The Herschel view of molecular cloud structure and star-formation

Nicola Schneider

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

Herschel images *70 - 500 µm*

(ESA/PACS & SPIRE Consortium)

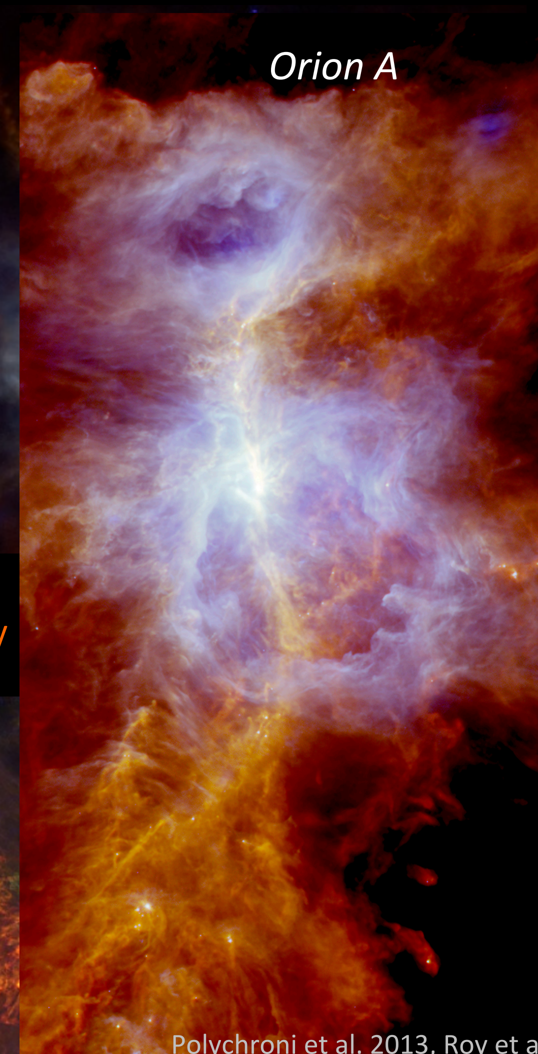
Gould Belt KP (SAG3)
PI: Ph. André (talk monday)

Cloud structure

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

heated gas
(PACS 70, 160 µm)

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



Schneider et al. 2013

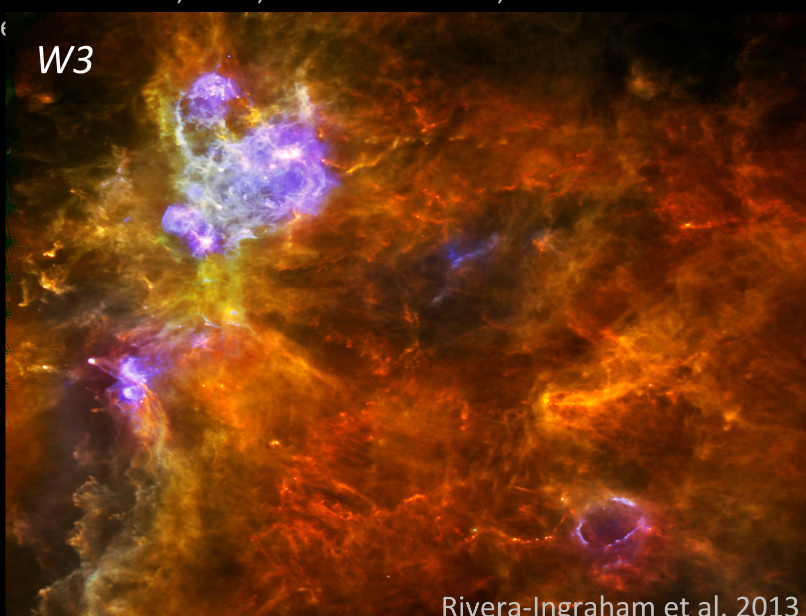
Herschel images *70 - 500 μm* (ESA/PACS & SPIRE Consortium)

HOBYS KP (SAG3)

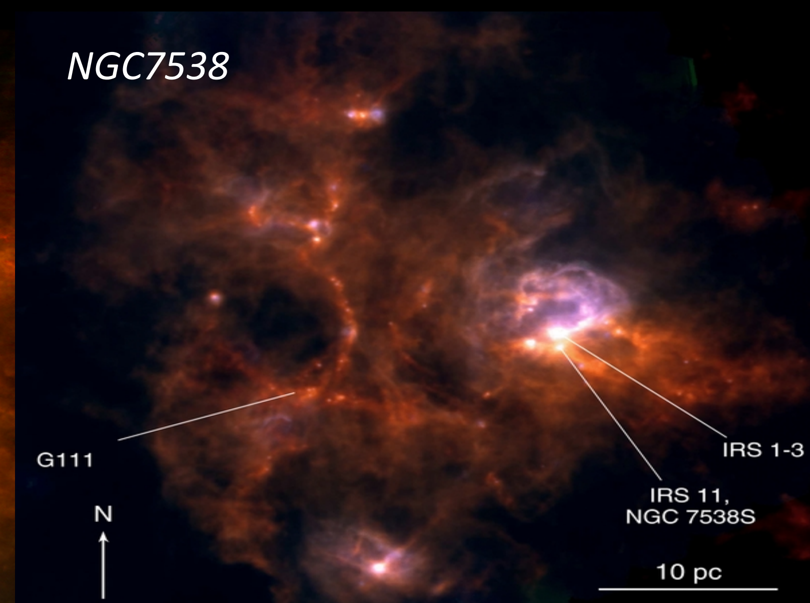
PIs: Motte, Zavagno, Bontemps

(Motte talk friday, Zavagno talk thursday)

Schneider et al. 2010, 2012; Motte et al. 2010;
di France



Rivera-Ingraham et al. 2013

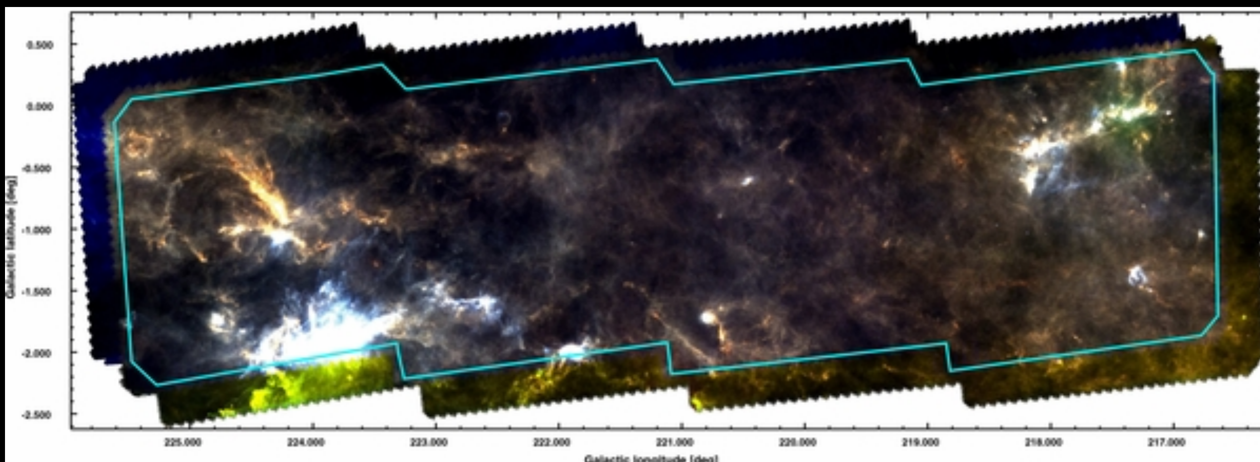


Fallscheer et al. 2013

Herschel FIR-imaging of Galactic regions

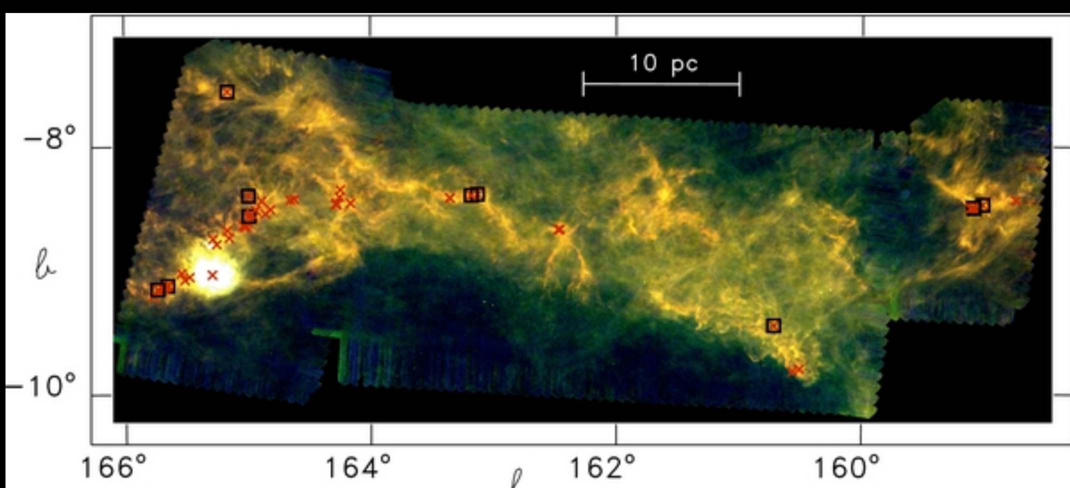
Open Time programs (some examples)

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



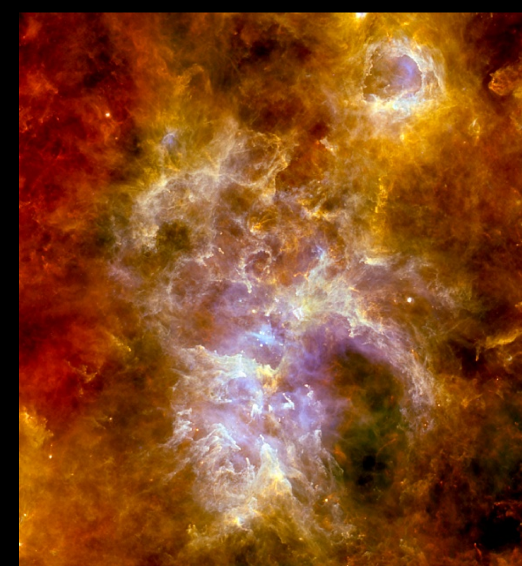
Elia et al. 2013

Carina: (PI: T. Preibisch)



California/Auriga (PI: P. Harvey)

