DYNAMICS OF STRONG RADIO SOURCES WITH UMRT-II

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Abstract

Radio astronomy is a new field in Southeast Asia. University Malaya Radio Telescope UMRT-II is located on the roof of Block B in the Department of Physics, University of Malaya to detect neutral hydrogen emission line. Doppler shift of 1420.4 MHz for different radio sources were observed to determine their dynamics. By measuring the Doppler shift, the velocity *V*, of each radio source can be determined. Hence the dynamic of radio source can be deduced. The radio spectrum of Coma Cluster was also analyzed and its dark matter content was estimated. The observation time effort was investigated for Coma Cluster spectra detection and it was found that the dark matter mass significantly high. It was successfully concluded that longer observation time improves spectrum detection of weak radio sources.

The observations of neutral hydrogen emission line were interfaced by man-made radio frequencies from unknown sources. This type of radio frequency is called Radio Frequency Interference (RFI). Two surveys for RFI at two sites were done. The first one was at the same site of our radio telescope UMRT-II, at the Department of Physics, University Malaya, and the second one was at another site (Lubuk China, Malacca). For these surveys, a simple technique was used using a discone antenna, Low Noise Amplifier (LNA) and a 2 GHz spectrum analyzer.

KEDINAMIKAN SUMBER RADIO GALAKTIK

Abstrak

Radio astronomi merupakan suatu bidang yang baru di Asia Tenggara. Teleskop Radio Universiti Malaya (UMRT-II) yang terletak di atas bumbung Blok B, Jabatan Fizik, Universiti Malaya digunakan untuk mengesan pancaran semulajadi garis hidrogen. Kami memantau anjakan Doppler bagi frekuensi 1420MHz dari sumber-sumber radio yang berbeza untuk menentukan kedinamikan sumber-sumber tersebut. Pengukuran nilai anjakan Doppler dapat memberi nilai halaju, *v* bagi sumber radio tersebut. Dari situ kita dapat menyimpulkan kedinamikannya dengan mengetahui sumber ini bergerak mendekati atau menjauhi bumi. Kami juga menganalisis spektrum radio daripada sumber-sumber radio yang berbeza untuk tujuan ini termasuk Coma Cluster menganggarkan kira-kira isi materi gelap di dalamnya. Kami juga meneliti waktu pemerhatian Coma Cluster upaya deteksi Spektra kami mencari massa materi gelap secara bermakna terlalu tinggi, tapi kami berjaya menyimpulkan bahawa waktu pengamatan lebih lama meningkatkan pengesanan spektrum sumber-sumber radio lemah.

Pemantauan kami pada pancaran semulajadi garis hidrogen juga akan diganggu oleh frekuensi-frekuensi radio yang berpunca dari sumber-sumber yang berbeza dan tidak diketahui puncanya. Gangguan ini dipanggil gangguan frekuensi radio atau *radio frekuensi interference* (RFI). Kami akan menjalankan dua pemantauan RFI di dua kawasan yang terpilih. Kawasan pertama adalah di tempat terletaknya teleskop radio UMRT-II iaitu di Jabatan Fizik, Universiti Malaya dan pemantauan frekuensi radio yang kedua dijalankan di Lubuk China, Melaka. Teknik ringkas diaplikasikan menggunakan antenna diskon, *low noise amplifier* (LNA) dan *spectrum analyzer* untuk tujuan pemantauan.

Acknowledgement

First, I would like to thank my father and mother, for their support, patience and love. I would like to thank our principles at ministry of higher education in Saudi Arabia for their concerned to pursued and qualify our self academically. On top of them our great gratitude of thanks to King Abdullah bin Abdul Aziz; King of Saudi Arabia.

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I would like to individually thank Dr. Zamri Bin Zainal Abidin for his knowledge, encouragement, and patience in helping make this project possible. His guidance allowed me to make the most of my stay at department of Physics; University Malaya and to create work of which I am proud of. Without his advocacy I could not have accomplished the goals I had set while at Phys. department. Also, individual thank for Dr. Zainol Abidin Ibrahim for his knowledge, encouragement. In Addition to that; I would like to thanks the staff of Electronic Laboratory, and all the staff at department of Physics.

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List of Notation and Abbreviation

UMRT-II	University Malay Radio Telescope
RFI	Radio Frequency Interference
LNA	Low Noise Amplifier
NRAO/AUI	National Radio Astronomy Observatory of the Associated Universities Inc.
HI	Hydrogen line
AGN	Active Galactic Nucleus
SNR	Galactic Supernova Remnant
VLA	Very Large Array
FWHM	Full-Width Half Maximum
Alt	Altitude
Az	Azimuth
DEC	Declination
RA	Right Ascension
ITU	International Telecommunications Union
WARC	World Administrative Radio Conference
ATA	Allen Telescope Array
LOFAR	Low Frequency Array
LWA	Long Wavelength Array
SKA	Square Kilometer Array
LST	Local Sidereal Time

UNITS

GHz	10^9 Hz
MHz	10^6 Hz

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CHAPTER I

Introduction

1.1 Introduction

Radio astronomy is the study of radio frequency emissions from few kHz to almost 300 GHz. The frequency observation of 1420 MHz (21 cm) is the most important spectrum line in astronomical observation, both within and outside of our galaxy, and this frequency is emitted by atomic hydrogen. Atomic hydrogen is the principal constituent of the interstellar medium, and is one of the most interesting tracers for dynamics and structures of radio sources.

A neutral hydrogen atom consists of one proton and one electron, both in orbit around the nucleus. The proton and the electron spin about their individual axes; however, they spin in two directions, not only in one direction. They can spin in the same (parallel) or in opposite (anti-parallel) directions. The energy carried by the atom in parallel spin is greater than the energy in the anti-parallel spin. Therefore, when the spin state flips from parallel to anti-parallel, energy is emitted at a radio wavelength of 21- cm. This 21-cm radio spectral line corresponds to a frequency of 1.420 GHz.

The first person to predict this 21-cm line for neutral hydrogen was H. C. van de Hulst in 1944. However, up until 1951, nobody was able to detect this spectral line. In 1951, a Harvard team detected this spectral line after they constructed the necessary equipment (Kelvin L. V, 2009). The discovery and detection of the 21 cm emission line played an important role in radio astronomy.

Galaxy clusters are the largest known gravitationally bound structure in the universe (Bird, C. M, *et al.* 1993) Coma cluster is one of the best-observed and richest nearby clusters (Jeffrey M. Kubo, *et al.* 2007). After these detections we are able to understand our galaxy (Milky Way) and beyond.

1.2 Motivation and research objectives

The objectives of this research are to measure the neutral hydrogen emission of different radio sources in our galactic such as Cygnus A, Cassiopeia A, the moon, Orion, etc; to determine the Doppler shift of these sources using University Malaya Radio Telescope UMRT-II, which is located on the roof of Block B ,Department of Physics, University Malaya; and to analyze the radio spectrum of Coma Cluster to estimate its dark matter content.

Finally, it is also one of the objectives of this research to detect the radio frequency interference (RFI) at the same place of our radio telescope (UMRT-II), at the Department of Physics, University Malaya, and at another site (Lubuk China , Malacca) using a simple technique.

1.3 Thesis outline

Chapter 1 presents the introduction and objectives of the study. Chapter II gives a brief history about radio astronomy, and a basic description about 21 cm neutral hydrogen line and its applications. As well as the background of radio telescope and astronomical coordinates system. At the end of this chapter, the radio frequency interference (RFI) and some methods for RFI mitigation were discussed. In Chapter III, we present some of the apparatus used in our experiments and their methods. The results and discussion are presented in Chapter IV. Finally, the conclusion is presented in Chapter V.

CHAPTER II

Literature review

This chapter discusses brief history of radio astronomy in section 2.1. Section 2.2 presents brief review of the 21 cm neutral hydrogen line (HI). The applications of the 21 cm neutral hydrogen line (HI) in literatures are presented in section 2.3. We discussed radio telescope in section 2.4. The Doppler Effect phenomenon is presented in section 2.5. In astronomy is important to know about Astronomical coordinates systems, which are presented in section 2.6. The last section is section 2.7 and it discusses radio frequency interference (RFI) and some method of RFI mitigation.

2.1 Brief history of radio astronomy

Radio astronomy was born in 1931, before that time we have only one choice to observe universe using optical telescopes. But, in 1931, nobody knew neither that radio waves are emitted by billions of extraterrestrial sources, nor that some of these frequencies pass through Earth’s atmosphere and reach us on the ground.

Karl G. Jansky (1905-1950) worked as a radio engineer at the Bell Telephone Laboratories. In 1931, he was assigned to study radio frequency interference from thunderstorms. He built his antenna and he detected unknown static.

As his antenna rotated, he found that the direction from which this unknown static originated changed gradually and he thought the source of static is the sun. However, he observed that the radiation peaked about four minutes earlier each day. Jansky therefore concluded that the source of this radiation must be much farther away than the sun. With further investigation, he identified the source as the Milky Way and, in

1933, published his findings (Kelvin L. V, 2008) because of that the field of radio astronomy recognize him with a unit named after him; the Jansky is equivalent to 10^{-26}watt $m^{-2}Hz^{-1.}$

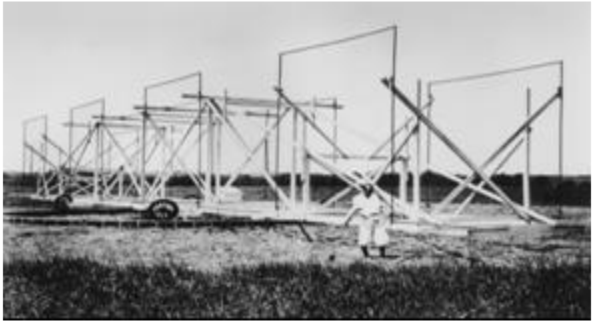

Figure 2.1 Jansky’s antenna (Source: NRAO/AUI)

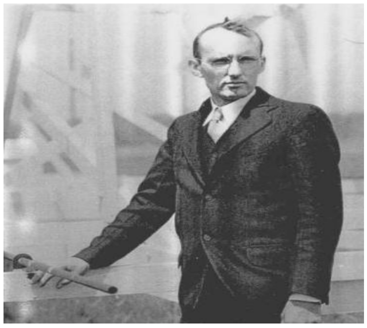

Figure 2.2 Karl Jansky (Source: NRAO/AUI)

In 1937, just six years after the groundbreaking discoveries of Jansky, Grote Reber constructed a parabolic-reflector antenna 9.5 m in diameter and operated it from his backyard. He built his antenna at his own expense while working for a radio company. The antenna relied on Earth’s rotation to change its right ascension and was adjustable only in declination. Reber’s goal was to continue where Jansky left off. He turned his antenna toward the nucleus of the Milky Way Galaxy and investigated the radio waves seen six years earlier by Jansky and in 1944 he published the first radio frequency sky maps. After of the World War II, radio astronomy developed rapidly, and has become of vital importance in our observation and study of the universe.

Figure 2.3 First steerable radio telescope, constructed by Grote Reber.
(Image courtesy of NRAO/AUI).

2.2 The 21 cm neutral hydrogen line (HI)

A neutral hydrogen (HI) atom has one proton and one electron. The 21 cm Hydrogen Line arises from the spin flip transition in the ground state of neutral hydrogen. The situation may be compared with the flip of two magnets when they are placed with same pole side by side. When the spin state flips from parallel to the antiparallel, energy (in the form of a low energy photon) is emitted. The emitted energy of this transition has been measured in laboratories at 1.420405753 GHz (e.g. Kerr, 1968). This frequency corresponds to 21 cm of wavelength or energy of $5.874 \, X \, 10^{-6}$Ev (J. Borowitz, 2005).

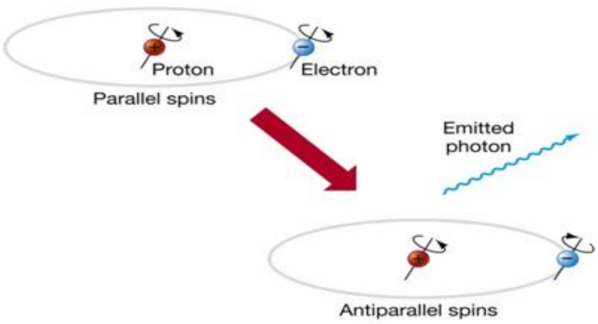

Figure 2.4 Emission of 21cm photon from neutral hydrogen

The first detection of neutral hydrogen line is done by three research groups in USA, Holland and Australia. These groups have done two surveys, one for the southern part of the sky and the second one for the northern parte of the sky. The survey of the southern part was undertaken by the group in Sydney and the survey of the northern part of the sky was undertaken by the group at Leiden, in Holland.

Figure 2.5 has been mapped by combining the data of two surveys from Australia and Holland (H. V Woerden and C. G. Strom, 2006).

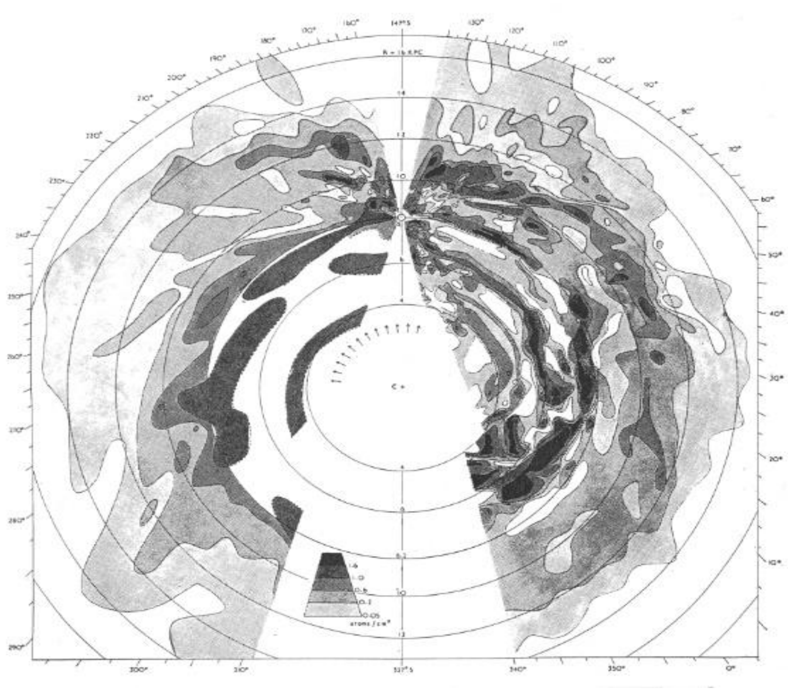

Figure 2.5 Radio map of neutral hydrogen distribution at 21 cm wavelength

In the Milky Way (Source: H. V Woerden and C. G. Strom, 2006)

2.3 Applications of the 21 cm neutral hydrogen line (HI)

People have studied galactic rotation curve. The sharpness of the 21-cm hydrogen line allows for very precise Doppler spectroscopy, we make use of the abundance of neutral hydrogen in the Milky Way to derive a galactic rotation curve (Lulu L, 2008). Lulu L (2008) models the galaxy as a differentially rotating thin disk with stellar and interstellar material in circular orbits around a center. This assumption allows the average velocity to be independent of polar angle. If we know the explicit velocity curve then allows dramatic insight into the distribution of mass within the galaxy and than we will be able to determine galactic structure.

HI emission has been able to trace structures in the interstellar medium because the brightness temperature of the line is proportional to the column density of gas. (Crovisier, J. and Dickey, J. M, 1983)

We know the frequency of the 21 cm hydrogen line (1420 MHz) so measurements of the redshift at different galactic longitudes allow for the calculation of the velocity of the source using the equation describing Doppler shift at distances that can be calculated using geometry describing the motion of the sun relative to the galactic center. Then the galactic rotation curve is plotted with the calculated distances vs. calculated radial velocities. When we measure the frequency of hydrogen at different lines of sight in the universe, the frequency 1420.4 MHz will be changed since there is relative motion between the source and the observer. Its frequency, however, will be shifted this phenomena known as the Doppler shift. The Doppler shift is given by following equation:

$$\mp \mho = \frac{\pm \Delta \nu}{\nu} c \qquad 2.1$$

Where $\mho$ is the velocity of approach (−) or recession (+), $\boldsymbol{c}$ is the speed of light, $\boldsymbol{\Delta \nu}$ is the frequency shift, and $\boldsymbol{\nu}$ is the rest frequency (for HI, $\boldsymbol{\nu}$ = 1420.4MHz) (Kelvin L. V, 2008)

The frequency of 21 cm radio waves (1420.4 MHz) is very low so, radio astronomy on this frequency is able to penetrate the dust clouds obscuring the center of the Milky Way, while optical astronomy fails. This is caused by the scattering of higher frequency radiation by the particulate form of the interstellar dust surrounding the galactic center. Hulst and others found that the Milky Way is indeed a galaxy separate from the observed nebulae, and that its structure is very similar to that of a spiral galaxy (Philip J. I., 2007) Measuring Doppler shifts within the centered spectra of 1420.4 MHz, the motion and velocity of galactic rotation was found by Ewen and Purcell in 1953 .Than , Hulst, Muller and Oort confirmed these results of the structure of the Milky Way, and also determined the velocity of galactic rotation (Hulst, C. Muller and J. Oort, 1954).

