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ARC CENTRE OF EXCELLENCE
FOR ALL-SKY ASTROPHYSICS

HI absorption-line science – current results and plans for ASKAP

Elaine Sadler
University of Sydney / CAASTRO
on behalf of the ASKAP FLASH team

ASKAP-FLASH

THE UNIVERSITY OF SYDNEY

Why 21cm HI absorption surveys?

Motivation: Use 21cm HI absorption to probe neutral atomic hydrogen in distant galaxies - unlike HI emission, *sensitivity is independent of z*

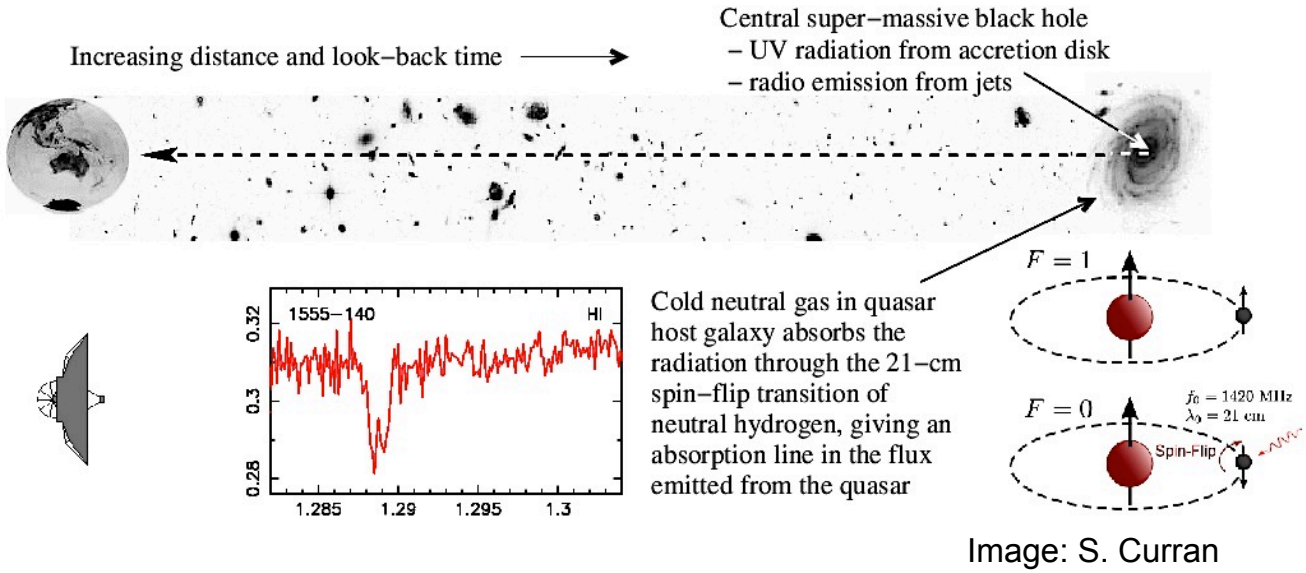
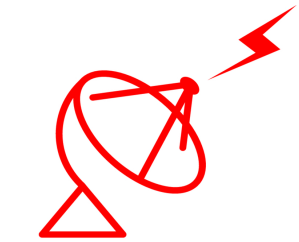


Image: S. Curran

Intervening absorbers: Cosmic evolution of HI in galaxies
Associated absorbers: AGN fuelling and feedback

ASKAP FLASH: the First Large Absorption Survey in HI



Key science goals:

- To provide the *first systematic probe* of the neutral hydrogen (HI) content of individual galaxies in the redshift range $0.5 < z < 1.0$
- To make *tests of current galaxy evolution and mass assembly models* in this redshift range, using the observed and predicted distributions of quantities like HI optical depth and line width.

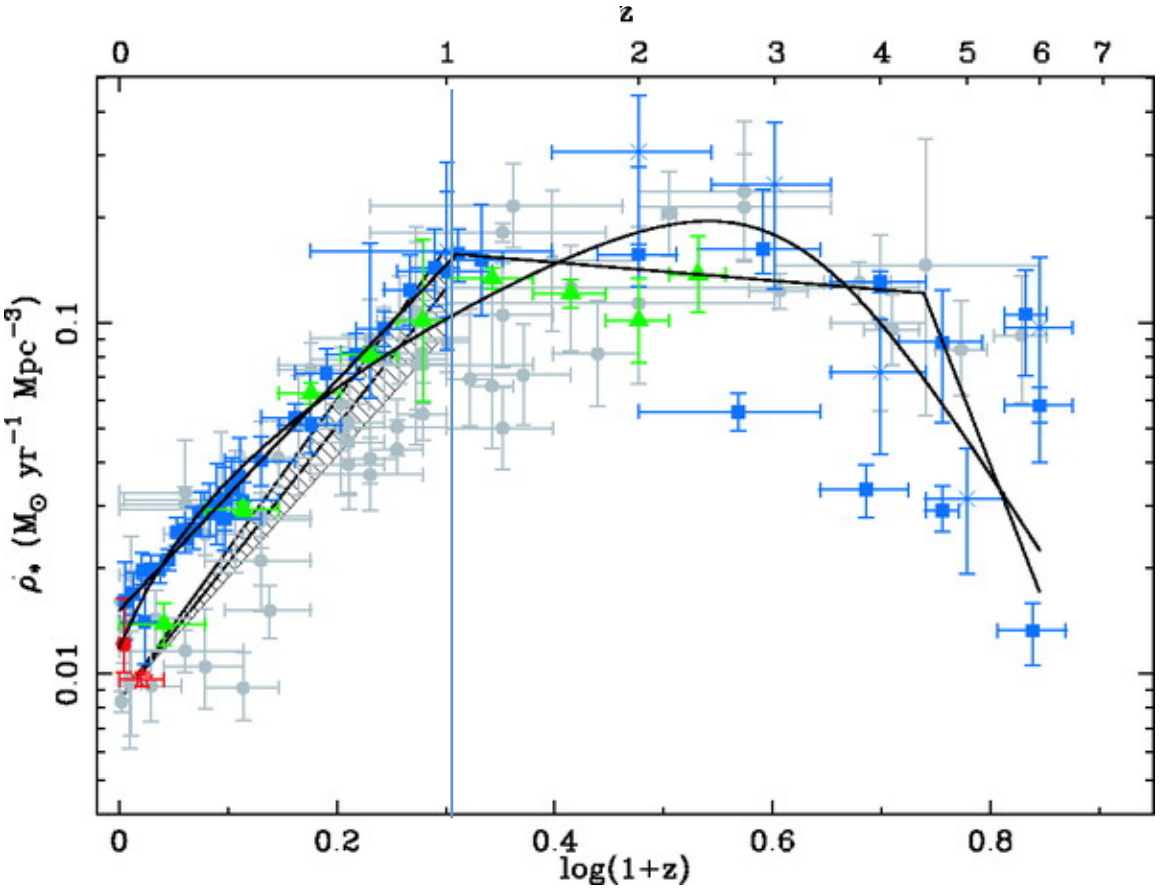
An HI-selected galaxy sample at z > 0.5

Team members: *Currently 38 members from 19 institutions in 9 countries*

Elaine Sadler (Sydney, PI), **James Allison** (Sydney), Chris Blake (Swinburne), Joss Bland-Hawthorn (Sydney), **Robert Braun** (UK), Matthew Colless (AAO), **Rob Crain** (Leiden), Scott Croom (Sydney), Darren Croton (Swinburne), Stephen Curran (Sydney), Jeremy Darling (USA), John Dickey (Tasmania), Michael Drinkwater (Qld), Alastair Edge (UK), Ron Ekers (ATNF), Sara Ellison (Canada), Bjorn Emonts (Spain), Ken Freeman (ANU), Bryan Gaensler (Sydney), Marcin Glowacki (Sydney), Dick Hunstead (Sydney), Helen Johnston (Sydney), **Baerbel Koribalski** (ATNF), Philip Lah (ANU), Tom Mauch (S. Africa), **Martin Meyer** (UWA), **Raffaella Morganti** (Netherlands), **Tom Oosterloo** (Netherlands), Max Pettini (UK), Kevin Pimbblet (UK), Michael Pracy (Sydney), **Sarah Reeves** (Sydney),Tim Robishaw (Canada), D.J. Saikia (India), **Lister Staveley-Smith** (UWA), Matthew Whiting (ATNF), Richard Wilman (UK), **Martin Zwaan** (ESO)

http://www.physics.usyd.edu.au/sifa/FLASH

Gas and galaxy evolution



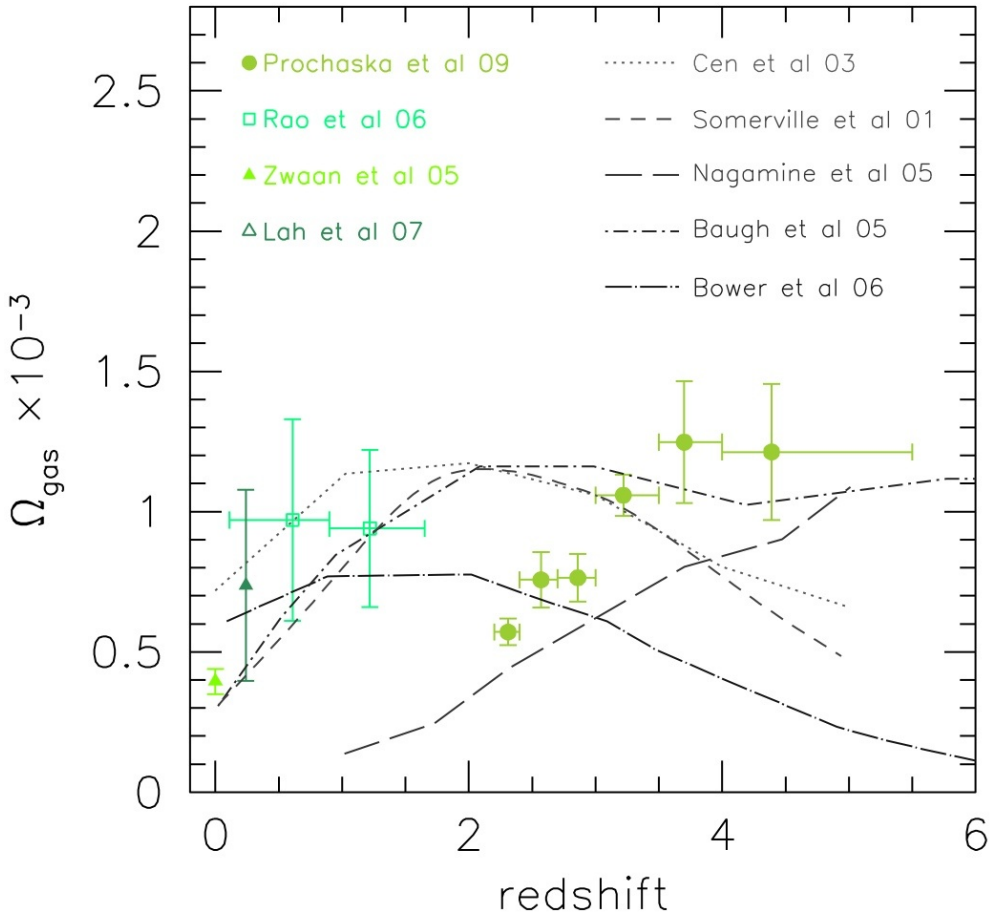
(Hopkins & Beacom 2006)

The rate at which new stars form in galaxies has decreased by about a **factor of 20** over the past 7-8 billion years (from redshift z~1 to 0).

What caused this?
A decline in the supply of cold neutral gas in galaxies?

We don't know!

