

ISO observations of the BL Lacertae object PKS 2155–304*

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Abstract. The BL Lacertae object PKS 2155–304 was observed by the Infrared Space Observatory in May and June 1996, during a multiwavelength campaign. These are the first observations in the mid- and far-infrared bands since IRAS. In the observing period, the source showed no detectable time variability at 4.0, 14.3, 60 and 90 μm . The spectrum from 2.8 to 100 μm is well fitted by a single power law with energy spectral index $\alpha = 0.4$, intermediate between the flatter radio spectrum and the steeper simultaneous optical spectrum. The overall infrared to X-ray spectral energy distribution can be well explained by optically thin synchrotron emission, with negligible contributions from thermal sources. We also show that the host galaxy flux is negligible in this spectral range.

Key words: galaxies: active – galaxies: BL Lacertae objects: individual: PKS 2155-304 – galaxies: photometry – infrared: general

1. Introduction

BL Lacertae objects are characterized by an intense and variable non-thermal continuum, that extends from the radio to the gamma-ray band. This is commonly attributed to synchrotron and inverse Compton radiation from a relativistic jet pointing toward the observer (see Ulrich et al. 1997 for a review). In a νF_ν representation, their overall spectrum has two broad peaks, one at low energies (IR–X) due to synchrotron radiation and one at higher energies (X– γ), plausibly due to inverse Compton scattering.

PKS 2155–304 is one of the brightest BL Lacs from the optical to the X-ray band with the synchrotron peak in the UV-soft X-ray range, corresponding to the definition of High frequency peak BL Lac objects (HBL) (Padovani & Giommi 1995), which

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have the synchrotron peak at the highest frequencies, low luminosity and a small ratio between the γ -ray and the synchrotron peak luminosities. The gamma-ray spectrum is flat ($\alpha_\gamma \simeq 0.7^1$ in the 0.1–10 GeV energy range), indicating that the Compton peak is beyond ~ 10 GeV. Recently it has been detected in the TeV band (Chadwick et al. 1999). Due to these characteristics, PKS 2155–304 has been the target of numerous multiwavelength campaigns (e.g. Edelson et al. 1995 for November 1991, Urry et al. 1997 for May 1994). The study of the simultaneous behavior of the source at different frequencies is important in order to understand the emission mechanisms and to constrain the physical properties of the emitting region.

In 1996 May–June, an intense multiwavelength monitoring was carried out involving optical telescopes, UV, X-ray and γ -ray satellites. Thanks to the Infrared Space Observatory (ISO), for the first time we had infrared simultaneous observations. These are the first observations of this object in the mid- and far-infrared since IRAS. PKS 2155–304 was detected by IRAS in 1983 at 12, 25, 60 microns with a flux of about 100 mJy in all three bands (Impey & Neugebauer 1988). In this object the IR emission is at frequencies lower than the synchrotron peak, and the spectral shape in this band can reveal if there are relevant thermal contributions (e.g. by the host galaxy or by a dusty torus around the nucleus) or if the emission can be entirely attributed to synchrotron radiation.

Here we present the ISO observations of PKS 2155–304, carried out during the campaign in 1996 May–June, covering a wavelength range from 2.8 to 200 μm . This is complemented by some simultaneous BVR observations from the Dutch 0.9 m ESO telescope. Results from ISO observations of 1996 November and 1997 May are also reported.

The paper is organized as follows: a brief description of the ISO instruments and of the observations are given in Sect. 2 and the results are reported in Sect. 3. In Sect. 4 we present the optical data and in Sect. 5 we compare our results with the theoretical models. PKS 2155–304 is a weak IR source for ISO. Therefore considerable care was taken in data reduction and background subtraction. Details are given in Appendix A.

¹ α is defined as $F(\nu) \propto \nu^{-\alpha}$.

Table 1. Characteristics of the filters used with ISOCAM and ISOPHOT.

| filter | ref. λ (μm) | range (μm) | $\lambda/\Delta\lambda$ |
|--------|----------------------------------|-------------------------|-------------------------|
| SW4 | 2.8 | 2.50–3.05 | 5 |
| SW2 | 3.3 | 3.20–3.40 | 17 |
| SW6 | 3.7 | 3.45–4.00 | 7 |
| SW5 | 4.0 | 3.00–5.50 | 2 |
| SW11 | 4.26 | 4.16–4.37 | 20 |
| SW10 | 4.6 | 4.53–4.88 | 13 |
| LW4 | 6.0 | 5.50–6.50 | 6 |
| LW6 | 7.7 | 7.00–8.50 | 5 |
| LW7 | 9.6 | 8.50–10.7 | 4 |
| LW8 | 11.3 | 10.7–12.0 | 9 |
| LW3 | 14.3 | 12.0–18.0 | 3 |
| LW9 | 14.9 | 14.0–16.0 | 9 |
| P2.25 | 25 | 19.2–28.4 | 2.5 |
| C1.60 | 60 | 49–63 | 2.5 |
| C1.70 | 80 | 55–105 | 2.5 |
| C1.90 | 90 | 69–121 | 1.9 |
| C1.100 | 100 | 82–125 | 2.4 |
| C2.160 | 170 | 129–219 | 2 |
| C2.180 | 180 | 150–211 | 2.6 |
| C2.200 | 200 | 171–238 | 3 |

2. ISO observations

PKS 2155–304 was observed with ISO between 1996 May 7 and June 8. Two additional observations were performed on 1996 November 23 and 1997 May 15.

The ISO satellite (Kessler et al. 1996) is equipped with a 60 cm Ritchey–Chrétien telescope and has four scientific instruments on board. For the PKS 2155–304 observations both the camera ISOCAM and the photometer ISOPHOT were used.

The 32×32 pixel imaging camera ISOCAM (Césarsky et al. 1996) has two detectors: an InSb CID (Charge Injection Device) for short wavelengths (SW detector; 2.5 – 5.5 μm) and a Si:Ga photoconductor array for longer wavelengths (LW detector; 4 – 17 μm). It is equipped with a set of 21 broad-band filters and a circular variable filter with a higher spectral resolution. The spatial resolution ranges from 1.5'' to 12'' per pixel.

The photometer ISOPHOT (Lemke et al. 1996) has three subsystems: a photo-polarimeter (PHT-P) (3 – 120 μm), which has 3 detectors, sensitive at different wavelengths, 14 broad-band filters and different apertures, from 5'' to 180''; an imaging photometric camera (PHT-C) (50 – 240 μm), with a 3×3 and a 2×2 pixel detectors, a field of view of $43.5'' \times 43.5''$ and $89.4'' \times 89.4''$ per pixel, respectively, and 11 broad-band filters; two low-resolution grating spectrometers (PHT-S) (2.5 – 5 μm and 6 – 12 μm).

