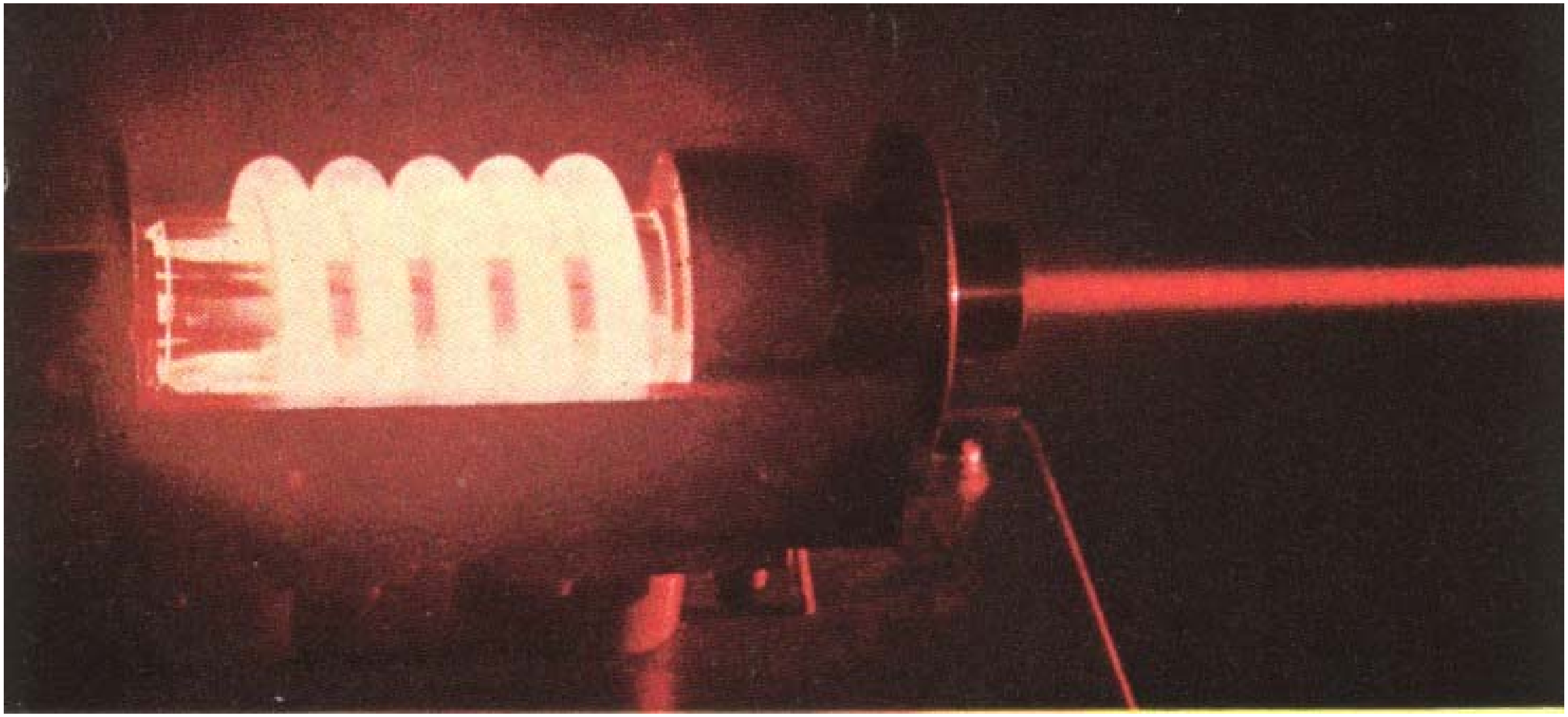
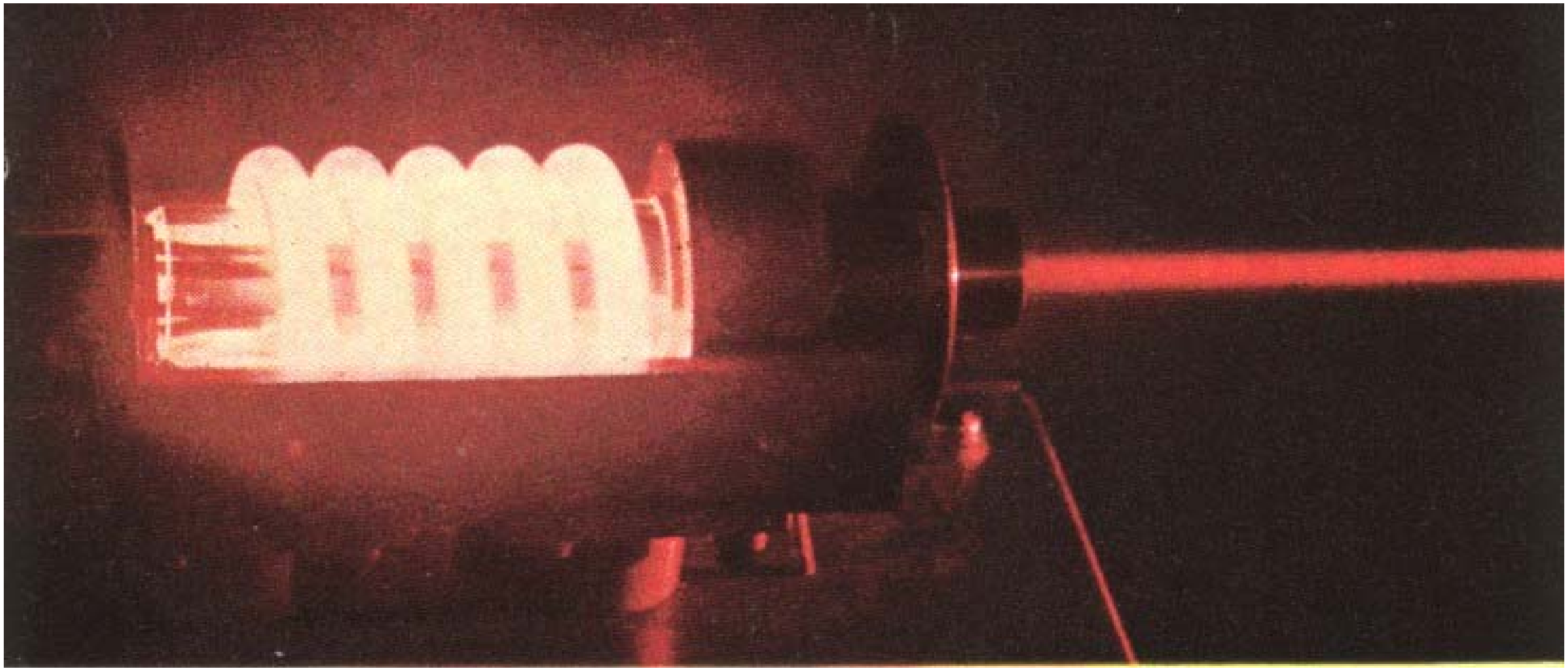
May 17, 1960: Ted Maiman's ruby laser



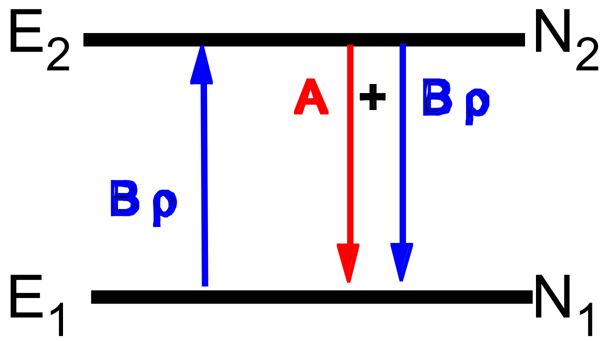
May 17, 1960: Ted Maiman's ruby laser



- Invented by a Stanford EE and Physics graduate
- Working in the Hughes Research Labs, on a hillside overlooking the ocean in Malibu CA

1916: Einstein introduces quantum transitions

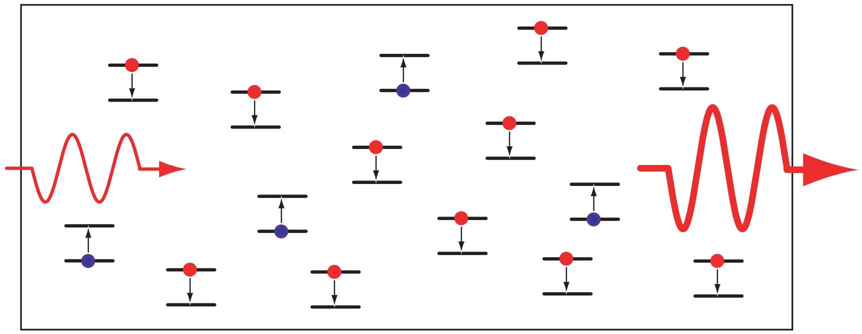
"We introduce the following quantum-theoretical hypothesis. Under the influence of a radiation density … a molecule can make an [upward] transition from state n to state m by absorbing radiation energy … We similarly assume that a [downward]* transition m to n associated with a liberation of radiation energy … is possible under the influence of the radiation field, and that it satisfies the [same] probability law … "



Einstein was mostly thinking about blackbody radiation and thermodynamic considerations. Van Vleck in 1924 was apparently the first to refer to downward stimulated transitions as "stimulated emission".

