HI Surveys in the era of SKA1

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(thanks to the SKA HI science working group)

International Centre for Radio Astronomy Research

CAASTRO ALL-SKY ASTROPHYSICS

Curtin University

The University of Western Australia

Outline

- Low-redshift (z<1.6) HI
- Key science:
  - Evolution of galaxies
  - Accretion of gas
  - ISM in external galaxies
  - Cosmic web
- Possible Key Survey Projects (KSPs)
- Commensal science

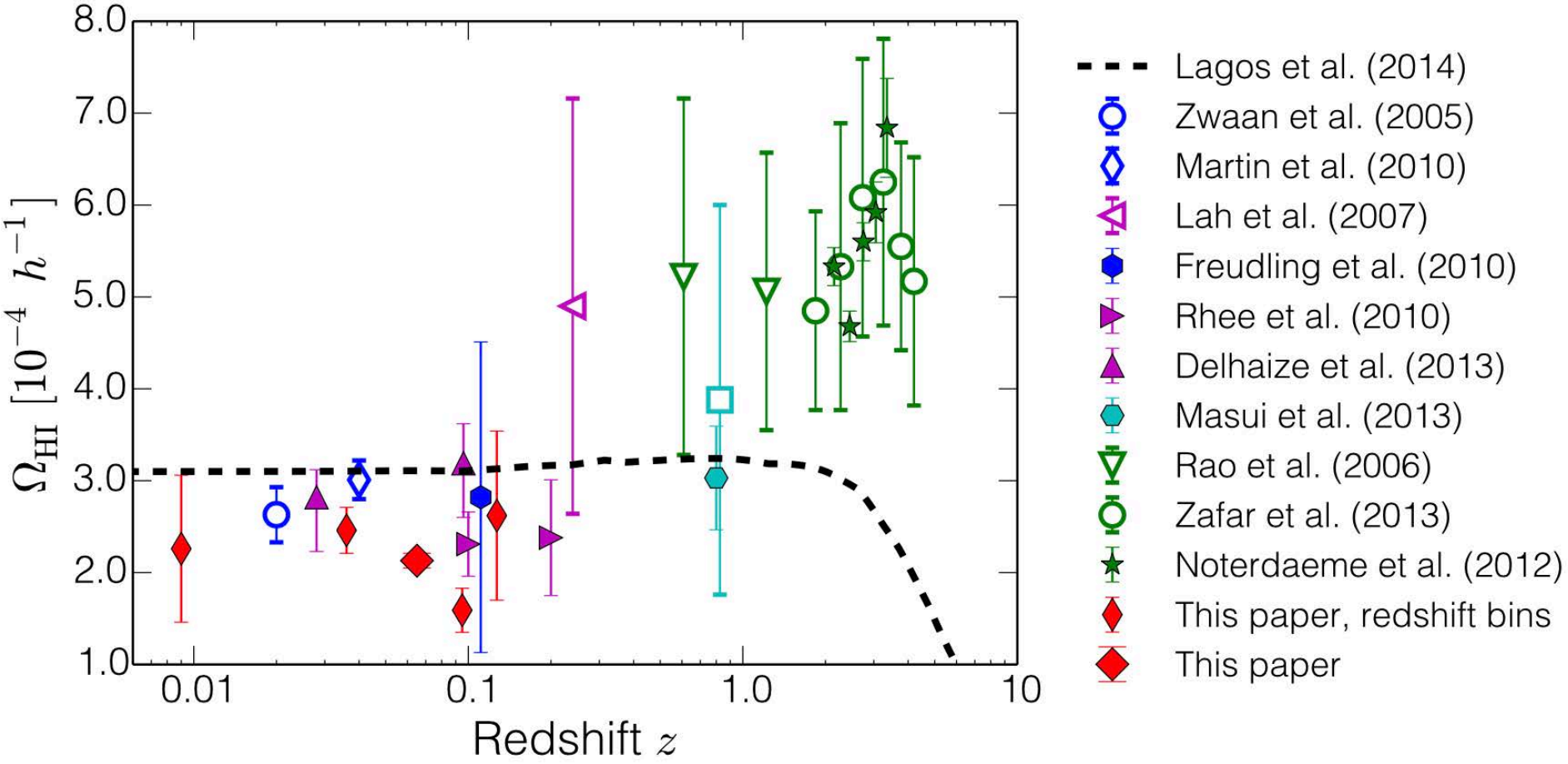
SKA HI SCIENCE CASE PAPERS

PROCEEDINGS OF SCIENCE

1. Overview: Staveley-Smith, Oosterloo (2015)
2. HI and Galaxy Evolution: Blyth et al. (2015)
3. The ISM in Galaxies: de Blok et al. (2015)
4. Galactic and Magellanic Evolution: McClure-Griffiths et al. (2015)
5. Baryons and Multiwavelength data: Meyer et al. (2015)
6. The IGM and the Cosmic Web: Popping et al. (2015)
7. Galaxy Formation: Power et al. (2015)
8. Outflows and Absorbers: Morganti et al. (2015)
9. Angular Momentum: Obreschkow et al. (2015)
10. The CNM and Radio Recombination Lines: Oonk et al. (2015)

