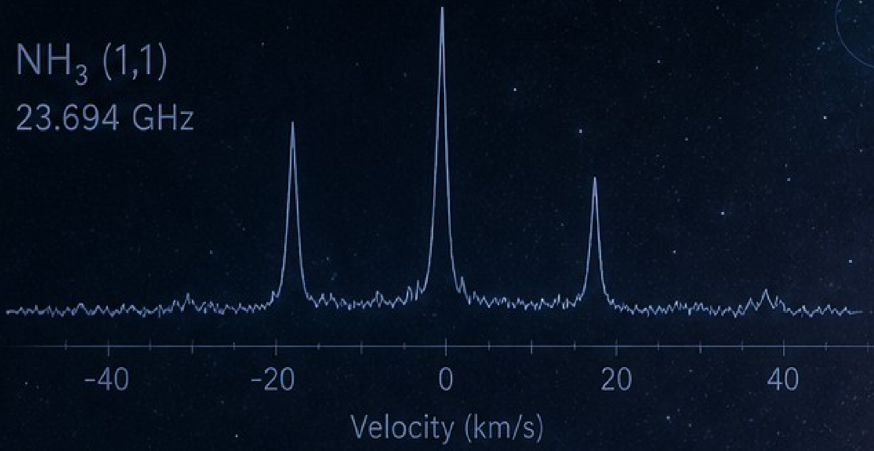
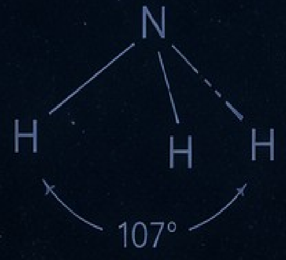
INTERSTELLAR AMMONIA

NH_3 IN THE INTERSTELLAR MEDIUM

Based on a paper from
Ho, P. T. P. Suche von Orcid ; Townes, C. H.
1983)





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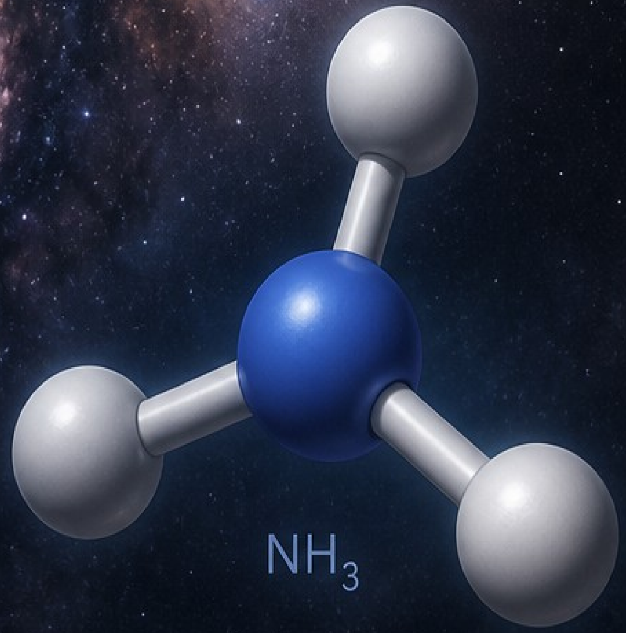
5.Mai 2026



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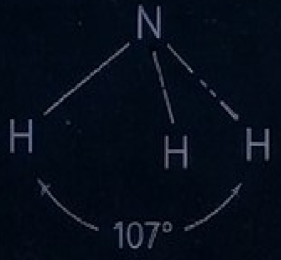
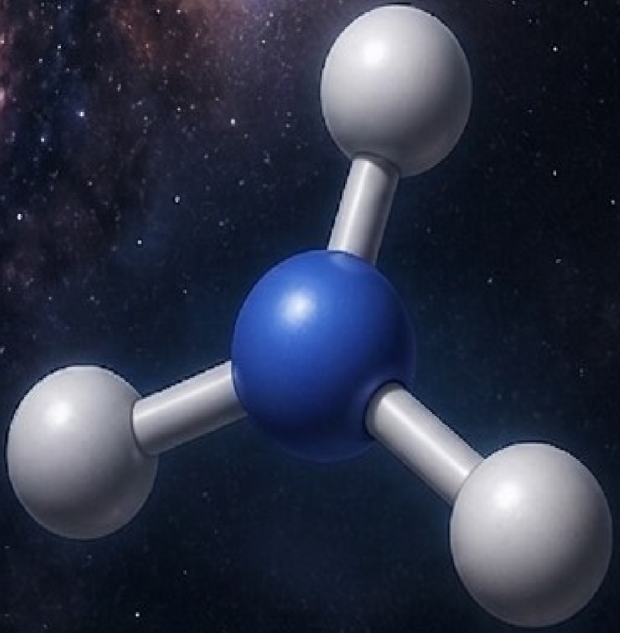
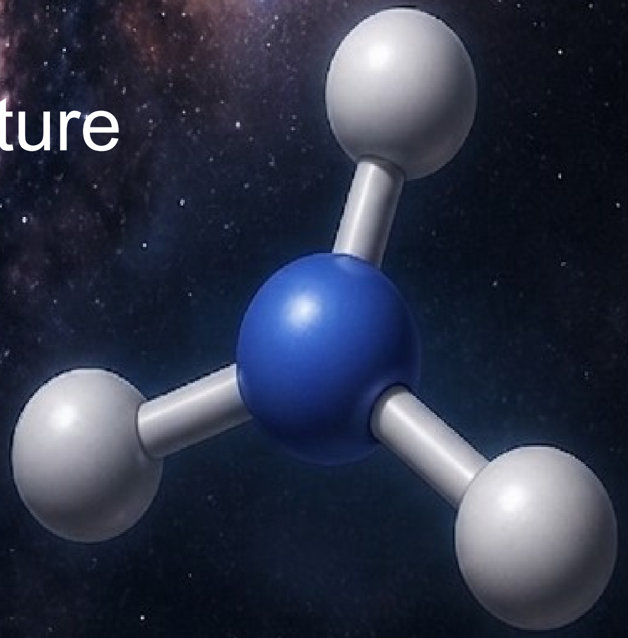


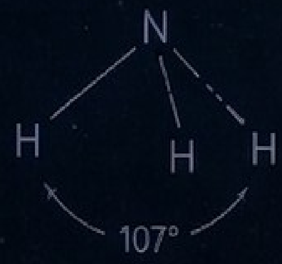


Why NH_3?

