Harmonization of CT for Densitometry Analysis

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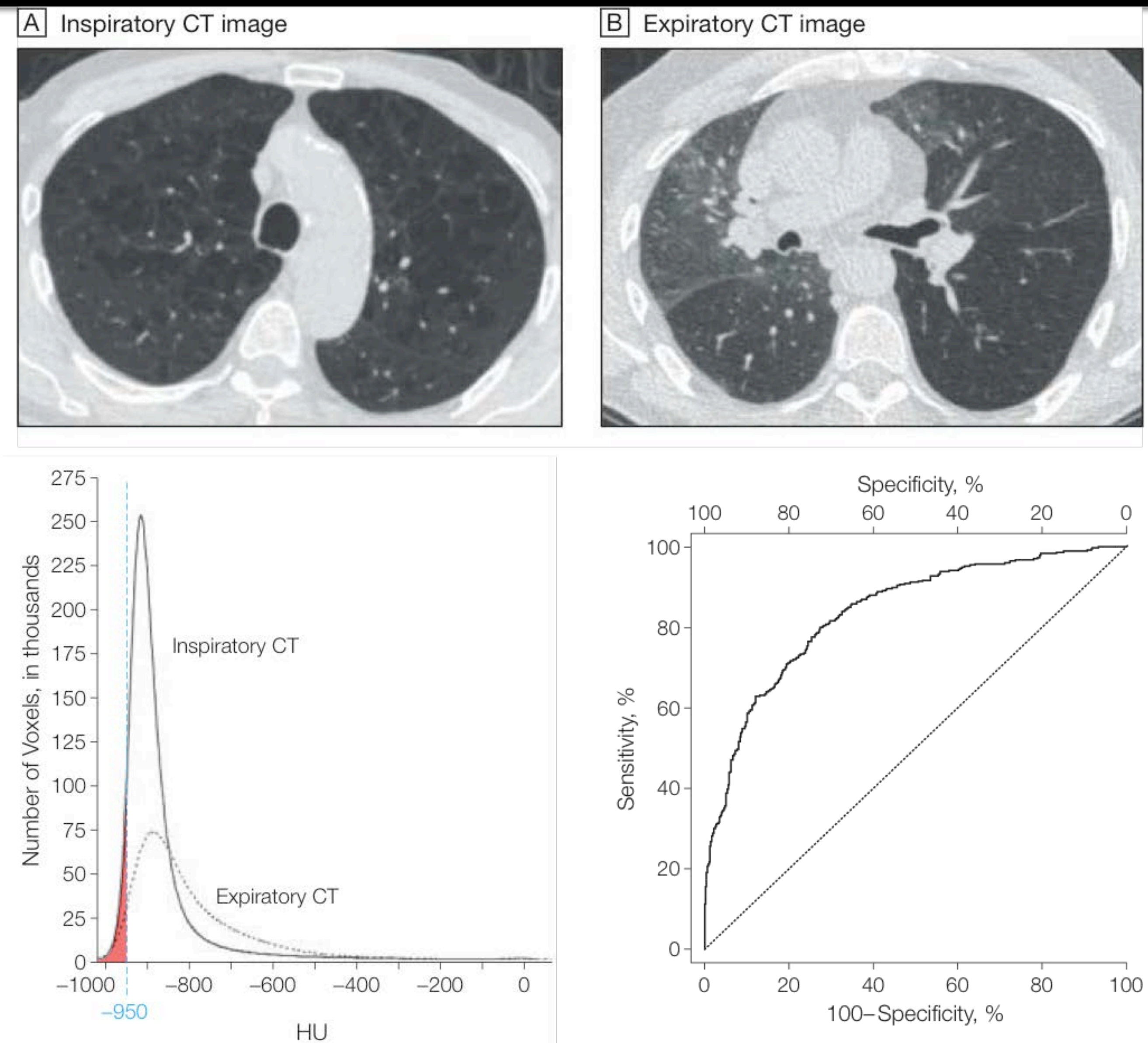
Densitometry Identifies CODP in LCS



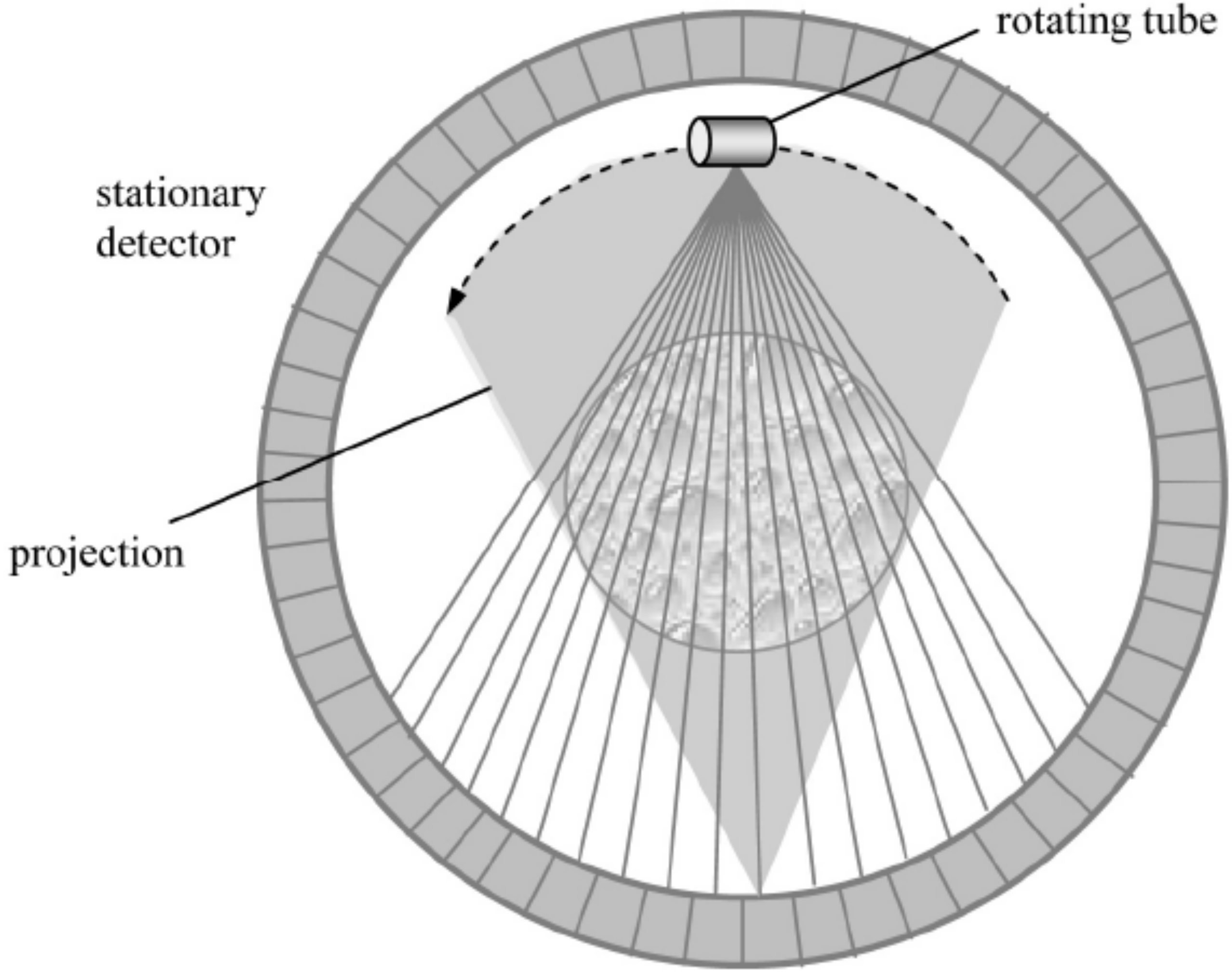
Mets et al. *JAMA* 2011;306:1775–1781.

Sources of CT Signal Bias

- Systematic bias due to mis-calibration among devices
  - Phantoms can address this problem

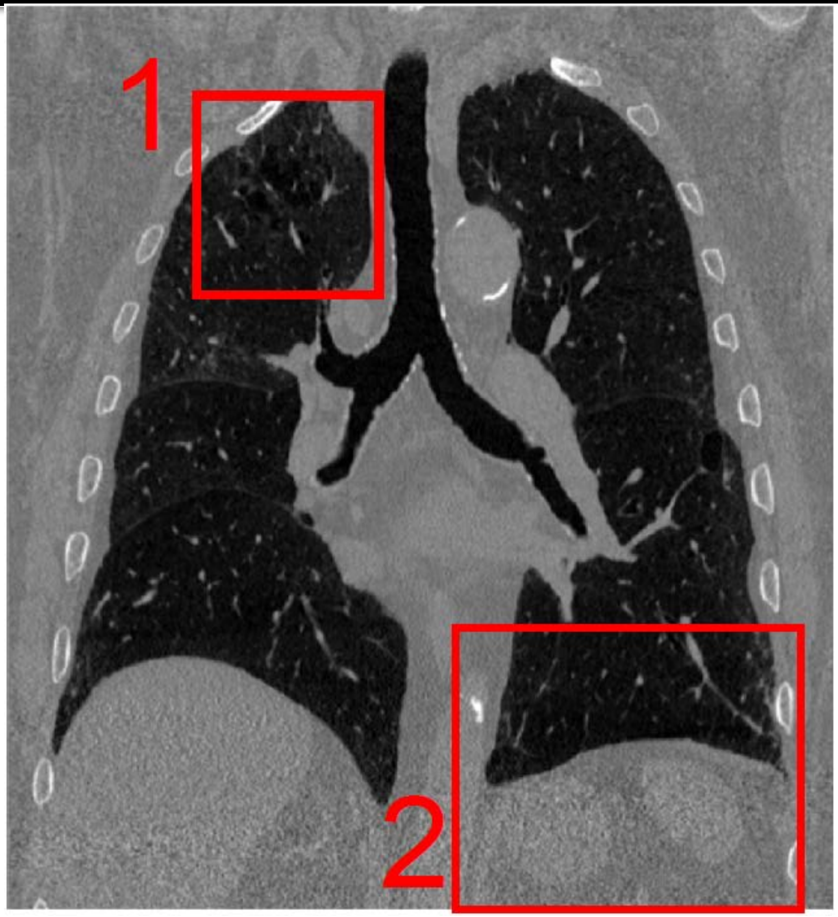
- Noise-induced bias
  - The intimate relation between noise and bias is not currently addressed.

