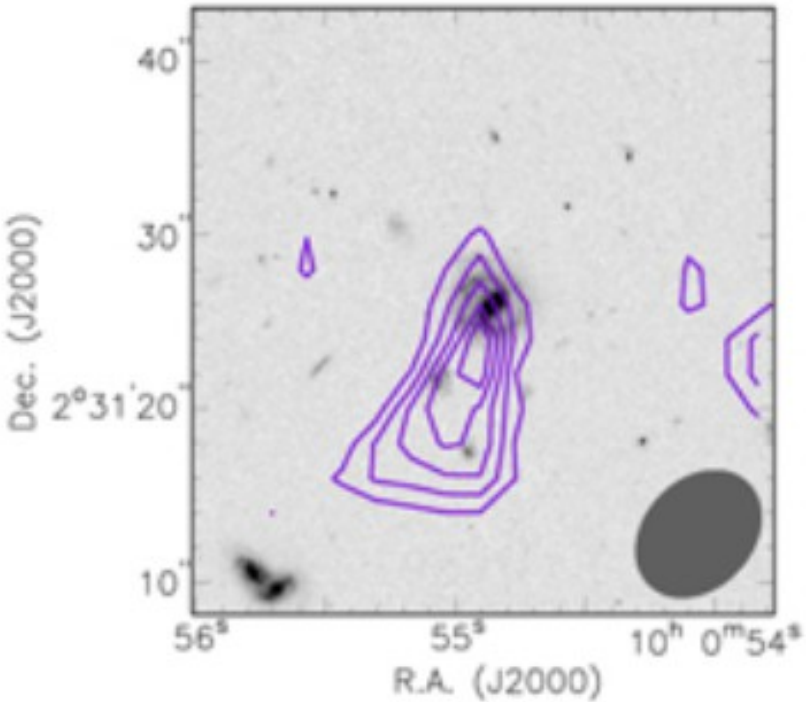
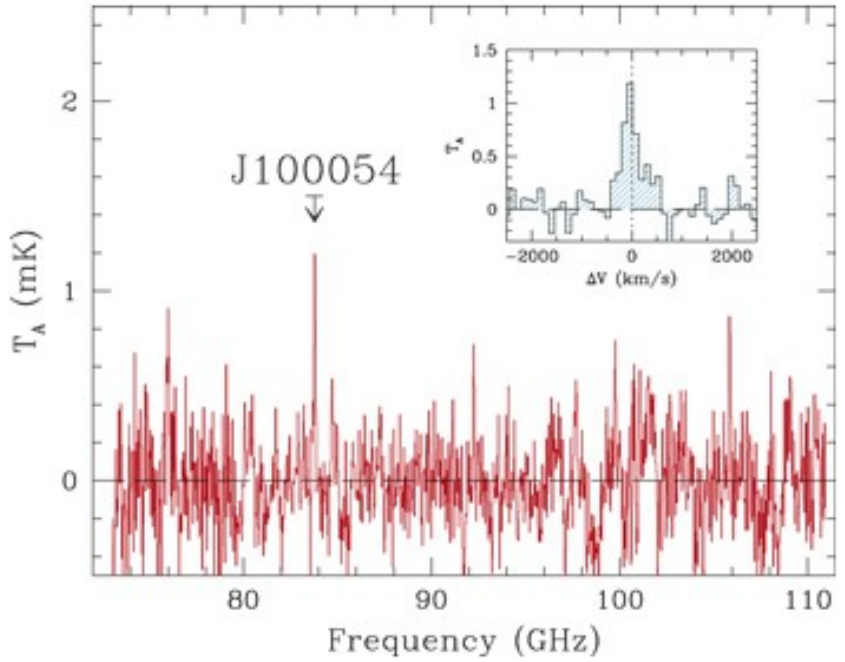
Looking At the Distant Universe with the MeerKAT Array

Andrew Baker (Rutgers, The State University of New Jersey)

Current HI emission redshift record

The COSMOS HI Large Extragalactic Survey (CHILES) team is using 1002 hours of VLA observations to study HI to $z \sim 0.45$.

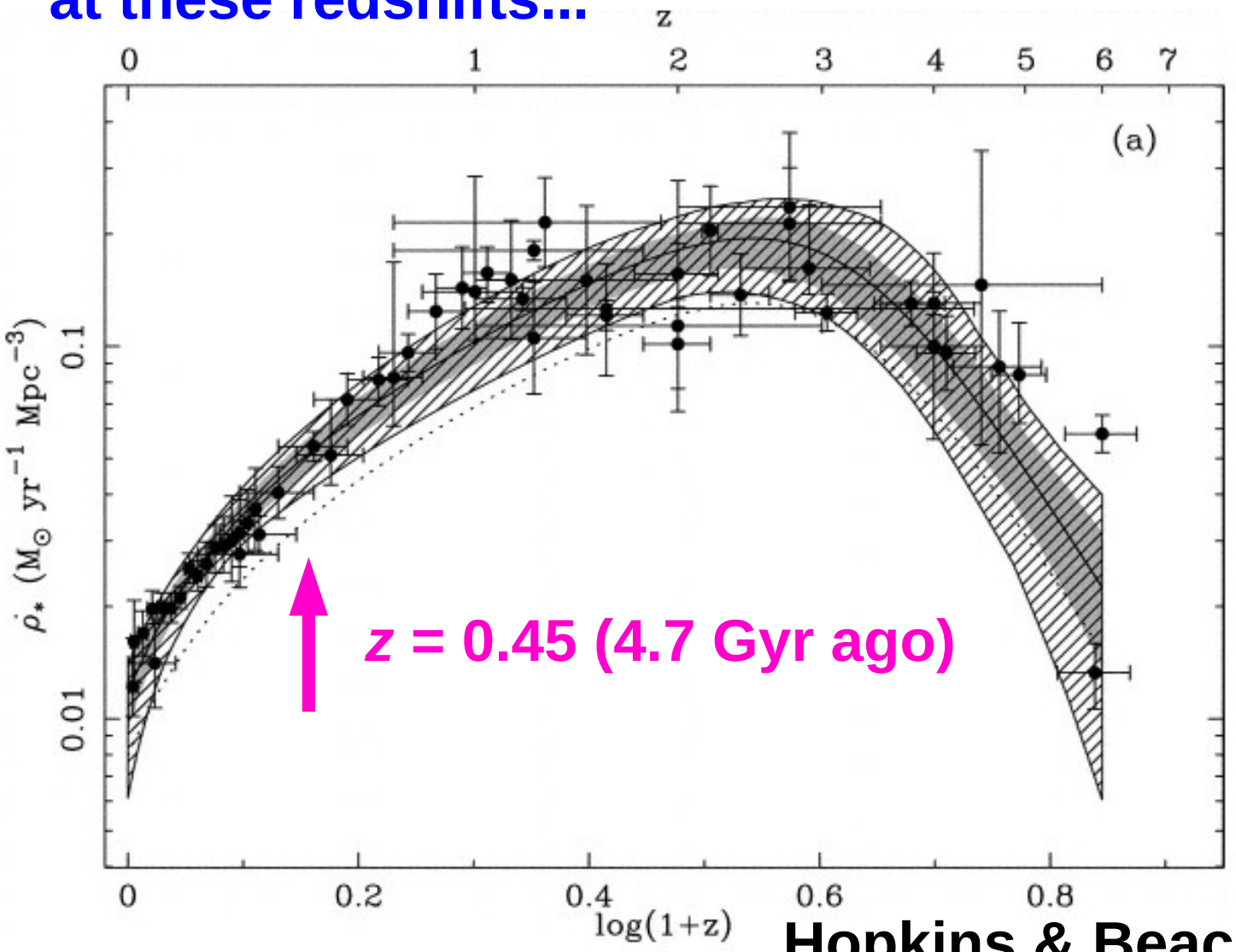




Fernández et al. (2016): blind HI detection at $z = 0.376$ (left) confirmed with CO($J = 1 \rightarrow 0$) detection (right) using the Large Millimeter Telescope – see D. Lucero talk.

