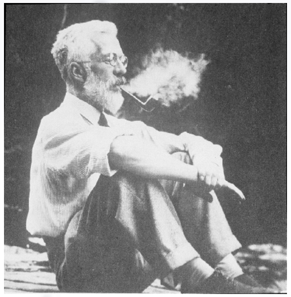
Applied Statistics

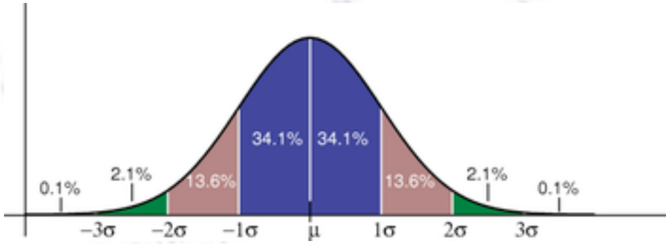
Calibration








Troels C. Petersen (NBI)



"Statistics is merely a quantisation of common sense"

Calibration definition

"Operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties (of the calibrated instrument or secondary standard) and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication."

[International Bureau of Weights and Measures]

Personally, I would shorten this to:

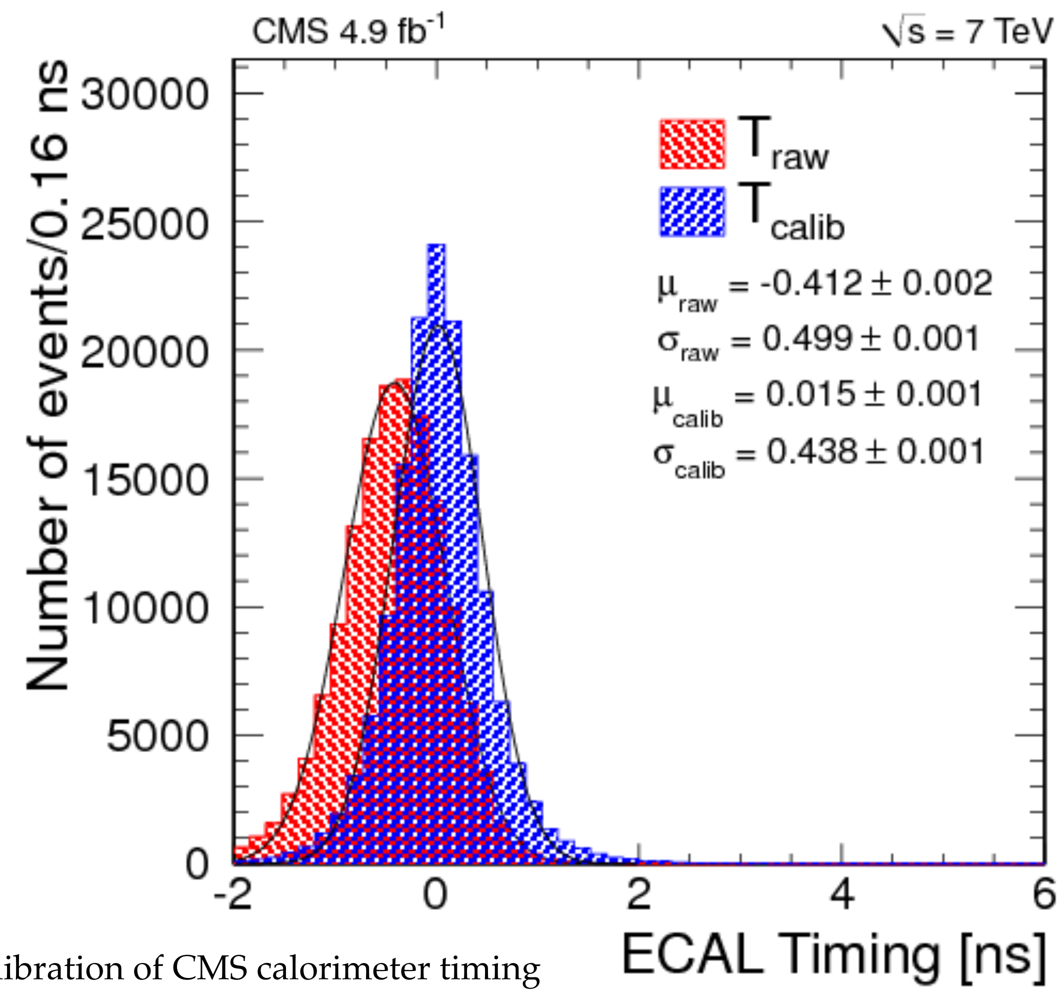
"Operation that, under specified conditions:
- Establishes a relation between the quantity of interest and associated information
- Uses this information to correct/improve the estimate of the quantity of interest."

