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Finding Extremely Compact Sources Using the ASKAP VAST Survey

Hayley E. Bignall [1], *David L. Jauncey* [2], *James E. J. Lovell* [3], *Roopesh Ojha* [4], *Cormac Reynolds* [1]

[1] *ICRAR/Curtin University of Technology*

[2] *CSIRO Australia Telescope National Facility*

[3] *School of Mathematics & Physics, University of Tasmania*

[4] *US Naval Observatory*

Contact author: Hayley E. Bignall, e-mail: `H.Bignall@curtin.edu.au`

Abstract

VLBI observations of intraday variable (IDV) quasars found in the MASIV (Micro-Arcsecond Scintillation-Induced Variability) 5 GHz VLA Survey of 500 flat-spectrum sources in the northern sky have shown that these sources are extremely compact, often unresolved, on milliarcsecond scales, and more core-dominated than their non-IDV counterparts. VAST: an ASKAP Survey for Variables and Slow Transients, proposes to observe 10,000 square degrees of southern sky daily for 2 years in the VAST-Wide survey component. This is expected to reveal of order 30,000 compact sources brighter than 10 mJy showing refractive interstellar scintillation (the cause of centimeter-wavelength IDV) at the survey frequency of about 1.4 GHz. Many of these sources may be suitable astrometric calibrators for VLBI at higher frequencies.

1. Introduction

Sufficiently compact radio sources will have their measured intensity modulated due to the effects of scattering in the inhomogeneous, ionized interstellar medium (ISM) of our Galaxy [1, 2, 3]. For observing frequencies between $\sim 1 - 5$ GHz, a source will typically show refractive interstellar scintillation (RISS) if a significant amount of its flux density is in a compact component of angular diameter ~ 0.1 mas or smaller, with the angular size cutoff for a source to show refractive or weak scintillation decreasing towards higher frequencies. For sufficiently compact extragalactic radio sources, the largest amplitude modulations may be observed close to the transition frequency between weak and strong scattering, which is typically a few GHz for sources observed at moderate to high Galactic latitudes, increasing toward lower Galactic latitudes.

The present paper discusses the use of interstellar scintillation as a means of selecting the most compact extragalactic radio sources as potential VLBI calibrators. Section 2 summarizes some results of the Micro-Arcsecond Scintillation-Induced Variability (MASIV) VLA Survey of the northern sky at 5 GHz, as well as results of VLBI follow-up of sources observed in the MASIV Survey. As outlined in Section 3, VAST: an ASKAP Survey for Variables and Slow Transients, will scan the southern sky daily at 1.4 GHz, to discover transient and variable sources. Variability observed in VAST is expected to reveal a large number of candidate astrometric calibrators suitable for higher frequency VLBI observations. This will be potentially important for future VLBI science, especially given the current relatively sparse density in the southern hemisphere of suitable calibrators for phase referencing, astrometry, and geodesy observations.

2. Results of the MASIV VLA Survey and VLBI Follow-up

The MASIV Survey [4] observed approximately 500 compact, flat-spectrum radio sources spread over the northern hemisphere to measure their short-timescale radio variability. The initial Survey comprised four sessions with the NRAO Very Large Array (VLA) observing continuously for 72 hours (96 hours for the 2002 September session), which were spread at ~ 4 month intervals over the course of a year. The observations were performed at 5 GHz, close to the expected transition between weak and strong scattering where the amplitude of ISS is expected to be largest, with the VLA split into 5 subarrays each observing a different declination range. “Strong” and “weak” source samples were observed, with the weak sources selected to have average flux densities ≥ 0.1 Jy, and the strong sources ≥ 0.5 Jy. The final analysis included 443 sources which were unaffected by confusion and unresolved with the VLA in all configurations [5].

Over half of the observed sources showed intraday variability (IDV) in at least one epoch. MASIV showed a clear Galactic dependence of IDV, with a strong correlation between variability amplitude and Hα emission measure along the line-of-sight, extracted from the published WHAM Survey [6]. This result demonstrates unequivocally that IDV is linked to the Galactic ISM; i.e., IDV is predominantly interstellar scintillation. The MASIV Survey was able to detect variability on timescales of hours to days. The observed root-mean-square (RMS) fractional variability on a 2-day timescale was typically 2-10%. Figure 1 shows an example of MASIV data for a scintillating source.

