Uncovering the earliest stages of massive star formation

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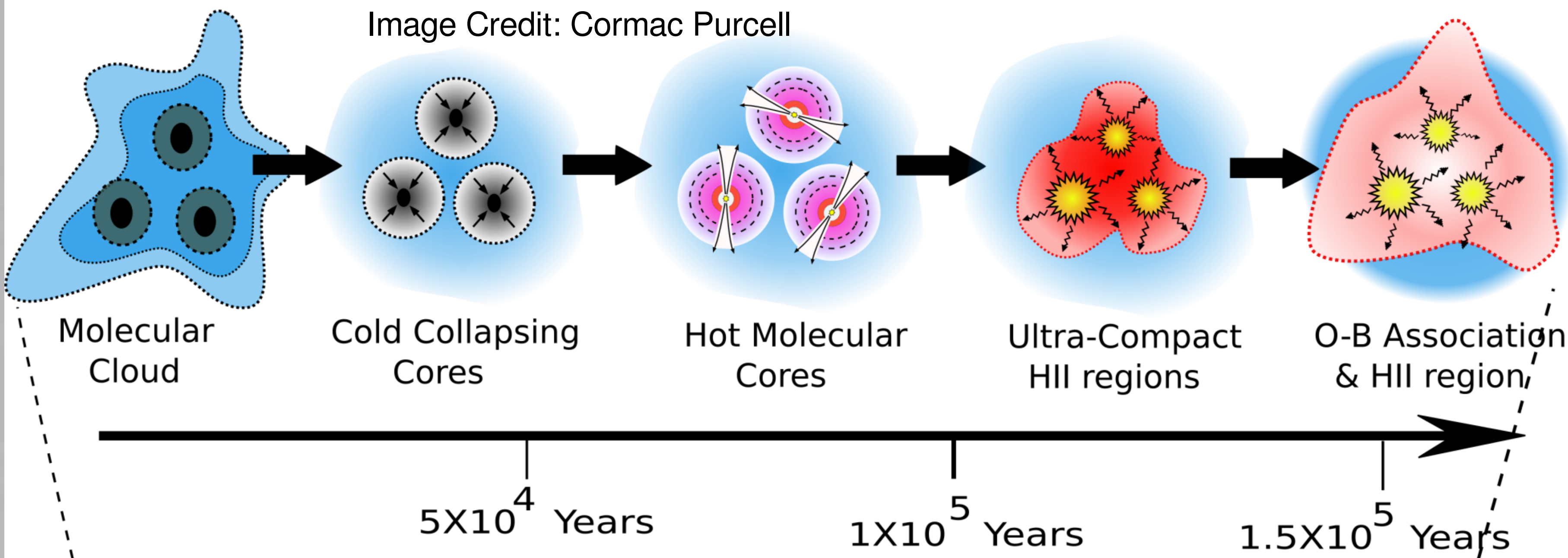
Motivation

Image Credit: Cormac Purcell



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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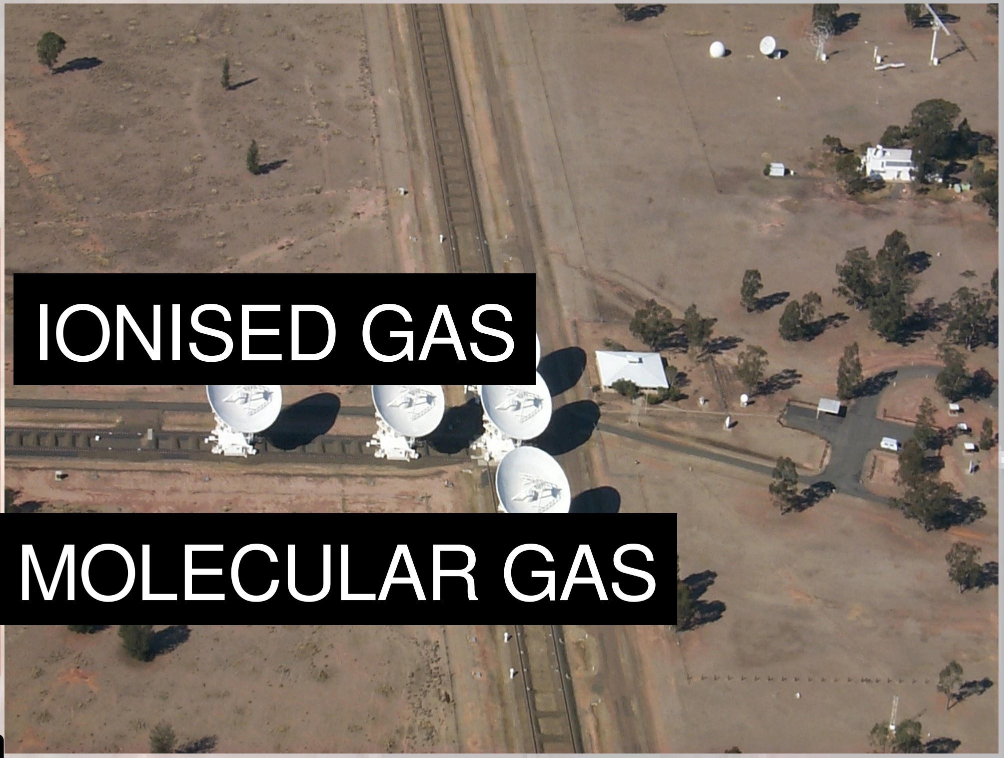
Observation details

