The PDRs around compact HII regions in the S235 complex

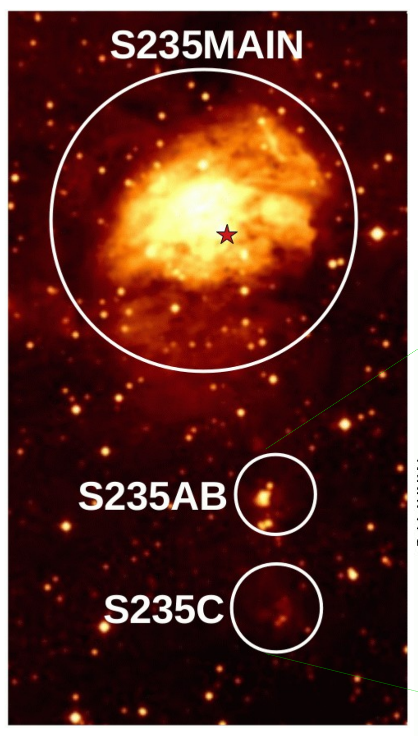
Volker Ossenkopf-Okada[1], Maria Kirsanova[2], Loren Anderson[3]

[1] I. Physikalisches Institut, Universität zu Köln, [2] Institute of Astronomy, Moscow, [3] West Virginia University, Morgantown

SFB 956 Cologne | Bonn

Motivation

Feedback from massive stars is thought to be one of the main drivers structuring the interstellar medium. The UV radiation from O and B stars heats the surrounding clouds, drives a photon-dominated chemistry, creates HII regions in their vicinity and provides a significant momentum impact leading to the expansion of HII regions and the neighbouring photon-dominated regions (PDRs). In spite of numerous detailed theoretical models, the expansion of the HII regions has not been directly measured yet. Velocity-resolved observations of tracers for the PDRs surrounding the HII regions can provide first direct measurements. Compact HII regions with approximately spherical geometries are the best targets, allowing for relatively simple modeling. We tried to model and observe the expansion of the compact HII regions S235A and S235C.



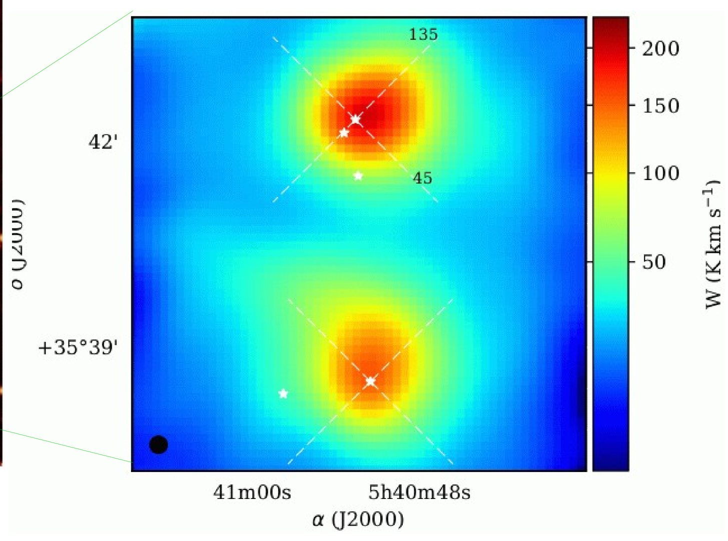


FIGURE 1: DSS red image of the S235 region showing ionized gas through the H-α line. We concentrate on the compact sources in the south. The zoom-in shows integrated [CII] intensities (Andersson et al. 2019). We have marked the positions of the illuminating sources and the directions of the position-velocity cuts used to measure the expansion.

Source structure

For spherical configurations an expanding shell should appear as a ring-like structure in position-velocity (p-v) diagrams. The inhomogeneous density structure, however, destroys this simplified picture.

