Radiation Effects on Gaia CCDs

Thibaut Prod'homme

Sterrewacht Leiden

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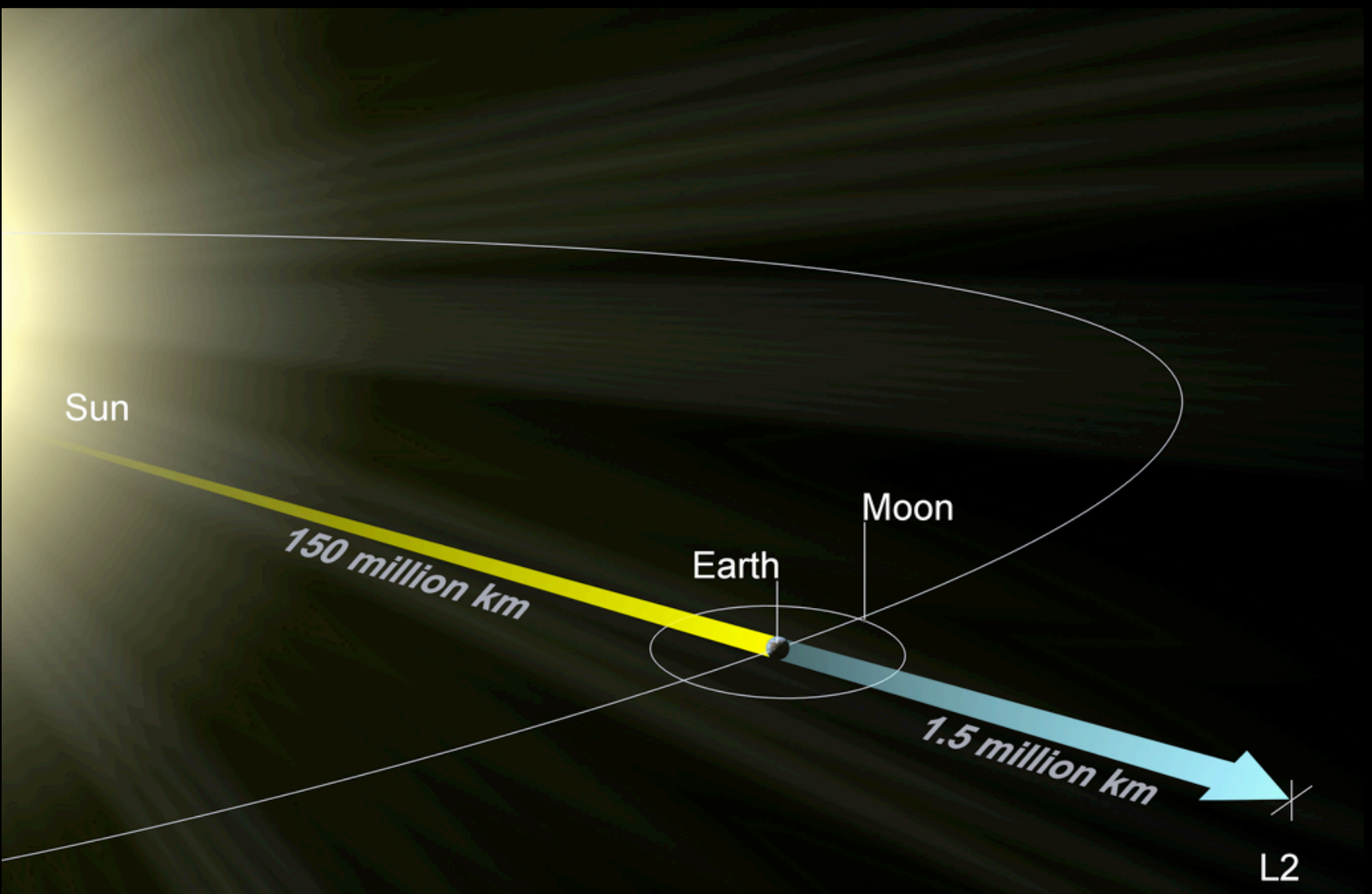
Outline

