



CAASTRO
ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

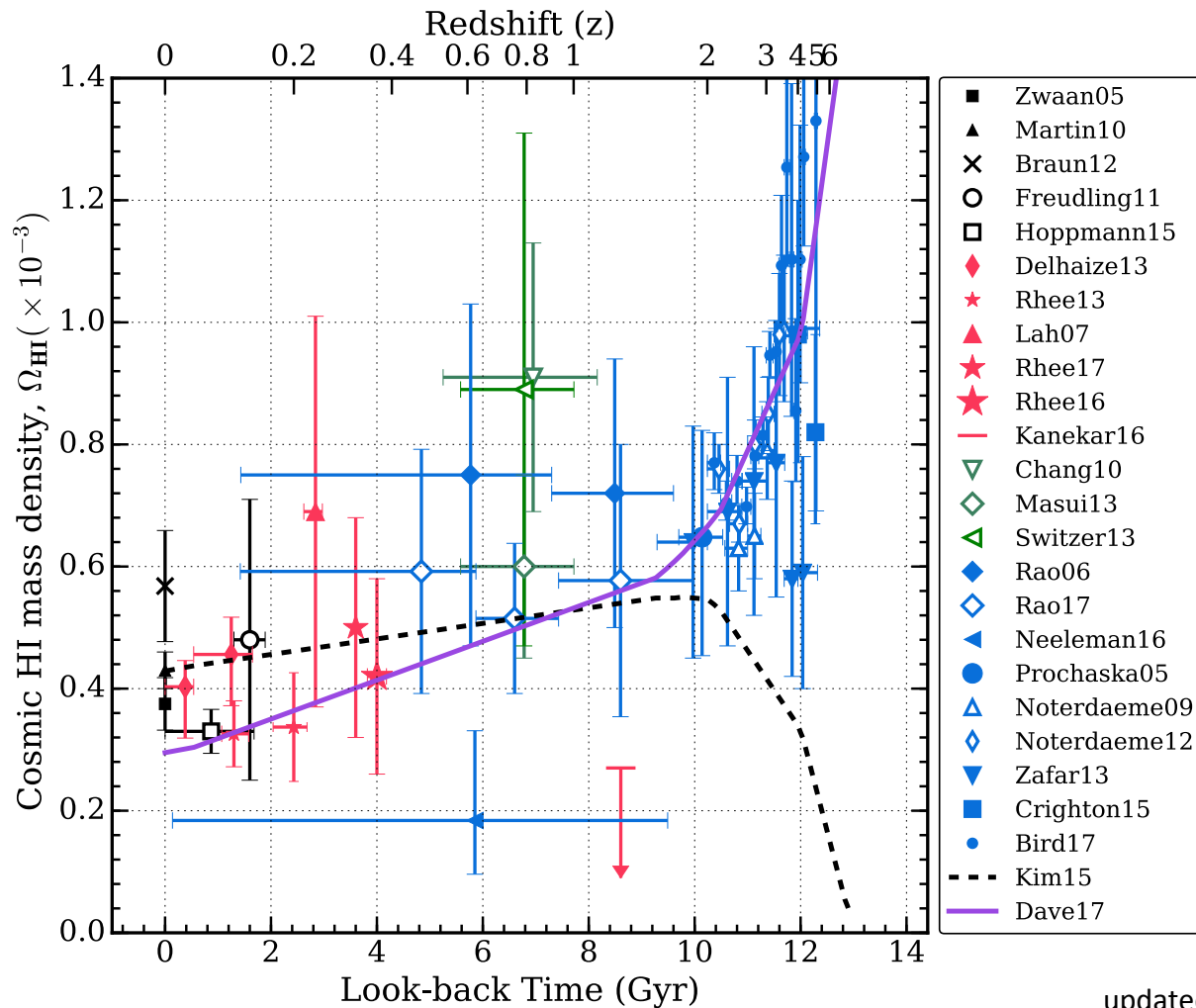
Evolution of Cosmic Gas Density

Lister Staveley-Smith

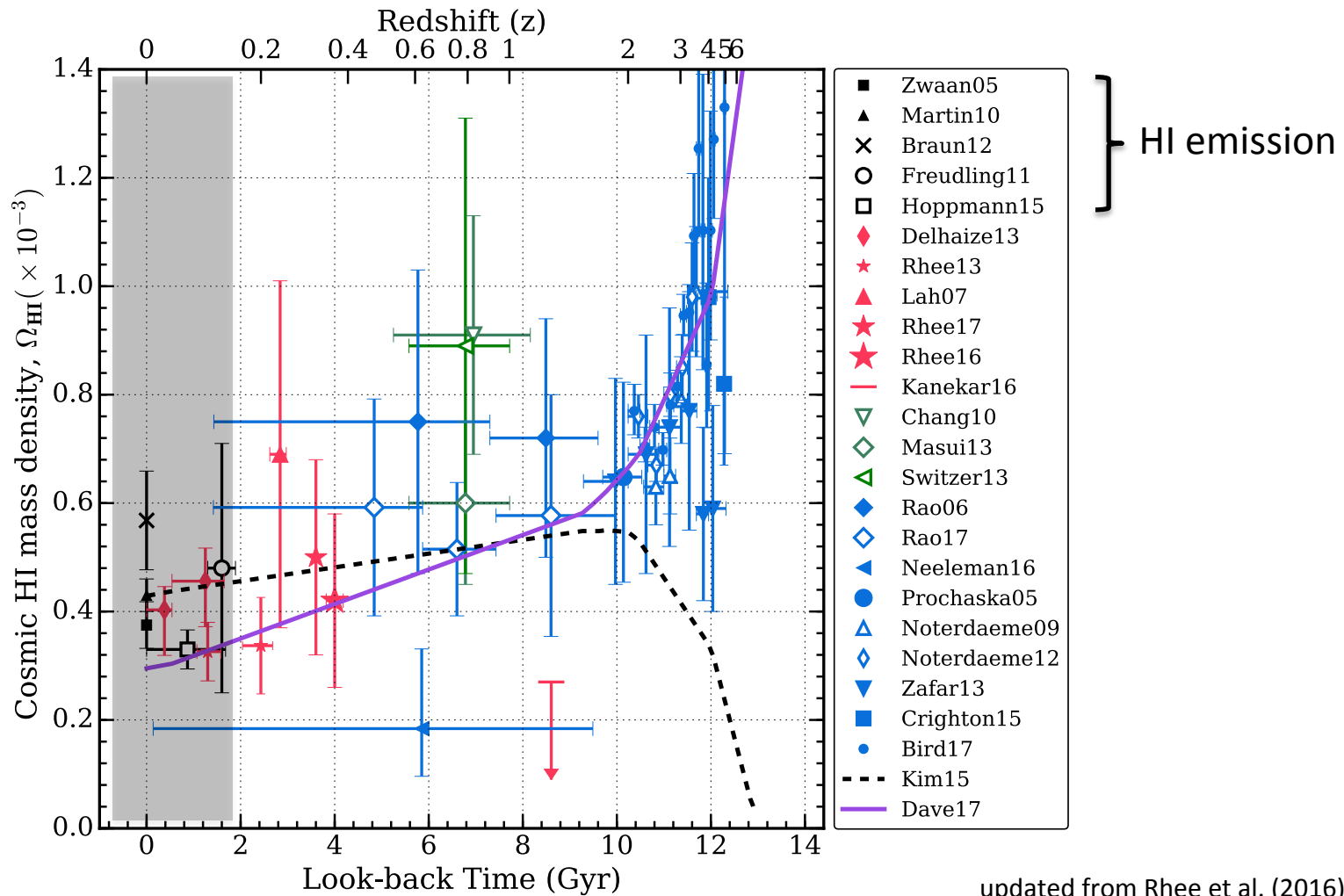
ICRAR/UWA