Cosmic HI mass density

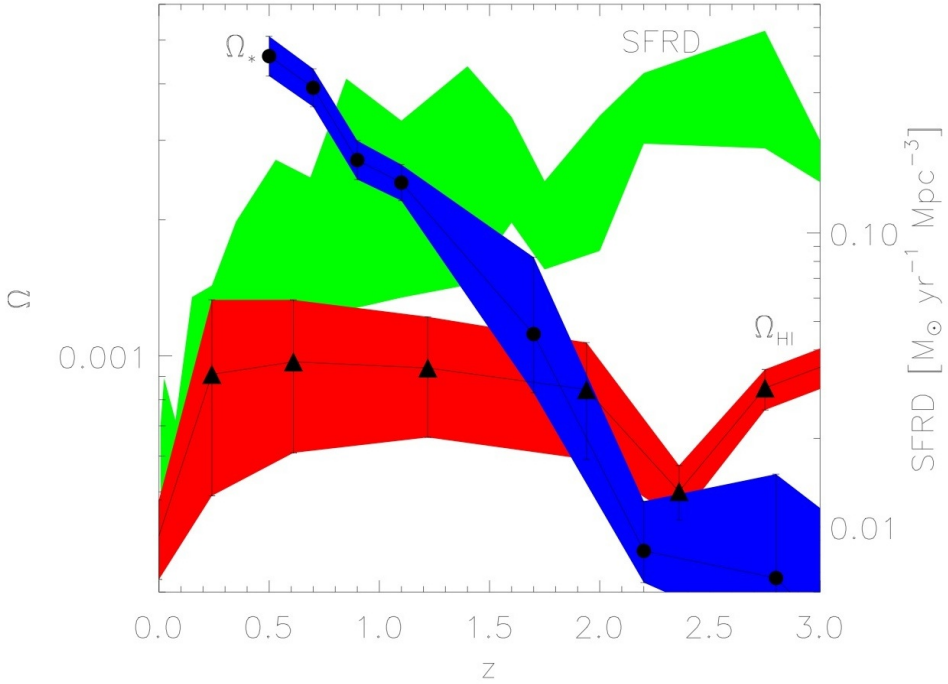


Neutral hydrogen is the *missing link* in our current understanding of galaxy evolution

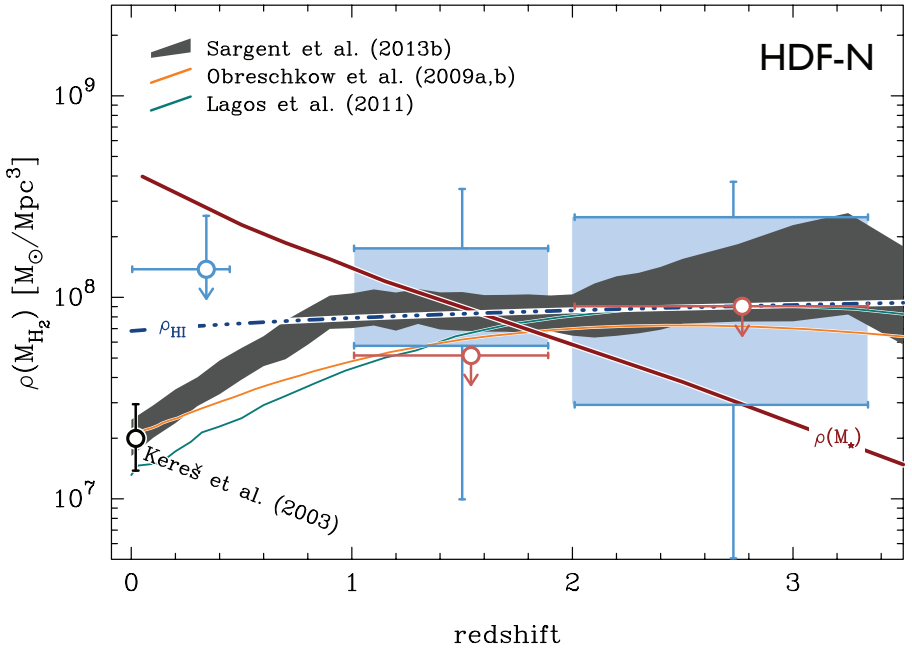
- We know almost nothing about the HI content of individual galaxies in the distant universe
- A wide range of models and simulations exist, with diverse predictions about the cosmic HI mass density at $z > 0$. Better observational constraints are needed, especially at $0.1 < z < 1$.

High-redshift data are available from observations of the Lyman-α absorption line in optical QSOs at $z > 1.7$, but far less information at low redshift!

Cosmic evolution of atomic and molecular gas



(Putman et al. 2009)



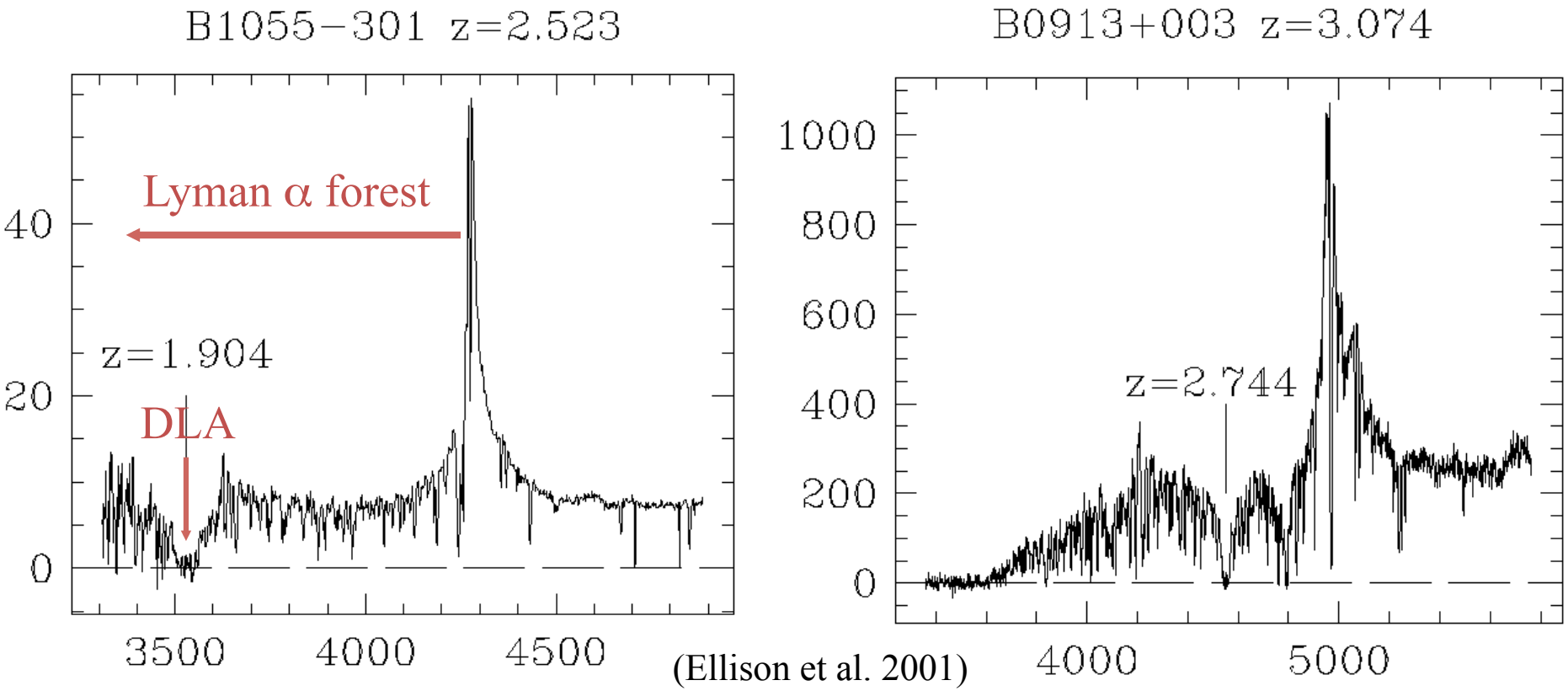
(Walter al. 2014)

HI in the distant universe

Technique	Redshift	Measures	HI detection rate
HI emission-line surveys	$z < 0.4$	Individual galaxies	**Drops** with redshift
HI absorption-line survey	$0 < z < 1.0$ (ASKAP)	Individual galaxies/clouds	**Independent** of redshift
HI emission-line stacking	$0 < z < 1.0$	'Average' HI properties	Depends on redshift **and** the amount and quality of optical redshift data

Absorption surveys can tell us what *kinds* of galaxies (uv-bright? dusty?) dominate in an HI-selected sample at high redshift. Need to know this to design/interpret stacking surveys. Low-redshift data are key to cross-calibrating all three methods .

Optical: Damped Lyα Absorbers

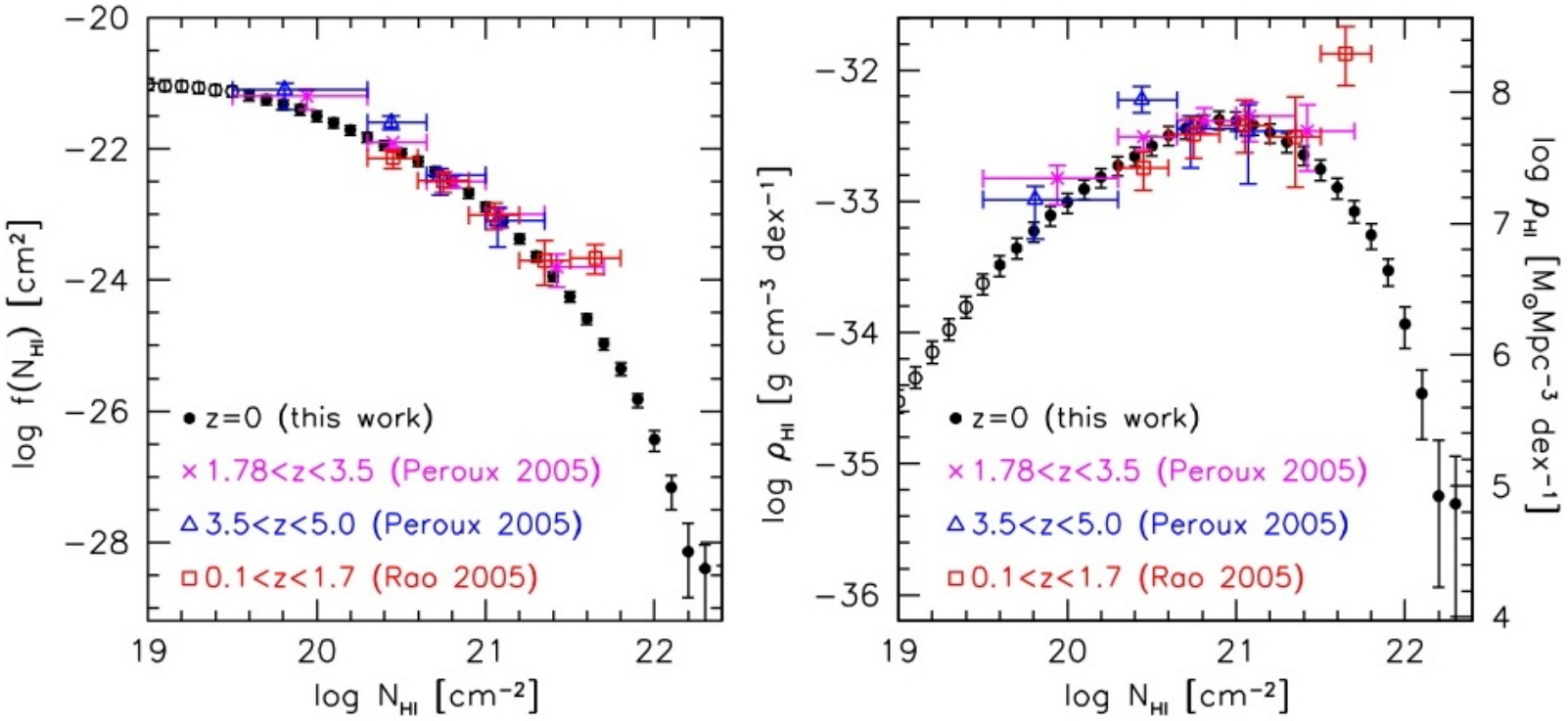


(Ellison et al. 2001)

