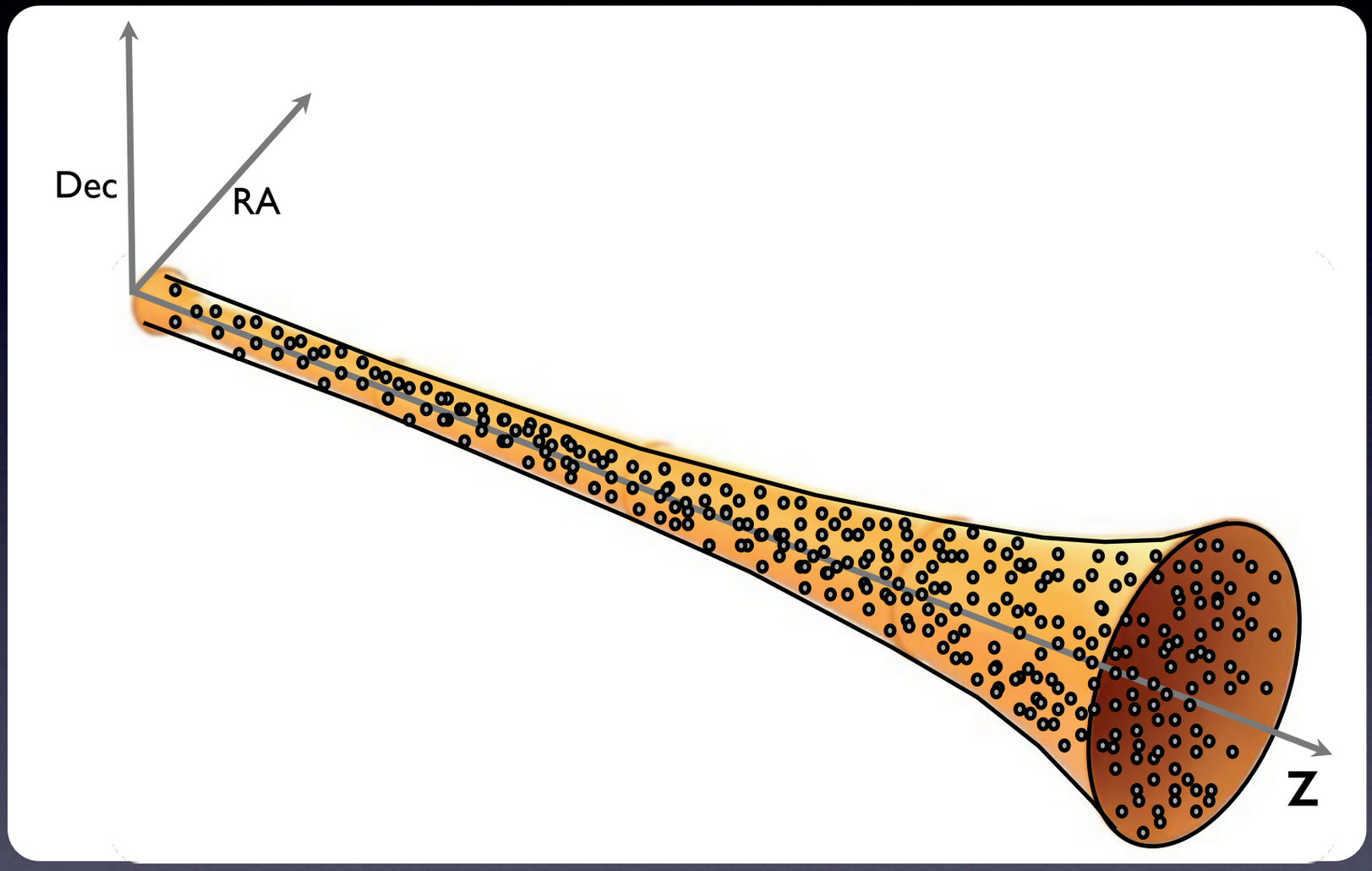
LADUMA

Looking at the Distant Universe with the MeerKAT Array



B.W. Holwerda[1], S.-L. Blyth[2] & A. J. Baker[3]

1) European Space Agency
2) Astrophysics, Cosmology and Gravity Centre (ACGC), University of Cape Town
3) Rutgers, the State University of New Jersey

B.W. Holwerda, *Gas in Galaxies*, Kloster Seeon, June 14

LADUMA Team

Two proposals merged: MUDHI + LADUMA! → **LADUMA**

MeerKAT TAC rating: Priority Group 1
Awarded 5000 h for a single pointing

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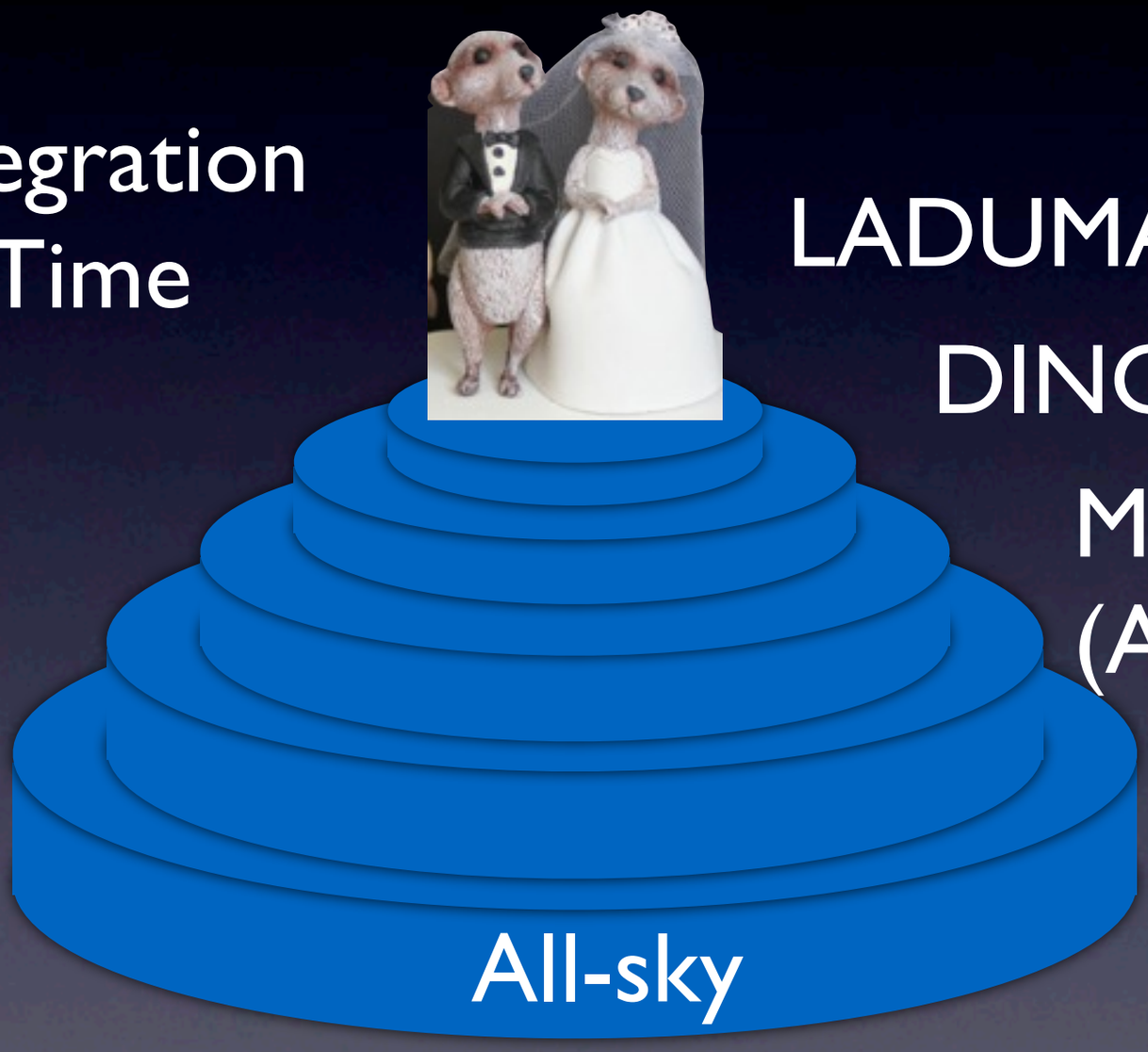
co-Is: B. Bassett, M. Bershady, A. Bouchard, F.H. Briggs, B. Catinella, L. Chemin, C. Cress, J. Darling, R. Dave, R. Dean, E. de Blok, E. Elson, A. Faltenbacher, B. Frank, E. Gawiser, T. Henning, J. Hughes, M. Jarvis, R. Johnston, S. Kannappan, N. Katz, D. Kereš, H-R. Klöckner, R.C. Kraan-Korteweg, P.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

