Starbursts in Interacting Galaxies: Observations and Models

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1 Introduction

Starbursts have been a puzzling field of research for more than a decade. It is evident that they played a significant rôle in the evolution of many galaxies but still quite little is known about the starburst mechanisms. A way towards a better interpretation of the available data is the comparison with evolution models of starbursts. The modelling of starbursts and the fitting of such model starbursts to observed data will be discussed in this paper. The models have been applied to a subset of starburst and post-starburst galaxies in a sample of 30 interacting systems. These galaxies are not ultraluminous FIR galaxies but rather ordinary starburst galaxies with FIR luminosities of a few 10^{10} to a few 10^{11} $L_{\odot}$.

2 Starburst models

The method basically follows the evolution method of Barbara Tinsley (1968) and others. Only the differences from older models will be described here. Instead of using a grid of fixed masses and ages, stars of all masses and ages are generated by using the Monte Carlo technique. Therefore one has to interpolate stellar evolutionary tracks somehow. This can be done very efficiently if they are available at equivalent evolutionary phases. It is of crucial importance that most of the post-main sequence evolution is included in these tracks. Several sets of tracks have been used or put together from various sources (Maeder 1976, 1981a,b, Matraka et al. 1982, Bertelli 1986, Maeder and Meynet 1988, 1989). The only homogenous set covering the whole mass range of interest so far is that of Maeder and Meynet. Another improvement is the generation of model spectra consisting of an old component and a starburst component with H II region emission lines. A library of dereddened stellar spectra (Jacoby 1984) is used to assemble the stellar components. The model spectra can be fitted to observed optical spectra, with independant extinction coefficients of the old and the new component. When the spectra can be used in addition to photometric and bolometric data they give much better constraints on model parameters than can be achieved without spectra.

3 Observations

The data includes long slit spectra covering the range from 3700 to 7000 Å at a resolution of 12 Å (FWHM) which are used for the model fits, and higher resolution spectra in the red to obtain dynamical masses. The sizes of starburst regions are taken from images in Hα or from

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published VLA maps. Photometric data of the starburst regions is obtained from calibrated CCD images in B, V, R, and I. Published data like IRAS and near-infrared data have been included if available.

4 The duration of starbursts and the deficiency of low mass stars

The first question is that of the duration of starbursts and the suspected deficiency of low mass stars in the starburst IMF. Constraints on both of them can be obtained from the ratio of mass to luminosity (here: bolometric luminosity), M/L. The extremely low M/L of many starbursts cannot be maintained for very long times. Since the pioneering work of Rieke et al. (1980) several groups came to the conclusion that the M/L of some starbursts is too small to be explained by even a very short starburst unless the starburst IMF has some kind of deficiency of low mass stars, which is usually described by a lower mass cutoff.

An example of that is NGC 520 with an M/L_{bol} of the starburst region of about 0.016 ($\pm 50\%$, assuming $H_0 = 75\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$). Even if the mass of stars and remnants formed during the starburst were 20% of the dynamical mass, the starburst population itself would have an M/L of only 0.003.

