Fitting a Pixel-Based CTE Model to the WFC3/UVIS CCD Detector

Jay ANDERSON and the WFC3 Team

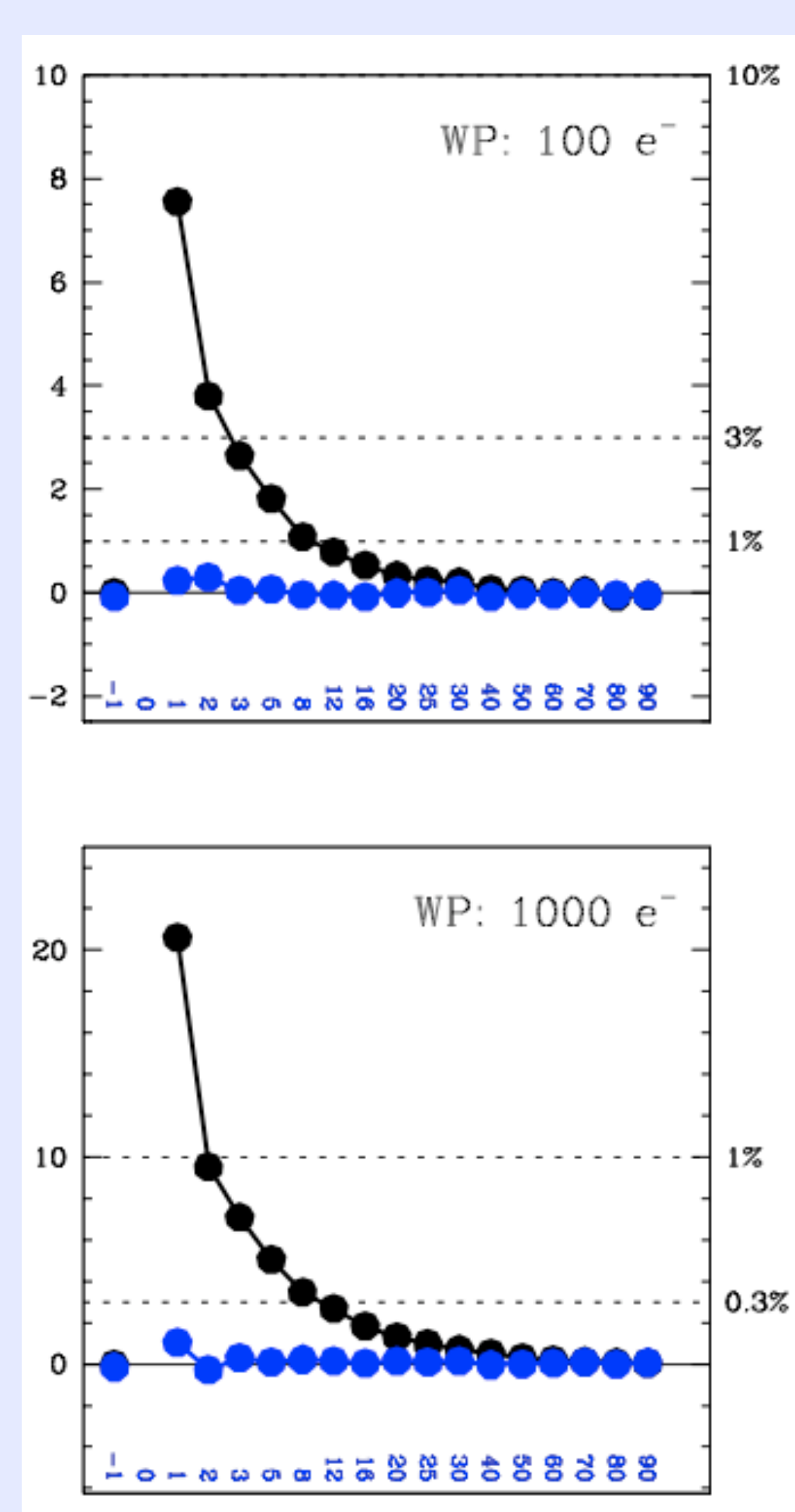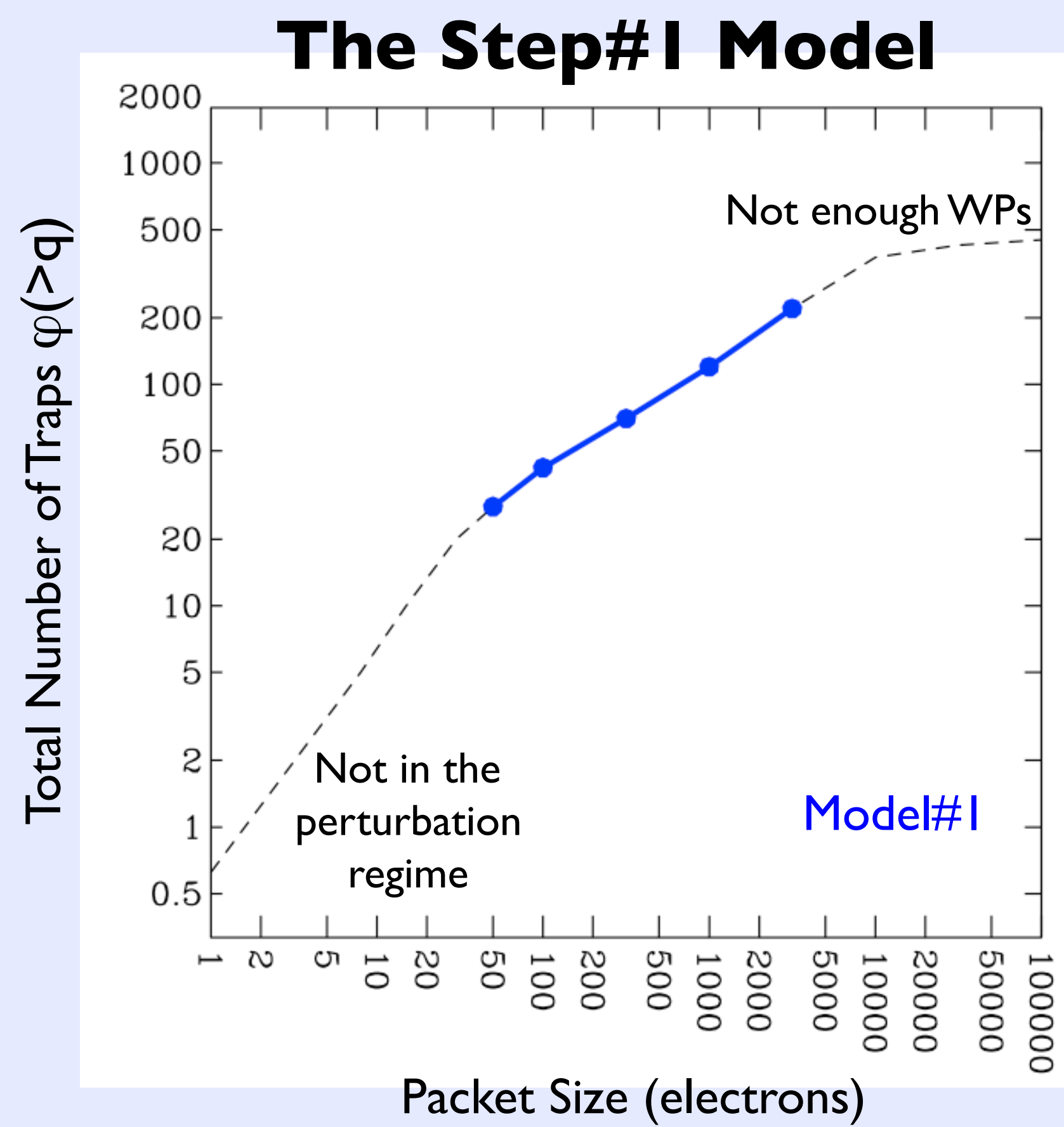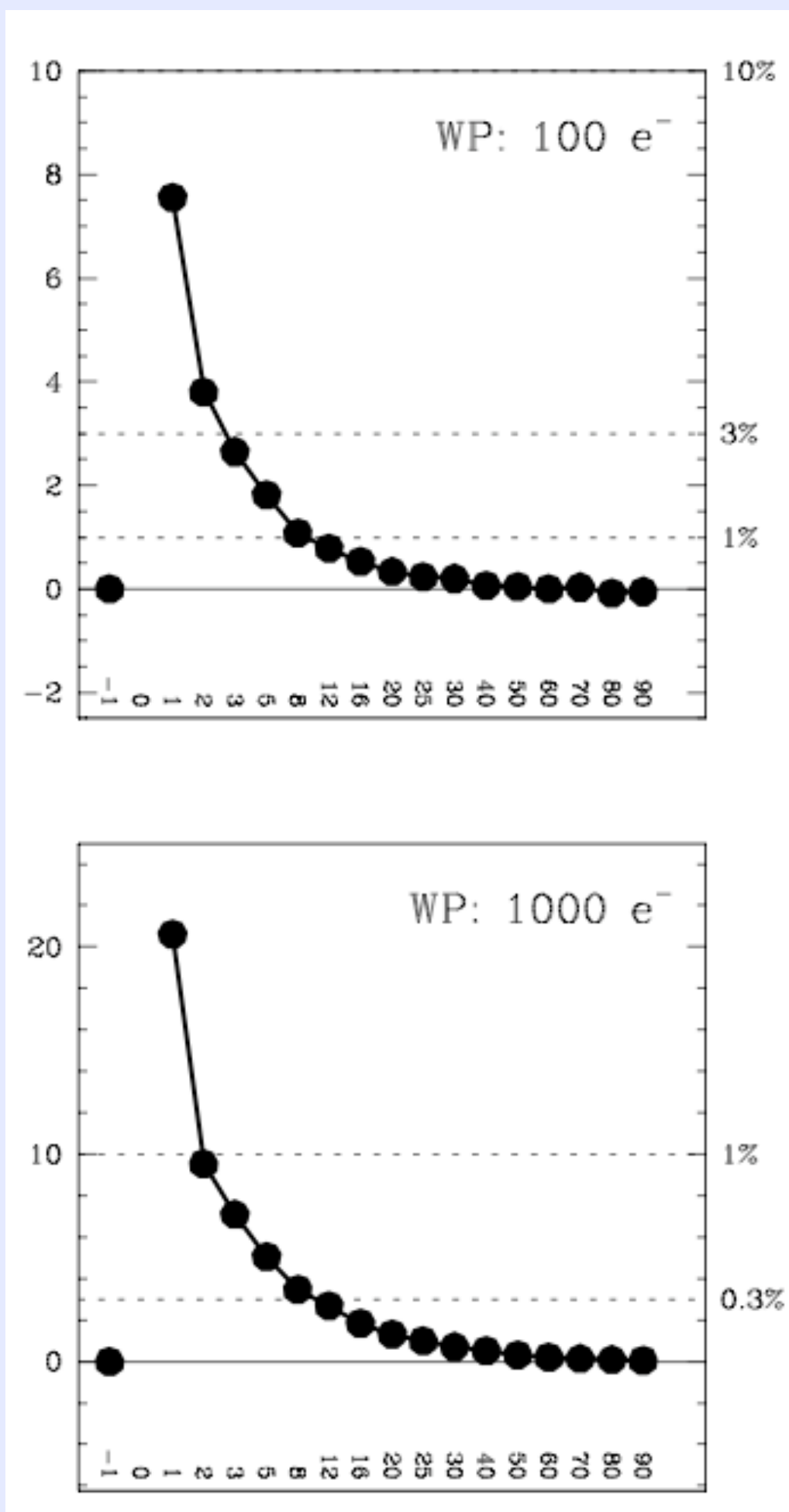