Calibration Results for the COR-1 Coronagraph on STEREO/SECCHI

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Abstract: COR-1 is the inner coronagraph of the Sun Earth Connection Coronal and Heliospheric Investigation (SECCHI) instrument suite aboard the two STEREO spacecraft. COR-1 is a classic Lyot internally occulting coronagraph, observing the solar corona in broadband red light around 656 nm, from 1.35 to 4 solar radii. A linear polarizer is used to suppress scattered light, and to extract the polarized brightness signal from the solar corona. Calibration was performed in the Naval Research Laboratory vacuum tunnel facility previously used for the LASCO experiment aboard SOHO. We report on the results for scattered light, photometric calibration, resolution, and polarization. All performance requirements are met or exceeded. Based on these results, we demonstrate that COR-1 will be able to carry out its scientific mission.

1 Optical layout

Figure 1 shows the optical layout of the COR-1 instrument. COR-1 is a classic Lyot internally occulted coronagraph. STEREO will mark the first time that a coronagraph of this design is launched into space. The salient points are as follows:

- A recloseable door, to protect the front objective. This door also contains a diffuser window, used to track the instrument flat field and performance over time.
- The objective focuses the solar image onto the occulter attached to the field lens (Figure 2), which then reflects it into the light trap surrounding the occulter.
- The field lens focuses the image of the front aperture onto the Lyot to remove diffracted light. A Lyot spot removes a ghost image of the Sun produced within the objective.
- The bandpass filter selects wavelengths around 656 nm (Hα).
- A rotating linear polarizer allows for polarization analysis. The axial design insures that instrumental polarization effects are minimized.
- A mask in front of the focal plane array (FPA) removes diffracted light from the edge of the occulter.
- Two doublets focus the solar corona onto a 2048$\times$2048 CCD in the FPA. A passive radiator at the back of the instrument cools the CCD down to -75 C.

Figure 1: Layout of the COR-1 instrument.

