



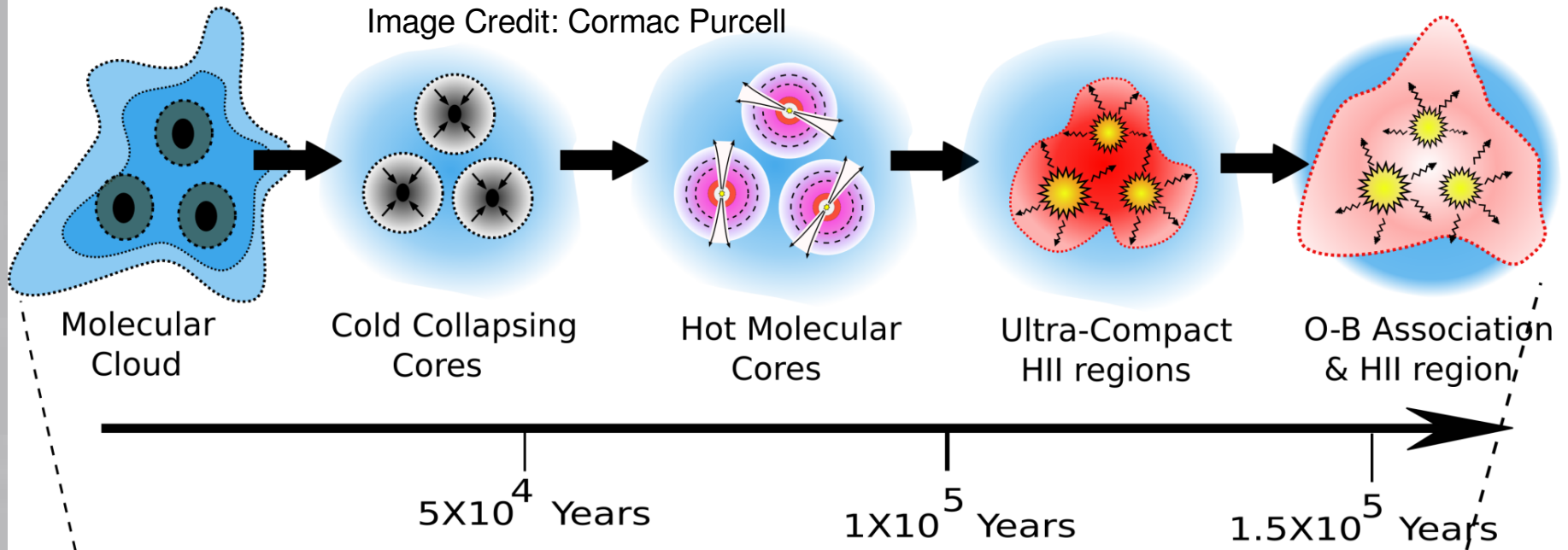
# Uncovering the earliest stages of massive star formation

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# Motivation



Simplistic Evolutionary Scenario

Can observational tracers (such as methanol maser emission) pin point a specific evolutionary stage?

If formation process is continuous rather than step-like, how accurately can we differentiate evolutionary age?

# Outline

- Observations
- Deriving physical properties of molecular/ionised gas
  - Column density
  - Temperature
  - Dynamics
- Evolutionary scenario revisited

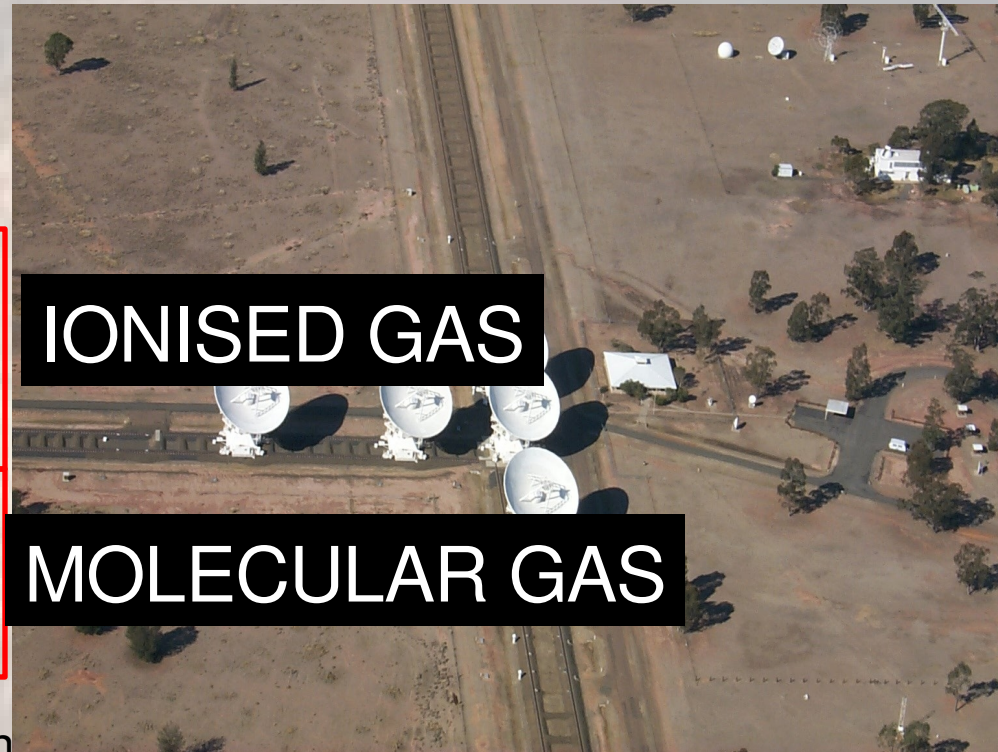
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# Observation details

