Extragalactic HI Surveys with the Arecibo L-band Feed Array

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Panoramic Radio Astronomy
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Extragalactic ALFA Surveys

- Arecibo Legacy Fast ALFA (ALFALFA) Team leaders: Giovanelli, Haynes (Cornell)
- Arecibo Galaxy Environments Survey (AGES) Team leader: Davies (Cardiff)
- ALFA Ultra-Deep Survey (AUDS) Team leader: Freudling (ESO)
- Zone of Avoidance Survey (ALFA ZOA) Team leader: Henning (UNM)

ALFALFA

Team: 82 names, see ALFALFA website!

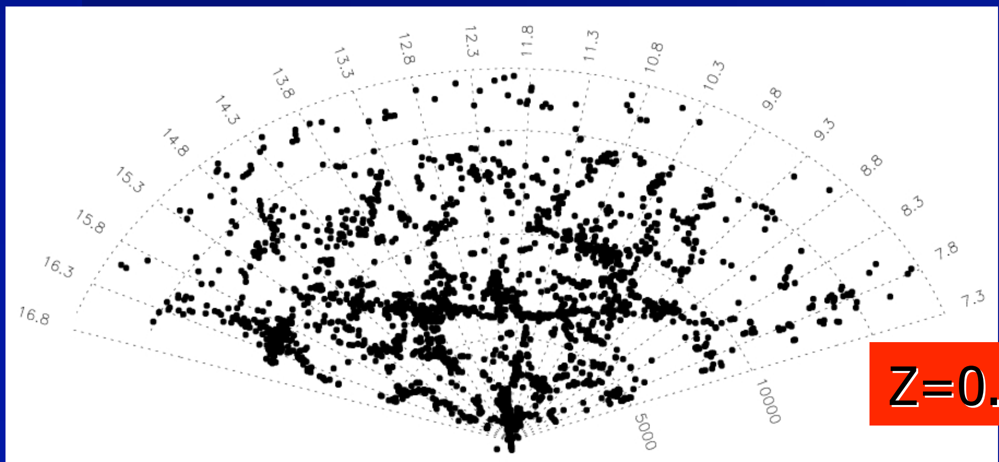
- Arecibo Legacy Fast ALFA Survey
  - 7000 deg^2 high-galactic latitude Arecibo sky
  - ~2.2 mJy per 3.5 arcmin beam, at 10 km/s velocity resolution
  - 100 MHz BW, -1600 – 18,000 km/s
  - ~30,000 expected detections in ~5 years, to z=0.06, hundreds of objects to HI mass to 10^8

ALFALFA science goals

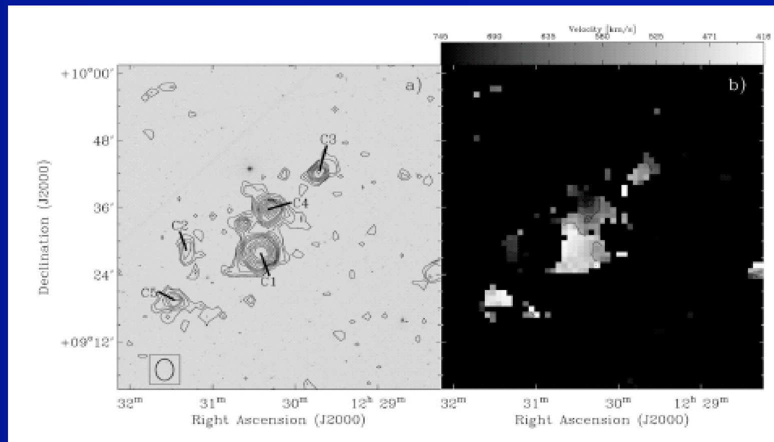
- A legacy survey: HI in the Nearby Universe
- The HI Mass Function and the "Missing Satellite Problem"
- Galaxy evolution and dynamics within local large scale structures
- Extent and origin of HI disks
- Nature of High Velocity Clouds
- Blind survey for HI absorbers $z < 0.06$
- Blind survey for OH megamasers $0.16 < z < 0.25$
- Comparison with other surveys

- Catalogs of selected regions published, more appearing
- An interim result: no cosmologically important pop of dark, HI sources (clouds in Virgo likely remnants of interactions)

2700 HI sources plotted with 7.5% of survey, much more has been done



Z=0.05



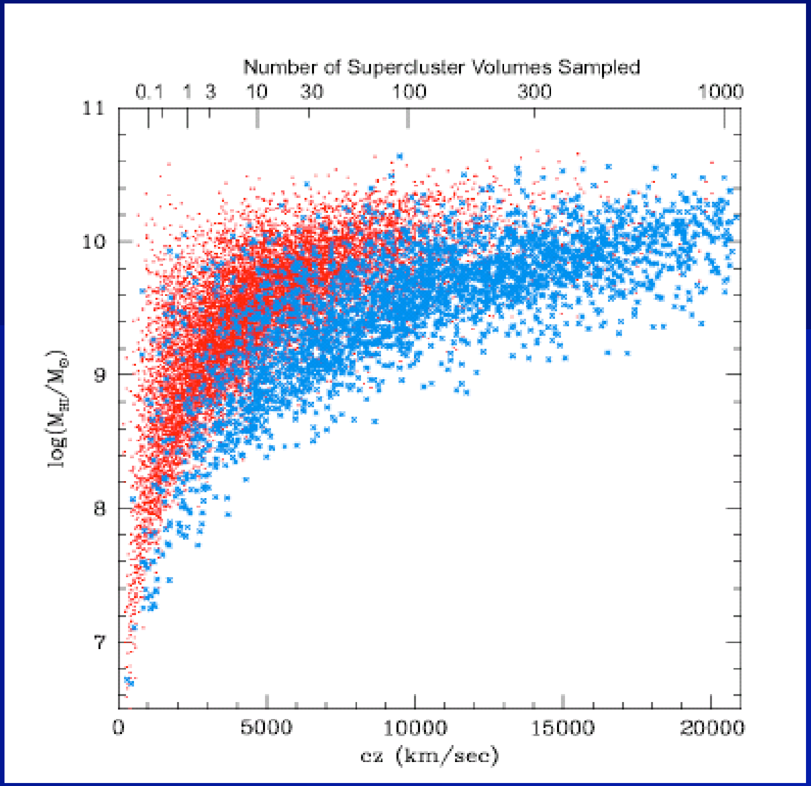
Kent et al. 2009

Arecibo Galaxies Environment Survey

Davies, Auld, Baes, Bothun, Boselli, Brinks, Brosch
Catinella, Cortese, de Blok, Disney, Gavazzi, Giovanelli, Haynes,
Henning, Hoffman, Irwin, Karachentsev, Kilborn, Linder,
Minchin, Momjian, Muller, O'Neil, Putman, Rosenberg,
Sabatini, Schneider, Scott, Spekkens, Taylor, van Driel

- Study HI properties in different environments to lower mass limits than ALFALFA (5 x 10^6 M_{Sun} at Virgo vs. 2 x 10^7 M_{Sun}), low N_{HI} (3 x 10^{18} cm^{-2})
- HIMF in various environments
- Spatial distribution of HI-selected objects
- Low mass, low N_{HI} objects, and low- N_{HI} extent of large objects
- HVCs
- Omega(HI)
- Signatures of mergers and interactions (tidal features), relation to galaxy formation simulations