1924: Richard Tolman hints at amplification

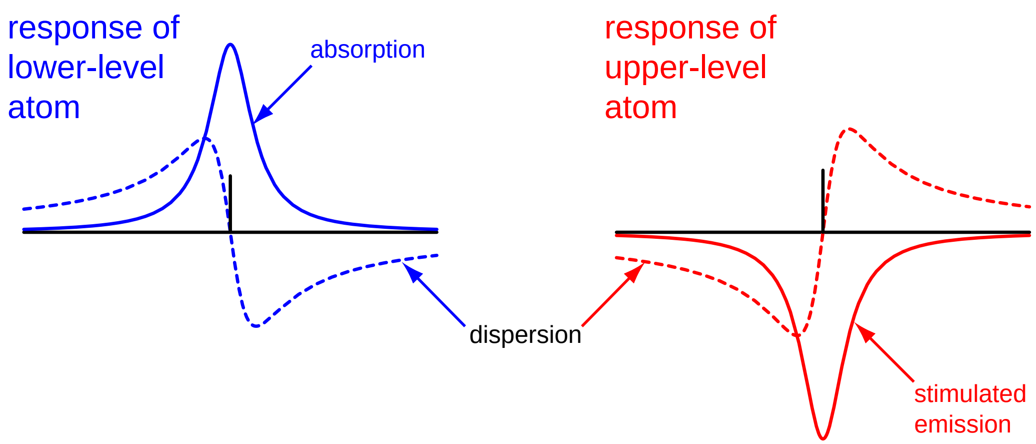
"The possibility arises … that molecules in the upper quantum state may return to the lower quantum state in such a way as to reinforce the primary beam by `negative absorption'."



"The process of negative absorption… from analogy with classical mechanics would presumably be of such a nature as to reinforce the primary beam."   *Phys. Rev.* ***23****, June 1924*. *(First recognition of the possibility of maser/laser amplification?)*

1924: Hendrik Kramers adds negative dispersion

"If the atom is in one of its higher states … the atom will then give rise to a kind of anomalous dispersion … with the sign of [the induced polarization] P reversed."

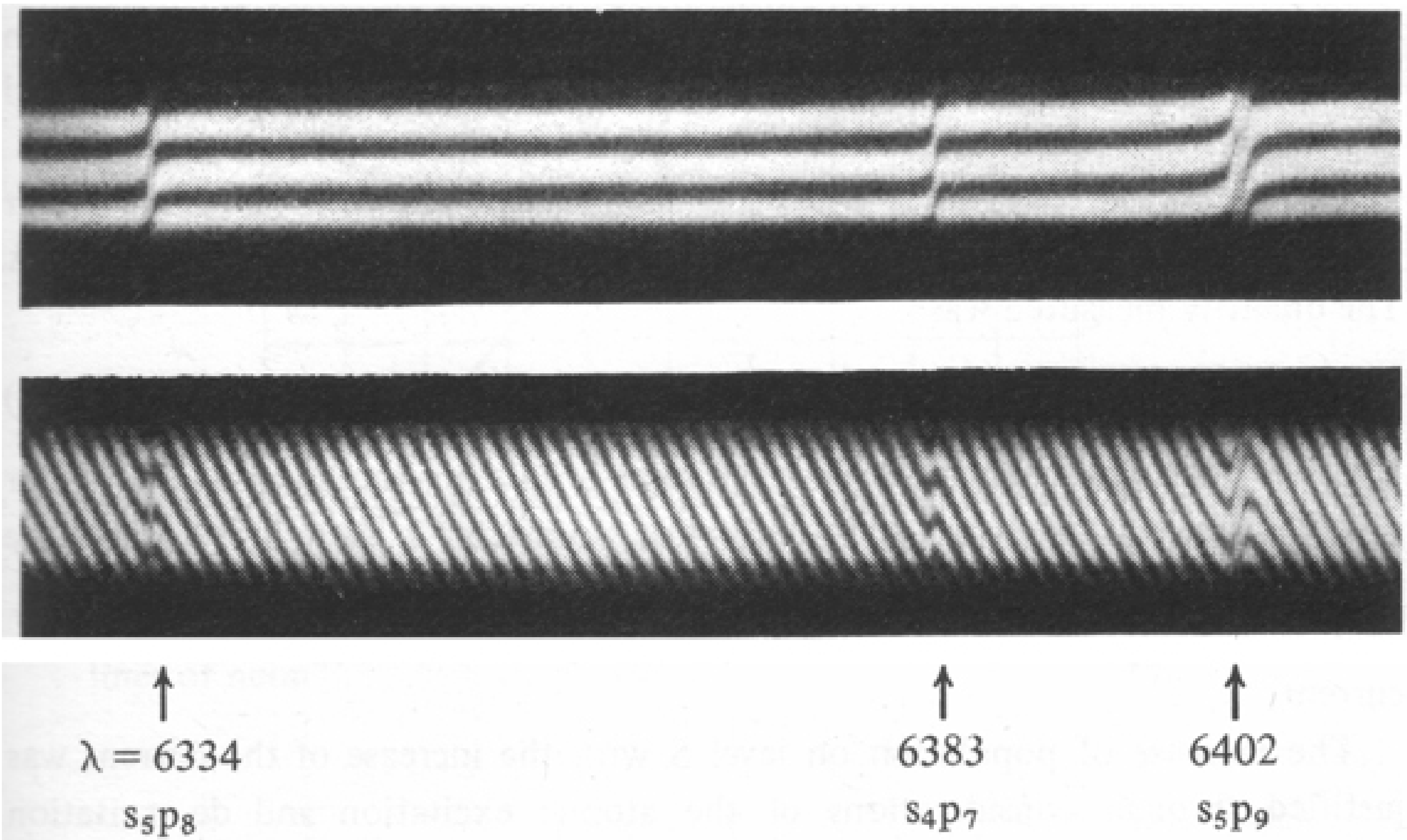


"This so called *negative dispersion* is closely connected with the prediction made by Einstein, that the atom for such a frequency will exhibit a *negative absorption*, I.e. light waves of this frequency, passing through a great number of atoms in the state under consideration, will increase in intensity."

1925–late 1930s: Quantum theory & resonance physics

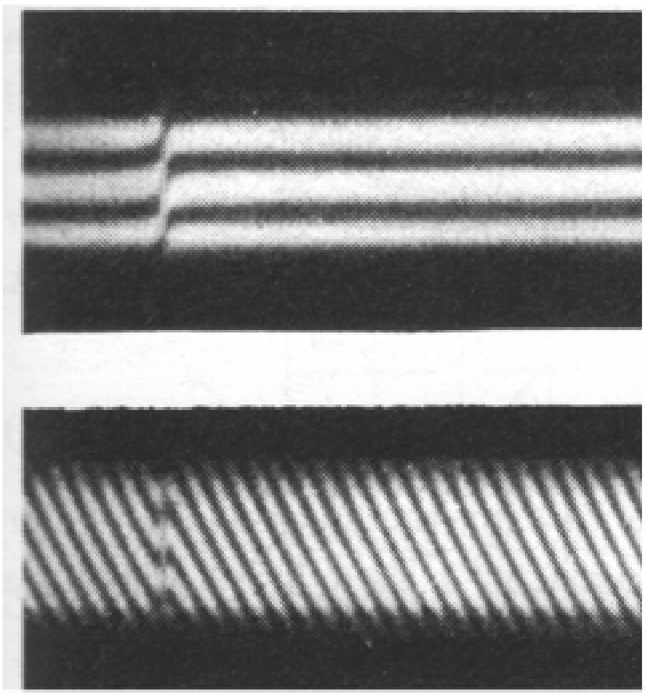
- Quantum mechanics is born
  - Heisenberg matrix mechancis, Schroedinger wave equation 1925
  - Born's probabilistic interpretation, Dirac's operator approach 1926
  - Heisenberg uncertainty principle 1927
- Atomic resonance physics is gradually understood
  - RF modulation of optical transitions: Fermi, Breit, others 1925
  - Magnetic resonance & relaxation theories and experiments: 1932–1939
    Rabi, Majorana, Gorter, Casimir, Waller, Van Vleck, many others
  - Optical pumping: Kastler, Brossel 1949
- RF and microwave tools are developed
  - Microwave waveguides: Southworth (Bell Labs) 1932
  - Microwave cavity: W.W. Hansen 1936
  - Klystron oscillators: Russell & Sigurd Varian 1937
  - Negative-feedback oscillators, signal generators, Hewlett Packard 1938

