Commissioning Plan and Performance Verification Milestones for the MROI

INT-414-TSP-0004 rev 0.5

Dated: November 7th 2007

Chris Haniff

Magdalena Ridge Observatory
New Mexico Tech
801 Leroy Place
Socorro, NM 87801,USA
Phone: (505)835-6431
Fax: (505)835-6807
http://www.mro.nmt.edu

Revisions

REV	*DATE*	*AUTHOR*	*COMMENTS*
0.1	2007/7/19	CAH	Initial draft
0.2	2007/7/20	CAH	Included inputs from IDT
0.3	2007/8/03	CAH	Revised up to PVM4, PVM5 not updated
0.4	2007/8/07	CAH	Working on PVM4 and 5
0.5	2007/11/07	CAH	Summary versions of all PVMs included

CONTENTS

1 Purpose

The purpose of this document is to present an outline plan for the technical commissioning of the MRO Interferometer. For the purposes of this document, we have taken the definition of this task to mean:

> *"Technical commissioning: the phase during which the technical and functional capabilities of the system are demonstrated in the final operational configuration under defined operating conditions. During commissioning, both verification and validation tests are performed on the complete system."*

This identifies technical commissioning of the interferometer as a separate exercise from subsystem testing, in which the different interferometer subsystems are tested **individually**. In this document it has been assumed that this sub-system testing has already been carried out successfully, and so here we are focusing on the testing of these systems as an integrated whole. The project must vigorously resist the temptation to use technical commissioning as the process by which individual subsystems are tested and debugged – this will simply not be possible in any efficient manner once multiple subsystem are integrated.

This document has three main purposes:

1. It sets out the **sequence of commissioning milestones**, hereafter referred to as "Performance Verification Milestones" (or PVMs) for the technical commissioning.

2. It describes **what each PVM seeks to achieve**, and describes what specific verification tasks need to be performed to allow the project to announce that the milestone has been reached.

3. It describes **what WBS elements need to be available** for each PVM to be realized and for each interferometer subsystem, what level of capability is required at each of these events.

It is likely that there will also be a separate activity at the MROI called "Scientific Commissioning". The detailed definition of this parallel activity – it is possible that elements of this activity might take place contemporaneously with the technical commissioning – and its specific function have yet to be specified. However, it is possible that its principal goal will be to provide an opportunity for the MROI teams to demonstrate to the scientific community the unique scientific capability of the interferometer **prior** to it becoming available for that community to use.

This "scientific commissioning" activity is unrelated to the formal verification process by which "*the technical and functional capabilities of the system are demonstrated in the final operational configuration*", and so does not fall within the scope of this document.

Readers should note that at this stage (revision 0.5), this is a working document. The final elaboration of the commissioning plan will involve a system-wide assessment of the complete set of PVM requirements and the resources that the project can make available at any given time by the PM.

Readers should also note that in this version of the document (0.5), the descriptions and information regarding the first 5 PVMs is presented in much more detail than for the remaining 8 PVMs because at this stage it was felt that introducing too much detail of later PVMs might be premature.

2 Introduction

The current plan for commissioning the MROI involves the definition of a set of 13 Performance verification milestones (PVMs) each of which must be passed, sequentially, to validate the technical and functional performance of the array.

2.1 Background to the process

Historically, most interferometers have been deployed in an environment in which the drive to produce results – often in the face of competitor arrays – has meant that it has been difficult to allocate time to the careful and considered assessment, debugging and mending of non-compliant hardware and software. The upshot of this can have multiple undesirable consequences, for example:

- The desired capability of the array may be delayed or never be realized.
- Downtime during scheduled observations can be high, leading to unhappy users and overstretched staff.
- Funding agencies can become wary of further support as the "promised" capability is never seen to emerge.

The early definition of a set of PVMs at the MROI is a deliberate strategy to help mitigate these types of problems.

2.2 The MROI approach

At the MROI the approach that has been proposed is to define a set of PVMs which provide a context within which the delivery of the interferometer and its subsystems can be delivered. The PVMs represent a set of high-level goals, each associated with a key functional capability of the MROI, which allows the project management and stakeholders to assess the progress of the delivery of the interferometer and to verify that the "advertised" capabilities of the array are indeed being delivered.

From an internal MROI project team perspective, the PVMs have a much more tangible and valuable role:

- They will implicitly define the sequence of tasks and subsystems that need to be delivered as a function of time.
- They will explicitly define the capability of each of the interferometer subsystems needed as a function of time.
- They will specify the basis from which the Project Manager will be able to assess the resource implications – including staffing, hardware, and levels of expertise – for the overall delivery of the interferometer.

One important point to stress is that the PVMs identify the minimum capability that each subsystem must have realized by the time that the milestone is reached. It may very well be that it is logistically easier and more cost-effective to deliver an enhanced capability earlier, than to "stretch-out" the delivery schedule for any given subsystem to the maximum time permitted by the PVM schedule. The Project Manager will need to take this into account when utilizing the PVM to manage the activities of his staff, especially as the hidden costs of deferring activities and then re-assembling a suitable team (often in the face of other deadlines) can easily be underestimated.

2.3 Structure of this document

In the following section (3), we present an outline of the 13 proposed PVMs for the MROI project. In each case, the PVM is described, the specific validation tests to be performed are outlined, and the implications on other sub-systems are highlighted.

In Section 4, a summary of the overall PVM timeline is presented. Finally, in Section 5 the System Architects provide some suggestion as to how they envisage this document will be used, and the next stages in developing a concrete implementation plan for the Technical Commissioning described herein.

2.4 Acronyms used in this document

ADC Atmospheric dispersion corrector

BCA Beam combining area

BCF Beam combining facility

DL Delay line

DLA Delay line area

ECS	Enclosure control system
FT	Fringe tracking
FTT	Fast tip-tilt
NAS	Narrow angle sensor
PVM	Performance verification milestones
TASS	Telescope array supervisory software
TCS	Telescope control system
UT	Unit telescope
UTCS	Unit telescope control software
WAS	Wide angle sensor
WBS	Work breakdown structure

3 Performance verification milestones (PVMs)

The thirteen proposed PVMs can be summarized as follows.

Single-telescope standalone milestones

- **PVM1 – First starlight on UT tip-tilt sensor**: demonstrates telescope and wide-angle sensor operation.
- **PVM2 – Closed loop operation of the TT system**: demonstrates TT system operation and supervisory control of TT loops to secondary mirror and UT mount.

Single-telescope milestones that require the BCA

- **PVM3 – First light in BCA on Fringe Tracker table**: demonstrates beam relay, delay lines, beam compressors, vacuum system, switchyard and aspects of the alignment system to the inner BCF.

Two-telescope milestones

- **PVM4 – First fringes at the FT combiner**: demonstrates the delivery of light to the FT combiner, the FT combiner itself, and the FT detector system.
- **PVM5 – First closed-loop fringe tracking**: demonstrates closing the FT/Delay line loop on a single baseline, stable fringe tracking and initial quick-look data analysis.

Three-telescope milestones

- **PVM6 – Closed-loop fringe tracking on long baselines**: demonstrates the bootstrapping capability of the array using a two-leg baseline. Verifies robustness to atmospheric fluctuations.
- **PVM7 – Sensitivity at H=10 on long baselines (FT)**: confirms the sensitivity of the FT combiner under realistic observing conditions and with bootstrapping operational.
- **PVM8 – First closure phase**: confirms the delivery and operation of the science beam combiner. Verifies the parallel operation of two beam combiners and multi-baseline fringe tracking. Tests initial data analysis capability for science combiner.
- **PVM9 – Sustained closure phase measurements on long-baseline triangles**: demonstrates robust bootstrapping with parallel combiners over

long timescales. Verifies data analysis techniques for science combiner.

- **PVM10 – Sensitivity at H=10 on long baselines (SCI)**: confirms the sensitivity of the Science beam combiner as advertised.

Multiple-telescope milestones only worth performing when the number of telescopes is greater than 3

- **PVM11 – First "rapid" relocation**: verifies the ability to reconfigure the array and return to scientific operations reliably and efficiently. All major subsystems now operational in largely "automated" modes so as to support rapid return to operational capability when things are changed.

Six-telescope milestones

- **PVM12 – First "snapshot" image with 6 telescopes (H-10)**: demonstrates the delivery of the Phase A hardware and software, and demonstrates the system robustness for a ~4-6 hour tracking observation. At this stage the project is largely complete.
- **PVM13 – First "snapshot" image with 6 telescopes (H=14)**: demonstrates the realization of the Phase A goals of the interferometer. Phase 1 ends.

The following subsections address each of these in more detail. In the first instance we outline the specific functionality to be verified, while in the second the requirements on other interferometric subsystems are identified.

3.1 PVM1 – First starlight on UT tip-tilt (TT) sensor

3.1.1 Task definition

The principal goal of this PVM is to demonstrate that stellar light, in the form of the full 95mm diameter collimated beam, can be delivered, routinely, for acquisition to the narrow-angle sensor on the UT optical table. Control of this PVM is to be local to a given telescope/enclosure combination.

The proposed sequence of events is:

1. Open dome (possibly manually);
2. Command telescope to point to a given target;
3. Acquire target in wide angle sensor;
4. WAS subsystem finds target, communicates with TCS and centers target;
5. Acquire target on narrow angle sensor – display and log data;
6. Repeat items [2] thru [5] on a number of different targets.

It should perhaps be made clear that PVM1 is not the same as the SATs for UT1. While some of the events are indeed components of the SATs for the first telescope delivered, the SATs include additional tasks for which a separate enumeration of Customer-provided "equipment" will need to be developed. Also, the SAT's will not cover all of the verification needed here. What equipment is needed to be delivered for the SAT of telescope 1 should be the focus of a separate document.

3.1.2 Items/tasks to be verified

For this PVM to be realized, it is suggested that at least the following activities need to have been demonstrated successfully:

<u>Obligatory components of this activity</u>

- That the UT can be mounted on one of its foundation interfaces. For reasons that will become evident at PVM3 and beyond, the central pad, or one on the western arm is preferable.
- That the UT can be integrated and operated successfully inside its enclosure.
- That all utilities can be provided to successfully operate a telescope inside its enclosure.
- That the control software associated with the telescope (TCS) and the narrow-angle sensor can be coordinated using the Unit Telescope Control System (UTCS).
- That the wide-angle-sensor (WAS) subsystem can detect light, focus it, interrogate its images, and communicate appropriately with the TCS.

- That the narrow-angle sensor (NAS) can detect light, focus it, and display this to a user sensibly.
- That appropriate local monitoring and logging of the activity of the enclosure, telescope, WAS and NAS systems takes place.

Optional (TBD) components of this activity

- That the control software associated with the environmental monitoring system, the enclosure (ECS), the telescope (TCS), the narrow-angle sensor and the wide angle sensor – i.e. all the subsystems that are being utilized during this PVM – can be coordinated using the Unit Telescope Control System (UTCS).
- That appropriate remote monitoring and logging of the activity of the enclosure, telescope, WAS and NAS systems takes place using a rudimentary version of the telemetry and engineering archives.
- That the sensing of the light on the NAS occurs at the same wavelengths that will be used during Phase 1 of the MROI deployment – this would imply delivery of the dichroic to be used in Phase 1.

