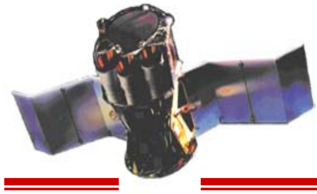
Submillimeter Wave Astronomy Satellite (SWAS)

SWAS Calibration

Volker Tolls, Gary Melnick, Ted Bergin
And the SWAS Team
Ball Aerospace, Millitech Corp., and University of Cologne



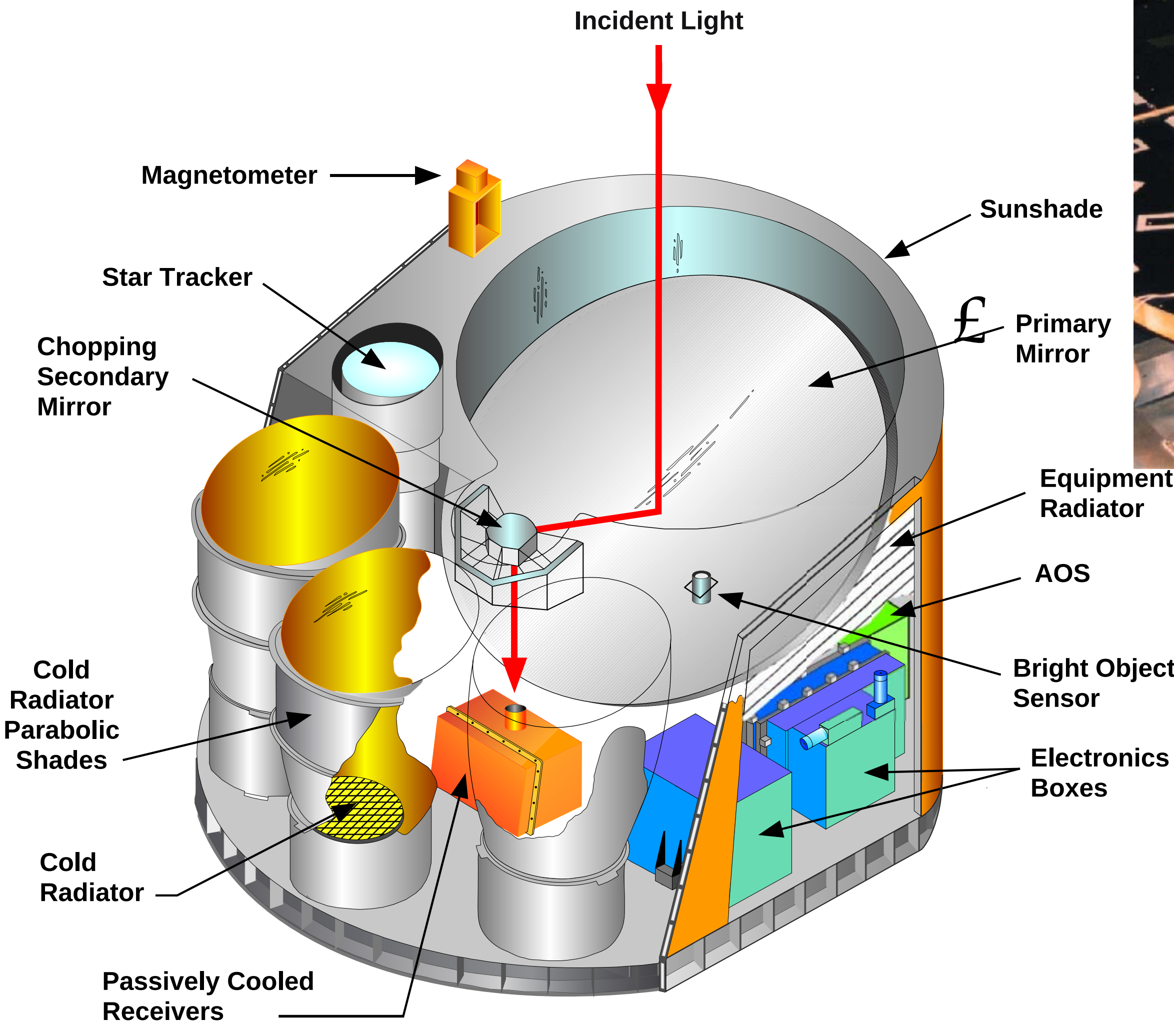
SWAS History

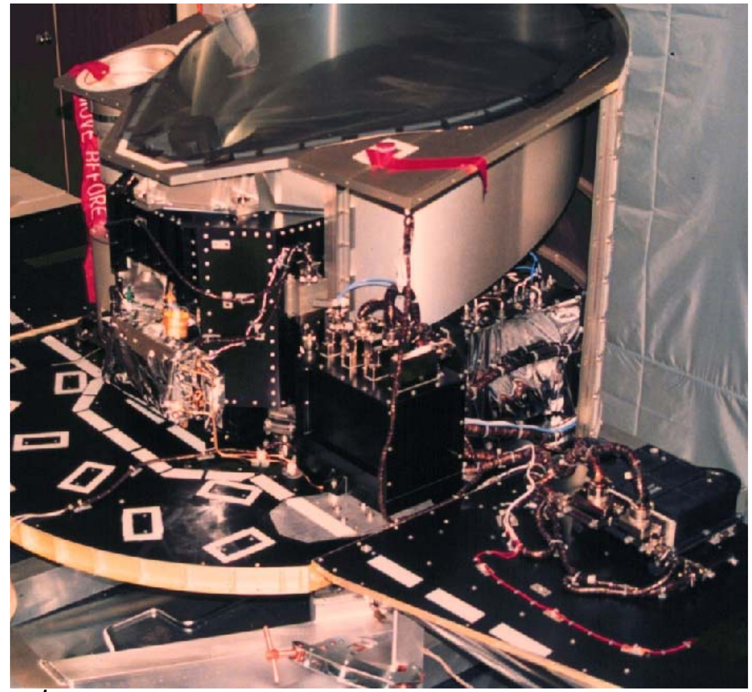
4/1/89	SWAS Mission selected
9/29/89	SWAS Project started
5/13/92	SWAS Instrument PDR
2/23/93	SWAS Instrument CDR
12/20/94	Delivery of SWAS Instrument
All 1995	SWAS Integration & Qualification
1996-1998	SWAS in Storage
12/5/98	SWAS launched on Pegasus XL
1998-2004	SWAS On-Orbit Operation

SWAS Overview

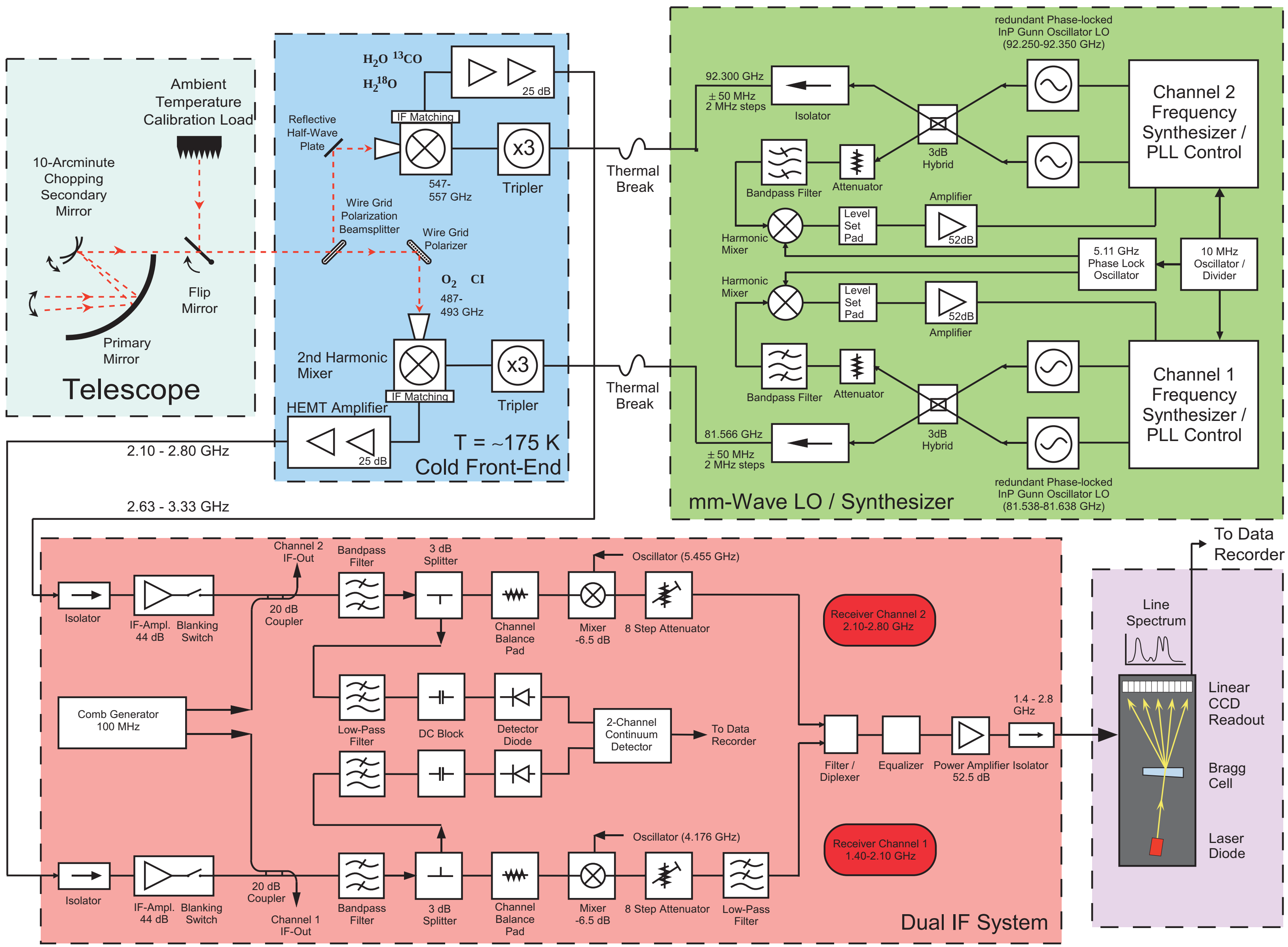
Telescope	54 cm x 68 cm off-axis Cassegrain
Beam Size	3.7 x 5.2 arcmin @ 490 GHz
	3.3 x 4.5 arcmin @ 550 GHz
Mirror surface accuracy	<16 µm rms total error @ 490 GHz
Absolute Pointing Error / Jitter	≤ 5 arcsec (1 σ)
Receiver Temperature	171 – 178 K (passively cooled)
Receiver Noise Temperature (DSB)	2500 K / 2250 K / 4000 K
Backend	AOS: 1.4 GHz; 1.0 MHz
Weight	102 kg (Instr.) / 180 kg (S/C)
Power	60 W (Instr.) / 270 W (S/C)
Orbit	662 km x 650 km; 69.9°

