X-RAY AND IR EMISSION OF THE YOUNG STELLAR POPULATION OF THE ORION B MOLECULAR CLOUD

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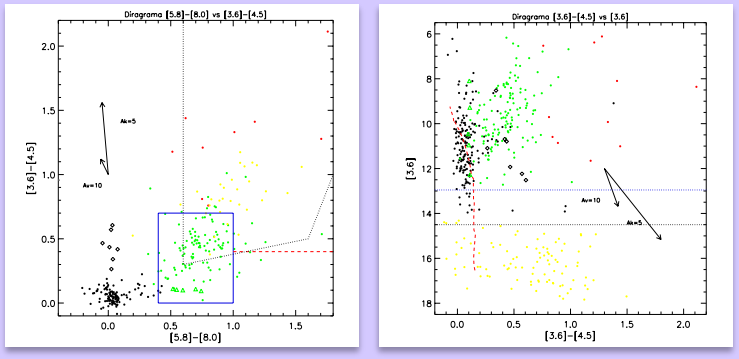
Abstract

Multiwavelength surveys are the key to explore the mechanisms of star formation. We focused on the Orion B region, a multicore star forming region with more than 1000 young stellar objects in different stages of formation. We are carrying out a multi-wavelength study for a significant part of the Orion B molecular cloud, based on 9 XMM-Newton archival observations, infrared (Spitzer, WISE, and 2MASS) and Optical (XMM Optical Monitor and UCAC4) photometry data. This work is focused on the classification and characterization of young stellar objects and the inhomogeneity along the cloud. After filtering for the background sources, we classify the sample into 332 Class III, 141 Class II and 11 Class 0/I and a dozen of brown dwarf candidates based on their infrared/optical properties. We explore the differences along the cloud and the stellar population distribution. We find 5 different regions where Class 0/I and Class II objects are located, coincident with the centre of NGC2023, NGC2024, NGC2068, NGC2071 and around V1647-Ori. In addition, we are currently carrying out an optical follow-up of the BD (brown dwarfs) candidates.

Infrared Properties

For the infrared analysis, we used the Spitzer data and 2MASS catalogue discussed in Megeath et al. (2012). The authors classified the source of the catalogue as stars with IR excess,Class II, or protostars, Class 0/I. We checked this classification and then we used color-color and color-magnitude diagrams to improve the characterization.

Fig 1. Details: Red points are Class 0/I, green points Class II, green triangles are transitional disks, black points Class III, black diamons are strong reddening Class III.



[3.6]-[4.5] vs [5.8]-[8.0] Diagram

- Using this diagrams and other color-color and color-magnitude diagrams we classified 332 Class III, 141, Class II, 11 Class 0/I and 120 background sources.
- Strong reddening Class III are the objects found in the Class III region with [3.6]-[4.5] excess.

[3.6] vs [3.6]-[4.5] Diagram

- Through the [3.6]-[4.5] vs [3.6] and [4.5]-[8.0] vs [4.5] Diagrams we classified determined the background population. Jørgensen et al. (2006) describe that non-stellar and background sources are objects with [3.6] ≥ 14.5 mag and [4.5] ≥ 14.0 mag. These objects are below the black dashed line and shown as yellow points.
- We draw the HBML (Hydrogen Burning Mass Limit), blue dashed line, the sources between the Jørgensen limit and the HBML are candidate to be brown dwarfs (under study).

X-ray Analysis

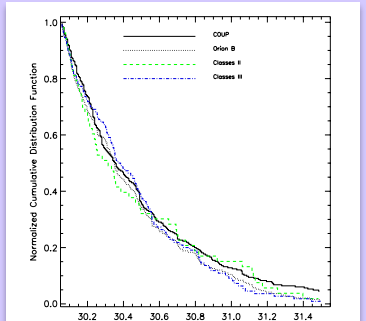
Using the Science Analysis Software (SAS) task *espfilt* we filted the event list and created the GTI (Good Time Intervals) files. We create one master source list for all available data in Orion B, with a total of 604 sources.

Spectra were analyzed for X-ray sources with more than 100 net count, in each instrument. The source must be detected on at lest one of the individual EPIC detector. Under this restriction, 45 of the total 604 source spectra were analyzed. The spectral fitting was computed using XSPEC version 12.7.1. For the fit we used a 1T or 2T-models, for all stars we fixed the abundance to $Z/Z_{\odot} = 0.3$.

We use the 45 stars for which spectral analysis could be performed to determine a conversion factor (CF) between the observed count-rate and flux (absorbed flux).

X-RAY CORONAL PROPERTIES

- Class III { kT_{mean} = 3.48 keV, NH_{mean} = 2.46 x 10^{22} cm^{-2}
- Class II { kT_{mean} = 2.04 keV, NH_{mean} = 1.12 x 10^{22} cm^{-2}
- Class 0/I { kT_{mean} = 2.01 keV, NH_{mean} = 0.53 x 10^{22} cm^{-2}



- We used the flux derived from the CF to obtain de X-ray luminosities (calculated with a fixed distance of d = 450 pc for all sources). We created the X-ray luminosity function using the Kaplan-Meier estimator and compare with the COUP data (Getman et. al 2005) between our limits. We censored data from our maximum and minimum flux, i.e. from 30.1 to 31.5 (in log(L_X)) for COUP and Orion B data. COUP, Orion B, and the curves for Class II and Class III are similar. The main difference between the curves are at high luminosities when COUP is slightly above.