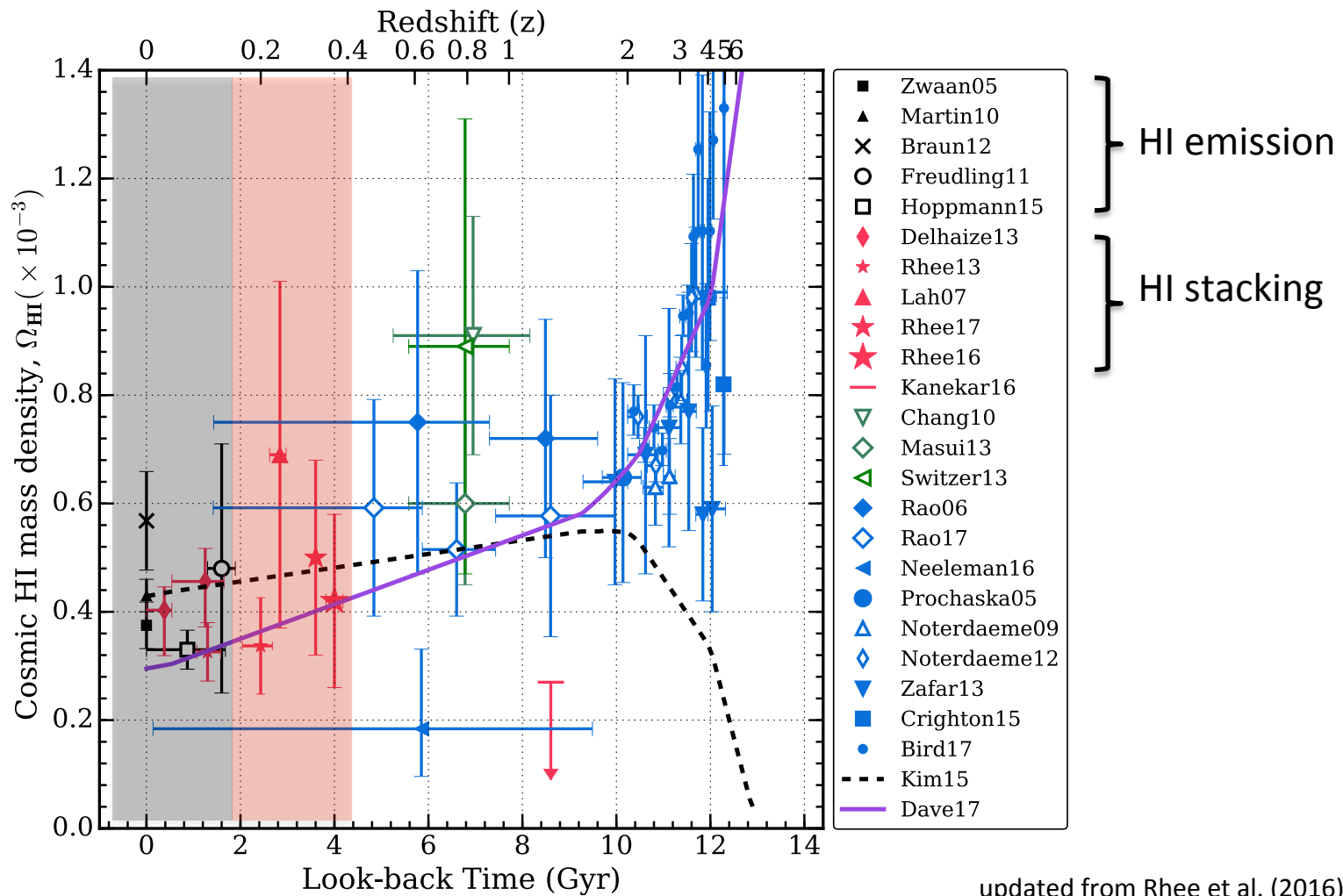
Outline

- What we know
- The role of HI absorption
- Gas bias
- Intensity mapping
- PAF

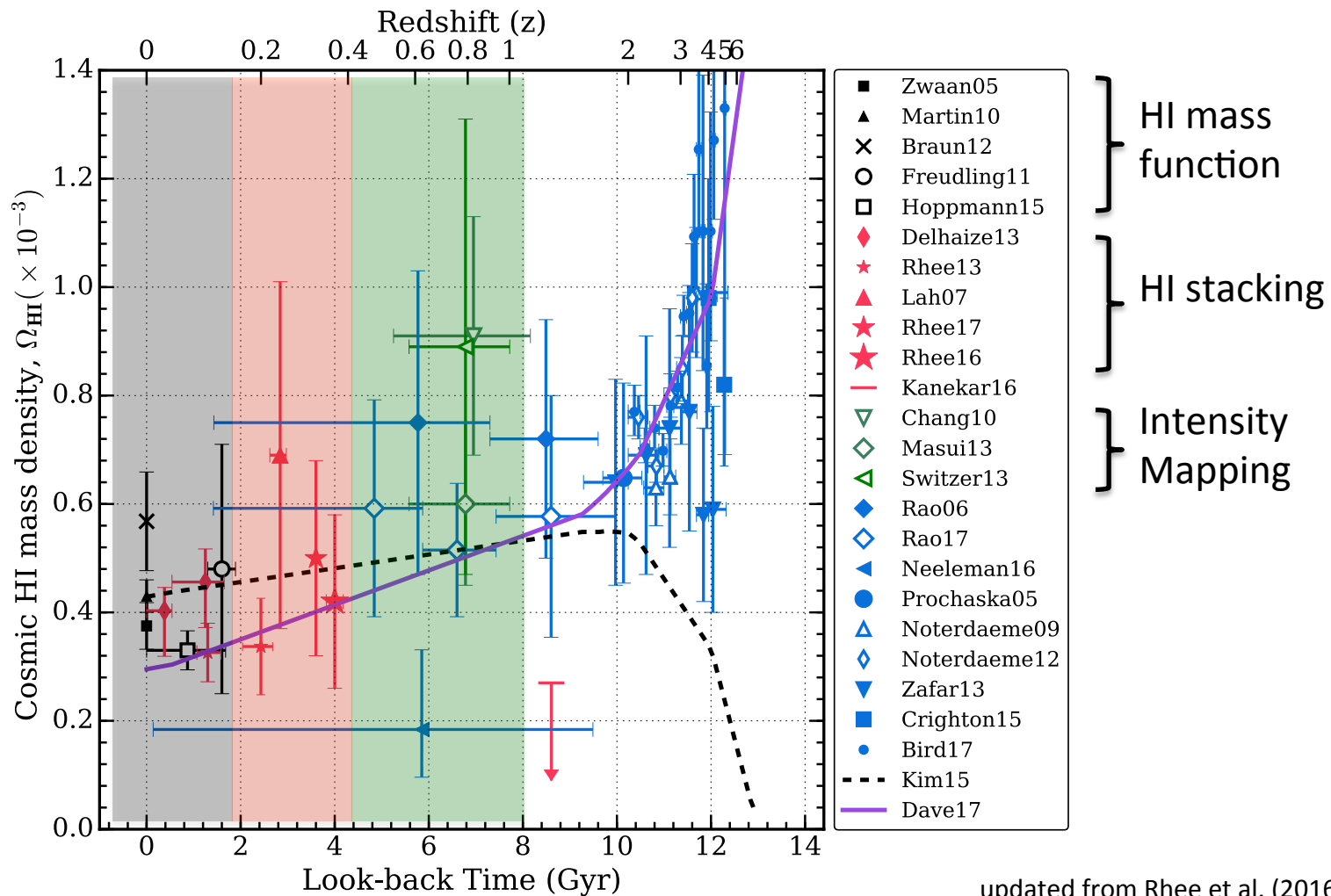


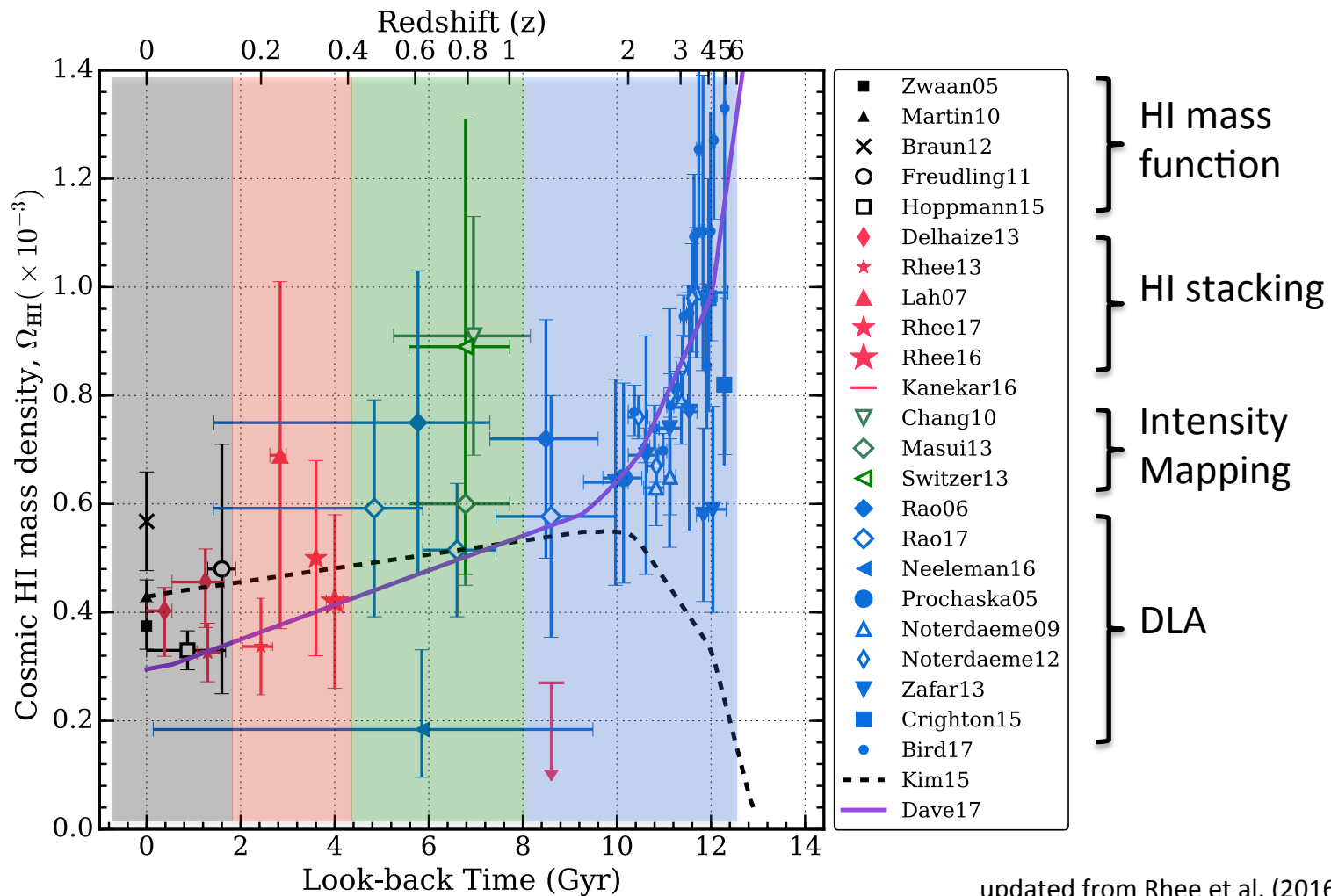
updated from Rhee et al. (2016)



