Cosmic Ray Simulations for JWST FGS

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Supported by NTCO-CREATE

FINE GUIDANCE SENSOR

The Fine Guidance Sensor (FGS), shown in Figure 1, was built by Honeywell Aerospace and is one of Canada's contributions to the James Webb Space Telescope (JWST).

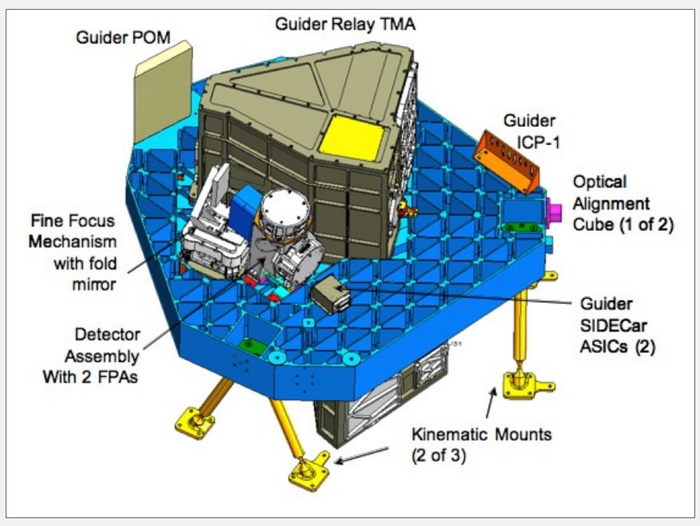


Figure 1: Diagram of the Fine Guidance Sensor optical components.[1]

The FGS has a near infrared camera and optical system functioning in the 0.6-5 μm wavelength range. Its function is to:

- Identify guide stars and their positions
- Provide this data to attitude control system for attitude determination and stabilization

It has two modes:

1. Track: used for course adjustment or to tracking moving objects
2. Fine Guide: calculates centroid to position guide stars exactly before observation

COSMIC RAYS

Cosmic rays (CRs) are very high energy protons and atomic nuclei moving through space near the speed of light.

There are two types of CRs:

1. **Primary:** originate from outside the solar system or even from another galaxy
2. Secondary: radiation and high energy particles produced when primary cosmic rays interact with the Earth's atmosphere

When primary CRs appear across the field of view of space telescopes, their brightness will be included in calculated centroid of guide stars, which could lead to inaccurate pointing.

PROJECT OUTLINE

GOAL: Limit the impacts of CRs on the FGS centroid, and thus JWST pointing.

Steps:

1. Create a CR flag to identify CRs and exclude them from centroid calculations
2. Inject simulated CRs of different patterns, intensities, and frequencies and measure their impact on centroids

METHODS

Cosmic Ray Flag

The CR flag was set to discount centroids greater than six standard deviations from the mean of the last 16 calculated centroids.

The criteria of six standard deviations was chosen because it led to no false positive detections of CRs, which is very important since the FGS should not exclude good centroids in order to have efficient pointing.

Cosmic Ray Simulations

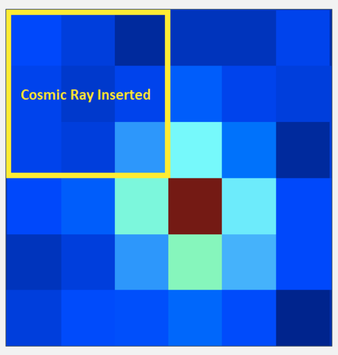
Cosmic rays are simulated at different intensities, patterns, and locations.

At each intensity level, an injection location is selected, and each of the four CR patterns are inserted in this location.

Then, the intensity level is increased, and the location and pattern cycling begins again.

5 intensities: 500 e-, 1500 e-, 5000 e-, 15000 e-, and 25000 e-, based on the typical energy categories of CRs.

16 locations:



CRs injected in 3x3 pixel windows across the 6x6 pixel guide star image, resulting in a total of 16 injection locations.

Figure 2: Sample 3x3 window where cosmic ray is inserted on star image.

4 patterns: The patterns are typical CR incidence patterns due to how they interact with the detector, as shown in Figure 3.

1	1	2	3
1	0	0.05	0
2	0.05	0.8	0.05
3	0	0.05	0

2	1	2	3
1	0.25	0.05	0
2	0.1	0.25	0.05
3	0	0.05	0.25

3	1	2	3
1	0	0.3	0
2	0.05	0.3	0.05
3	0	0.3	0

4	1	2	3
1	0	0.05	0
2	0	0.4	0.4
3	0	0.05	0.05

Figure 3: Each of the four incidence patterns used in the CR simulation at each injection location. The decimal in each grid cell represents the fraction of peak pixel intensity that will be inserted at that location.

