Non-metastable ammonia masers in the high-mass star-forming regions

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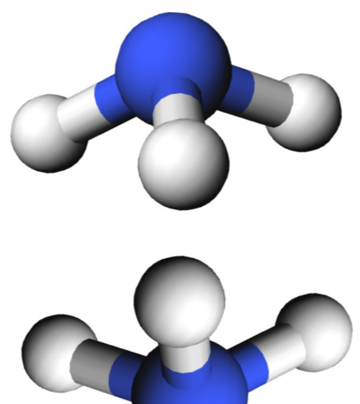
Physics of the ammonia molecule

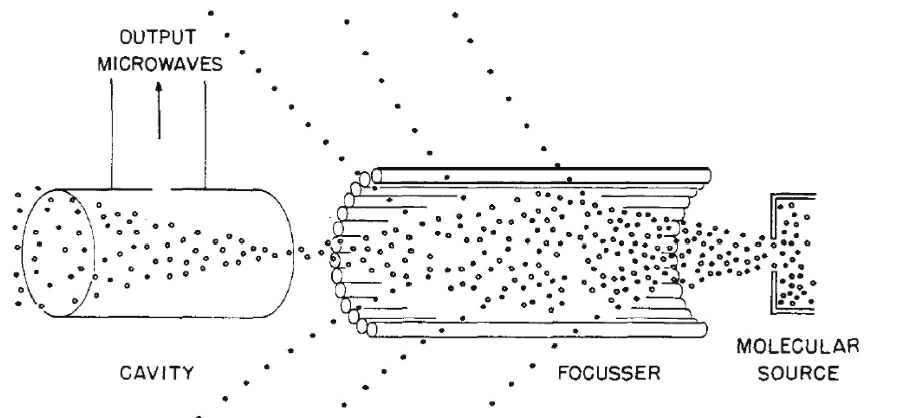


The inversion of the ammonia molecule.

- Symmetric top with inversion
- Two principal quantum numbers (J, K). J is the total angular momentum quantum number, K is the projection of J onto the NH_3 symmetry axis.
- Non-metastable (J > K), decay rapidly (10-10^2 s)
- Metastable (J = K), decay much slower (10^9 s)
- Ortho-NH_3 (K = 3n), all H spins parallel
- Para-NH_3 ($K \neq$ 3n), all H spins not parallel

Thermally excited transitions in the centimeter-wavelength inversion transitions of ammonia are regarded as a reliable thermometer of molecular clouds (Walmsley & Ungerechts+1983).

Discovery of masers/lasers

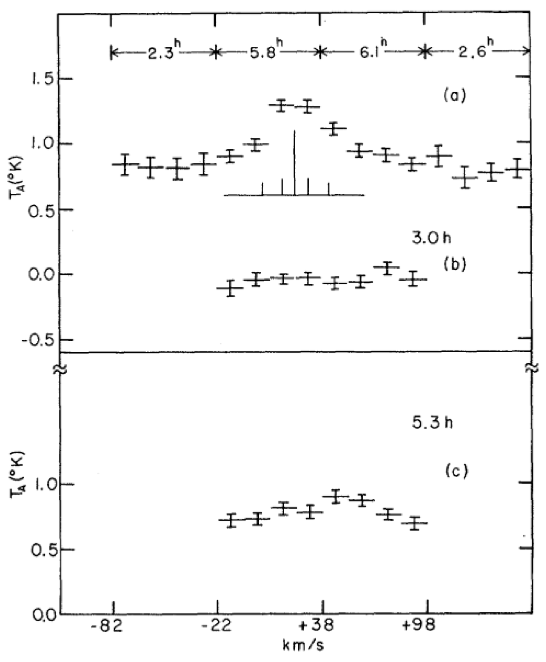


The first maser was obtained from a source of ammonia by **Charles H. Townes** and his group in the laboratory in 1954 (Gordon+1954). He then received the Nobel Prize in Physics in 1964. The figure was taken from Charles H. Townes's Nobel Lecture.

