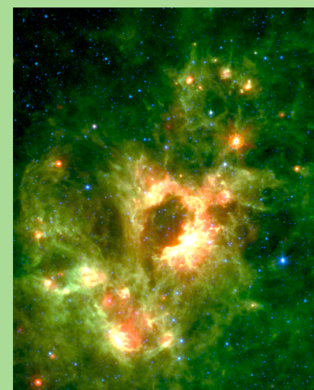
Massive Star Formation in the LMC HII Complexes

C.-H. R. Chen[1], Y.-H. Chu[2], R. A. Gruendl[2], K. Gordon[3], F. Heitsch[4], R. Indebetouw[1]

[1]U of Virginia, [2]U of Illinois, [3]STScI, [4]U of Michigan

We use the HII complexes N44 & N159 in the Large Magellanic Cloud to perform a detailed study of star formation in mild starbursts, as they host regions of star formation at different evolutionary stages and are not as complicated and confusing as the 30 Dor giant HII region. *Spitzer* observations of N44 and N159 have revealed a large number of shrouded young stellar objects (YSOs). These YSOs provide an excellent chance to study the properties of young massive stars. Also, as these YSOs have not dynamically altered the large-scale interstellar conditions, it is possible to assess the cause of the on-going star formation. Observations used in this study are listed in Table 1.

Observations
Stellar Sources
CTIO 4m Mosaic UBVI images
CTIO 4m ISPI JHK images
Spitzer IRAC 3.6–8.0 μm images
Spitzer MIPS 24 μm images
Interstellar Environments
HST WFPC2 Hα images
MCELS Hα images
ROSAT X-ray PSPC
ATCA+Parkes HI map



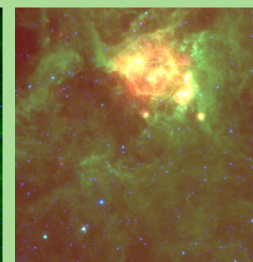


Fig 1. Color composite of 3.6, 8.0 & 24 µm images of N44 (left) & N159 (up). Diffuse features show PAH/dust emission. Dust shrouded objects, e.g., YSOs, appear red.

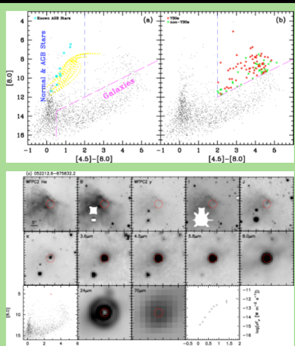


Fig 2. Upper: CMD of all sources in N44. YSOs occupy the right side of the CMD; the upper right wedge has minimal contamination from stars and galaxies. Lower: An example of Type I YSO to illustrate the identification process.

Identification & Classification of YSOs

1. Initial Selection of YSOs candidates. (Fig 2)
   2 color-magnitude criteria to exclude contaminants.
2. Spectral energy distribution from optical to 24 μm.
   Type I: rising from near-IR to 24 µm and beyond;
   Type II: a low peak at optical & a high peak at 8-24 µm;
   Type III: bright stellar & modest dust emissions.
3. High-resolution images. HST, CTIO 4m Mosaic & ISPI to examine multiplicity & irregularity.

- YSO candidates identified: 60 in N44, 30 in N159.
- > 65% YSOs, i.e., 39/60 in N44 & 23/30 in N159, resolved or appear extended in high-resolution images.

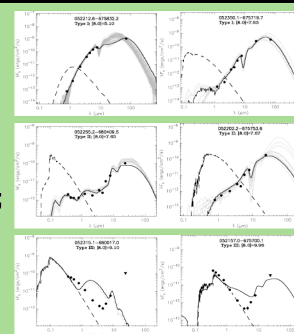


Fig 3. Examples of model fitting to SEDs of YSOs. Upper: Type I. Middle: Type II. Lower: Type III.

Physical Properties of YSOs

SEDs of YSOs are modeled for those appear single or dominant within a group (Fig 3):

1. Good fits for Type I & I/II YSOs.
2. Type II & II/III YSOs show deviation between observed SEDs & models w/o PAH emission.
3. Discrepancies in some Type III YSOs suggest large holes in their disk components. Holes ~1000AU needed to reproduce SEDs (Fig 4).
4. YSO counterparts found in 7 ultra-compact HIIR (Indebetouw et al. 2004): 1 Type I, 4 Type I/II, & 2 Type II. 5 YSOs w/ good 24 µm measurement have mass estimates consistent between SED fitting & ionization requirement of HIIR.

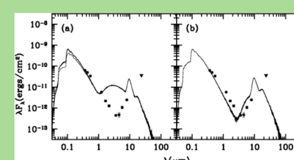


Fig 4. Model SEDs of Type III YSO with inner disk radii set as (a) 50 AU and (b) 1000 AU.

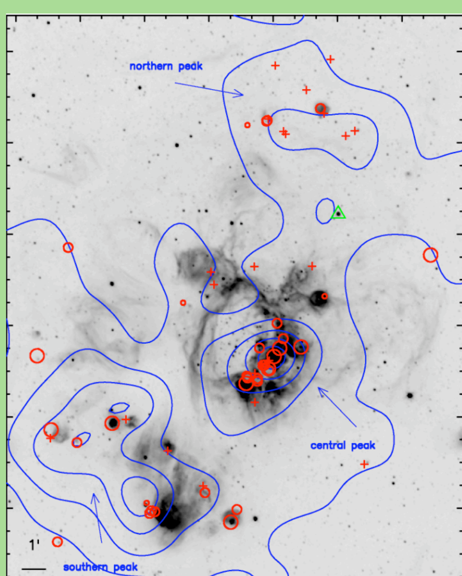


Fig 5. Distribution of YSOs on Hα image of N44. YSOs of different masses marked as follows: large circle – O, medium circle – early B, small circle – mid to late B, plus – no estimates. Contours from the Nanten CO survey (Fukui et al. 2001)

Distribution & Formation of YSOs

Figs 5 & 6 show the distribution of YSOs w.r.t. ionized gas and molecular clouds:

1. Most of the YSOs are found in molecular clouds.
2. ~ 75% of the YSOs in N44 & ~70% in N159 are associated with the ionized gas region, where massive stars were formed in the last few Myr. The correlation between past & current massive star formation is strongest for O-type YSOs.
3. Triggered star formation? The central supershell of N44 exhibits the most prominent association between energy feedback & star formation.

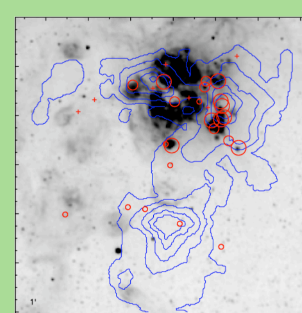


Fig 6. Distribution of YSOs on Hα image of N159. Same symbols as in Fig 5. Contours from SEST CO data (Johansson et al. 1998)

References: Chen et al. 2008, ApJ submitted (rchen@virginia.edu for preprint); Fukui et al. 2001, PASJ 53, 41; Indebetouw, Johnson, & Conti 2004, AJ 128, 2206; Johansson et al. 1998, A&A 331, 857.