- Abundant in dense molecular regions
- Resistant to depletion compared to CO in dense cores
- Strong inversion transitions (~23 GHz)
- Hyperfine structure → precise measurements

□ □Unique advantage:
Direct measurement of gas temperature





NH_3 is abundant in dense molecular regions

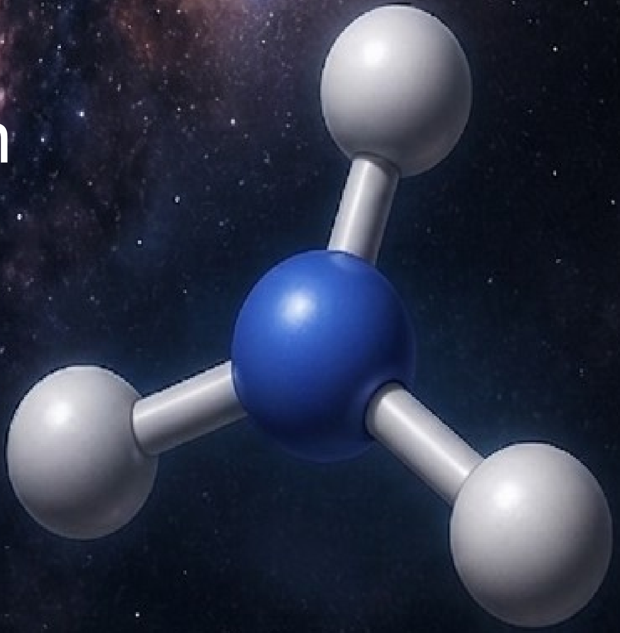
What are “dense molecular regions”?

These are parts of molecular clouds
with:

densities: ~10^4–10^6 cm^{-3}
temperatures: ~10–30 K
strong shielding from UV radiation

Typical environments:

star-forming cores
dark clouds



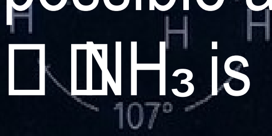
Why NH_3 forms there

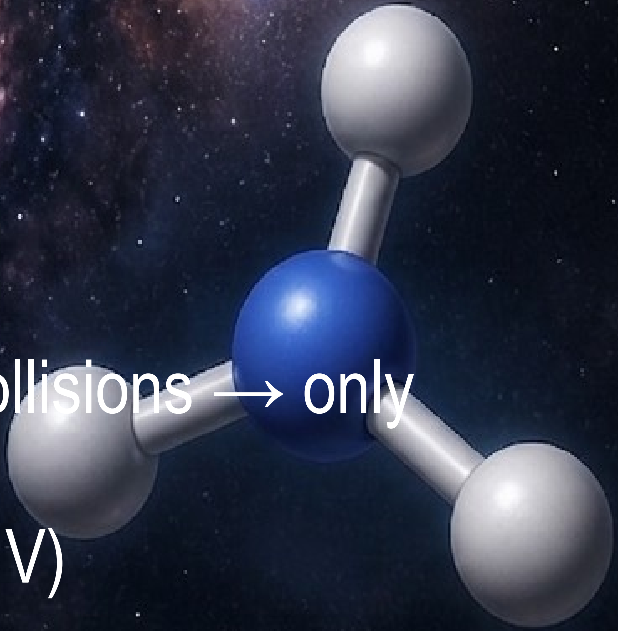
1. Gas-phase chemistry becomes efficient

In dense regions, particles collide often enough for reactions like:

Ion-molecule reactions:
$N^+ \rightarrow NH^+ \rightarrow NH_2^+ \rightarrow NH_3^+ \rightarrow NH_4^+$
Then:
$NH_4^+ + e^- \rightarrow NH_3 + H$

□ □These reaction chains require frequent collisions → only possible at high density
□ □NH_3 is not constantly photodissociated (UV)





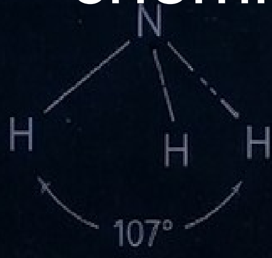
Formation timescales match cloud lifetimes

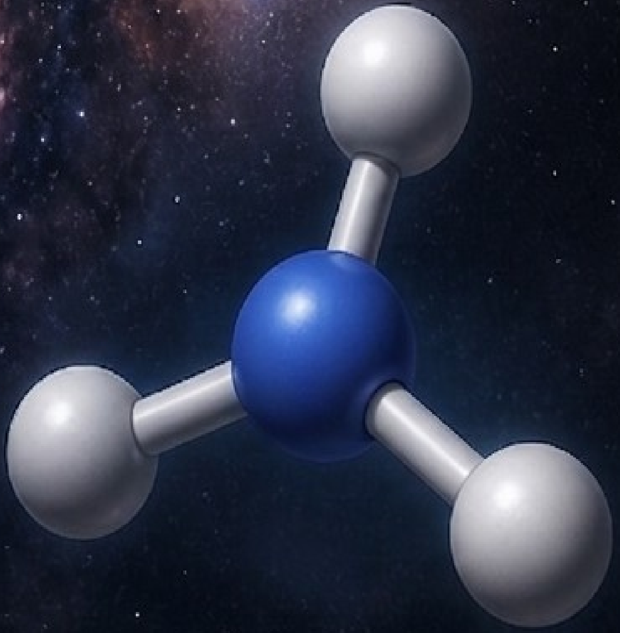
Dense cores live long enough (~10^5–10^6 years) for:

slow chemical networks to build up NH_3

In low-density regions:

chemistry is too slow → little NH_3

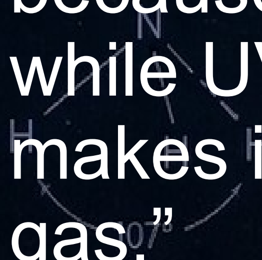




“Abundant” means:

NH_3 reaches relatively high fractional abundances (~10^{-8} to 10^{-7})

It is preferentially found in dense, shielded gas
It traces regions where stars actually form



“NH_3 is abundant in dense molecular regions because high densities enable its formation, while UV shielding prevents its destruction. This makes it an excellent tracer of cold, star-forming gas.”