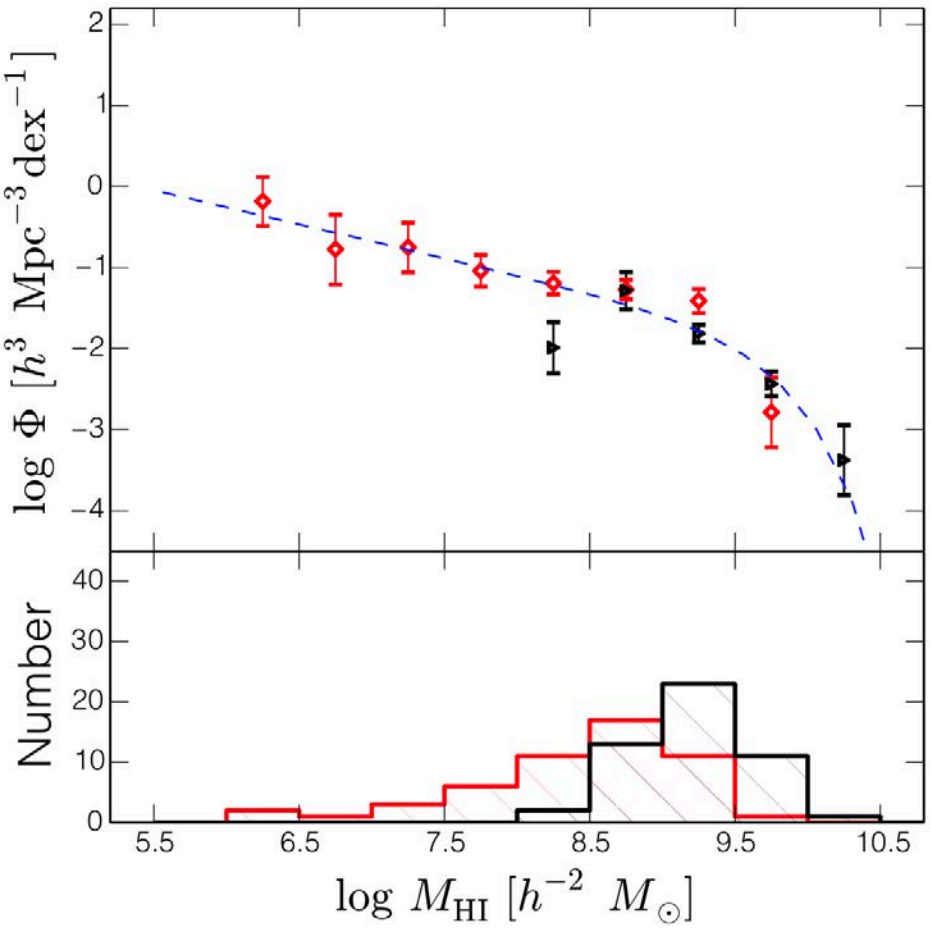
- *and Cosmology working group papers*

Cosmic HI evolution



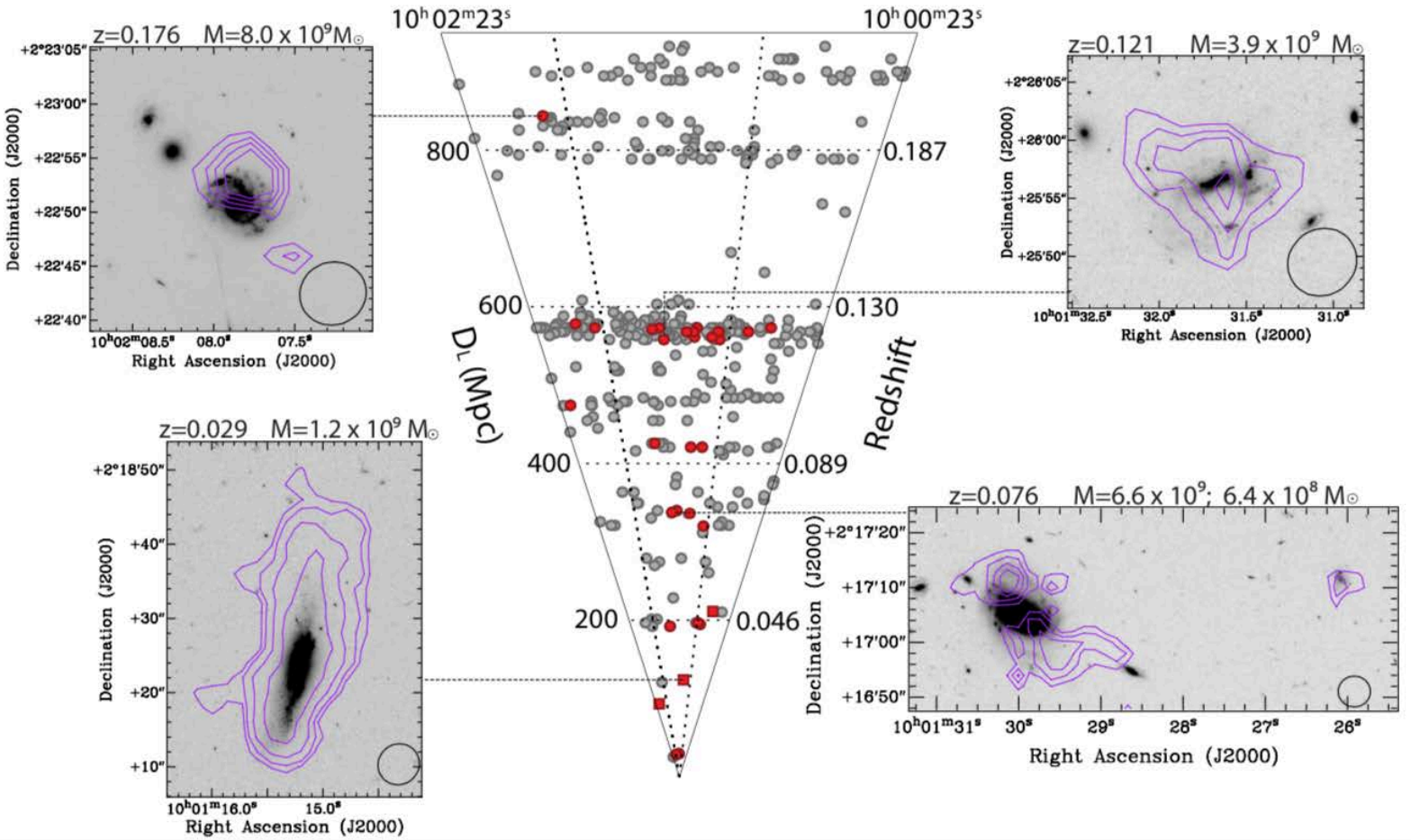
Hoppmann et al. (2015)

HI mass function evolution



HI mass function at z<0.06 (red) and z>0.06 (black) from the Arecibo Ultra Deep Survey (Hoppmann et al. 2015)

Accretion, interactions and growth in galaxies



- HIPASS/ALFALFA/AUDS: 3’-15’ resolution – galaxies are point sources
- CHILES (Fernandez et al. 2013) – JVLA 6” resolution: see Attila Popping’s talk
- SKA1 – 2”-6” resolution

Gas accretion (Blyth et al. 2015)

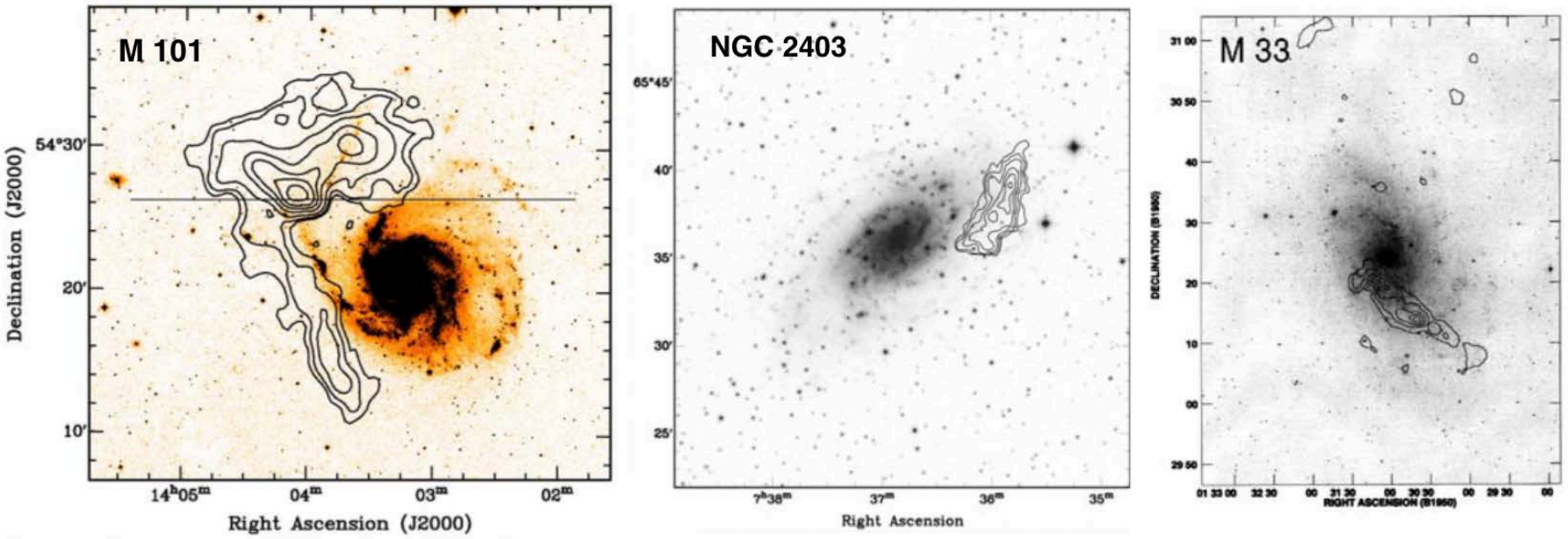
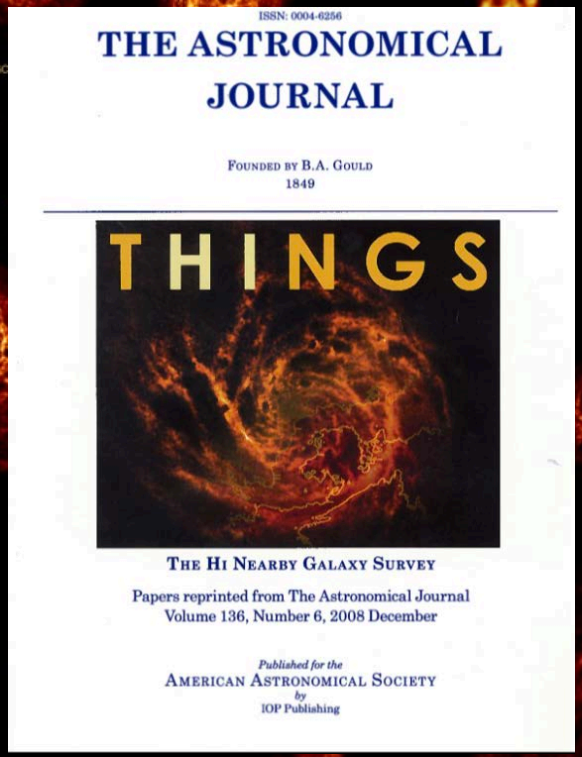
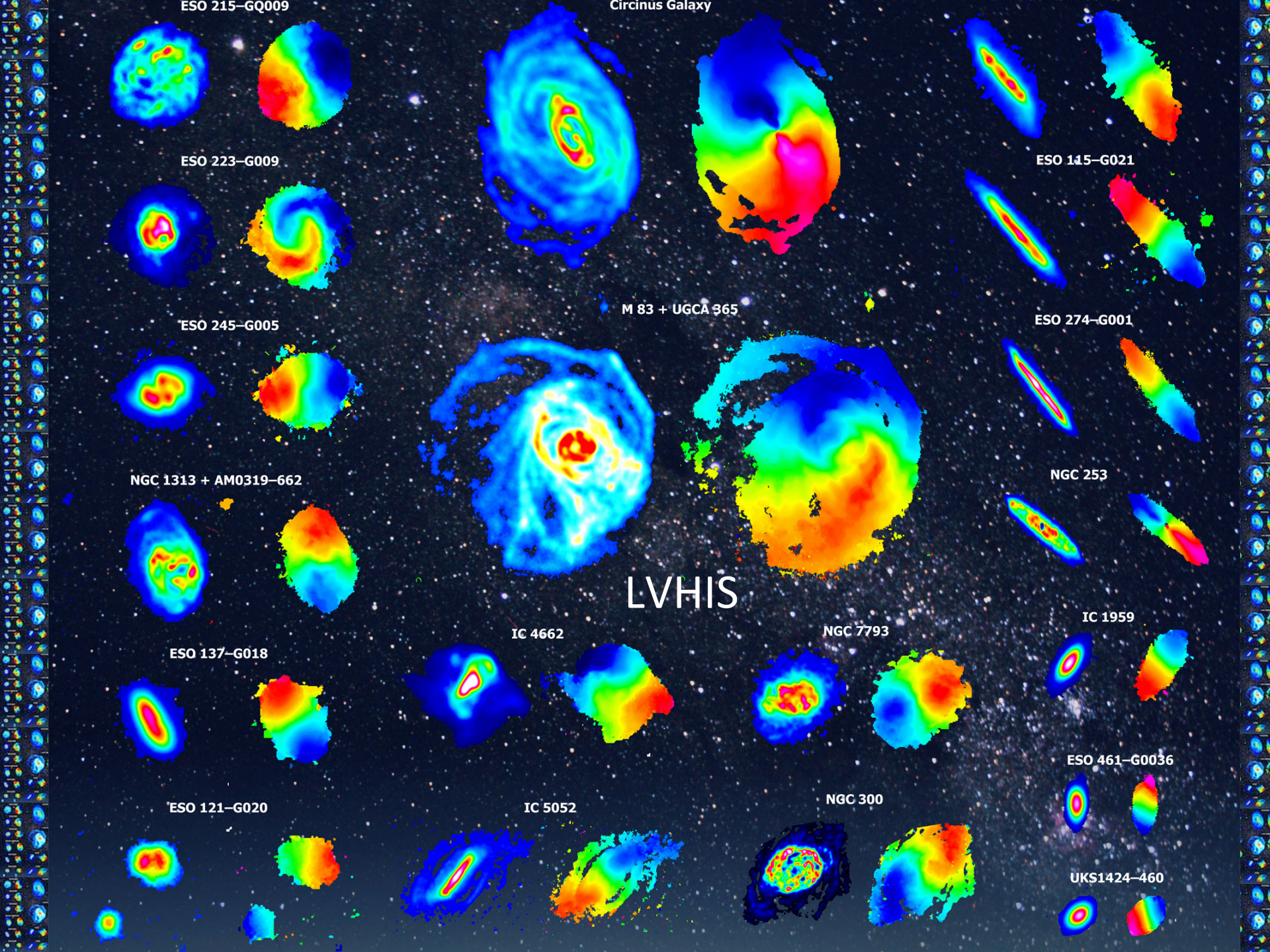


Figure 3: Three examples of possible accretion of H I in nearby spirals indicated by the presence of gas complexes at anomalous velocities: M 101 (van der Hulst & Sancisi (1988)), NGC 2403 (Fraternali et al. (2002)), and M 33 (Sancisi et al. (2008)).

