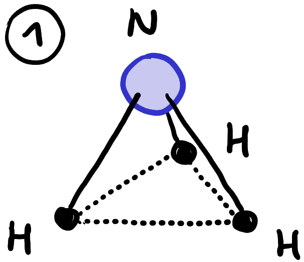
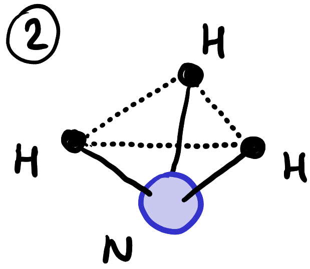
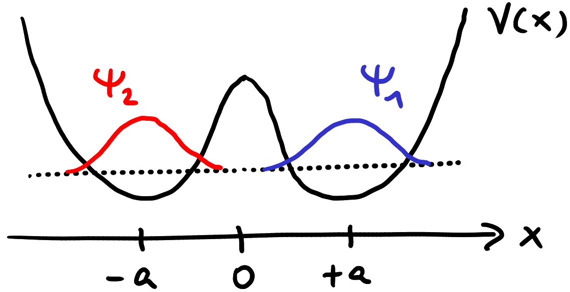
Amoniakový maser - dvouhladinový model







- pohyb částice s redukovanou hmotností $m = \frac{3m_H m_N}{3m_H + m_N}$ v potenciálu $V(x) \approx \lambda (x^2 - a^2)^2$

• 2D Hilbertův prostor $\mathcal{H}$ vlnová funkce $\psi_1(x) \leftrightarrow$ stav z $\mathcal{H}$ $|1\rangle$

$\psi_2(x) \leftrightarrow$ $|2\rangle$

ortonormální báze $|1\rangle, |2\rangle$ – zanedbáme překryv $\langle 1|2\rangle = \int_{-\infty}^{\infty} \psi_1^*(x)\, \psi_2(x)\, dx \approx 0$

→ obecný stav systému $|\psi\rangle = c_1 |1\rangle + c_2 |2\rangle$ $\quad |c_1|^2 + |c_2|^2 = 1$

$P(\text{nalezení } N \text{ v jámě } 1) = |\langle 1|\psi\rangle|^2 = |c_1|^2 = P_1$

$P(\text{nalezení } N \text{ v jámě } 2) = |\langle 2|\psi\rangle|^2 = |c_2|^2 = P_2$

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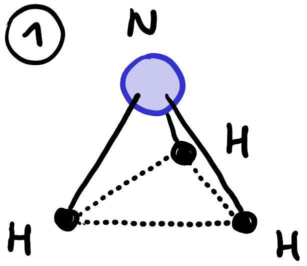
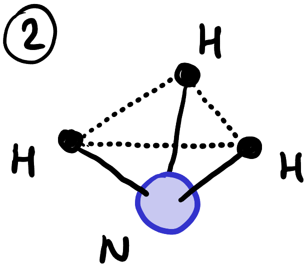
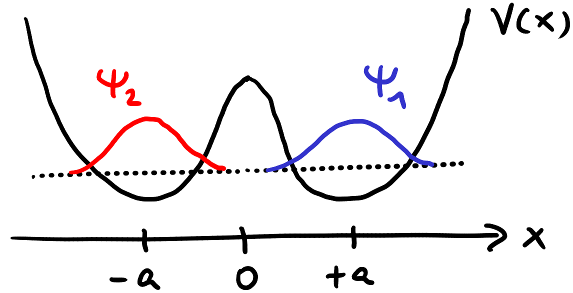






- operátory

operátor polohy – v dvourozměrném prostoru matice 2×2

$$X = \begin{pmatrix} \langle 1|\hat{x}|1\rangle & \langle 1|\hat{x}|2\rangle \\ \langle 2|\hat{x}|1\rangle & \langle 2|\hat{x}|2\rangle \end{pmatrix} = \begin{pmatrix} a & 0 \\ 0 & -a \end{pmatrix}$$

$$\langle 1|\hat{x}|1\rangle = \int_{-\infty}^{\infty} \psi_1^*(x)\, x\, \psi_1(x)\, dx = \int_{-\infty}^{\infty} x\, |\psi_1(x)|^2 \approx +a$$

$$\langle 1|\hat{x}|2\rangle = \int_{-\infty}^{\infty} \psi_1^*(x)\, x\, \psi_2(x)\, dx = 0 \quad (x \text{ lichá}, \ \psi_1\psi_2 \text{ sudé})$$