SWAS Instrument

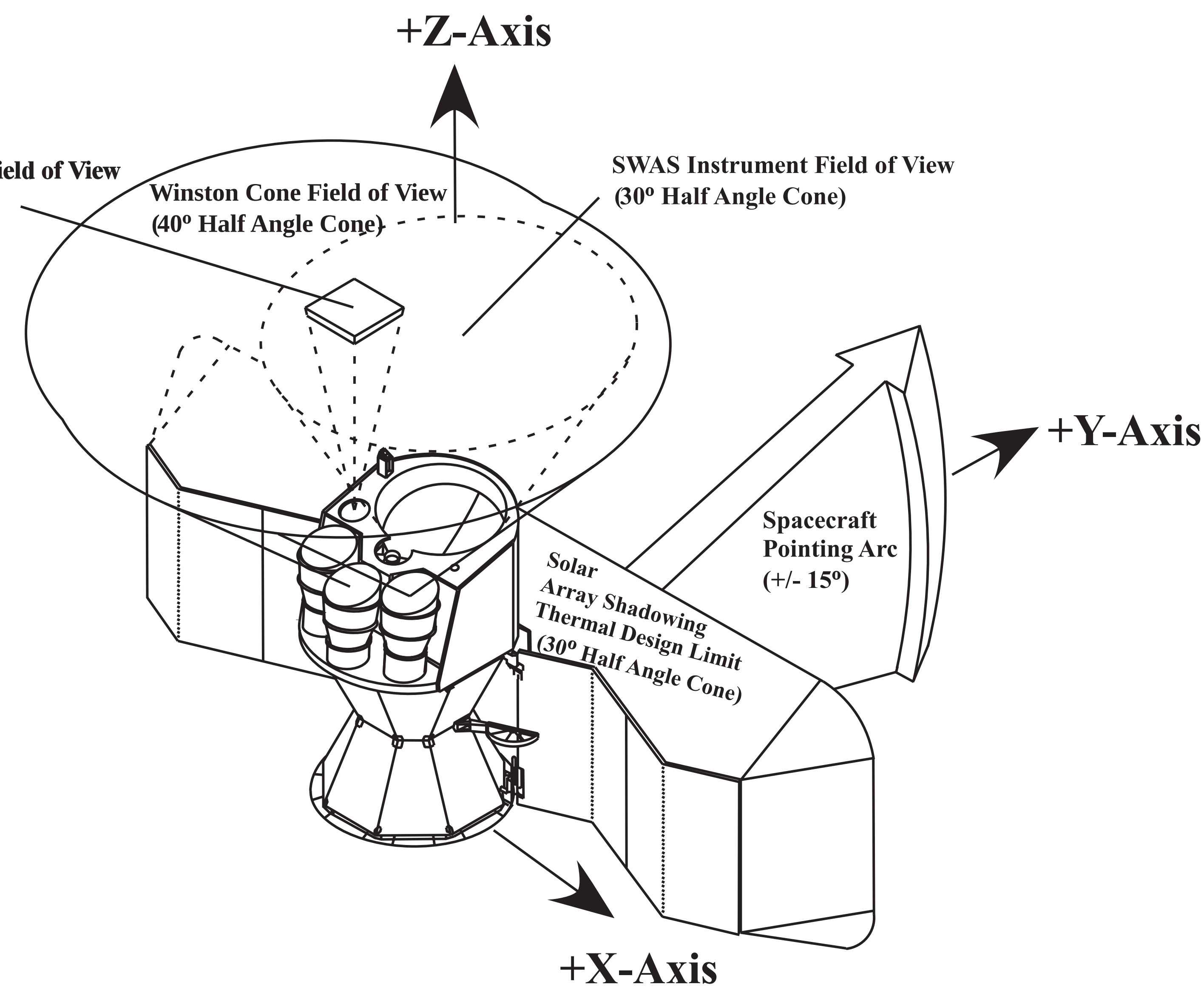




SWAS Block Diagram



SWAS Spacecraft Coordinate System



SWAS Ground Testing

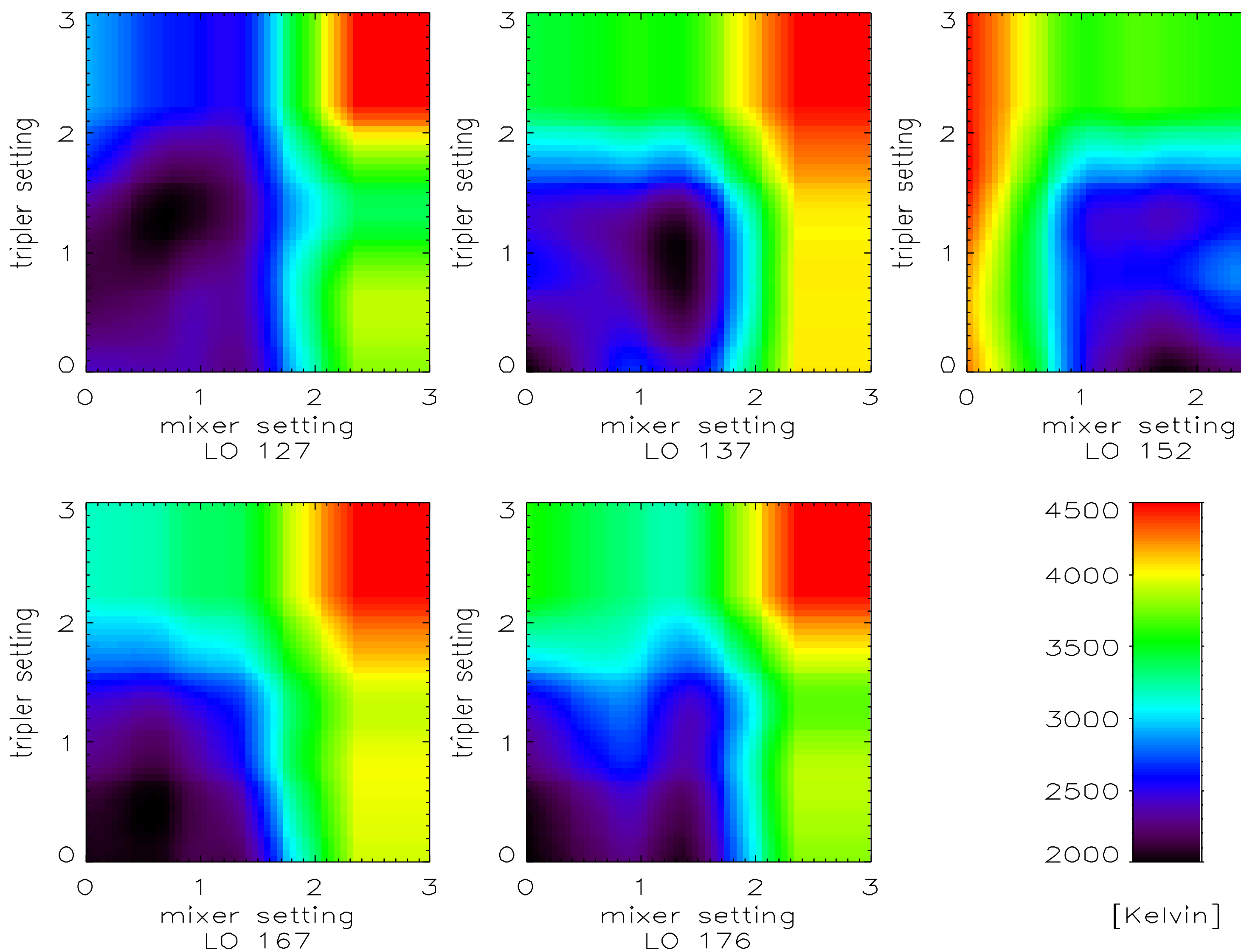
- Receiver System Noise Temperature
- Gas Cell Test
- Radiometric Performance Tests
- Antenna Measurements

SWAS Receiver System Noise Temperature Groundtesting

- Goal was to determine a receiver system noise temperature for all receiver settings. For each receiver we have:
  - 50 LO settings (± 300 MHz tuning range)
  - 2 Gunn Oscillators for each receiver (for redundancy)
  - 4 mixer settings
  - 4 tripler settings
  - 8 attenuator settings

