

Modelling the post reionization HI distribution for future 21 cm Intensity Mapping experiments

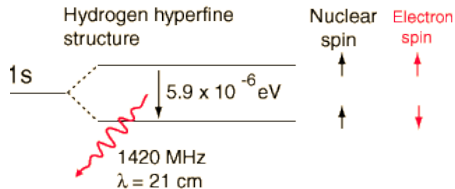
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Astro@TS



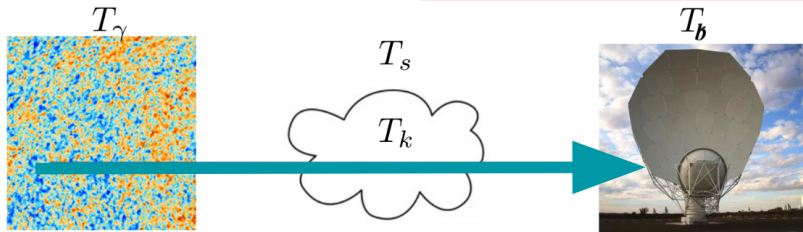
The 21cm probe



3 fundamental temperatures:

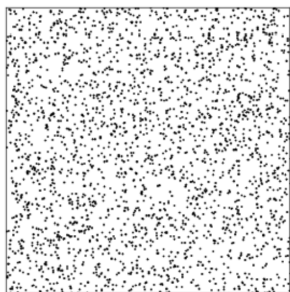
- T_γ the CMB temperature
- T_k the gas (IGM) temperature
- T_s the *spin temperature*

Post Reionization: $T_b \propto x_{\text{HI}}$

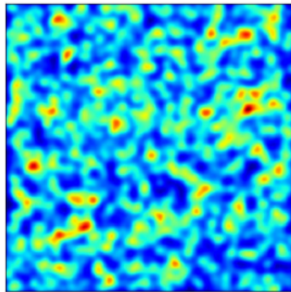


21 cm Intensity Mapping

- Look at the total intensity of the 21 cm emission line in a large 3d pixel (angle and frequency)
- Pixel will have joint emission from multiple galaxies
- Cheap for large volume



galaxies



Intensity map

Present and future instruments

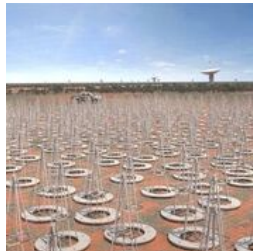
Taking data (some examples):

- CHIME (Canada)
- FAST (China)
- Parkes Radio Telescope (Australia)



The Square Kilometer Array (SKA):

- SKA-MID: ~ 200 dishes of 15 m in the Karoo Desert (South Africa)
350 MHz to 14 GHz
- SKA-LOW: $> 10^5$ simple dipole antennas in Western Australia
50 MHz to 350 MHz



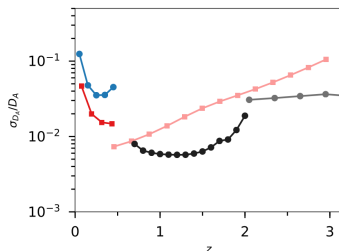
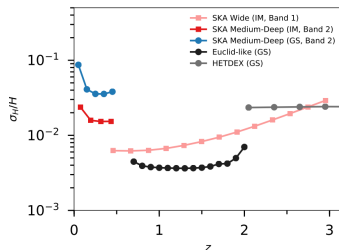
Cosmology with SKA

