

AWS Lunar Intrusion Analysis

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Based on initial analysis from August 2025

- AWS/EPS-Sterna MWR has nominally 25 space views
 - separated by 0.75°
 - covering 18° - ensures some Moon-free samples
 - From $\sim 74^\circ$ to $\sim 92^\circ$ (0° =nadir)
- AWS orbit: Sun-synchronous, LTAN 22:32

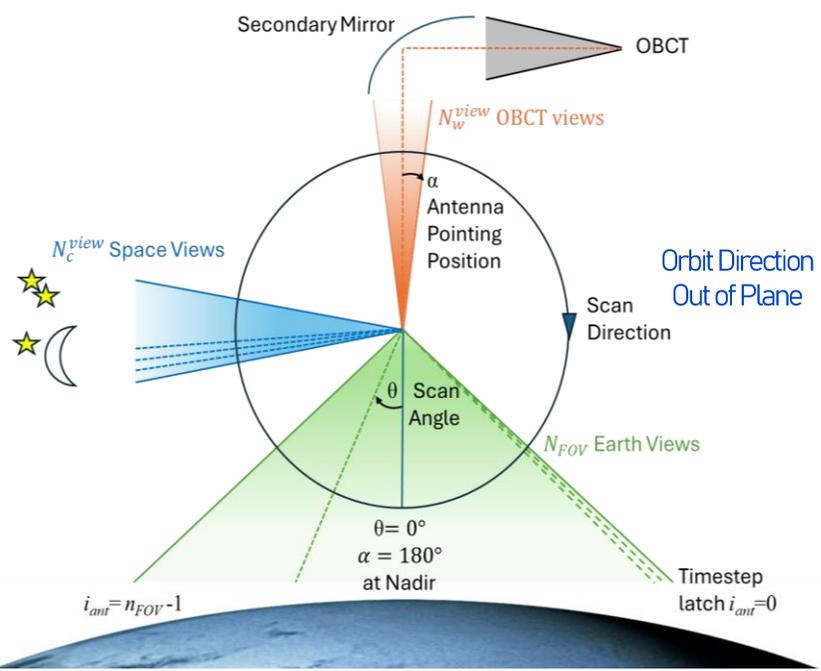
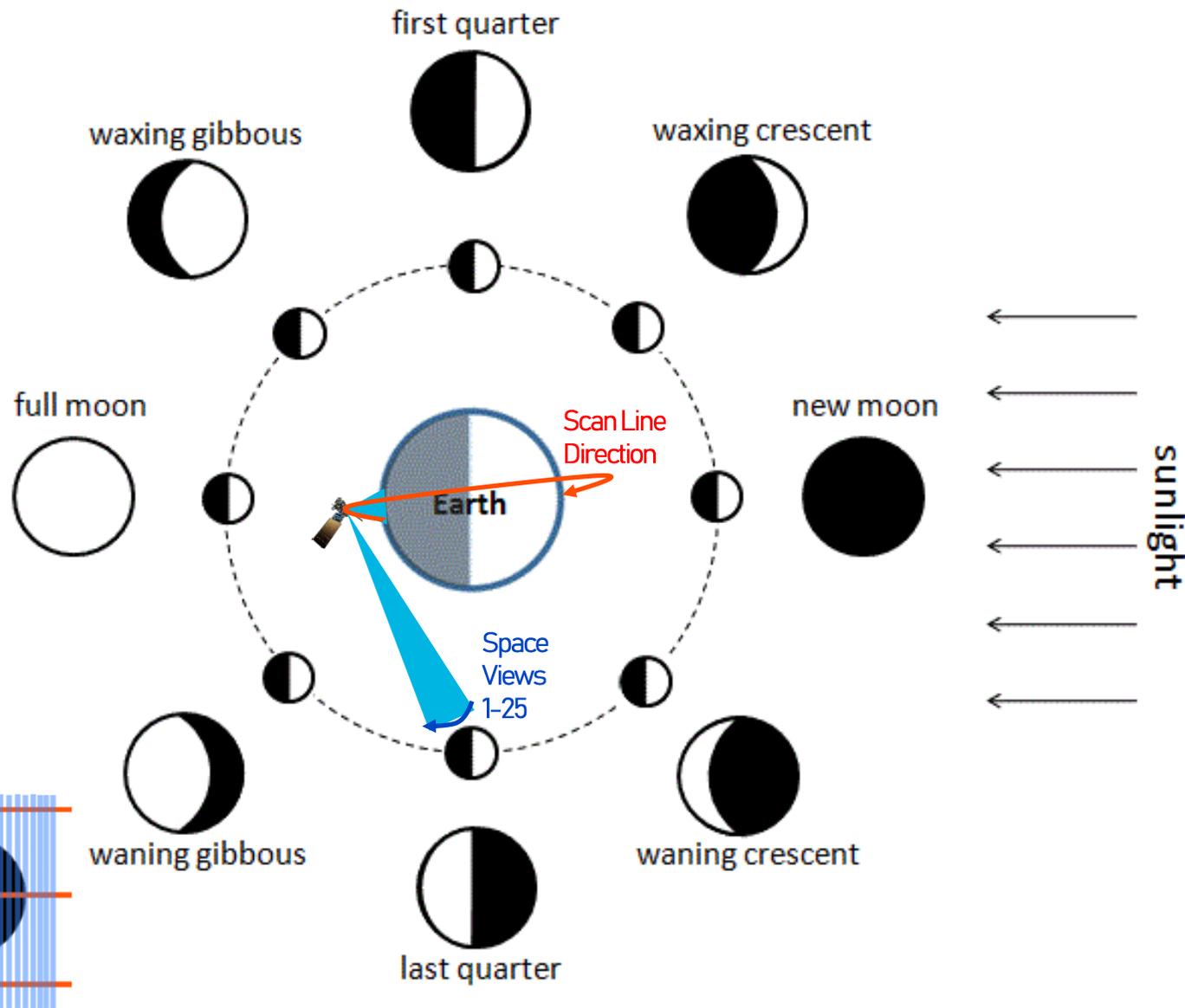


Figure 1: EPS Sterna microwave radiometer measurement cycle. The instrument measures N_{FOV} samples of the Earth scene, N_c^{view} samples of the cold space reference and N_w^{view} samples of the On-Board Calibration Target (OBCT) via a static secondary mirror.



