Young Low–Mass Stars and Discs in NGC 6611 and the Eagle Nebula

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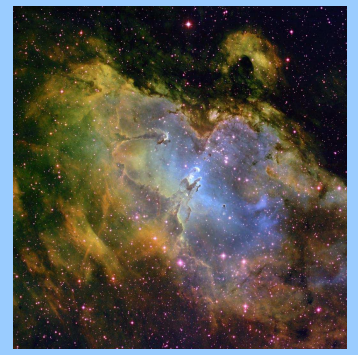


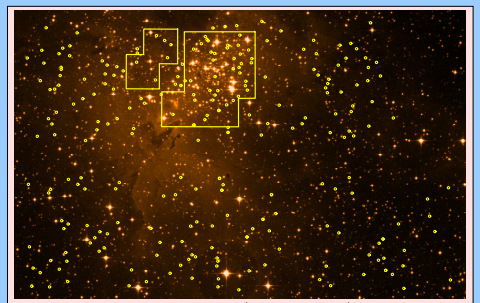
T.A.Rector (NRAO/AUI/NSF AND NRAO/AURA/NSF) AND B.A.Wolpa (NOAO/AURA/NSF)

Summary: We present $IZJHKL'$ photometry of the core of the cluster NGC 6611. This photometry is used to constrain the Initial Mass Function and the circumstellar disc frequency of the young stellar objects in this cluster. Optical spectroscopy of 258 objects is used to confirm membership and constrain contamination as well as individual reddening estimates. Our overall aim is to assess the influence of the ionising radiation from the massive stars on the formation and evolution of young low-mass stars and their discs.

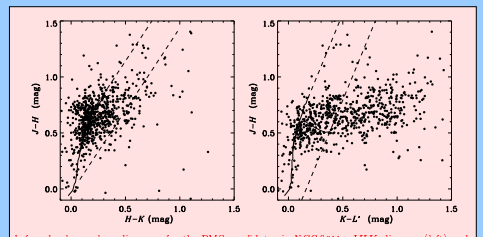
Brief introduction: star formation in hostile environments

A significant fraction of the solar-type stars in our Galaxy may be born in environments where very high mass stars are also present. The winds and ionising radiation from O-stars could be expected to change the properties of low-mass stellar populations in at least two ways: by inhibiting low-mass star formation in the central cluster area (i.e. changing the shape of the low-mass IMF) and by hastening the dispersal of their circumstellar discs. However, observations in numerous nearby OB-associations have so far revealed little conclusive evidence of either a significantly different IMF or a depleted disc population (when compared with quieter star forming regions).

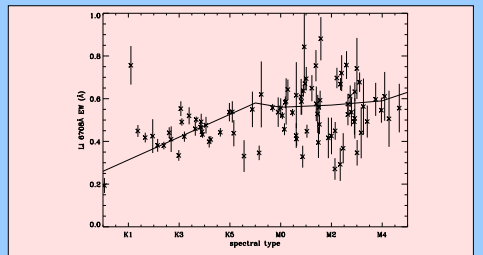
We are addressing these questions by conducting a census of low-mass ($0.4-2\,M_{\odot}$) stars and their discs in NGC 6611, a massive young cluster which ionises the Eagle nebula. It contains a dozen O-stars (earliest spectral type O4) that produce $\sim$10 times more ionising (Lyman continuum) radiation than the Trapezium. The visual extinction towards the cluster is known to be variable. The distance to the cluster is in the range $2-2.6$ kpc and the age of the young population is of the order of $2-3$ Myr with a reported age spread of a few Myrs (Hillenbrand et al., 1993, ApJ 106, 1906; Belikov et al., 2000, A&A 358, 886). We are analysing the low-mass IMF and disc populations in NGC 6611 with the goal of understanding the role of massive stars in galactic evolution and in determining what fraction of solar-type stars are capable of hosting planetary systems. We have $IZJHKL'$ photometry for the central area of the cluster and optical VIMOS/VLT spectroscopy of 258 pre-main-sequence (PMS) candidates spread over a larger area. Spectroscopic indicators (the lithium 6708Å line, gravity sensitive features and radial velocities) are used to identify cluster members and determine the reddening towards each object so that they can be placed in the intrinsic HR diagram. By combining photometry with optical spectroscopy we plan to validate the photometric techniques that will allow us to construct the cluster IMF over the whole cluster area.



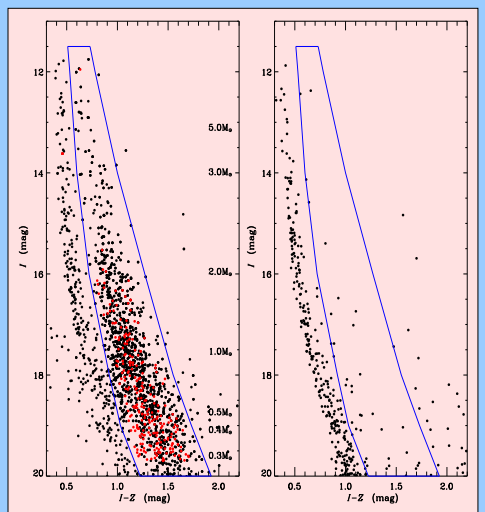
IR DSS image of the Eagle Nebula and NGC 6611 (25 arcmin × 16 arcmin) — North is to the top of the image and East to the left. The IZ survey (WFC/INT) covers this entire area; the yellow outline is the area covered by the $JHKL'$ survey (UIST/UKIRT, 7 arcmin × 5 arcmin); the yellow circles are the positions of the objects with optical spectroscopy, spread over an area of 25 arcmin × 15 arcmin.