Wedding Cake of Surveys



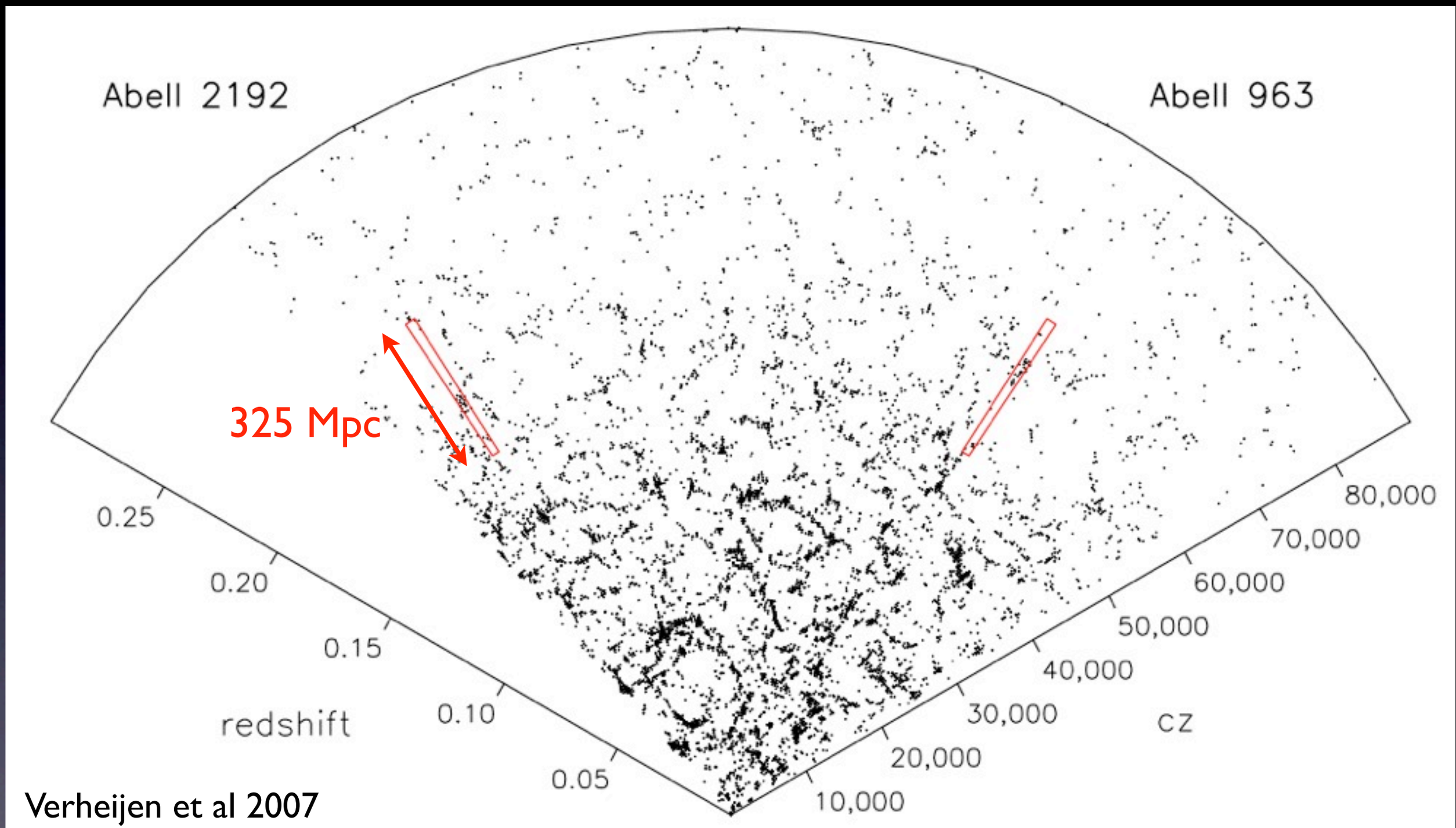
LADUMA (MeerKAT)

DINGO (ASKAP)

Medium-Deep Survey (APERTIF)

Wallaby + WNSHS (ASKAP, APERTIF)

