

Optical structure of a large sample of ultraluminous *IRAS* galaxies

K. J. Leech,^{1,2} M. Rowan-Robinson,¹ A. Lawrence³ and J. D. Hughes^{1,4}

¹*Astronomy Unit, School of Mathematical Sciences, Queen Mary and Westfield College, Mile End Road, London E1 4NS*

²*SAI, ESTEC, PO Box 299, 2200 AG Noordwijk, The Netherlands*

³*Department of Physics, Queen Mary and Westfield College, Mile End Road, London E1 4NS*

⁴*Five College Astronomy Department, University of Massachusetts, Amherst, MA 01003, USA*

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ABSTRACT

We present deep images for 34 out of a new sample of 36 ultraluminous *IRAS* galaxies (ULGs), as well as seven additional high-luminosity objects, selected from the North Galactic Wedge selected area and QDOT all-sky redshift surveys. Previous CCD data and Sky Survey material are used in the examination of the two remaining ULGs. All but one of the 43 high-luminosity and ultraluminous *IRAS* galaxies are classified according to the seven-band system of Lawrence et al., with the exception being unclassifiable due to the proximity of a bright star. Of the total usable sample of 42, we find that 28/42 (67 per cent) are interacting or merging, 4/42 (10 per cent) are in a close pairing but show no obvious signs of an interaction, and 10/42 (23 per cent) are isolated or have only distant companions. Given the clear preponderance of merging systems in infrared-luminous objects, the existence of a substantial fraction of exceptions is interesting. The starburst trigger in these cases is unknown. We discuss spectroscopic data on the galaxies and present new spectra of two objects.

Key words: galaxies: interactions – galaxies: starburst – infrared: galaxies.

1 INTRODUCTION

Because of the spectacular nature of the most extreme cases, galaxy–galaxy interactions have been of considerable interest to astronomers, especially since the seminal works of such authors as Arp (1966) and Toomre & Toomre (1972) (see also the review by Schweizer 1990). The launch of the *Infrared Astronomical Satellite (IRAS)* generated new interest in this field. Initial work showed that, while the fraction of galaxies of low IR luminosity in interacting systems was approximately the same as for optically selected galaxies, the fraction of galaxies of high IR luminosity in interacting systems was much higher. Galaxies of low IR luminosity were surveyed by Soifer et al. (1984), who found 12–25 per cent of minisurvey galaxies to have close companions, and Lawrence et al. (1986), who found 24 per cent of a complete flux-limited sample of galaxies from the Point Source Catalog (PSC) to have companions of some kind. These fractions are consistent with the results of work by Lawrence et al. (1989), who concluded that about 30 per cent of optically selected galaxies showed evidence for interactions or had close companions, and Armus, Heckman & Miley (1987), who found that 14 per cent of an optically selected control sample of 28 galaxies were morphologically peculiar, most exhibiting tidal features.

The fraction of galaxies with high IR luminosity in interacting systems was found to be much greater, but there was

some divergence in the estimates produced by different authors. Allen, Roche & Norris (1985) sampled 19 optically faint *IRAS* galaxies and found 68 per cent to be interacting or disturbed, or to have close companions. Sanders et al. (1986), in a CO study of 15 galaxies with $L_{\text{FIR}} > 10^{11} L_{\odot}$, noted that the majority, possibly all, appeared to be strongly interacting systems. Armus et al. (1987) discovered that two-thirds of a sample of 17 *IRAS* galaxies with $L_{\text{FIR}} > 10^{11} L_{\odot}$ were morphologically peculiar, most exhibiting tidal features. Sanders et al. (1988) surveyed 10 very high-luminosity *IRAS* galaxies, finding all to be interacting. Lawrence et al. (1989) found that 19 out of 41 galaxies with $L_{60\ \mu\text{m}} > 10^{11} L_{\odot}$ showed signs of interactions, but that only two out of six with $L_{60\ \mu\text{m}} > 10^{12} L_{\odot}$ showed such signs. Klaas (1989) and Klaas & Elsässer (1993), with a sample of 99 *IRAS* galaxies, found that the fraction of *IRAS* galaxies undergoing interactions increased as they went to higher IR luminosities. Melnick & Mirabel (1990) used the New Technology Telescope (NTT) to take images of 16 very high-luminosity *IRAS* galaxies, and found all to be interacting, while Zhenlong et al. (1991) studied 41 ultraluminous *IRAS* galaxies and found only 61 per cent to be in interacting systems.

In most cases, galaxies identified as interacting are strongly interacting or merging. Strongly interacting systems can have properties that are different from those of non-interacting systems [e.g. Larson & Tinsley (1978) for *UBV* excess; Joseph et al. (1984) and Joseph & Wright (1985) for

near-IR excess; Lonsdale, Persson & Matthews (1984) and Cutri & McAlary (1985) for mid-IR excess], but it is unknown by how much weak interactions affect the properties of the galaxies concerned. Bushouse, Lamb & Werner (1988) discussed the IR properties of optically selected interacting galaxies, and Telesco, Wolstencroft & Done (1988) surveyed interacting pairs of galaxies in the Arp–Madore catalogue (Arp & Madore 1986). Both groups of authors found that interactions do not necessarily enhance the IR luminosity of the interactors. This is probably accounted for by the geometry of the interaction and the relative sizes of the two objects, and is discussed further by Bushouse et al. (1988), Telesco et al. (1988) and Sopp, Alexander & Riley (1990), and in the theoretical papers of Noguchi & Ishibashi (1986) and Olson & Kwan (1990). Also, many authors assume, explicitly or implicitly, that it is the interaction that triggers star formation or feeds a ‘monster’, but we note the words of caution expressed by Thronson et al. (1990) against assuming that a burst of star formation (a ‘starburst’) is triggered by an interaction.

The disagreement concerning the fraction of high IR luminosity galaxies in interacting systems motivated us to study such systems further. The upper limit to this fraction was 100 per cent (Sanders et al. 1988), while the lower limit was 33 per cent (Lawrence et al. 1989). All studies were based on small samples of galaxies, or, in the case of Zhenlong et al. (1991), were based on studies of POSS prints. We therefore decided to obtain deep images of a large number of ULGs to obtain a better estimate of the fraction found in interacting systems. We are in the unique position of being able to carry out such a survey, as we have a large (>100) sample of clearly defined ULGs from the QDOT redshift survey.

There is also a subsidiary question that we wish to investigate, namely what powers these galaxies. How many ULGs exhibit AGN-like spectra, as opposed to H II region-like spectra? Sanders et al. (1988), in their survey of 10 very high-luminosity *IRAS* galaxies, found nine to have AGN-like spectra and postulated that all ultraluminous *IRAS* galaxies contain an embedded quasar which will eventually be exposed. Leech et al. (1989), however, found that only two out of six galaxies with $L_{60\mu\text{m}} > 10^{12} L_{\odot}$ show an AGN-like spectrum. Solomon, Downes & Radford (1992) concluded, from observations with the IRAM 30-m radio telescope of five ULGs, that star formation powers them, as did Sopp & Alexander (1991) from radio observations of five other ULGs. Condon et al. (1991) found that 25 out of 40 high-luminosity and ultraluminous infrared galaxies exhibit diffuse radio emission and are almost certainly starbursts, while only one galaxy has a source too compact to be a starburst and is probably a ‘monster’. They saw no evidence for the embedded quasar model of Sanders et al. Allen et al. (1991) found that 12 out of 20 galaxies with luminosities comparable to those of our ULGs are powered by star formation. They also noted that radio observations reported in Norris et al. (1990) prompted the surprising conclusion that there is a low probability of high nuclear extinction leading to a misclassification of galaxies from optical line ratio diagrams. Lonsdale, Lonsdale & Smith (1992) came to the opposite conclusion, and stated that an active nucleus can be hidden from view in the optical by dust.

Here we define ULGs to be those with 60- μm luminosities greater than $10^{12} L_{\odot}$, and high-luminosity galaxies to be those with 60- μm luminosities in the range $5 \times 10^{11} < L_{60\mu\text{m}} / L_{\odot} < 10^{12}$. The definition of ULGs is consistent with those given by most other authors, but the definition of high-luminosity galaxies is purely arbitrary. Note that Sanders et al. (1988), Condon et al. (1991) and Lonsdale et al. (1992) used L_{FIR} , equal to $\approx 2L_{60\mu\text{m}}$, but chose $H_0 = 75 \text{ km s}^{-1} \text{ Mpc}^{-1}$, so their luminosities are comparable to those presented here. Throughout this paper we assume $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $\Omega_0 = 1$, and we apply a *K*-correction assuming that $P(\nu) = \nu^{-\alpha}$, where $\alpha = 2$. Luminosities are calculated using νL_{ν} .