The 1420 MHz waves can be detected coming from hydrogen clouds throughout our galaxy. So, be able to map the hydrogen throughout our galaxy, and the stars associated with it. The motion of gas and stars within our galaxy is complex. Relative to us, hydrogen gas within spiral arms may be approaching, moving far away or not moving at all. As a result of the Doppler shift, the frequency of the hydrogen spectral line detected may be reduced if the emission is from hydrogen clouds that are moving away from us, or increased if they are moving towards us (T. Hill and K.Guernsey, 1995).

Typical hydrogen line profiles obtained from looking in specific directions along the Milky Way can be seen in Figure 2.6**.**

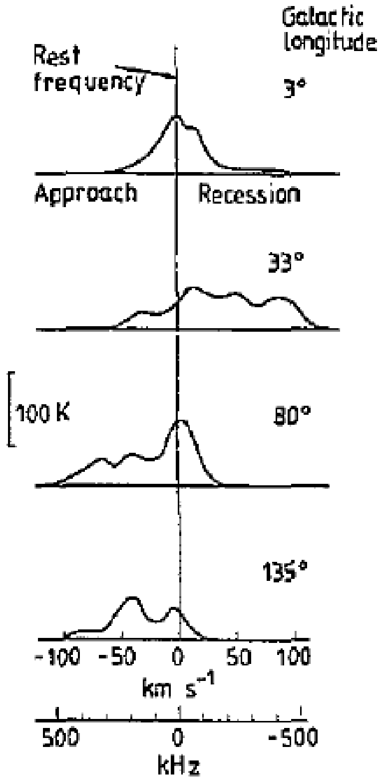

Figure 2.6 Hydrogen line profiles at different longitudes in the plane of our galaxy

(Source: T. Hill and K.Guernsey ,1995)

2.3.1 Cosmology applications

From detection of 21 cm neutral hydrogen, galaxy clusters can be studied. Virial theorem would furnish the total gravitational mass M_{TV} for fully relaxed isolated cluster with dark matter and galaxies distributed. To estimate hydrogen mass $M_{H,}$ equation (2.2) it will be used (O.G.Richter, et al. 1993).

$$M_H = 2.36 \times 10^5 D^2 \int S_v \, dv \;\; M_\Theta \qquad (2.2)$$

Where **D** is galaxy distance in Mpc, $\mathbf{S_v}$ is flux density in Jy, **v** is velocity Kms^{-1} and $\mathbf{M_\Theta}$ is solar mass in Kg.

2.4 Radio telescope

In radio astronomy there are different types of radio telescope, however, most familiar radio telescope antennas are parabolic (dish-shaped) reflectors, they can be pointed toward any part of the sky. Each radio telescope antenna (dish-shaped) consists of a parabolic reflector to collect and reflect the on coming radio wave from a source and focus them onto the feedhorn at its focal point. Parabolic antennas differ from each other in their design. The first "dish" radio telescope built by Grote Reber at Wheaton, Illinois, USA in 1937 (Figure 2.3). In radio telescope it is necessary to know some of its characteristics such as beamwidth and aperture efficiency.

The beamwidth is a range of angles over which the telescope is sensitive for a particular wavelength and is usually given with the telescope sensitivity at half its maximum value. The full-width half maximum (FWHM) beamwidth Θ_{FWHM} is given by equation 2.3, (Kelvin L. V, 2008).

$$\theta_{\mathrm{FWHM}} = \frac{1.22\lambda}{D} \qquad 2.3$$

Where D is the diameter

λ is the operating wavelength

And the aperture efficiency η_A defined as is a factor which includes all reductions from the maximum gain. It given by equation 2.4 (JacoA W.M., 2006)

$$\eta_A = A/A_g \qquad 2.4$$

Where $\boldsymbol{A}$ is the maximum absorption area

$\boldsymbol{A_g}$ the geometrical area of the antenna aperture.

With the developments in radio astronomy it is becoming necessary to build a new generation large radio telescope. So far, the largest single-aperture radio telescope is Arecibo Observatory in Puerto Rico, with 1000 feet dish. See Figure 2.7

Figure 2.7 Arecibo radio telescope (Source: http://www.naic.edu)

2.5 Doppler effect

The first person to describe this effect is Christian Doppler (1803–1853) in 1842 so; this effect bears his name (Doppler Effect). In 1845 this phenomena was verified experimentally by the Dutch meteorologist Christoph Buys-Ballot (1817–1890), (Robert L., 1997). The basic definition of The Doppler shift in astronomy is that, when the source (e.g. star) and observer of light waves move away, the observed light will be shifted to lower frequencies, towards the “red”, while if the source and observer move toward each other the light will be shifted to higher frequencies, towards the “blue” see Figure 2.8. In optical astronomy it has long been used to measure the radial velocities of stars through the wave line shift in spectral lines, and in the "red shift" of the light from distant galaxies. The Doppler effect can be used to determine the relative motion of the object, its velocity and the distance of the object. Most of distant galaxies are shifted toward the “red”, the interpretation of that is, the universe is expanding (J. S. Bagla 2009). Last but not least, the Doppler shift is very important in spectral-line radio astronomy.

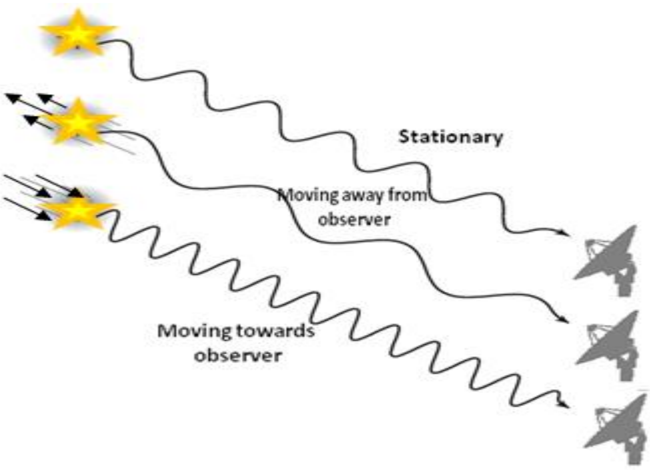

Figure 2.8 Doppler shift

2.6 Astronomical coordinates systems

2.7.1 The horizontal coordinate system

This system based on a plane parallel to the horizon. This coordinate system using Azimuth and Altitude (Elevation)

Altitude (Alt), is the angle between the object and the observer's local horizon. And the *Azimuth (Az)* is the angle of the object around the horizon, usually measured from the north point towards the east. Because of the rotation of the Earth during the day celestial object coordinates are continuously change (John D. Kraus, 1966). Our telescope operates under this system.

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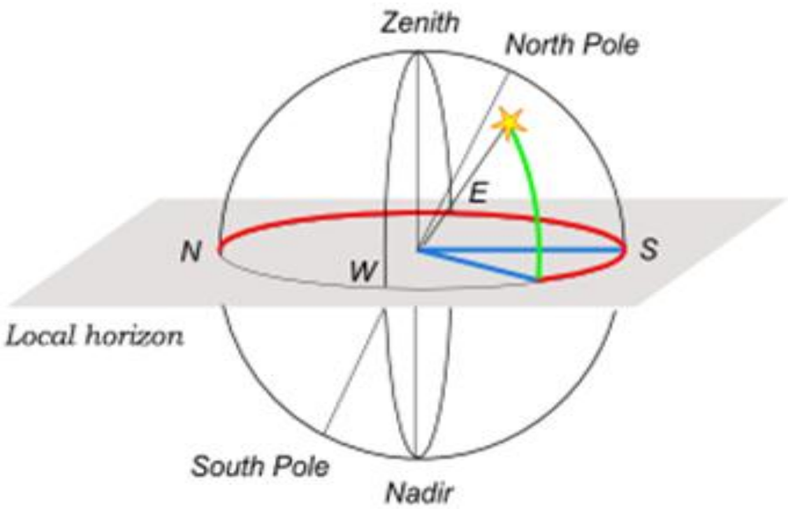


Figure 2.9 The horizontal coordinate system

2.6.2 The equatorial coordinates system

This system refers to the plane of the earth equator**.** The most important things in this system to know the two equatorial coordinates (right ascension RA and the declination DEC) which are use to determine location of a celestial object. The right ascension is measured eastward along the celestial equator from the vernal equinox. The right ascension is either specified in degrees from 0◦ to 360◦ or generally specified in units of hours, minutes and seconds from 0 to 24 hours. The declination (DEC) is measured north from the celestial equator along a celestial meridian (a great circle of constant RA)**.** The declination is specified in degrees and is positive if the object is north of the equator and negative if south $-90^0 \leq DEC \leq +90^0$ **.**

(1 hour of RA at constant DEC corresponds to an angle of 15◦cos(DEC) degrees subtended at the origin), **(**John D. Kraus, 1966).

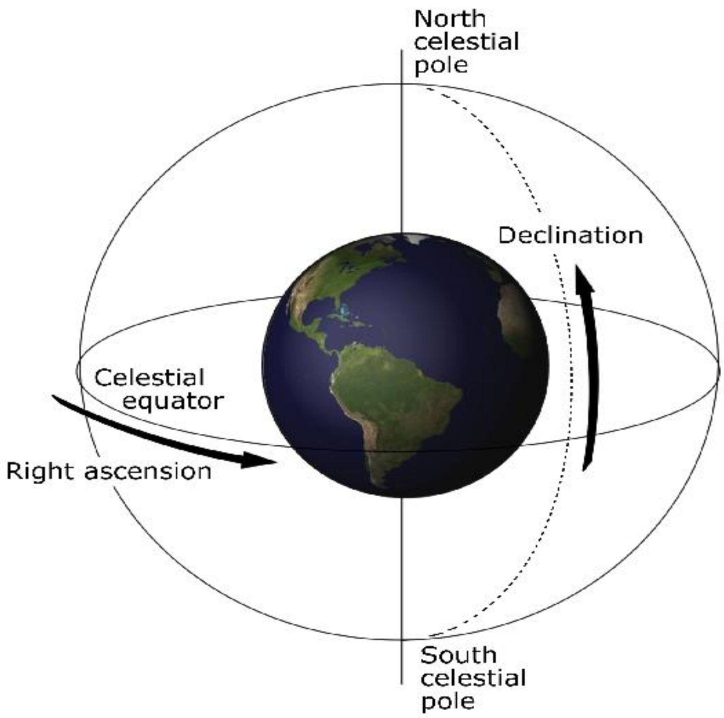


Figure 2.10 The equatorial coordinates system

2.6.3 The ecliptic coordinate system

In this system the reference is the plane through the earth's orbit (figure 2.15).

The coordinates measured from eastward along the ecliptic from the vernal equinox, and north or south from the ecliptic. This system is useful in the solar system studies.

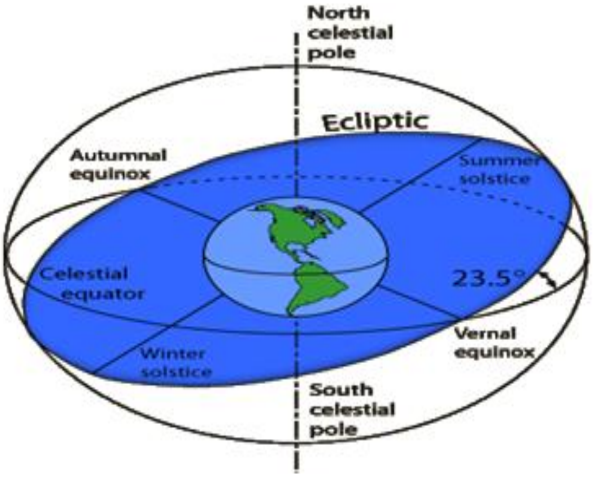


Figure 2.11 The ecliptic coordinate system

2.6.4 The galactic coordinate system

In this system the reference is the plane through the sun parallel to the plane of the galaxy (Figure 2.16) .The galactic coordinates of longitude ***l*** and latitude ***b*** are specified in degrees. The ranges of longitude ***l*** are from 0 to $360^{o,}$ same as right ascension at the galactic equator. The ranges of latitude ***b*** are from -90^o at the south galactic pole through 0^0 at the galactic equator to $+90^o$ at the north galactic pole.

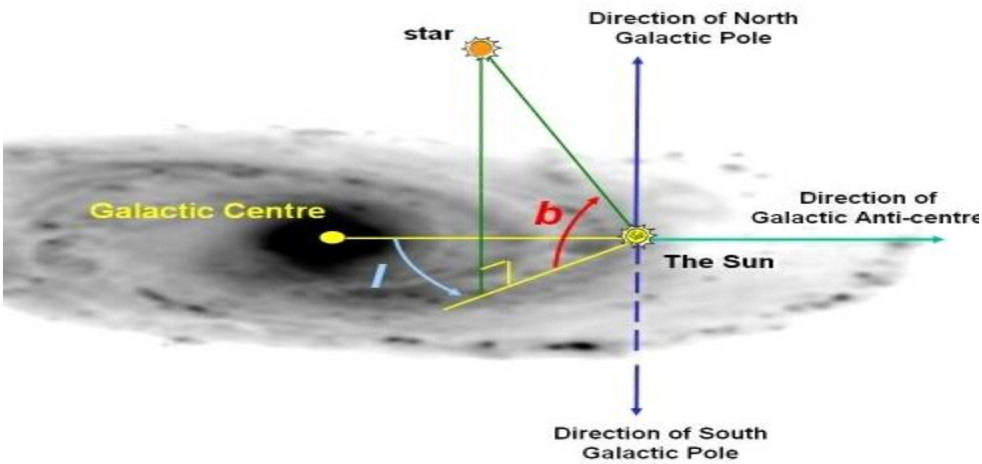


Figure 2.12 The galactic coordinate system

2.7 Radio frequency interference (RFI)

Radio astronomy studies radio frequency emissions at broad band between (a few KHz and approximately 300 GHz). A major problem in radio astronomy is that wireless communications use frequencies within this band. Many of the signals astronomers are trying to observe are very small. Because of this, even small power levels from satellites or other transmitting devices cause interference. This interference from communication devices is and all unwanted signals known as radio frequency interference (RFI). In addition, radio astronomers would like to study other important astronomical signals that are outside of protected bands (Chad K. H., 2004). For example, the search for Doppler-shifted spectral lines will need to be made outside the protected bands of radio astronomy (M.Kesteven, 2005). There are different sources of interference as well as different nature. So, different mitigation methods are required. Local sources of interference include internal equipments in the telescope building and facilities in the laboratory. Interference compliance testing, shielding, separate power circuits, minimizing nearby equipment are key steps that need to be taken to minimize this kind of interference. External interference may arise from fixed or moving sources. Not all methods of mitigation apply to both: in fact methods that work well for fixed sources, may not work at all for moving sources. The interference may happen naturally such as the ground, sun, other bright radio sources, lightning and human generated sources such as broadcast services (e.g. TV, radio), communications (e.g. mobile telephones, two-way radio, wireless IT networks), navigation systems (e.g. GPS, GLONASS), radar, remote sensing, military systems, electric fences, car ignitions, and domestic appliances (e.g. microwave ovens*)* (R. D. Ekers and J. F. Bell, 2000) and all radio telescope stations have basic facilities, the instruments in use and also the equipment under test are potential sources of interference.

Telecommunications technology and developed industries can not be prevented, however we can try to minimize its impact on passive users of the radio spectrum and maximize the benefits of technological developments. The allocated bands are fixed by national authorities and the ITU (International Telecommunications Union).

