Search for Transient Sources Using GMRT Galactic Plane Survey

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for the Partial Fulfilment of the Degree of
Master of Science (Physics)

Submitted by

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Certificate

This is to certify that the project report entitled '**Search for Transient Sources Using GMRT Galactic Plane Survey'** submitted by **Nibedita Mondal, Roll No- PG/VUWGP29/PHS-IV 034** to the Midnapore City College, Midnapore, West Bengal, India during the year of 2023 in partial fulfilment for the award of the degree of M.Sc. in **Physics** is a bona fide record of project work carried out by him/her under my/our supervision. The contents of this report, in full or in parts, have not been submitted to any other Institution or University for the award of any degree

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Declaration

We do hereby declare that the present Master thesis entitled "**Search for Transient Sources Using GMRT Galactic Plane Survey"** embodies the original research work carried out by me in the Department of Pure and Applied Sciences, Midnapore City College, Paschim Medinipur, West Bengal, India under the supervision of Dr. Sabyasachi Pal, Associate Professor, Department of Pure and Applied Sciences. No part thereof has been submitted for any degree or diploma in any University.

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This project report entitled “**Search for Transient Sources Using GMRT Galactic Plane Survey”** by **Nibedita Mondal** and **Dipanjan Banerjee** is approved for the degree of Master of Science (Physics).

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Dedicated to our Parents

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Abstract

The effective study of transient sources are made possible by significant advancements in the field of vision, particularly at low radio frequencies (325 MHz). We will search for transient and variable sources in the Galactic plane corresponding to Galactic latitude 53° < l < 63° and Galactic longitude |b| < 3° using the Giant Metrewave Radio Telescope (GMRT). In this survey, we will try to observe that specific field of the region with angular resolution 13 arc-sec ×12 arc-sec and sensitivity 0.04 mJy. From the survey conducted at higher galactic latitudes, we will analyse a number of light curves of radio sources to find one or more sources that follow the transient characteristics. To understand the transient properties here we will focus on its variation of flux intensity with the time scale, and periodicity of the source pulse. In this report, we will study the spectral properties of the transient sources and also follow up on the multi-wavelength. We want to study its behaviour and properties and will compare it with previously detected transient sources, to find the exact nature of the source. If we can trace a transient source then we will figure out the order of change of its circular polarisation by observing the emission of light.

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Chapter 1: Introduction

Introduction

The universe is a violent and dynamic place where stars can explode and outshine entire galaxies, stars are swallowed whole by supermassive black holes, merging neutron stars generate ripples in spacetime, and bursts of ultra-high intensity radiation can be seen.

Time-domain astrophysics is one of the main frontiers of modern astronomical research, from which we can implement the life and death of a star, the birth of black holes and neutron stars. In astronomy, Transient sources mean, a source that can change its property with time, moreover the word transient means variation of astronomical phenomena with durations of fractions of a second to weeks or years. When the telescope is not invented transient events that can be seen by the naked eye were very rare, though in 1054 CE 'SN 1054' was observed by Chinese, Japanese and Arab astronomers and another astronomical event known as "Tycho's Supernova" after Tycho Brahe who observed it until it fades after two years.

In History, Time-domain astronomy had come to include the appearance variable brightness of Cepheid-type variable stars. The interest in this field increased when large detectors made with charge coupled devices became available to the astronomical community. And when we have started to detect wavelengths invisible to the human eye such as radio wavelengths, infrared waves, etc., the amount of information that may be obtained when a transient is studied increases.

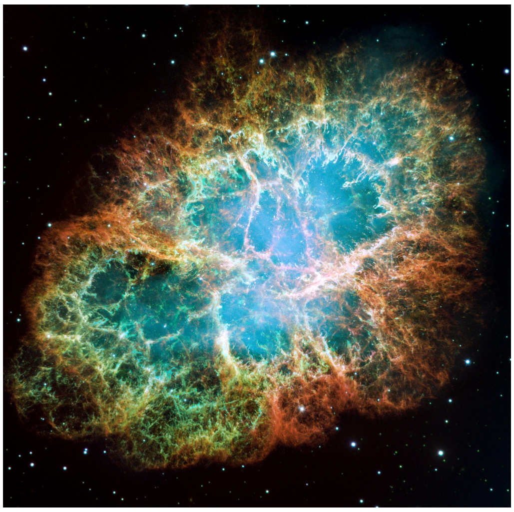


Fig-1 "SN 1054" (Source: NASA)

(First ever transient phenomena observed by humans from different parts of our world)

However, in the past radio astronomy suffered from narrow fields of vision caused by big dishes, just like optical astronomy, and was unable to survey the sky quickly enough to identify rare and rapid occurrences, which is the most important event in astrophysics. With the advent of a new generation of radio telescopes, all of this is about to change.

Fig-2: RS Puppis, one of the brightest known Cepheid variable stars in the Milky Way galaxy (Hubble Space Telescope)
(Source: NASA, ESA, and the Hubble Heritage Team.)

In present days, we have a lot of radio facilities like The Low-Frequency Array (LOFAR), The South African Karoo Array Telescope (MeerKAT) and The Australian SKA Pathfinder (ASKAP), and ultimately the Square Kilometer Array (SKA).

The universe is teeming with objects that exhibit drastic variations in brightness over time scale from milliseconds to years. These are known as transients and include events such as:

1. Fast Radio Bursts (FRBs):
Fast Radio Bursts (FRBs) are one of the most mysterious transient astrophysical phenomena discovered in the last decade. These powerful flashes of radio signals last only a fraction of a second and appear to originate from other galaxies, many millions, or even billions, of light years away. To date, the astronomy community has not been able to identify what physical processes result in FRBs.

2. X-ray binary systems (XRBs):
X-ray binaries are a class of binary stars that are luminous in X-rays. The X-rays are produced by matter falling from one component, called the donor (usually a relatively normal star), to the other component, called the accretor, which is very compact: a neutron star or black hole. The infalling matter releases gravitational potential energy, up to several tenths of its rest mass, as X-rays. (Hydrogen fusion releases only about 0.7 percent of rest mass.) The lifetime and the mass-transfer rate in an X-ray binary depends

on the evolutionary status of the donor star, the mass ratio between the stellar components, and their orbital separation.

3. Soft gamma repeaters (SGRs):

A soft gamma repeater is an astronomical object which emits large bursts of gamma-rays and X-rays at irregular intervals. It is conjectured that they are a type of magnetar or, alternatively, neutron stars with fossil disks around them.

4. Gamma ray bursts (GRBs):

In gamma-ray astronomy, gamma-ray bursts (GRBs) are immensely energetic explosions that have been observed in distant galaxies. They are the most energetic and luminous electromagnetic events since the Big Bang. Bursts can last from ten milliseconds to several hours. After an initial flash of gamma rays, a longer-lived "afterglow" is usually emitted at longer wavelengths (X-ray, ultraviolet, optical, infrared, microwave and radio).

5. Supernovae (SNe):

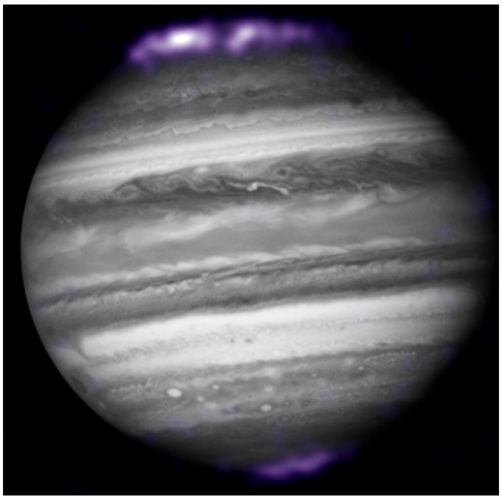
A supernova is a powerful and luminous explosion of a star. This transient astronomical event occurs during the last evolutionary stages of a massive star or when a white dwarf is triggered into runaway nuclear fusion. The original object, called the progenitor, either collapses to a neutron star or black hole, or is completely destroyed. The peak optical luminosity of a supernova can be comparable to that of an entire galaxy before fading over several weeks or months. Most of these transients are associated with ejections of matter, in some cases at (ultra)relativistic speeds that can produce radiation at radio frequencies.

6. Flaring Active Galactic Nuclei (AGN):

Supermassive black holes in the centers of galaxies generate active galactic nuclei. Flaring behavior, which involves abrupt and rapid spikes in radio emission, is seen in some AGN. The GPRS has assisted in the identification and observation of AGN that are flaring by supplying details on their physics.

The discovery of variable radio emission from a compact object (Dent 1965) encouraged the survey and monitoring of both time-variable and transient sources. In low frequency range, there are a variety of astronomical phenomena that are known to be transient or highly variable; for example, flares from brown dwarf stars (e.g. Berger 2006; Jaeger et al., 2011), flares from Jupiter (Zarka et al., 2001) and intermittent pulsars (e.g. Sobey et al., 2015). In other cases, propagation effects such as interplanetary scintillation (e.g. Kaplan et al., 2015) can cause compact background sources such as quasars and pulsars to vary in flux density and other local causes such as ionospheric distortions. Although they are normally minor impacts at the resolution of the Murchison Widefield Array at a few hundred megahertz (Loi et al., 2015), they can be crucial.

For sensors with greater resolving power (Intema et al., 2009; Van Weeren et al., 2016). for low frequencies, in particular, Cordes et al. (2004) and Bowman et al. (2013) provided an overview of the variety of physical events that contribute to radio variability. Gregory and Taylor (1981) detected the variability of LSI+61 303 and discovered four radio transients in a survey program of the Galactic plane using the National Radio Astronomy Observatory 91-meter antenna. In 2006, 11 transient radio bursts were found in a survey of radio pulsars using the Parkes radio telescope (McLaughlin et al.2006). These observations show that unknown radio transients still remain to be found.



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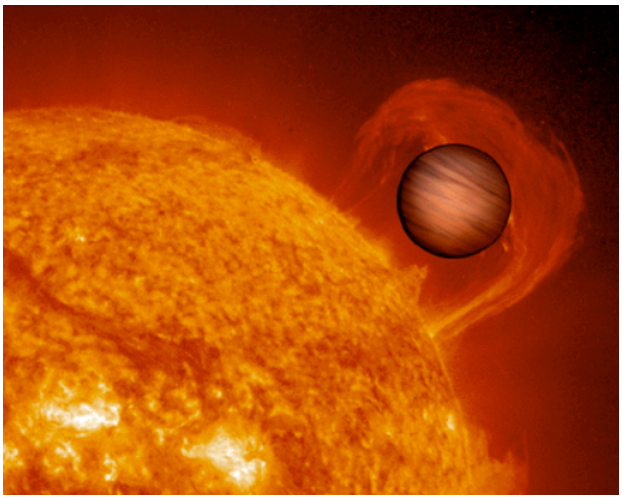

Fig-4

Fig-3:Flares from Jupiter

Fig-4: Flares from a brown dwarf star

(Source: NASA)

Huge improvements in the field of view, specially at low radio frequencies, help to study transient and variable radio sources more effectively (e.g., Macquart, 2014). However, no detection of any transient sources from the recent 12,000 deg^2 systemic transient search comprising 2800 pointings using the Jansky Very Large Array Low-band Ionosphere and Transient Experiment (VLITE) (Polisensky et al., 2016) and detection of only one transient source from monitoring of region close to the north celestial pole (Stewart et al., 2016) covering 175 deg^2 using the Low-Frequency Array (LOFAR) and no detection of the transient source from 1430 deg^2 search using Murchison Widefield Array (MWA) (Bell et al. 2014; also see the MWA study by Rowlinson et al. (2016)) show that detections of transient radio sources are currently not very common, especially at low radio frequencies.

Large archives of data from various telescopes are an important tool for searching for temporary and changeable radio emissions. In an earlier examination of 22 years' worth of archived data from the Molonglo Observatory Synthesis Telescope, which covered a 2776 deg^2 survey area, Bannister et al. (2011) reported 15 transient sources. Following a comparison of the TIFR GMRT Sky Survey Alternative Data Release 1 (TGSS ADR1, see Intema et al., 2017) and the Galactic and Extragalactic All-sky Murchison Widefield Array (GLEAM, see Hurley-Walker et al., 2017) survey catalogs, Murphy et al. (2017) recently discovered a candidate transient source at low frequency. From 22 years of archived data, the Karl G. Jansky Very Large Array (VLA) observations of a single field-of-view at 5 and 8.4 GHz yielded 10 milli Jansky (mJY) level transients (Bower et al., 2007).

Fig-5: The Karl G. Jansky Very Large Array is a centimeter-wavelength radio astronomy observatory located in central New Mexico on the Plains of San Agustin, between the towns of Magdalena and Datil, ~50 miles west of Socorro. (Source: National Radio Astronomy Observatory)

Two Galactic Center Radio Transient (GCRT) sources, GCRT J1745-3009 (Hyman et al., 2005; Hyman et al., 2007; Roy et al., 2010) and GCRT J1742-3001 (Hyman et al., 2009), were discovered earlier, thanks to a thorough search of the area close to the Galactic Center conducted with the VLA and the Giant Metrewave Radio Telescope (GMRT). The only three occasions that GCRT J1745-3009 was discovered in 2002 (Hyman et al., 2005), 2003, and 2004. (Hyman et al., 2007). Between the third and fourth times, the source was detected, the source's characteristics dramatically changed. This source showed ~10 minutes, ~1 Jy peak bursts with a ~77-minute interval in 2002. The source's emission was coherent (Hyman et al., 2005). The third identification of the source revealed an extremely steep spectral index (α= -13.5±3.0) (Hyman et al., 2007) and strong circular polarization (Roy et al., 2010). The source was detected three times, each time at 330MHz. There are no known mechanisms of emission in transient compact sources that match the parameters of GCRT J1745-3009. The source appears to represent a new class of coherently emitting objects as a result.

To observe the elements of a new transient source, its temperature and density, we need to study its spectral properties. Astronomical spectroscopy is the study of astronomy using the techniques of spectroscopy to measure the spectrum of electromagnetic radiation, including visible light, ultraviolet, X-ray, infrared and radio waves that radiate from stars and other celestial objects. A stellar spectrum can reveal many properties of stars, such as their chemical composition, temperature, density, mass, distance and luminosity. Spectroscopy can show the velocity of motion towards or away from the observer by measuring the Doppler shift. Spectroscopy is also used to study the physical properties of many other types of celestial objects such as planets, nebulae, galaxies, and active galactic nuclei.

