1. INTRODUCTION

This document outlines the series of BSM tests performed during the PV phase and reports on the final set of tuning parameters for both the photometer and spectrometer modes.

To determine the BSM tuning parameters, the BSM was either chopped between the nominal on/off positions or 7-point jiggle maps were performed. In order to accurately determine the chop axis stabilisation times for both the off –source and on-source positions, the BSM had to be chopped at low frequency and its position finely sampled. To achieve this goal the BSM was chopped at 1Hz (slow chop) and its position sampled at 4ms intervals.

1.1 REFERENCE DOCUMENTS

Ref	Document	Name	Version/Issue No.
RD01	**SPIRE-RAL-REP-003252**	**SPIRE BSM Flight Tuning – Initial Report**	**Issue 1.0**
RD02	**SPIRE-RAL-PRJ-001078**	**SPIRE Data ICD**	**Issue 3.0**
RD03	**Sap-SPIRE-CCa-076-02**	**DRCU/DPU Interface Control Document**	**Issue 1.3**
RD04	**LAM.PJT.SPI.NOT.011011**	**MCU/DPU Command List ICD**	**Issue 5.0**
RD05	**SPIRE-IFS-PRJ-001391**	**SPIRE OBS User Manual**	**Issue 4.0.0**
RD06	**SPIRE-RAL-PRJ-003018**	**SPIRE Commissioning Phase Plan**	**Issue 1.2**

1.2 CHANGE RECORD

Document	Change date	Changes
Issue 1		First Version

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2. SUMMARY OF BSM TESTS

Test #	CUS script/MC Configuration *MOIS procedure – where applicable*	Ops Day	OBSID	Date/Times	Execution Method Manual /MTL	Tuning parameters
1	SpireEngBsmTuner/ pvPhase_mconfig_61	196	0x500026DA	26-Nov-2009 00:01:54-04:51:10	MTL	• ChopFFGain & ChopKd • ChopJiggCouple • JiggFFGain & JiggKd
2	SpireEngBsmTuneFf/ pvPhase_mconfig_69 *SpireEngBsmTuneFf_03_02_2010_01.xls*	274	0x0000206C	11-Feb-2010 20:02:09-20:31:32	Manual	• ChopFFOffset • ChopFFGain
3	SpireEngBsmTuneChopPID/ pvPhase_mconfig_70	290	0x500036F1	27-Feb-2010 20:09:58-20:45:48	MTL	• ChopKp • ChopKi • ChopKd
4	SpireEngBsmTuneChopPID/ pvPhase_mconfig_74 *SpireEngBsmTuneChopPID_04_03_2010_01.xls*	302	0x0000211D	11-Mar-2010 21:02:00-21:33:25	Manual	Lowered the Ki limit and threshold • ChopKp • ChopKi • ChopKd
5	SpireEngBsmTuneChopPID/ pvPhase_mconfig_75 SpireEngBsmTuneChopPID_16_03_2010.xls	313	0x0000211E	22-Mar-2010 21:18:44-21:49:01	Manual	• ChopKp • ChopKi • ChopKd
6	SpireEngBsmTuneChopSettings/ pvPhase_mconfig_76	326	0x50004077	04-04-2010 21:50:27-22:49:48	MTL	• ChopKp • ChopKi • ChopKd Tried lowering the ChopFFGain
7	SpireEngBsmTuneChopSettings/ pvPhase_mconfig_78	361	0x50004980	09-05-2010 19:54:02-20:55:43	MTL	• ChopKp • ChopKi • ChopKd Tried increasing ChopKp, ChopKi and lowering ChopFFGain

Table 1 Summary of key BSM tuning tests

3. RESULTS OF BSM TUNING TESTS

3.1 BSM TUNING TEST #1

Before this test was even run, there was a concern expressed in **RD01** that the parameter ChopJigg_DCouple, which adds a cross-coupling compensation term proportional to the derivative of the chop sensor output (ChopSensSig), could be incorrectly set to 0 whereas it needed to be set to 32768 (0x8000). However, after the upload of OBS 4.0.0 and the update of nominal housekeeping to report the value of ChopJigg_DCouple, it soon became clear that this parameter was already set to its correct value.

This test attempted to tune several BSM tuning parameters as summarised in Table 2. The test was split up into sections as follows:

- First the ChopFFGain and ChopKd were varied simultaneously while chopping between the central positions of the 7-point jiggle map. This cycle was repeated for the central positions of the 64-point jiggle map. All the other tuning parameters were set to their nominal values as defined in Table 2.
- Next the chop and jiggle axes coupling term ChopJiggleCouple was varied while keeping other parameters set to their nominal values. Here again the cycle was repeated for both the 7-point and 64-point jiggle maps.
- The JiggFFGain and JiggKd terms were varied simultaneously while chopping between the central positions of the 7-point and 64-point jiggle maps. All the other tuning parameters were set to their nominal values as defined in Table 2.

Note that the ChopFFOffset was set to the fixed value of 37535 (0x929F), as previously determined from the BSM functional tests performed in the commissioning phase (see **RD01**).

BSM Tuning Parameter/s	Nominal Value (ADU)	Low (in units of nominal value)	High (in units of nominal value)	Step size (in units of nominal value)
ChopFFGain **ChopKd**	**3051 (0x0BEB)** **3240 (0x0CA8)**	**0.6** **0.2**	**1.4** **1.8**	**0.05** **0.2**
ChopJiggCouple	**33121 (0x8161)**	**0.989342**	**1.101065**	**0.001776**
JiggFFGain **JiggKd**	**6104 (0x17D8)** **7000 (0x1B58)**	**0.6** **0.2**	**1.4** **1.8**	**0.05** **0.2**

Table 2 BSM tuning parameters and their ranges for BSM Tuning Test #1

The key result of this test was the determination of the optimum chop and jiggle axes coupling term ChopJiggleCouple and the JiggFFGain. The coupling was found to be minimal with ChopJiggCouple set to 33297 (0x8211) while the optimum JiggFFGain was found to be 6104 (0x17D8).

However the sheer volume of test data from this observation and the complexity of data reduction made it very difficult to reach any definitive conclusions about the other tuning parameters. As a consequence of this test a new strategy was adopted in which a series of much shorter tests were to performed, with each test focussing on tuning a reduced set of parameters and the results then being fed into the next test in the sequence.

3.2 BSM TUNING TEST #2

This test set out to optimise the ChopFFOffset and ChopFFGain parameters. Chopping was only performed for the central positions of the 7-point jiggle map.