We can minimize most terrestrial interfering signals to radio astronomy observation by moving to a remote location, where the density and strength of unwanted signals is less. Although this method is difficult, however, it is still possible. So, we can say that site selection is the most important RFI mitigation technique available (G. C. Bower) . The ideal location would be the back side of the moon (Y.D. Takahashi, 2002).

Radio-astronomical observations are increasingly corrupted by RFI (A. L., Alle-Jan van der V, 2000). It is important to know the type of interference that will disturb your observation so the best way to avoid and mitigate the interference can be undertaken. Before doing an observation, radio astronomers want to know a recent RFI survey of the site and they will choose the best site for doing their observation which has less interference

The devices which emit radio-frequency radiation can be troublesome sources of interference to radio astronomers. Some commercial microwave ovens, which nominally operate in the 2450 - 50 MHz Industrial, Scientific, and Medical (ISM) band produce radiation from 1-6 GHz at levels above the harmful interference threshold even for an oven as far as 5 km from the radio telescope.

Radio astronomers have been assigned the use of many frequency bands, particularly as the result of the 1979 World Administrative Radio Conference (WARC). However, even the "allocated" bands are usually shared with other services

(Pamela j. W., 1984). For example, when a group research were doing their studies of RFI at Parkes Observatory in New South Wales, Australia, they found that the protected band for neutral hydrogen (1400-1427 MHz) occupied by narrow band RFI signals over 10% of the total L-band observing time (J. Tarter, et al. 2000). However, some of the astronomers would like to observe at other frequencies which are fixed in 1979 after (WARC).

Pamela j. Waterman, (1984) divided the situations of RFI into three separate categories: internal, external (nearby), and external (distant).

1. Internal situations:

Some of the worst problems are often caused accidentally by the astronomer himself due to the digital equipment inside the telescope control room.

2. External (nearby) situations:

The most important factors caused more RFI is the location of telescope. Radio astronomers should locate their telescopes at least several miles from populated areas and busy roads.

3. External (distant) problems:

Satellite transmitters, television stations, broadcasting stations, radar, TV stations, and the phone system are sources of radio interference.

So far, no specific methods of mitigation for radio astronomy observation. However, there are various methods for RFI mitigation and depend on three factors (P. A. Fridman, 2001)

1. The type of radio telescope: Single dish radio telescopes are most susceptible to RFI.

2. The type of observations.

3. The type of RFI.

2.7.1 Radio frequency interference (RFI) mitigation

RFI mitigation has become necessary because:

1. Telescopes are becoming ever more sensitive. This means that more detectable for signals from different sources (unwanted signals and others).

2. Also, The commercial use of the spectrum is increasing, that means more RFI present. So, RFI are increasing every year.

Next generation radio telescopes such as the Allen Telescope Array (ATA), the Low Frequency Array (LOFAR), the Long Wavelength Array (LWA), and the Square Kilometer Array (SKA)— are being designed and developed and they totally are different in their design from most present single-dish or interferometric telescopes (N. D. R. Bhat , J, 2005)

Some of RFI mitigation methods

M.Kesteven (2005), described some methods to mitigate RFI.

1. The Post-Correlation Adaptive Filter: The filter is able to remove RFI from a corrupted data channel when it is given an independent copy of the RFI. However, the filtered channel also has noise. Different design (see Figure 2.17, 2.18 and 2.19) which shows the result of imaging the raw data (2.18) and the image from the filtered data (2.19) for more details are referred to (M.Kesteven, 2005)

2. RFI mitigation in the image domain: RFI can be identified and removed within the image processing operation.

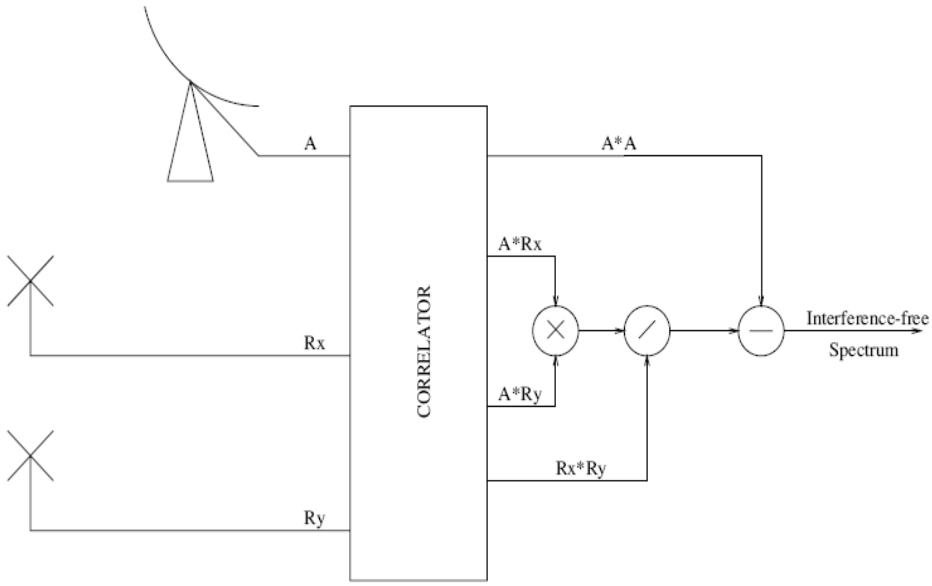
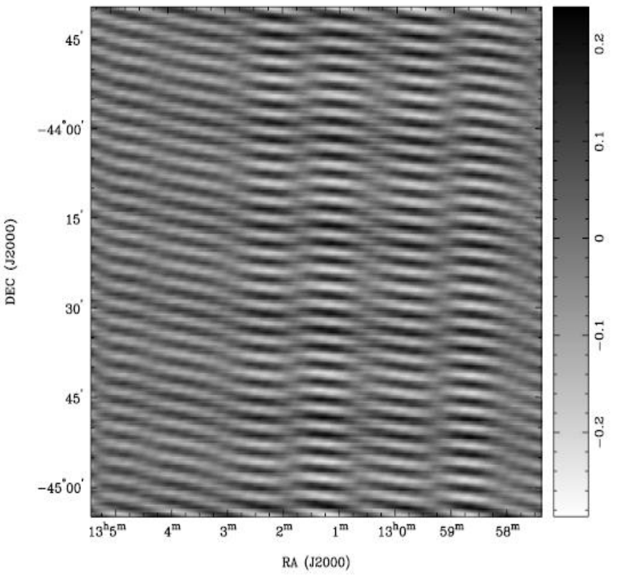


Figure 2.13 A single antenna post-correlation adaptive filter (Source:M.Kesteven, 2005)



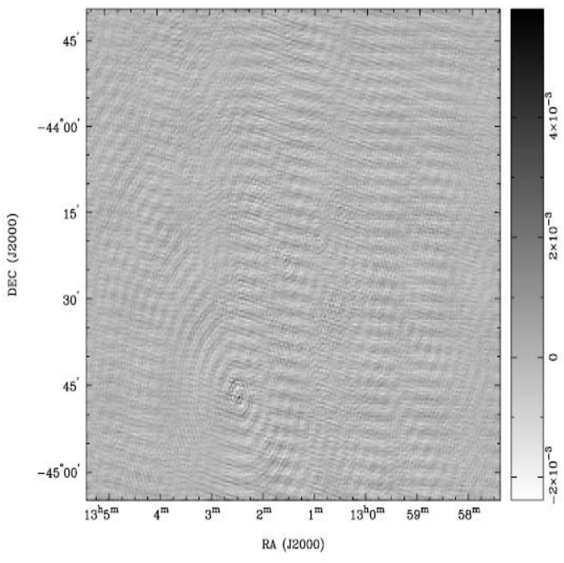


Figure 2.14 Image based on the raw unfiltered data (Source:M.Kesteven, 2005)

Figure 2.15 Image based on the filtered data (Source:M.Kesteven, 2005)

Also, Receiver must be designed to prevent very strong RFI from amplifier or other components.

P. A. Fridman and W. A. Baan (2001) described in details five methods for RFI mitigation in their paper in title "*RFI mitigation methods in radio astronomy*".

CHAPTER III

Material and methods

The study of applications of hydrogen line was carried out using the University Malaya radio telescope, UMRT-II, which consists of antenna dish, motors, radio receiver and ground controller. The radio frequency interference (RFI) surveys were carried out using discone antenna, low noise amplifier and spectrum analyzer. All of these apparatus are illustrated and explained in this chapter, followed by the experimental methods.

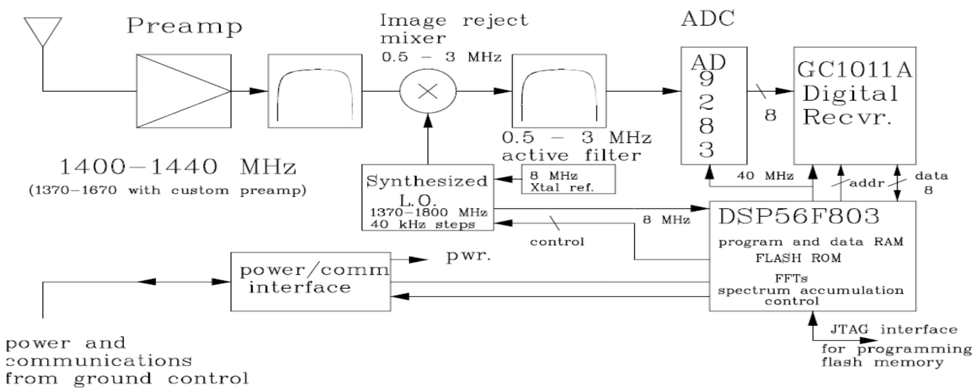
3.1 Experimental apparatus for Hydrogen line detection

3.1.1 Antenna and Motors

Figure 3.1 UMRT-II

University Malaya radio telescope, UMRT-II, was received from the contracted manufacturer, in separate pieces containing: the parabolic reflector, feed horn stands, feed horn, control box, cables, steel pieces of the telescope stand and Azimuth/Elevation motor. The 2.3 m diameter parabolic dish antenna collects radio wave coming from all directions from the sky (Karl D. Stephan, 1999). It has a focal length of 85.7cm and its beam's width is 7.0 degrees (L-band or 1420.4 MHz)· The dish is mounted on a two-axis azimuth/elevation mount. It is supported by an aluminum frame constructed from C/Ku band mesh that will reflect all incident radio wave energy if the surface holes are less than 1/10th of the incident wavelength. The system is controlled using a computer, and runs on a java applet. The software calculates radio sources coordinate positions from the azimuth-elevation coordinates and the knowledge of the local sidereal time (LST).

3.1.2 Receiver



Schematic diagram of the radio receiver board

Figure 3.2 Receiver

The UMRT-II uses a phasing type single sideband scanning receiver. Figure 3.2 shows the schematic diagram of the radio receiver board. Radio power arriving from directions close to the axis of the parabolic antenna is focused by reflection to an antenna feed horn. Signals then pass through a band pass filter, low noise preamplifier and mixer. The baseband signal is digitized and sent back to the controlling computer.

3.1.3 Ground Controller and Software Interface

Figure 3.3 Ground Controller

The ground controller serves as the interface between the computer and the antenna servo motors, as well as the digital receiver. The ground controller should be powered on before the JAVA software is run, and turned off again at the end of an experimental session.

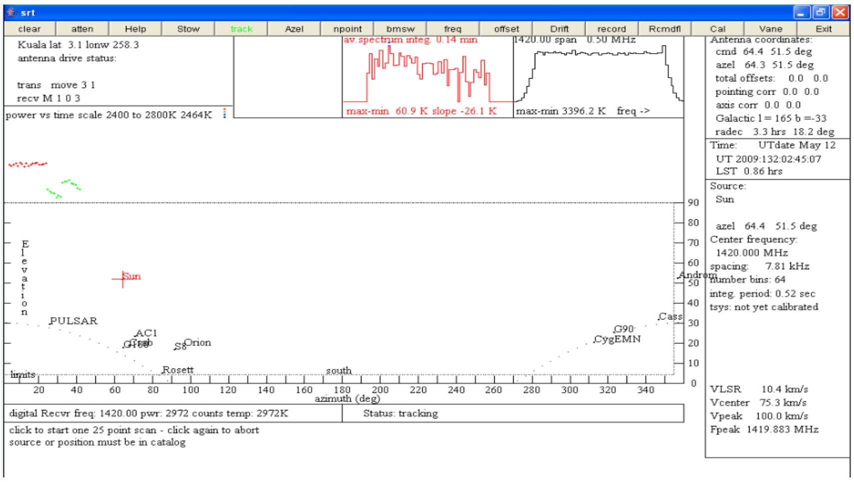


Figure 3.4 Software interface

The SRT control software interface is a JAVA-based program and it can be run by double-clicking its icon on the windows desktop.

Details of the software are available at

http://www.haystack.mit.edu/undergrad/srt/index/html

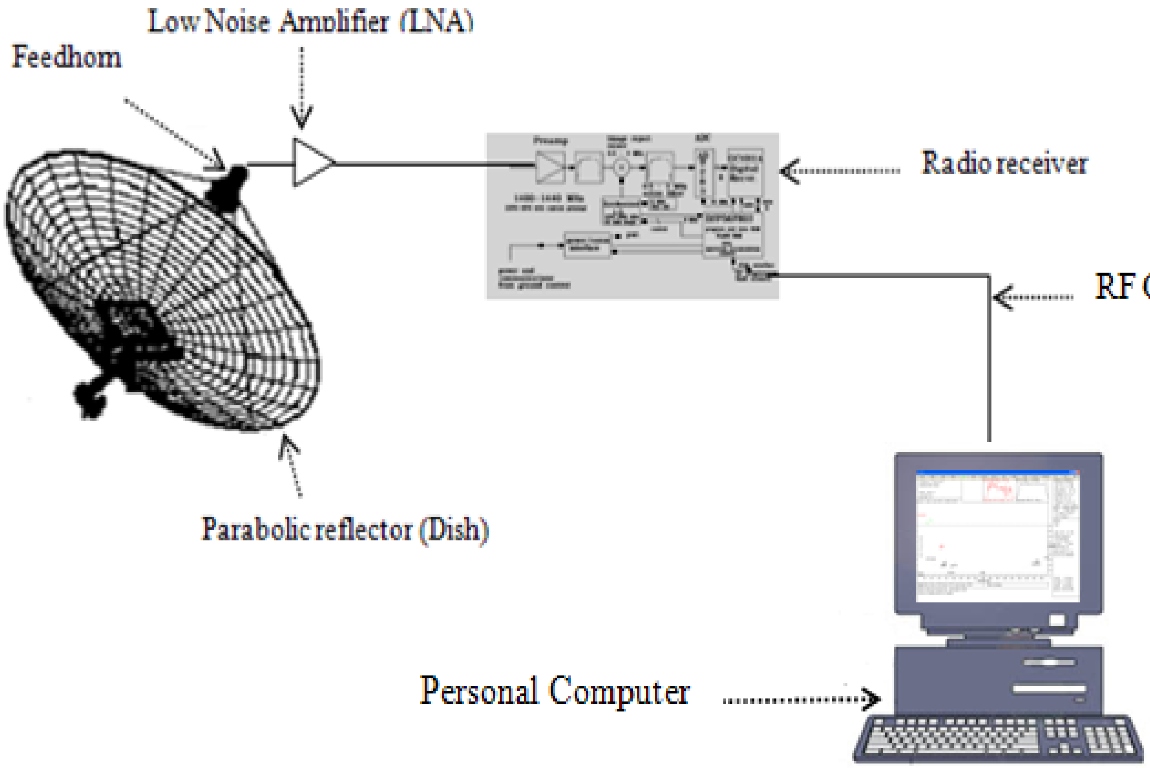


Figure 3.5 Schematic diagram of experimental set up

3.2. Experimental apparatus for RFI survey

For RFI survey a simple technique was used using a discone antenna, Low Noise Amplifier (LNA) and 2 GHz RF Field Strength Analyzer.