2 THE SAMPLE OF *IRAS* GALAXIES AND OBSERVATIONS

2.1 Sample selection

The list of targets was taken from the QDOT redshift survey of *IRAS* galaxies. Although the first published results (e.g. Rowan-Robinson et al. 1990) were based on an all-sky but one-in-six random selection of *IRAS* galaxies, the final catalogue (Lawrence et al., in preparation) also has smaller areas that were surveyed at full sampling. In particular, one of these is an extension and completion of the North Galactic Wedge (NGW) survey of Lawrence et al. (1986), covering $b > 60^\circ$, $l = 0^\circ - 110^\circ$. All samples are flux-limited at $S_{60} = 0.6 \text{ Jy}$. A complete list of 126 ultraluminous galaxies from these samples is given by Lawrence et al. (in preparation). The target list used in this paper is made up of four subsamples from the above.

(1) All known ULGs from the NGW sample: 13 objects. Out of a total of 389 objects in the NGW sample, only three remain with no measured redshift. Our completion rate in this sample is then at worst 13/16.

(2) All known ULGs from the QDOT sample in the range $13^{\text{h}}15^{\text{m}} < \text{RA} < 20^{\text{h}}$ and $-15^\circ < \text{Dec.} < 70^\circ$: 16 objects. In this area there are 380 QDOT sources, of which 12 currently have no redshift. Of these, six are not galaxies (they are cirrus, dust-shell stars or planetary nebulae), and two are bright galaxies that are almost certainly not ultraluminous. Our completion rate in this sample is then at worst 16/20.

(3) Other ULGs selected at random from the QDOT sample: eight objects.

(4) High-luminosity galaxies selected at random from the QDOT sample: seven objects.

We obtained CCD images for all of the above except for two objects: 140604.3 + 291900, of which a CCD image is available in Lawrence et al. (1989), and 164843.5 + 544736, which was only examined on Sky Survey prints. Data on these galaxies are listed in Table 1. We note that subsamples 1 and 2 together constitute an objective and highly complete sample of 28 ULGs (one galaxy is in both samples). There are at most seven further ULGs missing from this sample.

2.2 Imaging observations

Imaging observations were carried out at the Observatorio del Roque de los Muchachos (La Palma) using the CCD

Table 1. Objects observed and their interaction class.

RA ¹	DEC	<i>z</i>	Log(<i>L</i> _{60μm} / <i>L</i> _⊙)	Total int time (seconds)	Interaction Class ²	Comments
NGW ultraluminous galaxies, 13^h < RA < 15^h						
130131.2	352436	.2379	12.47	2000	0	Several very faint companions.
131429.3	235639	.1380	12.08	2000	1	Smooth elliptical image.
133412.5	393241	.1795	12.41	2000	5	Interacting with faint companion. Seyfert 1 (Leech et al. 1989). Previous CCD image (Lawrence et al. 1989)
133758.9	333951	.2473	12.64	2000	6	Seyfert 2 (Lawrence et al. 1993). Also in QDOT sample.
134417.8	232119	.1416	12.37	2000	2	Previous CCD image (Lawrence et al. 1989). NE dull, SW has emission. Spectrum of SW in Leech et al. 1989.
134447.4	283303	.2569	12.66	2000	6	Asymmetric Plume?
135354.4	292009	.1085	12.19	1000	5	Previous CCD image (Lawrence et al. 1989) & spectrum in Leech et al. 1989.
140604.3	291900	.1166	12.16	2000	6	From the Lawrence et al. (1989) paper. No image presented in this paper.
141704.4	454552	.1516	12.07	2000	6	Possible large tail.
142016.0	261543	.1592	12.41	1500	5	Possible plume in companion but IRAS Source does not appear disturbed. Previous CCD image (Lawrence et al. 1989) & spectrum in Leech et al. (1989).
143117.1	282507	.1749	12.21	2000	6	Seyfert 2 (Lawrence et al. 1993)
144852.1	352056	.2050	12.34	2000	2	Identification is not the interacting galaxy to the E.
145733.2	325651	.1140	12.01	2500	2	Previous CCD image (Lawrence et al. 1989) & spectrum in Leech et al. 1989.
QDOT Ultraluminous galaxies, 13^h 15^m < RA < 20^h						
131538.1	043507	.1133	12.01	1500	4	Emission from both galaxies, strongest from S. [O III] > Hβ.
133514.2	640203	.2366	12.64	1800	5	Two galaxies and plume or possible third galaxy
133758.9	333951	.2473	12.64	2000	6	Seyfert 2 (Lawrence et al. 1993). Also in NGW sample.
134656.2	583342	.1551	12.35	1800	5	Interaction with giant tails.
151650.6	004551	.1539	12.07	2000	5/6	Interaction seen edge on or merger with companion.
154122.4	-095945	(.1600)	(12.12)	2000	3?	Possibly asymmetric?
154352.0	043830	(.2370)	(12.60)	1800	6	
161558.4	-040230	.2126	12.53	2000	5	
164530.4	455340	.1906	12.42	1800	5	
164843.5	544736	.1044	12.31		0	Classification based on Palomar Sky Survey Print. No image presented in this paper.
165411.1	530112	.1937	12.28	1800	0	Seyfert 2 (Lawrence et al. 1993).
171754.3	544450	.1475	12.31	2000	6	
174618.9	580617	.3090	12.76	2000	6	Faint plume. S dull, N has emission with [O III] > Hβ.
181426.5	482351	.1605	12.13	2000	5	Seyfert 2 (see figure 1).
185802.6	652717	.1764	12.27	2000	5/6	Merger interacting with companion? East galaxy has two nuclei. West is Seyfert 2, East shows H II region spectrum (see figure 1). [O III] > Hβ.
190404.1	335612	.1812	12.22	2500	4	
QDOT ultraluminous galaxies outside the above RA range						
001505.3	493732	.1480	12.13	2000	6	Two nuclei in common envelope.
002538.8	-020830	.2763	12.60	2000	2	Possible plume to South. [O III] > Hβ.
004606.6	-072850	.2427	12.47	750	6	Faint plume.
121048.0	315736	.2065	12.53	2100	5	Companion causing plume. [O III] > Hβ.
124904.4	-100908	.1006	12.03	1500	6	
220649.6	270259	(.1550)	(12.09)	2000	U	Galaxy very near bright star.
232201.2	291920	.2401	12.59	2500	2	NE and SW both show emission. [O III] > Hβ.
234952.4	242328	.2119	12.56	2000	5	Multiple interaction. Seyfert 2 (Lawrence et al. 1993).
QDOT High luminosity galaxies						
160433.8	273303	.1139	11.86	2000	3	[O III] > Hβ.
163156.2	472507	.1163	11.74	1750	5	[O III] > Hβ.
213256.0	070552	.1165	11.78	2150	6	Faint plume.
213525.0	211424	.0687	11.73	2000	6	
223808.1	-133726	.1195	11.93	2500	6	[O III] > Hβ.
233017.8	521353	.1140	11.95	1300	6	Asymmetric.
234200.6	222750	.0868	11.83	1200	0	

imaging system at the *f*/3 focus of the Isaac Newton Telescope (INT) from 1989 June 26–30 and on 1990 April 30. We used the RCA 53612 thinned and back-illuminated CCD with the Kitt Peak *R* filter, except for one night when, due to problems with the RCA, we switched to the GEC chip. Flat-fields were obtained from the twilight sky. The seeing was between 1 and 2 arcsec. During the first observing run, high-altitude Saharan dust was present, resulting in all the images being non-photometric. The CCD was exposed several times per object, with an average total exposure time per galaxy of 2000 s, reaching a limiting isophote of *R* = 26. Imaging of

some galaxies was terminated early if definite signs of an interaction could be seen on individual frames. The data frames were reduced in the normal manner, and added to produce final images at the La Palma and Queen Mary & Westfield College (QMW) Starlink nodes. Object classification was carried out at QMW.

