

SALT Board Meeting #37

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SALT Edge Sensor (SAMS) Project

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Supported by the SAMS Project Team:

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1. SUMMARY

Chris Coetzee was tasked at Board meeting #36 in Pune to manage the SAMS project to conclusion since it is now more of an industrial project with large scale procurement of components from FOGALE Nanotech, bonding of buttons to segments, flexures to L-brackets, installation of cables, electronic racks and extensive testing towards acceptance of the system.

In order to assume the responsibility in a professional manner, an internal audit was commissioned that focused on the various processes followed during the project. It encompassed 4 main areas namely: commercial, project management, system engineering and software engineering. This audit uncovered some processes that were done well and some to which the project team must give more attention going forward. The activities needing more attention were included in the Action List for the project. An important action is the acceptance testing of the now modified Primary Mirror Alignment System (PMAS, see Figure 2 below), and not only the SAMS system.

The increasing pressure on telescope time has refocused efforts into testing and validating the performance of SAMS within the larger PMAS, simultaneously with science operations. Software effort and operator training has gone into testing the SAMS system in closed loop operation during observations whilst periodically (between targets and when appropriate) measuring the state of the mirrors and therefore the ability of PMAS and SAMS to maintain the mirror shape.

Significant effort is being directed towards resolving software bugs both within the PMAS system and the SAMS software. The SAMS system is in regular operational use and behaves very repeatably from night to night; it is only interrupted when applying software updates, repairing software bugs and when operator error forces a test to be restarted.

The very encouraging news is that the most recent results show the system is maintaining the required alignment specification of 0.1” RMS tip tilt over a 3 day period and 6 degree temperature change. There is on-going effort to increase the length of a test to at least 5 days, and to cover a temperature span of 10 degrees.

The project team is now of the opinion that the sensors and their control electronics can be declared acceptable and meeting specification. A final acceptance test report is in process and will be published before the Board meeting.

2. TECHNICAL DEVELOPMENTS, RESULTS AND ANALYSIS

Initial attempts to control the Global Radius of Curvature (GRoC) using the dihedral sensitivity of the sensors, as originally intended, had proven unsuccessful and were shelved in favour of a correction algorithm based on the change of gap with temperature. GRoC control by means of dihedral sensitivity can be re-evaluated for implementation in the future, should it be required.

Optimising this gap-based GRoC correction scheme has been successful and the most recent results at the time of writing allow for considerable optimism, given the difficulties of completing a test, as alluded to above.

The following plot shows the evolution of rms tip/tilt with time starting with an alignment late on the night of 2 May 2015. In the lower plot, the horizontal line shows the maximum allowed rms tip/tilt as in the SAMS specification. The vertical lines show the beginning of the observing night (blue) and the end (red). CCAS measurements are shown as black dots. The last three dots are shown in red because an operator error induced a change in GRoC, for which we have estimated a correction – in any case these three points are consistent with no significant change in tip/tilt during the night of 5 May. Bad weather prevented any CCAS measurements being obtained on the night of 6 May, but

SAMS remained in closed-loop control and the recorded actuator movements suggest there was little change in rms tip/tilt during that night. The temperature evolution is shown in the top plot, showing a range of almost 6 degrees over the period of the test.

