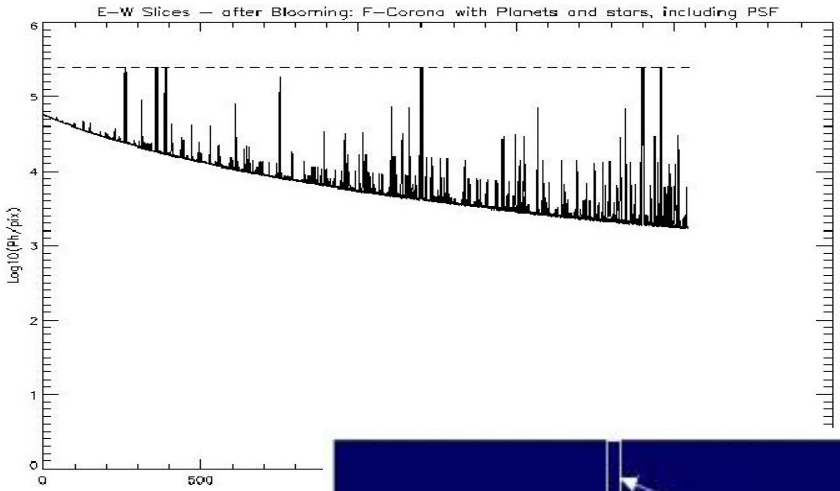
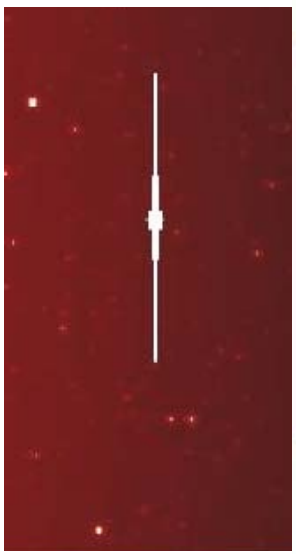
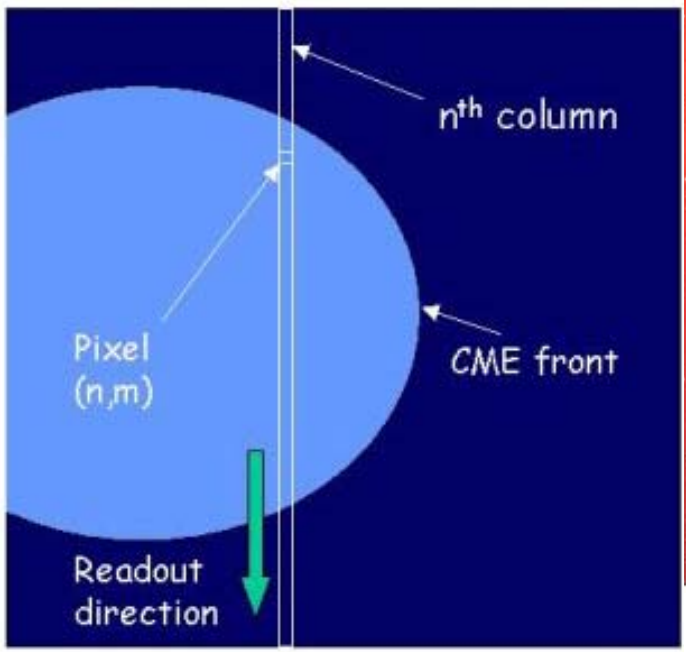
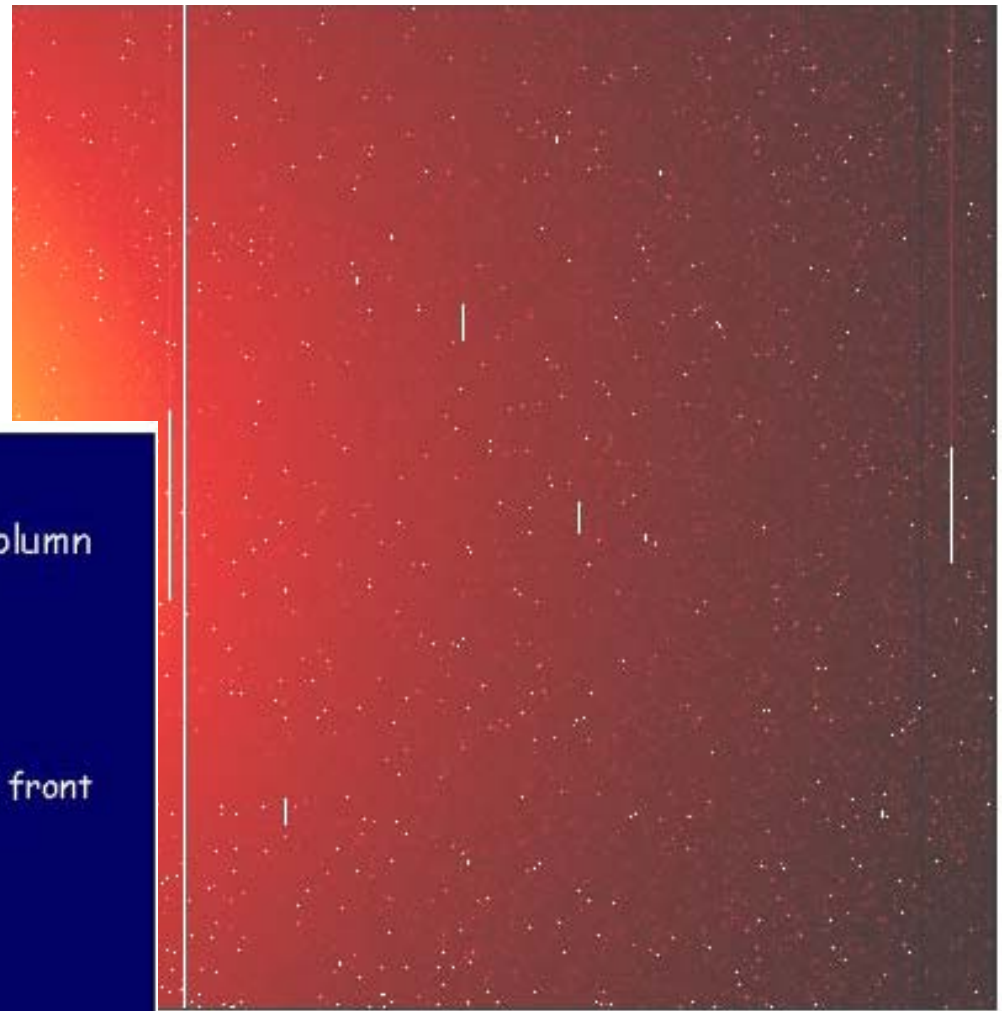
HI Image Simulation & Non-Shutter Operation

