THE INITIAL CONDITIONS AND TRIGGERS OF STAR FORMATION

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Context & motivation

We are interested in observing the early stages of star forming regions in order to probe the mechanisms which enable or disable star formation. In this context, we search for **imprints left in the gas** of both active and less active star-forming clouds. Characterising their physical properties and dynamics may help to unravel the mechanisms which allow or prevent star formation from taking place.

Here we show our study of (sub)millimetre molecular line data to look at the dynamics and physical properties of nearby star forming regions, with particular attention to the Serpens Main Cluster and the Pipe Nebula. Under the current era of large surveys, both in continuum and molecular lines, these studies can be extended to a number of star forming regions and help broaden our understanding of clustered star formation.

The Serpens Star forming region

Serpens is a low mass star forming region at 260pc from the Sun. It has undergone two distinct star forming episodes (Kaas et al. 2004, Harvey et al. 2006). The first, formed the older pre-main sequence stars now dispersed in the field. The later formed the young Class 0 and I sources in a compact 0.6pc long region (Fig.1).

From the continuum emission the two sub-clusters of Serpens do not seem to be hugely different. However, through molecular lines that we see a whole different story…

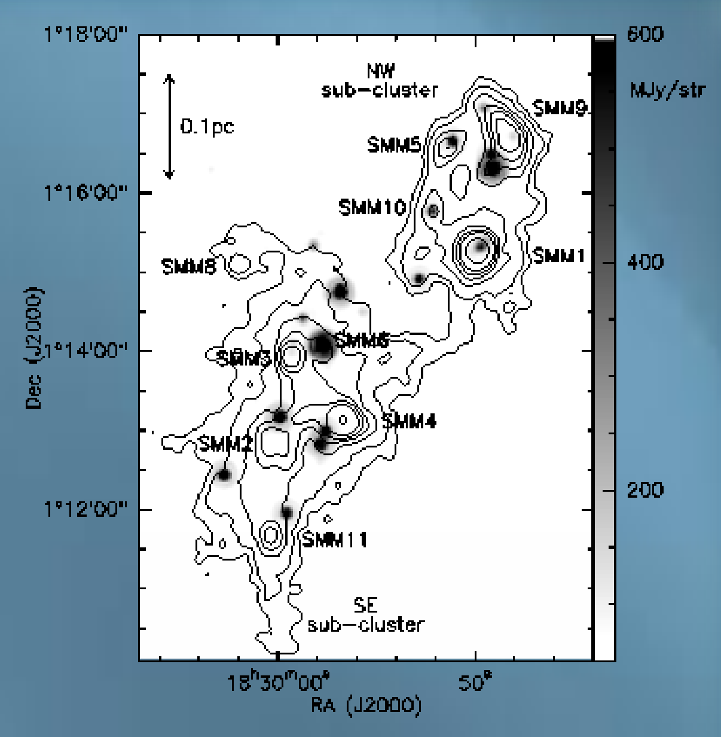


Fig. 1. Serpens with Spitzer/MIPS 24µm emission (grey scale), and JCMT/SCUBA 850µm emission (contours, Davis et al. 1999). All sources here are Class 0/I with only a few flat spectrum sources .

Dynamics

Previously interpreted as rotation , our velocity study of C^{18}O (Duarte-Cabral et al 2010) showed a complex structure towards the south: two clouds in the line of sight, overlapping along the filamentary structure of the SE sub-cluster (Fig. 4, 5 and 6).

