

# **Triggered Star Formation in the Small Magellanic Cloud<sup>†</sup>**

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### Abstract

The Large and Small Magellanic Cloud (LMC, SMC), our closest undisrupted neighboring dwarf galaxies, have an energetic star formation activity, which is demonstrated by the large variety of bright HII regions related to young stellar associations. Luminous (but short-lived) high-mass stars in such systems shape their surroundings through outflows, winds, and supernovae explosions, which eventually trigger sequential star formation in their vicinity. Large samples of low-mass stars (with  $M \leq 1 \, M_{\odot}$ ) currently in the act of formation are resolved in such regions with the Hubble Space Telescope and these pre-main sequence (PMS) stars provide a unique record of star formation processes triggered by their massive companions for the last 20 Myr. We present the latest results from our multi-wavelength study of the star formation in two such *bona-fide* HII regions in the SMC.

#### NGC 346/N 66: The brightest HII Region in the SMC



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The SMC association NGC 346 is related to the brightest SMC HII region, N 66. Deep Hubble observations with the Advanced Camera for Surveys (ACS) revealed a large number of low-mass pre-main sequence (PMS) stars in the vicinity of NGC 346 and the surrounding area [2]. The spatial distribution of these stars shows the existence of significant substructure indicating the loci of recent clustered star formation. Apart from the bar of N 66 within which NGC 346 is embedded, the area north of the association includes the most recent star formation. This area, outlined by the nebulosity as an arc-like feature, is characterized by the younger PMS stars, as well as by a high concentration of YSOs and emission-line stars [5]. Based on multi-wavelength observations of the ISM, we propose that this arc encompasses current star formation triggered by the action of a near-by corecollapse supernova, which in addition to the photo-ionizing action of the OB stars of the association shapes the current star formation history of N 66 [4] (FIGURE 1).



FIGURE 1: Color-composite image of the general area of NGC 346/N 66 (left) and schematic representation of the proposed SF scenario for this region (right). The color image is constructed from observations in X-rays with XMM-Newton (blue), [O 111] with NTT (green) and the 8 µm Spitzer/IRAC channel (red). Two major arc-like features are apparent (drawn with red thick curves): The one to the south (bottom) is considered to be the product of the energy output from the OB stars of the association. The other to the north, coincides very well with a shock-wave from the SN remnant B0057-724, which is clearly visible from the bright circular X-ray emission around it, to the east. The drawn isodensity contour map is constructed from counting the bright blue main sequence and faint red PMS stars, and it is shown to demonstrate the geometry of the youngest stellar concentrations [4].



NGC 602/N 90: A bright HII Region in the Wing of SMC

The coexistence of HII regions and PMS stars in stellar associations of the MCs indicate that star formation may be still active in their vicinity. Indeed, observations with the Spitzer Space Telescope of the region of NGC 602/N 90 revealed objects classified as candidate Young Stellar Objects (YSOs), and the comparison of the loci of these IR-bright sources with the Hubble images interestingly showed PMS stars to be their optical counterparts [3]. Our *Spitzer*/IRAC photometry revealed bright mid-infrared sources, which we classify with the use of a scheme based on templates and models of red sources in the Milky Way, and criteria recently developed from the *Spitzer* S<sup>3</sup>MC Survey [1] for the selection of candidate YSOs. We detected 57 sources in all four IRAC channels in a  $6'_{2} \times 4'_{8}$  field-of-view centered on N 90; 22 of these sources are classified as candidate YSOs.



FIGURE 2: Color-composite images of the region NGC 602/N 90 from Spitzer/IRAC observations (with IRAC-1 3.6  $\mu$ m channel in blue, IRAC-2 4.5  $\mu$ m in green, and IRAC-4 8  $\mu$ m in red; left) and from Hubble/ACS observations (in two broad-band filters,  $F555W \equiv V$  and  $F814W \equiv I$ , and one narrowband filter,  $F658N \equiv H\alpha + [N II]$ ; right). Red boxes indicate the positions of the candidate YSOs detected with our IRAC photometry [3]. These pictures clearly indicate that current star formation takes place at the periphery of the central association NGC 602. Probably, star formation started at the association, where the highest concentration of PMS stars has been found (see [7]), and propagated outwards, mainly to the east and south, with events of ongoing clustered star formation still taking place along the dust ridges.

We compare the locations of these objects with the position of optical sources recently found in the same region with high-resolution HST/ACS imaging of NGC 602 by [7], and we find that 17 candidate YSOs have one or more optical counterparts. All of these optical sources are identified as pre-main sequence stars, indicating, thus, ongoing clustered star formation events in the region. The positions of the detected YSOs and their related PMS clusters give a clear picture of the current star formation in N 90, according to which the young stellar association photo-ionizes the surrounding interstellar medium, revealing the HII nebula, and triggering sequential star formation events mainly along the eastern and southern rims of the formed cavity of the parental molecular cloud (FIGURE 2).

#### "Pillars of Creation" in $NGC \ 602/N \ 90$

A variety of objects is discovered to coincide with the candidate YSOs of NGC 602/N 90, such as single highly embedded sources and compact PMS clusters. Interesting cases are the candidate YSOs, both with and without optical counterparts, which are discovered at the edge of features similar to the "Pillars of Creation" or "Elephant Trunks" (found in the Eagle Nebula; see [6]). All these features are located at





The comparison of the positions of the candidate YSOs found in NGC 346/N 66 [8] with the isodensity contour map of the PMS stars detected with Hubble/ACS photometry [2], [5] (Solid dots show the positions of the "definite" YSOs, while the imes symbols denote for the "probable" YSO candidates; right map in FIGURE 4) shows an excellent coincidence with the highest concentrations of PMS stars. All young compact clusters of PMS stars found by [5] include one or two massive YSOs giving evidence of signatures of primordial mass segregation.

the periphery of NGC 602, along the dust ridges of the molecular cloud presumably blown-away by the action of the association itself.



FIGURE 3: "Pillars of Creation" in NGC 602/N 90

FIGURE 4: Active Star Formation in NGC 346/N 66

The color-composite image from three *Spitzer*/IRAC channels of the region around NGC 346/N 66 (with the 3.6  $\mu$ m shown in blue, 4.5  $\mu$ m in green, and 8  $\mu$ m in red; left image in FIGURE 4) reveals the loci, where star formation is active. A significant population of bright infrared sources, classified as YSOs are discovered from these observations in the general area of NGC 346/N 66 indicating that star formation still indeed takes place in the region. Spectral energy distribution (SED) fits based on models by [9] revealed 61 objects, which are classified as "definite" YSOs, in addition to another 50 "probable" YSOs [8].

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