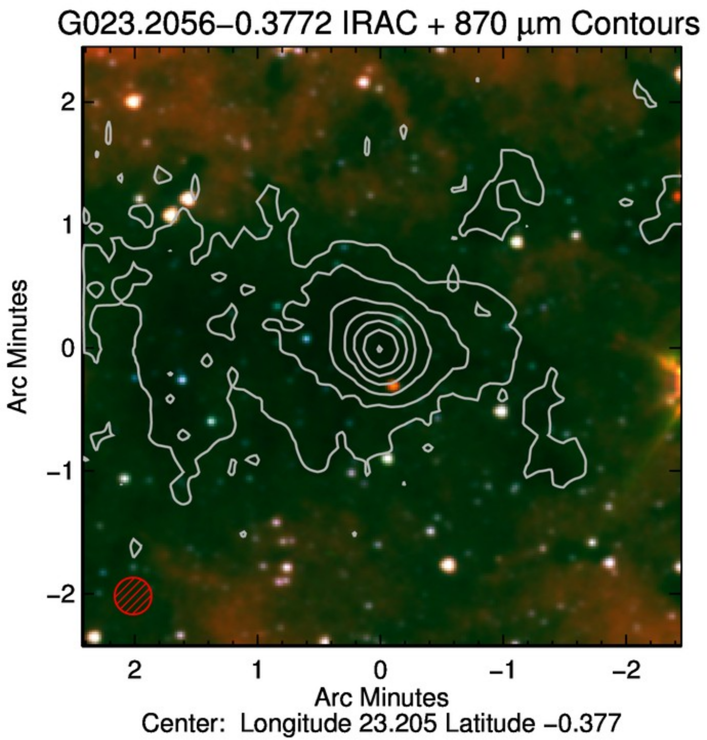
How does the gas flow from cloud to core scales?

Friedrich Wyrowski, MPIfR Bonn

From clouds to clumps to clusters

Infall is a fundamental process in SF!

ATLASGAL



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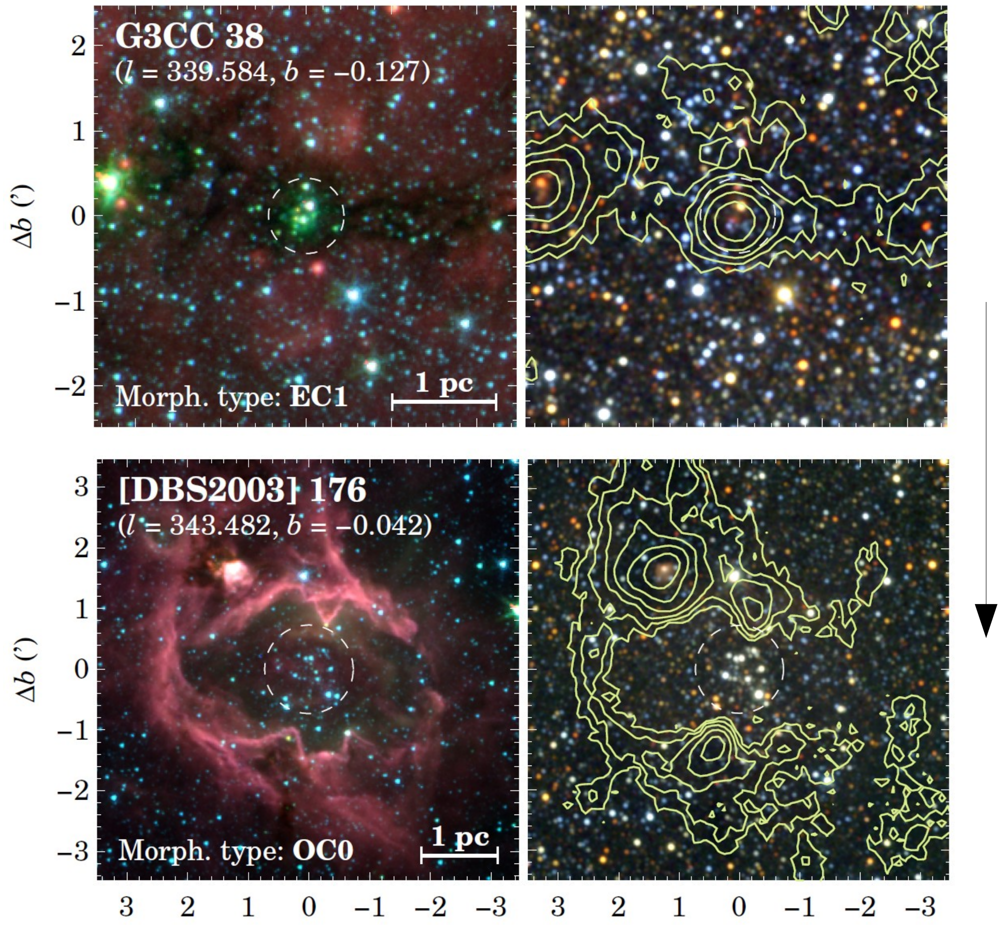