HI vs. cosmic star formation history

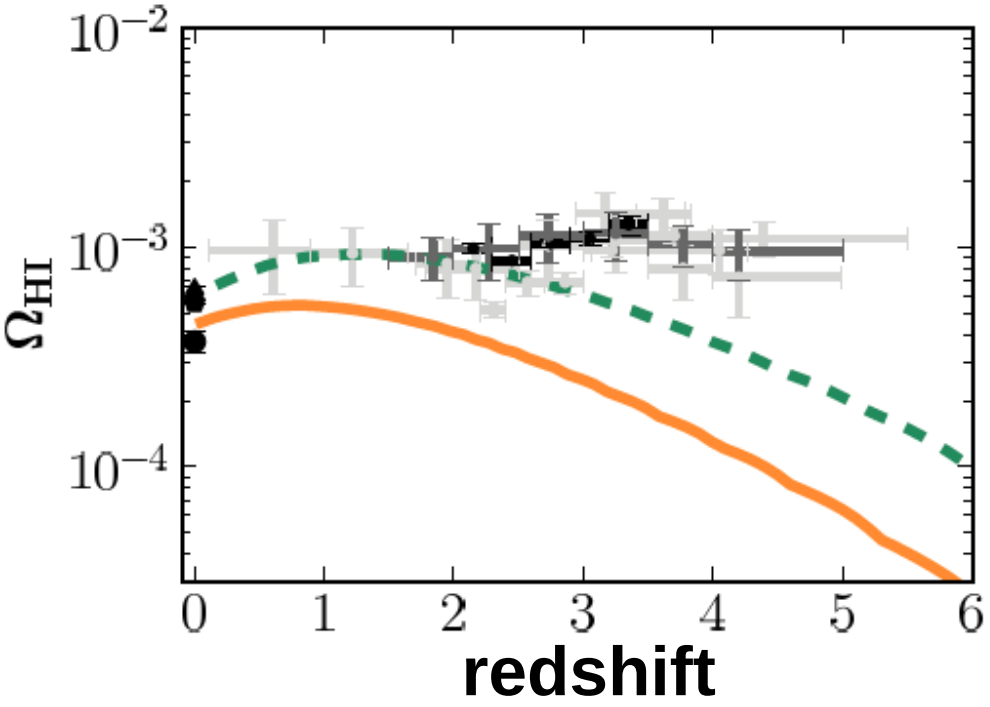
Still tracing only the tail end of the "cosmic star formation party" at these redshifts...

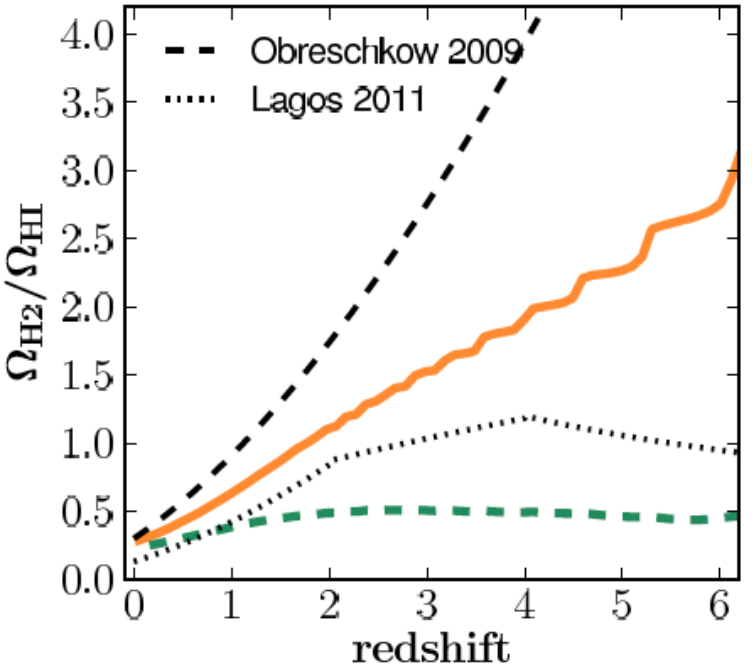


Hopkins & Beacom (2006)

Theorists can predict HI, H_2 evolution

Theorists can predict the evolution of galaxies' HI and H_2 over cosmic time.





Popping et al. (2014): two different recipes for "partitioning" HI and H_2 are used to produce the tan and green predictions.

Overheard in 2009...

Famous observer:

“What is the optimal number of observations for testing a theoretical prediction? One, two, three? How many?”

Overheard in 2009...

Famous observer:

“What is the optimal number of observations for testing a theoretical prediction? One, two, three? How many?”

Famous theorist:

“Zero. The optimal number of observations is zero.”

MeerKAT: frequency coverage

L band:

0.90–1.75 GHz

... corresponds to $0 \leq z_{HI} \leq 0.58$.

Redesigned in 2011 to access lower frequencies.

UHF band:

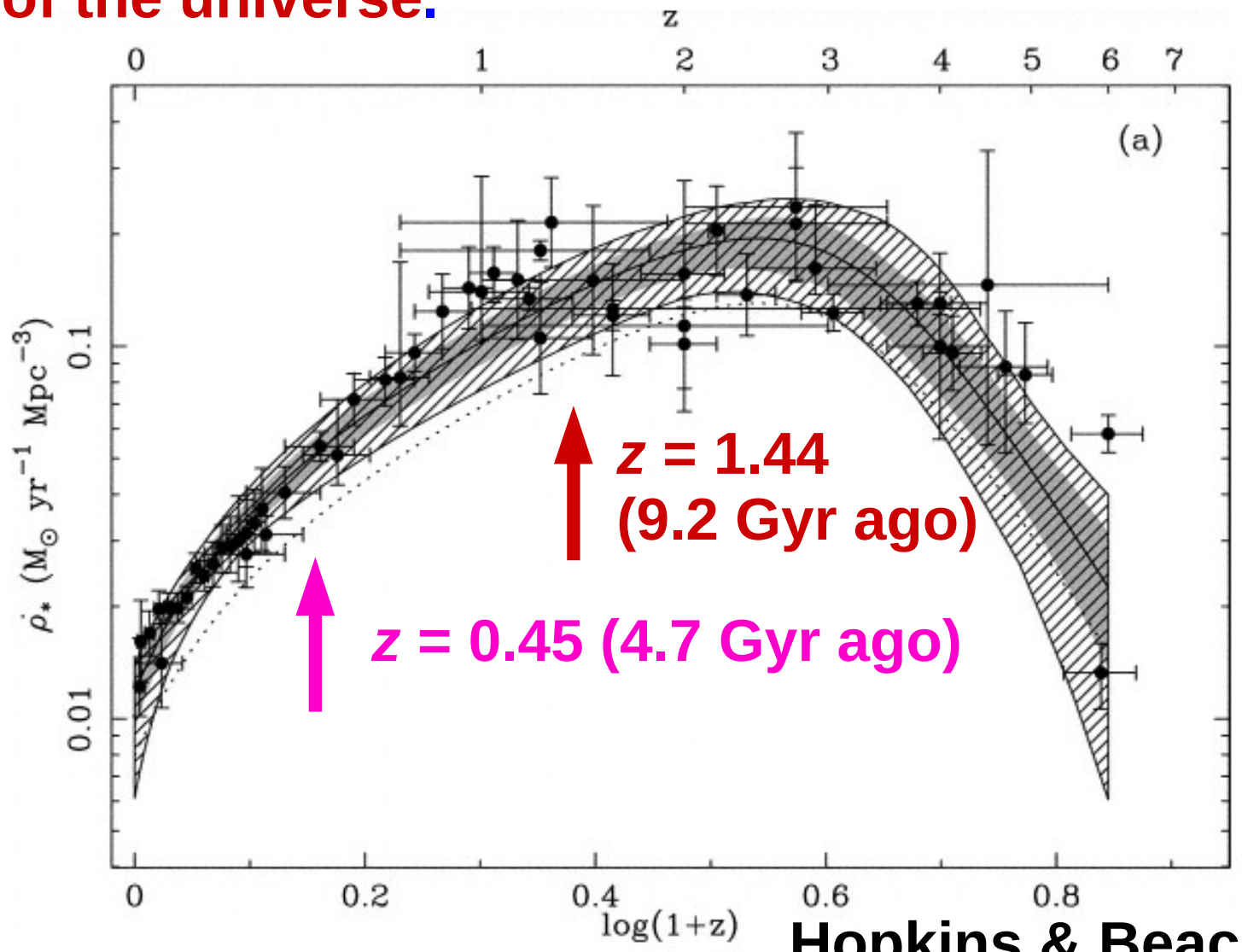
0.58–1.015 GHz

... corresponds to $0.40 \leq z_{HI} \leq 1.44$.

Redshift shell $0.40 \leq z_{HI} \leq 0.58$ observed by both receivers.

MeerKAT's redshift range

MeerKAT can probe HI emission in galaxies over 2/3 of the age of the universe.



Hopkins & Beacom (2006)

LADUMA: MeerKAT's deep HI survey

Looking At the Distant Universe with the MeerKAT Array:
5000 hr* survey of single well-studied field, to $z_{HI} = 1.44$.
See http://www.ast.uct.ac.za/laduma for details.

Three PIs inherited from merger of two proposing teams:

Sarah Blyth
University of Cape Town

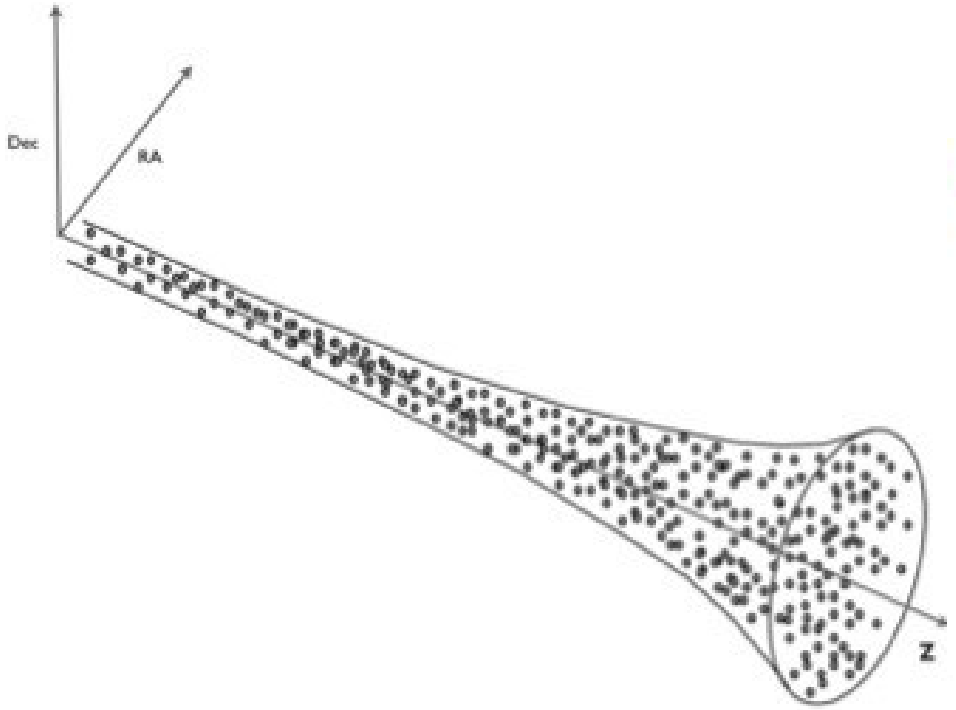
Benne Holwerda
University of Louisville

Andrew Baker
Rutgers, the State University of NJ

***in "2010 hours"**

Why “LADUMA”?

“Laduma!” = “It thunders!” in isiZulu = unique South African exclamation when a goal is scored in soccer.



Thanks to the $\propto (1+z)^2$ area of MeerKAT's field of view, LADUMA's data “cube” will be more of a data vuvuzela.