We are running this survey in the Giant Metrewave Galactic Plane. Galactic plane observations with a radio telescope at low radio frequencies pose a special challenge. This is due to the high brightness temperature of the Galactic plane which varies significantly depending on the Galactic longitude and latitude being observed. High brightness temperature of extended emission causes a corresponding rise in system temperature and it could be ~10 higher than observing the typical sky >10J away from the Galactic plane. Therefore, suitable arrangements are necessary to prevent any non-linearity in the telescope observing chain.

7. Transient and variable sources:

Variable sources are those whose flux density fluctuates between some lowest and maximum value, whereas transient sources are often thought of as those sources that exist and then vanish as a result of a cataclysmic event. The distinction between transient and variable sources as observed, however, is more nuanced. For instance, a source that appears and vanishes during an observation may be a changeable source with minimal flux density below the detection threshold in the image, or it may be actually fleeting. Transient sources are those that appear and vanish during the course of the observations, with the caveat that they might be previously unidentified variable sources.

8. Observing transient in radio frequency:

In Radio Astronomy, Some of the most intense astrophysical events in our cosmos have been found through the study of transient searches. This has made it possible for us to research the physics of these powerful and explosive sources. Radio telescopes often have a short timeframe sensitivity, but their fields of vision are substantially less than those of their high-energy equivalents. The majority of transient radio studies have been subsequent observations of phenomena already discovered at higher energies. However, radio transient studies are crucial because they may examine explosive and dynamic occurrences that may not have equivalents at other frequencies.Fast radio bursts were discovered as a new class of radio transient sources with high time resolution, typically 1 sec, pushing physics to its limits and allowing us to probe the contents of the universe.

9. Probing the time dependent astrophysical phenomena:

A unique opportunity to research the time-varying elements of astrophysical phenomena is provided by transients. Astronomers can learn more about the evolution of transient events, spot changes in their attributes, and acquire a better understanding of the dynamical nature of the universe by tracking and examining the emission from transient sources in radio frequency.

10. Large-scale radio sky survey in time domain:

In-depth sky surveys and monitoring projects require the use of transient radio sources. Astronomers can find and identify a wide variety of astrophysical phenomena by continuously searching the sky for transitory events. These investigations aid in the discovery of novel types of transients, the detection of uncommon or unexpected phenomena, and the mapping and comprehension of the radio sky.

11. Study the magnetic field of cosmos:

In the universe, the magnetic field lines can be studied in great detail using transient radio sources. Strong magnetic fields are present in some forms of transients, such as pulsars and magnetars, and it is possible to learn more about these magnetic fields' characteristics and dynamics by observing their radio emission. Numerous astrophysical phenomena, including the origins and progression of galaxies and the accelerated motion of extremely energetic particles, depend on our understanding of cosmic magnetism.

12. Fundamental laws of physics:

Some transient radio phenomena, including fast radio bursts (FRBs), pose intriguing puzzles that may put our current knowledge of astrophysical research and basic physics in trouble. Insights into exotic events like mergers of neutron stars, magnetars, or even speculative physics outside the standard model may be gained through studying FRBs, for instance, whose genesis is currently poorly understood.

13. Multi-messenger astronomy domain:

It is possible to correlate transients seen in the radio spectrum with astronomical measurements performed in higher energy spectrums such as gamma rays, X-rays and also optical, gravitational waves. This multi-messenger strategy gives researchers a more thorough understanding of the transient event and enables them to investigate several facets of it, including its electromagnetic radiation, emission of high-energetic particles and detect the signals of gravitational waves..

Transient events such as Gamma-ray bursts, pulsars, supernovae, black hole mergers and fast radio bursts are Studying, which allows scientists to understand the underlying physical processes and astrophysical environments associated with these events.

14. Advancement of Instrument:

We have been able to perform extensive surveys to methodically investigate the radio transient sky over a variety of time scales because of the quick development of new instrumentation like GMRT.. Recently, new equipment that can quickly survey broad sky areas with high sensitivity have made it possible to conduct in-depth explorations of the radio transient sky on a variety of time scales, resulting in the identification of transient and variable sources.The GMRT's aperture synthesis technique plays a crucial role in its imaging capabilities. Astronomers can examine objects and events at various spatial scales due to its capacity to see at diverse frequencies, leading to a thorough comprehension of the radio emission from these sources. The sensitivity and resolution of the GMRT also make it a good choice for time-domain studies, which entail the identification and evaluation of transient and time-variable sources. Phased Array Feed (PAF) is a novel technology that the GMRT has made available. The GMRT can observe numerous areas of the sky at once because of PAF, which greatly speeds up and improves the efficiency of the survey. PAF gives the telescope a larger field of vision and improves its capacity to find and analyze fluctuating and time-variable radio signals. The central signal processing facility (CSPF) performs various tasks, such as beamforming, correlation, and data recording. It handles the massive amount of data generated by the telescope during observations. Modern radio telescopes and viewing methods are being developed as a result of research into transient radio emissions. With the development of technology, new instruments and arrays will be created that have greater sensitivities, larger fields of view, and better temporal resolution, allowing the detection of fainter and farther away transient events.

Chapter 2: Literature Review

Literature Review

1. Anderson et al. (2019)

'Discovery of a radio transient in M81' in this paper they investigate transient radio sources focused on high source density regions of the sky within a single field of view. As part of the VLA scan of M81, the radio transient described in the paper is the first to have been found, resulting in a preliminary surface density of 13.2± 30. 210.9 deg2 to a 3σ flux density limit of 75μJy for this galaxy. They identified a new class of extragalactic nuclei, Some persistent ULX radio bubbles' inflation may be partially caused by their ejecta. Luminosity, time scales, and multiwave-length properties are comparatively studied for detected sources. They observed the physical properties of the radio transient and radio follow up. They assumed that the radio ejection is synchrotron in nature, they could deduce the luminosity and rise-time of the emitting plasma's physical parameters.

2. Pal et al. (2019)

Observed transient and variable radio sources NVSS J1957+35 using twenty years of data from a very large array (VLA) in the field of galactic micro-quasar Cygnus x-1 near 1.4 GHz. It is detected many times and noticed high intra-day variability and mainly observed variation of flux density with different time scales. In this report, study some similar properties of transient sources with other Galactic centre transient sources, it may belong to a new class of transient sources. Here suggested that a multi-frequency study is required to estimate the nature of the sources and also study the circularly polarised emission by the transient sources.

3. Hajela et al. (2019)

Used the Giant Metrewave Radio Telescope (GMRT) at 150 MHz to conduct a dedicated transient scan of the SDSS Stripe 82 region over an area of 300 deg2. They are able to examine variability and transient activity on four different time scales, starting with 4 h and going up to 4 yr. A semi-automated pipeline using the SPAM recipe was used to perform data calibration, RFI flagging, source identification, and transient search. As a result, we were able to create photos of the highest quality and conduct a dependable transient search over the whole survey zone in less than 48 hours after the observation. Their survey was intended to explore a more advanced region of the transient phase space; nevertheless, our transitory search turned up no noteworthy candidates. Therefore, beyond the 7 detection threshold, the transient (preferentially extragalactic) rate at 150 MHz is 0.005 on time scales of 1 month and 4 years, and 0.002 on time periods of 1 day and 4 hours. They compared these findings to those of earlier research and offer suggestions for upcoming low-frequency transient surveys.

4. **Gasperin et al. (2018)**

They have shown the biggest radio spectral index catalogue ever put together. The NVSS (1400 MHz) and a reimagined version of the TGSS were used to extract the data (147 MHz). In contrast to earlier research, they didn't cross-match published catalogues; instead, they looked for sources on photos with the same grid and resolution that combined overlapped emission zones. As a result of this technique, some systematic mistakes are addressed and a lower (combined) detection threshold for marginal detections in both surveys is made possible. There are 503647 full detections and 851845 upper/lower limits in the final spectral index catalogue. Furthermore, they offer the public a radio spectral index map of 80% of the sky at a resolution of 45 arcsec, pixel by pixel.They addressed two significant questions using the new catalogue. In the first instance, they investigated the mechanisms underlying the median spectral index's sensitivity to flux density. They discovered unmistakable evidence of spectral steepening with rising flux density. They also discovered that the faint end of the flux density distribution is populated by a significant number of compact, flat-spectrum (0.5) sources, which are the cause of this tendency. They contend that the presence of core-dominated and young AGNs is what causes these traits. The majority of the bright region of this phase space consists of sources with moderate redshift and good evolution. Since their expanded lobes dominate their emission, their spectral index is steeper (0.8).Second, they looked at an earlier report of an overabundance of steep-spectrum sources on the galactic plane using the catalogue. We confirm an excess after deleting the known pulsars and accounting for a systematic spectral index offset in the galactic plane.The excess's characteristics are typical of regular, non-recycled pulsars. They hypothesise that more than usual scattering along the line of sight may have prevented this pulsar population from being discovered during earlier pulse searches.

5. **Stewart et al. (2016**)

They presented the results of a four-month campaign searching for low-frequency radio transients near the North Celestial Pole with the Low-Frequency Array (LOFAR), as part of the Multifrequency Snapshot Sky Survey (MSSS). The data were recorded between 2011 December and 2012 April and comprised 2149 11-min snapshots, each covering 175 deg2. We have found one convincing candidate astrophysical transient, with a duration of a few minutes and a flux density at 60 MHz of 15–25 Jy. The transient does not repeat and has no obvious optical or high-energy counterpart, as a result of which its nature is unclear. The detection of this event implies a transient rate at 60 MHz of $3.9+14.7\ -3.7 \times 10^{-4}$ d^{-1} deg^{-2}, and a transient surface density of 1.5×10^{-5} deg^{-2}, at a 7.9-Jy limiting flux density and ~10-min time-scale. The campaign data were also searched for transients at a range of other time-scales, from 0.5 to 297 min, which allowed us to place a range of limits on transient rates at 60 MHz as a function of observation duration.In this paper, we have presented the results of a search for transient or variable sources at 60 MHz using the International LOFAR Telescope. The search was centred at the NCP, covering 175 deg2 of sky with a bandwidth of 195 kHz and conducted over the period 2011 December–2012 April. The search for transients and variables was performed using the automated, newly developed, Transients Pipeline (TRAP). No transient or variable sources were discovered at time-scales of 30 s, 2 min, 55 min and 297 min. However, several candidates were discovered at the 11-min time-scale.

6. **Murphy et al. (2016)**

   Offered a search that looks at lengthy time periods of 1-3 years for transient and highly variable sources at low radio frequencies (150-200 MHz). The GaLactic and Extragalactic All-sky Murchison Widefield Array (GLEAM) survey catalogues and the TIFR GMRT Sky Survey Alternative Data Release 1 (TGSS ADR1) were compared in order to undertake this search. They looked for compact GLEAM sources above a flux density limit of 100 mJy that weren't in the TGSS ADR1 and for compact TGSS ADR1 sources above a flux density limit of 200 mJy that didn't have a counterpart in GLEAM in order to account for the various completeness thresholds in the individual surveys. They compared the TIFR GMRT Sky Survey Alternative during the course of this inquiry. There were 99658 GLEAM sources and 38978 TGSS ADR sources that met our flux density cut-off and compactness criteria out of a total sample of 234333 GLEAM sources and 275612 TGSS ADR1 sources in the overlap zone between the two surveys. Three potential transient sources were identified through analysis of these sources. Two options were ruled out as imaging artefacts by further investigation. Our analysis of the third possibility, which has a flux density of 182 26 mJy at 147.5 MHz, indicates that it is most certainly the actual deal. The effect is fleeting.

7. **Bell et al. (2013)**

   The findings of a search for low-frequency transients and variables are provided at 154 MHz with the Murchison Widefield Array 32-tile prototype. In this paper, they discovered four short-duration variable sources with variability on timescales ranging from minutes to days. They address the realistic physical explanations for this variability and rule out inherent variability as well as potential causes like refractive, diffractive, and interplanetary scintillation. They propose that the low amounts of variability seen could be explained by ionospheric or instrumental effects. In a time period of 404 days, they discovered two sources that exhibit noticeable fluctuation. They come to the conclusion that either intrinsic to the source or refractive scintillation, or possibly both, is the mechanism for this variability. They set limits on the occurrence of such events on timescales ranging from minutes to years because no transients were found.

mainly observed variation of flux density with different time scales. In this report, study some similar properties of transient sources with other Galactic center transient sources, it may belong to a new class of transient sources. Here suggested that a multi-frequency study is required to estimate the nature of the sources and also study the circularly polarised emission by the transient sources.

8. **Fender & Bell (2011)**

This paper reviews the studies of radio transient populations conducted to date, many of which were based on archival surveys. Numerous of these radio transients and variables have been discovered in the image plane, but it is still unknown what their astrophysical origins are. They use this population and combine it with predictions for the sensitivity of the next-generation arrays to show that, in the next ten years, we might be able to detect 105 image plane radio transients annually, opening up a vast and rich field of study and a virtually infinite number of targets for multi-wavelength follow-up. Five years later, Bower et al. (2007)'s benchmark study is still standard for our knowledge of the transient sky at GHz facilities. There have been several more radio transient searches that have produced upper limits or detections that are consistent with this, but they have not significantly improved the statistics or found sources in anything close to real-time which is essential for multi-wavelength follow-up and our comprehension of the astrophysics of these sources.

9. **Jaeger et al. (2011)**

Using the Very Large Array (VLA), they presented 325 MHz (90 cm wavelength) radio observations of the ultracool dwarfs TVLM 513-46546 and 2MASS J0036+1821104 in June 2007. Observations at 8.5 GHz (3.5 cm) and 4.9 GHz (6 cm) have found sources with >100 Jy quiescent radio flux and >1 mJy pulses coinciding with star rotation, despite the fact that ultracool dwarfs are predicted to be undetected at radio frequencies. The abnormal emission is probably the result of cyclotron maser and gyro synchrotron processes operating in a large-scale, long-lasting magnetic field. Because each activity' characteristic frequency scales directly with the strength of the magnetic field, emission at lower frequencies may be observable from areas with reduced field strength. The combined radio observation history (0.3 GHz to 8.5 GHz) for these sources suggests a continuum emission spectrum for ultracool dwarfs that is either flat or inverted below 2–3 GHz. Further, if the cyclotron maser instability is responsible for the pulsed radio emission observed on some ultracool dwarfs, our low-frequency non-detections suggest that the active region responsible for the high-frequency bursts is confined within two stellar radii and driven by electron beams with energies less than 5 keV.

10. **Thagarajan et.al (2011**)

They studied multiple sources with variability in dynamic radio sky and observed many stars, pulsars, galaxies, unclassified stellar counterparts,unknown sources etc. Using almost 55,000 snapshot images from the Faint images of the Radio Sky at Twenty-cm survey, an in-depth hunt for variable and transient radio sources had been carried out. They reported an investigation that led to the finding of 1627 variable and transitory objects down to mJy levels spanning a variety of durations (a few minutes to years). They talk about these types of variables with follow-up observations in multi-wavelength and make certain assumptions about the nature of the things that don't have multi-wavelength counterparts. They built a detailed list of each object location and the related pixel coordinates in each of the grid images using the locations of confined point-like sources from the FIRST catalog.

