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Multiple stellar generations in massive star forming complexes

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Abstract: The formation of massive stars is an outstanding problem in stellar evolution. However, it is expected that they are (predominantly) born in hierarchical environments within massive young clusters, which in turn are located within larger star forming complexes that reflect the underlying structure of the natal molecular cloud. Initial observations of such regions suggest that multiple generations of stars and proto-stars are present, necessitating a multiwavelength approach to yield a full (proto-)stellar census; in this contribution we provide an overview of just such an observational approach for Galactic examples, focusing on the G305 complex.

1 Introduction

Imaging of external galaxies reveals that stellar formation yields large star cluster complexes of 10s-100s of parsec in size, and $>> 10^4 M_\odot$ in integrated mass. These are luminous across the electromagnetic spectrum; with emission at radio wavelengths from ionised gas, far-IR & submm from cold molecular material, IR from heated dust, optical-UV from the stellar population and X-rays from both pre-MS and massive stars. Therefore a multiwavelength approach is required to understand the ecology of such regions - and hence infer masses for unresolved regions from their integrated spectral energy distributions (SEDs) - as well as the evolution of massive ($>$40$M_\odot$) stars from cold molecular cores through to the Main Sequence. The latter goal is particularly important, since our knowledge of this process suffers from few current observational contraints and yet very massive stars play an inordinate role in the excitation of their environment via their UV radiation field and wind energy. Consequently, in order to address these interelated issues we are undertaking such a study of several Galactic star forming regions, of which the G305 complex is of particular interest given current estimates for its stellar content (Clark & Porter 2004). In this contribution we briefly review the observational dataset acquired for it as a result of this program and highlight some initial results arising from it.

2 The G305 star forming complex

Located in the Scutum Crux arm at a distance of $\sim$4 kpc the G305 star forming complex appears to be one of the most massive such regions in the Galaxy, with the radio luminosity alone suggesting the presence of >30 canonical O7 V stars (Clark & Porter 2004). Morphologically, it appears as a tri-lobed wind blown bubble with a maximal extent of $\sim$30 pc centred on the Young Massive Clusters Danks 1 & 2 (Fig. 1). Vigorous ongoing star formation is present on the periphery of the region as evidenced by significant IR-radio emission and the presence of numerous masers (Sect. 2.2).

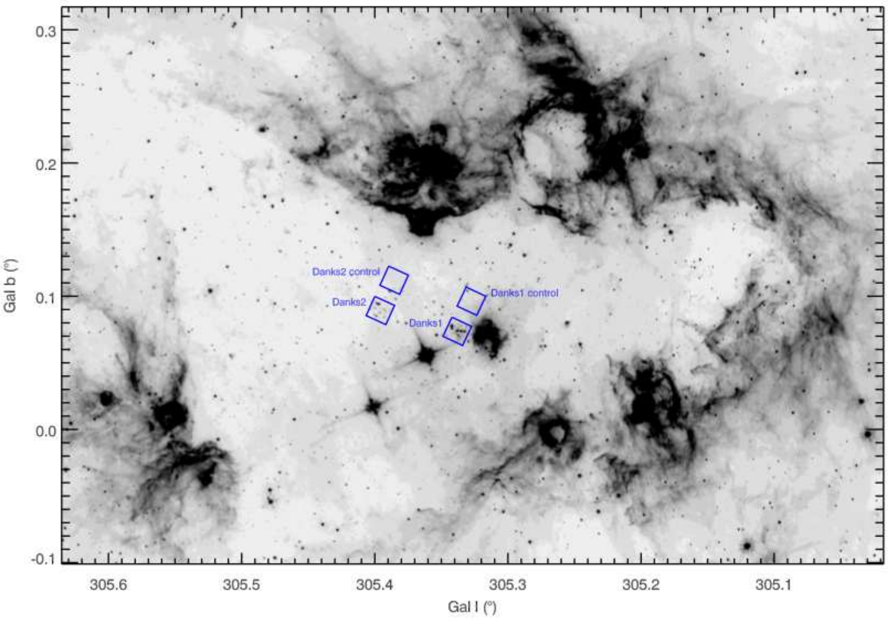

Figure 1: 5.8μm image of the G305 complex with the HST target fields for Danks 1 & 2 indicated.

2.1 The recent star formation history of G305

The location of ongoing star formation within the complex is indicative of triggered, sequential activity initiated by Danks 1 & 2. The presence of at least one Wolf-Rayet - the WC star WR48a - suggests that star formation must have been underway for at least $\sim$2.5 Myr while, following the arguments presented in Clark et al. (2009) for W51, the lack of a population of RSGs suggests an upper limit to the duration of the 'starburst' of $\leq$10 Myr. In order to more fully constrain the properties of Danks 1 & 2 and hence to determine whether they could have triggered the subsequent generations of star formation, we have undertaken near-IR imaging & spectroscopic observations of them with the HST & VLT/ISAAC and present a subset of the data focusing on Danks 1 in Figs. 2 & 3.