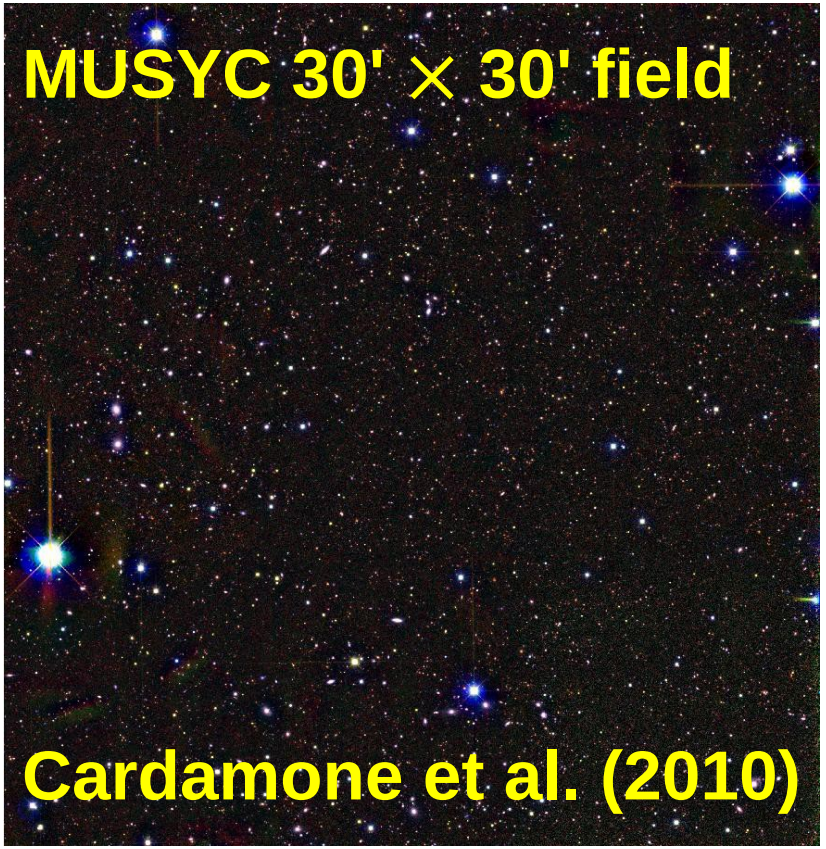
LADUMA team members

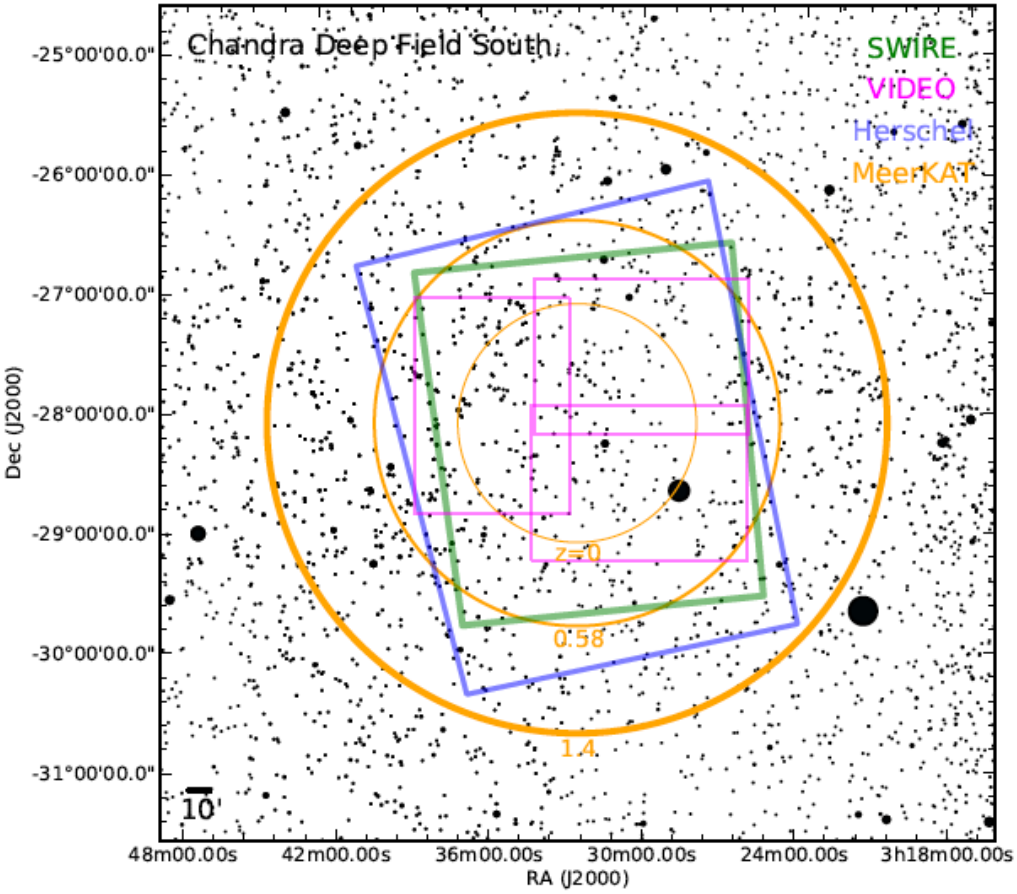
A. Baker, B. Bassett, M. Bershady, S. Blyth, A. Bouchard, F. Briggs,
B. Catinella, L. Chemin, S. Crawford, C. Cress, D. Cunnama, J. Darling,
R. Davé, R. Deane, E. de Blok, E. Elson, A. Faltenbacher, S. February,
X. Fernández, B. Frank, E. Gawiser, T. Henning,
K. Hess, I. Heywood, B. Holwerda, J. Hughes, M. Jarvis,
S. Kannappan, N. Katz, D. Kereš, H.-R. Klöckner, R. Kraan-Korteweg,
P. Lah, M. Lehnert, A. Leroy, N. Maddox, S. Makhathini, G. Meurer,
M. Meyer, K. Moodley, R. Morganti, D. Obreschkow, S.-H. Oh, T. Oosterloo,
D.J. Pisano, A. Popping, G. Popping, S. Ravindranath, E. Schinnerer,
A. Schröder, K. Sheth, O. Smirnov, 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, J. Wu, M. Zwaan, J. Zwart

9/69 = 13% of team is at this meeting.