3.2.1 Discone antenna

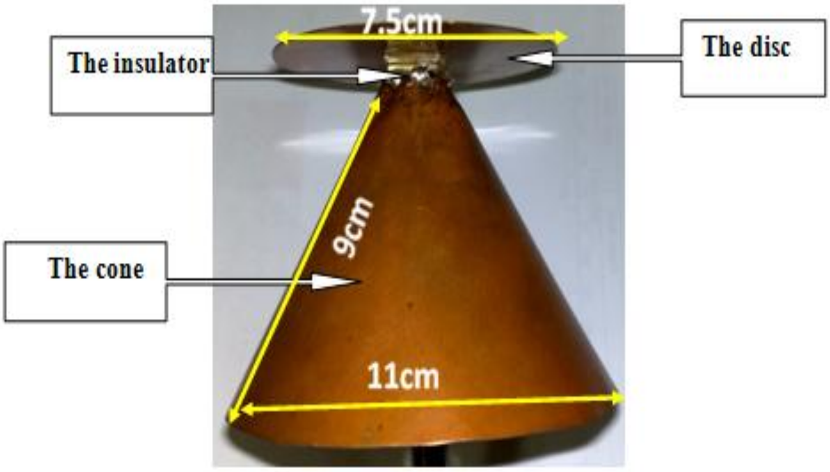


Figure 3.6 Discone antenna

Figure 3.6 shows the discone antenna which is used for RFI survey. It consists of three components: disc, cone and insulator as illustrated in Figure 3.6. This type of antenna is suitable for RFI survey. The discone antenna captures the surrounding signals and sends them to (LNA).

3.2.2 Low Noise Amplifier (LNA)

Figure 3.7 Low Noise Amplifier (LNA)

Because the received signals from discone antenna are very weak we use (LNA) to amplify these signals to be detectable by RF Field Strength Analyzer.

3.2.3 RF Field Strength Analyzer.

Figure 3.8 RF Field Strength Analyzer.

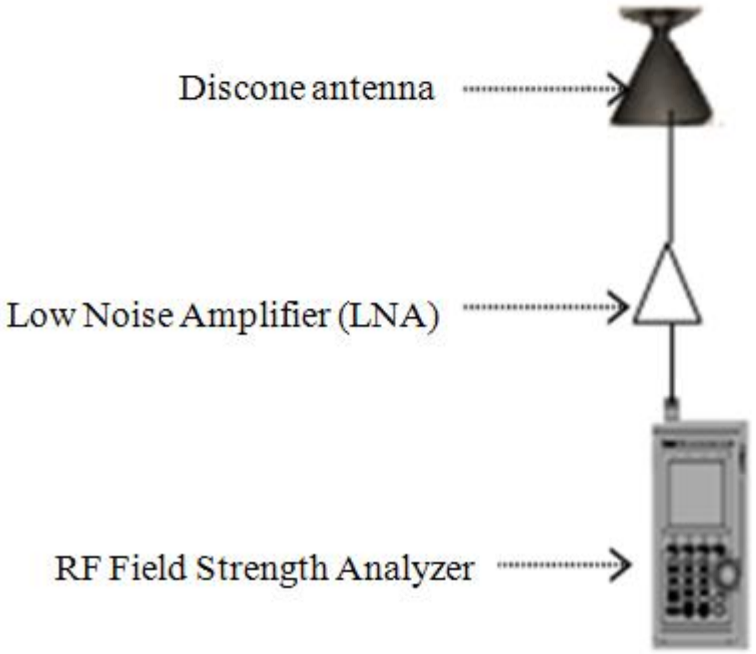


Figure 3.9 Schematic diagram of experimental set up

This study was divided into two parts. The first part was to study the dynamics of strong radio sources and the second part was about radio frequency interference (RFI) survey.

To study the dynamics of strong radio sources, a small-sized radio telescope was used. It is located on the roof of Block B in the Department of Physics, University of Malaya. First, the ALT/AZ coordinates of the radio source from its RA/DEC at the current time and location were obtained. The telescope was pointed in that direction. The source would be e.g. Cygnus A or Cassiopeia A, depending on which of these was above the horizon or the source to be studied. Each of these sources emits 1420.4 MHz radio wave. But when these sources moved, their 1420.4 MHz radio waves were shifted due to the Doppler shift when they reached our telescope. When the radio waves arrived at the telescope, they were reflected by the parabolic dish to the antenna feedhorn (See Figure 3.10). The dish was mounted on a two-axis azimuth/elevation mount. Then, the signal passed through a Schottky diode, which converts an incident signal at a given frequency to a voltage that is proportional to the power at that frequency. This signal was then transformed into a new pulse whose duration is inversely proportional to the power during the pulse. Finally, the microcontroller measured the duration of the pulses and converted them into signals parsed by the SRT software. The SRT software provides a graphical user interface that allows the user to control the telescope at different levels of detail. The same method was used for Coma cluster observation. However, the data analyses were different. In equation (2.2) $\int S_v \, dv$ from Coma spectra could be obtained. The spectra of radio sources are plotted as K vs. Kms^{-1} so K was converted into Jy, which then allowed the area under the graph to be calculated to obtain M_H.

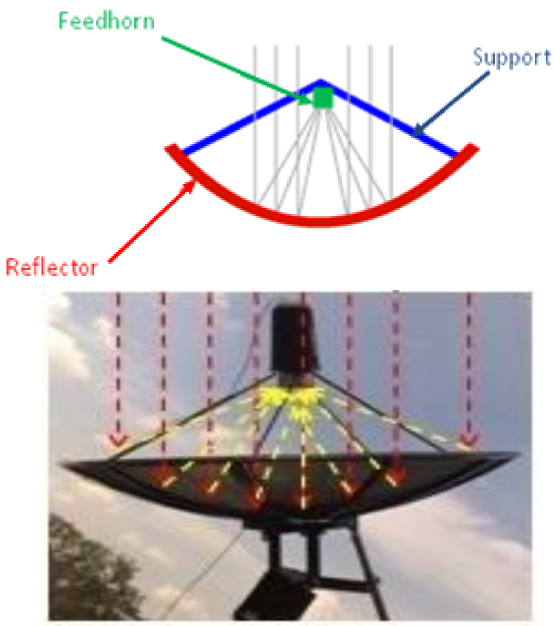


Figure 3.10: Radio waves reflection

Secondly, radio frequency interference (RFI) was studied at the Department of Physics, University of Malaya (same site of UMRT-II), and also, at another site (Lubuk China). For this study, the discone antenna was used to collect surrounding frequency, and the second equipment used was low noise amplifier (LNA). Because the received signals were very weak, we used (LNA) to amplify these signals for them to become detectable by the spectrum analyzer. Finally, 2GHz RF Field Strength Analyzer was used to collect the data. The method of this survey was quite simple. After the equipments were set up (to connect the discone antenna with LNA, LNA with the cable and the cable with the RF Field Strength Analyzer), the signals were captured by the discone antenna and sent to (LNA). LNA amplified the signals many times and the amplified signals were transferred through a cable to the RF Field Strength Analyzer. Then, the 2GHz RF Field Strength Analyzer was used to save and transfer the data to a personal computer for analysis. The duration of this survey was 24 hours. The data were saved every 15 minutes for narrowband signal, and every 3 hours for wideband signal.

CHAPTER IV

Results

Figures (4.1 to 4.8) show eight spectra for Cygnus, Cassiopeia, Centaurus A, Virgo A, the moon, Andromeda, Orion and Hercules. From these spectra, the Doppler shift for each radio source could be obtained. Equation (2.1) was used to calculate this. Table (1) summarizes the coordinates system and velocities of radio sources.

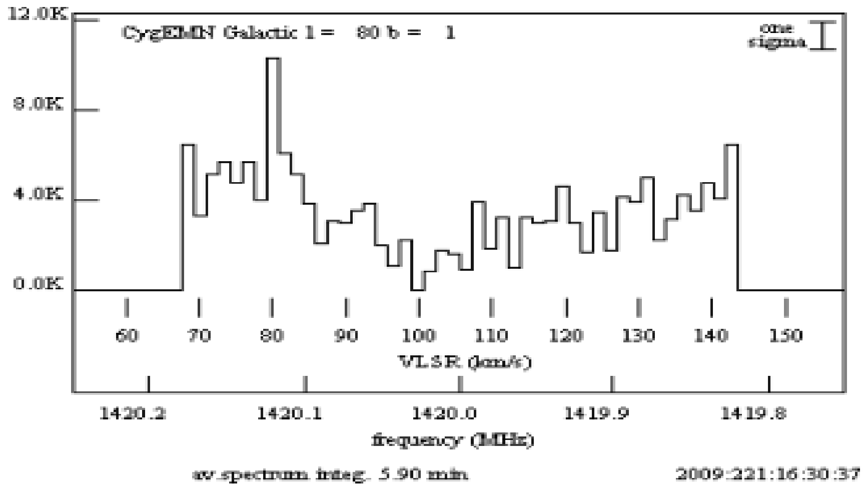


Figure 4.1Spectrum of Cygnus

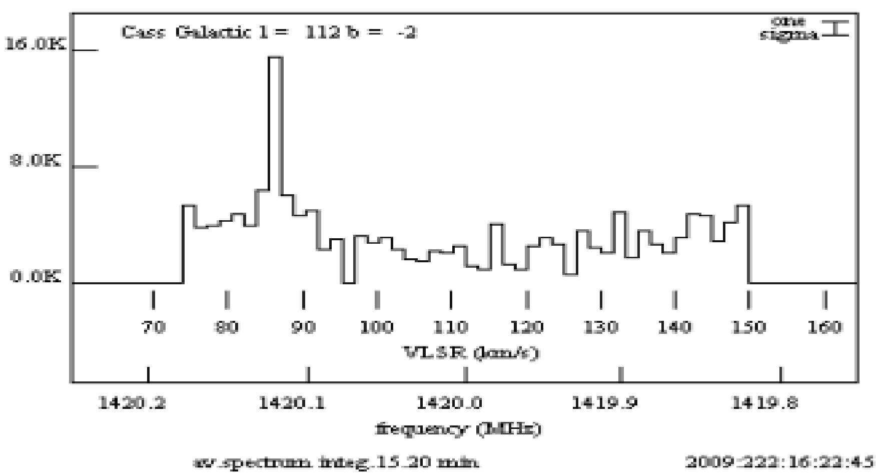


Figure 4.2 Spectrum of Cassiopeia

The graphs above show very sharp signals almost at 1420.17MHz, however, the expected sources of these signals are RFI not from radio astronomical sources.

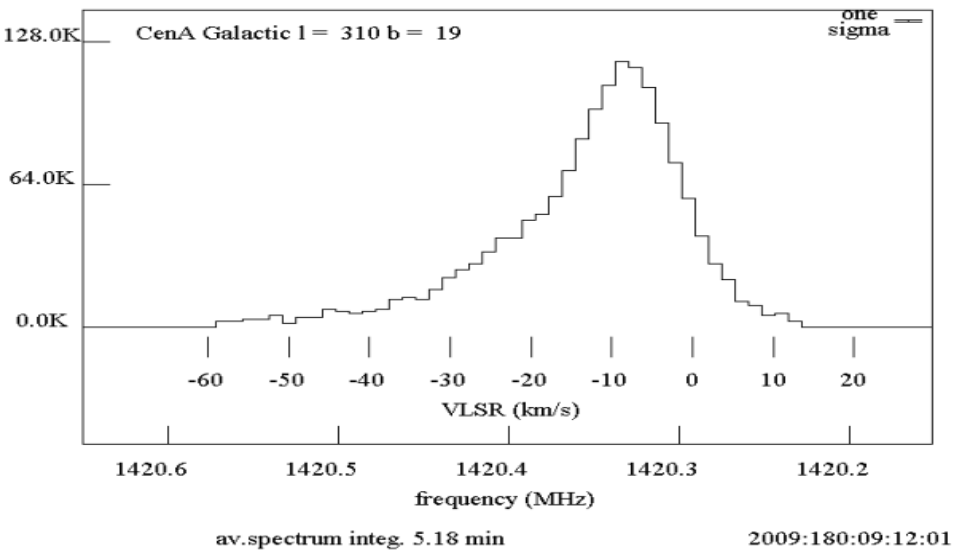


Figure 4.3 Spectrum of Centaurus A

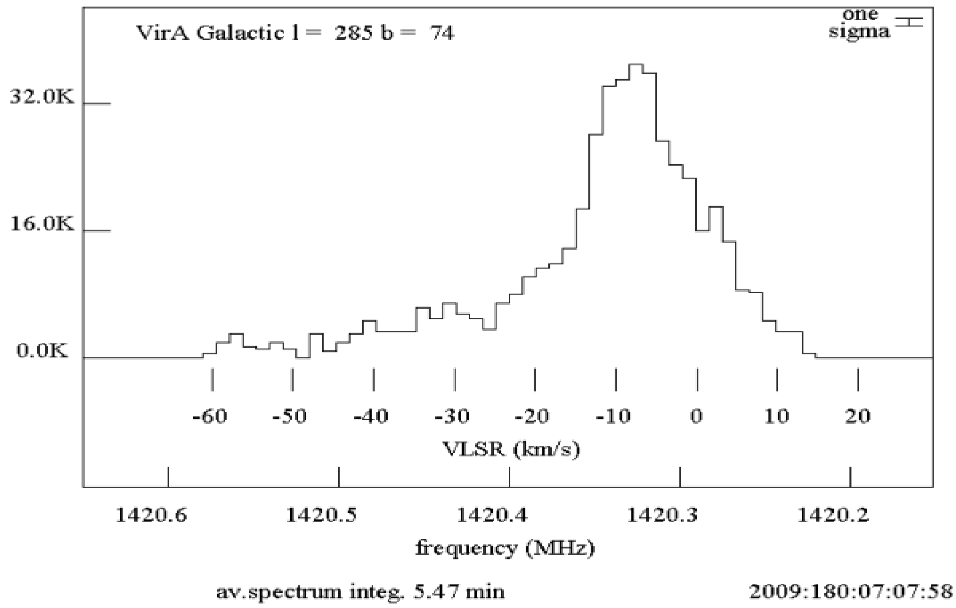


Figure 4.4 Spectrum of Virgo A

The graphs above show the signal level as function of temperature in Kelvin (k) vs. frequency (MHz). In figure 4.3 the highest signal can be observed at almost 14.34MHz and this signal should be caused by Centaurus A. in figure 4.4 the highest signal can be observed at almost14.32MHz and this signal should be caused by Virgo A.

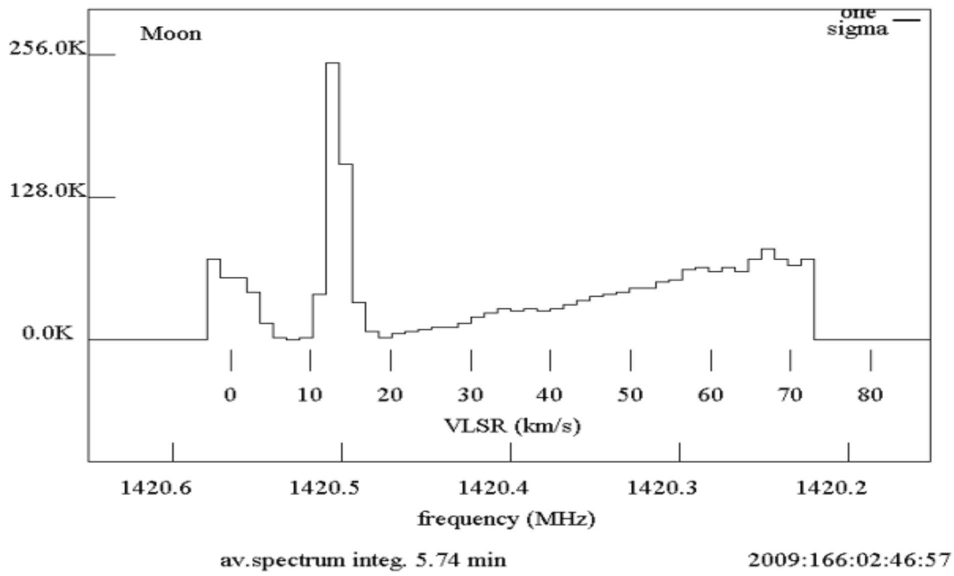


Figure 4.5 Spectrum of The moon

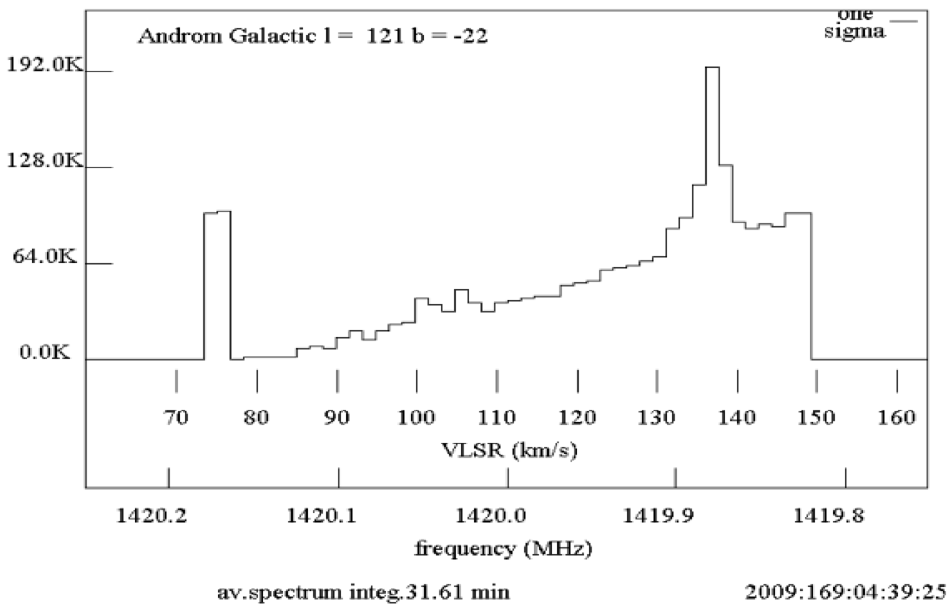


Figure 4.6 Spectrum of Andromeda

Figure 4.5 shows very sharp signal at almost 1420.5MHz. The expected cause of this signal is RFI not from the moon. Figure 4.6 shows two high signals one almost at 1420.19MHz and the second one almost at 1420.88MHz. Very high RFI level was presented while observation time.