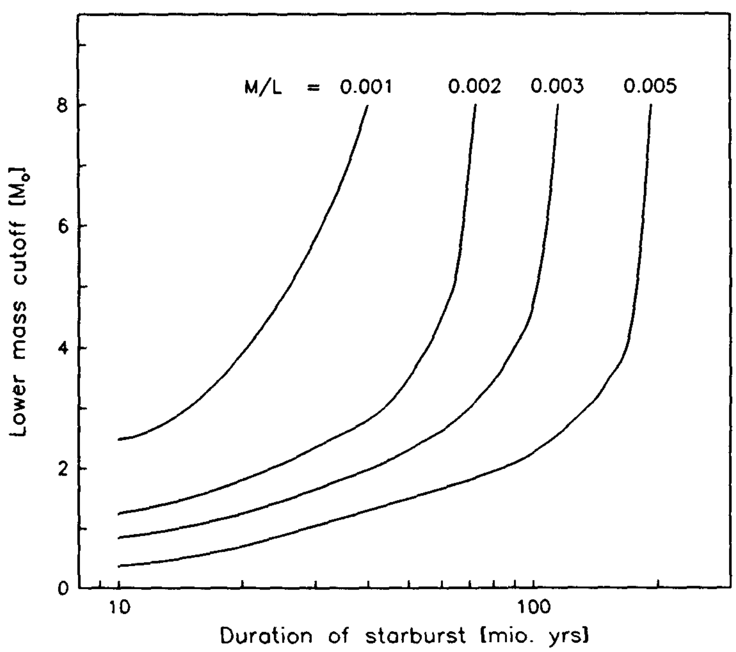

Fig. 1: Relation between the duration of a starburst and the required lower mass cutoff m_l for several values of the mass-to-bolometric-luminosity ratio M/L of the starburst population only. The IMF was assumed as a solar neighbourhood IMF (Scalo 1986) restricted to the mass range $m_l \leq m \leq 60\,M_\odot$.

Fig. 1 shows the relation between the duration of a starburst and the required lower mass cutoff of a solar neighbourhood IMF (Scalo 1986) for several values of M/L. It is evident that some low mass star deficiency is required even if the starburst is very short, corresponding to a lower mass cutoff of about 1–2 $M_\odot$. The diagram also shows that the starburst cannot be active for more than 100 mio. years even if only high mass stars were produced.

The starburst in NGC 520 is very obscured and the model spectra are of little help in this case. In the case of the starburst in NGC 7714 (see fig. 2) they are an excellent tool to examine the starburst parameters. The nulear starburst has a diameter of 9″ and a FWHM of 4.″5 in Hα. The dynamical mass inside the full diameter is about $6 \cdot 10^8\ M_\odot$. The spectrum of the

Tab. 1: Properties of the optimum starburst model for NGC 7714.

Duration: 20 mio. years, mass range: $1.2\,M_\odot \leq m \leq 50\,M_\odot$, distance: 39 Mpc.

	Observed	Model		Observed	Model
B	14.2±0.15 mag	14.1 mag	J	12.0 mag	12.4 mag
V	13.8	13.8	H	11.2	12.0
R	13.5	13.3	K	10.9	11.7
I	12.7	12.8	L	10.3	11.5
mass	$6 \cdot 10^8\,M_\odot$	$6 \cdot 10^8\,M_\odot$			
L_{bol}	$> 1.5 \cdot 10^{10}\,L_\odot$	$2.5 \cdot 10^{10}\,L_\odot$			

Tab. 2: Recalculation of M 82 model A.

	Rieke et al. (1980)	New models
L_{bol}	$4.6 \cdot 10^{10}\,L_\odot$	$4.6 \cdot 10^{10}\,L_\odot$
mass	$3.0 \cdot 10^8\,M_\odot$	$2.6 \cdot 10^8\,M_\odot$
M_K	−21.5 mag	−22.3 mag

(say less than 30 million years long) fit better than longer starbursts (say 100 million years long). About 15% of the dynamical mass are stars formed during the starburst, if no lower mass cutoff is applied. The dominating stars are in the mass range 6–8 $M_\odot$. Stars in the range 4–6 $M_\odot$, however, contribute sufficiently to test their presence or absence. It turns out that the spectra agree best when the 4–6 $M_\odot$ stars are included at approximately the expected amount. In older post-starbursts than this one, we should be able to test even lower masses. The problem with such tests is that in most post-starbursts, unlike in NGC 7715, the star formation has not ceased completely.

5 The time delay between starbursts

With the estimated starburst durations and post-starburst ages the time delay between starbursts in two interacting disk galaxies of very unequal (a factor of 5–10 different) masses can be determined. In the present sample there is a total of 8 such starburst systems:

- 5 pairs with a starburst in the minor component and little enhancement in the major component,
- 1 with starbursts in both components, and
- 2 with a starburst in the major component and post-starburst in the minor component.

Although this is statistically not very significant it gives some evidence that starbursts in the less massive component start earlier than in the more massive component. This could have several reasons: the stronger disturbance of the minor component by the major component than vice versa, smaller time scales for orbits and mass infall in the minor component, or even a larger fraction of gas mass to total mass in the smaller galaxy. The time delays determined so far are in the range 0–200 mio. years.

