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Unveiling the dominant gas heating mechanism in local LIRGs and ULIRGs

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We show preliminary results from a sample of Luminous and Ultra-Luminous Infrared Galaxies (LIRGs and ULIRGs, respectively) in the local universe, obtained from observations using the Very Large Array (VLA), the Multi-Element Radio Link Interferometer Network (MERLIN), and the European VLBI Network (EVN). The main goal of our high-resolution, high-sensitivity radio observations is *to unveil the dominant gas heating mechanism in the central regions of local (U)LIRGs.* The main tracer of recent star-formation in (U)LIRGs is the explosion of core-collapse supernovae (CCSNe), which are the endproducts of the explosion of massive stars and yield bright radio events. Therefore, our observations will not only allow us to answer the question of the dominant heating mechanism in (U)LIRGs, but will yield also the CCSN rate and the star-formation rate (SFR) for the galaxies of the sample.

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1. Introduction

Galaxies with infrared luminosities ($L_{\rm IR}[8-1000\ \mu m] \geq 10^{11} L_{\odot}$; LIRGs), become the dominant population of extragalactic objects in the local Universe (z $\lesssim$ 0.3). The trigger for the intense infrared emission appears to be the strong interaction/merger of molecular gas-rich spirals. Galaxies at the highest infrared luminosities ($L_{\rm IR}[8-1000\ \mu m] \geq 10^{12} L_{\odot}$), known as Ultra-Luminous Infrared Galaxies (ULIRGs), appear to be advanced mergers, and may represent an important stage in th formation of quasi-stellar objects and powerful radio galaxies [14]. The critical question concerning these galaxies is whether the dust in the central regions ($r \lesssim 1$ kpc) is heated by a starburst or an active galactic nucleus (AGN), or a combination of both. Mid-infrared spectroscopic studies of ULIRGs by [4] suggest that the vast majority of these galaxies are powered predominantly by recently formed massive stars, with a significant heating from the AGN only in the most luminous objects [15]. These authors also found that at least half of ULIRGs are probably powered by both an AGN and a starburst in a circumnuclear disk or ring, which are located at typical radii $r \simeq$700 pc from the nucleus of the galaxy, and also contain large quantities of dust.

Since a large fraction of the massive star-formation at both low- and high-*z* has taken place in (U)LIRGs, their implied high star-formation rates (SFRs) are expected to result in CCSN rates a couple of orders of magnitude higher than in normal galaxies. Therefore, a powerful tracer for starburst activity in (U)LIRGs is the detection of CCSNe, since the SFR is directly related to the CCSN rate. However, most SNe occurring in ULIRGs are optically obscured by large amounts of dust in the nuclear starburst environment, and have therefore remained undiscovered by (optical) SN searches. Fortunately, it is possible to discover these CCSNe through high-resolution radio observations, as radio emission is free from extinction effects. Furthermore, CCSNe are expected, as opposed to thermonuclear SNe, to become strong radio emitters when the SN ejecta interact with the circumstellar medium (CSM) that was expelled by the progenitor star before its explosion as a supernova. Therefore, if (U)LIRGs are starburst-dominated, bright radio SNe are expected to occur and, given its compactness and characteristical radio behaviour, can be pinpointed with high-resolution, high-sensitivity radio observations (e.g., SN 2000ft in NGC 7469 [3]; SN 2004ip in IRAS 18293-3413, [11]; SN 2008cs in IRAS 17138-1017, [12], [5], [6]; supernovae in Arp 299 [8], Arp 220 [9] and Mrk 273 [2]). However, due to (i) the large distances where (U)LIRGs are located and (ii) the likely contribution of a putative AGN, it is mandatory the use of high-sensitivity, high-resolution radio observations to disentangle the nuclear and stellar (mainly from young SNe) contributions to the radio emission, thus probing the mechanisms responsible for the heating of the dust in those regions.