3.1.3 Subsystem requirements

The requirements placed on the various subsystems of the interferometer by PVM1 are summarized in the table below:

WBS number	WBS name	Required	Notes
4.03.01	Unit telescope optics	✓	Full functionality is required for 1 telescope.
4.03.02	Unit telescope mounts	✓	Full functionality is required for 1 telescope.
4.03.03	Fast Tip-tilt systems	✓	Only at a level that includes minimal image analysis. Servo-loop software/hardware is not required, only detector setup, image capture and display. No dichroic necessary.
4.03.04	ADCs	No	
4.03.05	Wide field acq$^{n.}$ systems	✓	Full functionality is required.
4.04.00	Unit tel. enclosures	✓	Full functionality is required apart from full connectivity of control software with the UTCS and environmental monitoring system.
4.05.01	Beam relay system	No	
4.05.02	Vacuum system	No	
4.05.03	Beam compressors	No	

4.05.04	Turning mirrors	No	
4.06.01	Delay line (DL) system	No	
4.06.02	DL Trolleys	No	
4.06.03	DL pipes and supports	No	
4.06.04	DL metrology system	No	
4.06.05	DL software	No	
4.07.01	Fringe tracker	No	
4.07.02	NearIR science combiner	No	
4.08.00	Infrared arrays	No	
4.09.01	Software engineering	✓	Needed to write subsystem software.
4.09.02	Control infrastructure	✓	UTCS software to oversee WAS, NAS, TCS, and enclosure control system.
4.09.03	Supervisory system	✓	Only needed in a rudimentary fashion.
4.09.04	Data handling system	Possibly	Only needed in a rudimentary fashion if non-local archiving is verified.
4.10.01	Alignment system	No	
4.10.02	Wavefront sensors	✓	Needed at a level to align and focus the telescope.
4..11.01	Data reduction tools	No	
4.11.02	Observation prep. tools	No	
4.12.00	BCF	No	
4.13.00	Unit tel. transporter	No	
4.14.00	Technical commissioning	✓	
4.15.00	Environmental monitoring	✓	Only at a level that guarantees safety when opening an enclosure. Full software connectivity with the UTCS is not required.
4.16.00	Scientific preparation	No	
4.17.00	Operations planning	No	
4.18.00	Research office building	✓	Needed for design activity.
4.18.01	Workman lab	Possibly	May be needed for prototyping/test.
4.18.03	R&ED demonstraton facility	Possibly	May be needed for prototyping/test.
4.18.04	Lodging	No	
4.19.00	IT infrastructure	✓	Needed for design activity.

3.1.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM1 should occur as soon as the first unit telescope arrives on site and has been accepted.

Summary of key required hardware at this time:

- **Telescope pads**: all, because subsequent earthwork will disturb those already installed. In addition, existing pads will need time to settle before any telescopes are installed.
- **Beam relay and vacuum can piers**: all, because subsequent earthwork will disturb those already installed. In addition, existing piers will need time to settle before any hardware is installed.
- **Monumentation**: all, because subsequent earthwork will disturb those elements already installed.
- **Enclosure**: one, to enclose first UT.
- **WAS system**: one complete system.
- **NAS system**: one, but only the sensor and opto-mechanics. None of the control to close to FTT loop is needed.
- **Software**: only those aspects of the UTCS needed to co-ordinate telescope-based activities are needed. Some limited data handling functionality.
- **Environmental monitoring**: only at a level that supports safe use of one telescope.
- **Wavefront sensor**: needed at the level of aligning and setting up one UT.

Summary of key hardware items <u>not</u> needed at this time:

- **Beam relay system**: any of the pipes and cans.
- **Delay-line system**: any of the pipes or hardware & software.
- **Beam compressors**: any of this subsystem.
- **Turning mirrors**: any of this subsystem.
- **Switchyards**: any of this subsystem.
- **Alignment system**: any of this subsystem.
- **Fringe tracking beam combiner**: any of this subsystem.
- **Science beam combiner**: any of this subsystem.
- **Offline software**: none.

3.2 PVM2 – Closed loop operation of the TT system

3.2.1 Task definition

The principal goal of this PVM is to demonstrate that the FTT system can close the loop with the active secondary mirror such that a stellar image is stabilized sufficiently to meet the FTT performance requirements as the telescope tracks. In addition, the FTT system will need to demonstrate that it can send both fast control signals to the active secondary mirror and slow pointing updates to the telescope mount. Control of this PVM is to be local to a given telescope/enclosure combination.

The proposed sequence of events is:

1. Open dome (possibly manually);
2. Command telescope to point to a given target;
3. Acquire target in wide angle sensor (if necessary);
4. WAS subsystem finds target, communicates with TCS and centers target (if necessary);
5. Acquire target on narrow angle sensor – display and log data;
6. NAS subsystem finds target, communicates with TCS such that target is centered;
7. FTT system closes loop with active secondary actuators and telescope mount – display and log data;
8. FTT system stops active tracking, NAS system takes over and readies itself for same or a new target;
9. Repeat items [2] thru [7] on a number of different targets and TBD consecutive nights.

Once again, it should be made clear that PVM2 is not the same as the SATs for UT1. While some of the events are indeed components of the SATs for the first telescope delivered, the SATs include additional tasks for which a separate enumeration of Customer-provided "equipment" will need to be developed. Also, the SAT's will not cover all of the verification needed here. What equipment is needed to be delivered for the SAT of telescope 1 should be the focus of a separate document.

3.2.2 Items/tasks to be verified

For this PVM to be realized, it is suggested that at least the following activities need to have been demonstrated successfully. Activities successfully realized at PVM1 are <u>not</u> explicitly included in this list: however we assume here that all of these must still be realizable.

Obligatory components of this activity

- That the narrow angle sensor (NAS) be fed with the light required for Phase 1 operation of the MROI, while passing near-infrared light to the beam relay system. This implies that the dichroic and mount needed on the UT optical table is ready.
- That the narrow angle sensor (NAS) can acquire a target and pull it into the nominal "pointing center" using commands to the telescope mount.
- That the FTT subsystem can keep a target centered on the nominal pointing center for a typical interferometric exposure time, e.g. 120 seconds.
- That the opto-mechanical stability of the acquisition (i.e. the NAS) and fast guiding (i.e. FTT) hardware on the UT optical bench be demonstrated over representative nightly temperature cycles.
- That the sequencing of commands associated with the centering of a target, the FTT loop-closing, and the subsequent FFT loop-opening can be managed successfully by the NAS and FTT control software.
- That the co-ordination of the TCS and the NAS, FTT and WAS systems can be managed by the UTCS.
- That appropriate local monitoring and logging of the activity of the enclosure, telescope, WAS, FTT and NAS systems takes place.

Optional (TBD) components of this activity

- That the opto-mechanical stability of the acquisition and fast guiding hardware on the UT optical bench be demonstrated over representative day/night temperature cycles.
- That the control software associated with the environmental monitoring system, the enclosure (ECS), the telescope (TCS), the NAS, the FTT and the WAS – i.e. all the subsystems that are being utilized for this PVM – can be coordinated using the Unit Telescope Control System (UTCS).
- That appropriate remote monitoring and logging of the activity of the enclosure, telescope, WAS, FTT, and NAS systems takes place using a rudimentary version of the telemetry and engineering archives

3.2.3 Subsystem requirements

The requirements placed on the various subsystems of the interferometer by PVM2 are summarized in the table below. Items in red represent additional functionalities beyond those demonstrated in PMV1.

WBS number	WBS name	Required	Notes
4.03.01	Unit telescope optics	✓	Full functionality is required for 1 telescope.
4.03.02	Unit telescope mounts	✓	Full functionality is required for 1 telescope.
4.03.03	Fast Tip-tilt systems	✓	Full functionality is required, although not all diagnostic logging (i.e. the data needed for interferometric diagnostics) need be implemented. Offsetting under the control of the ADC subsystem is not needed.
4.03.04	ADCs	No	
4.03.05	Wide field acq$^{n.}$ systems	Possibly	Functionality is required only if the UT has been relocated immediately prior to this PVM.
4.04.00	Unit tel. enclosures	✓	Full functionality is required apart from full connectivity of control software with the UTCS and environmental monitoring system.
4.05.01	Beam relay system	No	
4.05.02	Vacuum system	No	
4.05.03	Beam compressors	No	
4.05.04	Turning mirrors	No	
4.06.01	Delay line (DL) system	No	
4.06.02	DL Trolleys	No	
4.06.03	DL pipes and supports	No	
4.06.04	DL metrology system	No	
4.06.05	DL software	No	
4.07.01	Fringe tracker	No	
4.07.02	NearIR science combiner	No	
4.08.00	Infrared arrays	No	
4.09.01	Software engineering	✓	Needed to write subsystem software.
4.09.02	Control infrastructure	✓	UTCS software to oversee WAS, NAS, FTT, TCS, and enclosure control system.
4.09.03	Supervisory system	✓	Only needed in a rudimentary fashion.
4.09.04	Data handling system	Possibly	Only needed in a rudimentary fashion if non-local archiving is verified.
4.10.01	Alignment system	No	
4.10.02	Wavefront sensors	✓	Needed at a level to align and focus the telescope.

4..11.01	Data reduction tools	Possibly	Only needed if non-local archived data needs to be interrogated.
4.11.02	Observation prep. tools	No	
4.12.00	BCF	No	
4.13.00	Unit tel. transporter	No	
4.14.00	Technical commissioning	✓	
4.15.00	Environmental monitoring	✓	Only at a level that guarantees safety when opening an enclosure. Full software connectivity with the UTCS is not required.
4.16.00	Scientific preparation	No	
4.17.00	Operations planning	No	
4.18.00	Research office building	✓	Needed for design activity.
4.18.01	Workman lab	Possibly	May be needed for prototyping/test.
4.18.03	R&ED demonstraton facility	Possibly	May be needed for prototyping/test.
4.18.04	Lodging	No	
4.19.00	IT infrastructure	✓	Needed for design activity.

3.2.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM2 should occur as soon as possible after the first unit telescope arrives on site and PVM1 has been reached.

Summary of key required hardware additional to PVM1:

- **NAS system**: one complete opto-mechanical system needed now.
- **Software**: additional UTCS capability to close FTT loops, and deliver diagnostic data to an archive.
- **Offline software**: optional capability to interrogate archived diagnostic data. This is not a hard requirement.

3.3 PVM3 – First light in the BCA on the Fringe Tracker table

3.3.1 Task definition

The principal goal of this PVM is to demonstrate the delivery of starlight from a unit telescope to the Fringe Tracker (FT) table. It is necessary that the light be near-infrared light, so that the performance of the ACD system be verified, but it need not be detected using the fringe tracker detector system, nor arrive at the FT optical table in the correct configuration for the beam combiner that will eventually be located there. The beam, however, should be collimated and stable in position and angle. The beam wavefront quality may be tested at optical wavelengths, as long as it is clear that this test is representative of the near-infared wavefront quality.

