# Class 6: Parameters cont.; Fisher matrix; triangle plots; variable backgrounds

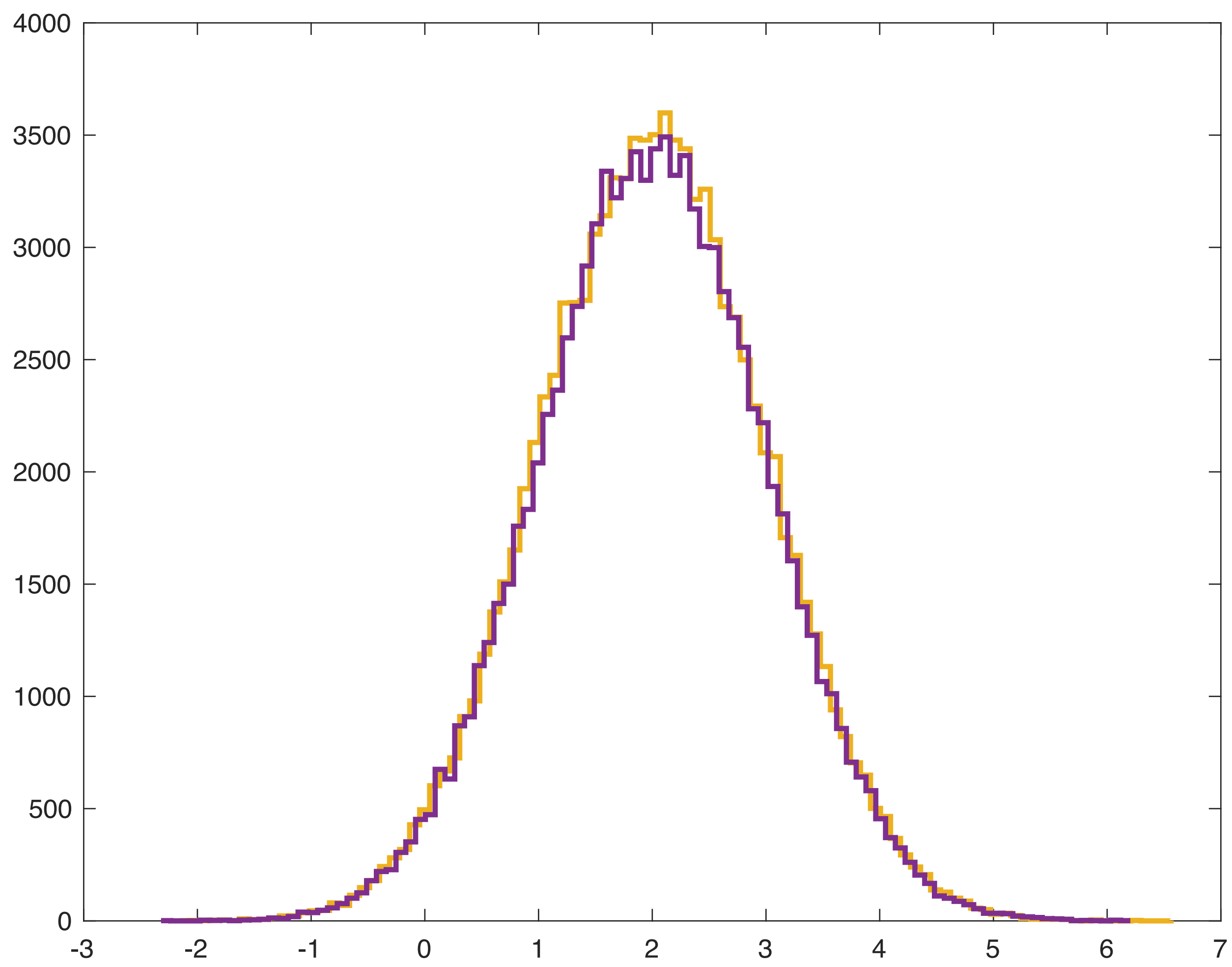
Starting to put it together

# Parameters

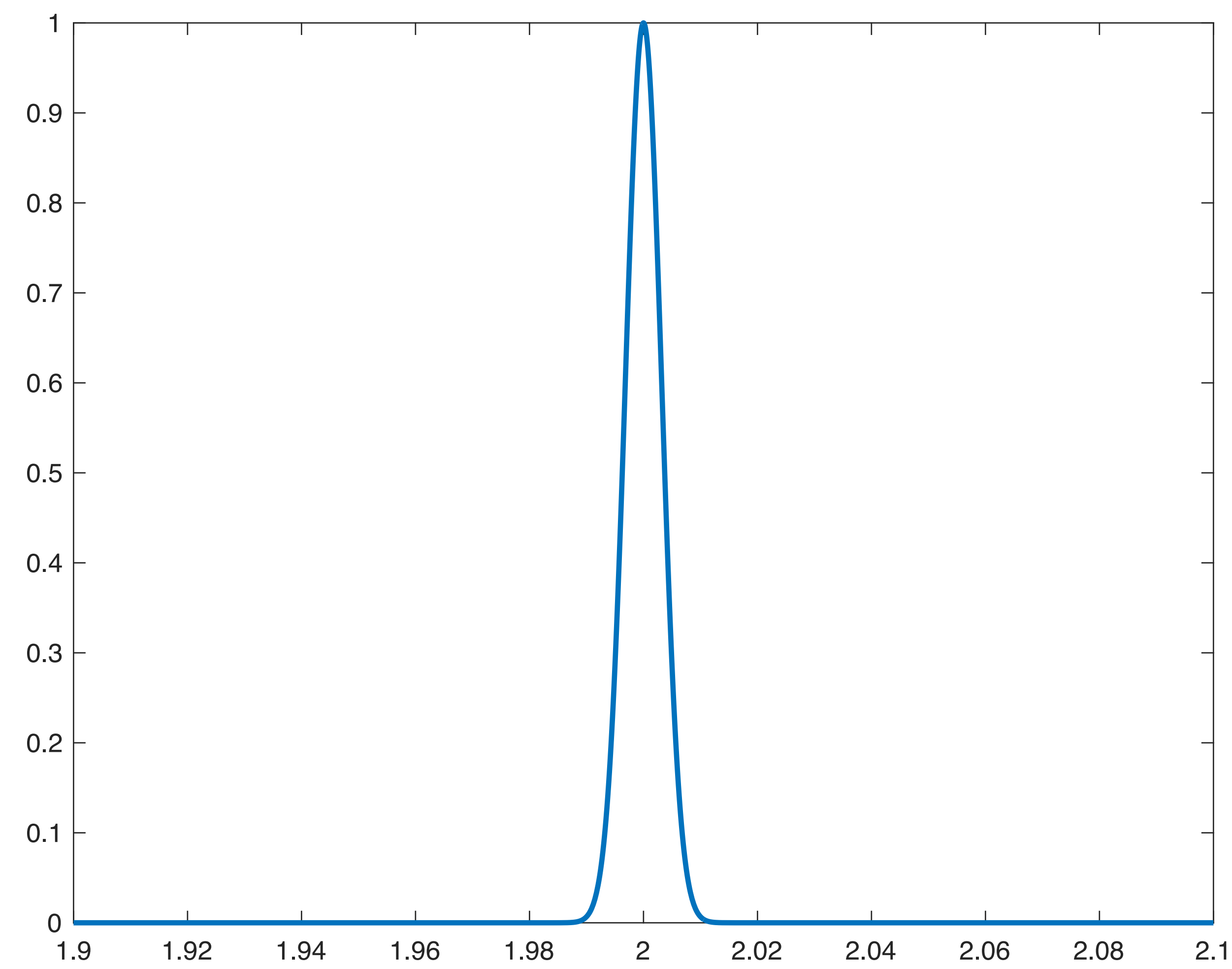
# Single parameter distribution

## Population distribution

($10^5$ measurements)



