Herschel Observations of the Shocked Gas in HH 54

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ABSTRACT

The star formation process is often revealed through the observations of molecular outflows. The ejection mechanism of these flows is most likely closely linked to the formation of protostellar disks. Swept up material from the parental cloud, excited in the interaction with the ambient medium, can be observed on parsec scale distances from the central source.

The Herbig-Haro object HH 54 is a shock that can be studied in detail using a very limited amount of *Herschel* time. It is located relatively nearby in the Chamaeleon II cloud, situated at a distance of 180 pc. The shocked region has an angular extent of roughly 30″ and is not contaminated with emission from other nearby objects. The nature of the central source has, however, been a matter of debate. Several IRAS point sources have in the past been suggested to be the driving source of the HH 54 flow. Here, we present spatially resolved observations of CO carried out with SPIRE and PACS onboard *Herschel*. The observations show a complicated picture and provide the possibility to measure the true CO abundance in a spatially resolved region.

1. INTRODUCTION

The HH 54 shock is located at the edge of the nearby Chamaeleon II cloud at a distance of roughly 180 pc (Whittet et al. 1997). The region contains several visible HH objects and the knots move at high velocities towards the observer. The molecular gas is detected at velocities up to $\sim -20\,\mathrm{km\,s^{-1}}$ with respect to the υ_{LSR} and it is noteworthy that only blue-shifted emission has been detected from the HH 54 flow. The red-shifted part of the outflow has for unknown reasons not been detected and the nature of the central source is also shrouded in mystery.

Over the years, several suggestions have been put forward regarding the location of the central source, e.g. the Class I sources IRAS 1500−7658 and IRAS 12553−7651 (Caratti o Garatti et al. 2009; Bjerkeli et al. 2011, respectively). The region has been fairly well studied, both with space-based and ground-based facilities. Recently, observations of pure rotational H_2 transitions (*Spitzer*), low-J CO transitions (SEST, *Odin*, APEX, and *Herschel*-HIFI) and the 557 GHz ground state transition of o-H_2O (*Herschel*-HIFI) were presented (Neufeld et al. 2006; Bjerkeli et al. 2011).

Here, we present spectroscopic observations of the region, covering the wavelength range 50 to 670 μm. The observations were carried out at a high spatial resolution, providing valuable information on the morphology, temperature and density distribution in the shocked region. Combined with previously published H_2 data, we also measure the true CO abundance in the region.

2. OBSERVATIONS AND RESULTS

Between July 1 and December 30, 2012, 5 hours of OT2 observing time were used to observe the CO ladder using the PACS and SPIRE instruments. The observations were centered on HH 54 B (Sandell et al. 1987). In Figure 1, the spectrum obtained with PACS and SPIRE towards HH 54 is presented. Detected H_2O, CO, OH and O[I] lines are marked in this figure.

3. TEMPERATURE, DENSITY AND THE ABUNDANCE OF CO WITH RESPECT TO H_2

The spectroscopic observations of CO transitions with PACS and SPIRE show a spatial displacement with increasing J. Figure 2 shows the position of the emission maximum for each of the CO transitions from CO(4–3) to CO(18–17). This likely reveals the temperature gradient along the post-shock gas and provides valuable information on the nature of the exciting source of the outflow. The displacement, in the northeast - southwest direction, could indicate that IRAS 1500-7658 is the driving source of the HH54 flow, which was also suggested by Caratti o Garatti et al. (2009). This source is located 20′ to the southwest from HH 54 at a projected distance of 1 pc. However, the apparent increase in temperature into the post-shock region is not easily reconcilable with that scenario.

