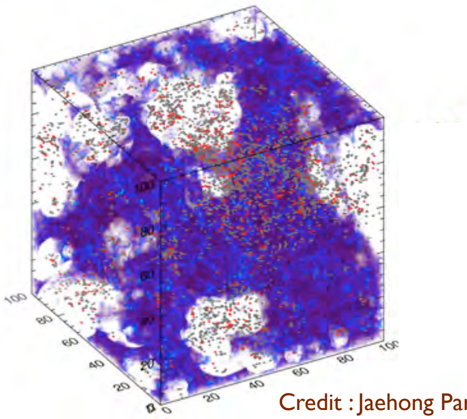
Understanding the Epoch of Reionization using Hierarchical galaxy formation models



Credit : Jaehong Park

Han(si)k Kim
with J. S. B. Wyithe, Jaehong Park, and GALFORMers

17/07/2013 Reionization in the Red Centre

Hello,
My name is Hansik Kim.

THE UNIVERSITY OF MELBOURNE

ICC Institute for Computational Cosmology

Understanding the epoch of reionization and the properties of the first galaxies represents an important goal for modern cosmology. The structure of reionization and hence
the observed power spectrum of redshifted 21-cm fluctuations are known to be sensitive to the astrophysical properties of the galaxies that drove reionization.
Thus, detailed measurements of the 21-cm power spectrum and its evolution could lead to measurements of the properties of early galaxies that are otherwise inaccessible.
In this talk, I will show predictions for the ionized structure during reionization and the 21-cm power spectrum based on detailed models of galaxy formation.

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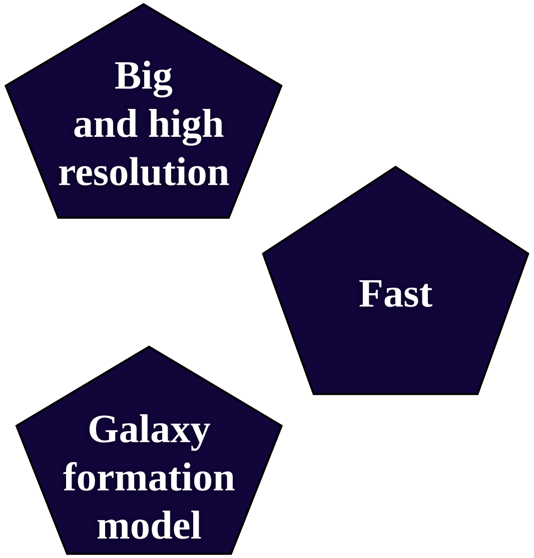


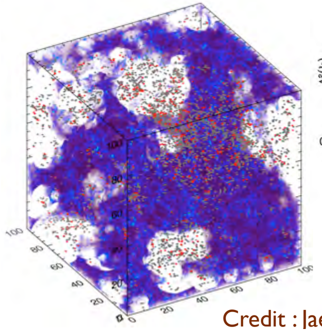
Making predictions for the ionized structure during reionization and the 21-cm power spectrum based on detailed models of galaxy formation.

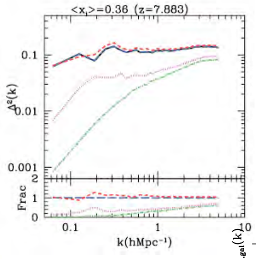
Combined the GALFORM model implemented within the Millennium-II dark matter simulation, with a semi-numerical scheme.

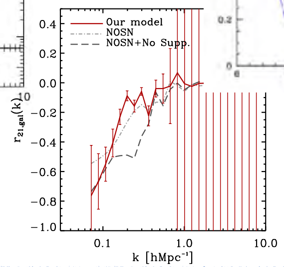
Halo mass resolution ~ 10^{8} solar masses corresponding to the faint sources thought to dominate reionization.

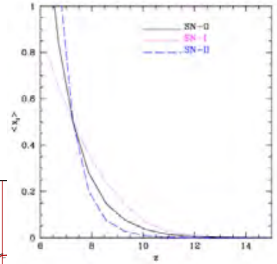
Using these models we show that the details of supernovae and radiative feedback affect the structure and distribution of ionized regions, and hence the slope and amplitude of the 21-cm power spectrum.