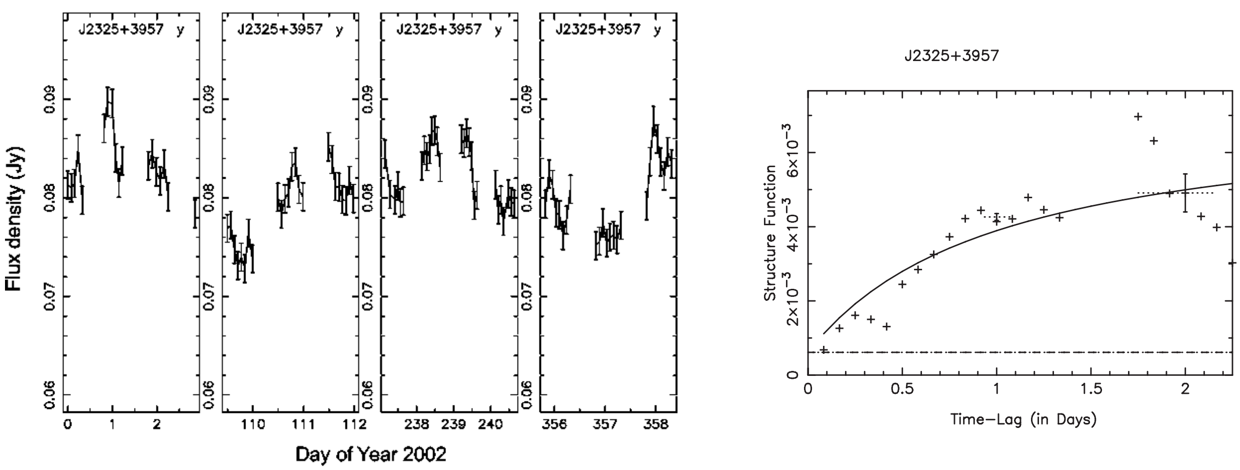

Figure 1. Example of a scintillating source observed in the MASIV Survey, from Lovell et al. 2008 [5]. Left: Flux density versus time for J2325+3957. Right: Structure function calculated from the combined data shown in the left-hand panel. The solid line shows a simple model fit used to characterize the timescale and amplitude of the variations.

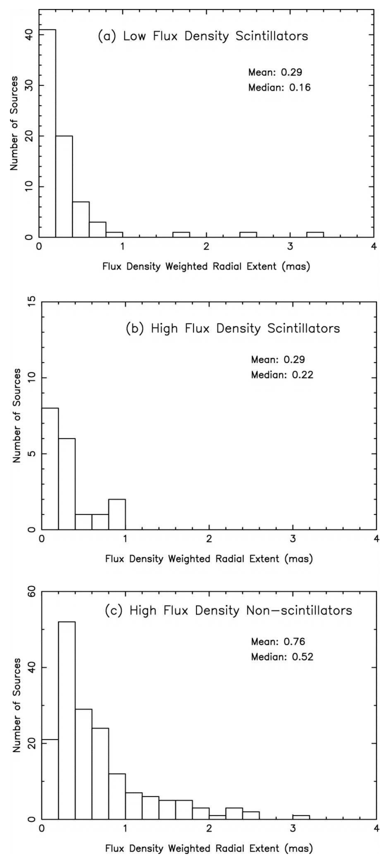

Figure 2. Distribution of flux density-weighted radial extent for samples of scintillating and non-scintillating MASIV Survey sources [7].

Follow-up observations of MASIV Survey sources with the NRAO Very Long Baseline Array (VLBA) [7, 8] showed that scintillating sources on average are more core dominant than non-scintillating sources. Furthermore, the overall angular size of scintillating sources is significantly smaller than that of non-scintillators. This is illustrated in Figure 2, from [7], which shows the 8.4 GHz flux density-weighted radial extent for low flux density scintillators, high flux density scintillators, and non-scintillators selected from the MASIV Survey. The flux density-weighted radial extent, R, is defined as

$$R = \frac{\sum_i S_i r_i}{\sum_i S_i},$$

where r_i is the radius at which the ith CLEAN component has flux density S_i. A Kolmogorov-Smirnov test rejects a common parent population for the scintillating (both low and high flux density) and non-scintillating sources at the 99% confidence level. These results imply that scintillating sources are more compact and core-dominated than non-scintillating sources, and hence are potentially good candidates for astrometric and geodetic calibration.

