Internal report

Listening of the Galaxy with a wire

Miljenko Čemeljić

July 29, 2023

Abstract

I give a brief account of a build of small radio telescope with Software Defined Radio. A low cost hardware became increasingly available during the last decade, and results obtained by both amateur practitioners and educational institutions are slowly making it to the wider community. The STEM educational potential of this effort is enormous, encompassing astronomy, mathematics, physics and informatics. Educators should be encouraged to engage and disseminate the information at the various levels.

1 Introduction

Amateur radio astronomy is not a new field, there vere heroic efforts since its beginnings. It is enough to recall that its very beginning was actually a hobbistic work of Grote Reber, who for more than a decade was the only radio-astronomer in the world. Many stories can be found online, and many will for certain be unearthed with the current flurry of activity in the field. For newbies, there is a comprehensible online textbook NRAO course (2013).

Still, until recently it was a domain of capable and experienced electronicians. Documentation was also not readily available, since the frequencies of interest, especially during the development of the radar, often collided with classified, military documentation. In 1982, the first Software Defined Radio (SDR) was developed in the lab of at RCA, by the Ulrich L. Rohde's department. They used the COSMAC (Complementary Symmetry Monolithic Array Computer) chip. Predecessor of the Raytheon company in USA coined the term "software radio" to refer to a digital baseband receiver. In such a radio, the analog detectors, mixers, filters, amplifiers, and (de)modulators are substituted by software, performing mathematical operations on a digital signal, and can be processed on computers Wikipedia on SDR.

The new possibilities, related to the downpricing of the needed electronic components, stem from the mass production of DVB-T TV tuner dongles based on the RTL2832U chipset. After discovering that, with a suitable driver, such TV tuner can be converted into a wideband software defined radio (SDR) RTL-SDR; Osmocom project, amateur radio astronomy, among others, got a new impulse. It became much simpler and less costly endeavour to acquire the components and assemble the working equipment than to do it classical way.

Aim of this work is to learn the basics of signal processing with the simplest possible tools, and then experiment with the variety of antennas, receivers and filters. The possible targets are, based on signal strength and experience of the amateur radio-astronomers with the current technics, our own Galaxy, Sun, Jupiter and, ultimately, pulsars. Idea is to grow in experience, technical and analytical skill and incrementally improve.

In what follows I give a shortcut through my efforts. There were many meanderings, most of them repeating similar experiences from the community, found in Internet on the topic. Still, it is a rewarding journey, both from the astronomical and technical aspect.