Outline

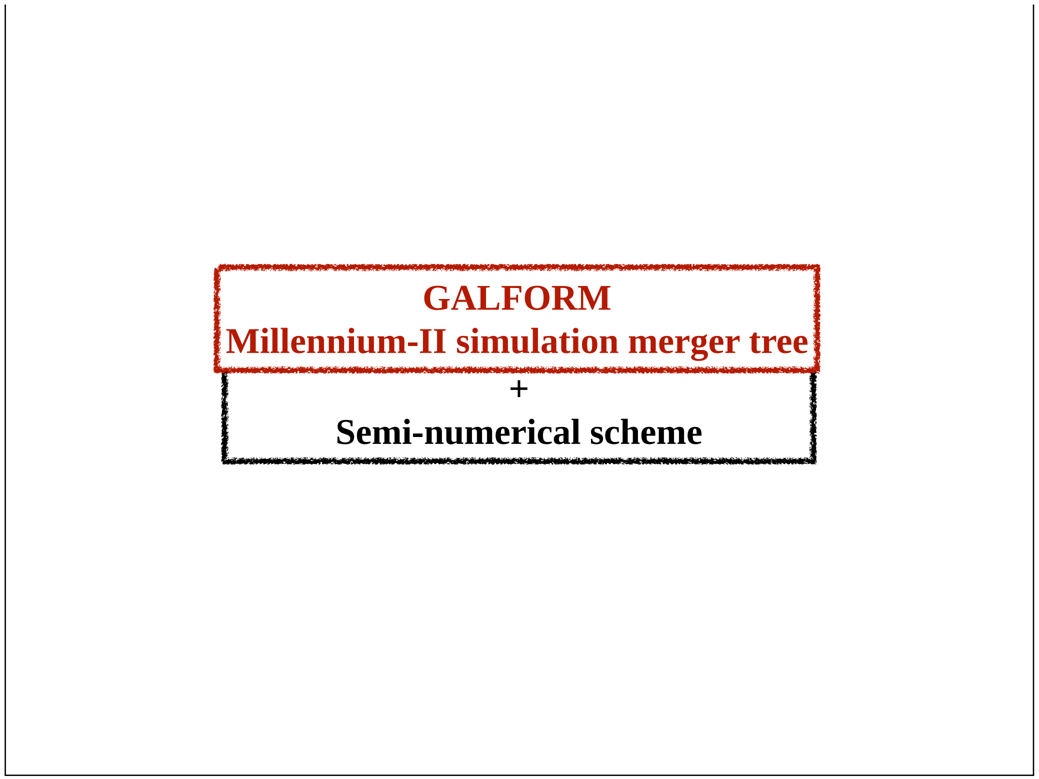


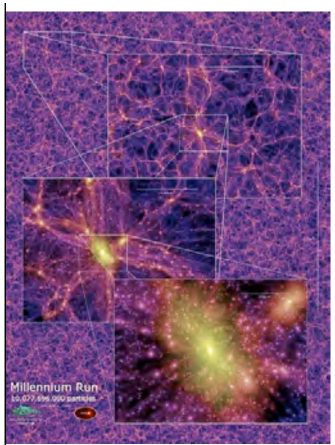




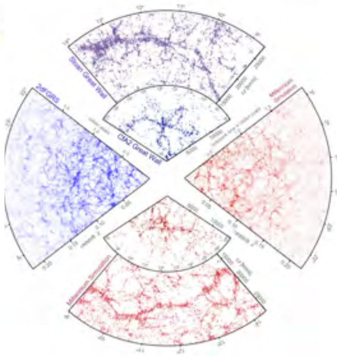


Our method.
21-cm power spectrum predictions.
(Kim+ 2013a : 2013MNRAS.428.2467K)
cross-power spectrum predictions between galaxy and 21-cm observations.
(Jaehong Park, Poster #10)
21-cm power spectrum from escape fraction dependencies.
(Kim+ 2013b : 2013MNRAS.tmp.1574K)