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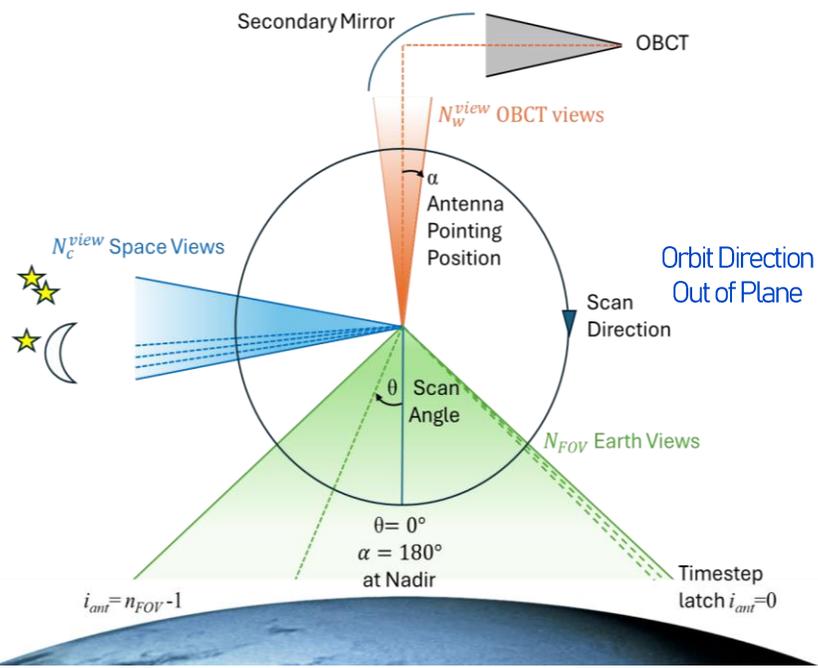
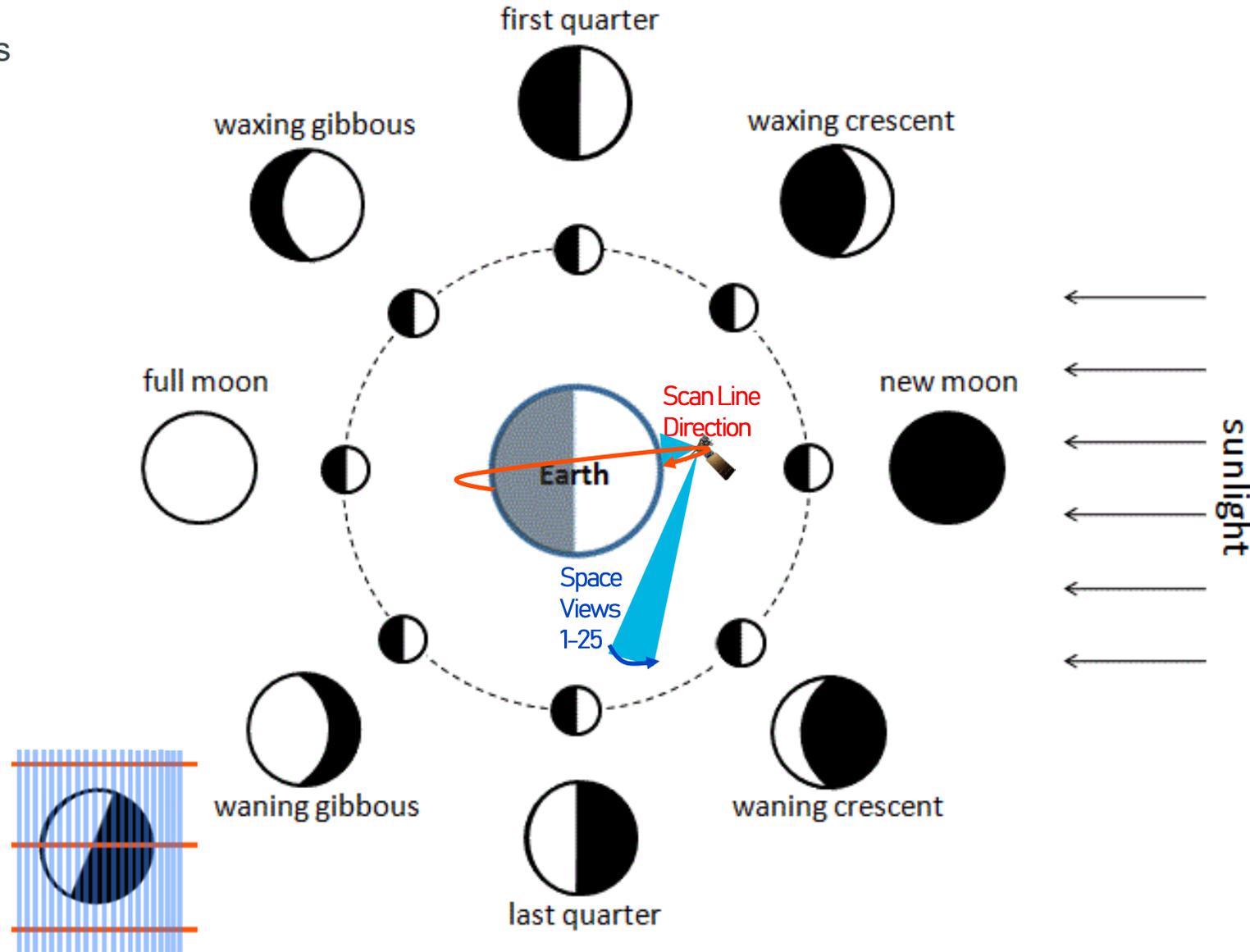


Figure 1: EPS Sterna microwave radiometer measurement cycle. The instrument measures N_{FOV} samples of the Earth scene, N_c^{view} samples of the cold space reference and N_w^{view} samples of the On-Board Calibration Target (OBCT) via a static secondary mirror.





Check SV Counts

- Found Moon in AWS Space View
- Thanks to Martin Burgdorf (U. Hamburg)
- 15, 16, 17 July 2025

- Moon present in 39 orbits
- in all channels in 11 orbits
- Some in last Space View
- Some near start/end of Orbit

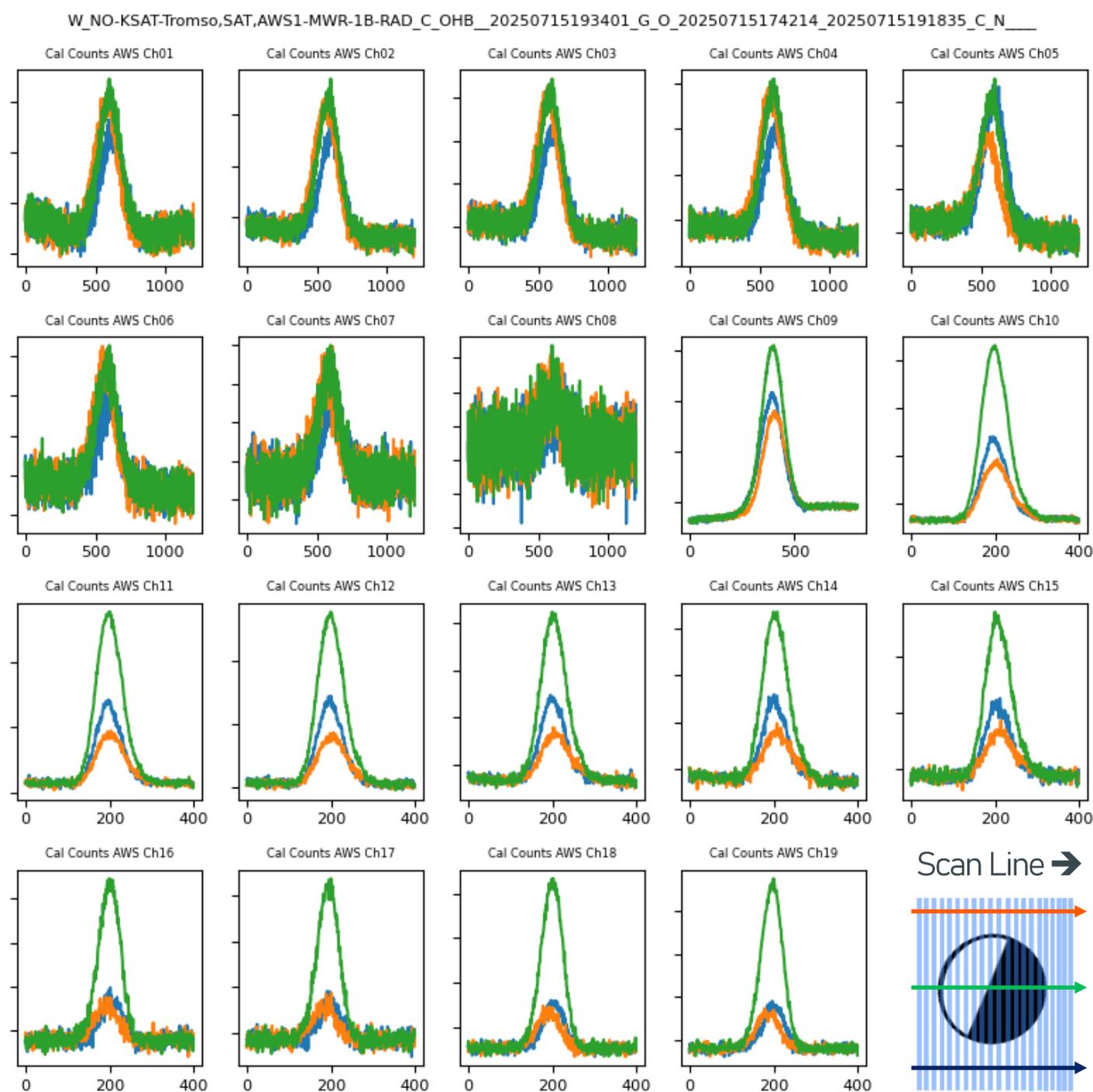
- Only first good case shown only:
 - 2025-07-15 17:51/18:00

1. Find peak in SV counts (isv, iscan)

2. Check Time Series of SV counts

- iscan \pm n00 scan lines
- isv-1, isv+1, isv
- isv-1 \approx isv+1 \Rightarrow Moon close to centre isv

Space View Counts



3. Put scan lines on angular scale

- Yang and Burgdorf 2020:

The conversion from scan number n_{scan} to r , i.e., the angular distance between the pointing direction and the position of the center of the Moon as seen by the microwave sounder (in degrees), is done with the following formula:

$$r = \frac{n_{scan} \frac{8}{3} 360^\circ \cos \alpha}{p} \quad (A2)$$

where α is the angular distance between the nadir and the direction of the DSV, P is the orbital period of the satellite in seconds, and $8/3$ is the duration of a scan in seconds.

