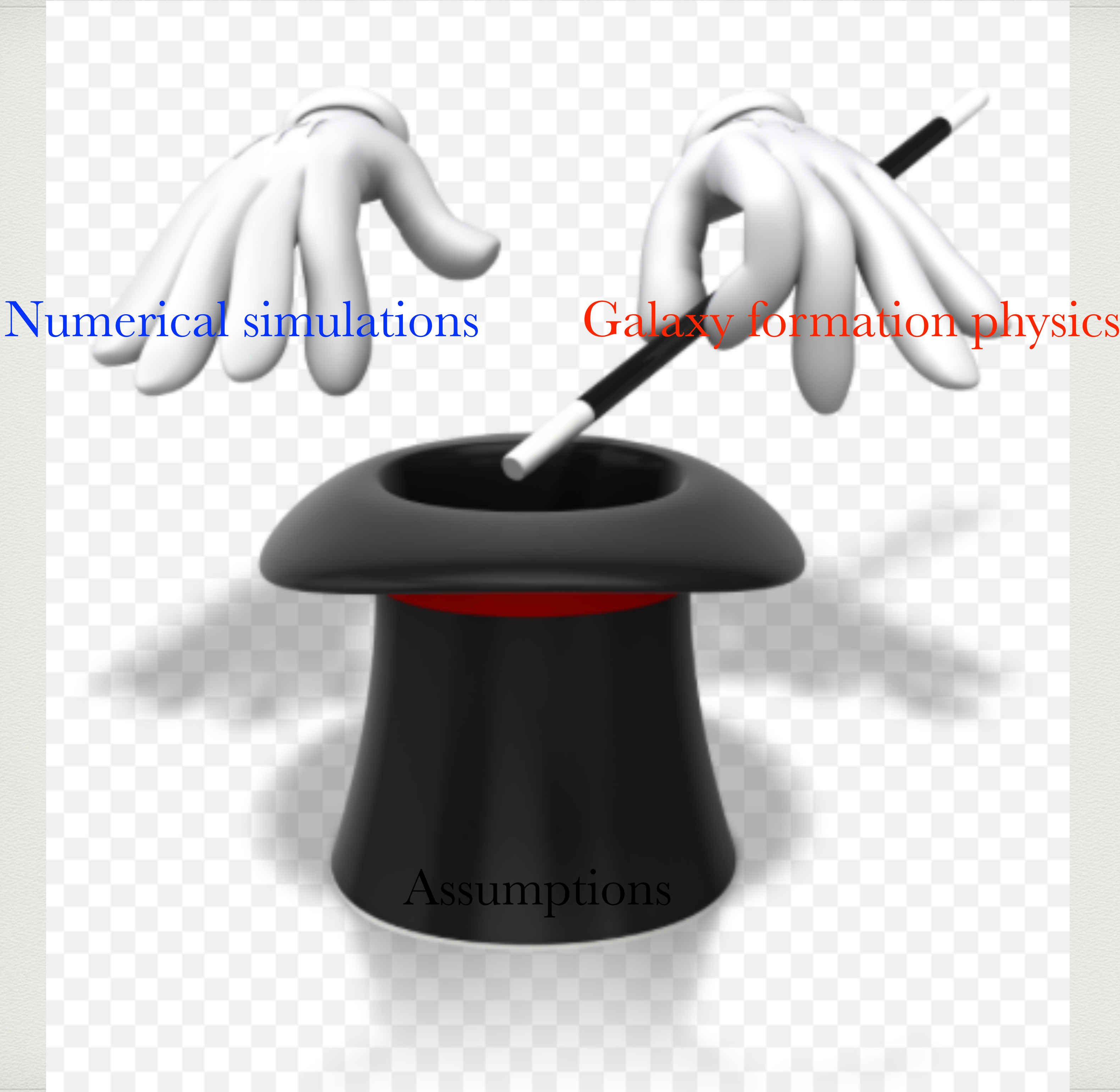
- Future redshift surveys using neutral hydrogen emission will make possible measurements of the BAO and constrain the dark energy equation of state.
- The HIMF is a more sensitive probe of the photoionisation feedback than the LF.
- Redshift dependent photoionisation feedback modelling is required to explain the low mass end of the HIMF.



the Big Bang
Years after the Big Bang
The Universe was filled with ionized gas
0.3 million
Hydrogen turned to be neutral
The Cosmic Dark Age
0.5 billion
First astronomical objects: formation of galaxies and quasars. Beginning of the cosmic reionization
Ionized inter-galactic space
Renaissance of the Universe - the End of the Dark Age
1 billion
Completion of the reionization: inter-galactic medium was ionized
2 billion
(The epoch observed in the present research)
Evolution of galaxies
9 billion
Formation of the solar system
13.5 billion
The Present Universe
images credit: NASA / WMAP Science Team, Subaru Telescope/NAOJ