2.3 Spectroscopic observations

Two of these galaxies (181426.5 + 482351 and 185802.6 + 652717) were observed in 1989 June during the

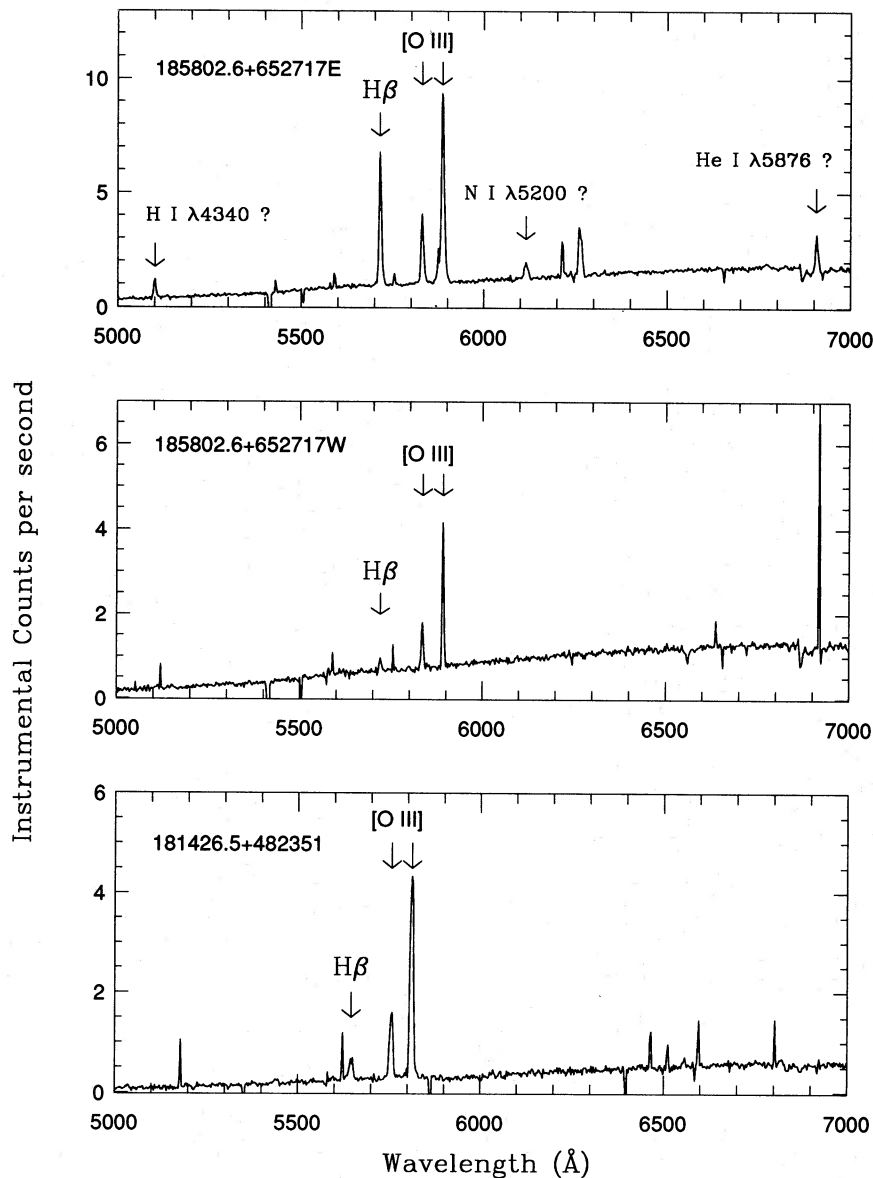


Figure 1. Spectra of two *IRAS* sources taken with *ISIS* on the William Herschel Telescope. As noted in the text, the data have not been calibrated by comparison with standard stars, and are therefore presented in instrumental counts per second. Any unmarked feature is probably a cosmic ray. See the text for more details.

commissioning of the *ISIS* spectrograph on the William Herschel Telescope (WHT) on the island of La Palma. They were observed using the EEV1 CCD chip at a dispersion of about $2.7 \text{ \AA pixel}^{-1}$ for exposure times of 2400 s each. Exposures were made around $H\beta/[O III]$. The data were wavelength-calibrated but not flux-calibrated, and are therefore in units of instrumental counts per second against wavelength. The spectra are shown in Fig. 1. All identified line features are marked, and unmarked features are probably cosmic rays.

3 RESULTS

3.1 Morphological classification

To classify the galaxies we used the system presented in Lawrence et al. (1989), which classifies a galaxy in one of

seven bands according to the existence and proximity of companions. These bands are:

- 0 galaxy has no companion within 200 kpc;
- 1 galaxy has a faint (defined as at least 2 mag but less than 4 mag weaker than the main galaxy) companion between 40 and 200 kpc away;
- 2 galaxy has a bright (less than 2 mag weaker) companion between 40 and 200 kpc away;
- 3 galaxy has a faint companion less than 40 kpc away but shows no evidence for an interaction;
- 4 galaxy has a bright companion less than 40 kpc away but shows no evidence for an interaction;
- 5 galaxy is obviously interacting with companion. There is evidence for tails or bridges;
- 6 galaxy is probably merging; it is disturbed or has two nuclei in a common envelope.

All distances used in the classification are distances projected on the sky.

Both the CCD images and Palomar Sky Survey prints were examined during galaxy classification. CCD images for all except two galaxies are shown in Fig. 2. The *IRAS* source is marked by an arrow. North is to the top and east to the left. Other information in Fig. 2 includes redshift, luminosity, interaction class and scale. Individual galaxy classifications, along with comments, are given in Table 1, and the totals for each of the seven classes are given in Table 2.

We could not classify one galaxy, 220649.6+270259, because of its proximity to a bright star. Exclusion of this unclassified ultraluminous galaxy leaves 9/35 ULGs classified as definitely not interacting (i.e. in groups 0–2), 3/35 as having a close companion but no signs of an interaction, and 23/35 as interacting/merging or peculiar. If we include the high-luminosity galaxies, these fractions do not significantly change (10/42 non-interacting, 4/42 having close companions and 28/42 interacting), although the size of the high-luminosity galaxy sample is admittedly small. Overall, we find that ≈ 67 per cent of ULGs are definitely interacting, and ≈ 76 per cent have a close companion, compared to the expected ≈ 30 per cent for galaxies in general.

One may worry that our most distant objects will be the hardest in which to find signs of interaction, such as tidal arms or bridges. There may indeed be individual objects that are interacting, and for which we have simply so far failed to find the signs, but the classifications of Table 1 show no tendency for the most distant objects to be found in the lower classes. Some of the most distant objects are clearly interacting systems. On the other hand, there are enough objects in the sample that are at relatively low redshift ($z < 0.15$) and have been classified as non-interacting (such as 131429.3+235639, 134417.8+232119 and 234200.6+222750) to make the point that *at least some* ULGs are not interacting, and that possibly as many as one-third are not interacting systems. It is not clear what is triggering the activity in these objects. Can starbursts and/or AGN activity occur spontaneously, or are we for instance missing a very close interaction with a dwarf companion? High-resolution data on the apparently non-interacting objects would be very instructive.

It is interesting to compare these deep images with the previous images obtained with the Jacobus Kapteyn Telescope (JKT). Of the four galaxies previously observed and classified as non-interacting in Lawrence et al. (1989), only two, 133412.5+393241 and 142016.0+261543, show evidence for interactions from the deeper image. While the size of this sample is too small to revise the estimates given in Lawrence et al. of the fraction of *IRAS* galaxies that are interacting, the important point to make here is that deeper images of two of these four galaxies still lead us to conclude that they are not interacting.

3.2 Spectra

We have spectra for all of these galaxies, obtained mainly in the course of redshift determination. The resultant spectra are of low quality. However, the spectra of 134417.8+232119, 135354.4+292009, 142016.0+261543 and 145733.2+325651 (Leech et al. 1989) were specifically obtained for the purpose of classification using

line ratio diagrams. All of these objects were classified as H II region-like galaxies. We also obtained two spectra during the ISIS spectrograph commissioning phase on the WHT in 1989. The spectra, shown in Fig. 1, are not flux-calibrated and only cover the region around the H β and [O III] emission lines. The [O III]/H β excitation ratio of 181426.6+482351 is large, possibly too large for an H II region, and the emission lines are broader than is normal for H II regions. This leads us to classify the object as a Seyfert 2 galaxy. 185802.6+652717 is composed of two galaxies in a close interaction. The western galaxy is probably an H II region-like galaxy, due to the narrowness of the emission lines and the H β /[O III] ratio, while the eastern galaxy is probably a LINER because of the presence of strong [N I] λ 5200 emission.

Comments are included in Table 1 regarding spectroscopic type. Spectra for the QDOT redshift survey were all taken with red-sensitive detectors, and with minimal signal-to-noise ratio, the requirement being only to get a redshift, usually from H α and [S II]. As a consequence, for *IRAS* galaxies as a whole we do not usually see [O III] λ 5007 at all. When it is seen, it is always stronger than H β . Of these galaxies, some clearly have [O III] \gg H β , and so have been classified as type 2 Seyferts. (In the present sample, only one object has broad lines, and so has been classified as a type 1 Seyfert.) However, a substantial number of the objects with detected [O III] have [O III] \approx 2H β , and so seem to be high-excitation (young?) starbursts. (These are labelled '[O III] > H β ' in Table 1.) Of the remainder, where no [O III] is detected, no spectroscopic comment is made in Table 1. The default assumption must be that these are low-excitation starbursts, but it remains possible that some of them are high-excitation objects with line-of-sight reddening. We do not, for example, have the signal-to-noise ratio to measure the ratio of [O I] λ 6300/H α . Overall, we see no evidence that ULGs are in general AGN, as has been claimed by Sanders et al. (1988), but much better spectra are needed to make a definitive statement.

