Star formation in the arms of grand-design spiral galaxies

Preben Grosbøl, European Southern Observatory, Garching, Germany
Horacio Dottori, Instituto de Fisica, Porto Alegre, Brazil

Abstract

Near-infrared K-band images of disk galaxies with strong spiral perturbations reveal bright knots in their arm regions. Both the alignment of such bright knots and their NIR colours suggest that they are massive, young stellar cluster with ages of less than 10 Myr. A main advantage in using NIR bands is the low attenuation by dust which allows to obtain almost complete samples of such clusters, even in the arm regions, and better estimates of ages using broad band colours.

Deep JHK maps of 4 nearby, grand-design spirals were obtained from HAWK-I/VLT reaching K=24^m with a seeing of 0.6". The colours of the extended sources identified in the disks of the galaxies are consistent with them being stellar clusters reddened by several magnitudes of visual extinction. The 2 galaxies with stronger spiral perturbations have relative more diffuse than compact sources with the diffuse sources being more concentrated in arm regions and reaching an absolute M_K around -15.5^m. The total (diffuse+compact) distributions of a 'reddening free' index Q are similar for all galaxies. This suggests that strong spiral perturbations may increase the probability of forming brighter, more massive stellar clusters. A radial trend of the K magnitude of extended sources is seen in NGC 157 only where they, on average, get fainter at larger radii.

Introduction

Blue, young objects (such as HII regions and OB associations) are often concentrated in the arms of grand-design spiral galaxies, however, strong and very varying attenuation by dust in the arm regions makes it difficult to study complete samples of such very young, stellar cluster in visual bands. It was noticed by Grosbøl & Patsis (1998, A&A 336, 840) that several spiral galaxies had bright knots along their spiral arms on K-band images. Grosbøl et al. (2006, A&A 453, L25) identified such knots in NGC 2997 with very young stellar cluster (ages <10 Myr) using K-band spectra obtained at ISAAC/VLT while Grosbøl & Dottori (2008, A&A 490, 87) discussed their statistics in a sample of 46 spiral galaxies.

The current paper uses a set of significantly deeper NIR exposures of 4 grand-design spirals to study their distributions of young stellar clusters in detail.

Table 1: General properties for the 4 galaxies such as Hubble type and distance derived from the 3K CMB velocities and H=73km/s/Mpc. Absolute total B magnitude and linear scale were computed from the distances listed. The level for S/N=5 per pixel and the FWHM seeing for the stacked K-band images are also given.

Galaxy	Type	Distance Mpc	M_{BT} mag	Scale pc/arcsec	S/N=5 (K) mag	Seeing (K) arcsec
NGC 157	Sc(s)I-II	18.0	-20.7	87	23.9	0.4
NGC 1232	Sc(rs)I	19.8	-21.3	96	24.0	0.5
NGC 1300	SBb(s)I.2	19.6	-21.1	95	23.8	0.6
NGC 1365	SBb(s)I	21.1	-22.2	102	23.8	0.4

Data and Reductions

Deep NIR exposures of 4 grand-design, spiral galaxies were obtained in the JHK-bands with HAWK-I/VLT which has a 7' field and 0.11" pixels. The observations were done in service mode, late 2008, using standard jitter techniques with interleaved offsets to 'empty' sky fields. The basic reductions followed the procedure outlined in Grosbøl et al. (2004, A&A 423, 849). The galaxies are listed in Table 1 which includes limiting magnitudes and seeing for the final, stacked K-band images (see Fig.1). The photometric zero-points were derived directly from 2MASS stars in the fields. The seeing of ~0.5" allows objects with a linear size of more than 50pc to be resolved.

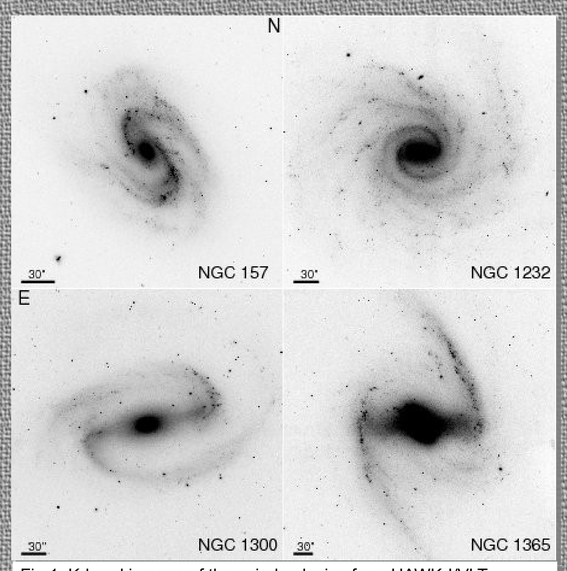

Fig.1: K-band images of the spiral galaxies from HAWK-I/VLT.