DLAs: Intervening absorbers with high HI column density ($N_{HI} > 2 \times 10^{20}$ cm^{-2}) can be used to detect and study neutral hydrogen in the very distant universe. *Ground-based observations of the Lyman-α line are only possible at redshift z > 1.7*

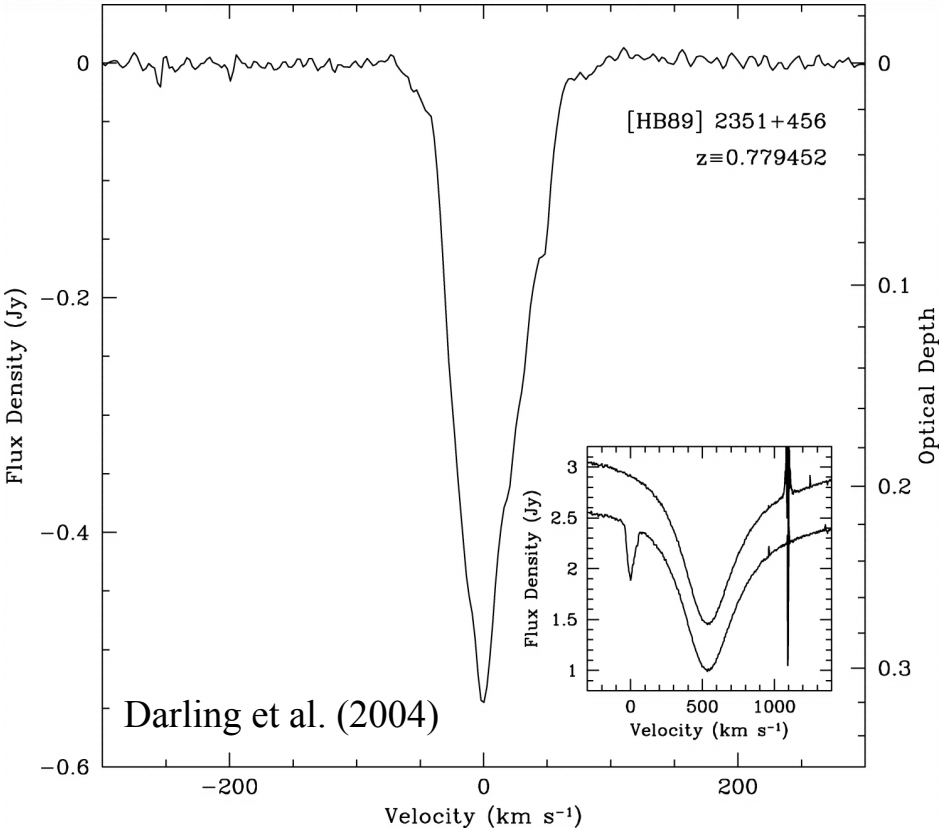
HI column density distribution

Zwaan et al. (2005)



Optical QSO DLA surveys do not detect the highest column-density absorbers expected on ~0.1% of sightlines, and *"do not trace the majority of star-forming gas in the universe"* (Ledoux et al. 2003). **Dust obscuration?**

Radio: Intervening HI absorption



Unlike optical, ***no redshift limit*** *for detecting radio 21cm absorption lines.*

But do need many targets, wide bandwidth

Radio 21cm measurements are particularly sensitive to cold HI (spin temp. $T_S < 200K$) .

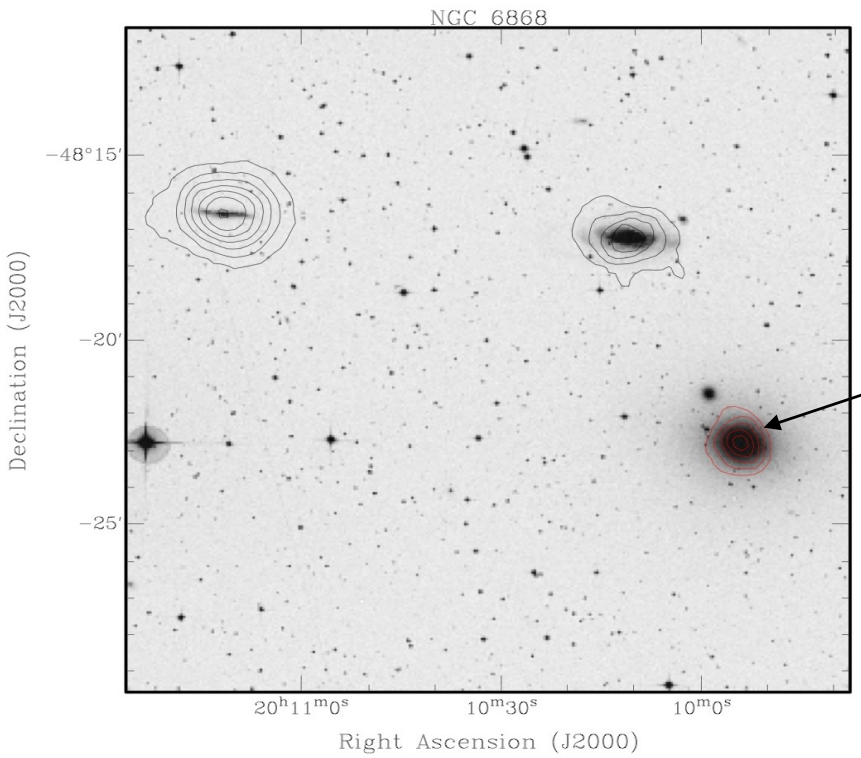
$\tau \propto N_{HI}/f.T_s.\Delta V$ for observed optical depth τ, line width ΔV

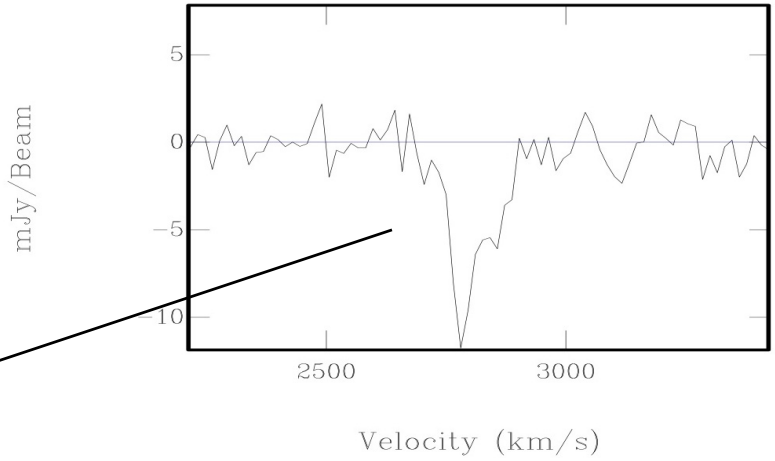
Probability of intercepting a DLA system ($N_{HI} > 2 \times 10^{20}$ cm^{-2}) on a random sightline:

$dN/dZ=0.055\ (1+z)^{1.11}$
(Storrie-Lombardi & Wolfe 2000)

i.e. ~6% for z=0.7, 300 MHz

Radio: associated HI absorption

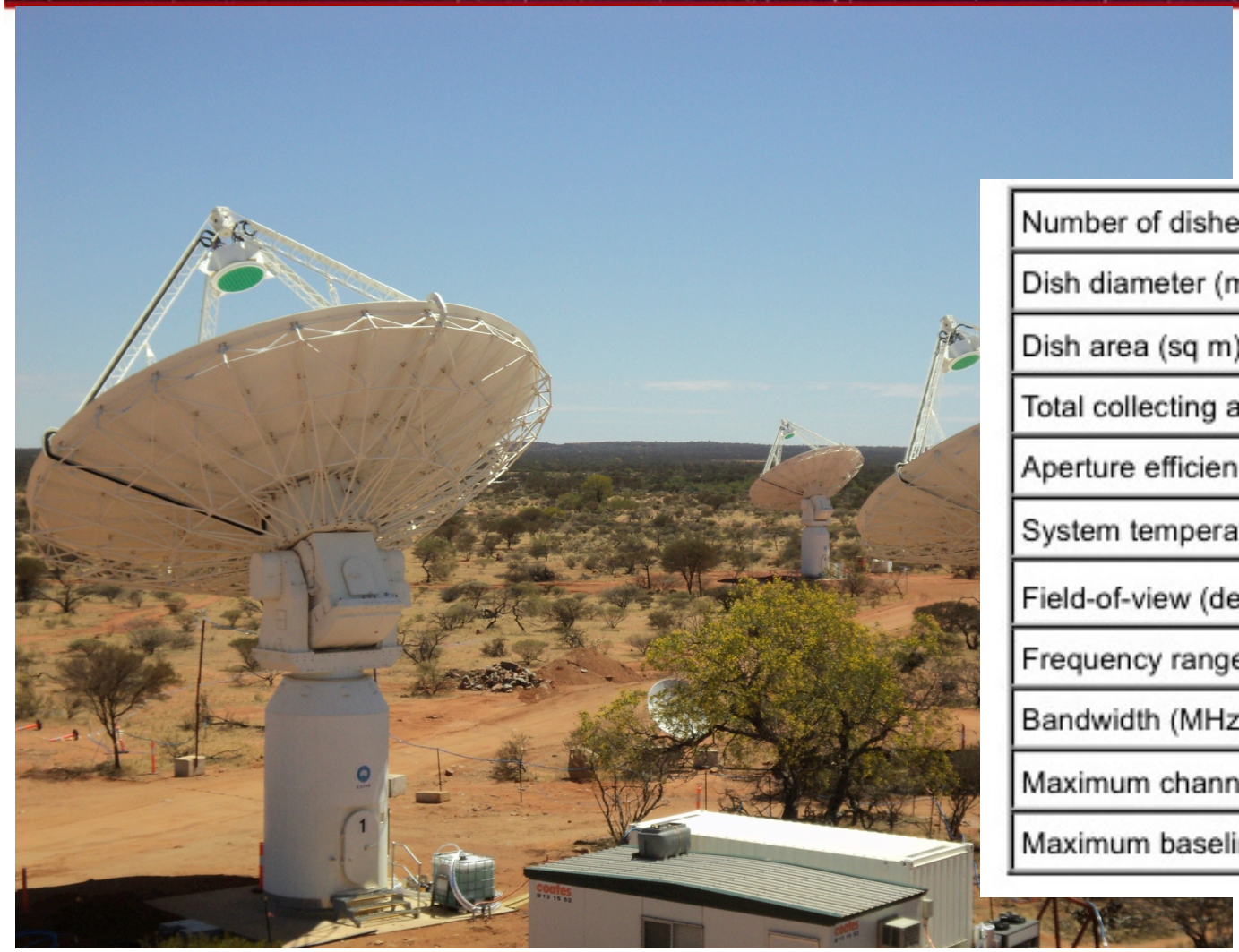




(Oosterloo et al., targeted HI, z = 0.01)

Associated HI absorption at or near the galaxy redshift is particularly common in compact, flat-spectrum radio galaxies (e.g. Morganti et al. 2001; Vermeulen et al. 2003)

