# Nature and Evolution of Starburst Activity

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**Abstract**

We present results of near-infrared integral field spectroscopy and mid-infrared *ISO* spectroscopy of the starburst galaxy M 82, as well as of a mid-infrared *ISO* spectroscopic survey of 27 starburst galaxies. Together with the application of starburst models, the data are consistent with the formation of massive stars ($\gtrsim 50-100$ M$_{\odot}$) in starburst environments, and support short decay timescales of starburst episodes ($\sim 10^6-10^7$ yr) indicating important negative feedback effects of starburst activity.

## 1 Introduction

We have carried out a detailed investigation of the starburst galaxy M 82 based on near- and mid-infrared observations and a mid-infrared spectroscopic survey of 27 starburst galaxies, in order to address crucial issues including the stellar initial mass function (IMF) in starbursts and the evolution of starburst activity. The near- and mid-infrared regimes are rich in starburst signatures and probe deep into obscured star-forming regions since extinction at these wavelengths is much less important than in the optical/UV. We interpreted the data with starburst models which combine stellar evolutionary synthesis and photoionization modeling with the codes STARS and CLOUDY (Sternberg 1998; Ferland 1996), and employ the Geneva tracks and recent non-LTE unified stellar atmospheres (Pauldrach et al. 1998). Full accounts of our studies are given by Förster Schreiber et al. (2001a; 2001b) and Thornley et al. (2000).

## 2 Case Study: M 82

M 82 is an ideal target for detailed studies due to its proximity (3.3 Mpc; Freedman & Madore 1988) and has attracted considerable attention in the past (see e.g. Telesco 1988, Rieke et al. 1993, and Satyapal et al. 1997 for reviews and earlier models). We have observed the central regions of M 82 with the MPE near-infrared integral field spectrometer 3D (Weitzel et al. 1996) at a spectral resolution of $R \sim 1000$ and angular resolution of $1.5''$. We complemented the 3D data with $R \sim 500-1000$ mid-infrared spectroscopy from the Short Wavelength Spectrometer (SWS; de Graauw et al. 1996) on board *ISO* (Kessler et al. 1996) [1] and results at other wavelengths from

[1]*ISO* is an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands, and the United Kingdom) and with the participation of ISAS and NASA. The SWS is a joint project of SRON and MPE.

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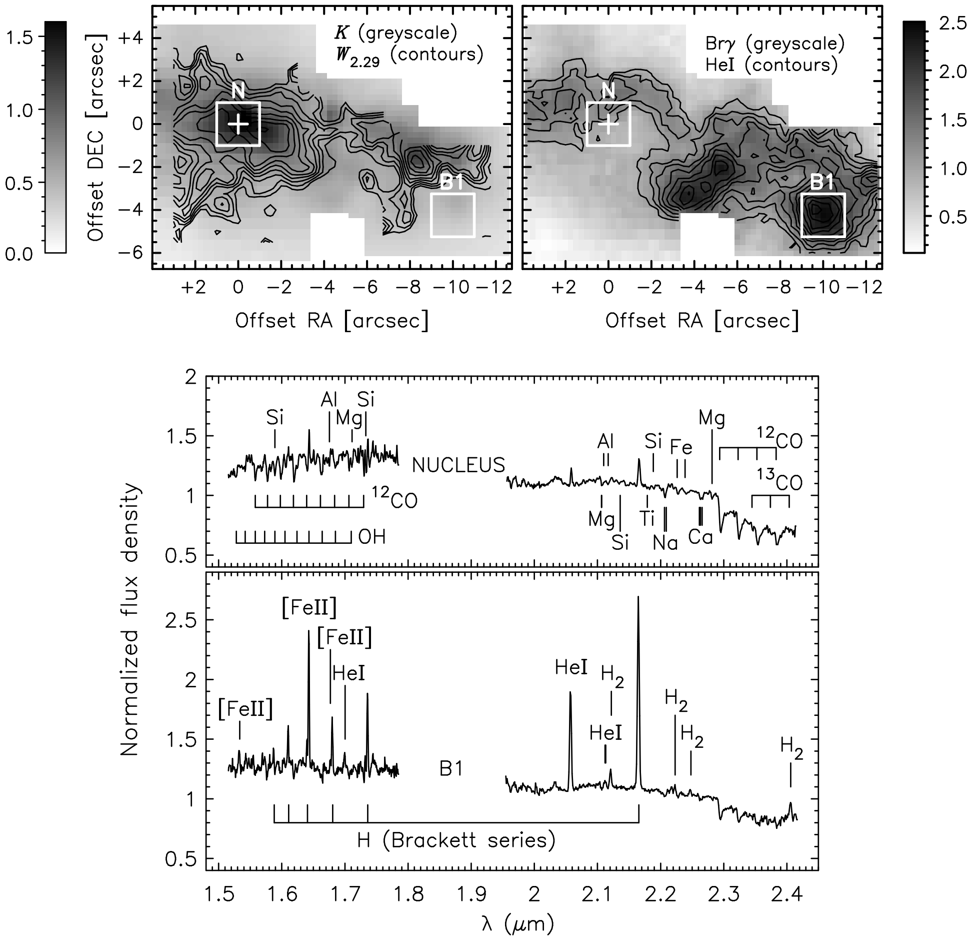


