Chin. J. Astron. Astrophys. Vol. 3 (2003), No. 3, 203–211
(http://www.chjaa.org or http://chjaa.bao.ac.cn)

Chinese Journal of
Astronomy and
Astrophysics

Nuclear Starburst Activity in the Seyfert 2 Galaxy NGC 2273 *

Qiu-Sheng Gu, Lei Shi, Shi-Jun Lei, Wen-Hao Liu and Jie-Hao Huang

Department of Astronomy, Nanjing University, Nanjing 210093; qsgu@nju.edu.cn

Received 2003 January 22; accepted 2003 April 16

Abstract We present spectrophotometric results of the Seyfert 2 galaxy NGC 2273. The presence of high-order Balmer absorption lines (H8, H9, H10) and weak equivalent widths of CaII K $\lambda3933$, CN $\lambda4200$, G-band $\lambda4300$ and MgIb $\lambda5173$ clearly indicate recent star-forming activity in the nuclear region. Using a simple stellar population synthesis model, we find that for the best fit, the contributions of a power-law featureless continuum, an intermediate-age ($\sim 10^8$ yr) and an old ($> 10^9$ yr) stellar population to the total light at the reference normalization wavelength are 10.0%, 33.4% and 56.6%, respectively. The existence of recent starburst activity is also consistent with its high far-infrared luminosity ($\log L_{\rm FIR}/L\odot = 9.9$), its infrared color indexes [$\alpha(25, 60) = -1.81$ and $\alpha(60, 100) = -0.79$, typical values for Seyfert galaxies with circumnuclear starburst], and its q-value (2.23, ratio of infrared to radio flux, very similar to that of normal spirals and starburst galaxies). Byrd et al. have suggested that NGC 2273 might have interacted with NGC 2273B in less than 10^9 yr ago, so the starburst activity in this galaxy could have been triggered by tidal interaction, as indicated in recent numerical simulations.

Key words: galaxies: Seyfert – galaxies: starburst – galaxies: stellar content

1 INTRODUCTION

The connection between starburst activity and AGNs is one of the most important and hotly debated issues in the study of active galaxies. Ten years ago, in order to solve the problem of low levels of continuum polarization in many Seyfert 2 galaxies, Cid Fernandes & Terlevich (1992, 1995) have proposed that the nuclear starburst could be the origin of the blue unpolarized light. After comparing the IUE spectra of 20 brightest Seyfert 2 galaxies with Seyfert 1 galaxies, Heckman et al. (1995) have also suggested that most of the UV continuum in Seyfert 2 galaxies may be produced by a circumnuclear population of massive stars. Nowadays, the coexistence of nuclear starburst and AGN activity in a few dozens of galaxies have directly been detected by high-quality observations from HST and large ground-based telescopes. For example, by the use of HST's high-resolution ultraviolet (UV) images and spectra, Heckman et al. (1997)

* Supported by the National Natural Science Foundation of China.

and Gonzalez Delgado et al. (1998) have revealed the most unambiguous signatures of young, massive starburst in the circumnuclear regions of four Seyfert 2 galaxies (Mrk 477, NGC 5135, NGC 7130 and IC 3639). Gu et al. (2001) detected a clear signature of young, massive nuclear starburst in NGC 7679 (Seyfert 2 galaxy) in its far and near-UV spectrum. More recently, Aretxaga et al. (2001) even detected prominent Balmer absorption lines in six radio galaxies, which are attributed to stars with ages less than 1 Gyr. In order to investigate the frequency of nuclear starburst in Seyfert 2 galaxies, Gonzalez Delgado et al. (2001) and Storchi-Bergmann et al. (2000) respectively analyzed the near-UV spectra of a northern and southern sample (each containing 20 Seyfert 2 galaxies), and found that about 30%–50% Seyfert 2 galaxies show the existence of nuclear starburst activity.