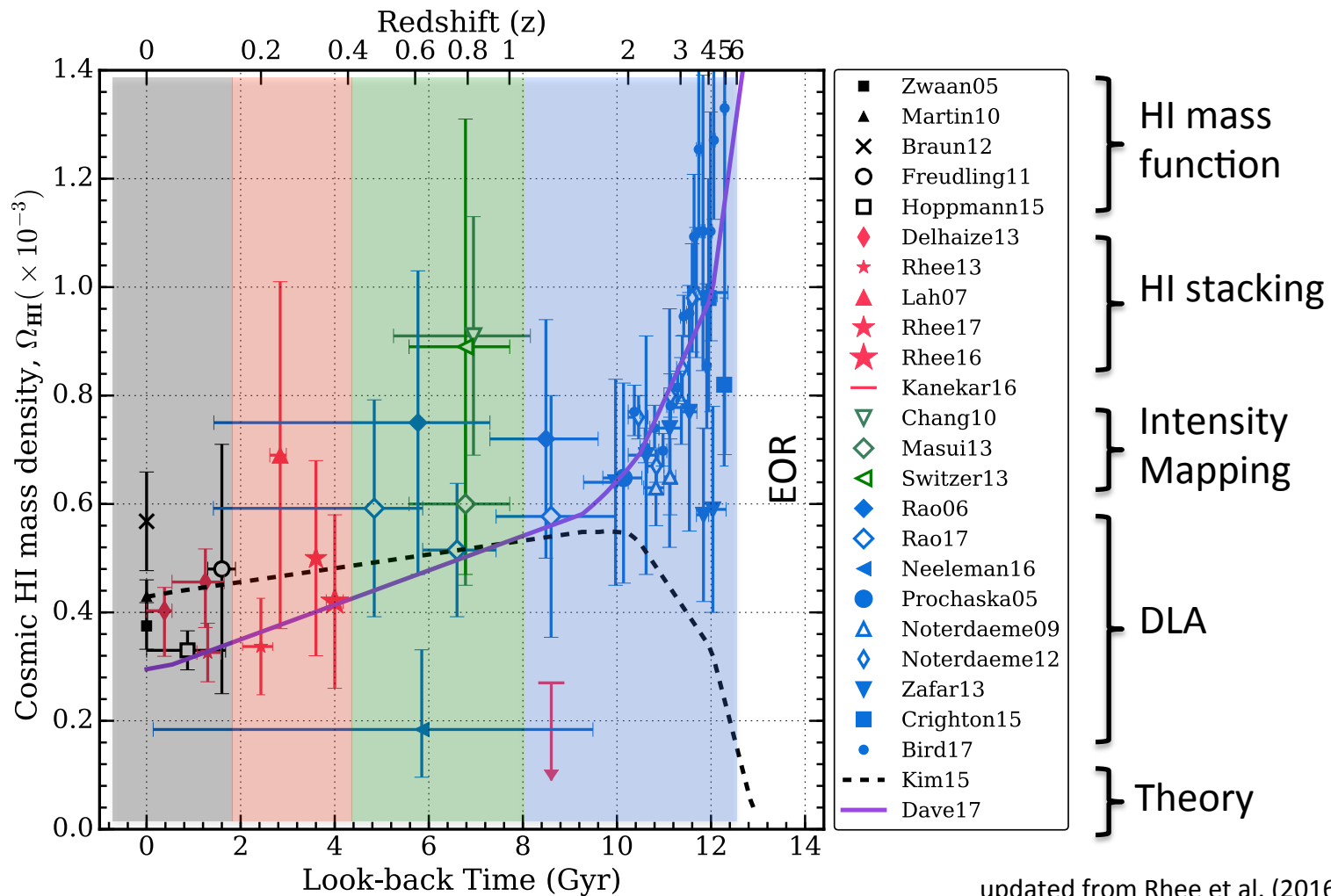


updated from Rhee et al. (2016)

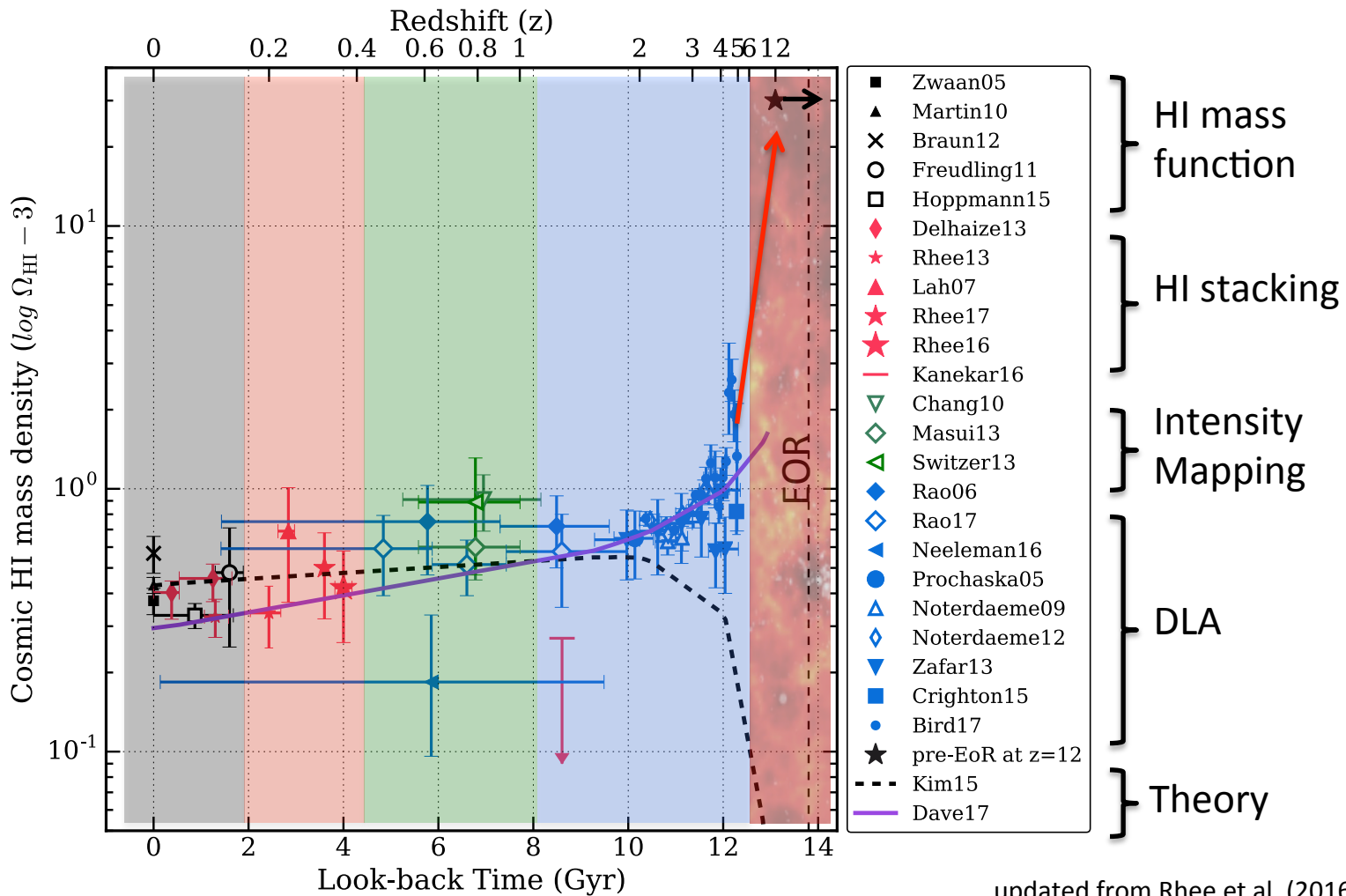




updated from Rhee et al. (2016)



→ LOG
SCALE



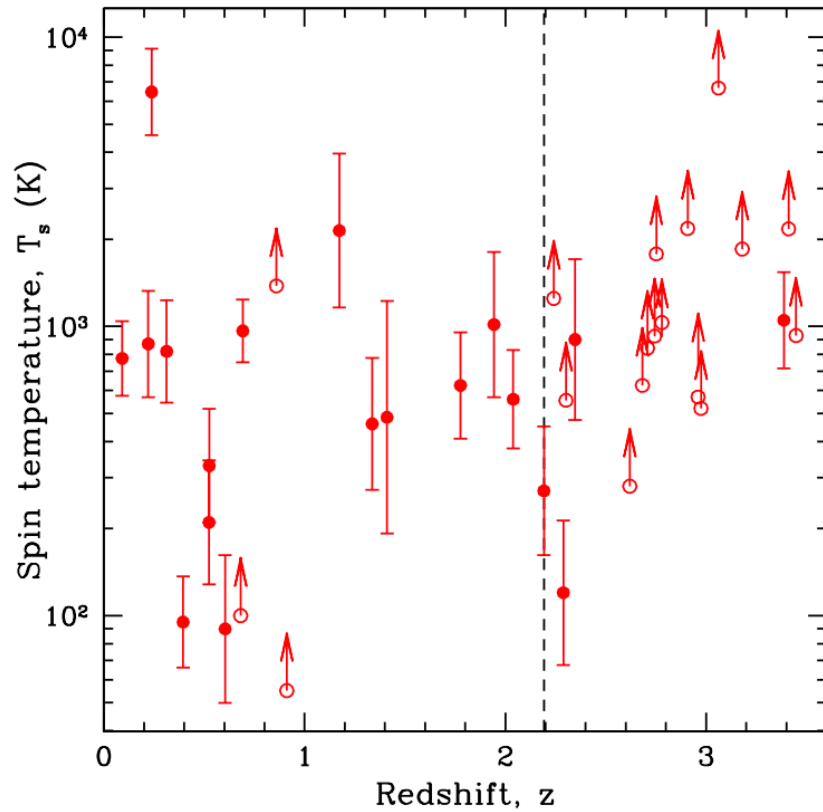
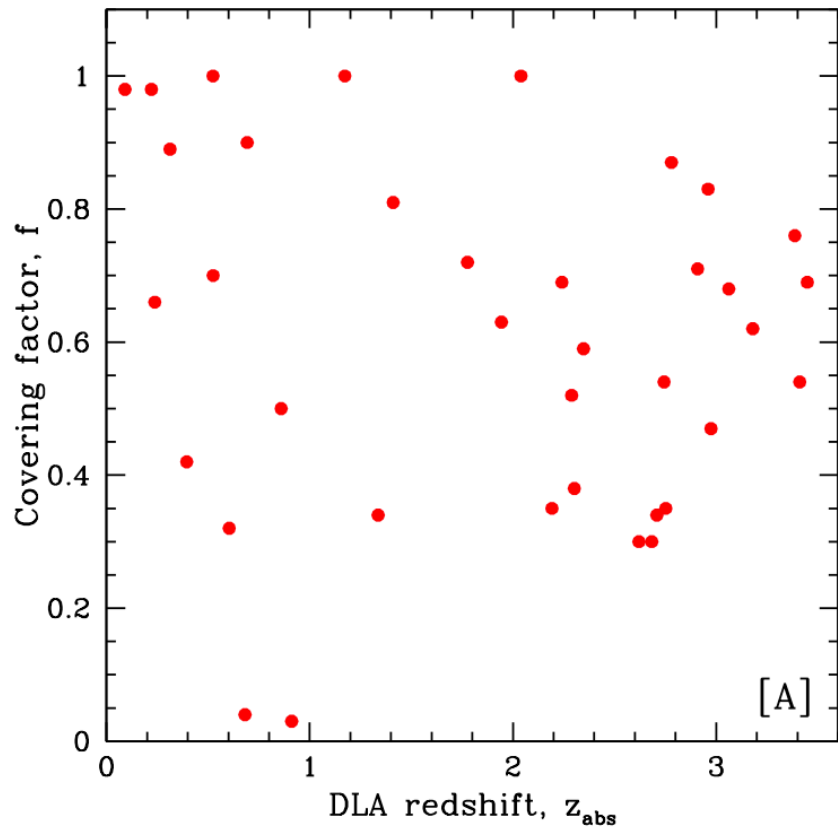
updated from Rhee et al. (2016)