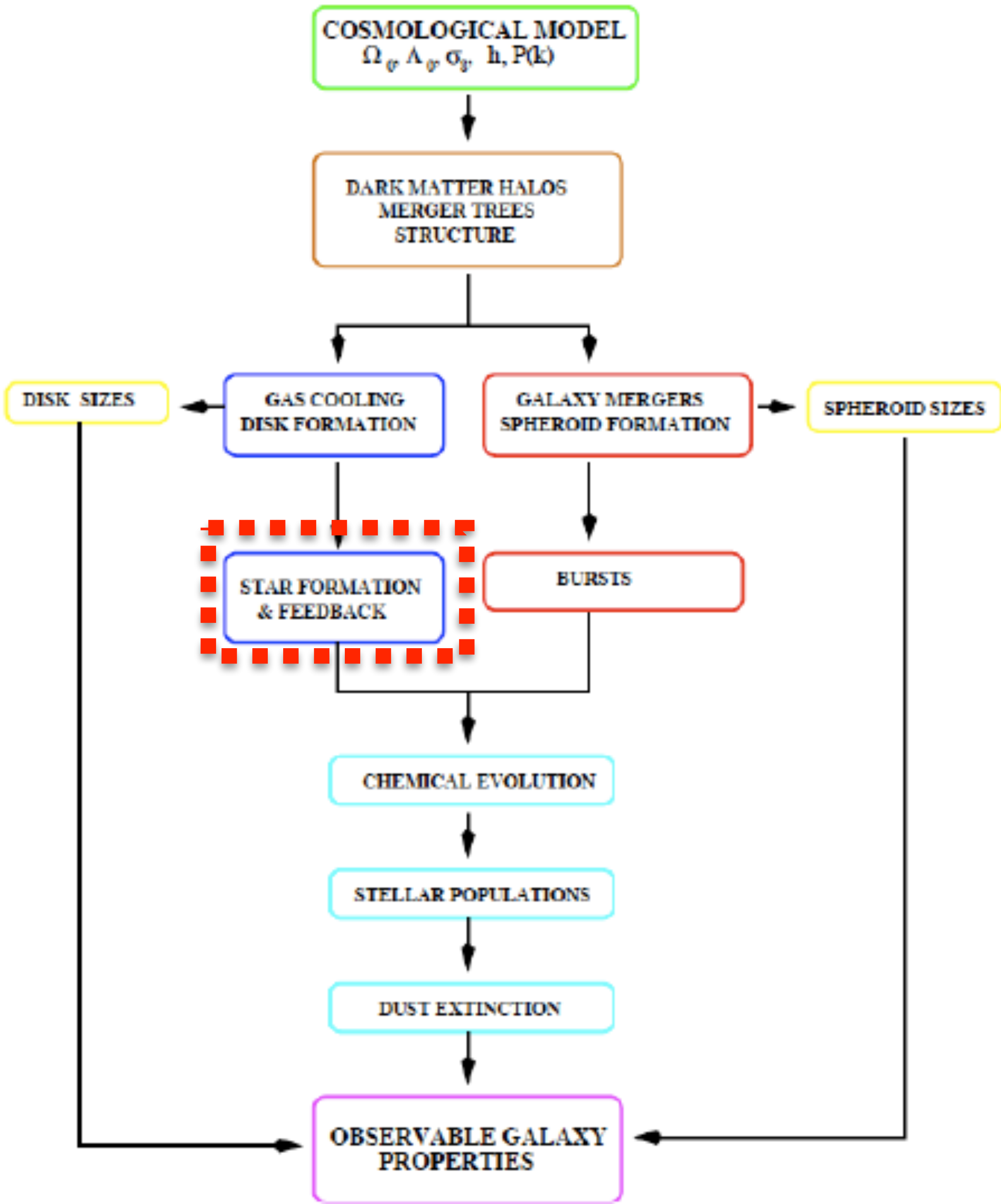


Credit : ESA


Numerical simulations
Galaxy formation physics
Assumptions

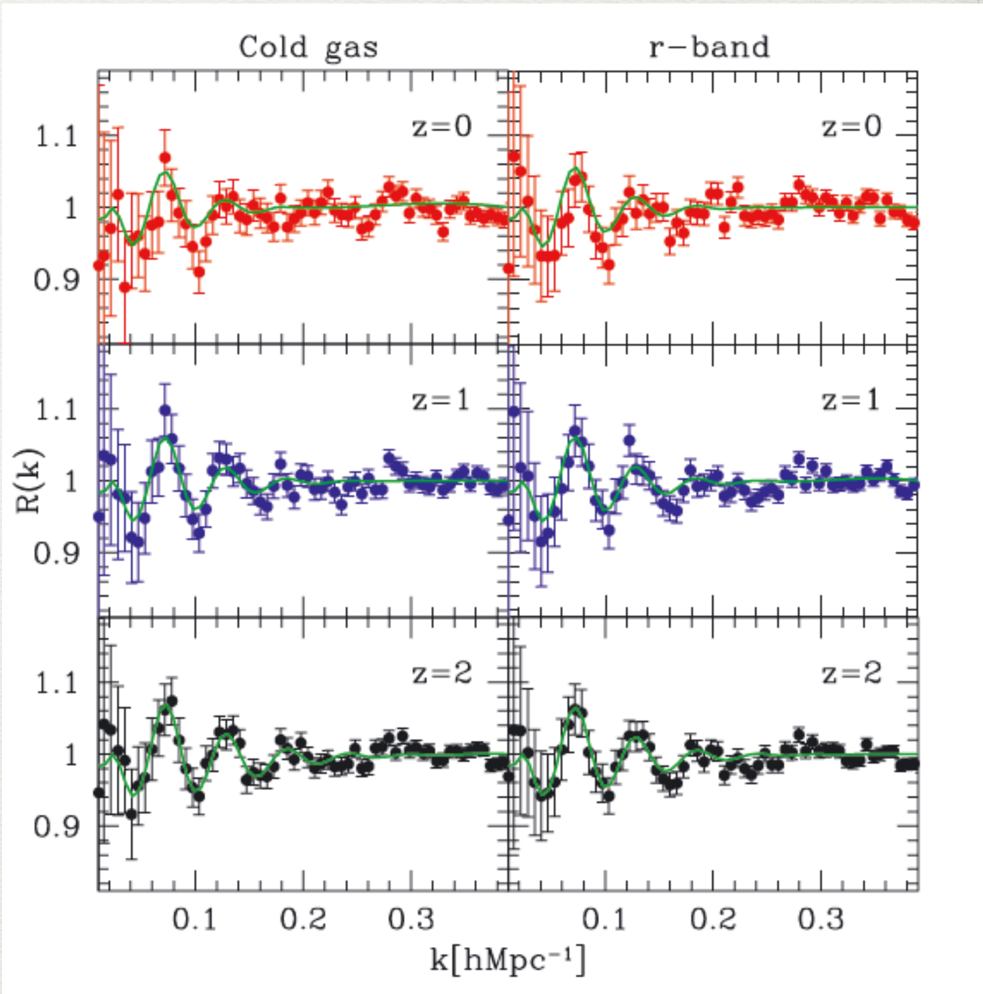

Credit : Illustris team

- Semi-analytic galaxy formation model : GALFORM
- Rapid exploration of the galaxy formation physics parameters.
- Large, statically useful samples with wide range of properties



Cosmology with HI galaxy

- BAO signal predictions : Future redshift surveys using neutral hydrogen emission will make possible measurements of the baryonic acoustic oscillations that are competitive with the most ambitious spectroscopic surveys planned in the near-infrared.

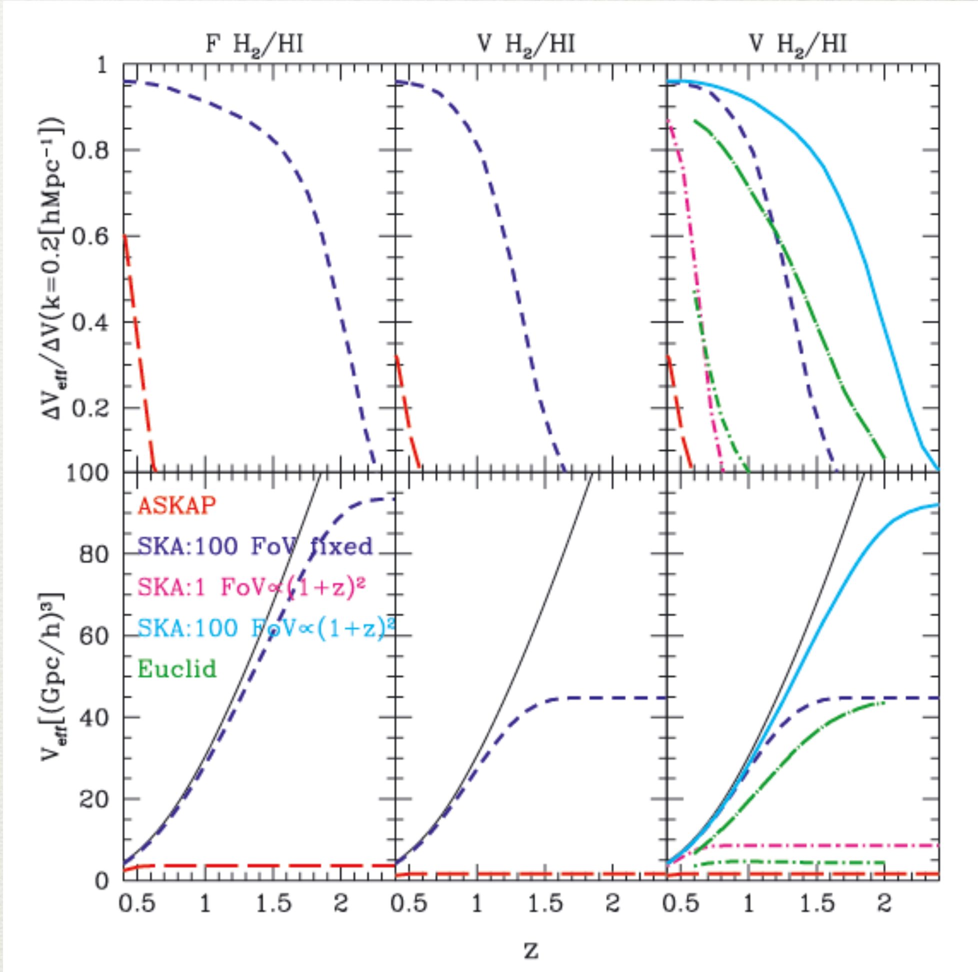


Kim et al. 2011

Cosmology with HI galaxy

- BAO signal predictions : Future redshift surveys using neutral hydrogen emission will make possible measurements of the baryonic acoustic oscillations that are competitive with the most ambitious spectroscopic surveys planned in the near-infrared.

- Effective volumes for surveys. : Powerful way to compare expected performance of different surveys.



Kim et al. 2011

Cosmology with HI galaxy

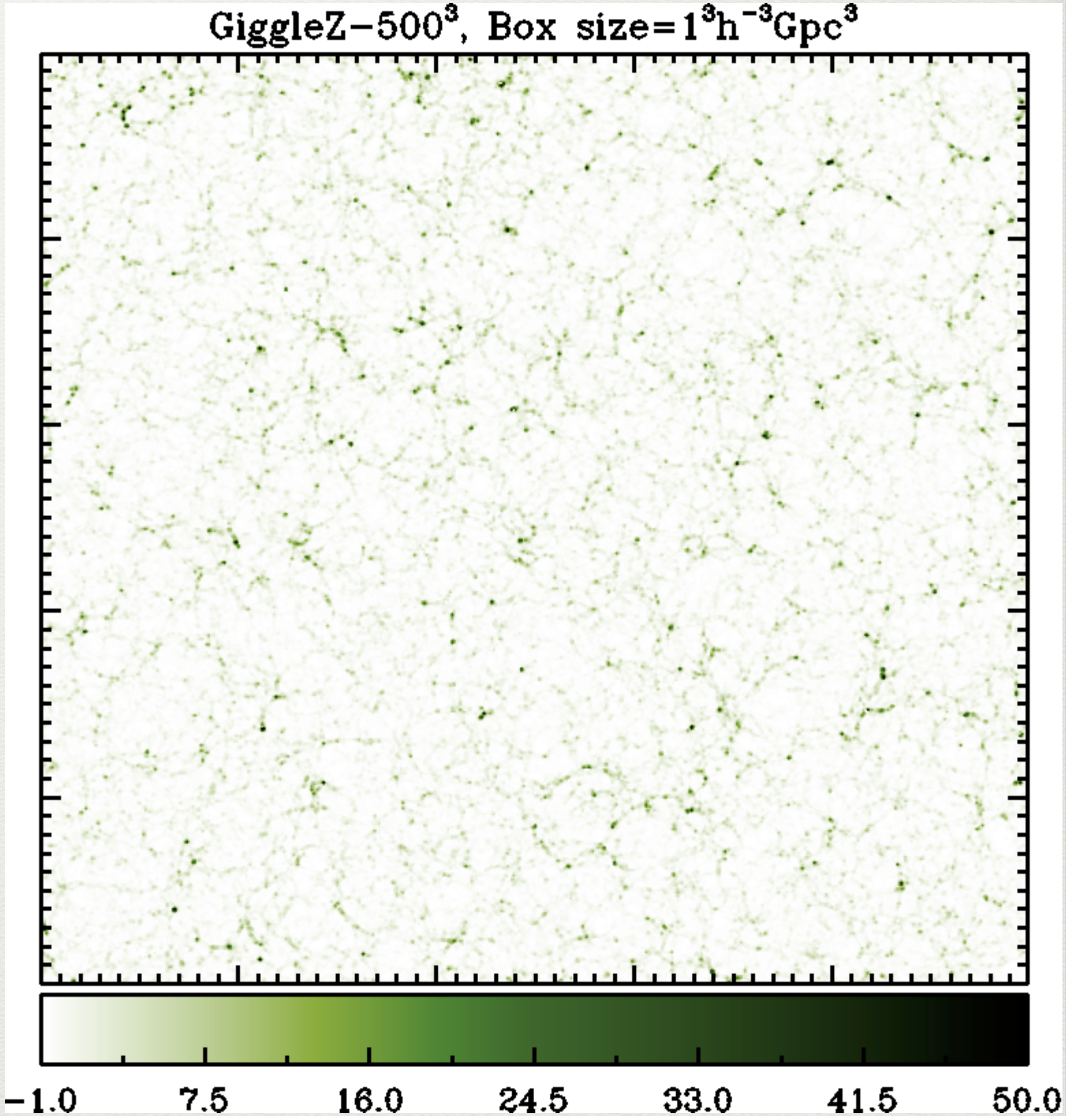
- BAO signal predictions : Future redshift surveys using neutral hydrogen emission will make possible measurements of the baryonic acoustic oscillations that are competitive with the most ambitious spectroscopic surveys planned in the near-infrared.
- Effective volumes for surveys. : Powerful way to compare expected performance of different surveys.
- Constraints of the dark energy equation of state.