[Shortening of the above]

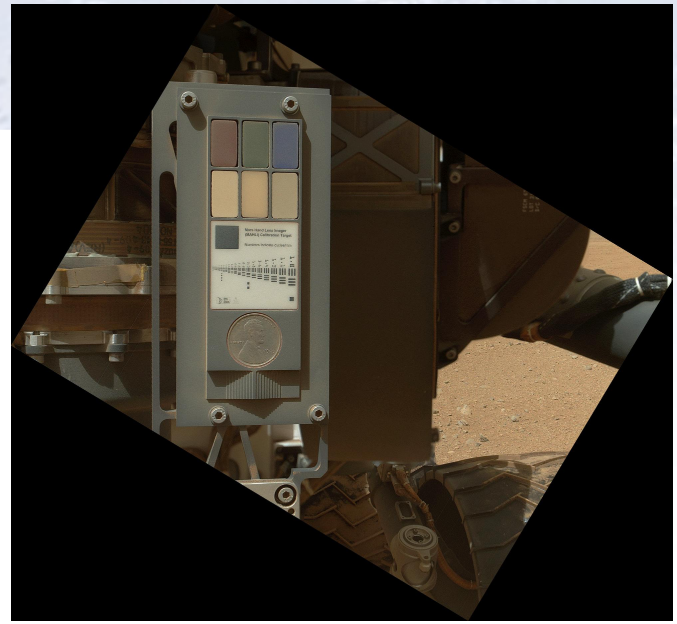
Let's have a few examples…

Calibration is many things!

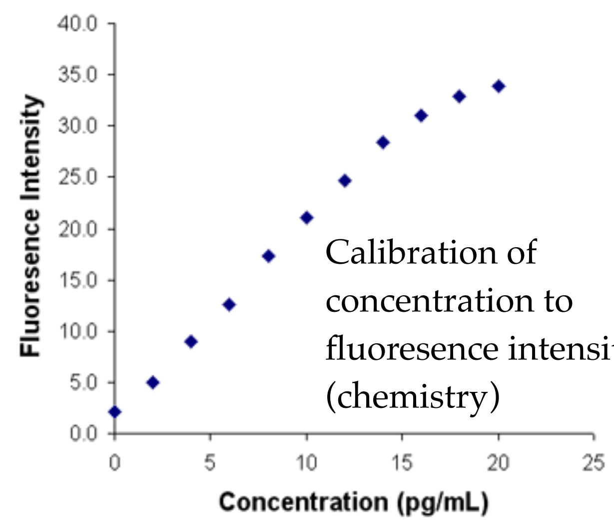
Every field of science involves calibration of some kind.



Calibration of CMS calorimeter timing



Calibration target of Mars rover "Curiosity"



Calibration of concentration to fluoresence intensity (chemistry)

General considerations

<u>Though calibration spans widely, there are a few general considerations:</u>

★ **Using control sample/group:**
- Purpose: To ensure that there is not some (inherent) bias.
- Aim: A good control sample is large and looks “exactly” like signal.
- Example: People without “signal” disease spanning same lifestyles.

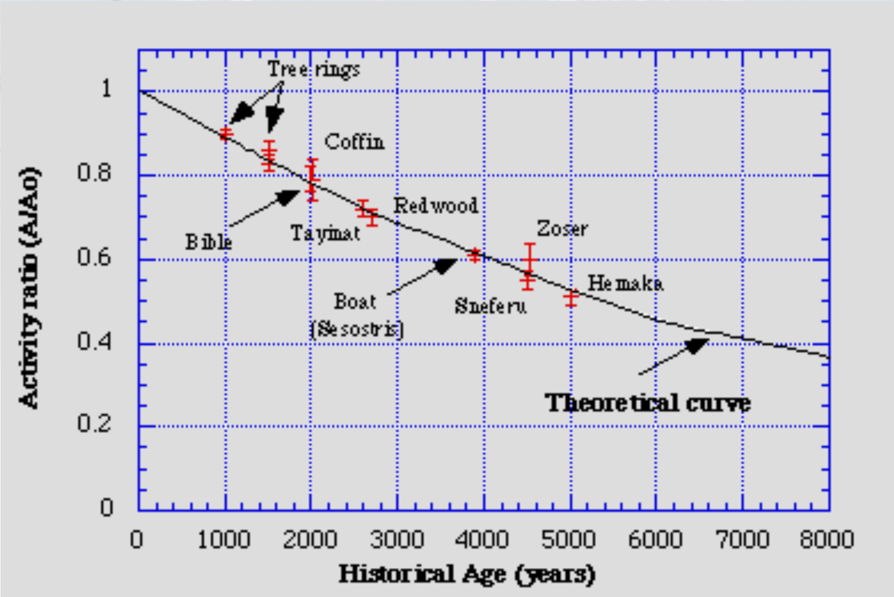
★ **Considering result for already well determined quantity:**
- Purpose: To ensure that there is not some (inherent) bias.
- Aim: A good control measurement is “easy” and well measured.
- Example: Unbiased momentum resolution using particle resonances (Z).