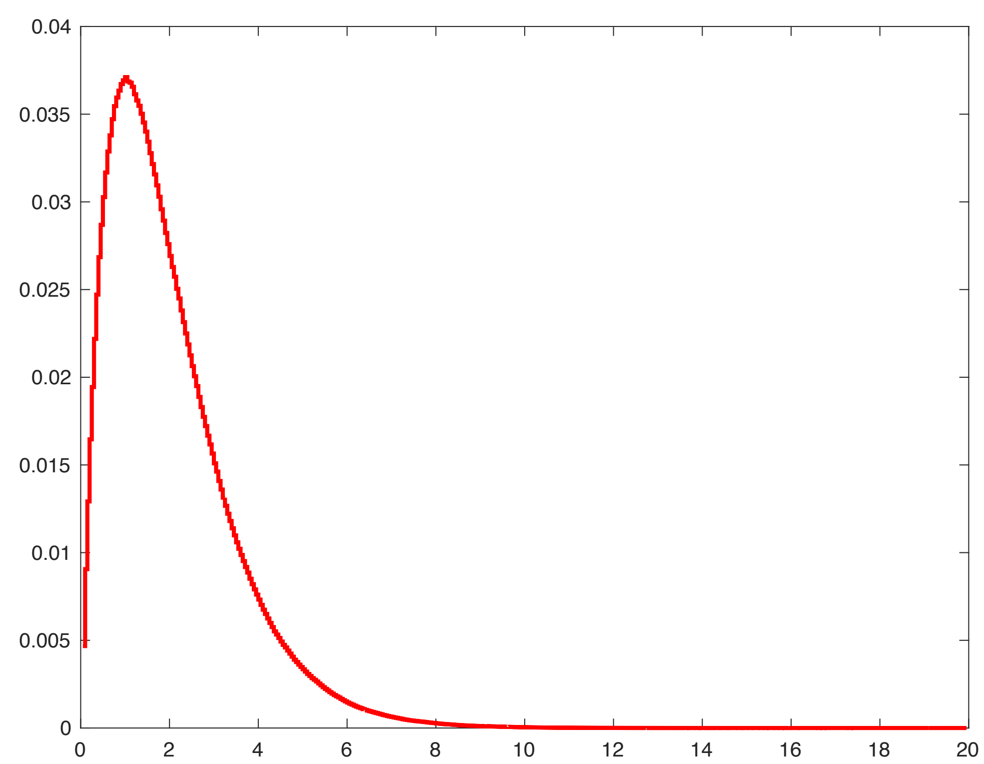

## Distribution of the mean




$$\hat{m} = \langle \text{data} \rangle$$

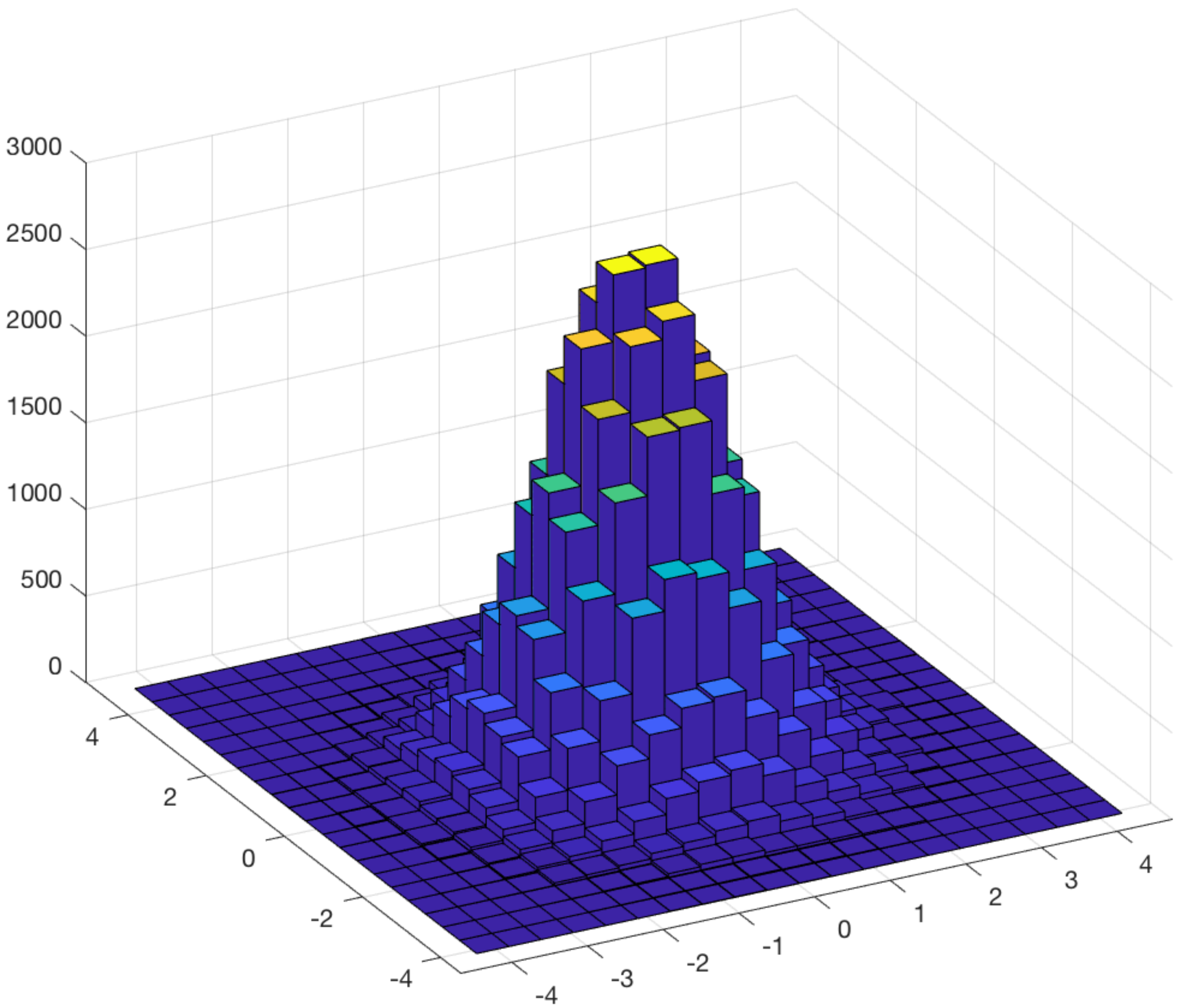
# Parameters

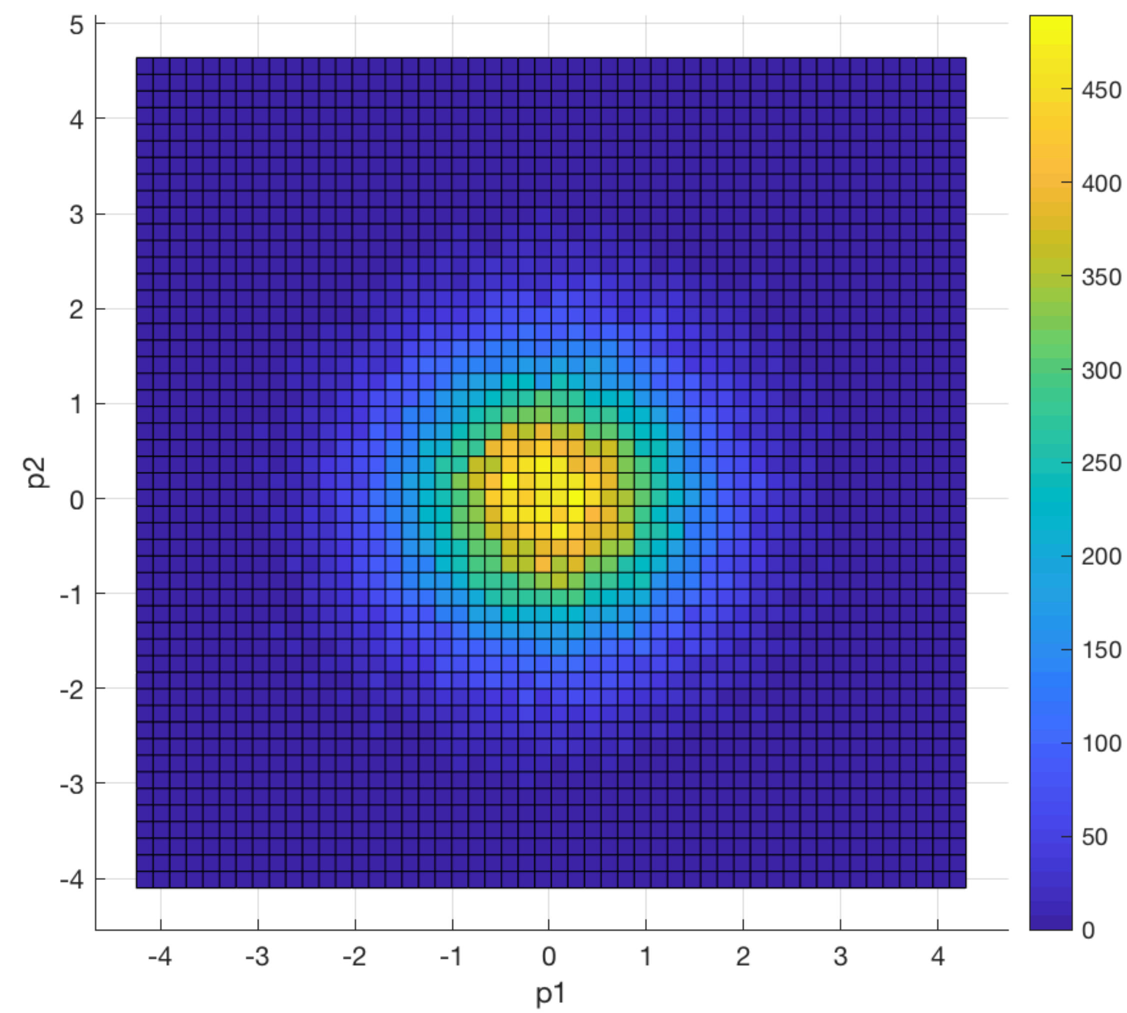
- Treat like a measurement—a value with some distribution
- Because the underlying is Gaussian does not mean the parameter is Gaussian, but can often propagate answer