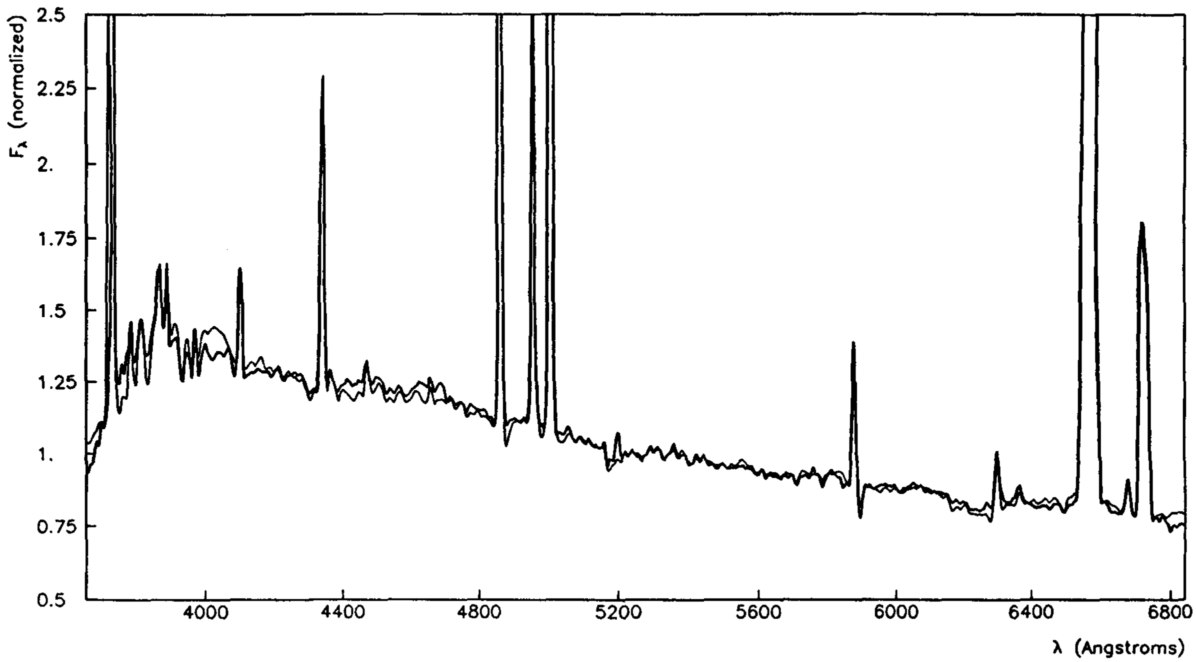

Fig. 2: Observed spectrum (thick line) and model spectrum (thin line) of the central starburst region of NGC 7714. Strong emission lines were clipped to emphasize the stellar continuum.

starburst region can be fitted very well with a starburst which has been active for about 15-50 mio years. Including uncertainties of the stellar evolutionary tracks and the heavy element abundances – which were assumed to be solar – the limits increase to about 10–100 million years. With spectra extending to shorter wavelengths and with better calibration quality at the blue end of the spectrum more precise limits could be obtained. Without a deficiency of low mass stars about half of the dynamical mass would be stars formed during the starburst. With a lower mass cutoff of about 1 $M_\odot$ this mass ratio would be in an acceptable range. In the 4.″5 diameter the situation is certainly even more severe but the resolution of the radial velocity maps is insufficient to derive a dynamical mass. Results for the best model with a starburst duration of 20 mio. years are shown in table 1. The B, V, R, and, I magnitudes agree very well but in the near infrared there is a significant excess of the observed brightnesses. This excess is probably due to late stages of stellar evolution either not properly included in the stellar evolutionary tracks or in the colour calibration. With the more incomplete stellar tracks used by Rieke et al. (1980) for M 82 this effect was even more severe. A recalculation of their model A with the same IMF and star formation rate history gives twice their K band luminosity (see table 2) which reduces the need for a lower mass cutoff in M 82.

Direct observational evidence for a lower mass cutoff should be easier with post-starburst which are in a low state of star formation. There the very bright massive stars are no longer present. Such a post-starburst can be seen in NGC 7715, the companion of NGC 7714.

