Dense core formation in the turbulent, magnetized Pipe Nebula

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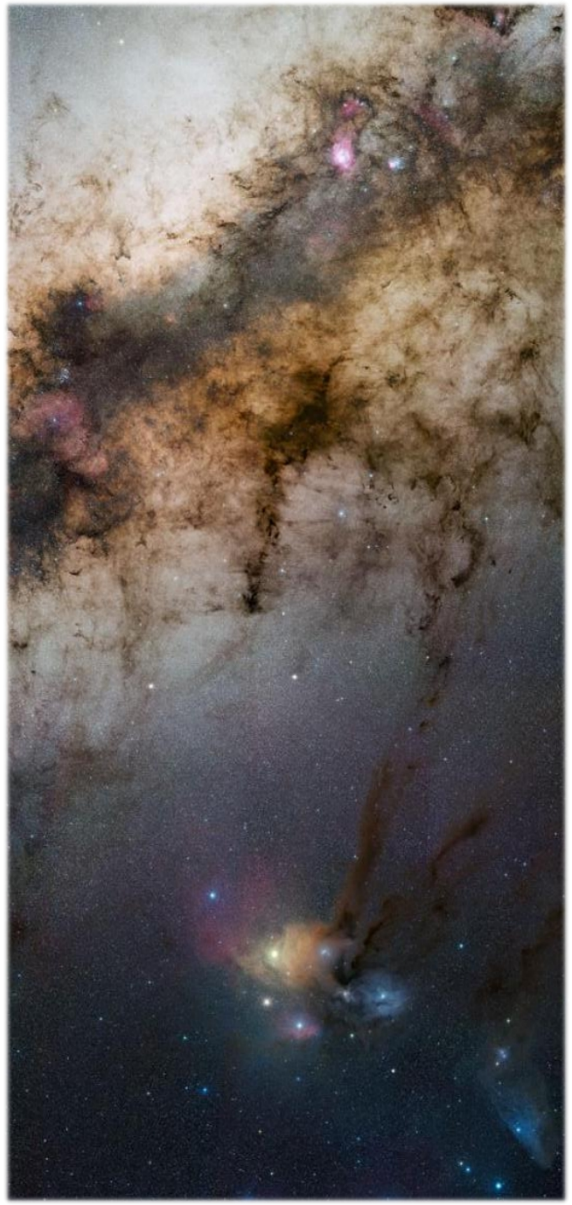

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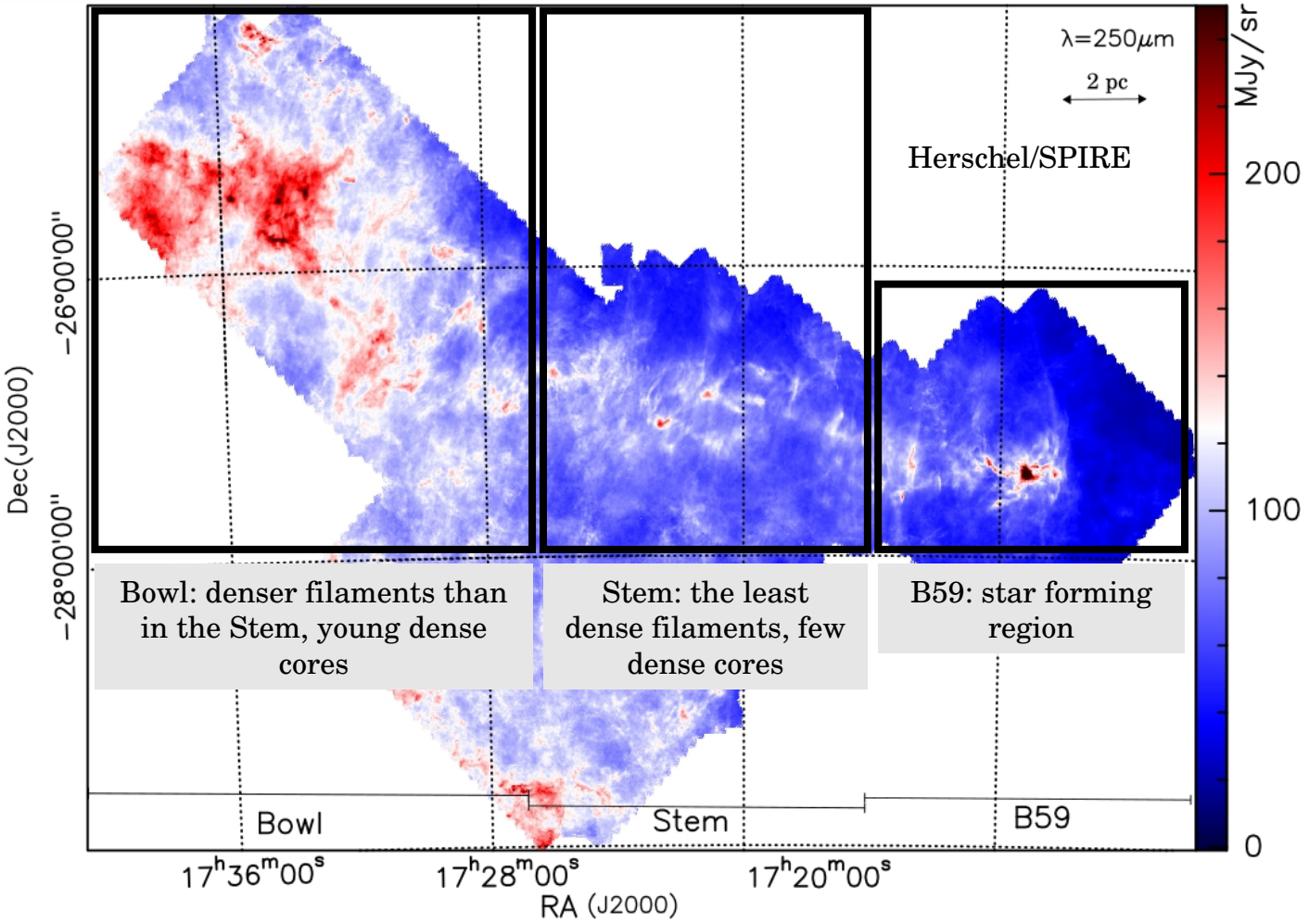
Outline of the talk

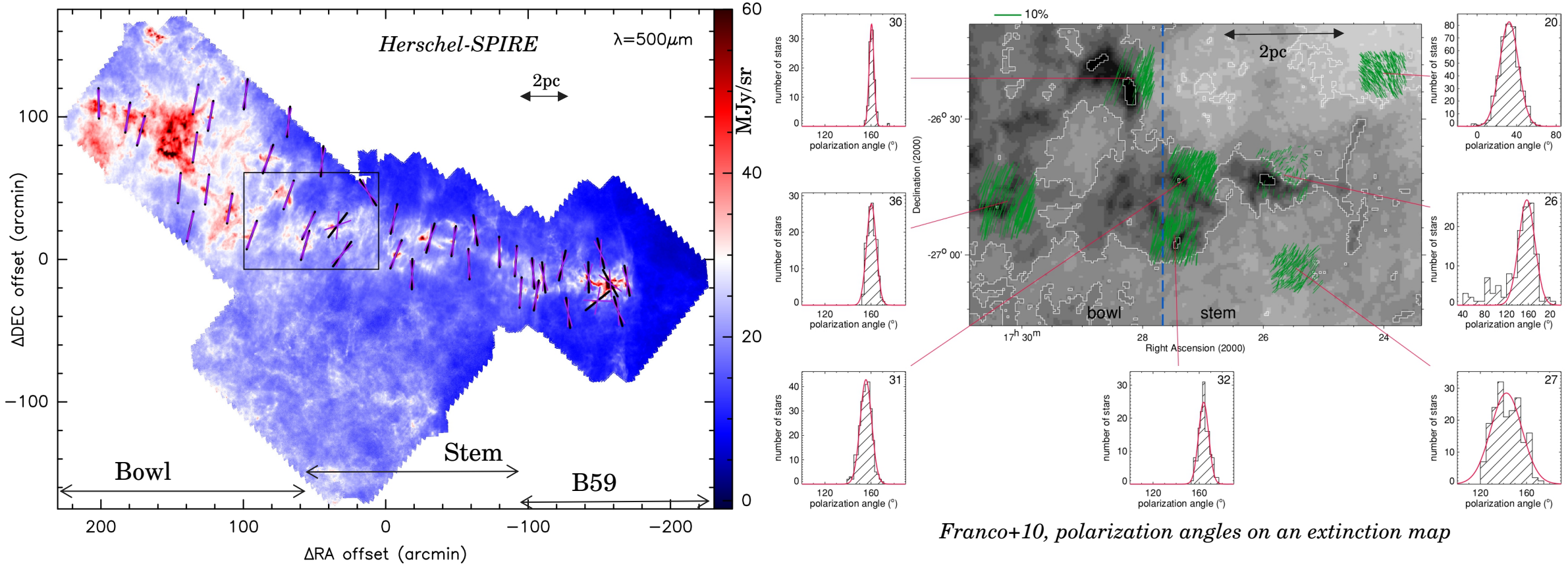
1. The Pipe Nebula
2. Large-scale gas kinematic properties
3. The low-extinction dense core population
4. Conclusions and perspectives

