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High resolution rotational spectroscopy of elusive molecules at the Center for Astrochemical Studies (CAS@MPE)

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Abstract. The laboratories at the Centre for Astrochemical Studies at the Max Planck Institute for Extraterrestrial Physics are devoted to spectroscopic studies of molecules of astrophysical relevance. In particular, in this paper we report on the two experiments that can produce and probe unstable molecules, like radicals and ions.

Keywords. High-resolution molecular spectroscopy, elusive molecules, astrochemistry

1. The Centre for Astrochemical Studies

The Centre for Astrochemical Studies combines theory (including plasma physics and non-ideal magneto-hydrodynamic simulations), observations, and laboratory spectroscopy to tackle questions about star and planet formation and the interstellar medium. Observations with IRAM, ALMA, Herschel, APEX, SOFIA and other far infrared to millimetre facilities play a key role. Chemical processes are included in dynamical models to follow the ionization fraction and drive observations, which are then used to constrain the theory of evolving interstellar clouds and the process of star/planet formation. A concerted program of lab spectroscopy is taking place at MPE, including two complementary approaches for the study of reactive species: CASAC and CASJET. The frequency range covered is 70-1600 GHz, which overlaps with the available frequency range at NOEMA and ALMA, as well as at the APEX and IRAM-30m telescopes. Measurements performed with CASAC and CASJET are needed to allow the detection in space of astrophysically relevant molecules, and then to use these molecules as powerful diagnostic probes of the physical and chemical conditions of interstellar matter.

2. Oxygen containing radicals with the CASAC experiment

CASAC (the CAS Absorption Cell) has been built to measure with high precision the frequencies of astrochemically important molecular ions and radicals. The instrument is equipped with a negative glow-discharge absorption cell made of a Pyrex tube (3 m long and 5 cm in diameter). Unstable molecules are produced in a negative glow-discharge cell containing two stainless steel, cylindrical hollow electrodes separated by 2 m (Bizzocchi *et al.* 2017). We recently extended the frequency coverage for HCCO and DCCO from 170 to 650 GHz (Chantzos *et al.* 2019), previously studied only in the 300 GHz frequency range. The spectra of HCCO and DCCO measured with the CASAC are shown in Figure 1. HCCO and DCCO are astrochemically relevant because connected to the radical and organic chemistry happening in the interstellar medium (ISM), as well as the

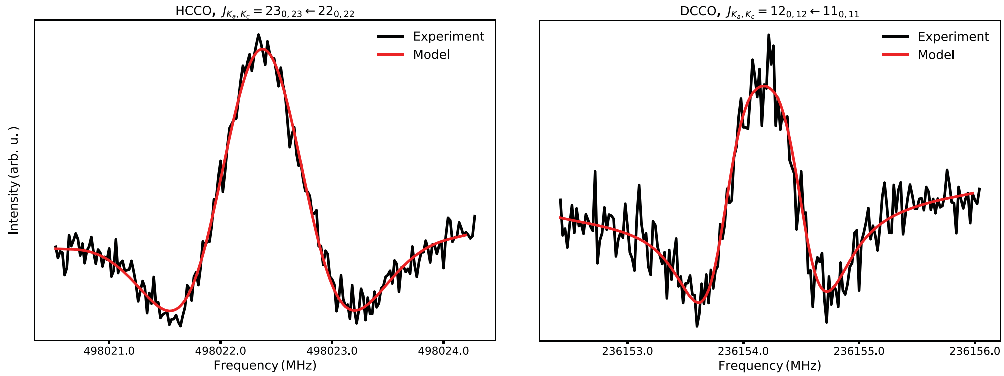

Figure 1. HCCO and DCCO measured with the CASAC experiment (Chantzos *et al.* 2019).

cosmic rays driven chemistry (Shingledecker *et al.* 2016). As a close collaboration with the chemical modellers in our group, we plan to work on the spectroscopy of isomers of HCCO (CCHO and CCOH), whose detection in the ISM will provide an indirect measure of atomic hydrogen, and will allow us to test our chemical models on the impact of cosmic rays on the chemistry of dense cores (Shingledecker *et al.* 2016, and priv. comm.). Furthermore, we have used the CASAC to observe the ground state transition of CH_2OH. These measurements allowed us to tentatively detect this molecules for the first time in the ISM. Additional observations are undergoing to confirm this detection.

3. Molecular ions with the CASJET

CASJET (CAS supersonic free-jet expansion) can measure with high precision the frequencies of astrochemically relevant molecular ions, radical, as well as complex organic molecules cooled down to ∼10 K. A gas mixture is injected into a vacuum chamber through a pulsed valve, producing a cold and confined molecular beam. Given the high pressure gradient ($\sim 10^7$), the beam undergoes a supersonic expansion and is adiabatically cooled. A high-voltage low-current DC nozzle, attached to the valve, allows the production of unstable species. The radiation source and the detector are the same as those used for the CASAC. As a proof of concept of the complementarity of the CASAC and CASJET, we recently used the CASJET to measure for the first time the *b*-type spectrum of $HSCO^+$ (Lattanzi *et al.* 2018). Furthermore, we have successfully combined the CASJET with our chirped-pulse Fourier transform spectrometer (FTS). We plan to use the large instantaneous bandwidth of the chirped-pulse FTS and the efficient cooling of the CASJET to study ions and radicals of complex molecules.

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