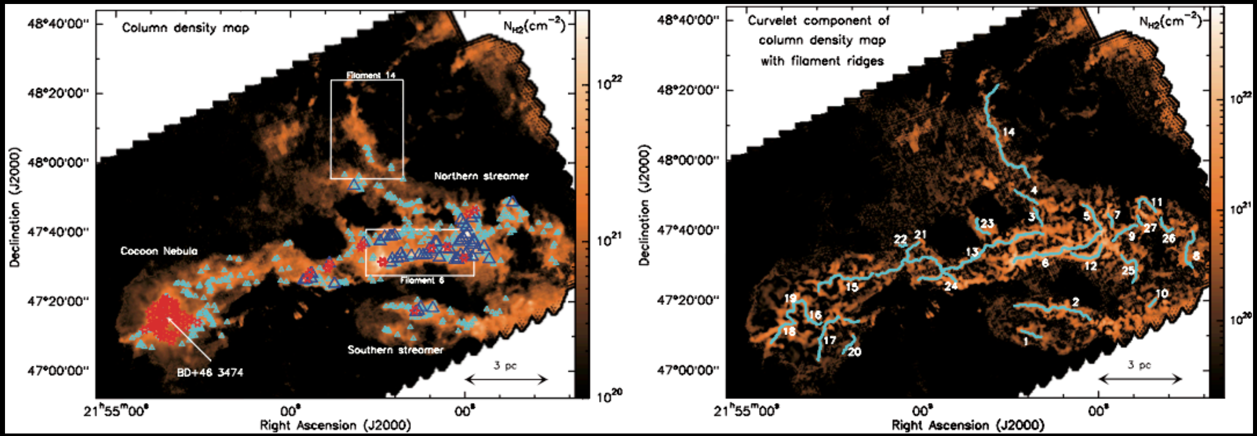
Harvey et al. 2013



Roccatagliata et al. 2013 talk thursday

Cloud structure:

1. column density and dust temperatur maps from SED (160-500 µm)
2. curvelet analysis to enhance structure, filament tracing (e.g. Disperse)



IC5146

Arzoumanian et al. 2011, poster P30

Sources:
starless cores,
prestellar cores,
protostars

Filament formation

- Large-scale MHD turbulence with shock collison (e.g. Padoan et al. 2001; Klessen et al. 2005…)
- converging flows (e.g. Heitsch et al. 2005; Va*quez-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…)

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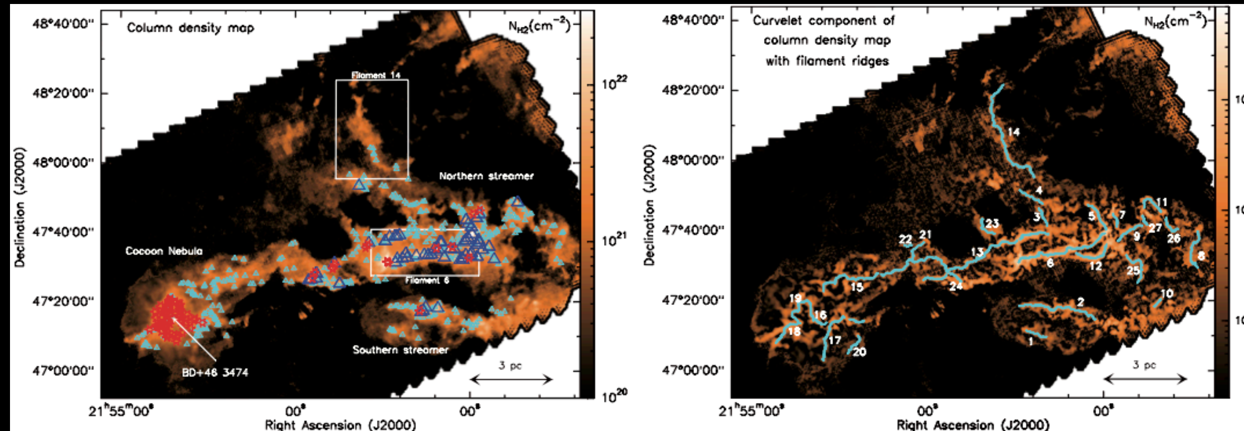
IC5146



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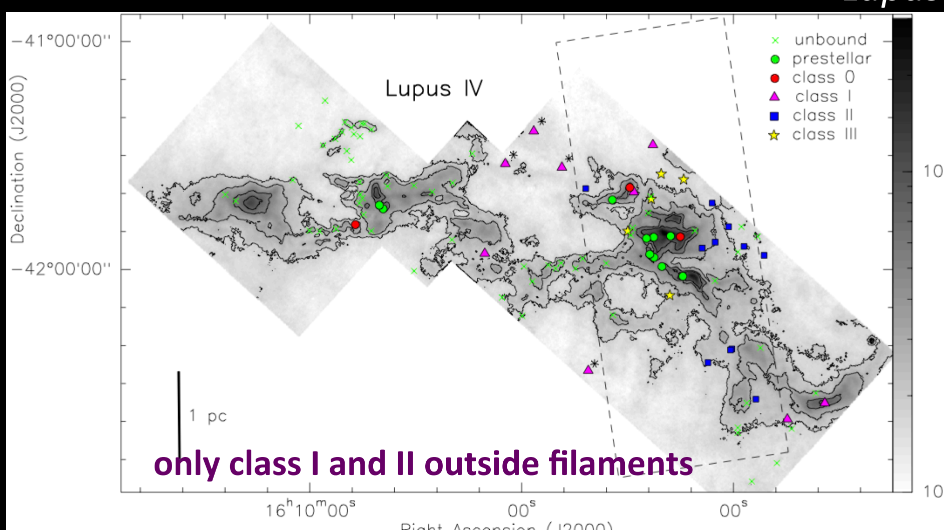
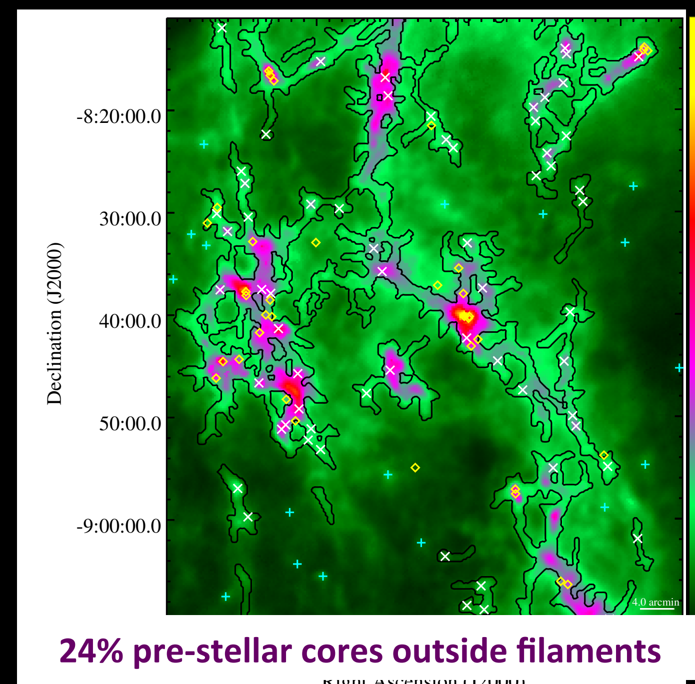
Lupus



