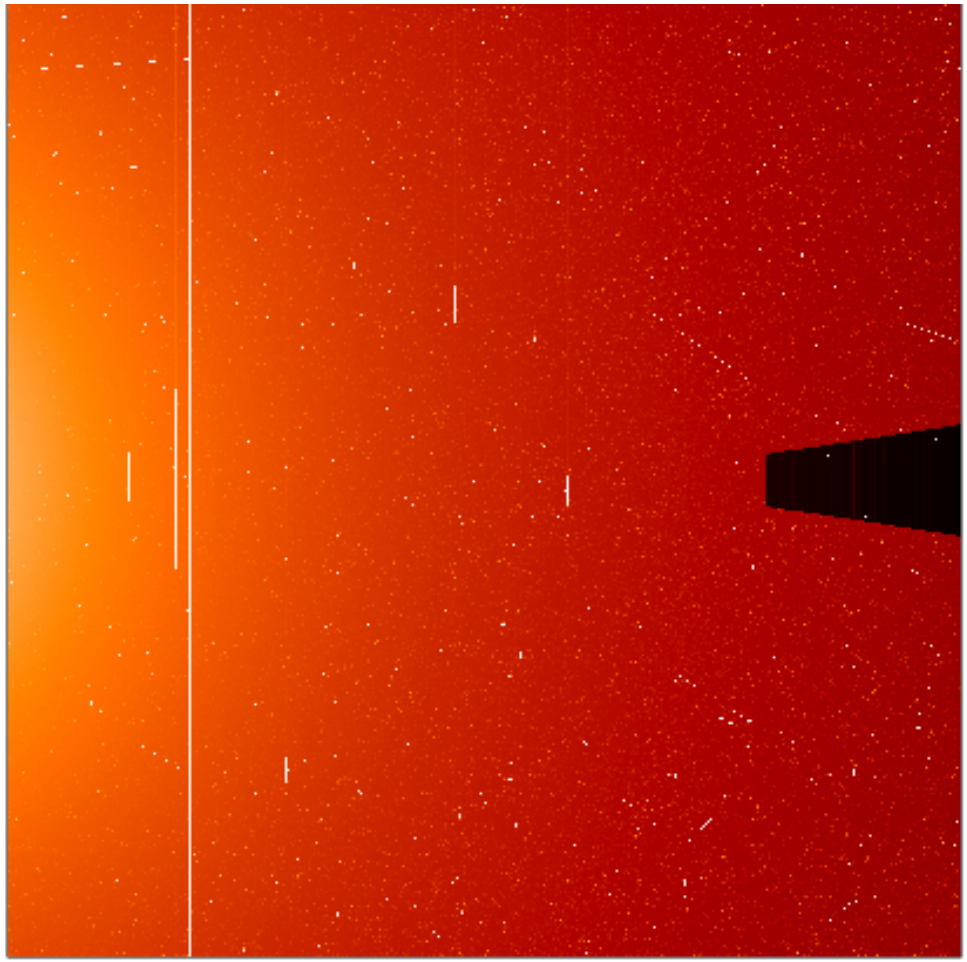
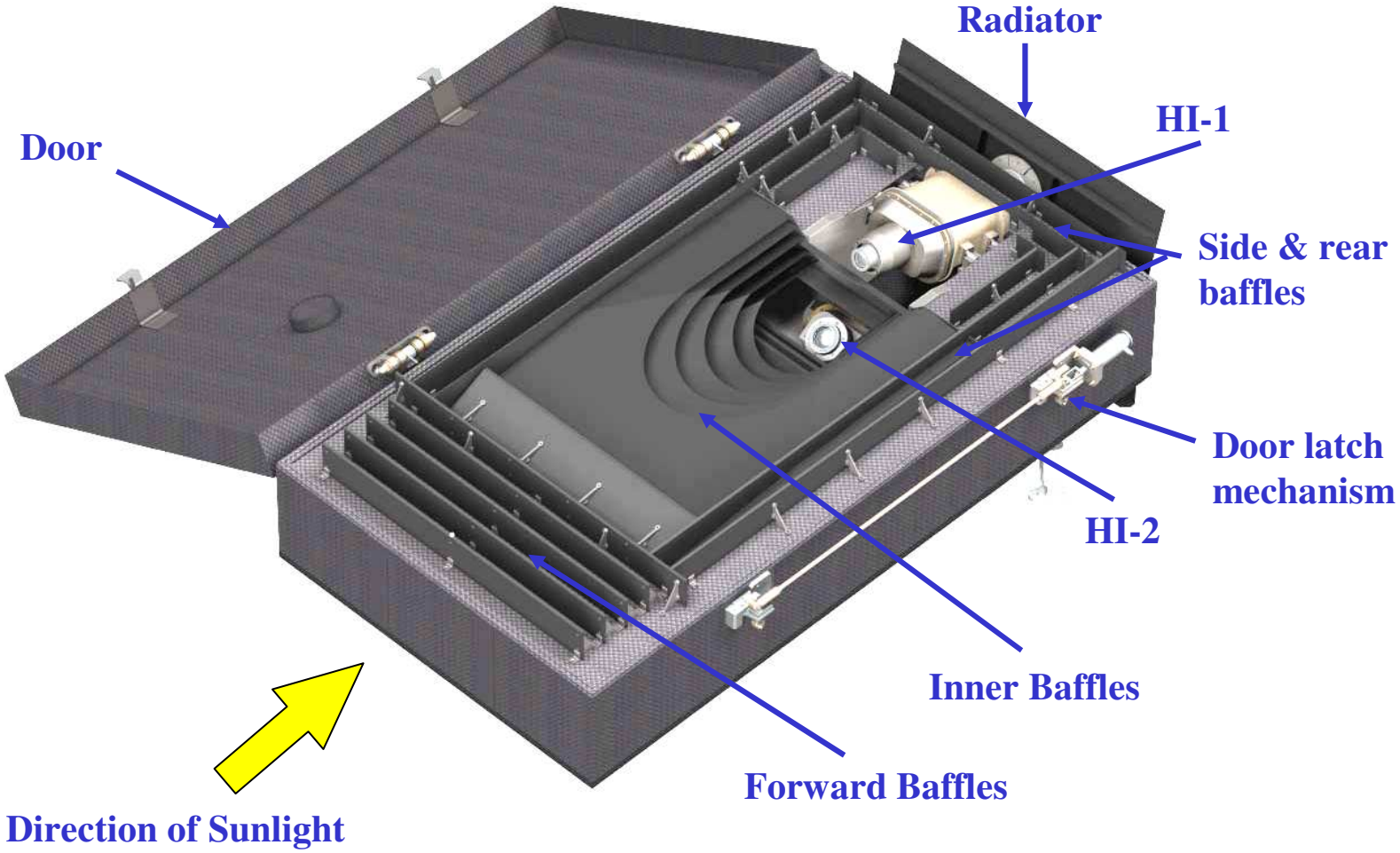
HI Image Simulation

