EXTREME GALACTIC-WINDS AND STARBURST
IN IR MERGERS AND IR QSOs

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ABSTRACT

We report –as a part of a long-term study of mergers and IR QSOs– detailed spectroscopic evidences for outflow (OF) and/or Wolf Rayet (WR) features in: (i) low velocity OF ongoing mergers NGC 4038/39 and IRAS 23128-5919; and (ii) extreme velocity OF (EVOF) QSOs IRAS 01003-2238 and IRAS 13218+0552. We also study the presence of OF and EVOF in a complete sample of ultra-luminous IR galaxies/QSOs ("The IRAS 1 Jy MKO-KPNO Survey", of 118 objects). We found EVOF in IRAS 11119+3257, 14394+5332, 15130+1958 and 15462-0450 (and probable OF in IRAS 05024-1941, 13305-1739, 13451+1232, and 23389+0300). The OF components detected in these objects were mainly associated to starburst processes: i.e., to galactic-winds generated in multiple type II SN explosions and massive stars. The EVOF were detected in objects with strong starburst plus obscured IR QSOs; which suggest that interaction of both processes could generate EVOF.

In addition, we analyze the presence of Wolf Rayet features in the large sample of Bright PG-QSOs (Boroson and Green 1992), and nearby mergers and galactic-wind galaxies. We found clear WR features in the Fe II PG-QSOs (type I): PG 1244+026, 1444+407, 1448+273, 1535+547; and in the IR merger Arp 220. We describe the properties of the [O III]λ5007-4959 emission, in strong and extreme Fe II+IR+BAL emitters (QSOs of types I and II).

HST archive images of IR+BAL QSOs show in practically all of these objects “arc or shell” features probably associated to galactic-winds (i.e., to multiple type II SN explosions) and/or merger processes.

Finally, we discuss the presence of extreme starburst and galactic wind as a possible evolutive link between IR merger and IR QSOs; where the relation between mergers and extreme starburst (with powerful galactic-winds and “multiple” type II SN explosions) plays an important role, in the evolution of galaxies/QSOs.

Subject headings: galaxies: individual (IRAS 00275-2859, IRAS 01003-2238, IRAS 04505-2958, IRAS 07598+6508, IRAS 11119+3257, IRAS 13218+0552, IRAS 14026+4341, IRAS 14394+5332, IRAS 15130+1958, IRAS 15462-0450, IRAS 19254-7245, IRAS 23128-5919, Mrk 231, NGC 4039/38, PG 1244+026, PG 1448+273, PG 1444+407, PG 1535+547, PG 1700+518, and I Zw 1) – galaxies: interactions – galaxies: starburst – quasar: general

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1. INTRODUCTION

Main current issues in astrophysics are the study of mergers, massive star formation processes, IR/BAL QSOs (and the relation between them). These three issues play an important role in practically all the scenario of formation and evolution of galaxies and active galactic nuclei (AGNs) (see for references §4.4). In addition, the presence of galactic-winds—associated mainly to extreme star formation processes—is also a main component for different theoretical models of galaxies formation (see Ostriker & Cowie 1981; Berman & Suchkov 1991).

Mergers are mainly luminous IR galaxies whose luminosities overlap with most luminous QSOs and Seyfert galaxies; and their optical, IR and radio properties show starburst and AGN characteristics (Joseph & Wright 1985; Schweizer 1980, 1982, 1996; Rieke et al. 1985; Sanders et al. 1988a; Sanders & Mirabel 1996). Luminous IR galaxies \( (L_{IR} \geq 10^{11}L_\odot; LIRGs) \) are dusty strong IR emitters where an enhancement of star formation is taking place (see for references Lipari et al. 2000a); and imaging surveys of ultraluminous IR galaxies \( (L_{IR} \geq 10^{12}L_\odot; ULIRGs) \) show that \( \sim 100\% \) are mergers or strongly interacting systems (Sanders et al. 1988a; Melnick & Mirabel 1990; Clements et al. 1996). And, there is compelling evidence for merger and interaction driven starburst and nuclear activity; probably by depositing large amounts of interstellar gas to the nuclear regions (see Sanders & Mirabel 1996; Scoville & Soifer 1991; Barnes & Hernquist 1992; Mihos & Hernquist 1996, 1994a,b). In addition galactic–winds, bubbles and Wolf Rayet features have been clearly detected, in starburst and IR galaxies (see for references Lipari et al. 2000a; Heckman, Armus, & Miley 1990, hereafter HAM90; Lipari & Macchetto 1992).

The discovery and study of luminous IR QSOs and IR selected QSOs (see Beichman et al. 1986; Vander et al. 1987; Lawrence et al. 1988; Sanders et al. 1988b; Low et al. 1988, 1989; Lipari, Macchetto, & Golombeck 1991; Colina, Lipari & Macchetto 1991b; Lipari, Colina & Macchetto 1994; and others) raises several interesting questions, in particular: are they a new or a special class of QSOs? In the last years, it has been proposed that luminous IR QSOs are normal AGNs, merely viewed at particular angles (Wills et al. 1992; Hines & Wills 1995; Boyce et al. 1997). While this hypothesis is interesting, it has problems to explain several observational results (Canalizo, Stockton & Roth 1998). On the other hand, we found that almost \( 100\% \) of extremely strong \( \text{Fe II} \) emitters are luminous IR QSOs and are radio-quiet. We suggested that these objects would be young IR active galaxies at the end phase of a strong starburst (Lipari, Terlevich & Macchetto 1993; Lipari 1994). In recent years, composite models (i.e., nonthermal–AGN plus starburst/superwind scenario) have become a widely accepted approach in studying the source of nuclear energy in IR galaxies and QSOs (see Genzel et al. 1999; Downes et al. 1999; Veilleux, Kim & Sanders 1999; Lutz, Veilleux, & Genzel 1999; Schmit et al. 1998).