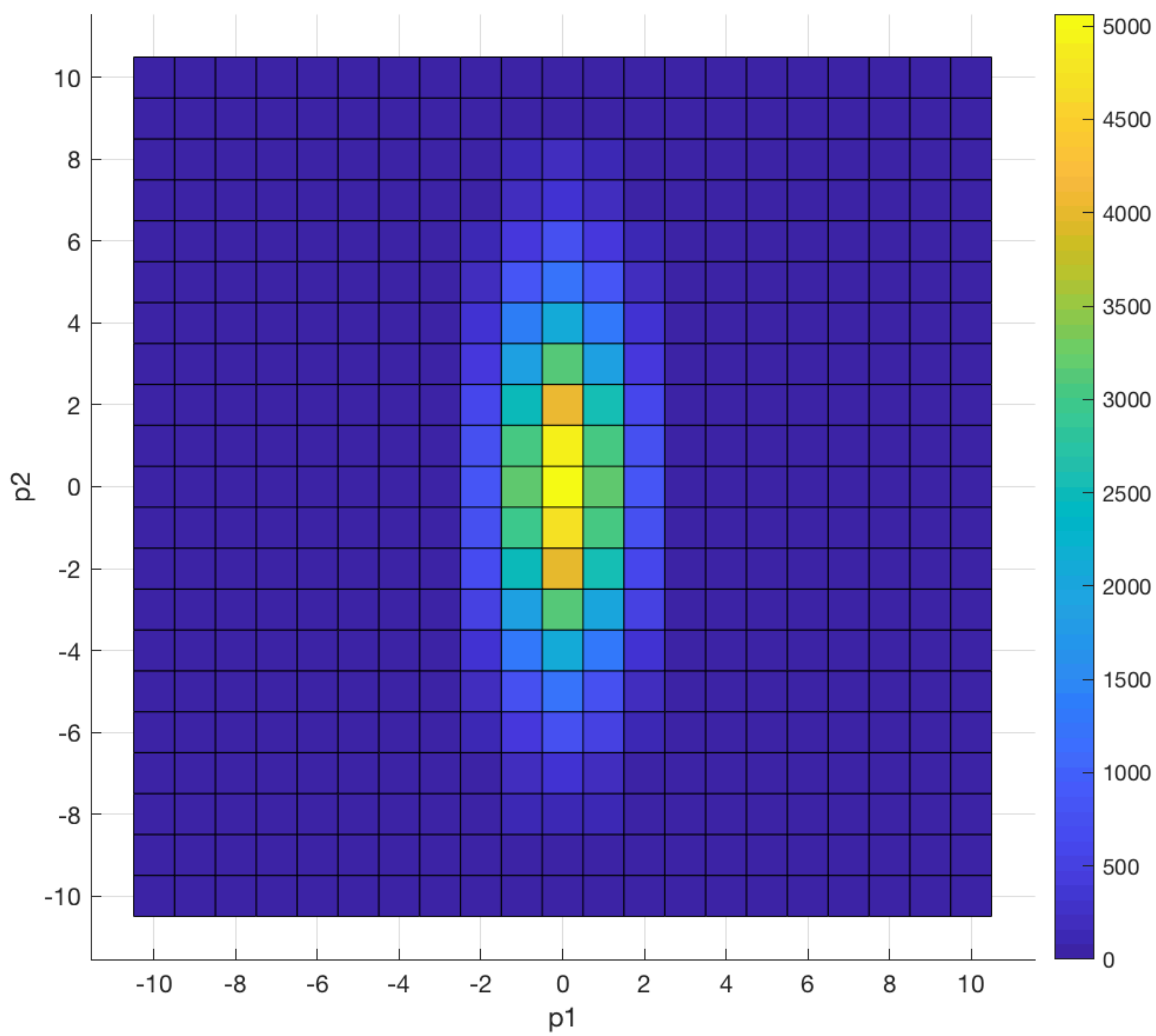

chi-square

# Multiple parameters



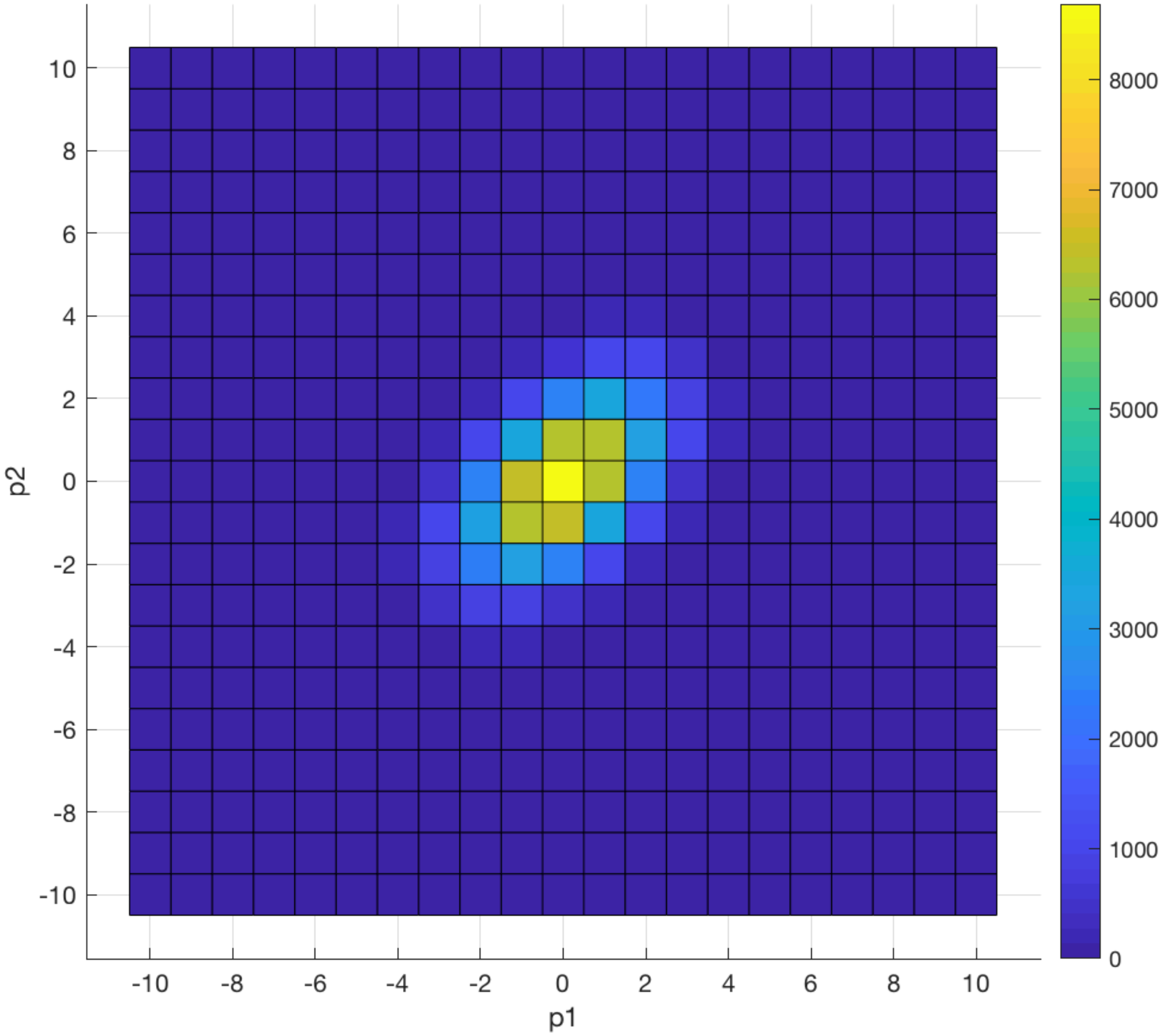



# Non-equal variance



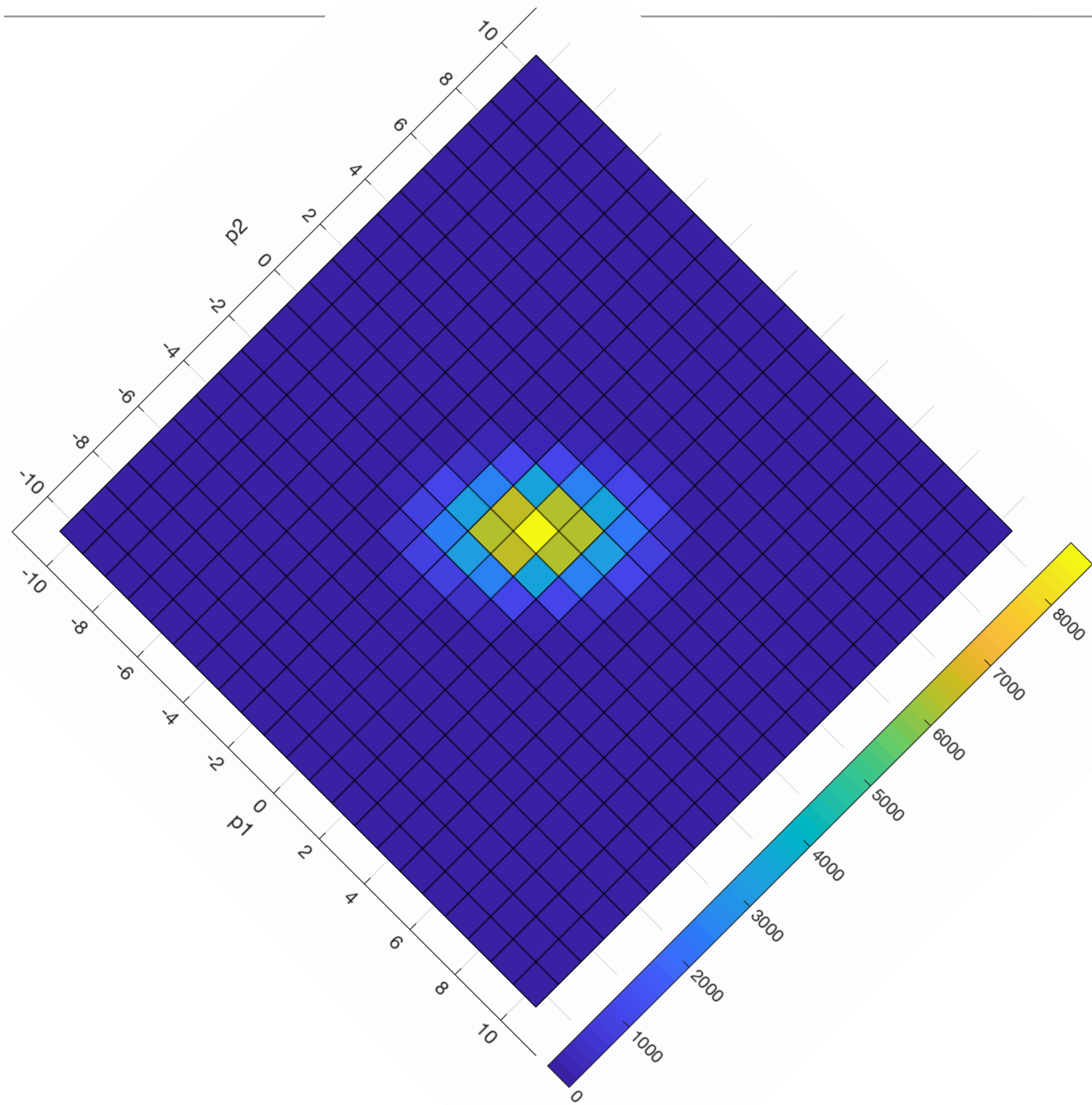

$$\sigma_1^2; \sigma_2^2$$

# Covariance




$$C(p_1, p_2) = \begin{bmatrix} \sigma_{11}^2 & \sigma_{12}^2 \\ \sigma_{21}^2 & \sigma_{22}^2 \end{bmatrix}$$

# Covariance




$$C(p_1', p_2') = \begin{bmatrix} \sigma_{11}^2 & 0 \\ 0 & \sigma_{22}^2 \end{bmatrix}$$

# Aside on Fisher information matrix

- Dark Energy Task Force technical appendix is a good resource
- $C = F^{-1}$
- $F$ is the second derivative of the log likelihood at peak $F_{ij} = -\left\langle \frac{\partial^2 \ln \mathscr{L}}{\partial p_i \partial p_j} \right\rangle$
- Conceptually is the Gaussian width ($1/\sigma_i^2$) of the $\ln \mathscr{L}$
- Assumes Gaussian statistics(!)
- Easy to marginalize over nuisance parameters by converting to $C$, dropping rows/columns, inverting back

# Triangle plot

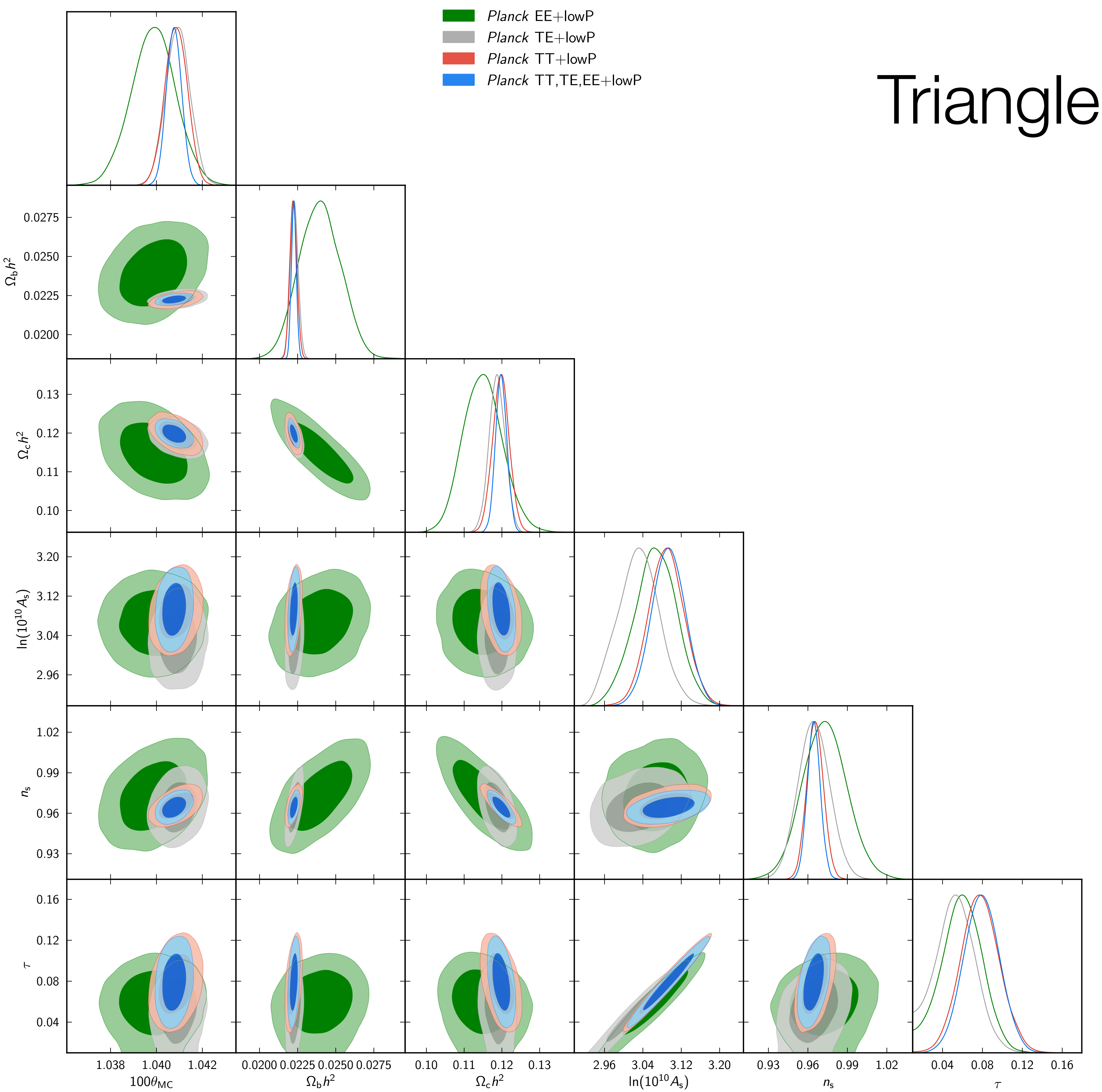
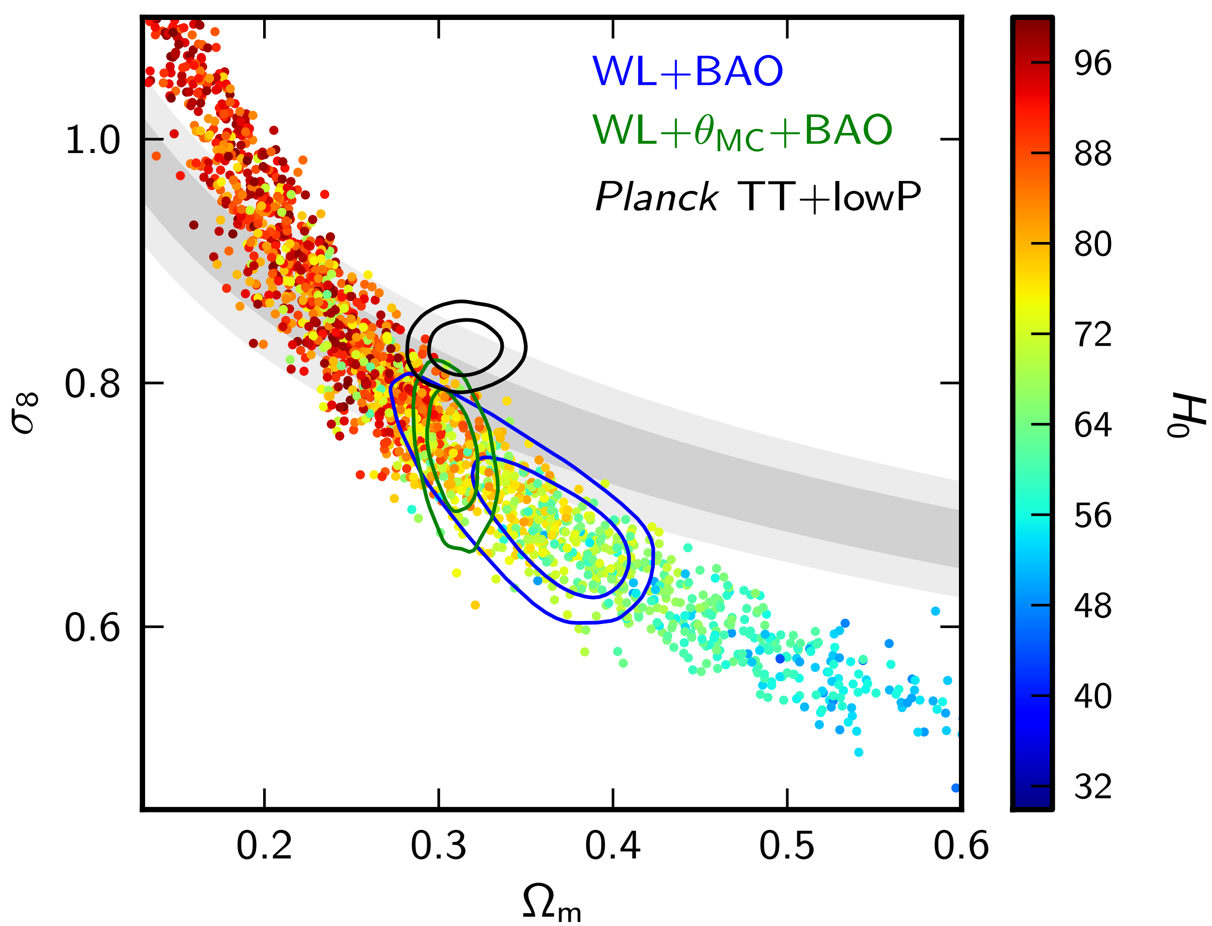
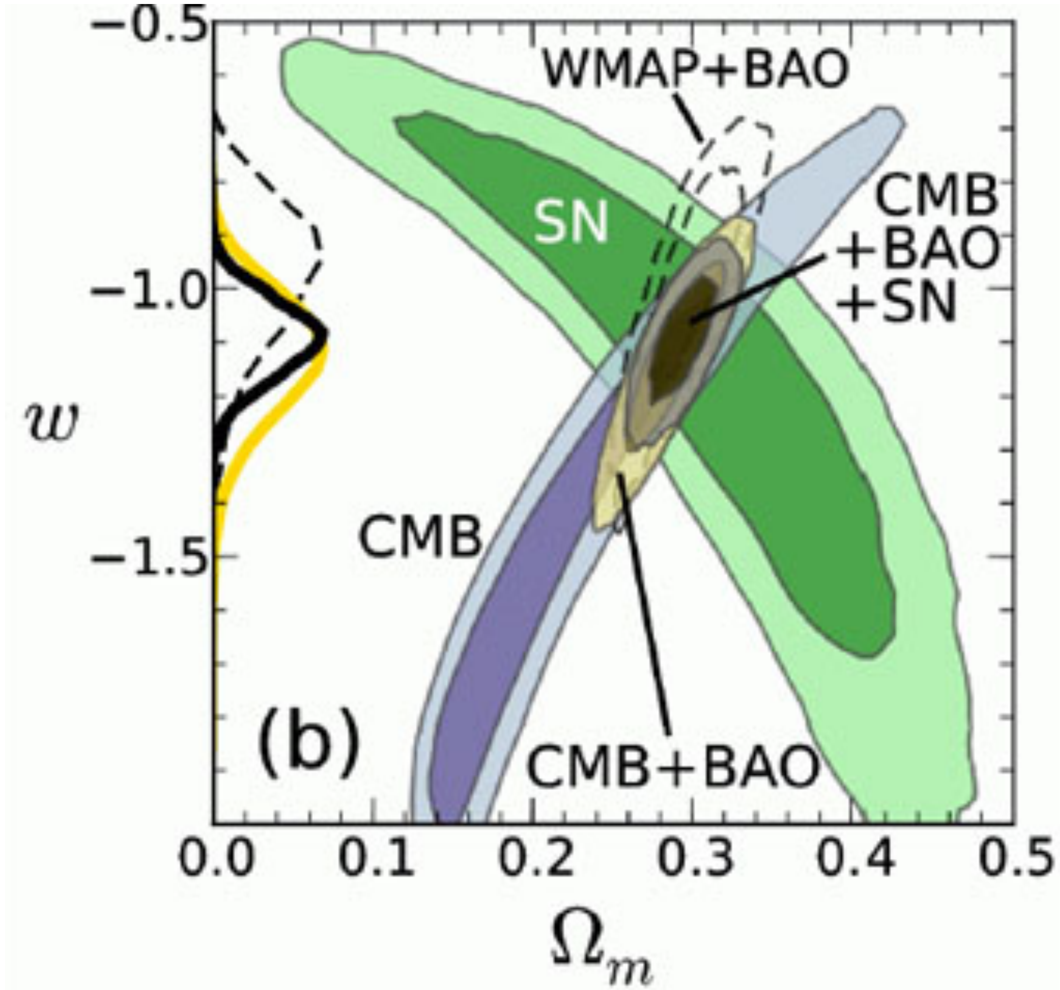