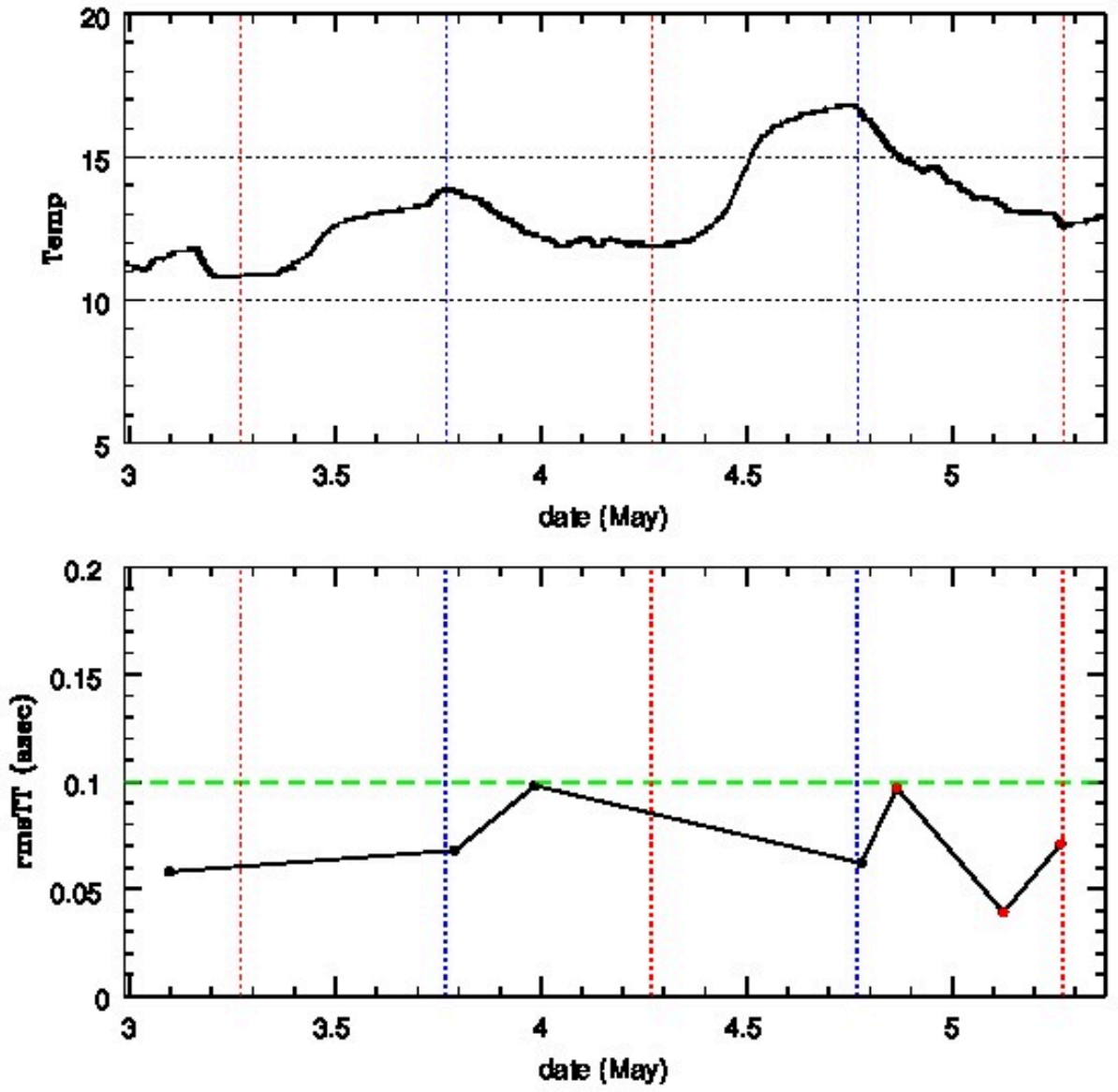


Figure 1. (Top) Temperature evolution during the test. (Bottom) evolution of rms tip/tilt. The last three points have been corrected as described above. The horizontal line shows the allowed maximum of tip/tilt as in the SAMS specification. The vertical lines show the beginning (blue) and end (red) of the observing night.

Another major achievement was that Ockert Strydom developed a comprehensive FEM model of the truss. This model was analysed to determine its behaviour during temperature change. It shows clearly that the truss does not move isentropicly during temperature changes, as the current control algorithm assumes. The main reason is the way that the kinematic mount was designed and works. The further development of this model can be incorporated into the control algorithm of the system so that better alignment can be done and held by the system. The size of the gaps currently used for

GRoC correction is a function of structure movement under temperature, and other second order factors. Darragh has indicated that he is also interested in this model for IQ issues.

2.1 Software

A sustained software campaign to debug all aspects of the PMAS system, which is being used for the first time in this sustained mode lasting days, has uncovered several software defects that were not hitherto visible – they were concealed by the repeated re-alignments resulting from no edge sensors. Fixes to all subsystems, MACS, SPS, SAMS, and CCAS have yielded stable performance that is close to demonstrating full compliance with specification (0.1” RMS tip tilt over 5 days).