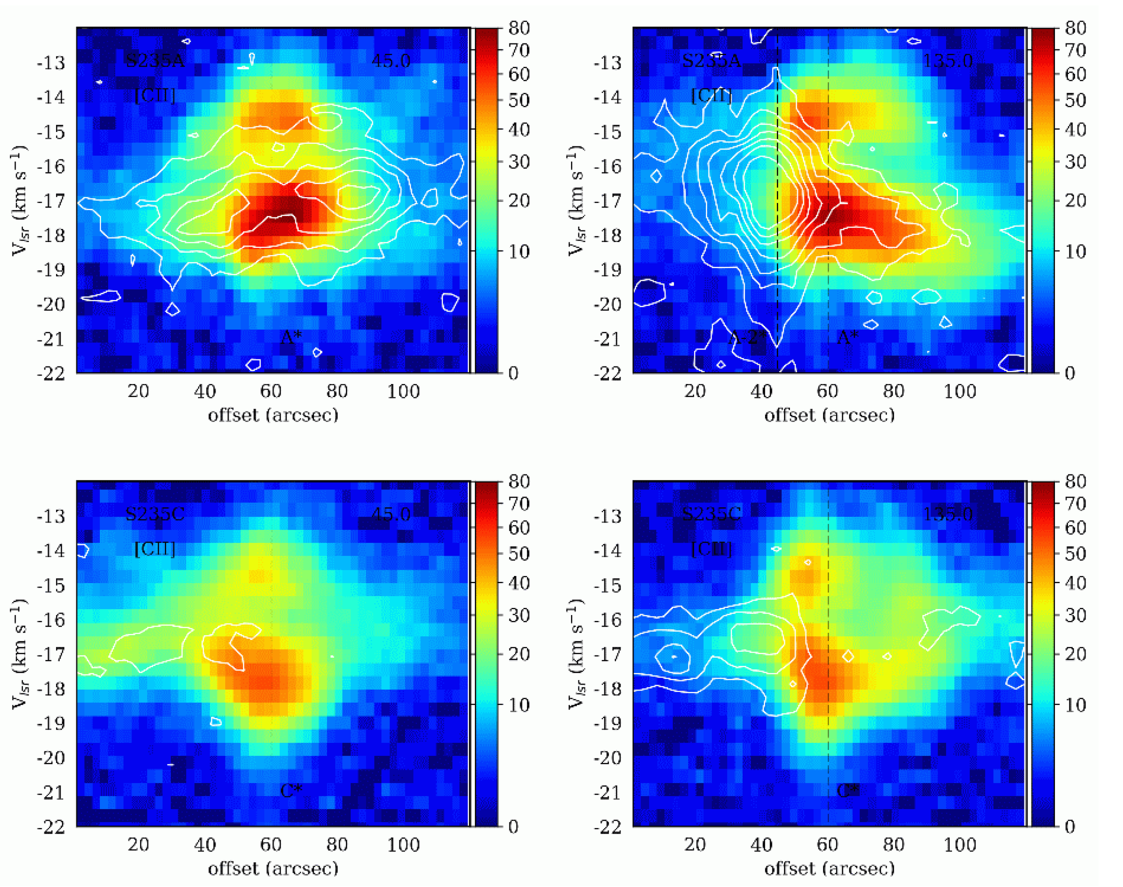


FIGURE 2: p-v diagrams of [CII] (colour) and HCO^+ 3-2 (contours) in the two perpendicular cuts across S235A (left) and S235C (right) shown in Fig. 1. The black lines indicate the position of the point sources. Intensities in K.

[CII] as PDR tracer shows a double-peak structure. The separation of the peaks would correspond to an expansion velocity around 2km/s.

