HST imaging and spectroscopy of Compact HII regions in the Magellanic Clouds: Revealing the youngest massive star clusters

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We present our results of the first high resolution imaging using the Hubble Space Telescope (HST) of a sample of high excitation "blobs" (HEBs) which constitute a rare class of compact HII regions in the Magellanic Clouds. Unlike the typical HII regions of these galaxies which are extended structures with sizes greater than 50pc, the compact HII regions are an order of magnitude smaller having diameters of less than about 4pc. HEBs are probably the final stages in the evolution of the ultra-compact HII regions -- whose Galactic counterparts are detected only at infrared and radio wavelengths. The resolving power of HST enables us to identify the massive young stars enshrouded in those regions and present a census of their population. Our sample includes N81, N88A, in the SMC as well as N159-5, N83B, N160A, and N11A of the LMC. Contrary to what it was originally thought and despite their small size, the HEBs studied are not excited by a single massive star. Direct measurement of their spatially varying extinction reveals clumps of dust suggesting a considerably higher dust absorption than what had been deduced from ground-based integrated measurements. Dust is locally associated with ionized gas and also lies outside the nebulae. The HII regions display fine structures due to a turbulent environment typical of newborn massive star formation sites.

Color-Magnitude diagrams of the exciting stellar population indicate that it is consistent with an O6-O8 type, and Far UV spectroscopy with HST/STIS of several of these stars further confirms their youth. Surprisingly though, it also shows an astonishing weakness of their wind profiles and their sub-luminosity, up to ~2mag fainter in Mv than the corresponding dwarfs. Our analysis suggests that these stars are probably in the Hertzsprung-Russell diagram locus of a particularly young class of massive stars, the so-called Vz luminosity class, as they are arriving on the zero age main sequence.

Object: **N81 (DEM138)**

Location: RA=01:09:13, Dec=-73:11:38 (J2000) in the SMC

Overall Morphology:

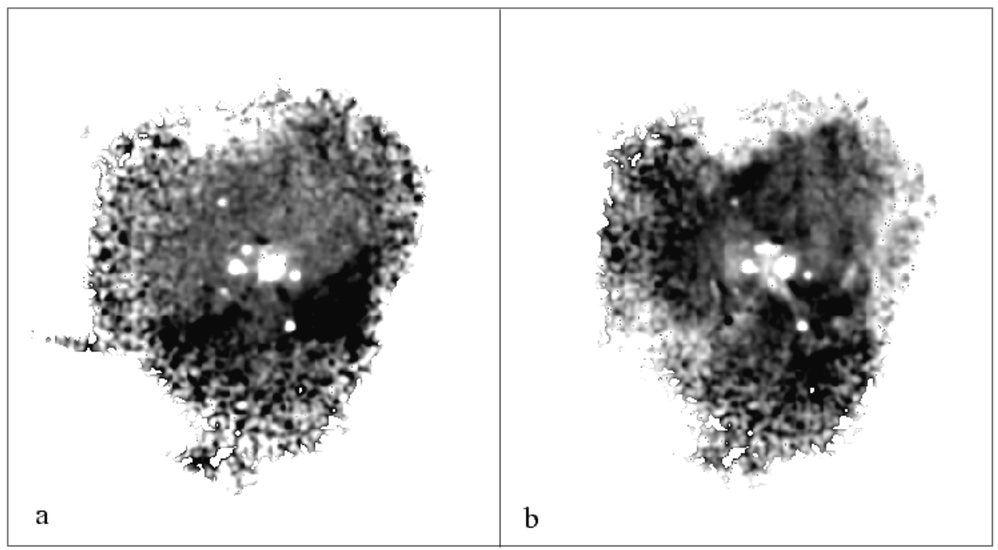
An apparent cavity has been created by at least two exciting stars at the center. Two prominent dark lanes and several ionized/shocked ridges are visible.

Nebular Emission:

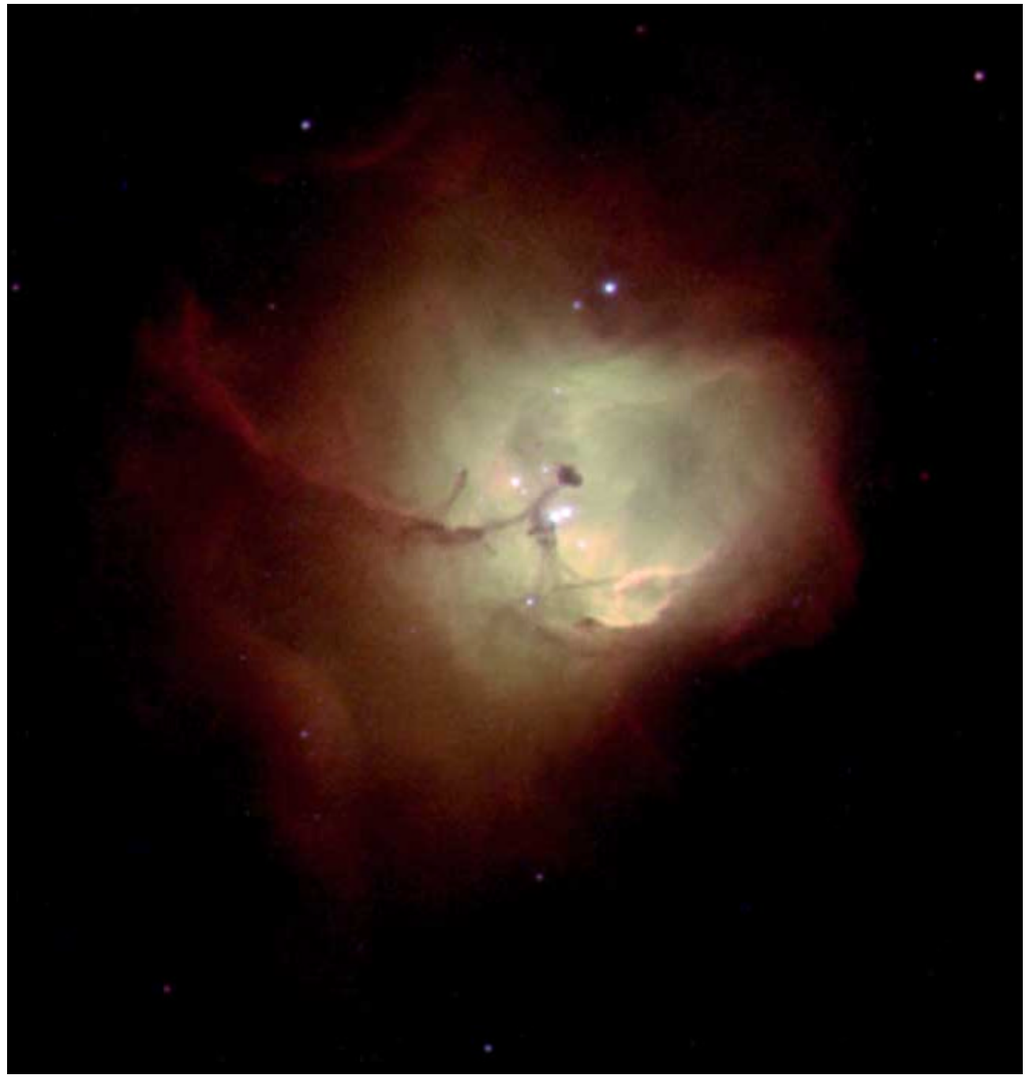
If the region is ionization bounded a de-reddened Hβ flux of Fo(Hβ)=1.2x10^{-11} erg cm^{-2} s^{-1} which corresponds to a UV flux of N_{lyman} = 1.36x10^{49} photons s^{-1} (consistent with an O6.5 or O7 star).

