2003: NAIC/NRAO Hands-On HI Absorption Project

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1. Introduction

1.1. Aims

This experiment is designed to illustrate the following;

1. Remote observing with the Arecibo 305-m telescope.
2. Obtaining good quality Arecibo spectral-line measurements for a source emitting significant continuum radiation.
3. Single-dish spectral-line data reduction.
4. Comparing the results of the experiment with those present in the literature.

1.2. Problems at Arecibo with Measuring the Line Spectrum of a Source emitting Significant Continuum Radiation

When the simple position-switched technique is used to measure the emission or absorption line spectrum of a source that also emits a significant amount of continuum emission, (i.e. sufficient continuum emission that the antenna temperature it produces, T_a, contributes a significant additional component to the system temperature, T_{sys}), problems can arise due to residual standing waves for any telescope with a partially blocked aperture. An extreme case of aperture blockage occurs with the Arecibo 305-m radio telescope, where the feed platform and a good fraction of its support cables are situated within the volume traversed by the incoming rays being focused on the telescope feed. This large structure can also scatter significant amounts of radiation from the surrounding hills, and other radiation sources arising outside the telescope main beam.

When making spectral-line observations at Arecibo of sources emitting at most weak continuum radiation, i.e. $T_a \ll T_{sys}$, bandpass effects are usually minimized by using a variant of the popular position-switching technique implemented such as to take account of the unique design of the 305-m telescope. Firstly, the target source is observed for a given length of time. Then, a reference region of "blank sky", whose position is chosen to traverse exactly the same azimuth and zenith angle range as that over which the source was measured, is observed for the same duration. As the suspended structure of the telescope is fixed relative to the ground, the assumption is made that the standing-wave pattern of the two observations are identical, and hence the quantity (ON(ν) – OFF(ν)) / OFF(ν) is formed, the subtraction providing a line spectrum free of standing-wave ripples caused by sources lying outside the telescope full beam or within the receiver system, while the division by the OFF spectrum corrects the signal for the system bandpass.

This approach breaks down when the target is a source which emits significant continuum radiation. Under these circumstances, the component of the standing-wave pattern due to the continuum emission from the target source is not at all cancelled by subtracting the source-free OFF data from the ON, and a standing-wave residual whose amplitude is proportional to the source intensity remains to degrade the spectrum. Some previous observers, (e.g. Briggs, Sorar & Taramopoulos, 1993, ApJ, 415, L99), have extended the above basic position-switching method such as to minimize the effects of the residual standing wave when observing a strong continuum source. To achieve this, another continuum source of different redshift (to avoid the possibility of its possessing an emission or absorption line near the same frequency as the target) is also observed in the same ON/OFF position-switched mode. For this, the azimuth-zenith angle track followed during this observation is made to be as near as possibly the same as for the target source. Division of the target spectrum by that of the reference source then cancels the residual standing wave. The result is a spectrum whose magnitude is proportional to the ratio of the target and reference flux densities across the observing bandwidth, including any spectral-line component that may be present in the target.

Ghosh & Salter (ASP Conf. Ser., 278, 521; for more details of the observing technique, see also http://www.naic.edu/~astro/atoms/performance.shtml and click on 2001-02.ps) explored this "double position-switching" (DPS) approach to improving Arecibo spectral baselines when observing sources having significant continuum emission and found it to be rather effective.

1.3. The Project

The galaxy Arp 220 (= IC 4553; RA = $15^h34^m57.26^s$, Dec = $23°30'11.1''$) is a prototype starburst system. The object possesses twin nuclei, and emits strong main-line OH maser emission. It also displays strong absorption in the λ21-cm hyperfine line of neutral hydrogen (HI), e.g. see Mirabel (1982, ApJ, 260, 75), and Baan *etal.* (1987, ApJ, 313, 102). The galaxy also has a continuum flux density at 1.4 GHz of 326 mJy, adding about 3.5 K to the 30 K system temperature of the Arecibo L-wide receiver.