Hamiltonián systému

$$H = \begin{pmatrix} \langle 1|\hat{H}|1\rangle & \langle 1|\hat{H}|2\rangle \\ \langle 2|\hat{H}|1\rangle & \langle 2|\hat{H}|2\rangle \end{pmatrix} = \begin{pmatrix} E_0 & -T \\ -T & E_0 \end{pmatrix}$$

$$\langle 1|\hat{H}|1\rangle = \int_{-\infty}^{\infty} \psi_1^*(x) \left[-\frac{\hbar^2}{2m}\frac{d^2}{dx^2} + V(x)\right] \psi_1(x)\, dx = E_0 \in \mathbb{R}$$

$$\langle 1|\hat{H}|2\rangle = \int_{-\infty}^{\infty} \psi_1^*(x) \left[-\frac{\hbar^2}{2m}\frac{d^2}{dx^2} + V(x)\right] \psi_2(x)\, dx = -T \in \mathbb{R}$$

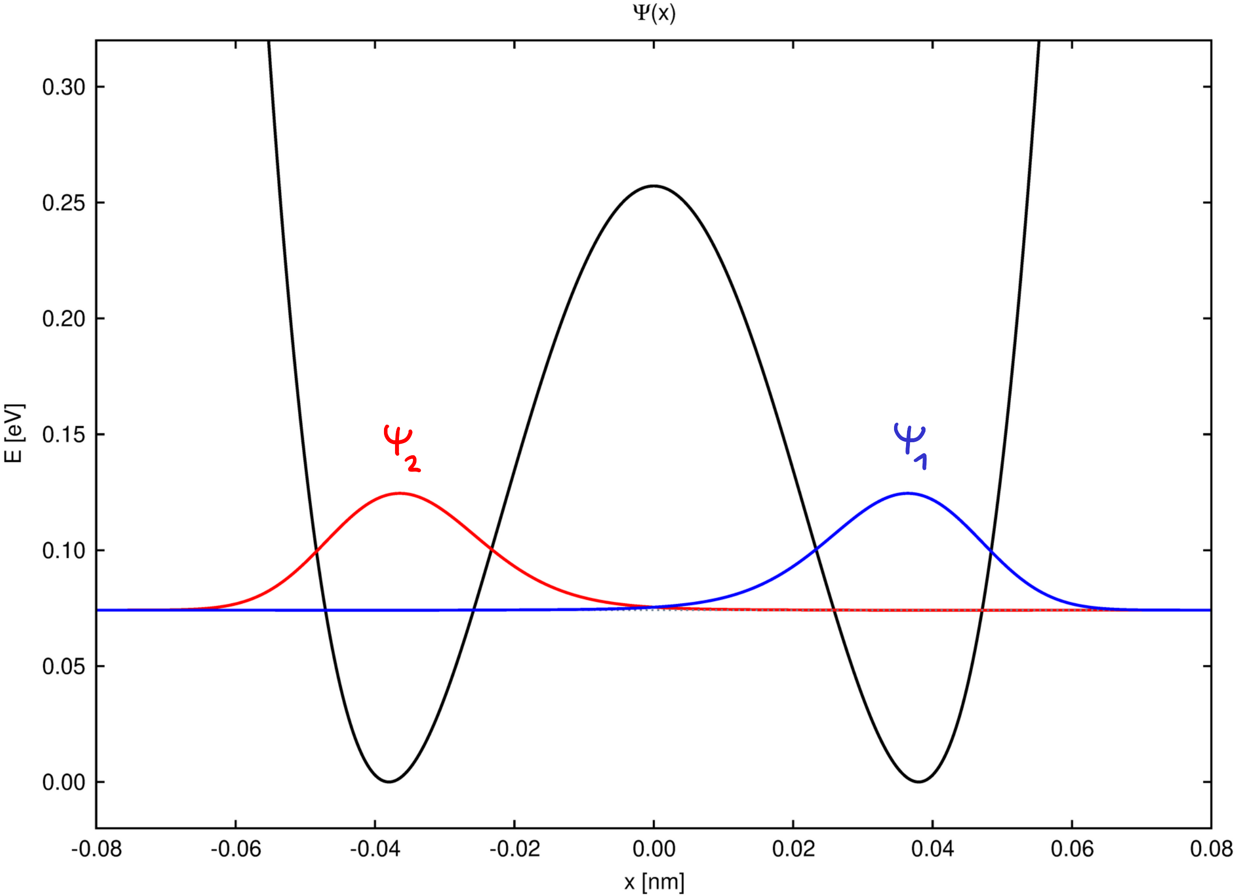
Amoniakový maser - numerická simulace

modelový potenciál

$$V(x) = \lambda (x^2 - a^2)^2$$

$a = 0.038\,\text{nm}$

$V(0) = 0.26\,\text{eV}$



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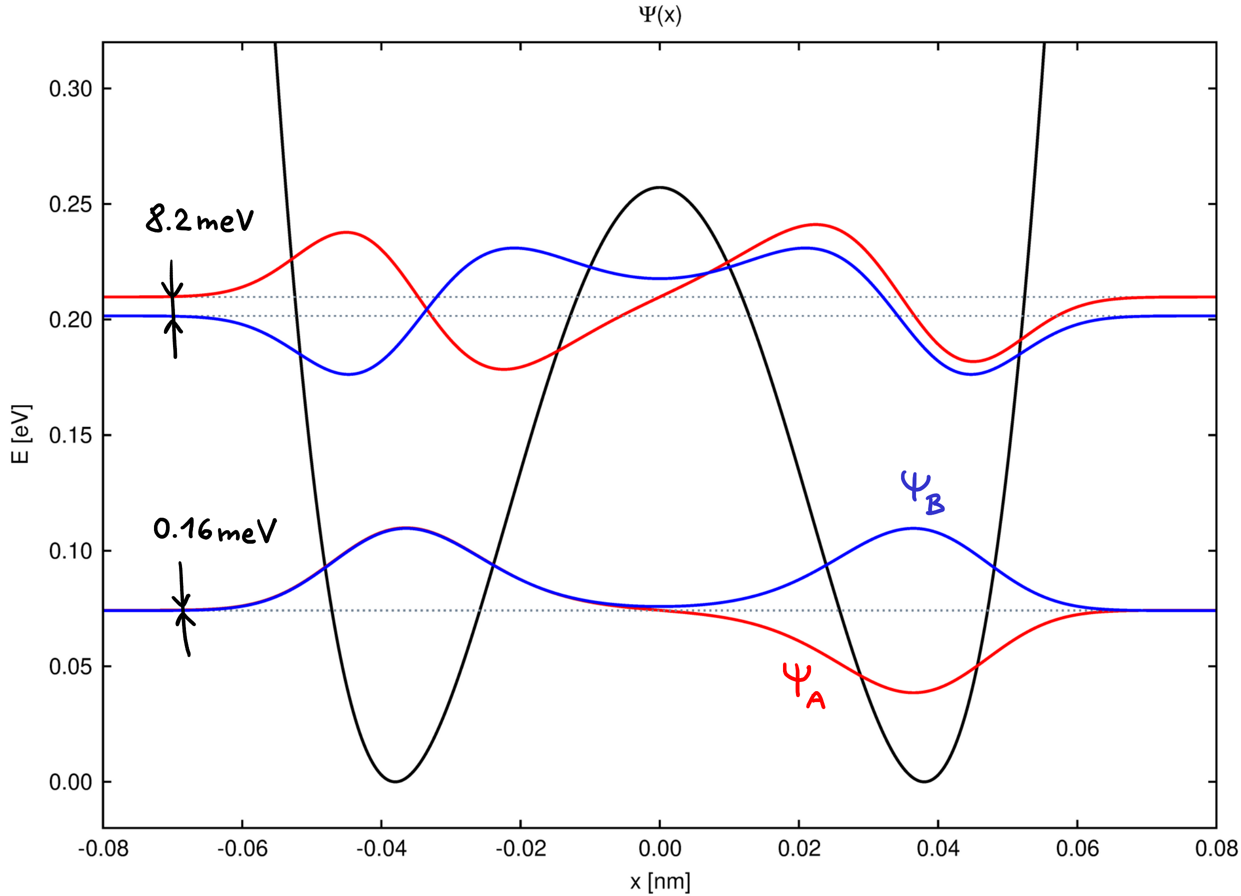
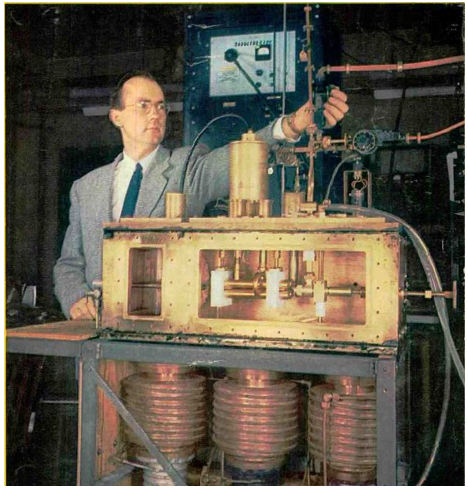