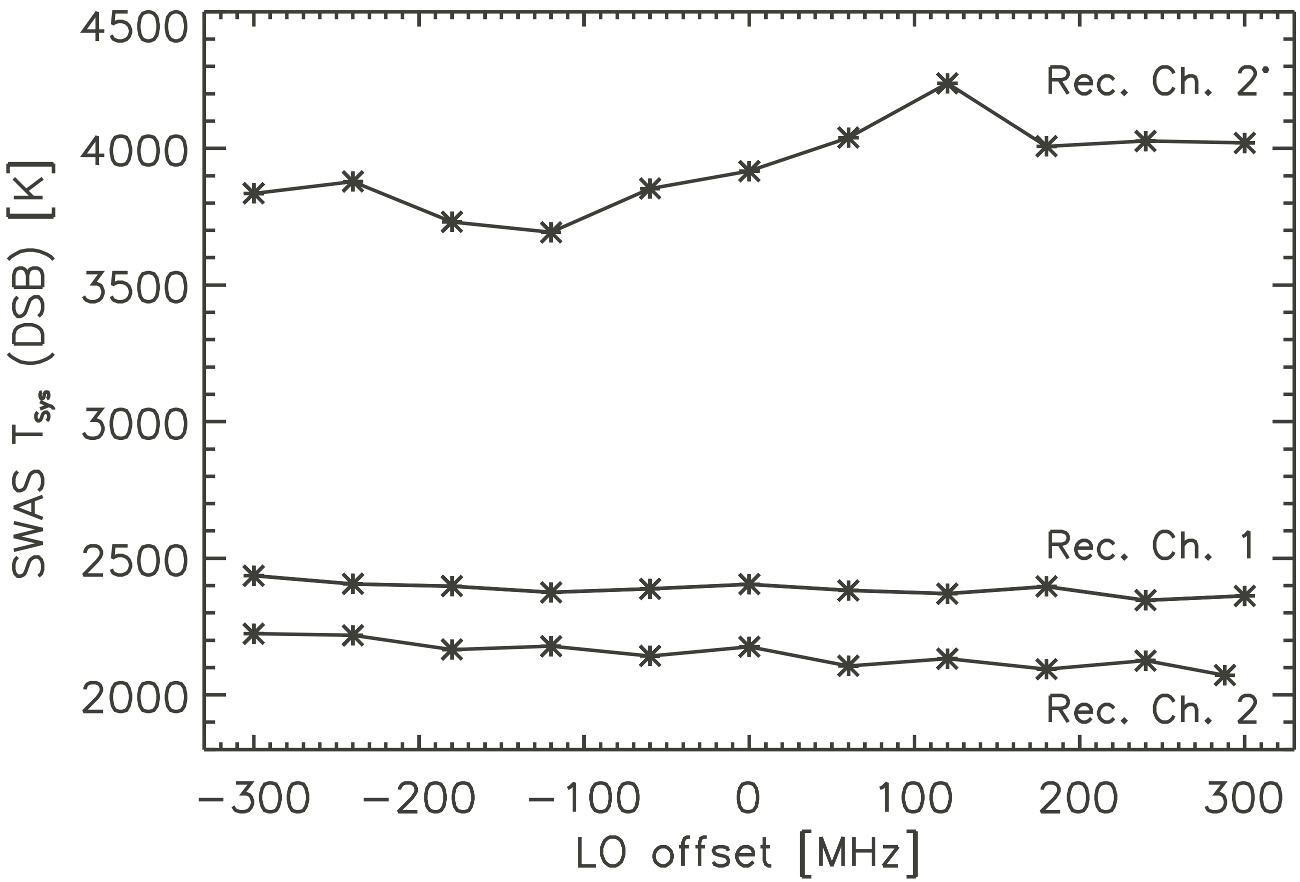
- Selection of best receiver settings for 24 LO settings per receiver with the lowest noise temperature for s/c look-up table

SWAS Receiver System Noise Temperature Groundtesting



backup Gunn, 5th Line off, T_{CoFE} = 170 K

SWAS Receiver System Noise Temperature Groundtesting



SWAS Gas Cell Test
Groundtesting

Goals of Gas Cell Test:

- Verification of Frequency accuracy and calibration
- Measurement of side band ratio

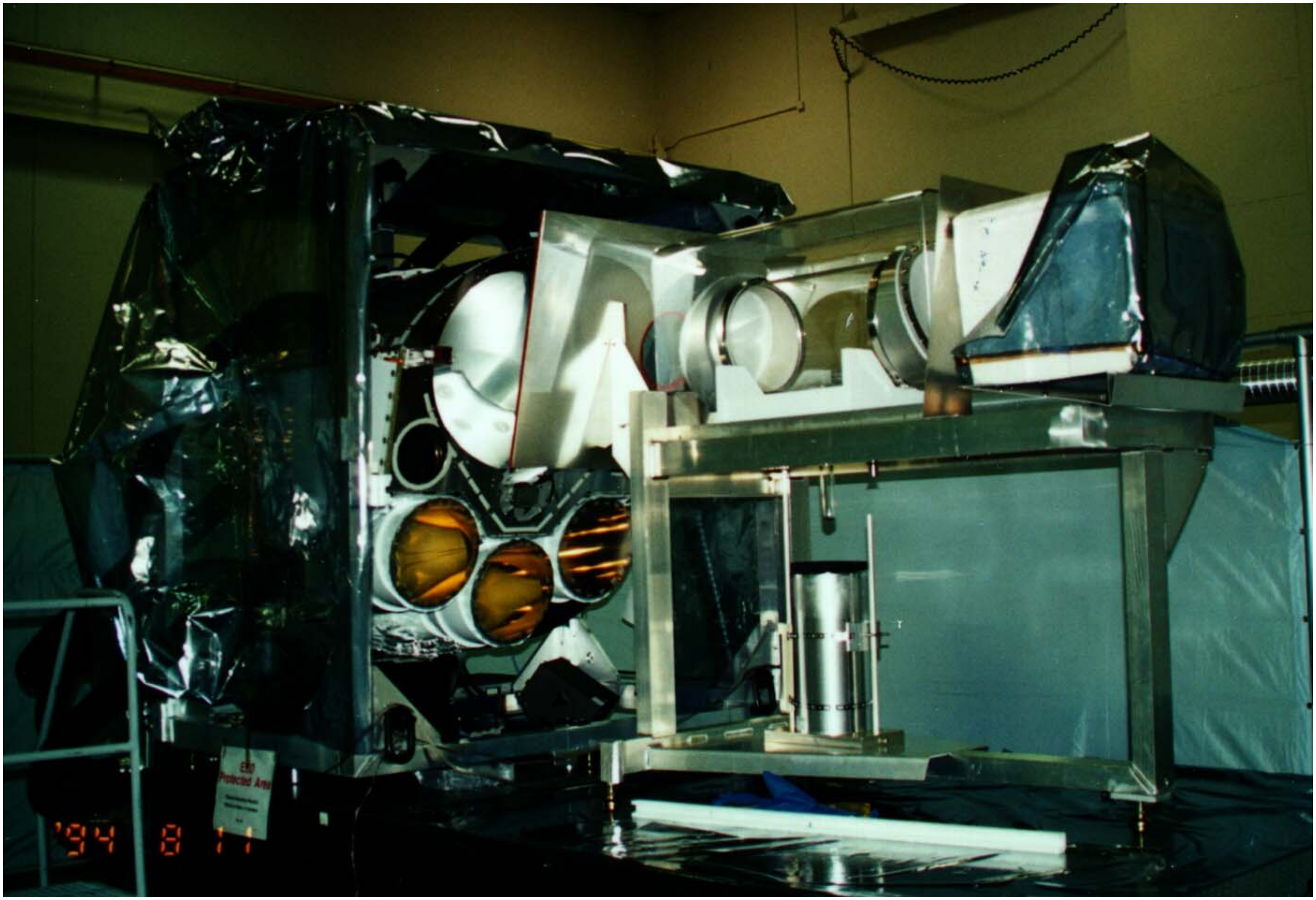
Measurement and Analysis:

$$S_i = \left(\frac{ref_i - sig_i}{ref_i - zero_i} \right)^f \Bigg/ \left(\frac{ref_i - sig_i}{ref_i - zero_i} \right)^e$$

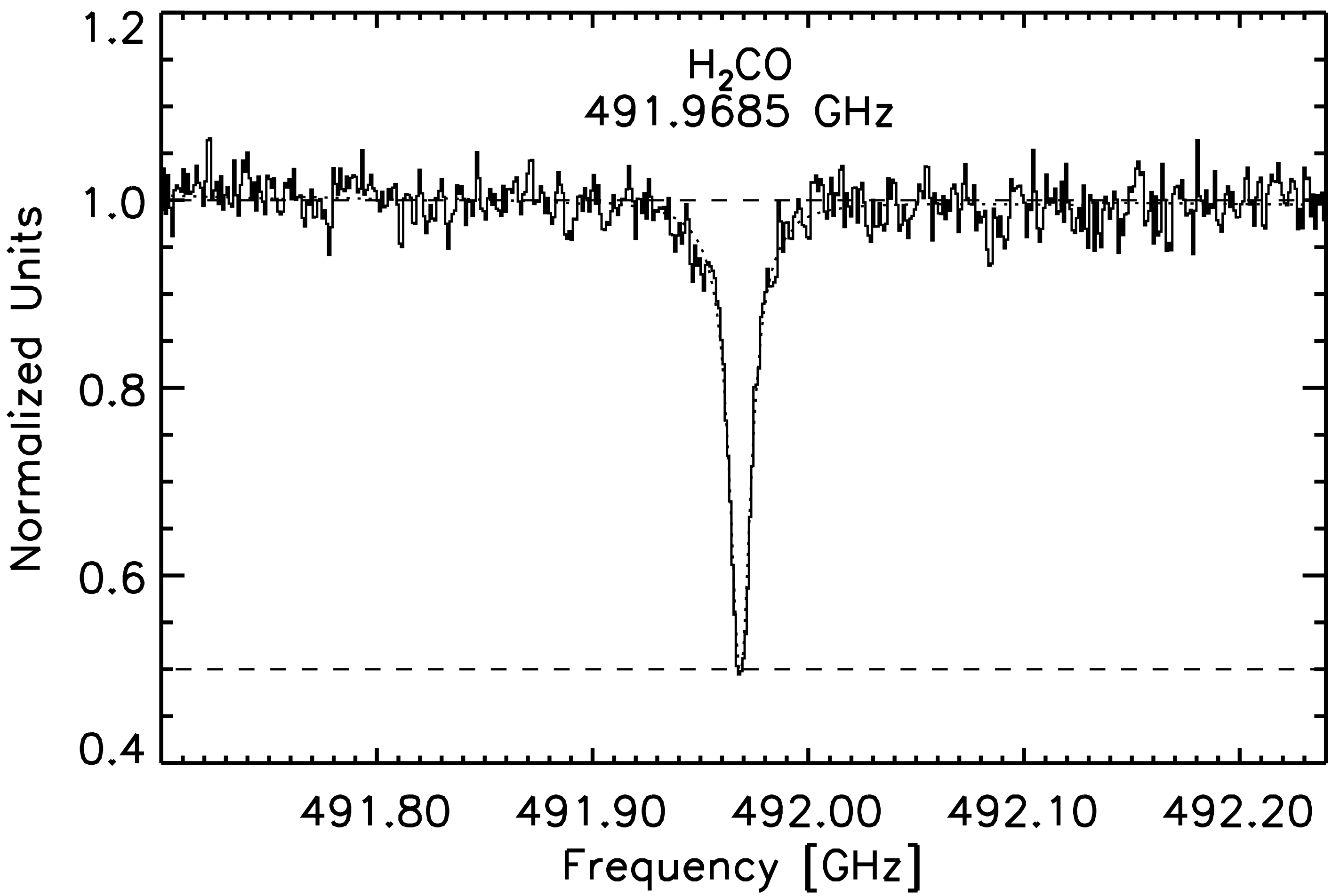
Test Gases:

$H_2{}^{16}O$, $H_2{}^{18}O$, and H_2CO

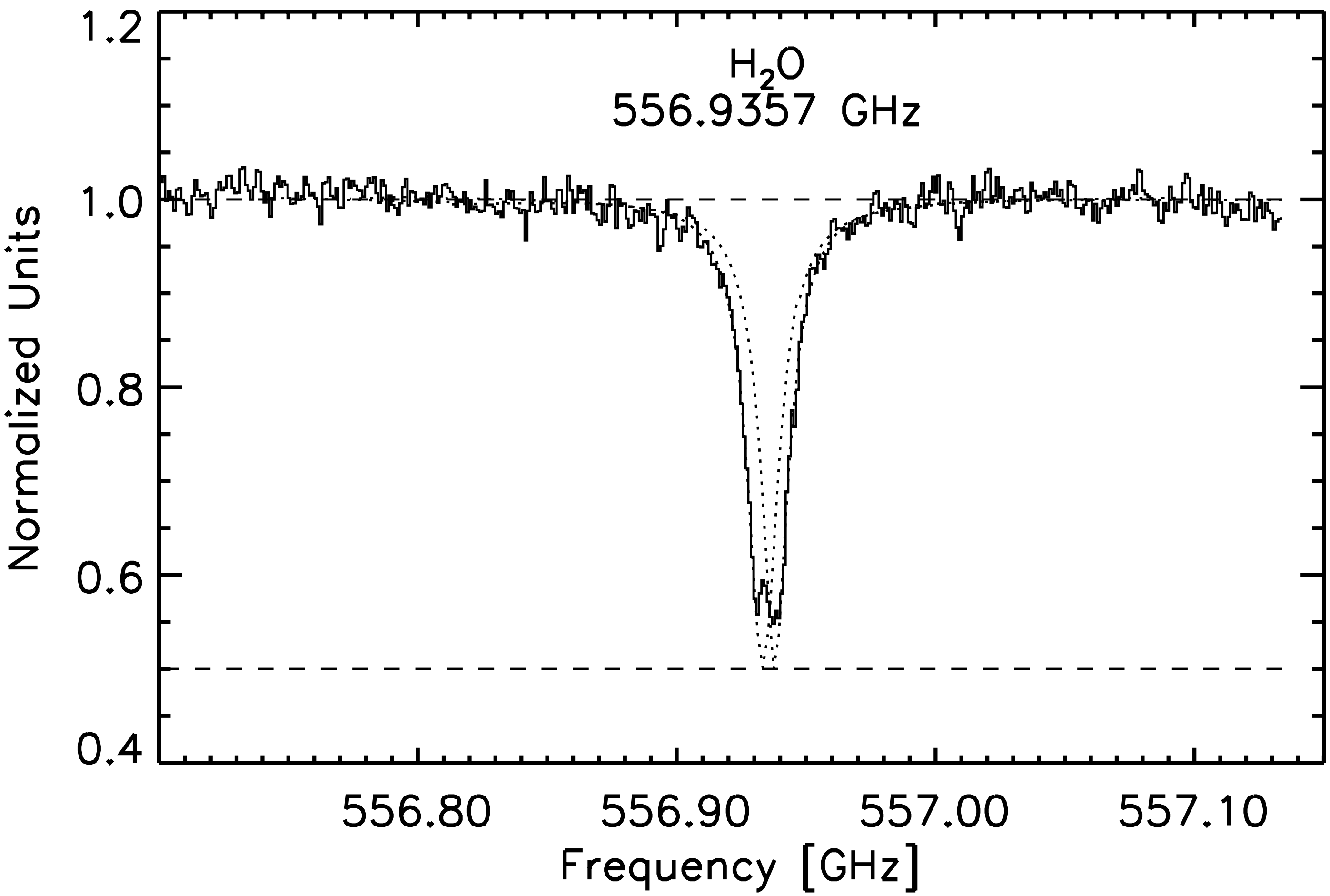
SWAS Gas Cell Test
Groundtesting



SWAS Gas Cell Test
Groundtesting



SWAS Gas Cell Test
Groundtesting



Remark: The water could not be removed completely from the sample cell for the reference measurements causing an absorption in the line center!

SWAS Gas Cell Test Groundtesting

Summary

- The gas cell test proved that the sideband ratio is 1:1 within the measurement error (5%) in both receiver channels
- The frequencies could be determined within 10%ofthe resolution bandwidth of a single AOS channel

Goal of the radiometric performance test:

- Determine the longest duration of ON-Off source integration time that is not affected by drift noise.

Methods:

- Allan variance
- Simulation of observations

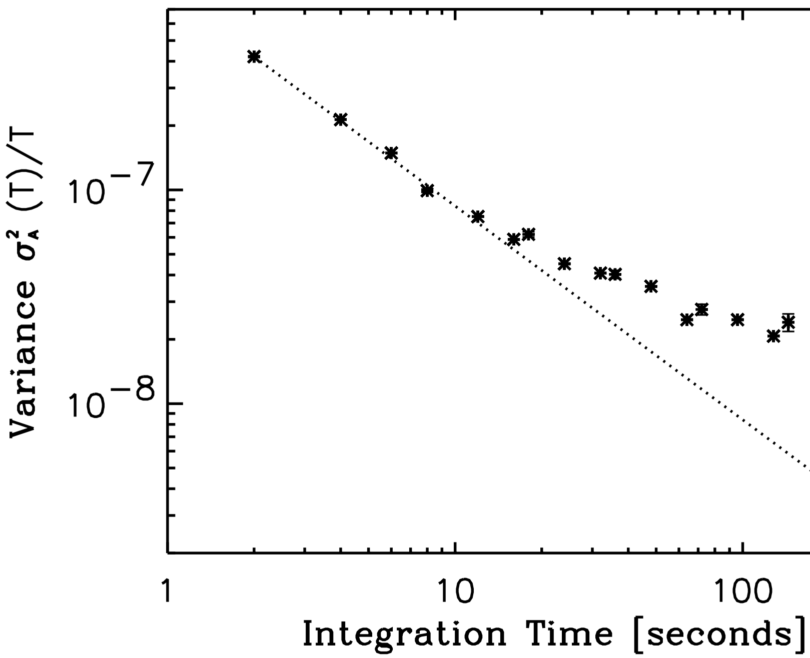
Allan Variance Method

- Method is well described in several papers by Schieder et al. 1992 and Kramer et al. 2003
- Test was performed with warm and cold receiver system
- Result: Allan variance minimum time is well beyond 100 sec. for thermally stable receiver system

Simulation of Observations

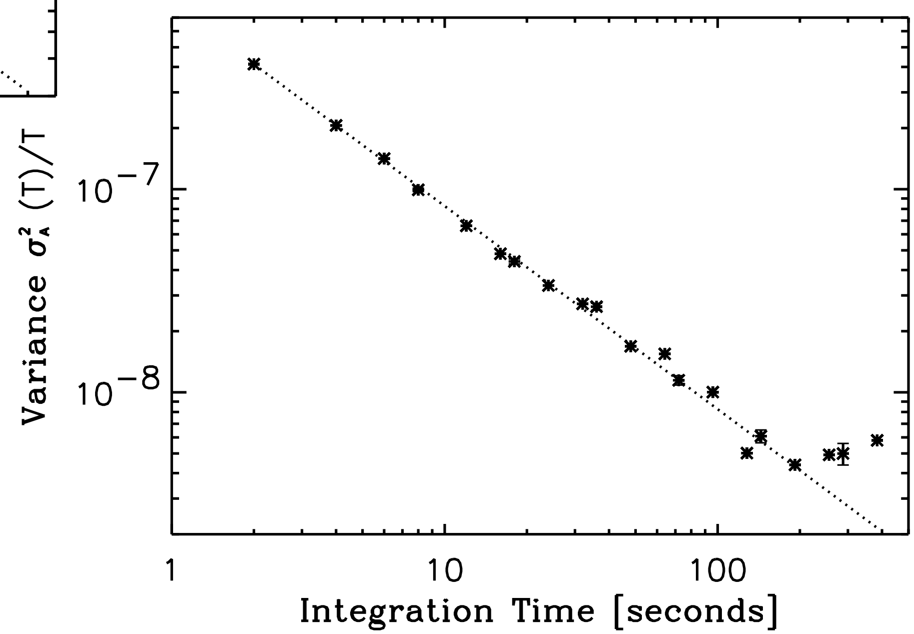
- Cross check of Allan variance by simulating observations
  - using the same data sets as for Allan variance tests
  - this check includes dead time due to slewing to OFF-position