In order to determine the variability characteristics in the infrared band, 15 identical observations were performed in the period between 1996 May 7 and June 8, at 4.0, 14.3, 60, 90 and 170 μm (see Table 1 for the filter characteristics). From May 13 to May 27 ISO observed

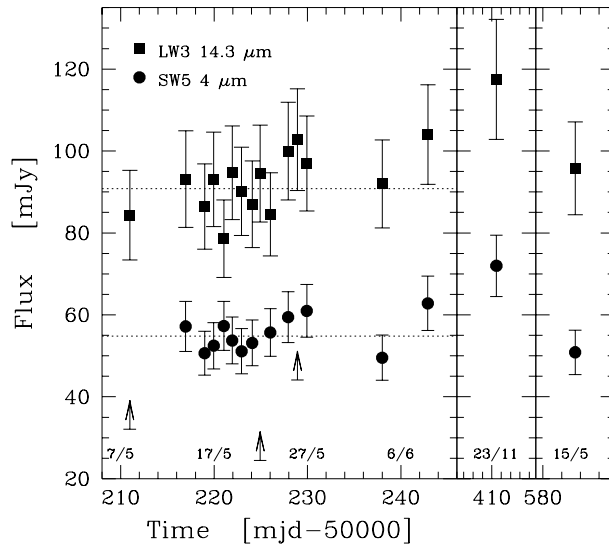


Fig. 1. ISOCAM light curves of PKS 2155–304. The dotted curves represent the fitted constant of the best sampled period, from 1996 May 13 to May 27. The upward arrows are the lower limits in the SW5 curve

PKS 2155–304 almost each day. The observing modes (AOTs, Astronomical Observation Templates) were CAM01 (ISOCAM Observer’s Manual 1994), in single pointing mode, and PHT22 (ISOPHOT Observer’s Manual 1994), in rectangular chopped mode (see Appendix A.2).

On 1996 May 27 the source was observed in a large wavelength range (from 2.8 to 200 μm) with 17 different filters in order to determine the infrared spectrum. The same AOTs as before were used, except the observation with the P2.25 filter, for which the PHT03, still in rectangular chopped mode, was used.

On 1997 May 15 two 3×3 raster scans, centered on PKS 2155–304 (R.A. 21h 58m 52s, Dec $-30^\circ 13' 32''$) were performed with the photometric camera PHT-C, at 60 μm and at 180 μm ; the distance between two adjacent raster positions was 180'', in order to have an almost complete sky coverage of an area of $9'$ side. This mapping was performed to search for any structure in the cirrus clouds; a non flat background could compromise a reliable photometry of the source. In this observation the AOT PHT22 was used in staring mode.

The ISOPHOT observation of 1996 May 25 failed because of problems during the instrument activation.

The complete log of the observations is shown in Tables 2 and 3.

3. ISO results

3.1. The light curves

The data and the corresponding light curves at 4.0 (SW5 filter), 14.3 (LW3), 60 (C1.60) and 90 μm (C1.90) are reported in Tables 4 and 5 and shown in Figs. 1 and 2. The discussion on the data analysis and error evaluation is given in Appendix A.

Table 2. ISOCAM observation log.

| obs. time | | filter | λ μm | pfov " | frames # | obs. time | | filter | λ μm | pfov " | frames # |
|-----------|-----------|--------|----------------------------|-----------|-------------|-----------|-----------|--------|----------------------------|-----------|-------------|
| yy/mm/dd | mjd–50000 | | | | | yy/mm/dd | mjd–50000 | | | | |
| 96/05/07 | 210.9703 | SW5 | 4.0 | 6.0 | 59 | 96/05/25 | 228.9254 | SW5 | 4.0 | 6.0 | 59 |
| 96/05/07 | 210.9715 | LW3 | 14.3 | 6.0 | 41 | 96/05/25 | 228.9266 | LW3 | 14.3 | 6.0 | 41 |
| 96/05/13 | 216.9549 | SW5 | 4.0 | 6.0 | 59 | 96/05/26 | 229.9227 | SW5 | 4.0 | 6.0 | 59 |
| 96/05/13 | 216.9564 | LW3 | 14.3 | 6.0 | 41 | 96/05/26 | 229.9240 | LW3 | 14.3 | 6.0 | 41 |
| 96/05/15 | 218.9896 | SW5 | 4.0 | 6.0 | 59 | 96/05/27 | 230.9207 | SW4 | 2.8 | 3.0 | 159 |
| 96/05/15 | 218.9909 | LW3 | 14.3 | 6.0 | 41 | 96/05/27 | 230.9243 | SW2 | 3.3 | 6.0 | 110 |
| 96/05/16 | 219.9621 | SW5 | 4.0 | 6.0 | 59 | 96/05/27 | 230.9270 | SW6 | 3.7 | 6.0 | 111 |
| 96/05/16 | 219.9634 | LW3 | 14.3 | 6.0 | 40 | 96/05/27 | 230.9299 | SW11 | 4.26 | 6.0 | 162 |
| 96/05/18 | 221.0461 | SW5 | 4.0 | 6.0 | 59 | 96/05/27 | 230.9337 | SW10 | 4.6 | 6.0 | 162 |
| 96/05/18 | 221.0473 | LW3 | 14.3 | 6.0 | 42 | 96/05/27 | 230.9376 | LW4 | 6.0 | 3.0 | 59 |
| 96/05/18 | 221.9426 | SW5 | 4.0 | 6.0 | 59 | 96/05/27 | 230.9391 | LW6 | 7.7 | 3.0 | 87 |
| 96/05/18 | 221.9438 | LW3 | 14.3 | 6.0 | 41 | 96/05/27 | 230.9413 | LW7 | 9.6 | 3.0 | 87 |
| 96/05/19 | 222.9401 | SW5 | 4.0 | 6.0 | 59 | 96/05/27 | 230.9435 | LW8 | 11.3 | 3.0 | 87 |
| 96/05/19 | 222.9414 | LW3 | 14.3 | 6.0 | 41 | 96/05/27 | 230.9462 | LW9 | 14.9 | 3.0 | 114 |
| 96/05/21 | 224.0848 | SW5 | 4.0 | 6.0 | 59 | 96/06/04 | 238.0014 | SW5 | 4.0 | 6.0 | 59 |
| 96/05/21 | 224.0897 | LW3 | 14.3 | 6.0 | 41 | 96/06/04 | 238.0026 | LW3 | 14.3 | 6.0 | 41 |
| 96/05/21 | 224.9352 | SW5 | 4.0 | 6.0 | 59 | 96/06/08 | 242.8894 | SW5 | 4.0 | 6.0 | 59 |
| 96/05/21 | 224.9365 | LW3 | 14.3 | 6.0 | 41 | 96/06/08 | 242.8906 | LW3 | 14.3 | 6.0 | 40 |
| 96/05/23 | 226.0251 | SW5 | 4.0 | 6.0 | 60 | 96/11/23 | 410.4845 | SW5 | 4.0 | 6.0 | 59 |
| 96/05/23 | 226.0263 | LW3 | 14.3 | 6.0 | 40 | 96/11/23 | 410.4857 | LW3 | 14.3 | 6.0 | 40 |
| 96/05/24 | 227.9279 | SW5 | 4.0 | 6.0 | 59 | 97/05/15 | 583.4535 | SW5 | 4.0 | 6.0 | 59 |
| 96/05/24 | 227.9291 | LW3 | 14.3 | 6.0 | 41 | 97/05/15 | 583.4548 | LW3 | 14.3 | 6.0 | 41 |

Note. The integration time of each frame is 2.1 s; the gain is 2.

