Saturated pixels and bleed patterns in LSST devices

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Blooming Model:

For the purpose of this test we model a star as a single Gaussian and calculate the extent of the saturated pixels together with the size of the bleed trail (by redistributing charge along the direction of the parallel registers). We consider three separate mechanisms for blooming and its possible mitigation: (a) no mitigation, all charge is accumulated on the device; (b) running the serial registers during integration such that any electron that reaches a serial register will be read out; (c) running the serial registers during integration and imposing a charge block (or charge stop) at row 2048.

Based on Chris Stubb's assessment of the impact of the charge block, we assume that 3 rows either side of the charge block will be impacted by the implant and will need to be discarded in any analysis (amounting to a fraction of 0.0015 science pixels lost for any exposure).

Using this model, and assuming a full well depth of 100,000 electrons, a star will saturate the device in a 15 second exposure at r~16 mag (assuming 0.67 arcsec seeing and a dark sky with ~150 counts per pixel). By magnitude 7.8 a star will produce 25310 saturated or bleed pixels, which will exceed the number of pixels lost to the charge block. A first magnitude star will generate sufficient charge to saturate 80% of a device (assuming all charge is retained). These results are consistent with the outputs of the image simulator.

Blooming or bleed pixels

For model (a), no running of the serial registers during integration, the presence of a charge stop has no impact on the size of the bleed trails. All charge is retained within a device and redistributed along the columns (to r ~8th magnitude) and then across columns. Running the serial registers during integration with charge readout as it reaches the serial register (model b) results in a reduction in the size of bleed trails by a factor of two at r~7 mag and a factor of 5 at r~3. The charge stop further reduces the size of the bleed trails; limiting the bleed to one half of the device. At r~5 the charge block reduces the size of the bleed trails by a factor of two (if the serials are run during integration). For magnitudes fainter than r~7 the impact of the charge stop is minimal. These results are illustrated in Table 1; the 2nd column is the total number of saturated pixels, the 3rd column is the number of saturated pixels if the serial registers are run during an integration (for a star placed at random on the device), and the 4th column is the number of saturated pixels if the serial registers are run during integration and there is a charge block at row 2048 (again for a star placed at random on the device)

r mag	# saturated pixels	# sat (serial)	# sat (serial and block)
1	13261402	46536	24008
2	5279496	42296	23128
3	2101834	39640	21208
4	836784	36148	19748
5	333160	32264	17928
6	132660	27656	16200
7	52834	22374	13704
8	21058	13869	11064
9	8412	6942	6942
10	3360	3360	3360
11	1364	1364	1364
12	550	550	550
13	234	234	234
14	94	94	94
15	38	38	38
16	6	6	6

Saturation using an all-sky model

We couple the charge blooming model with the distribution of stars as measured on the sky for r<16. We use the all-sky catalogs derived from a combination of PMM and 2MASS catalogs (Dave Monet, private communication). These catalogs are complete to r~16 and use the 2MASS observations to remove the over-counting of stars at the edge of the PMM plates. Figure 1 shows a representative view of the stellar distributions from the PMM machine using a lat-long projection with a pixel scale of 0.5 degrees per pixel.

To estimate the fraction of the sky lost due to bleed pixels we assume that stars within each 0.5x0.5 degree patch are placed at random within the CCD (i.e. at a random row within the device) and estimate the number of saturated pixels using the bleed models described above. The all sky distribution of number of bleed pixels is shown in Figure 2 for the same magnitude intervals used in Figure 1. The numbers at the top of each panel in Figure 2 represent the fraction of pixels that are saturated for models (a), (b), and (c) respectively.

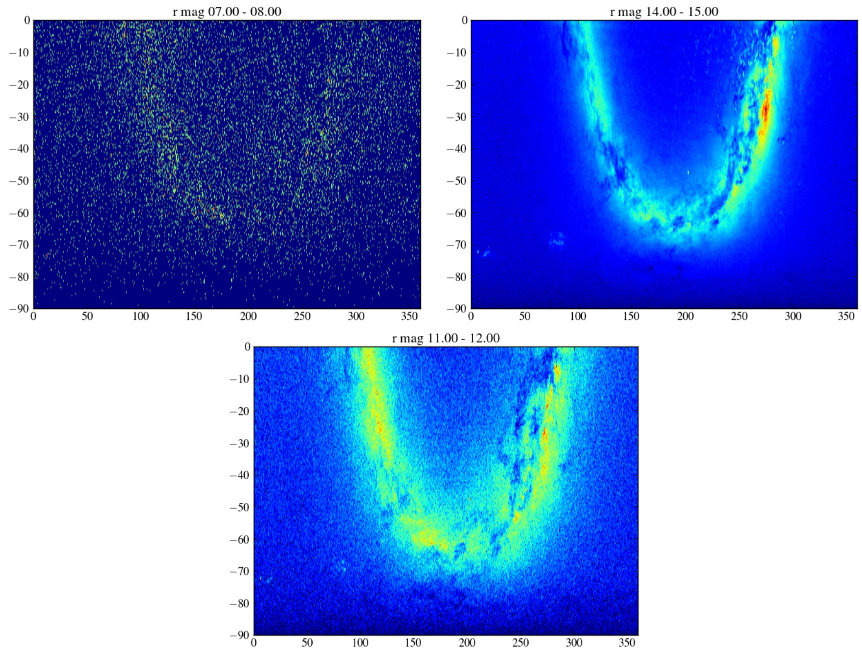

Figure 1 The distribution of bright stars for magnitude intervals 7<r<8, 11<r<12, 14<r<15 (counter-clockwise from the top left)