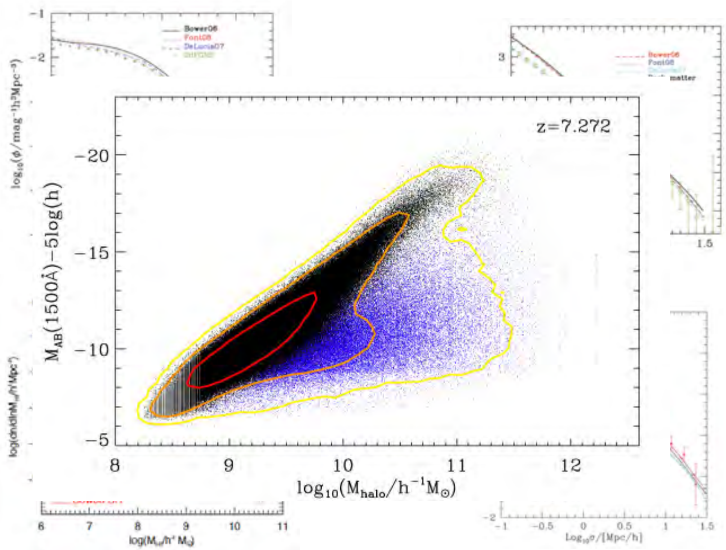

GALFORM
Millennium-II simulation merger tree
+
Semi-numerical scheme



- •Rapid exploration of the parameter space of galaxy formation physics.
- •Large, statically useful samples.
- •Wide range of properties, multi-wavebands.
- •Well explain local and moderate redshift observations.



Examples



Kim+ 2009; 2011

Method : Combine a semi-analytic model with semi-numerical scheme

GALFORM using N-body merger trees based on the Millennium-II simulation.

256x256x256 cells

escape fraction

$$N_{\gamma,\mathrm{cell}} = f_{\mathrm{esc}} \int_0^{t_z} \dot{N}_{\mathrm{Lyc,cell}}(t)\, dt,$$

$$Q_{\mathrm{cell}} = \left[\frac{N_{\gamma,\mathrm{cell}}}{(1+F_{\mathrm{c}})N_{\mathrm{HI,cell}}} \right],$$

recombination parameter

$$N_{\mathrm{HI,cell}} = n_{\mathrm{HI}}(\delta_{\mathrm{DM,cell}} + 1)V_{\mathrm{cell}},$$

$$\Delta T = 23.8 \left(\frac{1+z}{10} \right)^{\frac{1}{2}} [1-Q]\,(1+\delta_{\mathrm{DM,cell}})\ \mathrm{mK}.$$

$$\Delta^2(k) = k^3/(2\pi^2)P_{21}(k)$$

Ionization structure at EoR

21cm Power Spectrum

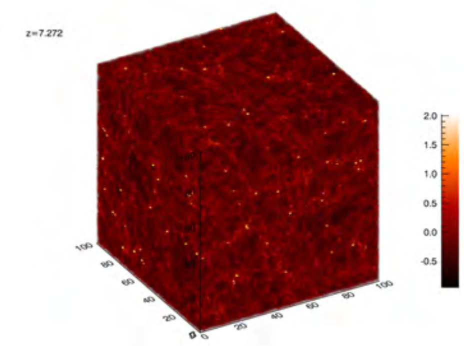
Kim+ 2013a

We combine the semi-analytic GALFORM model implemented within the Millennium-II dark matter simulation, with a semi-numerical scheme to describe the resulting ionization structure.

The M-II simulation enough to resolve the halo mass ~10^{8} which is donimant ionization source at redshift higher than 6.

Dark matter simulation (M-II)

$$N_{\mathrm{HI,cell}} = n_{\mathrm{HI}}(\delta_{\mathrm{DM,cell}} + 1)V_{\mathrm{cell}},$$



Over-density of neutral hydrogen follows the dark matter (computed based on the Millennium-II Simulation density field).

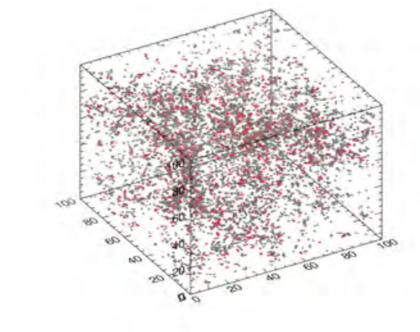
nHI is the mean comoving number density of hydrogen atoms.

Vcell is the comoving volume of the cell.

256^3 cells, side length 0.3906 Mpc/h and comoving volumes 0.0596 Mpc^3/h^3.

+
Semi-Analytic model (GALFORM)

$$\dot{N}_{\mathrm{Lyc},i}(t) = \int_{\nu_{\mathrm{thresh}}}^{\infty} \frac{L_{\nu,i}(t)}{h\nu} \mathrm{d}\nu,$$



$L_{\nu,i}$ is the spectral energy distribution of galaxy i
$h\nu_{\mathrm{thresh}}$=13.6eV.