The Pipe Nebula : a molecular cloud with low star formation efficiency



- In the Ophiuchus region, low latitude; observable with IRAM and ALMA
- Nearby: 163±5 pc *(Dzib+18, Gaia DR2)*
- Star formation limited to the B59 region

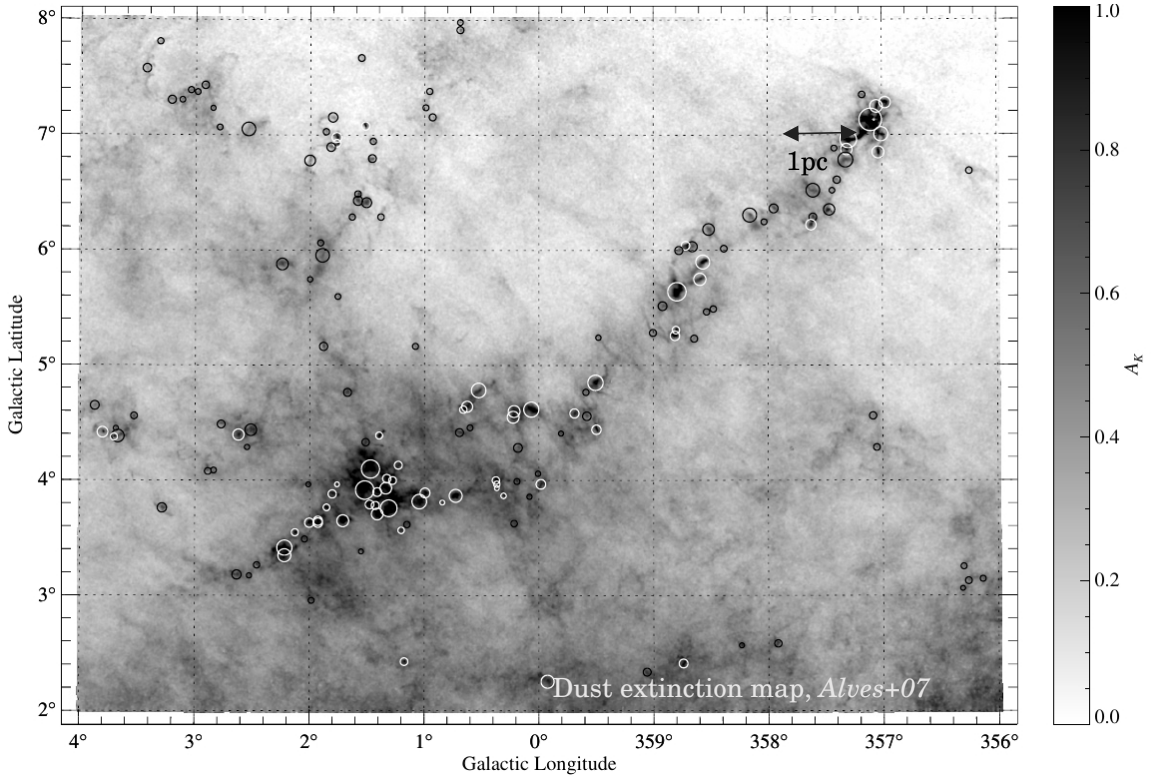
Strong magnetic field

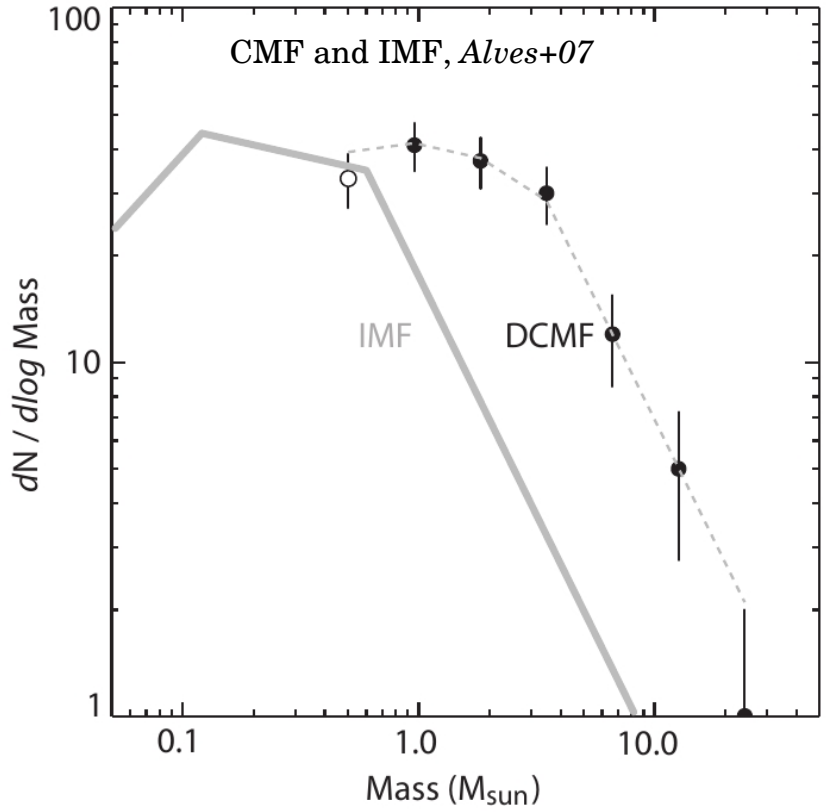


Franco+10, polarization angles on an extinction map

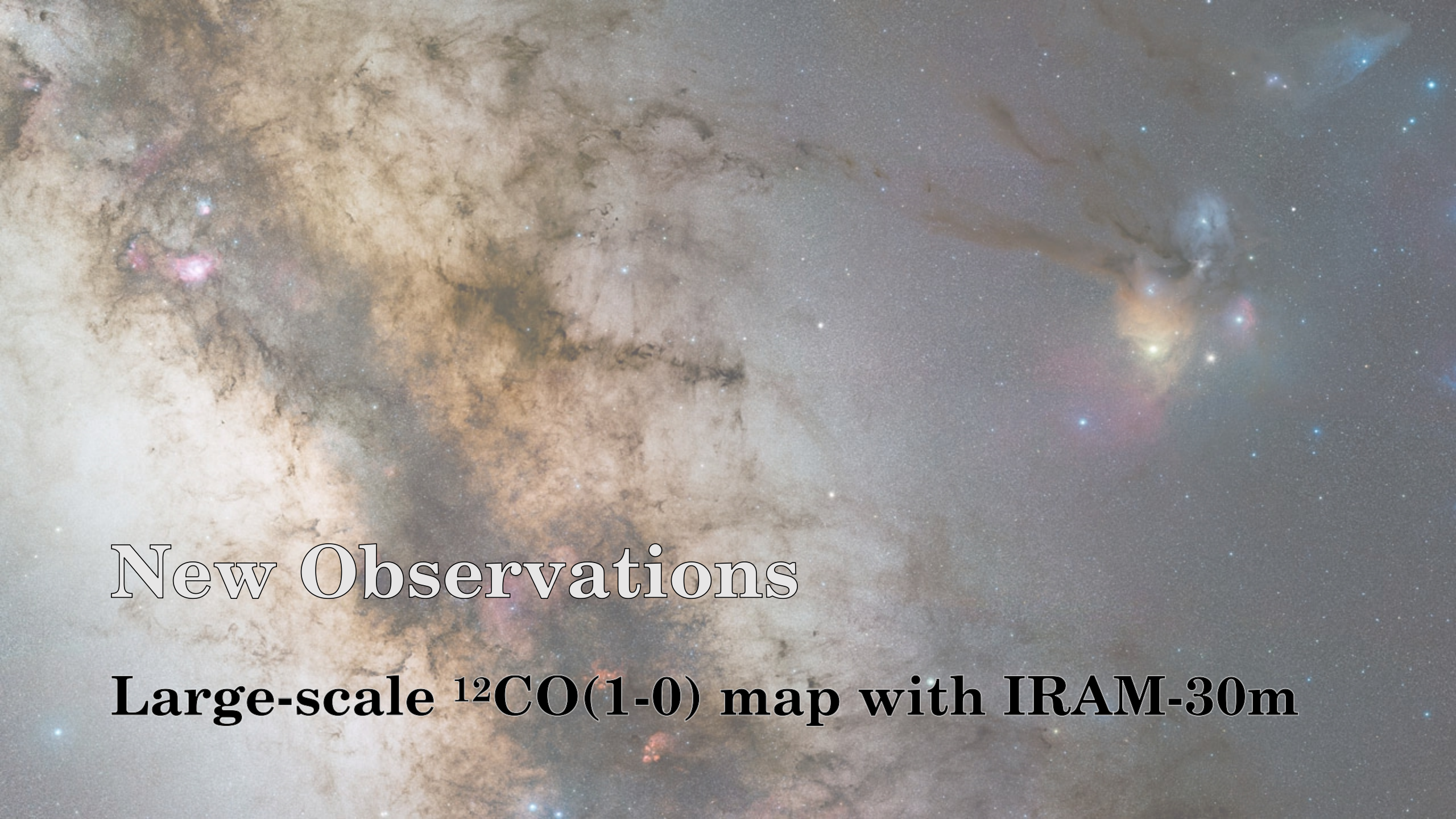
- Overall morphology: B-lines perpendicular to the Pipe filament on 20 pc scale
- Dispersion is largest in B59, and smallest in the Bowl