This PVM must be performed with a telescope located to the Western of the array, so that the opto-mechanical stability of the M4 mount on the UT optical table can be verified. The most convenient choice for this UT is at the central UT pad.

This PVM involves a very large number of the infrastructural elements of the array, notably the beam relay system, the delay lines, the vacuum system, the beam compressors, the turning mirrors, and a large fraction of the alignment system. Importantly, for this PVM, the coordination of the different subsystems is assumed to be achieved with some level of automation, i.e. the process by which the optical train is aligned to allow successful delivery of light cannot have been fully manual, even if efficient.

This PVM will thus verify three main aspects of the interferometer's design:

- The ability to align, and maintain alignment, of the several hundred metre long beamline from the telescopes to the inner BCA.
- The optical (tilt, focus, shear) stability of the beamline from the telescopes to the inner BCA.
- The co-ordinated operation of the alignment subsystem in concert with the beam relay system and the delay line system so as to efficiently (and ion some parts automatically) align the interferometer from the telescopes to beam turning mirrors.

The proposed sequence of events is:

1. In the afternoon pre-observing period, align the optical train from the alignment table out to the UT and also in, from the alignment table, to the fringe tracking table in the inner BCA;
2. Open the central telescope dome remotely;
3. Acquire a star with the central telescope;
4. Initiate fast guiding so as to send a "fixed" collimated beam of light out of the unit telescope;

5. Interrogate the collimated beam at the FT table with a standalone detector: display and log data;
6. Check the delivered beam stability in defocus, angle and shear as a function of time during a night and on consecutive nights.

3.3.2 Items/tasks to be verified

For this PVM to be realized, it is suggested that at least the following activities need to have been demonstrated successfully. As ever, tasks successfully realized at earlier PVMs are not explicitly included in this list, but are assumed to be realizable.

Obligatory components of this activity

- That the central telescope pad and telescope be operational, together with its associated beam relay train, delay line, beam compressor, turning mirror and slow switchyard components.
- That the alignment system can be used to define the nominal guiding center for the UT being used, by sending out a reference beam from the inner BCA all the way out to a unit telescope. Efficient execution of this task is obligatory, but full automation is not.
- That the alignment system can be used to define the expected arrival location of a beam at the fringe tracking optical table, by sending out a reference beam from the inner BCA to that table. Efficient execution of this task is obligatory, but full automation is not.
- That a 95mm diameter collimated beam of light, stabilized in angle and pupil location, and in either of the J, H or K near-infrared bandpasses, be delivered into the beam relay system at a unit telescope location.
- That the ADC system is able to correct for the differential angular dispersion between the beam of light detected on the FTT sensor and the beam of light to be sent to the fringe-tracker optical table.
- That the vacuum system be available and operational such that the beam relay and delay line trains can be evacuated and held at the required vacuum level for their minimum specified hold times. Fully automated operation of the vacuum system is not obligatory.
- That the delay-line system be available and operational such that at least one delay line pipe system is installed and its carriage aligned, and such that the delay line carriage can be slewed to the positions necessary to align the interferometer.
- That at least one beam compressor telescope is installed and aligned to the

nominal axis of its associated delay line.

- That the beam relay mirrors can be aligned efficiently such that the optical beam from the telescope be aligned in angle (tilt) and position (shear) with the nominal delay line/beam compressor optical axis. Full automation of this task is not obligatory.
- That the beam turning mirror and fringe-tracking combiner slow switchyard be available to direct light to the FT optical table. It is not required that the switchyard dichroics sending appropriate near-infrared light be used to direct light to the FT optical table, nor that that part of the alignment system associated with aligning the beam from the delay lines to the fringe-tracking beam combiner axis be available.
- That the sequencing of these alignment tasks and the associated co-ordination of the activities of the different interferometric subsystems involved in this PVM be managed successfully by the Interferometer sequencer. Full automation of these tasks is desirable, but not obligatory.
- That the beam of light delivered to the FT optical table is stable enough during the night in tilt and shear to meet the visibility loss error budget during a night to within 10%.
- That the beam of light delivered to the FT optical table is stable enough from day to day in tilt and shear to not exceed the design range of the alignment system.
- That appropriate remote monitoring and logging of the activities of the different interferometer subsystems involved in this PVM take place using a rudimentary version of the telemetry and engineering archives.

Optional (TBD) components of this activity

- None.

3.3.3 Subsystem requirements

The requirements placed on the various subsystems of the interferometer by PVM3 are summarized in the table below. Items in red represent additional functionalities beyond those demonstrated in PMV2.

WBS number	WBS name	Required	Notes
4.03.01	Unit telescope optics	✓	Full functionality is required for 1 telescope.
4.03.02	Unit telescope mounts	✓	Full functionality is required for 1 telescope.

4.03.03	Fast Tip-tilt systems	✓	Full functionality is required for 1 telescope. The majority of the diagnostic information logging expected to be needed for interferometric observations should have been demonstrated.
4.03.04	ADCs	✓	Full Phase 1 functionality is required (apart from adjustment of the FTT guiding center when "peaking up" the signal on the FT beam combiner).
4.03.05	Wide field acq$^{n.}$ systems	Possibly	Functionality is required only if the UT has been relocated immediately prior to this PVM.
4.04.00	Unit tel. enclosures	✓	Full functionality is required apart from full connectivity of control software with the UTCS and environmental monitoring system.
4.05.01	Beam relay system	✓	Full functionality is required to the central telescope foundation.
4.05.02	Vacuum system	✓	Full functionality is required for the beamline to the central telescope and hence the associated vacuum system "leg". Complete automation of this system is not required.
4.05.03	Beam compressors	✓	Full functionality is needed for the central telescope beamline.
4.05.04	Turning mirrors	✓	Full functionality is needed for the central telescope beamline.
4.06.01	Delay line (DL) system	✓	Full functionality is needed for the central telescope beamline, subject to the restrictions noted below.
4.06.02	DL Trolleys	✓	Full functionality is needed for one trolley associated with use of the central telescope beamline.
4.06.03	DL pipes and supports	✓	Full functionality is needed for the central telescope beamline. 100m of stroke is needed to fully test the stability of the optical train.
4.06.04	DL metrology system	✓	Full functionality is needed for the central telescope beamline. 100m of stroke is needed to fully test the stability of the optical train.
4.06.05	DL software	✓	Only the capability needed to align the delay line system is required, i.e. no modes that support astronomical observations are required.
4.07.01	Fringe tracker	Possibly	May be needed if the detector sub-system is used to interrogate the beam at FT optical table.

4.07.02	NearIR science combiner	No	
4.08.00	Infrared arrays	Possibly	May be needed if this is used to interrogate the beam at FT optical table.
4.09.01	Software engineering	✓	Needed to write subsystem software.
4.09.02	Control infrastructure	✓	The UTCS is needed, as is the inter-subsystem communications backbone.
4.09.03	Supervisory system	✓	The interferometer sequencer needed to coordinate the activities of the UTCS, the TASS, and the beam relay, delay line and alignment subsystems as needed. A rudimentary form of the queue execution system may be required.
4.09.04	Data handling system	✓	This is needed in a rudimentary fashion since non-local archiving of telemetry and engineering data is required.
4.10.01	Alignment system	✓	Only the capability to align the telescope optical axis to the delay line/beam compressor axis, and the delay line/beam compressor axis to a fixed axis in the BCA is required. Only one beam line needs to be aligned. Full automation of these tasks is not required: efficient execution is required.
4.10.02	Wavefront sensors	✓	Needed at a level to align and focus the telescope and to check the delivered beam in the BCA.
4..11.01	Data reduction tools	Possibly	May be needed if the FT detector is used to interrogate the beam at the FT optical table.
4.11.02	Observation prep. tools	Possibly	A rudimentary form of the module use to prepare the queue may be needed.
4.12.00	BCF	✓	Full functionality of the BCF is required, though only one of the four sets of optical tables associated with the beam combiners needs to have been installed.
4.13.00	Unit tel. transporter	No	
4.14.00	Technical commissioning	✓	
4.15.00	Environmental monitoring	✓	Only at a level that guarantees safety when opening an enclosure. Full software connectivity with the UTCS is not required.
4.16.00	Scientific preparation	No	
4.17.00	Operations planning	No	
4.18.00	Research office building	✓	Needed for design activity.

4.18.01	Workman lab	Possibly	May be needed for prototyping/test.
4.18.03	R&ED demonstraton facility	Possibly	May be needed for prototyping/test.
4.18.04	Lodging	No	
4.19.00	IT infrastructure	✓	Needed for design activity.

3.3.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM3 should be planned to occur as soon as possible after the first unit telescope arrives on site and PVMs 1 and 2 have been reached

Summary of key required hardware additional to PVM2:

- **NAS system**: additional diagnostic logging for those performance aspects related to interferometric performance.
- **ADC system**: functionality is required so as to send IR light down the beam relay pipes while fast-guiding at the telescope. In the case of a null ADC unit, this implies that the FTT system has knowledge of the appropriate pointing offset.
- **Beam relay system**: the beam relay pipes and vacuum cans associated with the central telescope must be installed.
- **Vacuum system**: safe and largely complete functionality of the vacuum system and the associated "volume" incorporating the central telescope is needed. Full automation is not required.
- **Delay-line system**: the full DL system associated with the central telescope pad must be installed. 100m of delay line pipe is needed as a minimum, and is probably optimal from the point of view of later milestones. No astronomical modes of operation are needed. Alignment and set-up modes are necessary.
- **Beam compressors**: full functionality for the central beam line is needed. Automation is not required.
- **Turning mirrors**: full functionality for the central beam line is needed. Automation is not required.
- **Switchyards**: a static switchyard to send light onto the Fringe Tracker optical table is needed. Automation is not required.
- **Fringe tracking beam combiner**: the optical table for this system is required. If the FT detector system is being used to interrogate the beam delivered to the FT optical table, then it must be available and able to detect

and characterize the beam.

- **Alignment system**: the parts of the system used to align the UT optical axis to the DL axis, and the DL axis to some fixed axis in the BCA are required. Only alignment of the central telescope beam line is necessary. Full automation is not required, only efficient execution.
- **Wavefront sensor**: this will be needed to set up the delay line and beam compressor focus.
- **Software**: the UTCS should be essentially complete. The TASS needs to be delivered, as does the interferometer sequencer that coordinates the activities of the UTCS, TASS, beam relay, delay line, and alignment systems. A rudimentary form of the queue execution system may be needed. In addition, a limited form the data handling system will be required for archiving of telemetry and engineering data.
- **Offline software**: some data reduction tools to examine data from the FT detectors system may be needed. Also, tools to examine data saved in the engineering and telemetry archives will be needed A rudimentary form of the code to prepare a "queue" may be needed.

- **Additional hardware**: a system that allows the shear, defocus and angle of arrival of the IR beam delivered to the FT optical table must be available. This must be able to measure these parameters of the beam to a level commensurate with the performance needed for successful interferometric observations.

