Converging Flows and the Formation of Molecular Clouds
The Star Formation Region W43 as a Case Study

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Star formation

- Stars form in cold and dense molecular clouds
- Initial gas is hot and atomic
- HI is a bistable gas (WNM and CNM)
- Molecular gas condensates from CNM
- Transition from atomic to molecular gas needs locally enhanced density regions

- Transition mechanism needs to be described
Time scales

- Assuming static initial gas yields unrealistically long formation timescales of molecular clouds
  - Glover & Mac Low (2007) find timescales of $\geq 10^7$ yr
  - Coagulation models of Blitz & Shu (1980) derive $\sim 10^8$ yr
- We know that molecular clouds form on the scale of a few Myr
  - We need something that works faster
Density fluctuations and gravity

- Density enhancements needed for stars to form
- These regions already form during the cloud formation phase
- Global gravity can sweep up material at the edges of clouds
- But density seeds inside the clouds are needed for collapse
- Density seeds must appear early and have to be non-linear

- Gravity cannot be the only cause
Possible models

Two categories of models come into consideration

- Turbulence
- Converging gas streams
Converging flows

- Collision of hot atomic gas streams
- Density variations and added ram pressure at collision point form CNM
- CNM can then become molecular
- Fluctuations form even if flows are smooth
- Clumps are bounded by sharp density jumps

Banerjee et al. 2009
Filaments and core formation

- Filaments form in collision plane
- Molecular clouds keep growing, mass flow across cloud borders
- Dense cores form along filaments
- Precursors of forming stars
- Magnetic fields can stabilize filaments

Fiege & Pudritz 2000
Question of star age

- Little variation in the age of stars that are close together is observed
- Variation would be larger if filaments would form spontaneously
- Converging flows lead to same cloud formation time across the collision plane

▶ Age of stars is similar
Cooling

- Proper heating and cooling mechanisms have only been included since 2005 (e.g. Audit & Hennebell 2005)
- Cooling works very effectively, leading to molecular cloud formation in a few Myr
- Typical coolants are metal fine structure lines (\text{CII}, \text{OI}, \text{SII})
  - \text{CII} as a tracer of the transition from atomic to molecular gas
  - Herschel/SOFIA observations
The W43 Complex

- Identified by Motte et al. 2003
- One of the most luminous and massive star forming regions in the Galaxy
- Located at the junction of Galactic spiral arms and Bar
- Intersection of circular and elliptic orbits
- Ideal place to study effects of colliding gas flows
IRAM 30m project overview

- 80h observation time with the IRAM 30m
- Observing large scale maps in $^{13}$CO (2-1) and $^{18}$C$^1$O (2-1) of the whole region:
- Probe low- to mid-density parts of molecular clouds
- Map structure and kinematics of clouds
- Beam size: $12'' \rightarrow 0.35$ pc
- Spectral resolution 0.15 km/s
Resulting map

- Distance: 6 kpc
- Linear size of $\sim 150$ pc
- Mass of $> 10^6 M_\odot$
- Velocity range: 80 - 120 km/s
- Structure across all scales
- Shear effects should play a minor role (calculated from Dib et al. 2012)
Position velocity diagram
HI absorption

Nguyen Luong et al. 2011

Integrated over 80–110 km/s
Colour: HI
Contour: $^{13}$CO 1–0

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HI absorption spectra

Spectrum in W43–Main (18:47:38.182 –01:57:46.53)

- HI
- $^{13}$CO (2–1)

Credits HI: H. Beuther

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HIFI target

• Pick one filament
• Size: 12 $\times$ 8 pc
• Mass: 6000 $M_{\odot}$
• Estimated density: $10^3$ cm$^{-3}$
• Velocity range: 4 km/s
HIFI target

- Dust emission visible
- No emission in 8 μm band (not just distance effect)
- No near UV-sources
Herschel space telescope

- 10h granted to observe C\(^+\) OTF-map
- Beam size of 12” matches IRAM 30m maps
- Spectral resolution of \(\sim 0.1 \text{ km/s}\)
The C$^+$ map

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Spectra at clump maximum

![Graph showing spectral data with labels for CII, $^{19}$C0 (2–1), and CO (8–5).]
The $\text{C}^+$ map properties

![Map of $\text{C}^+$ peak velocity](image1)

![Map of $\text{C}^+$ line width](image2)
Combination with CARMA data

- Reveals layered structure
- Typical filament formation as seen in models
- Assuming layers have mostly dynamical origin
- Mass flow across filament borders
Conclusions

- Dynamic formation of molecular clouds is necessary to explain observed star formation
- The Converging Flows model is one possible explanation
- Signature of dynamic formation of dense molecular cloud is observed
- Can we somehow distinguish different theories of cloud formation?