# Ammonia survey of cold high-mass clumps discovered with ATLASGAL

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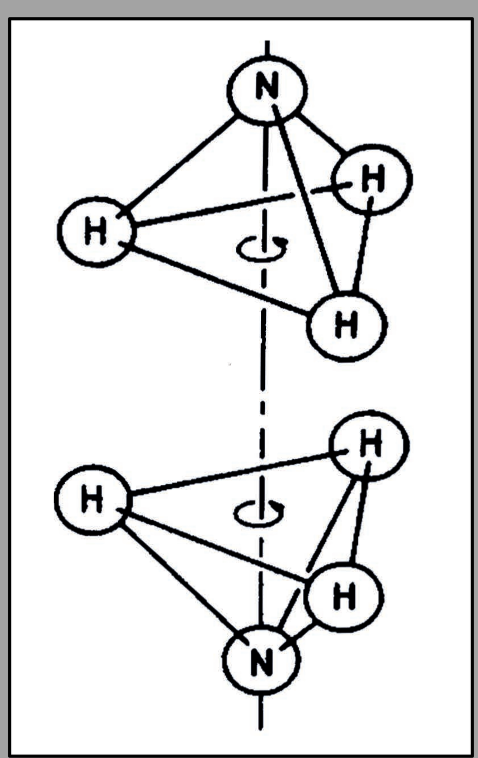
## Introduction & Observations

### High-mass star formation

It is well known that the first phase of high-mass star formation occurs in giant molecular clouds. Protostars which evolve in dense cores emit ultraviolet radiation, thus heat and ionize the remaining molecular cloud forming ultracompact HII regions (UCHIIs). In particular, progress has to be made in the investigation of the phases before UCHIIs have formed and the newly formed high-mass (proto) stars emerge in the infrared. These phases are best searched for and detected by (sub)millimeter dust continuum and high-density molecular tracers.

**ATLASGAL**, the first unbiased dust continuum survey of the whole Galactic plane at 870 μm, is providing a global view of all stages of massive star formation at submillimeter wavelengths [1].




### Ammonia

Ammonia is an important tool for measuring the physical conditions of dense molecular gas. From the intensity ratio of its inversion transitions the rotational temperature of the gas can be determined and from it the kinetic temperature of the clumps [2]. The $NH_3$ lines are split into distinct hyperfine components and their ratio provides a measure of the optical depth.

In particular, ammonia is an important probe for cold molecular clumps, because they consist of very high density gas ($10^5$ $cm^{-3}$, [3]) and in contrast to many other molecules such as CS and CO, $NH_3$ still exists in the gas phase.

The $NH_3$ (1,1) to (3,3) inversion transitions at ~ 23.7 GHz were observed towards clumps detected in **ATLASGAL** with typical spectral resolutions of 0.7 km/s (Effelsberg) and 0.4 km/s (Parkes) and a typical noise of 0.1 K.

- l=5°– 60°, b=±1.5°: using the Effelsberg telescope
- Flux-limited subsample of 862 sources in the 1st quadrant above ~ 0.4 Jy/beam

**Detections:**

- 87% in the (1,1) inversion transition
- 82 % in $NH_3$ (2,2)
- 48% of the (3,3) line

Fig. 3. Effelsberg 100-m-telescope

Fig. 4. Parkes 64-m-telescope

- l =300°- 359°, b=±1.5°: using the Parkes telescope
- Observations of 354 clumps in the 4th quadrant above ~ 1.2 Jy/beam

