Extragalactic HI Absorption with the Australian SKA Pathfinder

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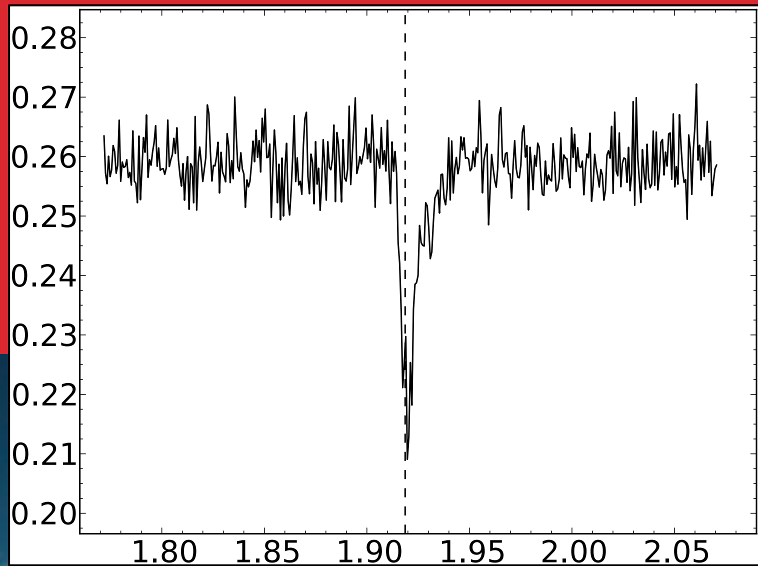

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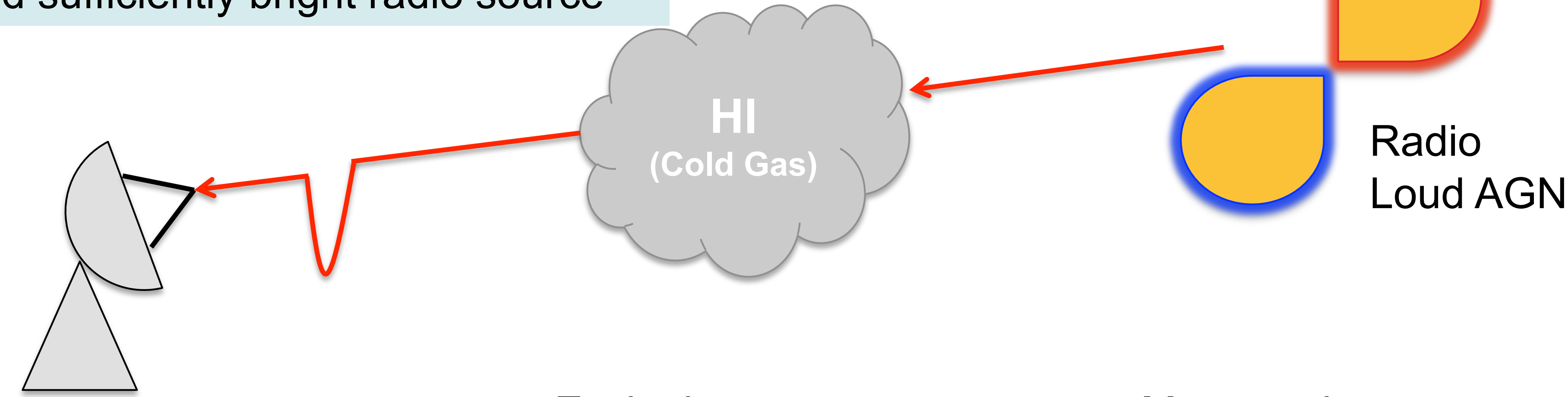
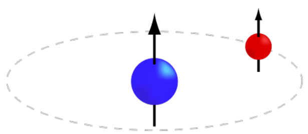
What is 21cm HI Absorption?

Requires alignment of foreground HI and sufficiently bright radio source





Spin-flip Transition

$$N_{\rm HI} = 1.823 \times 10^{18} \frac{T_{\rm spin}}{f} \int \frac{\sigma}{S}\, dv \,,$$

Excitation temperature for HI transition

Measured integrated optical depth from absorption

Fraction of background source

HI column density

HI Absorption vs Emission

Emission:

For any given collecting area A and integration time t, there is an limiting redshift z_{max} beyond which HI emission is effectively undetectable

This is currently z~0.2 for long integrations with the largest existing radio telescopes

For ASKAP	Wallaby (all-sky HI):	$0 < z < 0.26$
	Dingo (deep HI):	$0 < z < 0.4$

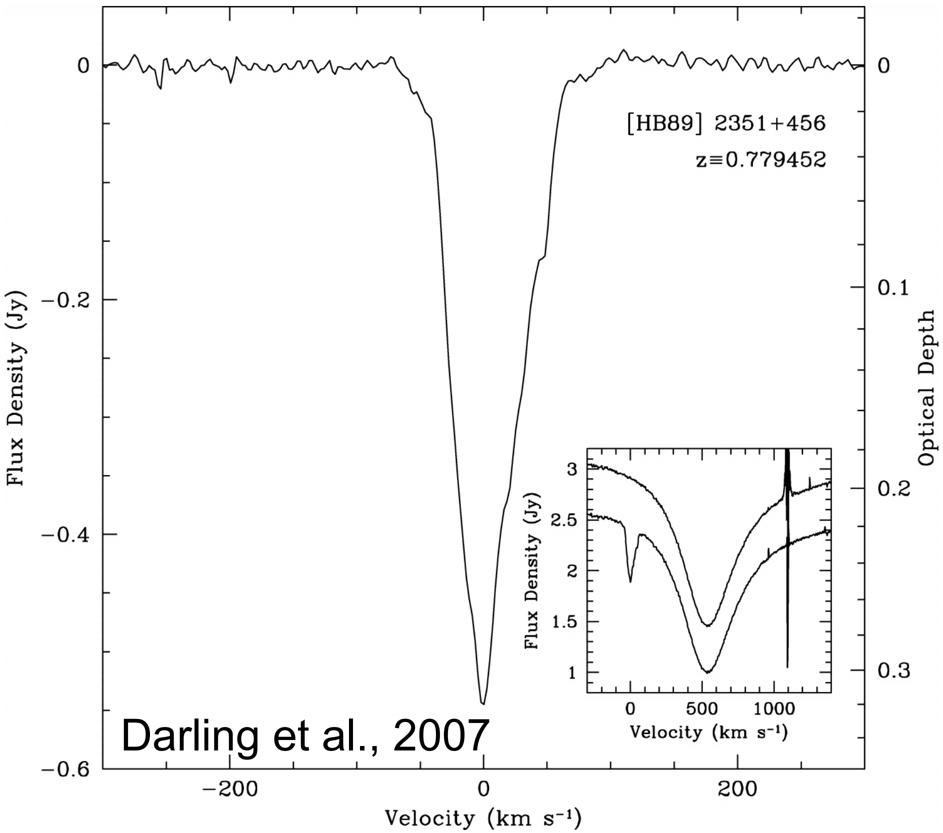
Absorption:

Sensitivity is independent of redshift!