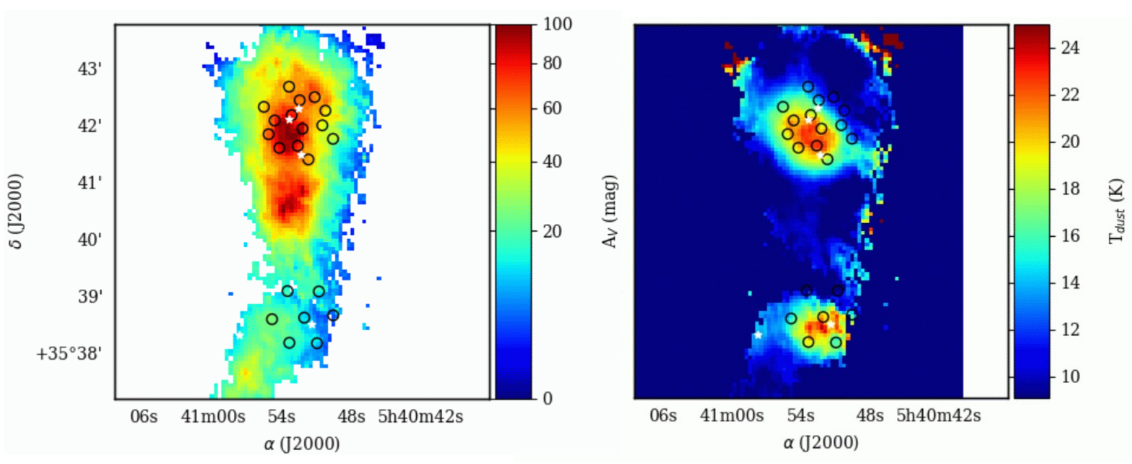


FIGURE 3: Dust column-density and temperature structure of the sources derived from SHARC-II, SCUBA-2, and BoloCam 1.1mm data. The circles indicate the positions of the [^{13}CII] observations. In particular S235C shows a strong column density gradient across the source.

The density structure is not uniform in spite of the apparently spherical structure of the HII regions. We find a clear gradient across the sources. In a more sophisticated model we fit this by a setup composed of two hemi-spheres with different densities..

Model

We model the HII and PDR regions through the MARION chemo-dynamical model (Kirsanova et al. 2009, Akimkin et al. 2017) scanning a grid of initial gas densities and effective temperatures of the illuminating stars, trying to fit the observed properties of the sources.

A reasonable agreement is found for

S235A: n=5·10^4 cm^{-3}, Teff=27000K, t_{exp}=6·10^{4}a

S235C: n=5·10^3 cm^{-3}, Teff=27000K, t_{exp}=3·10^{4}a

The shell expansion of ~ 1km/s (S235A) and 3 km/s (S235C) is measurable in the p-v diagrams.

