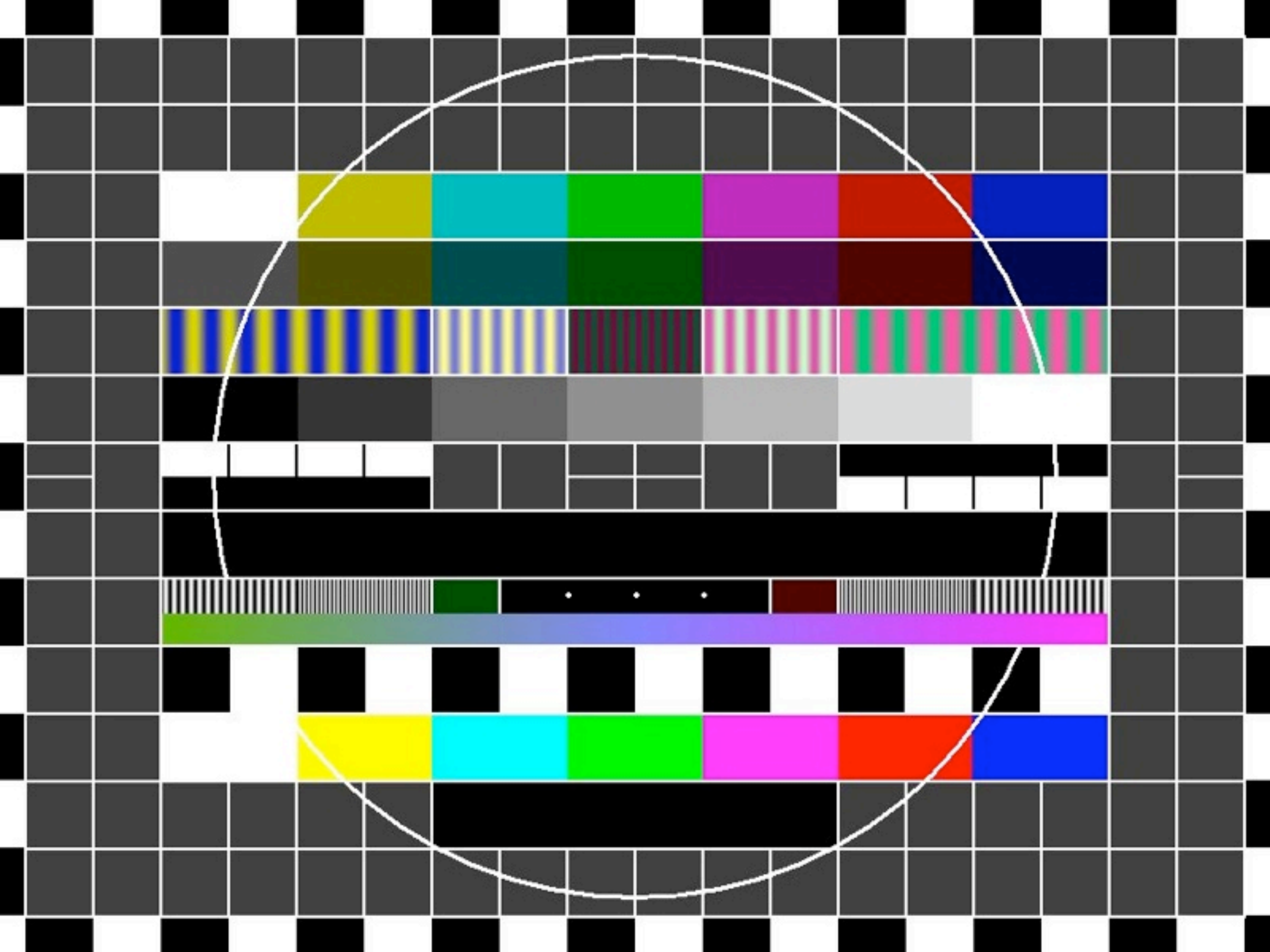

Radiation damage on Gaia CCDs

Modelling to Mitigate the Threat

Thibaut Prod'homme

Leiden Observatory

Edinburgh - Following the photons Workshop - 12 Oct 2011

1. What is CCD Radiation Damage?
2. Modelling to Mitigate the Threat!
3. Examples of Results
4. Mitigation at the Image Processing Level
5. Conclusion

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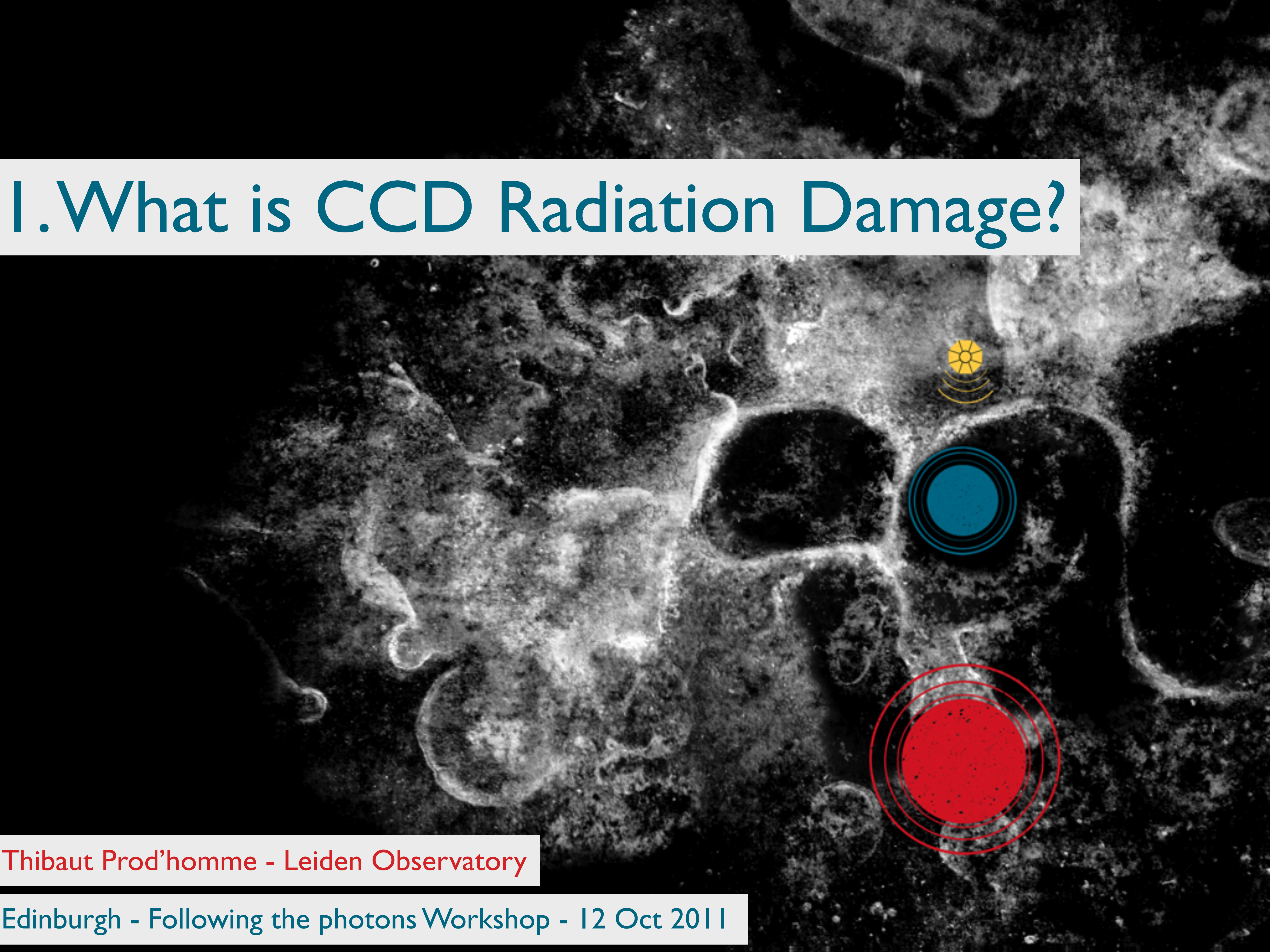
1. What is CCD Radiation Damage?



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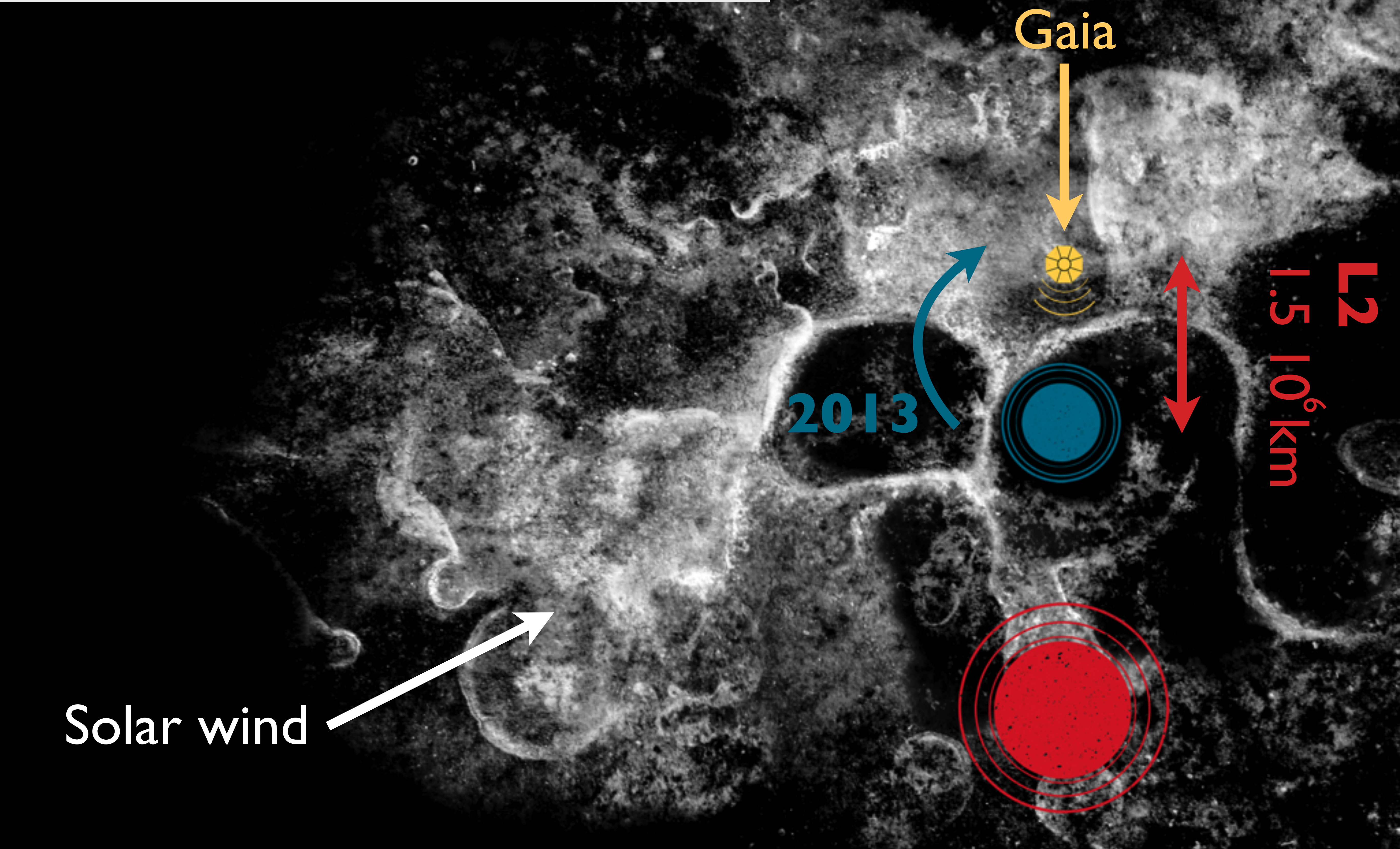
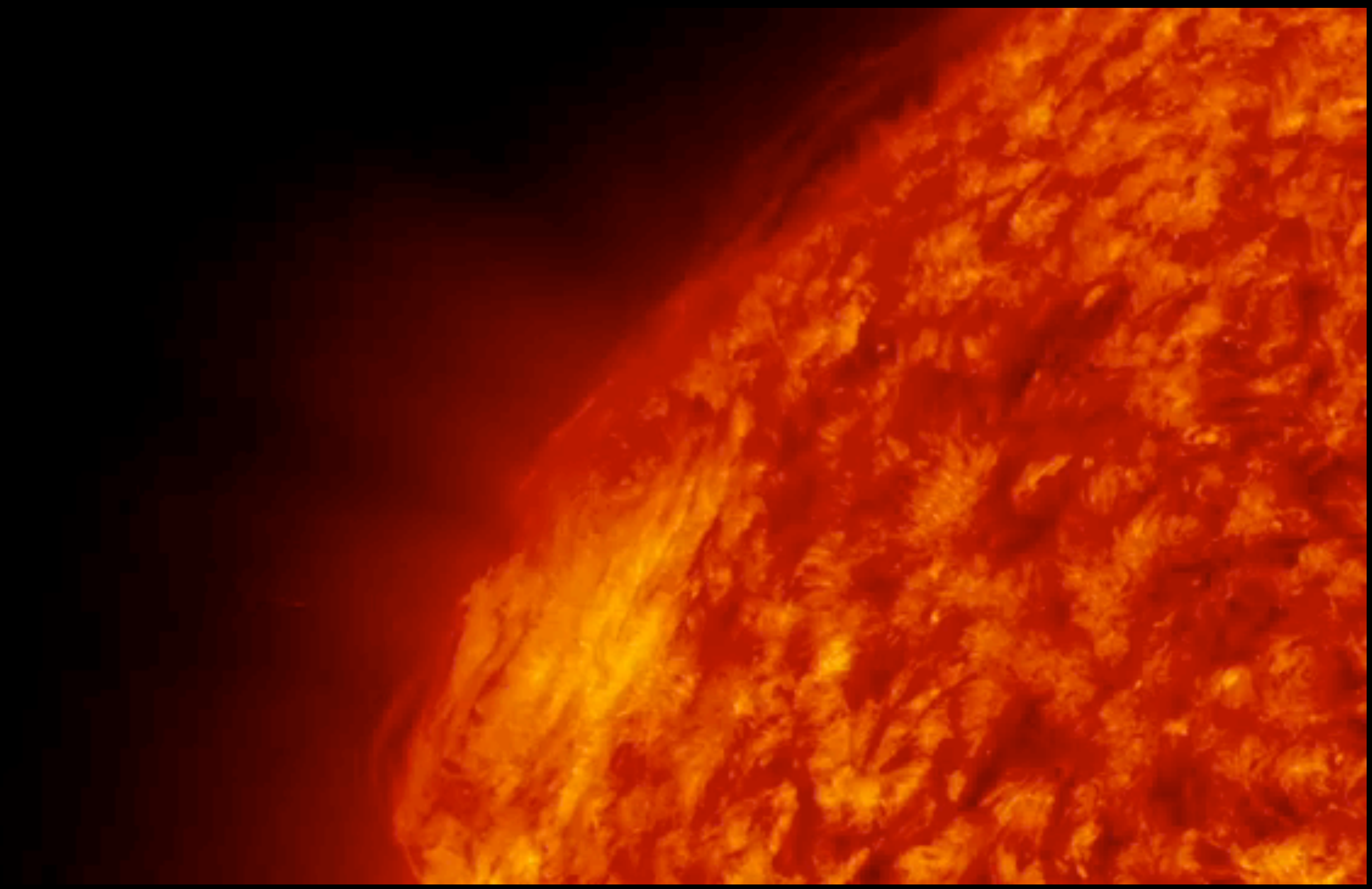
Radiation environment



