I. Physikalisches Institut, Universität zu Köln ISM SPP 1573/1

Comparing turbulent structures in models and observations

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Overview

Starting point:

- Large surveys on the structure of the ISM in dust continuum, HI (21 cm), low-J CO, [CI], and [CII] currently available or ongoing
- (M)HD simulations including large dynamic range, self-consistent heating and cooling, and chemical networks
- Large set of statistical tools to characterize turbulent structures for maps, velocity slices, and the correlation between different tracers

Methods:

- Systematically compare statistical properties of mapping observations in various tracers with simulated observations from turbulence models
- Identify observable tracers and statistical tools sensitive to different aspects of cloud structures – the statistics of their chemical, dynamical, and energetic state
- Measure observational bias introduced by the limitations of today's observational technology
- Determine scales of numerical artifacts in models

The project will bridge the gap between sophisticated (magneto-)hydrodynamic turbulence simulations and the large set of observational data obtained from extended mapping projects in lines and continuum.

Heritage and Embedding:

The project builds on a long standing expertise in

- structure analysis (Δ-variance, structure functions, size-linewidth relation, PDFs, …)
- radiative transfer (SimLine, 3-D codes, …)
- observations (KOSMA, NANTEN2, Herschel, …)

and on collaborations spanning

- turbulence simulations (e.g. Univ. Wisconsin, …)
- radiative transfer (e.g. Argelander Institute, ...)
- large-scale ISM mapping and chemical evolution (Herschel key projects, CEA Saclay, FCRAO, …)

It provides a complement to the activities in the SFB 956, which deal with energetics and chemistry in the interaction of stars and molecular clouds, by studying turbulence and structure formation.

Radiative transfer

We compute full 3-D line radiative transfer effects using a two scale-approximation (Ossenkopf 2002) applicable to any turbulent density and velocity field.

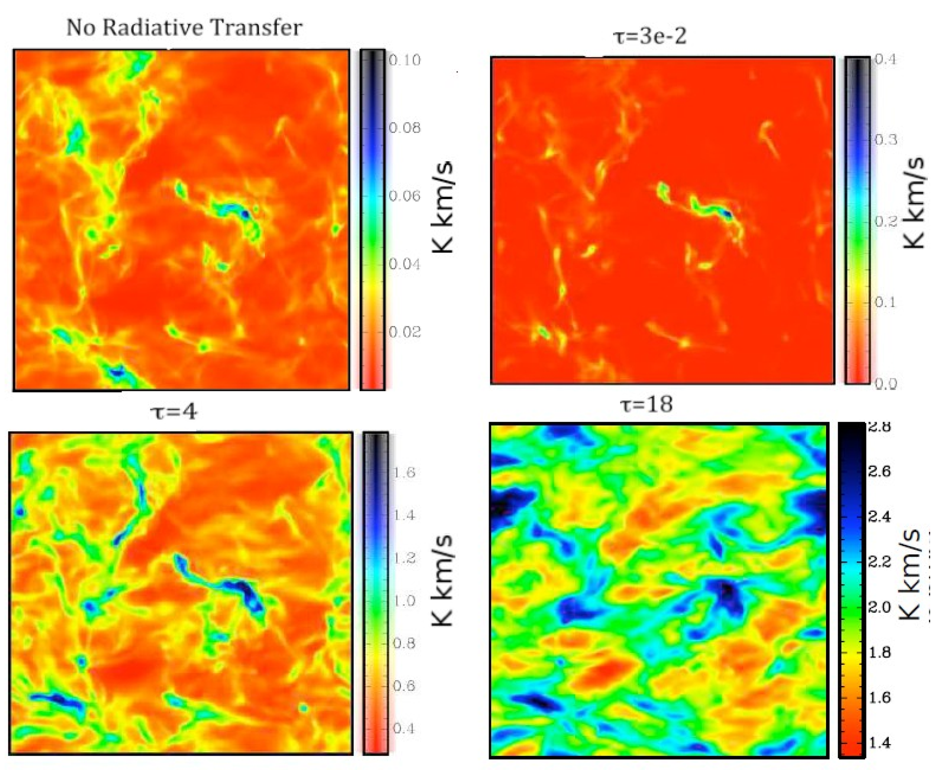

Figure 1: Radiative transfer and excitation effects in a MHD turbulence simulation with sonic Mach number 7.0 and Alfvenic Mach number 0.7. Line integrated intensities are computed for different density scalings of a simulated ^{13}CO 2-1 transition (Burkhart et al. 2009). At low densities and optical depths the transition is hardly excited; at high optical depths the variation of the velocity structure along the LOS dominates the integrated line intensities (Ossenkopf 2002).

