Flux Calibration of the Herschel-SPIRE Photometer

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Flux Calibration Equations

The derivative of the observed signal S_{Meas} was found empirically to be the following function of voltage V:

$$\frac{dS_{Meas}}{dV} = K_1 + \frac{K_2}{K_3 - V}$$

The integral of this equation gives the conversion from voltage to flux density:

$$S_{Meas} = K_1(V_{Meas} - V_0) + K_2 \log \frac{V_{Meas} - K_3}{V_0 - K_3}$$

The V_0 terms are zero-point voltages that (for convenience) are set to the mean values for "dark" sky.

An additional K_{MonP} term is applied to convert the flux densities to monochromatic values for sources where νS_ν is constant.

Flux Calibration Steps

The **K** parameters are derived for each functional bolometer in each array. Separate terms are used for the nominal and bright source voltage bias modes.

The $\mathbf{K_3}$ terms and the unscaled $\mathbf{K_1}$ and $\mathbf{K_2}$ terms are derived by performing staring observations of backgrounds with varying brightnesses while PCal (an internal calibration source) is flashed.

The $\mathbf{K_1}$ and $\mathbf{K_2}$ terms are then scaled using fine scan observations of Neptune in which each bolometer passes over Neptune in a series of zigzag patterns.

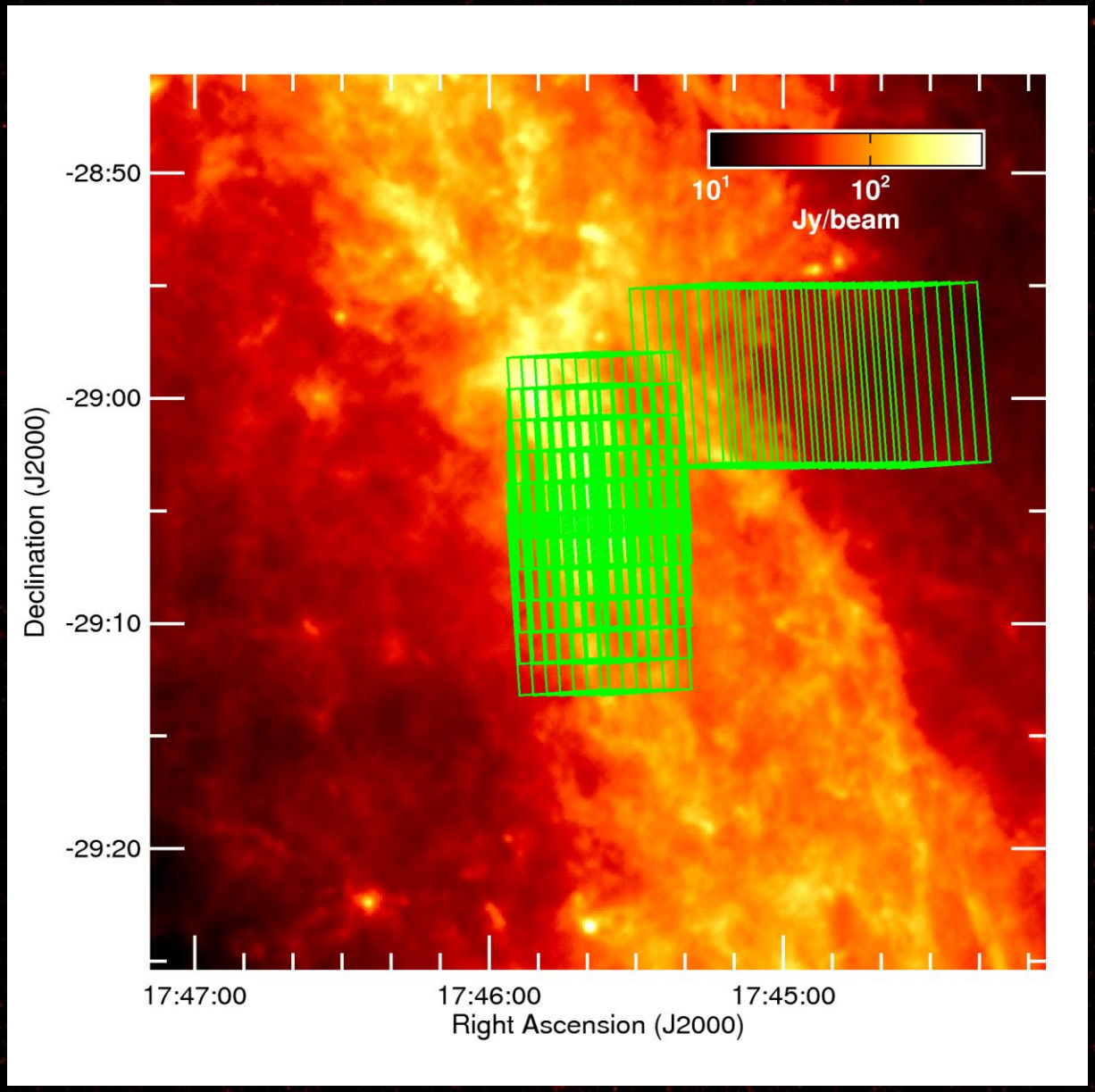
PCal Flash Observations

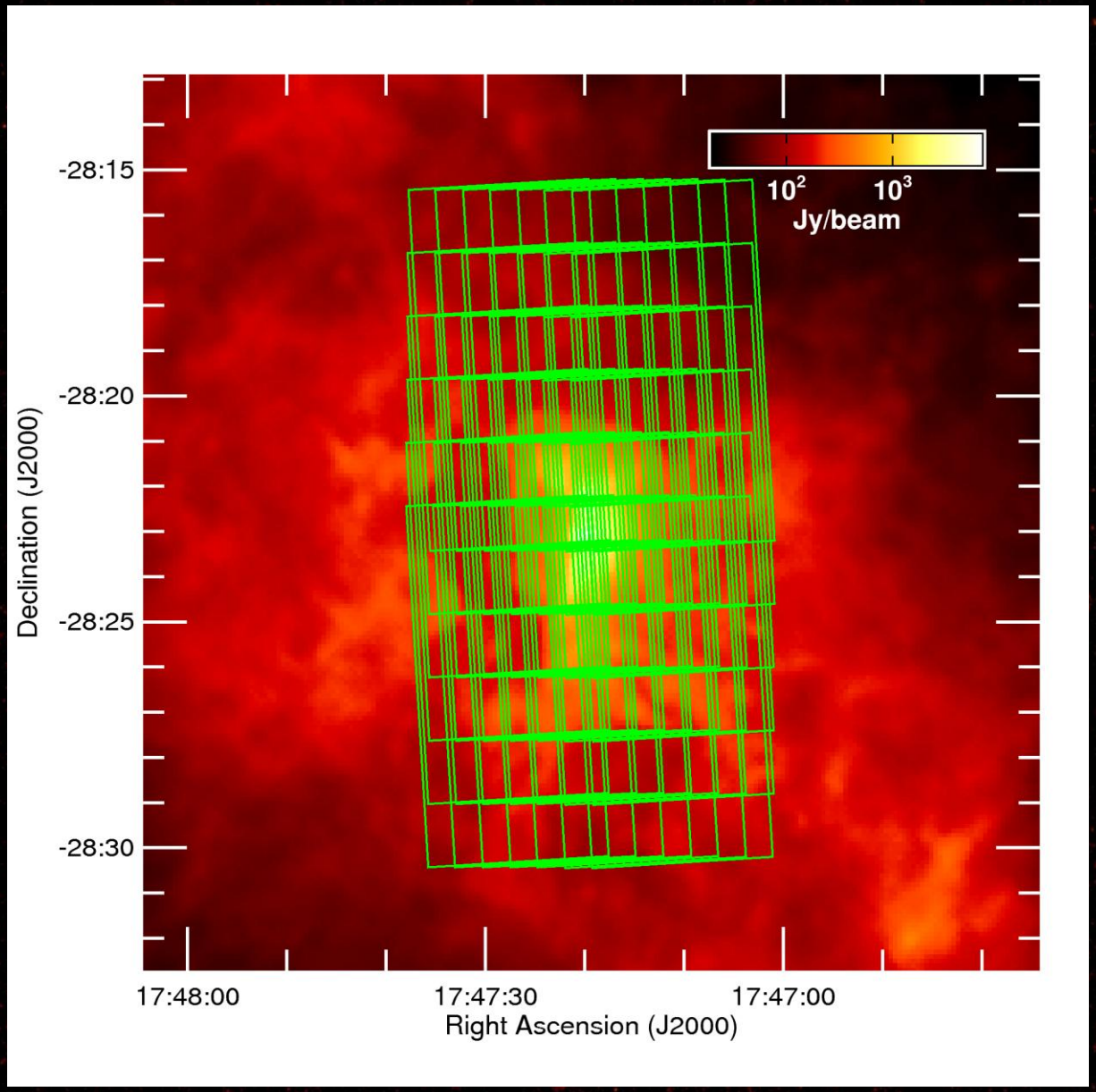
The background signals in the PCal flash observations need to vary over the full range of expected surface brightnesses, but the exact signals from the backgrounds themselves do not need to be known.