Survey	H_2/H I	t_{eff}	*WMAP* prior	*Planck* prior
ASKAP	fixed	fixed	10.3	3.7
ASKAP	variable	fixed	14.8	3.8
SKA:100	fixed	fixed	0.6	0.6
SKA:100	variable	fixed	1.0	1.0
SKA:100	fixed	$\propto (1+z)^2$	0.4	0.4
SKA:100	variable	$\propto (1+z)^2$	0.6	0.6
Hα	-	-	2.6	2.2
$H = 22$	-	-	0.8	0.8

Kim et al. 2011

Cosmology with HI galaxy

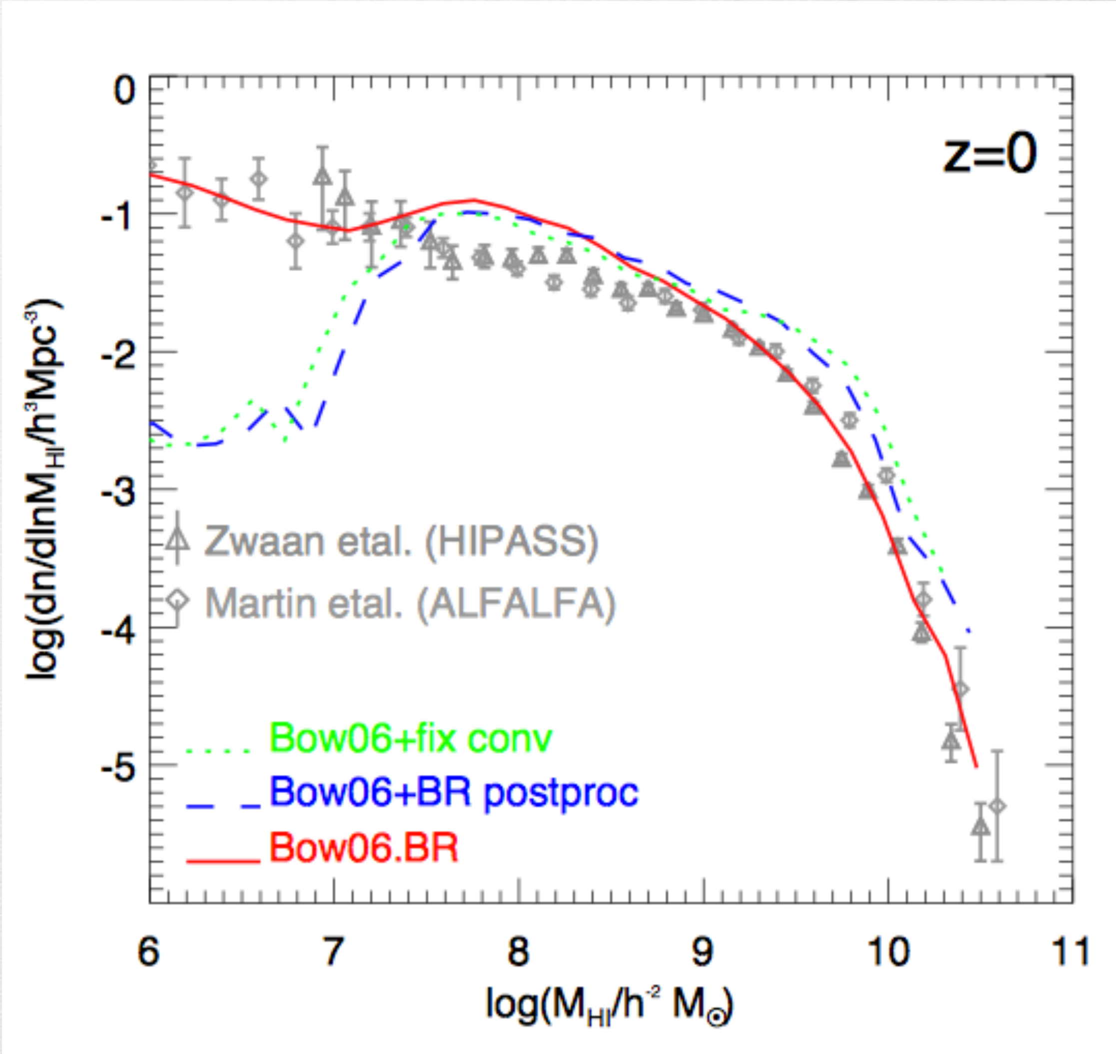
- HI intensity mapping is a novel technique capable of mapping the large scale structure of the Universe in 3D and delivering exquisite constraints on cosmology, by using HI, without the requirement to resolve individual galaxies, as a biased tracer of the dark matter density field.
- But it seems to be hard to get information about physics of galaxy formation from the HI intensity mapping.



Prep-2

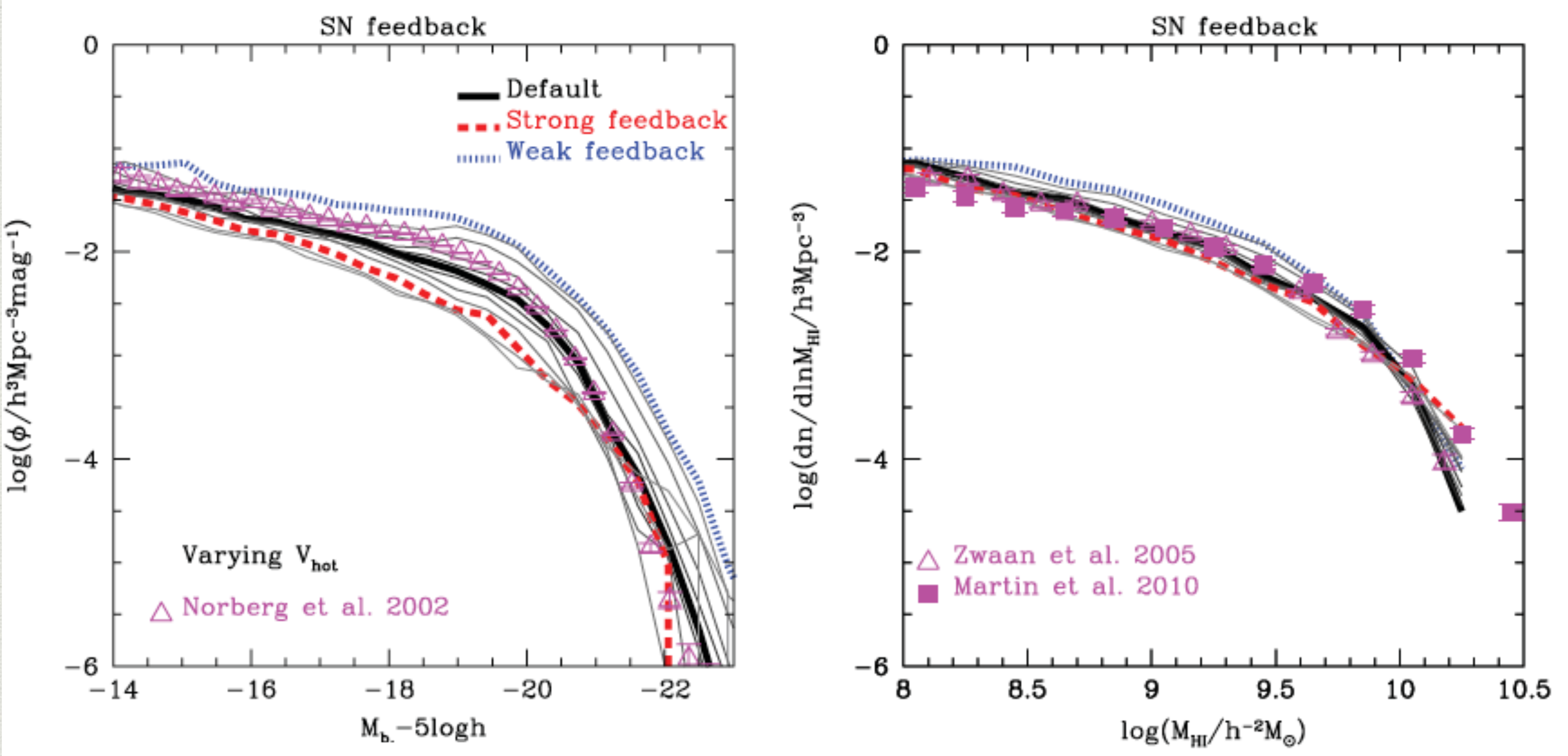
Impact of feedback on the LF and the HIMF

- Extended GALFORM by modelling the splitting of cold gas in the ISM into its HI and H2 components and by explicitly linking star formation laws.
- The empirical law of Blitz & Rosolowsky (2006) is favoured by observations.
- Blitz & Rosolowsky (2006) law is able to broadly reproduce the HIMF at z=0 at high and intermediate HI masses.



Lagos et al 2012.

