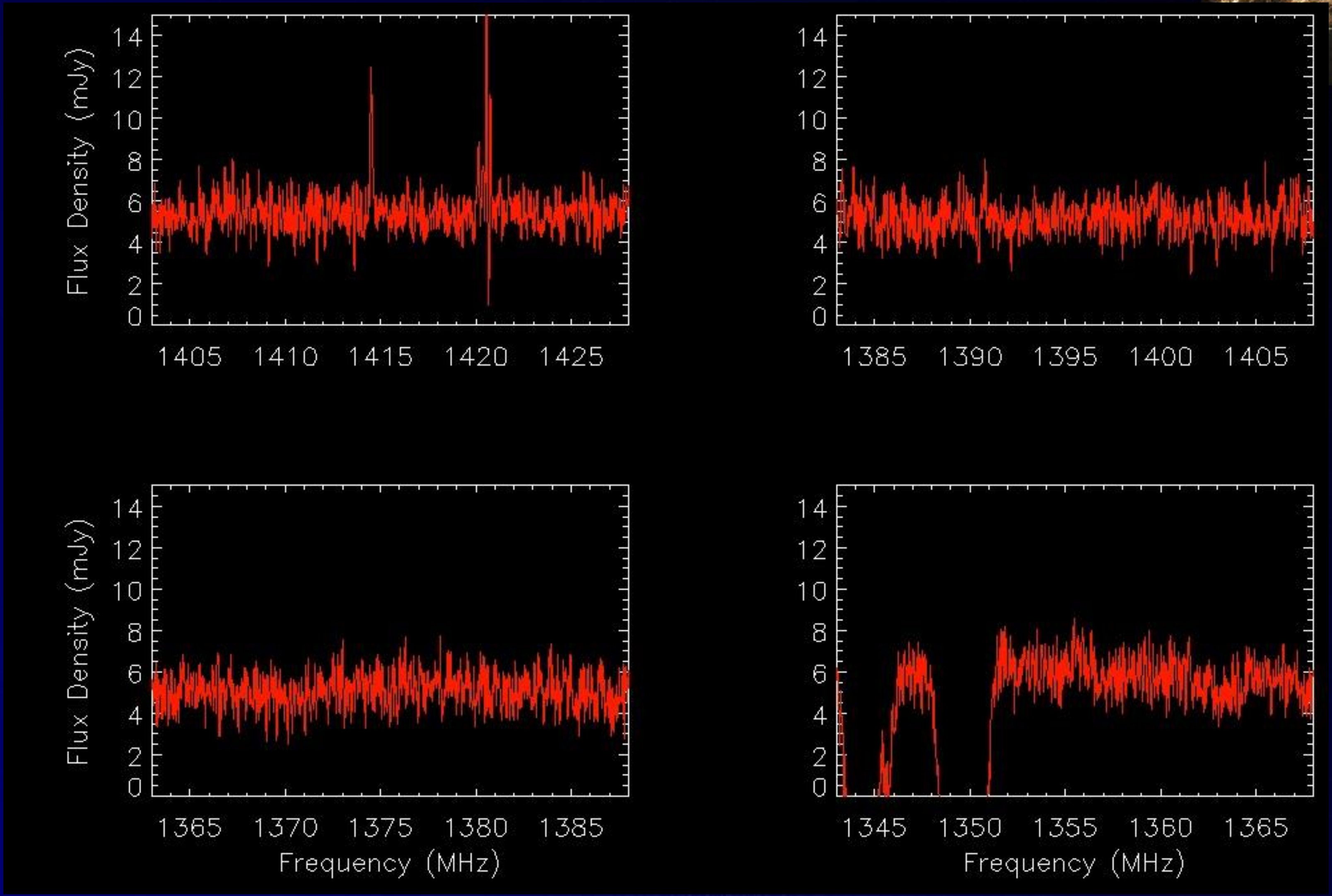
Introduction to LBW for ALFALFA followup



Martha Haynes UAT15 15.01.12

ALFALFA

ALFALFA vs LBW followup

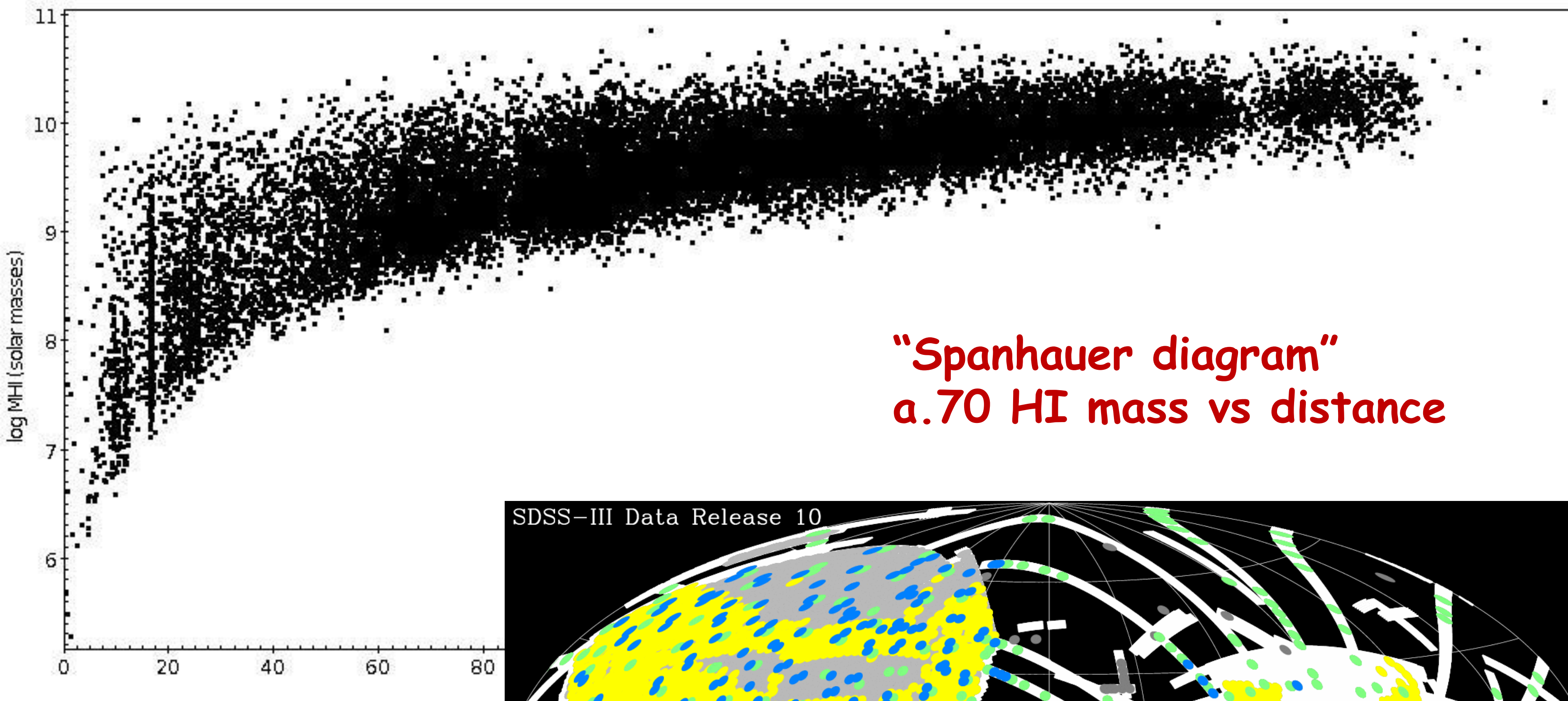
ALFALFA: "Blind HI survey"

- Drift-scan survey: park the dome on the meridian and let the sky drift by; repeat once (time/beam ~ 40 secs)
- Detect HI source regardless of optical appearance
- Identify "most probable" optical counterpart – or lack thereof

LBW followup: "Targeted HI survey"

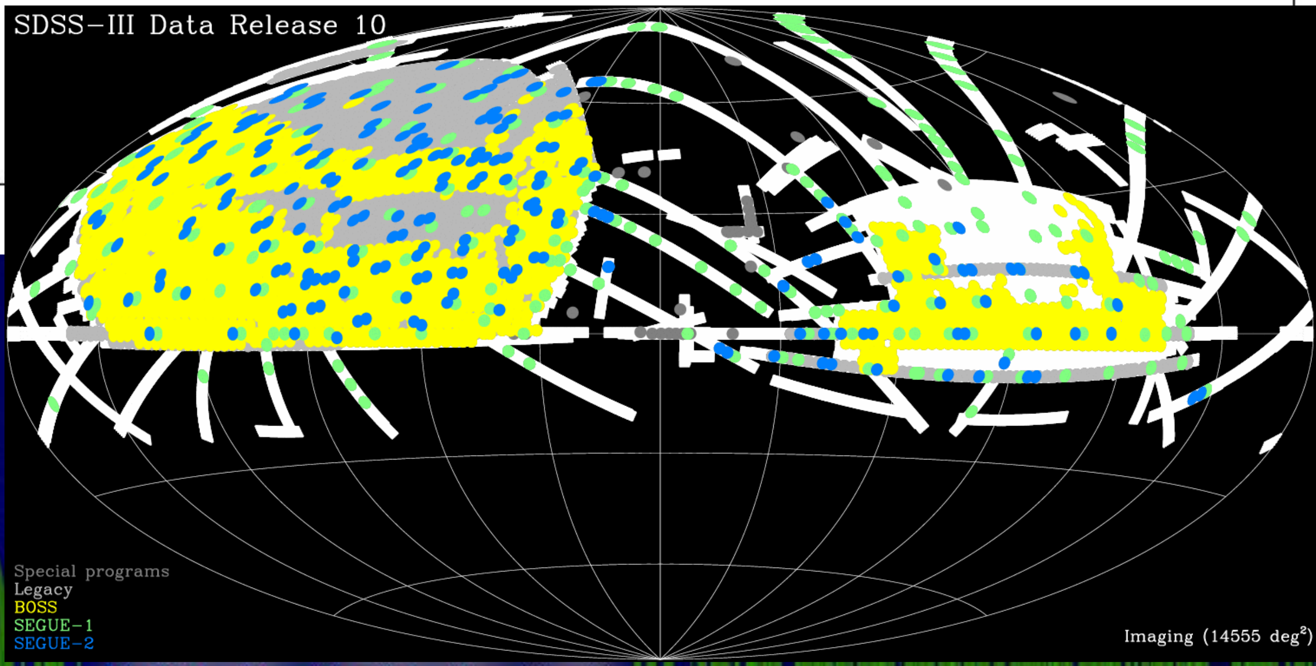
- Identify set of target galaxies based on some property
  - (1) Low SNR in ALFALFA
  - (2) Location in clusters
  - (3) Based on optical/UV properties (apparent magnitude, color, surface brightness structure)
- Set up spectrometer in one of two modes:
  - "Known redshift"
  - "Search mode"
- Point LBW at target position and observe ON-OFF