  - They have to be jointly corrected to have a proper densitometry assessment.


rotating tube
stationary
detector
projection

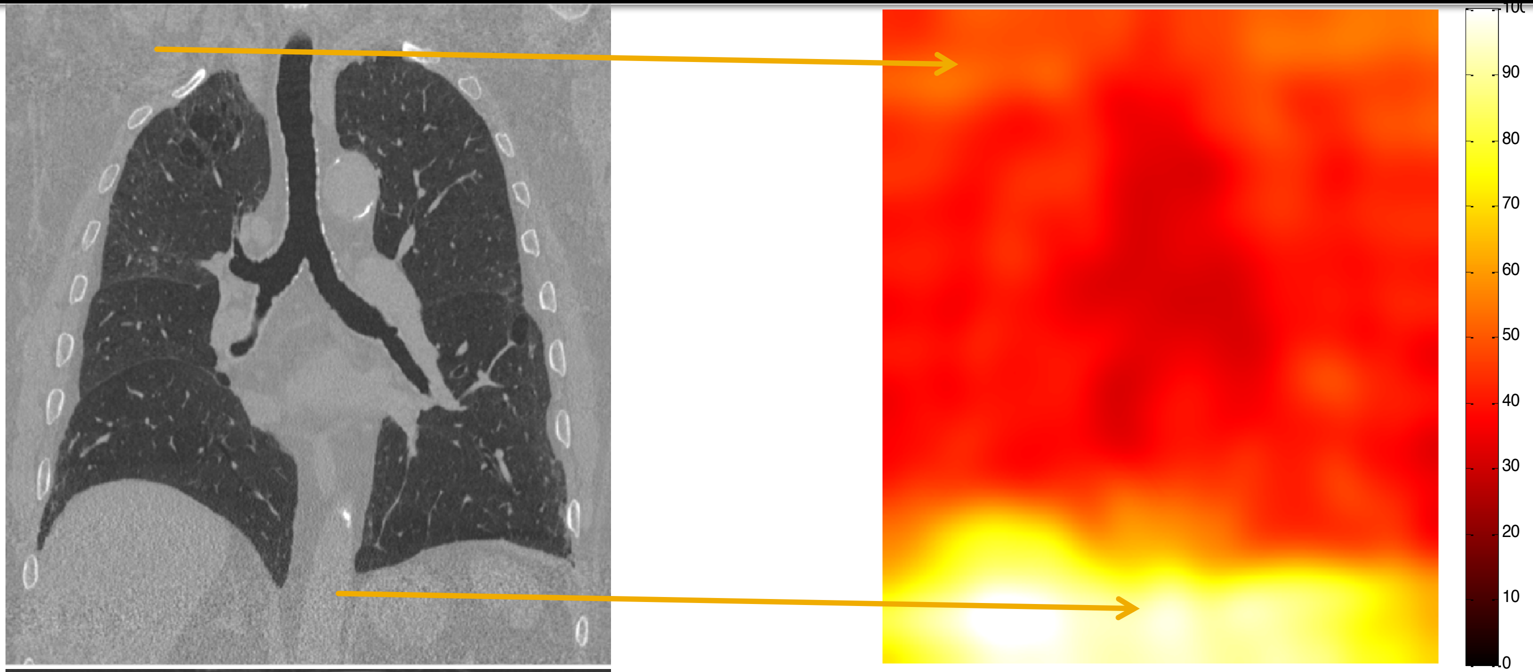
Sources of Noise in CT Acquisitions

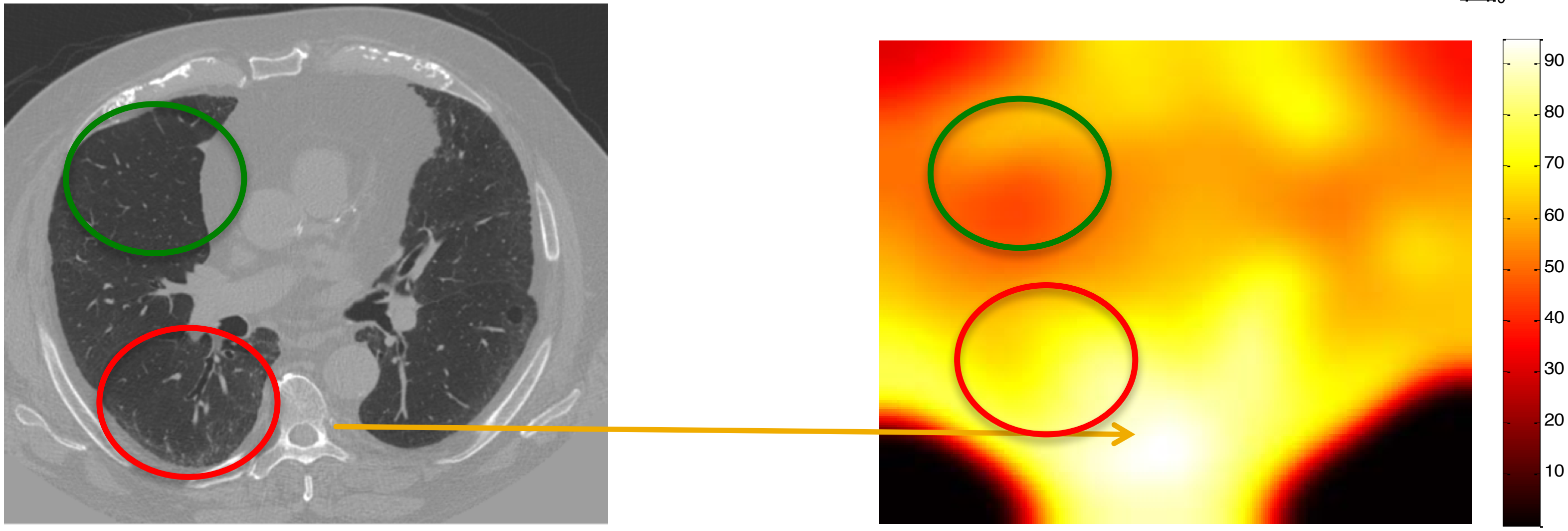
- **Intrinsic**
  - Dose
  - Reconstructions
- **Physiological Factors**
  - Volume Change
  - Weight Change
- **Extrinsic**
  - Implants



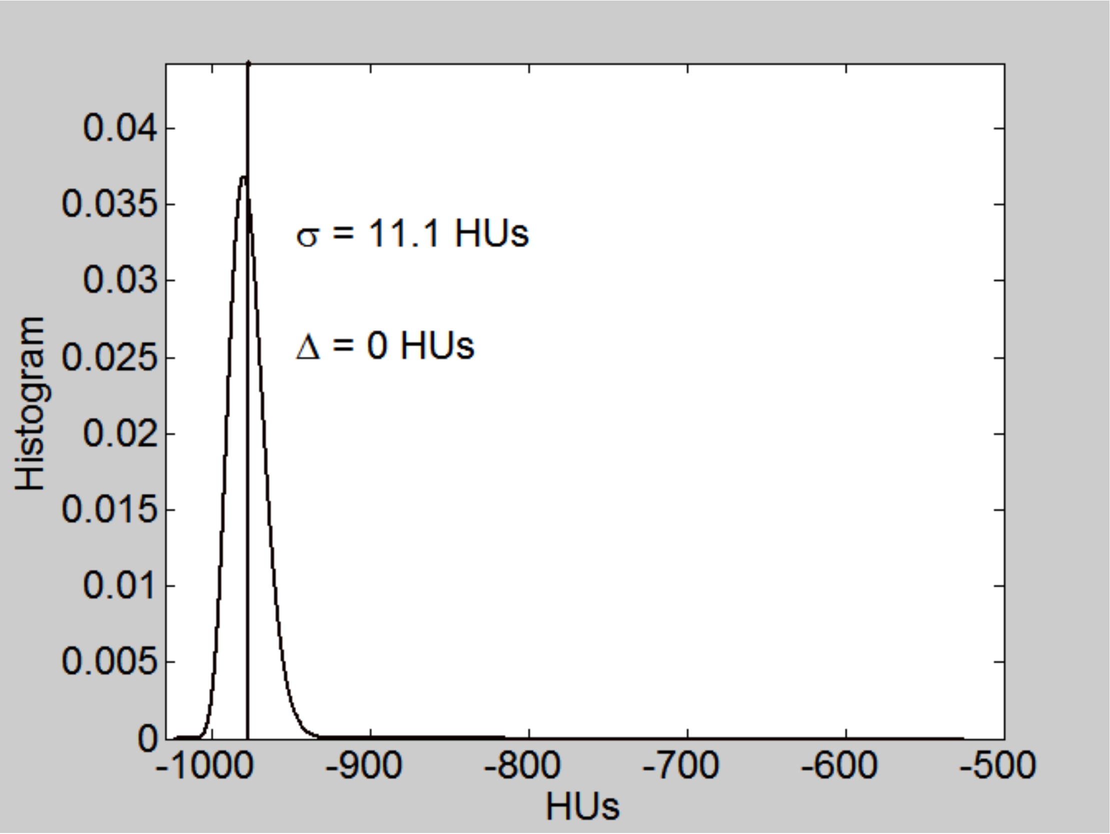
Noise is spatially variant
up to levels of ± 70 HU that can yield a bias of 30 HU

