CHANDRA
X-ray Center

MEMORANDUM

June 27, 2002

File: /data/acis33/MARX_archive/AO4/AO4-crab.ps

To: ACIS Operations Team

From: Shanil N. Virani

Subject: MARX Simulations of the AO4 Crab Nebula/Saturn-Titan Conjunction Proposals

1 Introduction

On January 5, 2003, a rare conjunction of the Crab Pulsar/Nebula with Saturn and Titan will occur. There are two GO proposals submitted for the AO-4 cycle that wish to observe this conjunction. One proposal requests two ACIS-I3 pointings, with the HETG deployed and dither turned **off**, for a total of 80 ks. The second proposal requests two ACIS-S3 pointings, only one with the HETG deployed, for a total 54.4 ks (dither is on).

I have conducted MARX simulations for the various ACIS configurations requested for the Crab Nebula/Saturn-Titan conjunction in order to assess the risk these observations pose to ACIS. In particular, I have determined the maximum photon counts in the peak pixel for all pointings. I have also considered single and double point failures that would lead to higher photon fluxes for a given pointing. A list of all the simulations performed (requested configurations as well as possible failure cases) for each proposal can be found in Tables 1 and 2 below. I should note that the ACIS-I3 proposal does not really request a Y-Target offset (see Table 1). They have chosen a pointing direction that is $117''$ north of the Crab pulsar position. Since the PSF does change with off-axis angle, and since we wish to perform accurate and robust simulations of the Crab pulsar on I3, I have implemented the observers pointing direction as a $117''$ Y-target offset. The ACIS-I3 proposers request a 10.8 mm SIM-Z offset to move the nominal aim point to the center of the I3 chip. It should be noted that neither proposal requests the Crab pulsar to be on-axis. Nevertheless, using Y. Butt's memo on operational limits for X-ray photon dose on ACIS, I in turn have calculated the dosage amounts in *krads* and expressed these values in terms of the percentage of the total mission dose budget (see table 4 for limits).

See Section 3 for a discussion of the various MARX simulations performed.

Table 1: **MARX Simulations of the ACIS-I3 Proposal**

Sim	Detector/Grating	SIM-Z (mm)	Y-Target Offset (′)	Observing Time (ks)	Dither
1	I3/HETG	10.8	1.95	40.0	**OFF**
2	I3/HETG	10.8	1.95	40.0	ON
3	I3/NONE	10.8	1.95	40.0	ON
4	I3/NONE	10.8	1.95	40.0	OFF
5	I3/HETG	10.8	0.0	40.0	OFF
6	I3/NONE	10.8	0.0	40.0	OFF

Table 2: **MARX Simulations of the ACIS-S3 Proposal**

Sim	Detector/Grating	Z-Target Offset (′)	Observing Time (ks)	Dither
1	S3/NONE	2.7224	22.0	ON
2	S3/HETG	2.7224	32.4	ON
3	S3/HETG	2.7224	32.4	OFF
4	S3/NONE	2.7224	22.0	OFF
5	S3/NONE	0.0	32.4	OFF

2 Model of the Crab Pulsar Spectrum

In order to perform the simulations listed in Tables 1 and 2, a model spectrum of the Crab Pulsar must first be generated. Willingale *et al*, have recently published a paper on the XMM observations of the Crab Nebula. They find that the spectral index of the Crab Pulsar is 1.63 ± 0.09. While they don't explicitly state the normalization for the pulsar, they find that the normalization for the pulsar plus Nebula is 9.59 ± 0.05 $photons\ cm^{-2}s^{-1}keV^{-1}$. However, the ratio of the pulsar flux over that of the Crab Nebula in the 0.4 - 3.0 keV band (the band over which the bulk of the flux is detected by EPIC MOS) is 0.051 ± 0.001. I therefore infer that the normalization for the pulsar alone is 0.49 $photons\ cm^{-2}s^{-1}keV^{-1}$.