11. **Banister et al. (2010)**

Measured 29230 radio light curves over a 22-year survey for radio variability at 843MHz. 53 candidate variable sources and 15 candidate transient sources have both been found. Previously, only three of the transients were known. They come to the conclusion that many variable sources can be accounted by scintillating Active Galactic Nuclei, and some of those connected with neighboring galaxies may be abnormally bright radio supernovae. Here the conclusion is that at least three of the transients are distinct from any known source and may be part of the category of radio transients without optical counterparts that Bower et al. (2007) identified. These transients have a variety of potential causes, such as giant M-dwarf flares or flaring Galactic neutron stars. Additionally, they have included other statistical methods that will be useful in the future.

12. **Fridman P.A (2010)**

‘A method of detecting radio transients’ in this paper single dish non periodic radio transient is observed. Because it is unknown when a transient will arrive or how wide it will be, a sequential analysis using the cumulative sum (cusum) approach is suggested here. Here, search processing and a transitory survey technique have been investigated. This paper illustrates the relevance of single-pulse detection over many-pulse detection for highly modulated pulse sequences. Coherent dispersion, non-coherent dispersion, and duration matching of transients all these methods are explained in this paper. The sequential probability ratio (CUSUM- cumulative sum method) is tested here. The detection algorithm is written based on the two hypotheses: one claims that the process variable is biased by a particular value, and the other claims that the process variable is within allowable bounds. The approaches suggested in this study do not rule out the application of the strongest likelihood criterion for the transient's celestial origin: simultaneous observations of the transient signal originating from the same region of the sky to numerous radio telescopes that are located very far apart from one another.

13. **Matsumura et al. (2006)**

In a survey between Δ=+41^0 and +42^0, found two radio transients: WJN J0445+4130 at low Galactic latitude and WJN J1043+4130 at high Galactic latitude. Here is the result from radio bursts of the 1 Jy class, short time durations ranging from 4 minutes to 2 days. The transient is most likely an extremely bright AGN. Even though it could be a rare source of a well-known group of radio transients, it might possibly be a part of a new class of doppler-boosting transients with a lot of energy. Compared to X-ray and gamma-ray regions, there are comparatively few survey projects over the wide-field sky at radio wavelengths. They have found multiple 1 Jy radio transients throughout their wide-field study, including the two described in this paper. Both low and high galactic latitude regions contain them. Because there are so few samples, research on the transients at high galactic latitude has lagged behind those at low galactic latitude. Blazars and magnetars are potential analogs for the extremely energetic one-time transients in the high Galactic latitude region, although most of their characteristics have never been fully revealed. Wide-field survey's observational findings provide examples for examining such exotic sources.

Chapter 3: Aims and Objective

Aims and Objective

Aims

To investigate the transient radio sources using Giant Metrewave Galactic Plane Survey (GMGPS) at the frequency 325 MHz and to study the variation of the flux intensity with different temporal time scales.

OBJECTIVES

1. To study the spectral properties of the radio transient sources.
2. Multi-wavelength follow-up of detected transient sources.
3. To estimate the nature of the radio sources.

Chapter 4: Observations and Data Analysis

Observations and Data Analysis

The GMRT is the largest and most sensitive radio interferometer with high resolution in the world. It was designed to observe a wide range of astronomical phenomena at radio frequencies and this cutting-edge radio telescope is located near pune, India.

Construction:

The first radio maps of the sky were made in 1937 by Grote Reber using the prototype of the present dish antenna, a 9.1 m. diameter prime-focus parabolic reflector antenna.The National Centre for Radio Astrophysics (NCRA) of the Tata Institute of Fundamental Research (TIFR) conceptualised and built the GMRT. After more than ten years of persistent work, the telescope finally went into service in 2000. Construction on it started in 1987. Since then, it has continued to push the limits of radio astronomy, enabling important discoveries and important advances in science.

Design and Configuration:

It has fully steerable 30 parabolic dish antennas, each with a diameter of 45 metres, spread out across a maximum distance of 25 km. The dishes can descend as low as 16 degrees, however, at this time, the elevation limit has been fixed at 17, covering a declination range - 53 to +90 degrees.The antennas' slew speeds are 20 deg. per minute on the elevation axis and 30 deg. per minute on the azimuth axis, and they are not utilised in winds above 40 kilometres per hour. The efficiency of the antennas varies from 60% to 40%, depending on the frequency, and the reflecting surface is made up of a wire mesh.

Fig-6: GMRT Antennas at daylight (Source: Official website of the GMRT)

It is a large dynamic radio telescope with a field of view of around 1 at 325 MHz and offers a sizable collecting area of about 30,000 square metres (Swarup et al., 1991). Thus, a fast and sensitive system is created. The hybrid arrangement of this interferometer, which is the largest in the world, places 14 antennas out of 30 in a core compact array with a size of approx 1.1 km and the additional antennas are arranged in a relatively 'Y' shape, resulting in a maximal baseline distance of around 25 km. The unique arrangement and configuration of these antennas allow the GMRT to effectively simulate a single large antenna, providing exceptional sensitivity and high-resolution imaging capabilities.

Frequency Coverage:

The GMRT's five receiver systems provide a wide frequency coverage. Each receiver system covers a different frequency band: 50-80 MHz, 120-180 MHz, 235-485 MHz, 610-1150 MHz, and 1260-1450 MHz. However, above this frequency range, the antenna performance rapidly deteriorates due to the mesh's declining reflectivity as well as fast rising aperture phase errors brought on by the facets of the plane mesh's divergence from a true parabola. This wide frequency range enables astronomers to study diverse astrophysical phenomena across different spectral regimes.

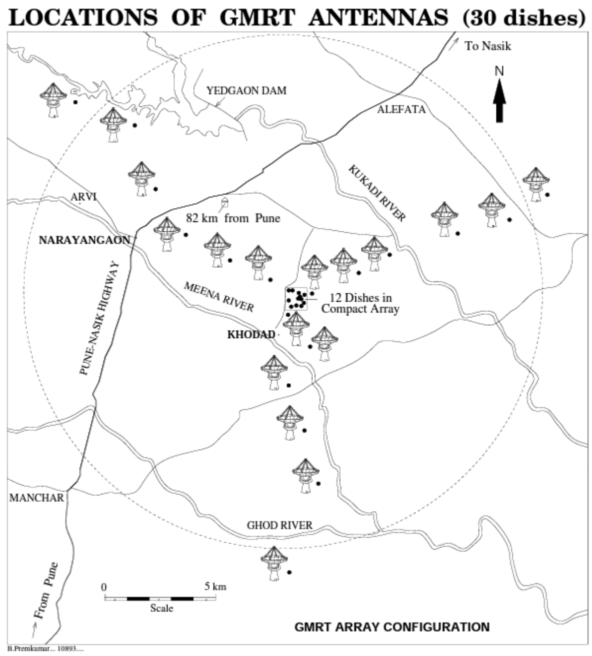

Fig-7 GMRT Array Configuration

(Source: **Low Frequency Radio Astronomy a.k.a. blue-book***)*

While the baselines produced from the arm antennas are comparable in length to the baseline lengths seen between VLA A-array and VLA B-array configurations, those obtained from the central square antennas are similar in size to the baselines obtained from the VLA D-array configuration. Therefore, one observation using the GMRT samples the (u, v) plane sufficiently on both shorter and longer baselines with appropriate sensitivity. Each antenna produces two orthogonal polarizations of signals, which are processed by a heterodyne receiver chain and transported to the central receiving facility. They are transformed into baseband signals and delivered to the digital back-end, containing a correlator and a pulsar receiver. Each antenna transmits both of its orthogonal polarizations to the control room. It is optional to calibrate the absolute flux in areas where the system temperature changes, such as the galactic plane.

Although faster sampling (down to 2 s) is possible, the typical integration times utilized are 8 or 16 s. One main factor that prevents radio telescopes from operating to their full potential is radio-frequency interference (RFI) signals. RFI limits the range of frequencies that can be used, effectively increases system noise, and exposes calibration results. The impact is especially noticeable at frequencies under 1 GHz. RFI from adjacent aircraft activity, especially during the day, can occasionally make it difficult to conduct observations at 325 MHz.In order to calibrate both the amplitude and the bandpass, the flux density calibrators 3C 48 (0137+331, J2000), 3C 147 (0542+498, J2000), and 3C 286 (or 1331+305, J2000) are utilized. The flux density scale used at GMRT is based on the scale developed by Parley & Butler (2013)

Fig-8 : A view of a GMRT antenna lit up at night (Source: The official website of GMRT)

Sensitivity and Resolution:

The Giant Metrewave Radio Telescope (GMRT) is well known for its remarkable sensitivity and resolution, both of which are essential to its capacity to investigate a broad range of celestial phenomena. Here is a summary of the GMRT's sensitivity and resolutionThe 30 separate antennae that make up the GMRT's huge collecting area help to explain its exceptional sensitivity. The GMRT can successfully mimic a much larger telescope, enhancing its overall sensitivity, by combining signals from various antennas through aperture synthesis. The telescope has the capacity to pick up very faint radio signals from celestial objects, including far-off and feeble sources that could otherwise go undiscovered. Because of its sensitivity, it is possible to explore a wide range of astronomical phenomena, including pulsars, radio galaxies, cosmic magnetism, and fast radio bursts (FRBs).

The GMRT is capable of achieving high-resolution imaging, which allows for detailed studies of structures and features within celestial objects. The resolution of a radio telescope is determined by the size of its aperture and the wavelength of the observed radiation. With its 45-metre diameter antennae and its ability to operate across a wide frequency range, the GMRT can achieve resolutions on the order of a few arcseconds. This level of resolution enables astronomers to observe and study fine-scale details in objects such as jets from active galactic nuclei, spiral arms in galaxies, and compact sources like pulsars.

Some parameters measured of the GMRT in 325 MHZ^{+}

Parameters	**Values in 325 Mhz frequency**
Resolution	9″
Primary Beam	81±4′
Receiver Temperature	53 K
Typical Sky Temperature of galactic plane	40 K
Typical ground temperature	13K
Total System Temperature	106 K
Antenna Gain	0.32 (K/Jy/Antenna)
Synthesized Beam(arc sec) i) Whole array ii) Central Square	 9 200
Largest detectable source	32′
Usable frequency range(Mhz) i) Observatory default ii) Range allowed by electronics	 305-345 305 to 360
Best rms sensitivities achieved	0.04 MJY
Typical dynamic ranges	>1500

Table-1:Useful parameter for GMRT

(Source-: GMRT Website)

Radio frequency interference

One of the primary reasons limiting the effectiveness of radio telescopes is radio-frequency interference (RFI) waves. RFI effectively reduces the frequency range that is available, raises system noise, and taints calibration results. At frequencies under 1 GHz, the effect is so effective. In spite of the fact that the RFI environment at GMRT is generally good, it can be extremely worrisome, especially at frequencies below the 235 MHz band. The RFI can occasionally reach several hundred Jy on some channels in the 150 and 235 MHz bands. Even more harm is nevertheless done by broadband RFI of up to several tens of Jy. As previously indicated, the RFI environment can sometimes be problematic at 235 MHz and can also be terrible at 150 MHz; the situation is typically better at night and on weekends. To reduce the risk of RFI saturating the downstream electrical chain for these two bands, it is advised to employ the solar attenuators in the common box. RFI from adjacent aircraft activity can occasionally interfere with 325 MHz observations, especially during the day. The all-pass mode at the 1400 MHz band is no longer accepted as an official mode due to increased interference from mobile phone signals at 950 MHz, and as a result, observations below 1000 MHz in this band are not supported. The user is urged to check for RFI impacts even for the lowest of the 4 sub-bands of the 1400 MHz band.

Radio Frequency Interferometry

Students of optics are familiar with the idea that optical instruments' resolution is constrained by the fact that light is a wave, and this idea is embodied in Rayleigh's criterion, which declares that the angular resolution of a telescope or microscope is ultimately constrained by diffraction and is given by $\theta = \lambda/D$, where D is some measure of the aperture size. The development of larger-sized instruments that operate at shorter wavelengths is a result of the demand for greater angular resolution. Even with big radio telescopes, the angular resolution in radio astronomy is still subpar compared to optical devices because the wavelengths are so large. Accordingly, even the greatest radio telescopes (300 m in diameter) have angular resolutions of only 100 at 1 metre wavelength, in contrast to the human eye's diffraction limit of 20 000 and even moderate optical telescopes' diffraction limitations of 0.1″.Higher resolutions can be attained by either decreasing the observation wavelength or, more practically, increasing the telescope's diameter further. As a result of the second possibility, radio telescopes have a propensity to operate at centimetre and millimetre wavelengths, which produces high angular resolutions. However, these telescopes can only examine sources that are luminous at cm and mm wavelengths. Telescopes with apertures hundreds of kilometers in size are required to provide great angular resolutions at meter wavelengths. This large telescopes cannot possibly be constructed as single objects. Instead, radio astronomers employ an approach known as aperture synthesis to attain such angular resolutions. The foundation of aperture synthesis is interferometry, whose ideas are well-known to most physics students. In actuality, there are many similarities between the radio two-element interferometer and the double slit experiment with quasi-monochromatic light. Instead of constructing this analogy, we choose the van Cittert-Zernike theorem, which is a more widely used approach to radio interferometry. (Blue-book or Low Frequency Radio Astronomy.

Radio Frequency Interference and Cosmic Signal

The discovered transients might be radio frequency interferences (RFI), and a method is suggested here that can tell celestial signals from artificial RFI. This process is founded on an examination of the signals' statistical characteristics. A control check at one radio telescope is proposed to distinguish between man-made transients (RFI with non-Gaussian variance and non-random behaviour) and natural transients (Gaussian variance, pure random noise) at the same level as the spatial-temporal check (when a transient must be simultaneously registered at the distant antennas pointed to the same radio source in the sky and taking into account geometrical delay) (Fridman P.A).

