

# **Bad Science**

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**The Scientific Process**  
**Systematic Error happens**  
**So does Human Nature**  
**Skepticism vs Enthusiasm**  
**The mark of Pathology**  
**The road to Fraud**  
**Uninformed Analysis**  
**Look at your Data!**  
**But what if you cannot?**  
**The Tyranny of Terabytes**  
**Petabytes: A New World**

# Scientific process

- (1) Observation. Experiment design is very important.
- (2) Compare with theory. The inducement of general hypotheses or possible explanations for what has been observed. *The simplest hypothesis is the best.* **A viable theory must be falsifiable.**
- (3) The deduction of corollary predictions that must be true if the hypothesis is true. Additional testable predictions are made, based on the initial hypothesis.
- (4) Testing the hypothesis by investigating and confirming the deduced implications.

**Not exactly true  
in practice**

Real discoveries of phenomena contrary to all previous scientific experience are very rare, while fraud, fakery, foolishness, and error resulting from over-enthusiasm and delusion are all too common.

A. Cromer 1993

# systematics

Particularly troubling today is that we don't fully know what we don't know

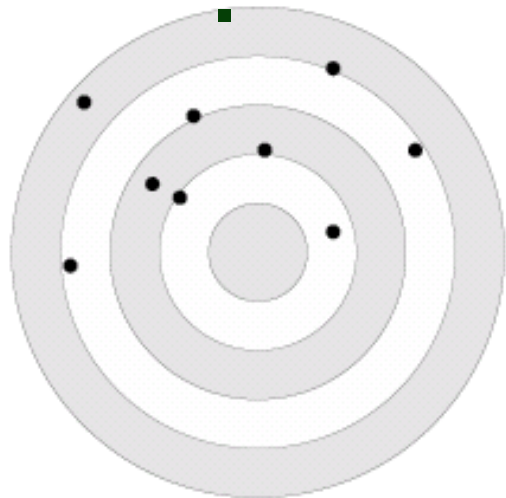
Testimony by Bert Ely to the Subcommittee on Financial Management, the Budget, and International Security of the Senate Committee on Governmental Affairs July 21, 2003