ASKAP – The Australian SKA Pathfinder



Number of dishes	36
Dish diameter (m)	12
Dish area (sq m)	113
Total collecting area (sq m)	4072
Aperture efficiency	0.8
System temperature (K)	50
Field-of-view (deg^2)	30
Frequency range (MHz)	700-1800
Bandwidth (MHz)	300
Maximum channels	16384
Maximum baseline (km)	6

FLASH early science 2015-16, full survey from 2016-17

First ASKAP HI spectral-line detection

http://www.atnf.csiro.au/projects/askap/news_science_04122013.html

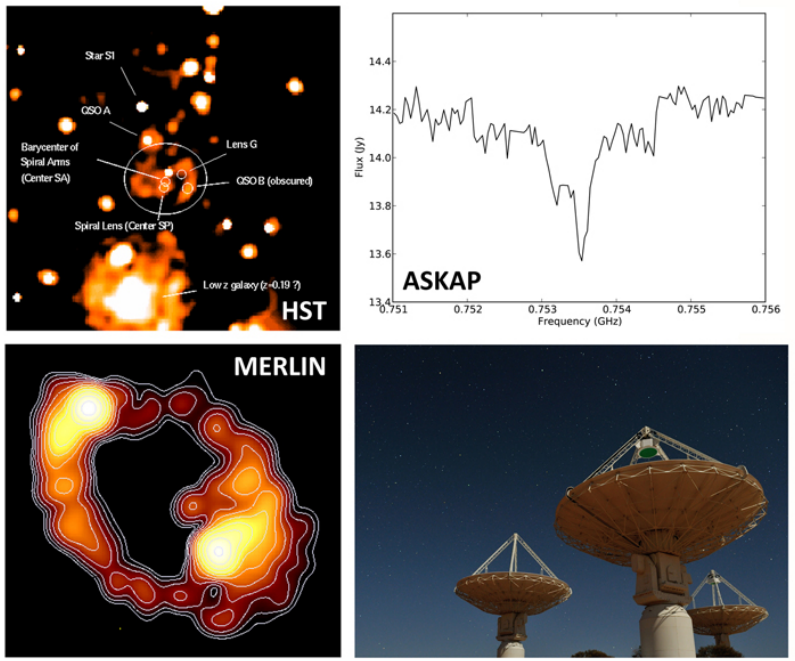


Image: CSIRO

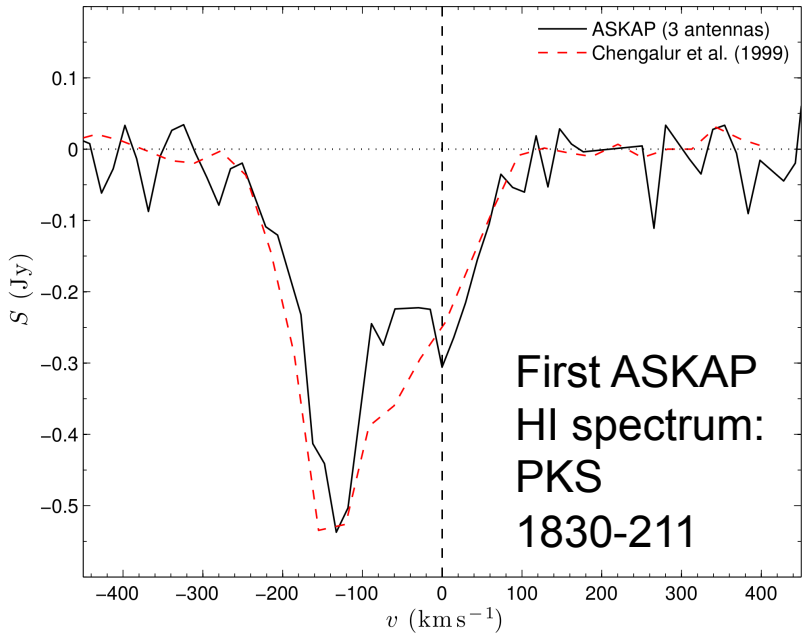


Image: CSIRO/J. Allison

In a six-hour observation with three ASKAP baselines, first-generation phased array feed (PAF) receiver system and the hardware correlator, a baseline-averaged cross correlation spectrum was produced of the gravitationally-lensed system PKS 1830-211. HI absorption is seen in an intervening galaxy at redshift z=0.89.

The advantages of ASKAP

ASKAP's

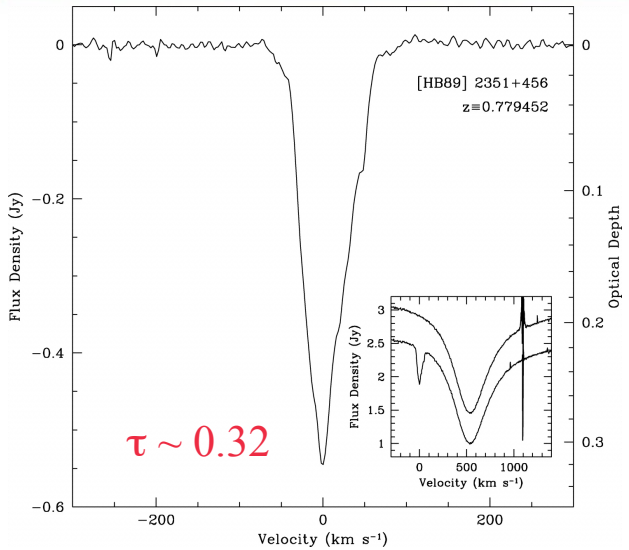
- Wide field of view
- Wide spectral bandwidth
- Radio-quiet site

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

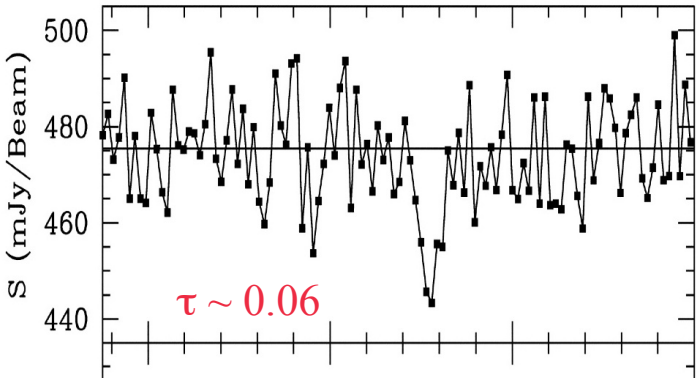
Only about 400 sightlines have so far been searched for HI absorption in the radio (roughly 200 each with single-dish (blind) and interferometer (targeted) programs).

In the ASKAP-FLASH survey, we plan to target more than 150,000 sightlines to bright background continuum sources, *an increase of more than two orders of magnitude over previous work.*

FLASH survey strategy (1)



Darling et al. (2007)



Lane et al. (2001)

Need to take into account:

- Surface density of suitably-bright background continuum sources *(known from SUMSS/NVSS, ~ 150 sources per ASKAP field)*
- Probability of intersecting an absorber of any given HI column density/optical depth *(estimated from Curran et al. (2005), Zwaan et al. (2005) values at z~0)*
- Observing time needed to detect the strongest lines *(calculated from ASKAP specs)*

Maximizing the survey area will also maximize the number of detections, so FLASH is an all-sky survey at 2 hours per pointing

FLASH survey strategy (2)

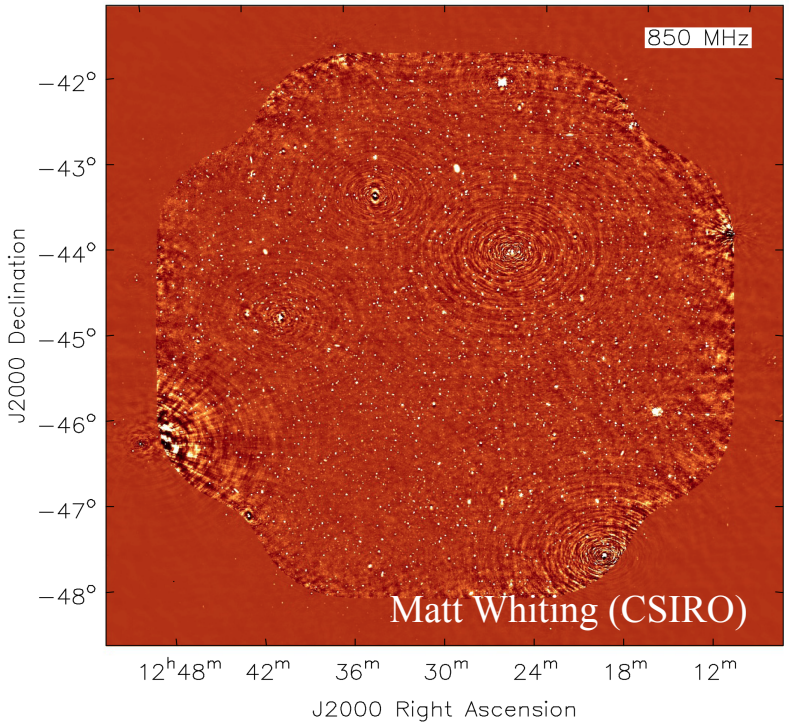
Source positions are known in advance, so

- *No need for source finders – only a line finder*
- *If necessary, need only keep <<1% of the data*

Thus absorption-line studies are a good commissioning/early science project for ASKAP.

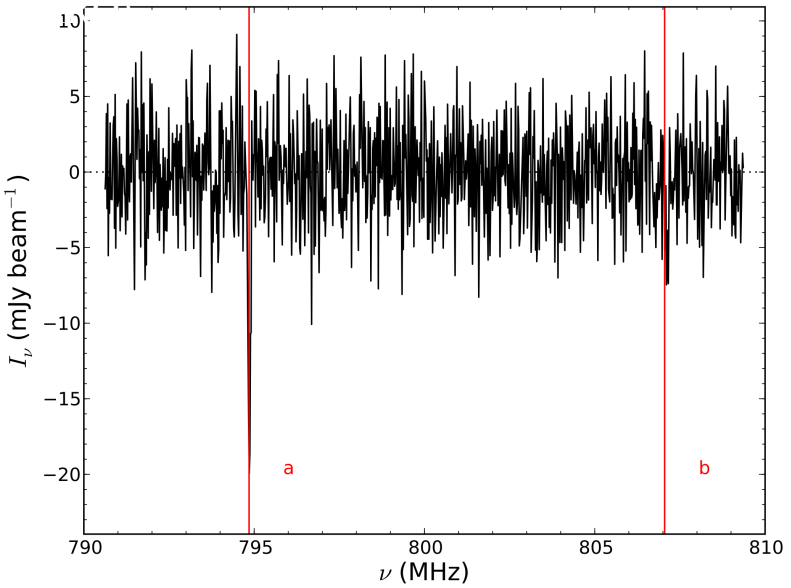
For intervening absorbers, most background sources will be faint galaxies *not* bright QSOs. This makes follow-up studies of the absorbing systems *relatively straightforward,* and such studies should provide a rich variety of additional astrophysical information.

