ISO observations of the Wolf-Rayet galaxy NGC 7714 and its companion NGC 7715

B.O’Halloran$^1$, L. Metcalfe$^2$, M. Delaney$^1$, B. McBreen$^1$, R. Laureij$^2$, K. Leech$^2$, D. Watson$^1$ and L. Hanlon$^1$

$^1$ Physics Department, University College, Belfield, Dublin 4, Ireland

$^2$ ISO Data Centre, Astrophysics Division, Space Science Department of ESA, Villafranca, P.O. Box 50727, E-28080 Madrid, Spain

Received 14 April 2000 / Accepted 7 June 2000

Abstract. The interacting system Arp 284 consisting of the Wolf-Rayet galaxy NGC 7714 and its irregular companion NGC 7715 was observed using the Infrared Space Observatory. Deconvolved ISOCAM maps of the galaxies using the 14.3 $\mu$m, 7.7 $\mu$m and 15 $\mu$m LW3, LW6 and LW9 filters, along with ISOPHOT spectrometry of the nuclear region of NGC 7714 were obtained and are presented. Strong ISOCAM emission was detected from the central source in NGC 7714, along with strong PAH features, the emission line [Ar II], molecular hydrogen at 9.66 $\mu$m and a blend of features including [S IV] at 10.6 $\mu$m. IR emission was not detected from the companion galaxy NGC 7715, the bridge linking the two galaxies or from the partial stellar ring in NGC 7714 where emission ceases abruptly at the interface between the disk and the ring.

The morphology of the system can be well described by an off-centre collision between the two galaxies. The LW3/LW2, where the LW2 flux was synthesized from the PHOT-SL spectrum, LW9/LW6 and LW3/LW6 ratios suggest that the central burst within NGC 7714 is moving towards the post-starburst phase, in agreement with the age of the burst. Diagnostic tools including the ratio of the integrated PAH luminosity to the 40 to 120 $\mu$m infrared luminosity and the far-infrared colours reveal that despite the high surface brightness of the nucleus, the properties of NGC 7714 can be explained in terms of a starburst and do not require the presence an AGN.

Key words: galaxies individual - NGC 7714 - NGC 7715 - galaxies interactions - galaxies starburst

1. Introduction

Wolf-Rayet galaxies are a subset of emission line and HII galaxies whose integrated spectra have a broad emission feature around 4650Å which has been attributed to Wolf-Rayet stars. The emission feature usually consists of a blend of lines namely, HeI $\lambda4686$, CIII/CIV $\lambda4650$ and NIII $\lambda4640$. The CIV $\lambda5808$ line can also be an important signature of Wolf-Rayet activity. Wolf-Rayet galaxies are important in understanding massive star formation and starburst evolution (Schaerer & Vacca, 1998; Mas-Hesse & Kunth, 1999). The Wolf-Rayet phase in massive stars is short lived and hence gives the possibility of studying an approximately coeval sample of starburst galaxies (Metcalfe et al., 1996; Rigopoulou et al., 1999). The first catalog of Wolf-Rayet galaxies was compiled by Conti (1991) and contains 37 galaxies. A large number of additional Wolf-Rayet galaxies have been identified and a new catalog containing 139 galaxies has been compiled by Schaerer et al. (1999).

The interacting system Arp 284 consists of an active starburst galaxy NGC 7714 and its post starburst companion NGC 7715. This system has been the subject of several investigations (Demoulin et al., 1968; Weedman et al., 1981) because of its unusual morphology. Van Breugel et al. (1985) first reported weak Wolf-Rayet features near 4846 Å, and possible HeII emission from the nucleus of NGC 7714. NGC 7714 is an SBb peculiar galaxy and classified by Weedman et al. (1981) as a proto-typical starburst. The heliocentric radial velocity is 2798 km s$^{-1}$ which places it at a distance of 37.3 Mpc assuming $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$ (Gonzalez-Delgado et al., 1994). The spectrum from X-rays (Stevens & Strickland, 1998) to VLA radio (Smith & Wailin, 1992) at 6 and 20 cm, was explained as a result of intense star formation in the nucleus (Weedman et al., 1981). Very detailed studies have been carried out in the ultraviolet, optical and near-infrared to quantify the gas properties in the nuclear and circumnuclear regions (Weedman et al., 1981; Gonzalez-Delgado et al., 1994; Garcia-Vargas et al., 1997). Hubble Space Telescope (HST) spectroscopy of the nuclear starburst revealed Wolf-Rayet features in the ultraviolet and indicate a population of about 2000 Wolf-Rayet stars (Garcia-Vargas et al., 1997). The B-magnitude of the galaxy is -20.4 and far-infrared luminosity of $2.8 \times 10^{10} L_\odot$ with IRAS far-infrared flux ratios $f_{25}/f_{100}$ and...
Deconvolved 15 µm LW3 map of NGC 7714 and NGC 7715 overlaid on an R band CCD image, showing the bridge between the two galaxies. Features denoted by 'T' give the positions of tails/arms emanating from both galaxies. Sources coinciding with NGC 7715 were determined to be glitches using robust deglitching techniques. An enlarged view of the NGC 7714 region is given in Figure 2. IR1 is a weak source without an identified optical counterpart.