On the observational side, possible signatures of starburst for Seyfert 2 galaxies are: (1) the presence of far-UV stellar wind resonance lines (such as N V λ1240, Si IV λ1400 and C IV λ 1550) due to O stars; (2) the broad emission line bumps around 4686Å and 5808Å from Wolf-Rayet stars and high-order Balmer absorption lines of HI and HeI originating in the photospheres of O, B and A-type stars (Gonzalez Delgado et al. 1999). Recently, Cid Fernandes et al. (2001) suggested a series of empirical criteria for the existence of starburst in Seyfert 2 galaxies, such as weak CaII K λ3933, low excitation lines and large far-infrared luminosity, etc.

As summarized by Cid Fernandes et al. (2001), there are three stages in the study of circumnuclear starburst in Seyfert galaxies: "(1) identifying starbursts in these systems; (2) characterizing the properties of the starburst (age and mass or star formation rate) and the AGN (black hole mass, accretion rate); and (3) investigating possible connections between these properties". This paper deals mainly with the first stage, where we present unambiguous evidence of star-forming activity in the nuclear region of NGC 2273.

Historically, narrow-band Hα + [NII] imaging by Pogge (1989) and Gonzalez Delgado et al. (1997) did not show any diffuse circumnuclear emission in NGC 2273, and they suggested that there was little, if any, active circumnuclear star formation in this galaxy. Though the radio-infrared ratio (q-value) of NGC 2273 is very similar to that of normal spirals and starburst galaxies, Lonsdale et al. (1992) suggested that NGC 2273 is powered by AGN, rather than starburst activity. Here, for the first time, we present unambiguous spectral signatures of starburst (high-order Balmer absorption lines and weak equivalent widths of CaII K λ3933, CN λ4200, G-band λ4300 and MgIb λ5173) in the central $2'' \times 2''$ region of NGC 2273 during our survey of a sample of nearby bright Seyfert 2 galaxies for nuclear starburst activity with the 2.16 m telescope of National Astronomical Observatory of China.

Table 1 Basic Data

Parameters		References
R.A. (2000)	$06^{h}50^{m}08.7^{s}$	de Vaucouleurs et al., 1991
Dec. (2000)	$60°50'45''$	de Vaucouleurs et al., 1991
Type	SB(r)a	de Vaucouleurs et al., 1991
Distance (Mpc)	28.4	Ho, et al., 1997
B_T^0	12.02	Ho, et al., 1997
S_{12} (Jy)	0.48 ± 0.03	Mouri & Taniguchi, 2002
S_{25} (Jy)	1.35 ± 0.02	Mouri & Taniguchi, 2002
S_{60} (Jy)	6.59 ± 0.05	Mouri & Taniguchi, 2002
S_{100} (Jy)	9.89 ± 0.13	Mouri & Taniguchi, 2002
$S_{1.49\,\mathrm{GHz}}$ (mJy)	52	Lonsdale et al., 1992
$N_{\mathrm{H}}(\mathrm{cm}^{-2})$	$\geq 10^{25}$	Bassani et al., 1999
$F^{\mathrm{obs}}_{2-10\,\mathrm{kev}}$ (10^{-11} erg cm^{-2} s^{-1})	0.09	Bassani et al., 1999

We suggest that the nuclear starburst activity detected in this galaxy (with age $\sim 10^8$ yr) might be triggered by its tidal interaction with NGC 2273B, as indicated by recent numerical simulations (Barnes & Hernquist 1996; Mihos & Hernquist 1996). Table 1 presents basic data for NGC 2273. This paper is organized as follows: In Sec. 2 we describe the observation, data reduction and present our results. In Sec. 3 we discuss the results of a simple stellar population synthesis model, starburst and AGN activity in NGC 2273, and in Sec. 4, we summarize our conclusions.