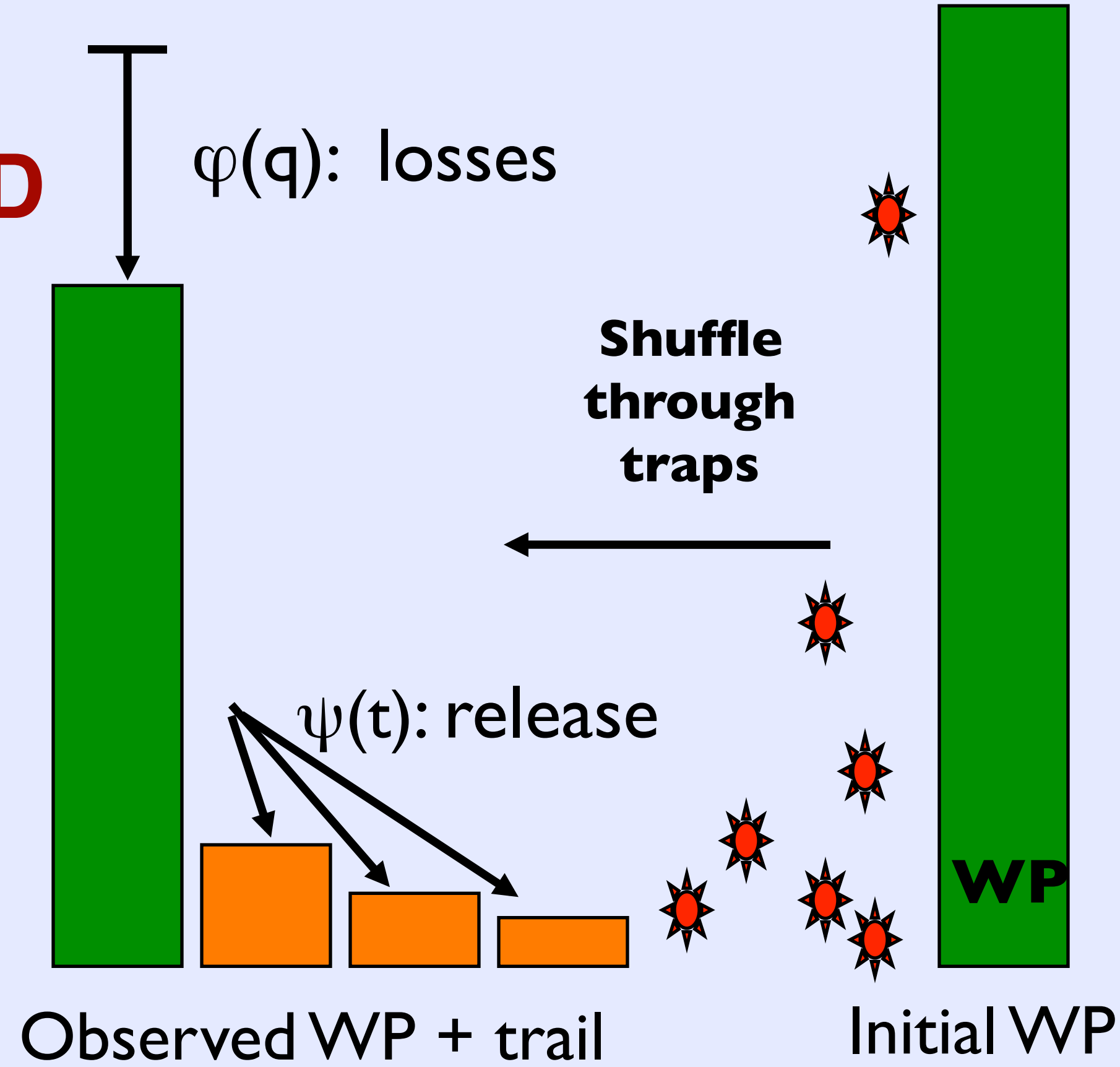Space Telescope Science Institute, Baltimore MD

