The Milky Way Project: Galaxies in the Zone of Avoidance*

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ABSTRACT

We present a method for identifying galaxies and protostars through data gathered from the citizen science website 'The Milky Way Project, and report the discovery of 33 previously unknown galaxies in the Zone of Avoidance. 47 candidate galaxies are identified through correlation of markings from volunteers, inspecting Spitzer GLIMPSE and MIPSGAL survey data on 'The Milky Way Project' website. The characteristics of these candidate, such as their locations, spectral energy distributions and redshift velocities are used to confirm whether they are galaxies. The magnitudes and integrated flux of the candidates are calculated in GLIMPSE bands 3.6μm, 4.5μm, 5.8μm and 8.0μm, and MIPSGAL band 24μm. The velocities of these 33 newly uncovered galaxies appear to correlate with the velocities of over-densities in the large-scale structure, at very low Galactic latitudes either side of the Zone of Avoidance. Our findings therefore suggest that the large-scale structure continues throughout the Zone of Avoidance, and highlight the potential for hundreds more galaxies to be found in far-infrared survey data.

Key words: H II regions – infrared: ISM – ISM: dust – stars: formation

1 INTRODUCTION

The Zone of Avoidance (ZoA) remains the missing piece in our map of the large-scale structure of the Universe. Previous studies have shown that careful inspection of far-infrared Galactic plane data (e.g. from the Spitzer Space Telescope) can reveal highly obscured, and thus highly reddened, galaxies in this region (Jarrett et al. 2007; Marleau et al. 2008).

2 THE MILKY WAY PROJECT

The Milky Way Project (MWP, Simpson et al. 2012) is the ninth online citizen science project created using the Zooniverse[1] platform (Smith et al. 2011). The Zooniverse platform supports the activities of all Zooniverse citizen science projects. Built originally for Galaxy Zoo 2 this software, and successive versions of it, have now been used by more than 20 different projects across a range of research disciplines. The Zooniverse toolset is designed primarily as a way to of

serving a large collection of 'assets' (for example, images or video) to a user interface, and collecting back user-generated interactions with these assets.

Galaxy Zoo (Lintott et al. 2008, 2011) and the larger suite of Zooniverse projects have successfully built a large community of volunteers[2] eager to participate in scientific activities. The Zooniverse has shown that enlisting these 'citizen scientists' via the internet is a powerful way to analyze large amounts of data. Human brains excel at pattern recognition tasks, and most people will reach a level of accuracy as high as any expert after a brief introduction. By enlisting citizen scientists, researchers can extend visual classification to large samples of images, having each image examined by a large number of independent classifiers. This allows researchers to tap into the 'wisdom of the crowd' effect where the consensus of a group of non-experts is often more accurate than the testimony of a single expert.

Another advantage of enlisting human classifiers is their ability to recognize unusual objects (e.g. galaxies, star clusters, dark clouds in the MWP) which computer search al-

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[1] http://www.zooniverse.org

[2] Over 750,000 registered volunteers at time of writing.
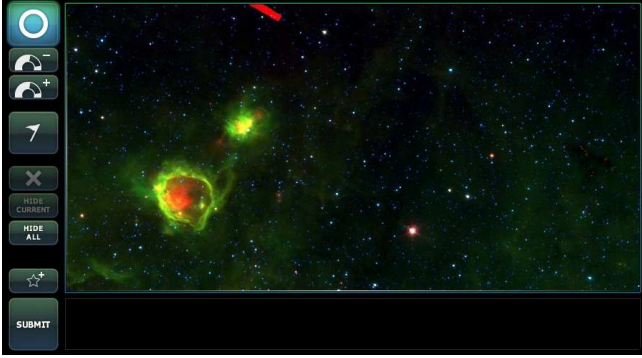
Figure 1. Screenshot of the Milky Way Project user interface. Colour figure available online.

gorithms may be unable to spot. This has been shown by the serendipitous discovery of Hanny's Voorwerp (Lintott et al. 2009) and the case of the Galaxy Zoo 'Green Peas' (Cardamone et al. 2009). Spitzer GLIMPSE data is ideally suited to classification by citizen scientists as the amount of data is large and the images contain complex, overlapping structures that are extremely difficult to disentangle using automated algorithms.