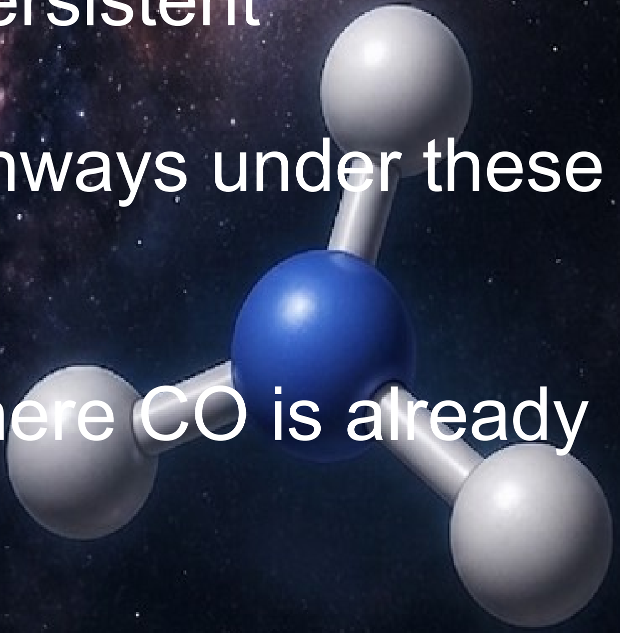
Why NH_3 is more resistant

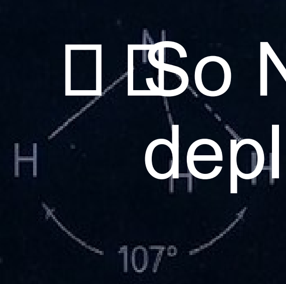
Even if some NH_3 freezes out:
it is replenished in the gas phase via ion–molecule reactions, especially through NH_4^+ recombination

Nitrogen chemistry is slower but persistent

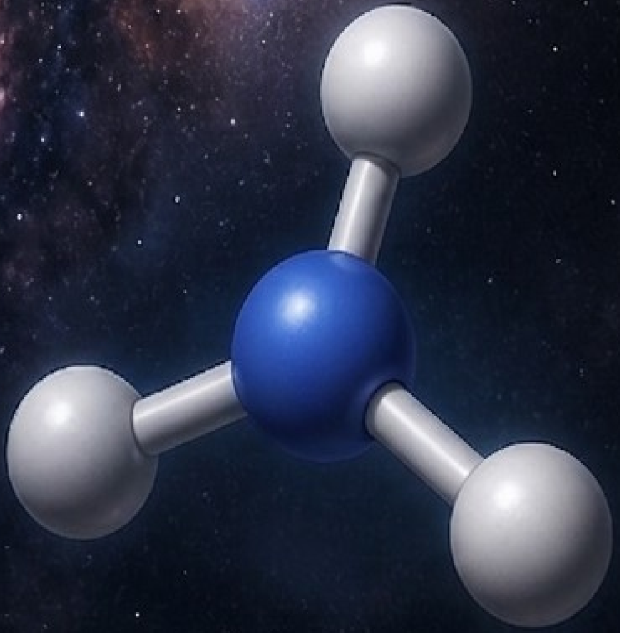
□ □CO has weaker reformation pathways under these conditions

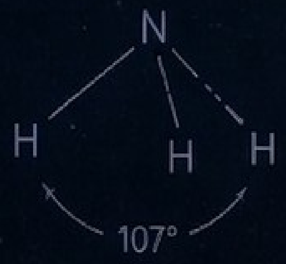
□ □So NH_3 abundance builds up where CO is already depleted