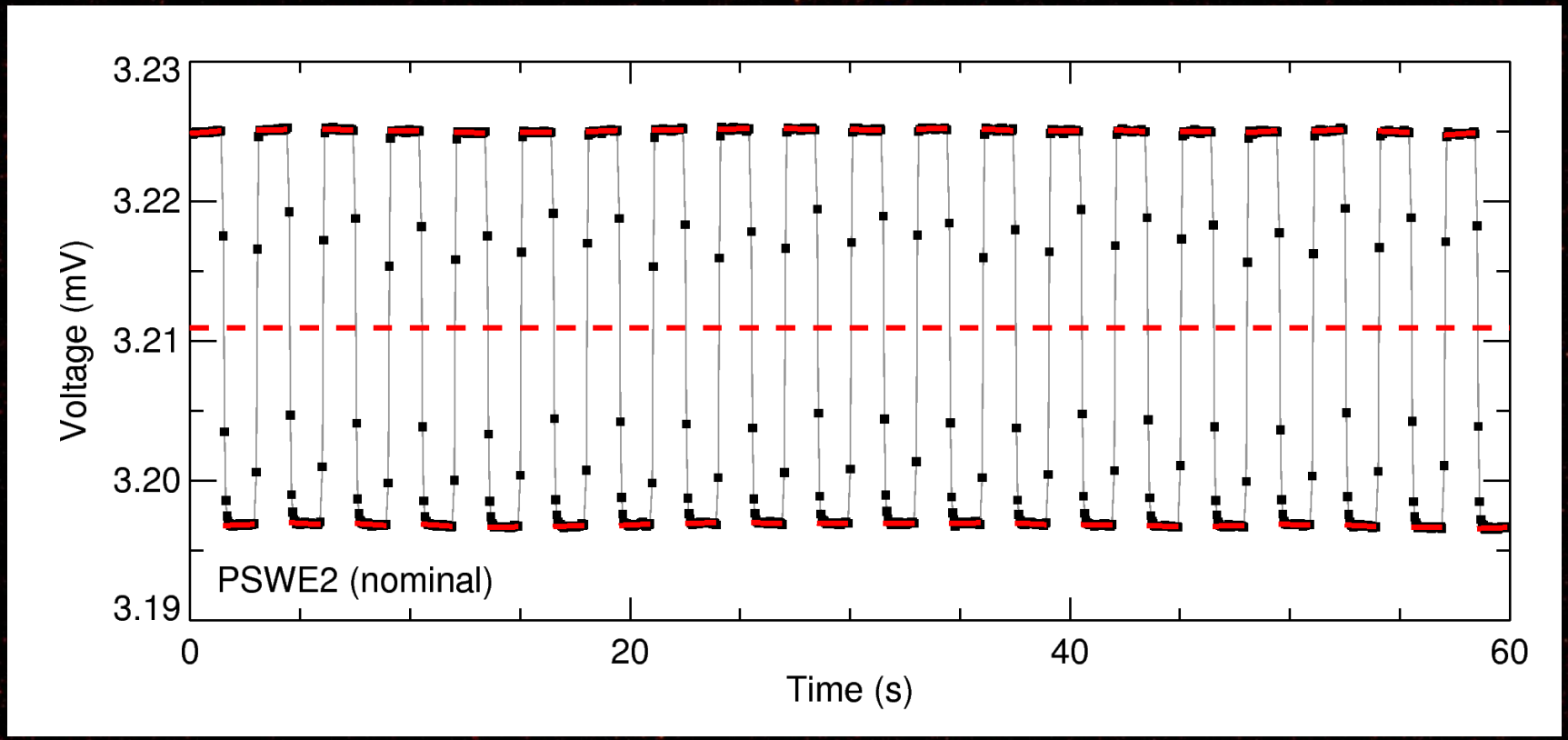
For nominal bias mode, PCal flash observations are made in Sgr A* region.

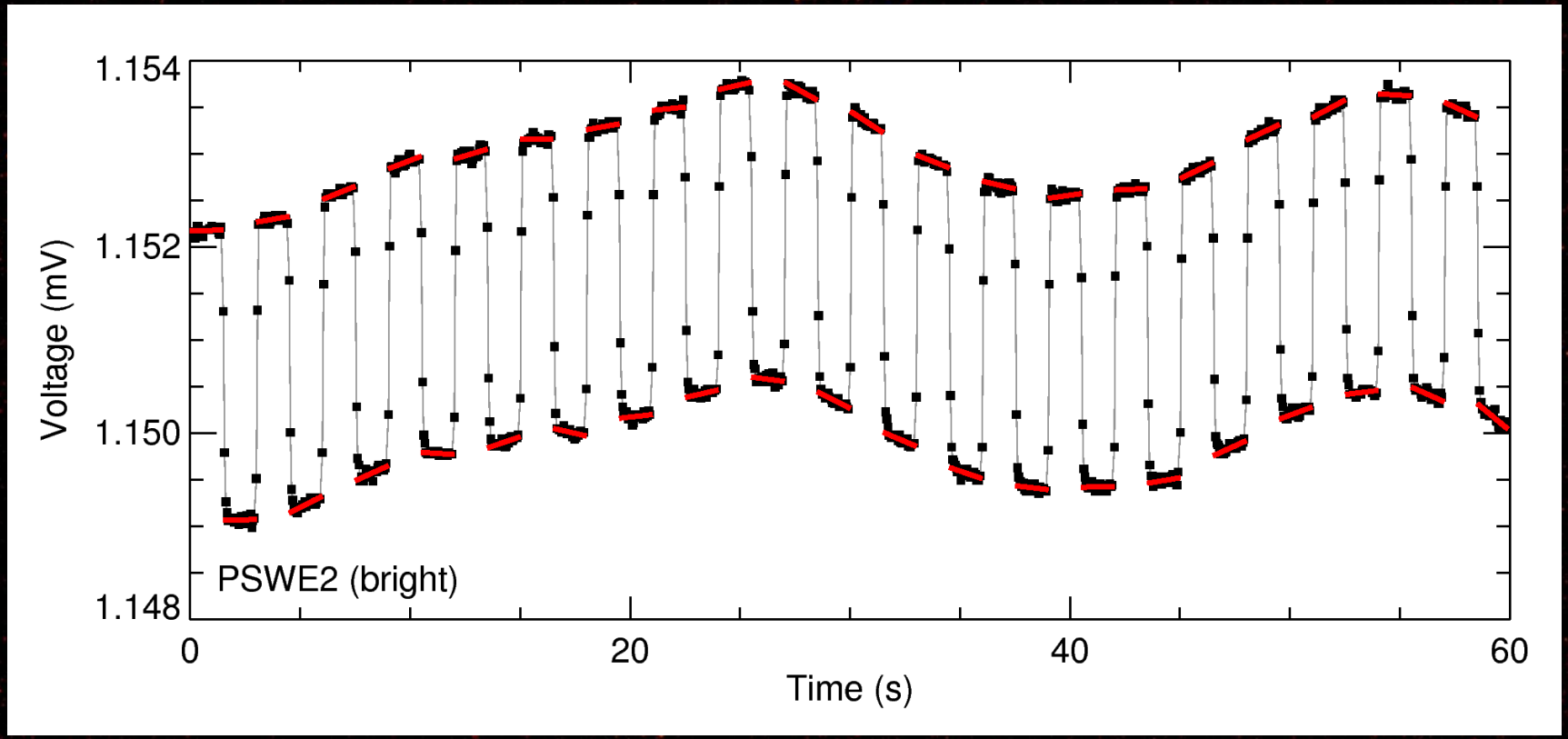
For bright source mode, PCal flash observations are made in Sgr B2 region.