- 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
    - NH3(1,1) to (5,5)
    - 18 mJy/beam rms per channel

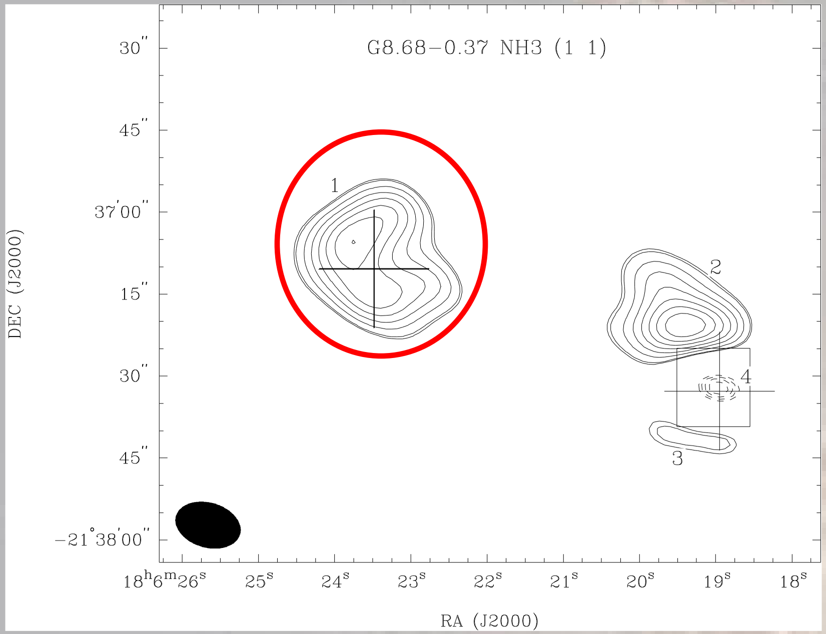
- Mapped 21 massive star formation regions traced by 6.7 GHz methanol maser emission.
  - Walsh et al 1998, Hill et al 2005, Purcell et al 2006