These parameters were used as input into a spectral model defined in XSPEC. My model consisted of two components: photoelectric absorption by the ISM (phabs) and a power law for the pulsar itself (pow). The neutral hydrogen density, nH, towards this source is 3.0 x 10^{21} cm^{-2}. Figure 1 is a plot of the resulting spectral model. Table 3 tabulates the XSPEC model parameters. The expected flux for such a model is 2.15 x 10^{-9} $ergs\ cm^{-2}s^{-1}$ (or 0.3076 $photons\ cm^{-2}s^{-1}$) in the 2 - 10 keV band. The predicted ACIS-I count rate is 221.8 counts/second.

Table 3: **XSPEC Spectral Model Parameters**

Model par	Component	Parameter	Unit	Value
1	phabs	nH	10^{22}	0.3000 +/− 0.
2	powerlaw	PhoIndex		1.630 +/− 0.
3	powerlaw	norm	$photons\ keV^{-1}\ cm^{-2}\ s^{-1}$	0.4900 +/− 0.

3 Notes on MARX Simulation

Since the four pointings in the two proposals have different exposure times, only 10 ks MARX simulations were performed. This was primarily done to limit the resulting event list to a manageable size since the results of a simulation can be easily scaled to a given integration time. Moreover, the dither pattern has a period of 1 ks; hence, a 10 ks simulation samples the dither pattern 10 times. Lastly, I assumed that the CCDs had ideal quantum efficiency (QE) (*i.e.*, a QE of unity). This was implemented by utilizing MARX QE files generated by Joe DePasquale. All filter transmission files were left at their default MARX values.

Simulation 1 in Table 1, and simulations 1 and 2 in Table 2 represent the "as proposed" ACIS configuration. (While the ACIS-I3 proposal requests two pointings, the ACIS configuration is virtually the same – they differ only in their pointing co-ordinates, integration time, and frame time.) Simulations 2 to 6 in Table 1, and simulations 3 and 4 in Table 2, represent various "failure modes" simulated. These consist primarily of dither being turned ON/OFF, the HETG failing to be deployed, and a Y-Target offset of $0'$ instead of $1.95'$ as specified in the ACIS-I3 proposal. Simulation 5 in Table 2 represents a triple failure and is the "worst case" scenario: dither failure, the HETG fail to deploy, and a pointing error such that the Crab pulsar is on-axis. It is expected that the "worst case", from a radiation dose perspective, will be captured by the union of these simulations for each detector.