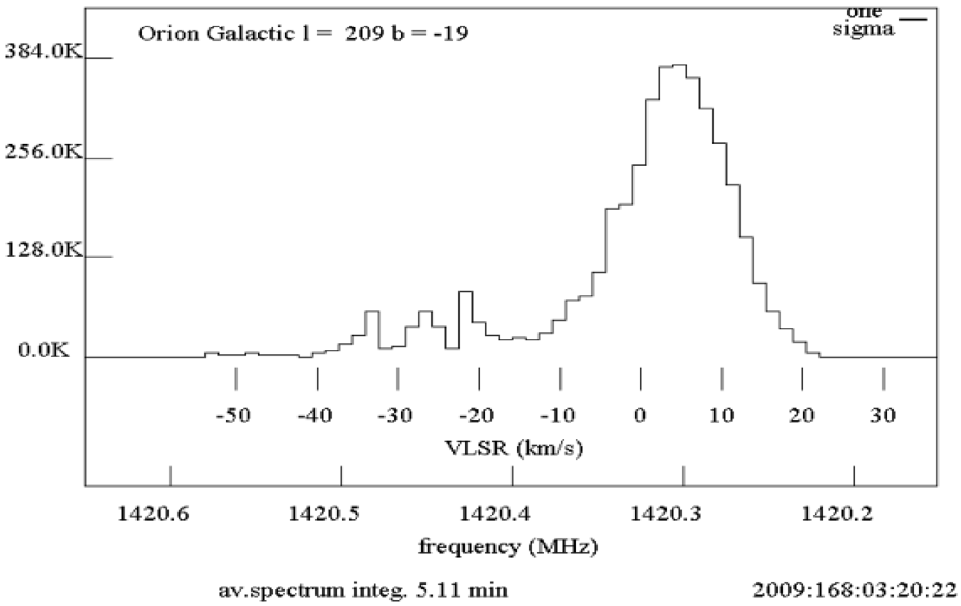


Figure 4.7 Spectrum of Orion

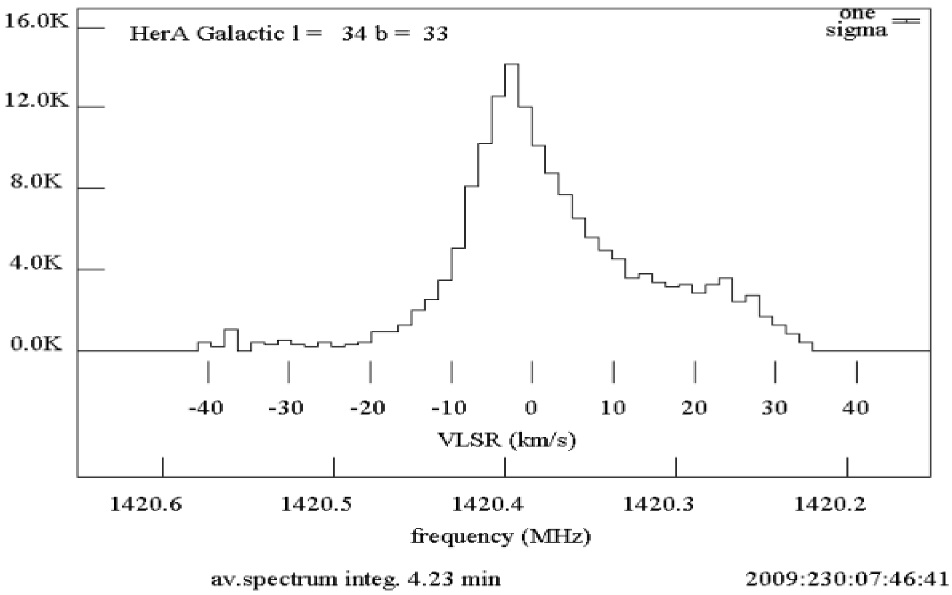


Figure 4.8 Spectrum of Hercules

Figure 4.7 shows the highest signal almost at 1420.3MHz and three gentle bumps in the left of the graph between 1420.5MHz and 1420.4MHz. Figure 4.8 shows the spectrum of Hercules and the highest signal almost at 1420.4MHz.

Table (1) Velocities of radio sources detected by UMRT-II

Object	**Coordinate system**	**Velocity ($x10^4$ ms^{-1})**	**Velocity kms^{-1} ***
Cygnus	RA 19^h 58^m 21.6756 Dec +35° 12′ 05.775″	2.3239 ±0.0162	16811
Cassiopeia	RA 23^h 23^m 26^s Dec +58° 48′	2.5352 ±0.0162	-
Centaurus A	RA 13^h 20^m De - 44° 58′	-8.448 ±0.0162	547
Virgo A	RA 12^h 27^m Dec +12° 43′	-8.448 ±0.0162	1307
Andromeda	RA 00^h 42^m 44.3^s Dec +41° 16′ 9″	-1.478±0.0162	-300
Orion	RA 05^h 35^m 17.3^s Dec -05° 23′ 28″	-2.112 ±0.0162	-
Moon	RA 5^h 4m 31^s :Dec +26° 23.6'	2.3232 ±0.0162	-
Rosett	RA 06^h 33^m 45^s Dec +04° 59′ 54″	-0.8448 ±0.0162	-
Hercules	RA 16^h 05^m 15.0^s Dec +17° 44′ 55″	-0.2112 ±0.0162	30000

*This information was taken from the NASA/IPAC Extragalactic Database (NED).

Coma cluster spectra

Coma cluster spectrum for 2 hours of observation

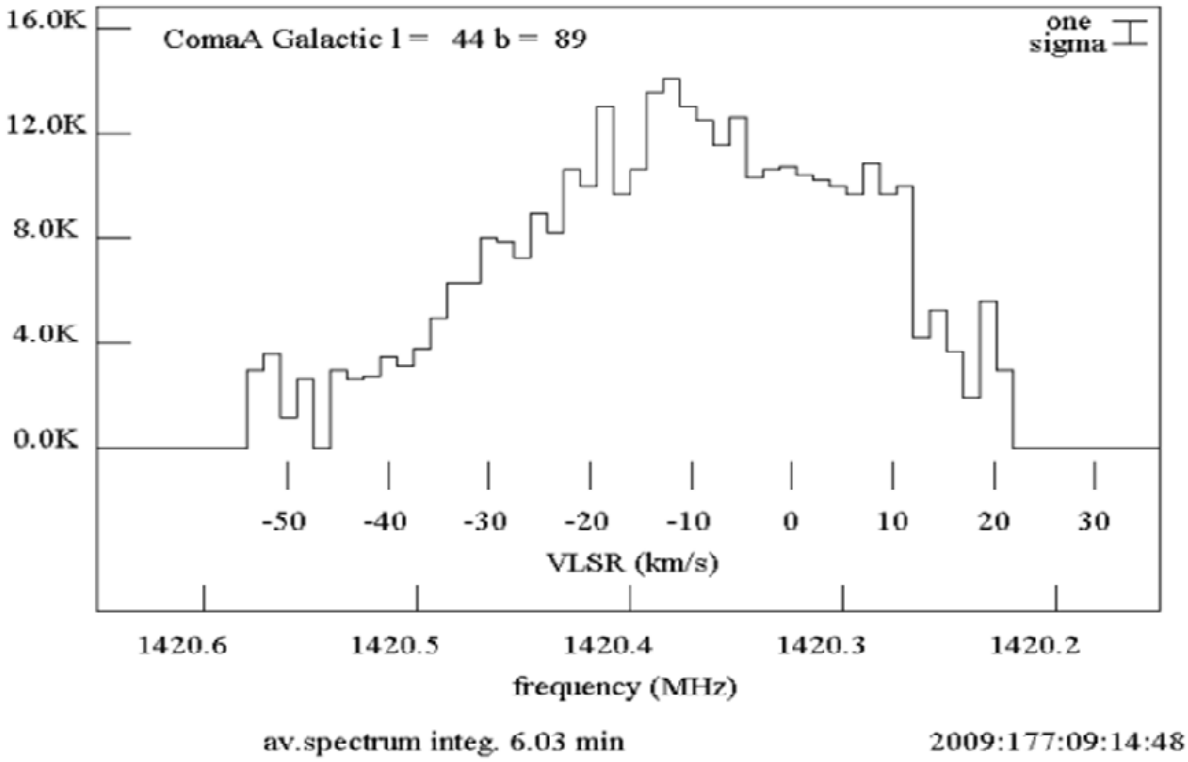


Figure 4.9 Spectrum of Coma cluster (2 hrs)

The integrated spectrum was used to determine the neutral hydrogen mass M_H using equation (2).

$$M_{VT} = 1.88 \times 10^{15}\, h^{-1}\, M_\Theta$$

$$\text{Observed Coma Mass } (M_H) = 0.000451622\, h^{-1}\, M_\Theta$$

$$\text{Dark matter} = M_{TV} - M_H$$

$$\text{Dark matter} = 1.879548378 \times 10^{15}\, h^{-1}\, M_\Theta$$

The result shows that the observed Coma mass is very small. There are few possible reasons for this error of our data. The first reason is the possibility that the size of our radio telescope was not adequate for this type of study. This error was due to the high level of RFI at the places of the observation. The most important reason is the time of observation. A longer time of observation would produce better result. In order to highlight this, Coma cluster was observed for varying times (2 hours and 4 hours) (see figures 4.9 and 4.10). The result shows that a longer time of observation gave a better Coma cluster mass value.

Coma cluster spectrum for 4 hours of observation

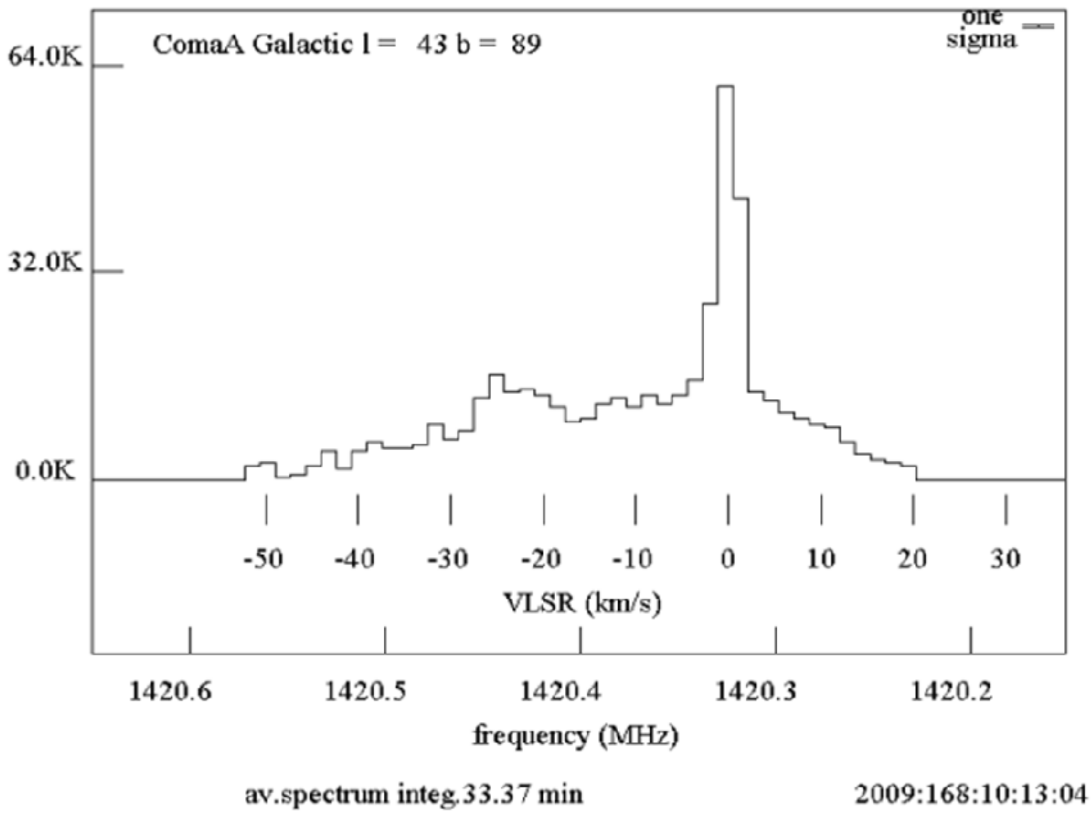


Figure 4.10 Spectrum of Coma cluster (4 hrs)

$M_{VT}=1.88x10^{15}\ h^{-1}\ M_{\Theta}$

Observed Coma Mass = $0.000580478\ h^{-1}\ M_{\Theta}$

Dark matter = $1.879419522 \times 10^{15}\ h^{-1}\ M_{\Theta}$

Collocated data of radio frequency interference (RFI)

Two observations were performed at two different sites (one in Lubuk China and the other at the Department of Physics, University of Malaya). The period of each observation was 24 hours. The data, for narrowband signal were saved every 15 minutes and every 3 hours for wideband signal.

Figures (4.11, 4.12, 4.21, 4.22 and 4.24) show that there was no peak, which means that there was no RFI at that period. However, figures (4.13, 4.14 and 4.23) show that there were some peaks, which means that there were some RFI at that time. Other figures for wideband signal (4.15-4.20 and 4.25-4.31) show high signal at certain frequencies and low signal at others frequencies. The highest signals come from mobile, mobile satellites and broadcasting, etc, (Z. Z. Abidin, *et al.* 2009), as illustrated in Figure 4.15.