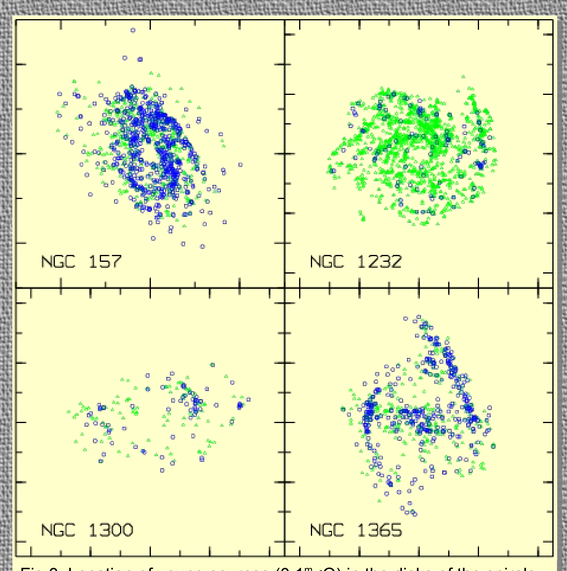

Fig.3: Location of young sources (0.1^m<Q) in the disks of the spirals. Symbols and colours are as in Fig.2.

Discussion and Conclusions

Deep JHK maps of 4 grand-design spirals were obtained and all extended sources in their disks with K<24^m identified. The 2 spirals with stronger perturbations have a higher relative fraction of diffuse, bright sources compared to compact, fainter ones than the galaxies with weaker arms. The strong spirals also display a higher concentration of diffuse sources in their arm regions. The (H-K)-(J-H) colour distribution is consistent with the extended sources being stellar cluster with several magnitudes of visual extinction. The combined (diffuse+compact) distributions of a 'reddening free' colour index Q are similar for all the galaxies suggesting that strong spiral perturbations increase the likelihood of forming bright, massive clusters in the arm regions but affect less general age distribution of clusters.

One galaxy, NGC 157, displays a radial magnitude trend for its clusters in the sense that clusters close to the centre are brighter, on average, than those at larger distances. This could be caused by the radial variation of the shock strength associated to a density wave, a radial surface density gradient in the molecular gas or systematic changes in the metallicity.

Detection and Distribution of Sources

All sources on the K-band images were identified using *Sextractor* (Bertin & Arnouts 1996, A&AS 117, 393) with a threshold of 2.5 and a background grid of 16 to better follow the surface brightness variations in the disks of the galaxies. With these positions, aperture photometry of the sources on the JHK frames were measured using a 2" aperture and local background. Individual errors were estimated also considering scatter in the background measure. Only sources within the galactic disks (i.e. those with a background significantly higher than the sky) were used. This reduced the 'pollution' of the sample by background galaxies.

The *Sextractor* class_star classifier (*cs*) for the sources is shown in Fig. 2 as function of their apparent K magnitude. The sources were divided into 3 groups: a) point-like objects with 0.8<*cs*, b) compact sources with 0.3<*cs*<0.8, and c) diffuse objects with *cs*<0.3. The ratio of diffuse to compact sources varies strongly and is much higher for the two galaxies, NGC 157 and NGC 1365, with strong spiral perturbations.

The spatial distribution of the young, extended sources is displayed in Fig. 3 where age was based on the colour-colour diagrams (see Fig.6). Young, diffuse objects are concentrated in the arm regions of the galaxies with strong perturbations whereas less preference to arms is seen for the weaker spirals. In NGC 157 only, a radial trend of the magnitudes of extended sources is observed where sources closer to the centre are brighter, on average, than the more distant ones (see Fig. 4).

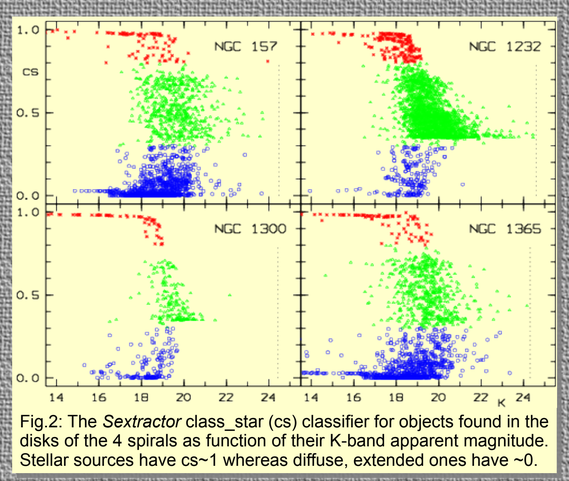

Fig.2: The *Sextractor* class_star (cs) classifier for objects found in the disks of the 4 spirals as function of their K-band apparent magnitude. Stellar sources have cs~1 whereas diffuse, extended ones have ~0.

