The Herschel view of molecular cloud structure and star-formation

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*Image:* Cygnus X (HOBYS) (ESA press release: 3-color image from Herschel PACS/SPIRE)
Cloud structure

cold dense gas
(SPIRE 250, 350, 500 μm)

heated gas
(PACS 70, 160 μm)

Herschel images 70 - 500 μm
(ESA/PACS & SPIRE Consortium)

Gould Belt KP (SAG3)
PI: Ph. André (talk monday)

André et al. 2010; Bontemps et al. 2010; Könyves et al. 2010 talk thursday

Orion B

Polychroni et al. 2013, Roy et al.

Schneider et al. 2013
Herschel images 70 - 500 μm (ESA/PACS & SPIRE Consortium)

HOBYS KP (SAG3)
Pls: Motte, Zavagno, Bontemps
(Motte talk friday, Zavagno talk thursday)

Schneider et al. 2010, 2012; Motte et al. 2010;
di Francesco et al. 2010; Hennemann et al. 2010;
Tremblin et al. 2013
Hill et al. 2011; Giannini et al. 2012;
Minier et al. 2013

Vela C
Rivera-Ingraham et al. 2013

NGC7538
Fallscheer et al. 2013
Herschel FIR-imaging of Galactic regions

Open Time programs (some examples)

Hi-Gal  (PI: S. Molinari) talk friday

Elia et al. 2013

Carina: (PI: T. Preibisch)

California/Auriga (PI: P. Harvey)  Harvey et al. 2013

Roccatagliata et al. 2013 talk thursday
Cloud structure:

Sources:
starless cores, prestellar cores, protostars

Filament formation
- Large-scale MHD turbulence with shock collision (e.g., Padoan et al. 2001; Klessen et al. 2005...)
- Converging flows (e.g., Heitsch et al. 2005; Vaquez-Semadeni et al. 2011; Klessen & Hennebelle 2010...)
- (gravity) (Bonnell 2008)
- ‘turbulent stretching’ (Hennebelle 2013)

Low-mass star-formation:
- Fragmentation and collapse of gravitationally unstable filaments,
- Accretion by striations (faint filaments)
- Prestellar/starless cores and protostars are mainly on filaments

(Andre et al. 2010; Arzoumanian et al. 2011, 2013; Palmeirim et al. 2013; see also SDP-papers; Kirk et al. 2013; Marsh et al., Bressert et al., in prep...)

Sources:
Arzoumanian et al. 2011, poster P30
**Cloud structure:**

**Sources:**
starless cores, prestellar cores, protostars

1. column density and dust temperature maps from SED (160-500 μm)

2. curvelet analysis to enhance structure, filament tracing (e.g. Disperse)

**Orion A**

**Lupus**

only class I and II outside filaments

24% pre-stellar cores outside filaments

Arzoumanian et al. 2011, poster P30

Rygl et al. 2013a

Polychroni et al. 2013
High-mass SF regions: no detailed study yet...

- sources ‘off’-filament by visual inspection of NGC7538 (Fallscheer et al. 2013)
- sources outside filaments in Vela C (Giannini et al. 2012)
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**Difference to low-mass SF regions:**

- feedback from massive stars (stronger UV-radiation, ionization, wind),
- pillars, globules, EGGs, condensations...
  may lead to a different mode of star-formation *no filaments but photoevaporation and compression*
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High-mass star-formation:

- merging of filaments into ridges and hubs to form OB-cluster  
  (talk Motte friday)


(but see also studies of Motte et al. 2010; di Francesco et al. 2010; Hennemann et al. 2010; Nguyen-Luong et al. 2011; Hill et al. 2011, 2012; Giannini et al. 2012; Rygl et al. 2013b; Rivera-Ingraham et al. 2013; Fallscheer et al. 2013 ....)

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**Rosette**

- column density map

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**filaments on curvelet image**

Schneider et al. 2012
Filaments and accretion in high- and low-mass star-formation:
- filaments parallel to magnetic field (input mass rate $\sim 2 \times 10^{-3} M_{\odot}/\text{yr}$)
- large-scale infall

**DR21** 3-color image

- mass of DR21 ridge $\sim 15 \, 000 \, M_{\odot}$

**HCO$^+$ spectra on N$_2$H$^+$**

- Taurus
  - mass of striation $\sim 150 \, M_{\odot}$

**Herschel** column density map and CO contours

- Schneider et al. 2010, Hennemann et al. 2012

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Fig. 3. (Left) DR21 3-color image

- DR21 Ridge & filaments

- mass of DR21 ridge $\sim 15 \, 000 \, M_{\odot}$

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Fig. 4. DisPerSE in the B211 filament and aligned with the direction of the striations overlaid in blue. The green, blue, and black segments in the lower right corner represent our B213 and B211 segments of the whole filament discussed in this paper, respectively.