SKA1-MID

20000 deg², 10000h,
single dish mode

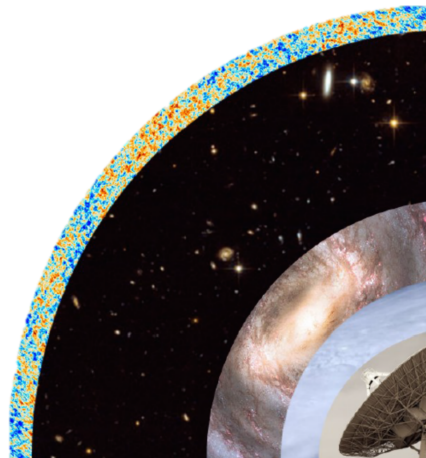
e.g. Baryon Acoustic Oscillations

- radial BAO scale sensitive to the **expansion rate**, $H(z)$
- transverse BAO scale sensitive to the **angular diameter distance**, $D_A(z)$
- constraints broad range of z
- complementary to **Euclid**



SKA Red Book 2019

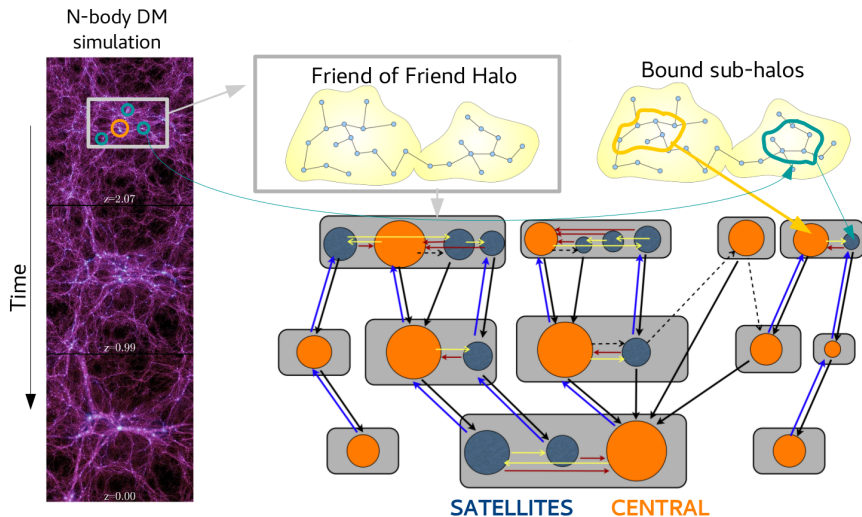
Challenges with HI observations



credit: D. Alonso

- HI IM signal
- Extragalactic Foregrounds
 - Point Sources (I,Q,U)
 - Free Free
- Galactic Foregrounds
 - Synchrotron (I,Q,U)
 - Free Free
 - Dust
- Earth
 - Atmosphere, RFI
- Instrument
 - Beam fluctuations
 - Polarization leakage

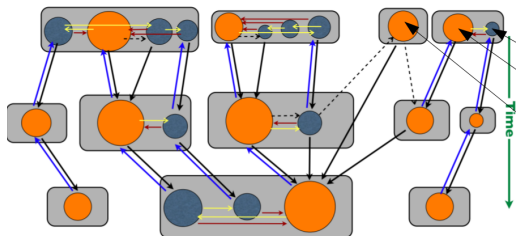
HI modeling: Millennium merger trees



credit: A.Zoldan

HI modeling: from dark matter to baryons

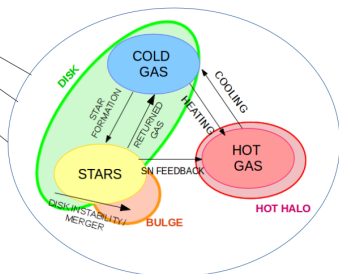
N-body DM simulation:
Millennium Simulation (Springel et al. 2005)



Sub-halo properties:

- M_{200} ;
- Spin;
- Rotational velocity;

Semi-analytic model



credit: A. Zoldan

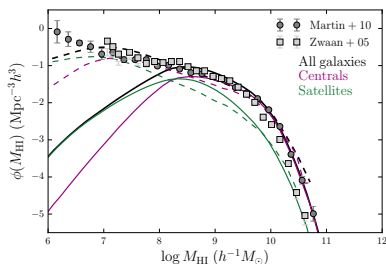
The Galaxy Evolution and Assembly (GAEA)