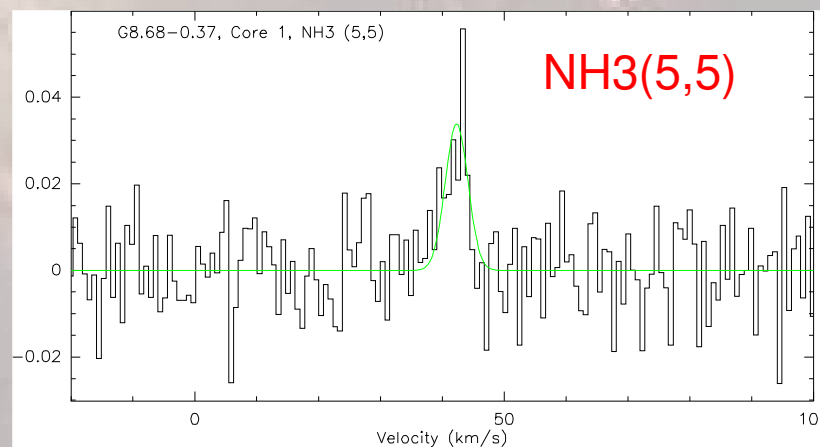
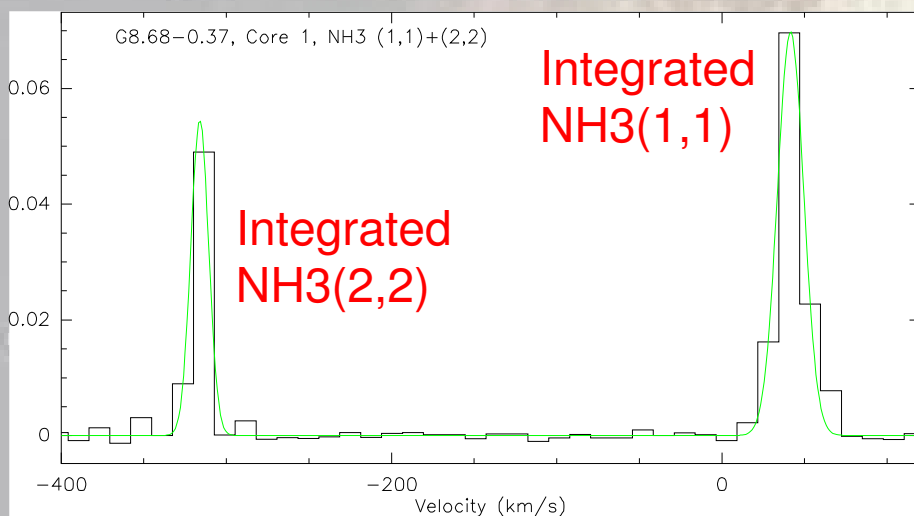
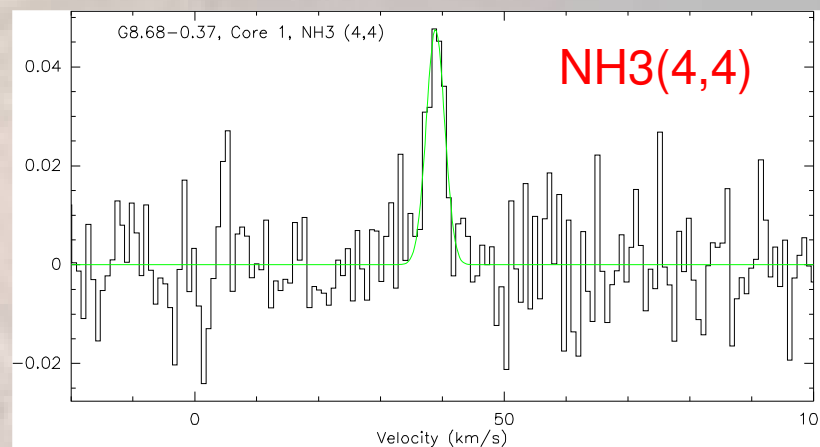
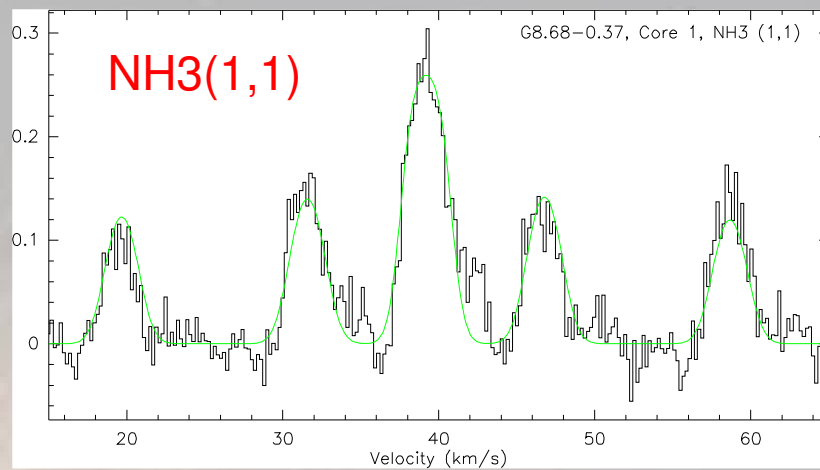
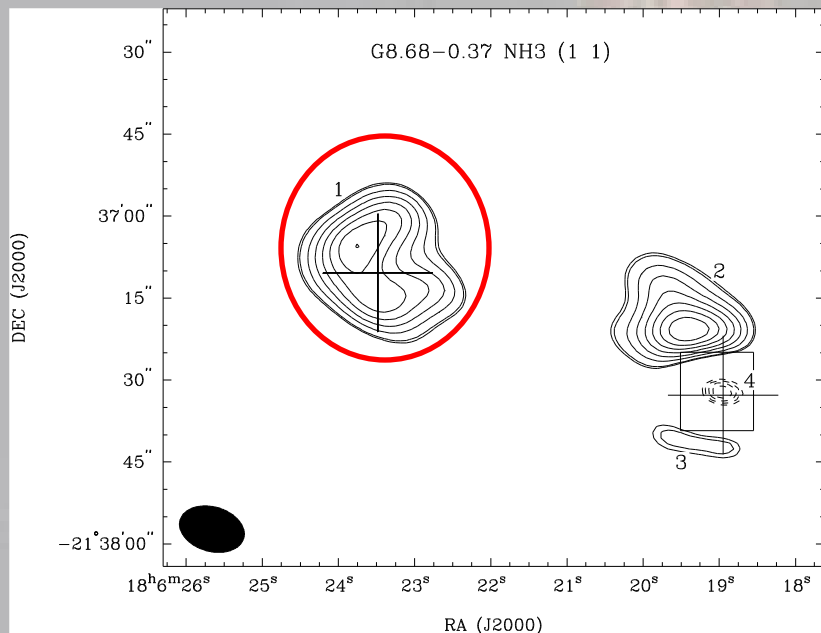
- Australia Telescope Compact Array (6x22m antennae)
  - ‘snap-shot imaging’ mode
    - 4x15 minute cuts
    - hybrid array configuration (NS+EW spurs)
    - 8 -11” spatial resolution
  - 24GHz (12mm) continuum
    - 1 mJy/beam rms
  - 8GHz (3cm) continuum
    - Previously observed (Walsh et al 1998)
  - Multiple Ammonia Inversion Transitions
    - $\text{NH}_3(1,1)$  to (5,5)
    - 18 mJy/beam rms per channel
- Mapped 21 massive star formation regions traced by 6.7 GHz methanol maser emission.
  - Walsh et al 1998, Hill et al 2005, Purcell et al 2006

