Pathological Science

Systematic Error happens

So does Human Nature

Skepticism vs Enthusiasm

The mark of pathology

The road to fraud

systematics

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

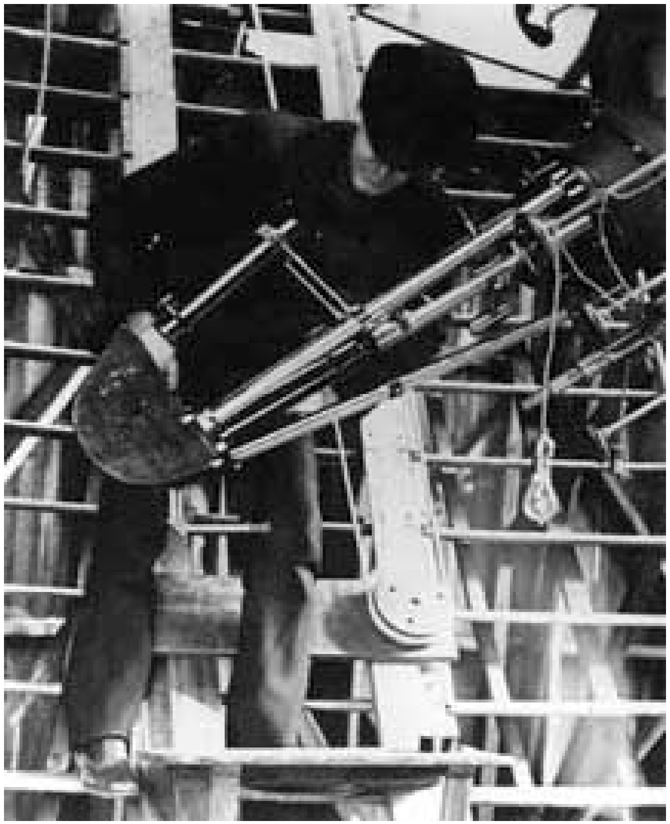
Testimony by Bert Ely to the Subcommittee on Financial Management, the Budget, and International Security of the Senate Committee on Governmental Affairs   July 21, 2003

Two kinds of error:

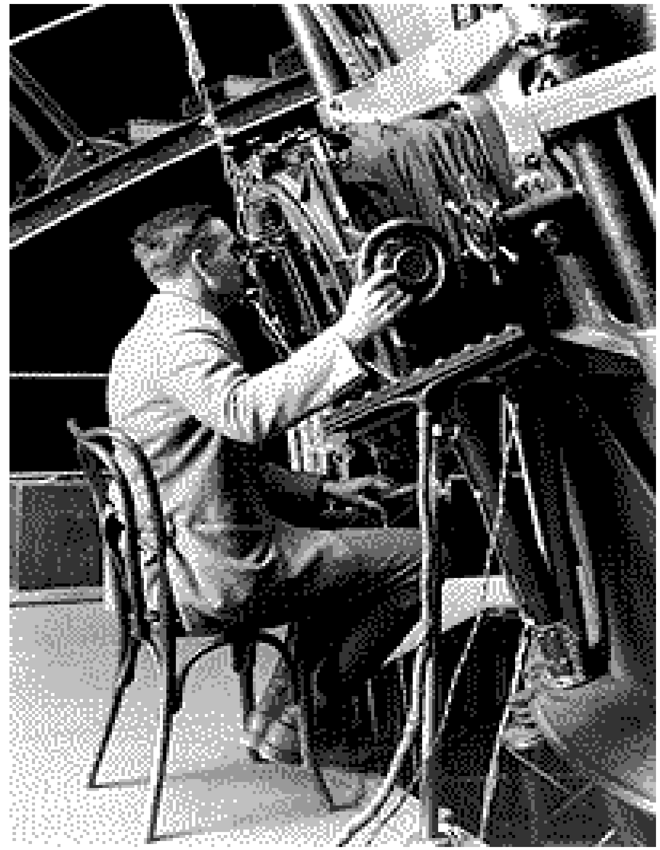
- **Random error**
- **Systematic error**

