

Chapter 7

Conclusions and Scope for Further Work

But leave the Wise to wrangle, and with me
The Quarrel of the Universe let be:
And, in some corner of the Hubbub coucht,
Make Game of that which makes as much of Thee.

For in and out, above, about, below,
'Tis nothing but a Magic Shadow-show,
Play'd in a Box whose Candle is the Sun,
Round which we Phantom Figures come and go.

Rubáiyát of Omar Khayyám, translated by Edward Fitzgerald

7.1 Summary of main findings

An investigation of centimetre wavelength variability in selected samples of compact, flat-spectrum radio sources has been presented in this thesis. Most sources have been optically identified as quasars or BL Lac objects, and hence fall into the “blazar” category, a term used to describe the phenomenon of a radio-loud AGN with a jet pointed toward us at a small angle to the line-of-sight.

Chapters 3 and 4 presented radio observations and analysis for a sample of blazars which were targets of the BeppoSAX X-ray satellite. All of these sources were found to be variable, at most or all of the observed frequencies, on time-scales of months to years, and sometimes on shorter time-scales. Typically, larger amplitude variability was observed towards higher frequencies. Opacity effects are sometimes evident in the light curves, in the sense that observed outbursts peak first at high frequencies, and at later times and with lower amplitudes toward lower frequencies. The linearly polarized flux density generally shows much greater fractional variability than the total flux density, indicating that much of the polarized emission comes from very compact regions in the source. All observed sources have flat radio spectra, yet there is significant correlation between average spectral index and observed variability. Sources tend to be most variable when the spectrum is optically thick at the observed frequencies. Much of the

observed long-term variability behaviour is consistent with outbursts occurring due to shocks forming in the inner jet which is opaque to radio emission, and subsequently propagating out until they are seen at longer wavelengths. Notably some BL Lac objects do not show this frequency dependence, but rather all observed frequencies vary simultaneously, which is consistent with findings of other studies (e.g. Aller, 1999).

Inverted radio spectra are characteristic of very compact sources, and these are also the sources likely to be most affected by interstellar scintillation (ISS). In modelling cm-wavelength variability of extragalactic radio sources, both intrinsic and extrinsic effects need to be considered. ISS is not just a low-frequency phenomenon but is extremely important at the frequencies observed here, 1–10 GHz, since they are close to the transition frequency between weak and strong scattering where the amplitude modulations resulting from scintillation are often greatest. ISS in the regime of weak scattering can produce very rapid variations in observed flux density, and a number of new intraday variable sources have been discovered as a result of the work presented in this thesis. Sources which are highly variable on long timescales are likely to also scintillate, however some scintillating sources do not show extreme long-term variability. This suggests that ISS is not only dependent on source properties, but may also depend strongly on the structure of the local ionised interstellar medium of our own Galaxy (Chapter 6).

ISS is potentially a powerful tool for probing the sub-pc scale structure of AGN, providing angular resolution of microarcseconds, much higher than currently achievable with any other technique, including even space VLBI. The serendipitous discovery of very rapid IDV in PKS 1257–326 (Chapter 6) provided an extremely valuable opportunity to show unequivocally that the rapid variability is due to ISS, and to test the techniques of using scintillation as a probe of both source structure and the local ISM.

For sources with slower scintillation time-scales (Chapter 5), it is more difficult to characterise the variability in a typical observing session, and hence more difficult to extract information on the scintillation process and the *annual cycle*. Longer datasets (several days or more) are required to obtain a reasonable number of independent samples of the scintillation pattern. The very rapid scintillation observed in a few sources is probably due to very nearby, localised scattering material in the line of sight. The proximity of the scattering screen relaxes the constraint on source size, i.e. the nearer the screen, the larger the source which can scintillate through it.

Results of the investigation of scintillation-induced variability, its use as a probe of microarcsecond-scale source structure, and the connection with intrinsic source variability, in particular for PKS 1257–326, are arguably the most new and interesting scientific results presented in this thesis. ISS studies of extragalactic radio sources open a new window on the structure and physics of these sources, and on the distribution of ionised material and turbulence in the local ISM.

7.2 Scope for further work

There is much further analysis to be done on the data presented in this thesis. Of particular interest is to analyse in more detail the scintillation in total and polarized flux density for the data presented in Chapter 5, in order to constrain the microarcsecond-scale polarized structure of these sources, and to further investigate possible “annual cycle” effects in the characteristic time-scales. A number of the sources show evidence for significant intrinsic variations on time-scales of months, especially in linear polarization, and this may considerably influence the scintillation pattern. Disentangling scintillation and intrinsic variability, especially in polarization, in many cases may not be straightforward.

Continued monitoring of the rapid scintillator PKS 1257–326 is also ongoing, and will show what effect, if any, the long-term outburst observed in this source is having on the scintillation. If there is evidence for no change in the scintillating component, this suggests that the outburst is occurring in a separate region of the jet which is expanding rapidly compared with the scintillating “core”. It is notable that a number of IDV sources are remarkably long-lived. High resolution VLBI observations may help to determine what is happening in the compact jets of these sources. Many of the scintillating sources are part of the International Celestial Reference Frame (e.g. Ma, 1997) and are being observed with improved resolution (compared with data presented in Chapter 3) at 2.3 and 8.4 GHz. Thus, a comparison of microarcsecond and milliarcsecond scale structure and evolution will be possible for a number of sources in the near future.

The realisation that ISS is the principal physical process responsible for centimetre wavelength IDV suggests that a large-scale scintillation survey may address many questions regarding both source microarcsecond structures and properties of the ISM not otherwise accessible. Previous IDV surveys have been restricted to the strongest sources. The two weakest IDV sources known, J1819+3845 (Dennett-Thorpe & de Bruyn, 2000) and PKS 1257–326 (Chapter 6), were found serendipitously and are also by far the most rapid, long-lived scintillators. Are there many other such rapid scintillators, then?

The large scale, 5 GHz Micro-Arcsecond Scintillation-Induced Variability (MASIV) survey recently undertaken with the VLA (Lovell et al., 2002, 2003) is expected to provide answers as to the distribution of scintillators over the sky. Unlike the observations presented in this thesis, which were of small collections of individual sources, MASIV involves a large, well-defined sample of 700 flat spectrum radio sources, covering the whole northern sky. Assuming that the extragalactic sources are distributed uniformly, the observed distribution of 100 or more scintillators may shed light on the distribution of scattering material throughout the northern Galaxy. In particular, the presence of new fast scintillators can reveal the presence of nearby scattering material. Furthermore, once the annual cycle distribution becomes known for these sources, then the overall distribution of the velocity of the ISM would be expected to follow.

For the sources themselves, the survey results and follow-up observations should lead directly to an understanding of the scintillation dependence on flux density, spec-

tral index, optical identification, redshift, luminosity, VLBI structure and evolution, and so on. Moreover, considerable information on the brightness temperature distribution may be expected as the properties of the scattering process become better understood.