Herschel Photometry of Brightest Cluster Galaxies in Cooling Flow Clusters

A. C. Edge
Durham University, UK

J. B. R. Oonk
Leiden University, The Netherlands

R. Mittal
Rochester Institute of Technology

S. W. Allen
Stanford University

S. A. Baum
Rochester Institute of Technology

Follow this and additional works at:
https://uknowledge.uky.edu/physastron_facpub

Part of the Astrophysics and Astronomy Commons, and the Physics Commons

Right click to open a feedback form in a new tab to let us know how this document benefits you.

Repository Citation
Edge, A. C.; Oonk, J. B. R.; Mittal, R.; Allen, S. W.; Baum, S. A.; Böhringer, H.; Bregman, J. N.; Bremer, M. N.; Combes, F.; Crawford, C. S.; Donahue, M.; Egami, E.; Fabian, A. C.; Ferland, Gary J.; Harner, S. L.; Hatch, N. A.; Jaffe, W.; Johnstone, R. M.; McNamara, B. R.; O’Dea, C. P.; Popesso, P.; Quillen, A. C.; Salomé, P.; Sarazin, C. L.; Voit, G. M.; Wilman, R. J.; and Wise, M. W., "Herschel Photometry of Brightest Cluster Galaxies in Cooling Flow Clusters" (2010). Physics and Astronomy Faculty Publications. 22.
https://uknowledge.uky.edu/physastron_facpub/22

This Letter to the Editor is brought to you for free and open access by the Physics and Astronomy at UKnowledge. It has been accepted for inclusion in Physics and Astronomy Faculty Publications by an authorized administrator of UKnowledge. For more information, please contact UKnowledge@lsv.uky.edu.
Herschel Photometry of Brightest Cluster Galaxies in Cooling Flow Clusters

Digital Object Identifier (DOI)
http://dx.doi.org/10.1051/0004-6361/201014572

Notes/Citation Information
Published in Astronomy & Astrophysics, v. 518, article L47, p. 1-5.
Reproduced with permission from Astronomy & Astrophysics, © ESO

Authors
A. C. Edge, J. B. R. Oonk, R. Mittal, S. W. Allen, S. A. Baum, H. Böhringer, J. N. Bregman, M. N. Bremer, F. Combes, C. S. Crawford, M. Donahue, E. Egami, A. C. Fabian, Gary J. Ferland, S. L. Hamer, N. A. Hatch, W. Jaffe, R. M. Johnstone, B. R. McNamara, C. P. O'Dea, P. Popesso, A. C. Quillen, P. Salomé, C. L. Sarazin, G. M. Voit, R. J. Wilman, and M. W. Wise

This letter to the editor is available at UKnowledge: https://uknowledge.uky.edu/physastron_facpub/22
**Herschel** photometry of brightest cluster galaxies in cooling flow clusters\(^*\),\(^{**}\)

A. C. Edge\(^1\), J. B. R. Oonk\(^2\), R. Mittal\(^3\), S. W. Allen\(^4\), S. A. Baum\(^5\), H. Böhringer\(^5\), J. N. Bregman\(^6\), M. N. Bremer\(^7\), F. Combes\(^8\), C. S. Crawford\(^9\), M. Donahue\(^10\), E. Egami\(^11\), A. C. Fabian\(^9\), G. J. Ferland\(^12\), S. L. Hamer\(^1\), N. A. Hatch\(^13\), W. Jaffe\(^2\), R. M. Johnstone\(^9\), B. R. McNamara\(^14\), C. P. O’Dea\(^15\), P. Popesso\(^5\), A. C. Quillen\(^16\), P. Salomé\(^8\), C. L. Sarazin\(^17\), G. M. Voit\(^10\), R. J. Wilman\(^18\), and M. W. Wise\(^19\)