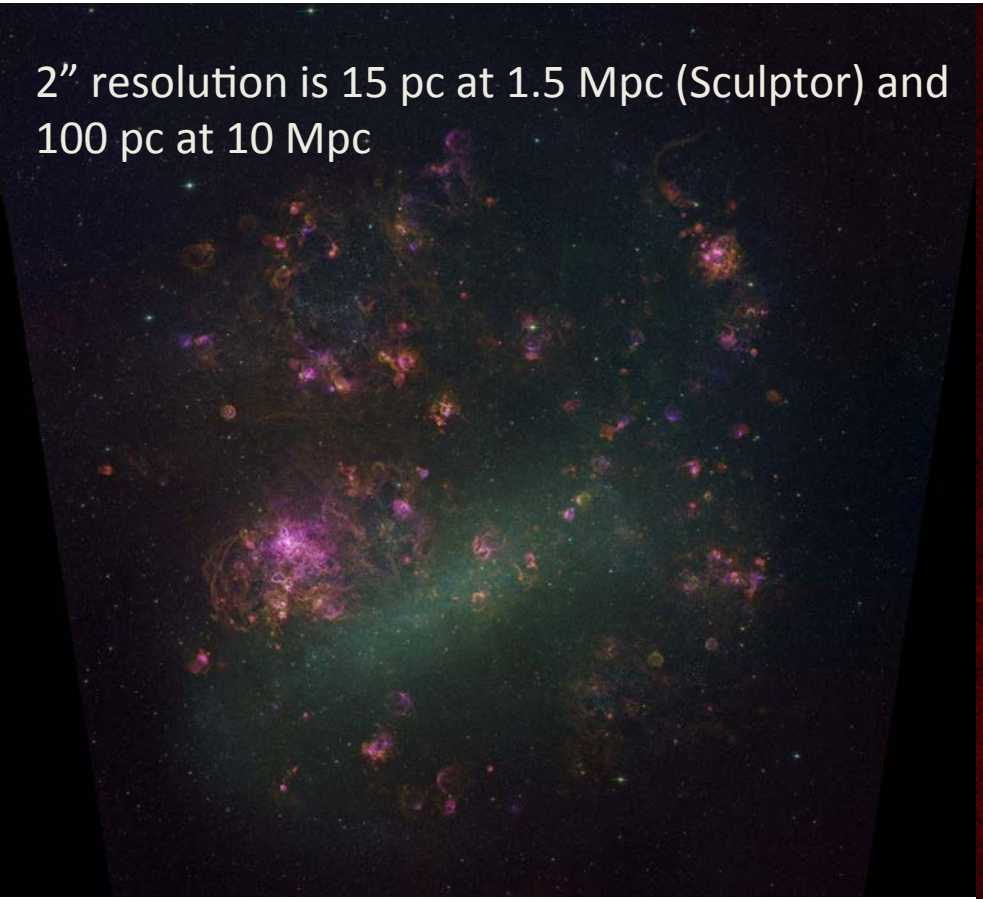
The *HI* Nearby Galaxy Survey (T*HI*NGS)

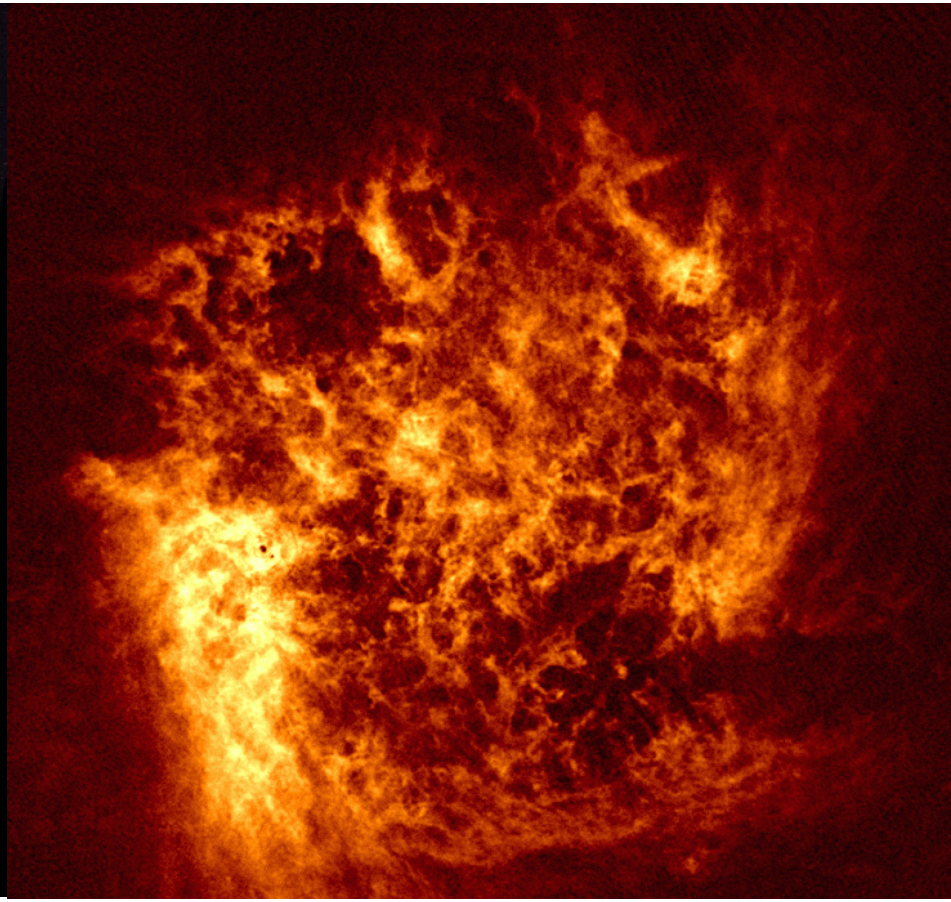
F. Walter, E. Brinks, E. de Blok, F. Bigiel, M. Thornley, R. Kennicutt




ESO 215–GQ009
Circinus Galaxy
ESO 223–G009
ESO 115–G021
M 83 + UGCA 365
ESO 245–G005
ESO 274–G001
NGC 1313 + AM0319–662
NGC 253
LVHIS
IC 4662
NGC 7793
IC 1959
ESO 137–G018
ESO 461–G0036
ESO 121–G020
IC 5052
NGC 300
UKS1424–460