The assets in the MWP are multiband, false-colour JPEG images, created by gridding the *Spitzer* GLIMPSE and MIPSGAL mosaics into smaller images at three different zoom levels. The highest zoom level provides users with tiles of $0.3°×0.15°$, and at a resolution of $800×400$ pixels these tiles nearly reproduce the $1.2''$ pixel scale of the GLIMPSE survey images. Larger tile sizes of $0.75°×0.375°$ and $1.5°×0.75°$ were also generated. The tiles were plotted in an overlapping grid to allow all parts of the inner Galactic plane ($|l| \leq 65°$, $|b| \leq 1°$) to be viewed by the MWP users, at all zoom levels. To provide an optimal representation of the dynamic range within each tile, each of 3 single-band images was independently scaled to a square-root stretch function (with the faintest 5% of image pixels clipped to black and the brightest 0.2% clipped to white), assigned to a colour channel (red=24 μm, green=8.0 μm, blue=4.5 μm), and finally composited into a 3–colour image. The MIPSGAL 24 μm mosaics frequently saturate in regions of bright nebulosity, and saturated 24 μm pixels were set to maximum red to preserve the visual appeal of the images and to avoid presenting MWP users with saturation artefacts. The resulting composite images allow visual identification of both bright and faint features within a given image tile.

The MWP user interface (see Figure 1) was built using Flash, based upon the pre-existing Moon Zoo interface (Joy et al. 2011). Volunteers are primarily encouraged to draw ellipses onto the image to mark the locations of bubbles. A short, online tutorial shows how to use the tool, and examples of prominent bubbles are given[3]. As a secondary task, users can also mark rectangular areas of interest, which can be labelled as small bubbles, green knots, dark nebulae, star clusters, galaxies, fuzzy red objects or 'other'. Examples of these are also given in a tutorial on the website, and these are discussed further in Section **??**. Users can add as many annotations as they wish before submitting the image, at

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[3] http://www.milkywayproject.org/tutorial

which point they are given another image for annotation. Each image's annotations are stored in a database as a classification, and users can see the images they have classified in a part of the site called 'My Galaxy'. Users can only classify a given image once.

Volunteers are primarily asked to draw bubbles on the images, by placing elliptical annuli that match the structures they see in the data. They are also encouraged to mark other regions interest on an image, marking these are either star clusters, green knots, etc. Do do so, volunteers simply draw rectangles. Since these objects are secondary to the main bubble-finding task, the site was designed so that they should be simple and quick to mark. Simple rectangles allow us to record the positions and approximate sizes of any these other interesting objects.