Stellar Content:

The photometry and CM diagram suggest the presence of several stars at Stromgren colors b-y=-0.05 u-b=-0.2 typical of massive OB type. The brightest is estimated to be at least 41 Msun and to have a logL=5.59 Lsun. New UV spectroscopy with STIS (see bellow) reveals that several of them belong to the Vz luminosity class.



Line intensity ratios of the center of N81. White spots are stars and dark colors correspond to high values. a) The Balmer decrement (Hα/Hβ) is typically 3.3 (Av=0.4 mag) reaching 4.5 at the dark globule. b) The [OIII]λ5007/Hβ ratio is almost everywhere higher than 4.5 and peaks at ~6 at the southern bright ridge.



A "true color" image (red = Hα, green = O[III], blue = Hβ) image of N81. The field is 33'' (10pc) on each side. North is up and East to the left. Note the two bright main exciting stars at the center of image with a projected separation of 0".25 (0.08pc) and the absorption lanes surrounding the cavity connecting to the dark globule at the center.

References: M. Heydari-Malayeri et al. 1999, A&A 344, 848
M. Heydari-Malayeri et al. 2002, A&A (@astro-ph/0110576)

Object: **N88A (part of N88 or DEM161)**

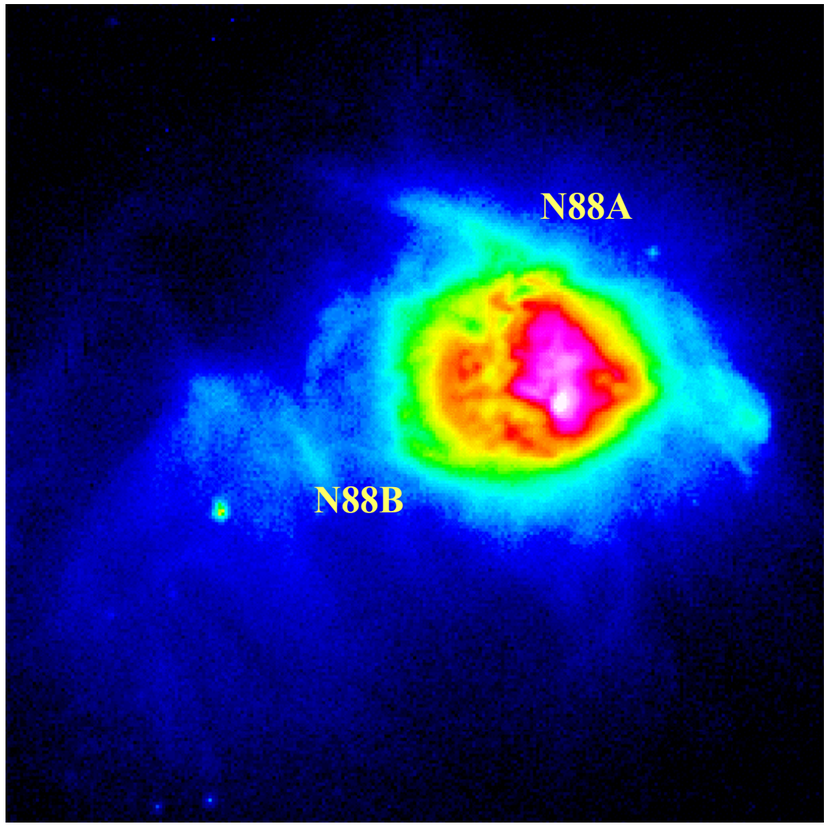
Location: RA=01:24:08, Dec=-73:08:55 (J2000) in the SMC

Overall Morphology: Extended Hα emission and several bright components. The brightest is N88A and N88B is just to its east. A bright rather diffuse and curling filament is seen extending to the south.

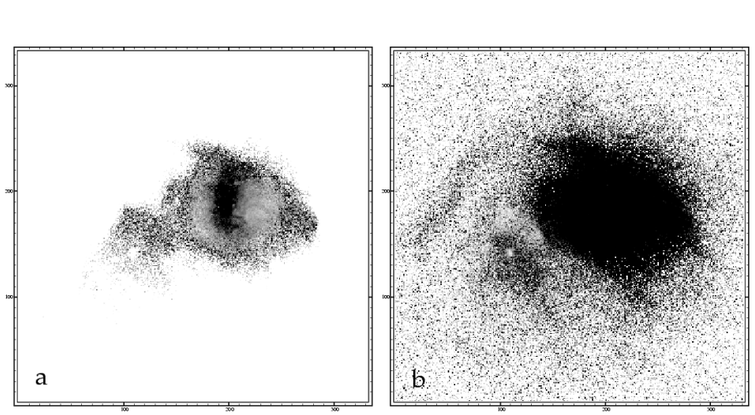
Nebular Emission: If the region is ionization bounded a de-reddened Hβ flux of Fo(Hβ)=1.97x10^{-11} erg cm^{-2} s^{-1} is measured which correspond to a UV flux of N_{lyman} = 2.1x10^{49} photons s^{-1} (consistent with a single O6.5V star).

Stellar Content / Extinction:

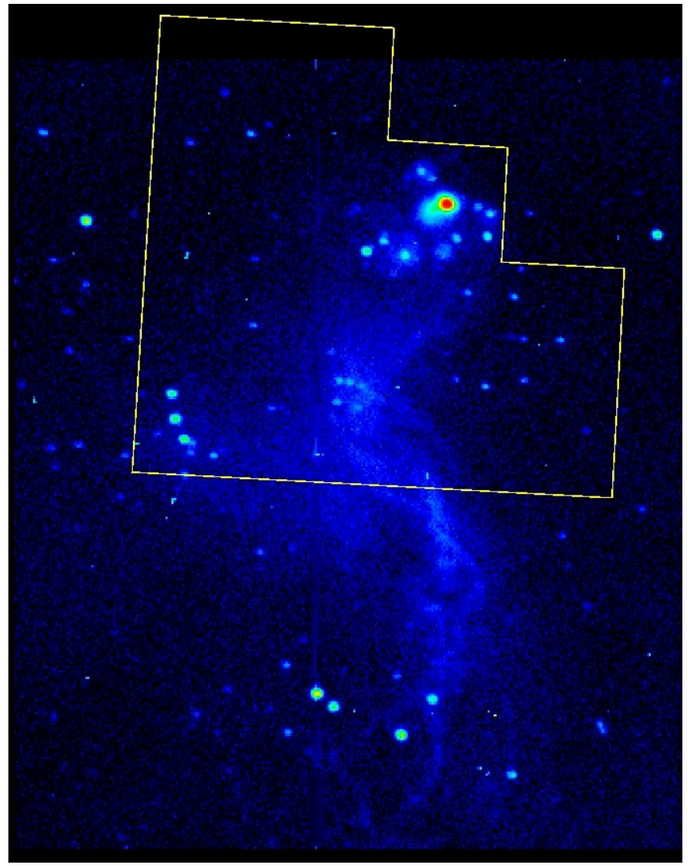
Tens of stars are identified in the overall area of N88 and several of them can be associated with the ionized small HII regions surrounding N88A. However in N88A we can clearly detect only two rather faint stars (of y~18.2 mag) while an even fainter one (y~20 mag) coincides with the Hα peak. If these are newborn massive stars (i.e.O9V) then the extinction in N88A is Av~3.4mag or even ~6mag at the peak.



