Extragalactic HI Surveys

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UAT Workshop at Green Bank

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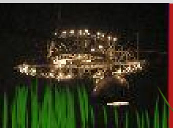
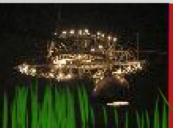


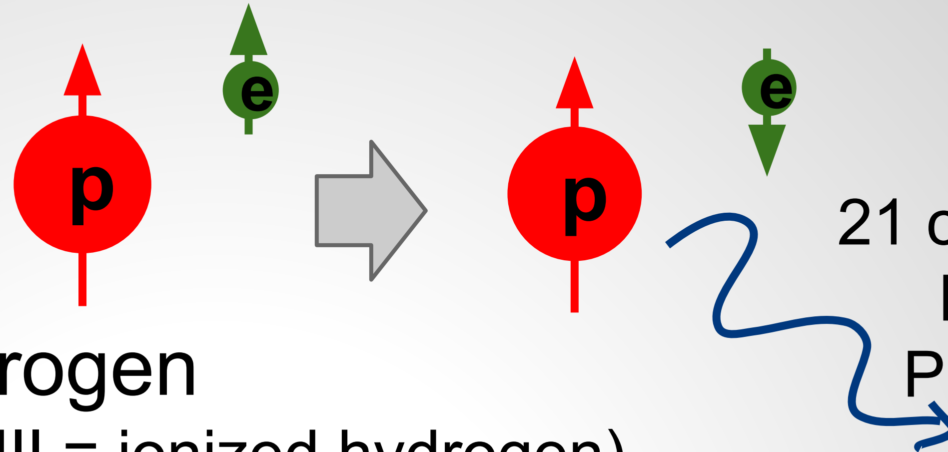
ALFALFA

Extragalactic HI Surveys: Outline

- Review: What is HI?
- Things to think about when designing a survey to look for HI in galaxies
  - The radiometer equation
  - Survey “Figure of Merit”
- Example HI surveys
  - What we do: ALFALFA
  - What we do: APPSS
- The Future of HI Surveys



What is HI?



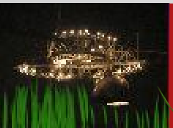
21 cm/1420 MHz Photon

- HI is atomic hydrogen
  - (as opposed to HII = ionized hydrogen)

- Why do we care about HI?
  - **Different biases than optical samples:**
    - Optical misses galaxies with few stars or diffuse objects, we still see them.
    - We see parts of galaxies we otherwise miss - gas traces a galaxy's rotation to large radii.
  - **Stars form from (molecular) gas:**
    - Atomic gas is a galaxy's reservoir of gas.
    - Gas rich galaxies are the galaxies forming stars.

Survey Design: Blind vs Targeted

- Targeted Surveys:
  - Choose specific galaxies to observe
  - Good: Efficient
  - Bad: Selection bias
- Blind Surveys:
  - Choose where to look without prior knowledge
  - Good: No selection bias
  - Bad: Time consuming (requires sensitive telescopes)



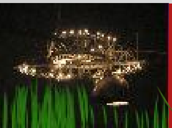
Survey Design: How Long to Look

- 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 Arecibo LBW:
$T_{sys} \sim 30K$
$G \sim 11$ K/Jy
For GBT L-band:
$T_{sys} \sim 20K$
$G \sim 2$ K/Jy

- Δf : is the bandwidth per channel
- t_s : is the effective integration time, in secs
- f_t : other losses (smoothing, bandpass subtraction, clipping, etc.)
- 2 from two independent polarizations.
- See Giovanelli + 2005, AJ 130, 2598



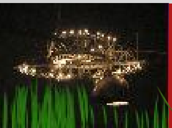
How "fast" is your survey?

$$FoM \propto (A_{\rm eff}/T_{\rm sys})^2 \Omega_{\rm fov} {\rm BW}$$

- HI survey "figure-of-merit" depends on:
  - Sensitivity: Collecting area & system noise
  - field-of-view & number of beams (pixels)
  - Bandwidth (redshift coverage)

Survey Design: Other Considerations

- Radio frequency interference (RFI)
- Angular Resolution:
  - Source confusion
  - Resolved sources; impact on sensitivity
- Computational requirements
- Telescope Scheduling
  - Possibility of commensal surveys
  - What part of the sky??
- Auxiliary data at other wavelengths?
- And more...



Which telescope do you choose?

Arecibo	GBT	Parkes
		
D=300m	D=100m	D=74m
Tsys=30K	Tsys=20K	Tsys=28K
FOV=7*3.5^2	FOV=1*9^2	FOV=13*15^2
Low Confusion	High Confusion	Very High Conf.
Bad RFI	Good RFI	Good RFI
Limited sky area	Large sky area	Large sky srea

Past and Current HI Surveys

Pre-1990s: Targeted Surveys

Mid-90s-present: Blind (and targeted) Surveys

Table 1 Comparison of major blind HI surveys

Survey	Beam (′)	Area (deg^2)	δ_v ($km\ s^{-1}$)	rms[a] (mJy)	V_{med} ($km\ s^{-1}$)	N_{det}
AHISS	3.3	13	16	0.7	4800	65
ADBS	3.3	430	34	3.3	3300	265
HIPASS	15.	30000	18	13	2800	5000
AGES	3.5	200	11	0.7	9500	2900
ALFALFA	3.5	6920	11	1.7	8200	31000

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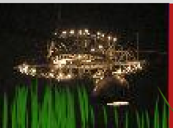
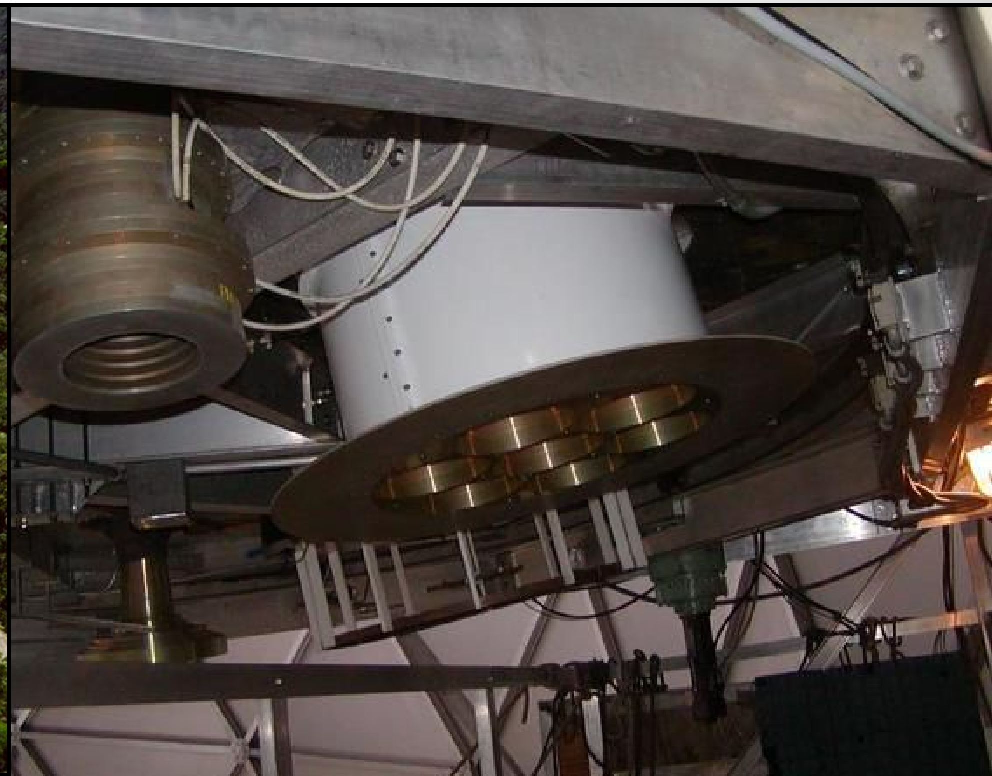


