Astronomical and Astrophysical Transactions (*AApTr*), 2015, Vol. 29, Issue 1, pp. 57–66,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Two giant stellar complexes

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Received 27 May, 2015

Common star complexes are huge (0.3–1 kpc in diameter) groups of relatively young stars, associations and clusters. The complexes usually form regular chains along spiral arms of grand design galaxies, being evidently formed and supported by magneto-gravitational instability developing along an arm. Special attention is given to a few large complexes which have signatures of gravitational boundness, such as round shape and high central density. Concentrations of stars and clusters in such a complex in M51 galaxy were found in this paper; we concluded it is possible to suggest that the complex is gravitationally bound. It is also stressed that some properties of the giant complex in NGC 6946 (such as its semicircular and sharp Western edge) are still enigmatic.

Keywords: Galaxies, spiral structure, stellar complexes

1 Introduction

In our Galaxy and especially in M31, star complexes are numerous; as always, they are genetically related to HI superclouds, inside of which star-forming molecular clouds concentrate. OB associations and HII regions are also mostly found inside stellar complexes. Thus, Efremov, Ivanov and Nicolov (1987) found that of 210 OB associations which they have independently found in M31 (with mean diameter 80 pc) only 13 are outside a star complex. The average diameter of a complex in M31 these authors have found to be 650 pc; it is close to the mean size of a complex everywhere (Efremov 1995).

About all Efremov, Ivanov and Nicolov's (1987) complexes in M31 were first picked out by van den Bergh (1964) as "stellar associations", but most of them are surely much larger than common associations and have composite structure, the genuine OB-associations being the younger sub-regions of complexes. Note that the famous "association" OB78 in M31 is in fact neither an association nor a complex; it is rather an isolated part of the arm about 2 kpc long, rich in OB stars.

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2 Chains of complexes along arms

As a matter of fact, M31 contains an unusually large number of complexes; most galaxies contain just a few complexes in its spiral arms (Elmegreen and Elmegreen, 1983); sometimes it is difficult to find even one complex in a galaxy. The regular distances and regular magnetic field in the NW arm of M31 suggests that complexes are formed due to magneto-gravitational instability developing along an arm, but the chains of complexes along arms are far from being omnipresent, they were found in only 10% of grand design galaxies (Elmegreen and Elmegreen, 1983). Their list is still the only published result of a systematic search for strings of complexes in spiral arms. It may be important to note that in 15 of their 22 galaxies the Elmegreens found regular chains of complexes in one arm only. Among these galaxies are M100 and probably M51. Pehaps, the surrounding (extragalactic) magnetic field has a certain influence on the separation of an arm into complexes, but there are no data to study this issue.

At any rate, the regular magnetic field is about omnipresent along galactic spiral arms. An important exclusion is the famous case of NGC 6946, where this field is observed just between the optical spiral arms (Beck, 2000). Generally, star complexes are rather rare entities; thus, NGC 6946 hosts just one genuine complex, though quite large (see also Efremov et al., 2011).

Galaxies of regular spiral structure (grand design) are numerous but most of them host no strings of star complexes and sometimes no complexes at all. The most evident example of such galaxies is given by M81 – it does contain a few bright associations but none of them could be called a complex. This is a galaxy without complexes, but it is the classical example of a galaxy hosting spiral density waves. Density waves (shock waves, seen as dust lanes) and star complexes (better to say, regular strings of complexes) seemingly do NOT meet together, at least along the same arm of a galaxy.

The participation of magnetic field in the formation and regular distribution of star complexes along the NW arm of M31 was argued by Efremov (2010). The major axis of the galaxy is oriented in his figures horizontally, star complexes are easily seen due to the concentration of HII regions (O-associations) there, and overlapping ticks (taken from Beck et al., 1989) outline the wavy magnetic field oriented along the arm (see Efremov, 2010 for more details).

R. Beck (2000) has noted that M31 is an exceptional galaxy with respect to magnetic fields and cosmic rays. The field in M31 is very regular and extends far beyond the radio-emitting regions. Star formation there is probably too weak to tangle the regular field. This is however true for NW – but not for the SW arm. Our Galaxy – with the chain of HI superclouds and magnetic field along the Carina arm – is a rare one too. The regular magnetic field is as well observed along the Carina arm (see figures in Efremov (this issue), – as well as along the part of the NW arm of M31 investigated in Beck et al. (1989). Bierman's et al. (2011) comment concerning the Carina arm is as follows: "the brightest Galactic emission is within two degrees of the plane and consists of smooth large scale features and compact sources along the plane; the intensity signal dominates over the noise in the plane at all three bands and the polarization vectors are mostly perpendicular to the plane. This indicates that the large-scale magnetic field is oriented parallel to the plane of the Galaxy".