only class I and II outside filaments

Rygl et al. 2013a

Orion A

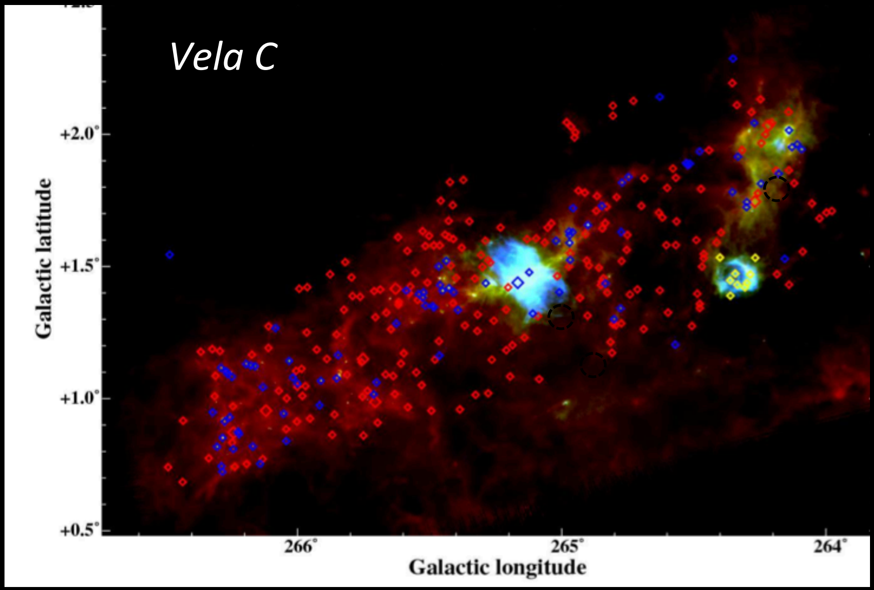


24% pre-stellar cores outside filaments

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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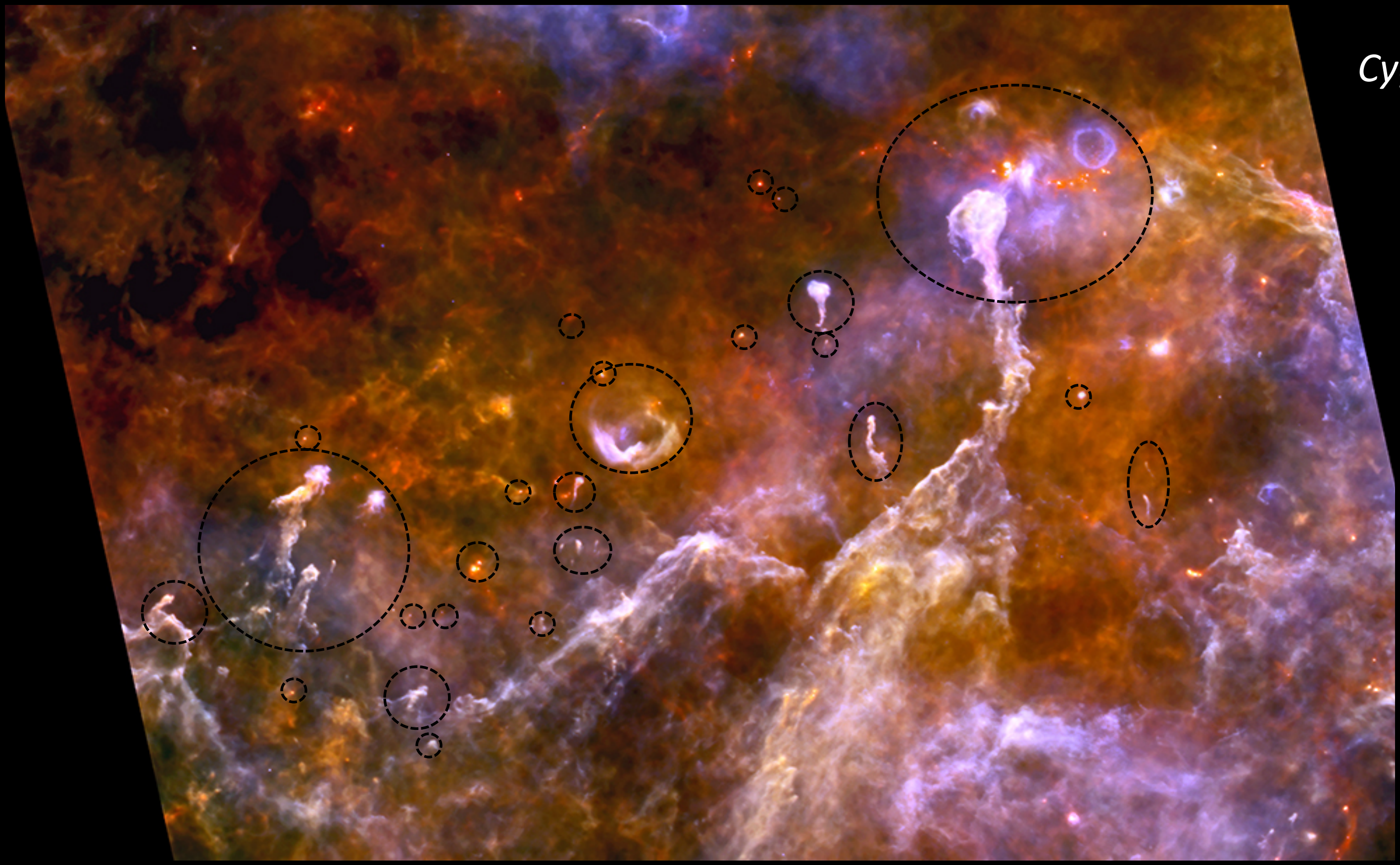

Cygnus

Schneider, Bontemps et al., in prep.

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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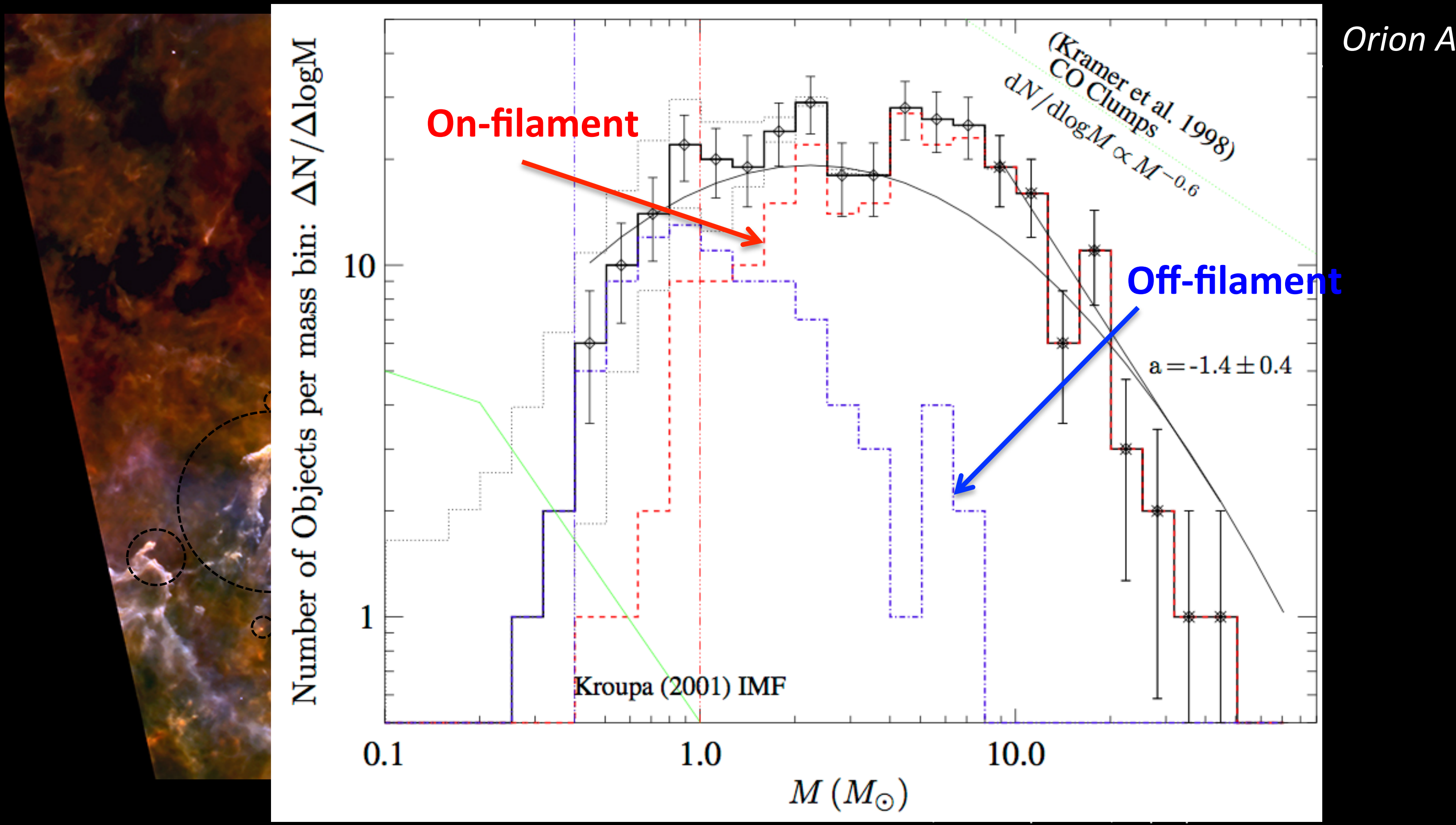

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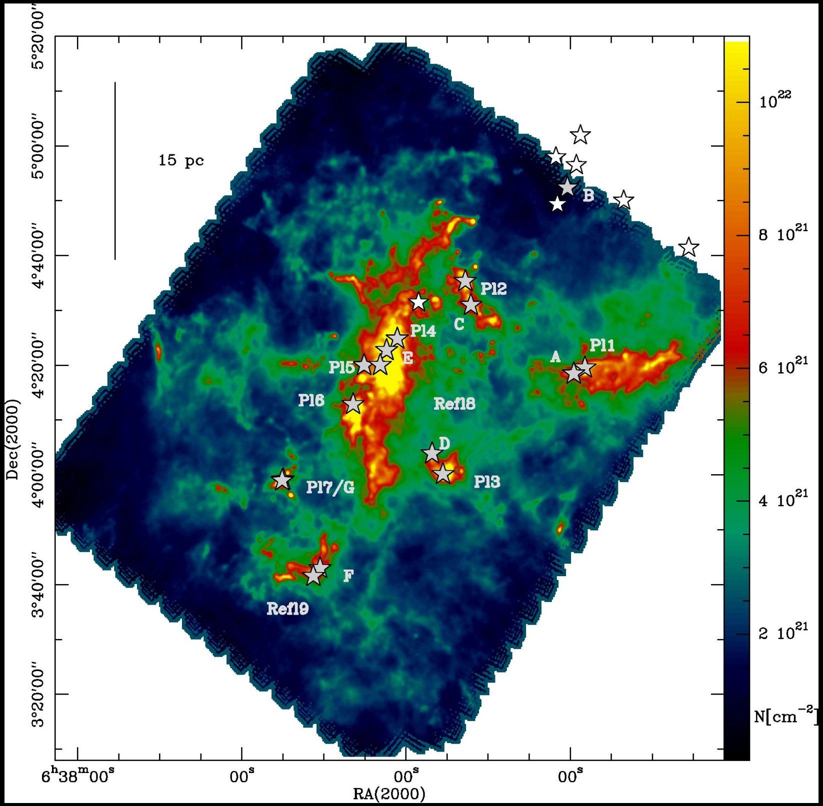
High-mass star-formation:

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

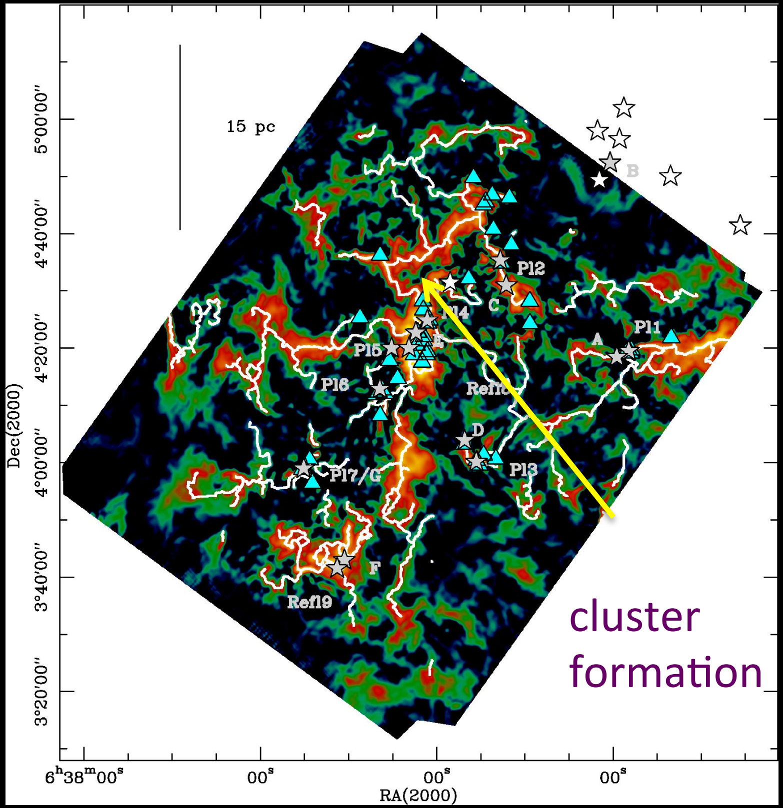
Schneider et al. 2010, 2012; Hennemann et al. 2012

(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 ….)

