Modern Analysis Techniques for Large Data Sets

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Graduate elective

- You get out what you put in
  - Homework (first ~7 weeks; 40%; 100%; + options)
  - Final project & presentation based on your research
  - No exams
- Fill in quiz describing what you'd like to get out of the course

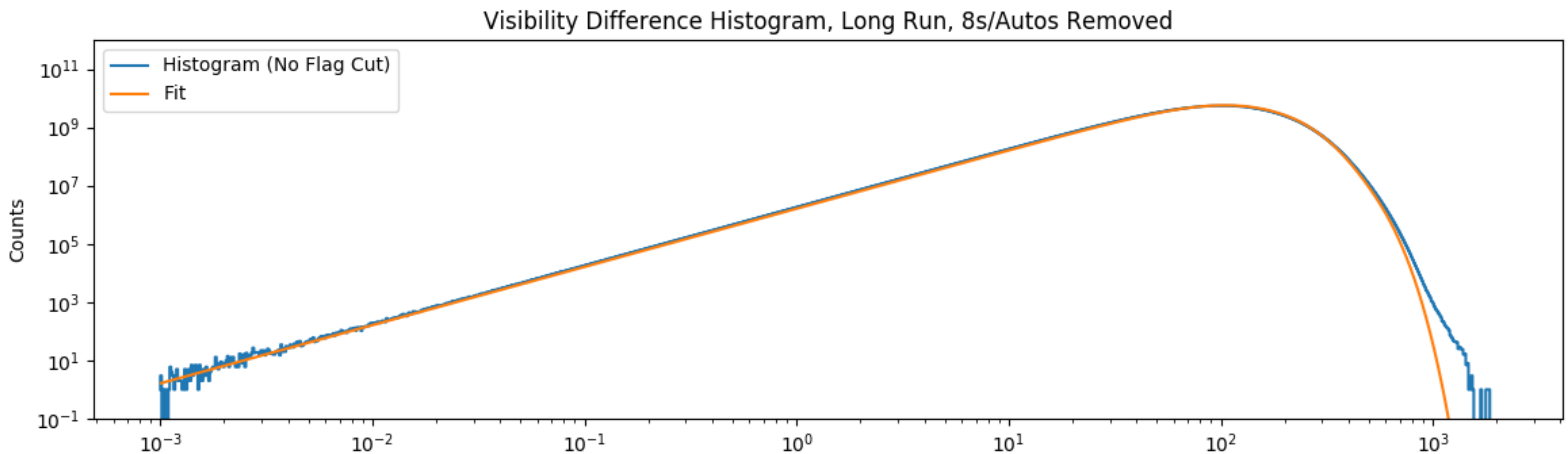
Key topics

Building blocks

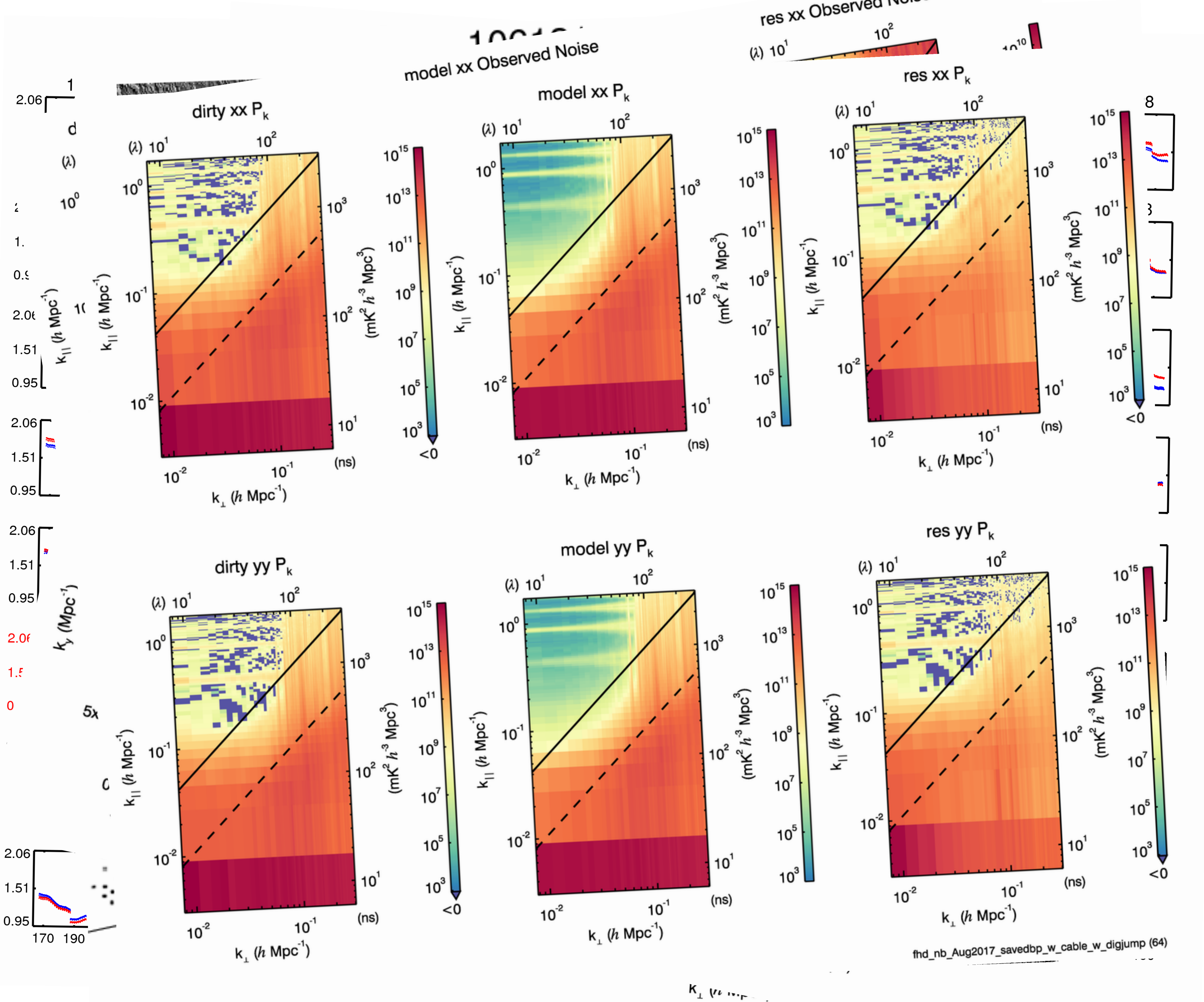
- Practical statistics
  - Turning research questions into statistical math
  - Systematics, non-Gaussianity, covariance, avoiding common mistakes
- Advanced data visualization
  - High quality visualizations (data density, perception, accessibility)
  - Statistically rigorous visualization
- Collaborative data analysis
  - Using GitHub to your advantage (branching, provenance)
  - Collaborative development
  - Peer reviewed code

- Advanced practices
  - Jackknife tests, metadata, testing below the noise
  - Analysis plans: statistical worries, git issues, testing framework
  - Machine learning, blind analyses, data rampages

Statistics



100 billion data points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res xx Observed Noise
dirty xx P_k
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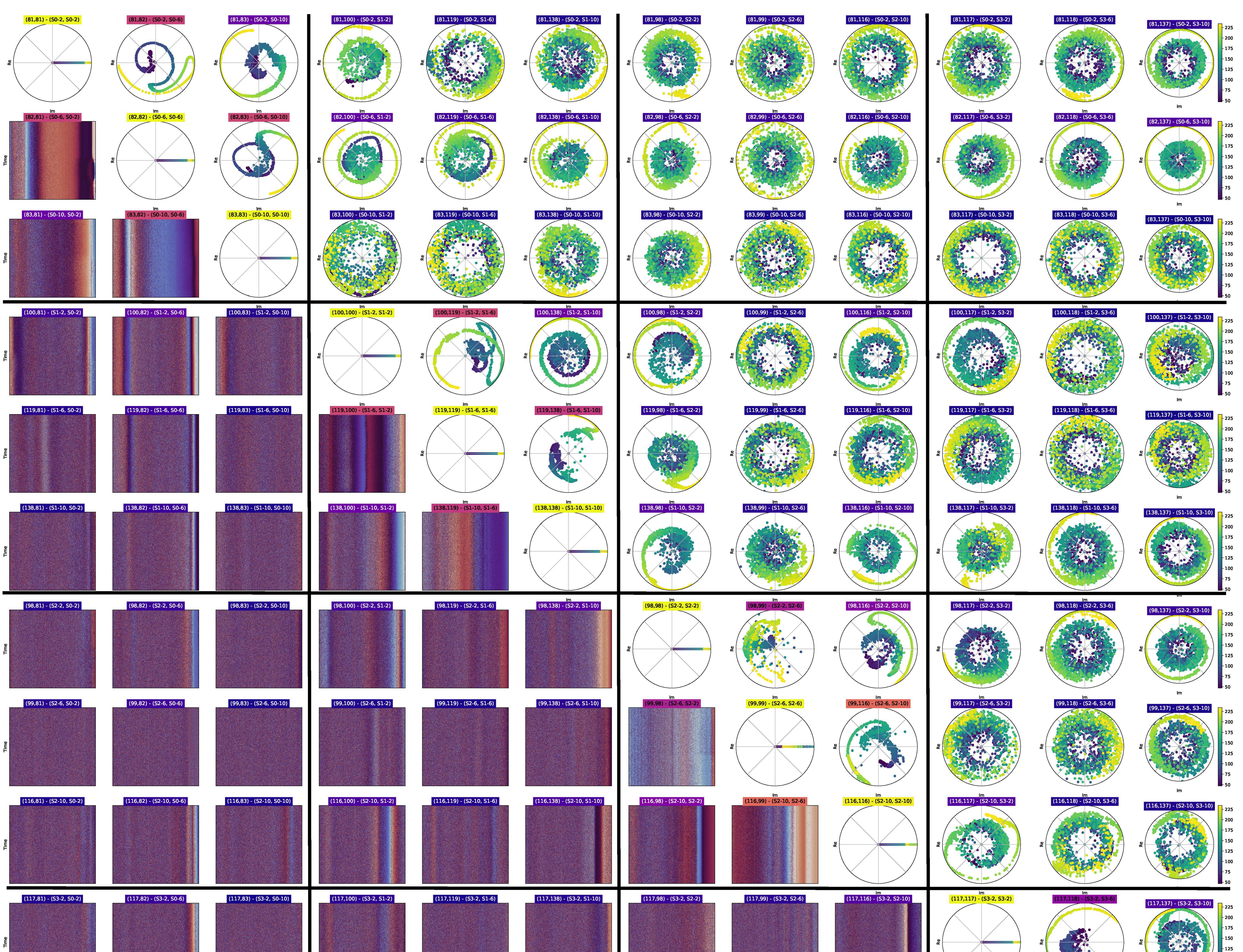