The observations and data reduction are presented in Sect. 2. The results are contained in Sect. 3 and discussed in Sect. 4. The conclusions are summarised in Sect. 5.

2. Observations and Data Reduction

The ISO observations were obtained using the mid-infrared camera ISOCAM (Cesarsky et al., 1996) and the spectrometric mode of the ISO photopolarimeter (Lemke et al., 1996). The astronomical observing template (AOT) used was CAM 01, for the raster observations and PHOT40, for spectrometry. The log of the CAM01 observations using the LW3, LW6 and LW9 filters and the PHOT40 observations are presented in Table 1.

2.1. ISOCAM

Each observation had the following configuration: 3″ pixel field of view (PFOV), integration time of 5.04 s with a 5″ × 2″ raster, 48″ stepsize, excluding discarded stabilization readouts (Siebenmorgen et al., 1999). All data processing was performed with the CAM Interactive Analysis (CIA) system (Ott et al., 1997; Delaney, 1998), and the following method was applied during data processing. (i) Dark subtraction was performed using a dark model with correction for slow drift of the dark current throughout the mission. (ii) Glitch effects due to cosmic rays were removed following the method of Aussel et al. (1999). (iii) Transient correction for flux attenuation due to the lag in the detector response was performed by the method described by Abergel et al. (1996). (iv) The raster map was flat-fielded using a library flat-field. (v) Pixels affected by glitch residuals and other persistent effects were manually suppressed. (vi) The raster mosaic images were deconvolved with a multi-resolution transform method described by Starck et al. (1998). The duration of the observations in Table 1 give the length of the actual observation including instrumental, but not spacecraft, overheads. Photometry was performed by integrating the pixels containing source flux exceeding the background by 3σ. Contour levels are based on a power scale, where the lowest level is approximately 2 times the standard deviation, or σ, of the background noise, using pixels from around the border of the image.

2.2. PHOT-S

PHOT-S consists of a dual grating spectrometer with a resolving power of 90. Band SS covers the range 2.5 - 4.8 µm, while band SL covers the range 5.8 - 11.6 µm. (Laureijs et al., 1998). The PHT-S spectra of NGC 7714 was obtained by pointing the 24″ × 24″ aperture of PHT-S alternatively towards the peak of the LW6 emission (for
Table 1. Log of the ISO observations of NGC 7714 and NGC 7715. The nine columns list the observation name, the AOT, the filter, the wavelength range \(\Delta \lambda\), the reference wavelength of the filter, the date and duration of the observation, and the position of the observation in RA and declination respectively.

| Observation  | AOT# | filter | \(\Delta \lambda\) | \(\lambda_{\text{ref}}\) | date       | duration  | Right Ascension (RA) | Declination (Dec) |
|--------------|------|--------|---------------------|-----------------|------------|-----------|---------------------|-------------------|
| NGC7714      | CAM01| LW3    | 12–18               | 14.3            | 24 May 1997 | 1936      | 23h 36m 18s         | +02° 09’ 18’’    |
| NGC7714      | CAM01| LW6    | 7.7–8.5             | 7.7             | 24 May 1997 | 1936      | 23h 36m 18s         | +02° 09’ 18’’    |
| NGC7714      | CAM01| LW9    | 14–16               | 15              | 27 May 1997 | 1936      | 23h 36m 18s         | +02° 09’ 18’’    |
| NGC7714      | PHT40| SS/SL  | 2.5–11.6            | 8.7             | 24 May 1997 | 1132      | 23h 36m 14s         | +02° 09’ 18’’    |
| NGC7715      | PHT40| SS/SL  | 2.5–11.6            | 8.7             | 24 May 1997 | 1132      | 23h 36m 22s         | +02° 09’ 25’’    |