Amoniakový maser - původci

- oscilace dusíkového iontu mezi polohami 1 a 2 spadají do mikrovlnné oblasti $f \approx 24 GHz$
- využívány v MASERu - zdroji koherentního mikrovlnného záření založeném na stimulované emisi



Nikolaj Basov & Alexandr Prochorov - 1952 teoretické principy maseru

Charles H. Townes - 1953 s kolegy sestavil první maser (NH_3)

1964 - Nobelova cena za výzkumy v oblasti stimulované emise

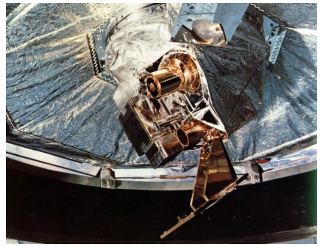
Maser jako zesilovač s ultra nízkým šumem a mise Mariner IV

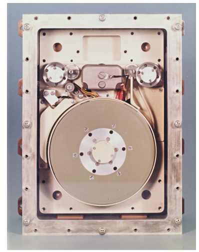
Uses [edit]

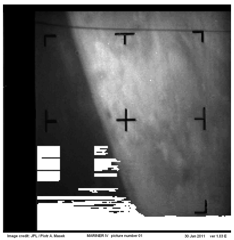
Masers serve as high precision frequency references. These "atomic frequency standards" are one of the many forms of atomic clocks. Masers were also used as low-noise microwave amplifiers in radio telescopes, though these have largely been replaced by amplifiers based on FETs.[13]

During the early 1960s, the Jet Propulsion Laboratory developed a maser to provide ultra-low-noise amplification of S-band microwave signals received from deep space probes.[14] This maser used deeply refrigerated helium to chill the amplifier down to a temperature of 4 kelvin. Amplification was achieved by exciting a ruby comb with a 12.0 gigahertz klystron. In the early years, it took days to chill and remove the impurities from the hydrogen lines.

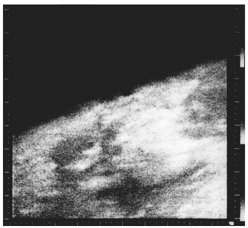
Refrigeration was a two-stage process, with a large Linde unit on the ground, and a crosshead compressor within the antenna. The final injection was at 21 MPa (3,000 psi) through a 150 μm (0.006 in) micrometer-adjustable entry to the chamber. The whole system noise temperature looking at cold sky (2.7 kelvin in the microwave band) was 17 kelvin. This gave such a low noise figure that the Mariner IV space probe could send still pictures from Mars back to the Earth, even though the output power of its radio transmitter was only 15 watts, and hence the total signal power received was only −169 decibels with respect to a milliwatt (dBm).