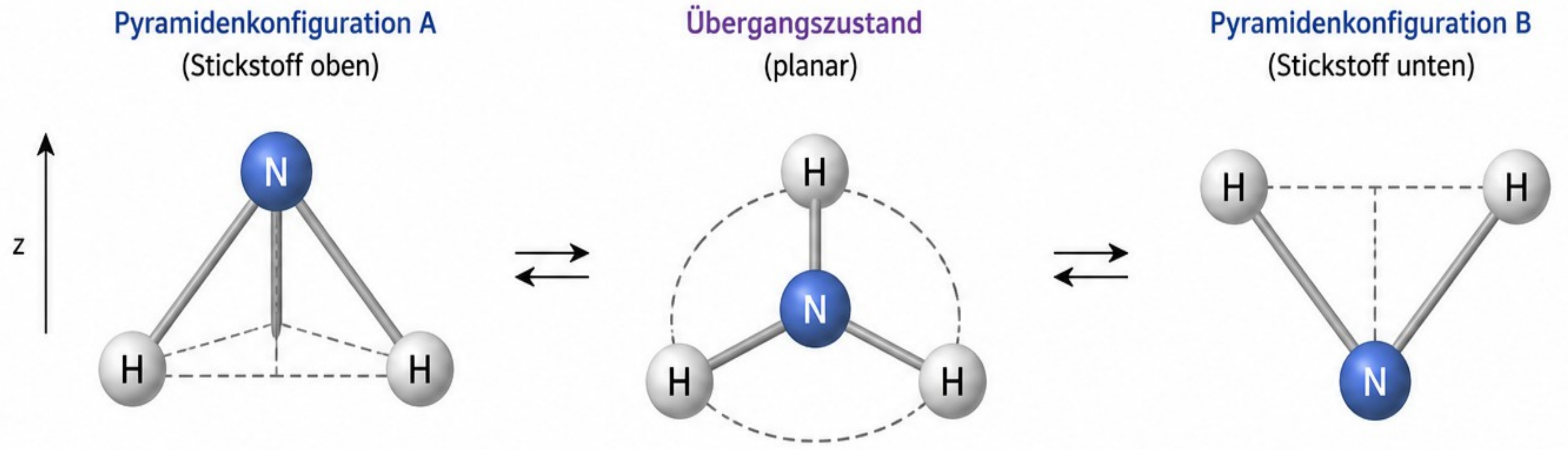


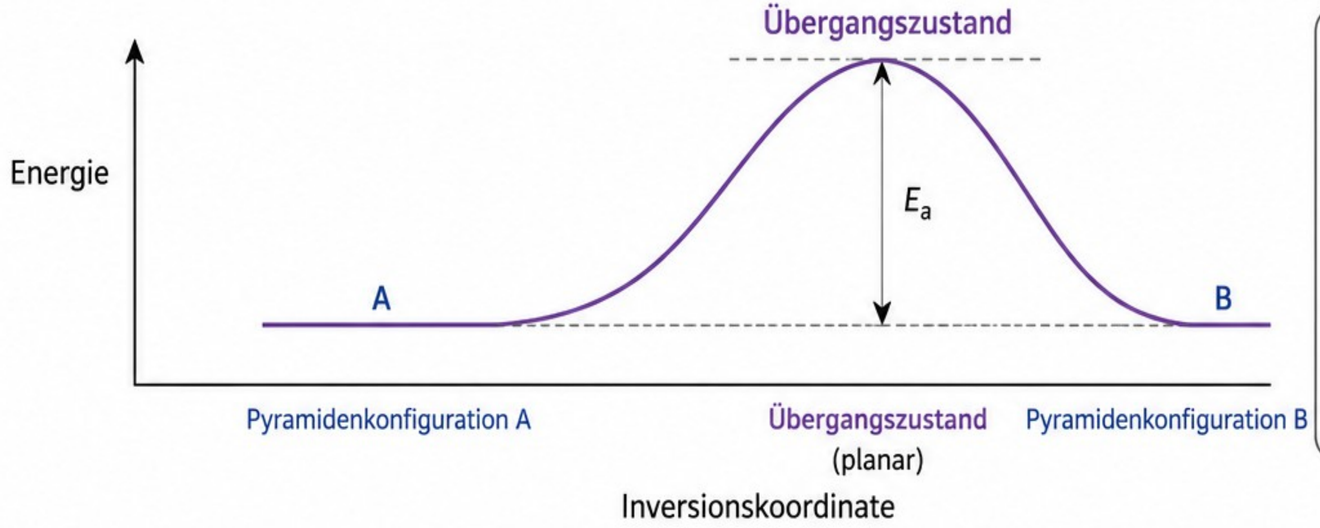
Property	CO	NH_3
Freeze-out	Strong	Moderate
Formation	Limited in cores	Ongoing
Traces density	Lower	Higher
Survives in cores	❌ No	✅ Yes



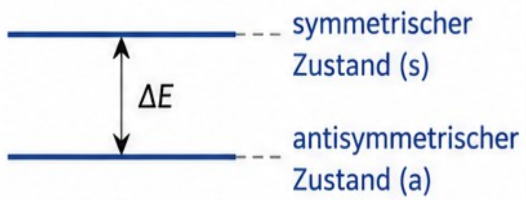


NH_3–Molekül: Inversionssplitting





Inversionssplitting



Durch Quantentunneln zwischen A und B entstehen zwei nahe beieinanderliegende Energieniveaus (Inversionssplitting ΔE).

Erklärung: Das NH_3–Molekül kann durch Tunneln des Stickstoffatoms durch die Ebene der Wasserstoffatome zwischen den beiden Pyramidenkonfigurationen A und B wechseln.

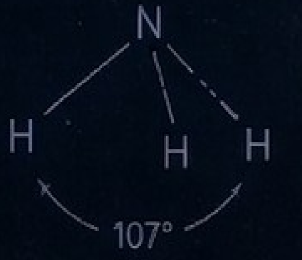
➡

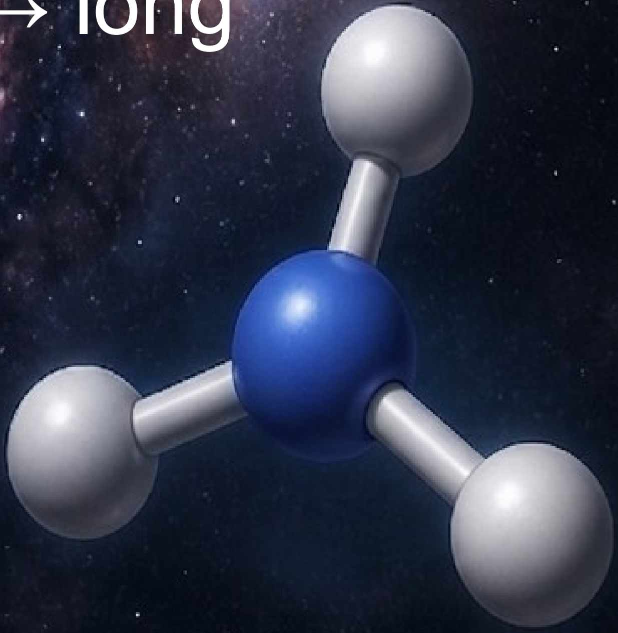
Diese Inversion führt zur Aufspaltung der Energieniveaus in einen symmetrischen (s) und einen antisymmetrischen (a) Zustand: Inversionssplitting ΔE.

Inversion Transitions

Occur between two nearly degenerate states
Observed in microwave/radio regime
Key transitions:
(1,1), (2,2), (3,3) rotational states

□ □These are metastable levels → long lifetimes

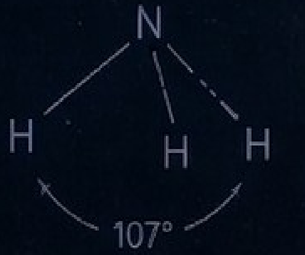


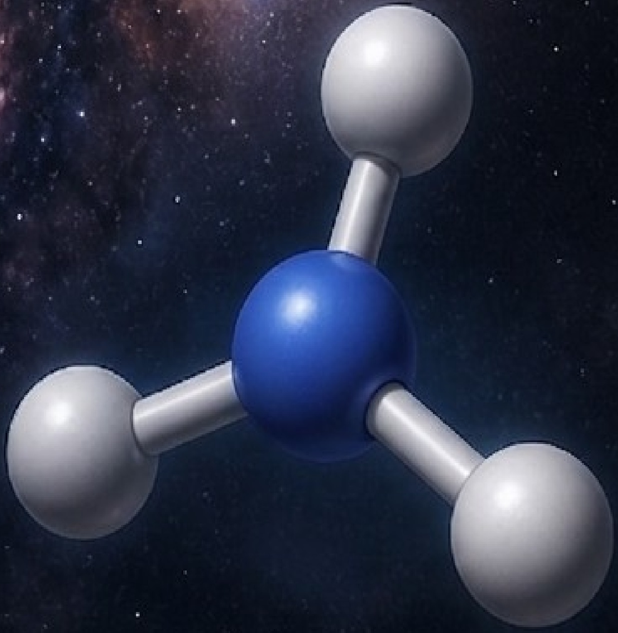


Radiative Transfer Equation (NH_3 line emission)