## Australia Telescope Compact Array

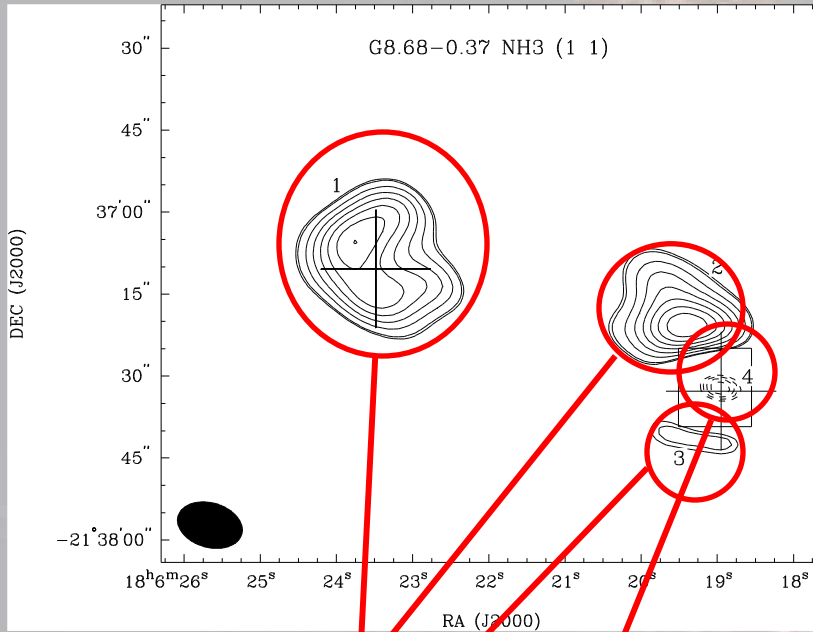


Longmore et al. 2007, MNRAS

# NH<sub>3</sub>(1,1) Integrated Intensity Map



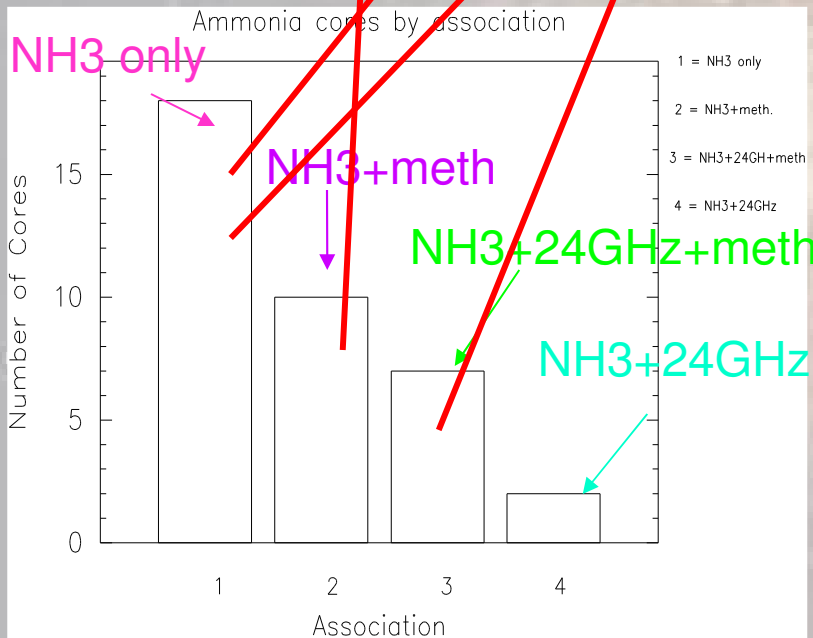
# NH<sub>3</sub>(1,1) Integrated Intensity Map



After ruling out possible selection effects/observational biases...