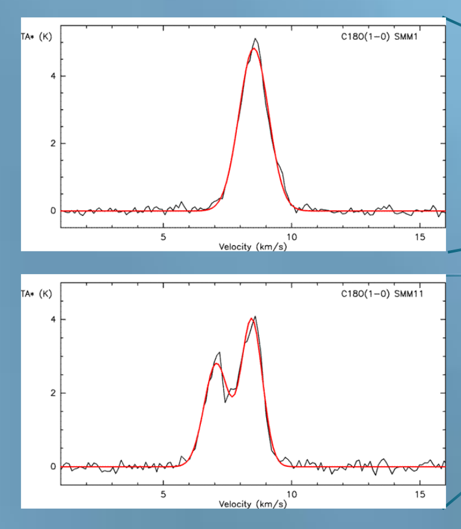


Fig 5 C^{18}O J=1-0 emission (IRAM 30m) in two positions: in SMM1 where the line has a single component and SMM11 where it presents a well defined double peak (Duarte-Cabral et al. 2010)

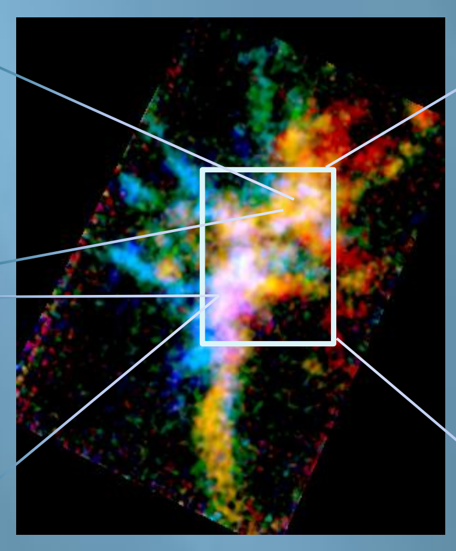


Fig. 4 C^{18}O (3-2) from JCMT Gould Belt Survey with HARP (Graves et al. 2010)
Blue: 5 – 7.7 km/s
Green: 7.7 – 8.3 km/s
Red: 8.3 – 11 km/s

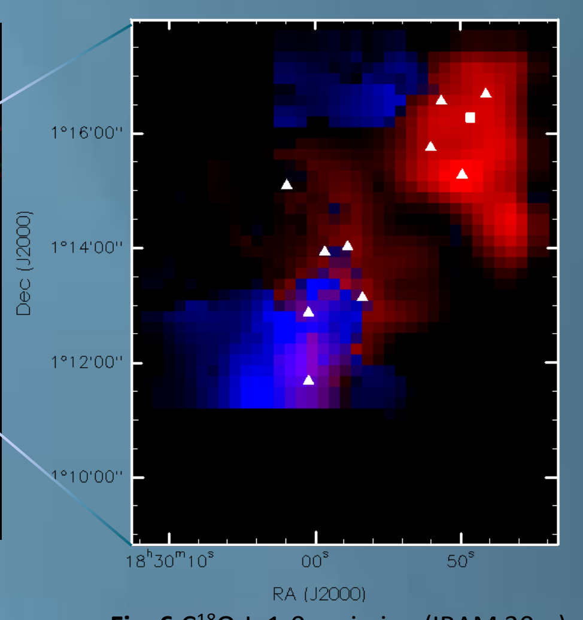


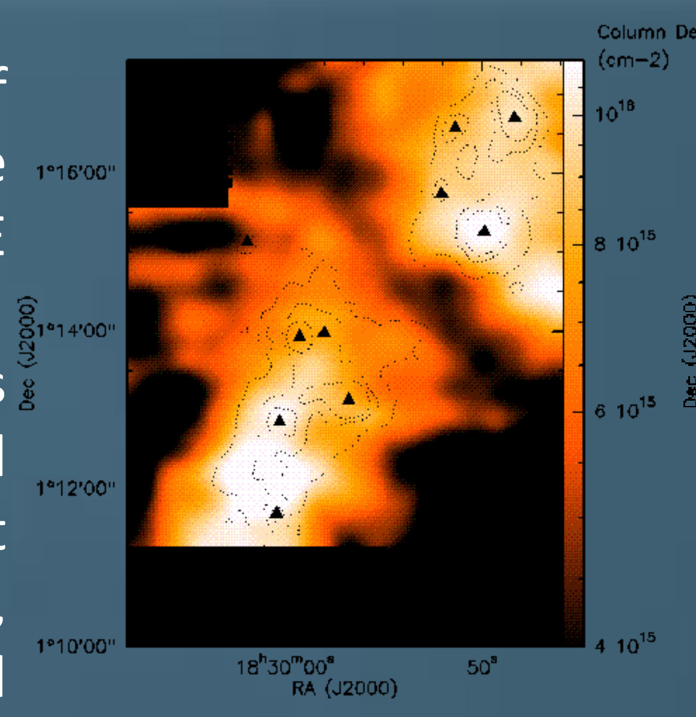
Fig. 6 C^{18}O J=1-0 emission (IRAM 30m) after splitting the line emission from each cloud. Red (and blue) represents the integrated intensity of the high (and low) velocity cloud (Duarte-Cabral et al. 2010)