The Noise is Spatially Variant



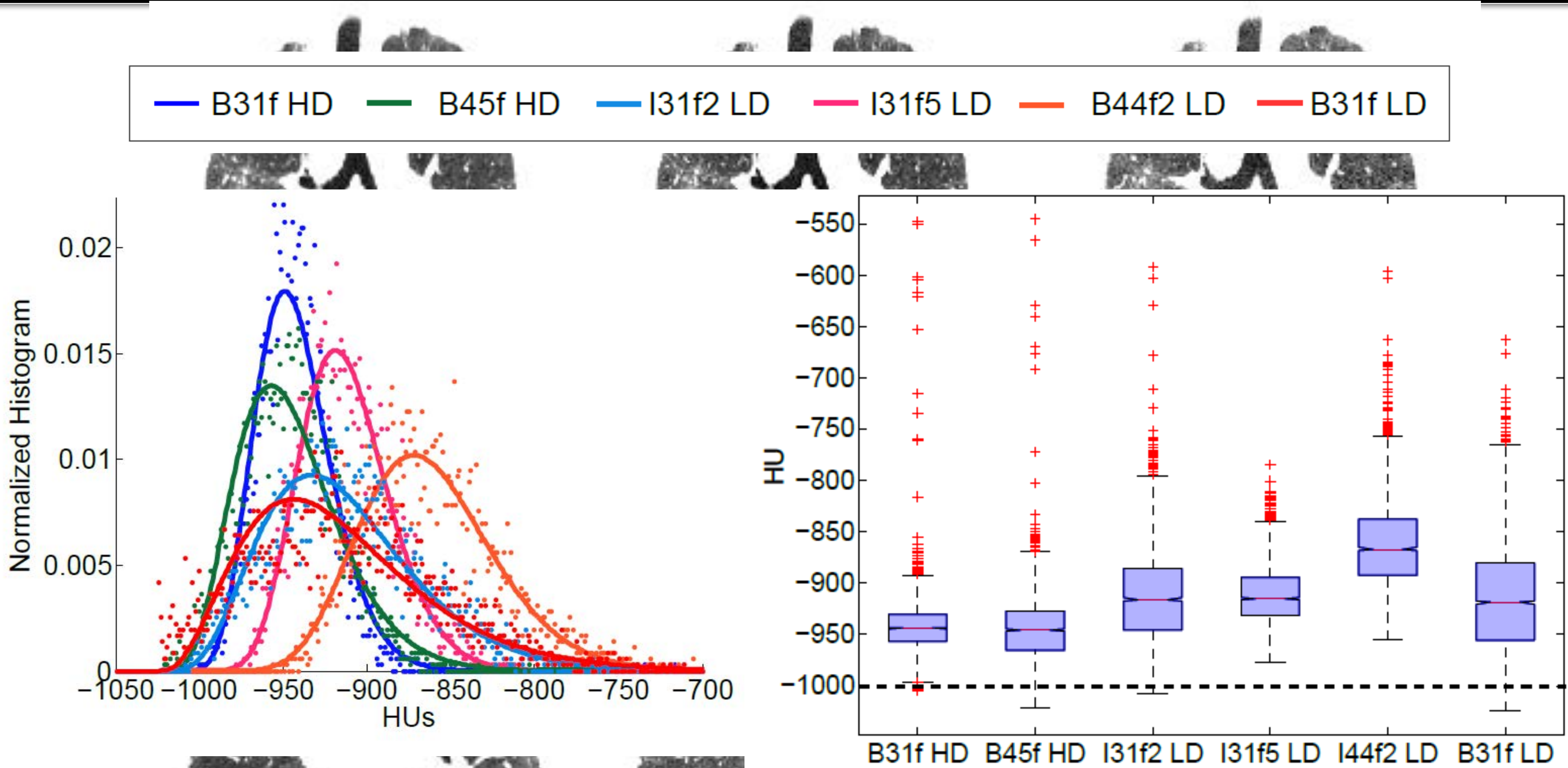


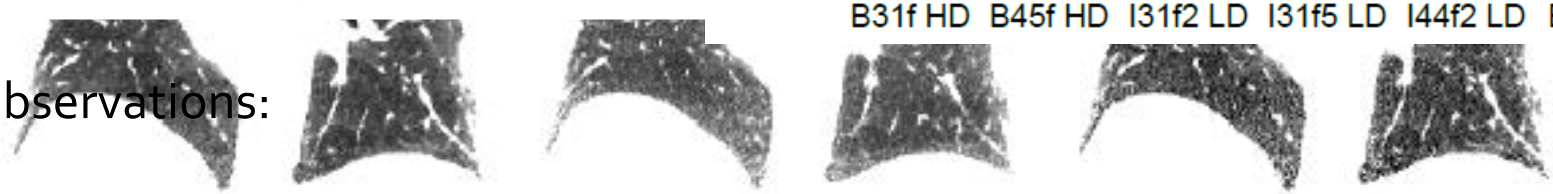
How Does Bias Affect the Signal?



- Variance of noise is **non-stationary**
- **Variance of noise** affects the average attenuation levels
- **Average attenuation levels are biased** due to non-homogeneous nature of noise

Noise Variance Introduces a Bias





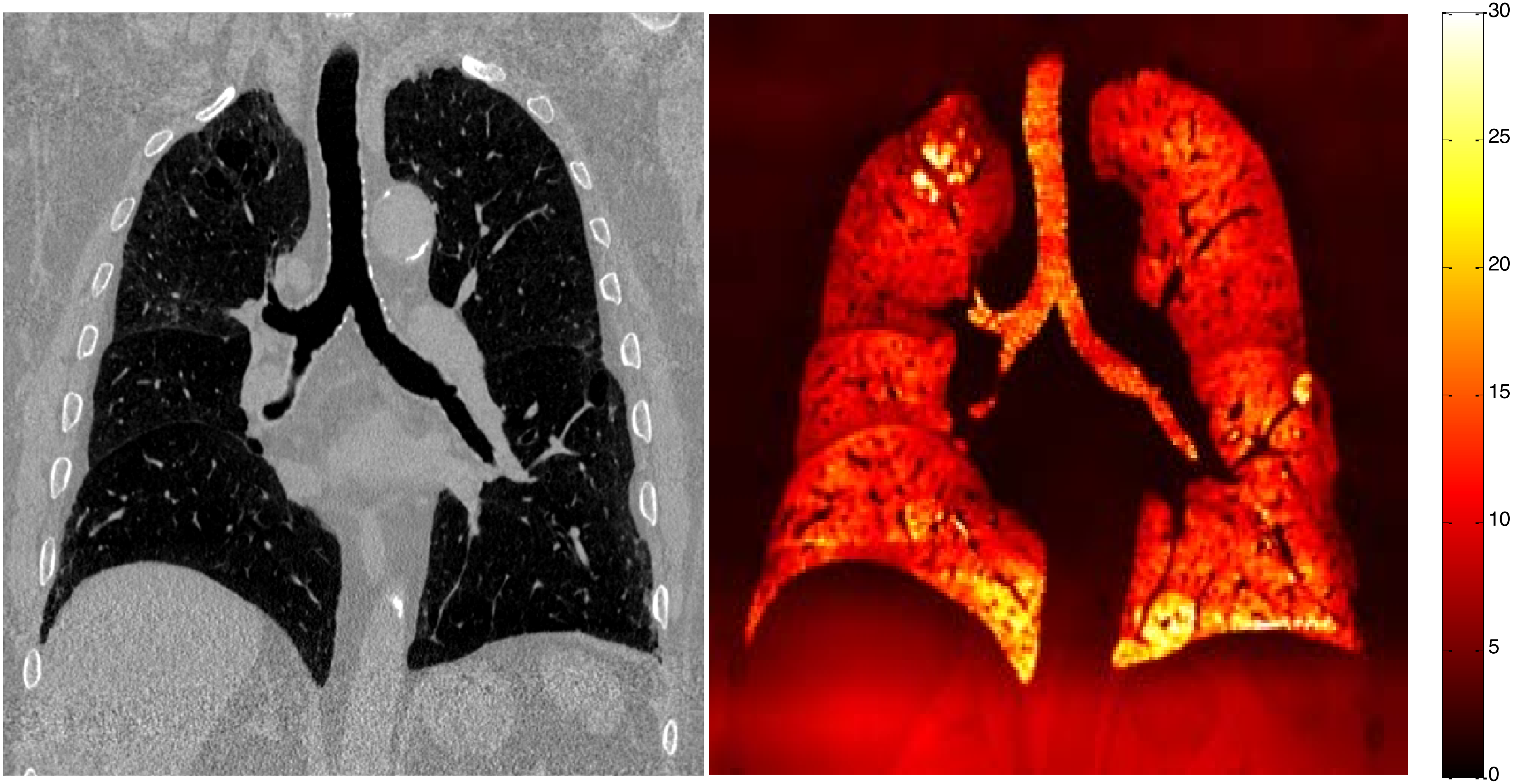
Observations:

1. **Histograms are right skewed and show different mean and variances**
2. **Current calibrations are not effective with spatially-variant noise**

What is The Bias We can Expect?

