Structure analysis from line observations

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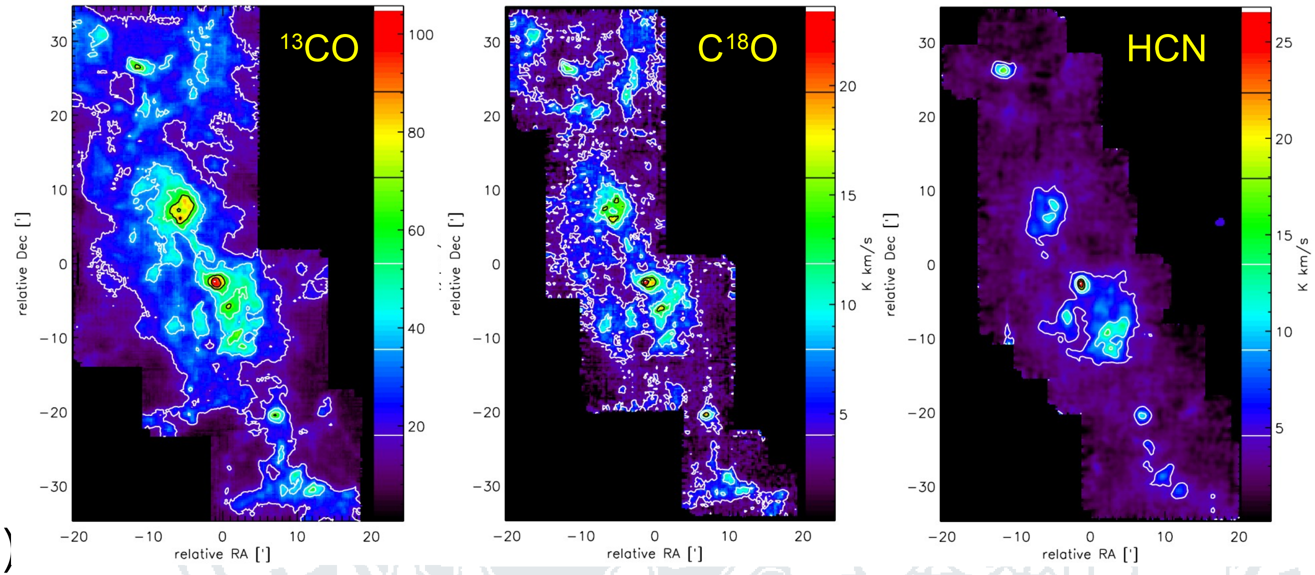
Overview

- Observational results
  - Wavelet cross-correlation
  - PDFs

- Simulations
  - Radiative transfer
  - PDFs
  - Wavelet cross-correlation

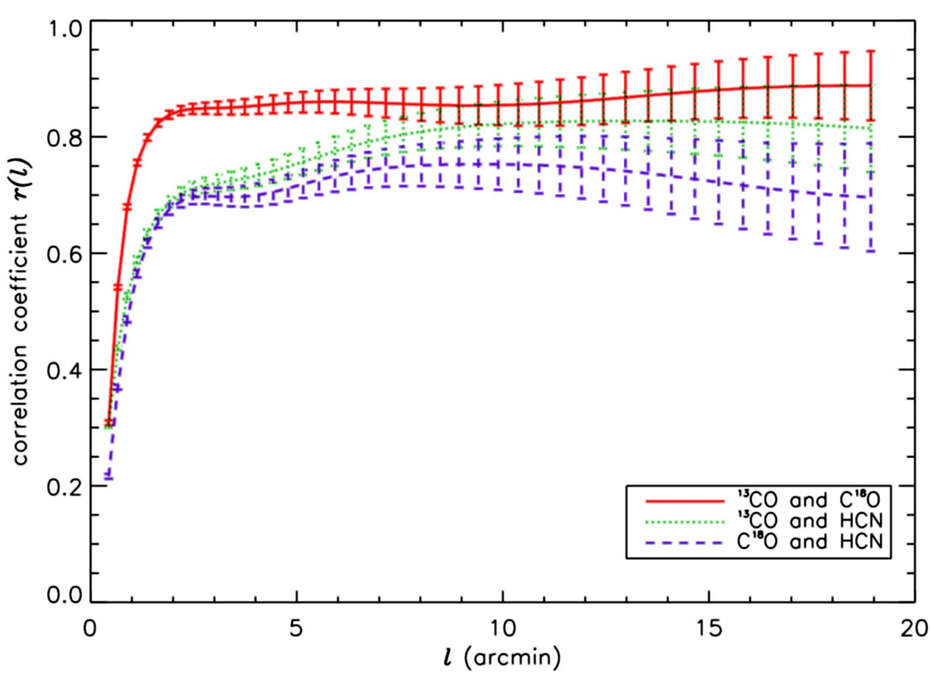
Starting point: Compare maps of different tracers