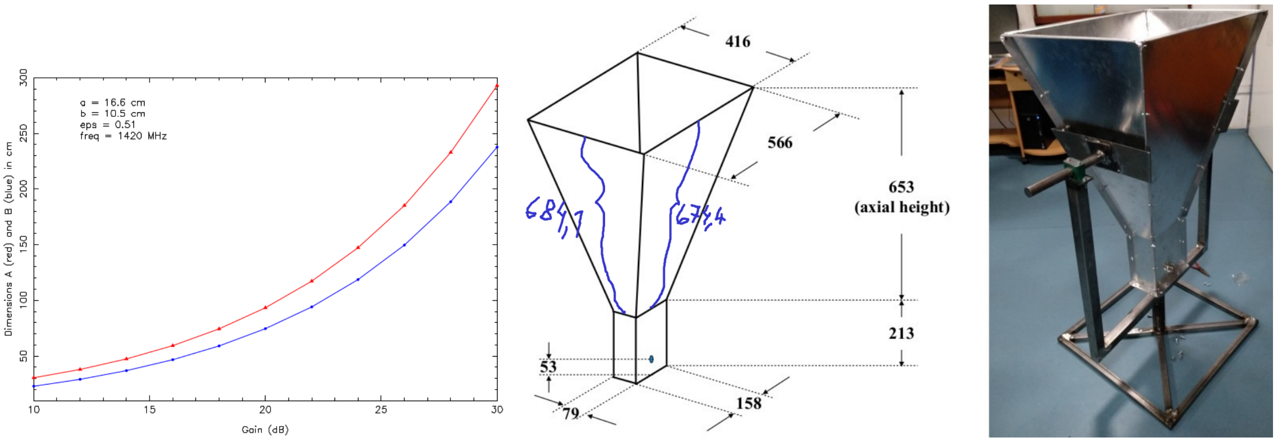

Figure 1: *Left panel*: Curves showing the dimensions of the pyramidal antenna with $A \times B$ opening for the best optimal gain $\epsilon = 0.51$. The active antenna element is a wire of $\lambda/4$ length, so for HI line of 21cm it is 5.25 cm. It is inserted inside the antenna, in the waveguide of the optimal dimensions $a \times b$. The distance of the active element from the bottom of the waveguide is $\lambda_{\rm w}$, the guide wavelength, which is different than the signal wavelength. Here it is 27 cm, so a quater of it gives 6.75 cm. *Middle and right panels*: an example of finished horn antenna (Mhaske et al., 2022).

2 Construction of a horn antenna

In the construction of the horn antenna prototype and choice of the minimal additional equipment, I followed abounding online resources (Schreiber). The first observational target is a 21 cm radiation from neutral hydrogen. This radiation is a result of spontaneous transition of hydrogen atom from excited state with parallel spins of the proton and electron to a lower state with their anti-parallel orientation. For this observation there is no need for great precision in orientation: the Galactic plane is the strongest, continuous source. The first observation of a hydrogen line was done by Purcell & Ewen at 25.03.1951. at Harvard University in USA, using a horn antenna.

The horn antenna was chosen in the first observation because of its superior sensitivity, which is also our reason for the choice. Another reason is good shielding from the surrounding sources, which is important in the urban environment in which educational institutions are usually located.

The needed dimensions of the antenna for the optimum characteristics can be found from the graph in the left panel in Fig. 1. In the same Figure is shown an example of the measures, and an finished antenna.

For the prototype, I decided to make the whole construction of cardboard, inlined with a standard kitchen aluminum foil. The foil is glued to the cardboard with a metal-wood glue and additionally fixed in the loose parts with the electrical tape. For the $\lambda = 21.206$ cm wavelength (frequency of 1420.406 MHz), precision of the antenna inlining should be up to a centimeter[1], so the connectivity of the parts of the foil is more important than the surface smoothness. The entire configuration is schematized in Fig. 2.

Dimension of the antenna active element depends on the wavelength of the signal which is to be observed. Since we aim to build a $\lambda/4$ antenna, a 5.25cm active element is needed. We take one end of about 12 cm of a standard RG58U coax cable with 5.25 cm of the coaxing removed, to expose the copper wire (this type of cable is 1 mm in diameter). For this project, variations in the wire gauge are not critical, thicker wire might provide better performance.

The active element is shown in the Fig. 3. The element is inserted and its footpoint glued or otherwise fixed inside the bottom part of the horn antenna, so that the ground of the cable is connected with the foil inside the antenna. The other end of the antenna is connected to the low-noise amplifier (LNA, see below). The LNA is connected by a longer, 3 m piece of the same kind of coax cable with SMA connectors, to a RTL-SDR

[1]See the Ruze equation in §3.34 in NRAO course (2013), which shows the aperture efficiency decrease of 50% with the surface errors of the order of $\lambda/16$.