The role of HI absorption

$$N_{HI} (cm^{-2}) = 1.82 \times 10^{18} \frac{T_s}{f} \int_{rest} \tau dv (km \cdot s^{-1})$$

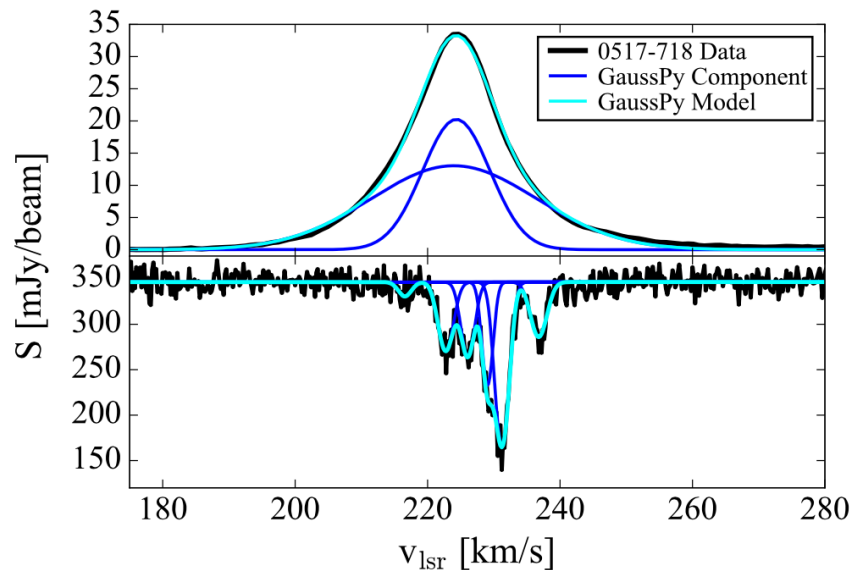
- Column density depends on:
 - Optical depth profile $\tau(v)$ - from HI spectrum
 - Frequency/redshift $(1+z)$ - from HI spectrum
 - Covering factor f - from VLBI
 - Spin temperature T_s - unknown

DLA Systems

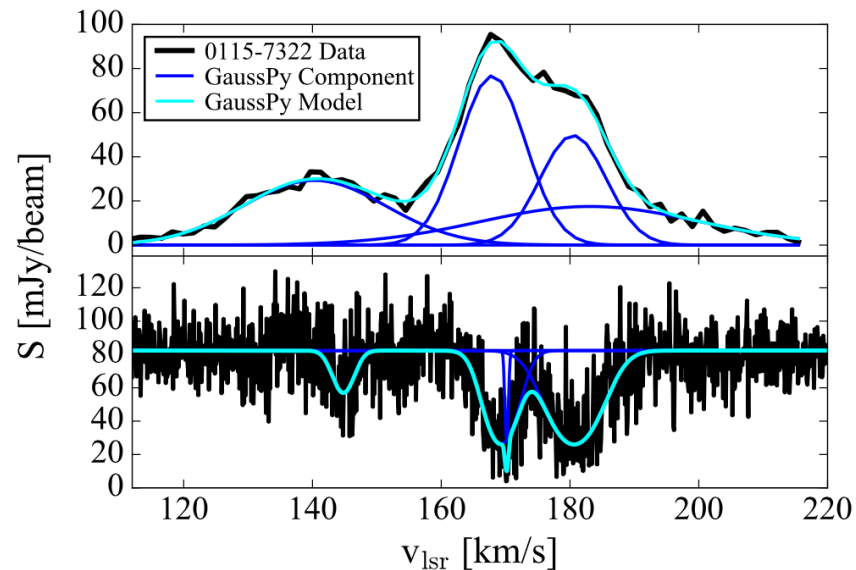


Emission/absorption spectra of the Magellanic Clouds

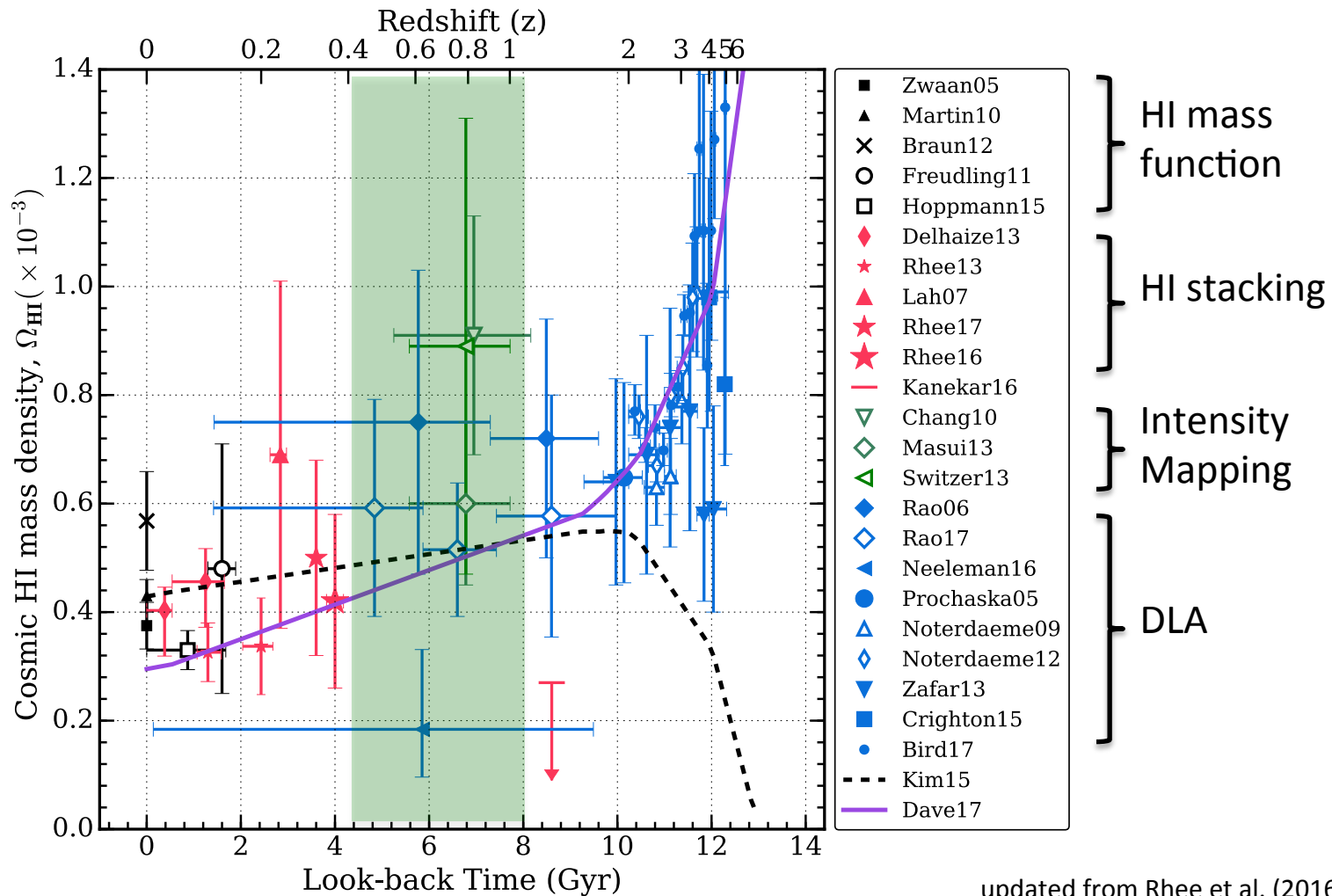
LMC ($Z=0.3Z_{\odot}$)



SMC ($Z=0.1Z_{\odot}$)