SWAS Radiometric Performance Groundtesting

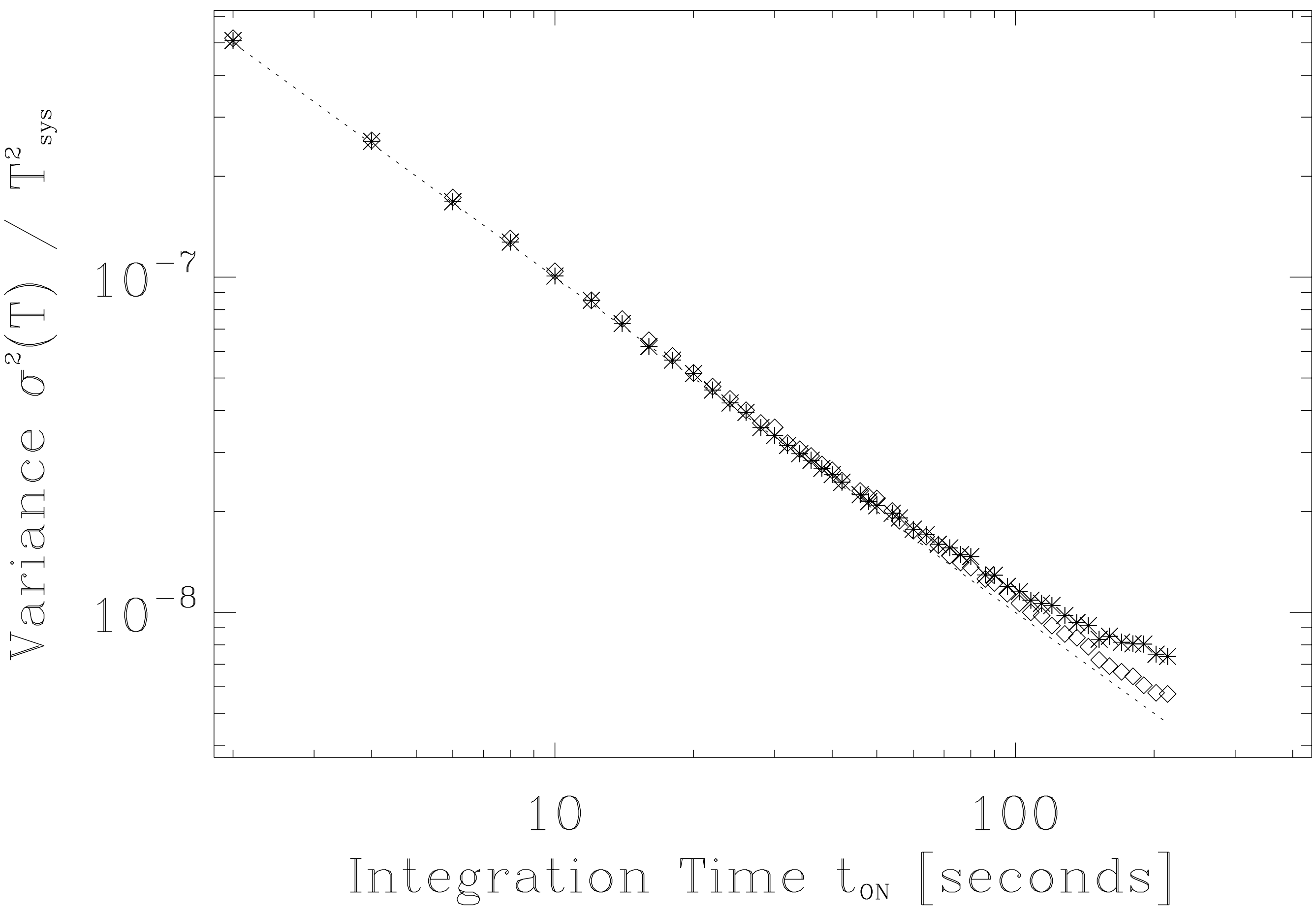


Receiver Channel 1

Receiver Channel 2



Result: Simulation of Observations (8 sec. deadtime)



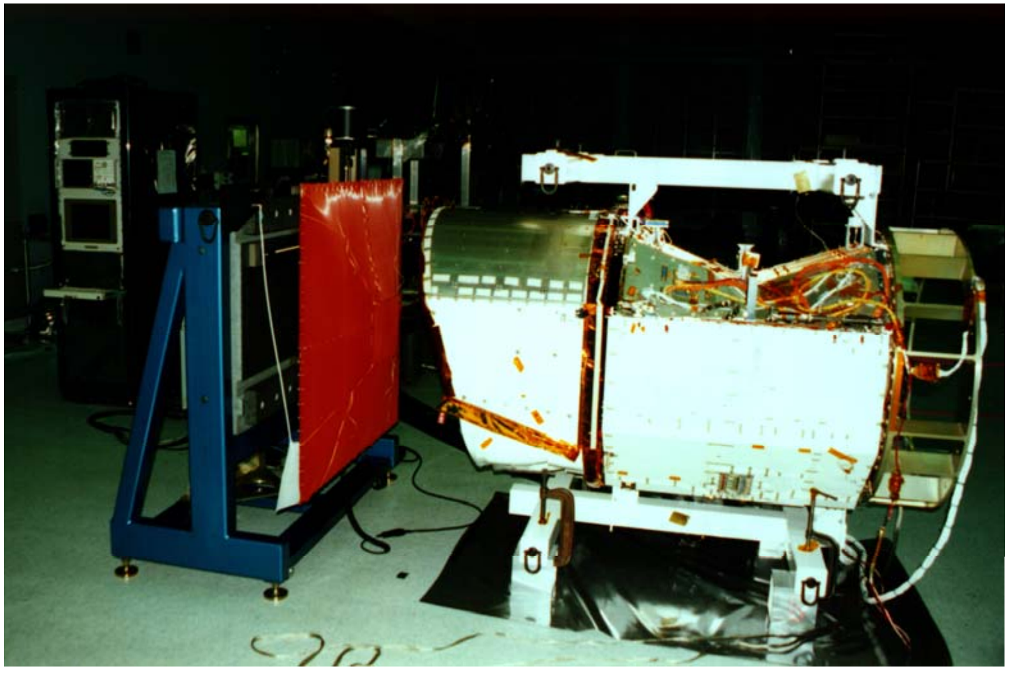
*: Receiver Channel 1 ◊ : Receiver Channel 2

Radiometric Performance:

- Extended noise performance tests were conducted during Thermal Vacuum Testing with about 24 hours of data taking.
- There was no departure from prediction by radiometer equation.
- Better demonstration later with over 200 hours integration time.

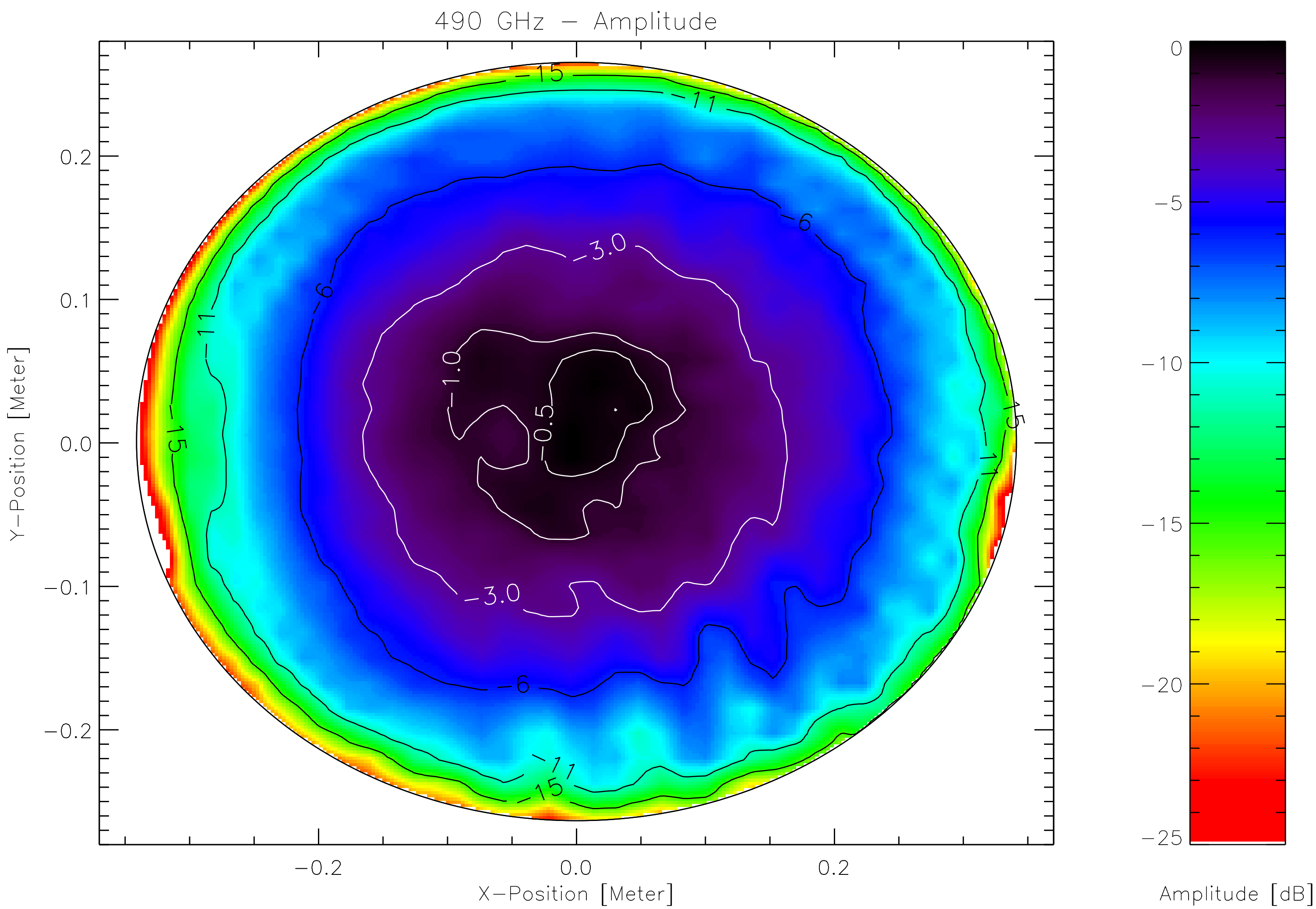
NFR Test:

- Nearfield of SWAS beams:
  - Determine edge taper (amplitude).
- Farfield of SWAS beams:
  - Determine angular separation of 492 GHz and 550 GHz beams.
- Surface accuracy of SWAS primary mirror:
  - Determine surface accuracy from phase of corrected nearfield beam (correction of wavefront tilt)