2 OBSERVATIONS AND RESULTS

Spectra of NGC 2273 were obtained on November 1–4, 2002, with the Boller & Chivens spectrograph attached to the 2.16 m telescope of National Astronomical Observatory, China. We used a 1024×1024 CCD and a 300 lines/mm grating, which provides a dispersion of 4.86 Å/pixel and a spectral resolution of 11 Å(FWHM) over the range 3500–7200 Å. The width of the long slit was set to $2''$(i.e., 275 pc for NGC 2273 with the distance of 28.4 Mpc, $H_0 = 75\,\mathrm{km\ s^{-1}\ Mpc^{-1}}$ is adopted in this paper). HeAr-spectra were taken before and after the object spectra for wavelength calibration, and Hiltner 600 was selected from KPNO standards for flux calibration. The total exposure time was 8 100 s (3×2700 s). All spectra were reduced using standard IRAF[1] procedures. In all cases, the spectra were bias-corrected, and divided by a normalized flat field image in order to remove the pixel-to-pixel variations. Cosmic rays were replaced by an average of their neighboring pixels. The wavelength calibration was accomplished with HeAr arc spectrum and a third-order spline3 function was typically used to fit over 20 comparison lines with the RMS less than 0.4 Å. All spectra have been flux-calibrated with a standard star. Finally, the observed line fluxes have been corrected for Galactic reddening of $E(B-V) = 0.071$ mag. We will discuss the correction of the internal reddening in Sec. 3.1.

Table 2 Absorption and Emission Lines in NGC 2273

Wavelength (Å)	Ion	Equivalent Width (Å)	Flux[a]
3727[b]	[O II]	16.36	4.29
3797	H10	3.56	1.24
3835	H9	5.50	1.98
3889	Hζ	3.09	1.20
3933	Ca II K	5.14	2.07
3970	Hϵ	5.41	2.23
4101	Hδ	3.28	1.46
4200	CN band	0.29	0.04
4300	G band	2.24	1.06
4340[b]	Hγ	0.75	0.35
4861[b]	Hβ	4.88	2.86
4959[b]	[O III]	11.06	6.21
5007[b]	[O III]	28.33	15.87
5173	MgIb	2.37	1.36
6300[b]	[O I]	3.10	1.86
6548[b]	[N II]	7.89	4.77
6563[b]	Hα	27.93	16.87
6583[b]	[N II]	23.69	14.31
6716[b]	[S II]	6.91	4.36
6730[b]	[S II]	6.83	4.31

[a] Observed flux in units of 10^{-14} erg s^{-1} cm^{-2}. [b] emission lines.

[1]IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

The spectrum of the central $2'' \times 2''$ region of NGC 2273 is shown in Fig. 1, and the properties of all the emission and absorption lines we identified in the spectrum are given in Table 2. Stellar absorption wings clearly evolved in the Hβ and Hγ emission lines. For these two lines, the flux and EW are obtained using the IRAF-*specfit* routine. The spectrum also shows the presence of high-order Balmer absorption lines (H8, H9, H10), and several weak absorption lines, such as, CaIIK λ3933, CN λ4200, G-band λ4300 and MgIb λ5173 (see Fig. 1).