**Fig. 6.** Comparison of the base ΛCDM model parameter constraints from *Planck* temperature and polarization data.

Planck

# Complicated interactions lead to curved multi-parameter plots (can't be described with $C$ or $F$ )



# Take home message

- Multiple parameters can depend on each other in complicated ways

- Don’t assume they are independent of one another

- Can be due to Theory, your model, instrument, nature, or interactions

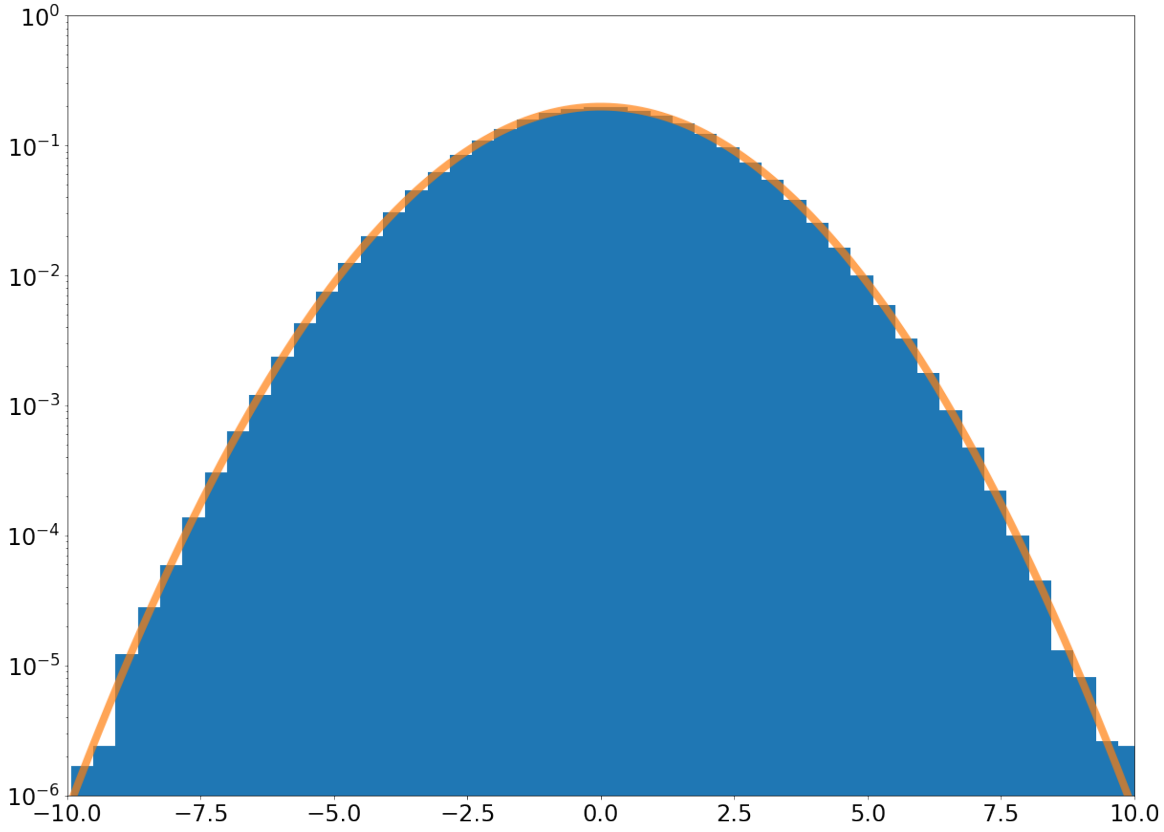
# Variable backgrounds

# Is your background constant?

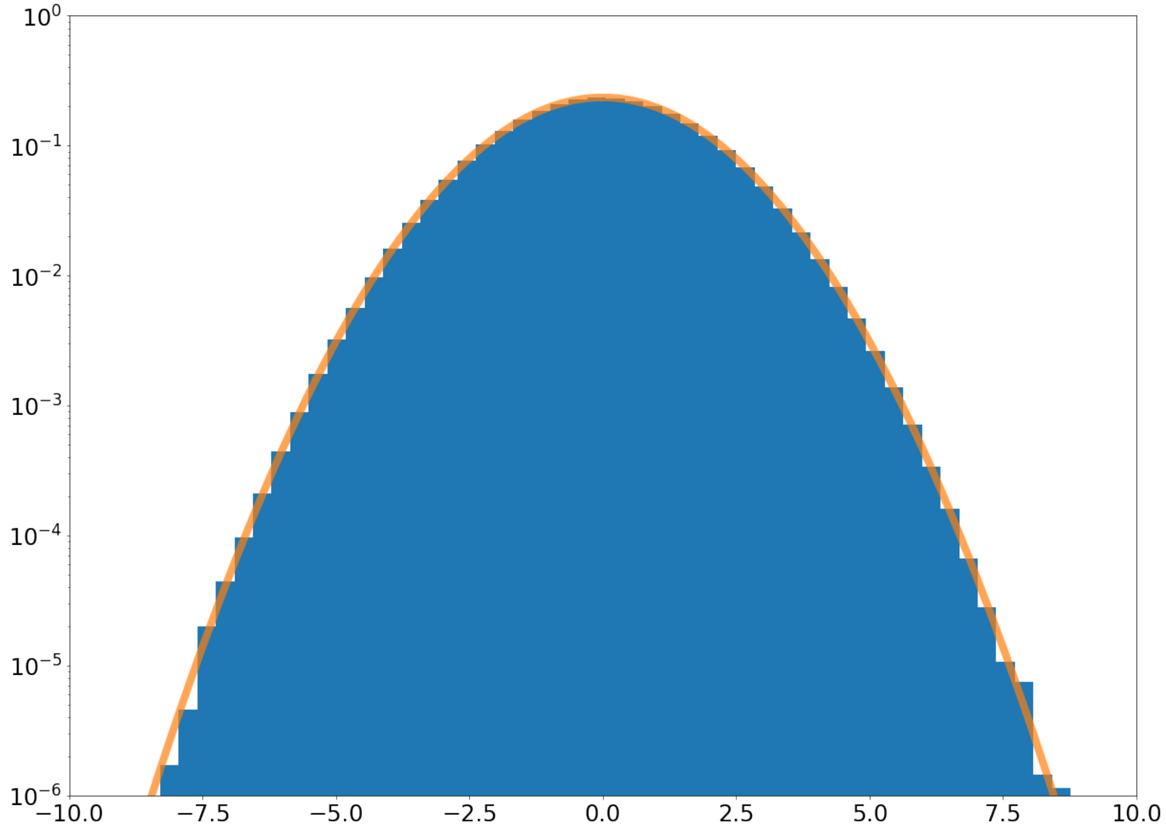
- The performance of an instrument—and thus the background pdf()—is almost never constant.
- This tells you about the physics of your experiment.

# Changing background

$\sigma = 2.0$




$\sigma = 1.7$



# Two levels of exploration

1. Scavenger hunt, looking for the unexpected

2. Jackknife tests to hunt for very subtle effects (specific worries)

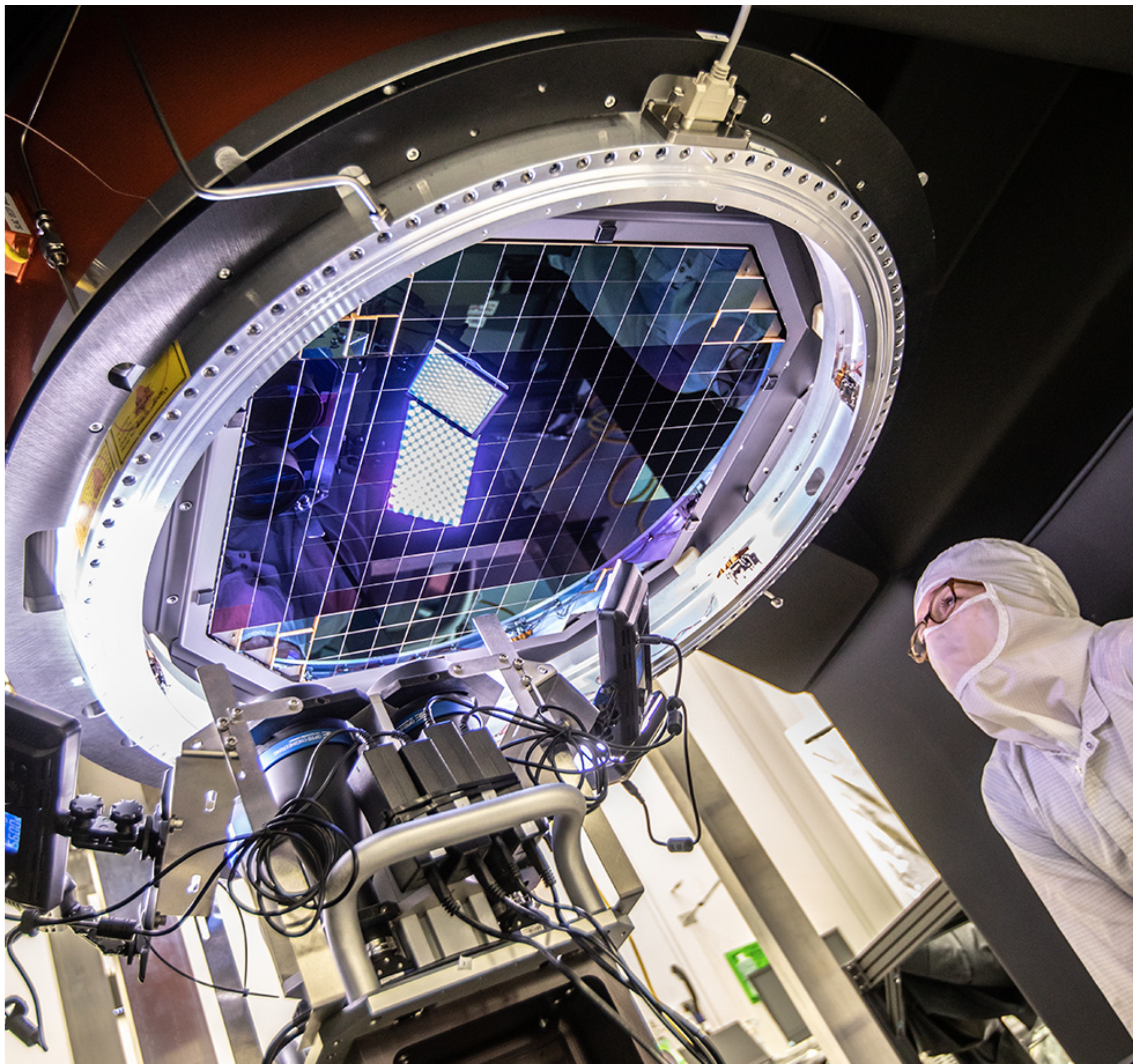
# Scavenger hunt, step 1)

- Explore your data
- Try and find gross variations
- Best done with plots

# Scavenger hunt, step 2)

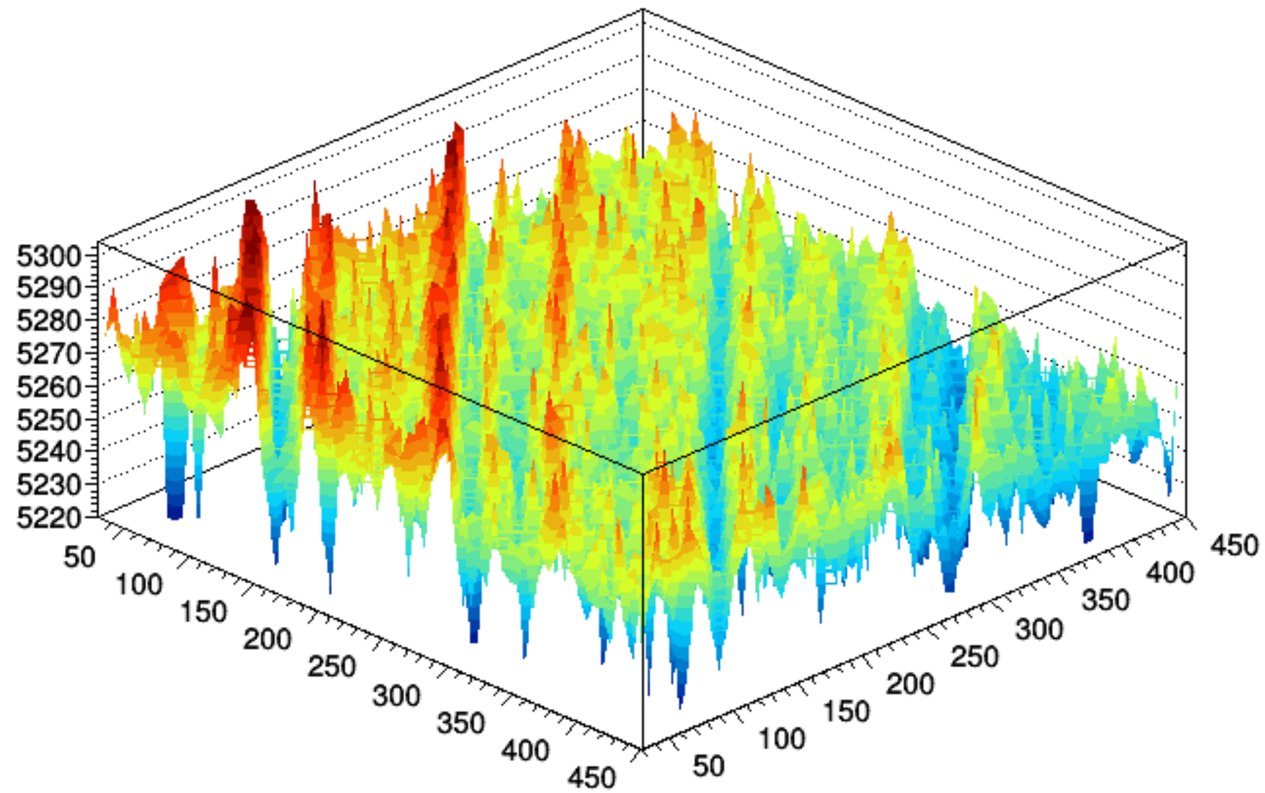
- Make a list of worries
- For each worry, come up with a plot and/or jackknife that highlights effect
- Keep track of both confirmed and unconfirmed worries!