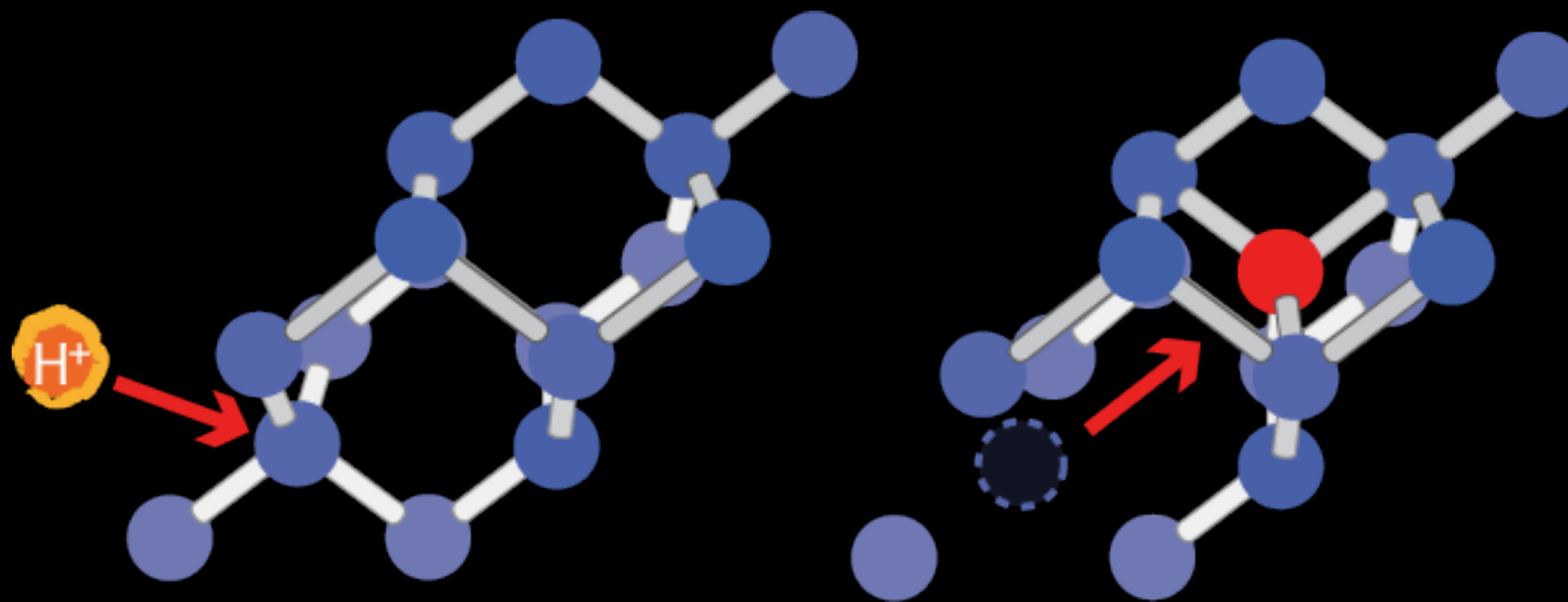
Radiation environment



NASA Solar Dynamics Observatory

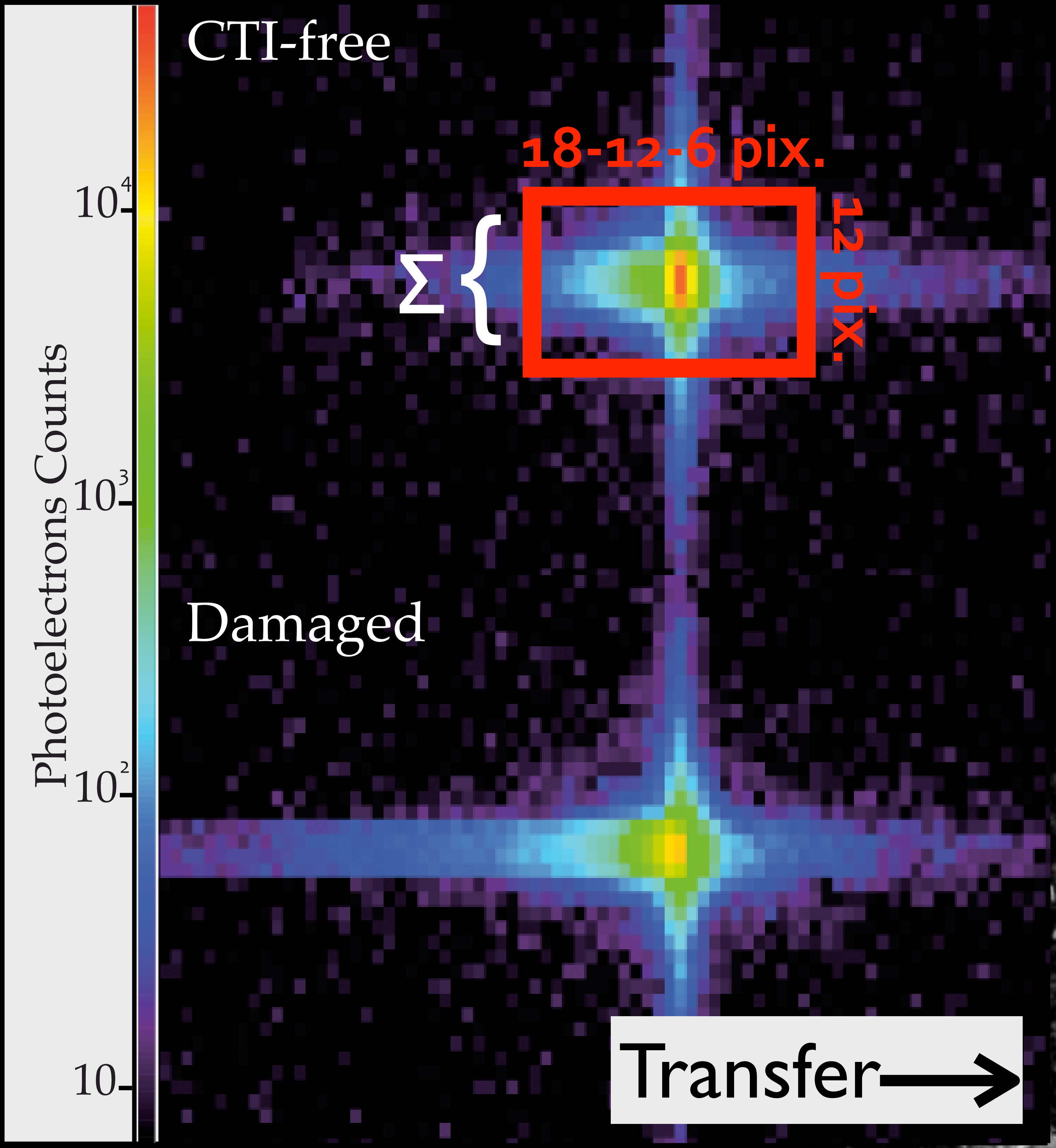
keV < E protons < MeV

Displacement damage

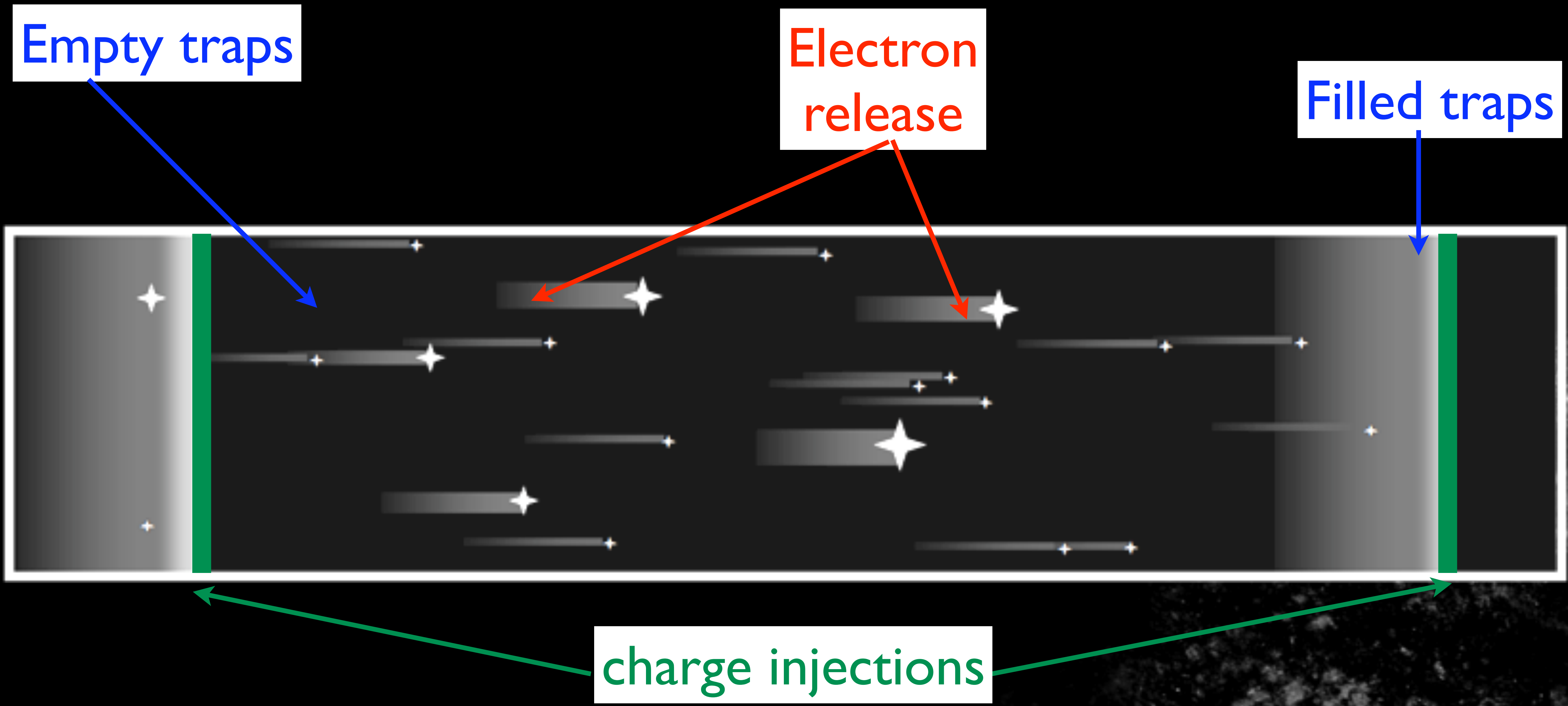


- Collision Proton - Si atom
  ➡ Vacancy - Interstitial atom
- Vacancy can bind with impurities (O, P)
- Vacancy - Impurity complex
  ➡ introduce energy level in semiconductor band-gap
- Energy levels trapped the transferred charges in the CCD
  ➡ increase the **Charge Transfer Inefficiency CTI**

CTI effects on the images

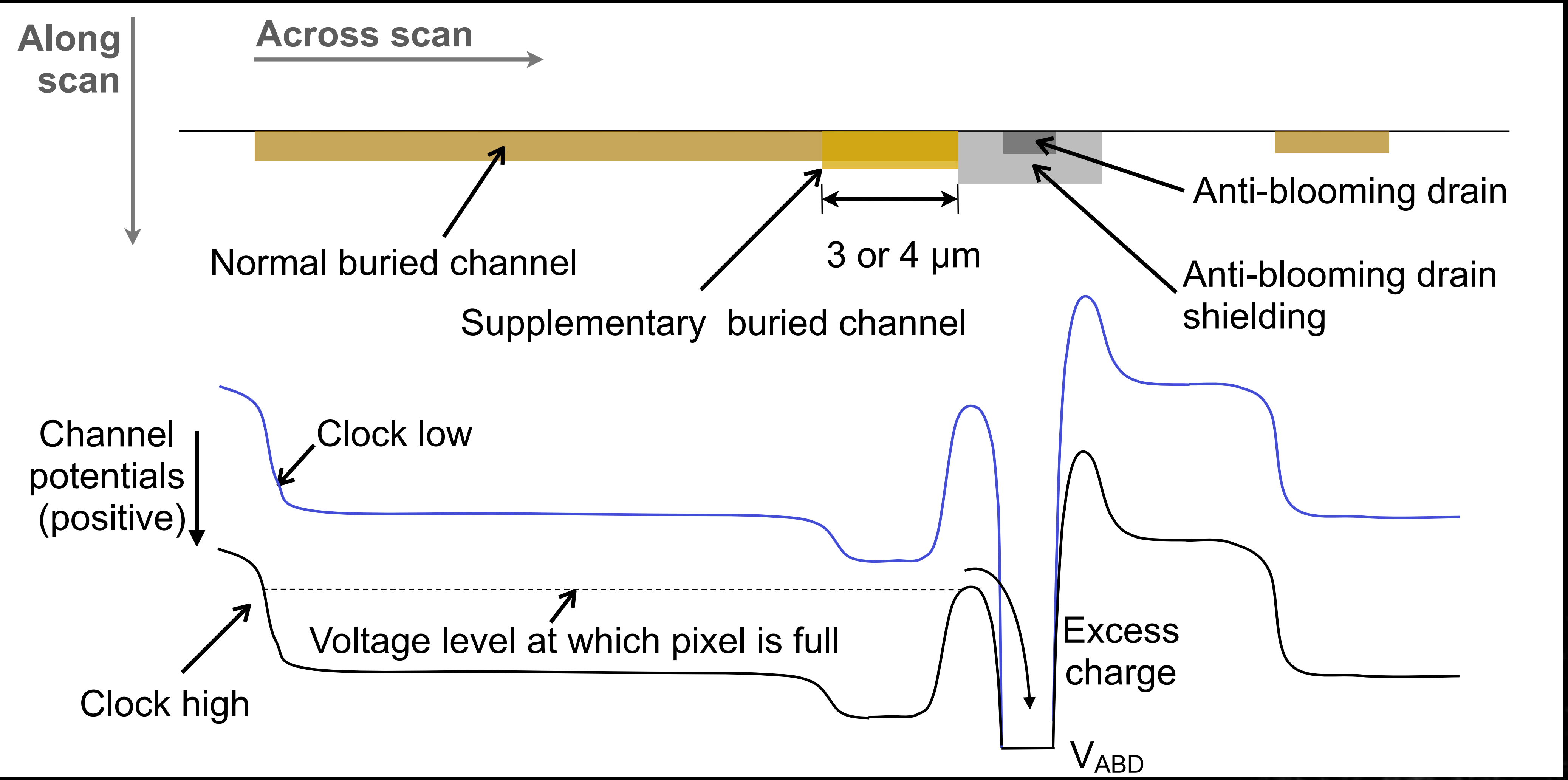


Hardware CTI countermeasures



Periodical Charge Injections

Hardware CTI countermeasures



Supplementary Buried Channel = notch

2. Modelling to Mitigate the Threat!

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How models supported CTI mitigation?