In addition, some of the results obtained for low ionization BAL QSOs, such as very weak \([\text{OIII}]\lambda 5007\) emission, strong blue asymmetry in H\(\alpha\), radio quietness, and strong IR and \( \text{Fe II} \) emission (Boroson & Mayer 1992; Lipari et al. 1993, 1994), can be explained in the framework of the starburst scenario (Lipari 1994). In our study of Mrk 231, IRAS 0759+6559 (the nearests extreme \( \text{Fe II}, \) IR and BAL systems), we detected typical characteristics of a young-starburst QSO and found evidence of a probable link between BAL systems and star formation regions (Lipari et al. 1994; Lipari 1994; Dyson et al. 1992). Specifically, our evolutive model for young IR QSOs (see for references Lipari 1994) suggested that BAL systems could be linked to violent supermassive starburst which produce an expanding shell and dust obscuration. Recently, several articles suggested that this evolutive model shows a good agreement with the observations (see Canalizzo, Stockton & Roth 1998, for references).

In the last years, several possible links between mergers, starburst/galactic-wind, and IR QSOs/galaxies have been proposed. Specifically, Joseph et al., Sanders et al. and Lipari et al. suggested three
complementary sequences and evolutive–links:

(i) merger → giant shocks → super-starbursts + galactic winds → elliptical galaxies;

(ii) merger → H2-inflow (starbursts) → cold ULIRGs → warm ULIRGs + QSOs;

(iii) merger → extreme starburst + galactic-wind (inflow + outflow) → extreme Fe II/BAL/IR composite-QSOs → standard QSOs and elliptical.

Studies of nearby mergers and IR QSO with high resolution is one observational way to study this relation. We have started a detailed morphological, spectroscopic and kinematical study of luminous mergers and IR QSOs (Lipari et al. 2000a); and we present -in this paper- several selected results from this program. We analyze in this paper the OF and WR features in: (i) two nearby mergers, the “Antennae” (z = 0.0055, L_{IR}[8–1000 µm] \sim 1.0 \times 10^{11} L_\odot); and IRAS 23128-5919 (z = 0.044, L_{IR}[8–1000 µm] \sim 2.0 \times 10^{12} L_\odot); and (ii) two relatively nearby IR QSOs, IRAS 01003-2238 (z = 0.118, L_{IR}[8–1000 µm] = 1.74 \times 10^{12} L_\odot) and IRAS 13218+0552 (z = 0.20, L_{IR}[8–1000 µm] = 4.26 \times 10^{12} L_\odot, L_{IR}/L_B \sim 90; see Armus, Heckman, & Miley 1988; Sanders et al. 1988b; Low et al. 1988, 1989; Remillard et al. 1993). In addition, we study EVOF and WR features in the large sample of ultra-luminous IR galaxies/QSOs (“The IRAS 1 Jy Survey”; Kim & Sanders 1998; Kim, Veilleux & Sanders 1998; Veilleux, Kim & Sanders 1999) and Bright PG-QSOs (of Boroson & Green 1992), respectively. Throughout the paper, a Hubble constant of H_0 = 75 km s\(^{-1}\) Mpc\(^{-1}\) will be assumed.

2. OBSERVATIONS AND REDUCTIONS

The observations were obtained at BALEGRE, Casleo, ESO, KPNO, MKO, and Palomar Observatories, with the 1.54 m, 2.15 m, 2.2 m, 3.6 m and 5.0 m telescopes. In addition, HST–(WFPC2/NICMOS) and ESO archive images were studied.

Long-slit spectroscopic observations were obtained at the 1.54 m telescope of Bosque Alegre Station of Cordoba Observatory using the Multi-functional Integral Field Spectrograph (Afanasev, Dodonov & Carranza 1994; Diaz et al. 1999) during 10 selected photometric nights between 1998 January and 2000 May. The observations were made mainly using a slit width of 1.0″ and 1200 1/mm grating, which gives an effective resolution of \sim 90 km s\(^{-1}\) and a dispersion of 40 Å mm\(^{-1}\) covering the wavelength range \lambda 6400–6900 Å. In order to have accurate spatial positions for the velocity determinations, zero order imaging of object plus slit were used. The seeing was in the range 1.3–2.3″ (FWHM).

Long-slit observations were obtained at the 2.15 m telescope of Casleo (San Juan, Argentina) during the period 1997 June to 2000 May. The observations were made using the instrumental configuration and technique described in previous papers (see §1, for references).

The data of the IRAS 1 Jy ULIRGs sample were obtained with Gold Cam spectrograph on the KPNO 2.15 m telescope using a grating of 300 lines mm\(^{-1}\) (8 Å, of resolution). And with the Faint Object Spectrograph at the f/10 Cassegrain focus of the University of Hawaii 2.2 m telescope at Mauna Kea; using a grating of 600 lines mm\(^{-1}\) (8 Å, of resolution). The details of the spectra obtained at Palomar 5.0 m telescope were published by Sanders et al. (1988a).

The ESO Faint Object Spectrograph and Camera (EFOSC) on the 3.6 m telescope at La Silla was used to obtain long-slit spectra and high resolution images. Medium-resolution spectra were obtained with the B150, O150, and R150 grisms, which provide a dispersion of 130 Å mm\(^{-1}\) in a range \lambda 3600–9800.