Probing the low mass star forming population



"Spanhauer diagram"
a.70 HI mass vs distance

SDSS coverage =>

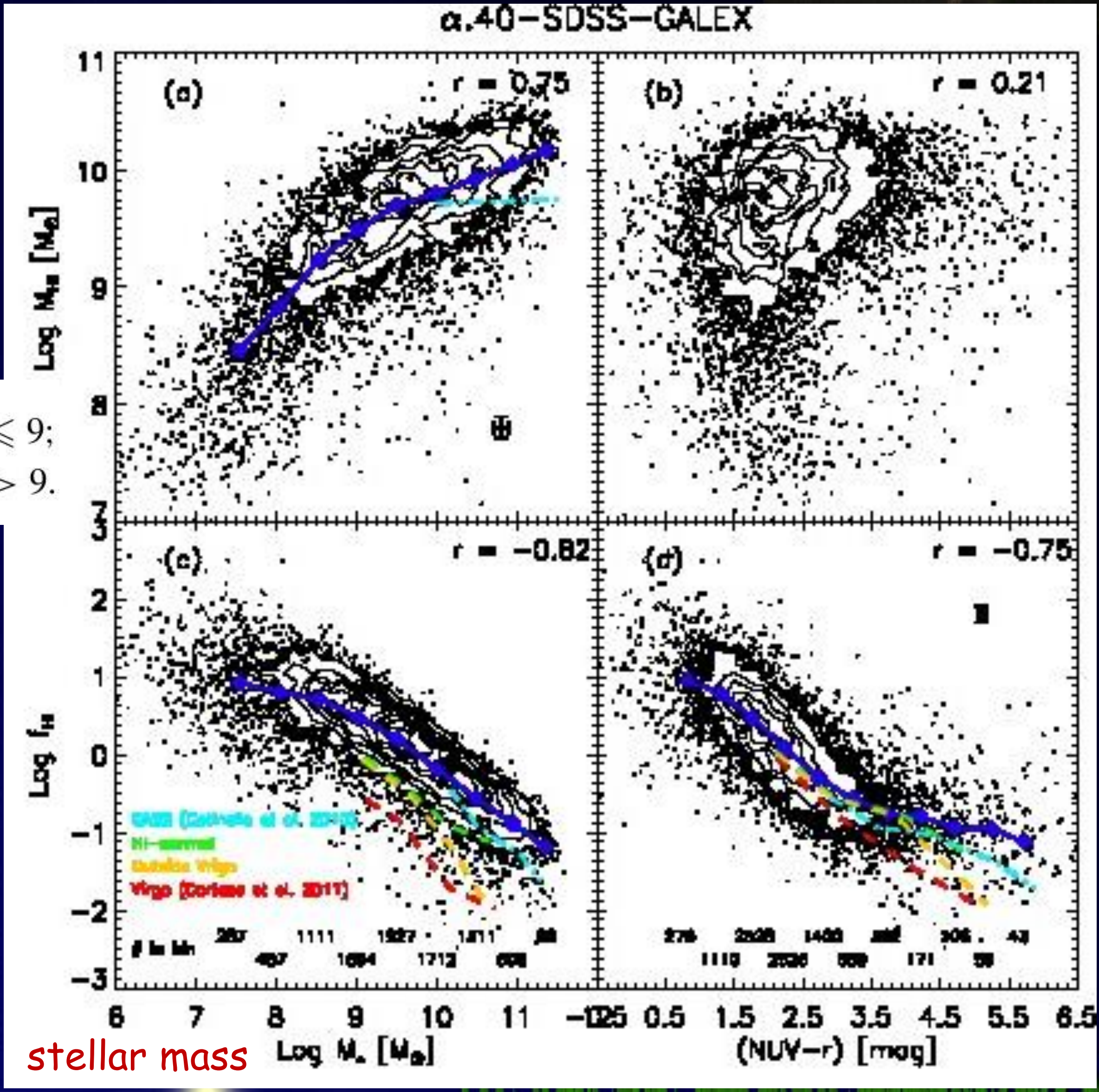


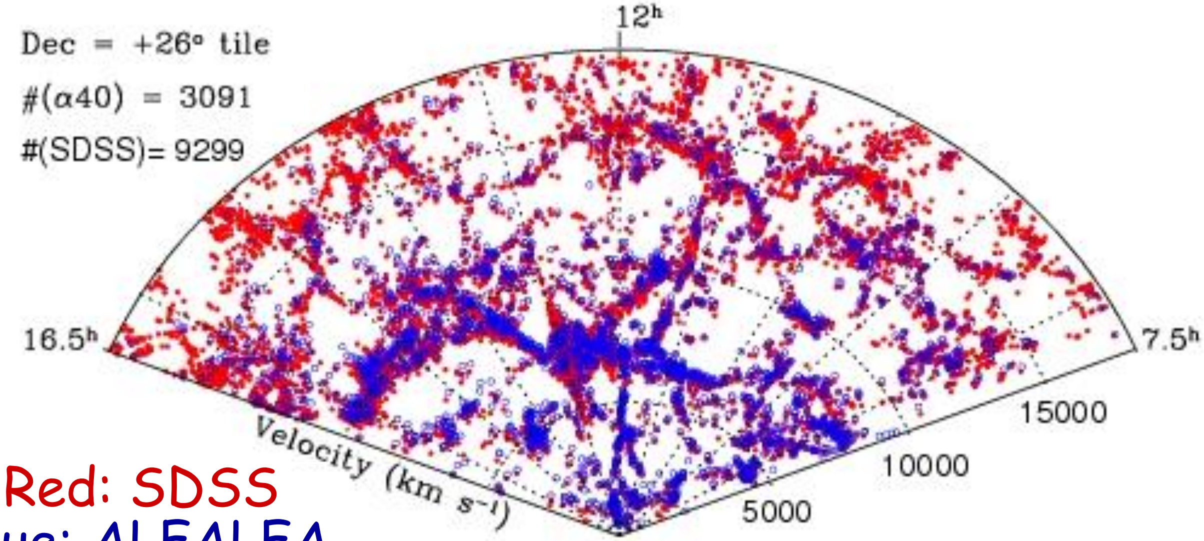
Probing the HI population at low HI masses log MH ~ 8-8.5

- The scaling relations that apply to HI masses > log M_{HI} ~9 break down below that mass.
- Huang+ 2011b Eqn (1)

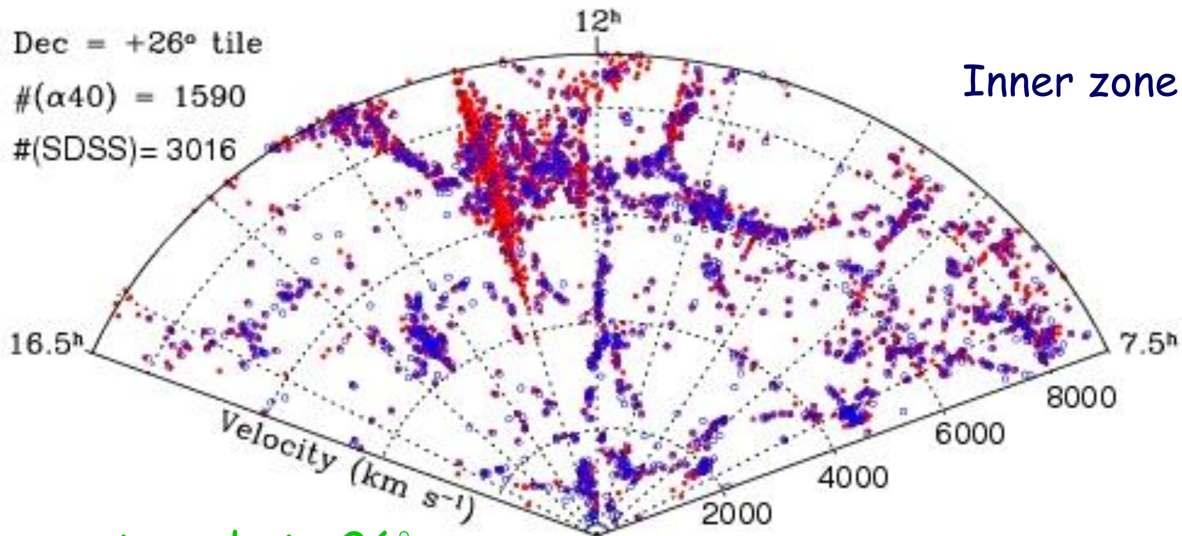
$$\langle \log M_{\rm H\,I} \rangle = \begin{cases} 0.712\langle \log M_* \rangle + 3.117, & \log M_* \leqslant 9; \\ 0.276\langle \log M_* \rangle + 7.042, & \log M_* > 9. \end{cases}$$

- At log M_{HI} < 8.5 the scatter increases a lot, in part due to
  - smaller numbers
  - distance uncertainties
  - photometric uncertainties





Red: SDSS
Blue: ALFALFA



Inner zone

4° tile centered at +26°

- 7000 sqd of high galactic latitude sky with median cz ~8800 km/s
- **Undersamples clusters** but traces well the lower density regions
- Large overlapping areas with SDSS and GALEX
- Adds constraints on the cool gas to models of galaxy evolution

ALFALFA

A2853 LBW followup

Targeted LBW observations of selected sources in the fields of the UAT groups project Hα images or with emission lines in SDSS

1. Objects detected in Hα images but
   - Only marginally detected in ALFALFA
   - Not detected in ALFALFA survey

2. Objects with Hα emission in SDSS spectra but
   - Only marginally detected in ALFALFA
   - Not detected in ALFALFA survey

ALFALFA: effective integration time of 40 seconds/beam
LBW: 5 minutes ON-source

See Will's poster/Alison's talk

ALFALFA

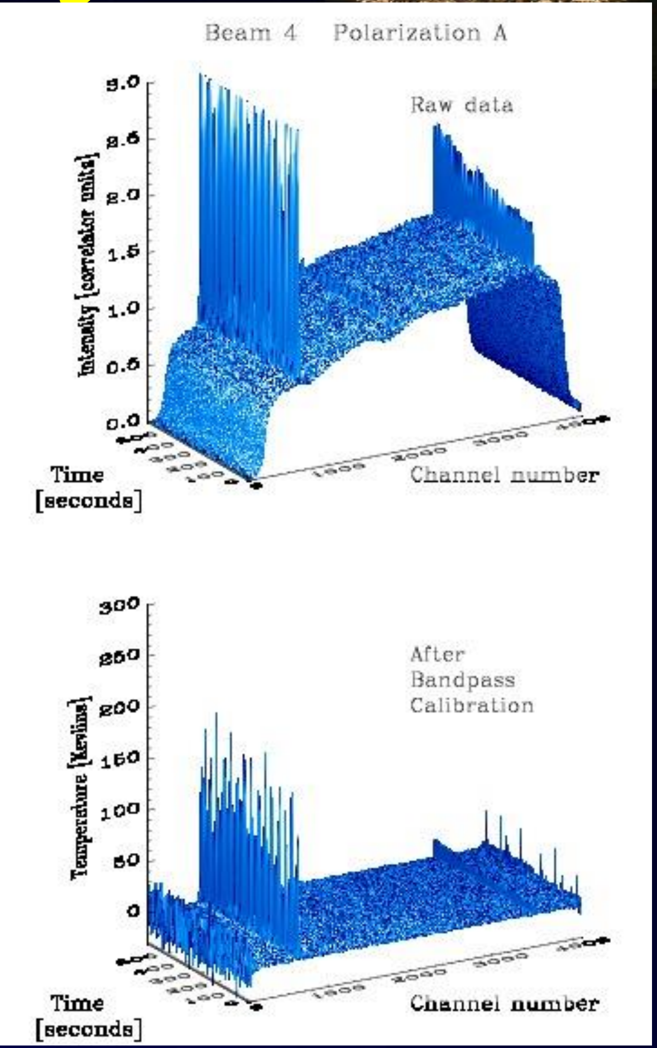
Position-switched observing

The signals we are trying to take are billions (and billions) of times weaker than the radio noise contributed by the receiver, electronics, antenna, cosmic microwave background and the sky overall.

Somehow, we have to subtract off all those unwanted contributions to find our signal.

We assume that a random position in the sky does not contain an HI line source at the exact same velocity as our target source.

We observe such a position, but track it over the exact same Az, ZA as our observations of the target source. => ON-OFF pair



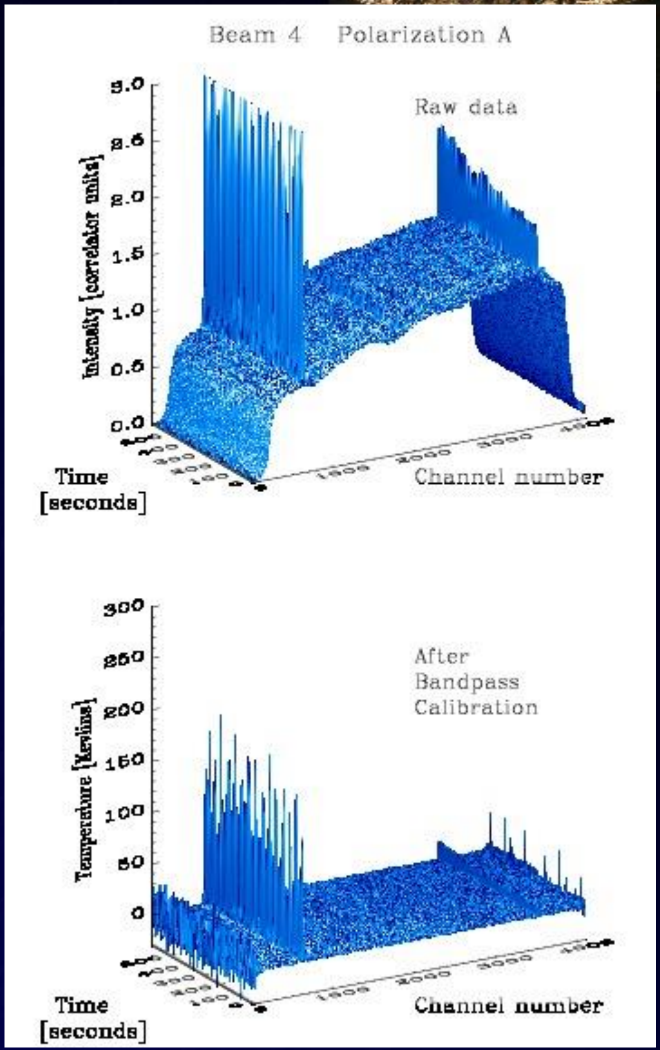
ALFALFA

Position-switched observing

- Position telescope on target source
- Track ON-source for 5 minutes
- Move to same Az,ZA as at start of ON-source track but ~6 mins from now; this is the OFF-source position.
- Track OFF-source for 5 minutes.
- Record noise with "CAL" (noise diode) – ON for 10 secs; then record noise for 10 sec with CAL-OFF.

- Go to next target.
- Repeat ON-OFF-CAL ON/OFF sequence

This is what the "command file" (for a set of sources for the whole night) does.



ALFALFA

Estimating how long we integrate

The radiometer equation for our observations

$$S_{\rm rms} = \frac{(T_{\rm sys}/G)}{\sqrt{2\Delta f_{\rm ch} t_s f_t}},$$

For LBW,
T~ 30K
G ~ 11 K/Jy

Δf : is the bandwidth per channel
t_s : is the effective integration time, in secs
f_t : accounts for the degree of smoothing, the technique applied for bandpass subtraction, clipping losses, etc.
The factor of 2 under the square root comes from the fact that we average the two independent polarizations.