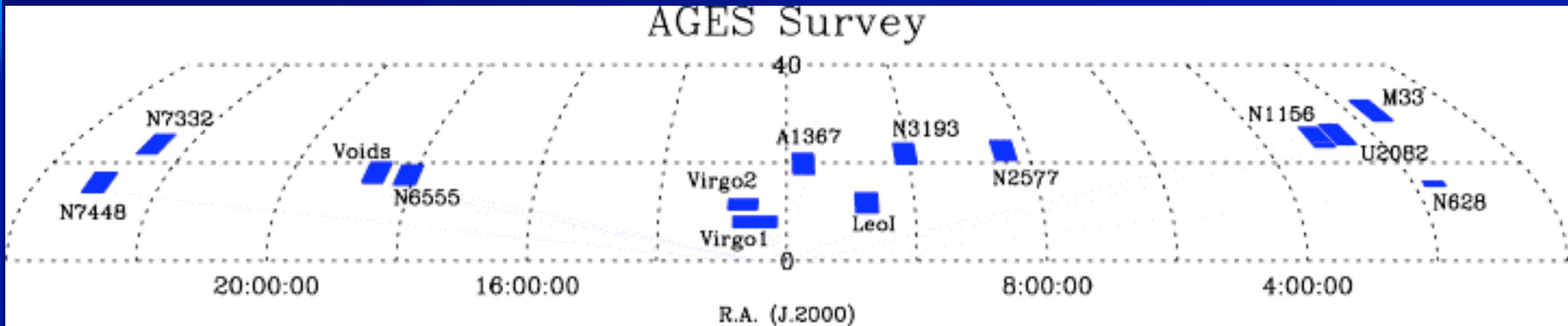
- Simulation showing two surveys, equal total time, surveys roughly same relative integration times of ALFALFA (red), and AGES (blue)
- Shallower detects more sources, deeper detects lower mass sources at all distances
- Top shows # of distinct volumes sampled as fcn of z
- ALFALFA excellent probe of high-mass end of HIMF, but deeper surveys critical for low-mass end of HIMF in environments beyond Local Supercluster



Schneider et al. 2008

AGES cont.

- 200 deg^2 total on 13 selected areas (Virgo, groups, individual gals, filaments, Local Void, also background volumes)

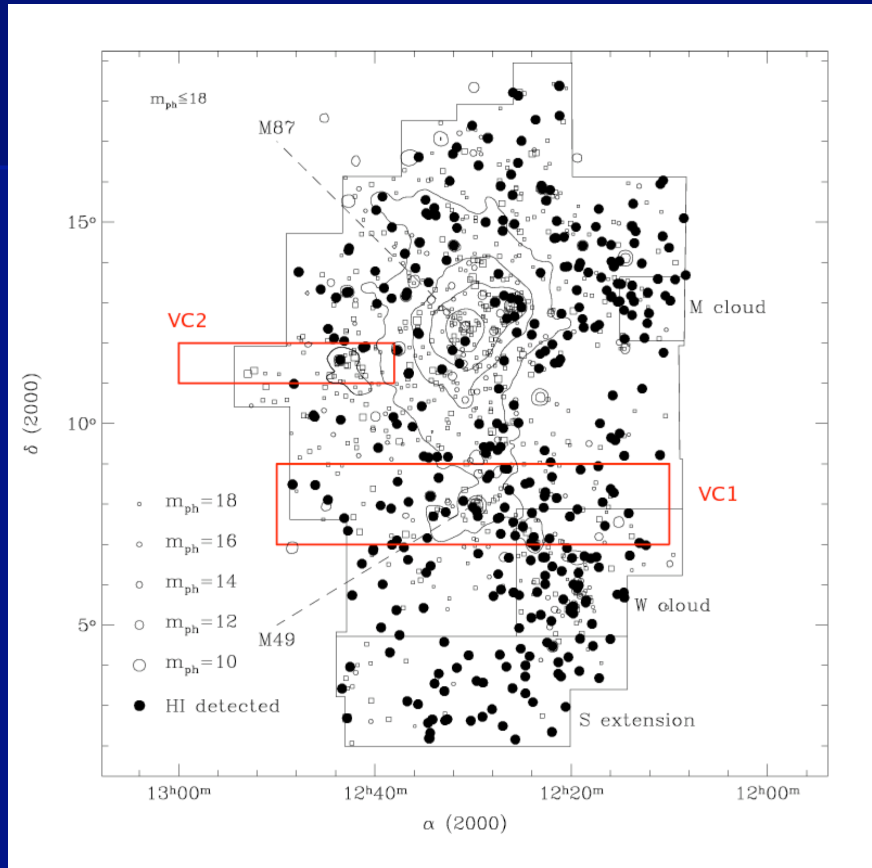


Auld et al. 2006

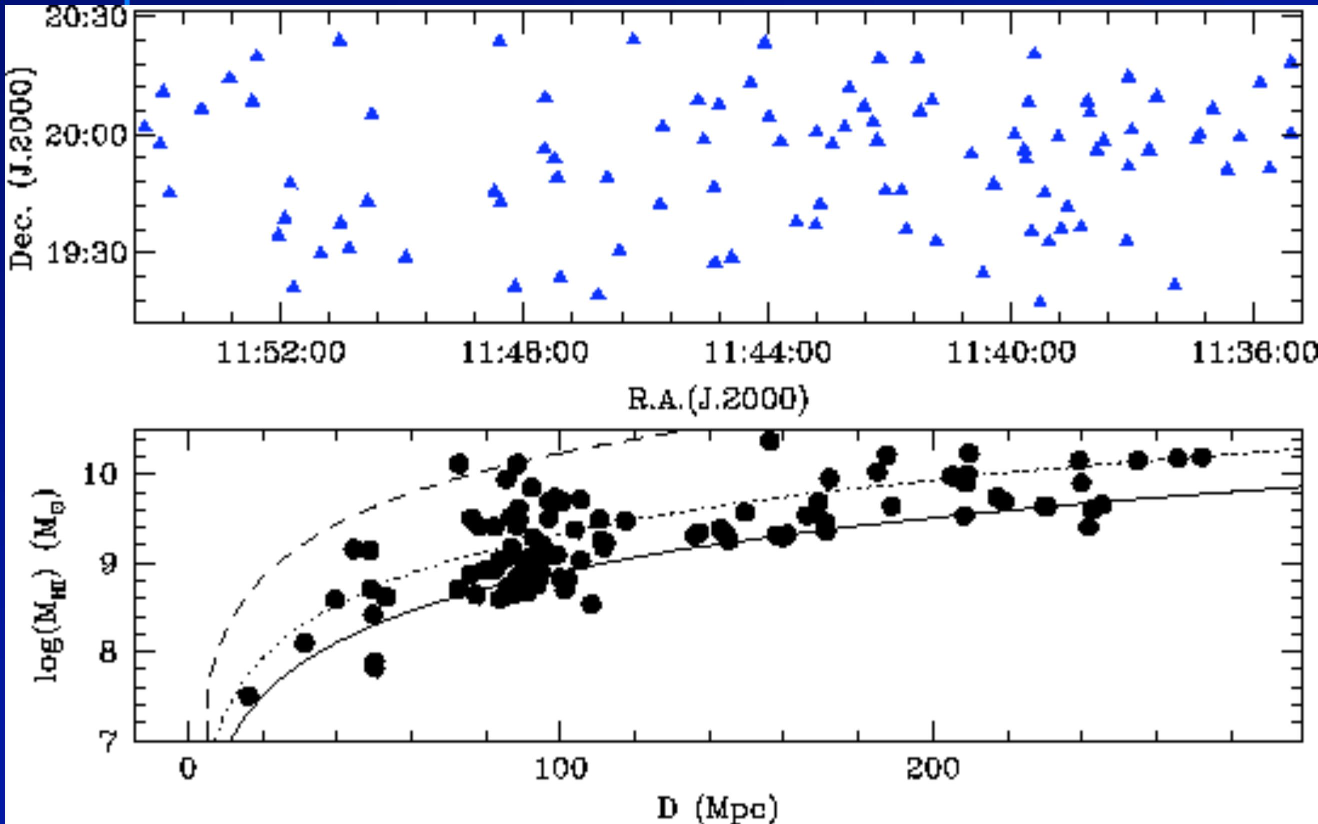
- ~0.8 mJy per 3.5 arcmin beam (300 vs. 40 sec per beam), at 10 km/s velocity resolution
- Finds low-mass galaxies to larger distances, (eg. 5 x 10^6 M_{Sun} at Virgo, 5 x 10^7 out to 3 times this distance) but not as large-angle survey