- Projected magnetic field intensity based on Davis-Chandrasekhar-Fermi: 17, 30, and 65 muG in B59, Stem, and Bowl (Alves+08)

The dense core mass function of the Pipe Nebula





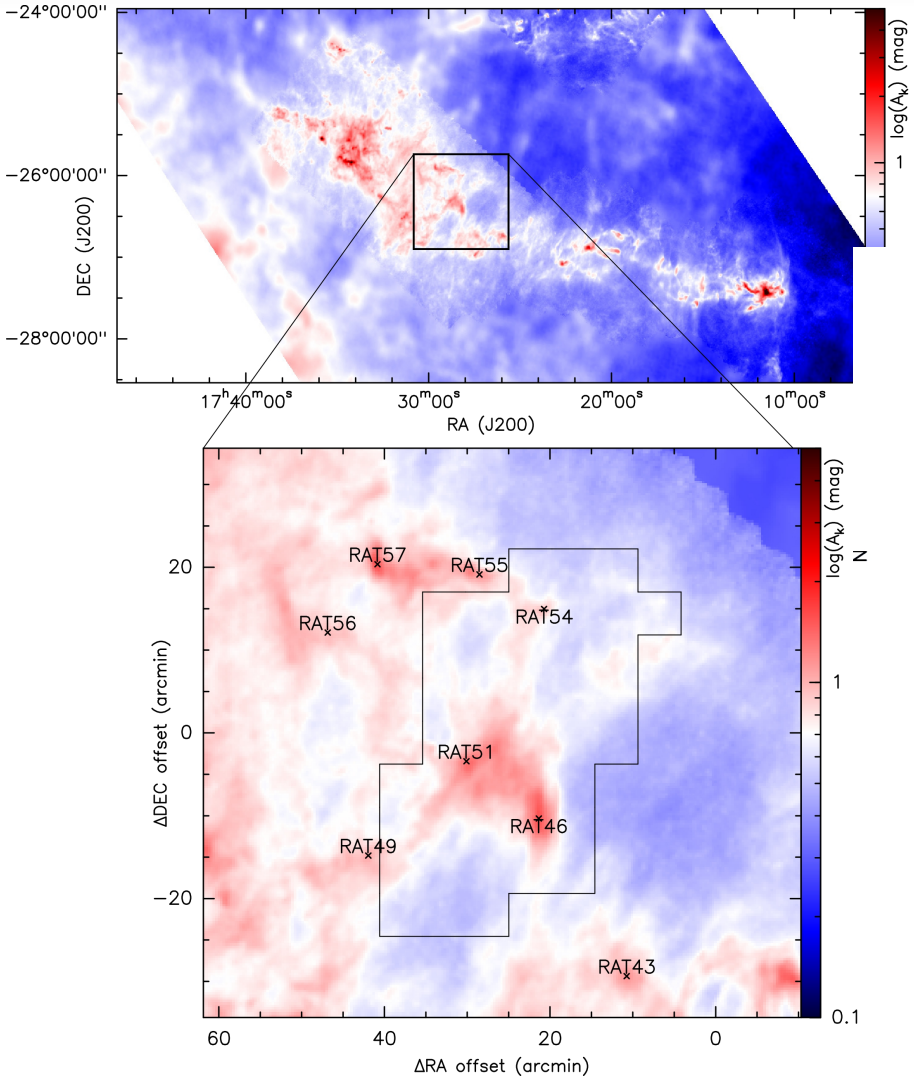
- Dense core population identified based on wavelet decomposition in 2MASS extinction map (Lombardi+06)
- Genetic link between the Initial Mass Function and the Core Mass Function (Motte+98, Alves+07)
- Core-to-star formation efficiency = 0.40±0.20
- Generalized to Gould Belt star forming clouds (HGBS Herschel key program, André+10, Könyves+15)