CT

Estimated Bias due to Noise



Lower attenuations **are the most biased ➔ Emphysema can be misclassified**

Location matters ➔ Lower regions of the lung are more biased

Systematic Bias between Devices

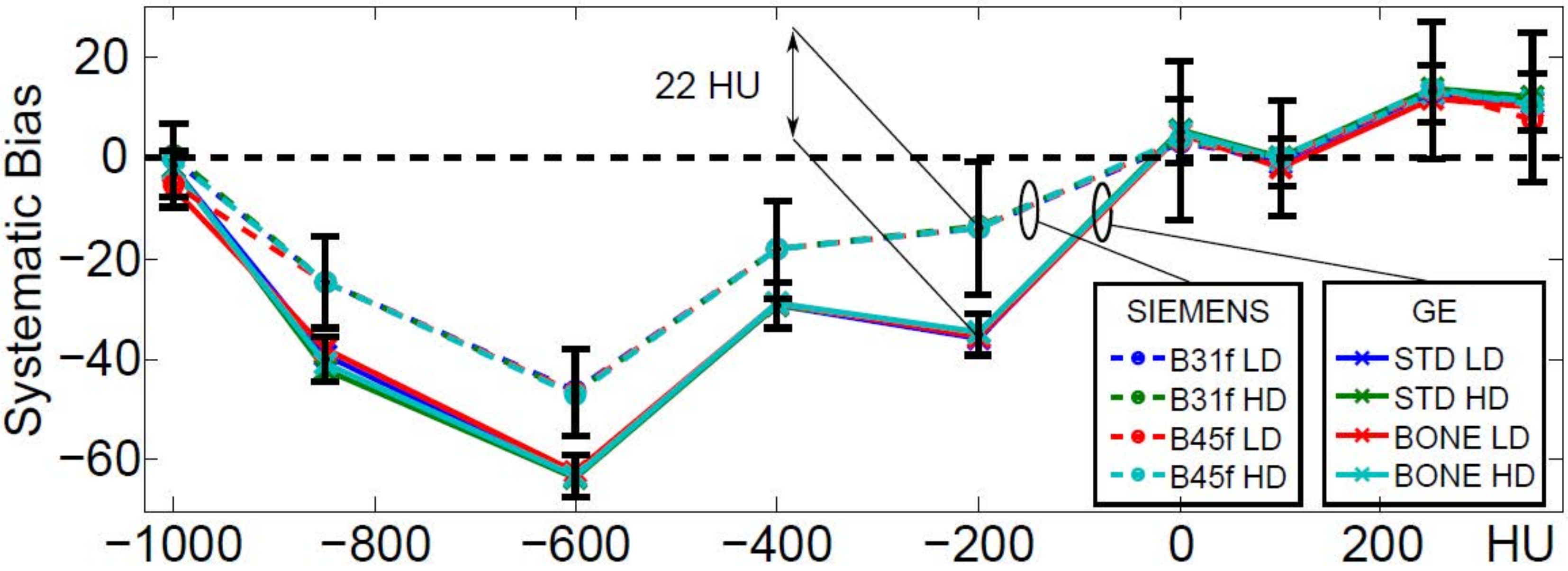


Figure 13: Systematic bias observed in each device. This bias depends on the calibration of the device and the DC contribution of the reconstruction.

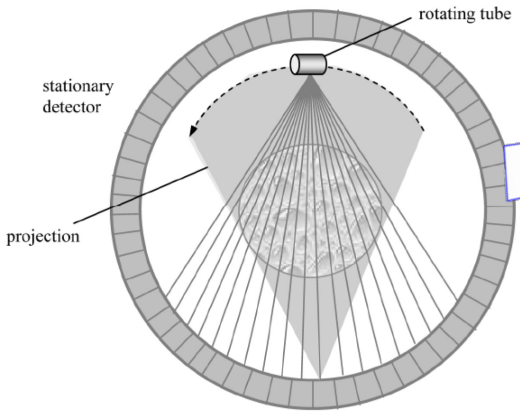
Observations:

1. **CT numbers behave equally for water and air**
2. **Strong deviations for other CT numbers**

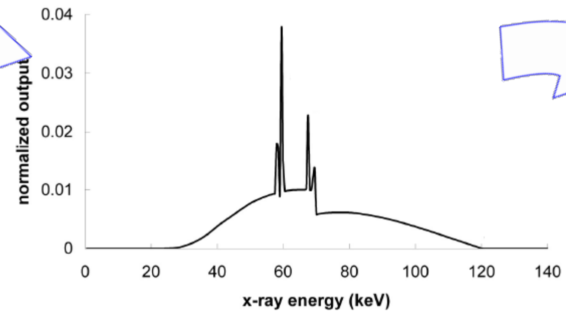
Stabilization of Noise for Harmonization

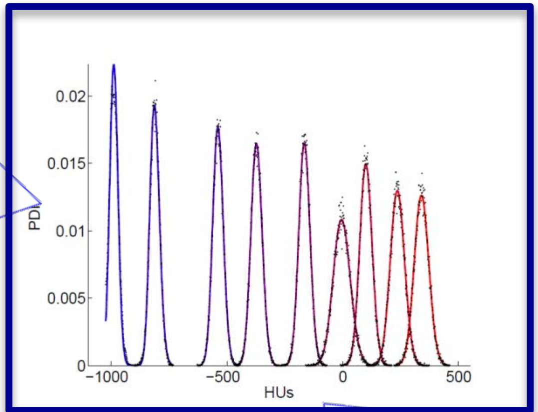
- Noise Stabilization:
  - Transform input signal in such a way that the output follows known statistical properties
    - Gaussian
    - Stationary
- Goal:
  - **Enabling statistical comparison** between **different regions** for different acquisition protocols (including **kernels**, **doses** and **reconstruction algorithms**)

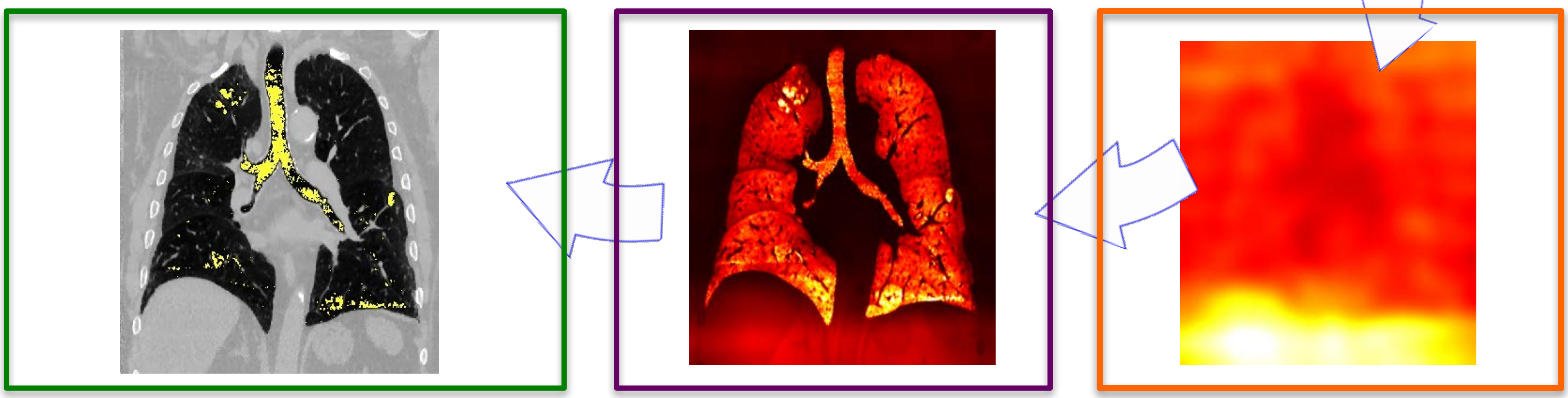
Stabilization of Noise for Harmonization