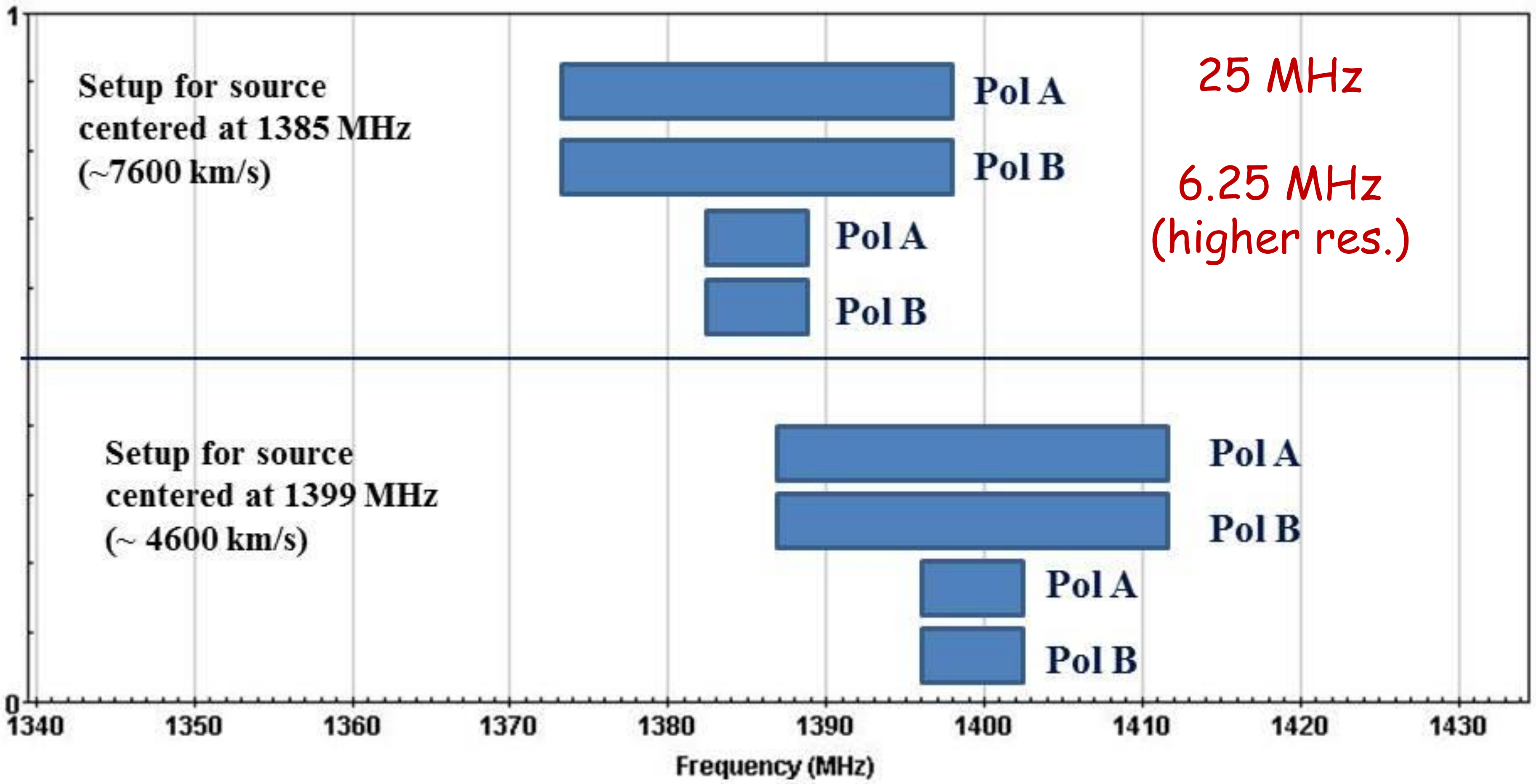
See Giovanelli + 2005, AJ 130, 2598

Jess' lecture

ALFALFA

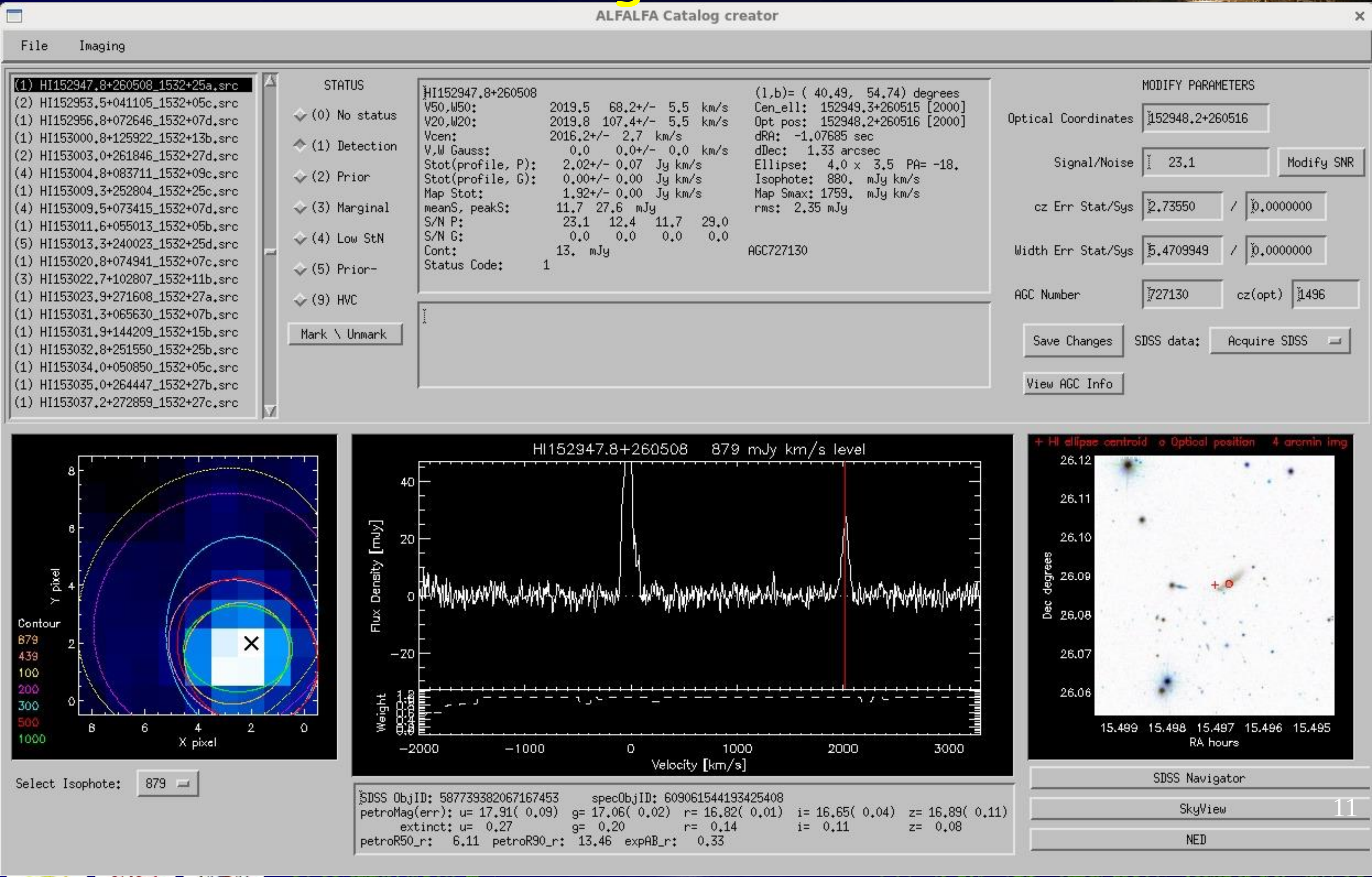
LBW followup: Known redshift

Interim Correlator dual-bandwidth mode



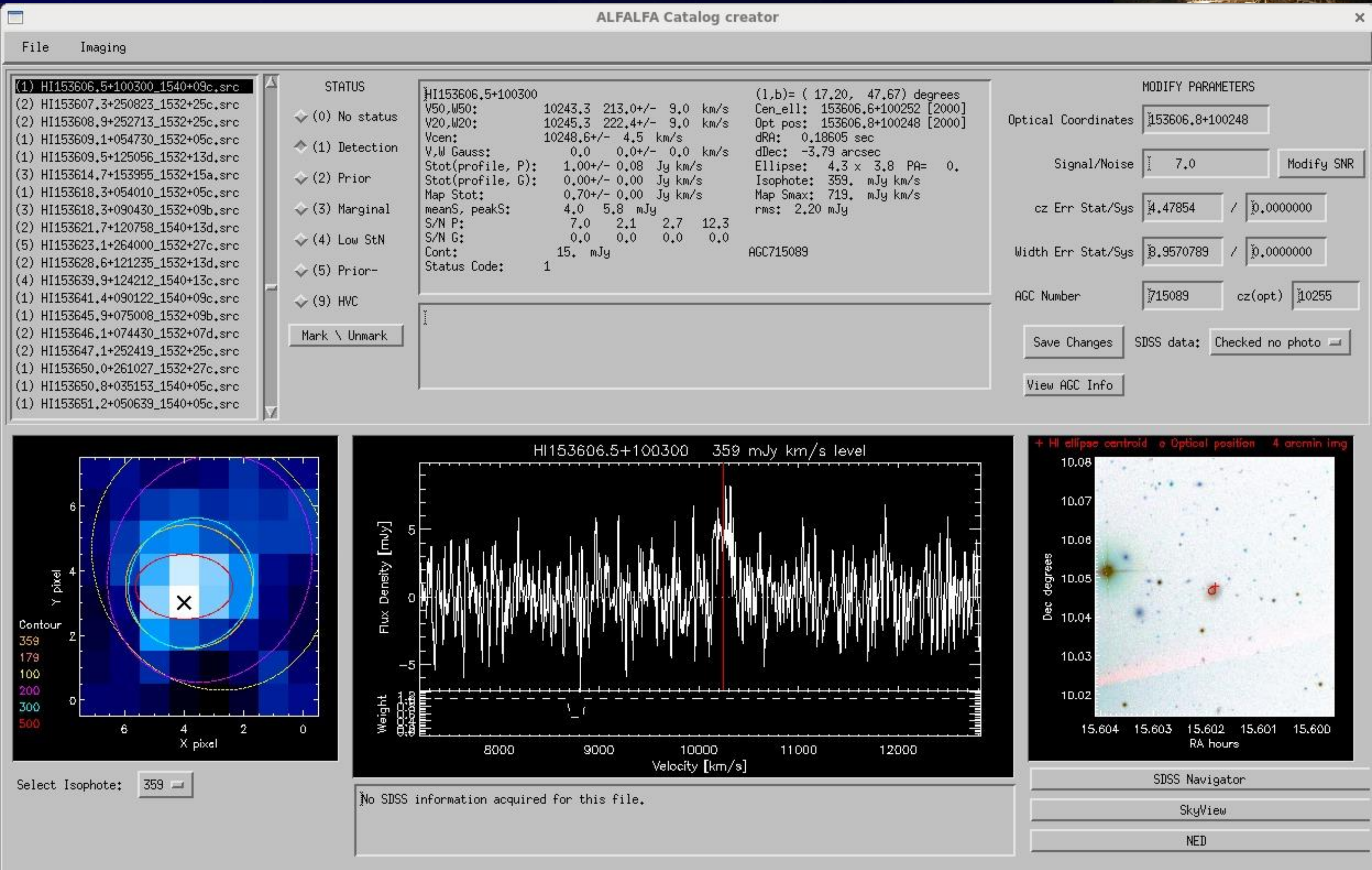
ALFALFA

High S/N



ALFALFA

Low S/N



ALFALFA

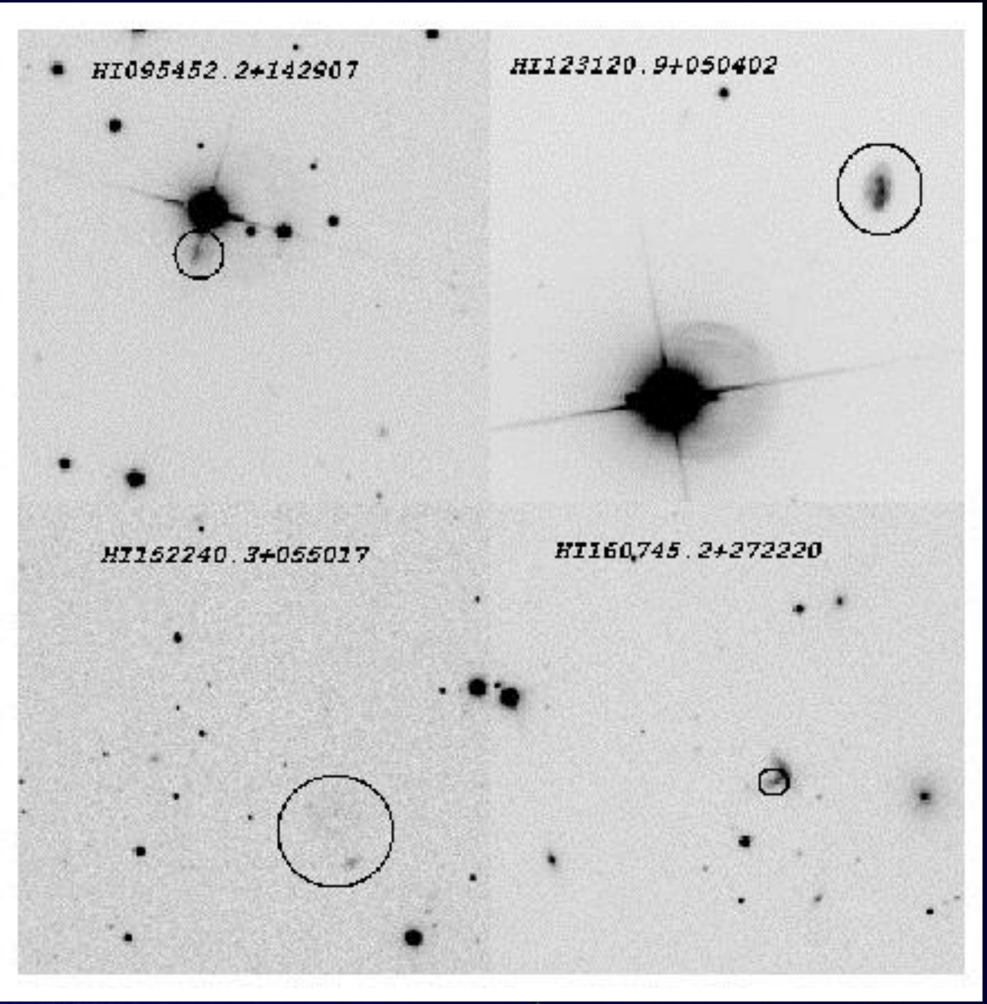

HI114310.1+141330
J114310.3+141328.9
HI121850.1+123621
J121851.3+123549.9
HI122022.6+121136
J122022.9+121108.9
HI122710.8+155407
J122711.8+155349.9
HI123506.6+123100
J123507.99+123020
HI124408.7+120707
J124409.59+120655
HI125602.2+120800
J125603.1+120759
HI122441.1+083007
J122439.59+083010
HI122650.7+113330
J122650.4+113329.9
HI122942.6+094202
J122942.96+094152
HI123019.2+093526
J123019.43+093516
HI123025.7+092809
J123025.92+092759
HI124316.2+085700
J124319.69+085710
HI124408.6+120707
J124409.59+120655
HI125401.5+092700
J125402.09+092648.9