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Time
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175
200
225

git & analysis traceability

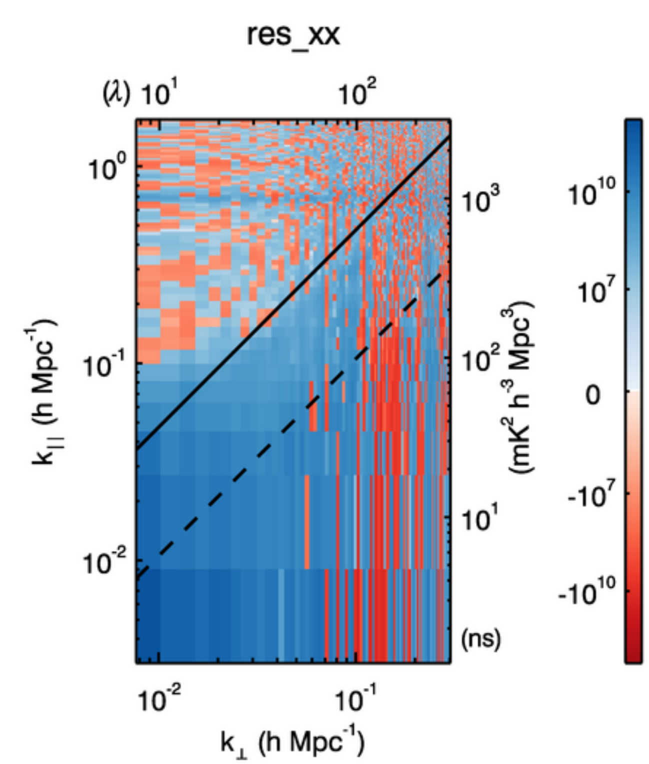
Data unit tests

2 fhd_core/fhd_struct_init_antenna.pro View

```
@@ -86,7 +86,7 @@ dec_use=dec_arr[valid_i]

 ;NOTE: Eq2Hor REQUIRES Jdate to have the same number of elements as RA and Dec for precession!!
 ;;NOTE: The NEW Eq2Hor REQUIRES Jdate to be a scalar! They created a new bug when they fixed the old one
-Eq2Hor,ra_use,dec_use,Jdate,alt_arr1,az_arr1,lat=obs.lat,lon=obs.lon,alt=obs.alt,precess=1
+Eq2Hor,ra_use,dec_use,Jdate,alt_arr1,az_arr1,lat=obs.lat,lon=obs.lon,alt=obs.alt,precess=1,/nutate
 za_arr=fltarr(psf_image_dim,psf_image_dim)+90. & za_arr[valid_i]=90.-alt_arr1
 az_arr=fltarr(psf_image_dim,psf_image_dim) & az_arr[valid_i]=az_arr1

```

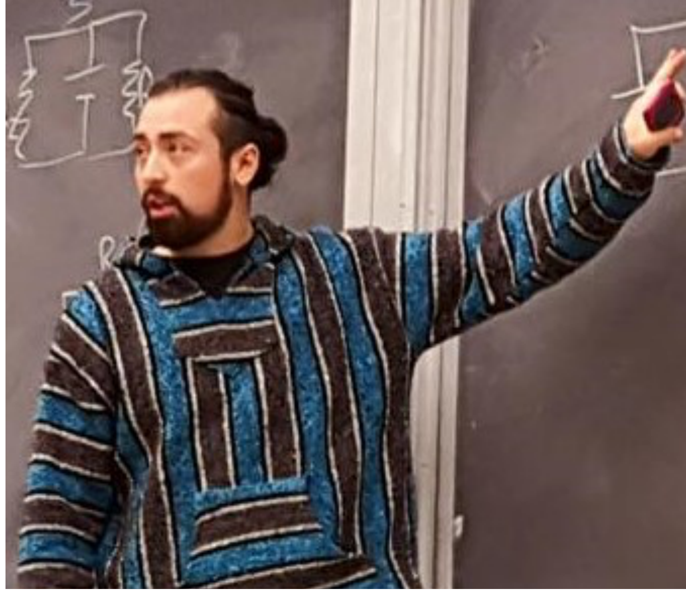


Final project

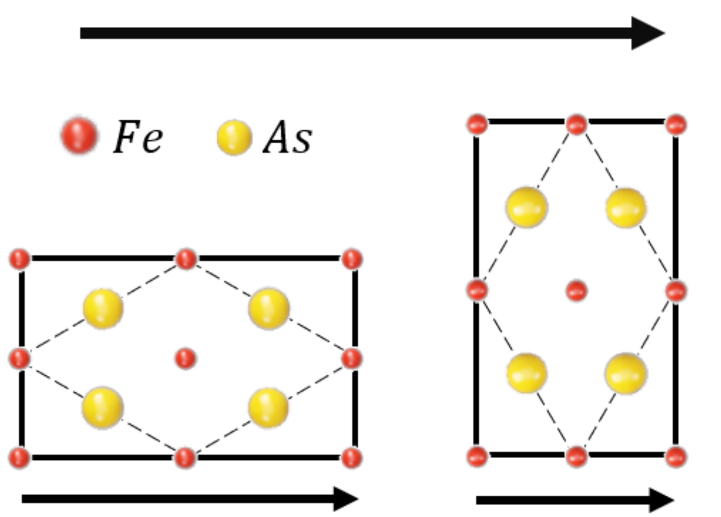
- Pick some aspect of your research you'd like to improve
  - Statistical or systematic improvement
  - Code organization & collaboration
  - Visualization for science

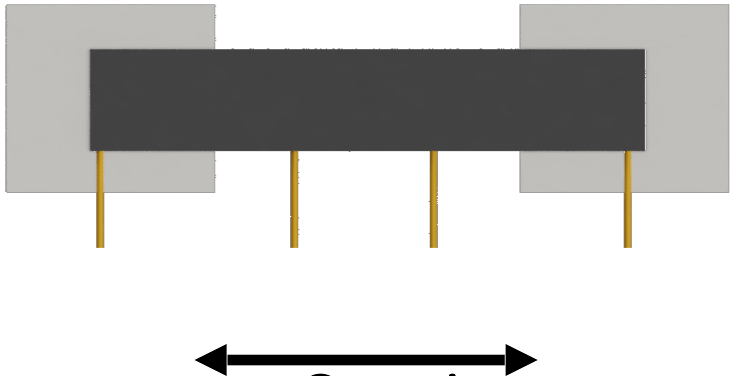
$BaFe_2As_2$ – Iron Based High Temperature Superconductor