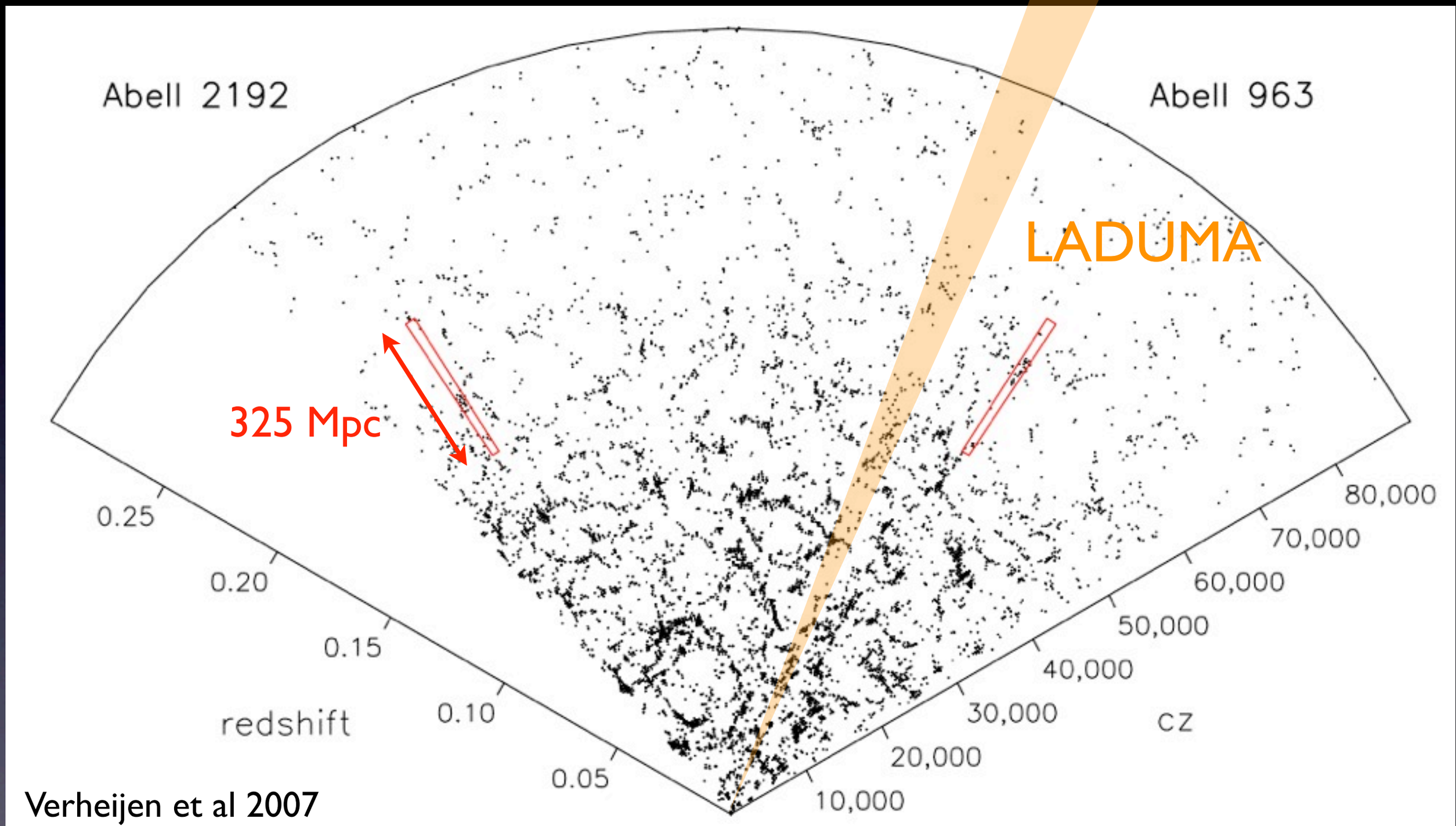
Single Deep Field



Verheijen et al 2007

SDSS redshift space

Single Deep Field



Verheijen et al 2007

SDSS redshift space

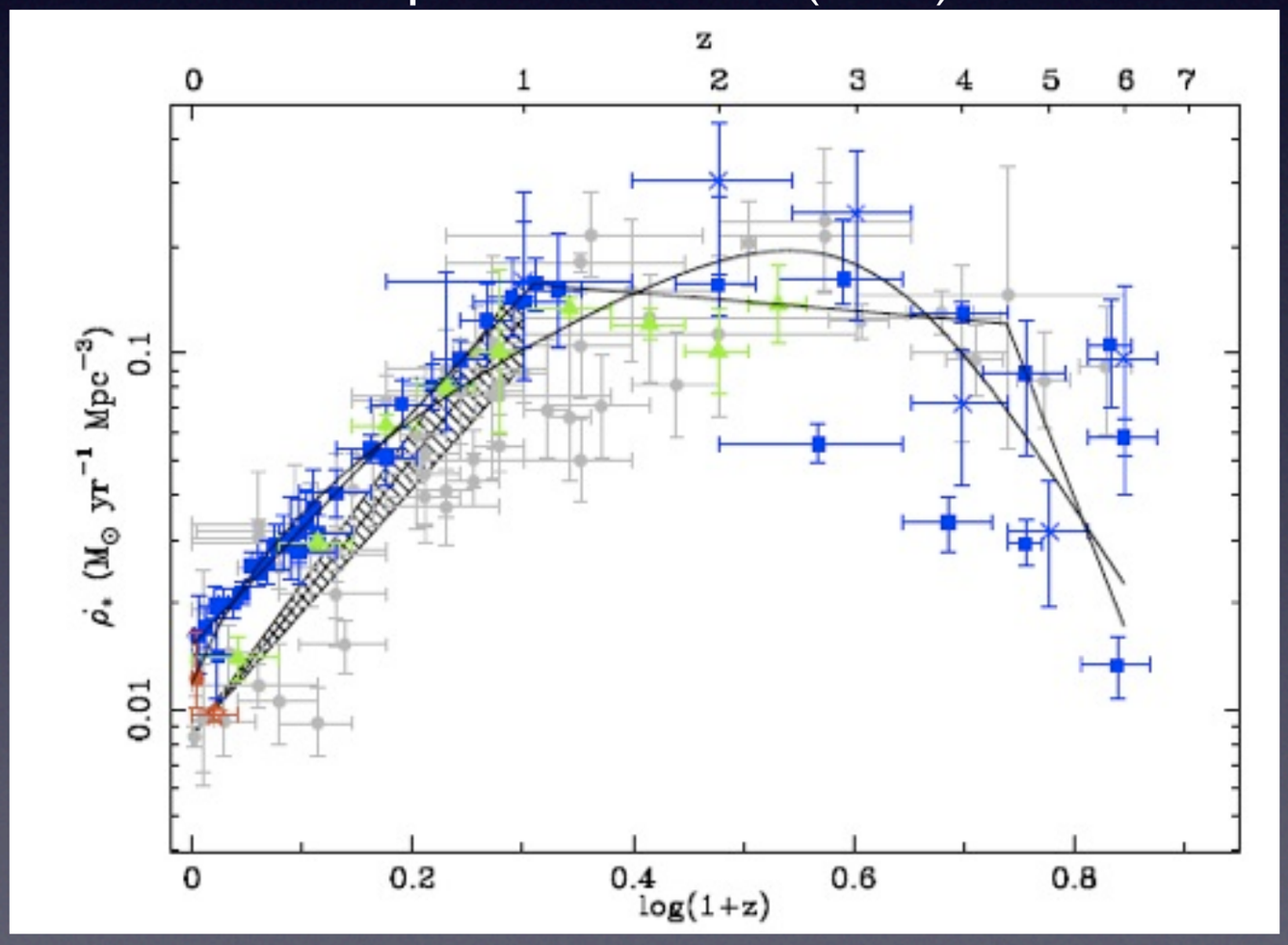
Motivation: Galaxy Evolution

Galaxies show significant evolution since z=1, but what drives this...

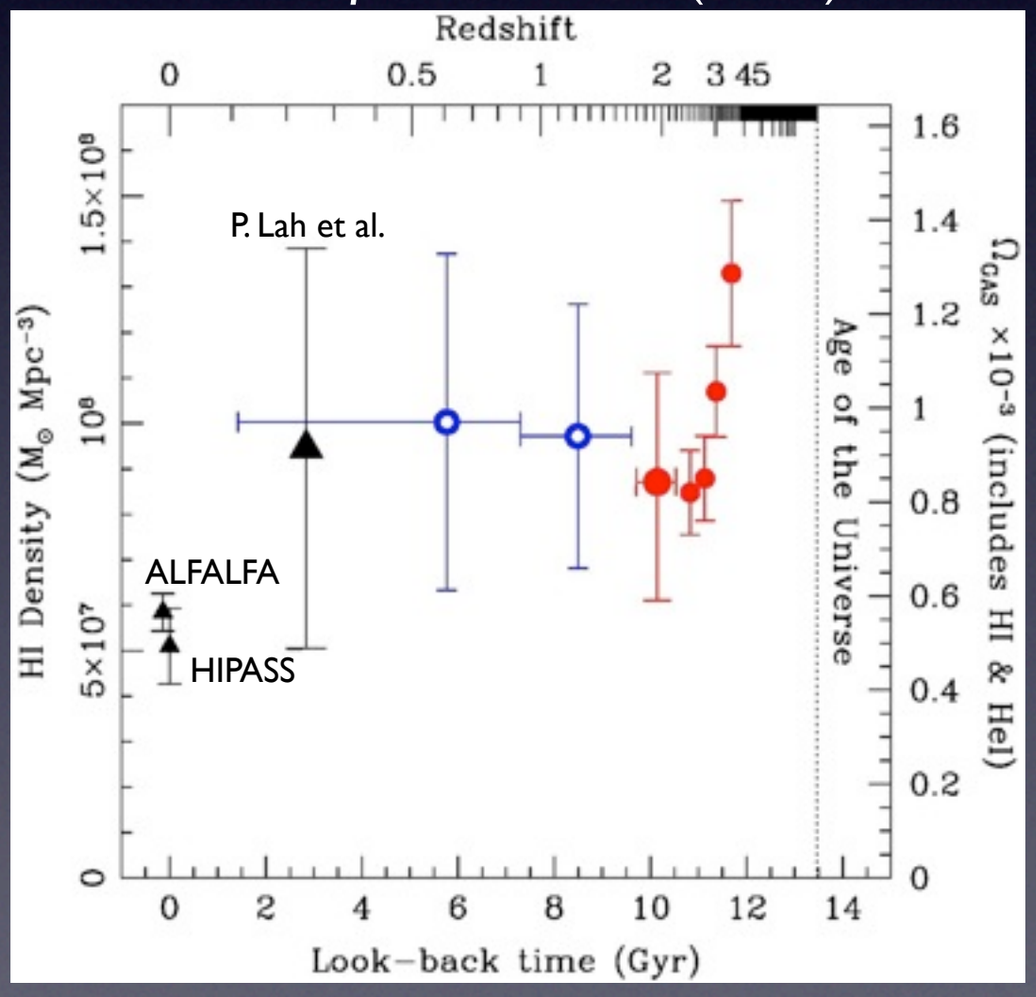
Since z~1:

- Number density of blue galaxies goes down (↓), and red galaxies up (↑).
- Star-formation rate (SFR) drops by order of magnitude but global hydrogen reservoir (Ω_{HI}) remains constant?

Hopkins & Beacom (2005)



