Observing Jovian Decametric Radio Emissions with a Software Defined Radio Telescope

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Introduction

It was discovered in 1954 by Burke and Franklin [1955] that the planet Jupiter emits radio transmissions in the decameter (DAM) range *10-100 m wavelengths*, and the inner Jovian satellite Io appeared to have an effect on these emissions occurring [Belcher, 1987]. Jupiter's radio emissions range between 4 MHz to 39.5 MHZ while emitting most strongly at 8 MHz or so [Wilkinson and Kennewell, 1994]. However due to interference from human short wave radio sources between 4-15 MHz coupled with the attenuation of these signals or refraction off Earths ionosphere, the majority of emissions have been observed up in the 15-25 MHz range where this interference is less. The emission signal strength quickly diminishes above this range [Wilkinson and Kennewell, 1994].

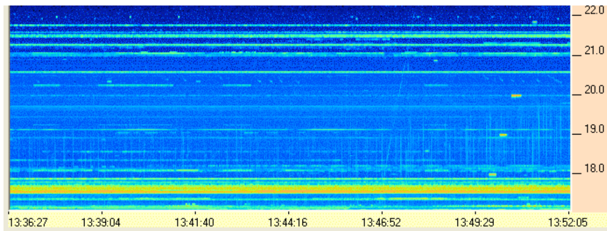

Fig. 1: Decametric Radio Emissions [Ashcraft, 2013]

Data collected by the two Voyager spacecraft in 1979 [Belcher, 1987] and the later Galileo mission in 1995 [Kivelson et al., 1996] added hugely to the understanding of the plasma interactions between Jupiter and Io and the source of the DAM emissions. It was discovered that the Io has a thin atmosphere made up of a number of neutral gasses namely sodium, potassium, sulfur, and oxygen as shown in fig: 2. It is generally thought these gasses have been emitted through volcanic activity on the surface of the moon [Belcher, 1987]. The gasses in orbit of Io have a very short life time, due to collisions with magnetospheric electrons. This gives rise to a plasma torus (IPT) which corotates with Jupiter itself [Belcher, 1987]. This can also be seen in fig: 2 which shows the IPT.

The local corotation speed of the plasma torus is faster than the Keplerian orbit of the moon, and the plasma overtakes Io in its orbit at $57km\ s^{-1}$ [Belcher, 1987]. Fig 4 details a diagram of the Io Flux Tube (IFT) which is a tube made up from Jovian of magnetic field lines [Belcher, 1987] which thread the satellite. A large portion of the decametric emissions come from the area where the IFT

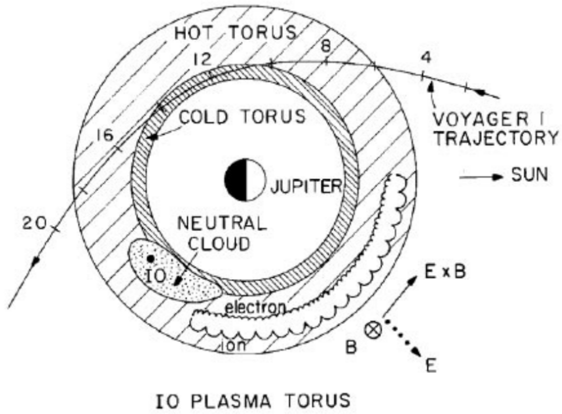

Fig. 2: Neutral Gasses in Orbit of Io [Belcher, 1987]

meets the Jovian ionosphere. As Io orbits within this flux torus it acts as a

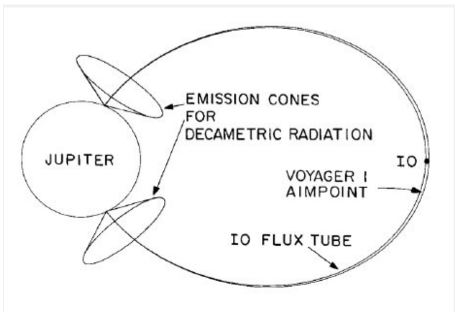

Fig. 3: Magnetic Flux Tube linking Jupiter and its satellite Io [Belcher, 1987]

unipolar conductor [Bose et al., 2008], and Alfvén waves are regularly produced which carry an electric charge along the magnetic field lines between Jupiter and Io [Bose et al., 2008]. These Alfvén waves reflect off Jupiters ionosphere at both north and south poles upto 9 times [Bose et al., 2008] while following Io through its orbit, thereby acting as a standing wave. It appears the source of the DAM emissions are largely due to these reflections of these Alfvén waves off Jupiter's ionosphere.