Shua Sanchez, Prof. Jiun-Haw Chu's Quantum Materials group

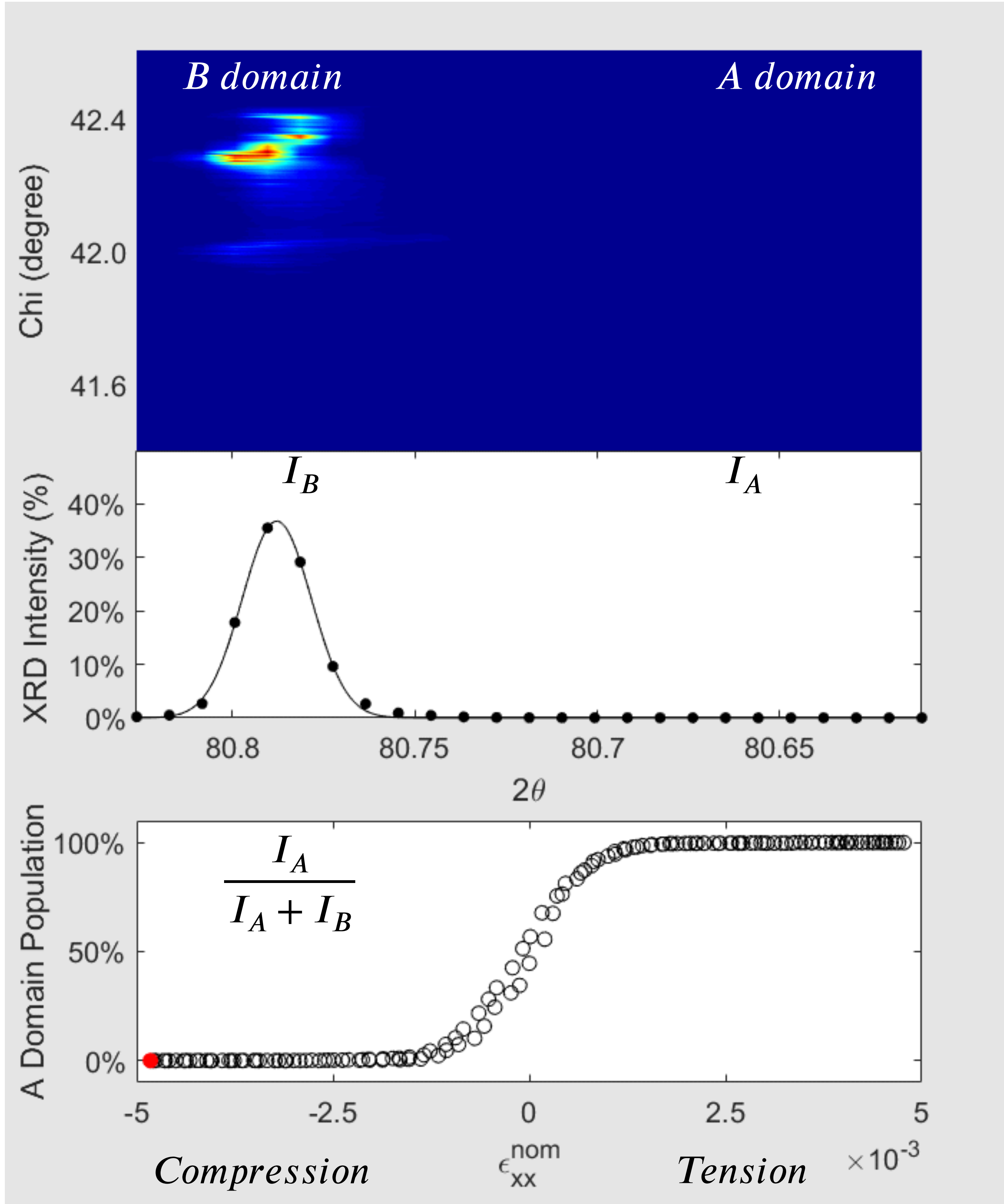


- Project goal: apply strains and x-ray to precisely detwin a sample and strain-tune superconductivity.
- This crystal has 2 structural domains (A and B) where iron atoms form rectangular lattice.
- Under zero stress, the A and B domains have the same total volume (domain population). Applying tension detwins the crystal to turn B domains into A, and compression to A to B.
- We combined x-rays to measure the a and b lattice constants directly while applying strain.
- The video shows 162 strain states sequentially and the intensity of the x-ray diffraction on the area detector





- (Top plot) the intensity position on the detector gives the length values of a and b which change with strain
- (Middle plot) the intensity is summed vertically and fit to 2 Gaussians
- (Bottom plot) The relative intensity $\frac{I_A}{I_A + I_B}$ gives the relative A domain population which change vs strain.



<u>Interesting result!</u>
Lattice constants freeze in place during detwinning!

Implies that the domain pinning is much softer than the crystal lattice

Can smoothly detwin the sample from B to A and back

Introductions

- Name
- Year
- Science
- What are you working on specifically?
- Familiarity with git/GitHub/source control?
- What language(s) do you use for data analysis?
- What do you want to get out of this class?

Thinking about statistics

What is significance anyway?

What is the question?

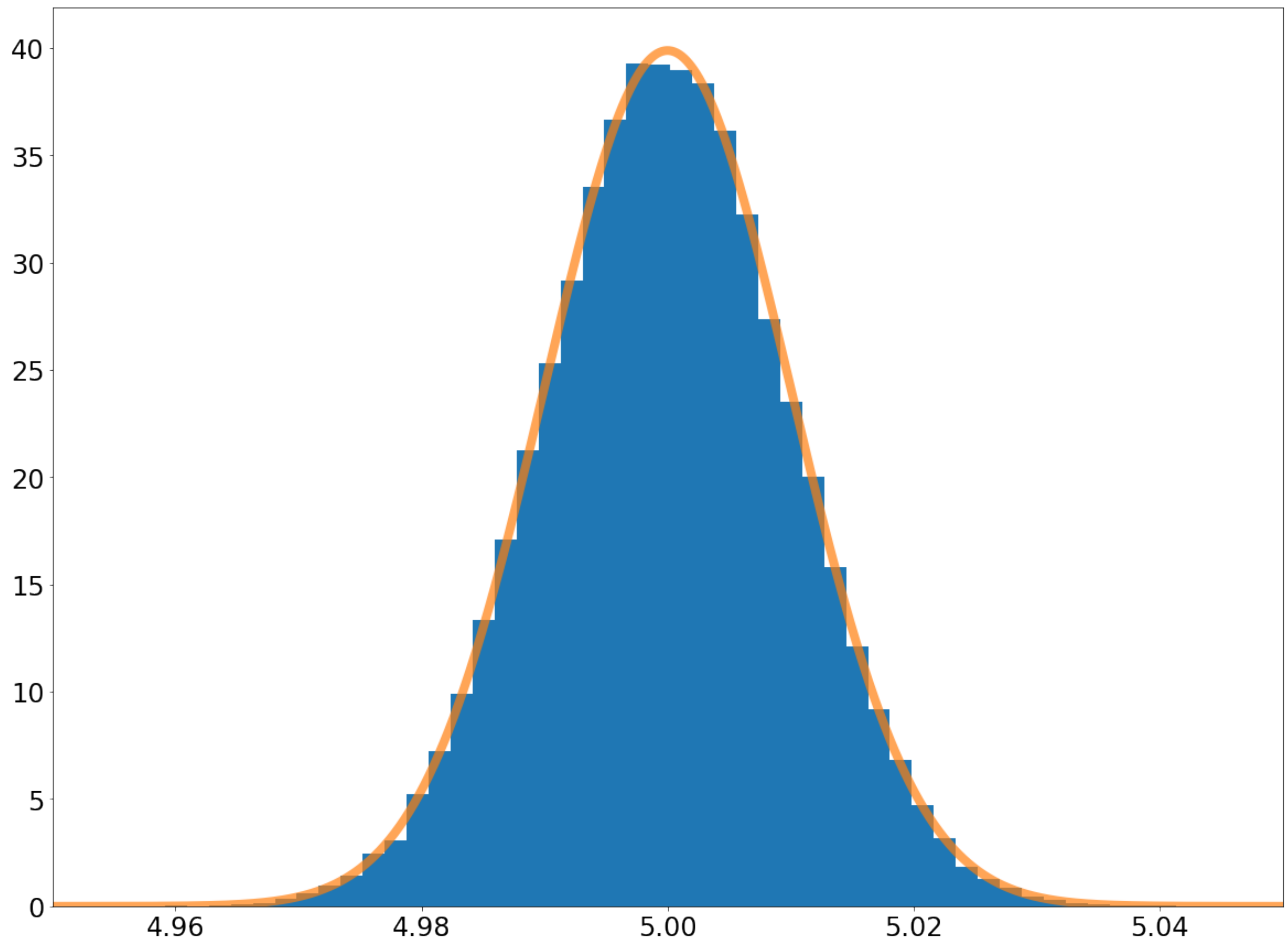
- Must clearly & precisely state the question

Example (null hypothesis):

If there is no signal; what is the probability that the background produces a signal that is equally or more signal-like than what I observed?

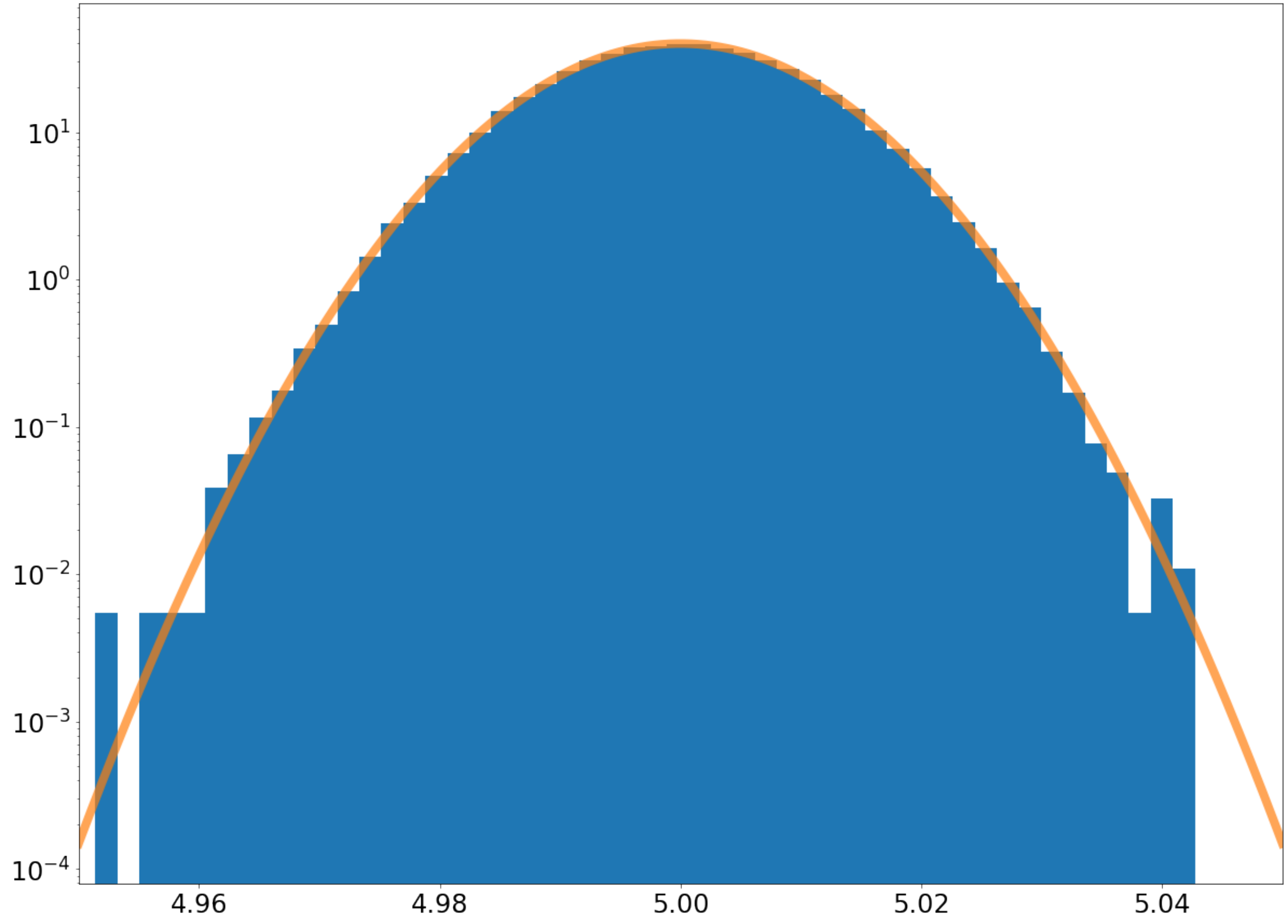
$$d = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\mu)^2}{2\sigma^2}}$$

```
data = stats.norm.rvs(loc = 5., scale = 0.01, size = 100000)
```