Observations

Using the XMM-Newton **archive data**, we selected all observations along the Orion B Cloud. The results are **nine observations** situated in Zeta Orionis, NGC 2023, NGC 2024, V1647 Orionis, NGC2071 and around the Herbig-Haro objects HH212.. The final X-ray list contains all sources detected in the merged EPIC observations (threshold of ML ≥15). We detected a total of 604 X-ray sources.

Table 1. Details of EPICs observations

Obs	Date	RA[a] (deg)	DEC[a] (deg)	PA[a] (deg)	Camera	Mode[b]	Filter	Exp Time (s)	Eff. Time[c] (s)
					PN	FF	Thick	38362	36323
0112530101	2002-09-15	85.171	-1.921	87.11	MOS1	SW	Thick	41731	40175
					MOS2	FU	Thick	41479	40215
					PN	FF	Medium	31427	15420
0112640101	2002-03-06	85.447	-1.932	263.97	MOS1	FF	Medium	31353	19500
					MOS2	FF	Medium	33126	21180
					PN	EFF	Medium	25090	13600
0112640201	2002-03-24	85.461	-2.301	271.71	MOS1	FF	Thin	29128	15000
					MOS2	FF	Medium	25090	15800
					PN	FF	Thin	47278	14640
0149890301	2003-09-17	85.948	-1.025	87.809	MOS1	FF	Thin	16117	14700
					MOS2	FF	Thin	16121	15540
					PN	FF	Medium	48035	18095
0153150101	2003-09-03	86.515	-0.145	82.292	MOS1	FF	Medium	49663	23100
					MOS2	FF	Medium	49676	23100
					PN	FF	Medium	38673	18615
0164560201	2004-04-03	86.567	-0.127	276.163	MOS1	FF	Medium	38665	26970
					MOS2	FF	Medium	37035	28715
					PN	FF	Medium	43637	27540
0201530101	2005-03-30	86.784	0.336	274.24	MOS1	FF	Medium	45173	28670
					MOS2	FF	Medium	45177	28612
					PN	FF	Medium	106924	63660
0301600101	2005-03-24	86.571	-0.125	271.885	MOS1	FF	Medium	93933	75000
					MOS2	FF	Medium	93993	76080
					PN	FF	Medium	32534	24360
0601960201	2010-02-28	86.573	-0.123	261.653	MOS1	FF	Medium	34121	27660
					MOS2	FF	Medium	34130	27720

Fig 2. XMM-Newton image mosaic of Orion B. The image is in the band: 0.3-7.5 keV.

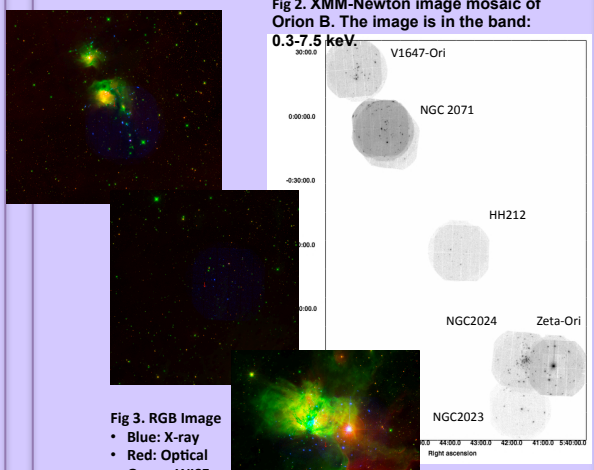


Fig 3. RGB Image

- **Blue: X-ray**
- **Red: Optical**
- **Green: WISE (W1 in 3.4 μm)**

Conclusions

We have carried out an analysis of the X-ray and infrared properties of the Orion B region. From 9 archived XMM-Newton observations we **classified 332 Class III, 141 Class II and 11 Class I**.

We looked for local difference in the star-forming rate. **North and South are not significantly different (see table below)**. Class 0/I and Class II objects appeared clustered into 5 groups, coincident with NGC2023, NGC2024, NGC2068, NGC2071 and around V1647-Ori.

	Class III	Class II	Class 0/I
North	125	48	5
Middle	71	24	0
South	136	69	6

The X-ray analysis (kT_{mean}=2.08 keV and N_{Hmean}=7.92x10^{21} cm^{-2}) shows parameters consistent with young T-Tauri stars. In this observations the completeness limits is $f_X \approx 4.7 \times 10^{-14}$ erg·cm^{-2}·s^{-1}

We have compared the **X-ray luminosity functions (XLFs) of different YSO classes**, we have seen that luminosity function from Class II and Class III follow a **similar distribution**. We also compare the complete sample of Orion B (and for Class II and Class III objects) with the COUP distribution, that show that the populations of both regions are very similar.

References

- Getman et. al 2005, ApJS, 160, 319
- Jørgensen et al. 2006, Ap, 184, 1246
- Megeath et al. 2012, AJ, 144, 192

ACKNOWLEDGEMENTS This work is supported by the Spanish Ministerio de Ciencia e Innovación under grant AYA2011-29754-C03-03