# SPIRE Spectrometer: Calibration of the Bright Mode

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# Outline

- SPIRE FTS spectrometer: nominal mode vs. bright mode.
- Current bright-mode pipeline in HIPE 10.
- HIPE 11 calibration change to the bright mode:
  - (A) Using PCAL data to do a full detector nonlinearity correction.
- HIPE 11 pipeline of the bright mode.
  - Tying the bright-mode data processing to the nominal-mode pipeline with only the following two additional corrections:
    - (B) An overall gain correction factor.
    - (C) An additional frequency-dependent gain correction factor.
- Bright-mode pipeline implementation in HIPE 11.
- HIPE 11 calibration results.

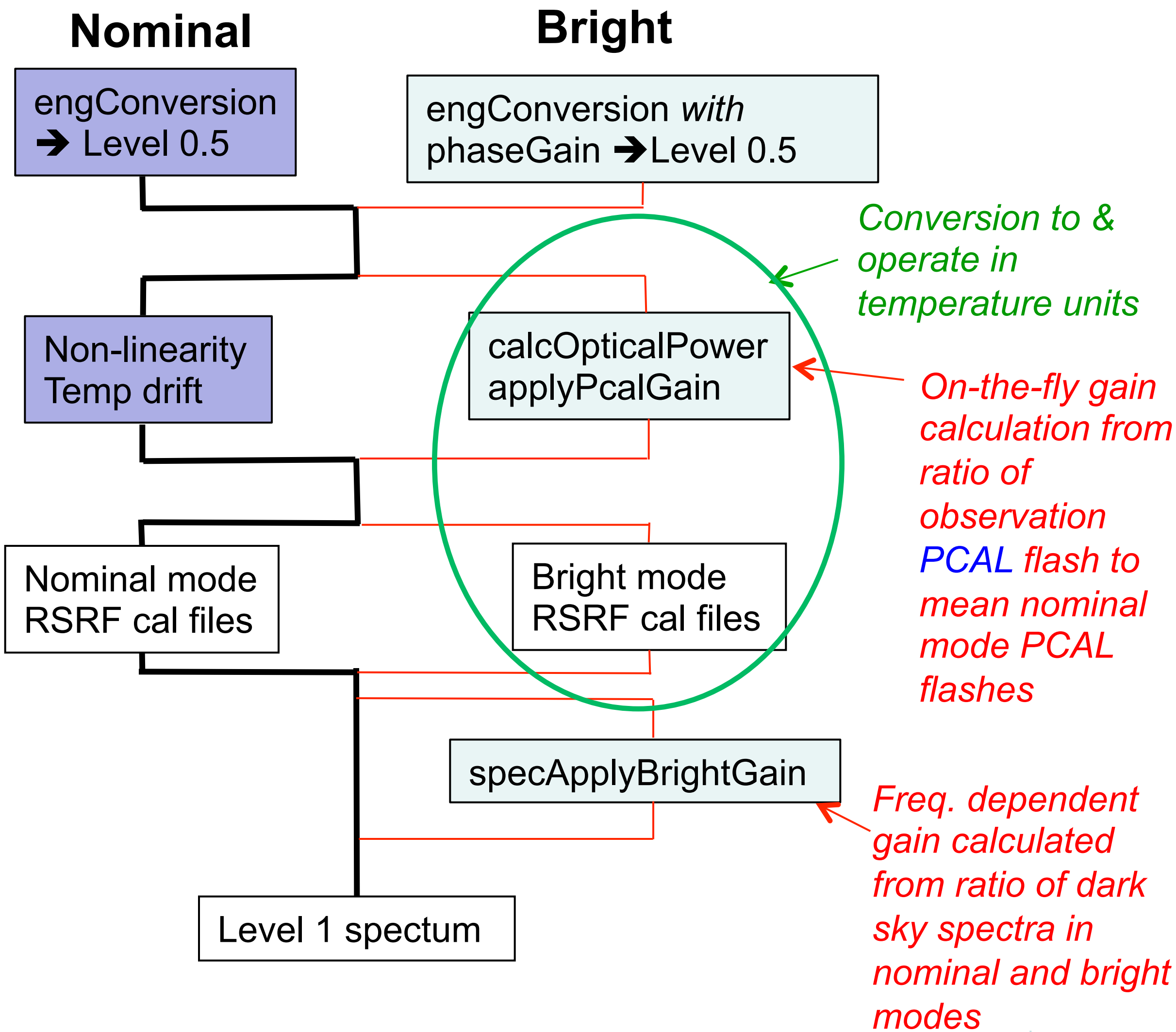
# SPIRE Spectrometer: Nominal vs. Bright Mode

Why do we need a bright mode?

- Targets > 500 Jy may seriously saturate the ADC in the nominal mode.
- Need an observing mode with lower overall system responsivity, sacrificing for moderately higher noise levels, but optimized for bright targets up to the flux levels of Mars (~ 8,000 Jy or ~ $10^6$ MJy/sr)

| | Nominal Mode | Bright Mode |
|---|---|---|
| • Detector biasing: (SSW/SLW; peak voltage) | 35.97/31.13 (mV) | 176.38/176.41 (mV) |
| • Detector NEP: | ~ $6\times10^{-17}$ W/Hz$^{1/2}$ | ~$18\times10^{-17}$ W/Hz$^{1/2}$ |
| • Amplifier: | Locked in phase. | Out of phase at 62 to 64$^{o}$. |
| • Targeted fluxes: | < ~ 500 Jy. | Up to ~ 8,000 Jy (i.e., Mars) |
| • Target examples: | Most celestial targets. | The Galactic center, … |
| • Actual usage: | 91% of observations. | 9%. |

# Bright-mode Pipeline (Prior to HIPE 11)




**Shortcomings**:

- Nominal mode pipeline in voltage, but bright mode in temperature.
- Nonlinear detector response in the bright mode is corrected on the fly, but short of a full-scale correction.
- Separate teleRsrf and instRsrf for the two observing modes.
- Rely on the single PCAL data contained in the observation itself.
- As a result, the bright mode flux calibration was good to only ~10%.