The CO data were analysed in conjunction with the previously published H_2 data using the LTE approach. From this analysis it is clear that the H_2 emission trace a warmer gas component than the CO emission. Unlike results from previous studies of outflows, the higher J CO lines seem to trace gas of relatively low temperature. Only one single temperature (~ 200 K) component is needed to explain the CO observations. Consequently, the H_2 gas is significantly warmer and at

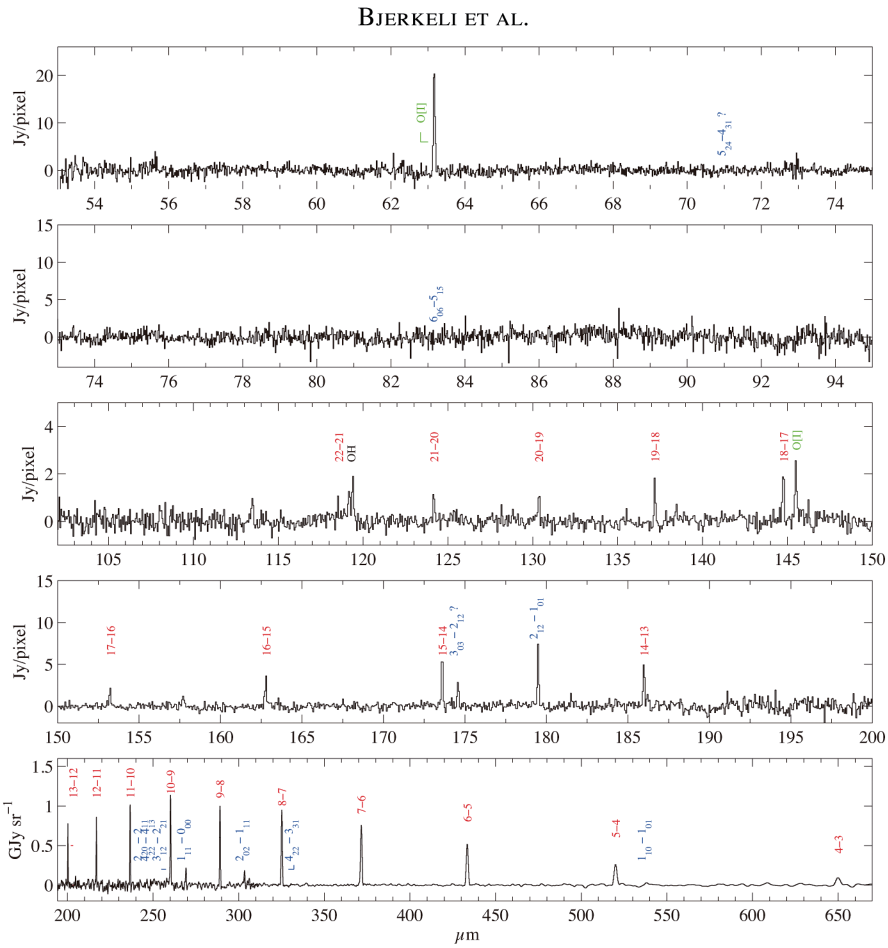

Figure 1. FIR spectrum obtained with PACS and SPIRE (lower panel) towards the position of HH 54 B. Detected CO, H_2O, OH and O[I] lines are marked with the colours red, blue, black and green, respectively.

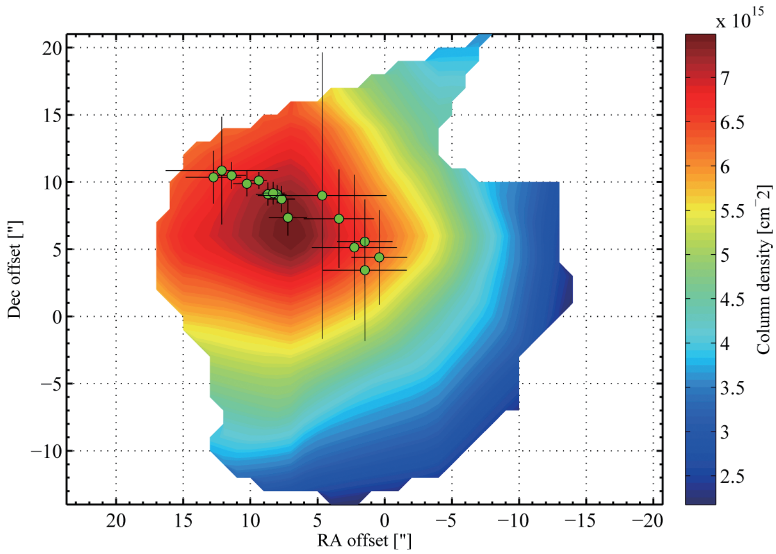

Figure 2. Colourmap show the CO column density in the observed region under the assumption of LTE. The green dots show the position of the emission maximum for each CO transition (from Gaussian fits). *J* is increasing from northeast to southwest. The error bars refer to the Gaussian fitting to each emission map. Offsets are with respect to HH 54 B.