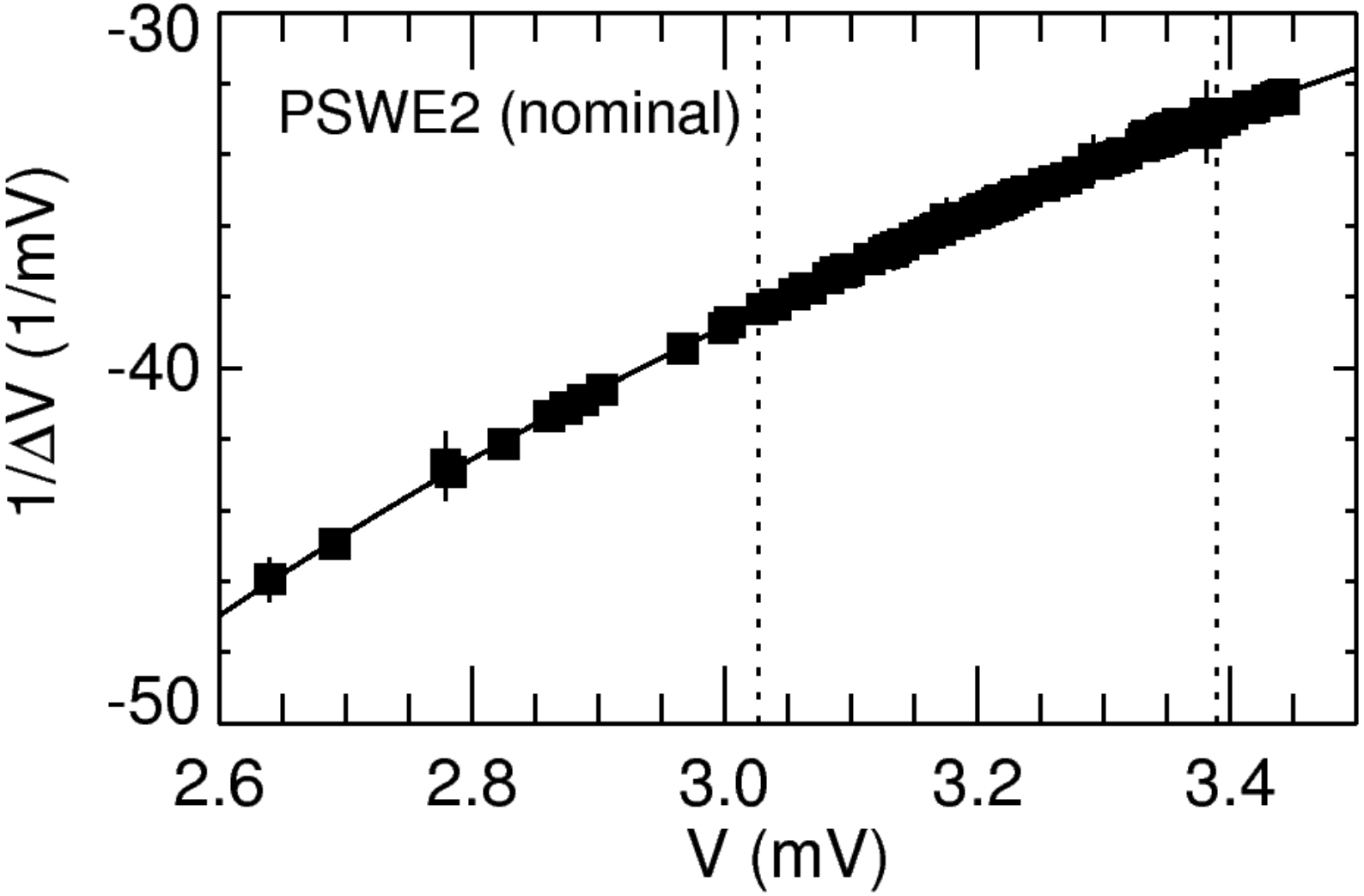
Additional calibration observations of dark fields and other sources are used to define the derivative of the curve at low surface brightnesses.

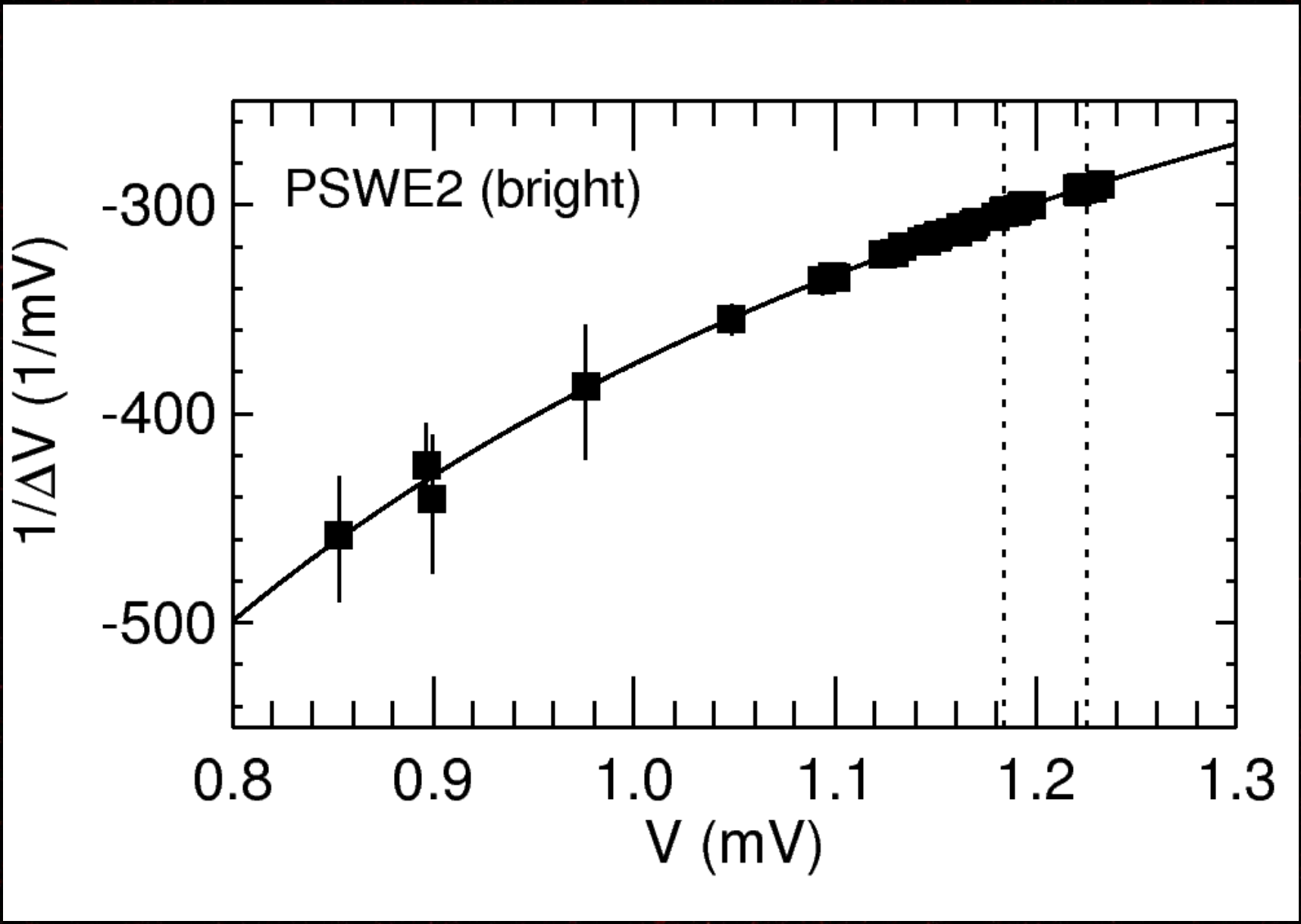

-28:50
-29:00
-29:10
-29:20
Declination (J2000)
10^1
10^2
Jy/beam
17:47:00
17:46:00
17:45:00
Right Ascension (J2000)


-28:15
-28:20
-28:25
-28:30
Declination (J2000)
10^2
10^3
Jy/beam
17:48:00
17:47:30
17:47:00
Right Ascension (J2000)


3.23
3.22
3.21
3.20
3.19
Voltage (mV)
PSWE2 (nominal)
0
20
40
60
Time (s)


1.154
1.152
1.150
1.148
Voltage (mV)
PSWE2 (bright)
0
20
40
60
Time (s)


PSWE2 (nominal)
-30
-40
-50
1/ΔV (1/mV)
2.6
2.8
3.0
3.2
3.4
V (mV)

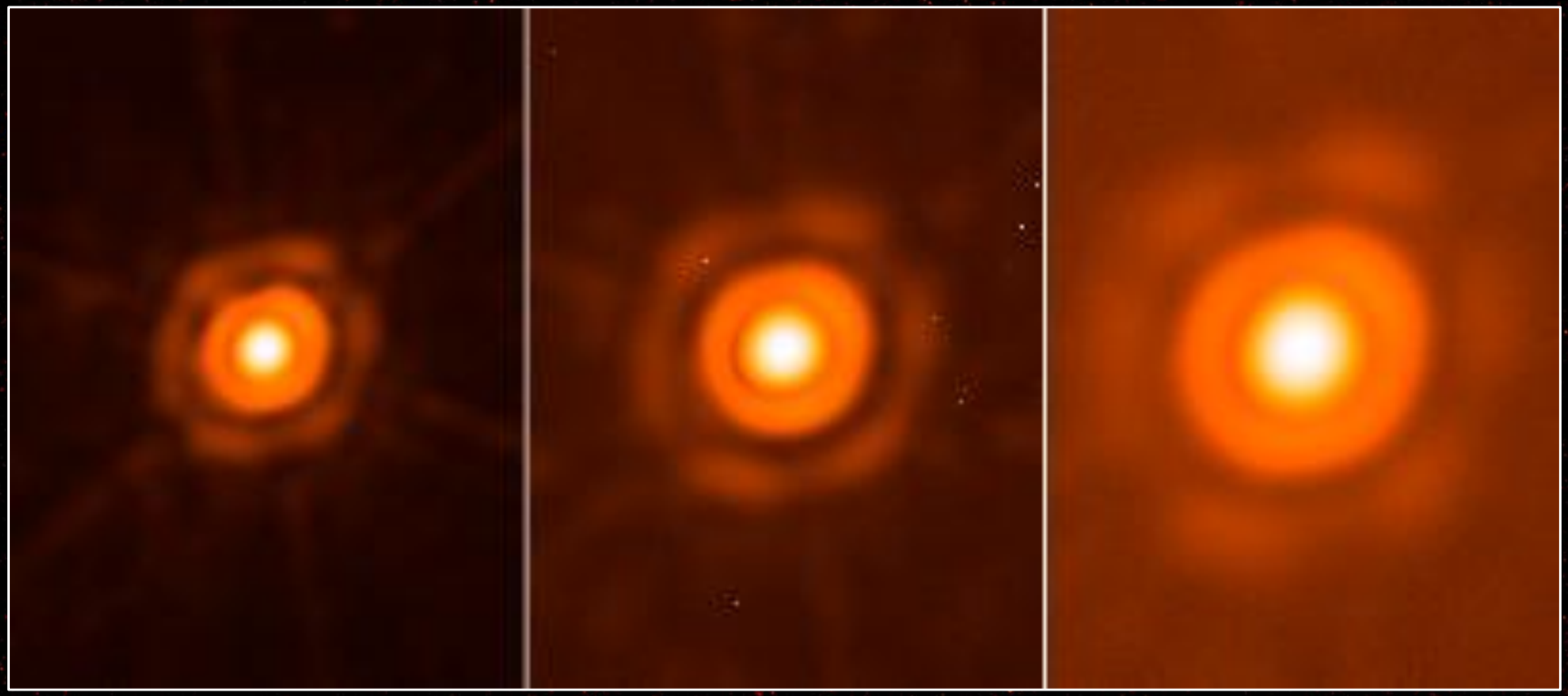

PSWE2 (bright)
-300
-400
-500
1/ΔV (1/mV)
0.8
0.9
1.0
1.1
1.2
1.3
V (mV)