**Two kinds of error:**

**Random error**

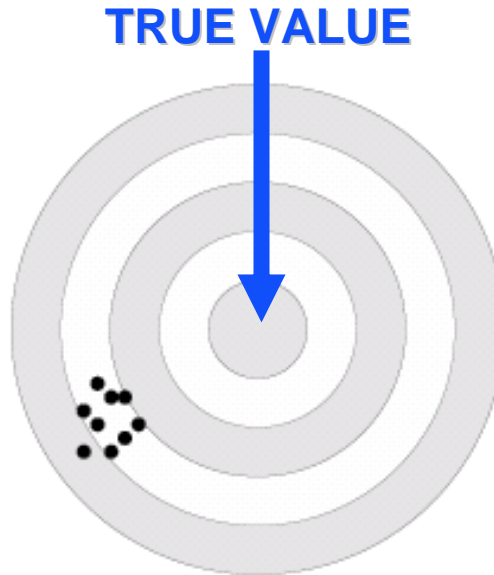
**Systematic error**

# accuracy and precision



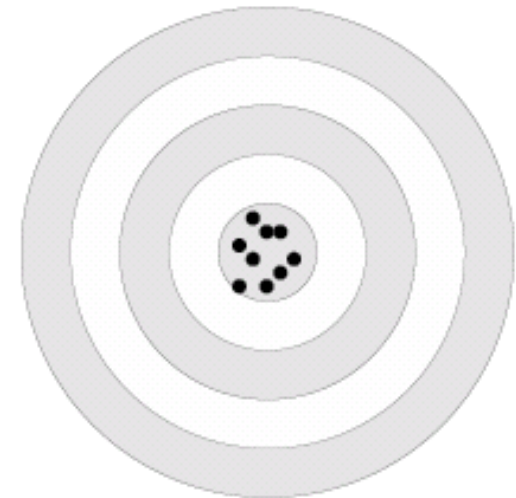
**not precise and  
not accurate**

**large random  
and *systematic*  
errors**



**precise but  
not accurate**

**small random  
error, large  
*systematic*  
error**

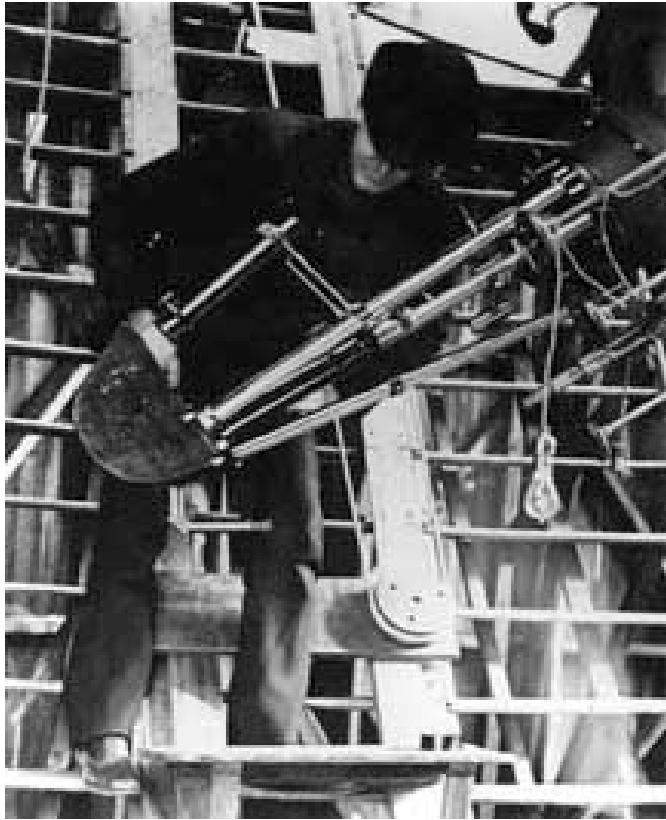


**precise and  
accurate**

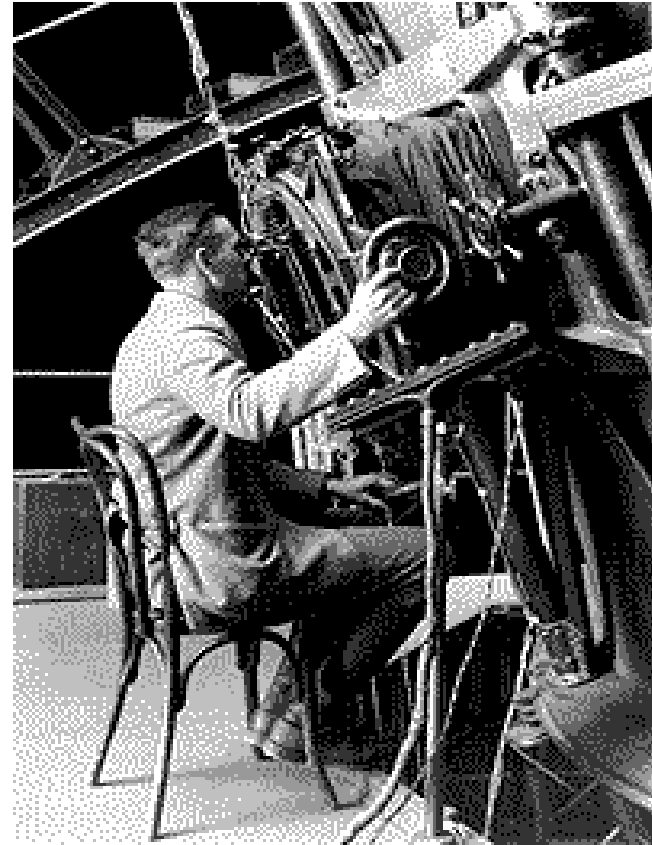
**small random  
error, small  
*systematic*  
error**

