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Four years of operation of the VATLY radio telescope: A summary of main results

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Abstract: We present a short summary of the main results obtained using the VATLY radio telescope during the past four years in Ha Noi. It covers the performance of the instrument and observations made on the Sun, on neutral hydrogen in the Milky Way and other weaker sources.

Key words: *radio telescope, radio sources, multipathing, neutral hydrogen, solar physics*

I. INTRODUCTION

The VATLY radio telescope was installed on the roof of the Institute for Nuclear Sciences and Technology in Ha Noi in April 2011. We bought it from CASSI [1], a company in close relation with the Haystack Laboratory and the Massachusetts Institute of Technology. The cost was just below 10'000 USD, which we had collected as gifts from private sources. We were at that time working mostly in cosmic ray physics, in collaboration with the Pierre Auger Collaboration, to study extragalactic cosmic rays at the upper end of the energy spectrum. The motivation for embarking in radio astronomy was the lack of hopeful short range perspectives in cosmic ray physics, following a very fruitful exploitation of the Pierre Auger Observatory in Argentina, and encouragements provided by Pr Nguyen Quang Rieu, who had been promoting astrophysics in Vietnam for many years and had introduced us to the basics [2]. Indeed, at that time, there were only two physicists doing active research in astrophysics in the country, both in radio astronomy, Prs Dinh Van Trung in Ha Noi and Phan Bao Ngoc in Ho Chi Minh City. Radio astronomy, with recent developments in the millimetric and submillimetric domain, is at the forefront of current research. It implies using observations made from major international observatories. For training students at home, it is much better adapted to the Vietnamese tropical sky than optical astronomy, for which observations are very rarely possible. In less than four years, the radio telescope has produced two master theses, two master dissertations and a number of publications in refereed journals. In addition to reports describing the performance and limitations of the instrument, in particular when observing weak sources, they include studies of neutral hydrogen in the disk of the Milky Way, of solar flares and of solar oscillations observed in correlation with a similar telescope located in Australia and now understood as being the result of multipathing from specular reflection on ground. The following pages describe briefly the main results.

II. THE TELESCOPE AND ITS PERFORMANCE

The telescope [3,4] is equipped with a fully steerable parabolic dish, 2.6 m in diameter, remotely adjustable in elevation and azimuth (Figure 1). It is operated at frequencies between 1400 and 1440 MHz. The reflected

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power is collected at the focus by a helical sensor, where it is locally pre-amplified, shifted to lower frequency using standard super-heterodyne, amplified and digitized. Standard data collection consists in a sequence of successive measurements of ~8 s duration each, digitized in the form of a frequency histogram covering ~1.2 MHz in 156 bins of ~7.8 kHz each. This is obtained by stitching together three adjacent bandwidths. Such a typical distribution is shown in Figure 2 left. The 21 cm hydrogen line is clearly seen above a slowly varying continuum. It signals the presence of hydrogen clouds in the field of view and is associated with electron spin flip in the hydrogen atom. The continuum signals the presence of ionized matter and is associated with thermal or "free-free" (bremsstrahlung) emission, including synchrotron radiation from free relativistic electrons accelerated in the interstellar magnetic field. Galaxies such as ours contain many HI clouds and the 21 cm signal of the disk of the Milky Way is particularly strong. On the contrary, the Sun emits exclusively in the continuum (Figure 2 right).

Fig.1. The VATLY radio telescope; left: installation; middle: close up view of the steering gear box; right: the dish and its sensor.

