Dwell-time specifications for the MROI unit telescopes

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1 Objective

To define the required range of “dwell times” that a telescope will stay pointed at a given astronomical source during operations, for the purpose of understanding the acceptable interval between focus adjustments.

2 Summary

A typical range of useful on-source times ranges between 60 seconds and 20 minutes. However, it is acceptable to make telescope focus adjustments at intervals of 5 minutes as proposed by AMOS.

3 Introduction

AMOS presented a strategy for meeting the Unit Telescope (UT) focus requirements at the Preliminary Design Review (PDR) in April 2008 which assumed that the telescope focus could be adjusted at intervals of 5 minutes. The PDR external reviewers raised the following question:

A five minute observation period is assumed though the Technical Requirements state (in Appendix A.2.2) that typical on-source dwell times of 60s to 600s are envisaged. There seems to have been some agreement over the reduction of this dwell time that is either not recorded anywhere or is not available to the reviewers.

This memo attempts to resolve this discrepancy.

4 Observing scenarios

The typical observation scenario detailed in Appendix 2.2 of INT-403-TSP-0003 “Technical Requirements: Unit Telescopes for the MRO Interferometer ” envisages that the time between ending an observation of one star and the start of taking data on a new star is typically 60 seconds. The interval between these events consists of overheads such as slewing the telescopes and delay lines, acquisition of the target star, engaging the fast tip/tilt correction system, and finding fringes.

At the end of this sequence the science instrument will start acquiring interferometric science data for a user-specified period. For a star which is sufficiently bright, a few seconds of data may be sufficient to achieve an adequate signal-to-noise ratio on the interferometric observables. However, the visibility of the fringes will be dependent on the instantaneous seeing which can fluctuate significantly on timescales of a few seconds (see e.g. Baldwin et al. A&A, 480, 589-597, 2008). Averaging the data over periods longer than this can help reduce the susceptibility of the measured visibility to short periods of particularly good or bad seeing, although this must be balanced against the gain to be made from rapidly switching to a calibrator star in order to monitor the effects of fluctuations in the average seeing which may take place on timescales of order minutes. Given the switching overhead of 60 seconds, it would appear reasonable to have a minimum observation time of the same order.

For faint targets, averaging over longer periods will allow an improvement in the SNR to levels which allow good imaging. For the faintest and most resolved targets, it might require more than an hour of integration before the SNR is high enough that further integration is of little use (for example because the SNR has reached a level where calibration effects dominate over SNR issues).

However, before this limit is reached, there is a further effect setting an upper limit to the useful integration time on a given target. Because of Earth rotation, the interferometer baselines will be sweeping out a track in the u-v plane which is fixed relative to the target. If the integration time is sufficiently long that the source Fourier component being sampled at the end of the integration is significantly different than that being sampled at the beginning of the integration, then the averaged quantity will be a “smeared” version of the true Fourier data. This smearing will result in a reduction of the quality of the interferometric images produced and so is to be avoided.

As a rule of thumb, the Fourier data will be correlated over a distance in the u-v plane of approximately b/N, where b is the maximum baseline, and the number of resolution elements (“pixels”) over which the target is spread is NxN. For a typical target to be imaged by MROI, N will be of order 10, so that the baseline should change by no more than 0.1 times the length of the maximum baseline during an observation. In the case of an E-W baseline observing a source at the North Pole, this will occur after 20 minutes. Integration times of less than this will be required for high-precision or wider-field imaging, while longer integration times may be allowable for less-resolved objects.

The optimum dwell time will likely be less than allowed by the u-v smearing limit because interleaving observations of calibrator stars in a long integration will likely prove to be better. For example observing a faint source for 8.5 minutes, followed the observation of a brighter calibrator for 1 minute and observing the faint source again for 8.5 minutes (plus 2 minutes of switching overhead) will greatly increase the accuracy of visibility calibration with only a small impact on the integrated SNR when compared with a single 20-minute integration. Thus it is likely that the vast majority of uninterrupted pointings at a single target will last less than 20 minutes.