Aperture Synthesis

Apart from a few unusual sources, the radio sky is constant. Therefore, not all of the Fourier components need to be measured at once. Thus, one can see measuring all necessary Fourier components, for instance, using just two antennas, one of which is mobile, and laboriously relocating the second antenna from one location to another. It is known as "aperture synthesis" to employ this technique of gradually accumulating all necessary Fourier components and employing them to picture the source. One may receive a sky image with precisely the same resolution as a telescope with an aperture size of 25 km, for instance, if one has recorded every Fourier component up to, let's say, a baseline length of 25 km. In other words, one has artificially created a 25 km aperture. In actuality, one can observe the U-V plane rather quickly by taking advantage of the Earth's rotation. The baseline vector between two transmitters on the Earth is always shifting due to rotation as seen from a far-off cosmic source. Alternatively, the Fourier components detected by a specific pair of antennas are continuously changing as the source arises and sets. If a collection of N antennas spread out throughout the surface of the Earth, one can measure NC2 Fourier components (or NC2 samples in radio astronomy parlance) at any given time. One examines more and more of the U-V plane as the Earth revolves. If a source is followed from rise to set using an array with 30 antennas, such as the GMRT, the sampling of the U-V plane is dense enough to enable exceptionally high quality reconstructions of even complicated sources. Traditionally known as "Earth rotation aperture synthesis," this method of enhancing "U-V coverage" by taking advantage of the Earth's rotation is now often known as "aperture synthesis" in modern usage.

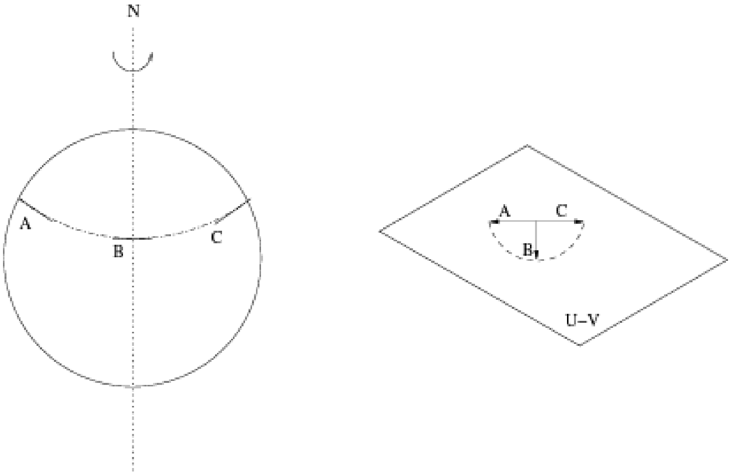

Fig-9: The track in the U-V plane traced out by an east-west baseline due to the Earth's rotation.

In summary,Aperture synthesis, a method used by the GMRT, merges the signals from various antennas to effectively produce a single huge aperture. The sensitiveness and angular resolution of the telescope are improved by this method. The GMRT can imitate a much larger telescope and provide high-resolution photographs of astronomical objects by merging the signals from various antennas.

Giant Metrewave Galactic Plane Survey:

It is an extensive observational campaign aimed at mapping and studying the radio emission from the Milky Way galaxy in the radio frequency range of 300-5000 MHz. It focuses on the region of the sky known as the Galactic Plane, which encompasses the disk of the Milky Way. Here are key aspects of the Giant Metrewave Galactic Plane Survey:

- The primary goal of the GMGPS is to create a comprehensive and detailed radio continuum map of the Galactic Plane.
- It aims to study the distribution and properties of various radio-emitting objects and phenomena within the Milky Way.
- The survey also seeks to identify and characterize transient and variable radio sources, such as pulsars and supernova remnants.
- The data obtained from the GMGPS undergoes extensive analysis and processing.
- Calibration procedures are applied to the recorded data to remove instrumental effects, such as radio frequency interference (RFI), antenna gain variations, and system noise and improve the accuracy of the measurements.
- Calibration techniques help ensure the accuracy and reliability of the data for subsequent analysis.
- The calibrated data undergoes a series of processing steps to extract useful information and identify transient sources.
- Data reduction techniques are applied to remove unwanted noise and artifacts from the data.
- Time-domain filtering is performed to isolate time-variable signals and suppress steady background emission.

Calibration

The observed spectrum has to be corrected for the telescope response as a function of frequency across the band to obtain an estimate of the true spectrum. The telescope response is in general complex with both amplitude and phase variations across the observing band. This overall response across the band can be split into two components:

(1) an overall gain (amplitude and phase) of the telescope for a reference radio frequency (RF) within the observing band, and (2) a variation of this gain across channels(the band shape). The telescope response is thus a combination of RF gain calibration and IF bandshape calibration. This way of looking at the telescope calibration is useful since the requirements for determining these two parts of the telescope response can be different. For e.g., the IF bandshape variation is expected to be slower in time than the RF gain variation and hence need to be estimated less often. The spectral scale for the IF bandshape is however narrower compared to that of the RF gain.

We have assumed till now that we have been working with calibrated visibilities, i.e. free from all instrumental effects (apart from some additive noise component). In reality, the correlator output is different from the true astronomical visibility for a variety of reasons, to do with both instrumental effects as well as propagation effects in the earth's atmosphere and ionosphere. At low frequencies, it is the effect of the ionosphere that is most dominant. As is discussed in more detail in Chapter 16, density irregularities cause phase irregularities in the wavefront of the incoming radio waves. One would therefore expect that the image of the source would be distorted in the same way that atmospheric turbulence ('seeing') distorts stellar images at optical wavelengths. To first order this is true, but for the ionosphere the 'seeing disk' is generally smaller than the diffraction limit of typical interferometers. There are two other effects however which are more troublesome. The first is 'scintillation', where because of diffractive effects the flux density of the source changes rapidly– the flux density modulation could approach 100%. The other is that slowly varying, large scale refractive index gradients cause the apparent source position to wander. At low frequencies, the source position could often wander by several arc minutes, i.e. considerably more than the synthesized beam. As we shall see below, provided the time scale of this wander is slow enough, it can be corrected for.

Gain Calibration

This is usually achieved by observing a bright, unresolved source which is called a calibrator. In the case of a synthesis array like, for e.g., the GMRT, the gain calibration amounts to estimating the gains of the individual antennas in the array. The gains of any given pair of antennas reflect in the visibility (or the cross correlation) of the calibrator measured by them. In an array with N antennas, there are N(N-1)/2 independent estimates of the calibrator (an unresolved bright source) visibility at any given instant of time. However, there are only 2N unknowns, viz., N amplitudes and N phases of the N antennas. Hence, the measured visibilities can be used in a set of simultaneous equations to solve for these 2N unknowns. In practice, a calibrator close (in direction) to the source is observed for a suitable length of time using the same setup as that for the spectral line observations towards the source. A suitable number of spectral channels are averaged to improve the signal-to-noise ratio on the calibrator which is then used to estimate the gains of the antennas. Apart from the instrumental part, the gains include atmospheric offsets/contributions also. The proximity of the calibrator to the source ensures that the atmospheric offsets/contributions are similar in both observations and hence get corrected through the calibration process. How often one does the calibration depends on various factors, like for e.g., the observing frequency, the length of the baseline involved, the telescope characteristics, the time scale for variations in the atmospheric offsets/contributions, etc.. The frequency of calibration can vary from once in ~ 10 minutes to once in an hour depending on these factors.

Bandpass Calibration

Bandpass calibration is the process of measuring and correcting the frequency-dependent part of the gains, $B_{i\,j}(t,\nu)$. $B_{i\,j}$ may be constant over the length of an observation, or it may have a slow time dependence. Good bandpass calibration is a key to detection and accurate measurement of spectral features, especially weak, broad features. Bandpass calibration can also be the limiting factor in the dynamic range of continuum observations.

Through radio astronomy, GMRT is essential to deepening our understanding of the cosmos. The GMRT has established itself as a pillar of astronomical study due to its distinctive design, outstanding capabilities, and important scientific achievements.

Data Reduction and Analysis

Radio transients are erratic signals, radio telescope backends must have the necessary hardware and software for their detection. Transient detection programmes may be specifically designed for that purpose or they may draw on observations made by other programmes. The Common Astronomy Software Application programme (CASA; McMullin et al. 2007) was used to perform the flagging, calibration, imaging, source position, and flux density measurements for each observation.

We have to analyze our data taken from the GMRT catalogue. During the active stages, 36 no of target sources was monitored on a weekly basis. center frequency of 306Mhz, a angular resolution= 13 arc-second×11 arc-second. Here we are using both primary and secondary calibrators. The main calibrators applied for solutions to amplitude and phase problems with delay, bandpass, and frequency independence. The secondary calibrator then is used to calculate the gain solutions with frequency dependency. The target data is then subjected to these solutions. To find both phase and delay solutions, a single self-calibration cycle was performed. The sample was reduced by excluding observations that could not be processed by this automated procedure. picture masking beyond the primary beam power point of 1%, a primary beam correction was lastly made to the images.

The following criteria are used to select sources that will accurately adjust for the absolute flux scale offset and fluctuations that are brought on by the source extraction methodology.

We use the source's average flux density across all observations as a benchmark against which to measure the flux density of each source extraction. We compare each source's extracted flux density against the average flux density. Then, each pixel value is multiplied by the flux density correction factor to correct the image's absolute flux density scale. Each observing frequency is subjected to this procedure separately.

In addition to actual variability, we have found a number of other factors that can produce outliers.

a. False detections are frequently caused by noisy images, images with deconvolution faults, and other issues.

b. In several cases, sidelobes from close sources had notable flux density in one grid image but were nonexistent or hardly present in another, creating an apparent source that appeared to be both real and changeable. To rule out sidelobes as erroneous variables, we carefully investigated all fields with bright sources.
c. Even after accounting for the grid image amplitude correction factors, inaccurate calibration might lead to sources that differ between various snapshot images. We wish to rule out any differences there scaling may be impacted by primary beam uncertainties.

The brightness of the sources must be high and well above the image noise. Point sources are required because extended sources can produce flux density using the catalogue to choose a small number of objects that are close to each outlier and also have a point-like shape in order to find and eliminate such sources. By their respective mean peak flux densities, these were normalised. Each was checked for any variations from the ideal, one-unit normalized value.There are still calibration issues because some neighbours showed the same fluctuation pattern as the outliers. Others were flat-out inconsistent, which raised doubts about the corresponding outliers. We applied this process to all outliers in order to choose a final list that seemed to be free of calibration issues.

The largest departure from the null argument is that the flux density is fixed at a value determined by the mean inferred peak flux density of every individual data point in a light curve that serves as an alternative measure of variability. In a light curve, the largest flux density change between data points gives us a sense of the variability's timescale.

Radio follow-up observation:

To calibrate and image the data, we followed the guidelines in the radio data reduction package CASA. We are using groups of independently calibrated spectral windows, we created sub-band pictures to boost the frequency resolution. We measured the peak flux using the CASA task imstat and estimated the uncertainty by taking the root mean square pixel value in an area of the image with no significant emission after confirming in each sub-band image that the target is detected, unresolved, and not significantly impacted by image artifacts.

Chapter 5: Results

Results

Radio transient sources are enigmatic celestial objects that emit brief bursts of radio waves, often of unknown origin. Philosophically, they embody the enigma of the universe, symbolising the boundless mysteries that continue to elude human understanding. Like transient moments in life, they offer glimpses of the fleeting and impermanent nature of existence, leaving scientists and thinkers pondering the deeper meaning behind their transient nature. As astronomers probe the heavens, these sources remind us that in our quest for knowledge, there will always be phenomena beyond our grasp, encouraging humility and reverence for the vastness of the cosmos and our place within it.

Philosophically, the quest to find radio transient sources in the cosmos represents a profound and intricate journey. These elusive phenomena, emitting short-lived bursts of radio waves, challenge human ingenuity and perseverance. The difficulty lies not only in the vastness of the cosmos but also in the ephemeral nature of these events.

Much like seeking meaning in life's transient moments, astronomers face the daunting task of capturing these elusive bursts in the vastness of space. It reflects the eternal human pursuit of knowledge, where the more we discover, the more we realise how much remains unknown.

The search for radio transient sources evokes questions about our place in the universe. It reflects our longing to understand our cosmic environment, to decipher the language of the cosmos, and to grasp the grand tapestry of creation. It beckons us to ponder whether there are cosmic signals, brief and fleeting, that hold deeper meanings, just as fleeting moments in life may carry profound significance.

In this cosmic exploration, scientists encounter the inevitability of limitations and uncertainty. As we peer into the vast abyss of space, we confront the limitations of human perception, technology, and our understanding of fundamental physics. Such contemplations cultivate humility, acknowledging that there are realms beyond our current grasp.

As we search for these enigmatic signals, we are reminded that knowledge is not a static destination but a ceaseless journey. The pursuit of radio transient sources embodies the spirit of curiosity, exploration, and human resilience, fostering a sense of wonder that fuels the advancement of science and deepens our philosophical reflection on the mysteries of existence.

In our research, we undertook a comprehensive analysis of ten different fields of views (FOVs) using data acquired from the archive of the Giant Metrewave Radio Telescope (GMRT) located in Pune, India. The GMRT is a prominent radio telescope renowned for its ability to capture celestial radio emissions and provide valuable insights into various astronomical phenomena.

The ten FOVs that we studied were as follows:

1. G054.1+1.0
2. G054.0-0.9
3. G054.6+2.0
4. G054.6-1.9
5. G055.1+1.0
6. G055.1-0.9
7. G055.7+0.1
8. G055.7+2.0
9. G055.7-1.9
10. G054.6+0.1

Each FOV presents a unique and intriguing cosmic perspective, offering potential clues about the objects and processes occurring within those regions of the universe. Our analysis involved the meticulous examination of radio signals emitted from these specific FOVs, seeking patterns, anomalies, and potential transient sources that might indicate astrophysical events of interest.

By harnessing the power of the GMRT and employing sophisticated data analysis techniques, we aimed to uncover hidden treasures within these regions of space. Our research contributes to the broader astronomical community's understanding of cosmic phenomena, such as pulsars, supernova remnants, and active galactic nuclei, which emit radio waves detectable by radio telescopes like the GMRT.

Moreover, studying multiple FOVs allows us to compare and contrast the characteristics of diverse cosmic environments, shedding light on the broader cosmic landscape. This comprehensive approach adds depth to our investigations and enables us to draw more robust conclusions about the nature of celestial objects and their interactions.

As we delve into the vast cosmos, the data from the GMRT archive serves as a valuable resource, empowering astronomers and researchers to explore the mysteries of the universe and gain a deeper appreciation for the wonders that lie beyond our terrestrial realm. By sharing our findings, we contribute to the collective endeavour of unravelling the secrets of the cosmos and furthering humanity's understanding of our place in the grand tapestry of the cosmos.

The data collection process involved recording observations within each field of view (FOV) over a period of three days, specifically on the dates 4th June, 19th May, and 21st May. The primary objective of this meticulous observation was to gain comprehensive insights into the transient characteristics of a radio source.

Subsequently, a thorough analysis of the obtained FOVs was conducted using advanced software tools, including AIPS (Astronomical Image Processing System) and CASA (Common Astronomy Software Applications). Leveraging these sophisticated software suites, we processed the data to generate high-quality images for each FOV across the three observed dates.