Richard A. Harrison, April 2003





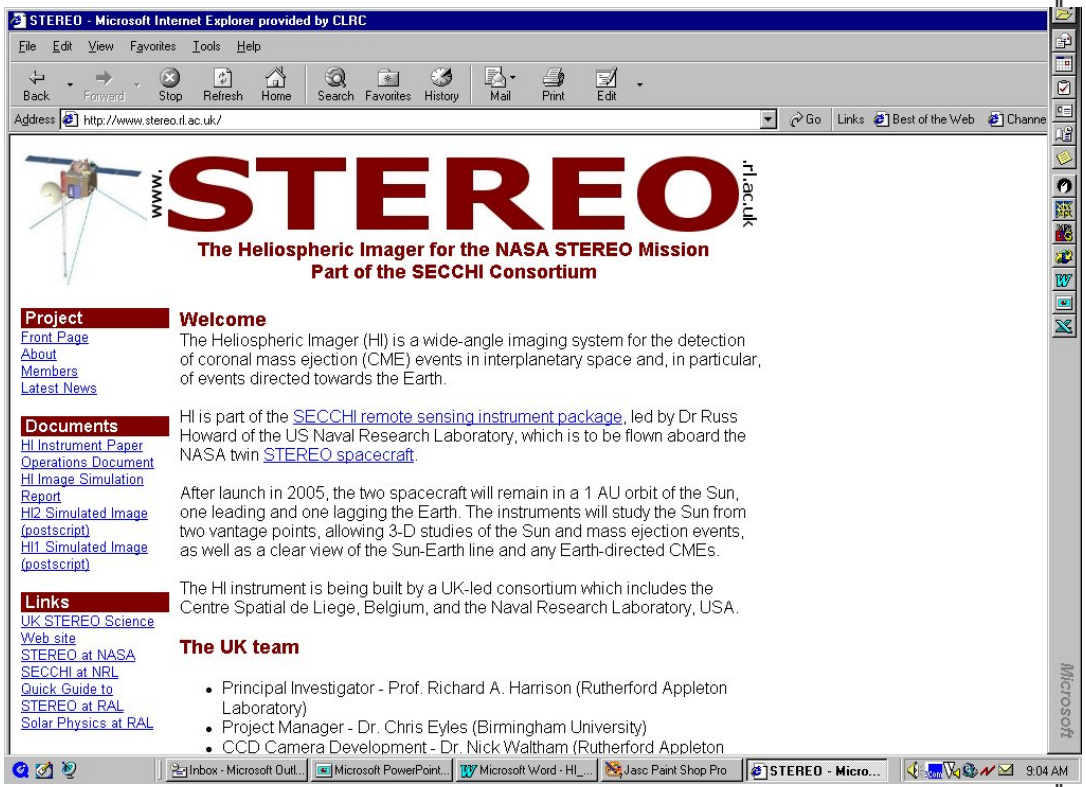


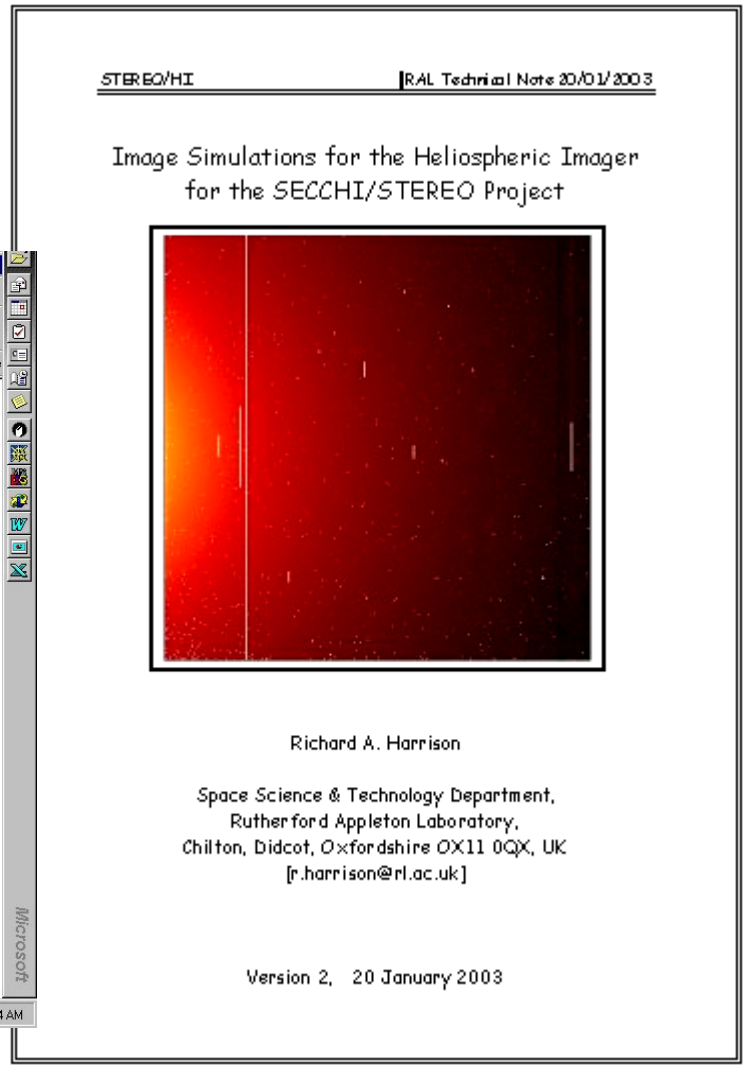


HI - Image Simulation

The HI image simulation activity started in Autumn 2002.

See 'Image Simulations for the Heliospheric Imager', R.A. Harrison, 20 Jan 2003 (Ref. 1), and http://www.stereo.rl.ac.uk.





HI – Image Simulation

Purpose:

- To assess the impact of all sources and effects, including saturation, non-shutter operation etc…
- To investigate image processing requirements for, e.g. cosmic ray correction, F-corona & stellar subtraction techniques, and other techniques for the extraction of CME and other science data.
- To provide a tool to explore operations scenarios with the user community.

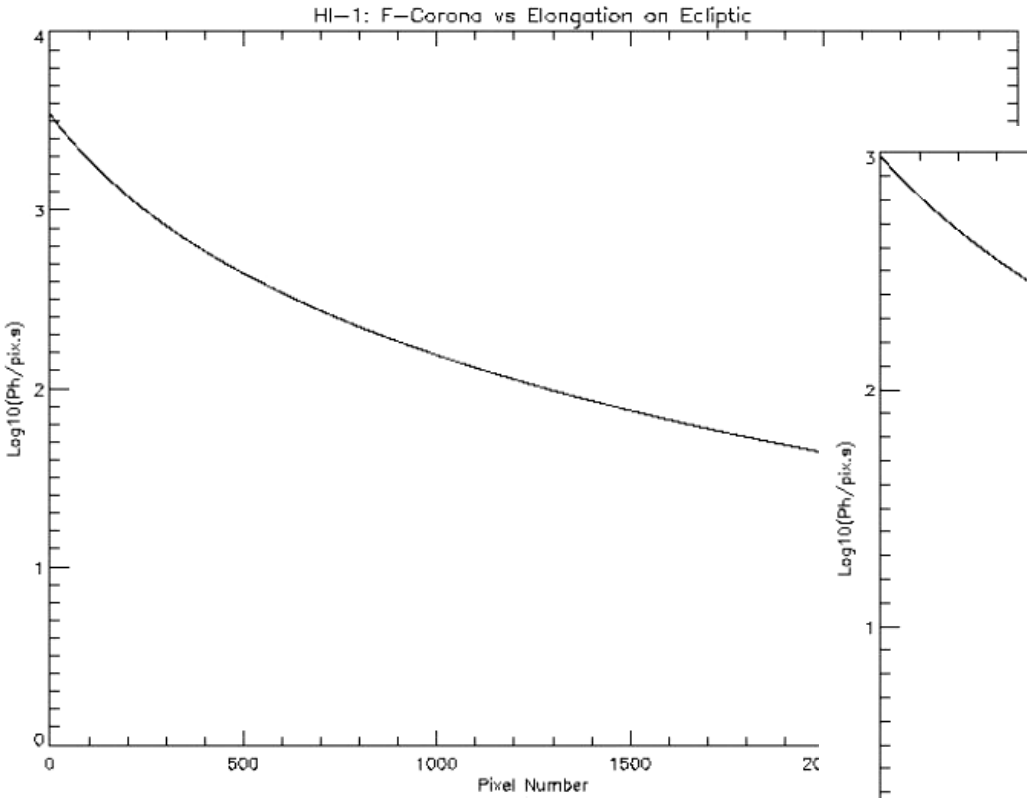
In addition to demonstrating that HI works, and exploring the ways we can use it, these efforts are providing requirements to the on-board and ground software efforts, to operations planning etc...

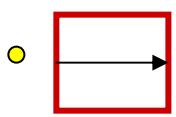
HI - Image Simulation

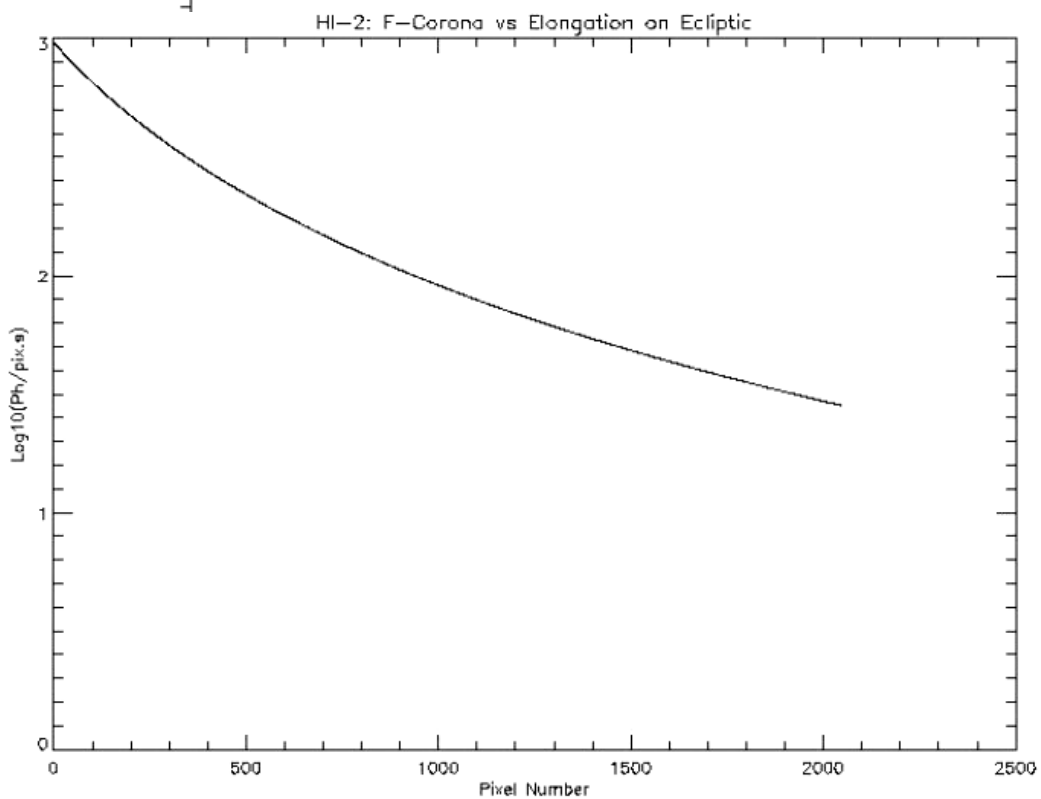
1. The F-coronal intensity

Calculated from Koutchmy & Lamy, 1985.

