7
Observation planning

Interferometric observations need to be planned in advance, because observing time on an interferometer is a scarce resource. This planning is often carried out in the context of a competitive proposal scheme like that operated by most research telescopes. The typical process involved is that potential observers submit proposals to a 'time-allocation committee' or similar body, this body ranks the proposals and the most highly ranked proposals are given time.

The criteria for ranking the proposals can be somewhat subjective, but usually involve a combination of the technical feasibility of the proposed observations and the likely scientific value of the information that will result from them. In order to be highly ranked, proposals must address both of these aspects, so developing such a proposal requires expertise in two areas: familiarity with a relevant science field to understand where the gaps in knowledge are and an understanding of the ways in which different kinds of interferometric observation can provide critical information to fill these gaps.

This chapter looks at the interaction between the scientific and technical aspects of an interferometric observing proposal, with the aim of highlighting the most important areas to consider. The details of writing a competitive astronomy proposal are beyond the scope of this book, but an online search for 'how to write an observing proposal' turns up many useful links on the topic.

7.1 Example proposal

The material in this chapter will be illustrated in part through an example proposal for the VLTI, which was awarded observing time in August and September 2012. The science background to the proposal is that of Mira variables, named after the prototype star of the class otherwise known as Omicron Ceti. The name Mira is latin for 'wonderful' or 'astonishing', a reference to its regular appearance and disappearance from the visible sky; pulsations in the star cause large changes in brightness on periods of a few hundred days.

Many Miras exhibit hydrogen emission lines in their spectra, thought to be signatures of shocks that accompany the pulsation of the star. The passage of these shocks may influence many of the physical conditions in the extended atmosphere of Miras but details of the locations and geometries of these shocks are poorly constrained. Interferometry has the required angular resolution to image these shocks and so could potentially cast a light on shocks and their roles in Mira atmospheres. The details of what kind of observations would best achieve this aim will be discussed in later sections.

7.2 Target selection

The subject of any astronomical observation is a selected object or class of objects that are of scientific interest for some reason. To be a suitable target for an interferometric observation the objects must pass a few additional tests.

7.2.1 Angular size

The angular scales of the objects, and especially the features of the objects which are of interest, need to be in an appropriate range. It is clear that targets which are known to be too small to be resolved by any available interferometer will be of little interest, as in these cases the visibility information can be deduced without needing to use any interferometer time: the visibility will be unity on all observable baselines.

The angular resolution of an interferometer is given approximately by

$$\Delta\theta_{\mathrm{res}} \sim \frac{\lambda}{B_{\mathrm{max}}}\,\mathrm{radians} \approx 200\frac{\lambda/\mu\mathrm{m}}{B_{\mathrm{max}}/\mathrm{m}}\,\mathrm{milliarcseconds}, \tag{7.1}$$

where B_{max} is the maximum baseline in the interferometer. Current interferometers have maximum baselines in the 200–400-m range so targets typically need to be bigger than about 0.2 milliarcseconds to be viable candidates for interferometric observation.

Less obvious is the fact that targets which are too large are also not good candidates for interferometric observation. One reason is that the structure on scales large enough to be accessible on single telescopes is typically easier to image using these systems than with an interferometer.

There will always be targets which are large enough for the target as a whole to be resolved by single telescopes but having structure on smaller scales appropriate to interferometic observations. In such cases there still remain a number of problems.

One of these is related to the fact that the source visibility for any given object typically falls off with baseline. From the examples in Section 2.2 it can be seen that the characteristic baseline at which the visibility falls by half is given approximately by

$$B_{\rm half} \sim 200 \frac{\lambda/\mu{\rm m})}{\theta/({\rm milliarcseconds})}\,{\rm m} \tag{7.2}$$

for an object of angular size θ.