A summarised status of the PMAS system is depicted below. Green meaning acceptable and yellow meaning that many risks have been mitigated. At the time of writing, the few known risks remaining are judged to be solvable (more detail to follow below). The fact that the PMAS system has not been tested over 5 days duration with a 10 degrees temperature span is the single most important reason why most of the sub-systems cannot be declared to have a green status. It must be pointed out that the sensors have been judged to have a green status.

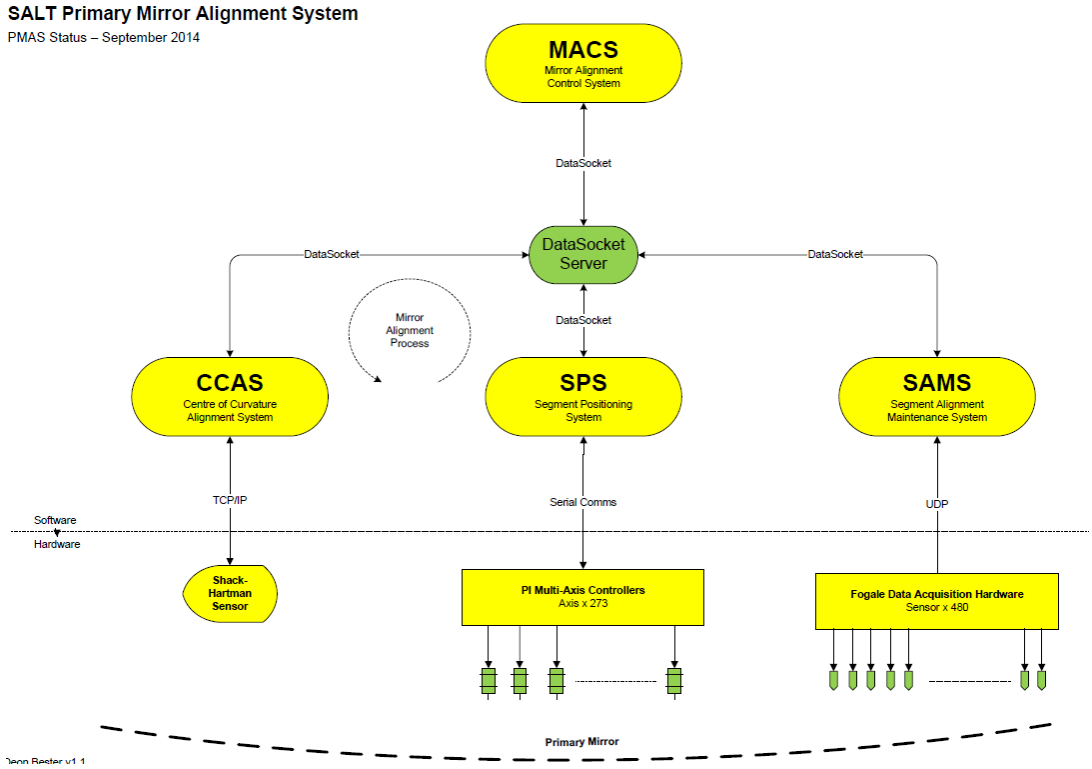


Figure 2. Breakdown Structure and Status of Primary Mirror Alignment System (PMAS)

A significant fraction of the latent software defects in the MACS, SPS and CCAS software have now been resolved. The SPS defects were particularly problematic and originally prevented tests longer than 24 hours in duration. The remaining software bugs involve incompatibilities between Labview and the most current versions (7 AND 8) of Windows. An experimental setup using virtual machines is currently being tested in an effort to resolve these issues.

2.2 Ongoing Work

The primary focus continues to be successfully demonstrating that the system operates to specification over a 5 day period and >10°C temperature span. Recent results are very encouraging, there being no fundamental technical problems with the system preventing us from achieving this.

In parallel with the system and software work, much effort is being directed towards the preparation of tools and equipment for the large scale deployment of the system (Combined Phases 2 and 3, now defined as Phase 2-1). This includes all the mechanical bonding equipment for the flexible sensors to the L-brackets, button bonding equipment and other installation details.