BY >>

- Understanding experimental data
- Deepening our understanding of CTI
- Characterizing in detail the CTI effects
- Calibrating for CTI in the on-ground data processing
- Testing the CTI mitigation strategy

This required a variety of models:

Publication date Author ‘name’ • level • type • computational load

1998 L. Lindegren • trap • MC physical • high

2005 A. Short • trap • MC physical • high

2007 A. Short • image • analytic physical • moderate

2008 L. Lindegren ‘CDM01’ • image • analytic phenomenological • low

2009 A. Short ‘CDM02’ • image • analytic semi-physical • low

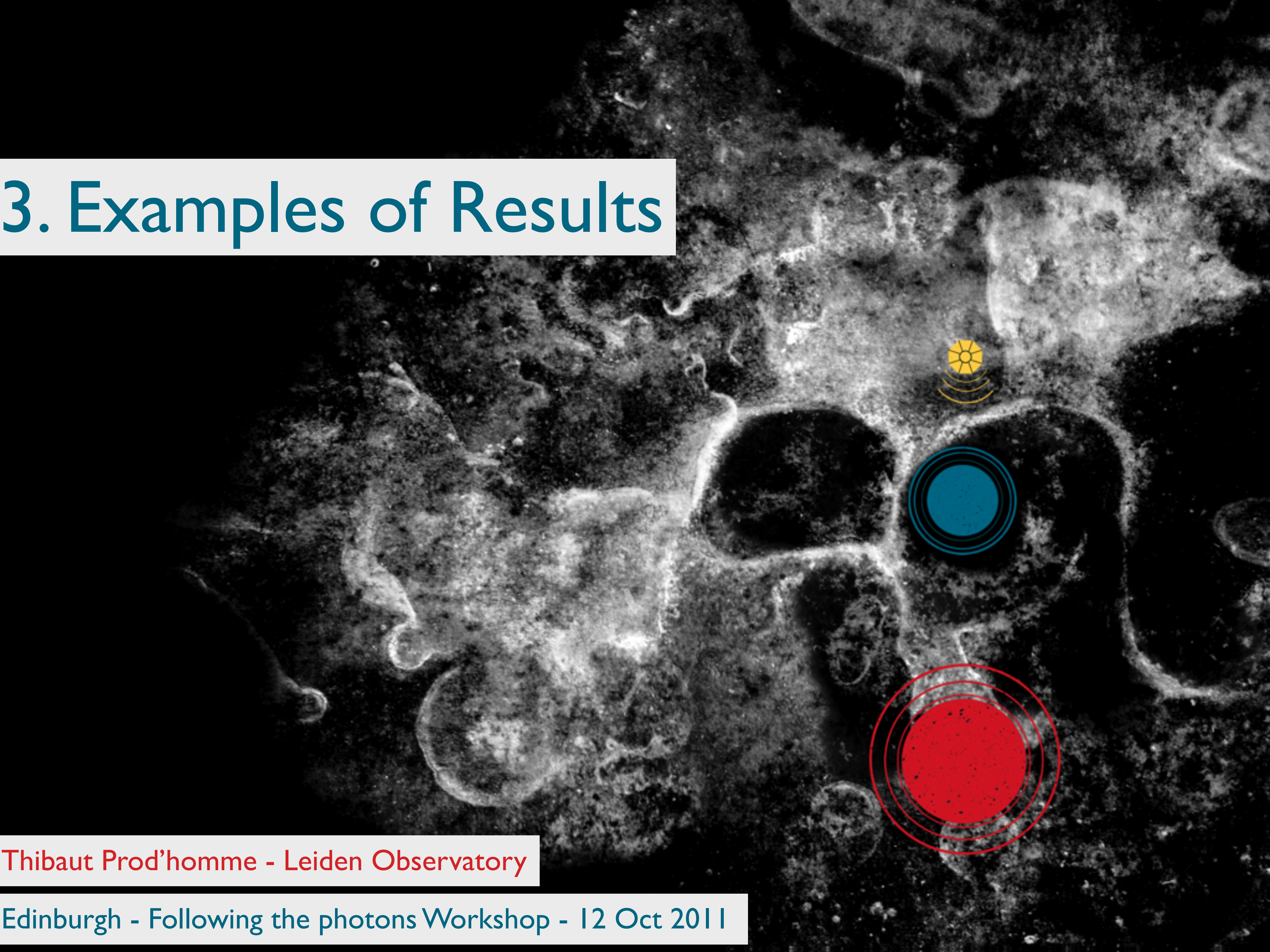
2010 G. Seabroke • pixel architecture • analytic physical • high

2010 A. Short ‘CDM03’ • image • analytic semi-physical • low

2011 T. Prod’homme • trap • MC physical • high

2011 B. Holl • statistical • analytic phenomenological • low

3. Examples of Results



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This required a variety of models

Why so many different models and why not using what already existed?

Different operation of the CCD than e.g., HST:

TDI Time-delayed integration = CCD constantly readout

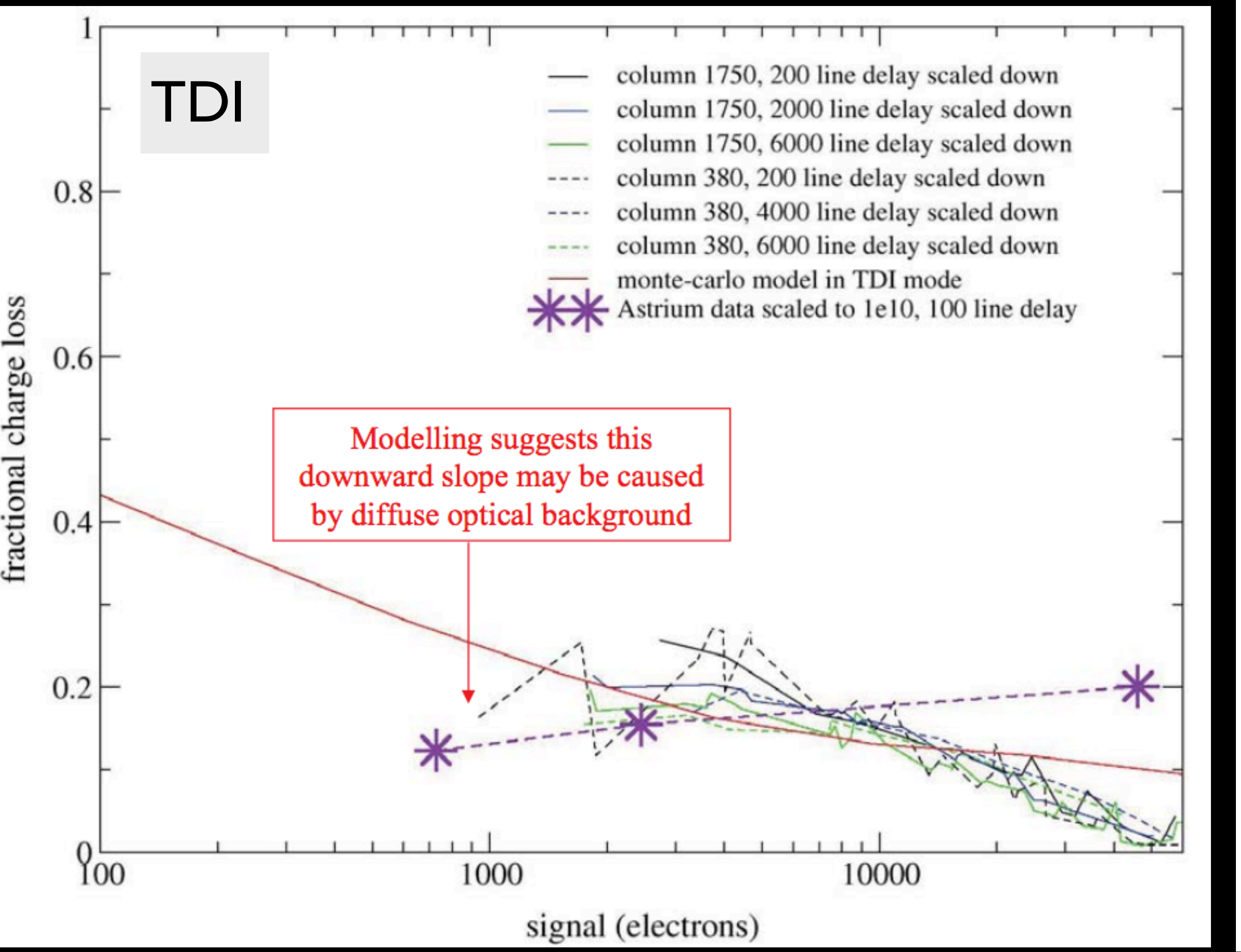
=> Very low background (1e-/pixel at readout),

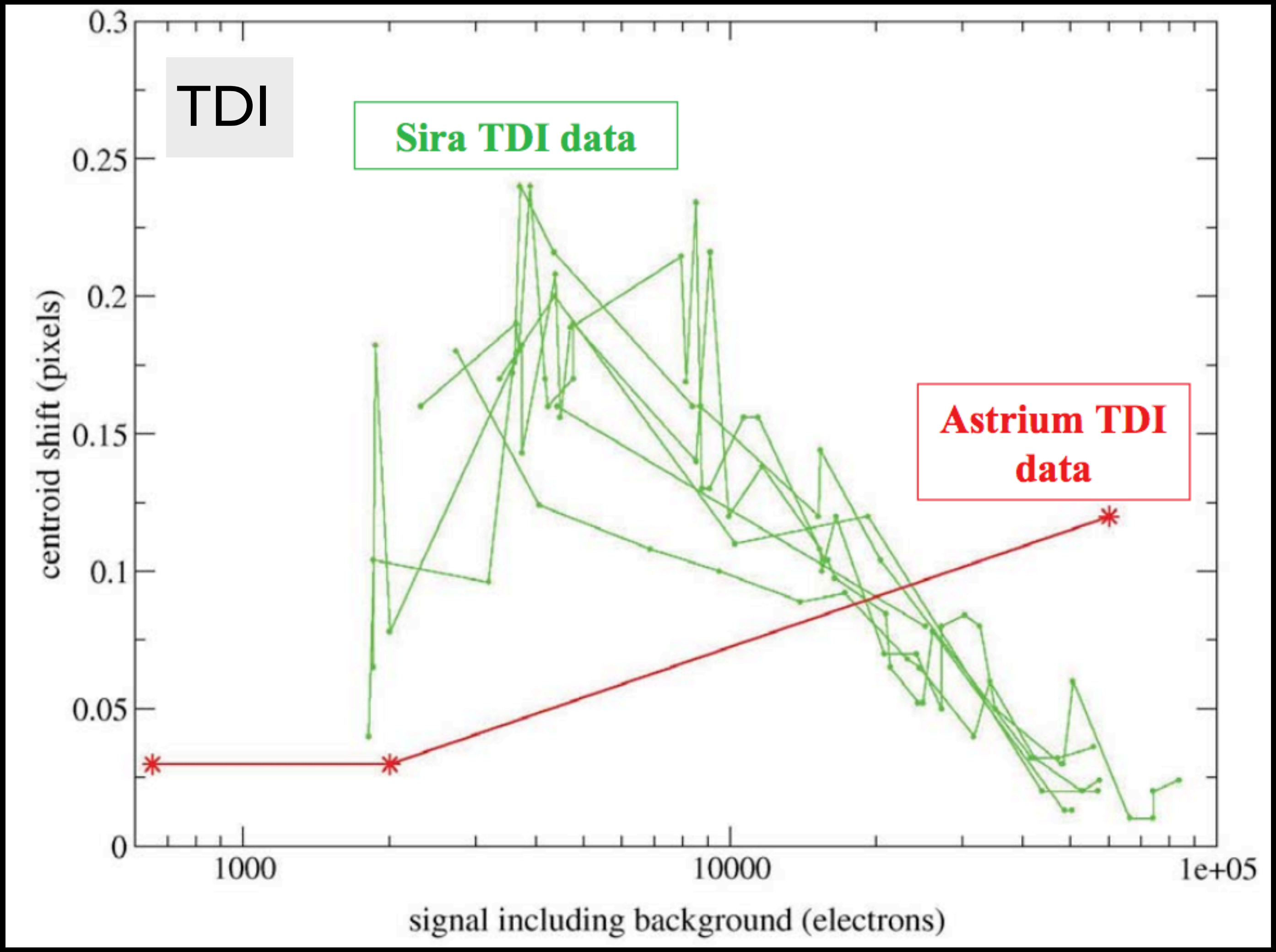
=> Very low signal level even for bright stars for a part of the transit

No full frame data, 1D images

Understanding experimental data

+ Deepening our understanding of CTI





Figs courtesy A. Short (ESA/ESTEC)

Discrepancy in image location bias and charge loss between Sira (now Surrey) and Astrium first tests at same signal level

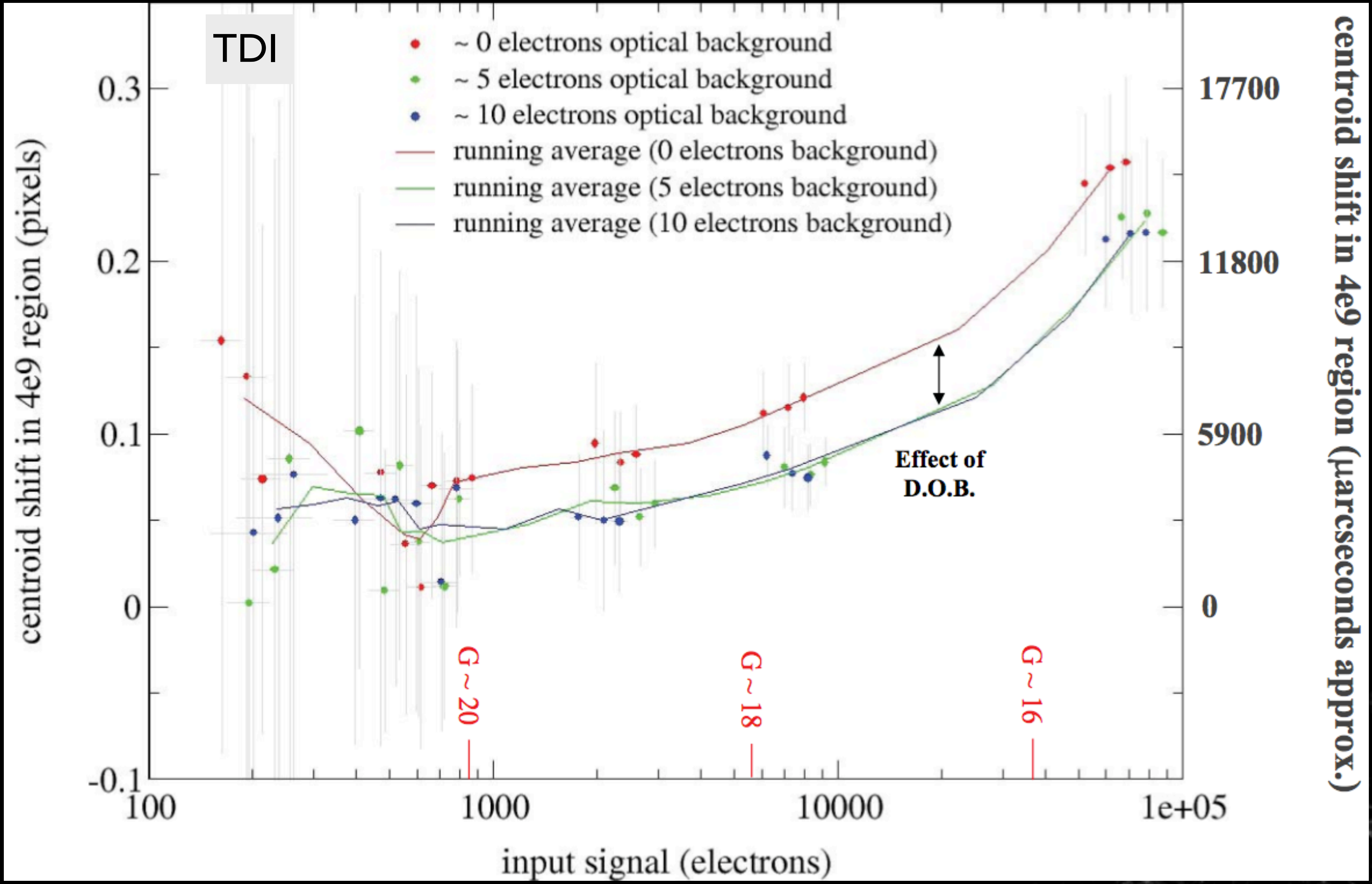


Fig courtesy A. Short (ESA/ESTEC)