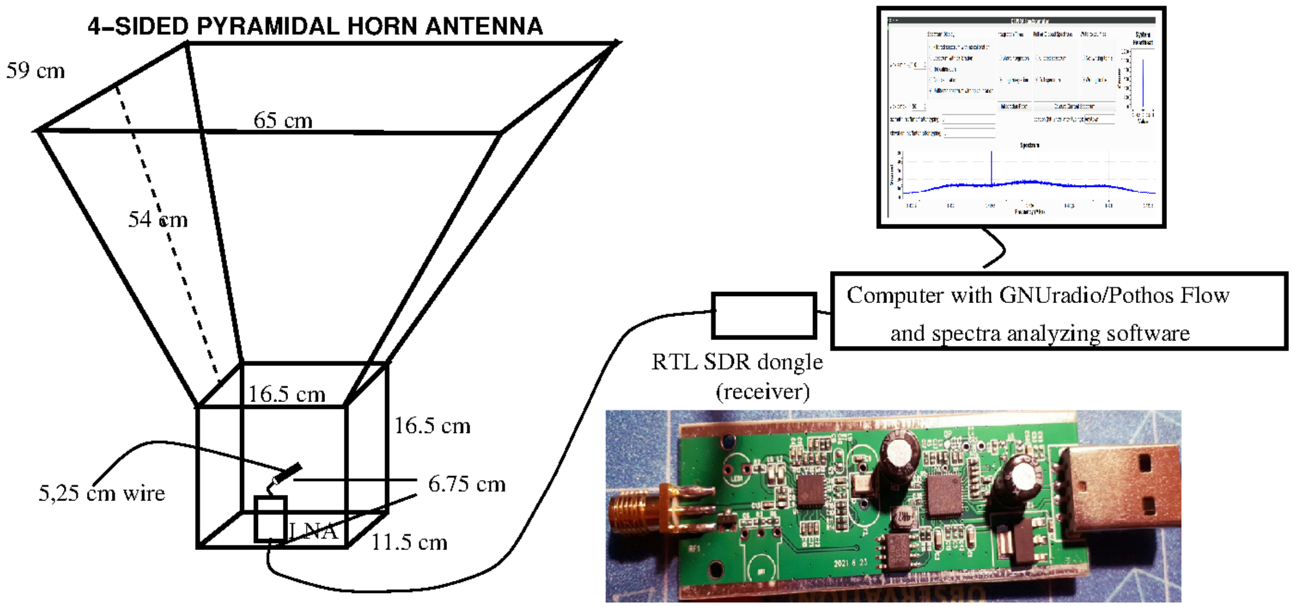

Figure 2: Schematic representation of the horn antenna and electronic components in our radio telescope, with the interior of the receiver also shown. The antenna is made of a cardboard, inlined with the aluminium foil. Geometry of the antenna is chosen in such a way to obtain the optimal gain.