BSM Tuning Parameter/s	Nominal Value (ADU)	Low (in units of nominal value)	High (in units of nominal value)	Step size (in units of nominal value)
ChopFFOffset	**37535 (0x929F)**	**0.93606**	**1.06394**	**0.021313**
ChopFFGain	**2300 (0x08FC)**	**0.843478**	**1.156522**	**0.052174**

Table 3 BSM tuning parameters and ranges for BSM Tuning Test #2

These two parameters were successfully optimised in the tests performed on OD274. The optimum ChopFFOffset has now been in use for all in flight observations since OD290.

3.3 BSM TUNING TEST #3

Theis test on OD290 attempted to simultaneously tune the chop PID parameters (viz. ChopKp, ChopKi and ChopKd) but the results were not very encouraging despite exploring extended ranges in parameter space. Stabilisation times in the chop direction were excessively long, i.e. ~100-150ms.

BSM Tuning Parameter/s	Nominal Value (ADU)	Low (in units of nominal value)	High (in units of nominal value)	Step size (in units of nominal value)
ChopKp	**1000 (0x03E8)**	**0.5**	**1.5**	**0.5**
ChopKi	**930 (0x03A2)**	**0.333333**	**1.666666**	**0.333333**
ChopKd	**4278 (0x10B6)**	**0.666666**	**1.333333**	**0.166666**

Table 4 BSM tuning parameters and their ranges for BSM Tuning Test #3

3.4 BSM TUNING TEST #4

In this test on OD302 the ChopKi and ChopKd parameter ranges were further extended and ChopKp significantly reduced. In addition the parameters ChopIntLimit and ChopIntRef, which control the chop integration limit and threshold, were lowered from a common default value of 65535 (0xFFFF) to 2048 (0x800) and 2000 (0x7D0) respectively.

BSM Tuning Parameter/s	Nominal Value (ADU)	Low (in units of nominal value)	High (in units of nominal value)	Step size (in units of nominal value)
ChopKp	**100 (0x0064)**	**0.0**	**1.0**	**1.0**
ChopKi	**930 (0x03A2)**	**0.0**	**4.0**	**1.0**
ChopKd	**4278 (0x10B6)**	**0.333333**	**1.333333**	**0.333333**

Table 5 BSM tuning parameters and their ranges for BSM Tuning Test #4

The stabilisation time approached ~50ms but only for ChopKi=0. For ChopKi≠0, the chop motor current was set to maximum negative value and drove the BSM to its minimum chop value of ~10000. This unexpected behaviour appears to be the result of a bug in the control algorithm inside the MCU DSP.

3.5 BSM TUNING TEST #5

For this test during OD313, the ChopKi range was decreased (but not set to 0) and the ChopKd range increased. ChopIntLimit and ChopIntRef were both reset back to their common default value of 65535 (0xFFFF).

BSM Tuning Parameter/s	Nominal Value (ADU)	Low (in units of nominal value)	High (in units of nominal value)	Step size (in units of nominal value)
ChopKp	**100 (0x0064)**	**0.0**	**1.0**	**1.0**
ChopKi	**930 (0x03A2)**	**0.0**	**4.0**	**1.0**
ChopKd	**4278 (0x10B6)**	**0.333333**	**1.333333**	**0.333333**

Table 6 BSM tuning parameters and their ranges for BSM Tuning Test #5

The stabilisation times were again very long (~150-200 ms) in all cases.

3.6 BSM TUNING TEST #6

For these tests on OD326, 7-point jiggle maps were run for each parameter set to ensure that the test was as representative as possible of the small map AOT. The ChopKi range was decreased yet further (including setting it to 0) and the higher end of ChopKd range was also explored.
A slightly lower than the nominal value of the ChopFFGain attempted while stepping very slowly in ChopKi.

For each parameter set the four corners corresponding to the BSM positions of the full spectrometer map (SM16) were visited immediately after the 7-point jiggle map. This was done to check for the positional and temporal stability for spectrometer map observations.

Jiggle Map #	ChopKp	ChopKi	ChopKd	ChopFFGain
JM01	0	100	4278	2350
JM02	100	100	4278	2350
JM03	100	100	7000	2350
JM04	100	100	8000	2350
JM05	100	100	9000	2350
JM06	100	0	4278	2350
JM07	100	0	7000	2350
JM08	100	0	8000	2350
JM09	100	0	9000	2350
JM10	100	10	4278	2350
JM11	100	10	7000	2350
JM12	100	10	8000	2350
JM13	100	10	9000	2350
JM14	0	0	4278	2350
JM15	0	0	7000	2350
JM16	0	0	8000	2350
JM17	0	0	9000	2350
JM18	0	100	4278	2200
JM19	100	100	4278	2200
JM20	100	100	7000	2200
JM21	100	100	8000	2200
JM22	100	100	9000	2200
JM23	100	0	4278	2200
JM24	100	0	7000	2200
JM25	100	0	8000	2200
JM26	100	0	9000	2200
JM27	100	10	4278	2200
JM28	100	10	7000	2200
JM29	100	10	8000	2200
JM30	100	10	9000	2200
JM31	0	0	4278	2200
JM32	0	0	7000	2200
JM33	0	0	8000	2200
JM34	0	0	9000	2200

Table 7 BSM tuning parameter sets (identified by the Jiggle Map #) for BSM Tuning Test #6

Optimum stabilisation time was found to be ~35-40ms, but only with ChopFFGain=2350, ChopKi=0, ChopKp=100 and ChopKd=4278, corresponding to parameter set JM #06 in Table 7.