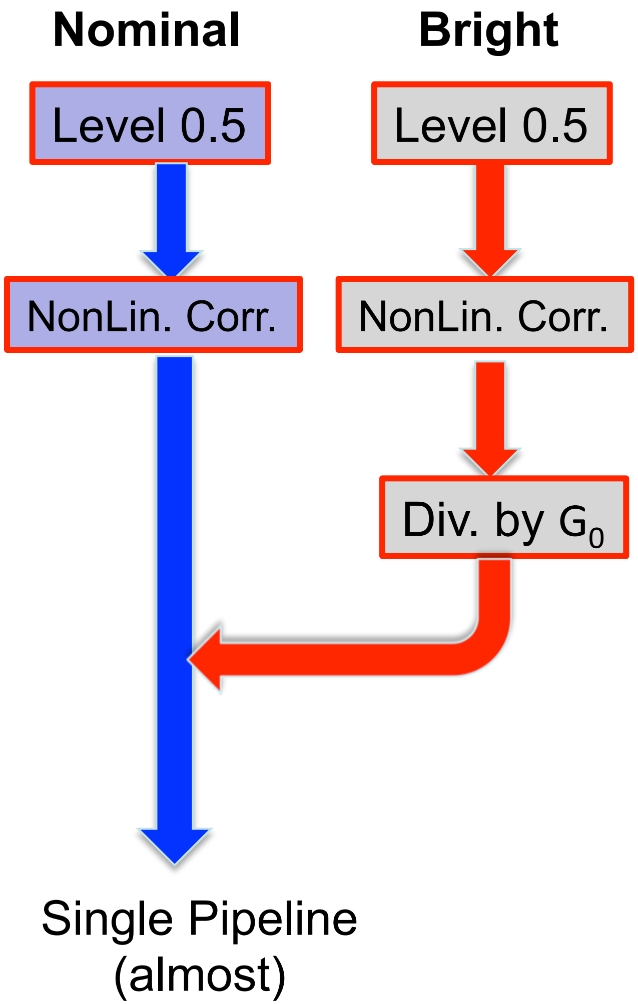
# Bright-Mode Calibration Strategy in HIPE 11

- Revamped the calibration strategy in HIPE 11:
  - We want to process the bright-mode data by making maximum use of the existing, well functioning, & still improving nominal-mode pipeline.
- As a result, the bright mode needs at most the following calibration products on its own:

A. Nonlinearity correction, but with the same form of function as in the nominal mode.

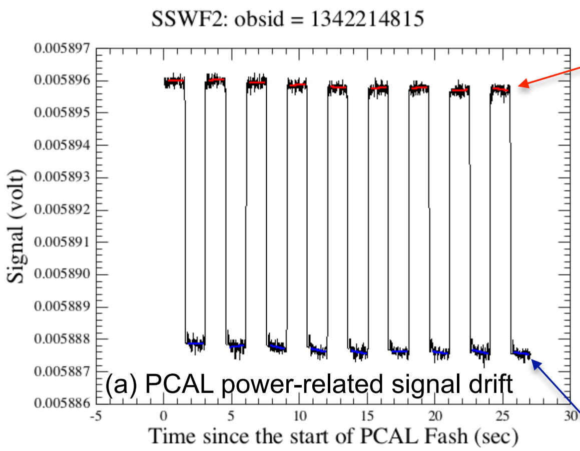
B. There should be an overall relative gain factor, $G_0$, to scale the linearized voltage, $V^c$, of the bright mode to that of the nominal mode.

C. The detectors may behave with different relaxation behavior in the bright mode, resulting in an additional, frequency-dependent, multiplicative factor. (This effect can be verified and empirically corrected for in the frequency domain.)



# (A) Nonlinearity Correction for the Bright Mode

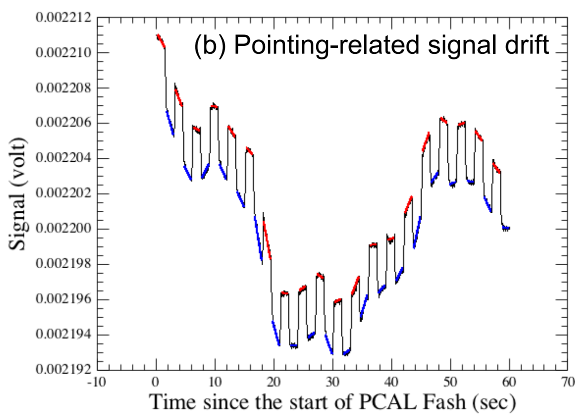
- Using the data from the SPIRE internal photometric calibrator (PCAL).
- Using *a pair-wise differencing algorithm* to minimize effect from both (a) a PCAL power induced signal drift and (b) a possible pointing related signal drift.