The HST–WFPC2 observations include broadband images, using the filters F450W (~B Cousins filter) and F814W (~I); with a CCD scale of 0.046” pixel\(^{-1}\), in the PC. HST–NICMOS observations include near-IR images, using the NIC2 and NIC1 CCD-camera.

The IRAF, SAO and ADHOC software packages were used to reduce the spectrophotometric data. Bias and dark subtraction and flat fielding were performed in the usual way. Wavelength calibration of the spectra was done by fitting two dimensional polynomials to the position of lines in the arc frame. The spectra were corrected for atmospheric extinction, galactic reddening, and redshift. The spectra and images were flux calibrated using observations of standard stars from the samples of Stone & Baldwin (1983) and Landoft (1992). The emission lines were measured and
decomposed using Gaussian profiles by means of a nonlinear least-squares algorithm described in Bevington (1969).

We have digitized the published spectra of IRAS 13218+0552 (from Remillard et al. 1993) and PG 1244+026, 1444+407, 1448+273 and 1535+547 (from Boroson & Green 1992).

3. RESULTS

In this section we study spectroscopic and morphological evidence of outflow — associated mainly to galactic-superwind— in mergers, IR QSOs, and ULIRGs (where previously were detected starburst and Wolf-Rayet features, bipolar extended emission, extreme IR emission, BAL systems, etc.). In addition, we analyze: (i) the presence of Wolf-Rayet features in the sample of Bright PG QSOs (Boroson & Green 1992) and in mergers or galactic-wind galaxies; and (ii) the host galaxies of IR+BAL+Fe II QSOs (using high resolution HST images).

It is important to note that the results presented in this paper are part of a log-term multi-wavelength study (including morphological, kinematical and physical conditions data) of luminous IR mergers and IR QSOs (see Lipari et al. 2000a). These observations were performed mainly in order to study their links.

3.1. Nuclear Outflow and WR features in “The Antennae” and IRAS 23128-5919

Read, Ponman & Wolstencroft (1995) and Fabiano, Schweizer, & Mackie (1997) already suggested the presence of outflow in The Antennae, from x-ray observations. In order to detect this component, in the nuclear and central regions of NGC 4038/39, long exposure spectroscopic observations were performed at CASLEO, with added long-slit spectra of \(~3\) h. This spectra were taken mainly through both nuclei. We found in the southern nucleus (NGC 4039) a defined blue component; which is evident mostly in the H\(\alpha\) and [N II] \(\lambda\)6584 emission lines (Fig. 1a). The velocity of this nuclear outflow is \(V_{Nucl, OF} = (-365 \pm 50)\) km s\(^{-1}\). In §4 this component will be associated to the nuclear starburst, detected previously in the nucleus of NGC 4039. We note that this blue outflow component (with relatively low velocity) was clearly detected only using data of moderate spectral resolution (\(~0.9\) km s\(^{-1}\) FWHM) and high S/N. We found a similar result in the main optical nucleus of the IR merger NGC 3256 (Lipari et al. 2000a).

We observed for the outflow components similar intensities in these emission lines; however, the outflow is stronger in the H\(\alpha\) line than in [N II] emission (we found in NGC 3256 and NGC 4945 the opposite result). It is interesting to note that Casleo spectra of NGC 4039 nucleus show LINER properties (Lipari et al. 2000b), and NGC 4038 nucleus show H II regions features. The values of the [N II] \(\lambda\)6584/H\(\alpha\), [O I] \(\lambda\)6300/H\(\alpha\) and [S II] \(\lambda\)6517-31/H\(\alpha\) emission line ratios in the nuclear region are clearly consistent with shocks driven into clouds accelerated outward by a starburst with galactic–wind (see Lipari et al. 2000b and HAM90: their Fig. 14). In addition, it is important to note that Rosa & D’Oddorico (1986) reported the presence of WR features in the HII regions of the Antennae.

The presence of outflow and WR-features in IRAS 23128-5919 has been previously suggested (Bergvall & Johansson 1985; Johansson & Bergvall 1988). We found, using CASLEO spectra, low velocity outflow and WR features in the bright southern nucleus of IRAS 23128-5919, with a value of \(V_{Nucl, OF} = (-300 \pm 70)\) km s\(^{-1}\).

Using spectra of Arp 220 of high S/N (obtained at Palomar 5.0 m telescope; Sanders et al. 1988) we detected in the bright north-west nucleus weak (but clear, at S/N \(~5\)) WR features at NI\(\lambda\)4640 and He II \(\lambda\)4686.

3.2. Outflow and WR features in IR QSOs IRAS 01003-2238 and IRAS 13218+0552

IRAS 01003-2238 and IRAS 13218+0552 are probably two of the more interesting IR QSOs (see §1, for references). In the spectrum of IRAS 01003-2238 and IRAS 13218+0552 (obtained at MKO and from Remillard et al 1993; respectively) we detected extreme multiple outflow components, mainly in the [OIII] \(\lambda\)5007-4959 and H\(\beta\) emission lines (Figs. 1b and 1c). We measured for IRAS 01003-2238 outflow-velocities of \(V_{OF1} = (-1530 \pm 60)\) km s\(^{-1}\) and \(V_{OF2} = (-710 \pm 50)\) km s\(^{-1}\), and for the main emission line component (MELC),
a value of $cz_{MELC} = 35505$ km s$^{-1}$. For IRAS 13218+0552 we have obtained $V_{OF} = (-1850 \pm 90)$ km s$^{-1}$, and $cz_{MELC} = 61000$ km s$^{-1}$.

In §4 these OF components will be associated to the nuclear starburst and the interaction between the starburst+QSO processes. Again this blue outflow was clearly detected only using high quality data.