Attenuation levels as a stochastic process

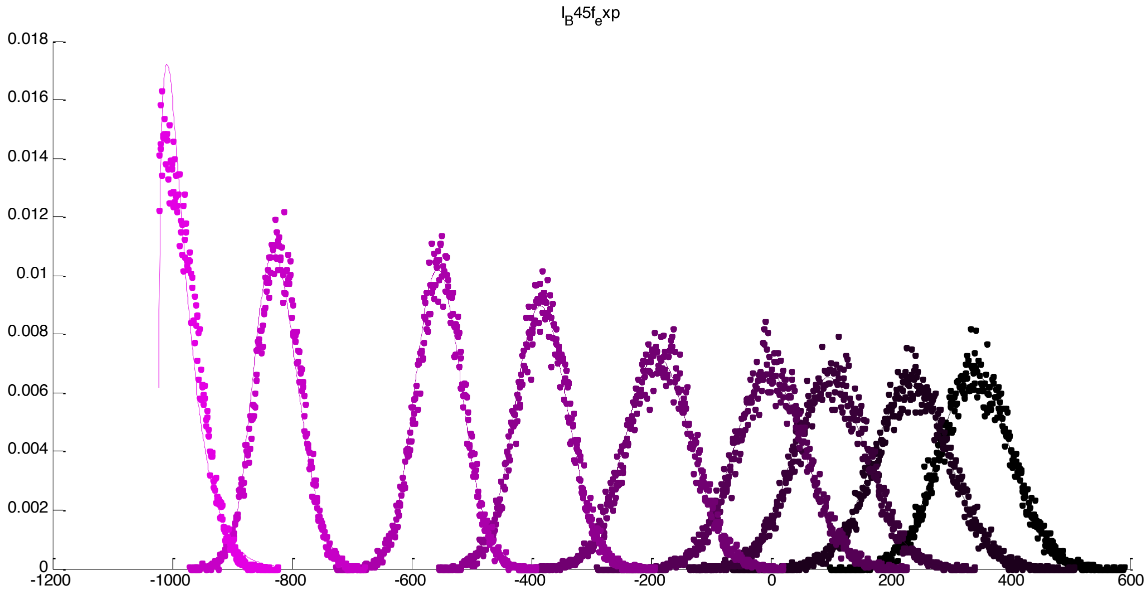






Vegas-Sánchez-Ferrero G, *Medical Image Analysis* 2017

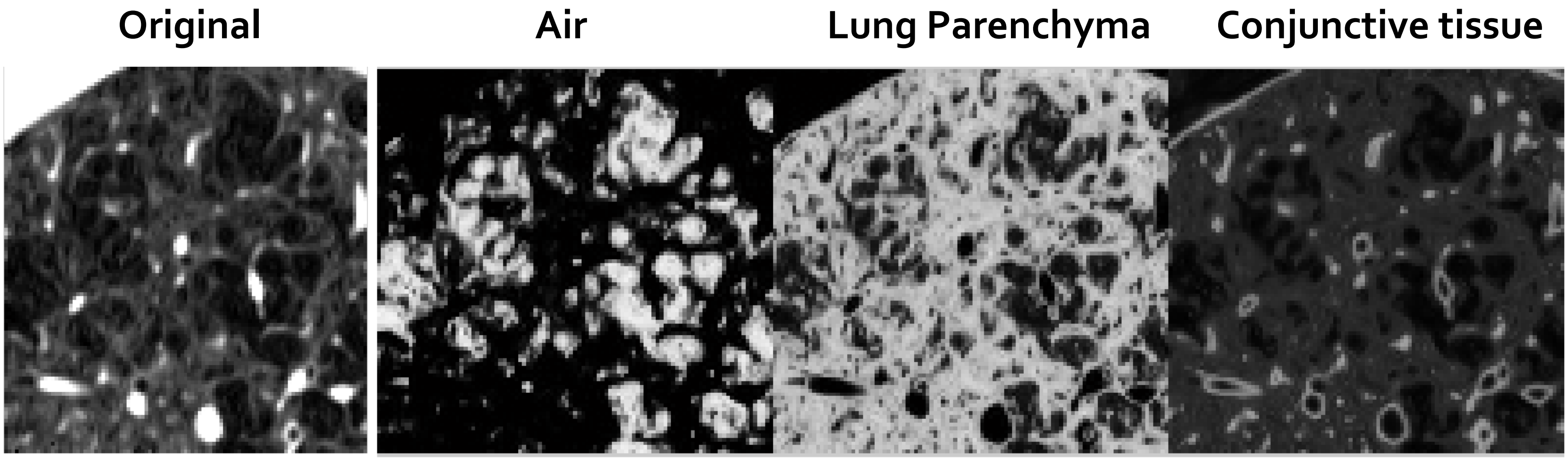
Statistical Model for CT signal



Mixture of Gammas:

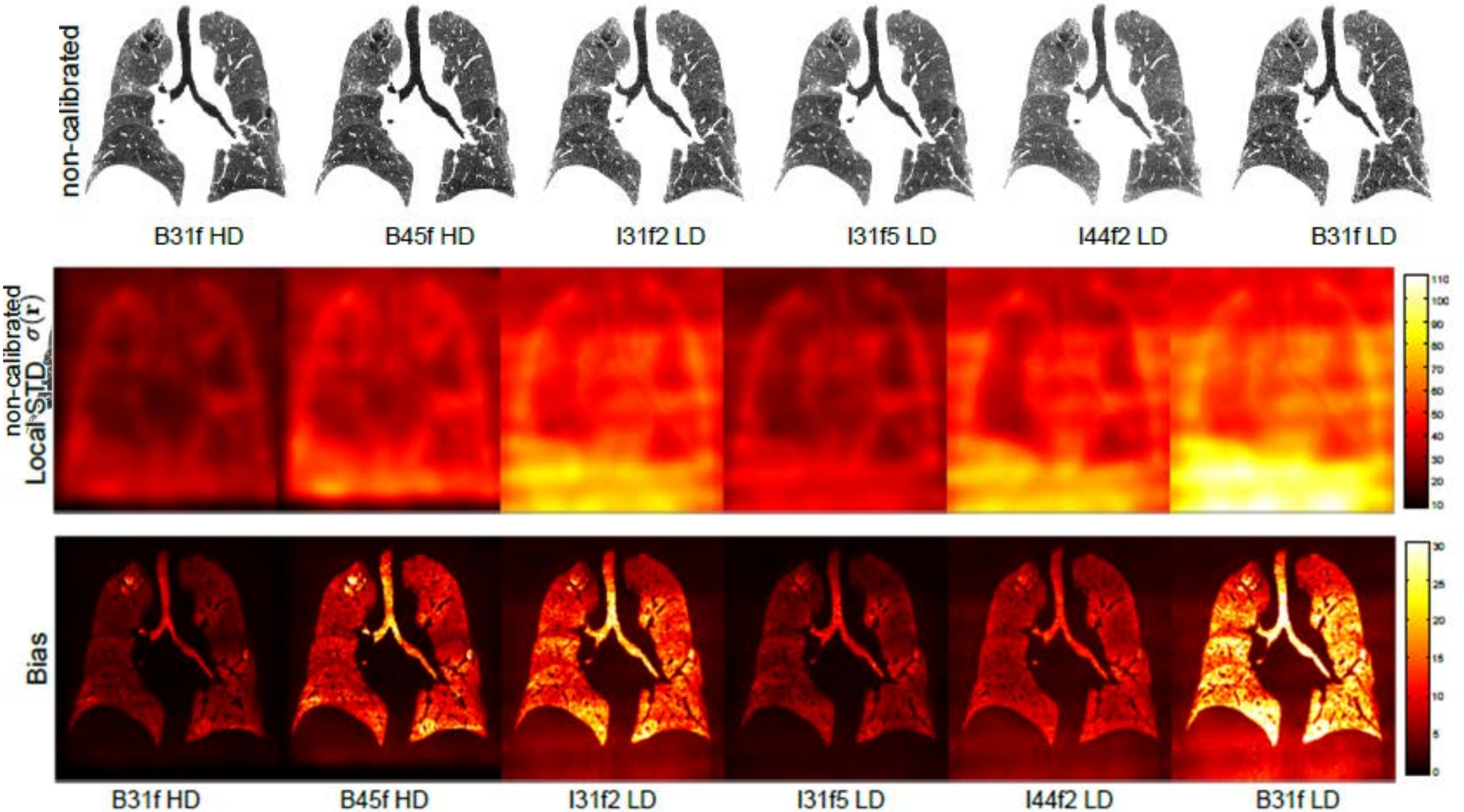
- Fits the statistical behavior of noise with different kernels, doses and reconstruction methods.
- Leads for the estimation of local statistics.
- Allows us to distinguish different tissue responses

- Main Advantage:
  - Enables the estimation of the signal considering the likelihood of each density component associate to a tissue type.