$V_{off}$ = Base voltage (when PCAL power off).

$$\Delta V = V_{on} - V_{off}$$

$V_{on}$ = Voltage when PCAL power on.

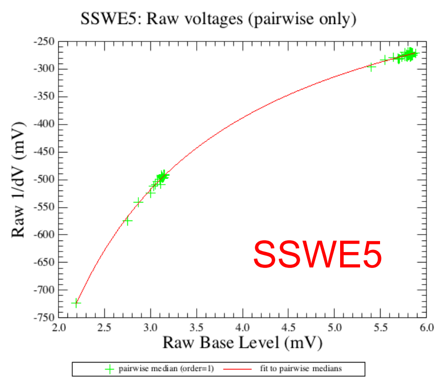


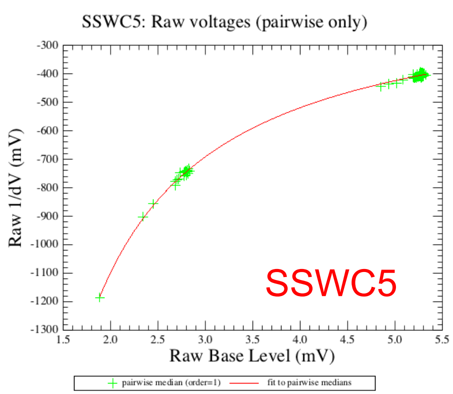

- PCAL power is fixed, leading to a constant illumination, ΔQ, on a given detector.
- For SPIRE bolometers, we can parameterize their inverse nonlinearity as:

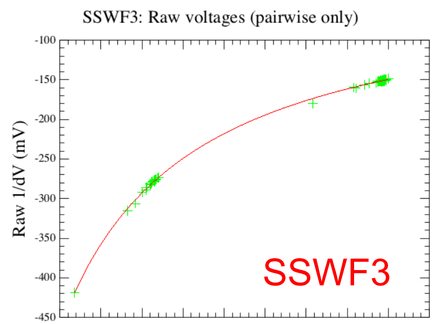
$$\Delta Q/\Delta V = K_1 + K_2/(V_{off} - K_3),$$

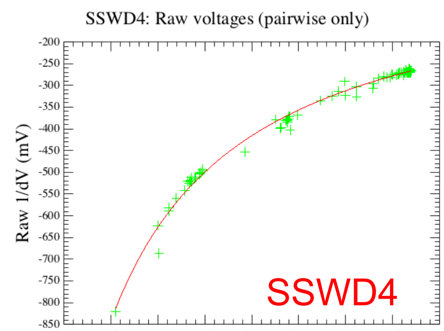
where $K_1$, $K_3$ & $K_3$ are constants to be fit to the PCAL data.

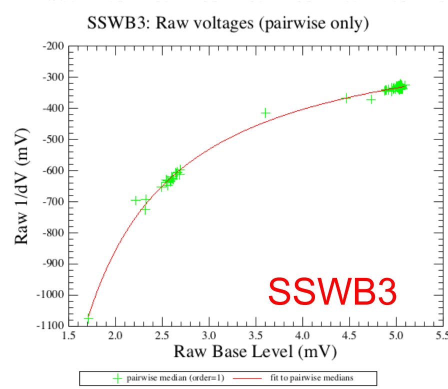
# (A) Non. Corr. for the Bright Mode (continued)

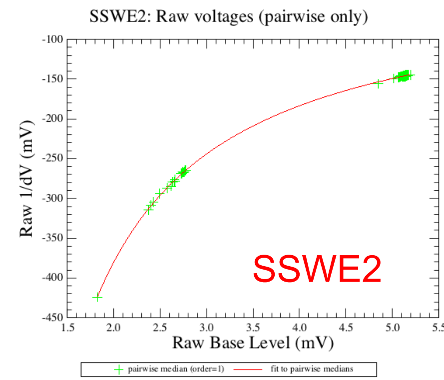


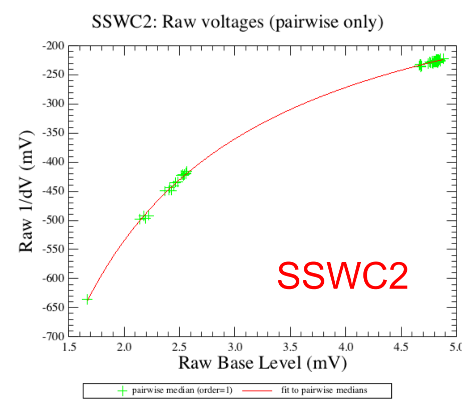



# (B) Overall Relative Gain Correction Factor $G_0$

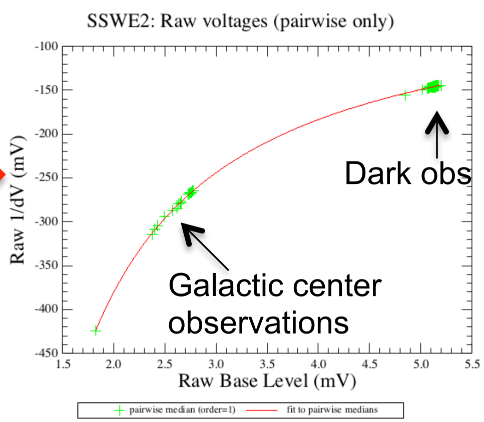
*We determine $G_0$ from PCAL data as the PCAL power is kept the same in both modes.*

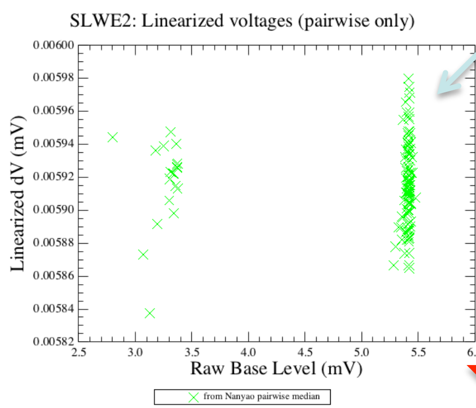
Raw voltages

Linearized voltages

Typically, sample std. dev. ~ 1-2%.