The shortest baselines available on most interferometers are greater than 2 m. Thus, for observing wavelengths of order 1 μm and targets larger than about 100 milliarcseconds in size, the visibility will be low on all baselines observed. This low visibility has two important consequences: first, the signal-to-noise ratio (SNR) of the visibility measurements will be low, especially if the source is faint, which means that fringe tracking may not be possible and so the object may not be observable. Secondly, image reconstruction will be compromised because the region of the Fourier plane which has the most signal, i. e. the high regions of the source visibility function that occur predominantly at low frequencies, is not sampled. This low-frequency flux is said to be 'resolved out' as it is essentially 'invisible' to the interferometer and this missing flux can cause problems in image reconstruction, especially if it accounts for the majority of the flux in the image.

A related issue for large objects is the interferometric field-of-view discussed in Section 2.4.3 and given by

$$\theta_{\rm FOV} \sim 200 \frac{\lambda/\mu{\rm m}}{\Delta B/{\rm m}}\,{\rm milliarcseconds}, \tag{7.3}$$

where ΔB is a measure of the 'typical' gaps in baseline sampling. There will usually be a gap in the sampling at low frequencies due to the issues of telescope spacing mentioned above, and for similar reasons there will typically be gaps in Fourier coverage at high frequencies of similar size. If these gaps are of order 2 m or more then observing objects which subtend angles larger than about 100 milliarcseconds at wavelengths of order 1 μm could result in ambiguities in the image because of Fourier undersampling.

7.2.2 Brightness

Chapter 6 explains why interferometers have difficulties observing objects fainter than a given limiting magnitude. These magnitude limits come in three forms: limits to the adaptive optics (AO) systems on each telescope; limits to the fringe acquisition and tracking; and limits to the SNR of the science data. Each of these limits relates not only to the total flux from the object but also to the angular size of the region from which this flux emerges: if this region is too big, then the object needs to be correspondingly brighter.

In the case of the AO system, the magnitude limit relates to the flux from a region compact enough to allow the wavefront sensor to work properly. Typically this size is of order an arcsecond or so across. If the target is diffuse so that it has a significant fraction of its flux on scales larger than this then usually it is better to use an off-axis star as a wavefront reference, as it is often the case that the wavefront sensor simply does not work on diffuse objects, no matter how bright they are. Particularly troublesome are binary stars with separations of a few arcseconds as the wavefront sensor may randomly switch from tracking one star to tracking the other or track at a point in between the two.

7.2.3 SNR estimation

In the case of the fringe tracking and science data, the flux limits relate to the SNR of the fringe data. If the SNR is too low in the fringe tracker then the zero-OPD position cannot be found and/or tracked and so no useful science data can be taken. If the fringes can be found in the fringe tracker but the SNR is too low in the science instrument, then the science data will be of limited value.

An acceptable value for the SNR is dependent on the application. For fringe trackers the SNR of the fringe-tracking signal, be it the fringe phase for cophasing or the group delay for coherencing, has to be greater than about 2 for tracking to work reliably. This SNR needs to be reached after an averaging time that is less than the time it takes for the quantity being tracked to change by a significant amount; this can be a few milliseconds or a few seconds depending on the type of tracking desired.

For the science instrument the acceptable SNR value depends on what precision of constraint is needed for the given science. At the low end, there are relatively few applications which can make use of data where the *averaged* SNR is less than about 2 or so; typical requirements are SNRs of 5–10 at the minimum while for detecting low-contrast objects, such as faint companions to bright objects, the SNR may need to be hundreds or even millions.

The SNR *in a single exposure* can be less than unity if many exposures are averaged. For example, with a 10-ms exposure time the SNR of the incoherently averaged data will be 100 times larger than the per-exposure SNR if

100 s of data are averaged. As a result per-exposure SNRs of 0.1 are acceptable because they can result in final SNRs of 10.

Several formulae allowing the calculation of SNRs for different observables such as the power spectrum and bispectrum are given in Chapter 5. To use these formulae often requires knowledge of the seeing, the interferometer throughput, the read noise of the detector and many other factors. Luckily, for most instruments the SNR has been calculated for a reference case (typically a limitingly faint source of a defined type), and so determining whether a given observation can be achieved at an acceptable accuracy requires only an understanding of the *scaling* of the SNR with different parameters.