1 Institute for Computational Cosmology, Department of Physics, Durham University, Durham, DH1 3LE, UK
e-mail: alastair.edge@durham.ac.uk
2 Leiden Observatory, Leiden University, PB 9513, Leiden 2300 RA, The Netherlands
3 Chester F. Carlson Center for Imaging Science, Rochester Institute of Technology, Rochester, NY 14623, USA
4 Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, 452 Lomita Mall, Stanford, CA 94305-4085, USA
5 Max-Planck-Institut für extraterrestrische Physik, 85748 Garching, Germany
6 University of Michigan, Dept. of Astronomy, Ann Arbor, MI 48109, USA
7 H H Wills Physics Laboratory, Tyndall Avenue, Bristol BS8 1TL, UK
8 Observatoire de Paris, LERMA, CNRS, 61 Av. de l’Observatoire, 75014 Paris, France
9 Institute of Astronomy, Madingley Rd., Cambridge, CB3 0HA, UK
10 Michigan State University, Physics and Astronomy Dept., East Lansing, MI 48824-2320, USA
11 Steward Observatory, University of Arizona, 933 N. Cherry Avenue, Tucson, AZ 85721, USA
12 Department of Physics, University of Kentucky, Lexington, KY 40506, USA
13 School of Physics and Astronomy, University of Nottingham, University Park, Nottingham NG7 2RD, UK
14 Department of Physics & Astronomy, University of Waterloo, 200 University Avenue West, Waterloo, N2L 3G1 Ontario, Canada
15 Department of Physics, Rochester Institute of Technology, 84 Lomb Memorial Drive, Rochester, NY 14623-5603, USA
16 Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627, USA
17 Department of Astronomy, University of Virginia, PO Box 400325, Charlottesville, VA 22904-4325, USA
18 School of Physics, University of Melbourne, Victoria 3010, Australia
19 ASTRON, Netherlands Institute for Radio Astronomy, PO Box 2, 7990 AA Dwingeloo, The Netherlands

Received 30 March 2010 / Accepted 2 May 2010

**ABSTRACT**

The dust destruction timescales in the cores of clusters of galaxies are relatively short given their high central gas densities. However, substantial mid-infrared and sub-mm emission has been detected in many brightest cluster galaxies. In this letter we present Herschel PACS and SPIRE photometry of the brightest cluster galaxy in three strong cooling flow clusters, A1068, A2597 and Zw3146. This photometry indicates that a substantial mass of cold dust is present (\(>3 \times 10^7 \, M_\odot\)) at temperatures significantly lower (20–28 K) than previously thought based on limited MIR and/or sub-mm results. The mass and temperature of the dust appear to match those of the cold gas traced by CO with a gas-to-dust ratio of 80–120.

**Key words.** galaxies: clusters: intracluster medium – galaxies: elliptical and lenticular, cD

1. **Introduction**

The cores of cluster of galaxies are very energetic regions with a high X-ray emissivity, particle density, cosmic ray flux, stellar density and AGN radiation. In this very hostile environment any dust grains are unlikely to survive for more than a few million years due to the action of collisional sputtering (Dwek & Arendt 1992) unless they are shielded (Fabian et al. 1994). It is therefore somewhat surprising to find that dust continuum emission from the brightest cluster galaxies in the most rapidly cooling clusters being detected at sub-mm and MIR wavelengths (Edge et al. 1999; Egami et al. 2006; O’Dea et al. 2008). The presence of cold molecular gas (Edge 2001; Salomé & Combes 2003) and dust absorption in HST imaging (McNamara et al. 1996) implies that the dust continuum traces a substantial, cold component to the ISM in these massive elliptical galaxies. However, the origin of the dust and how it is shielded are still poorly understood.

The limitations with the current observations of dust emission make it difficult to establish an unambiguous dust mass as they do not sample over the peak of the dust emission in the FIR. The unprecedented sensitivity of Herschel (Pilbratt et al. 2010) to FIR continuum offers the opportunity to accurately constrain the full FIR spectrum of the dust emission in cluster cores. The authors were awarded 140 hours of time in an open time key program (PI Edge) to investigate the FIR line and continuum properties of a sample of 11 brightest cluster galaxies (BCGs) in well-studied cooling flow clusters selected on the basis of optical emission line and X-ray properties. The full goals of the project are to observe at least five atomic cooling lines for

---

\(^*\) Herschel is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA.