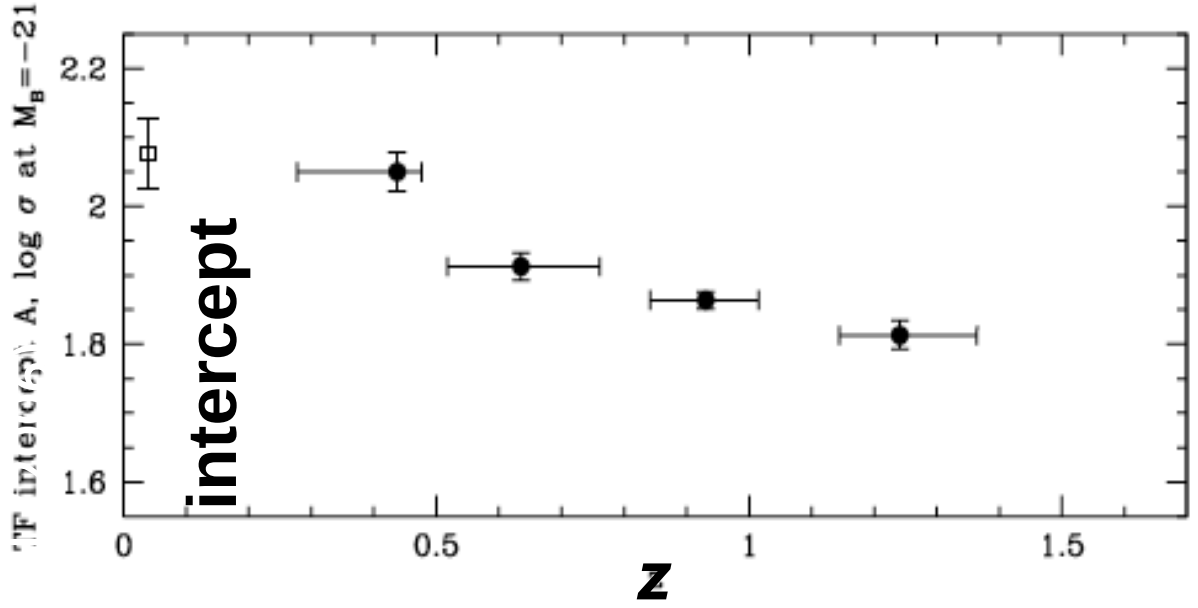
Target field: Chandra Deep Field South

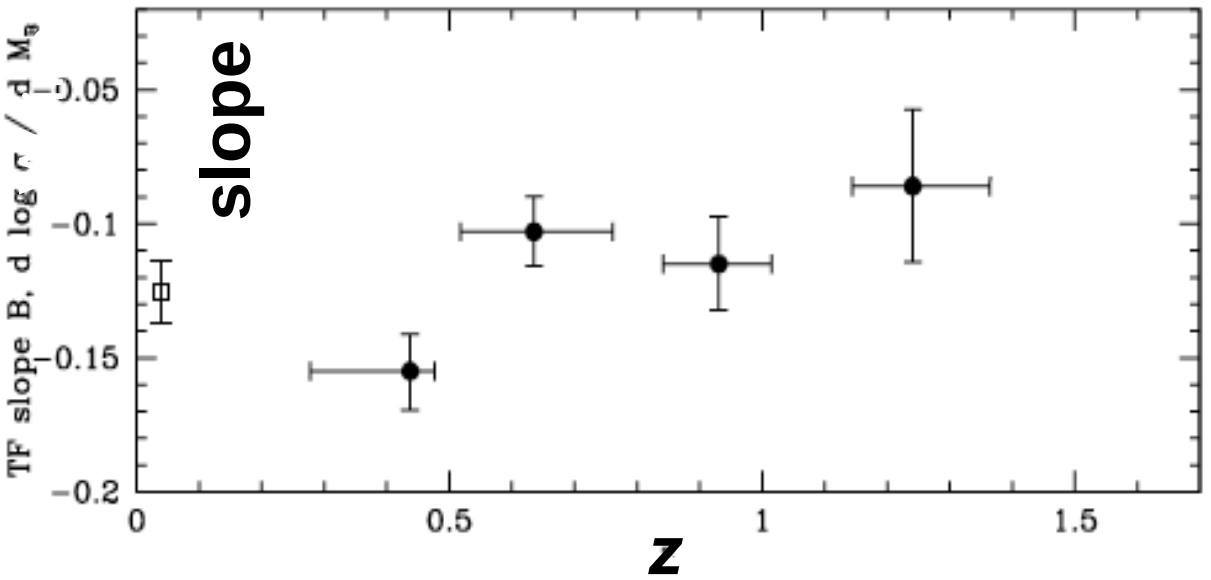
***Hubble Space Telescope* imaging ⊂ ground-based imaging**
for MUSYC (PI: Gawiser) ⊂ LADUMA footprint:
+ 5000+ new spectroscopic redshifts (AAT+SALT)
+ well-imaged in near-IR, mid-IR, far-IR bands





Science: scaling relation evolution



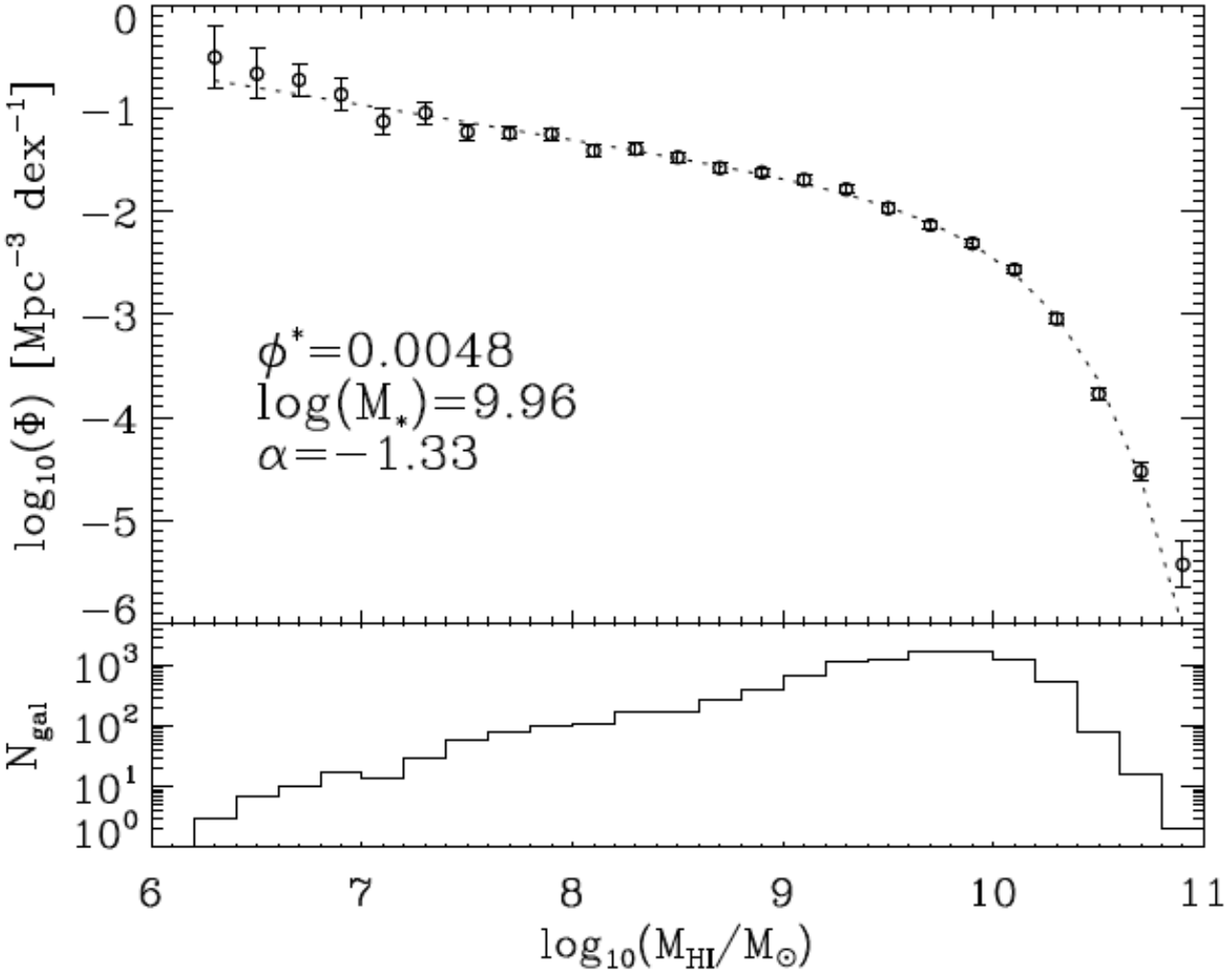


Tully-Fisher relation links a galaxy's stellar mass and its total (dark matter dominated) mass, and evolves with redshift.

How does baryonic Tully-Fisher relation evolves to *z* ~ 1.4? May depend on details of feedback...