ISM in nearby galaxies

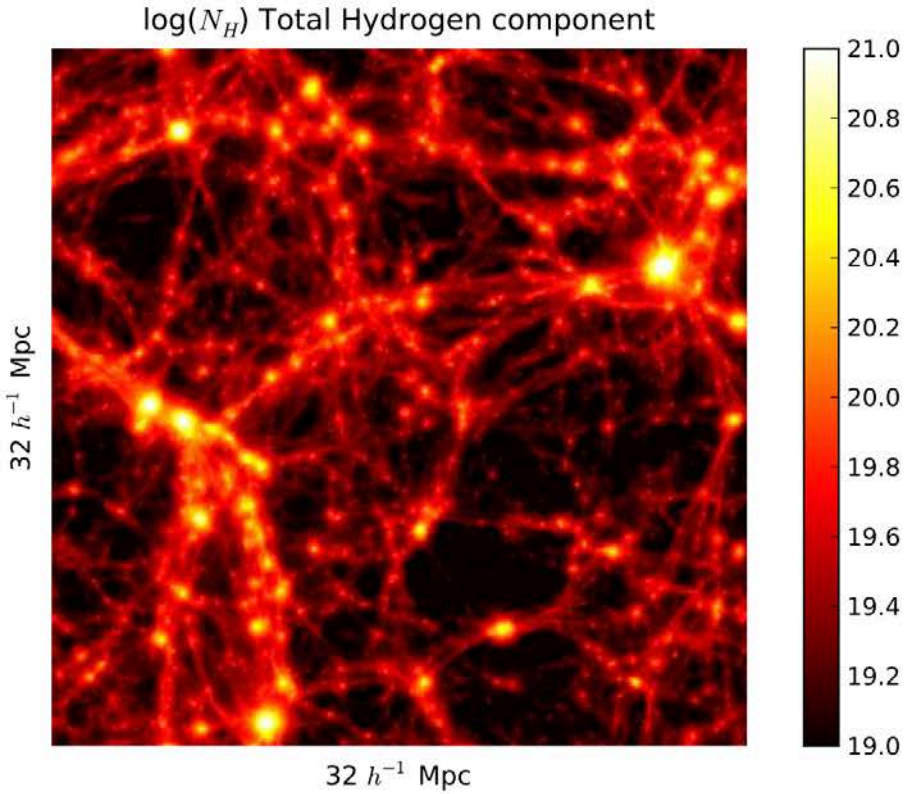


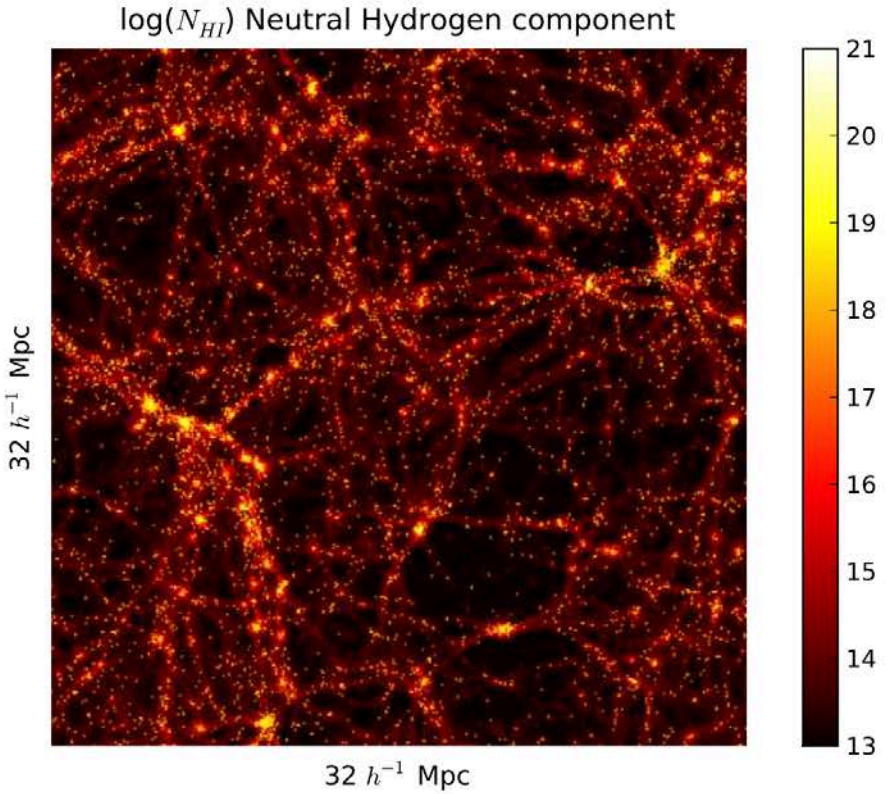


CTIO: Smith et al.

ATCA+PKS: Kim, Staveley-Smith et al. (2003)

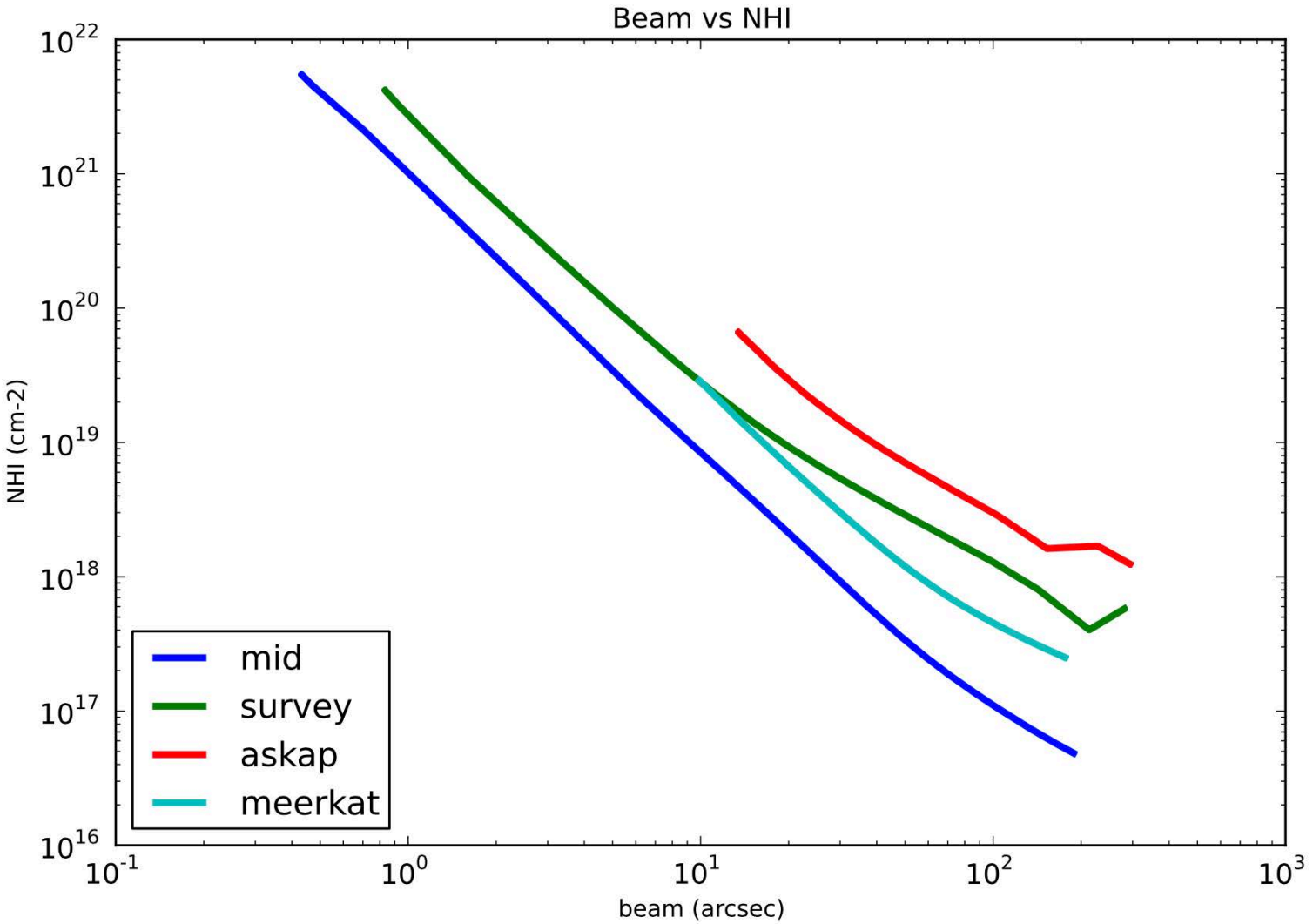
Cosmic Web





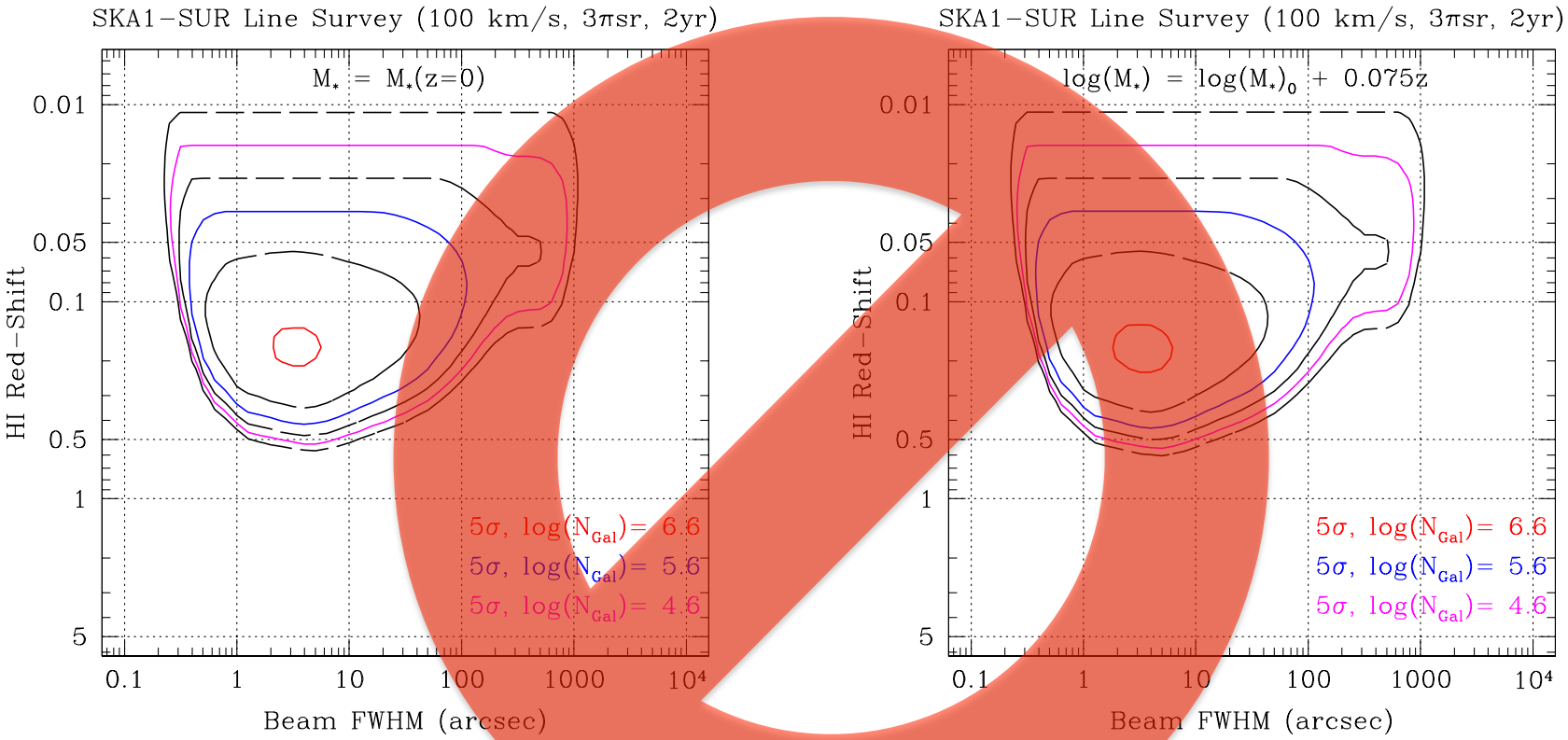
Simulations of ionised and neutral hydrogen in the Cosmic Web (Popping et al. 2009)