Ha image of N88A and N88B. Field size ~12”x12” (~3.5x3.5pc). The absorption lane splitting across N88A is visible.



Line intensity ratios of the center of N88A. a) The Hα/Hβ peaks at the narrow absorption lane where Av~3.5 mag. b) The [OIII]λ5007/Hβ ratio is typically ~7 and rises to ~9 at several areas.



Hα image of N88 (1’.7x2’.0 =31x27pc) taken with the ESO 3.6m, with the area imaged by HST marked. N88A and B, displayed in the other two figures of this page, are the brightest blob at the top while the other components are seen as spots around it. North is up and East to the left.

Reference: M. Heydari-Malayeri et al. 1999, A&A 347, 841

Object: **N159-5 (the "Papillon'' nebula)**

Location: RA=05:40:05, Dec=-69:44:38 (J2000) in the LMC

Overall Morphology:

Very turbulent medium with ionized subarcsec structures ridges and filaments. The brightest region has a butterfly-like morphology and dark lane associated to a molecular cloud can be seen to its south as well as a high excitation shocked arc visible in [OIII] to the southwest.

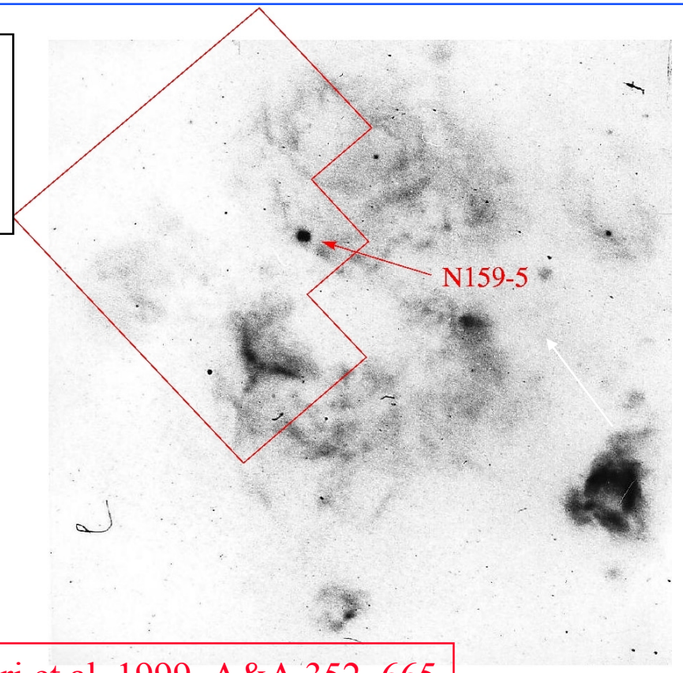
Nebular Emission:

If the butterfly region is ionization bounded correcting for reddening we find $Fo(H\beta)=2.68x10^{-13}$ erg cm^{-2} s^{-1} and $N_{lyman} = 4.17x10^{48}$ photons s^{-1} (consistent with an O8V star).

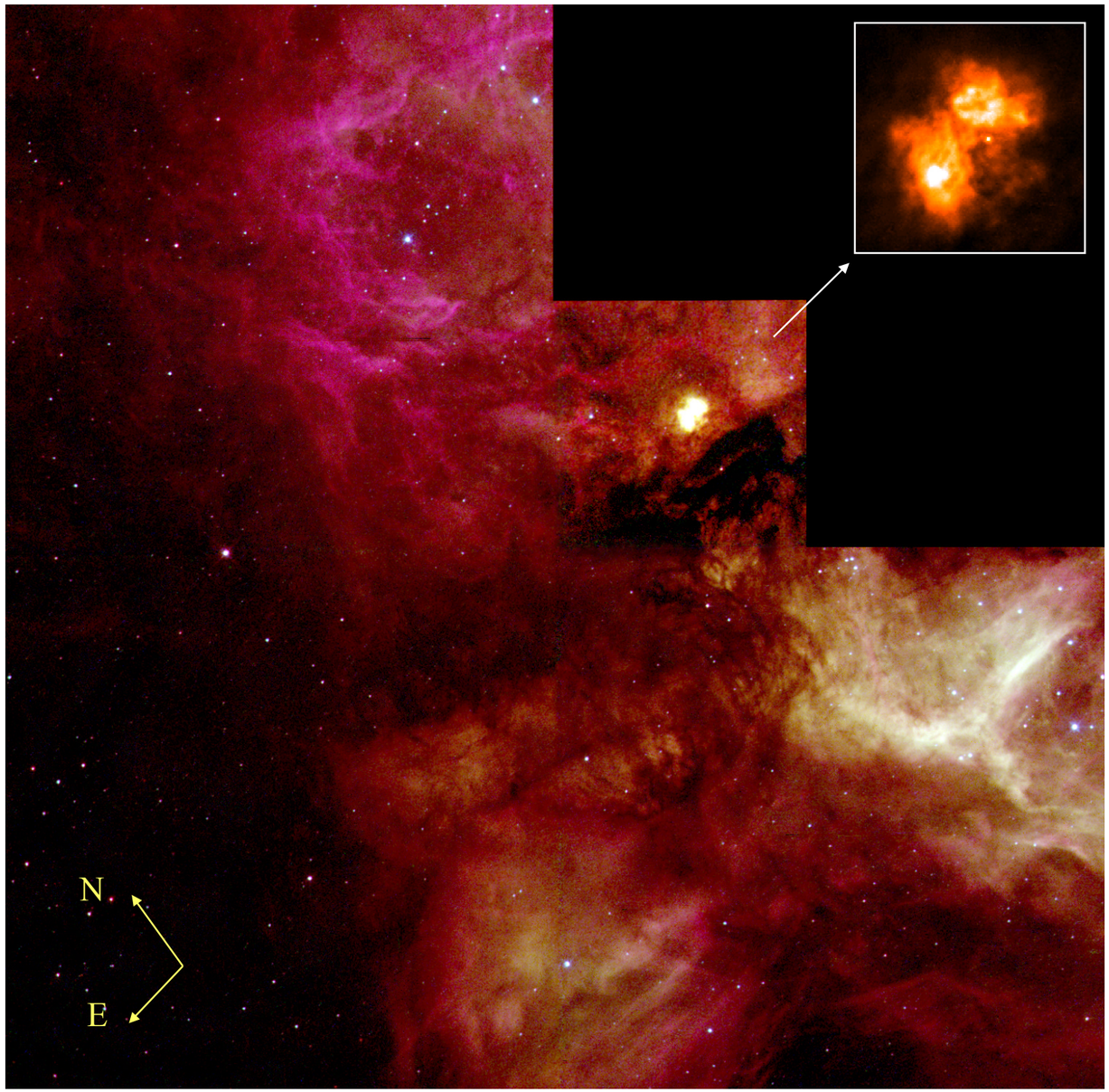
Stellar Content / Reddening:

Overall we measure that the Av ranges between **1.5 and 3.5 in the visible.** However, no prominent stars are visible in the center of the butterfly. It is very probable that this is due to very high extinction as the exciting stars of the region are still buried inside their cocoon. The photometric limit of detections suggest that for an O8 star to remain undetected the extinction in the center must be Av~6mag.

Hα image of N159 taken with the ESO 3.6m.. The area imaged by HST as well as N159-5 are marked.



Reference: M. Heydari-Malayeri et al. 1999, A&A 352, 665



A "true color" image (red = Hα, green = O[III], blue = Hβ) ~2x2arcmin (~32x32pc) of N159. The yellowish colors represent the higher excitation gas as traced by the [OIII] emission line and they are found in the blob and the giant southern ridge. In the inset (5" or 1.3pc on the side) we display an Hα image of the butterfly-shaped HII region. The unique morphology of this blob could result from a bipolar outflow from a rotating star. The apparent ring structure could be due to projection effects of a bubble formed from the subsonic motion of a mass losing star as it moves through the ISM.

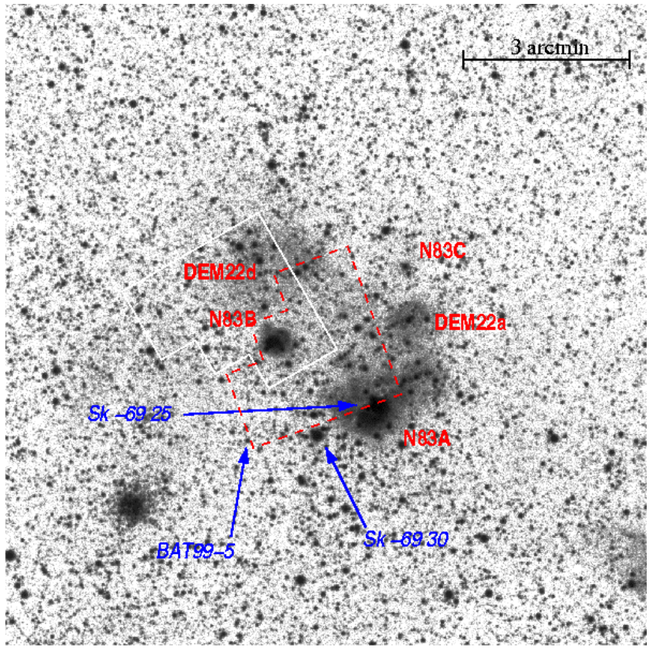
Object: **N83B** **Location**: RA=04:54:22, Dec=-69:11:04 (J2000) in the LMC

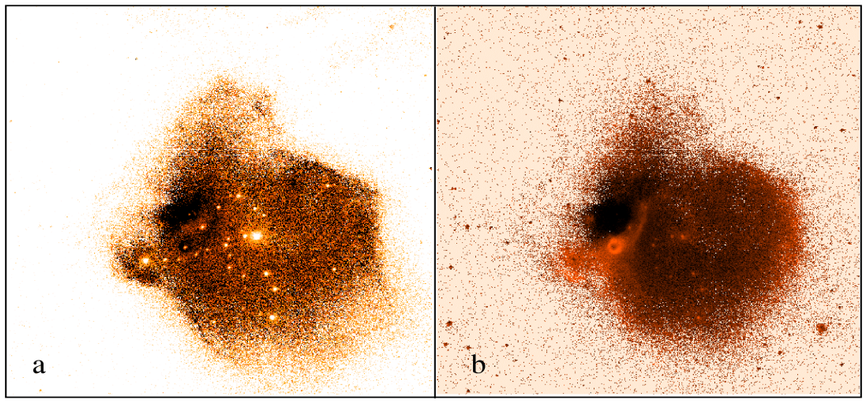
Overall Morphology: Two bright components (N83-1 to the north and 2 to the south) are resolved in the blob, each one associated with an exciting star. They are found to the east of an apparent cavity which has been created by another exciting star. There is strong evidence of sequential/hierarchical star formation.

Nebular Emission: If the region is ionization bounded correcting for reddening we find Fo(Hβ)=1.76x10^{-11} erg cm^{-2} s^{-1} and N_{lyman} = 1.37x10^{49} photons s^{-1} (consistent with an O6.5 or O7 star).

Stellar Content / Extinction: Numerous massive stars are identified throughout the nebula. The extinction peaks at Av~1.3mag with a mean of 0.7mag (see a) while the [OIII]λ5007/Hβ reaches ~6 (see b).

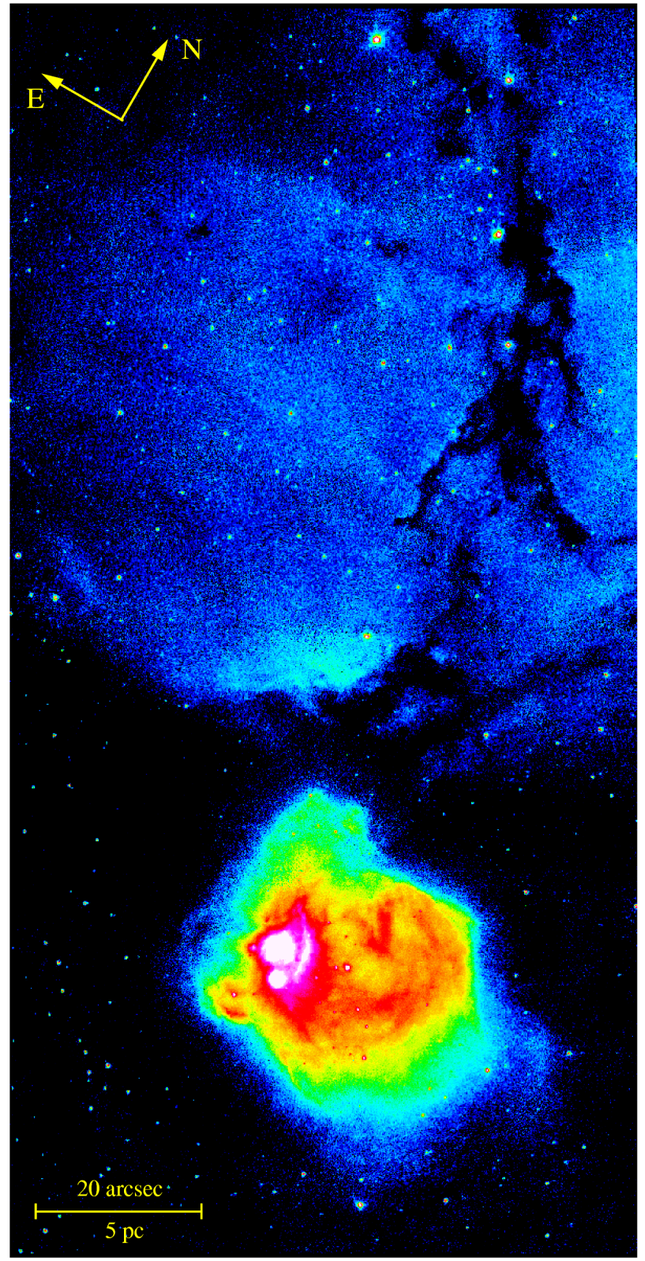
The LMC OB association LH5 and its HII complex N83. Our HST fields and various regions are marked.