The spectrum of the central 1.5 kpc (see fig. 3) is dominated by late B stars and the galaxy shows no emission lines as signs of current star formation. The time when star formation ceased can be determined very well by fitting with model spectra: about 40–50 million years ago. The fits are not as sensitive to the duration of the starburst as to its end but very short starbursts

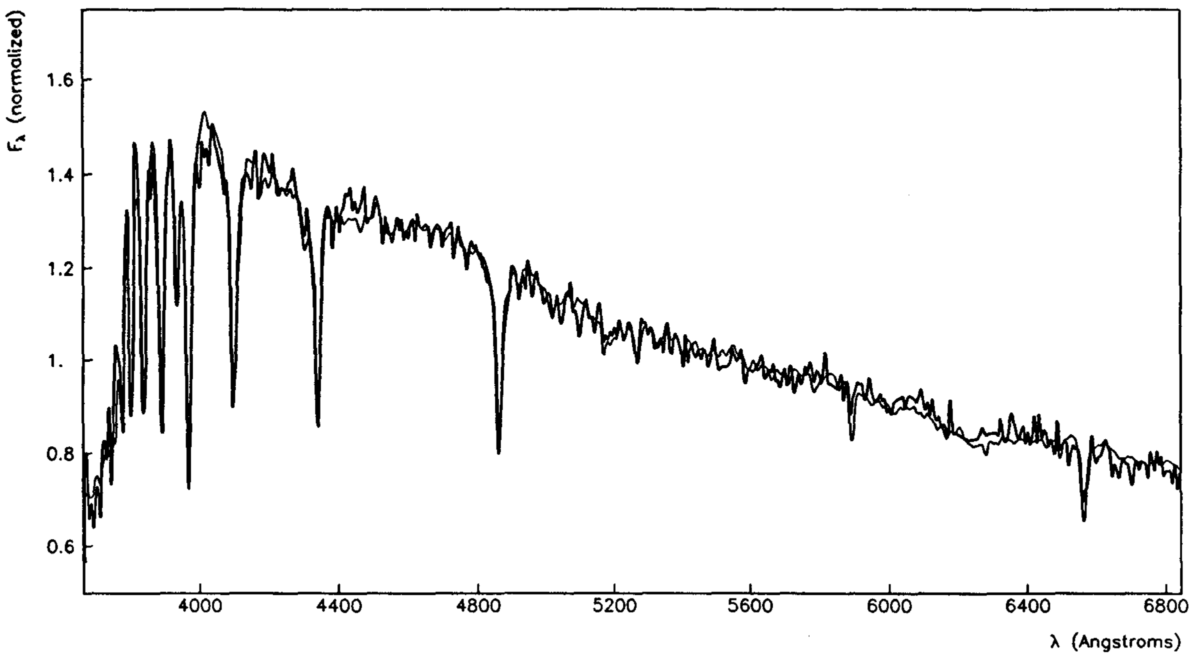

Fig. 3: Observed spectrum (thick line) and model spectrum (thin line) of NGC 7715.

6 Conclusions

There are signatures of a low mass star deficiency in several starburst galaxies. These can be explained with lower mass cutoffs of 1–2 $M_\odot$. No evidence was found for a cutoff of 6 $M_\odot$ or even more which was claimed by other investigators (Wright et al. 1988, Olofsson 1989). The lower mass cutoff found in post-starburst galaxies is less than about 4 $M_\odot$. There is little evidence for a low mass deficiency except from the mass-to-luminosity ratio. Starbursts in the less massive component of interacting pairs are triggered more quickly. The duration of a starburst is only a few 10^7 years but the delay between starbursts in two interacting galaxies may be a few 10^8 years. This can easily explain why so few pairs of interacting galaxies show starbursts in both components.

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DISCUSSION

Khachikian: You mentioned NGC 520. What kind of galaxy is this one?

Bernlohr: It is a close interacting pair. The main component is a disk galaxy seen edge-on. The center of the rotation curve of this component coincides with the radio continuum source, the peak in K-band images, and the peak of the CO emission. The active starburst in the nuclear region is highly obscured. The visually brighter northwestern knot is a less massive companion where a starburst happened about 200 million years ago.

Kochhar: If you form very big stars in the nuclear regions, their supernova explosions should also be important.

Bernlohr: Maybe, but I did not include supernovae. In the average spectrum they are not very important.

Xu: The observational data exceeds your model prediction most seriously in the L band. My question is: have you included the contribution from small grains in your model?

Bernlohr: No additional dust has been included in the models. The dust grains may be responsible for most of the excess in the L band. In the J, H, and K bands, late stages of stellar evolution probably account for the discrepancy.

Gerber: You said that the smaller galaxy undergoes a starburst before the larger galaxy in unequal-mass pairs. What are the masses differences between the two galaxies in these systems?

Bernlohr: They are in the range from 1:5 to 1:20.