- In the case of AWS:
 - n_{scan} is the scan line number
 - scan period is 1.1905s, instead of $8/3$ s
 - $P=5791.07250$ s
 - $\alpha = \text{dsdm.aws_antennapos_counts_coldview}/\text{plcEncoderM}$
 $x \ (45000) * 360$
 - Plus/minus feedhorn offsets!
(Not implemented yet)
 - 0.0300° between scan lines
(~17 scan lines over ~ 0.5° Moon disc)

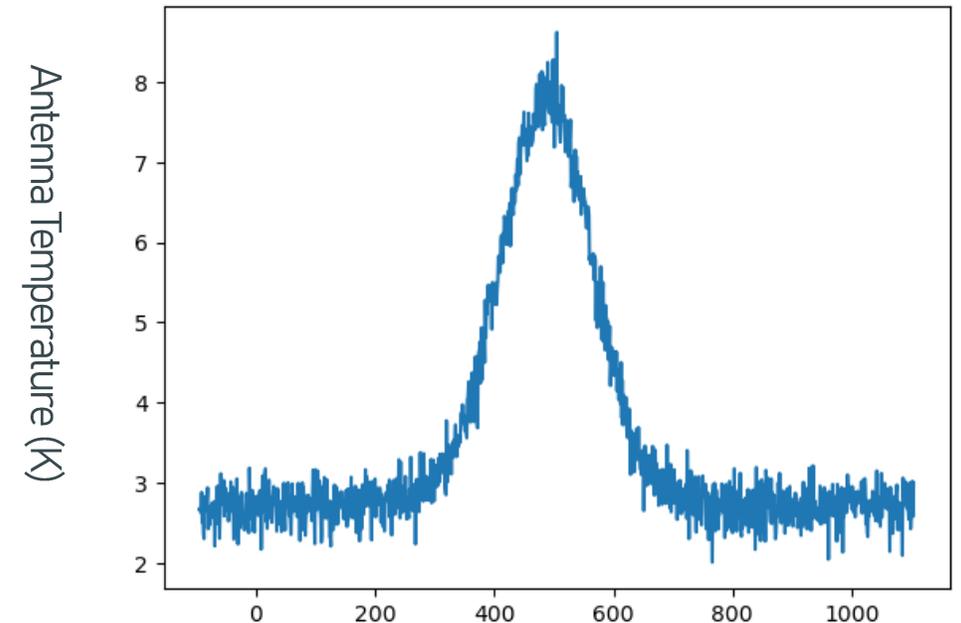
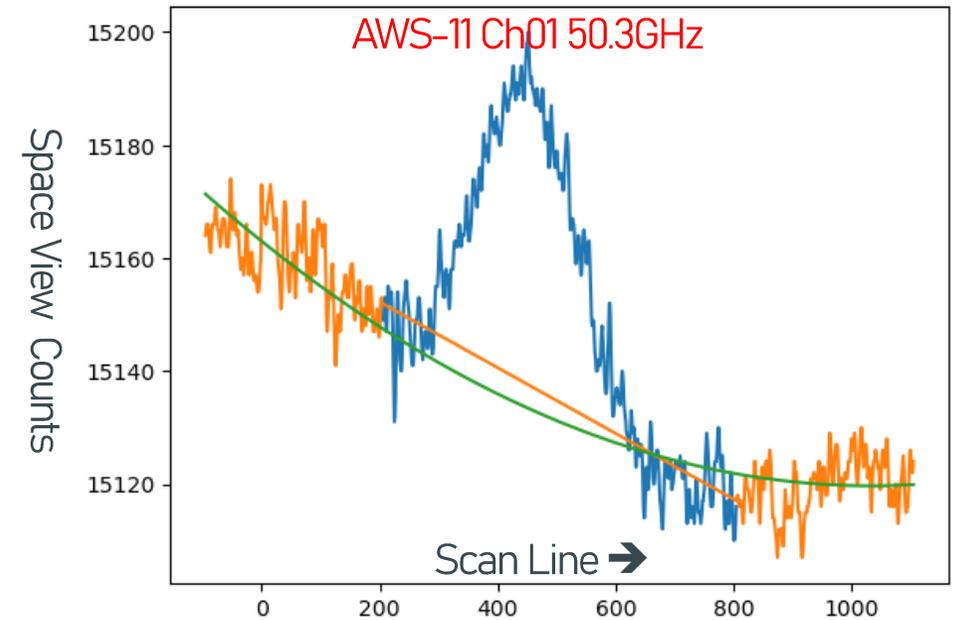
This formula can be derived considering the case where the SV is pointing at zenith, i. e. It describes a great circle during one orbit
- in this case alpha is 180 deg, and the SV moves from one scan to the next by 360 deg / (no. of scans per orbit)
- and the case where the SV is pointing in the direction of the orbital axis of the satellite - in this case the SV does not move at all from one scan to the next (except for the movement of the orbit axis).



Derive Approximate Antenna Temperatures

4. Apply crude calibration

- To convert counts to kelvin
- To account for calibration drift
- Take counts_coldview_average_over_scans, Cc
- Identify parts of scan n00 scan lines before/after lunar intrusion
- Fit quadratic curve (Cc') through uncontaminated space views
- Estimate gain for each scan line:
 - $\text{Gain} = (C_w - C_c') / (T_w - T_c)$
 - $C_w = \text{counts_warmview_average_over_scans}$
 - $T_h = \text{warm_target_effective_temperature}$
 - $T_c = \text{cold_target_effective_temperature} (\approx 2.7\text{K})$
- Calculate antenna temperature,
 $T_a = (C_c - \langle C_c' \rangle) / \text{gain} + T_c$
- n.b. No gain averaging, non-linearity, antenna pattern correction, scan mirror reflectivity correction...



- Use `curve_fit` from `scipy.optimize`

- To fit coefficients for

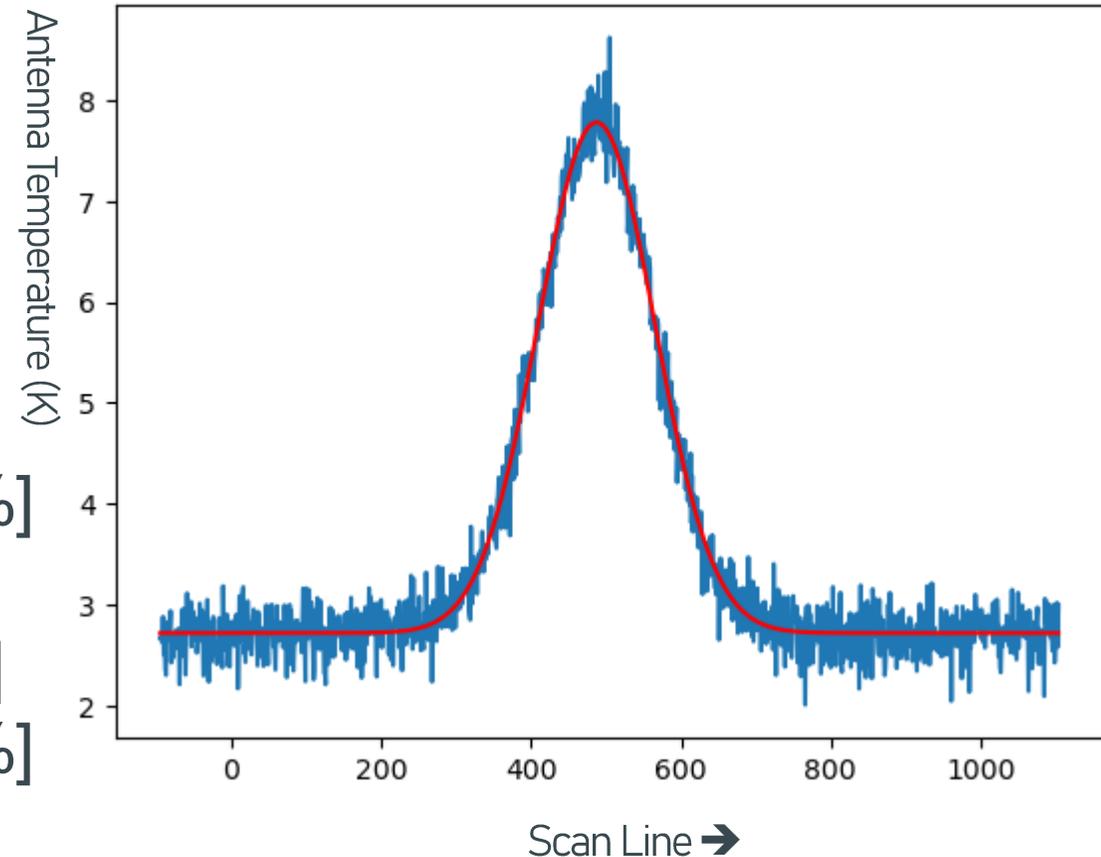
```
def gaussian_with_offset(x, A, mu, sigma, C):  
    return A * np.exp(-(x-mu)**2 / (2*sigma**2)) + C
```

- Provide First Guess [and Constraints]:

- A_0 = Amplitude wrt offset (K) $[\pm 50\%]$
- μ_0 = location of peak (scan line/ $^\circ$) $[\pm 10^\circ]$
- C_0 = offset (K) = 2.7K $[2-5K]$
- σ_0 = FWHM / $(2\sqrt{2.1\ln(2)})$ ($^\circ$) $[\pm 30\%]$