- both on Millennium I and II
more “cosmological” *vs.*
better resolution
($500 h^{-1}$ Mpc, $100 h^{-1}$ Mpc)

- explicit treatment of cold gas
partition in atomic (HI) and
molecular (H₂)
(Xie et al. 2017)

- Free parameters of the model
tuned to match the HI mass
function at $z = 0$
- Tested and upgraded during the years:
e.g. De Lucia & Blaizot 2007, De Lucia
et al. 2014, Hirschmann et al. 2016, Xie
et al. 2017, Zoldan et al. 2017

— MI — MII



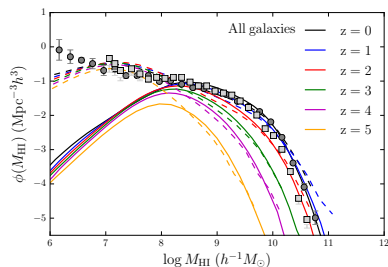
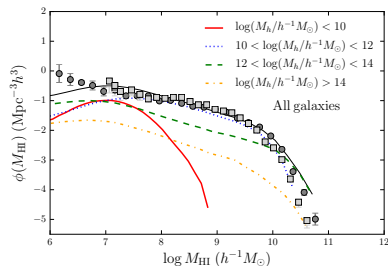
Centrals dominate from
intermediate to high HI masses

Satellites dominate for low HI
masses

HI mass function

Investigate different properties of HI selected galaxies:

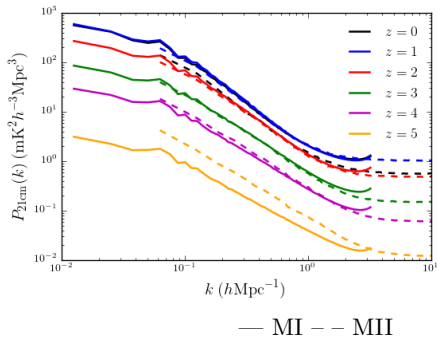
- In which halos do they live?
high mass end dominated by galaxies in big halos, at low masses small halos important
- How the HI mass function evolves with redshift?
hierarchical growth of structures, switch between $z = 0$ and $z = 1$ due to AGN feedback



21cm Power Spectrum

$$P_{21\text{cm}}(z, k) = \bar{T}_b^2 x_{\text{HI}}^2 \left[b_{\text{HI}}^2 (1 + \beta^2 \mu^2)^2 P_m(z, k) + P_{\text{SN}} \right]$$

e.g. Kaiser (1987), Bacon et al (2019)



x_{HI} : abundance of neutral hydrogen

b_{HI} : HI bias

$\beta^2 \mu^2$, with $\beta \equiv f/b_{\text{HI}}$
Redshift Space Distortions

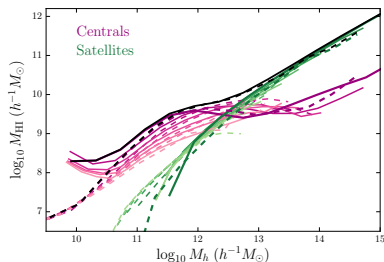
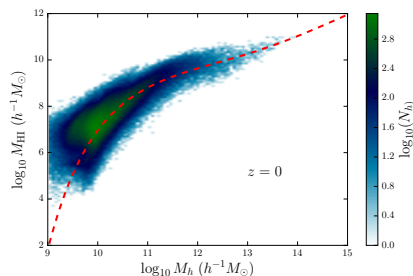
Shot Noise from small scales

HI halo mass function

In the Halo Model:

x_{HI} , b_{HI} and the shot noise can be predicted using the HI halo mass function $M_{\text{HI}}(M_h)$