Chris Davis, December 2003



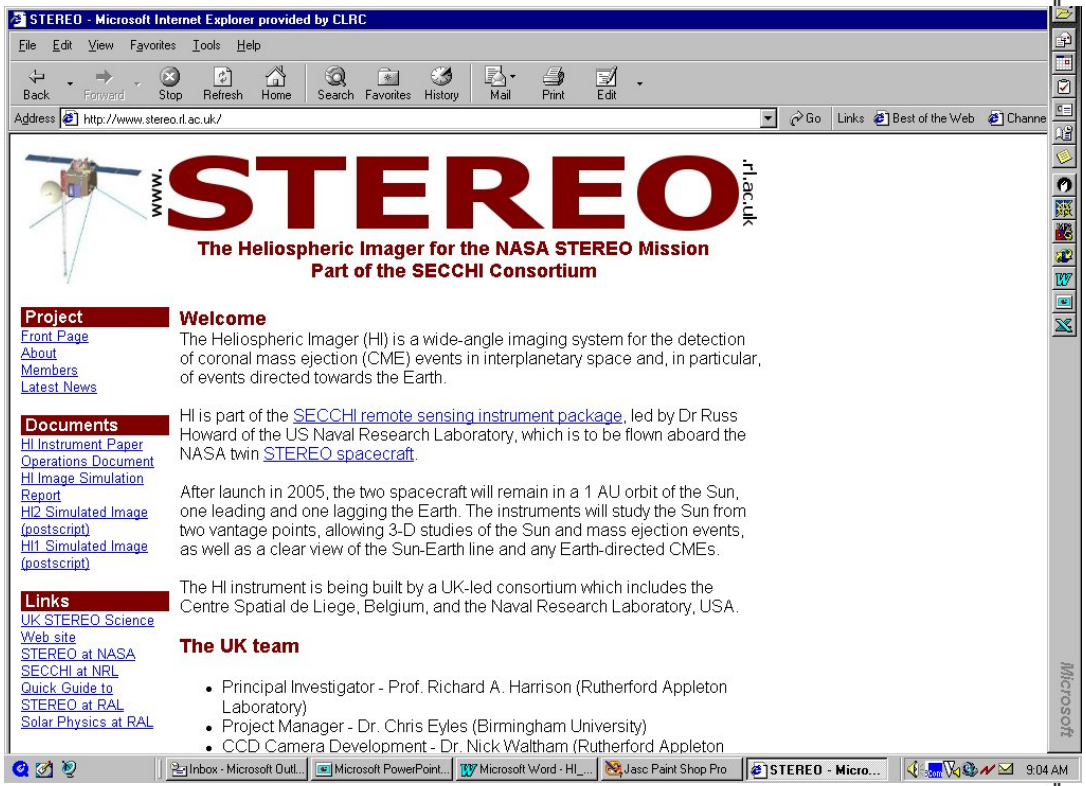
The HI Basic Design

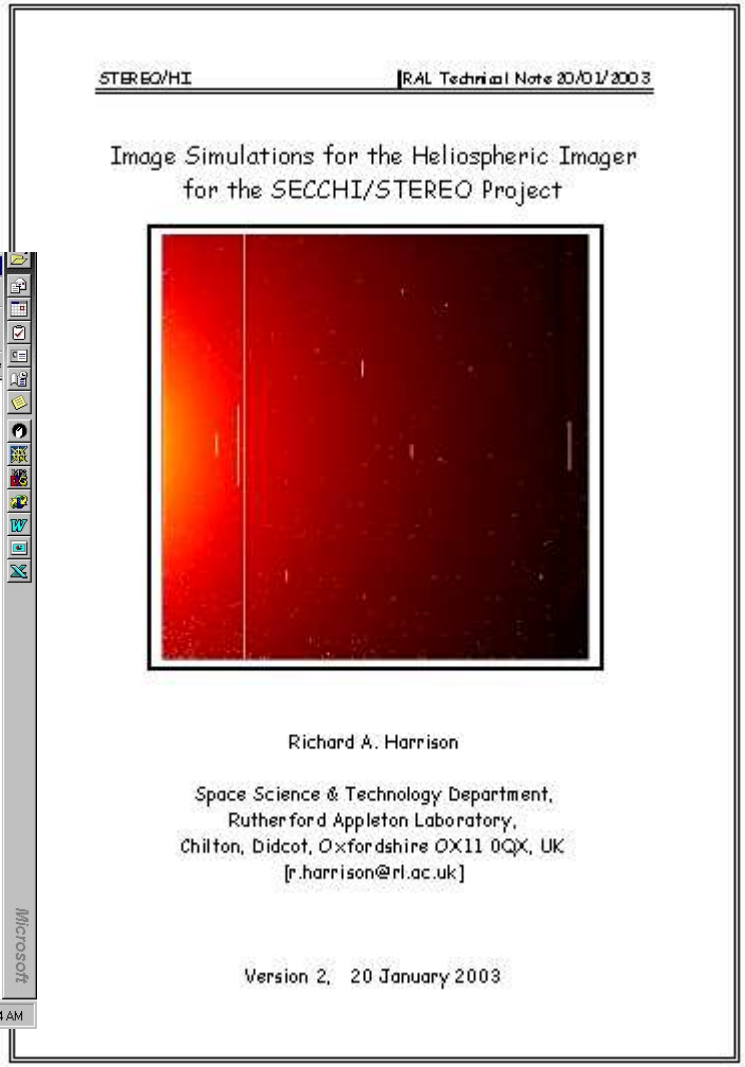


HI – Image Simulation

The HI image simulation activity started in Autumn 2002.

See 'Image Simulations for the Heliospheric Imager', C. J. Davis & R.A. Harrison, available at 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.

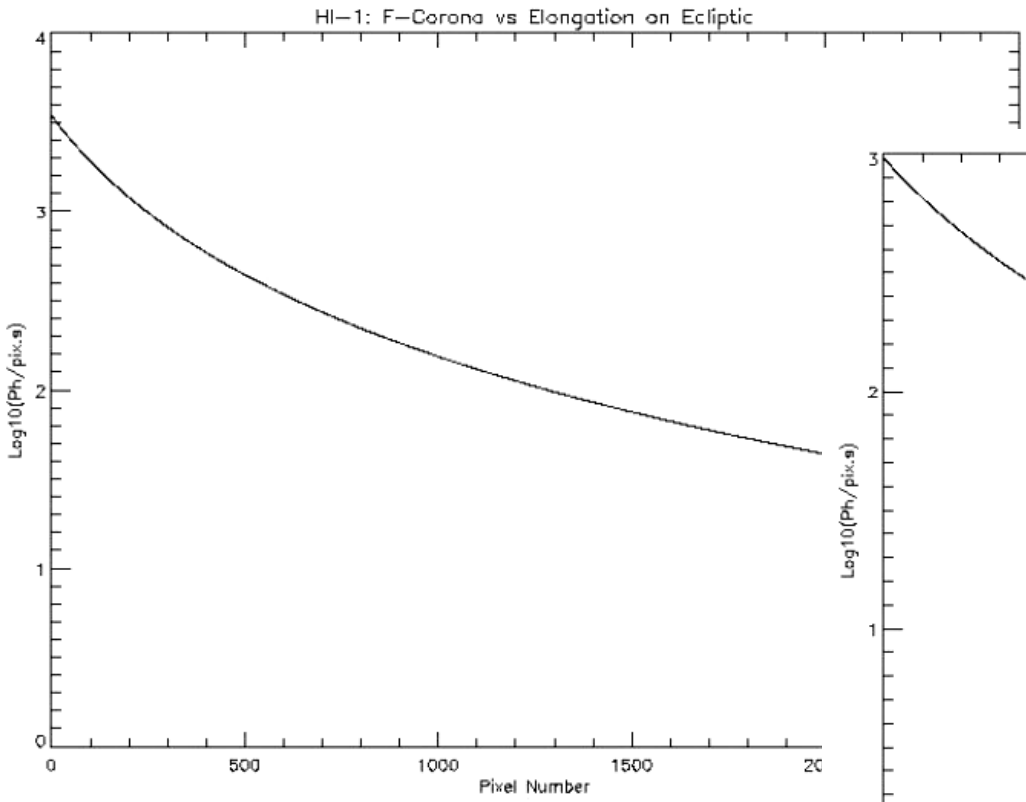
To provide a tool to explore operations scenarios with the user community.

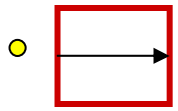
In addition to demonstrating that HI works, and exploring the ways we can use it, these efforts are providing requirements to the on-board and ground software efforts, to operations planning etc...

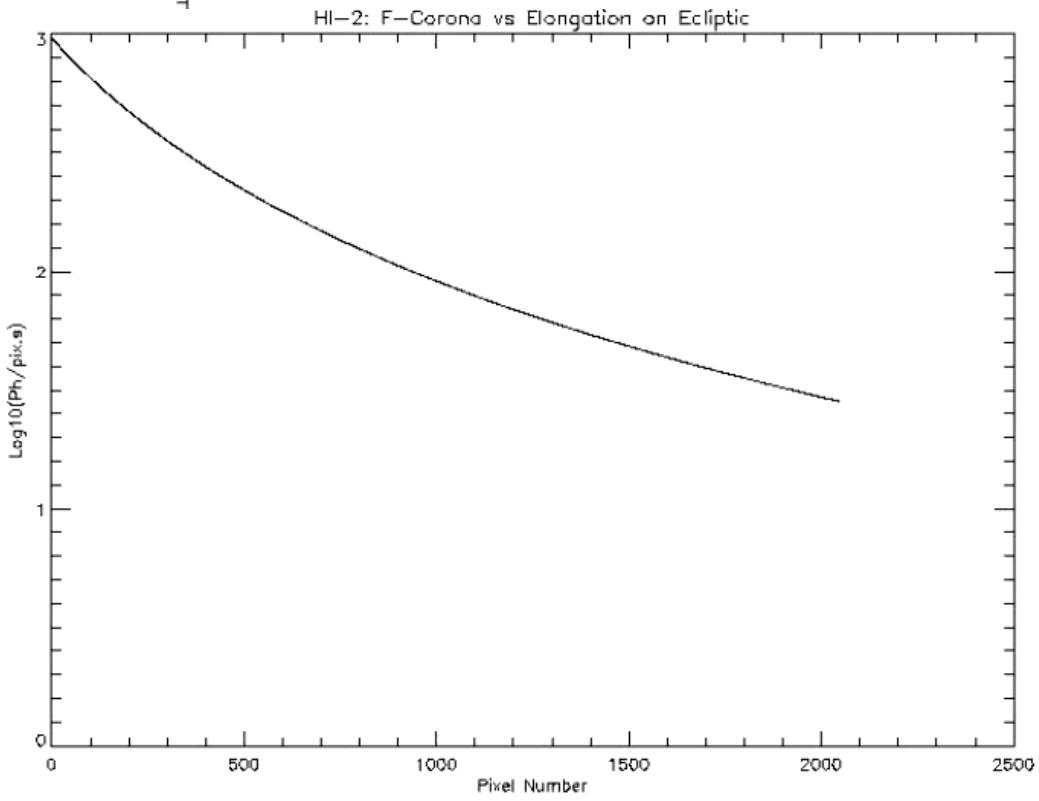
HI - Image Simulation

1. The F-coronal intensity

Calculated from Koutchmy & Lamy, 1985 - plotted below for HI-1 and HI-2, along ecliptic.





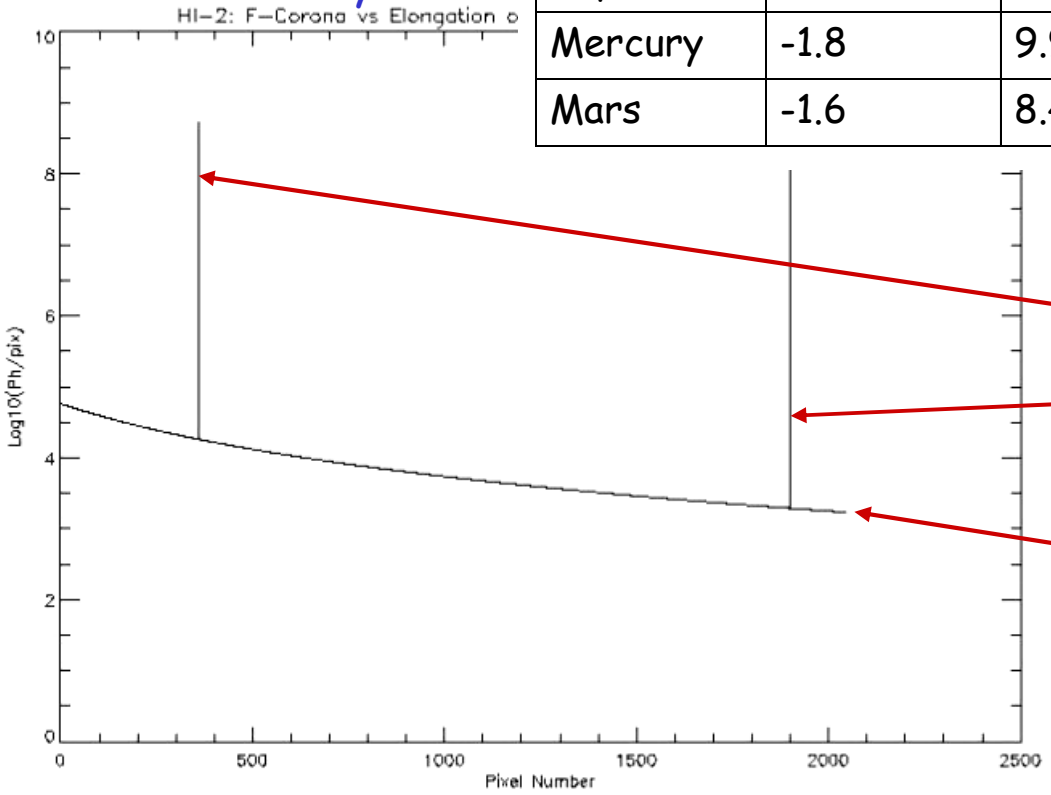


HI - Image Simulation

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.

