Origin of high-mass stars in Cygnus-X

T. Csengeri
Service d'Astrophysics, CEA-Saclay

S. Bontemps
LAB, Bordeaux,
Service d'Astrophysics, CEA-Saclay

N. Schneider
Service d'Astrophysics, CEA-Saclay

F. Motte
Service d'Astrophysics, CEA-Saclay

F. Gueth
IRAM, Grenoble

P. Hennebelle
LERMA-ENS, Paris

S. Dib
Imperial College, London

Outline

- Introduction

I. A sample of isolated massive dense cores

  - Fragmentation and kinematics

II. An in depth study of a rich cluster in the making:

  - The DR21(OH)-clump

Why high-mass stars?
Fundamental open issues

- Gravitational fragmentation forms objects around the Jeans-mass
- Radiation pressure barrier ~ 8-10 Msol

Why high-mass stars?
Fundamental open issues

- Gravitational fragmentation forms objects around the Jeans-mass
- Radiation pressure barrier ~ 8-10 Msol

Non-spherical infall + high accretion rates may solve the problem
(e.g.: Krumholz et al, 2009, Kuiper, 2010)

Why high-mass stars?
Fundamental open issues

- Gravitational fragmentation forms objects around the Jeans-mass
- Radiation pressure barrier ~ 8-10 Msol

Non-spherical infall + high accretion rates may solve the problem

(e.g.: Krumholz et al, 2009, Kuiper, 2010)

Quasi-static versus **dynamical** models

Why high-mass stars?
Fundamental open issues

- Gravitational fragmentation forms objects around the Jeans-mass
- Radiation pressure barrier ~ 8-10 Msol

Non-spherical infall + high accretion rates may solve the problem

(e.g.: Krumholz et al, 2009, Kuiper, 2010)

Quasi-static versus **dynamical** models

- additional support: high level of micro-turbulence (McKee & Tan, 2002, 2003)
- star-formation on several times the dynamical time-scale
- predicts the existence of high-mass pre-stellar cores

Why high-mass stars?
Fundamental open issues

- Gravitational fragmentation forms objects around the Jeans-mass
- Radiation pressure barrier ~ 8-10 Msol

Non-spherical infall + high accretion rates may solve the problem

(e.g.: Krumholz et al, 2009, Kuiper, 2010)

Quasi-static versus **dynamical** models

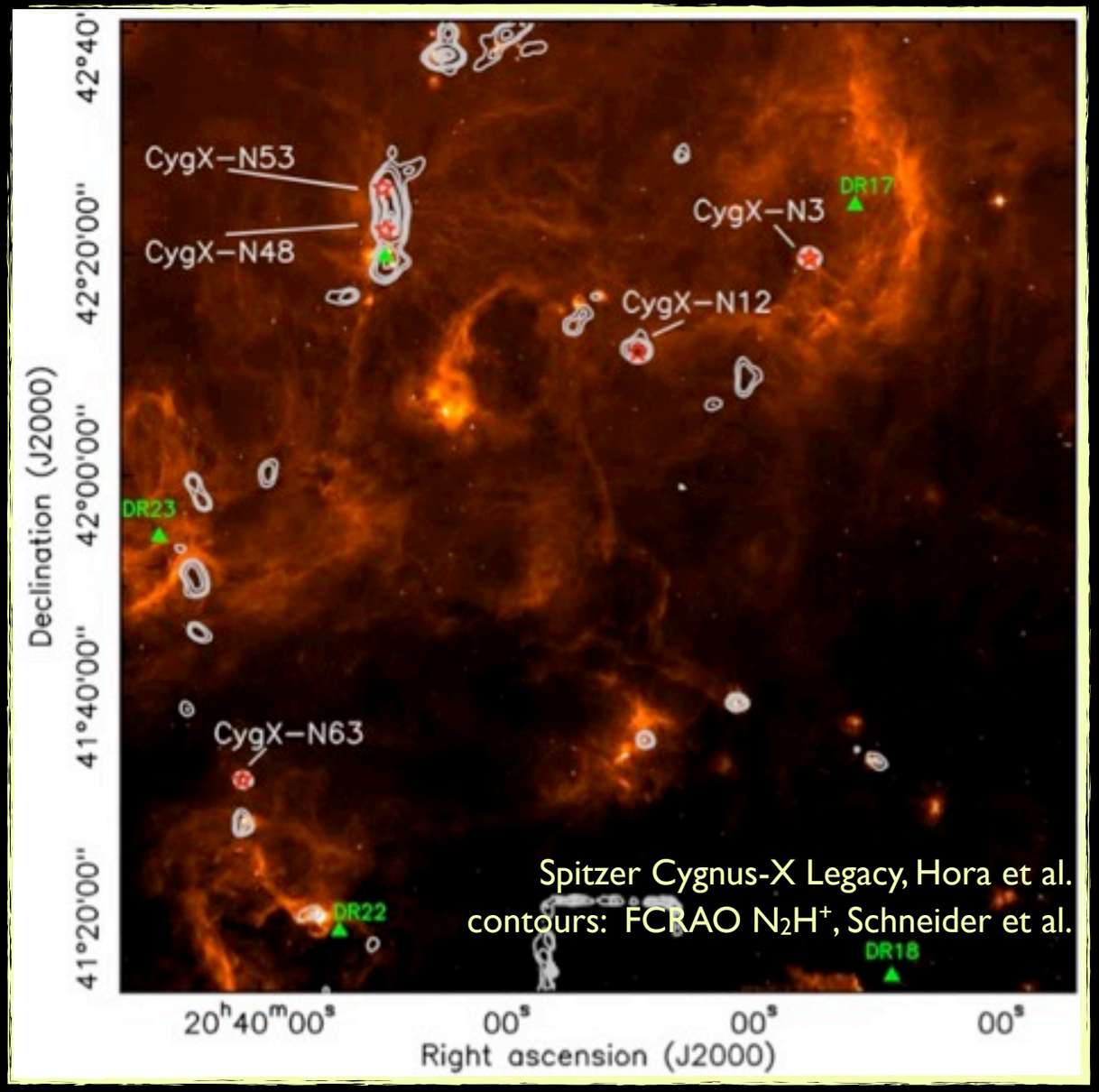
- additional support: high level of micro-turbulence (McKee & Tan, 2002, 2003)
- star-formation on several times the dynamical time-scale
- predicts the existence of high-mass pre-stellar cores

- gravoturbulent fragmentation + collective effects in clusters: (Klessen et al., 2005, Bonnell et al. 2001, Bonnell & Bate 2006)
- competitive accretion: material, which was originally not gravitationally bound to the core can be accreted
- evolution on dynamical time-scale

The earliest stages...
Follow-up of MDCs in Cygnus-X

7 $M_\odot$

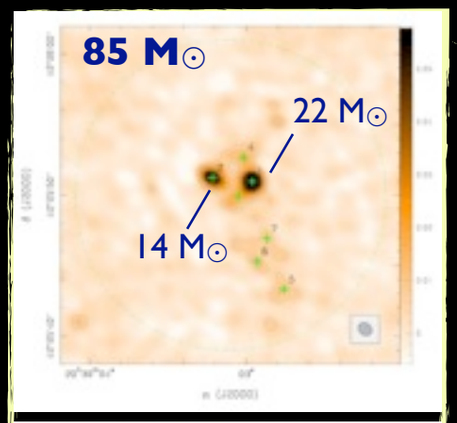
- Unbiased sample of dense cores at 1.7 kpc (Motte et al. 2007) → Massive Dense Cores
  - Mass: 60-200 M_{Sol}
  - Size: ~0.1 pc
  - IR-quiet
  - SiO emission

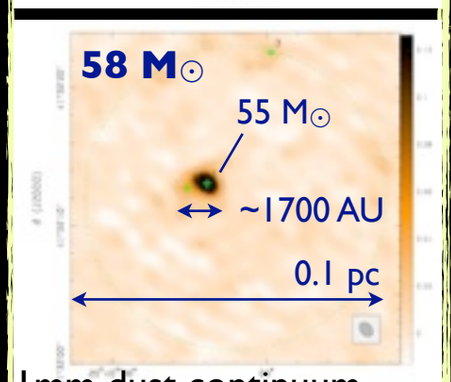


Homogenous sample for high angular-resolution follow-up with the PdBI in continuum and dense gas tracers

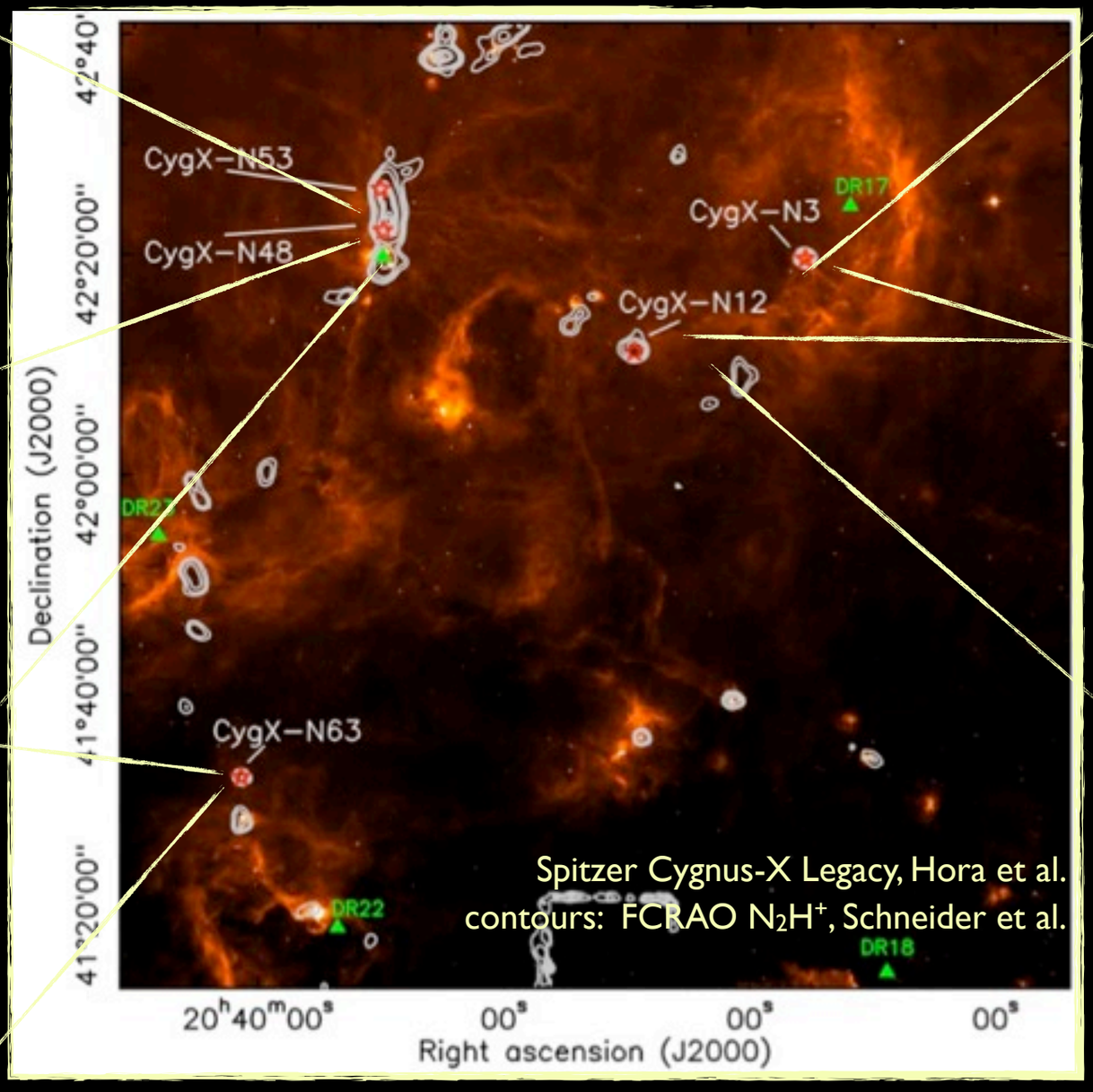
The earliest stages...
Follow-up of MDCs in Cygnus-X