Molecular line observations of G333 (MOPRA):



Analysis:

Wavelet weighted cross correlation analysis to compare map structures depending on their scale (Arshakian & Ossenkopf 2015)



Result:

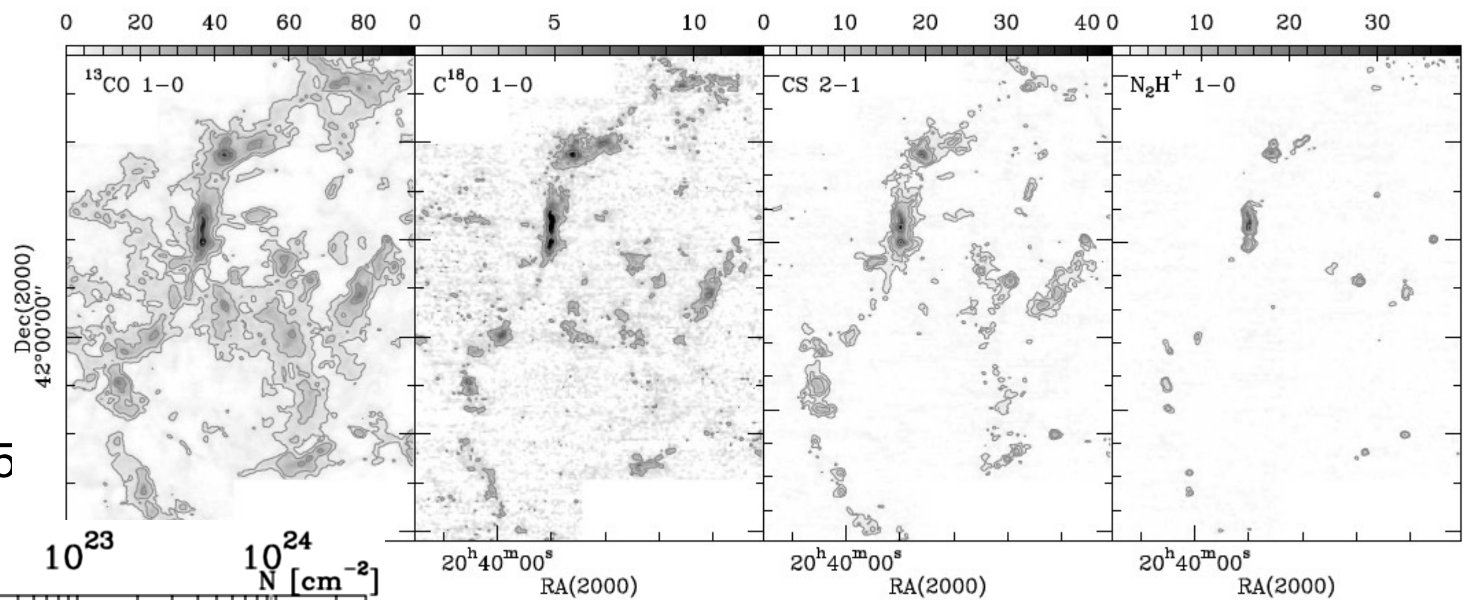
- ^{13}CO-C^{18}O perfectly correlated above the noise scale
- HCN behaves different at scales <7´ (~8pc)