Weiner et al. (2006), *B*-band Tully-Fisher

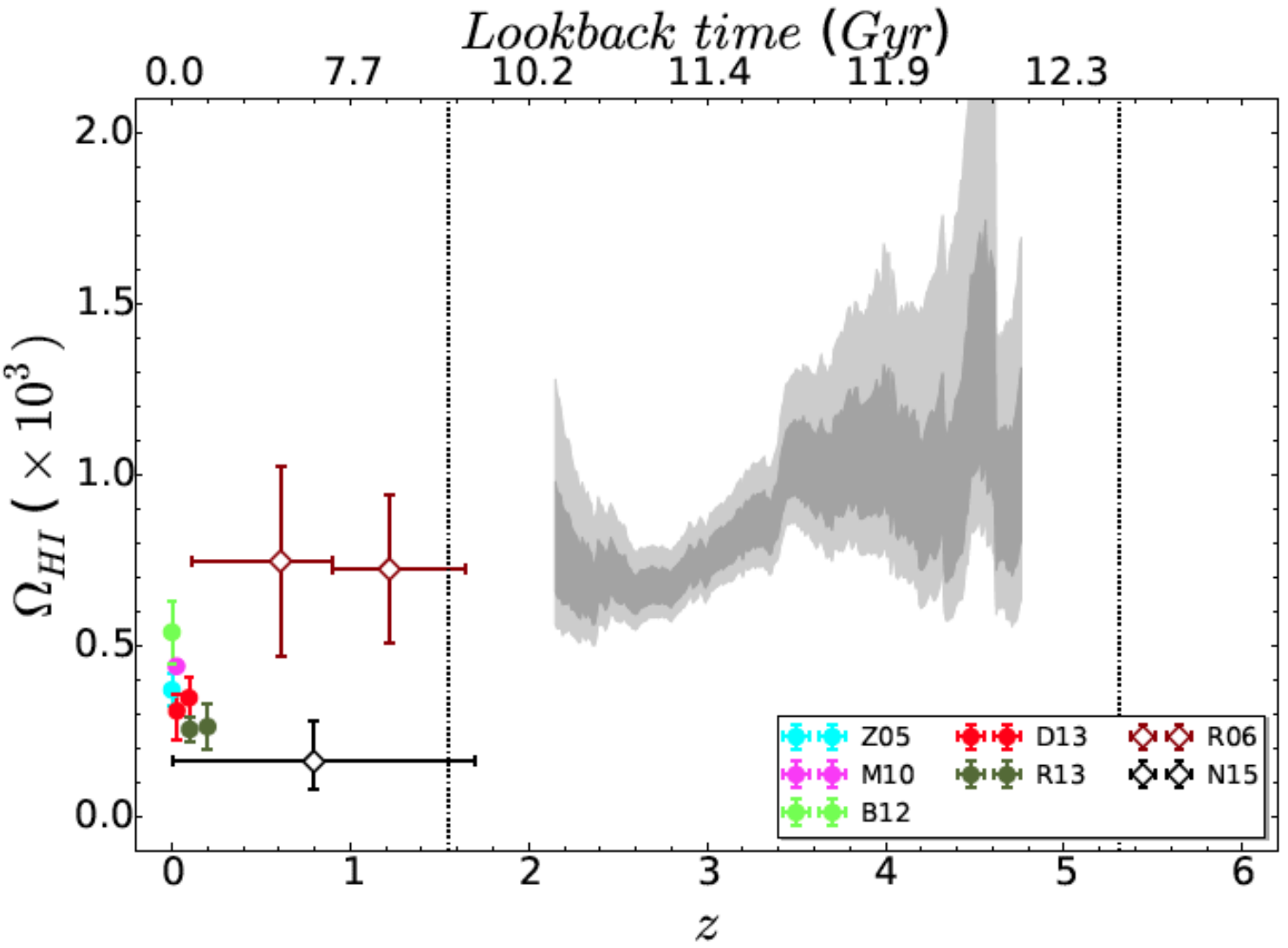
Science: HI mass function



How do parameters of HI mass function depend on redshift and environment?

Martin et al. (2010), *z* < 0.06

Science: cosmic HI density



What and where is Ω_{HI} as function of *z*?

HI emission vs. Lyα and Mg II absorber comparisons over same Δz range will be extremely valuable.

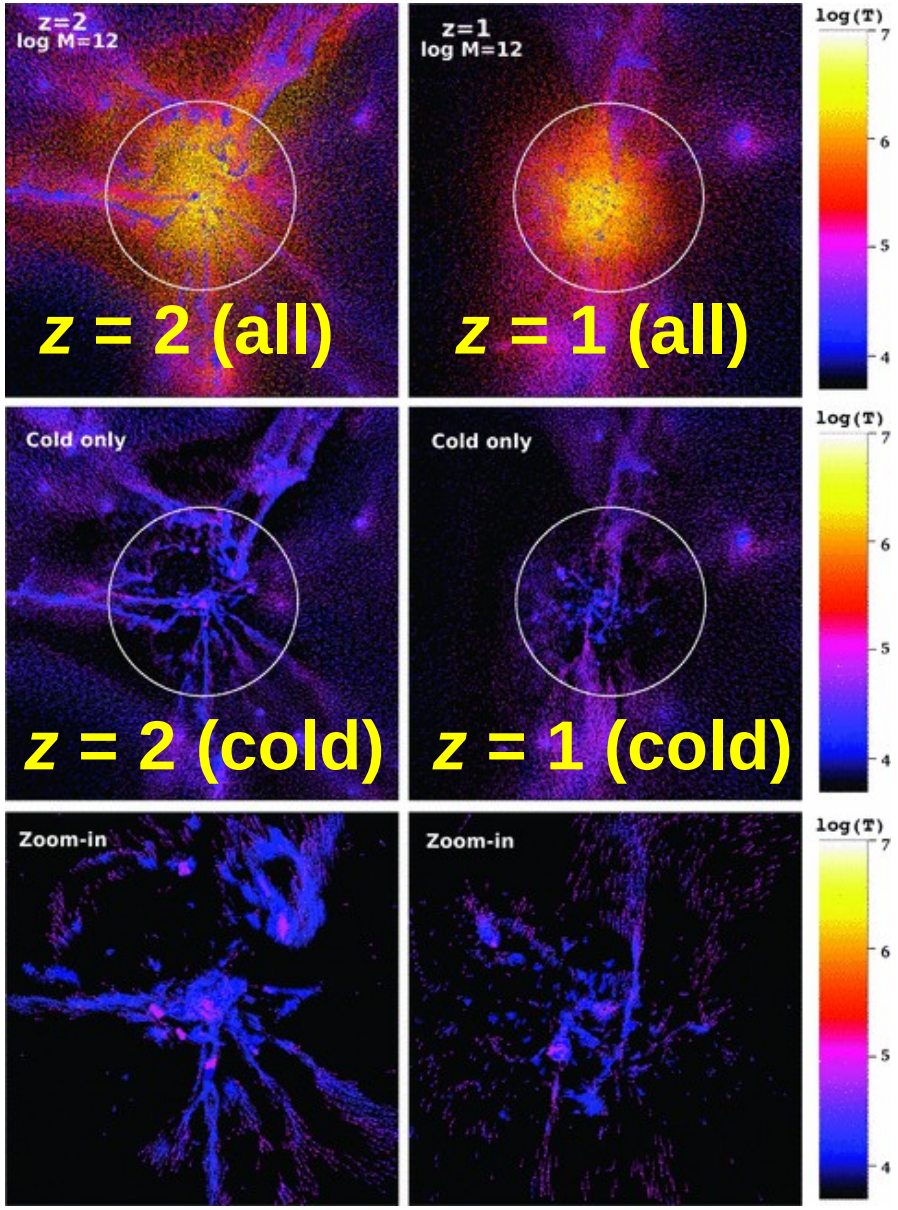
Sánchez-Ramírez et al. (2015)

Even optical astronomers agree!