Methodology

1. Bias correction



Methodology

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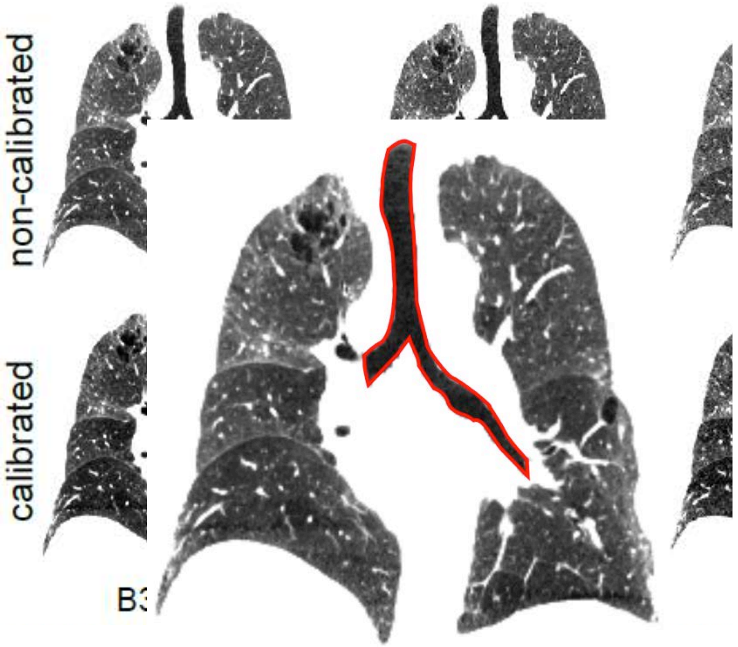
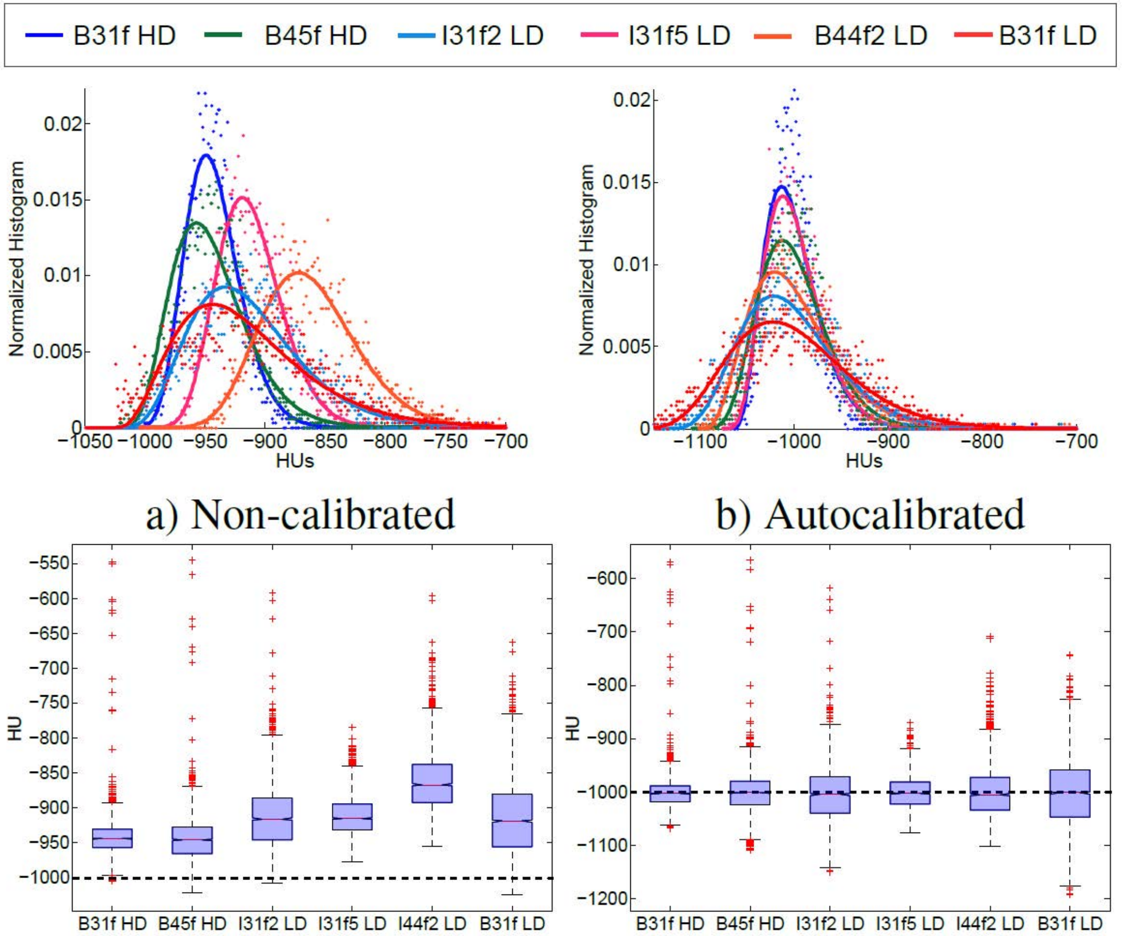




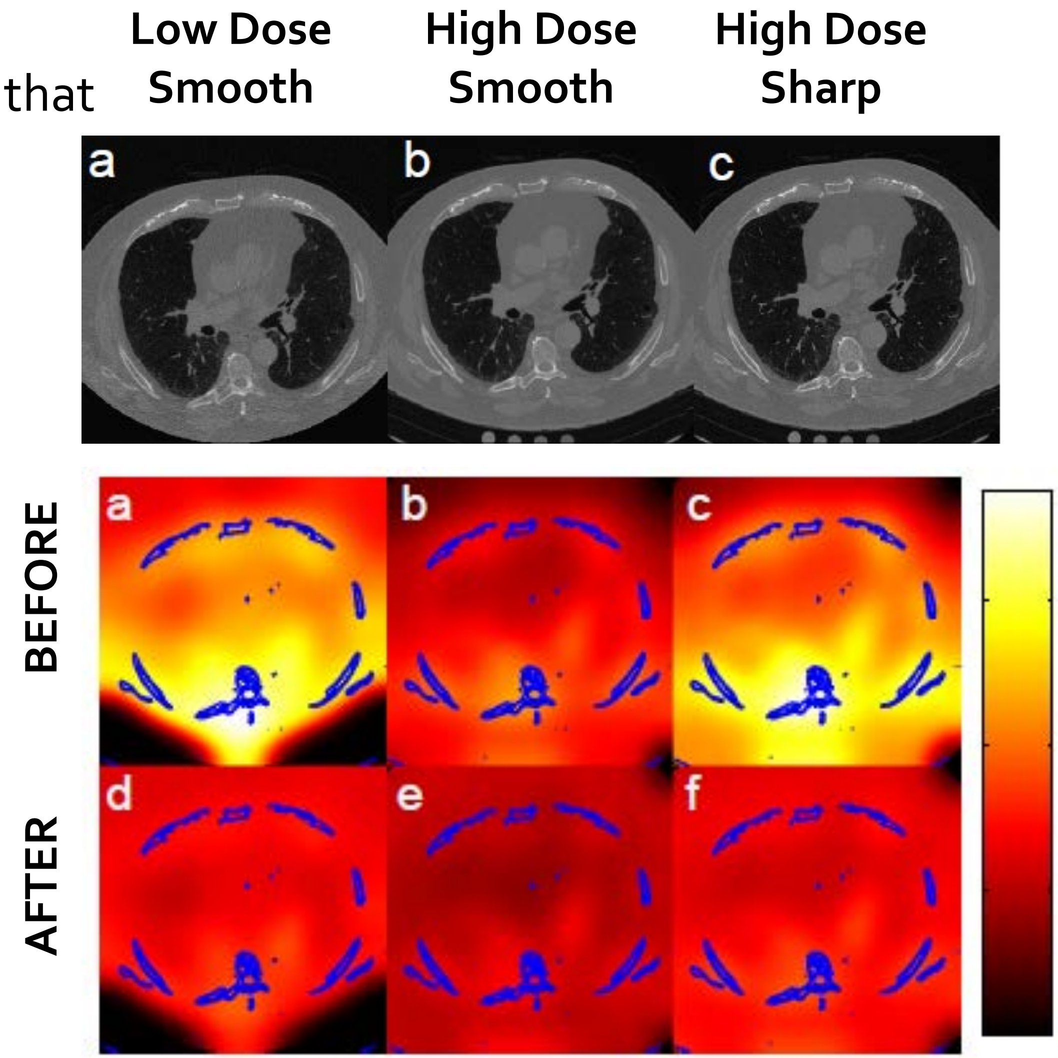
a) Non-calibrated b) Autocalibrated

c) Non-calibrated d) Autocalibrated

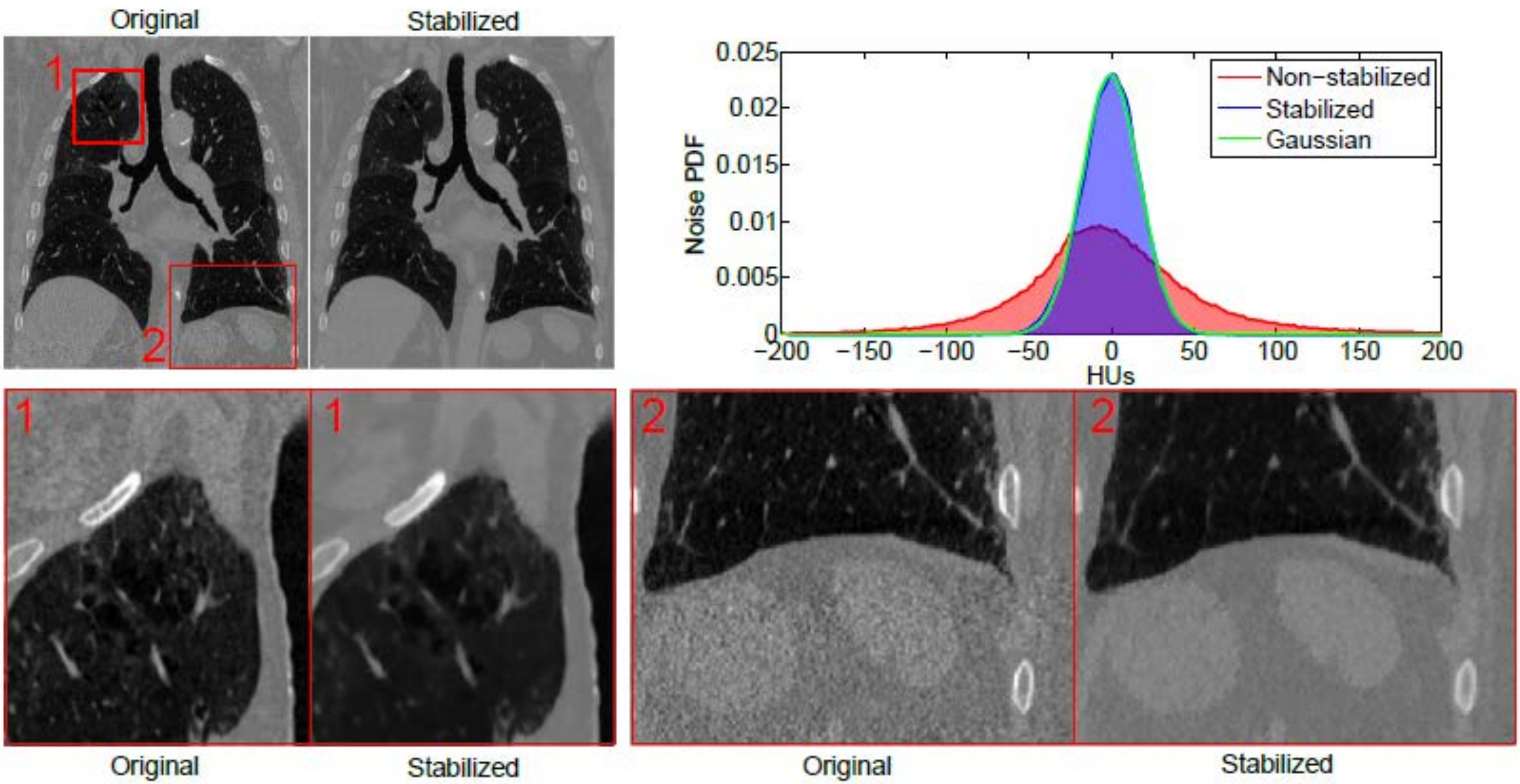
Methodology

2. Noise Stabilization

- Transformation of the CT signal that employs
  - Estimated signal
  - Estimated noise variance