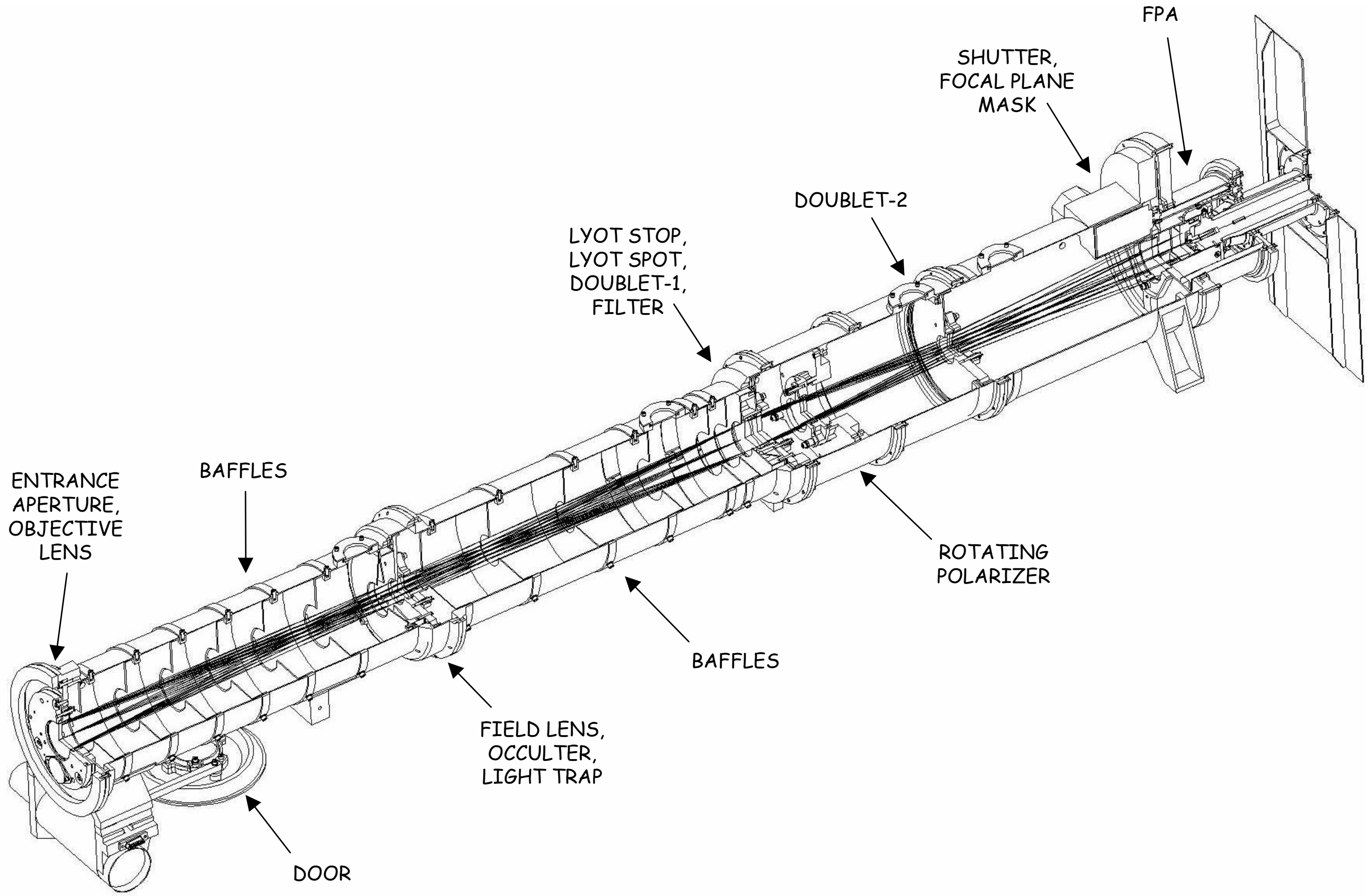
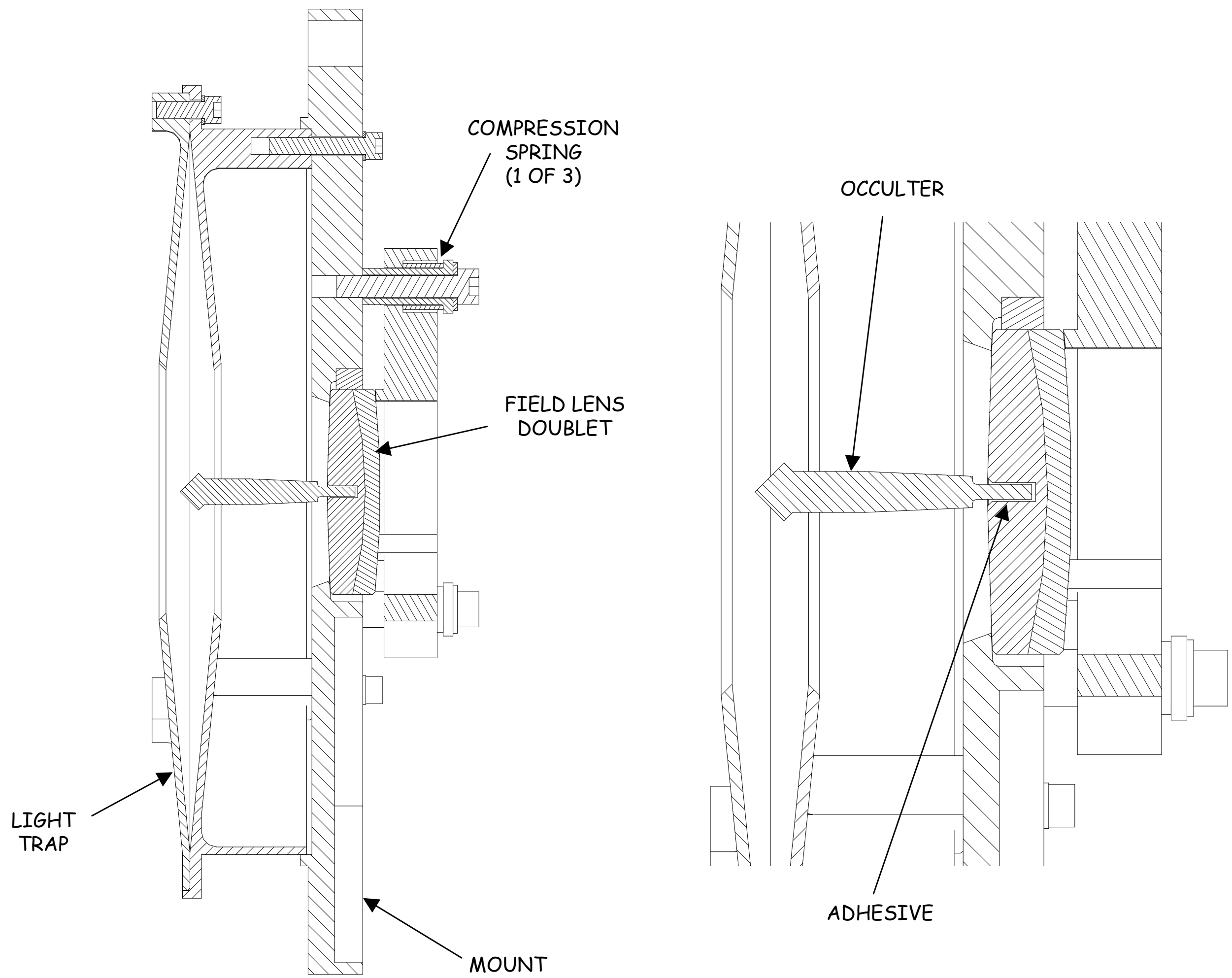