Line tracers are sensitive to narrow gas density intervals only, but the information from their profiles is essential to constrain the turbulent velocity structure.

Observations

We are involved in systematic, velocity-resolved mapping observations of interstellar clouds in multiple tracers with particular focus on the phase transition between diffuse, ionized, and molecular components.

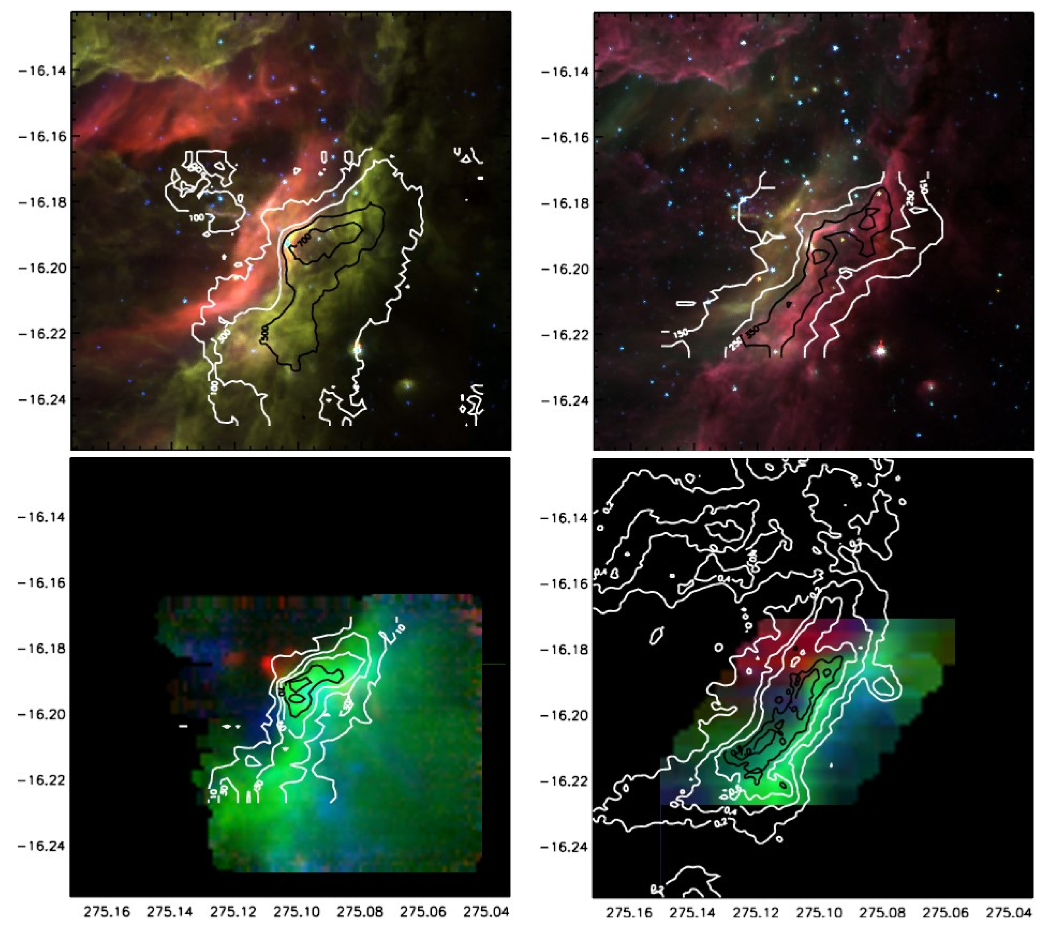

Figure 2: Comparison of the spatial structure of molecular, atomic, and ionized gas, dust, and PAHs in M17SW. The upper panels contain IRAC images at 3.6, 4.5 and 5.8μm or 4.5, 5.8, and 8.0μm as false color plots (Povich et al. 2007) superimposed by the integrated intensity of CO 6-5 (left, Pérez-Beaupuits et al. 2010) and [CII] (right). The lower panels show the velocity structure of those tracers in colors, representing velocities between 8, 18, 28, and 38km/s, superimposed by the integrated intensities of CO 13-12 and the 21cm free-free continuum (Brogan & Troland 2001).

