A project for polarimetric observations in single dish with Medicina and Noto 32 m antennas (*)

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Summary. — A project with multidisciplinary characteristics, aimed to implement the possibility of polarimetric measurements in single dish at the VLBI stations of Medicina and Noto, is presented. The project will open a new window on many astrophysical items that may be approached using the already existing instrumentation and facilities of the two Italian radioastronomical stations. We report here some scientific backgrounds, together with some technical evaluations, on which the feasibility of the project is based.

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1. – Introduction

Polarimetric observations at radio frequencies are a powerful and invaluable tool to investigate a large variety of astrophysical phenomena. They are essential, for instance, to study the magnetic field in interstellar and intergalactic space, in stellar systems, interstellar clouds and stellar objects. This project considers, for the moment, only some of the possible studies which could be performed with polarimetric measurements, taking into account the actual configurations of the available receivers at the Medicina and Noto VLBI stations. In preparing the project we kept in mind four desirable goals: accuracy, simplicity, reliability and flexibility. VLBI stations of Medicina and Noto are under the responsibility of the Istituto di Radioastronomia

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(IRA) of the Consiglio Nazionale delle Ricerche (Bologna - Italy), and usually operate in the VLBI Network, apart from a limited activity in single-dish observations. The relevant characteristics of the receivers currently available both at Medicina and Noto VLBI stations are listed in table I.

Considering the large frequency range covered by actual receivers, the implementation of a polarimeter in the IF section of receivers will permit to approach a very large number of astrophysical programs with high efficiency $(S/N)_s$, where S is the scientific advantage and N is the needed effort (funds + man power).

2. – Scientific background

2·1. *Monitoring of the AGN magnetic-field variability.* – Most Active Galactic Nuclei (AGN) are included in monitoring programs at visible, infrared (JCMT) and X (ROSAT) wavebands [1]. Programs to observe the low-frequency (73 cm) variability of AGN are carried on since 1975 by the Radio Astronomy Institute (IRA) of Bologna and many VLBI programs have studied the structure of AGN on parsec scales. The monitoring of the variability of the total radio flux density, together with the variability of intensity and polarization angle of the polarized component, is crucial to better understand the physical mechanisms of the jets.

Models linking the AGN variability at centimetric wavebands with the superluminal compact components discovered with VLBI observations, explain the observations at parsec scale in terms of shocks in relativistic beams. The variability of the flux density is produced by shocks passing through the fluid's surface with. In this phase the flux increases, then adiabatic energy losses produce a decrease of the flux. The model suggests that observed outbursts (both in total flux and polarization) are closely connected with the appearance and the following propagation of compact component in VLBI images. Radio polarimetric measurements could be able to detect such "isolated" shocks, as the very few existing monitoring programs seem to indicate.

2·2. *Measurements of galactic background polarization.* – Recent results of COBE-DMR [2-4] pointed out once more that the quality of Cosmic Microwave Background (CMB) experiments strongly depends on the accuracy in determining the Galactic Background emission (GB). When radiometric techniques are used [5-7], for instance, the linearly polarized component of the GB may seriously limit the sensitivity of CMB measurements, both of spectrum and anisotropy. The only measurements of GB polarization we know so far [8] cover the frequency range 0.408–1.410 GHz and, besides, they are spatially undersampled. For this reason they are not reliable to make models that also apply at higher frequencies and at angular scales < 0.5–1 degrees, characterising a lot of current, as well as future, CMB experiments. From [9] it can be seen that strong polarized structures are present in some regions, such as the North Celestial Pole and regions at high galactic latitude ($b > 30°$), where galactic emission is generally smaller and where most of the experiments to measure CMB anisotropies seem to minimize the galactic foreground contribution. Future space missions to investigate CMB anisotropies on angular scale of $\approx 30'$ using also radiometric techniques [10] may take advantage from more accurate and more frquency extended GB polarization measurements. Since any polarized component of non-galactic origin is, in principle, much lower than the CMB anisotropy [11, 12], a better knowledge of the GB polarization could be, in any case, a good tool to separate fluctuations of galactic origin from the extragalactic ones [3]. There are also experiments in progress to measure the CMB polarization [13]; they require new GB polarization data, more extended in frequency and sky coverage, in order to separate this contribution which is, in this case, the major source of foreground [14].

2˙3. *Investigation into the possibility of TEC evaluation using VLBI equipment.* – It is generally accepted that a satisfatory accuracy in Total Electron Content (TEC) measurements is 10^{16} el/m^2 (1 TEC unit). If this accuracy must be obtained using a polarimeter whose resolution is 0.1 degrees (about 3×10^{-4} cycles), this gives a limit for the maximum usable frequency of the observed radio source (RS). The Faraday rotation Ω (cycle) of the polarization of a signal of frequency f (Hz) propagating through the ionosphere is given by

$$\Omega = 3.86 \times 10^{-6} \times f^{-2} \times M \times \mathrm{TEC}\,,$$

where M (gammas) is the magnetic factor [15].