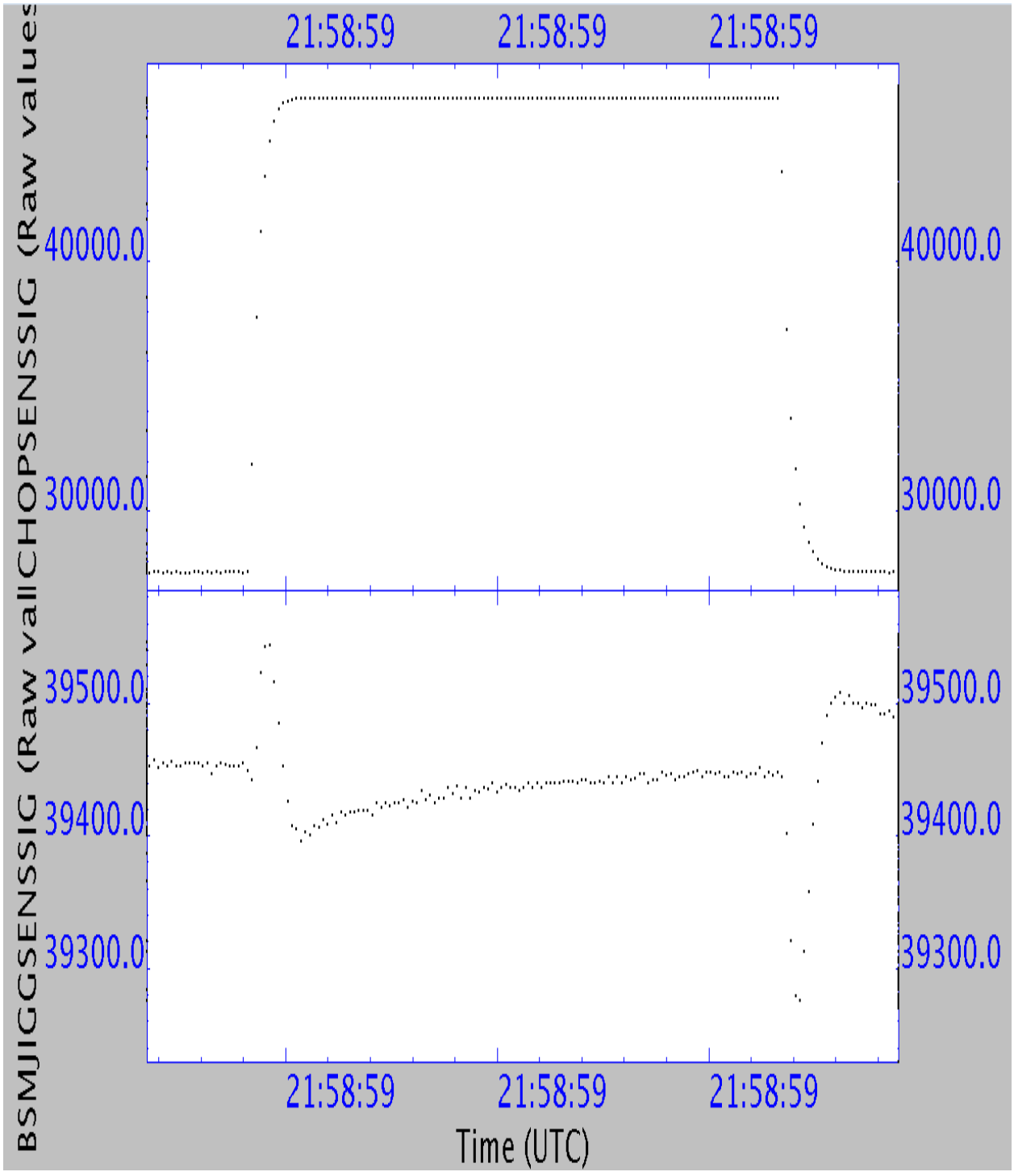

Figure 1 Chop cycle showing the stabilisation time for the "on" and "off" positions

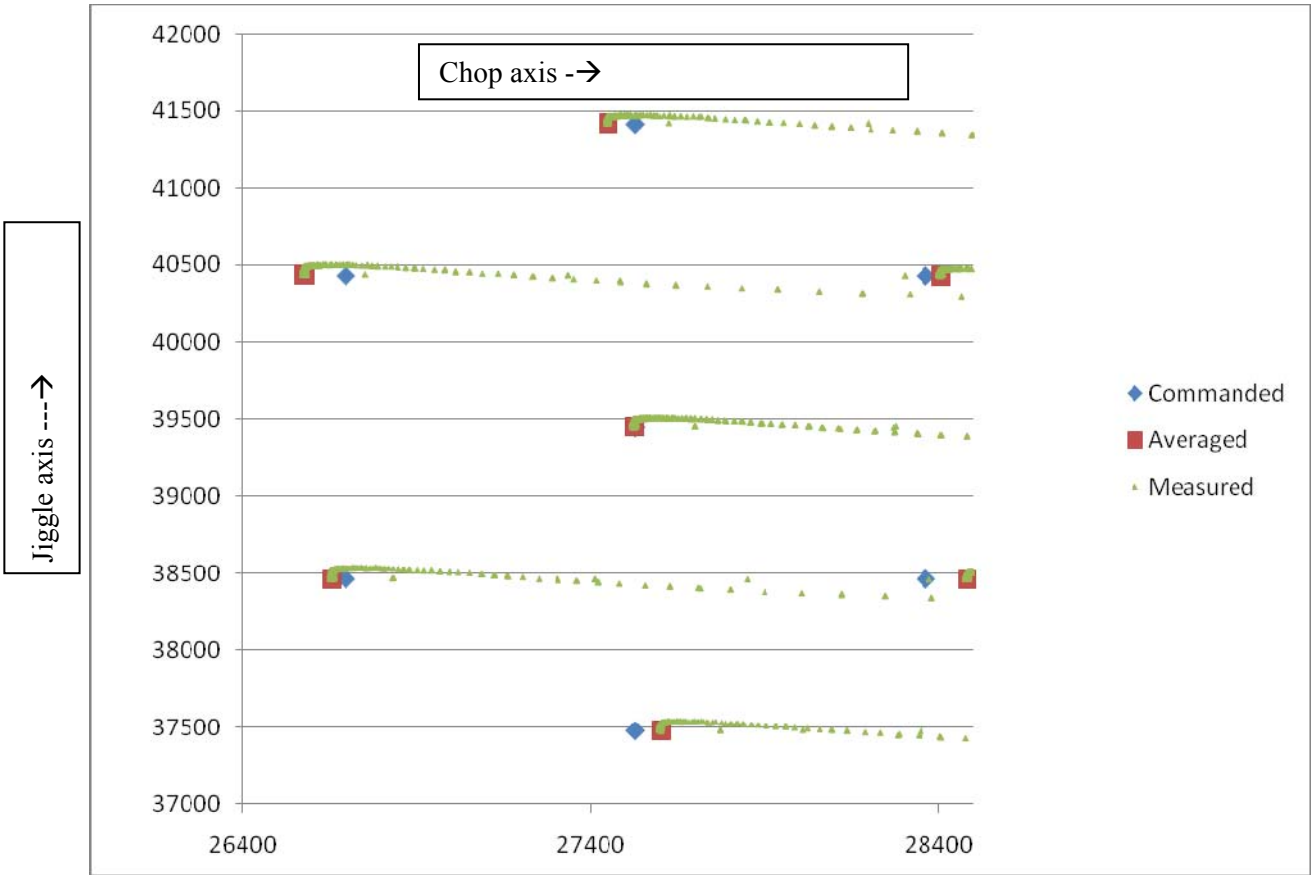

Figure 2 7-point Jiggle Map comparing the commanded and measured BSM positions for the "off" position.