Depends only on the intrinsic properties of the source and absorber

Analogous to the advantage gained by observing clusters of galaxies with the Sunyaev-Zel'dovich Effect over X-ray surveys

Two Types: Intervening



Intervening absorption due to galaxy intercepting continuum radiation from background source

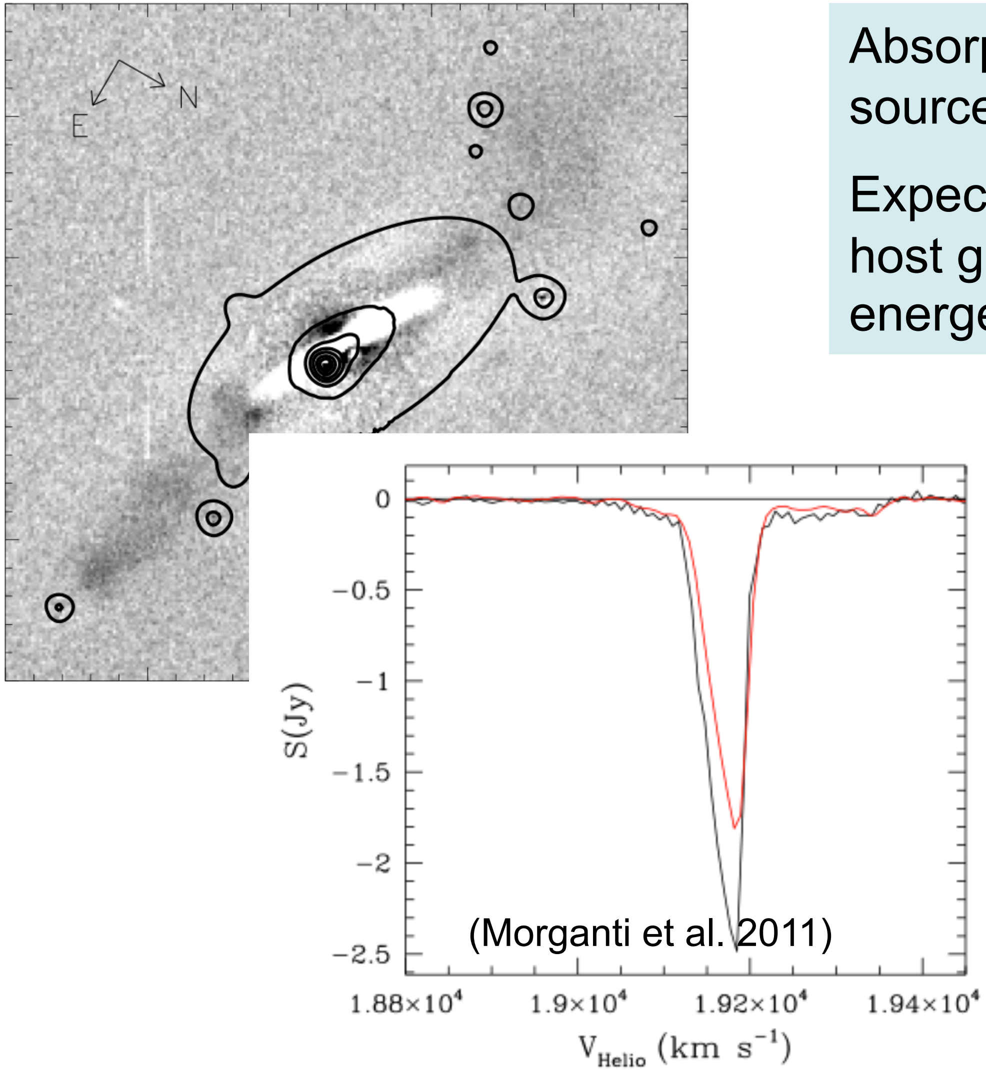
Targeted observations of DLAs (high HI column density) should increase probability of detection

Does the probability of HI absorption change with impact factor between source and galaxy? (e.g. Gupta et al. 2010)

Degeneracy between N_{HI}, f and T_{spin} is a problem for 21cm HI absorption

Can combine 21cm and Lyman-α observations to recover ratio of f and T_{spin}

Two Types: Associated



(Morganti et al. 2011)

Absorption at or near the redshift of the source

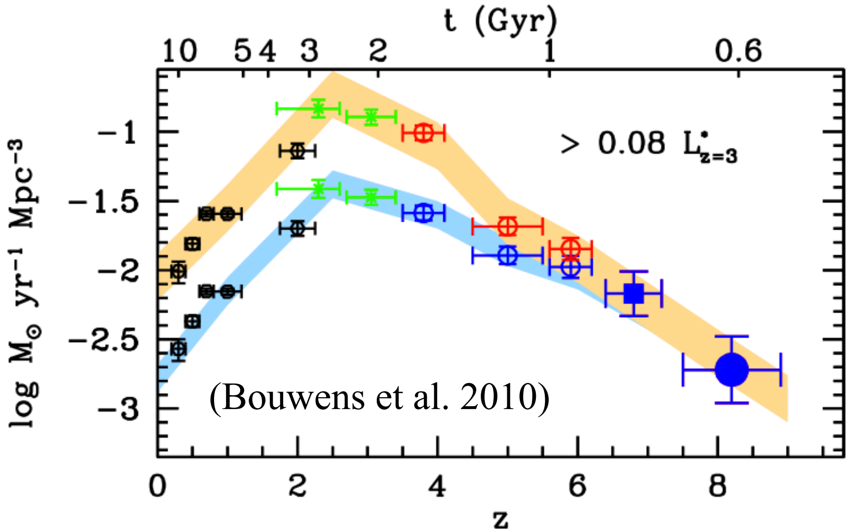
Expected to be associated with either the host galaxy, the circum-nuclear torus or energetic flows

Possible increase in probability of detection for compact sources (e.g.Vermeulen et al. 2003, Pihlstrom et al. 2003)

Apparent lack of detections at high UV luminosities might indicate strong dependence on this property
(e.g. Curran & Whiting 2010)