1. Gaia Radiation Environment
2. Radiation Effects on Gaia measurements
3. Modelling to mitigate the threat

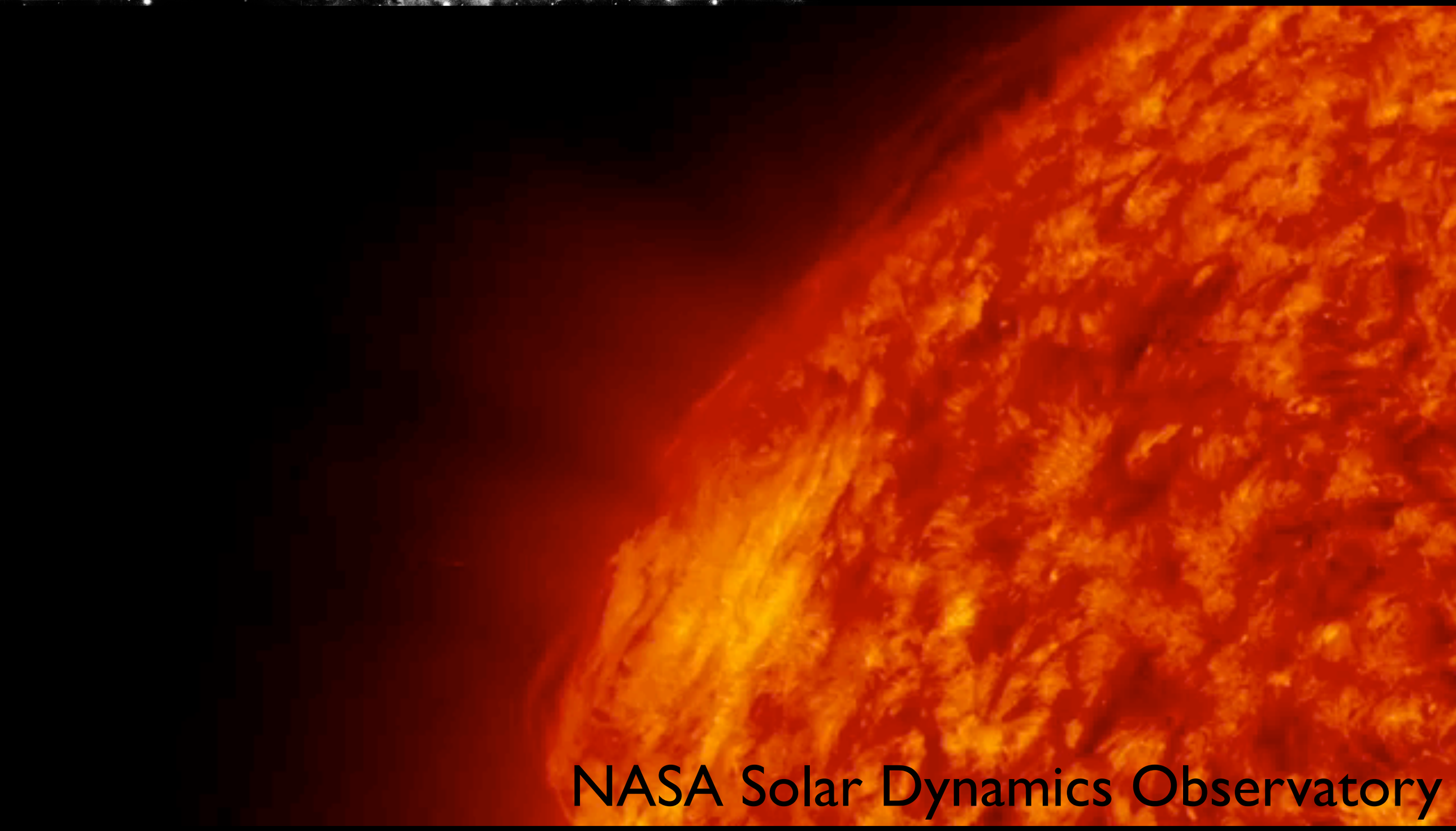
Radiation environment



- L2 environment dominated by protons
- Protons energy goes up to GeV

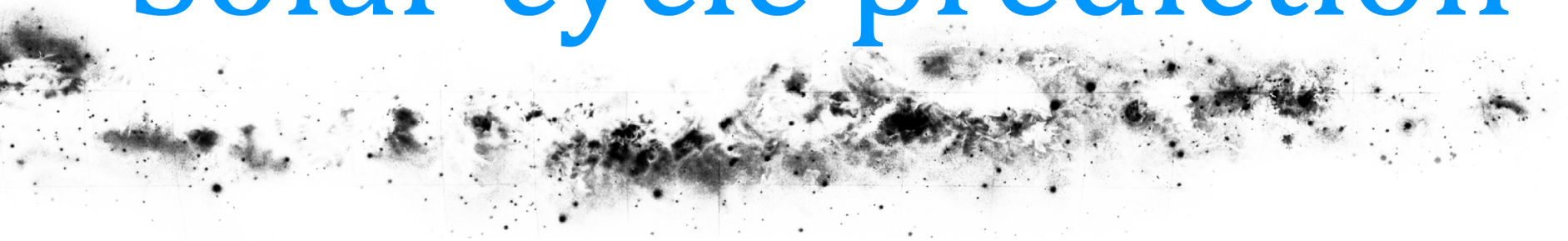
- Protons originate in solar (magnetic) events: flares, coronal mass ejections