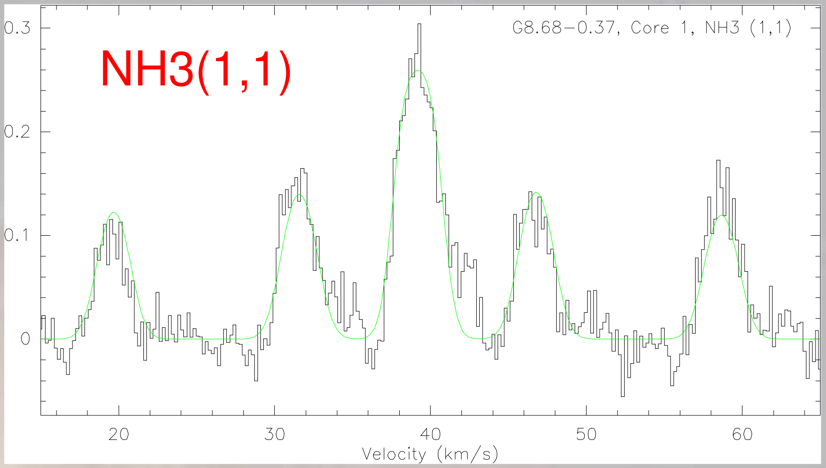
Australia Telescope Compact Array

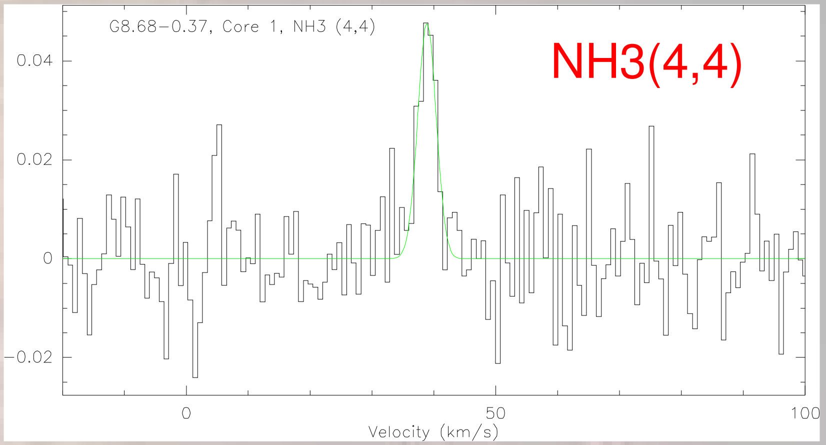


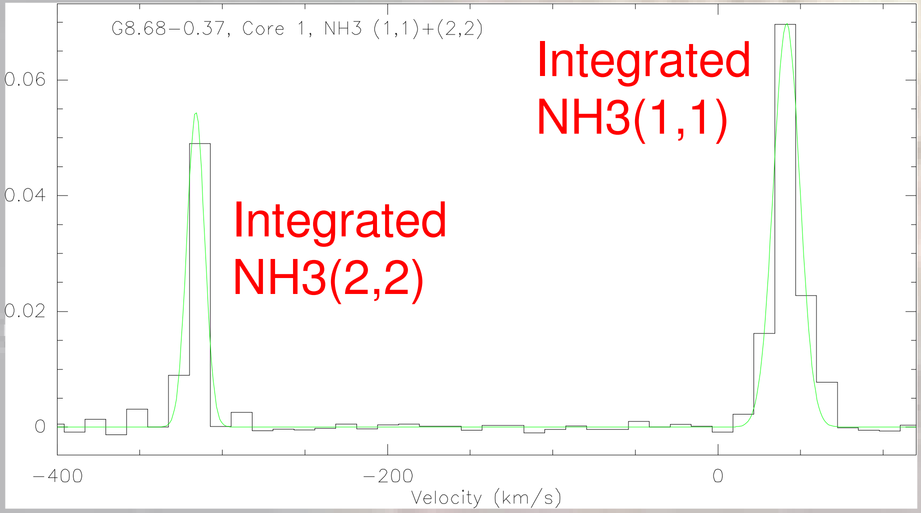
Longmore et al. 2007, MNRAS

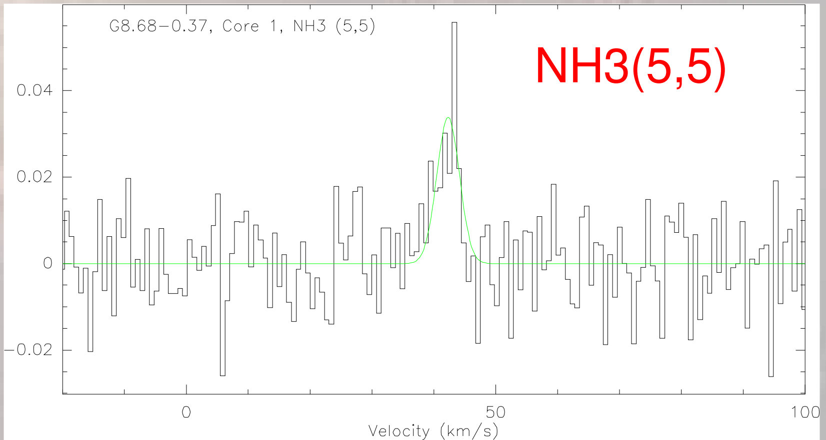
NH3(1,1) Integrated Intensity Map











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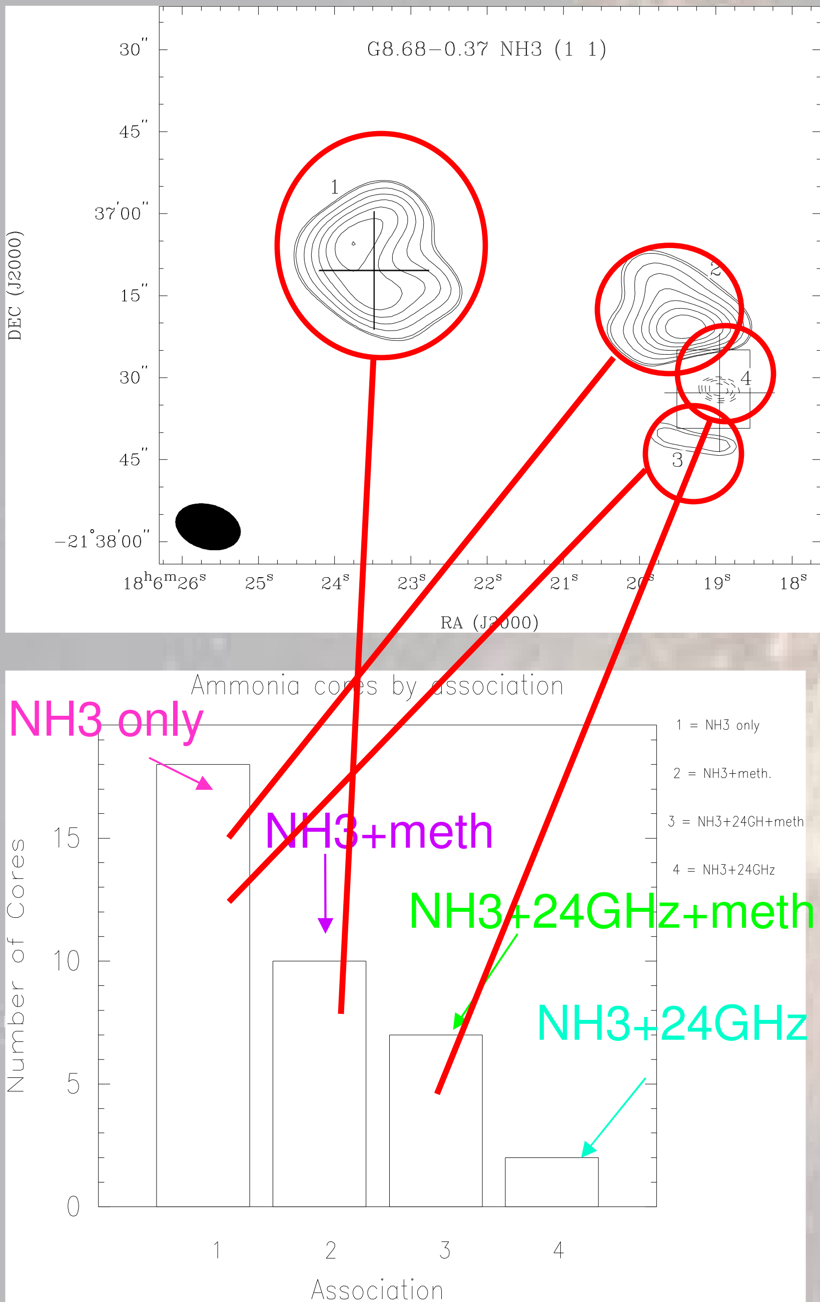