Introducing in the equation the polarimeter resolution for Ω and 1 TEC unit for TEC, one gets the maximum allowed frequency, which results to be about 2.5 GHz. Using lower frequencies could improve the accuracy. Assuming that the minimum operating frequency of the polarimeter is 1.4 GHz, the accuracy could reach 0.3 TEC units.

Since these measurements seem to provide satisfactory results, it is worth to investigate how to use them.

Inside the range of usable frequencies, at the minimum frequency one full cycle corresponds to 1000 TEC units, while the known highest values of TEC amount at most to some hundreds. Therefore, crossing the ionosphere, the polarization will never rotate more than one cycle, avoiding any phase ambiguity and the necessity of continuous observations needed when using lower frequencies (satellite systems).

If absolute TEC evaluations are requested, the problem of determining the initial polarization must be solved, unless the initial polarization is already known by other ways. The solution of this problem depends on the used method of measurements.

Two methods of measurements can be conceived:

i) The quasi-geostationary method: this relies on the observation of a circumpolar RS such that its elevation angle is greater than 30 degrees. To accomplish this requirement the polar angle of the RS must be smaller than $(\Phi - 30)$ degrees, where Φ is the latitude of the polarimeter. The corresponding ionospheric points at a height of 400 km of such RSs move inside a circle with an average diameter of about 450 km. This corresponds to a region where the ionosphere can be considered, according to the required accuracy, homogeneous and can be easily modelled. It is sufficient to know the initial polarization of only one RS to determine an absolute TEC using any RS in the same region. If some source existed emitting in different bands with the same polarization, it could be easy to find the initial polarization, either if the bands are in the measurement range (1.4–2.3 GHz) or, better, in the case that the higher band (22 GHz) is used, so that its polarization is scarcely affected by the ionosphere.

This technique of observation is very similar to the one carried out using radio beacons on geostationary satellite, as the same geographical area of the ionosphere is sounded. Every observed variation of the polarization can be ascribed to changes in time of the local ionosphere, caused by the normal diurnal variation, by the passage of disturbances and so on. The study of these phenomena would ideally require continuous observations. As this is unpracticable, an effective alternative would be to plan campaigns of continuous sounding lasting at least two weeks repeated five, six times in the year.

ii) The multisources method: observation of non-circumpolar RSs involves the sounding of different regions of the ionosphere, due to the Earth motion. If it is possible to observe sources at different azimuth and elevation (>30 degrees) in a time span short compared to the ionospheric variability, then estimates of TEC and simultaneously of initial polarization can be carried out, assuming a local mapping model of the ionosphere. A reasonably short span of time is, at mid latitudes, 15 minutes. This value results from the experience of evaluating TEC from GPS measurements. Also in this case one observes sources whose directions vary very slowly with time [16].

Both these methods conceived for ionospheric investigation require the observation of RS of fixed, but not necessarily known polarization. The result will provide an empirical model of the ionosphere above the station, and the way to get an absolute calibration, needed to study the sources presenting variable polarization.

2·4. *Polarimetric observations of masers.* – The characteristics of the polarization of maser emission provide a powerful probe to diagnose the physical conditions inside the maser cloud. If the Zeeman splitting is smaller than the linewidth of the maser, as is generally the case for water maser emission, theory predicts that saturated maser should emit linearly polarized radiation. Polarization may be quite large if the Zeeman frequency is larger than the maser stimulated emission rate [17]. Circular polarization is expected if the Zeeman splitting is at least comparable with the linewidth (as is usually the case for OH maser).

The polarization characteristics depend on the relative size of the stimulated emission rate, the decay rate of the maser levels, the Zeeman splitting and thus the magnetic field, the maser bandwidth, and the cross relaxation rate. In any case a full analysis of the problem must deal with: the strong nonlinear nature of the maser amplification, the different growth rate for the different polarization modes, and the statistical nature of the electromagnetic field [18].

Strong polarization (up to 65%) has indeed been observed during and after the Orion maser outburst in years 1980-1988 [19, 20], implying a magnetic field greater than 10 mG, but such studies are still rare.

The Zeeman splitting is important for OH masers, that are usually fully circularly polarized. It is, however, difficult to identify Zeeman line pairs, and thus determine a reliable value for the magnetic field, because the right and left polarized lines originate from different physical regions. Both linear and circular polarization has been detected in SiO stellar masers.

3. – Technical description and evaluations

A prototype of the correlation polarimeter which will operate in the IF section of receivers is already bench-tested at the VLBI station of Medicina (Bologna). The results of the first phase of tests on the prototype are very promising and show that it may be possible to measure polarization angles (γ_{p}) with an accuracy of $\sim 0.1°$, supposing to measure a polarized flux of ~ 0.5 Jy (and based on sensitivities as in table I).