Science: Cosmic SFR

Cosmic Star Formation Rate



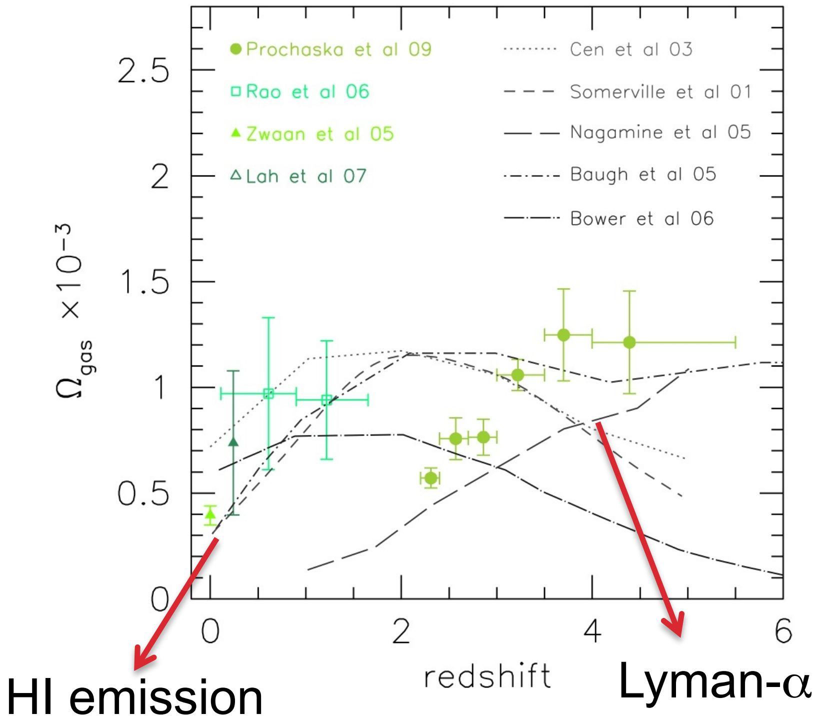
Star formation rate in galaxies drops off by a factor of 20 from redshift of 2

Why?

Star formation coupled to amount of cold gas available (fuel)

Does the neutral hydrogen content show the same redshift evolution?

Requires better constraints at z = 0.1 - 2



Science: Fundamental Constants

Fundamental Constants

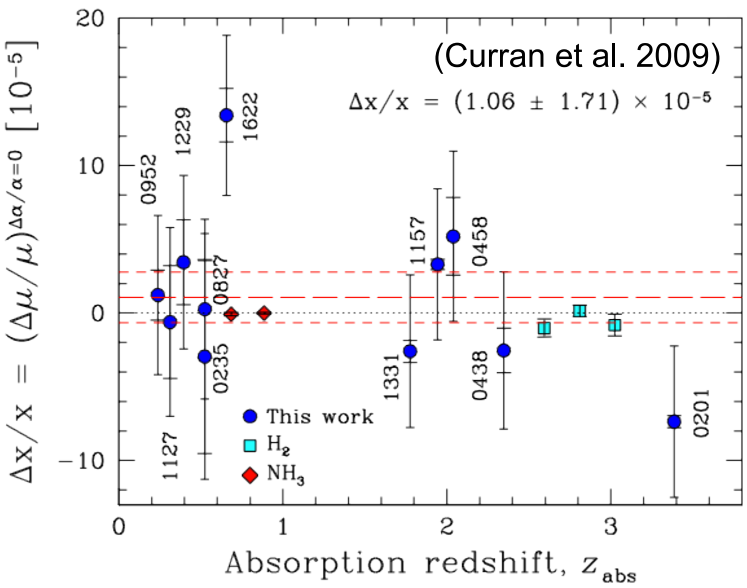
Combining HI 21cm with other transitions

Probe potential redshift evolution of fundamental constants

Summary of the various combinations of fundamental constants which can be constrained from various spectral lines, where g_p is the proton g-factor, $\alpha \equiv e^2/\hbar c$ is the fine structure constant and $\mu \equiv m_e/m_p$ the ratio of electron/proton masses.

Transition	"Anchor"	Constrained quantity
H I 21cm	Metal-ion (optical)	$g_p \mu \alpha^2$
	HCO^+	$g_p \alpha^2$
	OH 18cm ($\nu_{1665} + \nu_{1667}$)	$g_p[\alpha^2/\mu]^{1.57}$
OH 18cm ($\nu_{1665} + \nu_{1667}$)	HCO^+	$\mu^{1.57}\alpha^{-1.14}$
	OH 18cm ($\nu_{1665} - \nu_{1667}$)	$g_p[\alpha^2/\mu]^{0.13}$
	OH 18cm ($\nu_{1720} - \nu_{1612}$)	$g_p[\alpha^2/\mu]^{1.85}$
	OH 6cm	$[\alpha^2/\mu]^{-2.06}$

(Curran et al. 2004)



E.g. 21cm HI observations in Damped Lyman-α systems

$$x \equiv \alpha^2 g_p \mu$$

$$\Delta x/x \equiv \frac{x_z - x_0}{x_0} = \frac{z_{UV} - z_{21}}{1 + z_{21}}$$

The SKA Pathfinders

The SKA Pathfinders will provide us with the tools to perform completely **radio selected**, **blind** HI absorption surveys for the first time

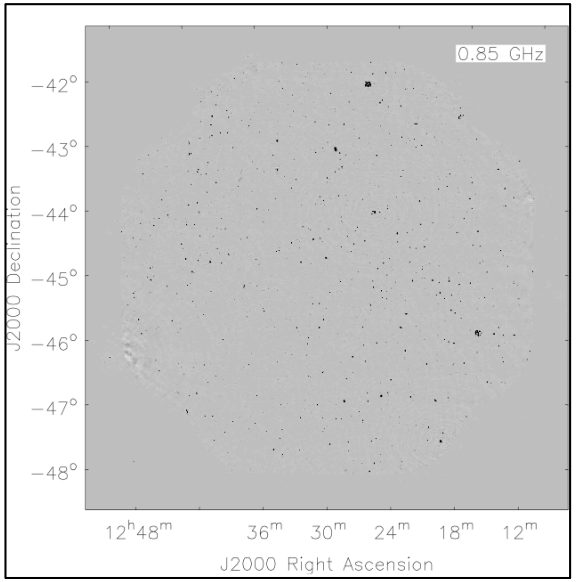
This will remove the current **uncertainties** in **detection rates** generated by **optical/UV** and **source type** selection

The Australian SKA Pathfinder

- Wide field of view
- Wide spectral bandwidth
- Radio-quiet site

make it possible to carry out the first *blind* radio survey for HI absorption

- 36 x12 m Antennas
- 300 MHz bandwidth
- Phased-Array Feeds
- 30 sqr-deg instantaneous FOV