A full analysis of these data will be provided in Davies et al. (in prep.) but we highlight that both clusters appear to have integrated masses $>>10^3 M_\odot$. Surprisingly, given their apparent proximity (a *projected* separation of $\sim$3.5 pc) there appears to be a notable age difference ($\sim$2-3 Myr) between them, evident in both the spectral types of cluster members and the location of the Main Sequence turn on. Focusing on Danks 1, we identify a number of emission line objects with spectra consistent with O Iafpe/WN7-9h stars; the cluster being reminiscent of the Arches in the Galactic Centre. The presence of such stars is of interest since they are expected to be massive core-H burning objects in which very high mass loss rates cause them to present a more evolved spectral type. Combined with their prodigious UV-fluxes, they are likely to be significant sources of feedback and detailed non-LTE model atmosphere analyses of these objects is currently underway in order to quantify this. In contrast such stars are absent in Danks 2, with the presence of a WC star and O supergiants of a later spectral type indicating an older spectral population.

However, massive (post-)MS objects are not restricted to these clusters. As well as the dusty WC star WR48a, recent IR observations have located a further 3 WC and 1 WN stars within the wind

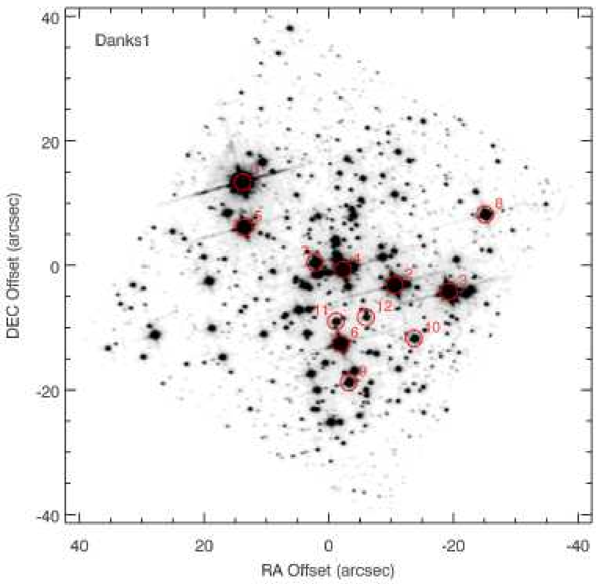

Figure 2: F160W mosaic of Danks 1

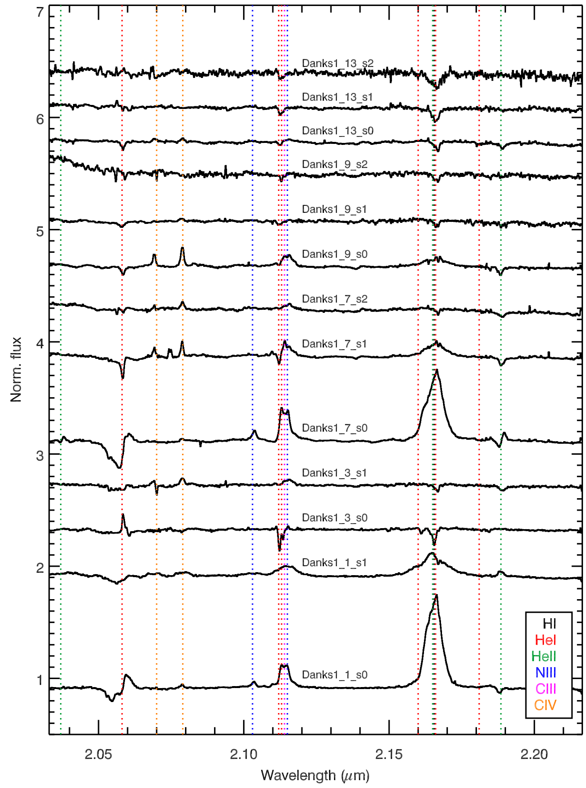

Figure 3: K band spectra of massive stars within Danks 1 (Davies et al. in prep.).

blown bubble (Shara et al. 2009, Mauerhan, van Dyk & Morris 2009), suggesting that an additional dispersed population is present within the complex, although their origin - e.g. ejected from a cluster or formed *in situ* - is uncertain. In this regard it closely resembles 30 Dor, which Walborn & Blades (1997) showed hosts a young central cluster and a diffuse, older population distributed across the wind blown cavity with an additional (pre-MS) component located on the periphery. Massive stars also appear present on the perimeter of G305, with Leistra et al. (2005) showing that the young cluster found within the cavity G305.254+0.204 contains at least one early O star. Moreover, early OB pre-MS stars are also found in the bubble PMN1308-6215 to the NW of the complex; the spectrum presented in Fig. 4 being dominated by H I line and CO bandhead emission, indicative of a hot ionising source surrounded by a cool accretion disc/torus, respectively. A full presentation and analysis of these and other data on the pre-MS population of G305 will be provided in Clark et al. (in prep.).