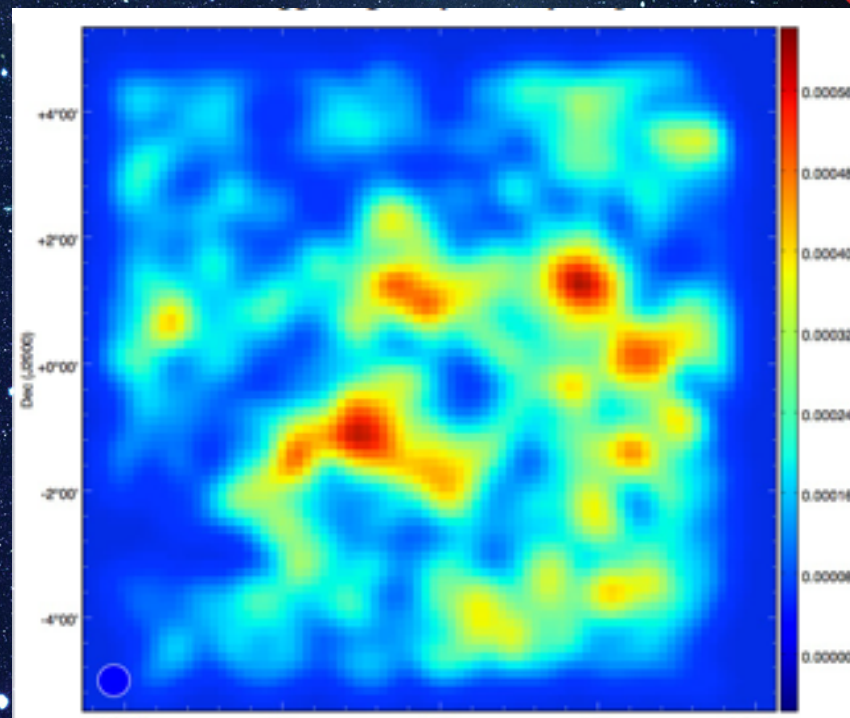
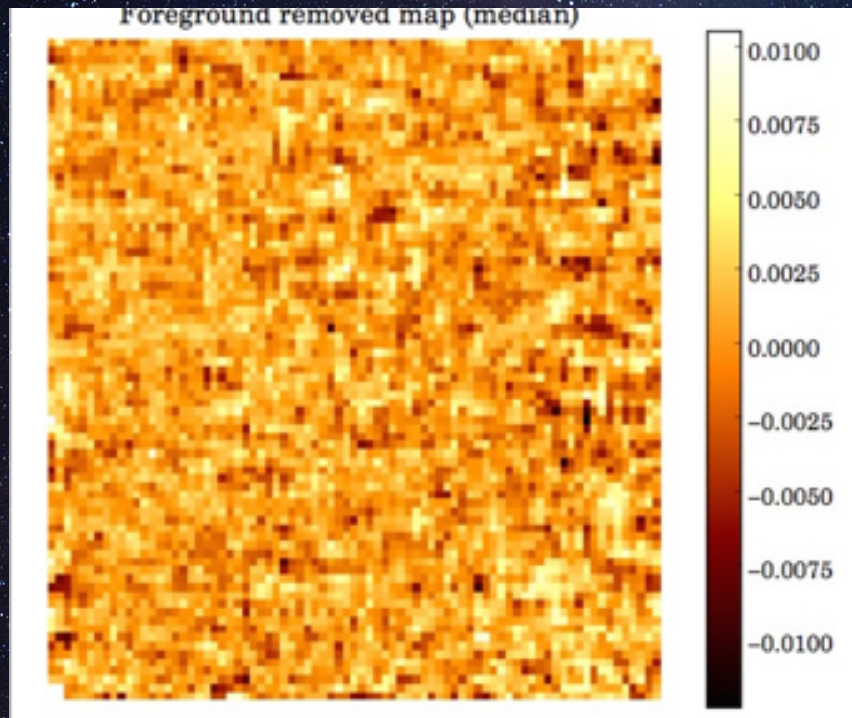


Ongoing ATCA Large Project (McClure-Griffiths et al.)



updated from Rhee et al. (2016)

Intensity mapping



HI intensity map

<- cross-correlate ->

WiggleZ density map

Cross-power spectrum

$$P_X = b_{HI} b_{opt} \bar{T}_{HI} r P_{dm}(k)$$

bias parameters

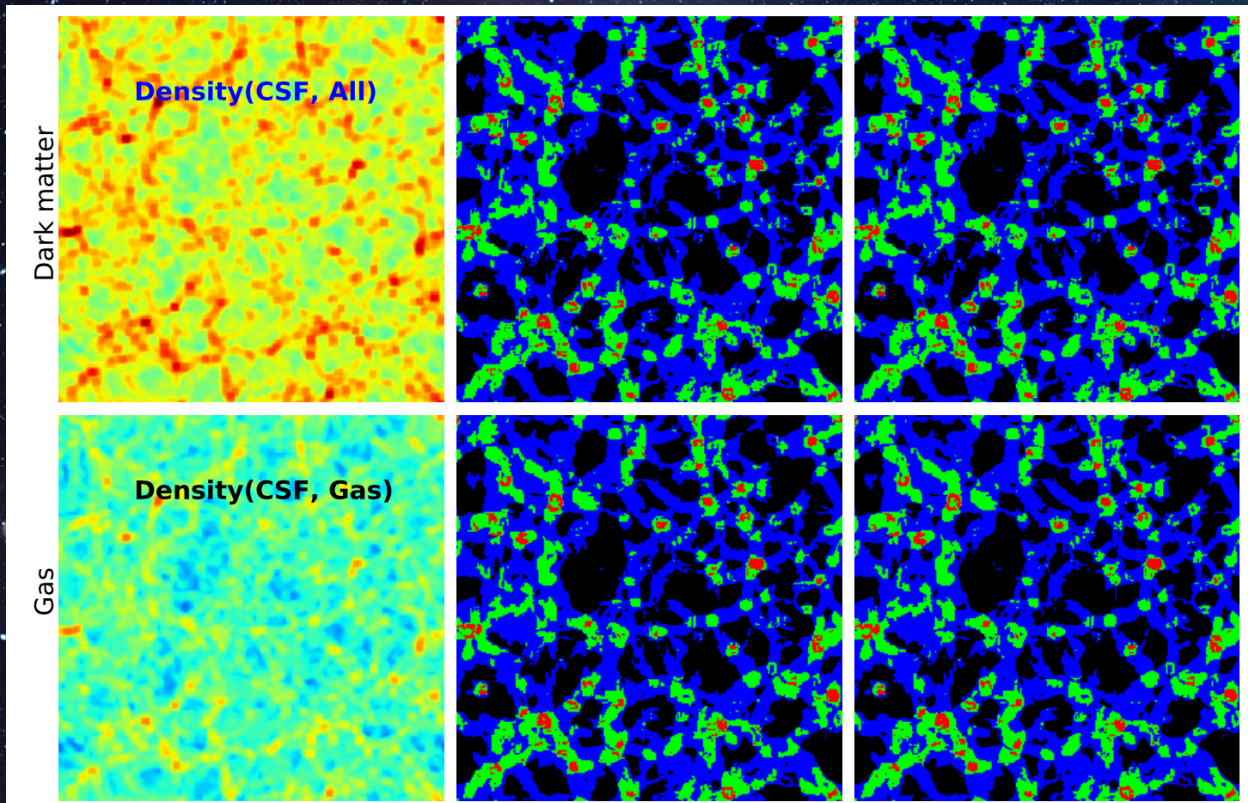
radio-optical correlation

DM power spectrum

cosmic gas density

$$\bar{T}_{HI} = 250 \left(\frac{\Omega_{HI}}{0.01} \right) (1+z)^{0.5} \mu K$$

VWEB (Hoffmann et al. 2012)

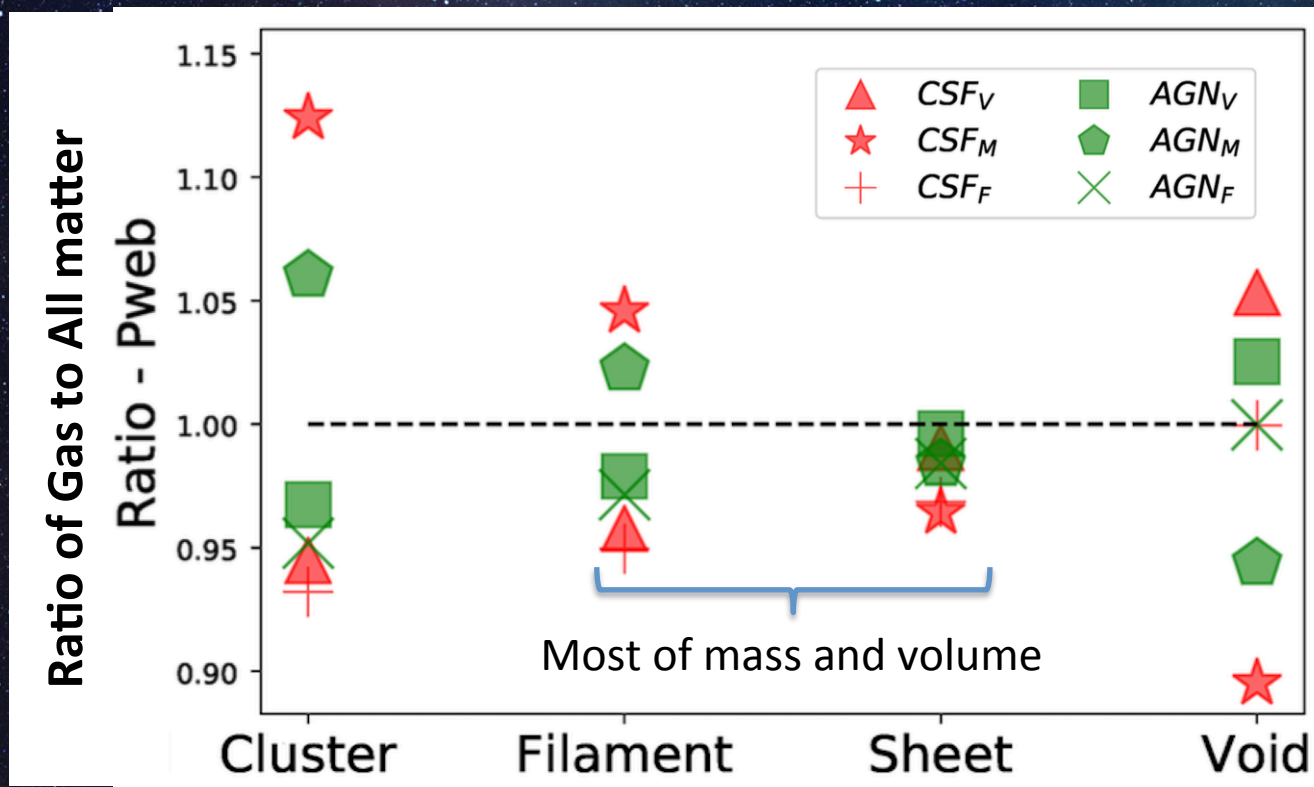


SIMULATIONS (Cui+ 2017)

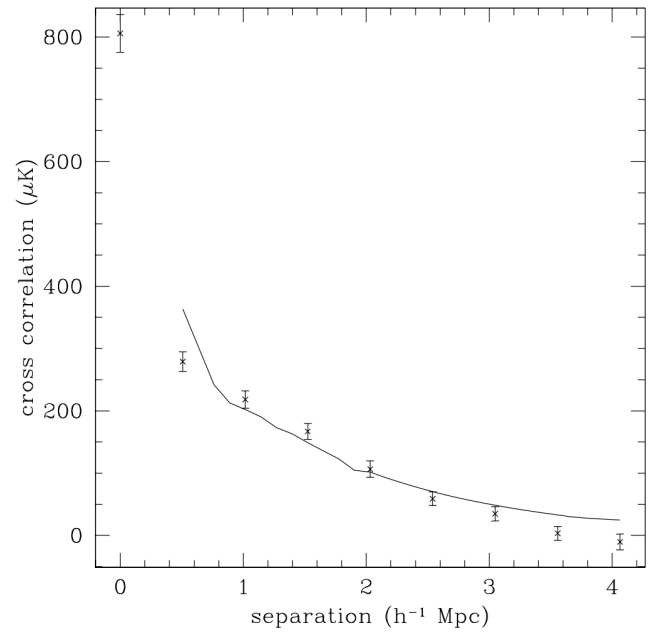
- Knots (red)
- Filaments (blue)
- Sheets (green)
- Voids (black)