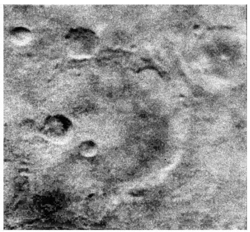




The first digital image from Mars



The first close-up image ever taken of Mars

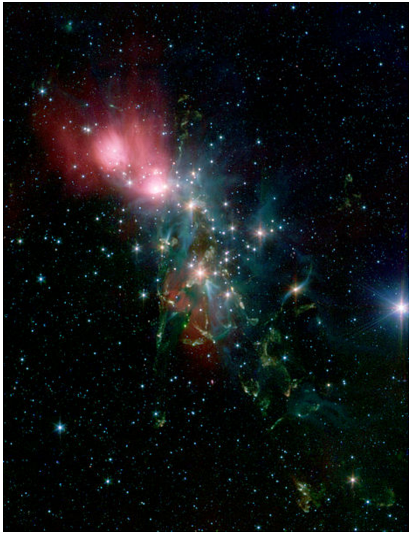


The clearest Mariner 4 image showing craters

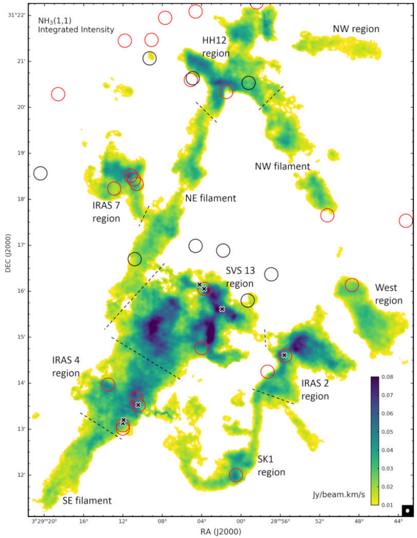
The total data returned by the mission was 5.2 million bits (about 634 kB). All instruments operated successfully with the exception of a part of the ionization chamber, namely the Geiger–Müller tube, which failed in February 1965.[2] In addition, the plasma probe had its performance degraded by a resistor failure on December 8, 1964, but experimenters were able to recalibrate the instrument and still interpret the data.[22] The images returned showed a Moon-like cratered terrain,[23] which scientists did not expect, although amateur astronomer Donald Cyr had predicted craters.[16] Later missions showed that the craters were not typical for Mars, but only for the more ancient region imaged by Mariner 4. A surface atmospheric pressure of 4.1 to 7.0 millibars (410 to 700 Pa) and daytime temperatures of −100 °C (−148 °F) were estimated. No magnetic field[24][25] or Martian radiation belts[26] or, again surprisingly, surface water[16] was detected.

https://en.wikipedia.org/wiki/Maser
https://en.wikipedia.org/wiki/Mariner_4

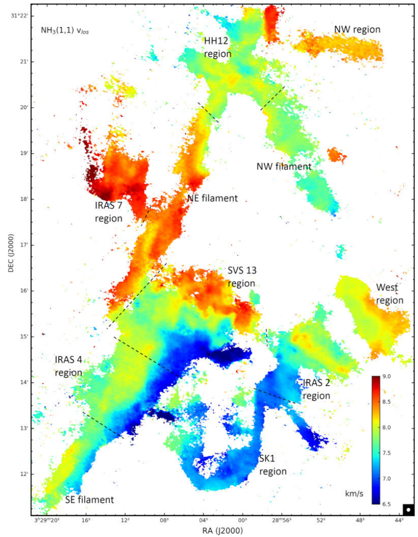
Užití 24GHz přechodu v NH_3 k radioastronomickému pozorování



reflexní mlhovina NGC 1333
v souhvězdí Persea
pozorovaná v IR spektru



integrální intenzita

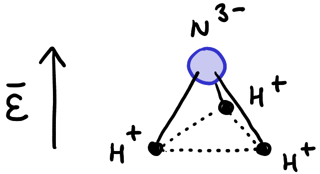


radiální rychlost

část reflexní mlhoviny NGC1333 pozorovaná na 24GHz přechodu NH_3

A. Dhabal, Astrophys. J. 876, 108 (2019) (data z VLA)

Molekula amoniaku v elektrickém poli



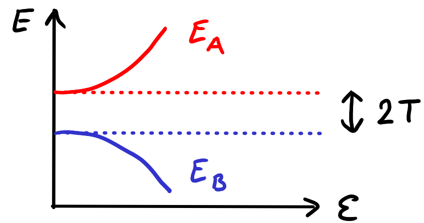
$$\Delta V(x) = -q\mathcal{E}x$$

$$\hat{H} = \hat{H}_0 - q\hat{x} \rightarrow \begin{pmatrix} E_0 - q\mathcal{E}a & -T \\ -T & E_0 + q\mathcal{E}a \end{pmatrix}$$

- statické elektrické pole $\mathcal{E}(t) = \mathcal{E}_0$ – **Starkův jev**

vlastní hodnoty $E_{A,B} = E_0 \pm \sqrt{T^2 + (q\mathcal{E}_0 a)^2}$

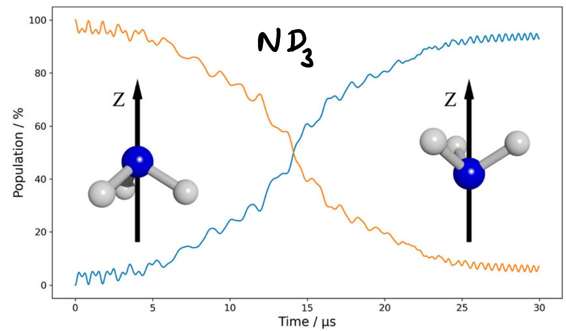
→ změna frekvence oscilací N iontu



- střídavé elektrické pole $\mathcal{E}(t) = \mathcal{E}_0 \cos \Omega t$ – **Rabiho oscilace**

přelévání pravděpodobnosti s Rabiho frekvencí

$$\Omega_R = \sqrt{\left(\Omega - \frac{2T}{\hbar}\right)^2 + \left(\frac{q\mathcal{E}_0 a}{\hbar}\right)^2}$$



S. Herbers et al., Molecular Physics e2129105 (2022)