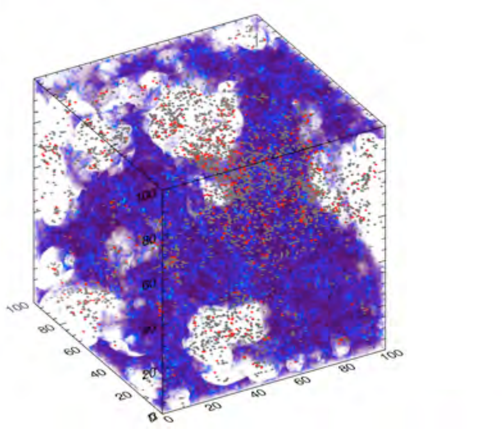
$$\dot{N}_{\mathrm{Lyc,cell}}(t) = \sum_{i=1}^{N_{\mathrm{cell}}} \dot{N}_{\mathrm{Lyc},i}(t),$$

The total Lyman luminosity continuum of N_{cell} galaxies within the cell expressed as the emission rate of ionizing photons.

$$N_{\gamma,\mathrm{cell}} = f_{\mathrm{esc}} \int_0^{t_z} \dot{N}_{\mathrm{Lyc,cell}}(t)\ dt,$$

escape fraction

+
Semi-numerical scheme



Dots : Galaxies from GALFORM

$$Q_{\rm cell} = \left[\frac{N_{\gamma,\rm cell}}{(1+F_{\rm c}) N_{\rm HI,cell}} \right],$$

recombination parameter

White area : HII region

Qcell ≧ 1 : ionized cell,

Qcell < 1 : may be ionized by photons produced in a neighbouring cell.

To find the extent of ionized regions using a sequence of real-space top-hat filter of radius R.

The brightness of blue : Intensity of HI

Variant models

	V_{cut}[kms^{-1}]	V_{hot}[kms^{-1}]	Υ	Comments
Bow06	30	485	1	Bower et al. (2006), V_{cut} value change
Lagos	30	485	1	Lagos et al. (2012)
Bow06(no suppression)	0	485	1	Bower et al. (2006), No radiative suppression
NOSN	30	0	4	Bower et al. (2006), No SNe feedback
NOSN(no suppression)	0	0	4	Bower et al. (2006) No SNe feedback and No radiative suppression

Table 2. The values of $(1 + F_c)/f_{esc}$ corresponding to the different models and redshifts shown in this paper.

Redshift (z) (x_i)	9.278 0.056	8.550 0.16	7.883 0.36	7.272 0.55	6.712 0.75	6.197 0.95
Bow06	4.85	3.24	2.72	3.10	3.83	4.82
Bow06 (no suppression)	4.856	3.24	2.71	3.12	3.85	4.81
Lagos	3.86	2.61	2.17	2.53	3.11	3.95
NOSN	417.98	189.28	106.70	85.59	74.83	68.94
NOSN (no suppression)	267.78	136.97	85.03	73.86	69.62	68.28

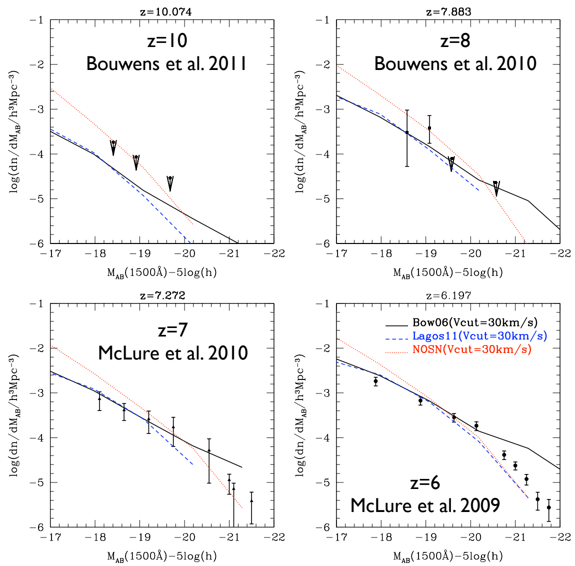
Υ quantifies the assumption for the IMF of brown dwarfs(m < 0.1M)

The suppression of cooling occurs when the host halo's circular velocity lies below a threshold value, Vcut.

Vhot is a parameter to control strength of SNe feedback.

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

UV Luminosity Function



Kim+ 2013a

The predictions of UV luminosity functions from the models together with observational data points at high redshifts.