Identifying Optical Counterparts

ALFALFA source centroids good to ~18″ (depends on S/N)

ALFALFA catalogs include:

- the HI centroid position
- the position of the most probable OC
- OC's SDSS PhotoObjID and SpecObjID (where applicable)

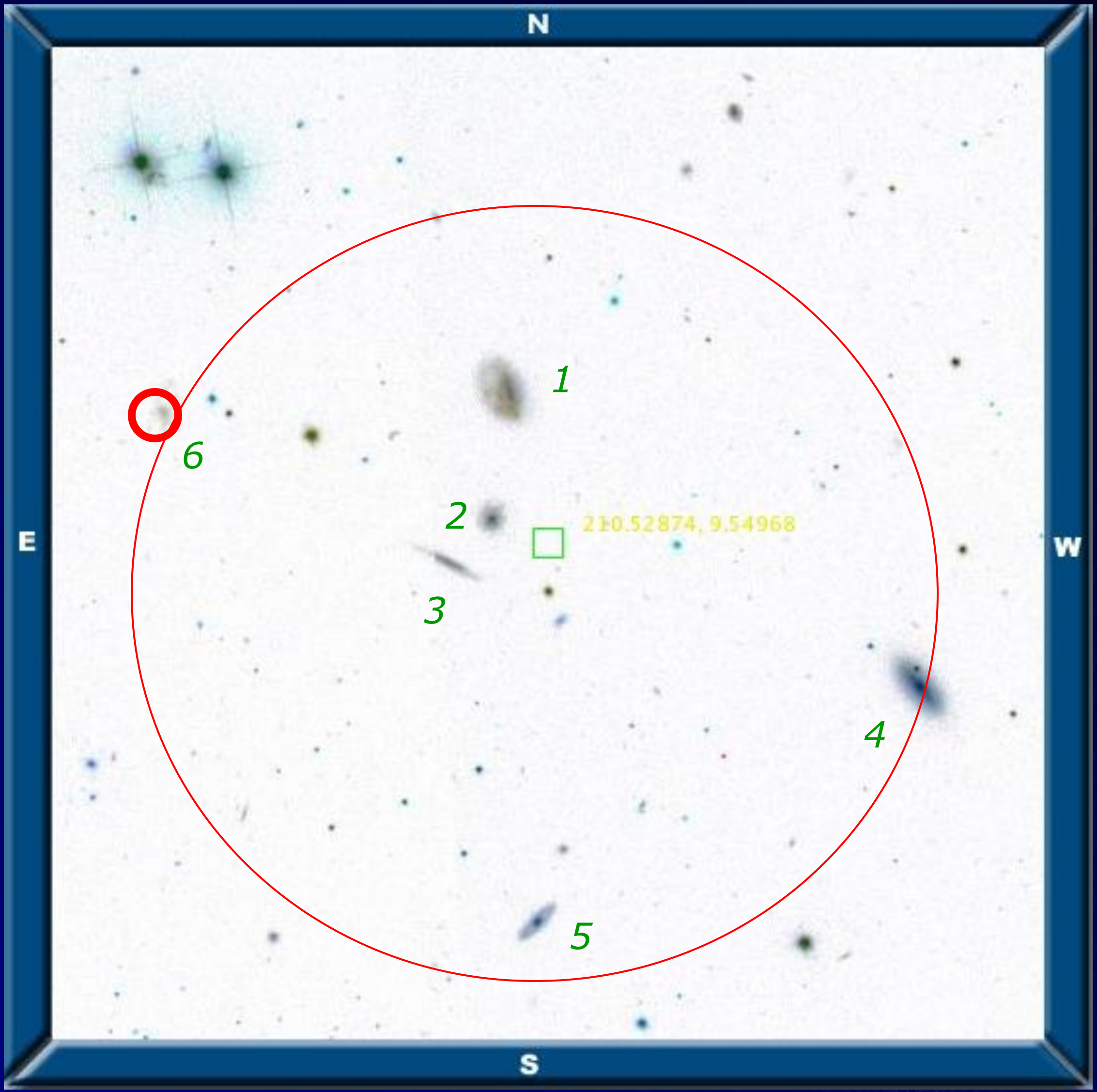


Of 15855 sources in α.40:

- 1013 have no OC
- 844 of those could be HVCs (or LG minihalos)
- 199 (<2%) extragalactic
- Of those, <50 are "isolated"

ALFALFA

ALFALFA advantage for finding the OC



Centroiding accuracy goes roughly as
HPFW(PSF)/(S/N)

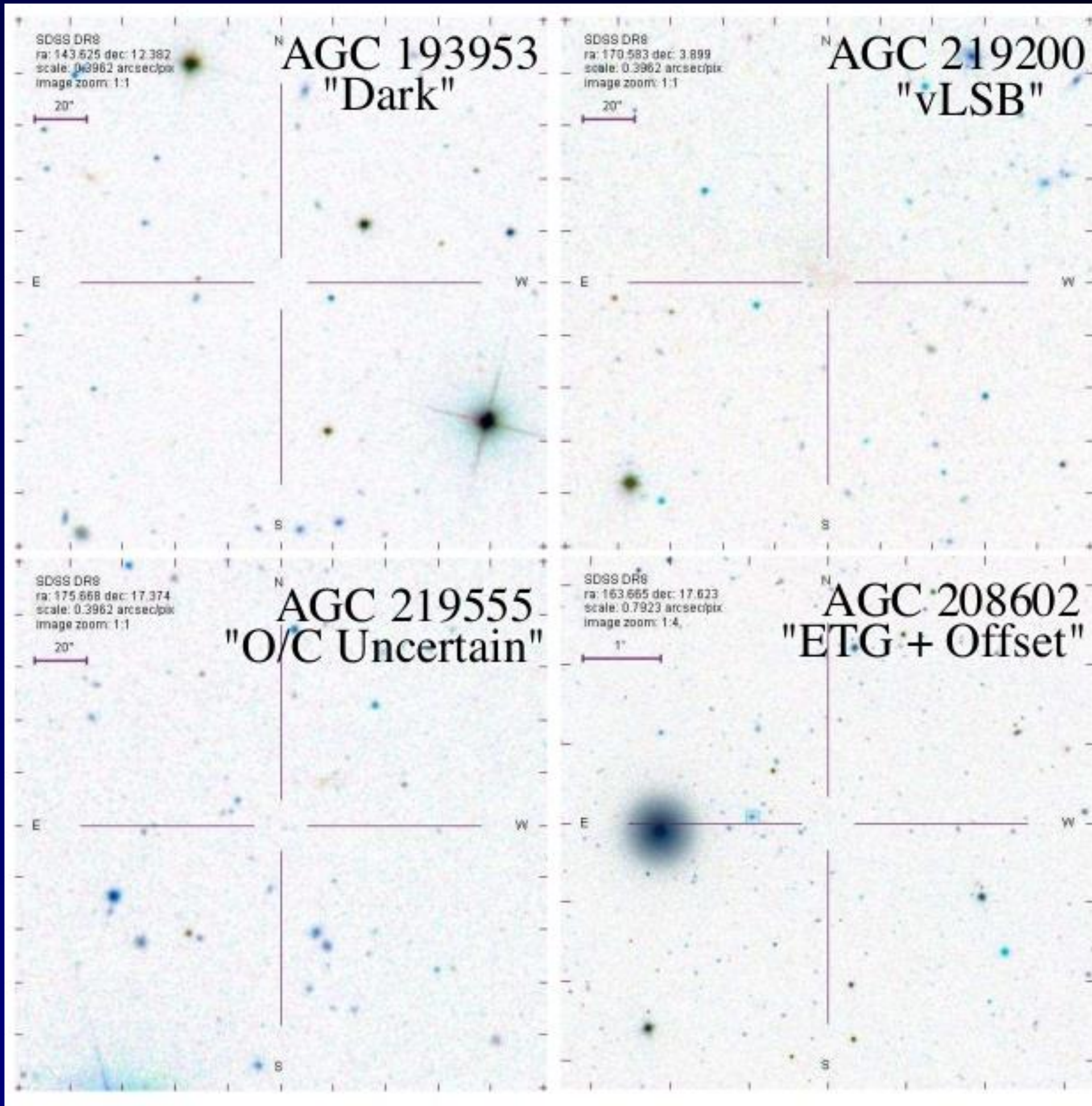
Suppose HIPASS detects a source at S/N~6 near 3000 km/s in this field. The position error box will have a radius of ~2.5′.

The opt counterpart could be gal #1, 2, 3, 4, 5 or 6.

ALFALFA will detect the same source with S/N~50

and the Arecibo beam is $\frac{1}{4}$ as wide as the Parkes one

➔ The same source will have an ALFALFA position error of ~ 0.1′



1. Confirm reality with AO/LBW
2. Observe with VLA (better centroid/HI distribution, signs of rotation)
3. Deep optical image

… Work in progress
"Harvesting ALFALFA"

One possibility:
OHM @0.16 < z < 0.25

ALFALFA

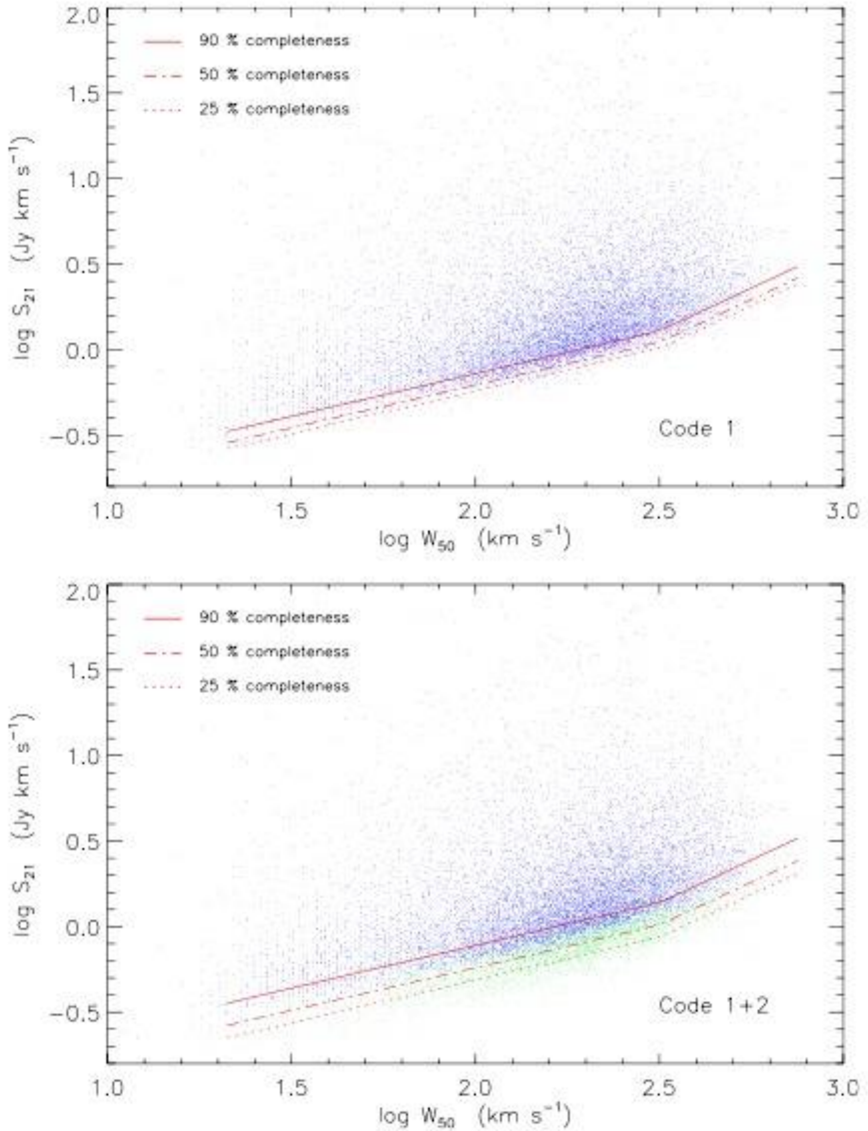


Figure 12. Distribution of α.40 extragalactic sources in the profile width vs. integrated flux density (log W_{50}−log S_{21}) plane. The upper panel shows the distribution of Code 1 detections only, while the lower panel shows the same for the whole α.40 catalog, including Code 1 (blue symbols) and Code 2 (green symbols) detections. In both panels, the solid red line corresponds to the 90% completeness limit, while the red dash-dotted line corresponds to the 50% ("sensitivity limit") and the red dotted line to the 25% ("detection limit") completeness limits. See Section 6 for the analytical expressions for the plotted limits, as well as for an explanation of the derivation method.