Figure 2: Details of the COR-1 occulter, light trap, and field lens.



2 Vacuum chamber setup

Calibration of COR-1 was performed in a vacuum chamber facility designed for this purpose at the U. S. Naval Research Laboratory. For the scattered light measurements, a 1500 Watt xenon arc source is used to illuminate a circular aperture at the far end of the vacuum chamber, 10.4 meters in front of the instrument. The aperture was sized to produce a solar-sized image on the COR-1 occulter. Slightly different aperture sizes were used for COR-1A and COR-1B to reflect the different perihelion distances of the two STEREO spacecraft. Liquid nitrogen was used to cool the CCD detector to flight-like temperatures. Other configurations of the same vacuum tank were used for photometric calibration, and polarization characterization.

Figure 3: COR-1A in the NRL vacuum chamber, as seen from the front of the instrument. The retracted vacuum bell jar can be seen in the background.

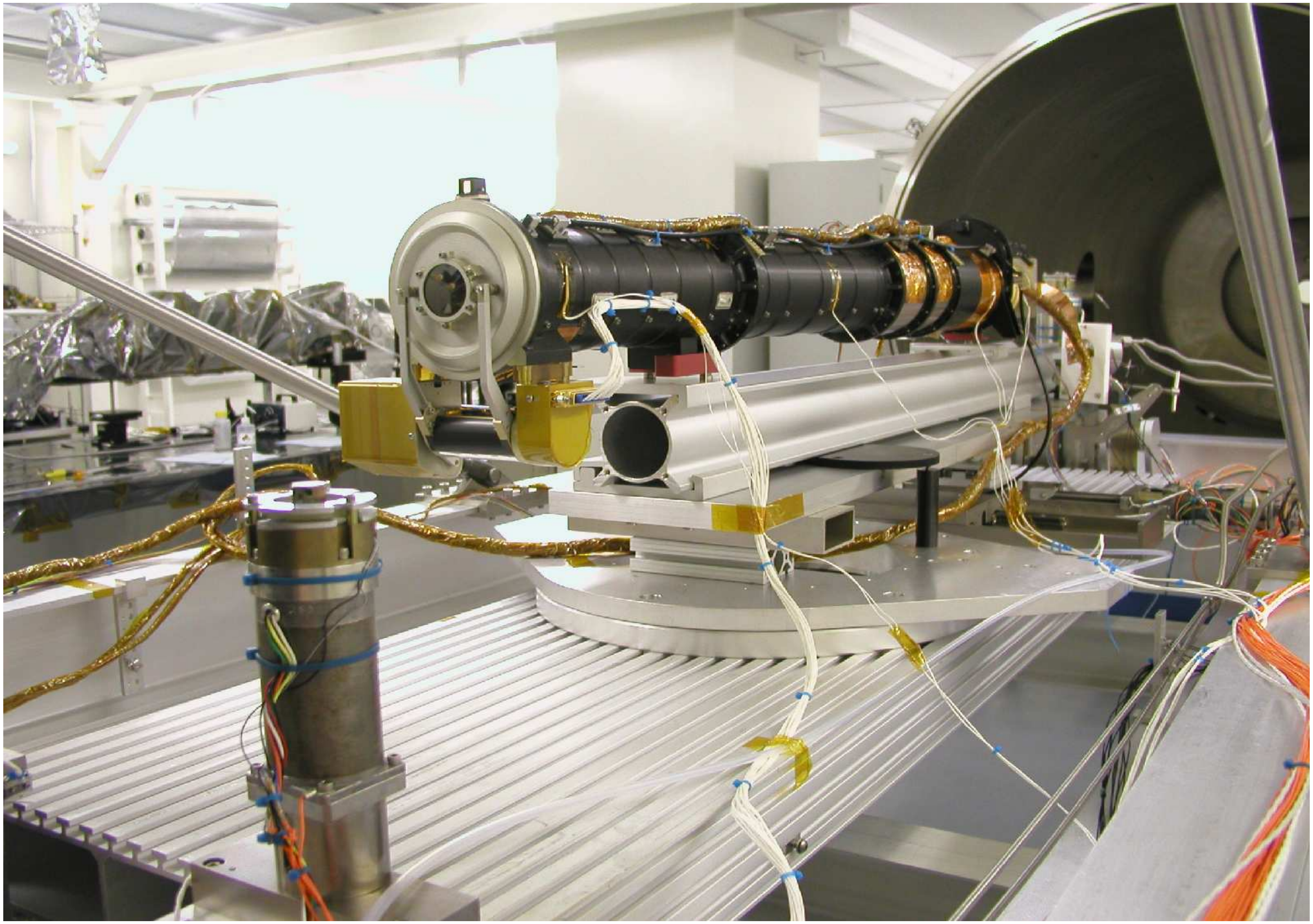
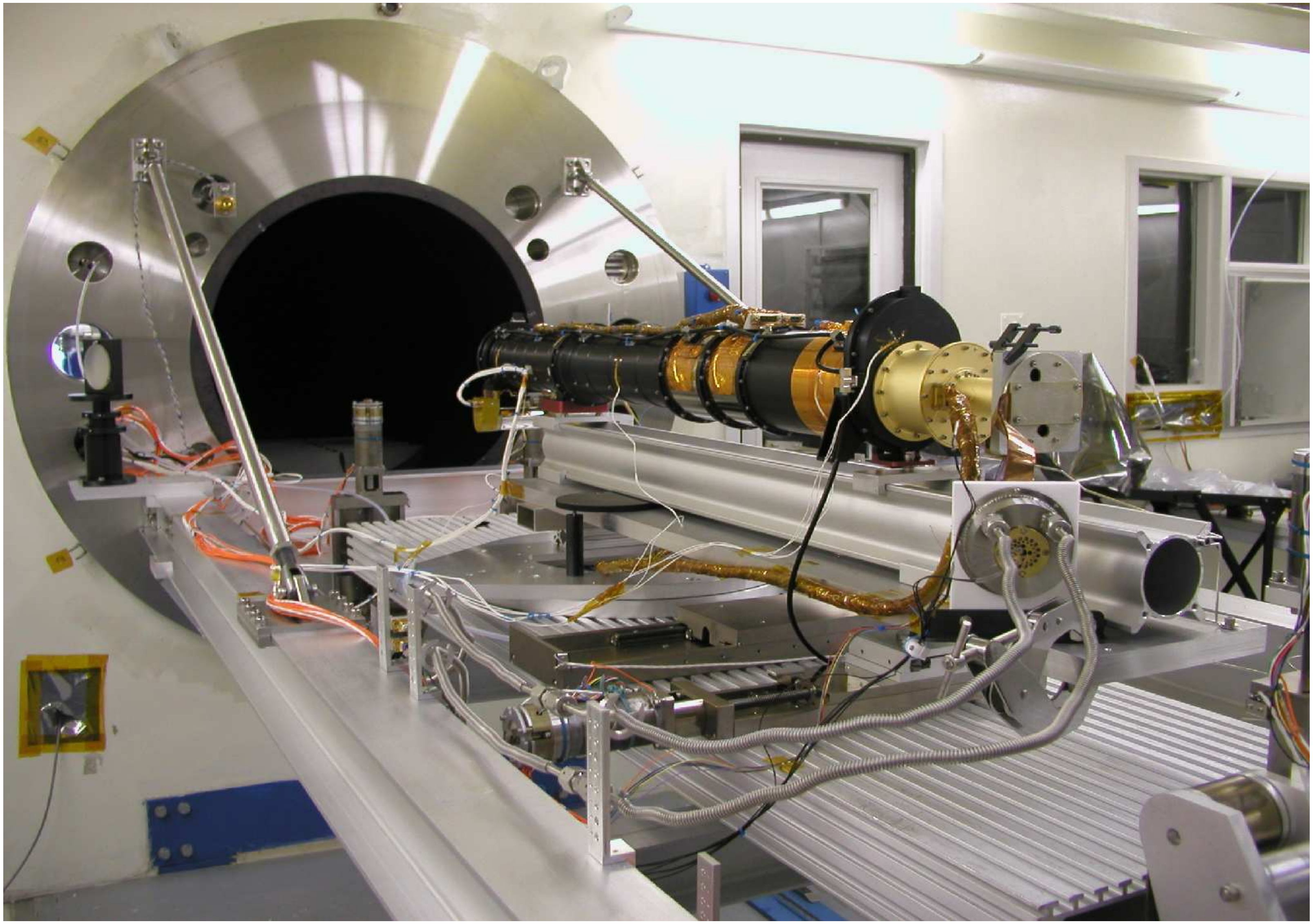