Are there any differences in the properties of the cores associated with ...

- methanol maser emission?
- NH<sub>3</sub> emission?
- continuum emission?



# Intermediate Results

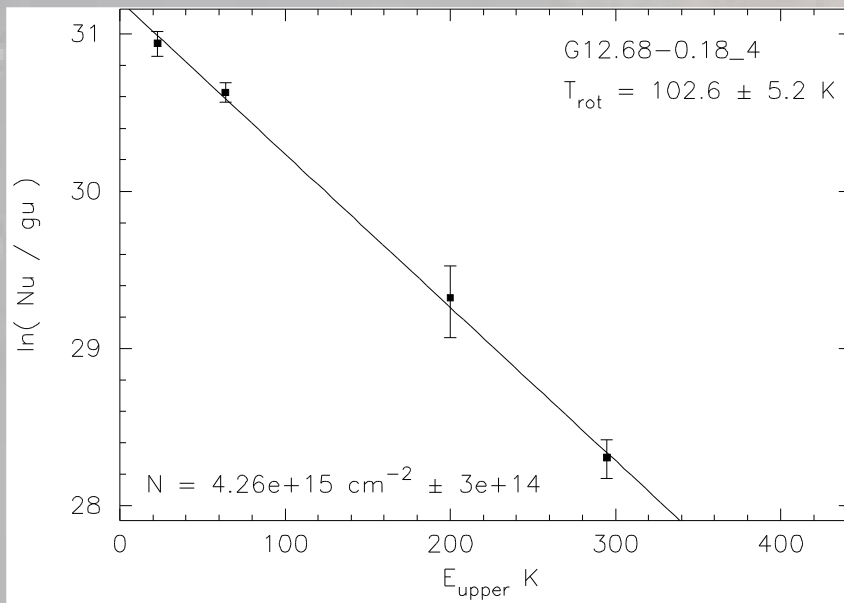
- NH<sub>3</sub> closely follows (sub-)mm dust emission for all cores
- NH<sub>3</sub>(4,4) & (5,5) emission = unresolved at maser position
  - Masers found at warmest part of core
- 24 GHz continuum sources at maser position with no corresponding 8GHz continuum emission
  - Appears to contradict Walsh et al 1998 (8GHz continuum NOT associated with methanol masers)
    - Optically thick free-free emission (hyper-compact HII)?
    - Extended emission resolved-out by previous observations?

# Outline

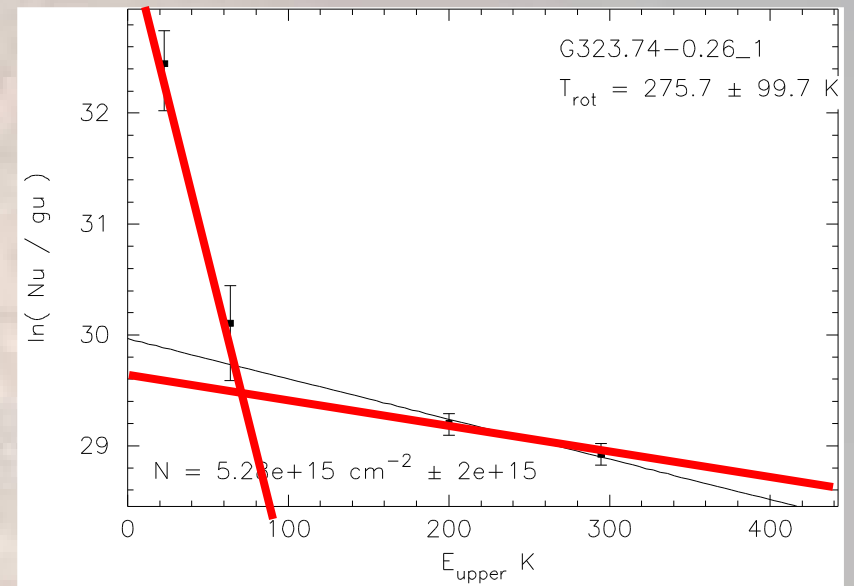
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# Preliminary Temperature Modeling

Boltzmann/Rotational diagram



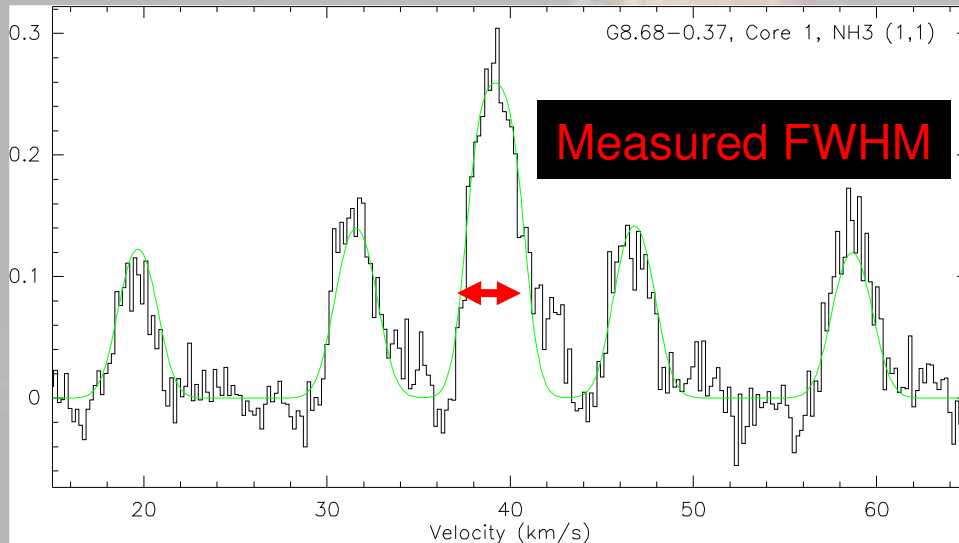
Core at well constrained single temperature