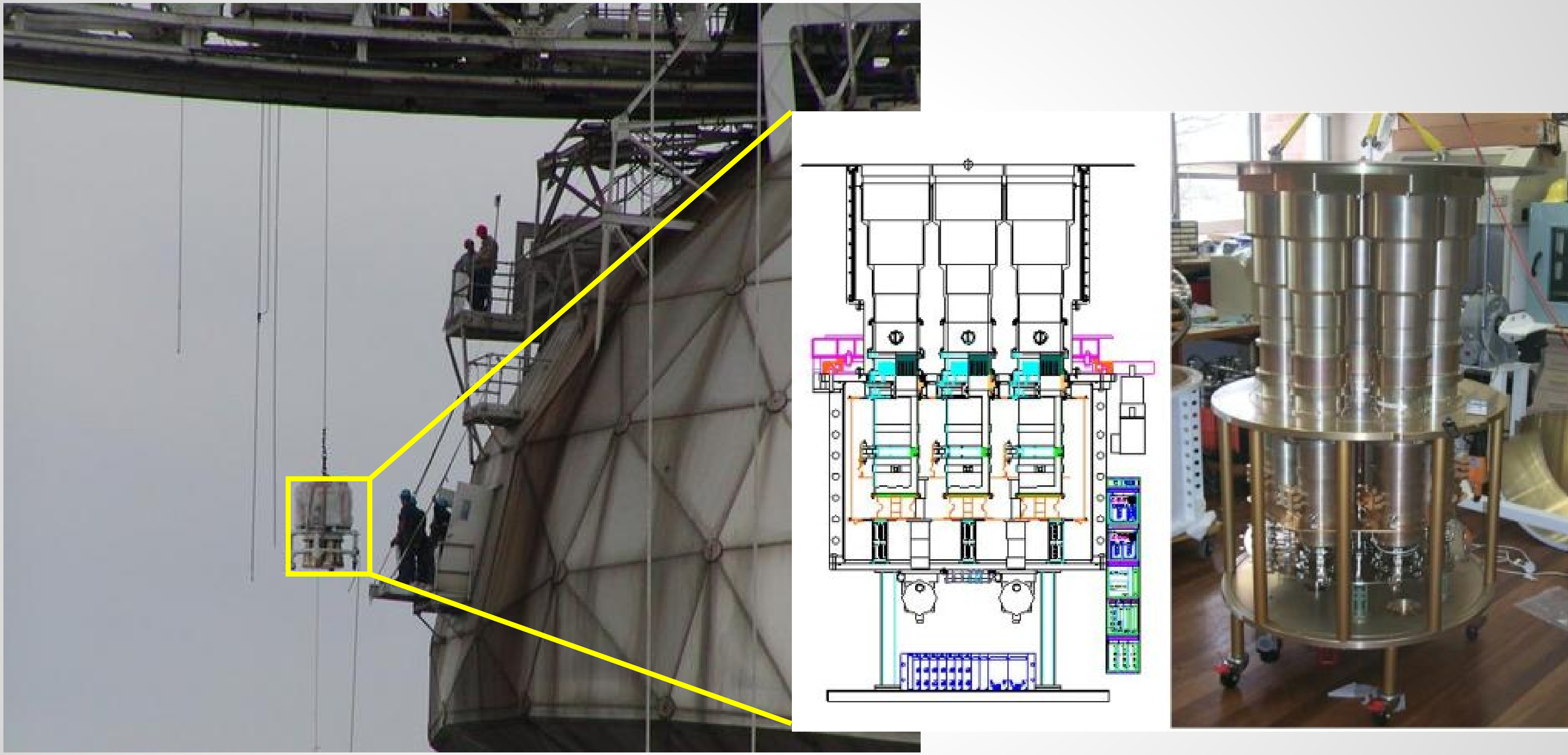
Design to Practice: Introducing...

<u>The Arecibo Legacy Fast ALFA Survey</u>

ALFA = Arecibo L-band Feed Array



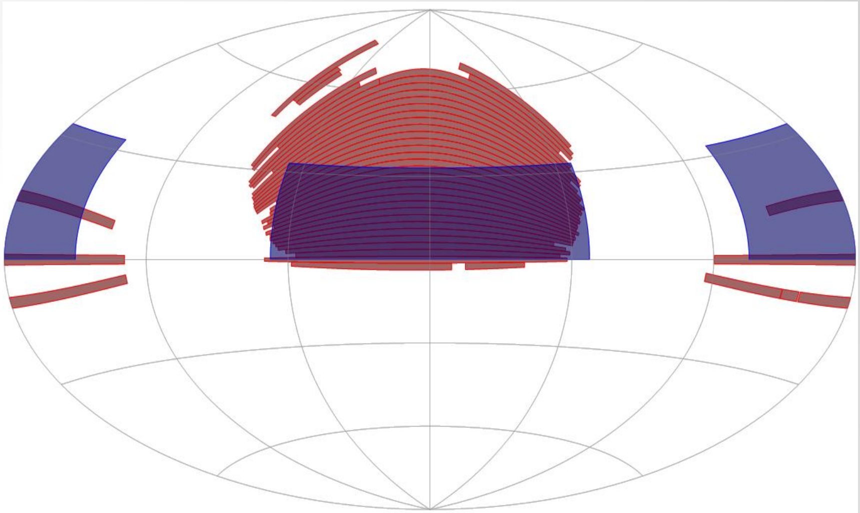
ALFA: A "Radio Camera"



Arecibo L-band Feed Array (ALFA)

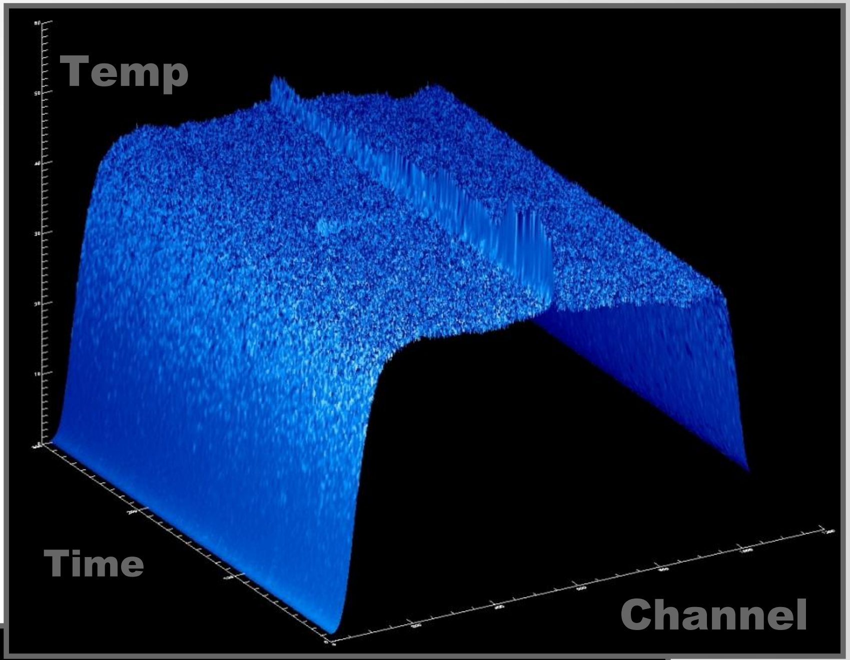
So what is ALFALFA?