Last sentence of Sánchez-Ramírez et al. (2015):

An accurate measure of $\Omega_{\rm HI}^{\rm DLA}$ at redshifts between 0.1 and 2 is therefore clearly of the utmost importance. Upcoming surveys with the Square Kilometre Array (SKA, Staveley-Smith & Oosterloo 2015) and its pathfinders present an exciting prospect for resolving the current uncertainty in the gas content of galaxies since $z \sim 1.5$.

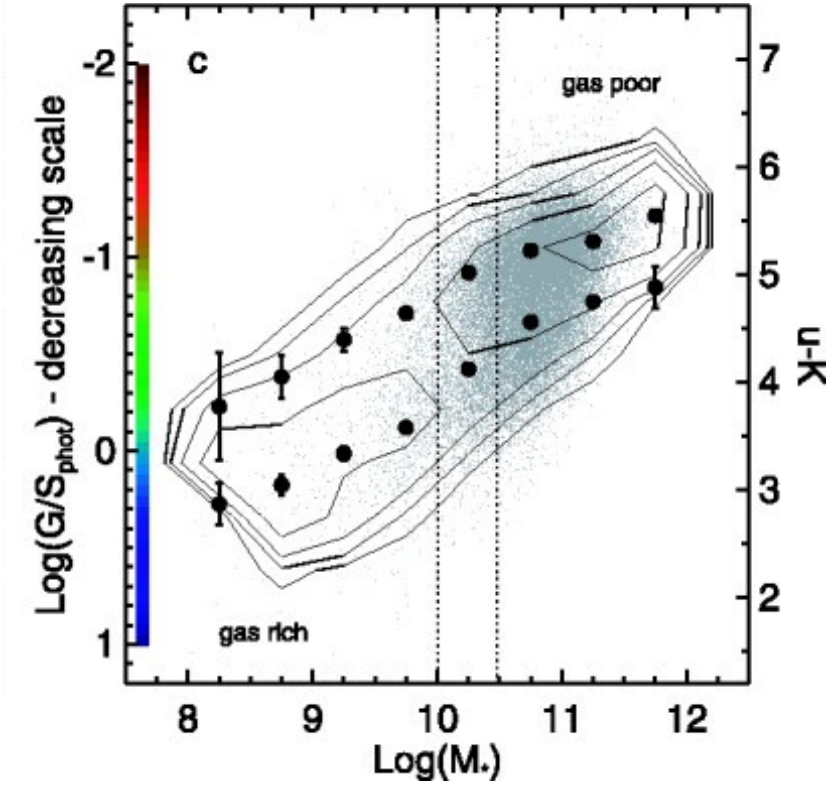
Science: HI vs. halo property

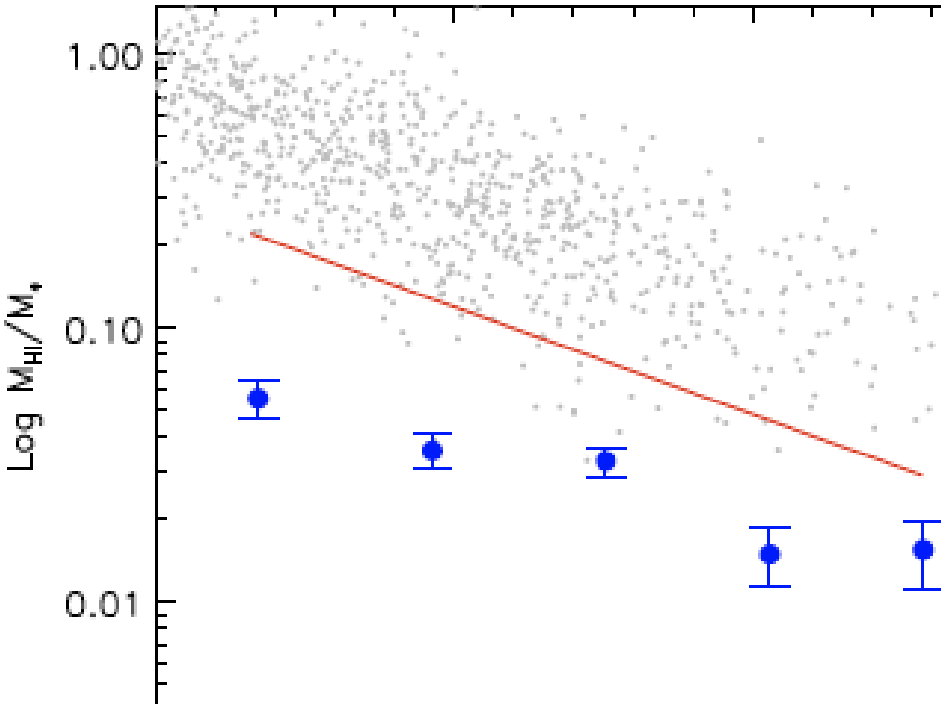


Kereš et al. (2010): simulations predict differences in hot/cold accretion based on dark matter halo mass and redshift.

Although clean tests are difficult, we can look for imprints of accretion mode on galaxies' HI contents.

Science: HI vs. galaxy property





Kannappan (2004): gas/stellar mass fraction calibrated with *u-K* correlates with *M at *z* = 0.**

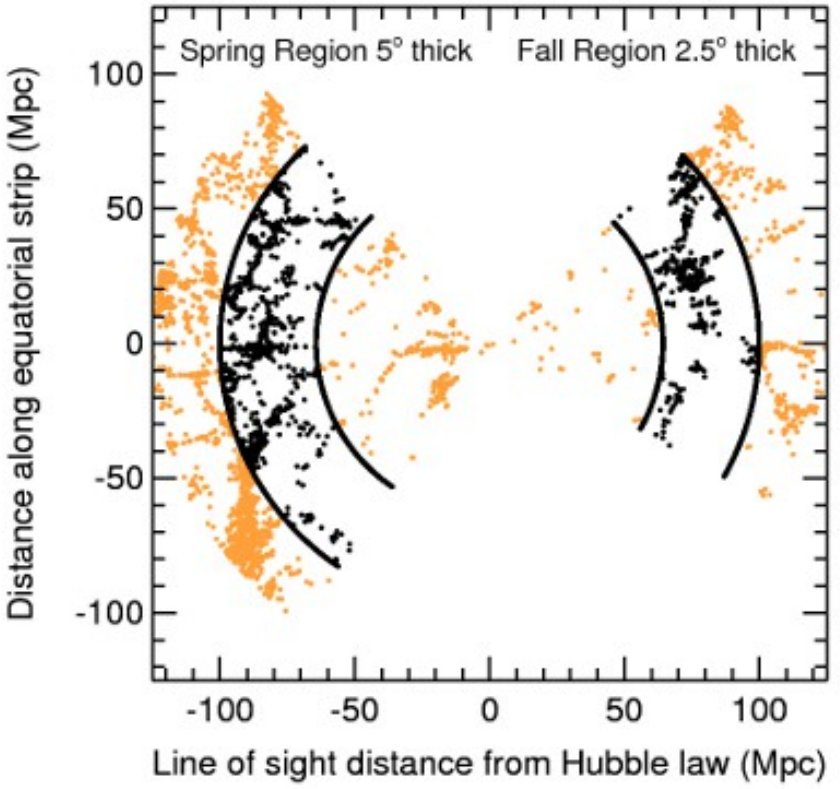
Fabello et al. (2010), stacking ALFALFA data: bulge-dominated galaxies have lower M_{HI}/M^* at fixed *M.**