Table 2. ISOCAM and IRAS fluxes for NGC 7714. The four columns list the filter used, the wavelength range, the reference wavelength for the filter and the flux measured. The fluxes have a photometric accuracy of about 15%. IRAS fluxes for NGC 7714 are also given for comparison (Moshir et al., 1990).

| filter | \(\lambda\) | \(\lambda_{\text{ref}}\) | flux       |
|--------|-------------|-----------------|------------|
| LW3    | 12.0–18.0   | 14.3            | 0.46 ± 0.07|
| LW6    | 7.0–8.5     | 7.7             | 0.35 ± 0.05|
| LW9    | 14–16       | 15              | 0.55 ± 0.08|
| IRAS 12\(\mu m\) | 8.5–15      | 12              | 0.47 ± 0.05|
| IRAS 25\(\mu m\) | 19–30       | 25              | 2.85 ± 0.26|
| IRAS 60\(\mu m\) | 40–80       | 60              | 10.36 ± 1.24|
| IRAS 100\(\mu m\) | 83–120      | 100             | 11.51 ± 0.69|

512 seconds) and then towards two background positions off the galaxy (256 seconds each), using the ISOPHOT focal plane chopper. The calibration of the spectrum was performed by using a spectral response function derived from several calibration stars of different brightness observed in chopper mode (Acosta-Pulido et al., 1999). The relative spectrometric uncertainty of the PHOT-S spectrum is about 20% when comparing different parts of the spectrum that are more than a few microns apart. The absolute photometric uncertainty is about 30% for bright calibration sources. All data processing was performed using the ISOPHOT Interactive Analysis system, version 8.1 (Gabriel, 1998). Data reduction consisted primarily of the removal of instrumental effects. Once the instrumental effects have been removed, background subtraction was performed and flux densities were obtained. These fluxes were plotted to obtain the spectrum for NGC 7714.

3. Results

A deconvolved LW3 map overlaid on a R band CCD image (Papaderos & Fricke, 1998) of Arp 284 is presented in Fig. 1. Deconvolved maps obtained using the LW3, LW6 and LW9 filters, overlaid on a R band CCD image (Papaderos & Fricke, 1998), are presented in Figs. 2, 3 and 4. It is evident that the strong compact source on each map coincides with the nuclear region of NGC 7714. Three giant H II regions are marked A, B and C. D is the partial ring and N denotes the nucleus with the Wolf-Rayet signature. The contour levels (mJy/arcsec\(^{-2}\)) are: 0 = 0.1, 1 = 1.0, 2 = 7.0, 3 = 20.0, 4 = 40.0. IR1 is a weak source without an identified optical counterpart.

Fig. 2. Deconvolved LW3 map of NGC 7714, superimposed on a R band CCD image. The three giant H II regions are marked A, B and C. D is the partial ring and N denotes the nucleus with the Wolf-Rayet signature. The contour levels (mJy/arcsec\(^{-2}\)) are: 0 = 0.1, 1 = 1.0, 2 = 7.0, 3 = 20.0, 4 = 40.0. IR1 is a weak source without an identified optical counterpart.
Fig. 3. Deconvolved LW6 map of NGC 7714, superimposed on a R band CCD image of NGC 7714. Contour levels (mJy/arcsec$^2$) are: 0 = 0.2, 1 = 1.0, 2 = 3.5, 3 = 9.0, 4 = 20.0. The map notation is the same as in Fig. 2. IR2 coincides with a weak radio source without an identified optical counterpart.

Fig. 4. LW9 map of NGC 7714. Contour levels (mJy/arcsec$^2$) are: 0 = 0.4, 1 = 1.0, 2 = 12.0, 3 = 33.0, 4 = 70.0. The map notation is the same as in Fig. 2. The nuclear region coincides with the strong LW9 emission.

The companion galaxy NGC 7715 was not detected in any of the three filter bands. Two weak sources were detected at the position of NGC 7715 in the LW3 filter in Fig. 1, but were determined to be glitches using robust deglitching techniques. The lack of emission from NGC 7715, along with the ring and spiral arms of NGC 7714 suggests that strong star formation is not present in these regions.

