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HIGHLIGHTS OF RADIOASTRONOMY IN BRAZIL FOR THE LAST THREE DECADES

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ABSTRACT

The development of radioastronomy in Brazil is strongly related to the installation of the 14 m Itapetinga radiotelescope, which operates in the frequency range 20-50 GHz. In the decade of 1970, it was crucial for the discovery of many southern hemisphere strong H_2O and SiO maser sources and to the follow up of their variable emission. It also resulted in the first detection of maser sources in external galaxies. The continuum thermal and non-thermal emission from galactic sources and from Active Galactic Nuclei were also studied, for which tracking and data acquisition techniques were developed, to overcome the limitations imposed by the fast changing sky contribution, typical at these frequencies. The Itapetinga radiotelescope participated in several VLBI campaigns related to the study of the changing structure of AGN cores, using the MARK II data acquisition system; the increase in the north-south baseline allowed the study of several equatorial sources with an almost circular beam.

SCIENCE WITH THE ITAPETINGA RADIOTELESCOPE

Since this workshop is dedicated specially to instrumental work, I will emphasize the improvements made to the Itapetinga radiotelescope, especially concerning its tracking facilities and data acquisition systems, which allowed most of the scientific work done during the last 30 years, which I will also discuss. The 13.7 m Itapetinga radiotelescope became available for radioastronomical work around 1973. It was the first radome enclosed radiotelescope build by ESSCO Corporation, and a large controversy arouse regarding its use for radioastronomy. Nowadays, similar radiotelescopes are used around the world (Finland, Spain, Korea, China, etc).

THE SCIENTIFIC CHALLENGE

Extragalactic Radioastronomy

During the decade of 1970, astronomers were discussing the nature of the recently discovered QSRs (Quasi Stellar Radiosources), specially their galactic or extragalactic nature (Hoyle et al., 1966; Rees, 1967; Jones and Burbridge, 1973; Burbridge, 1979). The main argument in favor of their galactic origin was the very high intrinsic luminosity that would result if they were at extragalactic distances.

The nature of the radio emission had been already attributed to incoherent synchrotron emission of a non thermal population of relativistic electrons rotating around the magnetic field lines (Alvén and Herlofson, 1950; Shklovsky, 1953). Soon after its association of QSRs with optical, high redshifted objects, it was discovered that its flux density varied in timescales of months (Dent, 1965; Scholomitskii, 1965), Variability put constrains to the actual size of the emitting object: $l < 2ct_\nu\ (1+ z)$, which allowed the calculation of the brightness temperatures, which needed to be $T_B > 10^{12}$ K, to avoid the Compton catastrophe. To explain the existence of sources with $T_B > 10^{12}$ K, Rees (1966) postulated the relativistic expansion of the emitting source. In this case, the time t_ν, in the observer frame, must be multiplied by the Doppler factor δ of the relativistic expansion, which can be large, increasing in the same proportion the actual size of the emitting source $l < 2ct_\nu\ \delta(1+ z)$.

The spectra of quasars soon extended up to 90 GHz, and presented different shapes. In some cases the spectra resembled that of the external regions of radiogalaxies, with the flux density decreasing with frequency as a power law. Other presented a canonical spectrum, decaying at both sides of a central frequency, also as power laws. However, a large portion of the spectra presented flat spectra, which would require a very specific combination of magnetic field and electron density distribution laws to be produced, this requirement was called the "cosmic conspiracy" (Cotton et al., 1980).

The decade of 1970 was dedicated to data collection. In Brazil, the recently inaugurated Itapetinga radiotelescope , with a radome enclosed 13.7 m dish, operated initially at 22 GHz and later on also at 30 and 43 GHz; it was used by Kaufmann et al. (1974) to obtain the brightness distribution of the central region of the nearest radiogalaxy NGC5128, also known as Centaurus A. Variability studies of this source in timescales of days and months showed some quiescent periods (Fogarty and Schuch, 1975), and others with variability in different timescales (Kaufmann et al., 1977; Kaufmann and Raffaelli, 1979).