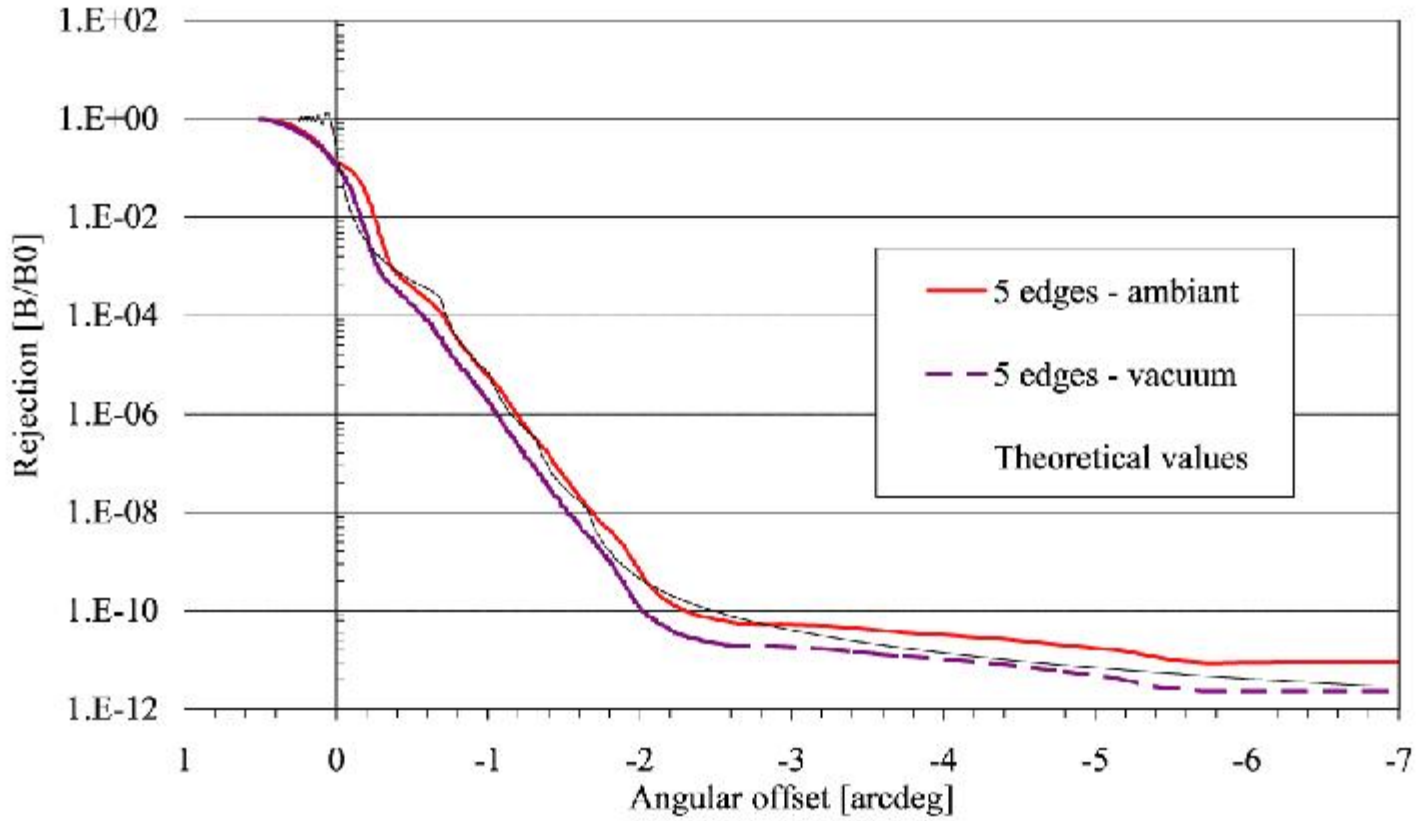
4. Noise

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

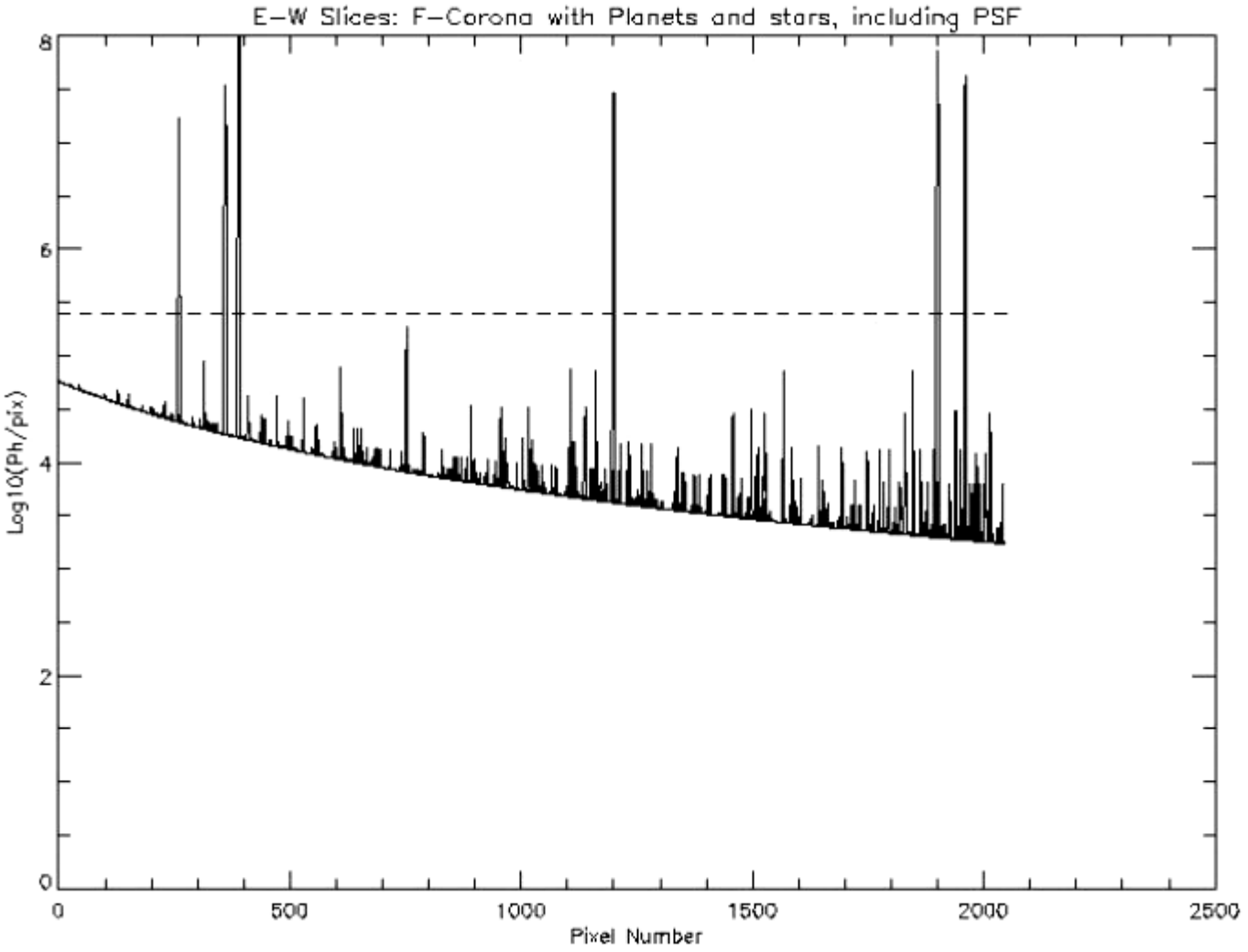
We require a distribution of point-like sources to mimic the stellar distribution - use C.W. Allen (Astrophysical Quantities) for stellar density as a function of magnitude.

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

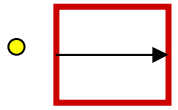
6. Stars (continued)



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

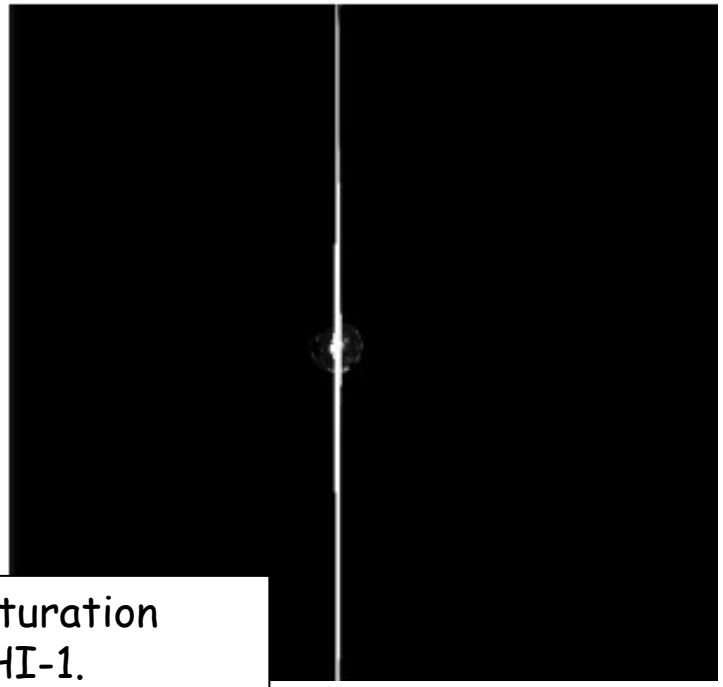
7. Saturation and Blooming

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.