Figure 1: 3D maps of M 82 and spectra of the nucleus (cross, "N") and region "B1." Greyscale levels are in $10^{-14}\,\mathrm{W\,m^{-2}\,\mu m^{-1}\,arcsec^{-2}}$ for the $K$-band map and $10^{-17}\,\mathrm{W\,m^{-2}\,arcsec^{-2}}$ for the Br$\gamma$ map. Contours for the $W_{2.29}$ map range from 12 Å to 16 Å in steps of 0.5 Å, those for the HeI 2.058 $\mu$m linemap range from 0.5 to 1.5 in steps of 0.1 and units of $10^{-17}\,\mathrm{W\,m^{-2}\,arcsec^{-2}}$. The spectra are normalized to unity in the range $2.2875 - 2.2910\,\mu$m (normalizing factors in $10^{-14}\,\mathrm{W\,m^{-2}\mu m^{-1}}$ are 6.52 for the nucleus and 1.78 for B1).

the literature. These data provide an extensive set of diagnostics, notably for hot massive stars (H and He recombination lines and atomic fine-structure lines originating in H II regions), and for red giants and supergiants (near-infrared continuum emission and absorption features produced in their atmosphere).

Fig. 1 presents various 3D maps of M 82 together with the $H$- and $K$-band spectra of the central 35 pc at the nucleus and of the Br$\gamma$ source $\approx 10''$ southwest of the nucleus (denoted "B1"). The 3D data show distinct burst sites as small as a few tens of parsecs and reveal important spatial variations in the strength of the absorption features and emission lines relative to the continuum. Application of the starburst models to the properties of the 500 pc–diameter "starburst core," selected regions, and all individual resolution elements within the 3D field of view allowed us to constrain the detailed spatial and chronological evolution of starburst activity in the central regions of M 82. With a Salpeter IMF extending up to 100 $M_\odot$ (see Sect. 3), the results indicate burst timescales of a few million years on scales ranging from a few tens of parsecs to 500 pc. The derived integrated star formation history (Fig. 2) shows two distinct starburst episodes. The spatial distributions of

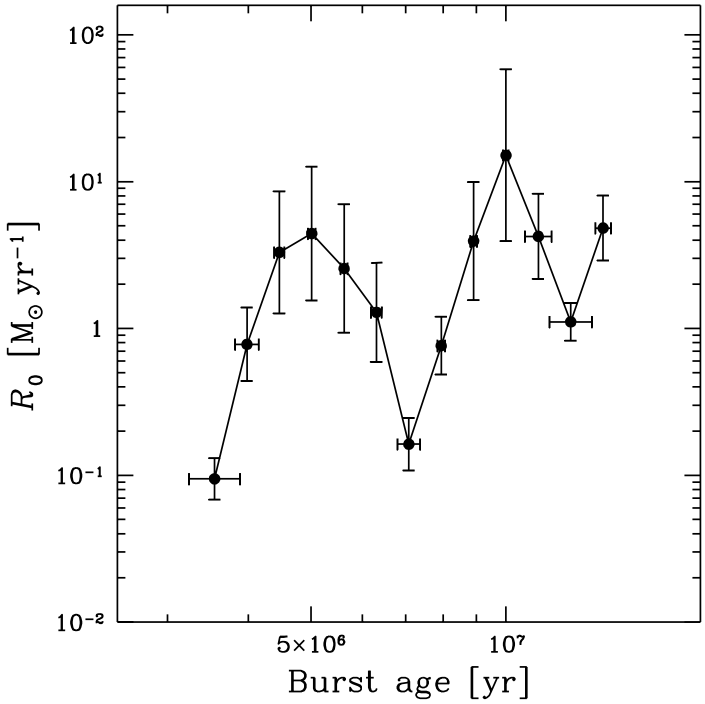


Figure 2: Global star formation history in the central regions of M 82 reconstructed from the spatially-detailed modeling by integrating the burst intensity per age interval.

burst ages and intensities, together with the morphological features of M 82, suggest the following scenario: (1) Following tidal interaction with M 81 $\sim 10^8$ yr ago, the interstellar medium (ISM) in M 82 experienced large-scale torques, loss of angular momentum, and infall towards the nuclear regions possibly channeled by the stellar bar. In the absence of dynamical resonances, the ISM can reach the nucleus. (2) A starburst episode took place $8-15$ Myr ago throughout the central 500 pc, declined rapidly, and was particularly intense near the nucleus. (3) A subsequent episode occurred $4-6$ Myr ago predominantly in a circumnuclear ring and along the bar, was likely triggered by bar-induced dynamical resonances, and also decayed rapidly.