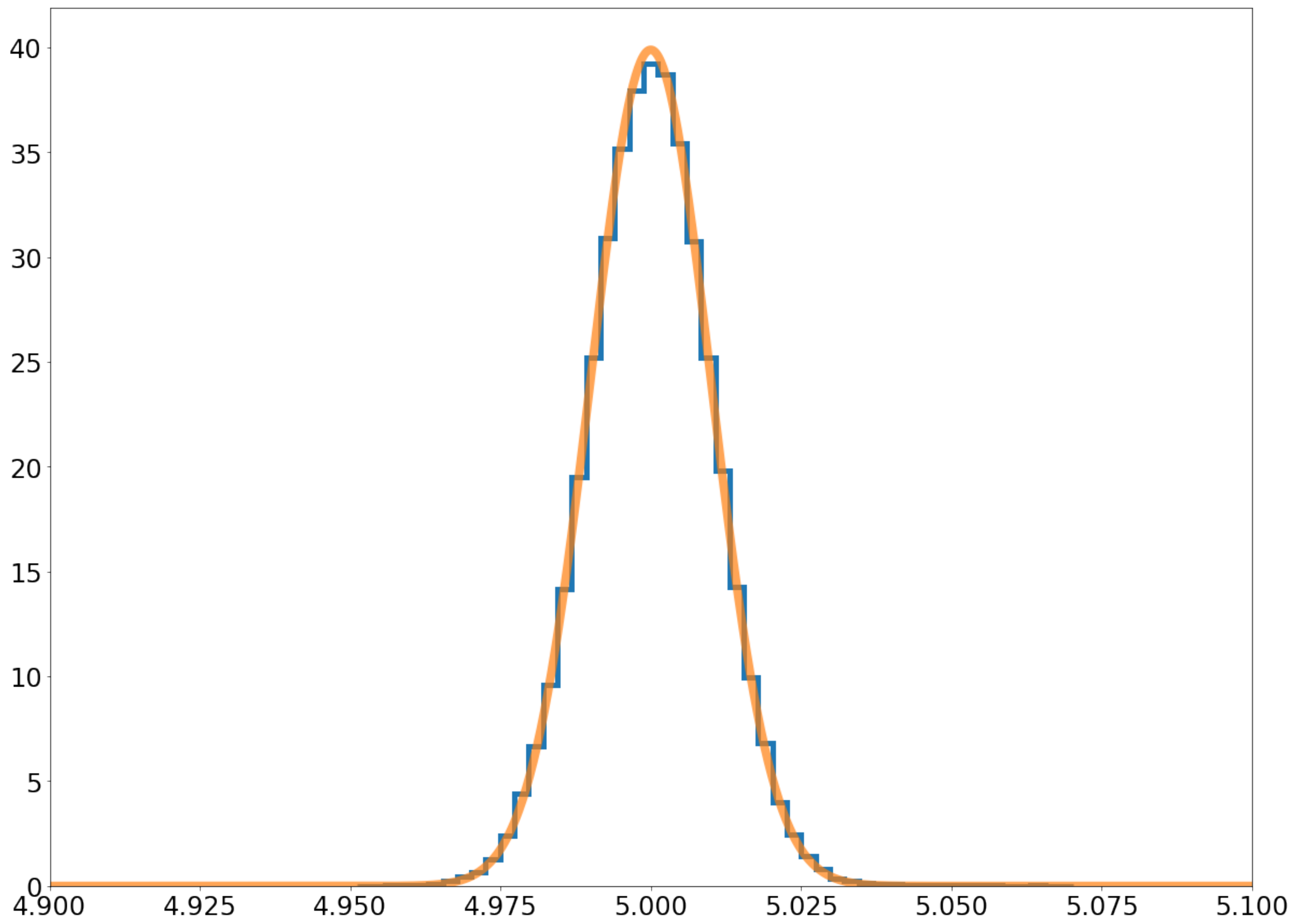


```
fig, ax = plt.subplots(1, 1)
ax.hist(data,50, density=True)
plt.yscale('log')
plt.tick_params(labelsize = 24)
plt.xlim([4.95,5.05])
x = np.linspace(4.95,5.05,1000)
ax.plot(x,stats.norm.pdf(x,loc = 5., scale = 0.01), linewidth = 8, alpha = 0.7)
plt.show()
```

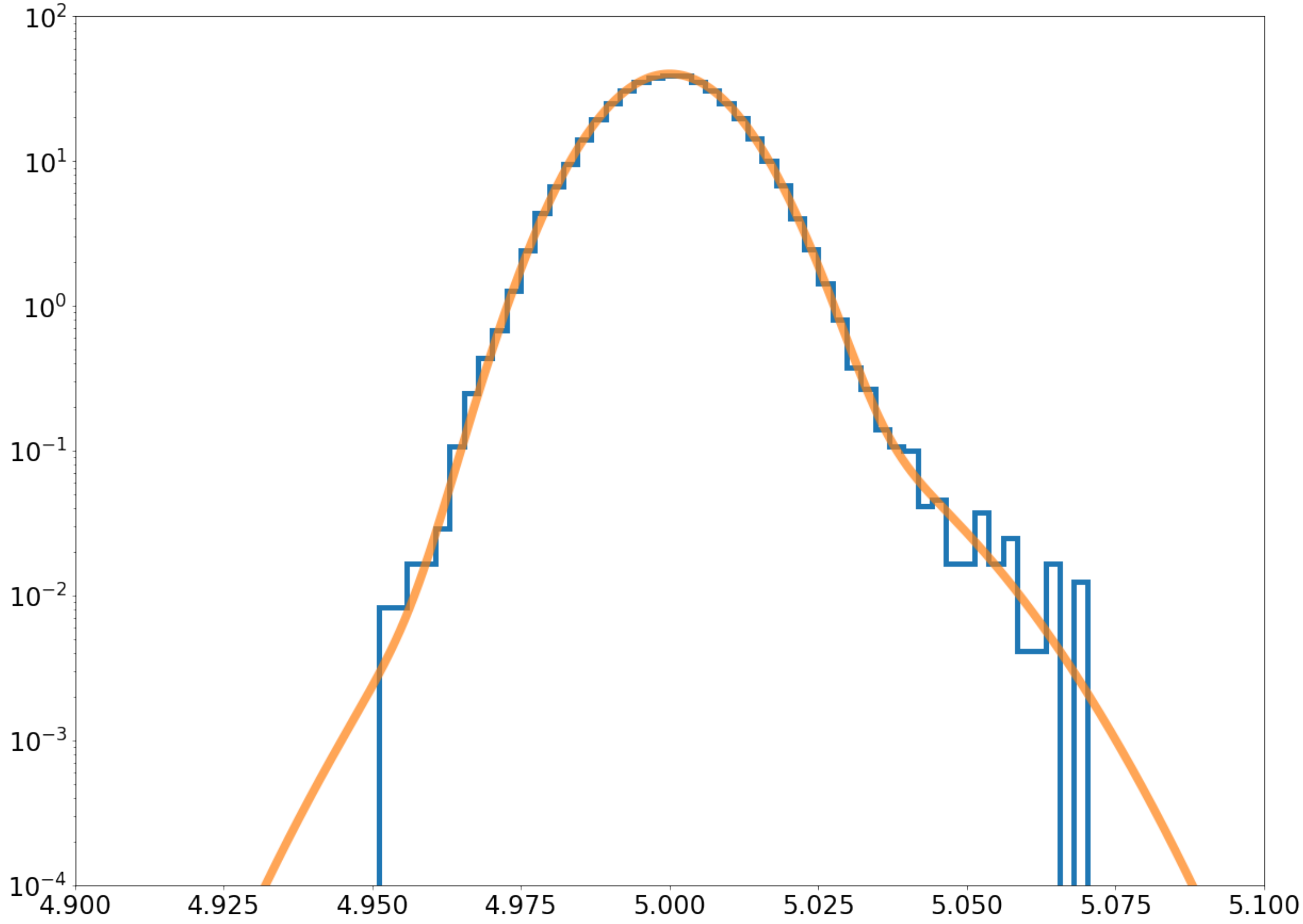
$$\log d = \frac{-(x-\mu)^2}{2\sigma^2} + c$$