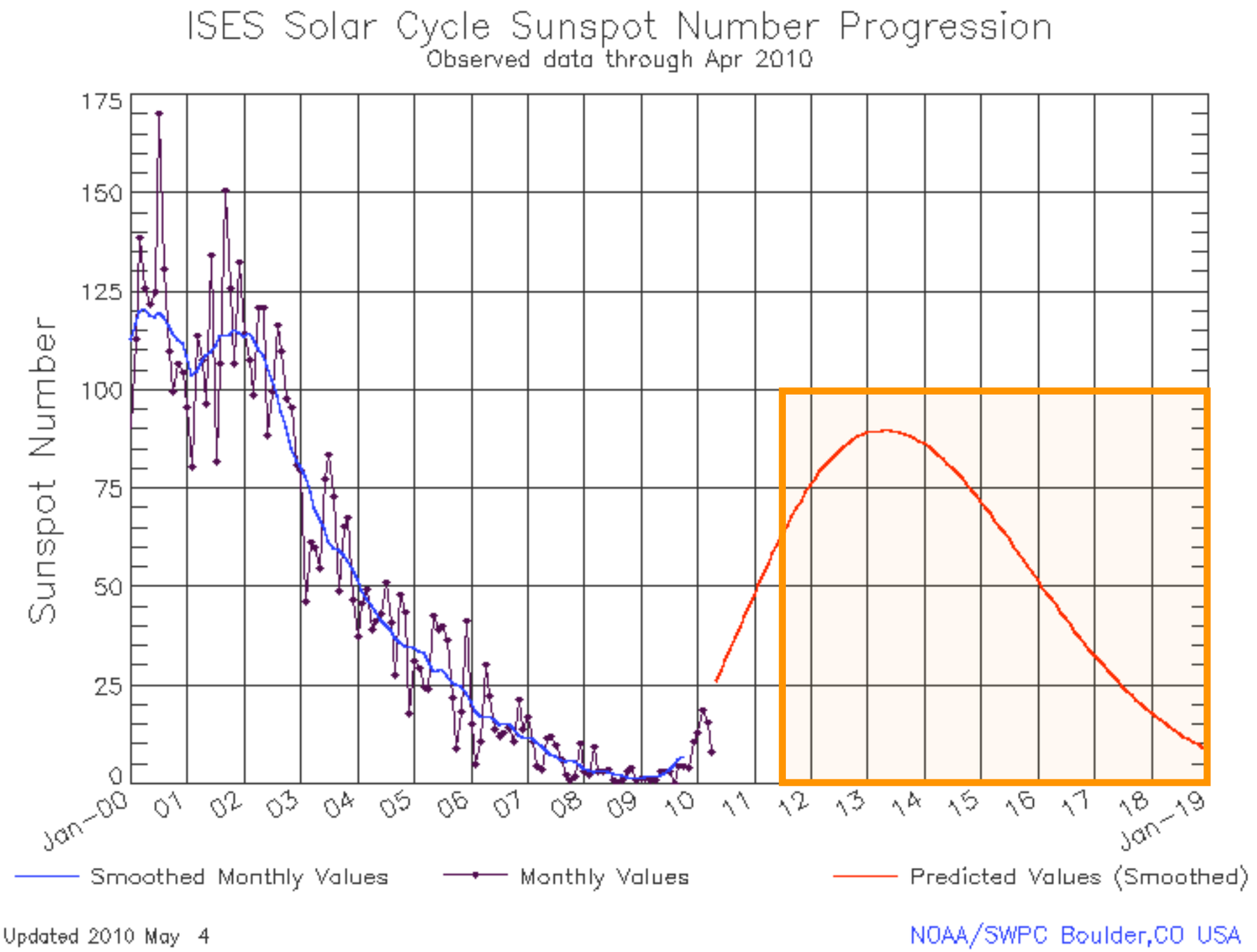
Radiation environment



NASA Solar Dynamics Observatory

Solar cycle prediction



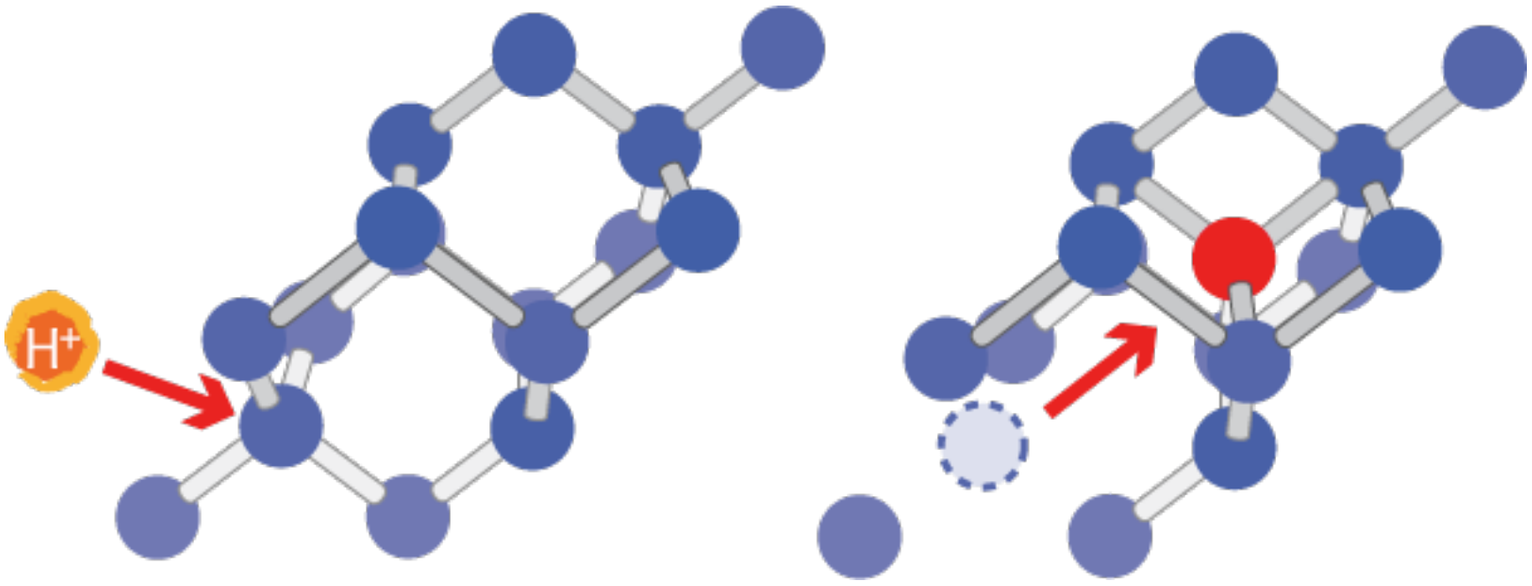


courtesy of NOAA Space weather prediction center

Radiation effects

proton collisions ⇒ displacement damage

⇒ charge transfer inefficiency (CTI)



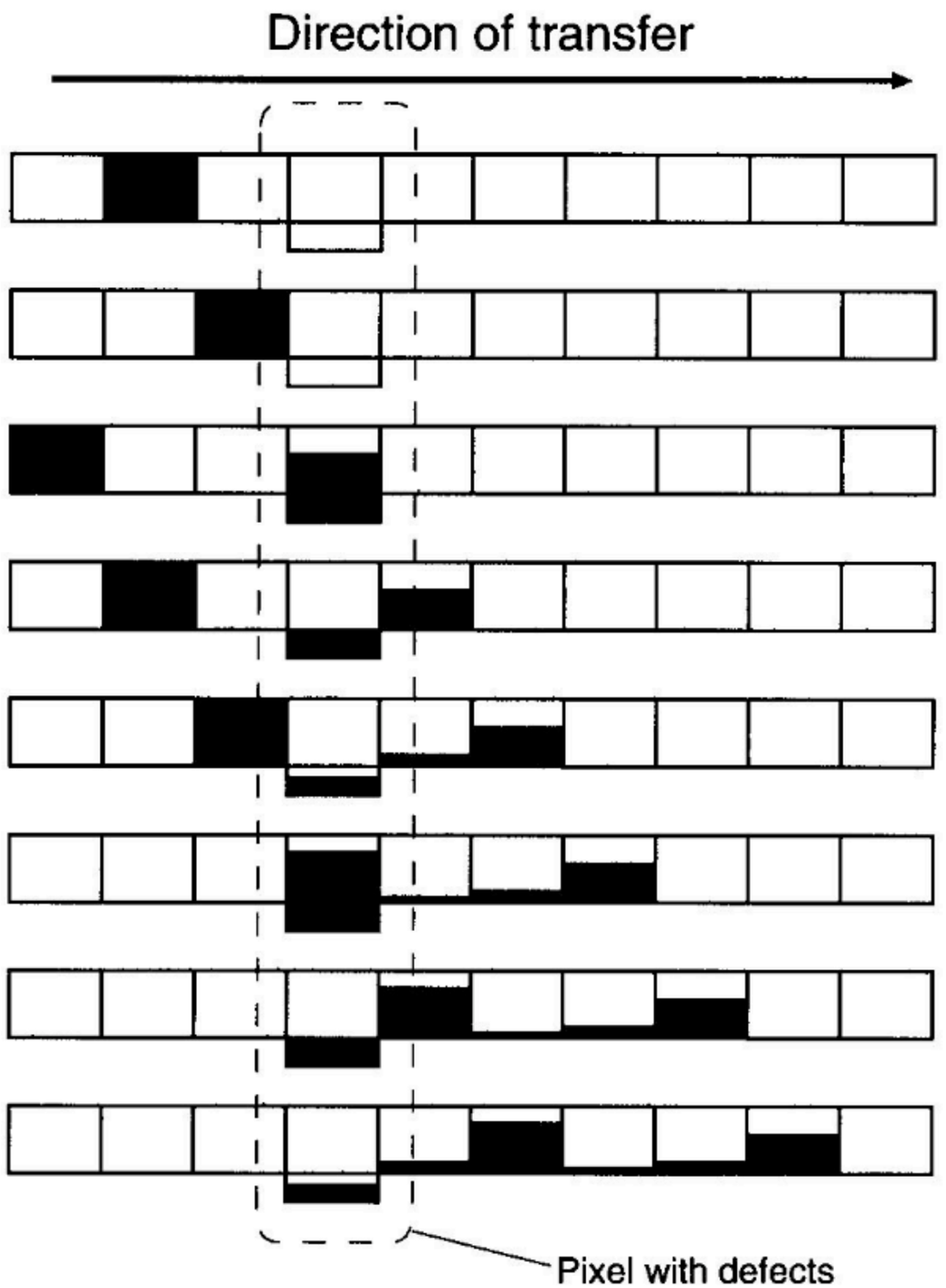
Trapping

- Capture and release = stochastic processes
- Probabilities:

$$P(t) = 1 - e^{-t/\tau}$$

- τ = capture and release time constant
- τ varies with T, E_t, σ
- $\Rightarrow$ τ is different for each trap species

