STRUCTURE OF THE MIR EMISSION IN THE CIRCUM-NUCLEAR REGIONS OF ACTIVE AND/OR STARBURST GALAXIES

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Abstract

We present broad band 7 μm (LW2) and 15 μm (LW3) images that have been obtained with ISOCAM for a sample of ten barred galaxies. The comparison of their mid-infrared properties reveals that star formation is differently taking place in these objects.

Key words: Galaxies: nuclei – Galaxies: circumnuclear regions – Galaxies: star formation

1. Introduction

Gravitational perturbations of galaxies are likely to play an important role in generating galaxy starbursts and in fueling active galactic nuclei (AGN). Whereas tidal forces between interacting or merging galaxies are strong enough to drive major gas flows, the compression of which leads to intense starbursts and/or activity in the nuclei, it is less clear whether forming bars alone are also able to trigger enhanced star formation either along the bar or near the centre. NGC 7479 is an example where this activity can be significantly high, the strength of the bar seeming to be an essential parameter to consider (Martinet & Friedli 1997). Therefore until recently the link between bar and starburst has not been very clear (see e.g. Hawarden et al. 1996).

The difficulty with ordering the processes involved in star formation is that they occur on widely different times scales, among which we mention: the bar growth time, the bar life time at its maximum strength, the time scale for driving the gas to the centre, the molecular cloud formation time, the gas cooling time, and finally all the time scales associated with stellar formation and evolution, such as the energy input from massive stars, the mass return to the interstellar medium from red giants, and the metal enrichment. The involved physics is so complex and some parts so poorly known that only a comparison between simulations and high resolution and multi-spectral observations of the central regions of galaxies can bring some enlightenment on these questions.

One severe issue for feeding AGN is how to accrete gas down to the centre at subparsec scale, which requires a process able to evacuate nearly all the angular momentum. It seems that the same trick to extract angular momentum working well at kpc scale, the bar, can be reused at smaller scales, leading to the often observed secondary bars embedded in the larger one (Wozniak et al. 1995, Friedli et al. 1996).

The broad aim of our ISO program is to clarify the intimate links between bar dynamics and star formation activity in barred galaxies. MIR (5–17 μm) imaging is indeed particularly powerful for locating the youngest star forming regions and for exploring broader issues like the dynamical origin of these activities. MIR wavelengths trace the hot dust associated with the most recent star formation, and thus might give powerful indicators of star formation activity. Location of sources of heating can be done at shorter wavelengths. Moreover, MIR imaging operate with larger arrays and better resolution than those available so far in the FIR allowing thus to investigate in a much more detailed way the intricate connections between global dynamics and star formation activity.

Among the sites of high star formation activity, the nuclear and/or circumnuclear regions have particularly hold our attention. We thus decided to observe the MIR emission with the highest pixel field of view (PFOV=$1.5''\mathrm{px}^{-1}$) allowed by the ISOCAM camera of the ISO satellite. The small field of view ($45''$) is sufficient to enclose the circumnuclear star forming regions of nearby barred galaxies.

2. The sample

We have selected a sample of ten nuclear and circumnuclear starburst galaxies for which low resolution MIR and/or millimeter maps have been done (cf. Table 1). All these galaxies show signatures generally associated with prominent star formation activity, like Hα emission (e.g. HII regions, hot spots), dust lanes, mini-spirals, nuclear bar and/or ring, etc.

The observations were done with the LW2 (5–8.5 μm) and LW3 (12–18 μm) broad band filters at the $1.5''\mathrm{px}^{-1}$ PFOV. The LW2 filter includes emission from the UIB bands at 6.2 μm, 7.7 μm and 8.6 μm as well as the underlying continuum. The LW3 filter collects continuum emission of small grains as well as [NeII] (12.8 μm) and [NeIII] (15.5 μm) emissions if present. The beamswitching mode with 2 reference fields was used to remove the MIR background. This program required roughly 12 hours. Further details on the reduction and calibration processes can be found in Wozniak (2001).