Figure 1 Spiral galaxy M100 = NGC 4321. Top: General view of the galaxy (ESO image obtained when the bright SN2006 shined there – the lower of the two bright yellow stars above the Southern arm); Bottom left: Southern spiral arm of M100 (from top to bottom – in 8 micron (Spitzer), with the VLT (rgb) of the European Southern Observatory, and with the HST(bw)); Right lower corner – enlarged and corrected for the galaxy plane inclination image of the most Eastern complex of this arm (the HST image). Its appearance in the upper left (8 micron SPITZER) image suggests that the complex is quite old; all other complexes along this arm contain HII regions. (See http://www.spitzer.caltech.edu/images/5208-sig12-007- The-Swirling-Arms-of-the-M100-Galaxy).

There are now many works confirming the conclusion first made by Elmegreen and Elmegreen (1983) that chains of complexes that arise along the arms are due to magneto-gravitational instability developing along arms.

Sometimes the largest complex in a galaxy is observed near the tip of a spiral arm. At least in one case such a complex is the oldest one and looks like a gravitationally bound one. We noted such a complex in M100 (known also as NGC 4321 – a sample

of mystic figures), at the tip of the southern arm of which we noted in the HST image the large complex, having no HII regions and infrared dust emission, surrounding other complexes of this arm (Fig. 1).

The enlarged and corrected for the galaxy plane inclination image of the complex located in the Southern arm tip shows an evident concentration of stars to its center, which may be a signature of gravitational boundness (Fig. 1). The lower right panel of Fig. 1 shows this complex enlarged from the HST image of the M100 southern arm; its image is corrected for the inclination of the M100 plane. At any rate, it is much older than all other complexes of this arm; it follows from the absence of HII emission there, but especially because it does not demonstrate a signature of far-IR emission of the warm gas – unlike all other complexes in this arm – as is evident in the left part of Fig. 1.

3 The star complexes in M51

A dozen of star complexes were picked out in the M51 galaxy by Bastian et al. (2005); many of them are pointed out in Fig. 2, and images of the most impressive ones are enlarged in Figs. 3 and 4. Two complexes are at the limits of the part of the inner arm, where the classical sequence across an arm – dark (HI + dust) lane, HII regions, stars – is observed.

The averaged density evaluations (the colored isolines in Fig. 5) were used to construct histograms in Fig. 6. The radius of the complex is thus ∼300 pc, and, if we include its halo, it is about 600 pc for clusters and 450 pc for stars. Inside the central 60 pc (the first row in Fig. 6) it hosts 5.6 clusters and stars, 1.8 clusters and 3.9 stars. The roundish shape of this complex suggest it is gravitationally bound, as



Figure 2 M51 with its largest star complexes pointed out. 1.2-m telescope, Calar Alto observatory, Spain. APOD: 2010, June 11.



Figure 3 One of the best M51 complexes, at NE of the inner arm, which includes the large cluster and strange dust arcs. The details of the HST image, as well as Fig. 4.

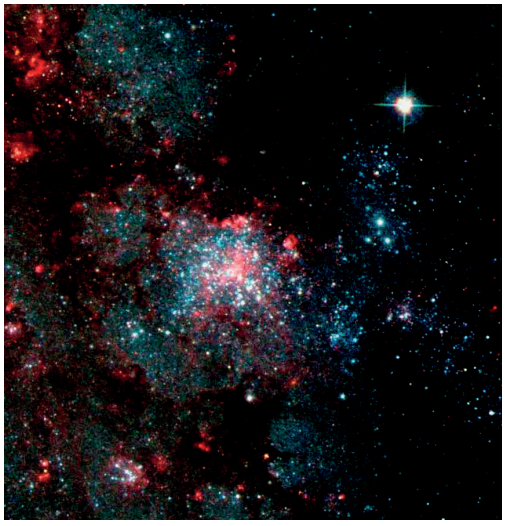


Figure 4 The giant star complex at the West of the M51 inner arm (designated as G2 in Bastian et al., 2005), which includes a number of clusters and HII regions. Maps of the complex in Fig. 5 have exactly the same borderlines. Dark regions to its West and North are really empty of stars or HII regions, whereas in other directions these are mostly dark clouds.

well as the complex at the tip of the M100 southern arm (Fig. 3). The origin of these giant dense complexes is unknown. Such objects look like superclusters of stars and common clusters; one of these very rare objects is known also in NGC 6946.

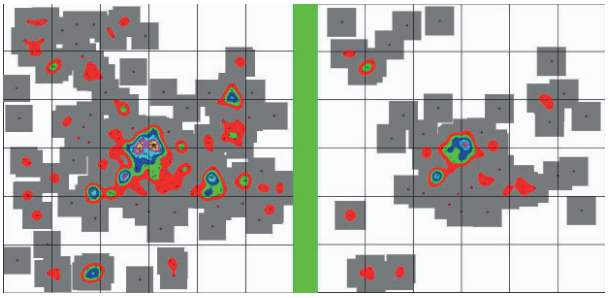


Figure 5 Maps of clusters plus stars (left), and only stars (right) in the complex G2. The size of each map is 600 × 600 pc and is equal to the size of the image in Fig. 4. Isolines of densities are shown by color.