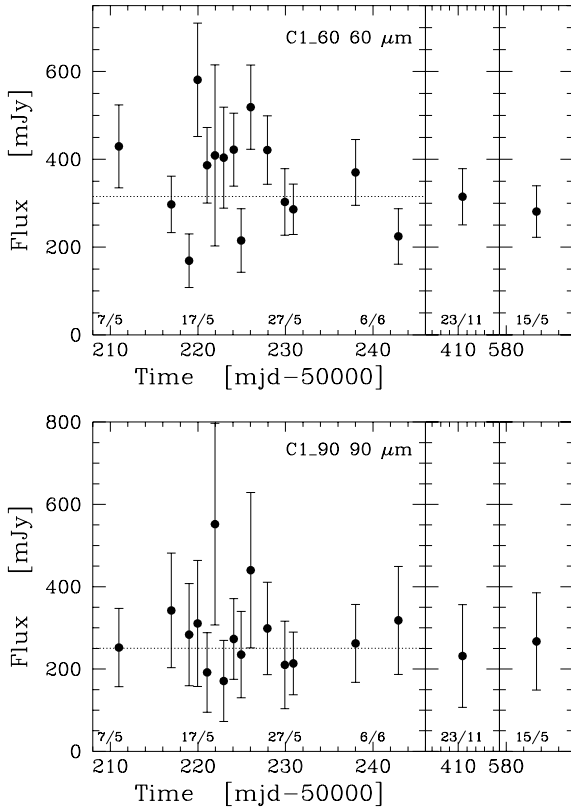


Fig. 2. ISOPHOT light curves of PKS 2155–304. The dotted curves represent the fitted constant curves of the best sampled period, from 1996 May 13 to May 27

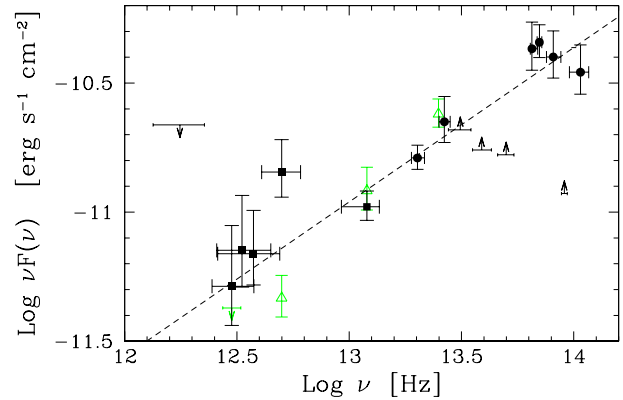


Fig. 3. ISO spectrum. The dashed curve represents the power law fit. Circles are the ISOCAM data; squares are the ISOPHOT data. The horizontal bars indicate the filter width energy response. The upward arrows are the ISOCAM lower limits. The downward arrow at $\log \nu \sim 12.2$ is the ISOPHOT upper limit at $170 \mu\text{m}$. Open triangles are the IRAS data (Impey & Neugebauer 1988) at 12, 25 and $60 \mu\text{m}$; the IRAS upper limit at $100 \mu\text{m}$ is partially hidden

At $170 \mu\text{m}$ (C2_160), the source is not detected: the three sigma upper limit at this wavelength is 1235 mJy (see Fig. 3).

When the purpose is to verify whether the flux is variable, the contribution of the pixel responsivity to the absolute error can be neglected and a smaller uncertainty can be associated to the relative flux values of the light curves. However, this can be done only for the two light curves of the photometer (see Table 5), due to the way the photometric error was determined.

Table 3. ISOPHOT observation log.

| obs. time | | filter | λ | pfov | t_{int} | t_{tot} | obs. time | | filter | λ | pfov | t_{int} | t_{tot} |
|-----------|-----------|--------|-----------|------|-----------|-----------|-----------|-----------|--------|-----------|------|-----------|-----------|
| yy/mm/dd | mjd–50000 | | | | | | yy/mm/dd | mjd–50000 | | | | | |
| 96/05/07 | 210.9736 | C2_160 | 170 | 89.4 | 4 | 128 | 96/05/23 | 226.0347 | C1_90 | 90 | 43.5 | 1 | 64 |
| 96/05/07 | 210.9778 | C1_60 | 60 | 43.5 | 2 | 256 | 96/05/24 | 227.9313 | C2_160 | 170 | 89.4 | 4 | 128 |
| 96/05/07 | 210.9798 | C1_90 | 90 | 43.5 | 1 | 64 | 96/05/24 | 227.9355 | C1_60 | 60 | 43.5 | 2 | 256 |
| 96/05/13 | 216.9585 | C2_160 | 170 | 89.4 | 4 | 128 | 96/05/24 | 227.9375 | C1_90 | 90 | 43.5 | 1 | 64 |
| 96/05/13 | 216.9627 | C1_60 | 60 | 43.5 | 2 | 256 | 96/05/26 | 229.9261 | C2_160 | 170 | 89.4 | 4 | 128 |
| 96/05/13 | 216.9648 | C1_90 | 90 | 43.5 | 1 | 64 | 96/05/26 | 229.9303 | C1_60 | 60 | 43.5 | 2 | 256 |
| 96/05/15 | 218.9930 | C2_160 | 170 | 89.4 | 4 | 128 | 96/05/26 | 229.9323 | C1_90 | 90 | 43.5 | 1 | 64 |
| 96/05/15 | 218.9972 | C1_60 | 60 | 43.5 | 2 | 256 | 96/05/27 | 230.9556 | P2_25 | 25 | 52.0 | 8 | 1024 |
| 96/05/15 | 218.9992 | C1_90 | 90 | 43.5 | 1 | 64 | 96/05/27 | 230.9691 | C2_200 | 200 | 89.4 | 16 | 1024 |
| 96/05/16 | 219.9655 | C2_160 | 170 | 89.4 | 4 | 128 | 96/05/27 | 230.9767 | C2_160 | 170 | 89.4 | 4 | 256 |
| 96/05/16 | 219.9697 | C1_60 | 60 | 43.5 | 2 | 256 | 96/05/27 | 230.9809 | C1_100 | 100 | 43.5 | 2 | 128 |
| 96/05/16 | 219.9718 | C1_90 | 90 | 43.5 | 1 | 64 | 96/05/27 | 230.9832 | C1_70 | 80 | 43.5 | 2 | 256 |
| 96/05/18 | 221.0495 | C2_160 | 170 | 89.4 | 4 | 128 | 96/05/27 | 230.9878 | C1_60 | 60 | 43.5 | 2 | 512 |
| 96/05/18 | 221.0536 | C1_60 | 60 | 43.5 | 2 | 256 | 96/05/27 | 230.9918 | C1_90 | 90 | 43.5 | 1 | 128 |
| 96/05/18 | 221.0557 | C1_90 | 90 | 43.5 | 1 | 64 | 96/06/04 | 238.0047 | C2_160 | 170 | 89.4 | 4 | 128 |
| 96/05/18 | 221.9460 | C2_160 | 170 | 89.4 | 4 | 128 | 96/06/04 | 238.0089 | C1_60 | 60 | 43.5 | 2 | 256 |
| 96/05/18 | 221.9502 | C1_60 | 60 | 43.5 | 2 | 256 | 96/06/04 | 238.0109 | C1_90 | 90 | 43.5 | 1 | 64 |
| 96/05/18 | 221.9522 | C1_90 | 90 | 43.5 | 1 | 64 | 96/06/08 | 242.8927 | C2_160 | 170 | 89.4 | 4 | 128 |
| 96/05/19 | 222.9435 | C2_160 | 170 | 89.4 | 4 | 128 | 96/06/08 | 242.8969 | C1_60 | 60 | 43.5 | 2 | 256 |
| 96/05/19 | 222.9477 | C1_60 | 60 | 43.5 | 2 | 256 | 96/06/08 | 242.9024 | C1_90 | 90 | 43.5 | 1 | 64 |
| 96/05/19 | 222.9498 | C1_90 | 90 | 43.5 | 1 | 64 | 96/11/23 | 410.4878 | C2_160 | 170 | 89.4 | 4 | 128 |
| 96/05/21 | 224.0918 | C2_160 | 170 | 89.4 | 4 | 128 | 96/11/23 | 410.4920 | C1_60 | 60 | 43.5 | 2 | 256 |
| 96/05/21 | 224.0960 | C1_60 | 60 | 43.5 | 2 | 256 | 96/11/23 | 410.4940 | C1_90 | 90 | 43.5 | 1 | 64 |
| 96/05/21 | 224.0981 | C1_90 | 90 | 43.5 | 1 | 64 | 97/05/15 | 583.4569 | C2_160 | 170 | 89.4 | 4 | 128 |
| 96/05/21 | 224.9386 | C2_160 | 170 | 89.4 | 4 | 128 | 97/05/15 | 583.4611 | C1_60 | 60 | 43.5 | 2 | 256 |
| 96/05/21 | 224.9428 | C1_60 | 60 | 43.5 | 2 | 256 | 97/05/15 | 583.4631 | C1_90 | 90 | 43.5 | 1 | 64 |
| 96/05/21 | 224.9448 | C1_90 | 90 | 43.5 | 1 | 64 | 97/05/15 | 583.4741 | C1_60 | 60 | 43.5 | 2 | 1260 |
| 96/05/23 | 226.0291 | C2_160 | 170 | 89.4 | 4 | 128 | 97/05/15 | 583.4920 | C1_180 | 180 | 89.4 | 4 | 1260 |
| 96/05/23 | 226.0326 | C1_60 | 60 | 43.5 | 2 | 256 | | | | | | | |