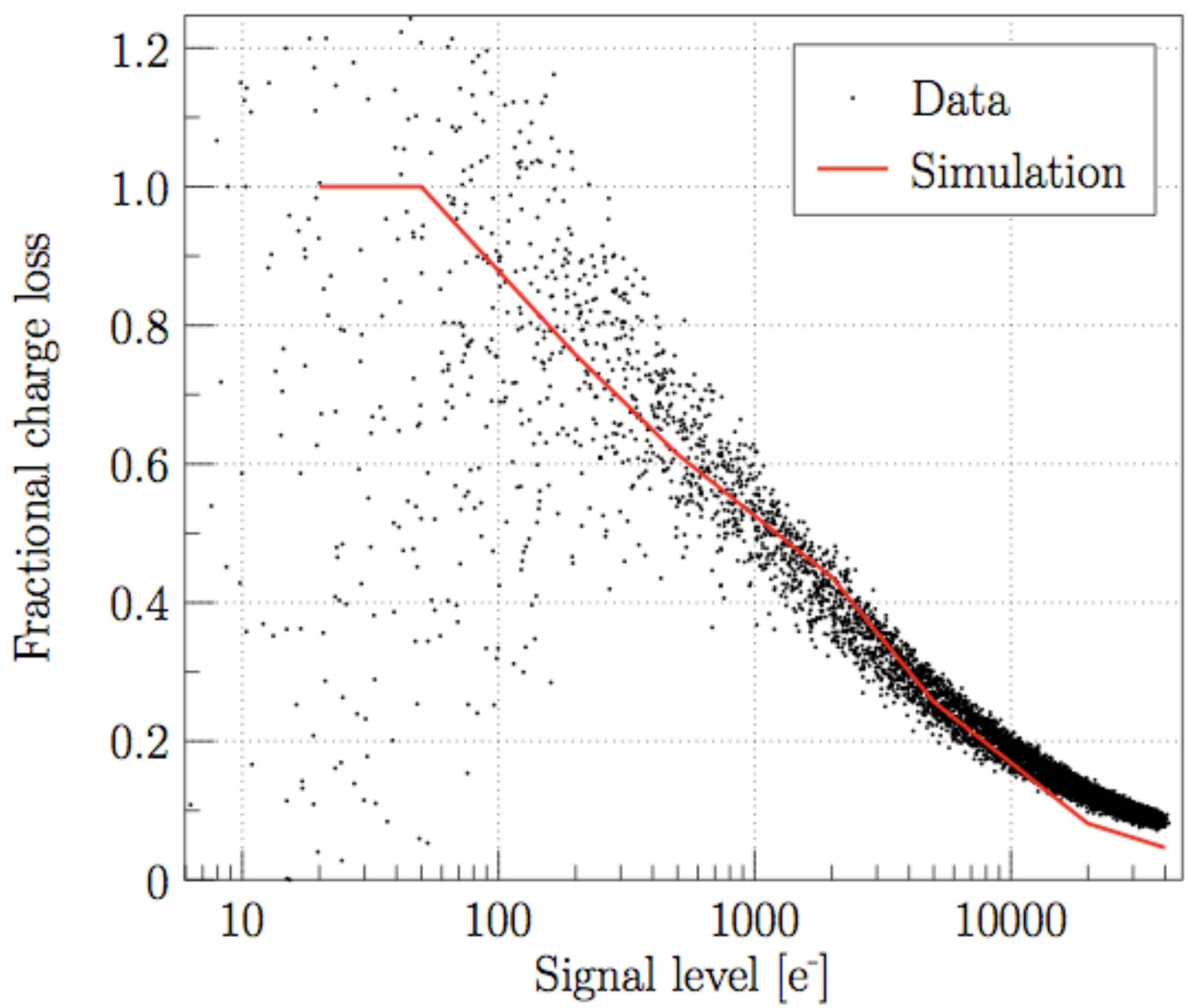
model 2005 A. Short (trap level • MC physical) showed that:

- A difference in the background level of a few electrons makes a big difference

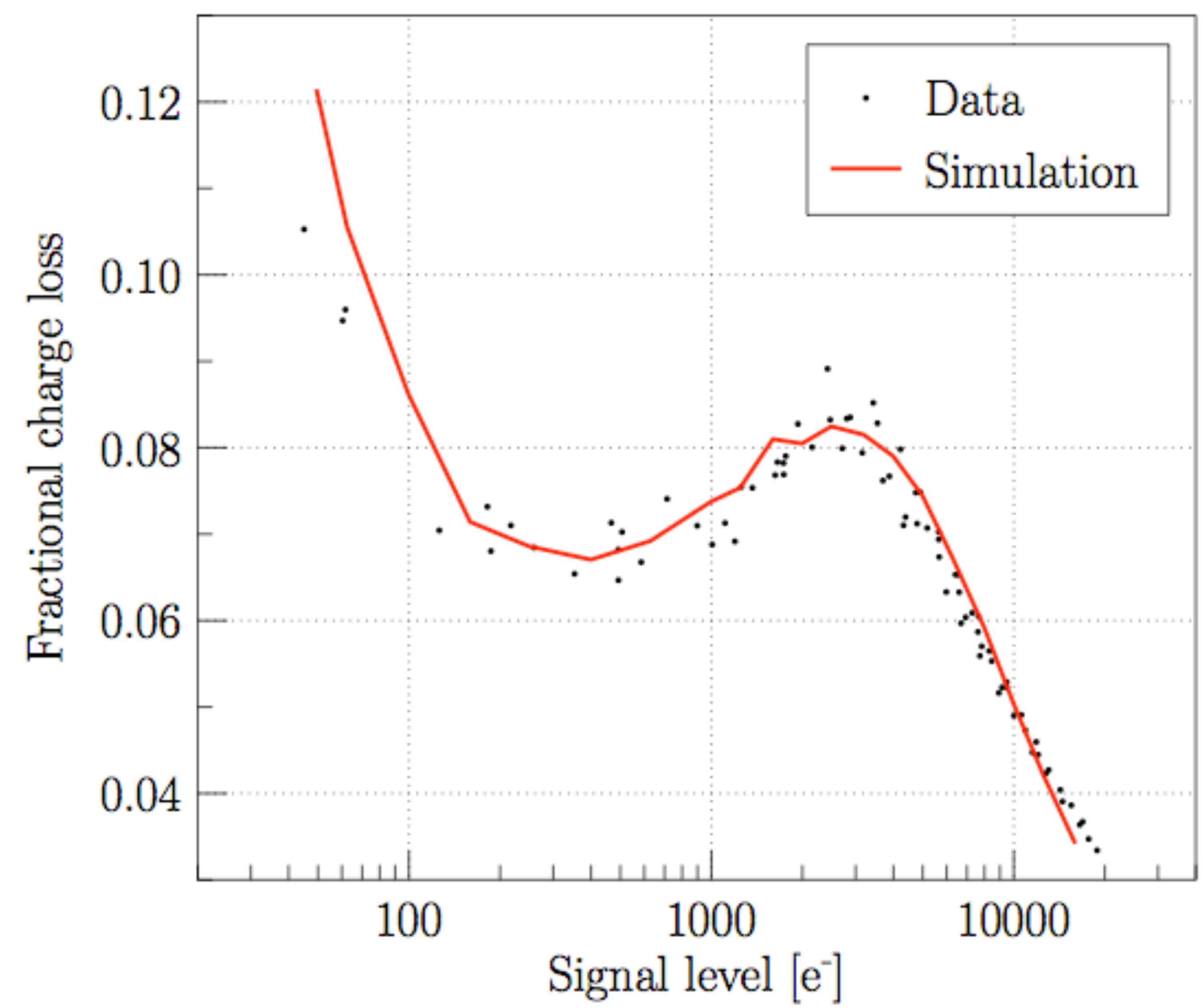
➡ CTI models must be density driven not volume driven

Understanding experimental data

Imaging mode SIRA



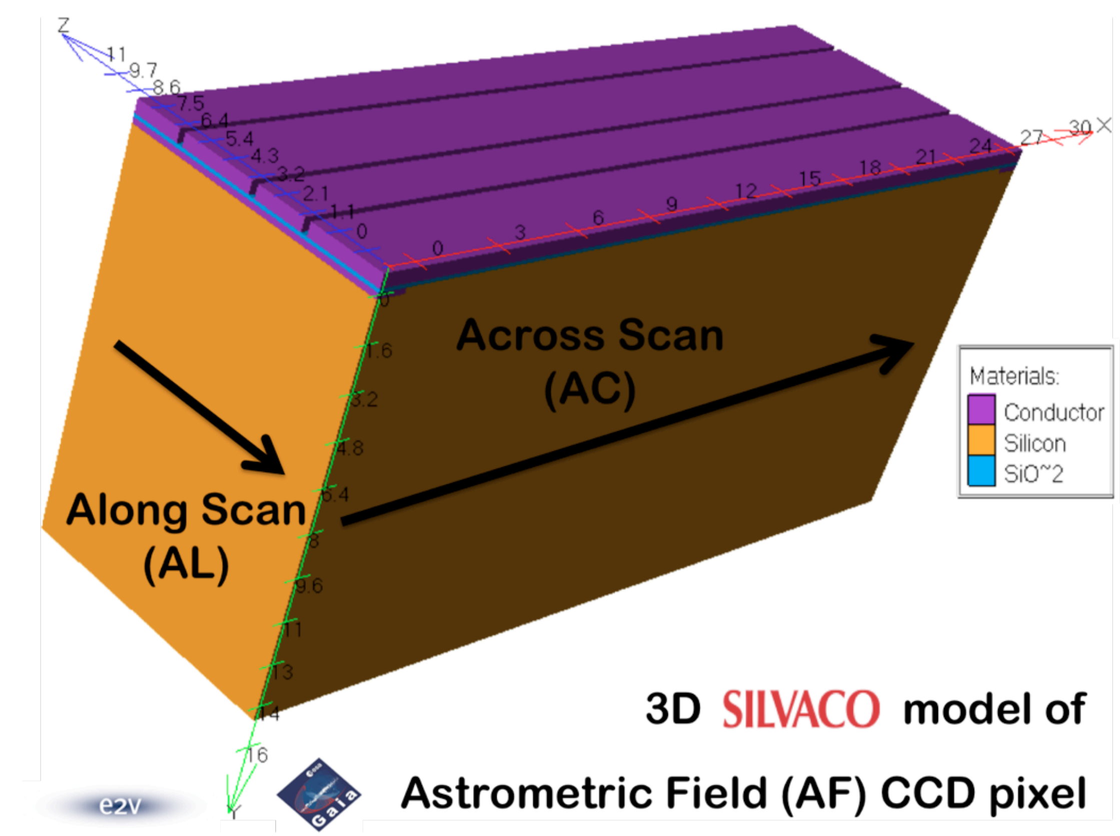
Imaging mode Astrium



model 2011 T. Prod'homme (trap level • MC physical)