3   CATALOGUE CONSTRUCTION

3.1   Galaxy images

3.2   Aperture photometry

3.3   Galaxy catalogue

4   RESULTS

4.1   Spectral energy distributions

4.2   Comparison with large-scale structure from 2MASS

5   DISCUSSION

6   SUMMARY AND FUTURE WORK

ACKNOWLEDGMENTS

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Lintott, C. J., et al. 2008, MNRAS, 389, 1179
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Marleau, F. R., et al. 2008, AJ, 136, 662
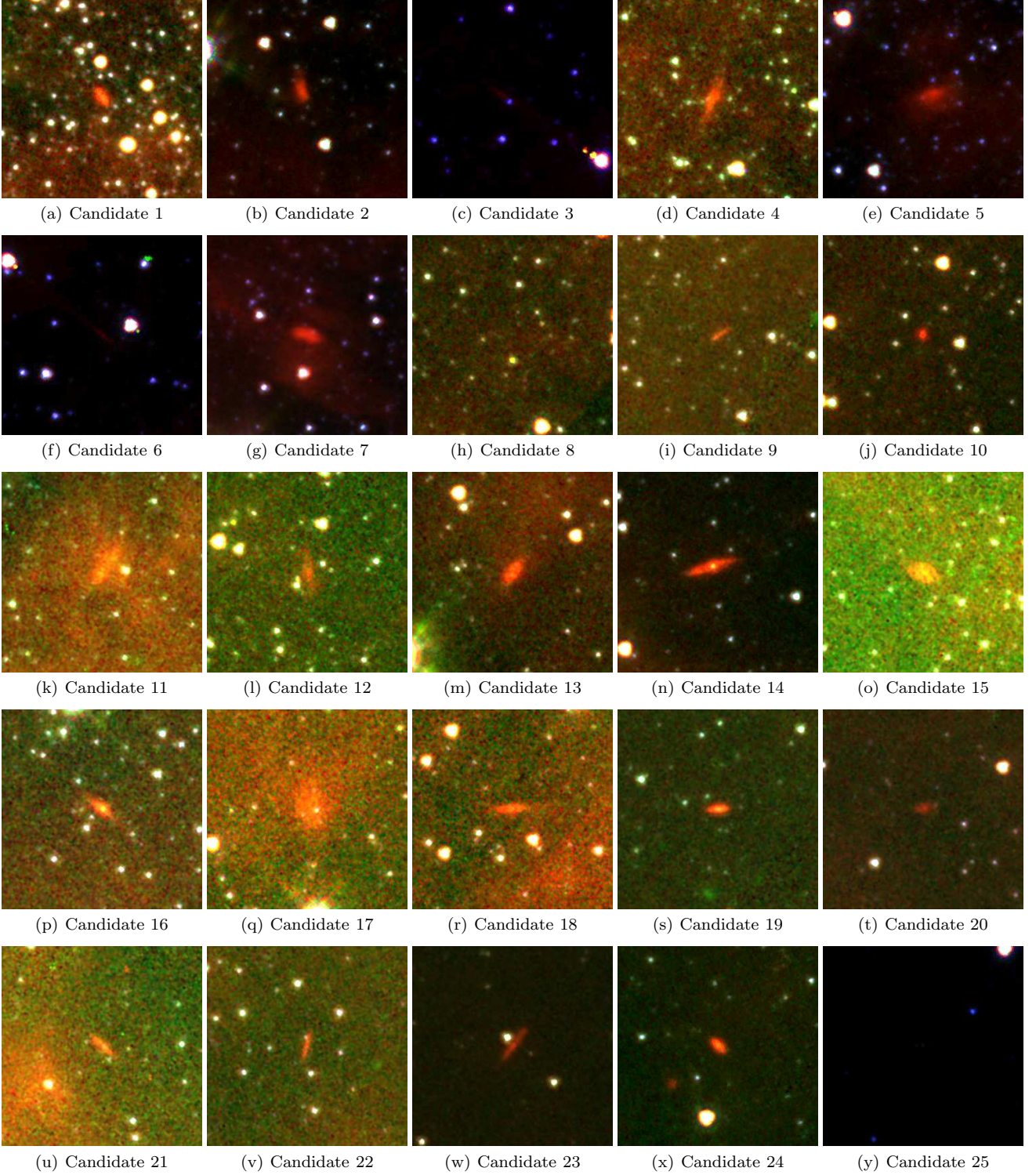
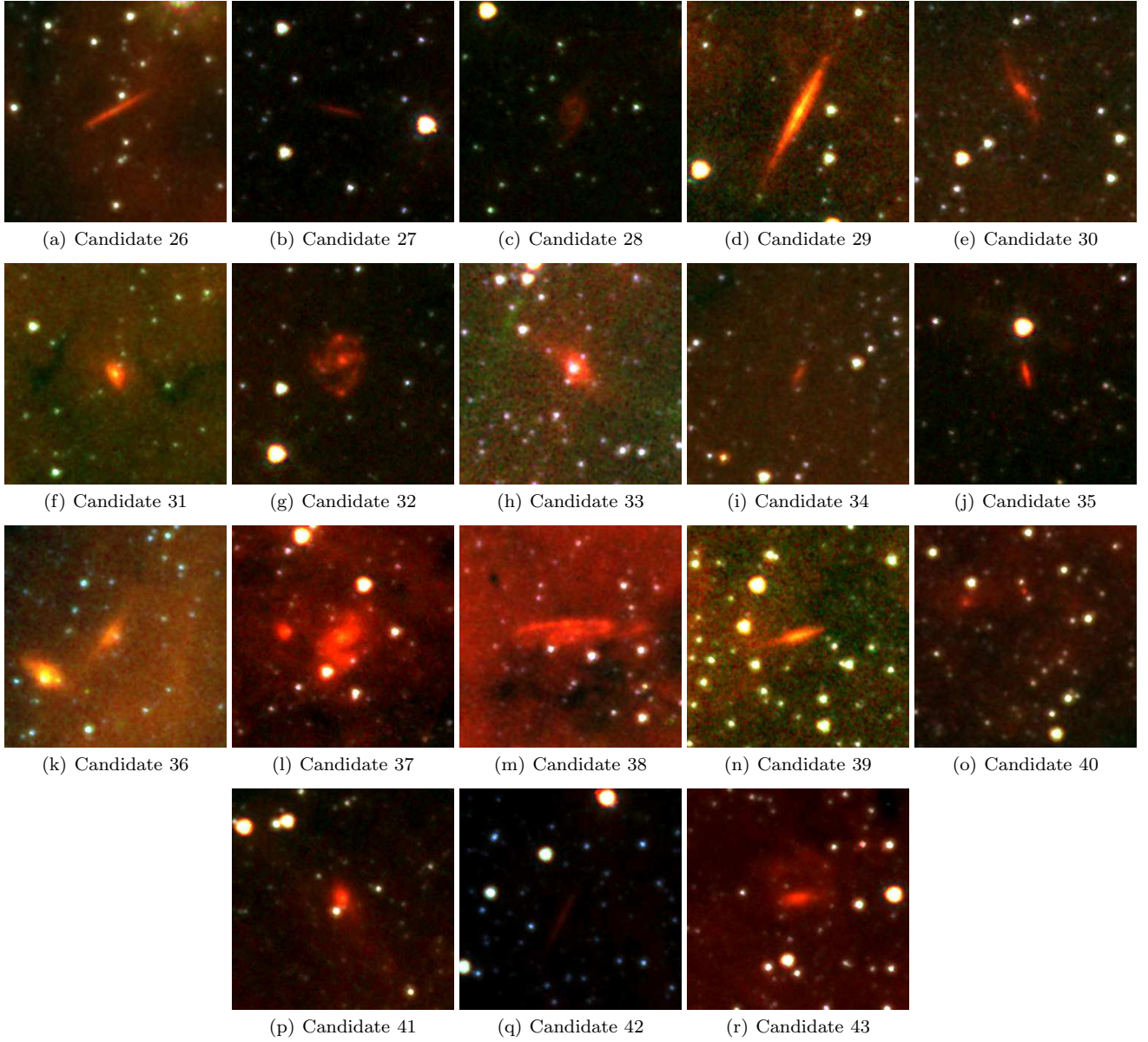**Figure 2.** Three-colour composite images of candidate galaxies 1–25, with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively.