The present project is to make remote Arecibo spectral-line observations of Arp 220 using the "double position switching" (DPS) technique, recording data for,

1. The 1420-MHz HI lines
2. The 1665- and 1667-MHz OH main-lines

3. The 1612-MHz OH satellite line.

4. The 1720-MHz satellite line.

As DPS bandpass calibration source, the nearby strong source, J1531+240, will be used. This has a position of RA = $15^h31^m50.71^s$, Dec = $24°02'43.3''$ and NVSS lists a flux density at 1.4 GHz of 2892 mJy.

The data will be reduced via the Arecibo IDL package, and can then be compared with prviously published information. In addition, the ON/OFF data for Arp 220 alone should be processed by the standard (ON – OFF)/OFF algorithm, and the results compared with the DPS spectra, i.e. was it worth the extra complication of using the DPS approach in this case?

2. Making the Remote Arecibo Observations

2.1. Remote login and Starting up

This is just a summary of all you need to do for remote astronomical observations with the 305-m telescope. More details can be found at http://www2.naic.edu/ aoui/manual/remote.shtml

- The remote observer calls the control room at least 15 minutes in advance to obtain the current "dtusr" password and pass on any special requests for setup in the observing room.
- Open an X-Windows display on your local machine, and perform a secure login to "remote" with your AO username (NOT "dtusr" at this point).

  "slogin remote.naic.edu –l username"
- Next, log into observer2 using slogin, i.e. slogin observer2 –l dtusr (use the password obtained from the telescope operator).
- From the observer prompt, type "cima" and follow the procedure in the subsection "Taking DPS data"

2.2. Starting up the AO Status Display ..by Jeff Hagen(Optional)

There is a display in the Arecibo control room that looks nice and is designed for the use of observers. It is available for observers and runs on linux or SunOs. Here is a quick tutorial.

The "aostatus" display is an X application and can be run from almost any Sun or linux box at Arecibo. The destination X server needs to have TrueType fonts installed. Solaris boxes need to set the fontpath as below. Linux displays need to configure themselves for TrueType fonts.

- Sun - To make “aostatus” work on the Sun, follow these directions. The Sun fonts come already installed. The font that is used is:

  Sun fonts: ”-monotype-arial-regular-r-narrow-*-22-*-*-*-*-*-*-*”

  Login to the Sun and start the openwindows if it didn’t start already. All that is needed is the following xset command:

  xset fp+ /usr/openwin/lib/X11/fonts/TrueType

  Then to run “aostatus” on the openwindows display:

  /home/aoui/display/solaris/aostatus

  The “aostatus” program will see if it can find one or the other of these fonts on the Xserver that it connects to. Otherwise it does the best that it can (which means the info is there but it is ugly). It doesnt matter where you run the executable.

- Linux - The version of Red Hat linux that is used at Arecibo does not come with the truetype fonts installed. The font that is used when connecting to a linux X11 server is:

  Linux Font: ”-monotype-arial narrow-*-r-*-*-22-*-*-*-*-*-*-*”

  Here are directions for sys admins to add the fonts to a particular machine running XFree86. Add the following lines to the XFree86 configuration file that you are using. Now on Jeff Hagen’s machine it is:

  /etc/X11/XF86Config-4 or XF86Config.

  Section ”Files”

  FontPath ”/usr/X11R6/lib/X11/fonts/TrueType”

  and

  Section ”Module” Load ”freetype” TrueType font handler

  Type:

  cd /usr/X11R6/lib/X11/fonts mkdir TrueType cd TrueType

  Expand the tar file with

  tar xfvz true.tar.gz

  Restart the X server - by logging out and logging back in. Then start the display for linux:

  /home/aoui/display/aostatus/aostatus

2.3. Taking DPS data with CIMA

Typing “cima” initiates the GUI and starts up four windows:

“Indentify New User”, “executive”, “AO Observer Display” and “CIMA Observer’s Interface”.