## 3 Mid-Infrared Fine-Structure Line Survey

We have gathered atomic fine-structure line fluxes using the SWS for 27 infrared-bright starburst galaxies, mostly with solar metallicities. We focussed on the [Ne III] 15.6 $\mu$m/ [Ne II] 12.8 $\mu$m ratio as indicator of the composition of the massive star population. Using results from the literature, we also collected for a subset of the sources estimates of the intrinsic Lyman continuum luminosity $L_{\rm Lyc}$, and of the infrared luminosity $L_{\rm IR}$ assuming it equals the bolometric luminosity of the OB stars reprocessed by interstellar dust. The modeling results (Fig. 3) indicate that most of the sample starbursts are currently deficient in very massive stars, either because they never formed due to a truncation of the IMF or because they have disappeared as a result of aging effects. Suppressed formation of very massive stars in starbursts is however difficult to reconcile with direct evidence for the presence of $\gtrsim 50-100$ $M_\odot$ stars in Galactic and near-extragalactic massive star-forming regions, as summarized by Thornley et al. (2000). With high upper mass cutoffs, the combination of neon and $L_{\rm IR}/L_{\rm Lyc}$ ratios suggests that most starbursts decay on short timescales of $\sim 10^6-10^7$ yr.

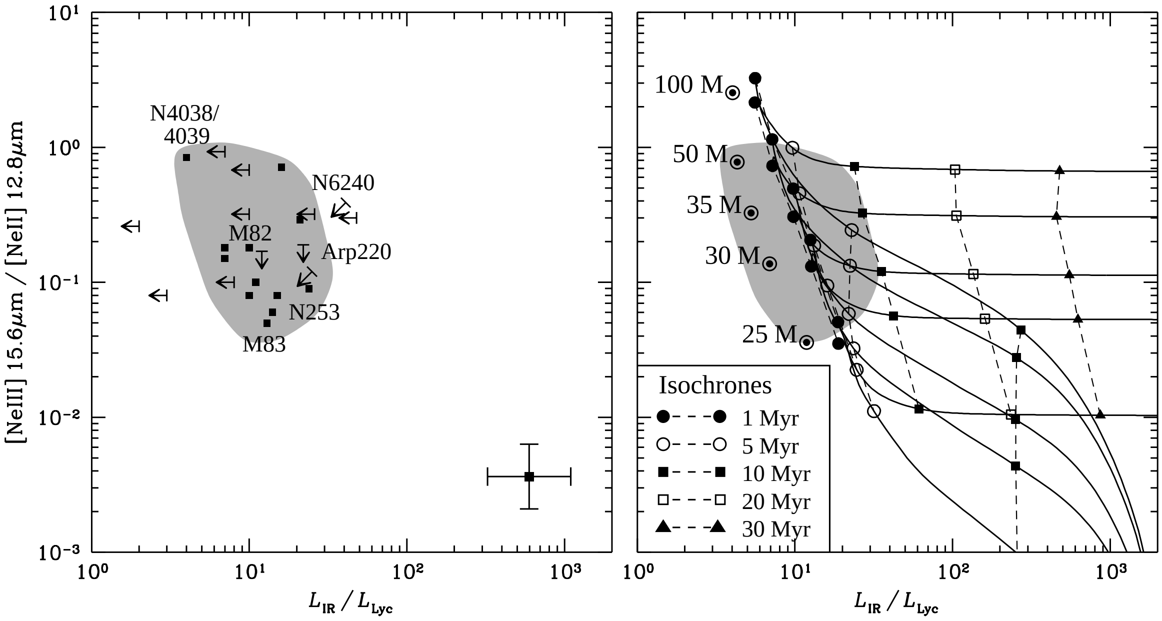


Figure 3: Neon line versus $L_{\rm IR}/L_{\rm Lyc}$ ratios for the solar-metallicity SWS starburst sample, compared to model predictions for various IMF upper mass cutoffs and burst ages (as labeled in right panel), and burst timescales of 1 and 5 Myr (steepest and flattest curves, respectively).

## 4 Conclusions

Our studies support that very massive stars form in starburst environments, and suggest that starbursts can be episodic and relatively short-lived, lasting $\sim 10^6 - 10^7$ yr. Such short timescales can be easily understood on scales of a few tens of parsecs due to strong stellar winds from massive stars and subsequent supernova explosions rapidly disrupting the surrounding ISM. Modeling of the SWS starburst sample and of the starburst core of M 82 suggests that starburst activity can have strong negative feedback effects on global scales as well.

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