ALFALFA sensitivity & completeness

- We want to integrate longer on the low S/N sources.
- Even on high S/N sources, we want to verify they are real.
- Point at OC if there is one or the HI centroid if not
  "Targeted observations"

- LBW has a single horn ("pixel") but higher gain and lower T_{sys} than ALFA

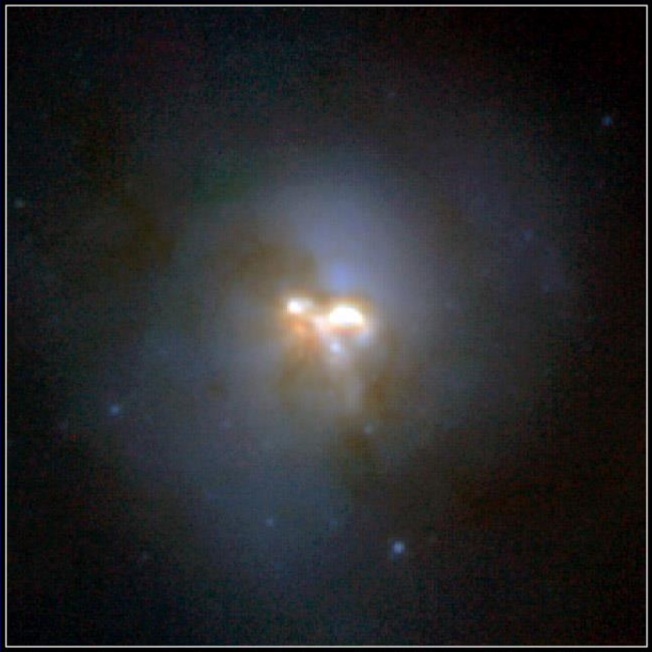
ALFALFA source codes

ALFALFA HI detections are coded according to:

Code 1	High quality sources, typically with S/N > 6.5
Code 2	Sources of lower S/N which are coincident with a probable OC of the same redshift (known from another source) => the "priors"
Code 3	Low S/N sources without identifiable OC
Code 4	Low S/N sources with a possible OC of unknown redshift
Code 5	Corresponding to Code 2, but of such low S/N or possible RFI contamination that they are untrustworthy
Code 6	Like OH megamasers at $0.16 < cz < 0.24$

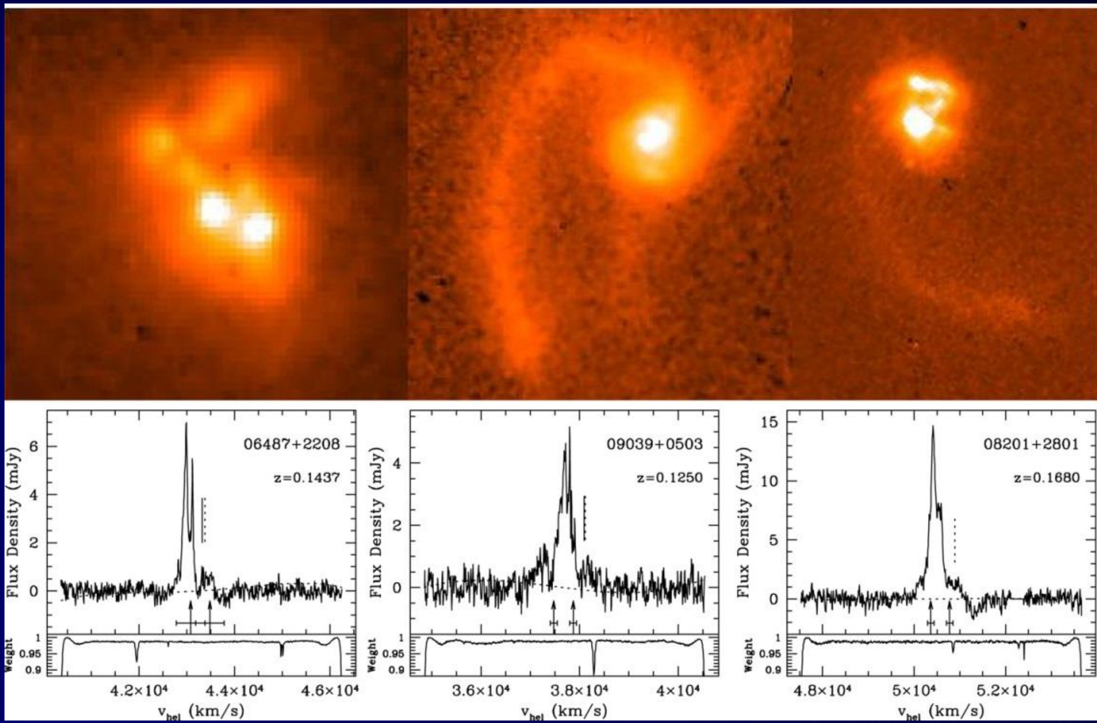
OH Megamasers: OHMs

- Arise in interacting/merging galaxy systems.
  - When galaxies merge, gas clouds close to their nuclei are shocked and heated by the collision, and the emission from certain molecules especially OH is strongly amplified.
- Since this stimulated emission is like the more familiar laser but occurs in the microwave region of the electromagnetic spectrum, it is called a "maser".
- When galaxies collide, the emission is millions of times stronger than in normal galaxies, hence the term "megamaser".
- Such objects are also typically (ultra) luminous in the far-infrared.



Ultraluminous Infrared Galaxy Arp 220 HST • NICMOS
PRC97-17 • ST ScI OPO • June 9, 1997
R. Thompson (University of Arizona),
N. Scoville (California Institute of Technology) and NASA

Redshifted 18 cm OHMs in ALFALFA



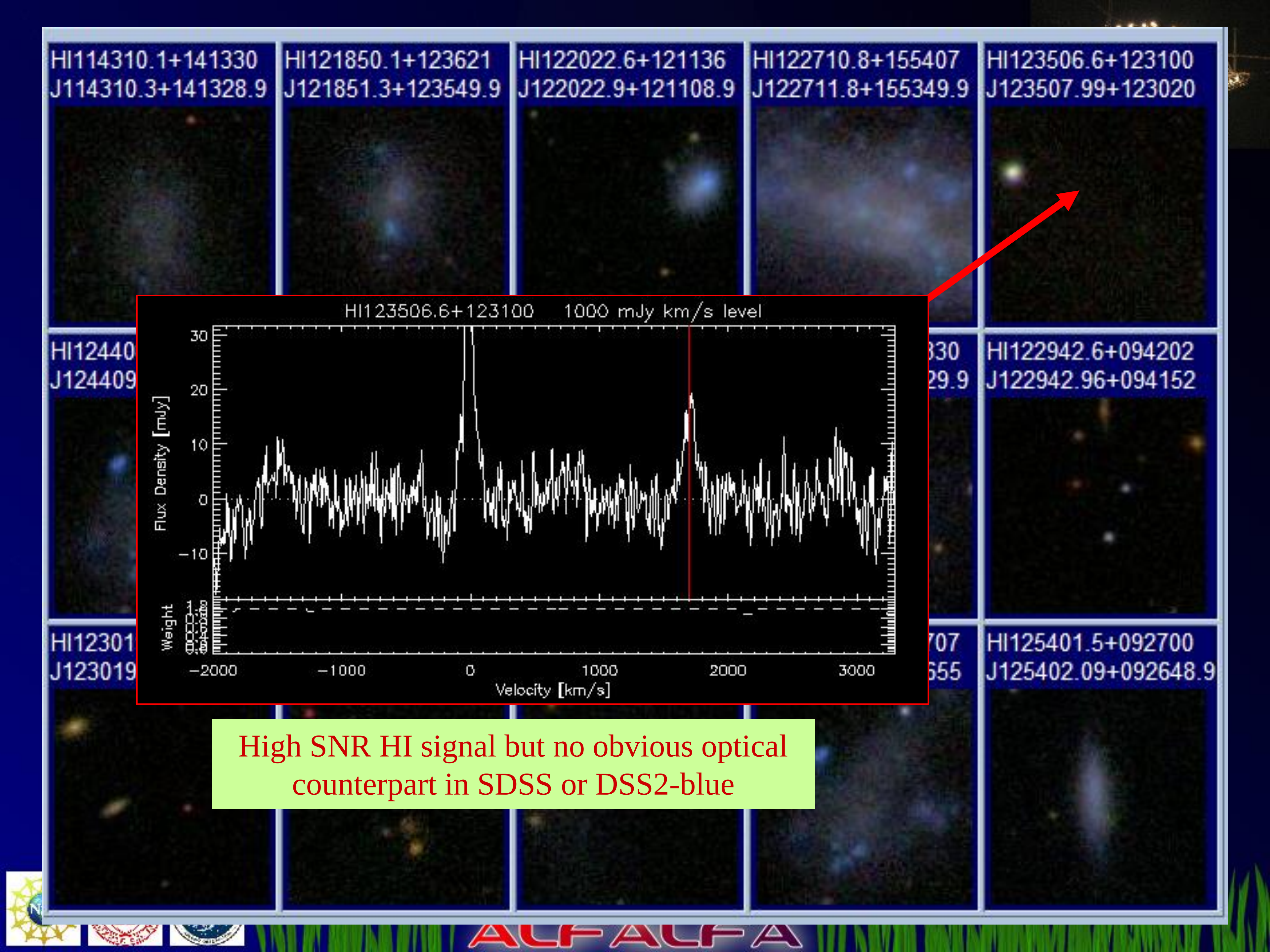
- f_5 = 1665.4018
- f_7 = 1667.3590

In OHMs, $S(f_7) > S(f_5)$

$f_{obs} = f_{rest} / (1+z)$

ALFALFA: 1340-1430 MHz, corresponding, for OH, to $0.166 < z < 0.244$

- Emission at f > 1422 MHz (blueshifted if HI)
- Emission associated with OC in $0.1666 < cz < 0.244$
- Emission with no OC


HI114310.1+141330
J114310.3+141328.9
HI121850.1+123621
J121851.3+123549.9
HI122022.6+121136
J122022.9+121108.9
HI122710.8+155407
J122711.8+155349.9
HI123506.6+123100
J123507.99+123020
HI122942.6+094202
J122942.96+094152
HI125401.5+092700
J125402.09+092648.9
HI123506.6+123100 1000 mJy km/s level
Flux Density [mJy]
Weight
Velocity [km/s]
High SNR HI signal but no obvious optical counterpart in SDSS or DSS2-blue
ALFALFA

ALFALFA: Are there "dark galaxies"?

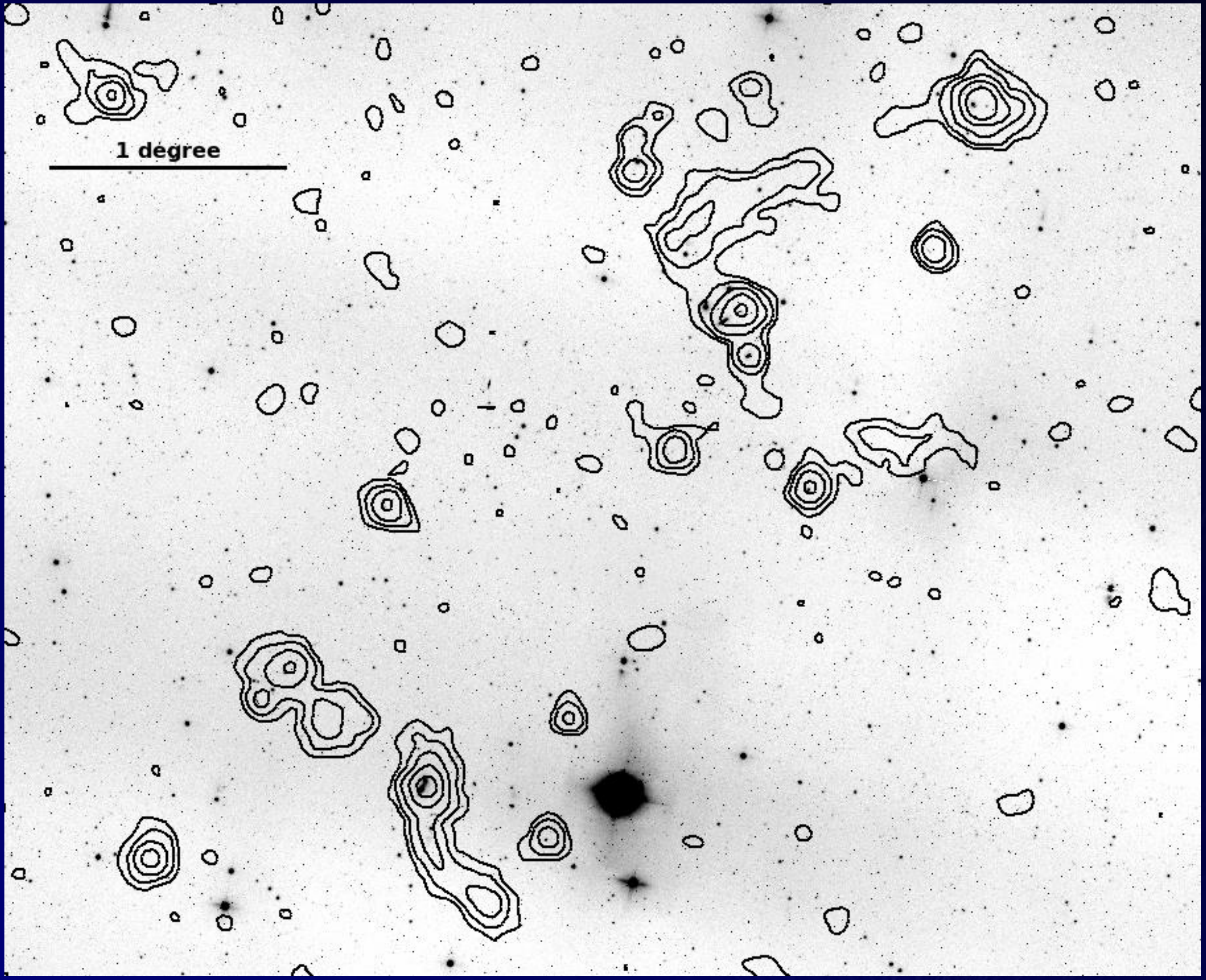
- In agreement with previous results, ALFALFA finds that fewer than 2% of (clearly extragalactic) HI sources cannot be identified with an optical counterpart.
- The majority of objects without OC's are found near to galaxies with similar redshifts.
- There are few interesting cases to be confirmed (work in progress):
  - LSB or dark galaxies
  - OHMs with $0.16 < z < 0.25$
  - Mystery lines?

