STAR FORMATION AROUND THE BIPOLAR NEBULA SH2-201
A HERSCHEL VIEW

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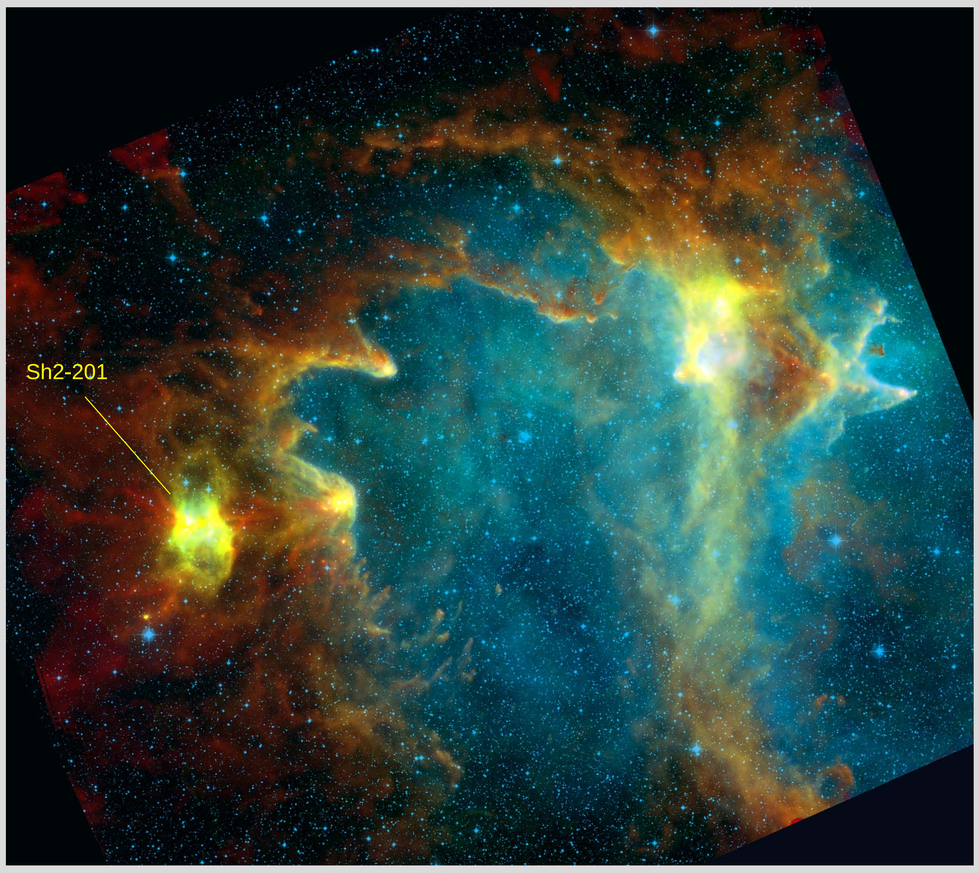

Figure 1: Composite colour image of the W5-E field observed by *Herschel*. Red is the 250 μm *Herschel*-SPIRE data, which traces cold dust emission, green is the 100 μm *Herschel*-PACS data, which traces emission mainly from dust at higher temperature located in the PDRs, and blue is the DSS2-red survey, which traces the Hα emission of the ionized gas.

Introduction

The W5-E HII region has been mapped by *Herschel* - PACS at 100 μm and 160 μm, and by *Herschel* - SPIRE at 250 μm, 350 μm, and 500 μm. These *Herschel* observations are part of the HOBYS key program (Motte et al. 2010) and of the "Evolution of Interstellar Dust" key program (Abergel et al. 2010).

W5-E is an optical Galactic HII region situated in the Perseus arm, at a distance of about 2 kpc. It is a well studied HII region. A view of W5-E is given in Fig. 1. **As an illustration of the results obtained on star formation in this region, we present here the case of the Sh2-201 HII region.**

Presentation of the Sh2-201 HII region

Sh2-201 is a small optical HII region, part the W5 complex. It coincides with the IRAS source IRAS 02593+6016, of luminosity ~11000 $L_\odot$. Sh2-201 is excited by a O9 star (Ojha et al. 2004).
The radio and Hα emissions have a similar morphology and angular extent. The brightest emission comes from the dense ionized layer boundering a molecular condensation (Felli et al. 1987).
The bipolar morphology of Sh2-201 is especially conspicuous in the *Spitzer-IRAC* image at 8 μm (Fig.2 and Koenig et al. 2008). This emission comes mostly from the PAHs located in the photo-dissociation regions surrounding the ionized gas.