4 CONCLUSIONS

We have made the deepest survey yet of the largest number of ultraluminous and high-luminosity *IRAS* galaxies. Even assuming that the galaxies classified as having nearby companions (groups 3 and 4) are interacting, eight (23 per cent) of the 35 ULGs that we can classify are isolated or have only distant companions and show no evidence for recent interactions. Including the high-luminosity galaxies, nine out of 42 (22 per cent) show no evidence for a recent interaction. We also find no evidence to support the view that the majority of high-luminosity and ultraluminous *IRAS* galaxies are powered by AGN – they must be powered by star formation. Given this, some trigger other than interactions is necessary to produce the starburst for ≈ 20 –25 per cent of high-luminosity and ultraluminous *IRAS* galaxies, assuming that a burst of star formation is necessary.

In our previous work (Lawrence et al. 1989), although we had good data for *IRAS* galaxies overall, our sample of actual ultraluminous objects was small, only six objects. We found only 2/6 to be interacting. (For the *same galaxies*, our new data could cause this number to be revised to 4/6.) Likewise, the Sanders et al. (1988) claim of 100 per cent merging

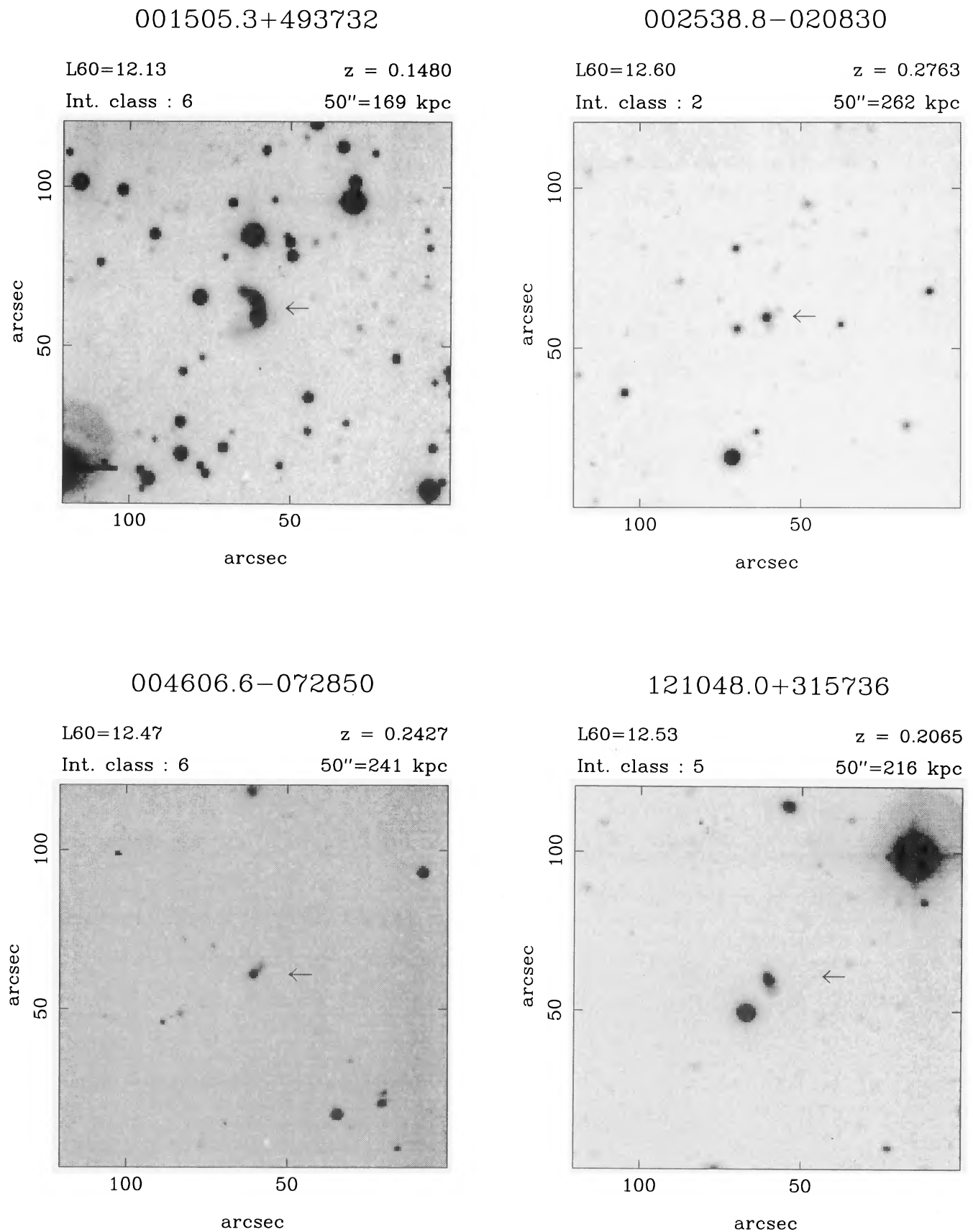


Figure 2. New CCD images of the *IRAS* sources and surrounding regions. Each image is 2 arcmin along each side. The galaxy identified with the *IRAS* source is marked. More than one galaxy is marked for ambiguous cases. The grey-scale is not identical for all images, but changes to bring out the relevant features in each image.