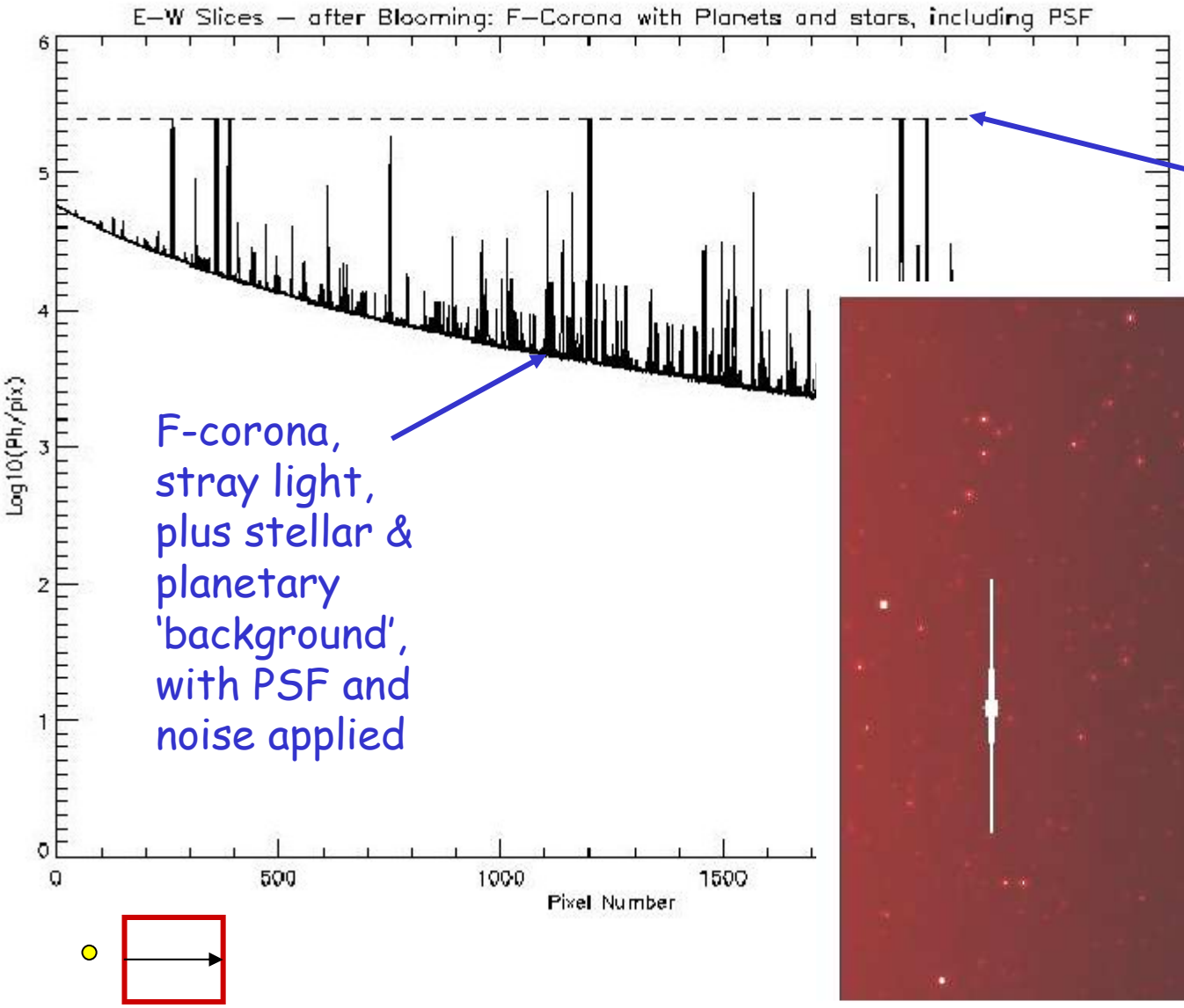
Aim: Minimise effect - restrict blooming to columns which include the bright source.

Tests confirm - detector saturation is confined to columns. 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.

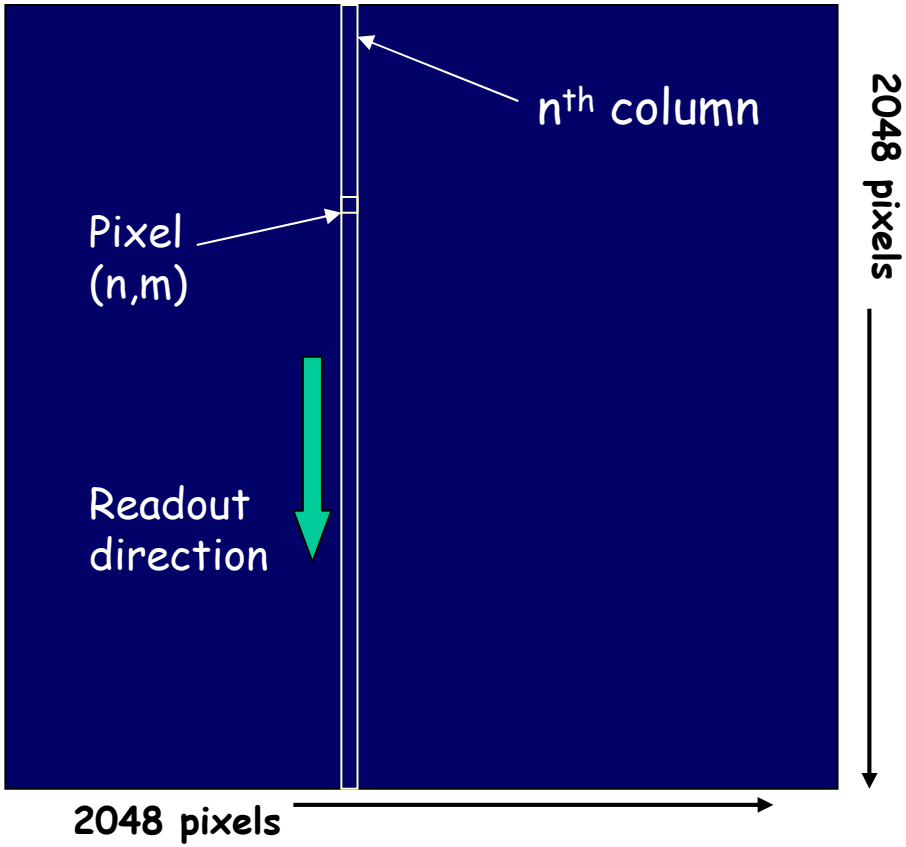
HI - Image Simulation



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).

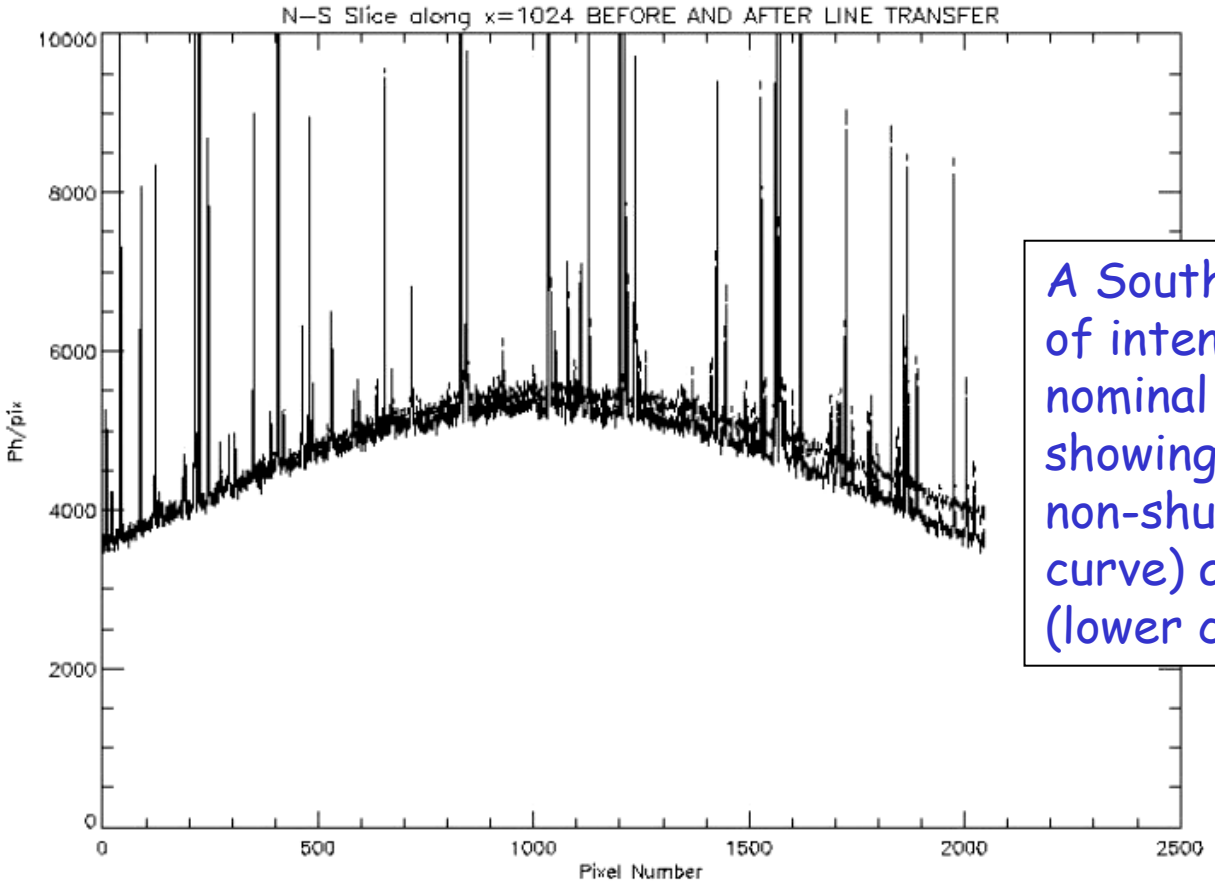
After the image is exposed, a line transfer process carries the image down the column at a rate of 2048 µs per line - thus we must add (m-1) exposures of 2048 µs to the nominal exposure.

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.

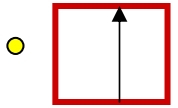
HI – Image Simulation

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.