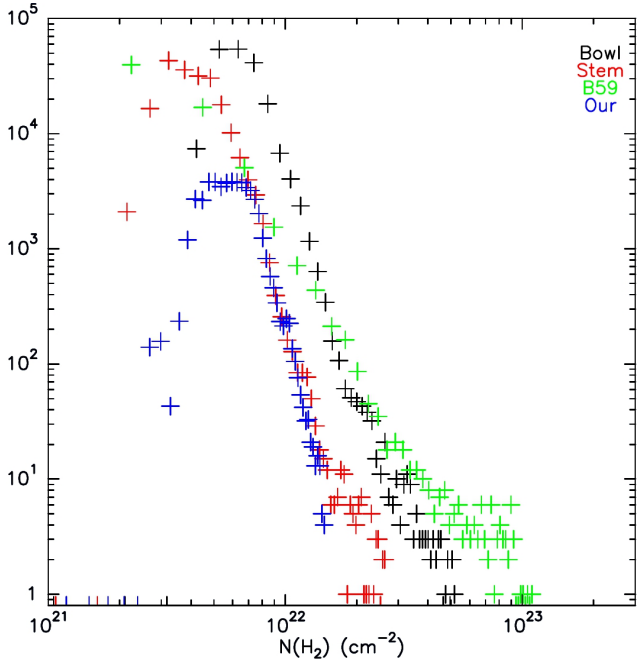
New Observations

Large-scale ^{12}CO(1-0) map with IRAM-30m

A large ^{12}CO(1-0) map of a strongly dynamical, magnetized region



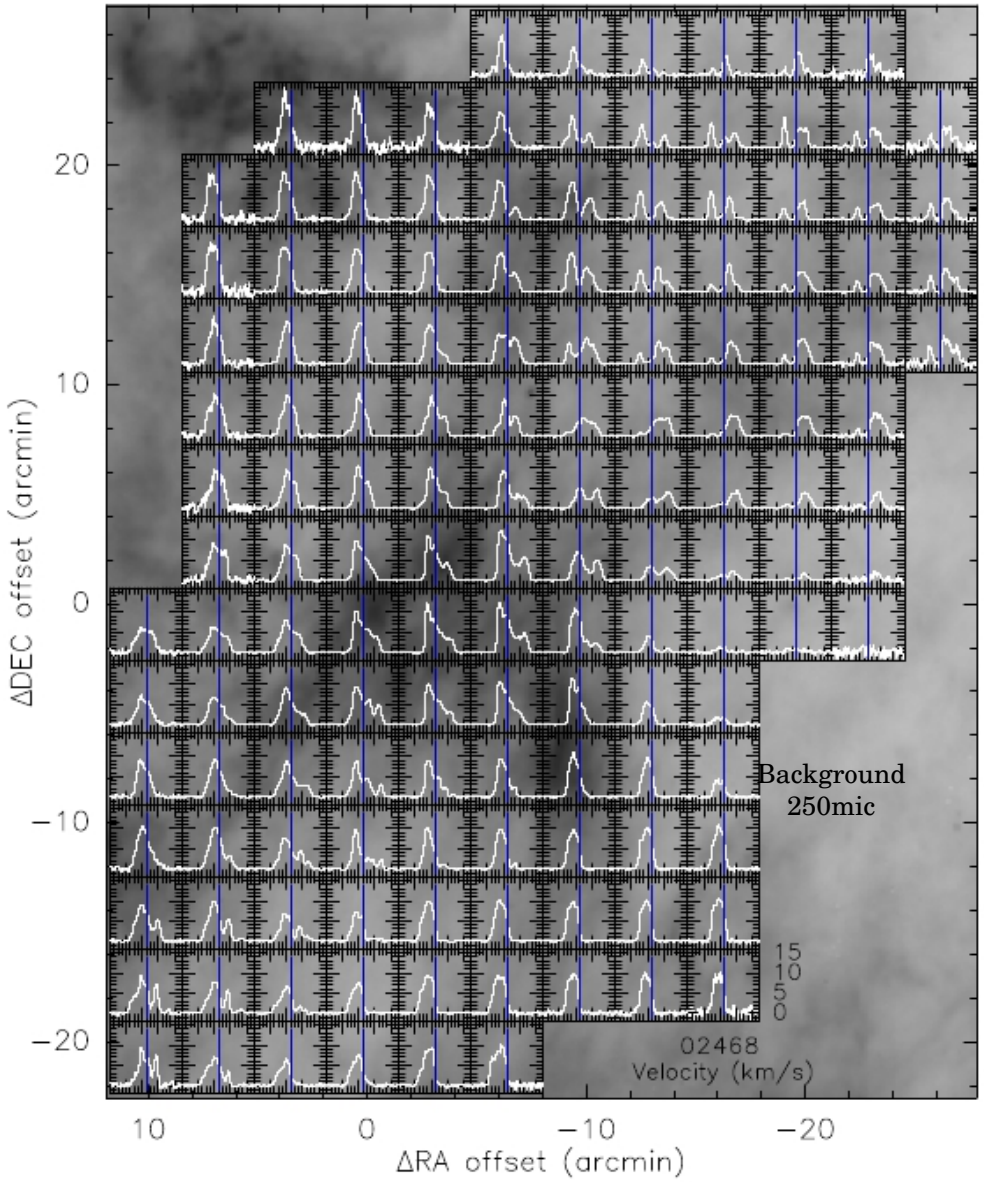
Extinction map, Hasenberger+18, based on Herschel+Planck

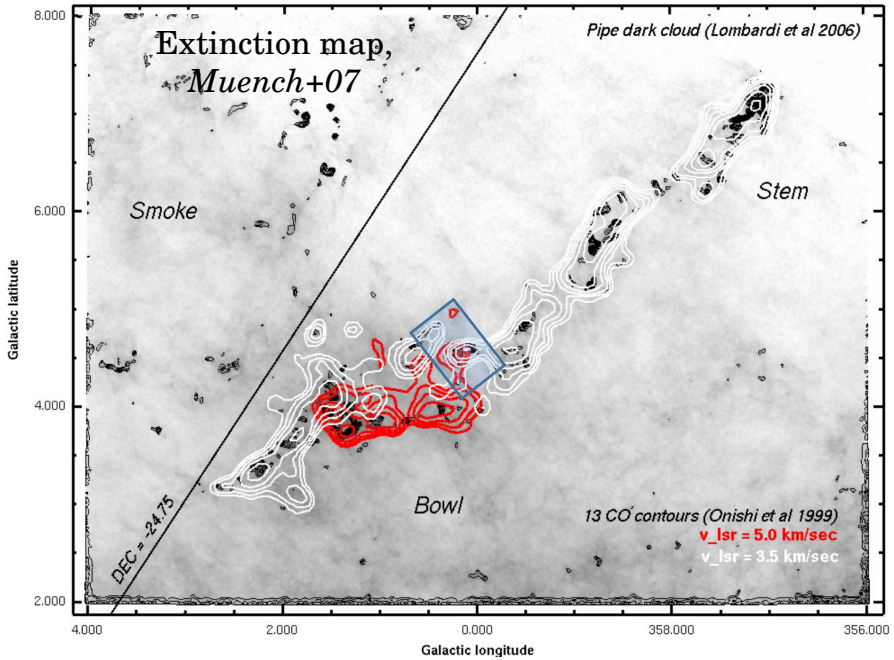


Column density N(H_2) computed from extinction map of Hasenberger+18

- Field of view located in a region where two velocity structures, proposed to be converging flows (Muench+07, Frau+10)
- The largest ^{12}CO(1-0) map (0.5x0.7deg or 1.4pc x 2.0pc,) at 22" (~3500 au) of the Pipe Nebula
- A_V covering 0.5-5 mag over the field of view
- Complemented by pointed, multi-line observations of eight cores candidates from Rathborne+09 catalog: ^{12}CO(1-0), ^{12}CO(2-1), ^{13}CO(1-0), C^{18}O(1-0)
- **Primary aims**
  - Analyse the orientation of structures with respect to magnetic fields
  - Determine the physical conditions and properties of dense cores in the region of converging flows