Line-finding: simulated ASKAP data



435 continuum sources with a total sample of 600 absorption components "painted on"

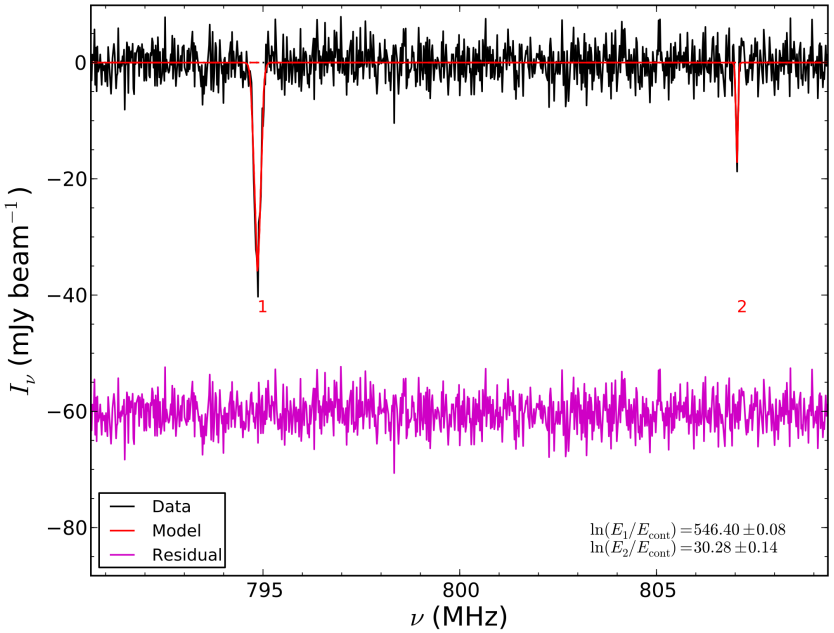
Absorption components have a range of parameters:
- z = 0.76 – 0.792
- Peak optical depth = 0.01 – 0.30
- Velocity width = 5 – 80 km/s



- Simulate 2hr integration of 30deg^2 field
- 18MHz bandwidth centred on 800MHz (vs 300MHz for ASKAP), with 1024 channels
- Select sources brighter than 10mJy at 800MHz

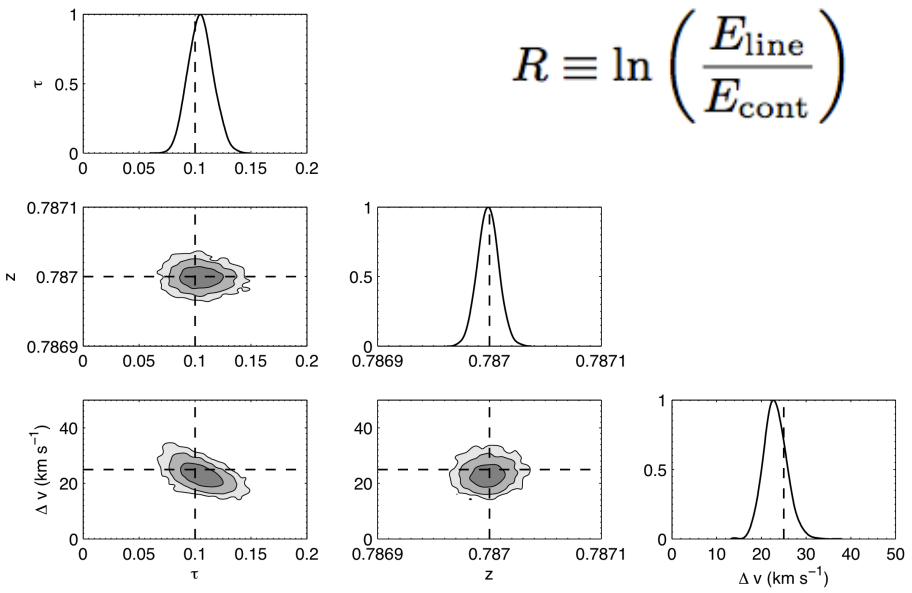
Results from ASKAP simulations (1)

(Allison et al. 2012)



Model using single Gaussian profiles

Detection significance given by the ratio of Evidence for Gaussian spectral-line and Continuum-only models



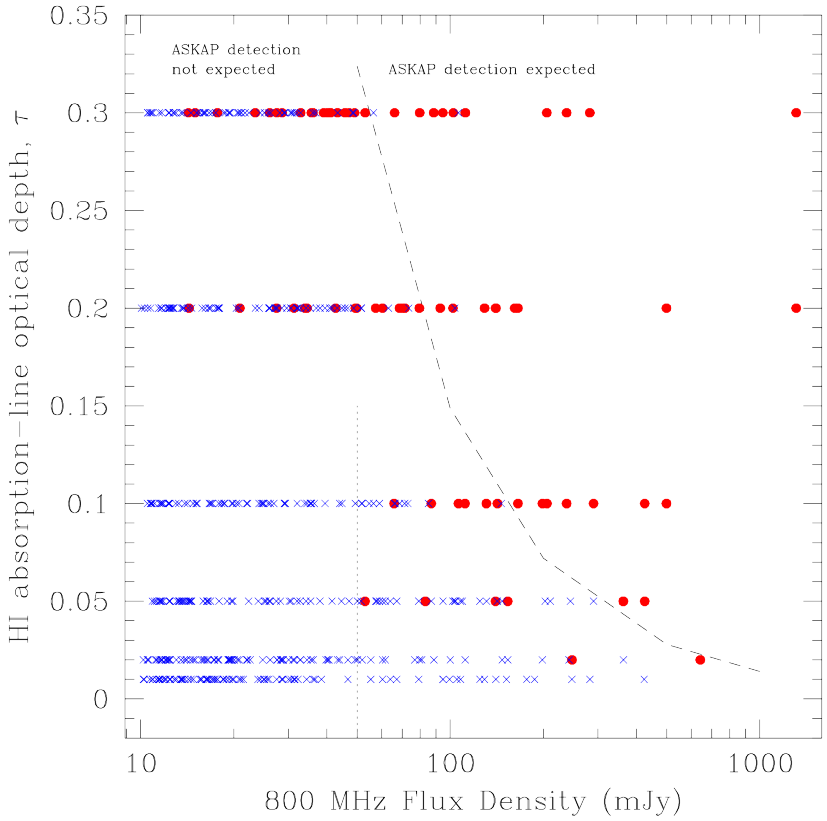
$$R \equiv \ln\left(\frac{E_{\rm line}}{E_{\rm cont}}\right)$$

Calibrate significance based on known false-positive detections

Method correctly reproduces simulated line parameters from the data

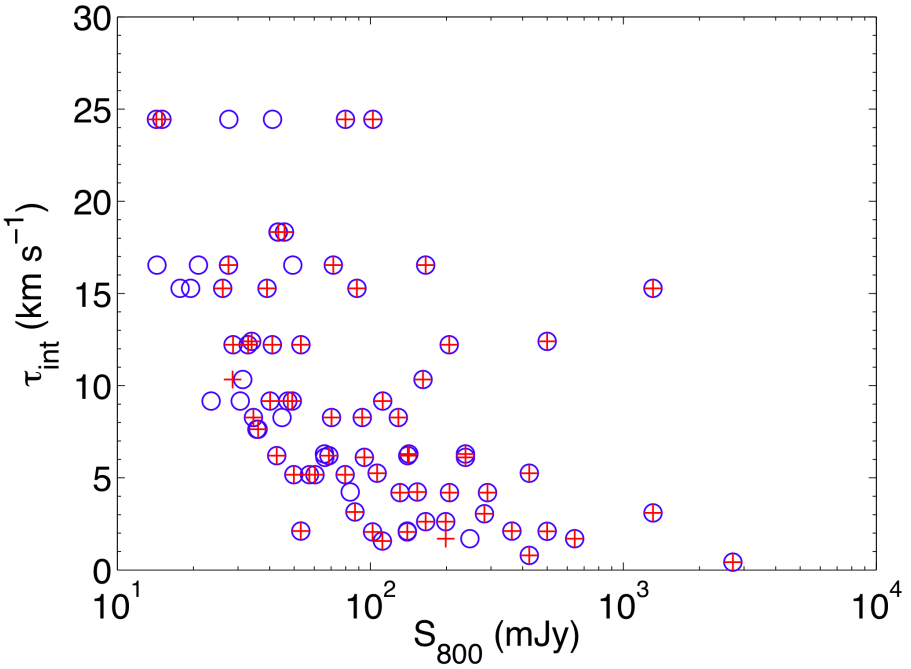
Results from ASKAP simulations (2)

(Allison et al. 2012)

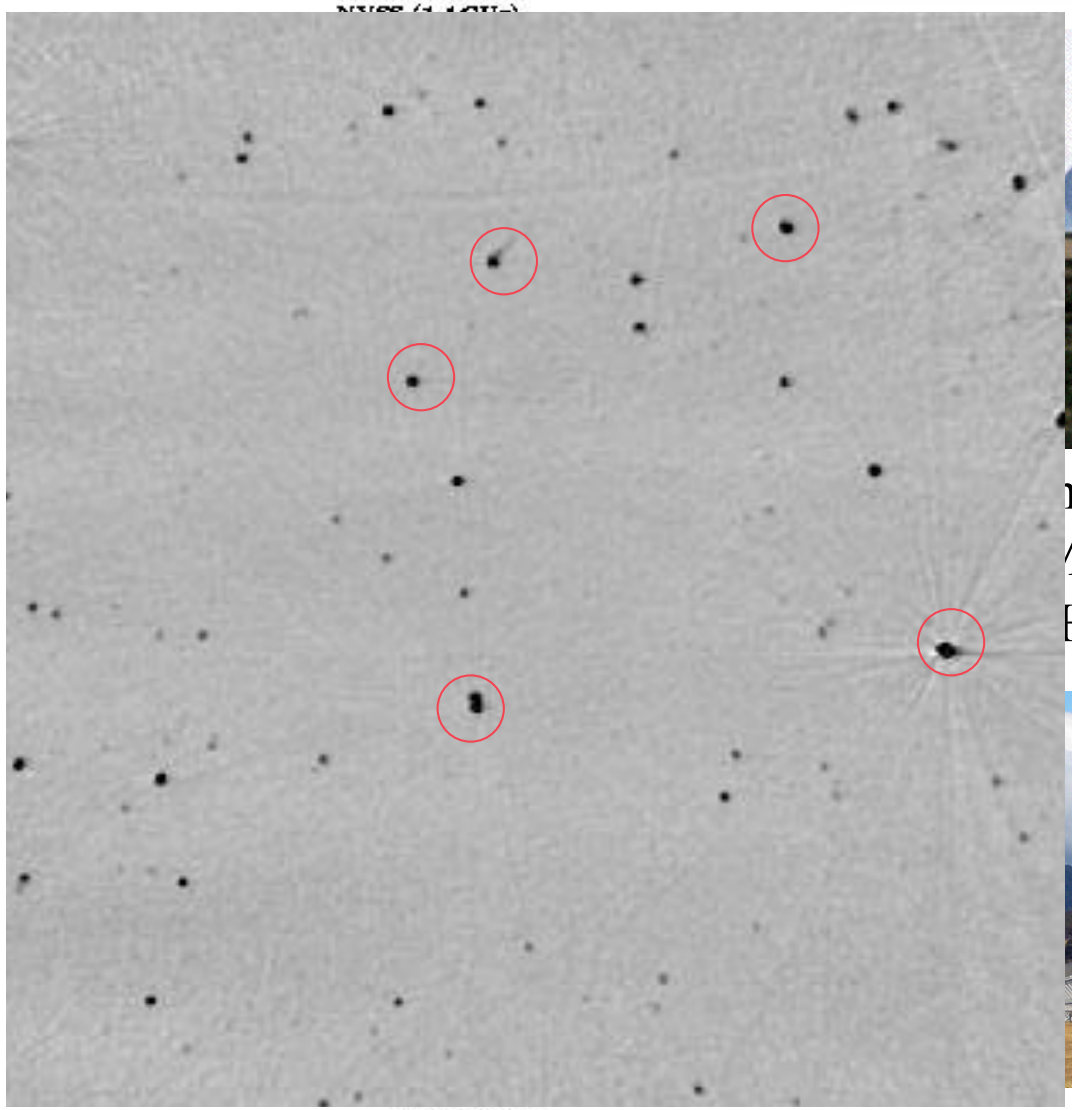


Expected vs actual detections

Comparison between Bayesian (blue) and Duchamp threshold algorithm (red)