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Table 1. MIR properties of our galaxy sample. Circular apertures of resp. 4.5 and 6″ have been used to integrate nuclear fluxes at 7 and 15 μm. Colour is computed as the ratio 7 over 15 μm.

	Nucleus properties			Quiescent or star-forming regions		
Objects	Activity	Flux (Jy) $F_{7\mu m}/F_{15\mu m}$	Mean colour	Location	Typical Surface Brightness (mJy $''^{-2}$) $S_{7\mu m}/S_{15\mu m}$	Mean or typical colour
NGC 1097	Seyfert 1	0.09/0.23	0.40	Circum-Nuclear ring	2.2/2.8	0.7
				Spots along the ring	**3.6/3.8**	**0.95**
NGC 1808	Seyfert 2	0.9/...	0.45	Around nucleus	3–4/...	...
NGC 4321	Liner	0.06/0.13	0.40	Circum-Nuclear ring	0.9/1.0	0.9
				Spots along the ring	**1.6/1.45**	**1.1**
NGC 4691		0.09/0.23	0.35	**Eastern spots**	**0.9–1.3/1.0**	**1.0–1.2**
NGC 5236	Starburst	0.6/1.7	0.35	**Northern bright spot**	**1.1/1.1**	**1.0**
NGC 6764	Liner & Sy2	0.068/0.18	0.38	Wolf-Rayet nucleus	(0.07)/0.03	...
NGC 7469	Seyfert 1.2	0.37/0.92	0.40	Around nucleus	0.08/0.1	0.5
NGC 7479	Liner & Sy2	0.2/0.62	0.22	Along the bar	0.2/0.22	0.9
				South bright spots	**0.41/0.32**	**1.3**
NGC 7552	Liner	0.66/1.5	0.44	Bar outside nucleus	0.35/0.4	0.8

3. Discussion

The first noteworthy result is the colour of the nuclei: $F_{7\mu m}/F_{15\mu m}$ ranges from 0.22 to 0.44. The nuclei are thus very blue independently of the kind of nuclear activity.

The colours of circumnuclear rings are, on the average, similar to other regions outside the nucleus. However, bright spots of star formation have $S_{7\mu m} \geq S_{15\mu m}$. NGC 4321 was the first case to display such red bright spots (Wozniak et al. 1998). NGC 4691 and 7479 showing the same result, this suggests that it could be a general properties of regions of recent star formation. These red colours can be due to an excess of 7 μm emission and/or a deficiency of 15 μm one. In the case of NGC 4321, Wozniak et al. (1998) argued that the carboned Wolf-Rayet circumstellar envelop emission around 7 μm could be responsible. However, this is still not confirmed by optical spectroscopy (Contini et al. 2001) and this is obviouly not the case for NGC 6764 (cf. Table 1) whose nucleus contain many Wolf-Rayet stars (Contini et al. 1997).

4. Herschel prospects

Several attempts have been made to relate the star formation rates to luminosities like e.g. $L_{\mathrm{H}\alpha}$, L_{B} and L_{FIR}. However, $L_{\mathrm{H}\alpha}$, related to recent star formation (10^6 to 10^7 yr), is very sensitive to dust absorption while L_{B} is more related to $1-3\,\mathrm{M}_\odot$ main sequence stars and thus traces star formation over longer time scales ($4\cdot10^8$ to $6\cdot10^9$ yr). Dust might not only be heated by young massive stars but also by older stars so that L_{FIR} (estimated from 60 μm and 100 μm IRAS measurements) remains a controversial tracer of recent star formation (Sauvage & Thuan 1992). Imaging a sample of nearby starbursts and/or active galaxies at better resolutions with `PACS` and `SPIRE` will partly remove the ambiguity.