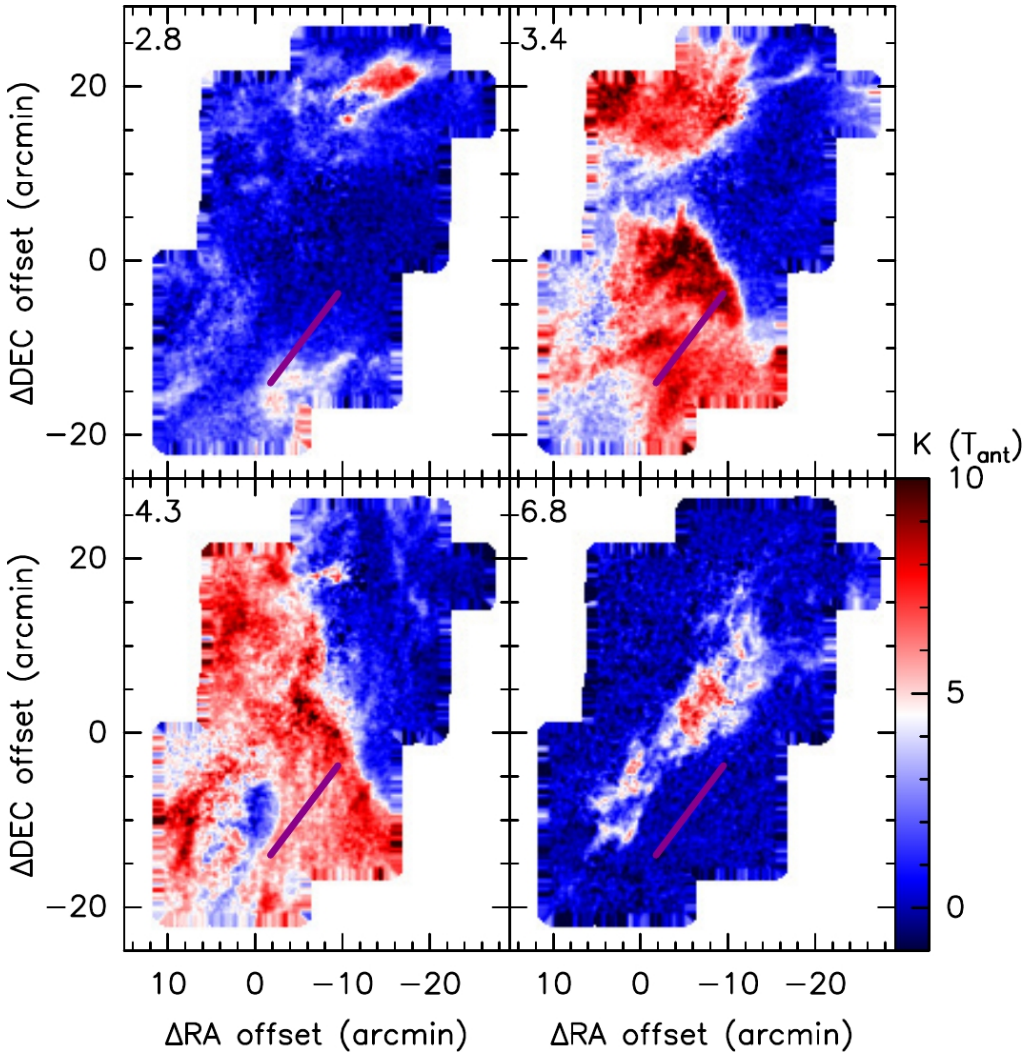
Connected, large-scale velocity components



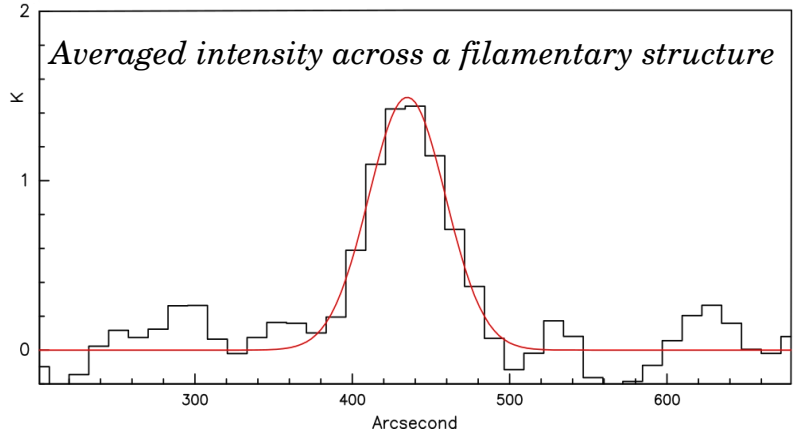


- Two velocity components (~3.5 and 5.0 km/s)
  - known from Onishi+99
  - Identified as converging flows (Muench+07, Frau+10)
- Connected in velocity space
- **Field of view in an interaction region**

A wealth of small-scale structures in velocity channels

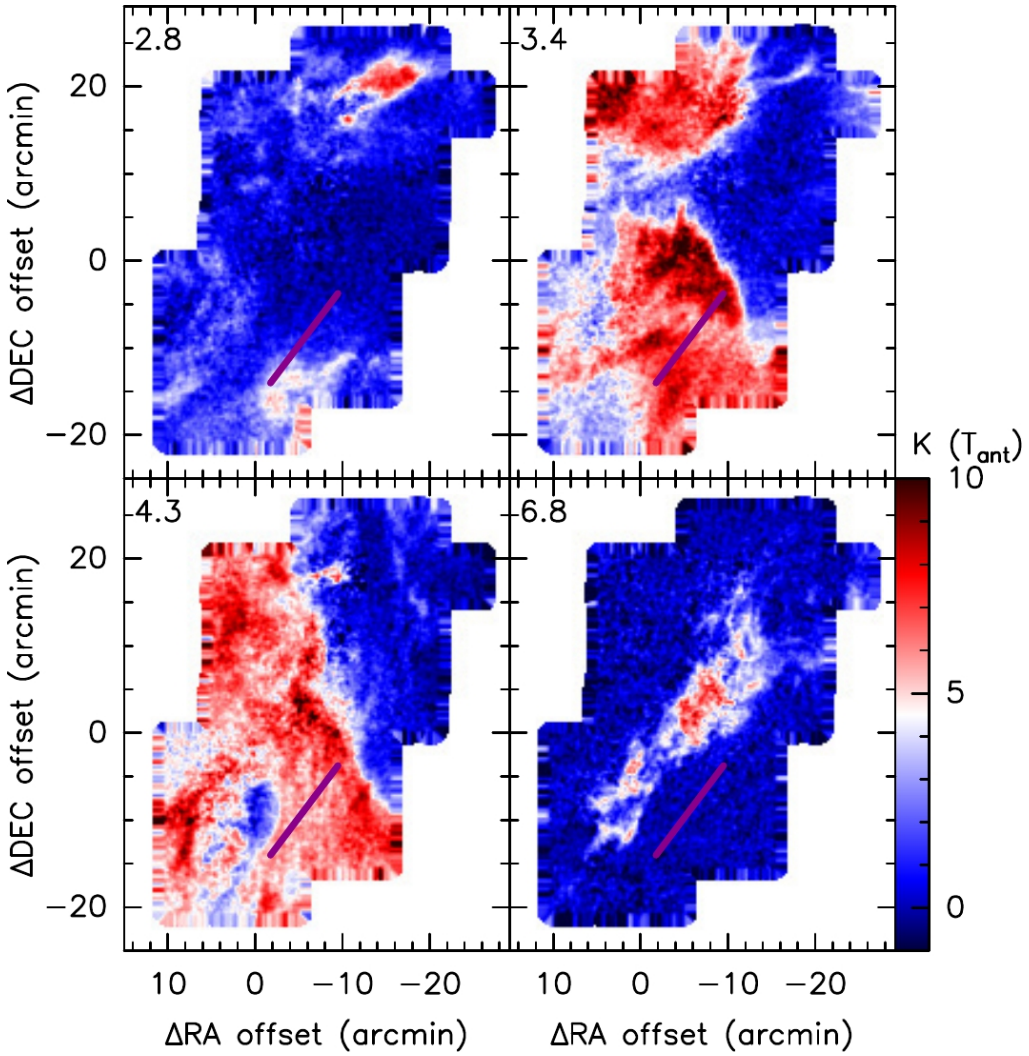


Intensity (K) at a given velocity (km/s). Magnetic field orientation indicated by a purple line