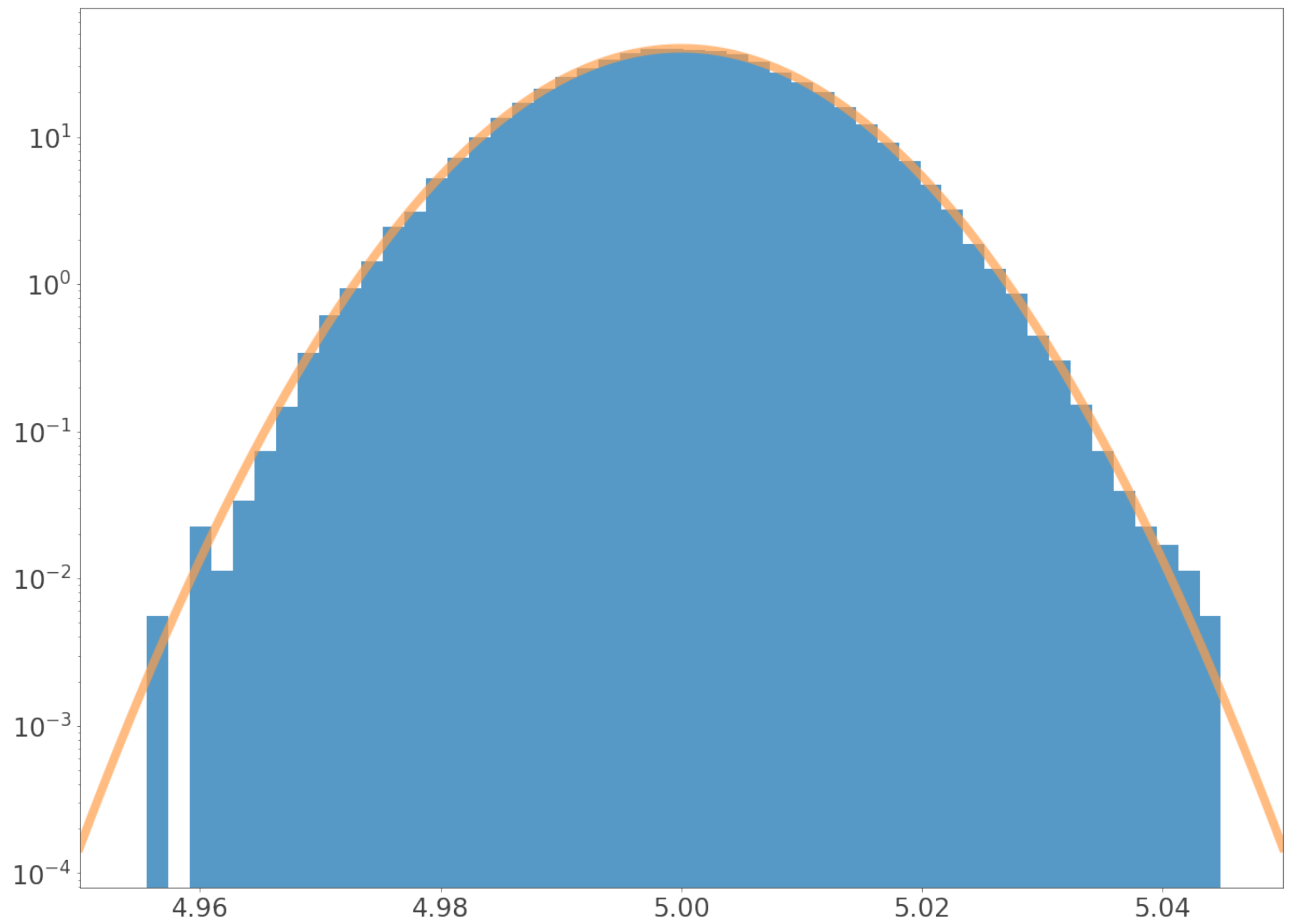
Never assume Gaussian statistics



Never assume Gaussian statistics



If there is no signal; what is the probability that the background produces a signal that is equally or more signal-like than what I observed?



$$\text{'Probability'} = \int_{a}^{\infty} \text{pdf(x)dx}$$

in this case!

In physics, $X\sigma$ is shorthand for a probability

- 5σ means: the probability of signal-free data giving a measurement that is equally or more signal like than your observation is less than 2.87×10^{-7} (or 1 in 3.5 million)

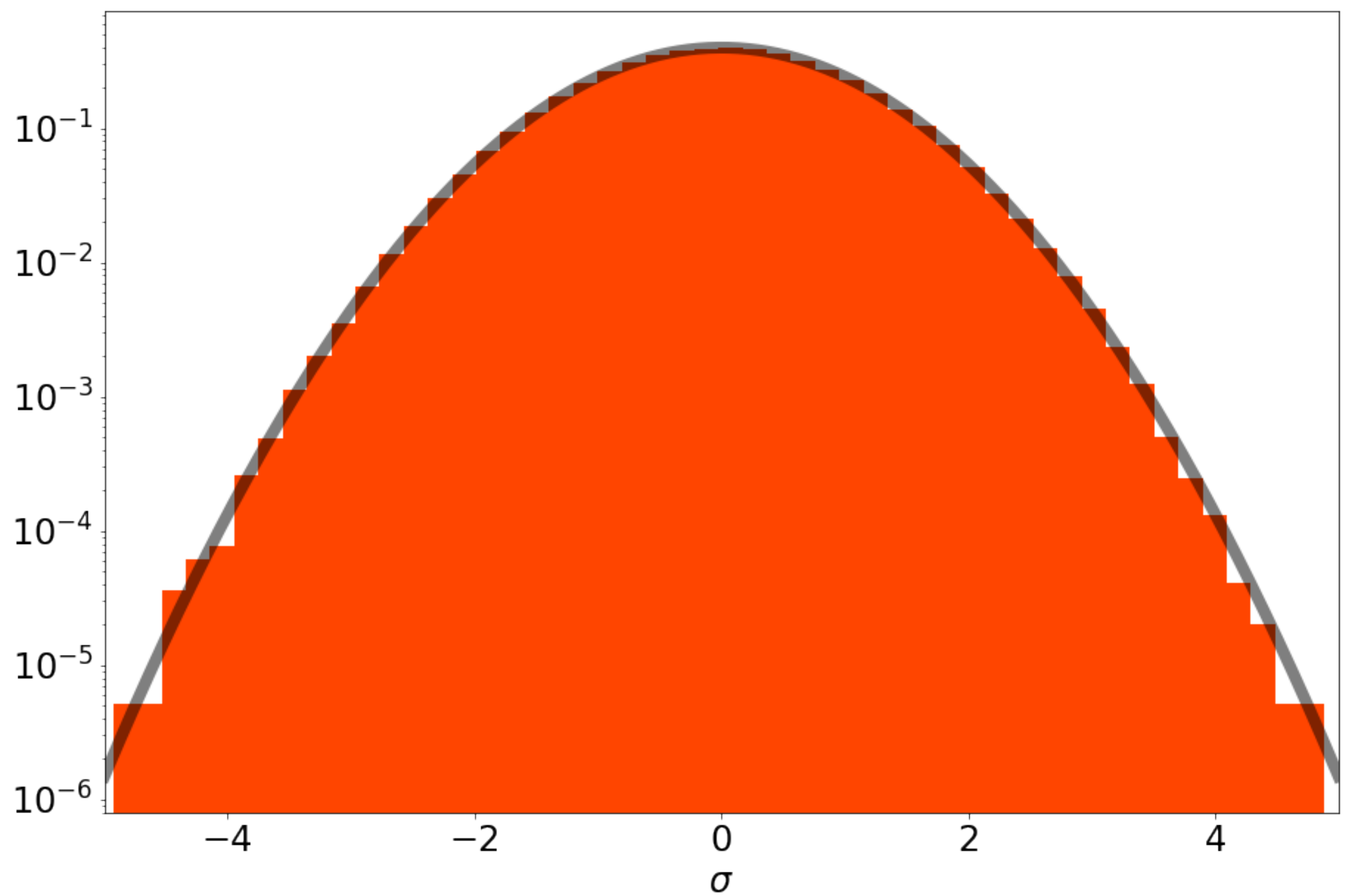
Common mistakes

- $X\sigma$ does not imply Gaussian distributed data
- $X\sigma$ is not $X\sigma$ away from the mean
- $X\sigma$ does not mean your question is one-sided

Best interpretation of $X\sigma$ (null hypothesis case)

- The probability of the background giving me a data point that looks as or more signal-like than the reading I have is the same probability as if my data was Gaussian and I was $X\sigma$ away from the mean