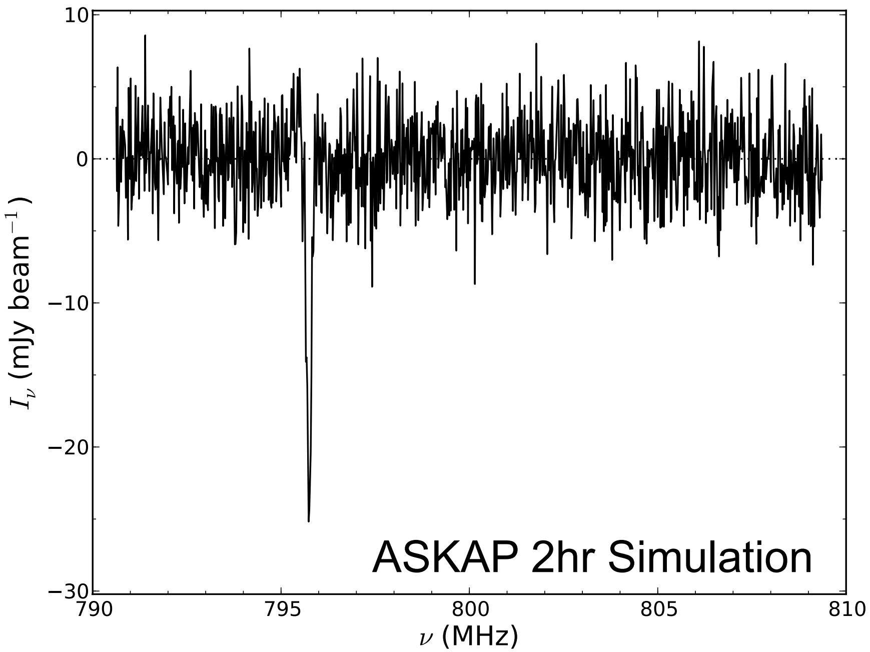


ASKAP 2hr Simulation

Matt Whiting, CASS

HI Absorption with ASKAP

ASKAP-FLASH



First Large Absorption Survey in HI (Sadler et al.)

- **150,000** sight-lines (SUMSS/ NVSS)
- **Blind** survey
- All-sky southern survey
- **Associated** and **intervening** lines (~1000s)
- FLASH-WALLABY “Piggyback” survey (0 **<** z **<** 0.26)
- Main FLASH survey 0.5 < z< 1

Other SKA Pathfinders

(Artist's Impression courtesy of SKA South Africa)

MeerKAT

Absorption Line Survey

(Gupta et al.)

- Deep blind survey
- Constants with OH absorbers at z < 1.8
- >600 intervening 21cm absorbers

(Image courtesy of ASTRON)

APERTIF

(Gupta et al.)

EOI Proposal, potential northern completion of HI absorption all-sky survey and complementary to ASKAP-FLASH

Analysing the Data

The advent of **wider bandwidth** and **larger field of view** will raise a number of issues that need to be considered for the detection and parameterization of absorption lines

(Image courtesy of CSIRO Astronomy & Space Science)

The Australia Telescope Compact Broadband Backend provides a test-bed for these issues

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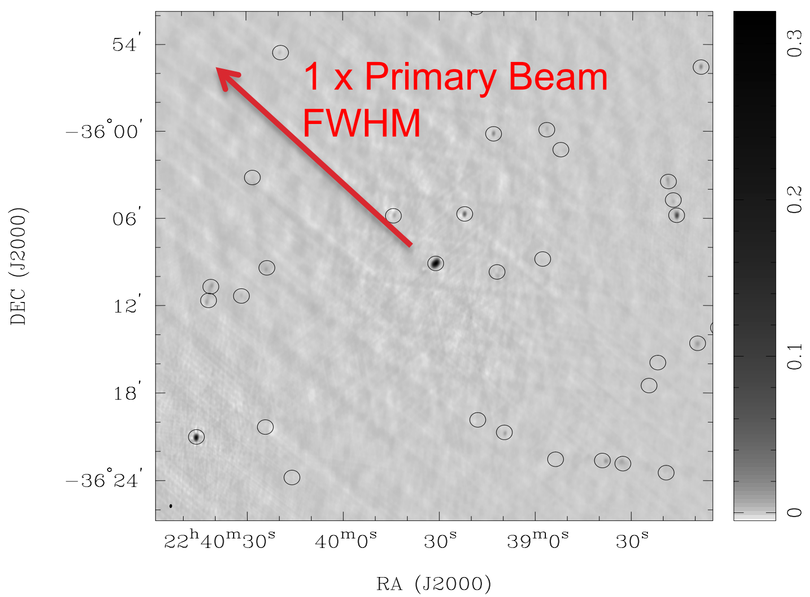
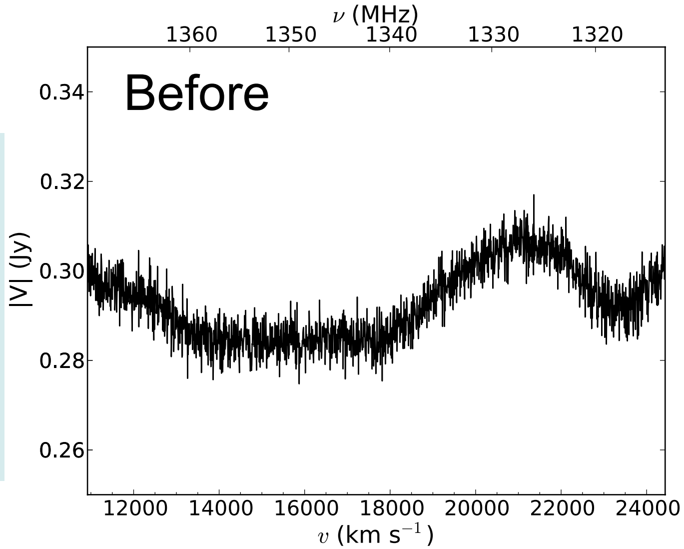
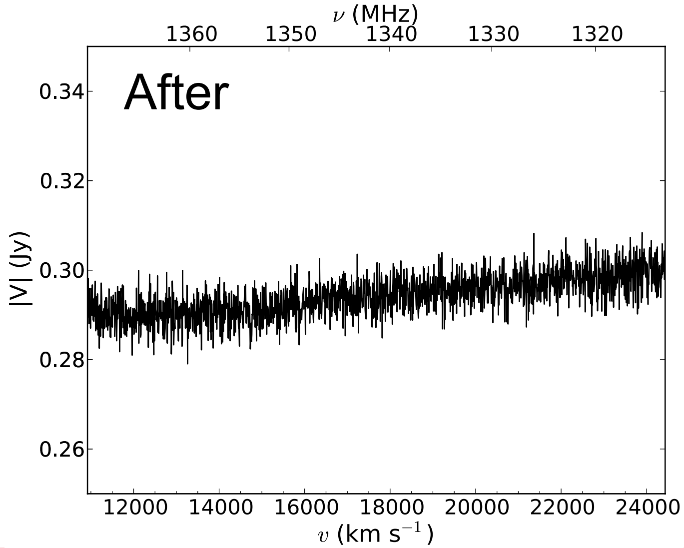
The problem with Continuum

Example: 2049 channel ATCA data

- **Finite UV coverage** generates continuum baseline ripple in extracted spectrum
- Broad shallow line or continuum **baseline ripple**?
- Requires accurate continuum sky-models
- For **ASKAP** team will need to be able to accurately **calibrate** and **subtract** continuum for whole data cube