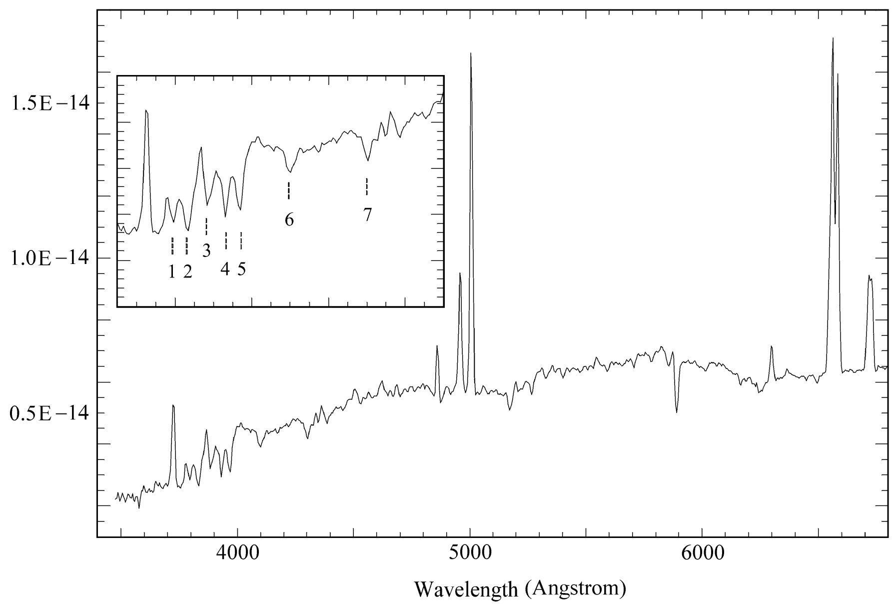

Fig. 1 Observed spectrum of NGC 2273. The inset is an enlargement of the spectral range 3650–4500 Å, where we can clearly find the high-order Balmer absorption lines and weak absorption lines of CaII K, G-band and Mg Ib, which are indicated by 1— H10, 2— H9, 3— H8, 4— Ca II K, 5— Hϵ + CaII H, 6— Hδ, and 7— G-band.

3 DISCUSSION

3.1 Stellar Populations

To estimate the stellar population in the nuclear region of NGC 2273, we compare our observed spectrum with the evolutionary synthesis model, GISSEL96 (Bruzual & Charlot 1996). Following Cid Fernandes et al. (2001), we take three components: an old and an intermediate population, with ages > 1 Gyr and $\sim 10^8$ yr, respectively, and an $f_\lambda \sim \lambda^{-1}$ power-law component to account for a scattered AGN continuum, since NGC 2273 is found to be a Seyfert 2 galaxy with hidden polarized broad emission lines (Moran et al. 2000). The form for the AGN continuum of $f_\lambda \sim \lambda^{-1}$ is consistent with the recent spectropolarimetric observations for Mrk 1210 and Mrk 463E (Watanabe et al. 2003).

First, we normalize all the spectra at 4800 Å, and compare the parameters of the continuum flux at 3682, 4020, 4510 and 5500 Å, as well as the EWs of the absorption lines of CaIIK λ3933, the G-band λ4300 and Mg Ib λ5173. The relative errors on these quantities are set to 5%–10% for the continuum fluxes and 1.0 Å for the EWs of absorption lines, which are similar to our measurement uncertainties. Following Schmitt, Storchi-Bergmann & Cid Fernandes (1999), Stochi-Bergmann et al. (2000) and Cid Fernandes et al. (2001), the observed fluxes are dereddened by different $E(B-V)$ values in the range of 0–0.5 mag, with steps of 0.01 and compared with the synthesized values. Since the spectral population synthesis is a degenerate problem: more than one acceptable solution can fit the observed data. For NGC 2273, we find that there are 42 151 solutions in total. The average contributions of three components (power-law, the intermediate and old populations) to the total 4800 Å monochromatic light are 11.8%, 32.8%, 55.4%, and their standard 1 σ error are 5.2%, 5.4% and 1.1%, respectively. We also derived the internal extinction ($E(B-V)$) to be 0.329 ± 0.02 mag. Our final result is given by minimizing $\chi^2 (= \sum_{i=1}^{4} [\frac{C_{oi}-C_{ti}}{C_{oi}}]^2 + \sum_{j=1}^{3} [\frac{EW_{oj}-EW_{tj}}{EW_{oj}}]^2$, C_{oi} and C_{ti} being the observed and synthesized relative continuum fluxes at 3682, 4020, 4510 and 5500Å, and EW_{oj} and EW_{tj}, the observed and synthesized equivalent widths of CaII K λ3933, the G-band λ4300 and Mg Ib λ5173). The fractions of the three components for the minimum χ^2 fit are 10.0%, 33.4% and 56.6%, respectively, and $E(B-V)$ is 0.32 mag, which is shown in Fig. 2.