Also PWEB (Hann+ 2006)

Gas traces large-scale structure

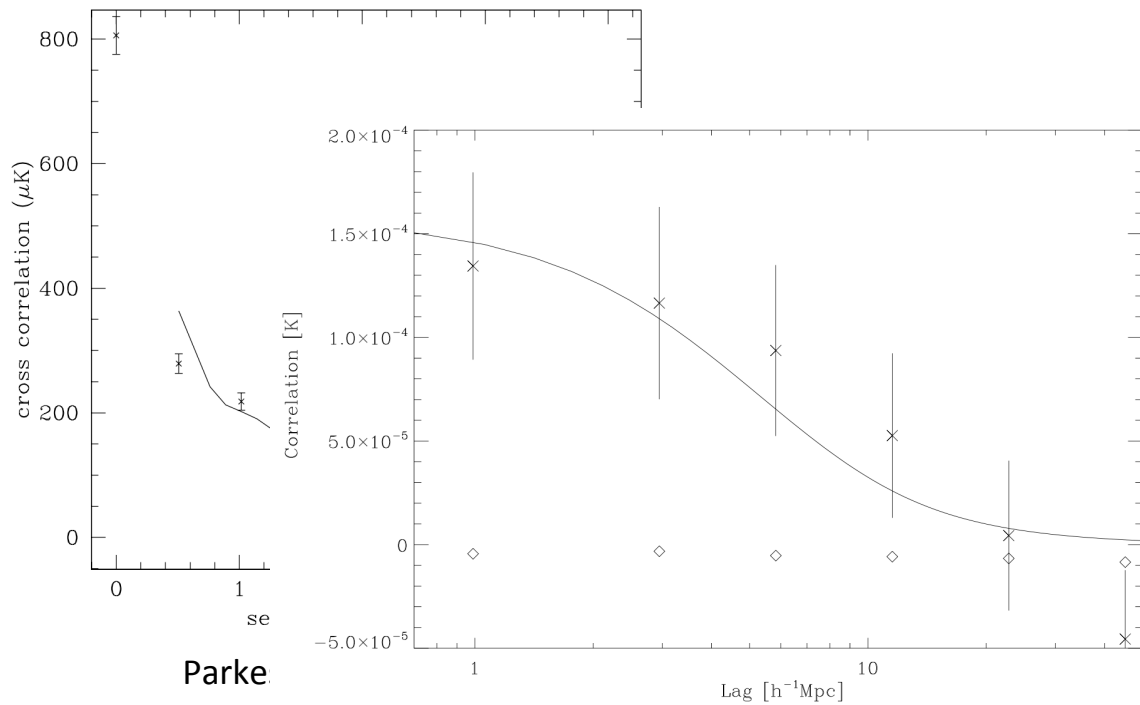


6dFGS-HIPASS cross correlation, $R > 63 \text{ h}^{-1} \text{ Mpc}$



Parke: Pen et al. (2009)

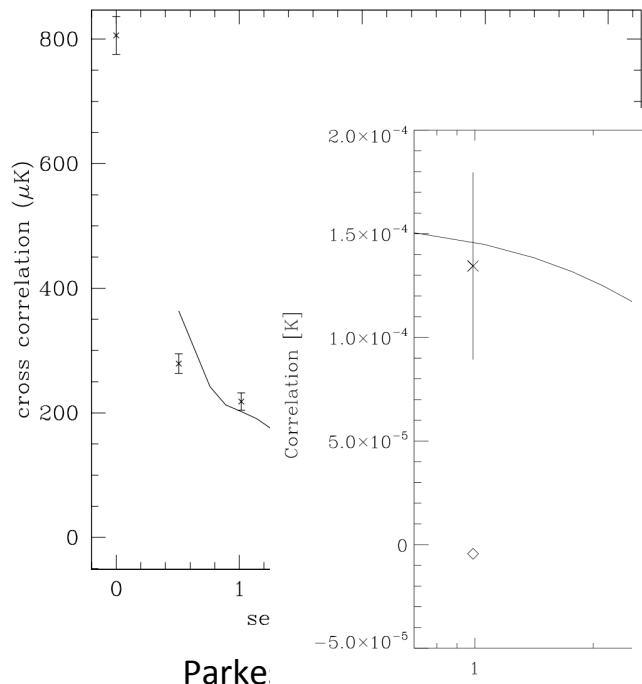
6dFGS-HIPASS cross correlation, $R > 63 \text{ h}^{-1} \text{ Mpc}$



Parke.

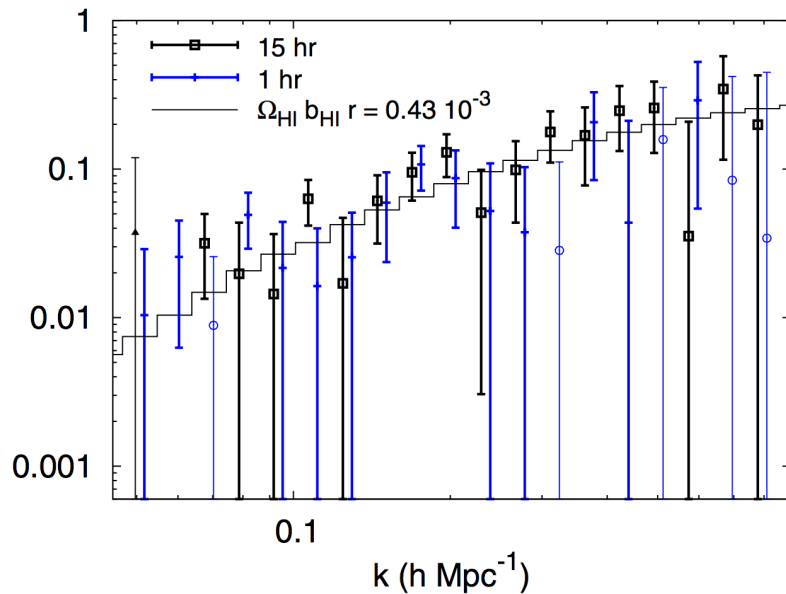
GBT: Chang et al. (2010)

6dFGS–HIPASS cross correlation, $R > 63 \text{ h}^{-1} \text{ Mpc}$



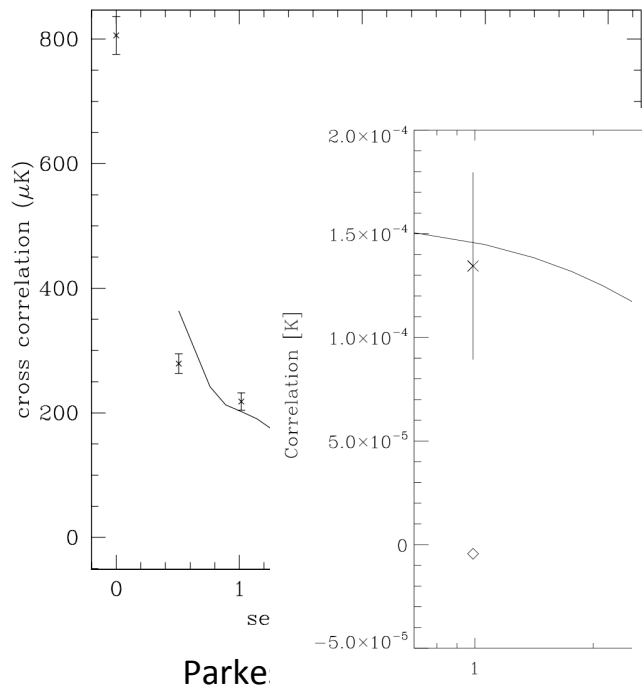
Parke

GB



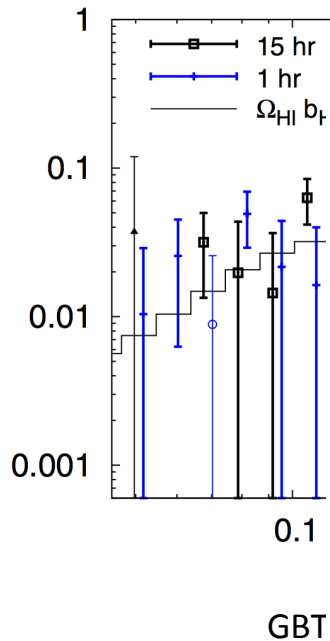
GBT: Masui et al. (2013)