Extracting the Spectrum

Extracting the spectrum

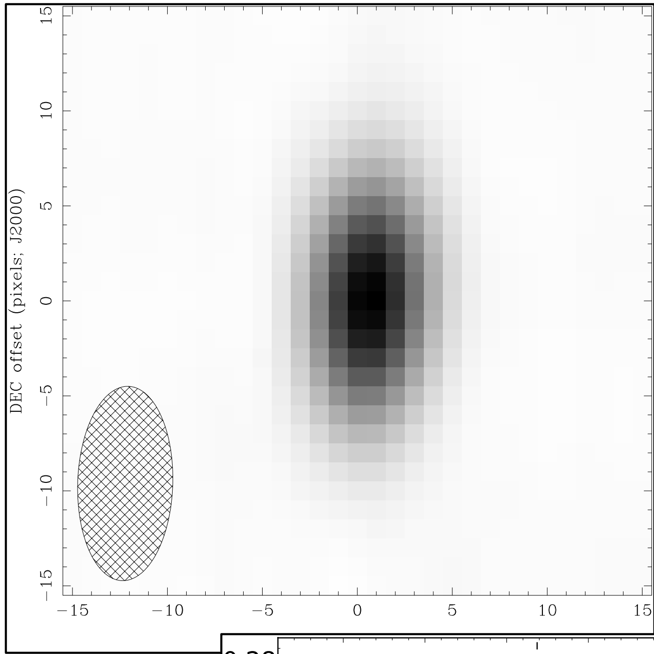
• Where do we extract the spectrum for 100,000s of sources?

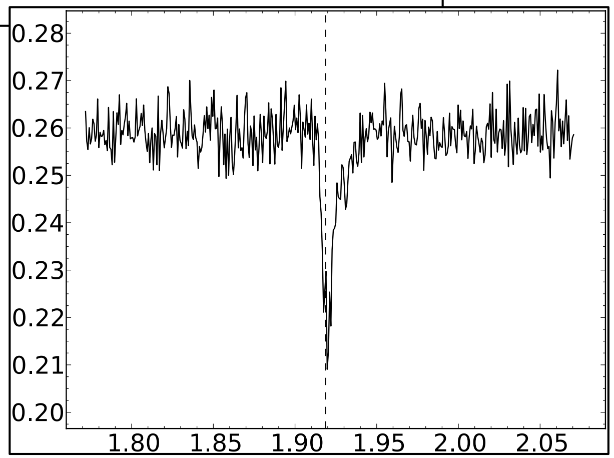
• The position of the peak flux might not be exactly the source position in NVSS, SUMSS etc

• For point sources perhaps calculate PSF weighted spectrum over source

• For extended sources and galaxies (for lower redshift) can extract spectrum at different regions and map HI absorption

• Mapping reveals gas dynamics and can provide information about the covering factor *f*





Detection

How do we **detect lines** down to the noise limit,
and be **confident** of that detection?

Detection

(ASKAP-FLASH Simulation, Allison et al. 2011)

One possibility is via Bayesian Inference …

Model hypothesis selection

$$\frac{\Pr(\mathcal{M}_1|\boldsymbol{d})}{\Pr(\mathcal{M}_2|\boldsymbol{d})} = \frac{\Pr(\boldsymbol{d}|\mathcal{M}_1)}{\Pr(\boldsymbol{d}|\mathcal{M}_2)}\frac{\Pr(\mathcal{M}_1)}{\Pr(\mathcal{M}_2)} = \frac{E_1}{E_2}\frac{\Pr(\mathcal{M}_1)}{\Pr(\mathcal{M}_2)}$$

$$E \equiv \Pr(\mathbf{d}|\mathcal{M}) = \int \Pr(\mathbf{d}|\theta,\mathcal{M})\Pr(\theta|\mathcal{M})\mathrm{d}\theta$$

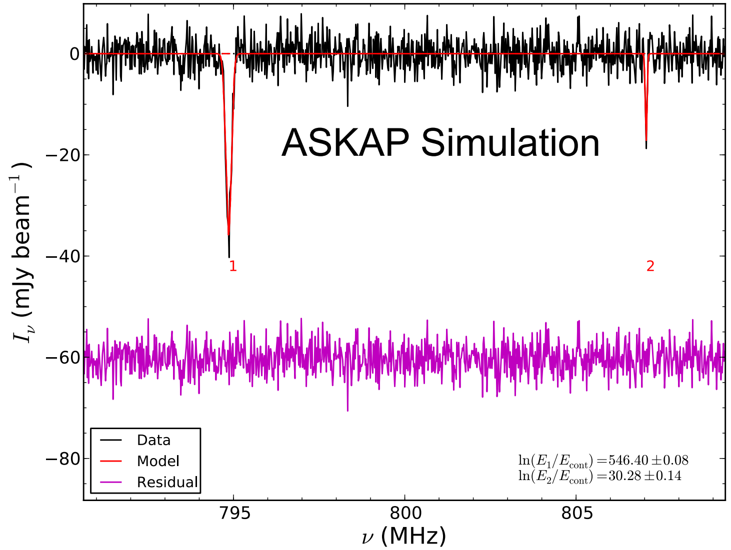
- We need to calculate the “Evidence” *E*
- Requires Monte Carlo Integration methods
- We use Multi-Nested Sampling

(see Feroz & Hobson 2008, Feroz et al. 2009)

Model using single Gaussian profiles

Detection significance given by the ratio of Evidence for Gaussian spectral-line to Continuum-only hypothesis

Very good for low signal-to-noise lines



Parameterization

How many **components** should we fit to our line detections?

Modeling real spectral lines

(ATCA Observations, Allison et al. 2012)

Modeling

- Detection and parameterization based on Bayesian inference

- Compare probability for Spectral-line & Continuum vs Continuum-only hypotheses

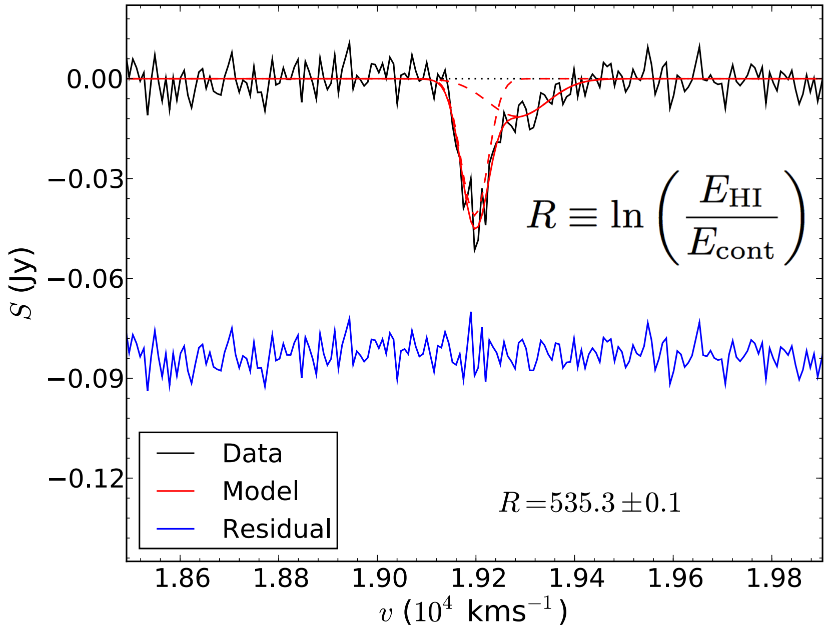
- Vary *n*-components until probability is maximised