# Case study:
# Vera Rubin Telescope (LSST) camera



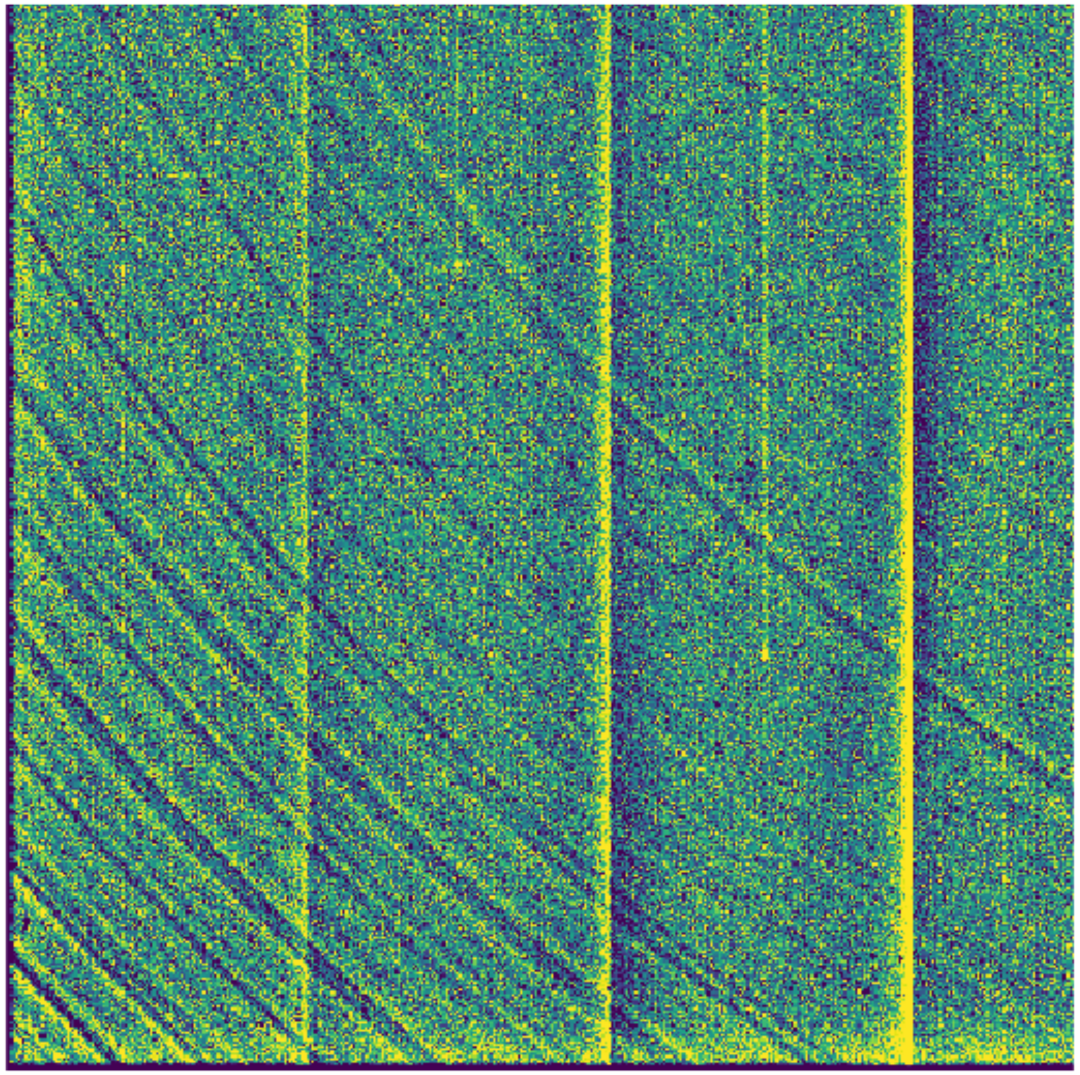
# Case study with LSST

**Worry: is the sensitivity constant across the CCD?**




(a)

# WTF?



# Is it related to color?

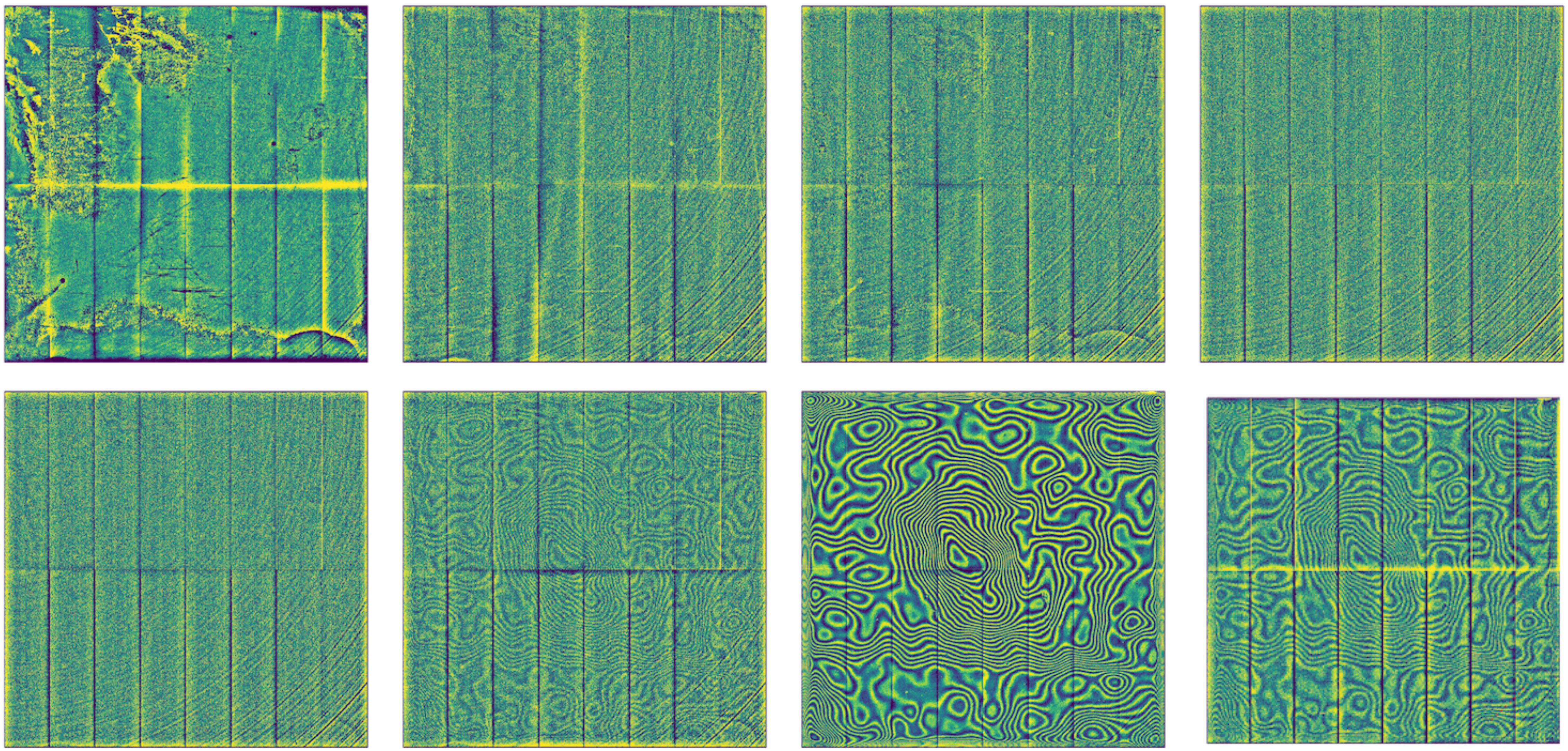
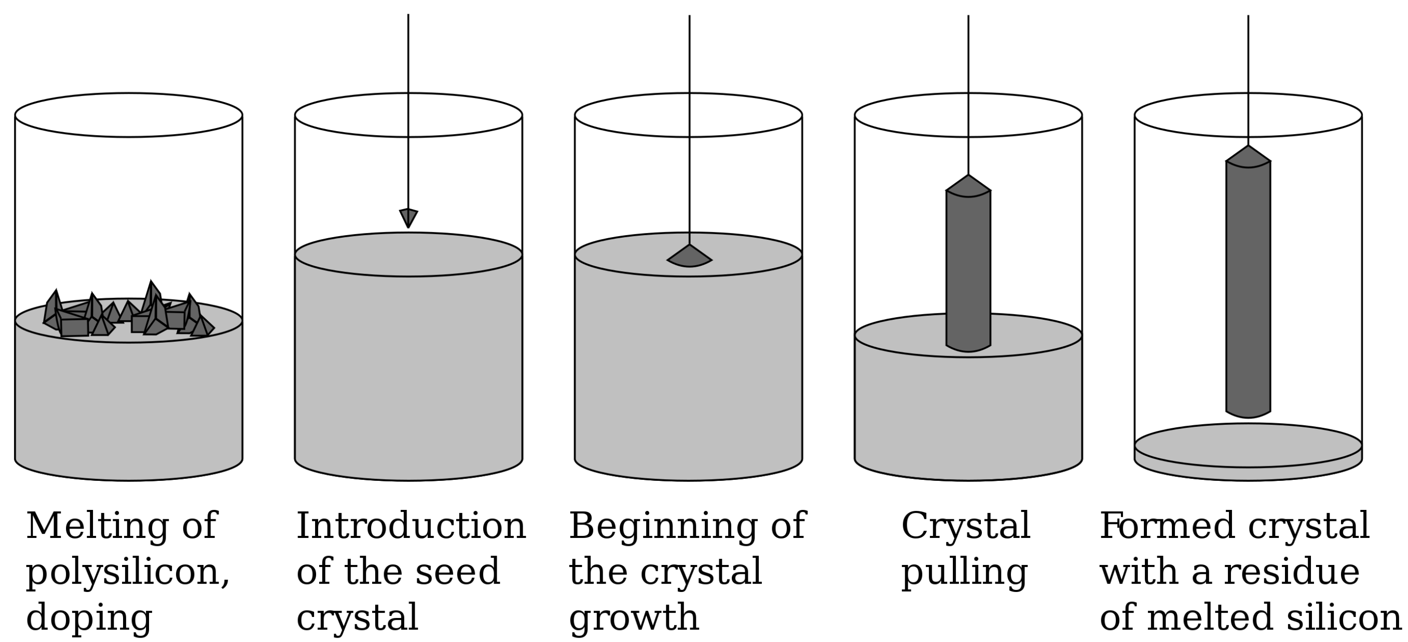


