Introduction to LBW for ALFALFA followup

Martha Haynes
UAT13 13.01.14
## ALFALFA source codes

ALFALFA HI detections are coded according to:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code 1</td>
<td>High quality sources, typically with S/N &gt; 6.5</td>
</tr>
<tr>
<td>Code 2</td>
<td>Sources of lower S/N which are coincident with a probable OC of the same redshift (known from another source) =&gt; the “priors”</td>
</tr>
<tr>
<td>Code 3</td>
<td>Low S/N sources without identifiable OC</td>
</tr>
<tr>
<td>Code 4</td>
<td>Low S/N sources with a possible OC of unknown redshift</td>
</tr>
<tr>
<td>Code 5</td>
<td>Corresponding to Code 2, but of such low S/N or possible RFI contamination that they are untrustworthy</td>
</tr>
<tr>
<td>Code 6</td>
<td>Like OH megamasers at 0.16 &lt; cz &lt; 0.24</td>
</tr>
</tbody>
</table>
Signal Extractor -- Introduction

- The signals are extracted by cross-correlations of a template with the spectra. => “matched-filter algorithm

- More sensitive than peak-finding algorithms.
- Sensitive to total flux, not only peak flux
- Especially important for low mass systems
- Using FFT's, cross-correlations are computationally fast

Saintonge 2007 AJ 133, 2087
Signal Extractor -- Application(2)

The process is:

- Repeat for a range of widths of the template
  - e.g. 10 km/s - 600 km/s
- Choose the width for which the convolution is maximised --> position of the signal
- Calculate the amplitude of the signal from the width
Low S/N
"Dark" galaxy candidate
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”
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'.
• In agreement with previous results, ALFALFA finds that fewer that 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).
“Dark” object in a group

HI peak with no optical/marginal UV: almost dark?

MH, RG (CU), Cannon (Macalester), Salzer (Indiana), Karen Lee-Waddell, K. Spekkens (RMCC/Queens)
Ongoing deeper B,R band imaging of HI detections with no OC

Salzer, Adams
**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 "megamasers".

- Such objects are also typically (ultra) luminous in the far-infrared.
18 cm OHMs
18 cm OH lines

- First molecular lines detected in radio.
- 18 cm lines formed by “lambda doubling” hyperfine structure
- 1612, 1665, 1667 and 1720 MHz

Pacholczyk, Radio Astrophysics
Redshifted 18 cm OHMs in ALFALFA

- $f_5 = 1665.4018$
- $f_7 = 1667.3590$

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

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

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 $0.166 < cz < 0.244$
- Emission with no OC
OHM candidates in α.40

<table>
<thead>
<tr>
<th>AGC</th>
<th>OHM Coords (J2000) (hh mm ss.s+dd mm ss)</th>
<th>Opt. Coords (J2000) (hh mm ss.s+dd mm ss)</th>
<th>z_{opt}</th>
<th>z_{OH}</th>
<th>cz_{21} (km s^{-1})</th>
<th>F_{OH} (Jy km s^{-1})</th>
<th>S/N</th>
<th>rms (mJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>102708</td>
<td>000337.0+253215</td>
<td>000336.1+253204</td>
<td>0.169</td>
<td>−1335</td>
<td>0.91</td>
<td>5.7</td>
<td>2.33</td>
<td></td>
</tr>
<tr>
<td>102850</td>
<td>002958.8+305739</td>
<td>002958.2+305832</td>
<td>0.172</td>
<td>−596</td>
<td>0.46</td>
<td>6.7</td>
<td>2.09</td>
<td></td>
</tr>
<tr>
<td>181310</td>
<td>082311.7+275157</td>
<td>082312.7+275138</td>
<td>0.16783</td>
<td>0.168</td>
<td>−1551</td>
<td>2.17</td>
<td>15.9</td>
<td>2.18</td>
</tr>
<tr>
<td>228040</td>
<td>124540.5+070337</td>
<td>124545.7+070347</td>
<td>0.172</td>
<td>−624</td>
<td>0.33</td>
<td>5.1</td>
<td>2.11</td>
<td></td>
</tr>
</tbody>
</table>

AGC 181310:
- Previously discovered OHM by Darling & Giovanelli (2001)
- Coincides with SDSS J083212.61+275139.8 at z=0.167830
- Also IRAS 08201+2801 and 5C 07.206

We need to confirm the others, and a few more low SNR sources.
AGC 181310: confirmed OHM

cz(HI) = -1518 km/s
• 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 $T_{\text{sys}}$ than ALFA
Position-switched observing

The signals we are trying to take are 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
Position-switched observing

- Position telescope on target source
- Track ON-source for 3 minutes
- Move to same Az,ZA as at start of ON-source track but 4 mins from now; this is the OFF-source position.
- Track OFF-source for 3 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.
Spectrometer setup for LBW

**ALFA spectra:**

16 x 4096 frequency channels (2 not used)

7 beams X 2 polarizations/beam

100 MHz wide

Centered at 1385 MHz

So resolution is 100 MHz/4096 channels
Spectrometer setup for LBW
Interim Correlator

LBW spectra:
4 x 2048 frequency channels
1 beam X 2 polarizations/beam
Low res/high res
25 MHz / 6.25 MHz
Centered at doppler velocity of target

So resolution is
Low res: 25 MHz/2048 channels
High res: 6.25 MHz/2048 channels
Estimating how long we integrate

The radiometer equation for our observations

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

\( \Delta f \): 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

For LBW,
\( T \sim 30K \)
\( G \sim 11 \text{ K/Jy} \)
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 megamasers (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 (A2669 only)

ALFALFA: effective integration time of 40 seconds/beam
LBW: 3 minutes ON-source
Scavenger Hunt #1

Next: 15 min break

Then: Work on SH #1
  Work in your groups
  ASK questions!

15:15: Remote observing demo