Continuum Model

$$S_{\rm cont} = S_0 \left[1 + \sum_{\rm i=1}^{n_{\rm poly}} s_{\rm i} \left(\frac{v}{v_0} - 1\right)^{\rm i}\right]$$

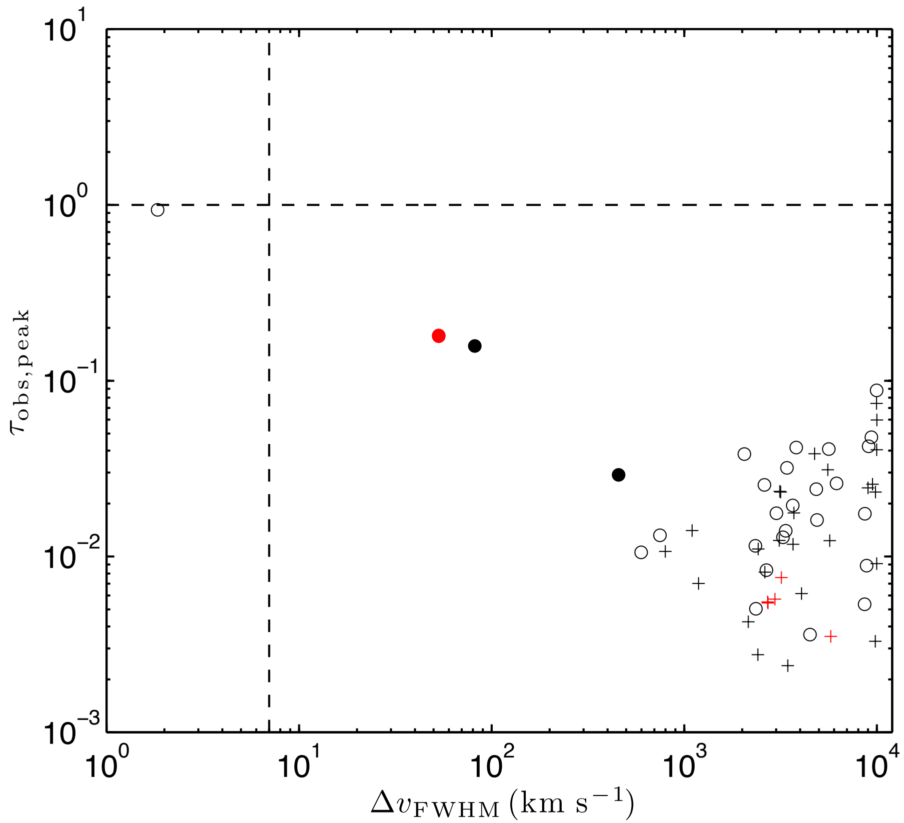
Line Model

$$\Delta S_{\rm line} = \sum_{\rm i=1}^{n_{\rm comp}} \Delta S_{\rm i} \exp\left[-4\ln(2)\frac{(v - v_{\rm i})^2}{(\Delta v_{\rm FWHM,i})^2}\right]$$



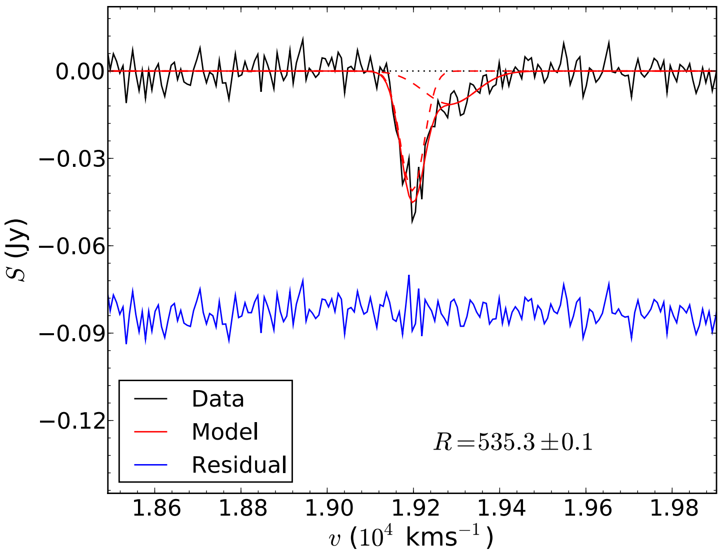
Results from ATCA Observations

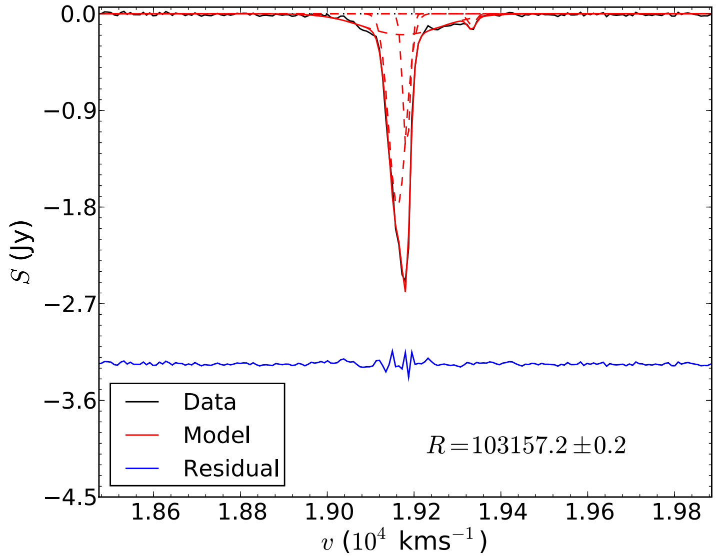
- Observations in 2011
- 29 target sources
- Used "zoom" mode on recently commissioned CABB system
- No frequency re-tuning required
- 0.04 < z < 0.08
- Bias towards compact and young
- 3 detections (10% detection rate)