Bright Mode PCAL Data

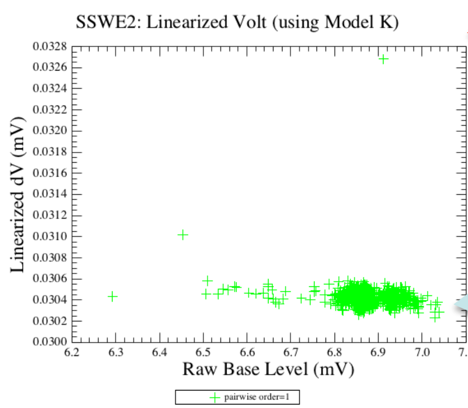



Ratio of medians gives a bright-to-nominal gain correction factor, $G_0$, per detector.

Nominal Mode PCAL Data

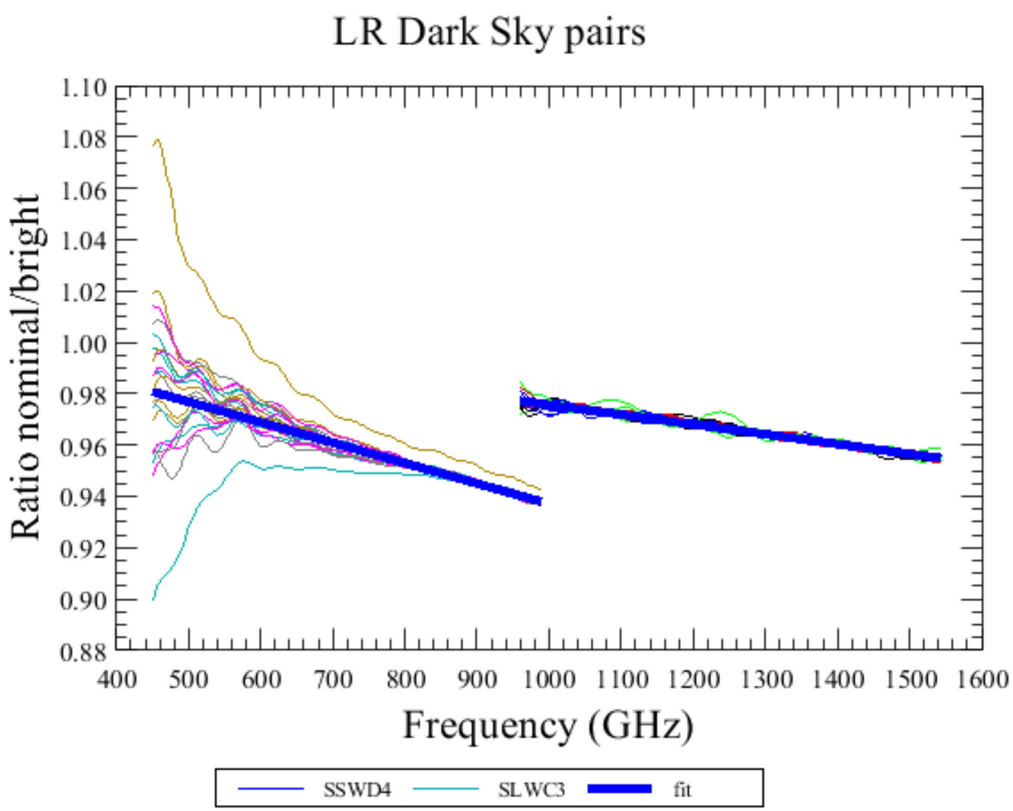
Apply the pipeline model-based nonlinearity correction




Typically, sample std. dev. < 1%.