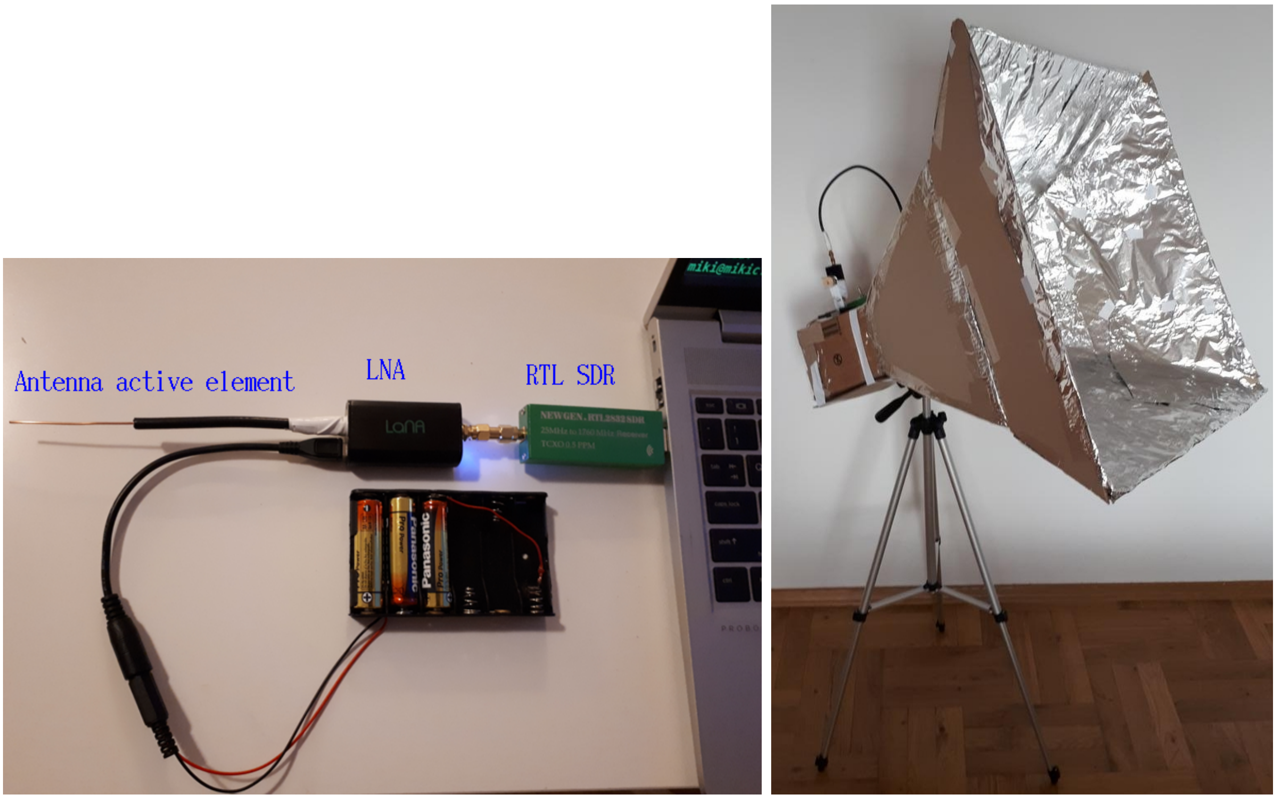

Figure 3: Left panel: antenna active element connected to the LNA paired with the RTL SDR receiver plugged into laptop for testing. The completed antenna is shown in the right panel, mounted to a light camera tripod.

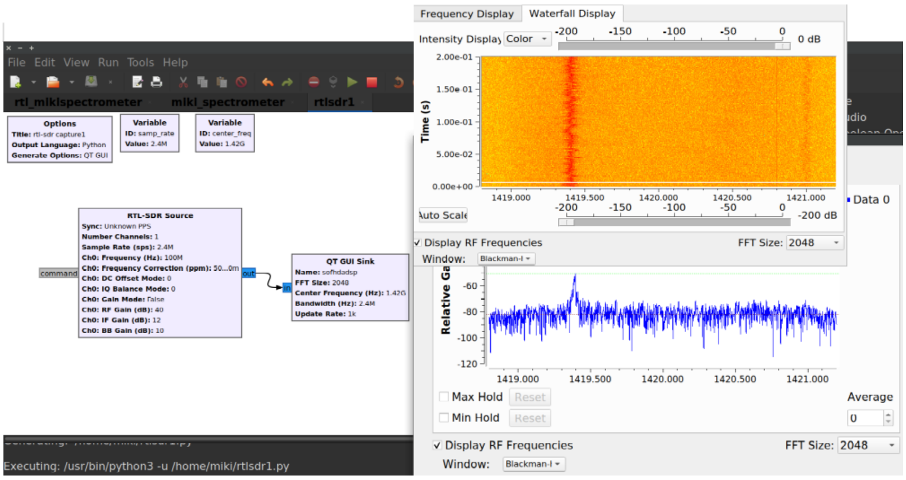

Figure 4: A simple GNUradio flow for obtaining the raw signal during the receiver testing, shown with the graphical results. The signal here is just an interference from the nearby source.

dongle, plugged into the laptop by its USB.

I check, by using the standard multimeter, that the inlining of the antenna and cable ground (external rim of the SMA connector) entering the LNA are connected-the resistance should be a very small, but finite amount.

The Low-Noise Amplifier (LNA) I used is NooElec Lana for 20-4000 MHz, powered by a 4.5V DC battery through its micro-USB. I also use the solar panel charged powerbank or a smartphone powerbank.

The receiver (dongle) is Realtek RTL2838UHIDIR SN: 00000001, NEWGEN.RTL2832SDR, encased in a metal box, with USB connector to the computer and SMA input from the LNA-or directly from the antenna, for testing. It is a 25MHz to 1760 MHz receiver, with R860 chip instead of the older R8232T, with Temperature Compensated Crystal Oscillator (TCXO) with 0.5 PPM frequency stability. I show it in Fig. 3, paired with the LNA and antenna active element for testing. The extensive testing of the electronical components is described in Higginson & Rollins (2013) and references therein.

3 Processing of the signal

A conventional radio would process a signal through amplification, mixing and filtering through a hardware electronical elements. Software Defined Radio (SDR) receiver is working on the digitalized version of the original (analog) signal, passed through an external Low-Noise Amplifier and digitalized through Analog/Digital (AD) converters, one for real, other for imaginary component. By the use of the Fast Fourier Transform (FFT), such signal is next analyzed into a separate waveforms in a number of samples which are an input for the further processing.