ABSTRACT

Anderson & Bedin (2010, AB10) developed a pixel-based model to describe CTE (Charge-Transfer-Efficiency) losses in the ACS camera. They studied warm pixels (WPs) in dark exposures as delta-function probes of the trapping and release of charge. We extend this approach to the WFC3/UVIS CCD detector and find that the same basic model works well for WFC3/UVIS, though the fitting parameters are different. Small charge packets are particularly susceptible to CTE losses in WFC3/UVIS, and this is exacerbated by the low background typical of WFC3/UVIS exposures.

THE PIXEL-BASED MODEL

PARAMETRIZATION

Our pixel-based model is similar to that developed by Massey et al. (2010). The charge collected in each pixel is shuffled down the detector to the readout register in an electron packet. Over time, radiation damage generates defects in the silicon lattice, and these defects can trap electrons and separate them from their original charge packet. The model is parametrized by two simple functions: the sinks and the sources.

SINKS: charge lost to traps: $\varphi(q)$ = the number of traps a pixel with q electrons will see in 2000 transfers

SOURCES: charge released by traps $\psi(t)$ = the probability that a trapped electron will be released after t transfers

SOME SIMPLE FACTS ABOUT THE MODEL

- A packet with more electrons is susceptible to more traps, so…
  → *the absolute losses increase as the packet size increases*.
- The first electron in a pixel has a much larger chance of getting trapped than the 100th, or the 10,000th electron, so…
  → *the fractional losses are larger for smaller packets*.
- If a bright pixel precedes another pixel, the second pixel will be shielded by the bright pixel, so…
  → *the higher the sky is, the fewer traps a particular source will encounter*.

STEP 1: INTERMEDIATE-SIZED PIXEL PACKETS

The original AB10 model was based entirely on the bright warm pixels. We observe the flux in the warm pixel, the flux in the trail, and find the model that describes this redistribution.

This can be done only for the pixels that show a clear head-tail structure, i.e., where the losses can be treated as a perturbation. For the current UVIS detector, this corresponds to WPs with about 50 or more electrons.