AGES Virgo fields

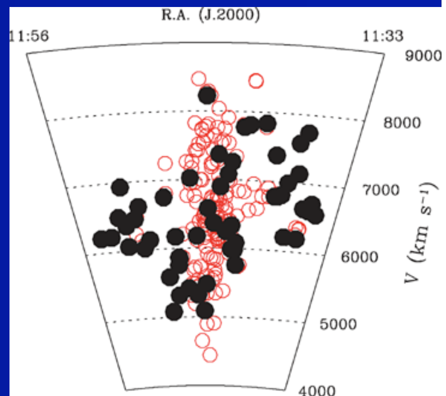
Rhys Taylor



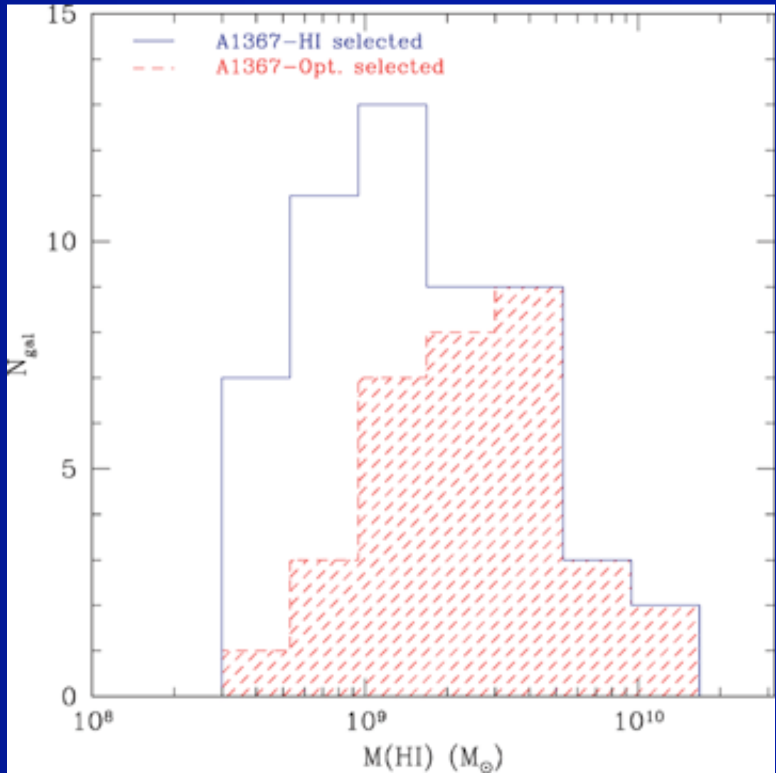
- A1367 and outskirts, 5^o x 1^o strip
- 100 HI detections (Cortese et al. 2008). Solid line detection limit S/N=6.5, W=200 km/s, dotted line same for ALFALFA, dashed HIPASS



HI does not show rich cluster
red is SDSS
g < 17 mag
($L_g > 2 \times 10^9 L_{Sun}$)



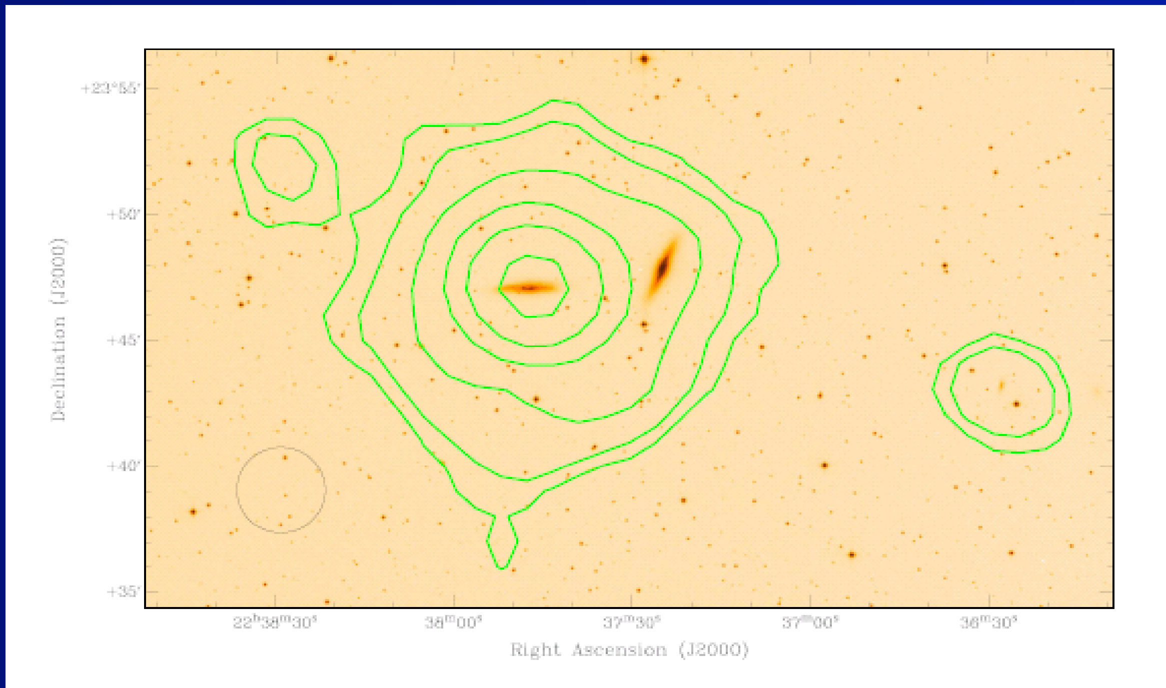
- Of 100 HI sources
  - 79 new HI measurements
  - 55 confirmed optical counterparts (redshift match)
  - Others have optical candidates (no redshift), only 4 with no optical, 3 in interacting groups
  - Optically-selected galaxies with HI measurements tend to be higher HI mass than HI-selected – do not include low-luminosity, low SB, gas-rich objects. Explains shallower faint end of optically-selected HIMF?



Optically-selected
= SDSS DR5, g <17 mag

- NGC 7332/7339 pair. HI belongs to NGC 7339, some distortion in direction of NGC 7332
- 2 previously uncataloged dwarfs, have optical counterparts