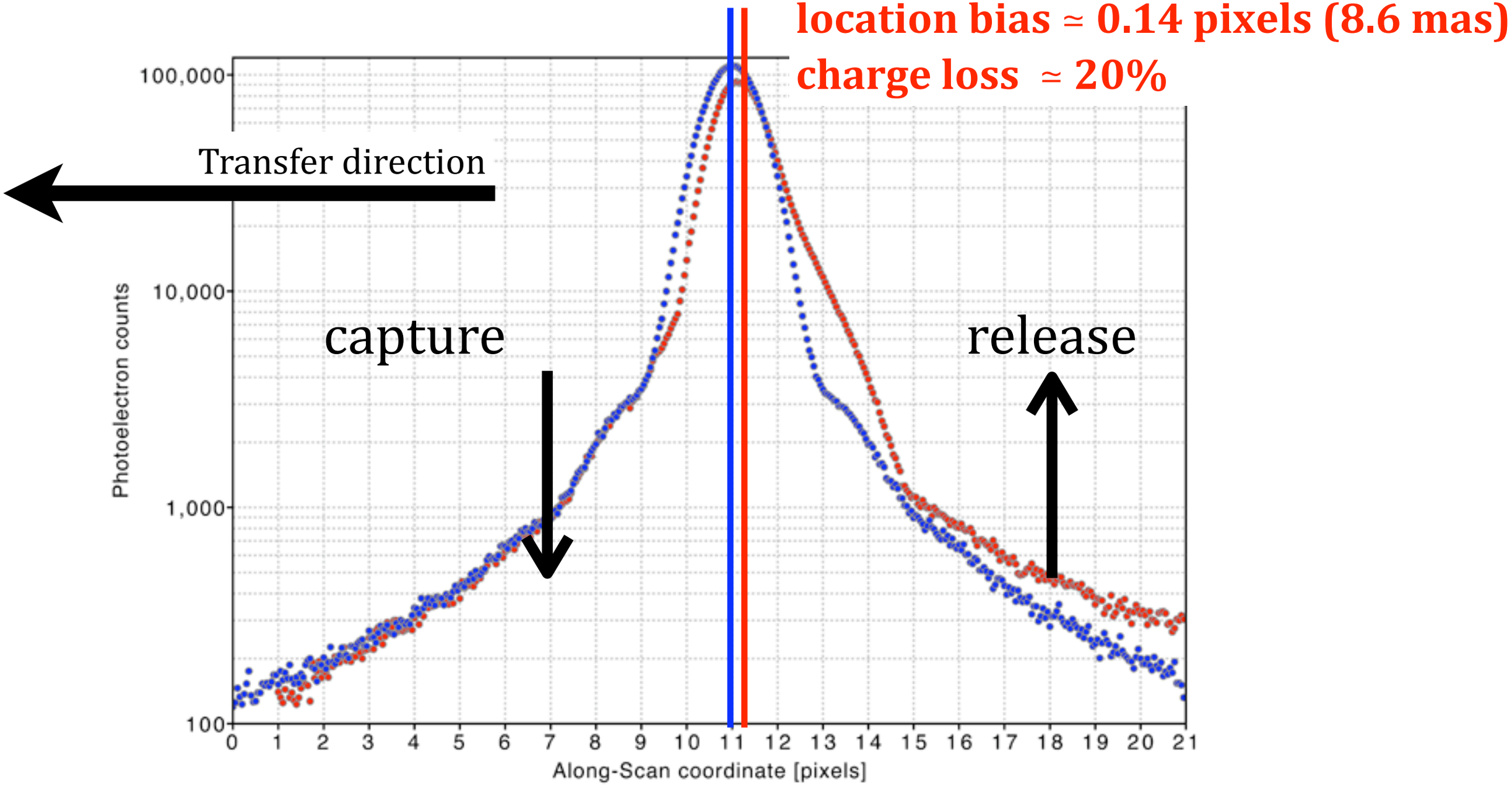
Charge Transfer Inefficiency



courtesy of J. Walder

CTI effects

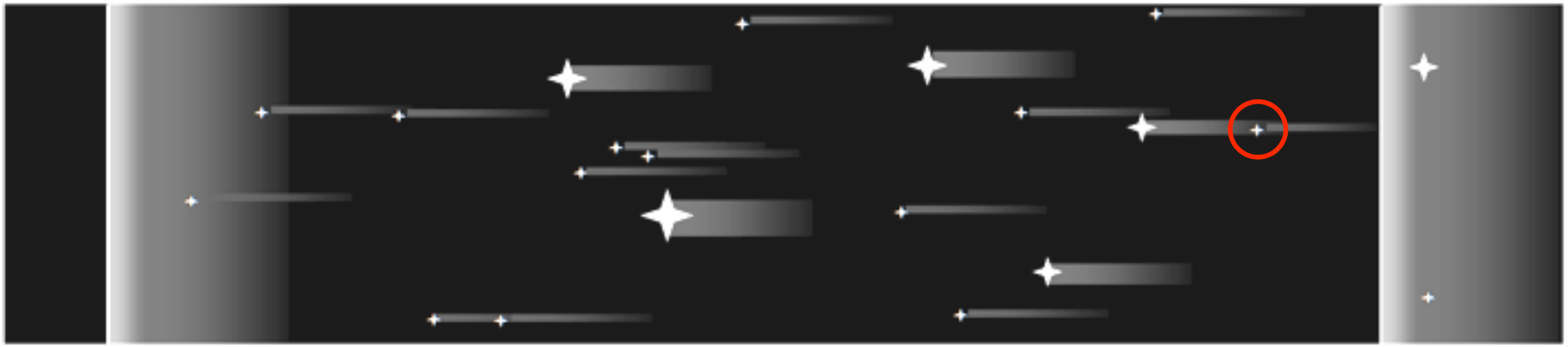
Realistic Monte-Carlo simulation: star mag14 + 3 traps/pixel



UNDAMAGED DAMAGED

CTI effects are not systematic

Transfer direction



charge injections

courtesy of A. Short

CTI effects Vs Accuracy

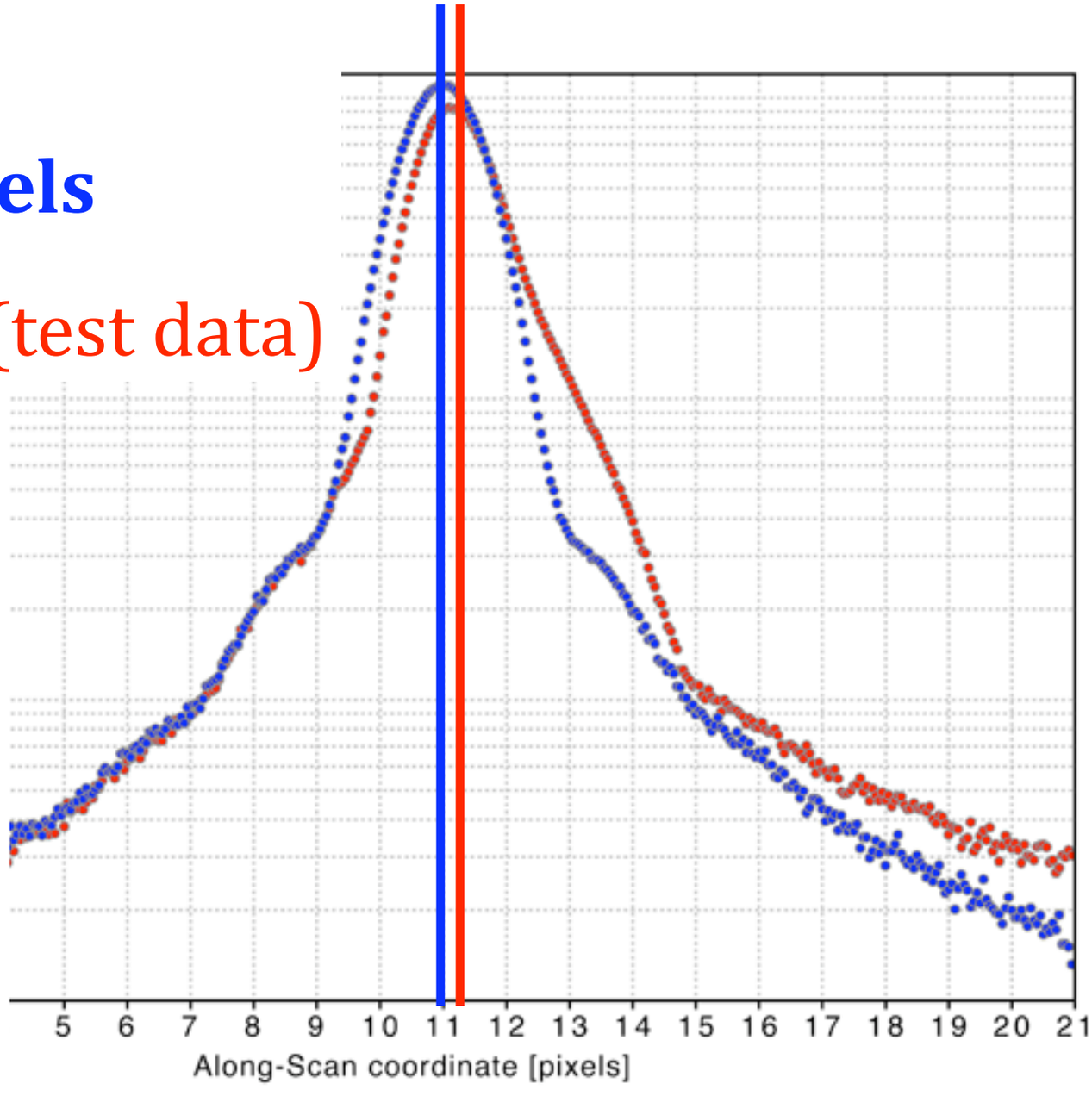
Extreme measurement accuracy, example for a <u>15 mag star</u>:

- location accuracy
  per CCD transit = **0.011 pixels**
- location bias = **0.17 pixels** (test data)

⇒ Data processing is required
to mitigate CTI effects

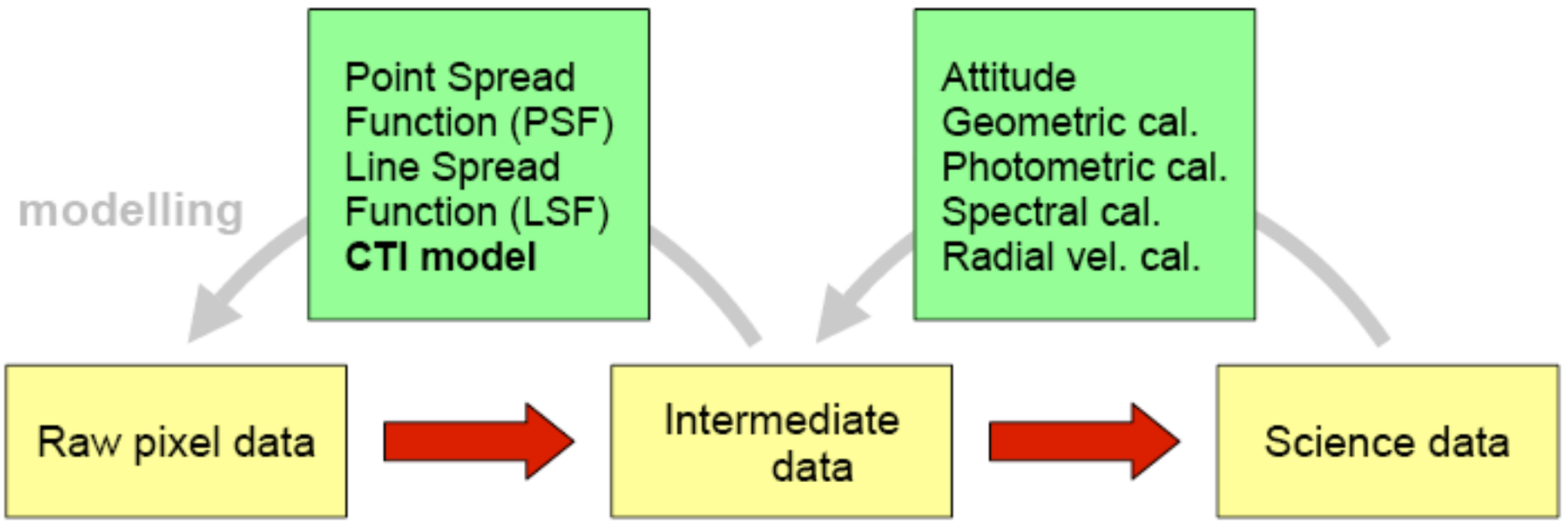
⇒ Data processing requires
<u>forward modelling</u>

⇒ 1 to 2 step is realized by a
<u>Charge Distortion Model</u>



1.EXPECTED 2.OBSERVED

Possible ways of handling CTI effects in the d.p.:
4. Direct modelling approach



Advantages:

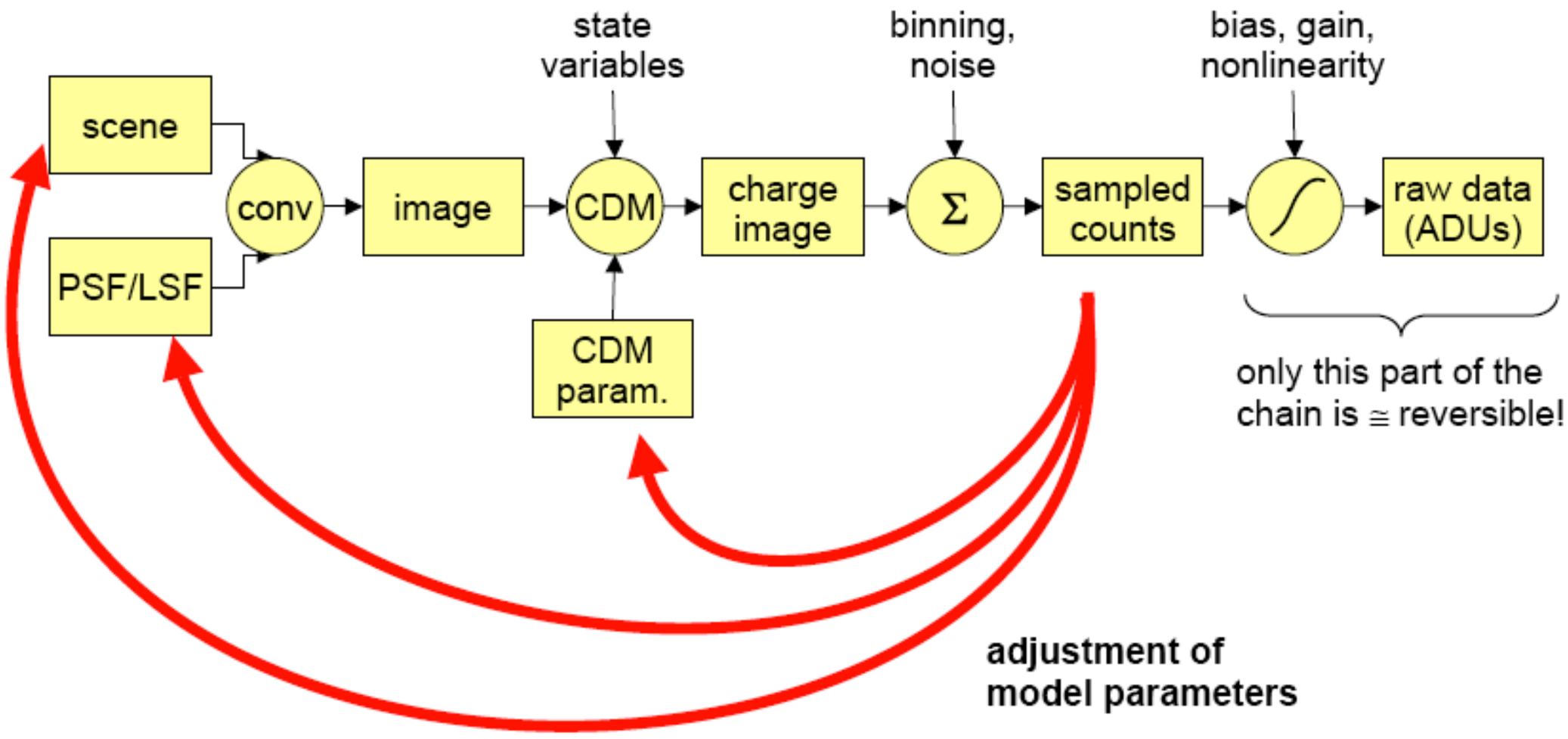
- potentially most accurate
- can in principle handle arbitrarily complex objects
- agrees with general data processing approach (self-calibrating)