The cartoon on the right shows what is happening schematically. The plots below show how we fit a model to the bright warm pixels.
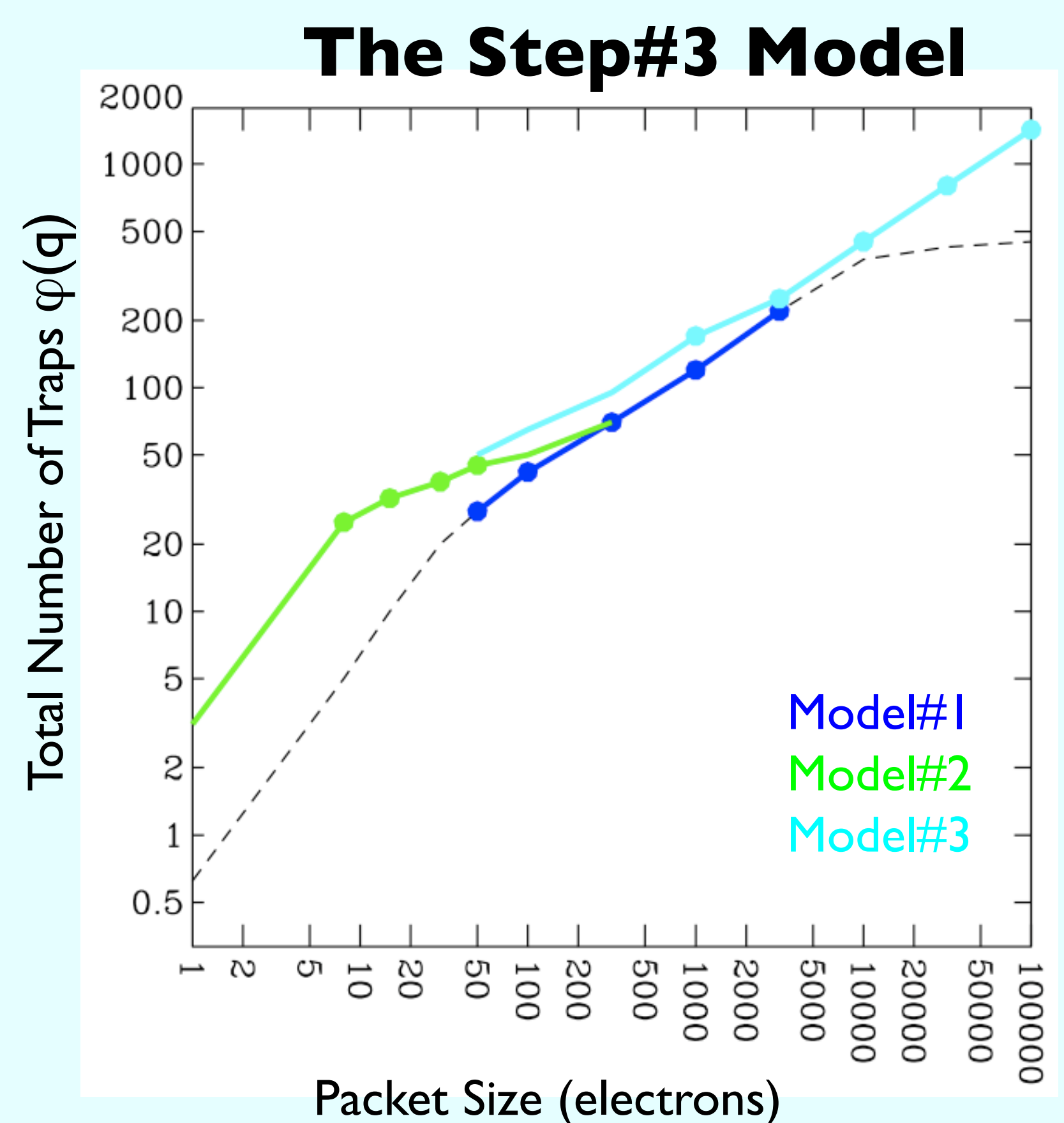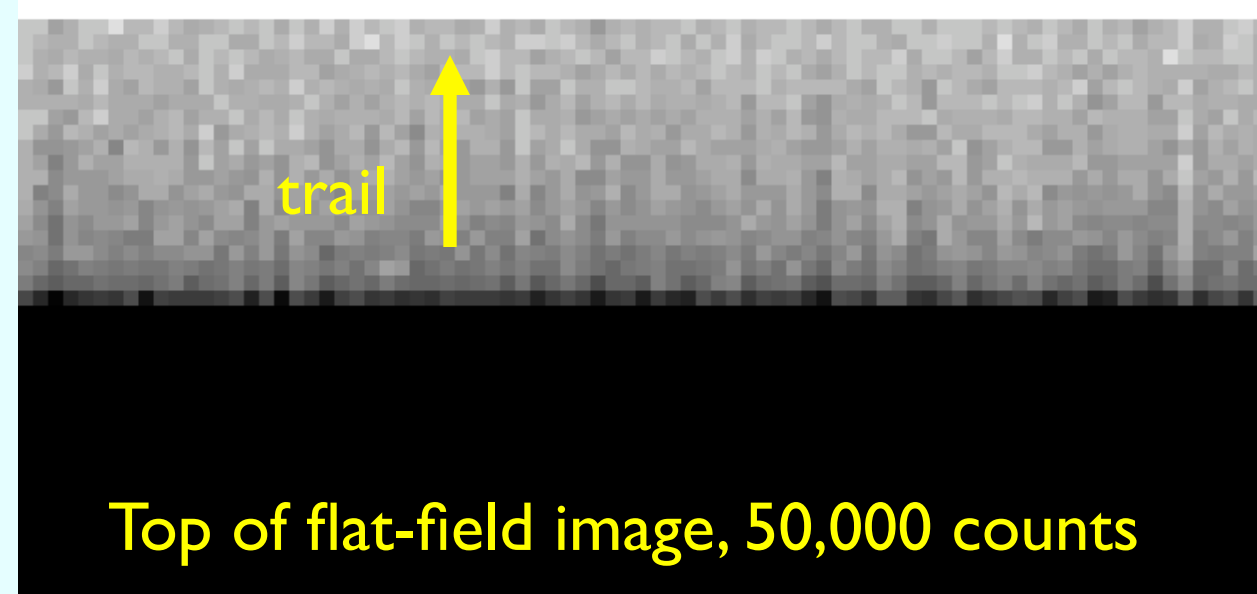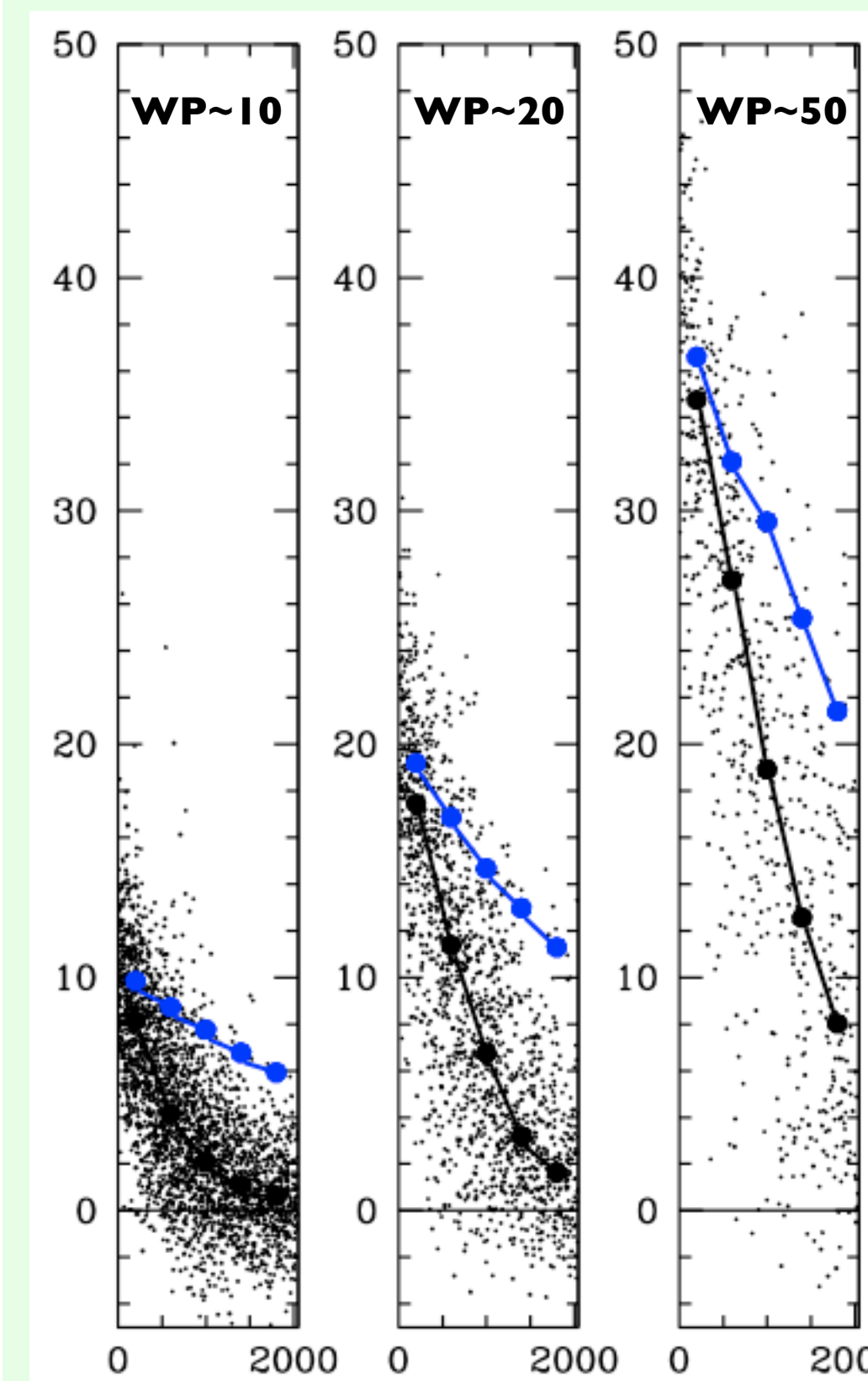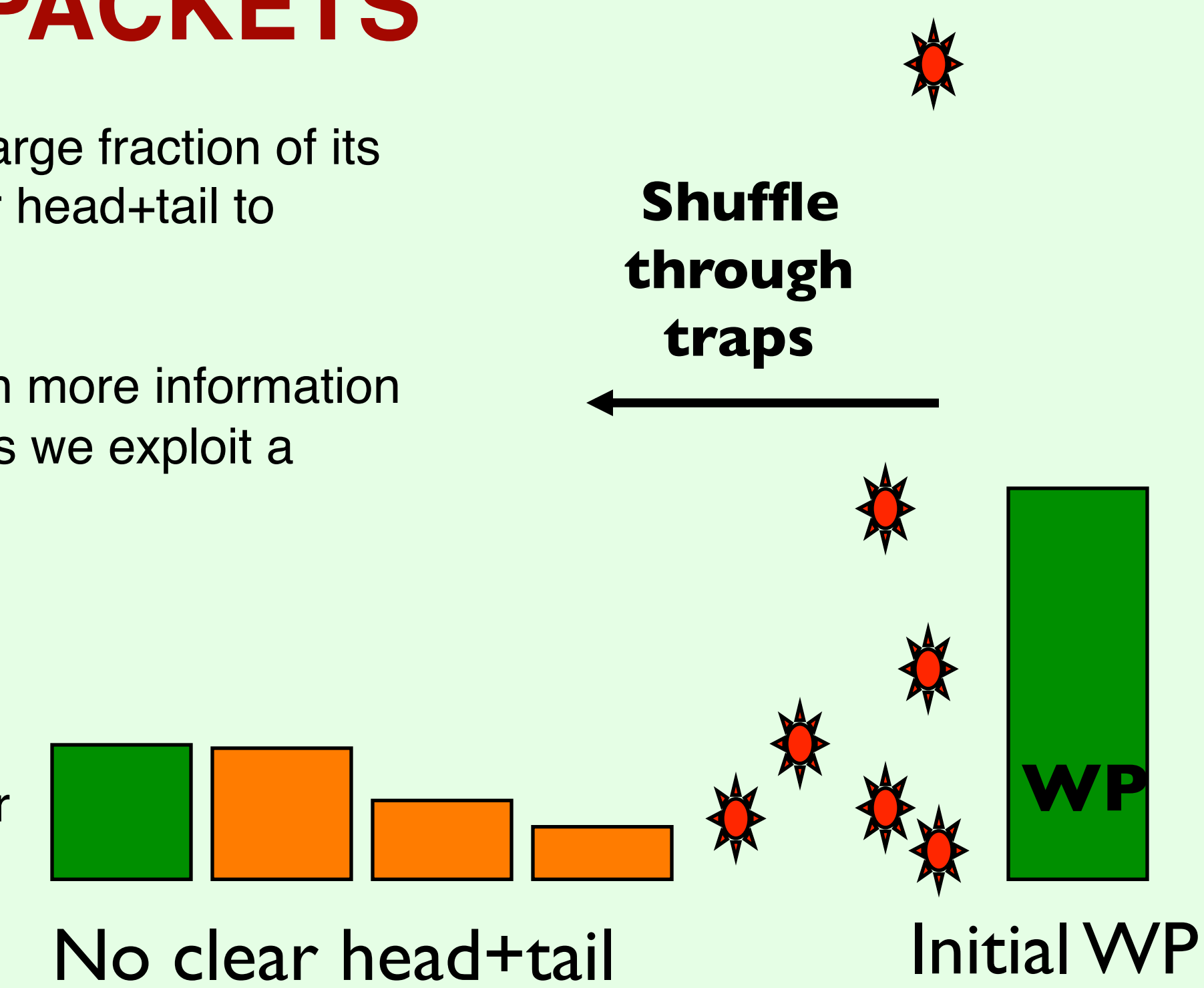