Rosette column density map



filaments on curvelet image

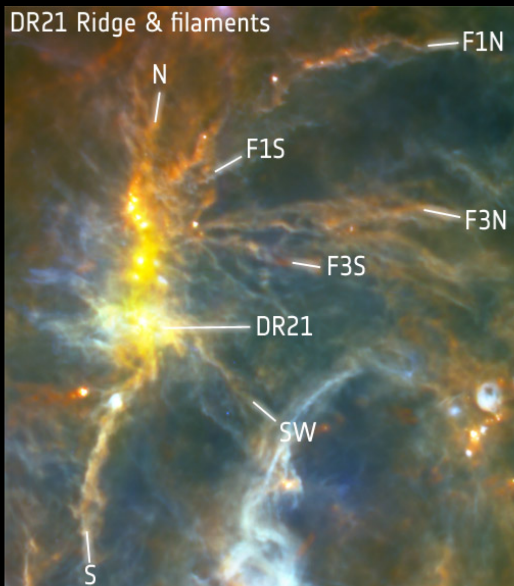


Schneider et al. 2012

Filaments and accretion in high-and low- mass star-formation:

- filaments parallel to magnetic field (input mass rate ~ 2 x 10^{-3} M_{sun}/yr)
- large-scale infall

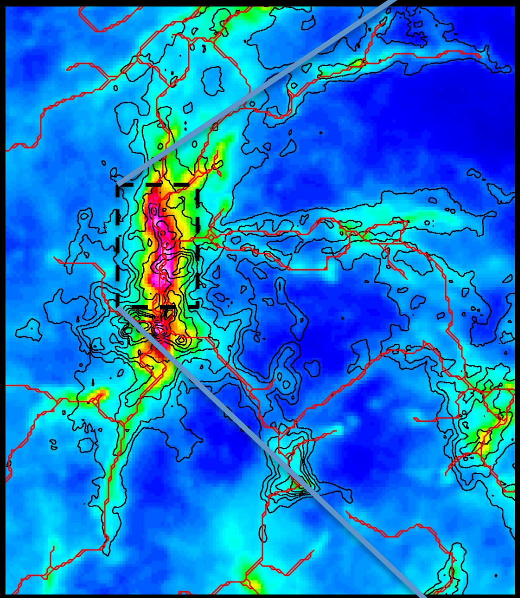
DR21 3-color image



mass of DR21 ridge ~15 000 M_{sun}

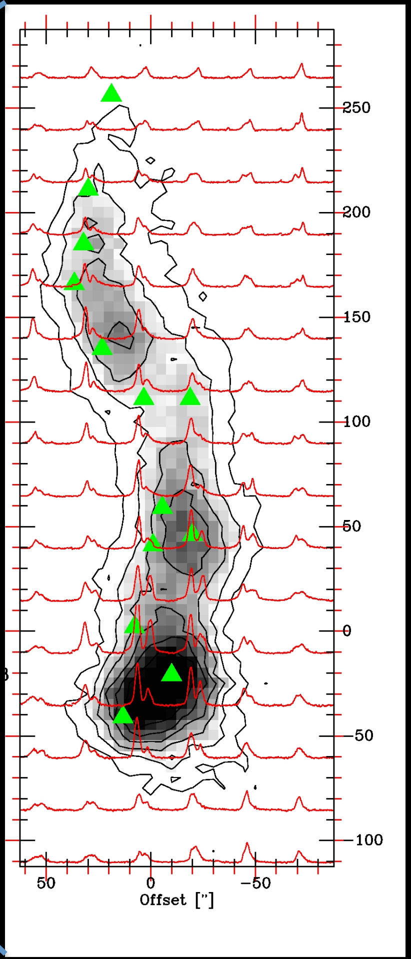
magnetic field

Herschel column density map and CO contours



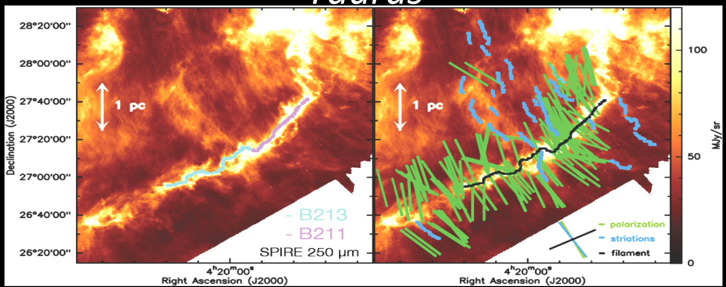
Schneider et al. 2010, Hennemann et al. 2012

HCO$^+$ spectra on N_2H^+



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

Taurus



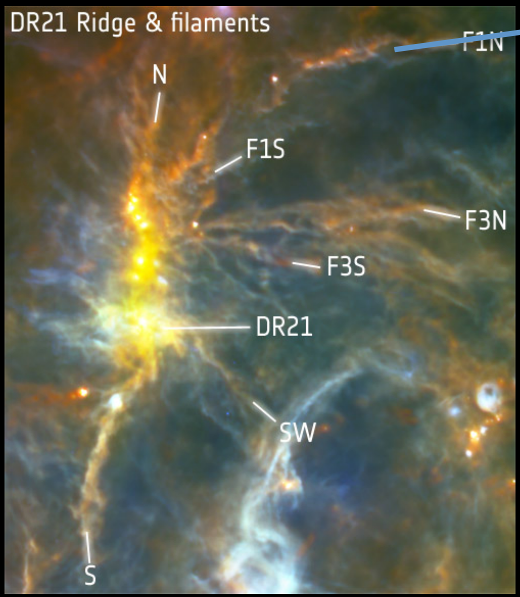
mass of striation ~150 M☉

Palmeirim et al. 2013

Filaments and accretion in high-and low- mass star-formation:

- filaments parallel to magnetic field (input mass rate ~ 2 x 10^{-3} M_{sun}/yr)
- large-scale infall
- core formation on filaments

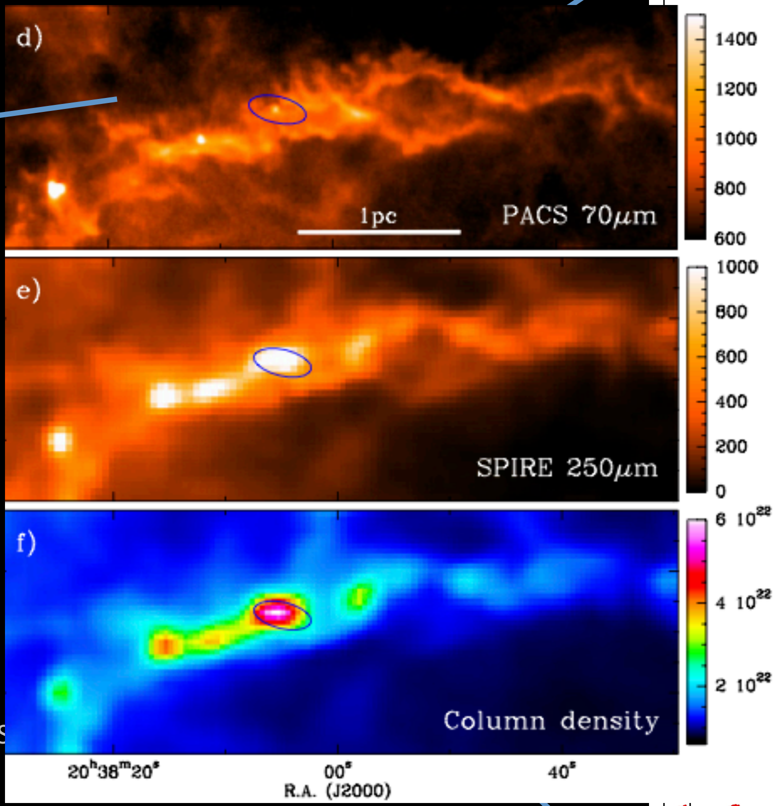
DR21 3-color image



mass of DR21 ridge ~15 000 M_{sun}

magnetic field

Filament F1N (mass 1200 M_{sun})



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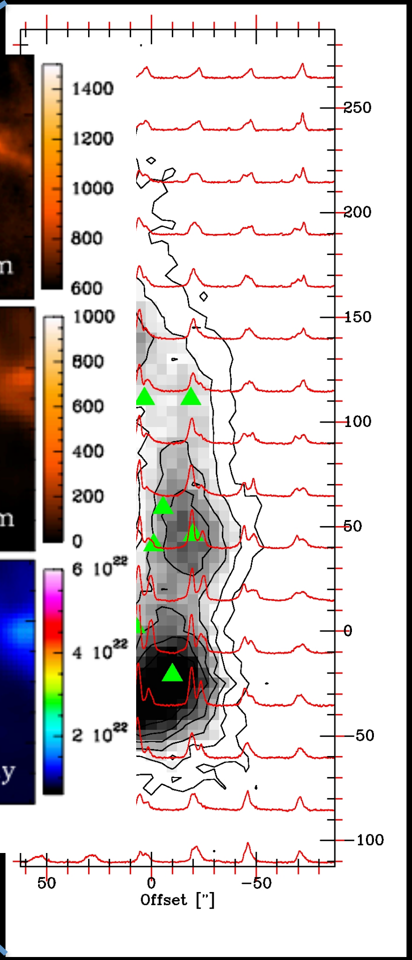

Hennemann et al. 2012

Schneider et al. 2010,
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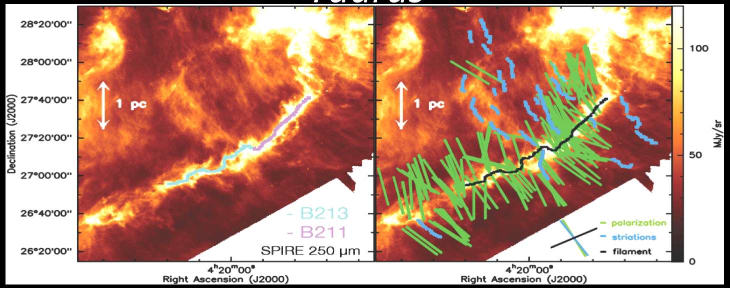
Motte et al. 2007,
Bontemps et al. 2010

Taurus



mass of striation ~150 M☉ Palmeirim et al. 2013

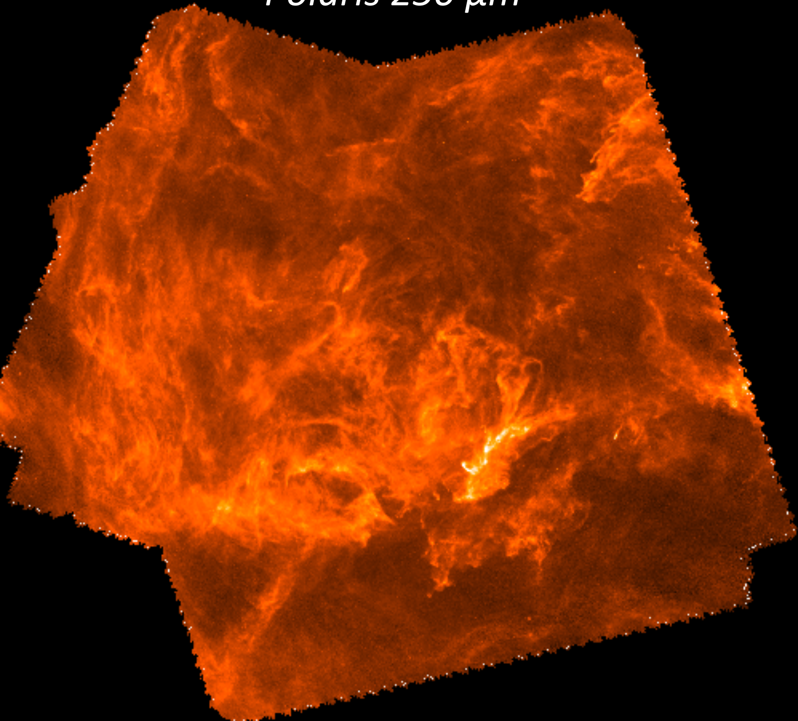
From *spatial* structure to *density* structure...