6dFGS-HIPASS cross correlation, $R > 63 \text{ h}^{-1} \text{ Mpc}$

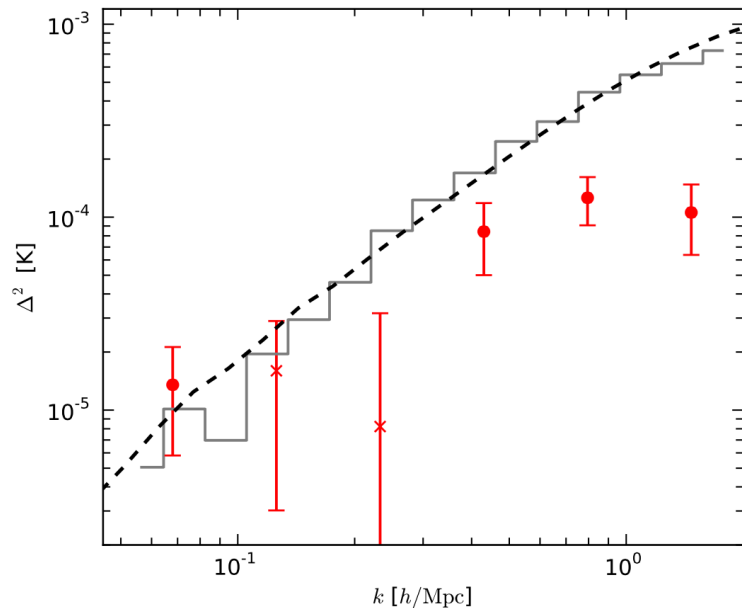


Parke

GB

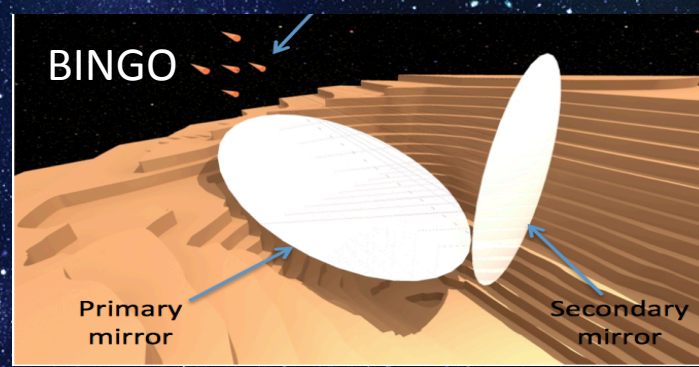
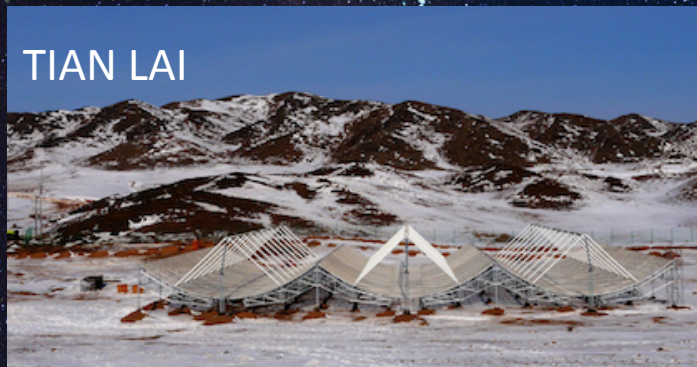
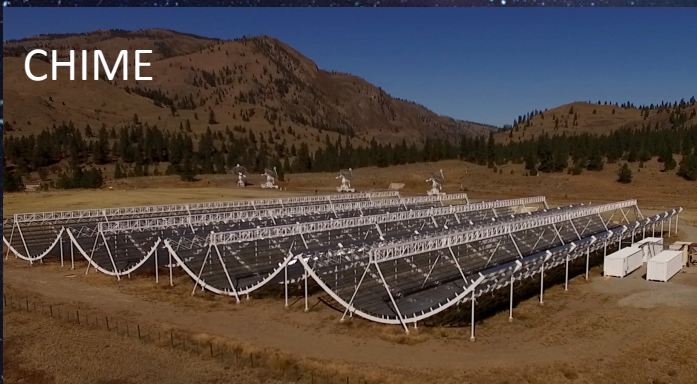


GBT



Parkes (Anderson et al. in prep)

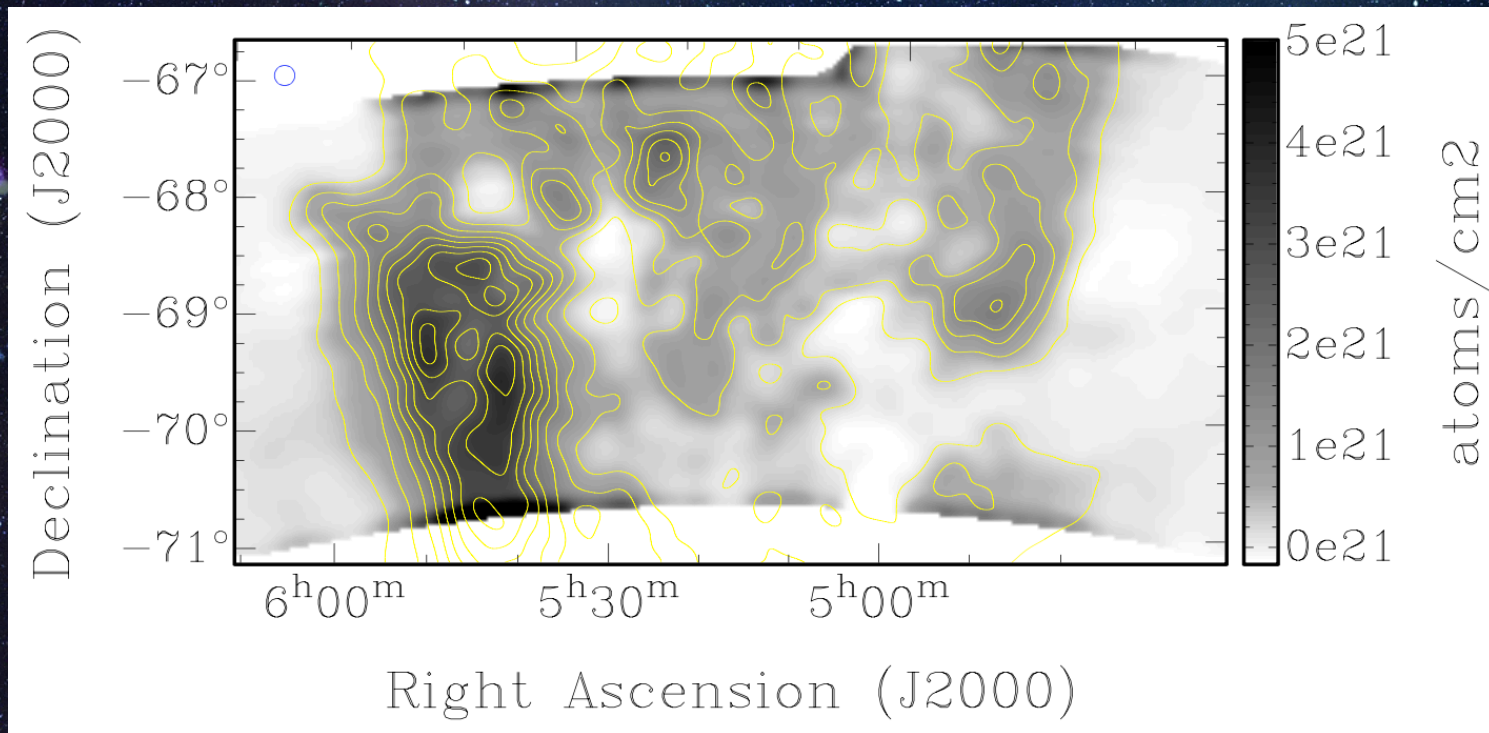
Forthcoming IM experiments





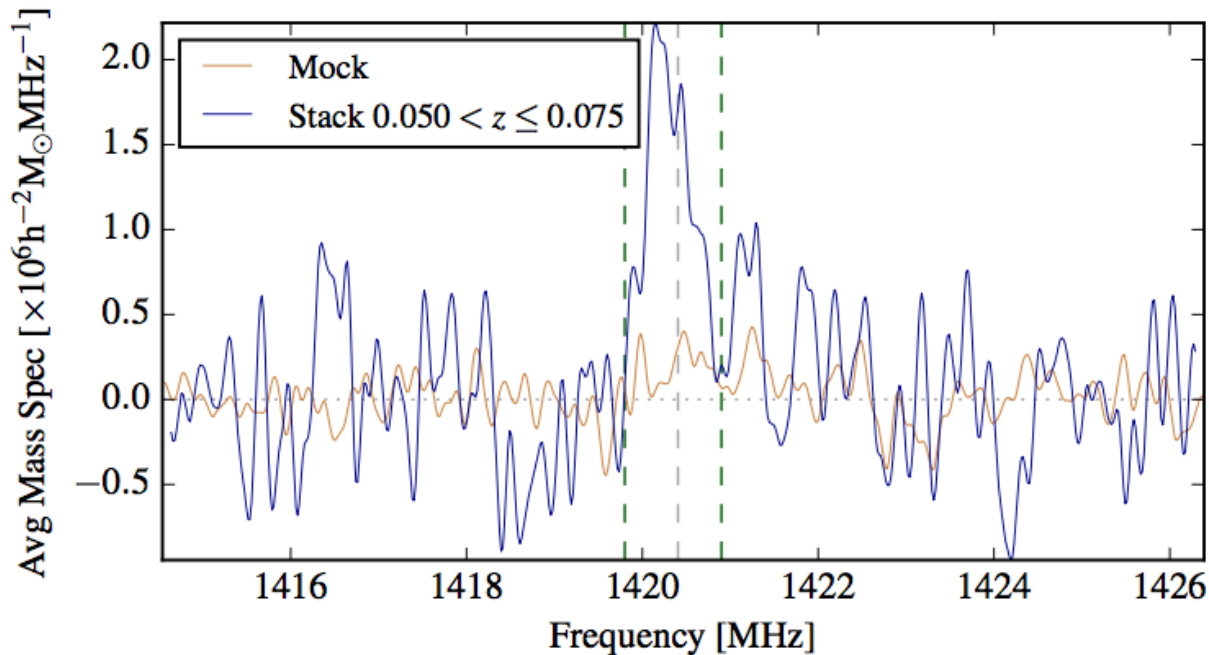
MPIPAF installed at the
CSIRO Parkes telescope on
10 Feb 2016