3.4 PVM4 – First fringes at the FT combiner

3.4.1 Task definition

The principal goal of this PVM is to demonstrate that stellar light from 2 telescopes can be delivered successfully (i.e. aligned correctly) to the fringe tracking combiner and that astronomical fringes can be measured with the fringe-tracking combiner sub-system.

It is not required that the fringes be found routinely (i.e. on the desired timescale associated with our observing goals), nor that they can be stabilized against atmospheric fluctuations. It is required that one of the telescopes be located at the central UT pad, and that the other be located on one of pads 1-4 on the Western arm of the array. For purposes related to the ease of installation of the delay line pipes, it is desirable that the second telescope utilize the W1 delay line adjacent to the delay line associated with the central telescope. For purposes related to the ease of installation of the beam relay pipes, it is desirable that the full length of the shortest beam relay pipe on the Western array arm be installed.

The fringes must be measured in either the H or K near-infrared photometric bands and have a median fringe visibility within a factor of 10% from that expected from the MROI error budget.

This PVM is primarily associated with the integration of the fringe-tracking beam combiner subsystem into the interferometer, and will establish empirically the OPD stability of much of the array infrastructure. In addition, as compared with PVM3, the additional capability of the alignment system to align the beams of light exiting the turning mirrors to the beam combiner axes will need to be demonstrated.

Successful realization of this milestone will thus verify four new aspects of the interferometer's design:

- The ability to align, efficiently, the interferometer optical train all the way from the unit telescopes to the detector back-end of the fringe-tracking beam combiner.
- The ability to operate multiple telescopes, relay systems, and delay lines simultaneously.
- The OPD stability of the beamlines from the telescopes to the inner BCA.
- The ability of the interferometric infrastructure and instruments to make useful astronomical measurements.

The proposed sequence of events is:

1. Align two optical trains during the pre-observation afternoon period;
2. Open two domes remotely;

3. Command enclosures, telescopes and delay lines to point to a given target;
4. Acquire stars with WAS and NAS sub-systems;
5. Activate FTT systems;
6. Acquire fringes (manually if necessary);
7. Start recording fringe data – displaying and logging data and real-time status information.

3.4.2 Items/tasks to be verified

For this PVM to be realized, it is suggested that at least the following activities need to have been demonstrated successfully. As ever, tasks successfully realized at earlier PVMs are not explicitly included in this list, but are assumed to be realizable.

Obligatory components of this activity

- That the remote operation of two telescope enclosures can be performed safely and efficiently.
- That the fringe tracking combiner slow switchyard be available to direct the appropriate H or K band light to the FT optical table.
- That the slow switchyard mirrors can be aligned efficiently such that the optical beams from the delay line/beam compressor can be aligned in tilt and shear with the nominal fringe-tracking combiner optical axes.
- That the alignment system demonstrates full and efficient alignment of the interferometer optical train all the way from the unit telescopes to the beam combiner detector for at least two telescopes. Complete automation of this task is not required.
- That, simultaneously, starlight from two telescopes can be acquired, fed through the beam relay system, the delay lines, the beam compressors, the turning mirrors and the FT switchyard so as to be delivered to the fringe tracking beam combiner to make interference fringes.
- That the "astronomical" modes of the delay-line system be available and operational such that two delay lines can be operated and controlled to find astronomical fringes and follow them at the sidereal rate. It is not obligatory to demonstrate automated fringe-finding, but efficient manual searching must be possible.
- That the sequencing of the required alignment tasks and the associated co-ordination of the activities of the different interferometric subsystems involved in alignment be managed successfully and efficiently by the

Interferometer sequencer.

- That the sequencing of the tasks involved in fringe searching and the associated co-ordination of the activities of the different interferometric subsystems involved in this be managed successfully and efficiently by the Interferometer sequencer.
- That appropriate remote monitoring and logging of the activities of the different interferometer subsystems involved in this PVM take place using a rudimentary version of the telemetry and engineering archives.

Optional (TBD) components of this activity

- None

3.4.3 Subsystem requirements

The requirements placed on the various subsystems of the interferometer by PVM4 are summarized in the table below. Items in red represent additional functionalities beyond those demonstrated in PMV3.

WBS number	WBS name	Required	Notes
4.03.01	Unit telescope optics	✓	Full functionality is required for 2 telescopes.
4.03.02	Unit telescope mounts	✓	Full functionality is required for 2 telescopes.
4.03.03	Fast Tip-tilt systems	✓	Full functionality is required for 2 telescopes.
4.03.04	ADCs	✓	Full Phase 1 functionality is required (apart from adjustment of the FTT guiding center when "peaking up" the signal on the FT beam combiner).
4.03.05	Wide field acq$^{n.}$ systems	Possibly	Functionality is required only if the UT has been relocated immediately prior to this PVM.
4.04.00	Unit tel. enclosures	✓	Full functionality is required for 2 enclosures apart from full connectivity of control software with the UTCS and environmental monitoring system.
4.05.01	Beam relay system	✓	Full functionality is required to the central telescope foundation and to the full length of the shortest of the western beam relay pipes.

4.05.02	Vacuum system	✓	Full functionality is required for the beamlines associated with the central telescope and the shortest western relay leg. Complete automation of this system is not required.
4.05.03	Beam compressors	✓	Full functionality is needed for the central telescope beamline and the adjacent western beam line (W1).
4.05.04	Turning mirrors	✓	Full functionality is needed for the central telescope beamline and the adjacent western beam line (W1).
4.06.01	Delay line (DL) system	✓	Full functionality is needed for the C and adjacent W1 delay lines, subject to the restrictions noted below.
4.06.02	DL Trolleys	✓	Full functionality is needed for the trolleys associated with the C and W1 delay lines.
4.06.03	DL pipes and supports	✓	Full functionality is needed for the C and adjacent W1 delay lines. 100m of stroke is needed to fully test the stability of the optical train.
4.06.04	DL metrology system	✓	Full functionality is needed for the C and adjacent W1 delay lines. 100m of stroke is needed to fully test the stability of the optical train.
4.06.05	DL software	✓	High astronomical functionality, e.g. sidereal tracking and manual fringe searching must be available for the C and W1 delay lines. Automated fringe searching is desirable but not obligatory. Tracking the atmospheric fluctuations is not required.
4.07.01	Fringe tracker	✓	Full functionality is needed apart from automated fringe finding, fringe-tracking, and flux-peaking-up. Only two input beams (C and W1) need to be accepted. Operation at a single near-infrared wavelength is acceptable. Some real-time capability to check fringe visibilities is desirable.
4.07.02	NearIR science combiner	No	
4.08.00	Infrared arrays	✓	The initial detector system needed for the FT beam combiner must have been delivered. Only the capability to readout a single fringe pattern and single IR wavelengths is necessary.
4.09.01	Software engineering	✓	Needed to write subsystem software.

4.09.02	Control infrastructure	✓	The UTCS is needed, as is the inter-subsystem communications backbone.
4.09.03	Supervisory system	✓	The interferometer sequencer needed to coordinate the activities of the UTCS, the TASS, and the beam relay, delay line, FT beam combiner, and alignment subsystems is needed. A rudimentary form of the queue execution system may be required.
4.09.04	Data handling system	✓	This is needed in a more advanced fashion since more non-local archiving of telemetry and engineering data is required.
4.10.01	Alignment system	✓	Full capability for the alignment of a single beam-combiner/interferometer configuration is needed. Only the C and W1 beamlines need to be aligned. Alignment need only be efficient enough that it can be easily performed in the afternoon prior to observing – full automation is not required.
4.10.02	Wavefront sensors	✓	Needed at a level to align and focus the telescope and to check the beam quality in the BCA if needed.
4..11.01	Data reduction tools	✓	Unless the FT subsystem provides real-time diagnostic data, a rudimentary form of the visibility extraction tool will be necessary. A rudimentary version of the tool needed to interrogate the FTT and DL archived telemetry when extracting visibilities should be demonstrated too
4.11.02	Observation prep. tools	Possibly	A rudimentary form of the module use to prepare the queue, including the delay line commands, may be needed.
4.12.00	BCF	✓	Full functionality of the BCF is required, though only one of the four sets of optical tables associated with the beam combiners needs to have been installed.
4.13.00	Unit tel. transporter	No	
4.14.00	Technical commissioning	✓	
4.15.00	Environmental monitoring	✓	Full functionality is required for 2 telescopes, including connectivity to the UTCS, TASS etc.
4.16.00	Scientific preparation	No	
4.17.00	Operations planning	No	
4.18.00	Research office building	✓	Needed for design activity.

4.18.01	Workman lab	Possibly	May be needed for prototyping/test.
4.18.03	R&ED demonstraton facility	Possibly	May be needed for prototyping/test.
4.18.04	Lodging	No	
4.19.00	IT infrastructure	✓	Needed for design activity.

3.4.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM4 should be planned to occur as soon as two unit telescopes are available on site.

It is perhaps worth noting that having reached this milestone, the level of automation required at MROI will be approaching that realized at the Mark III interferometer in the early 1990's. In particular, we will have demonstrated that we can efficiently align two beam trains, that these beam trains will stay aligned overnight, and that fringes can be found manually during the night. In addition, we should be able to estimate the fringe visibility and have an initial capability to interrogate engineering telemetry from the FTT and DL systems when performing quality assurance checks on the visibility data. By PVM 5 we should have reached the automation demonstrated by the MkIII interferometer.

Summary of key required hardware additional to PVM3:

- **UTs**: an additional, fully operational UT.
- **Enclosures**: an additional, fully operational enclosure.
- **NAS system**: an additional, fully functioning system for the second UT.
- **ADC system**: an additional, fully functioning system for the second UT.
- **Beam relay system**: the beam relay pipes and vacuum cans associated with the shortest (W1) beam line. At least 31m of this should be installed, there is a very strong preference for all 98m to be installed. This will be helpful from the point of view of later PVMs.
- **Vacuum system**: safe and largely complete functionality of the vacuum system and the associated "volume" incorporating the central telescope is needed. Full automation is not required.
- **Delay-line system**: the full DL system associated with the W1 delay line must be installed. 100m length of delay line pipe necessary. Sidereal tracking and manual fringe search modes are required, as are alignment and set-up modes are necessary.
- **Beam compressors**: full functionality for the W1 beam line is needed.

Automation is not required.

- **Turning mirrors**: full functionality for the W1 beam line is needed. Automation is not required.
- **Switchyards**: appropriate dichroics for the static switchyard to send light onto the Fringe Tracker optical table are needed. Automation is not required.
- **Fringe tracking beam combiner**: the full capability for the C and W1 beams must be delivered. This includes optics, detector, dewar, modulators, software etc. Internal alignment of the system must be possible. This need not be automated.
- **Alignment system**: the additional parts of the system used to align the C and W1 delay lines axes to the corresponding FT axes are required. Full alignment of these two (C & W1) beam lines is necessary. Full automation is not required, only efficient execution.
- **Software**: this needs to be upgraded to manage two telescope operation, including more telemetry and data archiving, more complex sequencing because we now have an instrument to control, and hence more parallel tasks.
- **Offline software**: this needs to be upgraded to include a first version of the visibility extraction tools, and enhanced "queue" preparation tools.
- **Environmental monitoring system**: this needs to be fully integrated with the UTCS and TASS since two telescopes will need to be remotely operable.