SKA1 sensitivity (8 hrs)



Popping et al. (2015)

An all-sky HI emission survey for BAO and $\Omega_{HI}(z)$



- Detect $10^{6.6}$ galaxies > 5σ with <z> ≈ 0.2, $10^{4.6}$ with <z> ≈ 0.5
  (dig into HI noise floor using optical counterpart requirement)
- Density ≈ 133 galaxies deg^{-2}
- Compare SDSS: $10^{6.2}$ galaxies with <z> ≈ 0.1 over 15,000 deg^2

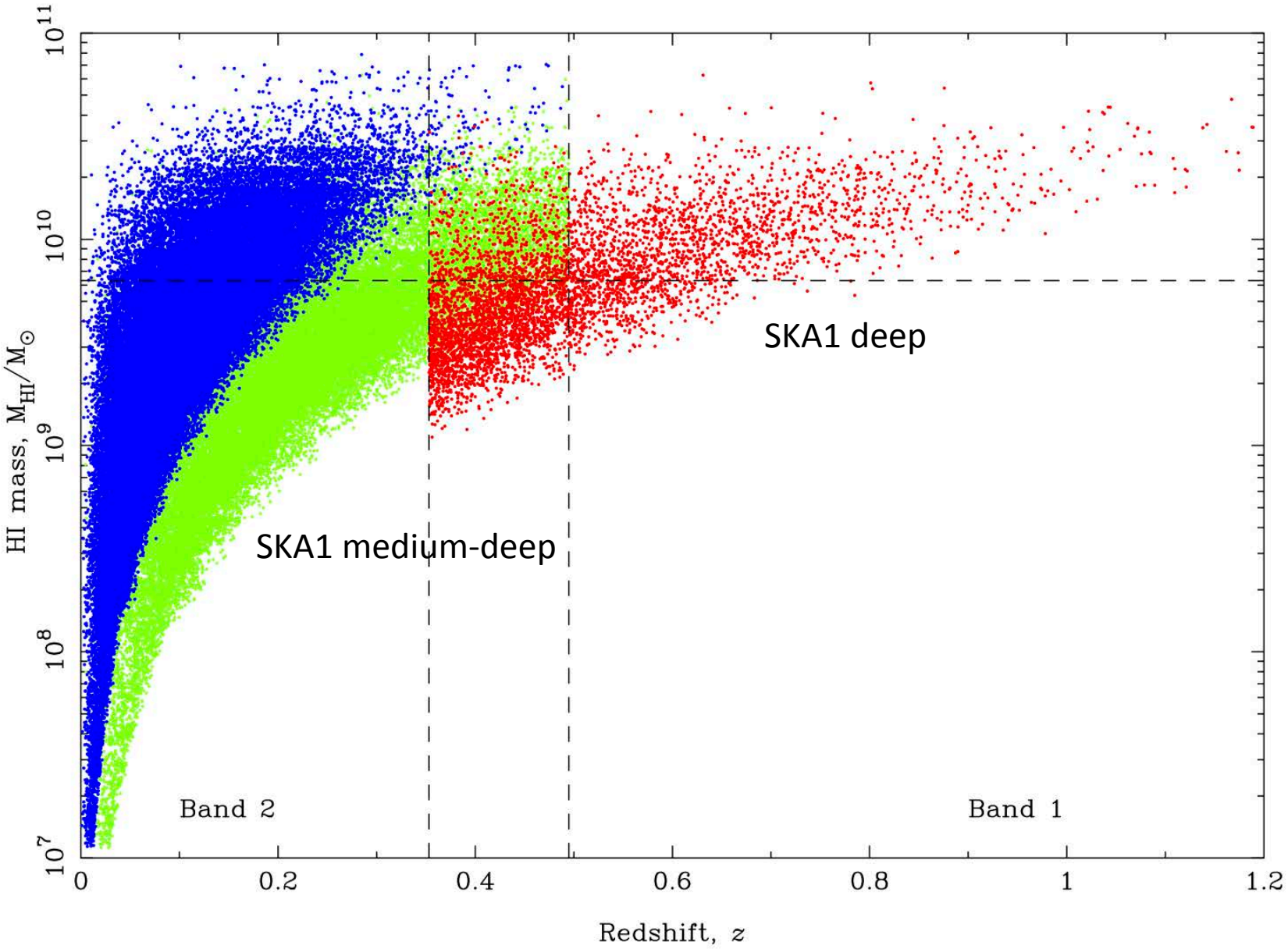
Braun (2013)

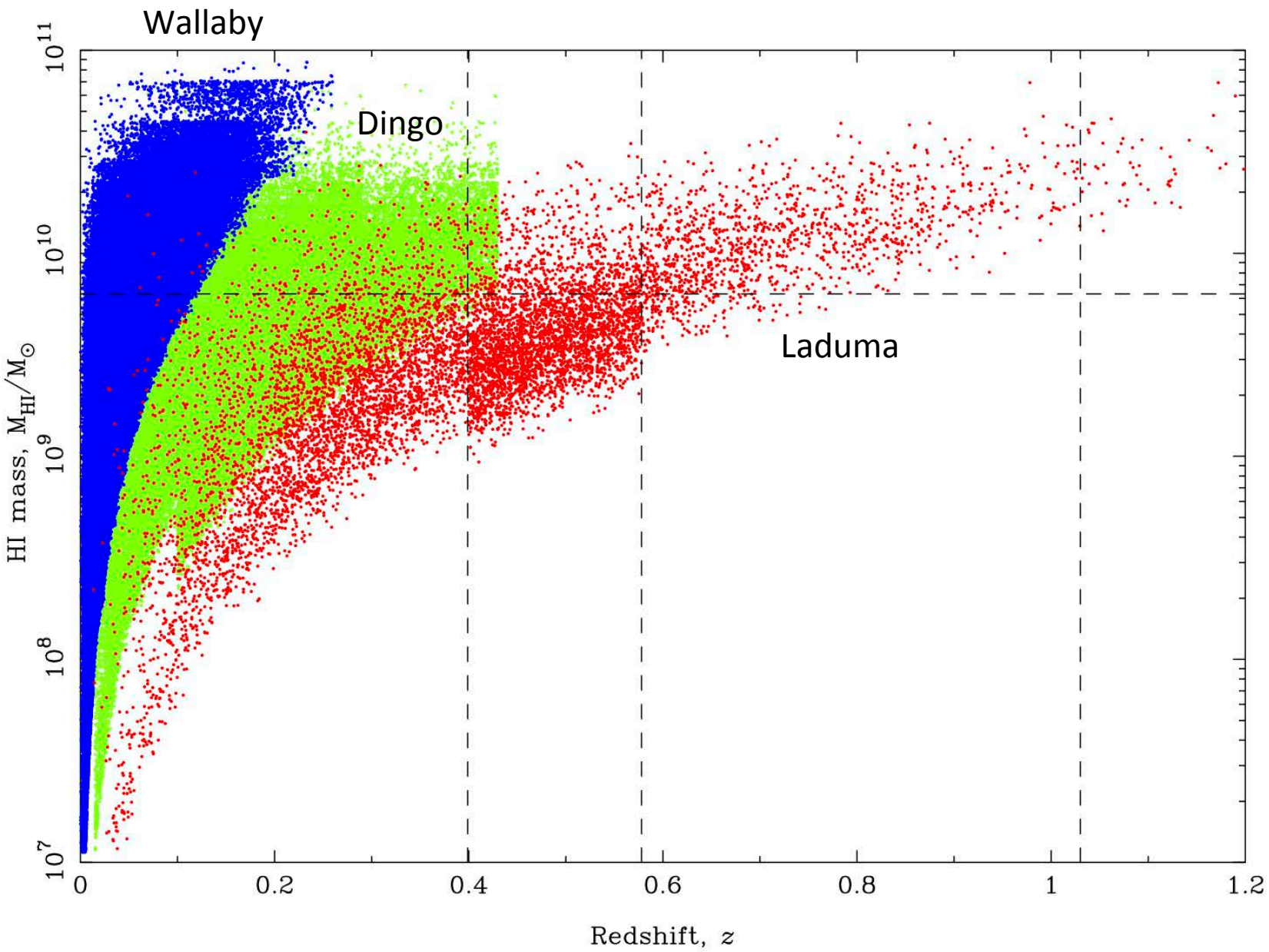
Possible SKA1 HI Key Science Projects

Survey	Ω deg^2	Frequency[1] MHz	Resolution	τ h	N	z_{lim}	Science chapter
Absorption	1000	350-1050	$2''$	1000	5,000	3	Morganti et al. (2015)
	1000	200-350[2]	$10''$	1000	?	6	
Medium wide	400	950-1420	$10''$	1000	65,000	0.3	Meyer et al. (2015); Obreshkow et al. (2015)
Medium deep	20	950-1420	$5''$	1000	40,000	0.5	Meyer et al. (2015); Obreshkow et al. (2015)
Deep	1	600-1050	$2''$	1000	5,000	1	Blyth et al. (2015); Meyer et al. (2015); Obreshkow et al. (2015); Power et al. (2015)
Targeted	–	1400-1420	$3'' - 1'$	1000	50	0.01	de Blok et al. (2015); Popping et al. (2015)
Galaxy/MS	5000	1418-1422	$10'' - 1'$	1000	–	0	McClure-Griffiths et al. (2015); Oonk et al. (2015)