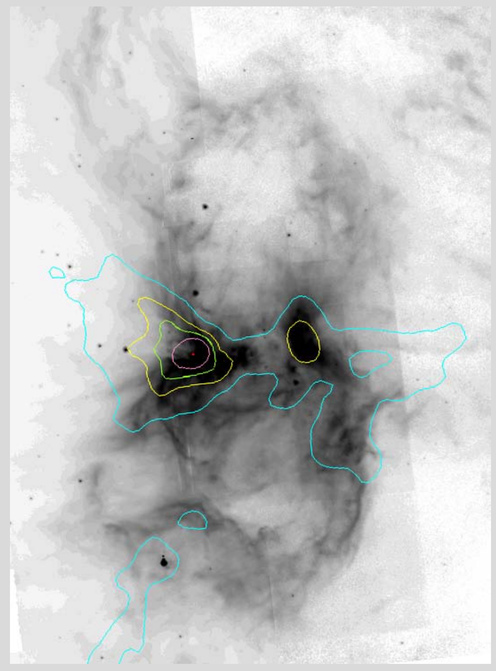

Figure 2: *Spitzer* 8 μm image revealing the bipolarity of Sh2-201. The column density contours (same as in Fig. 3) show the two condensations present at the waist of Sh2-201.

The large scale structure of the region

Fig.3 shows the large scale morphology of Sh2-201:
- **Red** is the emission at 500 μm, that of the cold dust; it indicates the location of the dense molecular material present in this region. Of particular interest is the east-west filament extending over more than 20 pc, from the east of Sh2-201 to the bright rimmed cloud BRC14; this filament is part of the W5 complex. Along this filament are the two condensations which have the highest column density of the whole W5-E field; one is located at the east waist of Sh2-201 ($N(H_2)$~$6x10^{22}cm^{-2}$), the other is enclosed by BRC14 ($N(H_2)$~$1.1x10^{23}cm^{-2}$). The dust temperature map shows that the filament and the condensations are cold, with T_{dust}<20 K.
- **Green** is the emission at 100 μm, that of hotter dust located in the photo-dissociation regions (PDRs) surrounding the ionized ones. The bipolar morphology of Sh2-201 is conspicious at 100 μm, with a very bright 100 μm emission at its waist, and fainter emission surrounding its two ionized lobes.
- **Blue** is the *Spitzer* emission at 24 μm, from even hotter dust located in the PDRs, in zones adjacent to the ionized gas, and also inside the ionized regions. This emission is seen in the center of W5-E and at the waist of Sh2-201.

YSOs appear as point sources at 24 μm and 100 μm.