# Discovery of expanding universe

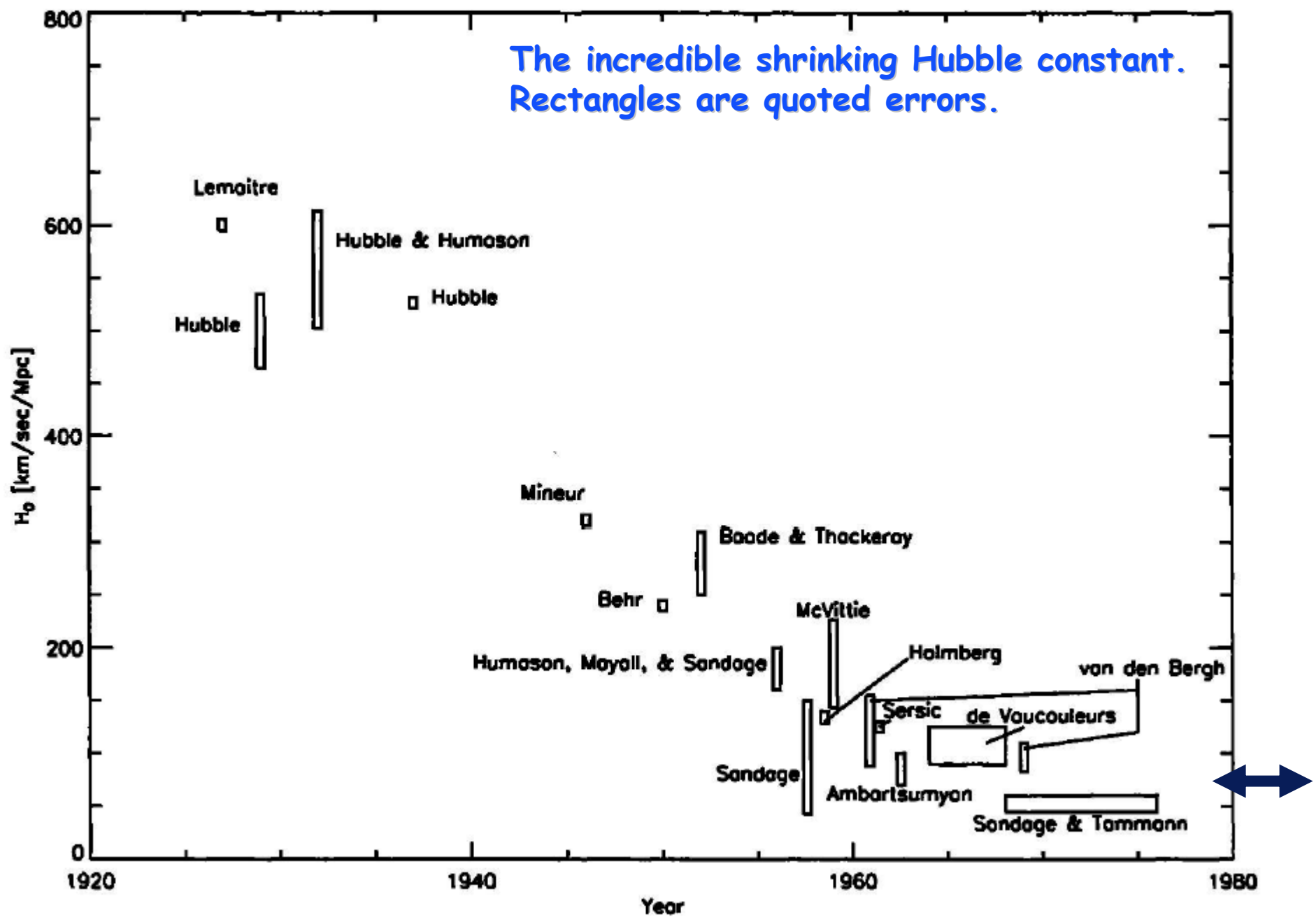
Vesto Slipher



Edwin Hubble



The incredible shrinking Hubble constant.  
Rectangles are quoted errors.





# Systematics: catch-22

The difficulty is this: if we understand the systematic we can correct for it, but if we don't understand the systematic we won't think of it at all or our error estimate will be wrong.

It is only at the edge of understanding where systematic errors are meaningful: we understand enough to realize it might be a problem, but not enough to easily fix it.

# Avoiding Systematics

The best prevention of systematic error is good experiment design.

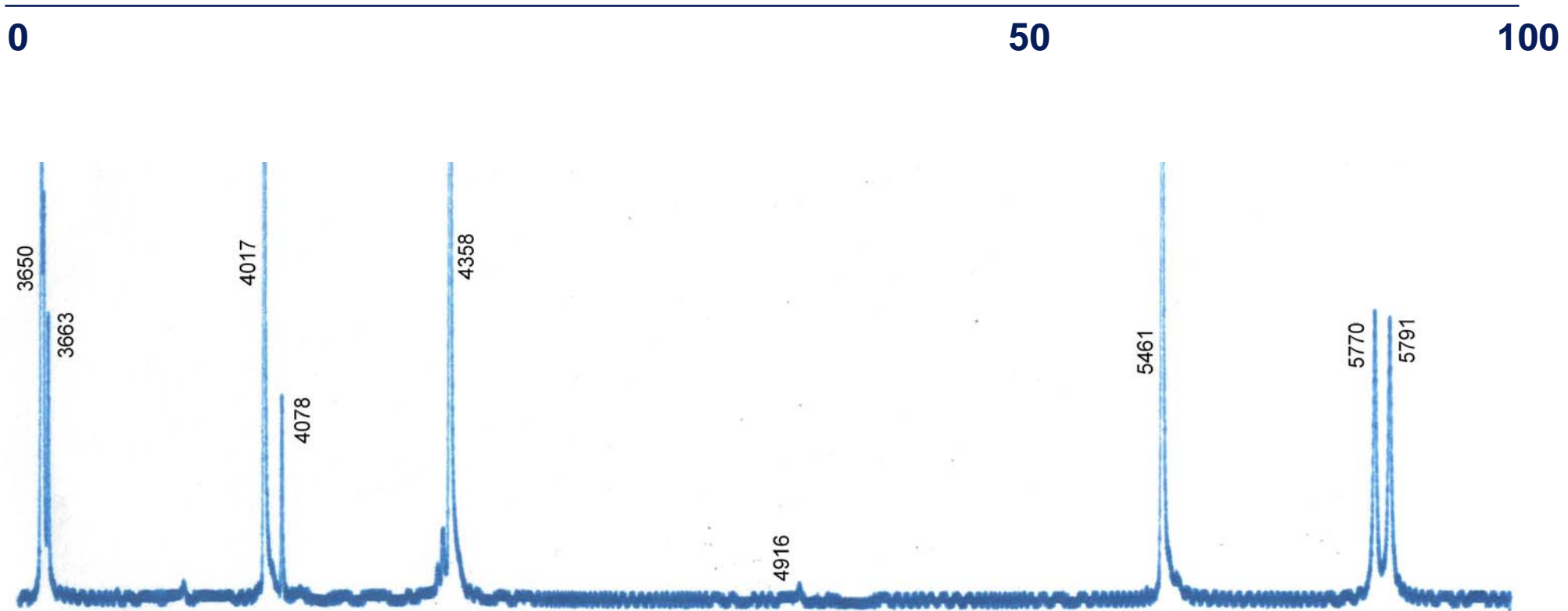
How can we robustly attack this problem in an existing experiment or observation?

