FINAL REPORT – N. HUELAMO

1 Purpose of the visit to Palermo Observatory (host: B. Stelzer)

Lambda Orionis (LOri) is a very young (1-5 Myr) star forming region at a distance of ∼400 pc. It contains a central cluster of 5 Myr, Collinder 69 (Coll 69, hereafter), and younger stellar clusters located in the LOri rim at ∼5 degrees radius (e.g. B30, B35, see Figure 1)). The LOri region is included in the GAIA-ESO spectroscopic survey (GES), which is a preparatory work for the GAIA mission.

As part of our study, we have collected X-ray data (with the XMM-Newton telescope) of B30, B35, and several regions between Coll 69 and B30 (what we called 'the bridge'). The goal of these observations is twofold: first, we want to identify the population of young low-mass stars within the clusters and to derive its properties. Second, we want to study the radial distribution of young stellar sources from the center to the rim to understand the origin of the region: while a continuous number of sources would be consistent with a supernova explosion (suggested by Dolan & Mathieu 2002), a clear discontinuity would point towards cloud fragmentation as the most probable formation scenario.

The **purpose of my visit** to Palermo was to reduce and analyze the X-ray data of two XMM pointings obtained in 2009 between the clusters Coll 69 and B30 and, if possible, optical data of the same two regions obtained in 2010 at the Isaac Newton Telescope (INT).

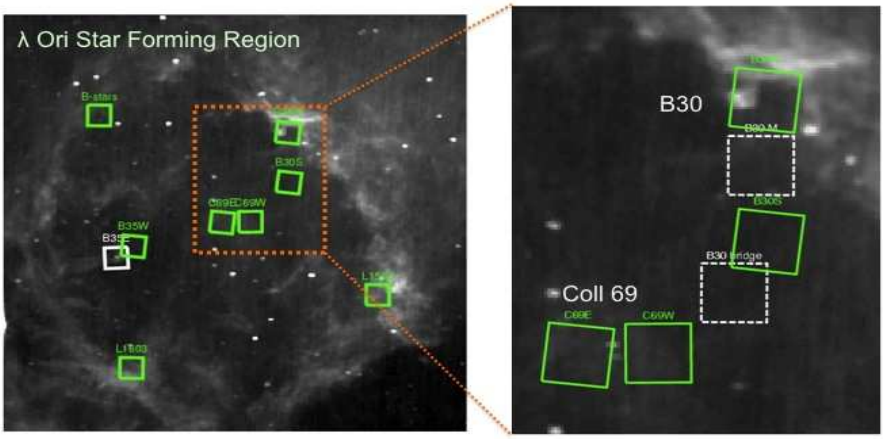

Figure 1: *Left panel*: IRAS far-infrared image of the LOSFR. We have overplotted the *XMM-Newton* observations (solid boxes) obtained by us or found in the archive. The analysis of the Coll 69 cluster (center) is completed and published in Barrado et al. (2011). *Right panel*: Zoomed region between B30 and Coll 69. The dashed boxes show the *XMM-Newton* pointings analyzed during the stay in Palermo.

2 Description of the work and preliminary results

2.1 X-ray data reduction and analysis

During my one week visit to the Palermo Observatory, I have been working with Dr. Beate Stelzer on the X-ray data reduction and analysis of two pointings within the LOri region. In

particular, we have analyzed two XMM-pointings located between the young clusters Coll 69 and B 30 (see Figure 1): B30_M and B30_bridge. The reduced images are displayed in Figure 2, where we have also included two older pointings obtained by our group that complement our data. As a result the XMM campaigns, we have obtained a full coverage of the X-ray emission in a field of ~ 1 deg ^{2} (see Figure 2).

In all four observations the prime instrument was the European Photon Imaging Camera (EPIC) ,that consists of three cameras, two EPIC-MOS detectors and one EPIC-pn detector. All data sets were analyzed with the *XMM-Newton* Science Analysis System (SAS) pipeline. The data reduction of the *XMM-Newton* observations was performed exactly in the same way as our previous study of Coll 69. For a detailed description we refer to Barrado et al. (2011). Here we summarize the basic steps.

B30 M and B30_bridge were observed with XMM on September 2009. They were affected to some point by high radiation background. We have filtered the EPIC events files of each observation and each of the three instruments (PN, MOS 1 and MOS 2) for time intervals of high background obtaining 'effective' exposure times. For some of the pointings this useful part of the exposure corresponds to only about half of the observation duration. With further data filtering steps we removed pixel pattern, events on chip boundaries, near bad pixels or outside the field-of-view.

