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]. Data collected by the two Voyager spacecraft in 1979 [Belcher, 1987] and the later Galileo 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 $57 km\ s^{-1}$ [Belcher, 1987]. Fig 5 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 meets the Jovian ionosphere. As Io

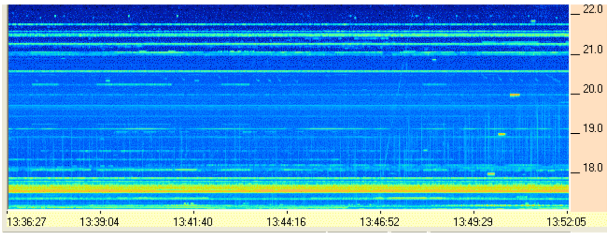
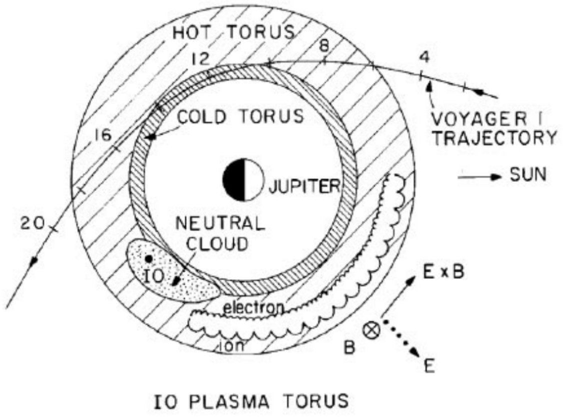


Fig. 1: Decametric Radio Emissions [Ashcraft, 2013]


HOT TORUS
12
8
4
COLD TORUS
16
VOYAGER I
TRAJECTORY
SUN
JUPITER
20
NEUTRAL
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E x B
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E
IO PLASMA TORUS

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

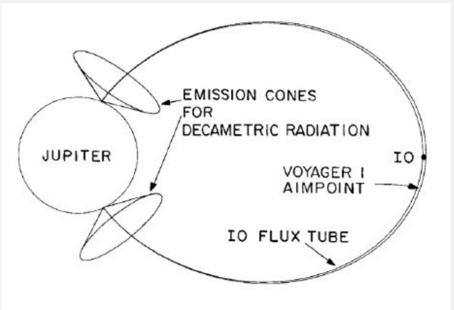
EMISSION CONES
FOR
DECAMETRIC RADIATION
JUPITER
IO
VOYAGER I
AIMPOINT
IO FLUX TUBE

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

orbits within this flux torus it acts as a 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: 5 [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.

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: 4 [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. Amateur radio operators also operate frequently in mid-late HF ranges while the higher frequency DAM emissions taper off in strength very quickly. Despite the obstacles affecting a monitoring station attempting to collect DAM signals, there are still large sections of the HF spectrum which are suitable to capture Jovian emissions. The radio receiver frequency to monitor Jovian DAM emissions which is recommended by the Radio Jove project is *20.1 MHz* [nasa, 2012]. 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]. The wavelength which corresponds with the frequency *20.1 MHz* can be obtained using the wavelength equation as

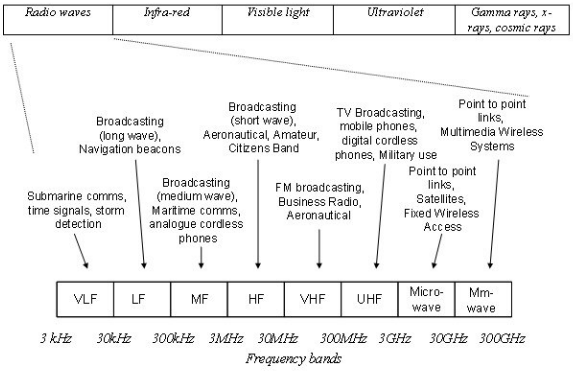
Radio waves
Infra-red
Visible light
Ultraviolet
Gamma rays, x-rays, cosmic rays
Broadcasting (long wave), Navigation beacons
Broadcasting (short wave), Aeronautical, Amateur, Citizens Band
TV Broadcasting, mobile phones, digital cordless phones, Military use
Point to point links, Multimedia Wireless Systems
Submarine comms, time signals, storm detection
Broadcasting (medium wave), Maritime comms, analogue cordless phones
FM broadcasting, Business Radio, Aeronautical
Point to point links, Satellites, Fixed Wireless Access
VLF
LF
MF
HF
VHF
UHF
Micro-wave
Mm-wave
3 kHz
30kHz
300kHz
3MHz
30MHz
300MHz
3GHz
30GHz
300GHz
Frequency bands