\(^{**}\) Figures 2 and 3 are only available in electronic form at [http://www.aanda.org](http://www.aanda.org)
each object that cover a range in density and temperature behaviour and obtain a fully sampled FIR spectral energy distribution. In this paper we present the Photodetector Array Camera and Spectrometer (PACS, Poglitsch et al. 2010) and Spectral and Photometric Imaging REceiver (SPIRE, Griffin et al. 2010) photometry for the three targets observed in the science demonstration phase (SDP), Abell 1068 ($z = 0.1386$), Abell 2597 ($z = 0.0821$) and Zw3146 ($z = 0.2906$). In a parallel paper (Edge et al. 2010), we present the FIR spectroscopy for the first two of these clusters.

The three clusters observed have quite contrasting multi-wavelength properties. Abell 1068 and Zw3146 both have strong MIR emission (O’Dea et al. 2008; Egami et al. 2006) with a relatively bright CO detection (Edge 2001) and a weak central radio source (McNamara et al. 2004). A1068 lies just below the luminosity threshold of a ULIRG ($10^{12} L_\odot$) and exhibits some contribution from an AGN (Crawford et al. 1999; O’Dea et al. 2008). On the other hand, Abell 2597 is a relatively weak MIR source (Donahue et al. 2007) with a weak CO detection (Salome, priv. comm.) and a powerful central radio source (Sarazin et al. 1995). The implied FIR luminosity of A2597 is a factor of around 30 below that of A1068 and, in addition, the fractional contribution from an AGN in the MIR is also lower in A2597.

2. Observations

We performed photometric imaging of A1068, A2597 and Zw3146 with PACS and SPIRE. The data were reduced with the Herschel interactive processing environment (HIPE) software version 2.3.1436 (Ott 2010). We used for both PACS and SPIRE the official scripts as presented by the PACS and SPIRE ICC teams during the Herschel SDP data processing workshop in December 2009.

2.1. PACS data

The PACS photometric observations were taken in LargeScanMapping mode in all three bands of the photometer, BS (70 μm), BL (100 μm) and R (160 μm) using the medium scan speed (20″ s$^{-1}$). The scan maps comprised 18 scan line legs of 4″ length and cross-scan step of 15″. Each observation had a “scan” and an orthogonal “cross-scan” direction and we calibrated the corresponding data separately before combining them into a single map of 9′ × 9′. The resulting maps have a resolution of 5.2″, 7.7″ and 12″ at 70, 100 and 160 μm, respectively and are presented in the electronic version of this paper. The PACS photometer performs dual-band imaging such that the BS and BL bands each have simultaneous observations in the R band so we have two sets of scans in the R band.

We adopted the PACS data reduction guideline to process the raw level-0 data to calibrated level 2 products and used the official script for PACS ScanMapping mode but with particular attention to the high pass filtering to remove “1/√π noise. We choose to use the HighPassFilter method with a filter of 20 readouts which will remove structure on all scales above 82″. The target BCG and other bright sources in the field were masked prior to applying the filter. The size of the mask was chosen to be less than the filter size so as to minimize any left-over low-frequency artefacts under the masks. We used masks with a radius of 15″ for our sources. We tried varying the size for the filter from 10 to 30 readouts and the mask radius from 10−30″ and found our results to not change significantly for these ranges in values. Finally the task “photProject”, was used to project the calibrated data onto a map on the sky in units of Jy pixel$^{-1}$. The “scan” and “cross-scan” maps were then averaged to produce the final coadded map. The PACS and SPIRE images are included in the electronic version of the paper. The spatial distribution and flux densities of our target sources were investigated using cumulative flux curves. The spatial flux distribution for each of our three sources is consistent with that expected from a point source. Flux densities in the BS, BL and R band were extracted using a 33″ by 33″ aperture centered on the BCG. Small aperture corrections were applied as outlined in the PACS Scan Map release note (PICC-ME-TN-035). Care was taken to calibrate these derived flux densities to account for the known flux overestimation in the used HIPE version by factors 1.05, 1.09 and 1.29 in BS, BL and R bands respectively. The absolute flux accuracy is within 10% for BS and BL, and better than 20% for R. These uncertainties are not believed to be correlated due to the BS and BL bands being taken at different times and the R band using a different detector.