*A mix of simulations and exploratory tests.*

Simulations are useful teachers of where sensitivity to systematics are. We may then explore these avenues; search for the signature of each systematic, isolate it, understand it, and gain control of it. In practice, for each experimental field it is a kind of "art" which demands familiarity with the likely systematics. It is the responsibility of the experimentalist to probe for systematics and of the theorist to allow for them.

# Calibration

Your instrument reading



# Healthy skepticism

- Be skeptical of your own work
- Test relentlessly for systematics
- Avoid early press conferences



# Pathological science

**Not fraud**

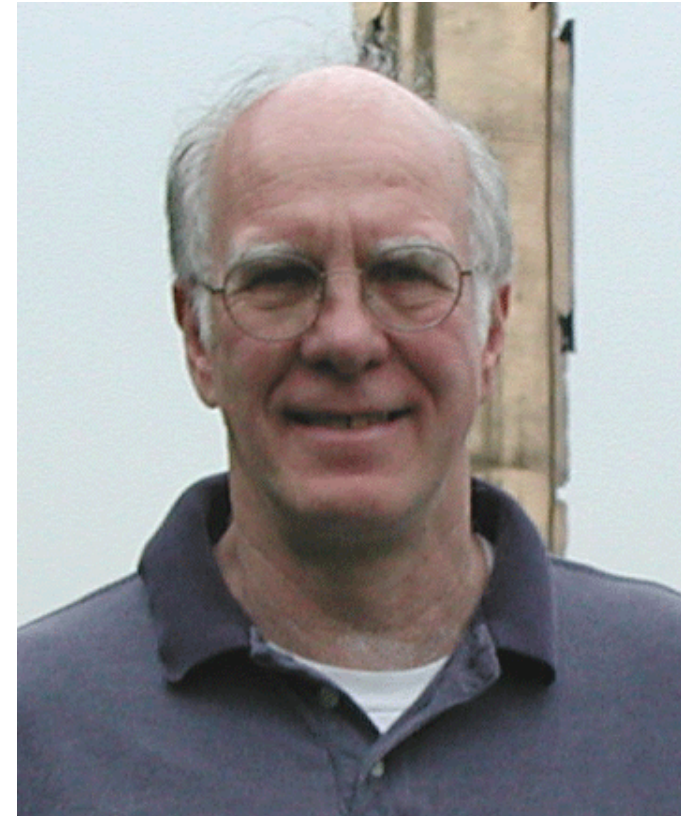
**Well intentioned, enthusiastic scientists are led astray**