Figure 4: COR-1A in the NRL vacuum chamber, as seen from the back of the instrument. The illumination source is at the far end of the 10 meter vacuum tunnel.



3 Scattered light

The core requirement for any coronagraph is that it have low stray light levels. The requirement for COR-1 is that the overall level of stray light be below 10^{-6} $B/B_\odot$, and that small discrete features be below 3×10^{-6} $B/B_\odot$. These requirements were achieved for both COR-1A (Ahead) and COR-1B (Behind). The scattered light patterns for each instrument are shown in Figure 5.

There are two classes of stray light features visible in Figure 5. First is the overall level of scattered light, which gradually declines from the edge of the occulter out to the edge of the field of view. Also visible are small bright features—these are defects in the front surface of the field lens, which catch and rescatter diffracted light from the front aperture. The results are summarized in the following table:

	Diffuse stray light		Small bright features
	Inner	Outer	
Requirement	$< 10^{-6}$	$< 10^{-6}$	$<3 \times 10^{-6}$
COR-1A	4.5×10^{-7}	1.1×10^{-7}	9.2×10^{-7}
COR-1B	1.8×10^{-7}	3.2×10^{-8}	1.4×10^{-6}

From these data, and a model of the solar K-corona, we can predict the average signal-to-noise characteristics of the instrument, which is shown in Figure 6.

Figure 5: Stray light patterns in the two COR-1 coronagraphs.