1933: Ladenburg observes anomalous dispersion



1933: Ladenburg observes anomalous dispersion

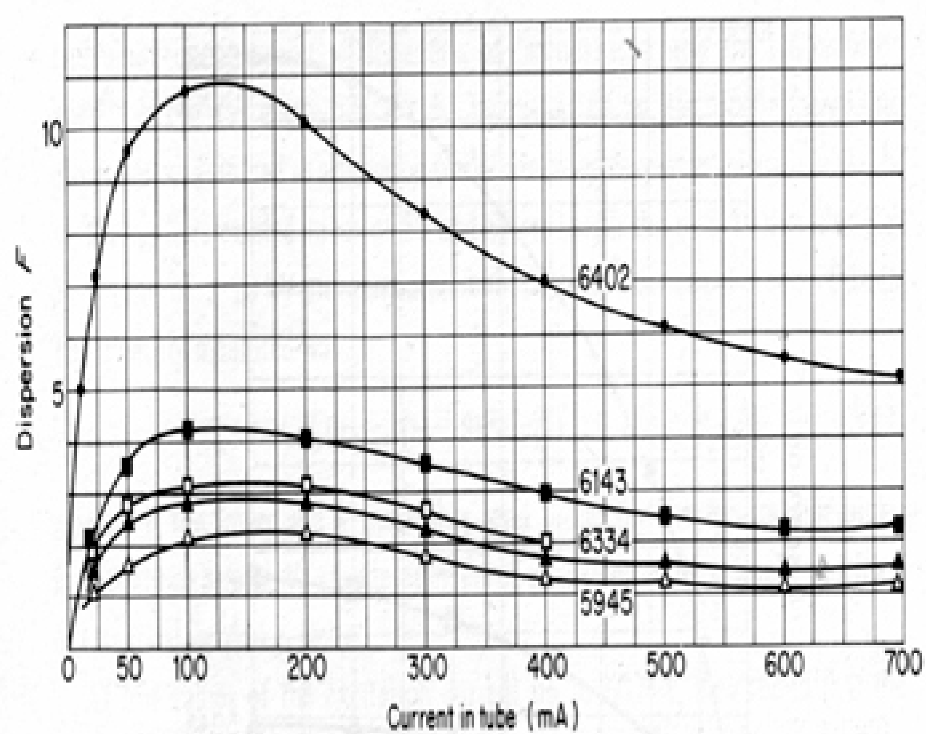
- But <u>not</u> actual inversion



↑

$\lambda = 6334$

s_5p_8



1939-1945: World War II

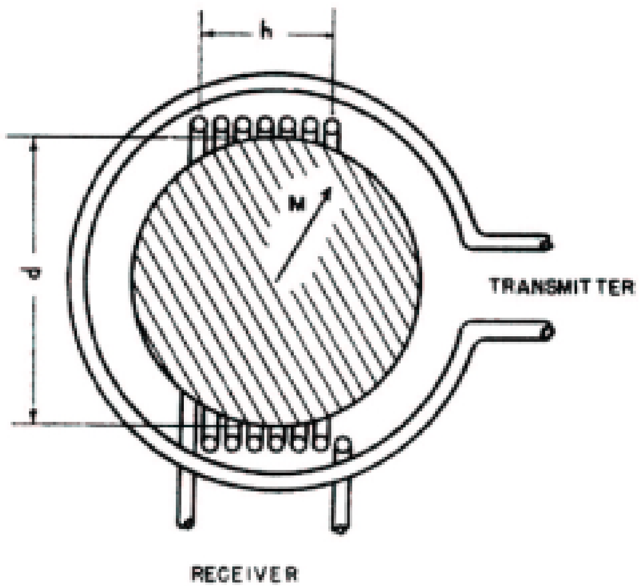
Wartime efforts lead to massive advances in electronics, radio frequency technology, microwaves, signal processing, radar and communications in the U.S., the U.K. and elsewhere.

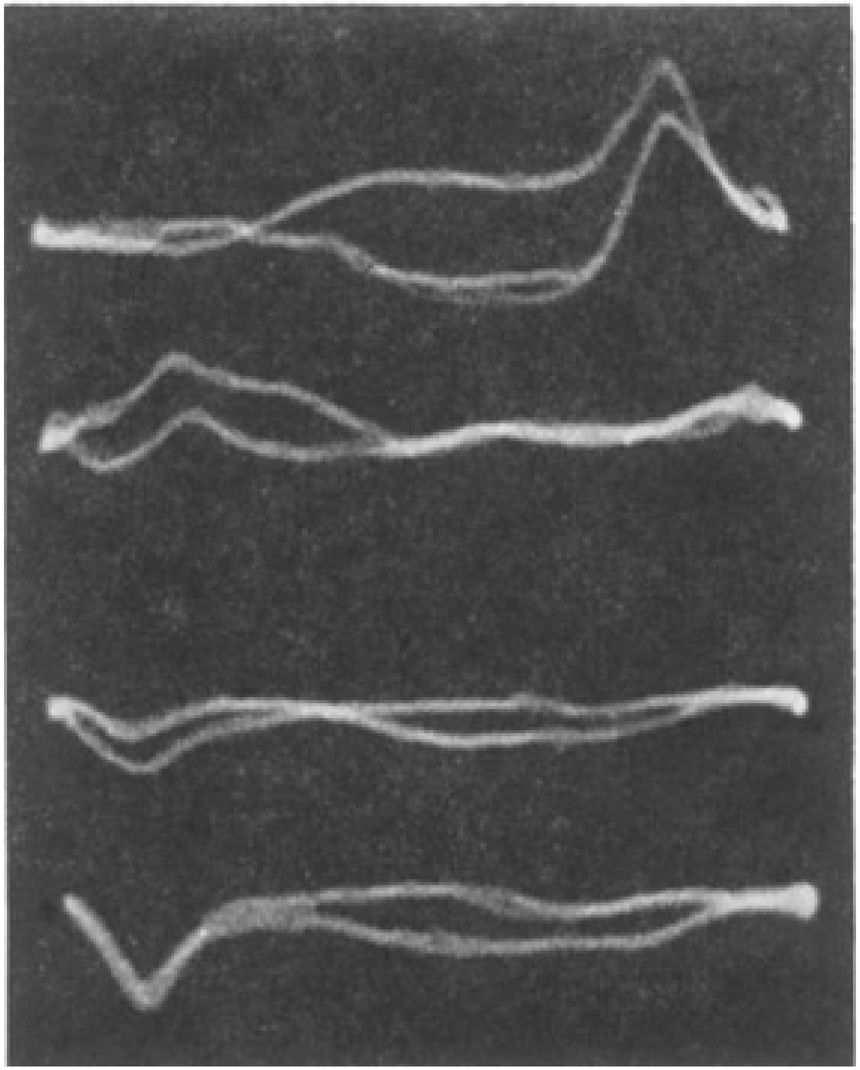
Many academic physicists participate at the MIT Radiation Laboratory (“The Rad Lab Series”), the Harvard Radio Research Lab (directed by F.E. Terman), Bell Labs, and elsewhere.

Wartime experience leads to unprecedented postwar funding of university research in science and engineerin: ONR, ARO, AFOSR are created; Rad Lab and RRL alumni later win a dozen Nobel prizes using their newly acquired tools.

1946: The first man-made population inversion?

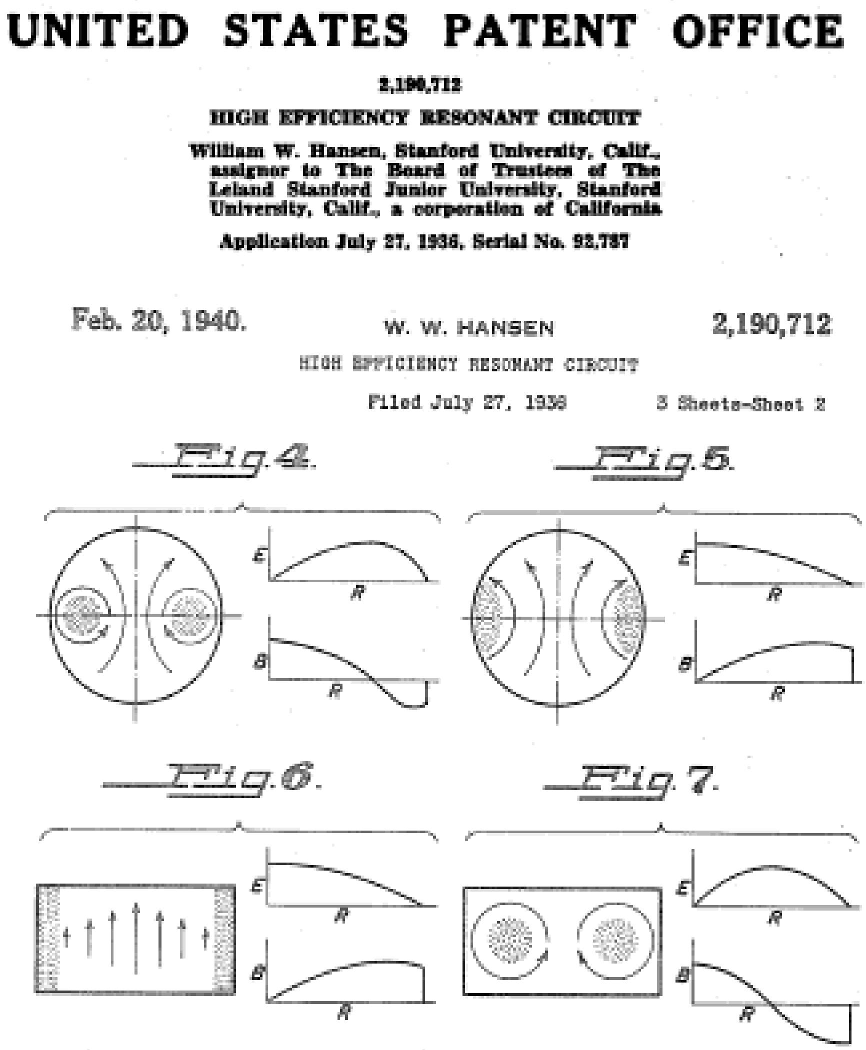
Felix Bloch, W. W. Hansen, Martin Packard: NMR expts in water carried out at Stanford University in July 1946





A bit more on W. W. Hansen:

Invented (and patented) the microwave cavity (1936) **and the linear accelerator (1947)**



UNITED STATES PATENT OFFICE

2,190,712

HIGH EFFICIENCY RESONANT CIRCUIT

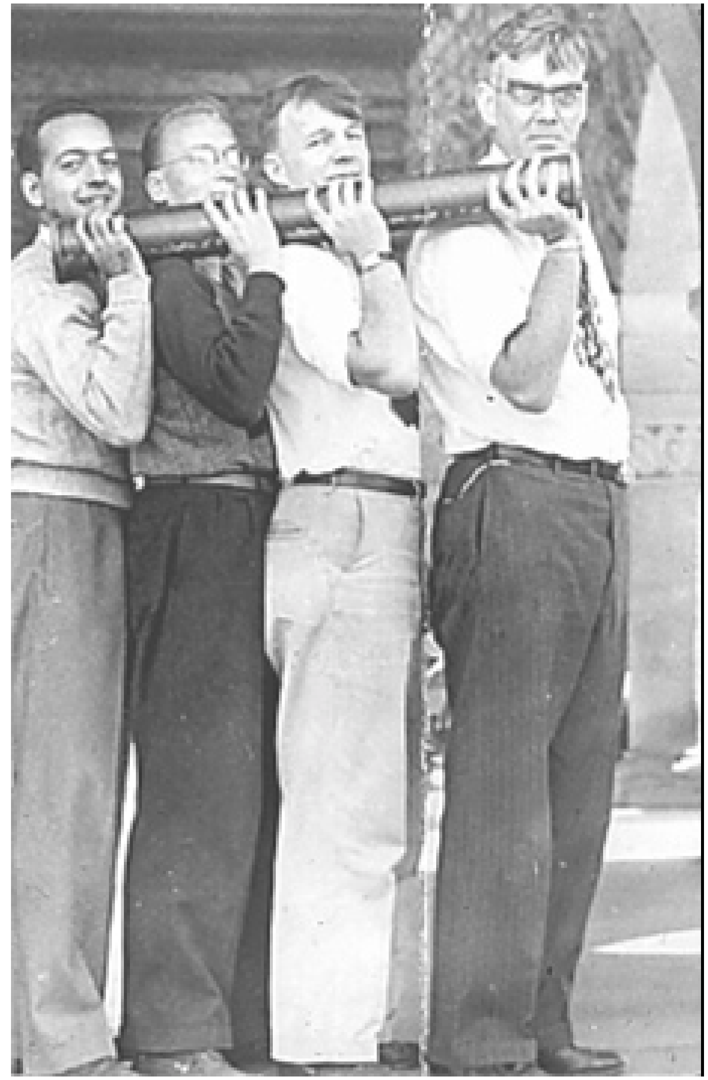
William W. Hansen, Stanford University, Calif., assignor to The Board of Trustees of The Leland Stanford Junior University, Stanford University, Calif., a corporation of California