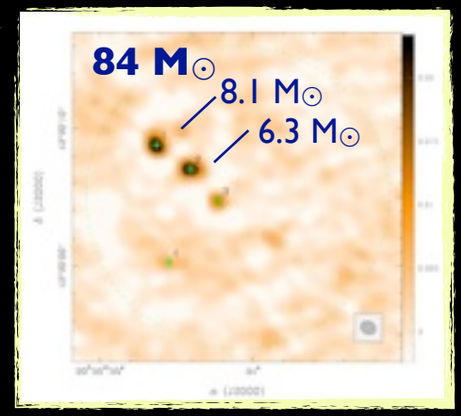
- Unbiased sample of dense cores at 1.7 kpc (Motte et al. 2007) → Massive Dense Cores

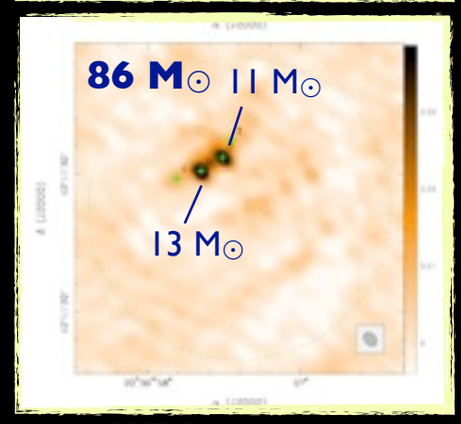


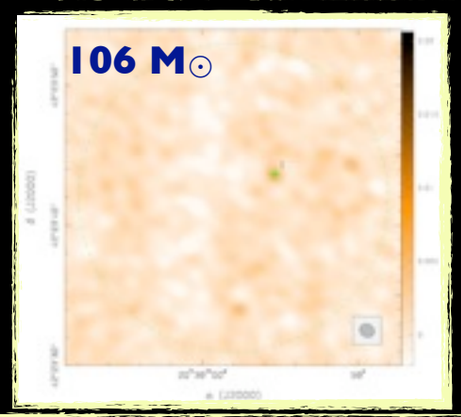


1mm dust continuum



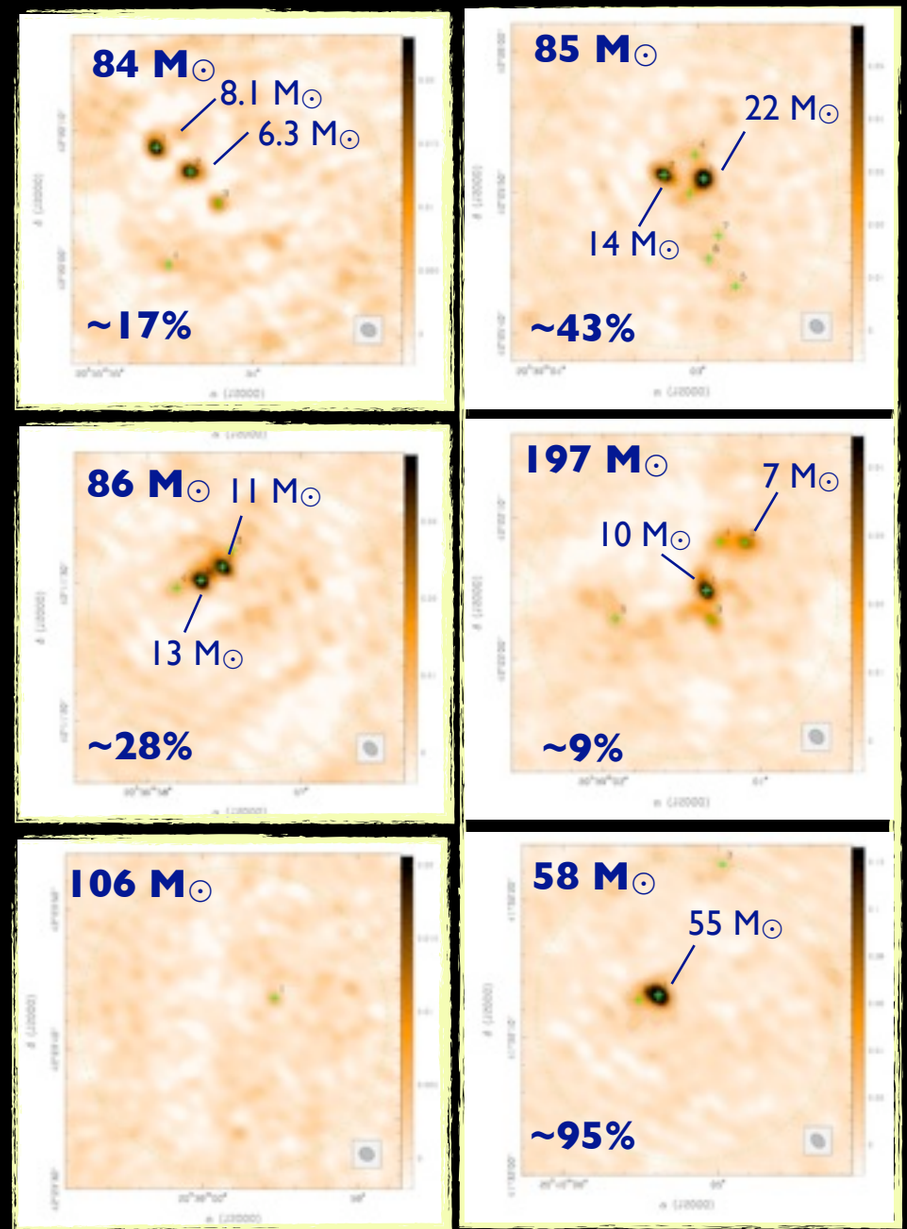






Diverse fragmentation properties - what plays a role?

- 4 MDCs not in monolithic collapse
- High fraction of the total mass in compact fragments
- not fully compatible with a gravo-tubulent + competitive accretion model
  e.g. Dobbs et al. (2005): isothermal HD simulations of a 30 M_{Sol} core forms ~ 20 obj.

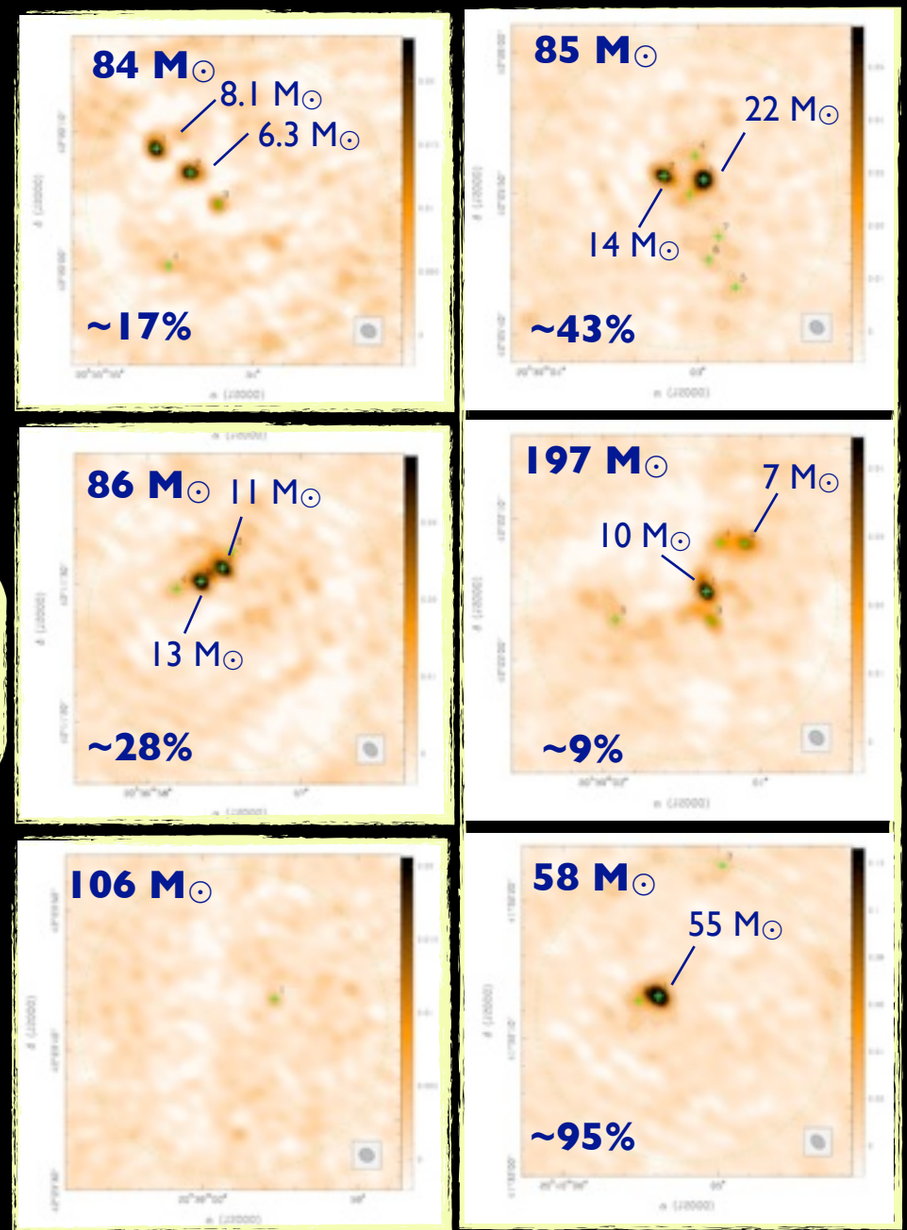


Diverse fragmentation properties - what plays a role?

- 4 MDCs not in monolithic collapse
- High fraction of the total mass in compact fragments
- not fully compatible with a gravo-tubulent + competitive accretion model
  e.g. Dobbs et al. (2005): isothermal HD simulations of a 30 M_{Sol} core forms ~ 20 obj.

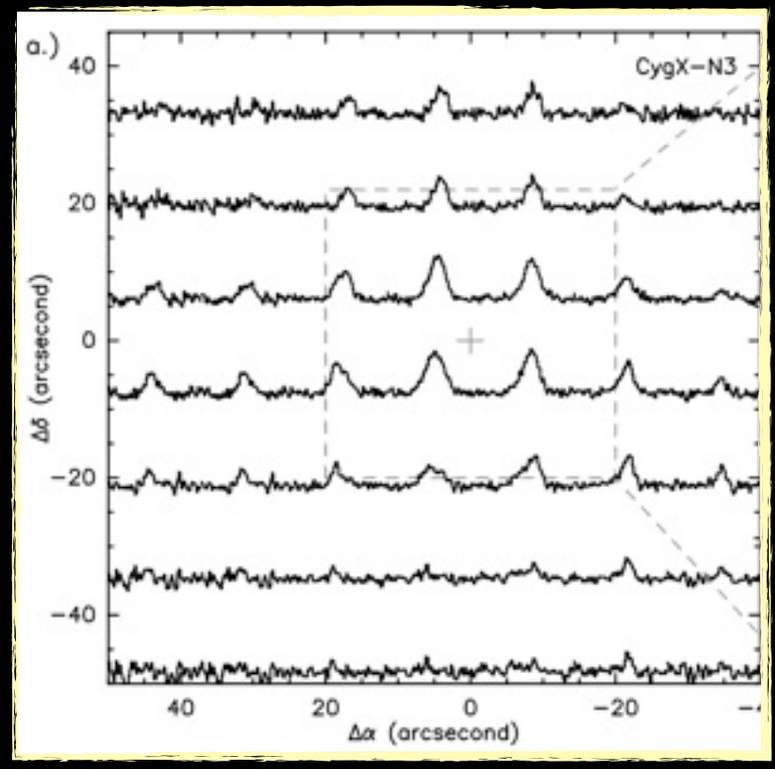
Bontemps, Motte, Csengeri, Schneider 2010 , A&A in press astro-ph/0909.2315

- **Kinematics** is essential to study bulk motions, such as rotation, infall, micro-turbulence
  - turbulent-core model: high-level of micro-turbulence as support expected
  - dynamical model: ?