Lessons learned from the central 7 segments in terms of the cabling, connectors and bonding experience are being incorporated into the production of sensors, cabling and electronics for phase 2-1.

3. COMMERCIAL

A SALT delegation visited Fogale and its subcontractors in France and Switzerland over a period of two days (2-3 March 2015) with the intention of assessing and addressing quality and production readiness concerns. The team consisted of the following members with the following responsibilities:

Chris Coetzee : Commercial and Contractual Concerns

Hitesh Gajjar : Engineering and Technical Issues

Keith Browne : Technical Quality and Integration

Vic Moore : Procurement

The 3 primary subcontractors supplying the electronics (Omicron), cabling (Industrifill) and flexible sensors (Cicorel) were visited and discussions regarding the various technical aspects ensued. The discussions uncovered a small number of uncertainties regarding the manufacture and more specifically the testing process. The overall conclusion is however that all suppliers including Fogale are well equipped and capable of delivering all the hardware at the required quality and production rates as quoted by Fogale. An in-depth report is available on request.

Final discussions with Fogale are underway concerning the consolidation of what were previously called Phases 2 & 3 into a single procurement, Phase 2-1. The BEC and Chair has given approval to go ahead with the procurement, the placement of the order is imminent.

A very important advantage of combining Phases 2 and 3 into a single Phase 2-1 is that the delivery schedule of FOGALE was shortened dramatically from 14 months to 7 months. This halving of the schedule will reduce the cost of the “marching army” as well and give us a fighting chance to complete the project within the current (2015-16) financial year. The SALT Foundation will also get the advantages of less science time lost, better mirror alignment with concomitant better image quality, 7 months earlier.

4. RISKS

The Risk Register is still a work in progress and will be refined, as we understand the production jobs better. The RESIDUAL RISKS must be understood to be the risk remaining after the mitigation actions have been successfully implemented. It does not mean that the risk are currently mitigated. The CURRENT STATUS is as defined in the RISK NUMBER column.

TABLE 1: RISKS

CURRENT STATUS					MITIGATED STATUS AT END OF THE PROJECT (RISK NUMBER INDICATES LATENT DEFECTS THAT MAY AFFECT OPERATIONS IN THE FUTURE)			
RISK	EFFECTS	IM-PACT	PROBABILITY	RISK NUMBER	MITIGATION IN PROCESS AND BEING PLANNED	IMPACT	PROBABILITY	RISK NUMBER
PMAS does not meet 5 day >10C specification	• Specification - alignments must be done daily to every 3 days until that test is completed and passed successfully. • Project – Schedule delay in commissioning because weather is not under our control	M	L	ML	• Keep on testing the 7 segment installation and achieve the 5 day, 10> C target as soon as operating and weather condition allow • Test production system in an incremental fashion as the installation becomes more mature • Do not only do a SAMS acceptance test but also a PMAS acceptance test	L	L	Low
Sensors system do not meet specification	• Specification - Incorrect measurements	0	0	0	• Completed • Report in process	0	0	0
Residual software bugs in PMAS	• Project - schedule delay to find and debug • Operations – sporadic uncover of bugs as the system is thoroughly tested during very large temp swings and full operations	L	M	LM	• Currently known bugs, as defined above, can be mitigated by an experimental setup using virtual machines currently being tested in an effort to resolve these issues • Software work is never completely done since the requirements for new functionality always comes to the fore but they can be vetted for and tested thoroughly before implementation • Unknown bugs may be uncovered as the array develops from 7 segments to the full 91 segments. They have to be found and fixed in a systematic way as is currently done with the 7 segment installation	L	L	Low and fit for purpose Requirements for new or modified function will continue during full scale operations as is the case with all s/w based systems
Bonding of buttons takes longer than estimated	• Project -schedule delay	M	M	MM	• Experiments are being done to establish a realistic production process and effort • The correct curing equipment have been supplied and tested • Hitesh has successfully bonded prototype buttons during the 7 segment installation. That time is available and is being used in the current calculations.	0	0	0
Button bonding delivers inconsistent quality	• Project - schedule delay • Operations – repairs required	M	L	LM	• Process proven on small scale • Implement prescribed process • Use FOGALE supplied bonding jigs and equipment • Train staff • Supervision • Regular quality inspections, audits, reports and reviews • Spares available – buttons can be removed and re-bonded during project phase and operations	L	L	Low
Flexure bonding takes longer than estimated	• Project - schedule delay	M	M	MM	• Training of team leader in June. • More production jigs to me made to deliver at the required rate.	0	0	0