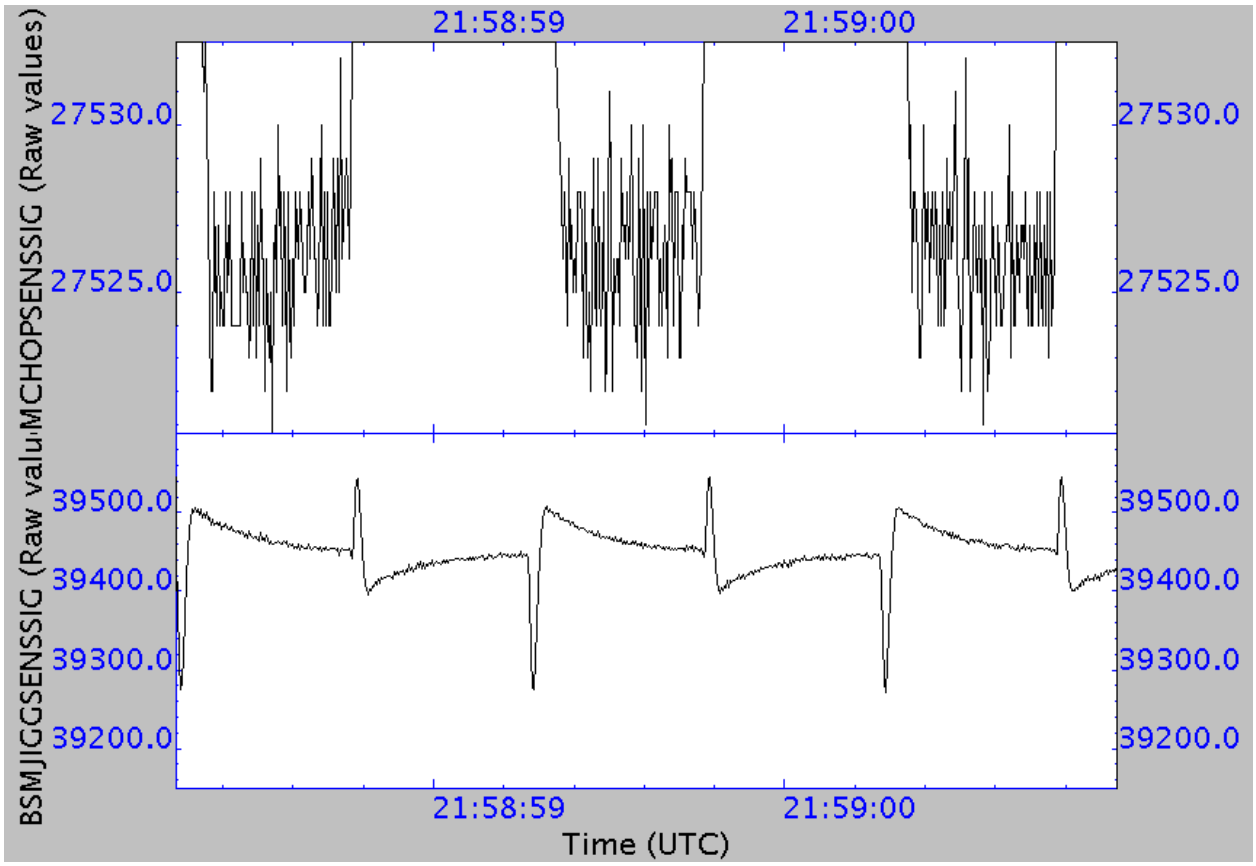

Figure 3 Typical chop and jiggle positional stability for the "off" position. For the chop axis the position appears stable to within ~±5 ADUs. An arcsecond corresponds to ~160 and ~300ADUs for the chop and jiggle axes respectively.