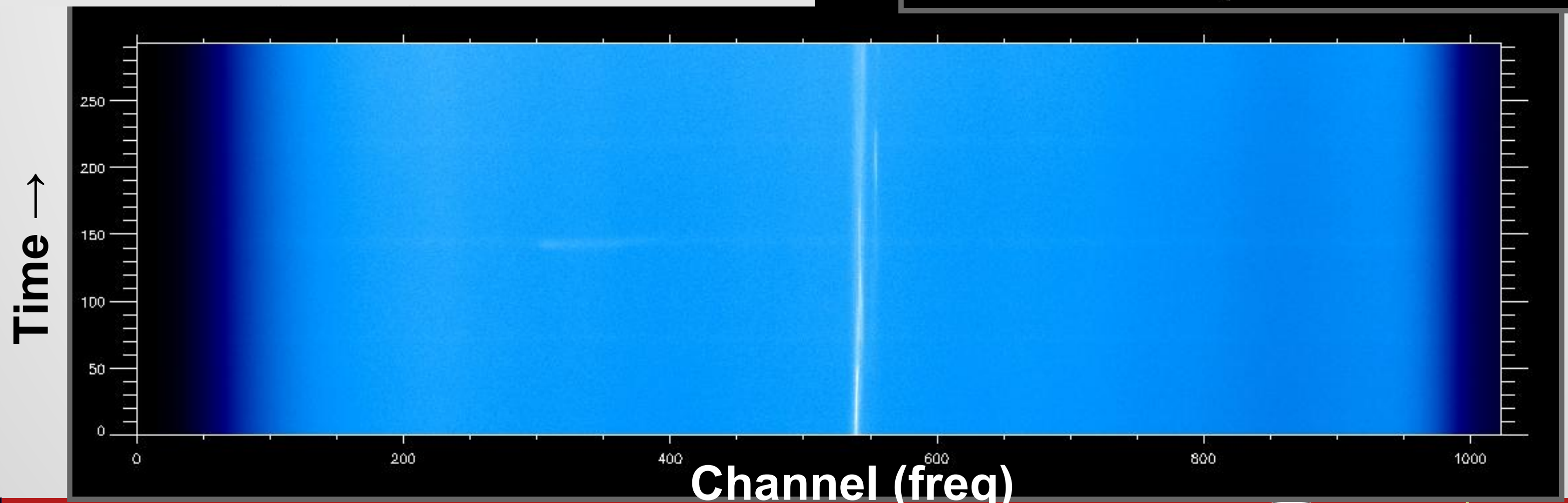
- A radio survey at 21cm
  - 4x better resolution and 10x better sensitivity than previous 21cm surveys
- Survey of local galaxies
  - z≤0.06, ie distance ≤250 Mpc (local group ~1 Mpc)
- “Blind” Survey of ~17% of the sky
- A perennial flowering plant in the pea family; often feeds large farm animals



How does ALFALFA work?