> The burden is always on us to prove that
> (1) the signal is real and (2) there is no OC even at low surface brightness

Luke Leisman,(Cornell)
Steven Janiowiecki (Indiana)
Karen Lee-Waddell (Queen's)
+ Cannon, Salzer, Rhode, Adams, Darling, Josza, RG, MH

ALFALFA

Wide area mapping with ALFALFA



- 4°×5° field around the interacting system Arp 94 (the bow-shaped feature on the bottom-left) and the compact group HCG 44 (top right).
- ALFALFA HI contours are superimposed on an i band SDSS mosaic.
- Several tidal features are clearly evident, but other ALFALFA detections are unresolved and optically-dark.
- At a distance of 25 Mpc, 1° ~ 350 kpc.

Luke Leisman in prep

ALFALFA source codes

ALFALFA HI detections are coded according to:

Code 1	High quality sources, typically with S/N > 6.5
Code 2	Sources of lower S/N which are coincident with a probable OC of the same redshift (known from another source) => the "priors"
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Code 5	Corresponding to Code 2, but of such low S/N or possible RFI contamination that they are untrustworthy
Code 6	Like OH megamasers at $0.16 < cz < 0.24$

A2669/A2707/A2752/A2899 LBW followup

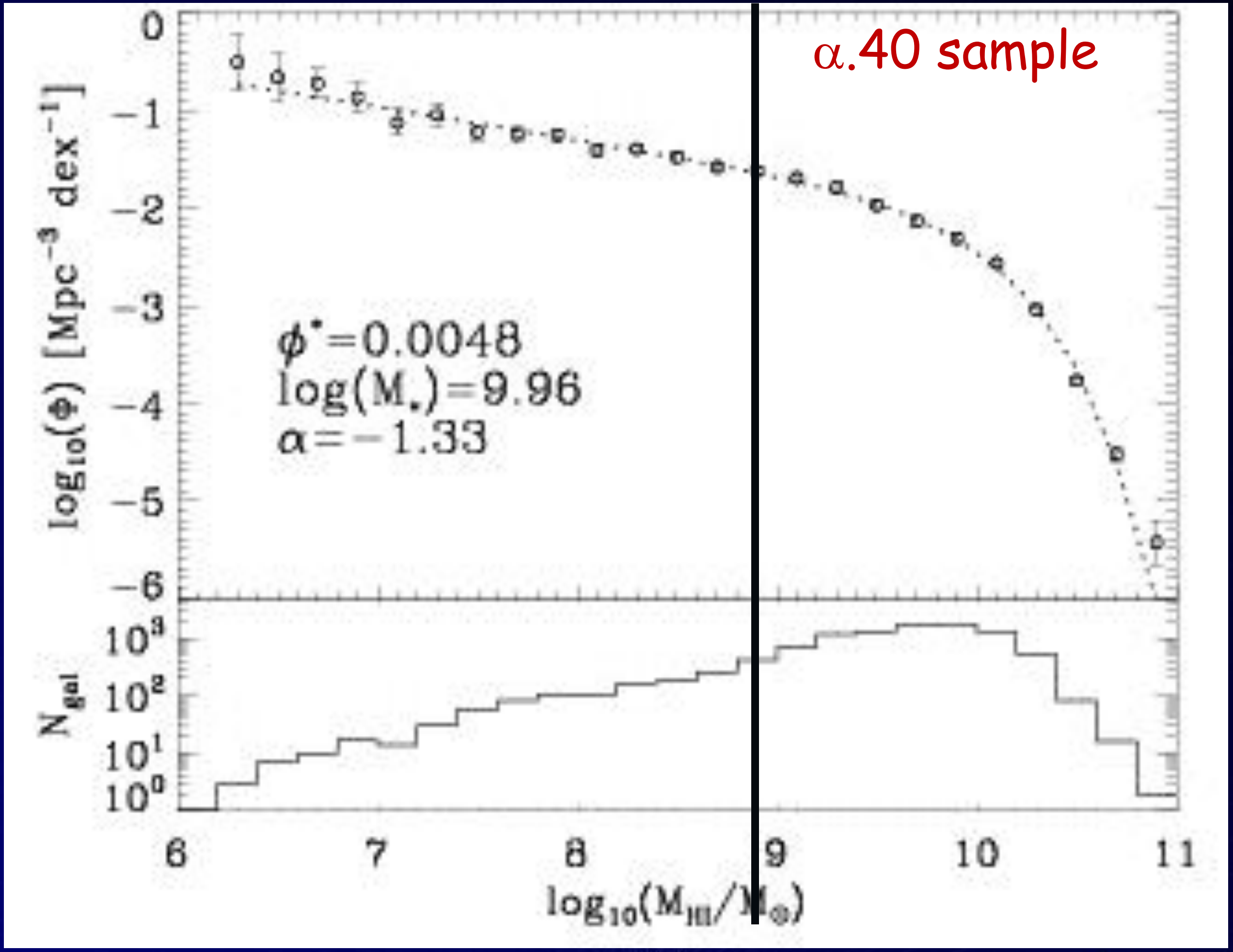
Targeted LBW observations of selected ALFALFA sources:

1. "Dark" galaxy candidates: high quality (Code 1) detections with no OC and not associated with known tidal debris fields
2. OH megamaser (OHMs) candidates: either at large blueshift or coincident (within centroiding accuracy) of OC of appropriate cz.
3. "Low mass dwarf candidates": low signal-to-noise ratio sources at low cz (< 1000 km/s)
4. Statistical samples of low S/N signals possibly associated with optical galaxies

ALFALFA: effective integration time of 40 seconds/beam
LBW: 3 mins (or 5 mins) ON-source

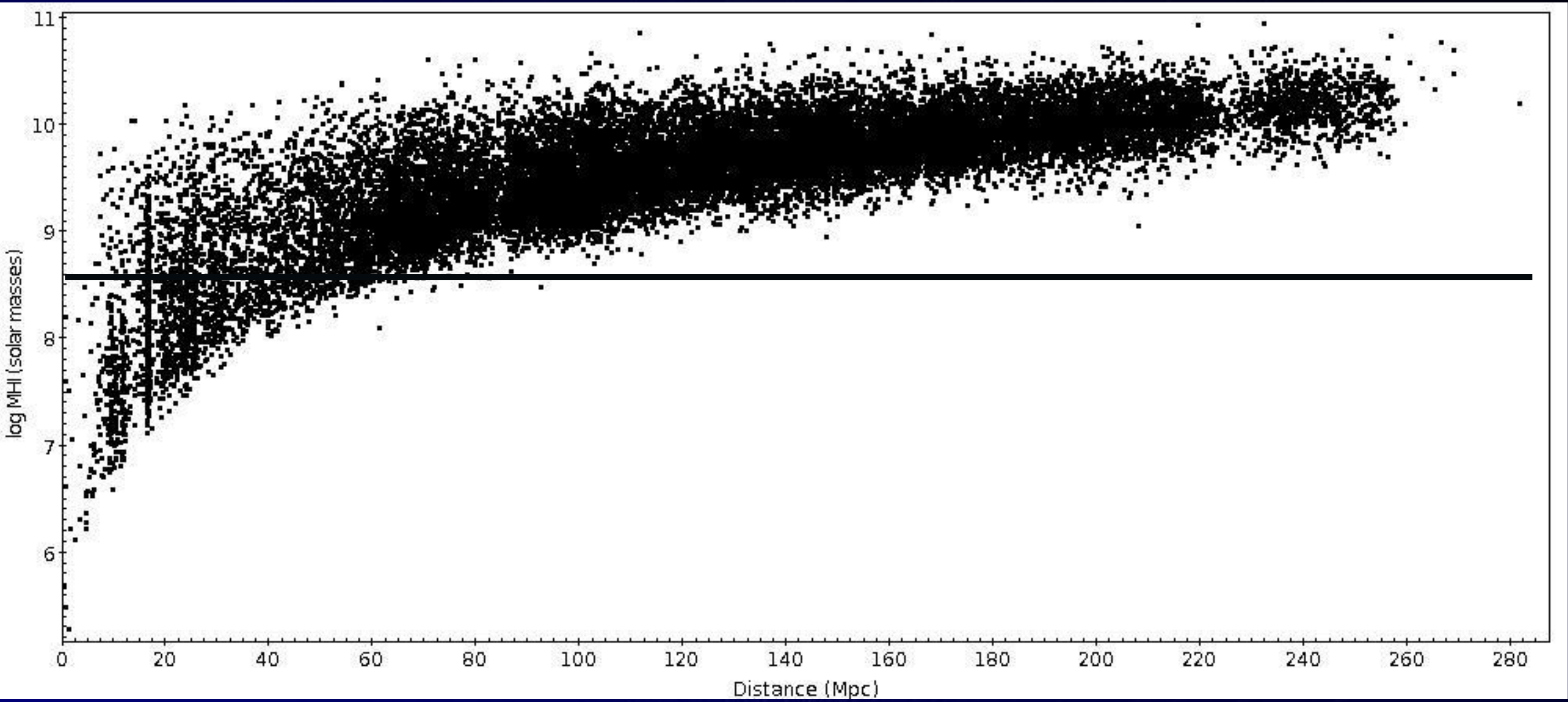
Too Shy to Shine

- We need better statistics at the low mass end of the HIMF and the low V_{rot} end of the HI Velocity/Width Function (HIV/WF).



"Too Shy to Shine"

- We need better statistics at the low mass end of the HIMF and the low Vrot end of the HIVF.



ALFALFA

Fall 2014 LBW proposal

- Explore region(s)[*See next slides*] in the spring sky with SDSS spectra to get LBW spectra of all objects within the target volume (out to 80 Mpc) in SDSS spectroscopic sample but not α.70
- Explore fainter SDSS/GALEX objects which are very blue and have sample range of AbsMag, r_d, SB => are they in the volume or not?
- Refine criteria for SDSS/GALEX selection; try to dig deeper
- Look at photometry issues (UAT project)

Future:

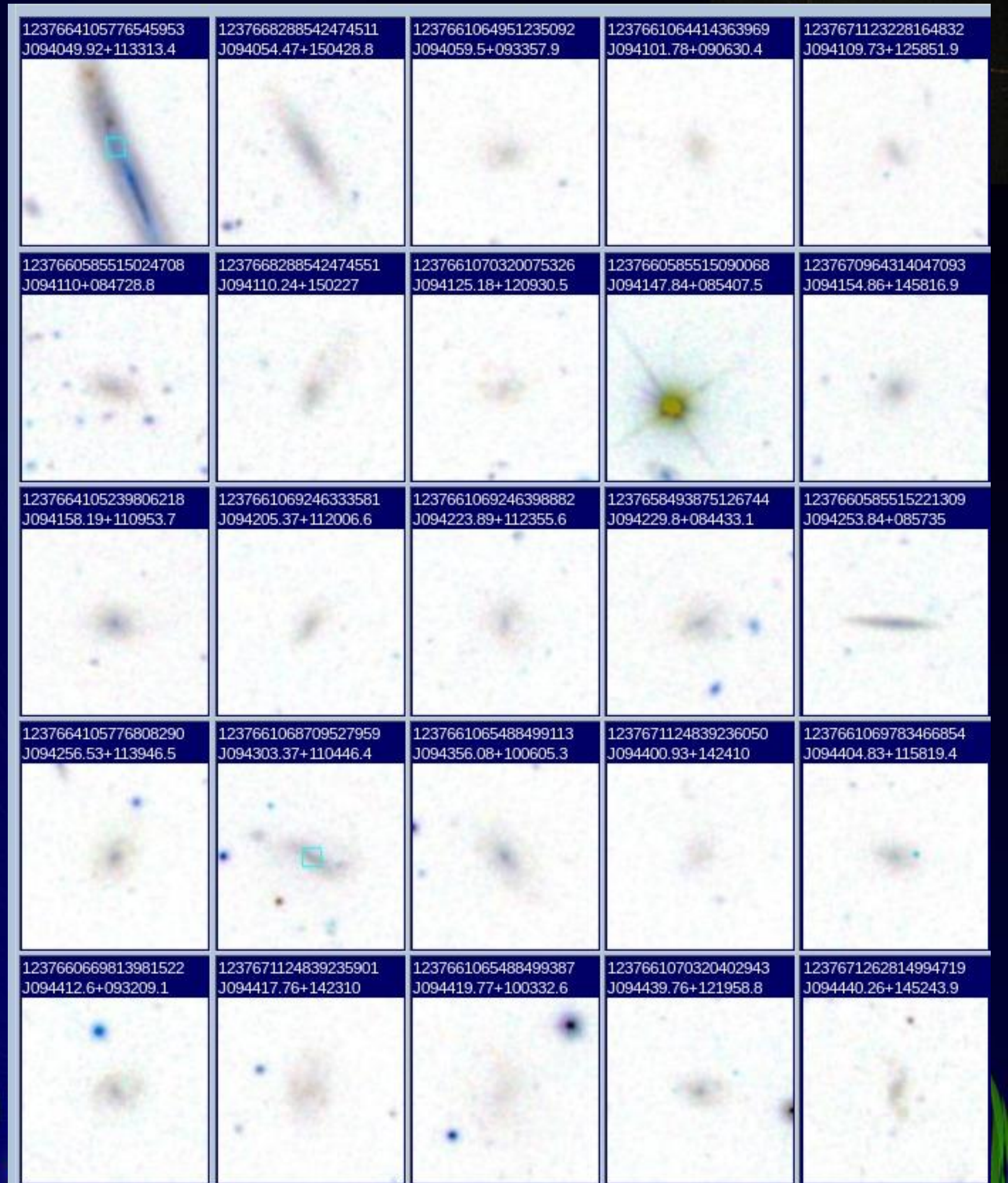
- Identify PPS targets meeting SDSS spectroscopic sample and blue (NUV-r), but not in a.70
- Conduct LBW survey of these targets
  - Explore dependence of HIMF/WF across range of environments sampled
  - Using T-F relation to measure infall onto PPS ridge

```
Query 19
SELECT
  p.objid, p.ra, p.dec,
  p.cModelMag_u,p.cModelMag_g,p.cModelMag_r,p.cModelMag_i,p.cModelMag_z,
  p.petroMag_r, p.petroR50_r, p.petroR90_r,
  p.expRad_g, p.expRad_r,expRad_i,p.expAB_g,p.expAB_r,p.expAB_i,
  p.fracDeV_g,p.fracDeV_r,p.fracDev_i,
  p.extinction_g, p.extinction_r, p.extinction_i,
  p.lnLDeV_r,p.type
FROM PhotoPrimary as p
WHERE
  p.ra >= 140 AND p.ra <= 175  AND
  p.dec >= 8 AND p.dec <=16 AND
  p.cModelMag_r > 16.5 AND p.cModelMag_r < 23. AND
  p.cModelMag_i > 16.5 AND p.cModelMag_r < 23. AND
  p.fracDeV_r < 0.8 AND
  p.cModelMag_r < 21.0 AND p.cModelMag_r > 17.5 AND
  (p.cModelMag_g - p.cModelMag_i) < 0.6 AND
  (p.cModelMag_g - p.cModelMag_i) > -0.5 AND
  p.expRad_g > 3 AND p.expRad_r > 3 AND p.expRad_i > 3 AND
  p.petroR50_r > 3 AND
  p.lnLExp_r > (13.81+p.lnLDeV_r) AND
  p.type = 3
order by p.ra
```

This is query I used, but need to refine further in future

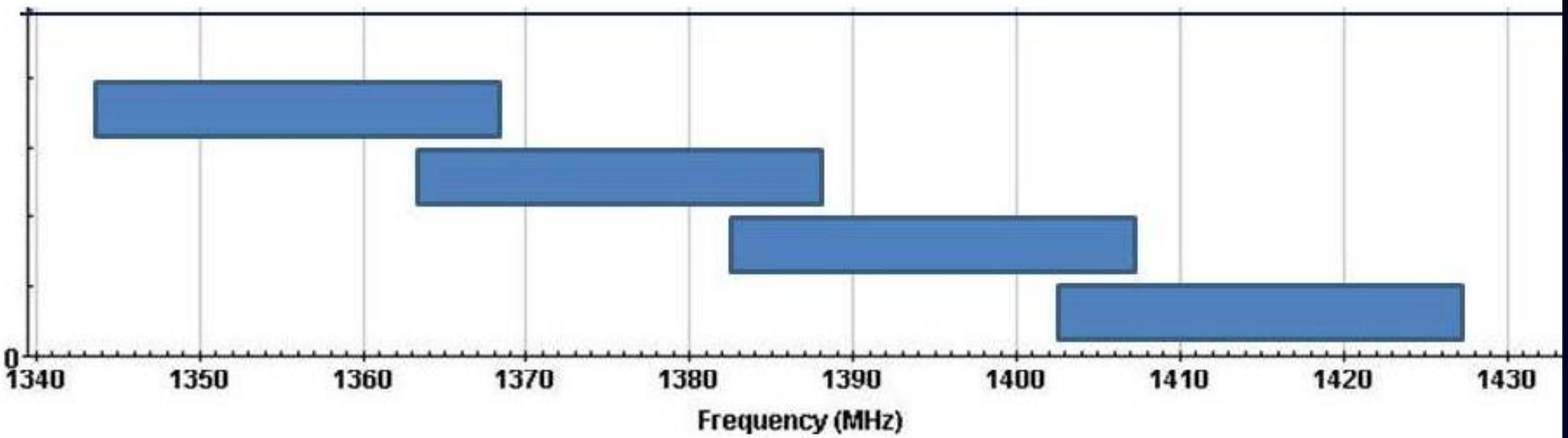
ALFALFA

- Query returns a lot of lsb, blue galaxies but also bogus objects.
- Further refinement (+GALEX) in progress.
- The question is: how many of these objects are actually in target redshift range, or are they more distant, higher mass objects.
- We will find out…



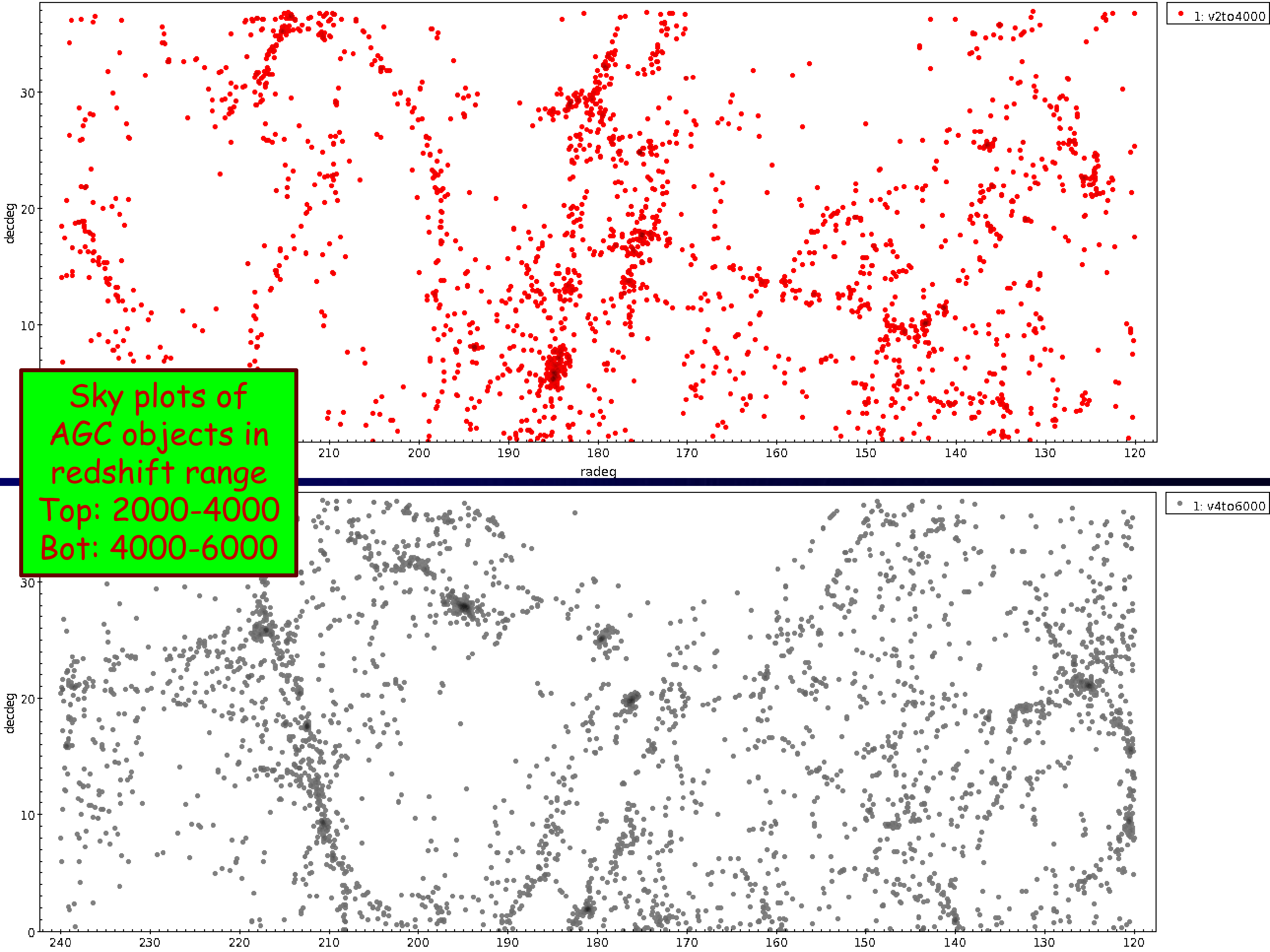
LBW followup: WAPP search mode

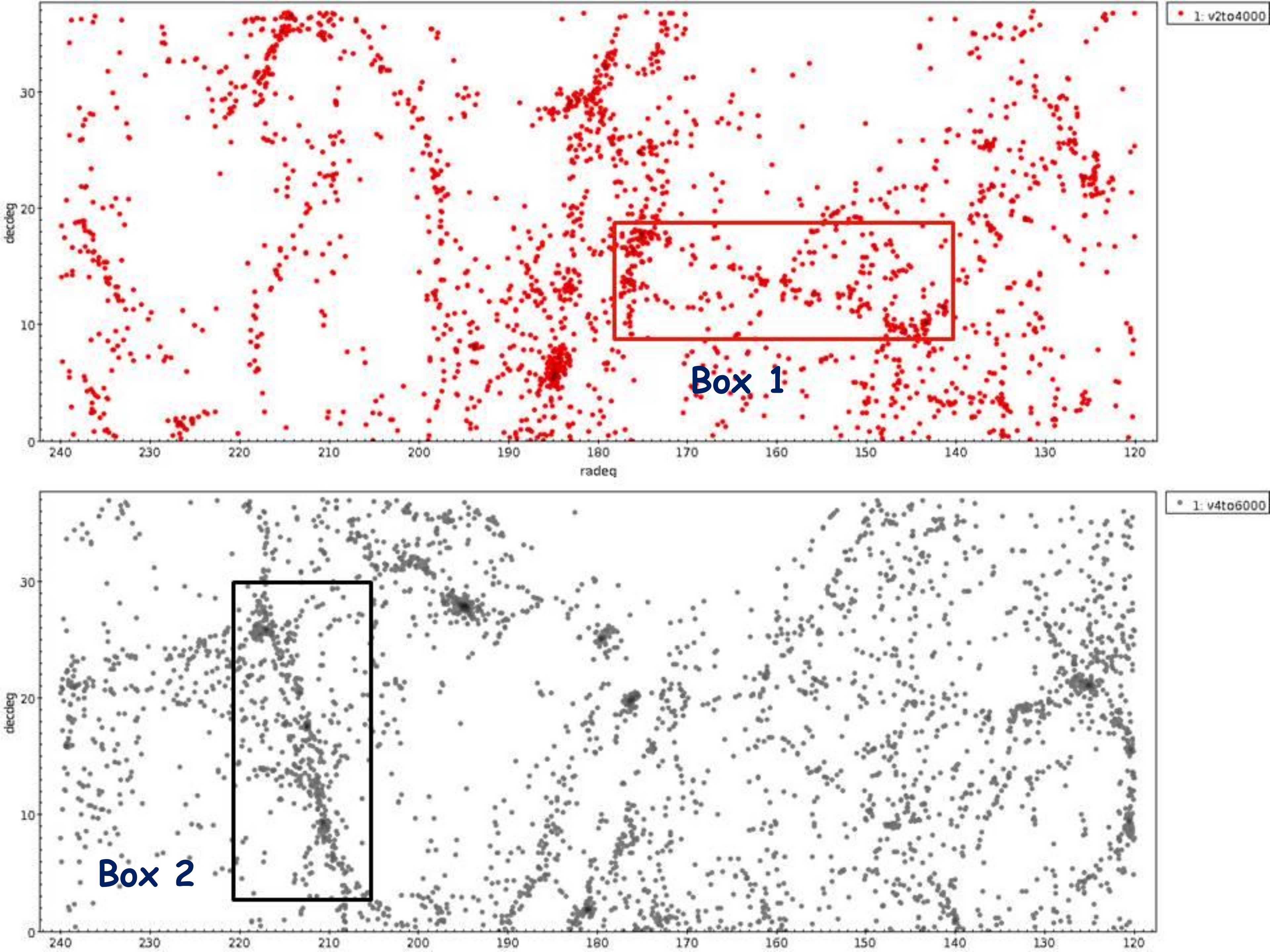
Since we do not know the redshift of our targets, we configure the WAPP spectrometer so that each quadrant (or "board" in WAPP-speak) covers a 25 MHz bandpass. We then set the center frequency of the boards so that they are offset by 20 MHz, yielding a total coverage of about 85 MHz, from ~1343 MHz to ~1428 MHz.