Models

	$V_{\rm cut}$[kms^{-1}]	$V_{\rm hot}$[kms^{-1}]	Υ	Comments
Bow06	30	485	1	Bower et al. (2006), $V_{\rm cut}$ value change
Lagos	30	485	1	Lagos et al. (2012)
Bow06(no suppression)	0	485	1	Bower et al. (2006), No radiative suppression
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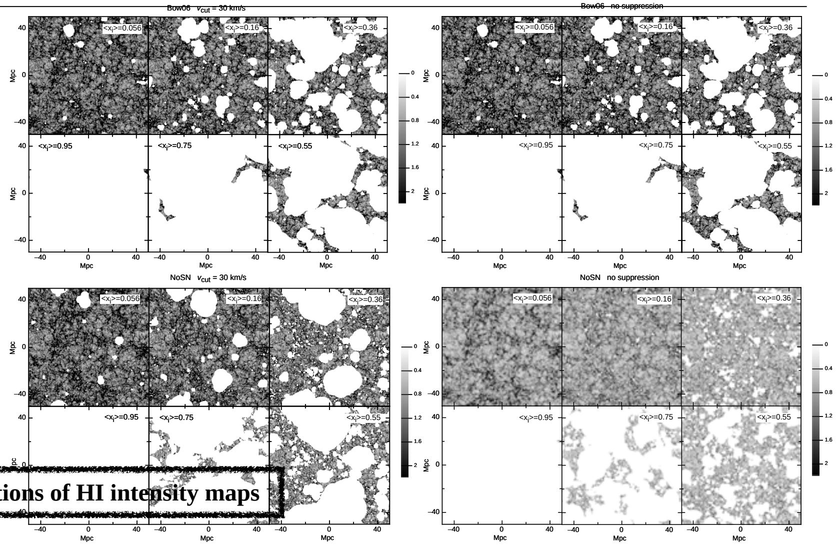

Predictions of HI intensity maps

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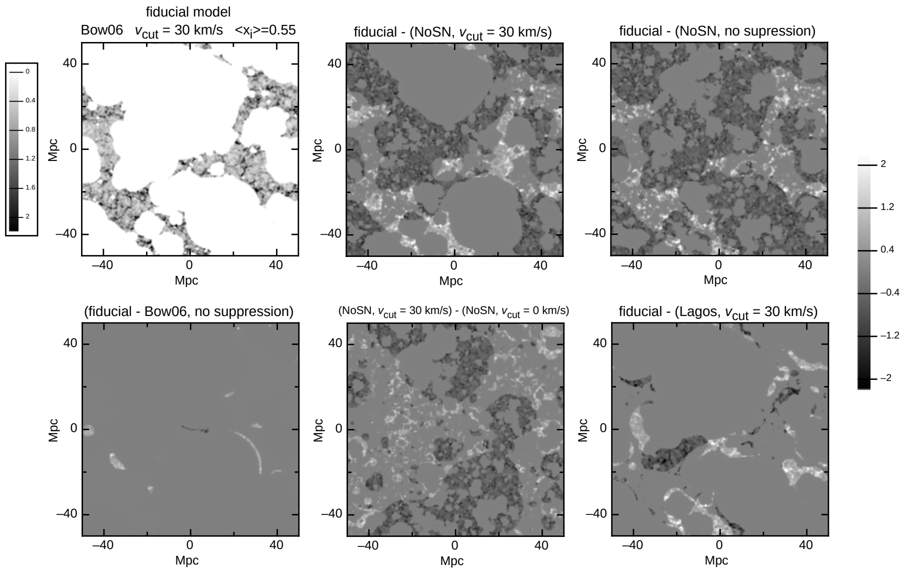
Substraction of Bow06 map from models' maps