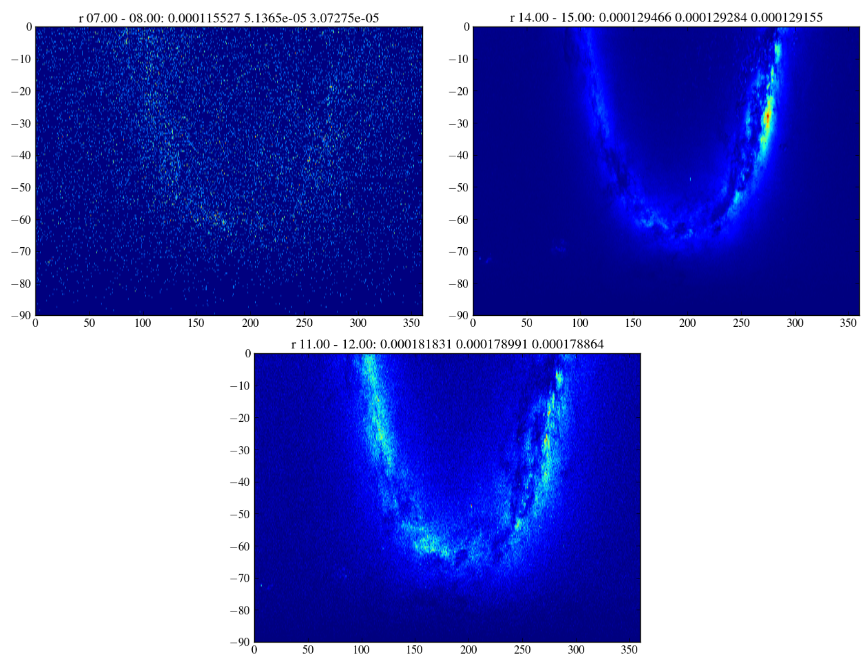

Figure 2 The distribution of number of saturated pixels (assuming no charge block but with the serial registers running during integration) for the magnitude intervals 7<r<8, 11<r<12, 14<r<15 (counter-clockwise from the top left).

Figure 3 shows the differential and cumulative counts of the bleed pixels as a function of limiting magnitude. All counts are as a fraction of sky coverage. The blue line represents the total counts (model a), the green counts the fraction of bleed pixels with the serial registers running (model b), and the red line the counts with the serial registers running and a charge stop (model c). The cyan line on the cumulative counts (right panel) is the fraction of the sky lost due to the impact of the charge block on the adjacent 3 rows either side of the implant. The number of saturated pixels for the survey barely exceeds the number of pixels lost to the charge block irrespective of any benefit from the block. The running of the serials during integration provides a factor of 2 reduction in number of bleed pixels. The additional improvement due to the charge block is an order of magnitude smaller than this.

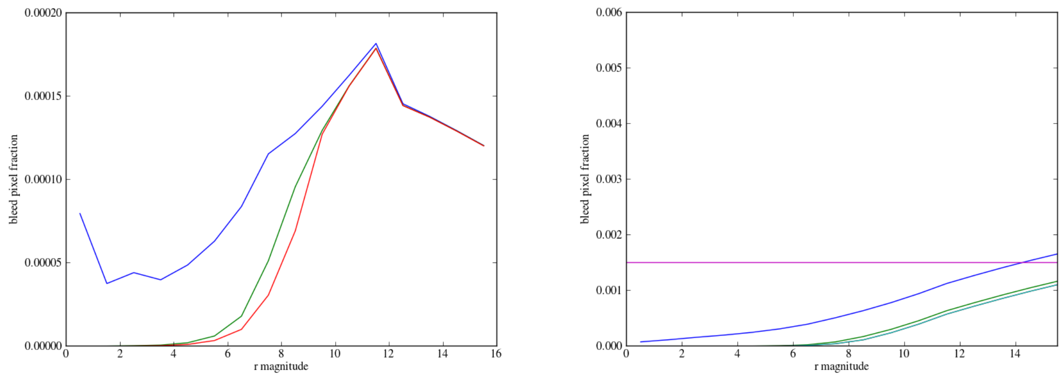

Figure 3 The left panel shows the differential counts for fraction of pixels lost due to blooming; without a running serial register (blue), with a running serial register (green), and with a running serial register and a charge stop (red). The right panel shows the same results for the cumulative star counts.

Summary

1. Running the serial registers during integration has the largest impact on reducing the size and extent of the blooming (reducing the number of pixels impacted by blooming by a factor of two).
2. The presence of a charge block is only beneficial if the serial registers are run during integrations. Under this scenario the charge block will reduce the number of saturated pixels by at most a factor of two (at $r<7$).
3. The loss of pixels due to the charge implant is 50% higher than the loss of pixels due to blooming
4. The impact of blooming peaks at $r\sim12$ mag under dark sky conditions.
5. There is no net gain implementing a charge block within the LSST devices.