On the other hand, both IRAS 01003-2238 and IRAS 13218+0552 show merger morphology (Surace et al. 1997; Boyce et al. 1997). Armus et al. (1988) found WR-features in IRAS 01003-2238; and we detected similar WR feature in IRAS 13218+0552 (using the MKO data, and our digitized spectra of the observation published by Remillard et al. 1993).

Finally, it is important to note that previously we found a very similar result (i.e., EVOF in [O III] emission line) for two ULIRGs. First, in the southern nucleus of the IR merger 19254-7245 (the “super-antennae”, with $V_{syst.} = 17900$ km s$^{-1}$, $L_{IR} = 1.1 \times 10^{12}$ L$_{\odot}$, $M_B = -23.3$ and $d_{nuclei} = 10$ kpc), we detected a massive star formation process with a strong galactic-wind and $V_{OutFlow} \sim -1000$ km s$^{-1}$, plus a type 2 QSO (Colina, Lipari & Macchetto 1991a). We also detected similar EVOF in Mrk 231 ($V_{OutFlow} \sim -1000$ km s$^{-1}$, in [O II]), this IR merger also has an obscured QSO (type 1) plus a strong circumnuclear starburst. In §4.2 we comment the properties of these EVOF objects.

3.3. Extreme Outflow in the 1 Jy Sample of ULIRGs

An interesting test in order to study the role of starburst/galactic-wind (GW) in IR mergers and IR QSOs (and their relation), is the analysis of outflow in a complete sample of luminous IR Galaxies and QSOs. Although the detection of low velocity outflow ($V \leq 600$ km s$^{-1}$) required detailed observation (see §3.2 and Lipari et al. 2000a). The study of outflow with large velocities (EVOF) -observed as strong multiple components in the emission line [O III]$\lambda 5007$- requires mainly spectra with moderate spectral resolution (objects showing very high FWHM([O III])).

Therefore, we performed a detailed study of EVOF, with FWHM ([O III]) $\geq 1000$ km s$^{-1}$, in the MKO-KPNO Survey of 1 Jy ULIRGs and IR QSOs (Kim & Sanders 1996; Kim, Veilleux & Sanders 1998; Veilleux, Kim & Sanders 1998). We study the ULIRGs: IRAS 05024-1941, 11119+3257, 13218+0552, 13305-1739, 14395+1232, 14394+5332, 15130-1958, 16462-0450, and 21219-1757. In addition, we study IRAS 23389+0300 that shows narrow plus broad [O III] components. And we found interesting results:

1. we detected clear EVOF in [O III] and H$\beta$ (see Table 1), in:
   - IRAS 11119+3257 (see Fig. 2), IRAS 14394+5332, IRAS 15130+1958, and IRAS 15462-0450.

2. and probable OF in: IRAS 05024-1941, 13218+0552, 13305-1739, 14395+1232, and 23389+0300. However, better spectral resolution and S/N are required, in order to confirm the presence of OF in these objects.

For the remaining object (IRAS 21219-1757), the high values in the FWHM([O III]) are due mainly to the blend of [O III] and Fe II emission lines (this IR QSO is a strong Fe II emitter).

3.4. Wolf Rayet features in a Sample of PG QSOs with Strong Fe II emission

We present in this section the results of the search of Wolf Rayet features in the large Sample of Bright PG-QSOs (of Boroson & Green 1992). This sample is very interesting since there is a subsample of moderate and strong Fe II emitters, and the authors published the observed spectra with and without the Fe II contribution (i.e., before and after the subtraction of an Fe II template). These fact allowed us to perform a careful search of the WR features in the rest-wavelength range of $\lambda 4600-4700$ Å (i.e., the strong lines of NII$\lambda 4640$ and He II$\lambda 4686$).

We found four Fe II PG-QSOs emitters with WR features: PG 1244+026, 1448+273, 1444+407 and 1535+547. In Fig. 3 we show the more clear case: the WR features in PG 1535+547, where the Fe II template was previously subtracted. In order to study in detail the WR features in these QSOs, we digitized these four spectra (from Boroson &
We discuss these interesting results, in §4.2.

3.5. \[\text{[OIII]}\lambda\lambda4959-5007 \text{ in Fe II Emitters (Strong and Extreme Fe II QSOs)}\]

In order to complement the study of multicomponents in the emission line \[\text{[OIII]}\lambda\lambda4959-5007\] we analyzed the behavior of this line in our sample of Fe II extreme (EFE2) and strong (SFE2) emitters (Lipari 1994).

In general, we detected weak \[\text{[OIII]}\lambda\lambda4959-5007\] in strong Fe II systems (Lipari et al. 1991; Boroson & Meyer 1992; Lipari et al. 1993, 1994; Lipari 1994). However, we found that only EFE2 of type 1 (i.e. with broad line emission, BLE) show very weak \[\text{[OIII]}\lambda\lambda4959-5007\] emission (i.e. a ratio Fe II $\lambda4925$/$\text{[OIII]}\lambda\lambda4959 \geq 1.0$). The explanation for this fact is complex in the framework of the standard model for AGNs, since we can see the emission from the BLR but not from the NLR! (the last is located in the more external parts).

Is important to note, that previously we found different distributions of SFE2 and EFE2 emitters (Lipari 1994: Fig. 5), in the IR color diagram (we define SFE2 and EFE2 as QSOs/galaxies with the emission line ratio of Fe II $\lambda4570$/H$\beta \geq 1$ or 2, respectively); which could be indicative of two QSO populations (see Lipari 1994). In particular, we found that EFE2 (type 1 and 2) are located between the power law and black body regions.

