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[Fe II] 1.64 MICRON EMISSION IN HIGH-LUMINOSITY AND ULTRALUMINOUS *IRAS* GALAXIES

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ABSTRACT

The starburst plus radio hypernovae scenario presented for high-luminosity (HLIRGs) and ultraluminous *IRAS* galaxies (ULIRGs) in Colina & Pérez-Olea (1992) is used to predict the [Fe II] 1.64 μm luminosity in these galaxies, as well as the [Fe II] 1.64 μm, radio, and Brγ luminosity rates. These are good indicators to characterize starbursts in heavily obscured environments, i.e., buried starbursts, such as those believed to exist in HLIRGs and ULIRGs.

The predicted [Fe II] 1.64 μm luminosity for HLIRGs and ULIRGs is in the range 10^{40}–10^{42} ergs s^{-1} while the rate of [Fe II] 1.64 μm to radio luminosity, with a mean value of 17, is almost independent of the initial mass function parameters. On the contrary, the [Fe II] 1.64 μm–Brγ luminosity rate changes from 0.05 to 1.42 as a function of the slope and upper mass limit of the initial mass function.

The starburst plus radio hypernovae hypothesis is consistent with the observations if a low upper mass limit of 25–30 $M_{\odot}$ is considered. However, starbursts have difficulties in explaining observed [Fe II] 1.64 μm/Brγ ratios well above 1.4, as in NGC 7469.

Subject headings: galaxies: active — galaxies: starburst — infrared: galaxies — radio continuum: galaxies

1. INTRODUCTION

Investigations related to the nature of high luminosity (HLIRGs, 10^{12} $L_{\odot} > L_{\rm FIR} \geq 10^{11}$ $L_{\odot}$), and ultraluminous *IRAS* galaxies (ULIRGs, $L_{\rm FIR} \geq 10^{12}$ $L_{\odot}$) have become a key area in AGN research. They represent the best candidates for circumnuclear massive star formation, i.e., starburst, triggered by collisions of galaxies with, it might be, the generation of an AGN as the end product of the starburst.

The existence of a dust-enshrouded quasar-like source in the center of ultraluminous *IRAS* galaxies has been suggested by Sanders and collaborators (Sanders et al. 1988). This hypothesis is somehow supported by the detection of broad Paschen-alpha emission lines in two luminous *IRAS* galaxies with a Seyfert type II optical spectrum (Hines 1991), and by the detection of IRAS 02366−3101 as an accretion disk candidate (Colina, Lipari, & Macchetto 1991b). Also, the presence of polarized broad emission lines in some luminous *IRAS* galaxies (see Antonucci 1992 for a review) favors the existence of an obscured central AGN ionizing source. A highly polarized dust obscured Seyfert type I nucleus has been detected in IC 5063, a nearby optical Seyfert II type galaxy (Colina, Sparks, & Macchetto 1991 and references).

On the other hand, most studies based on the optical emission line rates and Hα or IR luminosities (Armus, Heckman, & Miley 1989; Leech et al. 1989) conclude that luminous *IRAS* galaxies are places where an active star formation process is taking place. Extraordinarily large star formation rates, amounting up to a few hundred solar masses per year, and winds with velocities of the order of 500 km s^{-1} have recently been invoked to explain the structure of the narrow-line profiles, the emission-line ratios, and the energy budget in luminous *IRAS* galaxies (Heckman, Armus, & Miley 1990; Colina, Lipari, & Macchetto 1991a). Also, recent VLBI observations of the compact radio cores in luminous *IRAS* galaxies (Lonsdale, Lonsdale, & Smith 1992) show, in most cases, that the absolute radio luminosity of these few parsec-sized radio sources is still consistent with powerful radio supernova remnants (radio hypernovae; Colina 1992).