Lubuk China

Narrowband

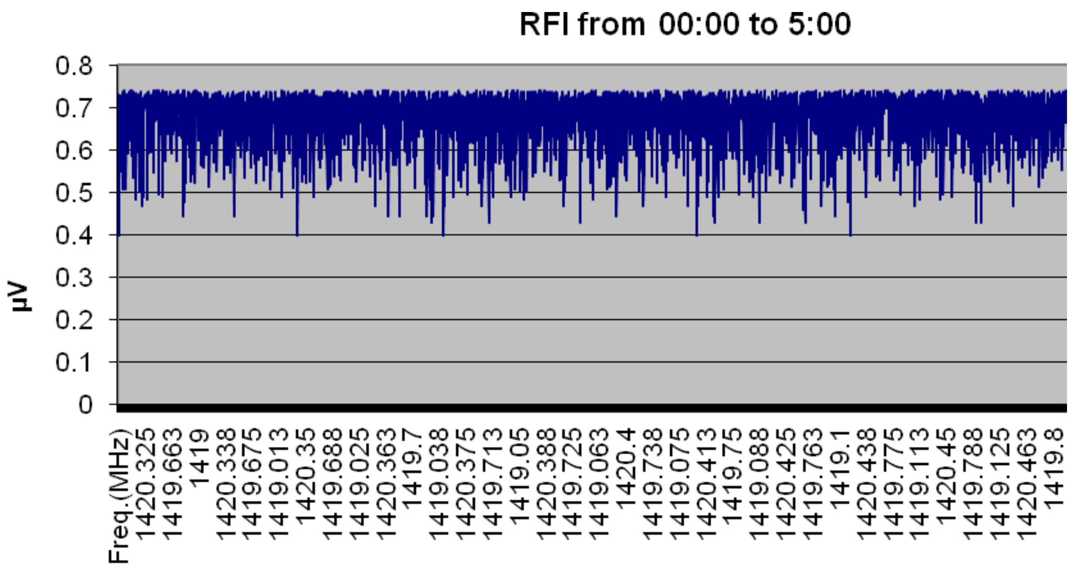


Figure 4.11 RFI survey from 00:00 to 5:00

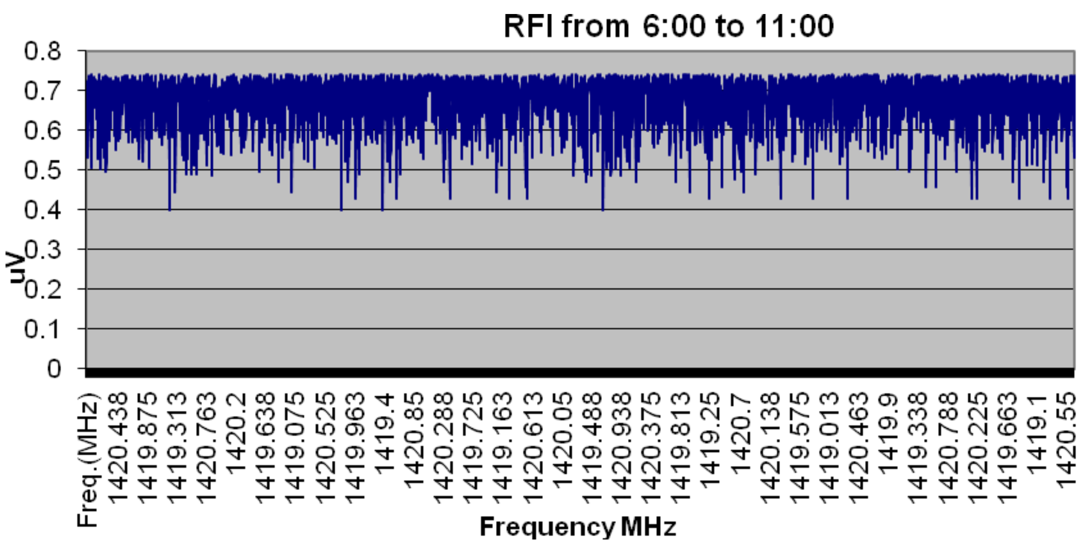


Figure 4.12 RFI survey from 6:00 to 11:00

The graphs show the signal level as function of power in (µV) vs. frequency (MHz). The noise of the spectrum analyzer is about 0.7µV. the figures 4.11 and 4.12 show no signals above 0.7µV that mean no RFI at the time from 00:00 to 11:00.

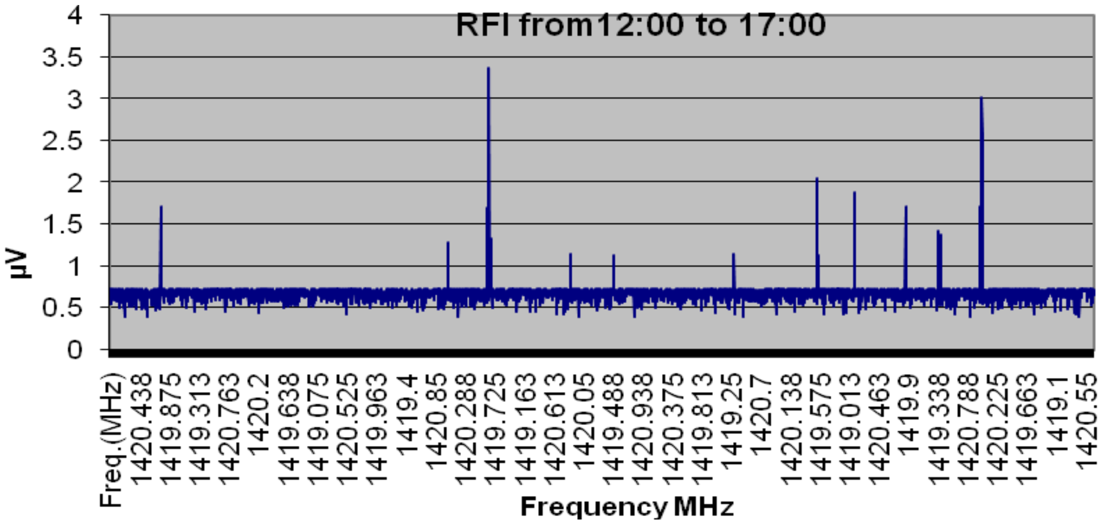


Figure 4.13 RFI survey from 12:00 to 17:00

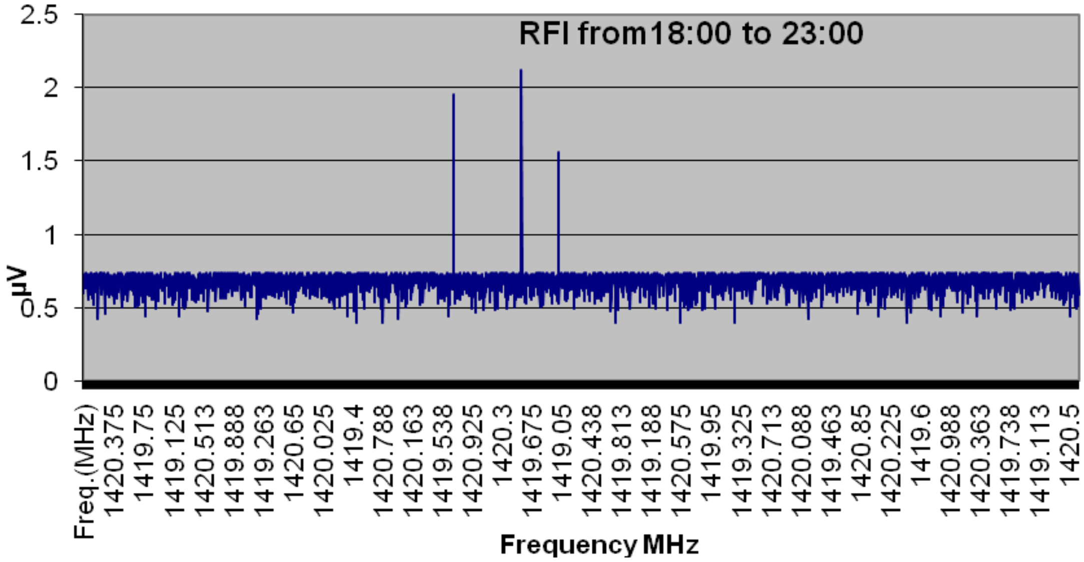


Figure 4.14 RFI survey from 18:00 to 23:00

Figure 4.13 shows more than 10 individual RFI signals and most of them less than 2µV the highest signal almost at 1419.725MHz; however, the sources of these RFI signals are unknown. Figure 4.14 shows around three RFI signals and all of them above 1.5µV. from the graphs can be concluded that RFI were presented at time from 12:00 to 23:00.

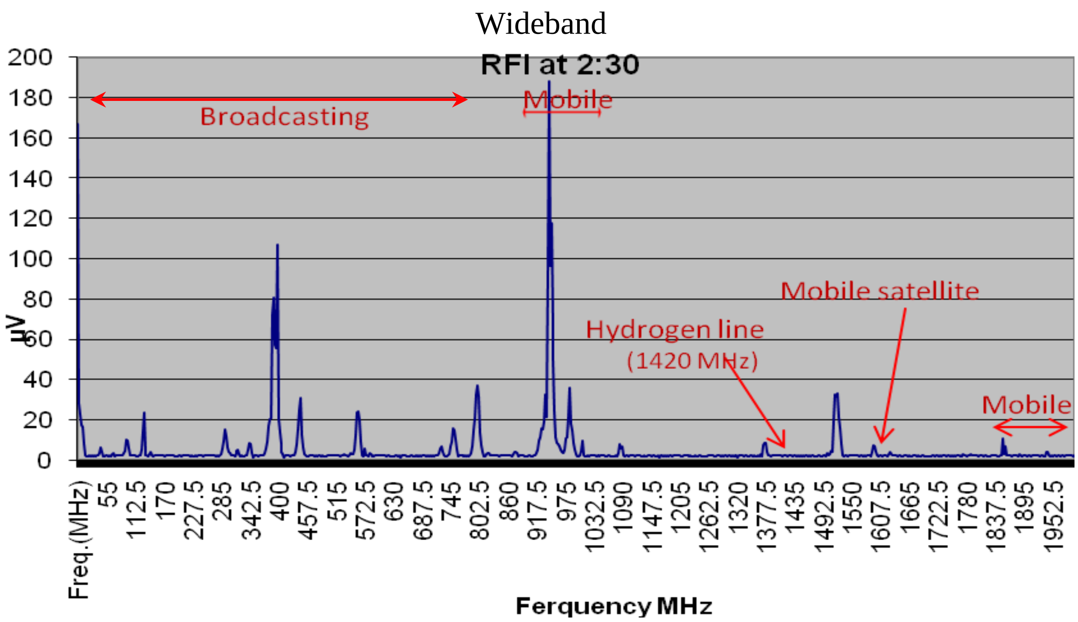


Figure 4.15 RFI survey at 2:30

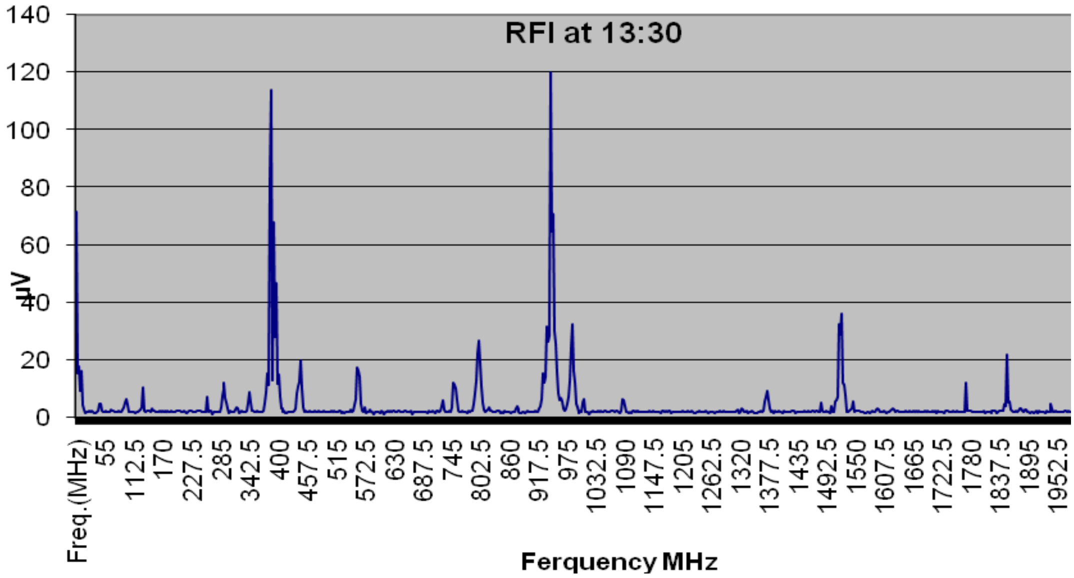


Figure 4.16 RFI survey at 13:30

Figures 4.15 to 4.20 show spectra of wideband frequency signal between 1MHz and 2060MHz. The highest signals in the graph above are between 975 and 917.5MHz. These signals caused by mobile phone (MCMC manual of spectrum plan, 2006). The other high signals caused by mobile satellite and broadcasting as illustrated in figure 4.15.

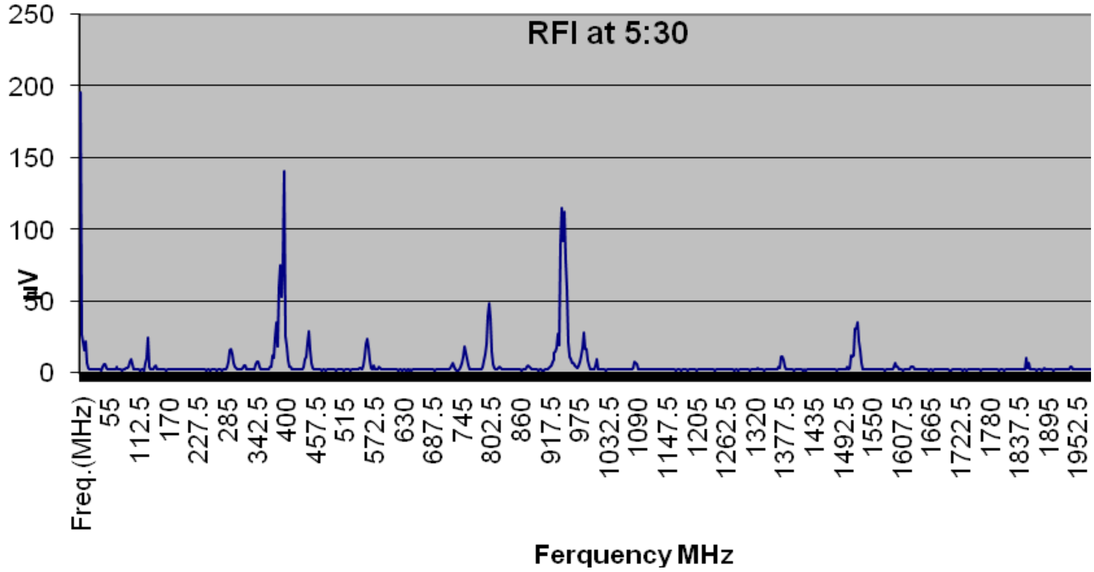


Figure 4.17 RFI survey at 5:30

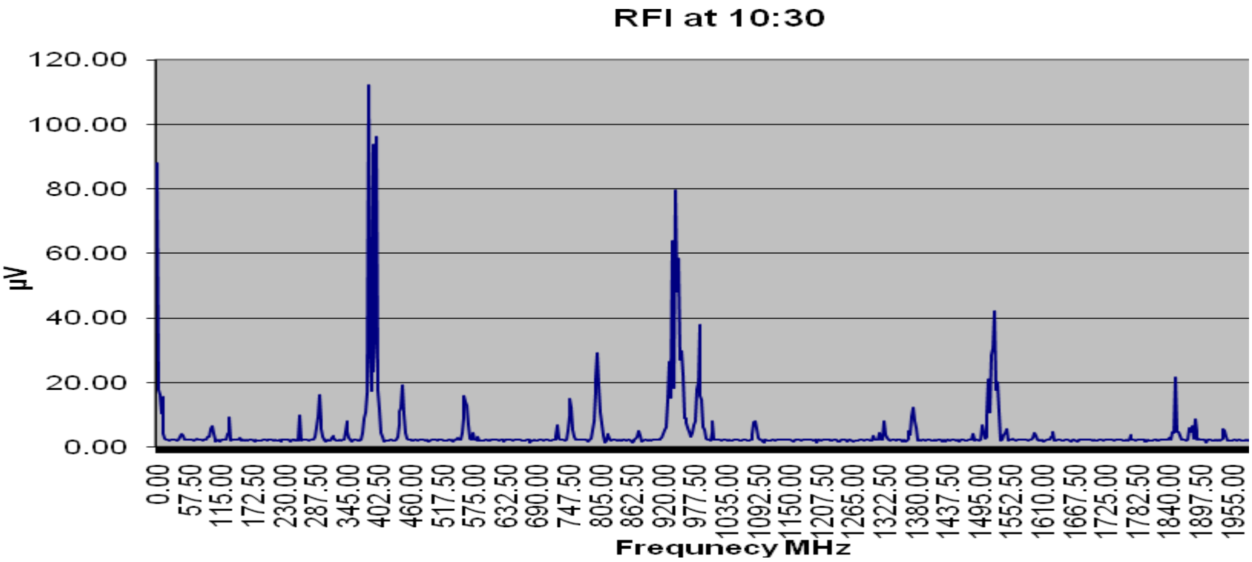


Figure 4.18 RFI survey at 10:30

The highest signals in the graph above between 402.5MHz and 345.0MHz and these signals caused by broadcasting.