2.2. SPIRE data

The SPIRE photometry was performed in the LargeScanMap mode with cross-linked scans in two orthogonal scan directions. The photometer has a field of view of 4′ × 8′, which is observed simultaneously in three spectral bands, PSW (250 μm), PMW (350 μm) and PLW (500 μm) with a resolution of about 18″, 25″ and 36″, respectively. The resulting maps measure 12′ × 12′ in size and are presented in the electronic version of this paper.

We used the standard HIPE pipeline for the LargeScanMap observing mode and the naïve map-maker. The pre-processed raw telemetry data were first subject to engineering conversion wherein the raw timeline data were converted to meaningful units, the SPIRE pointing product was created, deglitching and temperature drift correction were performed, and maps were created, the units of which were Jy beam$^{-1}$. Our targets are unresolved at the spatial resolution of SPIRE. We derived their flux densities by fitting the sources with the SPIRE point source response function. Care was taken to de-blend our target from other nearby sources at the longer wavelengths, where the sources are most likely to be background to the cluster. We account for the known flux calibration offset in the used version of HIPE by applying the following multiplicative calibration factors 1.02, 1.05 and 0.94 to the derived flux densities in the PSW, PMW and PLW bands respectively (see Griffin et al. 2010; Swinyard et al. 2010). We also performed aperture photometry using the HIPE point-source extraction (PSE) tool but this method gives accurate results only for isolated point sources. At 350 μm and 500 μm, the BCGs in A2597 and Zw3146 are close to the detection limit and at the confusion limit of SPIRE making the PSE method of determining the fluxes unsuccessful. A1068 has a relatively strong compact BCG in far infrared and so we performed the PSE to find that the flux estimates using AIPS and HIPE agree with each other to better than 5%.

3. Results

In the PACS photometry, A1068, A2597 and Zw3146 have been detected in all three bands. For A1068, 70 and 100 μm values are slightly less than the IRAS 60 and 100 μm measurements. This could be due to nearby sources that cannot be separated from the BCG in the much lower resolution IRAS observations but no sufficiently bright source is visible in our PACS imaging. There is a large difference between the Spitzer MIPS 70 μm flux (Quillen et al. 2008) and our PACS 70 μm flux, the PACS flux being a factor 1.7 lower than the MIPS flux. In the case of Zw3146 the MIPS and PACS 70 μm fluxes also differ with the PACS value being a factor 1.4 larger than the MIPS value (Egami et al. 2006). For A2597 the PACS fluxes differ from the Spitzer
70 and 160 μm fluxes reported by Donahue et al. (2007). Part of this difference was resolved when the MIPS 70 μm data were re-analysed and found to be a factor of two too high (Donahue, priv. comm.). The differences observed between the PACS and Spitzer fluxes require further investigation. In the SPIRE photometry, A1068 is detected in all three SPIRE bands, A2597 and Zw3146, while clearly detected in PSW and PMW bands, have a 1–2σ detection in the PLW band. Table 1 gives the photometric results for the three galaxies, with 2σ upper-limit for A2597 and Zw3146 in PLW. Figure 1 presents the radio to optical spectral energy distributions (SEDs) for the three targets. These plots show the significant variation in the relative radio–FIR contributions for each of our galaxies. Here we focus on the sub-mm/MIR dust emission as sampled by PACS and Spitzer photometry, complemented by published Spitzer and IRAS measurements.

We fit the SEDs of the dust emission using black bodies modified with a dust emissivity index, β. The FIR-MIR slopes of our sources require the presence of at least two dust components. Previous studies of star-forming galaxies have indeed established that a single modified black body (MBB) is inadequate to account for the observed dust emission (Wiklind 2003). Hence, our model for the SEDs consists of two MBBs with the dust emissivity index for each fixed to β = 2 and a mass absorption coefficient, $k_{\text{abs}}$, of 2.5 m$^2$ kg$^{-1}$ at 100 μm.