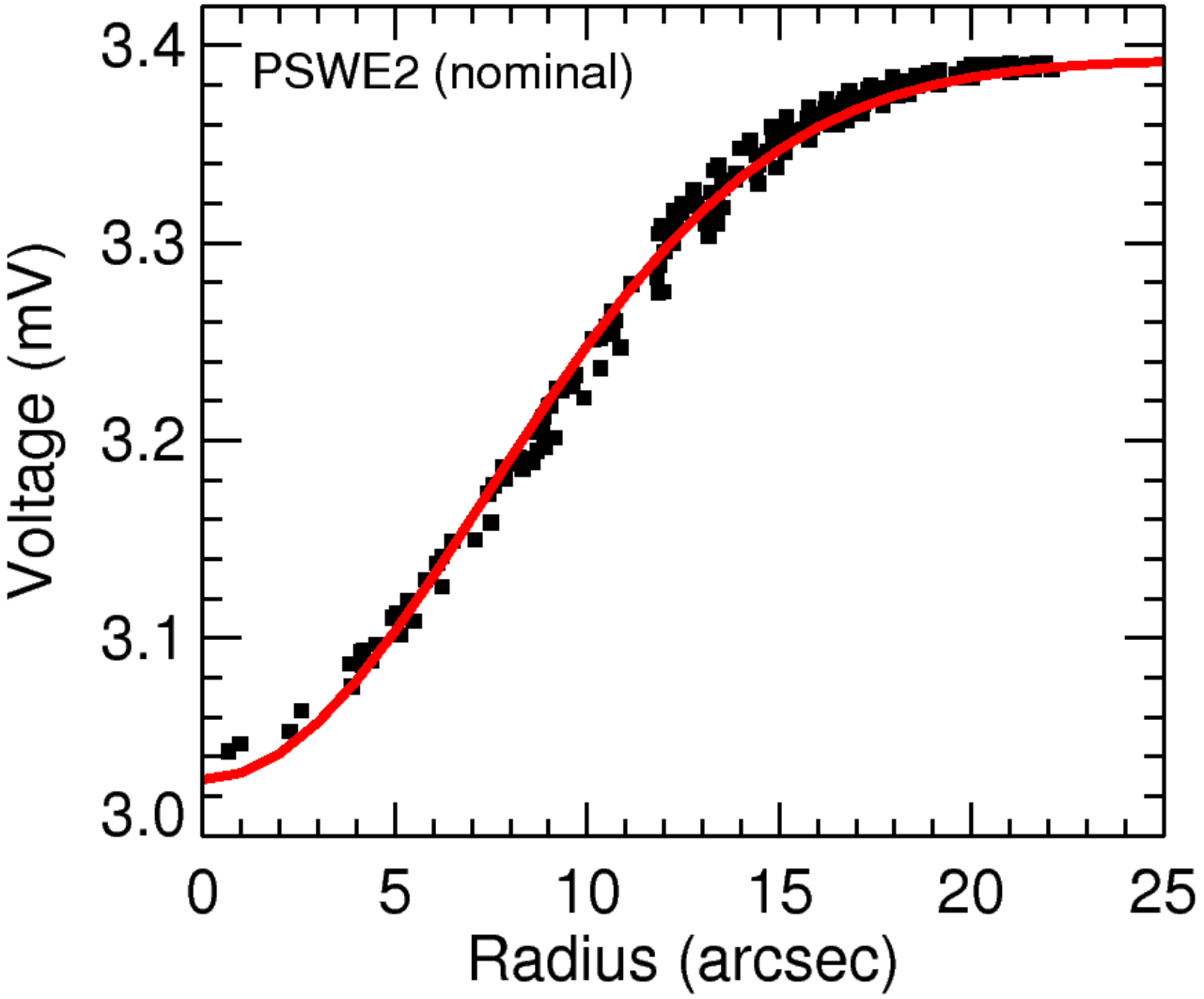
Neptune Fine Scan Observations

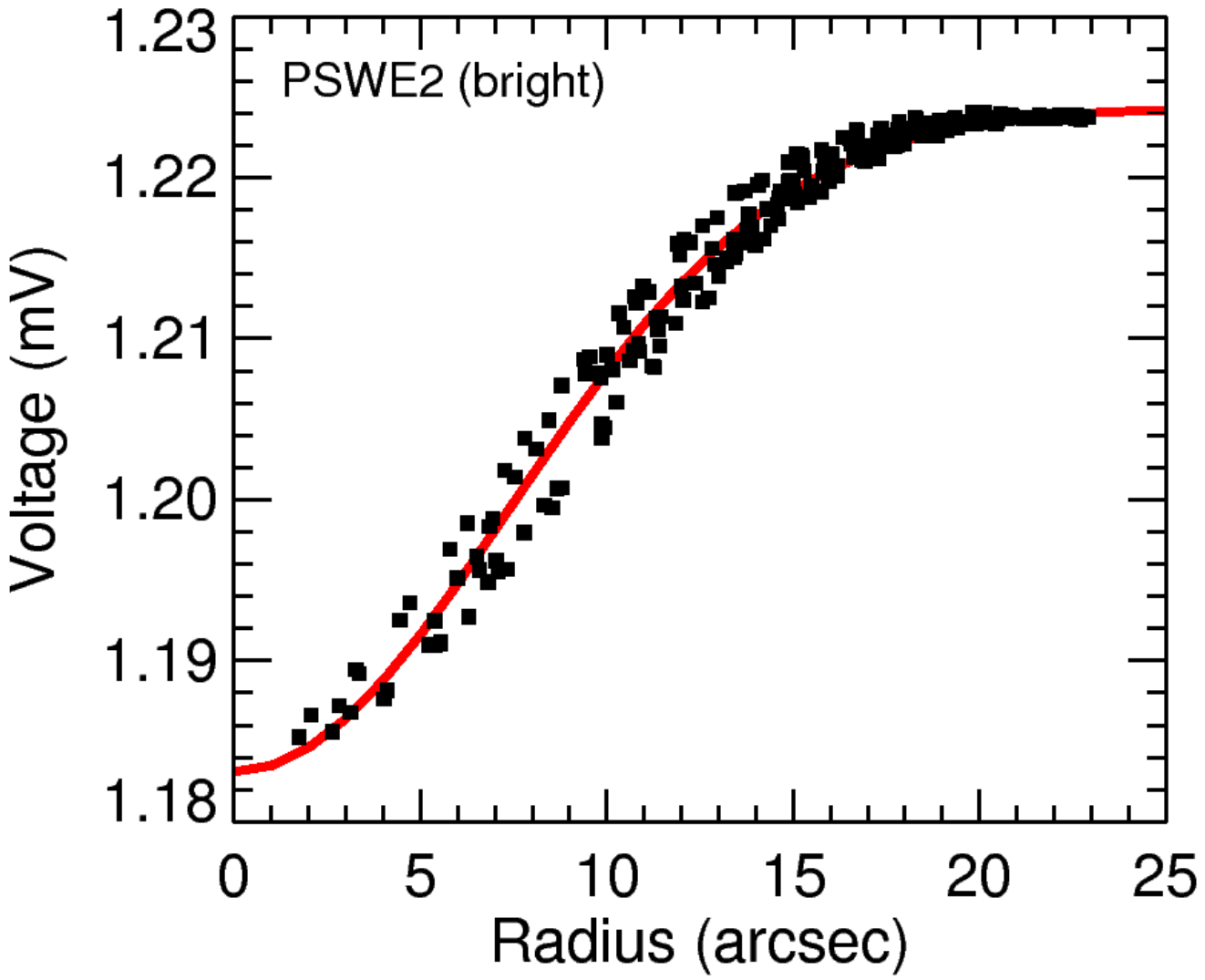
The fine scan observations are set up so that, in each observation, each bolometer scans over Neptune in a zigzag pattern. Scan legs are separated by 1″.