Bulk motions showing MDCs in equilibrium?

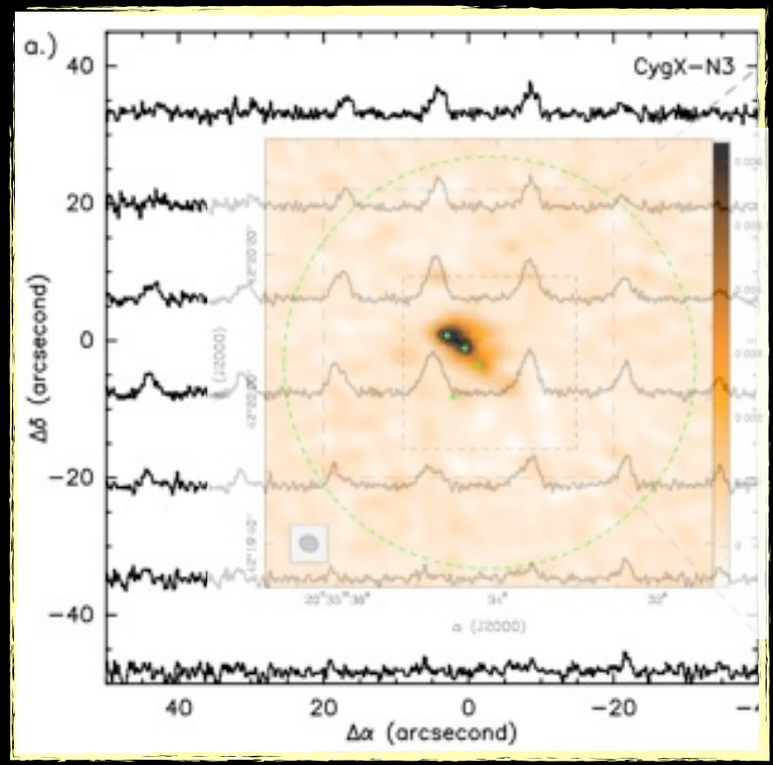
- Line-widths show no virial equilibrium



$H^{13}CO^+$ (J=1-0)

Bulk motions showing MDCs in equilibrium?

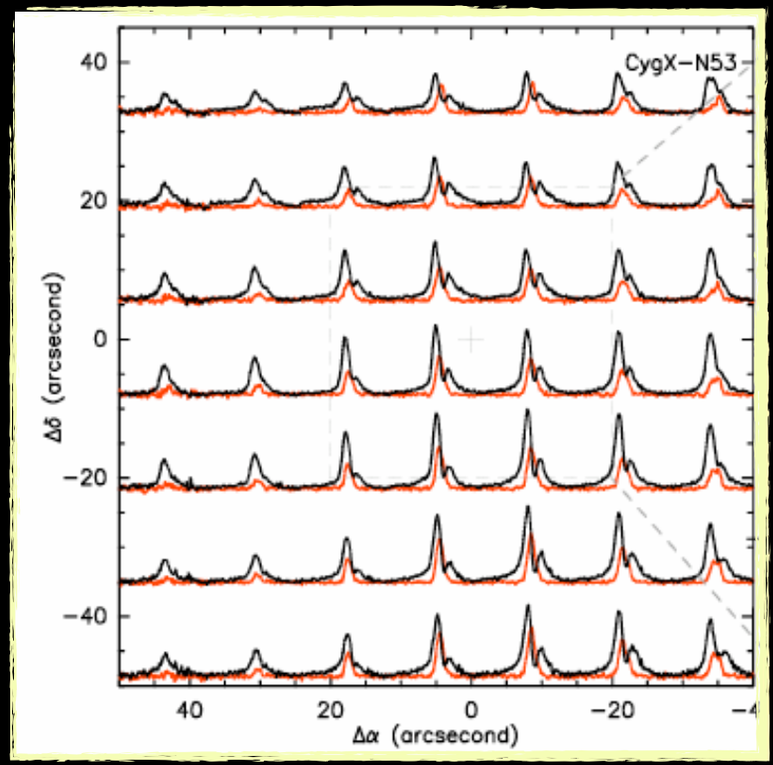
- Line-widths show no virial equilibrium



$H^{13}CO^{+}$ (J=1-0)

Bulk motions showing MDCs in equilibrium?

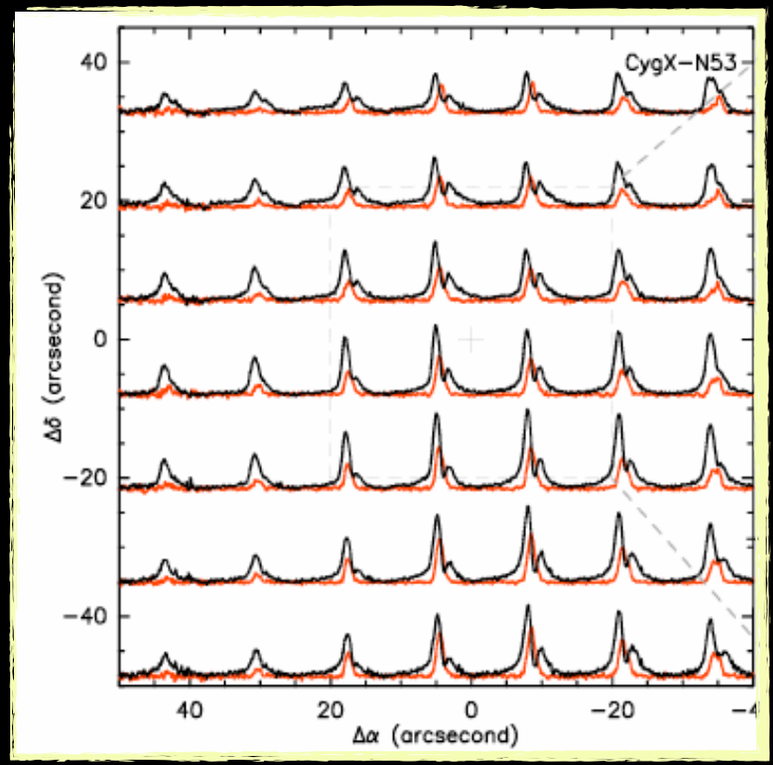
- Line-widths show no virial equilibrium
- Global infall



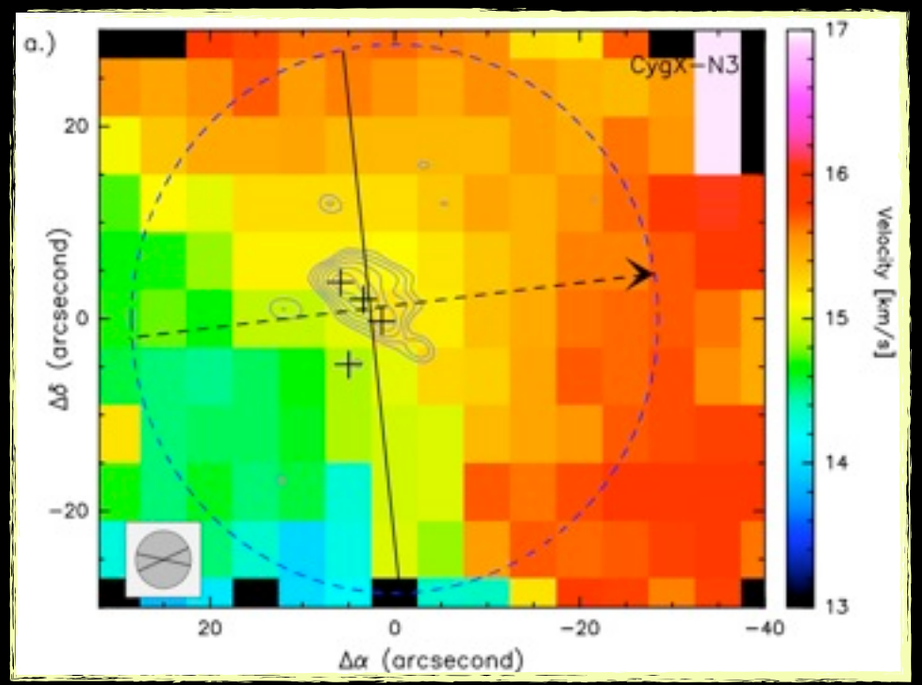
$H^{13}CO^+$ and HCO^+

Bulk motions showing MDCs in equilibrium?

- Line-widths show no virial equilibrium
- Global infall
- Rotation-like ordered motions, but the rotational energy is negligible to the gravitational



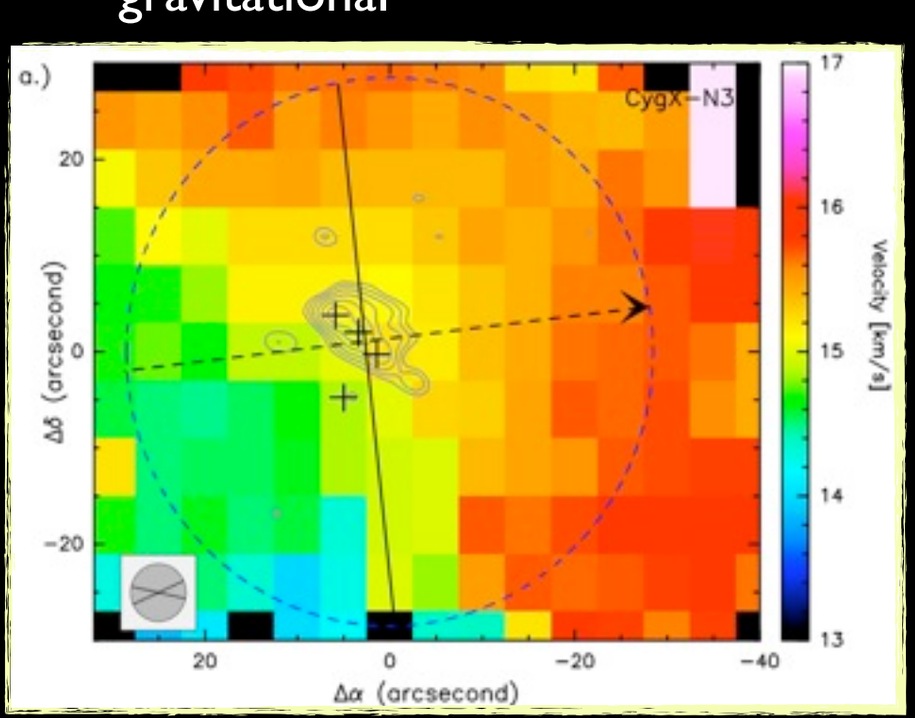
$H^{13}CO^+$ and HCO^+



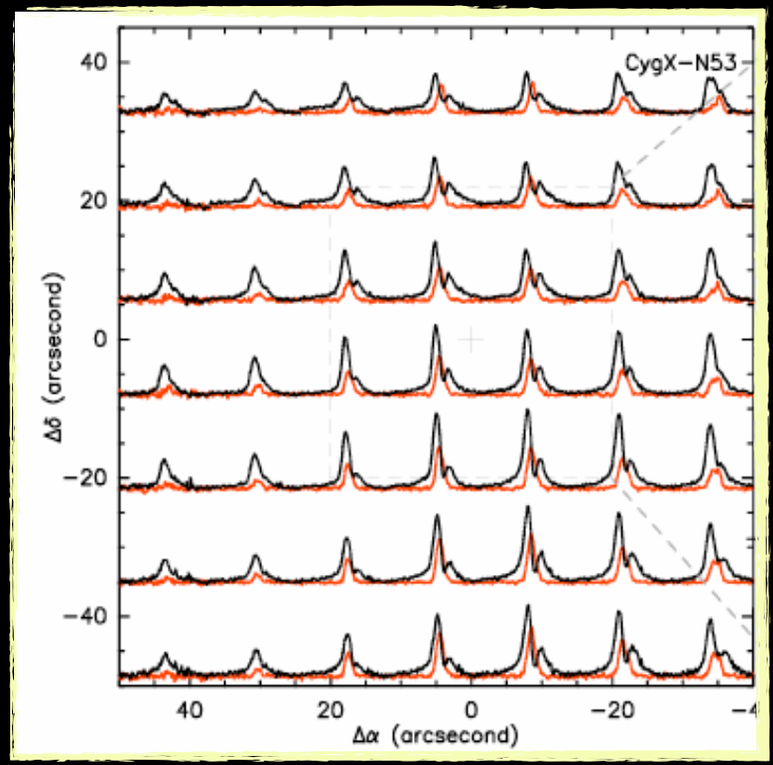
velocity field obtained from $H^{13}CO^+$ (J=1-0)

Bulk motions showing MDCs in equilibrium?