Estimated intensity along ecliptic for HI-1 & HI-2 plotted (from Ref. 1).





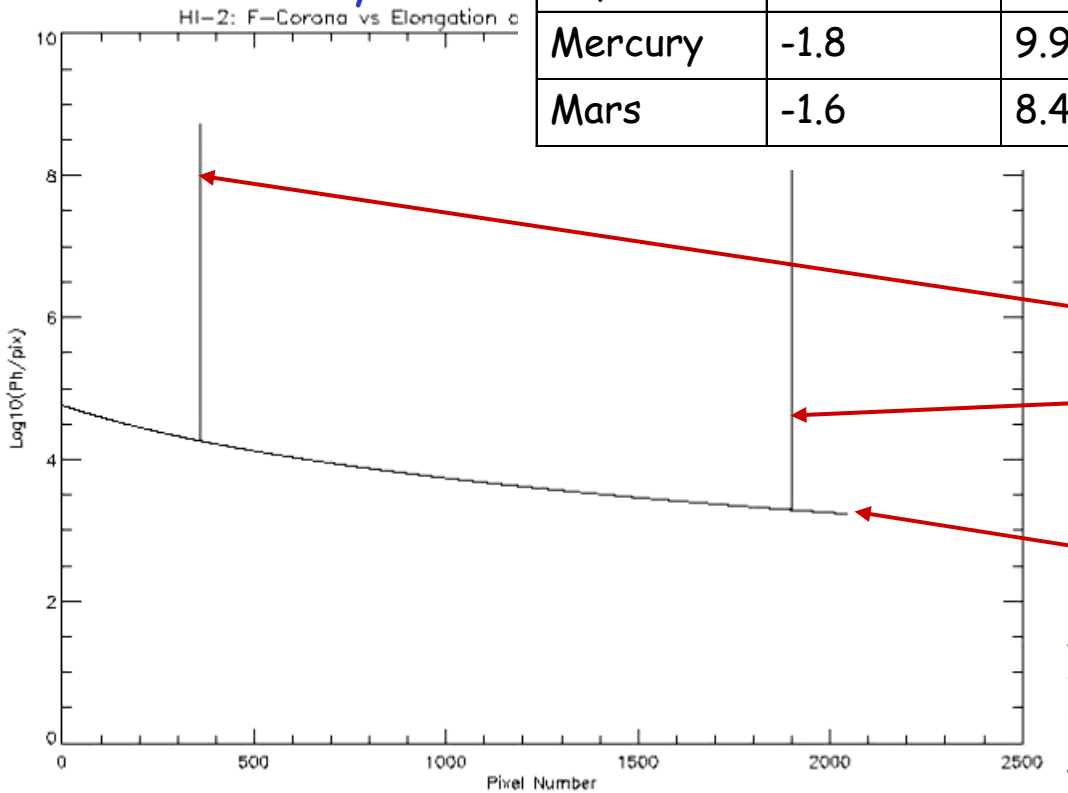


HI - Image Simulation

2. The Planets

Four brightest planets included, at their maximum intensity.

Planet	Maximum Magnitude	B/Bsun	HI-1 Ph/sec	HI-2 Ph/sec
Venus	-4.6	1.3×10^{-9}	1.10×10^{8}	1.24×10^{8}
Jupiter	-2.6	2.1×10^{-10}	1.78×10^{7}	2.00×10^{7}
Mercury	-1.8	9.9×10^{-11}	8.38×10^{6}	9.45×10^{6}
Mars	-1.6	8.4×10^{-11}	7.11×10^{6}	8.02×10^{6}



Intensity vs elongation (pixel number), including two planets - nominal HI-2 60 s exposure.

HI – Image Simulation

3. The HI Point Spread Function

Optical modelling by CSL:

'HI-1 Optical Design and Performances', TN/CSL/STE/01001, issue 2, 9 Oct 2001.

'HI-2 Optical Design and Performances', TN/CSL/STE/01002, issue 2, 5 Oct 2001.

All contributions modelled (including design, lens location tolerance, lens manufacture, surface form, CCD axial position accuracy etc…):

HI-1 & HI-2 RMS spot diameters = 45 to 66 μm (3.3 to 4.9 pix) & 105 to 145 μm (7.8 to 10.7 pix). Note - Pixel size = 13.5 micron.

The HI Image Simulation analysis assumes a Gaussian of width 50 and 100 μm for HI-1 and HI-2 respectively.

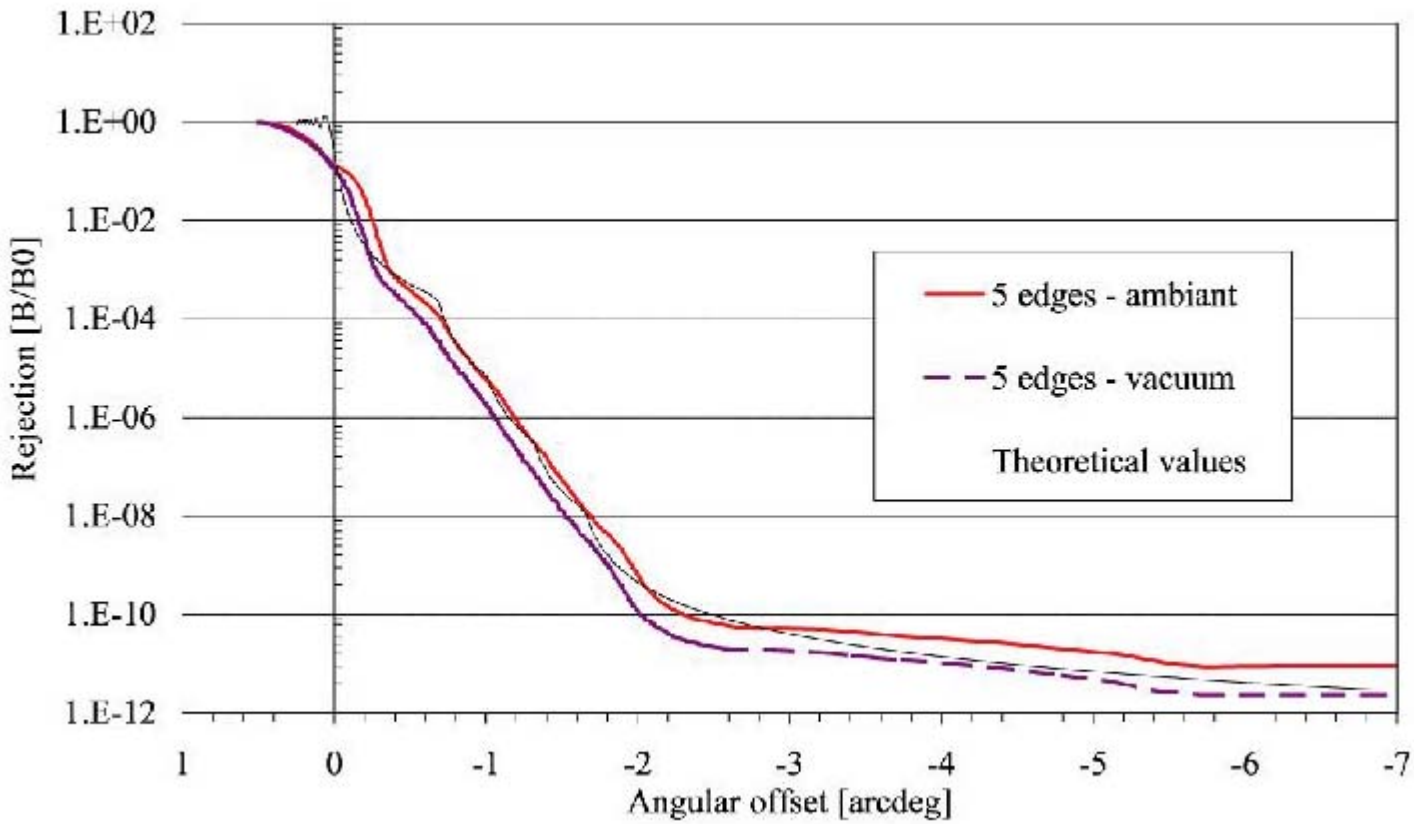
4. Noise

Included as a Poisson-like distribution using the IDL 'randomn' function applied to each pixel.