Core poorly fit by single temperature

Used LVG modeling with 2 temperature components  
(Thanks Christian Henkel!)

# Non-thermal velocity structure



$$\Delta v_{\text{thermal}} = (8 \ln[2] k_B T_{\text{kin}} / M_{\text{NH}_3})^{1/2}$$
$$= 0.23 (T_{\text{kin}} / 20\text{K})^{1/2} \text{ km/s}$$

$$\Delta v_{\text{measured}} = \Delta v_{\text{thermal}} + \Delta v_{\text{non-thermal}}$$

- Can derive non-thermal contribution to the measured linewidth from derived gas kinetic temperature.
- Linewidths dominated by non-thermal component.

• What is the nature of this injection?

– Outflows? →

Energy injection/timescale arguments plausible

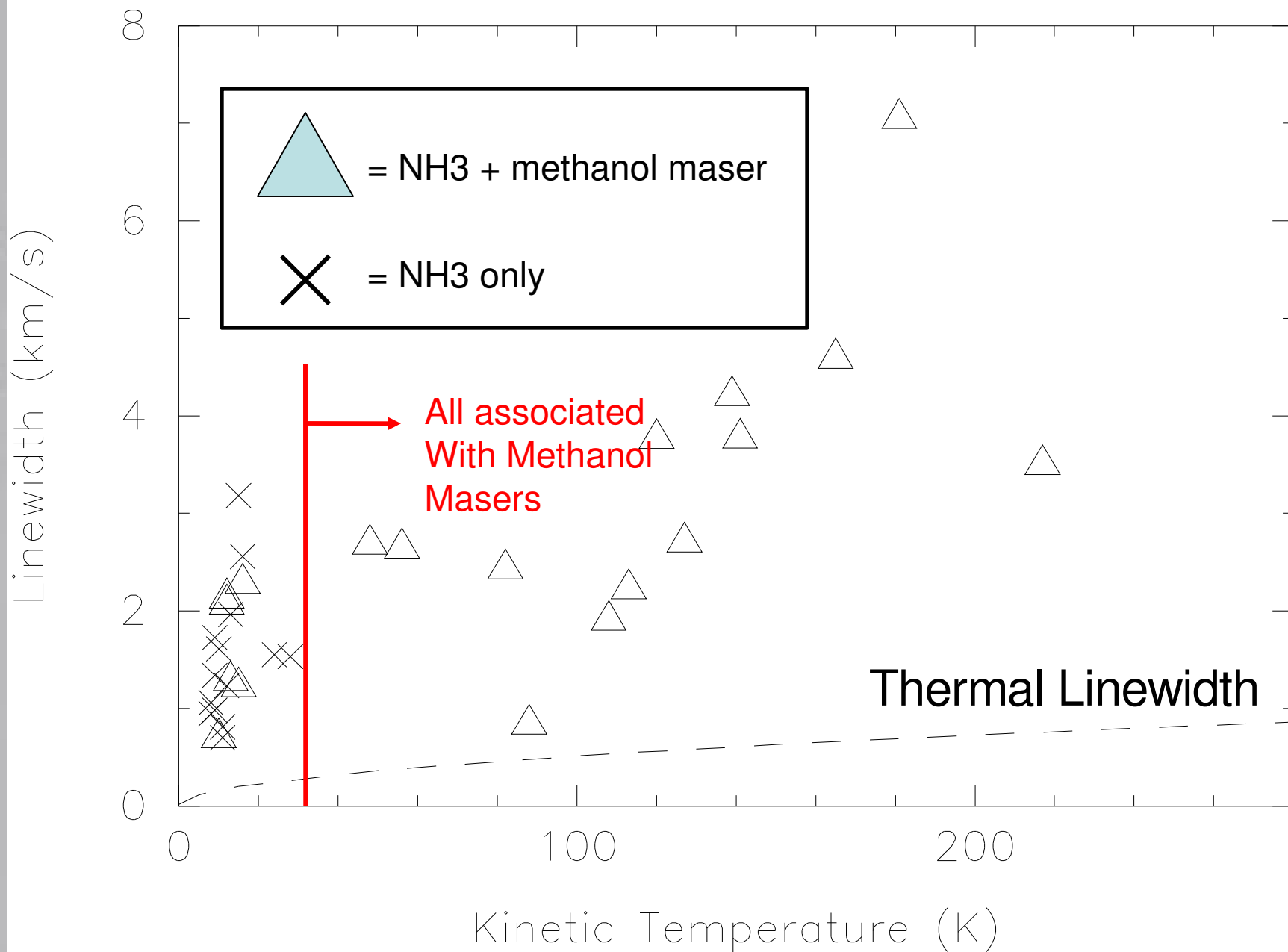
– Systematic motions? →

Need to resolve velocity structure

– Sub-clumps within beam?