- Uncertainty on retrieved coefficients

- $= \sqrt{\text{diag}(\text{covariance})}$





Fitted Coefficients A-T

Ch01 SV04 $Ta_{xs}= 4.94 \pm 0.03$ K $Ta_{bg}=2.75 \pm 0.01$ K $FWHM=3.177 \pm 0.025$ °
 Ch02 SV04 $Ta_{xs}= 5.06 \pm 0.02$ K $Ta_{bg}=2.72 \pm 0.01$ K $FWHM=3.080 \pm 0.017$ °
 Ch03 SV04 $Ta_{xs}= 5.13 \pm 0.03$ K $Ta_{bg}=2.73 \pm 0.01$ K $FWHM=2.993 \pm 0.021$ °
 Ch04 SV04 $Ta_{xs}= 5.19 \pm 0.02$ K $Ta_{bg}=2.73 \pm 0.01$ K $FWHM=2.997 \pm 0.017$ °
 Ch05 SV05 $Ta_{xs}= 5.04 \pm 0.03$ K $Ta_{bg}=2.72 \pm 0.01$ K $FWHM=2.906 \pm 0.021$ °
 Ch06 SV04 $Ta_{xs}= 5.10 \pm 0.05$ K $Ta_{bg}=2.76 \pm 0.02$ K $FWHM=2.998 \pm 0.036$ °
 Ch07 SV04 $Ta_{xs}= 5.35 \pm 0.08$ K $Ta_{bg}=2.71 \pm 0.02$ K $FWHM=3.014 \pm 0.051$ °
 Ch08 SV04 $Ta_{xs}= 4.99 \pm 0.39$ K $Ta_{bg}=2.00 \pm 0.43$ K $FWHM=10.77 \pm 1.063$ °

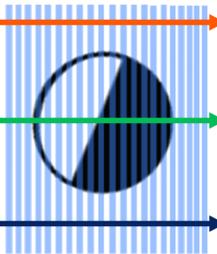
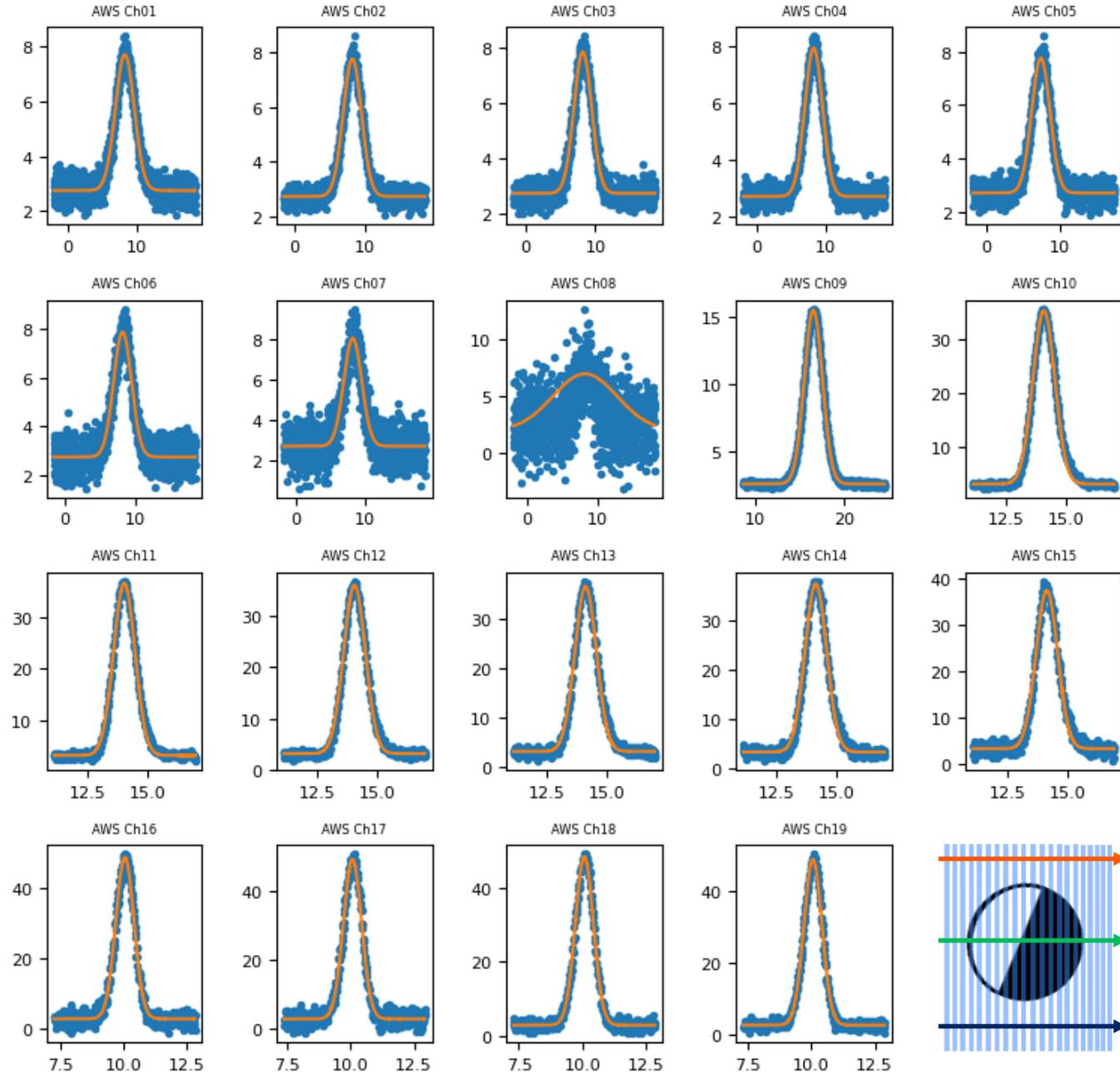
 Ch09 SV01 $Ta_{xs}=12.80 \pm 0.02$ K $Ta_{bg}=2.65 \pm 0.01$ K $FWHM=2.378 \pm 0.004$ °

 Ch10 SV06 $Ta_{xs}=31.99 \pm 0.11$ K $Ta_{bg}=3.23 \pm 0.04$ K $FWHM=1.082 \pm 0.005$ °
 Ch11 SV06 $Ta_{xs}=33.31 \pm 0.12$ K $Ta_{bg}=3.15 \pm 0.04$ K $FWHM=1.061 \pm 0.005$ °
 Ch12 SV06 $Ta_{xs}=32.85 \pm 0.13$ K $Ta_{bg}=3.13 \pm 0.05$ K $FWHM=1.071 \pm 0.005$ °
 Ch13 SV06 $Ta_{xs}=33.37 \pm 0.14$ K $Ta_{bg}=3.14 \pm 0.05$ K $FWHM=1.067 \pm 0.006$ °
 Ch14 SV06 $Ta_{xs}=34.11 \pm 0.15$ K $Ta_{bg}=3.20 \pm 0.06$ K $FWHM=1.065 \pm 0.006$ °
 Ch15 SV06 $Ta_{xs}=34.32 \pm 0.18$ K $Ta_{bg}=3.20 \pm 0.07$ K $FWHM=1.067 \pm 0.007$ °

 Ch16 SV07 $Ta_{xs}=46.23 \pm 0.31$ K $Ta_{bg}=2.66 \pm 0.10$ K $FWHM=0.841 \pm 0.007$ °
 Ch17 SV07 $Ta_{xs}=46.54 \pm 0.32$ K $Ta_{bg}=2.73 \pm 0.10$ K $FWHM=0.842 \pm 0.007$ °
 Ch18 SV07 $Ta_{xs}=45.75 \pm 0.21$ K $Ta_{bg}=2.79 \pm 0.07$ K $FWHM=0.838 \pm 0.005$ °
 Ch19 SV07 $Ta_{xs}=46.13 \pm 0.19$ K $Ta_{bg}=2.74 \pm 0.06$ K $FWHM=0.837 \pm 0.004$ °

W_NO-KSAT-Tromso,SAT,AWS1-MWR-1B-RAD_C_OHB_20250715193401_G_O_20250715174214_20250715191835_C_N__

Ta (K)