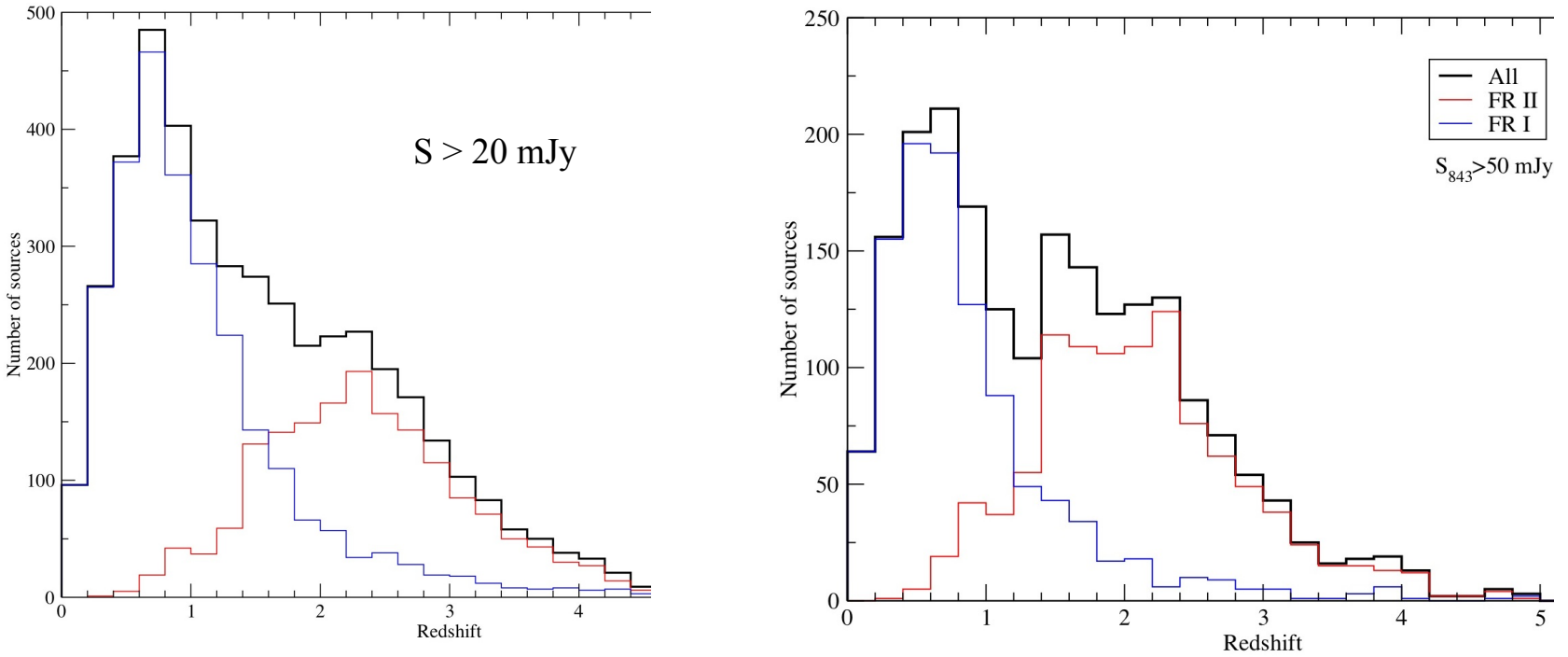


FLASH: background continuum sources



ng NVSS (1400 MHz) and SUMSS
MHz) catalogues provide the
H target list

Redshift distribution of continuum sources



Predicted redshift distribution for continuum sources brighter than 20 and 50 mJy at 843 MHz, from the SKADS simulated sky (Wilman et al. 2008)

Estimate that ~85% of bright (> 20-50 mJy) continuum sources are at z > 0.5 and 65% at z > 1.0

ATCA search for HI absorption at z < 0.1

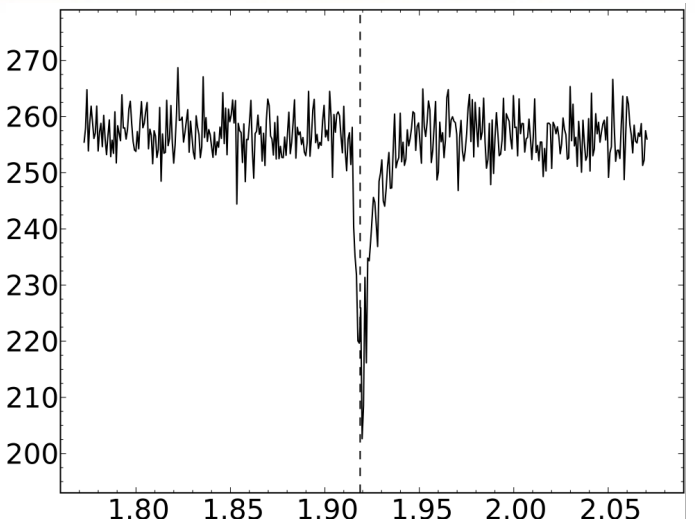
The ATCA CABB provides realistic wide-band data to test the FLASH data pipeline:

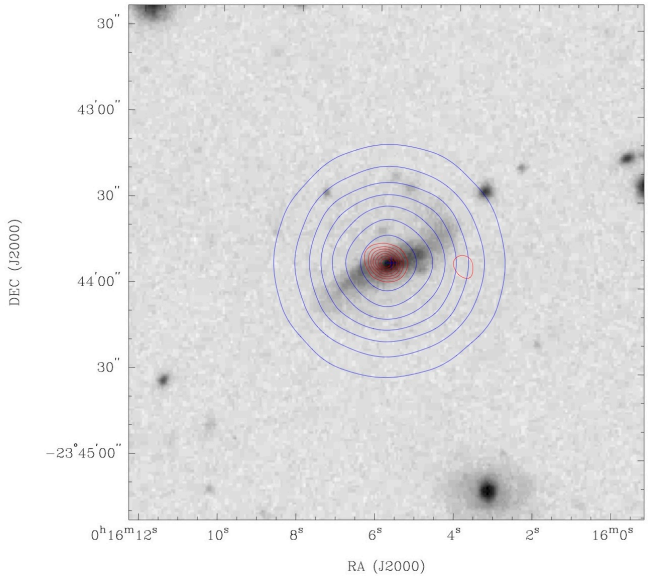
- 64 MHz band across 2049 channels
- Simultaneous z range 0.0338 - 0.0844
- Velocity resolution of 7km/s

Targeted ATCA observations of 40 compact radio galaxies at $z < 0.08$ and $S_{1400} > 50$mJy, from the AT20G survey (Murphy et al. 2010).

Constructed an automated data reduction pipeline using MIRPY (Miriad Python wrapper, Malte Marquarding), plus automated Bayesian line finder.
First test was to recover the known detection of PKS 1814-63 by Morganti et al. (2001, 2011).
Three new detections so far.

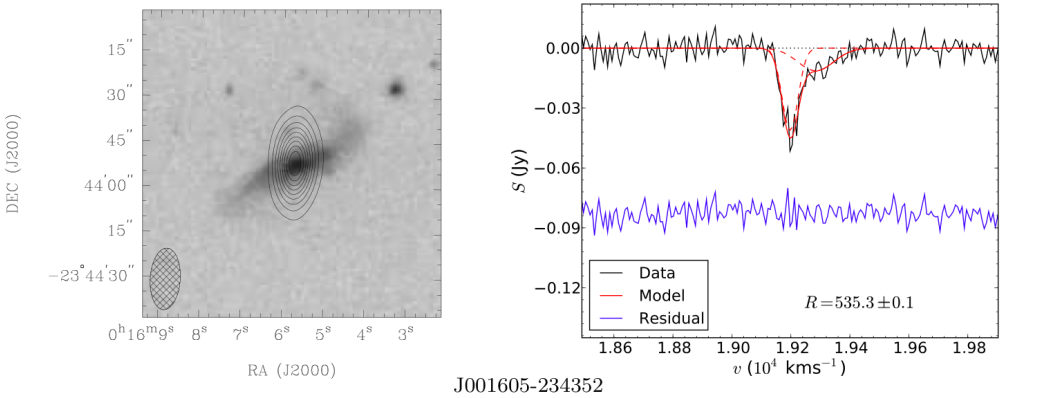
(Allison et al. 2012,2013)





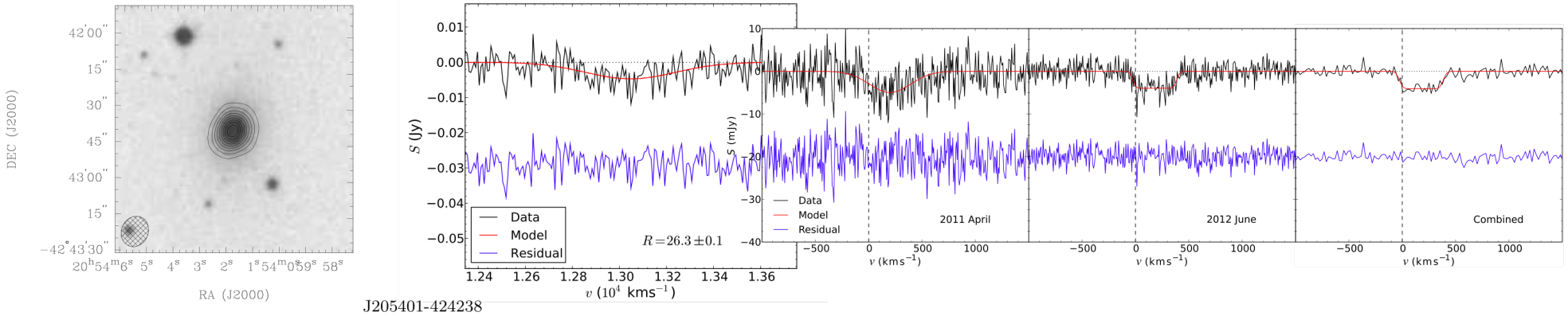
HI absorption in nearby compact radio galaxies

(with James Allison, Steve Curran, Bjorn Emonts, Katinka Gereb, Elizabeth Mahony, Sarah Reeves, Martin Zwaan)



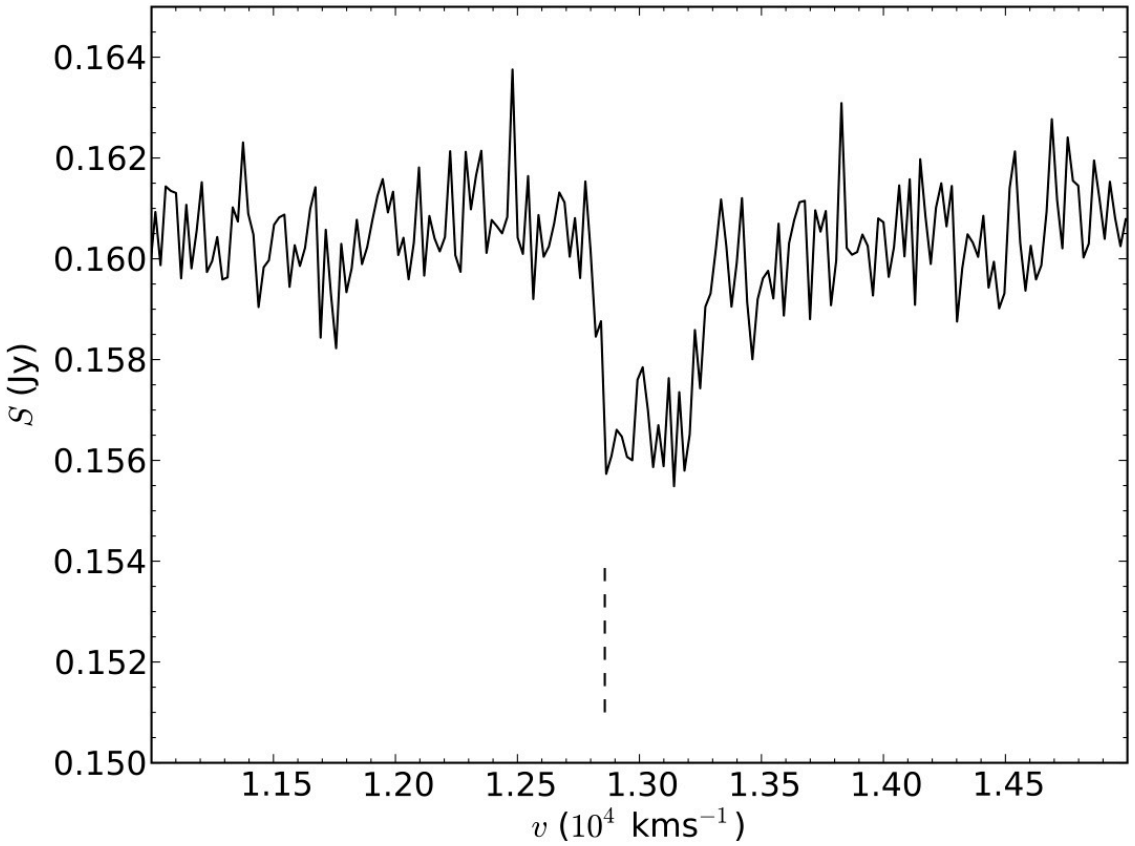
HI detection rate ~10%, mixture of early- and late-type galaxies.