2.2 Earlier phases of (triggered) star formation

We next turn to the more deeply embedded massive protostars and the reservoir of cold molecular material. The former may be identified with ultracompact H II regions, very bright mid-far IR sources and H_2O & methanol maser emission, while the latter may be mapped via molecular tracers such as NH_3 or sub-mm continuum emission from cold ($\leq$50K) dust. Hill et al. (2006) presented a survey of cold dust for select regions within G305, finding a total of $\sim$23000 $M_\odot$ material located in clumps with masses up to $\sim$4500 $M_\odot$, although it is expected that these will comprise lower mass subclumps at higher spatial resolution. Recently, Hindson et al. (2010) undertook a molecular survey of the whole complex which revealed a total reservoir of cold gas of $\sim 6\times10^5 M_\odot$ (Fig. 5); even allowing for a relatively low star formation efficiency ($< 10\%$) this is sufficient to yield a substantial stellar

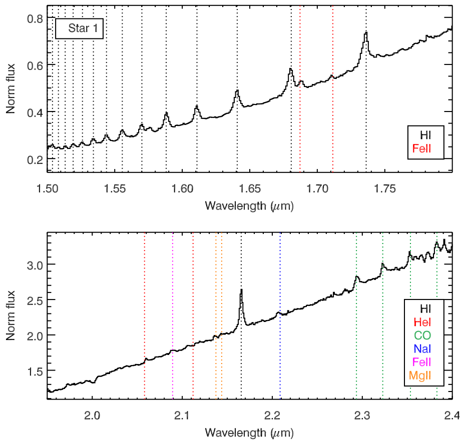

Figure 4: H and K band spectra of a pre-MS OB star in the star forming bubble PMN 1308-6215 to the NW of the complex proper.

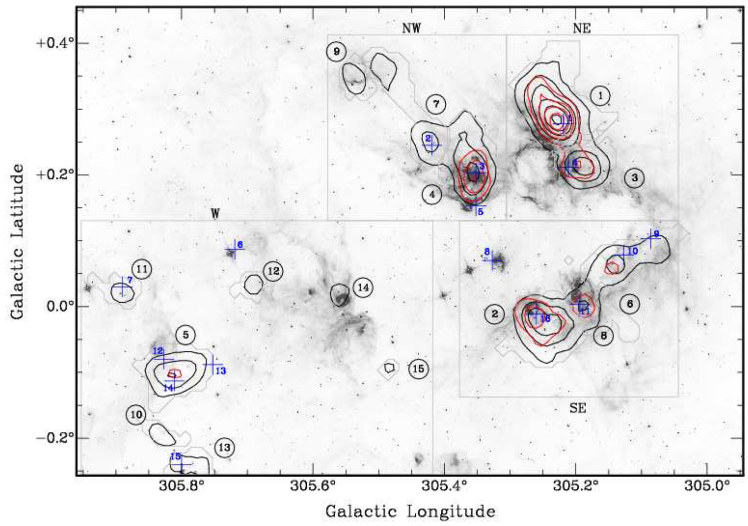

Figure 5: Overplot of NH_3 contours on a 5.4μm greyscale image. H_2O masers are indicated by crosses (Hindson et al. 2010).

population. In order to provide a higher resolution map of this material and to determine its properties such as clump mass function and temperature, we have obtained both APEX/LABOCA and Herschel far-IR - submm observations. A preliminary reduction of the 870μm LABOCA data is provided in Fig. 6, which shows the 'skeleton' of cold molecular material material upon which current star formation is occuring (see Clark et al. in prep. & Thompson et al. in prep. for a full analysis).

Finally, SEDs constructed from the full near-IR to sub-mm datasets allow the identification of Massive Young Stellar Objects (MYSOs) via their characteristic colours (e.g. Hoare et al. 2005), as well as a determination of their integrated bolometric luminosities. We show the location of such MYSOs in a subfield of G305 in Fig. 7 (as well as H_2O and methanol masers; Hindson et al. 2010). Clearly significant star formation that will result in a new population of massive stars is currently underway, and appears to be located on the surface of the molecular cloud adjacent to the nearby stellar cluster, suggesting that it has been triggered by the action of the OB stars contained within.