3.5 PVM5 – First closed-loop fringe tracking

3.5.1 Task definition

The principal goal of this PVM is to demonstrate that stellar fringes can be tracked successfully (using group delay methods) with the MROI fringe-tracking beam combiner. This PVM should thus demonstrate the closing of the control loop between the FT system and the DL system

It is required that fringes be found routinely (i.e. on the desired timescale associated with our observing goals) for different targets, and that they be stabilized against atmospheric fluctuations on timescales that are consistent with "observing blocks" of lengths of order 100 seconds. It is not required that fringe tracking be demonstrated on baselines longer than approximately 52 m.

The fringes must be measured in either the H or K near-infrared photometric bands and have a median fringe visibility within a factor of 10% from that expected from the MROI error budget.

As compared with PVM4, this milestone is primarily associated with two enhancements, (i) closing the loop between the fringe tracking beam combiner and the delay line system and (ii) performing an initial validation of the software for real-time fringe visualization and the off-line data reduction tools for fringe visibility estimation. Both of these will help establish empirically the OPD stability of the interferometer site and of the array infrastructure.

Successful realization of this milestone will verify three new aspects of the interferometer's capabilities:

- The ability to search for and find fringes routinely.
- The ability to group-delay-track these fringes for periods of time in excess of 60 seconds.
- The ability to assess and deliver quality assured visibility data.

The proposed sequence of events is:

1. Align two optical trains during the pre-observation afternoon period;
2. Open two domes remotely;
3. Command enclosures, telescopes and delay lines to point to a given target;
4. Acquire stars with WAS and NAS sub-systems;
5. Activate FTT systems;
6. Acquire fringes automatically;
7. Initiate group-delay fringe tracking servo loop;
8. Start recording fringe data – displaying and logging data;

9. Terminate group-delay tracking, returning to sidereal following mode;
10. Repeat items [3] thru [9] on at least 2 different targets.
11. Examine data offline and produce estimates for "raw" and "calibrated" fringe visibilities. By "calibration" we simply mean that it must be possible to compare the visibilities measured by the fringe tracker on two different calibrator stars and show that the average instrumental coherence losses for two calibrator stars are equivalent.

3.5.2 Items/tasks to be verified

For this PVM to be realized, it is suggested that at least the following activities need to have been demonstrated successfully. As ever, tasks successfully realized at earlier PVMs are <u>not</u> explicitly included in this list, but are assumed to be realizable.

<u>Obligatory components of this activity</u>

- That the delay-line system be available and operational such that two delay lines can be operated and controlled to find and follow astronomical fringes in a group-delay tracking mode.
- That fringe searching, tracking, and re-acquisition be demonstrated routinely in either the H or K near-infrared band.
- That the sequencing of the tasks involved in fringe searching, tracking and re-acquisition, and the associated co-ordination of the activities of the different interferometric subsystems involved in this be managed successfully by the Interferometer sequencer.
- That appropriate remote monitoring and logging of the activities of the different interferometer subsystems involved in this PVM take place using a version of the telemetry and engineering archives.
- That preliminary versions of the software modules needed to assess the instantaneous fringe visibility, and for post-processing recorded data to extract QA controlled "raw" visibility estimates be available and tested.

<u>Optional (TBD) components of this activity</u>

- That phase tracking be demonstrated for bright targets.
- That by this PVM preliminary versions of the software modules needed to extract QA controlled "calibrated" visibility estimates be available and tested. This is to make sure that this off-line software task is being worked on sufficiently early.

3.5.3 Subsystem requirements

The requirements placed on the various subsystems of the interferometer by PVM5 are summarized in the table below. Items in red represent additional functionalities beyond those demonstrated in PMV4.

WBS number	WBS name	Required	Notes
4.03.01	Unit telescope optics	✓	Full functionality is required for 2 telescopes.
4.03.02	Unit telescope mounts	✓	Full functionality is required for 2 telescopes.
4.03.03	Fast Tip-tilt systems	✓	Full functionality is required for 2 telescopes.
4.03.04	ADCs	✓	Full Phase 1 functionality is required (apart from adjustment of the FTT guiding center when "peaking up" the signal on the FT beam combiner).
4.03.05	Wide field acq$^{n.}$ systems	Possibly	Functionality is required only if the UT has been relocated immediately prior to this PVM.
4.04.00	Unit tel. enclosures	✓	Full functionality is required for 2 enclosures apart from full connectivity of control software with the UTCS and environmental monitoring system.
4.05.01	Beam relay system	✓	Full functionality is required to the central telescope foundation and to the full length of the shortest of the western beam relay pipes.
4.05.02	Vacuum system	✓	Full functionality is required for the beamlines associated with the central telescope and the shortest western relay leg. Complete automation of this system is not required.
4.05.03	Beam compressors	✓	Full functionality is needed for the central telescope beamline and the adjacent western beam line (W1).
4.05.04	Turning mirrors	✓	Full functionality is needed for the central telescope beamline and the adjacent western beam line (W1).
4.06.01	Delay line (DL) system	✓	Full functionality is needed for the C and adjacent W1 delay lines, subject to the restrictions noted below.
4.06.02	DL Trolleys	✓	Full functionality is needed for the trolleys associated with the C and W1 delay lines.

4.06.03	DL pipes and supports	✓	Full functionality is needed for the C and adjacent W1 delay lines. 100m of stroke is needed to fully test the stability of the optical train.
4.06.04	DL metrology system	✓	Full functionality is needed for the C and adjacent W1 delay lines. 100m of stroke is needed to fully test the stability of the optical train.
4.06.05	DL software	✓	High astronomical functionality, e.g. sidereal tracking and manual fringe searching must be available for the C and W1 delay lines. Automated fringe searching and tracking the atmospheric fluctuations on a single baseline is obligatory.
4.07.01	Fringe tracker	✓	Full functionality (including automated fringe finding and fringe-tracking) but not flux-peaking-up. Only two input beams (C and W1) need to be accepted. Operation at a single near-infrared wavelength is acceptable. Initial real-time capability to check fringe visibilities is obligatory.
4.07.02	NearIR science combiner	No	
4.08.00	Infrared arrays	✓	The initial detector system needed for the FT beam combiner must have been delivered. The capability to readout multiple fringe patterns required for fringe tracking on a single baseline is necessary. This must be possible at either H or K band.
4.09.01	Software engineering	✓	Needed to write subsystem software.
4.09.02	Control infrastructure	✓	The UTCS is needed, as is the inter-subsystem communications backbone.
4.09.03	Supervisory system	✓	The interferometer sequencer needed to coordinate the activities of the UTCS, the TASS, and the beam relay, delay line, FT beam combiner, fringe tracking engine and alignment subsystems is needed. A rudimentary form of the queue execution system may be required.
4.09.04	Data handling system	✓	This is needed in a more advanced fashion since more non-local archiving of telemetry and engineering data is required.

4.10.01	Alignment system	✓	Full capability for the alignment of a single beam-combiner/interferometer configuration is needed. Only the C and W1 beamlines need to be aligned. Alignment need only be efficient enough that it can be easily performed in the afternoon prior to observing – full automation is not required.
4.10.02	Wavefront sensors	✓	Needed at a level to align and focus the telescope and to check the beam quality in the BCA if needed.
4..11.01	Data reduction tools	✓	An initial version of the post-observing QA controlled visibility extraction tool will be necessary. An initial version of the tool needed to interrogate the FTT and DL archived telemetry when extracting visibilities must be delivered. A tool to deliver QA controlled calibtrated visibilities is desirable.
4.11.02	Observation prep. tools	Possibly	A rudimentary form of the module use to prepare the queue, including the delay line commands, must be delivered.
4.12.00	BCF	✓	Full functionality of the BCF is required, though only one of the four sets of optical tables associated with the beam combiners needs to have been installed.
4.13.00	Unit tel. transporter	No	
4.14.00	Technical commissioning	✓	
4.15.00	Environmental monitoring	✓	Full functionality is required for 2 telescopes, including connectivity to the UTCS, TASS etc.
4.16.00	Scientific preparation	No	
4.17.00	Operations planning	No	
4.18.00	Research office building	✓	Needed for design activity.
4.18.01	Workman lab	Possibly	May be needed for prototyping/test.
4.18.03	R&ED demonstraton facility	Possibly	May be needed for prototyping/test.
4.18.04	Lodging	No	
4.19.00	IT infrastructure	✓	Needed for design activity.

3.5.4 Proposed timescale

Successful execution of PVM5 should be planned as soon as possible after PVM4 (first fringes) has been realized using two unit telescopes.

Summary of key required hardware additional to PVM4:

- **Delay-line system**: Automated fringe search modes are required, as are automated alignment and set-up modes. A new tool to establish the baseline calibration/geometry needs to be implemented so that we can easily find fringes for different targets. This may be part of the software associated with off-line data reduction.
- **Fringe tracking beam combiner**: Automated operation of the system installed under PVM4 must now be available. This includes optics, detector, dewar, modulators, software, internal alignment, fringe searching and fringe tracking etc.
- **Supervisory software**: this needs to be upgraded so as to manage fringe finding and tracking automatically.
- **Data reduction tools:** these need to be upgraded to include first versions of the visibility extraction tools and (optionally) the visibility calibration tools. A new tool to establish the baseline calibration/geometry needs to be implemented so that we can easily find fringes for different targets. This may be part of the software associated with the delay-line system.

3.6 PVM6 – Closed-loop fringe tracking on long baselines

3.6.1 Task definition

Demonstrate the bootstrapping capability of the array using a two-leg baseline.

3.6.2 Items/tasks to be verified

The suggested sequence of events to demonstrate bootstrapping is:

1. Align three optical trains during the pre-observation afternoon period;
2. Open three domes remotely;
3. Command enclosures, telescopes and delay lines to point to a given bright target;
4. Acquire stars with WAS and NAS sub-systems;
5. Activate FTT systems;
6. Acquire fringes automatically on two different baselines;
7. Initiate group-delay fringe tracking servo loops on both baselines;
8. Start recording fringe data for either or both baselines – displaying and logging data for 60 seconds;
9. Terminate group-delay tracking, returning to sidereal following mode;
10. Repeat items [3] thru [9] on at least 2 different targets.
11. Examine data offline and produce estimates for "raw" and "calibrated" fringe visibilities. By "calibration" we simply mean that it must be possible to compare the visibilities measured by the fringe tracker on two different calibrator stars and show that the average instrumental coherence losses for two calibrator stars are equivalent.
12. Examine data offline and assess how successful fringe tracking has been on the bootstrapped baseline by analyzing frequency of drop-outs etc.

3.6.3 Subsystem requirements

See summary below.

3.6.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM6 should be planned as soon as possible after three telescopes have been delivered.