Very recently, a new method has been used to calculate, considering the starburst hypothesis, the supernovae rate and the star formation parameters in HLIRGs and ULIRGs (Colina & Pérez-Olea 1992, hereafter CPO). This method makes use of the radio luminosity of these galaxies and of the hypothesis that this emission is nonthermal synchrotron radiation generated in bright radio supernovae and supernova remnants, i.e., *radio hypernovae*. In this paper we further explore the starburst plus radio hypernovae hypothesis. In § 2.1 the expected [Fe II] 1.64 μm emission associated with radio hypernovae is calculated as a function of the observed radio luminosity. In § 2.2 the Brγ luminosity is calculated following the starburst hypothesis, while § 2.3 will discuss the expected rates of radio, [Fe II] 1.64 μm, and Brγ luminosities as a function of the starburst parameters (upper mass limit and initial mass function slope), and their use as reliable indicators of the star formation process. In § 2.4 a comparison between the model predictions and the observations is made, while the presence of buried AGNs is briefly discussed in § 3. Throughout the paper a Hubble constant of $H_0 = 75$ km s^{-1} Mpc^{-1} will be assumed.

2. HIGH-LUMINOSITY AND ULTRALUMINOUS *IRAS* GALAXIES AS STARBURSTS

It is believed that luminous *IRAS* galaxies are places where an extended, circumnuclear star formation process is taking place. These galaxies are also characterized by very large amounts of molecular gas and dust within the inner few kpcs (Scoville et al. 1991). It is most likely that this dust and molecular gas is mixed with massive young stars in these star forming regions. Internal extinction measurements using optical Balmer and IR Brackett emission lines give different results with the extinction derived from the IR lines much heavier than that from the optical lines (Kawara, Nishida, & Phillips 1989). It is clear that the extrapolation of the IR extinction to the optical is not the correct thing to do in many cases. Thus, infrared photons penetrate dust better than optical photons, and, consequently, infrared emission lines (see Table 1 for some examples) are most appropriate to characterize the strength and properties of these starbursts. Recent IR spectroscopic studies of supernova remnants (Oliva, Moorwood, & Danzinger 1989; Graham, Wright, & Longmore 1990; Lester et al. 1990; Greenhouse et al. 1991), show that these remnants are able to produce large quantities of [Fe II] 1.64 μm in emission, amounting to a luminosity of up to 10^5 $L_\odot$ in the brightest radio supernova remnants of M82. This is most likely understood as due to an enhanced gas phase abundance of Fe in the shock fronts, produced when the supernovae shells interact with the circumstellar/interstellar medium. Thus, the [Fe II] 1.64 μm infrared line can be a good indicator for the presence of supernova remnants and consequently of the ongoing star formation process.

2.1. *Predicted* [Fe II] 1.64 *Micron Emission Line Luminosity*

The radio luminosity of HLIRGs and ULIRGs has been used to calculate the supernovae rate within the framework of a circumnuclear starburst (CPO). It was argued that supernovea exploding in a high dense interstellar medium like those of circumnuclear starbursts could be able to shine as bright radio sources, i.e., *radio hypernovae*, opposite to supernovae exploding in a more diffuse medium like that of the disk or arms of spiral galaxies. Examples of this behavior are the compact radio sources detected in M82 (Kronberg, Biermann, & Schwab 1985), NGC 253 (Ulvestad & Antonucci 1991), and NGC 1808 (Saikia et al. 1990). Assuming that the radio emission in HLIRGs and ULIRGs is generated by radio hypernovae i.e., supernovae and supernova remnants 10^3 times brighter than Cas A at radio frequencies, where SN 1979c is the prototype, one obtains (CPO)

$$L_{\rm NT}(\nu) = 1.767 \times 10^{22}(\nu/8.44\ {\rm GHz})^{-0.74}\Upsilon_{\rm SN\,II}\ {\rm W\ Hz^{-1}}\ , \quad (1)$$

where $\Upsilon_{\rm SN\,II}$ represents the rate of Type II supernovae (SN II $\rm yr^{-1}$). Consequently, the Type II supernovae rate is obtained from the previous expression, assuming that the observed radio luminosity, $L_R(\nu;\ {\rm GHz})$ in W $\rm Hz^{-1}$, is synchrotron radiation associated with these remnants, i. e., $L_R(\nu) = L_{\rm NT}(\nu)$.