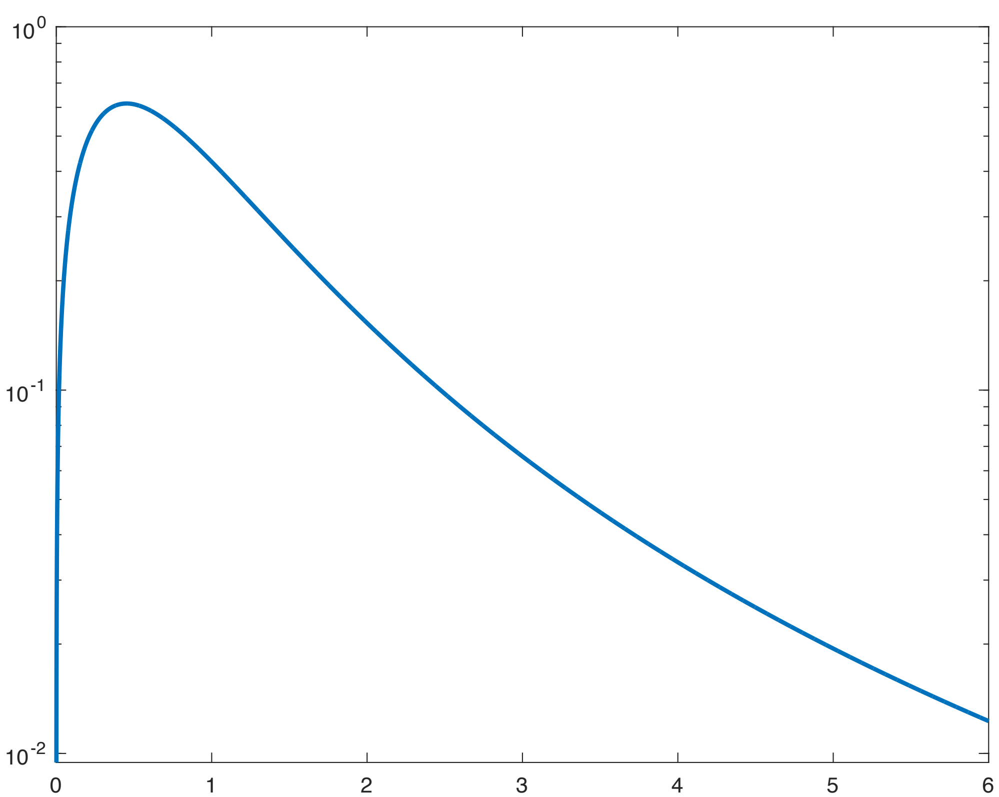
Standard normal or unit variance Gaussian distribution

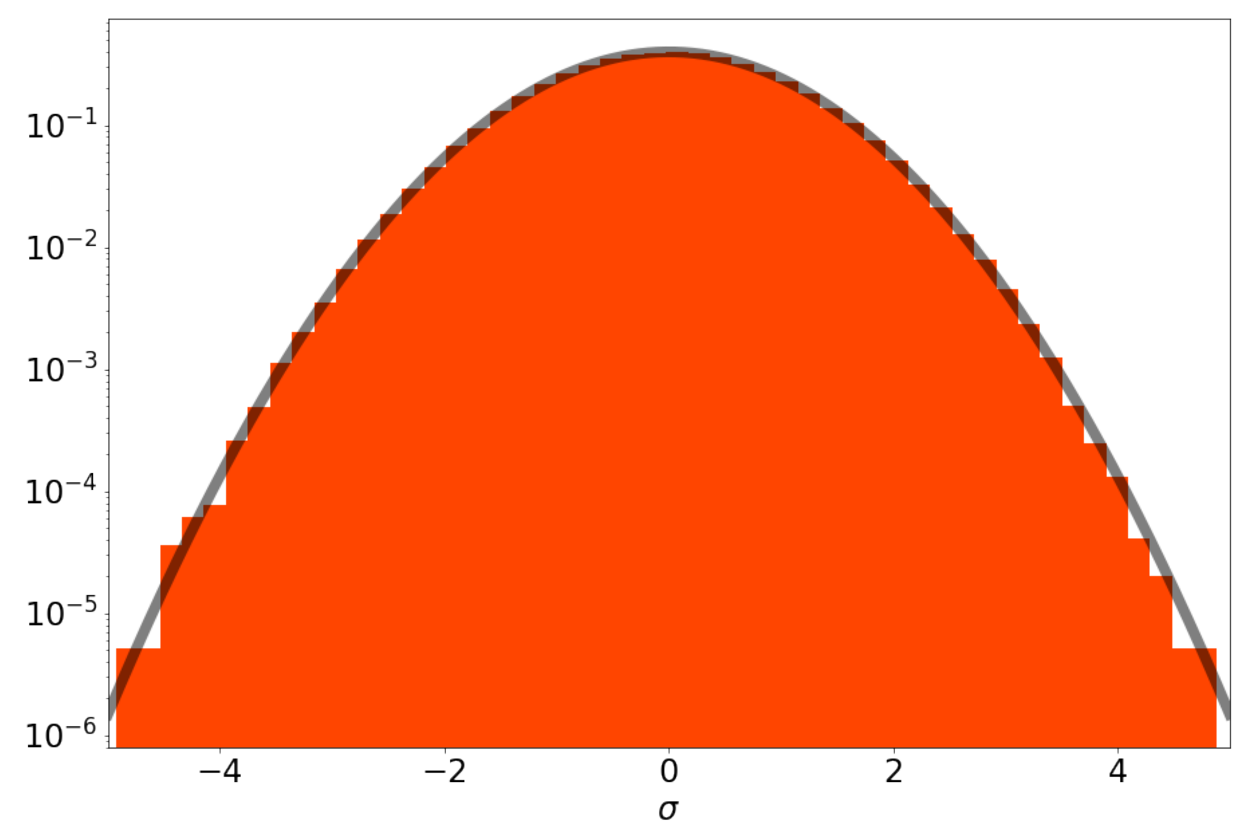


$$\text{Probability } X\sigma = \int_{X\sigma}^{\infty} \frac{1}{\sqrt{2\pi}} e^{\frac{-(x-0)^2}{2(1)^2}} dx = \frac{1}{2}\operatorname{erfc}\left(\frac{X}{\sqrt{2}}\right)$$

Best interpretation of $X\sigma$ (null hypothesis case)

- The probability of the background giving me a data point that looks as or more signal-like than the reading I have is the same probability as if my data was Gaussian and I was $X\sigma$ away from the mean

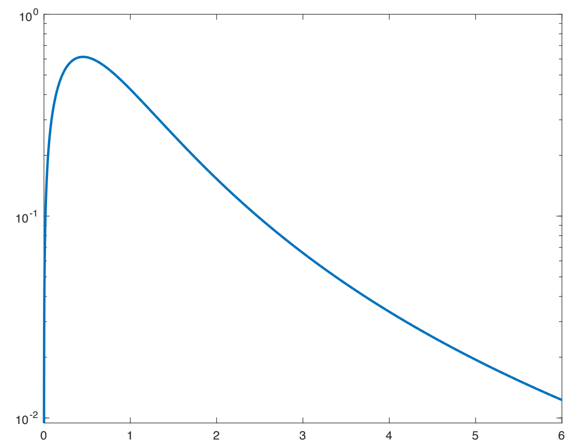


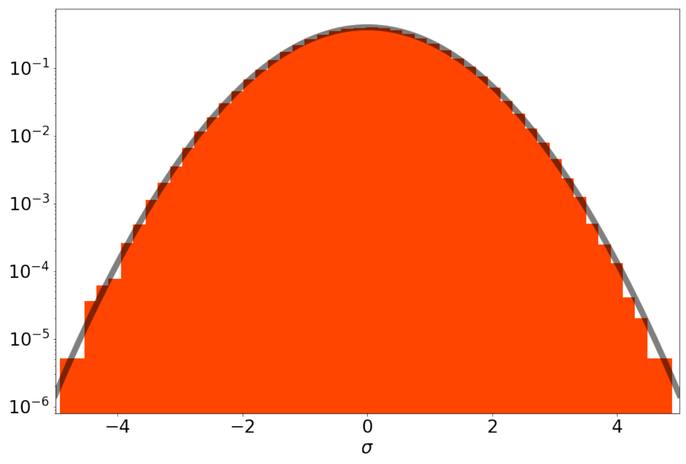


Key statistical steps

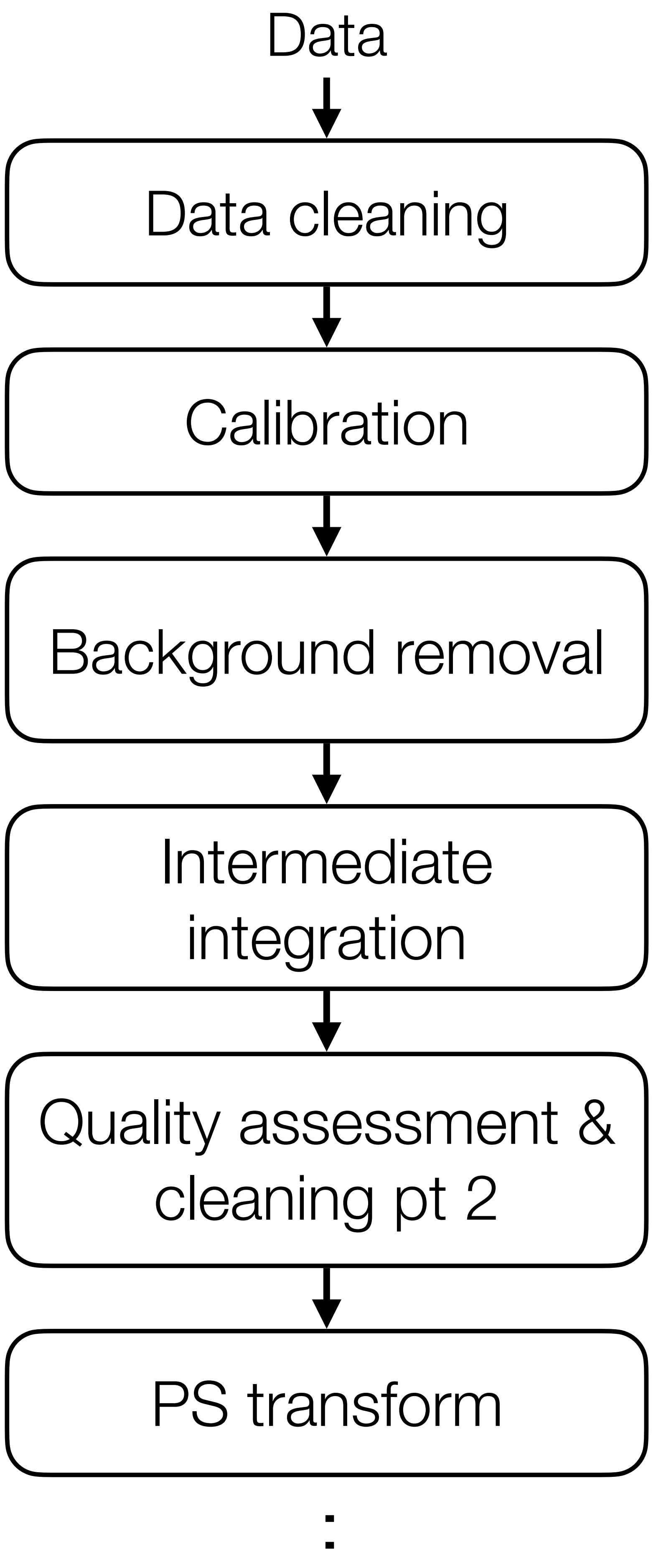
- Clearly state the question (& turn into math)
- Determine the background distribution
- Integrate background to find probability
- Convert probability into equivalent sigma