φ(q): losses
ψ(t): release
Shuffle through traps
Observed WP + trail
Initial WP
WP

Observed trails in 900s darks
(far from readout register)

The Step#1 Model

Post-correction

Not enough WPs
Not in the perturbation regime
Model#1

WP: 100 e⁻
WP: 1000 e⁻

STEP 2: SMALL-SIZED PIXEL PACKETS

The previous approach does not help us when the WP loses a large fraction of its charge during transfer, since in that case we do not have a clear head+tail to reconstruct into a delta-function WP.

To explore losses at for smaller packet sizes, we need to bring in more information regarding what the WP looked like before the transfer. To do this we exploit a combination of short and long darks.

The long 900s darks tell us how many counts per second each bright WP receives. This will tell us the number of counts the WP started with in the short 100s dark exposure. We can then observe how many electrons make it to the readout register to assess the absolute losses. The plots below show this graphically for three fiducial WPs.

Shuffle through traps
No clear head+tail
Initial WP
WP

The Step#2 Model
Model#1
Model#2

WP~10 WP~20 WP~50

Each dot represents a WP in the detector. We select the WPs that the 900s darks say should have 10, 20, and 40 electrons in the 100s darks. We plot the observed number of counts against the number of transfers. The loss trends are clear. The Model#1 in blue does not describe the losses.
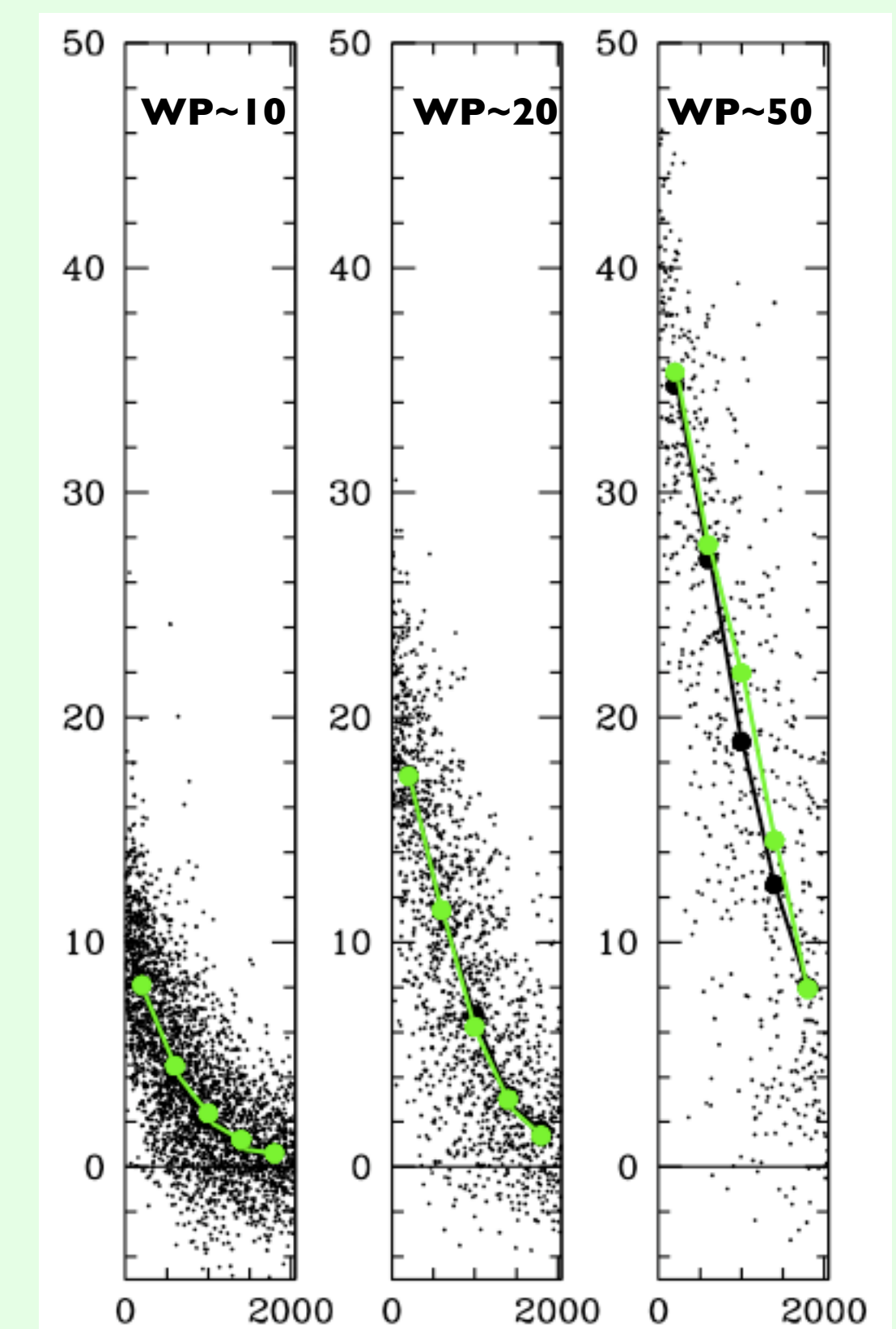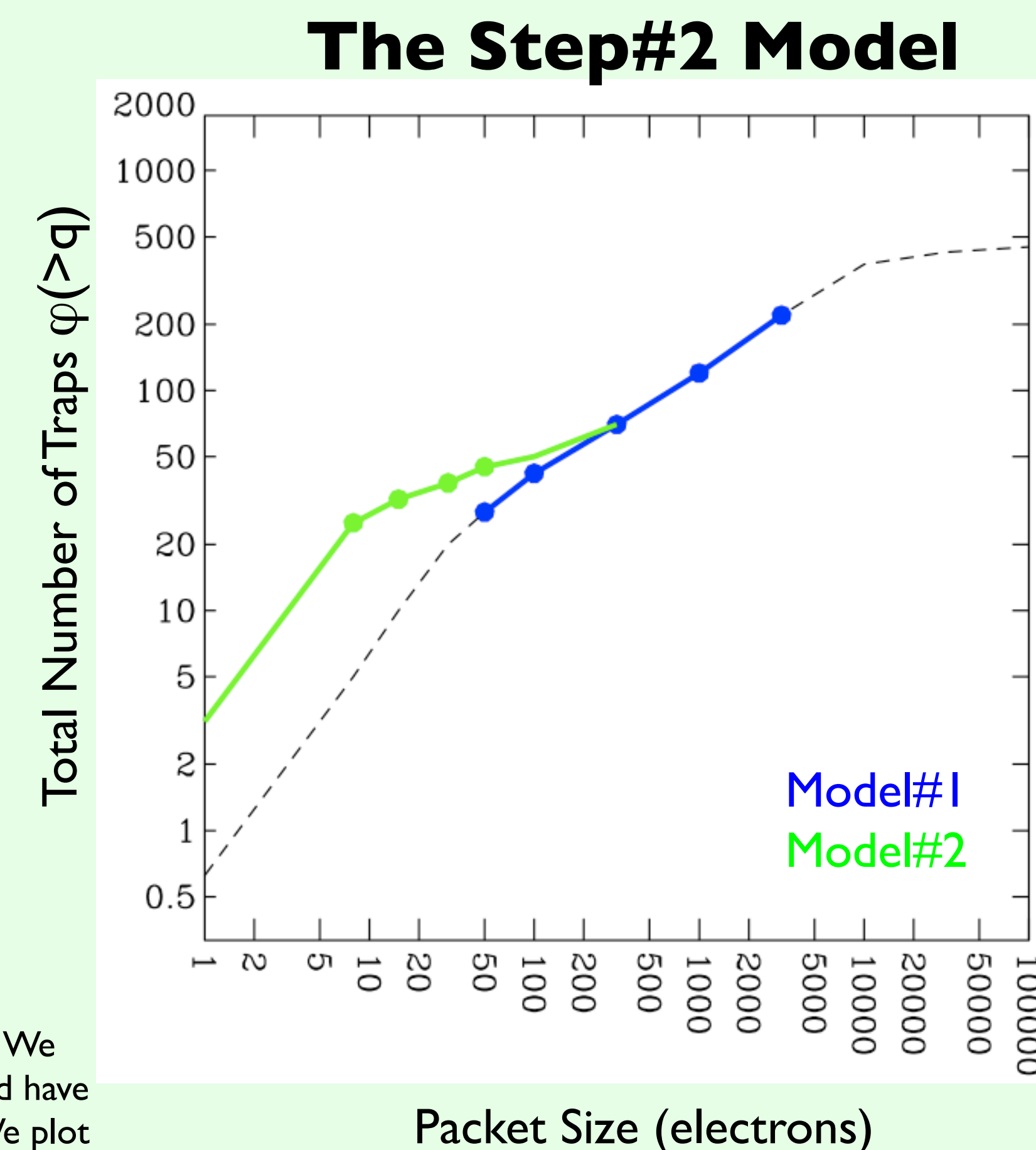
This figure shows that Model#2 does a better job predicting the observed losses for small electron packets.