The "executive" shows the actual commands going to the various subsystems in system specific language (not all of which are very intuitive). It is just a passive window most of the time.

The "AO Observer Display" is semi-passive, and also shows system functions, but in readable fashion. You may also use the top tool bars to execute a few operations, and these are clearly labeled.

Most of the commands are issued using the "CIMA Observer's Interface", however, you begin by typing into the "Identify New User" box.

- "Identify New User" - Fill the fields: "Observer – your name", "Enter Proposal Number – sdss2", " Select Observing Mode – Line".
- Choose a receiver - When you have filled in the first box, a new window will open up giving you a list of receivers. Choose "L-Band Wide", and click on "Select Receiver Now". On the "AO Observer Display", you will see that a Tsys measurement has been performed, and you should verify the values against the nominal values for that receiver. Click "Dismiss" to close the receiver window.
- Setup the Correlator - click on "Load Setup", choose "proj5.gui". If all parameters seem to be correct, then click on "Apply Current Setup".
- Observing mode - From the "CIMA Observer's Interface" menu bar, now click on "Spectral Line Observing". The mode and source selection, etc. should be set up for your run. You will be observing Arp220, with the BP calibrator being Arp220BP, and doing 3-min On and 3-min off, on each of these, in the order mentioned under "Pattern". click on the "Observe" button when you are ready.
- When all observing is completed - Click on "Move data", and then "Exit Normally" (from the left-side menu bar).

3. Reducing the Data

This assumes that either the IDL startup at GB is set up to use all Arecibo data reduction codes or that you are running IDL on one of the Arecibo Suns.

```
%idl

IDL>openr,lun,'/share/olcor/corfile',/get_lun
                  ! To open corfile for access

IDL>corlist,lun       !To list all scans in corfile
```

```
IDL>istat=corinpscan(lun,Ton,scan=scan#-for-Ton,/han,/sum)
                  ! Single scan, records summed, Hanning smoothed
                  ! use the scan number for the Target-On scan
                  ! spectrum written to the structure, Ton

IDL>istat=corinpscan(lun,Toff,scan=scan#-for-Toff,/han,/sum)

IDL>istat=corinpscan(lun,BPon,scan=scan#-for-BPon,/han,/sum)

IDL>istat=corinpscan(lun,BPoff,scan=scan#=for-BPoff,/han,/sum)

IDL>c1=cormath(Ton,Toff,/sub)   ! The structre, c1 contains Ton-Toff

IDL>c2=cormath(BPon,BPoff,/sub) ! c2 contains BPon - BPoff

IDL>rs=cormath(c1,c2,/div) ! rs contains (Ton-Toff)/(BPon-BPoff)
           ! Ratio Spectrum free of BP ripple.

IDL>corplot,rs,/vel ! plots the ratio spectrum. Drop /vel to plot vs
                    ! frequency
```

For comparison with the standard On/off procedure, you may also
construct the standard On-off/off spectrum as follows:

```
IDL>sp=cormath(c1,Toff,/div)
```

To accumulate a number of cycles;

```
IDL>coraccum,inp_struct,out_struct,/new
                 !Accumulate structures. Use ‘‘/new’’ only first time

IDL>corplot,out_struct
                 !First normalise by dividing by b.b1.accum

IDL>bpol=coravg(b,/pol)
                 !Average the 2 polns of structure b, placing the result
                 ! in structure bpol
```

In order to make a printable postscript file, you may use the following:

```
IDL> set_plot,'ps'
IDL> device, set_font="Times-Roman",filename='myplot.ps',ysize=12
IDL> corplot,rs ...
IDL>device,/close
IDL> set_plot,'x'
```

4. Some Possibly Useful References

Baan et al., 1982, ApJ, 260, L49

Baan et al., 1987, ApJ, 313, 102

Mirabel, I. F., 1982, ApJ, 260, 75