After ruling out possible selection effects/observational biases…

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

- methanol maser emission?
- NH3 emission?
- continuum emission?

Intermediate Results

- NH3 closely follows (sub-)mm dust emission for all cores
- NH3(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?

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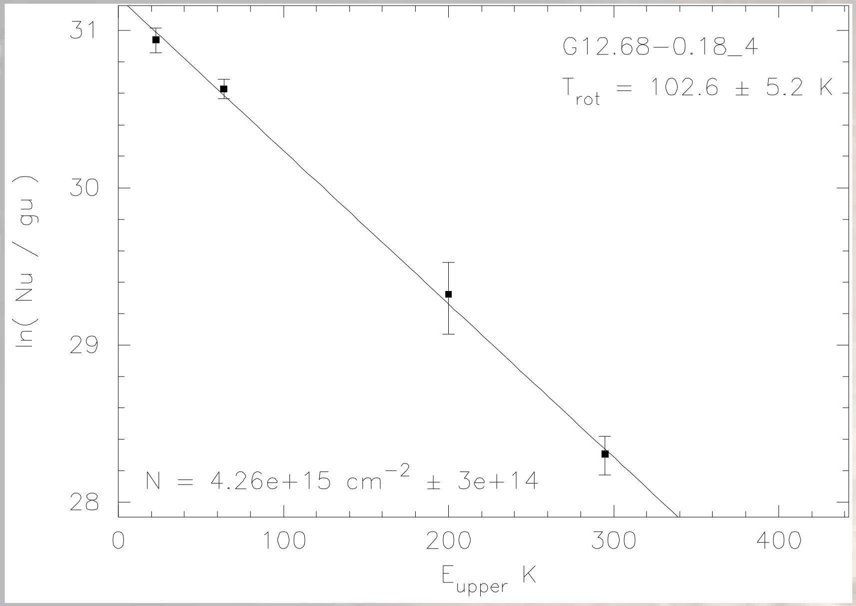
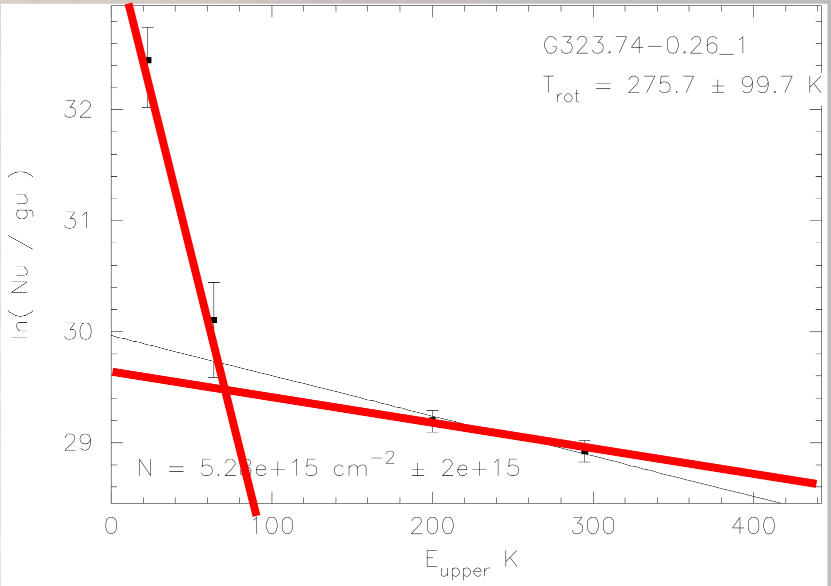
Preliminary Temperature Modeling