Application July 27, 1936, Serial No. 92,787

Feb. 20, 1940. W. W. HANSEN 2,190,712

HIGH EFFICIENCY RESONANT CIRCUIT

Filed July 27, 1936 3 Sheets-Sheet 2



1950: Purcell & Pound's dramatic observations

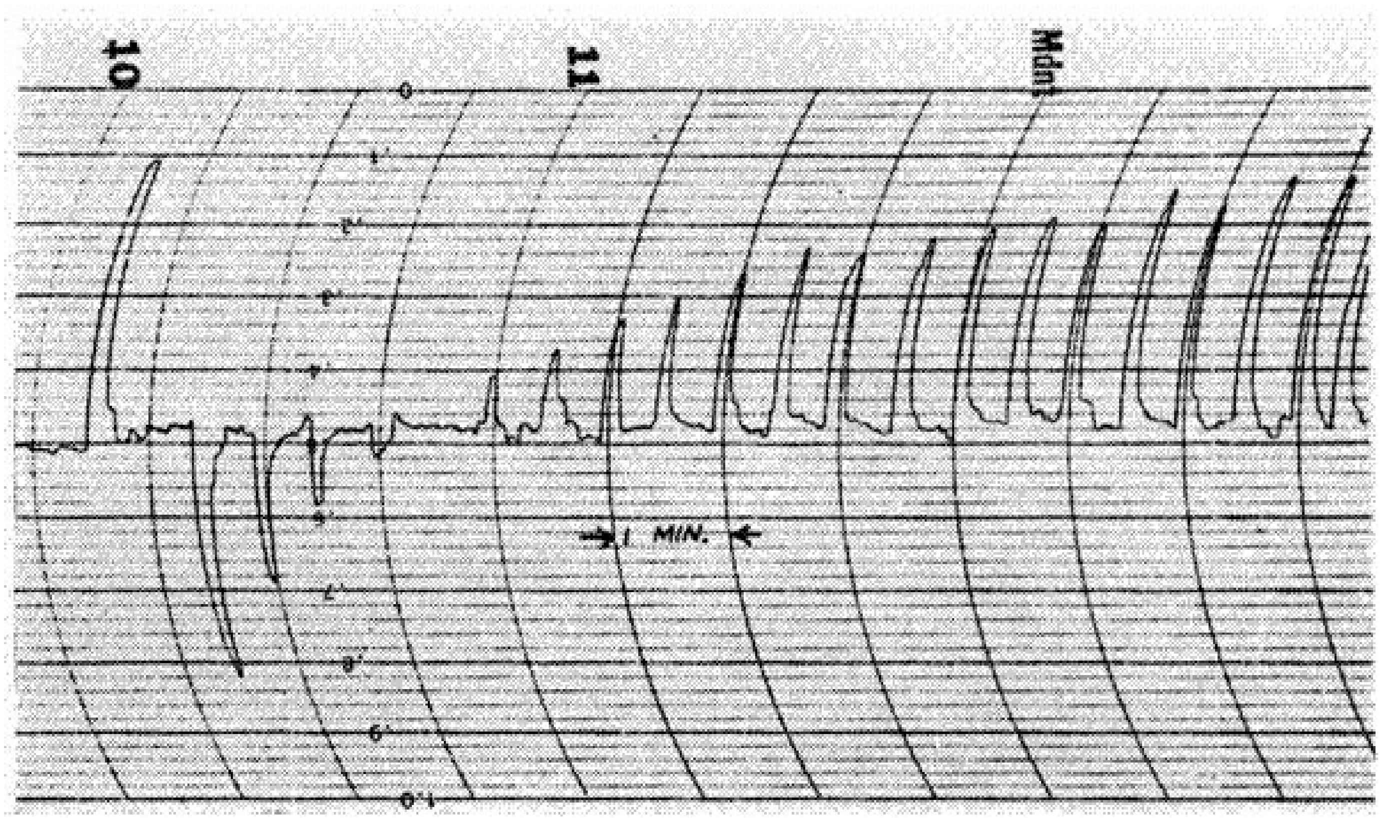
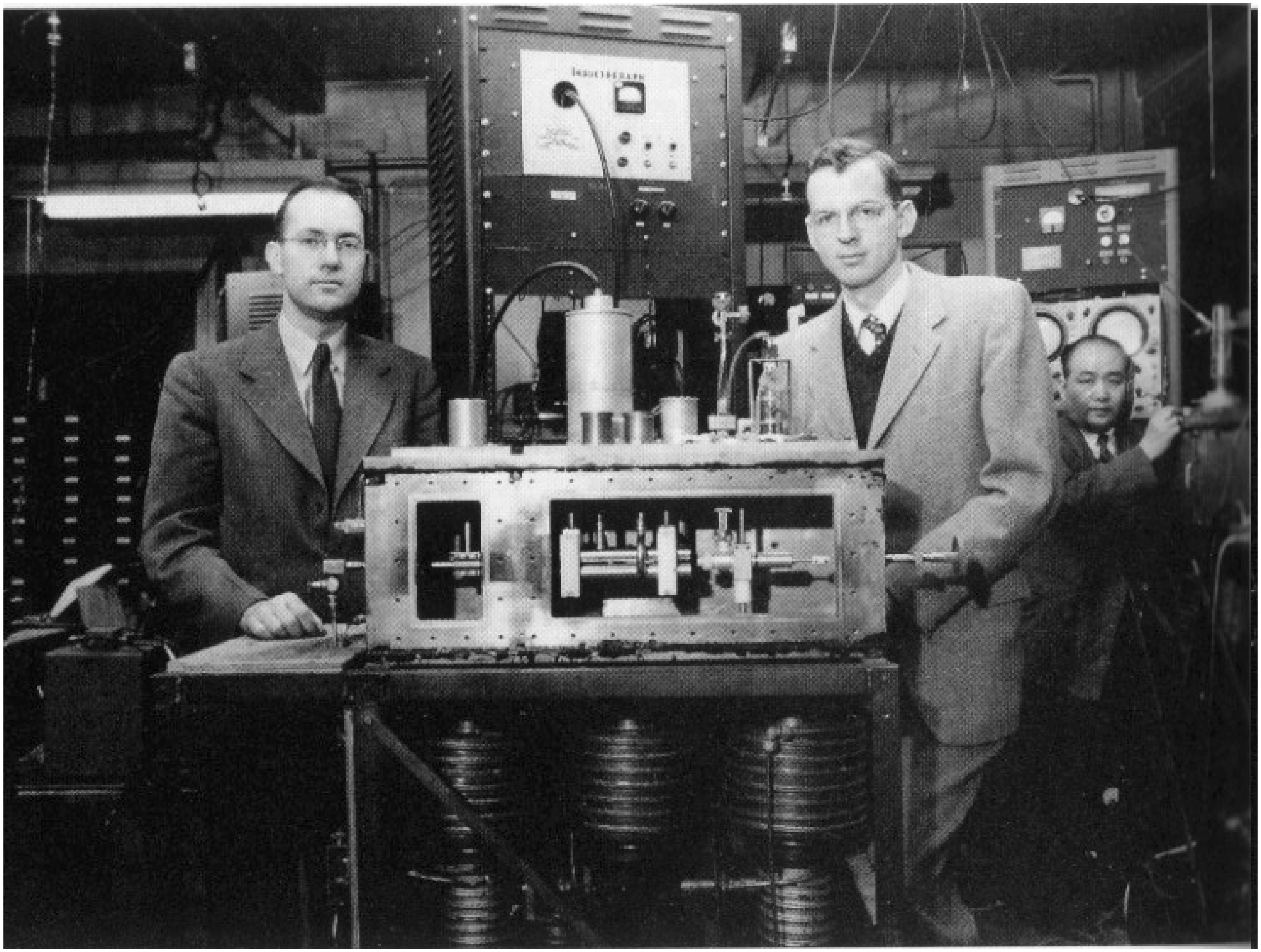


FIG. 1. A typical record of the reversed nuclear magnetization. On the left is a deflection characteristic of the normal state at equilibrium magnetization ($T \approx 300°K$), followed by the reversed deflection ($T \approx -350°K$), decaying ($T \rightarrow -\infty$) through zero deflection ($T = \infty$) to the initial equilibrium state.