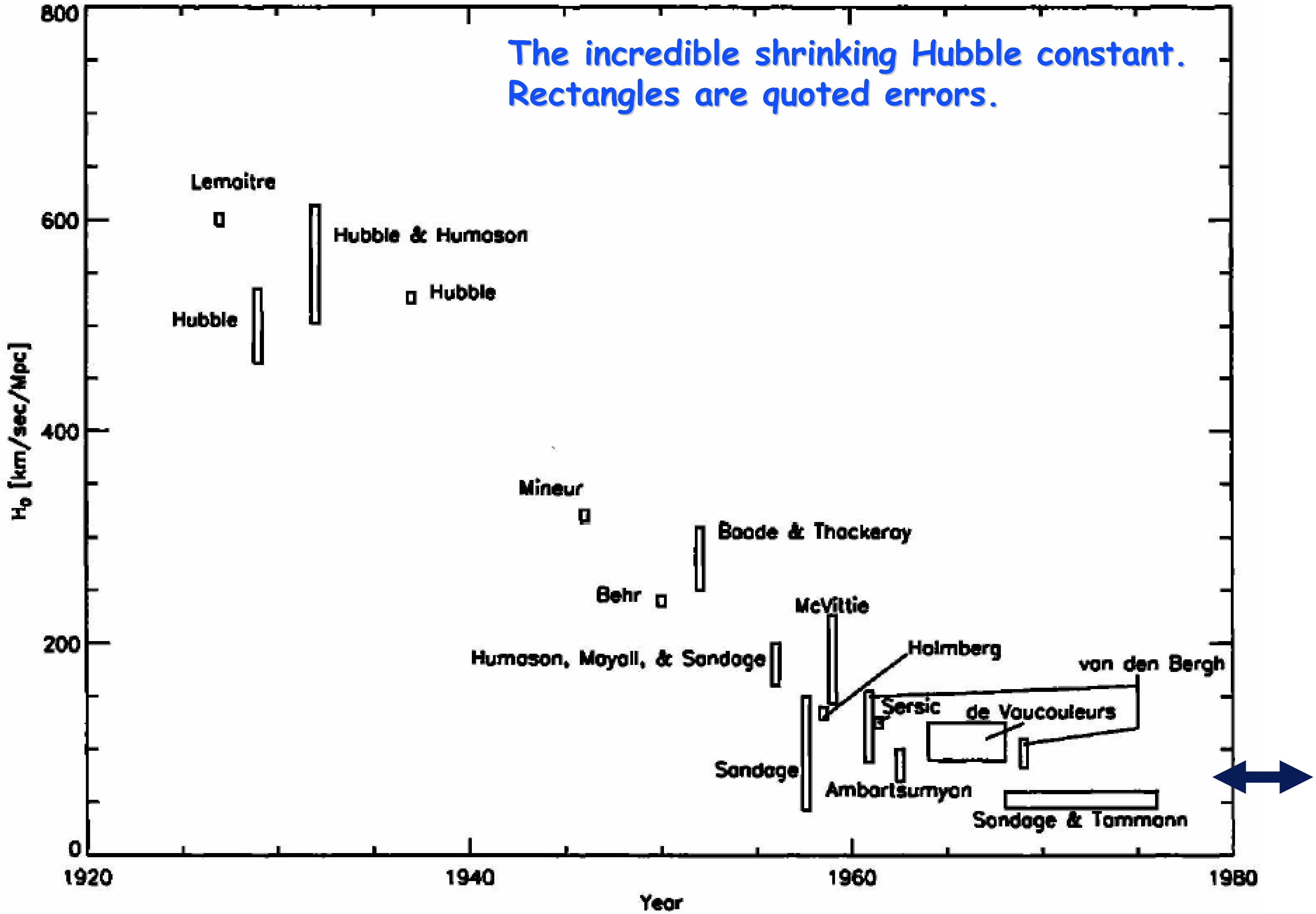
Discovery of expanding universe

Vesto Slipher



Edwin Hubble





Trimble (1996) PASP 108, 1073

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.

Healthy skepticism

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

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.

Pathological science

Not fraud

Well intentioned, enthusiastic scientists are led astray

Examples abound in every field of science

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 no where 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