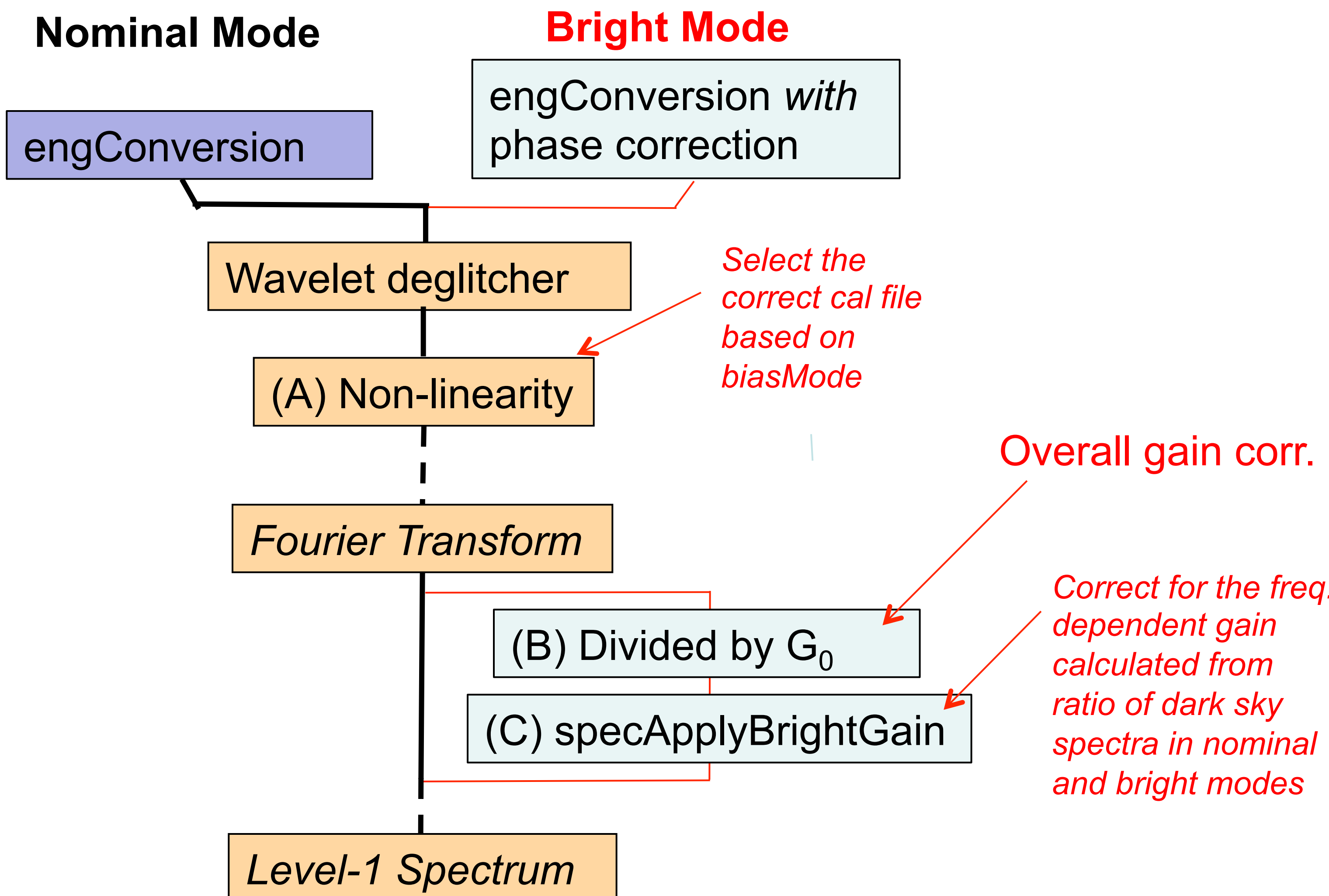
# (C) Additional Frequency-dependent Gain Correction

- Ratios of dark sky spectra of the data taken close in time in both nominal and bright modes show an additional frequency-dependent correction factor.

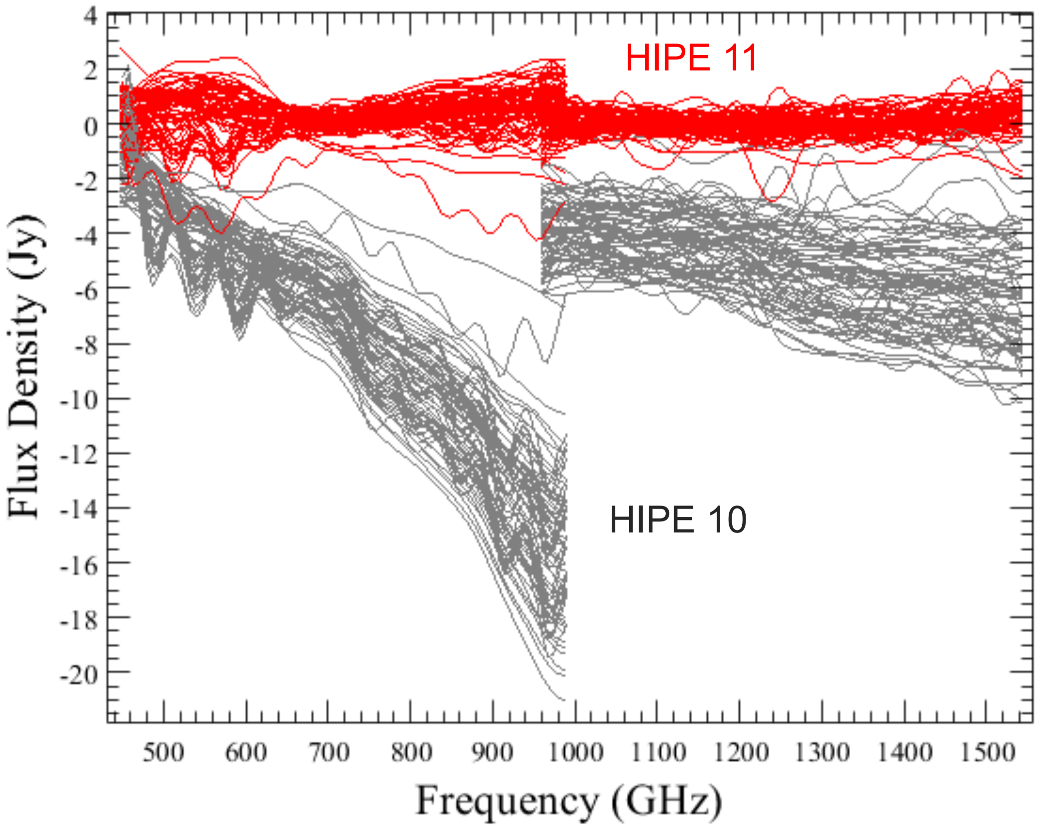



An empirical wavelength-dependent gain correction factor, to be applied after the Fourier Transform in the pipeline.