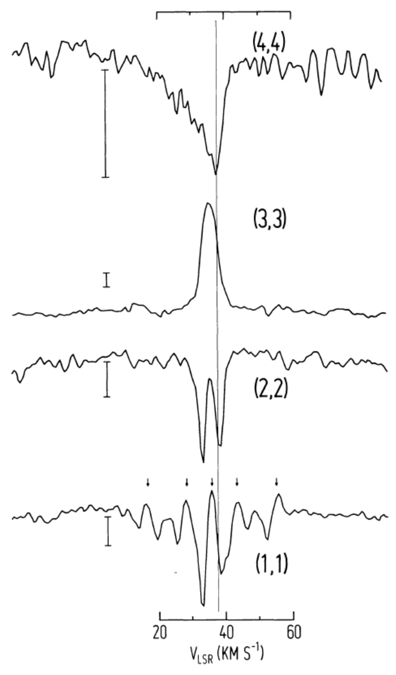
Maser: Microwave Amplification by Stimulated Emission of Radiation.

Molecular maser lines are signposts of high-mass star formation, probing the excitation and kinematics of very compact regions in the close environment of young stellar objects and providing useful targets for trigonometric parallax measurements.

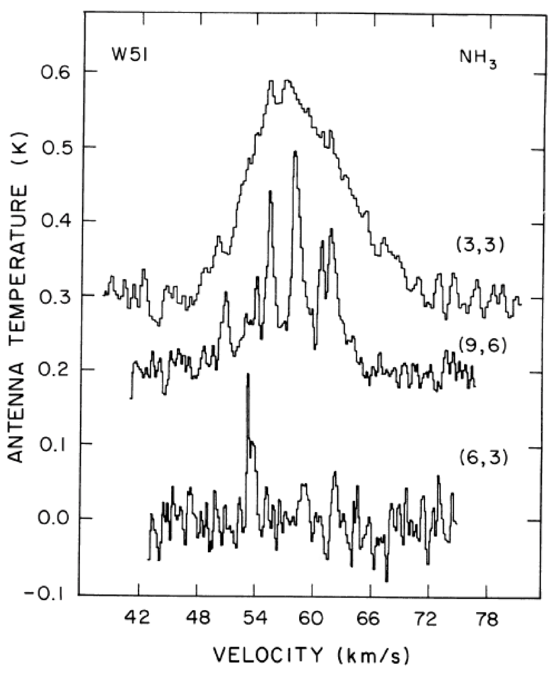
Detections of NH_3 maser sources in the interstellar medium (ISM)