The formulae will scale differently for different noise regimes, for example atmospheric-noise-dominated versus read-noise-dominated versus photon-noise-dominated. For bright objects, the SNR is atmospheric-noise-limited and independent of the source flux. For fainter objects, the limiting source of noise is detection noise of one form or another. In this case the SNR depends not only on the flux from the object but also on the fringe visibility. The fringe visibility is proportional to the source visibility function on the baselines being observed so flux limits are often quoted for an unresolved source, where the source visibility is unity on all baselines. As most sources of interest are resolved, the magnitude limit needs to be reduced by an amount depending on the predicted source visibilities.

For read-noise-limited or background-noise-limited observations, Equation (5.28) shows that the SNR of the fringes on a given baseline is proportional to the coherent flux. For some interferometric instruments, the limiting magnitude is therefore quoted as a coherent flux or 'correlated flux', computed by multiplying the source flux by the source visibility on the baseline in question. The correlated flux is often quoted as a 'correlated magnitude':

$$m_{\mathrm{corr}} = m - 2.5\log_{10}(V), \tag{7.4}$$

where m is the magnitude of the object in some waveband and V is the object visibility in that waveband.

7.2.4 Surface brightness

An important concept relating the ideas of the previous two subsections is that of *surface brightness* (known in optics as *spectral radiance*). The apparent brightness or flux of an object is the power received from the object per unit collecting area per unit of frequency bandpass. The surface brightness of a particular region of an object is the flux received from that region divided by the solid angle subtended by the region at the location of the observer. Conversely, the flux is the surface brightness integrated over the total 'angular area' of the object: the flux is what is usually measured by a telescope that is unable to resolve a given object. Astronomers typically measure flux in janskys (Jy), where $1\,\mathrm{Jy} = 10^{-26}\,\mathrm{W/m^2/Hz}$, and so surface brightness can be measured in Jy per steradian (Sr).

Importantly, the surface brightness of a given region does not change as the object is moved away from the observer (providing the intervening medium is transparent), because the solid angle subtended by the region decreases at exactly the same rate as the flux received from the region decreases. Thus, if the surface brightness of an object is known, the angular extent of an object can be estimated from the measured flux from the object without knowing the distance to the object or its physical size.

If the object is a star or other object which can be modelled as a black-body emitter, then the surface brightness of the object can be estimated if there is information about the temperature of the emitter. The surface brightness at frequency ν of a black body at temperature T is given by the Planck radiation law:

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/(k_\mathrm{B}T)} - 1}. \tag{7.5}$$

Thus, knowing the flux and the temperature of a target allows the angular size to be estimated and hence the range of appropriate baselines to be determined.

This technique can be used, for example, in the planning of observations of M-type giants and supergiants. These are favourite targets for interferometric observers partly because they are bright and have relatively large angular sizes. To observe these at a wavelength of $1.6\,\mu\mathrm{m}$ using an interferometer such as CHARA whose minimum baseline is around 30 m and maximum baseline is about 330 m implies selecting targets with angular sizes of between about 1 and 11 milliarcseconds. These supergiants have typical temperatures of about 3500 K, and so Equation (7.5) predicts a surface brightness of $8 \times 10^{-9}\,\mathrm{W\,m^{-2}\,Hz^{-1}\,Sr^{-1}}$ at a wavelength of $1.6\,\mu\mathrm{m}$.

The solid angle subtended by a disk of angular diameter $\Delta\theta \ll 1$ radian is approximately $\pi\Delta\theta^2/4$ steradians, and so stars of diameter 1 and 11 milliarcseconds will have fluxes of about 15 and 1800 Jy, respectively. The flux of a zero-magnitude star is about 1020 Jy in the H-band (Bessell *et al.*, 1998) and so these fluxes correspond to H-band apparent magnitudes of −0.6 and 4.6, respectively. There are dozens of M giants with H-band magnitudes brighter than −0.6; these need to be excluded from the target list because they are too large for observation with these baselines.