LMC MPIP AF image

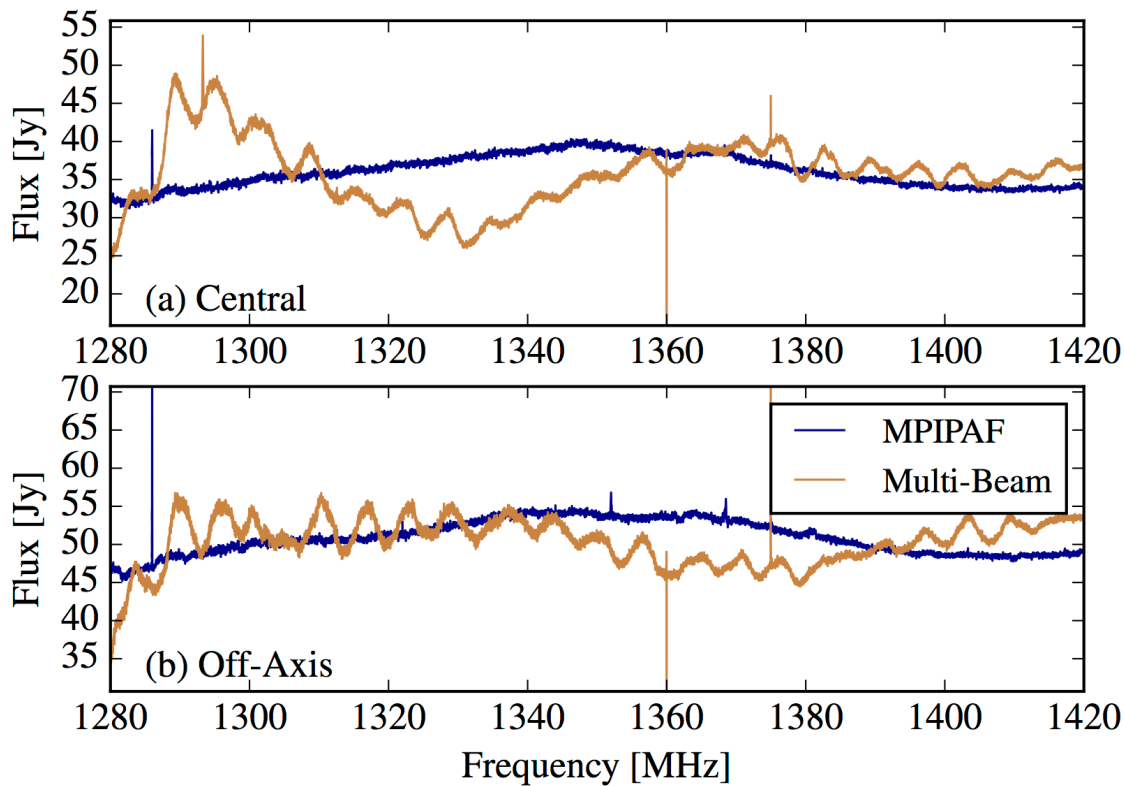


Greyscale: PAF; contours (S/Smith et al 2003)

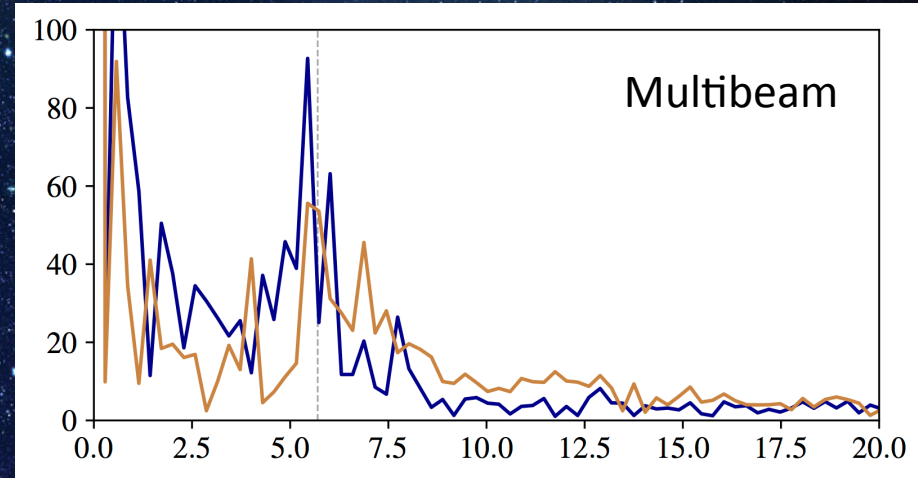
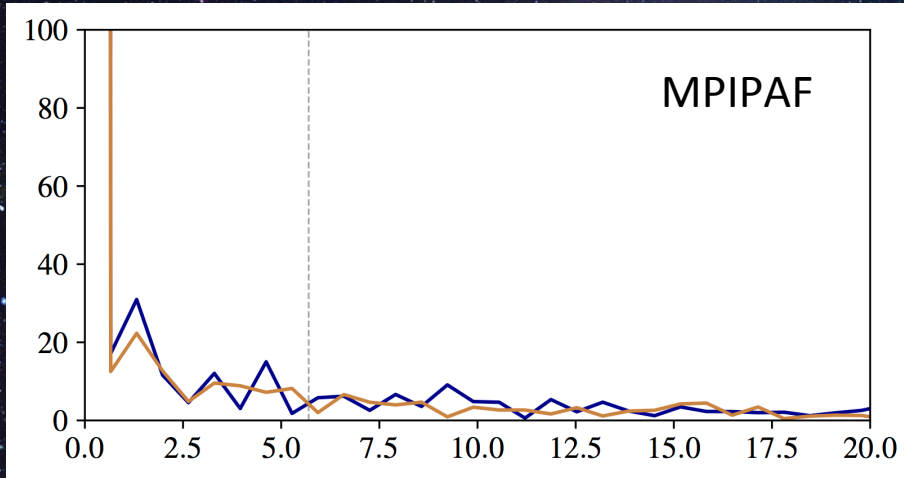
G23 stack



Standing waves



Fourier Analysis

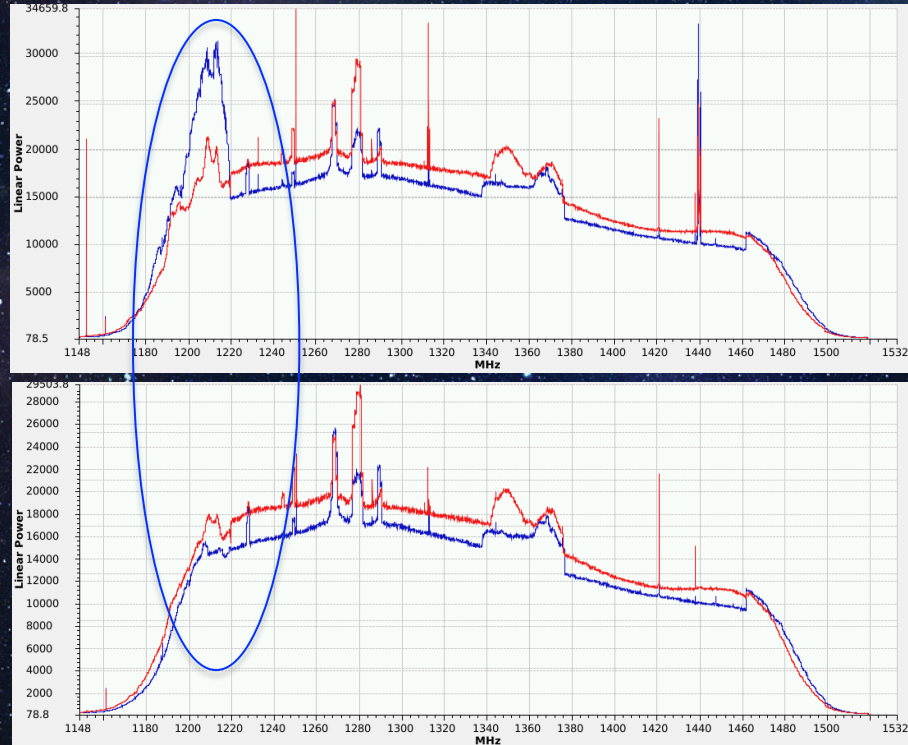


- PAF suffers less from interference from reflected radiation
- Natural standing wave frequency 5.6 MHz at Parkes (1200 km/s at $z=0$)
- T. Reynolds+ (2017)



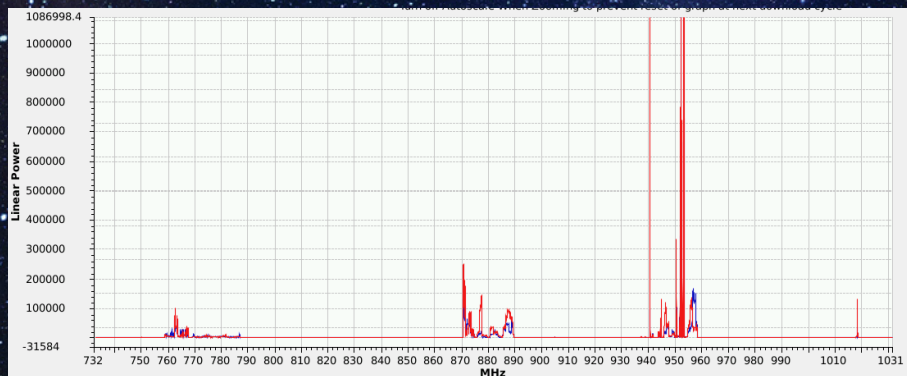
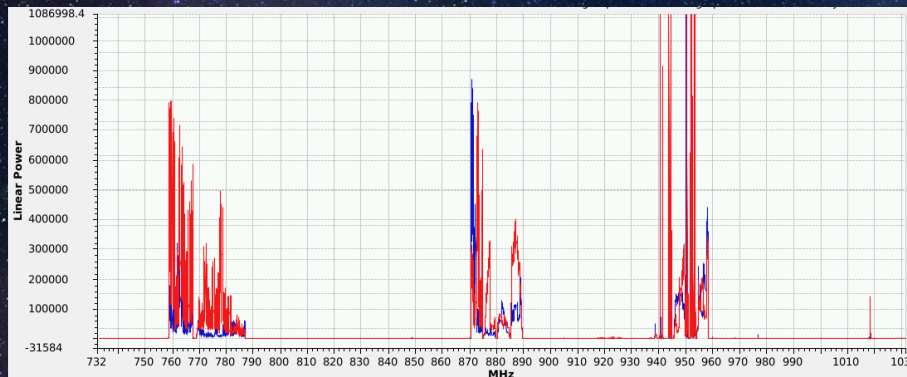
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RFI mitigation (band 2)



Oblique projection
(Chippendale &
Hellborg 2017)

RFI mitigation (band 1)



Oblique projection
(Chippendale &
Hellborg 2017)

Summary

- Cosmic gas (HI) density has most uncertainty in range $0.3 < z < 2$
 - Useful pre-SKA advances will be made by uGMRT, SKA precursors and IM
 - HI absorption experiments will inform ISM physics
- PAFs (esp. a cryo-PAF) will make a contribution to IM experiments