**Examples abound in every field of science**

# polywater

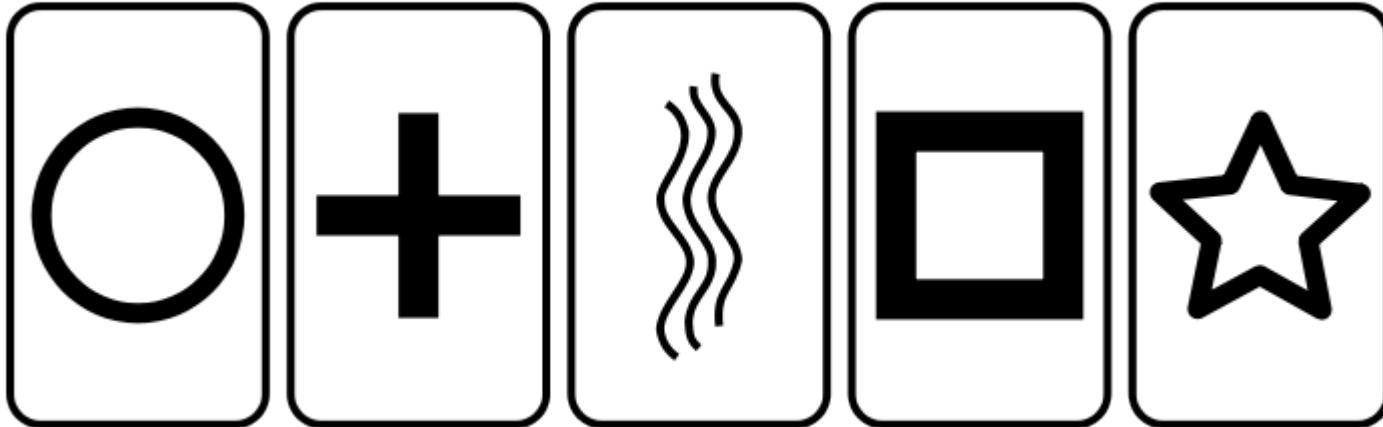
The case of polywater demonstrates how the desire to believe in a new phenomenon can sometimes overpower the demand for solid, well-controlled evidence. In 1966 the Soviet scientist Boris Derjaguin lectured in England on a new form of water that he claimed had been discovered by another Soviet scientist, N. N. Fedyakin. Formed by heating water and letting it condense in quartz capillaries, this "anomalous water," had a density higher than normal water, a viscosity 15 times that of normal water, a boiling point higher than 100 degrees Centigrade, and a freezing point lower than zero degrees. Over the next several years, hundreds of papers appeared in the scientific literature describing the properties of what soon came to be known as polywater. Theorists developed models, supported by some experimental measurements, in which strong hydrogen bonds were causing water to polymerize. Some even warned that if polywater escaped from the laboratory, it could autocatalytically polymerize all of the world's water.

Then the case for polywater began to crumble. Because polywater could only be formed in minuscule capillaries, very little was available for analysis. When small samples were analyzed, polywater proved to be contaminated with a variety of other substances, from silicon to phospholipids. Electron microscopy revealed that polywater actually consisted of finely divided particulate matter suspended in ordinary water. Gradually, the scientists who had described the properties of polywater admitted that it did not exist. They had been misled by poorly controlled experiments and problems with experimental procedures. As the problems were resolved and experiments gained better controls, evidence for the existence of polywater disappeared.



# Extrasensory perception

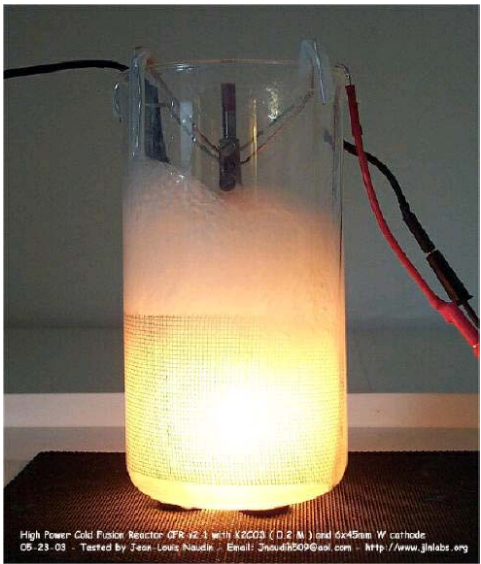
- Parapsychologist J. B. Rhine (1934)
- Common systematic error in “paranormal” statistics



“Remote viewing” experiments showing a significant effect have one thing in common: only one judge, the principal investigator, was used in all the remote-viewing experiments.

# Cold fusion

- Pons and Fleischman claimed bench-top fusion using a palladium battery
- Before peer review, they held a press conference



“Cold fusion” has since been debunked.



# Features of Pathological Science

- ❑ The maximum effect is produced by a barely perceptible cause, and the effect doesn't change much as you change the magnitude of the cause.
- ❑ The effect only happens sometimes, when conditions are just right, and no one ever figures out how to make it happen reliably. The people who can do it are unable to communicate how they make it happen to the people who can't.
- ❑ The effect is always close to the limit of detectability.
- ❑ There are claims of great accuracy, well beyond the state of the art or what one might expect.
- ❑ Fantastic theories contrary to experience are suggested. Often, mechanisms are suggested that appear nowhere else.
- ❑ Criticisms are met by ad hoc excuses thought up on the spur of the moment.