7.2.5 Mira example

Mira variables are even cooler than M giants and supergiants and so for a given brightness have even larger angular sizes. The prototype of the class known simply as Mira (o Ceti), is amongst the brightest and has an angular diameter of around 30 milliarcseconds. Putting this into Equation (7.2) shows that baselines of less than 13 m are required to adequately sample the low-frequency portion of the visibility function at a wavelength of 2 μm. The shortest VLTI baselines available at the period of the proposal were around 11 m and so were adequate.

In the chosen instrumental configuration (the AMBER instrument on the VLTI in HR–K mode, see below), the correlated magnitude limit was quoted as $K_{\text{corr}} = 5.5$. The Mira prototype has a K-band magnitude of -2.5; since Mira is resolved on the chosen baselines, a typical fringe visibility can be assumed to be of order 0.1 and so from Equation (7.4) its correlated magnitude is $K_{\text{corr}} = 0$, well inside the limit.

In order to achieve the quoted magnitude limit on the dispersed fringes the VLTI fringe tracker FINITO is required to allow long exposures (typically a second or more) on AMBER. FINITO has difficulty tracking on sources with H-band visibilities of less than about 5%, and so with a resolved source like Mira it is possible that the tracker would not work.

An alternative would be to record fringe data without the tracker using short exposures. No magnitude limit for this mode is given in the official documentation, but one can be estimated from the $K_{\text{corr}} = 6$ magnitude limit for short exposures in the low-resolution LR–K mode. The high-resolution mode has spectral channels which are 400 times narrower, and so an estimated correlated magnitude limit for short exposures in the HR–K mode is $K_{\text{corr}} \approx 6 - 2.5 \log_{10}(400) = -0.5$. Thus, the Mira observation would be marginal in this mode except on baselines where the source visibility is larger than the estimated value of 0.1.

Finally, the tip–tilt correction system on the VLTI has a magnitude limit of $V = 11$. Mira is highly variable in the V-band with a magnitude that oscillates between $V = 2$ and $V = 9.5$; even at its faintest the tip–tilt correction will work.

7.3 Wavelength and spectral resolution

The question of which waveband to observe a given object in depends on both the target physics and the characteristics of the available interferometric instruments. The aspects of the target physics which are important depend in part on the astrophysical question to be answered. For example, if velocity information or information about the emission from particular molecular or atomic species is required, the wavelengths to observe centre around relevant spectral emission or absorption lines in the source in question.

In other cases, the temperature of the feature of interest is relevant; for example, if it is required to make an image of the thermal emission from dust around a much hotter star, the contrast between the dust emission and the emission from the star will be most favourable at wavelengths near to the peak of the black-body curve at the temperature of the dust. For example, in dust discs around young stars, the inner rim of the dust will be at the sublimation temperature of the dust, perhaps 1500–2000 K. The peak of the black body in this case will be at a wavelength of around 2 μm, signifying that the near-infrared H and K bands are optimal. The cooler outer regions are better observed at longer wavelengths. Conversely, when scattering rather than thermal emission is to be observed, shorter wavelengths are often to be preferred.

Instrumental characteristics include the availability of suitable instruments working at a given wavelength; related to this is the sensitivity of these instruments. Few instruments work at the blue end of the visible spectrum because the sensitivity is so poor at these wavelengths (mainly due to the severity of the seeing) that there are few targets available. Similarly, there are few instruments targeting the mid-infrared because of the problems due to high levels of thermal background radiation.

Another instrumental factor is the availability of suitable baselines. If the highest angular resolution is needed this tends to favour using shorter wavelengths as the resolution is inversely proportional to the wavelength. Conversely, if the object is relatively large for the baselines available, going to longer wavelengths can help.