3 Concluding remarks

A multiwavelength approach to the study of star forming complexes allows us to locate the different stellar populations within these regions and hence determine the propagation (or otherwise) of star formation through the host GMC. Model atmosphere analysis of the massive stellar population constrains the feedback from such stars as well as helping date the onset of star formation via comparison to theoretical evolutionary tracks. Full analysis of the near-far IR SEDs of embedded sources yields their bolometric luminosity and hence an estimate of mass, while the far-IR - sub-mm SED will play a similar role for cold molecular cores - the first stage of massive star formation. Finally a synthesis of these data will provide a complete census of star formation within the cluster complex, an estimate of the efficiency of this process and - via comparison of the mass functions of the differing populations - constraints on the physics governing GMC fragmentation and subsequent cluster/star formation.

References

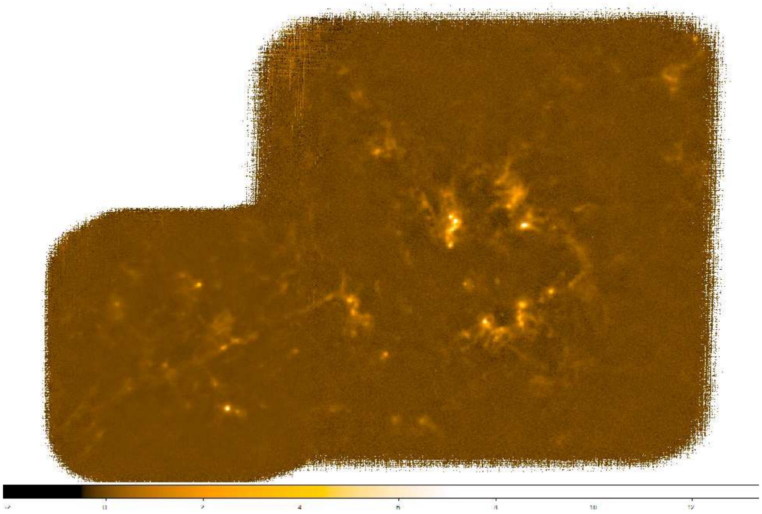

Figure 6: Preliminary reduction of APEX/Laboca 870μm continuum observations of the G305 complex.

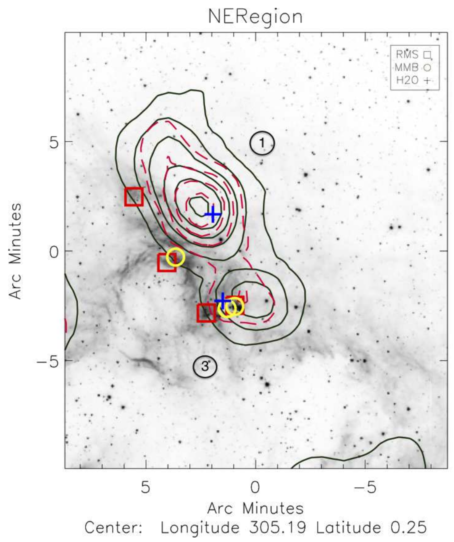

Figure 7: Blow up of the NE region of the complex from Fig. 5. Crosses and contours have the same meaning while squares represent MYSOs and circles methanol masers (Hindson et al. 2010).

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Discussion

L. Oskinova: When you estimate the ages of stellar population, do you use the evolutionary tracks for single stars only, or do you also account for binarity and e.g. rotation?
J.S. Clark: We used three different methods to estimate the age of the clusters: (i) fitting the MS turnoffs with both rotating and non-rotating Geneva isochrones, (ii) fitting the MS turnon with Schaller isochrones and (iii) a comparison of the (post-MS) stellar contents to other massive clusters with well defined ages. Neither of the first two methods accounted for binarity, but this will implicitly be addressed by method (iii) assuming a universal binary fraction.

M. Corcoran: Are there any X-ray observations with Chandra, and if so what do they show? Is there any evidence of diffuse emission?
J.S. Clark: X-ray observations have been made and are currently being analysed by Marc Gagné.

D. Bomans: A triggered SF claim is maybe too optimistic, yet, since you do not have an expansion velocity of the gas shell, therefore no proven causal connection of clusters, shell and young SF sites.
J.S. Clark: Forthcoming radio observations should provide an expansion velocity for the gas in the

region. However the location of various star formation diagnostics on the inner face of the wind evacuated cavity is certainly suggestive of triggered activity.

N. Smith: You mentioned possible evidence for triggered star formation at the edges of these regions (UCH II regions, protostars, etc). If you look nearby - i.e. interior to the edges of shells or outside - do you see evidence for recent star formation in the form of somewhat older YSOs (class II / T Tauri stars, etc)?
J.S. Clark: We are currently examining our data for this - and in particular are waiting for a new deep JHK imaging dataset from the VISTA/VVV survey to accomplish this (which will be significantly deeper than current 2MASS data).