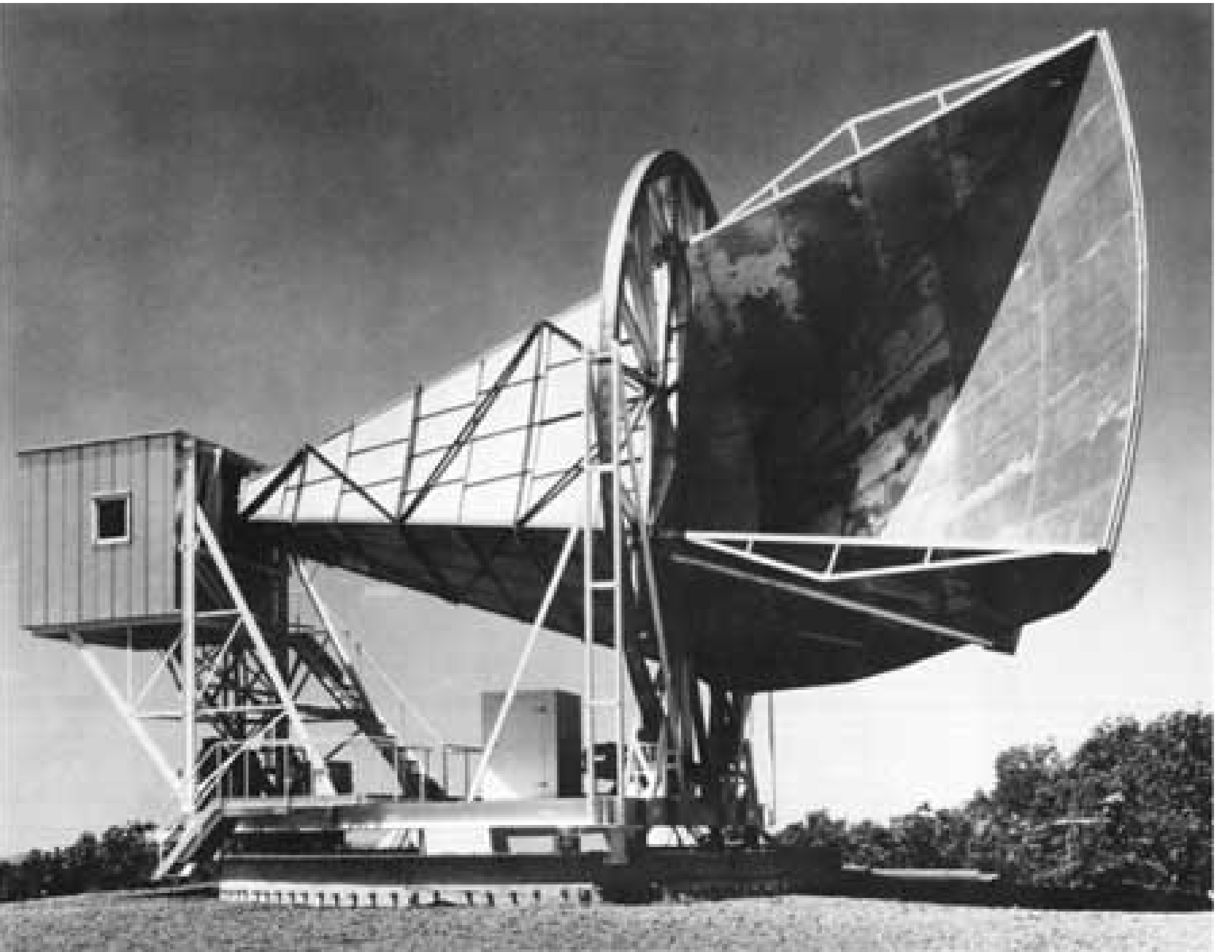
Not testing for systematics (control)

Ignoring sample selection effects (bias)

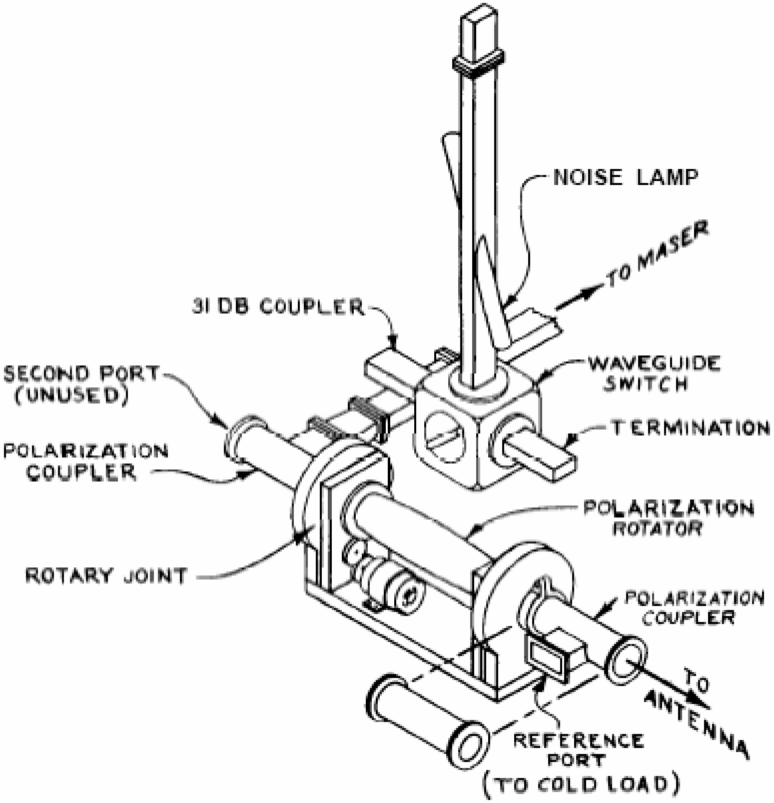
Bad statistics: assume wrong distribution (tails!)