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Fig. 5. Using the column density and temperature maps derived from Herschel data (see Appendix A), we produced radial column density and temperature structure of the B211 filament.
Filaments and accretion in high- and low-mass star-formation:
- filaments parallel to magnetic field
- large-scale infall
- core formation on filaments

Filament F1N (mass 1200 M$_{\odot}$)

**DR21** 3-color image

<table>
<thead>
<tr>
<th>N</th>
<th>F1S</th>
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<tbody>
<tr>
<td>F3N</td>
<td>DR21</td>
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<tr>
<td>SW</td>
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mass of DR21 ridge $\sim$15 000 M$_{\odot}$

**Taurus**

mass of striation $\sim$150 M$_{\odot}$

(input mass rate $\sim 2 \times 10^{-3}$ M$_{\odot}$/yr)

HCO$^+$ spectra on N$_2$H$^+$

Hennemann et al. 2012

Schneider et al. 2010, Csengeri et al. 2011a,b, Motte et al. 2007, Bontemps et al. 2010

Palmeirim et al. 2013
From *spatial* structure to *density* structure...

**Probability distributions functions of column density (PDFs)**

- A *statistical tool* to describe the probability of a volume $dV$ to have a density between $\rho$ and $\rho+dp$. To first order, the *2D-column density* can be used.

- Very useful to compare *observations* with *numerical* models.
PDF of column density from Herschel

Turbulence

Andre et al. 2010; Men'shchikov et al. 2010; Miville-Deschenes et al. 2010; Ward-Thompson et al. 2010; Schneider et al. 2013

(PDF) is lognormal:

\[ \eta = \ln(N/\langle N \rangle) \]

\[ \sigma = 0.22 \]

\( \text{Number of pixels per log bin} \)

\( \text{N(H2) [1e21 cm}^{-2}] \)

Federrath & Klessen et al. 2013

(M)HD modelling

\[ \rho_s \, ds = \frac{1}{\sqrt{2\pi\sigma_s^2}} \exp \left[ -\frac{(s - \langle s \rangle)^2}{2\sigma_s^2} \right] \, ds \]
Gravity

PDF of column density from Herschel

Power-law tail: \( \text{gravity} \) (Klessen et al. 2000; Kainulainen et al. 2009)

Individual core collapse (\( \alpha = 2 \))?

\[
\rho (r) \sim r^{-\alpha}
\]

\( \alpha = -2/s+1 \) (Federrath & Klessen 2012)
PDF of column density from Herschel

Two power-law tails with different slope?
$A_v \sim 4 - 10$ large-scale collapse, $A_v > 10$ core collapse

Source-subtracted (done by N. Cox using 'getsources', Men'shinkov et al. 2012) PDF is nearly lognormal.

Alves de Oliveira, Schneider et al. 2013; Spezzi et al. 2013; poster P36 (Cox)
**NGC6334**

A~12 ~ 100

Gravity + flows

**core collapse + convergent flows?**

A_v ~ 100

mass input by filaments + large-scale infall?

**MonR2**

A_v ~ 12

**W3: local stellar feedback.. compression and convergent flows**

Rivera-Ingraham et al., in prep  poster P65
Orion B column density map

Gravity + compression

Column density cuts

PDF of column density from Herschel

- external compression clearly visible in column density profile
  see also Peretto et al. (2012) for Pipe and Tremblin et al. (2013)
- broadens the PDF

Ionization + radiation + wind

Tremblin et al. 2013: talk thursday
Orion B column density map

Gravity + compression

Column density cuts

PDF of column density from Herschel

Gravity + compression clearly visible in column density profile

σ ~ 0.5

σ ~ 0.2

IRDC (from Kainulainen & Tan 2013)

not much background emission to correct for (see Peretto et al. 2010)

Schneider, Csengeri, Ossenkopf et al., in prep

Tremblin et al. 2013: talk Thursday
Rosette column density map

Schneider et al. 2010, 2012

Compression

HII-region/molecular cloud interface -> compressed shell?
‘double-peak’ PDFs are a characteristic feature of compressed shells ....

Compressed RCW120

Tremblin, Schneider et al. 2013
talk Thursday

RCW120

M16

Zavagno et al. 2010

Hill et al. 2012

Hydrodynamic simulation with ionization

Tremblin et al. 2012, 2013

ln (N/<N>)

Mach 1 without ionization
Mach 1 with ionization

Mass fraction

Density [cm⁻³]
The **spatial** structure of clouds (and its relation to the *sources*)

- Sources in low-mass SF regions are mainly *on filaments*, in UV-illuminated regions isolated features *off-filaments*
- maybe different modes of SF?

*Gravitational fragmentation of filaments* vs. *photoevaporation and compression*

The **density** structure of clouds

- *Probability distribution functions* of column density (PDFs) are very diverse tracing various effects:
  - -> lognormal for turbulence
  - -> broader PDFs due to compression
  - -> power-law tail(s) for gravity
    - -> medium densities: *large-scale infall*
    - -> high-densities: *core-collapse and convergent flows*