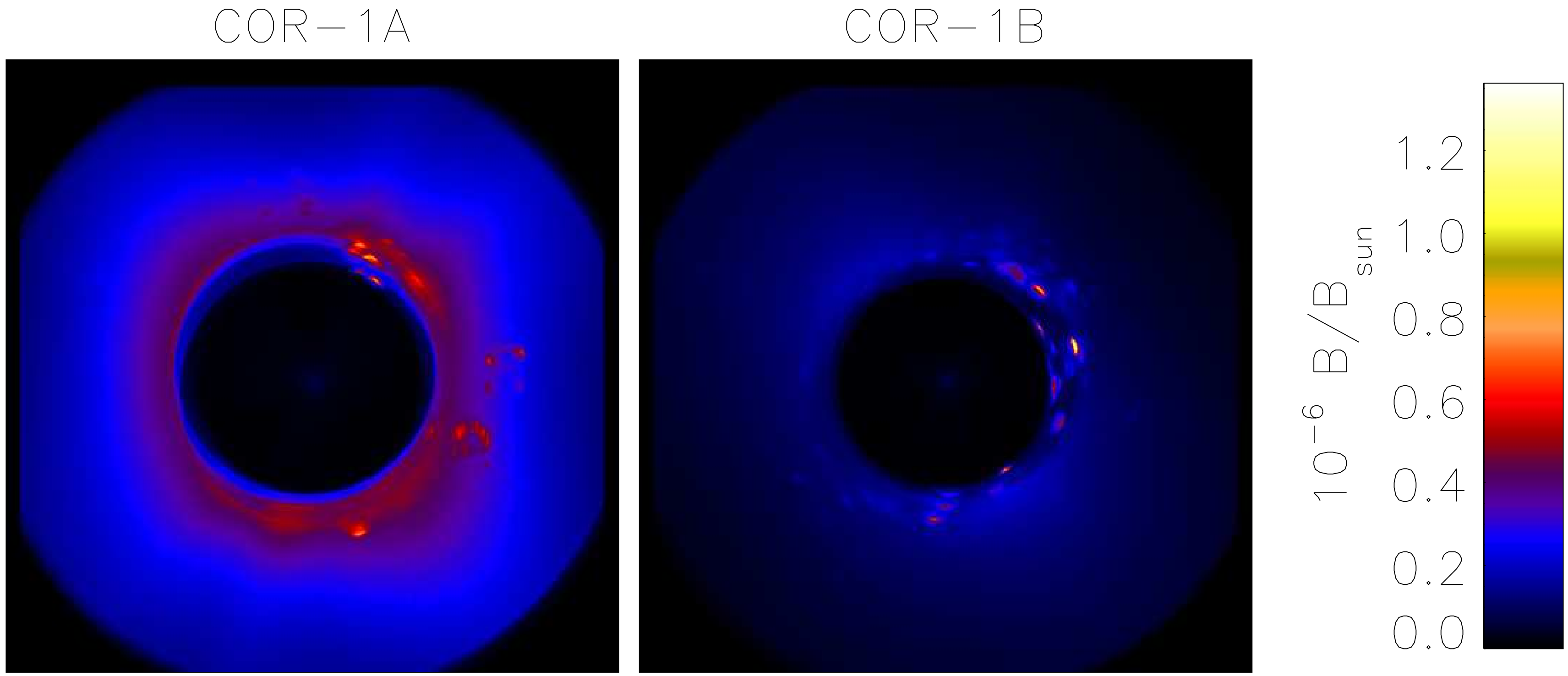
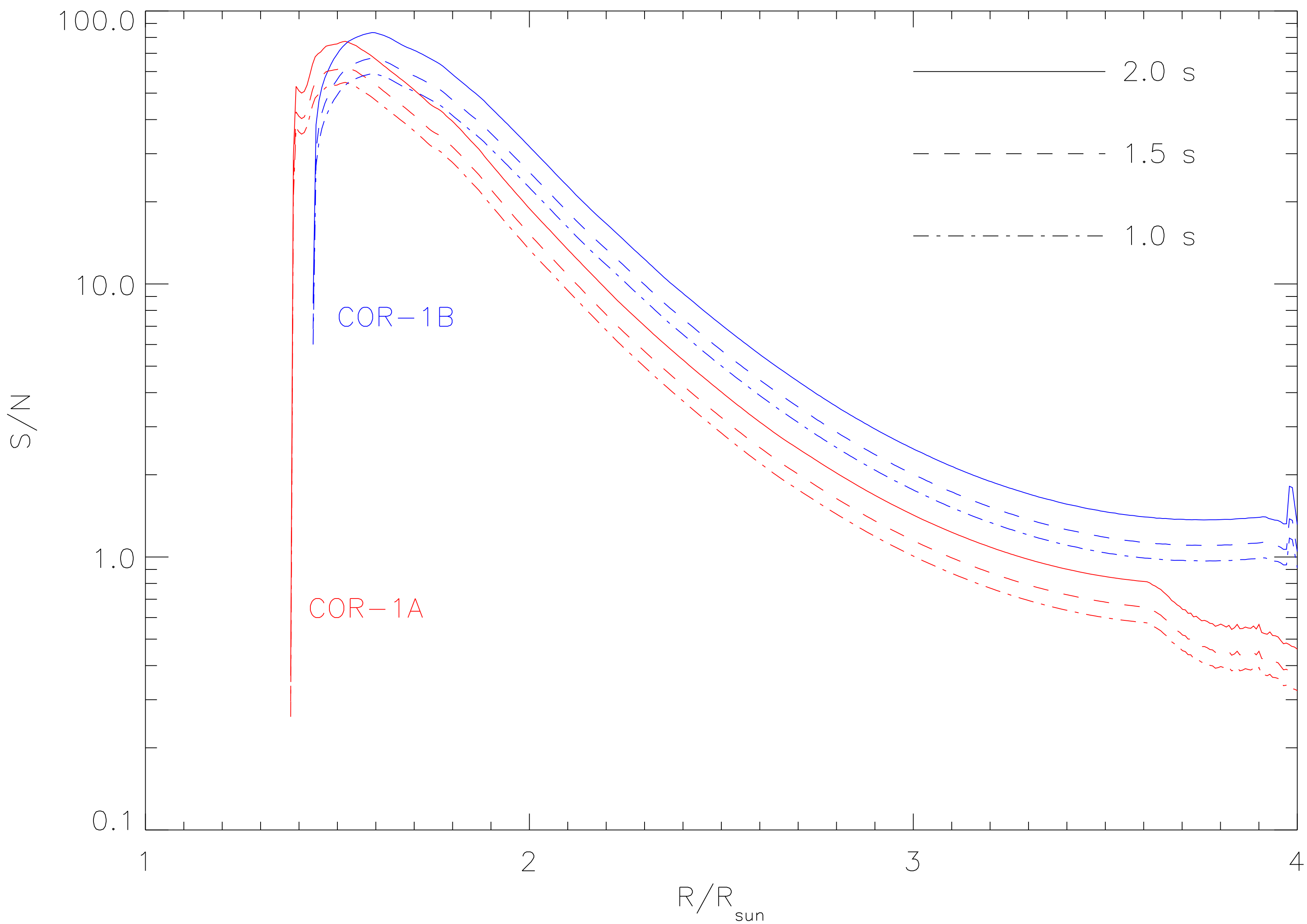


