ISO MID-INFRARED OBSERVATIONS OF ABELL 370[1]

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Abstract

We report on the mid-IR imaging at 7 and 10 μm of the galaxy cluster Abell 370, obtained with the ISOCAM instrument onboard ESA's Infrared Space Observatory (ISO), as part of an ongoing program to image gravitational arcs and arclets in distant clusters. We have recorded initial detections of the A0 giant arc in both bandpasses, the two central dominant galaxies at 7 μm, and several other cluster members and field galaxies.
These preliminary results are indicative of the potential output of our program when more extensive observational data become available.

1 Introduction

The cluster Abell 370 is a distant ($< z >= 0.374$ [15]), rich, massive cluster, with two central giant galaxies dominating its optical image. The X-ray luminosity of the cluster is[2] 3.7×10^{44} erg s^{-1} [8], which is as expected from the high value of the velocity dispersion of this cluster, 1340 km s^{-1}[15].

A370 was shown by [2], [3] and [15] to contain an anomalous fraction of blue objects, as compared to nearby clusters (50 % of the cluster members in the central region show

[1]ISO is an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with participation of ISAS and NASA

[2]We assume a Hubble constant $H_0 = 75$ km s^{-1} Mpc^{-1} and a deceleration parameter $q_0 = 1/2$ throughout this paper, giving a luminosity-distance to the cluster of 1613 Mpc.

evidence for star-formation activity, as compared to a mere 3 % in Coma). Based on optical and near-IR photometry, it has been shown ([1], [19], [14]) that most galaxies in the cluster are reasonably well fitted by passive evolution models, while the existence of galaxies in a post-starburst phase is controversial ([1] vs. [19]). The spectral energy distribution of the cluster galaxies must be known over a wider wavelength range before their nature can be firmly established, and in this context ISO observations are very important.

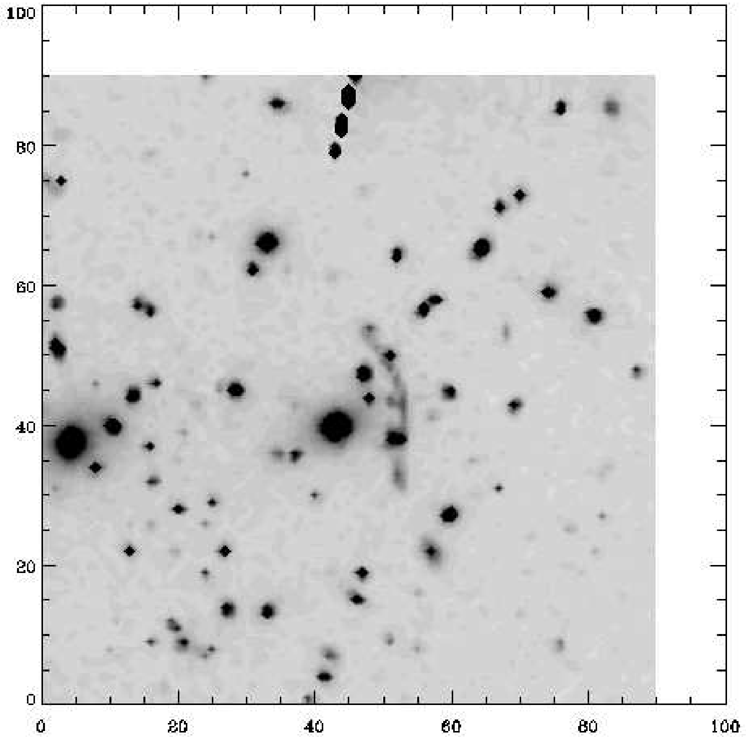

Fig.1. I-band optical image of A370 (from [9]); the original image has been transformed to match the ISOCAM image field-of-view. The coordinates are arcsec. The strange feature in the upper part of the figure is straylight from a very bright star off the image.

A370 contains the first spectroscopically confirmed gravitational arc, A0 at z=0.724 [18]. Other arcs have since been detected in the cluster ([9] and references therein). Based on *Hubble Space Telescope* images, [17] found evidence for a faint spiral structure and an apparent bulge. The spiral nature of the A0 arc was also indicated by its optical and near-IR colours and it was detected by its CO line in emission by [6].