Note. The two last observations are 3×3 raster scans.

The relative errors on the flux are, in any case, quite large, about 10–12% for the camera observations and from 20 to more than 50% for the photometer (see Appendix A). Within these uncertainties the light curves show no evidence of variability. To quantify this statement, we fitted the light curves with a constant term and the reduced chi-square values were computed in order to test the goodness of the fits. We first fitted the values of the best sampled period, from 1996 May 13 to May 27. The results are 54.8 ± 1.8 mJy at $4.0 \mu\text{m}$, 90.8 ± 3.2 mJy at $14.3 \mu\text{m}$, 315 ± 27 mJy at $60 \mu\text{m}$ and 250 ± 34 mJy at $90 \mu\text{m}$. To fit the data at $4.0 \mu\text{m}$ the lower limits were neglected. We then repeated the fits, taking the mean of the above-mentioned period and adding the other data, to look for possible longer-term variability. All the fits are acceptable within a confidence level of 95%. This means that PKS 2155–304 showed no evidence of variability at these wavelengths in the observed period.

However, the large uncertainty on the flux can hide smaller variations. We calculated the mean relative error and obtained 3 sigma limits for the lowest detectable variations of 32%, 36%, 76% and 132% at 4.0, 14.3, 60 and $90 \mu\text{m}$, respectively.

3.2. The infrared spectrum

The infrared spectral shape of PKS 2155–304 was sampled, using 16 filters, from 2.8 to $170 \mu\text{m}$. The photometer filter C2_200 was not considered reliable enough and its observation was discarded. The flux values are given in Table 6 and the spectrum is shown in Fig. 3, in a $\log \nu - \log \nu F(\nu)$ representation.

In Fig. 3 it is also shown the result of a power law fit, that gives an energy spectral index of $\alpha = 0.40 \pm 0.06$. The lower and upper limits were not considered in the fit; the reduced chi-square is $\chi_r^2 = 1.31$, with 9 d.o.f., that gives a confidence level of 77.4%.

From each simultaneous pairs of flux values of the SW5 and LW3 light curves, we obtained the spectral indices between 4.0 and $14.3 \mu\text{m}$ as

$$\alpha_i = -\log(f_{SW5,i}/f_{LW3,i})/\log(\nu_{SW5}/\nu_{LW3}).$$

The mean value is $\alpha = 0.403 \pm 0.017$, which is fully consistent with the index derived using 11 filters on a larger IR band.

The fit with a constant term of the spectral indices α_i vs. time has a reduced chi-square of 0.26, with 13 d.o.f., which

Table 4. ISOCAM light curves.

| SW5 filter (4.0 μm) | | | |
|---------------------------------|-----------|------------------------------------|----------------|
| obs. time | flux | flux ^(a) _{AAR} | |
| yy/mm/dd | mjd–50000 | mJy | mJy |
| 96/05/05 | 210.9703 | 32.1 ^(b) | 35.4 \pm 1.5 |
| 96/05/13 | 216.9549 | 57.2 \pm 6.1 | 51.8 \pm 1.9 |
| 96/05/15 | 218.9896 | 50.6 \pm 5.4 | 54.1 \pm 1.9 |
| 96/05/16 | 219.9621 | 52.5 \pm 5.7 | 49.8 \pm 2.0 |
| 96/05/18 | 221.0461 | 57.3 \pm 6.0 | 56.7 \pm 1.7 |
| 96/05/18 | 221.9426 | 53.8 \pm 5.7 | 48.9 \pm 1.8 |
| 96/05/19 | 222.9401 | 51.1 \pm 5.5 | 47.0 \pm 1.9 |
| 96/05/21 | 224.0848 | 53.2 \pm 5.6 | 55.3 \pm 1.8 |
| 96/05/21 | 224.9352 | 24.5 ^(b) | 21.4 \pm 1.5 |
| 96/05/23 | 226.0251 | 55.7 \pm 5.8 | 58.5 \pm 1.7 |
| 96/05/24 | 227.9279 | 59.4 \pm 6.2 | 60.2 \pm 1.9 |
| 96/05/25 | 228.9254 | 44.1 ^(b) | 47.8 \pm 2.0 |
| 96/05/26 | 229.9227 | 61.0 \pm 6.4 | 58.4 \pm 2.0 |
| 96/06/04 | 238.0014 | 49.5 \pm 5.5 | 39.4 \pm 1.9 |
| 96/06/08 | 242.8894 | 62.8 \pm 6.6 | 60.1 \pm 2.0 |
| 96/11/23 | 410.4845 | 72.0 \pm 7.5 | 75.4 \pm 2.1 |
| 97/05/15 | 583.4535 | 50.9 \pm 5.4 | 43.4 \pm 1.6 |

| LW3 filter (14.3 μm) | | | |
|----------------------------------|-----------|------------------------------------|-----------------|
| obs. time | flux | flux ^(a) _{AAR} | |
| yy/mm/dd | mjd–50000 | mJy | mJy |
| 96/05/05 | 210.9715 | 84.3 \pm 10.9 | 66.8 \pm 5.5 |
| 96/05/13 | 216.9564 | 93.2 \pm 11.8 | 100.3 \pm 7.8 |
| 96/05/15 | 218.9909 | 86.5 \pm 10.4 | 77.5 \pm 5.2 |
| 96/05/16 | 219.9634 | 93.1 \pm 11.5 | 80.6 \pm 5.9 |
| 96/05/18 | 221.0473 | 78.6 \pm 9.4 | 90.0 \pm 6.0 |
| 96/05/18 | 221.9438 | 94.7 \pm 11.4 | 91.8 \pm 6.2 |
| 96/05/19 | 222.9414 | 90.1 \pm 10.8 | 80.7 \pm 5.3 |
| 96/05/21 | 224.0897 | 87.0 \pm 10.6 | 89.8 \pm 6.2 |
| 96/05/21 | 224.9365 | 94.5 \pm 11.8 | 88.1 \pm 6.6 |
| 96/05/23 | 226.0263 | 84.5 \pm 10.1 | 78.4 \pm 5.2 |
| 96/05/24 | 227.9291 | 100.0 \pm 11.9 | 96.1 \pm 6.2 |
| 96/05/25 | 228.9266 | 102.8 \pm 12.4 | 100.8 \pm 6.8 |
| 96/05/26 | 229.9240 | 97.0 \pm 11.6 | 86.2 \pm 5.7 |
| 96/06/04 | 238.0026 | 92.0 \pm 10.8 | 82.2 \pm 5.0 |
| 96/06/08 | 242.8906 | 104.0 \pm 12.1 | 99.5 \pm 6.0 |
| 96/11/23 | 410.4857 | 117.5 \pm 14.6 | 125.1 \pm 9.3 |
| 97/05/15 | 583.4548 | 95.8 \pm 11.3 | 91.5 \pm 5.8 |