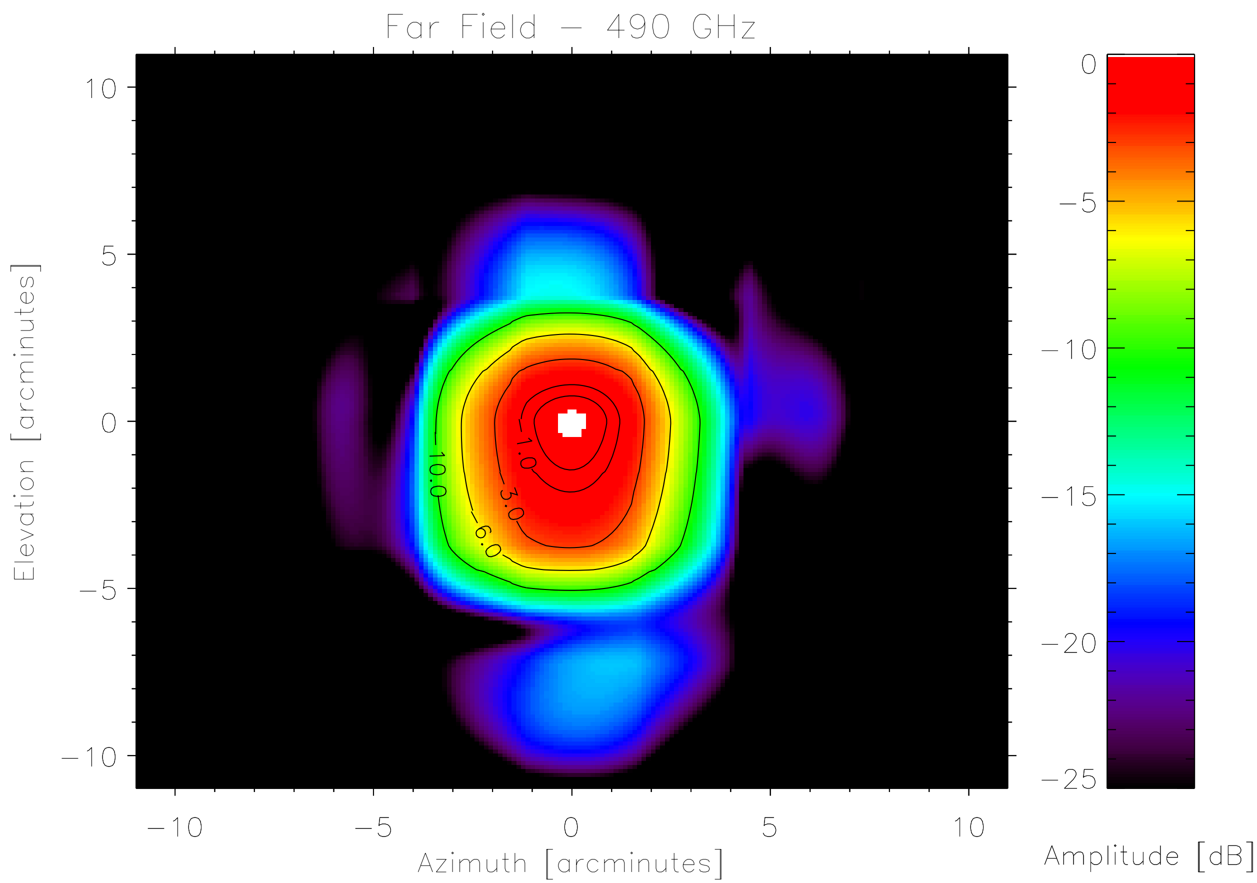
SWAS Beam Measurements
Groundtesting

Nearfield Measurement



SWAS Beam Measurements
Groundtesting

Farfield Beam via FFT

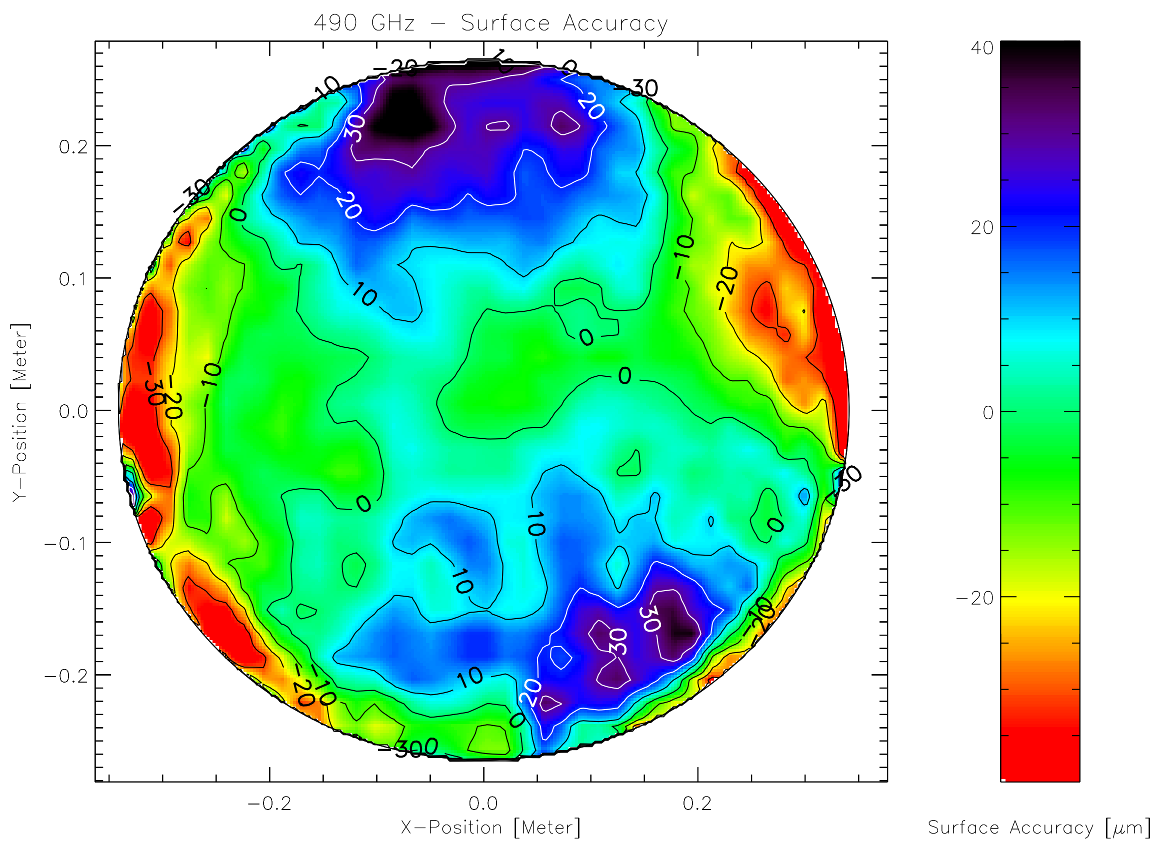


Verification of Co-alignment of SWAS beams to be within a few arcseconds

SWAS Beam Measurements
Groundtesting

Surface accuracy

- Only 490 GHz important due to better SNR
- 550 GHz channel lower SNR due to higher atmospheric attenuation



Limitations of SWAS nearfield beam measurements:

- Method excellent for determining beam, but edges of nearfield beam unreliable due to low SNR and extended size of probe beam.
- Method sufficient for surface accuracy test, but leak in signal path created undesirable features.
- Method insufficient for determining beam efficiencies due to insufficient SNR and unreliable edge taper.

SWAS On-Orbit Tests

Not all groundtests could be repeated for verification of in-orbit performance.

On-Orbit Tests:

- Beam characterization and beam centroiding
- Receiver system noise performance
- Frequency calibration / comparison with existing observations (CI)
- Stability tests / radiometric performance