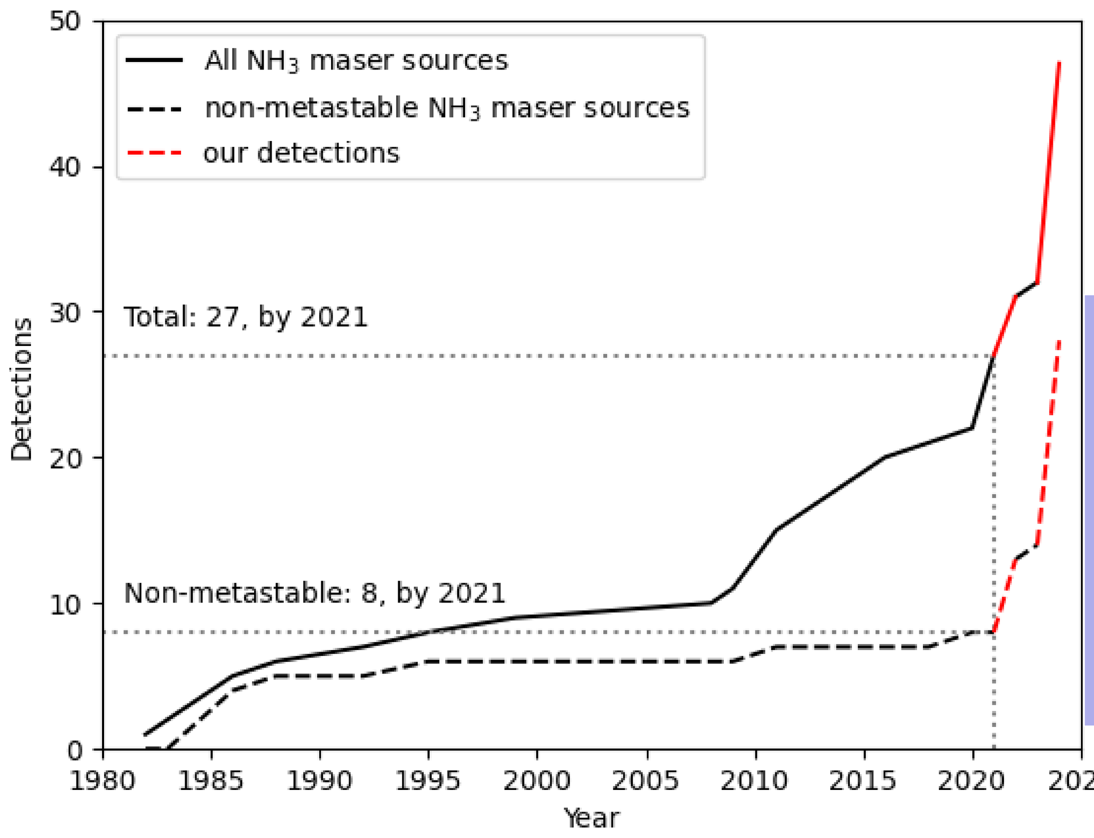
Discovery of NH_3 thermal emission in the ISM (Galactic center, Cheung+1968)



Discovery of metastable NH_3 maser emission in the ISM (W33, Wilson+1982)



Discovery of non-metastable NH_3 maser emission in the ISM (W51, Madden+1986)