- fit a functional form with:
 - low mass cut-off + power law with an inflection point (due to AGN feedback Baugh et al . 2019)
- can investigate role of
 - centrals and satellites also as function of redshift



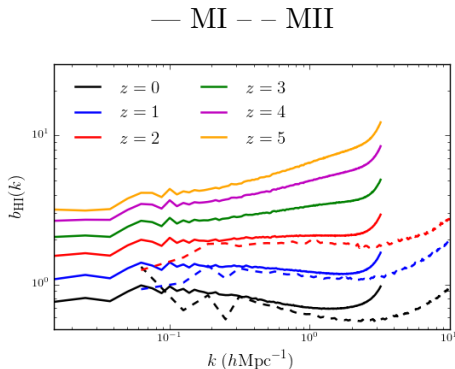
Bias

How do HI sources trace dark matter?

(cosmology is in $P_m(k)$)

$$b_{\text{HI}}(k) = \sqrt{\frac{(P_{\text{HI}}(k) - P_{\text{SN}})}{P_m(k)}}$$

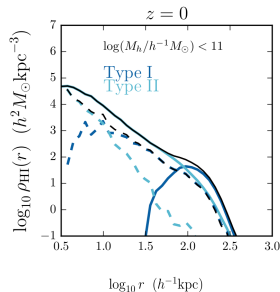
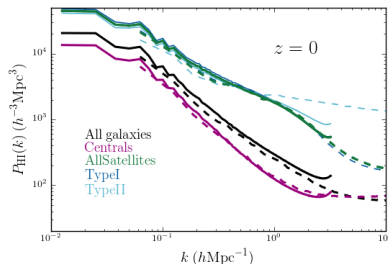
- *constant* at large scales, then scale dependence
- dip around $k \sim 1 h\text{Mpc}^{-1}$ at $z = 0$ (also in observations Anderson et al. 2018)
- bias grows with redshift (good news for IM!)



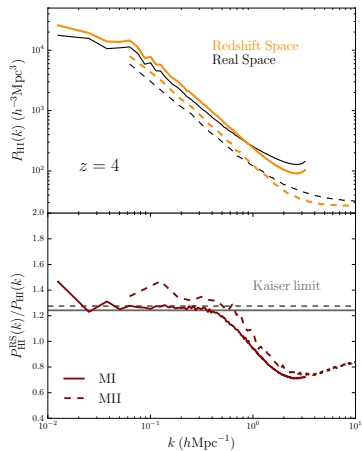
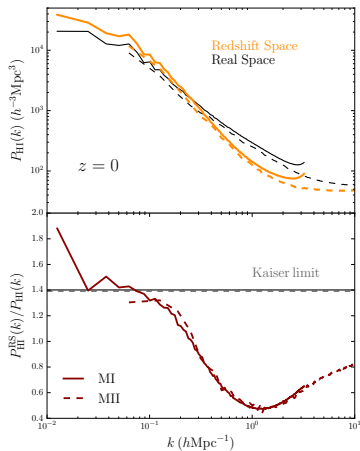
The role of satellites

Satellites and centrals different HI power spectrum

- satellites in big halos
- centrals in low and intermediate mass halos
- satellites: Type I (normal) and Type II (orphans) different role in HI profiles of halos
- can see this difference in the P_{HI}



Redshift Space Distortion



Conclusions

- 21 cm Intensity Mapping is opening up a new exciting window for cosmology
- We will need to control instrumental systematics and foreground emissions, but also to understand/simulate properly the signal
- Semi-analytic models are a powerful (predictive!) tool to investigate the connection between the signal and the details of galaxy evolution:
 - HI halo mass function $M_{\text{HI}}(M_h)$ precious to be reused for HOD techniques
 - investigate HI bias, Shot Noise and the effect of RSD
 - investigate HI clustering and its dependence on a variety of parameters (satellites and centrals but also halo mass, HI minimal mass)

an important bridge between cosmology and galaxy evolution