$$\text{'Probability'} = \int_a^\infty \mathrm{pdf(x)dx}$$

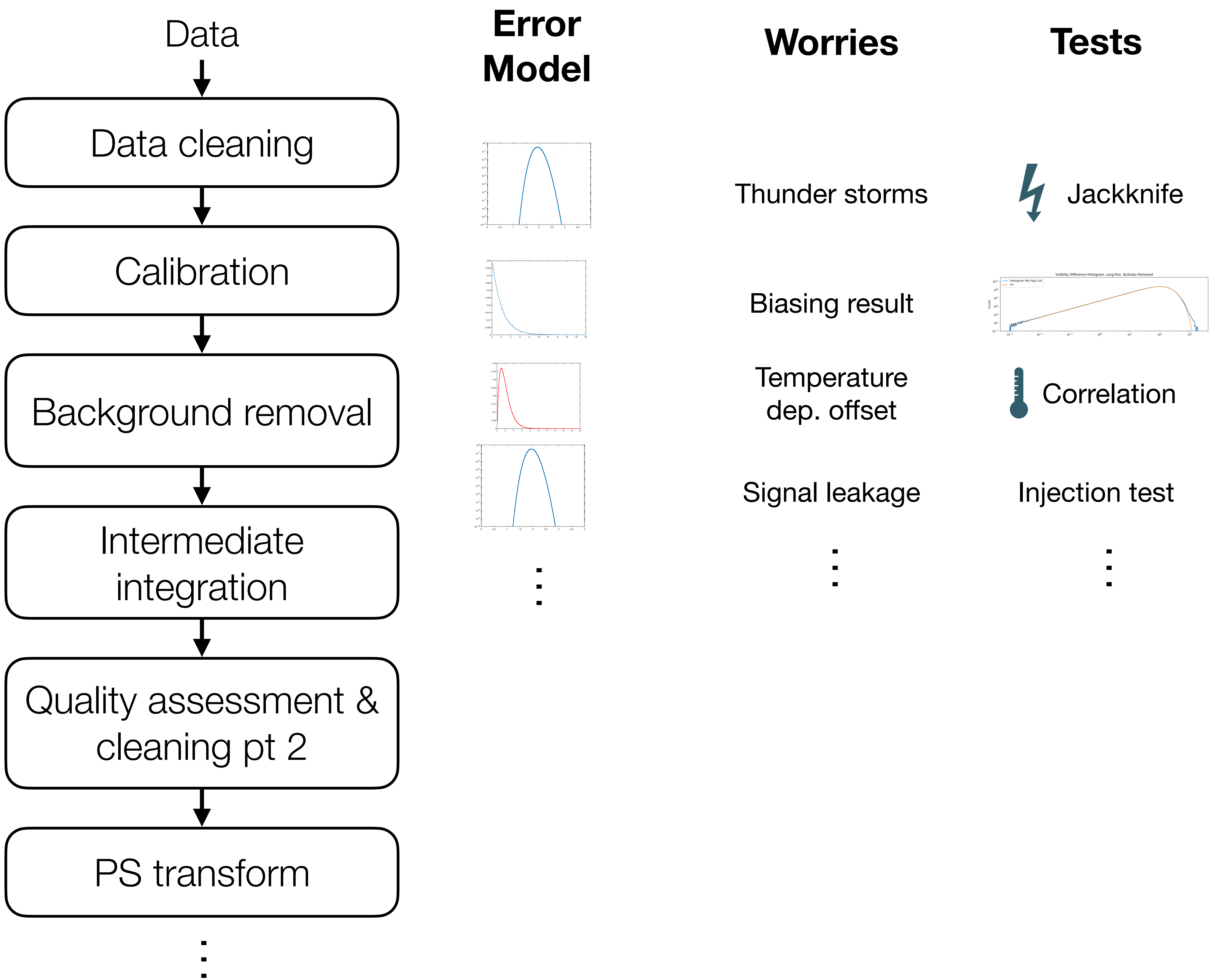




Analysis chains



How do you know the analysis is right?

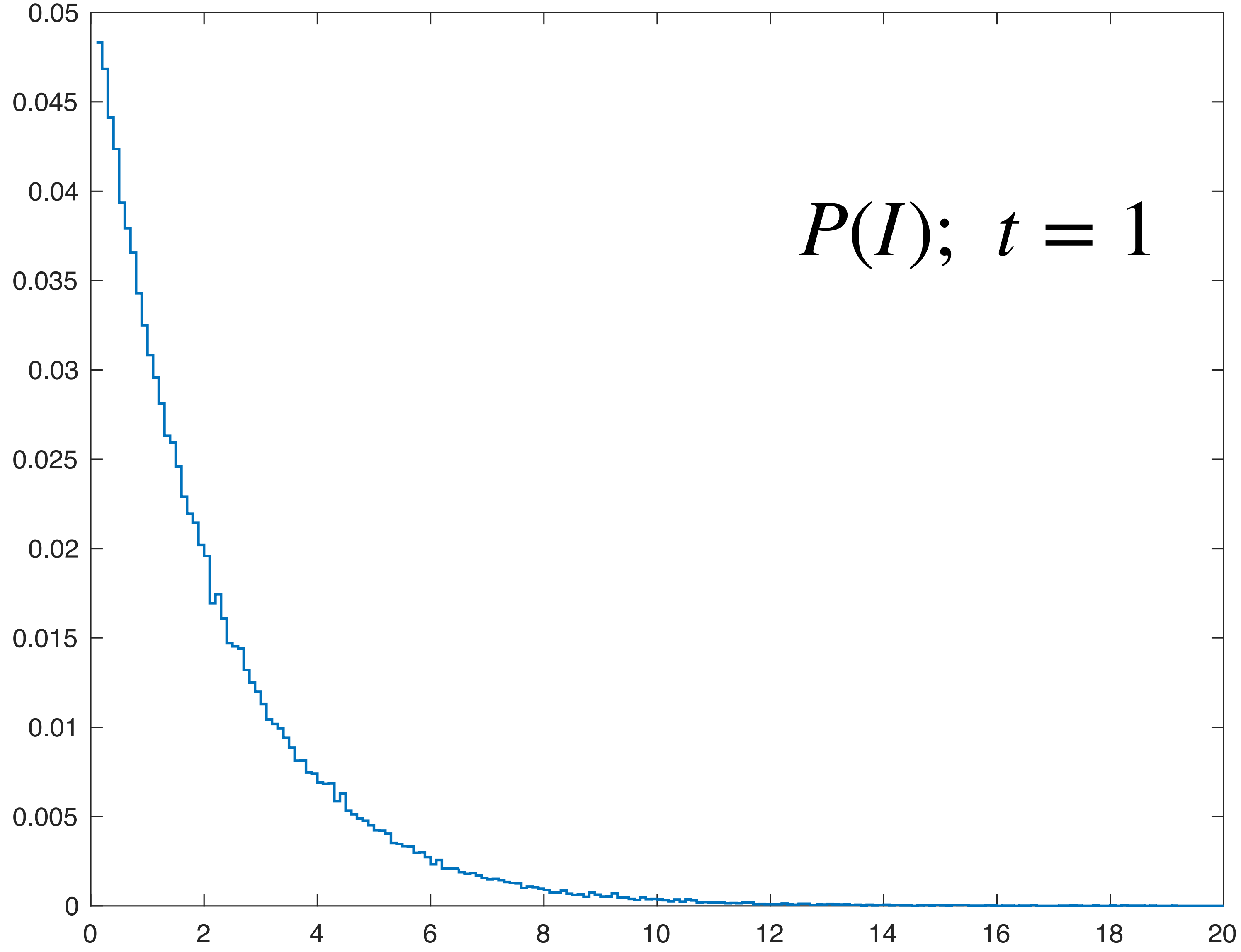

Data
Data cleaning
Calibration
Background removal
Intermediate integration
Quality assessment & cleaning pt 2
PS transform
Error Model
Worries
Tests
Thunder storms
Jackknife
Biasing result
Temperature dep. offset
Correlation
Signal leakage
Injection test