Probability distributions functions of column density (PDFs)

- A statistical tool to describe the probability of a volume dV to have a density between ρ and $\rho+d\rho$. To first order, the 2D-column density can be used.
- Very useful to compare observations with numerical models.

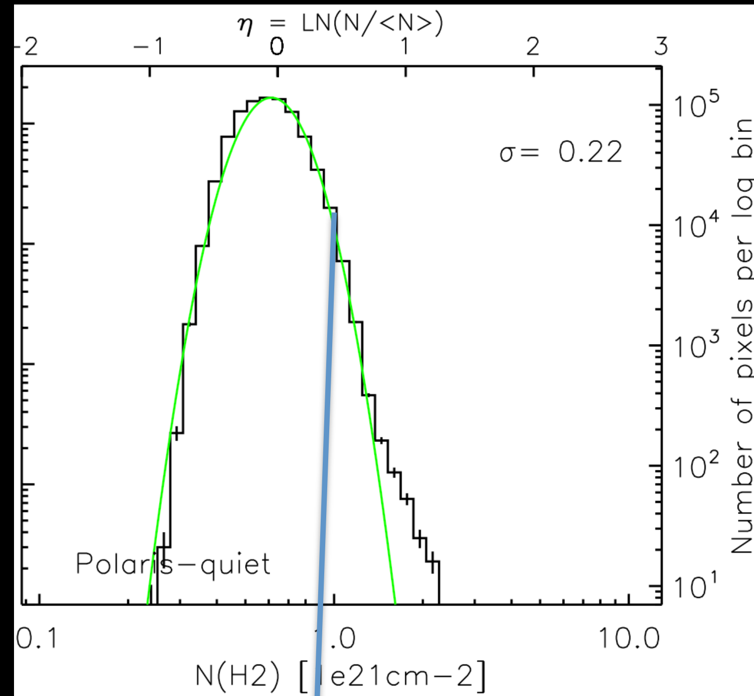
Turbulence

Polaris 250 µm



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

PDF of column density from Herschel

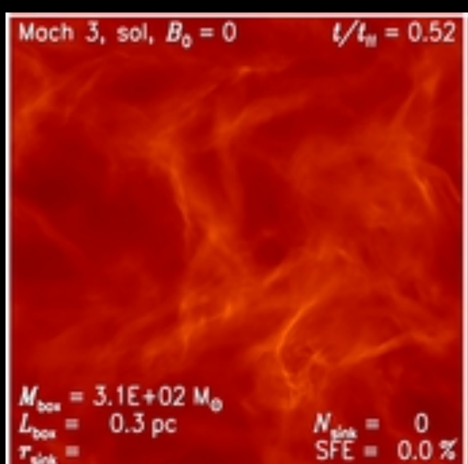


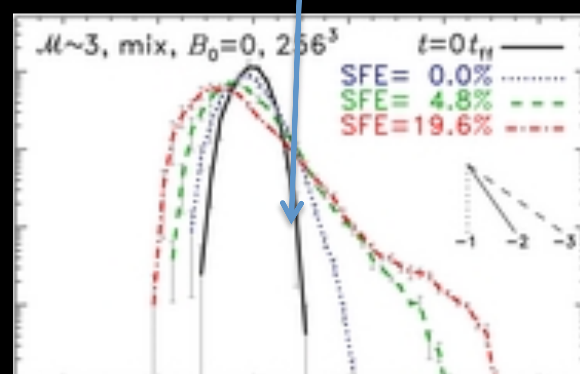
Schneider et al. 2013

PDF is lognormal:

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

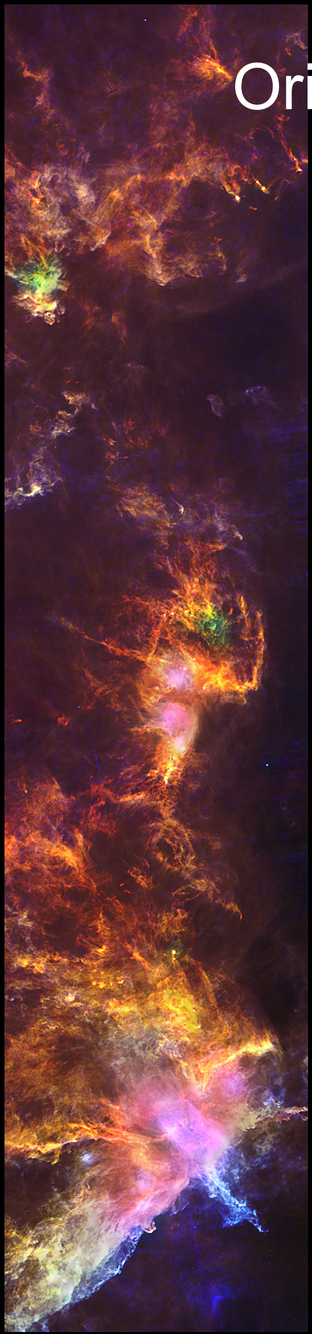
(M)HD modelling

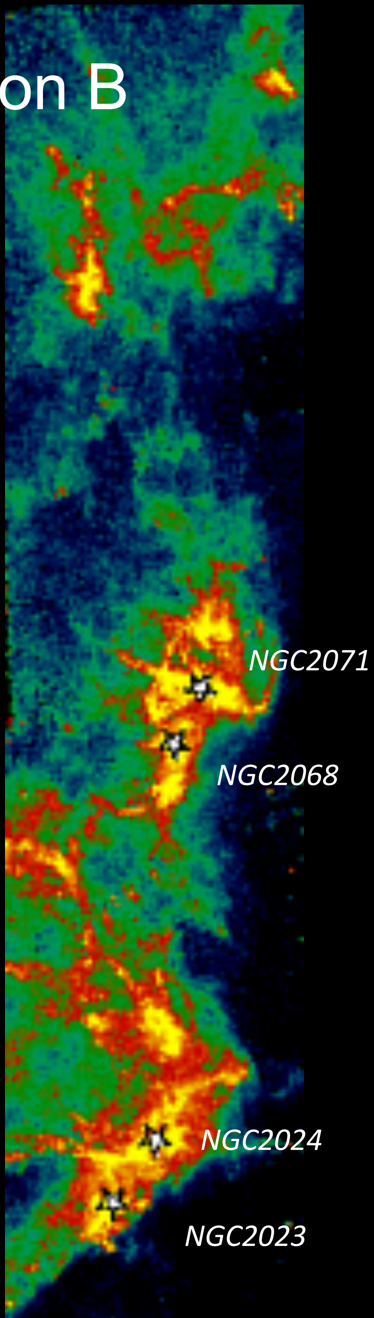




Federrath & Klessen et al. 2013

Gravity





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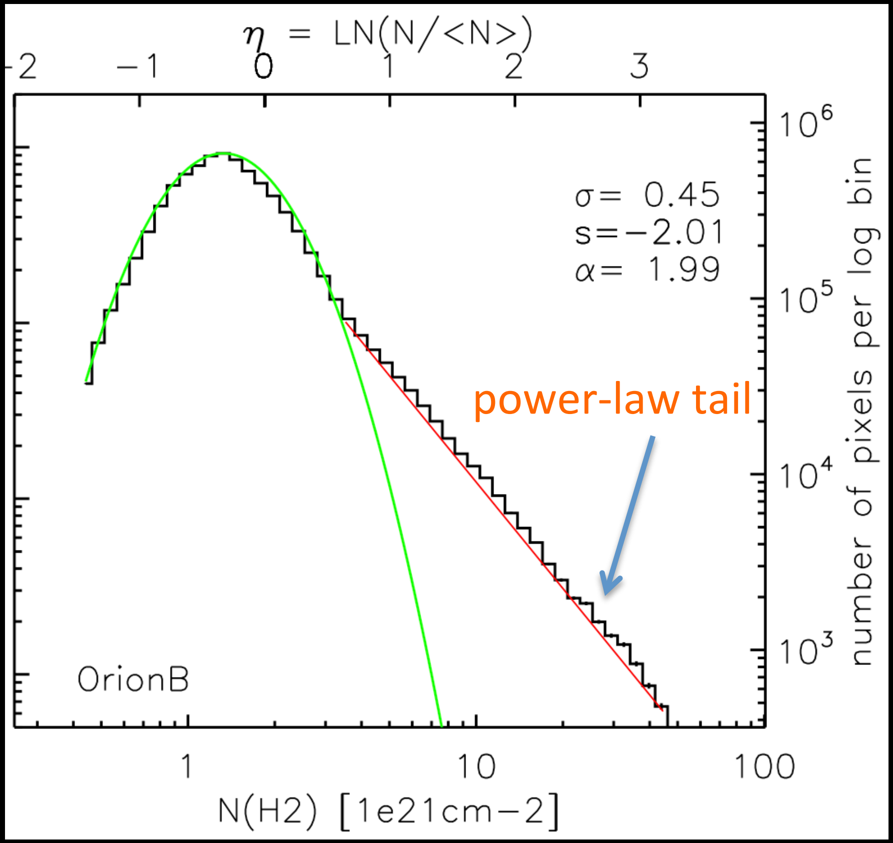


Power-law tail: **gravity** (Klessen et al. 2000; Kainulainen et al. 2009)