- Large scales (FoV=1.4pcx2pc)
  - Velocity component at 6.0 km/s: almost parallel to B_{proj}
  - Velocity component at 3.5 km/s: brightest and unrelated to B_{proj}
- Small scales
  - Elongated structures are visible in most velocity channels, from 2.5 to 7.5 km/s
  - Eye-identification in velocity channels as elongated (aspect ratio > 2), structures spanning > 4 channels
  - Narrow filamentary structures: FWHM down to 0.06 pc

Structures in transitions



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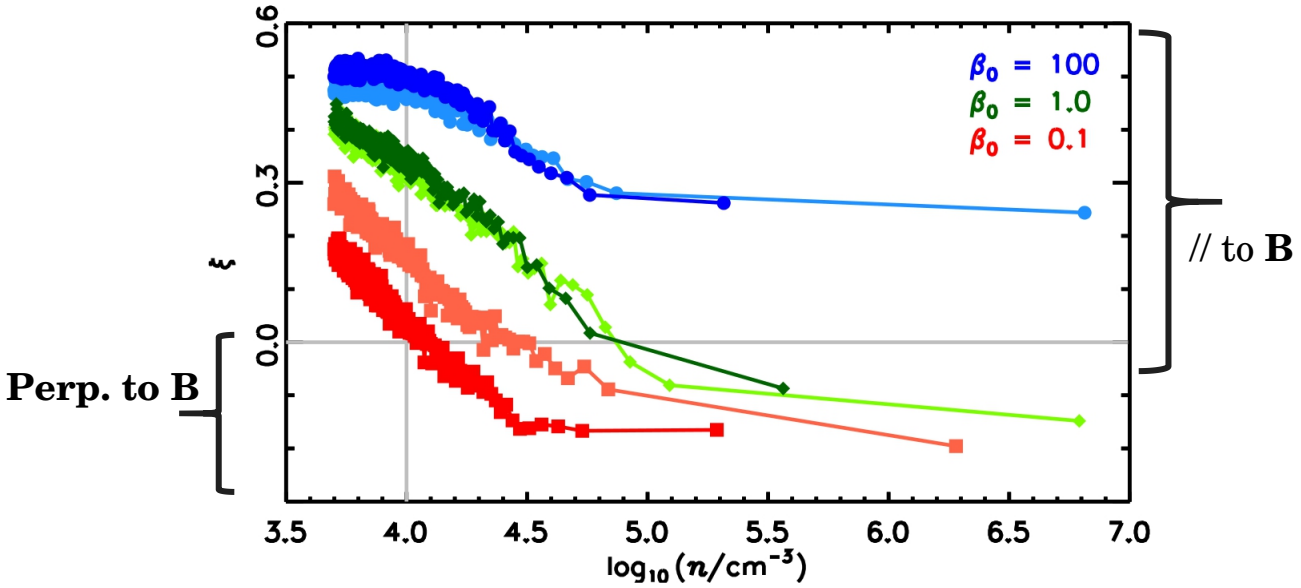

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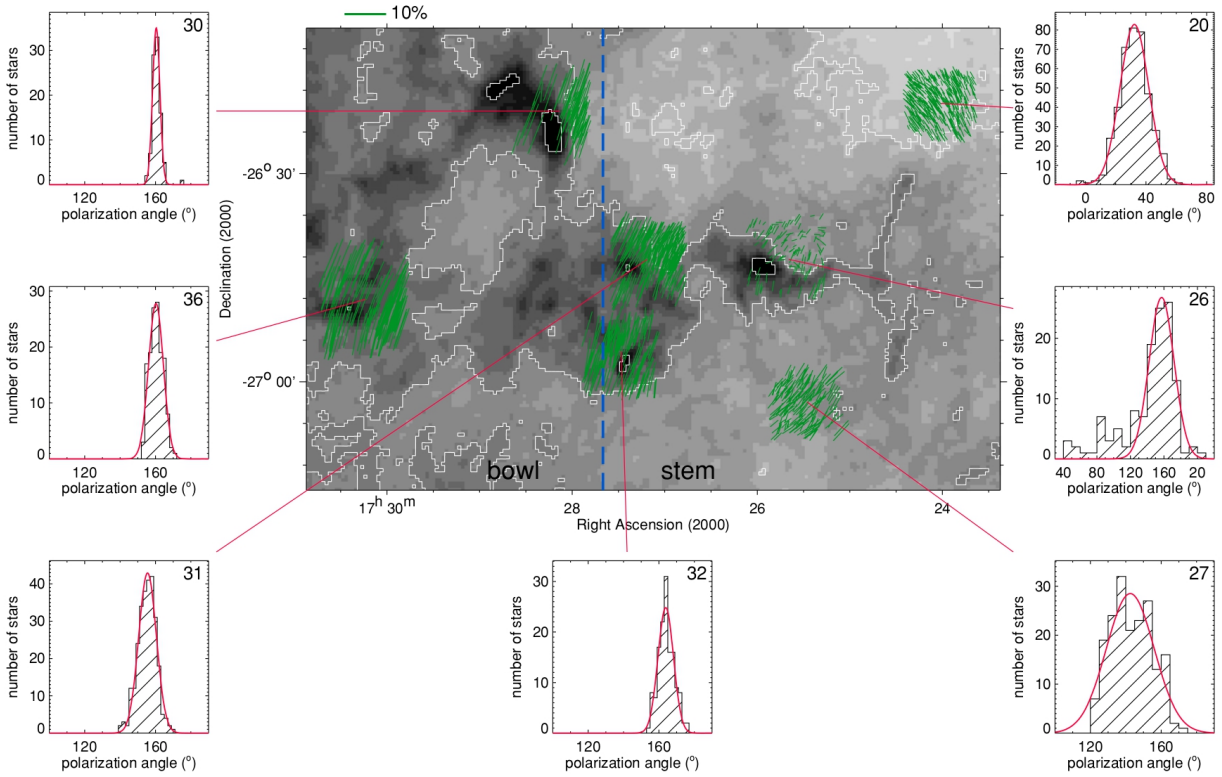
- **Preliminary results**
  - low-brightness structures, rather aligned with B_{proj}
  - 50% aligned or perpendicular
  - 50% neither aligned nor perpendicular

➢ **Probing the transition from aligned to perpendicular?**

A new estimate for the magnetic field intensity



Franco+10, polarization angles on an extinction map

- *Skalidis+21,* magnetic field intensity*:*

$$B_0 = 123\mu G\sqrt{2\pi}\left(\frac{\rho}{3.04\times10^{-21}\mathrm{g\,cm^{-3}}}\right)^{1/2}\left(\frac{\delta V}{1.70\times10^{5}\mathrm{cm/s}}\right)\left(\frac{3.65^{\mathrm{o}}}{\delta\phi}\right)^{1/2}$$