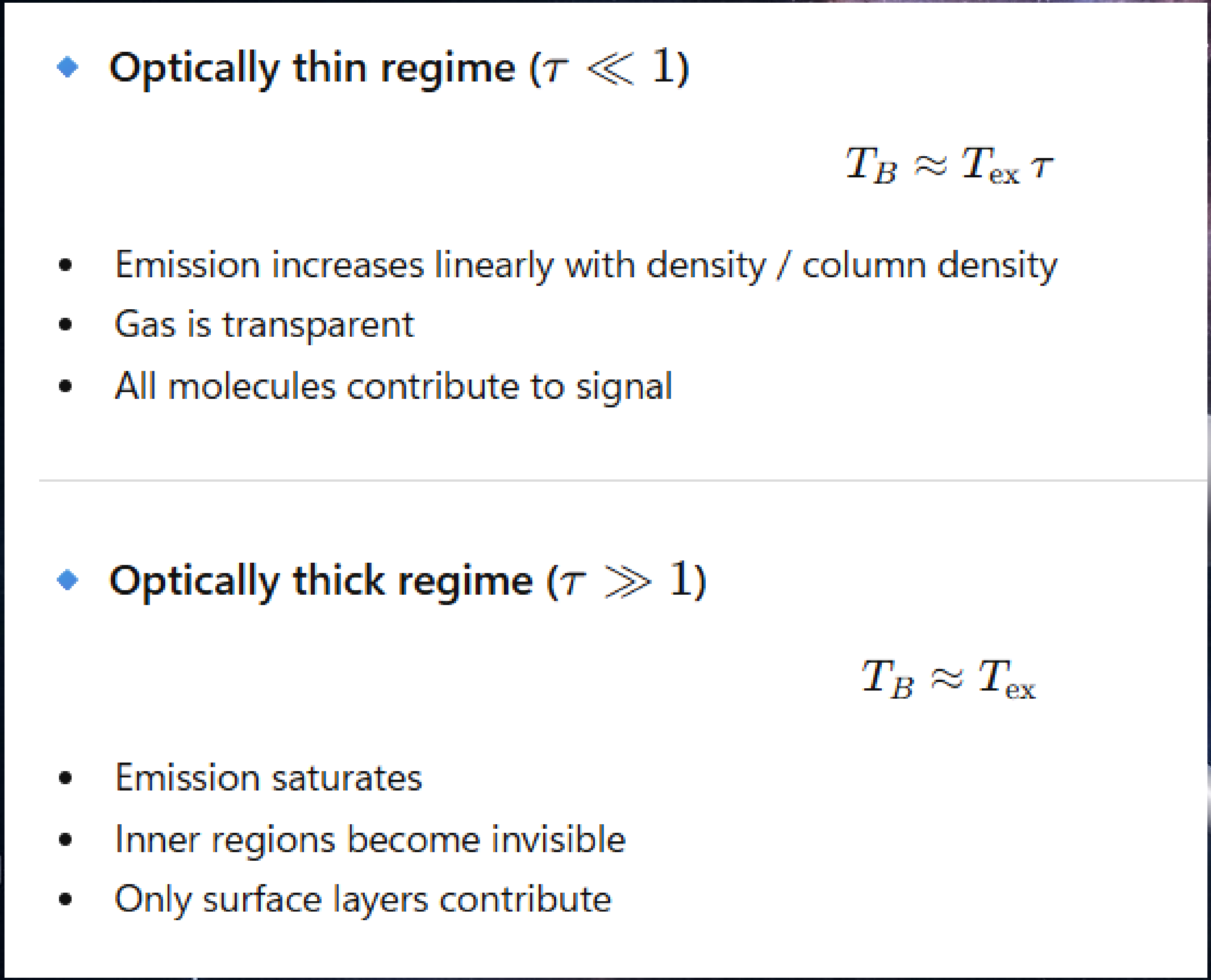
$$T_B = T_{\mathrm{ex}}\left(1 - e^{-\tau}\right)$$

TB: Brightness temperature (observed signal)
Tex: Excitation temperature (population temperature of the molecular levels)
т: Optical depth





Physical interpretation



◆ **Optically thin regime ($\tau \ll 1$)**

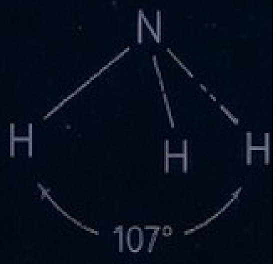
$$T_B \approx T_{\text{ex}}\,\tau$$

- Emission increases linearly with density / column density
- Gas is transparent
- All molecules contribute to signal

◆ **Optically thick regime ($\tau \gg 1$)**

$$T_B \approx T_{\text{ex}}$$

- Emission saturates
- Inner regions become invisible
- Only surface layers contribute