In this paper we report on the mid-IR observations of A370 done with ISOCAM onboard ESA's *Infrared Space Observatory* (ISO) satellite. A370 and another three clusters were selected for observation in the context of an ISO guaranteed-time project aimed at generating mid-IR images of known giant arcs and providing their mid-IR fluxes.

In § 2 we give a description of our observations and data-reductions; in § 3 we present the ISOCAM image, and compare it with an I-band image in order to derive a colour map. We give our conclusions in § 4.

2 Observations and data reduction

Abell 370 was observed on August 17, 1996 as part of an ISO program (LMETCALF.ARCS) of observations of lensing galaxy clusters with arcs and arclets: Abell 370, Abell 2218, Cl2244-02 and MS2137-23. An important criterion for target selection was to choose the clusters with the brightest arcs in the optical, spatially extended and the farthest from the lens, due to the limited spatial resolution of ISO.

The observation was performed by rastering in microscanning mode yielding some of the deepest ISOCAM images of a galaxy cluster. The pixel field-of-view was $3''$ and the microscanning steps were of $7''$ in both directions of the 5×5 raster. The cluster was imaged in the 2 filters, LW2 [5-8.5 μm] and LW7 [8.5-11 μm], at 5 and 10 sec integration times respectively, for total observing times of 3353 sec (LW2) and 5705 sec (LW7), covering a field of 2×2 arcminutes.

The data reduction was done partly within the IDL based (ISO)CAM Interactive Analysis (CIA) package[3] [16] and partly through the usage of C++ based Multi-resolution Median Transform (*wavelet*) techniques [20]. Cross-correlation of the two methods allows us to increase the reliability of source detections.

In Fig. 1 we show an I-band image of A370 (kindly provided to us in electronic form by J.P. Kneib [9]), which has been shifted, rotated, and rebinned to match the ISO-CAM field-of-view. The field-of-view of our observations as presented here is roughly $1.5' \times 1.5'$ centered on one of the two cluster dominant galaxies (no.9 in the list of [5], BOW9 hereafter), the one close to the giant arc A0.

One of the data reduction problems facing us in this analysis is the difficulty of comparing photometry obtained in or near the visible region at high spatial resolution ($<0.5''$) with the diffraction limited 7 and 10 μm photometry of ISO, where the diameter of the first Airy ring is $d'' = 0.84 \times \lambda(\mu m)$, so $\simeq 6''$ in the CAM LW2 filter. In order to make this comparison and so allow the galaxy colours to be compared with the predictions of models, we are developing the following approach. We take the I-band image (Fig.1) and convolve it with the relevant ISO point-spread-function and with a $3'' \times 3''$ square pixel – representative of the $3''$ square pixels used for these observations. The apparent resolution of the resulting image is well matched to the resolution obtained in our ISO rasters, which move the detector array over the source in steps which are multiples of 0.333 pixels (multiples of $1''$).

3 Results

An overlay of contours of the blurred I-band image onto the 7 μm LW2 ISO image is presented in Fig. 2. A similar data-processing for the 10 μm image is still underway. From Fig.2, one can clearly see a general good correspondence between the 7 μm and the I-band images. Pending the results of planned ISO follow-up observations, we have considered as tentative detections those sources seen at about the 5 sigma level ($\sim 50\mu$Jy) in the CIA-based ISO image and having clear counterparts in the I-band image, and we attach greatest reliability to detections confirmed in the *wavelet* tool output. Only when the follow-up results become available will we be able to firm-up the list of tentative detections reported here. Nevertheless, after extensive interactive examination of the data sets we believe that the majority of detections suggested in this paper will be confirmed when the further observations are analysed.

The most important detected sources are: the giant arc A0, which shows up clearly as an elongated structure, and the P1 image of the same gravitationally lensed galaxy. The two optical dominant galaxies look very prominent at 7 μm as well. While a full analysis of the 10 μm image is underway, we can nevertheless already state that A0 and P1 are detected at 10 μm as well, while the two dominant galaxies are much fainter, and almost disappear (particularly the one closest to the arc, BOW9).