  - ➢ Uncertainty due to measures = 5 μG

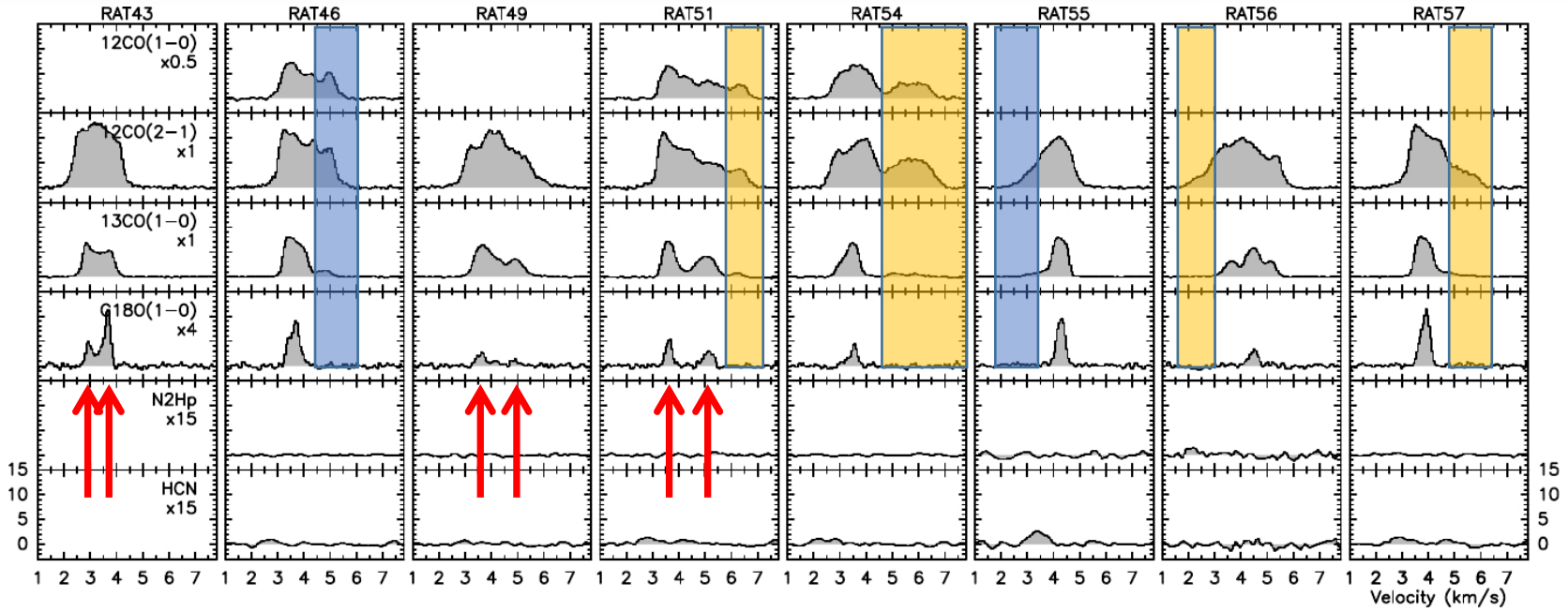
- *Ostriker+01,* Mach number*:*

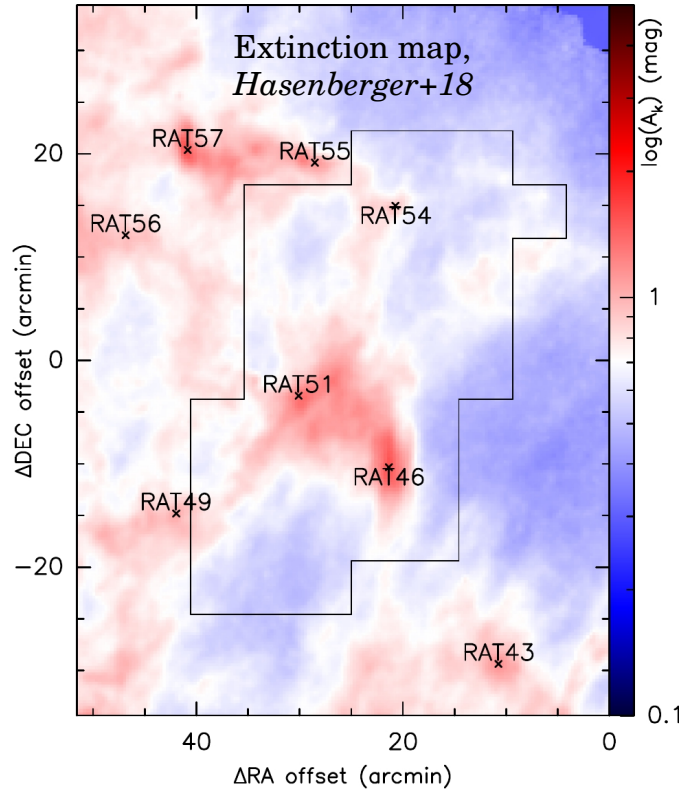
$$M = 2.39\left(\frac{\delta v}{1.7\times10^{5}\mathrm{cm/s}}\frac{2.97\times10^{4}\mathrm{cm/s}}{\mathrm{c_s}}\right)^{1/2}$$