From clouds to clumps to clusters

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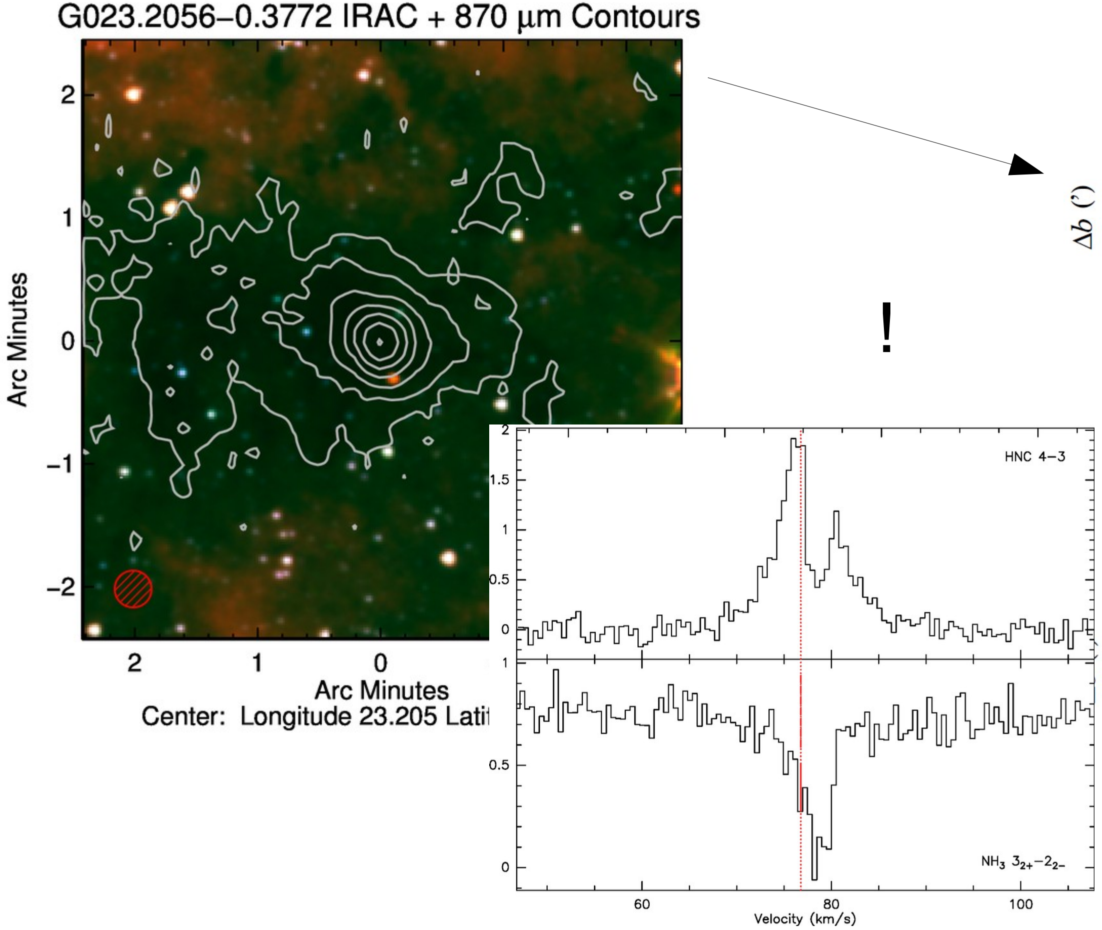
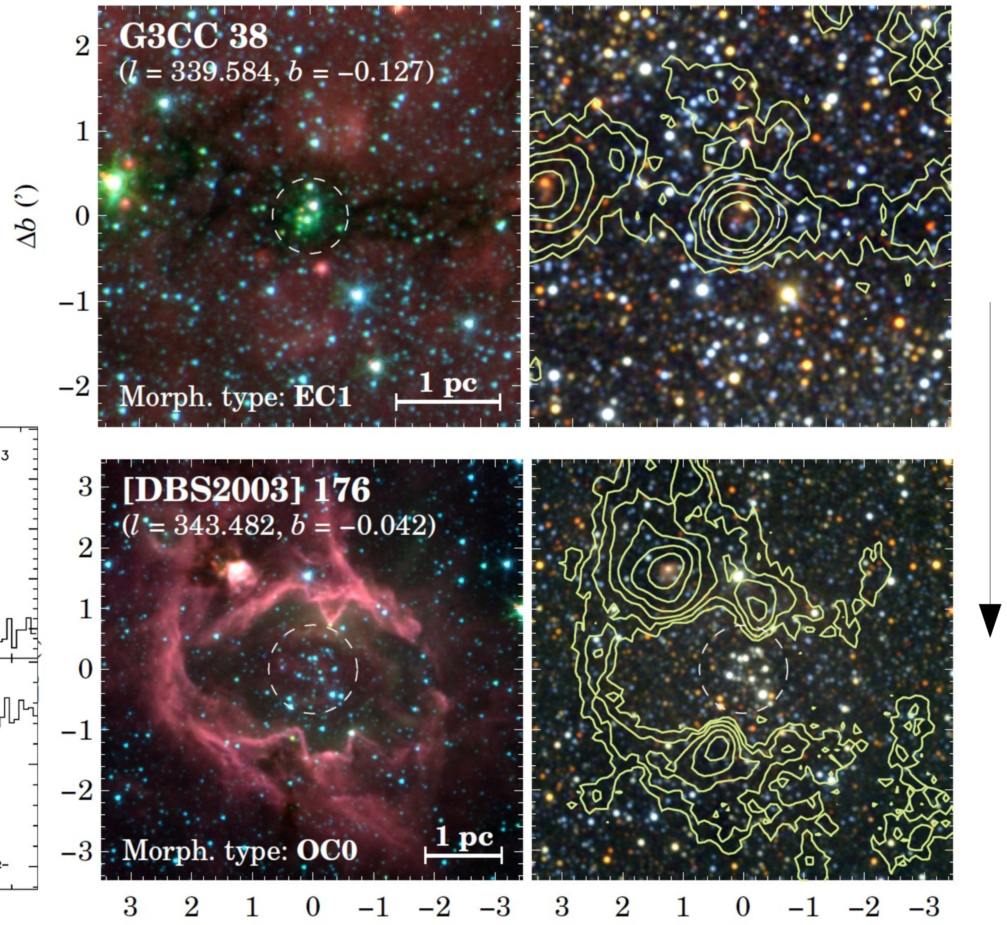
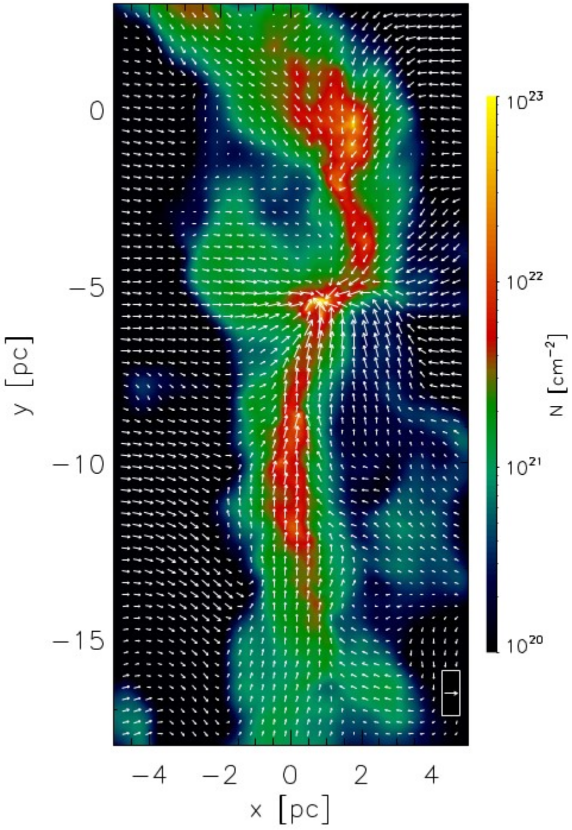