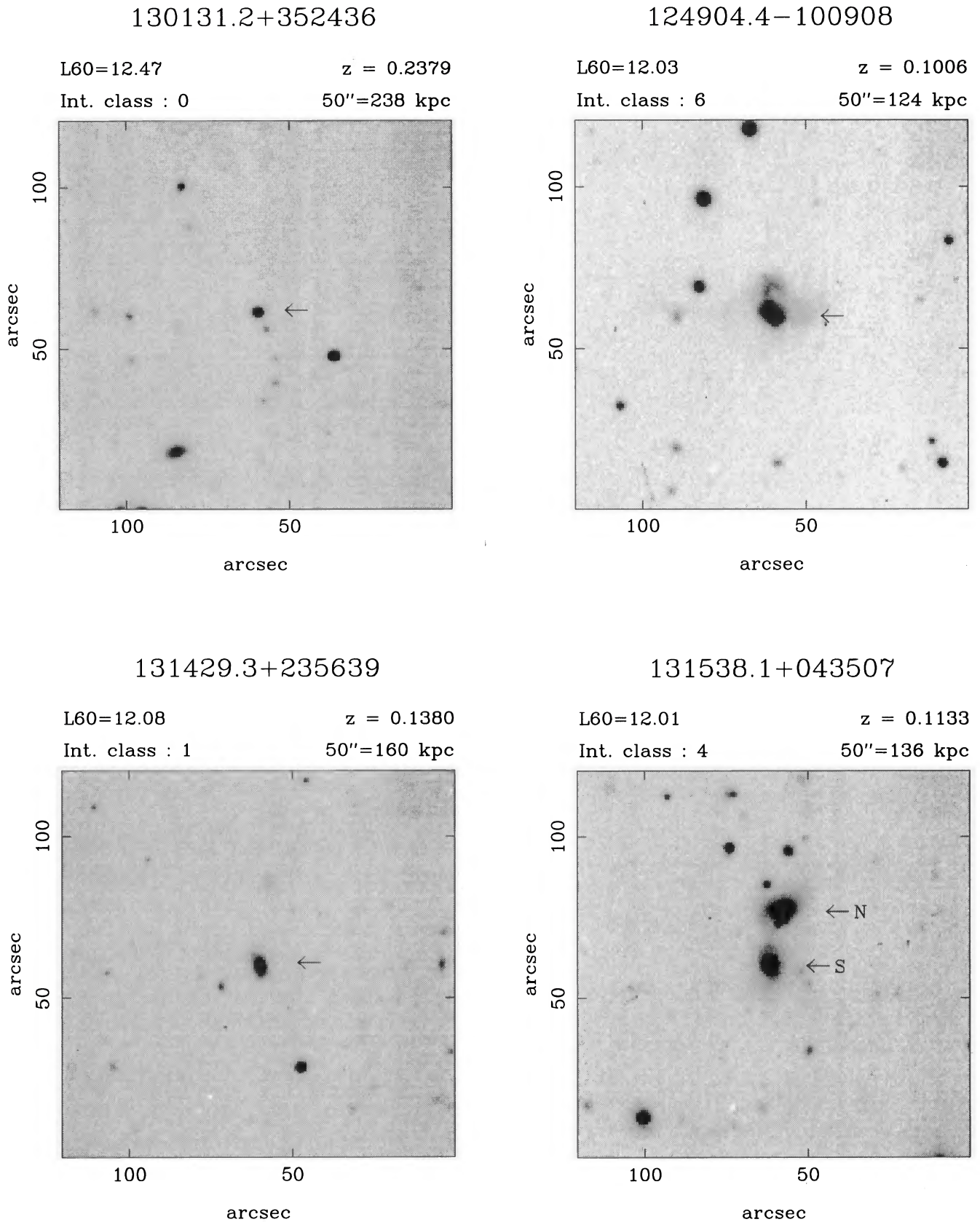


Figure 2 - continued

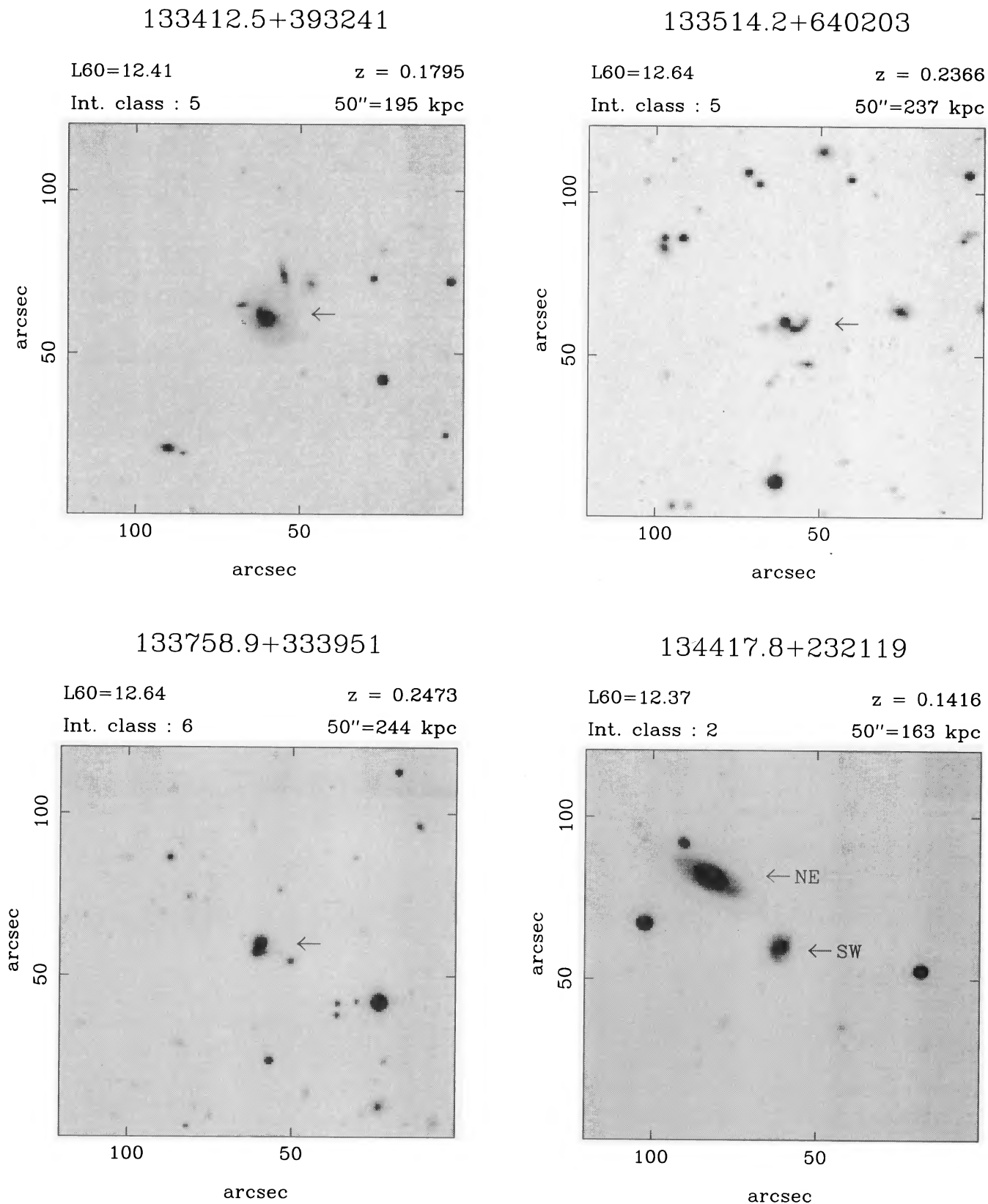


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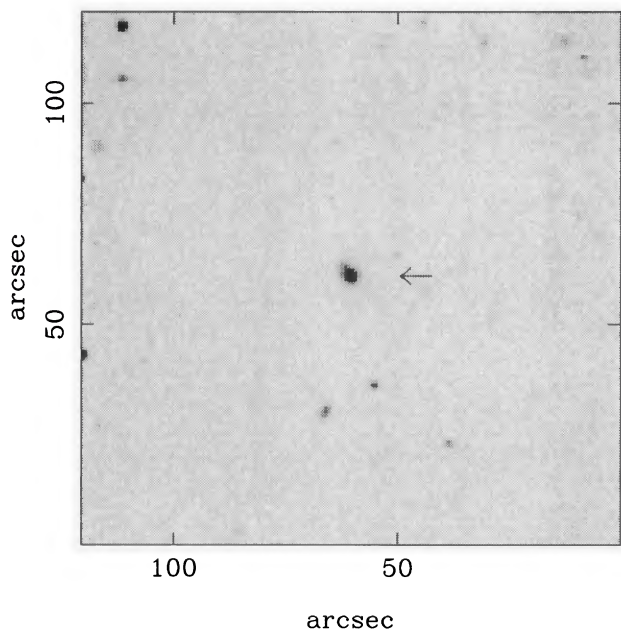
134447.4+283303