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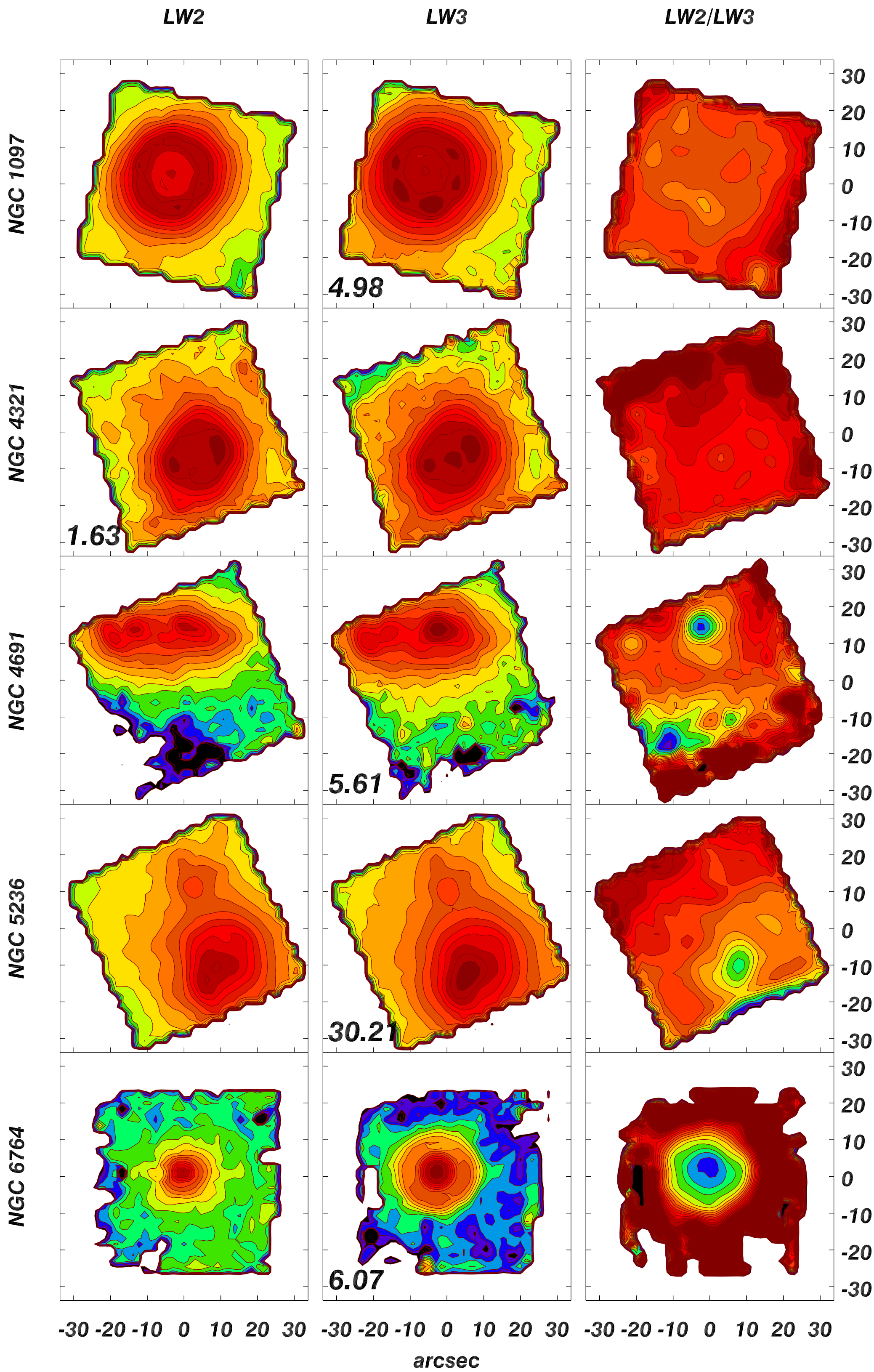

Figure 1. *Left and central panels: LW2 (7 μm), LW3 (15 μm) ISOCAM images for the whole sample. For each object, both bands are displayed with the same colour coding; the surface brightness (mJy arcsec^{-2}) ranges from 0.01 to the maximum written on the figure. Right panel: LW2/LW3 colour maps. The colours range from 0.1 to 2 with the same colour coding for all objects. The images have been convolved to reduce them to the same effective resolution. The PSF is shown for comparison with very bright nuclei.*