The problems

- Going from cloud densities of 10^{2-3} cm^{-3} to 10^{6-8} cm^{-3} in cores.
- Core masses seen with interferometers usually just “tip of the iceberg”
  - Cores, as progenitors of stars/multiples need to be fed
- We only see (mostly) PPV

Importance of cloud and clump scales



- SF as multi-scale process
- Mass flow through hub-filaments to cores
- Clumps: initial conditions for fragmentation
- "Inertial-Inflow Model" (Padoan+2020), filament to envelope 10-1pc (right)
- Global hierarchical collapse (Vazquez-Semadeni+2019, left)

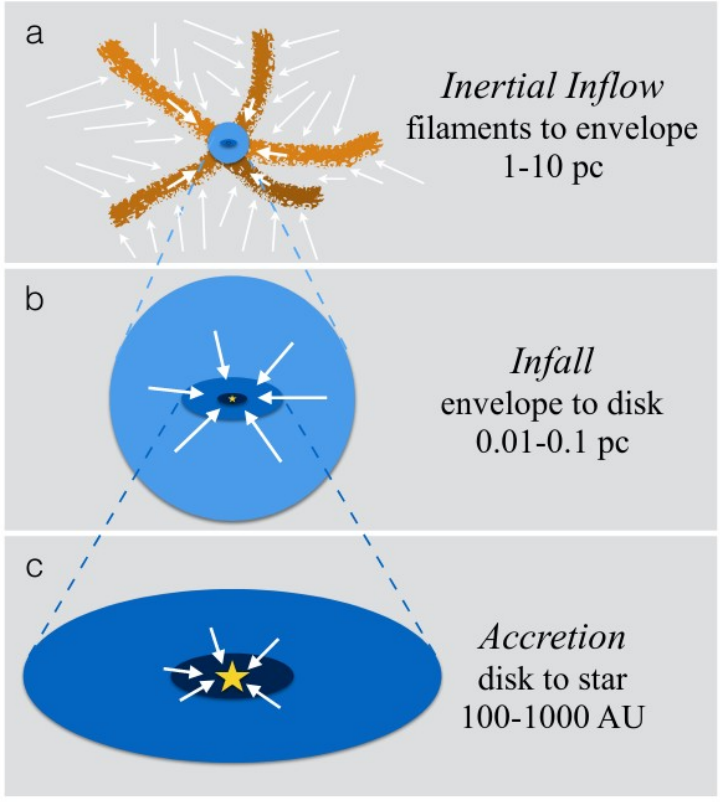


FIG. 1.— Sketch of the different scales and corresponding terminology adopted in our inertial-inflow model. The infall and disk-accretion scales inherit the filamentary structure of the larger scale, but are here depicted as smooth regions for simplicity.

Key questions

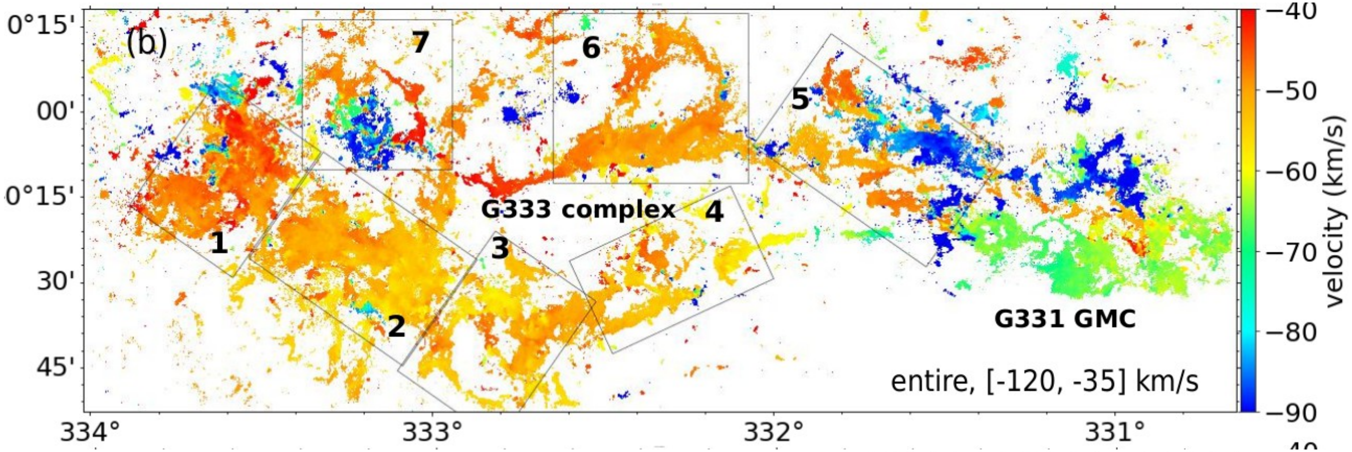
- How does the gas flow from large cloud scales to small core scales?
- • Do we find kinematic signatures of cloud collapse and which parts of the clouds take part in the infall? Is the infall local or global?
- What are the infall speeds? Are free-fall velocities measured or is the infall slowed down?
- What are the corresponding timelines, hence in which evolutionary stages can infall be measured?
- What are the infall rates and can they be converted into accretion rates? Are those rates compatible with model predictions?

What we can do observationally

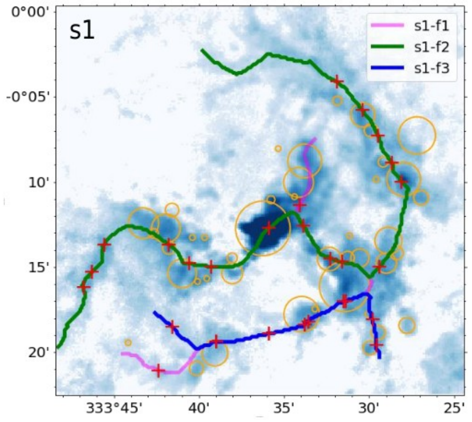
- Follow velocity gradients along filaments
- Measure blue-skewed line profiles
- With continuum (background): measure red-shifted absorption