					• **Extra short-term staff may be needed to produce at the required rate. They will have low labour rates. A firm request will be made once more detail is available but a fist order estimate is R75-R120k**			
Flexure bonding delivers inconsistent quality	• Specification - PMAS system performance will be compromised • Project – schedule delay as more flexures have to be bonded	M	L	ML	• Process proven on small scale • Process to be followed • Set-up production line to conform with requirements • Team leader to be trained • Team leader trains and supervise staff • Production jigs and equipment supplied by FOGALE to be used • Test and calibration equipment is being obtained from FOGALE • Regular quality inspections, audits, reports and reviews • Spares of flexures and L-brackets and connectors are available to replace faulty ones during project phase and operations	L	L	**Low** - Latent defects may become apparent during full scale opera-tions.
Cable installation faulty	• Project - PMAS system performance can be erratic and cause schedule delays to debug • Operations – connectors and small cables disturbed during mirror segment swapping	L	L	LL	• We have sufficient manpower to fix it if necessary • Spare cables and connectors available • Will probably have to develop support equipment to minimise inadvertent damage during mirror swapping	L	L	**Low** Inadvert ent damage to small cables and connecto rs during mirror segment swappin g
FOGALE delivers late	• Project - schedule delay	L	L	LL	• Production readiness review found that FOGALE and sub-contractors have the capacity to deliver the required volumes and required rate. • 20% Final payment at end of ATP will act as a motivator to deliver on time	0	0	0
FOGALE delivers non conforming products	• Specification - PMAS system performance can be compromised • Project -schedule delay	H	L	HL	• Production readiness review of FOGALE and sub-contractors completed. No show stoppers found as far as quality issues are concerned. • Quality problems with button manufacturing at SAAO attended to before full-scale production starts.	L	L	**Low** Very minor latent defects may be discover-ed during opera-tions and repairs should be possible
Telescope operations are affected by constant work on the PMAS and SAMS and primary mirror array. This means more Engineering downtime than budget for as we have seen with the installation and testing of the first 7 segments	• Project - PMAS test schedule delay since operations will get priority. • Project - Acceptance testing of the system may take longer than foreseen • Operations – newly swapped segments out of capture range	M	M	MM	• Refine current installation and operational procedures to take into account the challenges of much larger scale operations • Train operators (they are being trained and gaining valuable experience on the 7 segments system) • Co-ordination of installation and testing between project and operational teams. This is much easier now that both functions reside under one management team. • System is designed to allow for mirror swapping but more thought has to go into the operational process and then implemented in the software.	L	L	**Low**
Retention of key contractors as defined in SALT Operations report Chapter 3	• Project – some functions cannot be executed without them and the project will fail or be delayed for an unknown time until others can take over and become proficient in the job. This will also be the case even if current staff have to take over although the learning curve might be shorter..	H	M	HM	• Retain John Menzies (mathematician and analyst) • Retain Deon Bester (PMAS ans SAMS software engineer). Deon Bester has other options abroad so his contract needs **immediate** attention • Should they stay the residual risk is seen to be as indicated in the next 3 columns	L	L	**Low** Some latent defect s and bugs may still be uncov er-ed during full scale operati ons

Legend:

IMPACT	DEFINITION	PROBABILITY	DEFINITION
Low	Will not affect the performance of the mirror alignment and or minimally (1 w) affect the schedule	Low	May happened sporadically during operations and or project phase. Multiple failures will have to happened before this failure will occur
Medium	Will affect the mirror alignment from time to time but the system regains control after and anomaly has occurred and or somewhat (1w-1m)affect the project schedule	Medium	May happen from time to time during operations and or project phase. More than one smaller failures will have to occur before this particular probability will manifest itself
High	The alignment is affected to the extent that alignment must be done on a daily basis and or materially affect the project schedule (1m-6m)	High	May happened on a daily basis during operations and or project phase . Single point failure