An interaction between such clouds could explain the temperature rise and complex column density structure found. It could ultimately trace back to the trigger of star formation in Serpens.

Physical properties

Using three transitions of C^{18}O, we find a much more complex structure in the SE sub-cluster than in the NW.

The NW column densities and temperatures are well behaved and follow the dust emission. However, in the SE, the column density and temperature peaks appear between the submillimetre sources.



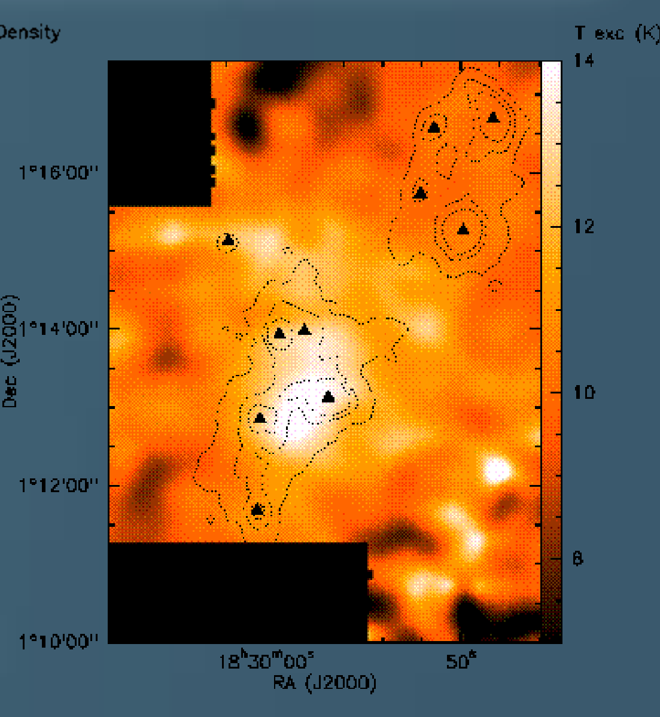


Fig. 3 LTE Column density map of Serpens **Fig. 4** LTE Excitation Temperature map of Serpens
These maps were built using a rotational diagram method on C^{18}O (1-0), (2-1) and (3-2) transitions (Duarte-Cabral et al. 2010). The (1-0) and (2-1) were observed with IRAM 30m and the (3-2) is from the HARP JCMT Gould Belt Survey. The contours are the SCUBA 850 µm emission, and triangle are the submillimetre sources.

Proposed Scenario and tests with SPH simulations

We propose a scenario where the most recent burst of star formation in Serpens results from the collision of two flows/clouds. We tested this hypothesis with SPH simulations of cloud-cloud collision and have been able to reproduce the mass, size and velocity structure of the SE sub-cluster (Duarte-Cabral et al. submitted).

The simulations showed that a second structure as the NW must have been only indirectly affected by the collision, with perturbations from the direct collision speeding up its collapse (Fig. 7).