1951–1954: The Ammonia Maser

- Townes invents the ammonia beam maser 1951
  - The early morning “park bench” invention
- First successful operation by Gordon, Zeiger & Townes April 1954
  - In Townes’ lab at Columbia University
  - A weak narrowband 22 GHz oscillator / amplifier / atomic clock
  - Townes and students coin the name MASER
  - Basov and Prokhorov achieve similar results in the Soviet Union
- Other maser proposals
  - Joseph Weber’s note on maser amplification 1953
  - Robert Dicke’s maser patent filed 1956, granted 1958
  - Proposals by Combrisson & Townes, M.W.P. Strandberg 1956–1957

1954: Charles Townes and Jim Gordon: the NH3 maser



1956: The Microwave Solid-State Maser

- Proposed by Nico Bloembergen at Harvard 1956
  - Short but definitive article in Physical Review, October 1956
  - Subsequent patent is very far reaching
  - Successful operation a few months later at Bell Labs
- <u>Many</u> immediate extensions & implementations 1958–1964
  - Traveling-wave masers; ruby as a microwave maser material; phonon (acoustic) masers; application to radio & radar astronomy; Echo satellite experiments; space communications & planetary radars; Penzias & Wilson's Nobel Prize…

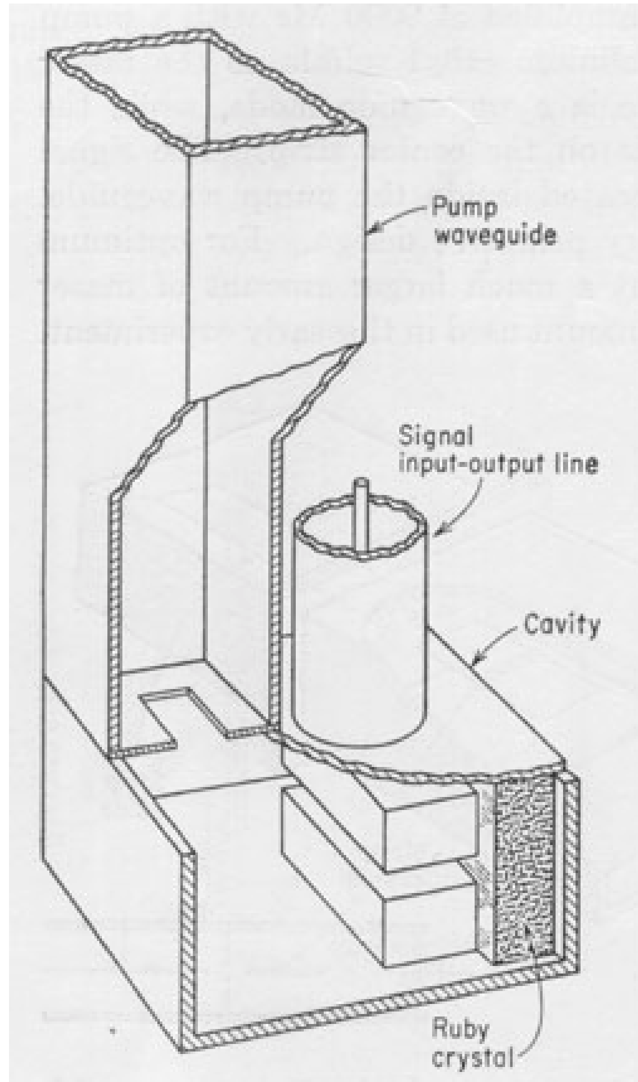
1957: Cavity-type ruby maser

X-band (10 Ghz) waveguide pump cavity

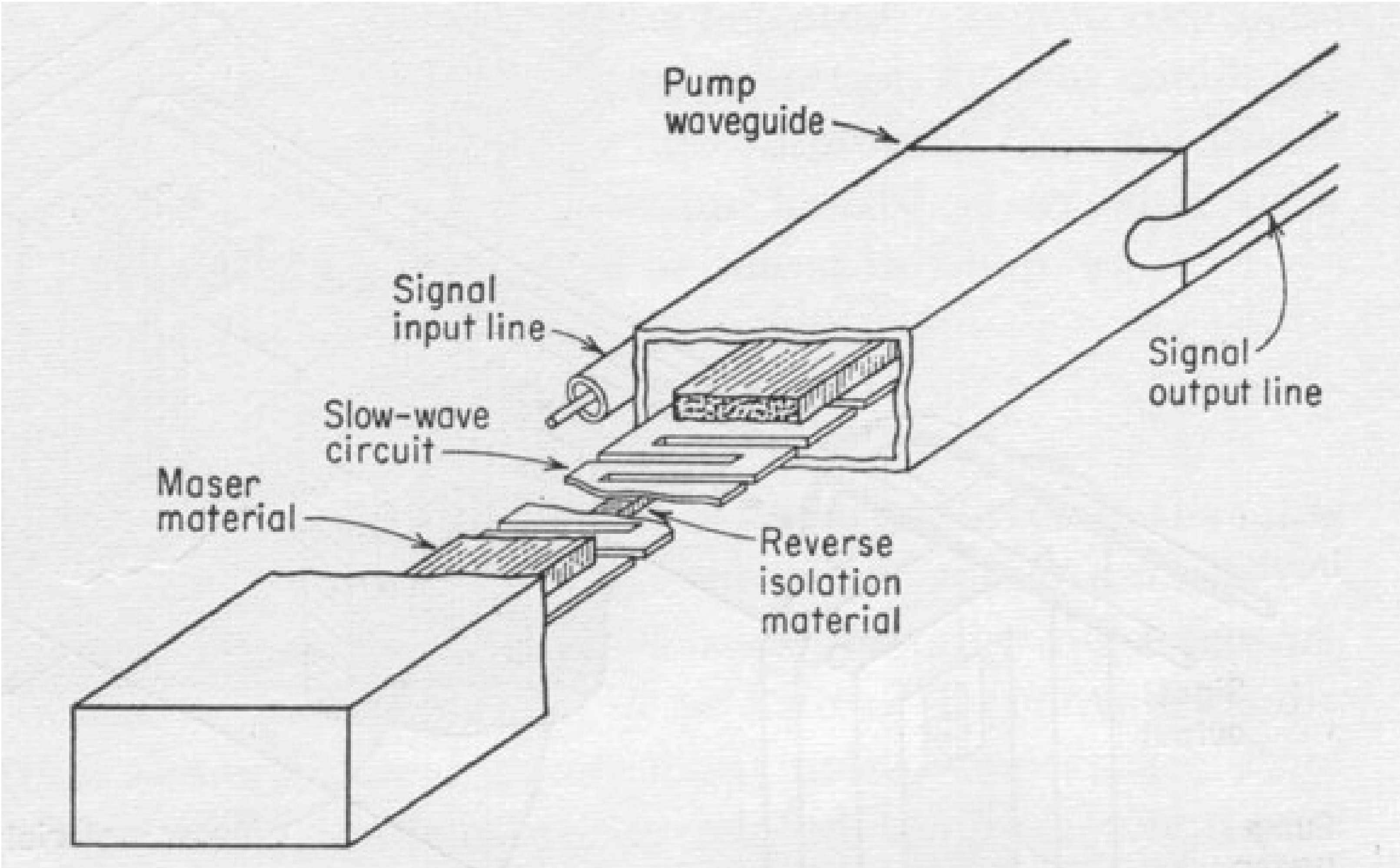
S-band (3 GHz) rectangular stripline resonance mode

Operated at liquid helium temperature, dc magnetic field of a few thousand gauss

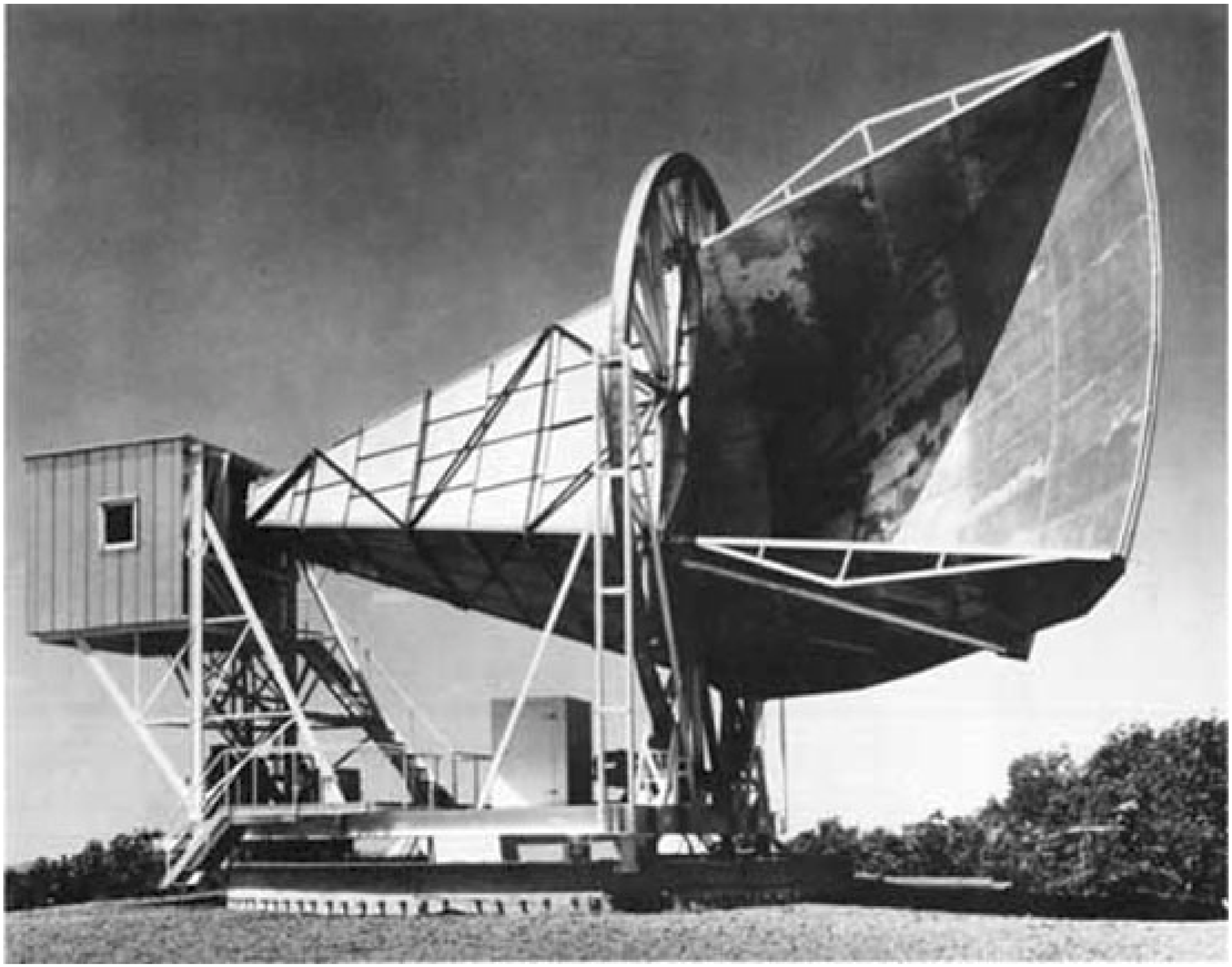
Very-low-noise microwave amplifier (few MHz bandwidth)