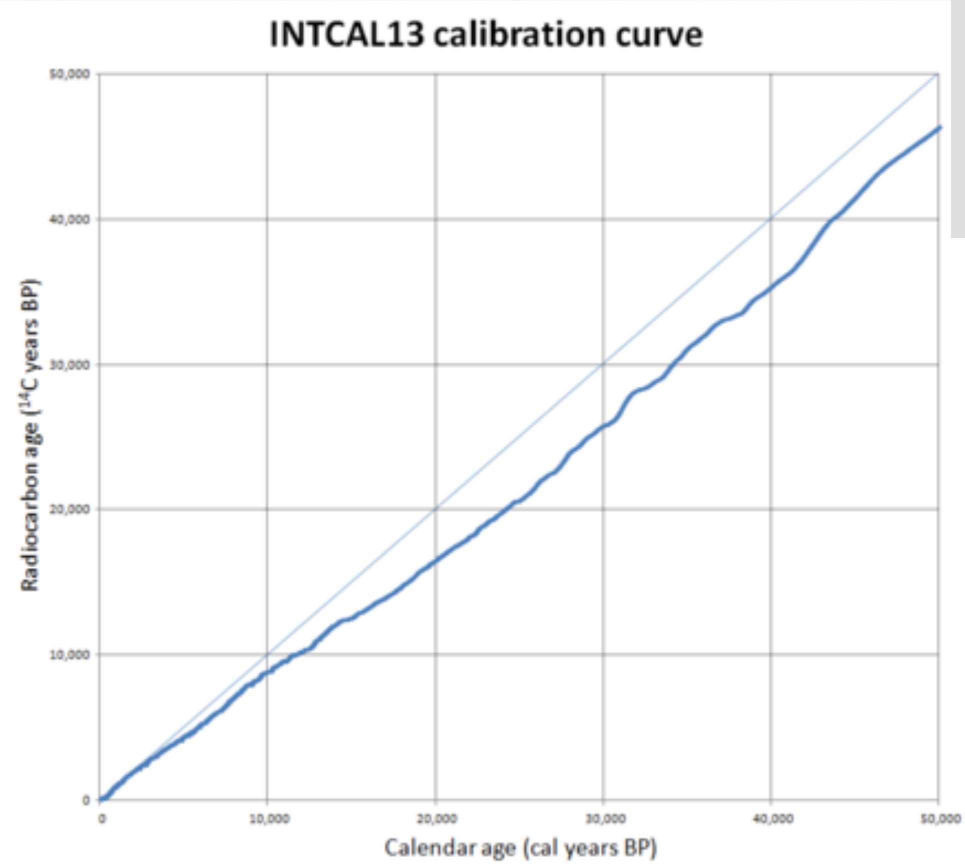
★ **Determining relation to well measurable quantity:**
- Purpose: Infer quantity in question from other sources / measurements.
- Aim: If one can’t measure directly, perhaps it can be done indirectly.
- Example: Measuring flow of liquid in pipe using microphone (noise!).

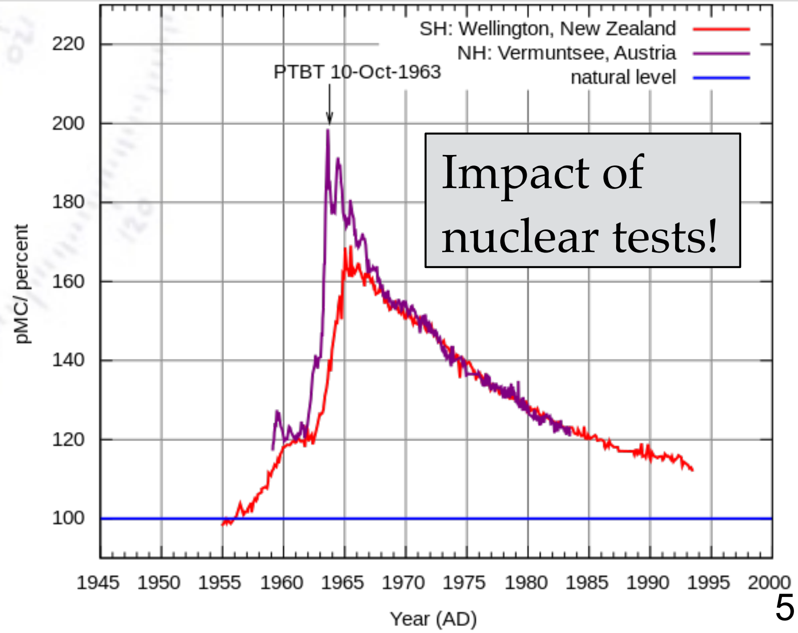
Each field of science have their own “tricks of the trade”, and sometimes breakthroughs are made through calibration (length scales in the Universe, search for the ether, accurate carbon 14 dating, etc.).

