Astrophysical Phenomena Revealed by Space VLBI
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The Origin of Intra-Day Variability

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Abstract

We report simultaneous flux density measurements at 4.86 GHz of the Intra-Day Variable (IDV) source PKS 0405−385 made with the VLA and the ATCA. These show a significant time difference between the arrival times of the variability patterns at the two telescopes, as expected if interstellar scintillation (ISS) is the origin of the IDV.

1 Introduction

Radio variability was discovered 35 years ago when the first quasar, 3C273, was found to double in intensity in 3 years at 8 GHz (Dent 1965). These observations led directly to the development of VLBI, to Space VLBI, to VSOP and to this Symposium. Super-luminal expansion was discovered and bulk relativistic motion (Rees 1966) found to explain the observed brightness temperatures of up to $\sim 10^{13}$ K, in excess of the inverse Compton limit (Kellermann and Pauliny-Toth 1969). And the variability proved to be intrinsic to the sources.

Twenty years later a new kind of variability, IDV, with a time-scale not of years, but of days, was discovered (Heeschen 1984). Recent observations find sources with time-scales from days to hours (Quirrenbach et al. 1989; Kedziora-Chudczer et al. 1997; Dennett-Thorpe and de Bruyn, 2000). If the variations are intrinsic, causality arguments imply nanoarcsecond sizes and brightness temperatures of 10^{18} K to 10^{21} K. While bulk relativistic motion was an acceptable explanation for brightness temperatures up to 10^{13} K, it is less so for 10^{21} K. Interstellar scintillation (ISS) was proposed as an alternative to avoid such extreme conditions (Heeschen and Rickett 1987).

If the variations are intrinsic, the pattern of variations should be the same when seen at two widely spaced radio telescopes. However, if ISS is the cause, the motion of the irregularities in the interstellar medium (ISM) can cause the patterns to arrive at different times at the two telescopes.

2 Observations

The source PKS 0405−385 was chosen since it shows large amplitude variations on a time-scale as short as an hour (Kedziora-Chudczer et al. 1997). In November 1998 it returned to an active state (Kedziora-Chudczer et al. 1998), and the observations were made on December 9 as the source set at the VLA in the USA and rose at the ATCA in Australia. The observations were centred at 4.86 GHz where both telescopes offer optimum performance. The VLA was in C configuration and separate sub-arrays were used at 1.4, 8, 15, 22 and 43 GHz to determine the overall spectrum. The ATCA was in a 750 m configuration with antenna CA02 excluded because of shadowing at low elevations.

We saw strong variability with very similar patterns at both telescopes, and were fortunate to observe a clear minimum, since an inflection is essential for precise alignment of the patterns. Close examination of the flux density curves shows that the pattern arrived first at the VLA then, ~ 2 minutes later, at the ATCA. Using the time-delay analysis of Pelt et al. (1996) we find a time difference of 140 seconds. A series of Monte Carlo trials was made to estimate the uncertainty. After 1000 trials we estimate the time difference as 140 ± 25 seconds. Such a large time difference, much greater than the light travel time difference, shows that the variations are not intrinsic to the source, and gives strong support to an ISS origin for IDV.

3 Discussion

A feature of the variability curves is that the flux density difference changes sign systematically before and after the inflection. Both the gain-elevation and atmospheric absorption corrections are such that they serve to increase the ATCA measured flux densities before the inflection and to also increase the VLA flux densities after the inflection. Thus, if the observations show a time delay *before* these corrections are applied, this delay can only *increase* after application of gain-elevation and atmospheric absorption corrections. Re-analysis of the observations, but without these corrections, yielded the smaller difference of 96 ± 25

seconds, and with the same sign. The Monte Carlo histogram is shown in Figure 1, where the strong peak around 100 seconds can be seen, with no differences smaller than 50 seconds.

Thus the observed time difference is clearly real. For the 10,000 km telescope separation the time difference of 140 ± 25 seconds corresponds to a velocity of $75 \pm 15\,\text{km s}^{-1}$, in good agreement with the $\sim$50 km s^{-1} typical of the ISM.

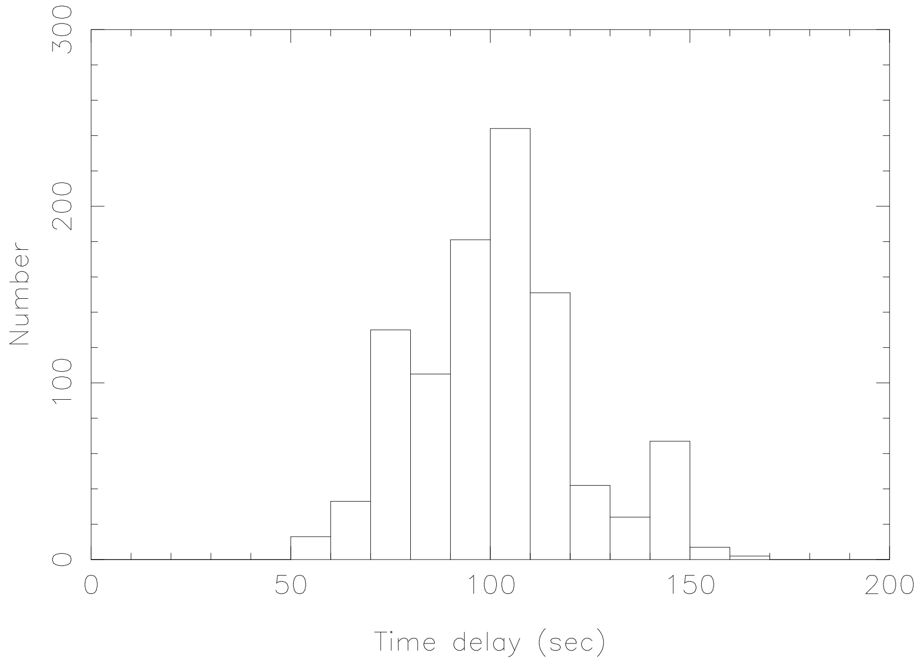

Figure 1: Plot of the VLA − ATCA Monte Carlo time difference, with no flux density corrections

4 Conclusions

The measured time difference shows that the intra-day variability observed in PKS 0405−385 is not intrinsic to the source, but rather is best explained by interstellar scintillation. A microarcsecond source angular size component is implied with brightness temperatures of $\sim 5 \times 10^{14}$ K. It seems natural, following these results for PKS 0405−385, to assume an ISS origin for IDV in general.

These results have significant implications for future Space VLBI missions, since IDV studies show that many sources possess microarcsecond angular size components at cm wavelengths. These components are generally weak, so that high sensitivity will be necessary on the space telescope, along with full polarization capability, since several IDV sources show both strong linear and circular polarization (Macquart et al. 2000; Kedziora-Chudczer et al. these proceedings). Retaining an 18 cm capability will be an important tool to investigate both source structure as well as properties of the ISM. Finally, ISS will ultimately limit achievable angular resolution at cm wavelengths.

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