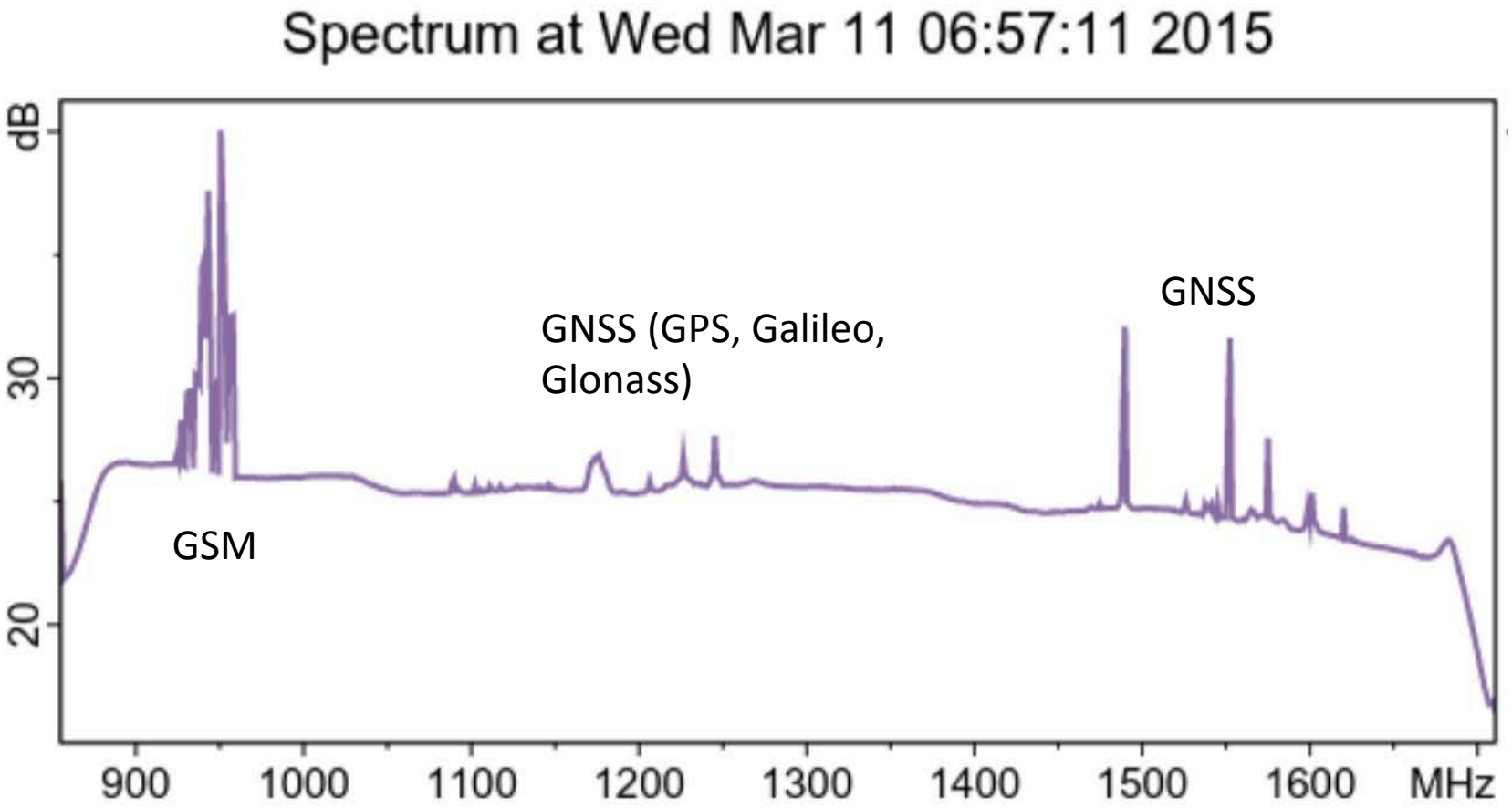
Re-baselined SKA HI surveys (Staveley-Smith & Oosterloo)

SKA1 medium-wide



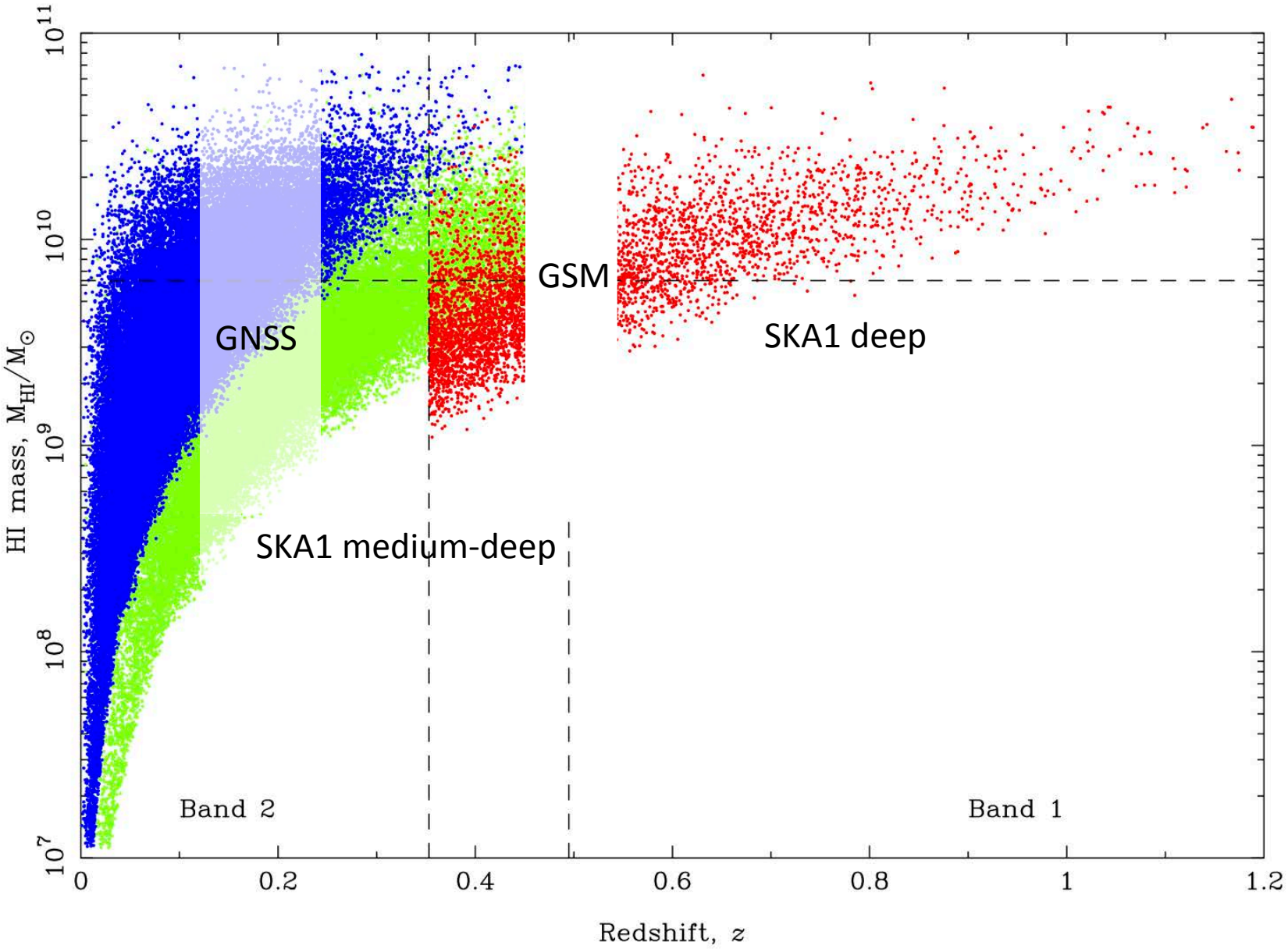

Wallaby
Dingo
Laduma
HI mass, $M_{HI}/M_\odot$
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
0
0.2
0.4
0.6
0.8
1
1.2
Redshift, z

RFI at the SKA-mid site



Schroeder (2015)