Example: Carbon 14 dating

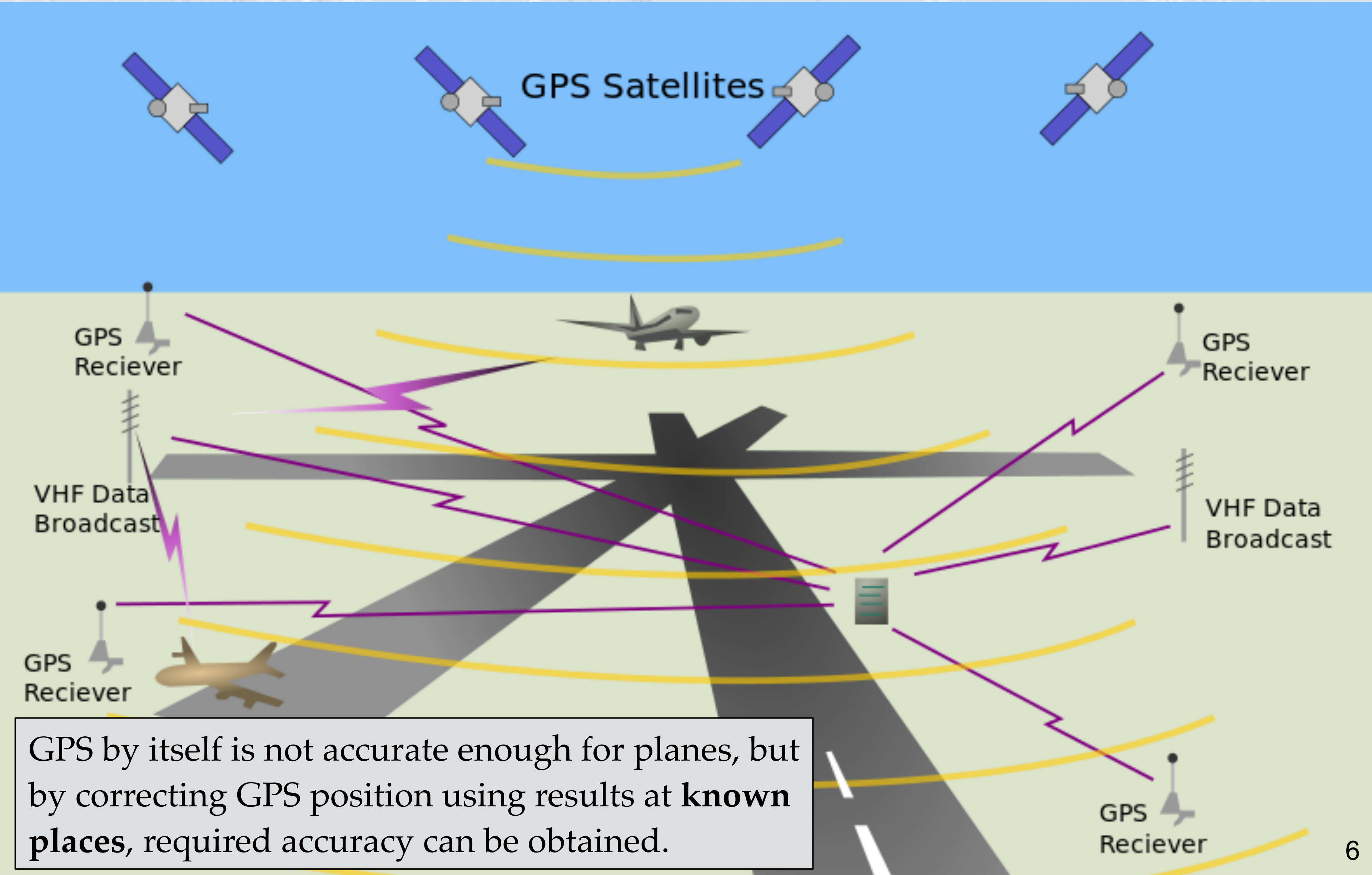
Carbon 14 dating used (and uses) samples of known age (from historical sources) to calibrate the scale and uncertainties.
Tree rings have played a central role!