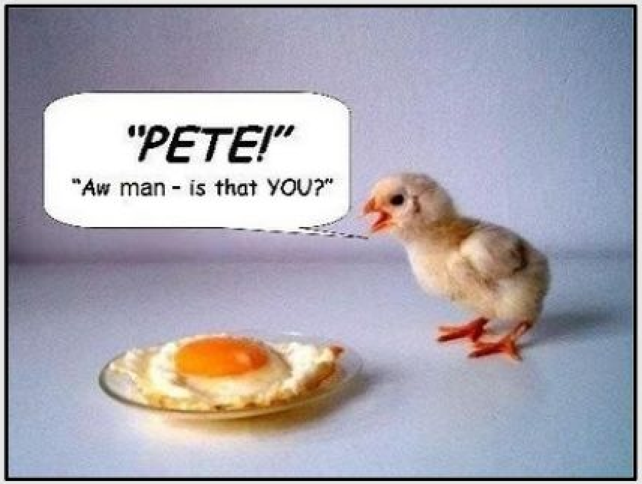
- Observing: Drift scan



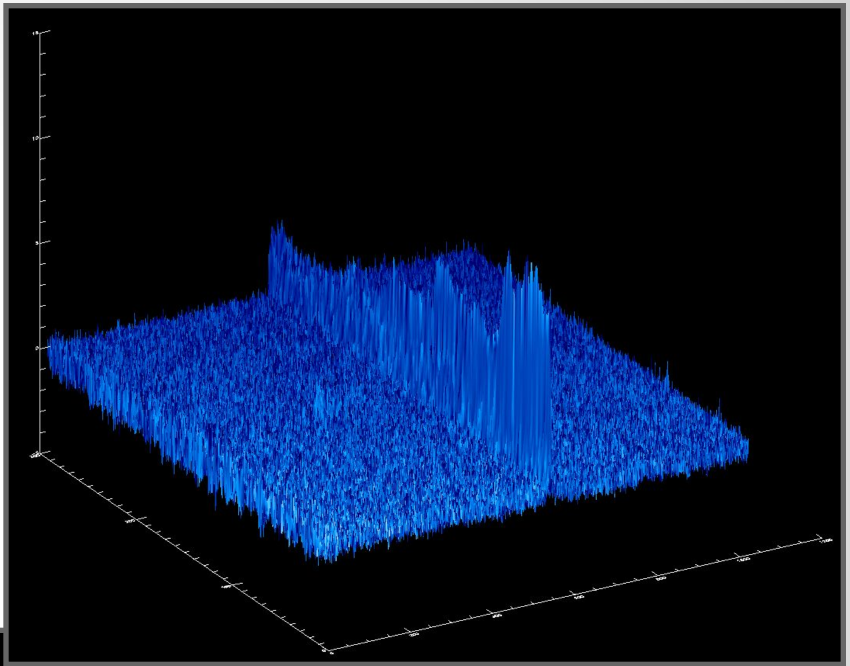


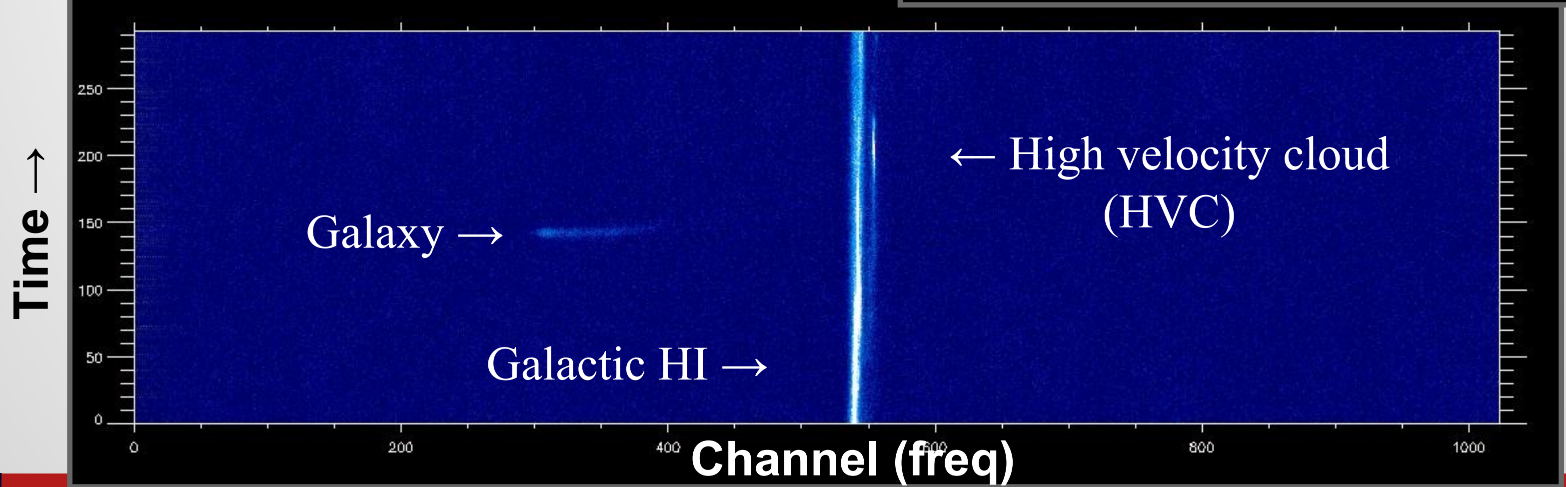
How does ALFALFA work?

- Data reduction

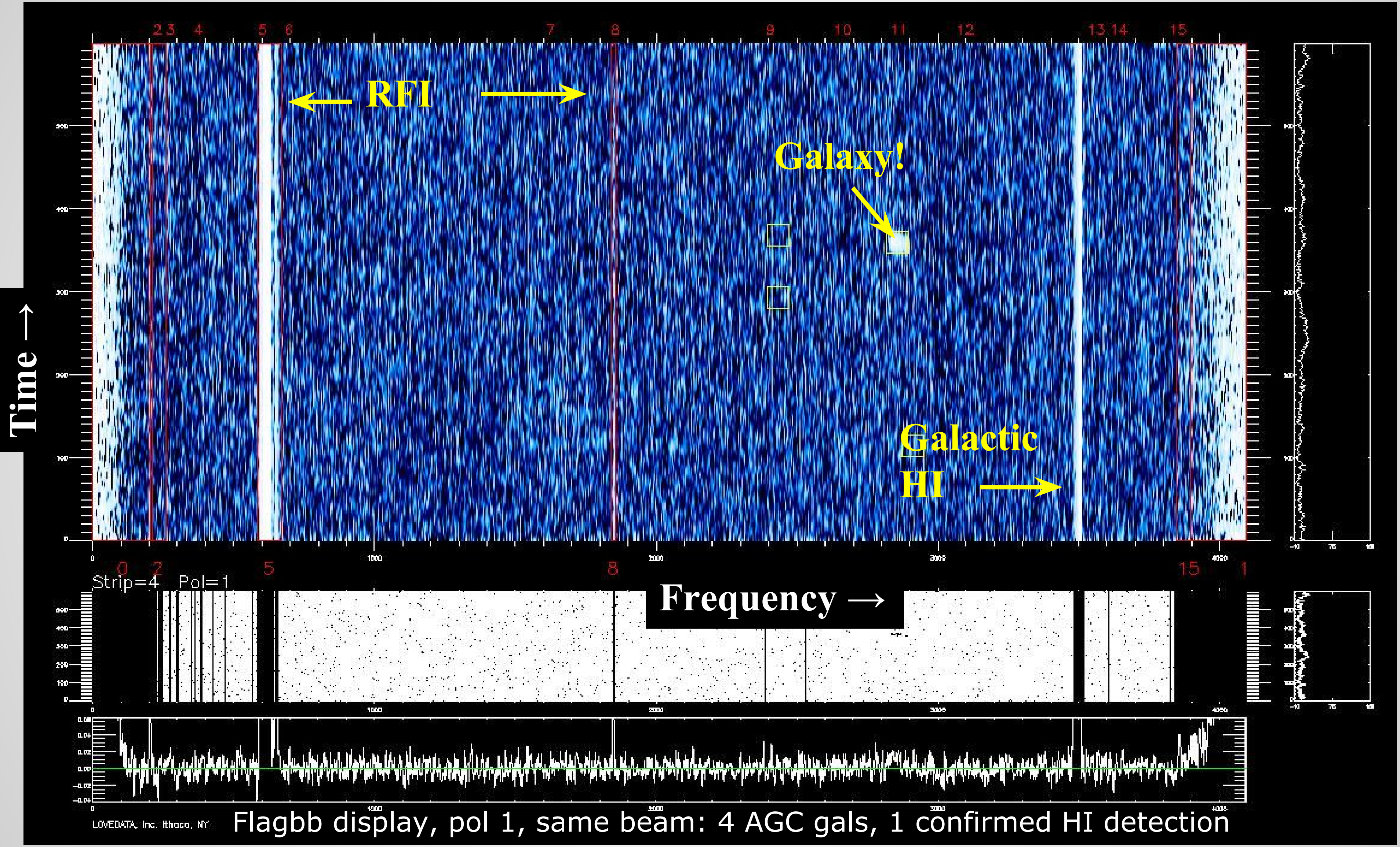


"If you want to make omelettes you've got to break some eggs!"



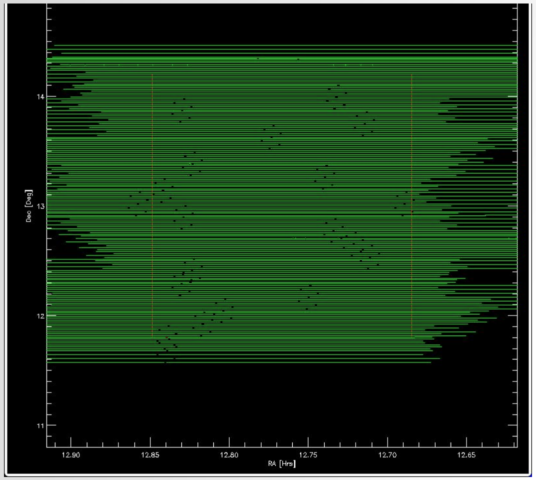


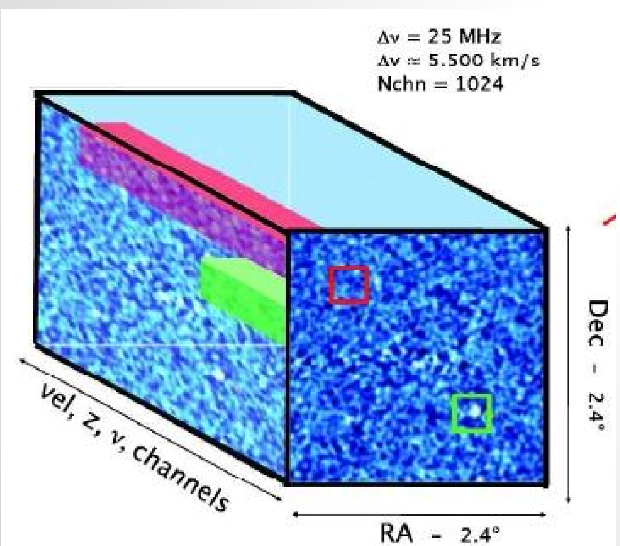
Dealing With RFI...