One can now predict the luminosity in the [Fe II] 1.64 μm emission line simply as

$$L([{\rm Fe\ II}]\ 1.64\ \mu{\rm m}) = L_{\rm SNR}\,\Upsilon_{\rm SN}\,t([{\rm Fe\ II}])\ {\rm ergs\ s^{-1}} \quad (2)$$

if the [Fe II] 1.64 μm luminosity remains constant over the lifetime of the remnant as a bright [Fe II] 1.64 μm source. In this expression, $L_{\rm SNR}$ represents the [Fe II] 1.64 μm luminosity in ergs $\rm s^{-1}$ per supernova remnant, $\Upsilon_{\rm SN}$ is the supernovae rate in units of supernovae per year, and t([Fe II]) is the lifetime in years of a supernova remnant as a powerful [Fe II] 1.64 μm source.

Combining equations (1) and (2), one obtains the [Fe II] 1.64 μm luminosity as a function of the observed radio luminosity.

$$L([{\rm Fe\ II}]\ 1.64\ \mu{\rm m}) = 5.66 \times 10^{-23}\phi(\alpha, M_u)L_R(\nu) \times (\nu/8.44\ {\rm GHz})^{0.74} \times L_{\rm SNR}\,t([{\rm Fe\ II}])\ {\rm ergs\ s^{-1}}, \quad (3)$$

where $\phi(\alpha, M_u)$ is a factor that gives the ratio of the supernovae rate ($\Upsilon_{\rm SN}$) to Type II supernovae rate ($\Upsilon_{\rm SN\,II}$). Thus, expression (3) depends, although slightly, on the slope and upper mass limit of the initial mass function.

Since the brightest radio compact sources in M82 (Kronberg et al 1985) belong to the radio hypernovae class, the [Fe II] 1.26 μm luminosities of the two brightest radio compact sources of M82 (41.9+58 and 44.0+59; Greenhouse et al. 1991) are used to estimate the [Fe II] 1.64 μm luminosity associated with single remnants. According to Greenhouse et al. L([Fe II] 1.26 μm) = 1.65 × 10^{38} and 2.82 × 10^{38} ergs $\rm s^{-1}$ for 41.9+58 and 44.0+59, respectively. Therefore, assuming the theoretical rate [Fe II] 1.64 μm/[Fe II] 1.26 μm = 0.7646 (Nussbaumer & Storey 1988), one obtains a mean [Fe II] 1.64 μm luminosity L([Fe II] 1.64 μm) = $L_{\rm SNR} \approx 1.71 \times 10^{38}$ ergs $\rm s^{-1}$ for each single remnant.

On the other hand, it was shown in CPO that due to the steep temporal decay of the radio luminosity of the remnants, a large fraction of the integrated radio emission is produced during the first 100 yr, even if the remnant lasts for a long period of time as a radio source. For SN 1979c, i.e., prototype of radio hypernovae, the integrated radio luminosity during the first 100 yr is only a factor 4 less than the corresponding luminosity over a period of 20,000 yr (see Table 3 of CPO). Thus, if the mechanism generating the radio emission relates directly to the one producing the [Fe II] emission line, i.e., shocks and turbulences induced by the expanding supernova shell into the surrounding circumstellar/interstellar medium, one can consider as a first-order approximation that the time scale while the remnant is a powerful [Fe II] 1.64 μm source corresponds also to t([Fe II]) ≈ 100 yr. Therefore, the [Fe II] 1.64 μm emission expected from a starburst with radio hyper-