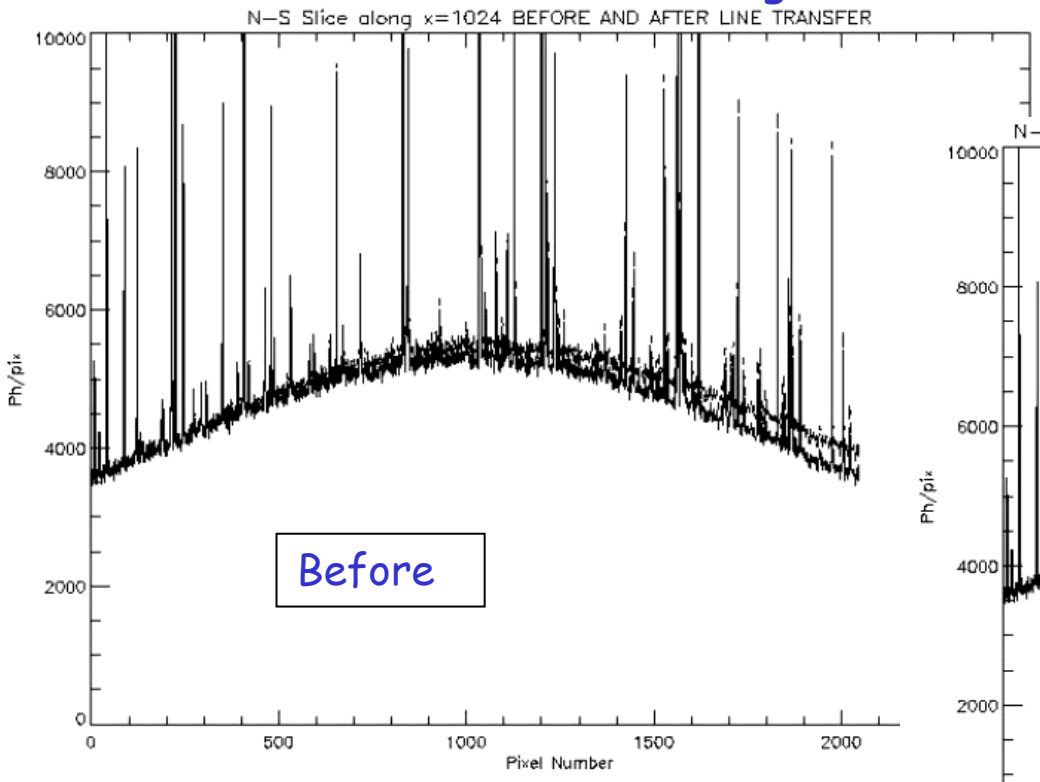
A South to North cut of intensity across a nominal HI-2 image showing the effect of non-shutter (upper curve) and shutter (lower curve).

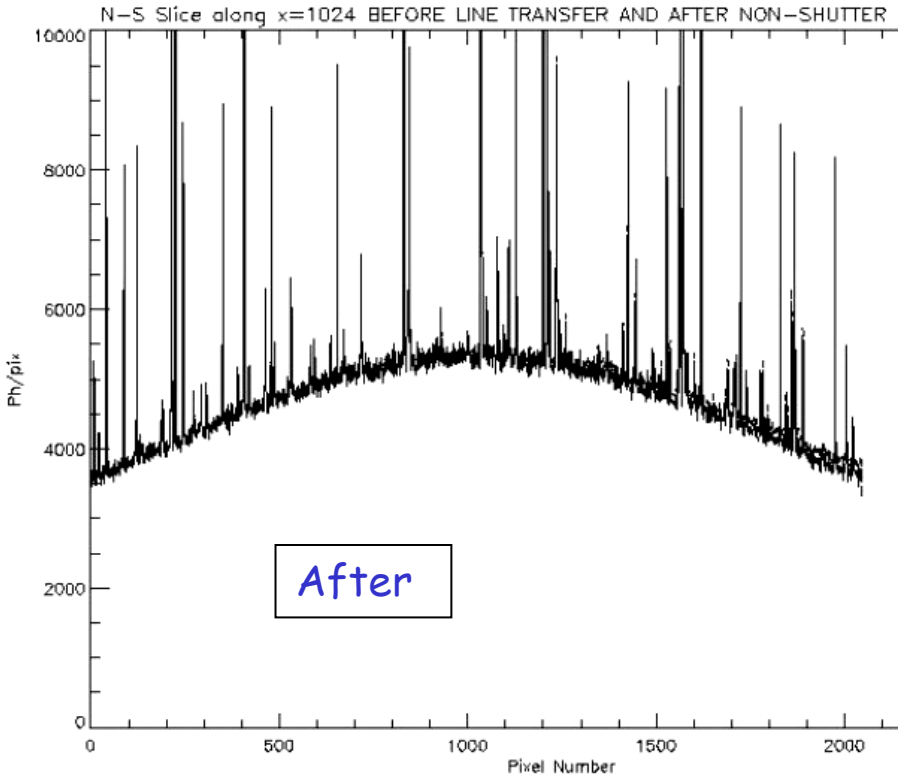


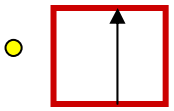
HI - Image Simulation

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.







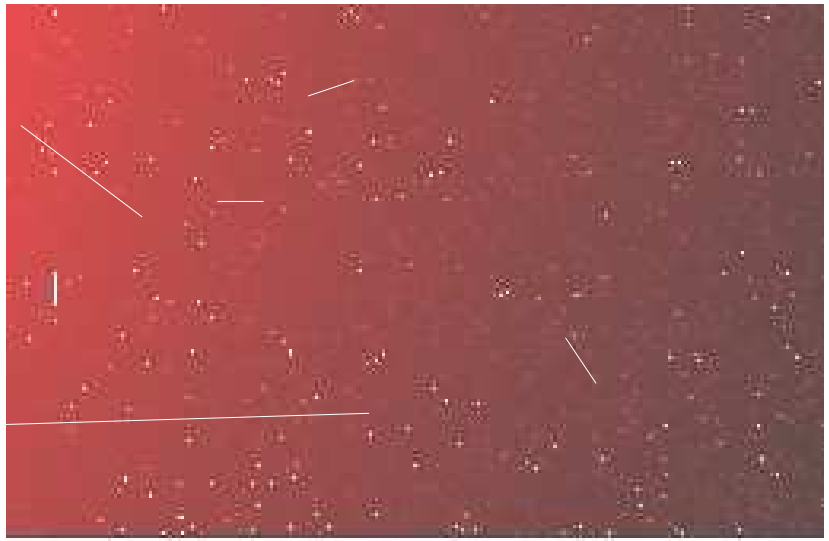
HI – Image Simulation

9. Cosmic Rays

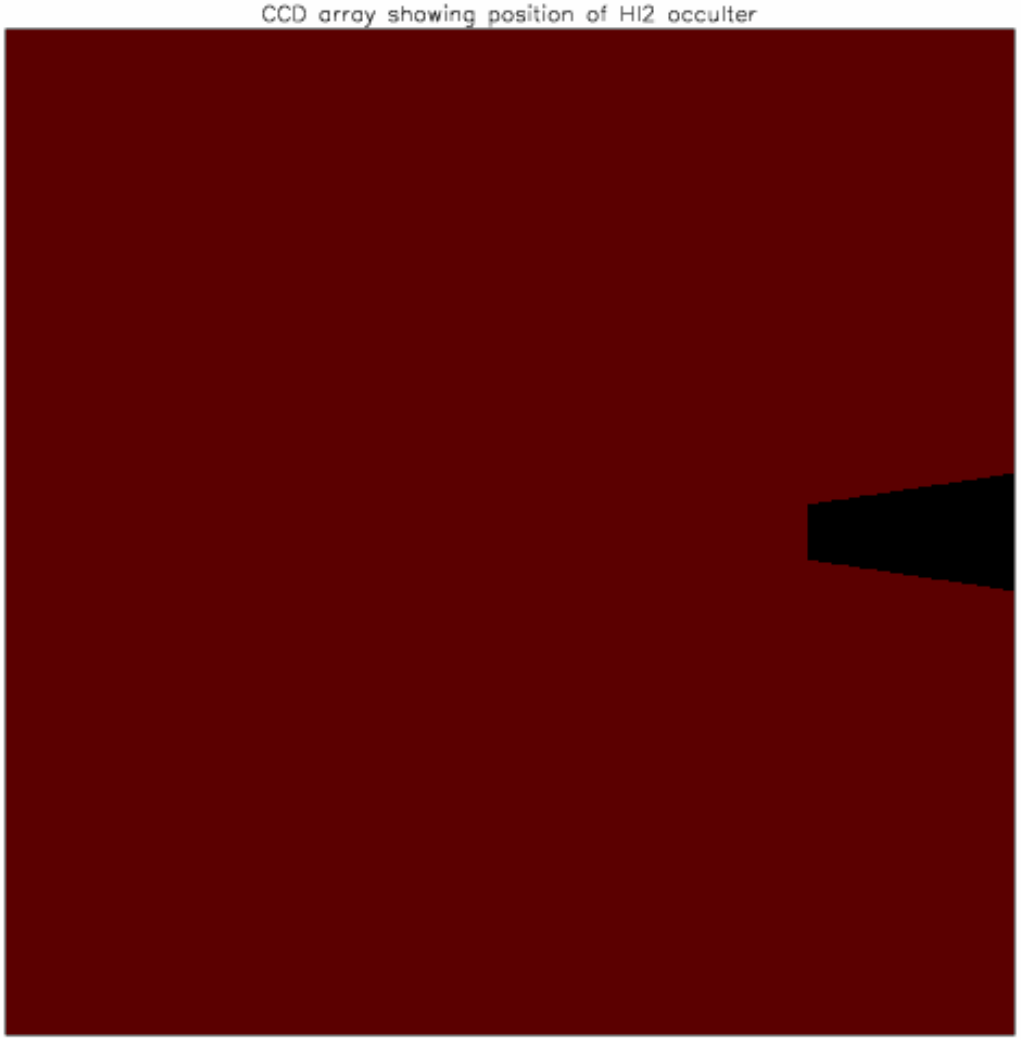
Cosmic ray hits will be a significant effect. The SOHO CCD hit data from Pike & Harrison (2000) are taken - assuming 4 hits/cm^{2}s - i.e. 30.5 hits per second on each of the HI CCDs.