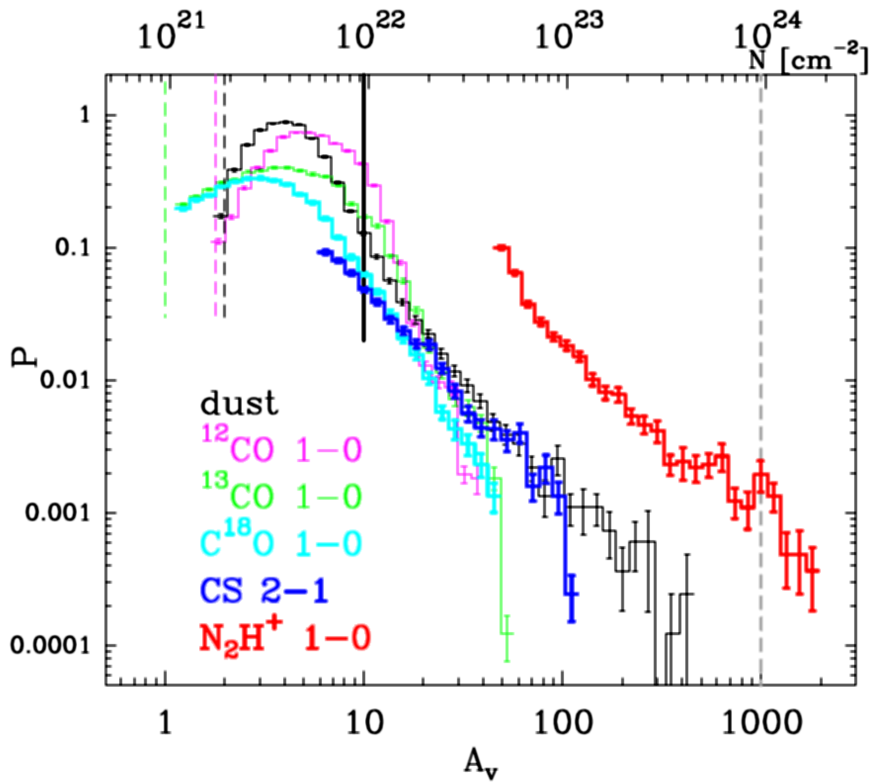
Difference in chemical structure or excitation conditions?

Starting point: Compare maps of different tracers

Line observations
of Cygnus:

Analysis:
PDF of column densities
(Schneider et al. 2015





Result:

- Dust PDF with turbulence-generated log-normal part and power-law tail from gravitational collapse
- High density line tracers confirm power law tail
- Uncertainty in the X-factors

Can we trust the PDFs seen in molecular lines?

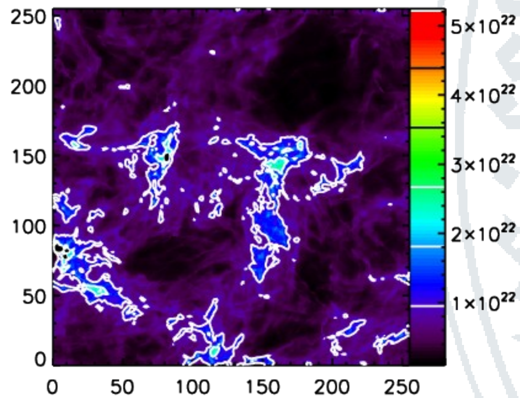
Simulations: (M)HD models from Federrath & Klessen (2012)

Compute line radiative transfer
(Simline3D, Ossenkopf 2002):

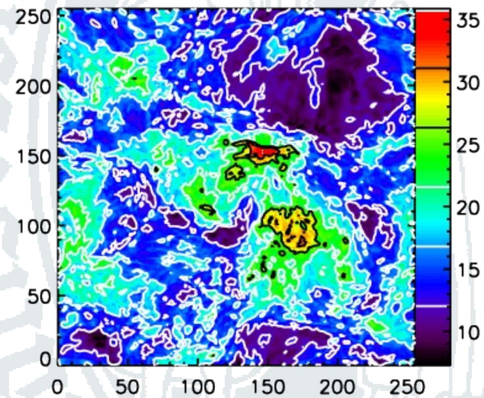
Integrated line intensities [K km/s]

Simplifications applied here:

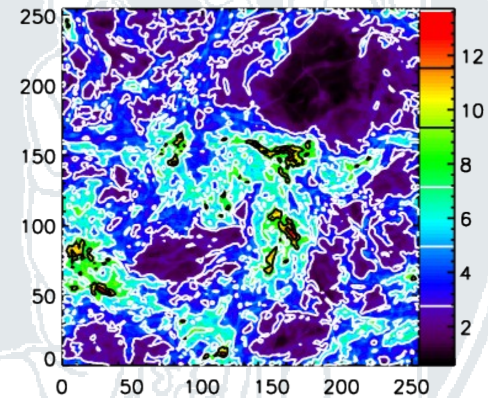
- Constant abundances
- Isothermal



Column density



CO 1-0



^{13}CO 1-0

FK12 Model 20:

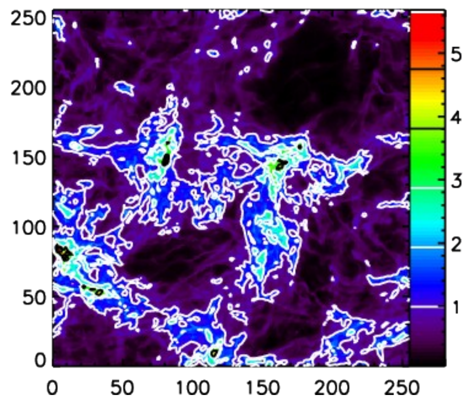
M = 10

D = 8pc

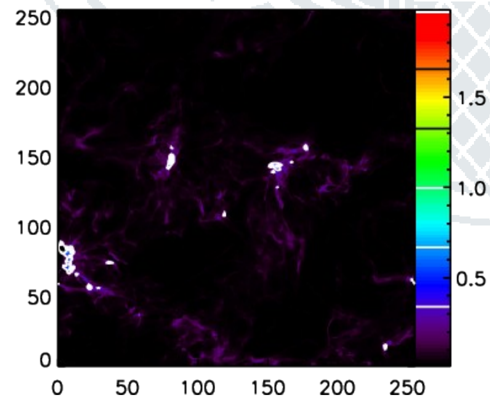
<n> = 207cm^{-3}

<B> = 3μG

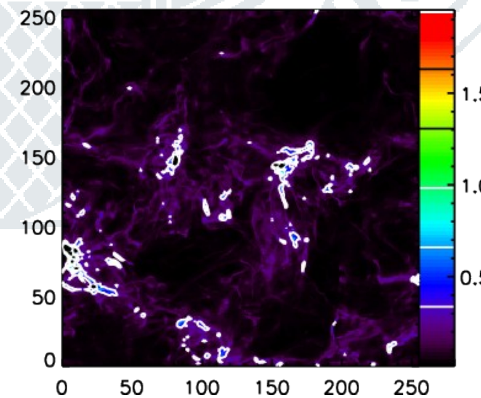
$C^{18}O$ 1-0



CS 2-1



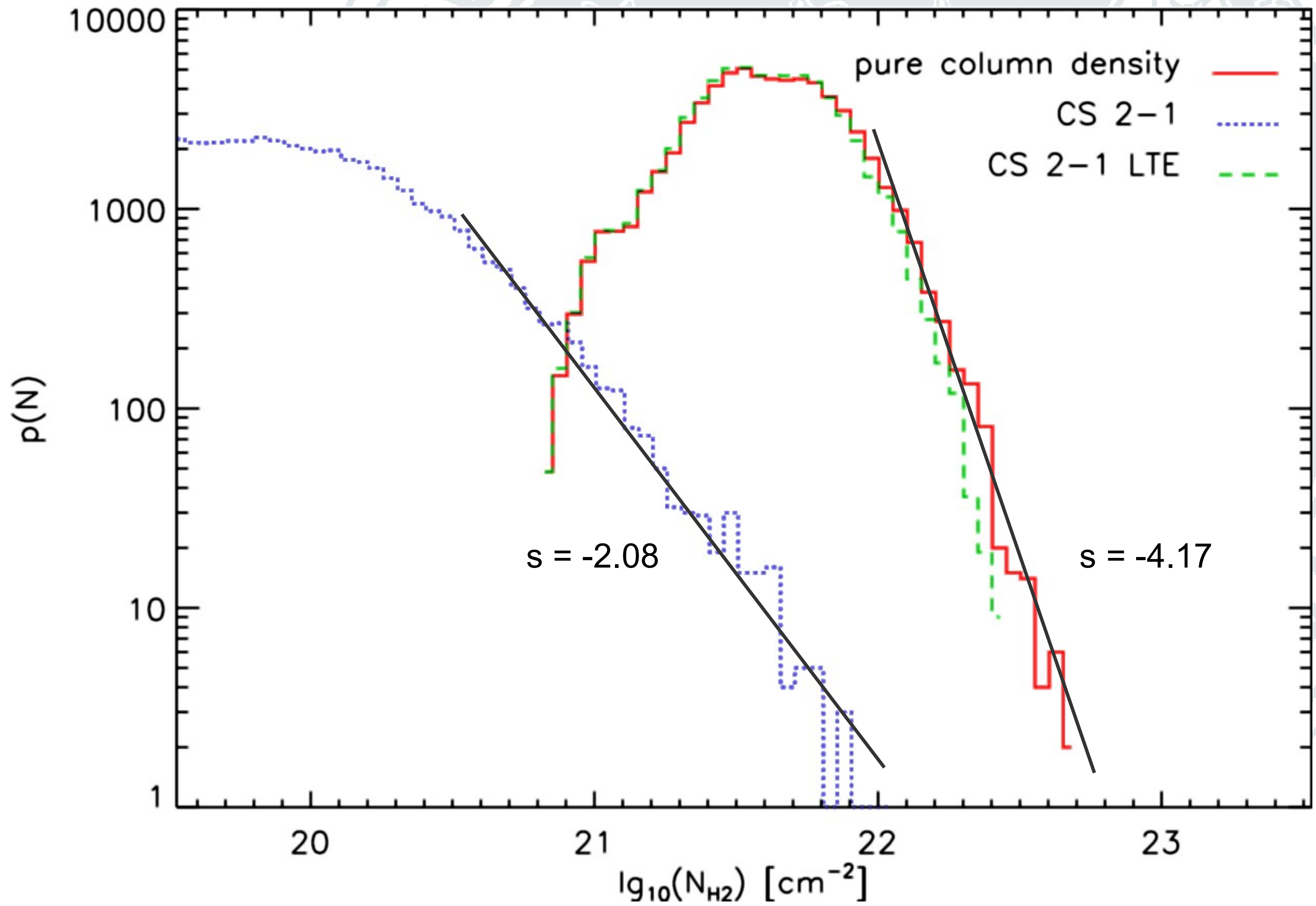
N_2H^+ 1-0



- No line traces true column density,
- Rare CO isotopes best approximation

Line radiative transfer results

PDF of column densities:

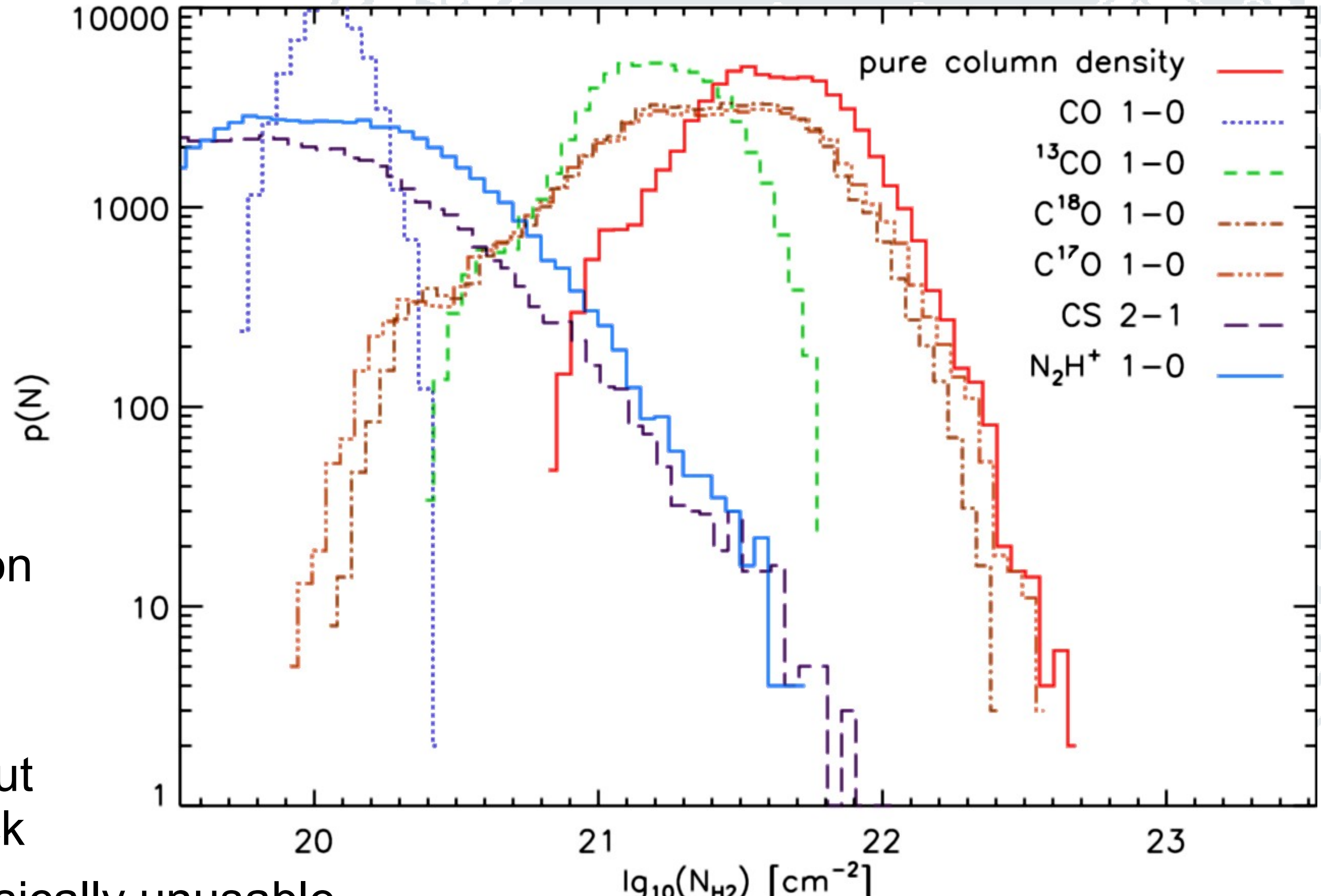


Two main effects:

- Cut of large columns due to line optical depth ≥ 1
- Shift of low column densities to lower intensities