Impact of feedback on the LF and the HIMF

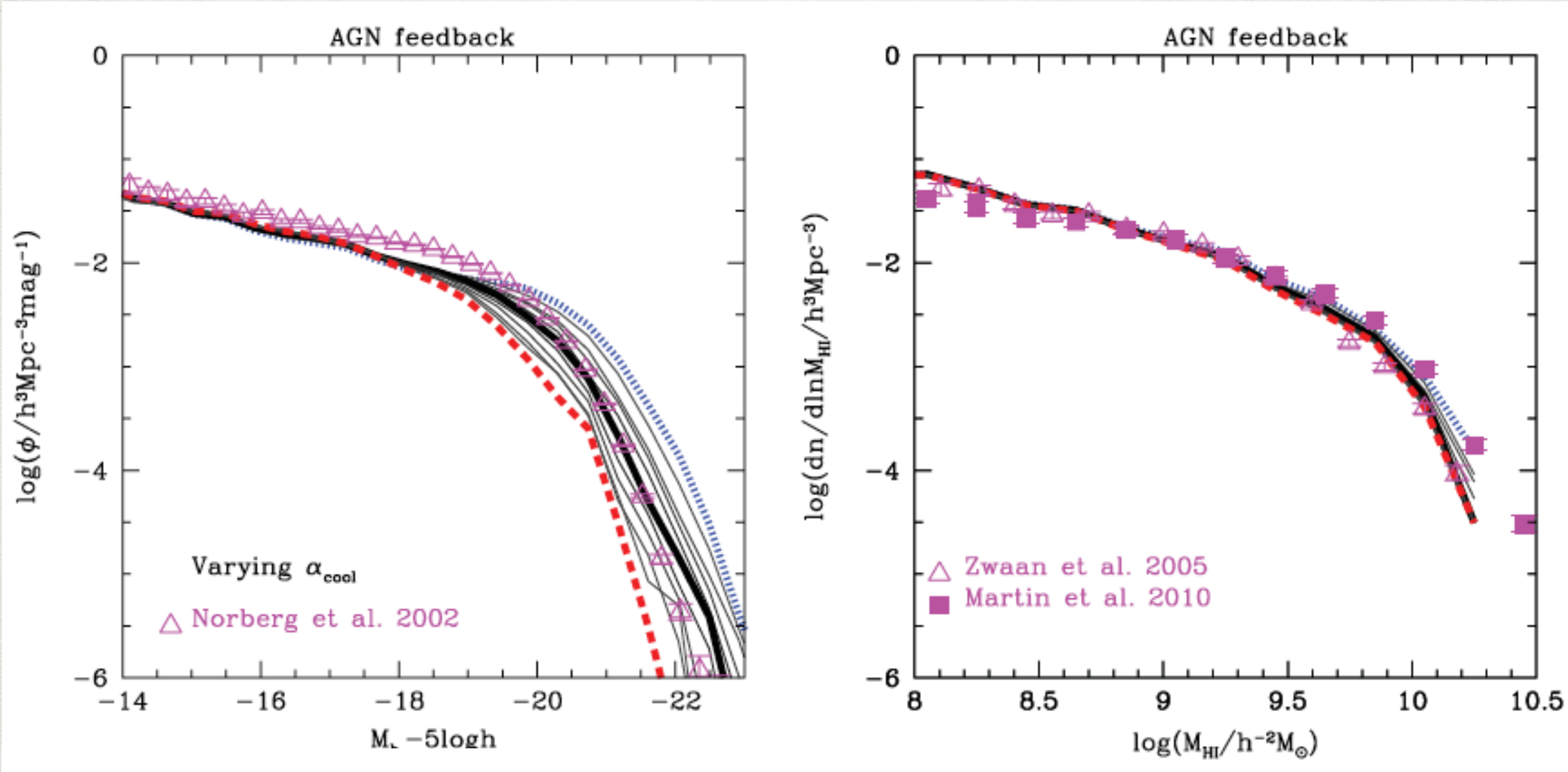


$$\dot{M}_{\rm eject} = \beta\psi,\ \beta = (V_{\rm disc}/V_{\rm hot})^{-\alpha_{\rm hot}}.$$

- SN feedback to be most effective in low-mass and intermediate-mass dark matter haloes because gas is expelled efficiently from their shallow potential wells.

Kim et al. 2013

Impact of feedback on the LF and the HIMF

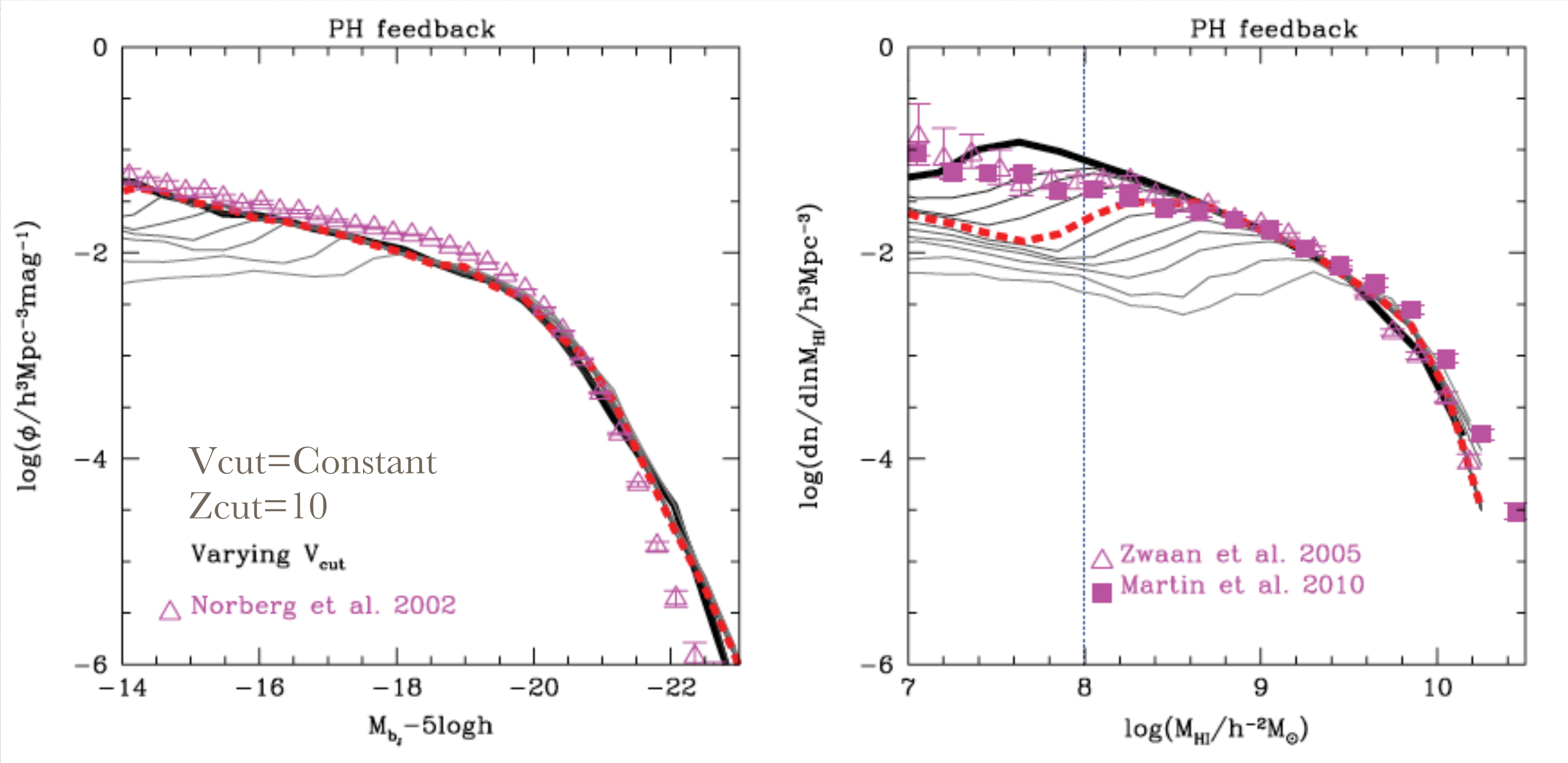


$$t_{\rm cool}(r_{\rm cool}) > \frac{1}{\alpha_{\rm cool}} t_{\rm ff}(r_{\rm cool})$$

- AGN feedback suppresses cooling flows in massive haloes. Physically this occurs because AGN are fuelled by supermassive black holes that grow by luminous accretion.

Kim et al. 2013

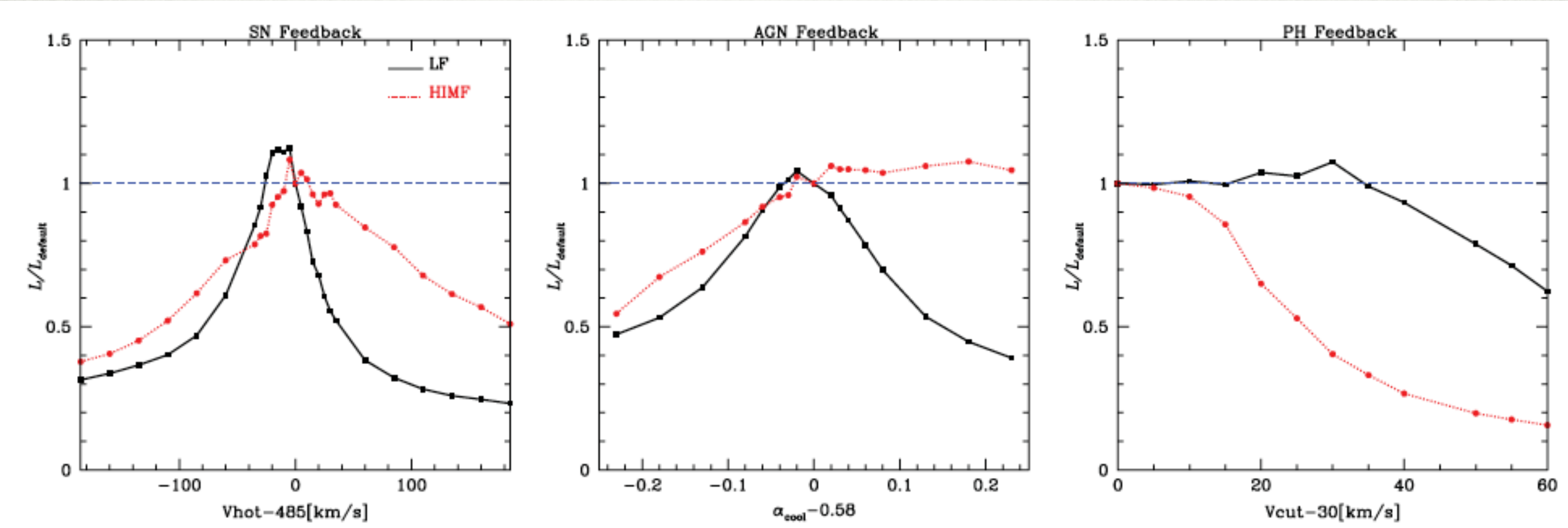
Impact of feedback on the LF and the HIMF



- Photoionization feedback is predicted to have a dramatic impact on SF in low mass galaxies. This is because the presence of a photoionizing background both modifies the net cooling rate of gas in haloes by removing the 'hydrogen peak' in the cooling curve and increases the temperature the intergalactic medium (IGM) such that its thermal pressure prevents gravitational collapse of baryons on to low mass haloes. As a result, only those low mass haloes that contained cold gas prior to reionization can form stars. GALFORM includes prescription for suppressing the cooling of halo gas on to the galaxy. This occurs if the host halo's circular velocity lies below a threshold and redshift of end of reionization.