For EFE2 systems like PHL 1092, where the width of the BLE is moderate (~1500 km s$^{-1}$) several works suggested a physical classification as EFE2 type 2; but this group of type 2 objects shows mainly strong \[\text{[OIII]}\lambda\lambda4959-5007\] emission, and this is not the case of PHL 1092. Therefore, the \[\text{[OIII]}\] emission could be a good parameter in order to clarify the properties of each group of EFE2 emitters. In our starburst scenario, the weak \[\text{[OIII]}\] in IR QSOs is mainly related to the dust present in these systems. And the presence of “extreme” Fe II and BLE is due -in part- to the presence of multiple SN events.

3.6. Morphological Evidence of Outflow, Arcs and Bubbles in Nearby Mergers and IR QSOs

In this paper, we report spectroscopic evidence of outflow in NGC 4039/38, IRAS 01003-2238, 13218+0552, 23128-5919, 11119+3257, 14394+5332, 15130+1958 and 15462-0450. Previously, we detected similar outflow features for the IR mergers NGC 3256, Mrk 231, and IRAS 19254-7245 (Super-Antennae). In addition, in Mrk 231 we associated the presence of outflow and a circumnuclear blue arc to a GW scenario; similar to that proposed for Arp 220 (by Heckman, Armus, & Miley 1987, 1990).

Recently, high resolution images of IR selected BAL QSOs show in practically all of these objects the presence of arcs or shells (Boyce et al. 1997; Stockton, Canalizo, & Close 1998; Surace et al. 1998; Hines et al. 1999) very similar to those observed in Mrk 231 (the nearest IR merger+GW+Fe II+BAL QSO; see Lipari et al. 1994) and in Arp 220 (the nearest IR merger+GW galaxy; see Heckman et al. 1987). These “circumnuclear and external arcs” could be associated mainly to the results of interaction of galaxies (tidal tails, rings, etc.) or to the final phase of the galactic–wind, i.e., the blowout phase of the galactic bubbles (Tomisaka & Ikeuchi 1988; Norman & Ikeuchi 1989; Suchkov et al. 1994). However, for distant AGNs and QSOs it is difficult to discriminate between these two related alternatives.

Even for low redshift BAL IR QSOs -like Mrk 231- there are different interpretations about the origin of these “blue arcs”. In particular, Lipari et al. (1994) found clear evidence of a powerful nuclear starburst with galactic–wind in the circumnuclear region of Mrk 231, and we proposed a galactic–wind scenario for the origin of this blue arc. While Armus, Surace et al. (1994) suggested that this arc has been originated in the interaction between the main and an obscured second nucleus (they also suggested that in this blue region and “shell” there is not evidence of star-formation process). Recently, HST–WFPC2(F439W) observations of Mrk 231 confirm that this blue arc is a “dense shell of star-forming knots” (see Surace et al. 1998: their Figs. 7 and appendix). In addition, these HST broad-band images (Fig. 4b) show blue spiral arms in the circumnuclear re-
region of Mrk 231 ($r \sim 1.5$ kpc), similar to those observed in the central region of NGC 3256 (Lipari et al. 2000a). For the remaining selected IR QSOs, showing BAL+Fe II systems, the HST WFPC2 & NICMOS high resolution data (Figs. 4) suggest that the observed arcs or shells could be related mainly: (i) in IRAS 04505-2958 and Mrk 231 to star-formation and outflowing material; (ii) in IRAS 07598+6508 and IRAS 14026+4341 to strong interaction processes; and (iii) in PG/IRAS 17002+5153 is –for us– not clear yet (see Lipari et al. 2000b).

The galactic-shell in Mrk 231 shows small extension ($r \sim 3$ kpc). It is important to study if these giant galactic-shocks -associated to the compression of the ISM, by the galactic-shell/wind- could generate new star formation processes. This mechanisms could produce the "dense shell of star-forming knots" detected in and around the arc of Mrk 231. And these type of galactic-shocks (associated to the galactic-wind) show some physical properties similar to those observed and studied -in detail- in the arms of nearby spirals.

In addition, in IRAS 19254-7245 (the "Super-Antennae"), new HST-WFPC2 broad band images using the filter F814W (Fig. 5a) show a complete arc around the southern nucleus, similar to a "giant SN-ring" with a $r \sim 4$ kpc and an angle to the line of sight of $i_c \sim 50–60^\circ$ (Lipari et al. 2000b). However, this ring was clearly detected only when the system was located in the PC CCD (when the southern nucleus was located in the WFC we observed only superposed and confused structures). In addition, our new NTT high resolution data -obtained for this ULIR merger- show very extended Hα emission in $r \sim 6-7$ kpc around the southern nucleus (i.e., including the region of the ring). In general, this result is similar to that obtained for NGC 3256 (i.e., extended Hα emission in $r \sim 5-6$ kpc; see §3.1). It is interesting to note that the ring detected in IRAS 19254-7245 is very similar to the double arc/shell observed in Arp 220 (Heckman et al. 1987; $r \sim 5$ kpc); and the presence of two arcs -in Arp 220- could be explained by the presence of two compact starburst nuclei.

On the other hand, the presence of “giant SN-shells or rings” were already suggested in order to explain the BAL system in the IR QSO IRAS 07598+6508 (Lipari 1994; $cz = 44500$ km s$^{-1}$).

Heiles (1987) and Tenorio-Tagle & Bodenheimer (1988) give references of observational and theoretical studies of “giant SN-shells and rings”, associated to multiple explosion of type II SNs.