HI – Image Simulation

5. Stray Light

To mimic the anticipated stray light contribution, the HI Simulation analysis uses the CSL forward baffle mock up tests (May 2002) including a 10^{-4} rejection from the lens-barrel assemblies.



HI - Image Simulation

6. Stars

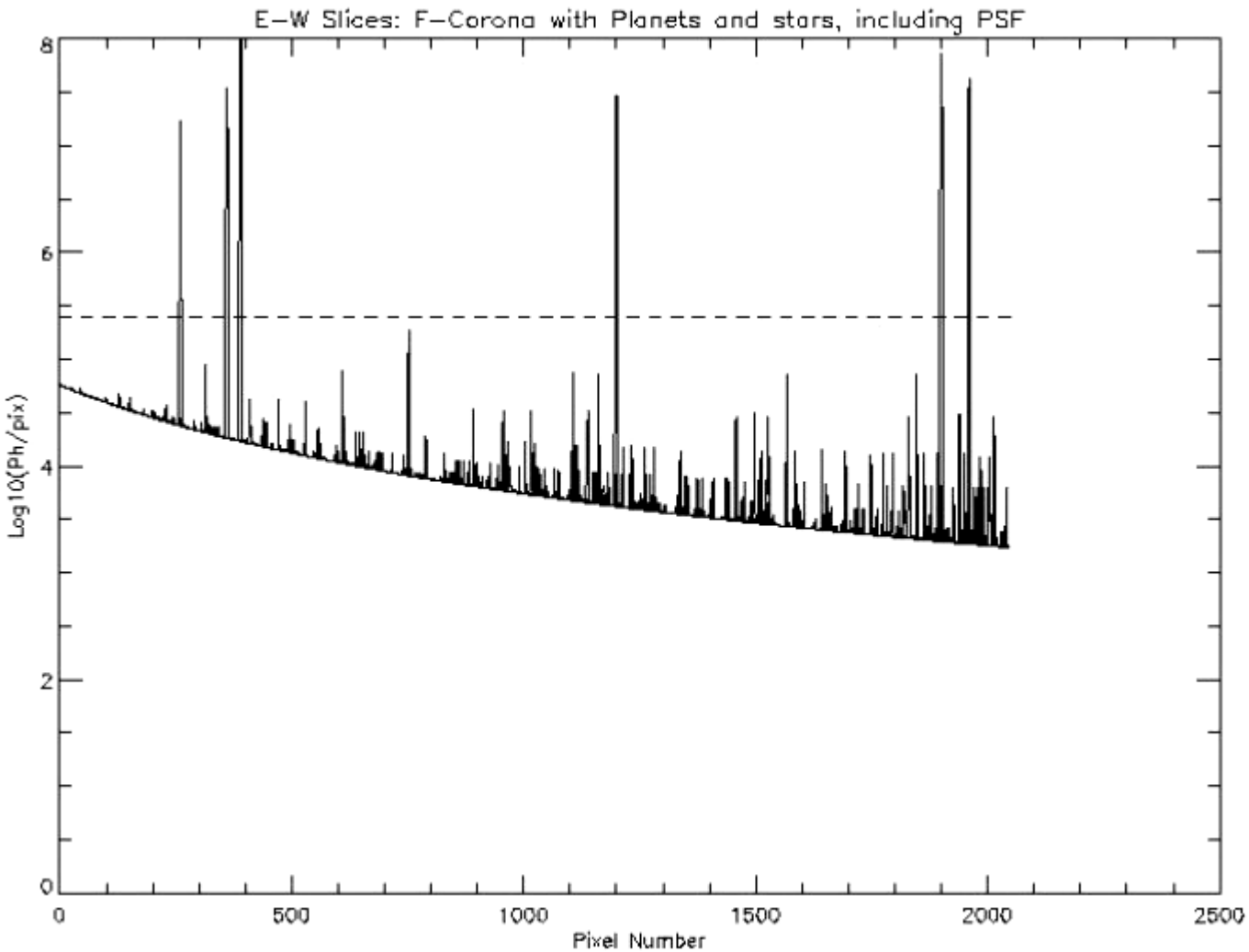
We require a distribution of point-like sources to mimic the stellar distribution - use C.W. Allen (Astrophysical Quantities) for stellar density as a function of magnitude.

Magnitude	No. in HI-1 FOV	HI-1 Intensity (Ph/sec)	No. in HI-2 FOV	HI-2 Intensity (Ph/Sec)
-1.47 (sirius)	<1	6.26×10^6	<1	7.07×10^6
-0.06 (Arcturus)	<1	1.78×10^6	<1	2.00×10^6
0.0 (Rigil)	<1	1.61×10^6	<1	1.81×10^6
1.0	1	6.43×10^5	1	7.26×10^5
2.0	1	3.21×10^5	4	3.63×10^5
3.0	1	9.31×10^4	14	1.05×10^5
4.0	4	4.82×10^4	48	5.44×10^4
5.0	13	1.61×10^4	150	1.81×10^4
6.0	39	6.43×10^3	450	7.27×10^3
7.0	109	2.54×10^3	1335	2.87×10^3
8.0	314	1.02×10^3	3848	1.15×10^3
9.0	884	4.06×10^2	10843	4.59×10^2
10.0	2552	1.61×10^2	31277	1.82×10^2
11.0	6867	6.43×10^1	84156	7.27×10^1
12.0	18068	2.54×10^1	221414	2.87×10^1

← Red entries are those that saturate.

HI - Image Simulation

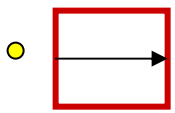
6. Stars (continued)



HI-2 nominal 60 s exposure shown as several superimposed slices across CCD.

Includes stars to 12th mag, four planets, F-corona and stray light. The PSF is applied.

This illustrates the impact of the stellar distribution!



HI – Image Simulation

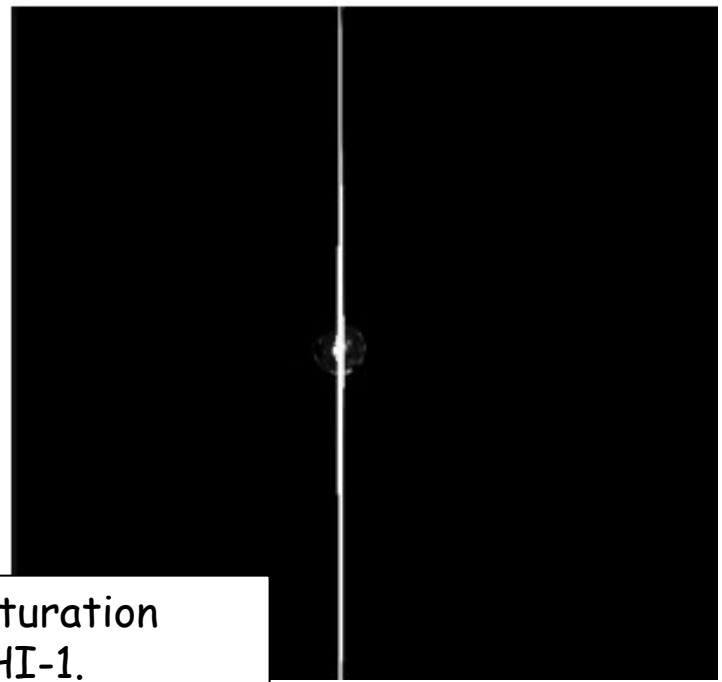
7. Saturation and Blooming

- The CCD pixels saturate at 200,000 electrons (full well). At DQE of 0.8 that is 250,000 photons. When pixels saturate excess charge spills into adjacent pixels (blooming). Images can be contaminated/swamped, by sources of excessive brightness.

- HI must detect brightness levels down to 10^{-13} to 10^{-14} Bsun; we know that sources will saturate.