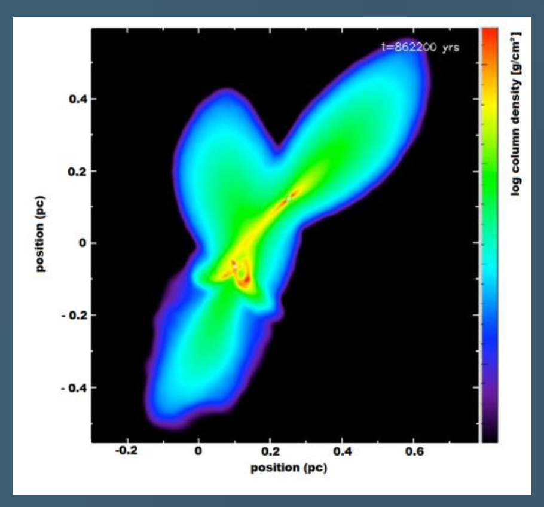


Fig. 7 SPH Simulation with two 1.5pc long cylinders, (one tilted and one vertical) colliding along the line of sight and forming a southern clump directly from the collision, and another in the north whose collapse was only speed-up by the southern collision (Duarte-Cabral et al. submitted).

The Pipe Nebula

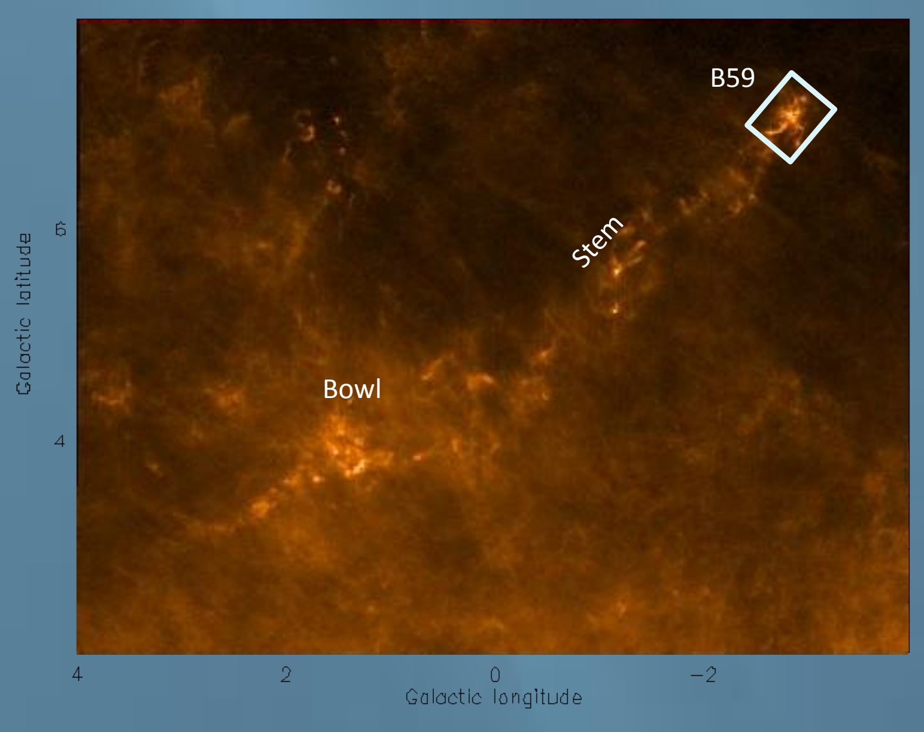


Fig. 8 Extinction Map of the Pipe Nebula, courtesy of Marco Lombardi, João Alves and Charlie Lada.

The Pipe Nebula, is a 6 degree long cloud, with no star formation found this far except on the B59 region (Fig. 8). The several extinction cores in the Stem and Bowl of the Pipe appear to be inert. With such a range of conditions within a same cloud, the Pipe Nebula becomes a perfect laboratory to understand the conditions that allow or prevent star formation.