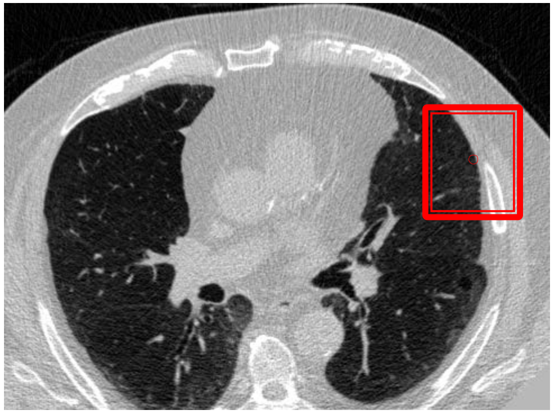
Results

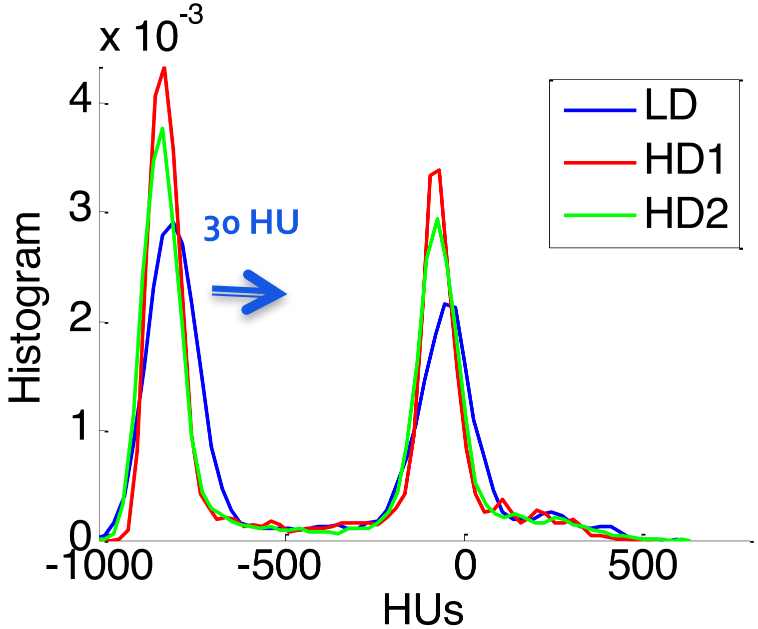


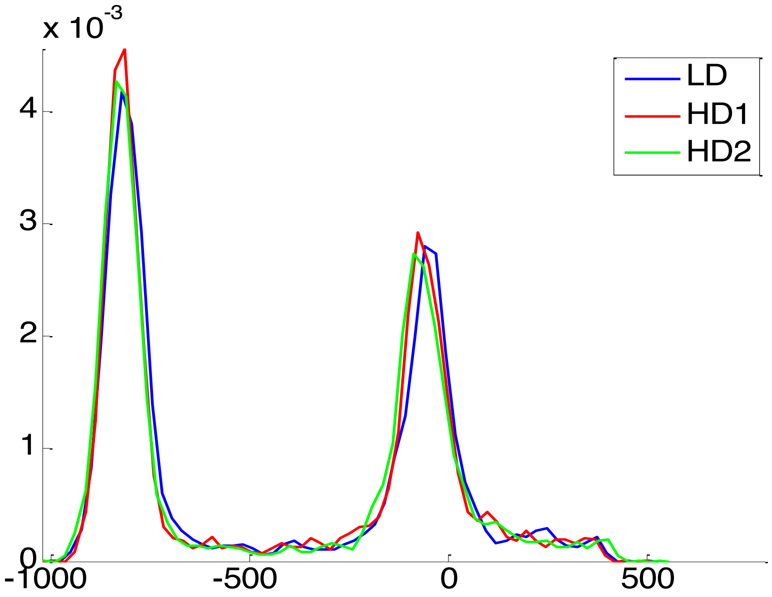
Observations:

The influence of noise is dramatically reduced throughout the image (contrast in soft tissues increases).

Difference between Local Histograms

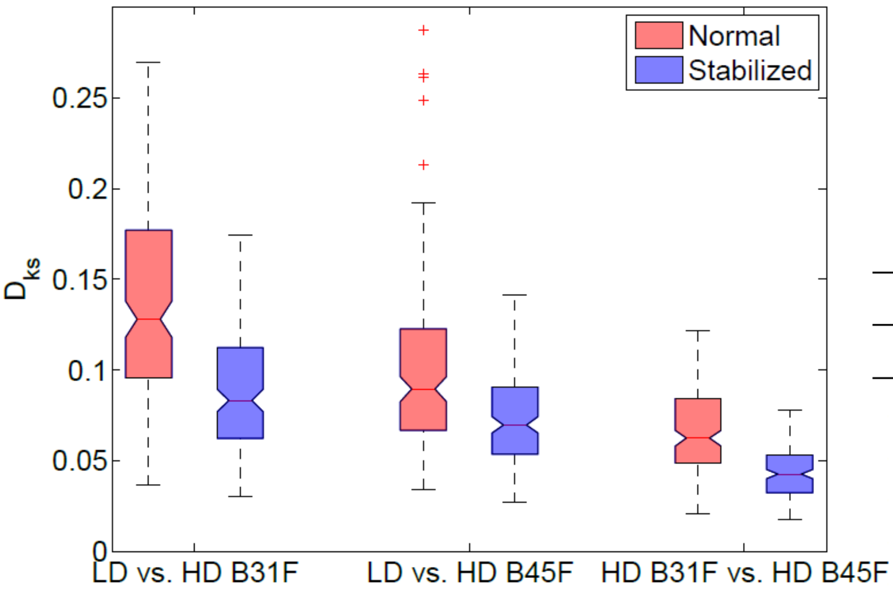






High Dose vs. Low Dose

High Dose Acquisition with Kernel (Sharp and Smooth) vs. Low Dose Reconstruction

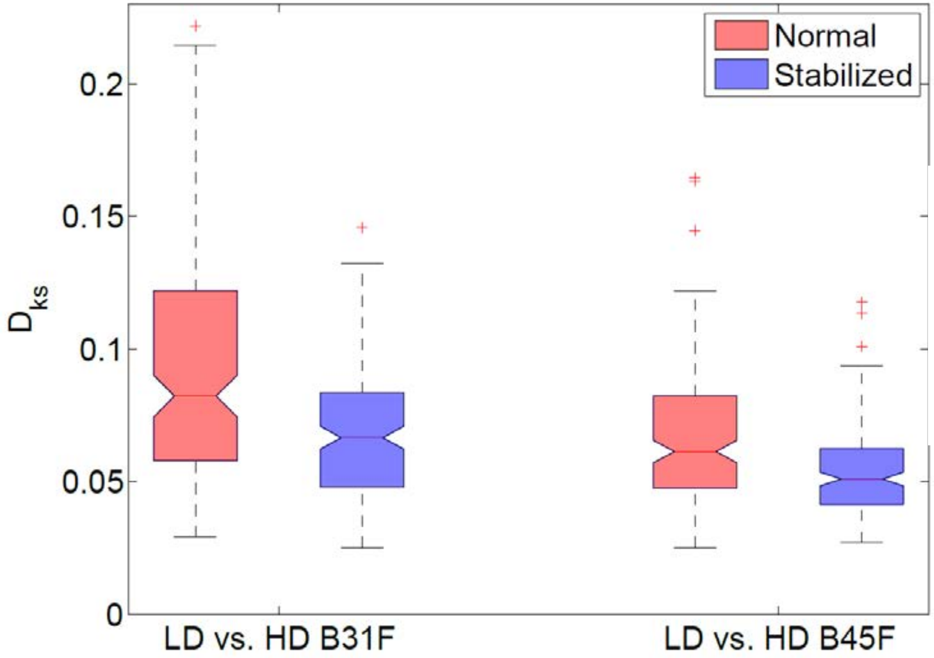


	LD B31f vs. HD B31f	LD B31f vs. HD B45f	HD B31f vs. HD B45f
Normal	21.21%	48.48%	80.00%
Stabilized	55.15%	72.73%	100.00%

Ratio of statistically equal histograms
(p-value < 0.0001)