The extended mapping observations allow to measure spatial scaling relations over a dynamic range covering more than three orders of magnitude and tracers of different phases of the ISM.

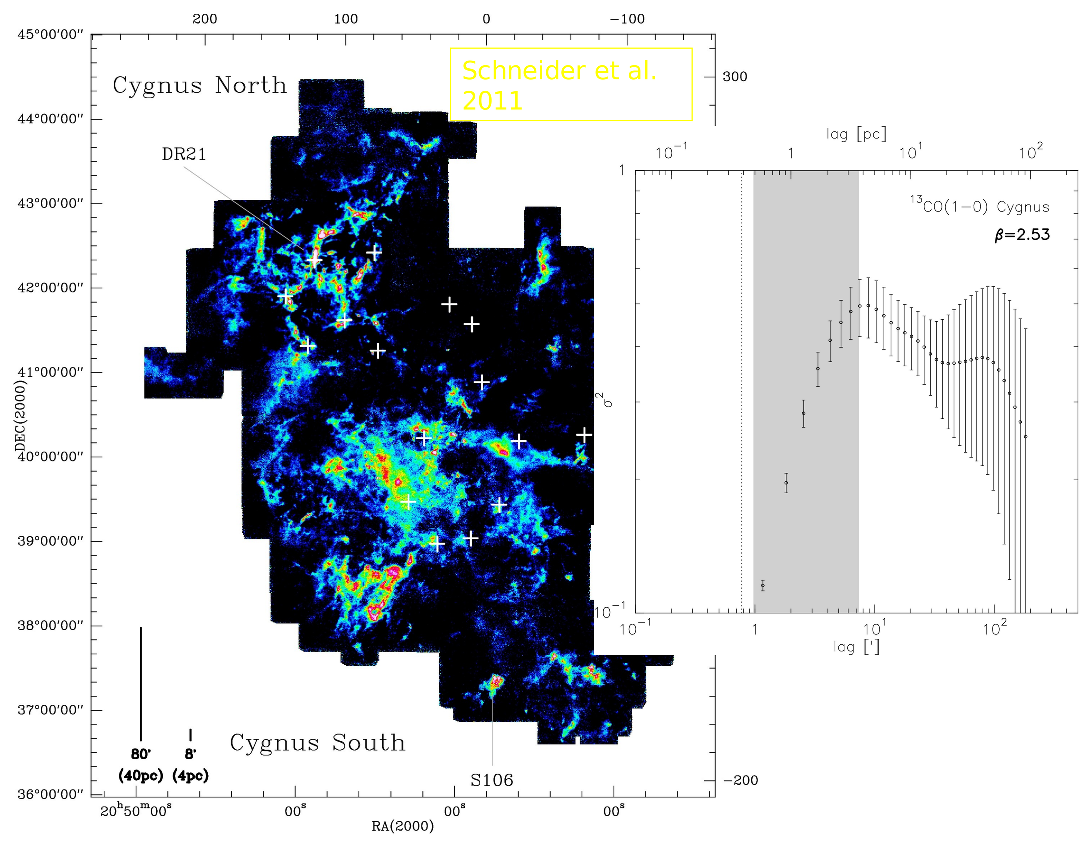

Figure 3: Map and Δ-variance spectrum of the large scale distribution of CO in the Cygnus molecular cloud complex (Schneider et al. 2011).

The density and temperature thresholds needed to excite different tracers allow to trace critical conditions for the different processes of structure formation from observations with limited S/N ratio.