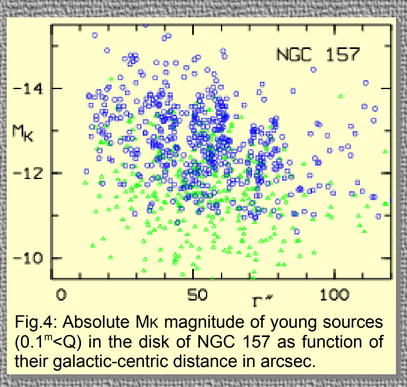

Fig.4: Absolute M_K magnitude of young sources (0.1^m<Q) in the disk of NGC 157 as function of their galactic-centric distance in arcsec.

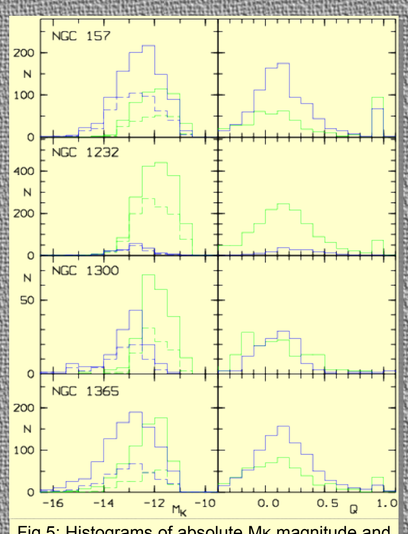

Fig.5: Histograms of absolute M_K magnitude and Q index for sources in the galactic disks of the 4 spirals. Full drawn line for all non-stellar sources with errors <0.2^m while dashed lines are used for young sources with 0.1^m<Q. Colours as in Fig.2.

Magnitude and Colour Distributions

Histograms of absolute K magnitudes M_K for extended sources in the 4 galaxies is shown in the left column of Fig. 5 where compact and diffuse objects are indicated by colour. The colour distributions are displayed in Fig. 6 as (H-K)−(J-H) diagrams using only data with errors <0.1^m. A typical evolutionary track for a stellar cluster with continuous star formation is shown by a dashed line using *StarBurst99* models (Leitherer et al. 1999 ApJS 123, 3; SB99). The galactic reddening vector for A_V= 5^m is indicated. With this extinction law, a 'reddening free' colour index Q = (H-K) – 0.59*(J-H) can be constructed. SB99 models suggest Q to be a good age indicator for 0.1^m<Q corresponding to ages younger than 10Myr. The distribution of Q is given in the right column of Fig. 5.

Both mean and median of the distributions of M_K for diffuse sources are brighter than those for compact objects. In addition, the diffuse objects have a bright tail which reaches -15.5^m for the two galaxies with strong spirals.

The colour-colour diagrams show that the extended sources are consistent with them being stellar clusters reddened by several magnitudes of visual extinction. All 4 galaxies have similar colour-colour distributions but they vary in total number and ratio of diffuse to compact sources. The spirals with weaker patterns have relative more compact sources, which are fainter, whereas the total distributions of Q are very similar with peaks around Q = 0.2^m.

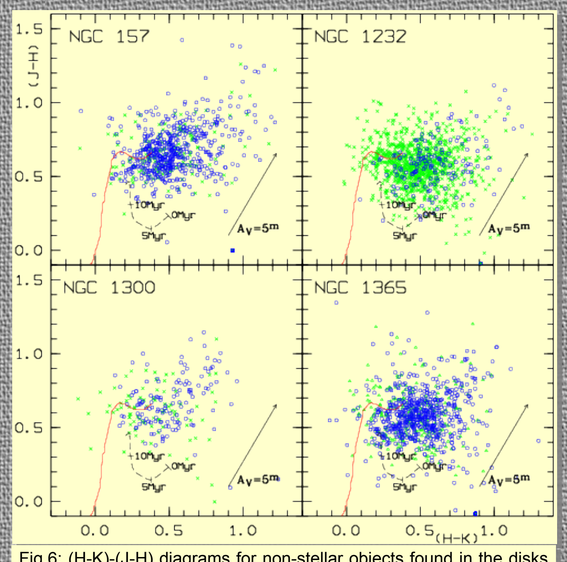

Fig.6: (H-K)-(J-H) diagrams for non-stellar objects found in the disks of the galaxies. The red line indicates the stellar main sequence and the dashed line a typical evolutionary track for a cluster using a SB99 model with continuous star formation. A reddening vector is shown.