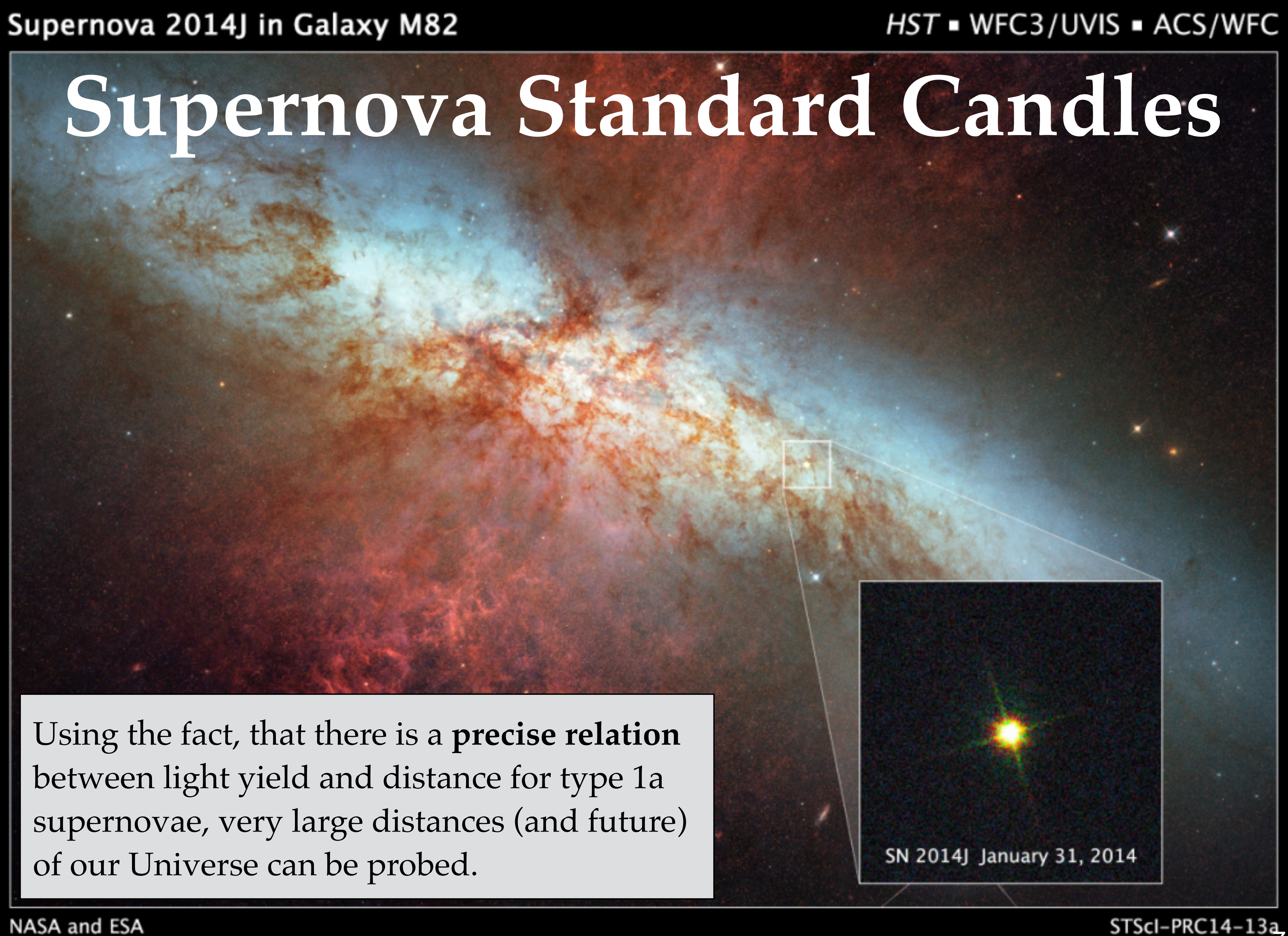


Example: Differential GPS



GPS by itself is not accurate enough for planes, but by correcting GPS position using results at **known places**, required accuracy can be obtained.

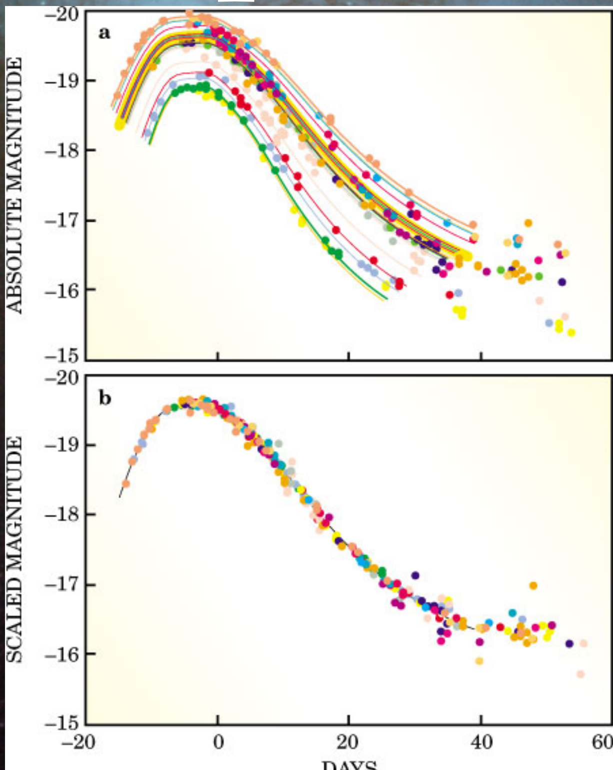
Supernova Standard Candles



Using the fact, that there is a **precise relation** between light yield and distance for type 1a supernovae, very large distances (and future) of our Universe can be probed.

Supernova 2014J in Galaxy M82 — *HST* ▪ WFC3/UVIS ▪ ACS/WFC

Supernova Standard Candles



But in order to get best precision, further calibration is needed!

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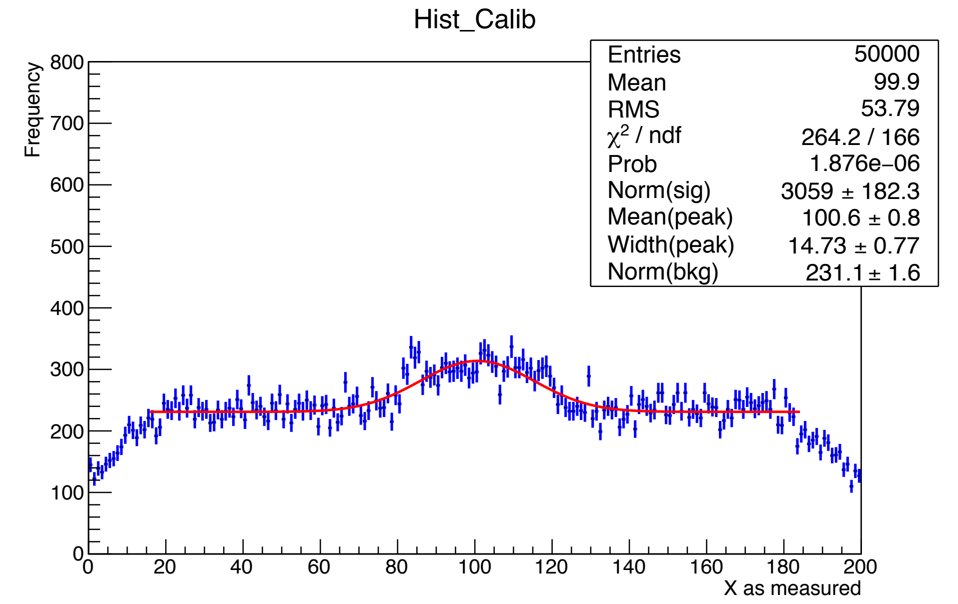
NASA and ESA

STScI-PRC14-13a

Example calibration

Imagine a variable, X, which has a peak in its spectrum, but which depends on another variable, Y. Variations in Y "smears out" the peak in X, and we would therefore like to calibrate for this.