Two states: symmetric / antisymmetric
Quantum tunneling phenomenon

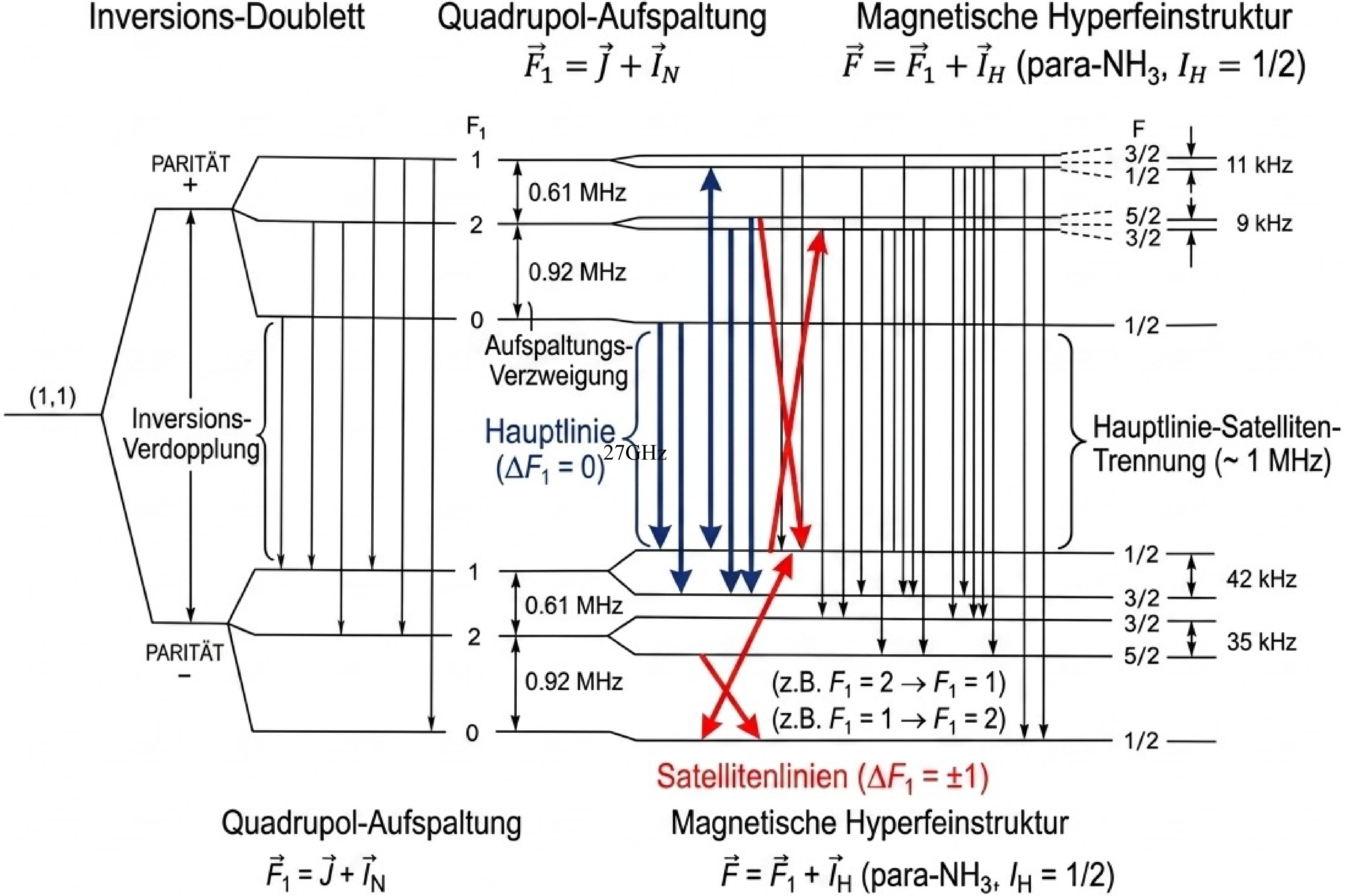


Figure 2 Hyperfine splitting of the $(J, K) = (1, 1)$ transition. The allowed transitions are indicated.

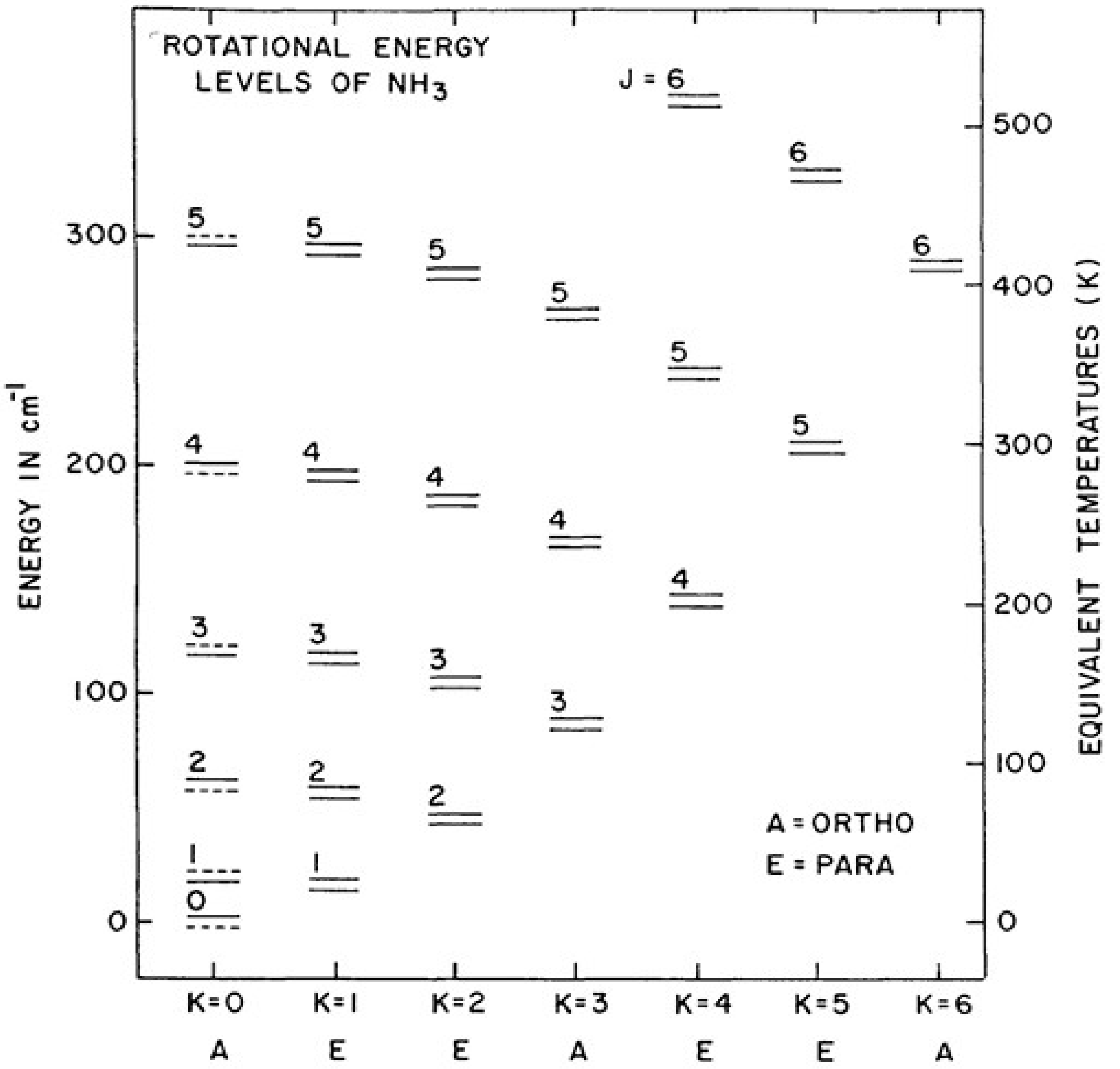


Figure 1 Energy level diagram of rotation-inversion states. *J* is the total angular-momentum quantum number, and *K* is the projected angular momentum along the molecular axis.