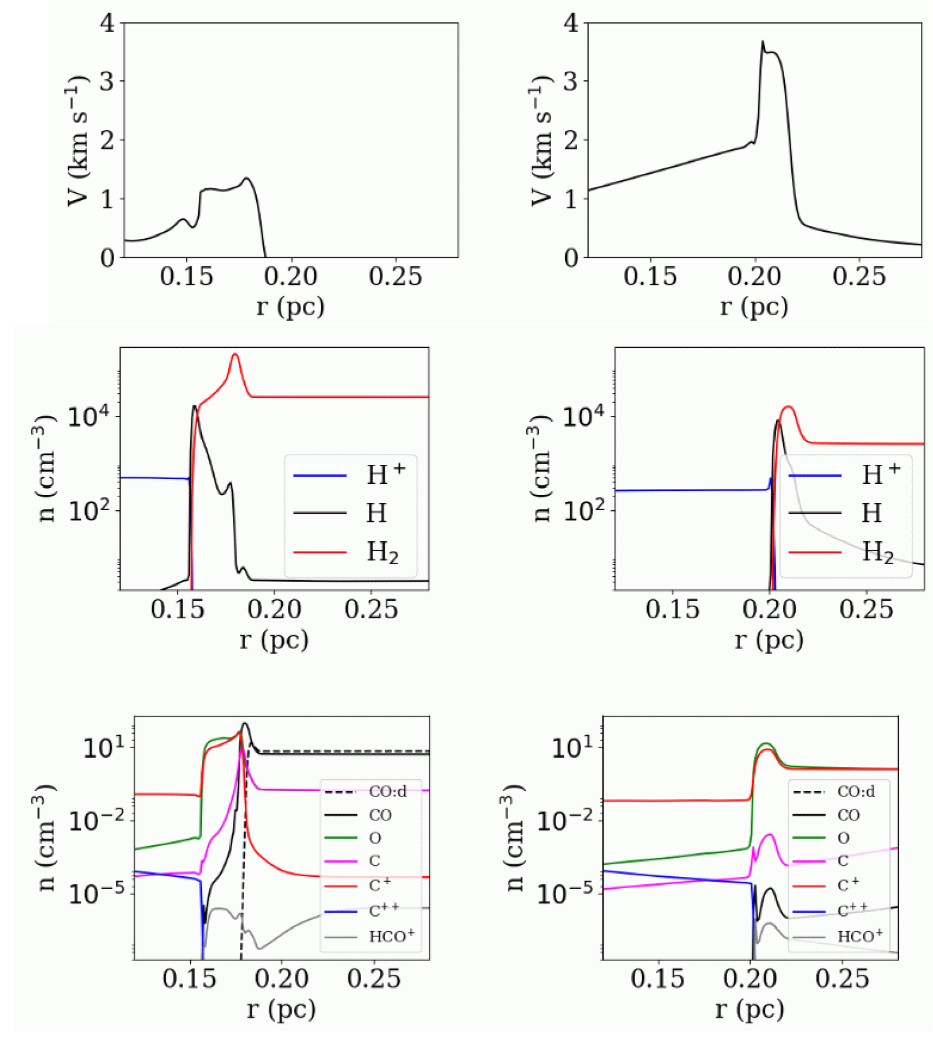


FIGURE 4: Radial structure of the models for S235A (left) and S235C (right). The upper plot shows the expansion velocity, the lower plots the abundance of the most important species (Kirsanova et al. In prep.)

