Formation, evolution, and survival of massive star clusters
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Comparing ALMA, VLT, and HST data for Massive, Young Clusters in Grand-Design Spirals

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Abstract. A population of young, massive stellar cluster complexes with near-infrared (NIR) colors indicating high extinction (i.e. Av $\sim 7^{\rm m}$) was identified on HAWK-I/VLT images of several nearby, grand-design spiral galaxies. Models suggest that they are very young cluster complexes still embedded in a dust/gas envelope which will be expelled after 5-7 Myr. This type of very young, embedded clusters are not seen in optical studies using HST data.

A detailed comparison of HST and HAWK-I images was done to better understand the discrepancy between the optical and NIR detection of stellar clusters in nearby galaxies. More than 70% of the NIR clusters are located close to dust lanes which would make an optical detection difficult. A comparison of the ALMA CO(1-0)-map of NGC 4321 and the young, massive clusters shows that 60% of them have CO emission within 2'' indicating a correlation between giant molecular clouds and formation of massive clusters.

Keywords. galaxies: star clusters, galaxies: spiral

1. Introduction

The populations of stellar clusters in 10 nearby, grand-design spiral galaxies were analyzed by Grosbøl & Dottori (2012) using deep, near-infrared (NIR) images observed with HAWK-I/VLT. All the NIR color-color distributions show a characteristic bimodal structure with a main group of sources located near ((H-K), (J-H)) = (0.4, 0.8) corresponding to old clusters with relative low extinction while the other smaller concentration was seen around (0.8, 1.0). Assuming the reddening law by Israel *et al.* (1998), this latter group is consistent with highly extinct, very young clusters.

The (J-K)–K color-magnitude diagrams clearly display the two groups as well separated branches i.e. at (J-K) = 1.2 and 2.0, respectively. The reddening corrected color index Q = (H-K) − 0.84*(J-H) shows a more continuous distribution suggesting that the two branches in (J-K) are due to a change in extinction. The gap between the branches suggests a rapid reduction of extinction in the clusters at an early evolutionary phase as indicated by models of Grosbøl & Dottori (2013).

Optical studies of nearby disk galaxies using HST data (see e.g. Larsen & Richtler (1999), Bastian *et al.* (2012)) do not find a similar population of clusters. This may be due to several reasons such as a) lower spatial resolution of the NIR data as suggested by Bastian *et al.* (2014), b) high attenuation by dust limiting detection at optical wavelengths, or c) such populations only exist in grand-design spirals due to the strong perturbations in their arm regions.

2. Comparison between VLT and HST images

For the 7 galaxies with overlapping HAWK-I/VLT and HST images, the reddest calibrated HST frames(drz) with reasonable quality were selected for comparison. All young sources (i.e. 0.0<Q) with high extinction (i.e. 1.5<(J-K)) were visually checked to see if there were dust in their vicinity. For two galaxies (NGC 1300 and NGC 1566) with open spiral arms and very low inter-arm intensity, some sources appeared to be background galaxies. The low surface brightness of NGC 7424 made the identification of dust on the HST frames rather uncertain. The vast majority (i.e. >70% or 109/145) of the young sources with very red (J-K) colors is located within 2" of dust lanes or patches which would make a detection in blue visual bands very difficult.

3. Comparison between VLT and ALMA CO-map

During the science verification of ALMA, a CO(1-0) line map of NGC 4321 was made in band 3. A total of 34 such clusters with 0.1<Q was found within the area of the ALMA map which detected CO clouds down to a brightness limit of 0.3 Jy/beam km/s. CO emission were detected within 2" for around 60% (i.e. 20/34) of the clusters.

Control samples of clusters with random positions within the map had a flat distribution of distances suggesting that a correlation between the young clusters and CO emission is significant at a 3σ level, even considering the relative shallow map.

4. Conclusions

The comparison of young cluster complexes with very red (J-K) colors on both HST image and K-maps suggests that a majority of them (>70%) is located very close to dust patches. This indicates that the main reason for the lack of this type of sources in HST studies is the high extinction. There may well be a resolution effect which will tend to make very young clusters, observed in larger apertures, redder in (H-K) (e.g. due to nebular Br_γ emission as suggested by Bastian *et al.* (2014)) but this cannot explain the observed increase in (J-H).

Only a larger sample of deep NIR observations of more flocculent spirals will allow to test if the population of very massive, young cluster complexes is unique to grand-design spirals (due to the stronger perturbation in the spiral arms) or not.

Finally, around 60% of the young complexes are found close to CO emission even on the relative shallow ALMA CO(1-0) map suggesting a correlation. Deeper maps would be required for a detailed comparison.

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