L60=12.66

 $z = 0.2569$

Int. class : 6

50''=250 kpc



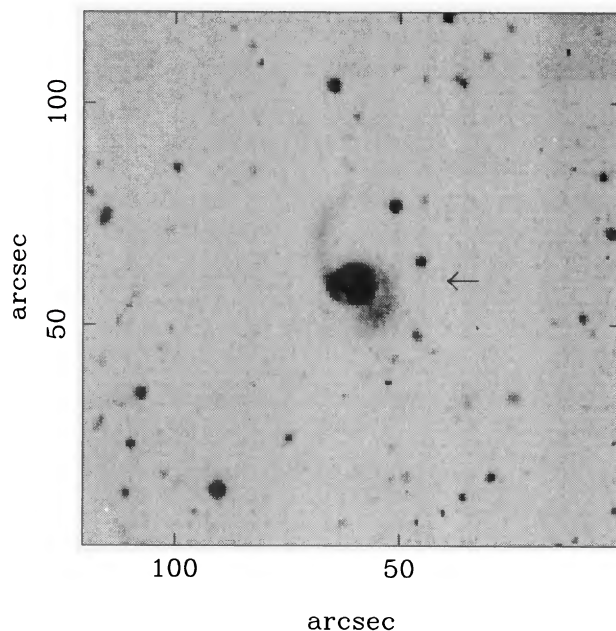
134656.2+583342

L60=12.35

 $z = 0.1551$

Int. class : 5

50''=175 kpc



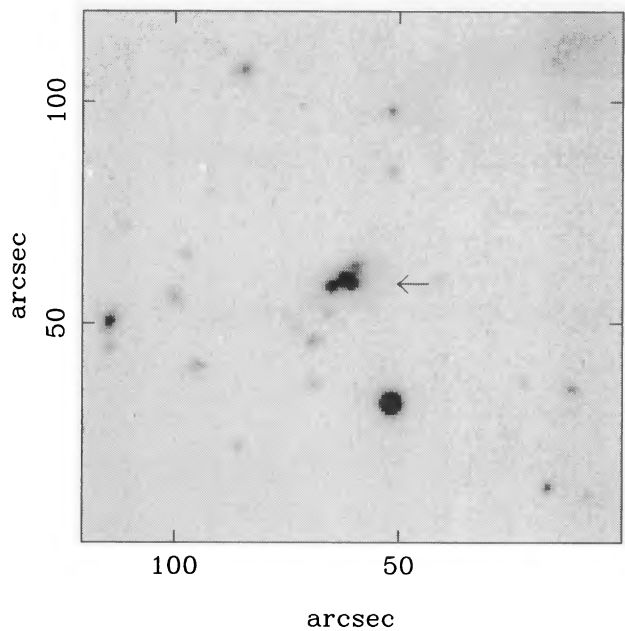
135354.4+292009

L60=12.19

 $z = 0.1085$

Int. class : 5

50''=132 kpc



141704.4+454552

L60=12.07