For A1068 we fit the 24–850 μm emission. For A2597 and Zw3146 the SCUBA 850 μm detections have been removed and we fit only the 24–350 μm range. In the case of A2597, this is due to the unknown amount of radio contamination at 850 μm. In the case of Zw3146 the BCG is blended with strong background source at 850 μm (Chapman et al. 2002). The data are weighted

Table 1. Log of Herschel observations.

| Cluster  | z     | Instrument | $\lambda$ (μm) | Obsid | Flux (mJy) |
|----------|-------|------------|----------------|-------|------------|
| A1068    | 0.1386| PACS       | 70 1 342 187 051|       | 542 ± 6    |
|          |       | PACS       | 100 1 342 187 053|       | 757 ± 6    |
|          |       | PACS       | 160 1 342 187 054|       | 769 ± 4    |
|          |       | SPIRE      | 250 1 342 187 321|       | 376 ± 6    |
|          |       | SPIRE      | 350 1 342 187 322|       | 135 ± 6    |
|          |       | SPIRE      | 500 1 342 187 323|       | 56 ± 8     |
|          |       | SCUBA      | 450 1 342 187 324|       | 39 ± 13    |
|          |       | SCUBA      | 850 1 342 187 325|       | 5.3 ± 1.1  |
|          |       | Spitzer    | 24 1 342 187 326|       | 74.5 ± 2.0 |
|          |       | Spitzer    | 70 1 342 187 327|       | 941 ± 50   |
|          |       | IRAS       | 60 1 342 187 328|       | 577 ± 52   |
|          |       | IRAS       | 100 1 342 187 329|       | 958 ± 144  |
| A2597    | 0.0821| PACS       | 70 1 342 187 118|       | 57 ± 5     |
|          |       | PACS       | 100 1 342 187 120|       | 67 ± 7     |
|          |       | PACS       | 160 1 342 187 123|       | 86 ± 4     |
|          |       | SPIRE      | 250 1 342 187 124|       | 30 ± 6     |
|          |       | SPIRE      | 350 1 342 187 125|       | 15 ± 6     |
|          |       | SPIRE      | 500 1 342 187 126|       | <16        |
|          |       | SCUBA      | 850 1 342 187 127|       | 14.5 ± 2.3 |
|          |       | Spitzer    | 24 1 342 187 128|       | 2 ± 0.2    |
|          |       | Spitzer    | 70 1 342 187 129|       | 49 ± 6     |
| ZW3146   | 0.2906| PACS       | 70 1 342 187 043|       | 94 ± 6     |
|          |       | PACS       | 100 1 342 187 045|       | 150 ± 6    |
|          |       | PACS       | 160 1 342 187 046|       | 139 ± 5    |
|          |       | SPIRE      | 250 1 342 187 047|       | 81 ± 6     |
|          |       | SPIRE      | 350 1 342 187 048|       | 30 ± 6     |
|          |       | SPIRE      | 500 1 342 187 049|       | <16        |
|          |       | SCUBA      | 450 1 342 187 050|       | <48        |
|          |       | SCUBA      | 850 1 342 187 051|       | 6.6 ± 2.6  |
|          |       | Spitzer    | 24 1 342 187 052|       | 4.1 ± 0.4  |
|          |       | Spitzer    | 70 1 342 187 053|       | 68 ± 14    |
|          |       | Spitzer    | 160 1 342 187 054|       | 157 ± 35   |

Notes. The Spitzer data are from Quillen et al. (2008), Donahue et al. (2007, priv. comm.) and Egami et al. (2006). The SCUBA data are from Edge (priv. comm.), Zemcov et al. (2007) and Chapman et al. (2002).
star formation rates (SFR) of 60 and 44 $M_\odot$ yr$^{-1}$ in these two systems using the Kennicutt (1998) conversion factor. For A2597 a much more modest SFR of 2 $M_\odot$ yr$^{-1}$ is inferred. These values are comparable to SFRs derived from H$\alpha$ line and/or UV continuum emission given the uncertainties of these tracers. However, the SFR values derived from Spitzer data are higher for A1068 and Zw3146. The difference for A1068 is the most pronounced and can be directly attributed to the stronger AGN contribution in this object (Quillen et al. 2008) which boosts the 24 $\mu$m flux compared other comparable sources. Therefore, when the total FIR luminosity is derived from the 15 $\mu$m flux inferred from Spitzer it will be overestimated. The value for Zw3146 from Egami et al. (2006) is higher than ours as their fit includes the SCUBA 850$\mu$m point from Chapman et al. (2002) which appears to be overestimated on the basis of our SPIRE data.