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Simpson, R. J., et al. 2012, MNRAS, 424, 2442

Smith, A. M., et al. 2011, MNRAS, 412, 1309

(a) Candidate 26   (b) Candidate 27   (c) Candidate 28   (d) Candidate 29   (e) Candidate 30

(f) Candidate 31   (g) Candidate 32   (h) Candidate 33   (i) Candidate 34   (j) Candidate 35

(k) Candidate 36   (l) Candidate 37   (m) Candidate 38   (n) Candidate 39   (o) Candidate 40

(p) Candidate 41   (q) Candidate 42   (r) Candidate 43

Figure 3. Three-colour composite images of candidate galaxies 26–43, with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively.
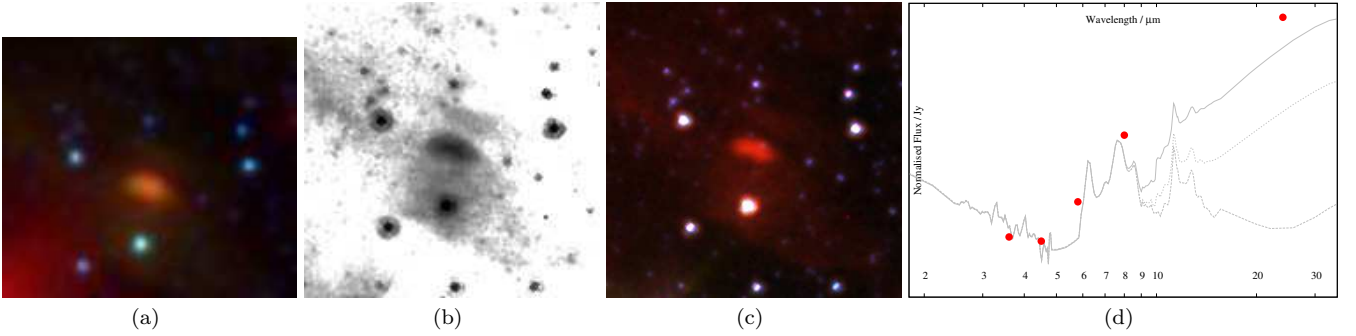
Galaxy Images and SEDs
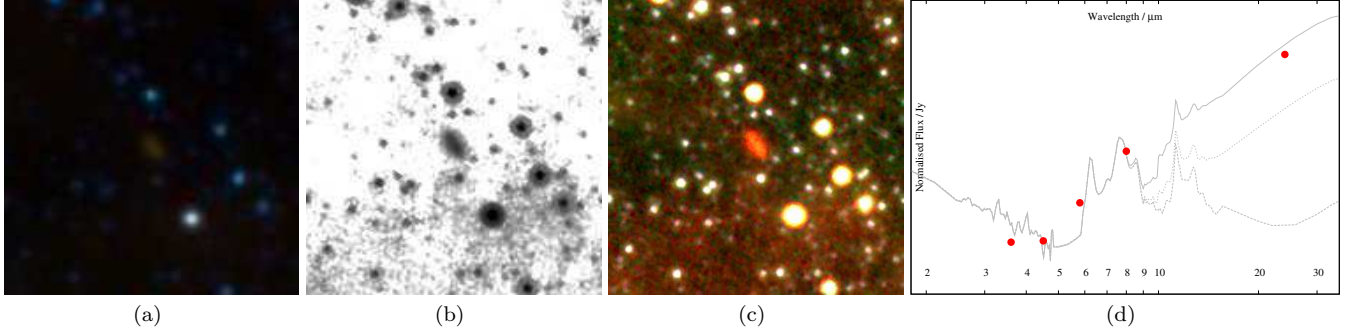
Figure 1. Data for galaxy candidate 1. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
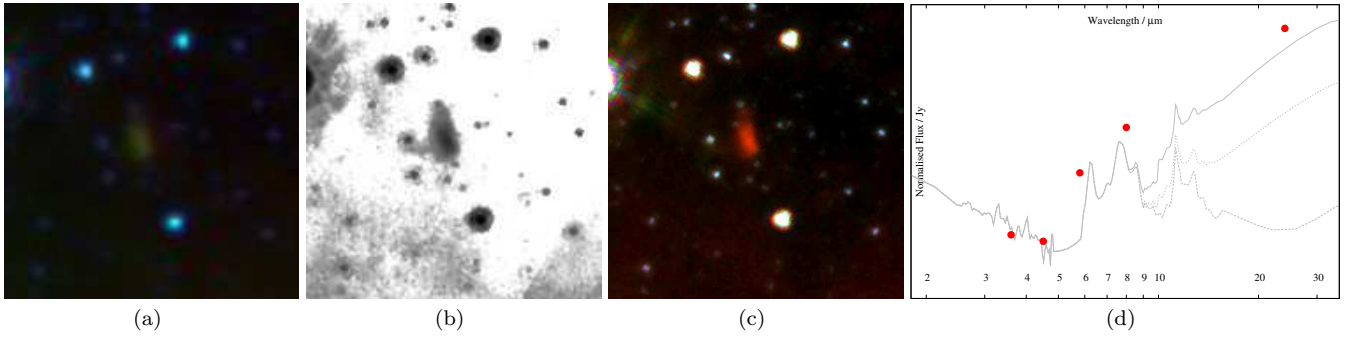
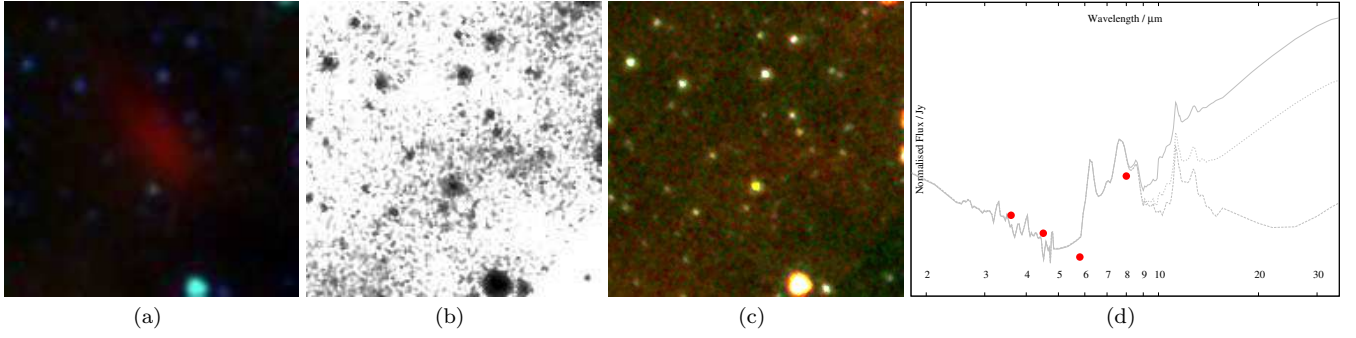
Figure 2. Data for galaxy candidate 2. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
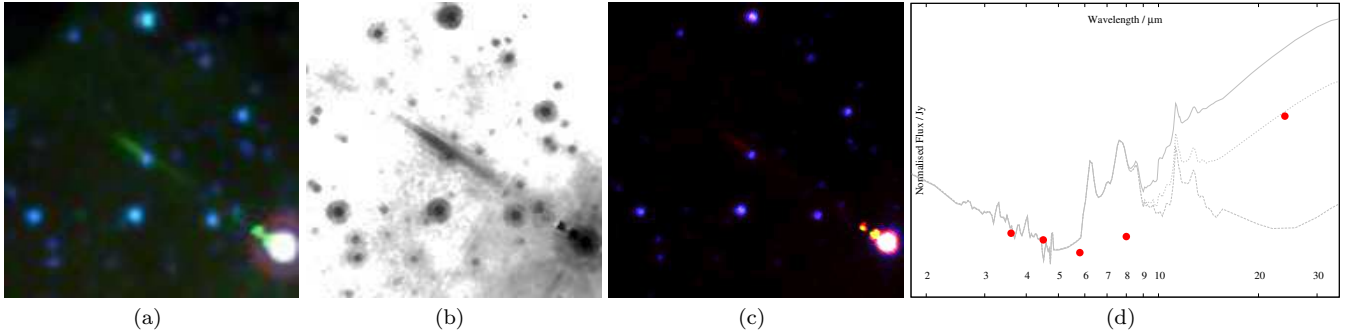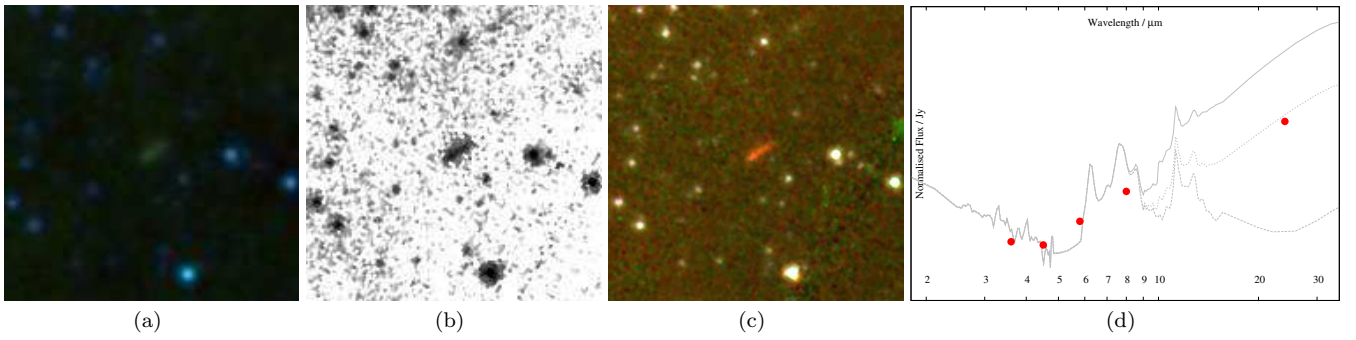