Summary of key required hardware additional to PVM5:

- **Unit telescopes:** one additional unit telescope.
- **Beam relay system:** additional beam relay pipes to allow for three telescopes to be utilized simultaneously. The best technical demonstration would allow for the three telescopes needed for this PVM to be located on 2 different interferometer arms, and bootstrapping thru the central telescope.
- **Vacuum system:** monitoring and control equipment to support the additional beam relay and delay line pipes needed with three telescopes.
- **Beam compressors:** one additional beam compressor.
- **Turning mirrors:** one additional beam turning mirror.
- **Delay-line system**: one additional run of delay line pipe and an associated carriage, metrology setup, electronics etc.
- **Fringe tracking beam combiner**: no additional hardware elements (it is assumed the full 6-way optical system will be installed from scratch), but enhanced software to cope with multiple baseline fringe tracking and bootstrapping.
- **Science combiner:** nothing additional needed here.
- **Infrared arrays:** nothing additional needed here.
- **Supervisory software:** whatever software is necessary to allow for monitoring and sequencing the additional subsystems.
- **Data handling system:** whatever software is necessary to allow for handling the additional monitoring and sequencing data arising from this PVM.
- **Alignment system:** additional components to support three telescopes and beam relay paths. Some enhanced automation commensurate with keeping the total time for alignment manageable even though an additional beamline has come up to speed.
- **Wavefront sensors:** whatever is needed to support an additional unit telescope and beamtrain.
- **Data reduction tools:** additional off-line software so that the performance of the fringe tracker can be assessed after the event.
- **Observation preparation tools:** nothing additional needed here.
- **BCF:** nothing additional needed here.
- **Environmental monitoring:** only the additional components needed to operate a third UT successfully and safely.

3.7 PVM7 – Sensitivity at H=10 on long baselines with the Fringe Tracker

3.7.1 Task definition

Operate the Fringe Tracking combiner under realistic observing conditions and with bootstrapping operational for targets as faint as 10th magnitude in H and K.

3.7.2 Items/tasks to be verified

These are broadly speaking (a) finding fringes on two baselines simultaneously with a faint target and (b) fringe tracking on a faint target on two baselines simultaneously for at least 60 seconds. These basically demonstrate that the fringe tracker, and all other current active systems (FTT and DL), are working successfully for faint targets.

The suggested sequence of events is:

1. Align three optical trains during the pre-observation afternoon period;
2. Open three domes remotely;
3. Command enclosures, telescopes and delay lines to point to a given faint target (at least 10th magnitude at H or K);
4. Acquire faint star with WAS and NAS sub-systems;
5. Activate FTT systems;
6. Acquire fringes automatically for faint target on two different baselines;
7. Initiate faint-source group-delay fringe tracking servo loops on both baselines;
8. Start recording fringe data for both baselines – displaying and logging data for 60 seconds;
9. Terminate group-delay tracking, returning to sidereal following mode;
10. Repeat items [3] thru [9] on at least 2 different targets.
11. Examine data offline and produce estimates for "raw" and "calibrated" fringe visibilities. By "calibration" we simply mean that it must be possible to compare the visibilities measured by the fringe tracker on two different calibrator stars and show that the average instrumental coherence losses for two calibrator stars are equivalent.
12. Examine data offline and assess how successful fringe tracking has been on the bootstrapped baseline by analyzing frequency of drop-outs etc.

3.7.3 Subsystem requirements

See summary below.

3.7.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM7 should be planned as soon as possible after PVM6.

Summary of key required hardware additional to PVM6:

- **Unit telescopes:** nothing additional needed here unless different algorithms for FTT operation are needed for faint targets.
- **Beam relay system:** nothing additional needed here.
- **Vacuum system:** nothing additional needed here.
- **Beam compressors:** nothing additional needed here.
- **Turning mirrors:** nothing additional needed here.
- **Delay-line system**: nothing additional needed here.
- **Fringe tracking beam combiner**: enhanced software to cope with multiple baseline fringe tracking and bootstrapping with faint targets. Optimization of detector performance for faint targets.
- **Science combiner:** nothing additional needed here.
- **Infrared arrays:** nothing additional needed here.
- **Supervisory software:** nothing additional needed here.
- **Data handling system:** nothing additional needed here.
- **Alignment system:** possibly upgraded components/software to support optimum sensitivity for fringe tracking with faint targets.
- **Wavefront sensors:** nothing additional needed here.
- **Data reduction tools:** nothing additional needed here.
- **Observation preparation tools:** nothing additional needed here.
- **BCF:** nothing additional needed here.
- **Environmental monitoring:** nothing additional needed here.

3.8 PVM8 – First closure phase

3.8.1 Task definition

Confirm the delivery and initial operation of the science combiner. Confirms the ability to operate two beam combiners in parallel, albeit perhaps only for a short while.

3.8.2 Items/tasks to be verified

The basic task will be to install and commission the science combiner in its very first incarnation so that we can see that (a) fringe tracking on one beam combiner can give good fringes on another (b) that the software to oversee the operation and monitoring of two combiners works at a basic level and (c) that we can test the software that provides quick-look and post-observing visibilities from the science combiner.

Of course, a key deliverable will be the first MROI closure phase, which must be reliable enough to warrant some sort of publicity.

The basic sequence of tasks envisioned for this PVM is as follows:

1. Install the science beam combiner and its associated switchyard;
2. Align the two separate beam combiners internally (note that the FT combiner is probably already aligned);
3. Check the alignment of the two beam combiners with respect to each other, including measurement and adjustment of any differential OPD;
4. Align three optical trains during the pre-observation afternoon period, now including the dichroic splitting between the two combiner optical trains;
5. Open three domes remotely and command the enclosures, telescopes and delay lines to point to a given bright target;
6. Acquire star with WAS and NAS sub-systems and then activate the FTT systems;
7. Acquire fringes with FT beam combiner automatically for the target on two connected baselines;
8. Check for the acquisition of fringes on the science combiner;
9. Initiate group-delay fringe tracking servo loops on both the fringe tracker baselines;
10. Peak-up the flux on the science combiner and adjust the differential OPD settings if needed (i.e. this needs to be checked with the stellar signal);
11. Start recording fringe data for both fringe tracker baselines – displaying and logging data for 60 seconds;

12. Start recording fringe date on science combiner on at least 3 baselines that close, and display and log the data while the fringe tracker is locked;
13. Terminate group-delay tracking (and science data recording), returning to sidereal following mode;
14. Examine the data offline to check that the fringes on the science beam combiner are well enough located in delay space that a closure phase has been recorded.
15. Verify that the initial software release that gives quick-look and post-observing visibilities from science combiner is working to spec.
16. Verify that the initial software to compare visibilities from the science combiner with diagnostic data from other system components, including fringe tracker data is operating at some level.
17. Analyze the science combiner data and establish the value and quality of the closure phase data recorded.

3.8.3 Subsystem requirements

See summary below.

3.8.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM8 should be planned as soon as possible after the science beam combiner has been delivered.

Summary of key required hardware additional to PVM7:

- **Unit telescopes:** software that provides the capability for the tip-tilt system to respond to a peak-up signal that originates from the science beam combiner.
- **Beam relay system:** nothing additional needed here.
- **Vacuum system:** nothing additional needed here.
- **Beam compressors:** nothing additional needed here.
- **Turning mirrors:** nothing additional needed here.
- **Delay-line system**: nothing additional needed here.
- **Fringe tracking beam combiner**: the hardware that provides the capability to manage OPD offsets between combiners (if required).
- **Science combiner:** initial delivery of combiner, switchyard (if necessary)

and all associated software. Only a single operating mode (i.e. presumably the lowest resolution mode) is necessary.

- **Infrared arrays:** detector system needed for science combiner – this may be an initial device. Only one dewar is necessary.
- **Supervisory software:** all enhancements needed to run two instruments at the same time and sequence these appropriately.
- **Data handling system:** major system enhancements associated with handling the science instrument data and monitoring its health.
- **Alignment system:** major system enhancements associated with a completely new system. Also OPD monitoring between two of the optical tables in the BCA.
- **Wavefront sensors:** nothing additional needed here.
- **Data reduction tools:** new tools are needed associated with the science instrument, both for quick look analysis, post-observing analysis and for looking for correlations between the science visibilities and other system diagnostics. A critical tool is that needed to assess the quality of the science beam combiner visibilities and their relationship to how well the fringe-traker has been operating in bootstrap mode. Only initial versions of these tools are needed for this PVM.
- **Observation preparation tools:** whatever tools are needed to select appropriate settings for operation of the science instrument. Only initial versions are needed.
- **BCF:** one new optical table for the science instrument, and all the components associated with the science switchyard (i.e. opto-mechanics, optical components, slides etc).
- **Environmental monitoring:** nothing additional needed here.

3.9 PVM9 – Sustained closure phase measurements on long-baseline triangles:

3.9.1 Task definition

To demonstrate reliable and robust fringe tracking while simultaneous science measurements are being secured. In particular to secure quality assured science measurements on baselines where the target would be too resolved to be fringe-tracked on that baseline.

3.9.2 Items/tasks to be verified

The basis task here will be to verify the reliable and robust operation of the science combiner (for bright targets), for repeated closure phase measurements on the same closure triangle (it is assumed only 3 telescopes are available). This implies enhancements as compared to PVM 8 in at least the following areas:

- Stability of the alignment of the beam combiners during a night, including differential OPD.
- Stability of the science beam combiner switchyard when switching beams.
- Both low and medium resolution modes of the science beam combiner should be available now.
- Stability of the tip tilt adjustment of beams entering the BCA from the UTs such that flux is peaked on science combiner after fringes are initially acquired.
- Enhanced software tools for quick-look and post-observing extraction of visibilities from the science combiner.
- Enhanced software tools to compare the visibilities from science combiner with diagnostic data from other system components, including fringe tracker data.

It will be important to demonstrate that we can measure closure phases (and visibility amplitudes) on baselines where the targets would be too resolved to observe were it not for fringe tracking.

It will also be important to demonstrate that the visibilities and closure phases extracted from the science combiner are reliable and can be quality assured. The software tools to demonstrate this must be available.

After successful completion, visibility amplitude and closure phase data from the MROI array will be of a quality that it should be straightforward to extract publishable quality results from them.

The basic sequence of tasks envisioned for this PVM is as follows:

1. Fully align three optical trains during the pre-observation afternoon period

for parallel fringe tracking and science beam combiner operation. This includes all differential OPD effects;

2. Open three domes remotely and command the enclosures, telescopes and delay lines to point to a given bright target;
3. Acquire the star with the WAS and NAS sub-systems and then activate the FTT systems;
4. Acquire fringes with the FT beam combiner automatically for the target on two connected baselines which sum to a long baseline on which fringe tracking is not expected to be possible;
5. Check for the acquisition of fringes on the science combiner;
6. Initiate the group-delay fringe tracking servo loops on both the fringe tracker baselines;
7. Peak-up the flux on the science combiner and adjust the differential OPD settings if need be;
8. Start recording fringe data for both fringe tracker baselines – displaying and logging data for 60 seconds;
9. Start recording fringe date on science combiner on at least 3 baselines that close, and display and log the data while the fringe tracker is locked;
10. Repeat the observations after exercising the switchyard but returning to its initial configuration;
11. Terminate group-delay tracking (and science data recording), returning to sidereal following mode;
12. Repeat the above sequences for at least 2 other targets;
13. Verify the data quality using both the quick-look and post-observing visibilities extraction software, checking especially to see that fringes remain centered as a function of time and after switchyard reconfiguration;
14. Verify that the upgraded software to compare visibilities from the science combiner with diagnostic data from other system components, including fringe tracker data, is operating successfully and allowing the relationships between these parameters to be identified;
15. Analyze the science combiner data and establish the value and quality of the visibility amplitude and closure phase data recorded. These should be of publishable quality (i.e. with errors matching those elaborated in the requirements documents on calibration for the array).