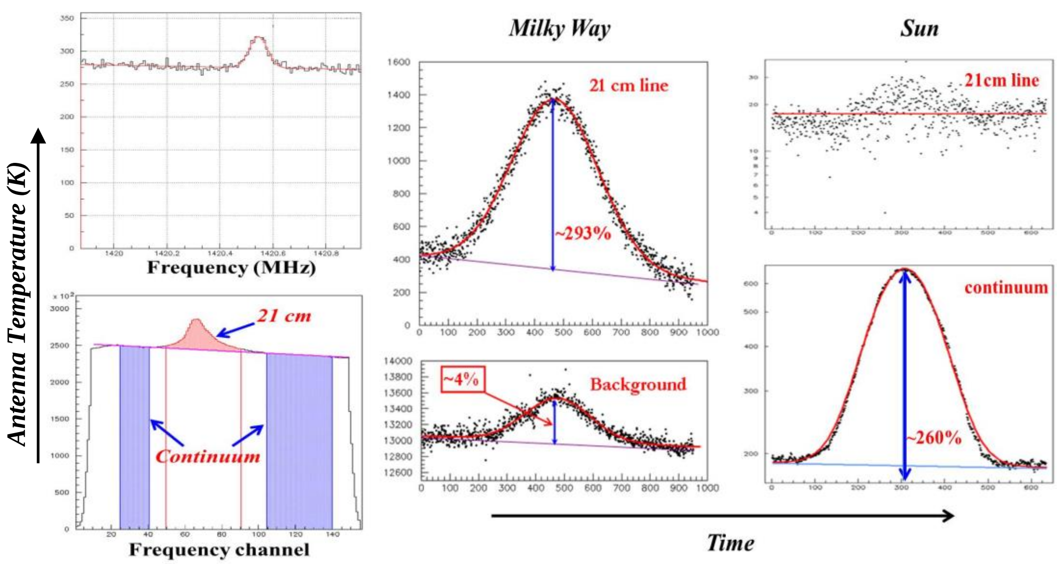

Fig.2. Left: a typical frequency spectrum showing the 21 cm hydrogen line and the underlying continuum (up) and a fit giving their separate contributions (down). Right: drift scans across Sgr A* at the centre of the Milky Way, showing the dominance of the 21 cm line, and across the Sun, showing the dominance of the continuum.

The telescope orientation is remotely adjustable and a small TV camera allows watching the antenna movement from the control room below where a desktop displays the data being recorded and other relevant information. The angular aperture of the main lobe (the "beam") is well described by a Gaussian having a σ of 2.3^o and the pointing accuracy is measured to be 0.22^o in *acos(h)* and 0.11^o in h where a and h are the azimuth and elevation respectively.

Data collected on the Sun, either "on the flight" (i.e. following the source) or in drift scans (waiting on the source trajectory for the source to pass by), have produced detailed measurements of the performance of the instrument: the gain is observed to drop slowly with frequency, by 70 to 130 ppm/kHz depending on the central frequency, and with amplitude, by about 5 ppm per Kelvin of antenna temperature. Small gain variations related to the three-bandwidth structure of the frequency spectra have been measured at the level of 2.5‰±1.5‰. An antenna efficiency factor of ~65% has been measured, meaning a conversion factor of 1.25±0.09 K/kJy in good agreement with measurements performed by the LEARMONTH Observatory (see below).

The sensitivity of the instrument has been evaluated at the level of a few 100 Jy, using data collected on weak sources, such as the Crab and the Moon, as well as from noise studies of the night sky. It is mostly limited by man-made radio-frequency interferences (RFI) and gain instabilities caused, in particular, by temperature variations.

III. THE HI LINE AND ITS MAP IN THE MILKY WAY

Velocity Doppler spectra have been collected along the disk of the Milky Way over three quarters of the galactic longitude. They have been reduced into peaks associated with different clouds of atomic hydrogen (Figure 3 left) and show clear evidence for differential rotation (Figure 3 centre). Given a differential rotation curve, these measurements allow for drawing a map of atomic hydrogen in the Milky Way disk (Figure 3 right) up to an occasional twofold ambiguity. The result [5] is displayed in Figure 4 and compared with the known arm and bar structure of the Galaxy as measured by the Spitzer Space Telescope in the infrared.