# Is it pathological?

**A single hit does not mark an idea as pathological, but multiple hits should serve to raise one's suspicions. This is a list primarily aimed at experiments, but many of the characteristics can also apply to theories.**

**Good science can often have one or two of these symptoms. This is because most experiments at the frontier deal with barely detectable signals.**

**There is always risk in undertaking such experiments (or interpreting them). But there is also great *opportunity!***

# Related sociology

- **Supporters are unable or unwilling to think about testing or disproving the effect. Tests that could lead to definitive disproof are never done by supporters.**
- **The implications of a theory or experiment are never extended outside its original domain. Supporters don't ask what implications it might have for neighboring fields.**
- **The ratio of supporters to critics rises rapidly to ~50% and then slowly decays to zero over a long time.**

# Good reading

**Robert L. Park. *Voodoo Science: The Road from Foolishness to Fraud*. Oxford University Press, New York, 2000. ISBN: 0-19-513515-6.**

**Rousseau, Denis L. *Case Studies in Pathological Science*. *American Scientist* 80: 54-63 (1992)**

# Pathological engineering

## Hydrogen result causes controversy

5 August 2005

**When is the ground state of a hydrogen atom not the ground state? When it is a "hydrino" state, according to Randy Mills and co-workers at BlackLight Power, a company based in Cranbury, New Jersey. In a series of papers Mills and co-workers have argued that the results of a variety of experiments on hydrogen plasmas can only be explained by the existence of a new state in which the electron has less energy than the  $n=1$  ground state. Mills argues that the hydrino state could be used as a new source of energy -- a claim that has led to a predictably negative response from other researchers -- and may even have some connection to the problem of "dark" matter. Now two theoretical physicists in Europe have joined the debate, with one opposing the hydrino hypothesis and the other supporting it.**

Hydrogen is the simplest of all the atoms, containing just an electron and a proton. It normally takes 13.6 eV of energy to separate the electron and proton when the atom is in the ground state. Similarly, if an electron and proton combine to form a hydrogen atom in the ground state, 13.6 eV of energy is released in the process. However, if there is a new energy state below the ground state it could be possible to release even more energy.

<http://www.blacklightpower.com>

# Some common mistakes

**Poor experiment design**

**Not testing for systematics (control)**

**Ignoring sample selection effects (bias)**

**Bad statistics: assume wrong distribution (tails!)**

**Failure to repeat the experiment using different sample with same physics**

# Image Manipulation

Journals find that authors have manipulated data in order to “enhance” appearance and support their conclusions.

Sometimes this blurs the line between standard accepted image processing (to remove artifacts of the detector) and fraud.

**PUBLISHED IMAGE DATA: MEGABYTES NOW  
SOON GIGABYTES AND THEN TERABYTES**

**Figure 1. Gross manipulation of blots**



Rossner, M. et al. J. Cell Biol. 2004;166:11-15



# Jan Henedrik Schön

**Schön joined Bell Labs in 1998, just before finishing his Ph.D. in Konstanz, Germany. In February 2000, Schön published some startling experimental results.**

**Schön and his partners had started with molecules that don't ordinarily conduct electricity, and claimed they had succeeded in making them behave like semiconductors. The researchers reported their findings in Science.**

**Less than five years after finishing graduate school, Jan Hendrik Schön was in contention for the Nobel prize.**



# Schön and collaborators



**For two and a half years, Jan Hendrik Schön of Bell Labs was the poster boy for productivity in physics research. During that time, Schön was the lead author of 89 papers. This practically superhuman pace averages to a paper every 10 days.**