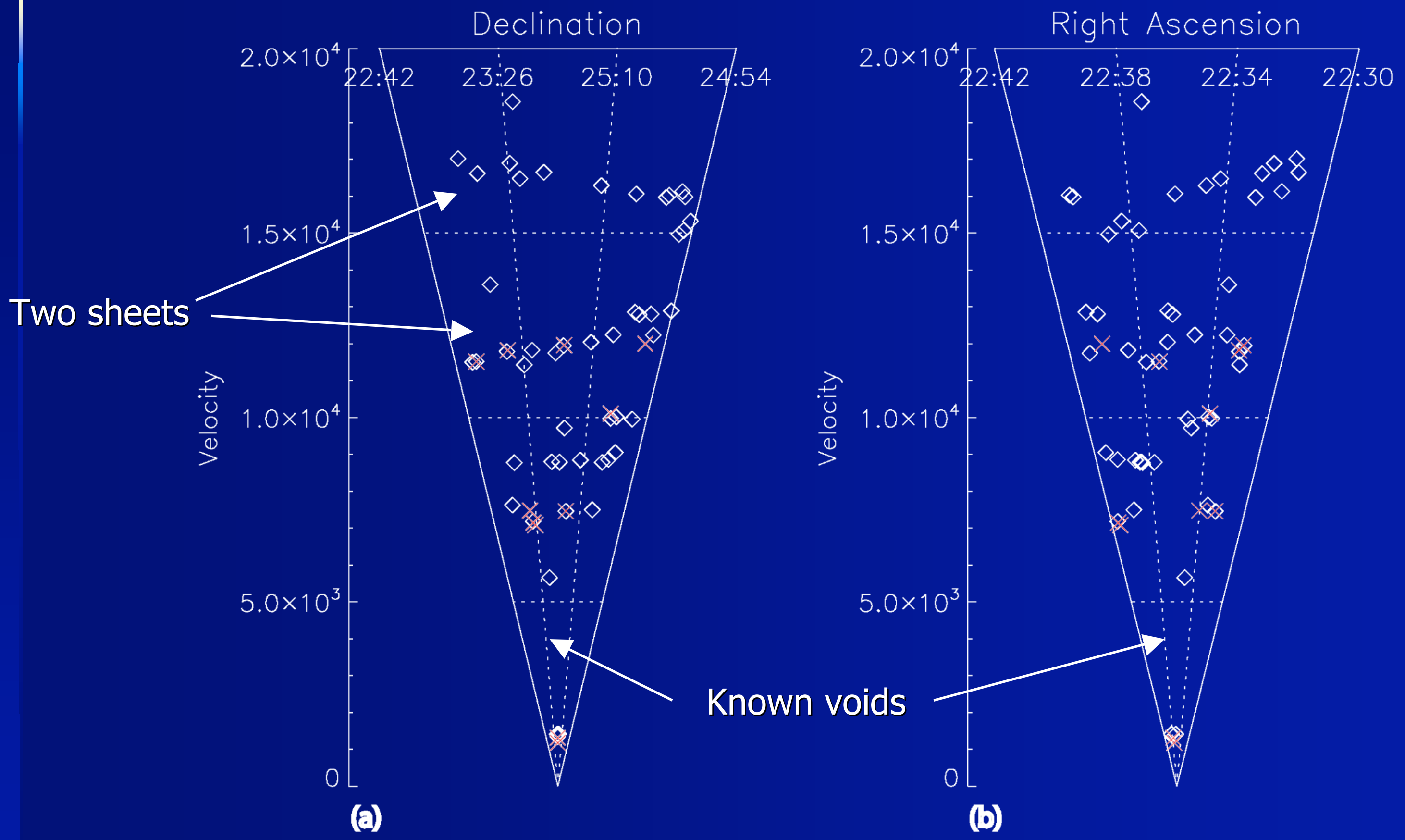
M_{HI} 5 x 10^7
M_{HI}/L_g 2.0+-0.2



Minchin et al.

M_{HI} 7 x 10^7
M_{HI}/L_g 0.13+-0.01

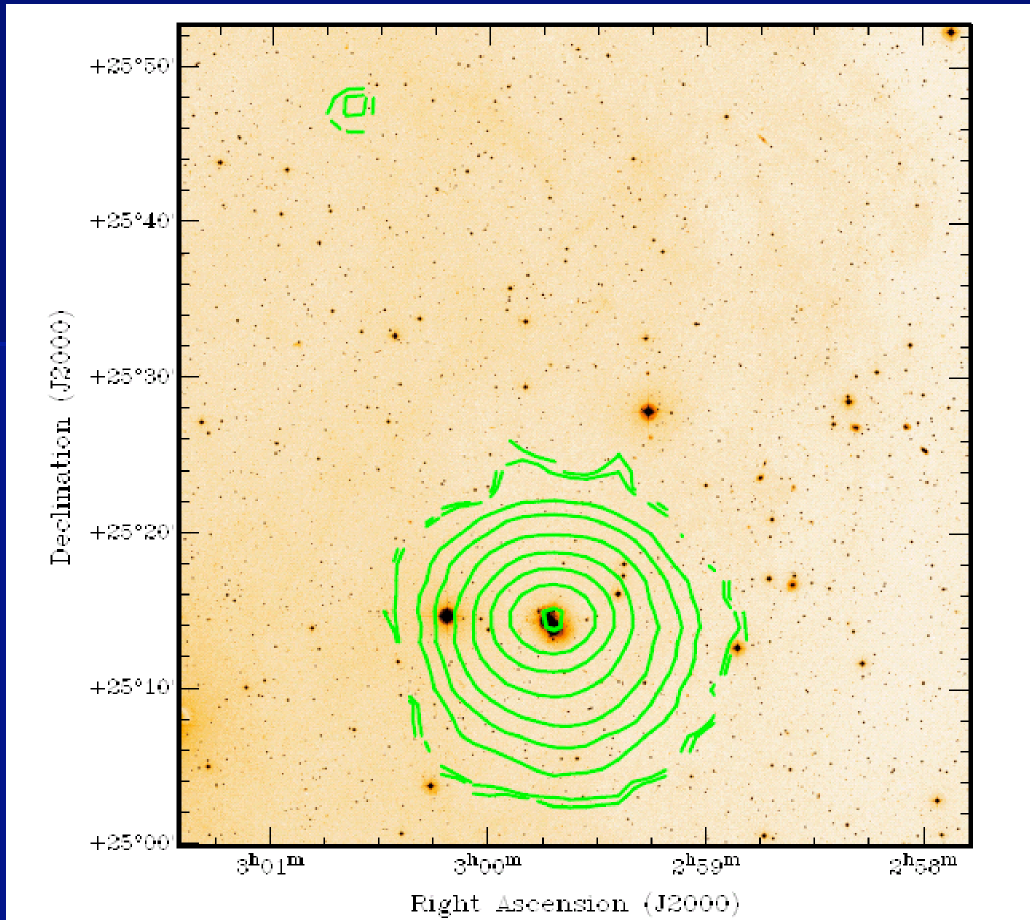
- 46 background galaxies (all with optical counterparts), 17 NED, 6 previously-known redshifts



Minchin et al.

- NGC 1156
- D=7.8 Mpc (Karachentsev et al.), very isolated, no cataloged companion within 10 deg
- AGES: M_{HI} = 1 x 10^9 M_{Sun}, and dwarf 25 arcmin away, counterpart on DSS
- 37 HI galaxies in volume behind NGC 1156, all with possible optical counterparts

Minchin et al.



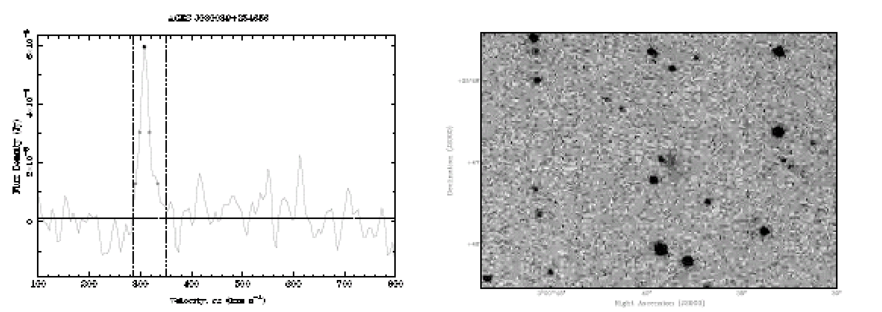
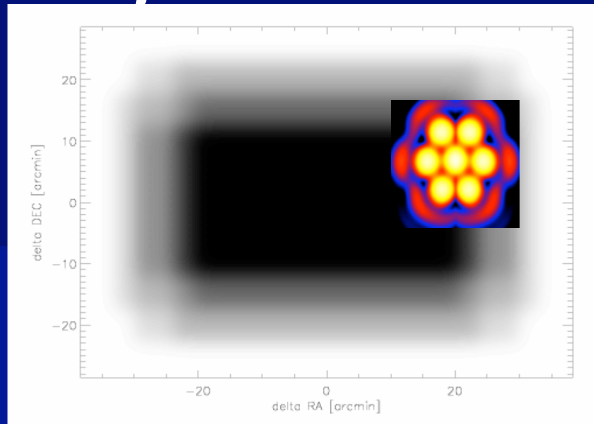


Fig. 11.— H I spectrum (left) and Super-COSMOS scanned POSS II B_J-band image (right) of AGES J030039+254656.

