Deep HI with the LADUMA Survey

XX

Sarah Blyth Department of Astronomy University of Cape Town



7th PHISCC Workshop, March 2014



The landscape

Optical surveys tell us that galaxies are located mainly on the 'red sequence' or in the 'blue cloud'



→ star-formation ongoing <u>OR</u> stopped Gyrs ago...
blue red

Star formation

• At z~2, star formation rate density (SFRD) was an order of magnitude higher than now...

[Hopkins & Beacom (2005)]





Gas evolution

...while the cosmic neutral gas density has remained relatively constant...

[Zafar et al. (2013)] **Obreschkow & Rawlings (2009)** (a) HI 8.10-4-(c) H_2/HI 10 This work Peroux et al. 2003b $\Omega_{H_2}(z)/\,\Omega_{HI}(z)$ Noterdaeme et al. 2012 2.0Lah et al. 2007 Rao et al. 2006 Zwaan et al. 2005 Martin et al. 2010 6·10⁻⁴ Braun 2012 Ó. $\Omega_{g}^{(x10^{-3})}$ 1.5 0.5 0.2 $4 \cdot 10^{-4}$ (b) H₂/ 1.03 $\underset{0}{\Omega_{HI}(z)/\Omega_{HI}(0)}$ $\Omega_{H_2}(z) / \Omega_{H_2}(0)$ $2 \cdot 10^{\circ}$ 2 5 0 3 1 4 Redshift 0.0 0 3 4 5 7 9 3 4 5 79 1 2 2 Redshift z Redshift z

> But semi-analytic models suggest could be due to changing H₂/HI ratio over the same time scale

SFR vs. neutral gas

• SF in THINGS spiral galaxies correlates with H₂...

[Bigiel et al., 2008]







- ...while SFRs in high gas fraction galaxies in ALFALFA seem to scale with M_{HI}...
 - perhaps follow a different SF law?

[Huang et al. (2012)]

Gas modelling

The contribution by different galaxies to neutral gas density is an area of intense study in semi-analytic models currently...



The baryon cycle

Recent theory and simulations (e.g. Davé et al.) suggest that both inflows and outflows of gas are important in maintaining a smooth rate of galaxy growth...

- outflow models with winds dependent on v-dispersion and supernovae (for dwarfs) match low mass end of HIMF well
- NB: consistent with hierarchical structure formation
- outflow models predict evolution of the HIMF vs. z



Observing neutral H

We need to measure HI as a function of redshift to:

understand the role of neutral gas in star formation and galaxy evolution
put constraints on the models



• ...But HI is hard to observe!

HI at higher z

The BUDHIES (Verheijen et al.) survey on the WSRT has observed 2 clusters at z~0.2 (1400h & 912h observing times!)

- Observed 150 galaxies in HI
- Find correlations between HI content and SFR as a function of environment
- Suggests progressive removal of HI as a function of group size



HI at higher z

The JVLA upgrade has made a deep HI survey possible with instantaneous bandwidth covering 0 < z < 0.45.

The CHILES pilot survey of the COSMOS field (60h) has resulted thus far in 33 HI detections out to intermediate z:



HI at higher z

The JVLA upgrade has made a deep HI survey possible with instantaneous bandwidth covering 0< z< 0.45.

The CHILES pilot survey of the COSMOS field (60h) has resulted thus far in 33 HI detections out to intermediate z:



MeerKAT

South Africa's SKA precursor instrument, MeerKAT, will have 64 x 13.5 m offset-Gregorian antennas and will be the most sensitive radio telescope in the Southern Hemisphere...

	Receiver bands (GHz)	UHF: 0.58 - 1.015 (2016/18) L-band: 0.9 - 1.67 (2016) X-band: 8.0 - 14.5 (2018)	
	A _e /T _{sys} (m²/K)	UHF: 213 L-band: 321 X-band: 321	
	Max. baseline	8 km	
	Min. baseline	29 m	
	Array config.	r < 400 m (50%) 400 - 1000 m (20%) 1000 - 4000 m (30%)	

Artist's impression of MeerKAT dish





LADUMA

The <u>Looking At the Distant Universe with the MeerKAT Array is one of 2 Priority-1</u> surveys to be done with MeerKAT (precursor SKA science)



Pls: Sarah Blyth (UCT), Benne Holwerda (Leiden) & Andrew Baker (Rutgers)

LADUMA Team

The team consists of 65 international researchers:

B. Bassett, M. Bershady, A. Bouchard, F.H. Briggs, B. Catinella, L. Chemin, S. Crawford, C. Cress, D. Cunnama, J. Darling, R. Davé, R. Deane,
E. de Blok, E. Elson, A. Faltenbacher, B. Frank, E. Gawiser, E. Giovannoli, T. Henning, K. Hess, I. Heywood, J. Hughes, M. Jarvis, R. Johnston, S. Kannappan, N. Katz, D. Kereš, H-R. Klöckner, R.Kraan-Korteweg,
P. Lah, M. Lehnert, A. Leroy, N. Maddox, G. Meurer, M. Meyer, K. Moodley, R. Morganti, D. Obreschkow, S.-H. Oh, T. Oosterloo, D.J. Pisano, S. Ravindranath, E. Schinnerer, A. Schröder, K. Sheth, M. Smith, R. Somerville, R. Srianand, L. Staveley-Smith, I. Stewart, M. Vaccari, P. Väisänen, K.van der Heyden, W. van Driel, M. Verheijen, F. Walter, E. Wilcots, T. Williams, P. Woudt, M. Zwaan, J. Zwart

LADUMA

LADUMA aims to study galaxy evolution over ~half the age of the Universe

Headline science goals:

To investigate:

- the HI mass function in different environments out to $z \leq 0.6$
- for the first time, the evolution of Ω_{HI} using HI emission out to $z \le 1 \sim 1.2$
- how galaxies' HI masses depend on stellar/halo mass vs. z
- evolution of the baryonic Tully-Fisher relation with z

HI Mass Function

HIMF vs. z



How is HI distributed within galaxies?