Line intensity ratios a) Hα/Hβ b) The [OIII]λ5007/Hβ

"True color" HST image of N83B (15x15pc). Note the outstanding shock ridge west of N83B-1 the violet (strong in Hβ) N83B-2 to its south, and the curly cavity with a bright star at the center to the east. Age estimates on the formations of these structures are in agreement with a scenario of fractal/hierarchical star formation (Elmegreen 2000 , ApJ 530, 277)



Hα image of N83B taken with HST. Notice the bright blobs N83B-1 and N83B-2 to the south engulfed to the east of the curly shell like emission nebula. A dark lane is extended to the north east.

Reference: M. Heydari-Malayeri et al. 2001, A&A 372, 495

Object: **N11A**

Location: RA=04:57:16, Dec=-66:23:21 (J2000) in the LMC

Overall Morphology:

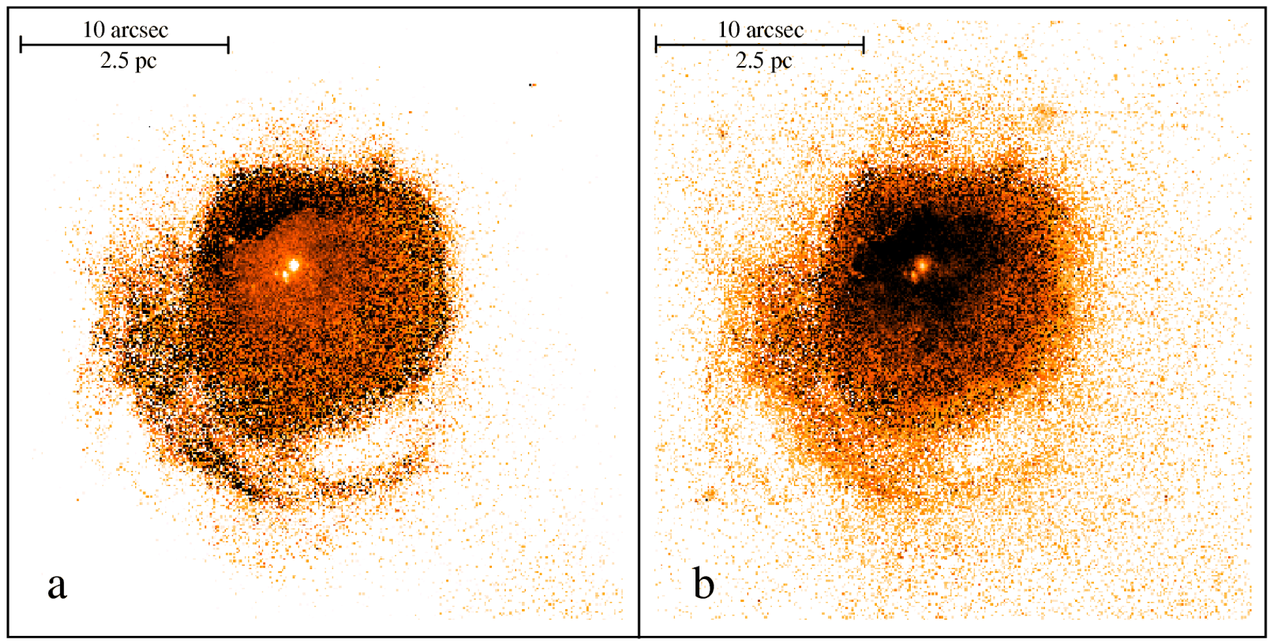
The whole region is rather compact with a core harboring 5 stars surrounded by a diffuse envelope, 8 arcesec in diameter. A bright ridge is seen to the north east, but it is ended abruptly by the edge of an absorption zone. The Hα flux beyond the ridge drops by a factor of 10.

Nebular Emission:

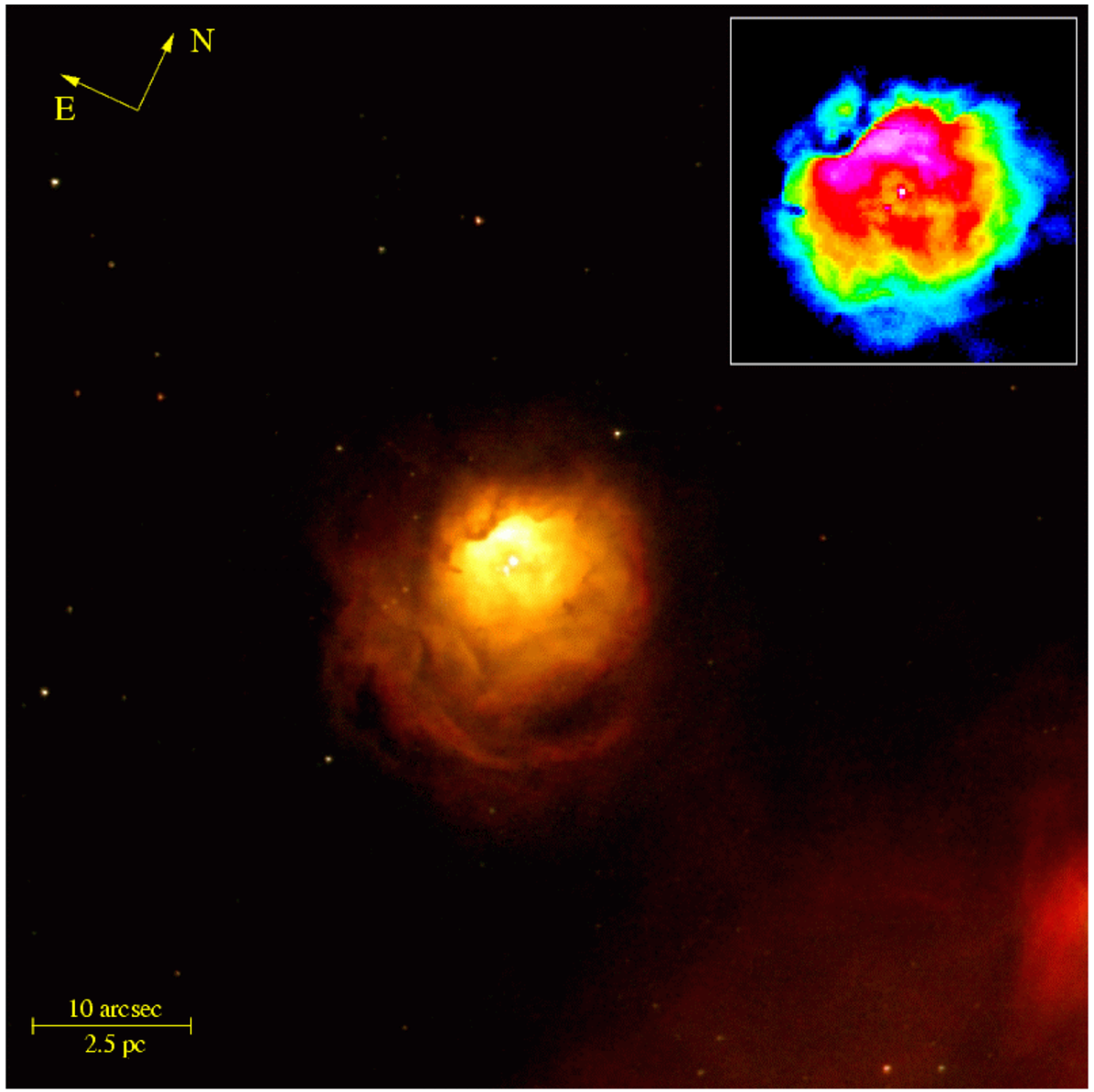
If the region is ionization bounded then correcting for reddening we find that $Fo(H\beta)=1.17x10^{-11}$ erg cm^{-2} s^{-1} and $N_{lyman} = 9.10x10^{48}$ photons s^{-1} (consistent with an O7.5-O8V star).