The PHOT-SL spectrum of NGC 7714 is presented in Fig. 5. Strong detections were made of unidentified infrared bands (UIBs) at 6.2, 7.7, 8.6 and 11.3 µm that are usually attributed to polycyclic aromatic hydrocarbons (PAHs) (Allamandola et al., 1989). A weak additional feature at 11.0 µm may also be PAH (Moutou et al., 1999). The 11.3 µm feature is quite strong relative to the 7.7 µm, with a flux ratio of 2:1. [Ar II] was detected at 6.99 µm in the unsmoothed spectrum at the 3 σ level. Two weak features were also detected at about 9.66 and 10.6 µm. The 9.66 µm feature may be due to the S(3) pure rotational line, $\nu = 0-0$, of molecular hydrogen, while the 10.6 µm feature may be a blend of [S IV] at 10.51 µm and an additional unidentified component at 10.6 µm to account for the width of the feature. The interpolated continuum between the ends of the wavelength range was subtracted to obtain the line fluxes. The identified line features and line fluxes are given in Table 3.

Table 3. PHOT-S fluxes for NGC 7714. The three columns give the line identification, the wavelength range and the integrated flux respectively.

| line ID | Wavelength range (µm) | flux (10$^{-15}$ W m$^{-2}$) |
|---------|----------------------|-----------------------------|
| PAH 6.2 | 6.0 - 6.6            | 2.73 ± 0.46                 |
| [Ar II] 6.99 | 6.8 - 7.2      | 0.74 ± 0.10                 |
| PAH 7.7  | 7.2 - 8.3           | 8.84 ± 1.10                 |
| PAH 8.6  | 8.3 - 8.9           | 1.22 ± 0.24                 |
| H$_2$ 9.66 | 9.3 - 9.9        | 0.78 ± 0.20                 |
| [S IV] 10.5 | 10.4 - 10.8     | 0.32 ± 0.08                 |
| PAH 11.0 | 10.8 - 11.1         | 0.23 ± 0.07                 |
| PAH 11.3 | 11.1 - 11.6         | 1.28 ± 0.26                 |

The spectral energy distribution of NGC 7714 using ISOCAM, PHOT-SL and IRAS fluxes is presented in Fig.
The partial ring within NGC 7714, populated by red giant stars like those found in the companion galaxy, seems to be deficient in warm dust and is not detectable in the CAM maps. The model of Smith & Wallin (1992) may explain the lack of ongoing star formation within the partial ring of NGC 7714. In more central impacts, occurring at less than 0.2 times the radius of the target disk, the resulting strong radial oscillations lead to the formation of rings similar to those observed in the Cartwheel and Arp 10 (Charmandaris et al., 1999). Smith et al. (1997) noted that the optical ring in NGC 7714 does not have a prominent H I counterpart, similar to that found in the non-star-forming inner ring of the Cartwheel but not in the outer ring (Higdon, 1996). Such differentiation of gas and stars is expected in partial rings formed during very off-center collisions. Thus, the lack of an H I counterpart does not rule out a collisional origin for the NGC 7714 ring. Another possibility is that the stellar ring may be a wrapped-around spiral arm caused by a noncollisional prograde planar encounter, rather than a collisional ring. The high column density of gas in the bridge, however, and its offset from the stars (Smith et al., 1997) supports the concept that gas was forced out of the main galaxy by a collision between two gas disks rather than merely perturbed in a grazing or long-range encounter.

The age of Wolf-Rayet stars in the central burst of NGC 7714 has been dated at between 4 and 5 Myr (Garcia-Vargas et al., 1997), yet this age is far short of the $\sim 10^8$ years since the interaction. Given the amount of time since the onset of the interaction, any burst of star formation initiated by the interaction should have long since ceased, for example the companion galaxy NGC 7715, which has been in a post starburst phase for the last 50 - 70 Myr (Bernlohr, 1993). For such a young burst, gas infall to the nucleus must be ongoing to power the burst, and indeed HI gas may be falling from the bridge to the nuclear region (Papaderos & Fricke, 1998; Smith & Wallin, 1992). In a survey of 10 interacting galaxies, Bushouse et al. (1998) noted that galaxies similar in morphological type to NGC 7714 possessed nuclear infrared sources that are 10-100 times brighter than normal galaxies in the mid-infrared and have high levels of star formation. The companion galaxies, such as NGC 7715, have passed through their own star formation epoch and now lack the gas and dust to support large-scale star formation.