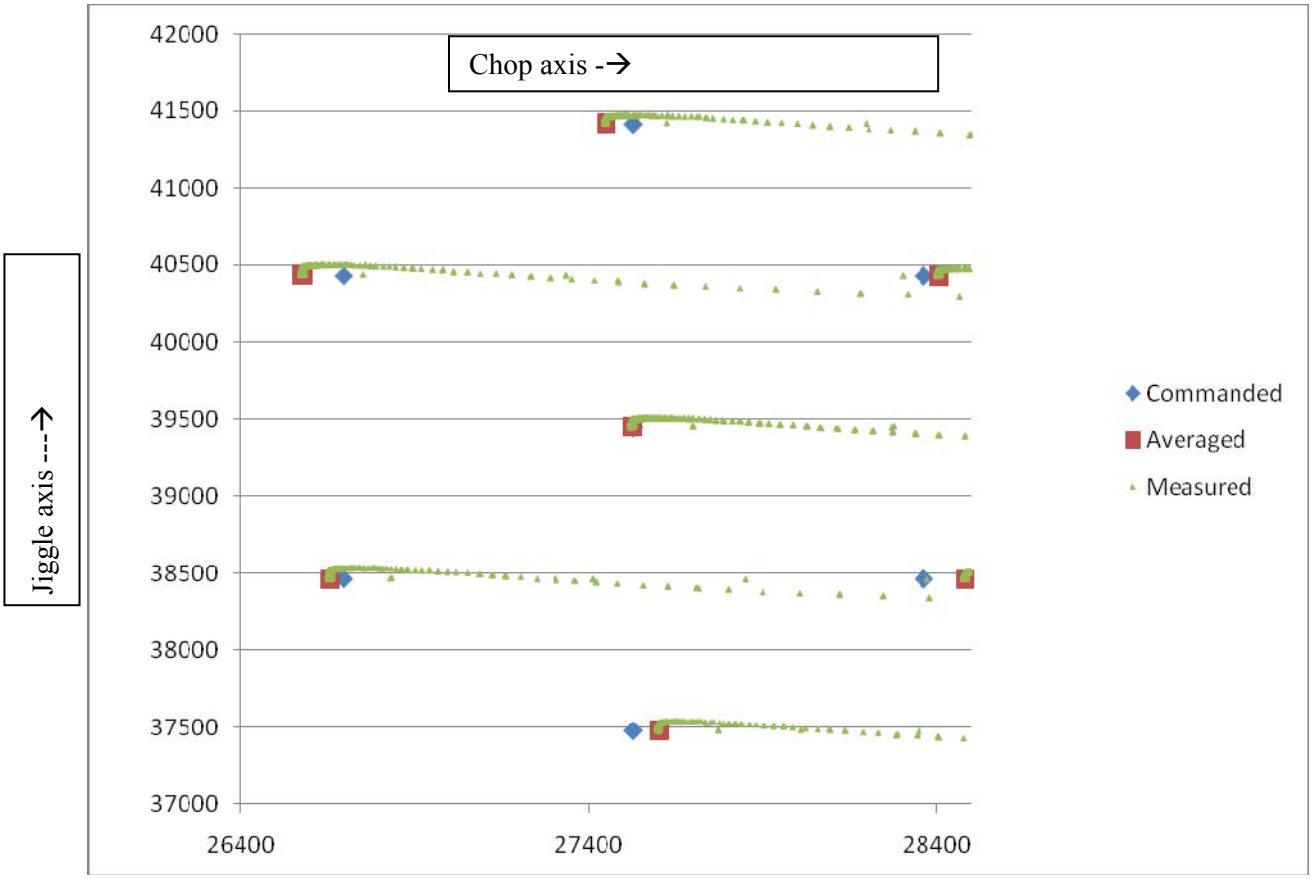

Figure 4 7-point Jiggle Map comparing the commanded and measured BSM positions for the "on" position.

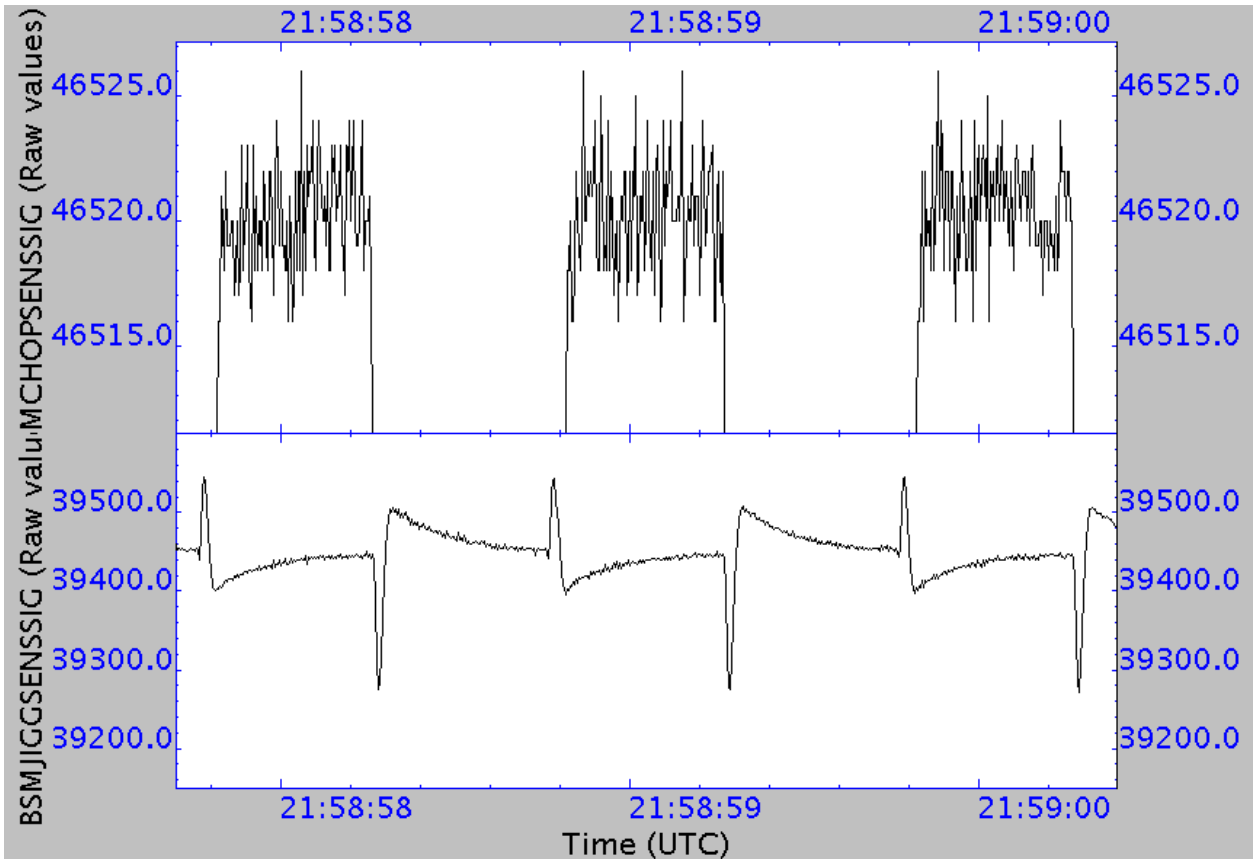

Figure 5 Typical chop and jiggle positional stability for the "on" position. For the chop axis the position appears stable to within ~±5 ADUs. An arcsecond corresponds to ~160 and ~300ADUs for the chop and jiggle axes respectively.