Flagbb display, pol 1, same beam: 4 AGC gals, 1 confirmed HI detection

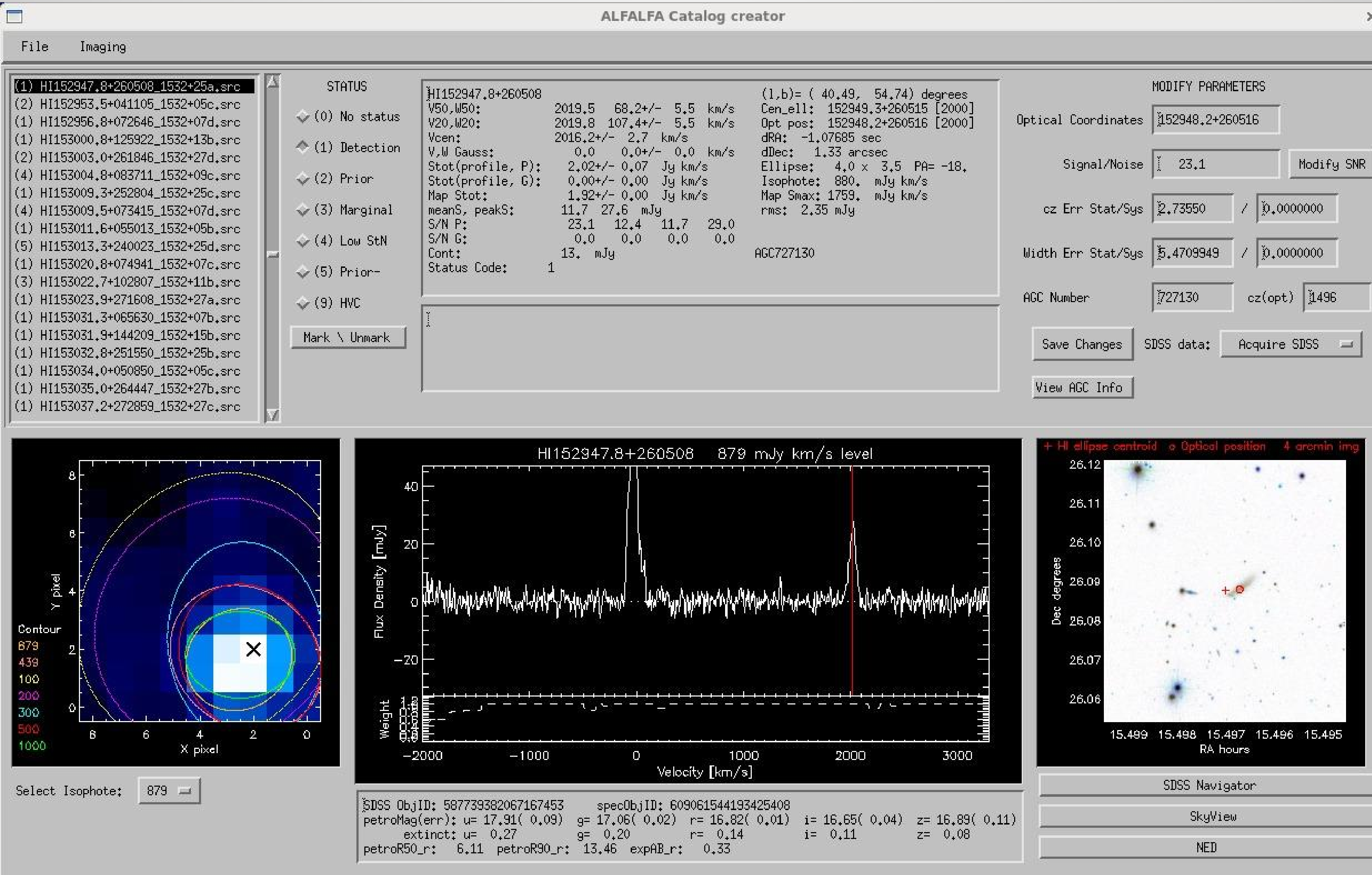
From Drifts to Grids





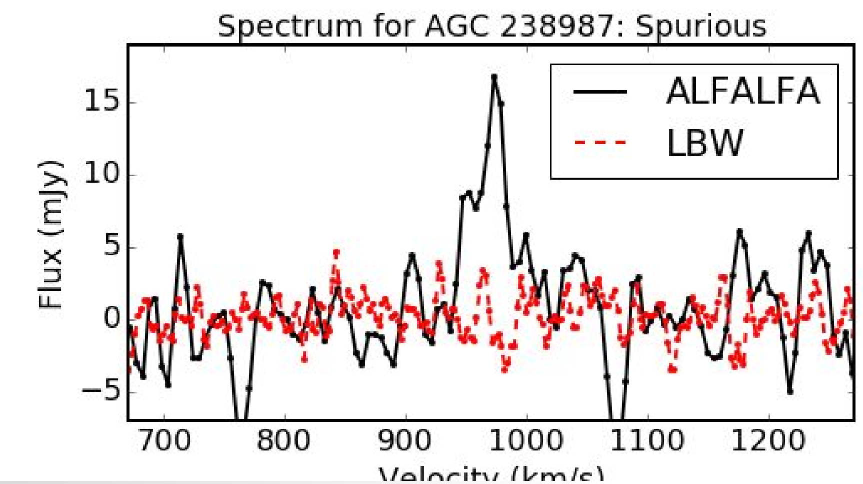
- Combine individual drift scans to produce a 3-D data cube, “grid”
- Standard ALFALFA grids are 2.4°x2.4°
- Each “grid” region of the sky is split into 4 frequency (cz), partially overlapping cubes, of 1024 freq/vel chans/each