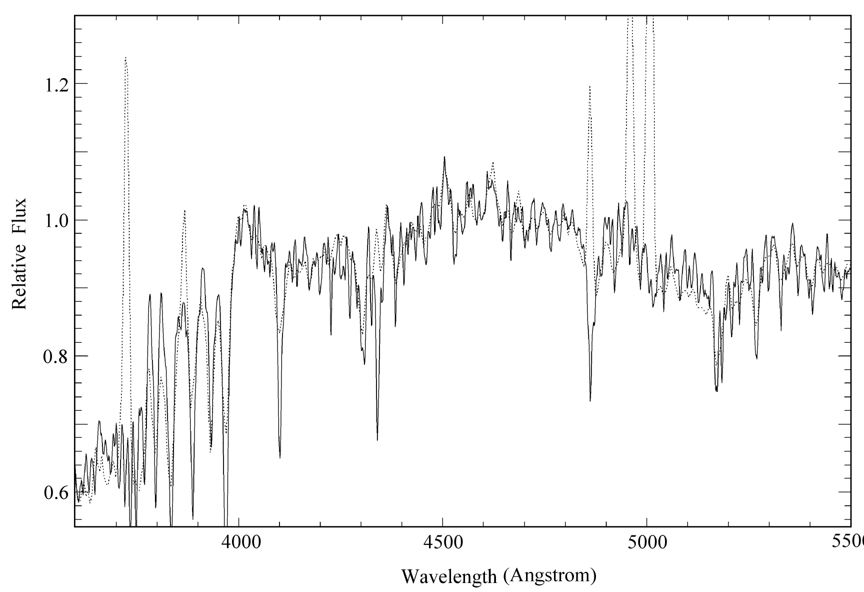

Fig. 2 Best-fitting (minimum χ^2) spectrum for NGC 2273 with a three-component population synthesis model (solid line), consisting of a power-law component and an intermediate age (10^8 yr) and an old (> 1 Gyr) stellar population. The relative contributions to the total 4800 Å monochromatic light are 10.0%, 33.4% and 56.6%, respectively. For comparison, the observed spectrum with internal extinction correction of $E(B-V) = 0.32$ mag is superimposed with the dotted line.

It is well known that the extinction for narrow emission line regions (NLRs) could be estimated from the observed ratio of Balmer decrement (Vacca & Conti 1992), which is $E_{B-V}^{\rm int} = 2.106\ \log(\frac{F({\rm H}\alpha)}{F({\rm H}\beta)} / \frac{I({\rm H}\alpha)}{I({\rm H}\beta)})$, where $F({\rm H}\alpha)/F({\rm H}\beta)$ and $I({\rm H}\alpha)/I({\rm H}\beta)$ are the observed and intrinsic H_α to H_β flux ratios, respectively. In this paper, we adopt an intrinsic ratio of 3.1 for AGN

(Gaskell & Ferland 1984). For NGC 2273, the observed $F(\mathrm{H}\alpha)/F(\mathrm{H}\beta)$ is equal to 5.90, then the extinction, $E(B-V)$, for NLRs is estimated to be 0.59 mag, which is different from the value derived from the stellar population synthesis [$E(B-V) = 0.32$ mag]. This is probably due to the intrinsic uncertainties associated with the reddening corrections (Cid Fernandes et al. 2001).

The stellar population in NGC 2273 consists mainly of a mixture of middle age ($\sim 10^8$ yr) and old stars. The lack of very young (a few Myr old) age population is also confirmed by the IUE spectrum, shown in Fig. 3, where stellar wind resonance absorption lines (such as N V λ1240, Si IV λ1400 and C IV λ1550) due to O stars are completely absent.