Boltzmann/Rotational diagram



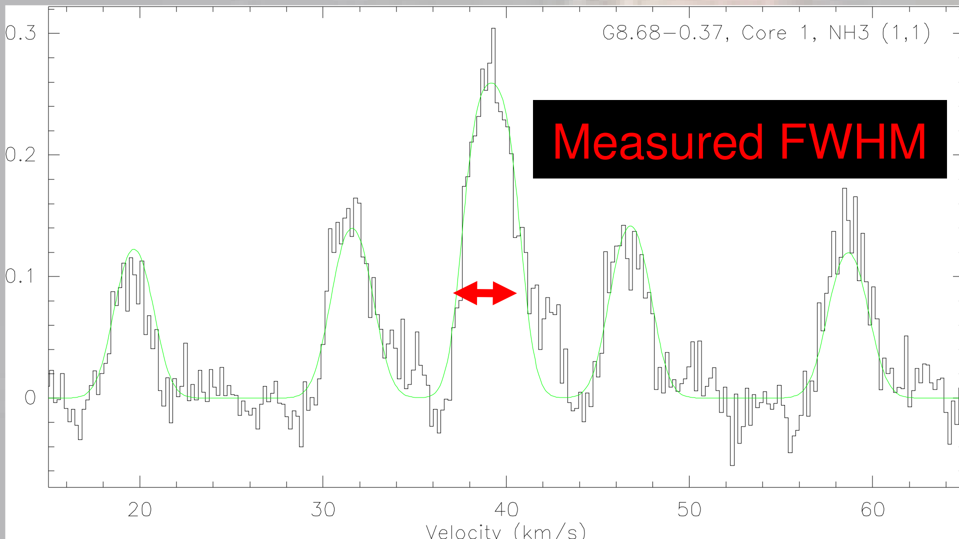
Core at well constrained single temperature