The Alfa Ultra-Deep Survey AUDS

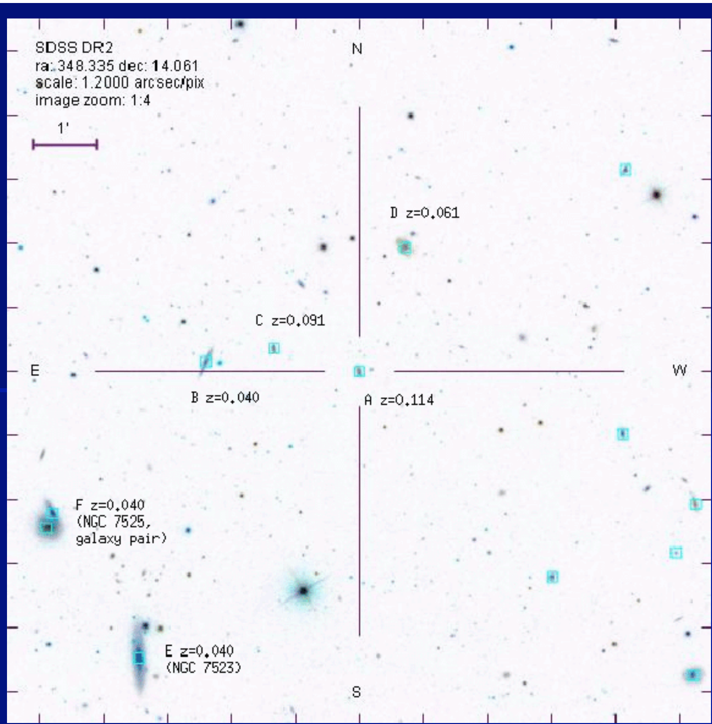
Freudling, Brinks, Brosch, Catinella, Conselice, Davies, de Blok, Kilborn, Linder, Masters, Meyer, Minchin, Momjian, O'Neil, Pisano, Quinn, Rosenberg, Spekkens, Staveley-Smith, van Driel, Zwaan



- 0.36 square degrees
- 2 fields, 1 within AGES NGC 2577 survey, 1 random at ra=17, dec=20
- "drift & chase": repeated drift scans
- 200 MHz => 0 < z < 0.16
- sensitivity 50 μJy corresponds to a few $10^8 M_\odot$
- 980 hours of observing time awarded
- precursor program of 60 hours demonstrated feasibility
- observations on field 1 started Nov 11, 2008
- End of March 2009: 70 observing sessions, more than 1100 scans of field 1
- Data processing at ICRAR, Australia, in progress
- Preliminary analysis suggests better s/n than in precursor observations

AUDS Precursor Results

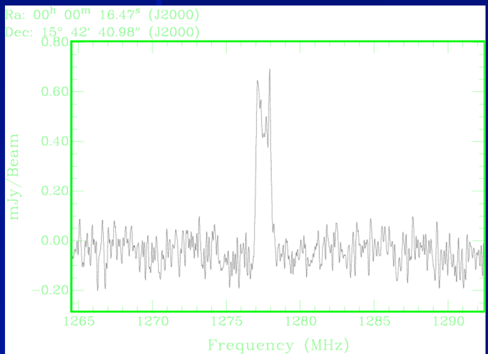
target field



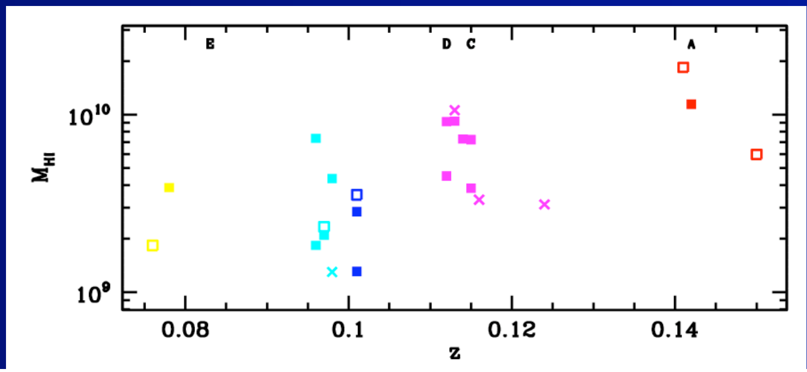
follow-up

60 hrs GMRT

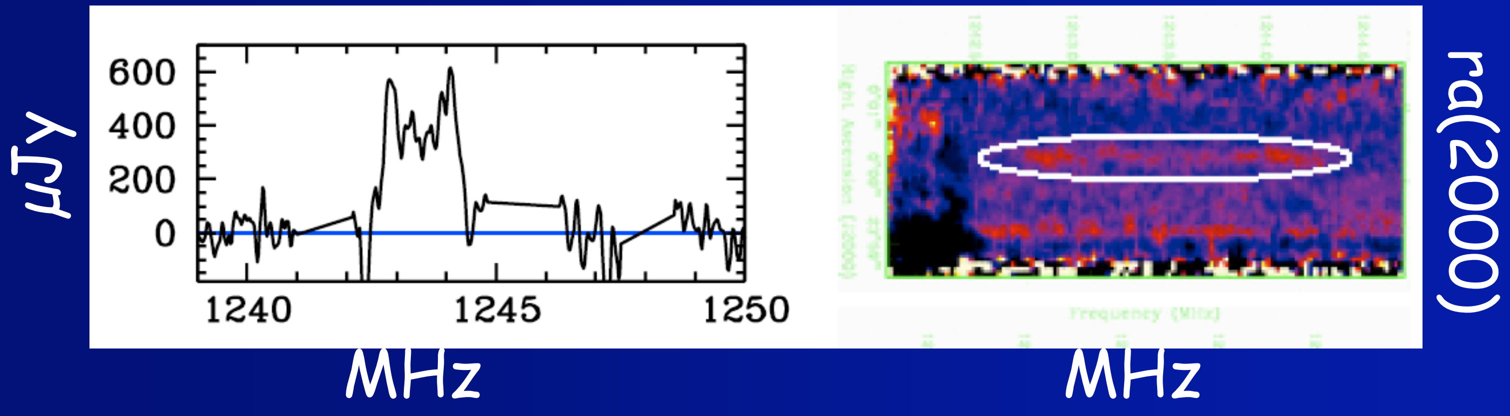
110 hours WSRT



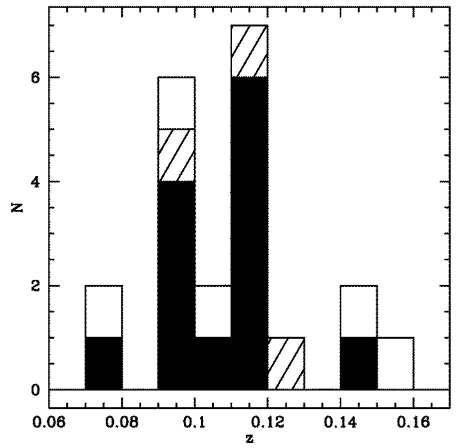
In precursor field: 13 certain AO detections, 21 including "possibles"