Images with a pixel size of $5''$ were binned from the cleaned events list. We performed source detection on the images in four energy bands using standard SAS tools. For consistency with our previous study of Coll 69, the energy bands soft (S), medium (M), hard (H) and broad (B) were defined as follows: $S = 0.5 - 1.0$ keV, $M = 1.0 - 2.0$ keV, $H = 2.0 - 7.3$ keV, and $B = S + M + H$. Again following our previous approach, we performed source detected in two steps. First, all EPIC instruments were analyzed separately. From these results the relative sensitivity of the detectors ($C_{\rm pn}/C_{\rm MOS}$) was computed for each energy band as described by Barrado et al. (2011), and the exposure maps of EPIC/pn were scaled accordingly.

Our final X-ray catalog contains all sources detected in the merged data ('EPIC sources') for a detection threshold of $ML \geq 15$. We have detected 75 sources in the B30 M field, and 70 sources in B30_bridge. Most of these sources were from the merged EPIC (PN + MOS 1 + MOS 2) data set. We have added a few sources detected only in an individual detector, e.g. because the X-ray source is located outside the FOV, near a chip gap, or in a region of low exposure (such as a bad column) in one or more of the instruments.

The X-ray coordinates of the final source list of each observation have been cross-correlated with the 2 MASS catalog. A boresight correction was computed as the median of the astrometric offsets in right ascension and declination between X-ray and 2 MASS coordinates, and the X-ray coordinates of all sources were shifted by this amount.

2.2 Photometric data from the Optical Monitor within XMM

Throughout the duration of each EPIC observation, the Optical Monitor (OM) was scheduled for several consecutive imaging exposures using one or several filters. All OM exposures were carried out in Full Frame Low Resolution imaging mode. We have reduced and calibrate the data obtained in three filters: UBV.

The OM data were reduced with the SAS metatask OMICHAIN with default parameters, performing all basic data reduction steps. The final output of the pipeline is a combined OM source list that contains for each source the average Johnson magnitude of all exposures in a

given filter.

We corrected the absolute positions of the detections by cross-correlating the combined OM source list with the 2 MASS catalog. A search radius of 3″ was used and only OM sources with $\geq 15\,\sigma$ detection significance were considered for the astrometry. Subsequently, the OM coordinates of all detected sources were shifted by these offsets.

A total of 344 sources have been detected in B30_M and 396 in B30_bridge. The completeness limit 17.5 mag which corresponds to 0.3 $M_{\odot}$ at a distance of 400 pc and age of 5 Myr.

2.3 Optical data from the Wide Field Camera at the INT

To complement the XMM data of B30_M and B30_bridge, we obtained optical observations of these two fields with the Wide Field Camera (WFC) at the Isaac Newton Telescope (INT) in 2010. The WFC camera is composed of 4 CCDs that cover a total FOV of ∼37x37 arcmin. In order to characterize all the population in these fields, we obtained a sequence of four short (10 seconds) and four long exposures (300 seconds) of each field. We repeated this sequence in 3 different filters: Vri.

During the stay in Palermo we have started with the data reduction of the WFC observations. In particular , we have reduced and extracted the photometry of the V-band data. Basically, for each of the fields we have created a mosaic that includes the combined data from the 4 individual CCDs renormalized to the gain of the first chip (see Fig. 2, right). Then we have extracted the aperture photometry of the two fields using *sextractor*. The variable PSF in the individual exposures prevented us from performing PSF-photometry in these fields. Our preliminary reduction shows the detection of more than 9000 source per field, being the completeness limit of ∼22.5 mag, which corresponds to 0.030 $M_{\odot}$ at a distance of 400 pc and age of 5 Myr. One the ri data is reduced, we will be able to characterize all the stellar population and part of the substellar population (down to 30 M_{Jup}) in the two regions.

Finally, we have cross-correlated the WFC V-band catalogue with the X-ray catalogue. As a result, we have found an optical counterpart for half of the detected X-ray sources (see Figure 3).

3 Future collaboration with host institution

Dr. B. Stelzer has been embarked in the study of the LOri region since the beginning of the project. As an X-ray expert, she is performing the X-ray analysis of all the XMM pointings. In addition, she is leading one paper on the LOri cluster B 35 that it is expected to be published by the end of this year.

We need to finish the work on the so-called 'bridge' region presented here. In addition there are additional XMM pointings within the LOri region not analyzed so far. Therefore, it is our purpose to continue collaborating with the Palermo Observatory.

4 Projected publications

The next steps of the work included in this report will be:

- X-ray data: we will identify the young stellar population (if any) of the two regions. We will do this by analyzing the optical data of the X-ray sources through magnitude-color and color-color diagrams. The diagrams will allow to discriminate between young stellar

candidates and background objects. We will also build the X-ray luminosity function of the two pointings and compare them with the one obtained in Coll 69.