Kim et al. 2013

Impact of feedback on the LF and the HIMF

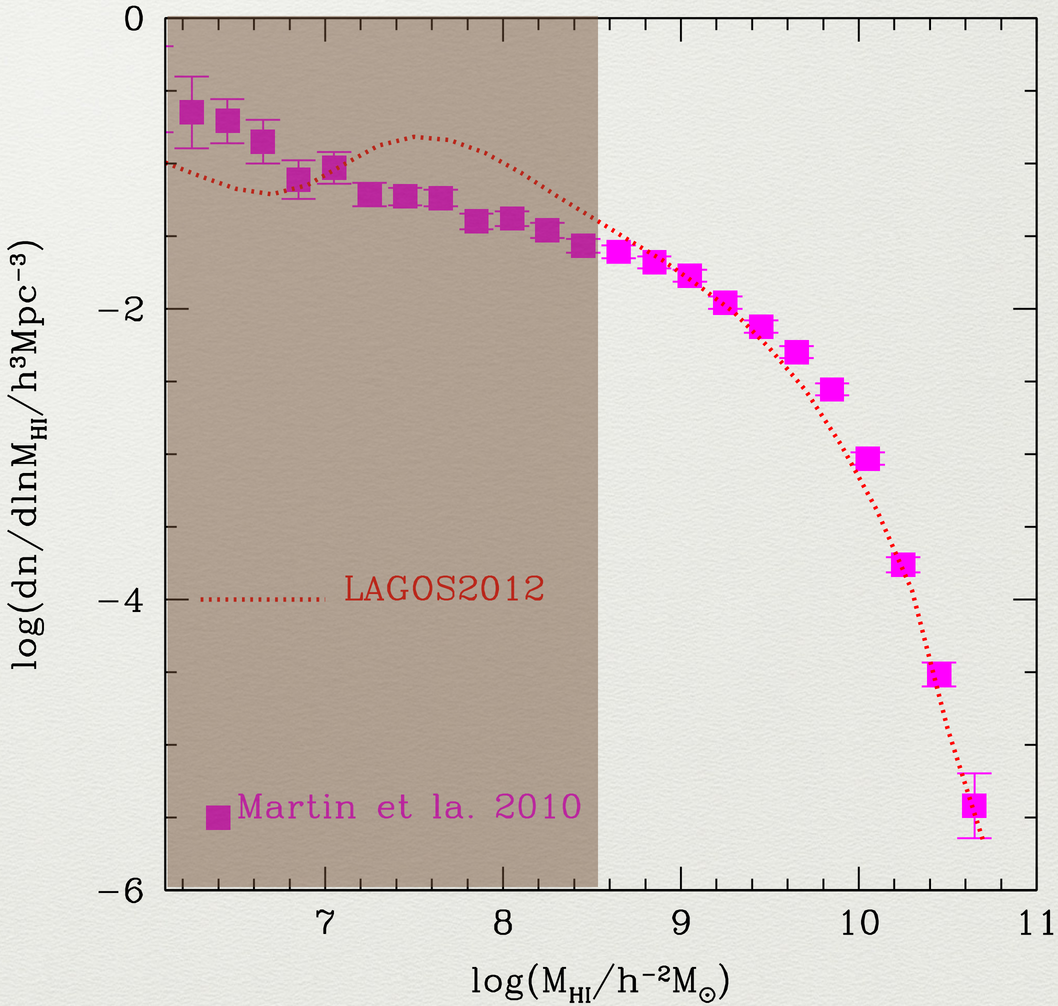


- The HIMF offers a weak constraint on SNe feedback and AGN feedback. In contrast, the HIMF is more sensitive to the strength of the photoionizing background than the LF.

Kim et al. 2013

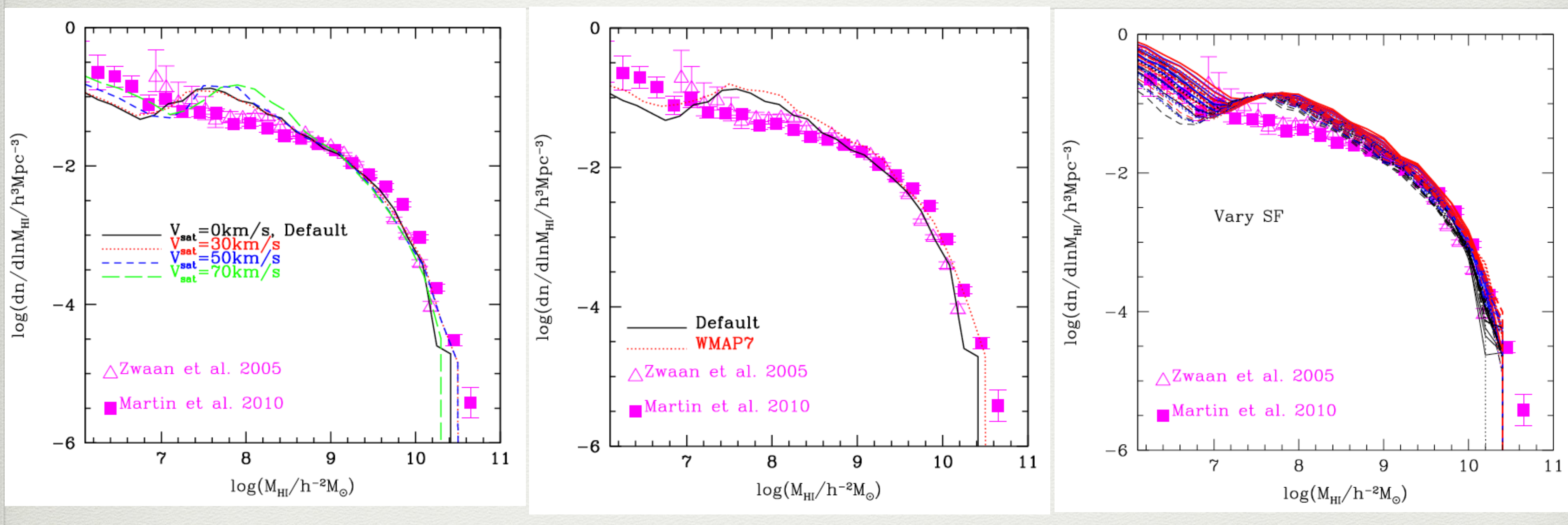
Probing photoionisation feedback on the HIMF

- Model predictions at the low mass end of HIMF.
- HIMF in the shade regime fails to capture the shape and abundance of the observed HIMF.
- Photoionisation feedback in the default model - the suppression of cooling occurs when the host halo's circular velocity below a threshold value (Vcut), at redshift less than Zcut.



Prep-1

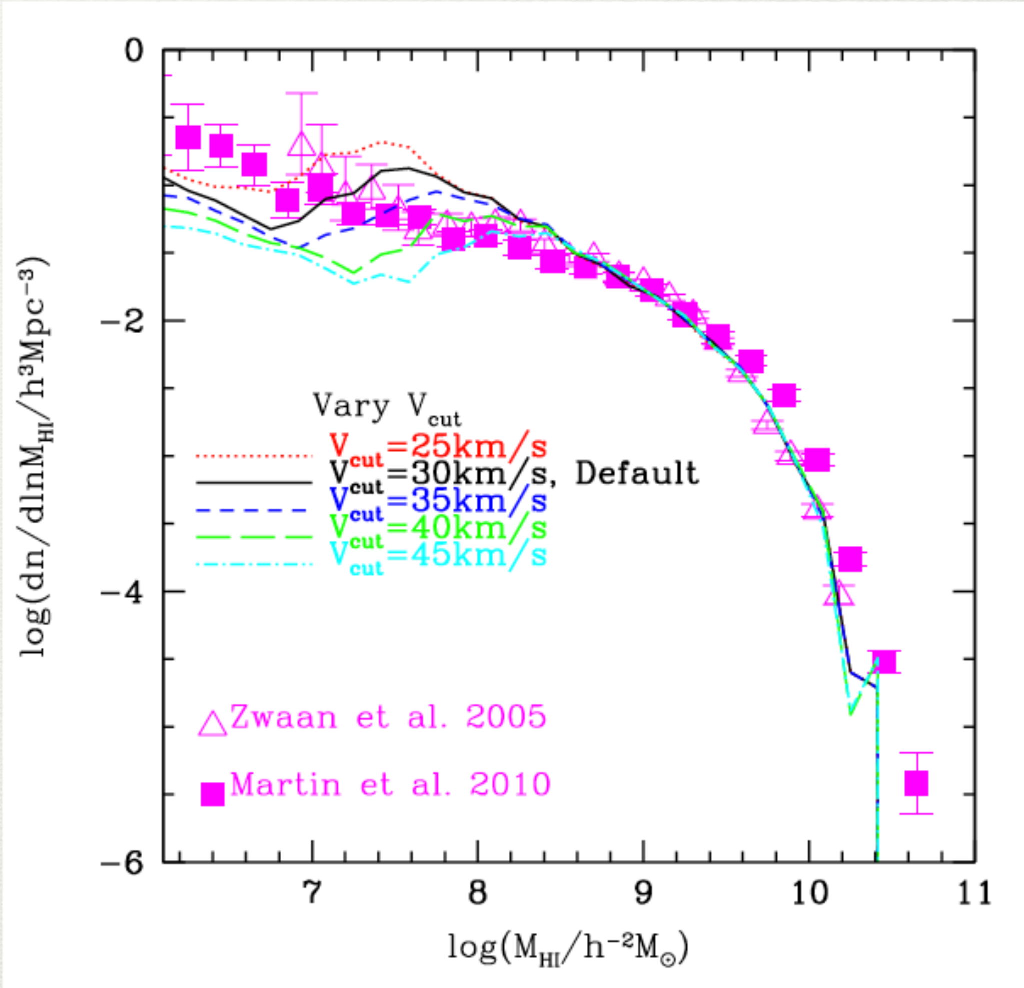
Probing photoionisation feedback on the HIMF



- SNe feedback recipes : SNe saturation model (Font et al. 2011)
- Cosmology : Millennium cosmology .vs. WMAP7 cosmology
- Varying values of parameters in the star formation law
  : star formation timescale for the molecular gas
  the internal hydrostatic pressure

Probing photoionisation feedback on the HIMF

- Varying strength of photoionisation feedback.
- The non-monotonic feature in the prediction that is not present in the data.