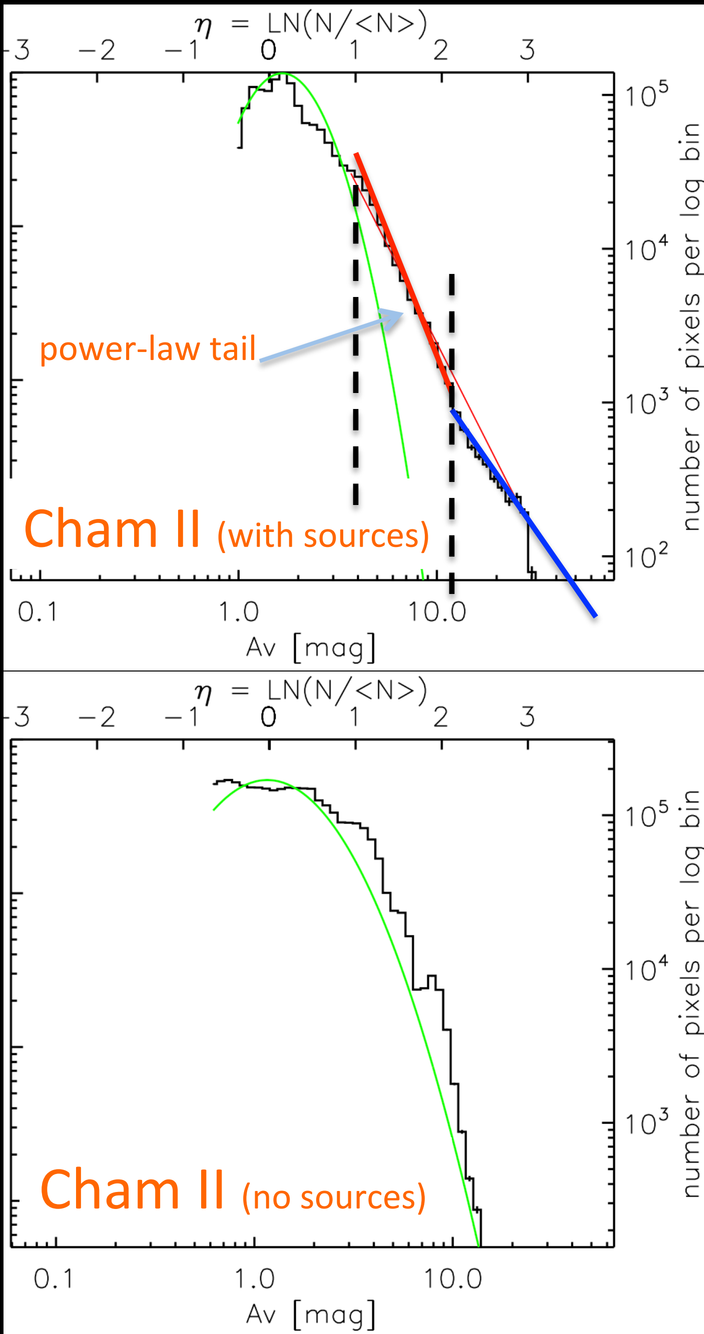
Individual core collapse ($\alpha = 2$)?

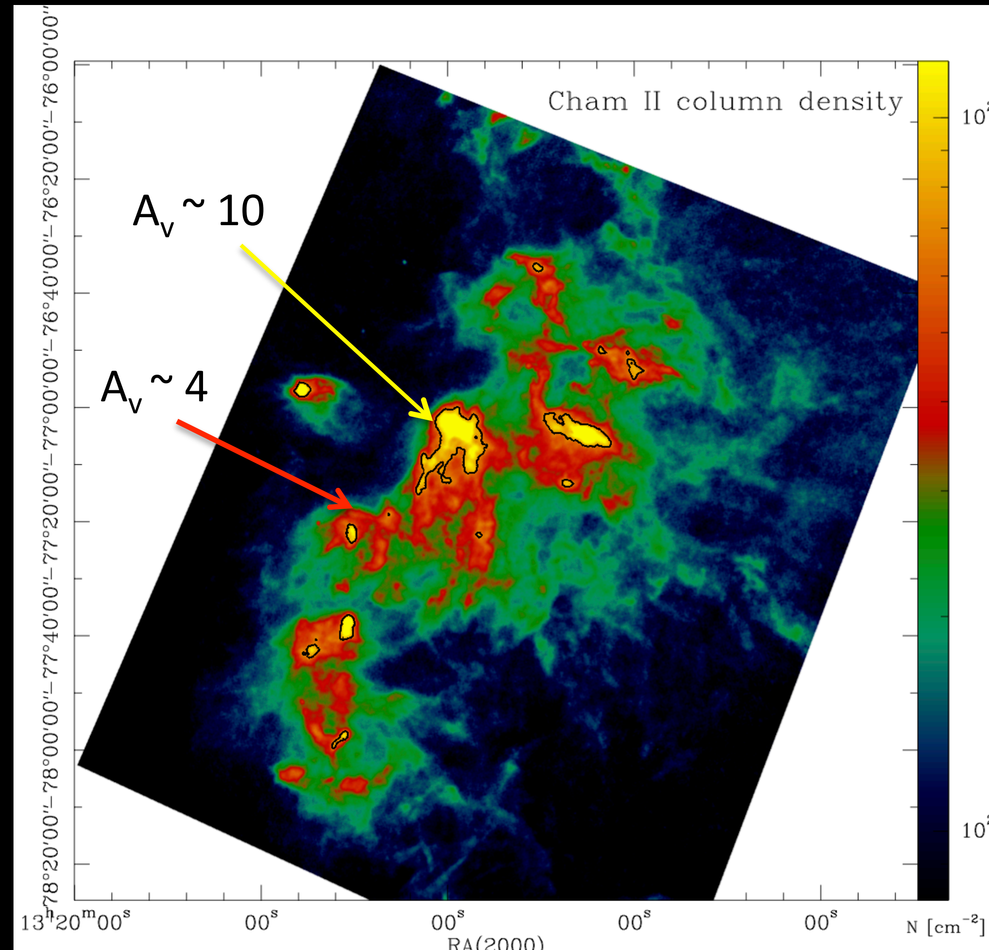
$\rho(r) \sim r^{-\alpha}$ $\alpha = -2/s+1$ (Federrath & Klessen 2012)

Left: ESA press release: 3-color image from Herschel PACS/SPIRE **Right**: Column density map (Schneider et al. 2013)

Gravity

PDF of column density from Herschel



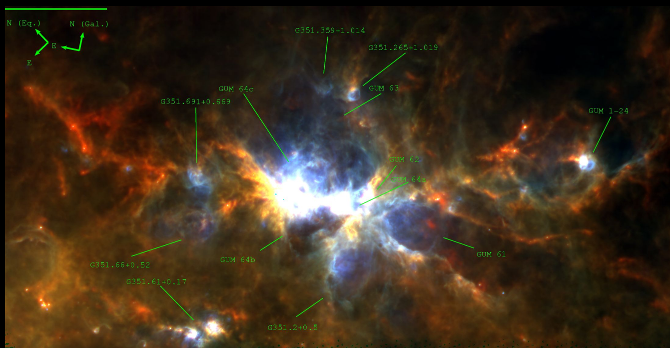


Source-subtracted (done by N. Cox using 'getsources', Men'shinkov et al. 2012) PDF is nearly lognormal.

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

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

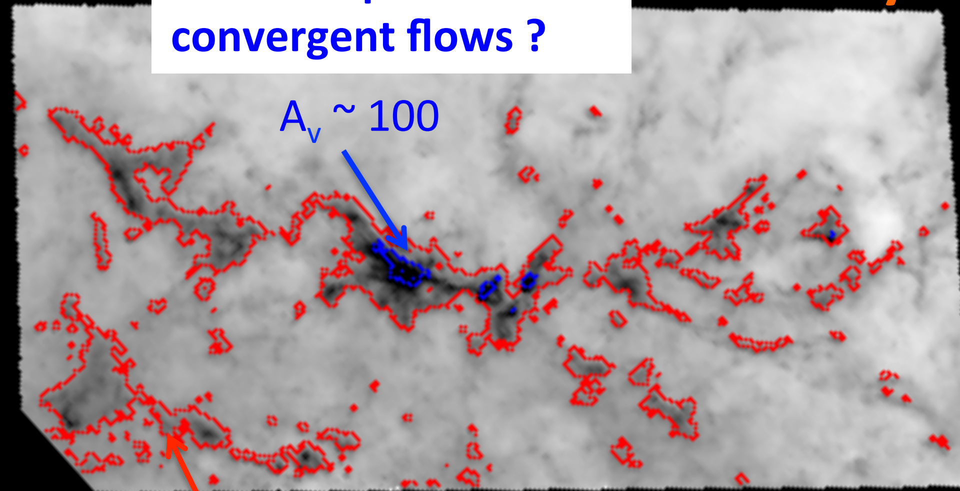
NGC6334



Russeil, Schneider et al. 2013

core collapse + convergent flows ?

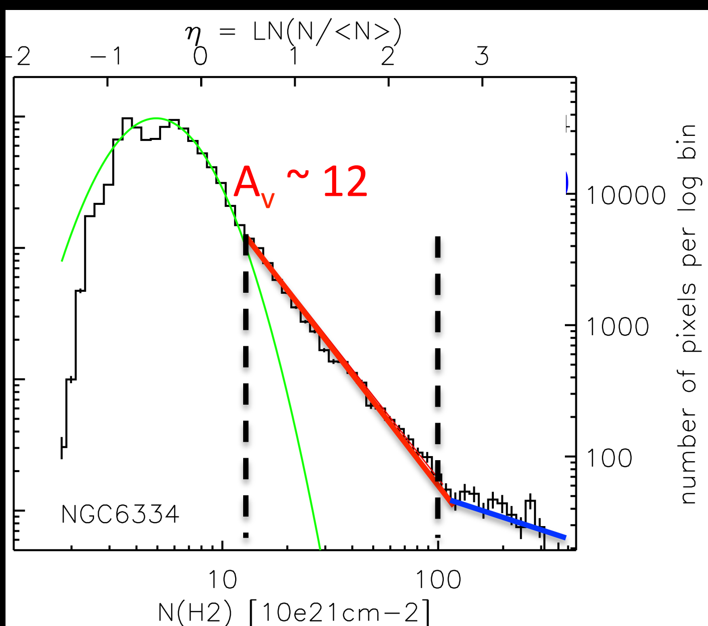
Gravity + flows



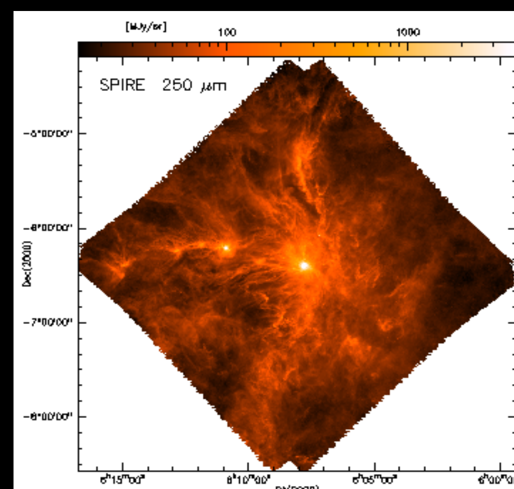
A_V ~ 100

A_V ~ 12

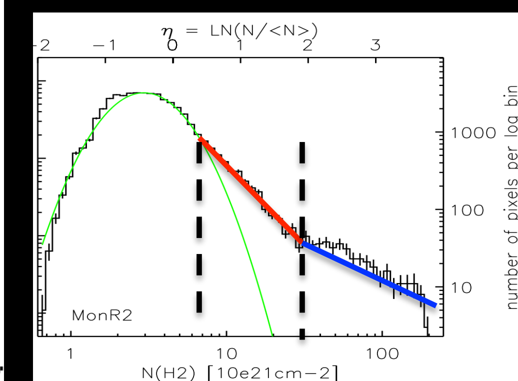
mass input by filaments + large-scale infall ?