Core poorly fit by single temperature

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

Non-thermal velocity structure

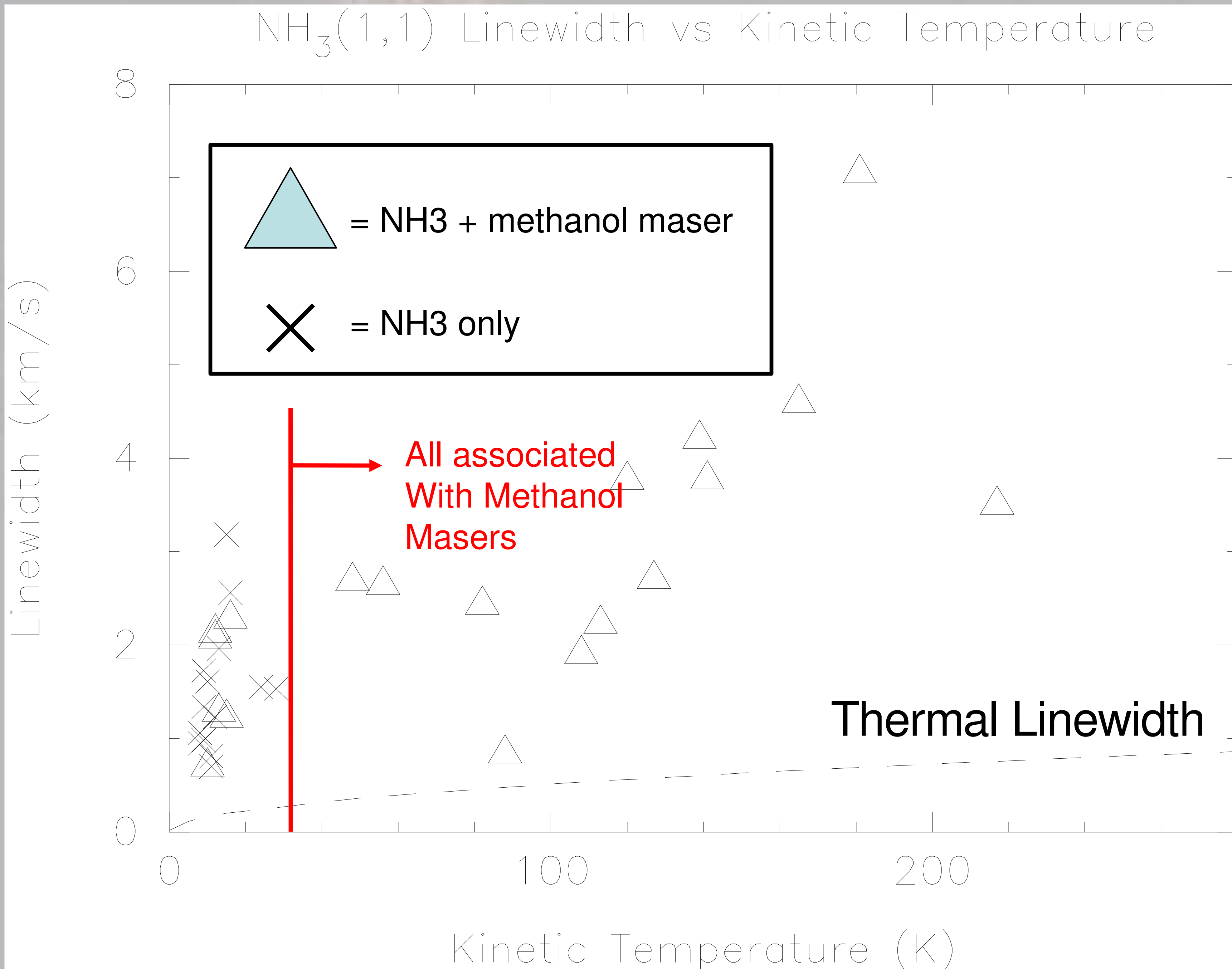


$$\Delta V_{thermal} = (8\ln[2]\, k_B\, T_{kin} / M_{NH3})^{1/2}$$

$$= 0.23\,(T_{kin} / 20K)^{1/2}\ \text{km/s}$$

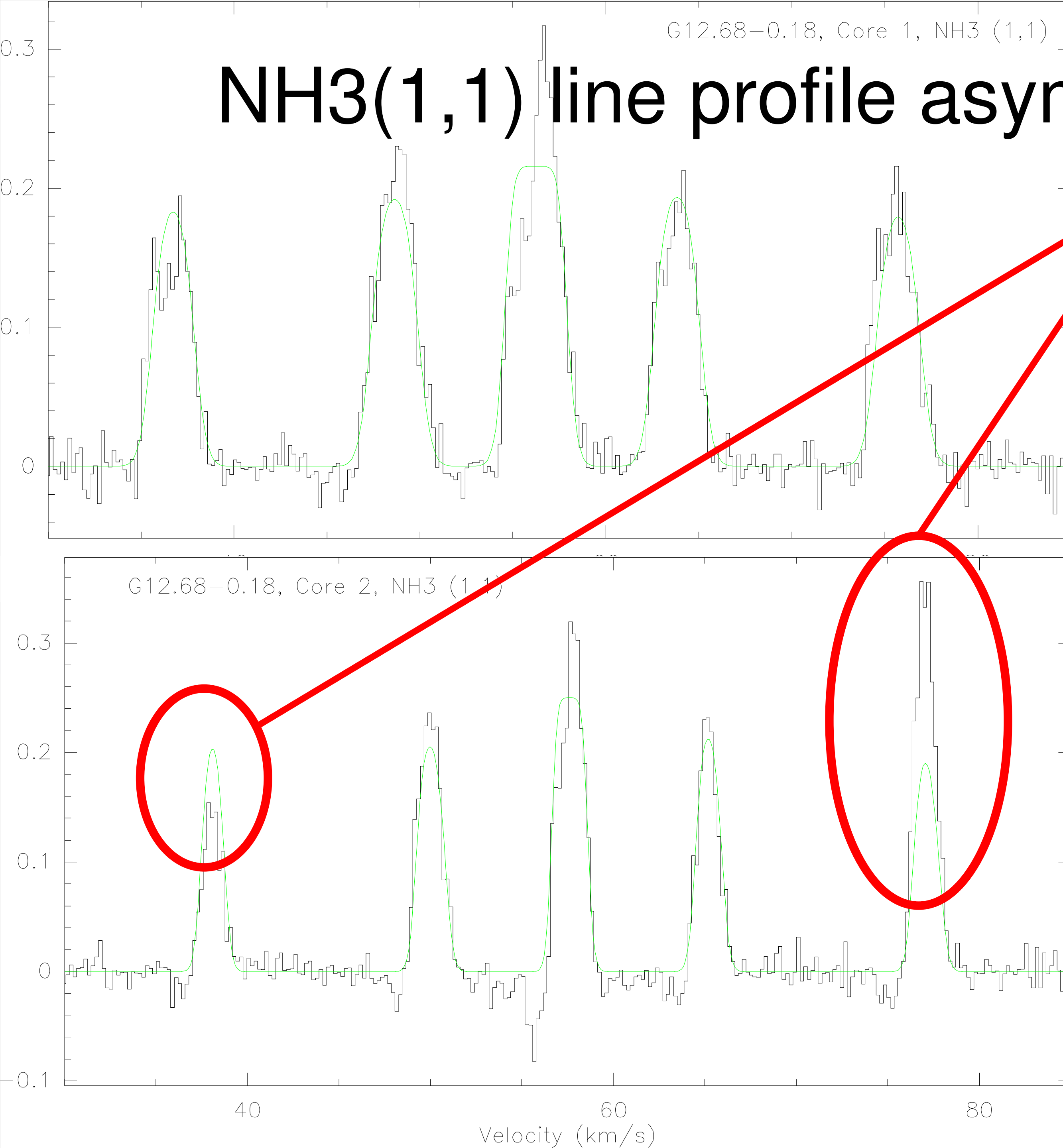
$$\Delta V^2_{measured} = \Delta V^2_{thermal} + \Delta V^2_{non\text{-}thermal}$$

- 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?