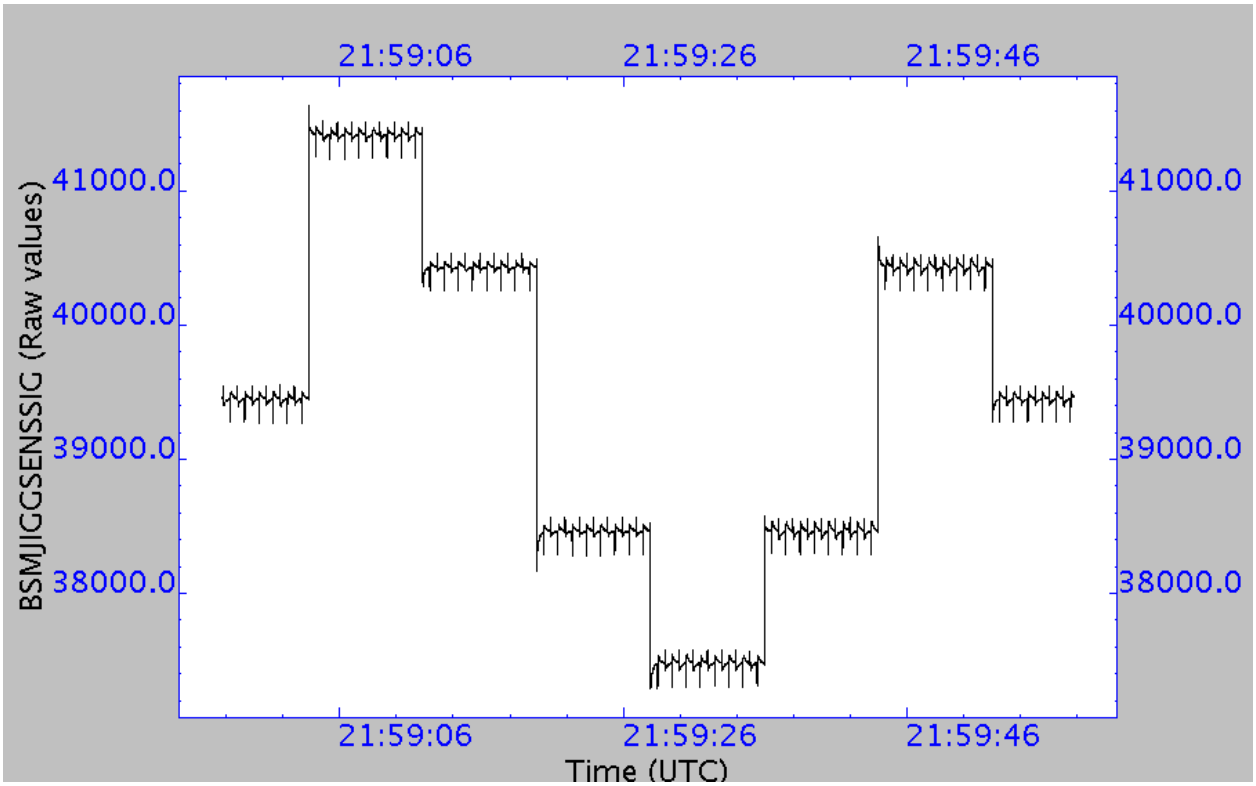

Figure 6 Plot showing the jiggle positional stability for all 8 positions of the 7-point Jiggle Map (central position of the map is repeated at the end).

3.6.1 BSM stability for spectrometer maps

The BSM tuning parameters as optimised for the 7-point jiggle map also give a measured timing stability of the order of ~40-50ms for the four corners of the SM16 full spectrometer map (see Figure 7), well within the required stability criterion of ≤1 second, However, the measured chop positions are as much as 800-900 ADUs (≡ ~8-9 arcseconds) away from the commanded positions, whereas the measured jiggle positions are almost exactly the same as the commanded positions, as can be clearly seen in Figure 8.

Using the default values of ChopKp, ChopKi, ChopKd, ChopFFGain and JiggFFGain, as determined during the commissioning phase the commanded chop and jiggle positions are reached to within ±10-20 ADUs (≡ < ~1 arcsecond), as demonstrated from the routine observation 0x5000548B shown in Figure 9.

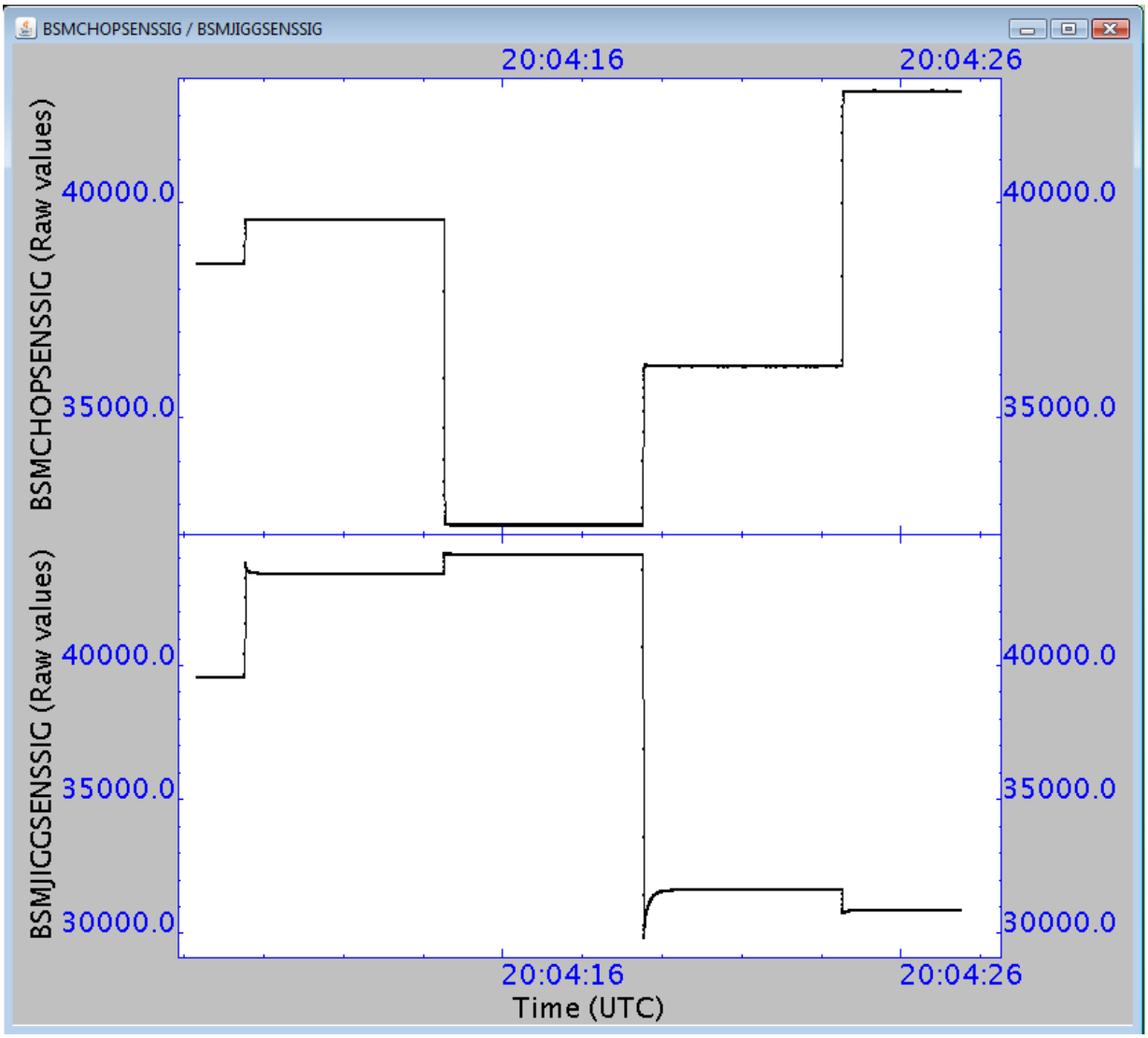

Figure 7 Plot showing the timing stability for reaching the BSM chop and jiggle positions for the four corners of the full spectrometer map. The initial position is the BSM hold position.