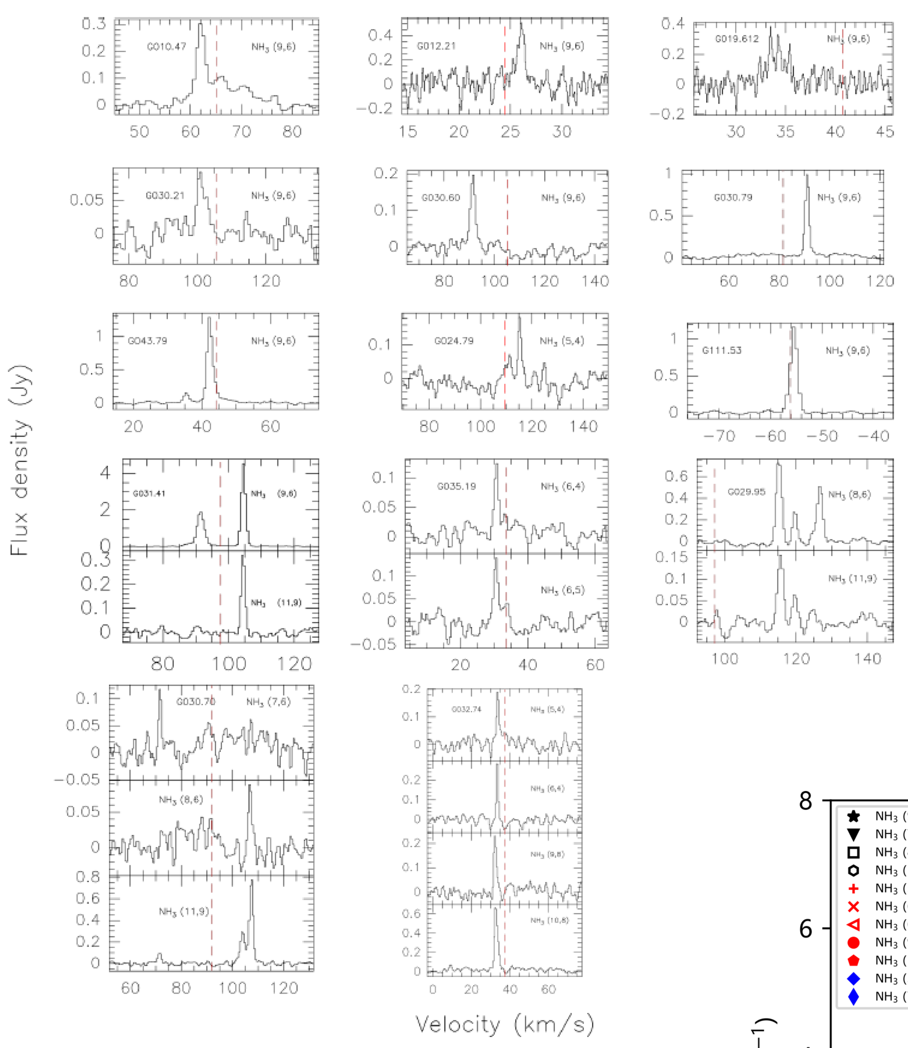


So far, a total of 33 $^{14}NH_3$ inversion transitions and three $^{15}NH_3$ inversion lines have been identified as masers in the ISM (see details in Table A.1 of Yan+2024).

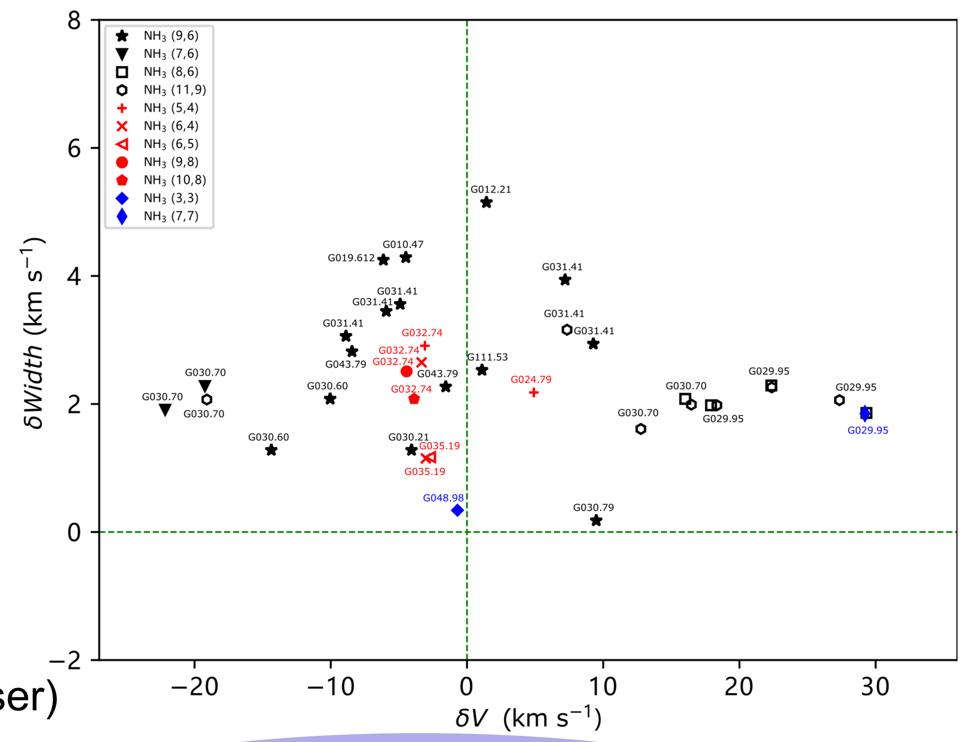
Ammonia maser lines have only been detected in 47 sources. Among them, 42 (90%) are high-mass star-forming regions.

Recently, we detected 17 non-metastable NH_3 maser sources and 2 metastable NH_3 maser sources (Yan+2022a,b,2024).