TABLE 1

OBSERVED RADIO FLUX AND IR EMISSION LINES IN LUMINOUS *IRAS* GALAXIES

Galaxy	Type	F(5 GHz) (mJy)	Reference	F([Fe II] 1.64 μm) (10^{-13} ergs $\rm s^{-1}$ $\rm cm^{-2}$)	Reference	F(Brγ) 10^{-13} ergs $\rm s^{-1}$ $\rm cm^{-2}$)	Reference
M82	SB	3400	1	10.6	4	15.6	4
NGC 253	SB	1250	1	3.18	5	1.79	5
NGC 1614	HLIRG	45	2	0.60	5	0.59	5
NGC 7469	HLIRG	65[a]	3	0.31	5	0.12	5
NGC 7469	HLIRG	43.8[b]	3	0.31	5	0.12	5

REFERENCES.—(1) Ho, Beck, & Turner 1990; (2) Hummel et al. 1987; (3) Wilson et al. 1991; (4) Lester et al. 1990; (5) Moorwood & Oliva 1988.

[a] Radio flux integrated within 5″ of nucleus.

[b] Radio flux within 5″ of nucleus but without the contribution of the unresolved central radio source.

novae will be given as

$$L([\text{Fe II}]\ 1.64\ \mu\text{m}) = 9.68 \times 10^{17}\phi(\alpha, M_u) \times L_R(8.44\ \text{GHz})\ \text{ergs s}^{-1}\ . \quad (4)$$

High-luminosity and ultraluminous *IRAS* galaxies have a radio luminosity between 10^{22} and 10^{24} W Hz^{-1} at 8.44 GHz (Condon et al. 1991). Therefore, according to the expression above, one expects a [Fe II] 1.64 μm luminosity in the range 10^{40}–10^{42} ergs s^{-1} for HLIRGs and ULIRGs, respectively. It is worthwhile to mention that the previous expression is obtained, implying that all the radio flux is from radio hypernovae. Consequently, the previous expression gives an upper limit to the [Fe II] 1.64 μm luminosity generated in this way. If only a fraction of the radio flux were generated in radio supernovae and young remnants, part of the [Fe II] 1.64 μm flux could be emission from a narrow-line region (NLR) as well (see § 3).

Finally, it is worthwhile to mention that the predicted [Fe II] 1.64 μm luminosity does not depend much on the IMF parameters. The IMF enters expression (4) indirectly through $\phi(\alpha, M_u)$. Thus, for IMF slopes in the range 1.35–3.35, and upper mass limits in the range 25–100 $M_\odot$, changes in the [Fe II] 1.64 μm luminosity by factors less than 2 are obtained.

2.2. *Predicted* Brγ *Emission-Line Luminosity*

To calculate the Brγ luminosity, it is assumed that its value corresponds to recombination case B, i.e., $L(\text{Br}\gamma) = 0.01L(\text{H}\alpha)$, where the luminosity of Hα as a function of the IMF slope and upper mass limit is given by (see CPO)

$$L(\text{H}\alpha) = 6.8 \times 10^{-13}k\left(1.575 \times 10^{51}\ \frac{40^{4.037-\alpha} - 20^{4.037-\alpha}}{4.037-\alpha} + 4.415 \times 10^{53}\ \frac{M_u^{2.347-\alpha} - 40^{2.347-\alpha}}{2.347-\alpha}\right)\ \text{ergs s}^{-1}\ , \quad (5)$$

where k is given by the expression

$$k = \Upsilon_{\text{SN II}}\left(\frac{10^{-\alpha+1} - 25^{-\alpha+1}}{\alpha-1}\right)^{-1}\ . \quad (6)$$

For IMF slopes in the range 1.35–3.35 and upper mass limits between 25 and 100 $M_\odot$, a Brγ luminosity in the range 1.2×10^{40}–7×10^{41} ergs s^{-1} is obtained, for a Type II supernova rate of 1. $\gamma_{\text{SN II}} = 1$ yr^{-1}.