MonR2



Rayner, Griffin et al., in prep.
Didelon et al., in prep.

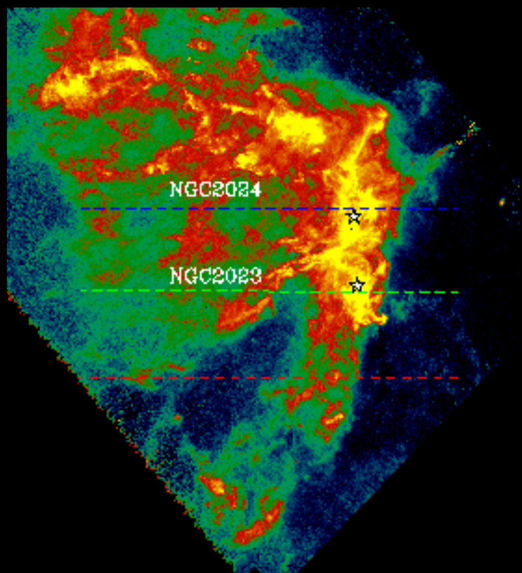


W3: local stellar feedback.. compression and convergent flows

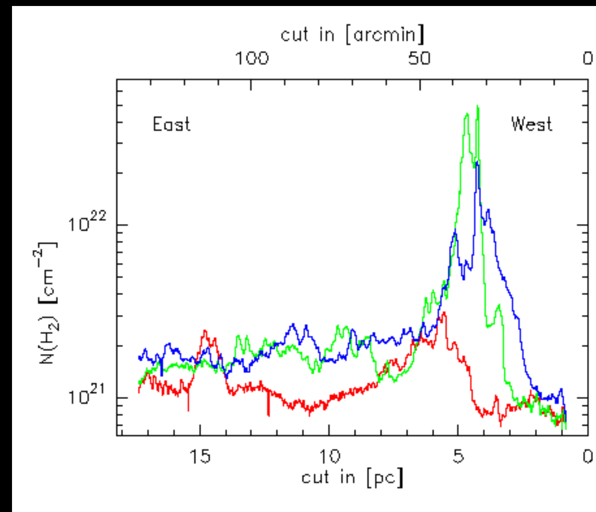
Rivera-Ingraham et al., in prep poster P65

Gravity + compression

Orion B column density map

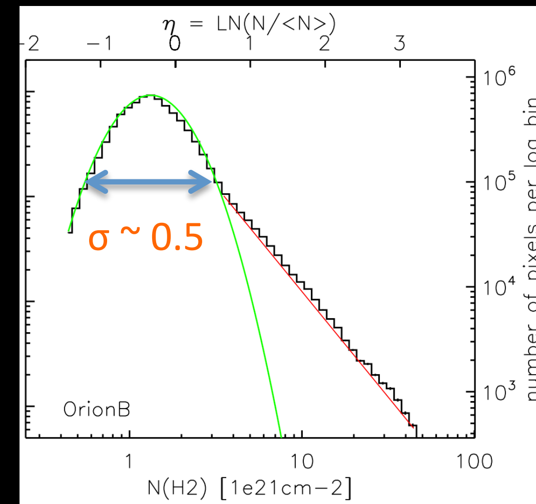


Column density cuts

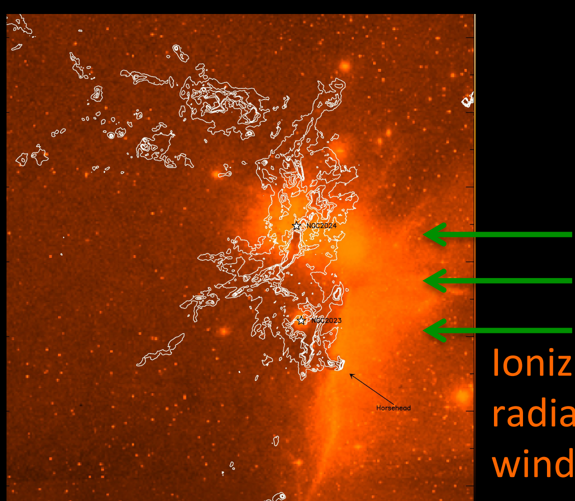


sharp cutoff in profile

PDF of column density from Herschel



broad PDF



Ionization+
radiation +
wind

- external compression clearly visible in column density profile

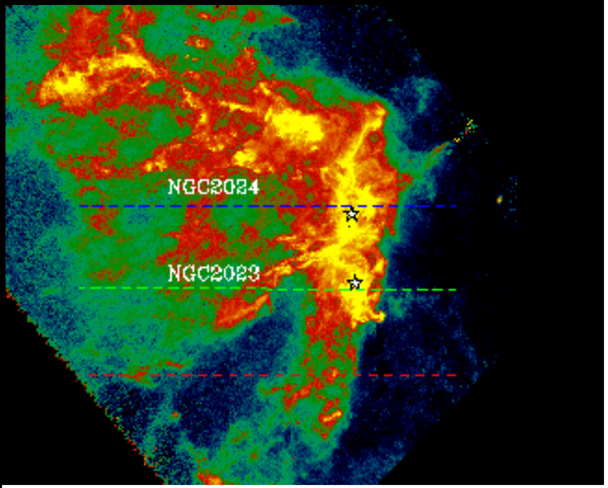
  see also Peretto et al. (2012) for Pipe and Tremblin et al. (2013)

- broadens the PDF

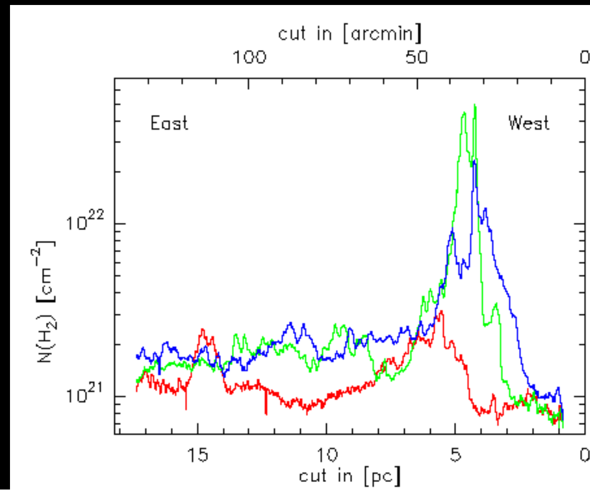
Tremblin et al. 2013: talk thursday

Gravity + compression

Orion B column density map



Column density cuts



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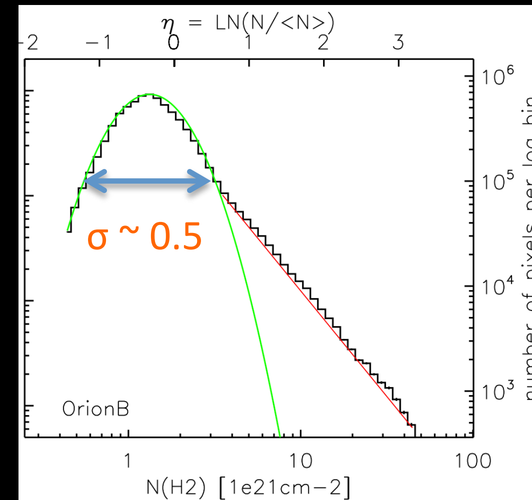
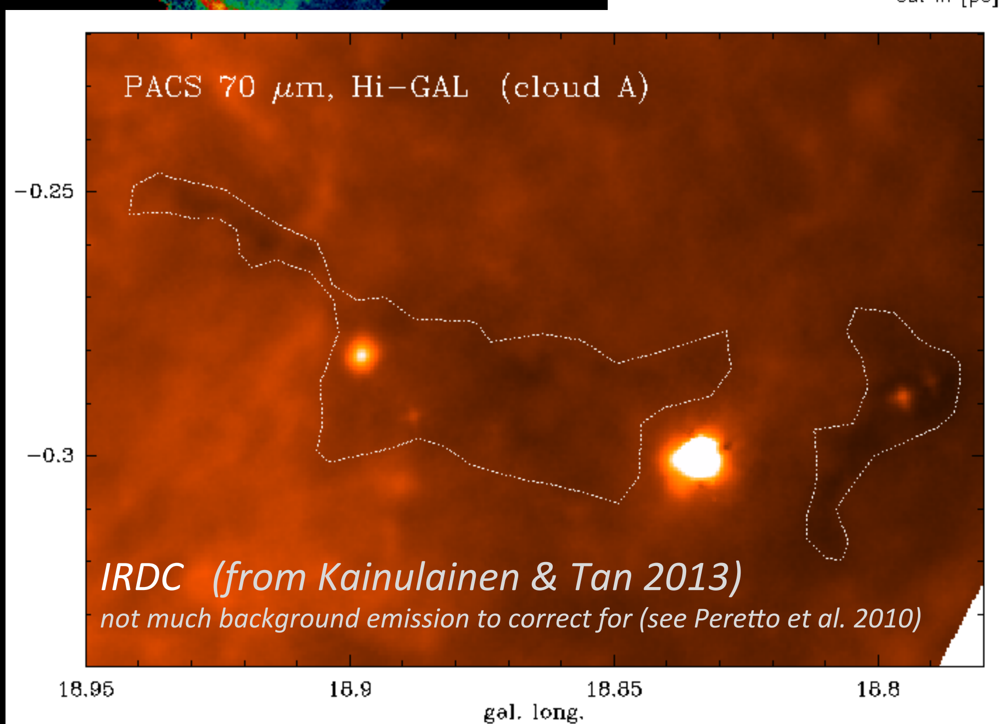