^(a) the automatic analysis results (OLP v7.0) are used to compute the photometric error (see text)

^(b) 1σ lower limits

corresponds to a confidence level of less than 1%. This indicates that the source showed no spectral variability in the 4.0 – 14.3 μm range, during the observed period.

4. Optical observations

4.1. Observations and data reduction

The optical data were obtained using the Dutch 0.9 m ESO telescope at La Silla, Chile, between May 17 and 27 1996. The

Table 5. ISOPHOT light curves.

| C1.60 filter (60 μm) | | | |
|----------------------------------|-----------|------------------------------------|-----|
| obs. time | flux | flux ^(a) _{var} | |
| yy/mm/dd | mjd–50000 | mJy | mJy |
| 96/05/07 | 210.9778 | 430 \pm 113 | 94 |
| 96/05/13 | 216.9627 | 297 \pm 77 | 64 |
| 96/05/15 | 218.9972 | 169 \pm 66 | 61 |
| 96/05/16 | 219.9697 | 581 \pm 154 | 129 |
| 96/05/18 | 221.0536 | 387 \pm 102 | 86 |
| 96/05/18 | 221.9502 | 409 \pm 215 | 206 |
| 96/05/19 | 222.9477 | 404 \pm 130 | 115 |
| 96/05/21 | 224.0960 | 422 \pm 103 | 83 |
| 96/05/21 | 224.9428 | 215 \pm 80 | 72 |
| 96/05/23 | 226.0326 | 519 \pm 123 | 96 |
| 96/05/24 | 227.9355 | 421 \pm 99 | 78 |
| 96/05/26 | 229.9303 | 303 \pm 91 | 76 |
| 96/05/27 | 230.9878 | 286 \pm 72 | 57 |
| 96/06/04 | 238.0089 | 370 \pm 93 | 75 |
| 96/06/08 | 242.8969 | 224 \pm 71 | 63 |
| 96/11/23 | 410.4920 | 315 \pm 79 | 64 |
| 97/05/15 | 583.4611 | 281 \pm 71 | 59 |

| C1.90 filter (90 μm) | | | |
|----------------------------------|-----------|------------------------------------|-----|
| obs. time | flux | flux ^(a) _{var} | |
| yy/mm/dd | mjd–50000 | mJy | mJy |
| 96/05/07 | 210.9798 | 252 \pm 102 | 95 |
| 96/05/13 | 216.9648 | 342 \pm 147 | 139 |
| 96/05/15 | 218.9992 | 284 \pm 131 | 124 |
| 96/05/16 | 219.9718 | 311 \pm 159 | 153 |
| 96/05/18 | 221.0557 | 192 \pm 100 | 97 |
| 96/05/18 | 221.9522 | 552 \pm 259 | 245 |
| 96/05/19 | 222.9498 | 171 \pm 102 | 99 |
| 96/05/21 | 224.0981 | 273 \pm 106 | 98 |
| 96/05/21 | 224.9448 | 235 \pm 111 | 105 |
| 96/05/23 | 226.0347 | 440 \pm 200 | 189 |
| 96/05/24 | 227.9375 | 299 \pm 120 | 112 |
| 96/05/26 | 229.9323 | 210 \pm 112 | 106 |
| 96/05/27 | 230.9030 | 214 \pm 83 | 76 |
| 96/06/04 | 238.0109 | 262 \pm 102 | 94 |
| 96/06/08 | 242.9024 | 318 \pm 139 | 131 |
| 96/11/23 | 410.4940 | 232 \pm 129 | 125 |
| 97/05/15 | 583.4631 | 267 \pm 124 | 118 |

^(a) error without the responsivity uncertainty

telescope was equipped with a TEK CCD 512 \times 512 pixels detector and Bessel BVR filters were used for the observations. The pixel size is 27 μm and the projected pixel size in the plane of the sky is 0.442 arcsec, providing a field of view of 3'.77 \times 3'.77.

The original frames were flat fielded and bias corrected using MIDAS package and photometry was performed using the Robin procedure, developed at the Torino Observatory, Italy, by L. Lanteri. This procedure fits the PSF with a circular gaussian and evaluates the background level by fitting it with a 1st order

Table 6. Fluxes of the observation of 1996 May 27, plus the upper limit at 170 μm .

| filter | ISO spectrum | | | |
|--------|----------------------------|-----------------------|---------------------|--|
| | λ μm | ν Hz | flux mJy | flux _{AAAR} ^(a) mJy |
| SW4 | 2.8 | 1.07×10^{14} | 32.5 ± 7.0 | 38.2 ± 3.1 |
| SW2 | 3.3 | 9.08×10^{13} | 13.0 ^(b) | 28.3 ± 5.6 |
| SW6 | 3.7 | 8.10×10^{13} | 49 ± 10 | 42.1 ± 2.4 |
| SW11 | 4.26 | 7.04×10^{13} | 64.7 ± 9.3 | 52.8 ± 5.5 |
| SW10 | 4.6 | 6.52×10^{13} | 66 ± 14 | 57.1 ± 3.9 |
| LW4 | 6.0 | 5.00×10^{13} | 33.4 ^(b) | 57.1 ± 2.8 |
| LW6 | 7.7 | 3.89×10^{13} | 44.7 ^(b) | 61.5 ± 2.6 |
| LW7 | 9.6 | 3.12×10^{13} | 66.7 ^(b) | 80.6 ± 2.4 |
| LW8 | 11.3 | 2.65×10^{13} | 84 ± 17 | 122.0 ± 3.7 |
| LW9 | 14.9 | 2.01×10^{13} | 80.6 ± 8.6 | 83.0 ± 3.1 |
| P2.25 | 25 | 1.20×10^{13} | 88 ± 11 | |
| C1.60 | 60 | 5.00×10^{12} | 286 ± 72 | |
| C1.70 | 80 | 3.75×10^{12} | 184 ± 59 | |
| C1.90 | 90 | 3.33×10^{12} | 213 ± 83 | |
| C1.100 | 100 | 3.00×10^{12} | 172 ± 72 | |
| C2.160 | 170 | 1.76×10^{12} | 1235 ^(c) | |

(a) the automatic analysis results (OLP v6.3.2) are used to compute the photometric error (see text)

(b) 1σ lower limit

(c) 3σ upper limit

polynomial surface. The magnitude of the object and the error are derived by comparison with reference stars in the same field of view. The typical photometric error is ~ 0.02 mag in all bands.