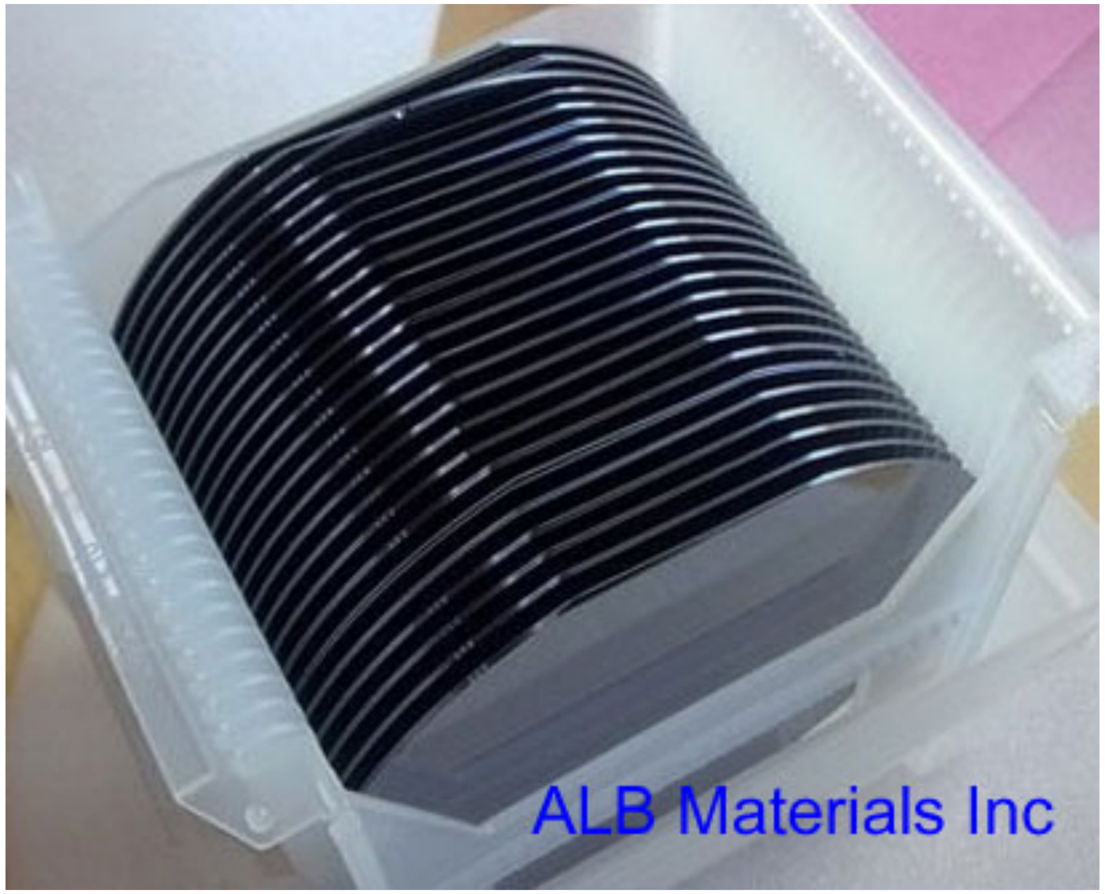
**Figure 5.** Uniformly illuminated images for the sensor ITL-3800C-017 taken at different wavelengths: 320, 400, 540, 770, 850, 900, 970, and 1080 nm (from top-left to bottom-right).

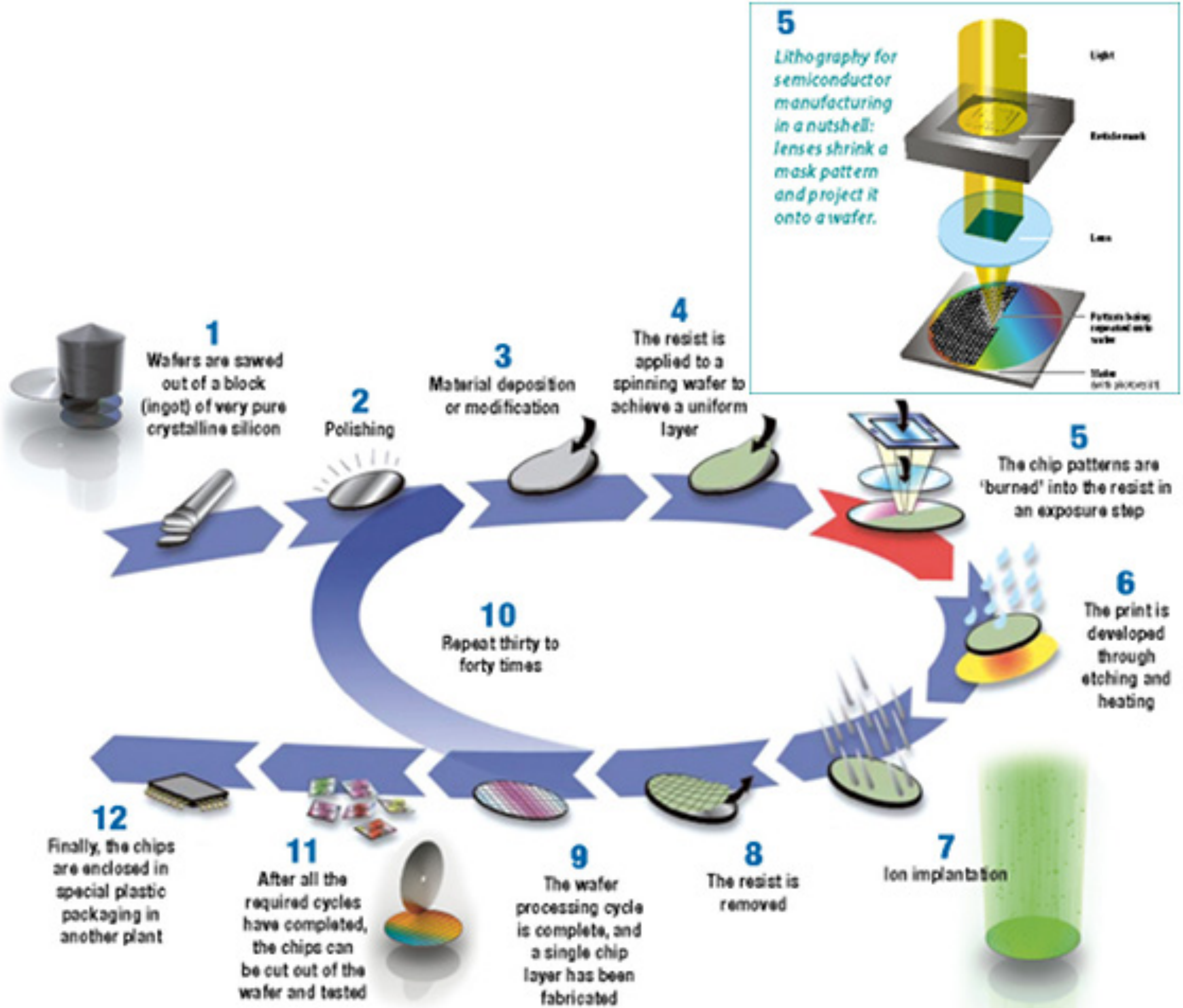
**Not really...**

# How was it made?

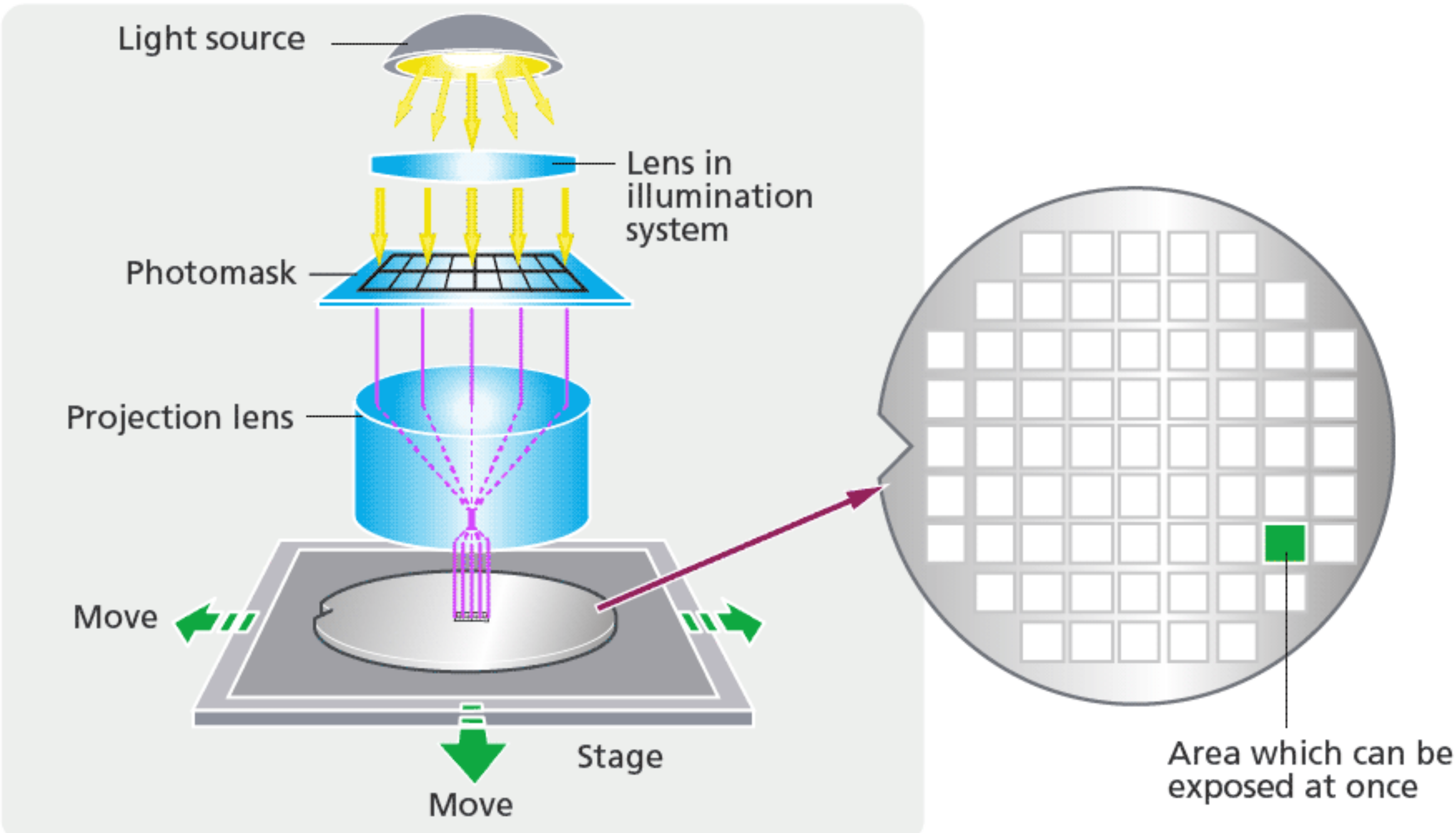
# Boule sliced to form wafers



5
Lithography for semiconductor manufacturing in a nutshell: lenses shrink a mask pattern and project it onto a wafer.
Light
Lens
1
Wafers are sawed out of a block (ingot) of very pure crystalline silicon
2
Polishing
3
Material deposition or modification
4
The resist is applied to a spinning wafer to achieve a uniform layer
5
The chip patterns are 'burned' into the resist in an exposure step
6
The print is developed through etching and heating
7
Ion implantation
8
The resist is removed
9
The wafer processing cycle is complete, and a single chip layer has been fabricated
10
Repeat thirty to forty times
11
After all the required cycles have completed, the chips can be cut out of the wafer and tested
12
Finally, the chips are enclosed in special plastic packaging in another plant