# Bright-Mode Pipeline in HIPE 11



# Bright Mode in HIPE 11: Better Dark Results

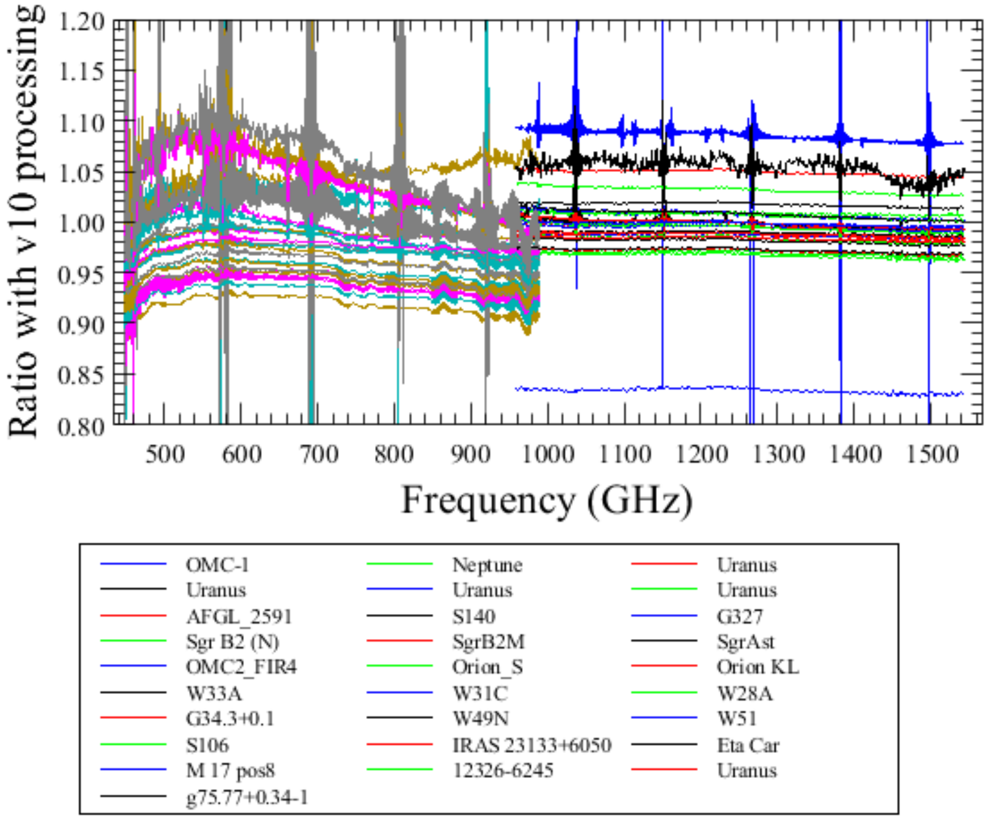



- HIPE 11 gives much better results on dark observations than HIPE 10.

NOTE: Ideally we want a flat spectrum at 0 Jy for these (telescope background-subtracted) darks.

# Bright Mode in HIPE 11: Non-Dark Observations

Ratio: HIPE 11 to HIPE 10

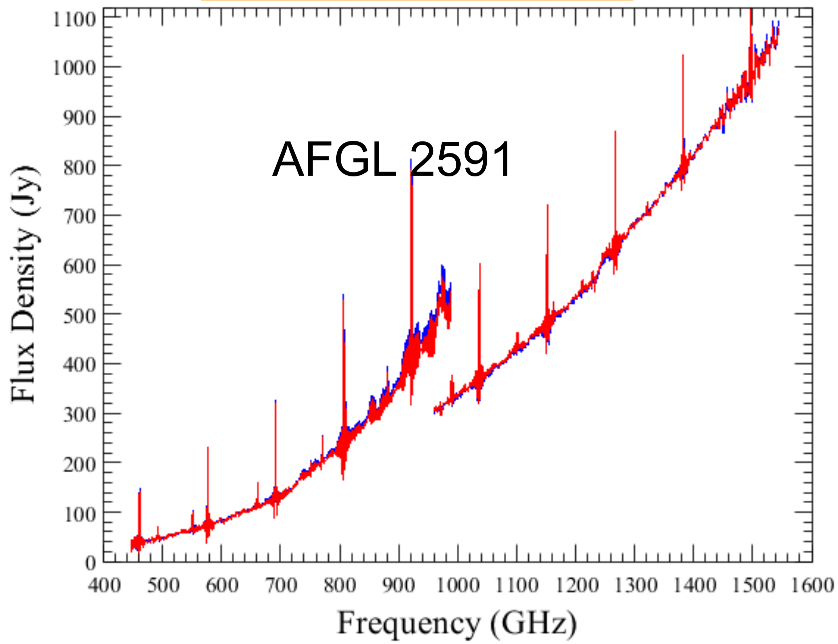



- HIPE 11 and 10 results of most non-dark data agree with each other to within 10%. (*Therefore, there should be no upset to previous papers – the difference is within the claimed errors on HIPE 10 spectra.*)