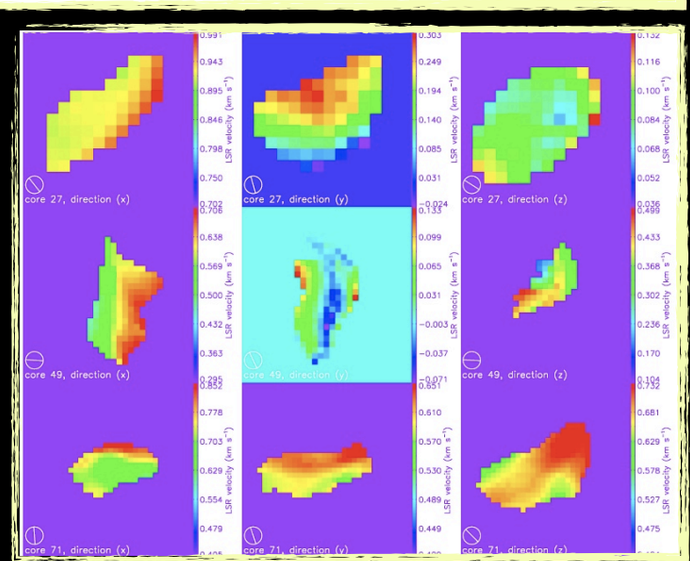
- Line-widths show no virial equilibrium
- Global infall
- Rotation-like ordered motions, but the rotational energy is negligible to the gravitational



velocity field obtained from $H^{13}CO^+$ (J=1-0)



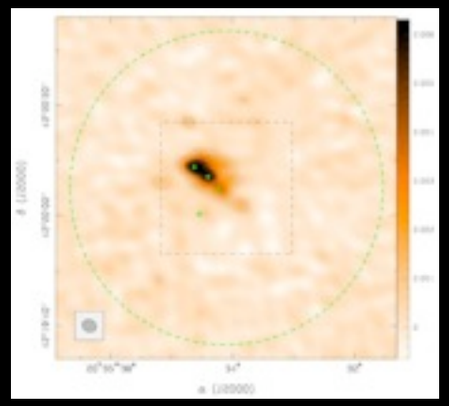
$H^{13}CO^+$ and HCO^+

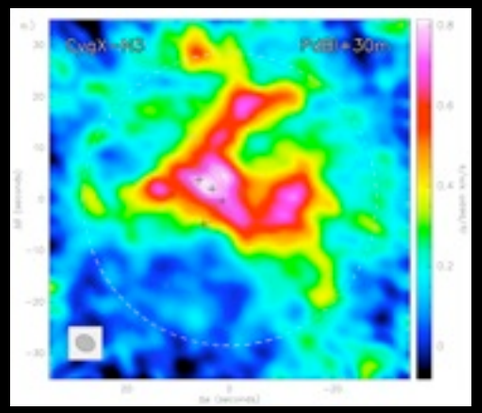


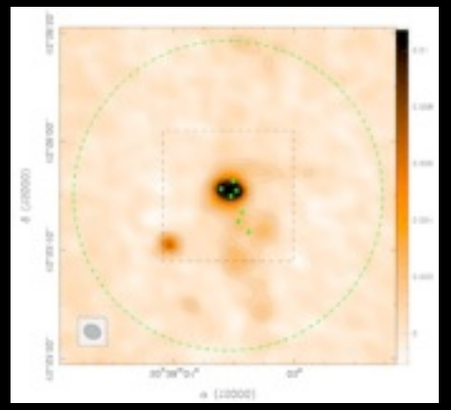
Velocity field of cores using numerical simulations (RAMSES (Dib et al.)

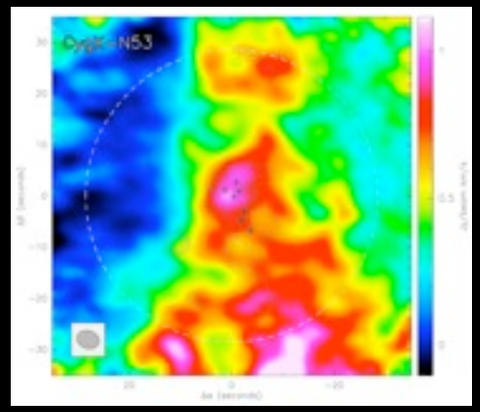
Dense gas at high angular-resolution

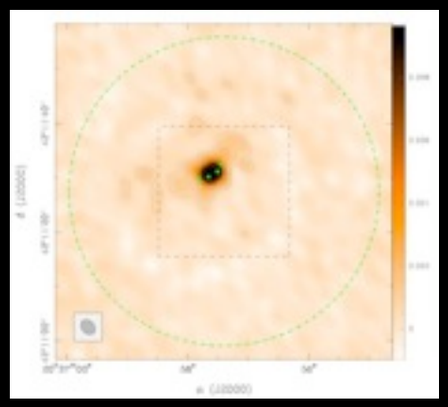
$H^{13}CO^+$

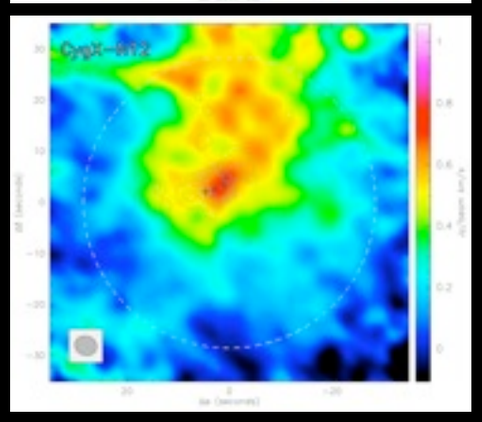


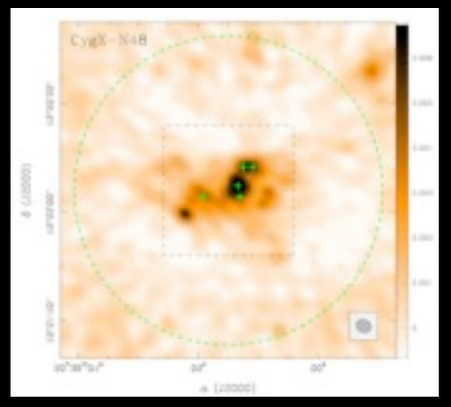


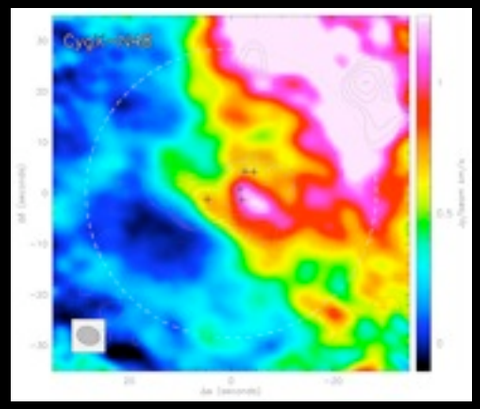


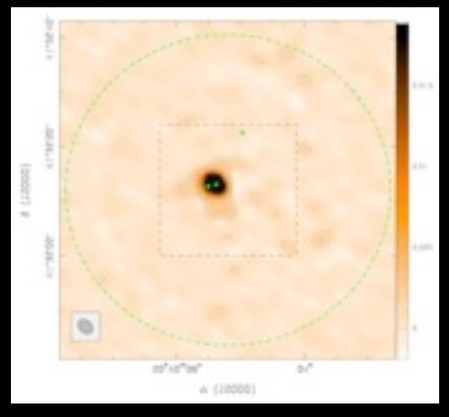


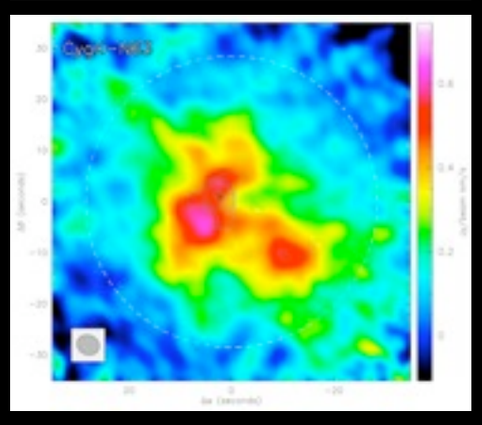












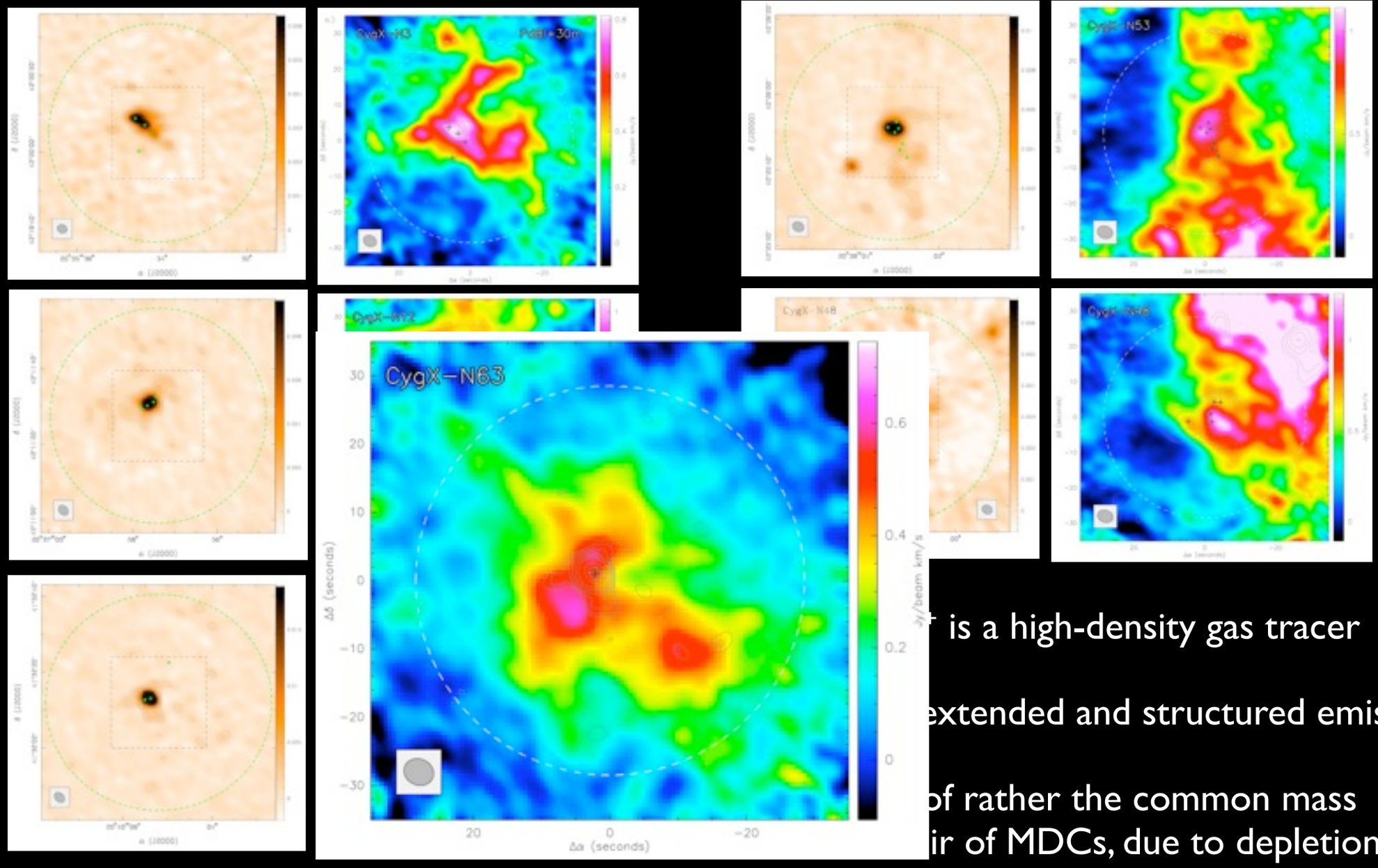
- $H^{13}CO^+$ is a high-density gas tracer
- Bright, extended and structured emission
- Tracer of rather the common mass reservoir of MDCs, due to depletion