For faint targets where insufficient SNR is achieved in a 20-minute period, scheduling observations at the same sidereal time on multiple nights will allow the astronomer to build up long integration times at a single point in the u-v plane.

5 Effect of adjusting the telescope focus

The above discussion shows that there are at least some operational scenarios where the user would like to have an on-source dwell time of greater than 5 minutes. AMOS has used this 5 minute figure as the interval at which the focus of the telescope secondary is adjusted. In this section we consider what impact these focus adjustments would have on an on-source integration lasting longer than this period.

The UT focus is adjusted in steps as a function of time according to a “feed-forward” model of the telescope, based on the telescope orientation with respect to the gravity load and on the measured temperatures at various points on the telescope structure. We shall assume that the focus is adjusted after every slew based on the prevailing conditions, so that for on-source integrations of less than 5 minutes then no focus adjustment is necessary. For longer integrations, the feed-forward model will indicate that the focus error is going outside of the acceptable range and instruct the hexapod holding the secondary to move by a distance of order 1 or 2 microns.

If the interferometer is making science measurements at this point, there will be a number of effects on the data. The most obvious of these is that there will be a rapid change in the optical path difference (OPD) between telescopes. To first order, all the telescopes, being of similar construction and operating under similar conditions, will make the same focus change. There will be some difference due to small differences in the telescopes and in the temperatures measured at each telescope. This is likely to result in a slightly different focus changes on different telescopes, and also the possibility that the focus changes will be initiated at different times on different telescopes. To overcome the latter effect, it is preferable to force all telescopes to make their adjustments simultaneously based on the prevailing conditions. The focus adjustment will take of order a second, and during this time it is likely that all the telescopes will not follow exactly the same path, leading to additional temporary OPD fluctuations.

Under these assumptions, there will be rapid changes in the OPD of the order of 1 micron which will stabilize after 1 second. During this time the OPD fluctuations may be fast enough to “blur” the fringe pattern during the elementary exposure time of order 5-50 milliseconds. This will cause some loss in fringe visibility in both the fringe tracker and the science combiner. The visibility loss in the fringe tracker may be enough to cause it to temporarily lose lock. Because of this it is essential to know when the focus adjustment occurs, so data from this interval can be edited out of the science data if necessary. In addition it would be helpful if the fringe tracker knows in advance that such an event is going to occur, so that it can know not to try and follow the dynamic excursions of OPD.

The focus adjustment may cause a permanent shift in the OPD of order 1 micron. The width of the group-delay peak for an H-band fringe tracker is of order 10 microns, so this shift is unlikely to make a significant difference to the long-term tracking of fringes. However, if the fringe tracker knows how much OPD change to expect and when, this will allow the fringe tracker to take appropriate action, and in the worst case re-acquire fringes rapidly. Even without this information, the fringes should not move out of the fringe-tracker's fringe detection range, which is of order 40-60 microns, and so fringe re-acquisition should be rapid, perhaps less than a second.

Another possible effect is that, during focus movement, the secondary mirror may tilt. This effect is likely to small but temporary, and it is likely that the tip/tilt system will correct this error quickly after the end of the movement.

A longer-term effect will be that the focus component of the spatial wavefront error will change. If the feed-forward model is correct, this change will be to a value which is closer to zero than just before the focus adjustment. The effect therefore will be that the fringe contrast will increase. For a focus shift of 2.2 microns, this change in fringe contrast will be about 0.6% in the J-band, so the effect on visibility calibration will be small. Furthermore, the visibility will then be nearly identical to the visibility measured at the beginning of the integration, so the effect on the average visibility will be less than this amount.

The end result is that the only effect of a focus shift is likely to be small and limited to a maximum of 2 or 3 seconds. Over a 10-minute integration, this represents a loss of less than 0.5% of the data, which is acceptable.

6 Conclusion

It is likely that, in some scenarios, it will be necessary to adjust the focus of the telescope in the middle of an on-source integration. Providing that the moment when the focus adjustment is made is known and synchronized amongst the different telescopes, the effect on the science data will be limited. Having a protocol which allows the fringe tracker to know in advance to expect a focus shift and gives the magnitude of this shift will further minimize the effect of the step-change in focus.