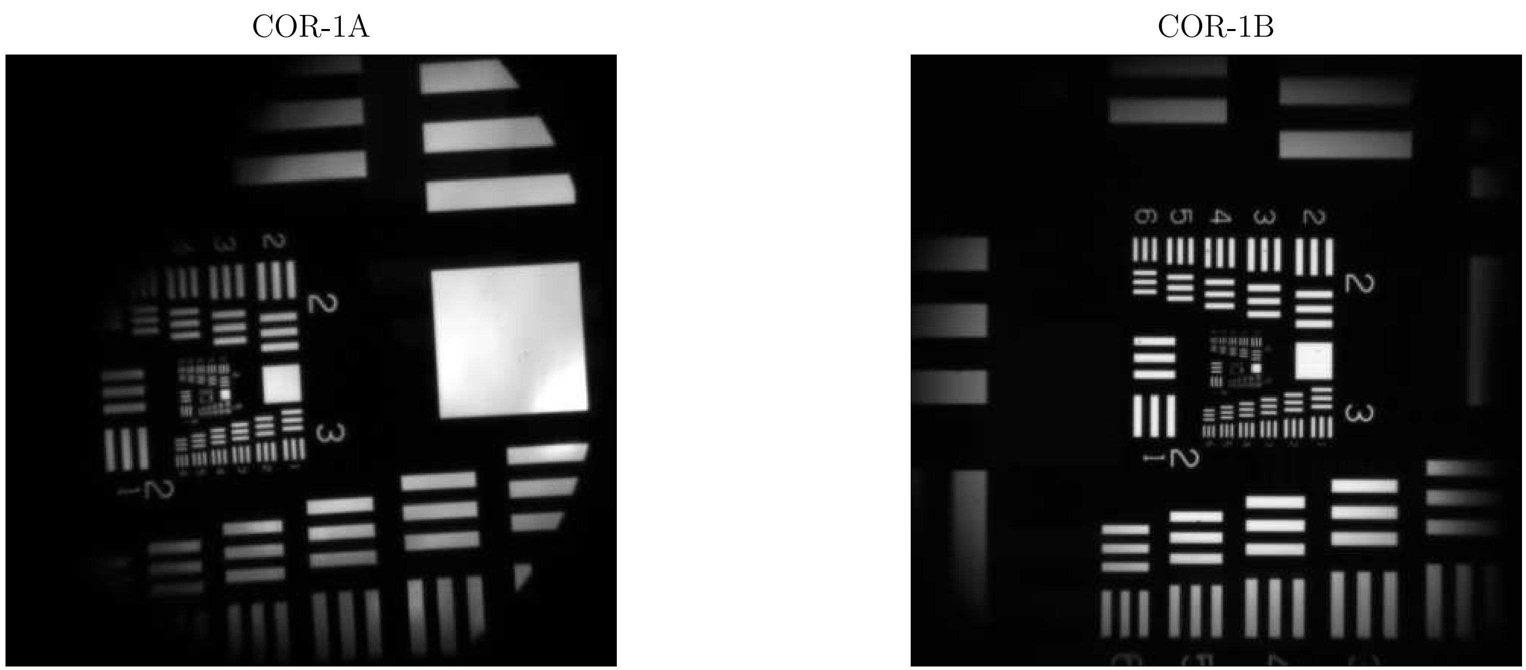
Figure 6: Signal-to-noise ratio as a function of radial distance, for several exposure times.