How distributions change

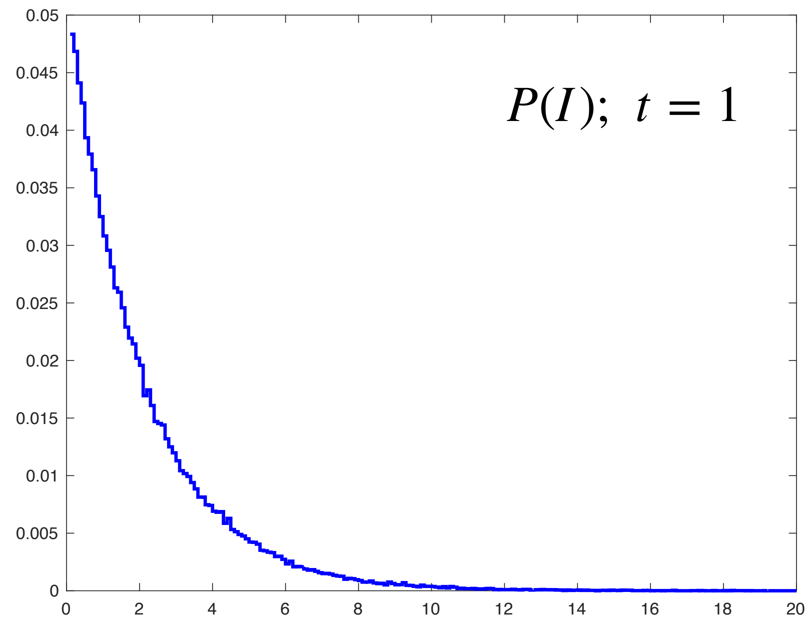
Convolution & the central limit theorem

Example: power of random electric field

$$I = \langle E^\dagger E \rangle_t$$



Average (or sum) is convolution of pdfs



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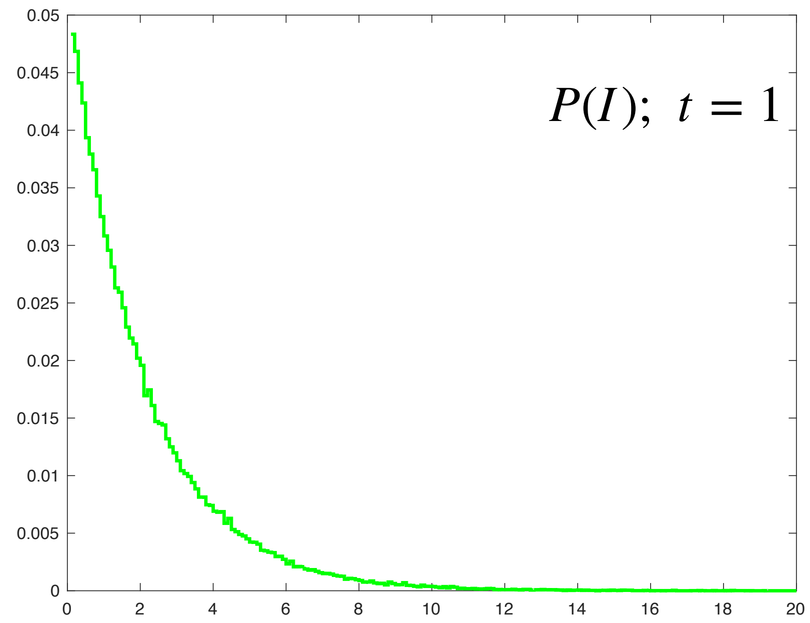
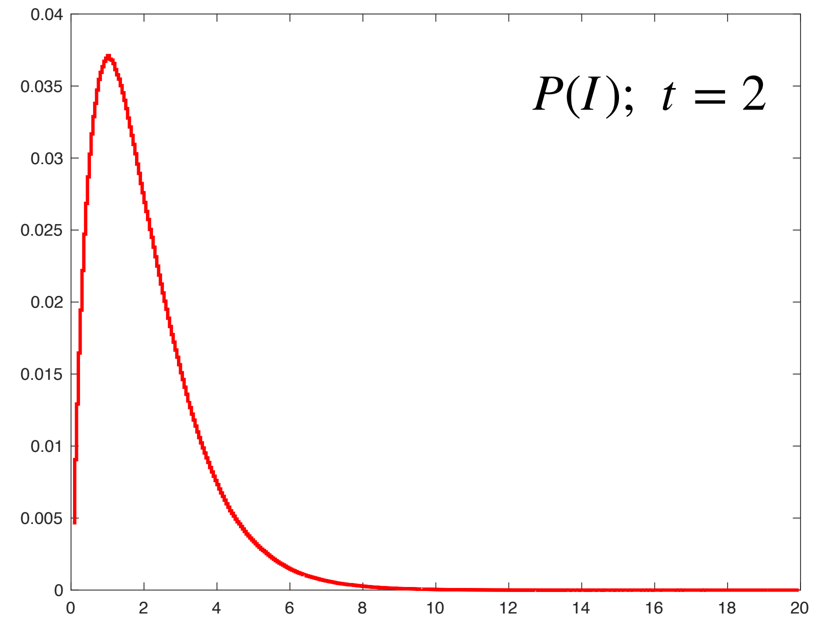
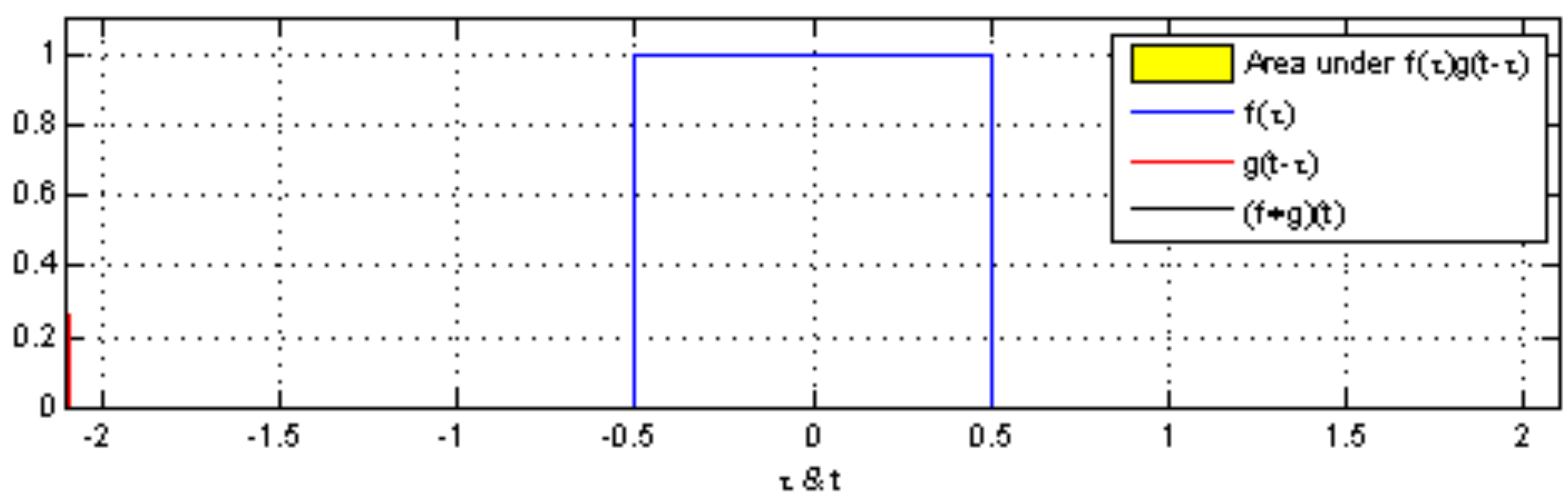
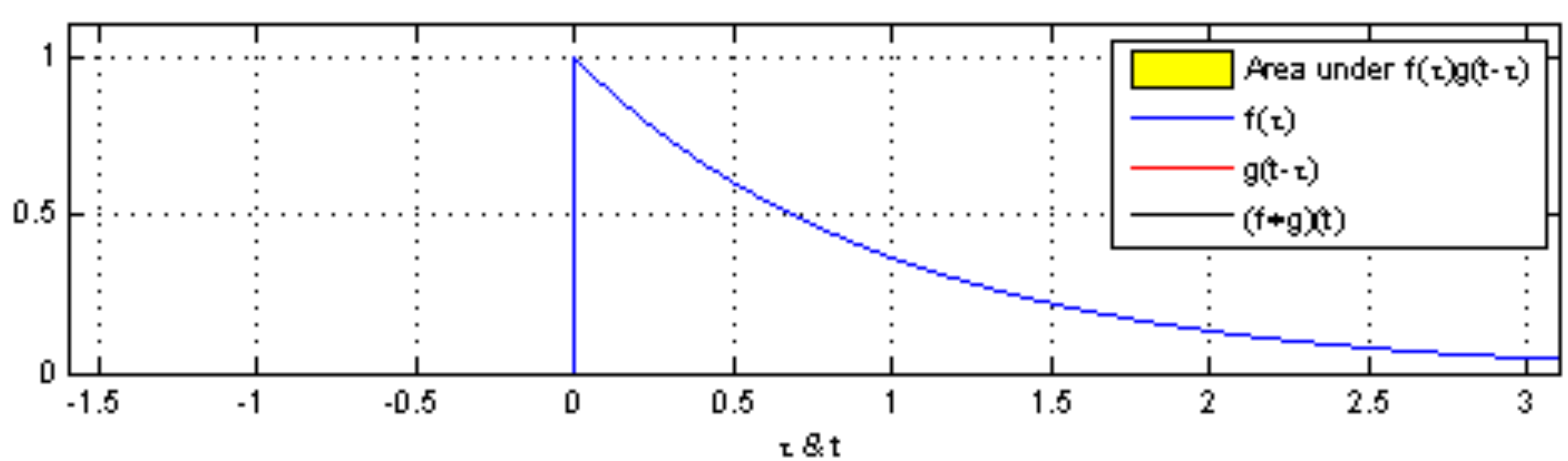




Convolutions

$$(f \star g)(t) = \int_{-\infty}^{\infty} f(\tau)g(t-\tau)d\tau$$





Brian Amberg

pdf of sums & averages

- pdf of a sum is given by the convolution of the two pdfs
- average is a sum with the horizontal axis rescaled
  - calculate sum pdf, rescale axis to get average pdf