3mm continuum

integrated intensity of $H^{13}CO^+$

Dense gas at high angular-resolution

$H^{13}CO^+$



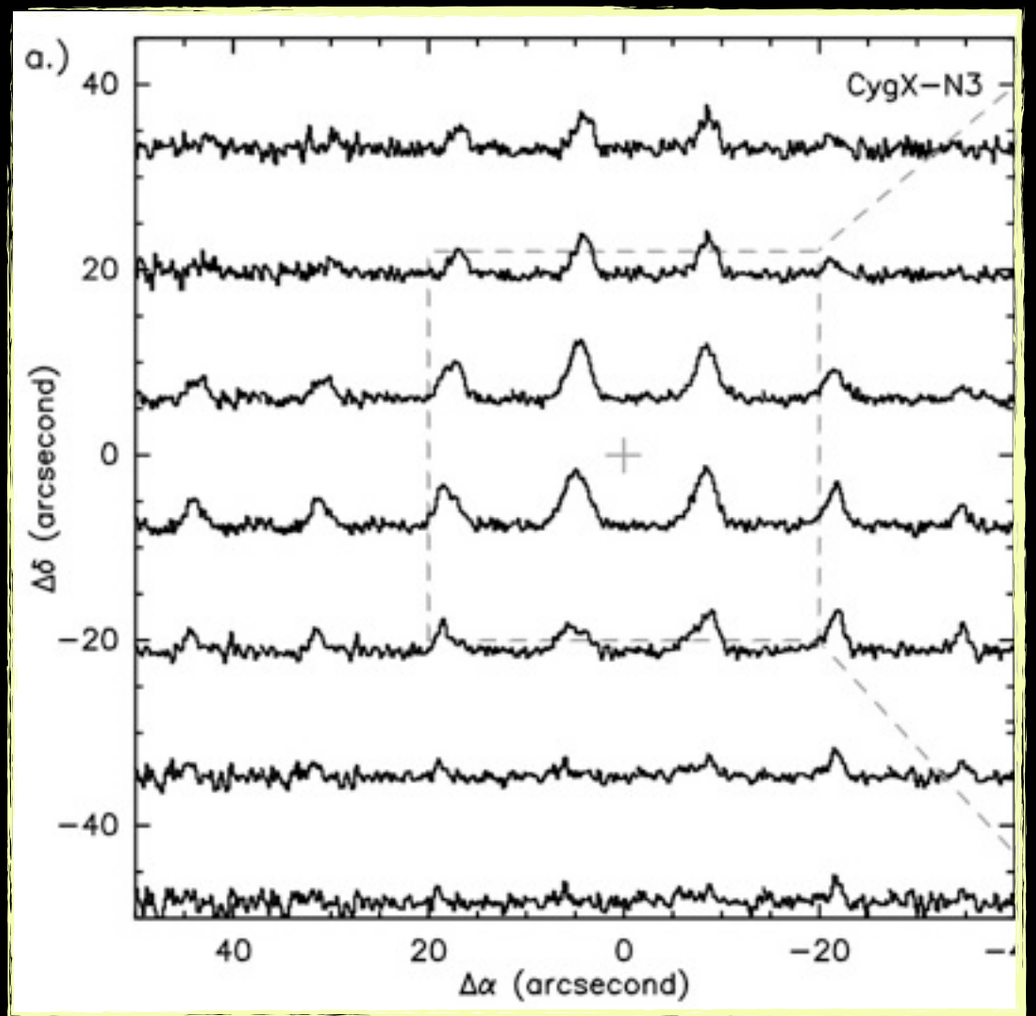
$^+$ is a high-density gas tracer

extended and structured emission

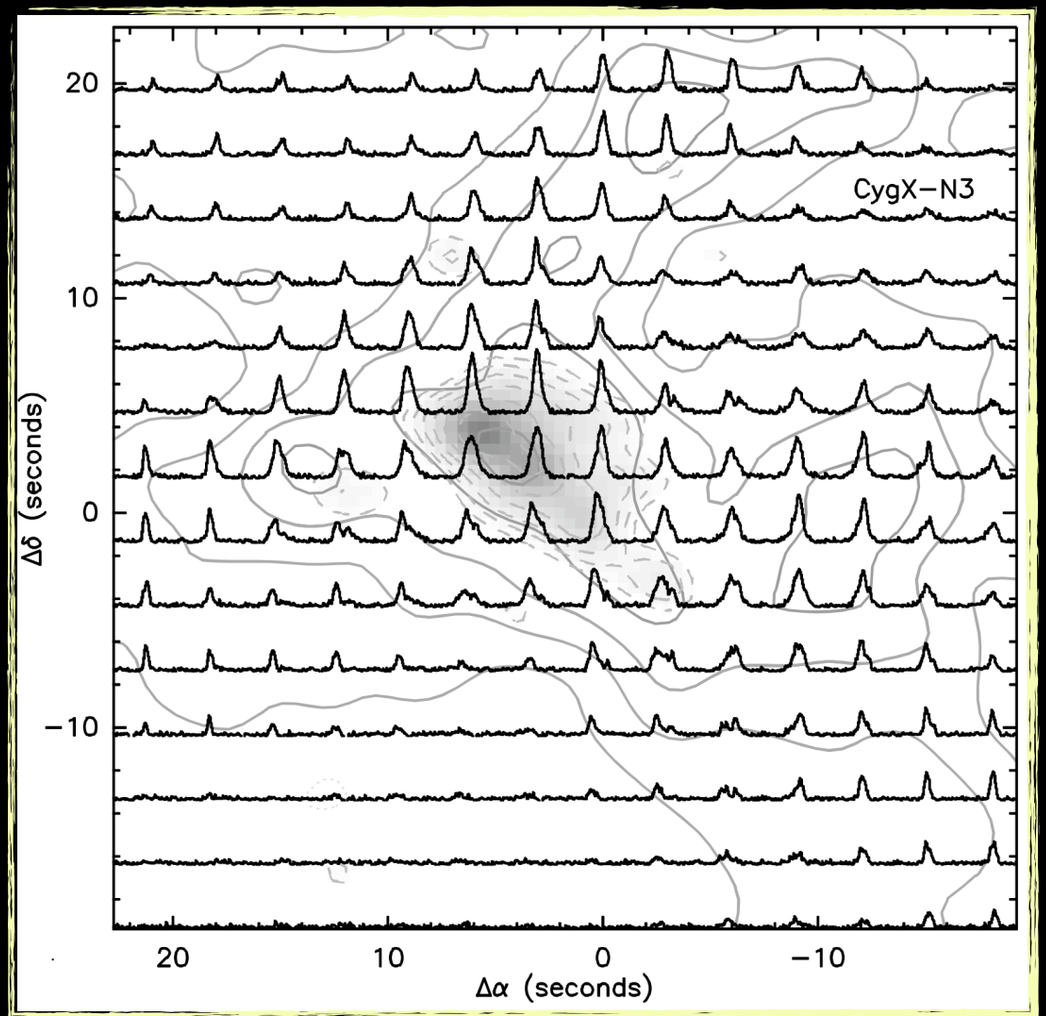
of rather the common mass
ir of MDCs, due to depletion

