

# Protostellar clusters in the Rosette Molecular Cloud

M. Hennemann<sup>1</sup>, F. Motte<sup>1</sup>, S. Bontemps<sup>1,2</sup>, N. Schneider<sup>1</sup>, T. Csengeri<sup>1</sup>, Z. Balog<sup>3</sup>, Ph. André<sup>1</sup>, J. Di Francesco<sup>4</sup>, A. Zavagno<sup>5</sup>

for the **HOBYS**\* consortium and the **SPIRE** Specialist Astronomy Group **Star formation in the Galaxy**



<sup>1</sup> Laboratoire AIM, CEA/IRFU – CNRS/INSU – Université Paris Diderot, CEA-Saclay, France, email: martin.hennemann@cea.fr  
<sup>2</sup> Laboratoire d'Astrophysique de Bordeaux, CNRS/INSU – Université de Bordeaux, France  
<sup>3</sup> Max-Planck-Institut für Astronomie, Heidelberg, Germany  
<sup>4</sup> National Research Council of Canada, Herzberg Institute of Astrophysics – University of Victoria, Department of Physics and Astronomy, Victoria, Canada  
<sup>5</sup> Laboratoire d'Astrophysique de Marseille, CNRS/INSU – Université de Provence, France

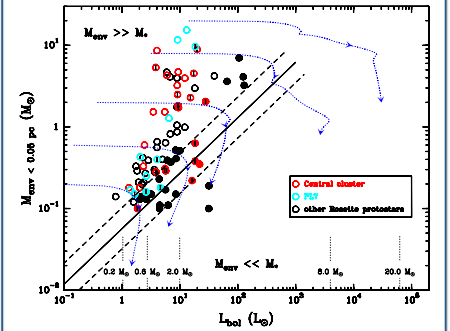


\* <http://hobys-herschel.cea.fr>

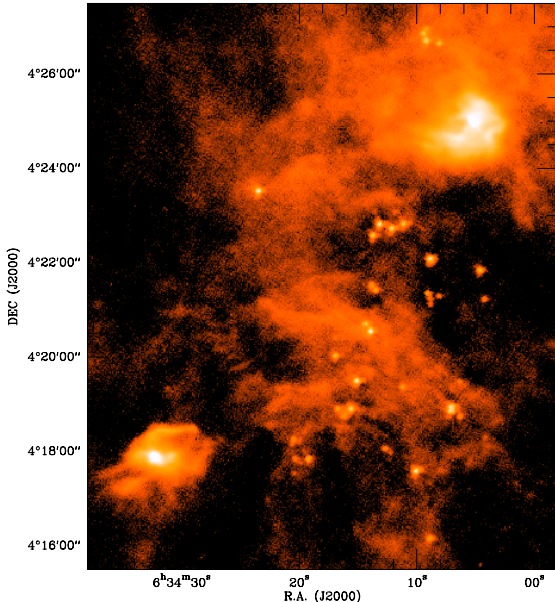
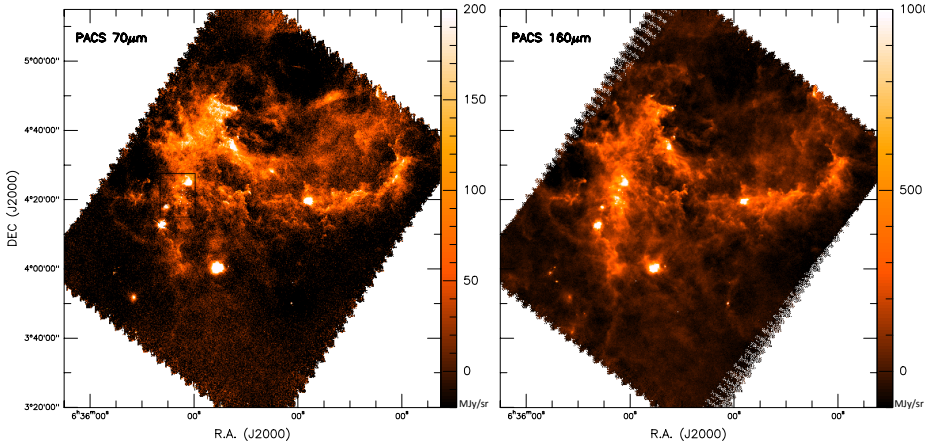
The *Herschel* OB young stellar objects survey (HOBYS, Motte, Zavagno, Bontemps et al.) has observed the Rosette molecular cloud providing an unprecedented view of its star formation activity. These new far-infrared data reveal a population of compact young stellar objects whose physical properties we aim to characterise. We compile a sample of protostars and constrain key properties in the protostellar evolution: Bolometric luminosity  $L_{bol}$  and envelope mass  $M_{env}$ . The  $M_{env}$  of the analysed protostellar population in Rosette ranges from **0.1 to about 15  $M_{\odot}$  with  $L_{bol}$  between 1 and 150  $L_{\odot}$**  which extends the evolutionary diagram from low-mass protostars into the high-mass regime. Some sources lack counterparts at near- to mid-infrared wavelengths indicating extreme youth. The central