4.2. Results

The light curves (Table 7 and Fig. 4) show an increase of luminosity of about 20% (~ 0.2 – 0.25 mag), between the starting low level of May 17–18 and the maximum of May 24. The flux is then decreasing during the last two days. The behavior is very similar in all of the three filters.

Assuming that the optical spectrum is described by a power law, we calculated the mean spectral indices using the simultaneous pairs data of the light curves. The results are $\alpha_{RV} = 0.62 \pm 0.02$ and $\alpha_{VB} = 0.60 \pm 0.02$ and indicate that the optical spectrum is steeper than the IR one.

5. Discussion

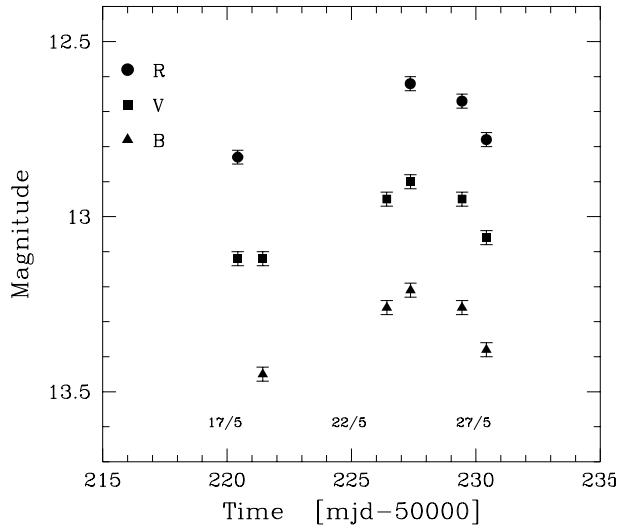
5.1. IR flux and spectral variability

The ISO light curves of May–June 1996 show that the time variability of PKS 2155–304 in the mid- and far-infrared bands is very low or even absent. The flux has not varied significantly in 1996 November and in 1997 May, one year later, and is quite similar to the 1983 IRAS state (Impey & Neugebauer 1988) (Fig. 3), except at 60 μm , where the IRAS flux seems significantly lower. This agreement could support the idea that the

Table 7. RVB light curves.

| obs. time | | R | V | B |
|-----------|-----------|-------|-------|-------|
| yy/mm/dd | mjd–50000 | mag | mag | mag |
| 96/05/17 | 220.4250 | 12.83 | ... | ... |
| | 220.4277 | ... | 13.12 | ... |
| 96/05/18 | 221.4298 | ... | ... | 13.45 |
| | 221.4354 | ... | 13.12 | ... |
| 96/05/23 | 226.4146 | ... | 12.95 | ... |
| | 226.4160 | ... | ... | 13.26 |
| 96/05/24 | 227.3625 | 12.62 | ... | ... |
| | 227.3660 | ... | 12.90 | ... |
| | 227.3688 | ... | ... | 13.21 |
| 96/05/26 | 229.4396 | 12.67 | ... | ... |
| | 229.4409 | ... | 12.95 | ... |
| | 229.4417 | ... | ... | 13.26 |
| 96/05/27 | 230.4194 | 12.78 | ... | ... |
| | 230.4202 | ... | 13.06 | ... |
| | 230.4215 | ... | ... | 13.38 |

Note: for all bands uncertainties are ~ 0.02 mag

**Fig. 4.** Optical light curves of PKS 2155–304

infrared flux level of this source is rather stable. We have to wait for future satellite missions to test this statement.

The infrared spectrum from 2.8 to 100 μm is well fitted by a single power law. This is a typical signature of synchrotron radiation, that can explain the whole emission in this wavelength range, excluding important contributions of thermal sources.

The variability in the optical bands is small too, while the simultaneous RXTE light curve (Urry et al. 1998, Sambruna et al. 2000) shows, on the contrary, strong and fast variability at energies of 2–20 keV: the flux varied by a factor 2 on a timescale shorter than a day. This seems to be a common behavior in blazars, for which there is a more pronounced variability at frequencies above the synchrotron peak (Ulrich et al. 1997).

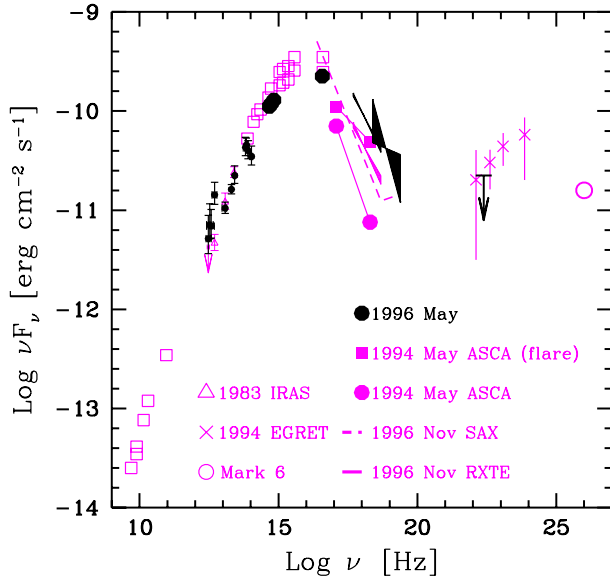


Fig. 5. Spectral energy distribution of PKS 2155–304. The black data are the simultaneous data of 1996 May: circles are ISO and BVR fluxes (this paper, data of May 27), and EUVE flux (Marshall H.L., priv. comm.); the X-ray spectra are from RXTE (Urry et al. 1998); the γ -ray upper limit is from EGRET (Vestrand W.T., priv. comm.). Open grey boxes are data from the multiwavelength campaign of 1994 May (Pesce et al. 1997, Pian et al. 1997, Urry et al. 1997). 1994 ASCA data are from Urry et al. (1997), 1994 EGRET data are from Vestrand et al. (1995), 1996 SAX spectrum is from Giommi et al. (1998), 1996 November RXTE spectrum is from Urry et al. (1998), IRAS data are from Impey & Neugebauer (1988), Mark 6 point is from Chadwick et al. (1999)

5.2. Contribution of the host galaxy to the IR flux

The absence of variability could be also explained by the contribution, in the IR, of a steady component, such as the host galaxy. The host galaxy of PKS 2155–304 is a large elliptical which is well resolved in near infrared images (Kotilainen et al. 1998), but the pixel field of view of the ISOCAM camera ($3''$ or $6''$) is too big to resolve it and its contribution is integrated in the flux of the active nucleus.

The magnitude of the host galaxy in the H band is $m_H = 12.4$ (Kotilainen et al. 1998). The color of a typical elliptical at $z = 0.11$ is $B - H = 4.6$ (Buzzoni 1995), from which we get $m_B = 17.0$, which corresponds to a flux $f_B = 0.7$ mJy. Mazzei & De Zotti (1994) calculated the flux ratio between the IRAS and the B bands for a sample of 47 elliptical galaxies: their results are $\log f_{12}/f_B = 0.01 \pm 0.05$, $\log f_{25}/f_B = -0.70 \pm 0.32$, $\log f_{60}/f_B = -0.22 \pm 0.155$, $\log f_{100}/f_B = 0.25 \pm 0.10$. From these relations we can estimate the host galaxy fluxes in the far-IR at 12, 25, 60 and 100 μm : we have $f_{12} = 0.7$ mJy, $f_{25} = 0.1$ mJy, $f_{60} = 0.4$ mJy, $f_{100} = 1.2$ mJy. If we compare these values with those of Table 6, we see that they are less than 1% of the active nucleus flux, and much less than the uncertainties. We thus conclude that the contribution of the host galaxy to the ISO far-IR flux is negligible.