8 test stars: guide stars of varying intensity were used to see different impacts.

Simulation Sets

Continues Injection

The CRs are inserted into every image, thereby impacting the centroid at each integration. This is not how CRs naturally occur, as they are rare in space.

Alternating Injection

The CRs are inserted on every 17th image, thereby impacting fewer centroids. This is more similar to how CRs occur in space.

RESULTS

Continuous Injection

As seen in Figure 4, the continuous CRs are only detected when the intensity changes, and pattern has some impact on centroid.

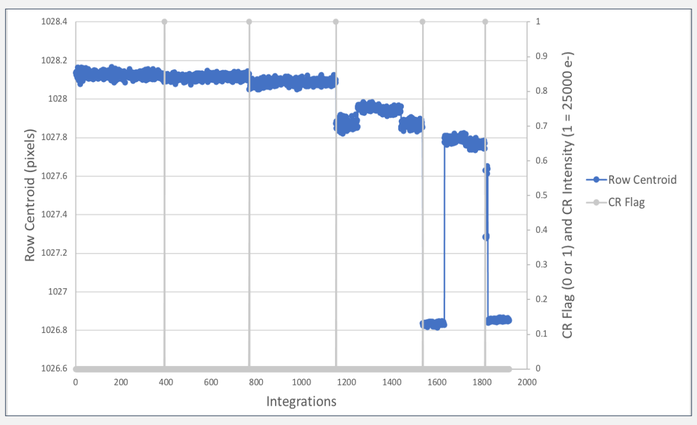


Figure 4: Cosmic ray detection with continuous injection for Guide Star 3961, mid-tier intensity of 604,259 e-.

Alternating Injection

As seen in Figure 5 and Table 1, alternating CRs are detected fully at the highest three intensities, partially at the second lowest, and rarely at the lowest. However, the CRs that are not detected have only a small impact on the centroid of the guide star, illustrated in Table 2, with less impact the brighter the star.

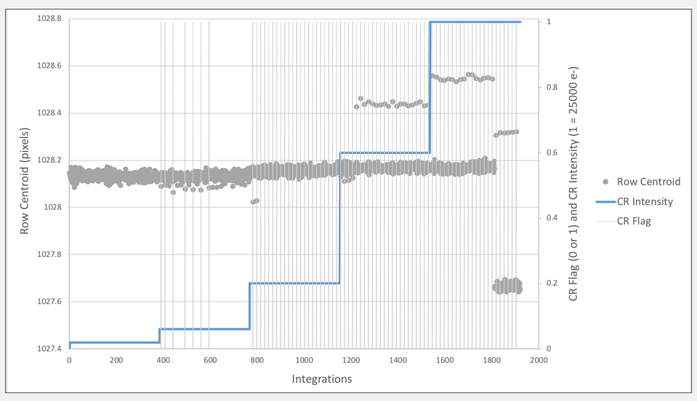


Figure 4: Cosmic ray detection with alternating injection for Guide Star 3961, mid-tier intensity of 604,259 e-.

Guide Star	3890	3895	3961	3957	3967	3973	3984	3978
Intensity	4,466,144	4,444,674	604,259	575,949	104,807	101,119	23,679	21,598
CR intensity	Percentage of CRs Detected (pixels)							
500	0	0	0	0	0	9	23	3
1500	0	0	32	29	100	100	100	100
5000	4	33	100	100	100	100	100	100
15000	100	100	100	100	100	100	100	100
25000	100	100	100	100	100	100	100	100

Table 1: Percentage of cosmic rays detected at each intensity for each guide star.

Guide Star	3890	3895	3961	3957	3967	3973	3984	3978
Intensity	Centroid Difference Due to CR (pixels)							
500	4.9E-5	9.4E-5	6.2E-5	0.02	0.03	0.03	0.015	0.21
1500	2.4E-5	3.0E-5	1.7E-4	7.4E-5				
5000	3.0E-7	2.0E-7						
15000								
25000								

Table 2: Change in guide star calculated centroid caused by undetected injected cosmic rays.

CONCLUSIONS

- The CR flag does a good job at detecting and excluding CRs, such that the centroid is not greatly changed.
- Low intensity stars will only be impacted by low intensity CRs
- High intensity stars are most impacted by ~5000 e- intensity CRs
- All CRs > 15000 e- are detected

1. LEARN MORE ABOUT JWST FGS: https://jwst-docs.stsci.edu/jwst-observatory-hardware/jwst-fine-guidance-sensor