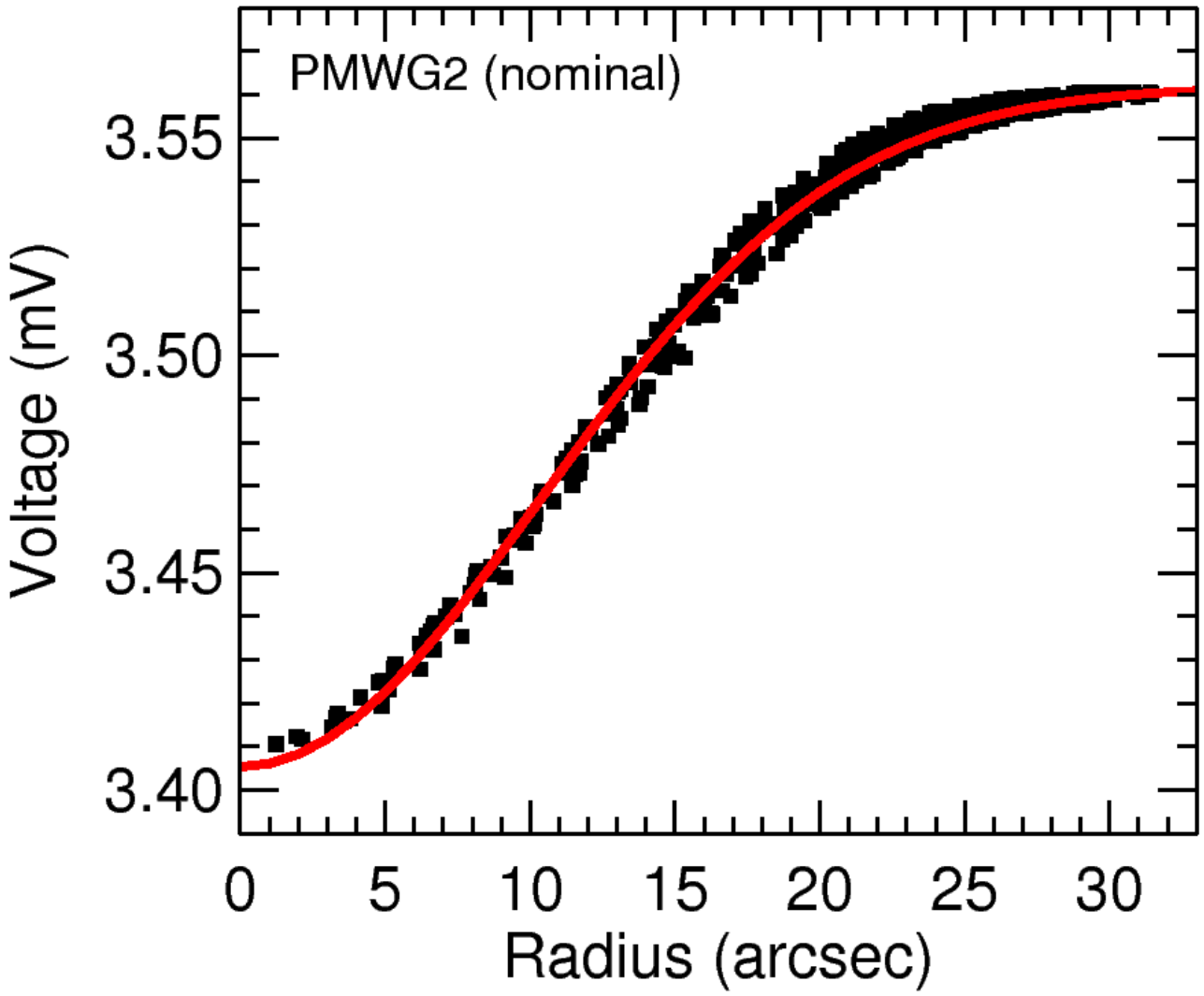
A total of four observations are performed in each bias mode, with two of the observations scanning in a direction perpendicular to the other two observations.

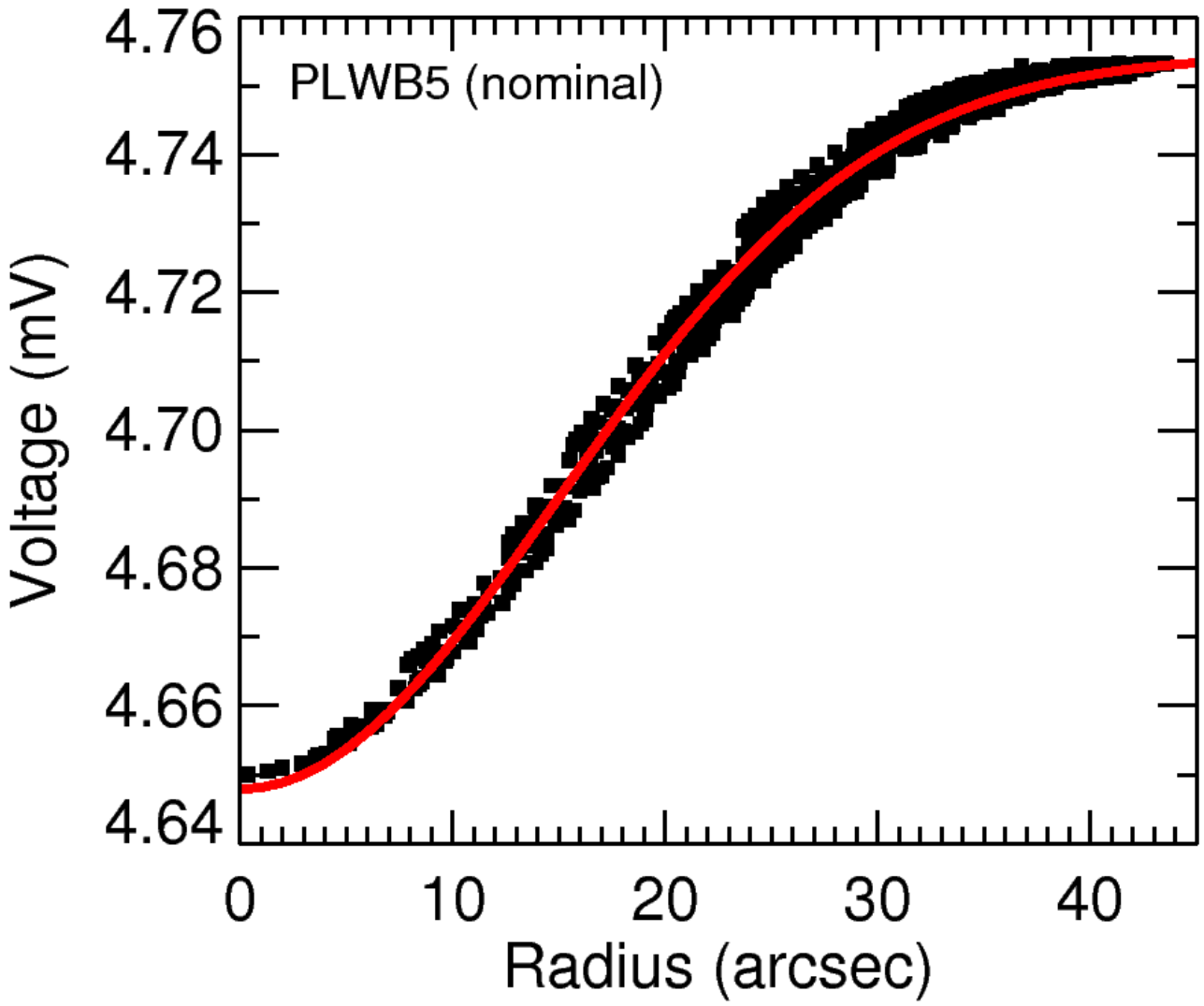
The signals in the timeline data for each bolometer from each observation are then fitted with Gaussian functions to find the peak signal from Neptune and the background signal.