Beam characterization and beam centroiding

1. Determine offset between s/c axis and telescope axis

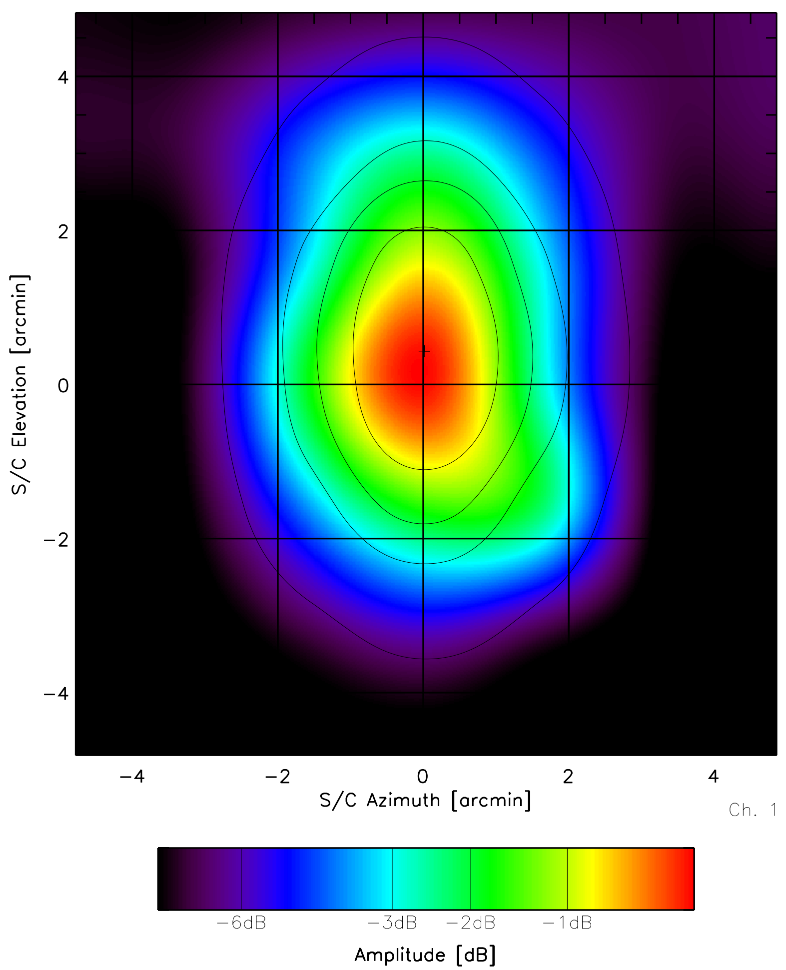
   => See E. Bergins presentation

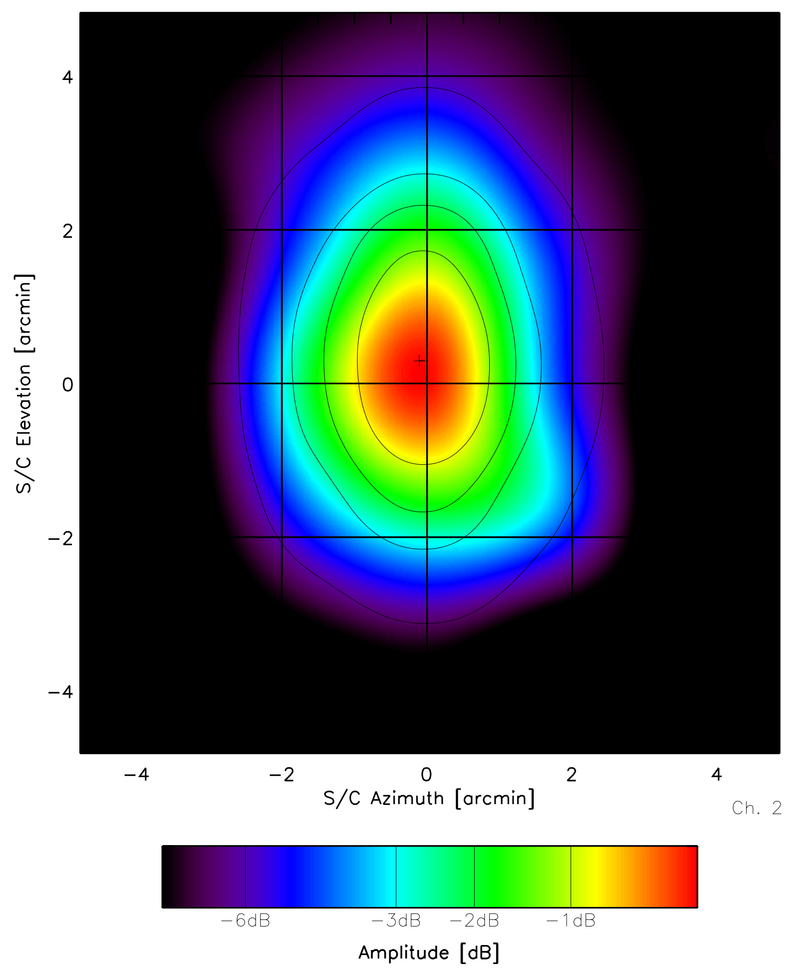
2. Determine SWAS beam:
   - FWHM
   - Gaussianity, sidelobes

3. Determine beam offset

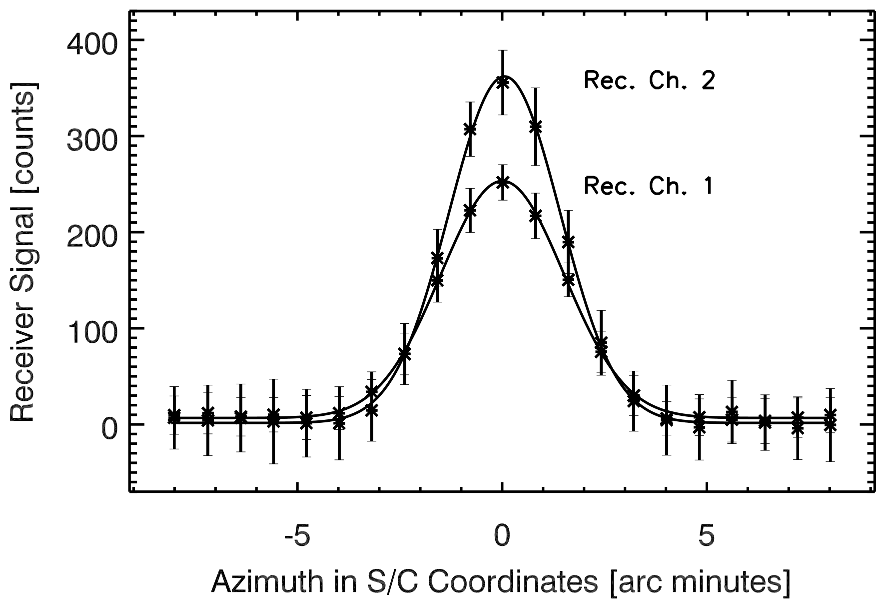
4. Determine chopped beam throw

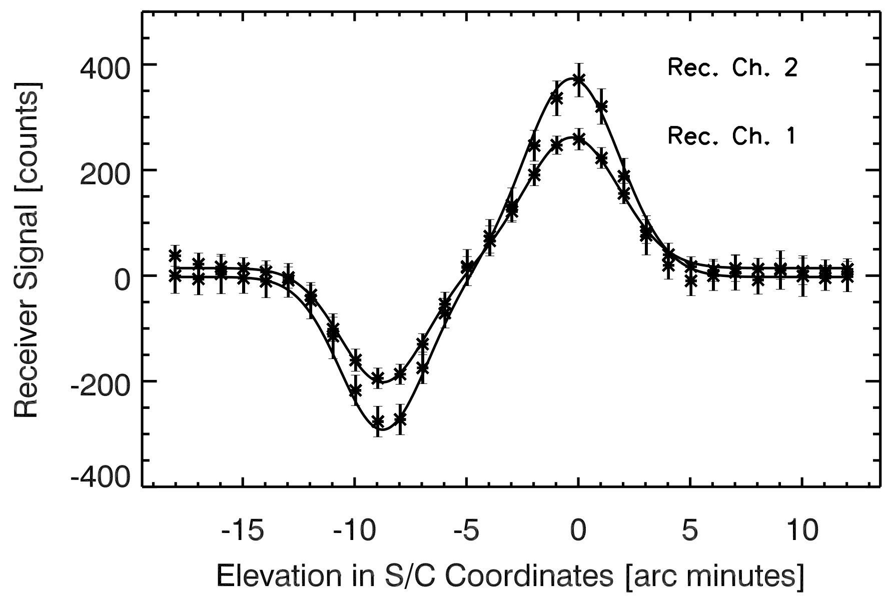
SWAS Beam from Jupiter Mapping





SWAS Jupiter Azimuth and Elevation Scans





SWAS On-Orbit Check-Out
Beam Characterization

SWAS Full Width at Half Maximum (FWHM)

	490 GHz		553 GHz		
Test	Azimuth	Elevation	Azimuth	Elevation	Error
Design	3.8	4.8	3.3	4.2	
NFR	3.8	5.0	3.4	4.2	±0.2
Jupiter Scans	3.7	5.2	3.3	4.5	±0.1

Center positions of SWAS beams are within 0.′10 ± 0.′02

Chopper Throw is:

8.′4 ± 0.′2 for 492 GHz

8.′5 ± 0.′2 for 557 GHz

SWAS On-Orbit Check-Out
Beam Characterization

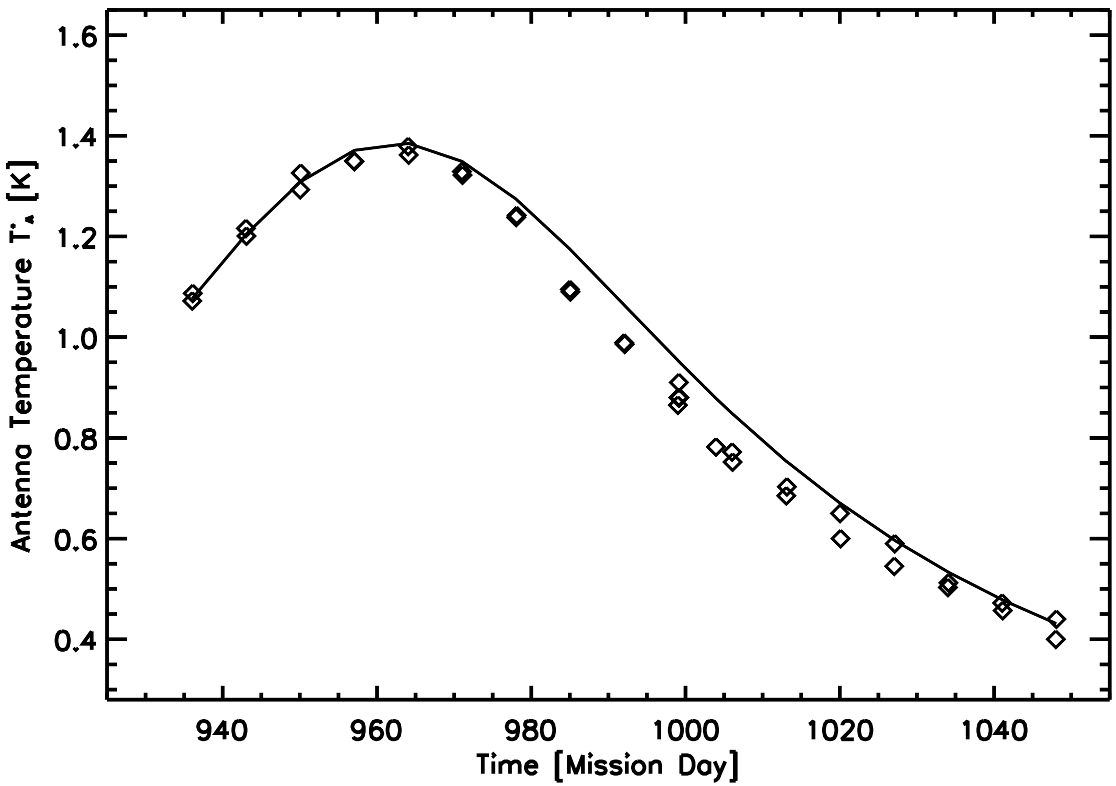
Beam efficiencies from 2001 Mars observation:

Aperture Efficiency: 0.68 ± 0.04 @ 492 GHz

Main Beam Efficiency: 0.96 ± 0.07 @ 492 GHz

Ruze: 0.90 @ 492 GHz, unbl., 11dB

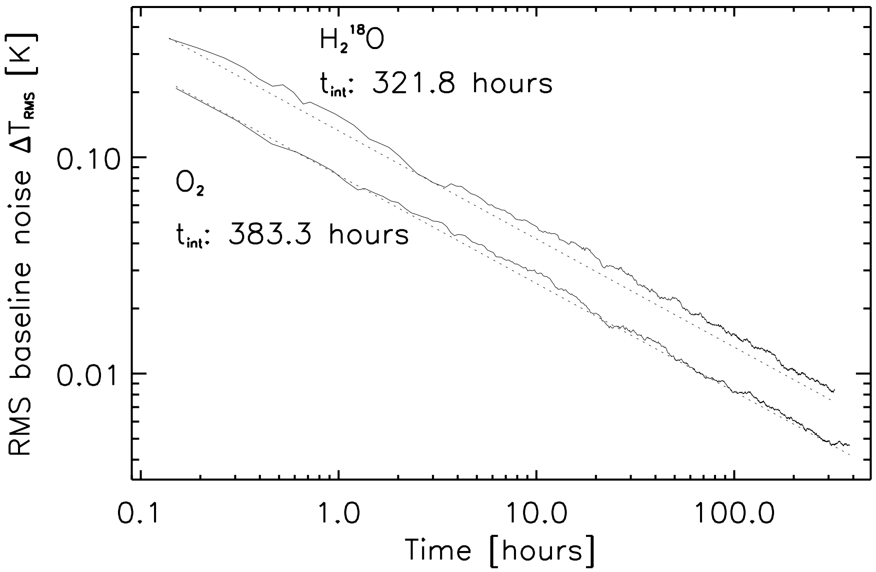
=> **SWAS Main Beam Efficiency: 0.90 ± 0.07 @ 492 GHz**



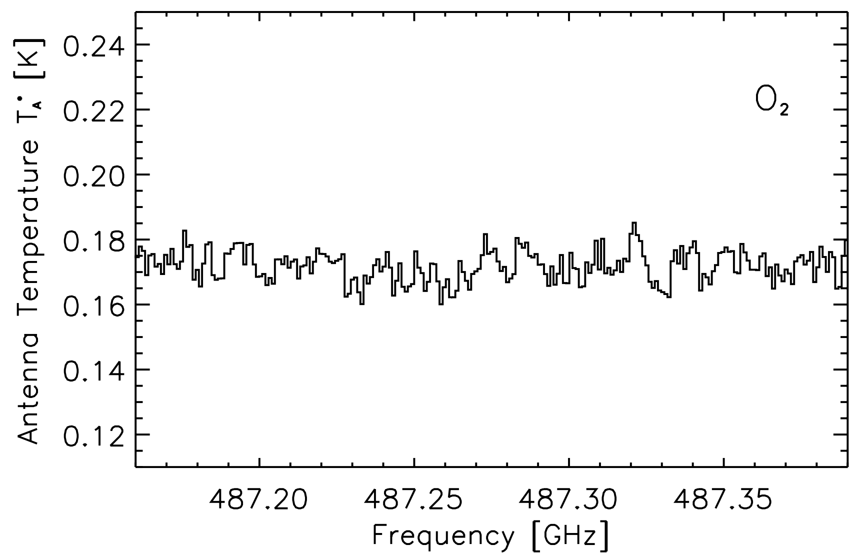
Summary of On-Orbit Radiometric Performance Tests

- Noise Temperature Matrix Test
  - Verification of the ground test results for reduced set of receiver settings
- Allan Variance Test
  - Verification of ground test results
- Long Duration Integration
  - No extra test performed
- Performance Trending during mission

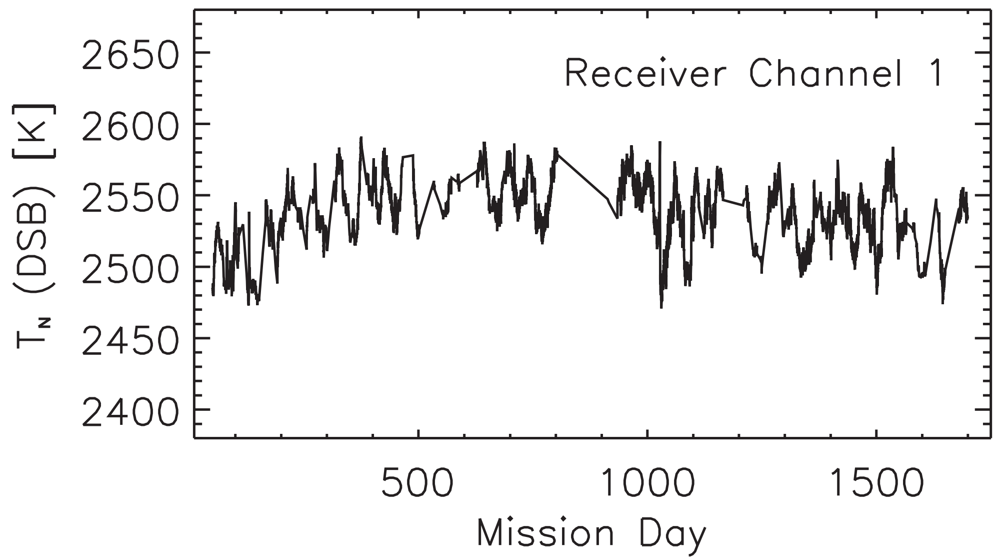
SWAS On-Orbit Performance
Long Duration Integration

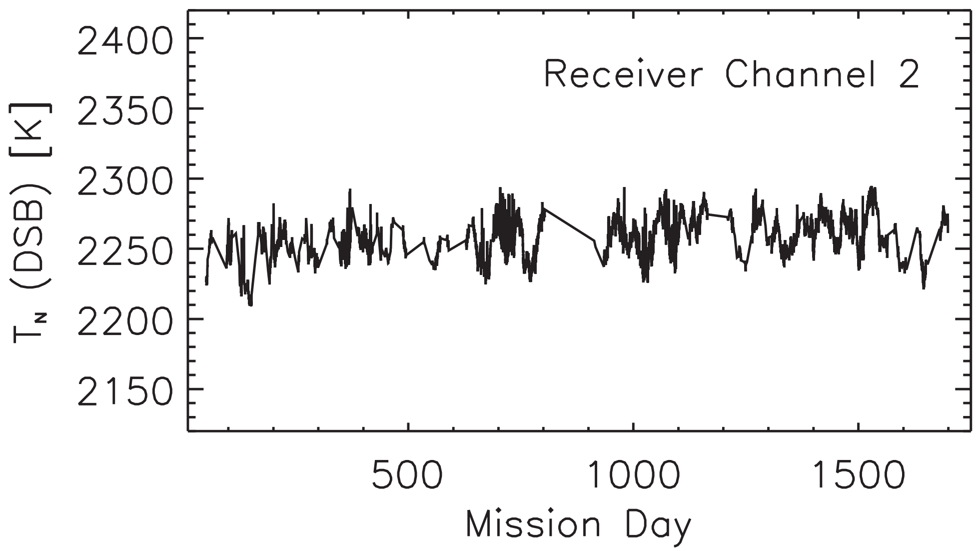


W49



SWAS Receiver System Noise Temperature Trending





SWAS Continuum Detector

- Purpose was to provide continuum offset for spectroscopic science observations.
- Only detector for fast chopping mode.

However, it has had problems:

- Instabilities: Allan variance minimum time was less than 0.25 sec. (integration time for fast chopping)

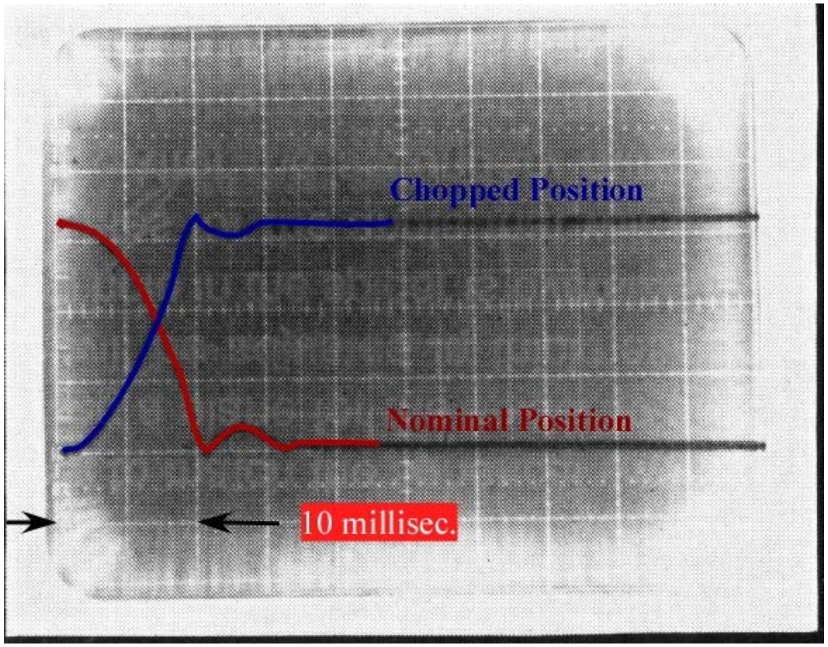
SWAS On-Orbit Performance
Chopping Secondary

The primary observing mode for SWAS was spacecraft nodding and secondary modes were:

- Slow chopping (utilizing the AOS and the continuum backends), 2 sec. integration time
- Fast chopping (utilizing only the continuum backend), 0.25 sec. integration time

But synchronization problems causing loss of signal.

SWAS On-Orbit Performance
Chopping Mode



Chopper Correction and Calibration

	T_A^* Rec. Ch. 1	T_A^* Rec. Ch. 2
ON-Beam Fast Chop	4.90 ± 0.44	4.82 ±0.41
OFF-Beam Fast Chop	3.83 ± 0.44	3.71 ±0.43
ON-Beam Slow Chop	6.14 ±0.92	6.21 ±0.90
OFF-Beam Slow Chop	4.37 ±0.91	4.15 ±0.95
ON-Beam Nodding	5.56	5.99
OFF-Beam Nodding	5.89	5.73

SWAS On-Orbit Performance
Chopping Mode

Correction of chopping error proved to be consistent with expectation when observing Mars. The corrected continuum detector measurements agreed with the expected antenna temperature from M. Gurwells Mars model.

In combination with a new observing mode for SWAS, balanced beam switching, chopped continuum observations became believable.

SWAS On-Orbit Performance
AOS – Laser Diode

The only parts in the SWAS satellite which showed significant degradation were the laser diodes in the AOS backend. However, both laser diode exceeded their expected lifetime of about 2 years by far.