Cosmic ray are now considered to have variable intensities and leave tracks depending on their direction of arrival (which is considered to be equally likely from any direction). The active depth of the HI CCDs (10 microns) means that long tracks are unlikely but possible.

Cosmic rays must be extracted, during nominal operations, after each exposure, on board. A set of simulated exposures for each instrument is available to test the on-board extraction codes. Can these be extracted without removing the faint images of Near Earth Objects (NEOs)?



HI2 – Earth-Moon Occulter

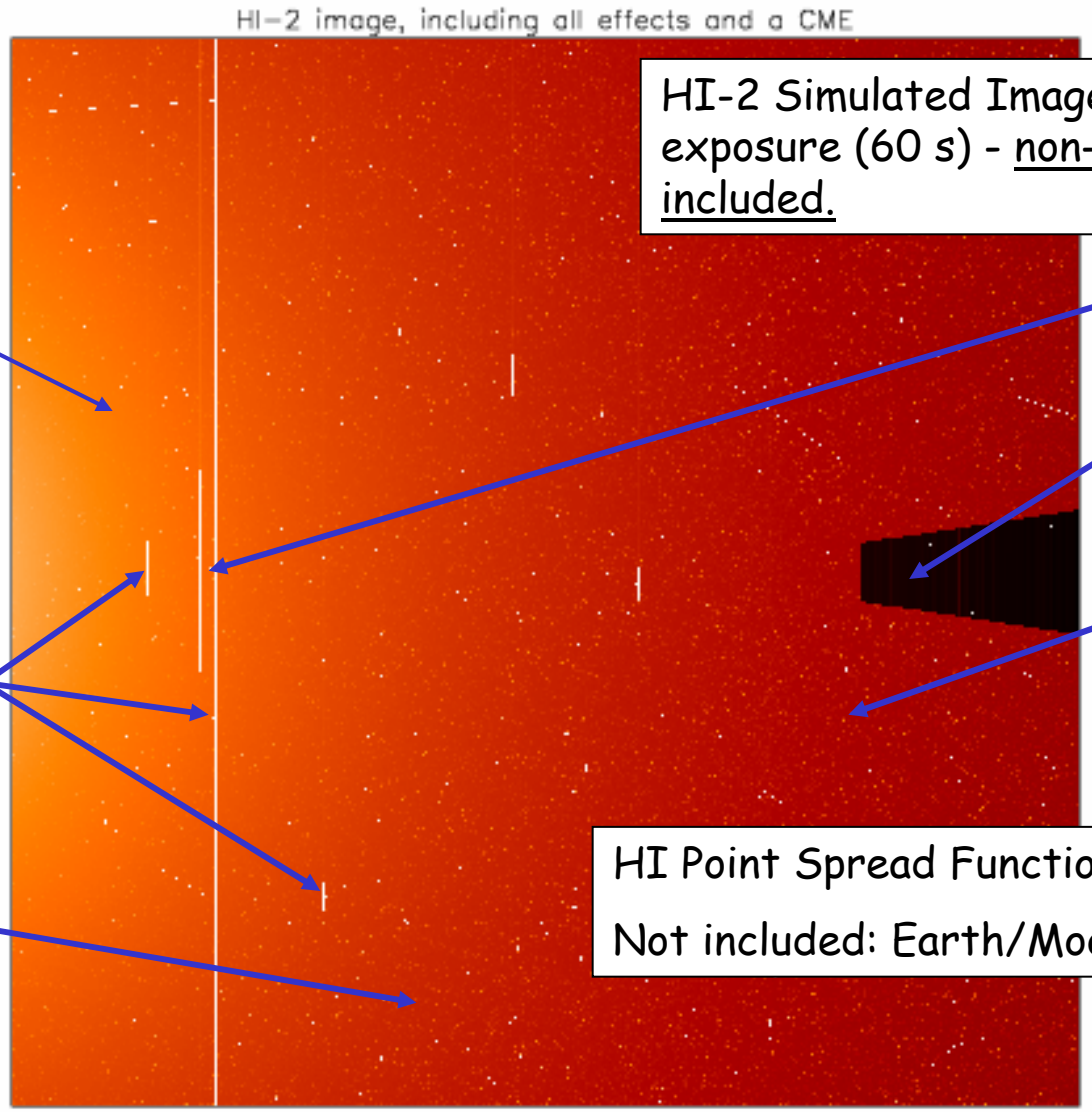


Byte array showing position of HI2 Occulter

An occulter is required on HI2 to mask the Earth and Moon until their magnitude has dropped to that of the other planets

HI - Image Simulation

The story so far...



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

F-corona & stray light

Planets

HI2 Occulter

Stellar 'background' down to 13th mag.

Saturation of brightest planets & stars

Cosmic rays

HI Point Spread Function & noise included.

Not included: Earth/Moon

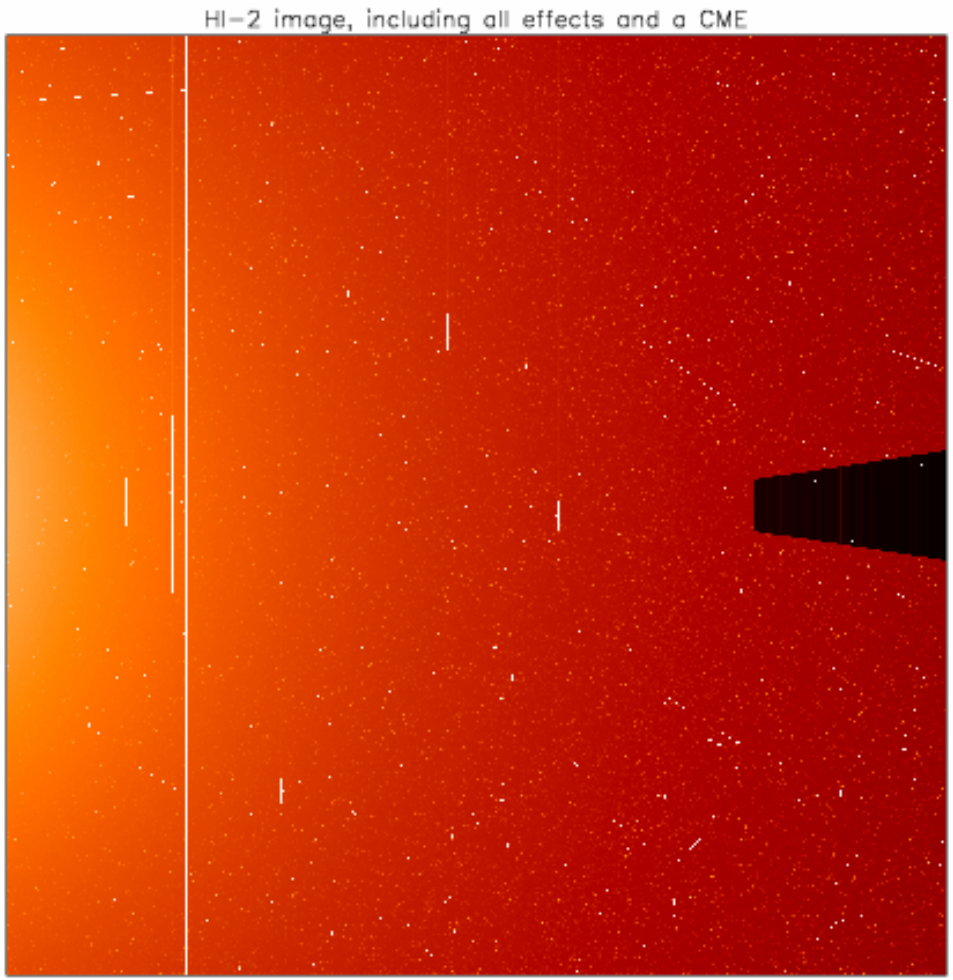
HI – Image Simulation

10. And finally… A NEO & A CME!

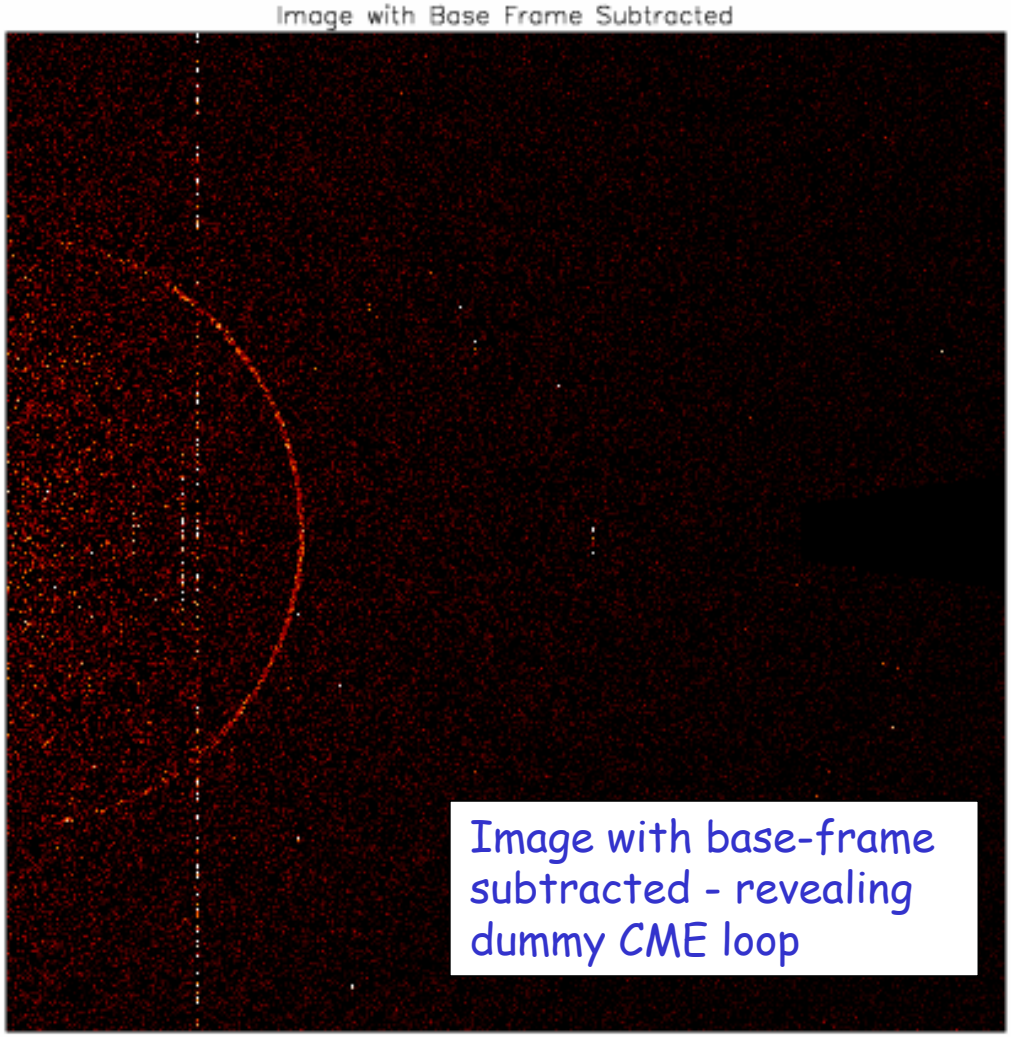
The simulation currently includes a simple semi-circular CME of rather weak intensity (Socker et al. 2000) and a 10thmagnitude NEA
- where are they ???