cluster and the *Phelps & Lada 7* cluster appear less evolved than the remainder of the population. We find indication that **about 25% of the protostars in the central cluster classified as Class I from near- to mid-infrared data are actually candidate Class 0 objects**. As a showcase for protostellar evolution, we analyse four protostars of low- to intermediate-mass in a single dense core which represent different evolutionary stages from Class 0 to Class I. Their mid- to far-infrared spectral slopes flatten towards the Class I stage, and the 160 to 70 $\mu$ m flux ratio is largest for the presumed Class 0 source. This exemplifies that the *Herschel* observations characterise the earliest stages of protostellar evolution in detail.

## Evolutionary stage of *Herschel* protostars in Rosette



The envelope masses and bolometric luminosities are plotted in an evolutionary diagram shown above. Evolutionary tracks are displayed for stellar masses between 0.2 and 20  $M_{\odot}$ . The diagonal lines indicate an approximate border zone between envelope-dominated Class 0 and star-dominated Class I objects based on the comparison of  $M_{env}$  to  $M_{*}$  (André & Montmerle 1994). A surprisingly large fraction of our sample ( $\approx 1/3$ ) falls into the candidate Class 0 regime above these lines. A practical criterion inferred from this diagram is  $L_{smm}/L_{bol} > 1\%$  for Class 0 (open plot symbols). The classification of objects lying near the border zone remains tentative. Nevertheless, it indicates that *Herschel* allows us to significantly extend the sample of known Class 0 objects. Both the central cluster and the PL7 cluster (Phelps & Lada 1997) appear younger compared to the remaining protostars.



PACS 70 $\mu$ m map of the Rosette molecular cloud centre. The region harbours the embedded clusters PL4 (north-west), PL5 (south-east), and a concentration of compact *Herschel* sources.

## Classification of protostars in the Rosette central cluster<sup>1</sup>

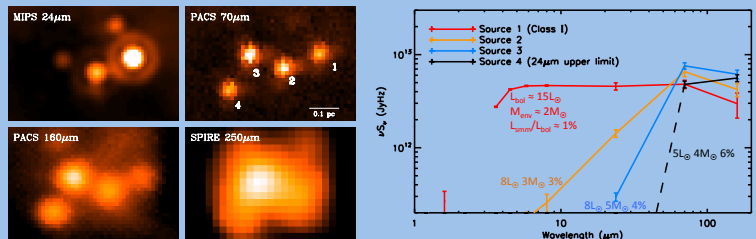
NIR/MIR classification	# total	# Class II	# Class I	# unclassified
<i>Spitzer</i> 24 $\mu$ m sources	83	39	26	18
Visible at 70 $\mu$ m	40 ( $\pm 3$ )	10 ( $\pm 1$ )	19 ( $\pm 1$ )	11 ( $\pm 1$ )
In analysed <i>Herschel</i> sample	22	1	12	9
Candidate Class 0: $L_{smm}/L_{bol} > 1\%$	14	0	7	7

<sup>1</sup> Cluster area:  $98.5^{\circ} < \text{R.A.} < 98.6^{\circ}$ ,  $4.25^{\circ} < \text{DEC} < 4.4^{\circ}$

Visual inspection gives a 70  $\mu$ m detection rate of about 50% for YSOs seen at 24 $\mu$ m. We expect more 70 $\mu$ m detections for Class I than for Class II, we find about  $\frac{1}{3}$  compared to about  $\frac{1}{4}$ . Roughly, we include about half of the visible 70 $\mu$ m sources in the analysed *Herschel* sample. About  $\frac{1}{3}$  of these are Class 0 candidates. This applies to 7 out of 18 unclassified sources which indicates that many of the latter could be Class 0 protostars. **About 25% of 26 previously classified Class I sources are also Class 0 candidates, possibly more.**

## *Herschel* resolves the early protostellar evolution

A particularly interesting large dense core is resolved into several protostars at 70/160 $\mu$ m. Four sources are clearly detected at 70 $\mu$ m (sources 1 to 4 from west to east). Based on the *Spitzer* data, source 1 is classified as Class I, the others remain unclassified due to non-detection in one or more of the IRAC bands (source 2 and 3) or non-detection in all near- to mid-infrared bands (source 4).



The SED slopes between 8 and 70 $\mu$ m for sources 1, 2, and 3 become increasingly steep. Beyond 70 $\mu$ m they are more shallow, and the 160 to 70 $\mu$ m flux ratio is the highest for source 4. Due to the assumption of a single dust temperature, the relative mass differences are not well constrained. Similar in mass, the sources represent successive evolutionary stages from early Class 0 (source 4) to "flat-spectrum" Class I (source 1).

## References

- André & Montmerle, 1994, *ApJ*, 420, 837
- Phelps & Lada, 1997, *ApJ*, 477, 176

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