Our detections of NH_3 maser sources



Spectra from 14 newly detected non-metastable ammonia maser sources, based on our recent K-band line survey with the 100-meter Effelsberg telescope (Yan+2024). The systemic velocities from NH_3 (1,1) emission are indicated by dashed red lines.



Comparison of velocities and line widths of ammonia maser lines to the intrinsic line widths of ammonia (J, K) = (1,1) thermal emission.

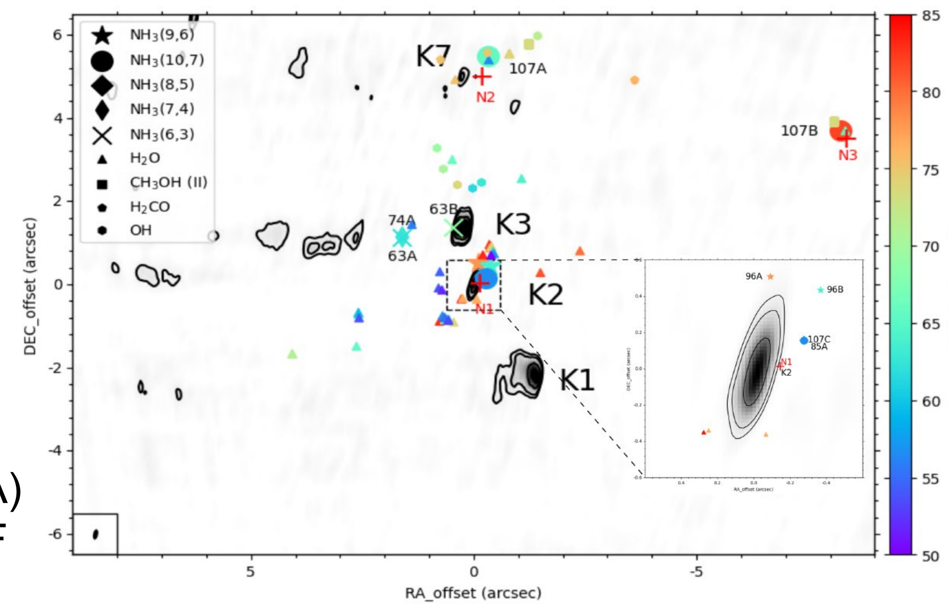
$\delta V = V_{LSR}(\text{maser}) - V_{LSR}(NH3(1,1))$

$\delta Width = \Delta V_{1/2}(NH3(1,1)) - \Delta V_{1/2}(\text{maser})$

Velocity offsets with respect to systemic velocities may suggest emission associated with outflows or disks.

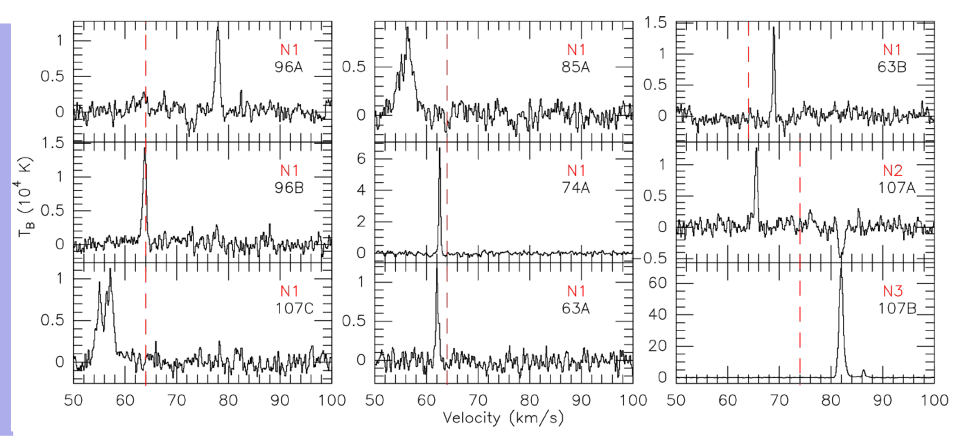
Higher-angular-resolution observations of non-metastable NH_3 masers in Sgr B2(N)

The Karl G. Jansky Very Large Array (JVLA)
Credit: Bettymaya Foott, NRAO/AUI/NSF



Grey area and black contours: JVLA 1.6 cm continuum. Red crosses: hot cores.