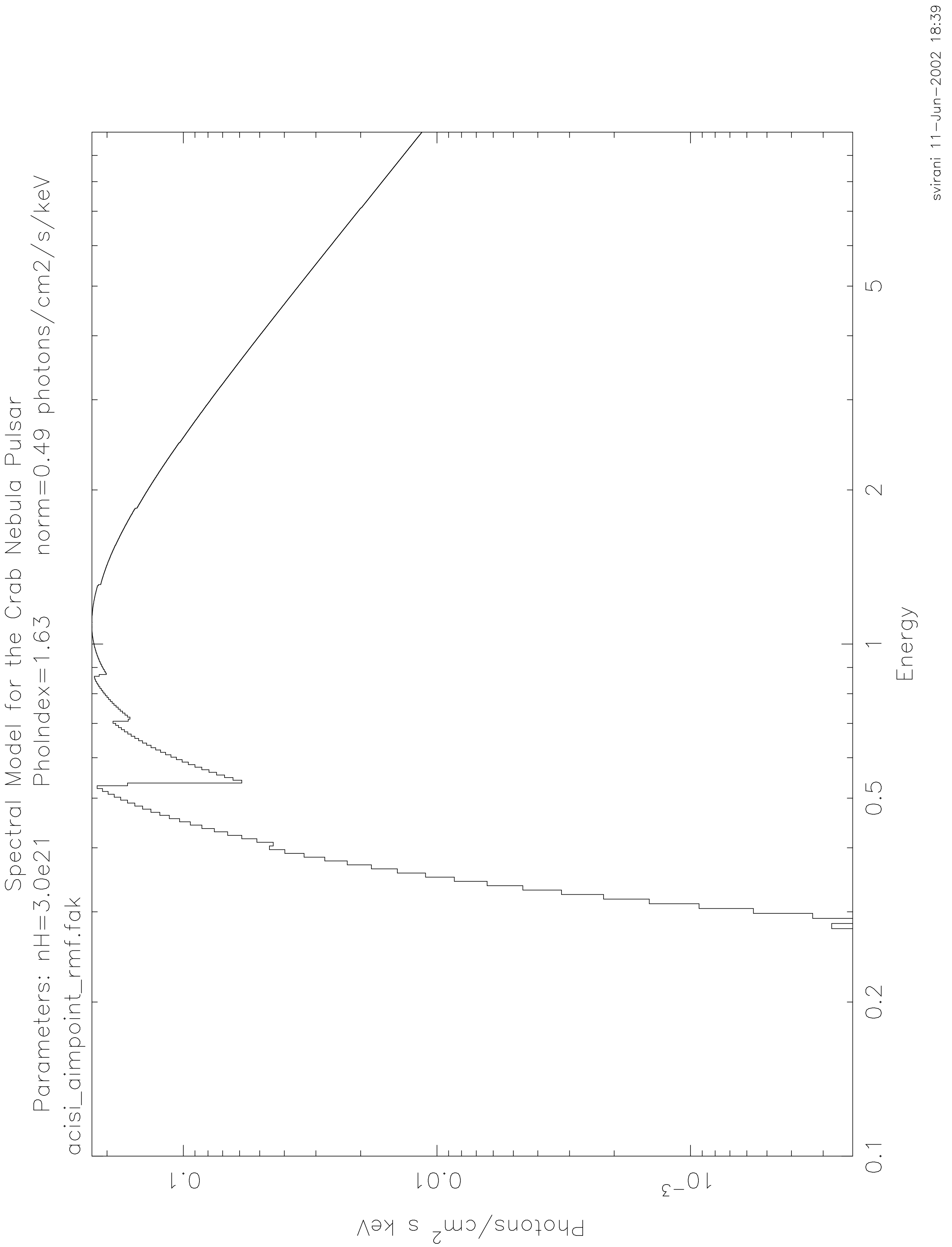

Figure 1: XSPEC Spectral Model for the Crab Pulsar

4 Results

Table 4 shows the limits adopted for this analysis as defined in Y. Butt's memo. Mission Dose (MD) is the total budgeted dose in *krads* for the life of the mission for a given CCD. The difference in structure between back-illuminated (BI) and front-illuminated (FI) CCD's results in a BI CCD having a higher threshold than a FI CCD.

Table 4: **Mission Dosage Limits**

CCD	MD (krad)	(cts/pix : rad/pix)
FI	25	135 : 1
BI	625	100 : 1

The results of the ACIS-S3 simulations are shown in Table 5, whereas the simulations of the ACIS-I3 proposal are shown in Table 6. Rows 1 and 2 in Table 5 (simulations 1 and 2) and row 1 in Table 6 (simulation 1) represent 10 ks MARX simulations in the "as proposed" configuration; *i.e.*, there are no (spacecraft or command load) errors with the observation. The number of counts produced in the 10 ks MARX simulation are then scaled by the requested observation time to produce the hypothetical damage to ACIS (columns labeled "Exp Scaled" and "Dose"). The radiation dose for each simulation is then expressed as a percentage of the mission dose for that CCD (column labeled "% MD"). Rows 3 and 4 in Table 5 (simulations 3 and 4) and rows 2 to 6 in Table 6 represent various "errors" in the simulated observation; *i.e.*, dither failure, HETG fails to deploy, or a pointing error that affects the Y-target offset. The expected radiation damage in each of these of failure cases is also calculated and expressed as a percentage of the mission dose. Lastly, Figures 2 and 3 are images from the 10 ks MARX simulation on S3 (simulation 1) and I3 (simulation 4).