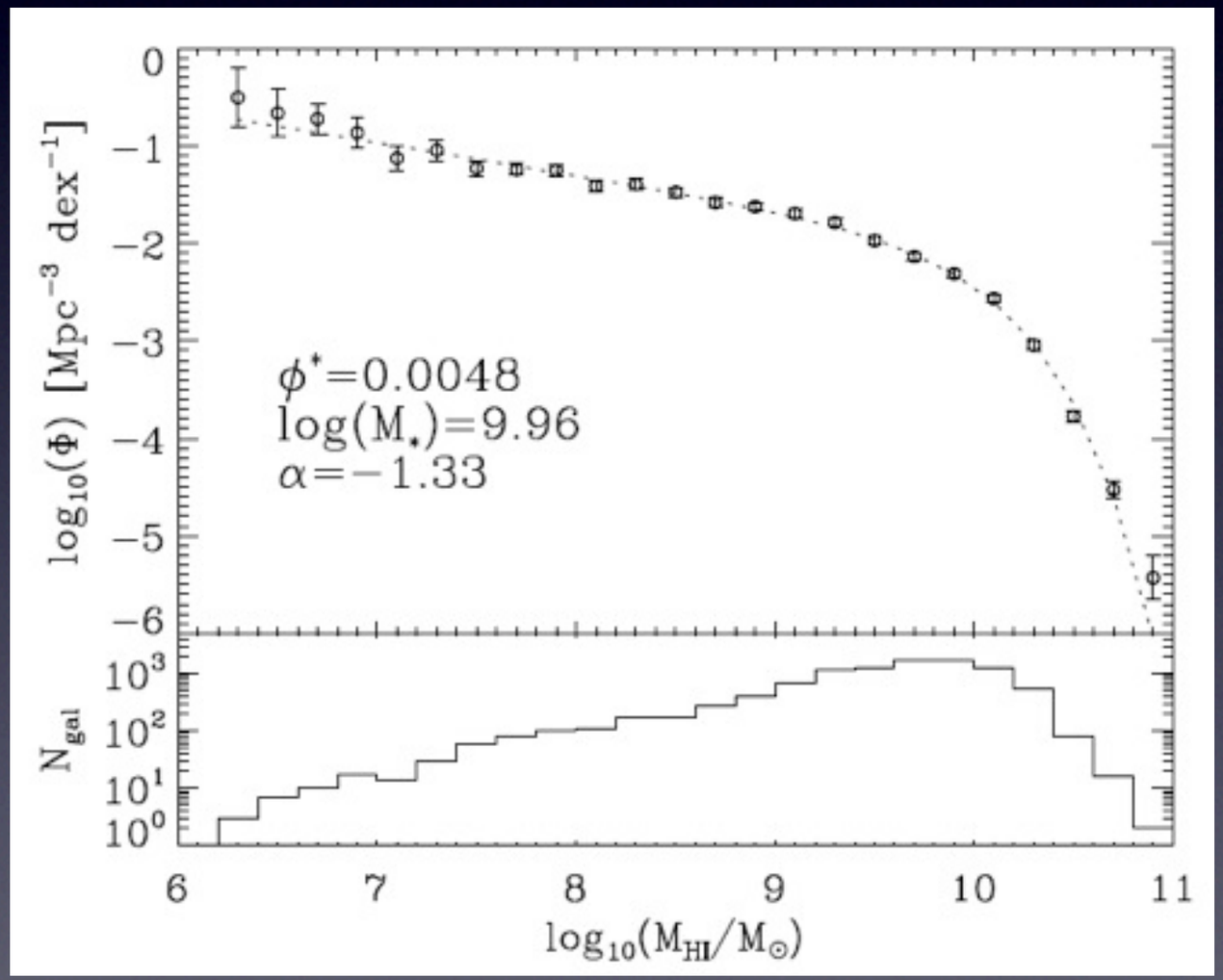
P. Lah, *private comm.* (2011)



Science: HI Mass Function

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

HIMF vs. z



Martin et al. (2010)

(measured for z<0.06)

How is HI distributed within galaxies?

- How do M^*_{HI}, α & normalization vary vs. z?
  - recent results by Martin et al. (2010)
- Help to constrain hierarchical galaxy formation models
- Differences with environment?

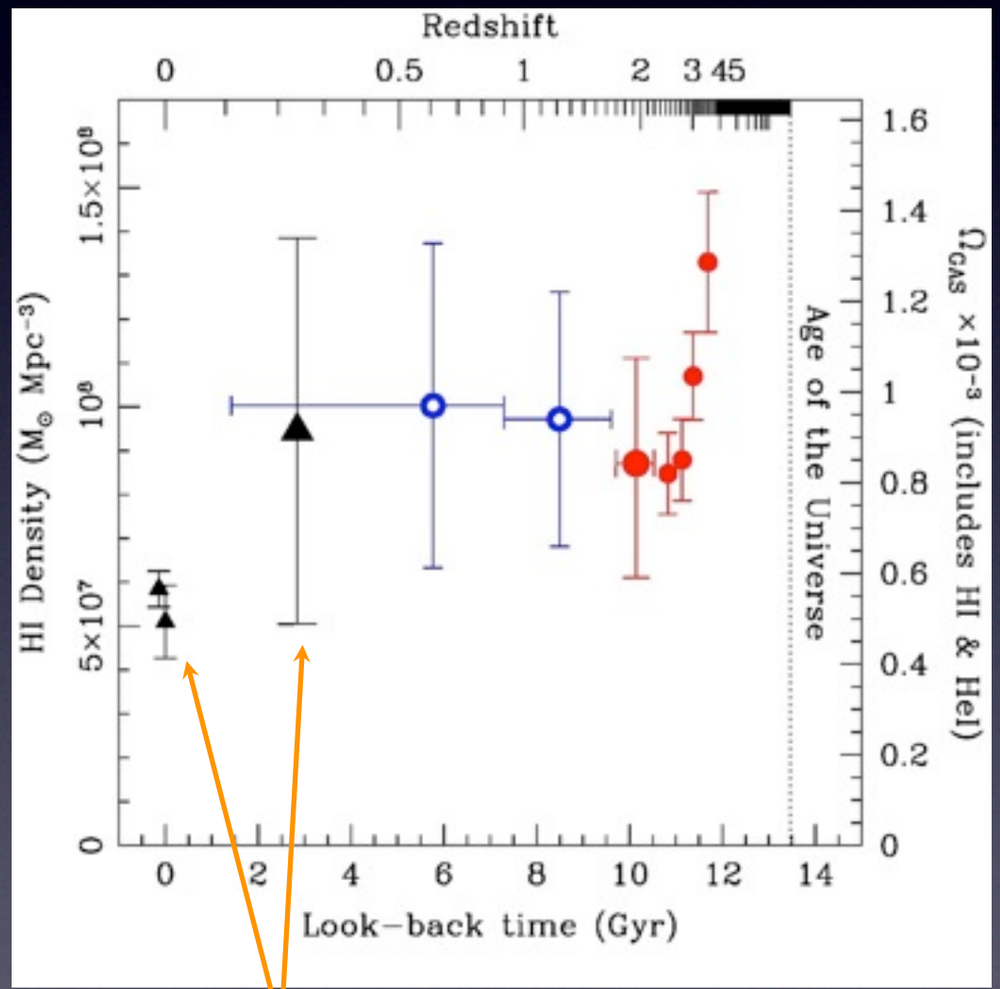
Science: Cosmic HI Density (Ω_{HI})

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

What is the average amount of HI at different z?

- What is the trend for 0.2< z <0.6 where SFR is decreasing?
- How will HI measurements compare to Lyα and MgII absorber results at high z?

Ω_{HI} vs. z



P. Lah, private comm. (2011)

direct HI line detections
(ALFALFA 16% higher than HIPASS)

Science: Fueling Galaxies

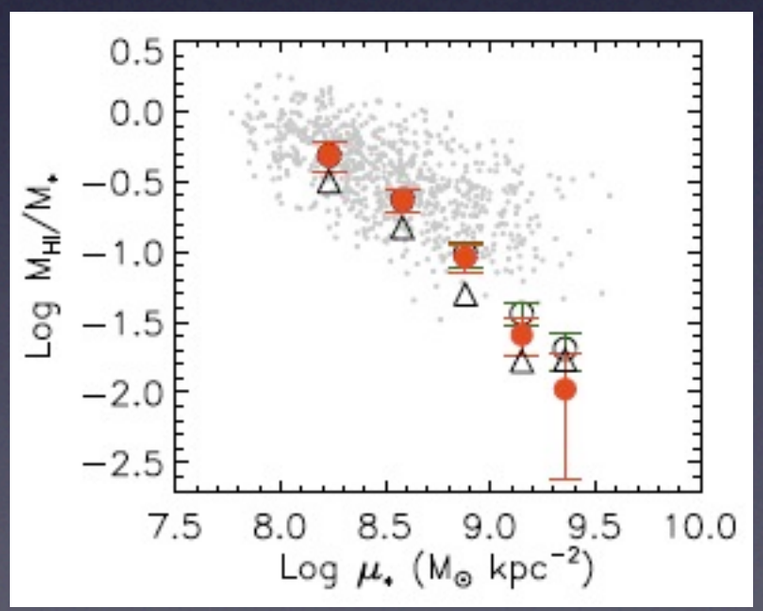
How does the cold gas mass depend on halo mass?