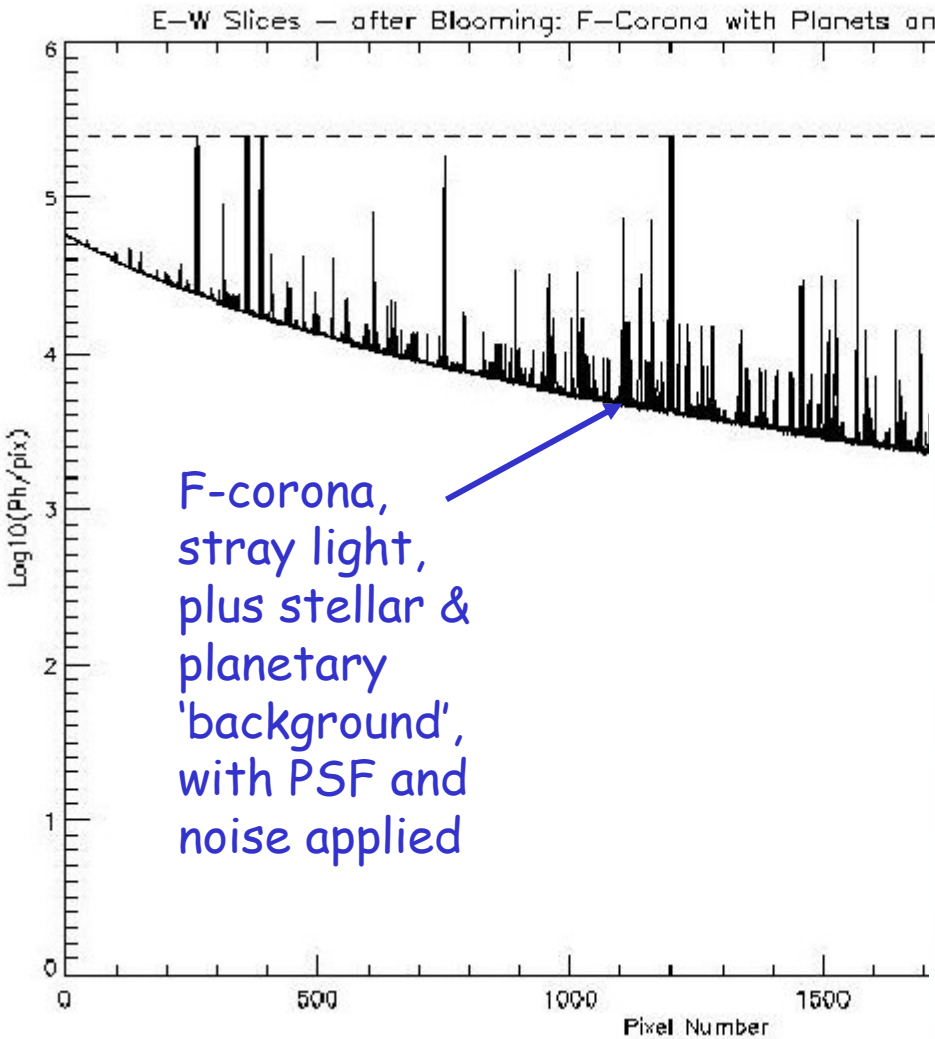
- Aim: Minimise effect - restrict blooming to columns which include the bright source.

- Tests confirm - detector saturation is confined to columns (see HI-status talk). For the simulation, first the PSF is applied, then blooming is calculated by distributing excess charge up and down the relevant columns.



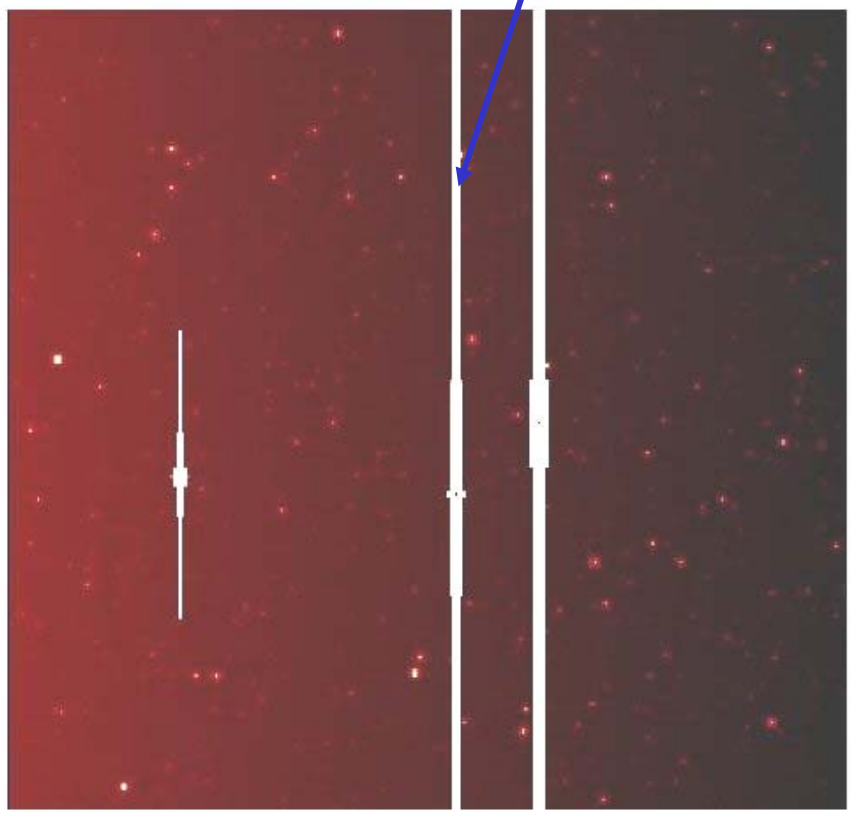
Test data: 512 ms exposure producing saturation factor of 764 - equivalent to Jupiter in HI-1.

HI - Image Simulation



CCD Saturation

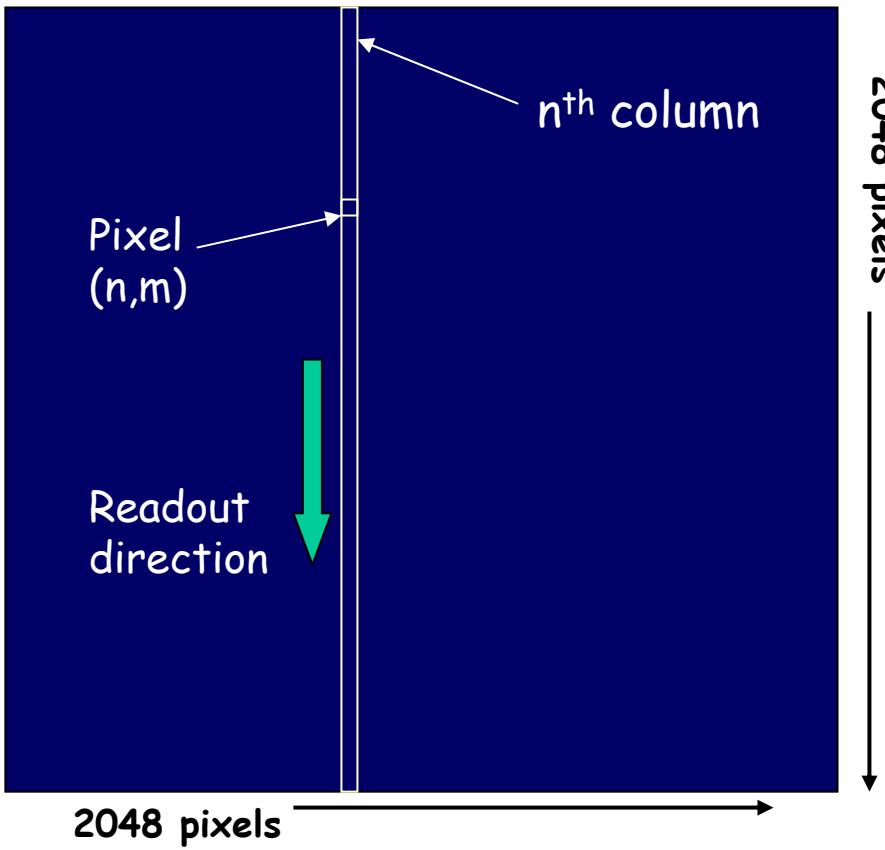
F-corona, stray light, plus stellar & planetary 'background', with PSF and noise applied



HI - Image Simulation

8. Line Transfer Function (non-shutter operation)

- HI does not have a shutter.



The CCD is read out from the bottom.