Table 5: **ACIS-S3 Proposal: MARX Simulation Results**

Sim	HETG	Dither	Pixel (x, y)	Counts (in 10 ks)	Exp Time	Exp Scaled	Dose (krads)	%MD
1	OUT	ON	(278, 190)	9,711	22.0 ks	21,364	0.214	**0.03**
2	IN	ON	(278, 190)	1,610	32.4 ks	5,216	0.052	**0.01**
3	IN	OFF	(261, 174)	50,584	32.4 ks	163,892	1.639	**0.26**
4	OUT	OFF	(261, 174)	315,568	32.4 ks	1,022,440	10.224	**1.64**
5	OUT	OFF	(262, 506)	975,836	32.4 ks	3,161,709	31.617	**5.06**

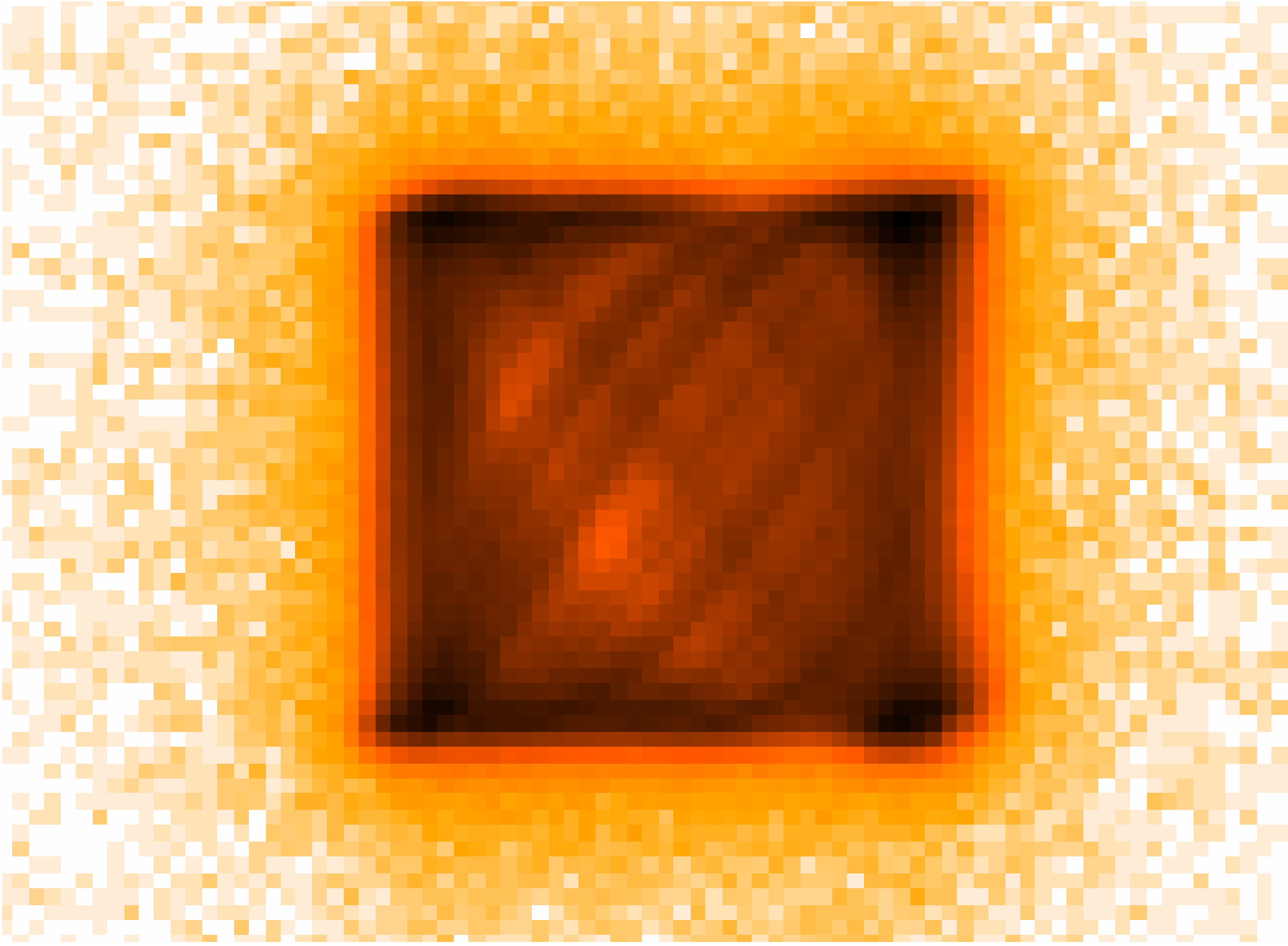

Figure 2: 10 ks MARX Simulation of the Crab Pulsar on S3 with dither ON and the HETG OUT (sim #1 in Table 5)