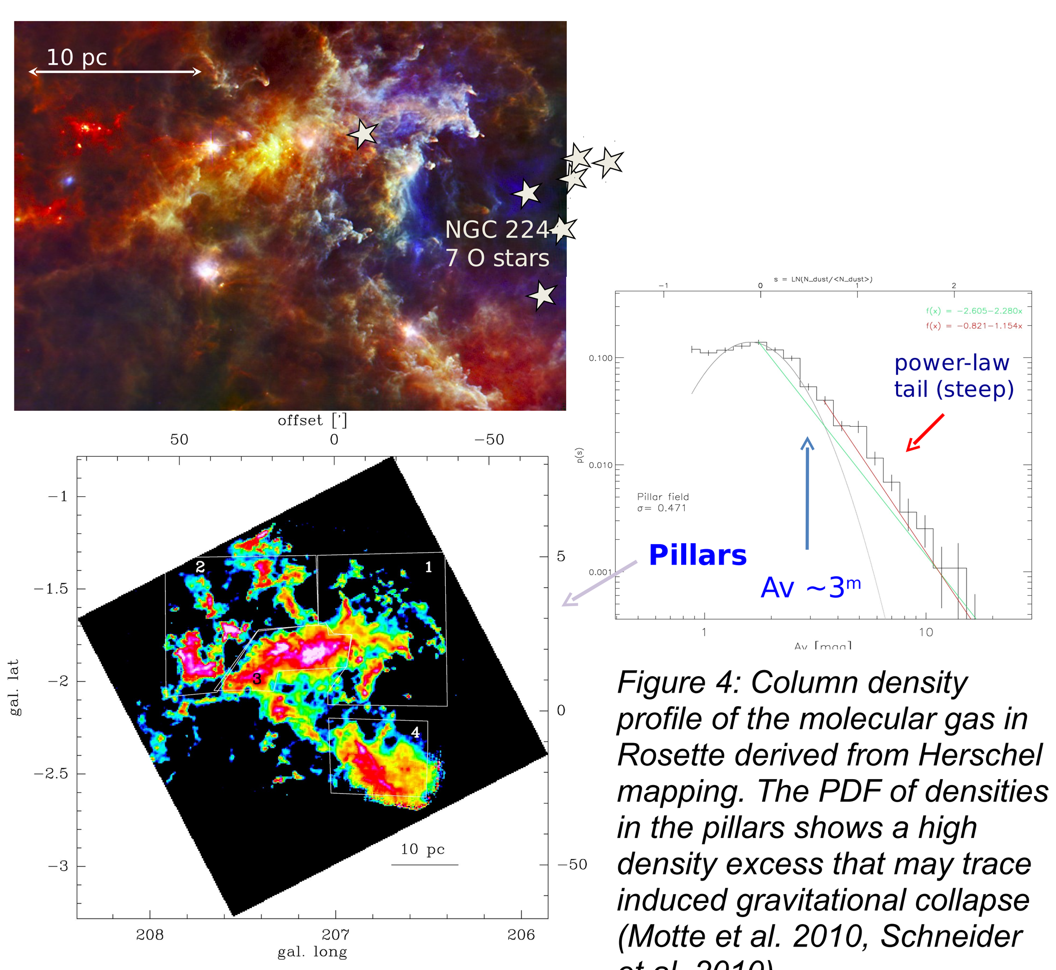

Figure 4: Column density profile of the molecular gas in Rosette derived from Herschel mapping. The PDF of densities in the pillars shows a high density excess that may trace induced gravitational collapse (Motte et al. 2010, Schneider et al. 2010).

The observational efforts are complemented by the systematic usage of existing mapping archives covering a variety of wavelengths.

Statistical measures

To quantify all aspects of the spatial and velocity distribution of the different ISM components various tools need to be investigated. Currently, we still do not know which method is most sensitive to which aspect of ISM turbulence. The following measures will be tested:

- PDFs of intensities and velocities
- PDFs of spatial increments
- Structure functions of variable order
- Principal component analysis
- Δ-variance spectra and spatial correlation analysis
- Clump decomposition
- Tsallis statistics
- Bispectrum