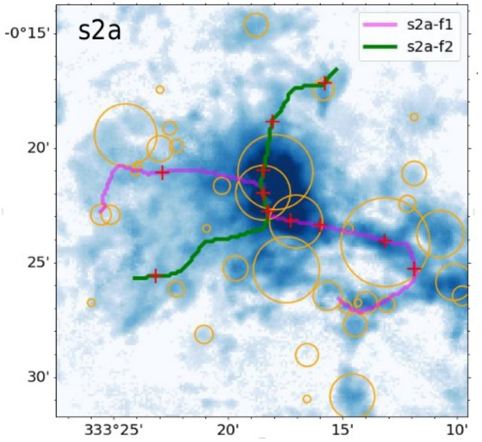
GMC G333 with LASMA@APEX

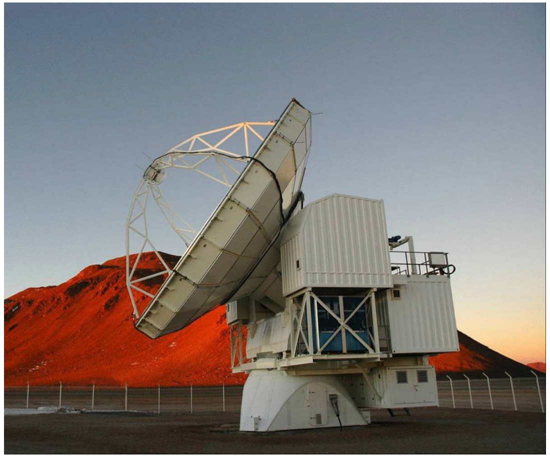
Zhou+2023



hub-
filament
systems

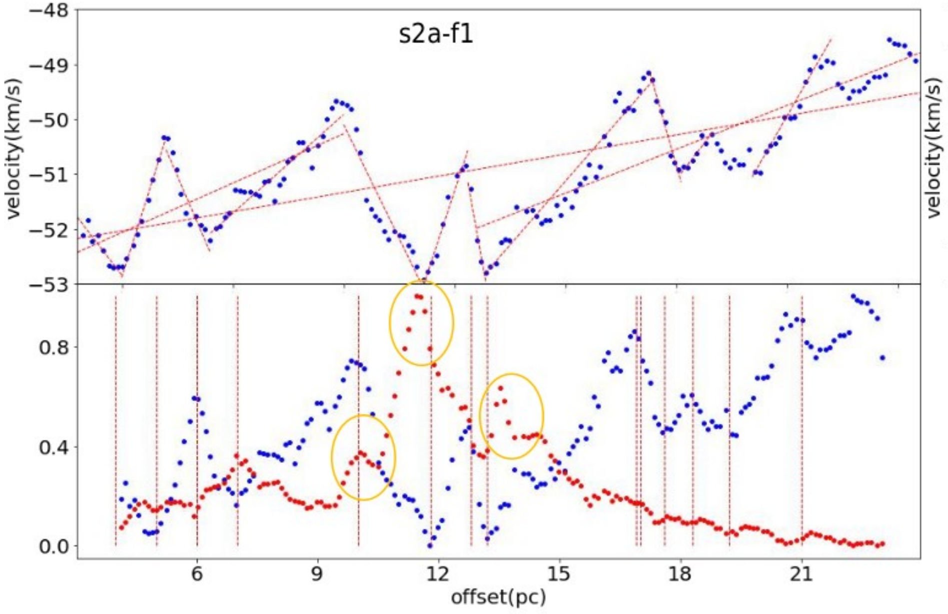


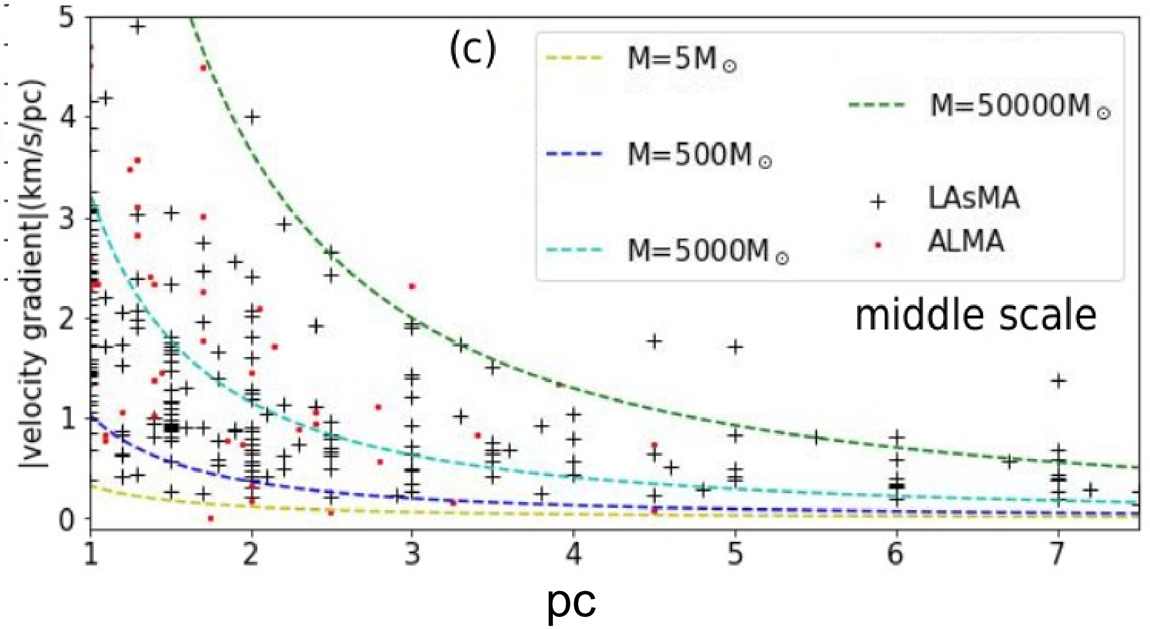




GMC G333 with LASMA

Zhou+2023 (+ALMA $H^{13}CO^{+}$)





"Funnel" structure of the velocity field in PPV space, indicative of a smooth, continuously increasing velocity gradient from large to small scales, and thus consistent with gravitational acceleration.