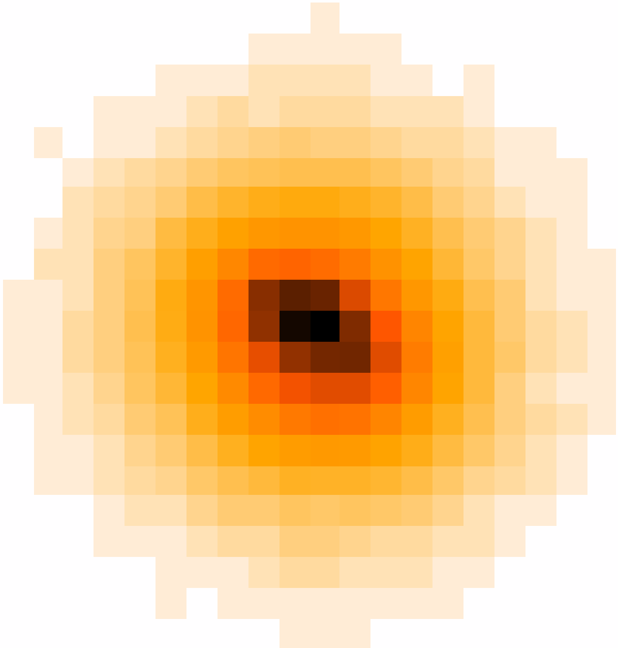

Figure 3: 10 ks MARX Simulation of the Crab Pulsar on I3 with dither OFF and the HETG OUT (sim #4 in Table 6)

Table 6: **ACIS-I3 Proposal: MARX Simulation Results**

Sim	HETG	Y-off (in ′)	Dither	Pixel (x, y)	Counts (in 10 ks)	Exp Scaled (in 40 ks)	Dose (krads)	%MD
1	IN	1.95	OFF	(515, 879)	85,444	341,776	2.53	**10.0**
2	IN	1.95	ON	(499, 895)	1,689	6,756	0.05	**0.20**
3	OUT	1.95	ON	(499, 895)	9,871	39,484	0.29	**1.20**
4	OUT	1.95	OFF	(515, 879)	504,508	2,018,032	14.9	**60.0**
5	IN	0.0	OFF	(509, 951)	101,921	407,684	3.0	**12.0**
6	OUT	0.0	OFF	(509, 951)	648,641	2,594,564	19.2	**77.0**

5 Discussion and Conclusions

5.1 Radiation Dose from X-rays

From Table 5, it is clear that the ACIS-S3 proposal generally poses no risk to S3. Two of the three failure cases simulated (sims 3 and 4 in Table 2) both have relatively small mission doses for the requested observation time. Simulation 5 clearly poses the greatest risk to S3. In this case, three failures would have taken place: 1) dither failure, 2) the HETG fails to deploy, and 3) a pointing error such that the Crab pulsar is on-axis. Of these three cases, I note that the increase in radiation damage is primarily the result of the dither being turned off rather than the HETG failing to deploy. Moreover, it is also worth noting that should a dither failure occur during an observation, we expect that SCS-107 would be quickly executed. Therefore, the radiation damage tabulated in simulations 3, 4, and 5 of Table 5 truly represent the “worse case” scenario. The likelihood of a triple failure occuring (such as sim 5) during an observation would seem to be quite small. The only issue with this ACIS-S3 proposal concerns the observing efficiency: the observers have requested TE/FAINT observations rather than TE/GRADED observations. In TE/FAINT mode, the telemetry saturation limit is 170.2 events/second, whereas in TE/GRADED mode the corresponding number is 375.0 events/second. Since telemetry saturation is an issue for this proposal, and the observers provide no reason for TE/FAINT observations, a switch to TE/GRADED mode is advised.

