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Statistics of the MASIV 5 GHz VLA Scintillation Survey

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We are undertaking a large-scale VLA 5 GHz variability survey of the northern sky searching for rapid intra-day variability. From four epochs of observations spread over a year we find 56% of the flat-spectrum sources showed significant variability on time-scales from hours to days, with many sources varying episodically on only one epoch during the year. We find that the weaker sources show more frequent variability as well as fractionally larger amplitude variability. Fewer sources were detected at high Galactic latitude, demonstrating that inter-stellar scintillation is the principal mechanism responsible for this IDV. We also see a significant dependence on spectral index with the flatter and more inverted sources more frequently exhibiting scintillation.

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1. Introduction

Over the past decade considerable evidence has accumulated demonstrating unequivocally that inter-stellar scintillation (ISS) in the turbulent, ionized inter-stellar medium (ISM) is the principal mechanism responsible for the intra-day variability (IDV) seen in many flat-spectrum AGN at cm-wavelengths. This arises principally from the measurement of a significant time delay in the pattern arrival times of the three rapid scintillators, PKS0405-385 [1], PKS1257-326 [2] and J1819+3845 [3], at widely spaced radio telescopes. In addition, an annual cycle [4] is seen in the variability characteristics of a number of IDV sources.

A source must be small to scintillate; in the weak scattering case for frequencies greater than about 5 GHz, the source angular size must be comparable to or smaller than the angular size of the first Fresnel zone, implying microarcsecond angular sizes for reasonable screen distances of tens to hundreds of pc. The long-lived nature of the scintillation seen in some sources, B0917+624 for example [5] [6], implies that such compact components are relatively long-lived despite their small sizes. ISS therefore probes AGN angular scales and brightness temperatures at cm-wavelengths that are unachievable at cm-wavelengths with ground-based VLBI and approaching the limits of space VLBI.

2. The MASIV Survey

The principal objective in undertaking the MASIV survey was to produce a sample of at least 100 to 150 scintillators. Previous IDV surveys had sampled of order 100 sources and found roughly 15% exhibited IDV. Our aim was to be able to undertake reliable statistical investigations, for example to explore their sky distribution and hence to explore the structure of the turbulent ISM, and to do so, needed such a large sample size [7] [8]. We started with a core sample of 525 flat-spectrum sources, the maximum number that could be monitored every two hours with the four VLA sub-arrays.

A further objective was to investigate the behaviour of both weak, ~ 100 mJy, and strong, ~ 1 Jy, sources to compare the incidence of IDV in both. The inverse Compton brightness temperature limit suggests that ISS would be more common with decreasing flux density. We also expected to find more of the very rapid scintillators like PKS0405-385, PKS1257-326 and J1819+3845, since two of the three had been found serendipitously. The presence of a larger population would signify the presence of nearby turbulent clouds.

The observations took place over four 72 hour sessions during January, May and September 2002 and January 2003. This was done to ensure that sources would not be missed because they were in the “slow” part of their annual cycle. A follow-up session was undertaken in January 2006. All of our observing time was allocated during periods of VLA reconfiguration.

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3. Classification of Variability

We tried a variety of classification schemes based on simple Chi-squared tests, but, because Chi-Squared is not an ordered statistic, and we were always able to find variables by inspection that were being missed by Chi-squared. We were left with little alternative but to undertake a “by-eye” examination to classify sources as variable or otherwise. This was done independently by two of us. We adopted a conservative null hypothesis that “each source was considered as non-variable unless otherwise demonstrated”. The number of disagreements was small, and any source where we could not agree was classified as non-variable.

The removal of 43 sources that showed structure or confusion left a total of 482 sources. Our variability classification revealed that 177 sources showed no significant variability on any of the four epochs, 98 showed variability on one occasion, 90 on two occasions, 61 on three and 56 showed variability each time we looked at them. The large fraction of sources that varied on multiple epochs firmly established our classification process as accurate and reliable. We also found that the majority of sources varied on time scales of longer than days or more; it would have required longer observing sessions to establish reliable time-scales.

An immediate question to ask is just how many sources varied on one or more of the four epochs? As four separate measurements were made it is necessary to correct for “false positives”, namely sources that were essentially non-variable, but which were mistakenly classified as variable on one occasion out of the four. Assuming the miss-classification uncertainty to be 5%, this reveals that a total of 56% of sources exhibited ISS on at least one occasion. This is a remarkably high fraction and larger than found for any previous survey.