Failure to repeat the experiment using different sample with same physics

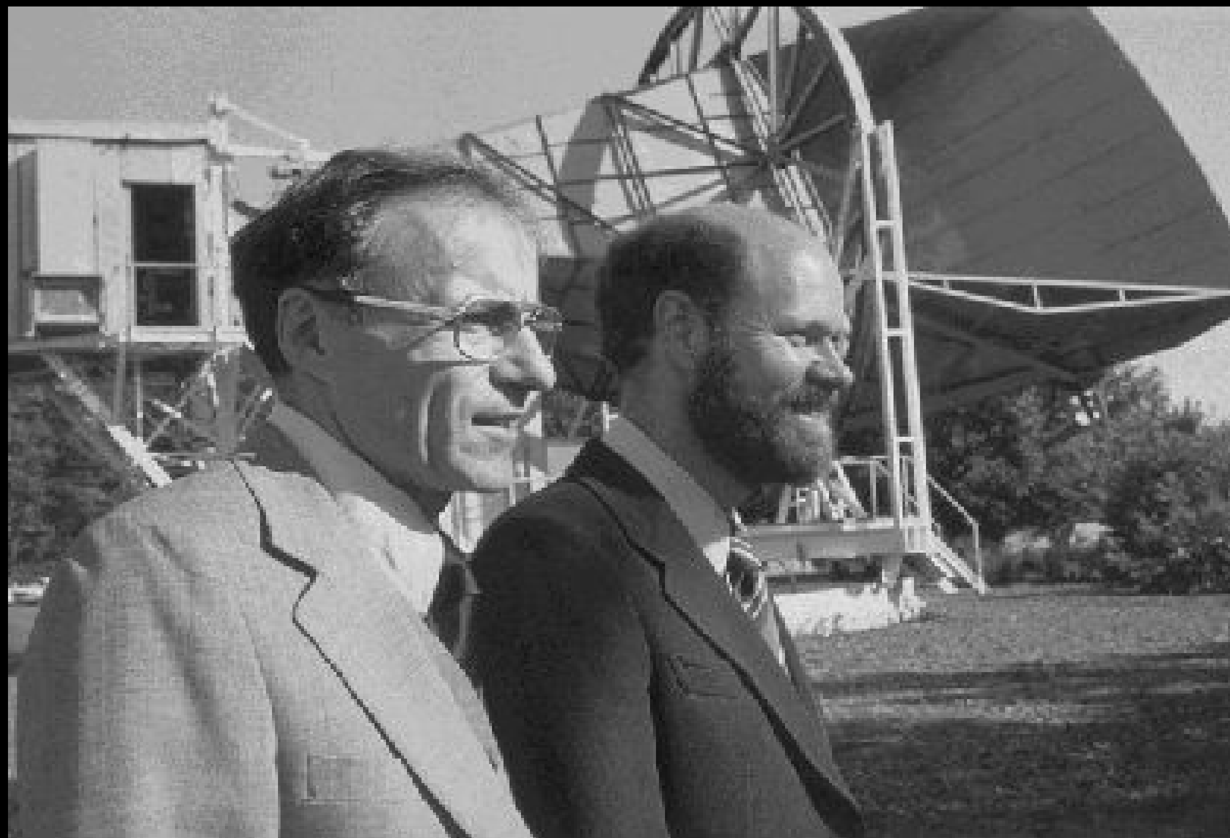
Discovery of the Cosmic Microwave Background



Control systematics.
Chop between sky and a cold load:



Arno Penzias and Bob Wilson



CMB Discovery missed

TABLE II — SOURCES OF SYSTEM TEMPERATURE

Source	Temperature
Sky (at zenith)	2.30 ± 0.20°K
Horn antenna	2.00 ± 1.00°K
Waveguide (counter-clockwise channel)	7.00 ± 0.65°K
Maser assembly	7.00 ± 1.00°K
Converter	0.60 ± 0.15°K
Predicted total system temperature	18.90 ± 3.00°K

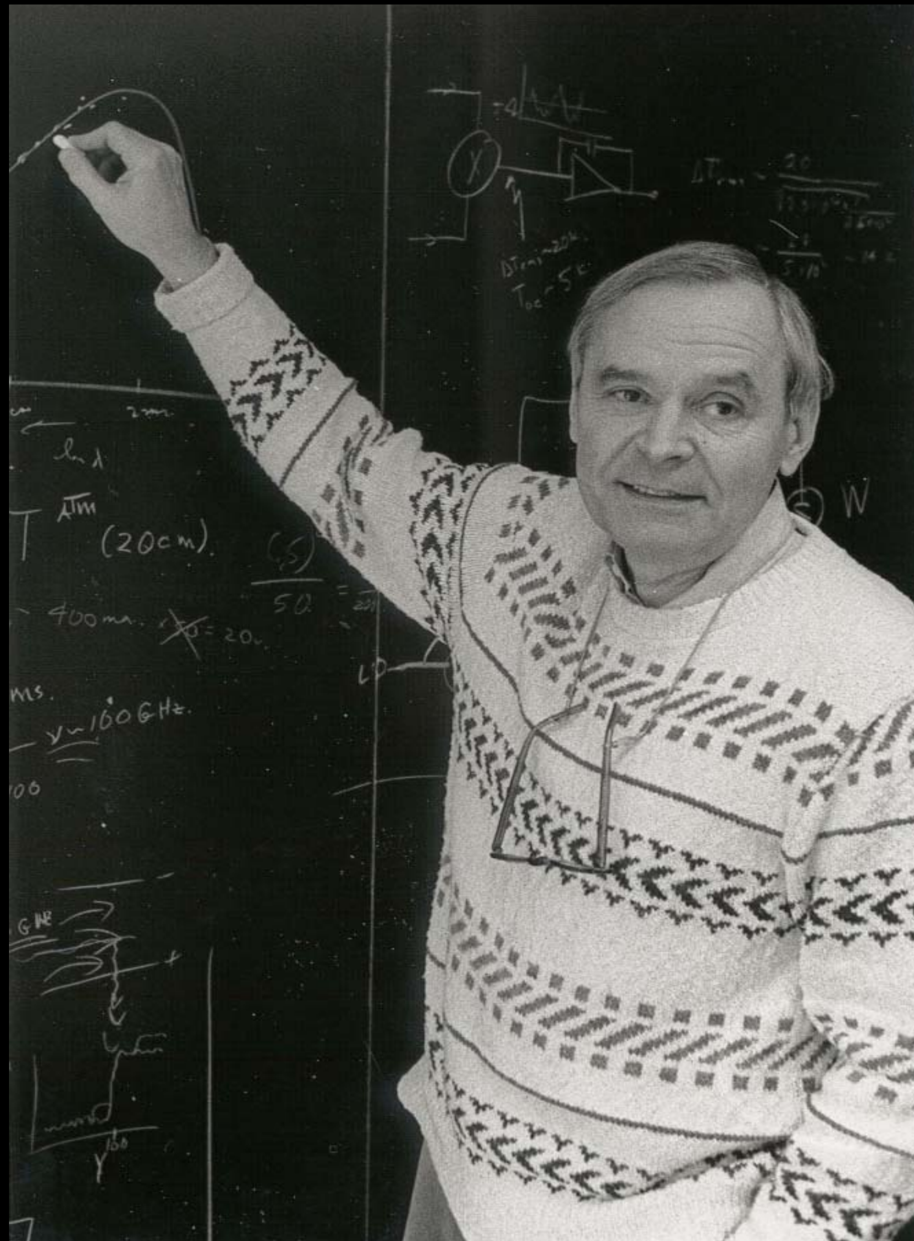
the temperature was found to vary a few degrees from day to day, but the lowest temperature was consistently 22.2 ± 2.2°K. By realistically assuming that all sources were then contributing their fair share (as is also tacitly assumed in Table II) it is possible to improve the over-all accuracy. The actual system temperature must be in the overlap region of the measured results and the total results of Table II, namely between 20 and 21.9°K. The most likely minimum system temperature was therefore