The utilisation of AIPS and CASA ensured the accuracy and precision of the image creation process, enabling us to obtain detailed visual representations of the radio sources within the observed regions.

In conclusion, the combination of rigorous data collection, advanced software analysis, and image generation techniques stands as a testament to the rigour and commitment applied to comprehending the transient nature of the studied radio source within the designated fields of view.

After analysing the datas and making the images we made a full catalogue of sources in all the fields of views that we've observed by using the software AIPS. As an example we are giving a source catalogue of field of view G054.0-0.9 for 4th June.

G054.0-0.9 (4th June)			
No.	Right Ascension	Declination	Flux
1.	292.8111	17.46623	29.572
2.	292.813	17.4522	26.752
3.	292.822	17.50217	56.502
4.	292.8295	17.48882	43.56
5.	292.8322	18.11934	26.25
6.	292.9017	17.51749	22.379
7.	292.9116	18.04315	46.398
8.	292.9142	18.03208	61.053
9.	292.938	18.04141	39.797
10.	292.9632	18.09986	42.609
11.	293.0254	18.08261	28.616
12.	293.0359	18.10143	66.208
13.	293.0599	18.15079	59.856
14.	293.0765	18.23286	27.981
15.	293.1015	18.75764	37.031

Table-2:of source catalogue in Field of View G054.0-0.9

Here only 15 sources are shown but actually we found 80 sources on average in each field of view and for each day.

So, for every 3 days of observations of 10 fields of views we got 30 catalogues of sources. After observing all these catalogues we tried to plot them by keeping Right Ascension in X axis and Declination in Y axis, taking data from 3 days observation in one plot. To get a proper visualisation of these sources. Here we are giving 6 fruitful plots from 10 FOV.

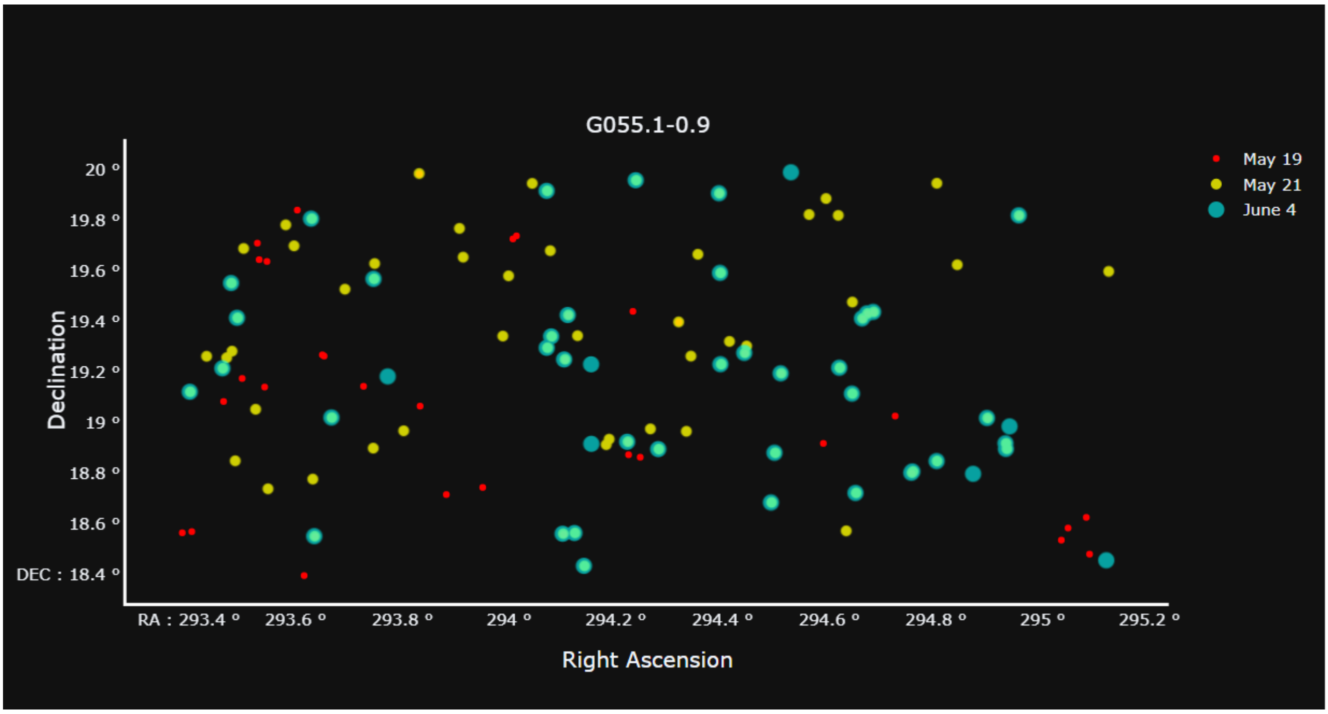

Fig-10: RA vs DEC plot of Field of View G055.1-0.9

In the above plot, we are seeing the sources found in the field of view in three days: 19th May, 21st May and 4th June. And after observing them we can see that some sources can only be seen on some particular days, that means we cant see them every day, concluding that maybe these sources have some transient nature in them. After further verifying them we can conclude that surely they are transient.

Just like the above plot, we are listing the RA vs DEC plot of other 5 Field of views in the next pages.

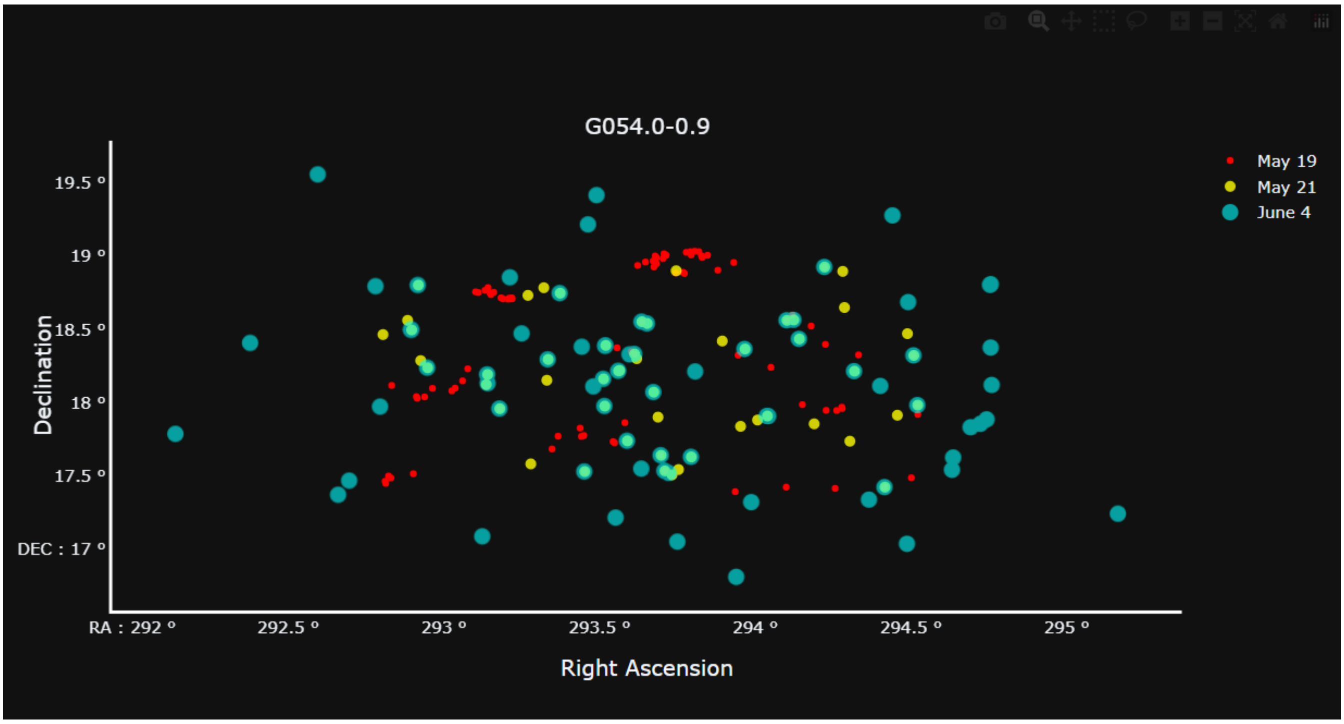

Fig-11: RA vs DEC plot of Field of View G054.0-0.9

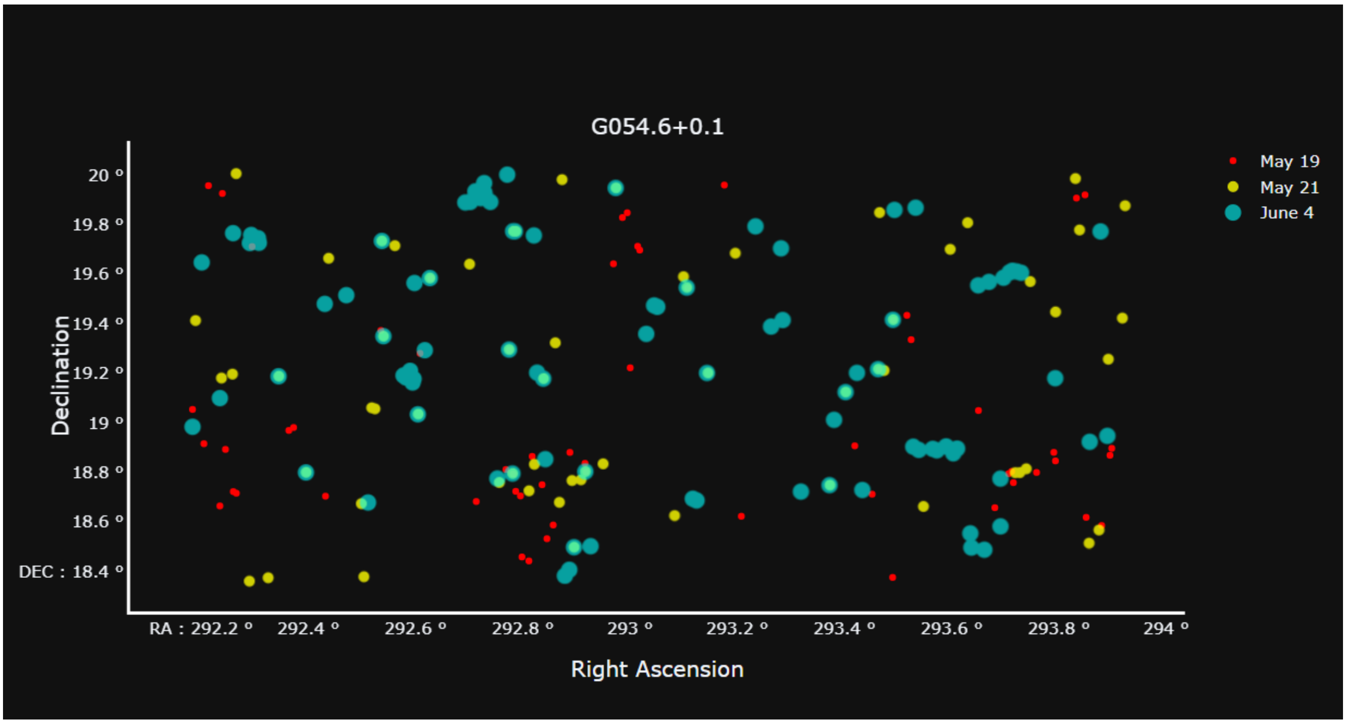

Fig-12: RA vs DEC plot of Field of View G054.6+0.1

As we can see that on every Field of Views, there are some sources that we failed to see in every day of our observations.