Hacar+2017: Gravitational collapse in Orion

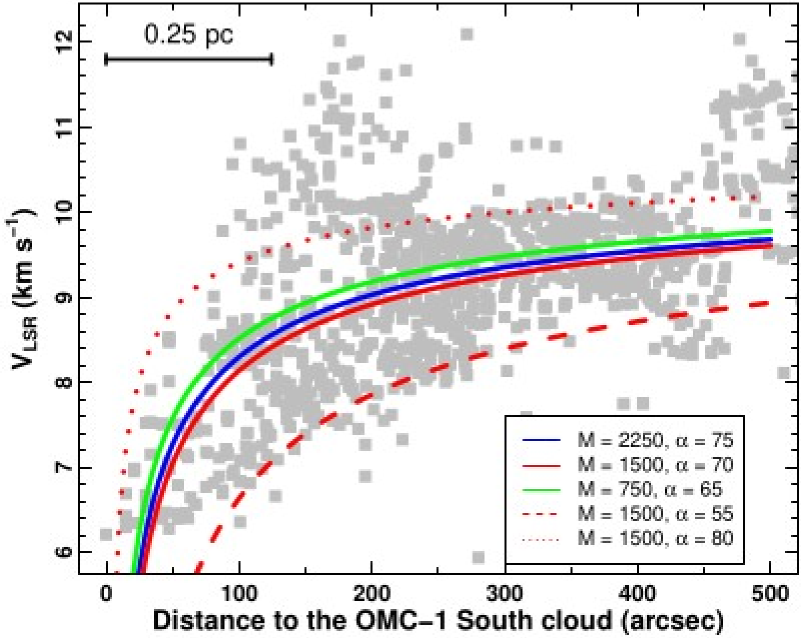
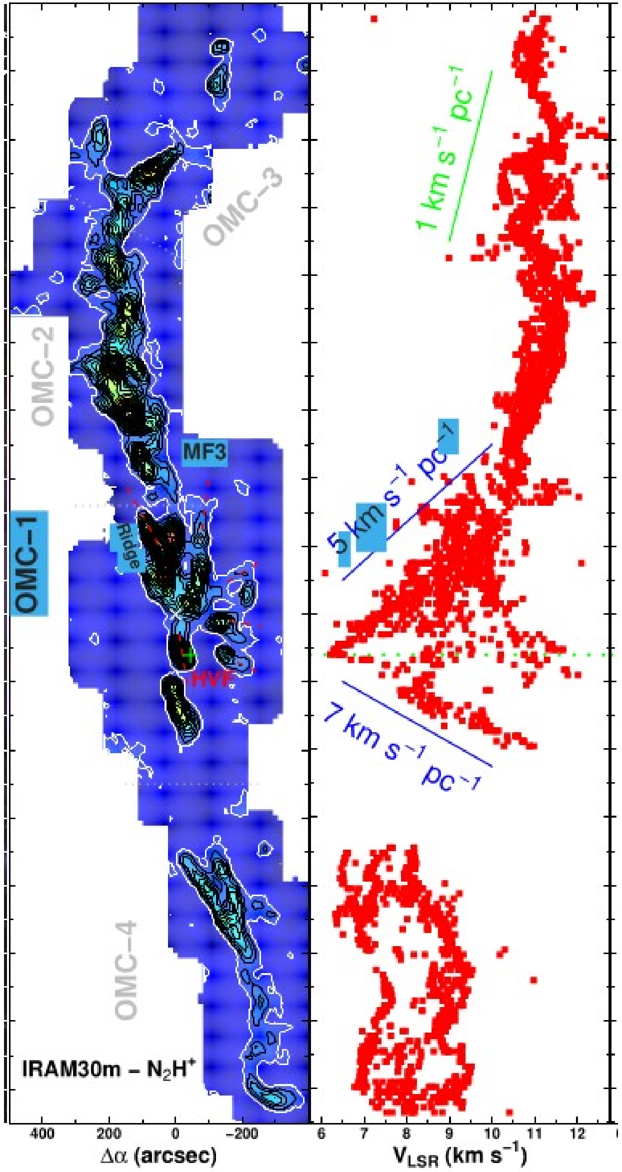


Fig. 2. Gas velocity structure as a function of the distance to the OMC-1 South cloud for all the gas components detected with S/N ≥ 3 (gray



NGC6334 APEX results: Arzoumanian+2022

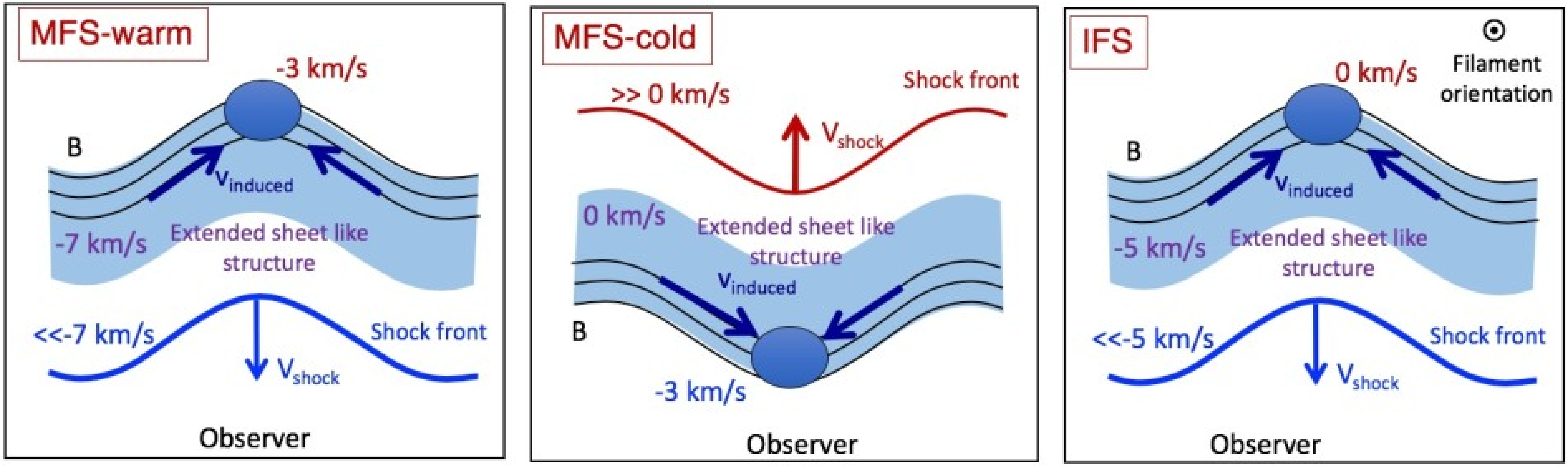
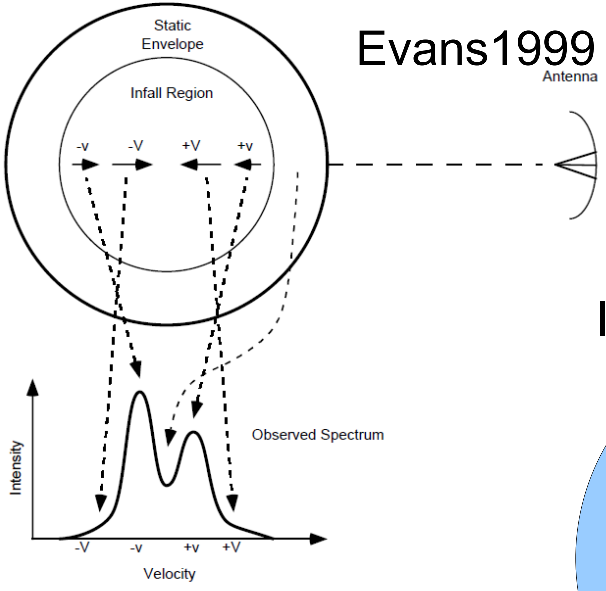