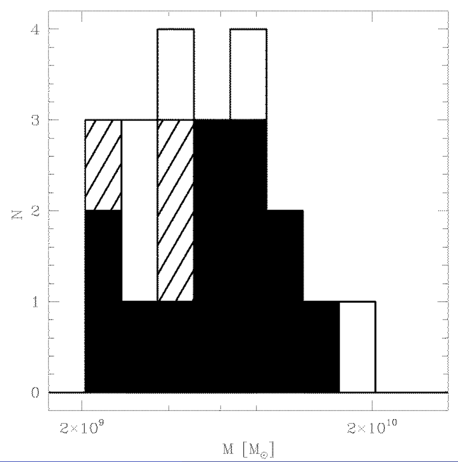


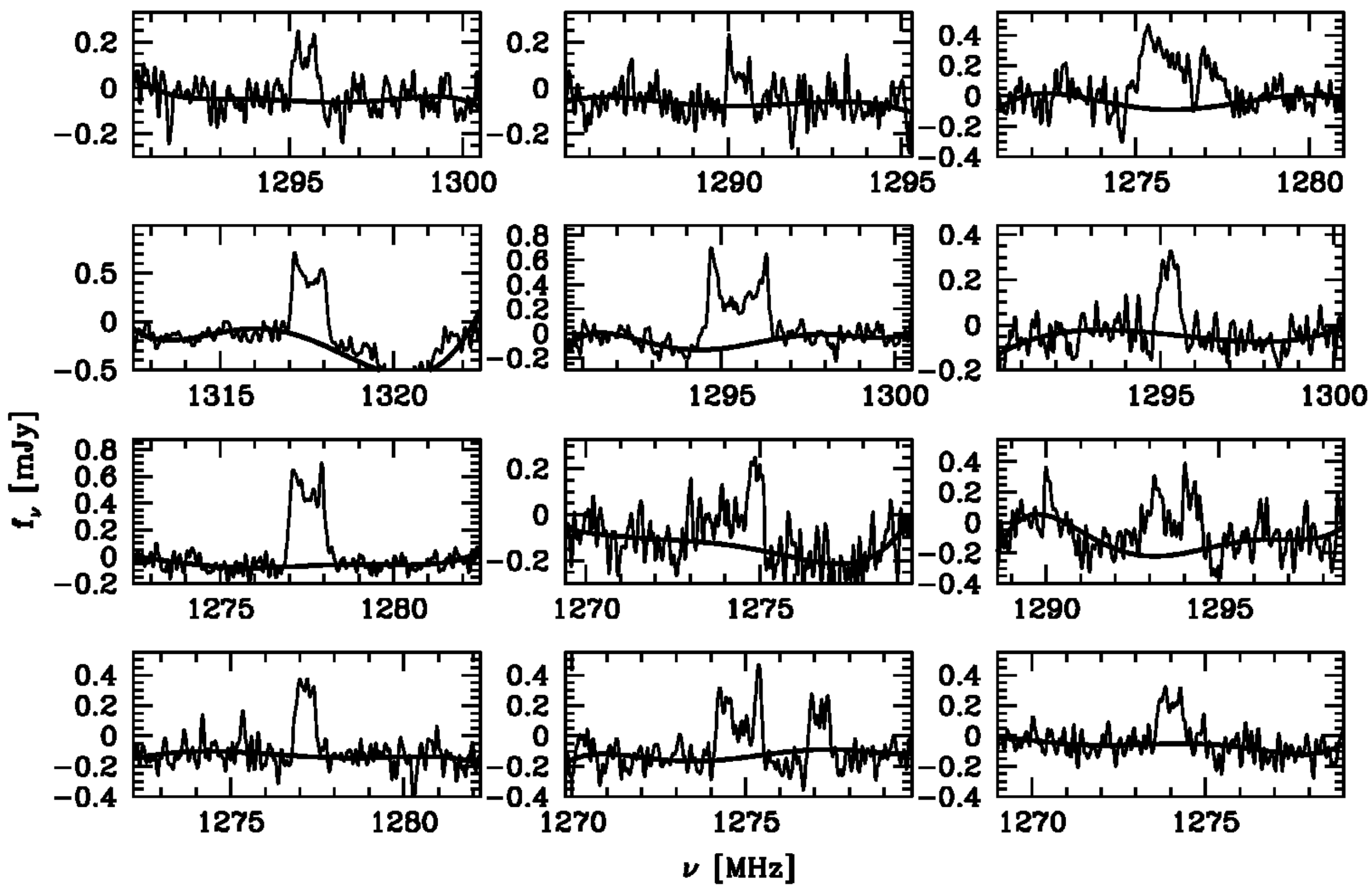
Precursor detected highest redshift 21 cm HI detection in blind survey, z=0.155



Detected Galaxies in AUDS Precursor Survey

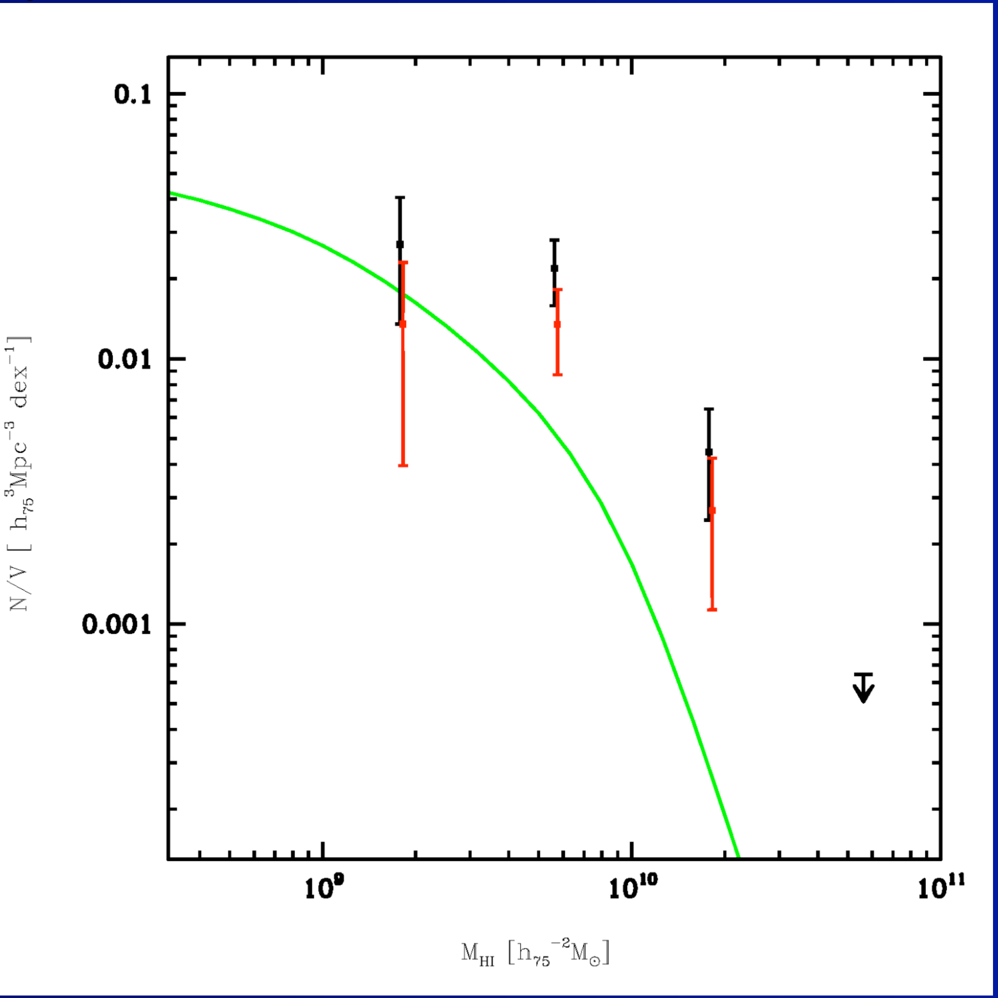






Solid=certain, hashed=prob, open=doubtful

Precursor observations detected more galaxies than expected



Green line: local HI mass function.

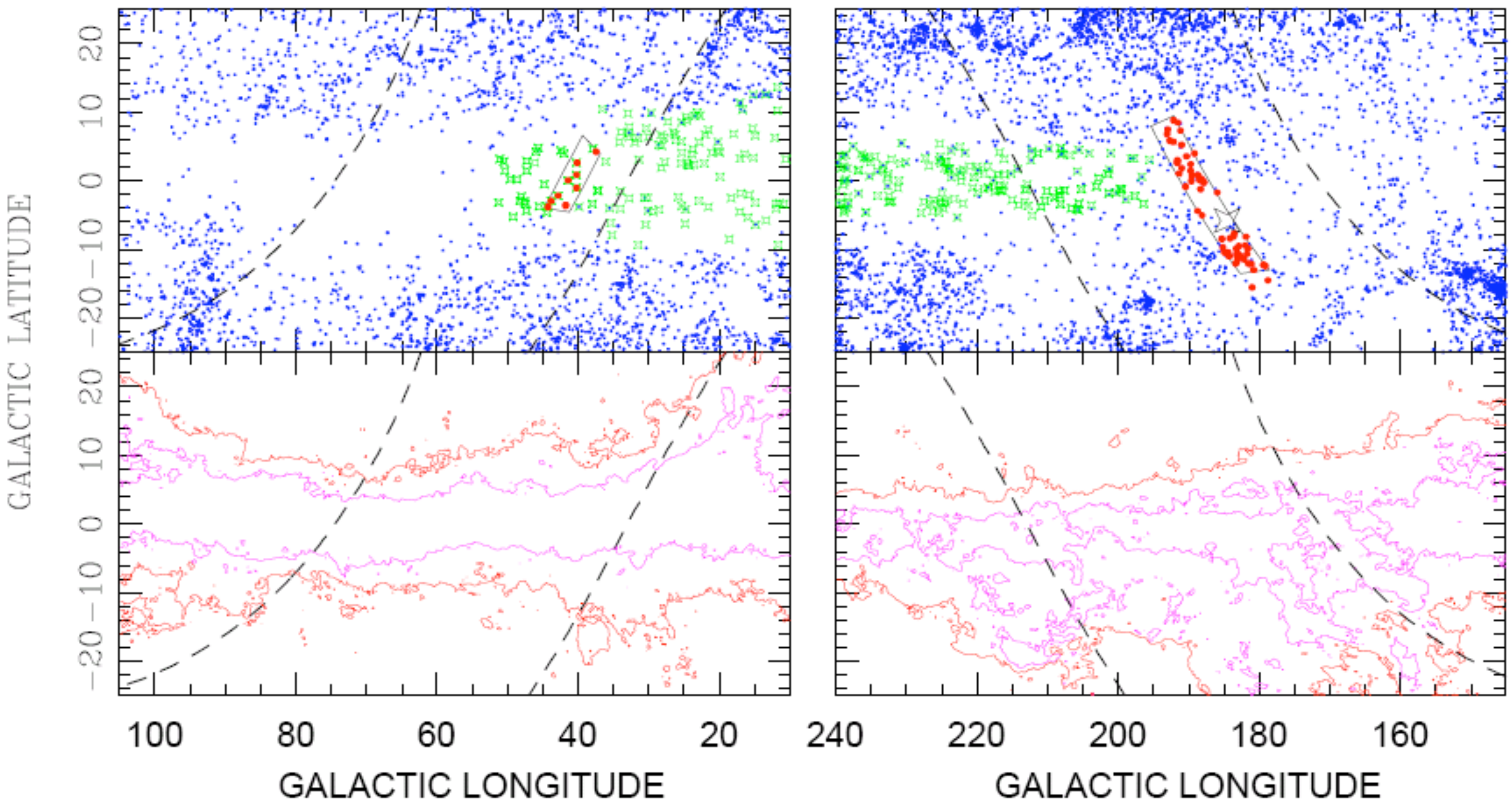
Error bars: two determinations (assumed W dist'n 1/Vmax)