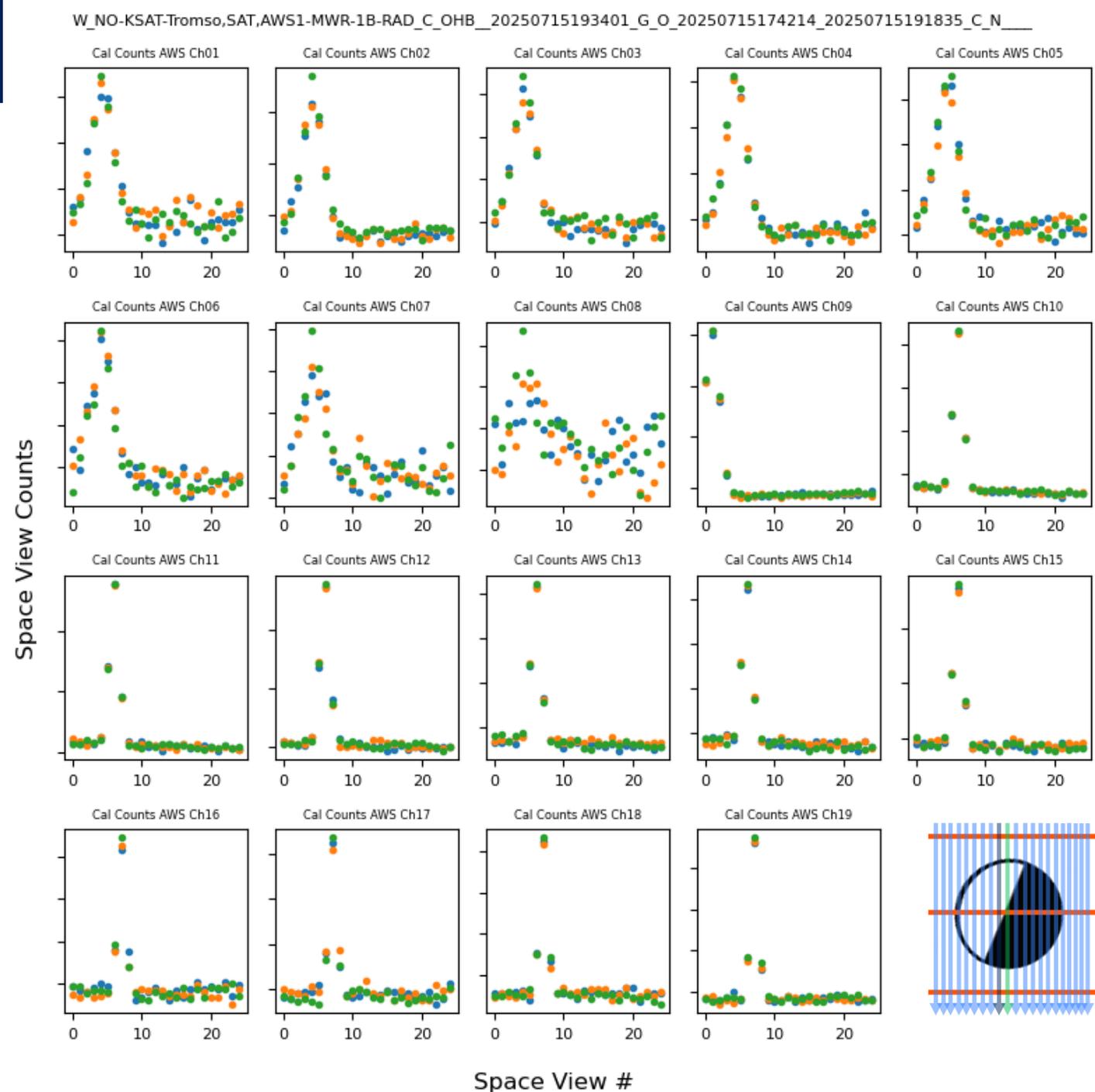


Angle (°)



Along-Scan Direction

- Also possible to exploit Moon samples in along-scan direction
- Inter-Spot separation = 0.75°
- Moon covers
 - ~7 space views in Band 1
 - ~5 space views in Band 2
 - ~3 space views in Bands 3-4
- Plots counts in scan lines
 - $i_{\text{scan}-1}, i_{\text{scan}+1}, i_{\text{scan}}$
 - $i_{\text{scan}-1} \approx i_{\text{scan}+1}$
=> Moon close to centre i_{scan}
- Only central scan line plotted here
 - Many more are possible
→ reduce uncertainty



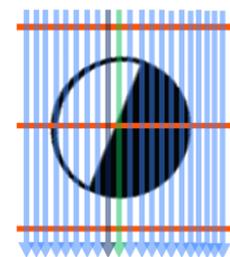
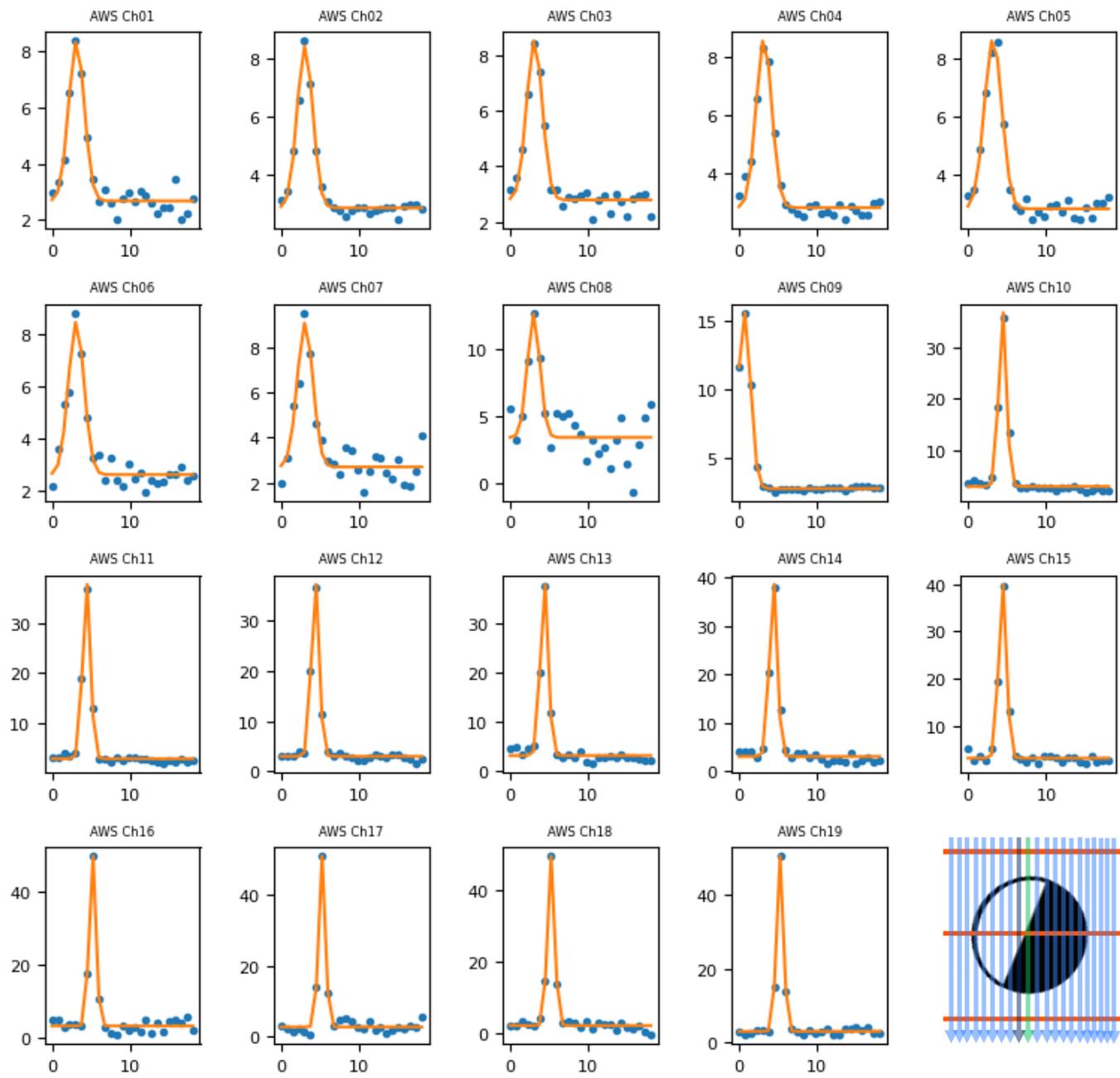