Fig. 13: Schematic view of the suggested scenario where propagating extended gas structures interact with the NGC 6334 complex, resulting in the formation or altering the properties of the filament systems MFS-warm, MFS-cold, and IFS from left to right. These

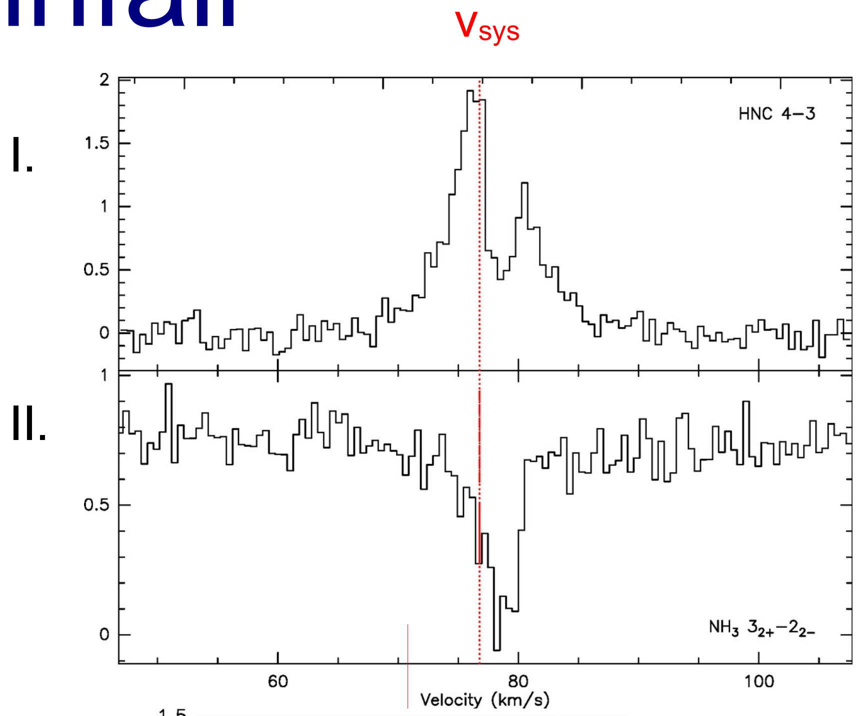
Search for infall

I: Blue-skewed profiles
    Needs excitation gradient, right tau
II: red-shifted absorption
    Needs high critical density, central continuum

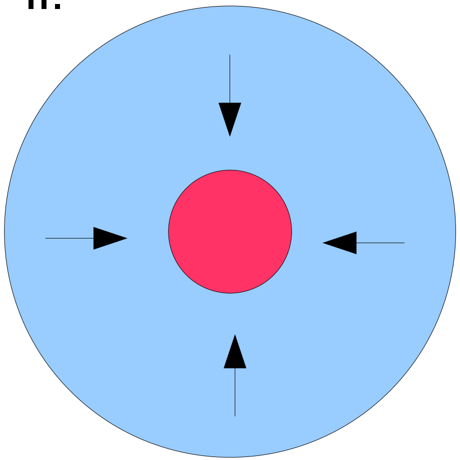
I.

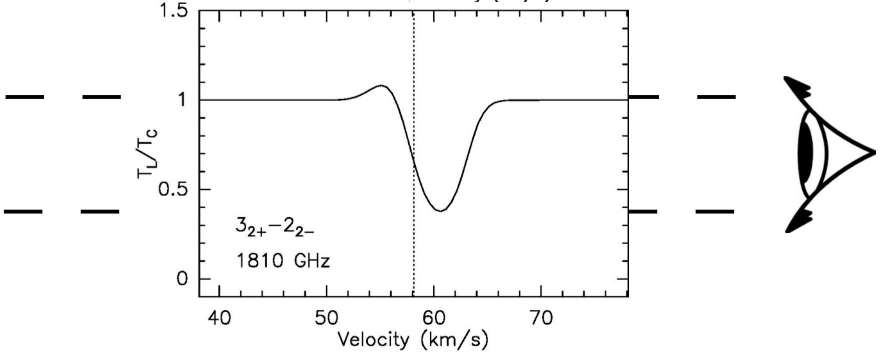


Evans1999



II.





Evans (1999):
"path towards salvation"