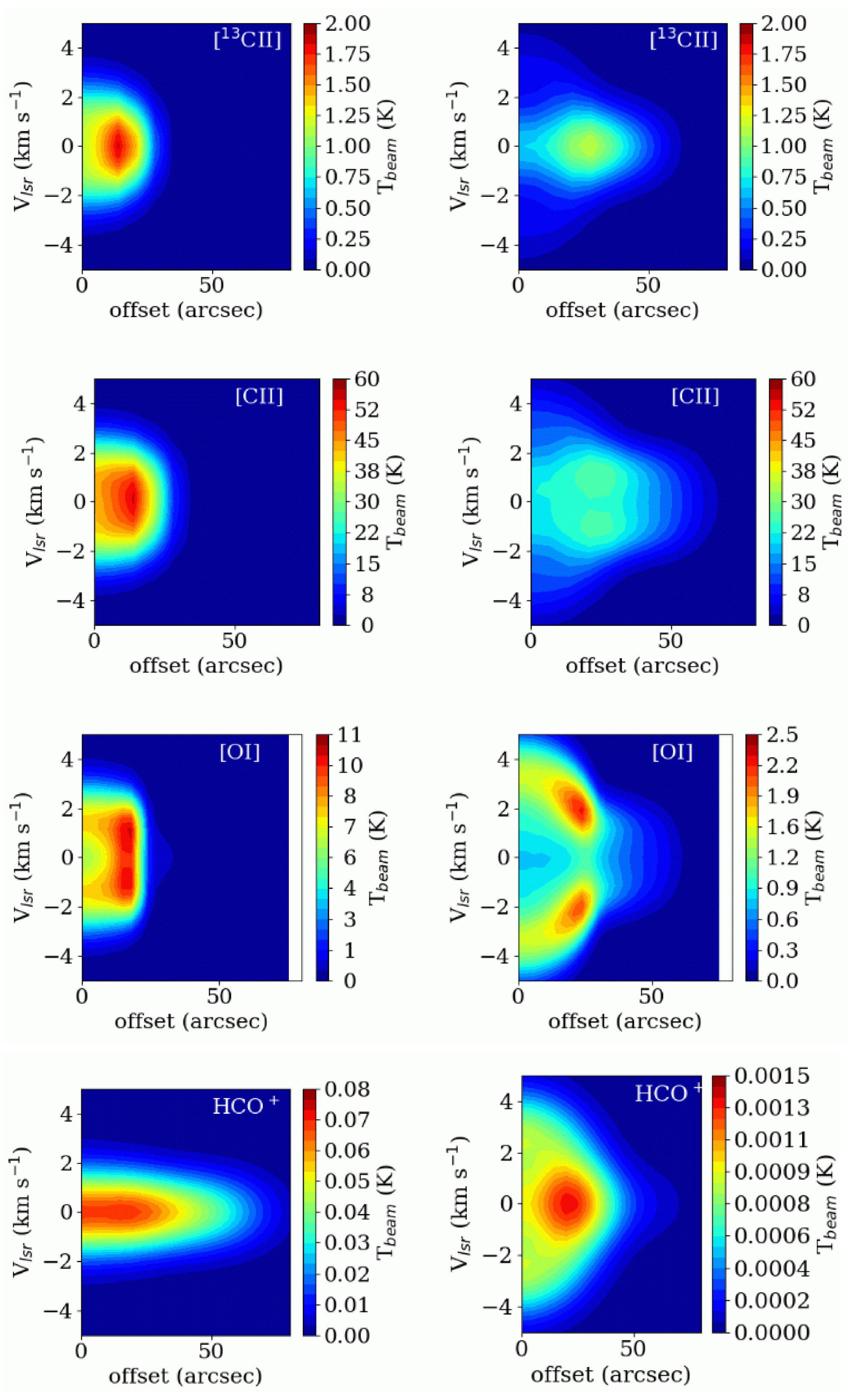


FIGURE 5: Resulting p-v diagrams when "observing" the MARION models in the different lines. A strong double-peak structure is seen in [OI] at 63µm. [CII] shows a weak double-peak structure due to self-absorption for the S235C model. The predicted [CII] intensities are somewhat lower than observed.

Conclusions

In spite of the apparent simplicity of the sources, an explanation of the large columns of warm and dense PDR material cannot be provided by one-dimensional models but requires an inhomogeneous, clumpy density structure, composed e.g. from evaporating globules around the HII regions. They are best modeled through a clumpy PDR model. Gas components neither visible in [CII] nor in low-J CO may contribute to the total column in several points across the sources.

Deep integrations

The upGREAT/SOFIA [CII] observations of the two sources showed double-peak profiles in many positions. To verify that the two peaks trace the expansion velocity, independent of possible self-absorption, we performed follow-up deep integrations of [^{13}CII] as an optically thin tracer.