As the chance of one miss-classification is small, it follows that the chance of miss classifying a source twice is very small at 1.3%. This allows a clear separation; we classify those sources for which we found no variation on each of the four epochs as “non-variable”, and those for which we found two or more epochs of variability as “variable”. This gives us two large and reliable samples each of approximately 200 sources, where one acts as a control sample for the other. Each was drawn with the same selection criteria and covers the same overall area of sky.

Another remarkable result is the large number of sources that were found to vary episodically, that is on only one of the four epochs. Such a high level of episodic variability had not been seen before in previous variability surveys. The remarkably rapidly variable source PKS0405-385 was one of the first to show such strong episodic behaviour with intermittent episodes lasting a few weeks to months, followed by long periods of inactivity [9]. It remains unclear if such behaviour is due to changes in the source or in the ISM. Also unanticipated (at least by us) was the lack of any new fast variables, indicating a singular lack of nearby clouds.

4. Galactic Latitude Dependence

We applied the test of comparing the fraction of scintillators at high and low Galactic latitudes to search for a Galactic latitude dependence. This asks the simple question “are the latitude distributions of the variables and non-variables the same?” A contingency test dividing the sources into low and high latitude samples at 40 degrees, shows that with 98% confidence the two distributions are indeed different. There are more scintillators in the low latitude sample than in the high latitude sample, so providing unambiguous evidence for inter-stellar scintillation as the origin for the variability seen in the ensemble of sources. This is in excellent agreement with the latitude dependence found in the GBI data [10].

5. Redshift Dependence

A literature search yielded redshifts for 154 of the MASIV sources. In addition we are undertaking our own redshift measurements with the Nordic Optical Telescope and with the Palomar 5 m telescope [11]. A plot of the redshift distributions of the scintillators and non-scintillators reveals a marked deficit of scintillators at redshifts in excess of two [8]. While the deficit is statistically highly significant, we are nonetheless concerned about a variety of possible selection effects, Malmquist bias in particular, as the redshifts from the literature are predominantly for the optically brighter objects. In addition, we note that for the BL Lac objects the redshift distributions appear to contain only a very small fraction of objects with redshifts above two. The redshift dependence, and possible causes, is discussed in more detail in an accompanying paper [12] in this volume.

6. Summary

- 56% of sources varied on one or more epochs, with many sources varying episodically on only one epoch during the year.
- We found significant Galactic latitude dependence in that there are fewer scintillators at high latitudes, confirming ISS as the principal mechanism responsible for IDV at cm-wavelengths.
- Rapid, inter-hour variable sources are rare, implying a low density of nearby clouds.
- We found significant spectral index dependence with more scintillators amongst the flat and inverted spectrum population.
- We find a significant decrease in the fraction of scintillators with increasing redshift above 2.

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References

[2] Bignall, H. E. et al., *Rapid Variability and Annual Cycles in the Characteristic Timescale of the Scintillating Source PKS 1257-326*, 2003, ApJ, **585**, 653

[3] Dennett-Thorpe, J., & de Bruyn, A. G., *Discovery of a Microarcsecond Quasar: J1819+3845*, 2000, ApJ, **529**, 65

[6] Jauncey, D. L., & Macquart, J.-P., *Intra-day variability and the interstellar medium towards 0917+624*, 2001, A&A, **370**, L9

[1] Kedziora-Chudczer, L., et al., PKS 0405-385: *The Smallest Radio Quasar?* 1997, ApJ, **490**, L9

[9] Kedziora-Chudczer, L., *Long-term monitoring of the intra-day variable quasar PKS 0405-385*, 2006, MNRAS, **369**, 449

[7] Lovell, J. E. J., et al., *First Results from MASIV: The Microarcsecond Scintillation-induced Variability Survey*, 2003, AJ, **126**, 1699

[8] Lovell, J. E. J. et al., *MASIV: The Microarcsecond Scintillation-Induced Variability Survey*, 2007, ASPC, **365**, 279

[4] Macquart, Jean-Pierre, & Jauncey, David L., *Microarcsecond Radio Imaging using Earth-Orbit Synthesis*, 2002, ApJ, **572**, 786

[5] Rickett, B. J., et al., *Annual Modulation in the Intraday Variability of Quasar 0917+624 due to Interstellar Scintillation*, 2001, ApJ, **550**, L11

[10] Rickett, Barney J., et al., *Interstellar Scintillation Observations of 146 Extragalactic Radio Sources*, 2006, ApJ, **637**, 346

[11] Pursimo et al. in preparation

[12] Rickett et al., *Cosmological decrease in brightness and angular broadening in the ionized inter-galactic medium detected in the MASIV quasar survey*, this volume