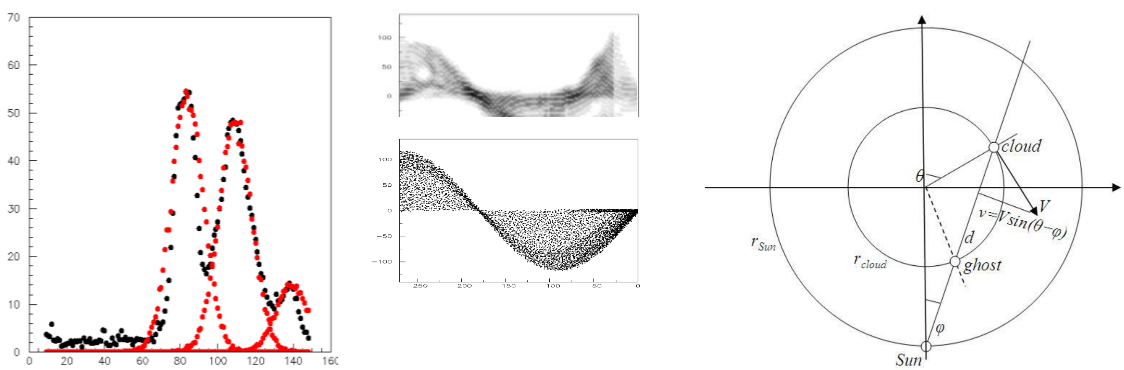

Figure 3. Left: a typical Doppler velocity distribution of the 21 cm line flux density and its decomposition in peaks associated with individual hydrogen clouds. Middle: the distribution of the Doppler velocity (km/s) as a function of galactic longitude as measured (up) and predicted (down); the sine wave is evidence for differential rotation. Right: schematic diagram of the mapping geometry.

Good agreement is achieved with the known rotation curve that implies the existence of a dark matter halo. Indeed, in the absence of dark matter, the recession velocity cannot exceed a well defined quantity that is found to be well exceeded by the data, providing direct evidence for the presence of a dark matter halo at large distances from the galactic centre.

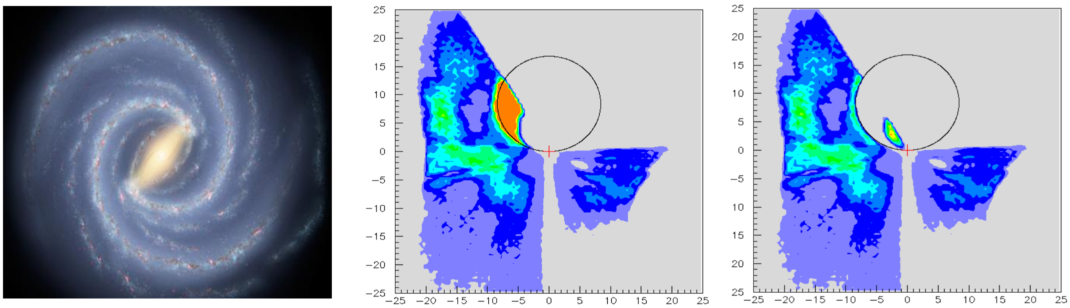

Fig. 4. Measured HI map of the disk of the Milky Way. Left: by the Spitzer Space Telescope in the infrared. Centre and right: using the VATLY radio telescope; the circle centred on the centre of the Galaxy and passing by the Sun is shown in black. Its inside is associated with ambiguous cases, its outside with non-ambiguous cases. Ambiguous cases are displayed separately in the two panels, farther away from the Sun in the middle and closer up on the right.