I used the DSPIRA `gnuradio` software (OpenLab, 2020). The simplest flow for the signal visualization is shown in Fig. 4. The full, much more complicated DSPIRA flow which we will use for the actual radio telescope, is shown in Fig. 5.

For a reference, I show the first test results in the top panels in Fig. 6. With more work on the quality of connections and searching for the appropriate gain setting and antenna positioning, I obtained the first spectra of the Hydrogen line. Both raw and calibrated spectra are shown in the bottom panels. This measurement was done with antenna pointed towards the part of the Galaxy in the Monoceros constellation, shown in the Fig. 7.

References

https://www.haystack.mit.edu/wp-content/uploads/2020/07/srt_2013_HigginsonRollinsPaper.pdf

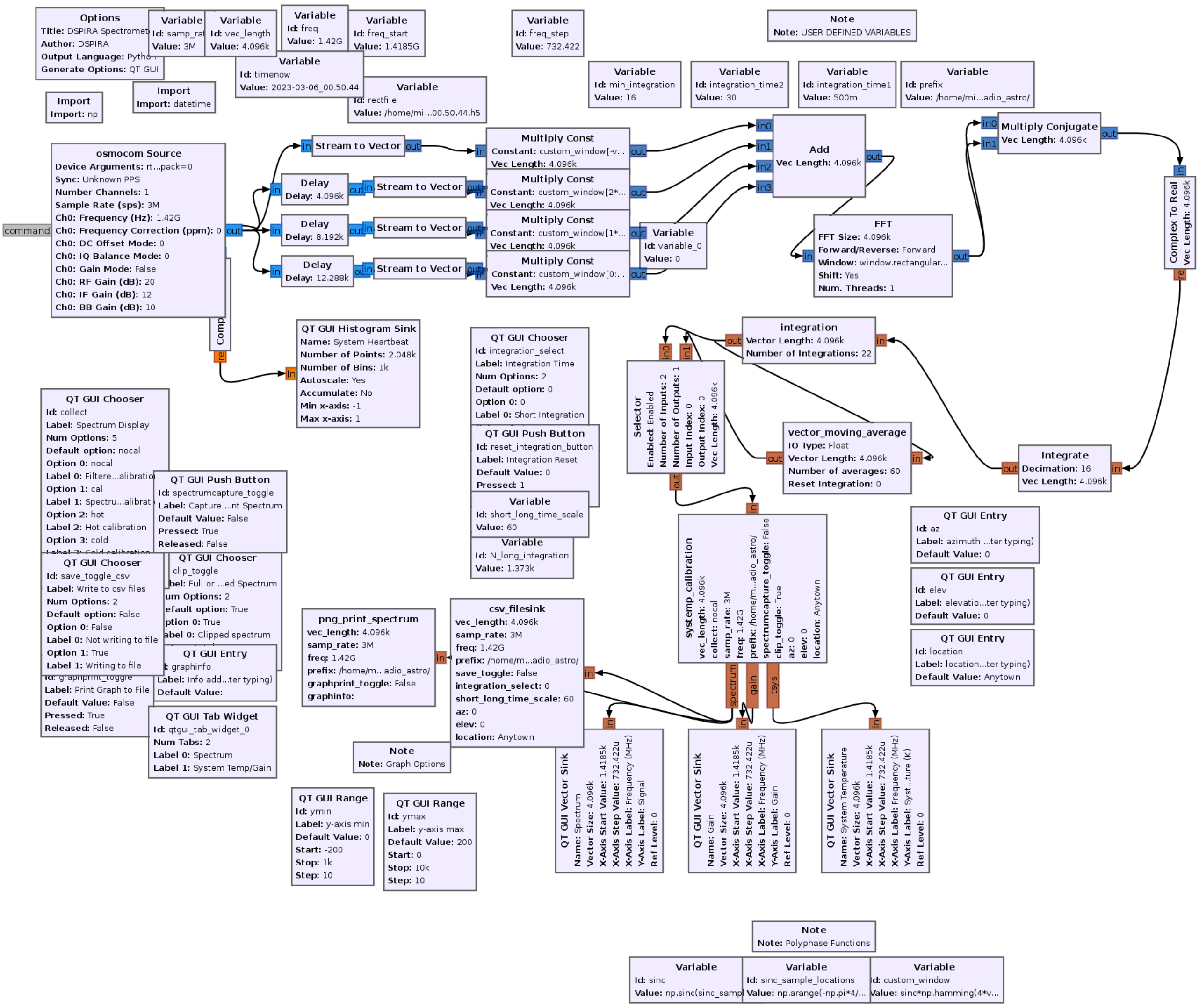

Figure 5: GNUradio flow of a spectrometer from DSPIRA project.