Consider one pixel (n,m) - its nominal exposure is made at location (n,m).

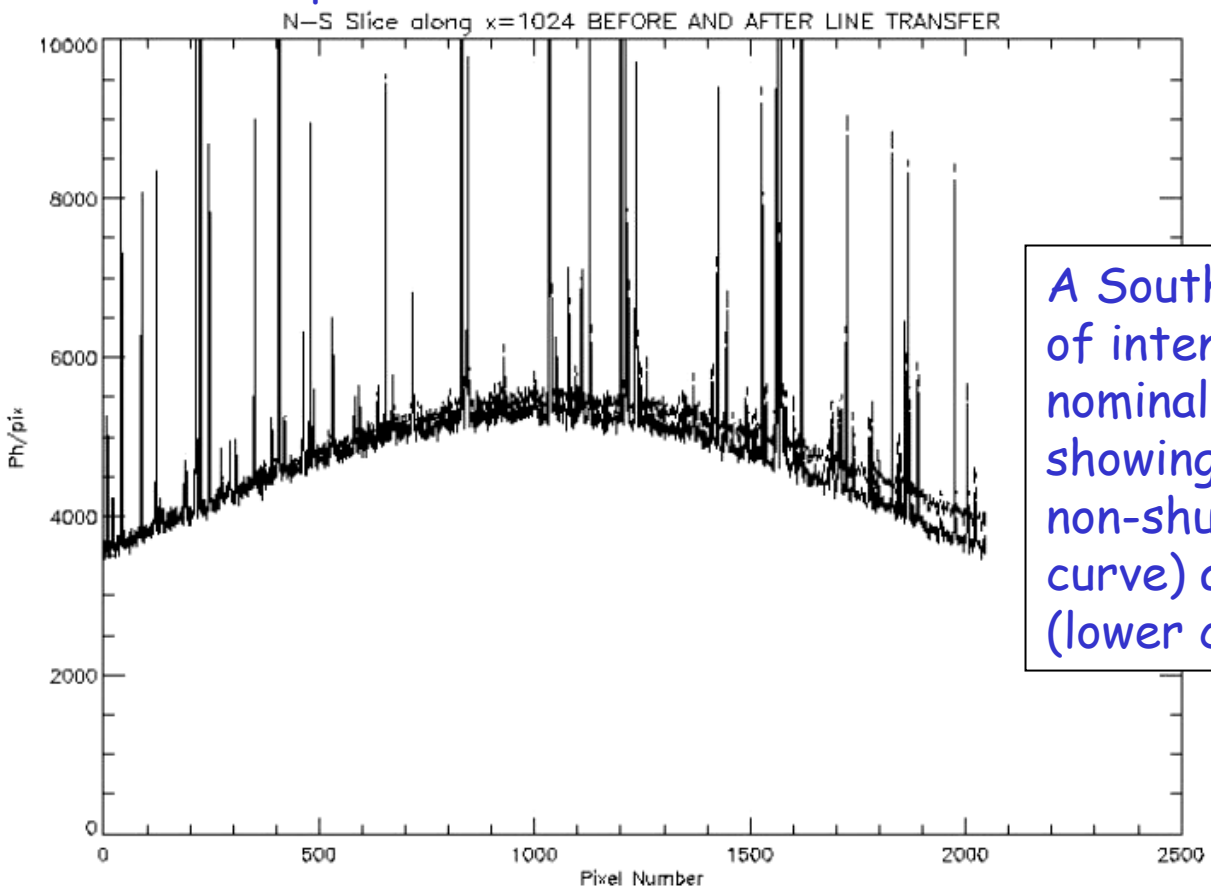
After the image is exposed, a line transfer process carries the image down the column at a rate of 2048 μs per line - thus we must add (m-1) exposures of 2048 μs to the nominal exposure.

After reading out the CCD, it is 'cleared' at a rate of 150 μs per line - i.e. the (2048-m) locations 'above' the location (n,m) contribute 150 μs exposures.

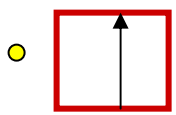
HI - Image Simulation

8. Line Transfer Function (non-shutter operation) (continued)

The HI simulated images are being used to investigate the effect of non-shutter operation - it is included as an option in the simulation code. This allows a comparison of the shutter and non-shutter exposures.



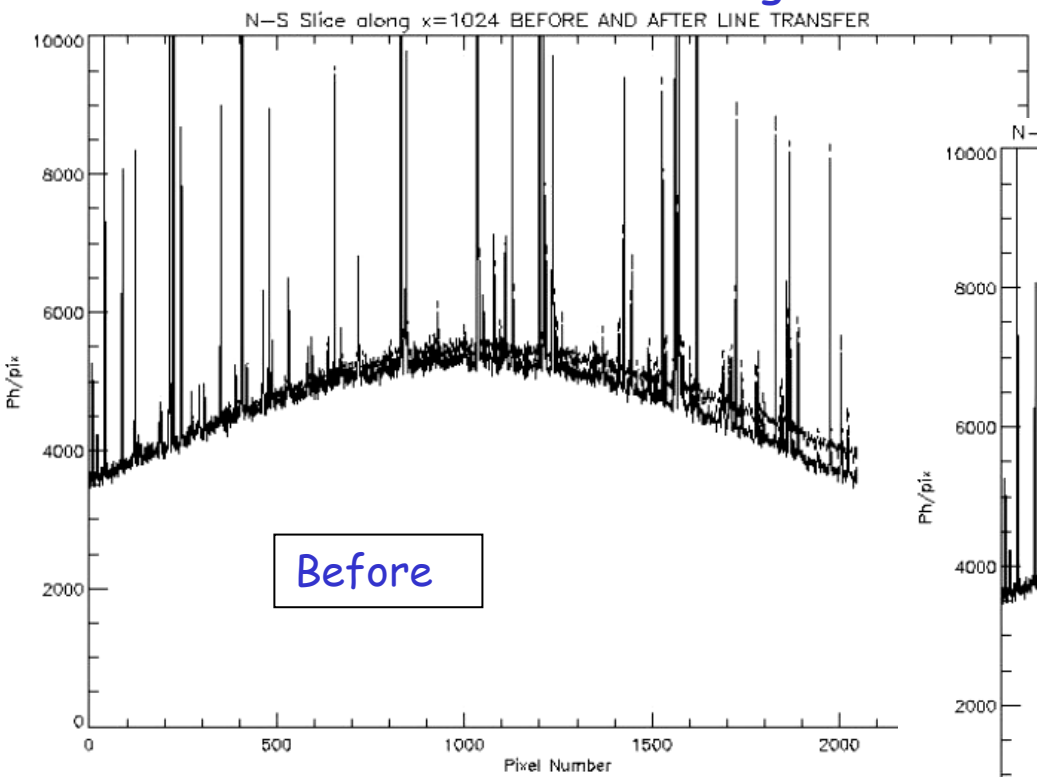
A South to North cut of intensity across a nominal HI-2 image showing the effect of non-shutter (upper curve) and shutter (lower curve).

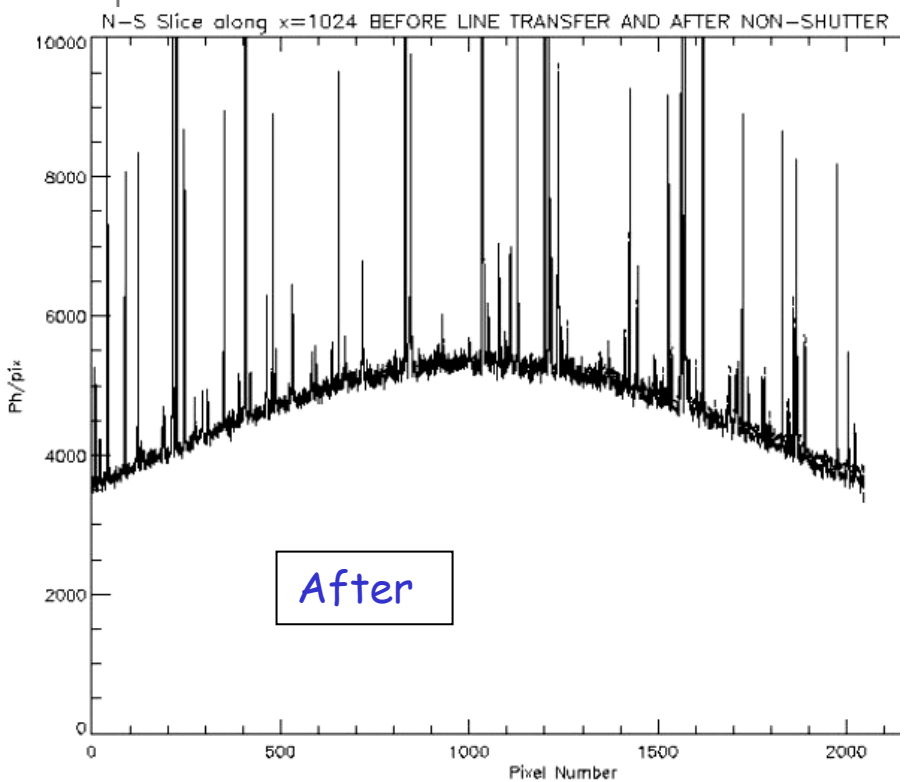


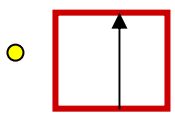
HI - Image Simulation

8. Line Transfer Function (non-shutter operation) (continued)

Several methods are being considered to correct for this - e.g. an averaged 'gradient' method is used to correct the HI-2 image below. These methods need further investigation - but initial results are promising.