It is interesting to note that the ratio of LW3/LW2, where LW3 emission is dominated by dust and LW2 by PAHs, varies depending on the separation between the interacting galaxies (Hwang et al., 1999). The LW3/LW2 ratio generally decreases as interactions develop, starbursts age and separations increase (Vigroux et al., 1999; Cesarsky & Sauvage, 1994; Charmandaris et al., 1999). To determine the LW3/LW2 ratio for NGC 7714, the LW2 flux was synthesized from the PHOT-SL spectrum in the equivalent range of wavelengths to the ISOCAM LW2 filter, 5 to 8.5 $\mu$m. In order to check the accuracy of the
The 11.3 μm PAH feature is quite strong relative to the 7.7 μm PAH feature. This ratio is particularly sensitive to the degree of ionization, implying that the detected PAHs may not have been ionized. A strong 11.3 μm feature is common in colder galaxies like NGC 7714, since it is linked to neutral PAHs and is indicative of a high degree of hydrogenation in the PAHs (Peeters et al., 1999; Lu et al., 1999). PAHs exposed to a harder radiation field, for example within the H II regions and on the interface between the H II and the molecular cloud, can be ionized, lose hydrogen atoms and/or disappear by photodissociation. Proximity to highly ionizing sources, such as young O stars within a burst may thus lead to dehydrogenation of the PAHs. Moving out past the H II/molecular cloud interface, the degree of hydrogenation increases (Verstraete et al., 1996; Roelfsema et al., 1999).

The compact nature of the nucleus of NGC 7714 and its extremely high surface brightness (Weedman et al., 1998) have led to suspicions that NGC 7714 harbours an active nucleus. While the galaxy has far-infrared IRAS colours more in line with Seyfert 2 galaxies than starbursts (Gonzalez-Delgado et al., 1994), the emission lines of Hα, [NII] λλ 6548, 6583, [SII] λλ 6716, 6731, He I λ 5876 and [OII] λ 6300 are not broad enough to suggest the presence of a Seyfert nucleus (Demoulin et al., 1968). UV observations by the HST (Gonzalez-Delgado et al., 1999) have shown that the nuclear region contains ~ 2000 Wolf-Rayet and 20000 O type stars, with an age for the burst of 4 to 5 Myr, while ROSAT (Papaderos & Fricke, 1998; Stevens & Strickland, 1998) has shown it to be a strong X-ray source. The high excitation of material within the nuclear region can account for the 6.99 μm [Ar II] line. The 9.6 μm feature may be due to the S(3) ground vibrational molecular hydrogen ground state of molecular hydrogen. Ultraviolet fluorescence, excitation by low-velocity shocks and heating caused by X-rays are considered to be the primary emission mechanisms for the excitation of molecular hydrogen (Black & van Dishoeck, 1987; Draine & Roberge, 1982; Mouri, 1994). These mechanisms require a source of dense gas to be located near the source of illumination such as a starburst. Excitation may also occur due to slow shocks induced by jets or by kinetic processes such as winds, supwinds and supernovae. Spectroscopic studies of Seyfert galaxies indicate that no single process in responsible for the H2 emission (Quillen et al., 1999).

Several diagnostic tools are available to probe the nature of the activity within the nuclear region. The ratio of the integrated PAH luminosity and the 40 to 120 μm IR luminosity (Lu et al., 1999) provides a tool to discriminate between starbursts, AGN and normal galaxies because the lower the ratio, the more active the galaxy. For NGC 7714, the ratio is 0.09 and is consistent with the values found for other starbursts (Vigroux et al., 1999). Similarly, the ratio of the 7.7 μm PAH flux to the continuum level at this wavelength can provide a measure of the level of activity within the nucleus (Genzel et al., 1998; Laureijs et al.).
2000). The ratio for NGC 7714 is 3.3 and is indicative of an active starburst. The results from these diagnostic tools indicate that NGC 7714 is home to a compact burst of star formation, and suggests that an AGN is not present within the nuclear region.