7.3.1 Mira example

In the case of the example observing proposal, the shocks are most evident in the emission lines of hydrogen. These lines have velocity dispersions of about 60 km s^{-1}, and so a spectral resolving power of 5000 would allow the line emission and the continuum to be separated. The hydrogen lines at visible wavelengths, for example Hα and Hβ, show a strong contrast with the stellar emission, but the only interferometric instrument with the required spectral resolution at visible wavlengths at the time was the VEGA instrument on CHARA, and the CHARA shortest baseline was around 30 m – much too long for objects of the size of Mira. Aperture masking on an 8-m class telescope using narrowband Hα filters would have been more appropriate but no system operating at the correct wavelengths was accessible for this programme. In the end the observing programme was targeted on the near-infrared Brγ line: although the contrast of this line with the continuum is poorer than for Hα, the HR–K mode of the AMBER instrument gave access to this line at an appropriate spectral resolution (R=12 000) and appropriate angular resolution for this target.

7.4 Baseline selection

Section 7.2 has already made the point that targets need to be selected based on the baseline range available; however, having selected the target, the choice of baselines within the range needs to be made. Ideally, one would observe the target on as many baselines as are available, but this can be prohibitive in terms of observing time and so the baselines which offer the most useful information should be prioritised.

The long baselines offer the highest resolution but the fringe visibility modulus tends to decrease with increasing baseline, and so if the baseline used is too long the SNR of the data may be too low to be of any use. Shorter baselines are needed to sample the low-spatial-frequency power in the object; a rule of thumb to estimate the shortest baselines to be included is given in Equation (7.2).

Adequate sampling of intermediate baselines is also required, depending on the field-of-view as given by Equation (7.3). With most current interferometers, achieving this level of sampling is difficult, but may not be necessary. As discussed in Chapter 9, it may be sufficient to sample the visibility at about N different points in the (u, v) plane where N is the number of free parameters in a physically plausible model of the source. In the case where the object can be modelled as a small number of point sources, N corresponds to the number of 'filled pixels' in the image; that is, the number of elements in an image pixellated at the resolution of the image which contain significant flux.

In such a case it is still essential to ensure that the N (u, v) samples are chosen to give a good diversity of coverage of the (u, v) plane in terms of both baseline length and the position angle of the baseline with respect to the source. Clearly, the use of Earth-rotation synthesis, i. e. observing the same source with a given pair of telescopes at different times of night, can help with this; choosing observation times spread evenly throughout the night can maximise the diversity with the minimum use of observing time: observations of multiple objects can be interleaved while waiting for the Earth to rotate.

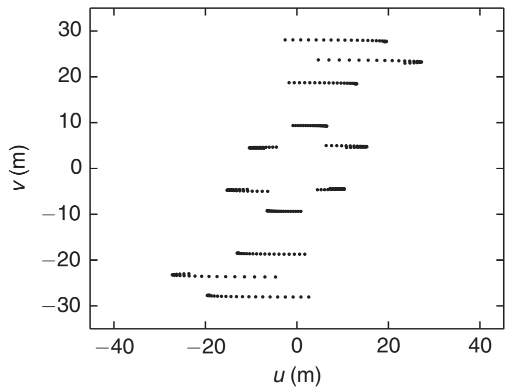

Figure 7.1 Baseline coverage tracks for observations of Mira (o Ceti) using the VLTI A0-B1-C2-D1 quadruplet of telescopes. The tracks shown are the coverage if Mira is observed at all elevations above 30°.

7.4.1 Mira example

The choice of baselines for the Mira observation was restricted by the available telescope positions for the semester of observations. A fixed number of layouts of the four VLTI auxiliary telescopes, known as ‘quadruplets’, were offered. Only the most compact of these, the A0-B1-C2-D1 quadruplet, allowed access to a baseline short enough to be inside the central lobe of the visibility function. It can be seen from Figure 7.1 that observations with this quadruplet will sample a good range of baseline lengths, but the position angle coverage of the (u, v) plane will be restricted. This means that circularly symmetric models can be well constrained, but making a model-independent image could be difficult.