One detection of an unusually broad and shallow line.



(Allison et al. 2012, 2013)

PMN J2054–4242



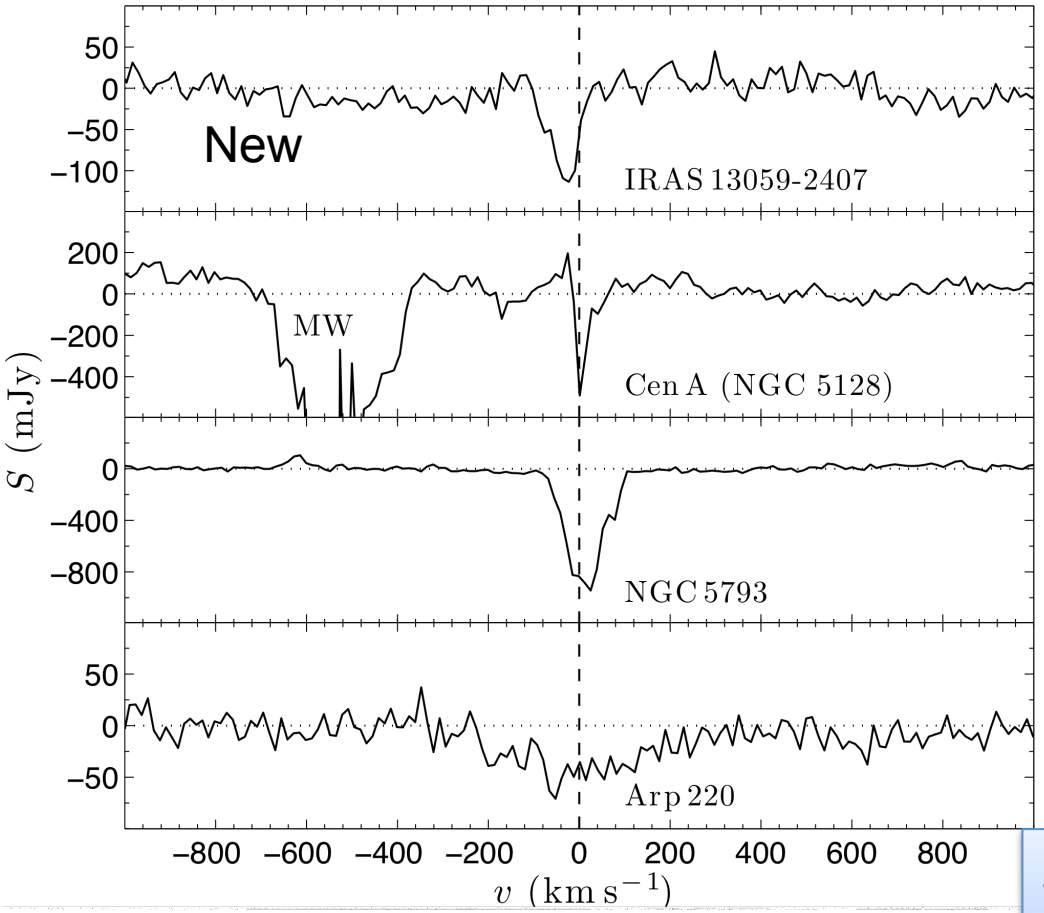
(Allison et al. 2013) - detection of broad (FWHM ~400 km/s), shallow HI absorption against the compact (<200 pc) radio core of an early-type galaxy at z=0.064.

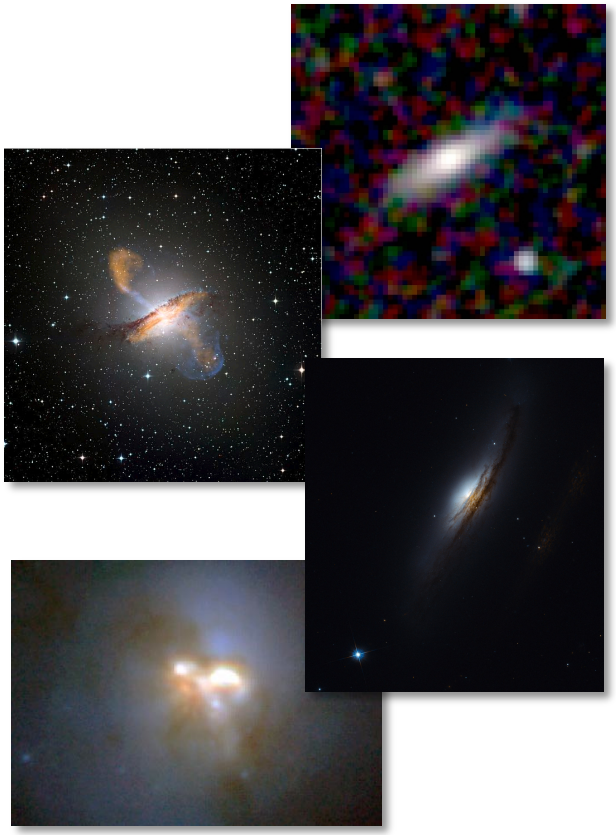
Infalling gas? Dusty torus? Follow-up planned with VLBI and ALMA

Associated HI absorption in HIPASS

4 detections in 210 nearby radio-loud galaxies (z < 0.04)

(with James Allison and Alex Meekin)

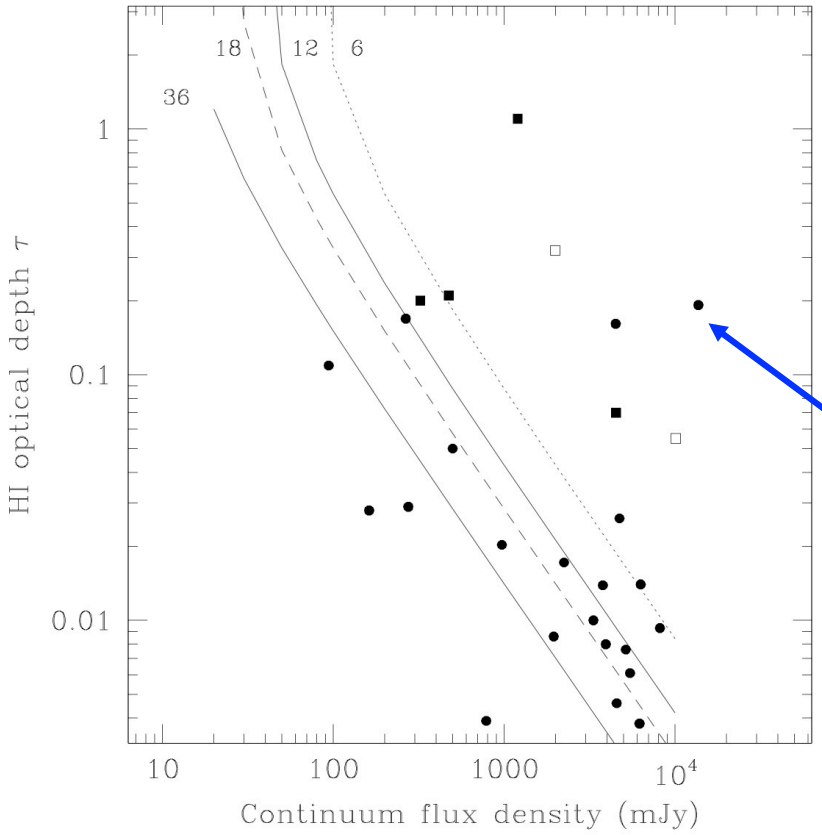




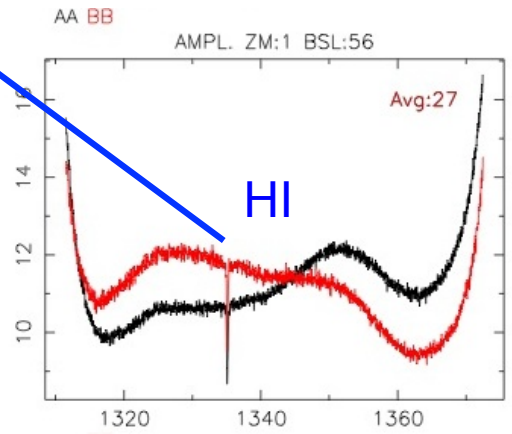
(Allison et al. 2014, MNRAS in press)

Strong associated HI absorption linked to presence of OH/$H_2$0 megamasers?

Early science with ASKAP-6



- 2hr integration with BETA can find the strongest (mainly associated) HI absorption systems. *Best strategy is to cover the whole sky, then build up sensitivity later as ASKAP is extended.*
- First glimpse into a new parameter space



PKS 1814-637: ATCA real-time display, 270 seconds int., HI line has $z=0.064$, $\tau = 0.19$

Lines show the detection limit in HI optical depth τ versus continuum flux density for a 2-hr integration with 6, 12, 18 and 36 ASKAP antennas. Some known associated and intervening HI absorbers are shown as individual points.