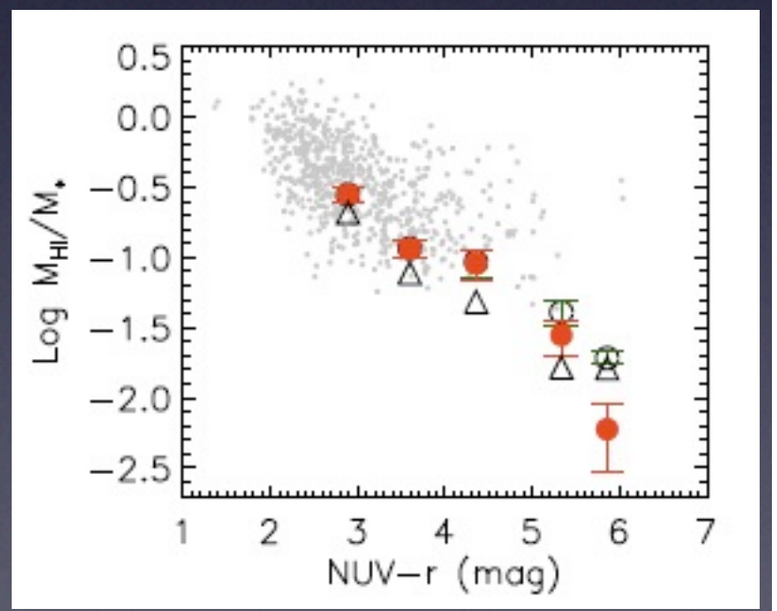
- Simulations by Kereš et al. (2009) predict differences in hot/cold accretion based on halo mass and z

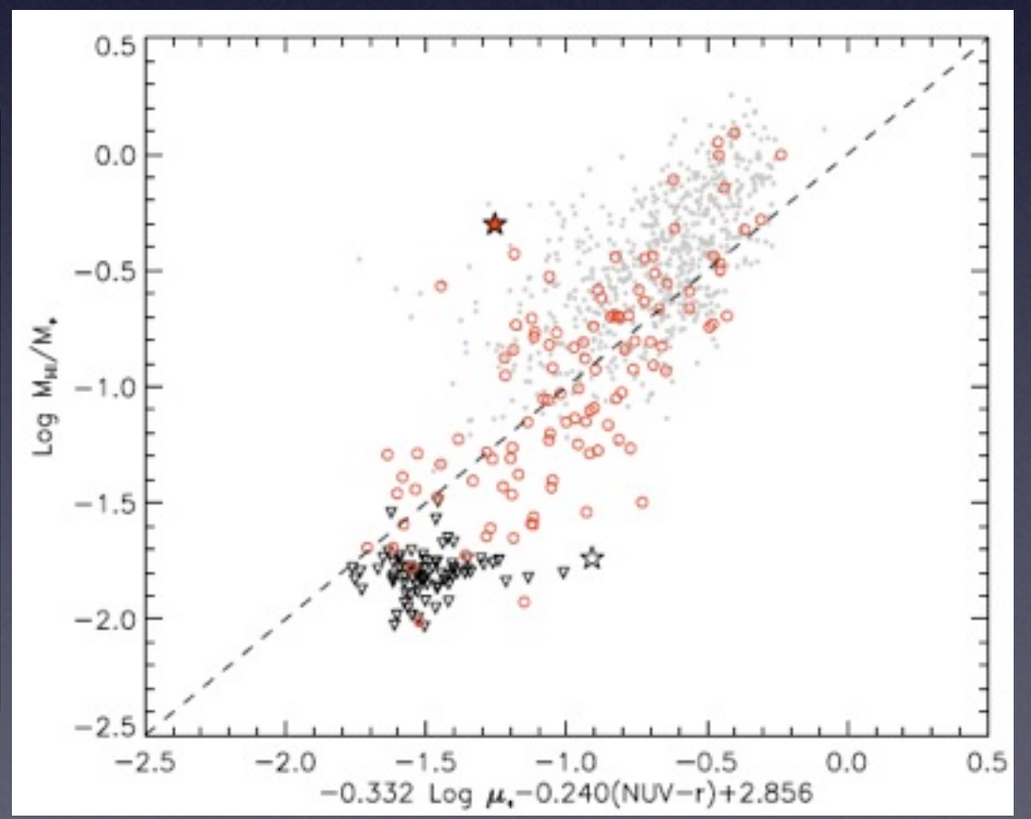
What is the relation between HI mass & stellar mass?

- e.g. Kannappan (2004)

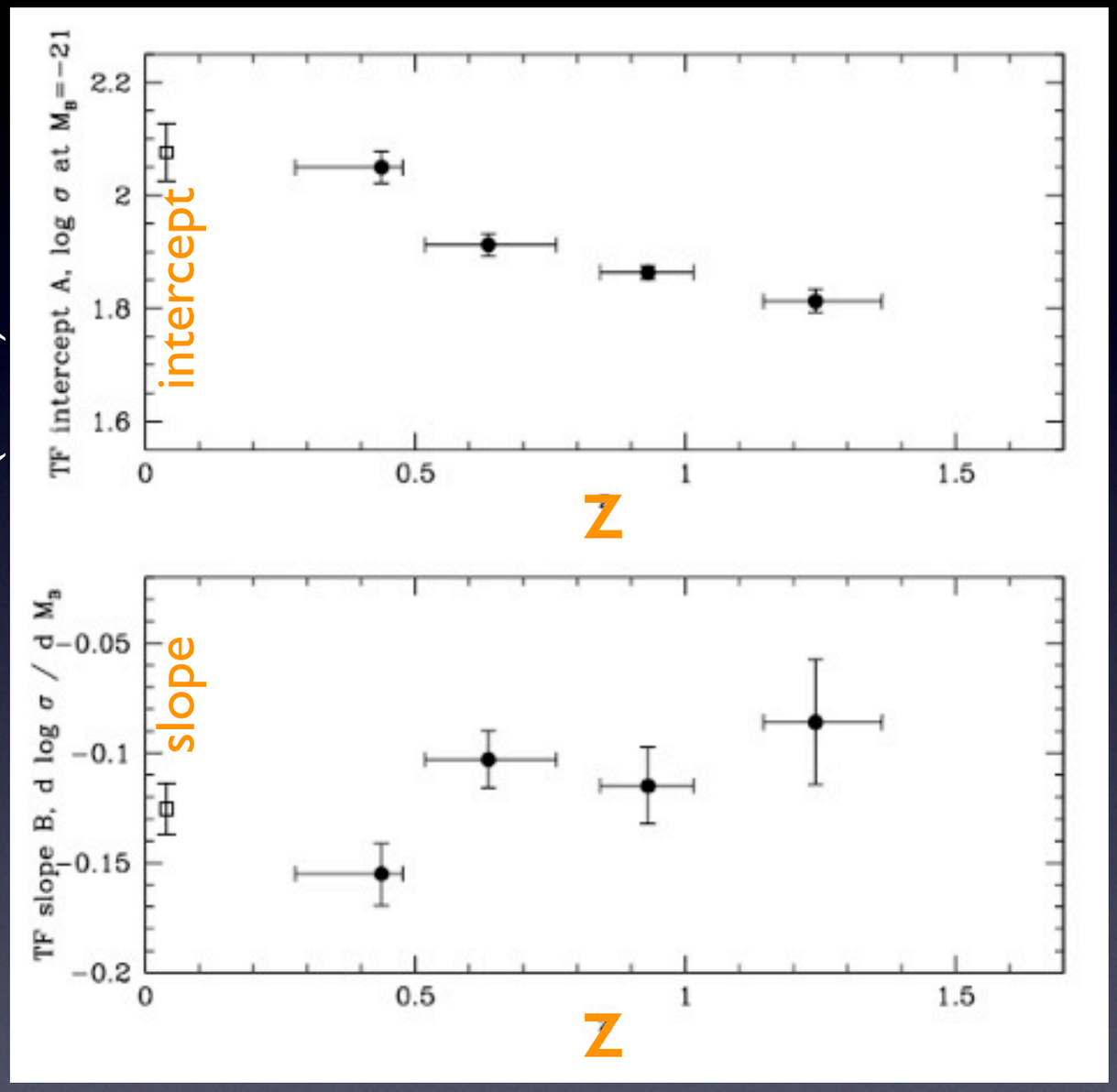
GASS: Catinella, Schiminovich, Kauffmann (2010)







Baryonic Tully-Fisher 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 the lower redshifts to accomplish this (*in addition* to detections at high z)
  - i.e. we need **wideband** frequency coverage

LADUMA Science Questions

Key:

- How does the (baryonic) Tully-Fisher relation evolve with redshift?
- How does the HI mass function (HIMF) vary with redshift and environment?
- How does the cosmic HI density (Ω_{HI}) evolve with redshift?
- How do galaxies' HI masses depend on their stellar and/or host halo masses, environment, and redshifts?

Bonus Science:

- A galaxy merger rate from OH masers.
- A closer look at any specific high-z galaxy population of interest.

Need spectroscopic redshifts + multiwavelength data

The LADUMA survey

The MeerKAT TAC recommended 5000 hours on a single pointing:

Extended Chandra Deep Field - South (ECDF-S)

- well situated for good *uv* coverage (dec. -27°).
- wealth of Multi-λ data (X-ray / UV / optical / mid/far IR).
- ~4000 spectroscopic redshifts already available.