$NH_3(1,1)$ Linewidth vs Kinetic Temperature
= NH3 + methanol maser
= NH3 only
All associated
With Methanol
Masers
Thermal Linewidth
Linewidth (km/s)
Kinetic Temperature (K)
0
2
4
6
8
0
100
200

NH3(1,1) line profile asymmetries

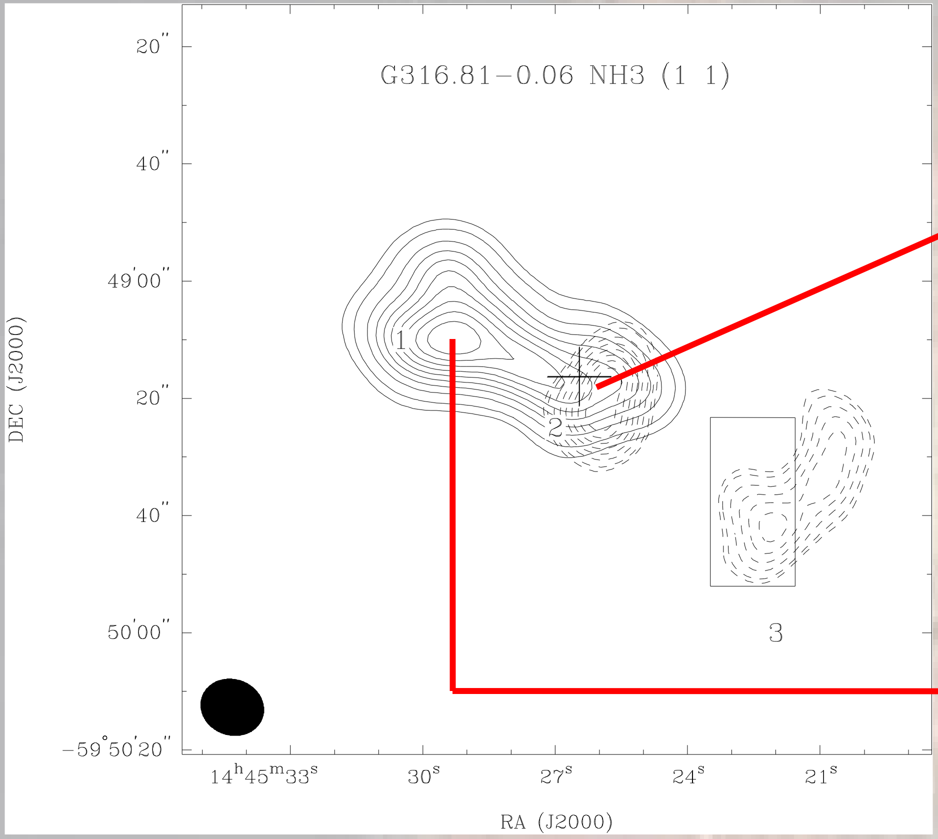


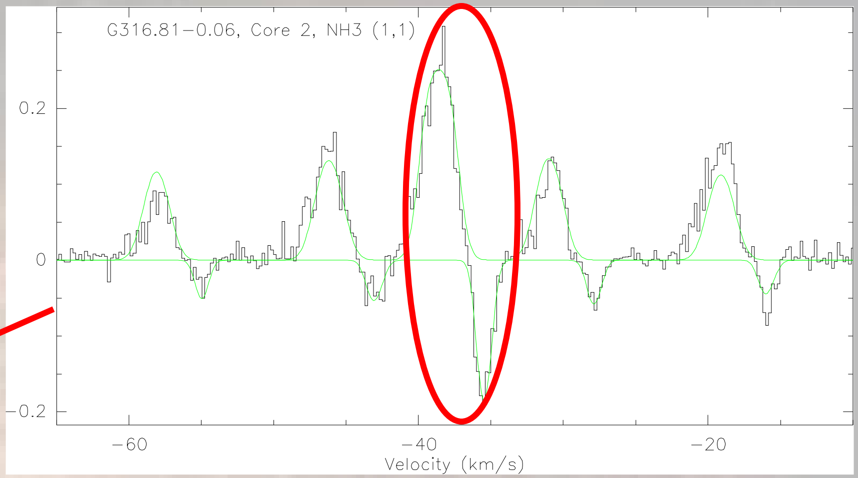
Extreme $NH_3(1,1)$ line profile asymmetries!