Due to its proximity, Centaurus A appears as a powerful source. Quasars, on the other hand, even being intrinsically brighter, are so far away that their flux density is very low. This fact, together with the high contribution of the earth atmosphere, results in a very small signal to noise ratio and prevents the detection of a large part of them. The scheme used for these observations was beam switching, in which the signal introduced by the source and the sky in one horn is subtracted from the contribution of the sky, measured by another horn, at an offset of about 20' in azimuth. The switching was made at a rate of about 100 Hz and the horn that observed the source switched periodically every minute (ON-ON). This method, which in principle eliminates the contribution of the atmosphere, can cause large errors in the measured flux, due to small difference of gain between the horns, inhomogeneities in the atmospheric emission and in the radome transmission. To eliminate these problems, several new observational methods were introduced in Itapetinga, involving changes in the tracking and data acquisition systems (Abraham, 1989). First, the interval in the ON-ON switching were reduced from 1 minute to 20 seconds, afterwards the ON-OFF synchronous method was introduced, intended to cancel the contribution of possible standing waves produced in the radome structure. Finally, the method of SCANS was introduced, in which the radiotelescope scans the sky with an amplitude, direction and duration fixed by the observer, passing in front of the source in the middle of the scan. This method resulted more reliable, because it allows visualizing a point source as a Gaussian at the center of the scan, with half power width equal to the beam width HPBW. Latter, a method was developed, using a noise source and a room temperature load, to compensate the atmospheric absorption even in the presence of a wet radome, which allowed variability studies, even when the source was visible during the night (Abraham and Kokubun, 1992).

The development of these observational techniques allowed the extension of the spectra of southern hemisphere QSRs to 22 and 43 GHz. They were, at that time, the highest frequencies used systematically (except for a few isolated measurements at 90 GHz). Initially, research was limited to the determination of the spectra of a sample of objects, which resulted to have either canonical, decreasing power law or flat shapes (Medeiros, 1981). Comparison with spectra obtained at other epochs, extracted from the literature, show that some of them, classified as flat, had presented variations, which converted them, at least at high frequencies, in canonical, so that the phenomenological classification of QSRs lost its validity (Abraham, Medeiros & Kaufmann, 1984). Studies of variability using the scanning method started in 1980 and extends up to the present (Abraham, Medeiros and Kaufmann, 1984; Botti and Abraham, 1988; Tornikoski et al., 1993; 1996).

The existence of very small sources in the cores of quasars was confirmed by the first measurements made with VLBI (Very long Baseline Interferometry, which provided mas resolution. This technique involves two or more radiotelescopes, without any physical connection, separated by hundreds or thousands of kilometers. Besides finding unresolved sources, with sizes smaller than 1 pc, complex sources were discovered, with their structure changing with time. Two of the strongest quasars at radio wavelengths, 3C273 and 3C279, were modeled by the simplest two component model, but structural variations indicated that the the components were separating with superluminal velocities (Whitney et al., 1971; Cohen et al., 1971). These velocities are easy to explain through special relativity, if the emission arises in a jet, with relativistic bulk motion, which forms a small angle with the line of sight.

The temporal evolution of the superluminal components show that their flux density decreases as they separate from the core; in a few cases it first increases when the component is very close to the core, and afterwards it decreases, showing that the source became optically thin. As the components separate from the core, new components are formed. It is believed that the process involves the formation of shock waves, which propagate along the jet. The electrons are first accelerated, and afterwards they lose energy, first by the synchrotron process and afterwards by the inverse Compton and adiabatic expansion (Marsher and Gear, 1985). From the point of vies of single dish observations, the birth of a new component can be seen as a flare, starting at high frequencies (optical and infrared), and propagating to millimeter and radio wavelengths. Observations of variability at 22 and 43 GHz made at Itapetinga allowed the identification of several peaks in the light curves of 3C273 with the formation of new components in the parsec scale jet, detected with VLBI techniques (Abraham and Botti, 1990).

A Mark II VLBI data acquisition system was built in Brazil through a CNPq-NSF agreement, involving Itapetinga and Hystack observatories, and a 10.7 GHz was provided by CALTECH. The participation of Itapetinga in the interferometric observations was very important because it improved the north-south coverage of the u-v plane, especially important for equatorial sources, The first observations of 3C273 were performed in 1984 (Biretta et al., 1985), and repeated several times afterwards, including 3C279. These are the only two strong enough objects that can be observed with good signal to noise ratio. Otherwise, the integration time is limited by the stability of the rubidium atomic clock; the appropriate hydrogen maser clock was, by that time, too expensive for the Brazilian budget. When the VLBI acquisition system changed to MARK III, it also became too expensive, especially the magnetic tape storage system, and the observations were discontinued. The advent of the VLBA was also a factor in this decision, since it somehow provides a better coverage of the north-south baselines.

Here, there seem to be an appropriate place to comment on the difficulties of radioastronomy in Itapetinga during the first decades of operation, not only for the low budget, but also because of market protection, meaning that the acquisition of imported equipment, even computers was very difficult, and sometimes impossible. When these restrictions were lifted, the problem became the opposite, foreign countries, especially the USA, did not allow exportation of high technology, for security reasons.