- How do M^*_{HI} , α & normalisation vary vs. z?
- Help to constrain hierarchical galaxy formation models
- Effect of different environments?

[Martin et al. (2010)]

Neutral Gas Density

To study galaxy evolution over cosmic time, we need to understand where & how much HI exists...

What is the average amount of HI vs. z?

 How will HI emission measurements compare to Lyα and MgII absorber results at higher z?



Ω_{HI} vs. z

HI vs. Stellar/Halo Mass

How do galaxy HI masses scale with their stellar masses?

- Gas to stellar mass fraction calibrated with u-K shows correlation with stellar mass (Kannappan 2004)
- ALFALFA-SDSS-GALEX sample shows HIfraction correlations with colour and stellar mass surface density (Huang et al., 2012)





HI vs. Stellar/Halo Mass

• Recent Galaxy Zoo analysis shows that late-type galaxy colour (SFR) correlates with halo mass:



 For late-type galaxies, M_{halo}~10¹² may be a stopping point for accretion...

Baryonic T-F Relation



- Stellar mass TFR shows evolution for 0<z<1.3
- Unknown how the Baryonic TFR evolves over cosmic time
- LADUMA will observe 1000s of HI profiles over a range of z
- Will need long integration times at lower z (resolved detections) and higher z (integrated detections)

Other science: OH megamasers

- OH megamasers (1.66 GHz) can be used to trace the galaxy merger rate out to z~1.8 (Briggs, 1998)
- Contaminant for HI line emission but relatively easy to distinguish (e.g. using photo-z, bright IR counterpart)

LADUMA specs

LADUMA will be the deepest HI survey prior to SKA, probing HI over 0 < z < 1.4. Awarded a total observing time of 5000 hours:



- Single MeerKAT pointing will encompass ECDF-S:
 - Dec -27° \rightarrow good UV coverage
 - Multi-wavelength data exist
 - ~ 4000 spec-z's publicly available (although more needed to cover high-z MeerKAT footprint)

Strategy

Final observing strategy TBD since MeerKAT requires 2 receivers to cover the range 0 < z < 1.4

Receiver bands (GHz)	L-band: 0.9 - 1.67 (2016) UHF: 0.58 - 1.015 (2018)
----------------------	-------------------------------------------------------



* numbers based on Oxford S³ simulations (Obreschkow et al., (2009))

HI Stacking

With the poor S/N at the higher redshifts, we will rely on HI spectral stacking to recover average HI properties of galaxies in various samples...

STEP 1: extract spectra using known positions and z



STEP 2: Using known z values, shift all lines to common channel



$$M_{\rm HI} = \frac{236}{(1+z)} \left(\frac{S_v}{\rm mJy}\right) \left(\frac{d_L}{\rm Mpc}\right)^2 \left(\frac{\Delta V}{\rm km\,s^{-1}}\right)$$



Recent work

HI vs. Optical redshifts:

- N. Maddox et al., MNRAS (2013)
- In general optical emission line z agree better with HI z, than do absorption line z
- While the z-errors < median W₅₀, stacking can be done (i.e. photometric redshifts not good enough for stacking)

Spectral Feature	${ m Centre} \ { m kms^{-1}}$	$ m Std~Dev$ $ m kms^{-1}$	u-r Centre $km s^{-1}$	$\dot{s} \ge 2.3$ Std Dev km s ⁻¹
$H\alpha$	-1.00	15.74	3.20	21.72
$H\beta$	10.55	20.38	3.56	28.31
[O 11] 3727 Å	-7.05	32.97	4.75	25.36
[O III] 5008 Å	0.24	21.73	0.34	27.85
Call K 3935 Å	11.22	48.13	-4.00	30.46
Ca11 H 3970Å	-0.42	51.36	33.90	38.72
G-band 4306 Å	-11.67	42.78	-17.91	31.09
${ m Mg} \to 5177{ m \AA}$	13.71	61.76	29.44	54.70

HI - Line velocity

Recent work

AAT spectroscopy (December 2013)

- 2 nights observing with AAOmega (A.J. Baker)
- observed 4260 objects in the LADUMA footprint
 - •r < 20.5 taken from SWIRE gri imaging catalogue (Rowan-Robinson et al., 2008)
- Measured 3750 redshifts (88% success rate) using autoz (Baldry et al., 2014)
 - ~ 3600 new redshifts

Outlook

Near future:

- Team meeting at ASTRON on Thursday
- Simulations and software to be written
- Further ancillary data to be gathered (redshifts)
- Exciting times ahead!

10:30 - 11:00	Justin Jonas - SKA-SA perspective on MeerKAT Large Survey Projects (timelines, time allocation, etc.)
11:00 - 11:30	Lindsay Magnus - SKA-SA interface with MeerKAT LSPs, data pipeline, archiving, etc.
11:30 - 11:45	Kelley Hess - KAT-7 observations of the Antlia cluster
11:45 - 12:00	Brad Frank - APERTIF calibration and data profiling