NICI Technical Memorandum

Memo Number: SDN 1014 Spider Mask Requirements
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Subject: NICI Secondary support induced flares strategy
Distribution: Dtoomey, Cftaclas

I. Introduction.

This memo addresses the determination of the best strategy for coping with the focal plane flares generated by the Gemini secondary mirror supports. The rotation of the field associated with alt-az mount tracking forces NICI to rotate with respect to the telescope structure. Consequently, if we decide to treat the spiders with a Lyot mask it must also rotate. This requires another cryogenic mechanism. In order to determine if this is indeed necessary, this analysis addresses the impact of the Gemini flares on the residual (i.e. post-coronagraphic) focal plane. The memo consists of three sections: this document and two power point presentations: spider1.ppt and spider2.ppt. In Section II below the general characteristics of spider flares are discussed and in Sections III and IV. The Power Point files are discussed.

II. Secondary Support Flares

The general theory of spider flares and their impact on image quality is discussed in (Harvey and Ftaclas, Applied Optics). In general, the total energy in the spider diffraction problems is equal to the energy the secondary supports block in the pupil (~0.3% for Gemini). To first order, the spider diffraction pattern can be considered a rectangle whose angular width is of order $2\frac{\lambda}{D}$ where λ is the wavelength and D is the telescope diameter. The angular extent of the spider flare is of order $2\frac{\lambda}{\delta D}$ where δ is the ratio of the spider with to the telescope diameter. Therefore the area occupied by the spider flares in the focal plane scales like $\frac{1}{\delta D^2}$ and the flare surface brightness like $\delta^2 D^4$. Clearly it pays to reduce spider with since the flare surface brightness decreases dramatically. Spider flares become visible because their intensity falls off very slowly compared to the circular pupil diffraction pattern falls off like θ^{-3}. There is one sense in which narrower spiders don't always pay-off. The contrast ratio0 between spider flare intensity and pupil diffraction scales like $\theta^3\delta^2 D^4$. If we use as a characteristic field angle the spider flare scale size $\frac{\lambda}{\delta D}$ we get an intensity ratio that scales like $\frac{\delta}{D}$. In other words narrower spiders produce longer, low surface brighness flares that reach further into the focal plane where the diffracted intensity is less. Consequently narrower spiders end up brighter relative to the background diffraction. This is very important for NICI because we reduce the background intensity making the contrast factor even higher.

III.. Spider1.ppt

This presentation follows the propagation of light through NICI assuming various options as to whether or not the spiders are masked in the pupil plane. As we can see from slide 4, in the re-imaged pupil plane the spiders are bright with a narrow concentration of residual diffracted light. This concentration makes them relatively easily handled compared to other edges in the pupils. Some gains are realized just by covering the spiders with a mask equal to their original width. Not addressing the spider flares results in the pupil diffraction level dropping but leaving the spider flares at their original level. They quickly become the brightest feature in the focal plane. As can be seen in slides 6 and 7 the wider the mask we use to cover the spiders in the re-imaged pupil the more the focal plane resembles the no spider case. There is some concern about aligning a spider mask because it is difficult to relay a high-resolution pupil image to the detectors. As the last two slides in the presentation show, it is possible to align the spider mask by using focal plane images and the interference effects that occur when the spider s and the spider mask are close to alignment.

III. Spider2.ppt

After discussions with Gemini it was decided to investigate the effects of spider flares by considering a realistic observational scenario. We chose a star with a K magnitude of 6 and modeled an observation centered on its zenith crossing of duration 2 hours. We did two cases that spanned much of the useful NICI observing range in declination. The star was assumed to have declinations that differed by 10 and 30 degrees from that of the observatory. These two cases gave star images that rotated by about 120 degrees for the near zenith case and about 70 degrees for the other. The observation was modeled by propagating through the coronagraph at 11 wavelengths at 120 different rotational positions.

The two-hour observation was divided evenly between target and sky frames each of duration 1 minute. Since it is computationally difficult to run an AO simulation for two real time hours, a set of AO corrected wave fronts was used. At each position one of the wave front maps was randomly selected and then randomly rotated inverted and reversed to give a variety of maps. After the coronagraph propagations was done the sky background, shot noise and read noise were added and a separate sky frame was synthesized. The two frames were differenced to give a final image.

Looking at slides 4 and 5 we can see the resulting first and second focal plane images of the two cases calculated. Because the pupil has 4-fold symmetry rotation by more than 90 degrees results in only region in excess of 90 degrees showing as excess light although the light level in the rest of the focal plane has already been elevated by the passage of the spider flares. We can see that when a large spider mask is applied the flares virtually disappear. I t is particularly important that the end results of both case are nearly indistinguishable because it means that we can combine observations from different times of the year or parts of the evening without inducing bright artifacts.

IV. Conclusions.

Leaving the spider flares uncorrected results in large residual bands in the focal plane corresponding to the duration of the observation. These bands can be treated on a frame-by- frame basis but only their brightest portions. That is, they also have diffraction side lobes that do not go away if the flares are simply masked in software. Assuming the spiders are masked then that mask would have to rotate to stay aligned in the telescope pupil. Fixing the size for the spider mask is a compromise between throughput, performance, alignment and manufacturability. Based on consideration of these factors we have base lined a mask that is 30 times the width of the spider image. Since the spiders occupy about 0.25% of the Gemini pupil plane this mask results in a throughput loss of order 6% for a nominal Lyot stop. Making it this wide, however, permits a free standing mask and eliminates another glass element from the beam