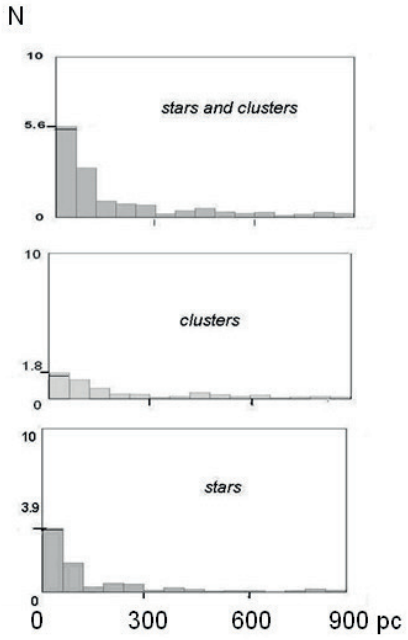


Figure 6 Distributions of column density of objects inside the complex G2. The densities are shown as a function of their distance from the center of the complex (up to 900 pc).

4 Strange supergiant complex in NGC 6946

The giant (some 700 pc in diameter) complex which seems to be located at the tip of a secondary faint arm of the peculiar galaxy NGC 6946, is remarkable not only due to its size, but also because of its sharp arc-like western edge, which is a 130-degree long segment of a regular circle.

The HI hole around it is only a bit larger than the complex itself. The case of NGC 6946 complex is the most mysterious one, although it has been investigated many times, with the HST also. It was first noted by P. Hodge long ago and then



Figure 7 The peculiar supergiant complex in NGC 6946. The detail of the image obtained at the KPNO.

was the goal of many investigations, the latest one is Efremov et al. (2011). This complex hosts both stars and clusters and is, therefore, not similar to a supergiant star cluster (as is the case for the giant complex at the tip of the arm in M100); it is rather similar to a dwarf galaxy of the regular shape, such as NGC 1705; like this galaxy, the Hodge complex hosts the supergiant young (30 Myr old) star cluster, as well as a number of smaller clusters.

If it is possible that the shape of the complex Western edge was formed owing to the complex moving to the West through the NGC 6946 plane. At any rate, this could explain both the regular shape of the Western edge of the complex; also, some structures visible near the complex East, are somewhat like the entities known as "von Karman vortex street downstream".

The regular and sharp semicircle, which forms the complex Western edge, recalls the objects which are moving through the gas medium and the leading edge of which was formed by the ram pressure. Providing it is the case, we have to assume that the Hodge complex is moving about parallel to the NGC 6946 plane inside its gas layer – because the radial velocity data disprove the suggestion that the complex is a foreground object. Occurrence of a HI mini-hole near the complex North-East border line has misled a number of investigators (for example, Efremov et al., 2007), but it is now evident that such mini-holes are very numerous at least in the NGC 6946 NW quadrant; this issue is the topic of a special investigation. All in all, the case of the NGC 6946 complex is the most mysterious one.

5 Conclusions

Apart from the nature of rare giant complexes, which are clearly bound and evidently were not formed in the same way as the usual members of complex chains along the spiral arms, the unresolved issues of morphology of galaxies is the origin of holes in their HI discs. Numerous mini-holes were found in NGC 6946 and we are in the very beginning of their studies; the possibility is open that clustering of these mini-holes

may give the explanation of giant holes (much larger than the thickness of HI layer in a galactic disk). Occasional concentrations of mini-holes and HI clouds might produce large holes in the gas disk of a galaxy, especially if it is thin enough. Something of this kind was proposed by Elmegreen (1997) in his picture of the turbulent origin of HI holes in fractal gaseous disks.

We would like to stress once more (see Efremov et al., 2011) that the signatures of shock excitation inside the holes of the gaseous disc of the NGC 6946 galaxy are typical of extraplanar warm diffuse ionized gas (EDIG) observed in a number of spiral galaxies at their relatively high Z-coordinates. This can most likely be explained by low density of the gas inside the NGC 6946 cavities, due to which we see through these HI holes the spectral features of the EDIG gas of our Galaxy (and to some degree of NGC 6946) projected onto them. This picture is strongly supported by the consideration of Fig. 5 in the paper by Boomsma et al. (2008) – in addition to the HI rotation curve of NGC 6946 we see there the horizontal HI strip due to the local (MW) neutral hydrogen. This is confirmed by its radial velocity, which is the same as observed inside the holes in HI disk of NGC 6946 – as well as by the typical for such Galactic warm ionised gas line ratios, observed inside mini-holes of NGC 6946 – as described in Efremov et al. (2011).

Heyles (1979), first finding out a dozen of super-shells in our Galaxy, noted that though they could be made by the large number of Supernovae of type II flashing in the same OB-association, the super-shells seem not to be connected with extreme objects of the population I, and it is a strong argument against such opportunity. He concluded that "Their [super-shells] production rate is so low that it is extremely improbable that we have ever directly observed the agent responsible for their existence. This agent may itself be a new unknown kind of astronomical objects".

Acknowledgements

We are deeply grateful to R.A. Scheepmaker, who compiled the enormous catalog of data on stars and clusters in M51, based on the HST images. We have used the classification of objects as stars or clusters as given in this catalog. The warm hospitality of Prof. Lamers in 2005 (during a stay of Yu.N. Efremov in Utrecht University) has made our work on M51 galaxy possible.

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