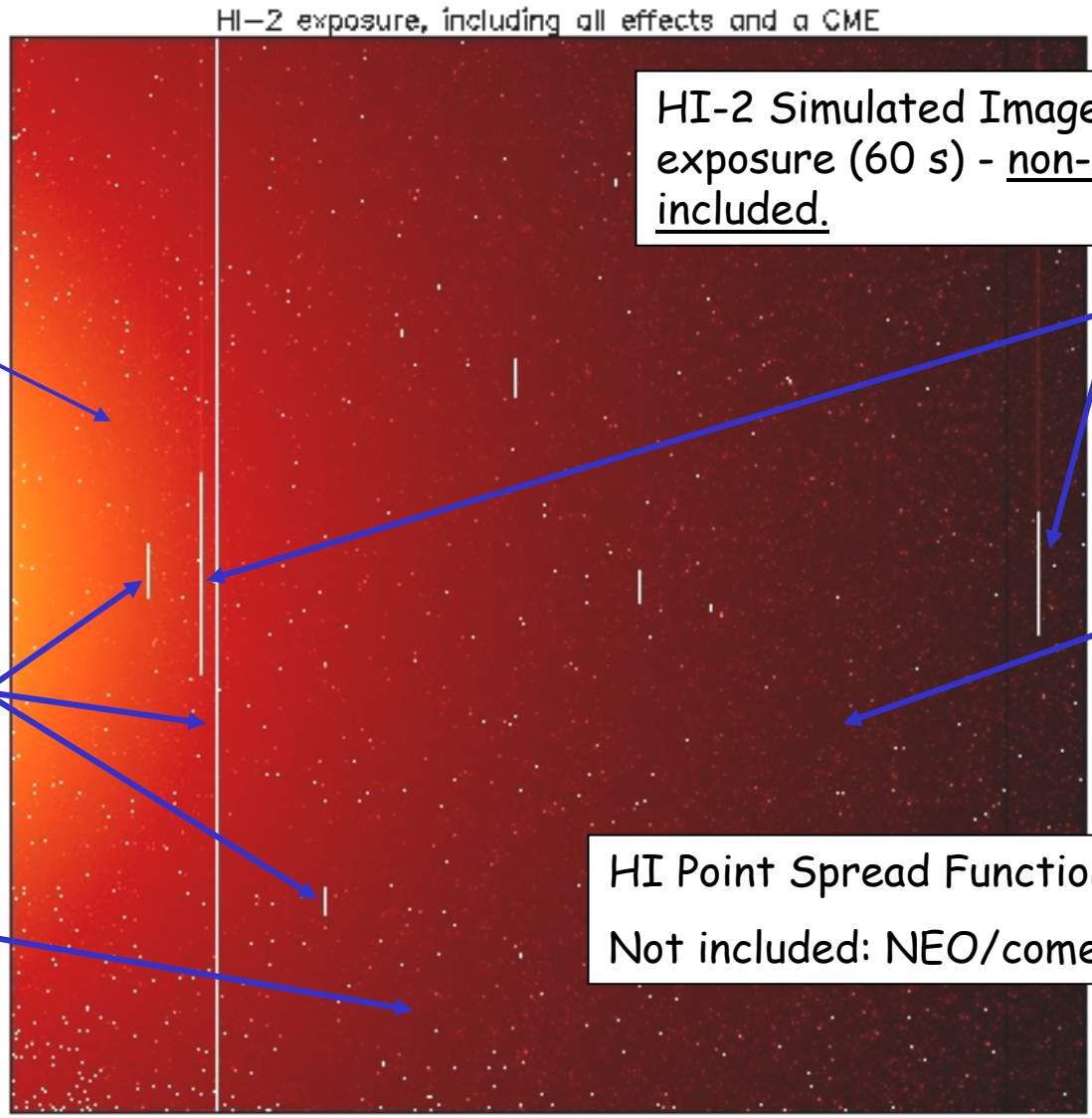


HI – Image Simulation

9. Cosmic Rays

- Cosmic ray hits will be a significant effect. The SOHO CCD hit data from Pike & Harrison (2000) are taken - assuming 40 hits/cm^{2}s - i.e. 305 hits per second on each of the HI CCDs.
- Currently, the simulation models cosmic rays as point-like, randomly distributed hits of a single intensity (full well). In future, plans to include tracks and variable intensities.
- Cosmic rays must be extracted, during nominal operations, after each exposure, on board. The simulated images will be used to test the on-board extraction codes.

HI - Image Simulation



The story so far...

HI-2 Simulated Image - nominal exposure (60 s) - non-shutter effect included.

F-corona & stray light

Planets

Stellar 'background' down to 13th mag.

Saturation of brightest planets & stars

HI Point Spread Function & noise included.

Not included: NEO/comets, Earth/Moon

Cosmic rays

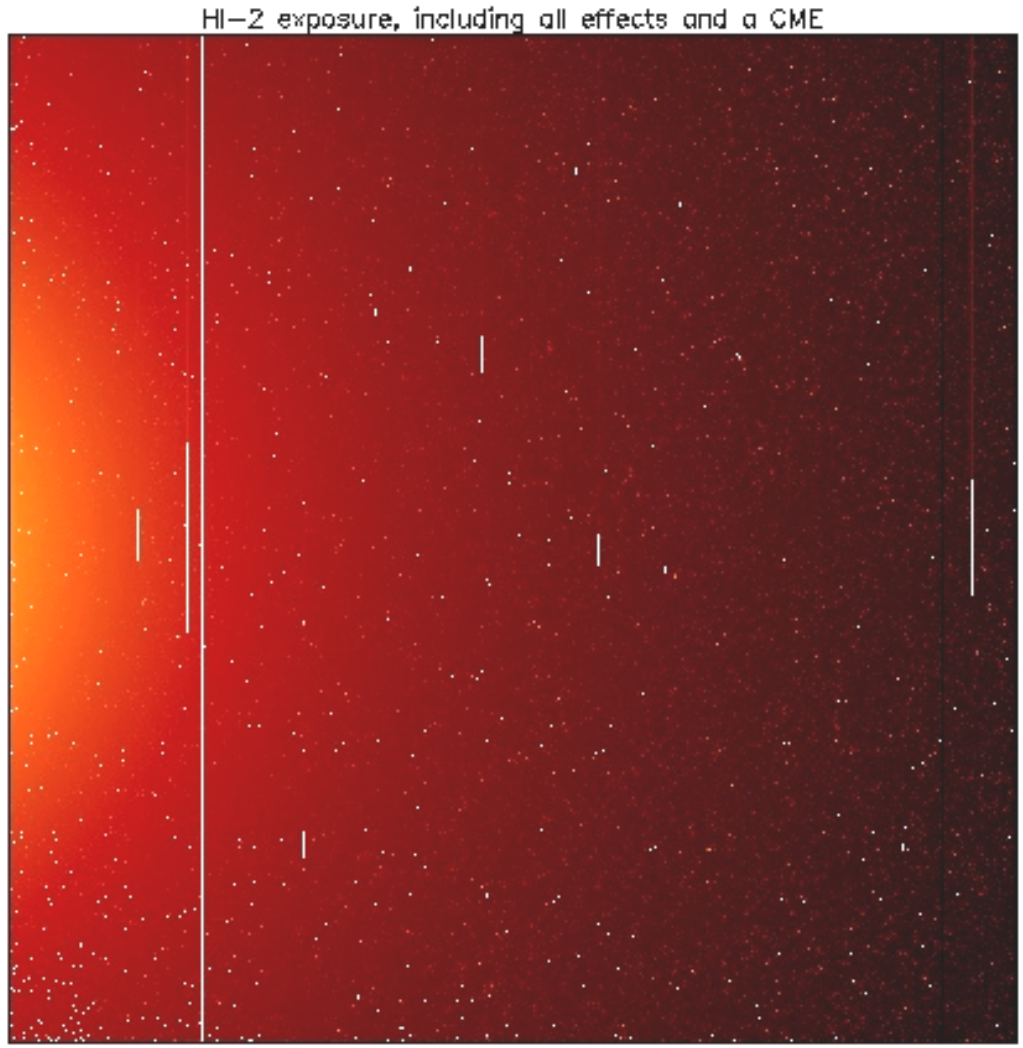
HI – Image Simulation

10. And finally… A CME!

The simulation currently includes a simple semi-circular CME of rather weak intensity (Socker et al. 2000)
- where is it???