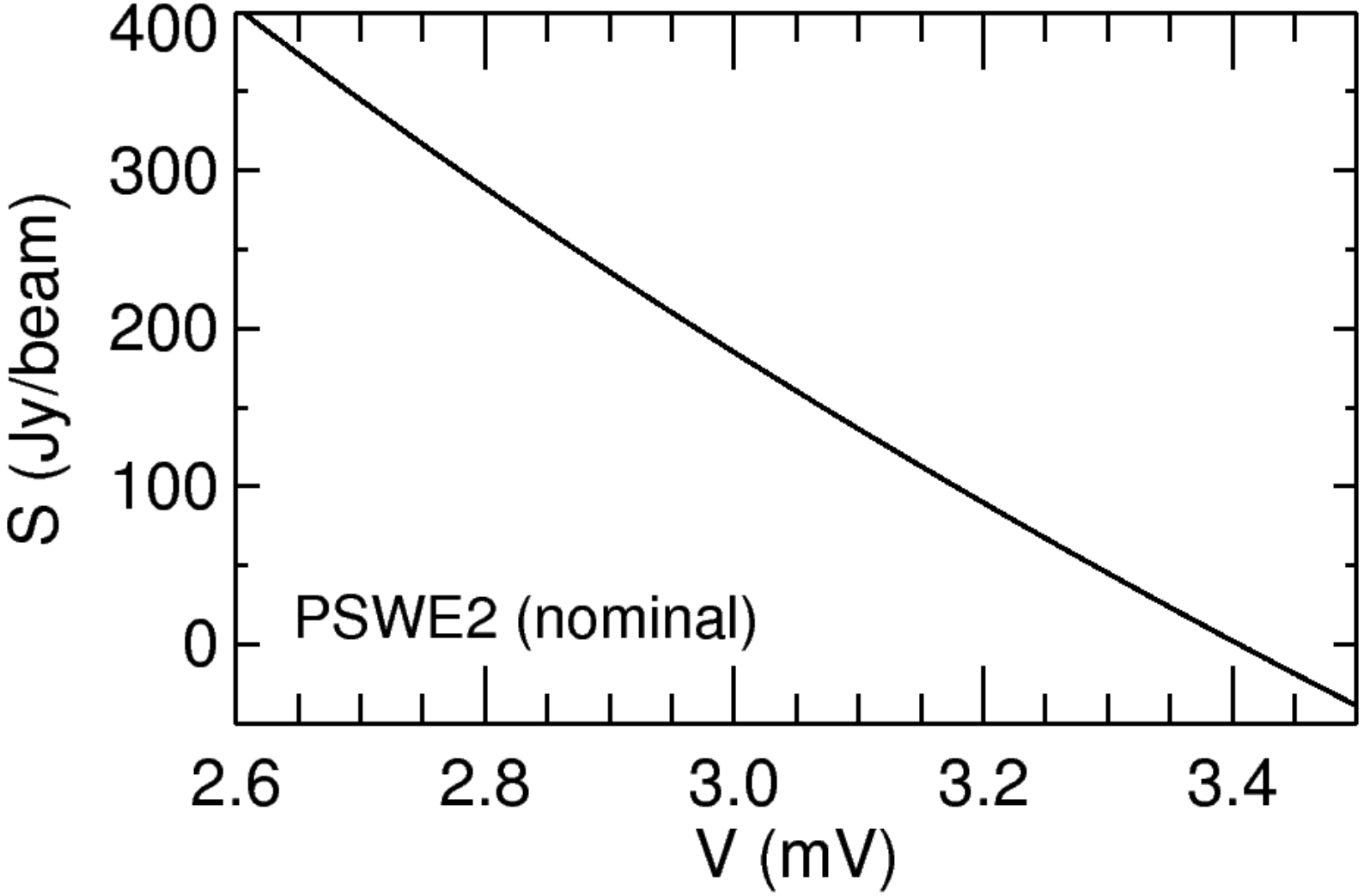


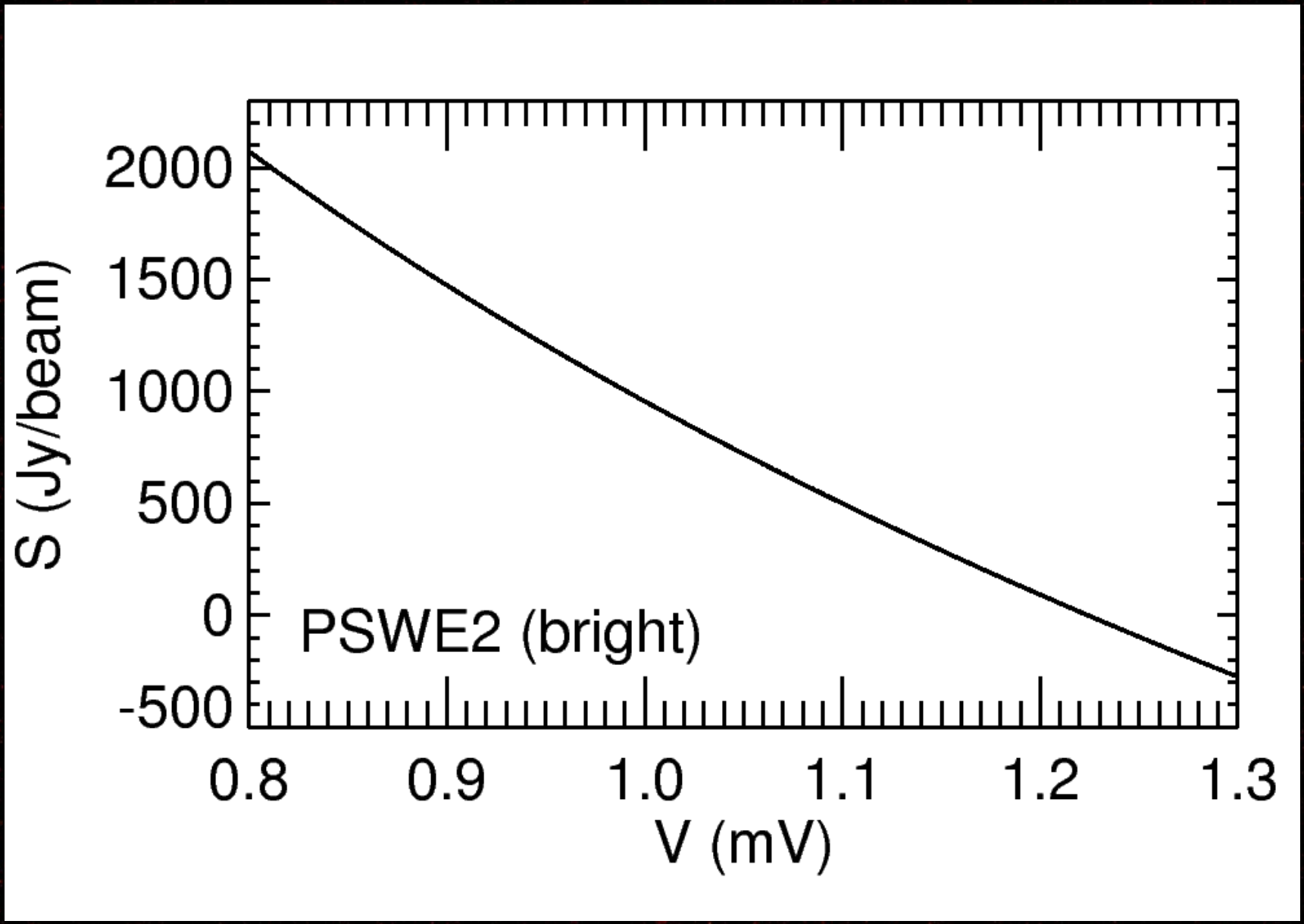

PSWE2 (nominal)
Voltage (mV)
3.4
3.3
3.2
3.1
3.0
0
5
10
15
20
25
Radius (arcsec)


PSWE2 (bright)
Voltage (mV)
1.23
1.22
1.21
1.20
1.19
1.18
0
5
10
15
20
25
Radius (arcsec)


PMWG2 (nominal)
Voltage (mV)
3.55
3.50
3.45
3.40
0
5
10
15
20
25
30
Radius (arcsec)


PLWB5 (nominal)
Voltage (mV)
4.76
4.74
4.72
4.70
4.68
4.66
4.64
0
10
20
30
40
Radius (arcsec)

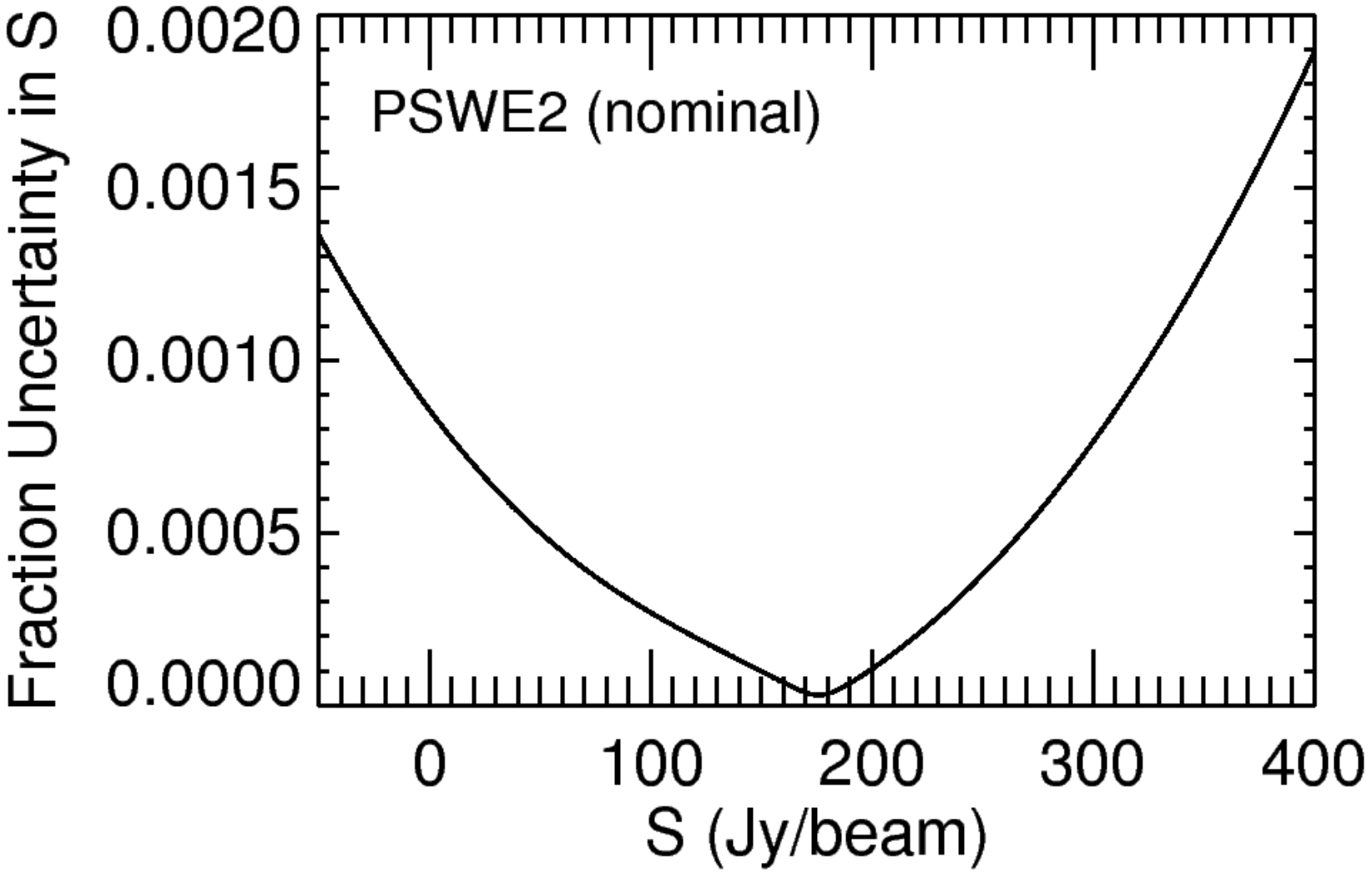

400
300
200
100
0
S (Jy/beam)
PSWE2 (nominal)
2.6
2.8
3.0
3.2
3.4
V (mV)