  - ➢ Uncertainty due to measures = 0.57

➢ **Region with a medium to strong magnetic field**

Dense cores with multiple velocity components

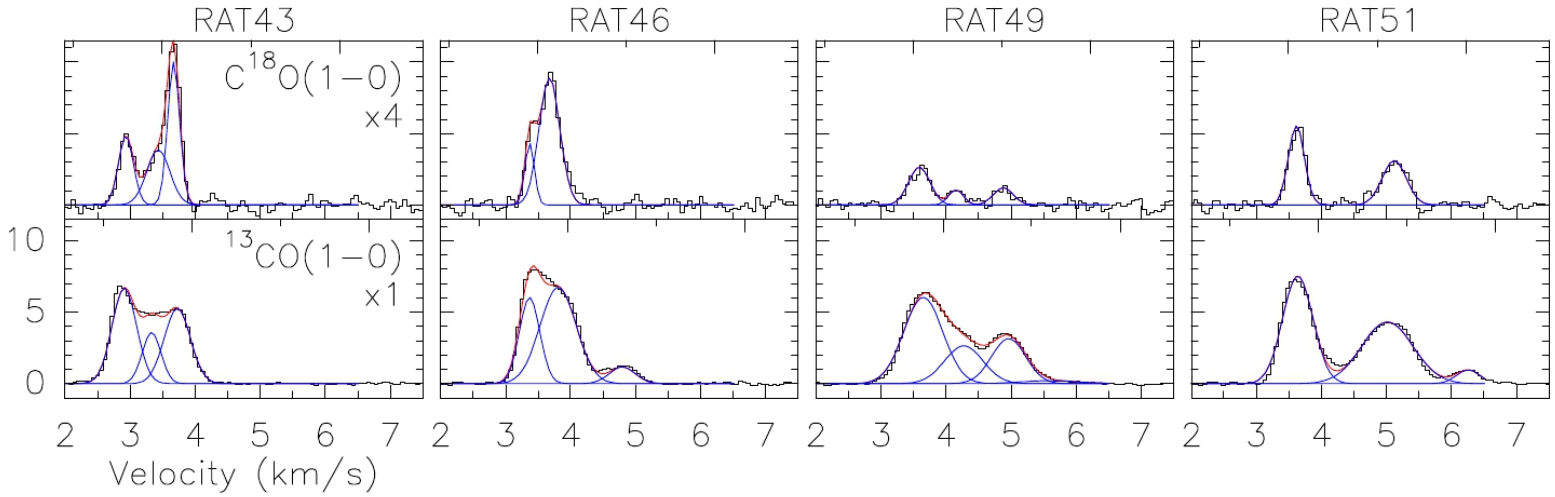


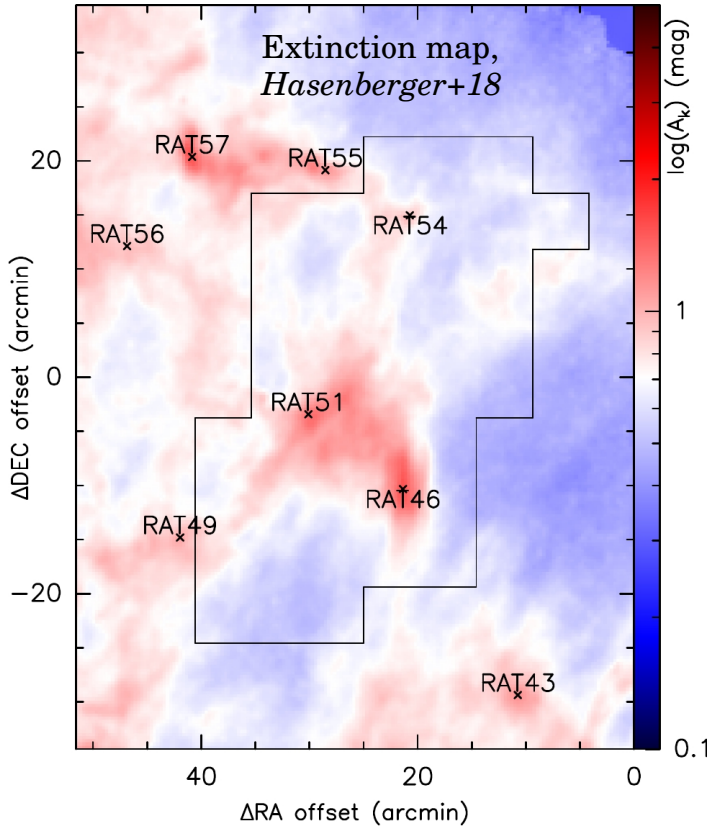


- Variety of line profiles
  - Multiple velocity components in $C^{18}O$(1-0): **RAT43, RAT49, RAT51**
  - Broad ^{12}CO emission with undetected counterparts in ^{13}CO and $C^{18}O$: **RAT51, RAT54, RAT56, RAT57**
  - Extended ^{12}CO with weak ^{13}CO and undetected $C^{18}O$: **RAT46, RAT55**
- Dense and/or evolved gas tracers not detected: HCN and N_2H^+

➢ **Are these local maxima of extinction really dense cores or false positives?**

Gas column density estimations





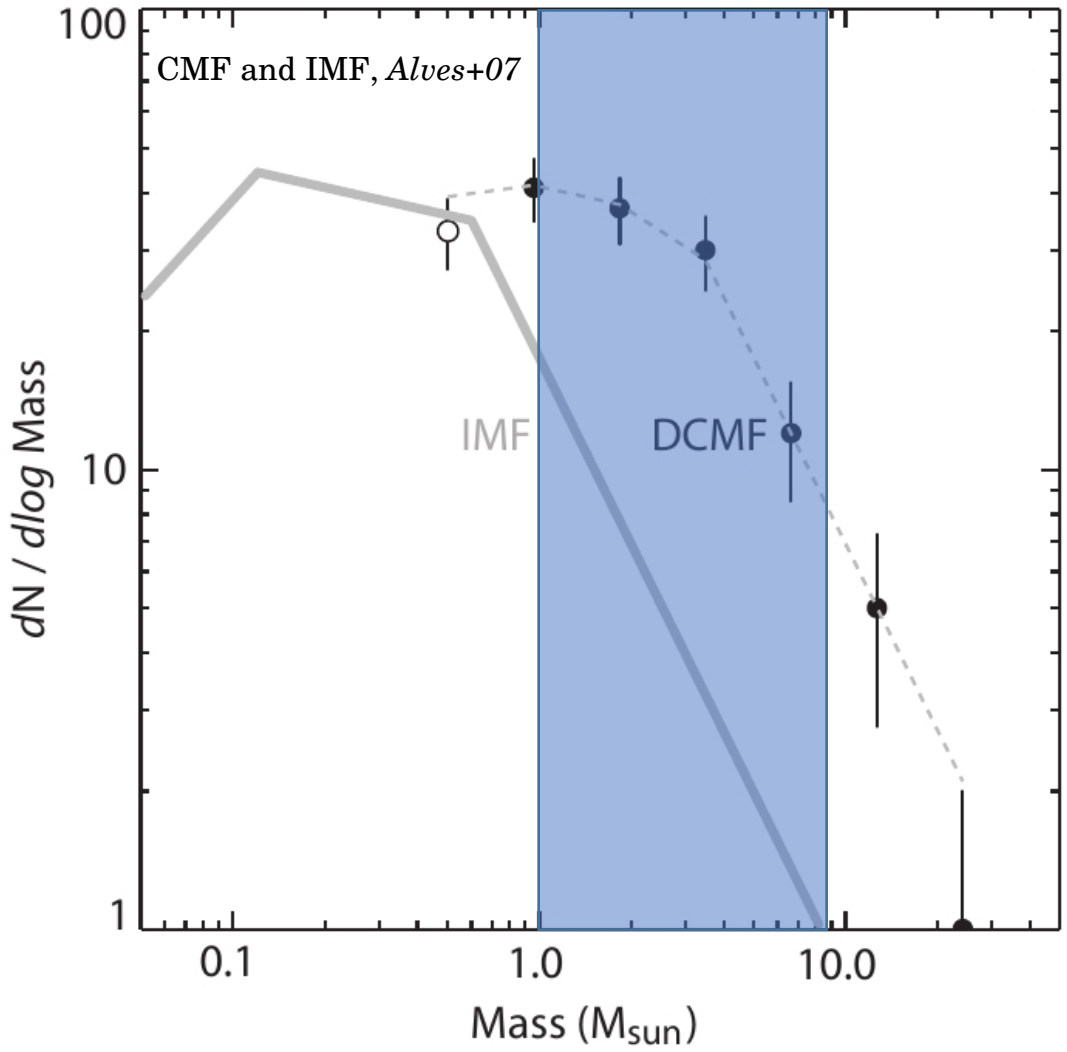
- Multi-component Gaussian fit to $C^{18}O$(1-0) emission line profiles
- Simplifying assumptions
  - Assuming same T_{ex} for all lines and homogeneous along line of sight
  - Gaussian $C^{18}O$ opacity profile
  - No fractionation: $^{12}CO/^{13}CO=70$, $^{12}CO/C^{18}O=500$, $^{13}CO/C^{18}O=7$
- Results
  - $C^{18}O$(1-0) center line opacity: $0.03\pm0.02 < tau18 < 0.64\pm0.04$
  - ^{12}CO column density: $7.1\pm2.4 \times 10^{15} < N(C^{18}O)\times500[cm^{-2}] < 8.8\pm0.6 \times 10^{17}$
  - CO/H=8.3×10^{-5}; $N_H = 8.6\times10^{19}$ to 1.1×10^{22} cm-2 or A_V=0.05 to 5.7 mag
  - ➢ **Core sample not representative of usual cores (A_V~10 mag): young starless cores or transients?**

Implication to the CMF

ID	Alves et al. (2007) $M_\odot$	Rathborne et al. (2009) $M_\odot$	Román-Zúñiga et al. (2010) $M_\odot$
43	3.2	1.2	0.58
46	9.6	5.6	4.90
49	2.6	0.8	0.61
51	5.9	4.6	2.03
54	7.3	0.9	0.39
55	7.3	2.2	1.70
56	1.2	0.4	–
57	5.0	2.8	2.52

- High uncertainties on dense cores masses estimated from dust extinctions

➢ **Implications to the break of the CMF !**



Conclusions and perspectives

- First large-scale map 1.4pc x 2.0 pc at 22” angular resolution of a highly dynamic, non star-forming region in the Pipe molecular cloud
- Two velocity components: first clear evidence of connection in velocity space
- Wealth of small-scale, elongated features, in ^{12}CO(1-0) channel maps
  - Preliminary results from eye-inspection in x-y-v cubes: ~40% aligned, ~10% perp, ~50% neither aligned or perp
  - Probing the formation of filamentary structures in the interaction region two (converging ?) flows
- Dense cores from previous studies
  - A_V from 0.05 to 5.7 mag for each velocity component separately: extinction peaks and projection effects
  - Transient structures?

- ➢ Characterisation of the filaments (density estimations, large-scale coherence)
- ➢ Dense core candidates
  - ➢ Constrain evolutionary stage with early/late type species (see also Frau+12)
  - ➢ New estimates of the mass from dust and gas

Thank you for your attention