TABLE 2

RADIO [Fe II] 1.64 MICRON AND Brγ RATIOS AS A FUNCTION OF IMF PARAMETERS

IMF(α, M_u)	L([Fe II])/L_{NT}(5 GHz)	L([Fe II])/(Brγ)
(2.35, 25)	13	0.88
(2.35, 30)	14	0.45
(2.35, 60)	17	0.15
(2.35, 100)	18	0.11
(1.35, 25)	13	0.58
(1.35, 30)	15	0.28
(1.35, 60)	22	0.08
(1.35, 100)	27	0.05
(3.35, 25)	13	1.42
(3.35, 30)	14	0.76
(3.35, 60)	15	0.32
(3.35, 100)	15	0.27

2.3. *Predicted* [Fe II] 1.64 *Micron, Radio, and* Brγ *Luminosity Rates*

Following the starburst hypothesis for HLIRGs and ULIRGs, one can consider that the radio emission and [Fe II] infrared emission lines are most directly associated with shocks, i.e., to supernovae and supernova remnants, while recombination lines, like Brγ, are produced by photoionization, i.e., relate mostly to the content of massive, young, and unevolved main-sequence hot stars. According to this, the [Fe II] 1.64 μm–radio flux ratio is almost independent of the detailed IMF parameters (Table 2). Changes on the IMF slope from 1.35 to 3.35 and on the upper mass limit from 25 $M_\odot$ to 100 $M_\odot$, produce variations by factors less than 2 in the L([Fe II] 1.64 μm)/L_{NT} ratio. On the contrary, a wide range of values, going from 0.05 to 1.42, are obtained for the [Fe II]–Brγ ratio (Table 2). These extreme values represent the two opposite cases of a flat, massive and of a steep, low massive star formation process, respectively. Similar results for the [Fe II] 1.64 μm /Brγ ratio have been obtained by Moorwood & Oliva (1988) based on star formation models by Gehrz, Sramek, & Weedman (1983).

2.4. *Comparison with the Observations*

The predicted and observed (not corrected for internal extinction) [Fe II] 1.64 μm luminosities in individual luminous *IRAS* galaxies are in good agreement (Table 3A). Considering the radio flux measured in the circumnuclear regions of NGC

TABLE 3A

[Fe II] 1.64 MICRON LUMINOSITIES IN LUMINOUS *IRAS* GALAXIES

Galaxy[a]	L_R(5 GHz) (10^{21} W Hz^{-1})	$\Upsilon_{\text{SN II}}$ (yr^{-1})	L([Fe II])$^{\text{model-1}}$ (10^{39} ergs s^{-1})	L([Fe II])$^{\text{model-2}}$ (10^{39} ergs s^{-1})	L([Fe II])$^{\text{obs}}$ (10^{39} ergs s^{-1})
M82	4.16	0.16	3.5	2.7	1.3
NGC 253	0.94	0.04	0.8	0.68	0.24
NGC 1614	20.0	0.77	16.9	13.1	26.6
NGC 7469[b]	34.3	1.32	28.9	22.5	16.4
NGC 7469[c]	23.1	0.89	19.5	15.2	16.4

[a] Assumed distances to the galaxies are 3.2 Mpc, 2.5 Mpc, 60.9 Mpc, and 66.4 Mpc for M82, NGC 253, NGC 1614, and NGC 7469, respectively.

[b] Values calculated using the integrated radio flux within 5″ of nucleus.

[c] Values calculated using the integrated halo radio flux. Model-1 and model-2 correspond to a Salpeter slope of $\alpha = 2.35$ and upper mass limit M_u of 60 and 25 $M_\odot$, respectively.