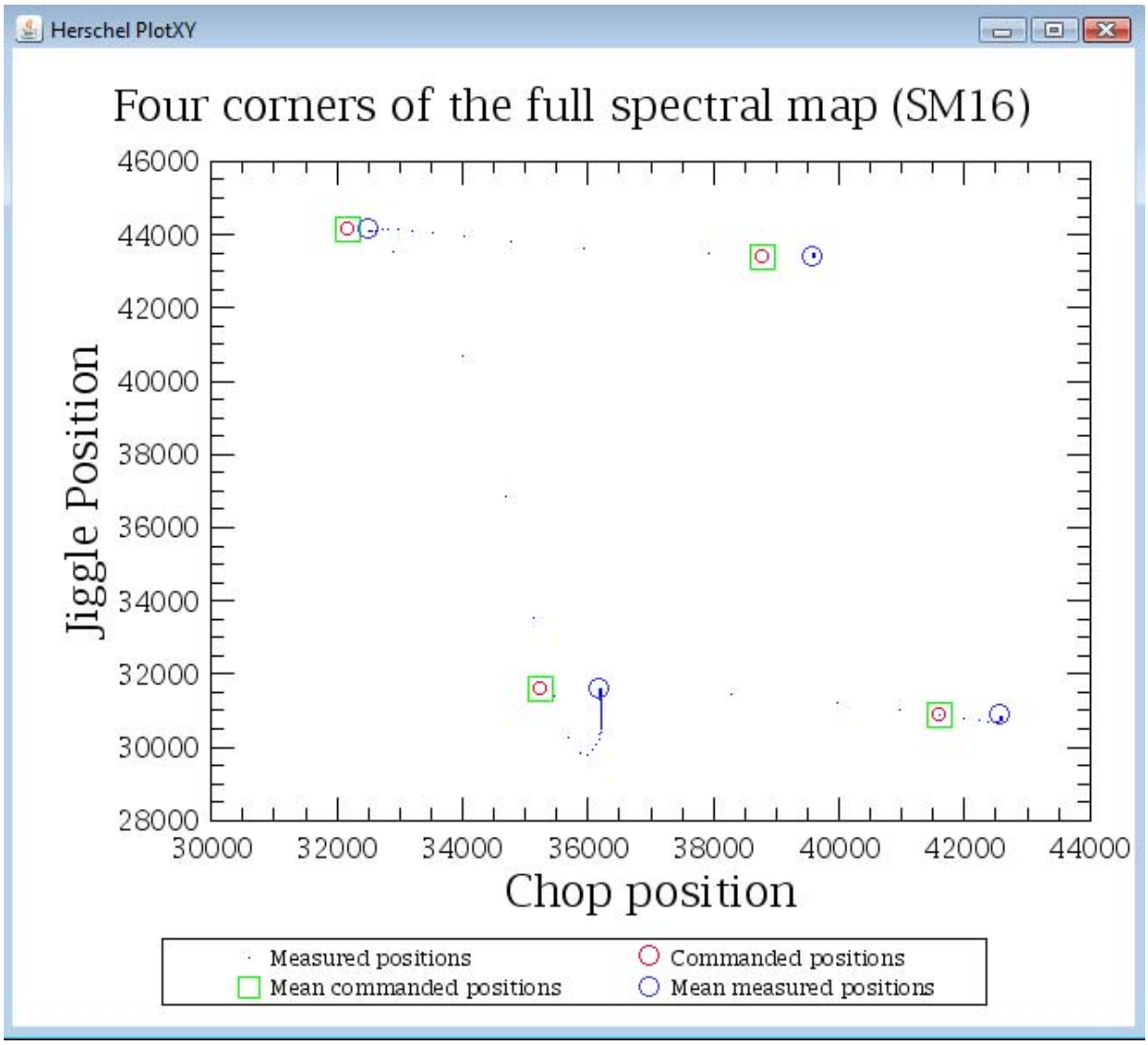

Figure 8 Plot showing the commanded and measured BSM positions for the four corners of the full spectrometer map