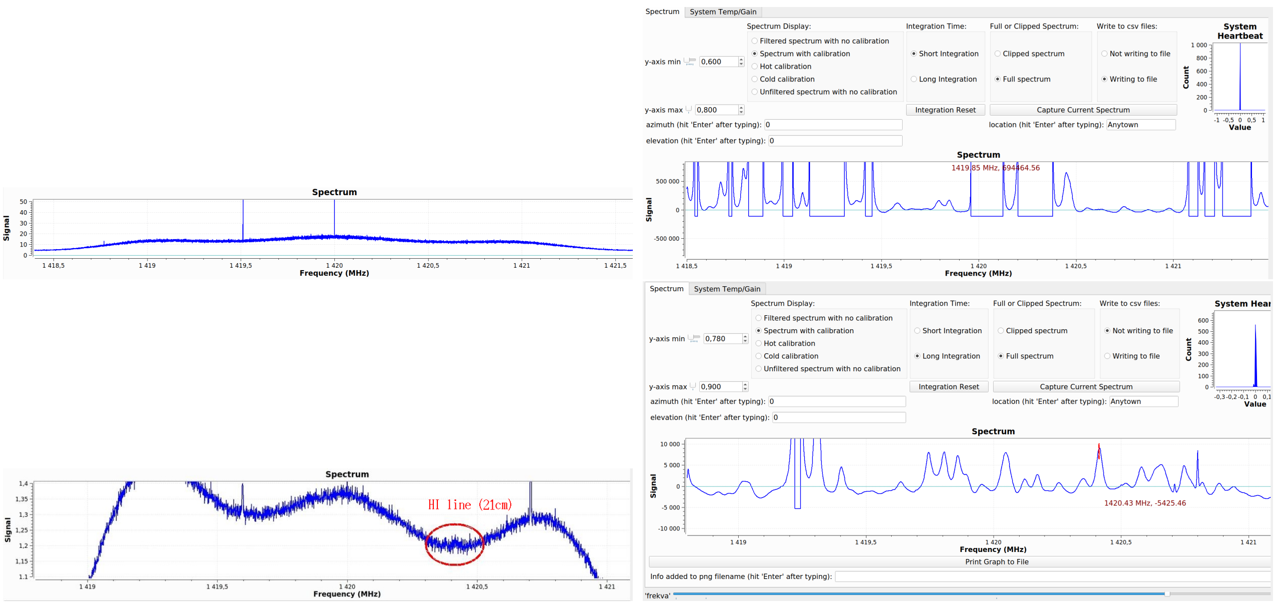

Figure 6: In the left and right top panels, respectively, are shown the first measurement at 1420MHz with the non-calibrated antenna and after the first attempts on calibration. In the bottom panels are shown the first successful results, without any refinements. The red ellipse at the left panel marks the Hydrogen H1 line "bump", and the number in red at the right panel gives the frequency of the peak marked about 1420.4 MHz.

Figure 7: Marked is a part of the sky in Monoceros constellation, from which I made the first H1 measurement with the prototype antenna.

Wiki:https://osmocom.org/projects/rtl-sdr/wiki

https://www.rtl-sdr.com/about-rtl-sdr/

https://www.instructables.com/How-to-Make-a-Radio-Telescope-From-Household-Mater/

Mhaske, A. A., Bagchi, J., Joshi, B.C., Jacob, J., and Paul, K.T., 2022, arxiv:2208.06070

https://physicsopenlab.org/2020/07/26/gnuradio-software-for-the-21-cm-neutral-hydrogen-line/

https://en.wikipedia.org/wiki/Software-defined_radio

https://science.nrao.edu/opportunities/courses/era/