[3] CIA is a joint development by the ESA Astrophysics Division and the ISOCAM Consortium led by the ISOCAM PI, C. Cesarsky, Direction des Sciences de la Matière, C.E.A., France.

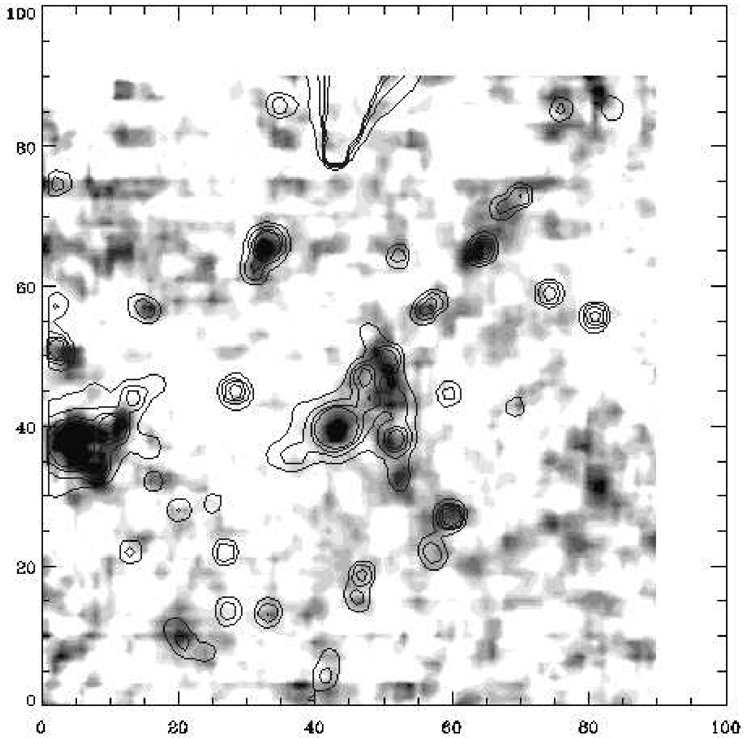

Fig.2 ISOCAM LW2 image (gray shading) with the blurred I-band optical image overplotted (contours). The contours in the upper part of the figure are an artefact due to the blurring of the straylight from the off-image bright star.

In Table 1 we list all the detections at 7 μm; for each detected source we give the coordinates in the LW2 image (Fig. 2) and the number of the identified galaxy in any of three catalogues (BOW: [5], MEC: [11], MT: [14]). When a single identification was not possible because of poor resolution or confusion, while a diffuse LW2 detection was clearly present, we give the identification numbers of all galaxies in that region. When no galaxy was visible in the I-band image at the location of an LW2 detection, we list it as "IR only" in Table 1. These tentative IR detections without corresponding optical sources are particularly interesting for future follow-up.

For the ISO image we convert to units of Watt m^{-2} by using the conversion value from ADU/sec to mJy given in the "ISOCAM Observer's Manual", after a 0.8 factor correction as indicated by [4]. We calibrate the I-band image via aperture photometry on a number of sources with optical and near-IR fluxes available in the literature [15], [19].

We can then make a ratio of the ISO image over the blurred I-band image which yields a colour map properly reflecting the IR/optical colours of the detected sources. The resulting colour map is presented in Fig. 3; more intense shading corresponds to higher IR/optical flux density ratios.

From this figure it can be seen that most galaxies have a bluer colour than the arc (A0 and P1). The colours corresponding to the lightest shading in the figure (0.01–0.02) are indeed typical of normal ellipticals (according to the models of [12]), but several galaxies are characterized by a slight IR excess with respect to the colors of normal 10–15 Gyr old ellipticals (including the two dominant galaxies, characterized by colours of 0.02–0.09). The arc (A0, P1) is characterized by a color of 0.2–0.3, which qualifies the gravitational lensed galaxy as a spiral with intense star formation activity, possibly in a starburst phase (according to the models of [13] and [7]). The starbursting phase of the gravitationally lensed galaxy seems also to be confirmed by our preliminary estimate of a high flux at 10 μm.