➡ SBCs are not functioning properly in the upper CCD half

Understanding experimental data

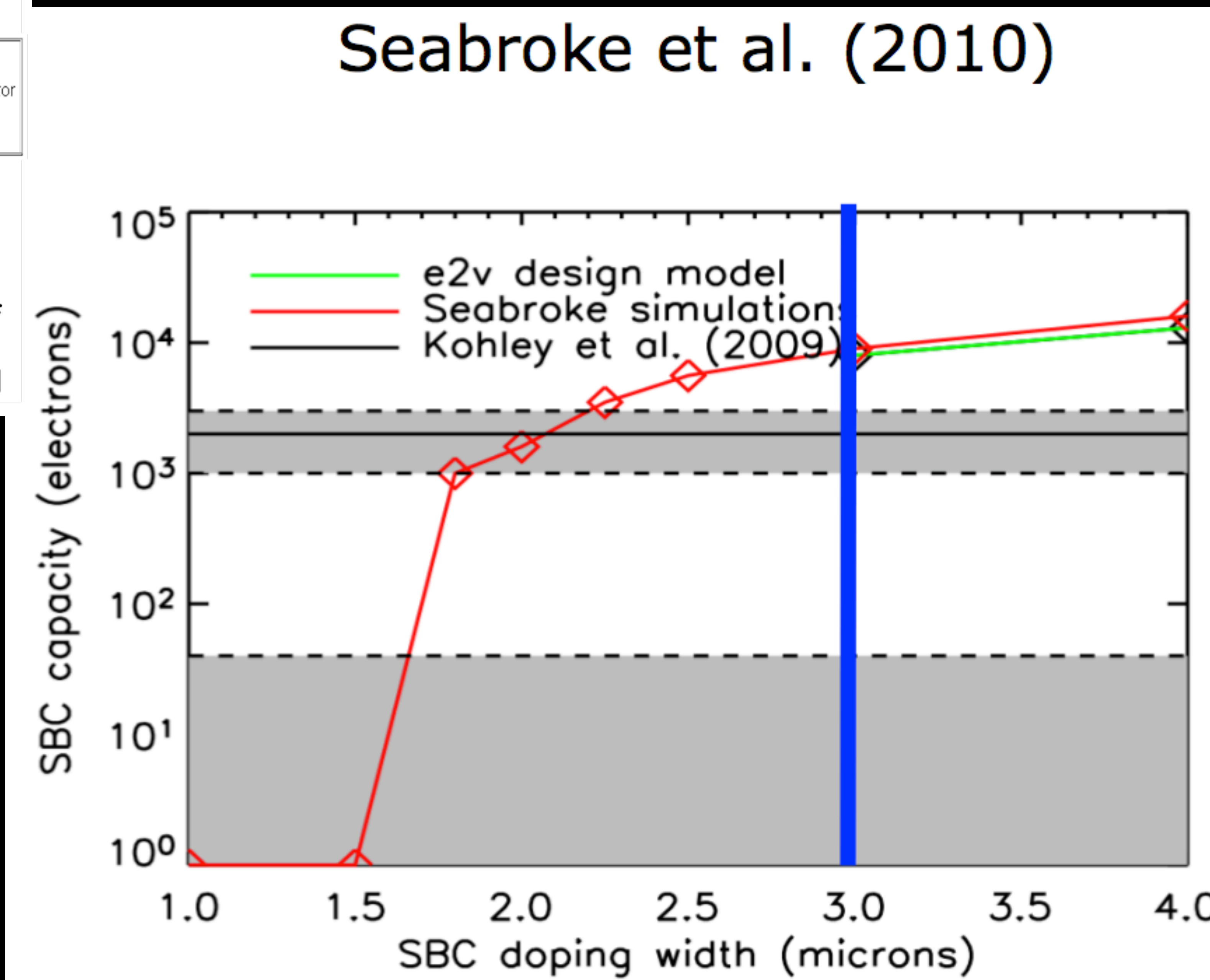


pixel architecture model

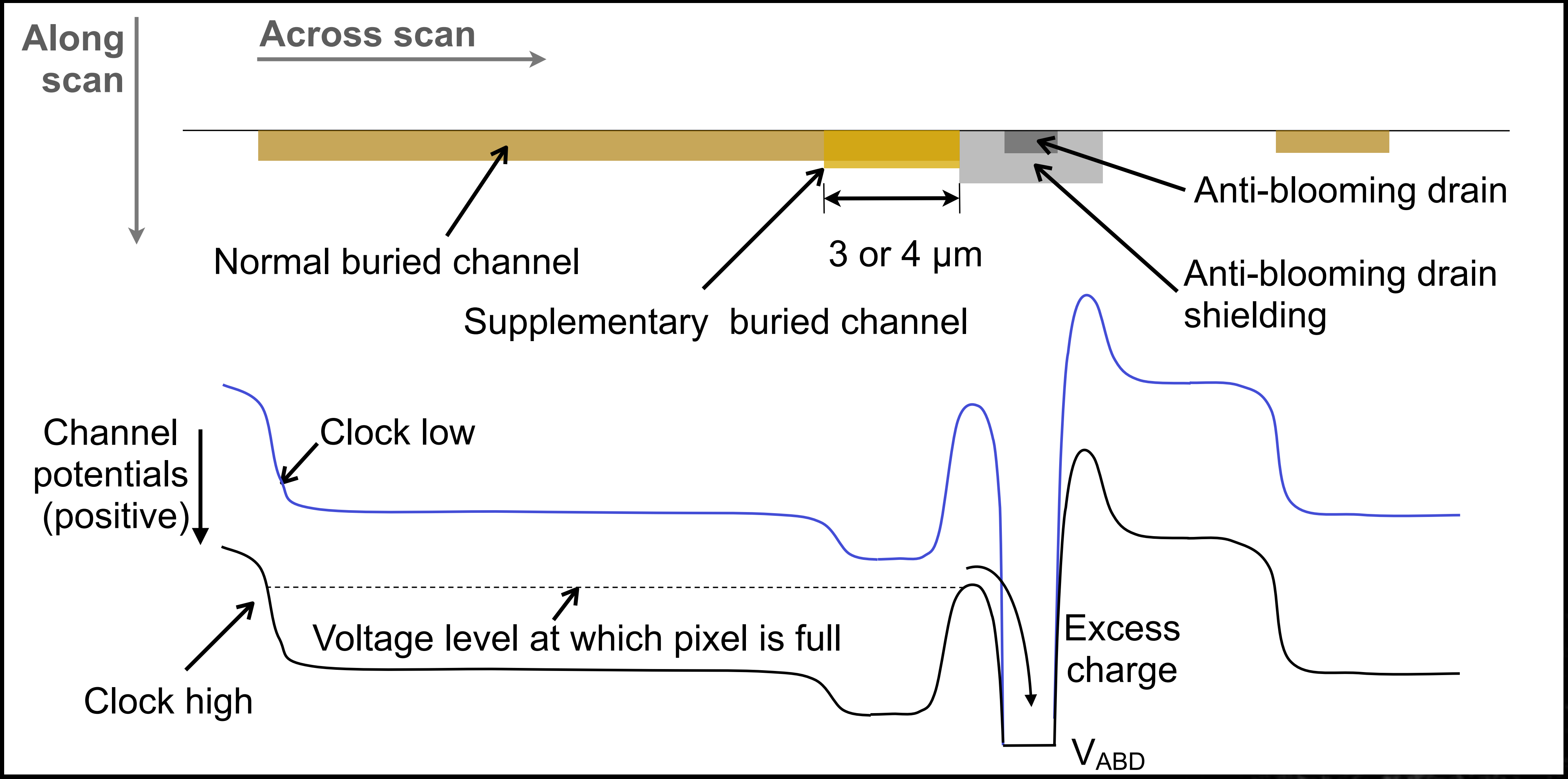
2010 G. Seabroke (Silvaco)

➡

mask alignment errors in the CCD fabrication process



SBC issue



Supplementary Buried Channel

Characterizing in detail the CTI effects

We assessed the impact of CTI on Gaia astrometry
Prod'homme et al. 2011b, Holl et al. 2011

I. on the image location estimation using
2011 T. Prod'homme MC physical

- Generating a large set of synthetic CTI-free and damaged Gaia-like images (~40 000 images) using CEMGA
- Computing the theoretical limit to image location
- Applying the Gaia image parameter determination algorithms

Image location

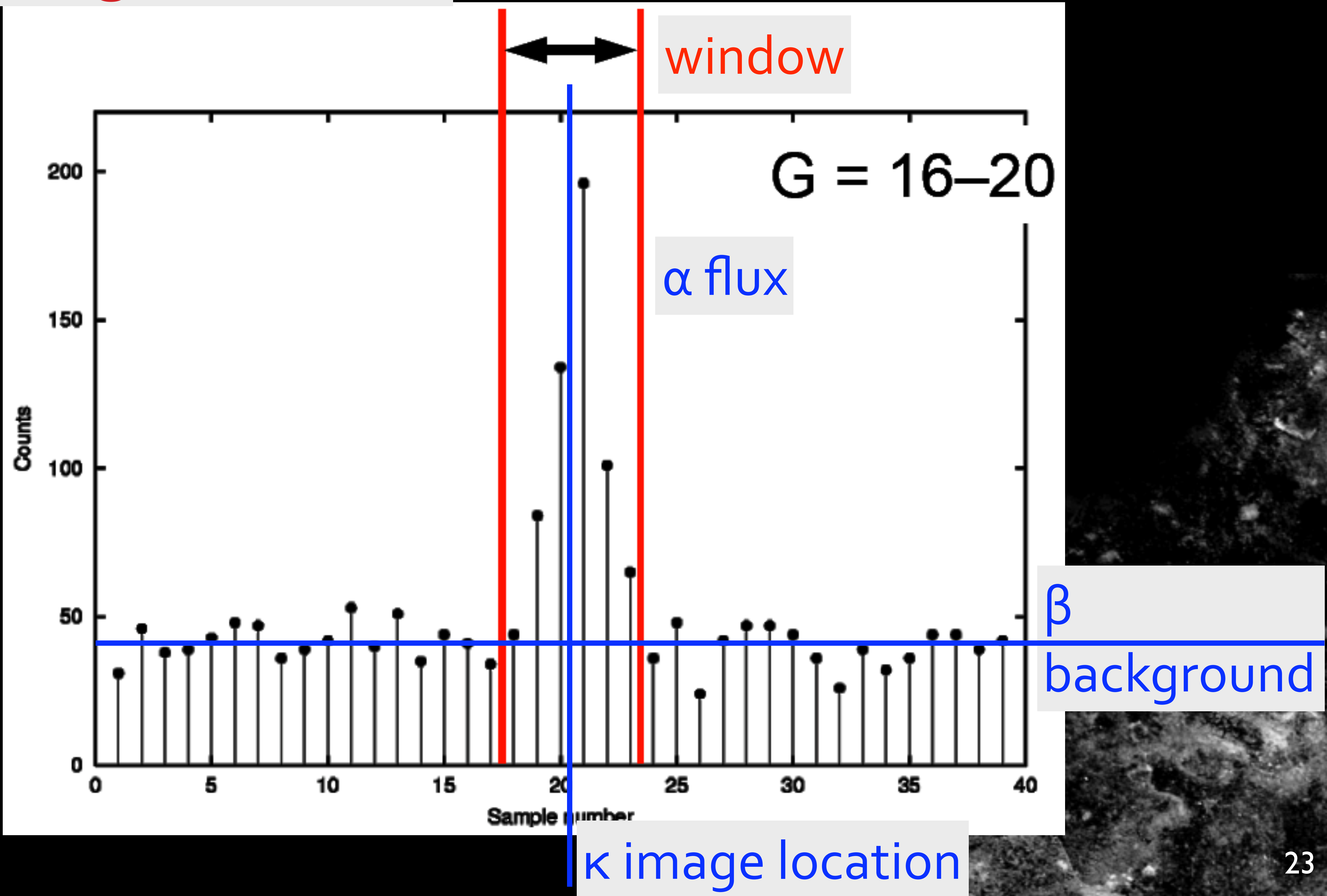
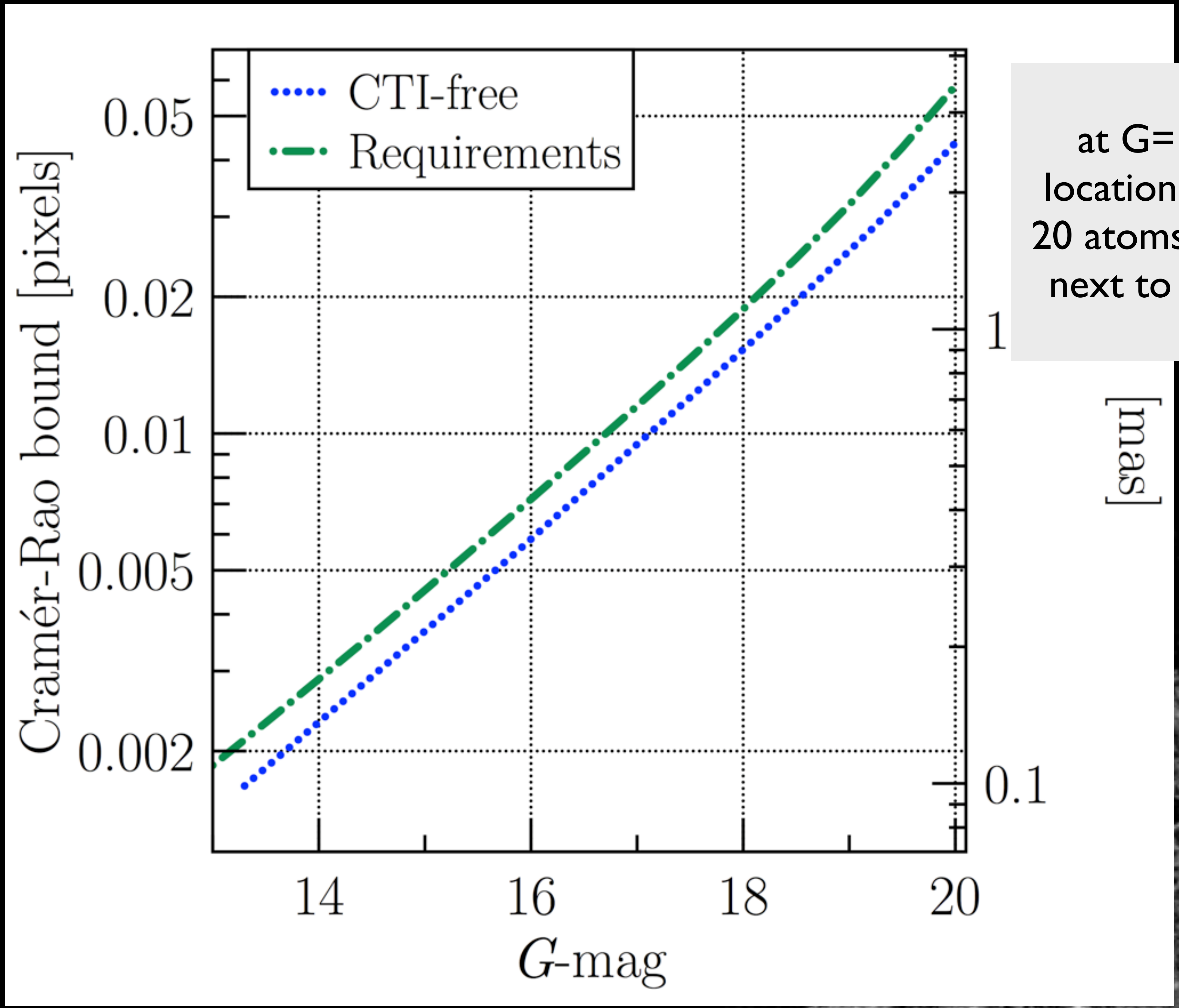
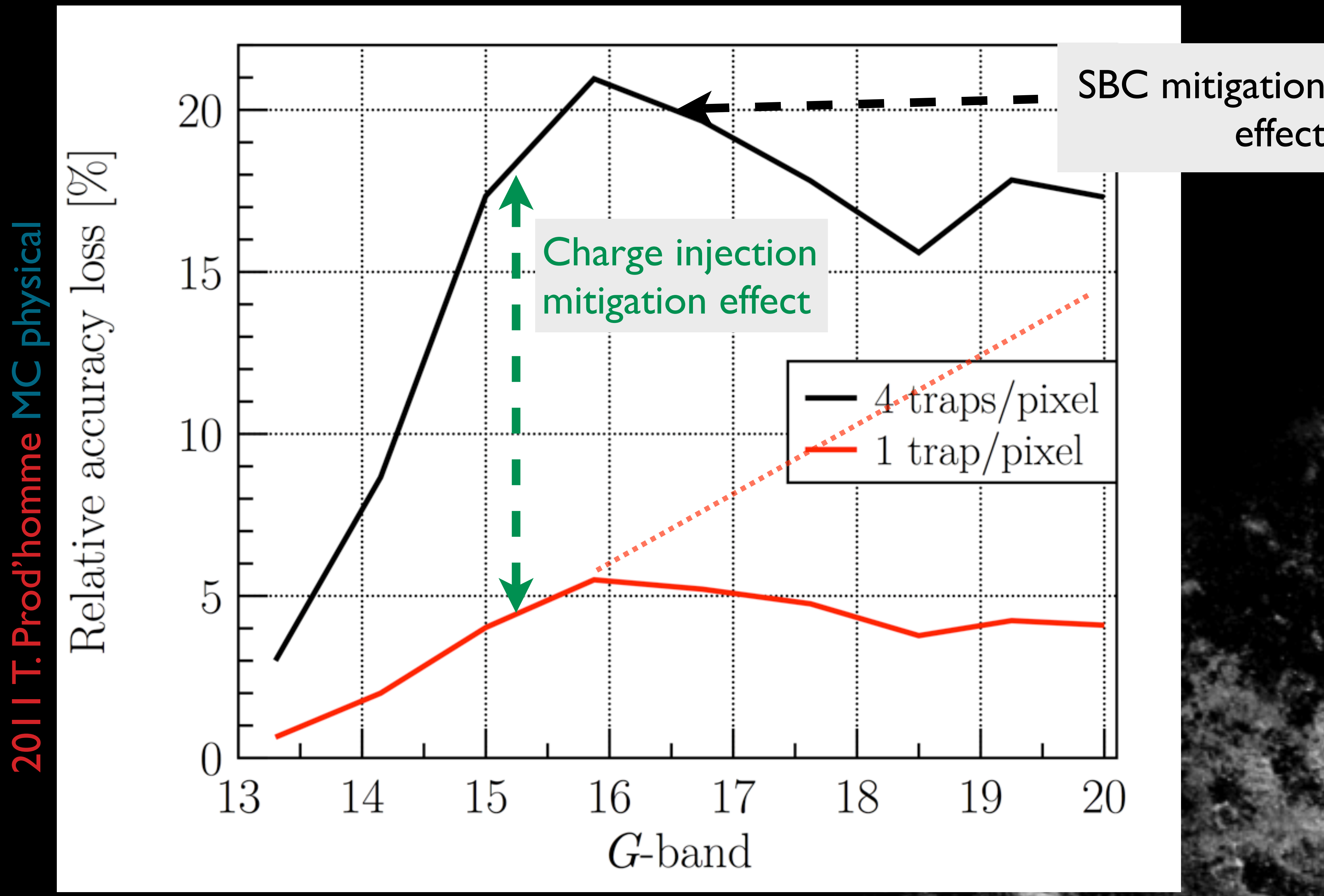