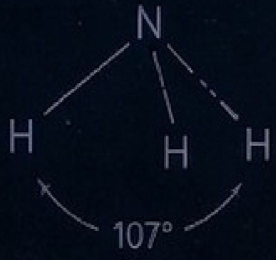
Interstellar Excitation

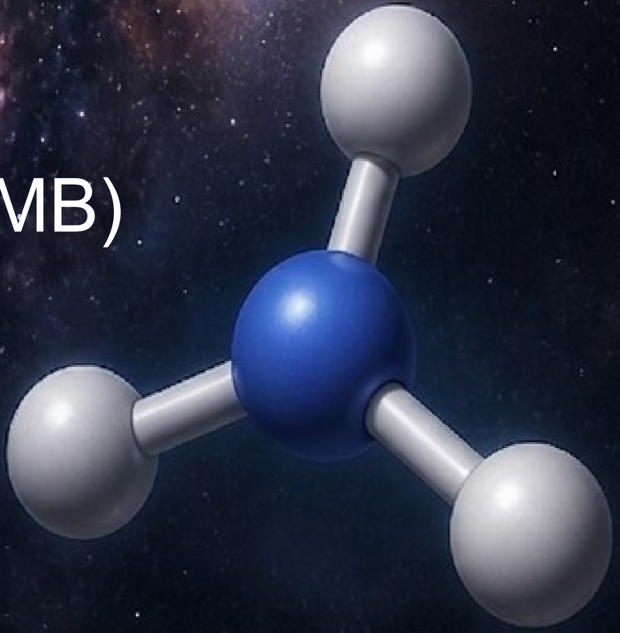
Basic idea

Molecules in space are not in thermal equilibrium.

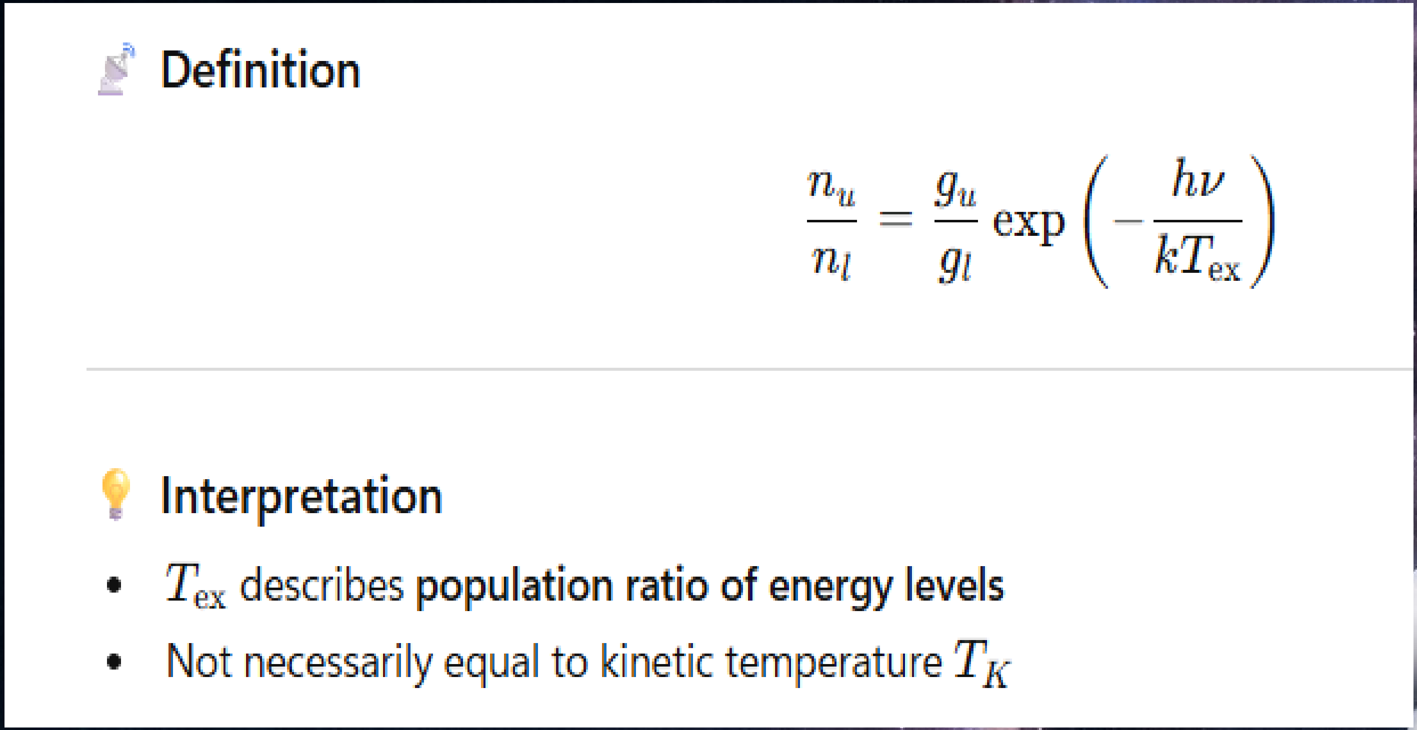
They are excited by:

* Collisions (H_2, electrons)
* Radiation fields
* Cosmic microwave background (CMB)