SKA1 medium-wide



Commensal surveys

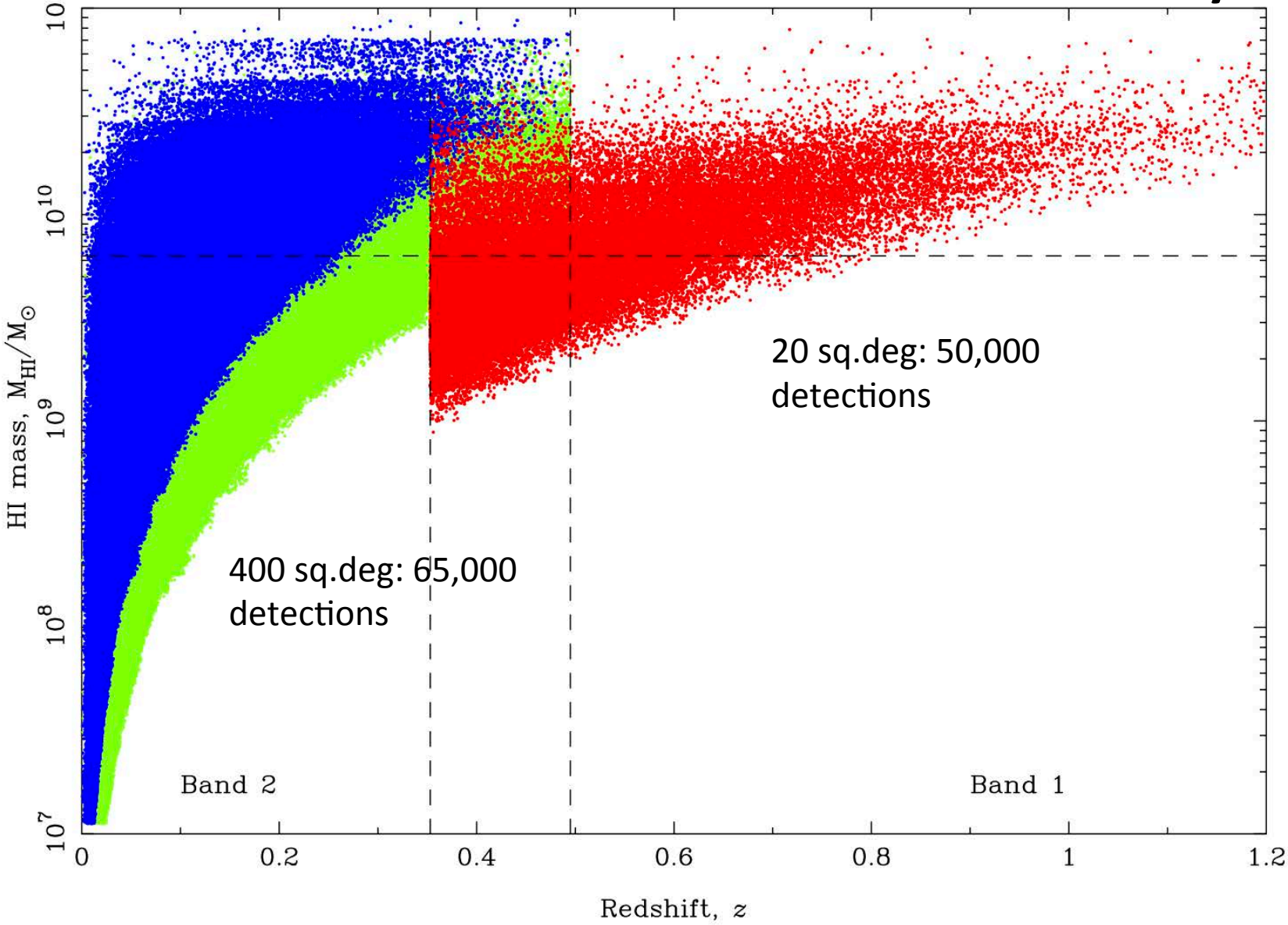
The SKA Key Science Workshop

24-27 August 2015
Wenner-Gren Center
Europe/Stockholm timezone

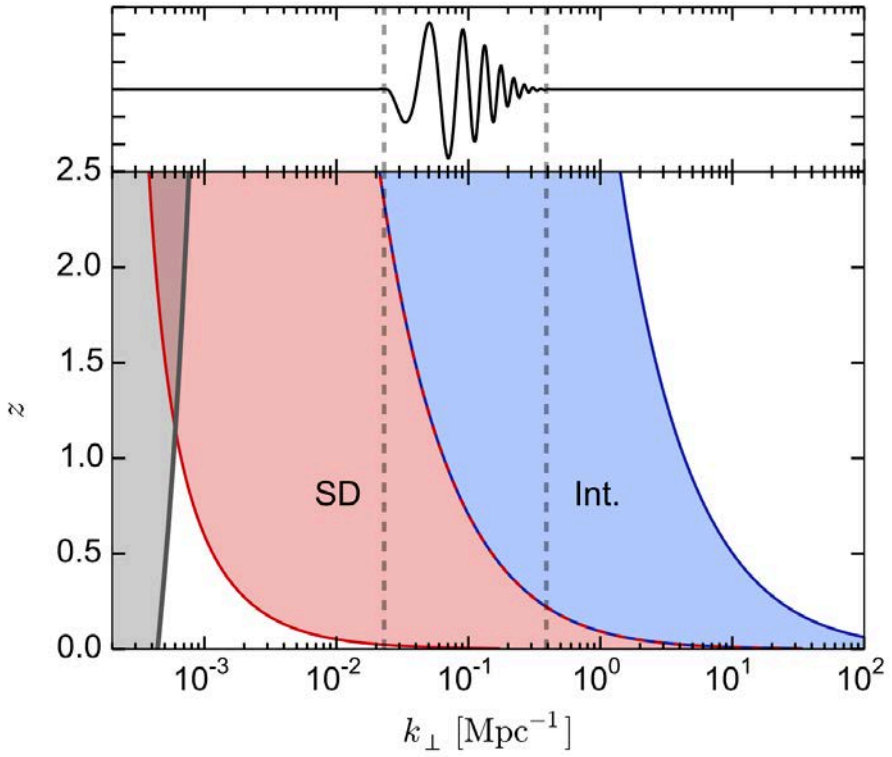
One of the workshop aims:

- Maximizing commensality
  - It is likely that the same data stream will serve multiple KSP or PI-led groups, each with limited data rights to address specific scientific objectives.
    - This workshop aims to provide a forum for early discussion of support for such commensal programs, including the development of efficient survey strategies intending to maximise the scientific return of the KSP package.

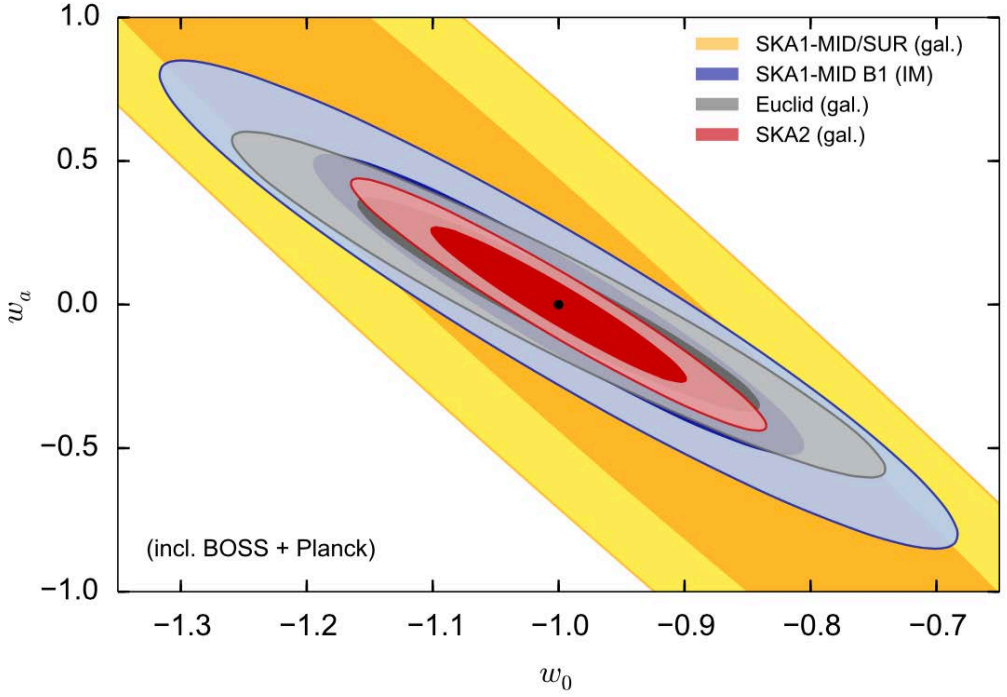
10,000 hr re-baselined SKA1 commensal surveys



Commensal cosmology: BAOs



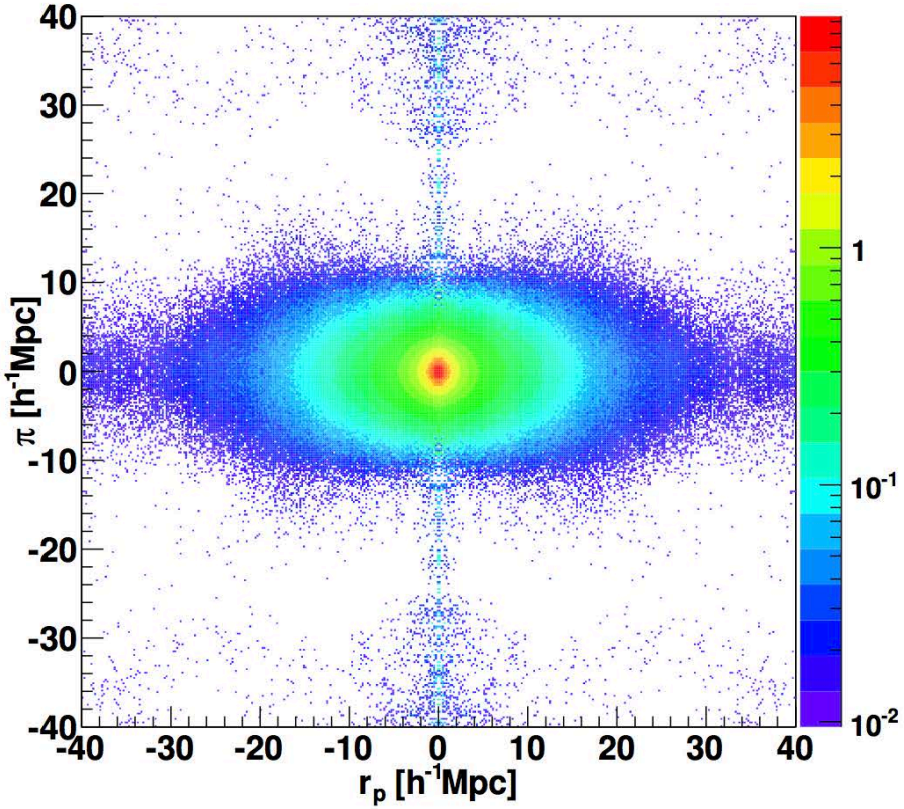
Baryonic Acoustic Oscillations (BAO) from Intensity Mapping (and galaxy surveys): competitive with BOSS (Bull et al. 2015)