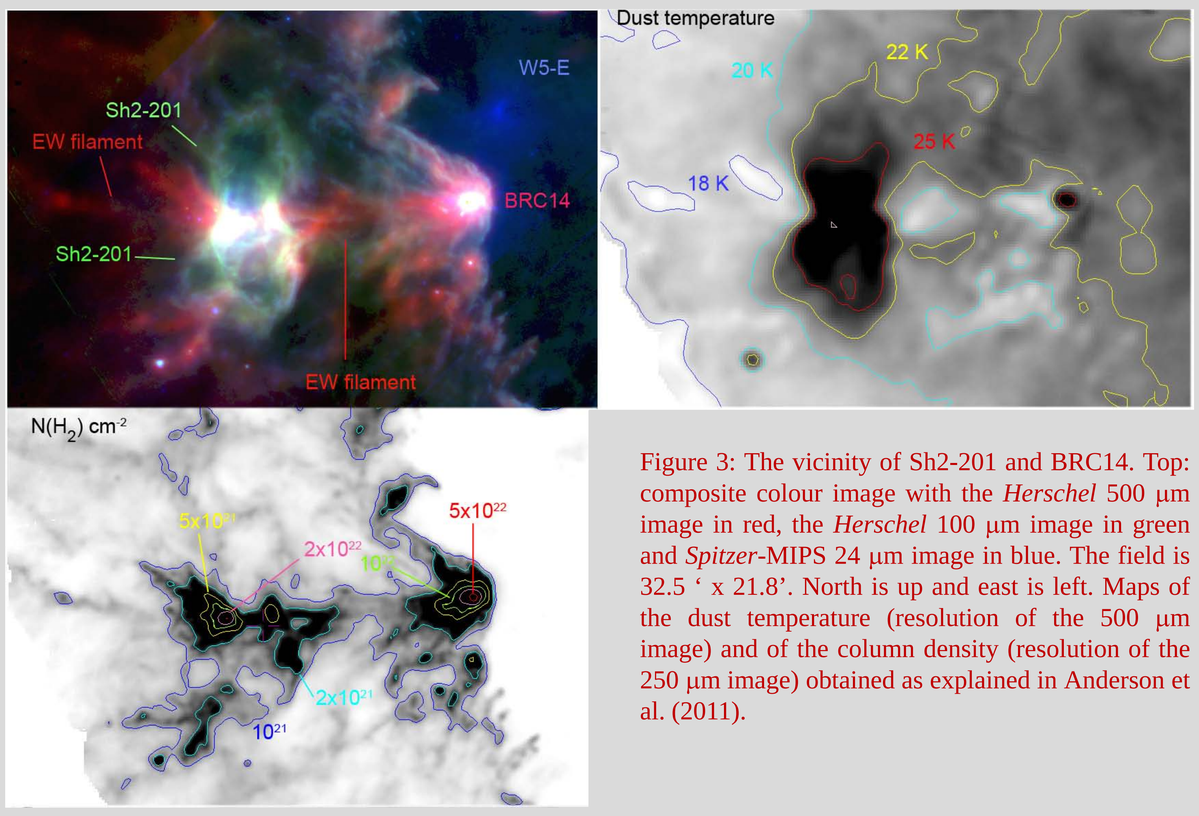

Figure 3: The vicinity of Sh2-201 and BRC14. Top: composite colour image with the *Herschel* 500 μm image in red, the *Herschel* 100 μm image in green and *Spitzer*-MIPS 24 μm image in blue. The field is 32.5 ' x 21.8'. North is up and east is left. Maps of the dust temperature (resolution of the 500 μm image) and of the column density (resolution of the 250 μm image) obtained as explained in Anderson et al. (2011).

Star formation around Sh2-201

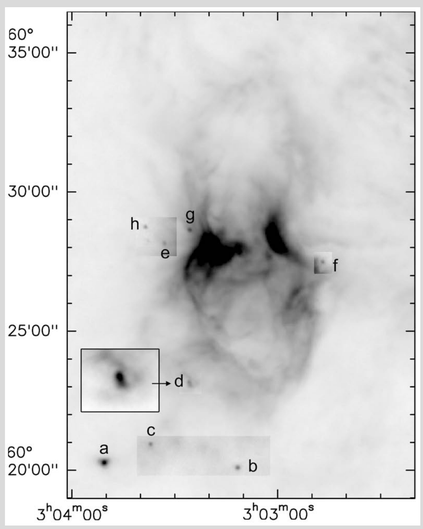

Figure 4: Young stellar objects detected as 100 μm point-sources in the vicinity of Sh2~201. They are identified on the *Herschel* 100 μm image.

All the 100 μm point-sources (Fig.4) have been measured *at Herschel* wavelengths, using DAOPHOT. Their 2MASS and *Spitzer* counterparts, if any, have been found in the Koenig et al. (2008) catalogue of YSOs. Their spectral energy distributions have been fitted using the SED fitting-tool of Robitaille et al. (2007). The parameters of the central objects and their evolutionary stages have been obtained. The temperatures and masses of their envelopes have been estimated using the *Herschel* fluxes and a model of modified blackbody.

- The bright **YSO a** is a stage I source. However it is probably not associated with Sh2-201 as it is at the origin of a CO outflow located in the far back-ground of the W5 complex (Ginsburg et al. 2011) .
- **YSO b and c** are stage I sources of rather low mass (<1.5) $M_\odot$
- **YSO d** is a stage II source (with no accreting envelope)
- The SED of **YSO e** is not well constrained
- **YSO f, g, h** are possibly Class 0 sources as they have no (or very faint for YSOf) emission at 24 μm or below. YSO g is especially interesting as it one of the most massive of the W5-E field (envelope of 50 $M_\odot$). It is associated with a CO outflow. Furthermore it is observed in the direction of the filaments bordering the massive condensation east of Sh2-201; this makes it a good candidate for triggered star formation by the HII region.
- Two other very bright 100 μm point-sources, **s1 and s2**, have been detected by *Herschel* at the east waist of Sh2-201 (Fig.5). They are located at the border of the massive condensation, in the 100 μm filaments adjacent to the ionized region. An H_2O maser (Blair et al. 1980) and a CO outflow (Ginsburg et al. 2011) are observed in their direction. S1 and s2 are good candidates Class 0 sources.