$$T_{system} = 21 \pm 1\text{°K.}^*$$

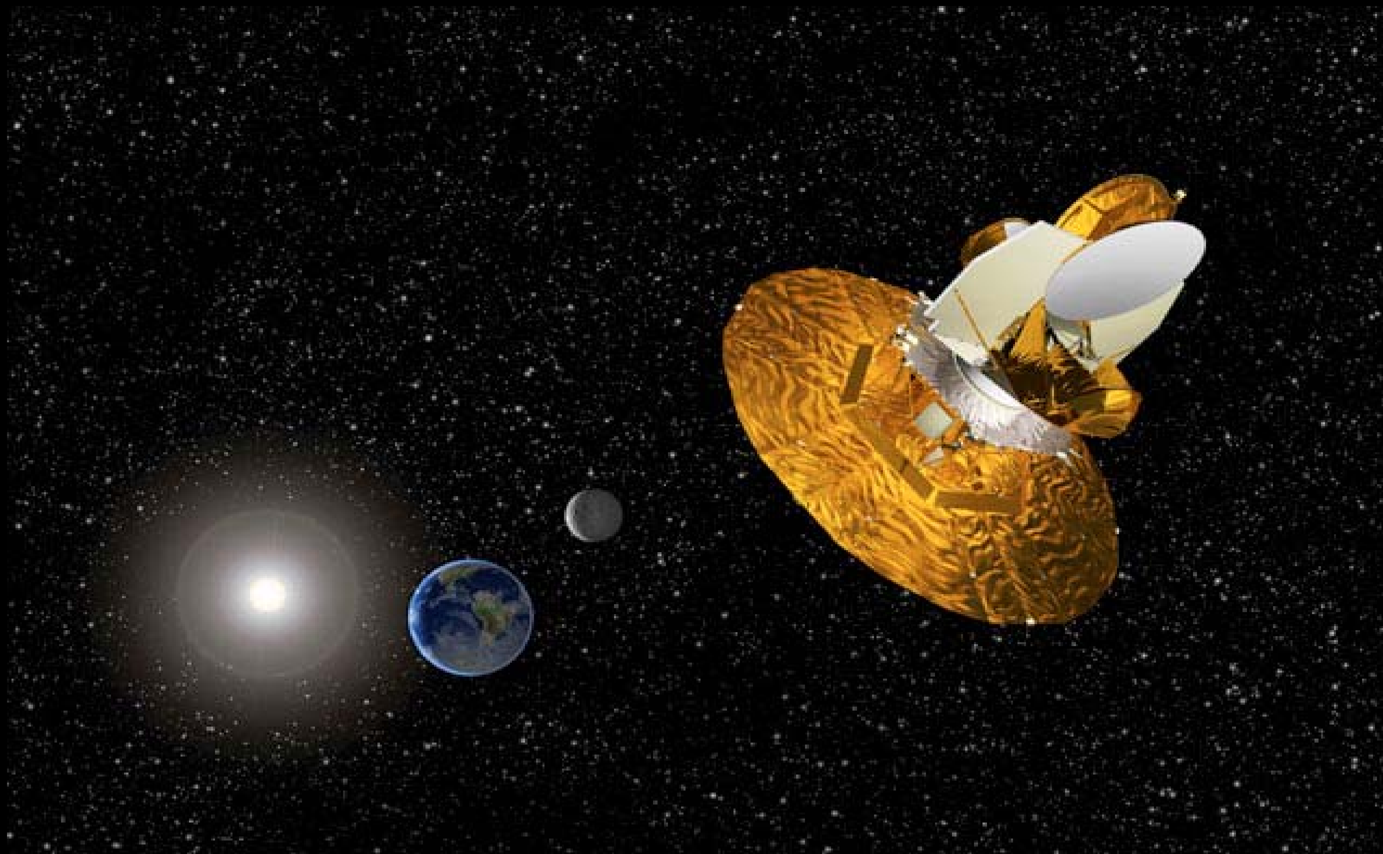
The inference from this result is that the "+" temperature possibilities of Table II must predominate.

Fig. 8 An excerpt from E. A. Ohm's article on the Echo receiver showing that his system temperature was 3.3K higher than predicted

Dave Wilkinson



WMAP satellite



Take risks

Exploration and discovery involves risk-taking

Interplay between theory and observation (experiment)