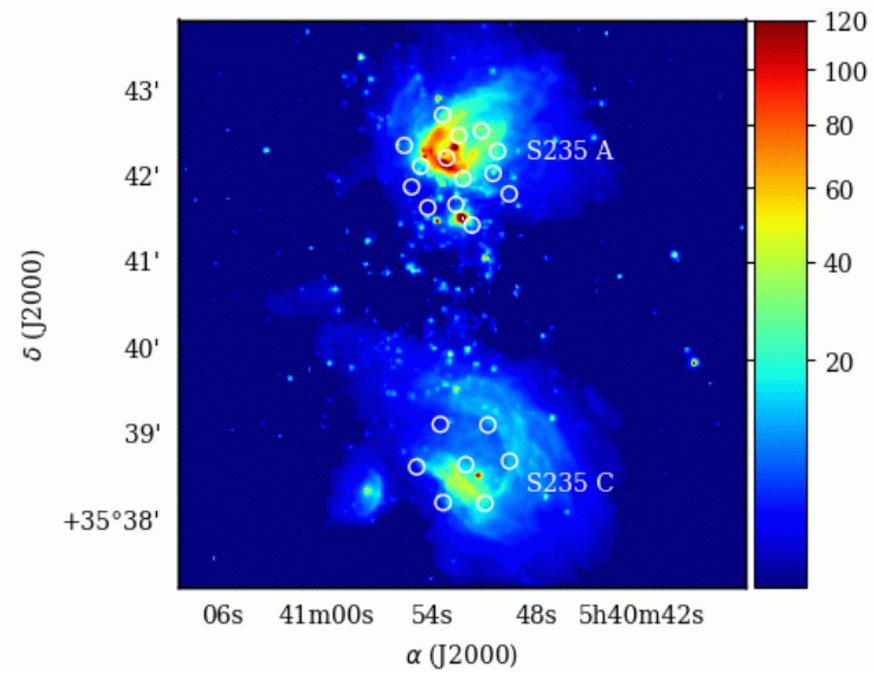


FIGURE 6: 3.6µm Spitzer image with the positions of [^{13}CII] deep integrations. The spatial pattern is governed by the upGREAT array structure.