The DAM emissions are carried along the surface of the emission cones as show in fig: 4 [Belcher, 1987]. When Io is at specific points in its orbit of Jupiter, emissions are released at the surface of this cone. When pointing in Earths direction, it can be picked up at ground based radio telescope listening stations.

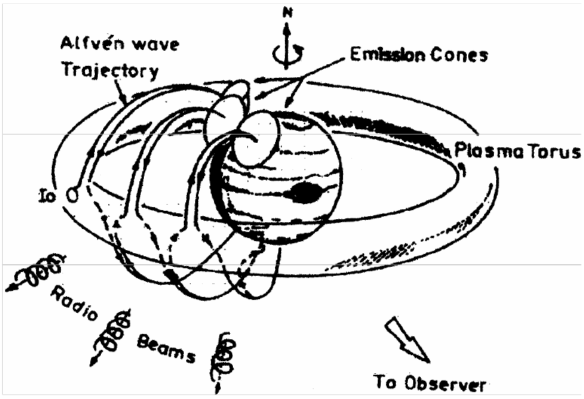

Fig. 4: DAM Emissions from Jupiter [Bose et al., 2008]

Research Topic

A ground based listening station aiming to record DAM emissions from Jupiter is most likely to succeed between 15-25 MHz [Wilkinson and Kennewell, 1994]. The *shortwave radio* bands extend from 2.3 MHz (120 m) all the way to 26.1 MHz (11 m) and were approved for broadcast at the 1997 World Radio communication Conference (WRC). ComReg, is the Irish Commission for Communications Regulation within Ireland, and maintains a list of the short wave frequencies which are designated for transmission in Ireland and can be seen in fig: 5 [Comreg, 2014].

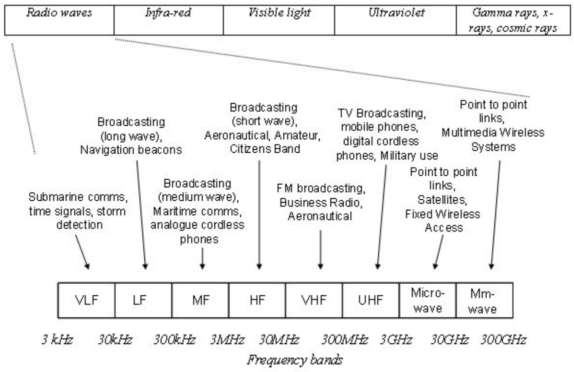

Fig. 5: Irish Regulatory Transmission Ranges [Comreg, 2014]

As many commercial shortwave radio stations transmit in the lower end of the high frequency (HF) 3-7 MHz range, it can be extremely busy and potentially difficult to monitor DAM emissions where they are strongest. Amateur radio operators also operate frequently in mid-late HF ranges while the higher frequency DAM emissions taper off in strength very quickly. This limits the potential listening range significantly. Despite these obstacles, there are sections of the HF spectrum which are suitable to capture Jovian emissions. The a suitable frequency to monitor Jovian DAM emissions which is recommended by the Radio Jove project is *20.1 MHz* [NASA, 2012b].

Sourcing a suitable antenna is one of the first requirements to satisfy in order to capture DAM emissions. Antennas generally are best suited to collect electromagnetic radiation at single specific frequencies, but may resonate and therefore operate over a range of frequencies depending on the design [NASA, 2012b].

The wavelength (λ) which corresponds with the frequency (f) *20.1 MHz* can be obtained using the wavelength equation as shown in fig 6. The corresponding wavelength for the frequency *20.1 MHz* works out to be *14.925 m* using this equation.

$$\lambda = \frac{c}{f} \tag{1}$$

$$\lambda = \frac{3x10^8 m/s}{20.1x10^6 Hz} = 14.925373134328359m \tag{2}$$

Fig. 6: Wavelength Equation

One simple antenna design for collecting DAM emissions is the *dipole*. A dipole antenna can be constructed simply and cheaply from two pieces of wire and three insulators [NASA, 2012b], while ensuring to cut the wires to a length matching half the desired wavelength being captured [NASA, 2012b]. However as the formula referenced in fig: 6 describes the use of an *infinitely thin* wire which is not possible in reality, *capacitive end effects* must be taken into account when working out the resonating wavelength for a dipole antenna [NASA, 2012b].