3mm continuum integrated intensity of $H^{13}CO^+$

Low level of micro-turbulence at small scales

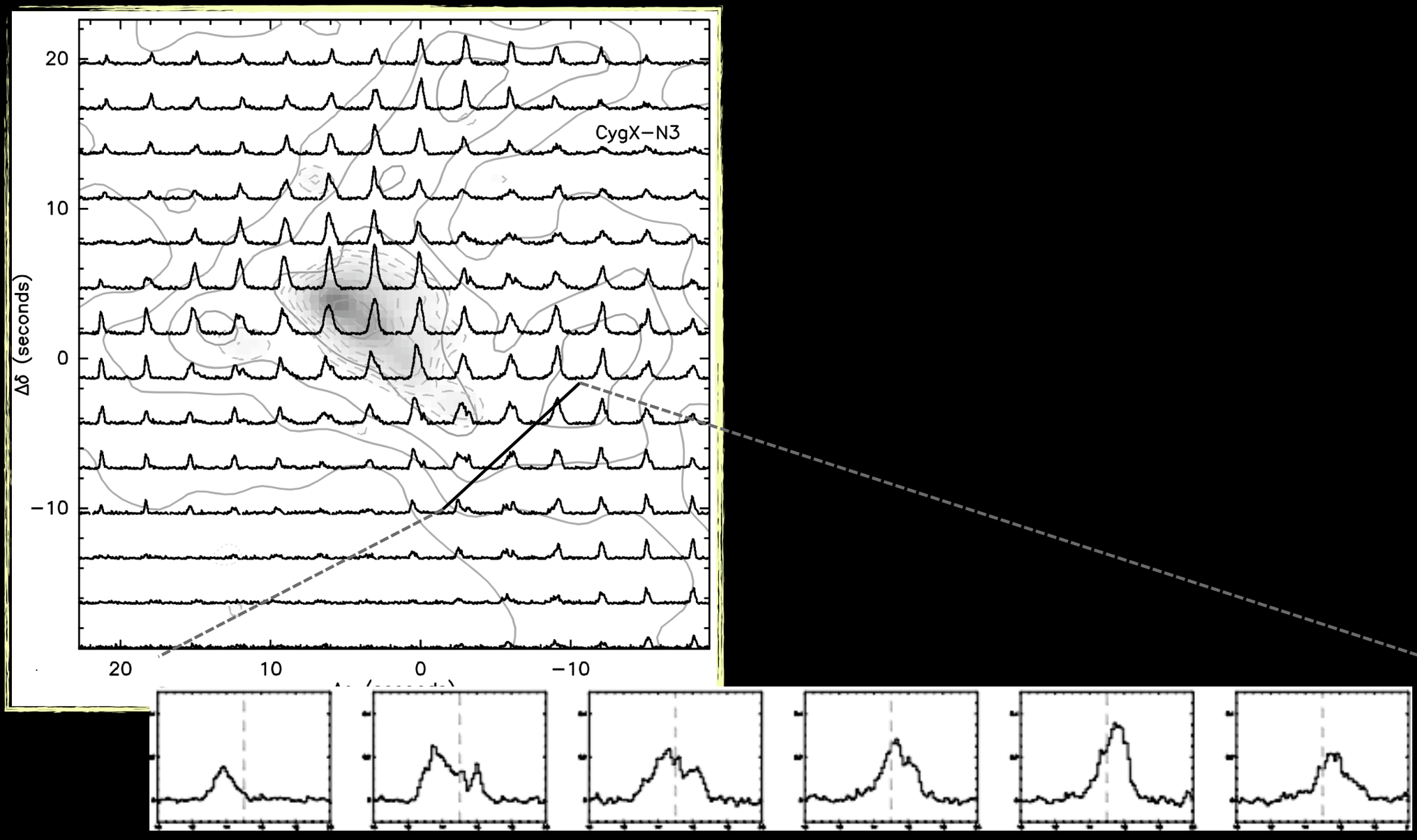


IRAM 30m $H^{13}CO^+$ spectra



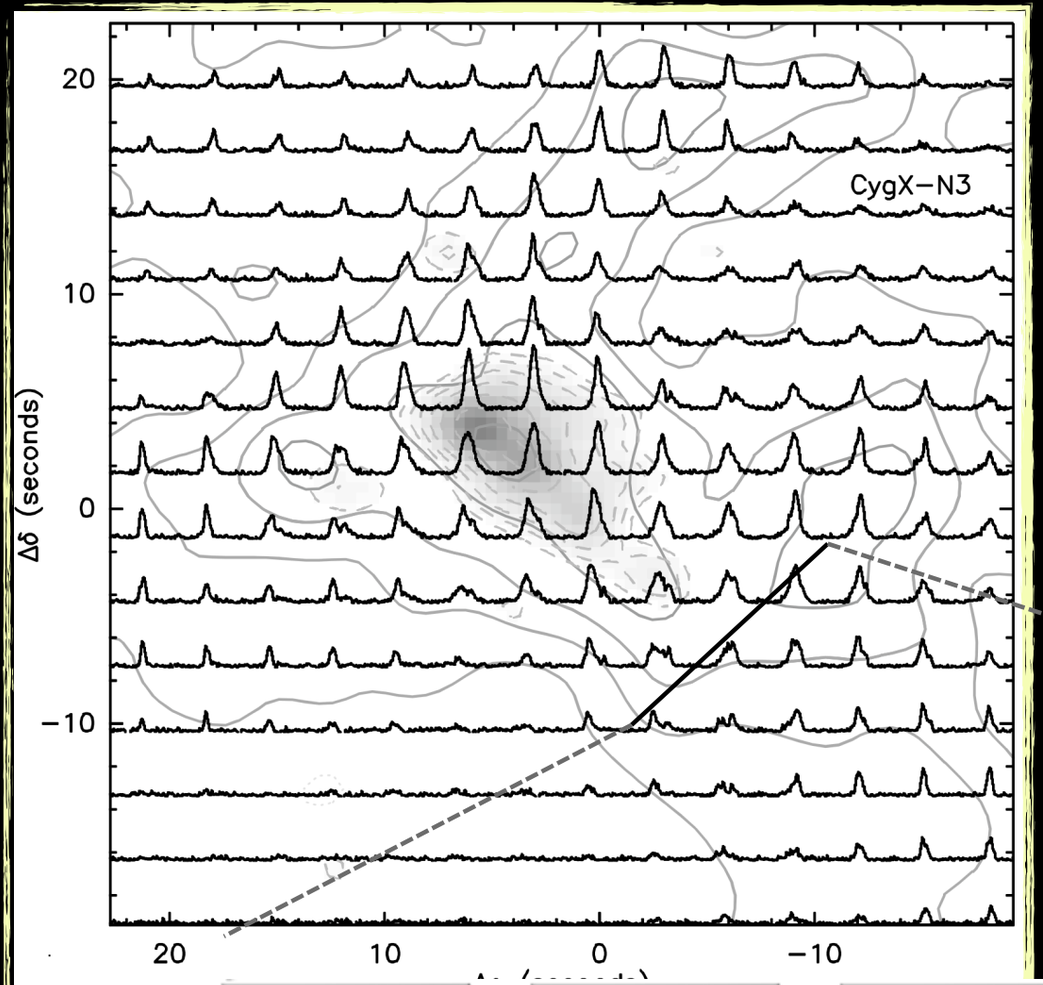
IRAM 30m+PdBI $H^{13}CO^+$

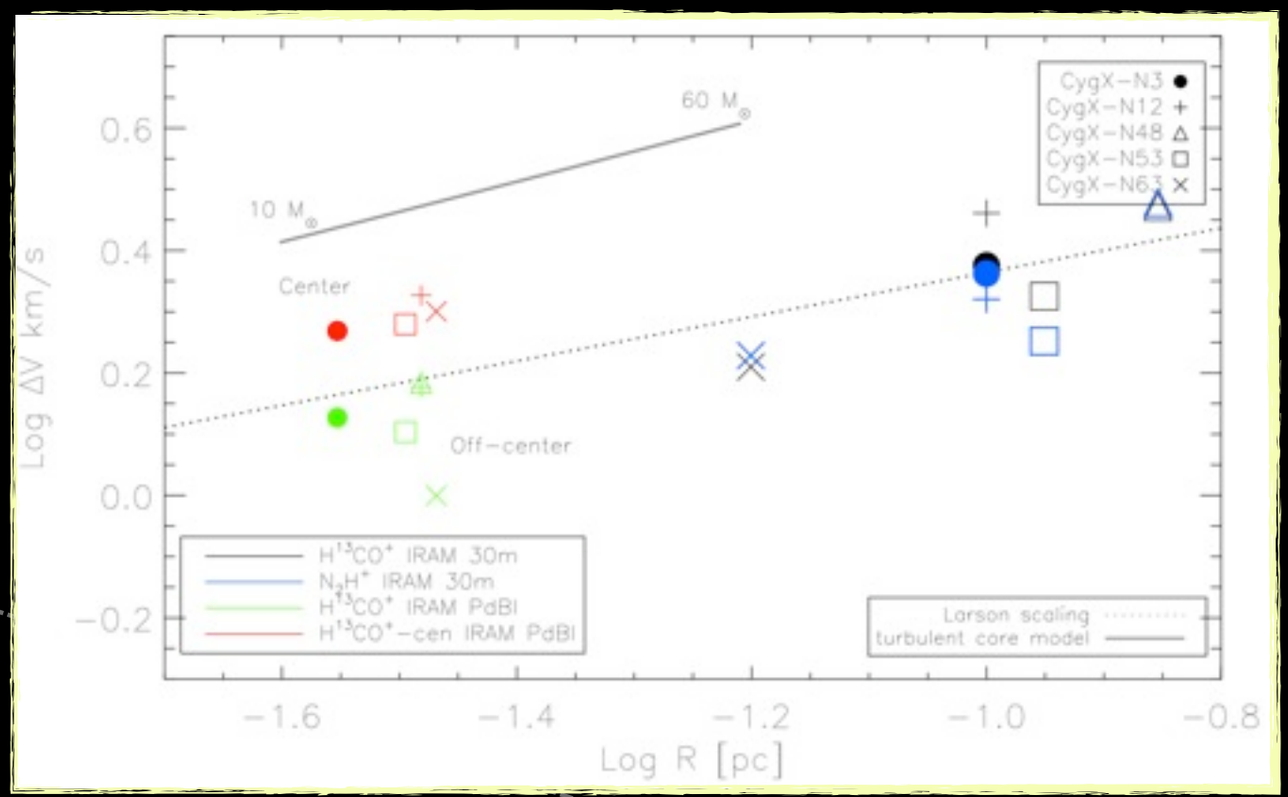
Low level of micro-turbulence at small scales