Excitation Temperature

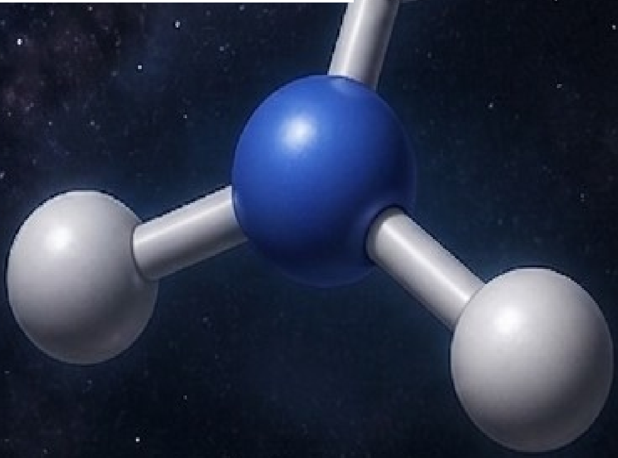


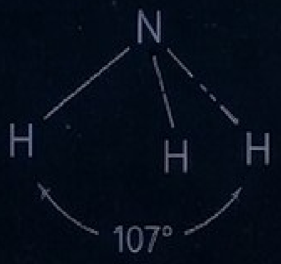
Definition

$$\frac{n_u}{n_l} = \frac{g_u}{g_l} \exp\left(-\frac{h\nu}{kT_{\text{ex}}}\right)$$

Interpretation

- T_{ex} describes **population ratio of energy levels**
- Not necessarily equal to kinetic temperature T_K



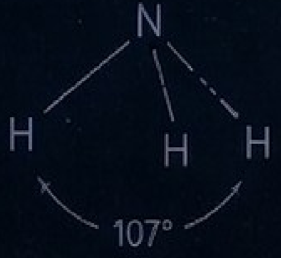


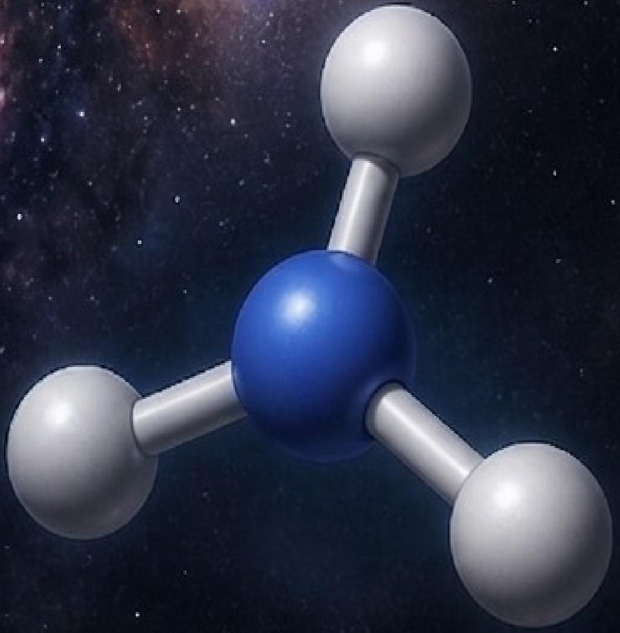
Observational Technique

Radio telescopes (~23 Ghz)

Measure:
* line profiles
* hyperfine components

Fit spectra → extract:
* optical depth
* linewidth
* velocity



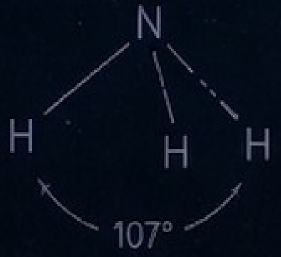


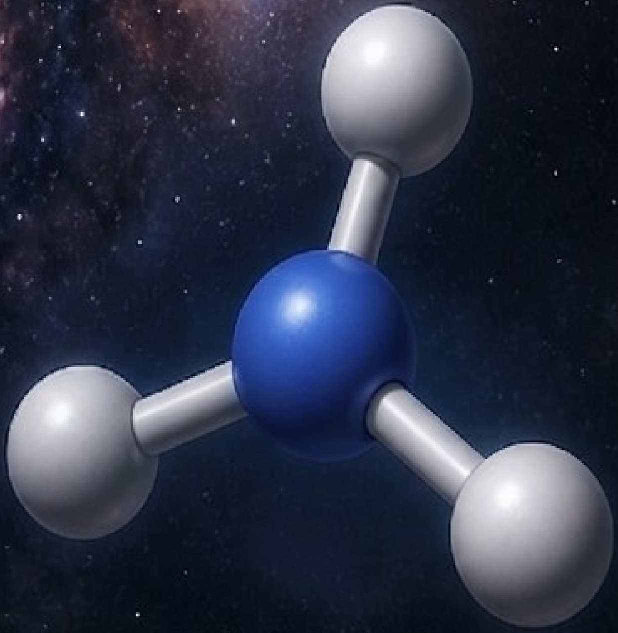
Conclusion

NH_3 is one of the most powerful probes of dense interstellar gas

Provides direct temperature measurements

Essential for understanding:
* star formation
* cloud structure





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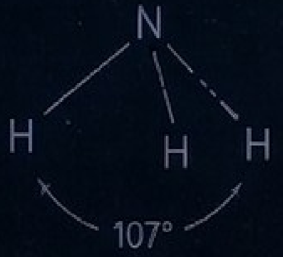

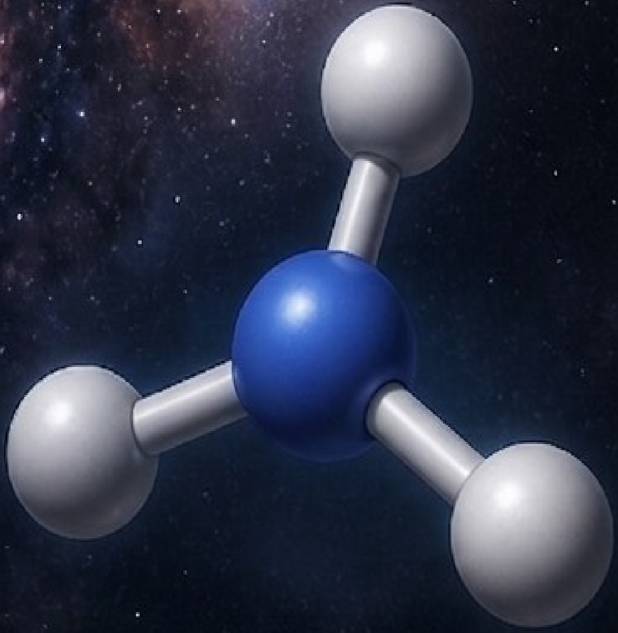

Background: ChatGPT

Fig1, Fig2: Ho & Townes (1983)

NH3-Molecule: E.Schubert, TiKZ

Formulas: E.Schubert, LaTeX