Unique discovery space for ASKAP-12

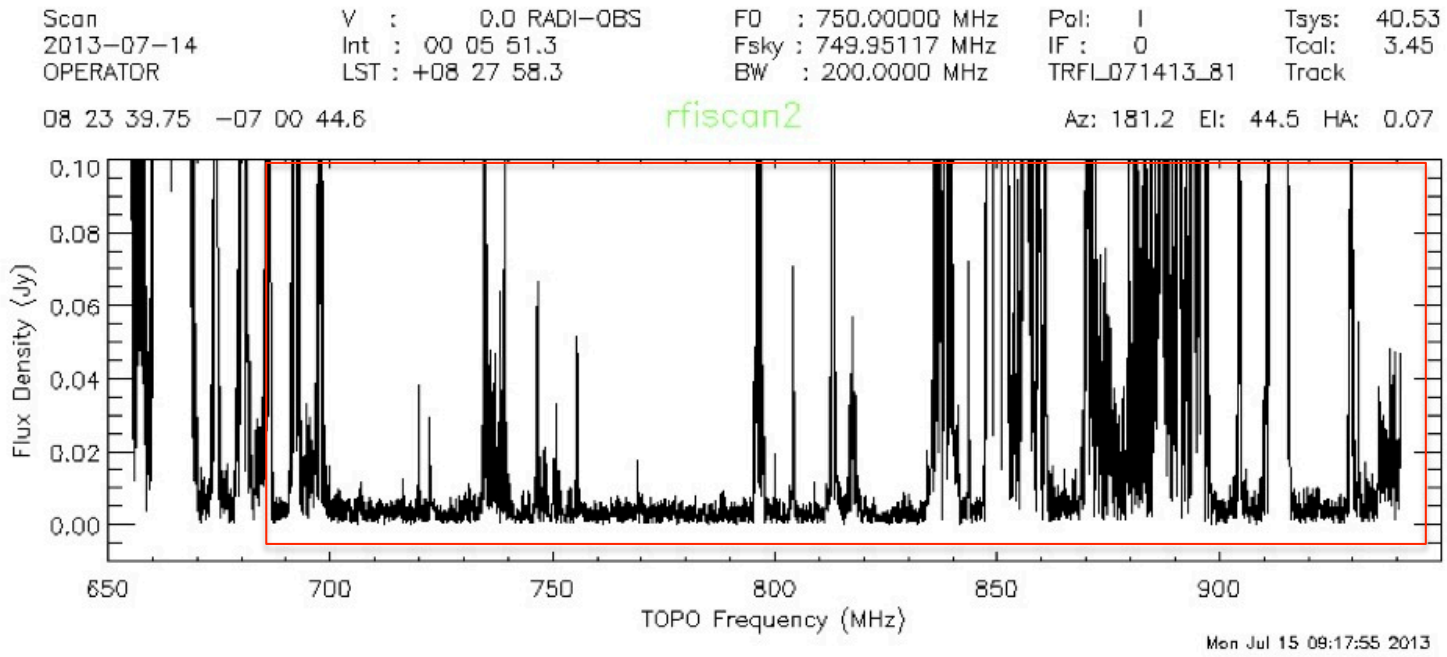
The only radio interferometer with a wide-band capability at 700-1000 MHz – provides unique coverage of the HI line at $0.5 < z < 1$ *Radio-quiet site!*

Telescope	Frequency range	Notes
JVLA (USA)	1 – 50 GHz	NRL providing a low-band system at 50-500 MHz
WSRT Apertif (NL)	1.0 – 1.75 GHz	1.0 GHz limit set by RFI
GMRT (India)	1.0 – 1.45 GHz	Low-frequency band at 590-630 MHz
Meerkat (S Africa) [Phase 1, 2016-18]	0.9 – 1.67 GHz	No capability below 900 MHz until at least 2018, possibly later
GBT (USA)	**290 MHz – 100 GHz**	**Single dish, affected by RFI**

RFI spectrum at the GBT site

(via NRAO web pages)

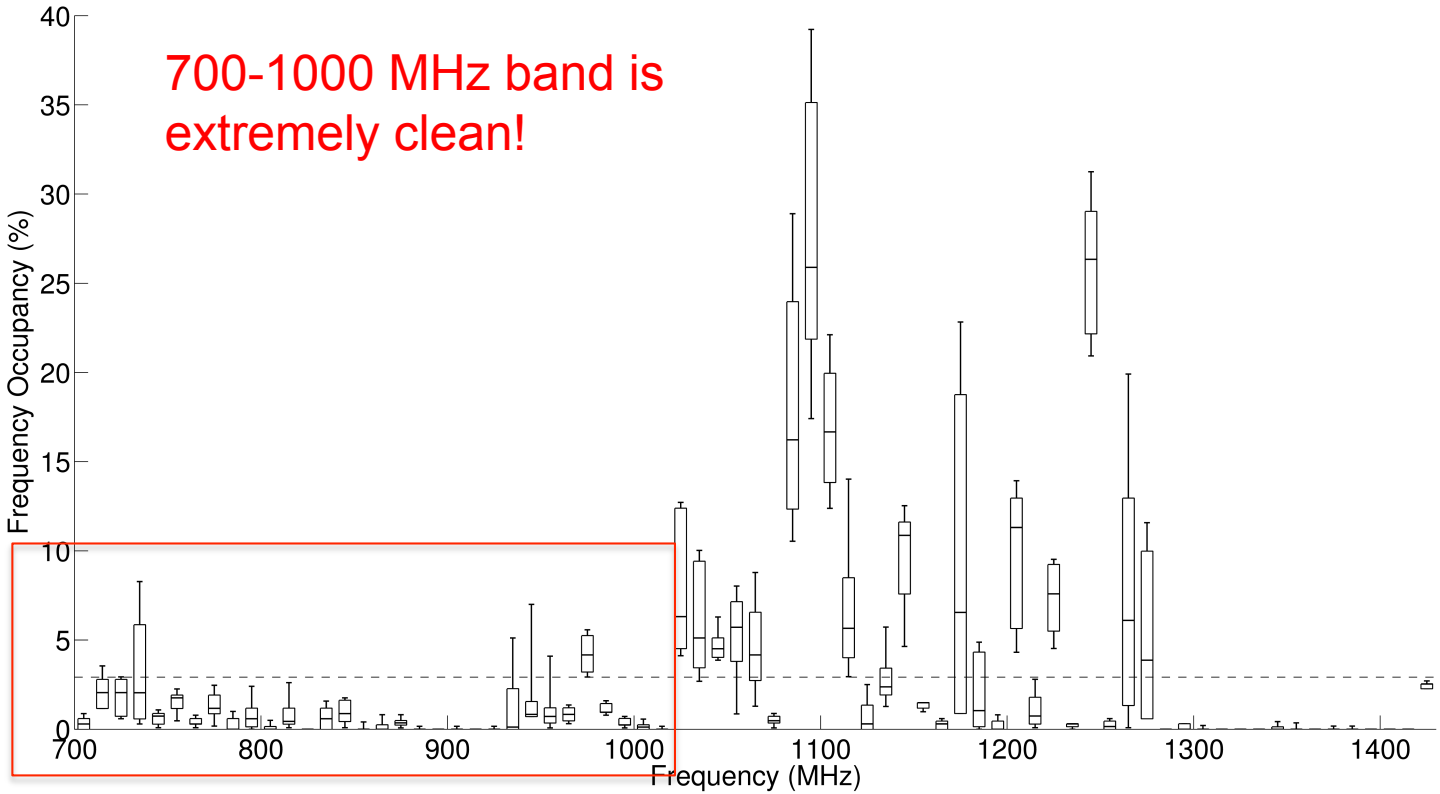
GBT RFI Plots http://www.gb.nrao.edu/IPG/rfiarchive_files/GBTDataImage...



Roughly half the GBT band below 1 GHz is lost to RFI.
700-1000 MHz is considered one of the better regions.

RFI spectrum at the ASKAP site

Measured Frequency Occupancy (plot from Aaron Chippendale)
What fraction of channels are RFI affected at high sensitivity?
(percentage of occupied 27.4 kHz channels in 10 MHz blocks in 2hr spectra)



Early Science: what can ASKAP do?

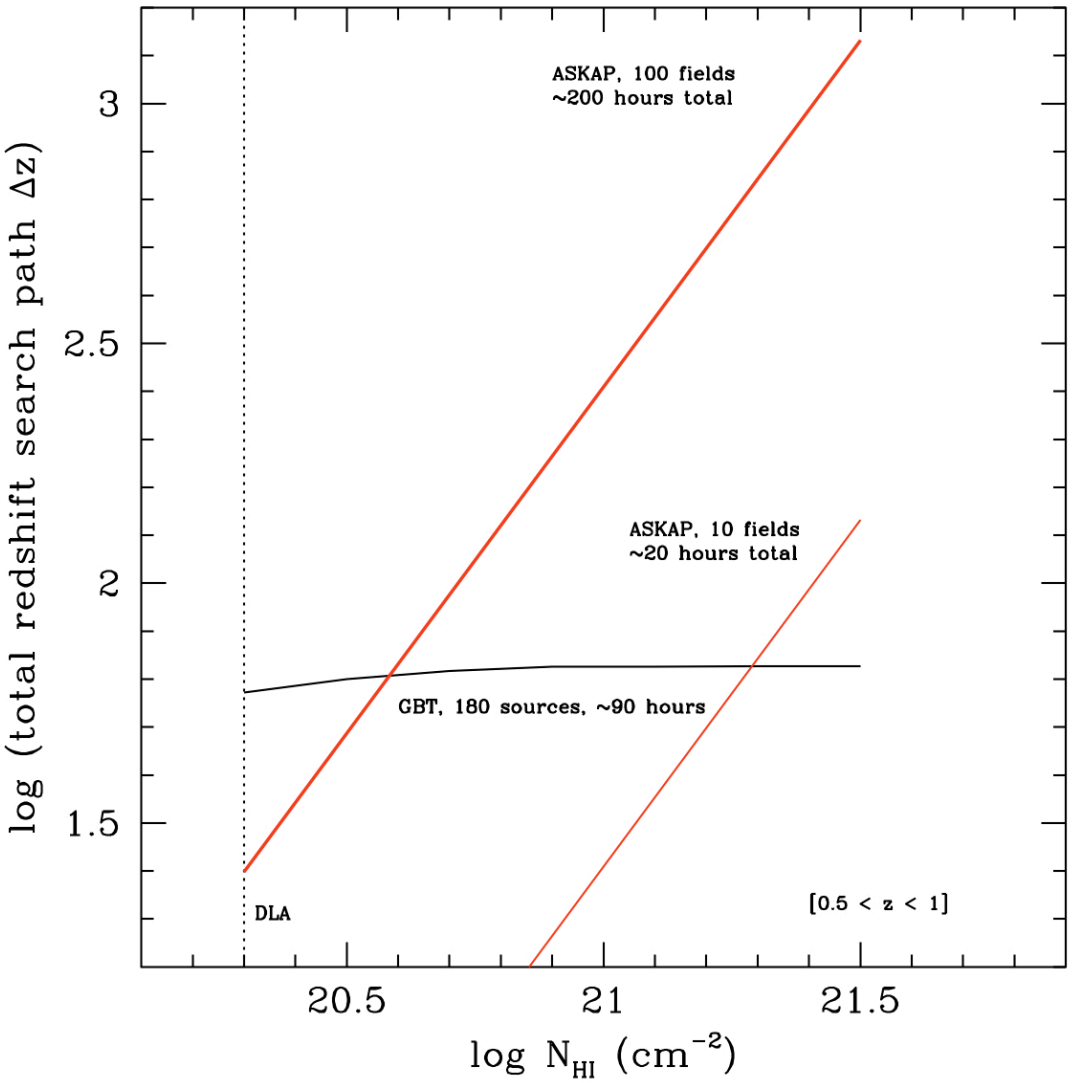


Figure of merit:
Search path Δz set by *Number of sources searched* (to a given column density limit) multiplied by the *Redshift interval searched* for each source.

ASKAP-12 can easily outperform any existing telescope in searches for *high column-density HI absorbers.*

Huge multiplex advantage from wide field of view!

Summary

• HI absorption is an important probe of galaxy evolution out to redshifts far higher than HI emission-line surveys can reach. A key goal of the ASKAP-FLASH survey is to detect intervening absorbers and assemble **an HI-selected galaxy sample at z>0.5** for studies of galaxy evolution.

• Exciting science can also be done with the associated absorption systems, which will allow us to identify samples of gas-rich powerful radio galaxies at high redshift.

• ASKAP can start to do interesting and important HI absorption science in the frequency range 700-1000 MHz (z = 0.5 to 1.0 for HI) with as few as 6-12 antennas (2014 onwards!).

• Follow-up strategy (ALMA, optical IFUs) and modelling are areas where collaboration would be particularly valuable in the near future!