Fitted Coefficients A-S

Ch01 Scan#487 $Ta_{xs}= 5.69 \pm 0.29$ K $Ta_{bg}=2.68 \pm 0.08$ K $FWHM=2.34 \pm 0.14$ °
 Ch02 Scan#505 $Ta_{xs}= 5.61 \pm 0.16$ K $Ta_{bg}=2.84 \pm 0.05$ K $FWHM=2.34 \pm 0.08$ °
 Ch03 Scan#500 $Ta_{xs}= 5.78 \pm 0.29$ K $Ta_{bg}=2.79 \pm 0.08$ K $FWHM=2.34 \pm 0.14$ °
 Ch04 Scan#491 $Ta_{xs}= 5.82 \pm 0.22$ K $Ta_{bg}=2.83 \pm 0.06$ K $FWHM=2.34 \pm 0.11$ °
 Ch05 Scan#491 $Ta_{xs}= 5.91 \pm 0.24$ K $Ta_{bg}=2.82 \pm 0.07$ K $FWHM=2.61 \pm 0.13$ °
 Ch06 Scan#504 $Ta_{xs}= 5.85 \pm 0.39$ K $Ta_{bg}=2.62 \pm 0.11$ K $FWHM=2.34 \pm 0.19$ °
 Ch07 Scan#501 $Ta_{xs}= 6.38 \pm 0.56$ K $Ta_{bg}=2.69 \pm 0.16$ K $FWHM=2.34 \pm 0.25$ °
 Ch08 Scan#483 $Ta_{xs}= 9.19 \pm 1.50$ K $Ta_{bg}=3.43 \pm 0.37$ K $FWHM=1.86 \pm 0.36$ °
 Ch09 Scan#843 $Ta_{xs}=12.92 \pm 0.11$ K $Ta_{bg}=2.75 \pm 0.03$ K $FWHM=1.85 \pm 0.02$ °
 Ch10 Scan#946 $Ta_{xs}=34.20 \pm 0.90$ K $Ta_{bg}=3.01 \pm 0.18$ K $FWHM=1.17 \pm 0.03$ °
 Ch11 Scan#944 $Ta_{xs}=35.54 \pm 0.75$ K $Ta_{bg}=2.87 \pm 0.15$ K $FWHM=1.17 \pm 0.03$ °
 Ch12 Scan#946 $Ta_{xs}=35.50 \pm 0.70$ K $Ta_{bg}=3.00 \pm 0.14$ K $FWHM=1.17 \pm 0.03$ °
 Ch13 Scan#946 $Ta_{xs}=36.06 \pm 1.03$ K $Ta_{bg}=3.14 \pm 0.20$ K $FWHM=1.17 \pm 0.04$ °
 Ch14 Scan#946 $Ta_{xs}=36.67 \pm 1.06$ K $Ta_{bg}=3.06 \pm 0.21$ K $FWHM=1.17 \pm 0.04$ °
 Ch15 Scan#942 $Ta_{xs}=37.56 \pm 0.90$ K $Ta_{bg}=3.10 \pm 0.18$ K $FWHM=1.17 \pm 0.03$ °
 Ch16 Scan#724 $Ta_{xs}=47.71 \pm 1.53$ K $Ta_{bg}=3.08 \pm 0.30$ K $FWHM=1.02 \pm 0.04$ °
 Ch17 Scan#732 $Ta_{xs}=48.40 \pm 1.39$ K $Ta_{bg}=2.62 \pm 0.29$ K $FWHM=1.01 \pm 0.03$ °
 Ch18 Scan#725 $Ta_{xs}=47.01 \pm 1.04$ K $Ta_{bg}=2.32 \pm 0.22$ K $FWHM=1.07 \pm 0.03$ °
 Ch19 Scan#729 $Ta_{xs}=47.58 \pm 0.69$ K $Ta_{bg}=2.96 \pm 0.14$ K $FWHM=1.04 \pm 0.02$ °

W_NO-KSAT-Tromso,SAT,AWS1-MWR-1B-RAD_C_OHB_20250715193401_G_O_20250715174214_20250715191835_C_N__

Ta (K)



Scan Angle (°)



Compare IPF with pre-launch beamwidth measurements

- 4 cases with all channels
 - 15, 16, 17 July 2025
 - All very similar Along-Track results
 - Quite different for Along-Scan (but only for 1st case analysed so far)
 - Especially Bands 1 & 2 – **needs checking!**
- Does not account for finite size of Moon
 - True FWHM will be smaller
- Along-Track FWHM compared to Ericsson 2025
 - Band 1: very similar ($\pm 2\%$)
 - Band 2: 41% larger!
 - Band 3: 10% larger
 - Band 4: 18% smaller

IPF L1B Band	Along-Track FWHM (°) Mean \pm Unc	Along-Scan FWHM Mean \pm Unc
1: 50-56GHz	3.02 \pm 0.09	2.40 \pm 0.30
2: 89GHz	2.43 \pm 0.10	1.50 \pm 0.38
3: 183GHz	1.07 \pm 0.01	1.17 \pm 0.00
4: 325GHz	0.84 \pm 0.01	1.01 \pm 0.04

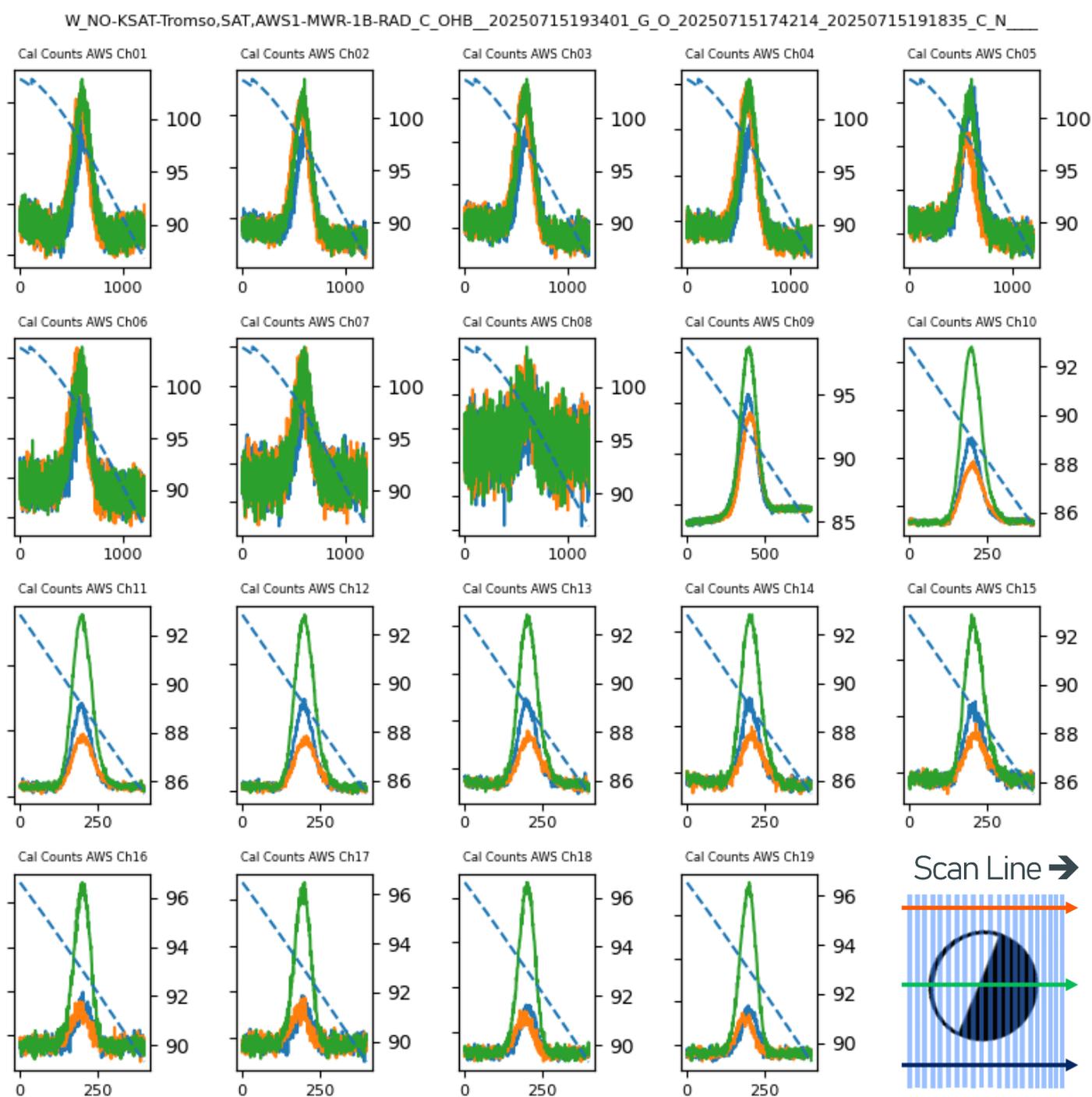
Table 19 AWS-SSRS-3303 measured FWHM footprint

Frequency [GHz]	FWHM [°]	FWHM [km]
50.0	3.10 (2.92, 3.28)	32.4 (30.6, 34.3)
53.0	3.08 (2.83, 3.31)	32.2 (29.6, 34.6)
57.0	2.99 (2.73, 3.24)	31.3 (28.6, 33.9)
88.8	1.72 (1.78, 1.68)	18.0 (18.6, 17.6)
165.0	0.98 (0.94, 1.02)	10.3 (9.8, 10.7)
176.4	0.95 (0.91, 0.98)	9.9 (9.5, 10.3)
330.0	1.03 (1.07, 1.04)	10.8 (11.2, 10.9)