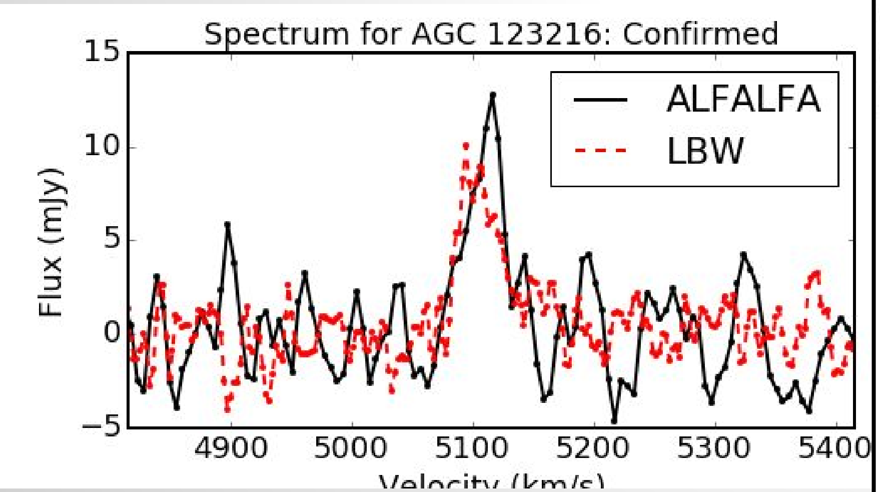
Source Extraction

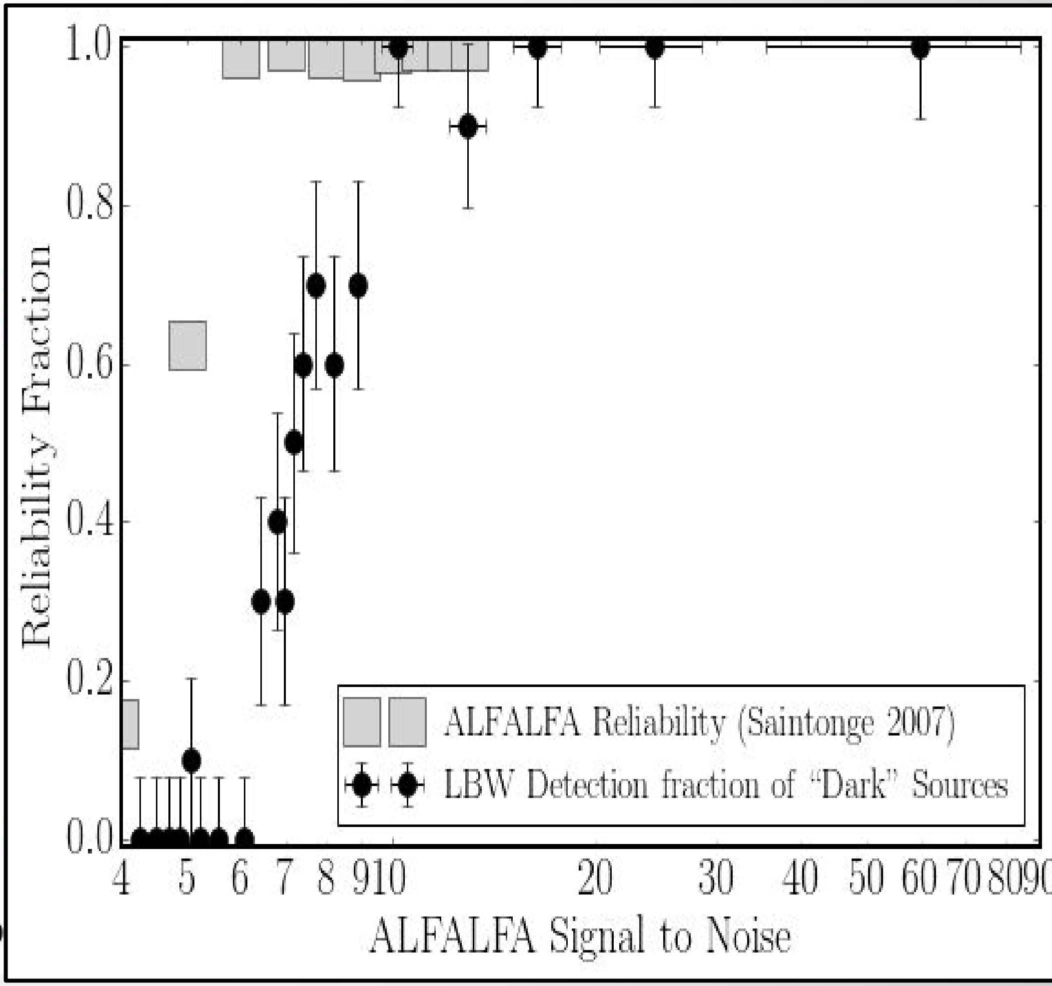


Problem: are the detections real?