2. VLA imaging of local LIRGs

The circumnuclear regions that are expected to host significant starburst activity in nearby LIRGs are typically located at radial distances of $\lesssim$1 kpc. To unambiguouly detect the radio emission from CCSNe, which highlight the presence of a recent starburst, it is crucial that the radio observations be taken with high angular resolution. In particular, the VLA-A at 8.4 GHz yields an

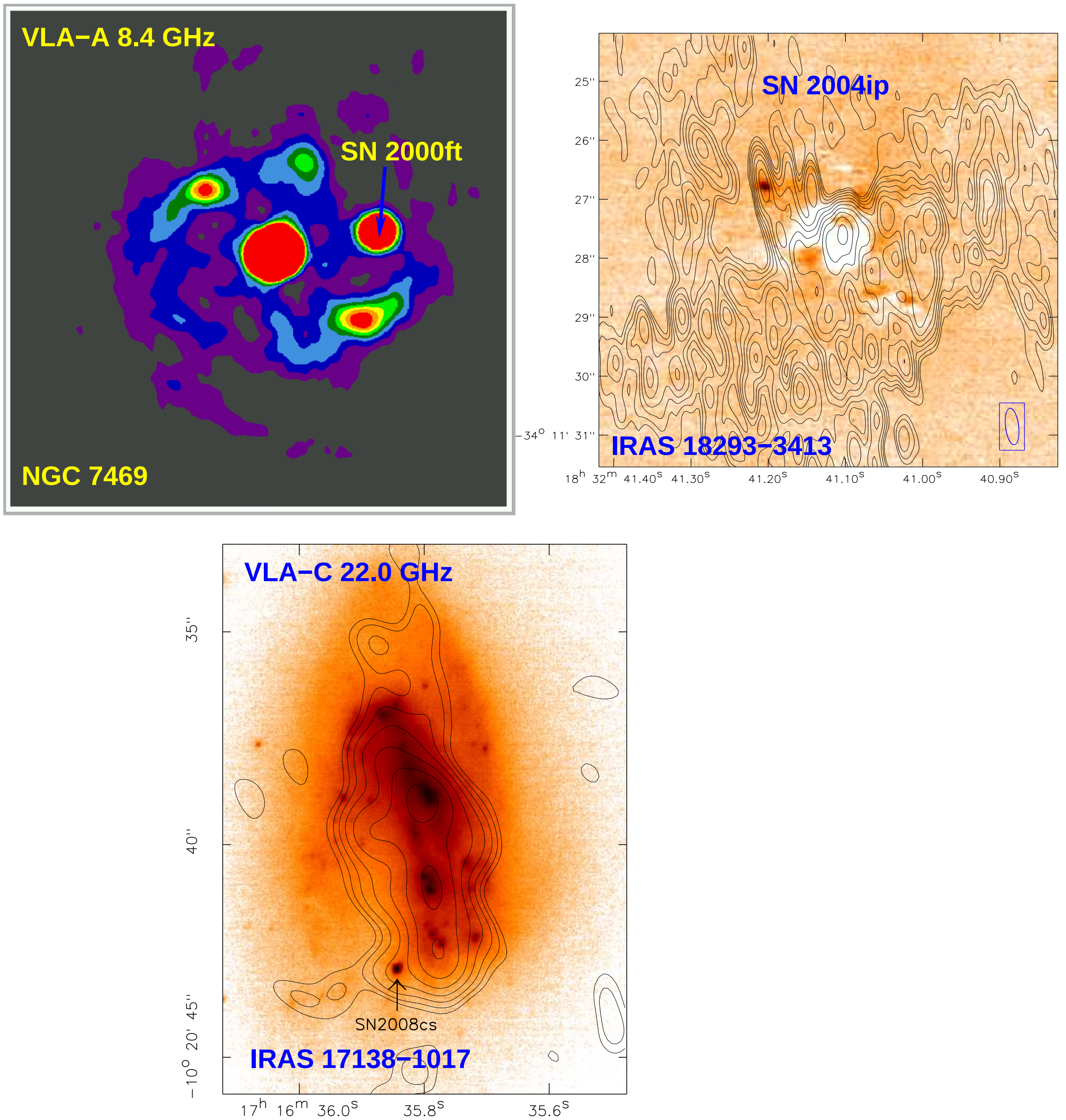

Figure 1: Top left: 8.4 GHz VLA discovery image of the radio supernova SN 2000ft in the galaxy NGC 7469 [3]. Top right: 8.4 GHz VLA contours of SN 2004ip, overlaid on top of the NIR 2.2μm discovery image of the supernova [7], whose detection at radio wavelengths three years after its explosion confirmed it core-collapse nature [11]. Bottom center: 22.0 GHz VLA contours of SN 2008cs, overlaid on top of a NIR 2.2μm GEMINI image [12], [5], [6].

angular resolution of 0.3”, which is enough to discern the contribution of exploding SNe from that of a putative AGN in nearby LIRGs (up to a distance of $\sim$100 Mpc).