1958: Traveling-wave microwave maser

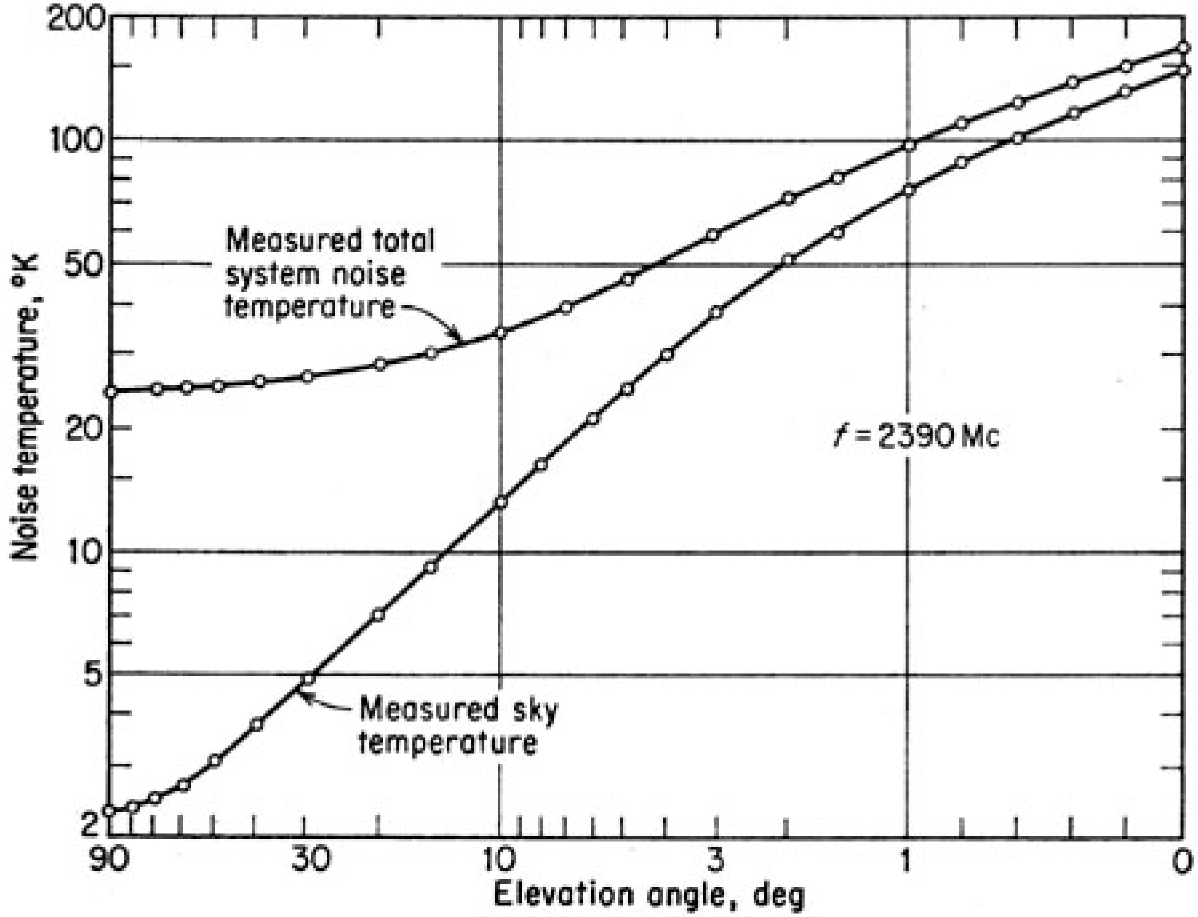


Late 1950s: Bell Labs Sugar-scoop antenna



Late 1950s: A Nobel prize for measuring noise

- Maser receiving system noise temperature



Late 1950s: Evolving toward the laser . . .

- Schawlow & Townes' proposals 1957–1958
  - *Detailed analysis of laser theory and requirements*
  - *Published as lengthy Phys Rev paper in Dec 1958*
  - *Stimulated much interest among other workers*
- The First QE Conference (Shawanga Lodge) Sept 1959
  - *Organized by Townes, published by Columbia*
  - *Brought together all the active people in the field*
- Gordon Gould & his ideas Late 1957
  - *The notebook, the candy store notary,*
    and the Thirty-Year Patent Wars

1959: The First Quantum Electronics Conference

- *Program Committee meeting*

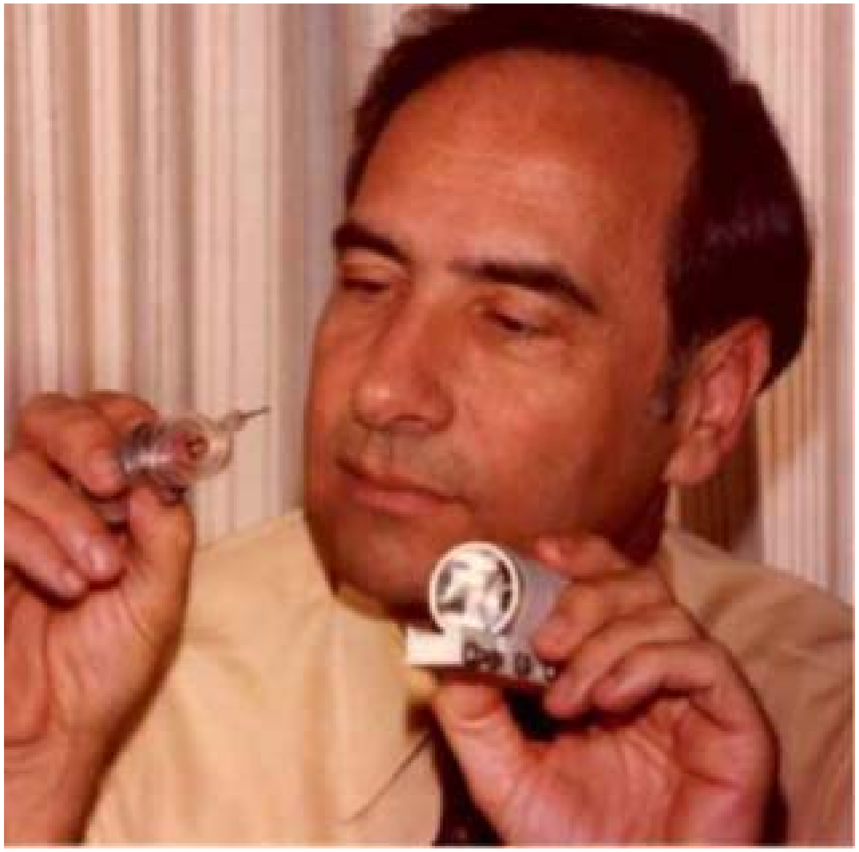
1959: First Quantum Electronics Conference

- *Three future Nobel Laureates meet at Shawanga Lodge, September 1959*

1960: The Laser Era opens . . .

- The ruby laser (6943 A)
  - Maiman, Asawa and D'Haenens, Hughes Res Labs May 1960
  - Immediately reproduced by numerous laboratories
- Trivalent uranium in cooled CaF2 (2.5 µm)
  - *Sorokin and Stevenson, IBM Res Labs mid–1960*
  - *First four-level solid-state laser*
- Divalent samarium in CaF2 (7085 A)
  - *Also Sorokin and Stevenson, IBM ~Nov 1960*
- First He-Ne gas laser (1.15 µm)
  - *Javan, Bennett & Herriott, Bell Labs ~Dec 1960*
  - *RF excitation, "collisions of the second kind"*

Ted Maiman and his “stubby ruby”



First ruby laser, disassembled

1961–1962: The laser field explodes

• *Nd: glass laser*	*Snitzer 1961*
• *Laser Q-switching*	*Hellwarth 1961*
• *Optical harmonic generation*	*Franken 1961*
• *Optical fiber lasers*	*Snitzer 1961*
• *He-Ne 6328A visible laser*	*White & Rigden 1962*
• *Other gas lasers*	*Patel, Bennett, Faust 1962*
• *Raman laser action*	*Woodbury & Ng 1962*
• *GaAs diode lasers*	*GE, IBM, Lincoln Labs 1962*