Stellar Content / Reddening:

Overall we measure that the Av of the absorption zone to the NE of N11 peaks at 1.8 which its mean values is 1.3. Outside the area the extinction is much lower and the measured Av=0.6. Consequently, N11 appears as one of the most dust free blobs. Only 7 stars are seen directly associated with it.



Line intensity ratios: a) Hα/Hβ b) The [OIII]λ5007/Hβ



"True color" HST image of N11A, with an inset of the Hα emission. Note the cavity around the bright central star (y=14.7mag), as well as the strong absorption zone to its NE. The region is relatively isolated compared to the N159-5, N160A1, and N160A2.

Reference: M. Heydari-Malayeri et al. 2001, A&A 372,527

Object: **N160A (NGC2080 - the "Ghost Head Nebula'')**

Location: RA=05:39:44, Dec=-69:38:45 (J2000) in the LMC

Overall Morphology:

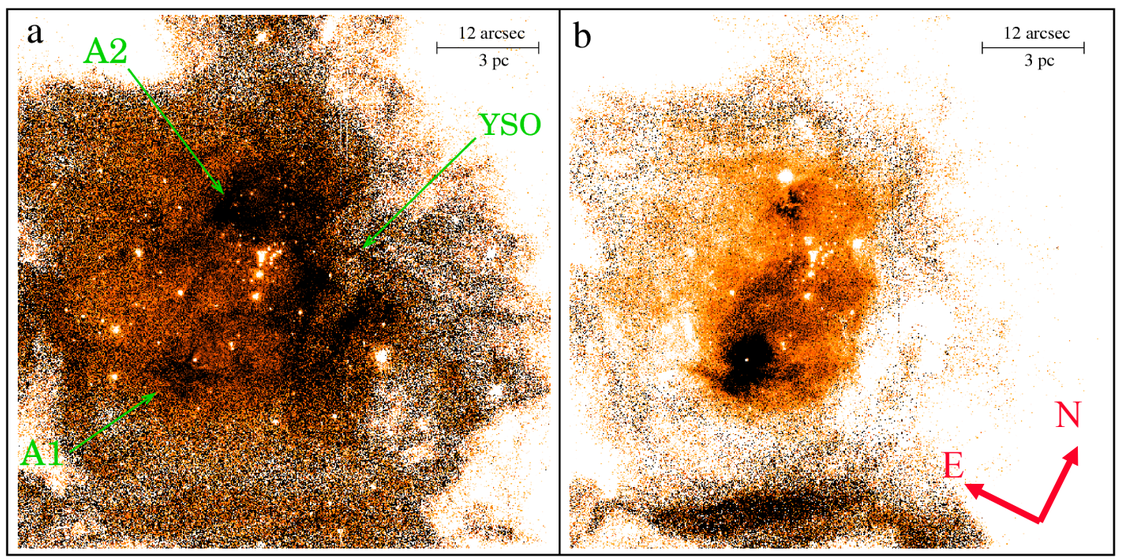
An impressive image of an extremely turbulent medium with ionized subarcsec structures, long ridges and filaments. The HST image resembles the face of a ghost with the two bright HII blobs as the eyes and the strong absorption zone as its mouth.

Nebular Emission:

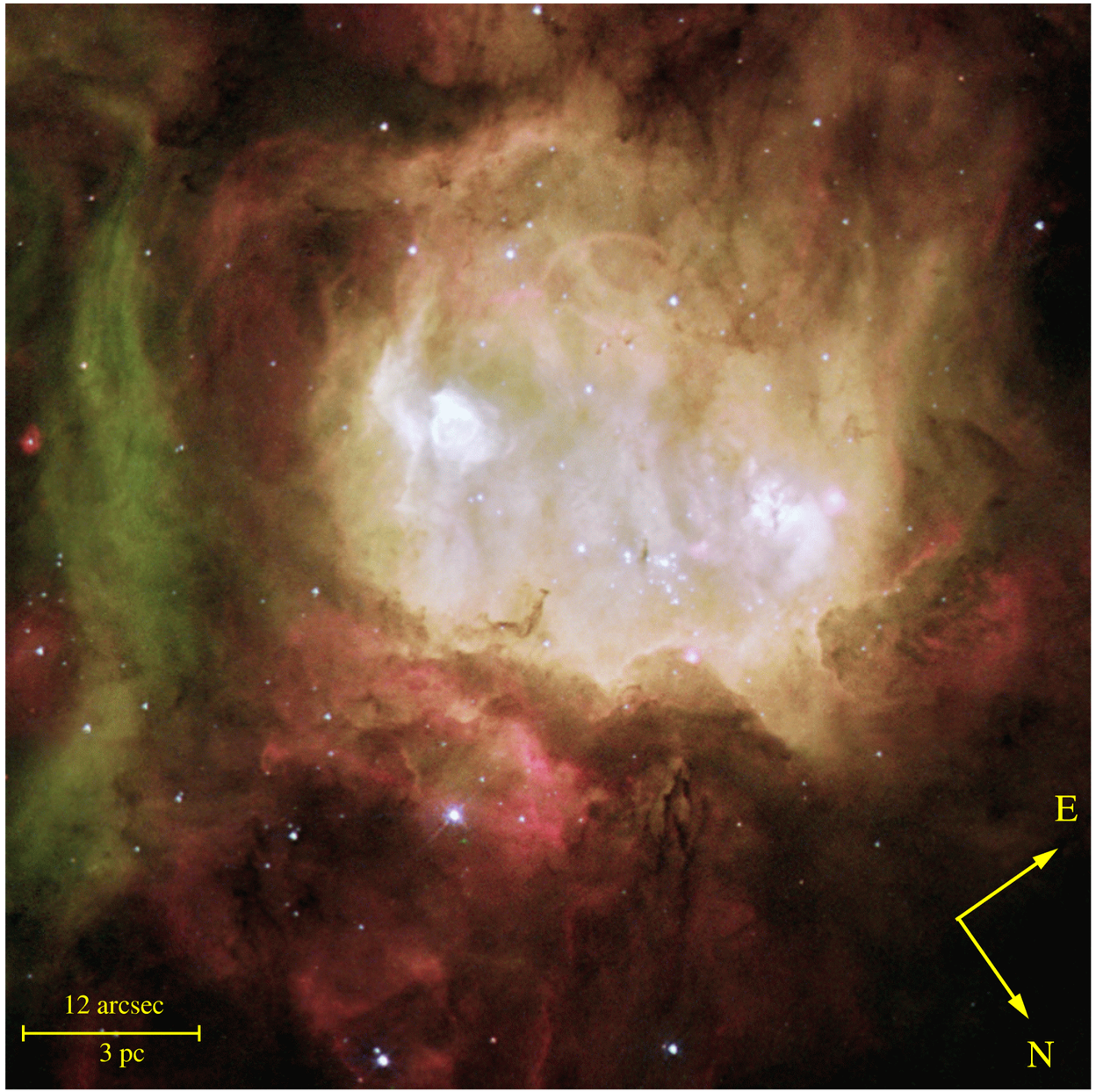
If the whole region is ionization bounded then correcting for reddening we find that $Fo(H\beta)=2.2x10^{-13}$ erg cm^{-2} s^{-1} and $N_{lyman} = 1.17x10^{50}$ photons s^{-1}. If we treat A1 and A2 separately we find an $Fo(H\beta)=1.10x10^{-11}$ erg cm^{-2} s^{-1} and $N_{lyman} = 8.50x10^{48}$ photons s^{-1} for A1 (one O7.5-O8 star) and $Fo(H\beta)=1.55x10^{-11}$ erg cm^{-2} s^{-1} and $N_{lyman} = 1.20x10^{48}$ photons s^{-1} for A2 (one O7-O7.5 star).

Stellar Content / Reddening:

Most of the dust is seen in the enshrouded western side where the average Av is ~1.4 peaking at 2.2mag. More than 100 stars with y>21mag are detected. For typical mass loss rates and based on the observed parameters, the bubble surrounding A2, the higher excitation region of the two, suggests an age of only ~2500-8600 years for the feature.



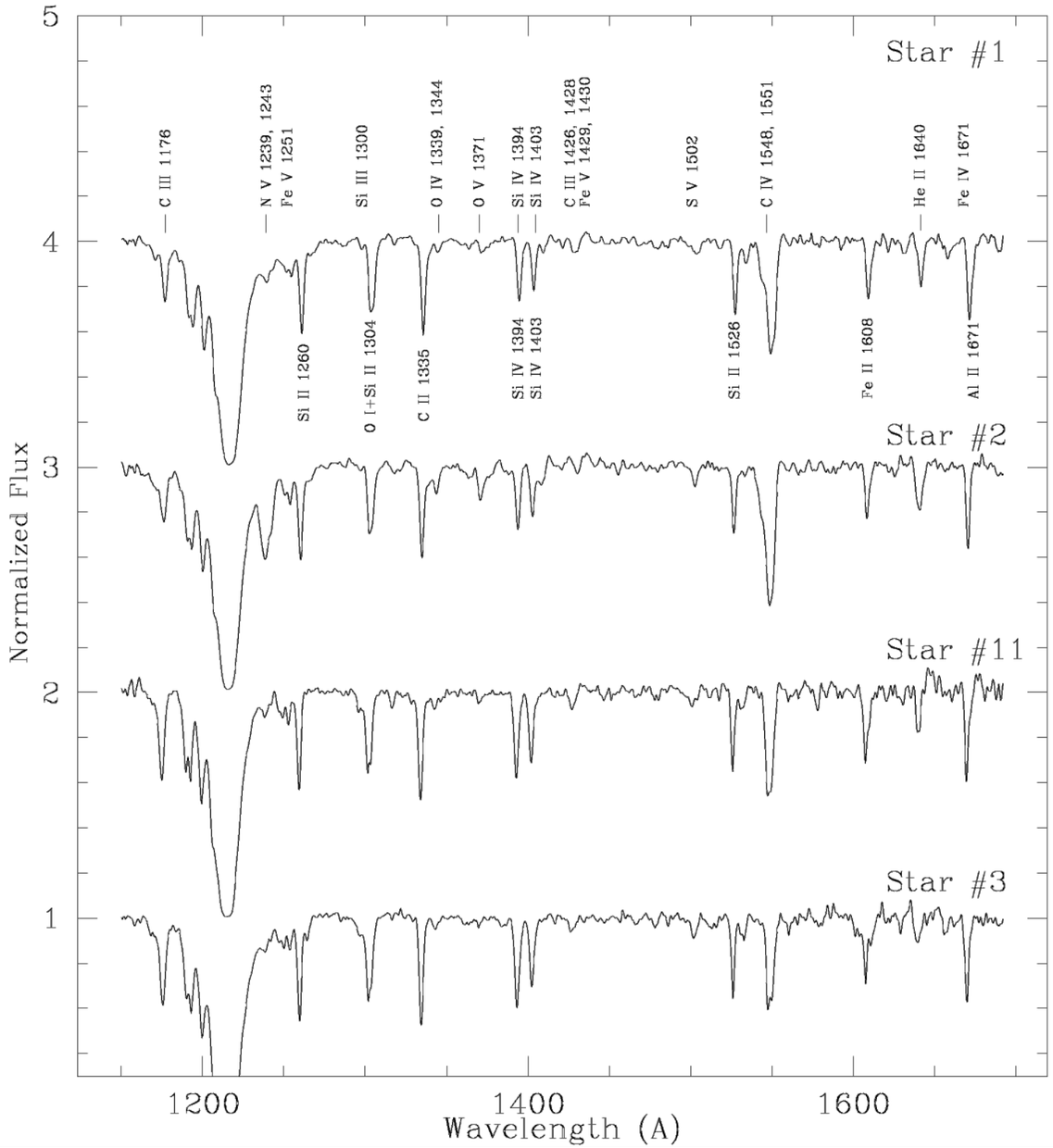
Line intensity ratios: a) Hα/Hβ b) The [OIII]λ5007/Hβ