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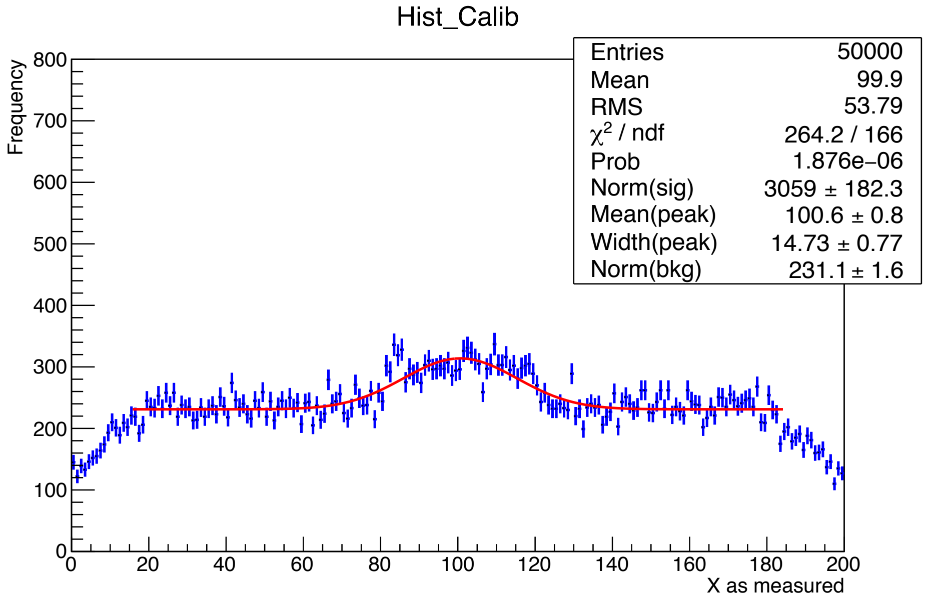

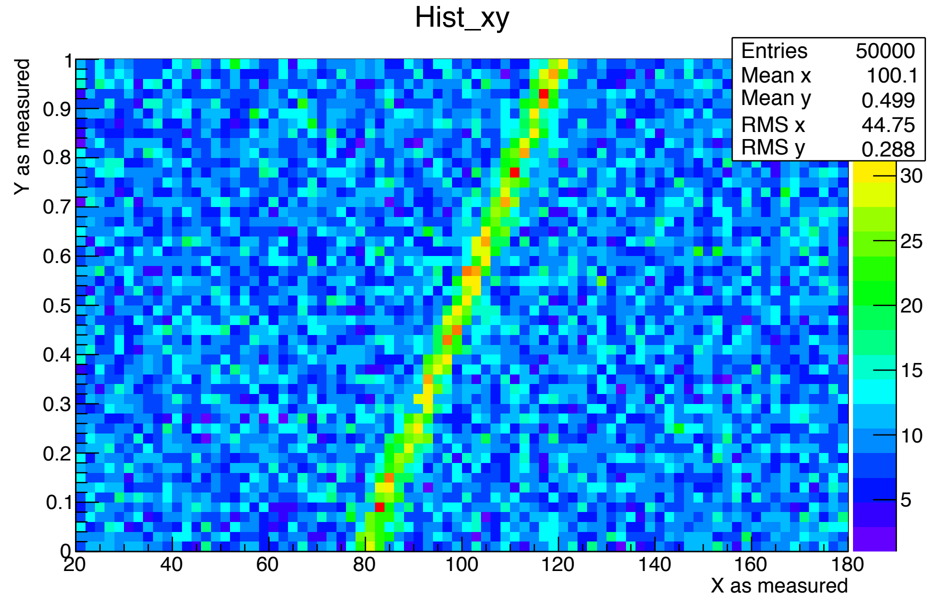

We therefore plot X as a function of Y, and notice a (in this case clear) correlation between Y and X. From this we can deduce how much the peak is shifted as a function of Y, and hence correct for it.

