1 Introduction

The purpose of this tutorial is to help the user become familiar with how to observe with LWA1 and work with the various data formats. Specifically, this tutorial emphasizes the LWA Software Library (LSL) Python module and the three extensions to that module that are currently available.

Before beginning you this tutorial should make sure that you have the request software installed. This includes LSL, the three LSL extensions, TEMPO, and PRESTO. In addition, the relevant environment variables need to be set for TEMPO[1] and PRESTO[2]. It is also recommended that an environment variable be set to the place where the extensions are, e.g.,

```
export EXTENSIONS=/home/packages/lwa/extensions/
```

If you are using the LWA User Compute facility (lwaucf1, lwaucf2, ...) then all these packages should be installed.

The data for this tutorial can be found at http://lda10g.alliance.unm.edu/tutorial/. It is recommended that this tutorial be carried out on a computer with at least 4 GB of RAM and 200 GB or free hard disk space.

Information about LWA, LWA1, and LSL can be found at the following websites:

- LWA websites http://lwa.unm.edu and http://blogs.li.vt.edu/lwa1
- LSL website http://fornax.phys.unm.edu/lwa/trac/wiki
- LWA User's Forum http://lwa1.freeforums.org
- LWA Memo Series http://www.ece.vt.edu/swe/lwa/

Information about the second LWA1 call for proposals can be found at http://www.phys.unm.edu/~lwa/proposals.ht

2 Observing with LWA1

Goal: Setup a DRX (beam) observation to look at the flux of Cyg A.

1. Start the LWA observation scheduling GUI that is part of the `SessionSchedules` extension:

   ```
   $EXTENSIONS/SessionSchedules/sessionGUI.py
   ```

   This will bring up a GUI to help prepare the session definition files (SDFs) used for scheduling observations at LWA1.

2. Define a new set of observations using the `File -> New` menu or by clicking the "New Project" icon. This will open up the observer and project information window. In this window you can define your name, the project, what LWA1 mode is to be used to collect the data, and how the data are be returned to you[3]. The nomenclature is that a project is made of one or more sessions. Each session uses one of the five LWA1 outputs (four DRX beams and TBW or TBN) and consists of multiple sequential observations. For DRX observations, the available modes are track a RA/Dec. position, track the Sun, or track Jupiter.

[1] TEMPO is available at http://tempo.sourceforge.net/.
[2] PRESTO is available at http://www.cv.nrao.edu/~sransom/presto/.
[3] Observer and project IDs are assigned by LWA1 when proposals are accepted. Observer IDs are numeric and project IDs consist of two letter followed by a three digit number, e.g., LF001.

3. After defining the observer information, create an observation to look at Cyg A. This can be done through the `Observations -> Add -> DRX - RA/Dec` menu or the "New RA/Dec Target" icon. This will add a new blank observation to the window. To find the coordinates of Cyg A, enter the source into the target field, select the observation via the checkbox on the left side of the screen, and choose `Observations -> Resolve Selected`.

4. Define the parameters of the observation (observing time, tuning, bandwidth, etc.). For the DRX mode each pointing has two independent tunings that can be tuned anywhere in the 10 to 88 MHz band of LWA1. To get the list of filter codes, go to `Help->Filter Codes`.

5. Check the visibility of the source using the `Observations -> Session at a Glance` feature. This will plot the elevation of the source throughout the observation.

6. If you have selected raw data to be returned (DRSUs or USB hard drives), check the data volume of your observations using the `Data -> Estimated Data Volume` feature. This will display a window with the raw data volume for each of the observe rations as well as the session total.

7. Once you are happy with the observation setup save the observation to disk. Before the file is saved it will be validated. If any of the observations have invalid parameters, those observations will be highlighted in red. The terminal window will also listed the invalid parameters.

3 Low Frequency Pulsar Demo

Goal: Use 50 minutes of data from a single LWA beam to detect a pulsar, in the example below the target is B0823+26. In the process get a feel for how to examine beam data.

1. Take a look at a few milliseconds of the time-series data to make sure that the data is well sampled and not clipping. You can use:

   ```
   $EXTENSIONS/Commissioning/DRX/drxTimeseries.py 056047_000255699_DRX_s0900.dat
   ```

   which will plot up the raw voltage time series for 100 μs. Skip a few seconds into the file using the `-s` flag, and look in the middle as well.

2. Make a waterfall plot to show the spectrum with time. Use the `-a` option to select an averaging time (default is 1 second) and the `-d` option to set a duration over which to compute the spectra.

   ```
   $EXTENSIONS/Commissioning/DRX/drxWaterfall.py -a 1 -d 900 \
   056047_000255699_DRX_s0900.dat
   ```

   This will create a NPZ file called "056047_000255699_DRX_s0900-waterfall.npz" that can be examined with `plotWaterfall.py`. Notice any RFI?

3. Now convert the file into PSRFITS format in preparation for hunting down the pulsar using PRESTO.

   ```
   python2.7 $EXTENSIONS/Pulsar/writePsrfits.py --ra=08:26:51.4 --dec=+26:37:22.0 \
   --sum 056047_000255699_DRX_s0900.dat
   ```

   This will create two files "drx_56047_81101_b4t1_0001.fits" and "drx_56047_81101_b4t2_0001.fits", one for each tuning[4].

[4] This step may take up to two hours to complete.

4. Masking out RFI

   Start with one of the PSRFITS file and make a mask to feed into `prepsubband`:

```
$PRESTO/bin/rfifind -time 2.0 -o themask drx_56047_81101_b4t1_0001.fits
```

   Start up step 5 and then while that is working you can look at the resultant mask and statistics to see how much data was flagged.

5. (a) Assume that we know the dispersion measure (DM) of this pulsar is around 19.5 pc cm^{-3}. Apply incoherent dedispersion to the data using:

```
$PRESTO/bin/prepdata -dm 19.5 -o outfilename_DM -numout "power-of-2" \
-mask themask_rfifind.mask psrfitsfilename
```

   You can figure out the value used for numout by looking at the number of points that `prepdata` reports when it starts, and then looking for the closest power of 2.
   Then use `accelsearch` to look for the pulsar frequency:

```
$PRESTO/bin/accelsearch -zmax 0 -numharm 16 -harmpolish outfilename_DM.dat
```

   (b) *OR* if you don't know the DM, search with PRESTO by first making the trial DMs. Lets assume the DM is between 15 and 25 pc cm^{-3}.

```
$PRESTO/bin/prepsubband -lodm 15 -dmstep 0.1 -numdms 100 -nsub 128 \
-mask themask_rfifnd.mask -numout "power-of-2" -o $file psrfitsfilename
```

   For each trial DM file search for a pulsar using:

```
$PRESTO/bin/accelsearch -zmax 0 -numharm 16 -harmpolish $file
```

6. Once you know the DM and period, make a plot of the pulsar. This searches over a small range of DM and period to get the best fit.

```
$PRESTO/bin/prepfold -dm "DM" -p "period" psrfitsfilename -nsub 128 \
-mask themask_rfifind.mask
```

   Print out your pulsar and note the final DM and period.