Solution: follow up with more Arecibo observations

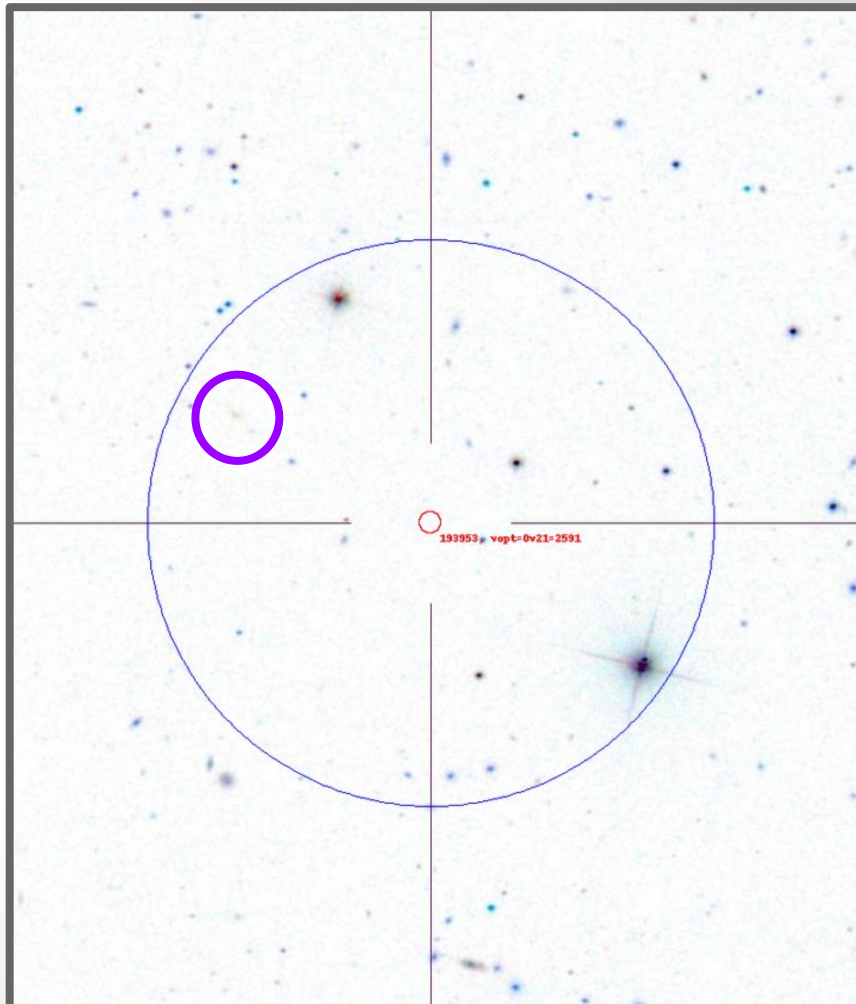






Identifying Optical Counterparts

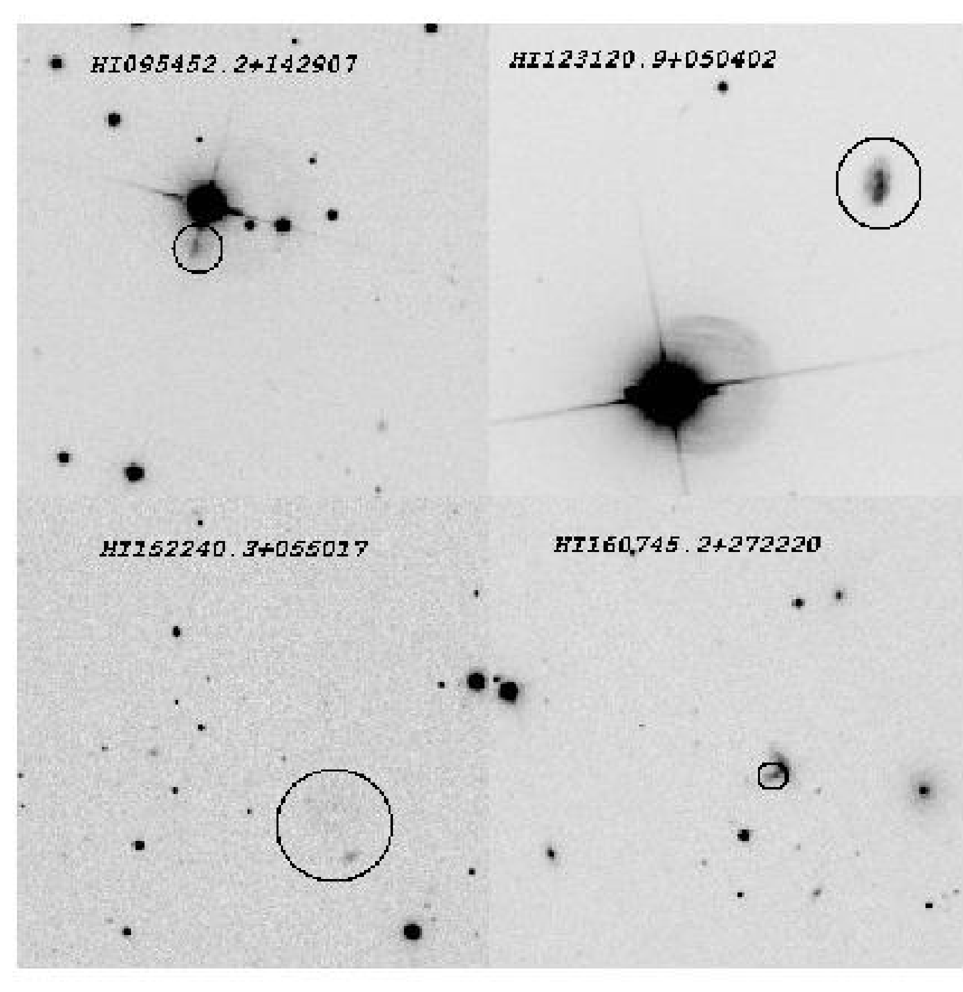
- ALFALFA does not resolve galaxies
- Beam (resolution) ~3.5’ (~200x normal optical telescopes)
- Sources not in the center of the beam
- Sometimes stars in the way



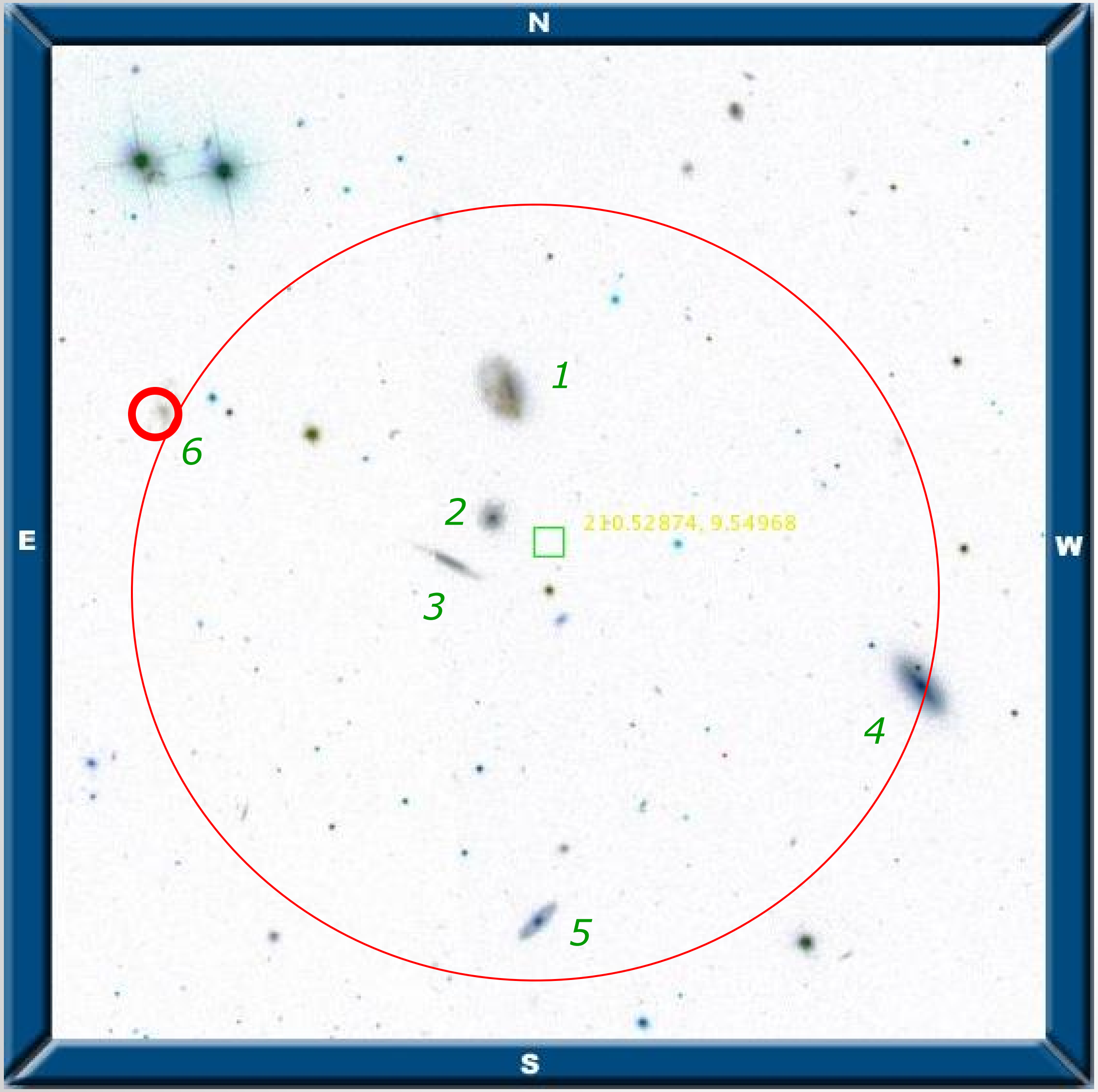
Identifying Optical Counterparts

Of 15855 sources in α.40:

- 1013 have no OC
- 844 are likely part of the MW
- 199 (<2%) extragalactic "darks"
- Of those, <50 are "isolated"