The formula for calculating the resonating frequency for a half wavelength dipole is described in fig 7 and produces the value which should measure from tip to tip on the wires used to construct the dipole antenna [NASA, 2012b].

$$\left(\frac{\lambda}{2}\right)m = \frac{142.65}{20.1MHz} = 7.097014925373134m \tag{3}$$

Fig. 7: Wavelength Equation for Real World Half Wavelength Dipole Antenna

The radio emissions come in several different forms each with slightly different characteristics. Table: 1 shows a list of the more widely known types which can be picked up using ground based listening equipment, and also has some information about their different characteristics [Wilkinson and Kennewell, 1994]. Any particular observation session might be made up of some or all of these different types of DAM emission and can last from a few minutes to several hours for larger noise storms [Wilkinson and Kennewell, 1994].

Type	Emission Length	Emission Description
S-Bursts	short generally 1-10 milliseconds	wideband bursts, several MHz wide
L-Bursts	long 0.5 - 5 seconds	wideband bursts, several MHz wide
N-Bursts	milliseconds upto seconds	narrowband bursts, several kHz wide

Table 1: Most common types of DAM Emissions from Jupiter [Wilkinson and Kennewell, 1994]

Fig: 8 shows an ideal case of the *S-Burst* and *L-Burst* DAM emissions and what they might look like on a frequency spectrum graph. S-Burst emissions are short, generally $1 - 10x10^{-3}s$ long while L-Bursts can be *0.5-5s* in length.

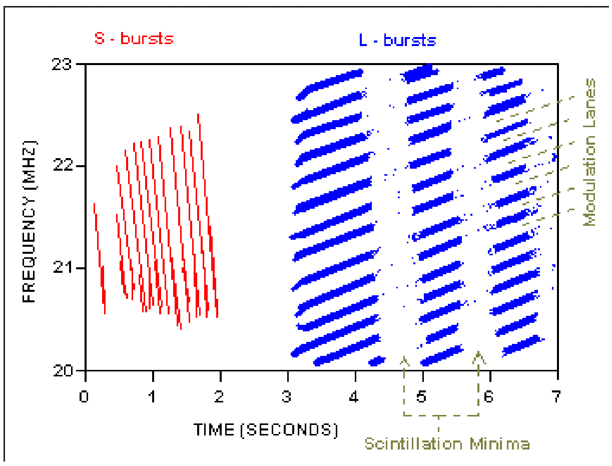

Fig. 8: Ideal DAM Emissions types from Jupiter [Wilkinson and Kennewell, 1994]

Research Problem

The aim of this project is to design and construct a low cost, self sufficient software defined radio (SDR) telescope listening station, which can capture signals for transmission to a central data aggregation point for signal processing and analysis. This telescope should be suitable to study signals in the DAM (10-100 m) band at or near the *20.1 MHz* frequency in order to pick up emissions produced by either Jupiter or the Sun.

There are a number of challenges which need to be overcome to achieve this, such as Jupiter only being visible for a number of months each year and then generally in the evening, night, or morning hours. Often at highly unsociable times. For this reason a radio telescope listening site should be as automated as possible.

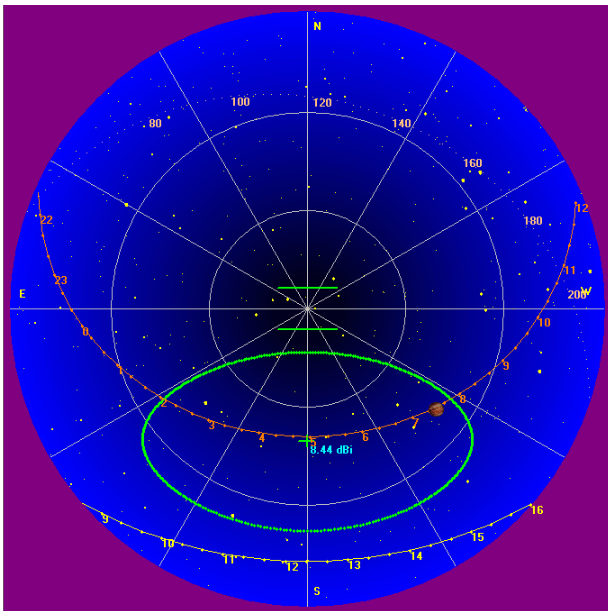

Fig. 9: Dual Dipole Antenna Beam at 20FT and 135deg phasing S [NASA, 2012b]

During daylight hours, the ionosphere becomes opaque to signals in the DAM band due to becoming ionised by solar radiation [NASA, 2012a]. The proposed system will have a short window in the order of 1-6 hours every second night and early morning or so during which it may be possible to capture DAM emissions from Jupiter. The Sun is a source of DAM emissions also, and the telescope can capture solar storm emissions without modification, providing the Sun passes through the antenna beam. The telescope may require manual reconfiguration in order to pick up solar storm emissions during the day.