due to subthermal excitation
  - Flattens power-law tail by factor ½

Line radiative transfer results

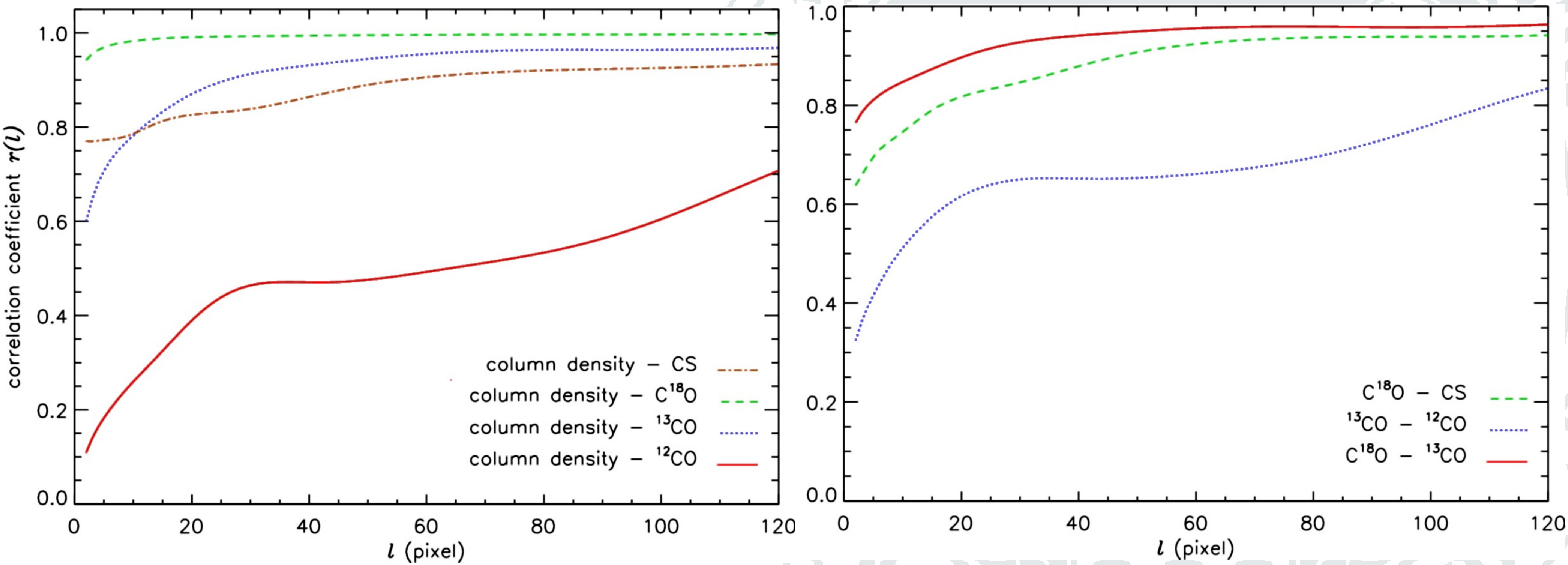
PDF of column densities:



Results:

- High-density tracers most affected by subthermal excitation
  - CS and N_2H^+ very similar
- CO easily excited but quickly optically thick
  - Main isotope basically unusable
  - ^{13}CO also optically thick
- Frequently accidential match of original PDF with adjusted X-factor
- Only $C^{17}O$ traces the high-density tail

Cross-correlation function



Results:

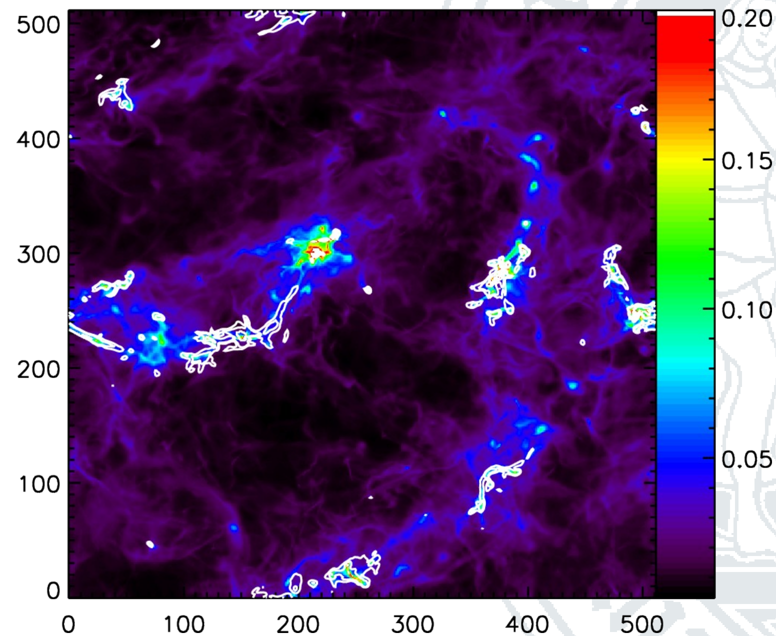
- Perfect correlation between spatial density structure and $C^{18}O$ emission
  - High correlation between $C^{18}O$ and ^{13}CO like in the observations
- Lower correlation for CS (like HCN in observations)
  - But no critical size scale
- ^{12}CO hardly reflects underlying density structure
  - only measures the velocity structure

Cross-correlation function

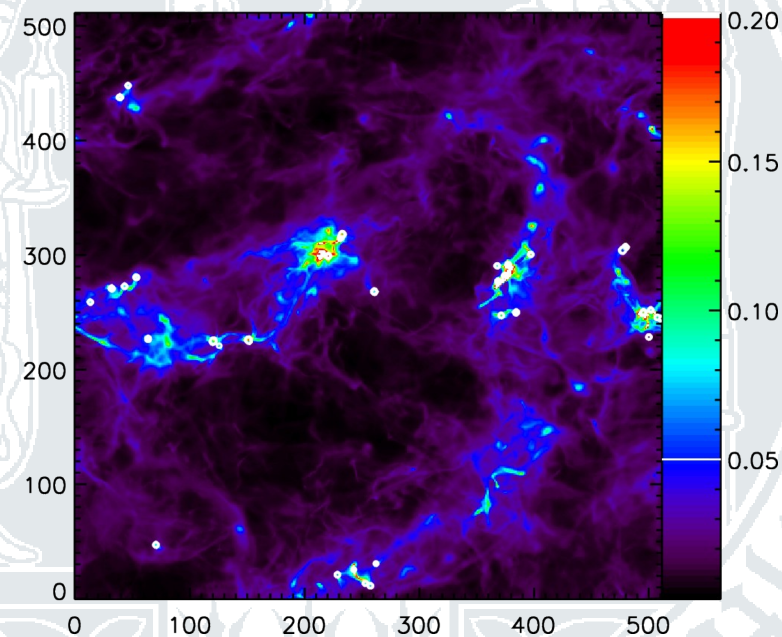
Compare direct properties of simulations:

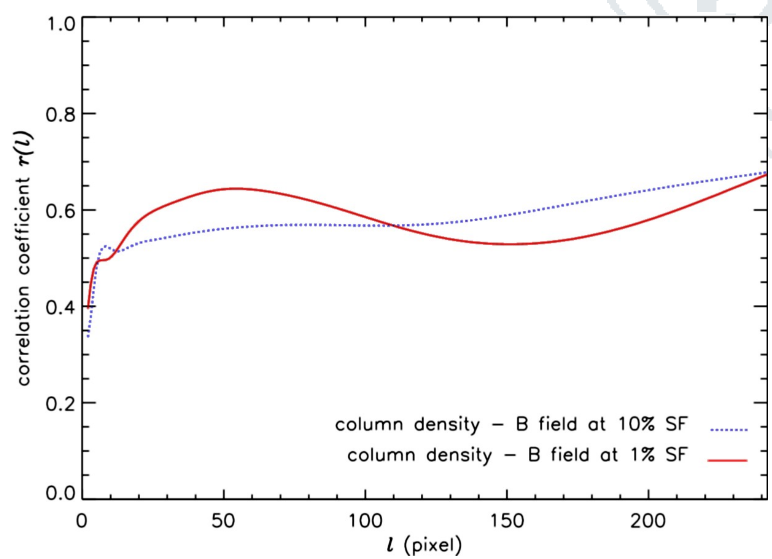
- Weak and constant correlation between density and B-field
- Growing scale of SF feeding with time

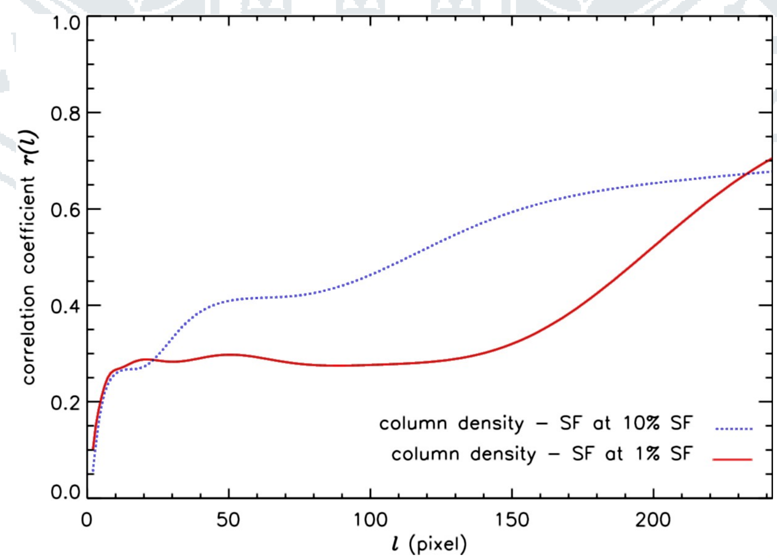
Column density – magnetic field



Column density – Protostellar cores







Conclusions

- **Molecular lines can never trace the full density distribution:**
  - **They scan only a narrow interval of the density PDF**

    (Dust traces larger dynamic range, but 2-D information only.)
  - **Any line is affected by**
    - **Optical depth**
      - **Creates steeper tails**
    - **Subthermal excitation regimes**
      - **Creates shallower tails**
  - **In addition: abundance and temperature variations**

- **The effects can be used to measure scales of relevant densities**
  - **The wavelet cross-correlation function traces conditions of excitation or abundance changes**
    - **Prominent scales for HCN and CS measure the size scale where critical densities are reached**
  - **We see how star-formation is affected by growing scales with time**
  - **Optically thick lines measure the velocity structure (VCA)**
    - **Planned follow-up work on line profiles**