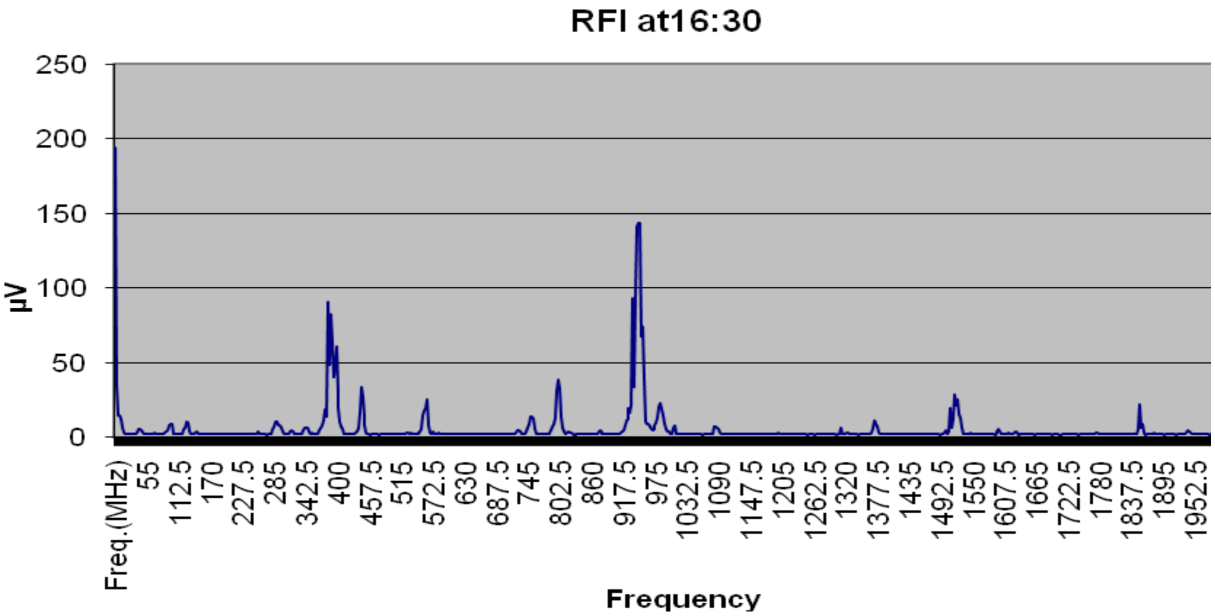


Figure 4.19 RFI survey at 16:30

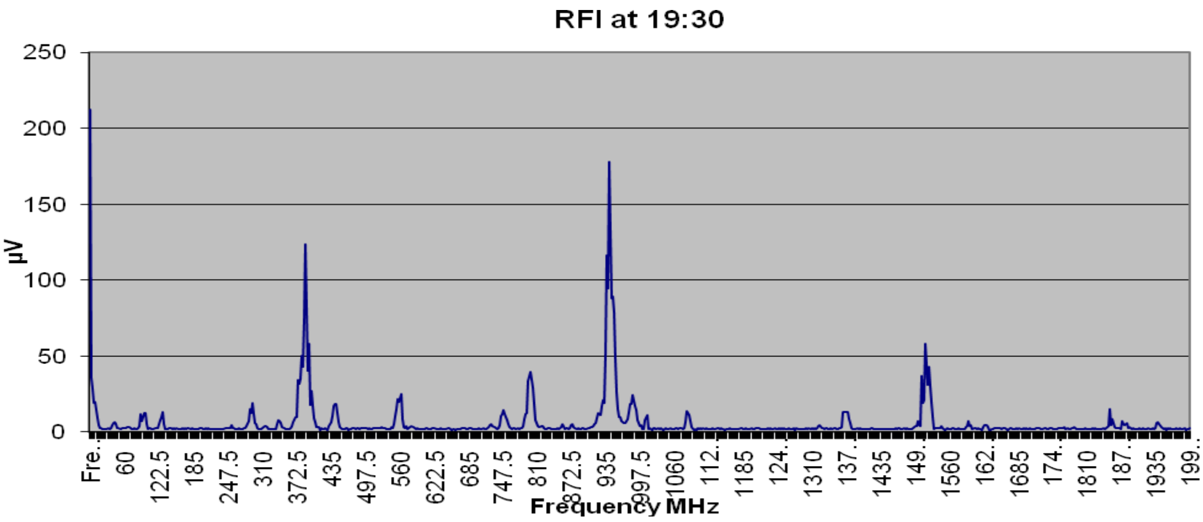


Figure 4.20 RFI survey at 19:30

The highest signals in the graph above are between 975MHz and 97.5MHz. These signals caused by mobile phone**.**

Physics department

Narrowband

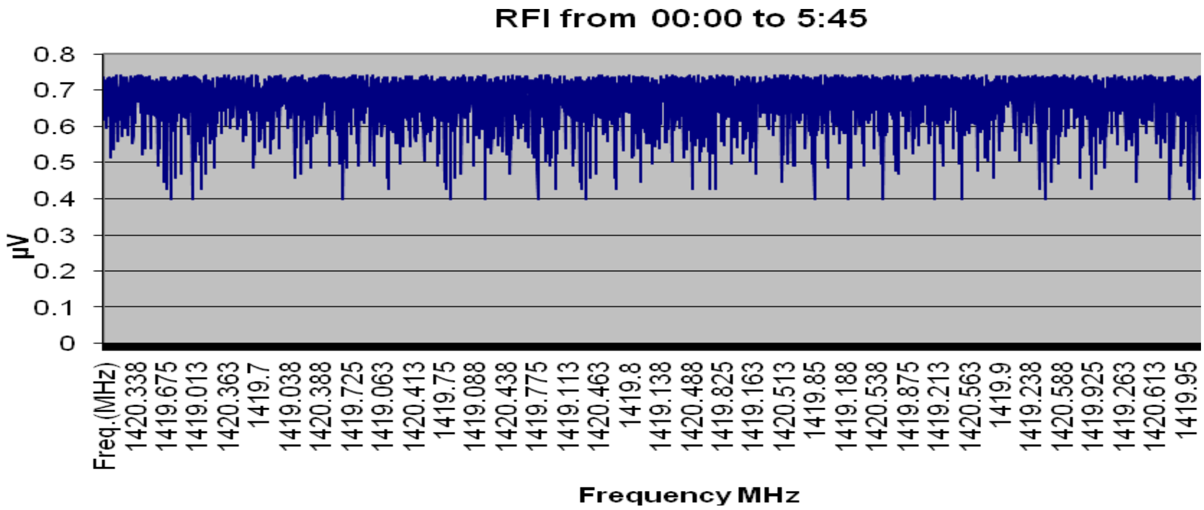


Figure 4.21 RFI survey from 00:00 to 5:45

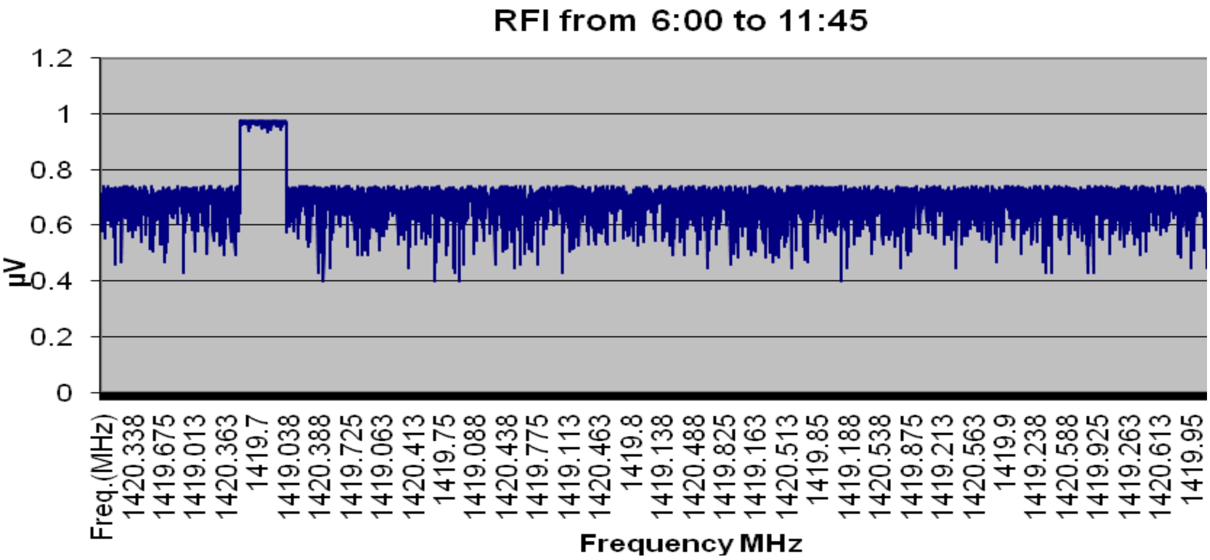


Figure 4.22 RFI survey from 6:00 to 11:45

The figure 4.21 shows no signal above 0.7μV that mean no RFI at the time from 00:00 to 5:45. Figures 4.22 shows very high signal at 1419.7MHz and this signal may be caused by some movement of the instrumentation while observation time not real RFI.

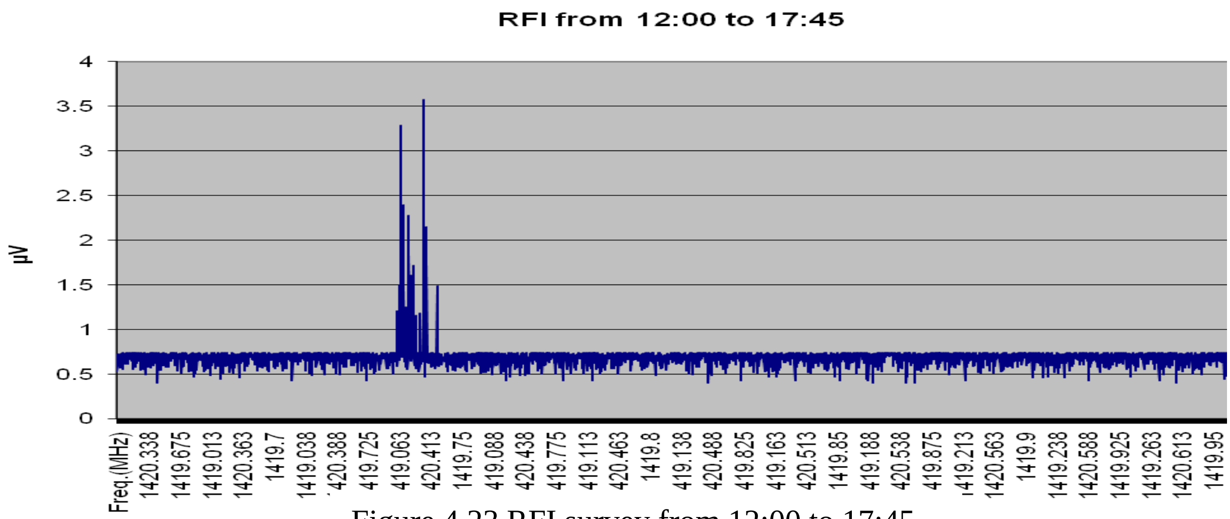


Figure 4.23 RFI survey from 12:00 to 17:45

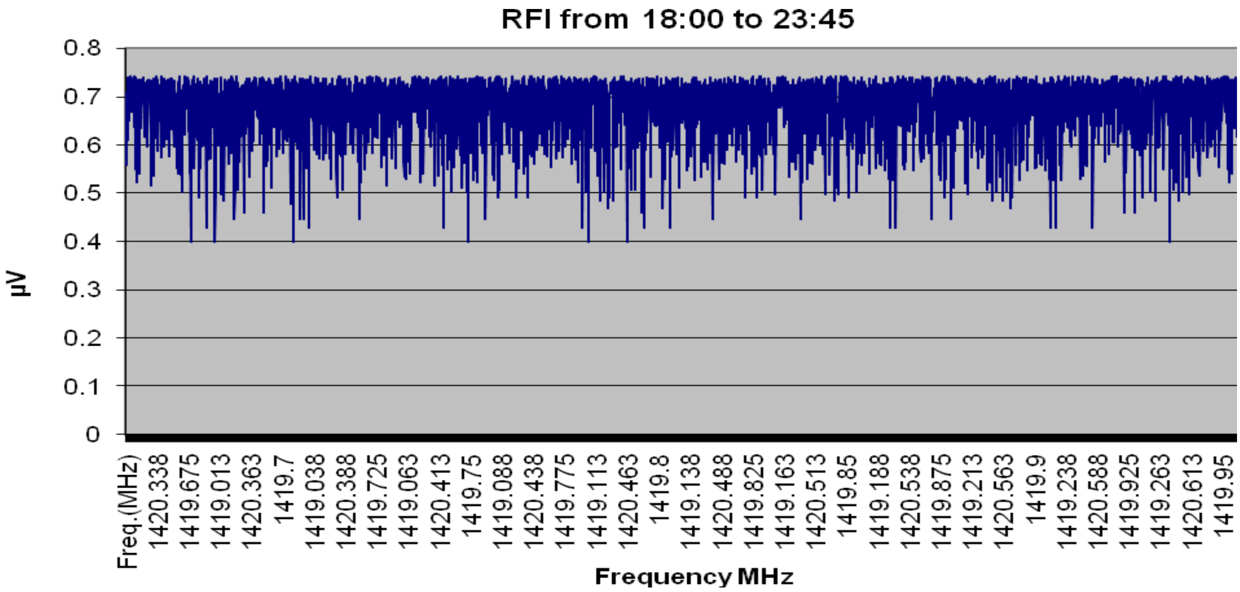


Figure 4.24 RFI survey from 18:00 to 23:45

Figure 4.23 shows very high signals between almost 1420413MHz and 1419.063MHz , however, the sources of these RFI signals are unknown. Figure 4.24 shows no signal above 0.7µV that mean no RFI at the time from 18:00 to 23:45