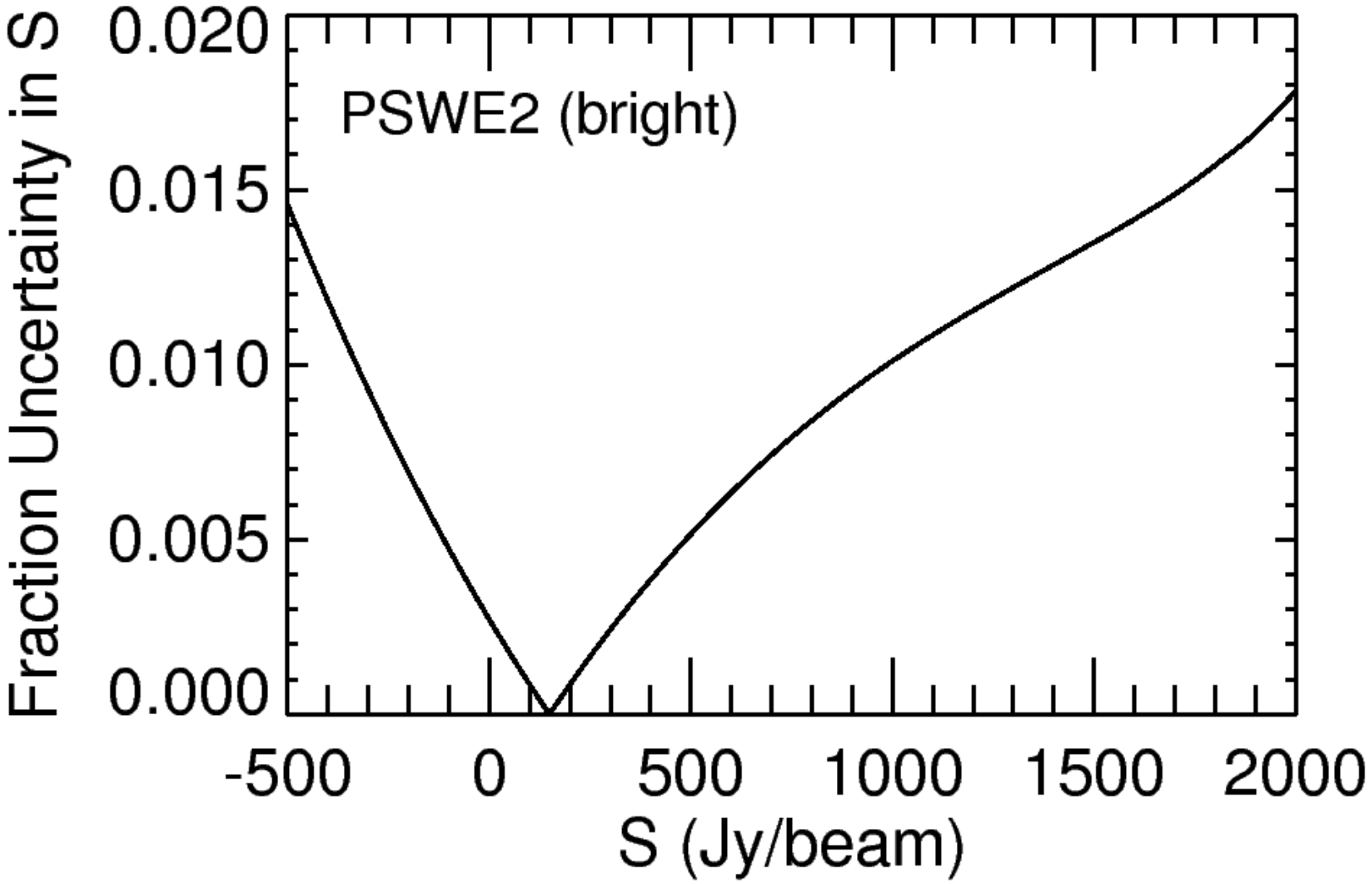

2000
1500
1000
500
0
-500
S (Jy/beam)
PSWE2 (bright)
0.8
0.9
1.0
1.1
1.2
1.3
V (mV)

Calibration Uncertainties for Individual Bolometers

The calibration for the individual bolometers have three sources of uncertainty:

- Uncertainty from the fits to the PCal flash data
- Uncertainties from determining the scaling terms from the fine scan data
- Uncertainties from the model flux densities of Neptune (4%)


PSWE2 (nominal)
Fraction Uncertainty in S
0.0020
0.0015
0.0010
0.0005
0.0000
0
100
200
300
400
S (Jy/beam)


PSWE2 (bright)
Fraction Uncertainty in S
0.020
0.015
0.010
0.005
0.000
-500
0
500
1000
1500
2000
S (Jy/beam)

Uncertainties for Individual Bolometers from Fitting PCal Flash Data

Array	Median Fractional Uncertainty	
	Nominal Mode	Bright Source Mode
250 μm	0.00021	0.0061
350 μm	0.00022	0.0051
500 μm	0.00016	0.0020

Uncertainties for Individual Bolometers from Scaling Terms

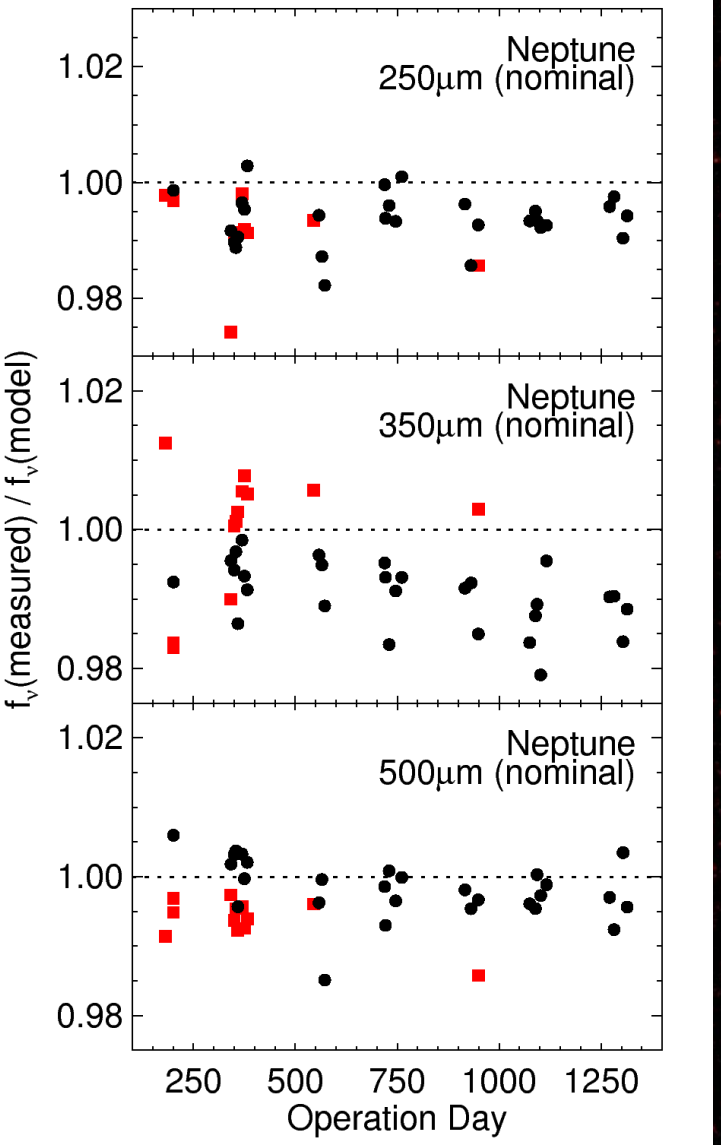
Array	Fractional Uncertainty			
	Nominal Mode		Bright Source Mode	
	Median	Max	Median	Max
250 μm	0.0059	0.047	0.0032	0.0072
350 μm	0.0042	0.045	0.0023	0.012
500 μm	0.0052	0.012	0.0038	0.014