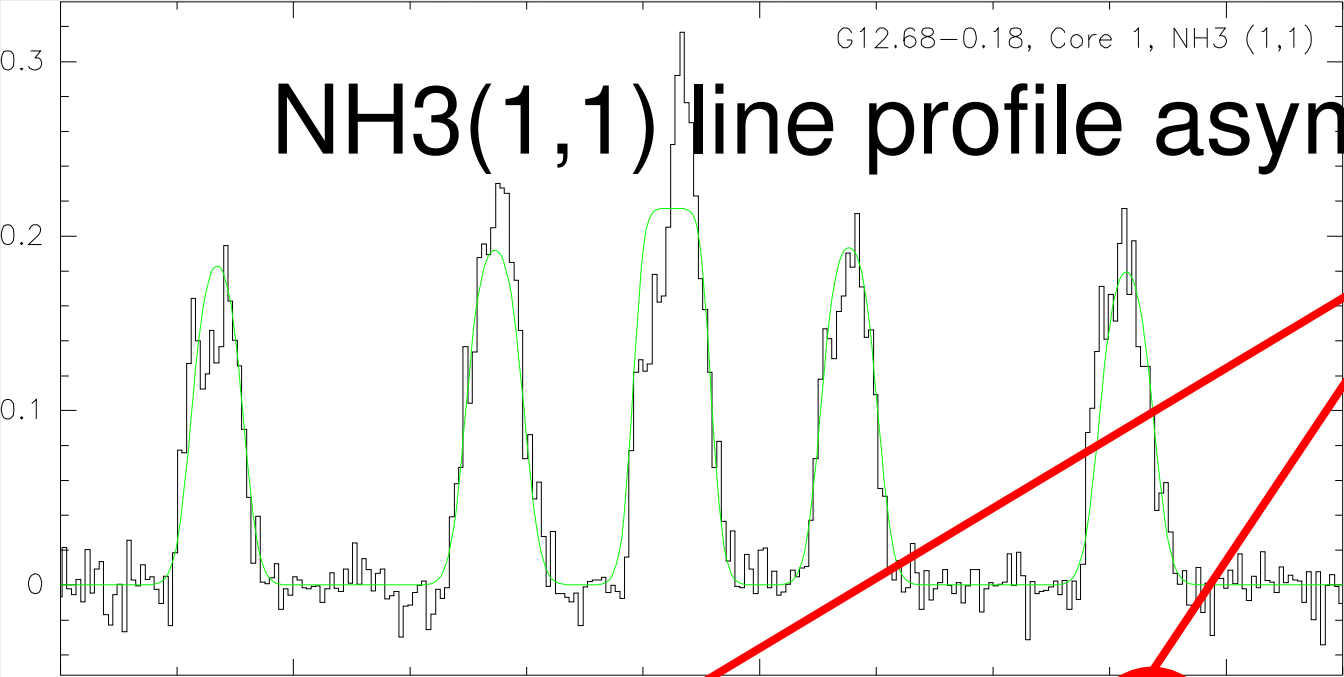
– Turbulence?

# NH<sub>3</sub>(1,1) Linewidth vs Kinetic Temperature



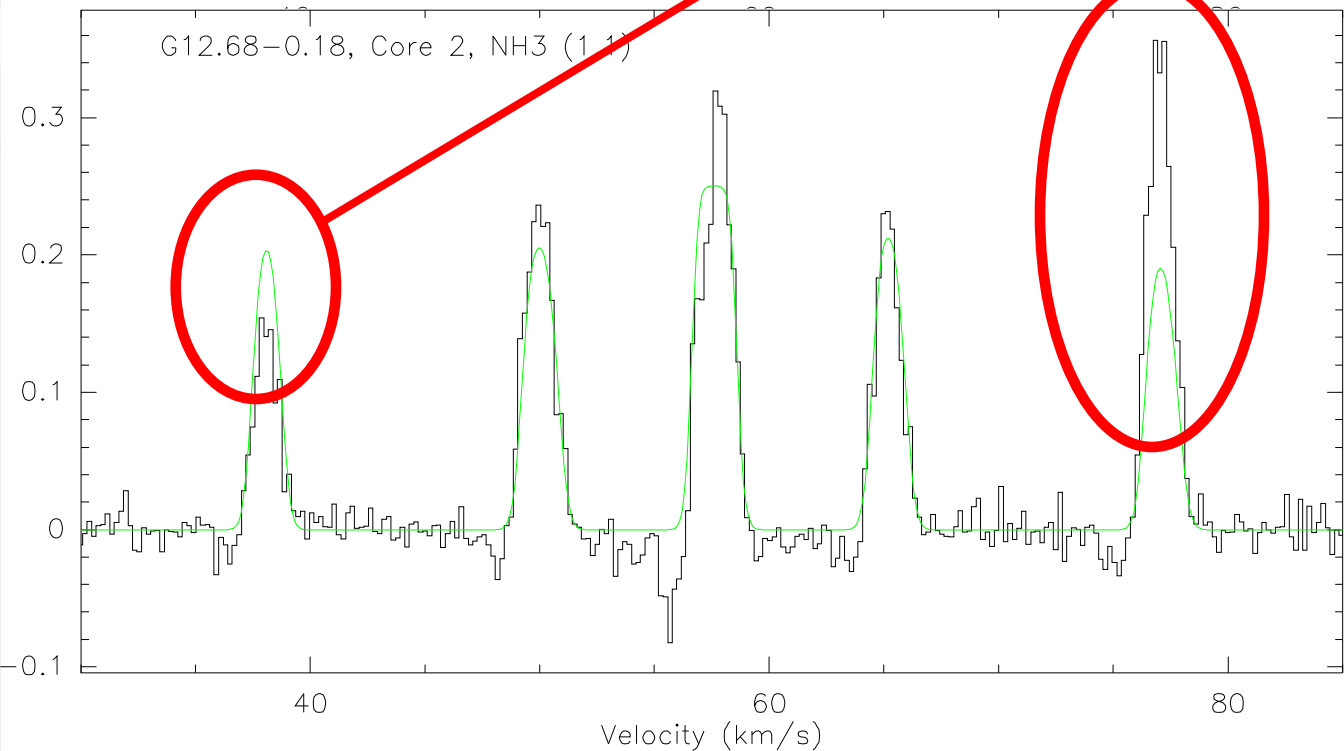
G12.68-0.18, Core 1, NH<sub>3</sub> (1,1)