Risk Summary:

The highest risk items are:

- The retention of specialist as defined and motivated in Chapter 3 of the SALT Operations Report
- The bonding of buttons to segments,
- The bonding of flexures to L-brackets
- The effects of disturbing the primary mirror during the 9 months as the system is installed and tested. It is a well know fact that teething problems surface when a complex system is disturbed and or modified to such a large extent.

Mitigation actions have been defined in the table above.

5. SCHEDULE

A tentative schedule is presented below (see Figure 3 at the end of the document) incorporating Fogale's proposed delivery schedule. The schedule is subject to change once the actual project commences, but does nominally predict an operational array including ATP towards the end of March 2016.

The delivery of hardware is being accelerated as far as possible by Fogale to expedite the installation of hardware within the array. Sensors will be incorporated into the working system progressively as they are bonded and electronic racks delivered.

As indicated above, uncertainty exist in the schedule mainly due to the fact that the staff who will be doing the bonding of buttons to segments have very limited experience in that process to date and some large scale production challenges are under investigation. The team have not bonded any flexures to L-brackets as yet. Jonathan Love, the leader of the bonding team, will only receive training in that regard during the first week in June. Current calculations of man-hours required and durations are therefore based on very limited information. This will of course be reviewed when more facts become available. That is the reason why the team has incorporated a month's worth of schedule buffer at the end. Every effort (e.g. carefully planning of holidays per team member to have the minimum affect on the schedule) is going to be made to complete the project by 31 March 2016.

An important factor to keep in mind is that sufficient and the correct skilled and experienced people, currently all contracted for very short remaining period until end of May, and motivated in the SALT Operations Report Chapter 3 must be retained to have any chance of keeping to schedule. Certain functions just can not be execute without them, in particular mathematics and in depth data analysis (John Menzies) as well as crucial SAMS and PMAS software (Deon Bester).

6 BUDGET

The situation of the actual expenditure versus budget is included in Ismail's Financial Report. The cost of the request for the extension of key specialists' contracts have been included in the CFO's submission.

7. CONCLUSIONS

The initial stages of the engineering implementation of the edge sensor system is going well:

- Technical progress has been good in the last few months: the GRoC control problem has been solved; control of the 7 central segment array by SAMS has been demonstrated to specification for a period of 3 days and temperature range of 6 deg C; hitherto unrecognized problems with the individual components of the Primary Mirror Alignment System are being systematically uncovered and fixed.
- The commercial features of the project are firmly under control following the visit to the suppliers. Prior to this contact, risks of procurement problems were deemed to be serious. A shortened procurement period has been negotiated by combining hitherto distinct phases.
- Risks have been identified, so have mitigation actions and they are being managed and implemented in a systematic way. At the time of writing, it is the Project Teams' opinion that, with the knowledge and experience gained since installation and testing of the first 7 segments started in September 2014, the PMAS, which includes the SAMS, can be made to work to specification.
- There is some schedule risk because of the inexperience of the team with some aspects of the work, and the complex teamwork required for installation of 456 edge sensors pairs (pair =transmitter and receiver) on the mirrors, wiring them up and making them work. We are grateful that SALT is not a thirty metre class telescope with about 1000 mirror segments.

8 RECOMMENDATIONS

a. The Board funds the retention of the specialists, Dr John Menzies and Deon Bester, as motivated and costs defined in Chapter 3 of the SALT Operations Report