**Method of stepper**



# 4 CCDs per wafer

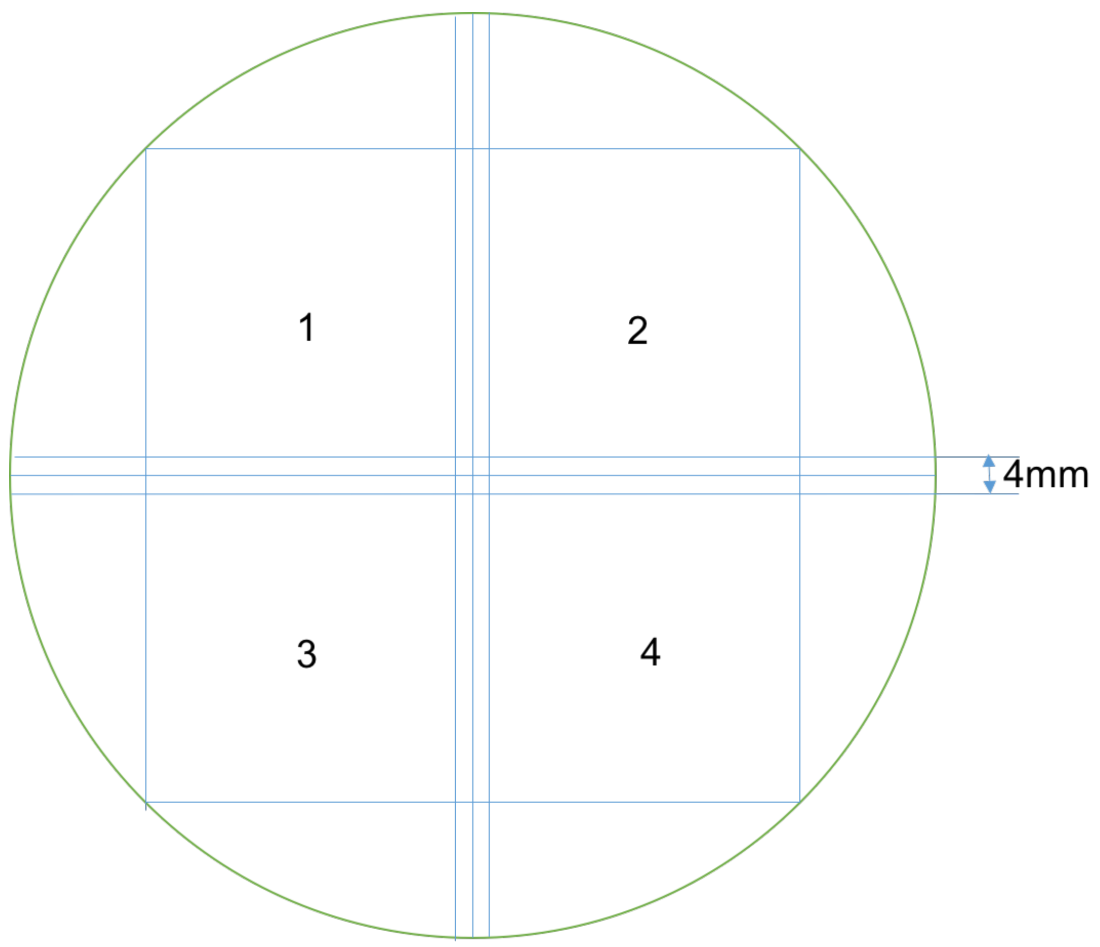
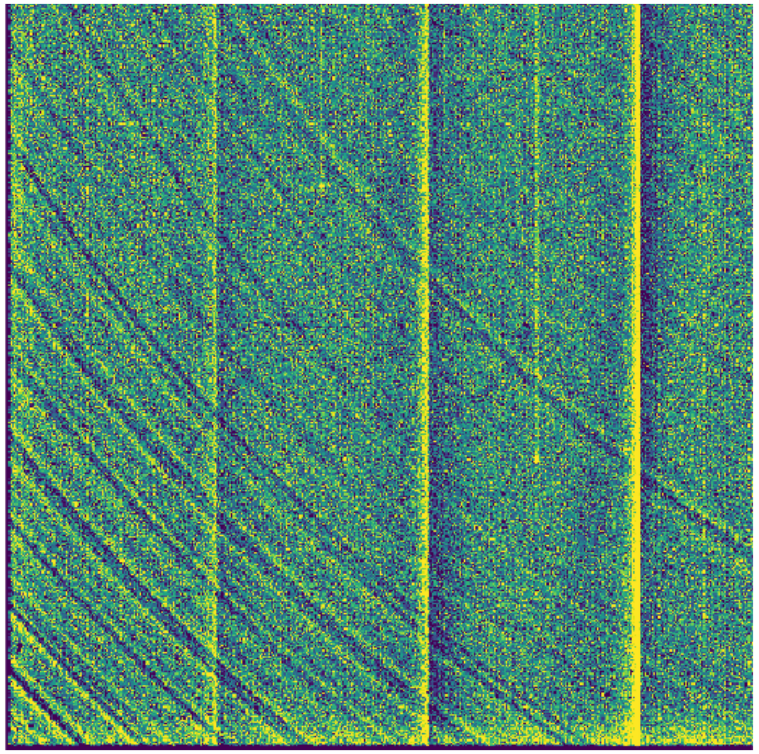
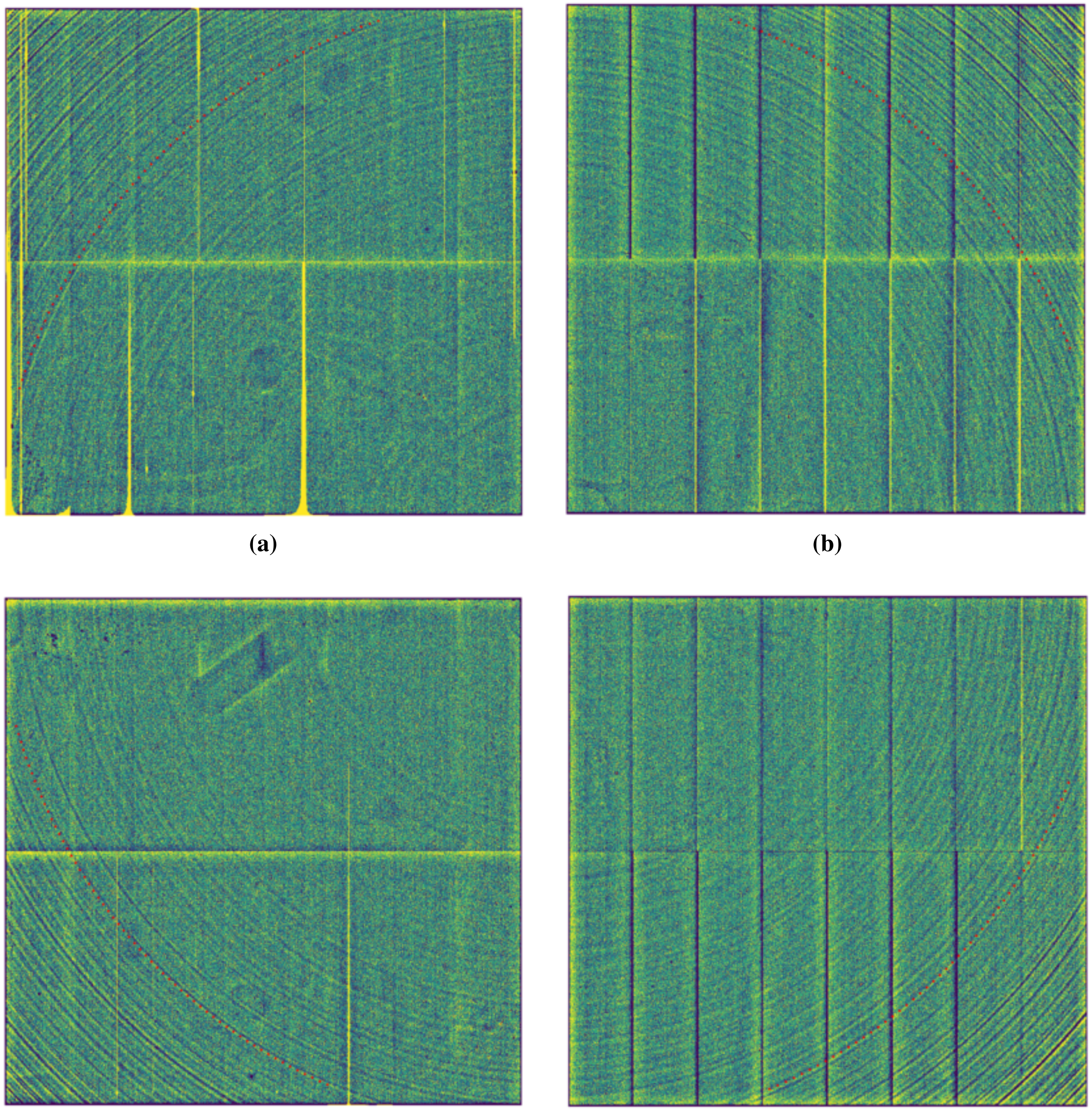



**Figure 2.** Layout of the silicon wafer. Because the wafer is cut into four sensors, tree rings on each sensor will have four possilble orientations.

# Brainstorming…





**(a)** **(b)** **(c)** **(d)**

**Figure 3.** Examples of flat images recorded for sensors ITL-3800C-021 (a), ITL-3800C-022 (b), ITL-3800C-032 (c) and ITL-3800C-017 (d). Red dots are the points on radius of 4400 pixels.Sensors in (b) and (d) originate from the same wafer.

# Looking in more detail

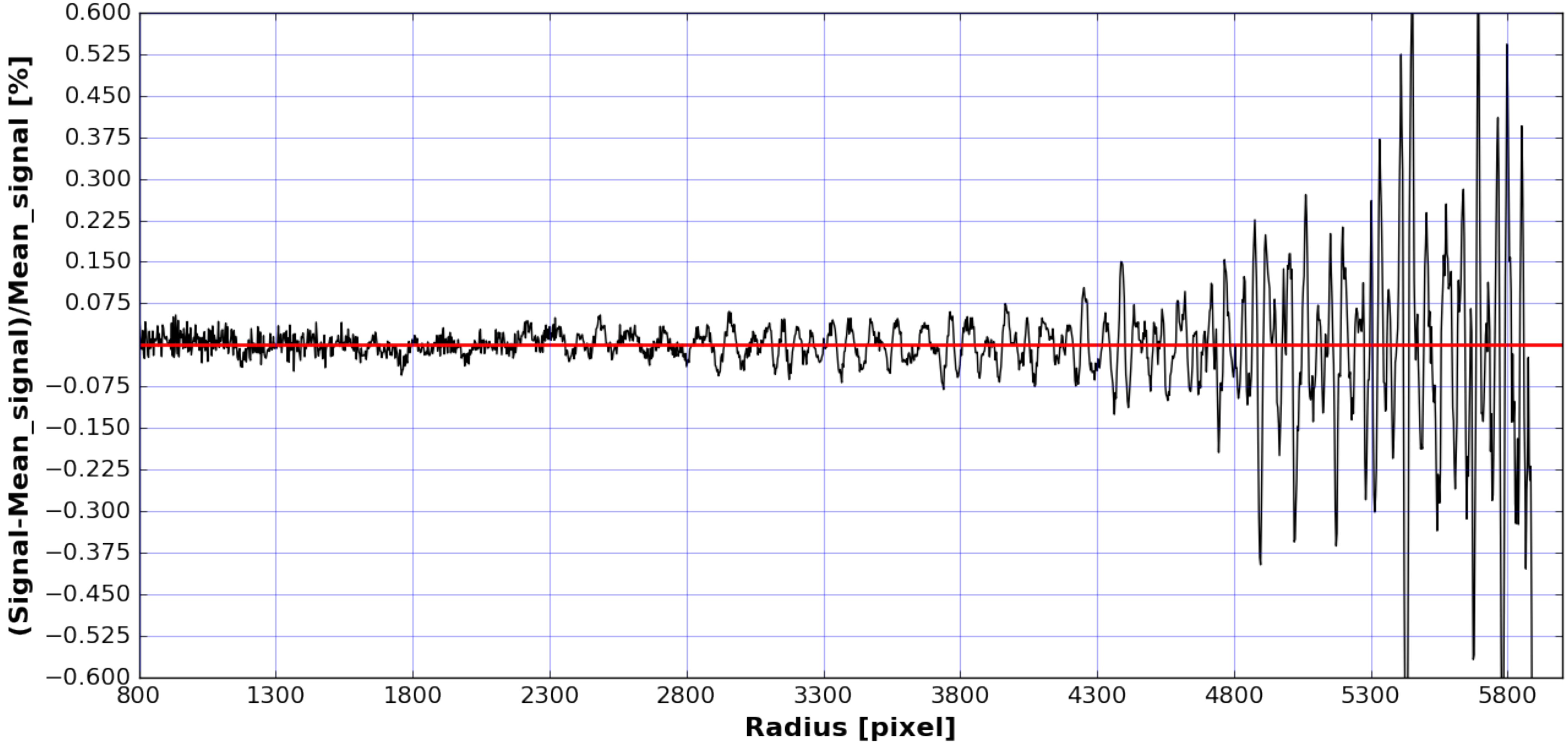
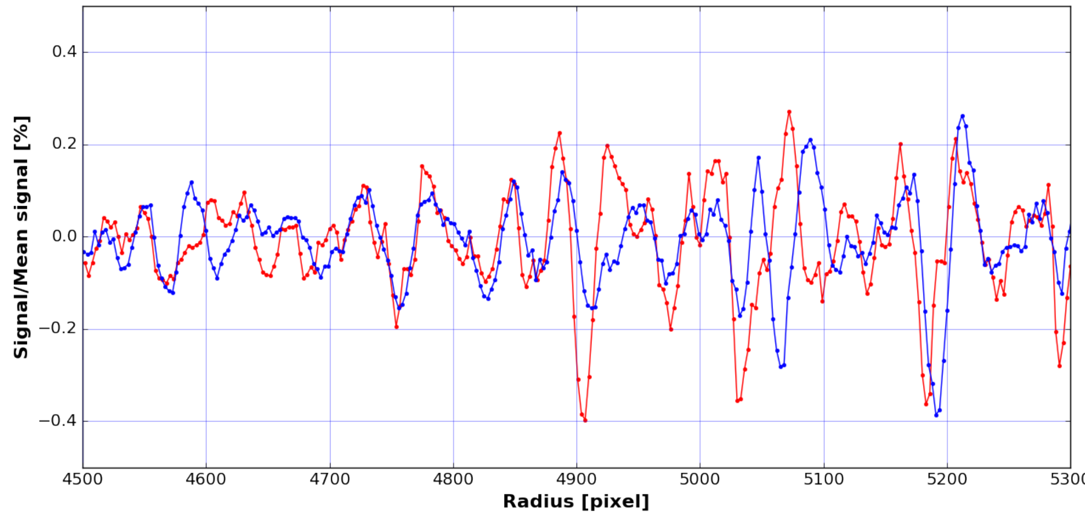
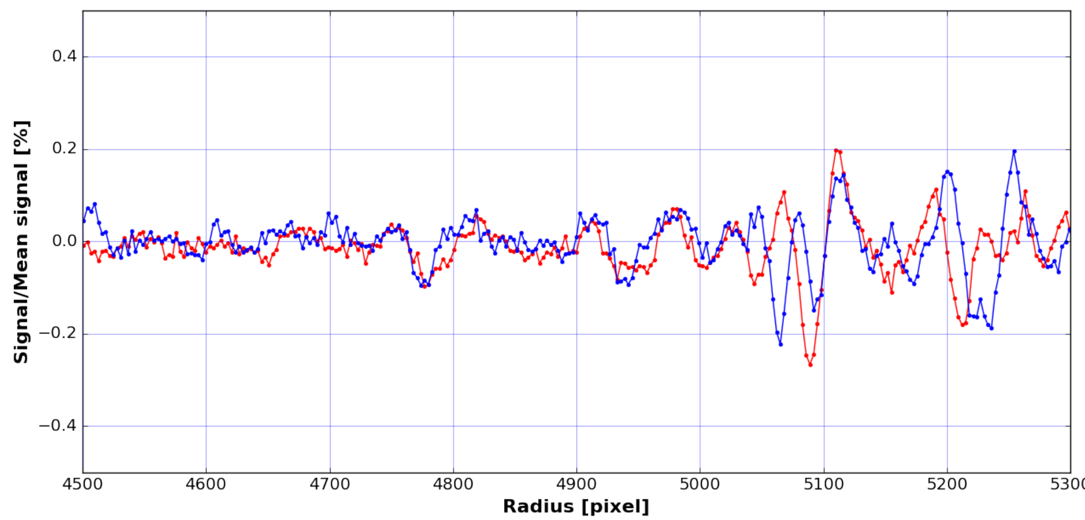