# NH<sub>3</sub>(1,1) line profile asymmetries



Extreme NH<sub>3</sub>(1,1) line profile asymmetries!

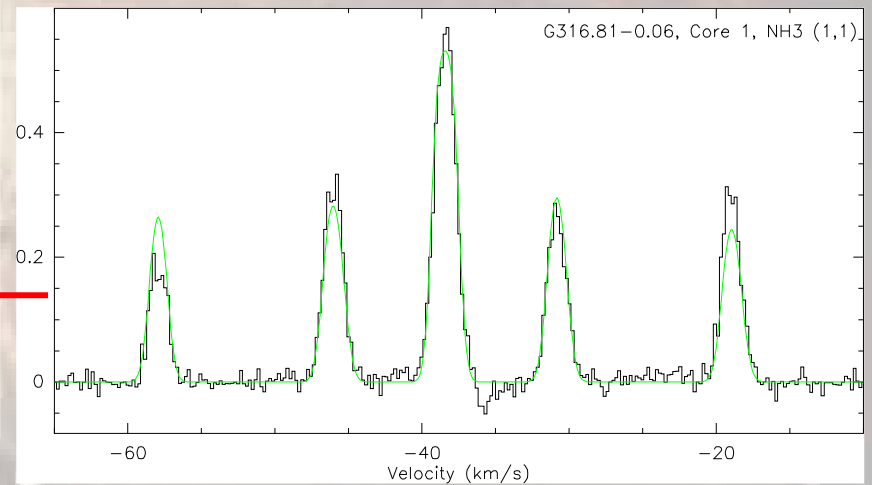
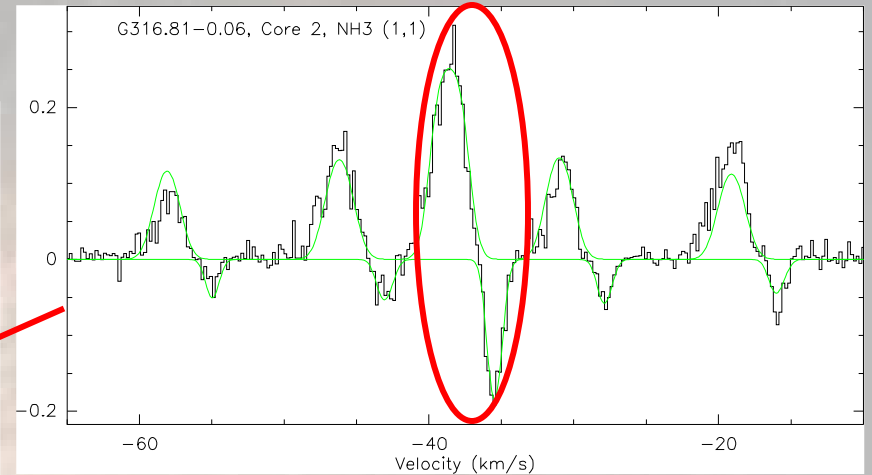
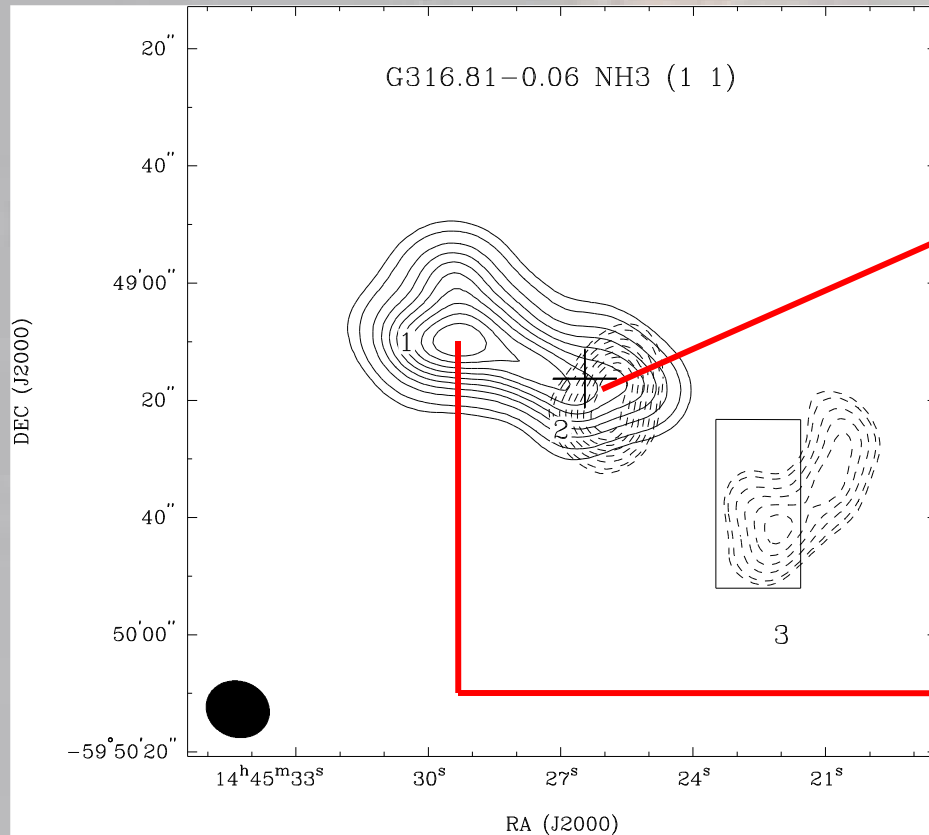
G12.68-0.18, Core 2, NH<sub>3</sub> (1,1)