In view of the masers' velocity differences with respect to adjacent hot molecular cores and/or UCHII regions, it is argued that all the measured ammonia maser lines may be associated with shocks caused either by outflows or by the expansion of UCHII regions (Yan+2022b).



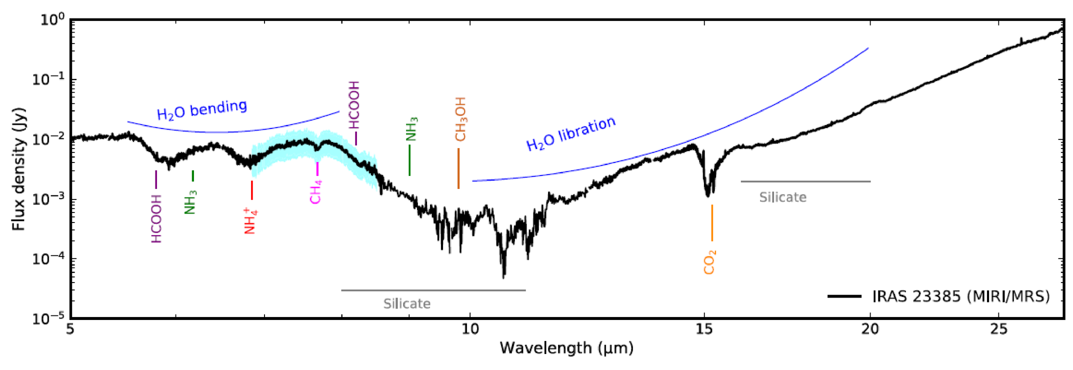
NH_3 maser spectra in Sgr B2(N). The dashed red lines indicate the systemic velocities of the associated hot cores.

Considerations on pumping scenarios

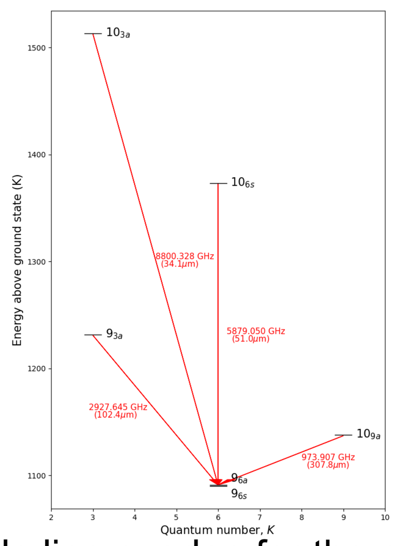
The metastable NH_3 (3,3) masers are thought to be collisionally pumped (e.g., Walmsley & Ungerechts+1983, Mangum & Wootten+1994). Pumping scenarios of other NH_3 transitions are still speculative.

Three main pumping scenarios (Madden+1986, Brown & Cragg+1991, Henkel+2013):

1. collisional pumping: measurements of collisional rates of ammonia are needed (J > 6)
2. **infrared radiation at 10 μm from the dust continuum, can cause significant populations of vibrationally excited NH_3**
3. **line overlap between the rotational NH_3 transitions in the far-infrared band**



JWST MIRI MRS spectrum around 10 μm of the high-mass protostar IRAS 23385+6053, taken from Rocha+2024.



Possible line overlap for the population inversion of NH_3 (9,6) maser.

Future infrared observations toward NH_3 maser sources at 10 μm and measurements of rotational NH_3 transitions are needed to clarify the pumping scenarios of NH_3 masers.

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