Disadvantages:

- requires a CTI model that is both accurate and general
- calibration of CTI model is non-trivial
- computationally intensive

courtesy of L. Lindegren

Calibrating the LSF/PSF and CDM parameters



courtesy of L. Lindegren

Path toward CDM

1. Different levels of modelling:

- **microscopic** to get an understanding
- **macroscopic** for data processing and simulation
- **statistical** for large-scale telemetry simulation

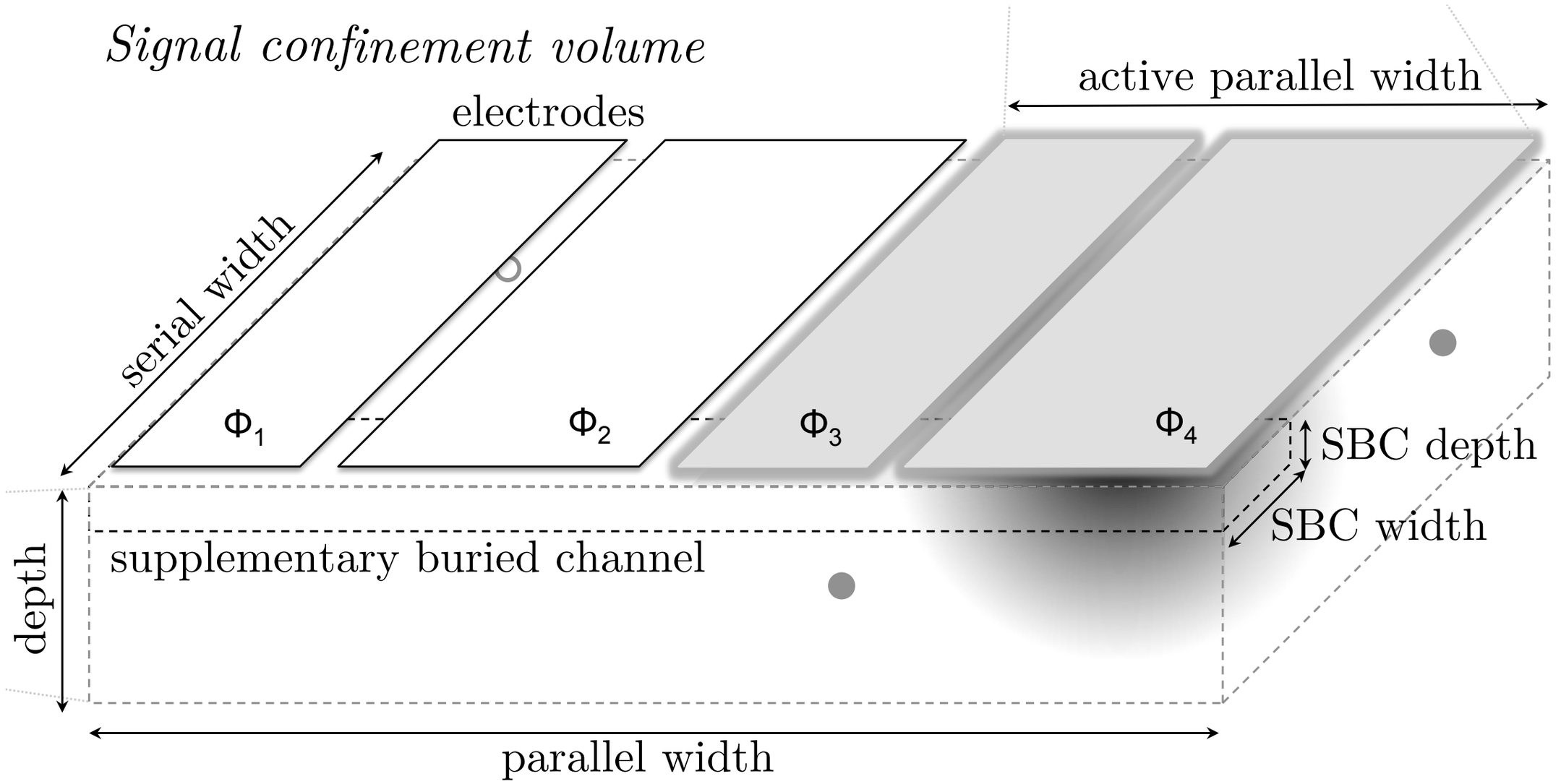
2. Experimental tests on irradiated CCD for constructing and verifying models (radiation campaings)

Microscopic MC simulation

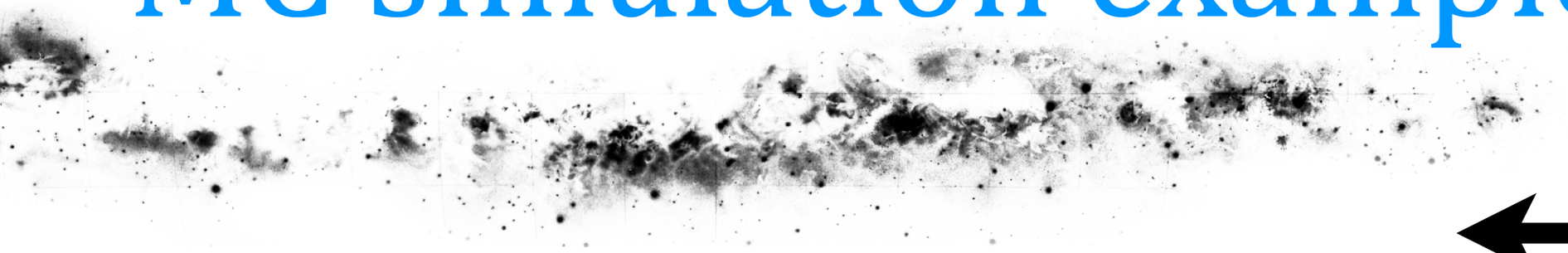
Why accurate CTI modelling?