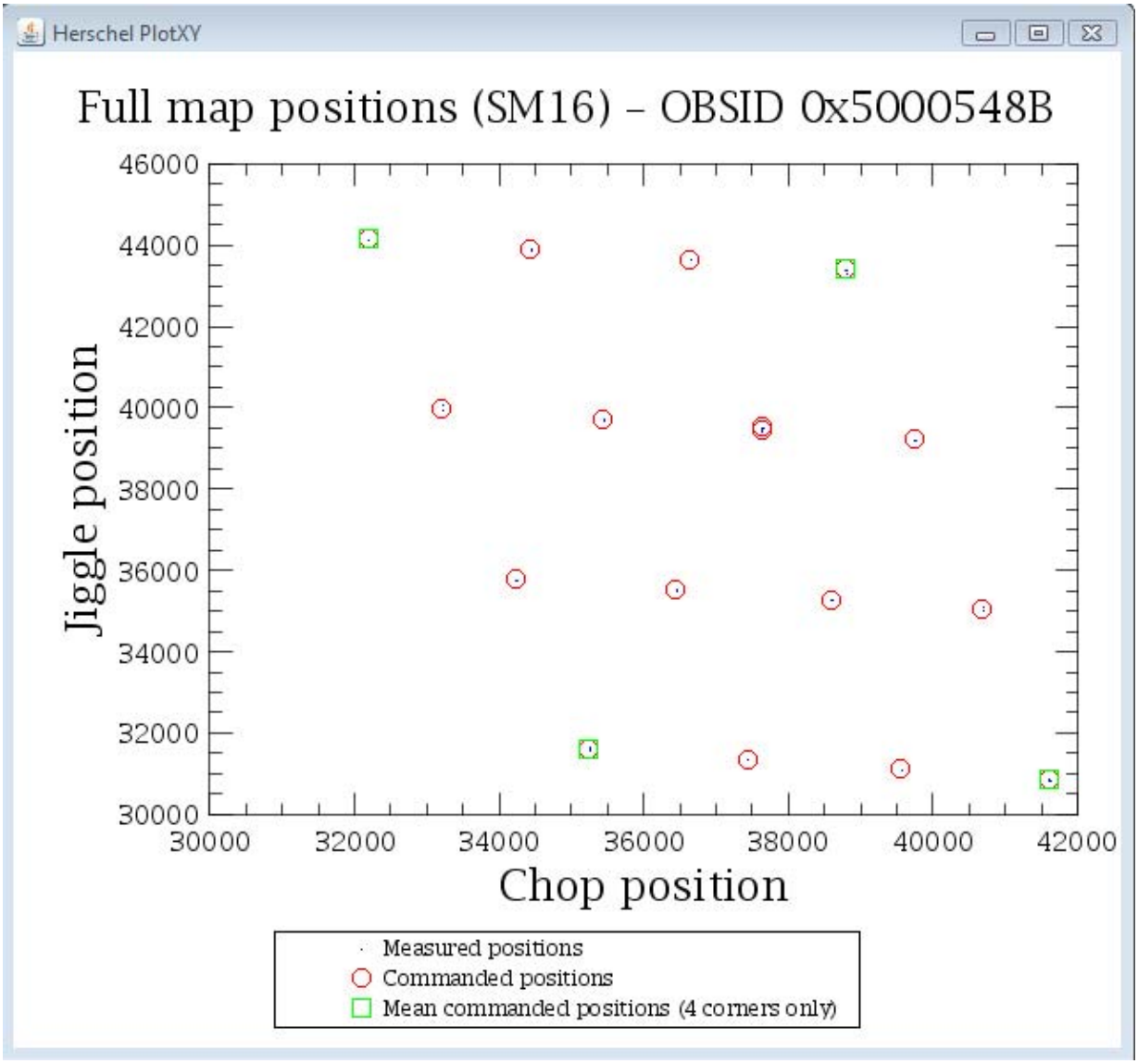

Figure 9 Plot showing the chop and jiggle positions for the full spectrometer map (SM16) observation 0x5000548B taken in OD 404.

3.7 BSM TUNING TEST #7

This test, which was performed in OD 361, was very similar to BSM Tuning Test #6 but with following exceptions:

- the second value of ChopFFGain was decreased from 2200 to 1900 and higher settings of ChopKp and ChopKi also explored.
- the four corners corresponding to the BSM positions of the full spectrometer map (SM16) were visited using the direct DRCU commands to move the BSM, rather than the BSMMove VM.

Jiggle Map #	ChopKp	ChopKi	ChopKd	ChopFFGain
JM01	0	100	4278	2350
JM02	100	100	4278	2350
JM03	100	100	7000	2350
JM04	100	100	8000	2350
JM05	100	100	9000	2350
JM06	100	0	4278	2350
JM07	100	0	7000	2350
JM08	100	0	8000	2350
JM09	100	0	9000	2350
JM10	400	0	4278	2350
JM11	400	0	7000	2350
JM12	400	0	8000	2350
JM13	400	0	9000	2350
JM14	0	0	4278	2350
JM15	0	0	7000	2350
JM16	0	0	8000	2350
JM17	0	0	9000	2350
JM18	0	100	4278	1900
JM19	100	100	4278	1900
JM20	100	100	7000	1900
JM21	100	100	8000	1900
JM22	100	100	9000	1900
JM23	100	200	4278	1900
JM24	100	200	7000	1900
JM25	100	200	8000	1900
JM26	100	200	9000	1900
JM27	100	50	4278	1900
JM28	100	50	7000	1900
JM29	100	50	8000	1900
JM30	100	50	9000	1900
JM31	100	300	4278	1900
JM32	100	300	7000	1900
JM33	100	300	8000	1900
JM34	100	300	9000	1900

Table 8 BSM tuning parameter sets (identified by the Jiggle Map #) for BSM Tuning Test #7

The effect of lowering the ChopFFGain and increasing ChopKi did not lead to any improvement in the chop position and timing instability. So the results from section 3.6 are applicable for all photometer flight operations.

4. SUMMARY OF FINAL BSM TUNING PARAMETERS

4.1 Photometer Parameters

The final set of BSM tuning parameters for the photometer is given in Table 9. These parameters are valid for the 7-point jiggle map mode (POF2) and all released mapping modes (viz. POF5 and POF10).

Parameter	Value/Decimal	Value/Hex	Tuned on Ops Day
ChopFFGain	**2350**	**0x092E**	**274**
ChopKp	**100**	**0x64**	**326**
ChopKi	**0**	**0x0**	**326**
ChopKd	**4278**	**0x10B6**	**326**
JiggFFGain	**6104**	**0x17D8**	**196**

Table 9 Final set of BSM tuning parameters for the photometer

4.2 Spectrometer Parameters

The final set of BSM tuning parameters for the spectrometer is given in Table 10. These parameters are valid for *all* spectrometer modes.

Parameter	Value/Decimal	Value/Hex	Tuned on Ops Day, if applicable
ChopFFGain	**1904**	**0x092E**	**Ground**
ChopKp	**100**	**0x64**	**106**
ChopKi	**0**	**0x0**	**106**
ChopKd	**4278**	**0x10B6**	**106**
JiggFFGain	**3950**	**0x0F6E**	**Ground**

Table 10 Final set of BSM tuning parameters for the spectrometer

4.3 Common Parameters

There are just a few tuned BSM parameters which are applicable to both the photometer and spectrometer, as can be seen in Table 11. All other tuneable BSM parameters not explicitly referenced in this report have been left set to their default values as specified in **RD04**.

Parameter	Value/Decimal	Value/Hex	Tuned on Ops Day, if applicable
ChopJiggCouple	**33297**	**0x8211**	**196**
ChopDiffTC1	**4096**	**0x1000**	**Ground**
ChopFFOffset	**36742**	**0x8F86**	**274**
JiggFFOffset	**39238**	**0x9946**	**Data taken in OD 6 but value set in OD 196**

Table 11 Final set of common BSM tuning parameters for the photometer and spectrometer