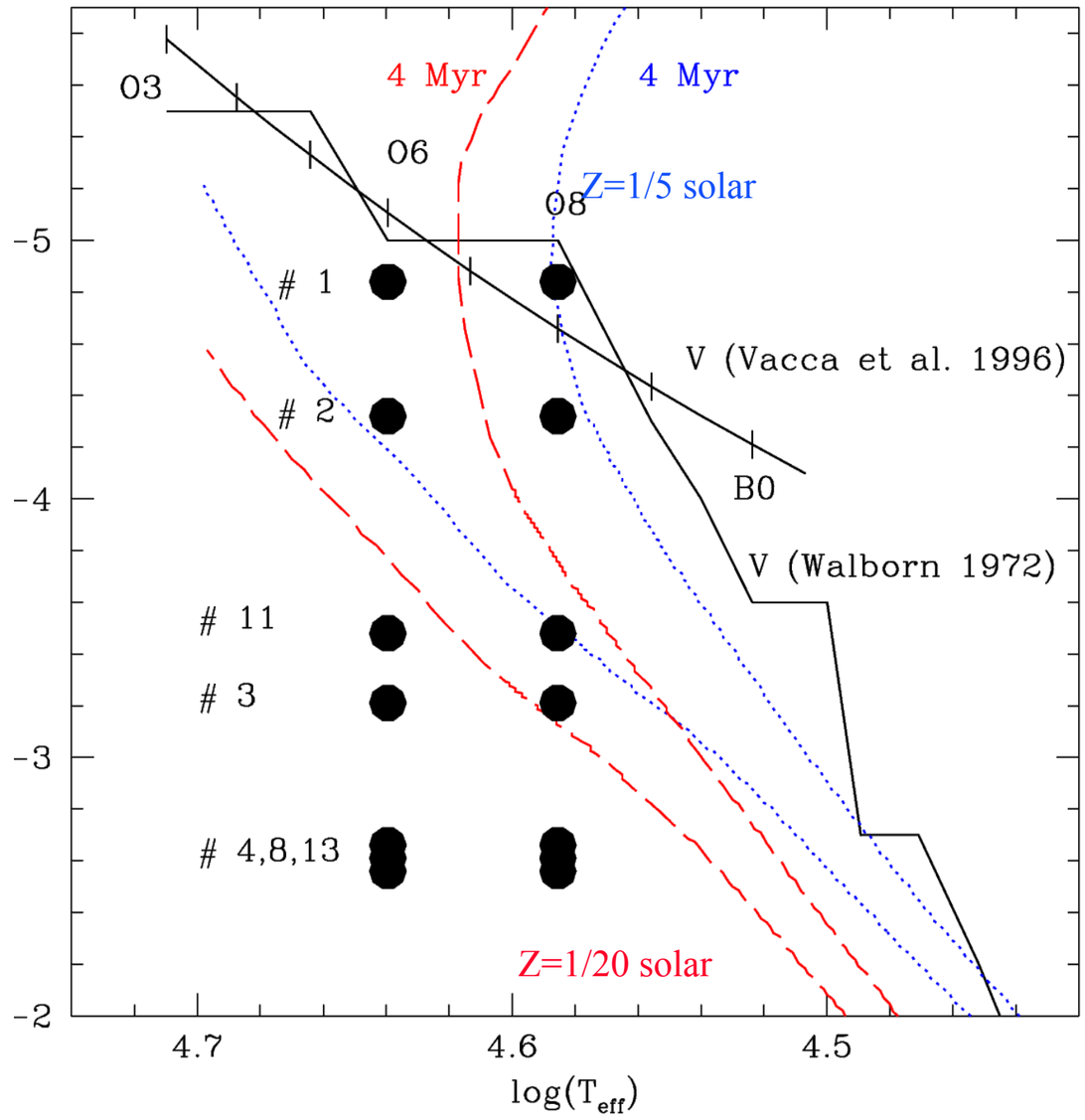
"True color" HST image of N160A. The two bright emission nebulae are the high excitation HII blobs A1 (left) and A2 (right). Note the numerous arcs and filaments through out the area imaged. Interesting a few "dust pillars" ~1pc in length are also visible.

Reference: M. Heydari-Malayeri et al. 2002, A&A (@astro-ph/0110622)

HST/STIS Spectra of N81: What is the type of the exciting stars of the HEBs?



Typical UV spectra of the brightest stars of N81. The prominent absorption feature at λ=1210 Angstroms is due to Lyα. The wind profiles are indicated with tick marks and the features possibly contaminated by an interstellar component are labeled.



The M_V/ Teff diagram of the N81 stars is compared to the ZAMS and 4 Myr isochrone models at **Z=1/5** and **Z=1/20** solar metallicities. Note that four of the observed stars are situated n a locus of the HRD-like diagram suggesting that they are either on the ZAMS or they have a very young age. The lower luminosity stars are possibly hotter than the ZAMS.

Reference: M. Heydari-Malayeri et al. 2002, A&A (@astro-ph/0110576)

Conclusions / Perspectives

- **The discovery of the very young and compact HII regions more than 10 years ago is entering a new era with the high resolution capabilities of the HST. Our new observations reveal the stellar content of these objects, so far out of reach from ground-based telescopes, and indicate a turbulent environment typical of newborn massive star forming regions.**
- **We infer that the true number of massive stars in the Magellanic Clouds is underestimated since a large number of them are hidden in dust enshrouded unresolved small clusters.**
- **While all compact HII regions belong to the same category of high excitation young objects (HEBs) our high resolution observations show several distinct characteristics i.e.:**
  - **SMC N81 while it is young it is relative more evolved than N88A. It also represents a really isolated massive starburst.**
  - **SMC N88A is the latest massive starburst in a region where former generations of massive stars are present over a large area. It has an extraordinary extinction as high as Av~3.5 mag in the visible, which is unique for the gas content of the SMC.**
  - **LMC N159-5, similarly to SMC N88A shows no conspicuous stars probably due to its extreme youth.**
  - **LMC N83B represents a rare opportunity where by means of the high resolution of the HST we can examine smaller spatial scales which when combined with large scale images shows an interesting age / spatial distribution of the massive stars. We find that this distribution is consistent with the model of fractal / hierarchical structure for the gas (Elmegreen 2000, ApJ 530, 277) which gives rise to the star formation.**
  - **LMC N11A is rather isolated compared to the other LMC blobs and harbors the smallest number of stars for its size.**
  - **LMC N160A reveals an extremely turbulent environment and contains two unique HEBs harboring numerous stars.**
- **HST/STIS spectroscopy of N81 reveals a number of O6-O8 stars with astonishingly weak wind profiles and an Mv of ~2mag fainter than the corresponding dwarfs. This suggest that those young stars belong to the Vz luminosity class.**
- **Upcoming near-IR observations (using VLT/ISAAC) in those regions will better address the question of high extinction which could be larger than our Ballmer decrement estimates. We will also address the issue of the initial mass function (IMF) and in particular whether a population of lower mass stars is present in the HEBs.**

For more details visit: http://wwwusr.obspm.fr/~heydari/projects/ or send an e-mail to heydari@obspm.fr