**Detections:**

- 89% in the $NH_3$ (1,1) line
- 74% in $NH_3$ (2,2)
- 53% of the (3,3) line

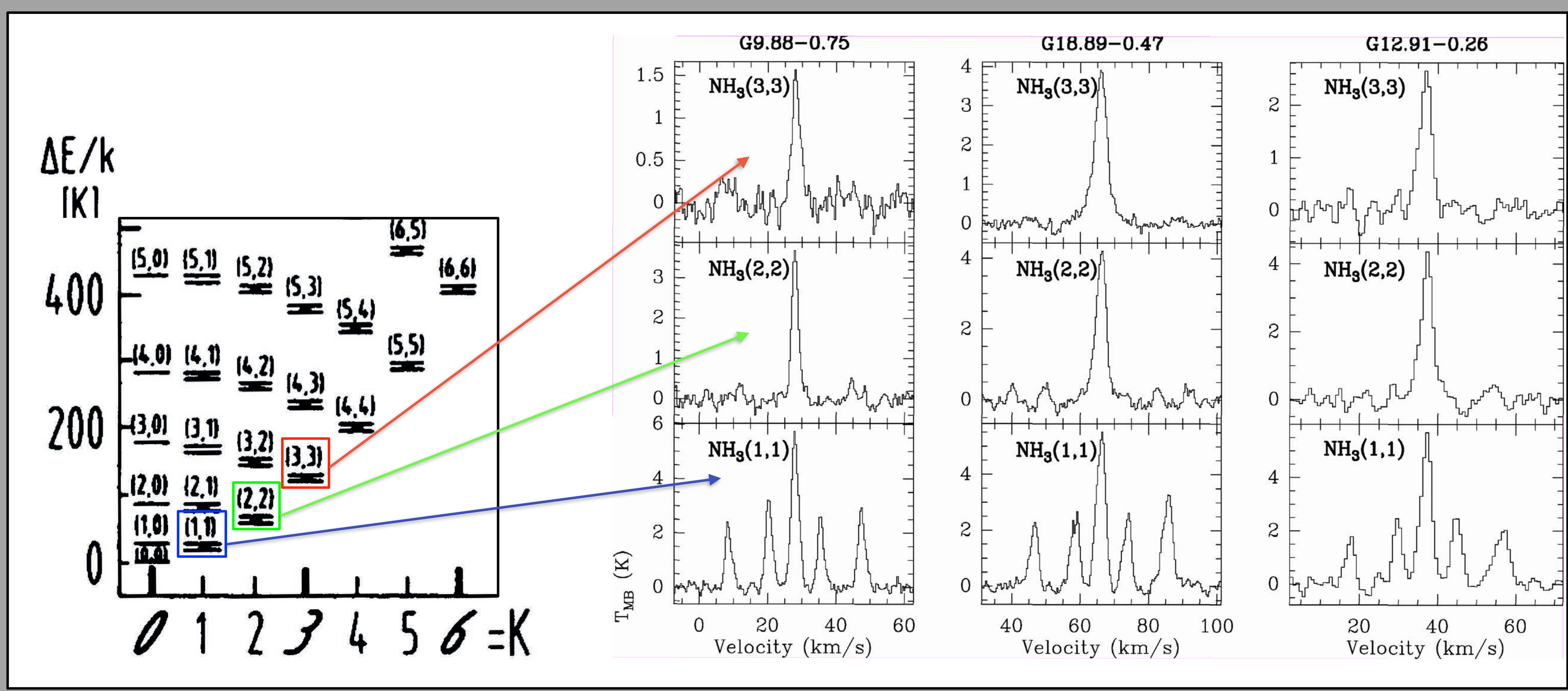



Fig. 1. $NH_3$ rotation-inversion states from Ho & Townes, 1983, ARA&A, 21, 249

Fig. 2. Example spectra of $NH_3$ (1,1) to (3,3) inversion transitions

## Galactic distribution & Distances

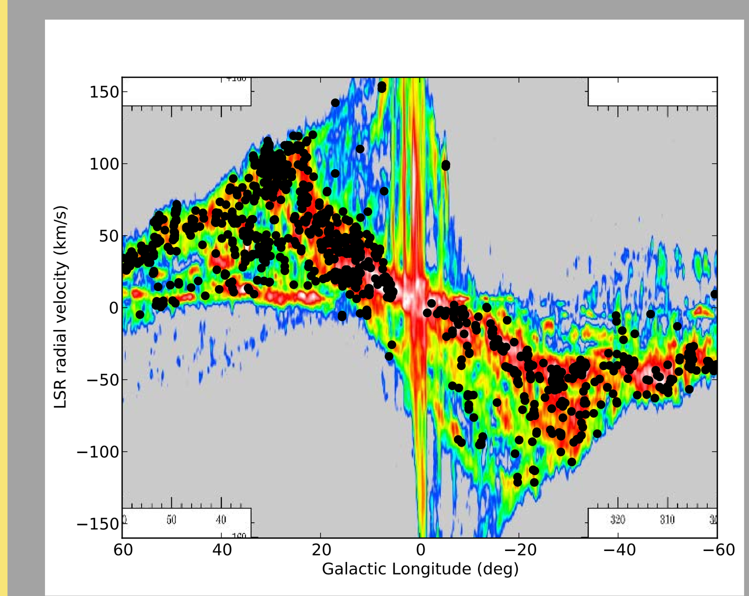



Fig. 5. Comparison of LSR velocities against Galactic longitude with CO (1-0) emission (Dame et al. 2001) shown in the background.

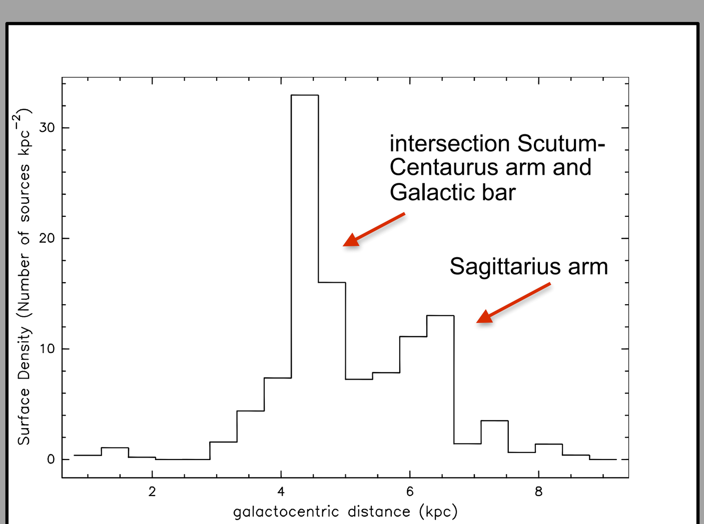



Fig. 6. Number distribution of clumps in 1st quadrant with Galactocentric distance.

$NH_3$ velocities have been pivotal in determining the three-dimensional distribution of dense gas.