STEP 3: LARGE PIXEL PACKETS

The annealing process has had the salutary effect of minimizing the number of permanent hot pixels. This is good for science images, but the dearth of hot pixels makes it harder to constrain the CTE model.

We used the overscan trails from flat-field images to constrain the trap density at the bright end.

The Step#3 Model
Model#1
Model#2
Model#3

trail
Top of flat-field image, 50,000 counts

COMPARISON WITH ACS

Users began to notice the signs of imperfect CTE in UVIS images much sooner than was seen for WFC/ACS. This is partly attributable to the fact that UVIS was installed during solar minimum, when the CR flux is greatest and we would naturally expect UVIS to suffer radiation damage faster than ACS did.

However, much of the increased losses can be traced to the lower backgrounds typical in UVIS images, and the fact that the model shows that losses are particularly bad for small charge packets. The background in UVIS is lower than in ACS for several reasons:

1) Low dark current: even deep exposures have almost no background
2) Narrow-band filters naturally have lower backgrounds
3) Smaller pixels receive background from sky
4) UV sensitivity: observations in the UV have low sky backgrounds
5) The low read-noise encourages users to look for fainter sources

For all these reasons, CTE losses hit UVIS observations particularly hard.

FUTURE PLANS

A pixel-based model will be available soon, both inside and outside of the pipeline.

Unfortunately, even a perfect model cannot restore signal-to-noise in the image. To do this, Cycle 20 users will be asked to make use of new post-flash options to add a few electrons to the background to take CTE losses from the pathological to the manageable stage. A few electrons shouldn't change the noise properties significantly, but they will dramatically mitigate CTE losses for faint objects. Stay tuned to changes in APT!

REFERENCES

Anderson, J. & Bedin, L. R. 2010, *PASP*, **122**, 1035–1064
Massey, R. et al. 2010 MNRAS 409 L109

SPACE TELESCOPE SCIENCE INSTITUTE — Operated for NASA by AURA
NASA
esa