5. Conclusions

Deconvolved ISOCAM maps of the Arp 284 system were obtained with the LW3, LW6 and LW9 filters, with strong emission detected from the central source in NGC 7714. IR emission was not detected from the companion galaxy NGC 7715, the bridge linking the two galaxies or from the partial stellar ring, where emission ceases abruptly at the interface between the disk and the ring. ISOPHOT spectrometry of the nuclear region of NGC 7714 was also obtained, with strong PAH features, the emission line [Ar II], molecular hydrogen at 9.66 µm and a blend of lines including [S IV] about 10.6 µm all present within the spectrum.

The morphology of the system is well described by an off-centre collision between the two galaxies. A series of diagnostic tools allowed an investigation to be performed regarding the activity within the central region of NGC 7714. The LW3/LW2, where the LW2 flux was synthesized from PHOT-S measurements, LW9/LW6 and LW3/LW6 ratios suggest that the central burst within NGC 7714 is moving towards the post-starburst phase. The ratio of the integrated PAH luminosity to the 40 to 120 µm infrared luminosity and the far-infrared colours reveal that despite the high surface brightness of the nucleus, the properties of NGC 7714 can be explained in terms of a starburst and do not require the presence an AGN.

Acknowledgements. We thank P. Papaderos and K. Fricke for kindly allowing the use of their CCD image of the Arp 284 system. The ISOCAM data presented in this paper was analysed using ‘CIA’, a joint development by the ESA Astrophysics Division and the ISOCAM Consortium. The ISOCAM Consortium is led by the ISOCAM PI, C. Cesarsky, Direction des Sciences de la Matiere, C.E.A., France. The ISOPHOT data was reduced using PLA, which is a joint development by the ESA Astrophysics Division and the ISOPHOT consortium.