- to study the CTI effects on Gaia measurement
- to generate realistic synthetic data
- to understand CTI effects themselves:
  - electron density distribution
  - very low signal level

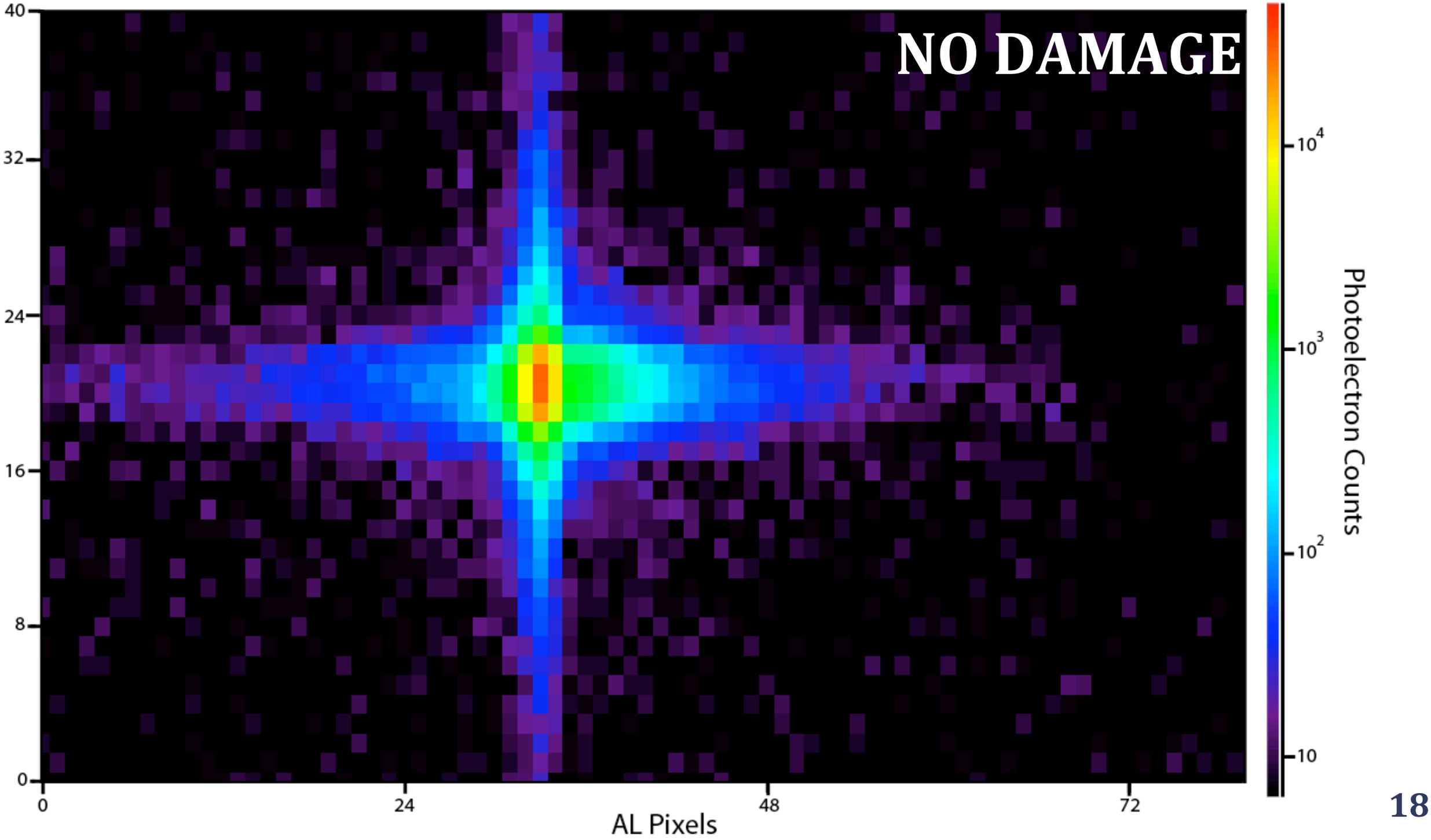
Microscopic model



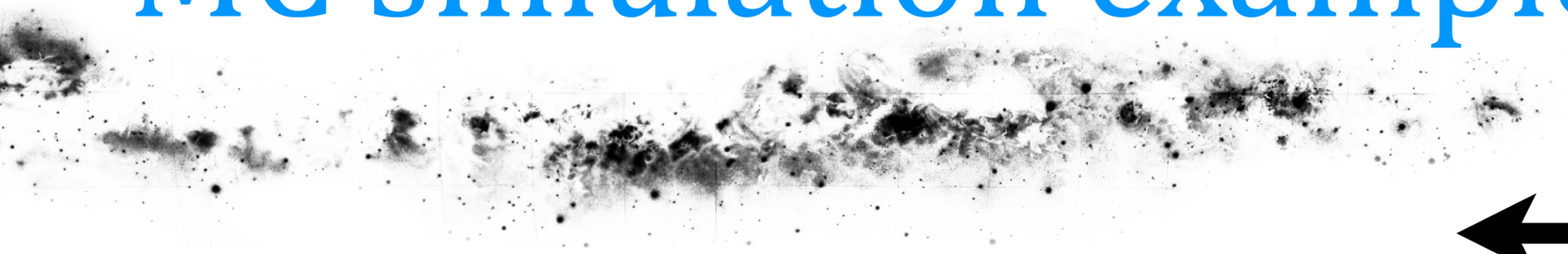
MC simulation example



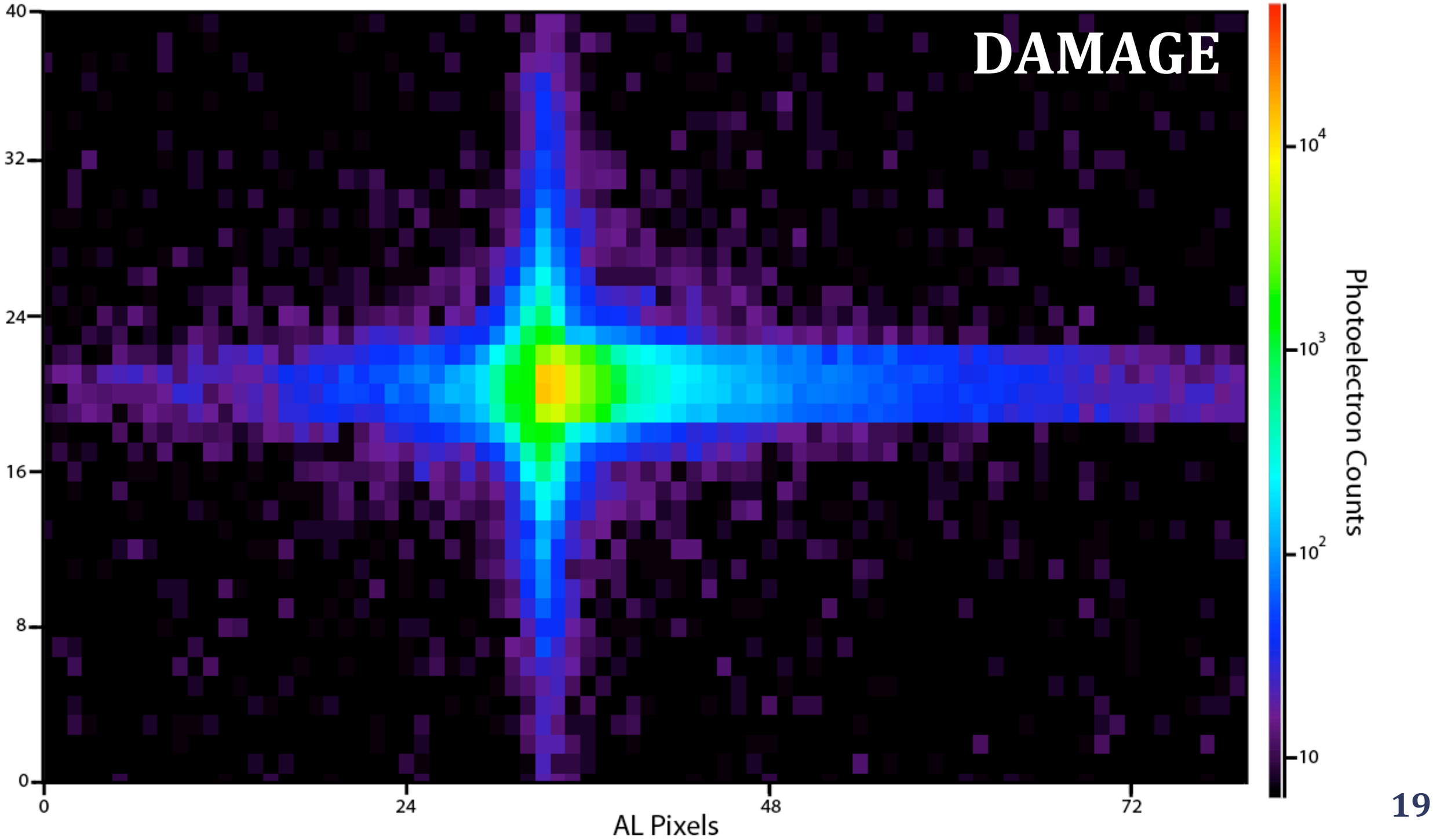
Transfer direction



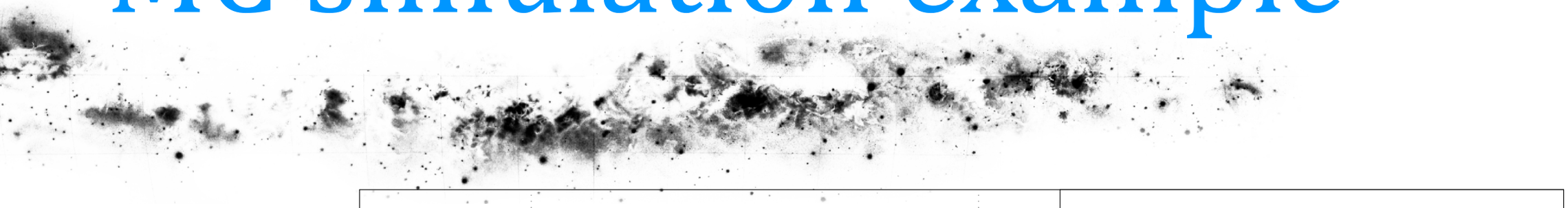
MC simulation example

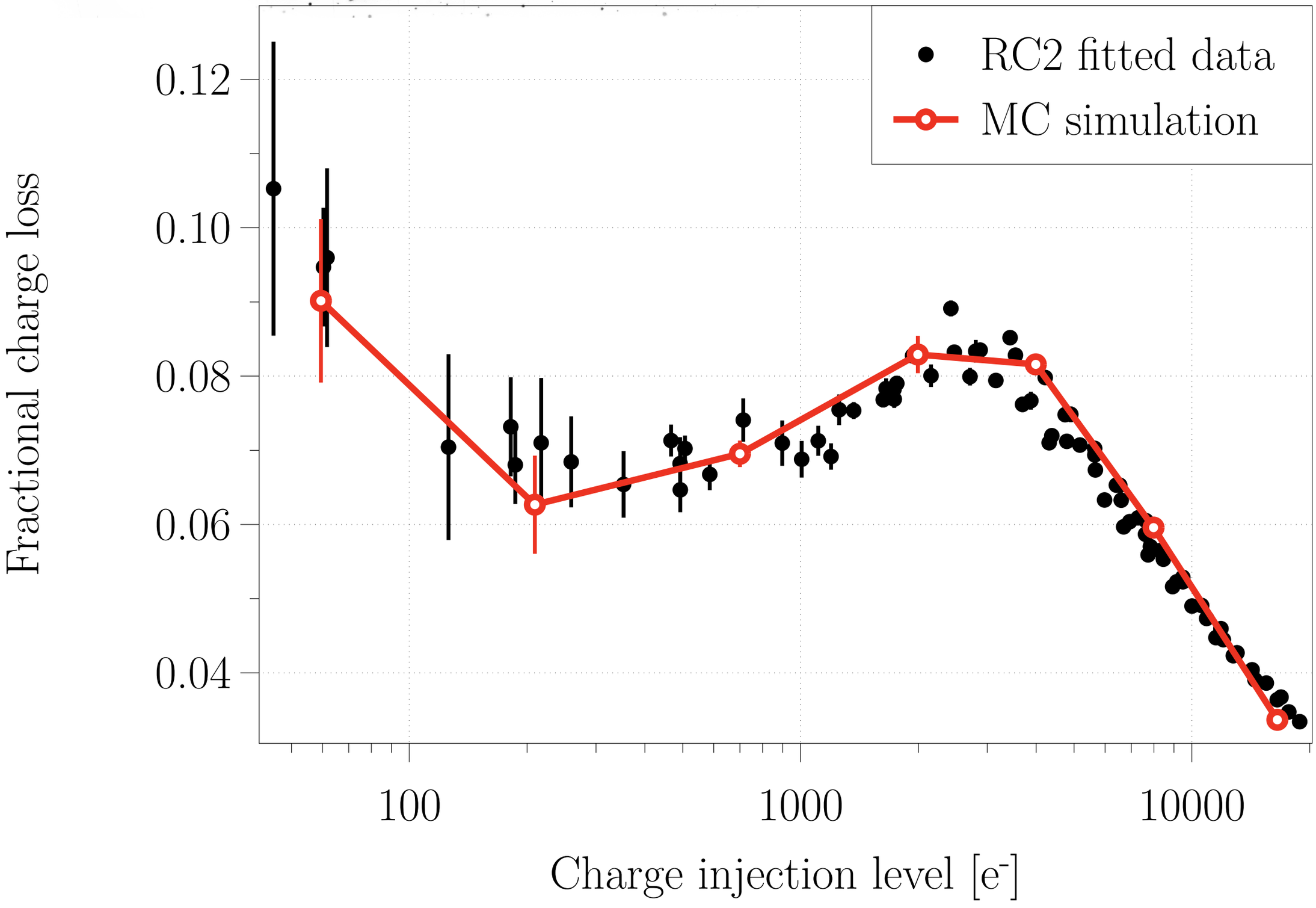


Transfer direction



MC simulation example





Conclusion

- Radiation damage is a serious threat to Gaia scientific requirements
- Forward CTI modelling to mitigate the threat
- Radiation tests + several levels of modelling are necessary for CDM elaboration
- Current microscopic modelling is capable of reproducing RC2 data over a wide range of signal levels
- Other (L2 + CCD) missions will benefit from all the harvested knowledge

Acknowledgment

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- ESA colleagues: J. de Bruijne, R. Kholey, A. Short

- And finally:

Contact information

Thibaut Prod'homme

www.strw.leidenuniv.nl/~prodhomme
prodhomme@strw.leidenuniv.nl

Leiden Observatory
Niels Bohrweg 2
NL-2333 CA Leiden
The Netherlands

+31 (0)71 527 8431