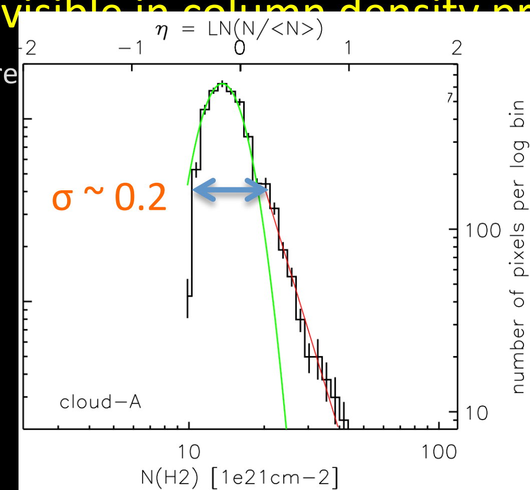


utoff in profile

broad PDF

sion clearly visible in column density profile

12) for Pipe and Tre

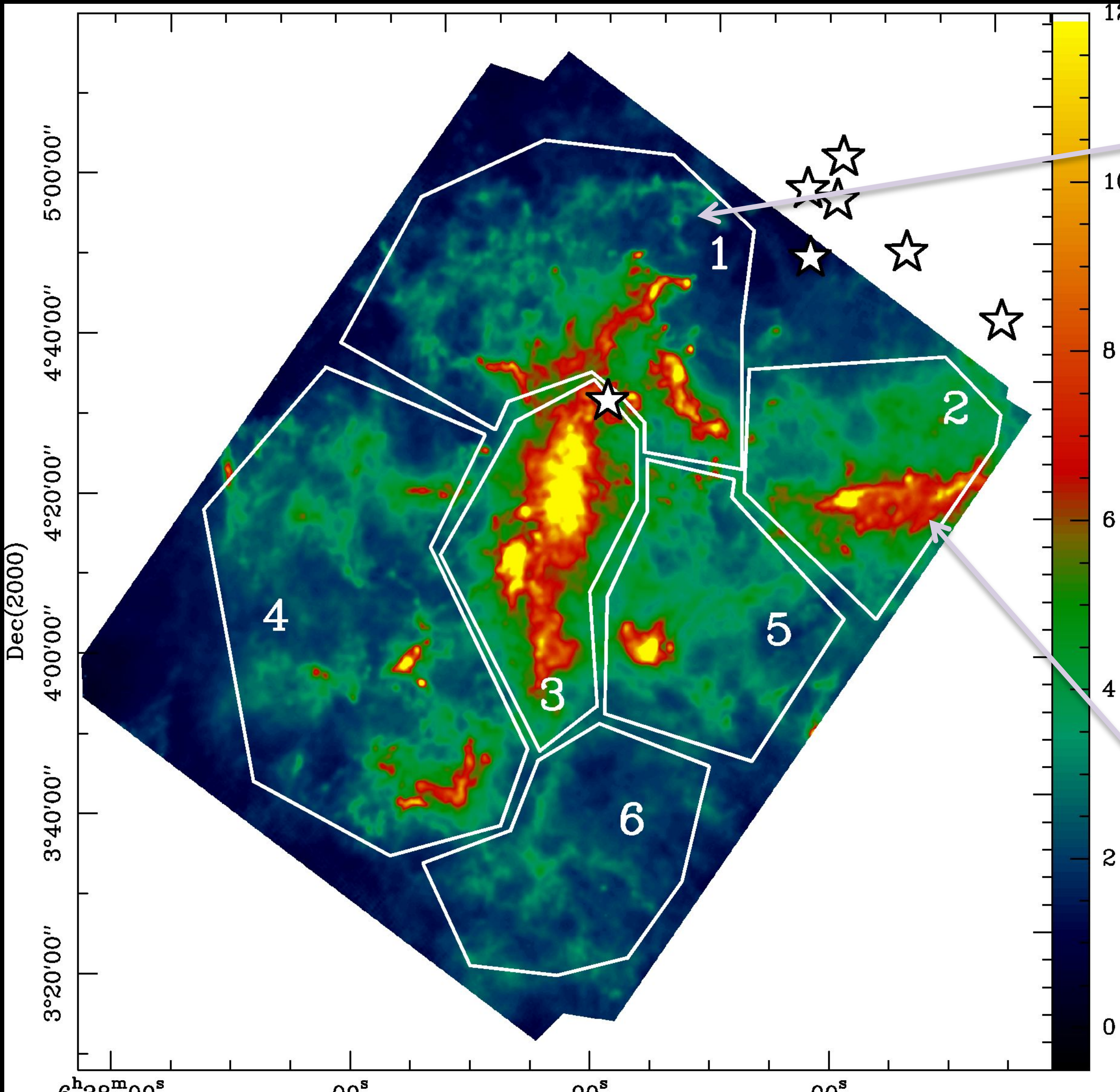


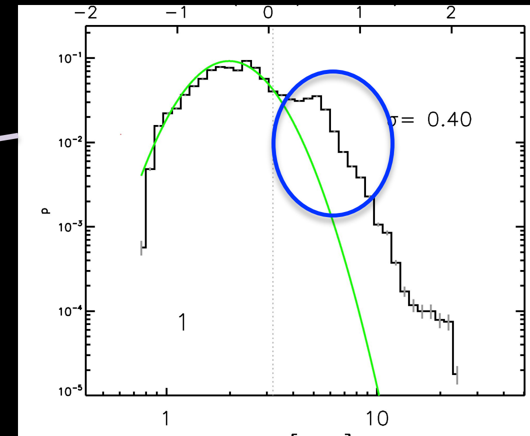
Schneider, Csengeri, Ossenkopf et al., in prep

Tremblin et al. 2013: talk thursday

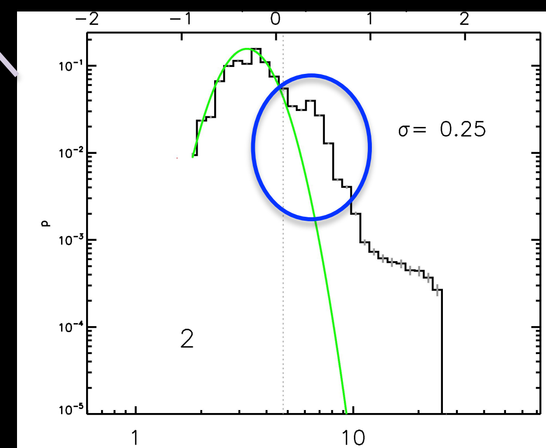
Rosette column density map

Compression





HII-region/molecular cloud interface -> compressed shell ?

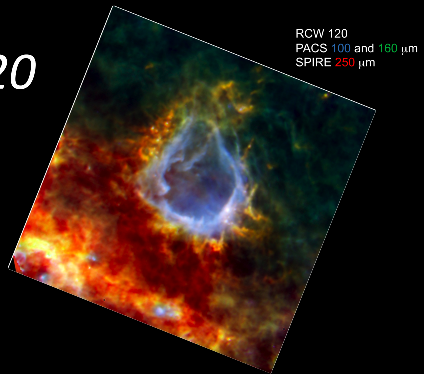


Schneider et al. 2010, 2012

‘double-peak ‘ PDFs are a characteristic feature of compressed shells ….

Compression

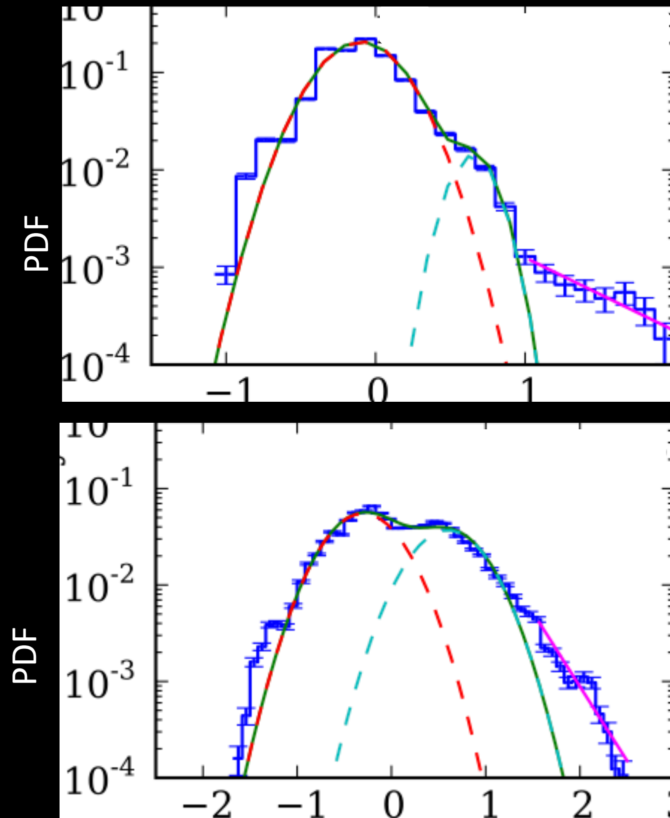
RCW120



Zavagno et al. 2010

M16

Hill et al. 2012

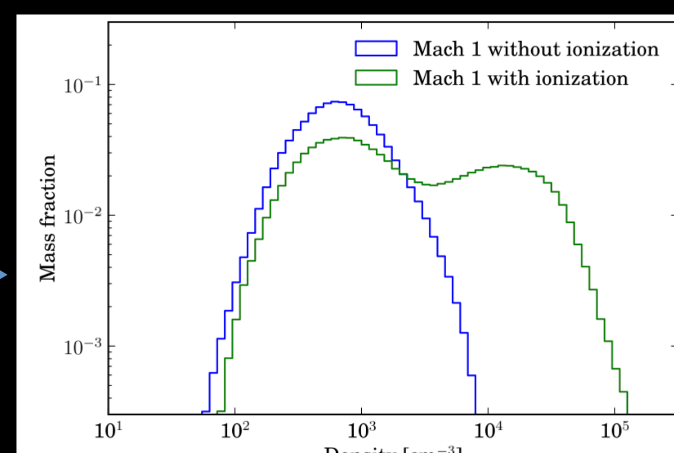


ln (N/<N>)

Tremblin, Schneider et al. 2013

talk thursday

Hydrodynamic simulation with ionization



Tremblin et al. 2012, 2013

Summary ...

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 covergent flows*