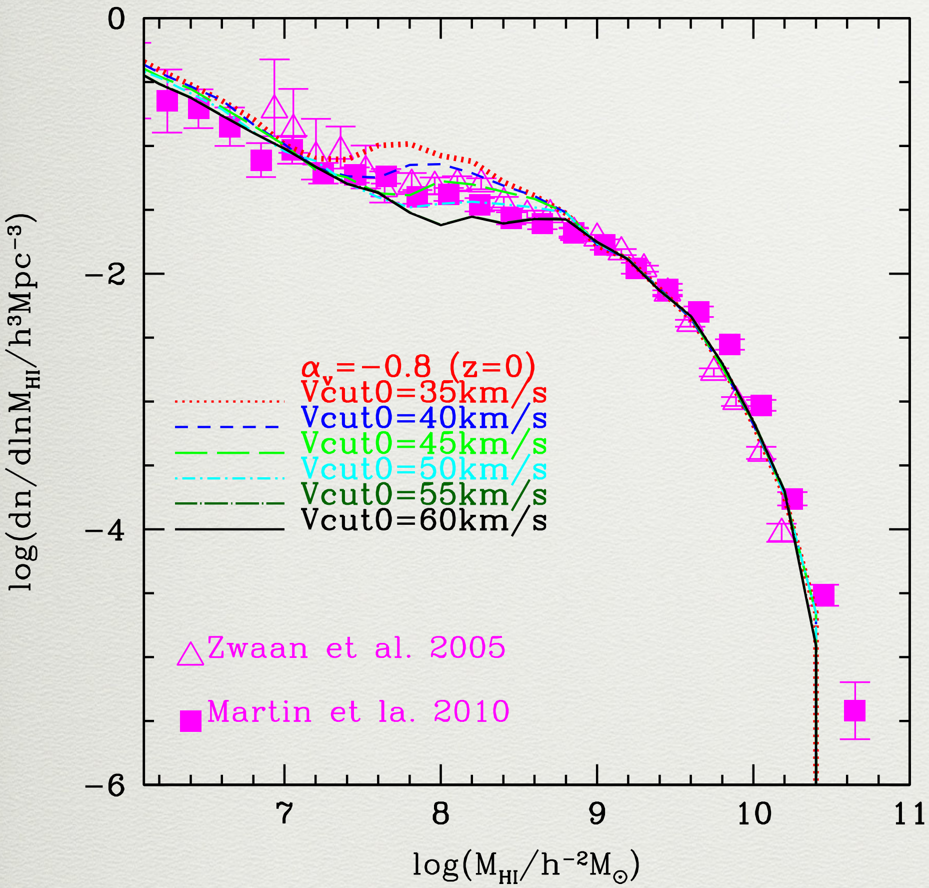
Probing photoionisation feedback on the HIMF

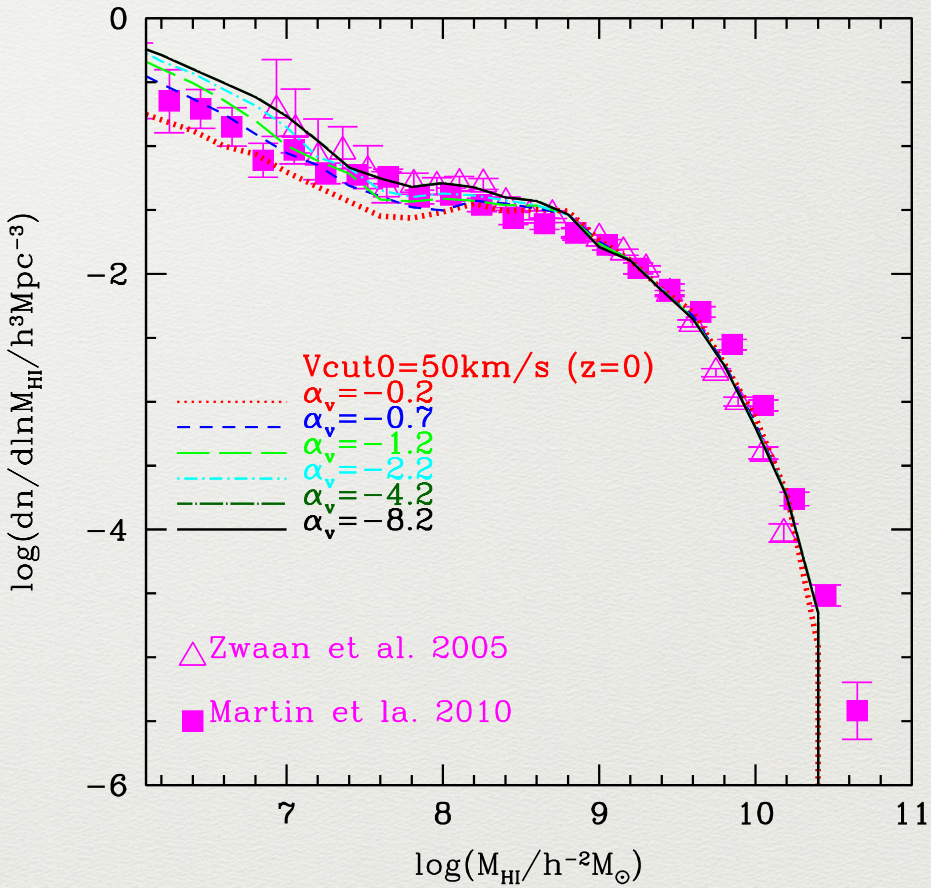
$$V_{\rm cut}(z)[{\rm km/s}] = V_{\rm cut0}(1+z)^{\alpha_v}\left[1-\left(\frac{1+z}{1+z_{\rm IN}}\right)^2\right]^{2.5/3}$$

- Motivated by the calculation of Sobacchi & Mesinger 2013 using hydrodynamic 1D collapse simulation.
- Redshift dependence of photoionisation feedback modelling.
- S&M2013 explored a large parameters space of halo masses (Mcrit~Vcut0), UV background intensity, redshift (Z), and redshift of UV background exposure of galaxies ($Z_{\rm IN}$).
- Use best fit parameters suggested by S&M2013.
- Varying two parameters to match the data.

$$V_{\rm cut}(z)[{\rm km/s}] = V_{\rm cut0}(1+z)^{\alpha_v}\left[1-\left(\frac{1+z}{1+z_{\rm IN}}\right)^2\right]^{2.5/3}$$

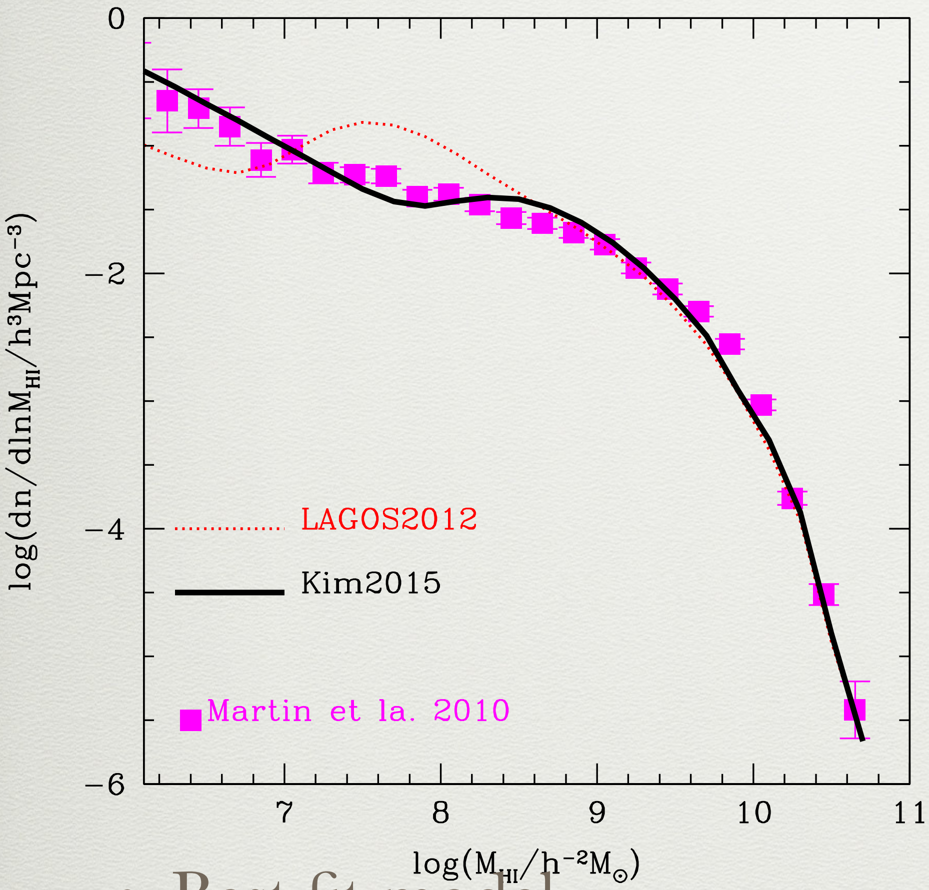
Probing photoionisation feedback on the HIMF