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 which is being developed. The unique aspect of HI is the need to subtract carefully the stellar contribution.



HI - Image Simulation



HI- Simulation Movies

Each frame in the movie represents the summation of 60, 60s exposures.

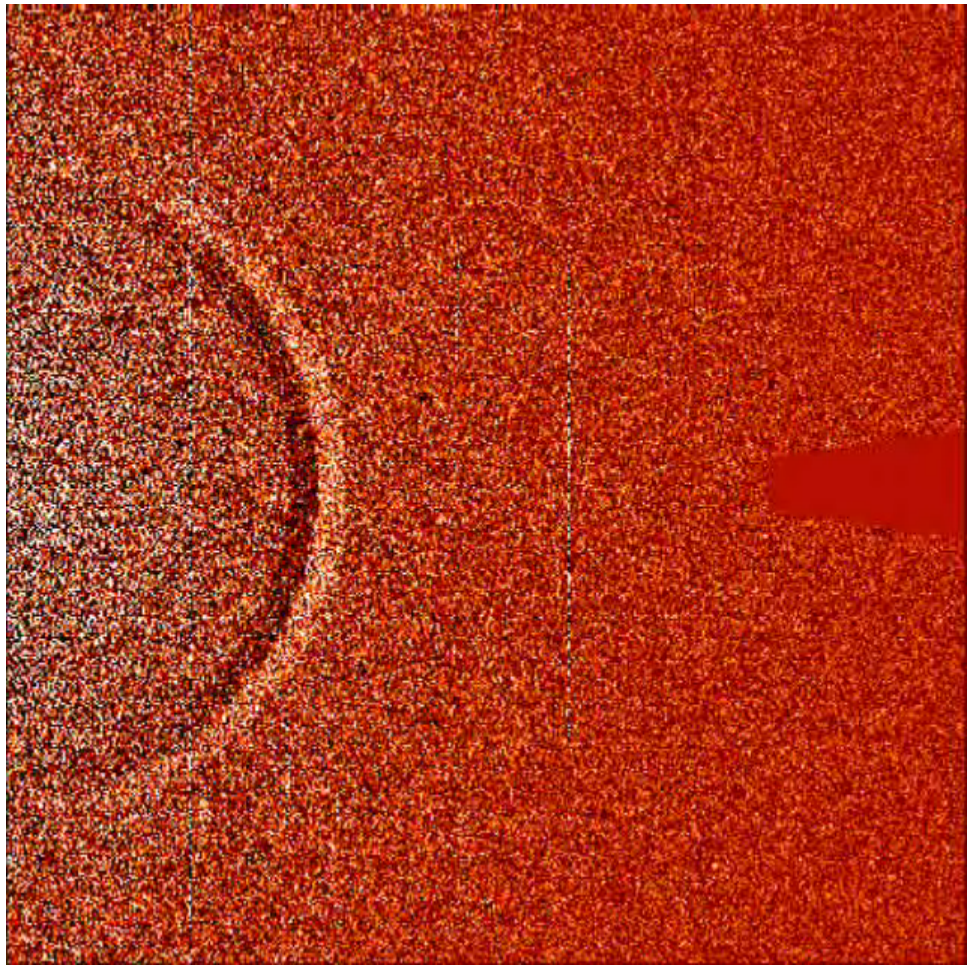
Cosmic rays were assumed to have been cleaned from each exposure before being summed into an image.

It was also assumed that this process did not remove the faint NEO.

The dummy CME moves at 1 pixel/60s exposure ≈ 725 km/s for HI2.

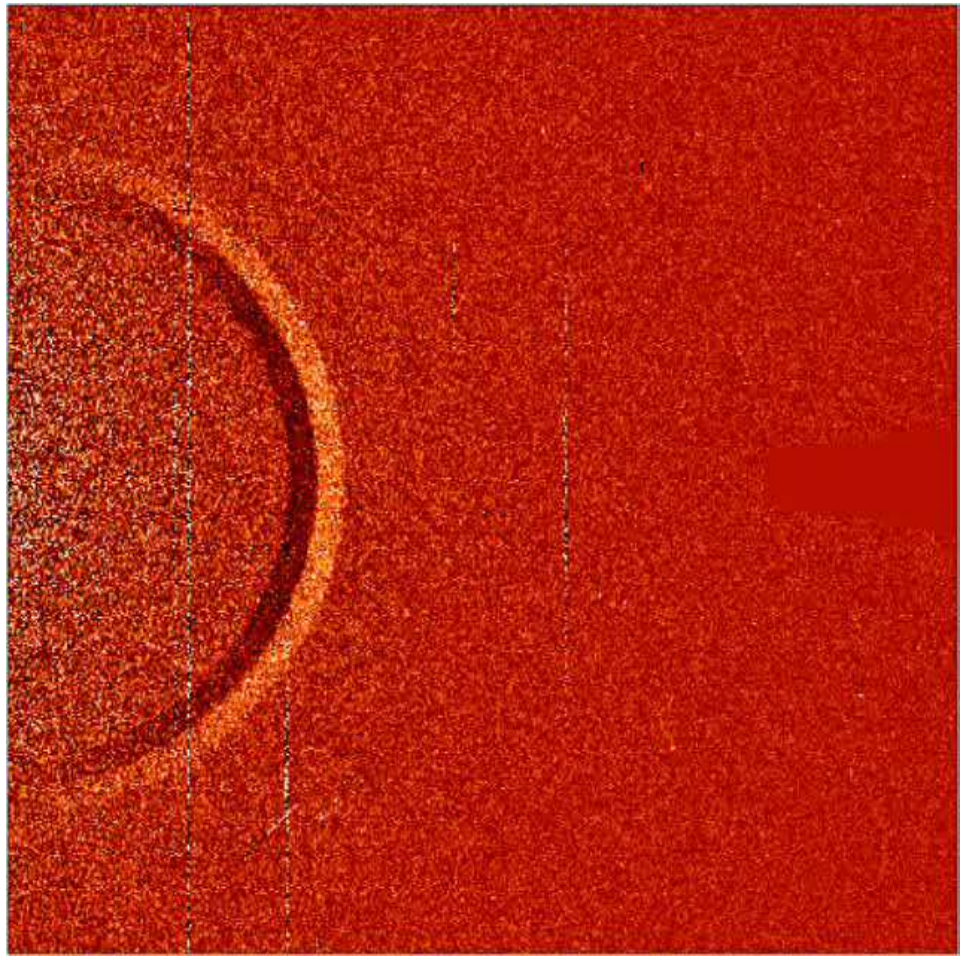
For these simple movies, the first frame in the sequence is subtracted from all subsequent frames.