Moon angle

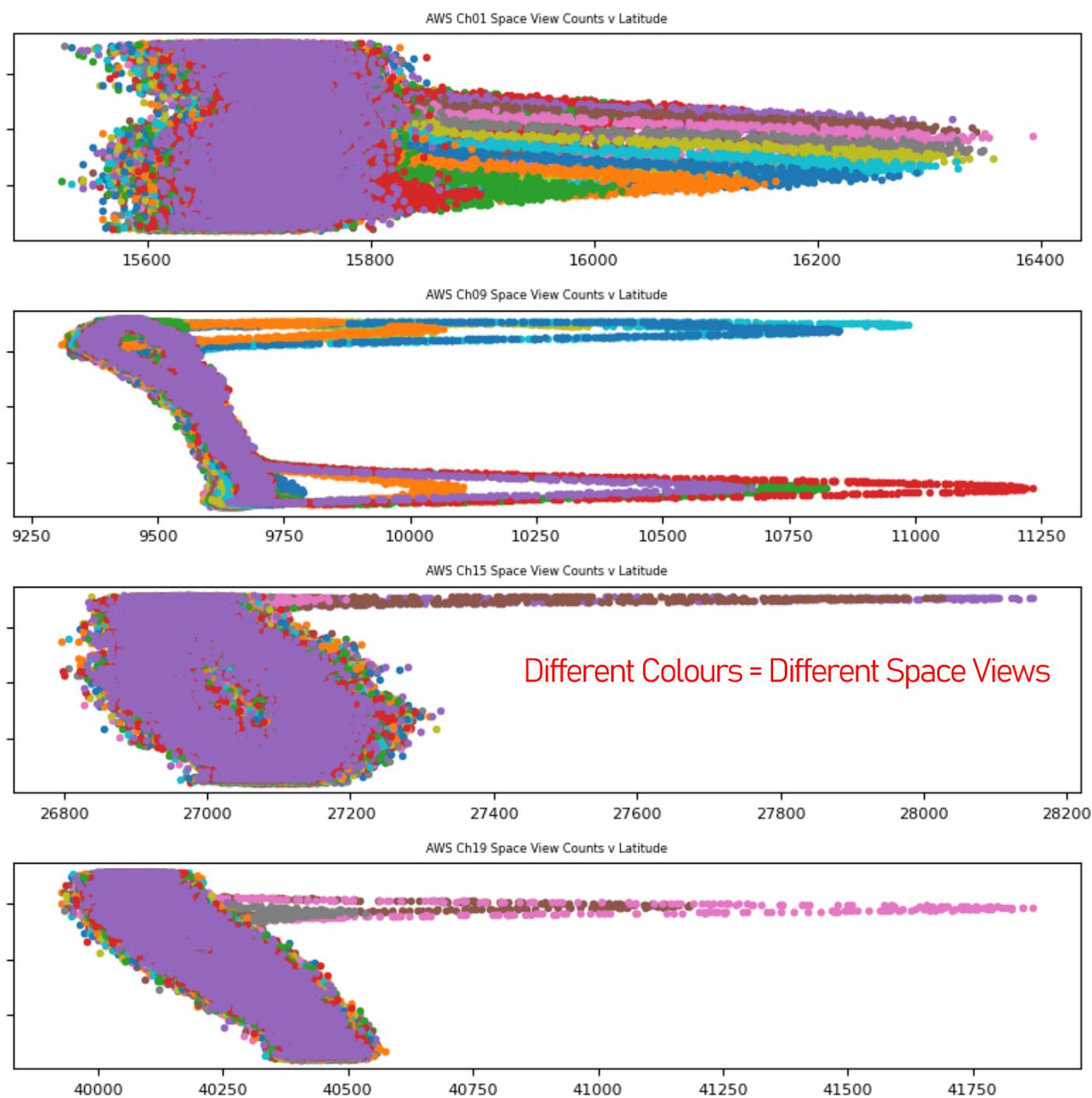
- Overplotted `aws_moon_angle` on right-hand axes for each channel
- Was difficult to find Moon in IPF L1B AWS data
- IPF L1B data `navigation/aws_moon_angle` ~90° higher than expected!
= 90° ± feedhorn pointing?
- `processing_information/aws_moon_contamination_flag` not set
- Suitable values for `moon_angle_threshold` = 2*FWHM
 - Currently 65° for all channels!





How many Moons?!

- One example had “ghost peak” near Moon
- Peak was near end of orbit
- Indices were wrapping!
- Can be 3 Moons per orbit!
- E.g. if Moon is near pole
- Need careful approach for automated processing!
- Could detect lunar intrusions checking for excess over median SV counts per orbit



- Flag for Moon contamination correction of each Space View position
 - Threshold for difference between lunar angle and antenna space view
 - for which the data are flagged as calibration contaminated
- EPS-Sterna MWR has nominally 25 space views
 - covering 18° - ensures some Moon-free samples
- In worst case (Moon in centre of space views):
 - for the 50-57 GHz temperature-sounding channels, which have a FWHM beamwidth of $\sim 3.8^\circ$
 - only ~ 9 space views flagged by a median filter with a threshold equivalent to $2 \cdot \text{NE}\Delta T \sim 0.93 \text{ K}$
 - further 10 space views: significant ($>0.01 \text{ K}$) unflagged contamination
 - bias mean brightness temperature of unflagged space view by $\sim 0.07 \text{ K}$.
 - This is deemed to be acceptable.
- Lunar Intrusion Correction unlikely to be needed for EPS-Sterna
- Recommend the MAD filter in the Cold Counts Quality Control sufficient to reject lunar intrusions,
 - given a suitable threshold equivalent to $2 \cdot \text{NE}\Delta T$.

