Deepspace Interplanetary Navigation Operations Colorado Research EXplorer (DINO C-REx)

DINO C-REx Technical Memorandum

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SYSTEMS ENGINEERING REPORT 4.5: BACKGROUND SIGNAL AND CAMERA NOISE MODEL

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Scope/Contents
Description of signal and noise sources modeled in the DINI C-REx Camera Module.

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Contents

1 Overview **2**

2 Signal Sources **2**

3 Noise Sources **2**

4 Background Signal Implementation **3**

4.1 image.addBkgdStarLight() 3

4.2 image.addZodiacalLight() 3

5 Noise Implementation **3**

1 Overview

This SER documents the sources of signal and noise modeled in the DINO C-REx camera module. Although the signal from stars and navigation beacons (i.e. planets and asteroids) are clearly important in modeling a spacecraft camera, they are not discussed in detail here [1]

2 Signal Sources

Although as stated above, the primary signal sources in the DINO C-REx camera model are stars and solar system bodies, they will not be discussed here. Instead, the signal sources documented here focus on those sources that would be present in an image with no stars or beacons. This document takes its models for extraneous signal from Leinert's *The 1997 reference of diffuse night sky brightness* (1998)[2] and Merlene and Howell's *A Realistic Model for Point-Sources Imaged on Array Detectors" The Model and Initial Results* (1995)[3].

In his paper, Leinert describes five contributors to background signal in astronomical measurements: airglow, zodiacal light, integrated starlight, diffuse galactic light, and extragalactic background light. Immediately we can exclude airglow as Leinert's paper is directed at both ground and space-based observers. Since there is no significant atmosphere in space, we may ignore airglow out of hand. Of the four remaining sources, an order of magnitude comparison leads us to keep zodiacal light, which ranges in brightness from 72-11500 $S10_{\odot}$[4] (p. 36) and background starlight, which ranges from 36-1393 $S10_{\odot}$ (p. 79). Extragalactic background and diffuse galactic light are both poorly characterized, but account for at most 1 $S10_{\odot}$ (which is engulfed by the error measurements on zodiacal light alone) and are ignored here.

The final source that is modeled by the camera module is dark current, which is captured as a flat count of electrons per second applied to every pixel of every scene equally.[5]

3 Noise Sources

Within the scope of the DINO C-REx camera module, noise refers to the random variability of the signals described above. Following Merline and Howell, two noise sources are modeled: photon (or shot) noise and read noise.

Photon noise is applied to all signal sources described in section 2. It is modeled as a Poisson distribution. Photon noise is added at each time step (once per scene).

Read noise is modeled as a Gaussian distribution whose standard deviation is set by the user when initializing the camera object. Because read noise is an artifact of the reading of counts off of a CCD, it is only added once at the conclusion of the image creation process. Therefore longer exposure times will have the effect of washing out the effect of read noise. Because read noise is modeled as a Gaussian distribution, it is possible for a very dim pixel to end up with a negative photon count after it has been has been applied. For this reason, the last thing the camera module does when generating an image is to set all pixels with a negative photon count to have zero photon count.

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1 See DINO C-REx SERs 4.1, 4.7, and 4.9 for more detail on stellar/beacon modeling.

2 Leinert, C. The 1997 reference of diffuse night sky brightness. Published by EDP Sciences, on behalf of the Board of Directors, European Southern Observatory, 1998.

3 Merline, W. J., and Steve B. Howell. A realistic model for point-Sources imaged on array detectors: The model and initial results. Experimental Astronomy, vol. 6, no. 1-2, 1995, pp. 163210

4 From Leinert, $S10_{\odot} = 1.18 \times 10^{-8} W/m^2 sr\mu m$ at 550nm (p. 3)

5 Although dark current is added equally to every pixel, the final output will not be equal as Poisson photon noise is applied as described in section 3