While there may not be any significant issues with the ACIS-S3 proposal, the same **cannot** be said for the ACIS-I3 proposal. As row 1 of Table 6 indicates, the “as-proposed” configuration would result in an unacceptably large radiation damage – 10% of the radiation mission budget of I3 would be accrued in 40 ks. Moreover, should the HETG fail to deploy (a failure case we have already witnessed in orbit), the resulting radiation damage would increase by a factor of 6 (*i.e.*, 60% of the radiation mission budget on I3 would accrue)! Rows 2 to 6 investigate other possible I3 configurations and the resulting radiation damage. I note that should dither be left **ON** for these I3 pointings, the resulting radiation damage would be significantly less. This scenario results in approximately 1% of the mission dose – undesirable but not a catastrophe.

5.2 Observation Times and Perigee Transit

Since both proposals are time-constrained observations, I investigated at what points in the Chandra orbit these pointings would occur. I requested to FOT MP that they provide me with date and time of perigee transits for the first week of January 2003. The transit that is of relevance to these two proposals occurs at 02:22:51.37 on DOY 005. Of course, from an operations point of view, radiation shutdown is nominally defined as the time period between RadMon Disable and RadMon Enable. However, these two commands are linked to the times of electron entry and exit as determined by the AE-8 model. Even though there is an asymmetry in the times of EE1RADZ0 and XE1RADZ0 with respect to perigee, to first order it is sufficient to assume:

$$\text{EE1RADZ0} = \text{perigee - 5.5h}$$
$$\text{XE1RADZ0} = \text{perigee} + \text{4h}$$

This gives:

EE1RADZ0 @ 2003:004 20:52:51.37

XE1RADZ0 @ 2003:005 06:22:51.37

We now need to account for our 10 ks pad on each time stamp. 10 ks = 2.78 hrs. So we need to subtract 2.78 hrs from the EE1RADZ0 timestamp and add 2.78 hrs to the XE1RADZ0 timestamp to get an approximate time span for radiation shutdown. I get:

RadMon DS @ 2003:004 18:05:51.37

RadMon EN @ 2003:005 09:09:51.37

While both proposals list the time window for their observations, they do not agree with each other. In order to independently verify the time of conjunction as seen by Chandra, Scott Wolk determined conjunction times for both Saturn and Titan. After providing him with my estimate for radiation shutdown on January 4-5, he produced a figure that overlays the motion of both Saturn and Titan on the Crab Nebula (see Figure 4). In this figure, hollow circles represent the Saturn transit while dots represent the motion of Titan. More importantly, the circles and dots colored in red represent times when Chandra is **unable** to perform science observations due to radiation zone shutdown; circles and dots colored in blue represent times when Chandra is able to perform science observations. It is immediately clear that the conjunction of Saturn and the Crab Nebula cannot be observed by Chandra, but the conjunction of Titan and the Crab Nebula is certainly possible.

Since the Saturn conjunction is not possible, it would be prudent to understand why the proposers of the ACIS-I3 proposal chose I3 for their pointings. The observers state that they chose ACIS-I because of the potential for optical light from Saturn to affect the bias calculations. However, since the Saturn transit is not visible, the light leak from Saturn is not an issue. The light leak from Titan will produce a signal of only 4 ADUs in ACIS-S3. Since the split threshold is 13 ADUs and the event threshold 20 ADUs for the BI CCDs and 38 ADUs for the FI CCDs, this level of light leak will not adversely affect the identification of events by the on-board software. We conclude that the rationale for choosing ACIS-I3 over ACIS-S3 is not correct for the Titan transit observation, and therefore, should not be the determining factor in selection of the instrument configuration.

Since the "as proposed" Titan ACIS-I3 observation results in an unacceptably large radiation dose for the FI CCD, we therefore recommend that (should the ACIS-I3 proposal be accepted) that the observers switch to the ACIS-S3/HETG configuration with dither off, **or** that they use ACIS-I/HETG with the dither **on**.

For future reference, all of the MARX parameter files and images in sky and detector coordinates for these simulations are located on the HEAD LAN at:

/data/acis33/MARX_archive/A04/Saturn-Titan_transit_CrabPulsar/

6 References

1. Y. Butt, "Operational Limits for X-ray Photon Dose On ACIS", CXC Memo, 3 May 2002
2. Willingale, R., et al. A & A 365, L212-L217 (2001).