- WFC/INT Optical data: since there could also be young stars undetected in the X-ray data, we will use magnitude-color and color-color Vri diagrams to unveil a possible young stellar population in the two fields. As a complementary work, we will analyze the spectral energy distribution (SED) of all the selected candidates to refine our selection. We will build the SEDs using our WFC/INT optical data and archival data in the near- and mid-infrared from 2MASS, and WISE. We will use the tool VOSA (Bayo et al. 2008) to build and analyze the SEDS in an automatic way.

We plan to publish all these results in a refereed paper once we have finished with all the analysis.

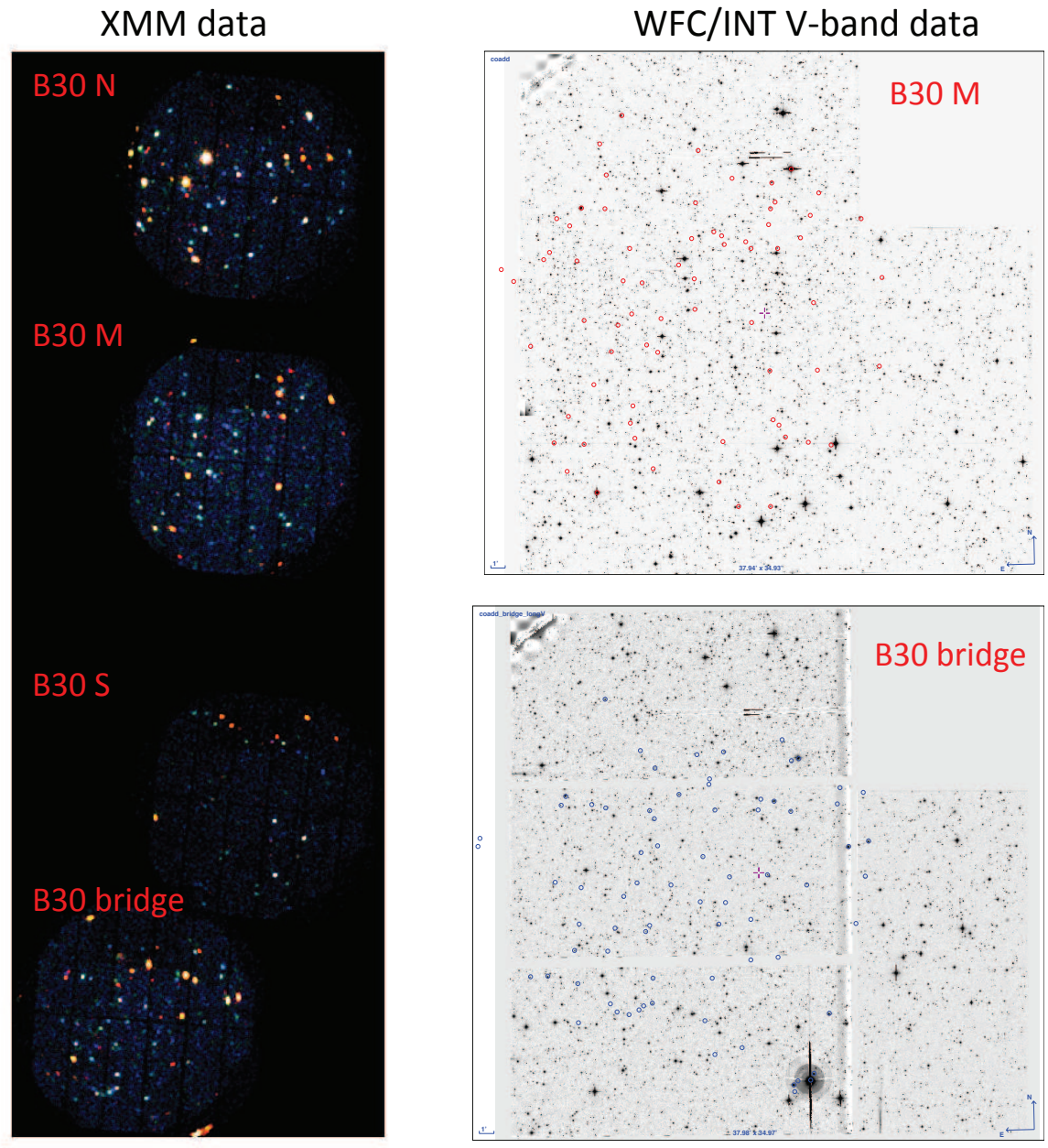

Figure 2: *Left panel*: Mosaic of XXM X-ray observations in B30 and the bridge. During the short stay in Palermo, we have analyzed the XMM pointings of B30_M and B30_bridge. *Right panel*: WFC/INT mosaics of the these two regions in the V-band. The total FOV is $\sim 37\times37$ arcmin. We have overplotted the X-ray detections with red and blue open circles in B30_M and B30_bridge, respectively.