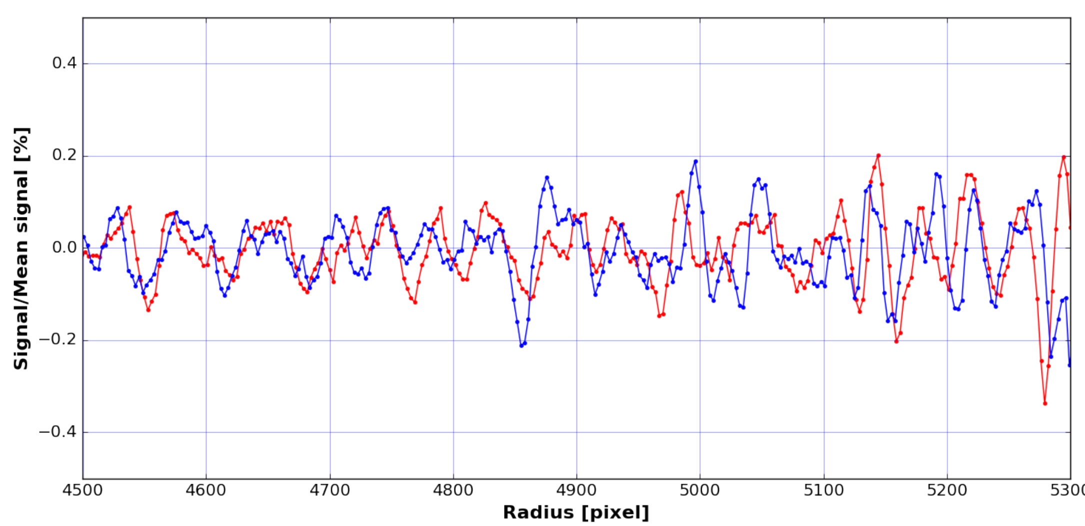

**Figure 6.** Relative flux variation as function of tree ring radius for the sensor ITL-3800C-017.




**(a)**



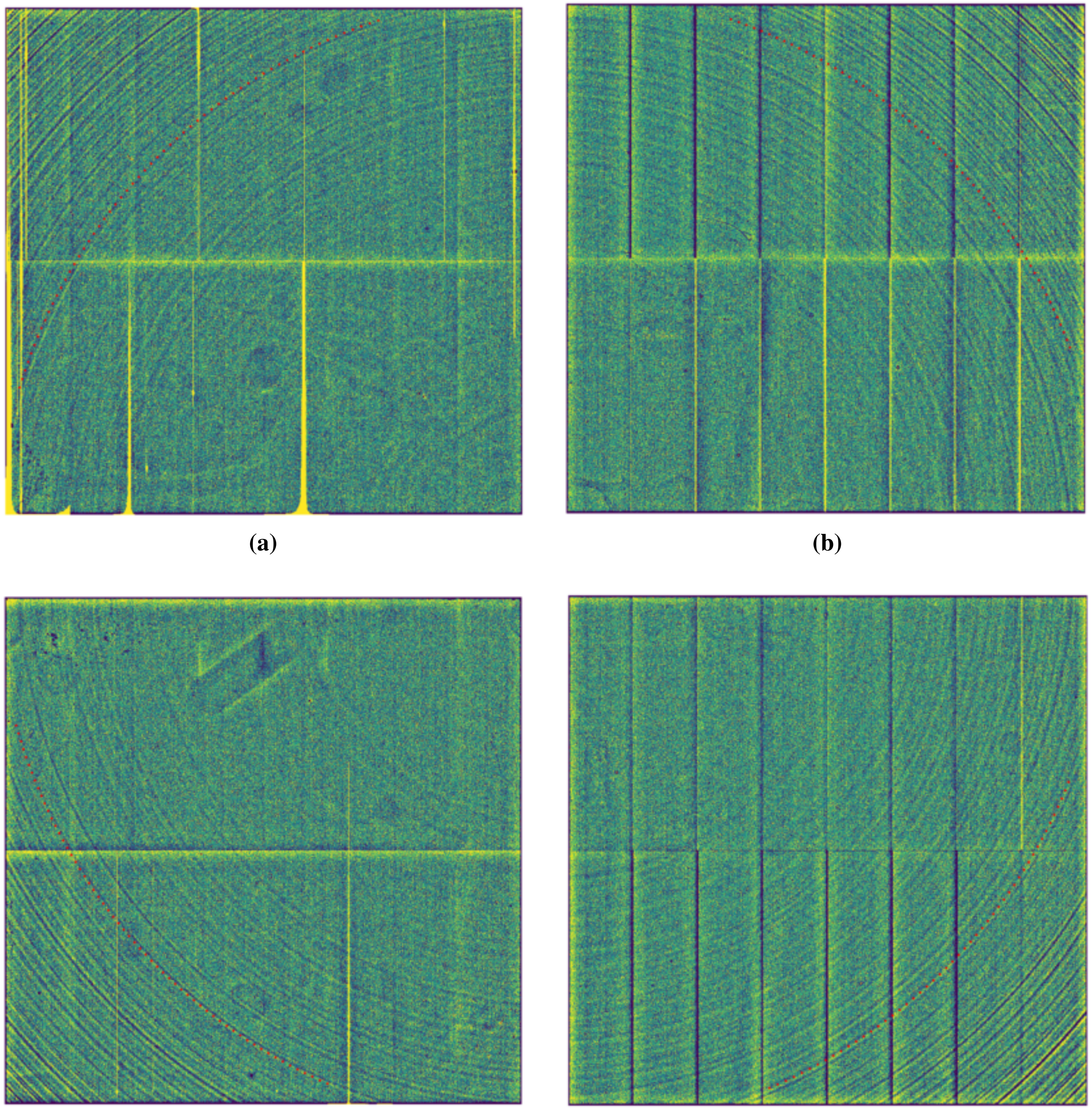

**(b)**




**(c)**

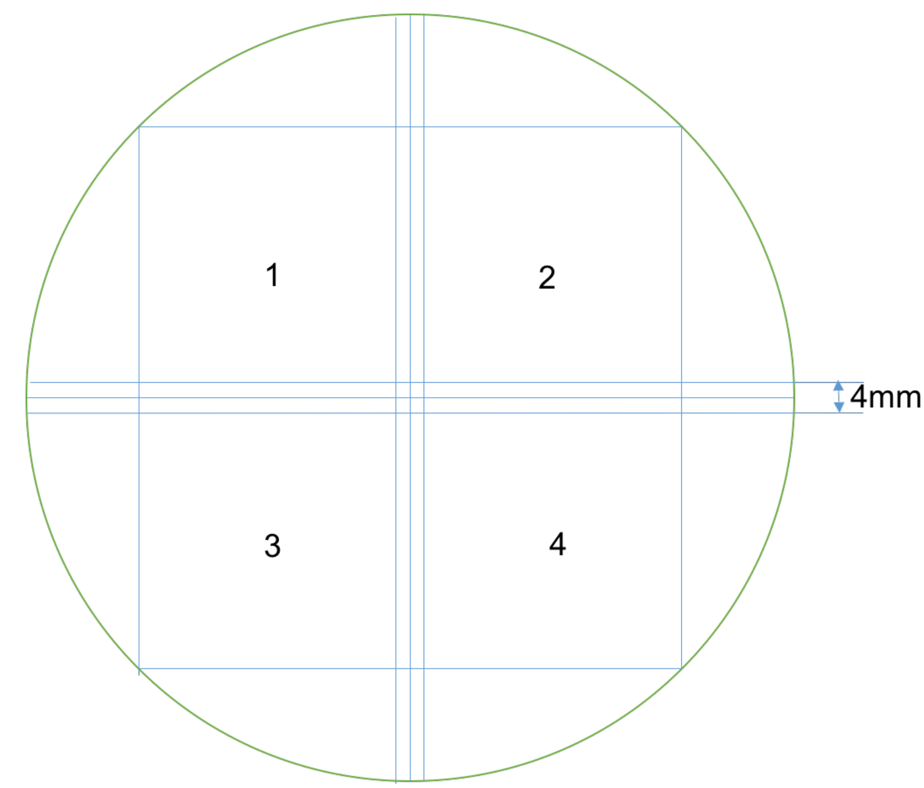
**Figure 8.** Comparison of the tree rings for sensor pairs originating from the same wafer. Relative flux variation as function of the tree ring radius in the range from 4500 to 5300 pixels for (a) ITL-3800C-017 (die4, red) and 022 (die2, blue), (b) 145 (die2, red) and 107 (die3, blue), and 097 (die4, red) and 091 (die2, blue).

Metadata!



(a) (b) (c) (d)

**Figure 3.** Examples of flat images recorded for sensors ITL-3800C-021 (a), ITL-3800C-022 (b), ITL-3800C-032 (c) and ITL-3800C-017 (d). Red dots are the points on radius of 4400 pixels.Sensors in (b) and (d) originate from the same wafer.



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# Properties of tree rings in LSST sensors

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Abstract: Images of uniformly illuminated sensors for the Large Synoptic Survey Telescope have circular periodic patterns with an appearance similar to tree rings. These patterns are caused by circularly symmetric variations of the dopant concentration in the monocrystal silicon boule induced by the manufacturing process. Non-uniform charge density results in the parasitic electric field inside the silicon sensor, which may distort shapes of astronomical sources. In this study we analyzed data from fifteen LSST sensors produced by ITL to determine the main parameters of the tree rings: amplitude and period, and also variability across the sensors tested at Brookhaven National Laboratory. Tree ring pattern has a weak dependence on the wavelength. However the ring amplitude gets smaller as wavelength gets longer, since longer wavelengths penetrate deeper into the silicon. Tree ring amplitude gets larger as it gets closer to the outer part of the wafer, from 0.1 to 1.0%, indicating that the resistivity variation is larger for larger radii.

Keywords: Detectors for UV, visible and IR photons; Photon detectors for UV, visible and IR photons (solid-state) (PIN diodes, APDs, Si-PMTs, G-APDs, CCDs, EBCCDs, EMCCDs etc); Systematic effects

[1]Corresponding author.


doi:10.1088/1748-0221/12/05/C05015

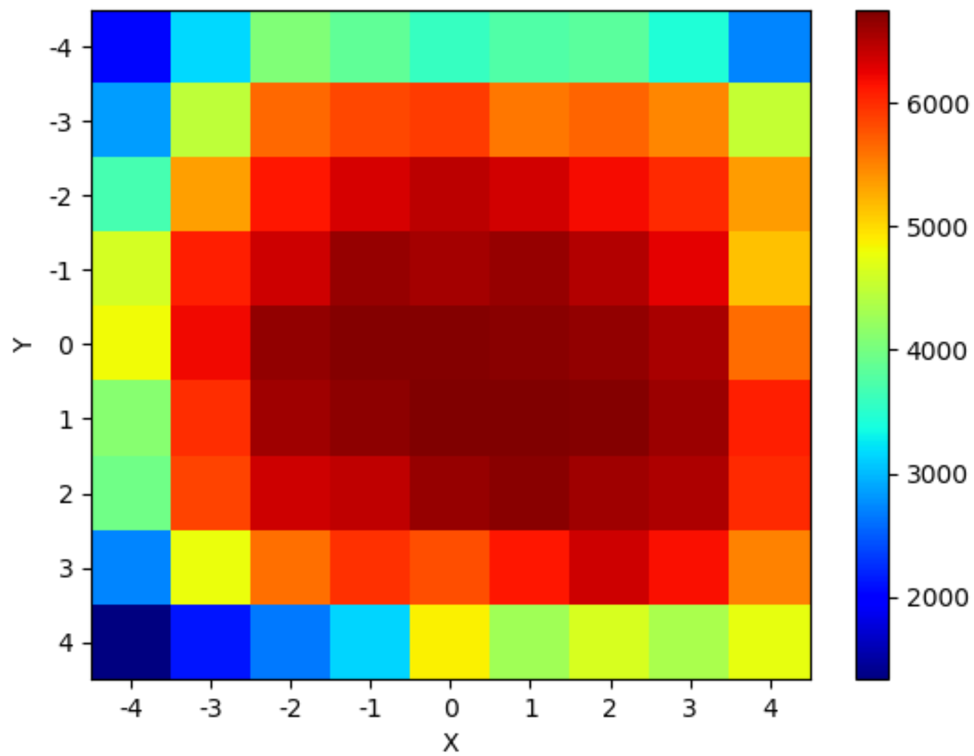


Fig. 8. The response of a single pixel (the POI) for each of the $(x, y)$ positions of the $9 \times 9$ optical spots, aggregated into a 2D raster. These measurements were fitted to our model (3). The color scale represents the pixel signal value in digital number (DN).



# Spurious shear induced by the tree rings of the LSST CCDs


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*E-mail:* `yuki.okura@riken.jp`



ABSTRACT: We present an analysis of the impact of the tree rings seen in the candidate sensors

# Review

- Using successive plots to isolate an issue
  - Each plot asks an improved question
- 2 classes of plot
  - Exploratory
  - Jackknife
- Usually based off of ‘worries’