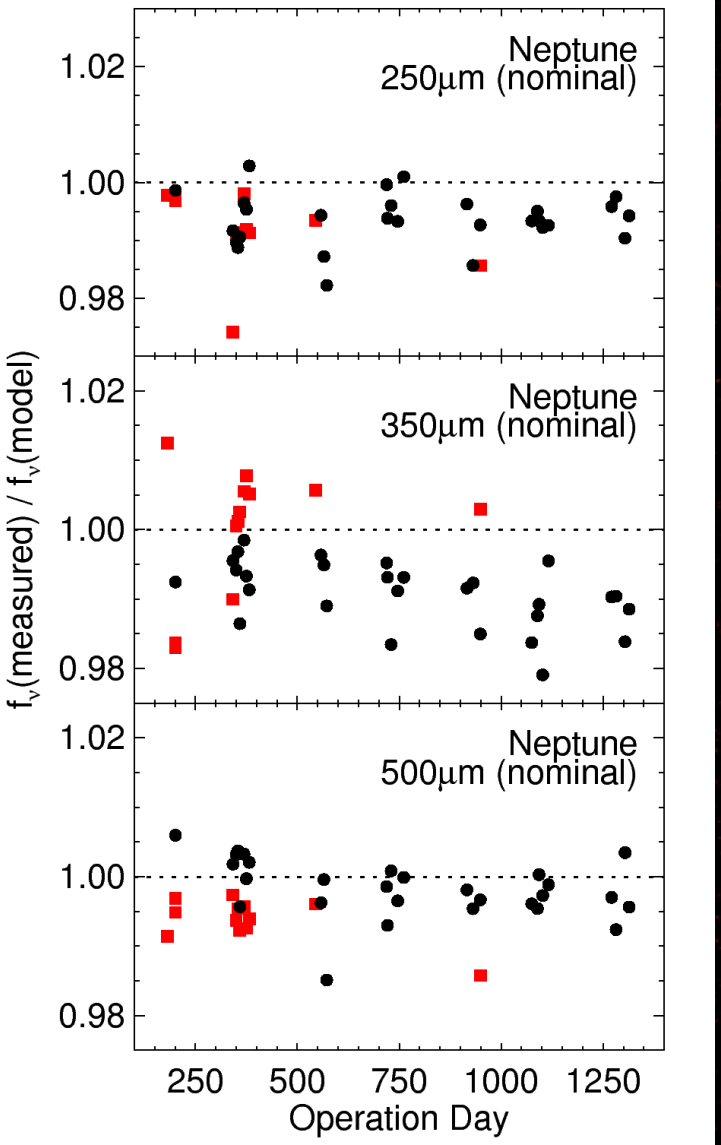
Tests of the Flux Calibration

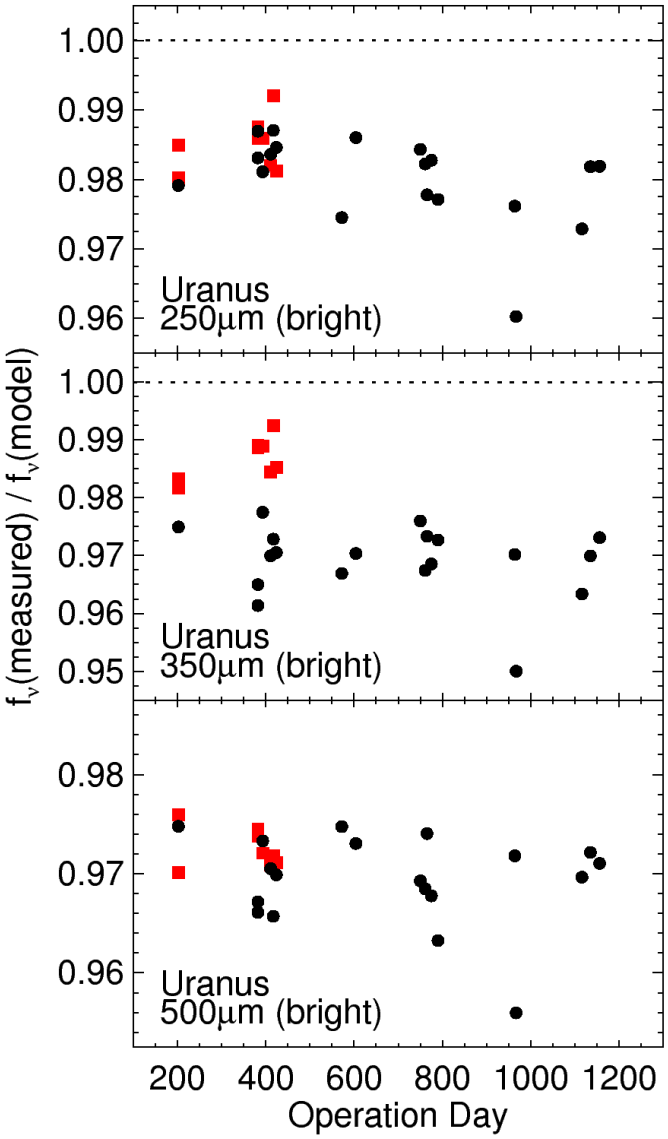
We tested the new flux calibration terms on typical SPIRE observations of three sources:

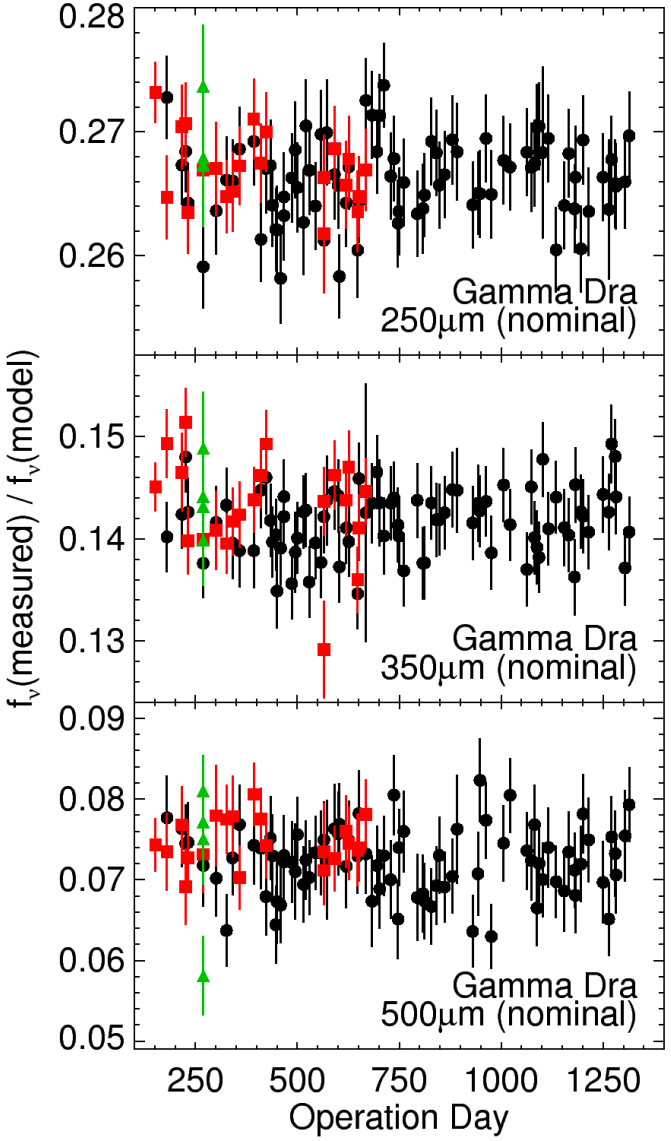
- Neptune
- Uranus
- Gamma Dra

Photometry is done in the timeline data.


Neptune
250μm (nominal)
Neptune
350μm (nominal)
Neptune
500μm (nominal)
1.02
1.00
0.98
250
500
750
1000
1250
Operation Day
f_v(measured) / f_v(model)


Neptune
250μm (nominal)
Neptune
350μm (nominal)
Neptune
500μm (nominal)
1.02
1.00
0.98
250
500
750
1000
1250
Operation Day
f_v(measured) / f_v(model)


1.00
0.99
0.98
0.97
0.96
Uranus
250μm (bright)
1.00
0.99
0.98
0.97
0.96
0.95
Uranus
350μm (bright)
0.98
0.97
0.96
Uranus
500μm (bright)
200
400
600
800
1000
1200
Operation Day
f_ν(measured) / f_ν(model)


0.28
0.27
0.26
Gamma Dra
250μm (nominal)
0.15
0.14
0.13
Gamma Dra
350μm (nominal)
0.09
0.08
0.07
0.06
0.05
Gamma Dra
500μm (nominal)
250
500
750
1000
1250
Operation Day
f_ν(measured) / f_ν(model)

Results of Photometry Tests

Array	Neptune Measured /Model Ratio (nominal)	Neptune Measured /Model Ratio (bright)	Uranus Measured /Model Ratio (bright)	Gamma Dra Flux Densities (nominal; mJy)
250 μm	0.993±0.005	0.997±0.005	0.982±0.006	266±3
350 μm	0.993±0.008	0.996±0.007	0.973±0.010	142±4
500 μm	0.997±0.004	0.998±0.003	0.971±0.004	73±4

Conclusions (PRELIMINARY)

- Sources of instrumental uncertainty for flux calibration of individual bolometers is ~0.5%, although some bolometers have uncertainties of 1-5%.

- Instrumental sources of uncertainty in flux calibration for entire arrays is 1.5% for most sources (sources fainter than Neptune).

- Uncertainties in flux calibration probably dominated by uncertainties in model flux densities of Neptune (4%).