TABLE I. – *Available receivers at Medicina and Noto VLBI stations.*

ν (GHz)	λ (cm)	Polarization	HPBW (arcmin)	T_{sys} (^{a}) (K)		BW (MHz)	ΔS_{min} (mJy s^{-2})	ΔT_{min} (mK s^{-2})
				L	R			
1.4	21	L & R	24.5	65	65	80	73	7.3
1.6	18	L & R	21.5	58	58	80	65	6.5
2.3	13	L & R	18	50	50	160	33	3.9
5	6.5	L & R	7.5	46	52	350	16	2.7
8.3	3.6	L & R	4.9	39	37	400	14	2.0
22	1.3	L & R	2.0	92	95	400	47	4.7

(a) T_{sys} refers to the noise antenna temperature at the zenith, including the atmosphere (L = left-hand polarization, R = right-hand polarization).

To be operative for observations, in any case, the polarimeter needs a complete system able to manage all the operations requested by polarimetric measurements. The realization of a s/w package to send commands to the hardware (h/w) components, as well as to receive, digitalize and store data is in progress. Moreover, since the polarimeter should operate in parallel to the normal operations of the radiotelescope, that is reducing to the minimum the h/w interventions on the receiver chain when switching to polarimetric mode, it requires to be controlled by a dedicated computer.

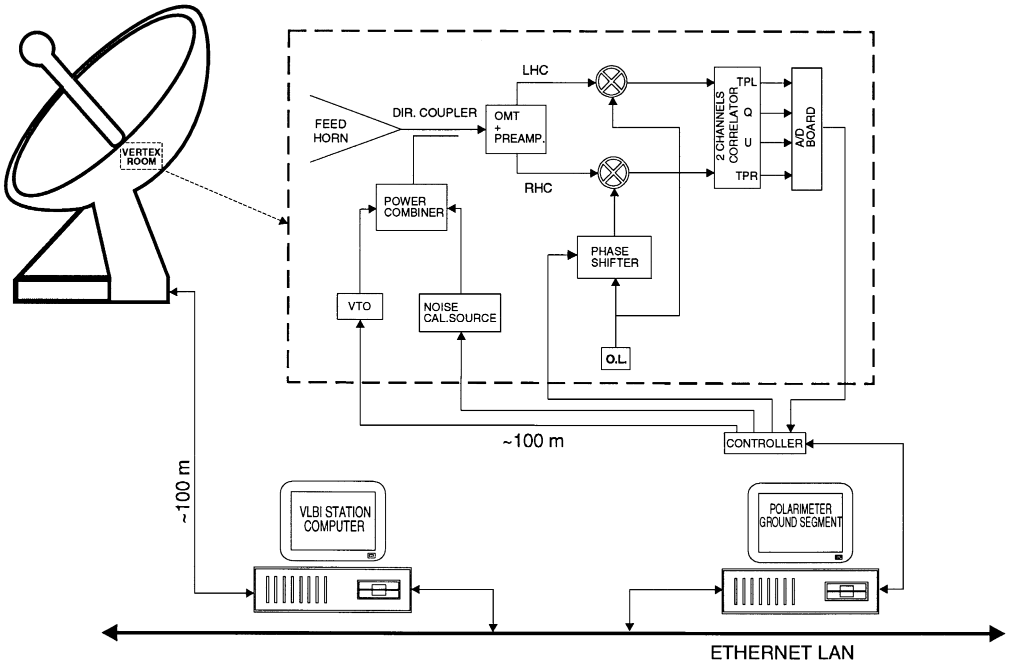

Fig. 1. – Schematic diagram of the overall polarimetric system at the VLBI station of Medicina.

This computer will communicate with the main computer of the VLBI station which controls and executes all the commands regarding radiotelescope, will provide a real-time quick-look of the observations together with the data storage, and will run the observation's programs in polarimetric mode. It provides the user's interface of the whole system, the block diagram of which is represented in fig. 1.

Due to the Faraday rotation in the ionosphere (see subsect. **2˙3** before), polarimetric measurements require to be corrected for this effect, then it will be necessary to account for this by including dedicated procedures in calibration/observation programs.

The project would take two years to be completed, starting from the availability of funds and following this schedule:

First year:

a) integration of the polarimeter prototype in the receiver chain of the VLBI station of Medicina;

b) preliminary tests to define instrumental calibration procedures and Ground Segment (GS) functions;

c) start of the GS development;

d) evaluation/optimization of instrumental characteristics (cross polarization, sensitivity, ...);

e) definition of a set of calibration sources suitable to monitor ionospheric parameters.

Second year:

a) completion of the GS including procedures for observations/calibrations, data acquisition and quick-look analysis;

b) final set-up of observational programs and start of measurements.

As a step of the schedule is successfully completed, it will be implemented also at the VLBI twin station of Noto.

Four institutes will participate in the project and will ensure all the necessary know-how: IRA (Bologna), TESRE (Bologna) and IROE (Firenze) of the CNR, and the Osservatorio Astrofisico di Arcetri (Firenze).

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