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Chemistry in velocity: Investigating gas chemical properties in 4D

Alvaro Hacar and Ewine van Dischoeck

Leiden Observatory, Leiden University, P.O. Box 9513, 2300-RA Leiden, The Netherlands
email: hacar@strw.leidenuniv.nl

Abstract. Gas chemistry is typically characterized comparing integrated intensities of different molecular species. With the advent of ALMA, chemistry is now resolved not only in space but also in velocity. When observed at high spectral resolution, most of the clouds, filaments, and cores in the solar neighbourhood show a complex internal structure with multiple velocity components. This intrinsic complexity should be disentangled in order to correctly interpret their chemical properties. We present the first results of the FIVE+ analysis technique combining both state-of-the-art structure reconstruction (2D), kinematic decomposition (+1D), and chemical analysis (+1D) in large molecular datasets.

Keywords. Astrochemistry, ISM: kinematics and dynamics, ISM: molecules

1. Introduction

The unprecedented spectral coverage of the new broad-band (sub-)millimeter observations is revolutionizing the analysis of the ISM chemistry. Due to sensitivity constraints, molecular surveys have classically focused their analysis on the gas chemistry in localized positions in star-forming regions (e.g., Blake *et al.* 1987). Similarly, mapping studies have surveyed large areas of the sky investigating the gas structure and kinematics using few (mainly CO isotopologues) of the brightest line tracers (e.g., Goldsmith *et al.* 2008). Now, ALMA routinely produces high-fidelity molecular line maps simultaneously observed in multiple tracers and transitions (e.g., Jørgensen *et al.* 2016). Resolved out in hundreds or thousands of beams, these new observations allow us to investigate the gas chemistry both in space and velocity. However, the intrinsic complexity of these multi-line spectral cubes challenges most of the traditional analysis techniques. In parallel to instrumental developments, innovative analysis tools are needed to characterize the rich gas chemistry revealed in these new molecular datasets.

2. Initial FIVE+ results: chemical properties of the NGC1333 fibers

In this poster we present the first results of the FIVE+ analysis technique. Based on the previous FIVE algorithm (Hacar *et al.* 2013), FIVE+ is designed to combine both observations and radiative transfer calculations in order to constrain both the physical and chemical gas properties from the simultaneously analysis of multiple line tracers. FIVE+ investigates the gas distribution and structure (2D), kinematics (+1D), and chemical composition (+1D) in complex molecular datasets. From the detailed study of the gas velocities in the Position-Position-Velocity (PPV) space, the 4D analysis carried out by FIVE+ is designed to reconstruct the emission of individual gas components independently disentangling their main physical properties (i.e., kinetic temperature, gas kinematics, molecular abundances...). The development of this new methodology is part

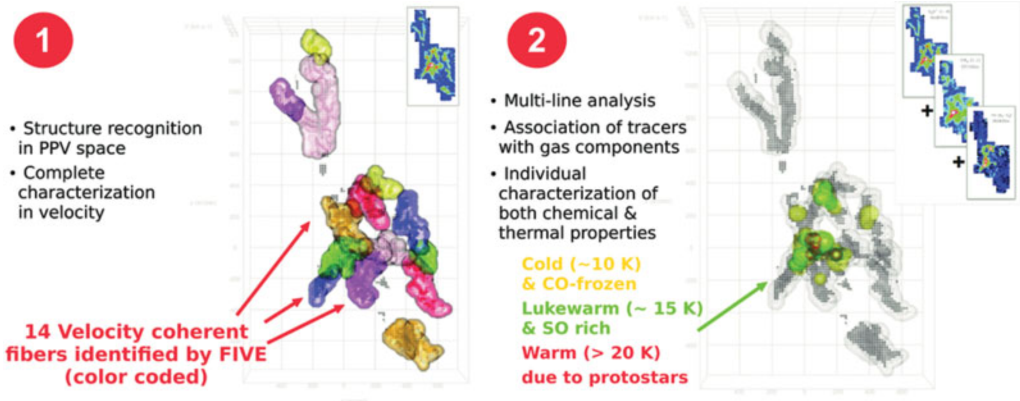

Figure 1. Preliminary FIVE+ results in the NGC1333 proto-cluster. **(Left)** 14 velocity–coherent fibers identified in the PPV space in N_2H^+ (color coded; Hacar *et al.* 2013). A full visualization of these results can be found in `https://sites.google.com/site/orion4dproject/visualization`. **(Right)** New multi-line FIVE+ analysis combining the information of all N_2H^+ (1-0), NH_3 (1,1) & (2,2), and SO (6_5-5_4) tracers within the same region. This joint analysis makes possible to systematically characterize the gas density (N_2H^+; grey structures), gas temperature (SO + NH_3; red and green regions), and chemical compositions of each individual structure both in position and velocity (see PPV iso-surfaces).

of the ORION-4D project (PI: Hacar, see also `https://sites.google.com/site/orion4dproject`).

We have carried out a pilot study of the chemical properties of the NGC 1333 proto-cluster using FIVE+. The dense gas substructure within NGC1333 has been extensively studied using large-scale N_2H^+ (1-0) observations (Hacar *et al.* 2017). As illustrated in Fig. 1 (Left), a complete characterization of the different gas components within this region reveals the presence of 14 independent velocity structures, the so-called fibers, forming a complex network. In Fig. 1 (Right), we have combined the above N_2H^+ emission with similar large-scale NH_3 (1,1) and (2,2), plus SO (6_5-5_4) observations. The combined analysis of these selective tracers allow us to identify, both in space and velocity, those regions presenting systematic CO-freeze out (aka rich in N_2H^+ and NH_3; grey and yellow PPV iso-surfaces), lukewarm regions affected by their internal stellar population (SO bright; green iso-surfaces), and warm material in the surroundings of the most massive protostars (via NH_3-derived temperatures) within this region. Our preliminary results indicate the potential of this multi-line analysis technique for the study of complex molecular datasets. Future developments of this new FIVE+ algorithm are expected to include the combination of additional line observations and radiative transfer codes (e.g., Brinch & Hogerheijde 2010) deriving better estimates for the excitation conditions, gas column density, and molecular abundances for each individual gas component.

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