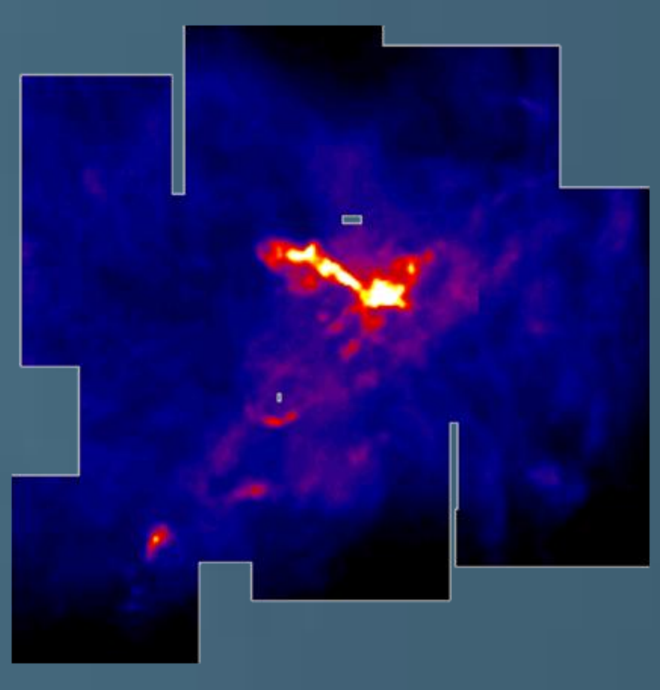


Fig. 10 JCMT HARP ^{12}CO J=3-2 integrated emission in B59, from 1.5 to 4.5 km/s (taken with Antonio Chrysostomou DDT time)

As part of a larger study of the Pipe Nebula, we have mapped B59 with ^{12}CO, ^{13}CO and C^{18}O (3-2) at JCMT. What we found, was that, unlike Serpens, this regions seems to be under extreme influence from its outflows (Fig. 9 and 10). The shape of the dense material, both seen in extinction and in C^{18}O is in close relation to the outflow bows and shocks, making the underlying dense structure hard to unravel. The conditions of the cores in B59 is of extreme importance for comparison with the remaining cores in the Pipe.

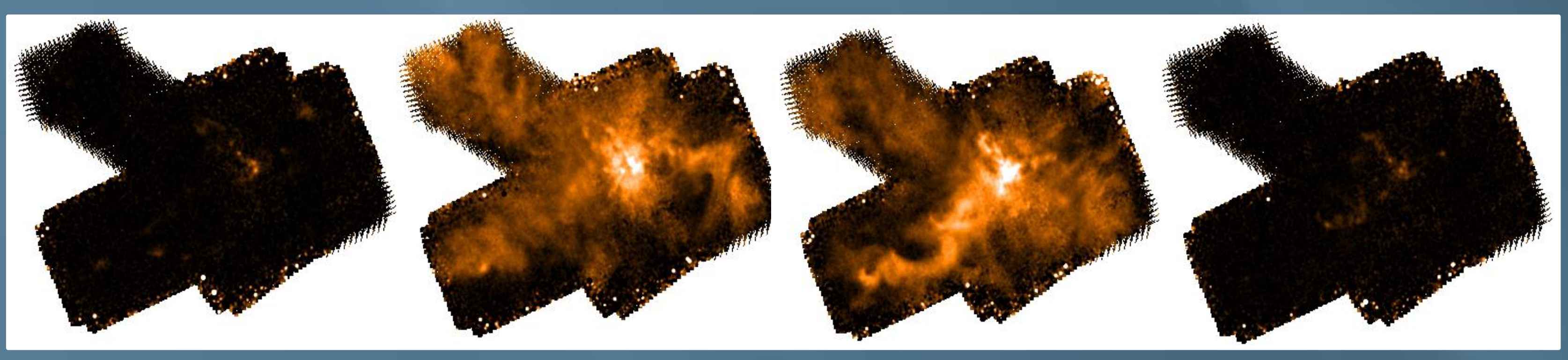


Fig. 9 JCMT HARP ^{13}CO J=3-2 emission in B59, from 1.5 to 4.5 km/s (Duarte-Cabral et al. in prep)

Acknowledgments

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