7.5 Calibrator selection

A critical component of any interferometric observation is the observation of one or more calibrator stars immediately before and/or after the target observation. These stars serve to calibrate any systematic effects on the interferometric observables, particularly the power spectrum but also in some cases the closure phase and differential phase.

Calibrators need to have an object visibility function which can be predicted from existing data. Typically single stars with known angular diameters and limb darkening at the wavelength of observation are used. Stars with smaller angular diameters have the advantage that the visibility on a given baseline is a less strong function of the diameter, so any error in knowledge of the diameter or the limb darkening translates to a smaller error in the visibility.

Lists of interferometric calibrator stars for different wavelengths are now available (see Mérand *et al.*, 2005, and references therein) and these should be used where possible, as using a star which is not on these lists can be fraught with danger. A randomly chosen star has a high chance of being part of a multiple-star system and, depending on the brightness difference and angular separation, could have highly variable visibility on the observed baselines.

In addition to having a known visibility, an ideal calibrator should be as similar as possible to the science target in the parameters which are likely to affect the visibility. In order of priority these are:

1. Calibrators should be chosen to be close on the sky to the science target. This is beneficial for a number of reasons. The largest and most variable contributor to visibility degratation is the atmospheric seeing, so observing under as similar seeing conditions as possible is critical to good calibration. Seeing can vary with pointing direction, and varies systematically with distance from the zenith. Having nearby calibrators is particularly critical when the target is at low elevation, where the seeing degrades more rapidly with zenith distance. Mechanical vibrations such as wind-induced telescope vibrations can affect the visibility in the same way the seeing does and will also tend to be similar for pointing directions which are close to one another. The seeing and vibrations can also vary with time, and it is quicker to switch between the observation of a target and a nearby calibrator than one which is further away.

   An additional benefit of using close-by calibrators is that the delay-line positions and speed will be similar for the observations of the target and calibrator, and so any visibility-degrading phenomena (for example vibrations or diffraction), which depend on these factors, will be similar.
2. Calibrators should have similar brightnesses to the science targets in the science waveband. Non-linearities in the fringe detection process can lead to artefacts which depend on the total flux level. Also, many fringe analysis algorithms are non-linear and so the averaged fringe parameters could be degraded differently at different light levels unless care is taken to remove such systematic effects.
3. The wavelength dependence of the brightness of the calibrator should be similar to that of the science target, i. e. the colours should be similar. This aids in simultaneously matching the brightnesses at the science wavelength and at the wavebands at which the fringe tracker and AO systems work at. The performance of the active systems like the fringe tracker and AO system are light-level-dependent and so the level of residual phase perturbations will depend on the object brightnesses at the relevant wavelengths.

In addition, if a wide bandpass is being used for the science fringes, the effective wavelength of the fringes will be dependent on the colour of the object being observed and the visibility can be a function of this.

In reality, it is difficult to satisfy all these criteria at the same time and the choice of calibrators is based on a compromise between criteria, which requires judgement as to which are likely to be the more important sources of error. Using more than one calibrator for any given source confers a number of advantages. First, different calibrators can reflect different compromises between criteria. For example, choosing a close-by calibrator, which is different in brightness, and a further-away calibrator, which is more similar in brightness, allows the decision as to whether closeness or similarity in brightness is the more critical to be made after the fact, based on the actual data. Secondly, additional calibrators provide insurance against unexpected problems with a calibrator: for example, if a calibrator turns out to be binary, this can be checked against another calibrator and discarded if need be.

7.5.1 Mira example

Selection of the calibration stars for Mira was problematic because it is so bright. Stars which are of similar brightness are rare and therefore a long distance on the sky from Mira. Additionally, stars which are bright in the infrared are more likely to be cool stars: surface brightness constraints imply that such stars will have comparable angular diameters to Mira, and so the calibrator visibilities on the sampled baselines will be sensitive to any errors in the assumed calibrator diameter. The calibrators chosen were α Ceti and γ Eridani: both are fainter than Mira. The former is closer to Mira in brightness but further away in terms of angular separation while the latter is fainter but less distant and less resolved.