References

Aberfeld A., Bernard J.P., Boulanger F. et al., 1996, A&A 315, L329
Acosta-Pulido J.A., Gabriel C., Castaeda H., 1999, accepted for publication in Experimental Astronomy, Kluwer Academic Publishers (1999)
Allamandola L.J., Tielens A.G.G.M., Barker J., 1989, ApJS 71, 733
Aussel H., Cesarsky C.J., Elbaz D. et al., 1999, A&A 342, 313
Bernlohr K., 1993, A&A 268, L25
Black J.H., van Dishoeck E.F., 1987, ApJ 322, 412
Boulanger F., Boissel P., Cesarsky D. et al., 1998, A&A 339, 194
Bushhouse H., Telesco C.M., Warner M.W., 1998, AJ 115, 938
Cesarsky C., Sauvage M., 1999, Kluwer Academic Publishers, in press
Cesarsky C., Aberfeld A., Agnese P. et al., 1996, A&A 315, L32
Cesarsky C., Genzel R., 2000, astro-ph 002184, Ann.Rev.Astron.Astrophys., in press
Charmandaris V., Laurent O., Mirabel I.F. et al., 1999, In: Cox P., Kessler M.F. (eds) The Universe as seen by ISO, ESA SP-427, volume 2, p. 869
Charmandaris V., Laurent O., Mirabel I.F. et al., 1999, In: Combes F., Manon G.A., Charmandaris V. (eds) Galaxy Dynamics : from the Early Universe to the Present, ASP Conference Series, in press
Conti P.S., 1991, ApJ 377, 115
Delaney M., 1998, ISOCAM Interactive Analysis User’s Manual 3.0, ESA SAI/96-5226/DC
Demoulin M.H., Burbidge E.M., Burbidge G.R., 1968, ApJ 153, 31
Draine B.T., Roberge W.G., 1982, ApJ 259, L91
Gabriel C., 1998, PHOT Interactive Analysis User Manual, ESA, [http://www.iso.vilspa.esa.es/manuals/]
Garcia-Vargas M.L., Gonzalez-Delgado R.M., Perez E. et al., 1997, ApJ 478, 112
Genzel R., Lutz D., Sturm E. et al., 1998, ApJ 498, 579
Gonzalez Delgado R.M., Perez E., Diaz A.I. et al., 1994, ApJ 439, 604
Gonzalez Delgado R.M., Garca-Vargas M.L., Goldader J. et al., 1999, ApJ 513, 707
Heisler C., De Robertis M., Nadeau D., 1996, MNRAS 280, 579
Higdon J.L., 1996, ApJ 467, 241
Hwang C.Y., Lo K.Y., Gao Y. et al., 1999, ApJ 511, 17
Jarrett T.H., Helou G., Van Buren D. et al., 1999, In: Cox P., Kessler M.F. (eds) The Universe as seen by ISO, ESA SP-427, volume 2, p. 897
Kruegel E., Siebenmorgen R., 1994, A&A 282, 407
Laurent-Mueheisen S.A., Kollgaard R.I., Ryan P.J. et al., 1997, A&AS 122, 235
Laureijs R., Klaas U., Richards P.J. et al., 1998, ISOPHOT Data Users Manual, ESA, [http://www.iso.vilspa.esa.es/manuals/]
Laureijs R., Watson D., Metcalfe L. et al., 2000, A&A in press
Lemke D., Klaas U., Abolins J. et al., 1996, A&A 315, L64
Lu N.Y., Helou G., Silbermann N. et al., 1999, In: Cox P., Kessler M.F. (eds) The Universe as seen by ISO, ESA SP-427, volume 2, p. 929
Mas-Hesse J.M., Kunth D., 1999, A&A 349, 765
Metcalfe L., Steel S., Barr P. et al., 1996, A&A 315, L105
Moshir M., Kopan G., Coron T. et al., 1990, In: The Faint Source Catalog, version 2.0, Infrared Astronomical Satellite Catalogs, Infrared Processing and Analysis
Centre
Mouri H., 1994, ApJ 427, 777
Moutou C., Sellgren K., Leger A. et al., 1999, In: d'Hendecourt L., Joublin C., Jones A., (eds) Solid interstellar matter: the ISO revolution, Les Houches Workshop, EDP Sciences and Springer-Verlag
Ott S., Abergel A., Altieri B. et al. 1997, In: Hunt, G., Payne, H. (eds.), Astronomical Data Analysis Software and Systems VI, Vol. 125 of ASP Conf. Series, p. 34
Papaderos C.P., Fricke K.J., 1998, A&A 338, L31
Peeters E., Tielens A.G.G.M., Roelfesma P.R. et al. 1999, In: Cox P., Kessler M.F. (eds), The Universe as seen by ISO, ESA SP-427, volume 2, p. 739
Quillen A.C., Alonso-Herrero A., Rieke M.J. et al., 1999, ApJ 527, 696
Rigopoulou D., Genzel R., Lutz D. et al, 1999. In: Cox P., Kessler M.F. (eds), The Universe as seen by ISO, ESA SP-427, volume 2, p. 833
Roelfesma P.R., Cox P., Tielens A.G.G.M. et al., 1996, A&A 315, 289
Schaerer D., Vacca W.D., 1998, AJ 497, 618
Schaerer D., Contini T., Pindao M., 1999, A&AS 136, 35
Siebenmorgen R., Krugel E., Chini R. 1998, A&A 351, 495
Siebenmorgen R., Blommaert J., Sauvage M. et al., 1999, In: ISO Handbook Volume III (CAM), Version 1.0 ESA SAI-99-057/Dc, Version 1.0 July 16, 1999, http://www.iso.vilspa.esa.es/manuals
Smith B., Wallin J.F. 1992, ApJ 393, 544
Smith B., Struck J., Pogge R., 1997, ApJ 483, 754
Starck J., Murtagh F., Bijaoui A., 1998, In: Image Processing and Data Analysis: The Multiscale Approach, Cambridge Univ. Press
Stevens I., Strickland D., 1998, MNRAS 294, 523
Storchi-Bergmann T., Fernandes R.D., Schmitt H.R., 1998, ApJ 501, 94
Taniguchi Y., Kawara K., 1988, AJ 95, 1378
Van Breugel W., Fillipenko A.V. , Heckman T. et al., 1985, ApJ 293, 83
Verstraete L., Puget J.L., Falgarone E. et al., 1996, A&A 315, 337
Vigroux L., Charmandais V., Gallais P. et al, 1999. In: Cox P., Kessler M.F. (eds), The Universe as seen by ISO, ESA SP-427, volume 2, p. 805
Weedman D.W., Feldman F.R., Balzano V.A. et al., 1981, ApJ 248, 105
Weedman D.W., Wolovitz J.B., Bershady M.A. et al, 1998, AJ 116, 1643