Canadian VLBI

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1 Introduction

Very Long Baseline Interferometry (VLBI) combines radio telescopes separated by large distances, and correlates the signals offline to form visibilities and ultra high resolution images.

Canada was a pioneer half a century ago, achieving the world's first VLBI between the Penticton 26m and the Algonquin 46m in 1967. This achievement was recognized with a IEEE milestone[1] and documented by the NFB[2].

After funding cuts, VLBI stopped on Canadian soil at the end of the century. Since the 2010 LRP, a new window of opportunity for pulsar VLBI scintillometry opened. A group centered at Toronto developed new receivers for ARO and DRAO, and has successfully achieved fringes at 150 MHz with the LOFAR telescope in Europe and GMRT in India[3].

2 Science

Pulsar radiation is scattered by the interstellar plasma, and reaches the earth by multipath propagation, as shown in Fig 1. Recent VLBI observations (Brisken et al 2010, ApJ 708, 232) enabled the constructive use of the scattering screen as a giant billion km baseline telescope to measure 50 picoarcsecond motions in the pulsar magnetosphere (Pen et al 2014, MNRAS, 440, 36).

The use of the ISM as a coherent VLBI telescope is called pulsar VLBI scintillometry. This high precision imaging opens a range of new pulsar and ISM science, and Canada is uniquely positioned to exploit this opportunity.

We list several new science areas enabled by picoarcsecond astrometry.

[1]http://www.ieeeghn.org/wiki/index.php/Milestones:List_of_IEEE_Milestones

[2]http://www.cita.utoronto.ca/~pen/Video/VIDEO_TS/VTS_01_1.VOB

[3]http://www.theglobeandmail.com/news/national/researchers-give-algonquin-observatory-a-second-life/article13707523/

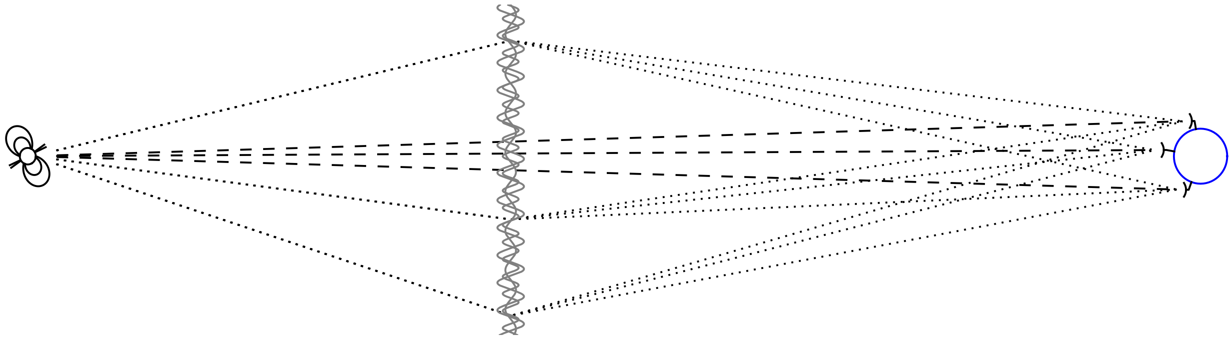

Figure 1: Utilization of ISM as coherent radio telescope, resolved by VLBI on earth.

2.1 Binary Pulsar Orbital Parameters

Many of the most interesting pulsars are in binary systems, including most millisecond pulsars. Timing gives the line of sight orbital information, and is often degenerate with inclination angles. VLBI scintellometry maps an absolute angular scale to the orbit, and results in potentially precise inclinations, distances, pulsar masses, etc.

2.2 Pulsar Magnetosphere Structures

Pulsar radio emission mechanisms have remained enigmatic over decades of research, in large part due to lack of new data to constrain models. Km accurate maps of pulse components has the potential to rejuvenate this poorly understood field of astrophysics.

2.3 Pulsar Gravitational Wave Timing Arrays

Without pulsar distances, a detection of gravitational waves through the pulsar timing arrays (PTA) are thought to represent a stochastic background of several black hole binaries, whose position on the sky is not reconstructable. When distances to the pulsars are known, the sensivity of the PTA doubles due to coherent addition of the pulsar intrinsic timing term. The angular resolution improves to arc minutes, instantly deconfusing all sources, and pinpointing their position on the sky (Boyle and Pen 2012, PRD, 124028). Scintillometry has the potential to measure precise distances and enable the coherent use of the PTA.

2.4 ISM Structure

The nature of the ISM structures which cause the pulsar scattering has become controversial in the past decade. Hill et al 2003 (ApJ, 599, 457) discovered highly regular structures in the pulsar secondary spectrum, and the recent Brisken et al VLBI images confirm the picture that scattering is often dominated by a small number of discrete co-linear lenses.

The bending angle leads to an inference regarding their physical size if one assumes the line-of-sight size to be comparable to the transverse size. The implied free electron density of $\sim 100/\mathrm{cm}^3$ has led to proposed new physical phenomena, including strange quark nuggets (Perez-Garcia et al 2013, PhLB, 727, 357), evaporating dark matter (Walker 2001, ApSS 278, 149), and magnetic reconnection sheets (Pen and Levin 2014, MNRAS 442, 3338). The traditional picture of turbulent diffraction appears not reconcilable with the VLBI data.

Monitoring of the VLBI screens over several months would test the nature of small scale structures in the ISM, and perhaps shed light on the density and magnetic features on AU scales.

3 National Access

VLBI is intrinsically a collaborative and international effort. The pulsar scintillometry has received substantial directorial telescope time support from Jodrell Bank, Effelsberg, GMRT, LOFAR, MWA, DRAO, and scientist collaborative involvement from Astron (Netherlands), Max-Planck Radioastronomie (Germany) and Curtin University (Australia).

The newly opened global VLBI pulsar windows has already drawn users from different communities. The CHIME experiment in Penticton has also used the DRAO-ARO-VLBI to implement pulsar polarization calibration. Canada has pulsar groups at McGill and UBC, which have expressed in principle interest in VLBI scintillometry. At Toronto, the co-authors represent three different units: CITA, Dunlap and DAA. Dr John Antoniadis came to Toronto as Dunlap fellow in large part for opportunities in the nascent scintillometry technique.

A major resource of equal importance to the hardware facilities is the software pipeline. This has contributions from M. van Kerkwijk, PDF's Aaron Berndson, PhD students Liam Connor, Rober Main, Siqi Liu, undergrads N. Price-Jones and A. Bahmeyer. It is open-source, accessible nationally and internationally. Dr F. Kirsten, based in Perth (Australia) recently joined the growing team. The rapid growth is likely to continue for the second half of the decade.

4 Opportunities

VLBI provides an opportunity for substantial Canadian international impact, especially at low frequencies. Below 300 MHz, the ARO and DRAO are the largest available telescopes in the western hemisphere, providing unique opportunities for VLBI with LOFAR and GMRT.

The unique requirements of VLBI require modest staff support at NRC. Specifically, telescope operator support is requested to support remote operation of the John A. Galt 26m telescope in Penticton during VLBI observations.

The university VLBI initiative is primarily funded by industrial collaboration grants developing new technology with Thoth Technology Inc. A strong endorsement by the MTR for this modest cost initiative enables the pursuit of NSERC CRD and provincial OCE funds which are otherwise not generally accessible to astronomy.