Table 1. Detected sources in the LW2 image.

x	y	identification	x	y	identification
79	87	BOW167+BOW189	12	41	MEC3
69	73	BOW130+BOW152	43	40	BOW9, dominant galaxy
52	66	BOW142	6	38	BOW10, dominant galaxy
12	65	IR only	51	38	MEC101
32	65	BOW29	9	33	MEC2
64	65	BOW60	18	33	BOW363
31	62	BOW154	52	33	P1 gravitational image
16	58	BOW124	82	31	IR only (maybe MT111)
56	57	MT41	60	28	BOW119
4	50	BOW61	21	10	BOW247+MEC25
51	47	Giant Arc, A0			

4 Conclusions

In this paper we have presented the results of observations of A370 with ISOCAM onboard ISO. We have detected the giant arc at 7 and 10 μm; this is the first detection ever of a gravitational arc in a galaxy cluster at these wavelengths. Moreover, we have also detected many other galaxies, in the cluster field.

The comparison of an I-band image and the ISOCAM 7 μm image in the LW2 filter has allowed us to build a colour-map which seems to indicate a starbursting phase for the gravitationally lensed galaxy. Most cluster galaxies however appear to have a ratio of 7 μm to 0.9 μm flux density as predicted from spectral energy distribution models of normal ellipticals [12].

While our data reduction methodology is still being developed and refined, and while a full exposition of quantitative results remains to be achieved, the present results already demonstrate the capability of ISO in detecting faint mid-IR sources at large distances. With our ongoing program we hope to detect other gravitational arcs in clusters, and so to constrain the evolutionary status of these high redshift sources. We will widen the wavelength coverage of the spectral energy distributions for cluster galaxies, thus providing a better leverage for constraining models of galaxy formation and evolution. An additional exciting perspective of our future observations is the serendipitous discovery of optically undetected "IR-only" arcs or arclets.

Acknowledgements. We thank J.P.Kneib for providing us with a digitized I-band image of the cluster.

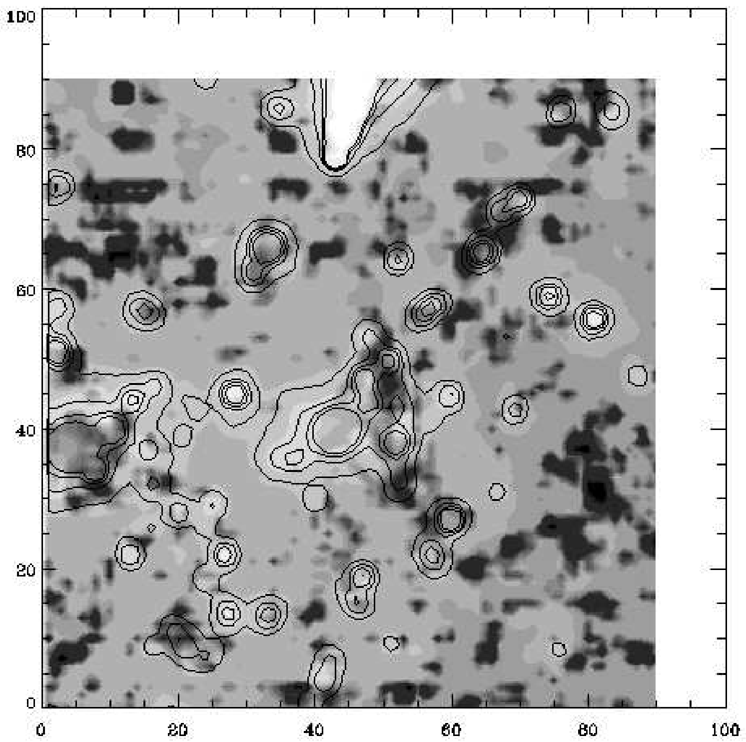

Fig.3 The colour map (gray shading) with the blurred I-band optical image superposed (contours). The colour image is the ratio of the power density in the LW2 band to the power density in the I-band. Darker shadings correspond to higher IR to optical flux ratios.

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