LADUMA's *z* = 0 reference: RESOLVE

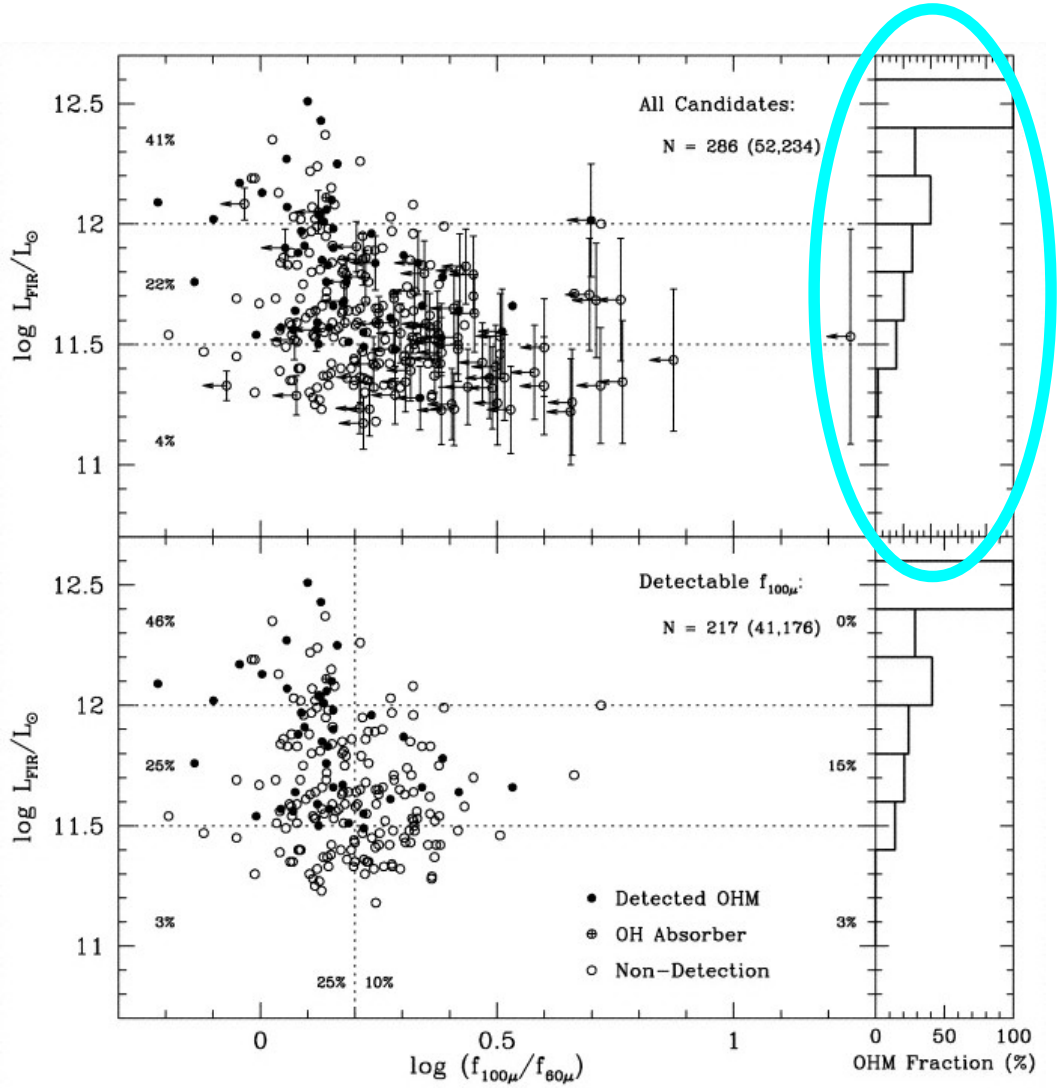
Every high-*z* survey needs a *z* = 0 reference dataset.

For LADUMA, this will be the REsolved Spectroscopy Of a Local VolumE (RESOLVE) survey, led by Sheila Kannappan at the University of North Carolina:

- **+ volume-limited survey**
- **+ *cz* = 4500–7500 km/s**
- **+ 50,000 Mpc^3**
- **+ HI data from Arecibo, Green Bank Telescope**
- **+ high-resolution ionized gas and/or stellar kinematics for every galaxy**



Interlopers?



OH megamaser galaxies "contaminate" HI samples, but provide an interesting view into cosmic history of galaxy mergers.

Photometric redshifts and long-wavelength star formation tracers (e.g., dust and radio continuum) will allow HI/OH separation.

Darling & Giovanelli (2002)

Outcome of 2010 proposal review

12 October 2010 letter from Project Director:

- **+ deep HI survey placed in Priority Group 1**
- **+ "two deep HI teams [are] requested to undertake this project jointly"**
- **+ "allocated 5000 hours, with a recommendation to focus on a single field"**
- **+ "will naturally yield a continuum field, which should be incorporated in [the MIGHTEE] project"**

Working assumption: 1000 hr in L + 4000 hr in UHF.

2016–17 project review

MeerKAT receivers more sensitive than projected in 2010.

All MeerKAT large survey program teams asked to submit revised project plans, taking account of improved performance and scientific developments since 2010.

Project plans submitted in June 2016.
+ internal (technical) review complete
+ external (scientific) review pending – now March 2017?

LADUMA has requested a time allocation < 5000 hr to achieve its original science goals in ~ 4 years.

LADUMA outreach activities

At our 2012 collaboration meeting, 19 LADUMA team members visited 17 high schools across Cape Town area to speak about astronomy, MeerKAT, LADUMA, and pursuing scientific and technical careers. Over 2100 learners reached. Including 2016 team meeting visits, now up to 25 schools.

Herschel Girls School

Oval North High School

Summary

LADUMA survey with MeerKAT will probe the evolution of gas in galaxies to z_{HI} ~ 1.4 (lookback time 9.2 Gyr) at ~ 8.3 (1 + z_{HI}) arcsec resolution, starting in 2018.

Observing commensally with the MIGHTEE continuum survey (PIs Jarvis & Taylor) and the time domain surveys ThunderKAT (PIs Fender & Woudt) and MeerTRAP (PI Stappers).

Narrowest and deepest tier of the southern HI survey wedding cake vs. WALLABY, DINGO, MIGHTEE (HI).

*** visit us at http://www.facebook.com/MeerKATLaduma ***