4. DISCUSSION

4.1. The Galactic-Wind and WR features in NGC 4038/39, IRAS 23128-5919, and Nearby Mergers

Fabbiano et al. (1997), from high resolution X-ray Rosat images, found extended emission associated to NGC 4039; and they suggested that detailed spectroscopic observations were required in order to study a possible nuclear outflow. The result obtained in §3.1 shows the first direct kinematical evidence for nuclear outflow, in NGC 4039. Which could be only associated to the nuclear starburst in NGC 4039 (and “galactic–winds”); since, there is not evidence of AGN properties in all the multiwavelength studies of The Antennae (including new ISO observations: Kunze et al. 1997; Fisher et al. 1997; Vigroux et al. 1997).

A similar situation could be explained for IRAS 23128-5919: previous studies suggested the presence of outflow and WR features, but only the observations at Casleo, with high S/N, confirmed the presence of both features in the bright southern nucleus of this IR merger (§3.1).

These and previous results for Arp 220, Mrk 266, Mrk 273, NGC 1222, NGC 1614, NGC 3256, NGC 3690, NGC 4194, NGC 6240, and other objects (see HAM90), strongly suggest that the relation between merger, starburst, galactic–wind, and IR emission, could play a main role in the evolution and formation of galaxies and AGNs (see §4.4).

It is important to note, that mean values of OF -observed in these and previous studies of mergers (Lipari et al. 2000a; HAM90)- are in the velocity range of $100 \leq V_{OF} \leq 700$ km s$^{-1}$. And the situation is different for IR mergers with strong starburts+QSOs (see the next §).
4.2. The Extreme Galactic-Wind and WR features in IRAS 01003-2238, IRAS 13218+0552 and IR QSOs/galaxies

We found EVOF ($V_{OF} \geq 1000 \, \text{km s}^{-1}$) and/or WR features in 8 objects, including IR mergers, IR QSOs and ULIRGs. These objects with EVOF show mainly strong starburst plus the presence of an obscured IR QSO or AGN; and the nearest objects -Mrk 231 and IRAS 19254-7245- display clear arcs or shells (associated clearly to “extreme starburst and GW”). This fact suggests that the interaction between the two main processes of nuclear activity could generate extreme outflow. This result is in agreement with a composite model as the source of nuclear energy in ULIRGs and LIRGs (i.e., starburst plus standard AGN; Perry & Dyson 1992; Dyson, Perry & Williams 1992; Perry 1992).

In addition, the presence of strong Wolf Rayet features in several PG QSOs is indicative of a large number of massive stars (Armus, Heckman & Miley 1988); and therefore is indicative -in the future- of the presence of SN of type II. This fact is also in agreement with a “composite” model for the source of energy in these PG QSOs with strong Fe II emission.

4.3. The Relation Between: Mergers, Starbursts+ Galactic-Winds, and BAL+FeII IR-QSOs

The relation between mergers, starbursts and IR QSOs, is important specially for the study of broad absorption line (BAL) IR selected QSOs. Mainly for the following reason: (i) Low et al. (1989), Boroson & Meyer (1992) found that IR selected QSOs show a 27% low-ionization BAL QSO fraction as compared with 1.4% for the optically selected high-redshift QSOs sample (Weymann et al. 1991); (ii) extreme IR galaxies (LIRGs & ULIRGs) are mainly mergers (§1); (iii) these objects are also extreme/strong Fe II emitters (Boroson & Meyer 1992; Lipari 1994); (iv) Lipari et al. (1994, 1993a); Lawrence et al. (1997); Egami et al. (1997); and Terlevich, Lipari & Sodre (2000) proposed that the extreme IR+Fe II+BAL phenomena are related –at least in part– to the end phase of an “extreme starburst” and the associated “powerful galactic–wind”. At the end phase of a strong starburst, i.e., type II SN phase ($8-60 \times 10^6 \, \text{yr}$ from the initial burst; Terlevich et al. 1992; Norman & Ikeuchi 1989; Suchkov et al. 1994) naturally appear giant galactic arcs, extreme Fe II+BAL systems and dust+IR-emission (Lipari 1994; Lipari et al. 1994, 1993a; Perry & Dyson 1992; Dyson, Perry, & Williams 1992; Perry 1992; Scoville & Norman 1996; Franco 1999, private communication).

Specifically, in the starburst scenario two main theoretical models for the origin of BAL systems were proposed: (i) for IR dusty QSOs/galaxies, in the outflowing gas+dust material the presence of discrete trails of debris (shed by individual mass-loss stars) produce the BAL features (Scoville & Norman 1996); and (ii) in SN ejecta, which are shock heated when a fast forward shock moves out into the ISM (with a velocity roughly equal to the ejecta) and a reverse shock moves and accelerates back towards the explosion center; the suppression of red-shifted absorption lines arise since SN debris moving toward the central source are slowed down much more rapidly -by the wind- than is material moving away (Perry & Dyson 1992; Perry 1992). These two alternatives are probably complementary and both explain the main observed properties of the BAL phenomena (Scoville & Norman 1996; Perry 1992; Scoville 1992). And, in the next paragraphs we will propose a 3rd. scenario for the BAL systems.

The presence of arcs or shells in IR QSOs could be a 3rd. (or complementary) explanation -in the starburst scenario- for the origin of BAL systems in IR QSOs. The physical processes could be similar to those suggested by Perry (1992) and Perry & Dyson (1992), but at larger scale ($r \sim 2-6 \, \text{kpc}$). We found for Mrk 231 -in the blue arc, the nuclear and circumnuclear regions- a range of expanding velocities ($\Delta V$) from 500 to 8000 km s$^{-1}$ (in the absorption and emission lines; Lipari et al. 1994). This range is exactly which is required in order to explain the observed BAL systems and also for theoretical starburst scenarios where giant expanding arcs or rings generate fast giant shocks in the ISM. In this model, the high fraction of IR selected QSOs showing properties of low-ionization BAL QSO could be explained by the high fraction of arcs, shells, and giant SN-rings present in these systems (probably originated in the starburst type...
II SN phase). And in this starburst scenario, the effects of the orientation of the line of sight and the dust obscuration are also complementary processes (Perry 1992).