		Task Name	% Complete	Duration	Start	Finish	Predecessors	Successors	Resources
1		+ Completion of Phase 1	0%	14 days?	2015/02/16	2015/03/04			
6		+ Commercial Preparation for Phases 2 and 3	0%	19 days?	2015/02/16	2015/03/11			
14		+ Technical Preparation for Phases 2 and 3	13%	97.94 days?	2015/04/01	2015/07/31			
22									
23		+ Button Manufacture and Bonding	0%	96 days?	2015/05/18	2015/09/28			
46									
47		- Delivery and Testing of First 115 sensors + Test Rack	0%	160 days?	2015/03/12	2015/10/21	9		
48		Preparation of 35 sensors at FOGALE	0%	30 days	2015/03/12	2015/04/22			
49		Delivery of 35 sensors	0%	1 day?	2015/07/07	2015/07/07	50,51		
50		Delivery of Test rack + modules + cables	0%	1 day?	2015/07/08	2015/07/08	49	52	
51		Bond 35 sensor pairs rate at 5/day	0%	7 days	2015/07/08	2015/07/16	49	52,54	
52		Characterise 35 sensor pairs (Cape Town)	0%	14 days	2015/07/17	2015/08/05	51,50		
53		Delivery of 20 sensor pairs	0%	10 days	2015/08/17	2015/08/28	49	54,56	
54		Bond 20 sensor pairs rate at 5/day	0%	4 days	2015/08/31	2015/09/03	53,51	57	
55		Characterise 20 sensor pairs	0%	4 days	2015/07/17	2015/07/22	51	58	
56		Delivery of 20 sensor pairs	0%	10 days	2015/08/31	2015/09/11	53	57,59	
57		Bond 20 sensor pairs rate at 5/day	0%	4 days	2015/09/14	2015/09/17	56,54	58,60	
58		Characterise 20 sensor pairs	0%	4 days	2015/09/18	2015/09/23	57,55	61	
59		Delivery of 20 sensor pairs	0%	10 days	2015/09/14	2015/09/25	56	60,62	
60		Bond 20 sensor pairs rate at 5/day	0%	4 days	2015/09/28	2015/10/01	59,57	61,63	
61		Characterise 20 sensor pairs	0%	4 days	2015/10/02	2015/10/07	60,58	64	
62		Delivery of 20 sensor pairs	0%	10 days	2015/09/28	2015/10/09	59	63,66	
63		Bond 20 sensor pairs rate at 5/day	0%	4 days	2015/10/12	2015/10/15	62,60	64,68	
64		Characterise 20 sensor pairs	0%	4 days	2015/10/16	2015/10/21	63,61		
65									
66		- Manufacture of 341 sensor pairs (FOGALE)	0%	77 days	2015/10/12	2016/01/26	62		
67		Delivery of 341 sensor pairs	0%	7 days	2015/10/12	2015/10/20	68		
68		Bond 341 sensors at 5/day	0%	70 days	2015/10/21	2016/01/26	67,63		
69		Characterise 341 sensors (5 /day)	0%	70 days	2015/10/21	2016/01/26			
70									
71		- Electronics + Cable Delivery and Installation	0%	185.94 days	2015/05/15	2016/01/29	9	83	
72		Procurement of RACKS and cable components	0%	110 days	2015/05/15	2015/10/15		73	
73		Expedition of 1 rack, 12 P and 12 SC cables	0%	7 days	2015/10/16	2015/10/26	72	74	
74		Expedition of 1 rack, 12 P and 12 SC cables	0%	7 days	2015/10/27	2015/11/04	73	75	
75		Expedition of 2 racks, 2x12 P and 12 SC cables	0%	7 days	2015/11/05	2015/11/13	74	76	
76		Expedition of 2 racks, 2x12 P and 12 SC cables	0%	7 days	2015/11/16	2015/11/24	75	77	
77		Expedition of 2 racks, 2x12 P and 12 SC cables	0%	7 days	2015/11/25	2015/12/03	76	78	
78		Expedition of 2 racks, 2x12 P and 12 SC cables	0%	7 days	2015/12/04	2015/12/14	77	79	
79		Expedition of 2 racks, 2x12 P and 12 SC cables	0%	7 days	2015/12/15	2015/12/23	78	80	
80		Expedition of 2 racks, 2x12 P and 12 SC cables	0%	7 days	2015/12/24	2016/01/01	79		
81		Installation of sensors, electronics and cables	0%	69.94 days	2015/10/26	2016/01/29		83	
82									
83		+ 3 ring Array ATP	0%	60 days	2016/02/04	2016/04/28	71,81		

Figure 3: Schedule