Our results of the high percentage ($\sim 33\%$) of the middle-age stellar component in NGC 2273 are also consistent with those of Cid Fernandes et al. (2001). In their sample, there are two galaxies (Mrk 78 and ESO 362–G08) located in the post-starburst phase with high-order Balmer absorption lines, just as in NGC 2273, and the contributions of the three components (featureless continuum, intermediate and old stellar populations) are 6.8%, 21.2% and 72.0% for Mrk 78; 4.9%, 38.5% and 56.6% for ESO 362–G08, respectively.

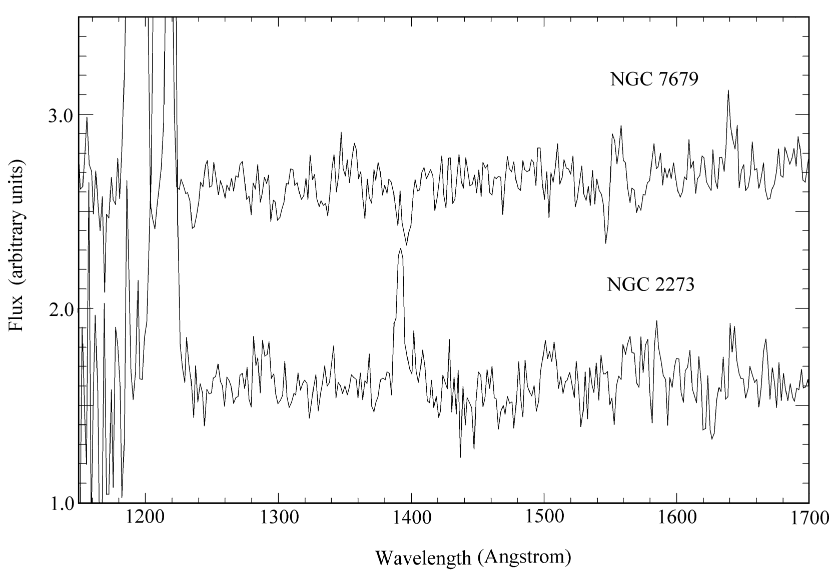

Fig. 3 Comparison of the IUE UV spectrum of NGC 2273 with that of NGC 7679, which has been shown to be a young starburst + AGN system (Gu et al. 2001). Several stellar wind absorption lines, such as N V λ 1240, Si IV λ 1400 and C IV λ 1550, can be identified in the IUE spectrum of NGC 7679, which are completely absent in NGC 2273.

3.2 AGN Activity in NGC 2273

NGC 2273 is originally classified as a Seyfert 2 galaxy by Huchra, Wyatt & Davis (1982). Our results ([OIII]/Hβ = 5.55, [OI]/Hα = 0.11, [NII]/Hα = 0.85 and [SII]/Hα = 0.51) also confirm their classification. The VLBI observation by Lonsdale et al. (1992) indicated that NGC 2273 contains a milliarcsecond, high brightness temperature (with $T_\mathrm{B} \sim 4 \times 10^8$ K) core, which is a classical indicator for AGN activity. The more direct evidence of AGN activity comes from the polarized broad Hα emission line with full width at zero intensity (FWZI) of $\sim 5000\,\mathrm{km\,s^{-1}}$, discovered by Moran et al. (2000). ASCA X-ray images (at soft- and hard-band) indicate that NGC 2273 is point-like, and the spectrum shows a heavily absorbed continuum with $N_{\mathrm{H}} > 1.0 \times 10^{24}\,\mathrm{cm^{-2}}$ and a strong fluorescent Fe K line with EW of 1.0 keV (Pappa et al. 2001; Terashima et al. 2002).

Though NGC 2273 contains a hidden Seyfert 1 nucleus which is detected in polarized light, the contribution of the AGN at the optical band is nearly negligible, this is probably because the AGN is highly obscured (Compton-thick with $\mathrm{N_H} \geq 10^{25}$, Bassani et al. 1999), any direct nuclear emission is completely absorbed.