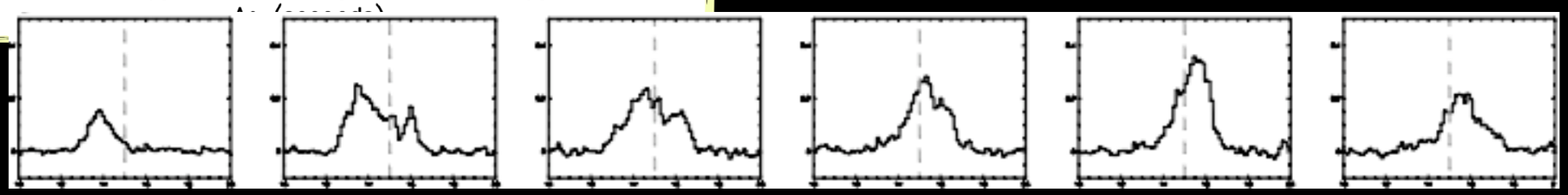


IRAM 30m+PdBI $H^{13}CO^+$

Low level of micro-turbulence at small scales

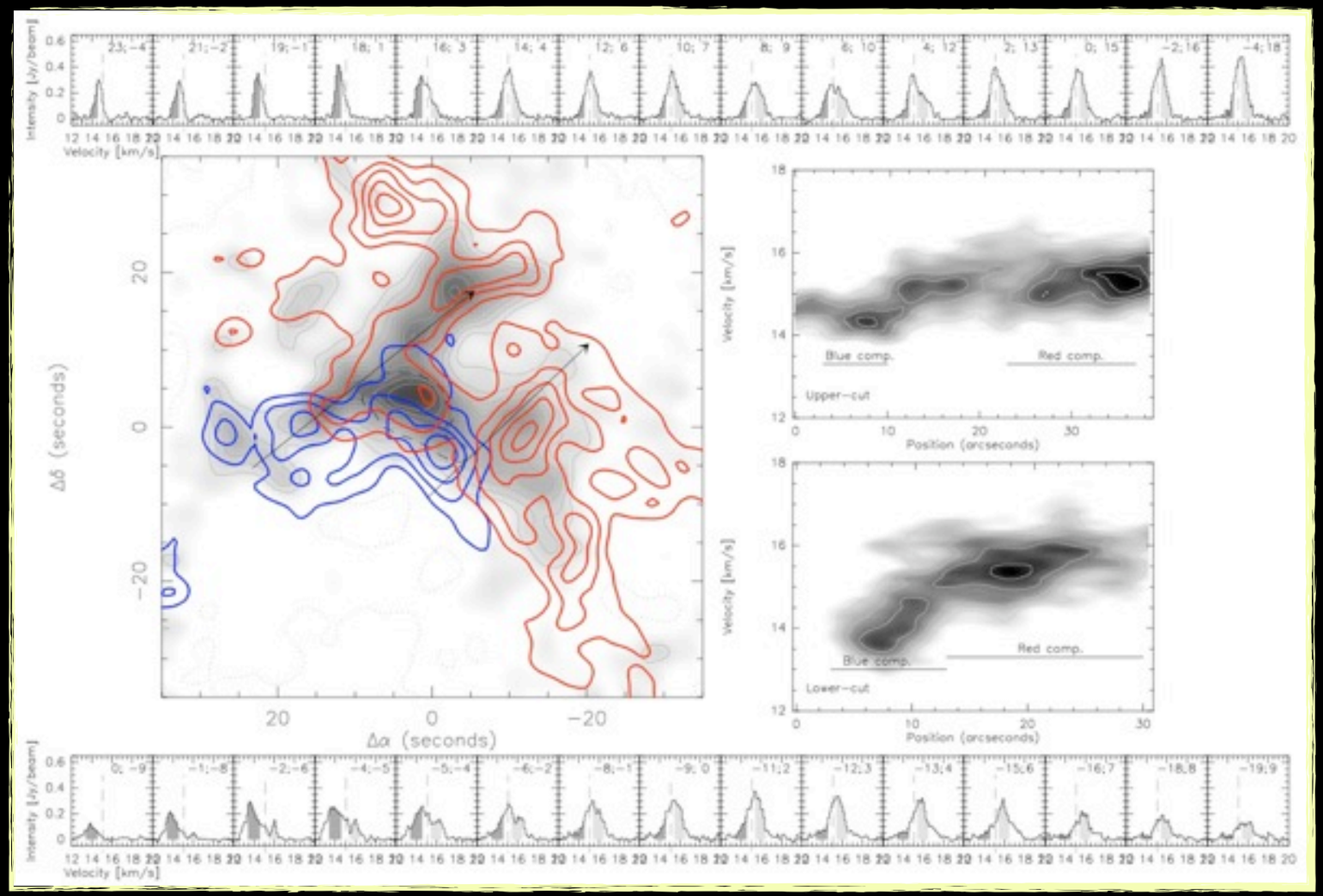






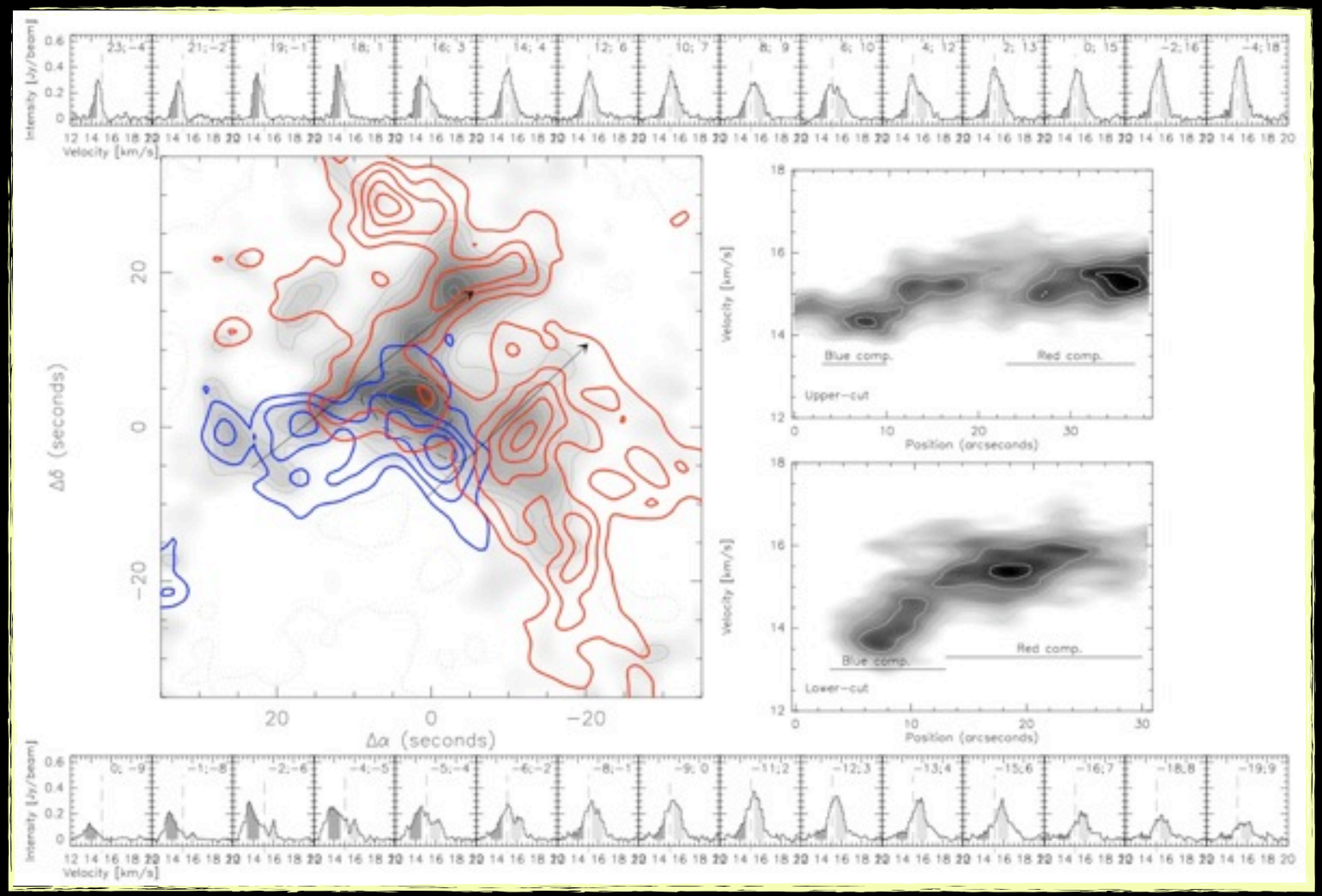
IRAM 30m+PdBI $H^{13}CO^+$

Coherent flows in the mass reservoir of MDCs



- The individual velocity components show organized, coherent structures
- The best way to understand these structures is that they converge to the central potential of MDCs

Coherent flows in the mass reservoir of MDCs



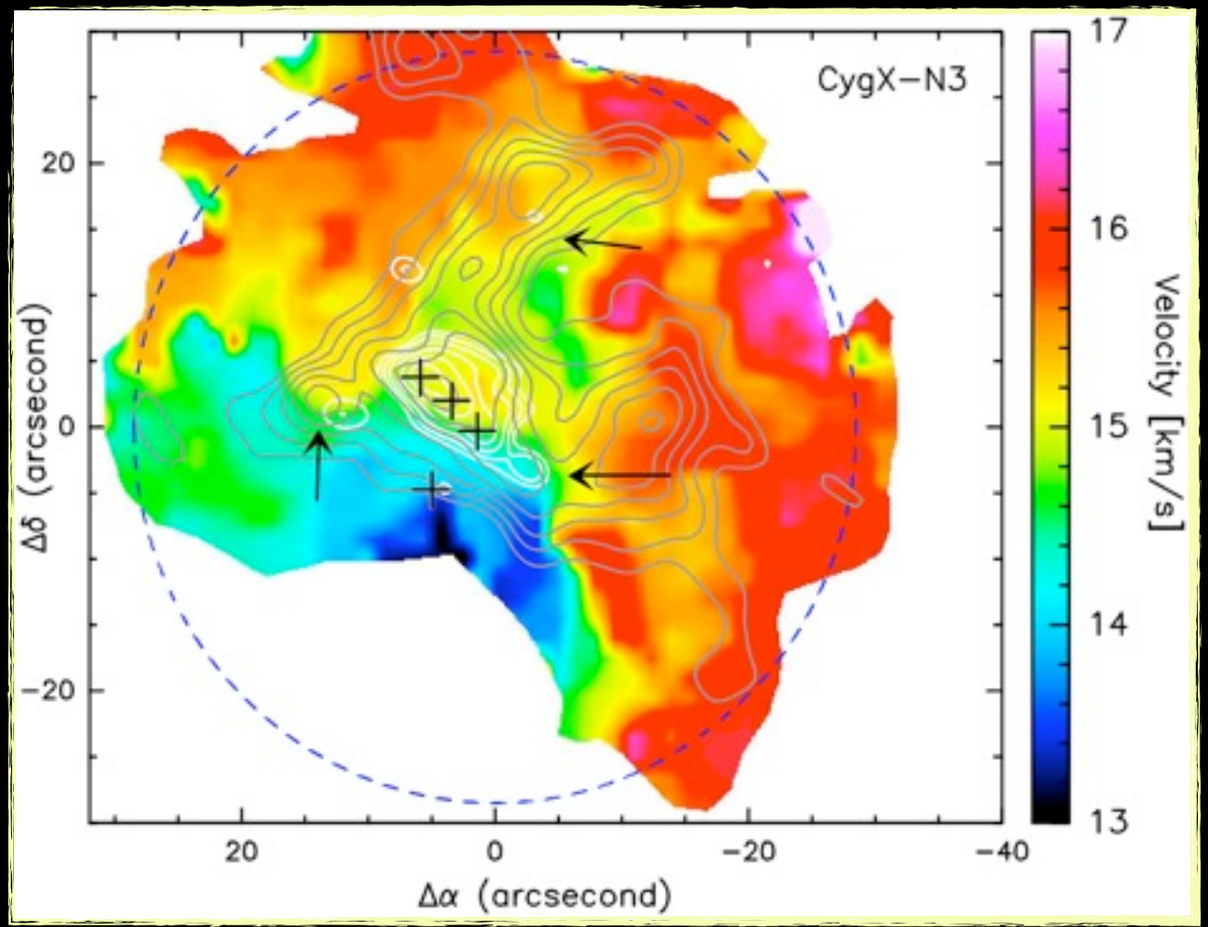
- Velocity difference of ~2-3 km/s on ~0.1 pc
- Short dynamical time-scales ~ free-fall time-scale

- The individual velocity components show organized, coherent structures
- The best way to understand these structures is that they converge to the central potential of MDCs

Dynamical scenario: where do new fragments form?

- Flow-dominated formation
- New seeds form at the velocity shears
- Weak continuum peaks seen towards the velocity shears
- We may witness the formation of new seeds

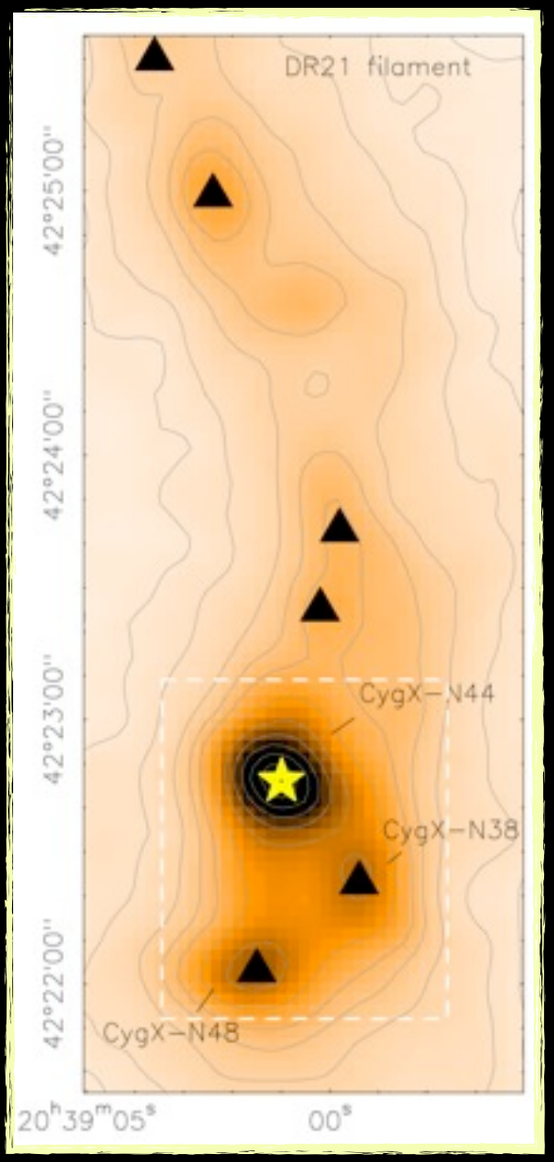
Csengeri et al., 2010, A&A in press
ArXiv: astro-ph/1009.0598



- The context of the whole sample: link between the kinematic properties and the fragmentation?
- Differences be due either to different initial conditions or evolutionary effects?