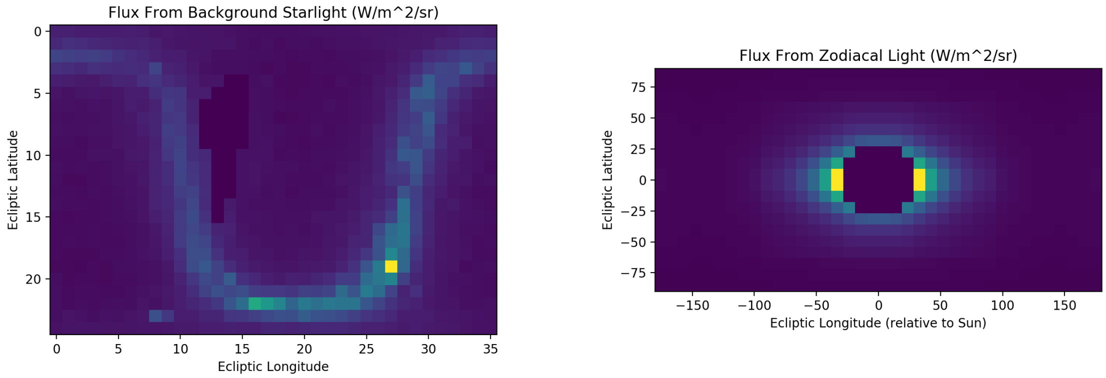

Fig. 1: Illustration of the values for the Background Starlight (left) and Zodiacal Light (right) lookup tables.

4 Background Signal Implementation

As there are two sources of background signal modeled in DINO C-REx, there are two places where it is implemented, one for each source, image.addZodiacalLight() and image.addBkgdStarLight(). Each type of light is added once per scene.

4.1 image.addBkgdStarLight()

Background starlight is added via the function image.addBkgdStarLight(). The function begins by converting the intertial to camera frame DCM into 3-2-1 Euler angles. The first two of these serve as right ascension and declination. The function then finds which bin of a predefined lookup table is closest to the attitude given by the 3-2-1 conversion.The flux value for that bin is read in from the lookup table, and applied to every pixel in each scene.

4.2 image.addZodiacalLight()

Zodiacal light is added similarly to background starlight, but because it is dependent on the position of the sun in the sky, it must be taken into account as well. The same 3-2-1 Euler angles are found for the camera, as well as the position of the sun in right ascension space. The position of the sun is then subtracted form the position of the camera to find the relative position. Those angles are then used with a lookup table similar to the one used for image.addBkgdStarLight(), and the resulting value is applied to all bins in each scene.

5 Noise Implementation

Noise modeling in DINO C-REx is illustrated in the block diagram in figure 2. All elements described in section 3 are present.

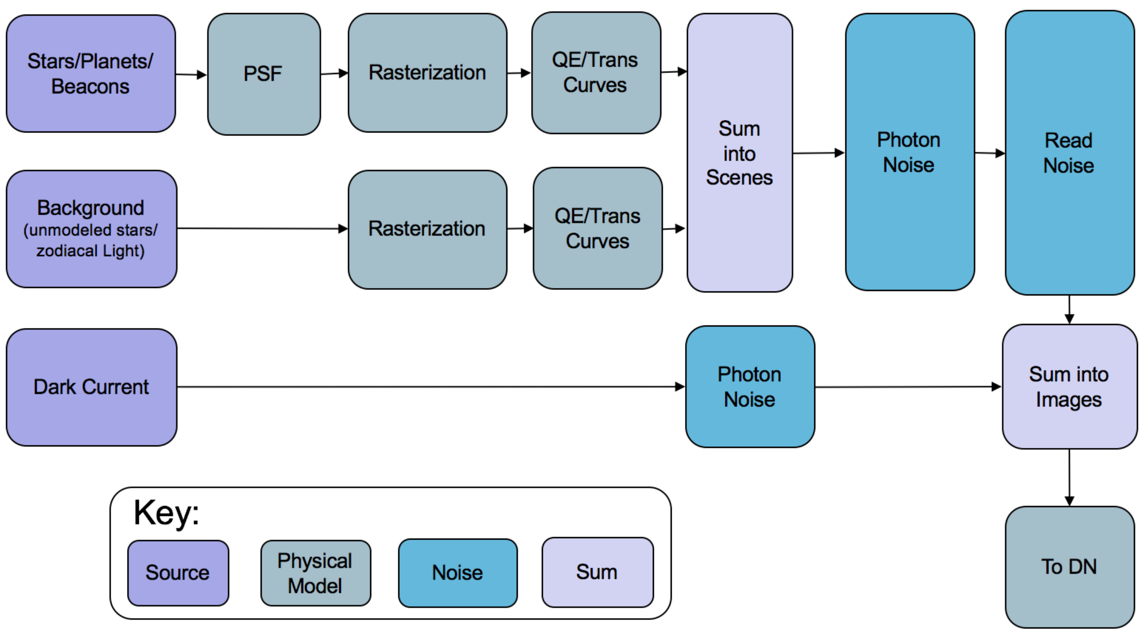

Fig. 2: Block diagram of noise model in DINO C-REx