- Observing strategy will depend heavily on MeerKAT bandwidth rollout (still under discussion).

Commensality with other MeerKAT projects:

- Share observation time with MIGHTEE (deep continuum project).
- Data-spigot for ThunderKAT (and other transient surveys).

Ancillary Data Requirements:

- Large spectroscopic redshift survey for HI line stacking.
- Deep optical/infrared images for pre-selection and morphologies.

MeerKAT Concept Design Review

- Critical Review of feasibility of MeerKAT (2010).
- Focus on sensitivity (dish design in same direction as SKA).

MeerKAT Roll-out Phases

	2011	**2016**	**2018**
	Precursor (KAT-7)	MeerKAT Phase 1	MeerKAT Phase 2 & 3
Number of dishes	7	64	64
Receiver bands (GHz)	0.9 - 1.6	1.00 - 1.75	0.58 - 1.015 1.00 - 1.75 8 - 14.5
Max processed BW (GHz)	0.256	0.75	2 (goal 4)
Max baseline (km)	0.2	8	20
Min baseline (m)	20	29	29

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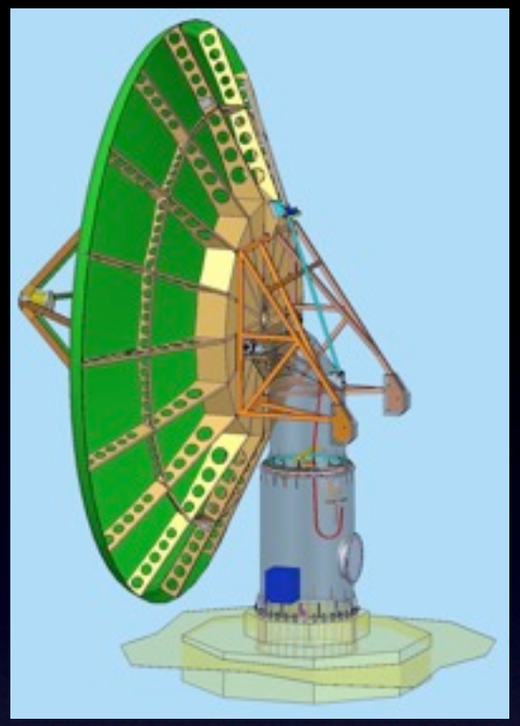


MeerKAT

- 80+7 dishes
- 12 m.
- Prime focus
- “spur” for high spatial resolution.

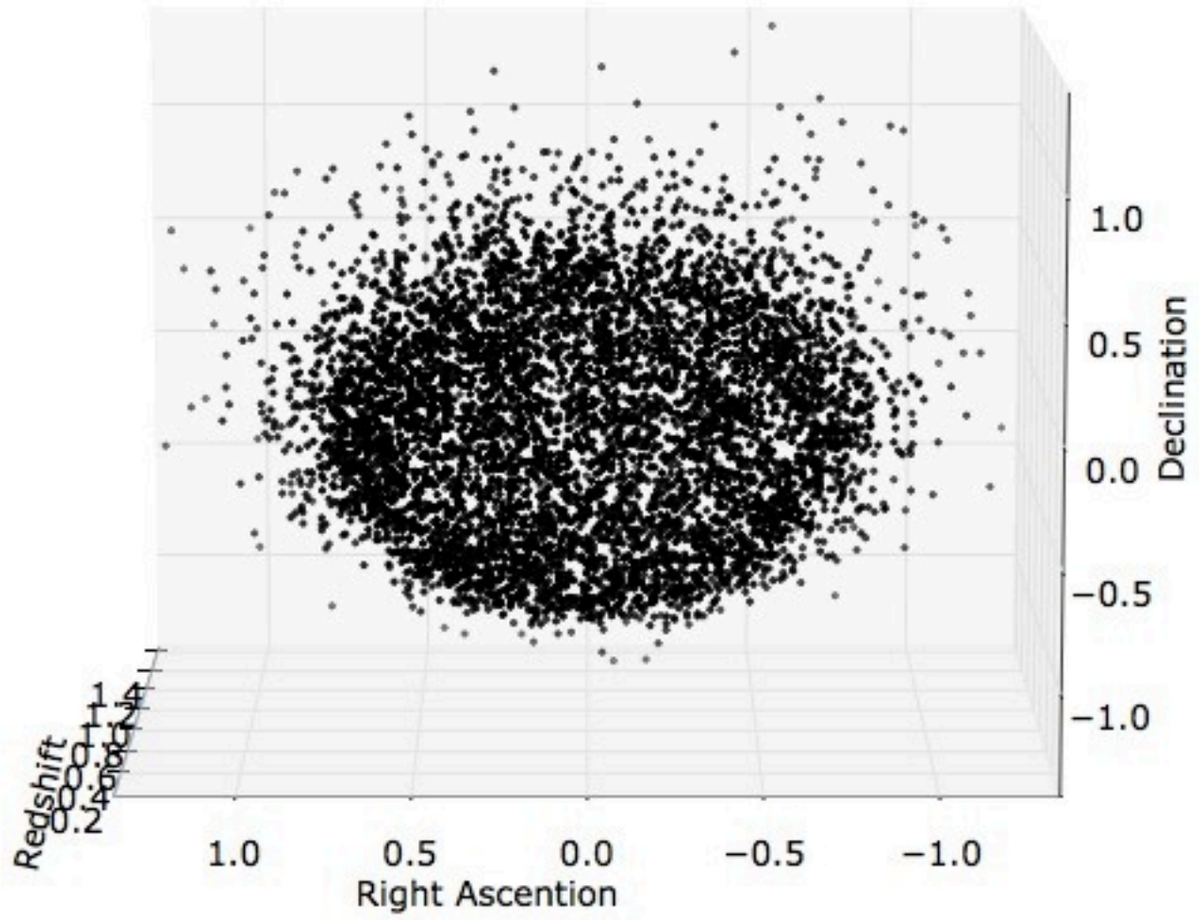
- 64 dishes
- 13.5 m.
- Off-axis Gregorian
- Dense core with most dishes close.

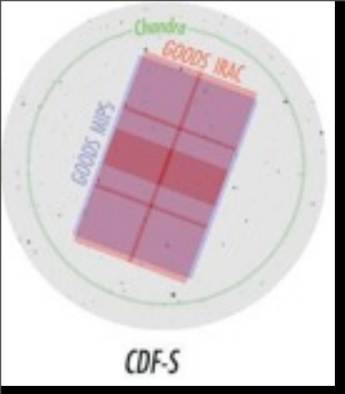
Expected Numbers

Redshift Range (z)	Integration Time hours	Direct detections (5σ)	Direct detections (4σ)
<0.4	1000	2218	2986
0.4-0.58	5000	1974	2769
0.58-1.44	4000	1725	3021

Yes lots...big volume but direct detections diminish with redshift and not the only science driver.