- *Much of this 10% difference originates from the calibration uncertainty in HIPE 10. In other words, HIPE 11 flux calibration is better.*

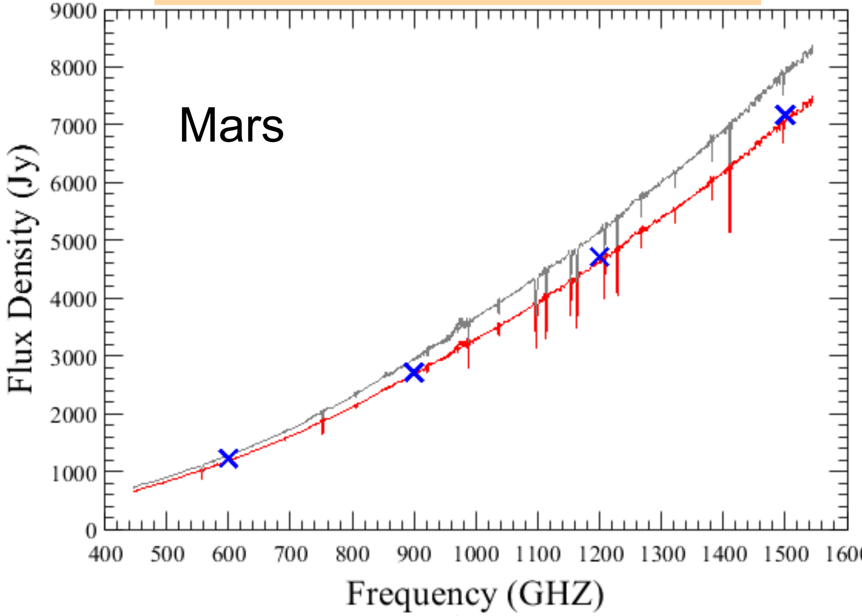
# Comparisons with Nominal Mode and Model Data

## Bright vs. Nominal




Red: HIPE 11 spectrum (bright-mode data);
Blue: HIPE 10 spectrum (nominal-mode pipeline).

## Bright vs. Model Spectrum

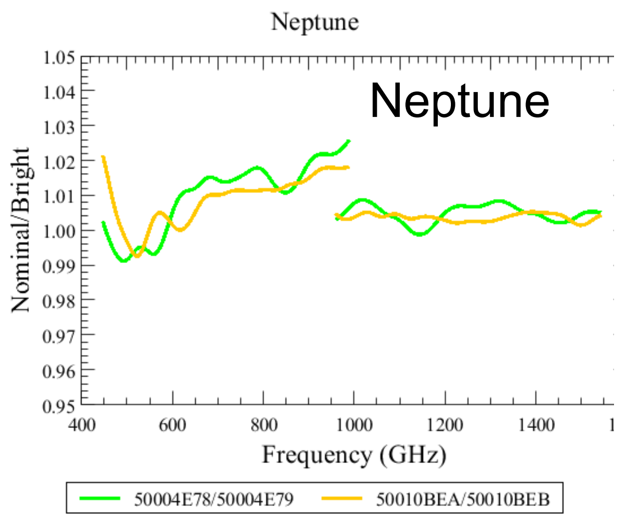


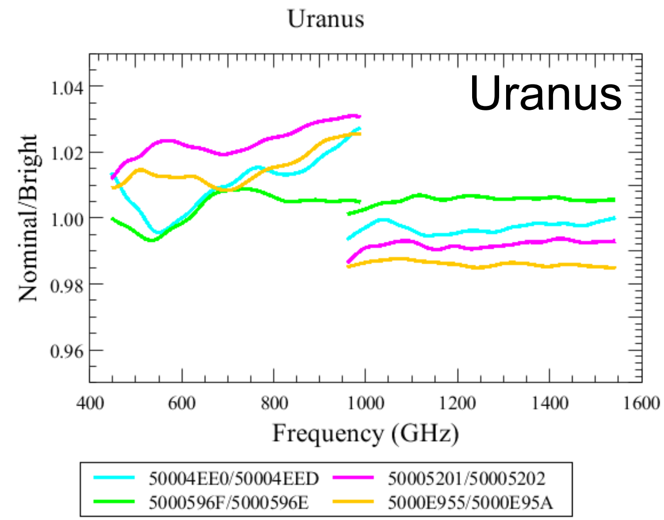

Red: HIPE 11 spectrum (bright-mode pipeline);
Blue crosses: Mars model fluxes.
Gray: HIPE 10 spectrum (bright-mode pipeline);

Also see a poster on a good agreement of SPIRE/FTS bright-mode results to a modeled flux variation (~ 5%) due to Mars rotational modulation (S. Sidher).