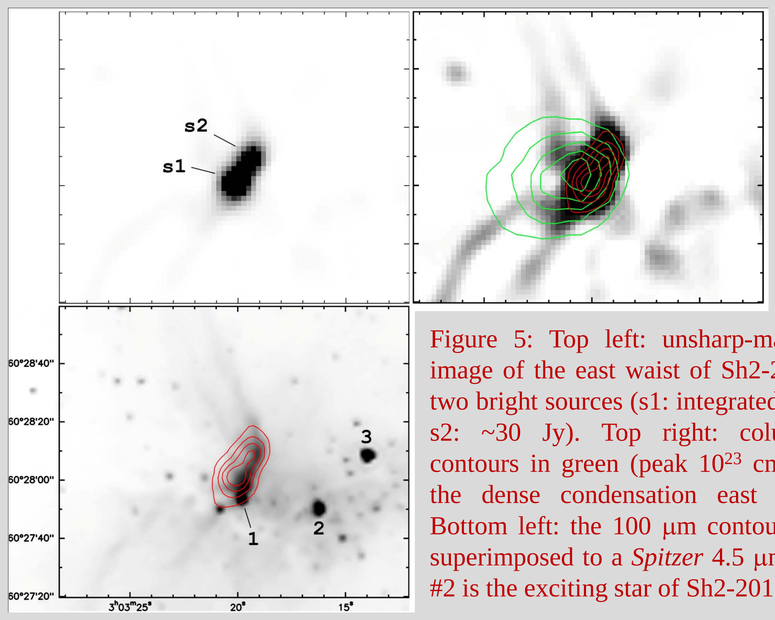

Figure 5: Top left: unsharp-mask 100 μm image of the east waist of Sh2-201, showing two bright sources (s1: integrated flux ~80 Jy; s2: ~30 Jy). Top right: column density contours in green (peak 10^{23} cm^{-2}), showing the dense condensation east of Sh2-201. Bottom left: the 100 μm contours in red are superimposed to a *Spitzer* 4.5 μm image; star #2 is the exciting star of Sh2-201.

Conclusions

The observations suggest the following scenario for the history of star formation in this region.The exciting star of Sh2-201 formed in a dense east-west filament. During the expansion of the HII region the ionization front reached the low density regions bordering the filament. Then, the ionized gas expanded away from the dense regions, in two opposite directions perpendicular to the filament. This explains the presently observed bipolar morphology of Sh2-201. During the expansion of Sh2-201, neutral material was collected around the ionized region.This collected material surrounds the two ionized lobes; the emission of its associated dust is observed at all *Herschel* wavelengths. No star formation is detected in these directions (low column density ~10^{21} cm^{-2}). More material has been collected along the dense filament, forming two massive condensations at the waist of the nebula (column density >$5x10^{21}$ cm^{-2} in the east condensation). YSOs are observed there, Class I and Class 0 sources.; some of them may become massive stars. They are situated close to the ionized region, in the direction of the bright 100 μm filaments adjacent to the ionized gas. Their formation has most probably been triggered by the expanding HII region. The process responsible for the triggering is not clearly identified.

References

Abergel, A., Arab, H., Compiegne, M. et al. 2010, A&A, 518, L96; **Anderson**, L.D., Zavagno, A., Deharveng, L. et al. 2011, submitted to A&A; **Blair**, G.N., St Clair Dinger, A., Dickinson, D.F. 1980, AJ, 85, 161; **Felli,** M., Hjellming, R.M., Cesaroni, R. 1987, A&A, 182, 313; **Ginsburg**, A., Bally, J., Williams, J.P. 2011, submitted to MNRAS; **Koenig**, X.P., Allen, L.E., Gutermuth, R.A. et al. 2008, ApJ, 688, 1142; **Ojha**, D.K., Ghosh, S.K., Kulkarni, V.K. et al. 2004, A&A, 415, 1039; **Motte**, F., Zavagno, A., Bontemps, S. et al. 2010, A&A, 518, L77; **Robitaille**, T.P., Whitney, B.A., Indebetouw, R., Wood, K. 2007, ApJS, 169, 328;