Very recently, detailed new-technology interferometric (IRAM and VLT) and spectroscopic (ISO) studies with high resolution millimetric, near/mid-IR and radio data, confirmed the presence of “extreme” starburst in ULIRGs: 1000 times as many OB stars as 30 Dor in the IR mergers Mrk 231, Arp 220, Arp 193 (see Downes & Solomon 1998; Genzel et al. 1998 and Smith et al. 1998, respectively). Lipari et al. (2000a), using new-technology data (ESO NTT and HST) combined with detailed and extensive optical observations (BALEGRE, CASLEO, CTIO) show new and clear evidences that NGC 3256 is another example of nearby luminous IR merger showing a strong nuclear and extended massive star formation process, with an associated powerful galactic–wind.

The new detailed results presented in this work (related to extreme GW, §3) give support to the previous conclusion that the properties of the merger and the associated “extreme” starburst+galactic–wind play an important role in the evolution of LIRGs/ULIRGs and IR QSOs (Rieke et al. 1985; Joseph & Wright 1985; Heckman et al. 1987, HAM90; Lipari et al. 1993a, 1994, 2000a).

In the last years, Thompson, Hill & Elston (1999) and Elston, Thompson, & Hill, (1994) reported more than 15 QSOs at redshift 2 < z < 5, observed at the restwavelength of UV and optical Fe II + BAL spectral region. Approximately 50% of these objects show “strong” Fe II emission, and many of these objects are also BAL+IR QSOs. In the starburst plus galactic–wind scenario extreme/strong Fe II + BAL+IR emitters are “young IR QSOs/mergers” where the starburst is probably the dominant source of output energy (Lipari et al. 1994, 1993a; Lipari 1994). Therefore, in order to study the real nature of these high redshift QSOs it is required a better understanding of the merger, starburst, galactic–wind processes in low redshift IR galaxies and QSOs (like NGC 3256).

In addition, Thompson et al. (1999) found a lack of iron abundance evolution in high redshift QSOs: i.e., the absence of increase in the Fe II/Mg II line ratio and Fe II equivalent width from the earliest epoch (z = 4.47 and 3.35) to the present. Which represents a problem, since this fact would indicate that 1 Gyr may be an underestimate of the universe age at z = 4.47 (assuming that SN type Ia is the dominant source of Fe enrichment in standard models of QSOs); and consequently q0 could be ≤ 0.20 for H0 = 75 km s⁻¹ Mpc⁻¹.

In our proposed starburst scenario, both results: the detection of strong Fe II in QSOs at redshift 2 ≤ z ≤ 5 (or even at z ≥ 5), and the lack of iron abundance evolution in high redshift QSOs agrees with the prediction of our models (Lipari et al. 1993a, 1994; Lipari 1994; Terlevich et al. 1992, 2000). Specifically, since in our scenario the time for the strong Fe enrichment in the shell of SN type II and in the ISM is ~ 8-60 × 10⁹ yr (i.e., the end phase of an “extreme starburst”). This time is very short in relation to that required for the Fe enrichment of the ISM by SN type Ia: i.e., 2 × 10⁹ yr (see Friaca & Terlevich 1998). Therefore, in this scenario the results obtained by Thompson et al. (1999) do not represent a problem with the present accepted age of the universe at z ~ 5: ~10⁹yr for q0 = 0.5 and H0 = 75 km s⁻¹ Mpc⁻¹.

The evolutive end product of this interaction between mergers and extreme starburst+GW could be: (i) SMBHs and IR-QSOs in the nuclear region, according to the conditions of the merger/starburst processes, such as the nuclear compression of the ISM gas, the inflow and outflow rate, etc (Genzel et al. 1998; Downes & Solomon 1998; Taniguchi et al. 1999; Lipari et al. 2000a); and (ii) elliptical, cD, radio galaxies for the multiple-merger process as a whole (Toomre 1977; Schweizer 1978, 1982; Sanders et al. 1988a; Barnes 1989; Barnes & Hernquist 1992; Shier, Rieke, & Rieke 1994, 1996; Weil & Hernquist 1996).

4.4. The Relation between Mergers+ Starbursts/ galactic-winds and the Formation and Evolution of Galaxies

The results obtained in §3 are also interesting in the study of high redshift objects and galaxies formation, since it is expected that the properties of the initial collapse, merger and starburst+galactic–wind play an important role, in practically all the scenarios of galaxy formation.
(see Larson 1974; Ostriker & Cowie 1981; Dekel & Silk 1986; Ikeuchy & Ostriker 1986; Lacey & Silk 1991; Berman & Suchkov 1991; Cole et al. 1994). In particular, in luminous IR mergers the SFRs are close to those inferred of a galaxy forming itself: IR luminosities of $\sim 10^{11-12} L_\odot$ imply SFRs of $\sim 300-500 M_\odot$ yr$^{-1}$, if such SFRs are sustained for galaxy free-fall times $10^8-9$ yr$^{-1}$, the total mass of newly formed stars would be $10^{10-11}$ $M_\odot$ (see HAM90).

