Commissioning an Experimental Radio Station

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Introduction

Data-intensive science is a new fourth paradigm of research following closely those of experimentation, theory and computer simulation [1]. Characterised by large-scale data gathering, this approach requires new innovative data handling and analysis techniques.

To investigate such techniques on a small-scale, we built a small experimental radio station and carried out two experiments:

- Detecting meteors from radio scatter
- Tracking the Milky Way HI emission

The radio station was built upon the framework of Software Defined Radio (SDR), the basic principle of which is to transfer as many of the functionalities of traditional radio hardware components to programmable software devices as possible [2].

Theory

Meteor Scatter

Meteors leave behind ionising columns of air as they pass through the atmosphere and are vaporised. These can be dense enough to reflect radio waves in the VHF band at around 40-100 MHz [3] but only last for a few seconds, allowing brief long-distance communications. The radio wave scatter from these trails is completely specular [3], behaving like a mirror, and can be used to detect the presence of meteors.

Milky Way HI Emission

Much of the Milky Way galactic disk is filled with neutral atomic hydrogen gas. This gas has a distinct marker: a unique 21 cm emission line corresponding to a hyperfine splitting of the atomic ground state due to the relative spin orientations of the proton and electron [4]. Measurement of this emission will vary with direction as more gas will be in the line-of-sight when looking through the galactic plane than when looking out of it. We can point a detector at the sky and collect data as its line-of-sight traces out a path across the sky due to the Earth's rotation.

Results

Meteor Scatter

We detected an event (Fig. 1) using CubicSDR, a real-time signal viewer, during a trial run to test the setup. This had the expected features of a meteor scatter: it only lasted around a second and had the appearance of a commercial station when it was there.

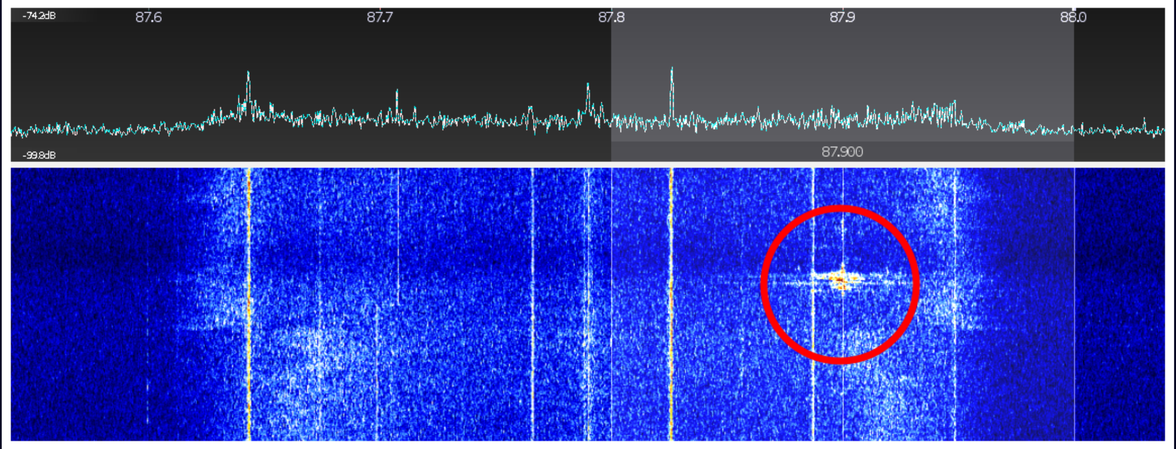
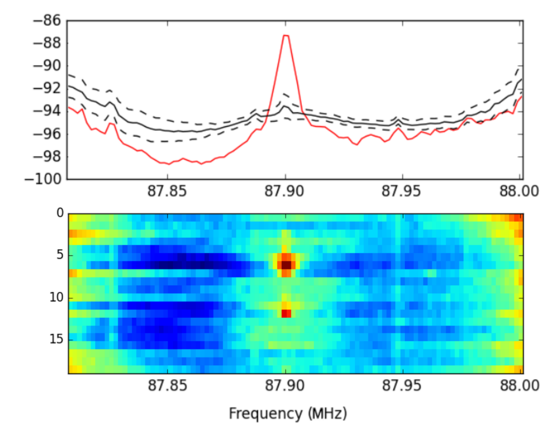


Figure 1: The first meteor detection, from CubicSDR. The vertical axis is time, horizontal axis is frequency in MHz and redder colours indicate stronger signal. The meteor signal is highlighted with a red circle.

Further data was taken with the same setup and analysed with Python scripts. As we were trying to find localised events within a large data-set, this allowed us to apply methods for doing so. In Fig. 2 is an event detected by comparing an integration spectrum against the median and standard deviation of the previous 50, with an event threshold of 6.3σ.

Figure 2: The strongest peak from the detected event (above) and a heatmap plot of the 20 integrations around the event (below). The red line is the event and the black solid and dashed lines are the median and 1σ envelope, respectively. In the heatmap, redder colours indicate a stronger signal.



There were many issues involved in the software installation and interfacing with the SDR receivers and rectifying these problems was a large time sink. No more data was taken, or event detection software implemented, as we ran out of time and had to move on to the second experiment.

Milky Way HI Emission

We tested the tuning of the antennas once they were built; unfortunately they did not seem to be accurately tuned to the HI emission line so we were not confident in how successful they would be. Nevertheless, we mounted one of the antennas to the dish (Fig. 3) and left it gathering data overnight. Nothing meaningful could be gleaned from what resulted.

