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Refinements to the Iterative Self-Calibration Program for the SIRTF GOODS Legacy Project

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Abstract. A self-calibration program for processing data from the upcoming SIRTF GOODS Legacy Project has been developed to derive the sky and flat field for idealized data. The actual on-orbit data will doubtless suffer from geometric distortion and cosmic rays at some level, while calibration is required to simultaneously derive the sky and flat field in the presence of these effects to a level of better than a part in 10,000. Because this translates to the requirement that the calibration be shot-noise limited, routines to remove both of these effects within an iterative version of the self-calibration code have been developed. Results of tests using these routines will be discussed. The algorithm applied to correct geometric distortion is a new method that allows arbitrary transformations with sub-pixel shifts - a substantial improvement over clipping techniques and other distortion removal techniques currently in use. This enhanced self-calibration program is general, allowing it to be used for high-quality calibration of data from JWST and other future missions. The development of these methods demonstrates the feasibility and effectiveness of enhancing the powerful technique of iterative self-calibration to reduce or eliminate anticipated effects in realistic data.

1. Introduction

The original iterative self-calibration program has been described in the poster "Self Calibration for the GOODS Legacy Project" presented at ADASS 2002 (Grumm & Casertano 2003) . In short, the iterative routine simultaneously solves for the sky and gain for ideal data (integer pixel shifts, no geometric distortion, no cosmic rays). The new refinements to this program as described here were tested on data generated by the simulators for SIRTF's IRAC and MIPS instruments, as on-orbit data was not yet available.

2. Geometric Distortion

Geometric distortion will be present at some level for both the IRAC and MIPS instruments on SIRTF. For MIPS, this distortion has been measured, and is on the order of one pixel at the edge of the 128x128 array. Distortion was added to the simulated data using the "drizzle" routine described later. We have investigated two types of algorithms for the self-calibration to remove the distortion. In the first, outlier clipping is done so that the effect of the distortion will be reduced because the pixels in the brightest sources (which would be expected to have the largest effect in the self-calibration) will be masked. In the second, the variable pixel linear reconstruction task "drizzle" (Hook & Fruchter 1997, Fruchter & Hook 2002) is used to effectively remove the distortion . As this method makes use of all of the data, it is preferable in instances where the distortion is well known and characterized. The results of routines applying each of these two methods are discussed.

2.1. Clipping Self-Calibration for Distortion Reduction

Clipping will reduce the impact of the brightest sources on the self calibration, and does not require a quantitative characterization of the distortion. In this approach, an initial flat field was determined by running the program for several iterations. The data was then flat-fielded, and data pixels exceeding a given threshold were masked. The self-calibration program was then run on this masked dataset until convergence. The threshold was set by specifying a value that exceeds the mean by a given fractional amount. In this way the rms of the derived flat field was determined as a function of the threshold. It would be expected that as the threshold is reduced the rms would at first improve due to the lower impact of the distortion, and then worsen due to an insufficient number of available pixels. For a distorted set of noiseless images, the rms of the gain image was minimized with a value of 4.55E-5 when the threshold was set to 2.5% above the flat-fielded average, at which point 2% of the pixels were masked. Without masking, the rms is 2.62E-4. For a set with shot noise, the rms had a shallow minimum of 4.77E-4 when the threshold was set 1.5% above the mean. Without masking the rms is 5.37E-4. The results are shown in Table 1; the 'base' rms pertains to the fit without clipping, and the efficiency shown in brackets is the fraction of equivalent noise removed. Results for undistorted datasets are shown for comparison.

Table 1. Clipping and drizzle results for 186-frame datasets.

Noise	Distortion	Base RMS	Clipping RMS [eff.]	Drizzle RMS [eff.]
No	No	4.66E-8	NA	NA
No	Yes	2.62E-4	4.55E-5 [0.83]	1.02E-7 [0.9994]
Yes	No	4.00E-4	NA	NA
Yes	Yes	5.37E-4	4.77E-4 [0.44]	4.11E-4 [0.92]

2.2. Drizzle-based Self-Calibration for Distortion Reduction

In instances where the distortion is well known and characterized, the variable pixel linear reconstruction task "drizzle" is preferable to remove the distortion. The data is projected onto the sky using drizzle, and the inverse routine "blot" is used to project the sky back to the detector. The distortion is specified by a distortion coefficient file, which allows fairly general (cubic and higher order polynomial) specification. For the same datasets as were used for the clipping routine, the results are shown in Table 1. The drizzle-based self-calibration can be seen to better remove the distortion, even in the presence of noise.

3. Cosmic Rays

As cosmic rays will appear in the data at some level, routines to reject them were developed, based on the assumption that they may not be completely removed by the standard pipeline. To simulate cosmic rays within the data, templates based on ground-level data containing cosmic rays were used. A typical template contains several dozen cosmic rays. Cosmic rays are rejected using an outlier rejection scheme as follows:

1. data containing the cosmic rays are run through the self-calibration routine.
2. from the derived sky and gain, a 2nd set of observations is created.
3. pixels in this 2nd observation set that differ from those in the original observations by more than a defined threshold are considered pixels containing cosmic rays, so are masked; neighboring pixels are also masked, creating a 3rd observation set.
4. the 3rd observation set is input to the self-calibration routine.

The results of the rejection routines on undistorted datasets with and without shot noise are summarized in Table 2. The threshold value used for rejection was $\alpha * \sigma(predicted\ data) + \beta * (predicted - sky)$, with α=3.0 and β=0.01. From the 3 noiseless cases shown, it can be seen that 96% of the equivalent noise (additional rms due to cosmic rays) is removed.

Table 2. Cosmic Ray rejection results for 720-frame datasets.

Noise	CR added	RMS w/o CR rejection	RMS with CR rejection [eff.]
No	No	4.21E-8	NA
No	Yes	1.38E-4	5.73E-6 [0.96]
Yes	No	2.01E-4	NA
Yes	Yes	2.43E-4	2.09E-4 [0.81]

The results of simultaneously using both the distortion-removal and rejection routines are shown in Table 3 for all combinations of shot noise, cosmic rays, and added distortion for 720-frame datasets. For cases with distorted datasets, the distortion removal routine was used.

Table 3. Cosmic Ray rejection results for 720-frame datasets.

Noise	CR added	Dist. added	rms w/o CR rej.	rms with CR rej. [eff.]
No	No	No	4.21E-8	NA
No	Yes	No	1.38E-4	5.73E-6 [0.96]
Yes	No	No	2.01E-4	NA
Yes	Yes	No	2.43E-4	2.09E-4 [0.81]
No	No	Yes	6.11E-8	NA
No	Yes	Yes	1.39E-4	5.71E-6 [0.96]
Yes	No	Yes	2.02E-4	NA
Yes	Yes	Yes	2.43E-4	2.08E-4 [0.85]

4. Discussion

Tests using realistic simulated SIRTF data show that if geometric distortion is well characterized, it can be removed by the drizzle-based self-calibration to almost the shot-noise level. If the distortion has not been quantified, the use of clipping can reduce the effect of the distortion by roughly half. The use of an outlier rejection method within the self-calibration allows cosmic rays to be rejected to nearly the shot-noise level.

Currently we are investigating a low-level aliasing in some of our results. It is evident as alternating high and low pixels in the derived sky and gain, and is most noticeable in areas of the sky having relatively low exposure. This aliasing seems to be due to the combination of undersampling and the iterative nature of the algorithm. Various methods are being investigated to eliminate or reduce this effect.

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