least the higher excited lines do not seem to be of the same origin as the CO emitting gas. Like in the case of other outflow observations carried out with *Herschel*, most recent shock models do not easily explain the observations.

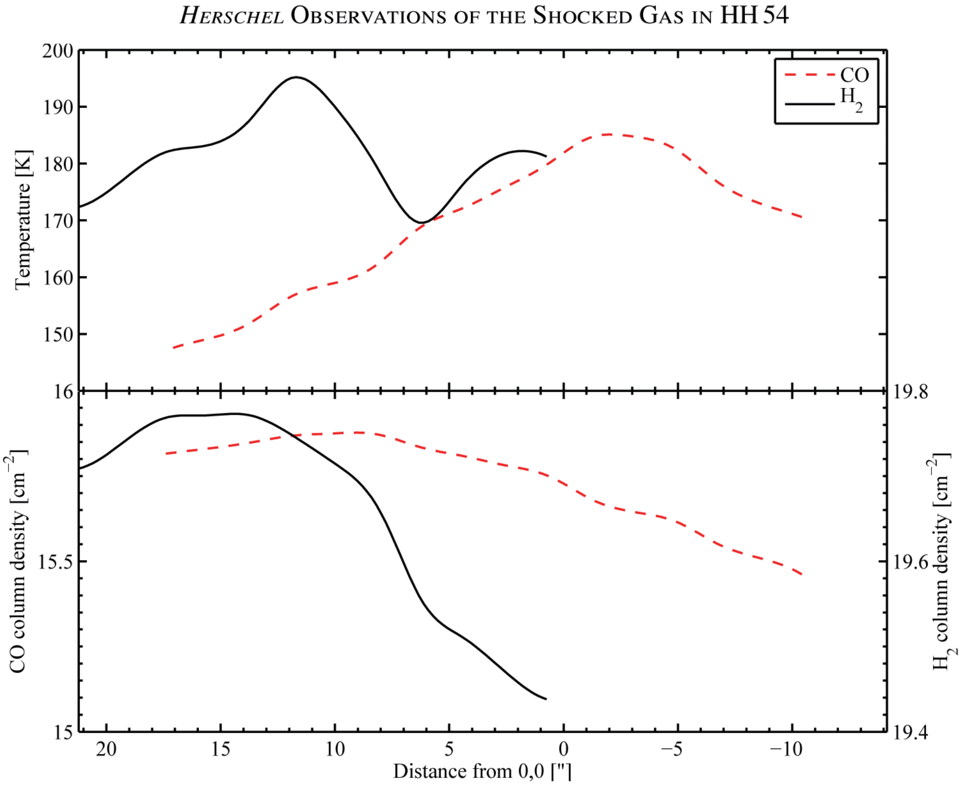

Figure 3. The upper panel show the temperature of H_2 (solid black line) and CO (dashed red line) versus offset from the position of HH 54 B in the northeast - southwest direction. The temperature of the CO emitting gas is increasing in the southwest direction. The lower panel show the column density of the two molecules with respect to offset.

Assuming that the ground state transitions of H_2 trace a colder gas component (suggested from H_2 rotation diagrams), we can obtain a rough estimate on the variation of the CO abundance in the region. The computed column densities are presented in Figure 3 along with the temperature distribution for the two species. Offsets in this figure are from the (0,0) position in the northeast to southwest direction. The abundance of CO with respect to H_2 varies between 1×10^{-4} and 2×10^{-4} from the northeast to the southwest.

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