Using the model from Brand & Blitz [4] for the rotation of the Milky Way we get the kinematic distance from the measured radial velocity. Each velocity in the inner Galaxy corresponds to two distances, **a near and far distance**.

Independent of the near/far kinematic distance ambiguity the distribution of Galactocentric distances can be studied. We find a correlation between the number of ATLASGAL sources as a function of Galactocentric radius and the position of spiral arms.

To resolve the kinematic distance ambiguity we examine HI self-absorption toward $NH_3$ observations and for 21 cm continuum sources, e.g. HII regions, absorption features in the HI 21 cm continuum.

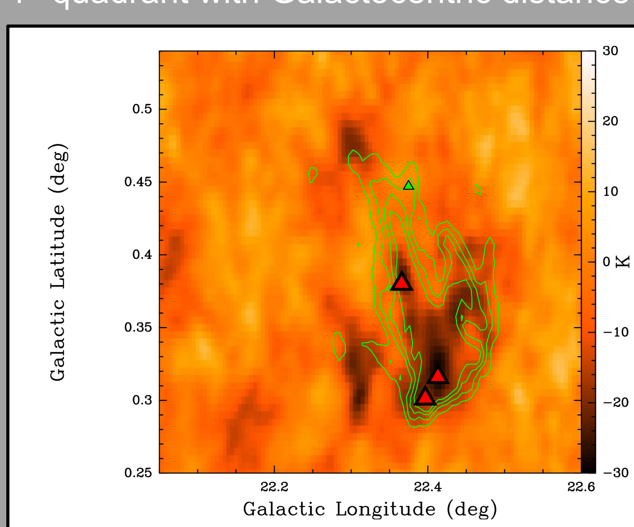



Fig. 7. Example of HI self-absorption: HI data in the background show absorption toward $NH_3$ sources (red triangles) with GRS $^{13}CO$ emission as green contours, which reveals the near distance.