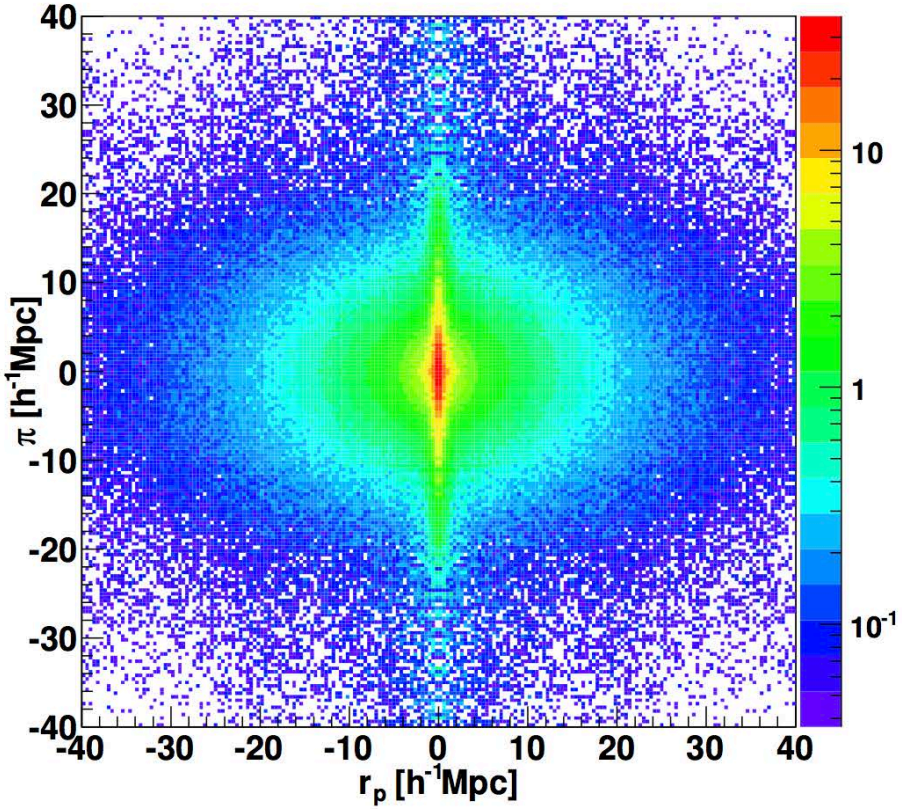


BAO forecast for Dark Energy equation of state parameters (w_o, w_a) for BAO IM and galaxy survey compared with Euclid (Bull et al. 2015)

21cm IM brightness: $\delta T_b = \overline{T}_b \delta_{\rm HI}(\mathbf{k}) = \overline{T}_b (b_{\rm HI} + f\mu^2) e^{-\frac{1}{4}k^2\sigma^2_{\rm NL}(z,\mu)} \delta_M(k),$

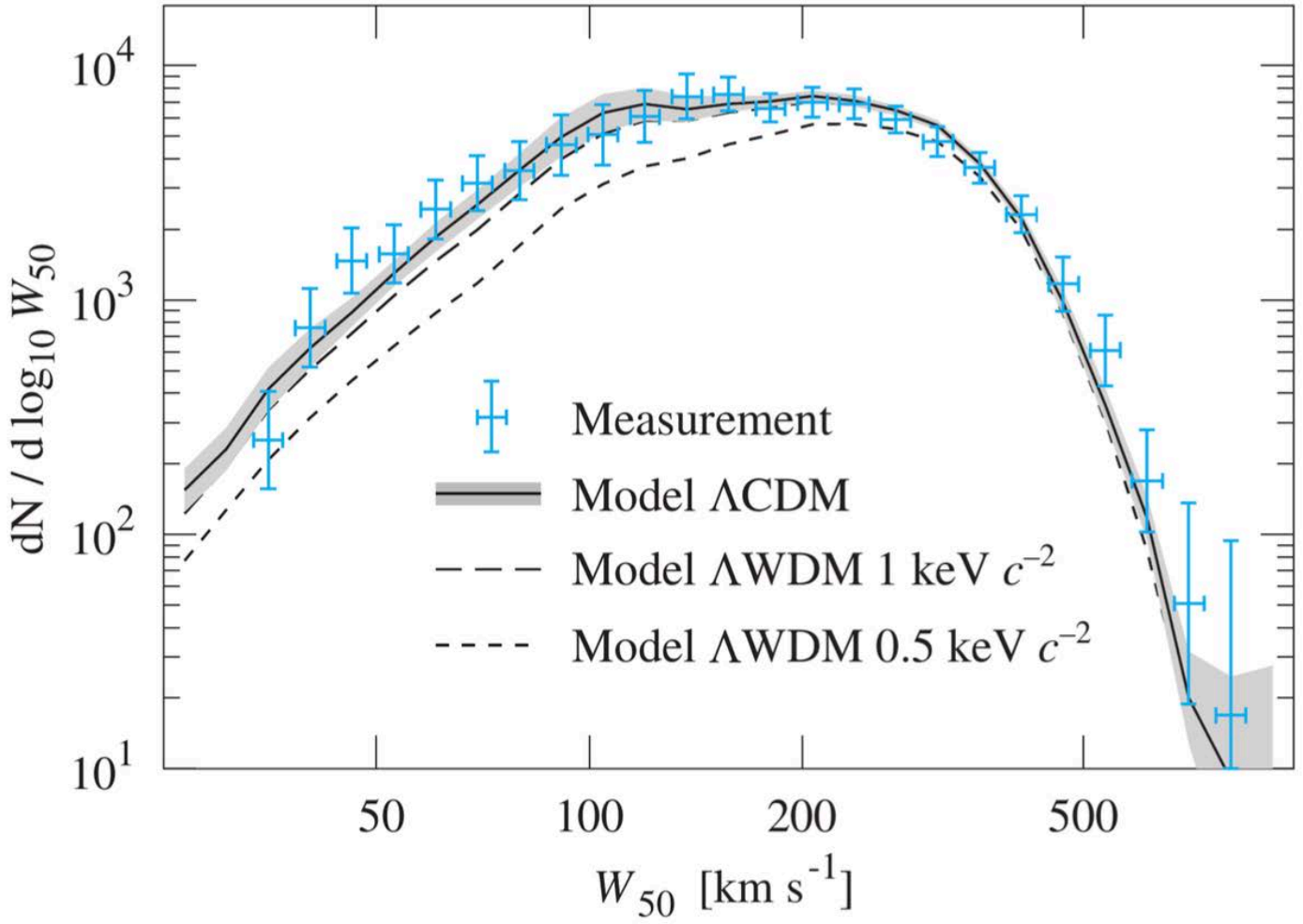
Commensal Cosmology: RSDs





Redshift space distortions for Wallaby (predicted) and 6dFGS (Beutler 2012): excellent measure of growth rate $f\sigma_8$ as a function of redshift or growth index γ. (Raccanelli et al. (2015)

HI kinematics: velocity function



Obreschkow et al. (2013)

Commensal surveys?

Science Goal	SWG	Objective	SWG Rank
1	*CD/EoR*	Physics of the early universe IGM - I. Imaging	1/3
2	*CD/EoR*	Physics of the early universe IGM - II. Power spectrum	2/3
4	*Pulsars*	Reveal pulsar population and MSPs for gravity tests and Gravitational Wave detection	1/3
5	*Pulsars*	High precision timing for testing gravity and GW detection	1/3
13	*HI*	Resolved HI kinematics and morphology of ~10^10 M_sol mass galaxies out to z~0.8	1/5
14	*HI*	High spatial resolution studies of the ISM in the nearby Universe.	2/5
15	*HI*	Multi-resolution mapping studies of the ISM in our Galaxy	3/5
18	*Transients*	Solve missing baryon problem at z~2 and determine the Dark Energy Equation of State	=1/4
22	*Cradle of Life*	Map dust grain growth in the terrestrial planet forming zones at a distance of 100 pc	1/5
27	*Magnetism*	The resolved all-Sky characterisation of the interstellar and intergalactic magnetic fields	1/5
32	*Cosmology*	Constraints on primordial non-Gaussianity and tests of gravity on super-horizon scales.	1/5
33	*Cosmology*	Angular correlation functions to probe non-Gaussianity and the matter dipole	2/5
37 + 38	*Continuum*	Star formation history of the Universe (SFHU) – I+II. Non-thermal & Thermal processes	1+2/8

Summary

- Major post-re-baseline SKA1 HI areas include:
  - High resolution studies of galaxies at z~1
  - High resolution studies of the ISM in galaxies
  - Low-resolution, high-sensitivity observations of the cosmic web, interactions, gas accretion (compact core)
  - (HI absorbers - Allison; Galactic halo – McClure-Griffiths)
- Above science can be executed by KSP surveys of ~1,000 hrs
- Large-area KSPs not competitive with ASKAP

BUT

- Major advances possible with commensal surveys; e.g. a 10,000 hr survey over 5000 sq.deg => 0.8M galaxies in HI