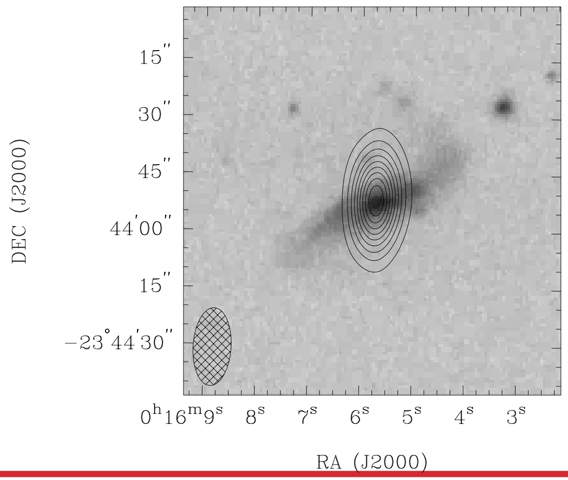


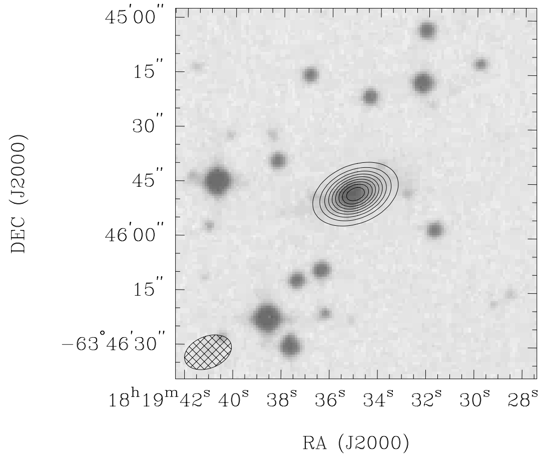
Results from ATCA Observations

Absorption in late-type hosts



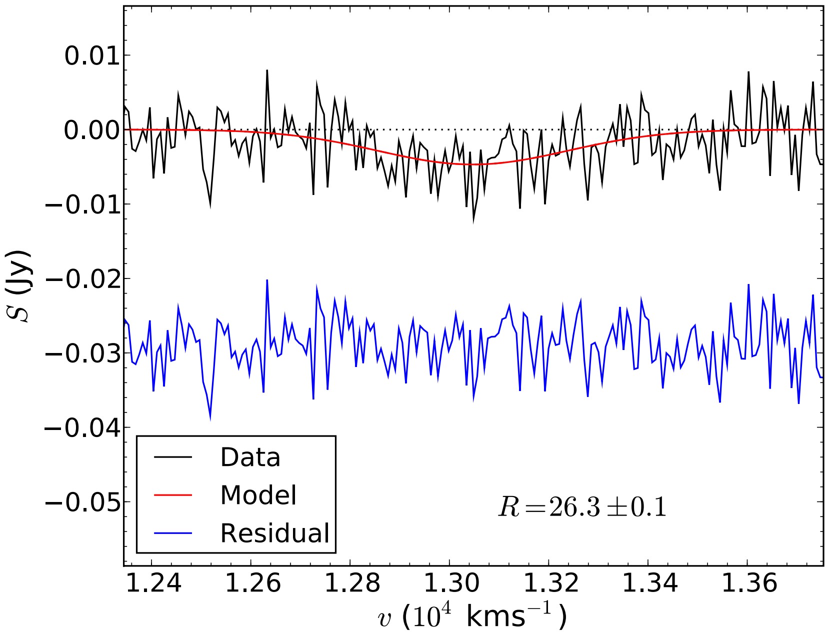


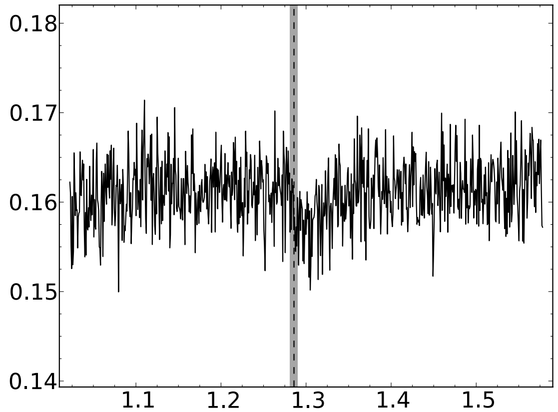


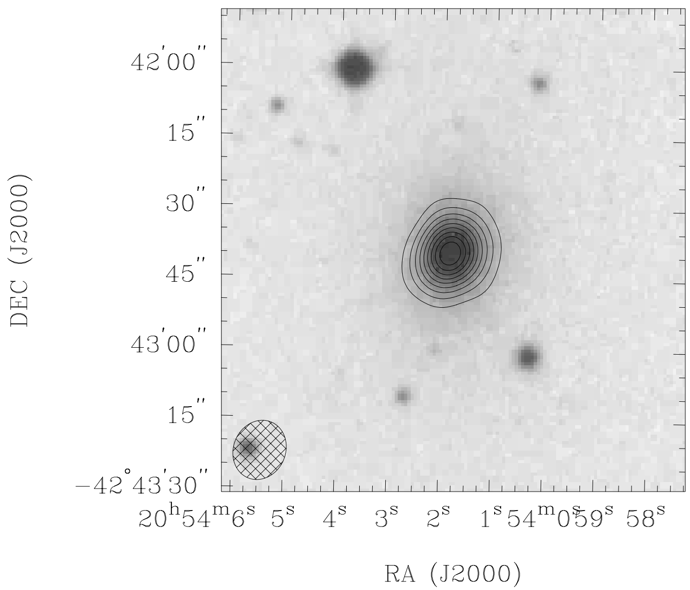


Results from ATCA Observations

Absorption in an early-type host



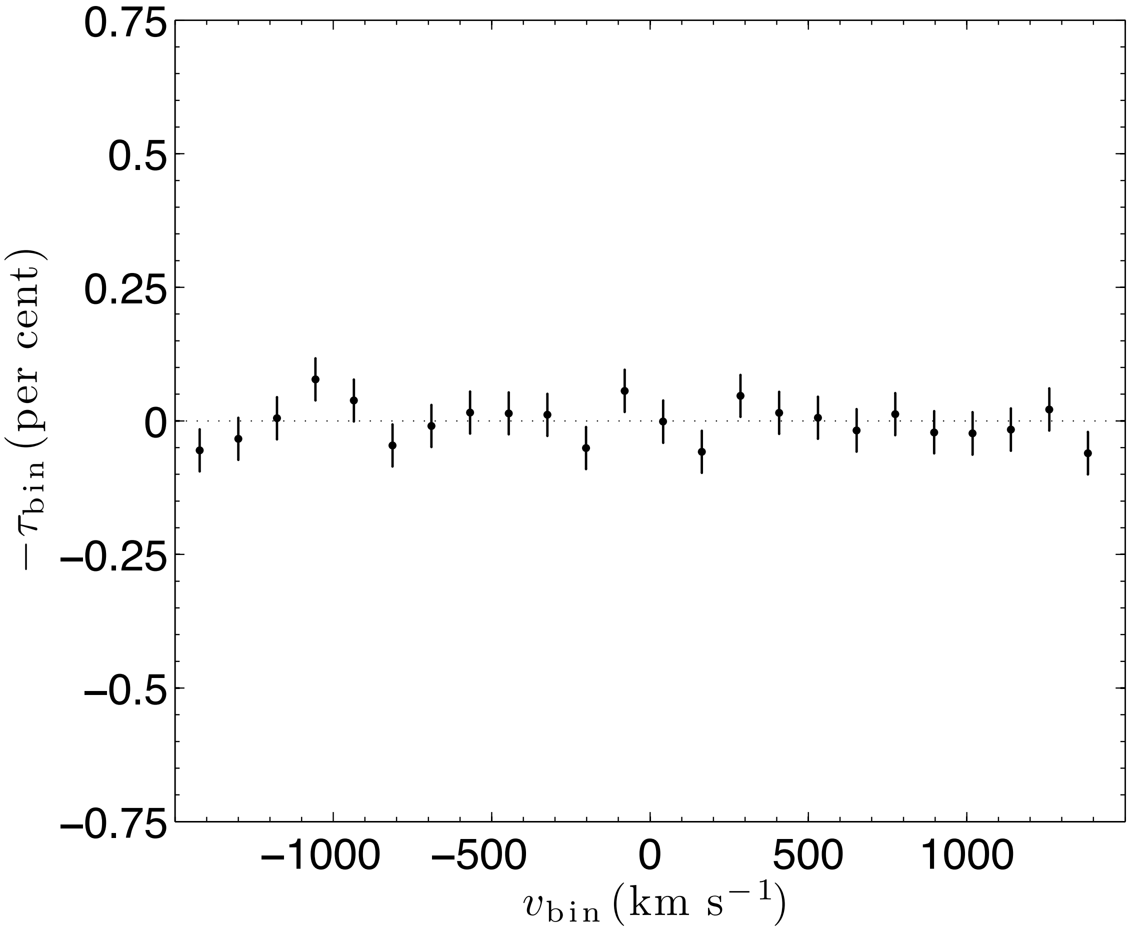




Results from ATCA Observations

Stacked non-detections

- Calculate optical depth spectrum using best-fit continuum
- Shift to velocity given by optical redshift
- Weight each datum based on per channel variance
- Bin to velocity typical of optical redshift accuracy



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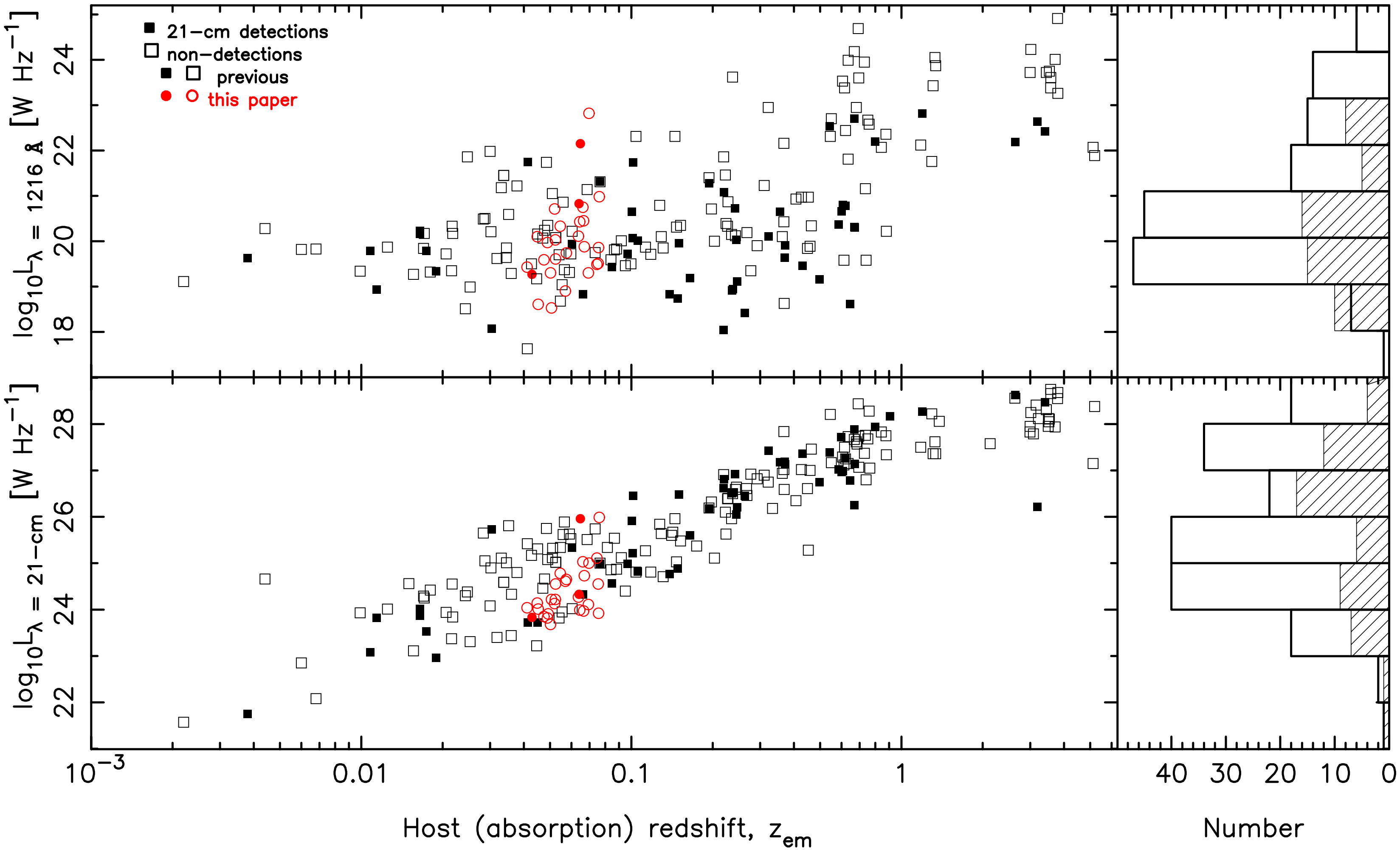
Results from ATCA Observations

Comparison with other surveys



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Summary

- HI 21cm absorption probes cold gas to **higher redshifts** than currently obtainable from emission

- At present constrained to **targeted searches** in order to boost detection rates = **selection effects** (UV luminosity, compactness, source type etc)

- SKA pathfinders will provide first **blind**, **radio selected surveys** of 21 cm absorption for 100,000s of sight-lines (FLASH, MALS, APERTIF)

- Data reduction and parameterization challenges from **very wide bandwidths** and **fields of view**

- Detection methods are required to confidently detect shallow absorption lines at **low SNR**

- Low redshift sources will provide **parameterization challenges** and wealth of information from superposition of **emission and absorption**