TABLE 3B

Brγ Luminosities in Luminous *IRAS* Galaxies

Galaxy[a]	$\Upsilon_{SN II}$ (yr^{-1})	$L(Br\gamma)^{model-1}$ (10^{39} ergs s^{-1})	$L(Br\gamma)^{model-2}$ (10^{39} ergs s^{-1})	$L(Br\gamma)^{obs}$ (10^{39} ergs s^{-1})
M82	0.16	23.4	3.0	1.9
NGC 253	0.04	5.8	0.77	0.13
NGC 1614	0.77	112.4	14.9	26.1
NGC 7469[b]	1.32	192.7	25.5	6.4
NGC 7469[c]	0.89	129.9	17.2	6.4

Assumed distances to the galaxies are 3.2 Mpc, 2.5 Mpc, 60.9 Mpc, and 66.4 Mpc for M82, NGC 253, NGC 1614, and NGC 7469, respectively.

[b] Values calculated using the integrated radio flux within 5″ of nucleus.

[c] Values calculated using the integrated halo radio flux. Model-1 and model-2 correspond to a Salpeter slope of $\alpha = 2.35$ and upper mass limit M_u of 60 and 25 $M_\odot$, respectively.

1614 and NGC 7469 (Table 1), and assuming a Salpeter IMF slope with an upper mass limit of 60 $M_\odot$ (model-1 in Table 3A), the predicted [Fe II] 1.64 μm luminosities are 1.69×10^{40} and 2.89×10^{40} ergs s^{-1} for these two HLIRGs, respectively. For the same galaxies, the [Fe II] 1.64 μm luminosities corresponding to a flux measured through a 6″ by 6″ aperture (Table 1) correspond to 2.66×10^{40} and 1.64×10^{40} ergs s^{-1} (Table 3A). An even better agreement can be obtained for NGC 7469 if one considers the radio emission within 5″ of the nucleus once the contribution from the unresolved central source is subtracted (Tables 1 and 3A).

Part of the discrepancy in nearby starbursts, particularly in NGC 253 (Table 3A), is most likely understood as a consequence of the different aperture used to measure the radio and [Fe II] 1.64 μm flux in the galaxies. While the radio maps (Ho et al. 1990) cover the entire starburst region in these galaxies, the [Fe II] 1.64 μm emission-line flux has been obtained through a smaller aperture (Lester et al. 1990; Moorwood & Oliva 1988). Also, correction by internal extinction could increase the [Fe II] 1.64 μm luminosity by small factors.

For the Brγ emission line, models with a Salpeter IMF and high upper mass limit ($M_u \geq 60\ M_\odot$) predict too much Brγ luminosity (model-1 in Table 3B), contrary to what is observed. Discrepancies by factors of 10 or larger are obtained. Internal extinction corrections could help in decreasing the discrepancy, but they cannot account for these large differences between models and observations, in general. The expected corrections for M82, NGC 253, and NGC 1614 correspond to a luminosity increase by factors 1.7, 3.4, and 4.0, respectively (Ho, Beck, & Turner 1990). A better agreement is achieved however, if a low upper mass limit of $M_u = 25$–$30\ M_\odot$ is considered (model-2 in Table 3B).

Finally, when comparing the predicted radio, [Fe II] 1.64 μm, and Brγ luminosity ratios (Table 2) with the observed values (Table 4), a best compromise is obtained for IMFs with a low upper mass limit, $M_u = 25\ M_\odot$, and Salpeter's slope, or steeper. Since the [Fe II] 1.64 μm–radio luminosity ratio does not depend much on the specific IMF parameters, this conclusion is mainly obtained from the [Fe II] 1.64 μm–Brγ luminosity ratio. In this relation, extinction effects are almost not important since the differential extinction between 1.64 and 2.17 μm corresponds to $0.07A_V$ mag. However, if the measured visual extinction is very large, i.e., $A_V \geq 15$ mag, the corrected [Fe II] 1.64 μm–Brγ ratio would be increased by factors of the order of 5 or larger. Therefore, extinction effects would work against a high upper mass limit.