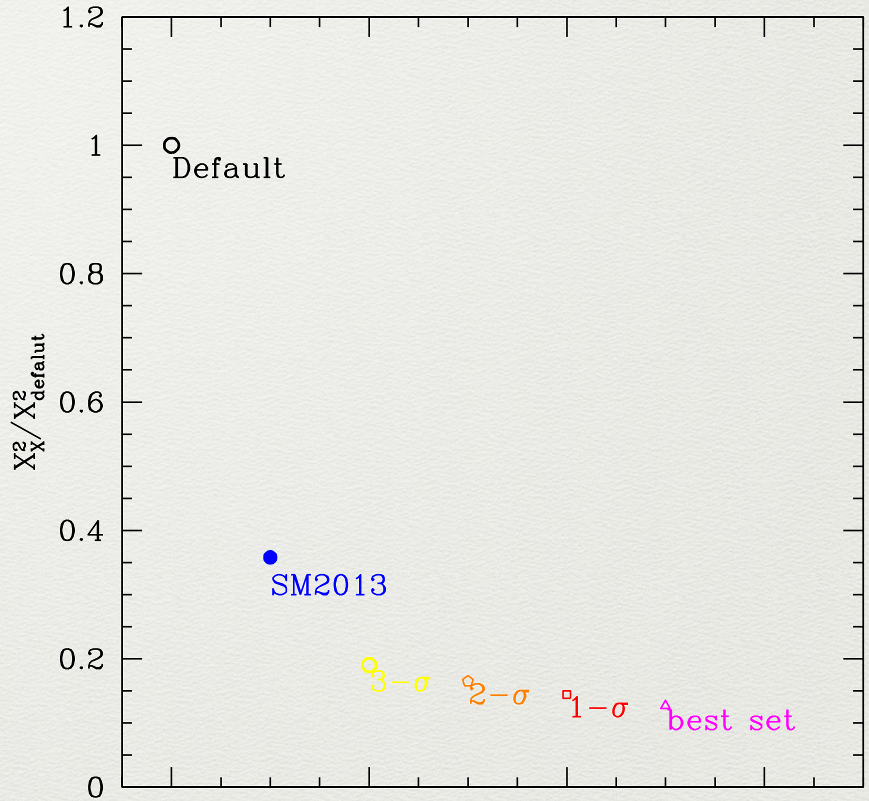




- Redshift dependent photoionisation feedback modelling

Probing photoionisation feedback on the HIMF

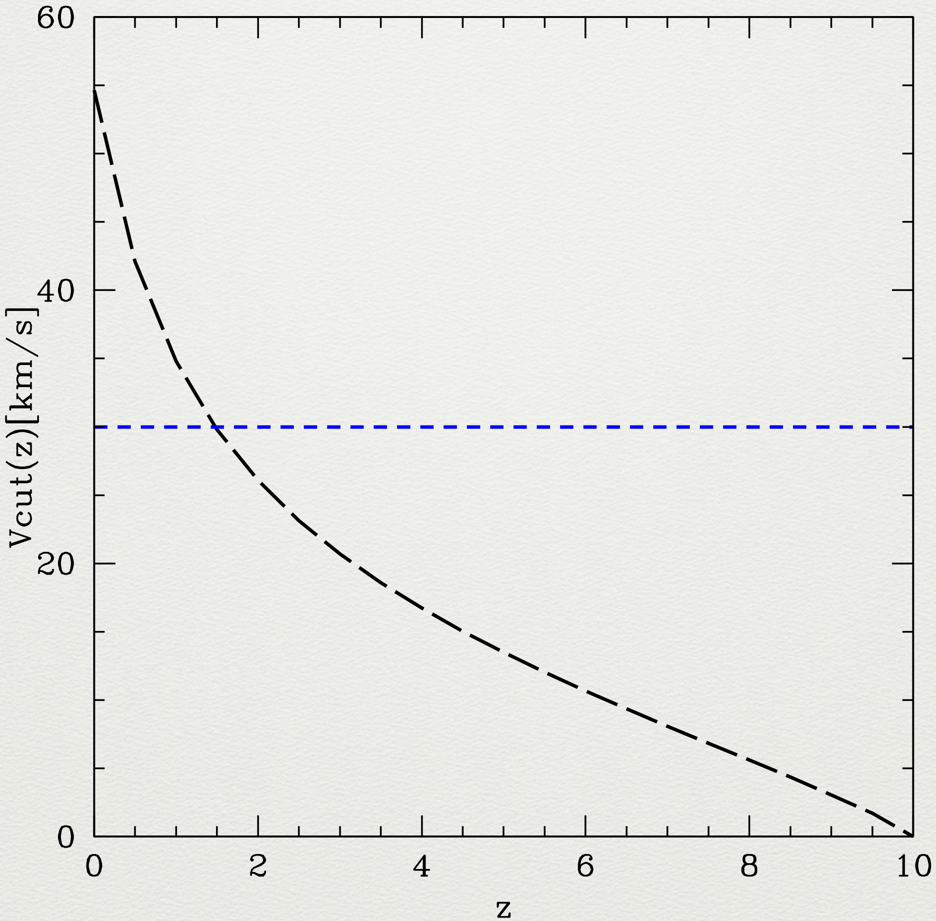




- Best fit model.
- Huge improvement of model prediction to the observation.

Prep-1

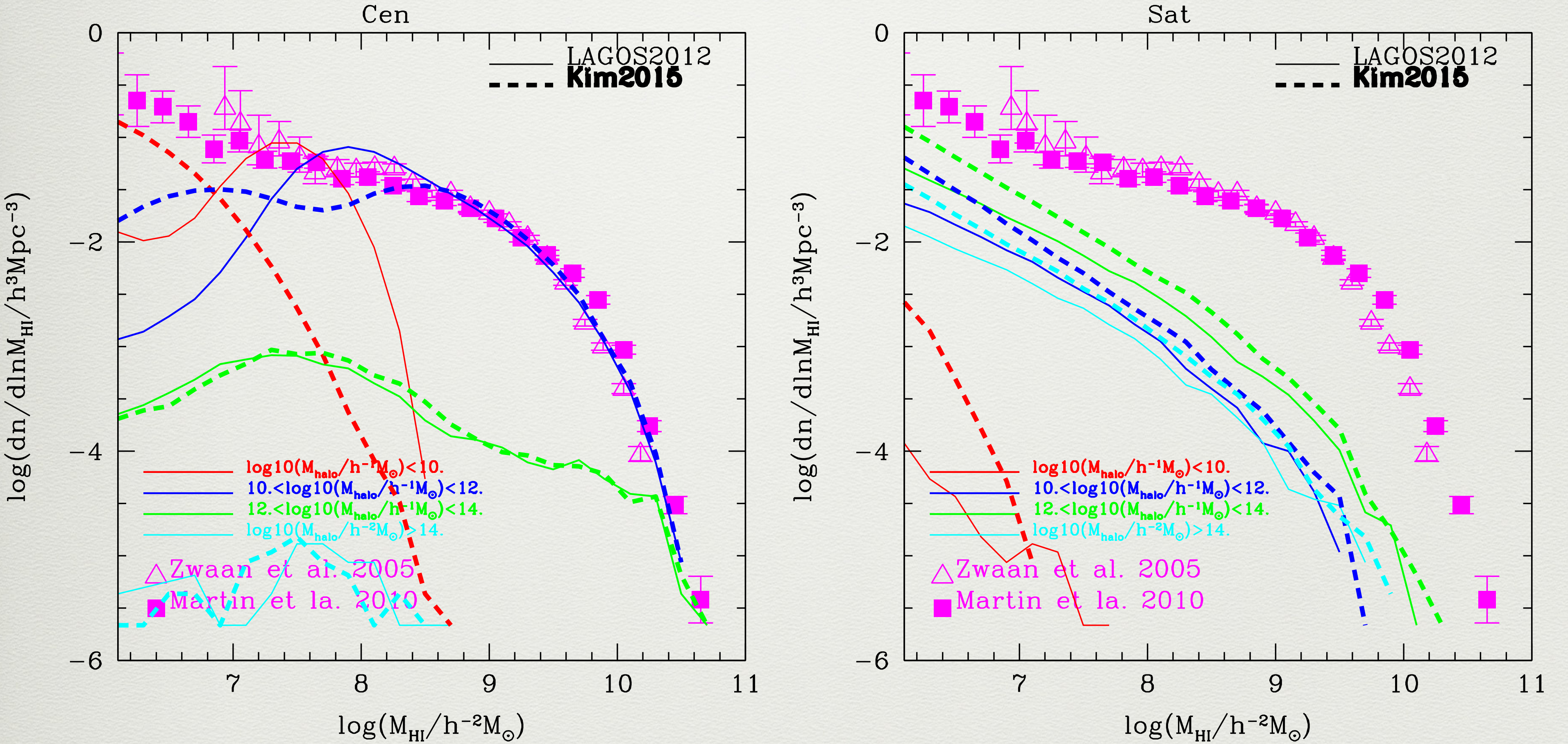
Probing photoionisation feedback on the HIMF



- The suppression of cooling by photoionisation background occurs when the host halo's circular velocity below Vcut and Vcut(z).