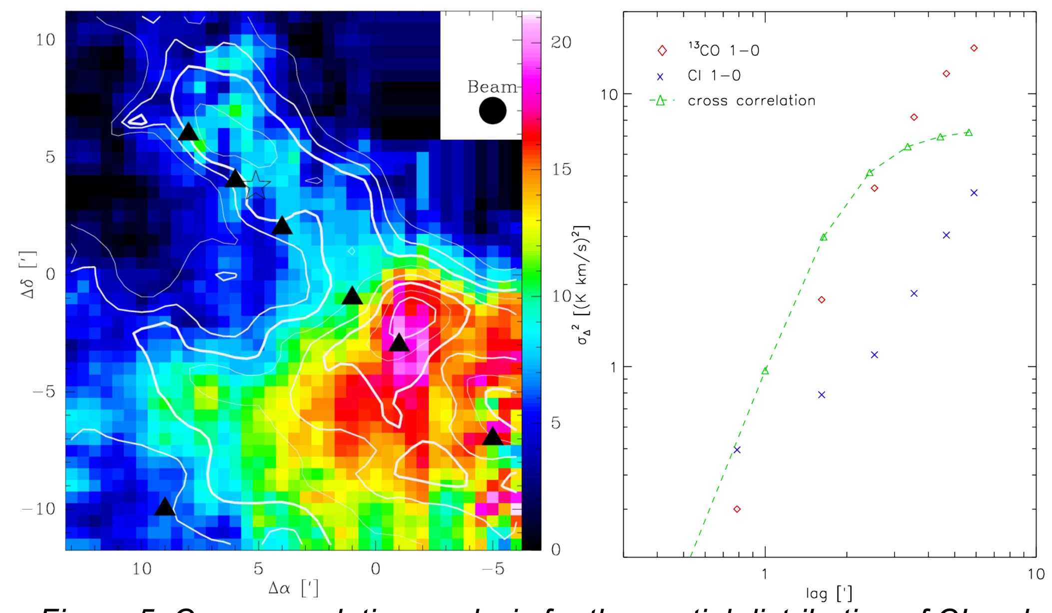

Figure 5: Cross correlation analysis for the spatial distribution of CI and ^{13}CO in IC348. The left panel shows CI in colors and ^{13}CO 1-0 in contours (Sun et al. 2006). The right panel contains the Δ-variance spectra of the two maps and the cross correlation spectrum indicating a characteristic chemical correlation scale of 2-3' where the spectrum saturates.

Main focus on the ability to:

- measure the spatial correlation and systematic variation between different tracers
- cope with maps with typical observational limitations, like variable noise and a limited dynamic range

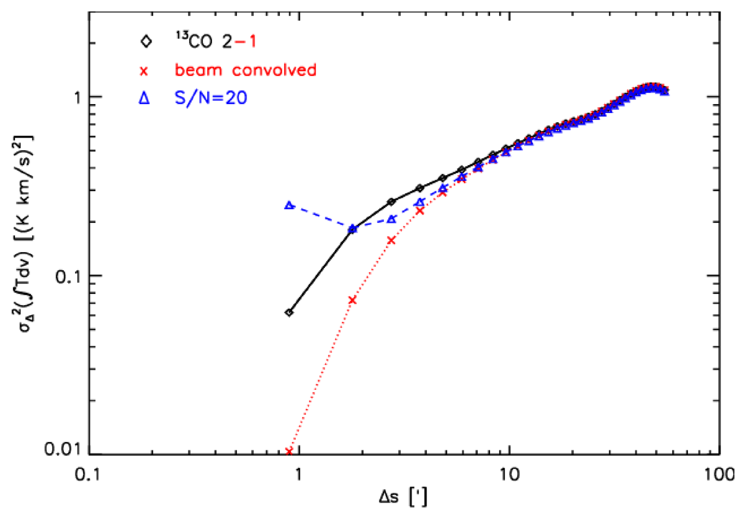

Figure 6: Impact of finite telescope beam and the typical S/N of observed data on the Δ-variance spectrum of a simulated, fully sampled ^{13}CO 2-1 map from an HD turbulence simulation (Ossenkopf 2002).

Main goals

By the systematic comparison of models and observations of turbulence in the the interstellar medium, we will quantify the impact of physical and chemical processes in the structure formation:

- phase transition from atomic to molecular gas at cloud boundaries
- formation of essential cooling species (C^+,O)
- local energy balance and deviations from LTE
- impact of optically thick cooling lines
- dynamical instabilities driven by ram pressure
- turbulent heating and mixing
- radiation pressure from the ISRF

References

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