In Figure 1, we show VLA images of several nearby ($D \lesssim 100$ Mpc) LIRGs. In particular, we show VLA-A images of NGC 7469 ($D = 70$ Mpc), IRAS 18293-3413 ($D = 79$ Mpc), and IRAS 17138-1017 ($D = 75$ Mpc), where a number of supernovae have been discovered (SN 2000ft in NGC 7469 [3]); SN 2004ip in IRAS 18293-3413 [11]; SN 2008cs in IRAS 17138-1017 [12] and [5], [6]). We note here that those SNe were not discovered in the optical, since they are dust-enshrouded in the dense medium of their host galaxies, but at radio wavelenghts (SN 2000ft) and in the NIR and radio (SN 2004ip and SN 2008cs). Those cases show that high-resolution radio observations of (circumn)nuclear starbursts are crucial to unveil CCSNe in dust-enshrouded environments. In addition, if the exploding CCSNe are bright enough, their monitoring allows to gain insight in both the progenitor and the interaction between the supernova and its circumstellar medium (CSM), and eventually the interstellar medium (ISM), by means of a radio follow-up. For example, the monitoring of SN 2000ft showed that SN 2000ft is a type IIn SN [1], which result in long-lasting radio events, e.g., SN 1986J in NGC 891 [10], and seems to follow an evolution similar to that of radio supernovae in normal galaxies.

3. EVN+MERLIN imaging of local ULIRGs

We have recently embarked ourselves in a project to image at radio wavelengths four of the most distant ULIRGs in the nearby universe, combining simultaneous observations with the European VLBI Network (EVN) and the Multi-Element Radio Linked Interferometer (MRLIN). The use of those arrays is mandatory because, at the distances where those ULIRGs are located (from 250 Mpc up to 350 Mpc), the VLA neither is able to discern the compact radio emission from single supernovae, nor can separate it from a putative AGN contribution.

We have obtained the deepest and highest resolution radio images ever of those ULIRGs, using quasi-simultaneous observations with the EVN at 1.6 and 5.0 GHz (see Figure 2 and [13]). The top and middle panels show preliminary images of IRAS 07251-0248 (D=344 Mpc, $L_{FIR} = 10^{12.32}\,L_{\odot}$, CCSN rate $\approx$ 8 SN/yr); IRAS 2336+3604 (D=252 Mpc, $L_{FIR} = 10^{12.13}\,L_{\odot}$, CCSN rate $\approx$ 5 SN/yr); IRAS 19295-0406 (D=338 Mpc, $L_{FIR} = 10^{12.37}\,L_{\odot}$, CCSN rate $\approx$ 8 SN/yr); We have found a number of bright, compact components, some of which are suggestive of CCSNe exploding in the innermost regions of those ULIRGs, and whose radio luminosities are typical of Type IIL and Type IIn SN, which yield bright radio SNe. The images of IRAS 07251-0248 and IRAS 2336+3604 show that not all of the the 5.0 GHz brightness peaks are coincident with those seen at 1.6 GHz. As discussed in [13], this is consistent with a scenario where we are witnessing the radio emission of recently exploding CCSNe, so that their 5.0 GHz emission would now be around their peak, while their 1.6 GHz emission would still be rising. On the other hand, we have also found several 1.6 GHz peaks without a clear counterpart at 1.6 GHz. This can be explained if their emission arises from CCSNe that are already in their optically thin phase, as indicated by their two-point spectral indices. Finally, the bottom panels show the simultaneous 5.0 GHz MERLIN (left) and EVN (right) images of IRAS 19295-0406. Note that the MERLIN image cannot resolve the radio emission from single (or chained of) supernovae. However, the EVN can pinpoint the precise location of the compact radio emission. As with the cases above discussed, the inferred luminosities are in agreement with young, bright radio events, typical of Type IIL and IIn supernovae. Future observations with the EVN+MERLIN of those ULIRGs (already granted), will allow us to confirm all of the SN candidates, as well as to precise locate the putative AGN in those galaxies.

To summarize, high-resolution radio observations of (U)LIRGs in the local universe are a powerful tool to probe the dominant dust heating mechanism in their nuclear and circumnuclear regions, as they are free from extinction, unlike optical observations. The most direct way of probing whether the main mechanism is due to recent starbursts is the radio search of core-collapse supernovae (CCSNe), whose detection will permit us to establish, independently of models, the CCSN rate for the galaxies of our sample and, by assuming an Initial Mass Function (IMF), their Star Formation Rates (SFR).