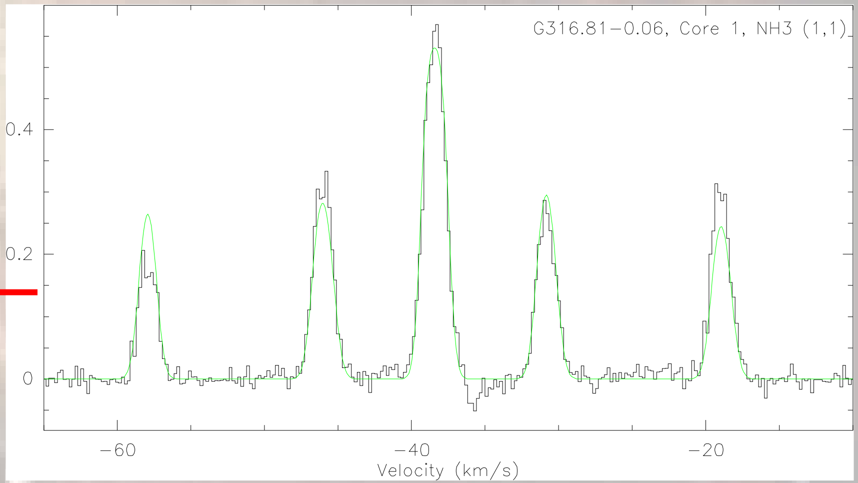
Asymmetries arise due to non-LTE conditions caused by a number of sub-clumps within the beam (Stutzki & Winnewisser 1985)

Gas Dynamics

Classic infall profile







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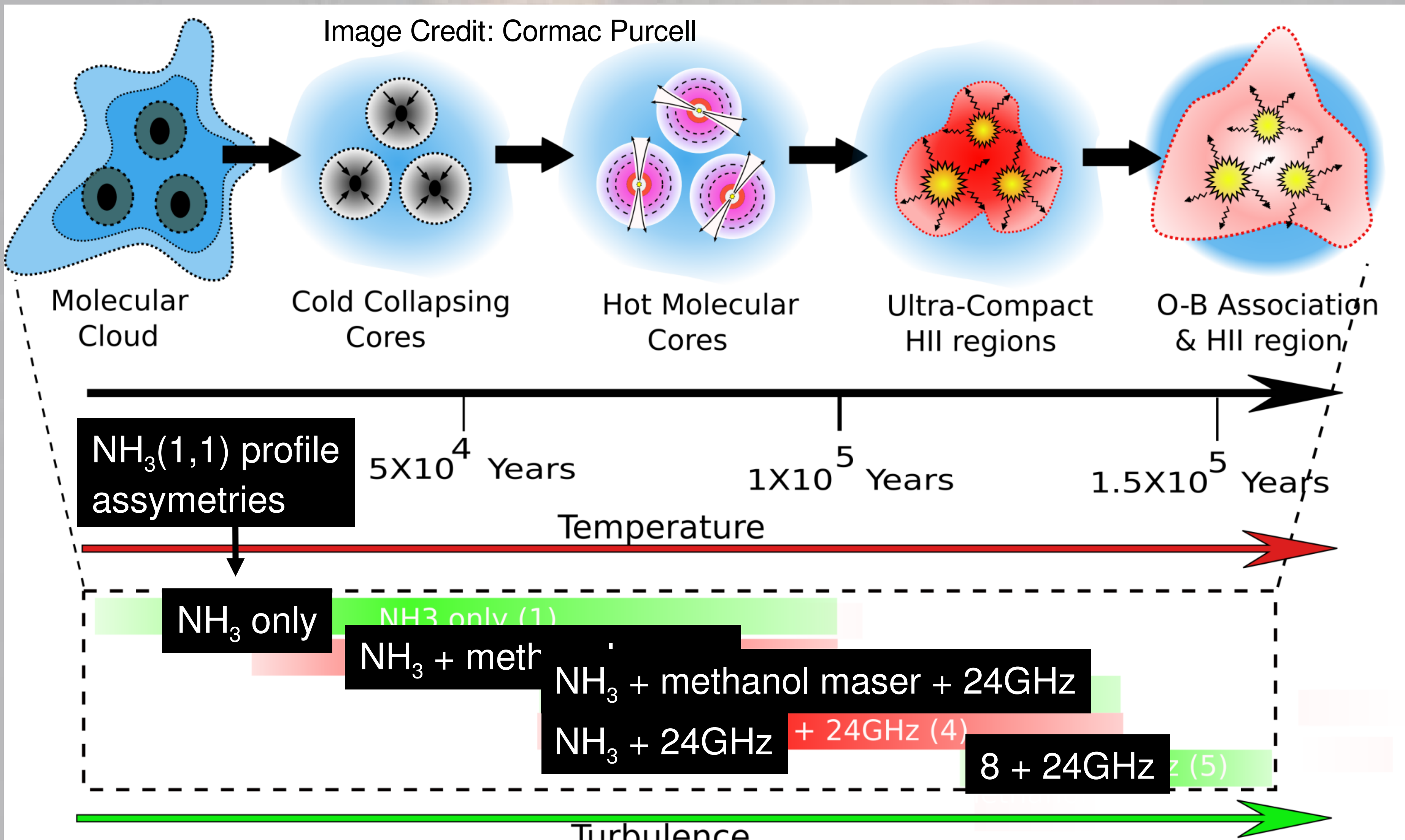

Conclusions

- 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
  - NH3(1,1) hyperfine asymmetries

The End