 $z = 0.1516$

Int. class : 6

50''=172 kpc

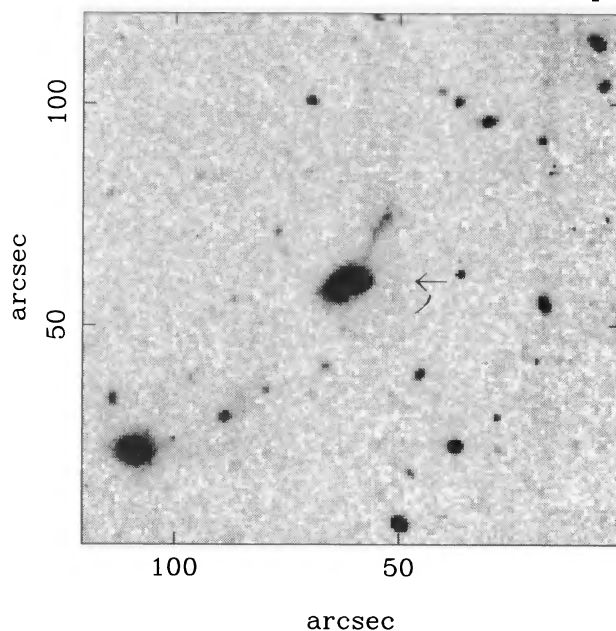


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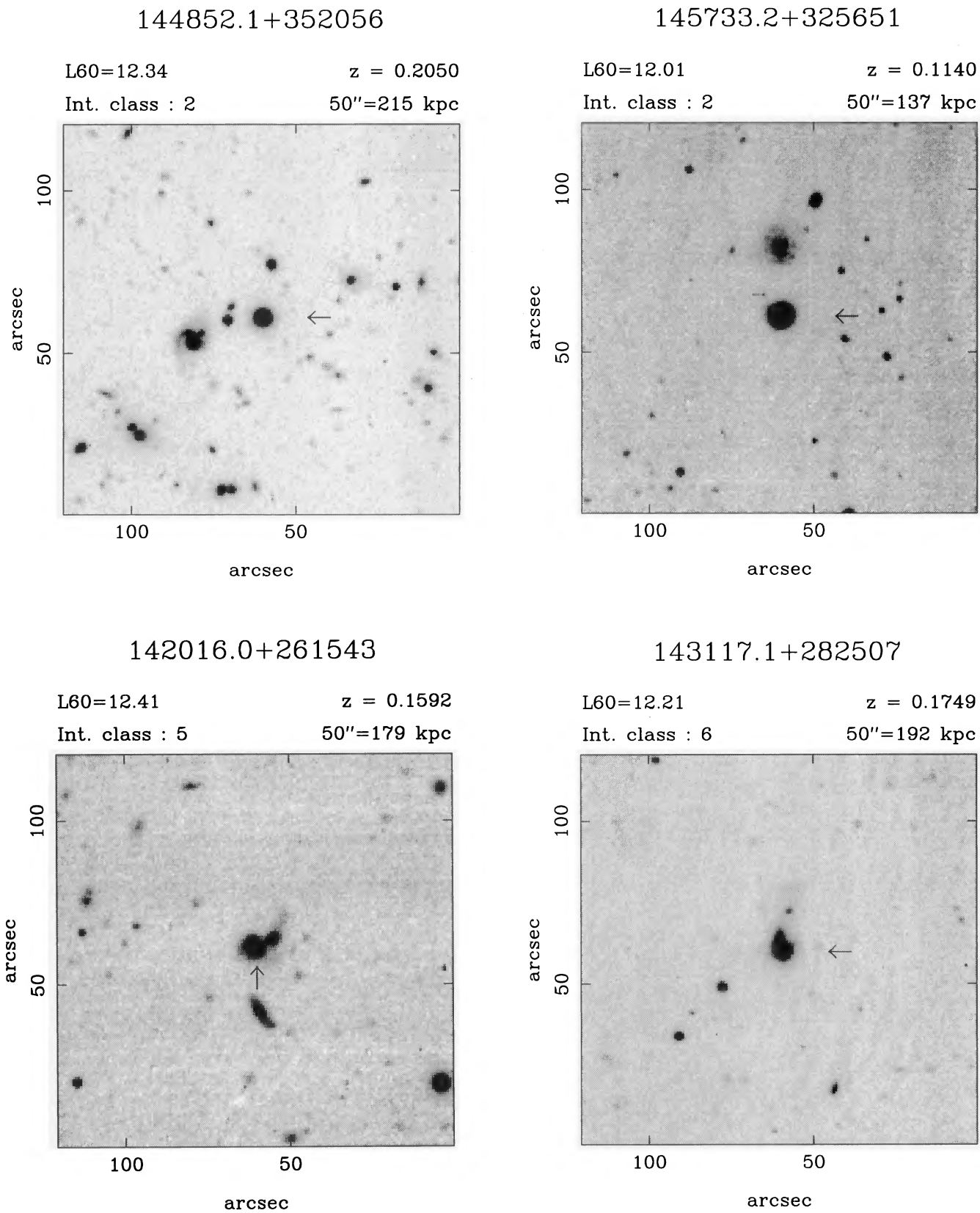


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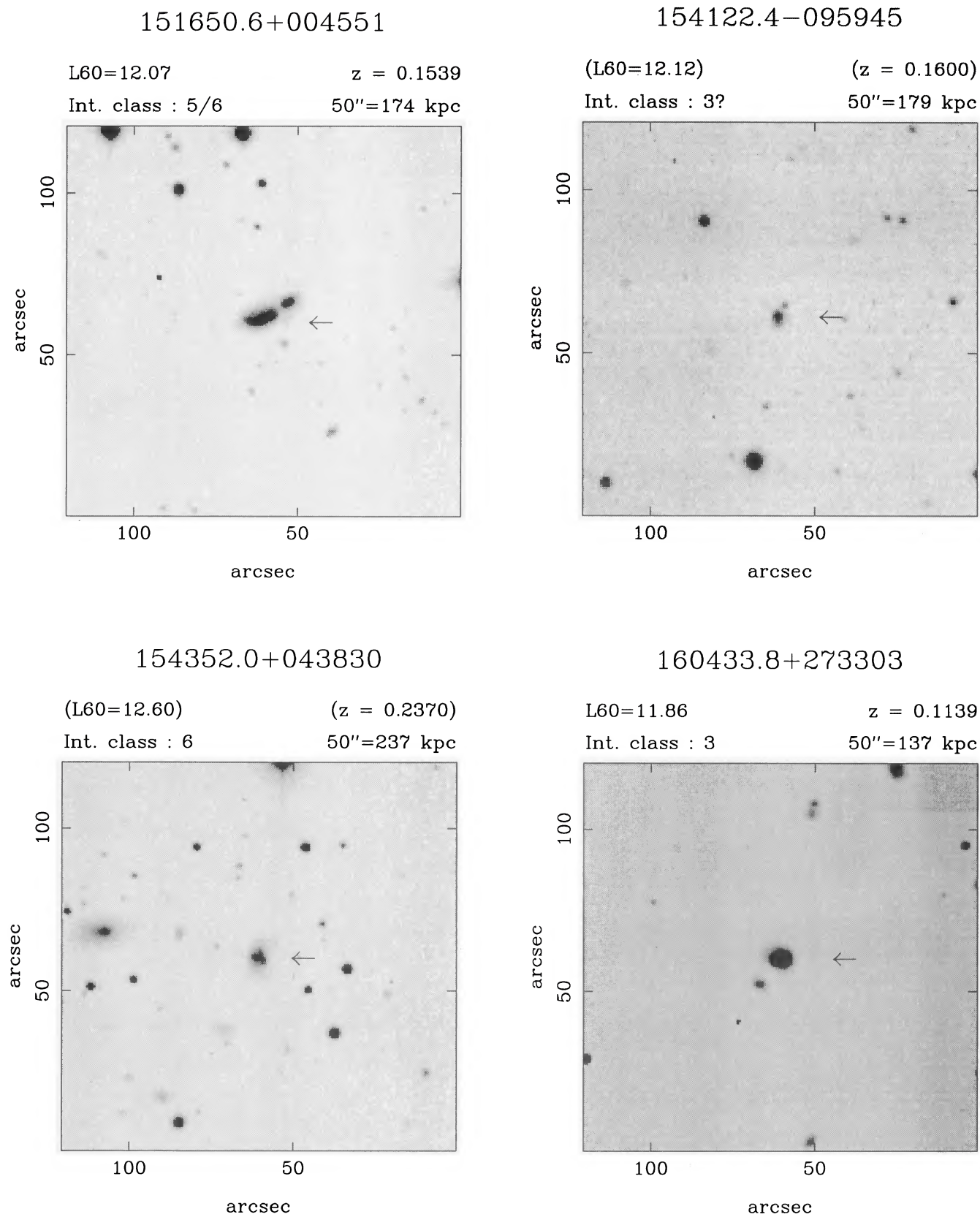
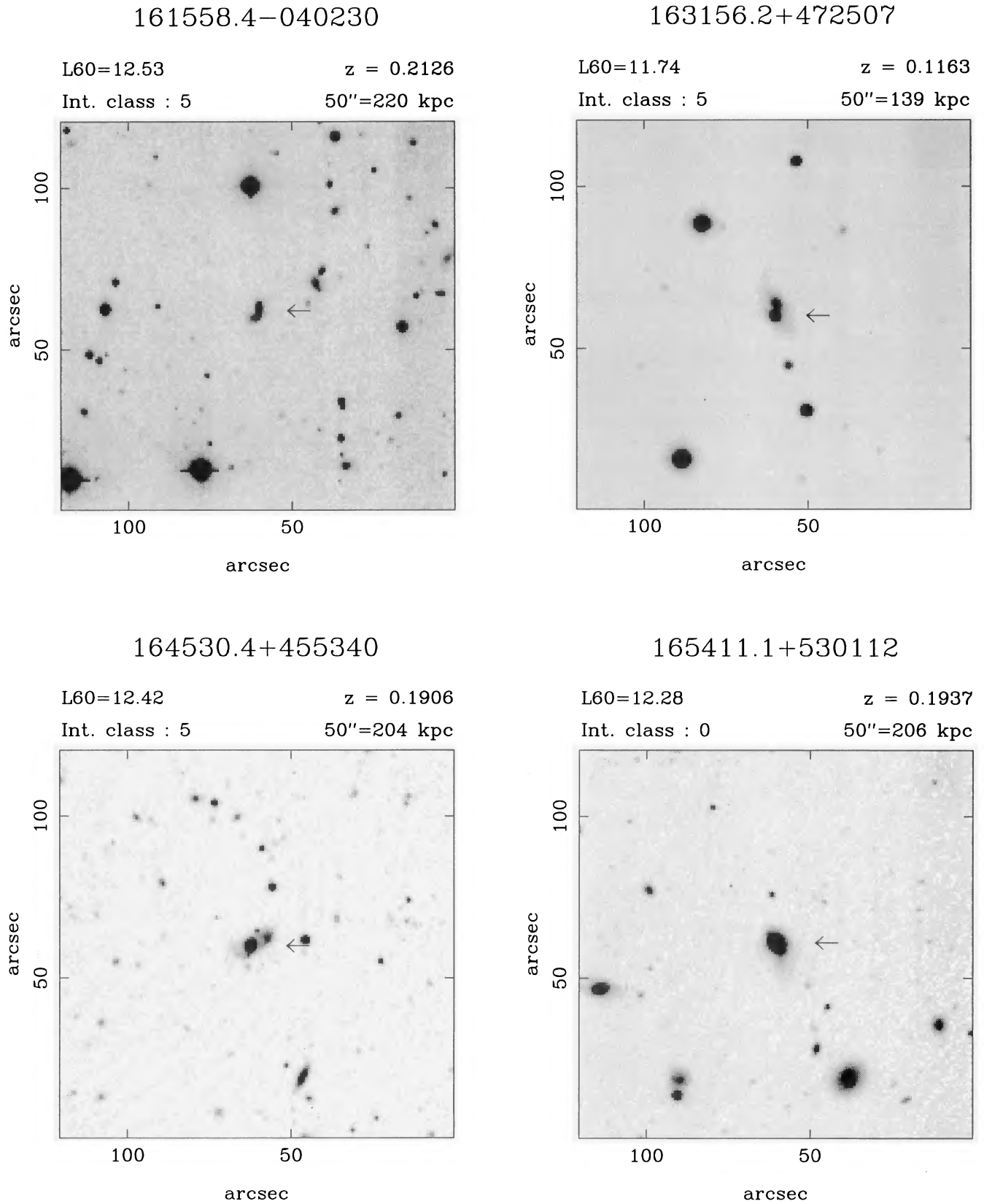