TABLE 4

Observed Radio, [Fe II] 1.64 Micron, and Brγ Ratios in Luminous *IRAS* Galaxies

Galaxy	L([Fe II])/L_R(5 GHz)	L([Fe II])/L(Brγ)
M82	6	0.68
NGC 253	5	1.78
NGC 1614	27	1.02
NGC 7469	10	2.58

Consequently, a star formation process with a Salpeter initial mass function and low upper mass limit ($M_u \approx 25\ M_\odot$) gives the best agreement with the observations. This low upper mass limit has also been concluded for the star formation process in different starburst galaxies, based on multiwavelength models (see Joseph 1991 for a review). However, Wolf-Rayet spectral features, indicating the existence of a lot of massive stars with $M \approx 40\ M_\odot$, has been detected in one luminous *IRAS* galaxy (Armus, Heckman, & Miley 1988). Also some starburst galaxies show indications of very massive ($M_u \approx 30$–$60\ M_\odot$) stars in their nuclei (Ho et al. 1990).

3. HIGH-LUMINOSITY AND ULTRALUMINOUS *IRAS* GALAXIES AS BURIED QSOs

It is interesting to note that the starburst hypothesis has some difficulties in explaining [Fe II] 1.64 μm/Brγ ratios above 1.0–1.4. This is the case for NGC 7469 where the measured ratio gives [Fe II] 1.64 μm/Brγ = 2.58 (Table 4). This galaxy is known to have a circumnuclear starburst, but it also shows a Seyfert I type nucleus.

It is also known (Mouri et al. 1990) that the previous ratio increases steadily when moving from starburst galaxies to Seyfert galaxies. Although the scattering is still very large, typical values of the [Fe II] 1.64 μm/Brγ ratio for starburst and Seyfert samples are 1.2 and 3.8, respectively. If one believes that this [Fe II] excess is produced in the inner narrow-line regions (NLRs) of Seyferts, the detection of these high values in HLIRGs and ULIRGs could be a proof of the dust-enshrouded QSO hypothesis (Sanders et al. 1988). However, detailed models of photoionization by a power law are required since it is known that optical iron emission (Fe II multiplets and high-excitation coronal iron lines) detected in some Seyferts is not well explained by current models (Netzer & Wills 1983; Penston et al. 1984).

4. SUMMARY

In this paper the starburst plus radio hypernovae hypothesis for high-luminosity and ultraluminous *IRAS* galaxies has been considered in order to predict their [Fe II] 1.64 μm emission-line flux. Luminosities covering the range from 10^{40} to 10^{42} ergs s^{-1} are obtained, almost independent of the detailed IMF parameters.

Also, the rates of [Fe II] 1.64 μm luminosity to radio and Brγ luminosities have been calculated as a function of the IMF slope and upper mass limit. While the rate of [Fe II] 1.64 μm to radio luminosity is almost independent of the IMF parameters, the [Fe II] 1.64 μm to Brγ rate covers the range 0.05–1.42 when moving from flat massive to steep low massive IMFs.

Models with a Salpeter IMF and low upper mass limit ($M_u = 25$–$30\ M_\odot$) are in good agreement with the emission-line luminosities and line ratios measured in individual starburst and luminous *IRAS* galaxies.

The starburst hypothesis has difficulties in explaining [Fe II] 1.64 μm/Brγ ratios larger than 1.5. Observed rates above the previous limit could indicate the existence of a dust-enshrouded AGN.

Large uncertainties can be present in the determination of the [Fe II] 1.64 μm emission-line luminosity. Accurate extinction measurements of these heavily obscured regions are suitable. Further observations are needed to define the [Fe II] 1.64 μm luminosity function of supernova remnants in circumnuclear starbursts. Also, the effects of obscured AGNs, i.e., production of [Fe II] 1.64 μm and Brγ emission lines by a power law, should be modeled in more detail.

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