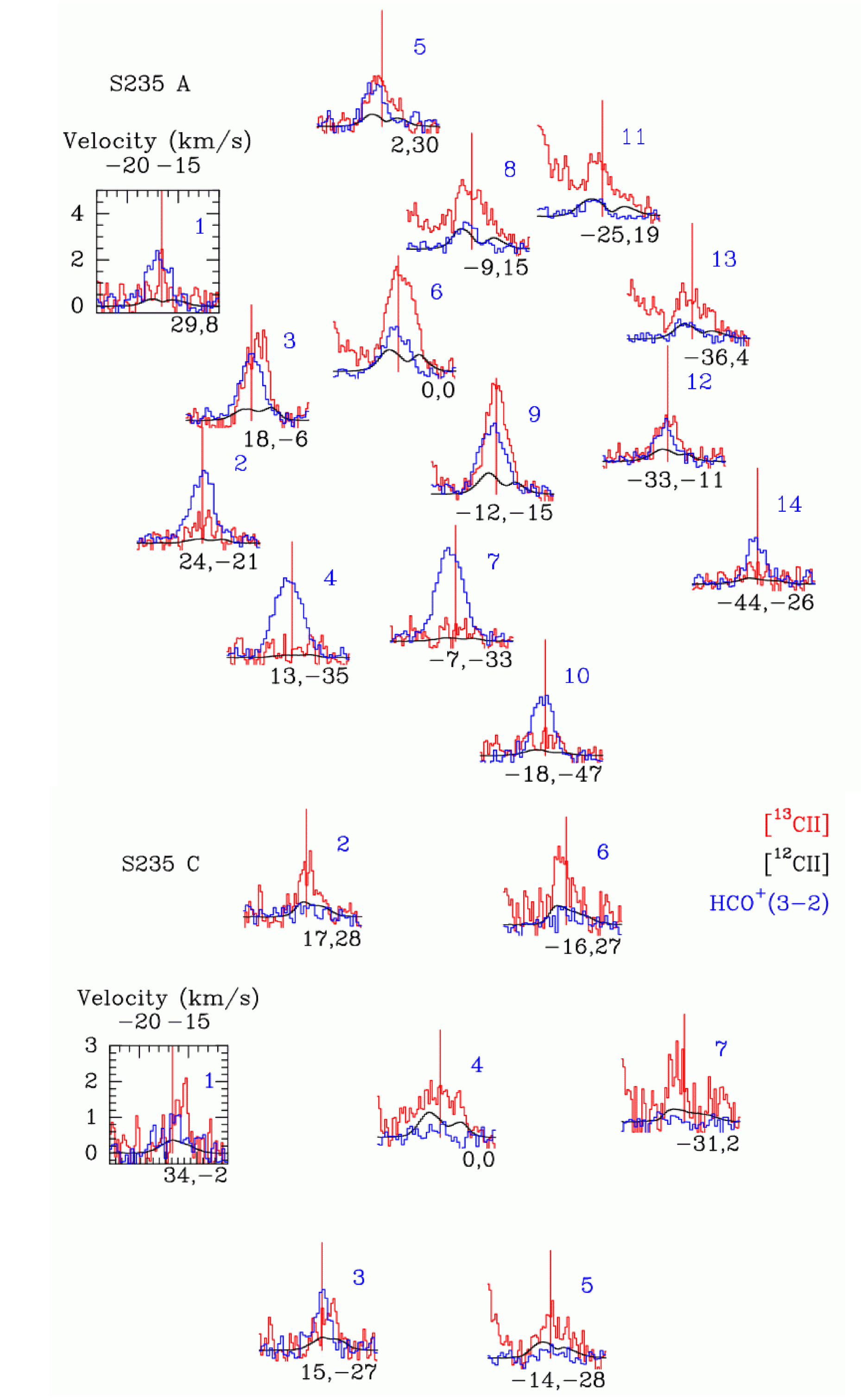


FIGURE 7: Comparison of spectra at the positions of the [^{13}CII] deep integrations. The [CII] spectra are scaled down by a factor 80 representing the abundance relative to [^{13}CII].

The [^{13}CII] observations prove that [CII] is heavily optically thick. The double-peak structure in [CII] is not reproduced in [^{13}CII] but stems from self-absorption.

We can use the line ratio of the two isotopes to measure the actual column density of C^+. Together with the molecular lines this allows to assess the carbon budget of the region.

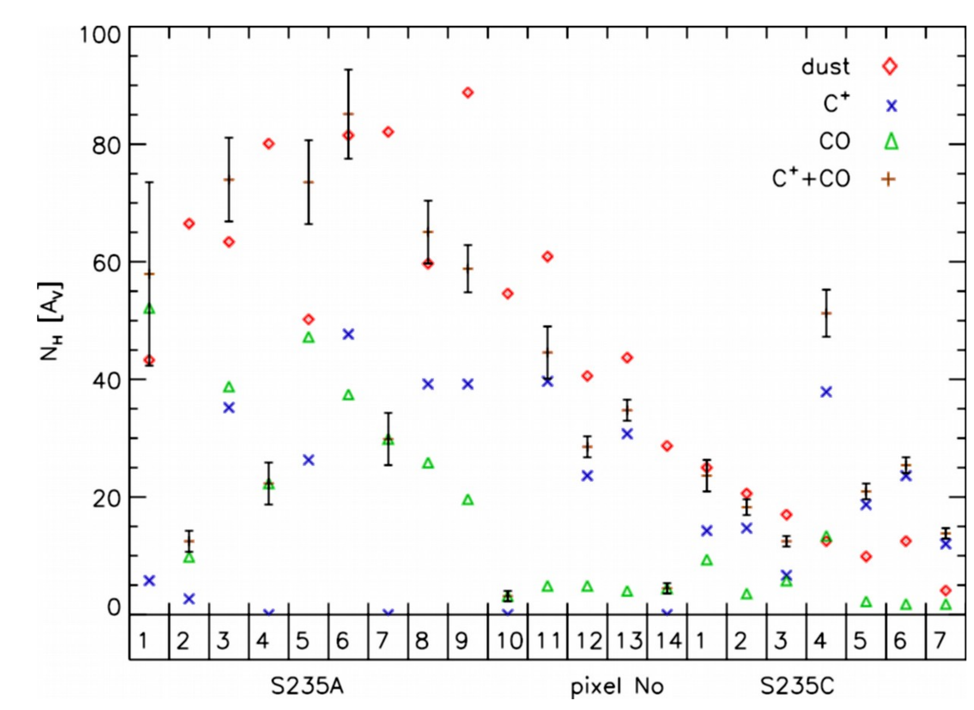


FIGURE 8: Comparison of the total column densities measured through the dust emission, molecular gas and C^+, assuming standard carbon abundances. The sum of carbon in molecular and ionized form roughly reproduces the total gas column. Mismatches are probably due to differences in the beams.

The C^+ columns correspond to visual extinctions of up to 40 magnitudes in contrast to our model and many other PDR models. In many lines of sight C^+ is the dominant C-bearing species.