The gas to dust ratio is found to be between 80 and 140 (see Table 2). Gas temperatures can be inferred from CO measurements (Edge 2001; Salome & Combes 2003). These estimates infer gas temperatures of 25–40 K thus implying that the gas and dust share a common environment and are potentially co-located in the denser regions of cold, molecular gas clouds. We have attempted to determine how much extended emission is present from our highest spatial resolution PACS 70 $\mu$m image but we find no evidence for more than 10% additional flux beyond a point source. Clearly these limits will improve with a better characterisation of the instrument but we believe that we can conclude that the dust emission in our targets has an extent comparable to that of the bulk of the CO emitting gas and optical emission lines (<5" or 5–20 kpc).

### Table 2. Summary of results and other cluster properties.

| Cluster      | A1068 | A2597 | Zw3146 |
|--------------|-------|-------|--------|
| Dust Temperatures | 24 ± 4 K | 21 ± 6 K | 23 ± 5 K |
| Cold Dust Mass  | 5.1 ± 10$^5$ $M_\odot$ | 2.3 ± 10$^7$ $M_\odot$ | 5.4 ± 10$^6$ $M_\odot$ |
| Warm Dust Mass  | 3.9 ± 10$^6$ $M_\odot$ | 2.9 ± 10$^8$ $M_\odot$ | 1.9 ± 10$^7$ $M_\odot$ |
| Total FIR Luminosity | 3.5 ± 10$^{11}$ $L_\odot$ | 8.8 ± 10$^{10}$ $L_\odot$ | 2.5 ± 10$^{11}$ $L_\odot$ |
| Star Formation Rate | 60 ± 20 $M_\odot$ yr$^{-1}$ | 2 ± 1 $M_\odot$ yr$^{-1}$ | 44 ± 14 $M_\odot$ yr$^{-1}$ |
| SFR Spitzer     | 188 $M_\odot$ yr$^{-1}$ | 4 $M_\odot$ yr$^{-1}$ | 70 ± 14 $M_\odot$ yr$^{-1}$ |
| SFR optical/UV  | 20–70 $M_\odot$ yr$^{-1}$ | 10–45 $M_\odot$ yr$^{-1}$ | 47 ± 18 $M_\odot$ yr$^{-1}$ |
| CO gas mass     | 4.1 ± 10$^{10}$ $M_\odot$ | 2.0 ± 10$^5$ $M_\odot$ | 7.7 ± 10$^6$ $M_\odot$ |
| Hz Sli Luminosity | 8 × 10$^{15}$ erg s$^{-1}$ | 3 × 10$^{14}$ erg s$^{-1}$ | 3 × 10$^{12}$ erg s$^{-1}$ |

Notes. The Spitzer SFR values are from O'Dea et al. (2008), Donahue et al. (2007) and Egami et al. (2006). The Optical/UV SFR values are from McNamara et al. (2004), Donahue et al. (2007) and Egami et al. (2006). The CO gas masses are from Edge (2001) and Salomé (priv. comm.) and the Ho slit luminosities are from Crawford et al. (1999).
**Fig. 2.** Colour images from the three PACS bands (BS, BL and R in the blue, green and red channels) for the three clusters within radius of 2.5′ of the BCG. The *top row* are images combined in their original resolution and the *bottom row* are the images combined with a common smoothing of 12″ to match resolution.

**Fig. 3.** Colour images from the three SPIRE bands (PSW, PMW and PLW in the blue, green and red channels) for full field covered for the three clusters covering approximately 12′ × 12′. The *top row* are images combined in their original resolution and the *bottom row* are the images combined with a common smoothing of 36″ to match resolution and clipped to remove areas of low exposure. The BCG is at the centre of the image and in A2597 and Zw3146 is the bluest object present (see text).