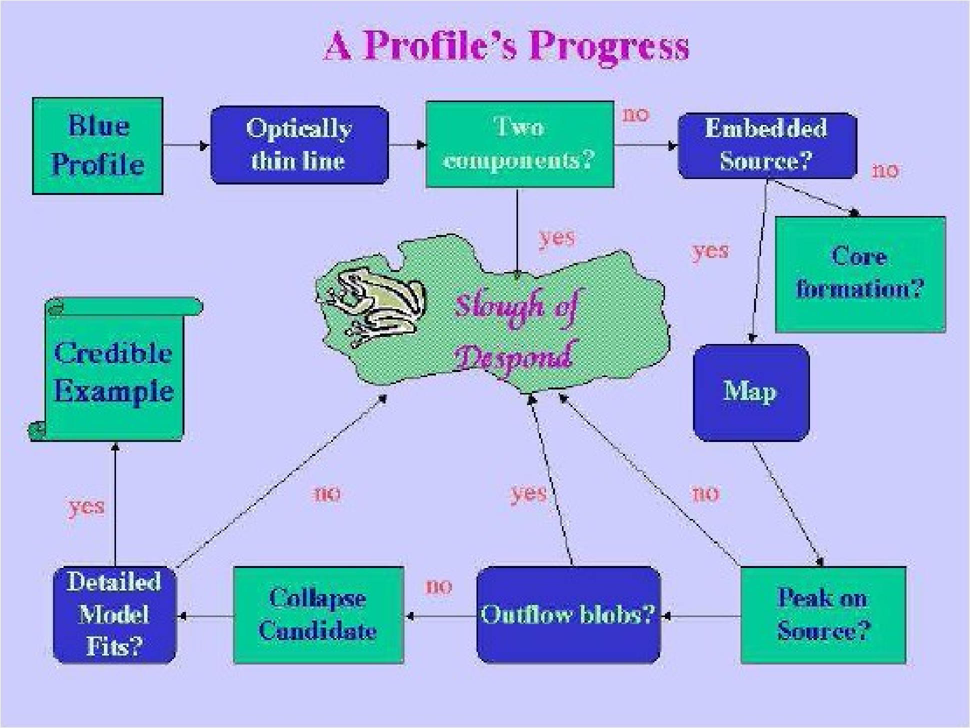


Figure 4. The progress of a blue profile through the many pitfalls on the path toward "salvation," as a credible example of collapse (with apologies to John Bunyan).

Red-shifted absorption measurements as rescue

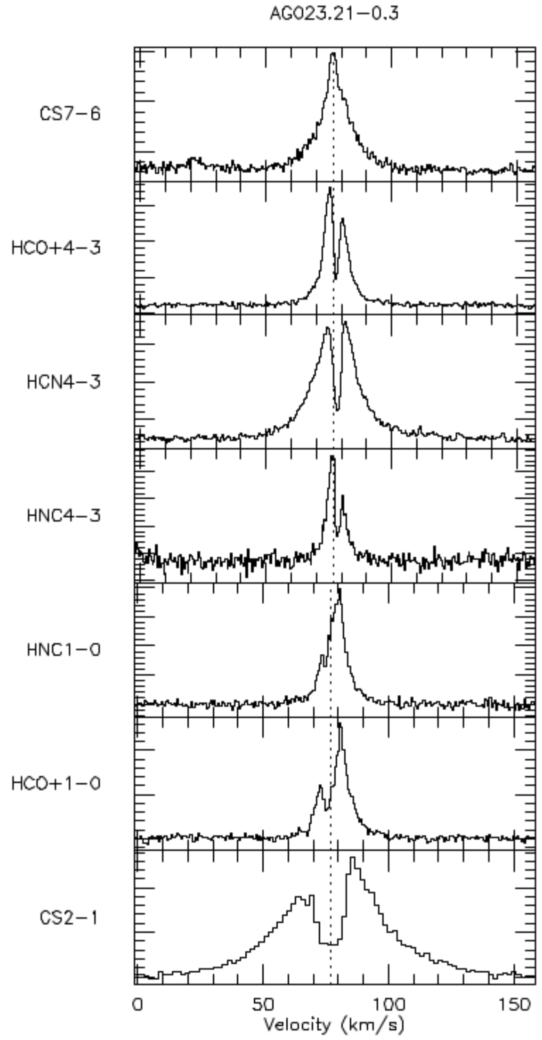
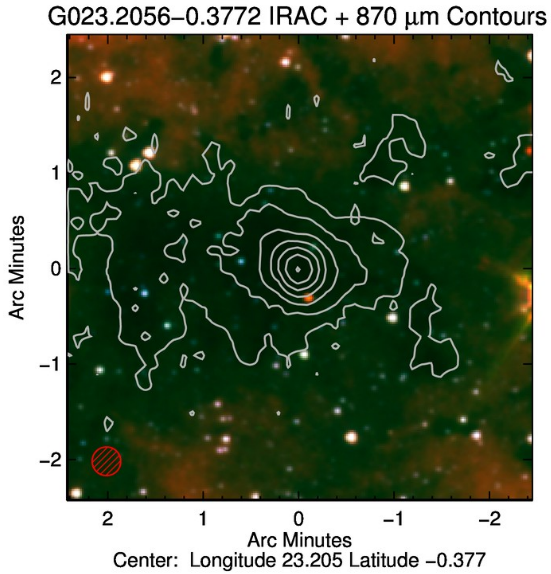
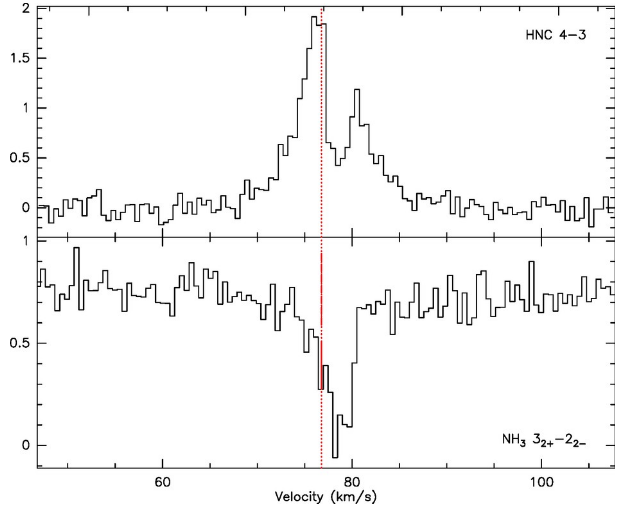


Fig. 3. Ground-based observations of millimeter and submillimet transitions of the dense gas tracers HCN/HNC/CS/HCO^+ in G23.21–0.3 observed with the IRAM 30 m and APEX telescopes. The systemic velocity from $C^{17}O$ (3–2) is indicated with a dashed line.