IV. THE SUN

The Sun, which just went over its maximum of activity, has been tracked for several months. A joint analysis of data collected in 2012 at 1415 MHz with similar data taken by the Learmonth Solar Observatory in Australia (Figure 5 up left) has shown the presence of occasional flares and has given evidence for small mHz oscillations at the percent level simultaneously observed by the two observatories. The presence of a strong correlation (Figure 5, up right) between the periods of oscillations observed simultaneously in Ha Noi and at Learmonth, both in the 5 to 8 min range, was puzzling and seemed to exclude an instrumental origin. Having contacted several experts in solar physics and obtained no hint at a solution, we submitted a report to Solar Physics which was accepted for publication [6]. New data were then collected in 2013 and separate analyses were performed of the Ha Noi and Learmonth oscillations, no longer requiring simultaneity. We then observed characteristic patterns that revealed their instrumental origin, caused by interferences between the direct signal detected in the main lobe of the antenna and its specular reflection on ground detected in a side lobe (Figure 5 middle and lower panels). We were then able to show that this causes the observed correlations between the Ha Noi and Learmonth oscillation periods; essentially, as the period of multipathing oscillations is defined by the velocity of the motion of the source, and as the velocity of Earth rotation is the same in Ha Noi and at Learmonth, the observed periods measured simultaneously by both telescopes have to be correlated. A detailed account of the new analysis and an explicit model of the correlation mechanism have been published in the journal of the Australian Astronomy Society to honour the Australian pioneers of radio interferometry who used a similar multipath mechanism sixty years ago: the principle of the method was to observe a radio source as it rises above the horizon with a single antenna located on top of a cliff above the ocean; the direct wave and its reflection on the water surface interfere and produce interference fringes that allow for considerably improved angular resolution with respect to what was possible at the time. Observations of solar spots, soon followed by observations of various radio sources, had then been reported.

Solar flares observed simultaneously in Ha Noi and Learmonth have been studied and found to reveal interesting features of the response to very large fluxes [8,9,10].