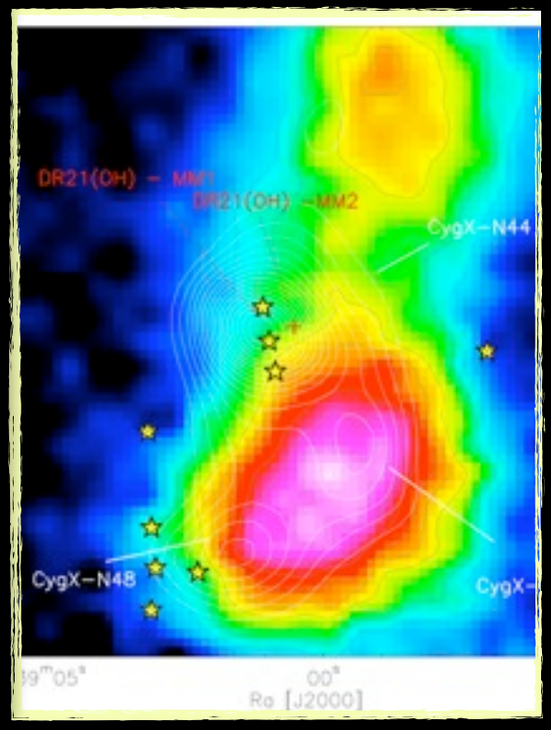
A step further: in-depth study of a rich cluster in the making, the DR21(OH) clump

What determines star-formation at smaller scales?



MAMBO 1mm continuum map (Motte et al. 2007)

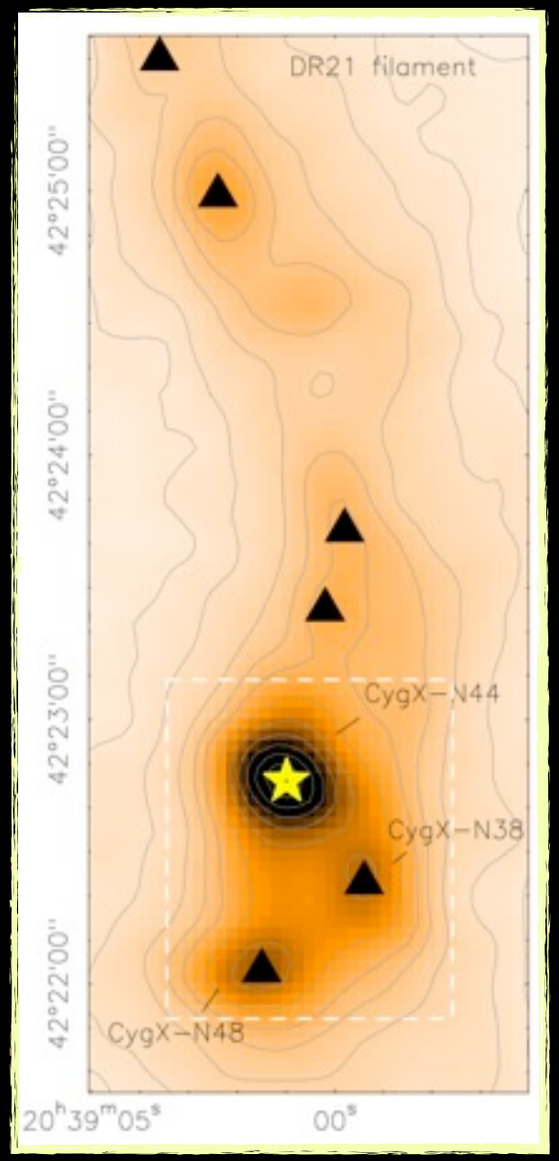
- ~7000 M_{Sun}
- Maser & hot core emission
- 2 IR-quiet MDCs



IRAM 30m map N_2H^+ (Schneider et al. 2010, A&A, 520, 49)

A step further: in-depth study of a rich cluster in the making, the DR21(OH) clump

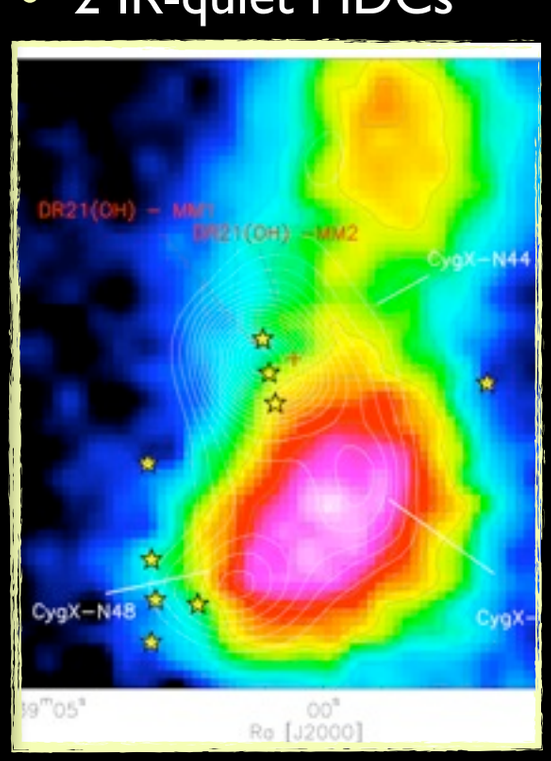
What determines star-formation at smaller scales?



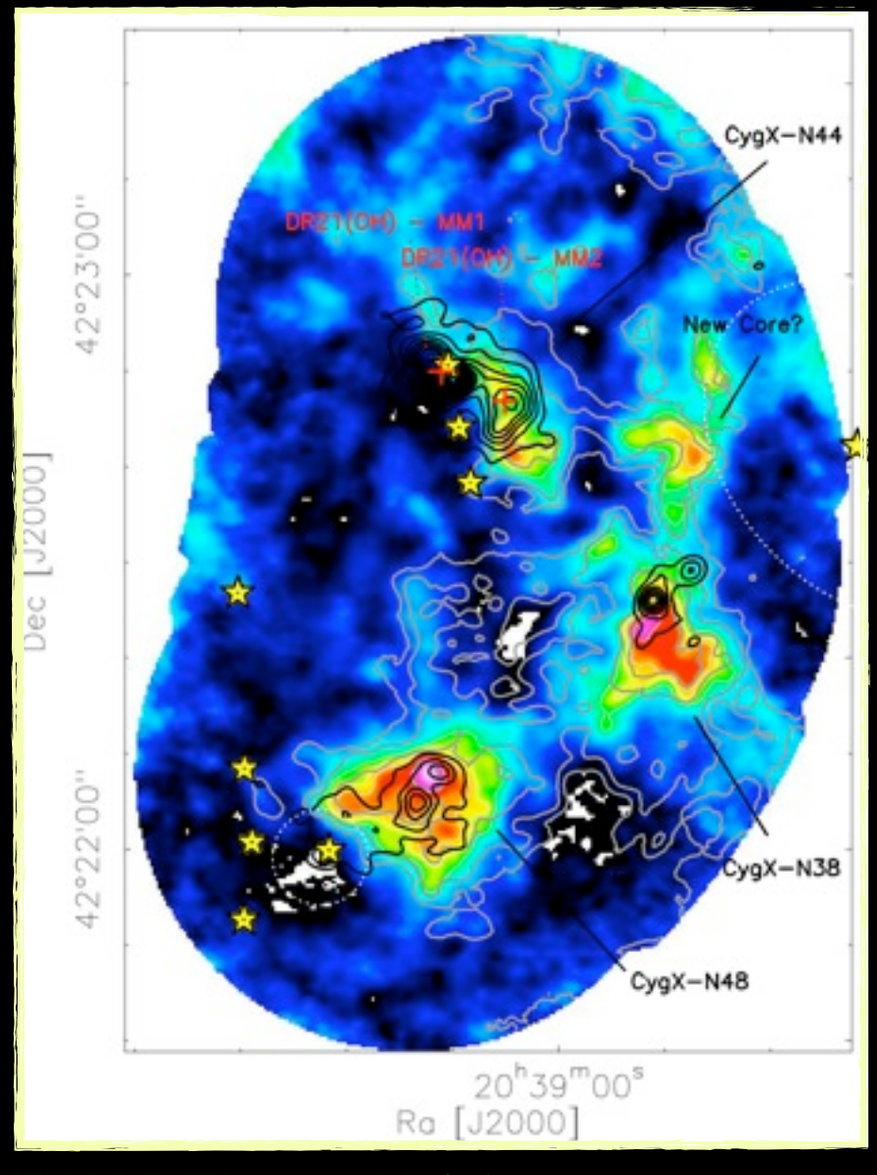
MAMBO 1mm continuum map (Motte et al. 2007)

High angular-resolution follow-up of the most massive part: mosaic with the PdBI

- ~7000 M_{Sun}
- Maser & hot core emission
- 2 IR-quiet MDCs



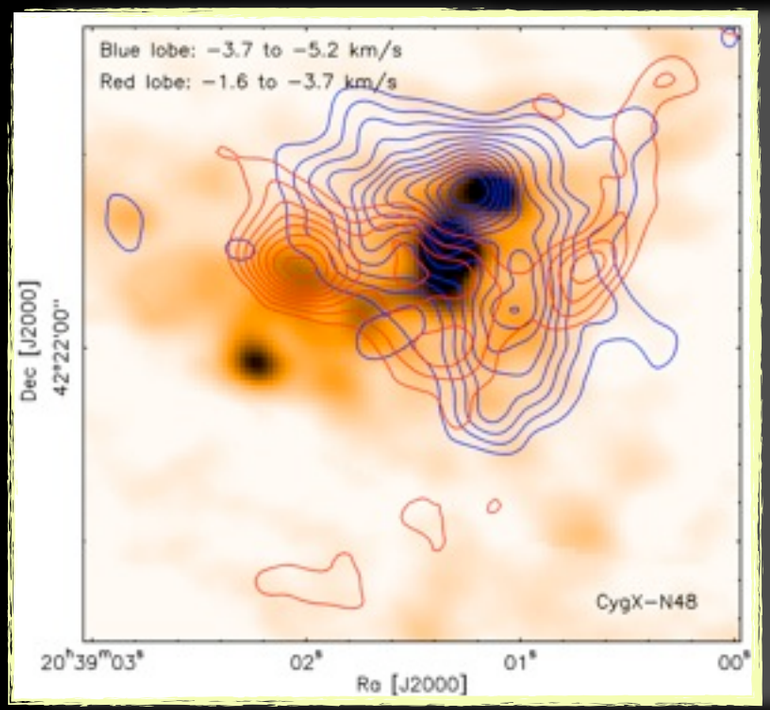
IRAM 30m map N_2H^+ (Schneider et al. 2010, A&A, 520, 49)



IRAM PdBI map N_2H^+, 3mm cont. contours (Csengeri et al. in prep)

Complex kinematics towards the Massive Dense Cores

- Individual velocity components seen in N_2H^+
- Coherent structures



3mm continuum + N_2H^+ contours

- Relative velocities
  ~ up to 2 km/s
- Short dynamical time-scales
- Diffuse emission of warm gas associated with the MDCs
- Do we witness an interaction of dense flows?

Summary and open questions

I. Sample of isolated MDCs

Bontemps, Motte, Csengeri, Schneider 2010 , A&A in press, astro-ph/0909.2315

- Massive Dense Cores in Cygnus-X form high-mass stars
- MDCs are not in monolithic collapse
  (only one MDC is found, which stays compact on ~1700 AU scales)
- A high fraction of the total mass in few compact fragments
- Where is the low-mass population?
- At what scales will the IMF be reproduced?

Csengeri et al., 2010, A&A in press ArXiv: astro-ph/1009.0598

- The gas reservoir around high-mass fragments seems not to be in equilibrium
- Several velocity components found:
  decreasing turbulent velocity dispersion at higher angular-resolution
  coherent, organized flows
- Short crossing time-scale: dynamical process are important in the mass reservoir of MDCs

II. An in depth study of a rich cluster in the making *Csengeri et al., A&A letter, in prep*

- IR-quiet MDCs are bright in N_2H^+
- Similarly high level of dynamics
- Organized flows of dense gas provide replenishment of material to the cores?