Wideband

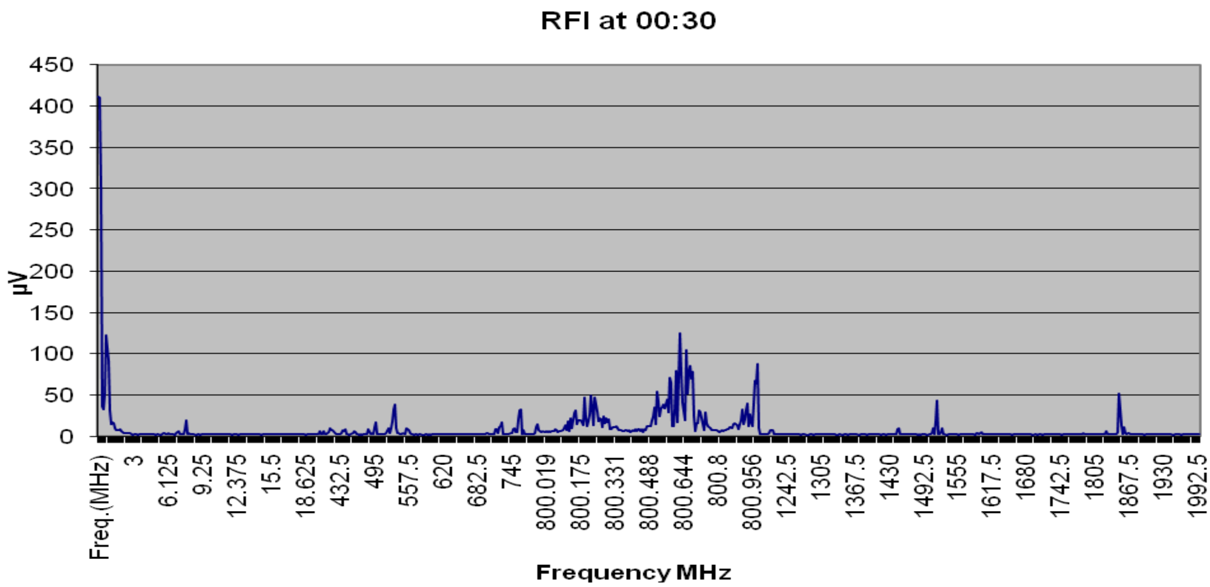


Figure 4.25 RFI survey at 00:30

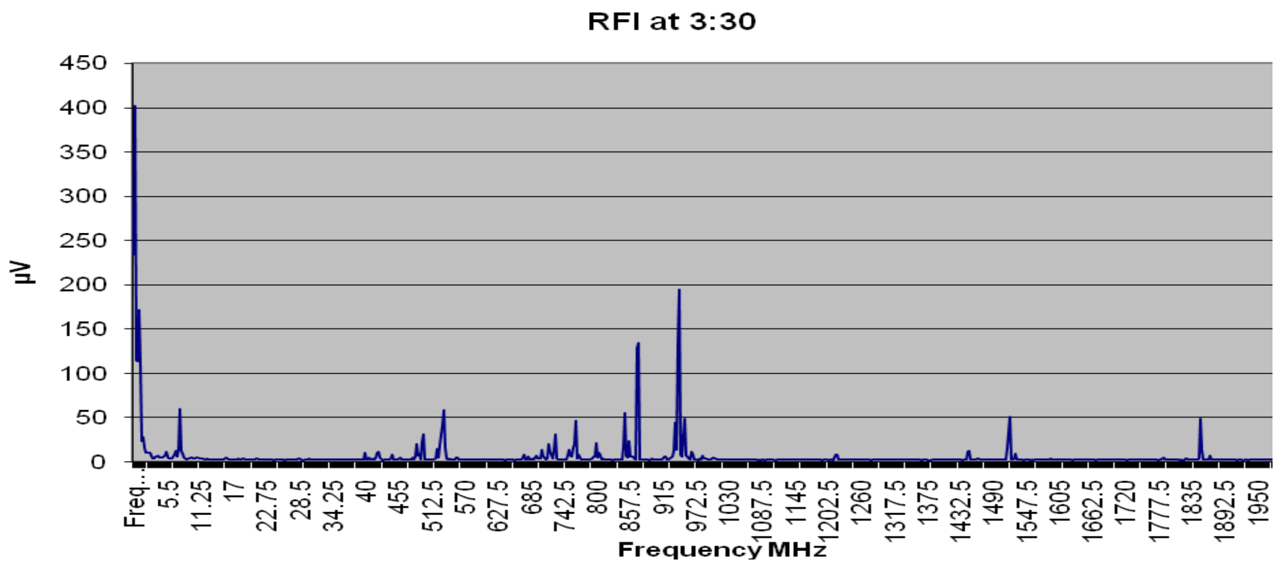


Figure 4.26 RFI survey at 3:30

The figures above show very high signal at almost 2MHz. this signal caused by broadcasting, however, this signal is very far from the important radio astronomical frequency of 1420MHz.

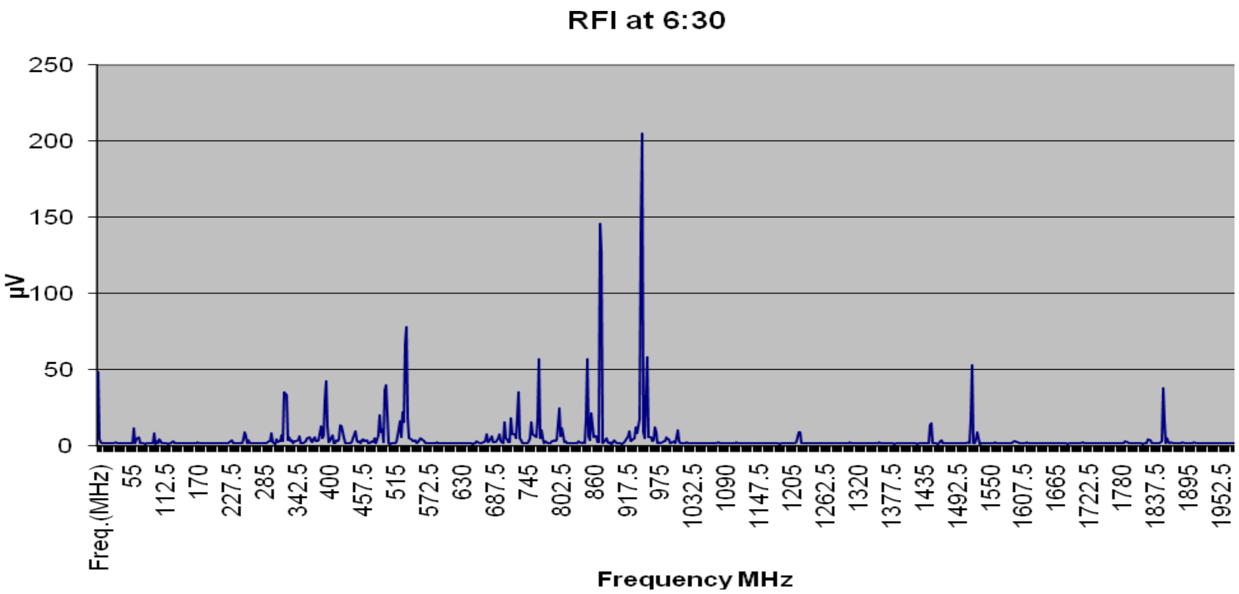


Figure 4.27 RFI survey at 6:30

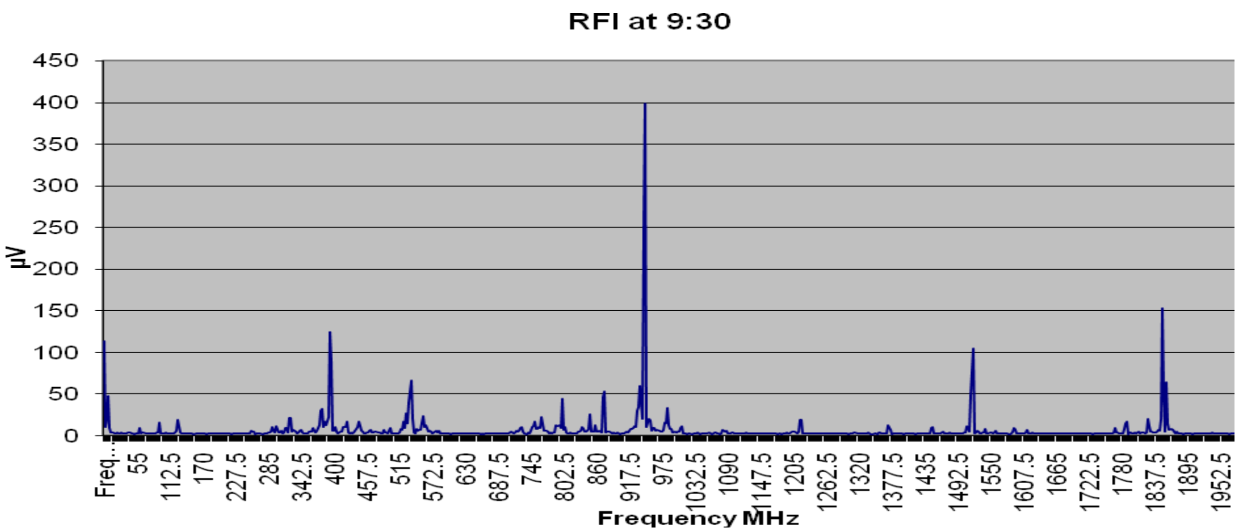


Figure 4.28 RFI survey at 9:30

Figures 4.27 and 4.28 show the highest signals in the graph above are between 975 and 917.5MHz. These signals caused by mobile phone.

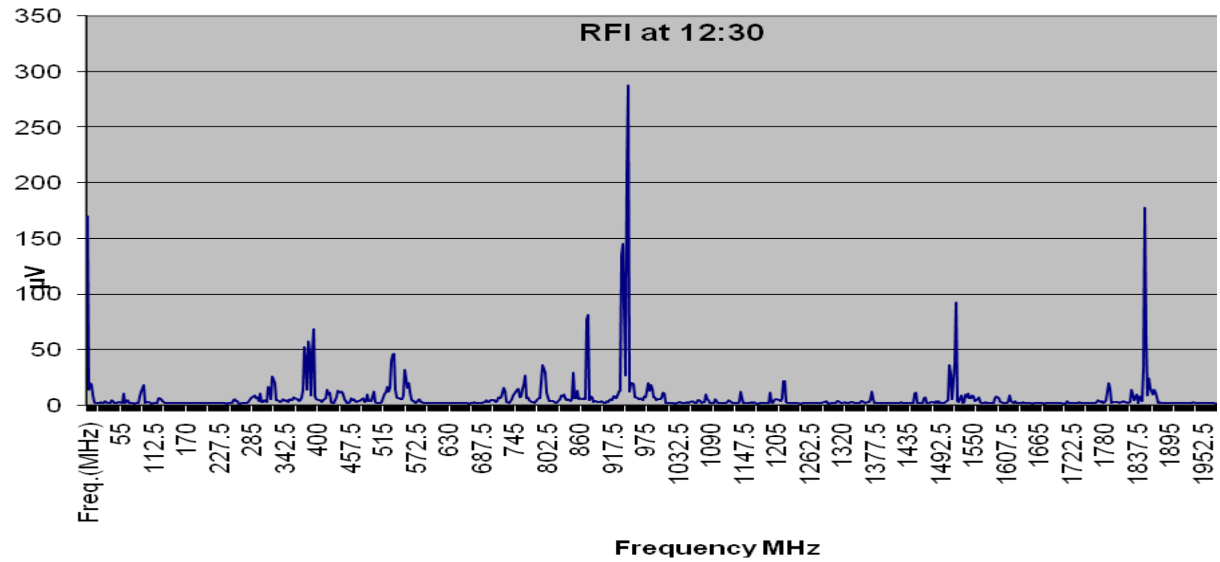


Figure 4.29 RFI survey at 12:30

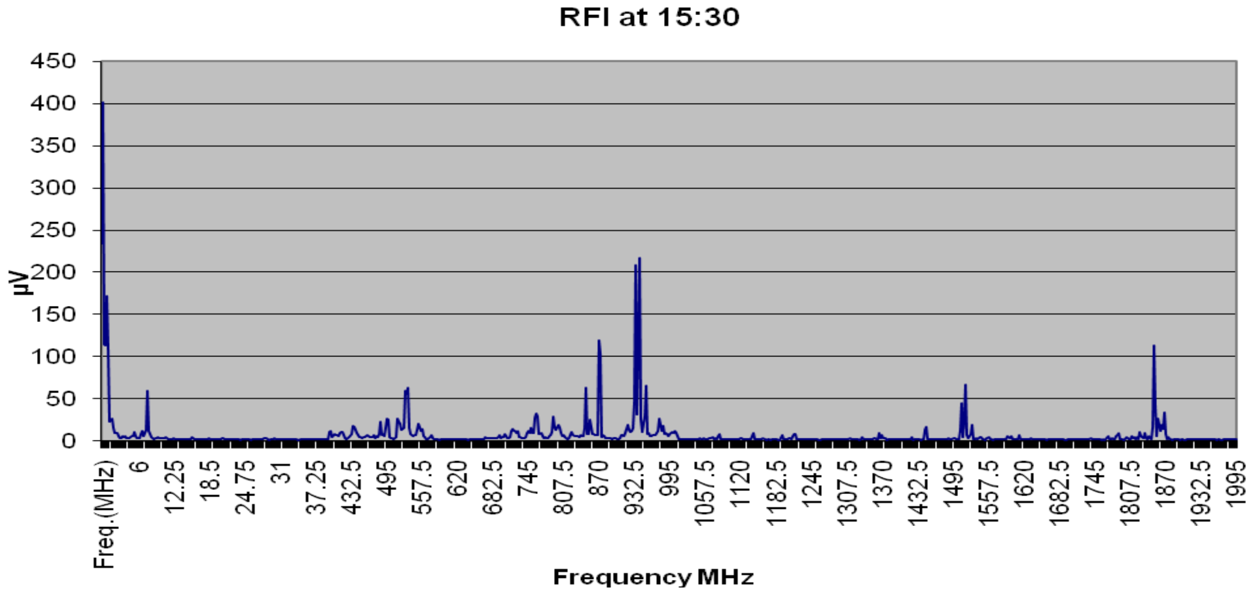


Figure 4.30 RFI survey at 15:30

Figure 4.29 shows the highest signal in the graph above is between 975 and 917.5MHz. These signals caused by mobile phone**.** Figure 4.30 shows very high signal at almost 2MHz and this signal caused by broadcasting.

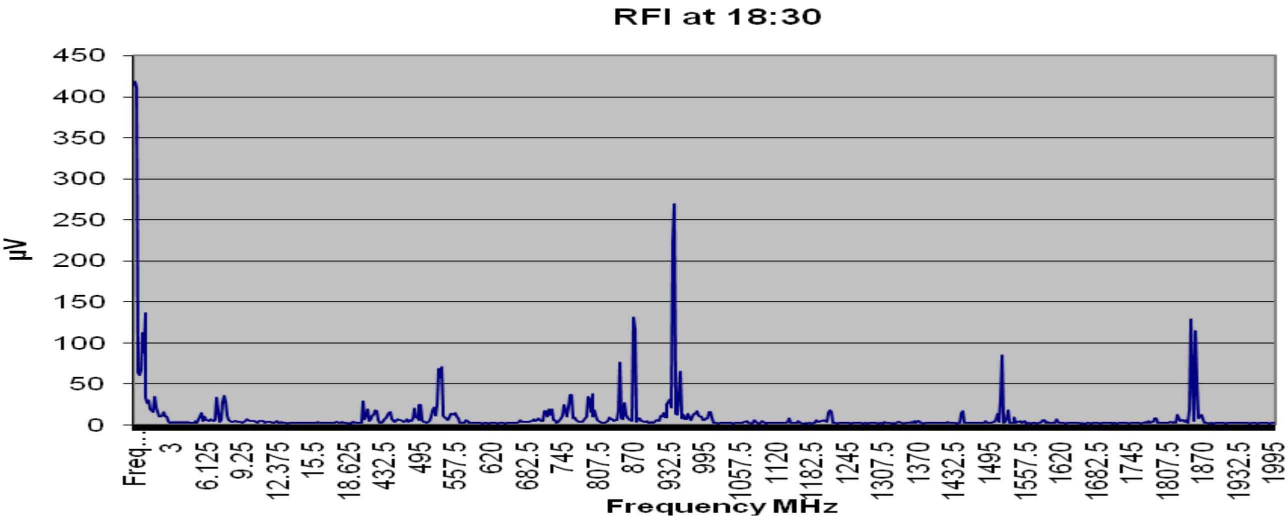


Figure 4.31 RFI survey at 18:30

Figure 4.30 shows very high signal at almost 2MHz and this signal caused by broadcasting.

CHAPTER V

Conclusion

5.1 Conclusion

The value of Doppler shift for radio sources were inaccurate due to high level of radio frequency interference (RFI) at the site of our radio telescope and minimum detectability of instrumentation. The Coma spectra observed were too weak. The radio frequency interference was too strong at the reference point (RFI was too strong at the site). During daytime, the 1.42 GHz from the sun affected the observation; however signals from radio sources could still be detected. The level of temperature was uncalibrated or in other words, no noise calibration was used. A single dish of 2.3 m was insignificant, so interferometer (arrays of parabolic dishes) is necessary. However, a single dish should be enough for very long observation time (i.e. a few months). This was the first ever effort to observe galaxy clusters with a small radio telescope, as well as the first ever radio astronomy observation in Malaysia. It could be concluded that the conceptual testing was successful.

The results show that these two sites (Lubuk China and the Department of Physics of University Malaya) have high level of RFI. Locating the radio telescope away from a city is a good method to mitigate RFI.

5.2 Suggestions for the future work

It is suggested that one should make a study on different radio sources to compliment the result obtained here. For this study longer time observation should be emphasized. Also bigger antenna dish or interferometer will be more significant.

A good method to avoid RFI is to build the radio telescope, (UMRT-II), at site that has low RFI e.g. Langkawi (Z.Z.Abidin, *at el*. 2009).

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