This fact can be also inferred from the spectral energy distribution (SED), built with the simultaneous data of May 1996 (Fig. 5), that shows that the ISO data lie on the interpolation between radio and optical spectra.

5.3. Synchrotron self-absorption

The observed IR spectrum is rather flat, and one can wonder if this is due to a partially opaque emission, i.e. if we have, in the IR, the superposition of components with different self-absorption frequencies, as for the flat radio spectra.

To show that this is *not* the case, we calculate the self-absorption frequency assuming that the IR radiation originates in the same compact region responsible for most of the emission, including the strongly variable X-ray flux. This is a conservative assumption, since the more compact is the region, the larger is the self-absorption frequency. In the case of an isotropic population of relativistic electrons with a power-law distribution $N(\gamma) = K\gamma^{-p}$, the self-absorption frequency is given by (e.g. Krolik 1999)

$$\nu_t = \frac{\delta\nu_B}{1+z} \left[\frac{3^{\frac{p}{2}}\pi\sqrt{3\pi}}{4} \frac{\Gamma(\frac{3p+22}{12})\Gamma(\frac{3p+2}{12})\Gamma(\frac{p+6}{4})}{\Gamma(\frac{p+8}{4})} \frac{e\tau}{B\sigma_T} \right]^{\frac{2}{p+4}},$$

where Γ is the gamma function, ν_B is the cyclotron frequency, δ is the beaming factor, R is the size of the source, $\tau \equiv \sigma_T KR$, and p is the slope of the electron distribution appropriate for those electrons radiating at the self-absorption energy. In the homogeneous synchrotron self-Compton model, the optical depth τ is approximately the ratio of the Compton and synchrotron flux at the same frequency. This ratio can be estimated from the SED (Fig. 5), where the Compton flux is obtained by extending at low frequencies the Compton spectrum with the same spectral index of the synchrotron curve. The upper limit for the γ -ray emission in 1996 May corresponds to an upper limit for the value of the optical depth of $\tau \lesssim 10^{-5}$. From the ISO spectrum, we have $p = 2\alpha + 1 = 1.8$. Although we cannot a priori determine the other two parameters, namely B and δ , a reasonable estimate can be derived through the broad band model fitting. In particular if we adopt the values derived by Tavecchio et al. (1998), $B = 0.25$ G and $\delta \sim 30$, we get $\nu_t \lesssim 1.4 \times 10^{11}$ Hz. For less extreme values of δ , ν_t becomes smaller, while much larger values of the magnetic field (making ν_t to increase) are implausible, if the significant γ -ray emission is due to the self-Compton process, which requires the source not to be strongly magnetically dominated. The frequency of self-absorption is thus significantly lower than the IR frequencies, implying that the IR emission is completely thin.

5.4. Spectral energy distribution

In Fig. 5 we show the SED of PKS 2155–304 during our multiwavelength campaign, from the far IR to the γ -ray band. We also collected other, not simultaneous, data from the literature, especially in the X-ray band, to compare our overall spectrum with previous observations. As can be seen, our IR data fill a

hole in the SED and, together with our optical results, contribute to a precise definition of the shape of the synchrotron peak. It is remarkable that although the X-ray state during our campaign was very high (one of the highest ever seen), the optical emission was not particularly bright. Also the upper limit in the γ -ray band testifies that the source was not bright in this band.

All this can be explained assuming that the X-ray flux is due to the steep tail of an electron population distributed in energy as a broken power law. The first part of this distribution is flat and steadier than the high energy, steeper part. In this case *without changing significantly the bolometric luminosity* large flux variations are possible above the synchrotron (and the Compton) peak. An electron distribution with these characteristics can be obtained by continuous injection and rapid cooling (see e.g. Ghisellini et al. 1998). In fact, if the electrons are injected at a rate $Q(\gamma) \propto \gamma^{-s}$ between γ_1 and γ_2 , the steady particle distribution will be $N(\gamma) \propto \gamma^{-(s+1)}$ above γ_1 , and $\propto \gamma^{-2}$ below, until radiation losses dominate the particle escape or other cooling terms (e.g. adiabatic expansion). Electrons with energy $\gamma_1 m_e c^2$ are the ones responsible for the emission at the synchrotron and Compton peaks (as long as the scattering process is in the Thomson limit). Since it is possible to change s without changing the total injected power, large flux variations above the peak are compatible with only minor changes below. This model also predicts that the spectrum below the peak has a slope $\alpha = 0.5$, which is not far from what we have observed in the far IR.

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Appendix A: data reduction

A.1. ISOCAM

The observations were processed with CIA² v2.0.

Each observation consisted in a sequence of frames, which had an elementary integration time of about 2 s. By this way the temporal behaviour of each pixel was known.

First, the dark current was subtracted from each raw frame, using the dark images present in the software library, flagging the bad pixels of SW and LW detectors.

The impact of charged particles (glitches) on the detectors create spikes in the pixel signal curve. To remove these spurious signals, we first used the Multiresolution Median Transform method (Starck et al. 1996), then every frame was inspected to make sure that the number of suppressed noise signals was negligible and finally a manual deglitching operation was done to

detect the glitches left and flag them. Some glitches caused a change in the pixel sensitivity: in this case we flagged the pixel in all readouts after the glitch.

The library dark images were not good enough to remove all the effects of the dark current: the signals in rows and columns showed a saw-teeth structure, that was eliminated using the Fast Fourier Transform technique (Starck & Pantin 1996).

The response of the detector pixels to a change in the incident flux is not immediate and the signal reaches the stabilization after some time. This time interval depends on the initial and final flux values and on the number of readouts (ISOCAM Observer's Manual 1994). Therefore, the time sequence of a pixel signal shows, after a change in the incident flux, an upward or downward transient behaviour. At the beginning of every observation, after a certain number of frames, the signal should reach the stable value. As this ideal situation could not always been achieved, CIA provides different routines to overcome this problem and apply the transient correction. These routines use different models to fit the signal curves, in order to identify the stable value.

In the SW5 observations, the photons coming from PKS 2155–304 fell mainly in one or two pixels, whose signals showed an upward transient behaviour that never reached the stabilization. On the contrary, the background, being very low, was stabilized. No transient correction routines were able to adequately fit the source signals, either underestimating or overestimating the stable flux. Observing the signal curves, we noticed that the behaviour of the first part of the curves were far from the expected converging trends that are used in the models of the correction routines, while the remaining part of the curves seemed to be well described by a converging exponential trend. So, after having discarded the starting readouts, we fitted the signal with a simple exponential model $s_{fit} = s_{\infty} + c \cdot e^{-t/\tau}$, where the optimized parameters are c , τ and s_{∞} , that represents the stable signal. We chose the fit which showed a reasonable result and optimized the determination coefficient $R^2 = 1 - \frac{\sum_i (s_i - s_{fit})^2}{\sum_i (s_i - \bar{s})^2}$, where s_i are the measured signals and \bar{s} is the mean of the part we considered. In three cases, the results were not acceptable and we could define only lower limits, as the upward transients had not reached the stabilization.

For the transient correction of the LW3 observations, the model developed at the *Institut d'Astrophysique Spatiale* (IAS Model) (Abergel et al. 1996) has been used. As the corrected curves attained stable values in the second half only, we did not use the first half of the frames.