3.3 Starburst Activity in NGC 2273

Lonsdale et al. (1992) noticed that there might be some absorption underlying the emission line Hβ, and Ho et al. (1997) observed the spectrum of the central $2'' \times 4''$ region in NGC 2273 with spectral coverage $\sim 4230-5110$ Å and $\sim 6210-6860$ Å. From their spectral analyses, they found that the EWs of stellar absorption lines at Hα, Hβ, Hγ and G-band are 1.87, 2.25, 2.06, and 1.52 Å, respectively. Due to their spectral range, they could not provide the near-UV data where high-order Balmer lines are located. Here we present, for the first time, the existence of high-order Balmer absorption lines (H8, H9 and H10) and weak equivalent widths for CaII K λ3933, CN λ4200, G-band λ4300 and MgIb λ5173, which clearly indicate recent star-forming activity in the nuclear region ($R < 150\,\mathrm{pc}$).

Other indicators for nuclear starburst in NGC 2273 include the IR color indexes and IR-radio ratio. According to Neugebauer et al. (1986), the region with IR color indexes $\alpha(25, 60) \leq -1.5$ and $\alpha(60, 100) \geq -1.1$, where $\alpha(\lambda1, \lambda2) = -\log(F_{\lambda2}/F_{\lambda1})/\log(\lambda2/\lambda1)$, is where one could find Seyfert galaxies with a circumnuclear starburst. For NGC 2273, $\alpha(25, 60) = -1.81$ and $\alpha(60, 100) = -0.79$, which confirm that NGC 2273 is really a composite (starburst + AGN) system. It is well known that a tight correlation exists between radio and far-infrared (FIR) emission for normal, starburst and Seyfert galaxies (the latter with larger scatter, which is ascribed to additional contribution from the AGN) (Helou et al. 1985). Hill et al. (2001) suggested that in starburst + AGN systems, FIR and radio properties are dominated by star-forming activity at 90% confidence level, even the presence of compact radio cores. The radio-FIR ratio ($q = 2.23$) of NGC 2273 is very similar to that of normal spirals and starburst galaxies, which might indicate that both the FIR and radio emission are powered by starburst activity, rather than by the AGN.

There are many observational examples to show that tidal interaction between galaxies plays a key role in triggering galactic nuclear activity (both nuclear starburst and AGN activities) (Zou et al. 1995). NGC 2273 is a member of the Group LGG137 (Garcia 1993), and Byrd et al. (1987) proposed that tidally induced activity occurs when the companion passes the perigalacticon, and the activities (both starburst and AGN) can continue as the companion recedes towards the apogalacticon. They suggested that NGC 2273 might have interacted with NGC 2273B within the last 10^9 years (the difference of their radial velocities is $61\,\mathrm{km\,s^{-1}}$, and the projected separation is 41 arcmin, corresponding to 330 kpc). So the starburst activity in this galaxy (with age $\sim 10^8$ yr) could have been triggered by the tidal interaction, as indicated by recent numerical simulations (Barnes & Hernquist 1996; Mihos & Hernquist 1996).

4 CONCLUSIONS

In this paper, we present unambiguous lines of evidence for recent starburst activity in the nuclear region of NGC 2273, including: the high-order Balmer absorption lines and the weaker CaII K λ3933, CN λ4200, G-band λ4300 and MgIb λ5173. The best fit with a simple three-component model gives the following percentages in the nuclear stellar population: intermediate age (10^8 yr) stars, 33.4%; the old (>1 Gyr) stars, 56.6%; and a possibly scattered AGN power-law component, 10%.