However, we could still simulate what the expected outcome would have been. By determining a path of observation across the sky and applying it to a full-sky survey image, the pixel intensity values along the path could be plotted (Fig. 4). The two peaks each day correspond to when the line-of-sight is within the galactic plane with the strength showing how much of the galaxy is being looked through.

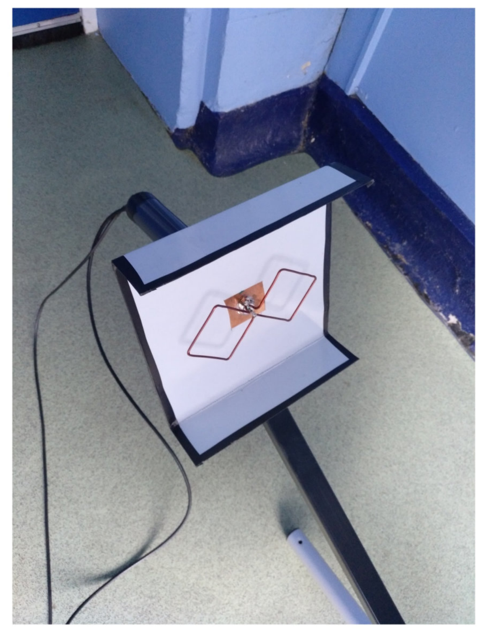


Figure 3: The second antenna built, mounted on the radio dish.

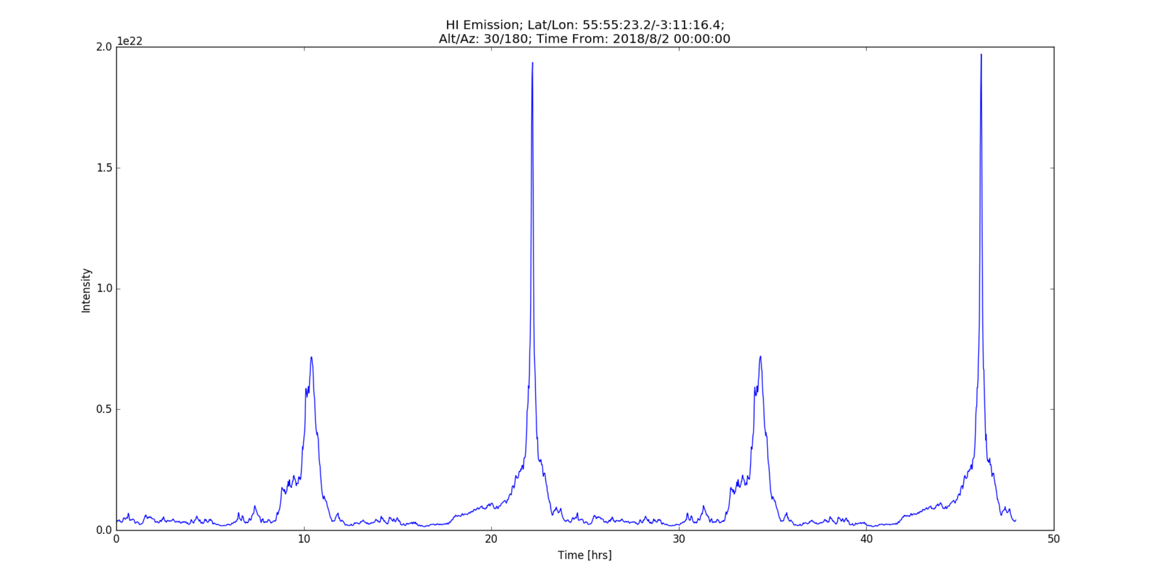


Figure 4: The results of an expected emission simulation with an observer located at the Royal Observatory looking South at an altitude of 30° for two days from midnight on the 2nd August 2018. The vertical axis is an arbitrary relative intensity scale and the horizontal axis is time in hours.

Methods

Meteor Scatter

We used the FM band frequency range (87-108 MHz) as there are many commercial radio stations across Europe we could try to detect reflected signal from. We also used a couple of SDR receivers, driven by the SoapySDR library via terminal commands and custom Python scripts, and a Yagi array antenna which was set up on the roof of the Royal Observatory.

Milky Way HI Emission

We built two bi-quad antennas, suitable for the high frequency of the HI emission and with good directionality and a relatively high gain. The HI signal is quite weak, so pre-amplifiers were connected, and the antennas mounted at the focal point of a radio dish when in use. The same software was used as in the meteor scatter experiment.

Conclusions

A small experimental radio station was set up at the Royal Observatory to investigate data-intensive research techniques on a small scale. Two experiments were carried out with moderate results.

The first produced some usable data and some data analysis techniques were able to be applied with promising success, although time constraints limited just how much could be drawn from it. The second did not provide any usable data as the experimental setup did not function as intended.

Many unforeseen challenges were faced and solved, which was a major consumer of the available time. However, as many of those challenges pertained to the initial setup and configuration of the equipment and the software, most of them need not be faced again, leaving open the door for future attempts. It is hoped that the station could become a useful educational aid for others in the future.

References

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4. D. J. Griffiths, "Hyperfine splitting in the ground state of hydrogen," *American Journal of Physics*, vol. 50, pp. 698–703, aug 1982.

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