Asymmetries arise due to non-LTE conditions caused by a number of sub-clumps within the beam (Stutzki & Winnewisser 1985)

# Gas Dynamics

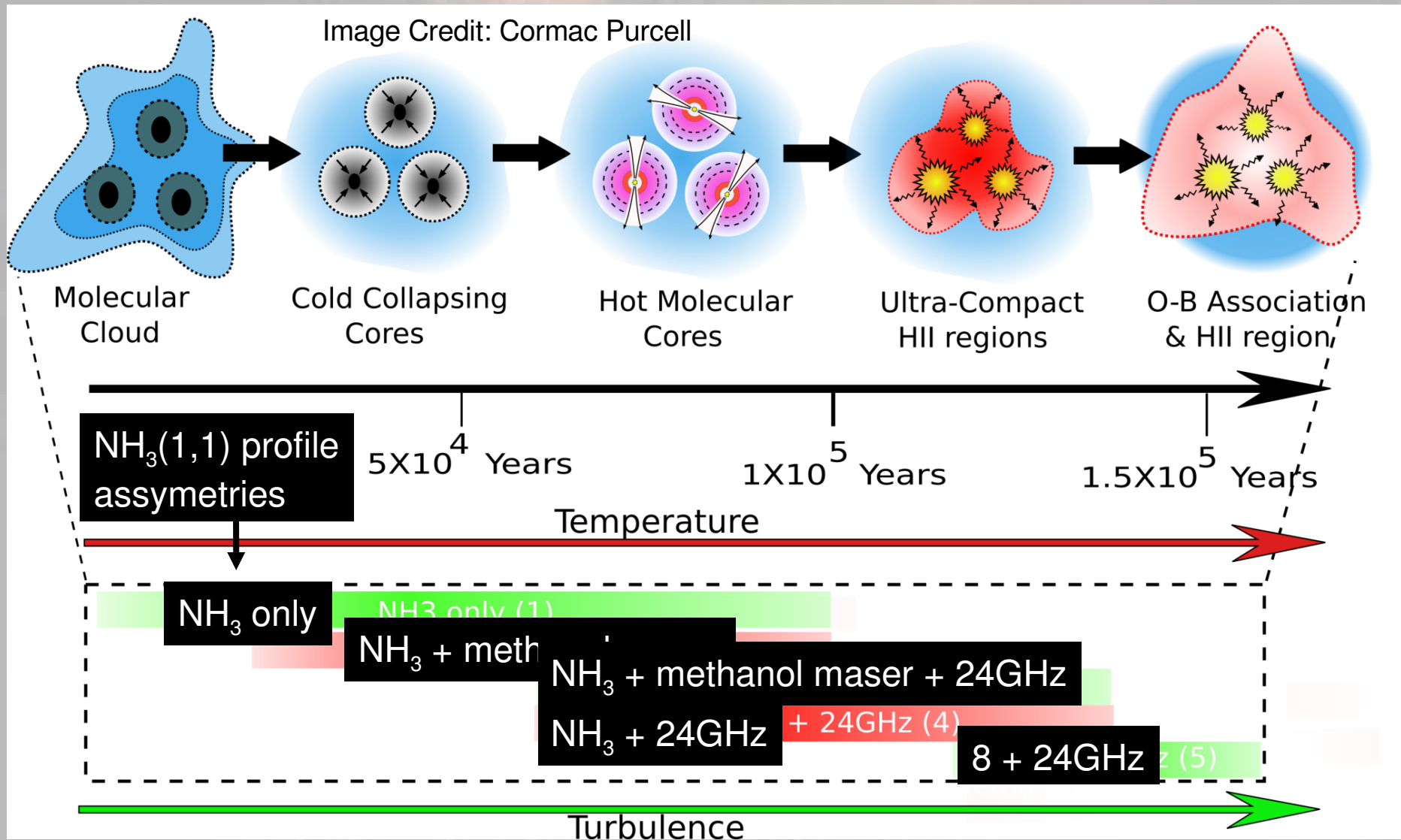
Classic infall profile



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# Simplistic Evolutionary Scenario



# Conclusions

- Making some simple assumptions about how physical properties may evolve, we separate the cores by their evolutionary state
- Methanol maser cores are generally warmer, have larger linewidths and 24GHz HII
  - more evolved with internal heat source (?)
- However, some methanol maser sources are cold
  - powering source only just switched on(?)
- Youngest sources have no methanol maser emission
  - Cold
  - Narrow linewidths
  - NH<sub>3</sub>(1,1) hyperfine asymmetries

The End