This shows the WAPP bandpass setup for a single polarization; the WAPPS record both polarizations separately, and normally we average them right away.

Sky plots of AGC objects in redshift range
Top: 2000-4000
Bot: 4000-6000

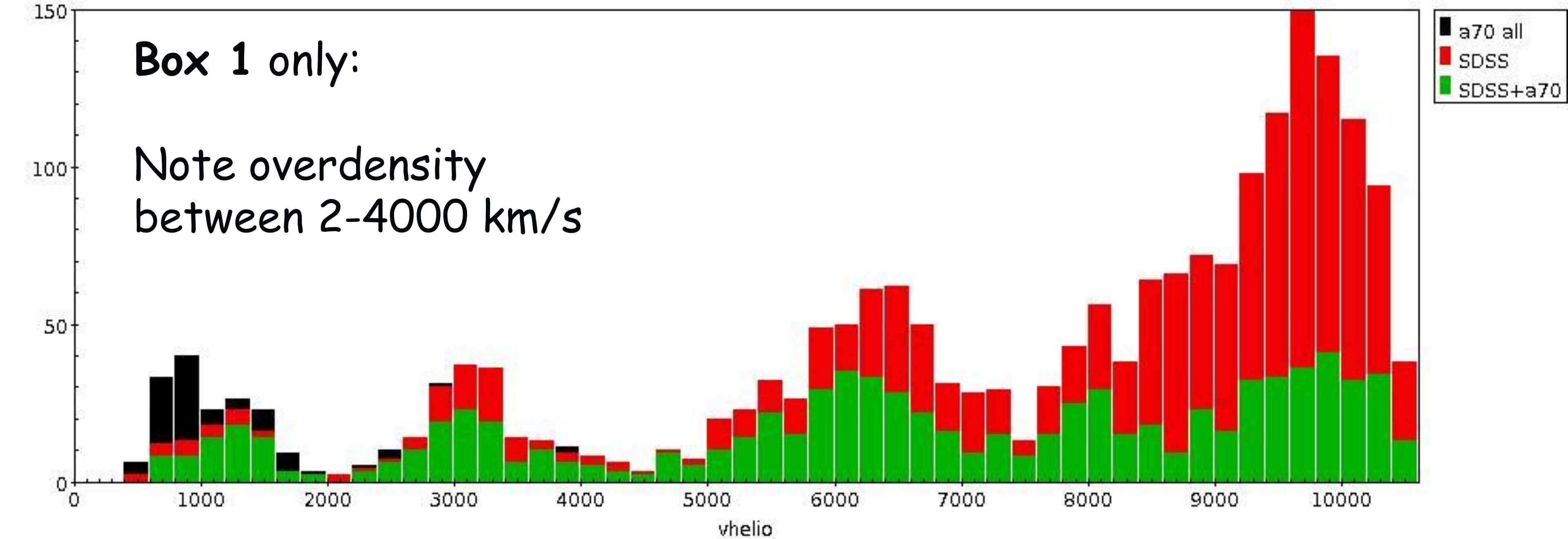


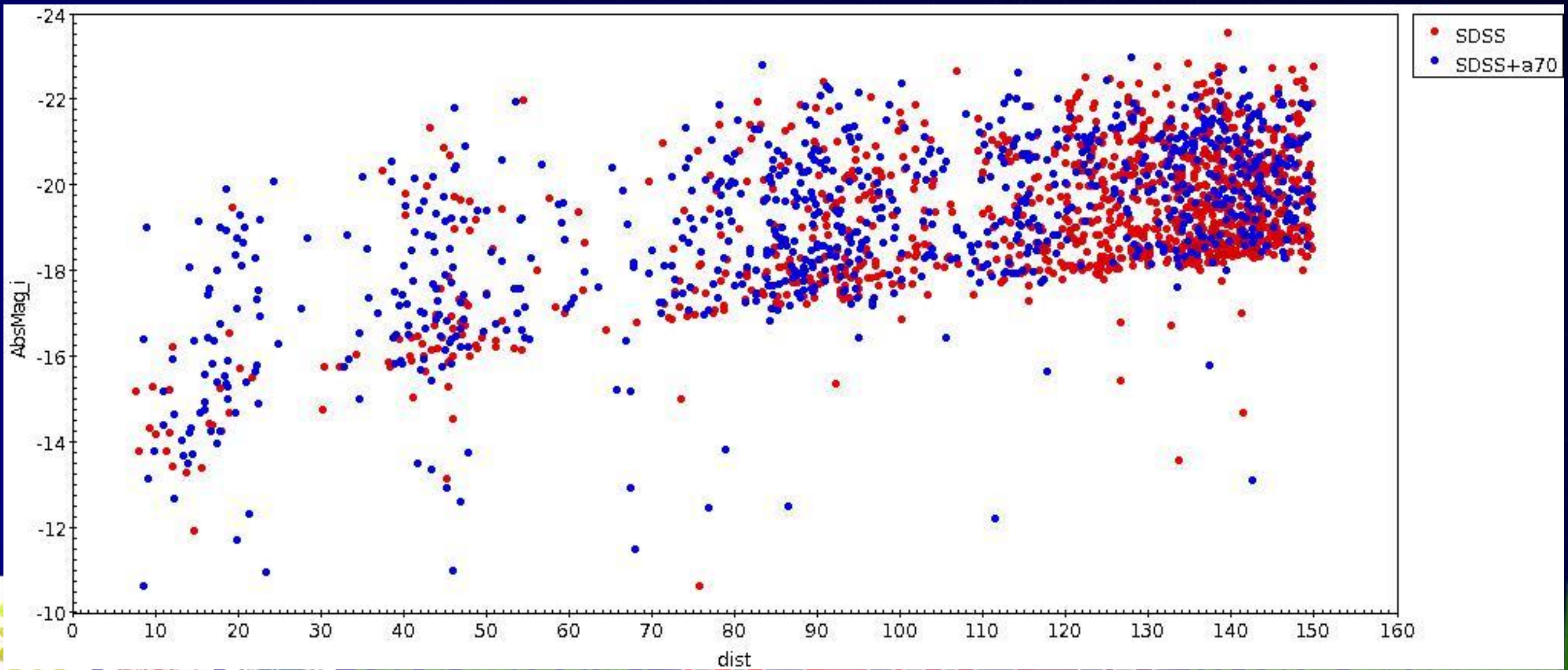


1: v2to4000
Box 1
decdeg
radeq
1: v4to6000
Box 2
decdeg

Box 1 only:

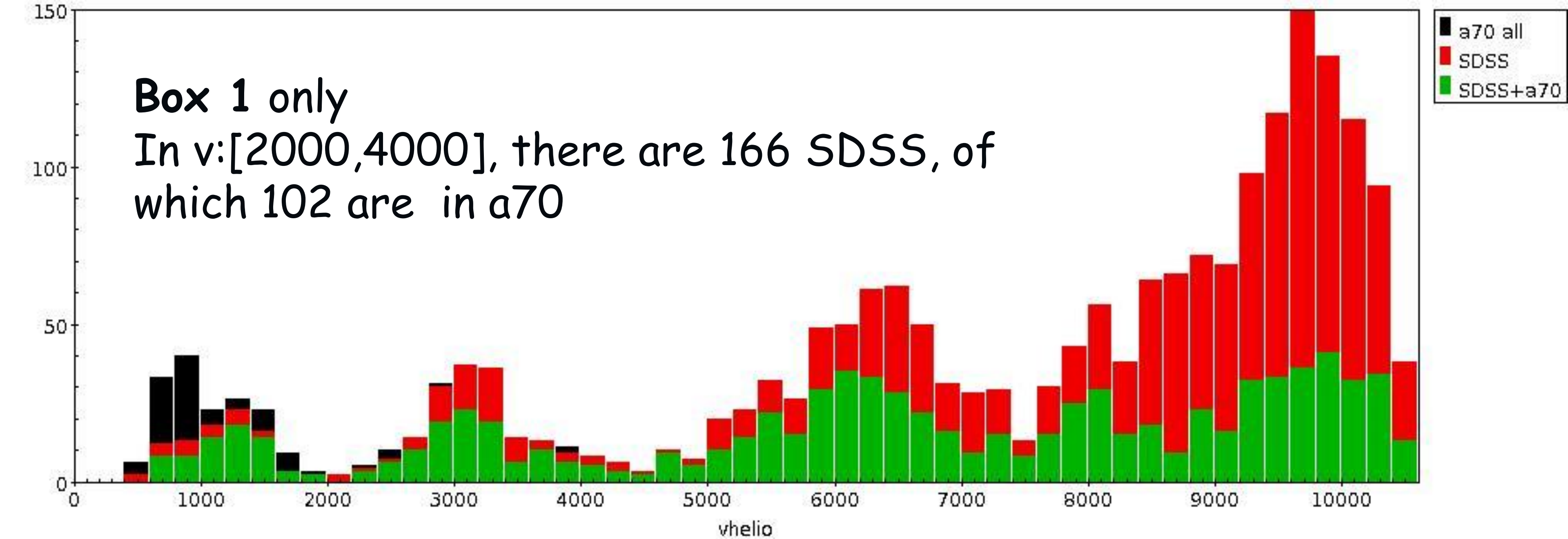
Note overdensity between 2-4000 km/s

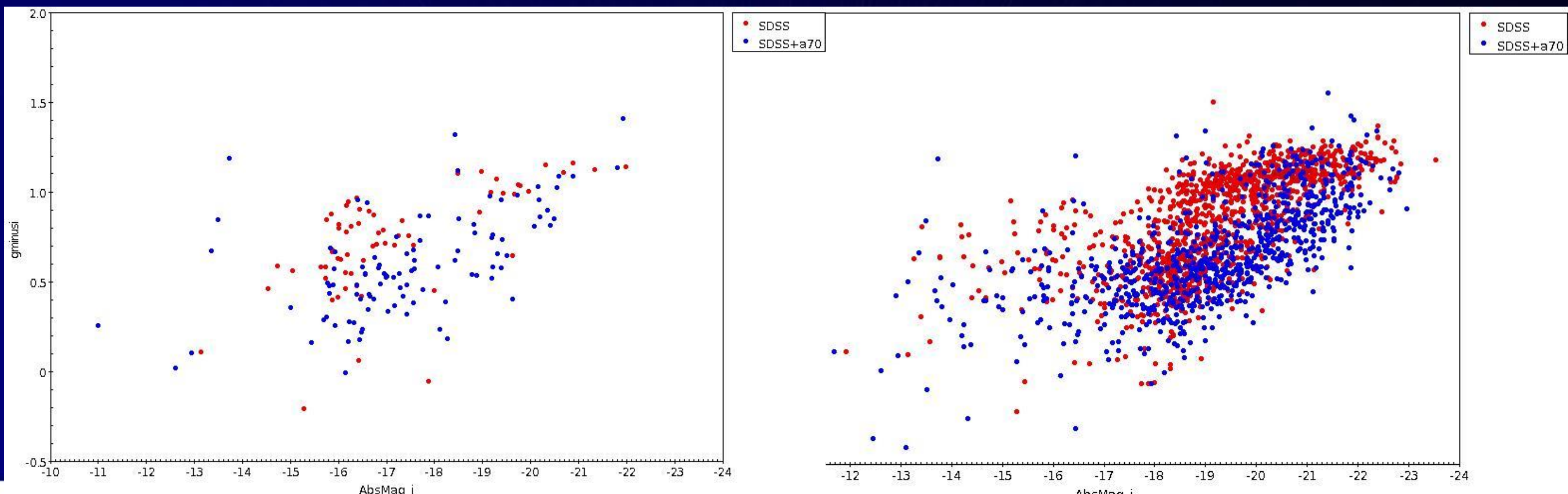




Box 1 only

In v:[2000,4000], there are 166 SDSS, of which 102 are in a70





Overall points

- We need better statistics at the low mass end of the HIMF and the low Vrot end of the HIVF.
- Even with ALFALFA, our ability to detect galaxies with $\log M_{HI} < 8.5$ is limited to a very nearby volume.
- Nearby, the distance uncertainties are a killer.
- New simulations predict "colors"/types of galaxies; we only need the blue and low L ones.

1. Get HI of complete SDSS sample cut in cz/distance= (20,80 Mpc) at least in selected spring regions=> A2941.
2. Use SDSS/GALEX photometry in fall to conduct redshift survey complete to SDSS limit for blue galaxies.
3. Reprocess SDSS/GALEX as necessary to get better photometry, inclinations etc. (Shan examined each gal; reprocessed those needing it; many don't but others are clearly bogus => scatter!)
4. Can we define the sample well enough to be able to correct for its **bias?**