Despite the observational difficulties, important theoretical work was inspired in the VLBI and single dish variability studies. Interferometric studies along the years showed that the velocities and position angles in the plane of the sky of the different superluminal components remain constant for each component, but can vary by a large amount between components, (Carrara et al., 1993; Abraham et al., 1996). This behavior was attributed to jet precession and applied successfully to several objects: 2C279, 3C273, OJ287, 3C345, 3C120, BL Lac (Abraham and Carrara, 1998; Abraham and Romero, 1999; Abraham, 2000; Caproni and Abraham, 2004a; 2004b). The origin of the precession could be either a black hole system), with an accretion disk not coincident with the plane of the orbit (Romero et al., 2000), or the Bardeen-Peterson effect, produced by the misalignment between the relativistic jet and spin axis of a Kerr black hole (Caproni, Mosquera-Cuesta and Abraham, 2004; 2006a; 2006b; 2007).

Galactic radioastronomy

The decade of 1970 was also important for galactic radioastronomy. Surveys of the galactic plane were made at 408 MHz and 5 GHz, which allowed the classification of the sources in thermal HII regions and non-thermal synchrotron sources (Goss and Shaver, 1970; Shaver and Goss, 1970). These surveys are very important, because many of these regions are not visible at optical wavelengths because of the high extinction. At the same time, H and He recombination lines, representing the transitions between high quantum number states, were observed in the direction of HII regions, and the source distances determined using kinematic methods (Wilson et al., 1970). However, the detection of maser emission in transitions of molecules like OH, H_2O and SiO, was probably the principal discovery of that epoch (McGee et al., 1965; Cheung et al., 1969; Thaddeus et al., 1974). Itapetinga was specially equipped for maser observations, first with the 22 GHz receiver, appropriate for the water maser transition and latter at 43 GHz, for several transitions of the SiO molecule. Several unknown water sources associated with star forming regions and late stars were detected (Kaufmann et al., 1974; 1976; 1977; Scalise and Braz ,1980; Braz and Scalise, 1982). The SiO J=1-0 (v=3 transition was observed for the first time at Itapetinga at several late type supergiants detected (Scalise and Lépine, 1978; Lépine, Scalise and Le Squeren, 1978). The receivers were room temperature superheterodyne systems with a multichannel spectrograph consisting of 45 channels with 100 kHz bandwidth (about 1.3 km s^{-1} velocity resolution at 22 GHz). Weak sources were observed with a cryogenic H maser receiver lent by Haystack, in costly campaigns, since the He cooling system was not closed. Here again, we must emphasize the lack in Brazil of competitive receivers, which were lent by foreign observatories because of their interest in the new southern hemisphere discoveries. Besides new galactic masers we must emphasize the discovery of the first water vapor megamaser, in the galaxy NGC4959 (dos Santos and Lépine, 1979), in the Large Magellanic Cloud (Scalise, Gahm and Sandell, 1981) and the strongly polarized maser in Orion (Abraham et al., 1981; Abraham, Vilas Boas and del Ciampo, 1986; Vilas Boas and Abraham, 1988; Abraham and Vilas Boas, 1996).

In the decade of 1990, a close cycle cryogenic receiver, operating at 22-24 GHz, was acquired from NRAO though a FAPESP grant, which allowed the observation of the NH_3 transitions (Vilas Boas and Abraham, 2000; Caproni, Abraham and Vilas Boas, 2000). The H66α recombination line was also detected towards HII regions, and evidences of non-LTE conditions discovered in some of them; they must be produced in the very high density gas present in ultra-compact regions (Celoni, 1997).

The recent advances in infrared astronomy, with the construction of very sensitive imaging cameras, showed the existence of very young stellar clusters still embedded in their parent molecular cloud, as already predicted by the presence of far infrared IRAS point sources, with colors of ultra-compact HII regions (Wood and Churchwell, 1989) and molecular line emission from high density gas (Bromfman, Nyman and May, 1996). Most of the radio continuum surveys have angular resolution of the order of 4' (Goss and Shaver, 1970; Shaver and Goss, 1970; Haynes, Caswell and Simons, 1978; Griffith and Wright, 1993; Condon, Broderick and Seielstad, 1989; 1991), which is not enough to study individual clusters, or very high resolution (obtained with interferometers, eg. Walsh et al., 1998), in which case only the very compact sources are detected. Itapetinga's 43 GHz detector has a HPBW of about 2', and turned out to be an intermediate tool to detect the embedded HII regions (Barres de Almeida, 2006).

FINAL REMARKS

Radioastronomy in Brazil had a difficult development; it suffered first from difficulties in the acquisition of competitive equipment, due to market protection, first in Brazil and afterwards in the rest of the world. It suffered also, especially in the last decade, for the lack of engineers in the technical staff of Itapetinga. It suffered finally of the hot and humid tropical weather that makes difficult to eliminate atmospheric emission at cm and mm wavelengths. However, the scientific work that can be done with the radiotelescope is still large: we have the whole galaxy to be mapped at 22 and 43 GHz, H recombination lines to be observed at wavelengths at which non-LTE effect can be large, and high density molecular clouds that can be map in the NH_3 and CS transitions.

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