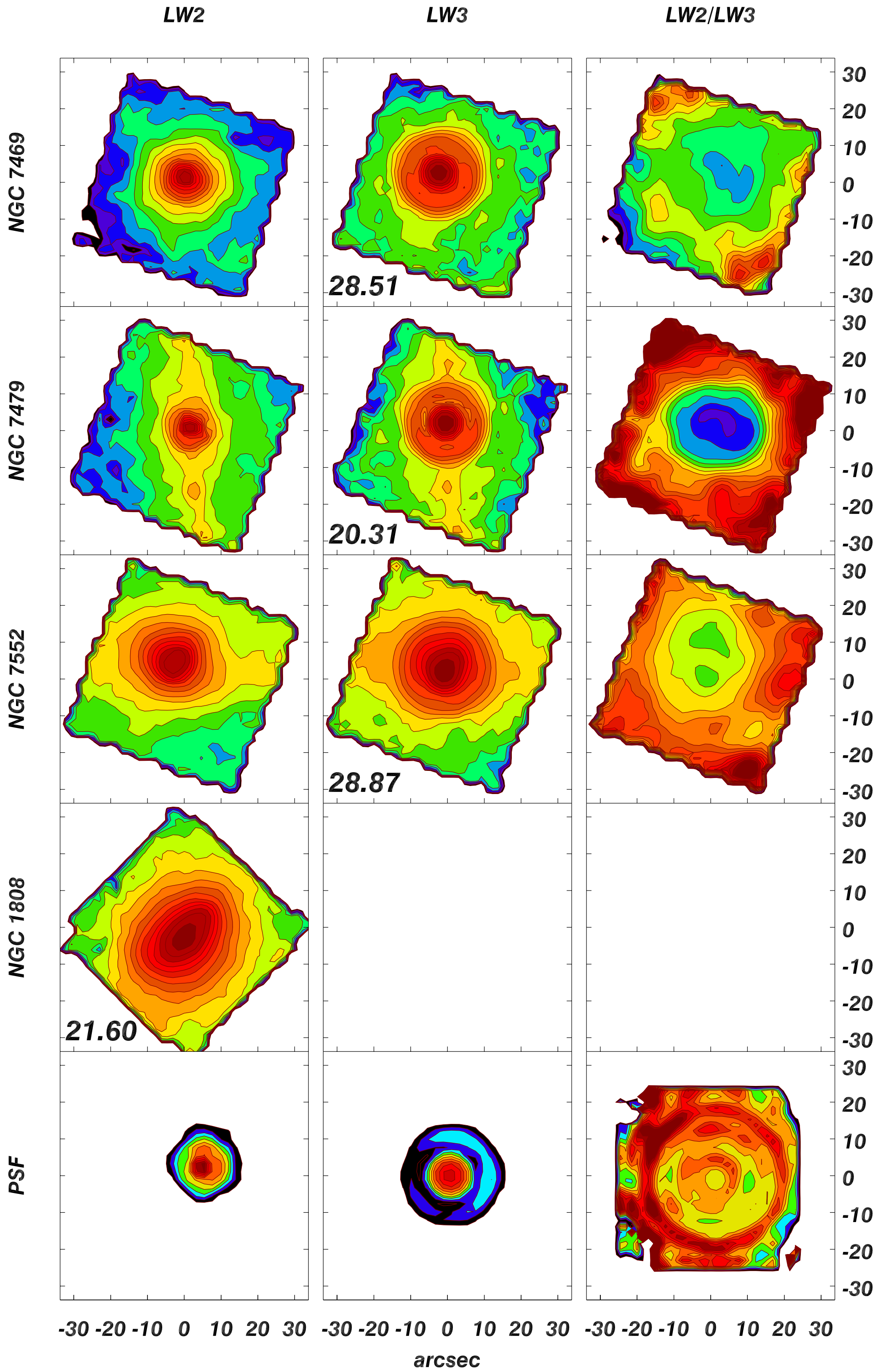

Figure 2. *As for Figure 1.*