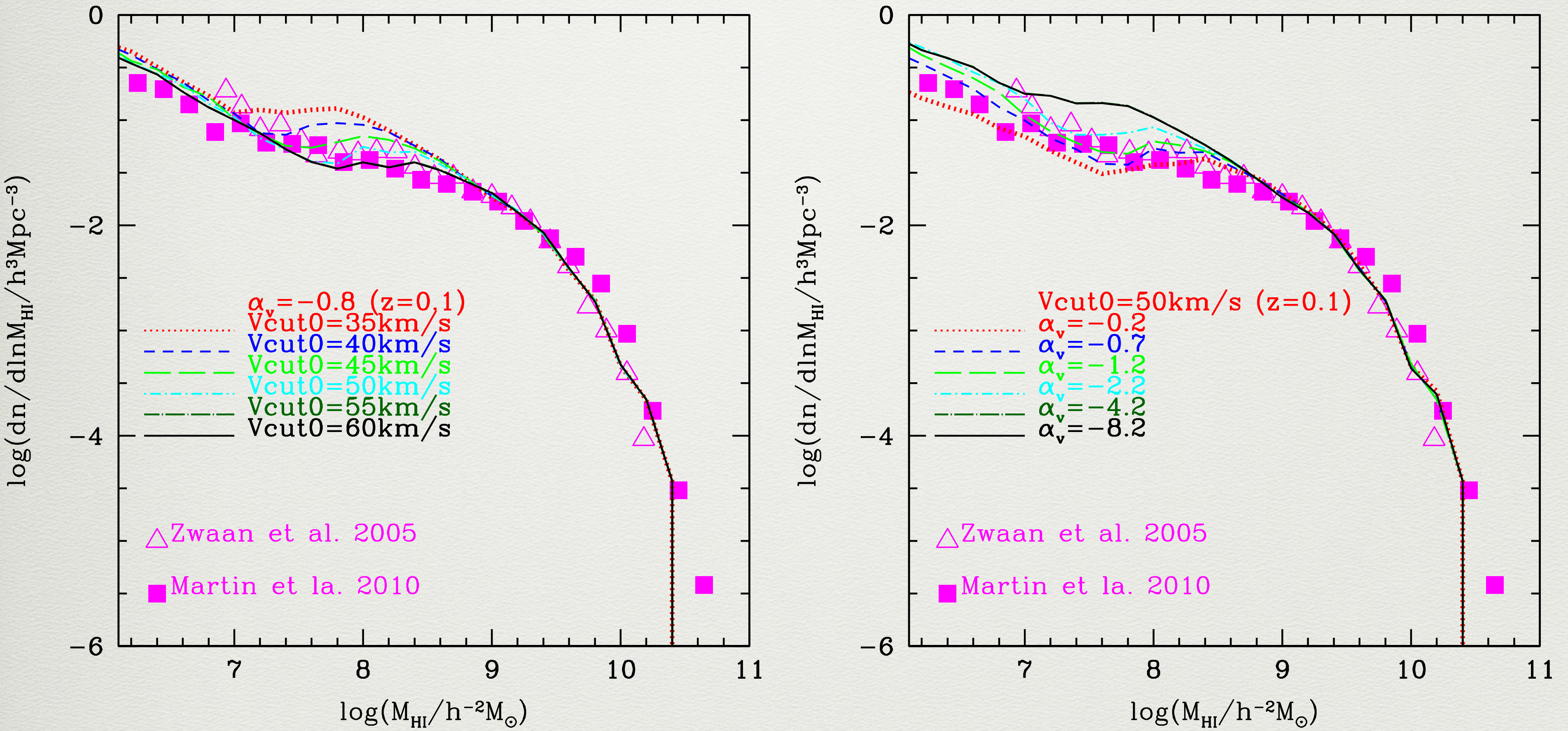
Prep-1

Probing photoionisation feedback on the HIMF

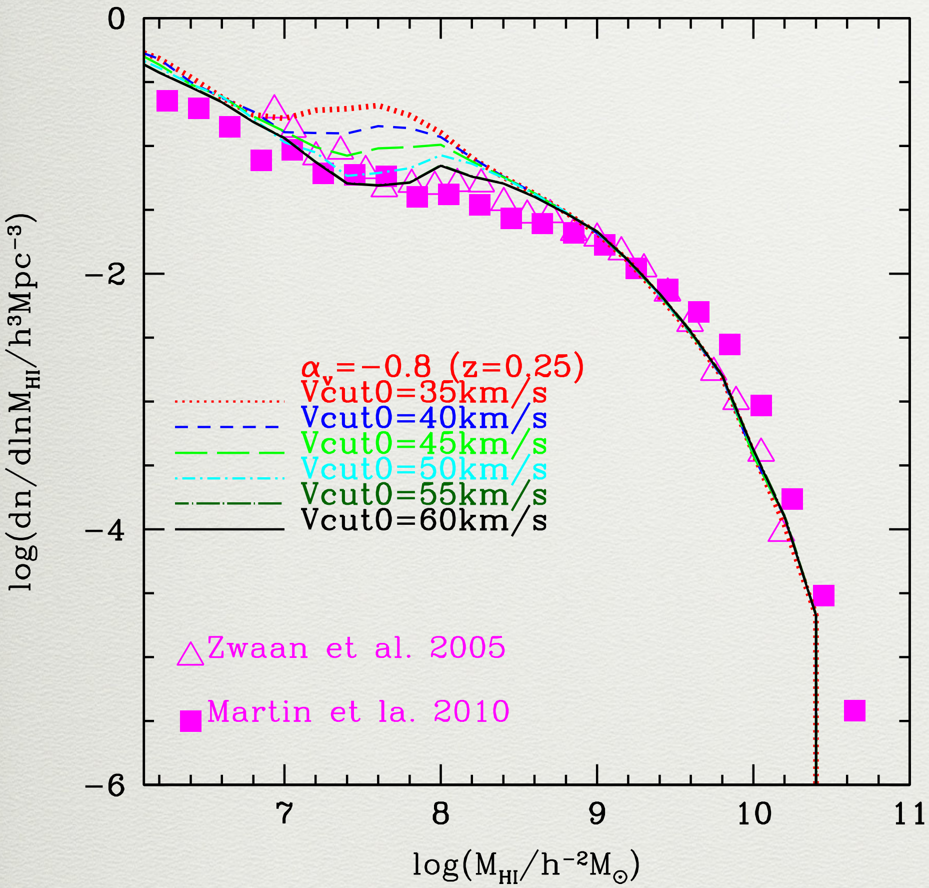


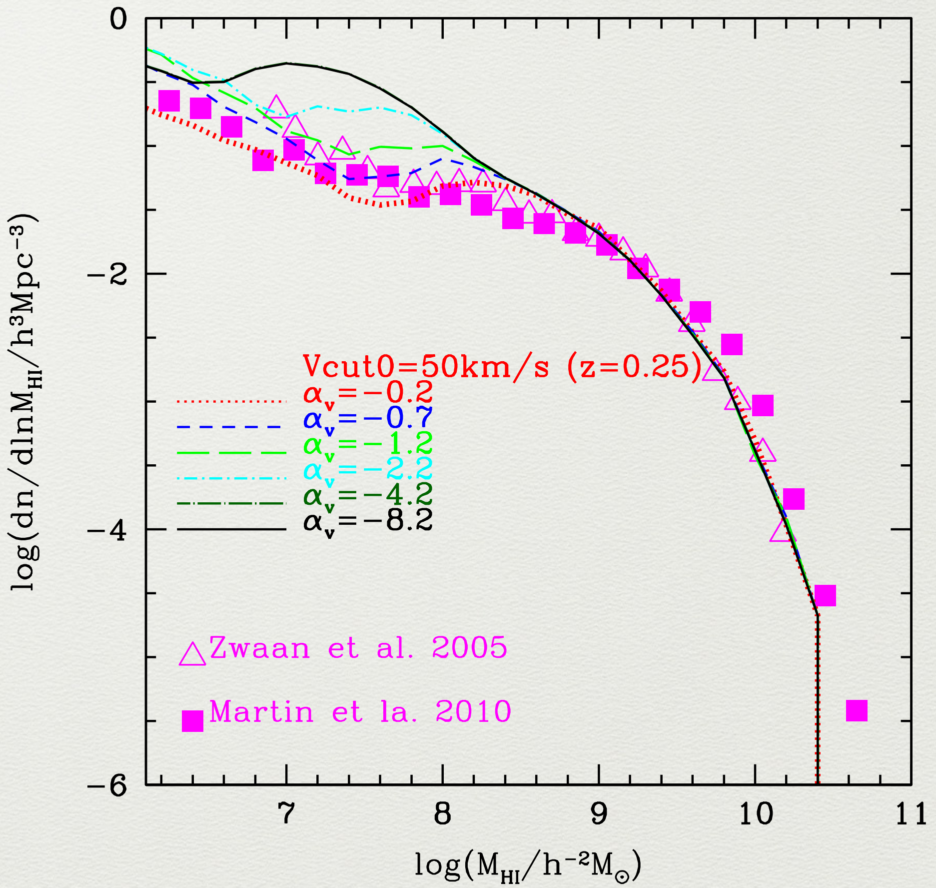
- Contributions of dark matter haloes to the HIMF

HIMFs at high-z

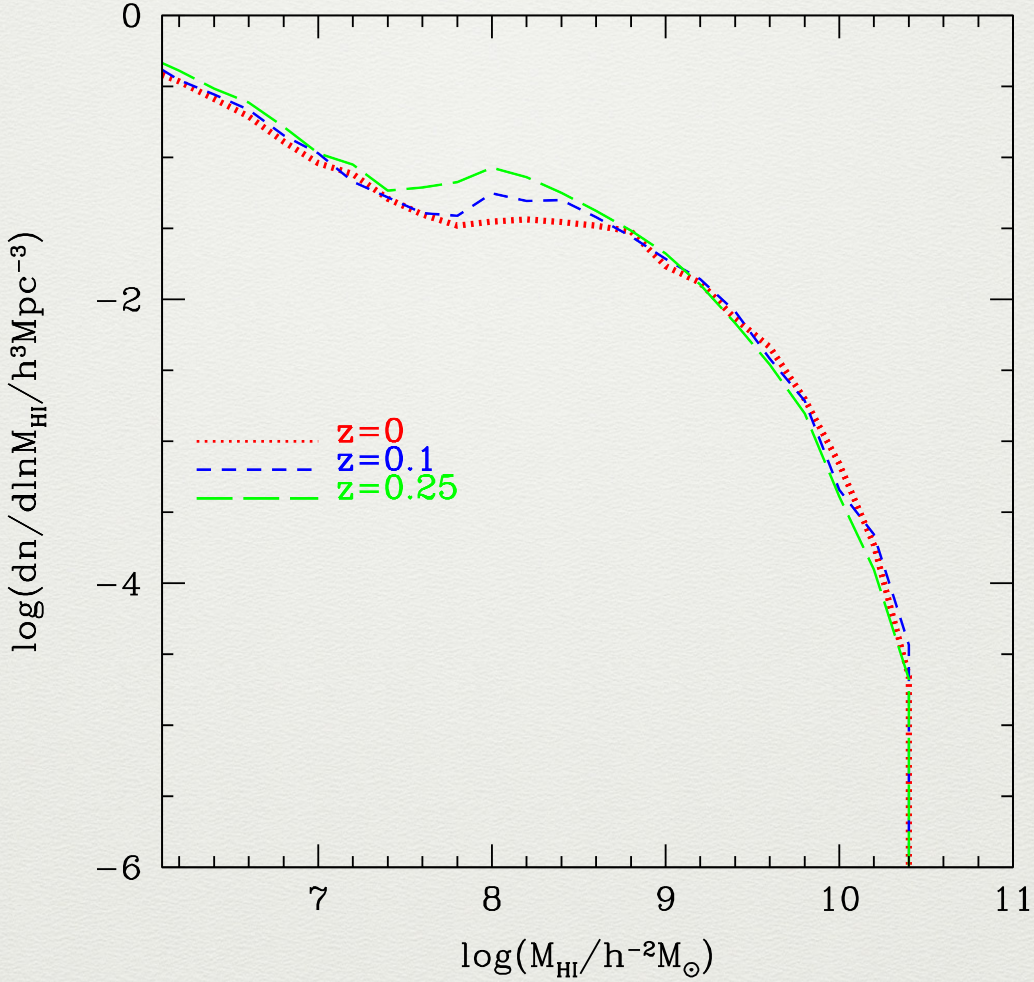


HIMFs at high-z





Evolution of HIMF



Summary

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- The HIMF is a more sensitive probe of the photoionisation feedback than the LF.
- Redshift dependent photoionisation feedback modelling is required to explain the low mass end of the HIMF.
- To understand see the imprinted feedback effect on the galaxy from the neutral hydrogen, we need surveys for individual HI galaxies not only the local Universe also high redhisfts.