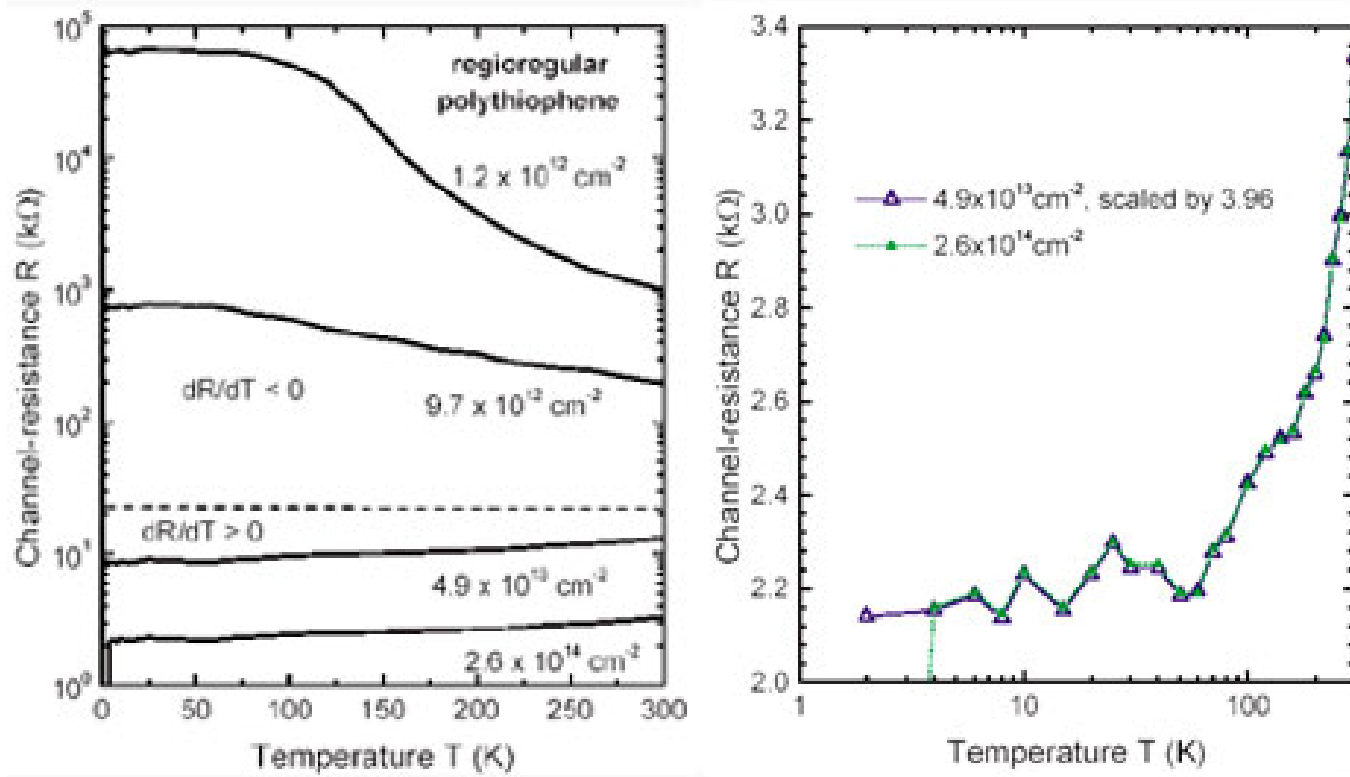
# The unraveling

Concern arose when some researchers within Bell Labs told Lydia Sohn of Princeton University that they had noticed a strong resemblance between two papers by three of their Bell Labs colleagues, one appearing in *Nature* and the other in *Science*. Both papers described field-effect transistors made from self-assembled monolayers of organic materials, but the two papers dealt with slightly different materials.

One morning she got in to work to find a message waiting on her answer phone. Prof LYDIA SOHN: "I just happened to check my voicemail messages in my office and I had a very interesting voicemail message and it said, Lydia this is your homework, look at these two papers by Hendrik. And by the tone of his voice I knew something very juicy was going on and so I quickly downloaded the, these two papers, one from *Science* and one from *Nature*."

BBC interview, 2004

# Data substitution



Data substitution was found in a paper describing gate-induced superconductivity in polythiophene. The published figure (left panel) shows resistance for four values of surface charge density. Superconductivity sets in at the highest density. The bottom two curves are replotted in the right panel, with one curve divided by 3.96. An investigation found that the data were the same, except for one point.

## Science magazine on the Beasley committee report

**We have been asked whether this sad incident has given us doubts about how well the peer review process at *Science* works. Unhappy experiences should generate efforts to learn from them, and we will use the report to evaluate what we might have done differently in these cases. That said, we would reiterate that it is asking too much of peer review to expect it to immunize us against clever fraud.**

# Take risks

Exploration and discovery involves risk-taking

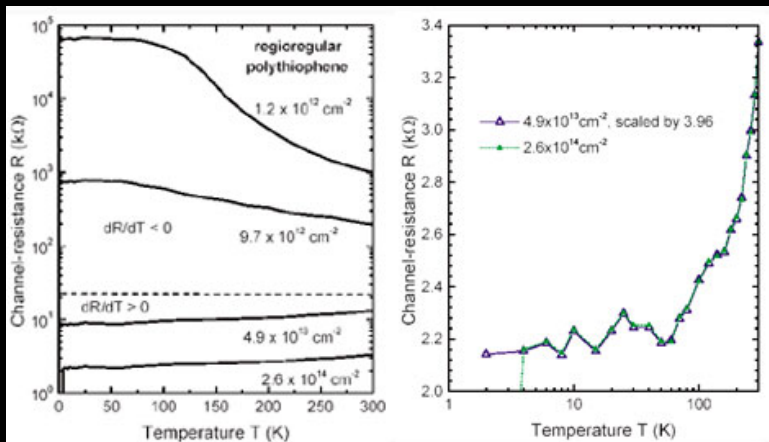


Interplay between theory and observation (experiment)

# Take care

The scientific process demands integrity

Recall how Schon's research was debunked:  
Interested scientists LOOKED at his data.  
i.e. they used the brain's pattern recognition  
to uncover unexpected correlations.