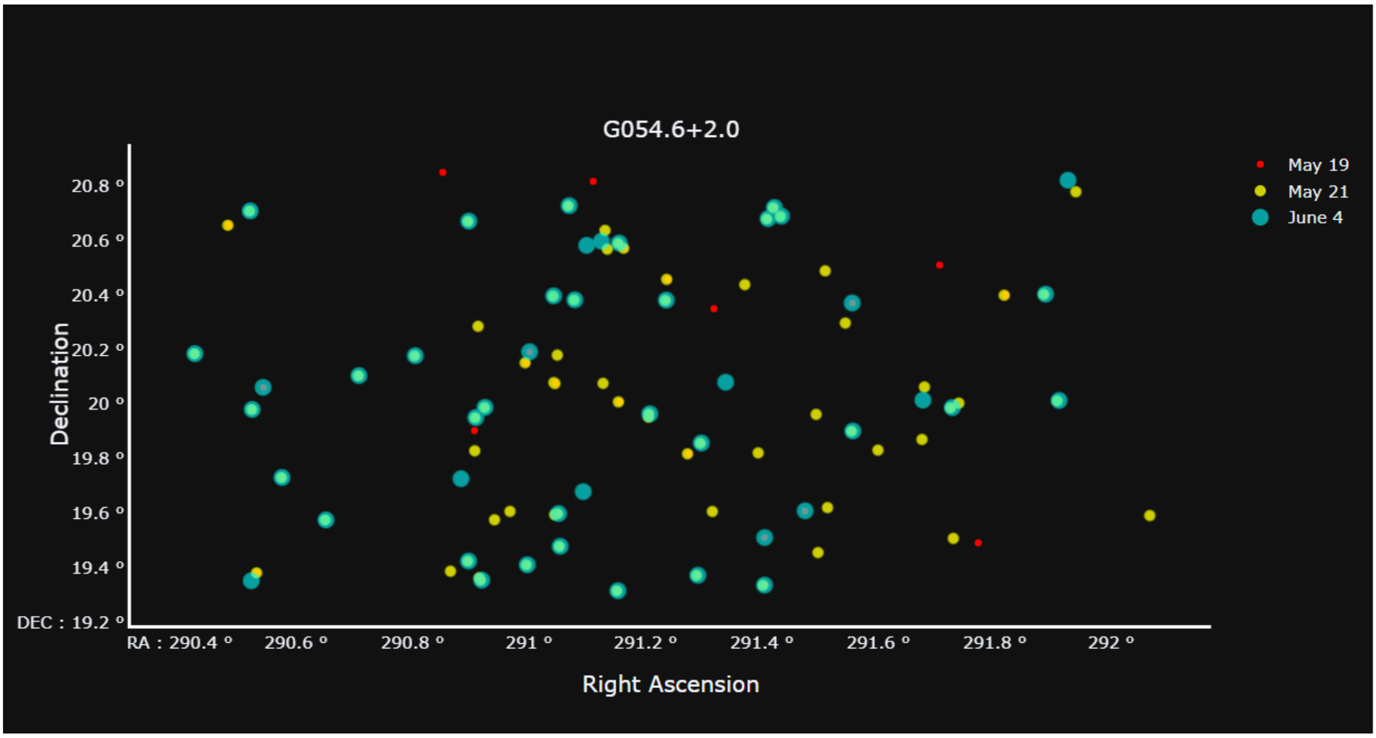

Fig-13: RA vs DEC plot of Field of View G054.6+2.0

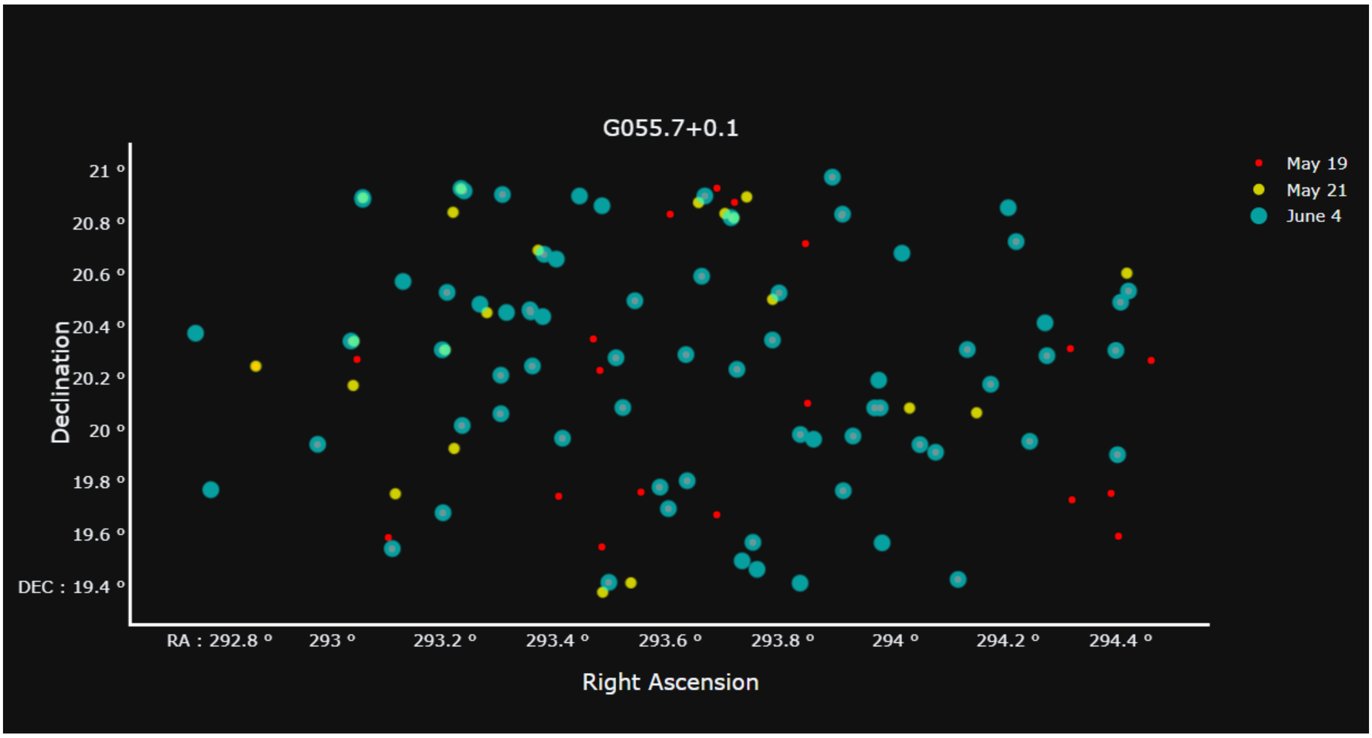

Fig-14: RA vs DEC plot of Field of View G055.7+0.1

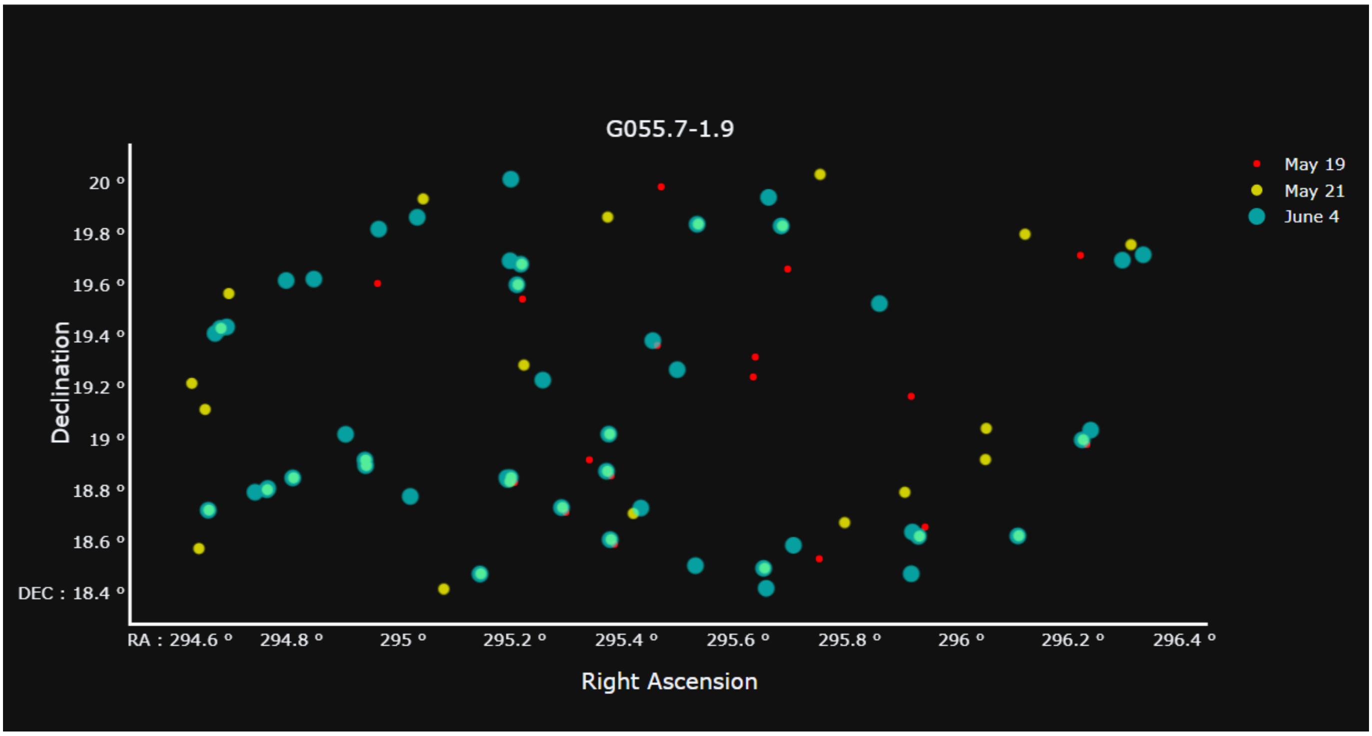

Fig-15: RA vs DEC plot of Field of View G055.7-1.9

For further study of these sources, who might have any transient nature, we analysed there fluxes with respect to time for each day and plotted them in a 3D plot by using RA in X-axis and DEC in Y-axis and varying bubble sizes with respect to their fluxes.

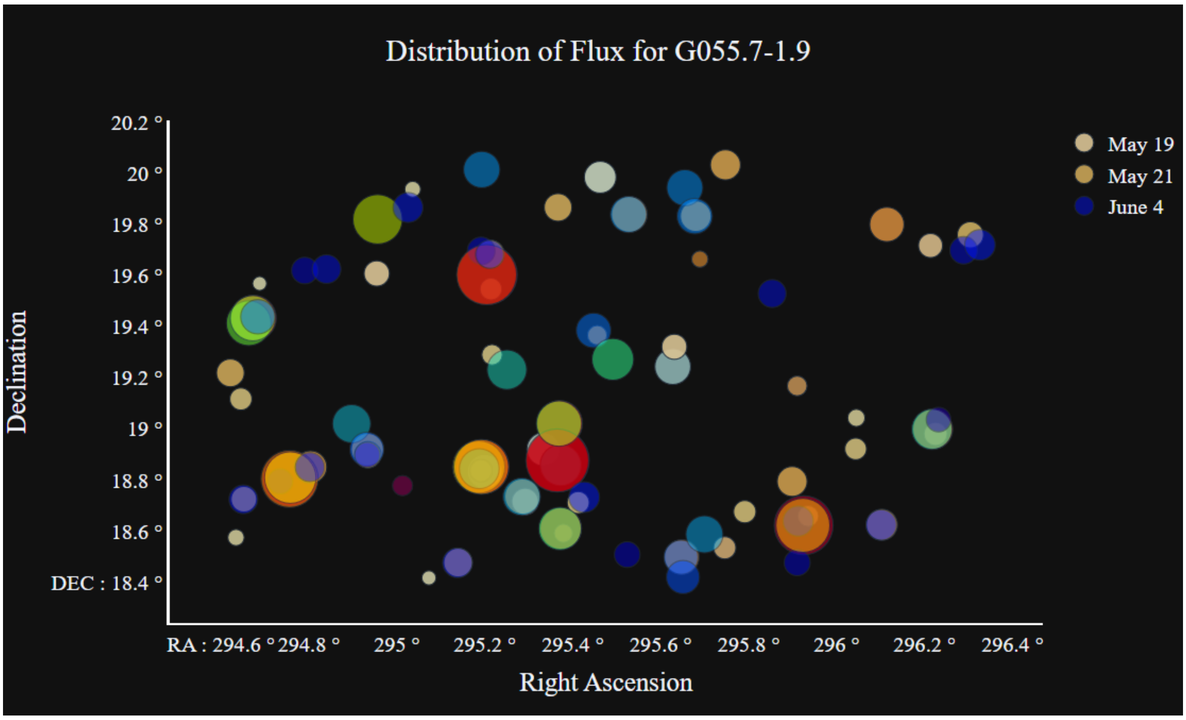

Fig-16: Distribution of Flux for Field of View G055.7-1.9

If we clearly observe the above plot then we can see for some sources there are three concentric bubbles. That means flux changed with time for that particular source.

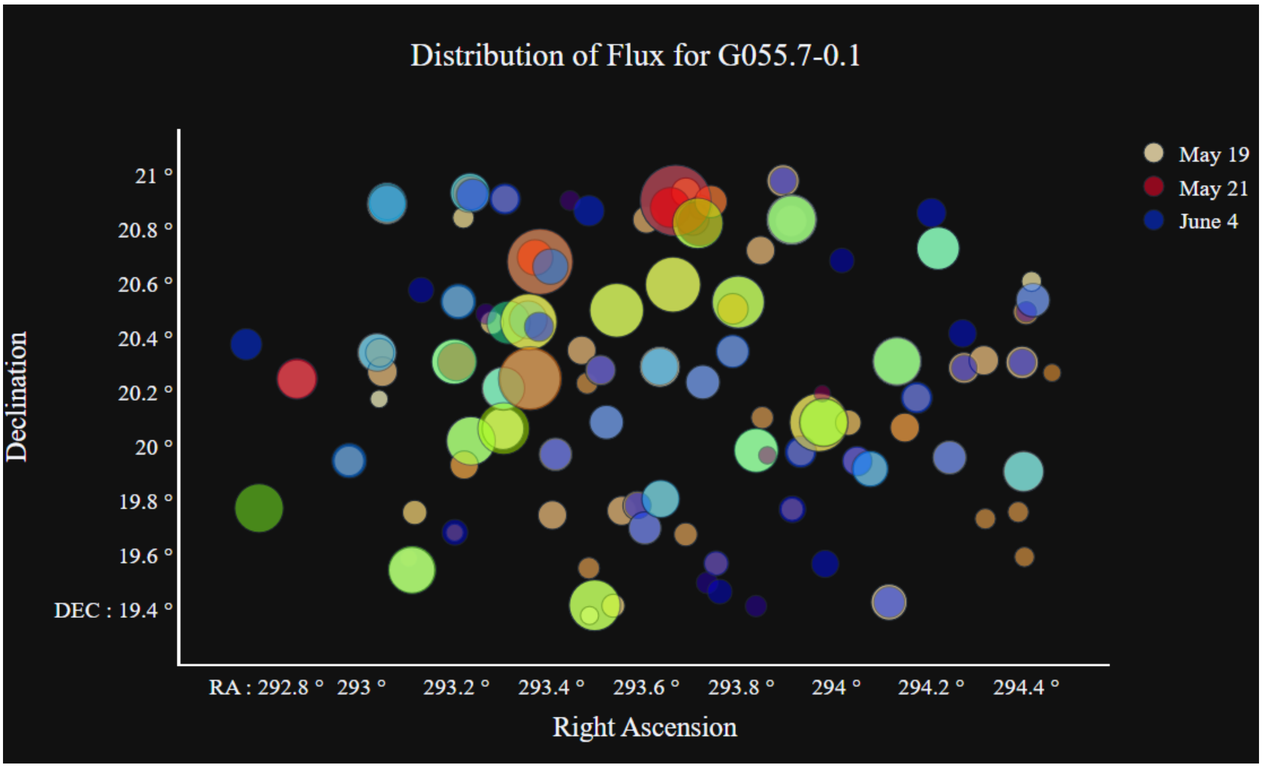

Fig-17: Distribution of Flux for Field of View G055.7-0.1

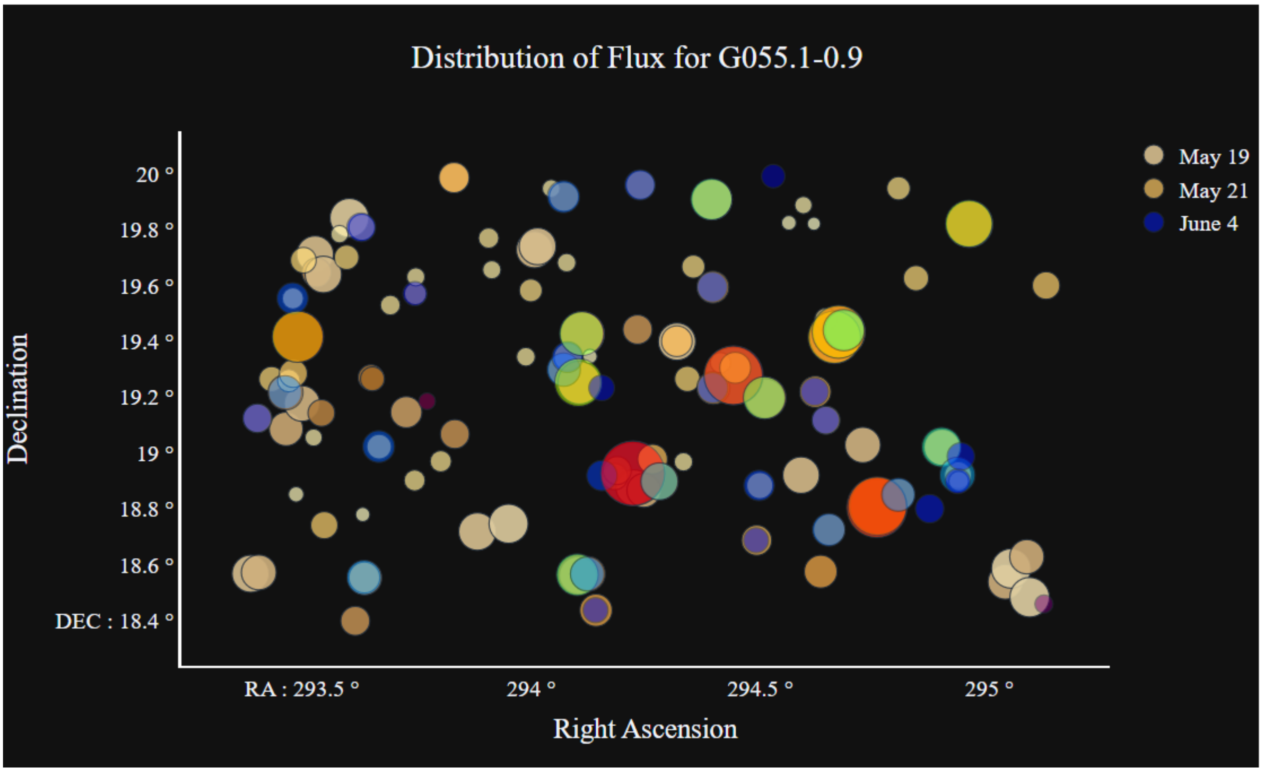

Fig-18: Distribution of Flux for Field of View G055.1-0.9

Here we are listing another two plots of distribution of fluxes for two different Field of Views.