7.6 Surveys

Astronomy makes a lot of use of statistical analysis of multiple exemplars of a given class in order to infer information about the class or about relatively short-lived phenomena in the class. This technique can be equally powerful in interferometry, but does present problems in terms of the time taken to gather sufficient data. With most existing interferometers, gathering visibility information at a small number of (u, v) points on a single object can take anything from a few minutes to an hour, and sampling enough of the (u, v) plane to make a detailed image can take a large fraction of a night. With this kind of performance imaging surveys of more than a dozen objects or so can become impractical.

An alternative is not to try to image all the objects in the survey but rather to extract simple but scientifically important parameters, which require significantly less (u, v) coverage. One example is looking for binary stars, where in principle a single 'snapshot' with a small number of baselines may be sufficient to determine with reasonable confidence whether a system is binary (Le Bouquin and Absil, 2012). In such a case it may be possible to survey tens or even hundreds of stars in a reasonable time.

7.7 Short-timescale phenomena

Interferometry gives access to smaller physical scales than is possible with conventional imaging. This makes it likely that the phenomena that are observed on these scales are changing on shorter timescales, as the time taken for information to cross the object (at the speed of sound if the object is dense enough or at the speed of light if the object is transparent enough) or the time taken for orbital motion is correspondingly smaller.

To illustrate this principle one can consider a binary star system 10 parsecs away from the Earth: if it is 'visual binary' with a separation of order 1 arcsecond it will have an orbital period of around 30 years, while if it is an 'interferometric binary' with a separation of 10 milliarcseconds it will have a period of less than 9 hours. Another example is a nova occuring at a distance of 1 kiloparsec. If the ejecta from the star are travelling outwards at a speed of $1000\,\mathrm{km\ s^{-1}}$ then the diameter of the envelope will change by about 1 milliarcsecond per day.

Since interferometric observations can take significant fractions of a night or many nights if multiple telescope configurations are needed, it is possible that the object will change during the course of an observation. This can be taken into account if a model-fitting procedure with an explicit time-dependence is used, but making model-independent image reconstructions becomes much more problematic if object evolution is added as an additional dimension to the problem. Thus, evolution timescales must be taken into account when determining what kind of observation is feasible.

7.7.1 Mira example

The timescale of shock propagation in Mira was the main time constraint: if the shock is propagating radially from the star at speeds of $60\,\mathrm{km\ s^{-1}}$, the diameter of the shock front would change by about 5 milliarcseconds per week if Mira is at a distance of 100 parsecs, so observations within a few-day window could be considered as ‘simultaneous’; observations separated by a few weeks would allow shock motion to be easily detected.

7.8 Complementary observations

The ultimate aim of any astronomical observation is to understand the physics of some particular phenomenon. The high-angular-resolution information provided by interferometry is typically critical in bringing new insights into the phenomenon that is the subject of an interferometric observing proposal, but the interferometric data can best be interpreted in the light of other information about the phenomenon. This information can often be gleaned by using lower-angular-resolution techniques such as spectroscopy or photometry, and by using information at different wavelengths, e. g. information about radio or X-ray emission.

While it is likely that some such general information already exists for the objects in the same class as those being observed, it is often the case that additional observations, such as photometry or spectroscopy of the targets in question, can provide valuable information. One example of this is the observation of binary stars, where spectroscopic information about the target system can in many cases be combined with interferometric measurements to derive all the physical parameters of the system.

Thus, the scientific value of an interferometric observation can often be maximised by considering it as just one observation in an observational campaign centred on a common scientific question, and making sure that observations on other telescopes are planned to provide any complementary information which is required to interpret the interferometric data.

Advance planning is especially important for time-variable objects where details about the object at the time of the interferometric observation can be critical. For example, Mira variables show cycle-to-cycle variations in many of their properties and so observations which are within the same cycle as the interferometric observations may prove valuable.