Ammonia redshifted absorption:

Wyrowski+2012,2016

SOFIA/GREAT:

- 1.8THz NH_3 3-2 line
- Mostly redshifted absorption with shifts of 0.2 – 1.6 km/s with respect to $C^{17}O$
- Modeling of sources results in infall with fractions of free-fall of 3 – 30 %. Clump scale probed

Clumps in IRDCs

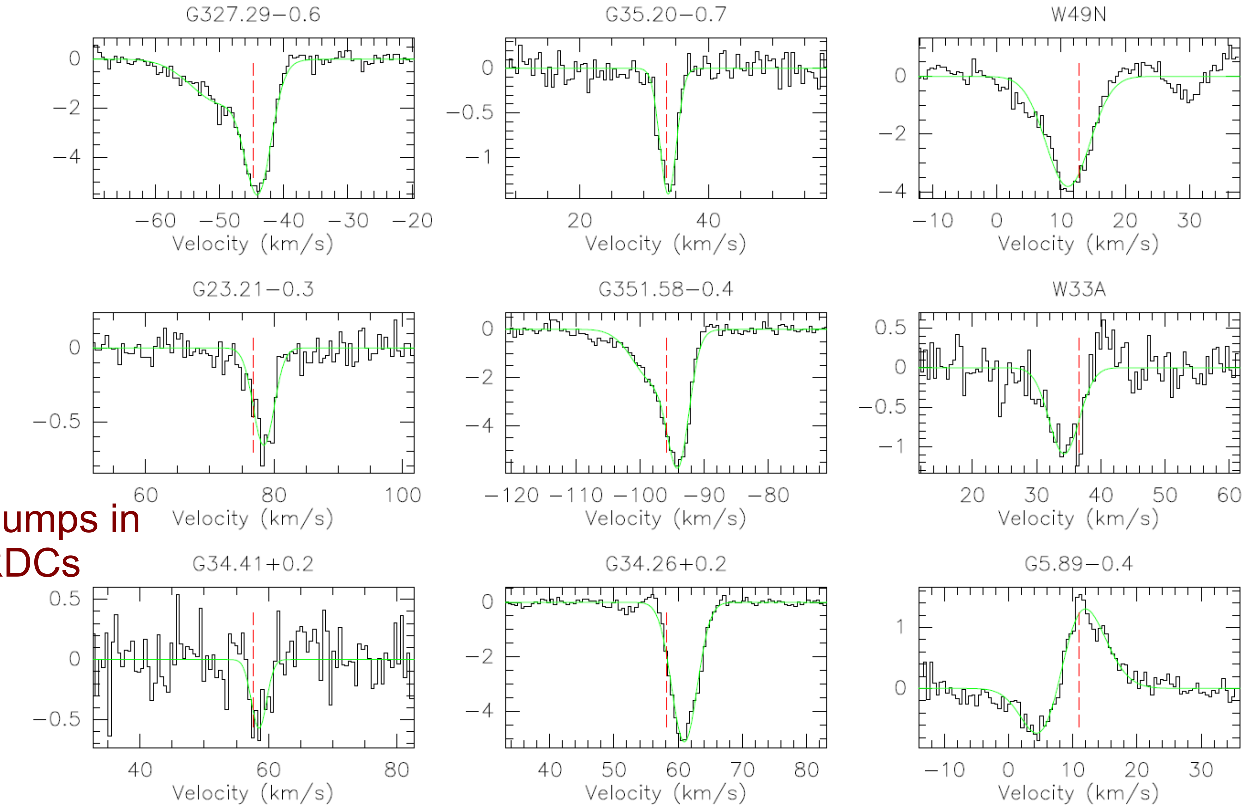
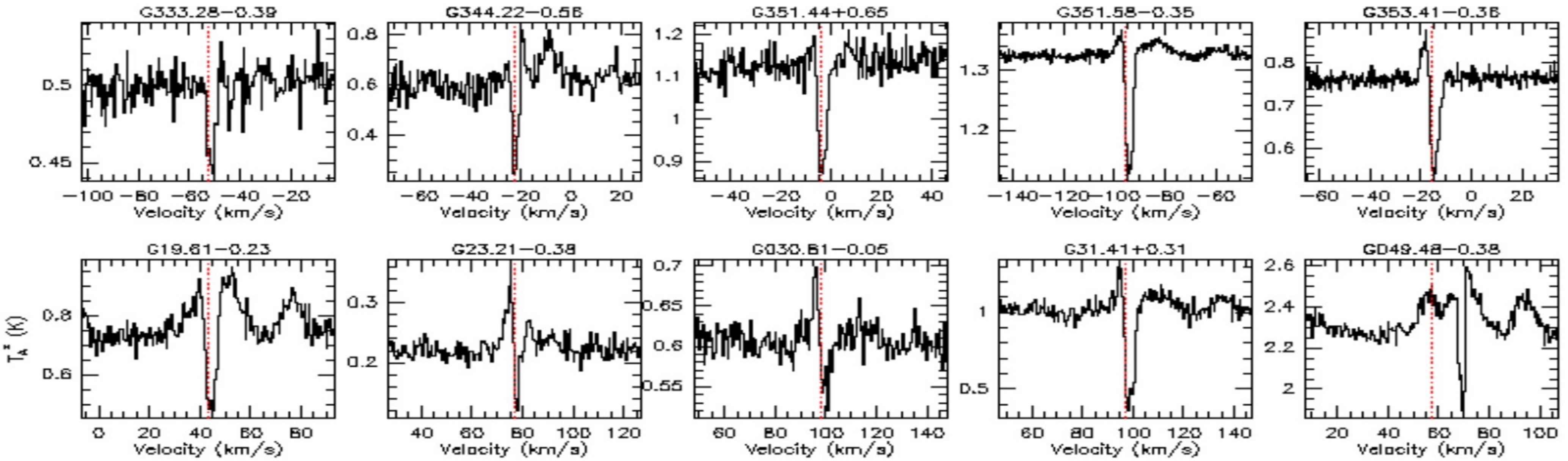


Fig. 2. NH_3 $3_{2+} - 2_{2-}$ spectra of the observed sources. Results of Gaussian fits to the line profiles are overlaid in green. The systemic velocities of the sources, determined using $C^{17}O$ (3–2), are shown with dotted lines. W49N shows in addition at 30 km/s the NH_3 $3_{1+} - 2_{1-}$ from the other sideband.

NH_2D with APEX

- Submm ground-state transitions at 332, 470,494 GHz (o,p)
- 470 GHz line turns partly in absorption: Potential new redshifted absorption tool



Caveats, limitations, outlook

- Large scale velocity structure: 3D missing
- Blue skewed profiles: see Evans 1999
- Redshifted absorption: needs bright background

- Compare with synthetic observations of simulations
- Combine different methods
- Increase statistics

Puzzles remain

- Free-fall, or fraction thereof, can describe velocity profiles
- But processes to slow down the infall motions need to be at work to be consistent with measured overall star forming rates.
- Role of turbulence, magnetic fields, sheer & tide effects (Zhou+2024), rapid feedback.