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′

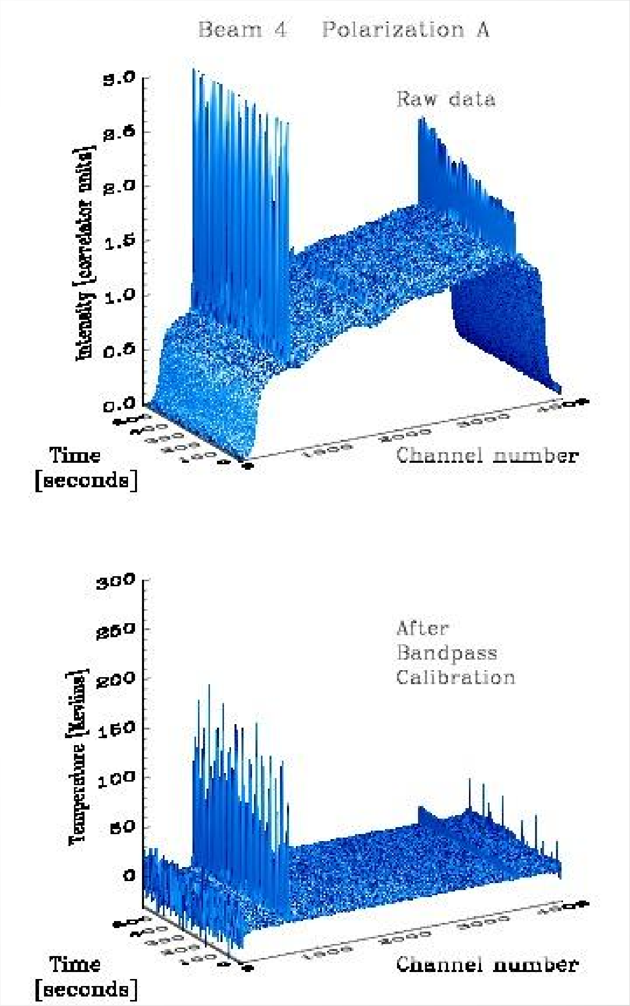
The current state of ALFALFA

- Observing is done!
  - 4742 hours over almost 8 years
  - 808 observing runs
  - 99 observers
- All level 1 processing done
- Catalog >70% complete
- >25,000 extragalactic sources!

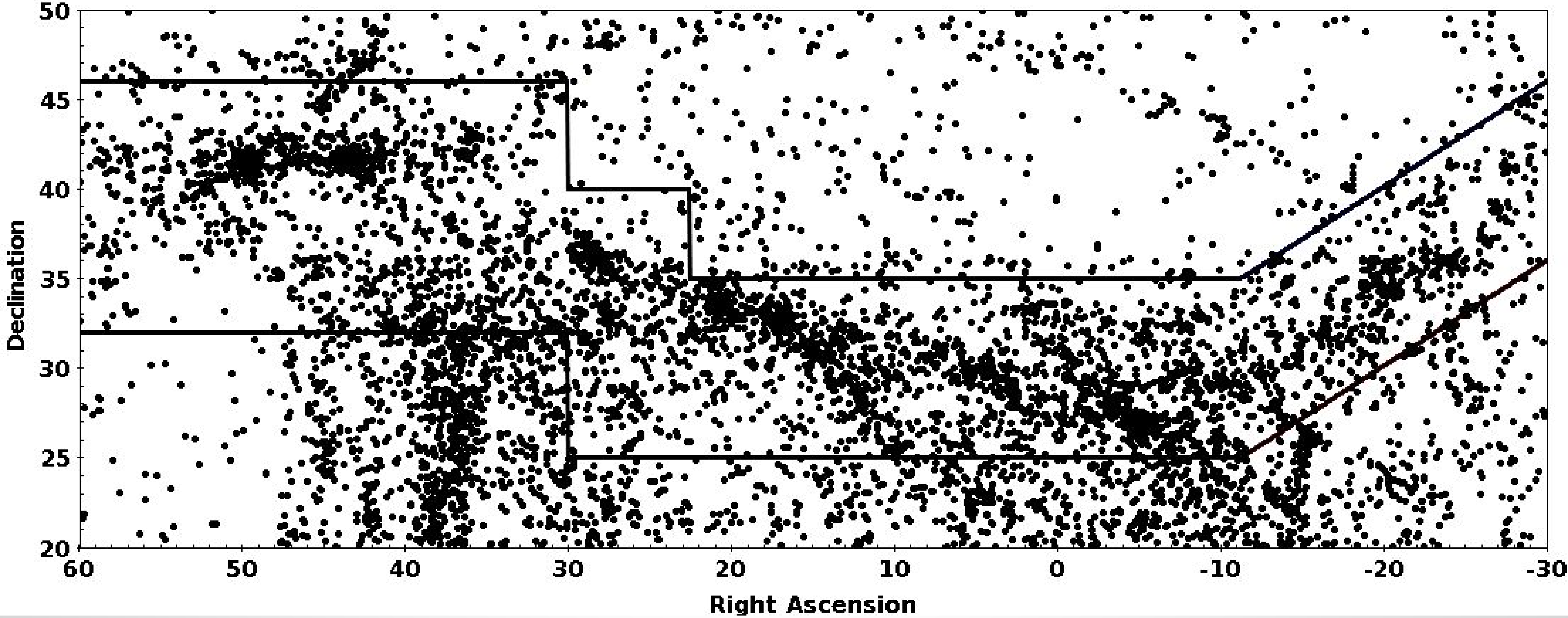
Aside:
Drift Scan vs Position Switching

- Sources much weaker than noise (Tsys)
- Need to subtract away known noise = blank sky

- Drift scan: lots of blank sky
- Pointed observing: Need to also point at blank sky (ON/ OFF pointings)



APPSS



50
45
40
35
30
25
20
Declination
60
50
40
30
20
10
0
-10
-20
-30
Right Ascension

Future HI Surveys: Interferometers

<u>Upgraded Telescopes</u>

The JVLA

WSRT

<u>New Telescopes</u>

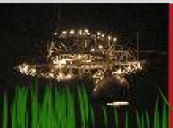
ASKAP

MeerKAT

Future HI Surveys

Survey	Res.[#] (″)	Area (deg^2)	z	$N_{det}^{\dagger}$	Ref	Note
VLA-B						
CHILES	5	0.8	<0.5	300	a	COSMOS deep field
WSRT/APERTIF						
WNSHS*	15	3500*	<0.26	50000*	b	Shallow, wide area
MediumDeep*	15	200*	<0.26	1×10^{5}*	c	Selected fields
ASKAP						
WALLABY	30	30000	<0.26	$>3\times10^{5}$	d	Shallow, wide area
DINGO-DEEP	10	150	0.1–0.26	50000	e	GAMA region
DINGO-UDEEP	10	60	0.1–0.43	50000	e	GAMA region
FLASH	30	Targeted	0.5-1.0	few 100s	f	HI absorption
MeerKAT						
MHONGOOSE[&]	12	30 × 0.8		30[&]	g	30 nearby galaxies
LADUMA	12	4	<1.4	10000	h	ECDF-S deep field

Giovanelli & Haynes 2016



Summary

- Lots to consider designing HI surveys
  - How long to look
  - How fast can you survey a volume of space
  - Lots of other things (RFI, confusion, etc.)
- ALFALFA is a state of the art blind HI Survey
  - Drift scan observing
  - Lots of reduction steps
  - Identifying OCs
- Lots of Exciting Future Science
  - APPSS
  - Surveys with upgraded and new telescopes