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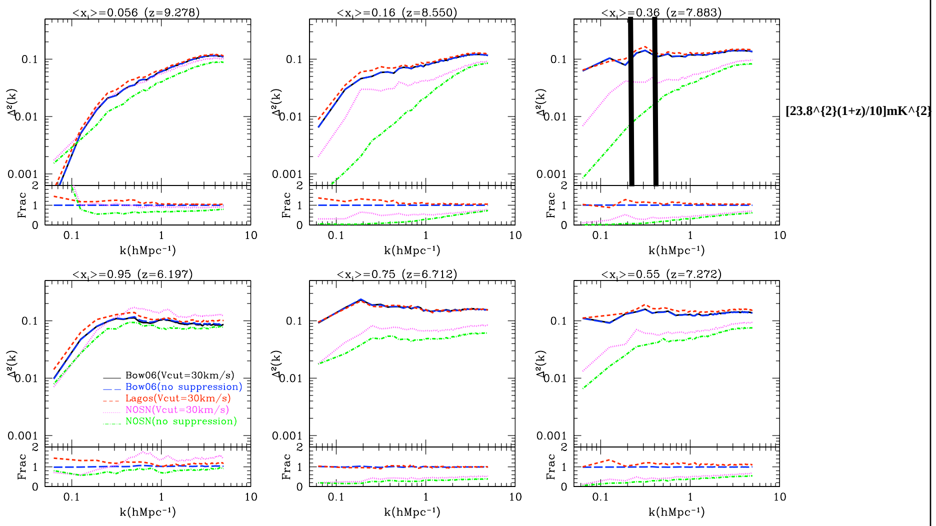
Predictions of 21 cm power spectrum at EoR



The SNe feedback impacts on the 21cm PS at EoR not only amplitude but also slope.

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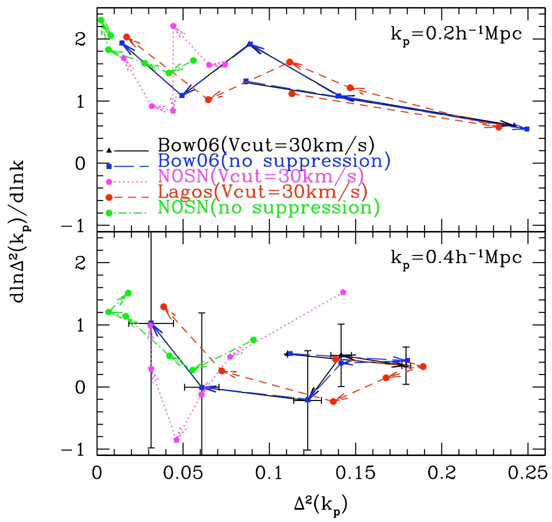
Prediction for upcoming observation.



The predicted estimation from MWA with 1000hrs integration time and 6MHz of bandpass. (500 tiles from Lidz et al. 2008)

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The cross-power spectrum between 21cm emission and galaxies in hierarchical galaxy formation models

THE UNIVERSITY OF MELBOURNE

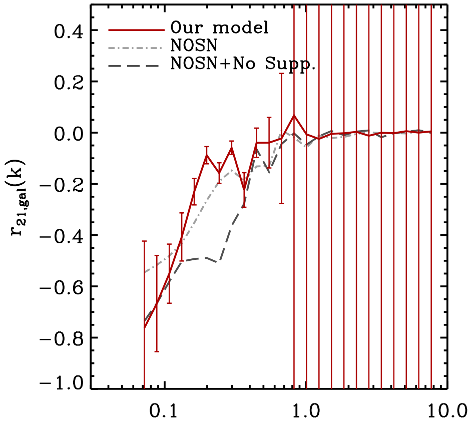
Jaehong Park[1], Han-Seek Kim[1], J. Stuart B. Wyithe[1,2]

[1]School of Physics, University of Melbourne

[2]ARC Centre of excellence for All-sky Astophysics (CAASTRO)

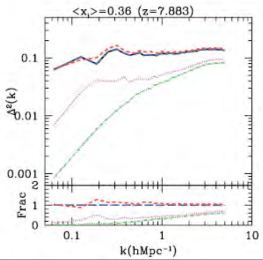
1. Abstract

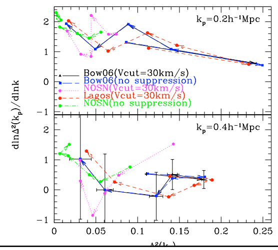
The correlation between 21cm fluctuations and galaxies is sensitive to the astrophysical properties of the galaxies that drove reionization. Thus, detailed measurements of the cross-power spectrum and its evolution could provide a powerful measurement both of the properties of early galaxies and the process of reionization. In this work, we study the evolution of the cross-power spectrum between 21cm emission and galaxies using a model which combines the hierarchical galaxy formation model GALFORM implemented within the Millennium-II dark matter simulation, with a semi-numerical scheme to describe the resulting ionization structure. We find that inclusion of different feedback processes changes the predicted cross-power spectrum, predominantly because the size of ionized regions at fixed ionized fraction is significantly affected by the strength of supernovae feedback. We calculate predicted observational uncertainties of the cross-correlation coefficient based on specifications of the Murchison Widefield Array (MWA) combined with galaxy surveys. We find that the cross-power spectrum could be detected over several square degrees of galaxy survey with galaxy redshift errors less than 0.1.