In the spectral observation of May 27, the uninterrupted sequence of filters used created either upward or downward transients and the stabilization of the source signal was reached just in few cases. The five observations made with the SW channel were corrected using the same method as the SW5 ones, except for the SW11 filter, in which the stabilization was reached for all pixels. In this case, we just discarded the first half of the 162 frames. In the SW2 filter data, at the end of the observation, the source signal was so far from stabilization that we could define only a lower limit. The five observations made with the

² ISOCAM Interactive Analysis, CIA, is a joint development by the ESA Astrophysics Division and the ISOCAM Consortium led by the ISOCAM PI, C. Césarsky, Direction des Sciences de la Matière, C.E.A., France.

LW channel were corrected using the IAS model. As this model takes into account all the past illumination history, we fitted a unique curve that was built linking together all the LW filters data. This method worked fine for two filters only (LW8 and LW9), while for the other three filters again we defined lower limits.

We averaged all the frames neglecting the flagged signal values and then the images were flat fielded, using the library flat fields of CIA.

The total signal of the source was computed integrating the values of the signal in a box centered on the source and subtracting the normalized background obtained in a ring of 1 pixel width around the box. The boxes had dimension ranging from 3×3 to 7×7 pixels, depending on the filter and on the pixel field of view (pfov). The results were colour corrected and divided for the point spread function (PSF) fraction falling in the box. This fraction also depends on filters and pfov. To compute it, we extracted from the library, for each combination of filter and pfov, the nine PSF images centered more or less on the same pixels of PKS 2155–304. For calibration requirements, in each PSF image the centroid of the source was placed in a slightly different position inside the same pixel. As we do not know with enough accuracy the position of the centroid of PKS 2155–304 in the ISOCAM images, the nine PSF were averaged and the result was normalized. The PSF correction was calculated by summing the signal of the pixels in a box of the same dimension of that in which we extracted the source signal. For the LW detector, a further correction factor was applied to take into account the flux of the point-like source that falls outside the detector (Okumura 1997). For the SW channel, we adopted for all filters the SW5 PSF, because, along with SW1, was the only one present in the calibration library, however the error we introduced can only be of a few percent.

Finally, the source signal was converted to flux density using the coefficients in Blommaert (1997).

To compute the photometric error we divided the uncertainty sources in two parts: the first one took into account the dark current subtraction, deglitching, flat fielding operations and signal to flux conversion, while the second one considered the transient correction. The first group of error sources are derived from the Automatic Analysis Results (AAR; OLP v7.0 for the light curves data, OLP v6.3.2 for the spectrum data). The source flux values f_{AAR} given by the AAR are not reliable because the transient correction is not performed, but the AAR absolute flux errors σ_{AAR} are a good estimate of the first group of errors (the AAR fluxes are given in Tables 4 and 6). We assumed that the fluxes f_{src} that we derived have the same relative error $\sigma_{rel} = \sigma_{AAR}/f_{AAR}$. Thus, for our fluxes this part of error is $\sigma_f = \sigma_{rel} f$, which accounts for all the uncertainties sources, but the transient correction. We estimated that the error due to the transient correction is of the order of 10%, which is the rounded maximum error on the stable signal s_∞ , obtaining a total error of $\sigma = \sqrt{\sigma_f^2 + \sigma_{tr}^2}$. We assumed then a σ_{tr} of 10% for all our measurements (20% for SW4 and SW10 filters).

A.2. ISOPHOT

The observations were done in rectangular chopped mode: the observed field of view switches alternately between the source and an $180''$ distant off-source position. This is necessary in order to measure the background level. The chopping direction was along the satellite Z-axis, which was slowly rotating by about one degree per day. Thus, every time the background was sampled in different fields of the sky and a raster map was performed just to check the stability of the background all around the source. The standard deviation of the background flux measured in the central pixel of the C100 detector, in the eight off-source positions of the scan, is 37 mJy. This value is much less than the error of the source flux (see Table 5). This small background fluctuation would lead to a rise of the scatter of the source flux, in any case our results are compatible with absence of variability (see Sect. 3).

Each observation of an astronomical target was immediately followed by a Fine Calibration Source (FCS) measurement, using internal calibrations sources. These measurements were made in order to determine the detector responsivity, which is necessary to compute the target flux.

Each observation consisted in a series of integration ramps, each one made by the sequence of voltage readouts between two destructive readouts.

The observations were processed with PIA³ v7.0 (Gabriel et al. 1997).

PIA separates the operations to be performed on the data in different levels: at each level PIA creates a data structure on which it operates. This data structure takes its name according to the properties of the data. The first part of the data analysis was common for all the observations, then the procedures changed according to the different characteristics of the observation (whether it was chopped or not or whether the detector was receiving photons from the astronomical target or from the FCS).

At the beginning, PIA automatically converted the digital data from telemetry in meaningful physical units and created the structure of data, called Edited Raw Data (ERD). At the ERD level, some starting readouts and the last readout of each ramp were discarded, because they are disturbed by the voltage resetting; we also manually discarded the part of the ramp before or after a glitch (that causes a sudden jump of the readout value) in the cases where most part of the ramp was unchanged and the glitch did not modify the detector responsivity. A correction for the non-linear responsivity of the detector was applied, using special calibration files. Then, each ramp was fitted by a 1st order polynomial model. A signal (in $V s^{-1}$) was obtained from the slope of every ramp: the slope is proportional to the incident power. At Signal per Ramp Data (SRD) level, the first half of the signals per chopper plateau were discarded, because of stabilization problems. As the signal value depends on the

³ ISOPHOT Interactive Analysis (PIA) is a joint development by the ESA Astrophysics Division and the ISOPHOT Consortium. The ISOPHOT Consortium is led by the Max-Planck-Institute for Astronomy, Heidelberg.

integration time, a correction factor was applied and the signal was normalized for an integration time of 1/4 s. The dark current was subtracted using the PIA calibration files, which take into account the satellite position in the orbit. An algorithm was applied to discover and discard the signals that were anomalously high, because of glitches; then, the signals of each chopper plateau were averaged. At Signal per Chopper Plateau (SCP) level, the responsivity of each detector pixel was computed taking the median of the FCS2 signals of the calibration measurements; then, the vignetting correction was performed on the target observations. In the chopped measurements, the background, that was calculated at the off-source position, was subtracted to get the source signal.

As for the camera, the response of the photometer detectors has some delays after a change in the incident flux. This effect causes losses in the signal values measured in the chopped measurements, so a correction factor was applied. The signal was finally converted into power, using the responsivity obtained from the FCS measurement.

In the observations performed with the 3×3 pixel C100 detector, only the central pixel was used to compute the source flux density, because, as the most of the Airy disk of a point-like source centered in the pixel lies in the same pixel (69% for C1.60 and 61% for C1.90), to use the outer pixels just adds more noise than signal. The source flux density is defined as $F_\lambda = P_{src}/(C1f_{psf})$, where P_{src} is the incident power, $C1$ is a conversion factor of each filter (as given in the PIA calibration file `pfluxconv.fits`) and f_{psf} is the fraction of PSF that falls on the pixel considered when the source is located in the centre (ISOPHOT Observer's Manual 1994, Tables 2 and 4).

The absolute photometric error was computed by PIA, during the data reduction process, and took into account the uncertainty in the determination of the slope of the ramp and the errors associated to the other performed correction operations.

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