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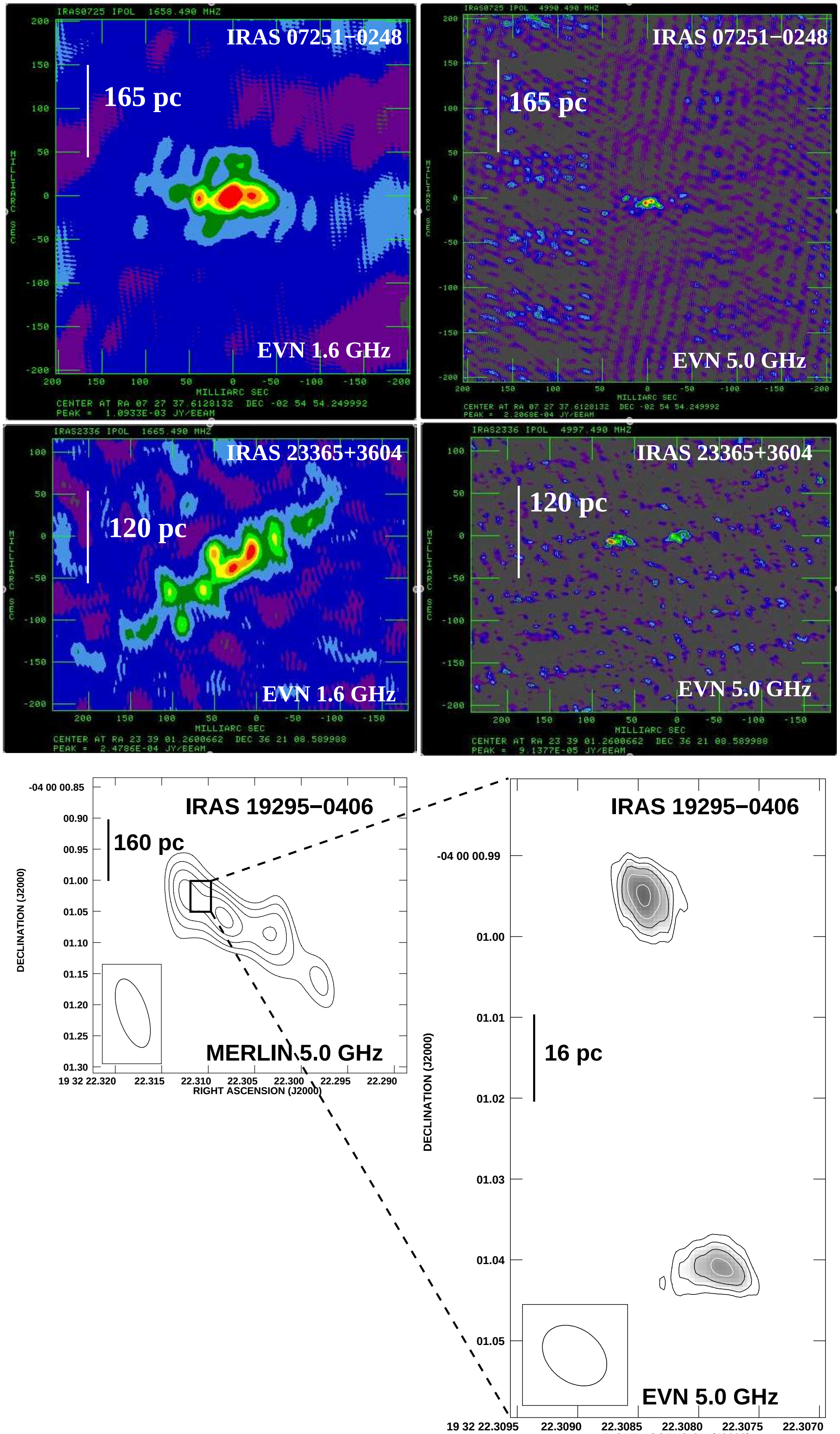

Figure 2: Top panels: 1.6 and 5.0 GHz EVN images of IRAS 07251-0248. Middle panels: 1.6 and 5.0 GHz EVN images of IRAS 2336+3604. Bottom panels: 5.0 GHz MERLIN (left) and EVN (right) images of IRAS 19295-0406. (See text for details.)