3.9.3 Subsystem requirements

See summary below.

3.9.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM9 should be planned as soon as possible after the science beam combiner has been initially commissioned.

Summary of key required hardware additional to PVM8:

- **Unit telescopes:** optimized software that provides the capability of the tip-tilt system to respond to a peak-up signal that originates from the science beam combiner and does this reliably for multiple targets of different color.
- **Beam relay system:** nothing additional needed here.
- **Vacuum system:** nothing additional needed here.
- **Beam compressors:** nothing additional needed here.
- **Turning mirrors:** nothing additional needed here.
- **Delay-line system**: nothing additional needed here.
- **Fringe tracking beam combiner**: ability to manage OPD offsets between combiners for extended periods of time during the night.
- **Science combiner:** commissioning of the additional medium resolution mode of the science combiner is necessary, as is the ability to exercise the switchyard and check its state is repeatable and stable.
- **Infrared arrays:** the commissioning of the medium resolution mode of the science combiner may need additional dewar and detector.
- **Supervisory software:** all the enhancements needed to run two instruments and sequence these appropriately throughout a night.
- **Data handling system: any** system enhancements associated with science instrument data and monitoring all night.
- **Alignment system:** any possible system enhancements associated with a maintaining the alignment of the interferometer all night and monitoring the stability of the switchyard after reconfiguration.
- **Wavefront sensors:** nothing additional needed here.
- **Data reduction tools:** finalized tools for the science instrument, both for quick look analysis, post-observing analysis and correlations between science visibilities and other system diagnostics.

- **Observation preparation tools:** finalized tools needed to select appropriate settings for operation of the science instrument.
- **BCF:** nothing additional needed here.
- **Environmental monitoring:** nothing additional needed here.

3.10 PVM10 – Sensitivity at H=10 on long baselines with the science combiner

3.10.1 Task definition

To demonstrate reliable and robust fringe tracking while simultaneous science measurements are being secured on targets as faint as 10th in the low and medium resolution modes of the science combiner. Also, to ensure this operation secures quality assured science measurements on baselines where the target would be too resolved (or faint) to be fringe-tracked on that baseline.

3.10.2 Items/tasks to be verified

In comparison with the previous PVM, the new task here will be to push the sensitivity of the science beam combiner so that faint/resolved targets can be observed in both the low and medium resolution modes. That is we will be able to report reliable and robust operation of the science combiner (for targets as faint as 10th magnitude), for repeated closure phase measurements after switchyard reconfiguration (note if only 3 telescopes are present, we simply need to exercise the switchyard then return to the original state and check that the behavior is known and predictable).

This implies enhancements as compared to PVM 9 in at least the following areas:

- Minimization of all alignment and other losses over a whole night so as to deliver good sensitivity with the science combiner.
- Optimization of the science detector performance such that the science data is of appropriate S/N.
- Optimization of any software used for quick-look and post-observing extraction of visibilities from the science combiner so that it can cope with faint targets.
- Optimization of the software to compare visibilities from science combiner with diagnostic data from other system components, including fringe tracker data, when the target is faint.

After successful completion of this PVM, visibility amplitude and closure phase data from the MROI array should be as sensitive as that from any existing interferometric array (as of fall 2007).

The basic sequence of tasks envisioned for this PVM is as follows:

1. Fully align three optical trains during the pre-observation afternoon period for parallel fringe tracking and science beam combiner operation. This includes all differential OPD effects;
2. Open three domes remotely and command the enclosures, telescopes and delay lines to point to a given faint (i.e. 10th magnitude) target;

3. Acquire the star with the WAS and NAS sub-systems and then activate the FTT systems;
4. Acquire fringes with the FT beam combiner automatically for the faint target on two connected baselines which sum to a long baseline on which fringe tracking is not expected to be possible;
5. Check for the acquisition of fringes on the science combiner;
6. Initiate the group-delay fringe tracking servo loops on both the fringe tracker baselines;
7. Peak-up the flux on the science combiner and adjust the differential OPD settings if need be;
8. Start recording fringe data for both fringe tracker baselines – displaying and logging data for 60 seconds;
9. Start recording fringe date on science combiner on at least 3 baselines that close, and display and log the data while the fringe tracker is locked;
10. Repeat the observations after exercising the switchyard but returning to its initial configuration;
11. Terminate group-delay tracking (and science data recording), returning to sidereal following mode;
12. Repeat the above sequences for at least 2 other 10^{th} magnitude targets;
13. Verify the data quality using both the quick-look and post-observing visibilities extraction software, checking especially to see that fringes remain centered as a function of time and switchyard status for these fainter targets;
14. Verify that the upgraded software to compare visibilities from the science combiner with diagnostic data from other system components, including fringe tracker data, is operating successfully and allowing the relationships between these parameters to be identified for faint targets;
15. Assess whether the behavior of the interferometric subsystems is impacted negatively – and in a non-calibratable way – when observing faint targets.
16. Analyze the science combiner data and establish the value and quality of the visibility amplitude and closure phase data recorded. These should be of publishable quality (i.e. with errors matching those elaborated in the requirements documents on calibration for the array).

3.10.3 Subsystem requirements

See summary below.

3.10.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM10 should be planned as soon as possible after the science beam combiner has been commissioned with bright targets.

Summary of key required hardware additional to PVM9:

- **Unit telescopes:** optimized software that provides ability of tip-tilt system to respond to a peak-up signal originating from the science beam combiner and maintain this all night even if target is faint.
- **Beam relay system:** nothing additional needed here.
- **Vacuum system:** nothing additional needed here.
- **Beam compressors:** nothing additional needed here.
- **Turning mirrors:** nothing additional needed here.
- **Delay-line system**: nothing additional needed here.
- **Fringe tracking beam combiner**: ability to manage OPD offsets between combiners all night even for faint targets.
- **Science combiner:** optimized algorithms for faint source detector readout and fringe extraction.
- **Infrared arrays:** optimized detector performance.
- **Supervisory software:** nothing additional required here.
- **Data handling system:** nothing additional required here.
- **Alignment system:** possible system enhancements associated with optimizing the system alignment for maximum S/N and maintaining this.
- **Wavefront sensors:** nothing additional needed here.
- **Data reduction tools:** optimized tools for science instrument, both for quick look analysis, post-observing analysis and correlations between science visibilities and other system diagnostics for faint sources.
- **Observation preparation tools:** optimized tools needed to select appropriate settings for operation of the science instrument for faint targets.
- **BCF:** nothing additional needed here.
- **Environmental monitoring:** nothing additional needed here.

3.11 PVM11 – First "rapid" relocation

3.11.1 Task definition

To demonstrate that the array can be reconfigured and science operations be reinitiated within the time period specified in the top-level array requirements. To do this it is assumed that at least one UT be physically moved, i.e. internal readjustment of mirrors and switchyards alone, for example, would not constitute a true "relocation".

3.11.2 Items/tasks to be verified

This will be the first PVM to be undertaken to demonstrate the "relocation" capabilities of the MROI array. To achieve this goal, it is assumed that at least 4 Unit Telescopes are present on site, and that at least one is relocated to a new station, and that science operations can be initiated thereafter using only the amount of downtime specified in the top-level MROI requirements.

This will imply enhancements as compared to PVM 10 in at least the following areas:

- At least 4 UTs will need to be present.
- The UT transporter must be available and able to relocate at least one UT to a new station.
- There must be a sufficient constellation of UT pads that a UT can be relocated such that the new array configuration is largely similar to the initial configuration. This is to allow a clear and easy assessment of how the interferometer performance after the relocation is changed with respect to its initial state.
- The beam relay systems and delay line systems must be augmented to allow for the presence of additional telescopes and telescope stations.
- Automation of most of the interferometer subsystems must now be in-place such that any alignment and initialization tasks can be executed rapidly and meet the requirement associated with "rapid relocation".
- The vacuum system must be developed such that it now be routine to break a beamline, relocate a telescope, and then pump back the system to an observation-ready state.
- Software that allows the "health" of all of the interferometer subsystems to be monitored and assessed routinely must be delivered. This need not be in its final polished state, but all basis functionality and especially all components related to safety of the system and its staff, must be tested and working.

- The supervisory software must be able to “shutdown” and “awake” the whole interferometer in readiness for a “relocate”.

After successful completion of this PVM, the reconfigurability of the MROI will exceed that of any existing interferometric array (as of fall 2007) in terms of downtime and reliability.

The basic sequence of tasks envisioned for this PVM is as follows:

1. Fully align at least four optical trains during the pre-observation afternoon period for parallel fringe tracking and science beam combiner operation. This includes all differential OPD effects;
2. Open four domes remotely and command the enclosures, telescopes and delay lines to point to a given bright target;
3. Acquire the star with the WAS and NAS sub-systems and then activate the FTT systems;
4. Acquire fringes with the FT beam combiner automatically on the appropriate nearest-neighbor baselines;
5. Check for the acquisition of fringes on the science combiner;
6. Initiate the group-delay fringe tracking servo loops on the appropriate fringe tracker baselines;
7. Peak-up the flux on the science combiner and adjust the differential OPD settings if need be;
8. Start recording fringe data for the fringe tracker baselines – displaying and logging data for 60 seconds;
9. Start recording fringe date on science combiner on at least 3 baselines that close, and display and log the data while the fringe tracker is locked;
10. Repeat the observations (if necessary) to secure all relevant closure phase data;
11. Terminate group-delay tracking (and science data recording), returning to sidereal following mode;
12. Shutdown the interferometer in readiness for a UT “relocate”;
13. Relocate a UT (the multiple sequential tasks needed to undertake this procedure are not elaborated here yet).;
14. “Waken” the array after a “relocate” (it is assumed that this will involve a large amount of safety checking etc);
15. Verify that the time taken to reach this phase is satisfactory;
16. Repeat steps 1 thru 11 (i.e. from initial alignment thru observing a target) for

the same target as before, but with a slightly different array configuration (i.e. one UT moved);

17. Verify that interferometric data take prior to and after the "relocate" are of comparable nature and quality, and can be understood;
18. Verify that the performance of the interferometric subsystems – especially those associated with the UT that has been moved (e.g. its FTT system) and the new beam-relay/delay line path– are working as expected, with no unintended degradation in performance;
19. Ensure that any changes in system performance can be understood.

3.11.3 Subsystem requirements

See summary below.

3.11.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM11 should be planned as soon as possible after four telescopes have been delivered together with a suitable arrangement of UT foundations and beam-relay pipes.