When we observe locally (in NGC 3256, Arp 220, Mrk 231, and others) the galactic–wind in luminous IR mergers, we are probably observing the feedback processes from massive star formation that may have important influence in determining the overall structure of galaxies in the "general dissipative collapse" (Rees & Ostriker 1977; Silk 1977; Martin 1999; Norman & Ikeuchy 1989; Kormendy & Sanders 1992; Bekki & Shioya 1998; HAM90; Tenorio-Tagle, Rozyczka, & Bodenheimer 1990; Chevalier & Clegg 1985). More specifically, in the early stage of galaxy formation (when the SFR is expected to be higher) the "galactic-wind" plays a decisive role in the feedback process: reheating the ISM, and contributing to stop the initial collapse, and therefore would determine the overall structure of galaxies. The "galactic-wind" also plays a central role in some particular galaxy formation scenarios, for example in the "explosive" and "hot" scenarios (postulated by Ostriker & Cowie 1981 and Berman & Suchkov 1991, respectively) where the SN explosions and galactic–wind are the process of SFR self-regulation in young galaxies (see also McKee & Ostriker 1977; HAM90; Lipari et al. 1994).

And, these properties are very similar to those proposed for Mrk 231 and "The Super-Antennae" (see §3, and Lipari et al. 2000a), in the observed extended massive star formation and the "extreme" galactic–wind processes (with their associated shells/arcs).

SNs of type II are highly concentrated in space and time, and arise from massive stars ($m \geq 5 M_\odot$) in young stellar clusters and associations (of tens or hundreds; Heiles 1987). And giant galactic–shells have been detected (see for references Heiles 1992; and Tenorio-Tagle & Bodenheimer 1988). In addition, the presence of "extreme" starburst and the associated SN events in ULIRGs (Downes & Solomon 1998; Genzel et al. 1998 and Smith et al. 1998) is also a confirmation of the existence of "multiple" type II SN explosions. These "multiple" type II SN explosions are the main galactic process capable to generate the blow-out phase of the galactic–winds (arcs and shells), large amounts of dust and IR-emission, Fe overabundance, and the BAL phenomena (Norman & Ikeuchi 1989; Perry & Dyson 1992; Lipari et al. 1993a, 1994; Lipari 1994; Scoville & Norman 1996). However, in the dusty nuclear regions of LIRGs and ULIRGs (with $A_V \sim 10-100$ mag; see Sakamoto et al. 1999; Genzel et al. 1998), the presence of type II super/hyper–nova could be detected only for nearby systems and using interferometric radio data (Smith et al. 1998).

New submillimeter-wavelength surveys show a population of very dusty star forming galaxies at high redshift (Hughes et al. 1998; Berger et al. 1998), with very similar properties to those observed in LIRGs and ULIRGs (Scott 1998). Therefore, in order to study distant IR mergers, objects with composite source of nuclear energy (QSOs plus starburst), and very dusty galaxies, the more clear signals of "extreme starbursts" are the above described features associated to the presence of powerful galactic–winds and "multiple" type II SN explosions (e.g., galactic-shells/arcs, spectra with outflow or WR components, very blue spiral arms, "extreme" amount of dust and abundance of Fe II, etc). Those features are similar to those observed –at low redshift– in Arp 220, Mrk 231, NGC 3256, IRAS 19254–7245, IRAS 07598+6508, IRAS 22419–6049, IRAS 04505–2958 and others.

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FIGURE CAPTIONS

Fig. 1. (a) CASLEO optical spectrum of NGC 4039 in the H\alpha+[N II]λλ 6548,6583 region and along PA 174°, through the nucleus. It shows the OF nuclear component.
   (b-d) MKO optical spectra of the QSOs IRAS 01003-2238, IRAS 13218+0552 and CASLEO spectra of IRAS 19254-7245. In the H\beta+[O III] λλ 4959,5007 region, showing the EVOF components.

Fig. 2. MKO optical spectrum of the IRAS 11119+3257 in the H\beta+[O III] λλ 4959,5007 region, showing the EVOF components.

Fig. 3. Optical spectrum of the QSOs PG 1535+547, showing WR features at NII λ4640 and He II λ4686. The spectrum was digitized from Boroson & Green (1992), and a Fe II template was subtracted.

Fig. 4. HST broad–band images of 8 strong IR+Fe II QSOs (the first 4 objects are also BAL QSOs), the N-S lines are rotated, from the top. Note that all these IR objects show “arcs or shells” and/or merger features.
   (a-d) IRAS 07598+6508, IRAS 12540+5708 (Mrk 231), IRAS 14026+4341, IRAS/PG 1700+518.
   (e-h) IRAS 04505-2958, IRAS 00275-2859, IRAS 13349+2438 and 1 Zw 1.

Fig. 5. HST broad–band images of luminous IR QSOs with OF (the N-S lines are rotated, from the top).
   (a-c) IRAS 19254-7245, IRAS 13218+0552 and IRAS 23128-5919.
| Object (IRAS) | $V_{OF1}$ km s$^{-1}$ | $V_{OF2}$ km s$^{-1}$ | cz km s$^{-1}$ | Comments |
|---------------|----------------------|----------------------|----------------|----------|
| 01003-2230    | -1530                | -710                  | 35505          | at O III |
| 13218+0552    | -1850                | —                     | 61000          | ”        |
| 19254-7245    | -1000                | —                     | 17900          | ”        |
| Mrk 231       | -1000                | —                     | 12670          | at O II  |
| 11119+3257    | -2120                | -1330                 | 56230          | at O III |
| 14394+5332    | -1750                | -850                  | 31475          | ”        |
| 15130+1958    | -1380                | -890                  | 32700          | ”        |
| 15462+0450    | -1800                | -970                  | 30030          | ”        |
Flux

PG 1535+547

Rest Wavelength
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