Acknowledgements The authors are very grateful to Prof. Xiaoyang Xia, for her constructive comments, which helped substantially improve the manuscript. We also thank the staff of National Astronomical Observatory (China) at Xinglong station for their assistance during the observations. This work has been supported by the NSFC (No. 10103001) and National Key Basic Research Science Foundation (NKBRSF G19990754). This research has made use of NASA's Astrophysics Data System Abstract Service and the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

Aretxaga I., Terlevich E., Terlevich R. et al., 2001, MNRAS, 325, 636
Barnes J. E., Hernquist L., 1996, ApJ, 471, 115
Bassani L., Dadina M., Maiolino R. et al., 1999, ApJS, 121, 473
Bruzual A. G., Charlot S., 1996, Galaxy Isochrone Syntheis Spectral Evolution Library, AAS, CD-ROM Series Vol. VII (GISSEL 96)
Byrd G. G., Sundelius B., Valtonen M., 1987, A&A, 171, 16
Cid Fernandes R. J., Terlevich R., 1992, In: A.V. Filippenko, ed., ASP Conf. Ser. 31, Relationships between Active Galactic Nuclei and Starburst Galaxies, San Francisco: ASP, 241
Cid Fernandes R. J., Terlevich R., 1995, MNRAS, 272, 423
Cid Fernandes R. J., Heckman T., Schmitt H., Gonzalez Delgado R. M., Storchi Bergmann T., 2001, ApJ, 558, 81
de Vaucouleurs G., de Vaucouleurs A., Corwin J. R., Buta R. J., Paturel G., Fouque P., 1991, Third Reference Catalogue of Bright Galaxies, 1991, New York: Springer-Verlag (RC3)
Garcia A. M., 1993, A&AS, 100, 47
Gaskell C., Ferland G., 1984, PASP, 96, 393
Gonzalez Delgado R. M., Perez E., Tadhunter C. et al., 1997, ApJS, 108, 155
Gonzalez Delgado R. M. et al., 1998, ApJ, 505, 174
Gonzalez Delgado R. M., Leitherer C., Heckman T., 1999, ApJS, 125, 489
Gonzalez Delgado R. M., Heckman T., Leitherer C., 2001, ApJ, 546, 845
Gu Q., Huang J., de Diego J. A. et al., 2001, A&A, 374, 932
Heckman T. M., Krolik J., Meurer G. et al., 1995, ApJ, 452, 549
Heckman T. M., Gonzalez Delgado R. M., Leitherer C. et al., 1997, ApJ, 482, 114
Helou G., Soifer B. T., Rowan-Robinson M., 1985, ApJ, 298, L7
Hill T. L., Heisler C. A., Norris R. P. et al., 2001, AJ, 121, 128
Ho L., Filippenko A. V., Sargent W., 1997, ApJS, 112, 315
Huchra J., Wyatt W., Davis M., 1982, AJ, 87, 1628

Lonsdale C., Lonsdale C., Smith H., 1992, ApJ, 391, 629
Mihos J. C., Hernquist L., 1996, ApJ, 464, 641
Moran E. C., Barth A. J., Kay L. E., Filippenko A. V., 2000, ApJ, 540, L73
Mouri H., Taniguchi Y., 2002, ApJ, 565, 786
Neugebauer G., Soifer B. T., Rowan-Robinson M., 1986, In: G. Giuricin, F. Mardirossian, M. Mezzetti, M. Ramella, eds., Structure and Evolution of Active Galactic Nuclei, Dordrecht: Reidel, 11
Pappa A., Georgantpoulos I., Stewart G., Zezas A., 2001, MNRAS, 326, 995
Pogge R. W., 1989, ApJ, 345, 730
Schmitt H., Storchi-Bergmann T., Cid Fernandes R., 1999, MNRAS, 303, 173
Storchi-Bergmann T., Raimann D., Bica E. L. D., Fraquelli H. A., 2000, ApJ, 544, 747
Terashima Y., Iyomoto N., Ho L., Ptak A., 2002, ApJS, 139, 1
Vacca W., Conti P., 1992, ApJ, 401, 543
Watanabe M., Nagata T., Sato S. et al., 2003, ApJ, in press
Zou Z., Xia X., Deng Z., Wu H., 1995, A&A, 304, 369