Summary of key required hardware additional to PVM10:

- **Unit telescopes:** the 4^{th} UT, its enclosure and the UT transporter.
- **Beam relay system:** the additional relay pipes and vacuum cans (and associated components and foundations) needed to support this PVM.
- **Vacuum system:** a fully automatic supervisory system needed to "shutdown" and "waken" the system when a scheduled breach of the vacuum system is required.
- **Beam compressors:** nothing additional needed here.
- **Turning mirrors:** nothing additional needed here.
- **Delay-line system**: nothing additional needed here.
- **Fringe tracking beam combiner**: nothing additional needed here.
- **Science combiner:** nothing additional needed here.
- **Infrared arrays:** nothing additional needed here.
- **Supervisory software:** possible enhancements associated with fully automating "shutdown" and "wakening" of full interferometer.
- **Data handling system:** nothing additional required here.
- **Alignment system:** possible system enhancements associated with fully

automating the system alignment post relocation.

- **Wavefront sensors:** nothing additional needed here.
- **Data reduction tools:** nothing additional needed here.
- **Observation preparation tools:** nothing additional needed here.
- **BCF:** nothing additional needed here.
- **Environmental monitoring:** nothing additional needed here.

3.12 PVM12 – First "snapshot" image with 6 telescopes (H-10)

3.12.1 Task definition

To demonstrate the delivery of all Phase A hardware and software, and demonstrate that imaging science observations can be undertaken with an observation lasting from between 4 and 6 hours. At this stage the project should be largely complete apart from system optimization to realize the very best sensitivity.

3.12.2 Items/tasks to be verified

This will be the last of two PVMs that mark completion of MROI Phase A. All hardware and software must be delivered, and operating to allow imaging observations of a target as faint as 10^{th} in the H band. It must be demonstrated that this capability can be undertaken within a single night, and without array reconfiguration. The target must be sufficiently complex (i.e. not a simple bright binary star) that multiple *uv* data secured during the night are necessary to deliver a good image.

Realizing this PVM will imply the following enhancements as compared to PVM 11:

- All UTs will need to be present.
- There must be a sufficient constellation of UT pads and beam relay pipes that one of the nominal configurations of the array (A/B/C/D) can be populated.
- All the beam relay hardware and all components within the BCA must be installed and ready for 6-telescope operation.
- The software that allows the "health" of all the interferometer subsystems to be monitored and assessed routinely must be delivered in its final state.
- The software needed to plan and optimize an observation must be available.
- The software needed to secure, extract, and calibrate visibility data and then recover images from them must be available.

On completion of this PVM, the map delivered must be of publishable quality, i.e. be of a quality assured status.

The specific sequence of tasks we imagine associated with this PVM is as follows:

1 Fully align six optical trains during the pre-observation afternoon period for parallel fringe tracking and science beam combiner operation;

2 Open six domes remotely and command the enclosures, telescopes and delay lines to point to a given 10^{th} magnitude calibrator star;

3 Acquire the star with the WAS and NAS sub-systems and then activate the FTT systems;

4 Acquire fringes with the FT beam combiner automatically on the appropriate nearest-neighbor baselines and check for the acquisition of fringes on the science combiner;

5 Initiate the group-delay fringe tracking servo loops on the appropriate fringe tracker baselines, peak-up the flux on the science combiner and adjust the differential OPD settings if need be;

6 Start recording fringe data for the fringe tracker baselines and science combiner baselines – displaying and logging data for 60 seconds;

7 Repeat the observations (if necessary) to secure all relevant closure phase data;

8 Terminate group-delay tracking (and science data recording), returning to sidereal following mode;

9 Repeat items 3 thru 8 for a science target and thereafter for another calibrator star;

10 Reduce the interferometric data, calibrate the science measurements and send the calibrated data to an image reconstruction tool;

11 Reconstruct an interferometric image. This may involve user/expert intervention – this process is not meant to be automatic;

12 Assess the reliability and credibility of the image, checking that it is consistent with the quality and type of raw interferometric data recorded;

13 Ensure that all anomalies in demonstrated system performance can be understood.

3.12.3 Subsystem requirements

See summary below.

3.12.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM12 should be planned as soon as possible after six telescopes have been delivered.

Summary of key required hardware additional to PVM11:

- **Unit telescopes:** all UTs now installed and commissioned.
- **Beam relay system:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed.

- **Vacuum system:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and fully automated.
- **Beam compressors:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Turning mirrors:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Delay-line system**: all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Fringe tracking beam combiner**: all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Science combiner:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Infrared arrays:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully – this may need additional dewar(s).
- **Supervisory software:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Data handling system:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Alignment system:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Wavefront sensors:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Data reduction tools:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Observation preparation tools:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and

operating successfully.

- **BCF:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.
- **Environmental monitoring:** all components necessary for supporting at least one 6-telescope configuration of the array must be installed and operating successfully.

3.13 PVM13 – First "snapshot" image with 6 telescopes (H=14)

3.13.1 Task definition

To demonstrate meeting the original design goals of Phase A of the MROI, in particular the sensitivity goal.

3.13.2 Items/tasks to be verified

This will be the last PVM and as such will mark the completion of MROI Phase A. All hardware and software must be delivered, and operating to allow imaging observations of a target as faint as 14th in the H band. The type and complexity of the target is not relevant for meeting this milestone.

Realizing this PVM will imply the following enhancements as compared to PVM 12:

- All the UT pads and beam relay pipes needed for all the nominal configurations of the array (A/B/C/D) must be present.
- All software and hardware must be optimized for maximum sensitivity.

On completion of this PVM, the map delivered must be of quality assured status.

The specific sequence of tasks we imagine associated with this PVM is as follows:

1 Fully align six optical trains during the pre-observation afternoon period for parallel fringe tracking and science beam combiner operation;

2 Open six domes remotely and command the enclosures, telescopes and delay lines to point to a given ~12th magnitude calibrator star;

3 Acquire the star with the WAS and NAS sub-systems and then activate the FTT systems;

4 Acquire fringes with the FT beam combiner automatically on the appropriate nearest-neighbor baselines and check for the acquisition of fringes on the science combiner;

5 Initiate the group-delay fringe tracking servo loops on the appropriate fringe tracker baselines, peak-up the flux on the science combiner and adjust the differential OPD settings if need be;

6 Start recording fringe data for the fringe tracker baselines and science combiner baselines – displaying and logging data for 60 seconds;

7 Repeat the observations (if necessary) to secure all relevant closure phase data needed for imaging;

8 Terminate group-delay tracking (and science data recording), returning to sidereal following mode;

9 Repeat items 3 thru 8 for a 14th magnitude science target – this need not be a very resolved target – and thereafter for another suitably matched calibrator star;

10 Reduce the interferometric data, calibrate the science measurements and send the calibrated data to an image reconstruction tool;

11 Reconstruct an interferometric image. This may involve user/expert intervention – this process is not meant to be automatic;

12 Assess the reliability and credibility of the image, checking that it is consistent with the quality and type of raw interferometric data recorded;

13 Ensure that all anomalies in demonstrated system performance can be understood.

3.13.3 Subsystem requirements

See summary below.

3.13.4 Proposed timescale and summary of required infrastructure

Successful execution of PVM13 should be planned as soon as possible after six telescopes have been delivered and initially integrated. It will likely take some time to realize this level of performance.

Summary of key required hardware additional to PVM12:

- **Unit telescopes:** all high-sensitivity enhancements operational.
- **Beam relay system:** all components necessary for supporting all 6-telescope configurations of the array must be installed.
- **Vacuum system:** all components necessary for supporting all 6-telescope configurations of the array must be installed and fully automated.
- **Beam compressors:** no additional hardware required.
- **Turning mirrors:** no additional hardware required.
- **Delay-line system**: no additional hardware required.
- **Fringe tracking beam combiner**: all components necessary for supporting all 6-telescope configurations of the array must be installed and operating successfully.
- **Science combiner:** all components necessary for supporting all 6-telescope configurations of the array must be installed and operating successfully.
- **Infrared arrays:** all software/hardware enhancements for highest sensitivity

must be operating successfully – this may need additional dewar(s).

- **Supervisory software:** all components necessary for supporting all operational modes of the array must be operating successfully.
- **Data handling system:** all components necessary for supporting all operational modes of the array must be operating successfully.
- **Alignment system:** all components necessary for supporting all operating modes of the array must be installed and operating successfully.
- **Wavefront sensors:** all components necessary for supporting all operating modes of the array must be installed and operating successfully.
- **Data reduction tools:** all components necessary for supporting all operating modes of the array must be installed and operating successfully.
- **Observation preparation tools:** all components necessary for supporting all operating modes of the array must be installed and operating successfully.
- **BCF:** all components necessary for supporting all operational modes of the array must be installed and operating successfully.
- **Environmental monitoring:** all components necessary for supporting all operational modes of the array must be installed and operating successfully.

14 Schedule summary in context of UT deliveries

The following table places the individual PVMs in time order as far as their relationship with the UT deliveries are concerned. The absolute dates included in the table below are to be considered as tentative – however, the relative timing of various technical commissioning tasks is likely to not change much. Items in green correspond to dates that have elapsed.

Quarter	UT procurement activities	1-tel PVMs	2 to 4-tel PVMs	5 and 6-tel PVMs
2007 Q1 Jan-Mar				
2007 Q2 Apr-Jun				
2007 Q3 Jul-Sep	Start of design in Jul			
2007 Q4 Oct-Dec				
2008 Q1 Jan-Mar				
2008 Q2 Apr-Jun				
2008 Q3 Jul-Sep	Design complete in Jul			
2008 Q4 Oct-Dec				
2009 Q1 Jan-Mar				
2009 Q2 Apr-Jun				
2009 Q3 Jul-Sep	T1 accepted in Jul	PVM 1-3		
2009 Q4 Oct-Dec		PVM 1-3		
2010 Q1 Jan-Mar	T2 accepted in Jan		PVM 4-5	
2010 Q2 Apr-Jun			PVM 4-5	
2010 Q3 Jul-Sep	T3 accepted in Jul		PVM 6-10	
2010 Q4 Oct-Dec			PVM 6-10	
2011 Q1 Jan-Mar	T4 accepted in Jan			
2011 Q2 Apr-Jun				
2011 Q3 Jul-Sep	T5 accepted in Jul			PVM 11-14
2011 Q4 Oct-Dec				PVM 11-14
2012 Q1 Jan-Mar	T6 accepted in Jan			PVM 11-14
2012 Q2 Apr-Jun	Technical commissioning complete in Jun			PVM 11-14

15 Suggestions for process for moving ahead with this document

- SAs and PM refine Technical commissioning plan, so that it becomes consistent with the resources (time, manpower and budget) that the PM has available. SAs provide oversight to ensure that technical plan is fit to task and does not undermine the successful execution of commissioning interferometer.
- WP leaders develop timelines, budgets and labor resourcing needed for individual subsystems.
- WP and PM develop system-wide timeline, budget and labor resourcing plan so that a critical path analysis and risk assessment can be completed.

------------------------------------ End of document ------------------------------------