Arthur Schawlow puts the laser to use

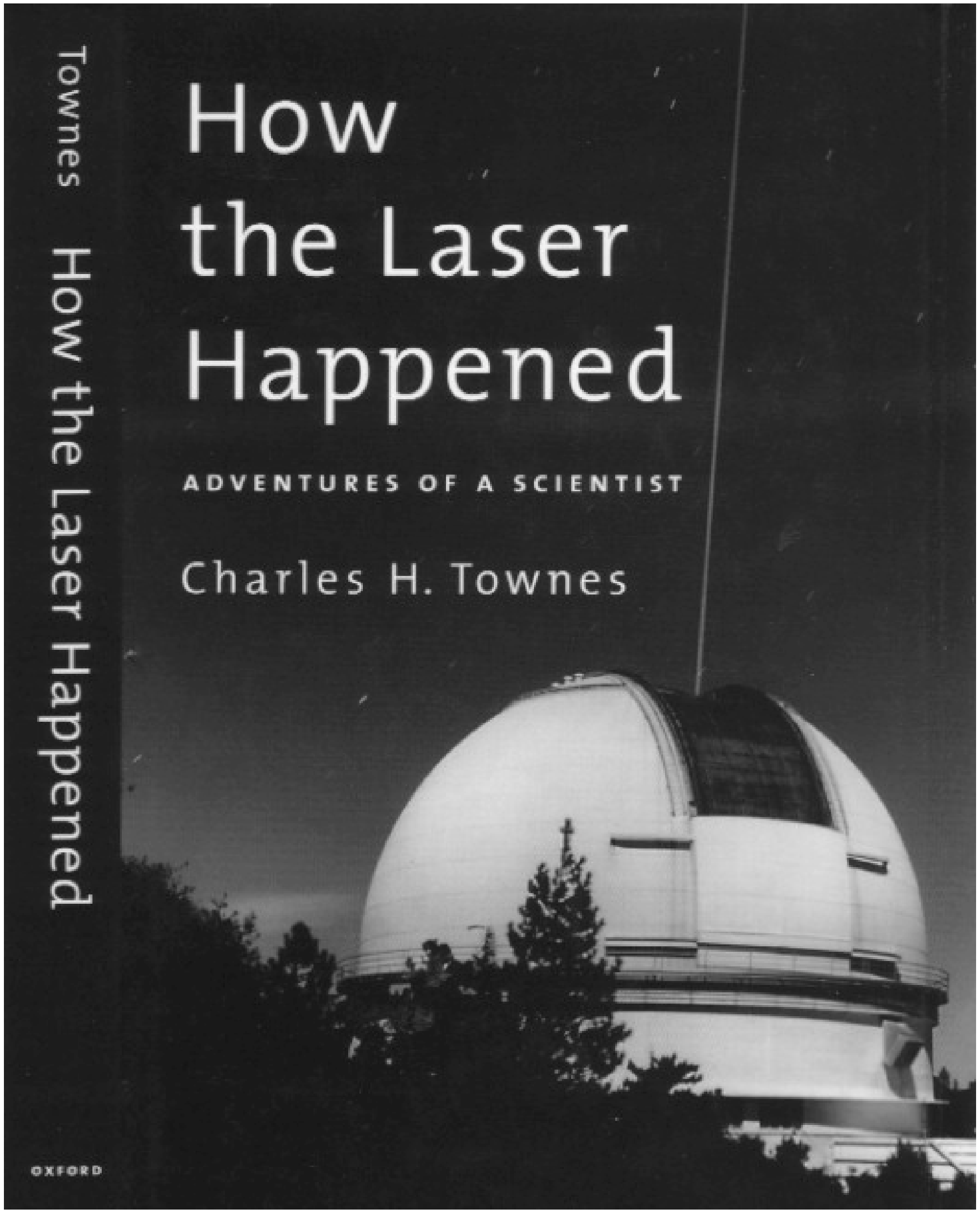
1961: First laser medical treatments

"In December 1961 the Columbia-Presbyterian Hospital used a laser on a human patient for the first time, destroying a retinal tumor with the American Optical [ruby laser] photocoagulator."

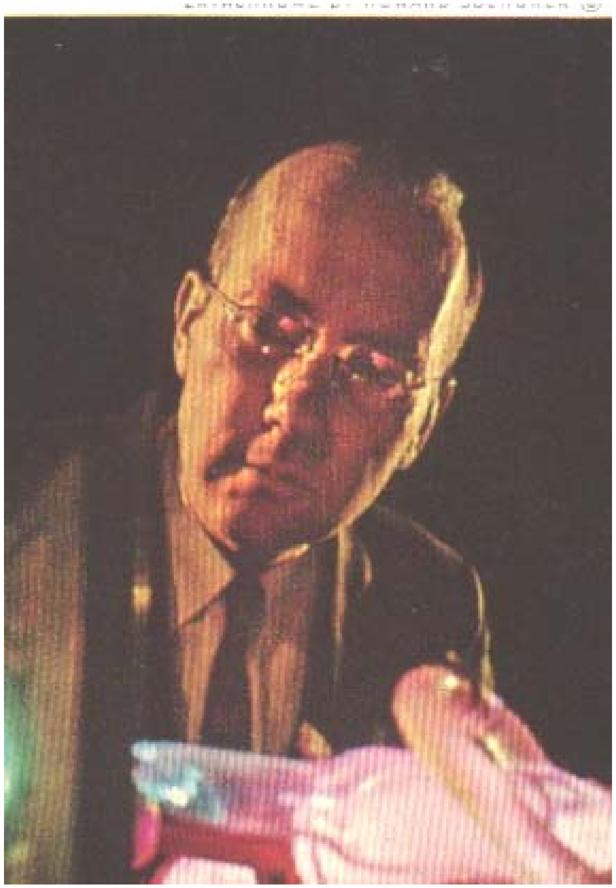
Joan Lisa Bromberg
The Laser in America, 1950—1979
Laser History Project / MIT Press, 1991

1963–1966: The immensely rapid evolution continues

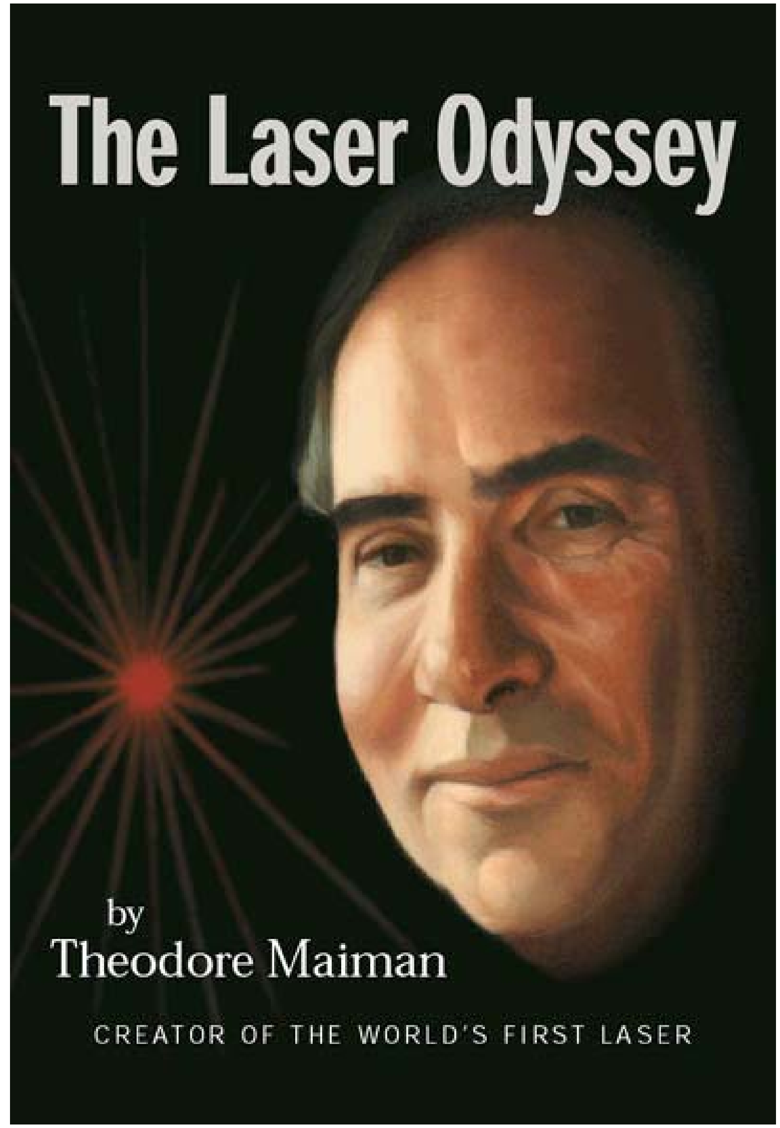
• *Liquid lasers*	*Lempicki & Samelson 1963*
• *Laser mode locking*	*Various groups 1963*
• *CO2 laser*	*Kumar Patel 1964*
• *Nd:YAG laser*	*Joe Geusic et al 1964*
• *Ion lasers*	*Bill Bridges, Gene Gordon 1964*
• *Iodine photodissociation laser*	*Kasper & Pimentel 1964*
• *HCl chemical laser*	*Kasper & Pimentel 1965*
• *Organic dye lasers*	*Peter Sorokin, Fritz Schaefer 1966*