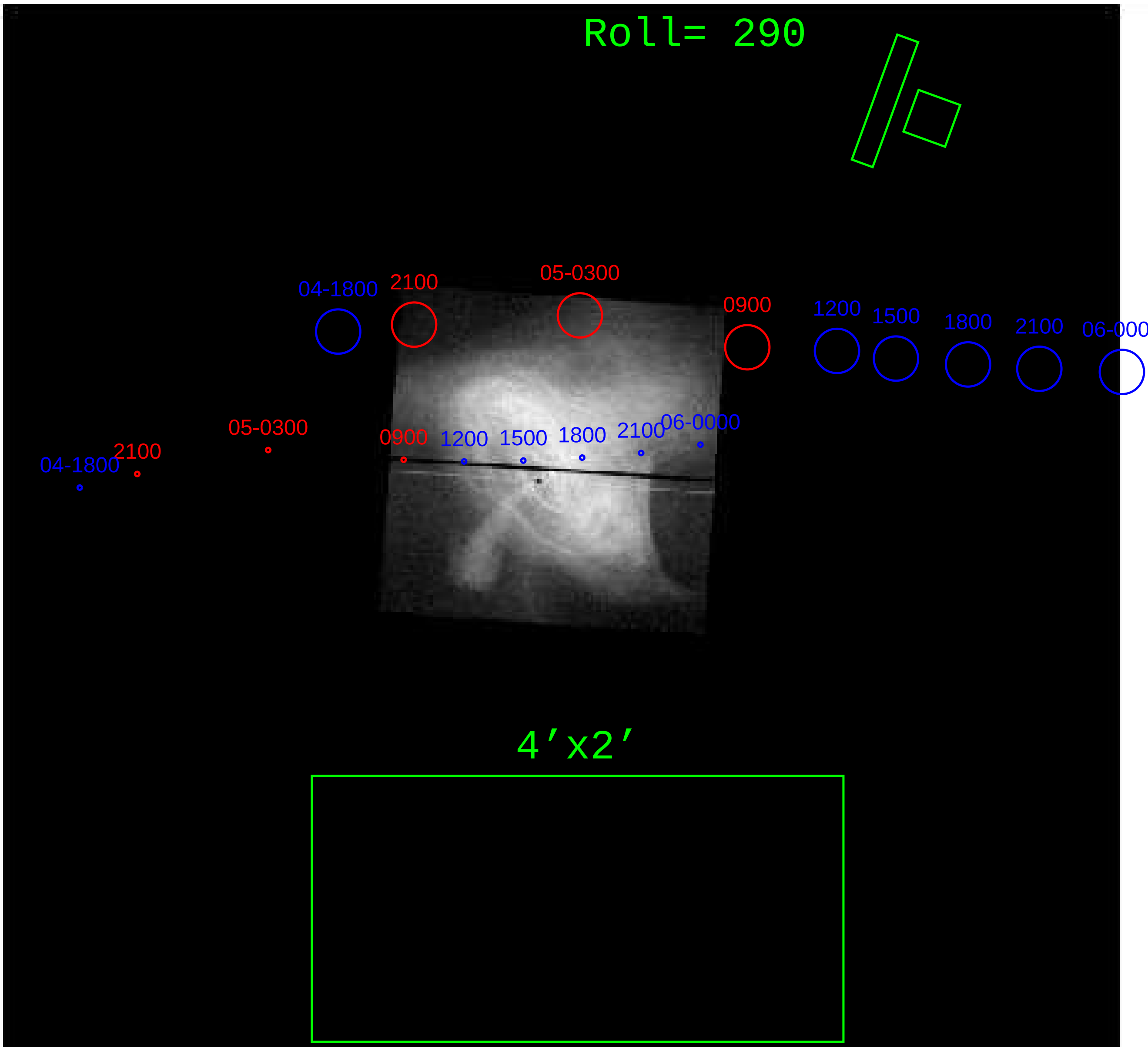

Figure 4: Proposed Crab/Saturn-Titan Conjunction: Hollow circles represent Saturn transit while dots represent the motion of Titan