HI- Simulation Movies



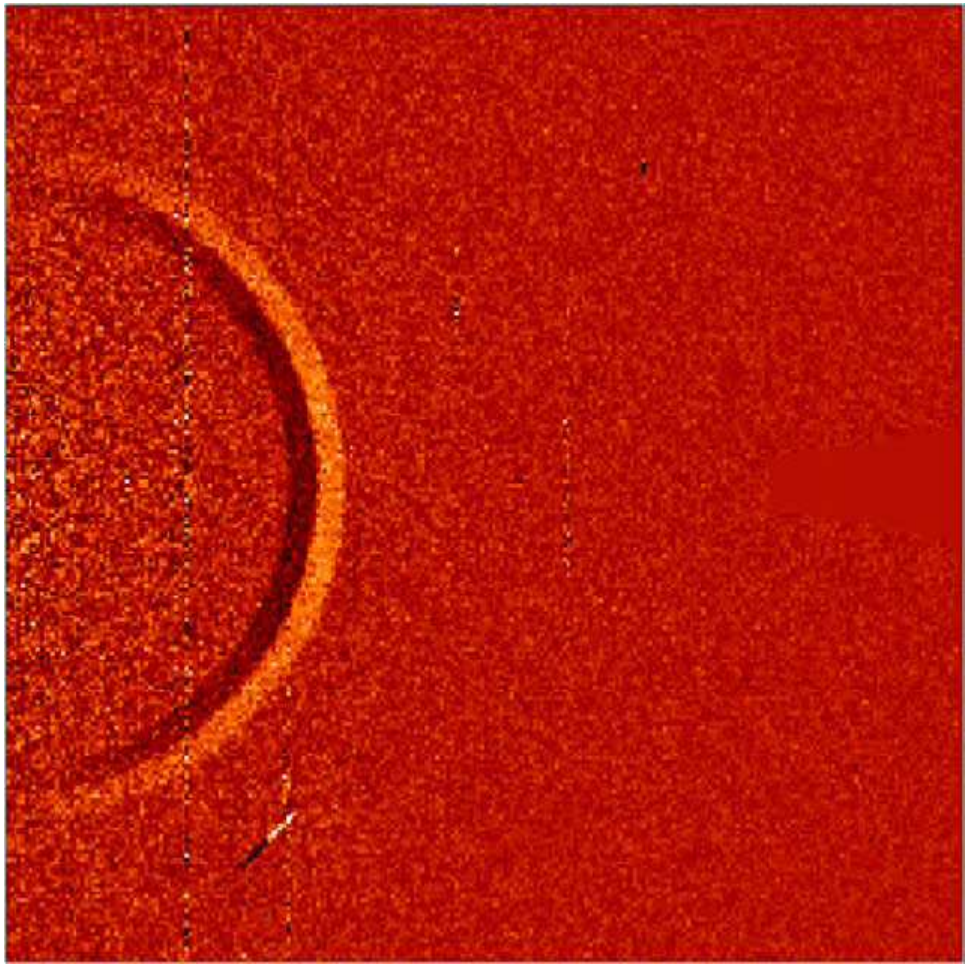
1024 x 1024

HI- Simulation Movies



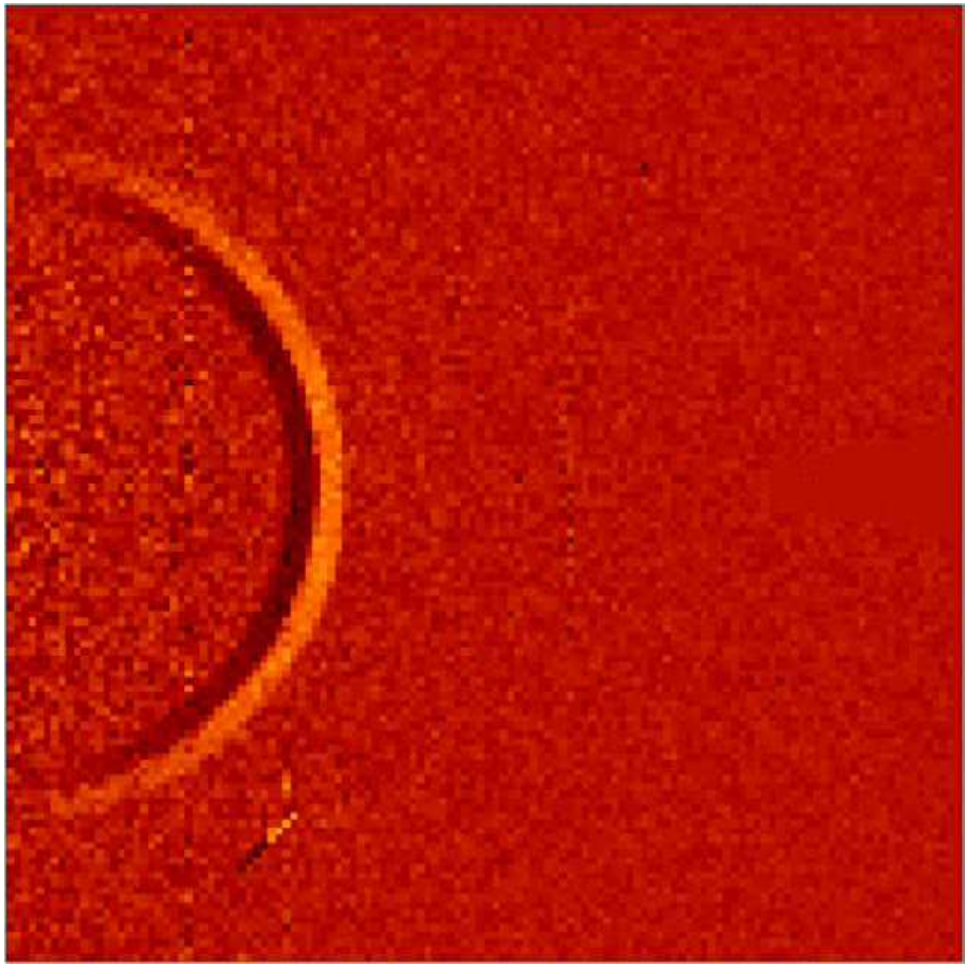
512 x 512

HI- Simulation Movies



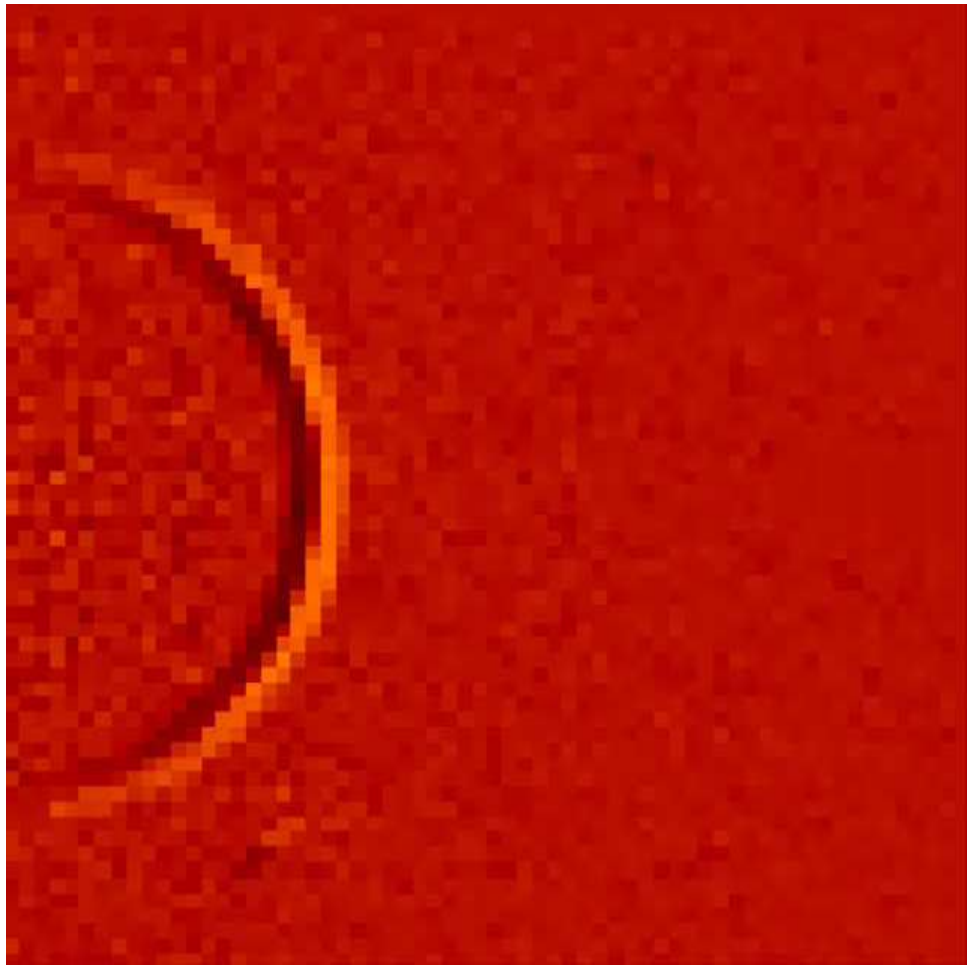
256 x 256

HI- Simulation Movies



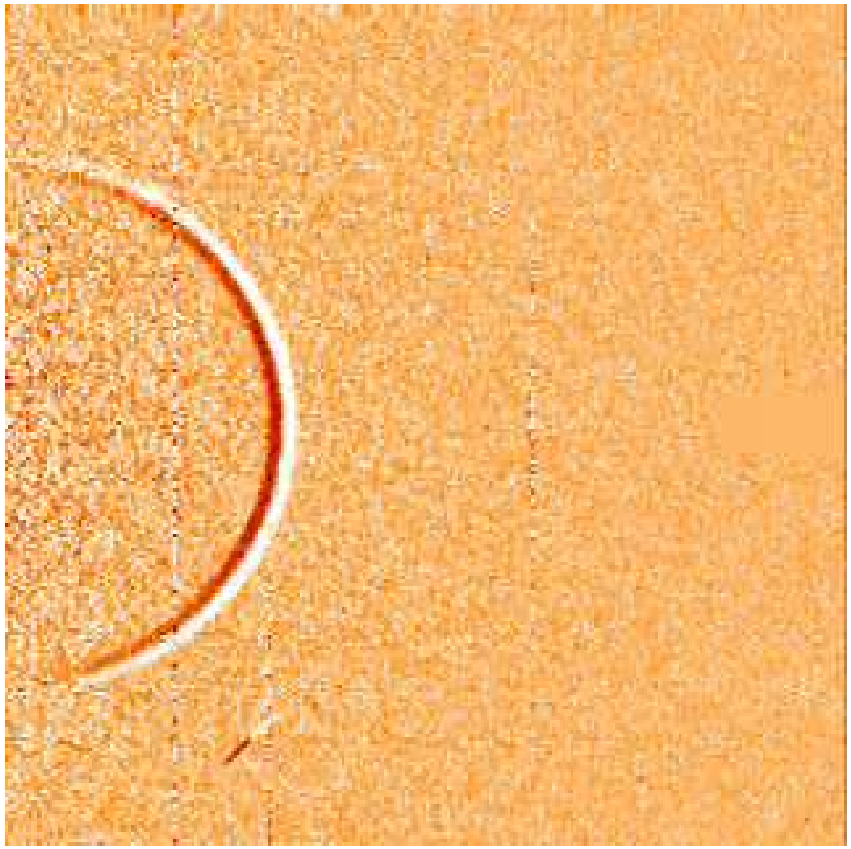
128 x 128

HI- Simulation Movies



64 x 64

- HI-2 difference movie, 1st frame subtracted.
- V ≈400 km/s
- $1/R^2$ decrease in intensity
- Re-binned to 256x256



HI Beacon Mode

- HI is a unique instrument for space weather, providing the first opportunity to view CMEs heading along the Earth-Sun line - vital that the data that goes into the Beacon telemetry stream is most useful it can be.
- Current SECCHI Beacon telemetry allocation allows for 7 256x256 images per hour.
- Simulated HI images with a base frame subtracted indicate signal to noise and resolution is good in images binned to 256x256.
- Current proposal is to alternate HI1 and HI2 images of this resolution every hour.

HI Beacon - questions

- Time taken for a CME to cross into the HI2 FOV is approx 27 hours at 400 km/s and 5.5 hours at 2000 km/s - do we want to consider the use of a trigger to switch between HI1 and 2 FOVs?
- Would we miss events doing this given CMEs are sometimes close in time?
- For fast events do we want more than one image per hour?
- Are there other simulations that would be useful?
- Do we have to worry about compression?

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 moving NEO and 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:

(i) further investigations of base-frame subtraction;

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

(iii) Modelling of a more realistic CME!

(iv) Application of techniques such as wavelet analysis to extract CME signatures.