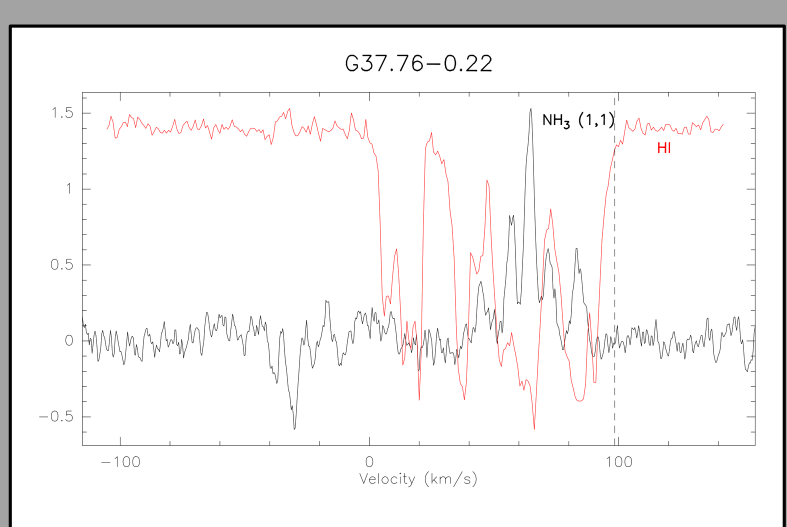



Fig. 8. Absorption of 21 cm continuum between source velocity of $NH_3$ (1,1) line and velocity of the tangent point (dashed line) by foreground molecular clouds, which indicates the far distance.

## Physical properties of ATLASGAL clumps

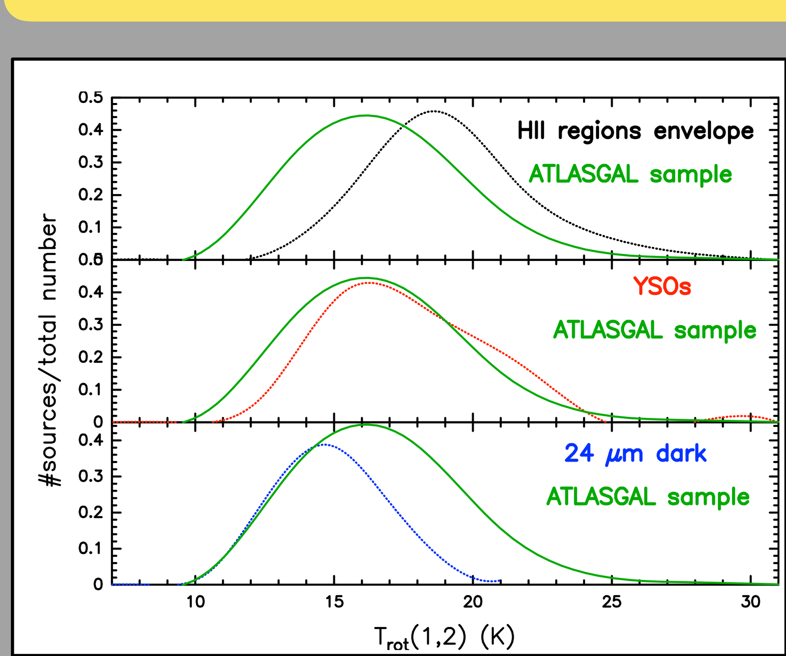



Fig. 9. Histogram of rotational temperature for samples in different evolutionary phases.