3. VAST: an ASKAP Survey for Variables and Slow Transients

3.1. The Australian Square Kilometer Array Pathfinder (ASKAP)

The Australian Square Kilometer Array Pathfinder is a next-generation radio telescope currently under construction in Western Australia, led by CSIRO ATNF. It is planned that ASKAP will comprise an array of 36 antennas each 12 m in diameter. The system temperature design goal is 35 K. The specified operational frequency range is from 0.7 to 1.8 GHz, with an instantaneous bandwidth of 300 MHz. ASKAP will use phased array feed technology to provide 30 independent beams, each of 1 square degree, yielding a 30 square degree field-of-view at 1.4 GHz. The specified maximum baseline is 6 km, and full cross-correlation of all antennas is planned. In the first five years of observations, anticipated to start in 2013, it is planned that at least 75% of ASKAP time will be devoted to large surveys. After an open international competition, ten major surveys have been selected to proceed to a design study phase.

3.1.1. ASKAP "BETA" Phase

The Boolardy Engineering Test Array (BETA) will consist of six antennas operating at the Murchison Radio-astronomy Observatory (MRO) by 2011. It is planned that BETA will have the same wide field-of-view as the full ASKAP array, but lower sensitivity due to having only $1/6^{\mathrm{th}}$ of ASKAP collecting area. BETA is therefore potentially useful for large-area sky monitoring surveys for relatively bright sources.

3.2. The VAST Survey

VAST is one of the ASKAP Survey Science Projects now beginning a design study. VAST aims to discover and investigate variable and transient phenomena occurring on timescales of 5 s and longer; e.g., flare stars, intermittent pulsars, X-ray binaries, magnetars, extreme scattering events, intraday variables, radio supernovae, and 'orphan' afterglows of gamma ray bursts. VAST will probe hitherto unexplored regions of phase space to search for new classes of radio transient sources. The planned VAST Survey includes wide, deep and Galactic plane components. The VAST-Wide component proposes to observe 10,000 square degrees of southern sky (400 pointings) daily for two years, requiring 6 hours of ASKAP time per day. The total time requested is thus 4380 hours. This assumes 40 seconds per pointing plus overheads, resulting in an RMS sensitivity of 0.5 mJy/beam according to ASKAP specifications.

Based on radio source counts [9, 10], approximately three flat-spectrum radio sources with flux density $S > 10$ mJy are expected per square degree. Based on the findings of the MASIV Survey, a large fraction of these would be expected to show RISS at 1.4 GHz, implying component angular sizes typically no larger than ~ 0.1 mas. While only the most extreme variables would be detected at a 10 mJy flux density limit, VAST should be able to reliably detect variations down to a few percent in sources with total flux density $S \geq 0.1$ Jy.

Due to the strong frequency dependence of the timescale of ISS (expected to be close to ν^{-2} in the refractive scintillation regime, where ν is the observing frequency), timescales of variability at 1.4 GHz are expected to be an order of magnitude longer than those at 5 GHz. Thus, instead of the variability with typical timescales of days observed in the MASIV Survey, the VAST Survey will observe variability with characteristic timescales of weeks to months, except for a very small fraction of sources scintillating through scattering screens in the local ISM which will exhibit shorter characteristic timescales [11]. As was shown in early studies [12], active galactic nuclei which show RISS generally have "flat" or inverted radio spectra and can be expected to be very compact also at higher frequencies where astrometric observations are ideally performed. Moreover, higher frequency VLBI observations avoid the most severe effects of interstellar scattering, such as refractive apparent position shifts and angular broadening, which would decrease astrometric accuracy.

4. Conclusions

Only the most compact, core-dominated sources exhibit interstellar scintillation. The ASKAP VAST Survey is expected to find thousands of good candidate astrometric calibrators in the southern hemisphere. The detection of scintillating sources will also help to provide potential phase-reference calibrators in the vicinity of any transients detected, for rapid VLBI follow-up, e.g., to measure proper motions of Galactic transients and pin down their origin.

5. Acknowledgements

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