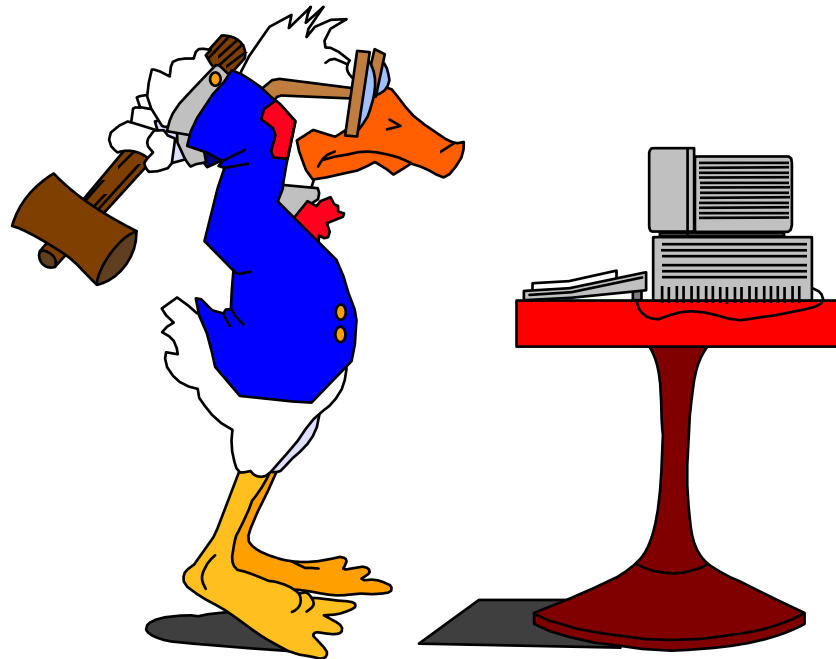


What if there is SO MUCH DATA  
that the human mind cannot begin  
to search for patterns?

# Petabytes!

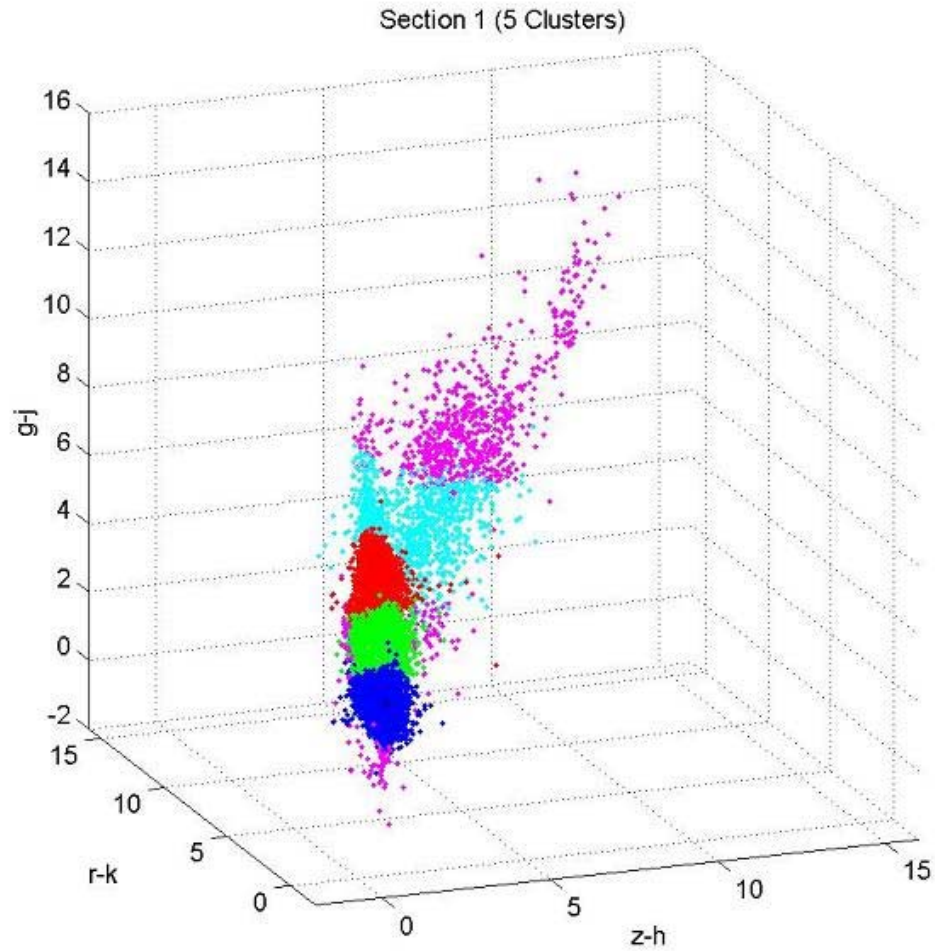
**We cannot even look through all our Terabyte data now.**

**What can we do when we have 1000's of Terabytes?**





# Automated hyperspace cluster analysis



# **a dichotomy**

- **In the scientific method, high value is placed on negative findings.  
(Theories can be disproved, not proved)**
- **Current science culture places little value on “null” results.  
(Journal articles finding no effect are valued less than articles reporting a positive effect)**