Iterative Low Dose vs. High Dose FBP

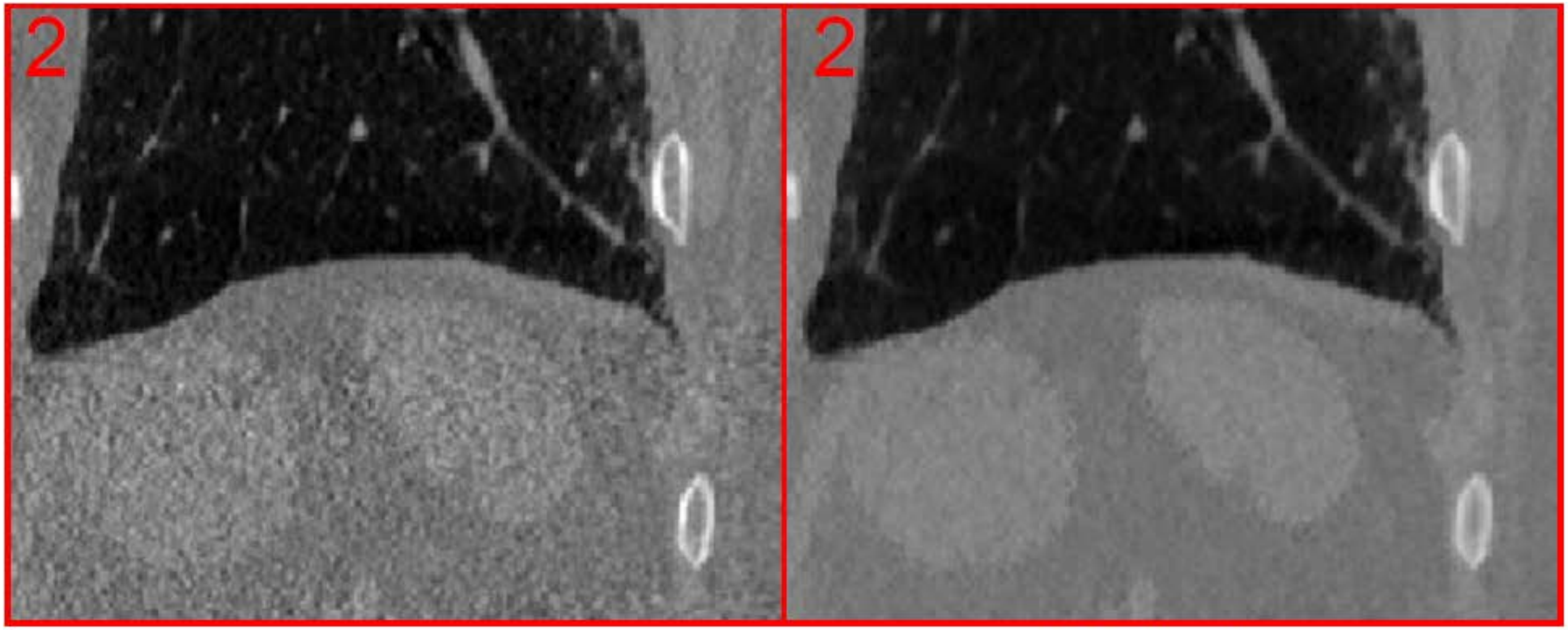
LD Iterative Reconstruction vs. **HD Filtered Back Projection**



	LD I44f vs. HD B31f	LD I44f vs. HD B45f
Normal	52.12%	80.61%
Stabilized	80.61%	96.97%

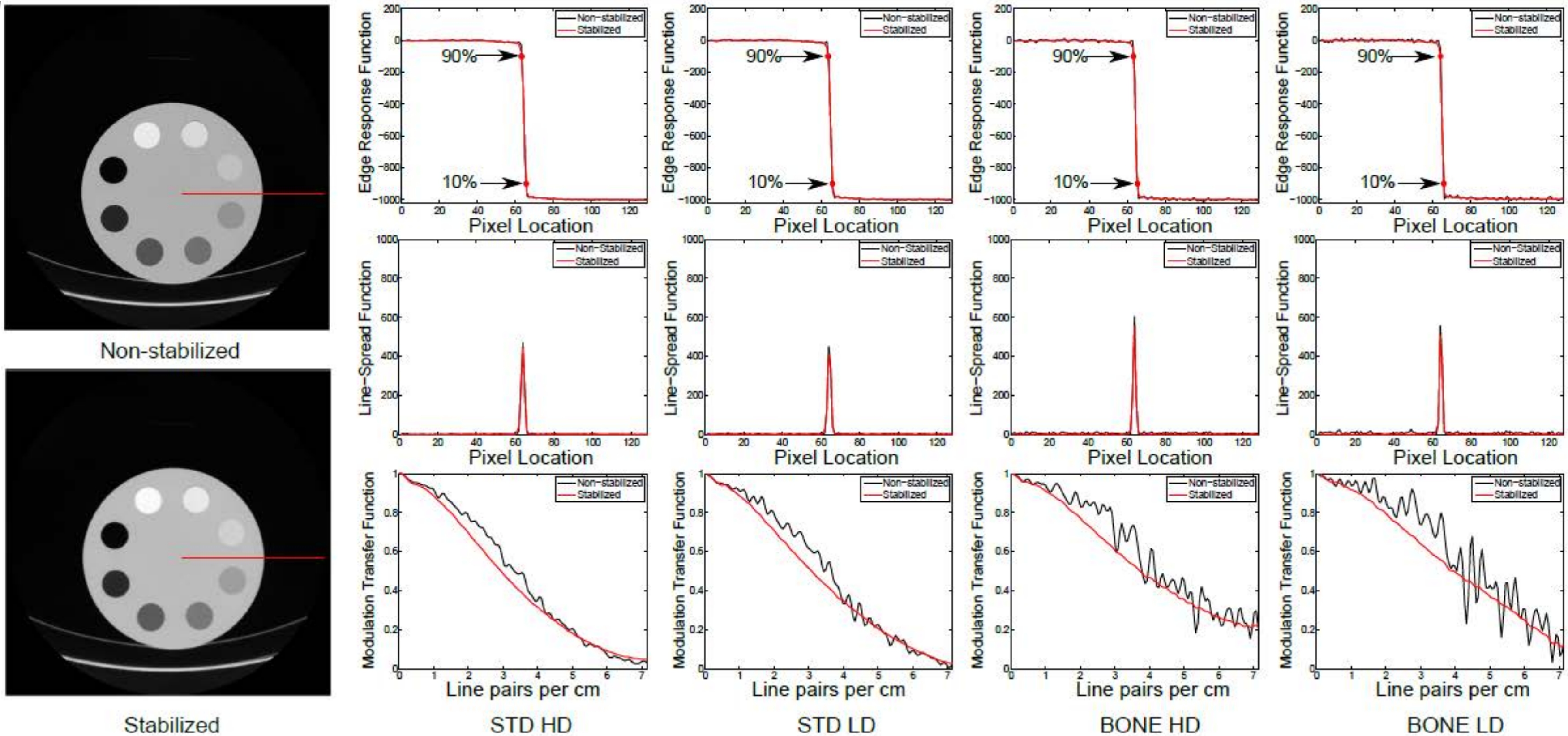
Ratio of statistically equal histograms (p-value < 0.0001)

Noise Stabilization and Resolution



Original Stabilized

Noise Stabilization and Resolution



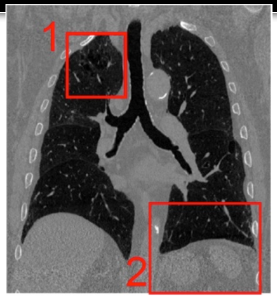
The MTFs are unaltered after noise stabilization

GE	Normal	Stabilized
STD LD	2.14	2.50
STD HD	2.38	2.63
BONE LD	1.67	1.83
BONE HD	1.99	2.32

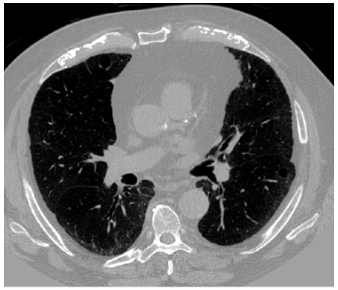
Siemens	Normal	Stabilized
B31f LD	1.99	2.31
B31f HD	2.12	2.36
B45f LD	1.36	1.54
B45f HD	1.36	1.52

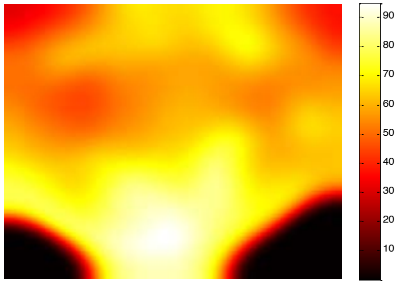
Table 5: Distance of the 10%-90% of the edge response in pixel units for stabilized images with $C = 0$. The differences between both measures is always below 0.5 pixels.

Conclusions

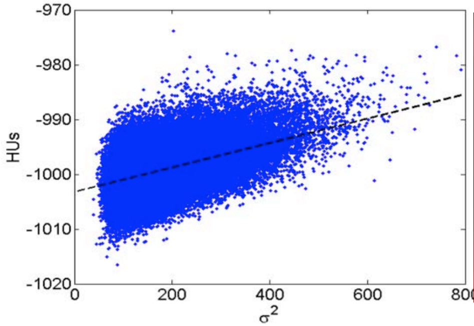


- Noise **also depends on the scanned subject**
  - Current calibrations should consider this





- Variance of noise is **spatially variant**
  - Local Effects



- Variance of Noise introduces a **Bias in low CT numbers**

- Systematic Bias between devices is **non-linear**