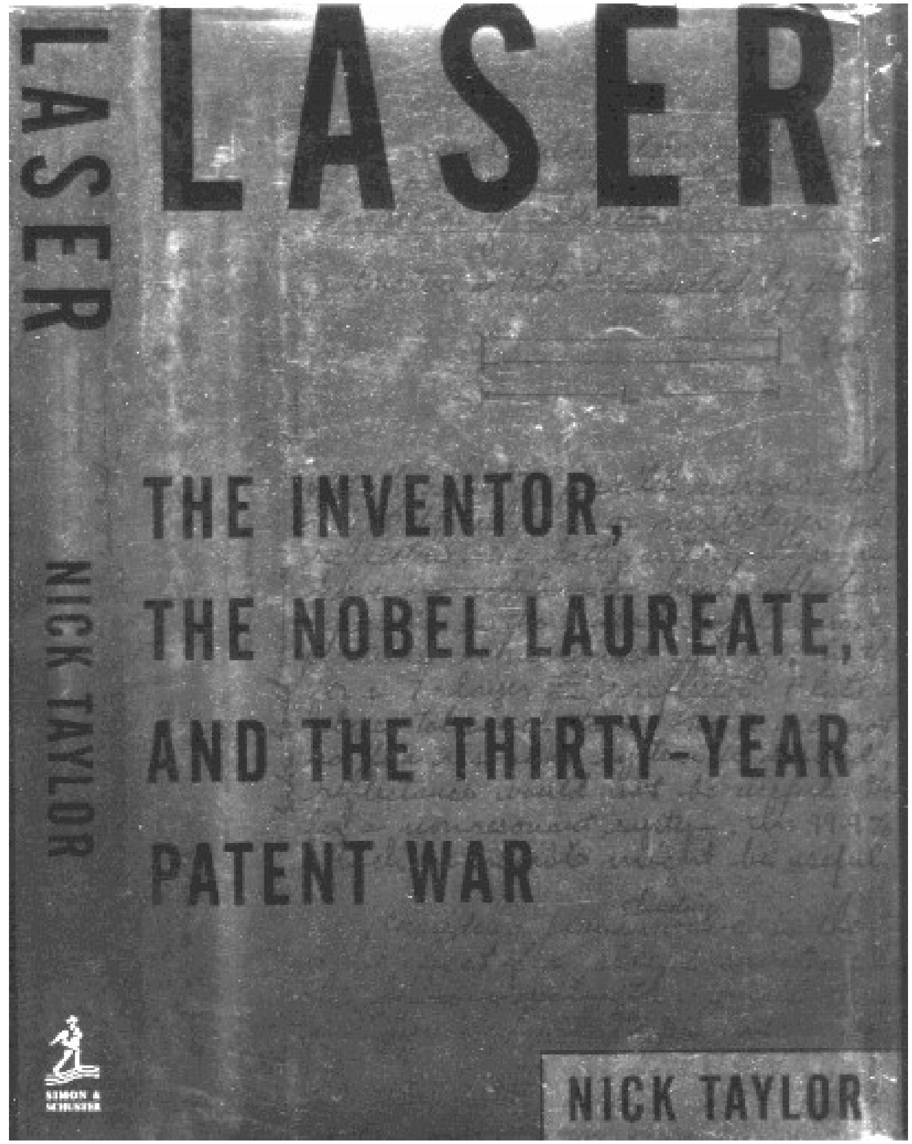
Charles Townes, *How the Laser Happened: Adventures of a Scientist (1999)*



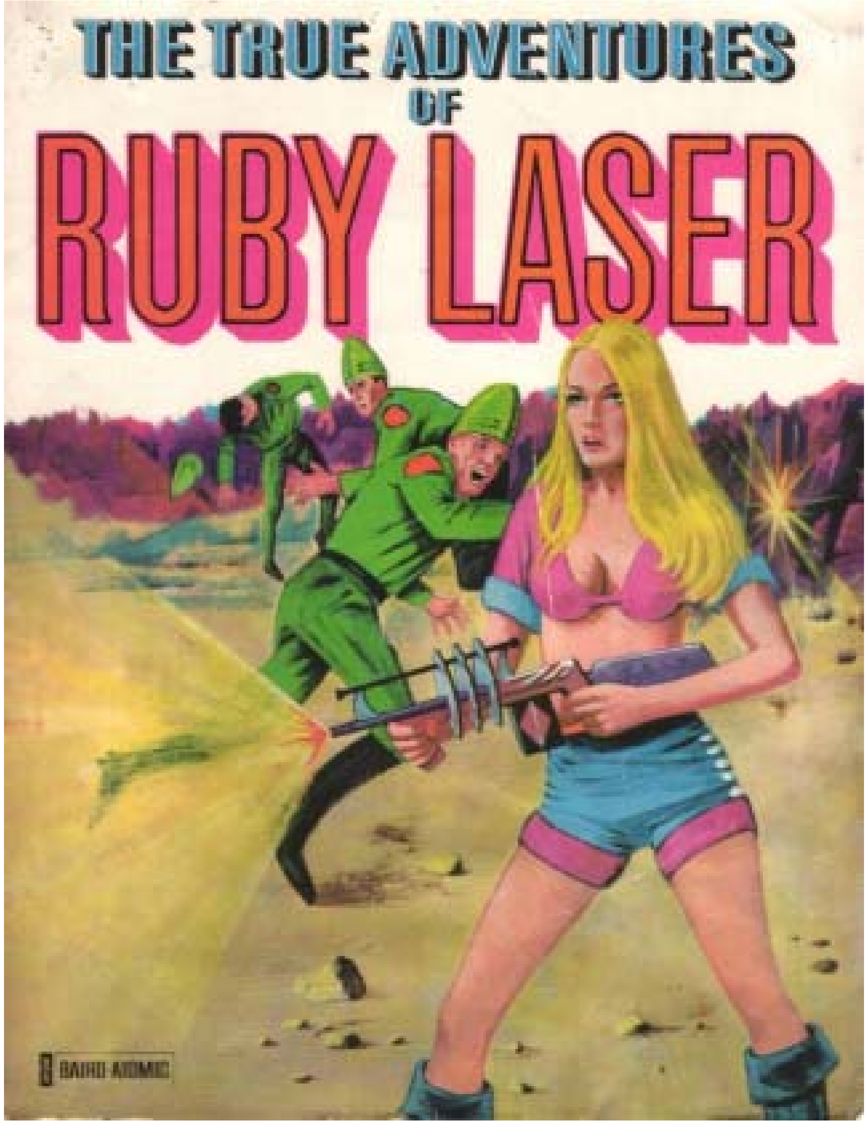
Theodore Maiman, *The Laser Odyssey (2000)*



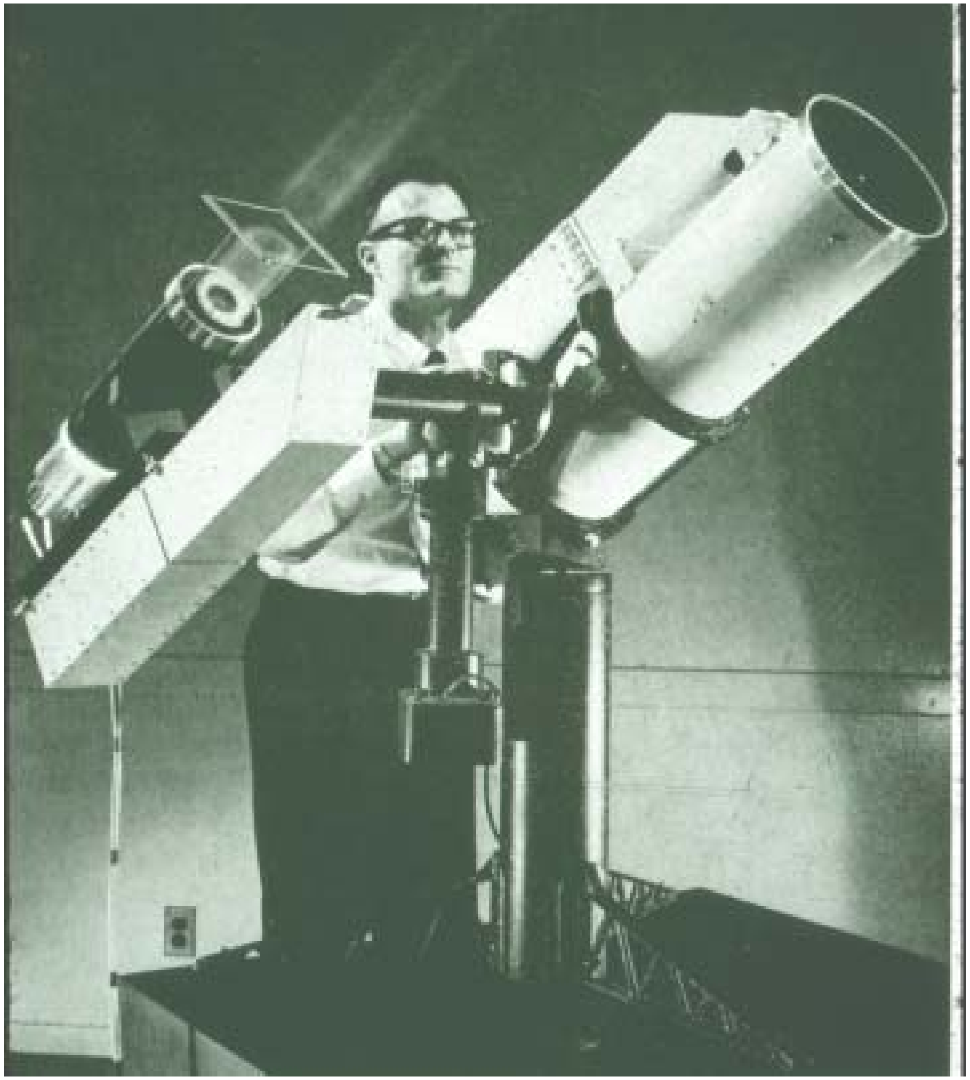
LASER: The Inventor, the Nobel Laureate, and the Thirty Year Patent War (biography of Gould by Nick Taylor; 2000)



Who was the real Ruby Laser?



What was Mal Stitch's <u>real</u> claim to fame?



How can you make a really low-cost laser?

- $300 HeNe laser from University Laboratories, Berkeley CA, mid–1960s

By really saving on parts costs . . .

What are lasers really good for?

(In the early days you were still allowed to smoke in your lab…)

Special thanks to

- Mario Bertolotti, author of *Masers and Lasers* (Adam Hilger, 1983), for his outstanding book on the intellectual history of masers & lasers
- Joan Bromberg, *The Laser in America, 1950–1979* (Laser History Project / MIT Press, 1991)
- Mother Nature, who was operating masers and lasers long before we humans discovered them

Mother Nature's natural masers & lasers

- Astrophysical masers (1965)
  - *Molecular maser action in interstellar hydrogen clouds*
  - *Pumped by UV radiation from nearby stars*
  - *OH (1670 MHz), H20 (2.2 GHz), SiO2 (4.3–13 GHz)*
  - *Brightness temperatures* $\geq 10^{15}$ *K; immense power outputs*
- CO2 lasers in planetary atmospheres (1976)
  - *10 µm amplification in atmospheres of Mars and Venus*
  - *Directly pumped by sunlight; low gains*
- Hydrogen recombination masers (1994–1996)
  - *Hydrogen clouds near MWC 349A & other stars (?)*
  - *ASE at 850 µm, 450 µm, 169 µm, 89 µm, 52.5 µm*