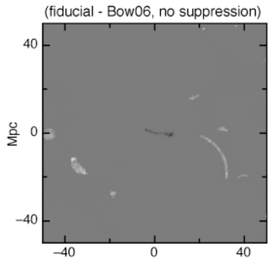


Summary-I

- **The new method combines a hierarchical galaxy formation model (based on Millennium-II merger trees) with semi-numerical scheme to predict redshifted 21cm power spectrum during the EoR.**
- **We could see the SNe feedback effect imprinted on the 21cm power spectrum at EoR.**
- **If SNe feedback is effective at suppressing star formation at high redshift galaxies, radiative feedback does not lead to self-regulation of the reionization process.**







Unknowns about escape fraction

The escape fraction of ionizing photons from their host galaxies is one of the most important unknowns for the reionization history.

Observational estimates show a broad range of escape fraction values from a few per cent in the local Universe to a few per cent or a few tens of per cent at redshift z ~1–3.

(Hurwitz, Jelinsky & Dixon 1997; Bland-Hawthorn&Maloney 1999; Putman et al. 2003; Inoue, Iwata & Deharveng 2006; Shapley et al. 2006; Chen, Prochaska & Gnedin 2007; Siana et al. 2007).

However, there are no observational constraints on the escape fraction during the epoch of reionization.

Theoretically, the escape fraction is predicted to span a very broad range from 0.01 to 1.

(Ricotti & Shull 2000; Wood & Loeb 2000; Benson et al. 2002; Ciardi et al. 2003; Fujita et al. 2003; Sokasian et al. 2003;Wyithe & Loeb 2007;Wise & Cen 2009; Raiˇcevi´c et al. 2011; Kuhlen & Faucher-Gigu`ere 2012).

We assume several different models for fesc. We model dependencies of the escape fraction with halo mass and redshift using

$$f_{\rm esc} = A \times \left(\frac{1+z}{7}\right)^{\alpha} \left(\log_{10}(\mathrm{M_{halo}/h^{-1}M_{\odot}})/10\right)^{\beta}$$

$$\dot{N}_{\mathrm{Lyc},i}(t) = f_{\rm esc} \int_{\nu_{\rm thresh}}^{\infty} \frac{L_{\nu,i}(t)}{h\nu}\, \mathrm{d}\nu$$

	A	α	β
Model 0	0.5348	0	0
Model I	0.1488	5	0
Model II	1.6791	-5	0
Model III	0.3649	0	5
Model IV	0.8966	0	-5