Base-frame subtraction methods (to remove F-corona & stellar background), & image subtraction, are under investigation.

The simulation activity is providing requirements on the ground software to be developed.
The unique aspect of HI is the need to carefully subtract the stellar contribution.



HI - Image Simulation

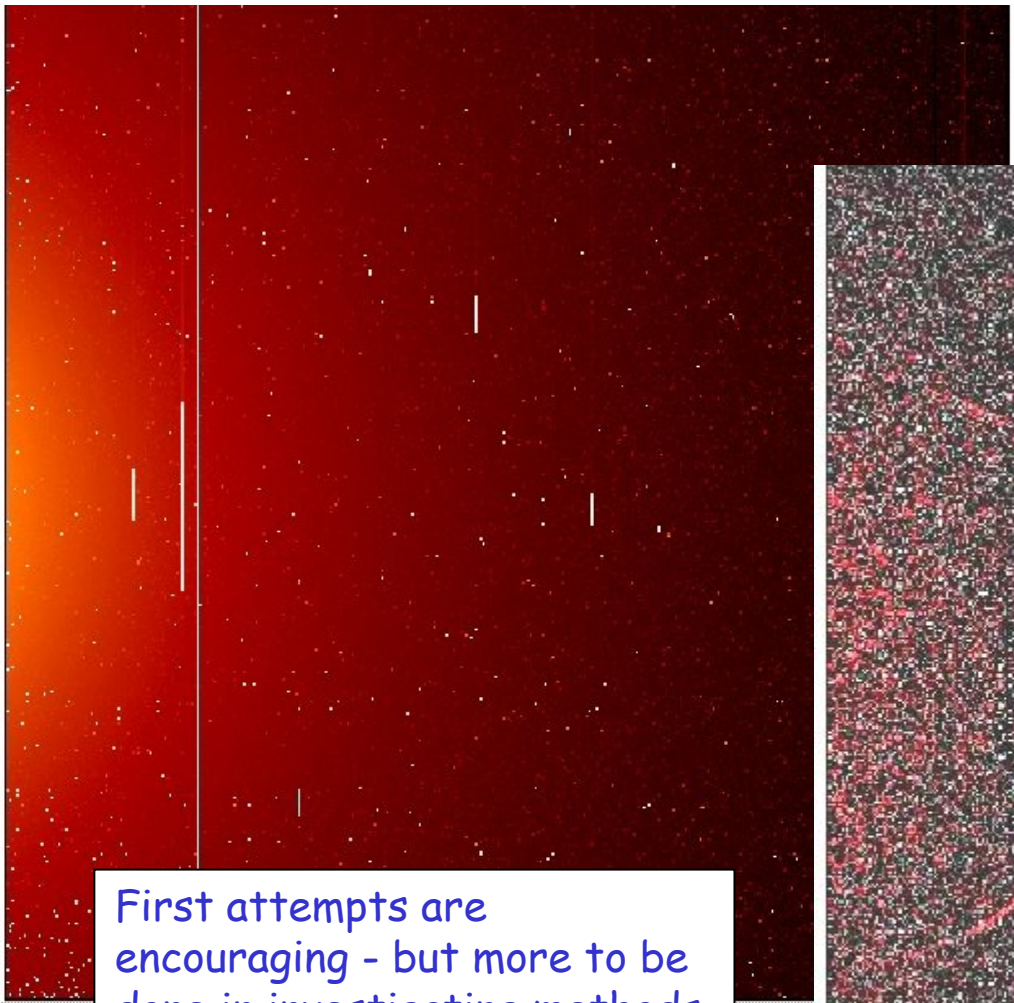
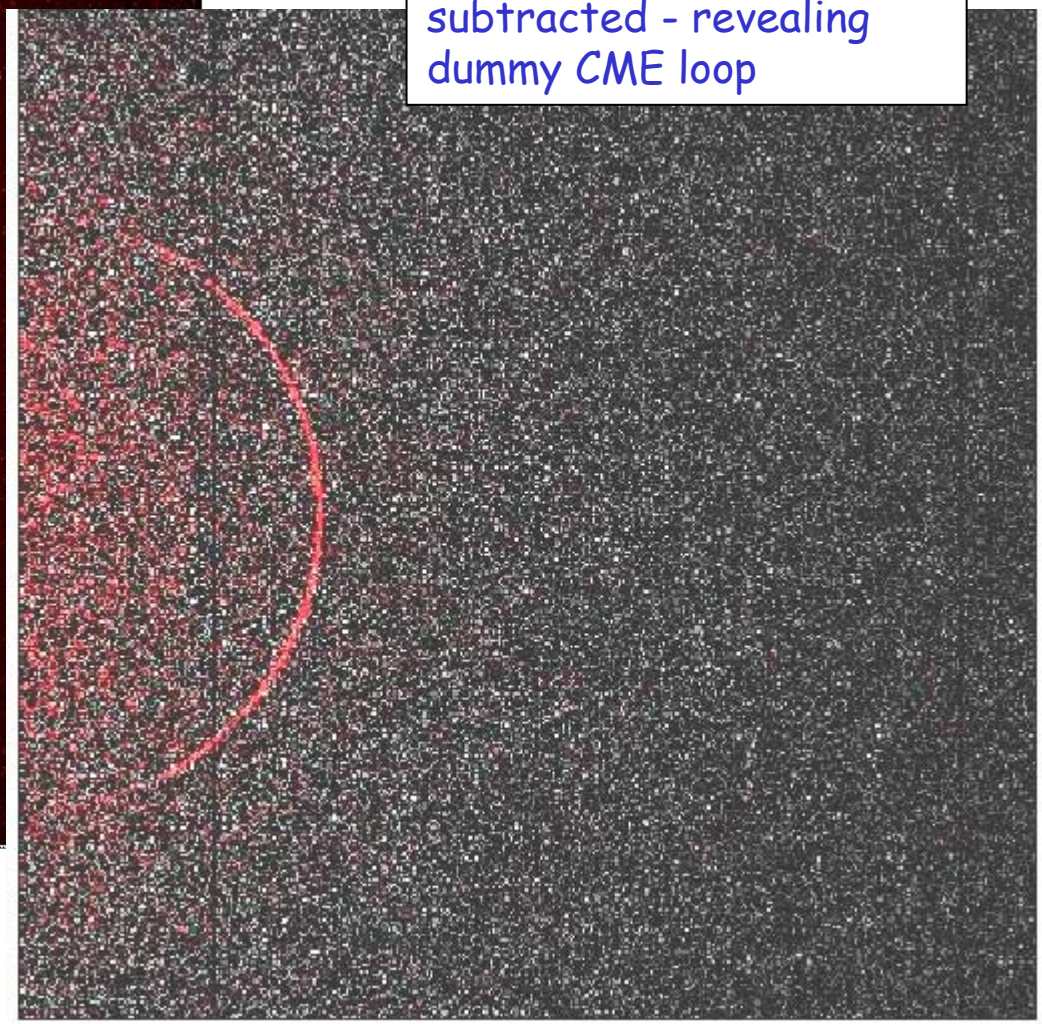


Image with base-frame subtracted - revealing dummy CME loop



First attempts are encouraging - but more to be done in investigating methods for stellar extraction in particular.

HI – Image Simulation

- The image simulation activity has so far included the effects of: the F-corona, planets, stars (to 12th magnitude), the PSF, stray light, noise, saturation and blooming, cosmic rays, non-shutter operation - and a CME.
- It is providing a valuable insight to the anticipated data from HI and allowing both a thorough investigation of image handling and processing, and of the needs for on-board and ground software.
- The next steps include (in no particular order):

(i) inclusion of a more complex cosmic ray contribution (with tracks and variable intensities);

(ii) further investigations of base-frame subtraction;

(iii) further refinements to the correction methods for non-shutter operation;

(iv) expansion into a temporal approach, i.e. producing series of images including moving CMEs, to test cosmic ray removal software, CME identification and analysis approaches.