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Figure 2 - *continued*

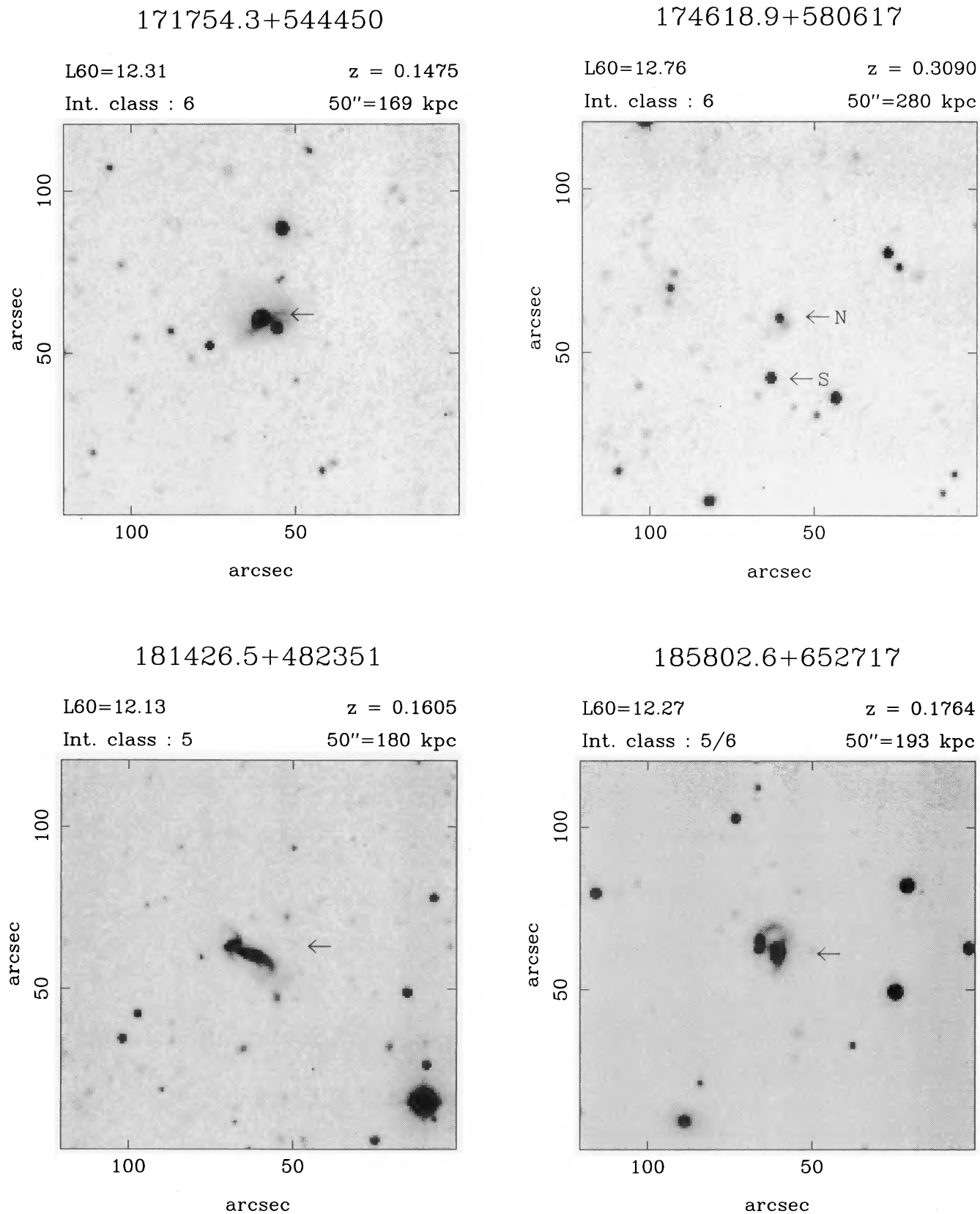


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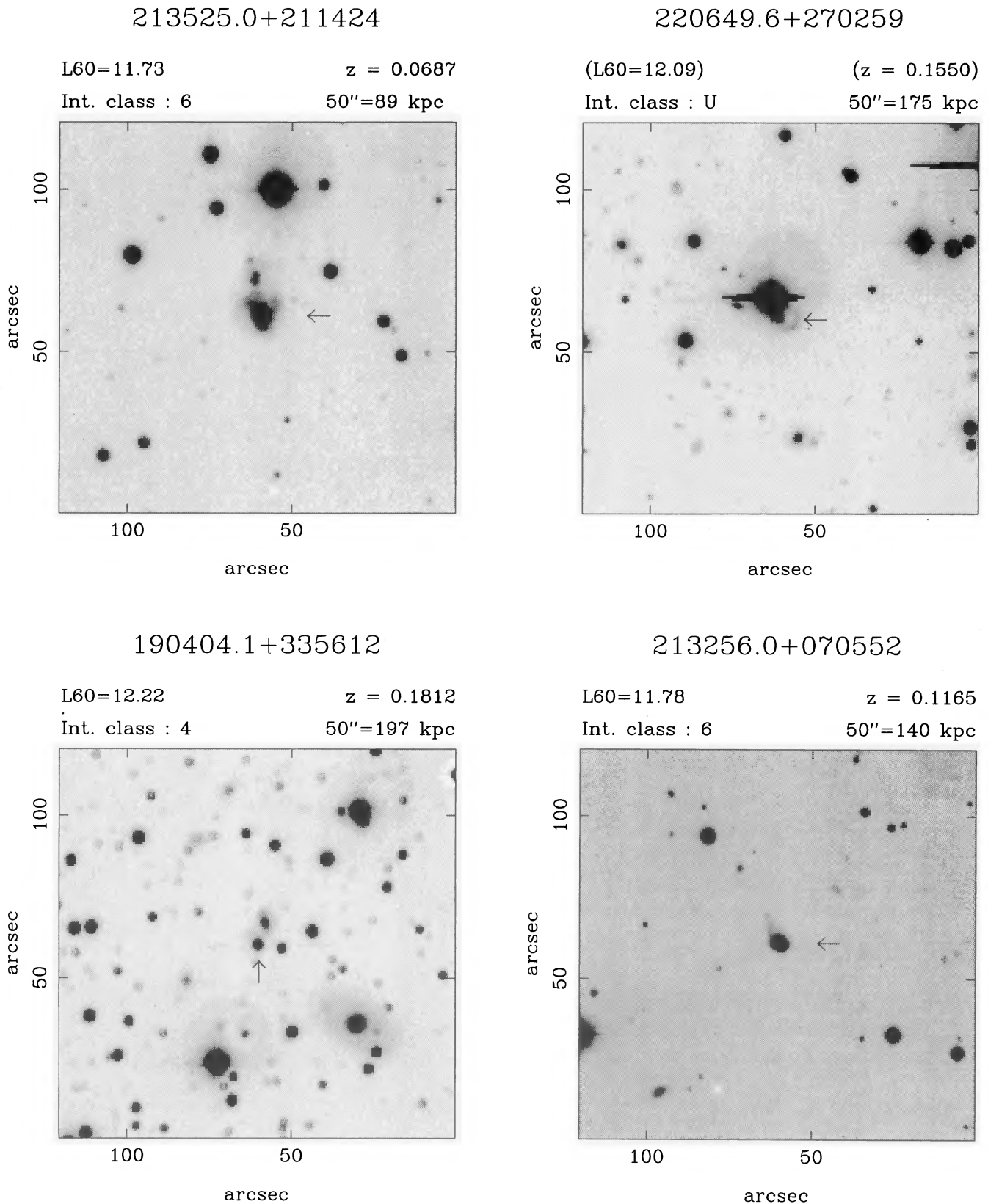


Figure 2 – continued

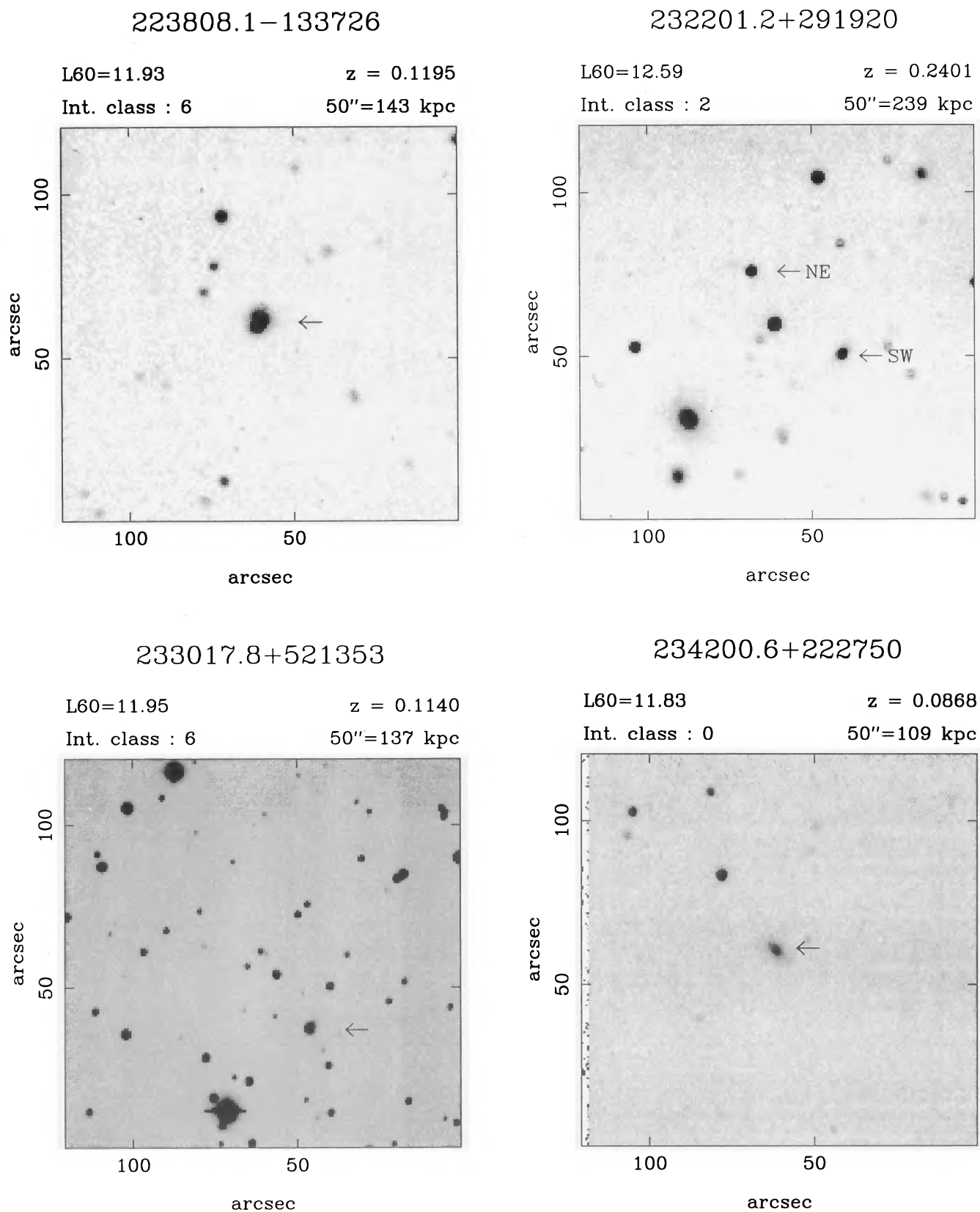


Figure 2 - continued

systems was based on only 10 galaxies. Our new finding is that 23/35 ULGs are strongly interacting. In retrospect, the originally conflicting claims are all statistically consistent with the true figure, which seems to be emerging as about 2/3. It is therefore now safely established that galaxy interactions are the most common cause of a burst of star formation. However, there seems to be a persistent minority of objects for which this is not true. Is this simply because their signs of interaction are hard to detect – e.g. because the merger is almost complete or because the interaction is with a dwarf companion – or is it for example possible that bursts of star formation can develop unaided in galaxies? Closer study of the non-interacting objects seems the most interesting path.

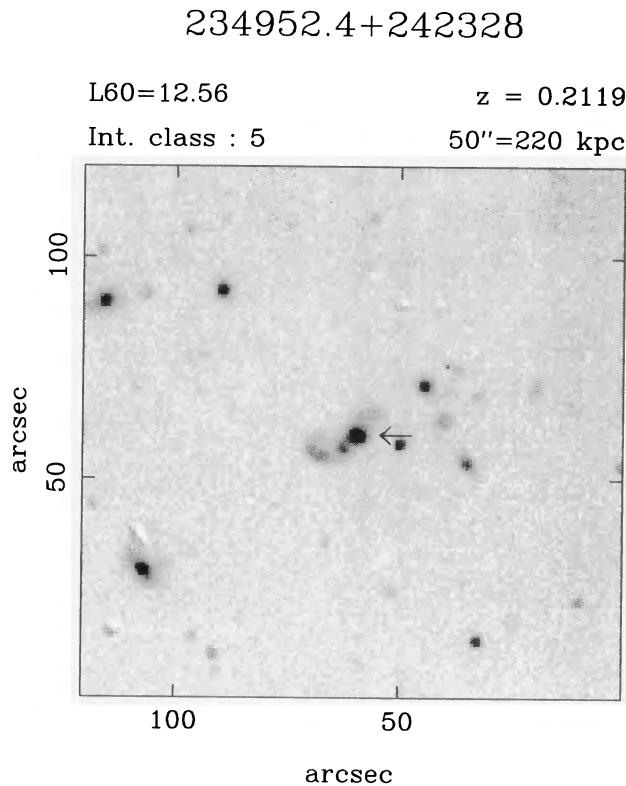


Figure 2 – continued

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Table 2. Summary of galaxy classifications.

Sample	Interaction				class		Total	Comment
	0	1	2	3	4	5		
NGW Complete	1	1	3	0	0	3	5	13
QDOT Complete	2	0	0	1	2	6	5	16
QDOT Other	0	0	2	0	0	2	3	7
All ULG	3	1	5	1	2	11	12	35
High luminosity	1	0	0	1	0	1	4	7
Total	4	1	5	2	2	12	16	42

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