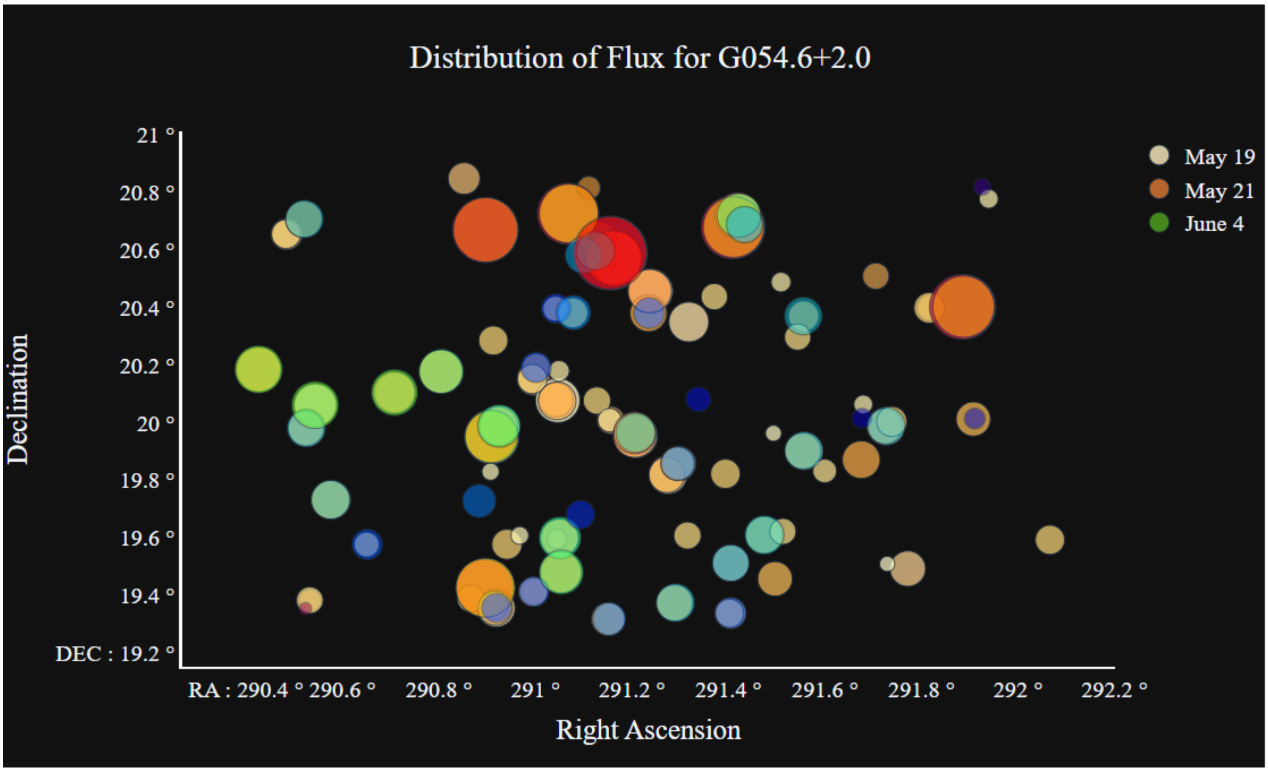

Fig-19: Distribution of Flux for Field of View G054.6+2.0

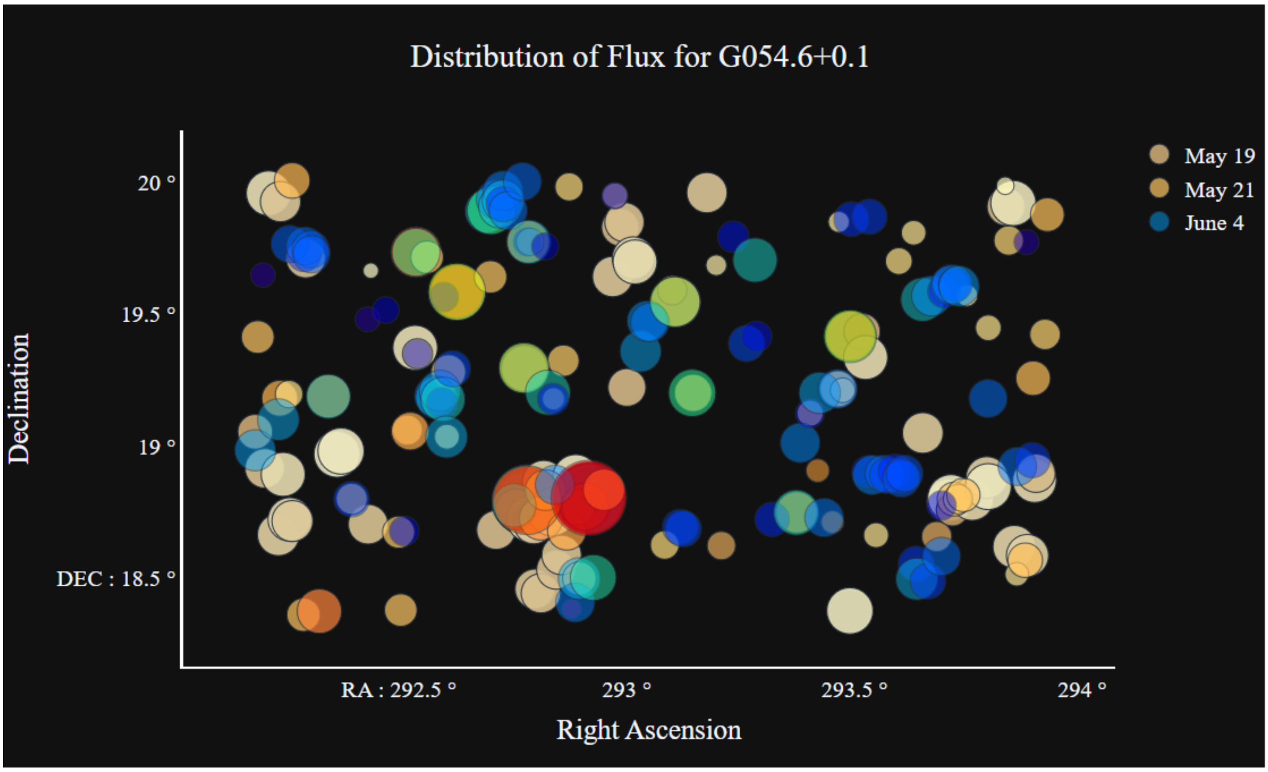

Fig-20: Distribution of Flux for Field of View G054.6+0.1

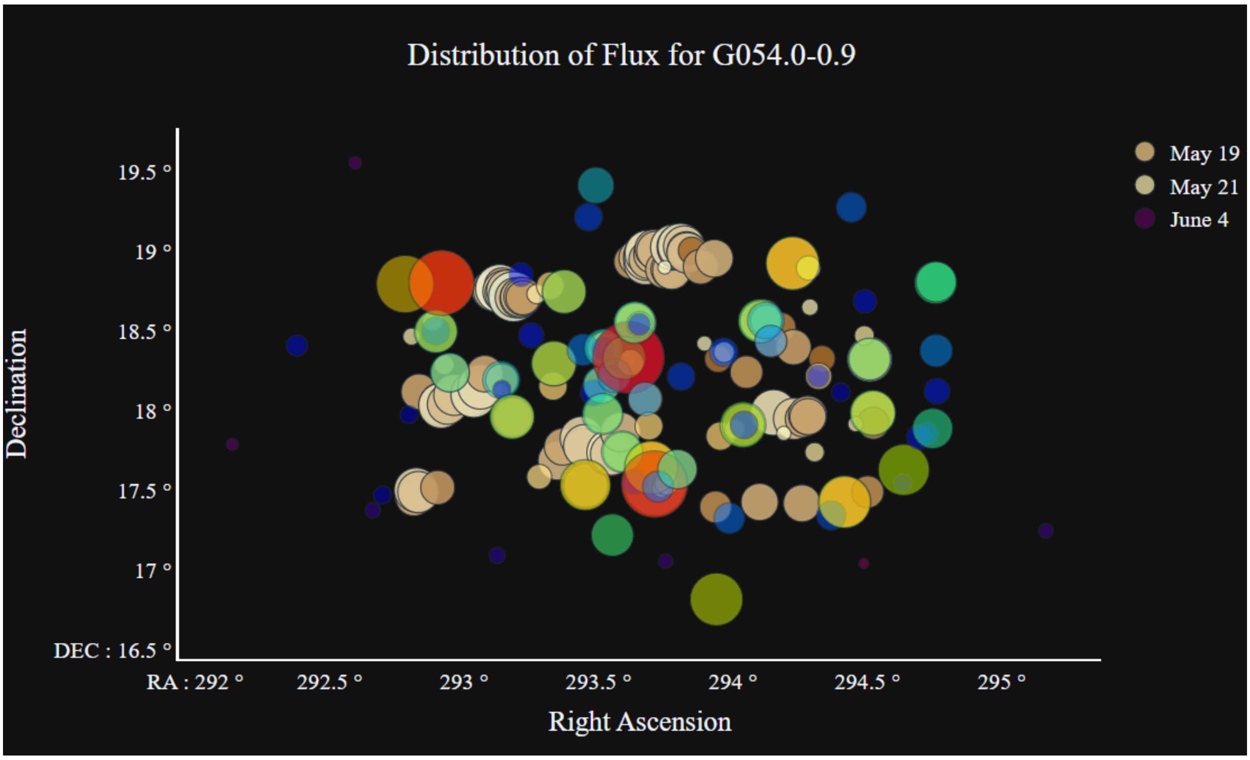

Fig-21: Distribution of Flux for Field of View G054.0-0.9

After deeply analysing all the bubble plots mentioned above, we found four astronomical sources which have transient natures in them; they have different flux values in our different observing dates.

We present a comprehensive table comprising all transient astronomical sources detected through meticulous analysis of data obtained from GMRT (Giant Metrewave Radio Telescope). The table includes precise coordinates in degrees and flux values from three distinct observing dates: 19th May, 21st May, and 4th June. This invaluable compilation sheds light on the dynamic nature of celestial phenomena and paves the way for further research in the field of astronomy.

Field of Views	**Right Ascension (In Degrees)**	**Declination (In Degrees)**	**Flux Values**		
			19th May (In Mjy)	**21st May (In Mjy)**	**4th June (In Mjy)**
G054.0-0.9	293.70	17.53	283.958	390.671	447.76
	293.61	18.33	594.662	639.483	704.43
G054.6+0.1	292.91	18.80	552.90	647.62	932.87
G055.1-0.9	294.22	18.92	305	354	340

Table-3: ***List of Transient Sources Found in Galactic Plane Survey***

After enlisting the above five astronomical sources which have transient nature in them, we have tried to plot individual light curves (Amplitude vs. Time graph) for all five transient sources. We are giving this light curves below:

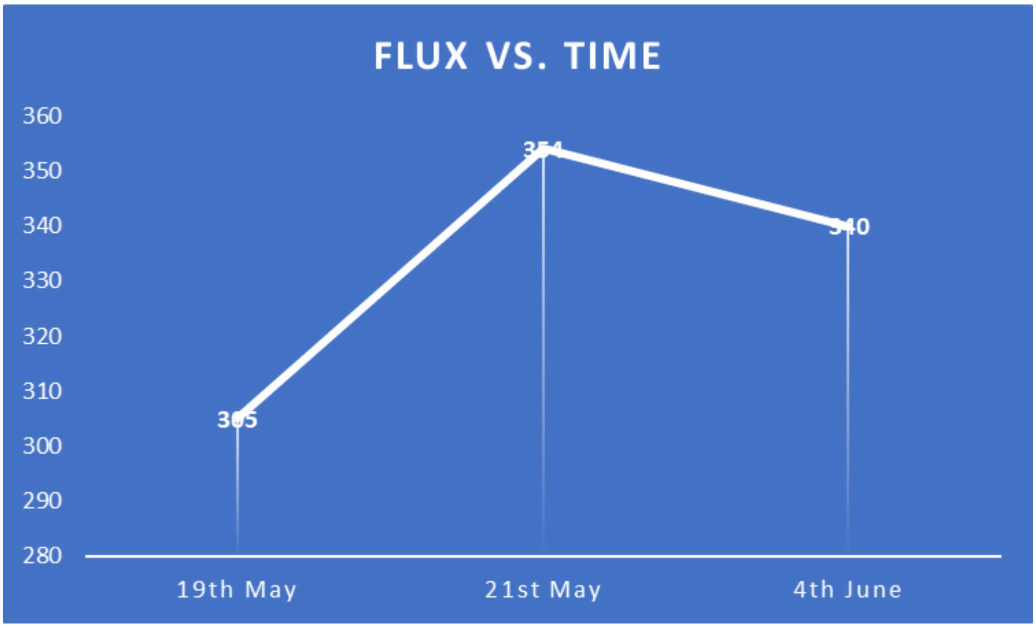

Fig-22: Light Curve for the transient source having coordinate RA=294.22 and DEC=18.92

By observing this light curve we can clearly see how amplitude or Flux is varying with time here.