of HI mass function from precursor observations.

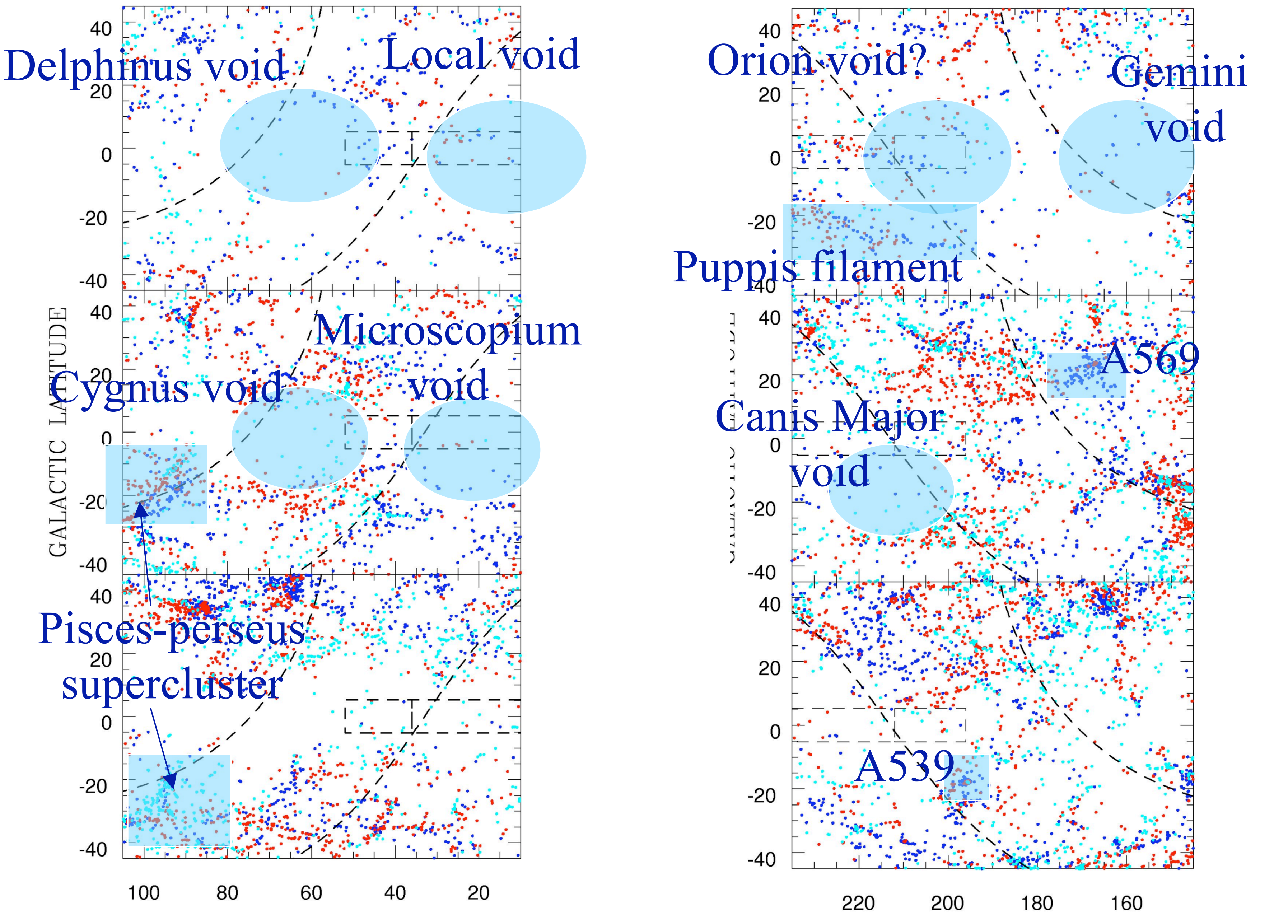
The ALFA ZOA survey

Henning, McIntyre, Day, Springob, Minchin, Momjian, Catinella,
Muller, Koribalski, Masters, Pantoja, Putman,
Rosenberg, Schneider, Staveley-Smith, van Driel

– Map obscured galaxies, large-scale structures at low Galactic latitude over AO-accessible sky
– Provide redshifts for partially-obscured galaxies, particularly 2MASS for all-sky flow fields
– "Commensal" with both Galactic ALFA (shallow; 5 mJy basketweave, 100 MHz), Pulsar ALFA (deep; ~1 mJy point and dwell, 200 MHz)
– Deep survey will have ~sensitivity of AGES over ~2-4 times sky area, HIMF study over "fairer" volume



Precursor: 38 deg^2 near l=40, 100 deg^2 near l=190
Inner Galaxy: 10 galaxies detected, only 1 has a cataloged counterpart in any other waveband (IR)
Outer Galaxy: 62 galaxies detected, 49 have counterparts
25 previous redshifts



Delphinus void
Local void
Microscopium void
Cygnus void
Pisces-perseus supercluster
Orion void?
Gemini void
Puppis filament
A569
Canis Major void
A539
GALACTIC LATITUDE
40
20
0
-20
-40
100
80
60
40
20
220
200
180
160