Image location requirements per CCD observation



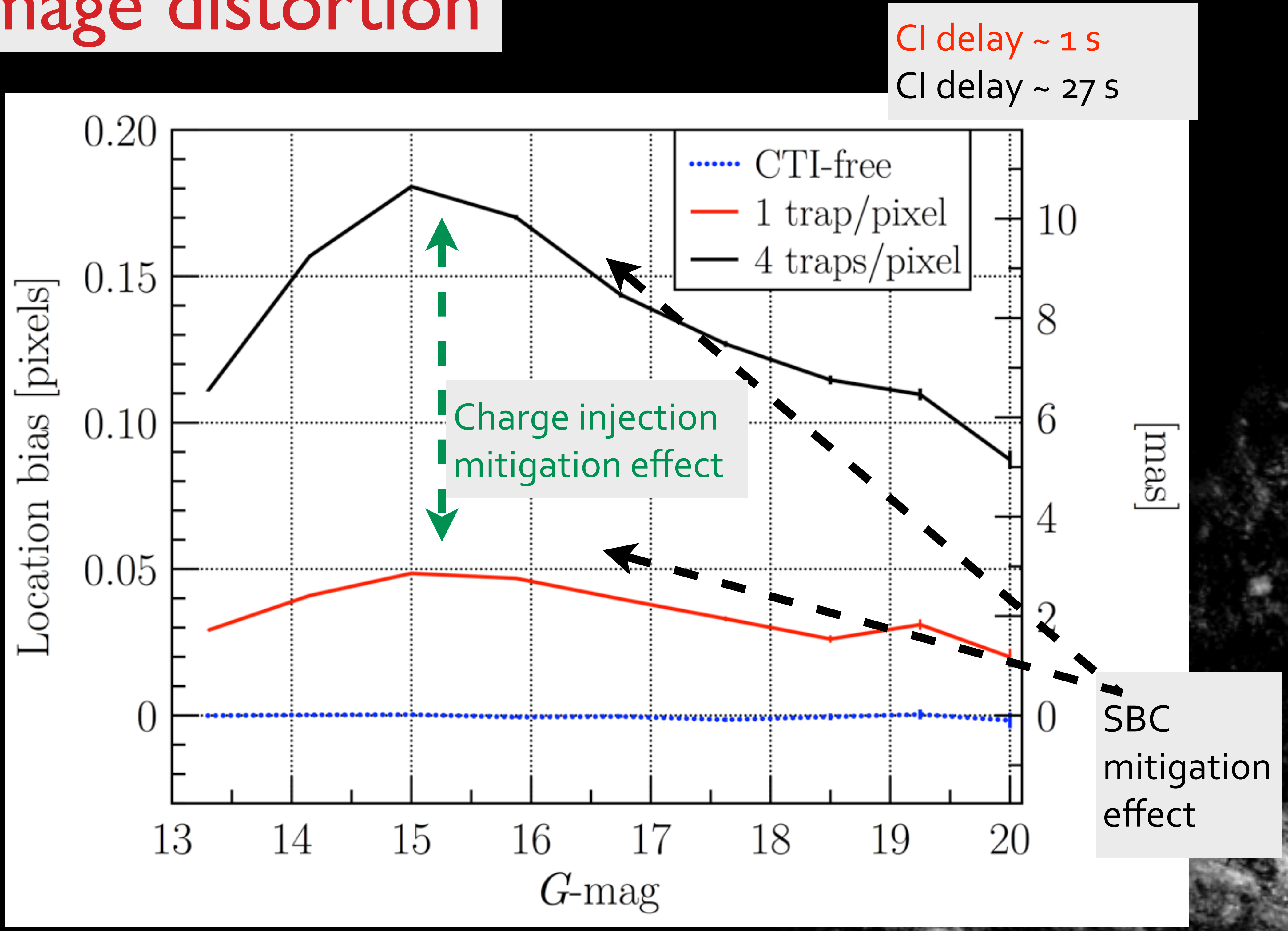
at G= 13 image location accuracy < 20 atoms of Si sitting next to each other

Intrinsic loss of image location accuracy due to decrease in S/N induced by charge loss



Can only be prevented by avoiding trapping
Need for Hardware CTI countermeasures

Strong bias in the image location due to image distortion



Hardware CTI countermeasures useful but not enough
Need for CTI calibration

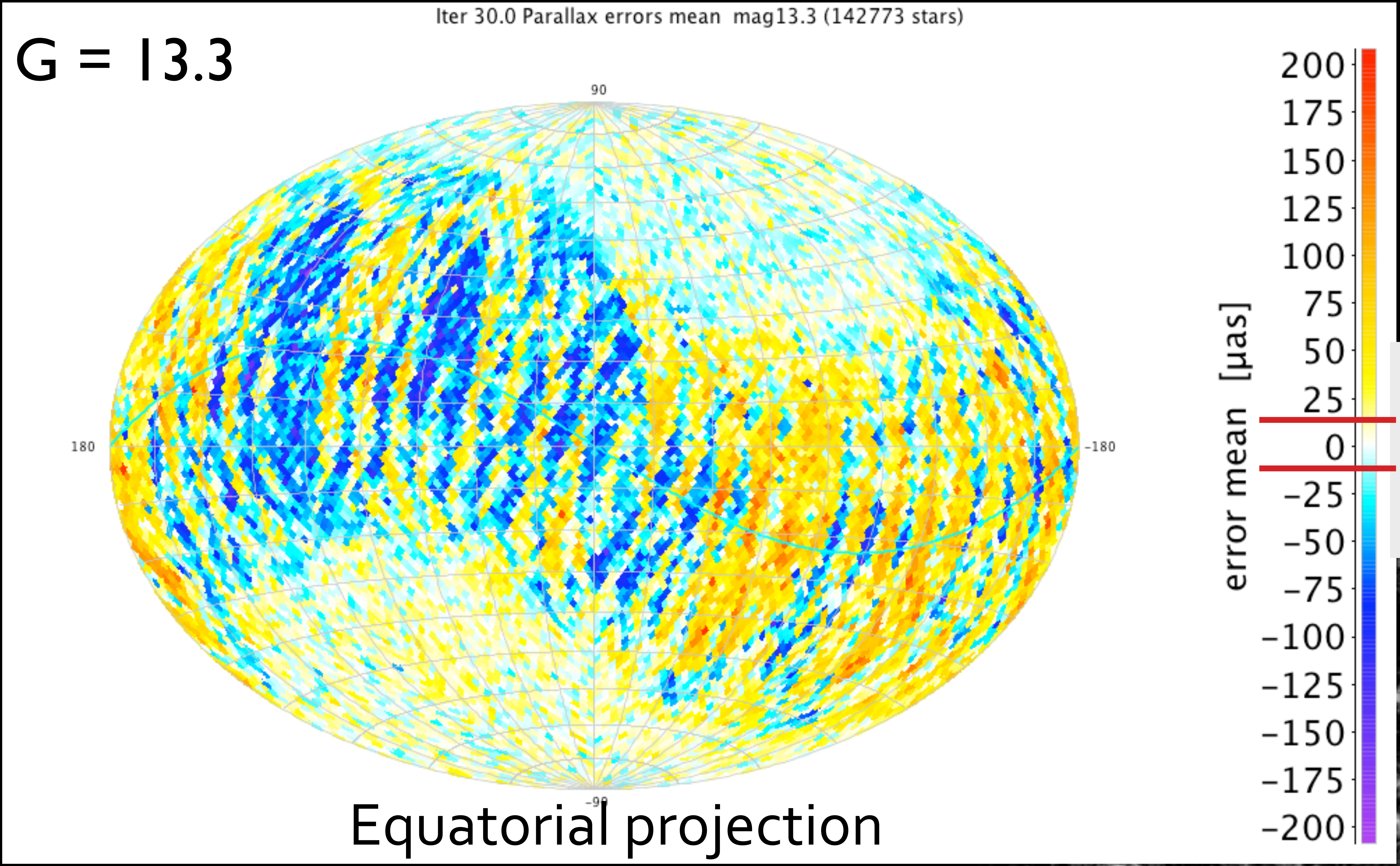
Characterizing in detail the CTI effects

We assessed the impact of CTI on Gaia astrometry
Prod'homme et al. 2011b, Holl et al. 2011

II. on the astrometric solution AGIS using
2011 B. Holl (statistical level • analytic phenomenological)

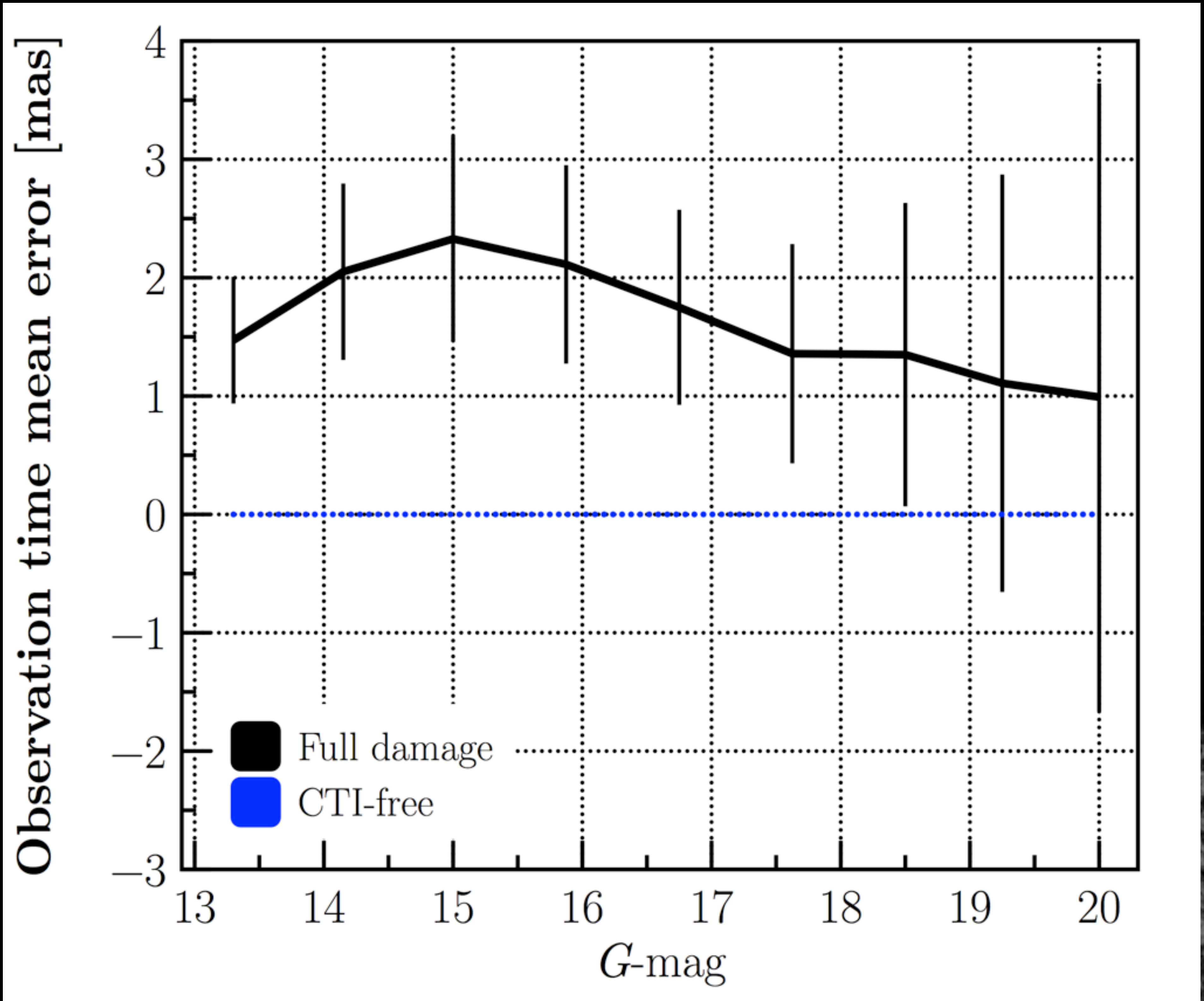
- AGIS + image locations for all (single) stars = astrometric parameters for each stars
- Solution for 1 million stars (semi-realistic star distribution in G)
- CTI errors vary as func. of *G*, t since last CI, (prev.) Solar Cycle

