JWST TECHNICAL REPORT

Title: Nonlinearity in JWST Detectors: II. The Effect of Non-linearity Correction Errors on the Measurement of Transit Depth	Doc #: JWST-STScI-007963, SM-12 Date: 24 September 2021 Rev: -
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1 Abstract

Measuring the variation of the light during the transit of a planet in front of a star is a goal of many time series observations on JWST. The maximum depth of the light curve during the transit is one of the primary metrics. Because this important measurement can be affected by errors in the correction for the nonlinearity of the detectors, there is concern about what these effects are. In this report, we quantify the error introduced to the depth of the transit by errors in the correction. We show that for a 1% error in the total nonlinearity at saturation, the error in the measurement of the ratio of in-transit to out-of-transit fluxes would only be 10^{-5}. This small relative error is due to the fact that the nonlinearity correction does not significantly change when there is only a 1% flux change. In fact, even with no nonlinearity correction, the relative error would only be 10^{-3}.

2 Introduction

When a planet transits in front of a star, the relative loss of flux is a direct measurement of the radius of the planet relative to the radius of the star. Because these measurements can be made with broadband filters, they can be made on the faintest stars or the smallest planets. Due to the inherent nonlinearity of the detectors on JWST, we need to correct the raw measurement of the relative flux to obtain the correct flux ratio. The corrections themselves have errors, and in this report, we quantify the effect of errors in the nonlinearity correction on the ratio of the in-transit flux to the out-of-transit flux. We show that 1% errors in the correction yield an error in the ratio of 10^{-5}. Thus, these errors will not be a significant error source.

3 Method

To measure the error, we determine the actual depth of the transit using a set of nonlinearity coefficients derived from measurements in the Operations Detector Lab (ODL) of a flight batch NIRSpec detector. In Paper I, we showed that the standard method is to derive a correction factor using simple polynomials that operate on the raw Data Number (DN)values. In this report, we will use the 3rd order solution obtained from a set of 24 flat illuminated images.

Using the median values of the coefficients yields

$$DN_{cor} = DN_{raw} + 3.9x10^{-6}DN_{raw}^{2} + 2.2x10^{-10}DN_{raw}^{3}.$$

The gain settings used in the experiment yielded a hard saturation limit at approximately 17,000 DN. At hard saturation, the 2nd order term yields a correction of 1127 DN, and the 3rd order term yields a correction of 1081 DN. The very similar magnitude of the corrections allows us to reduce each coefficient by 1% to create a 1% error in the total correction at saturation.

To start with, we will assume that the out-of-transit integrations of the star have a final DN value of 15,000. Because at this level the noise is completely Poisson, the pipeline measurement of the slope will just be the DN value in the last frame divided by the total measurement time. We will also assume that the magnitude of the transit is ~1% in corrected DN units.

4 Calculations

In Table 1, we show the calculation of the effect of the 1% error in the nonlinearity on the measured magnitude of the transit. The table shows that the relative error in the transit depth is about one part in 100,000. Even with no correction, the relative error in the transit depth is only 0.1%.

The small magnitude of the error is because the transit depth is a relative measurement and the total nonlinearity correction change over a 1% change in flux is small. Thus, even a relatively poor nonlinearity correction (1% error at saturation) yields a small error in the transit depth.

Table 1 - Effect on Nonlinearity Correction Errors for a 1% transit

Perfect Nonlinearity Correction			**1% Error in Nonlinearity Correction**		
2nd order NL Coefficient	3.90E-06	Relative error in 2nd degree	1.00%	3.86E-06	
3rd order NL Coefficient	2.20E-10	Relative error in 3rd degree	1.00%	2.18E-10	
Raw out of transit flux	15000			15000	
Corrected out of transit flux	16620.00			16603.80	
Raw In transit flux	14881.58			14881.58	
Corrected in transit flux	16470.33			16454.45	
Difference between in transit and out of transit fluxes	149.67			149.35	
Relative light lost due to transit	0.00998			0.00996	
Ratio of corrected In transit flux to corrected out of transit flux	0.99099			0.99100	
Ratio of uncorrected in transit flux to uncorrected out of transit flux	0.99211				
Relative error in transit depth due to NL correction error		**-1.012E-05**			
Relative error in transit depth with no NL correction		**-1.121E-03**			

In Table 2, we show the effect on the same nonlinearity error for a transit that is 10 times smaller, leading to a 0.1% change in the flux from the star. Here we see than the relative error is also 10 times smaller at 10^{-6}. The decrease in the relative error is due to the fact the flux change is smaller leading to a smaller change in the nonlinearity correction.

Table 2 - Effect on Nonlinearity Correction Errors for a 0.1% transit

Perfect Nonlinearity Correction			**1% Error in Nonlinearity Correction**		
2nd order NL Coefficient	3.90E-06	Relative error in 2nd degree	1.00%	3.86E-06	
3rd order NL Coefficient	2.20E-10	Relative error in 3rd degree	1.00%	2.18E-10	
Raw out of transit flux	15000			15000	
Corrected out of transit flux	16620.00			16603.80	
Raw In transit flux	14988			14988	
Corrected in transit flux	16604.82			16588.65	
Difference between in transit and out of transit fluxes	15.18			15.15	
Relative light lost due to transit	0.00101			0.00101	
Ratio of corrected In transit flux to corrected out of transit flux	0.99909			0.99909	
Ratio of uncorrected in transit flux to uncorrected out of transit flux	0.99920				
Relative error in transit depth due to NL correction error		**-1.027E-06**			
Relative error in transit depth with no NL correction		**-1.137E-04**			

5 Conclusions

With these relatively simple calculations, we have shown that relatively high errors in the nonlinearity correction yield only a small effect on the measured transit depth. For a 1% error in the nonlinearity correction at saturation, there is only a 10^{-5} relative error in the transit depth. This error scales linearly with the depth of the transit.

6 References

Regan, M. W. & Bergeron, E, “Nonlinearity in JWST Detectors: I. The Most Common Errors in Determining Nonlinearity Corrections”, JWST-STSci-007934 (Paper I)