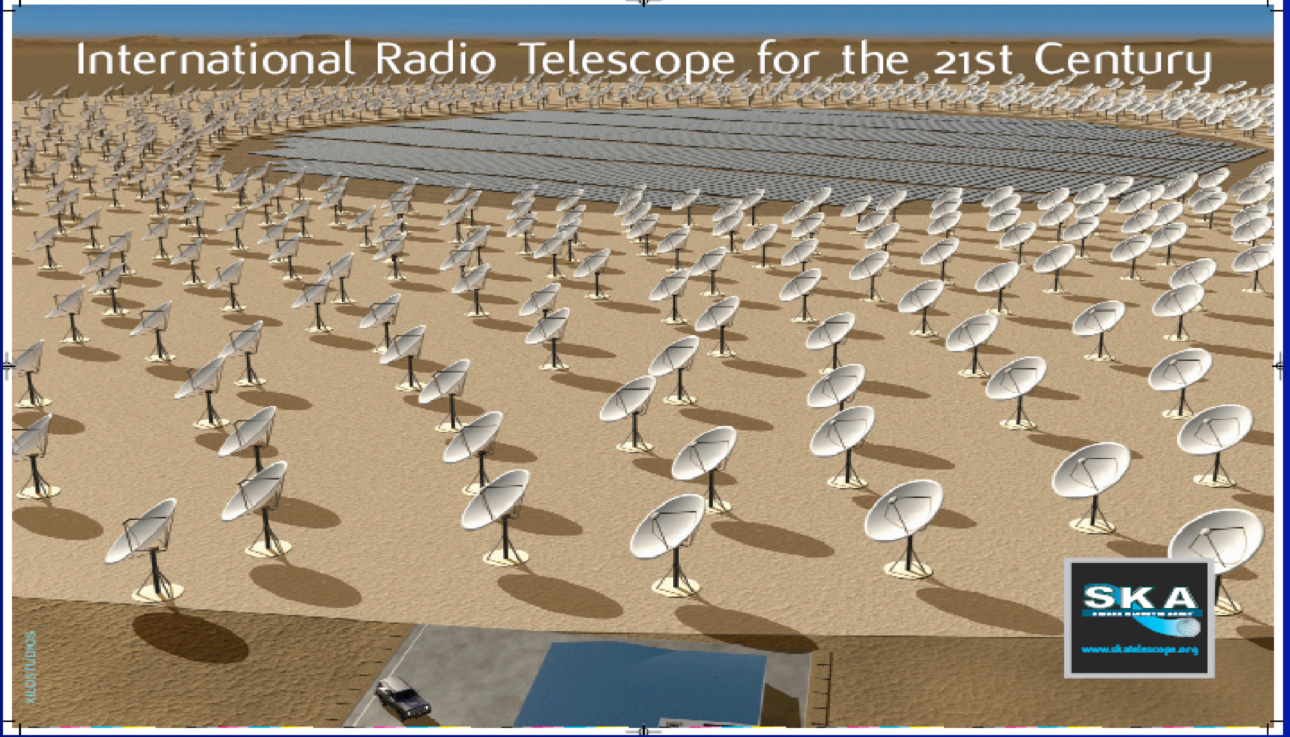
The point

- These current generation ALFA surveys will yield samples of several x 10^4 HI galaxies, measure local HIMF very well, and as function of environment, other low-z HI science
- Lay groundwork for higher z surveys, test commensal observing modes

extra

Square Kilometer Array

- Existing and near-term facilities will push to intermediate z, do pathfinding science work for ultimate deep, hi-res SKA surveys
- HI at cosmological distances original driver toward ~1 km^2
- Key Science Project for the full SKA: HI galaxies to z=1.5 and beyond ("billion galaxy survey"), for cosmology, galaxy evolution



- Halo clouds beyond Virgo, discriminate between modes of cold gas accretion, and any HI beyond z=1 requires SKA
- MW to z~1.5 in all-sky survey, to z~2-3 in deep survey
- Angular resolution: eg. 2" corresponds to ~15 kpc at z=2 (60 km baseline at 500 MHz), exquisite detail in local Universe
- Connection to multi-λ: large optical/IR surveys (e.g. LSST) going concerns in the 2010's, time will be ripe for deep HI surveys
- Today, surveys of HI in galaxies in infancy cp to large optical surveys. With SKA, bring HI picture to maturity

Number of galaxies detectable as a function of redshift per square degree

redshift	*lookback time* Gyr	*HI mass limit (M_{sun})* $t = 360$ h	*# detections*	*HI mass limit (M_{sun})* $t = 1000$ h	*# detections*
0.5 – 1.0	5.0 – 7.7	5.0×10^8	1.6×10^6	3.0×10^8	2.4×10^6
1.0 – 1.5	7.7 – 9.3	1.3×10^9	1.8×10^6	7.9×10^8	2.7×10^6
1.5 – 2.0	9.3 – 10.3	2.7×10^9	1.9×10^6	1.6×10^9	2.7×10^6
2.0 – 2.5	10.3 – 11.0	4.8×10^9	1.7×10^6	2.9×10^9	2.5×10^6
2.5 – 3.0	11.0 – 11.5	7.8×10^9	1.6×10^6	4.7×10^9	2.3×10^6
3.0 – 3.5	11.5 – 11.8	1.2×10^{10}	1.4×10^6	7.3×10^9	2.0×10^6
3.5 – 4.0	11.8 – 12.1	1.8×10^{10}	1.2×10^6	1.1×10^{10}	1.8×10^6
4.0 – 4.5	12.1 – 12.3	2.7×10^{10}	1.0×10^6	1.6×10^{10}	1.5×10^6

vd Hulst 2004
with A/T=20,000

Not for circulation

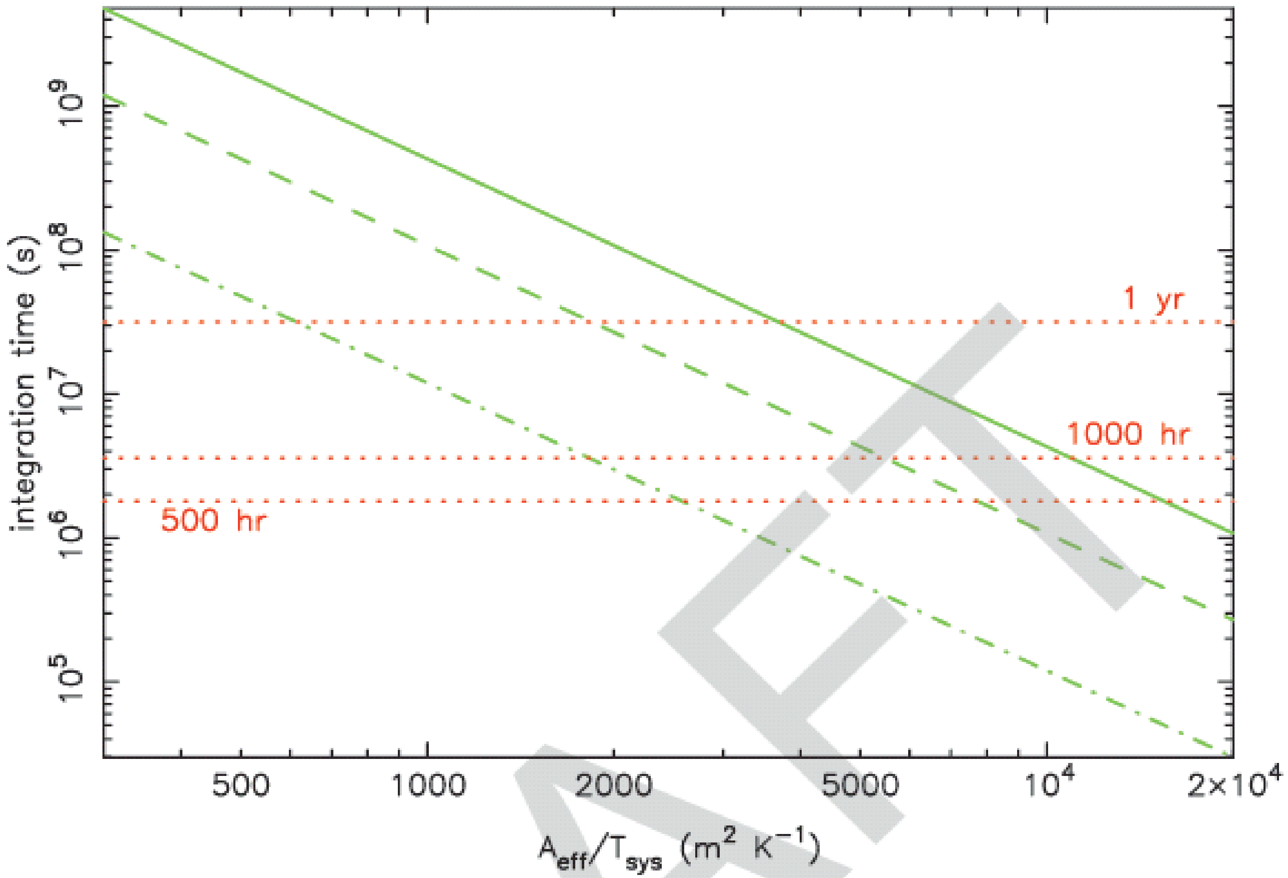


Fig. 1.— Integration time required to detect H I galaxies at redshift $z = 2$ as a function of telescope sensitivity. Three H I masses are shown, $5 \times 10^9\, M_\odot$ (solid), $10^{10}\, M_\odot$ (dashed), and $3 \times 10^{10}\, M_\odot$ (dot-dash). Horizontal dotted lines indicate various fiducial integration times.