CTI induced parallax errors

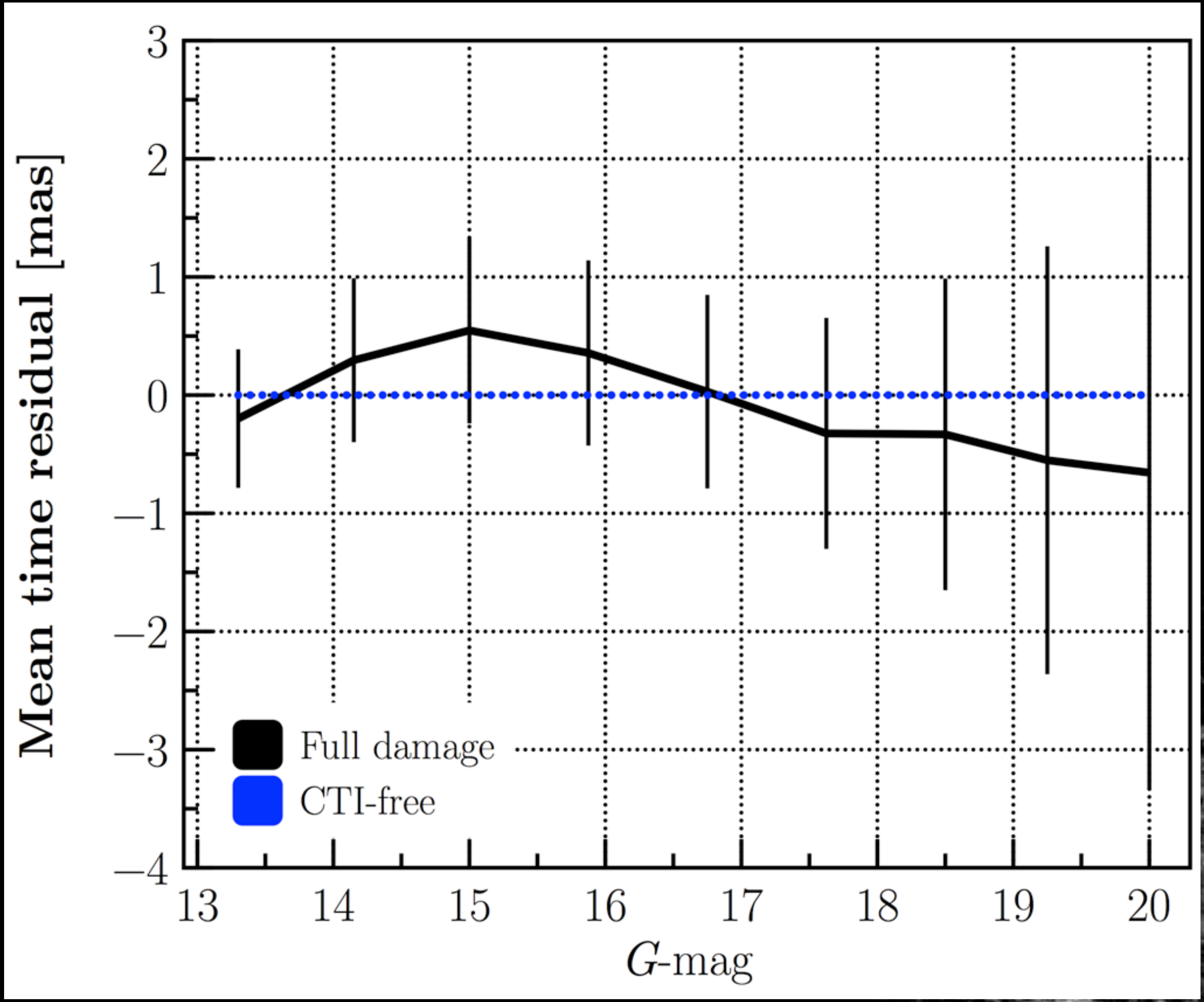


Equatorial projection

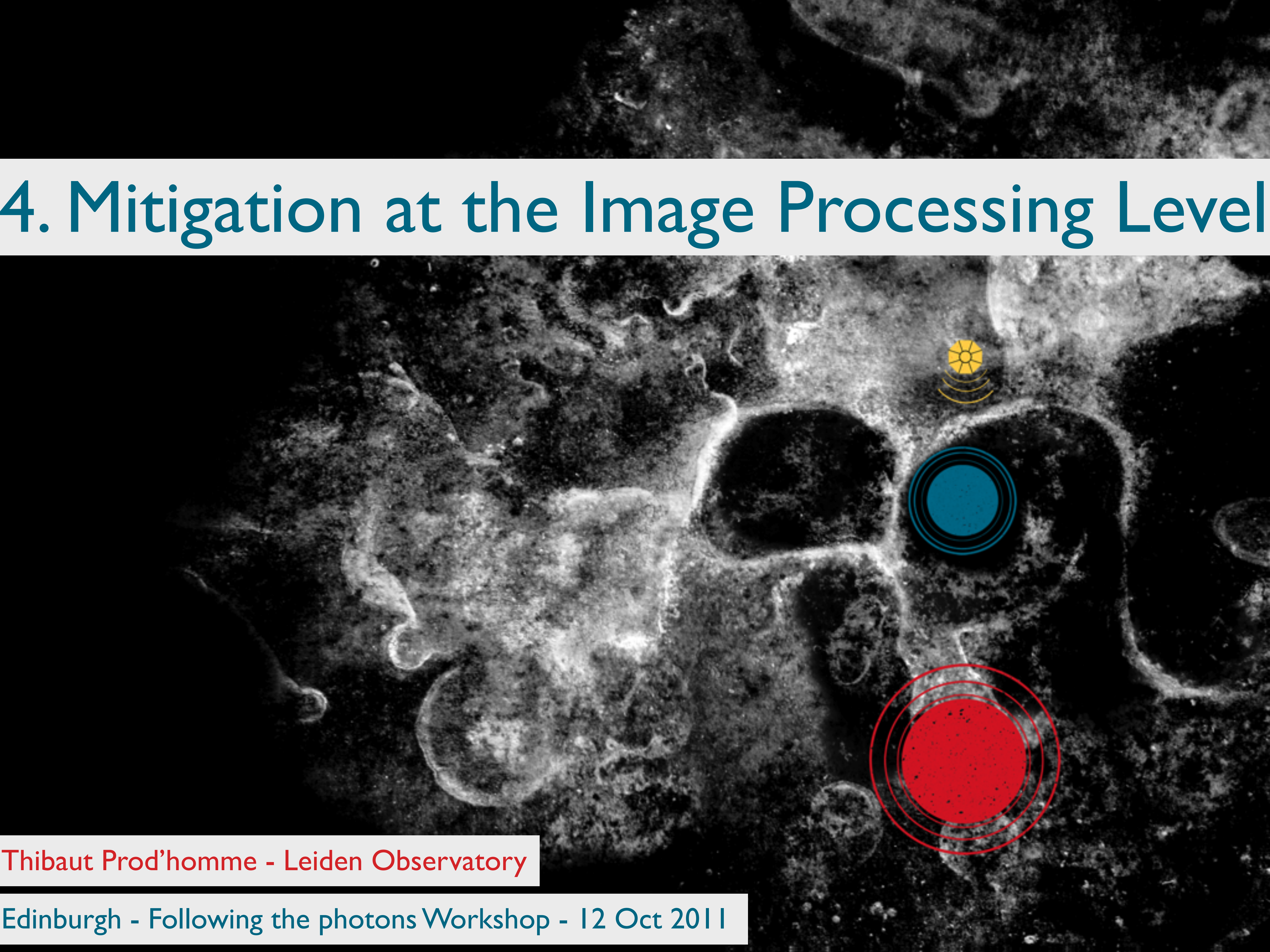
Errors vs Solution Residuals



Errors vs Solution Residuals



4. Mitigation at the Image Processing Level



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Forward modelling approach

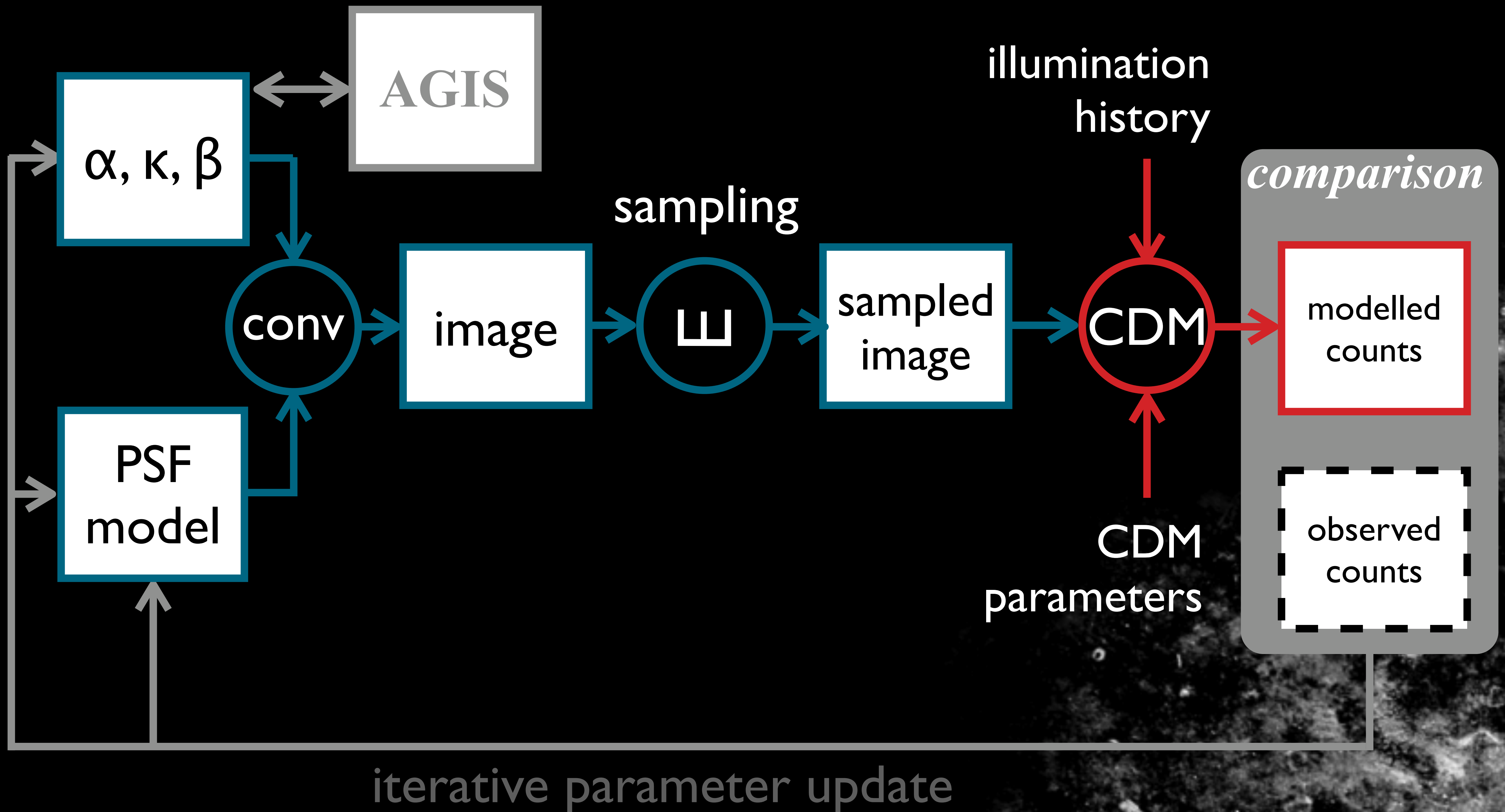
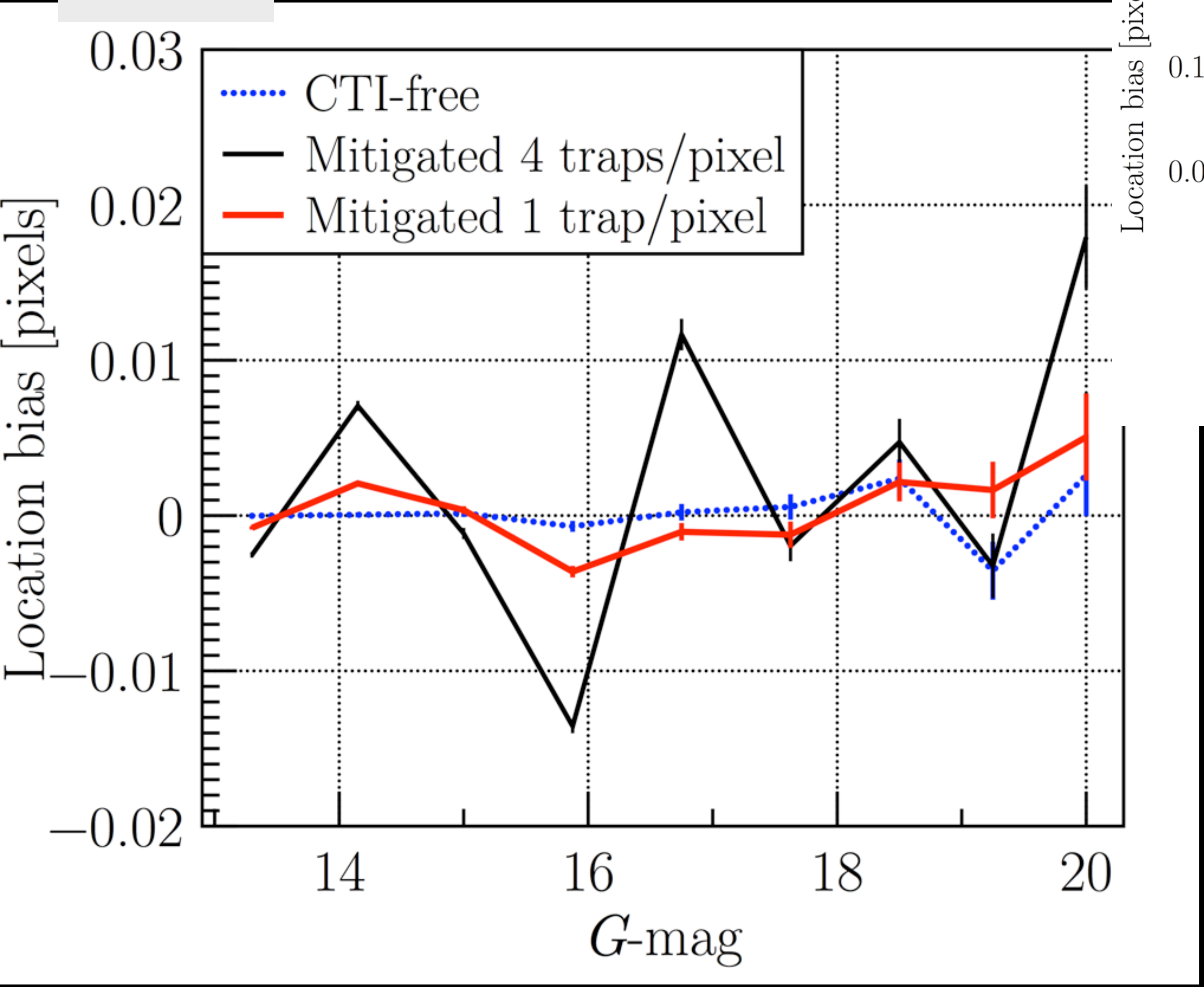
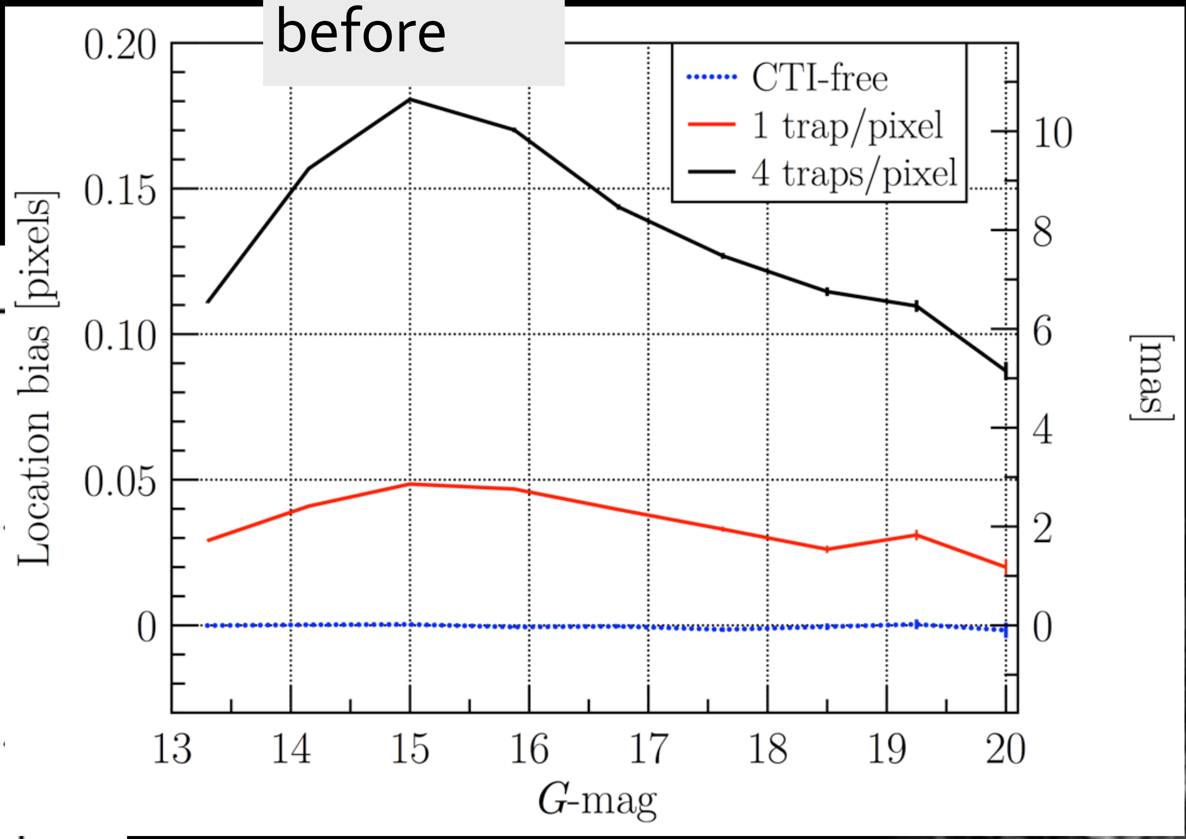