- A clear trend of increasing rotational temperatures with evolutionary phase for ATLASGAL samples ranging from 24 μm dark sources to clumps with embedded HII regions is found.

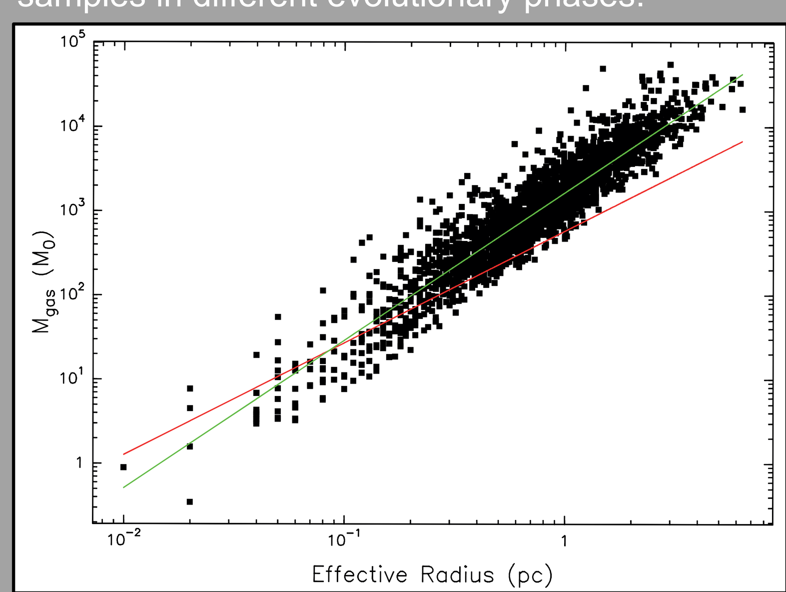



Fig. 10. Mass-size relation.

- 92% above threshold for high-mass star formation $M(r) = 580\ M_\odot\ (R_{eff}\ pc^{-1})^{1.33}$ [5] (red line)
- power law fit (green line) gives slope consistent with that of methanol masers and UCHIIRs [6]

most ATLASGAL clumps are already forming high-mass stars or have the potential to form massive stars in the future

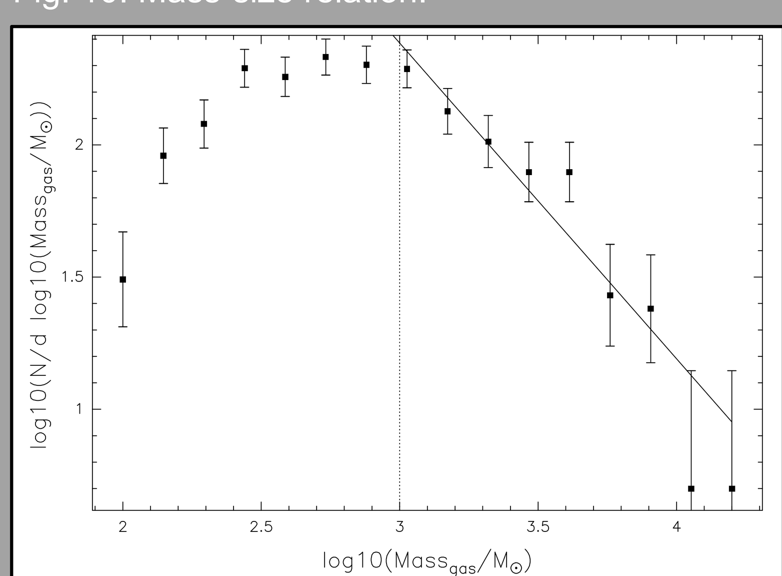



Fig. 11. Differential clump mass function of sources within distances from 2 to 5 kpc.

- Mass spectrum of ATLASGAL sources within 2 to 5 kpc
  $dN/dM \sim M^{\alpha}$
  with $\alpha = -2.2$
- α agrees with power-law exponent of clusters and interstellar clouds (Lada & Lada 2003)

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