4 Resolution

To test the instrument resolution, a collimated image of an Air Force 1951 resolution test target was sent down the vacuum chamber. The results are shown in Figure 7. These images were taken when the focal plane array was cooled to close to flight temperatures. Features are visible down to the Nyquist limit.

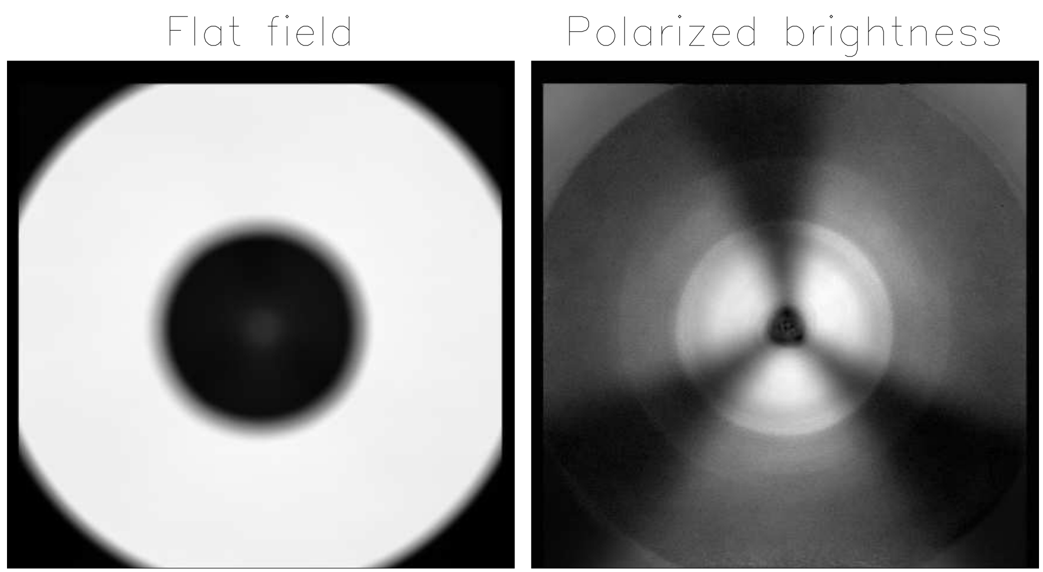
Figure 7: Images of Air Force 1951 resolution test targets.



5 Photometric calibration and flat field

Photometric response was established by placing a calibrated double-opal diffuse source in front of the instrument. This also tests the instrument flat field—the results agree with those derived from the window in the aperture door, as shown in Figure 8. During flight, this window will be used to monitor changes in the instrument calibration.

Figure 8: Flat field image, using the calibration window in the COR-1B door. Also shown is a polarized brightness image of the same data (not on the same scale). The results for COR-1A are similar.



6 Polarization

The polarization response of the instrument was tested by successively rotating two linear polarizers, at 0° and 45° respectively, in front of the same double-opal source used for the photometric calibration. The results are shown in Figure 9. WIthin the noise, the results are consistent with 100% polarization. There's a slight offset in the alignment of the internal polarizer between the two instruments, which is calibrated by these measurements.

Figure 9: Polarization response of COR-1A (red) and COR-1B (blue) to light polarized at 0° (solid) and 45° (dashed).