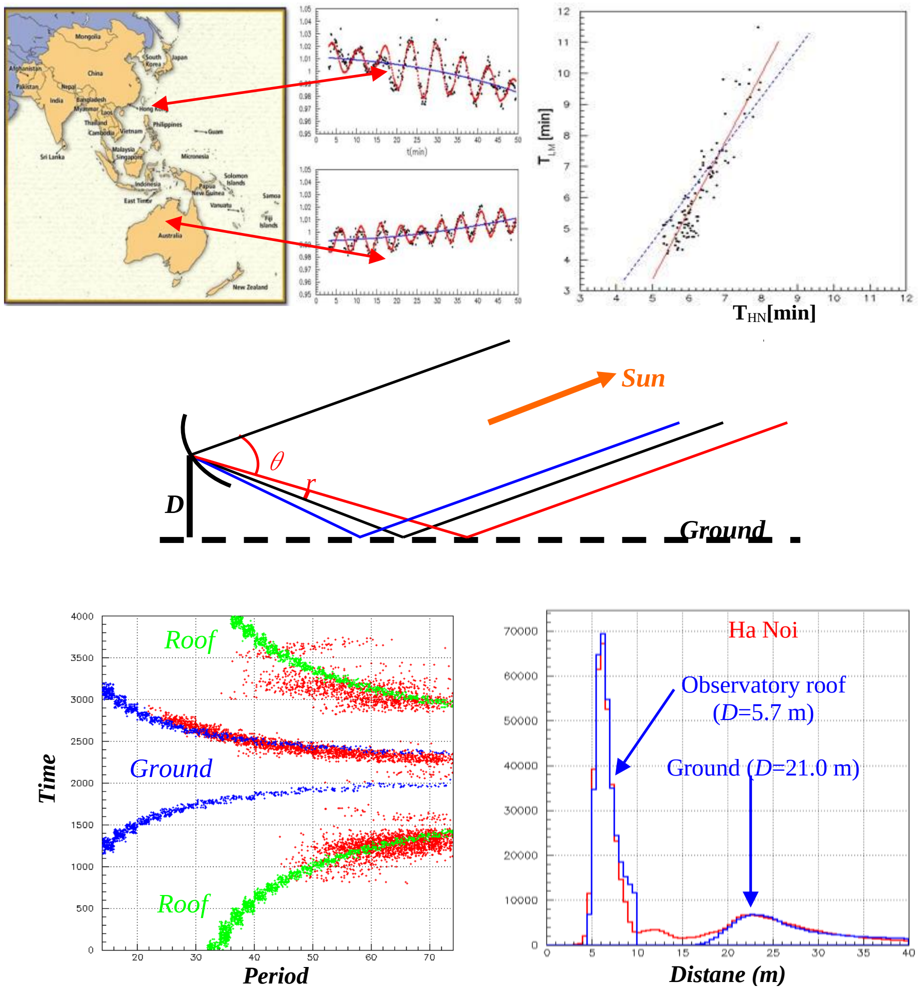

Fig. 5. Top left: location of the Ha Noi and Learmonth telescopes and typical simultaneous oscillations. Top right: correlation between the periods of oscillations simultaneously measured in Ha Noi (abscissa) and Learmonth (ordinate); the red line is a linear fit through the data and the blue line the prediction of the multipath model. Centre: Schematic multipath mechanism between direct detection and specular reflection on ground. Bottom left: typical pattern observed in Ha Noi between the period of oscillations (abscissa, full scale of ~10 min) and time in the day (ordinate, full scale of ~9 hr). Bottom right: distribution of the distance between the antenna and the reflecting surface measured in Ha Noi (red) and predicted by specular reflection (blue). In both lower panels reflections on ground and on the roof of the laboratory are indicated.

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REFERENCES

[1] Custom Astronomical Support Services, Inc., Boston, Mass, USA; http://www.haystack.mit.edu/edu/undergrad/srt/index.html.

[2] P.T. Anh, *Radio Detection of the Sun*, Master thesis presented at the Institute of Physics, Hanoi, (September 2010).

[3] N.V. Hiep et al., *The VATLY radio telescope*, Comm. Phys. Vietnam 22/4, 365 (2012).

See also:

N.V. Hiep (on behalf of VATLY), Presented at the Second Academic Conference on Natural Science for Master and PhD students from Cambodia, Laos, Malaysia and Vietnam, Vinh, Vietnam, 11-15 (October 2011).

P.T.Anh (on behalf of VATLY) presented at the 7th Annual Conference of the Thai Physics Society, May 9-12, Phranakhon Si, Ayutthaya, Thailand, (2012).

N.V.Hiep (on behalf of VATLY) presented at the 1st Southeast Asian Young Astronomers Collaboration (SEAYAC) Meeting, November 5-9, Puerto Princesa City, Palawan, Philippines, (2012).

[4] N.T. Phuong et al., *The VATLY radio telescope: performance study*, accepted for publication in Comm. Phys. Vietnam.

[5] N.V. Hiep et al., *Mapping atomic hydrogen in the disk of the Milky Way*, Comm. Phys. Vietnam. Vol.23, 107-119, No 2 (2013).

N.V. Hiep, *Observation of the 21 cm sky using the VATLY radio telescope*, Master thesis, presented at Vietnam Institute of Physics, (2012).

[6] N.V. Hiep et al., *Radio Observation of Solar-Activity-Related mHz Oscillations*, Sol. Phys. 289, 939-950, 3 (2014).

N.T. Phuong (on behalf of VATLY) presented at 2nd South East Asia Young Astronomer Colaboration, November 19-22, Bandung, Indonesia (2013).

P.T. Nhung (on behalf of VATLY) presented at the Conference "Windows on the Universe", August 11-17, Quy Nhon, Vietnam, (2013).

[7] P.N. Diep et al., *Correlated Oscillations Due to Similar Multipath Effects Seen in Two Widely Separated Radio Telescopes*, Publications of the Astronomical Society of Australia, 31, e029 doi:10.1017/pasa.24, (2014).

N.T. Phuong (on behalf of VATLY), presented at Workshop on Astronomy and Astrophysics in Vietnam, April 7-11, Institute for Nuclear Science and Technology, Ha Noi, Viet Nam.

P.N. Diep (on behalf of VATLY), presented at 12th Asia – Pacific Region IAU Meeting, Daejeon, Korea, (2014).

[8] N.T Phuong, *Solar and other observations using VATLY radio telescope*, Master thesis, in preparation.

[9] B.V. Tuan, *A study of the six major solar flares recently detected from Ha Noi and Learmonth at 1415 MHz compare with other frequencies*, summer Master internship, presented at University of Science and Technology of Hanoi, (September 2014).

[10] N.H. Phuong Thanh, *A study of 34 solar flares detected by Hanoi and Learmonth telescope at 1415 MHz between 2012 and 2014*, summer Master internship, presented at University of Science and Technology of Hanoi, (September 2014).