$$X_{calib} = X_{meas} + ???$$

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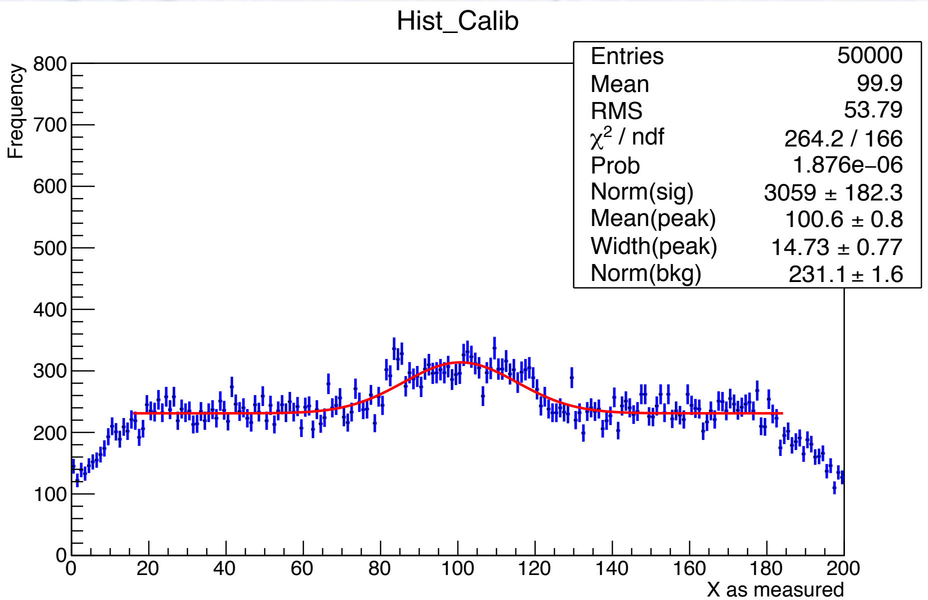
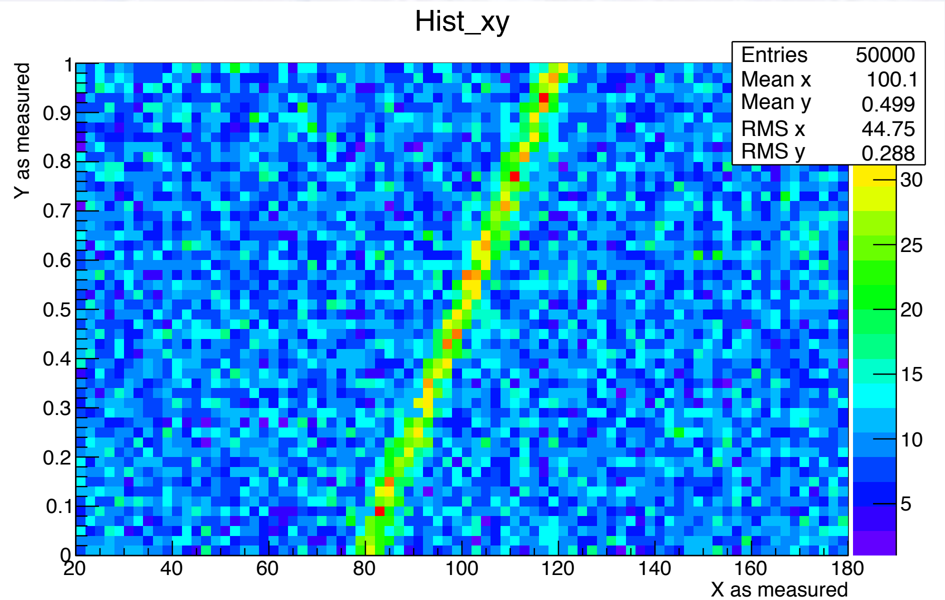


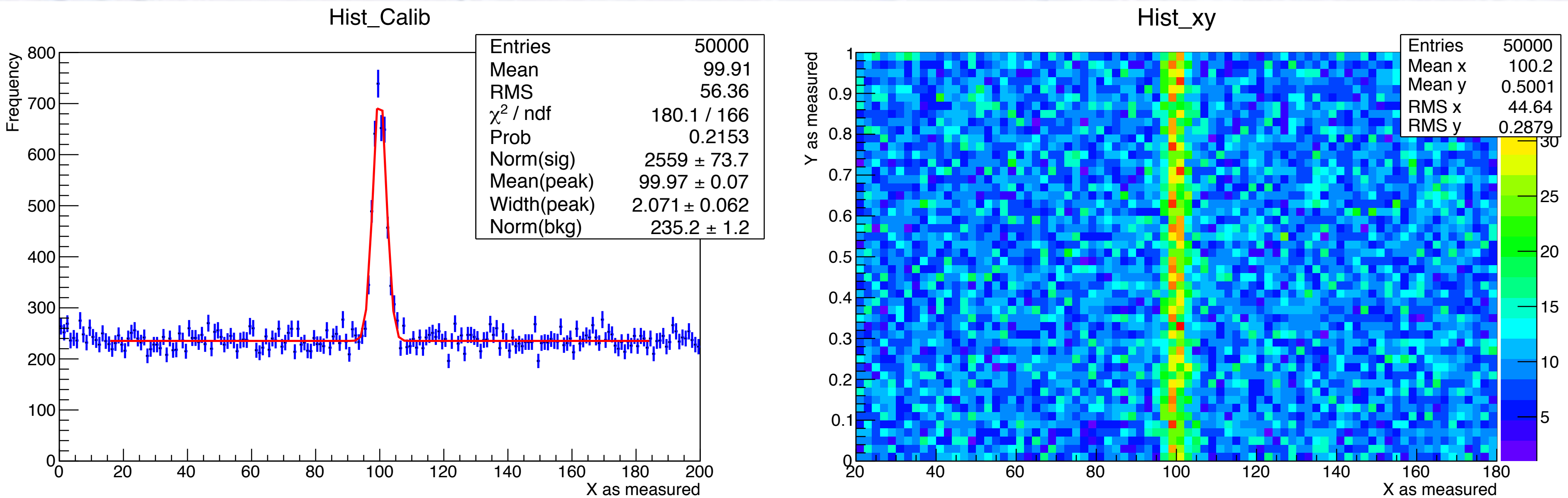


We therefore plot X as a function of Y, and notice a (in this case clear) correlation between Y and X. From this we can deduce how much the peak is shifted as a function of Y, and hence correct for it. A simple inspection yields:

$$X_{calib} = X_{meas} - 40(Y - 0.5)$$

Example calibration

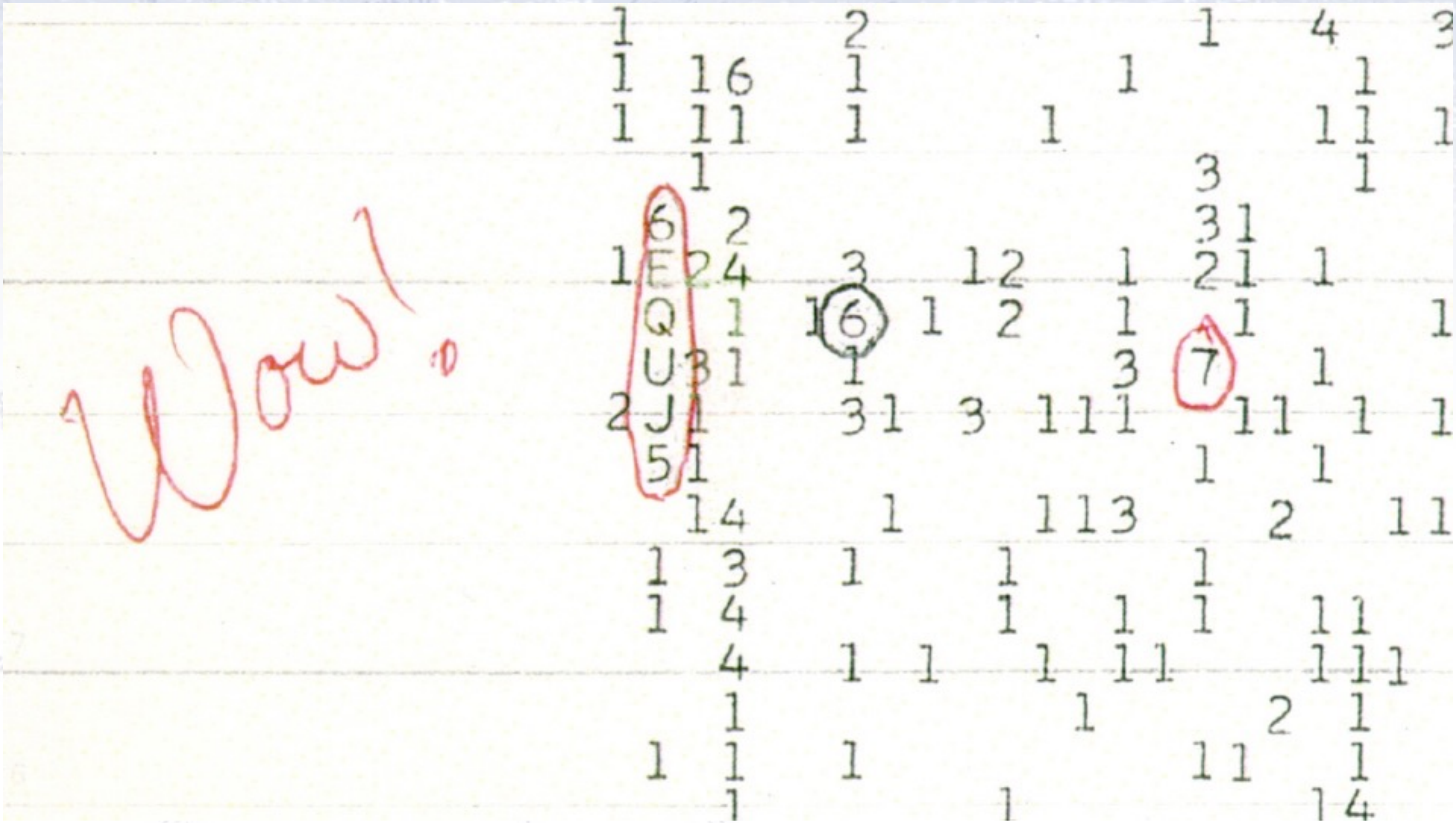
Applying this yields a new and (much) improved resolution of the peak in X, as would also be expected. At the same time, we can check, that now there is no dependence of the calibrated value of X on Y.



We thus conclude, that the calibration worked, and (of course) describe our calibration in the paper we publish. Note that sometimes, one needs a "control sample" for which the correct value is known through other sources.

$$X_{calib} = X_{meas} - 40(Y - 0.5)$$

Things to avoid doing...



On August 15th 1977 while working on SETI Dr. Jerry R. Ehman though he saw a signal...

While interesting to consider, the mistake could very easily be repeated!

Conclusions

Calibration is usually a central part of analysing data in order to:

- Ensure that measurements are correct and correct them if they are biased.
- Establish/calibrate the uncertainty on measurements.

But it requires foresight and good planning of an experiment to be able to calibrate precisely. Being able to do so, distinguishes the **good experimenter**.