Interference from human sources such as shortwave radio stations or amateur radio operators are also likely to affect the collection of DAM emissions from Jupiter. The ability for automated flagging or removal of interference would be a desirable feature of the system. Lightning storms can also produce interference which will affect observations, it might be desirable for the system to handle natural interference sources also.

Problem Summary

To summarise the problem briefly:

- Low cost self sufficient SDR telescope platform suitable for amateur observers
- Study Jupiter in the decametric band 3MHz - 40MHz (10-100 m)
- Jupiter emissions near 20Mhz, are least likely to be interfered with from human short wave sources
- Earths atmosphere is transparent at these frequencies during the night time
- Study Solar emissions during the day as solar emissions are strong enough to penetrate the ionosphere during the day
- Backhaul system for capturing, processing and storage of listening site data
- API for accessing data, and or integrating into another system
- Amateur listening sites can compliment larger telescope arrays around the world

Research Questions

- Can a software defined radio solution be developed to flag or filter human radio interference from radio signal observations?
- Can this same solution be used to flag or filter natural radio interference?
- How cheaply can a fully automated software defined radio signal listening station be built using current IOT technologies?

Methodology

Potential Pitfalls

Predecisions on how I want to collect data, creating the research questions itself I might need to carefully look at this, because I've made some initial ideas on how I want to collect this data.

Its going to be lower cost than other methods, or its using something new compared to other devices

The radio telescope design incorporates a hardware *dual dipole antenna* array which resonates strongly at *20.1 MHz*, with a *HackRF* software defined radio transceiver.

Due to the latitude of Ireland being 53.3 degrees N, the telescope configuration will apply only to locations at this or a similar latitude, but will be universally applicable at this latitude without modification, and with relatively minor modifications can ensure the end solution can be used at all locations. Kivelson et al. [1996]

- build and validate the telescope
- monitor the frequencies im interested in
- based on the ability to collect data, can we use it to answer our research questions
- show the errors from lightning
- show the errors from human signals
-

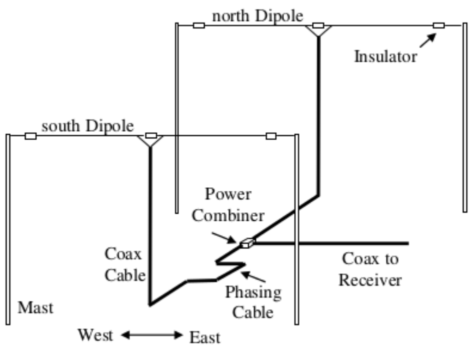

Fig. 10: Dual Dipole Antenna Array [NASA, 2012b]

Preliminary Literature Review

This should contain a review of a number of books, journal articles and web references of relevance to the research area proposed. The literature should contain seminal and recent referenced research material that is categorised under a number of relevant sub-themes.

I've read about 15 papers already related to the background of the interactions between Jupiter and Io, and papers detailing results from similar telescopes to the design I intend to build. I've hit a paywall on some of the earliest seminal papers which were the first to detail the phenomenon of decametric emissions being emitted by the Jupiter-Io system. I will attempt to get a copy through the inter library loan system at WIT.

My literature review can be broken down into the following areas:

- What are the decametric radio emissions and what are they caused by
- Research journals detailing potential radio telescope designs which could be replicated in order to collect DAM emissions
- I need to look into journals involving signal processing and maybe some rudimentary filtering or AI for identifying spurious signals
- Something else

Contribution to Research Knowledge Anticipated

A dissertation is a work of scholarly investigation that is grounded in the research literature and differs from a report or a book. It is judged on a prescribed set of academic criteria. Although the likely outcomes are tentative at hte start of the program, it is useful to incorporate them into the research proposal to help focus the work program.

Description of the Experimental Design / Validation Methodology

A dissertation must employ rigorous scientific argument. The experimental design and the validation methodology must be specified in great detail in the proposal. At this proposal stage you should define clear evaluation criteria.

- Identify data caused by lightning
- Identify data caused by human emissions
- Perform a site survey with the spectrum analyser
- Replicate the testbed at a second site

Special Resources Required

The research work may require access to specialised equipment, software, journals and so on.

Access to the HackRF or another similar SDR is required. Access to the RadioJove Prediction software

Main Milestones Anticipated

Students should agree a number of milestones and their likely delivery dates with their supervisor at the start of the progress.

- Design the testbed
- Build the telescope
- Perform a site survey with the spectrum analyser
- Replicate the testbed at a second site

Glossary

DAM decameter radio emissions. 3–5

HF High Frequency. 5

IFT Io Flux Tube. 3

IPT Io Plasma Torus. 3

WRC World Radiocommunication Conference. 5

List of Tables

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Appendix

Here is some content in the appendix

How I became inspired

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