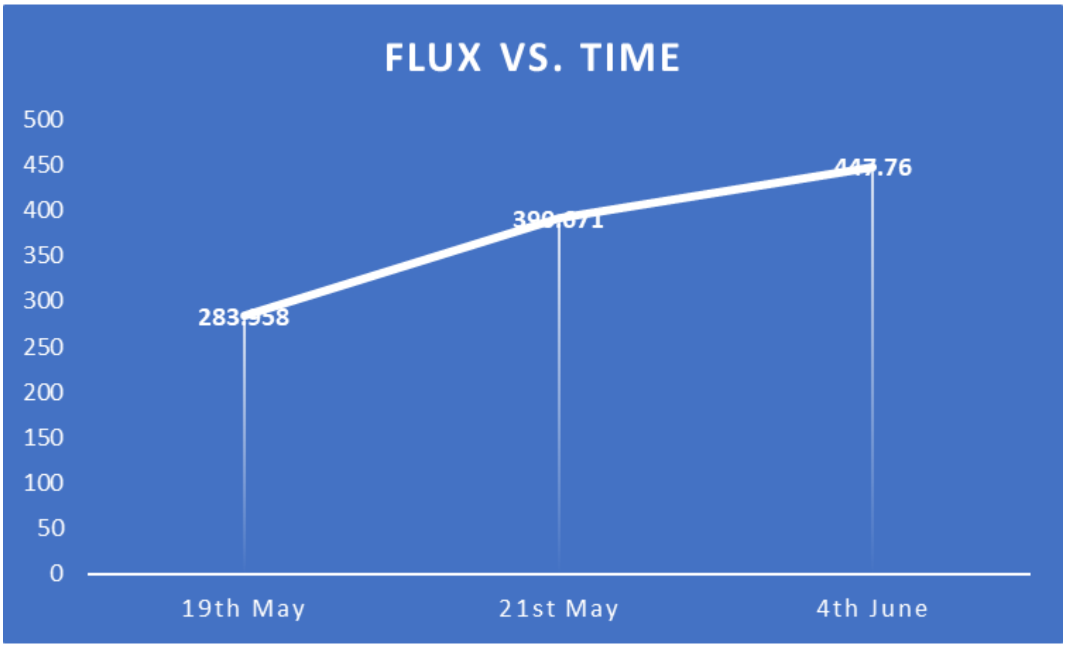

Fig-23: Light Curve for the transient source having coordinate RA=293.70 and DEC=17.53

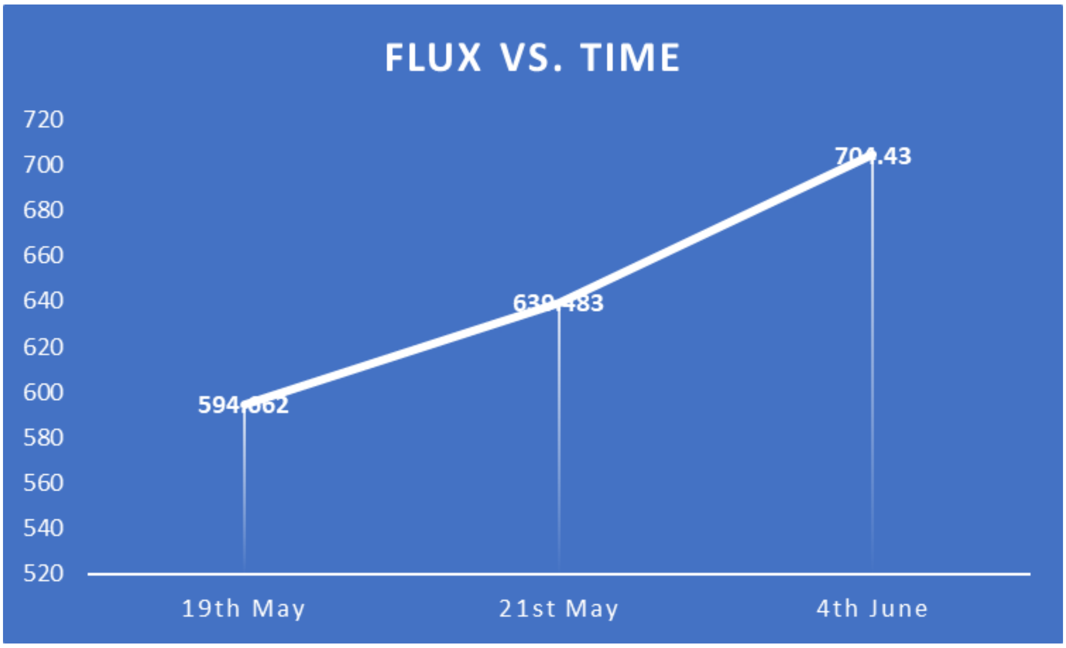

Fig-24: Light Curve for the transient source having coordinate RA=293.61 and DEC=18.33

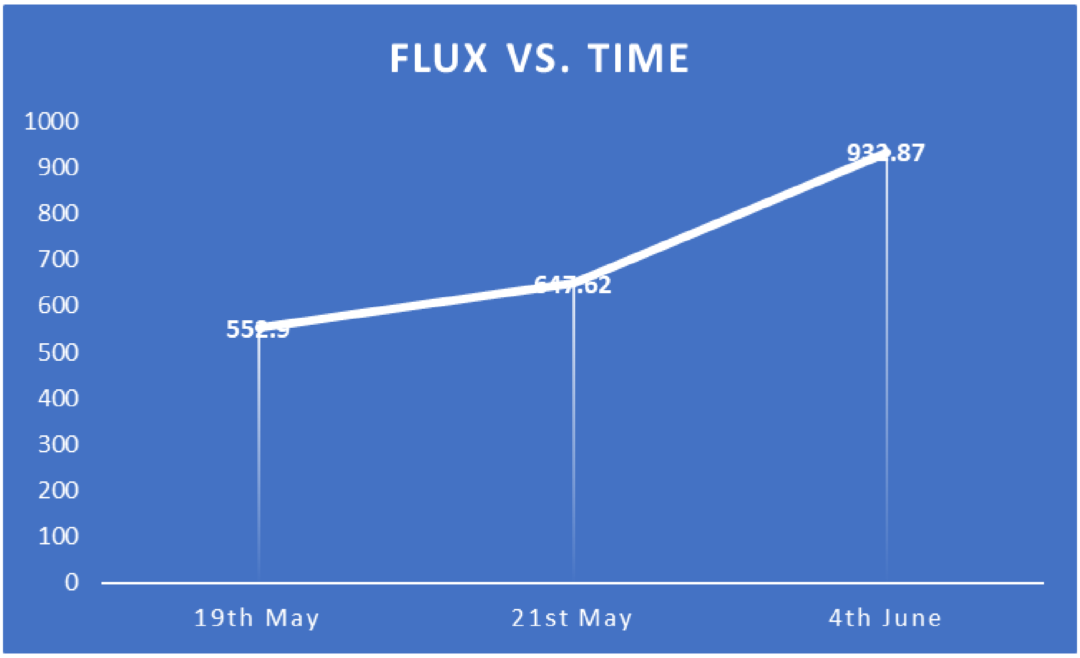

Fig-25: Light Curve for the transient source having coordinate RA=292.91 and DEC=18.80

Our research thesis rigorously analysed GMRT data spanning three days: 19th May, 21st May, and 4th June. This investigation yielded the identification of four transient astronomical sources, crucial for gaining profound insights into the universe. These transient phenomena serve as valuable tools for advancing our knowledge and comprehension of the cosmos.

The significance of our work lies in its potential to fuel future scientific endeavours. With further analysis, our findings hold the promise of contributing to the realms of both science and nature. By better understanding these transient sources, we can deepen our appreciation and comprehension of the universe's intricate complexities.

Chapter 6: Discussion

Discussion

Transient sources are objects in the sky that exhibit sudden and temporary increases in brightness or other observable properties. The rarity of detecting transient sources is mainly due to their unpredictable nature and short-lived appearances. In some cases, transient events may occur randomly and may not be in the field of view during observations, making their detection even more challenging. So the detection of the more than one transient sources from just three days of observation is indeed quite remarkable, indicating that the observation was conducted with excellent efficiency and sensitivity. This discovery can contribute valuable data to the field of astronomy, potentially leading to further investigations and studies of these transient events. The first step in the discussion involves confirming the authenticity of the detected transient sources.

A. G054.0-0.9

The type of the detected transient source (galactic longitude= 53.416503 deg., galactic latitude= -1.275457 deg) is still unknown. We looked for possible periodicity in 2MASS J19344809+1731532 as was found in some other radio transients. The light-curve data was systematically folded with a different period to search for the signature of any periodicity in the emission.

The another transient source (galactic longitude= 54.076147, latitude= -0.812772) is not detected by any other previous all-sky catalogues except WISEA (WISEA J193426.76+181957.6), 2MASS (2MASS J19342677+1819578) and SSTSL (SSTSL2 J193426.76+181957.5) , the nature and other properties of the source is not possible to study still now. No periodicity was found in the source light curve.

B. G054.6+0.1

The source is mentioned in 2MASS catalogue (2MASS J19313849+1948034) with galactic coordinates are 55.041158 deg (latitude) , 0.477109 deg (longitude). The nature of the source and other properties are not known. Flux density-time plot shows linearity in nature.

C. G055.1-0.9

The detected transient source is presented in 2MASS catalogue (2MASS J19365304+1855151) with galactic latitude and longitude is 54.871225 deg, -1.031042 deg respectively. The nature of the source is unknown. The variation of the flux density with time is increment order.

We were unable to detect the more transient event in the remaining six field of view. To locate more transient event, it is essential to observe a few more field of view with extend the observation period.

. These transient source studied contribute to the broader field of astronomy. Transient sources provided crucial information about the life cycles of stars, the dynamics of galaxies, and even the nature of the universe itself. Understanding these events can help refine existing models and theories in astrophysics.

The number of source counts decreased rapidly with increased the flux density,it is possible to that noise will scatter fainter sources to high flux densities. The radio source counts at high flux-densities are typically due to double-lobed radio galaxies. The source count distribution of radio sources can be explained by two populations of radio sources The source population, where the radio emission is primarily from disc stars and related nebulae, is described as ‘star-burst’, whereas a population with the emission from nuclear supermassive compact objects is described as ‘monsters’. Most ‘star-burst’ galaxies are spiral galaxies, and the most ‘monsters’ are elliptical and lenticular galaxies. Above 1 mJy, the source population is dominated by elliptical galaxies. The radio source population at high flux densities mostly consists of double-lobed radio galaxies and quasars. Scattering by the interstellar free electrons in the Galactic plane plays a role in broadening the size of the source.

These sources require a pulsar search in the time-series data to confirm their nature. The probability of finding a pulsar candidate is much higher in the Galactic Center region compared to other areas of the Galaxy due to the higher source density in the region. Since we observed apart from the galactic centre, the detected transient sources are unlikely to be pulsar in nature.

Chapter 7: Conclusion

Conclusion

Detecting more than one transient source within just three days of observation is quite a successful outcome. We have verified from the study of light curves and the flux density of source catalogue that the observed events are genuine transient phenomena. We attempted to locate the transient sources in ten fields of view but we were successful in locating four transient sources in onl three of these fields of view. The sources varies its flux density with time but we found that during our study, the percentage of deviation measurement of flux density was equal or greater than the values of 10% , that is considered as transient sources. Most of our detected sources are in 2MASS with some sources in the SSTSL and WISEA. Our detected transient sources, nature is still unknown and further studies are needed to determine their properties.

We often need to conduct extensive and systematic observations over extended periods to increase the chances of capturing such events. As the technology and methods for astronomical observations continue to improve, the detection and study of transient sources are likely to become more frequent, providing scientists with valuable insights into the dynamic and ever-changing nature of the universe. Based on the observations and properties of the transient sources, we could propose theoretical models and interpretations to explain the phenomena. Different astrophysical processes might be considered to understand the origin and evolution of the detected events. Detecting transient sources can be highly serendipitous, but systematic and continuous observations can improve the chances of capturing more events.

We may propose follow-up observations using other telescopes or instruments to gather more data on the detected sources or to search for similar events in different regions of the sky. Some cases, transient radio sources can be faint and short-lived, making them challenging to detect with lower sensitivity instruments. This can result in missed detections or a lower rate of detection for weak transient sources. The time resolution of the telescope may not be sufficient to capture such rapid events, leading to potential missed detections. Precisely localising transient radio sources is crucial for understanding their origin and nature.

Chapter 8: Future Scope

Future Scope

After transient radio source detection, there is a broad future potential that includes fundamental astrophysical research, technological breakthroughs, and practical applications. Exploration and study in this area will definitely result in fascinating findings that will improve our comprehension of the cosmos.

We can learn more about the nature and features of transient radio signals by continued detection and research. Scientists can improve pre-existing models and theories, offering insights into their causes and behaviour, by analysing their characteristics, such as intensity, duration, and frequency.

Transient radio sources can provide as starting points for additional observations at different wavelengths and with different kinds of detectors, such optical, X-ray, or gravitational wave observatories. It is possible to get a more complete picture and a better understanding of the underlying physical processes by combining the study of transitory events at several wavelengths.

The identification and investigation of FRBs may result in the creation of new communication methods and technologies. In the future, the propagation of gravitational waves and understanding the nature of dark matter can be studied through radio emission from transient sources.

Pulsars, rotating neutron stars that are highly magnetised, are examples of transient radio emissions. We can learn more about these objects' emission mechanisms, study extreme physics in powerful magnetic fields, and perhaps investigate gravitational wave backgrounds with more investigation.

Researchers can learn more about the distribution of matter along the line of sight by examining objects' dispersion measures and redshifts. This can help them comprehend the universe's large-scale structure and possibly probe into the nature of dark matter.

Transient radio sources have the potential to provide important details about the early cosmos, such as the cosmic dawn and the reionization epoch. The origin and evolution of the first stars, galaxies, and black holes can be studied by scientists by identifying and examining radio waves emission from the transient sources.

The mapping of the transient radio sky will be possible due to the study of the transient source. Astronomers can create a thorough database that will help with future research by finding and cataloguing these sources. The distribution and evolution of transient radio emissions can be better understood by using this to identify statistical trends, correlations, and probable clustering.

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