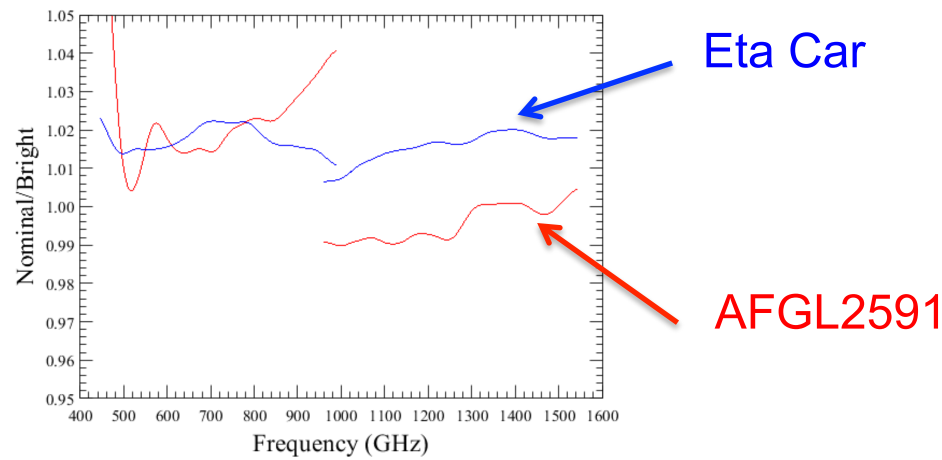
# More Bright vs. Nominal

Smoothed spectral ratio for various sources:
Nominal mode to bright mode (HIPE 11)



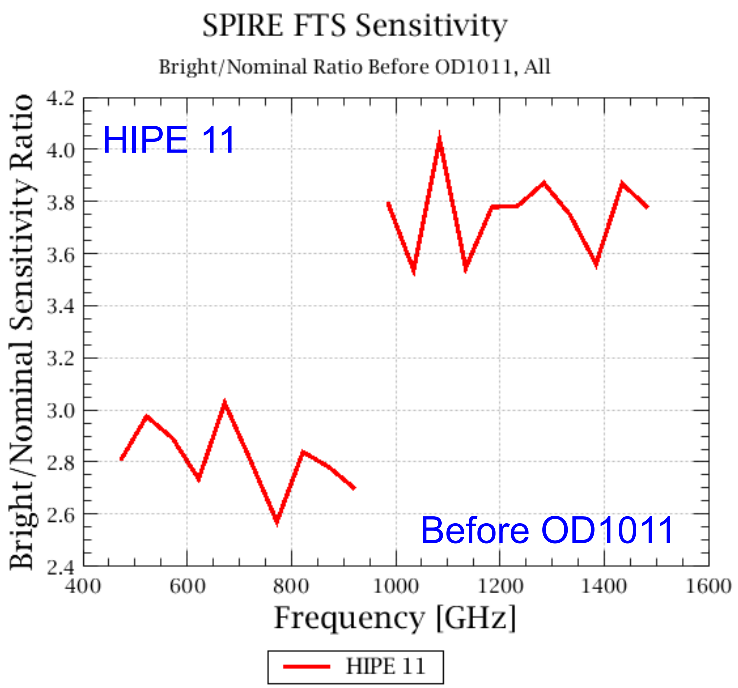



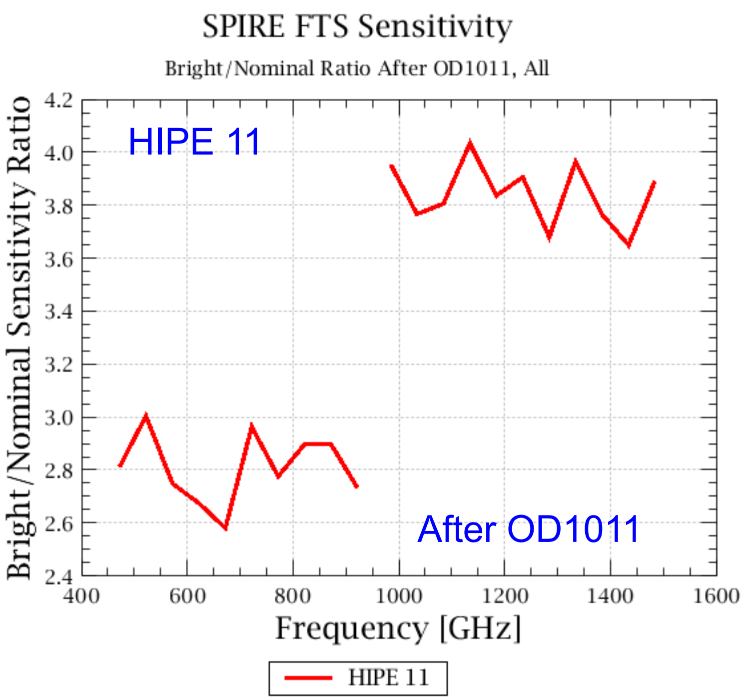

Ratios are all within ~ 2%.



# HIPE 11 Bright-Mode Sensitivity

- Only marginal improvement in sensitivity from HIPE 10 to HIPE 11.
- Bright mode is still a factor of 2-3 less sensitive than the nominal mode.




Note: OD 1011 is when we reset the reference position of SPIRE internal beam stirring mechanism (BSM)

# Summary

- SPIRE spectrometer bright-mode calibration went through a major upgrade from HIPE 10 to HIPE 11, by adopting a new full nonlinearity correction scheme based on PCAL data.
- New bright-mode pipeline in HIPE 11 is simpler – same flux calibration products for both nominal and bright modes.
- Bright-mode sensitivity remains the same, 2-3 times less sensitive than the nominal mode.
- Bright-mode flux calibration is within ~2% of that of the nominal mode.
- Change from HIPE 10 flux calibration is <10%,
  - i.e. changes are within the claimed errors of the previous pipelines.
- Calibration is good up to the fluxes of Mars (~ 8,000 Jy).
- We will seek further refinements in HIPE 12.