Image location residual bias

after

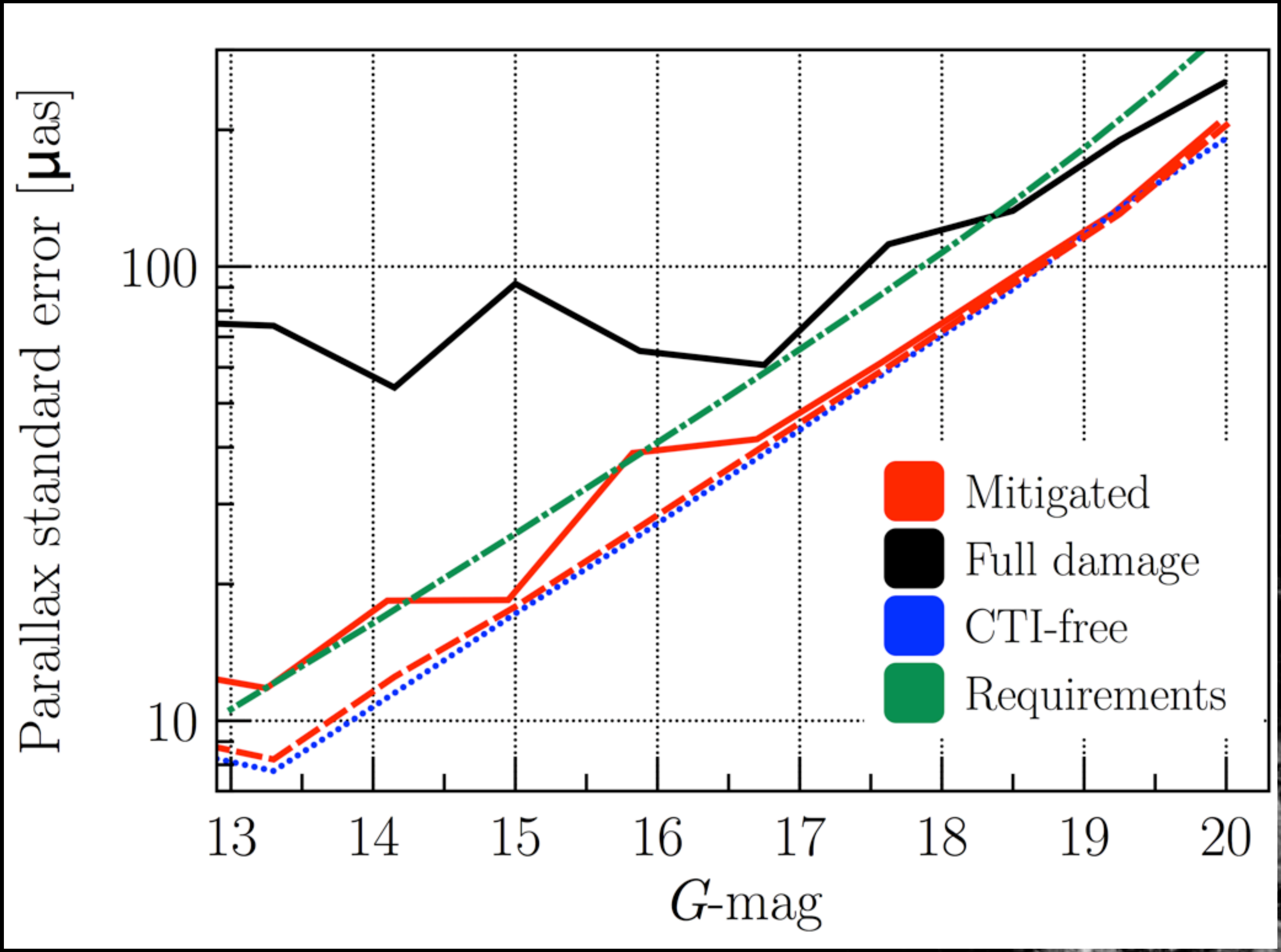


before

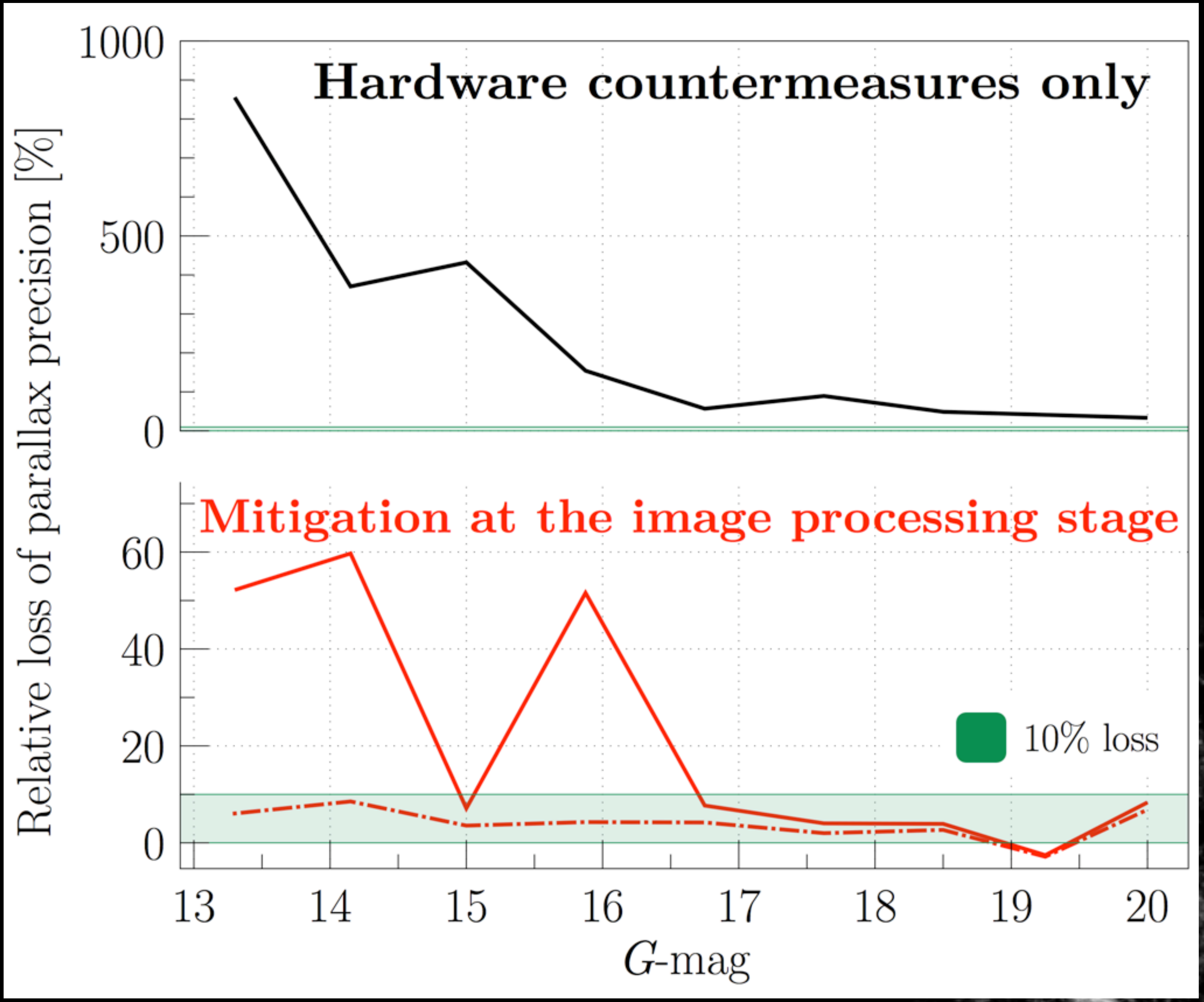


Better than a factor
ten decrease in the bias

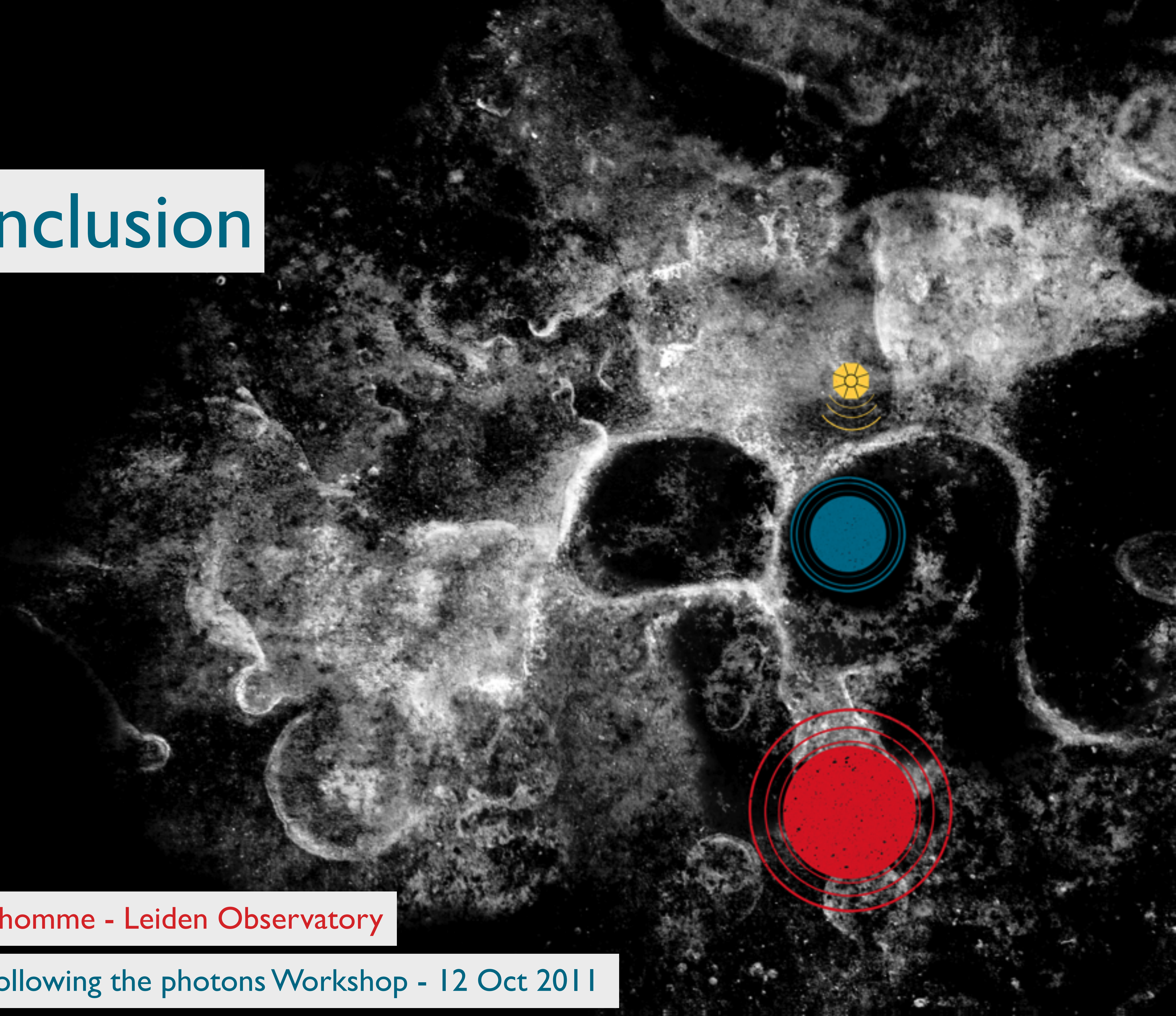
Final astrometric accuracy



Final astrometric accuracy



5. Conclusion



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Thanks to important modelling efforts
supported by experimental tests
we were able to demonstrate that:

CCD radiation damage
is not a threat to Gaia anymore;
we can calibrate for it!

however...

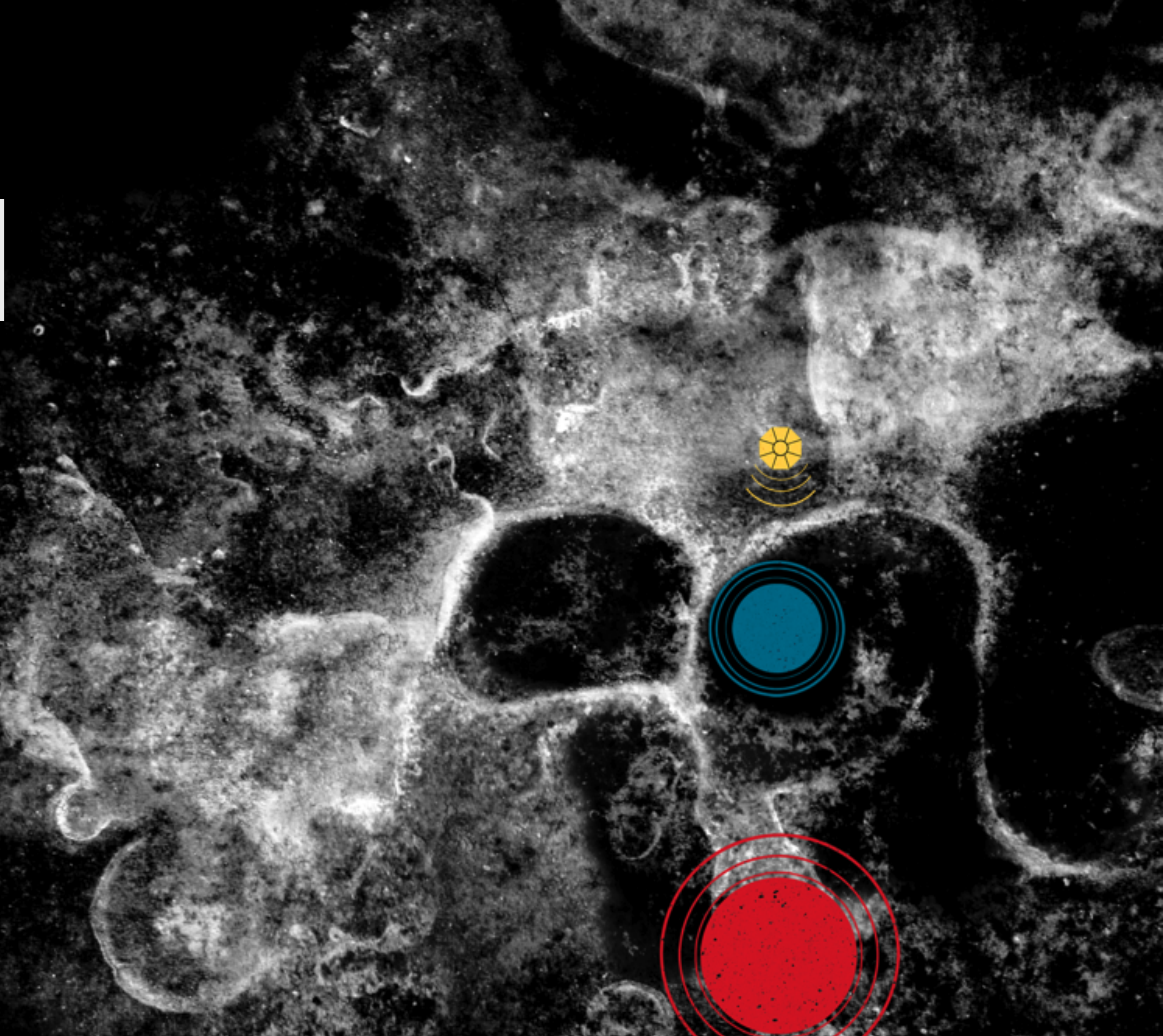
Implementation of the CTI mitigation strategy
in the on-ground data processing
remains a challenge

&

only first data from Gaia in 2013
will tell us if our predictions were right

The END

Thank you!



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