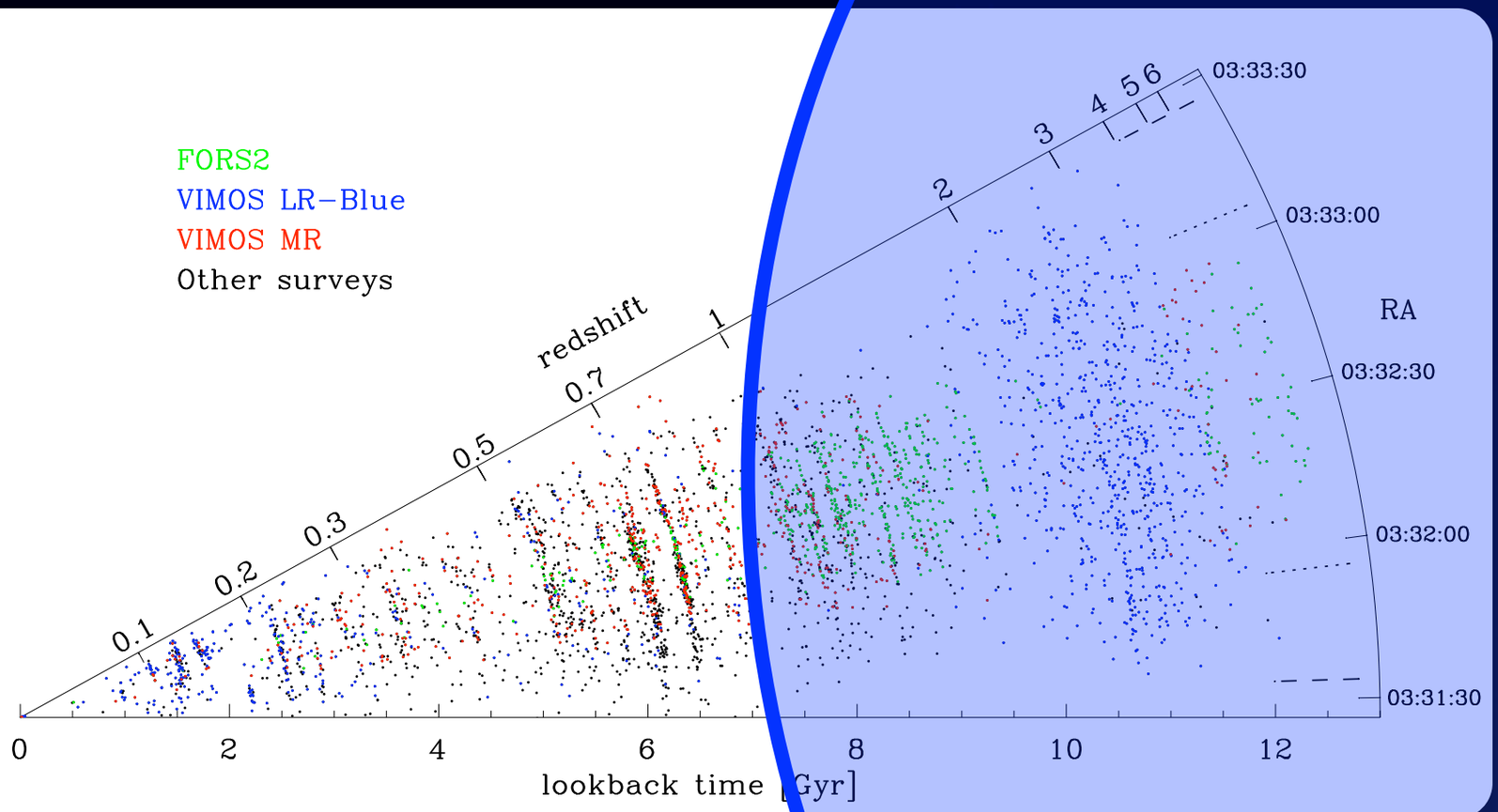
The Vuvuzela

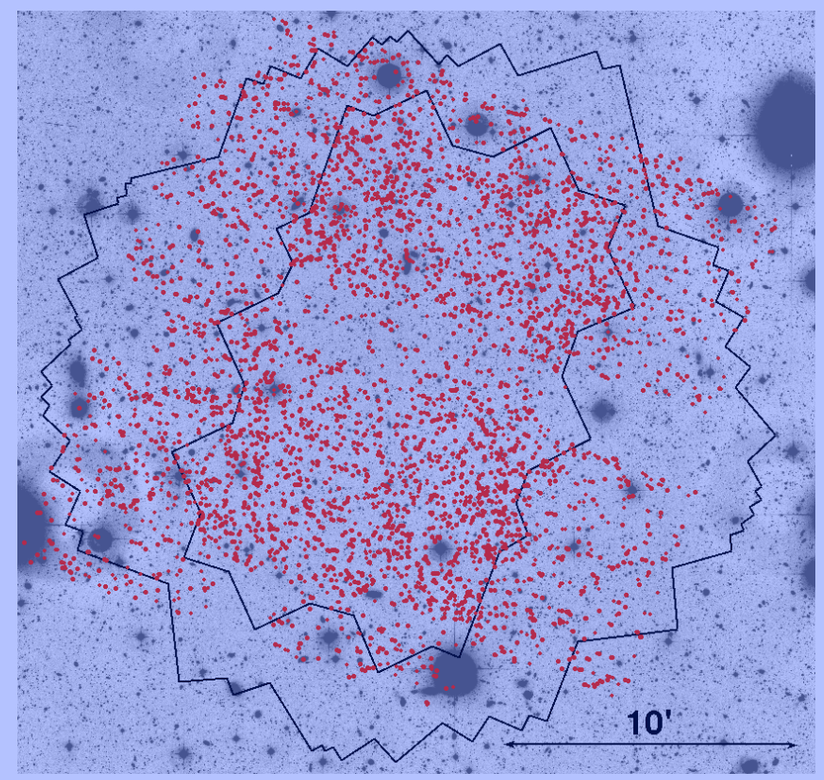




VLT coverage

MeerKAT FOV at z~1.4





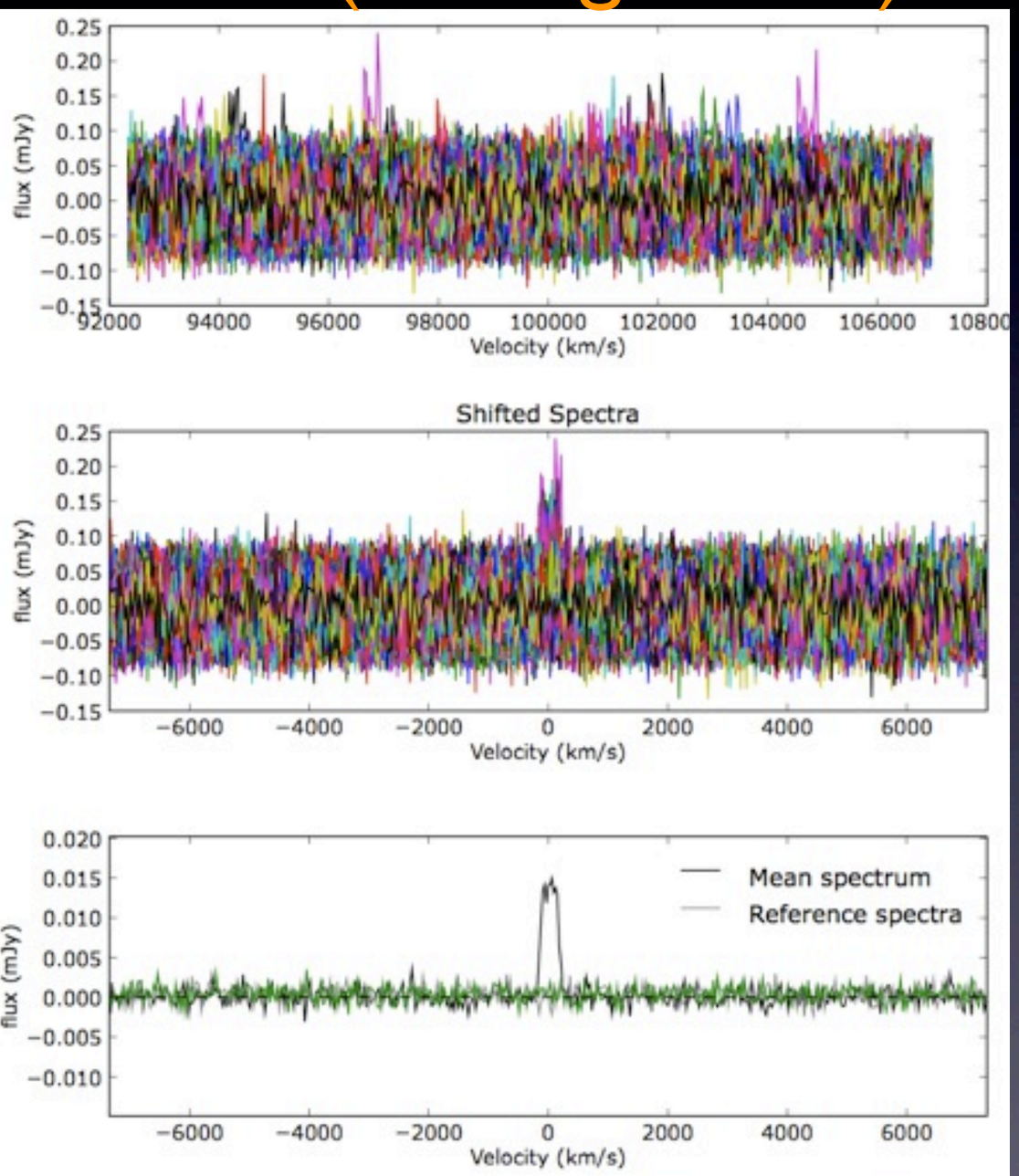
Blind HI Survey

Multi-Wavelength

Balestra et al. 2010 A&A 512, A12

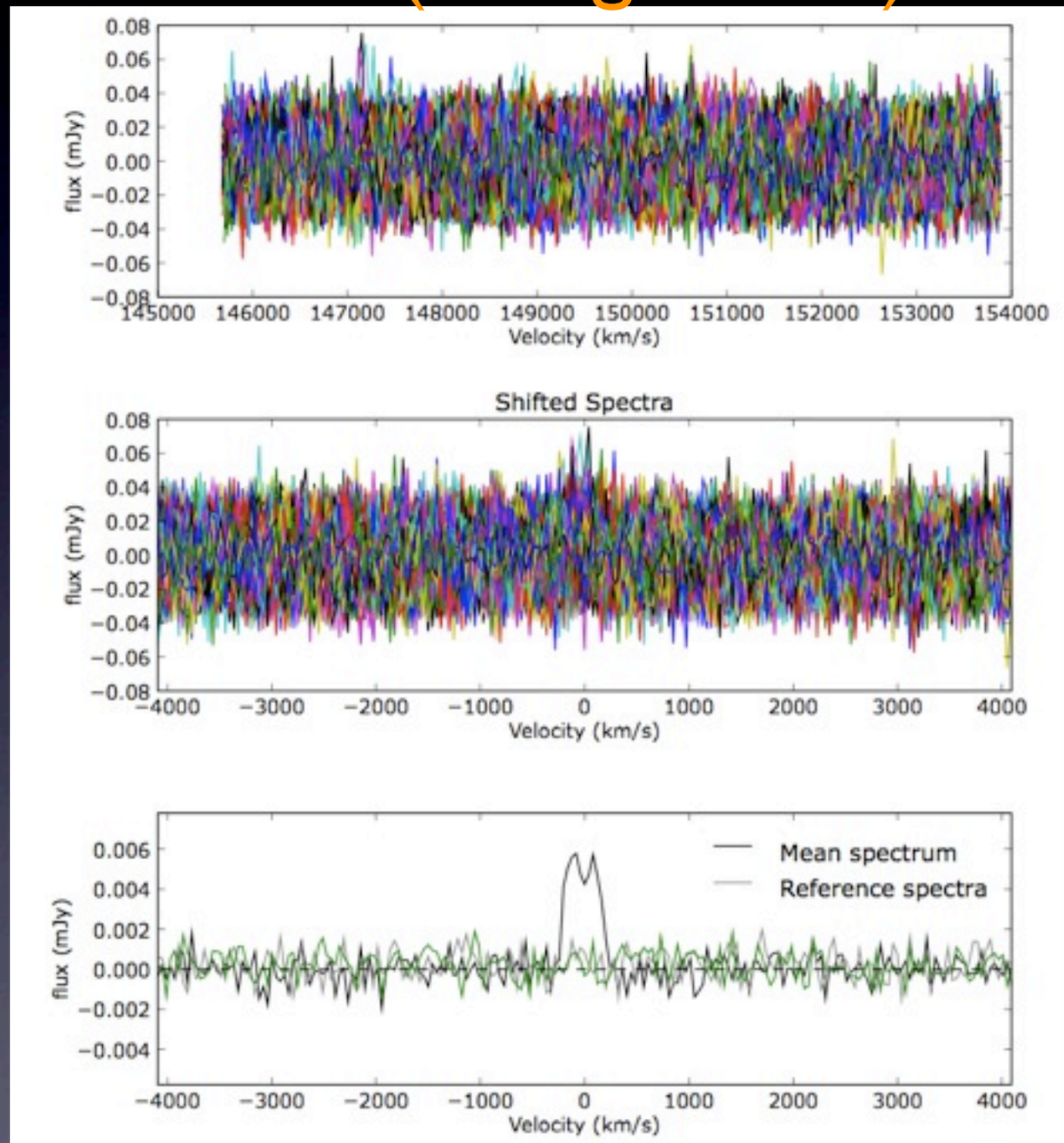
HI Line Stacking

z=0.5 (1000 galaxies)



1000 hours, σ = 0.0286 mJy, Δv = 30 km/s

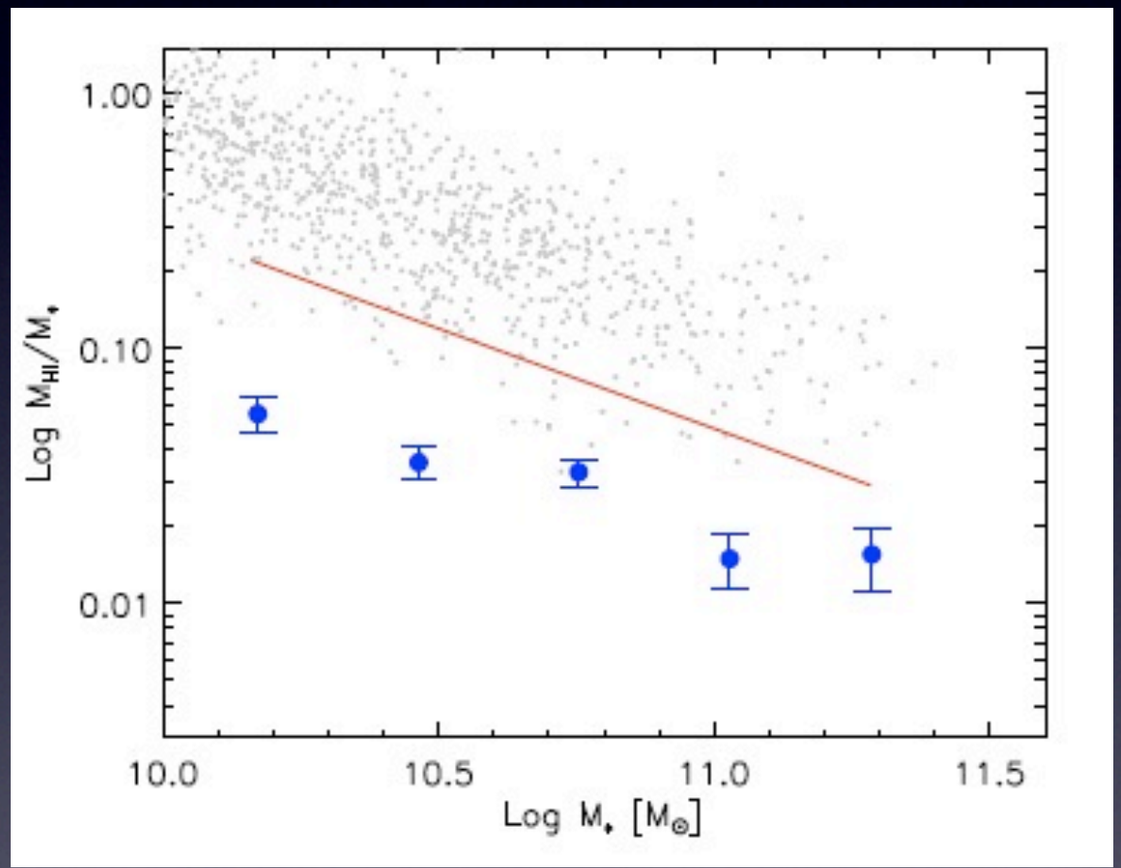
z=1.0 (500 galaxies)



4000 hours, σ = 0.0143 mJy, Δv = 40 km/s

Recent applications of stacking at low z

- Stacking has enabled investigation of subsets of ALFALFA galaxies based on e.g. type



- Bulge-dominated galaxies have a lower HI gas fraction at a given stellar mass than the average (Fabello et al. 2010)

Ancillary Data

The LADUMA team has submitted 3 survey proposals (2 spectroscopic, 1 imaging) so far...

- NOAO proposal for deep U-band imaging over 2 deg^2.
- SALT commissioning proposal of 20 hours (8 x 30min exposures) on GOODS-S.
  - Also verification of RS Spectrograph and MOS mode on subsample of VLT spectra
  - Follow-up early science proposal (cycle-1) being worked out as well.
- Submitted LoI for ESO Public Spectroscopic Survey
  - 752 hours on VLT/VIMOS to get 18 800 spectra over 2 deg^2 on ECDF-S
  - currently exploring commensal VLT/VIMOS surveys of this field.
- *Possibility to use AAT for lower redshift spectroscopy (details to be confirmed).*

Take-Home

- Single deep stare to detect HI; a blind HI and multi-wavelength survey.
- Line stacking and direct detections.
- Science:
  - How does the (baryonic) **Tully-Fisher** relation evolve with redshift?
  - How does the **HI mass function** (HIMF) vary with redshift and environment?
  - How does the **cosmic HI density** (Ω_{HI}) evolve with redshift?
  - How do **galaxies' HI masses** depend on their stellar and/or host halo masses, environment, and redshifts?
- Data will be public! Legacy HI cube till SKA fires up.

Thank you!

- www.ska.ac.za
- www.ska.ac.za/meerkat
- http://www.ast.uct.ac.za/LADUMA/