Fig. 4: Irish Regulatory Transmission Ranges [Comreg, 2014]

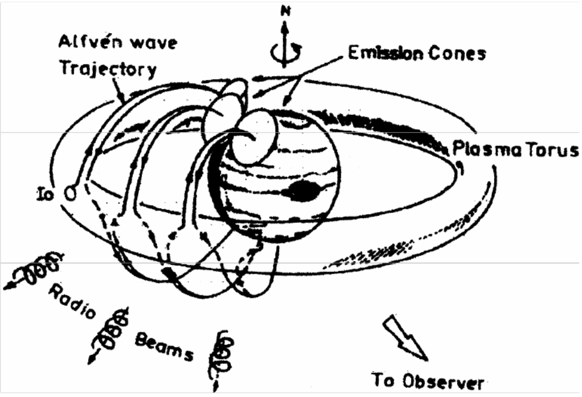

Fig. 5: DAM Emissions from Jupiter [Bose et al., 2008]

shown in fig 6, which in this case corresponds with *14.925 m*. Some text about

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

$$\lambda = \frac{300,000}{20.1} \tag{2}$$

$$\lambda = 14.925373134328359m \tag{3}$$

Fig. 6: Wavelength Equation

something

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.

SDR Radio Telescope study Jupiter / Sun in the Decametric Band

- Study Jupiter in the decametric band 3MHz - 40MHz
- Jupiter emissions near 20Mhz, are least likely to be interfered with from short wave transmissions
- Earths atmosphere is transparent at these frequencies during the night time
- Study Solar emissions during the day

Type	Emission Length	Emission Description
S-Bursts	short generally millisecond	wideband bursts, potentially several MHz wide
L-Bursts	long upto several seconds	wideband bursts, potentially 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]

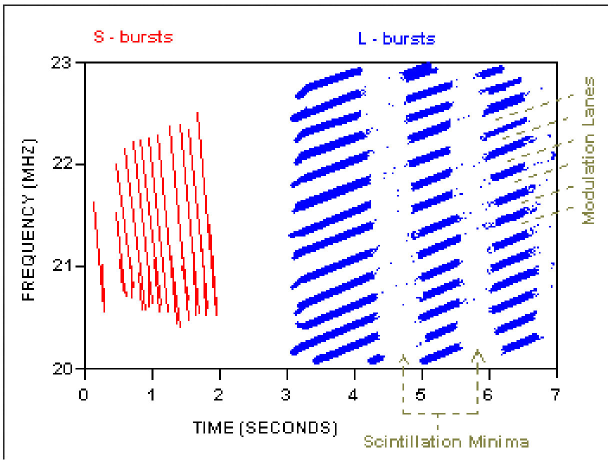

Fig. 7: Ideal DAM Emissions types from Jupiter [Wilkinson and Kennewell, 1994]

- Solar emissions are strong enough to penetrate Earths atmosphere during the day

- Low cost to deploy
- Can be run by an Amateur observer
- Mechanism for sending data from listening site back to a network connection (Ardtweeno)
- 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

A clear, precise definition of the problem is very important to focus on the research activity. great care should be used in devising the research questions. They define the structure of the investigation/innovation that will be used and an essential metric of the quality of the dissertation is the degree to which the research question has/have been answered.

- can I use this antenna to pick up signals from planetary bodies
- Signal Processing issues
- Can I address these natural signal noises
- Can I address these human signal noises

- Do amateur radio emissions adversely affect radio astronomy in the 15m band?
- What can be done using software defined radio to filter local radio interference from radio astronomy observations?
- How cheaply can a fully automated radio telescope listening station be built using current IOT technologies?

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

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]

Methodology

This should outline the approach and methodology being proposed by the student to address the research question.

- 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
-

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

List of Tables

1 Most common types of DAM Emissions from Jupiter [Wilkinson and Kennewell, 1994] 7

Glossary

DAM decameter radio emissions. 3–5

IFT Io Flux Tube. 3
IPT Io Plasma Torus. 3

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Appendix

Here is some content in the appendix

How I became inspired

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