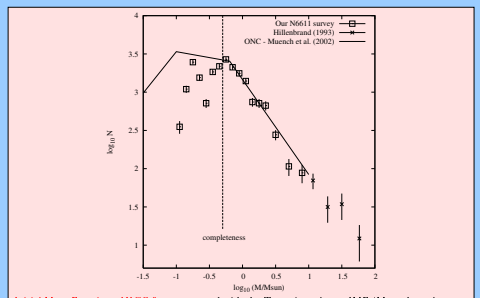
Infrared colour-colour diagrams for the PMS candidates in NGC 6611: JHK diagram (left) and $JHKL'$ diagram (right). The thick lines are the main-sequence and giant loci and the dashed lines are the reddening band. Objects to the right of the reddening band have an excess in $(H-K)$ or $(K-L')$ that indicates the presence of a circumstellar disc. An $(H-K)$ excess diagnoses accretion discs, while a $(K-L')$ excess is a more reliable indicator (at this young cluster age) as it diagnoses both passive and actively accreting discs. From these diagrams we derive a disc frequency for NGC 6611 of 55–60% for objects down to 0.5 $M_{\odot}$ (Oliveira et al., 2005, MNRAS358, L21). The disc frequency for the fields to the East of the brightest O-stars is not significantly different from the disc frequency nearer the massive stars. This hints that the effect of the ionising radiation from the O-stars is not very severe.



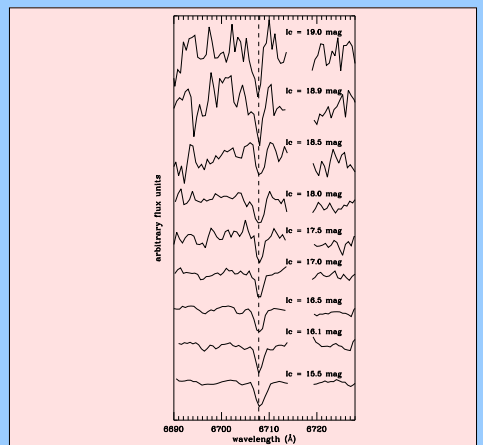
Lithium 6708 Å Equivalent Width (EW) versus spectral type for cluster members. The solid line is the undepleted EW for an initial lithium abundance A(Li) = 3.3, (Baraffe et al., 1998, A&A 337, 403; Baraffe et al., 2002, A&A 382, 563) and curves of growth (Zapatero Osorio et al., 2002, A&A 384, 937). The measured EW follows the expected trend for undepleted lithium, with a larger scatter for late spectral types.



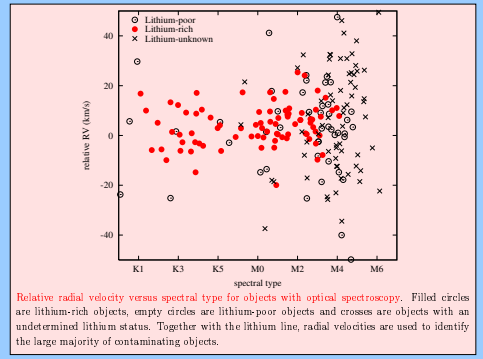
$I/(I-Z)$ colour-magnitude (CMD) diagram for the central (4 arcmin radius) region of NGC 6611 (left) and for a control field 16 arcmin to the West of the cluster (right). The PMS can be clearly seen, separated from the bulk of "contamination". Thus objects within the outline are pre-main-sequence photometric candidates. As it can be seen from the CMD of the offset field, contamination by field dwarfs is not severe. The red symbols are the objects for which we have VIMOS/VLT spectroscopy. Approximate PMS masses are indicated assuming an age of 3 Myr, a uniform $A_V = 3$ mag and evolutionary models from Siess et al. (2000, A&A 358, 593).



Initial Mass Function of NGC 6611 compared with the Trapezium cluster IMF (Muench et al., 2002, ApJ 573, 366). There seems to be no significant difference in the shape of the IMFs of these two clusters, down to $\sim 0.5\,M_{\odot}$. However, environmental effects on the shape of the IMF are expected to be more noticeable towards lower masses. Recently obtained deep HST images of the core of NGC 6611 will allow us to constrain the substellar IMF in this cluster.



Lithium 6708 Å spectra of NGC 6611 cluster members, with increasing I-band magnitude from bottom to top — the contribution of the sky lines redward of the lithium line is removed for clarity. The lithium line is a reliable youth indicator for objects of K and M spectral types. From the sample of 258 objects, 4 are very bright cluster members included for calibration, 92 objects are lithium rich, 71 objects are lithium poor and for 91 objects no decision could be made on the lithium line (these are objects fainter than $I-19$ mag with low S/N spectra). The lithium-rich objects are NGC 6611 cluster members. NGC 6611 members concentrate towards the O-stars but there are lithium-rich objects as much as 14 arcmin from the massive stars.



Relative radial velocity versus spectral type for objects with optical spectroscopy. Filled circles are lithium-rich objects, empty circles are lithium-poor objects and crosses are objects with an undetermined lithium status. Together with the lithium line, radial velocities are used to identify the large majority of contaminating objects.

Current Work and Outlook:

* constrain the substellar IMF using HST imaging (ACS and NICMOS) to assess the role of environmental parameters;
* use VISIR/VLT imaging to identify embedded star formation and investigate the physical conditions in dense clumps;
* use SALTICAM/SALT imaging to measure UV excesses and mass accretion rates.