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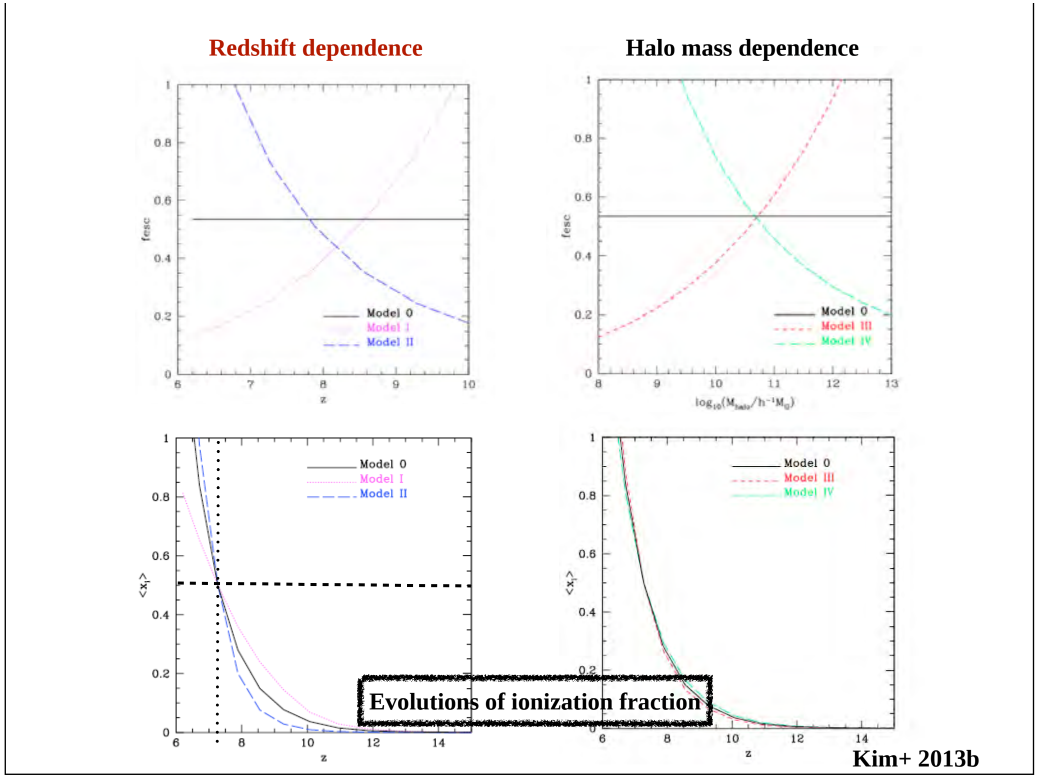
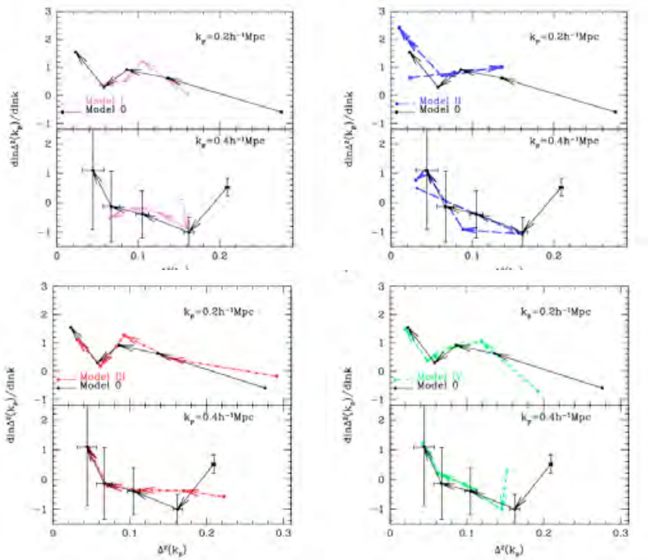


We force to fesc=0 when the value of Eq. 7 is negative and fesc=1 when the value greater than unity. We also consider a fiducial model with fesc=constant.
We assume Fc to equal 0.5.

Prediction for upcoming observation



Redshift dependence

Halo mass dependence

The slope and amplitude of the 21 cm power spectrum, is dependent on the variation of ionising photon escape fraction.

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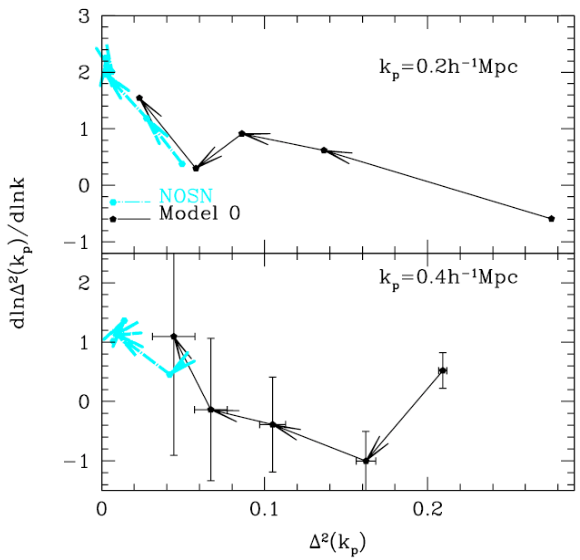

The dominant astrophysical effect provided by SNe feedback strength in high redshift galaxies influence bigger than unknown escape fraction and its evolution.

Kim+ 2013b

Summary-II

- We find that the influence of the unknown escape fraction and its evolution is smaller than the dominant astrophysical effect provided by SNe feedback strength in high redshift galaxies.

Summary-I+II

- The new method combines a hierarchical galaxy formation model (based on Millennium-II merger trees) with semi-numerical scheme to predict redshifted 21cm power spectrum during the EoR.
- We could see the SNe feedback effect imprinted on the 21cm power spectrum at EoR.
- If SNe feedback is effective at suppressing star formation at high redshift galaxies, radiative feedback does not lead to self-regulation of the reionization process.
- We find that the influence of the unknown escape fraction and its evolution is smaller than the dominant astrophysical effect provided by SNe feedback strength in high redshift galaxies.

Thank you!!