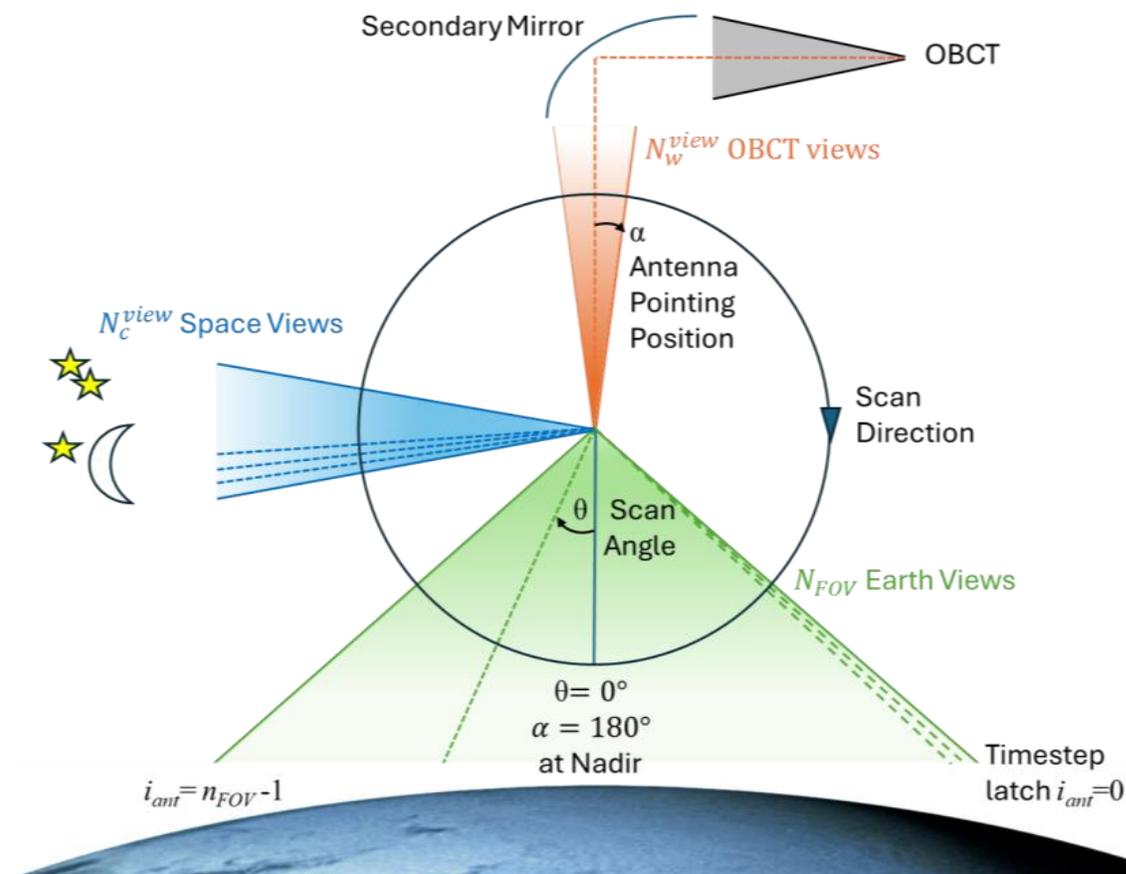
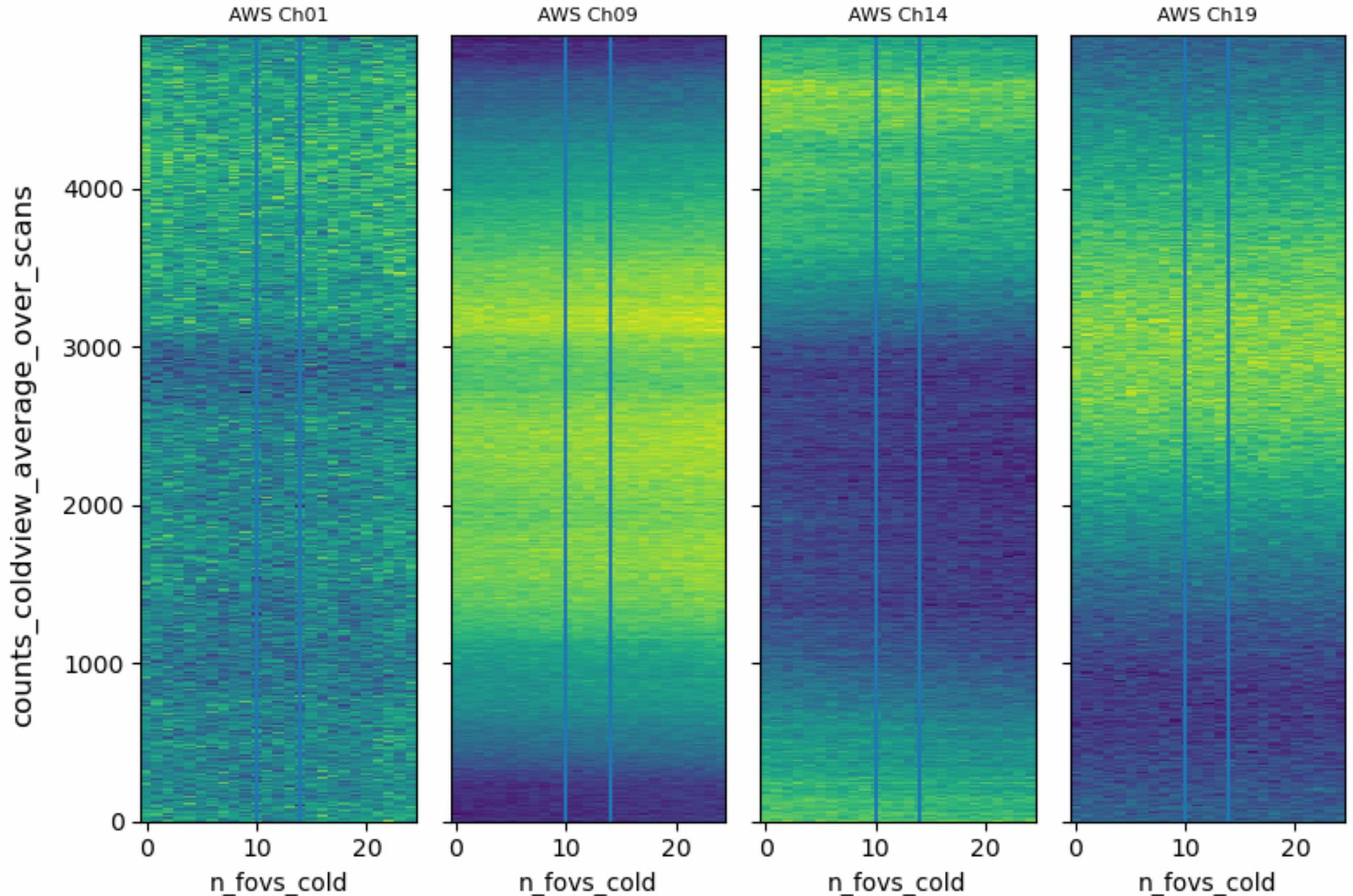
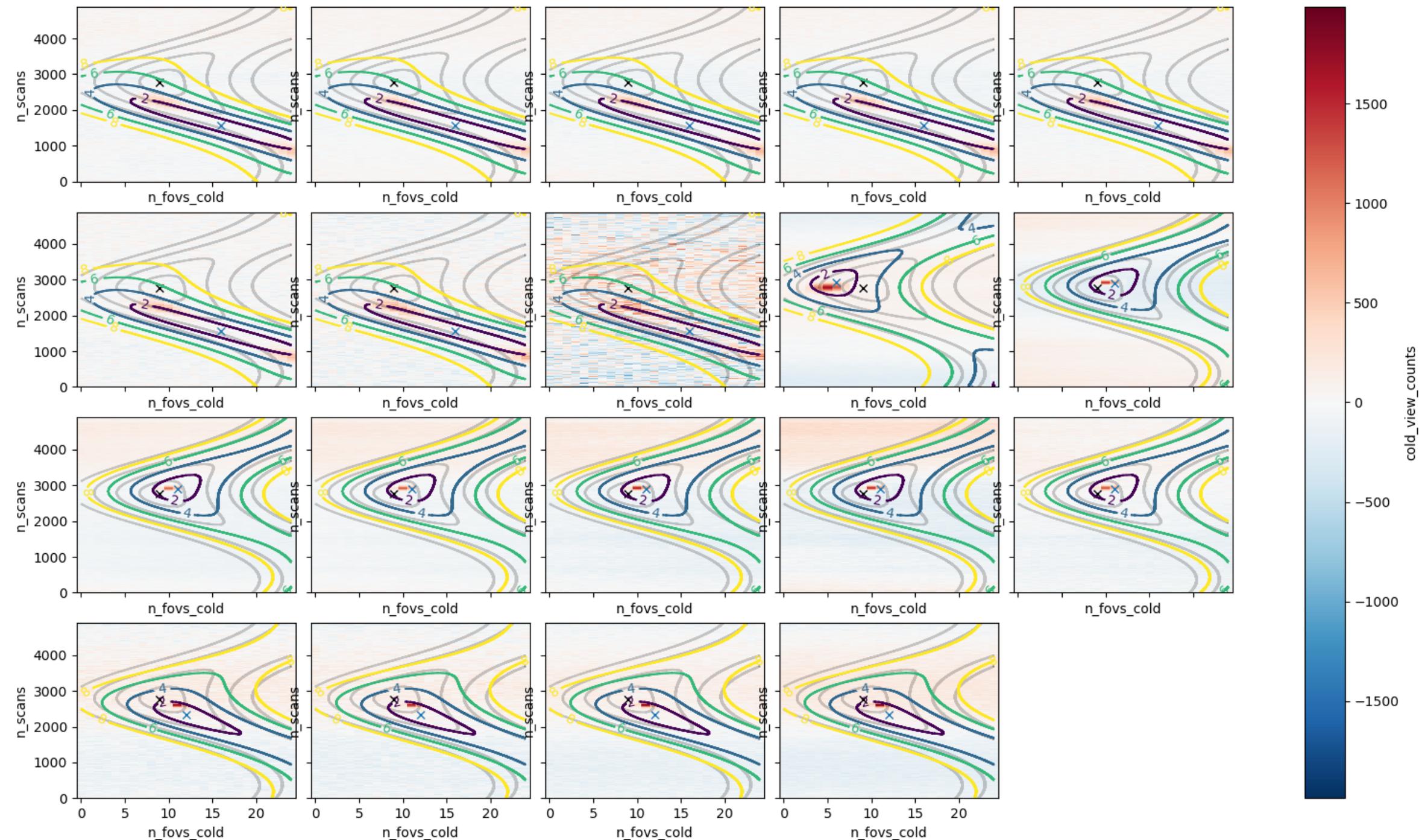


Figure 1: EPS Sterna microwave radiometer measurement cycle. The instrument measures N_{FOV} samples of the Earth scene, N_c^{view} samples of the cold space reference and N_w^{view} samples of the On-Board Calibration Target (OBCT) via a static secondary mirror.



- Animation
- Counts in AWS Space Views
- Over ~2 days
- July 2025
- 1 frame = 1 orbit







- Check calculation of angles and Moon phase
 - Consolidate differences between beamwidths estimated along-scan and along-track
- Account for finite size of Moon ($\sim 0.5^\circ$)
 - Ideally also shape wrt scan orientation – but difficult!
- Repeat fits in along-track and along-scan directions systematically
 - Moon appears in 39 orbits over 2.5d period 2025-07-15/17 (not all channels)
 - Consolidate statistics – confirm differences with AWS-OMN-TR-0058 [PFM optical performance](#)
- Check calculation of `moon_angle` in IPP L1B
 - Validate pointing per feedhorn
- Check appropriate `moon_angle_threshold`
- Check `moon_contamination_flag`
- Could refine antenna temperature calculation
 - Minimal benefits expected, except allowing :
- Use data to validate lunar disc brightness temperature model
 - e.g. [Liu & Jin 2020](#), [Mo & Kigawa 2007](#) used for MWI
 - Especially valuable for 53 & 325GHz channels



Thank you!
Questions are welcome.