Figure 3. Data for galaxy candidate 3. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
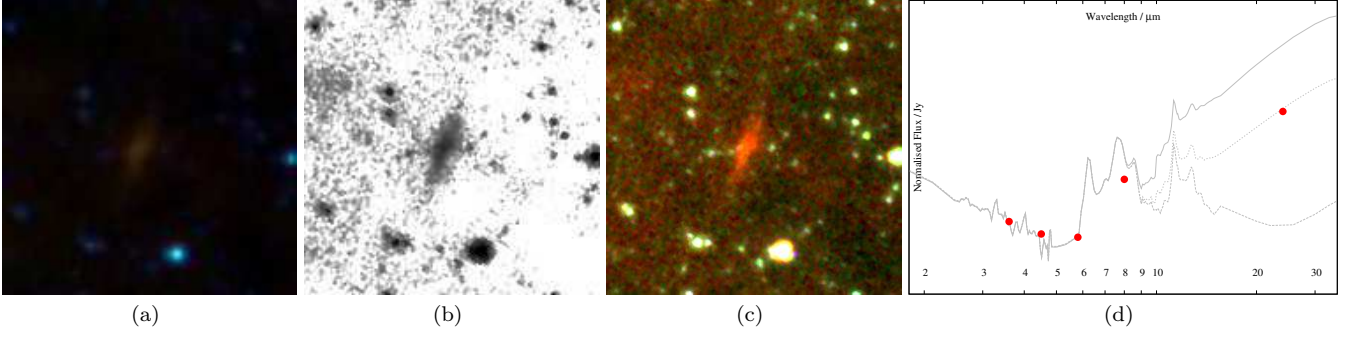
Figure 4. Data for galaxy candidate 4. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
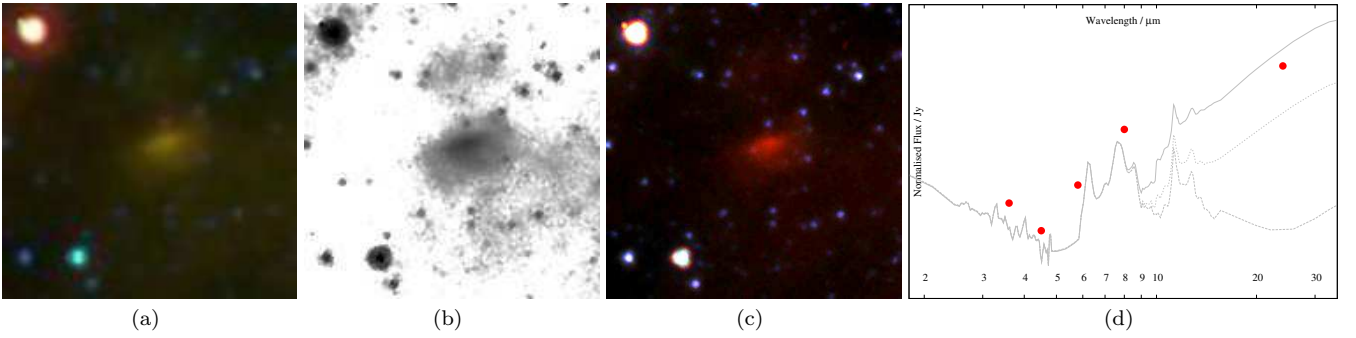
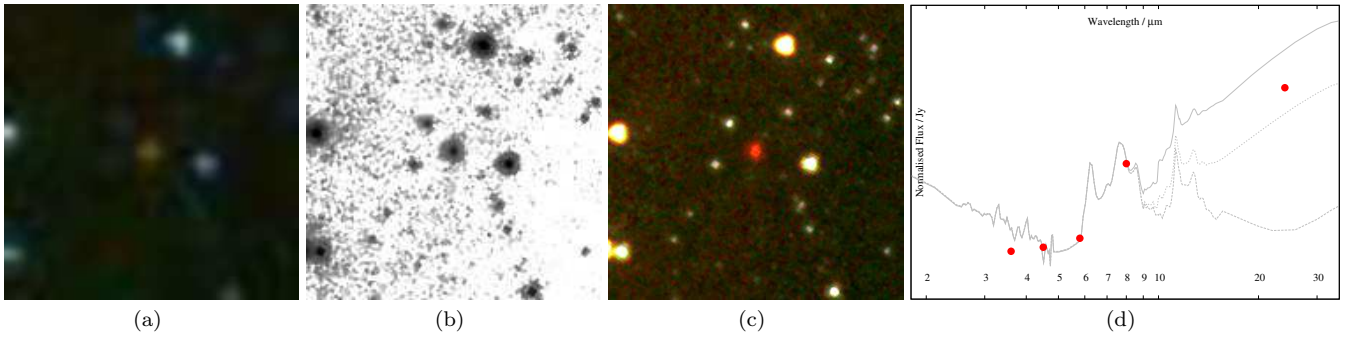
Figure 5. Data for galaxy candidate 5. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
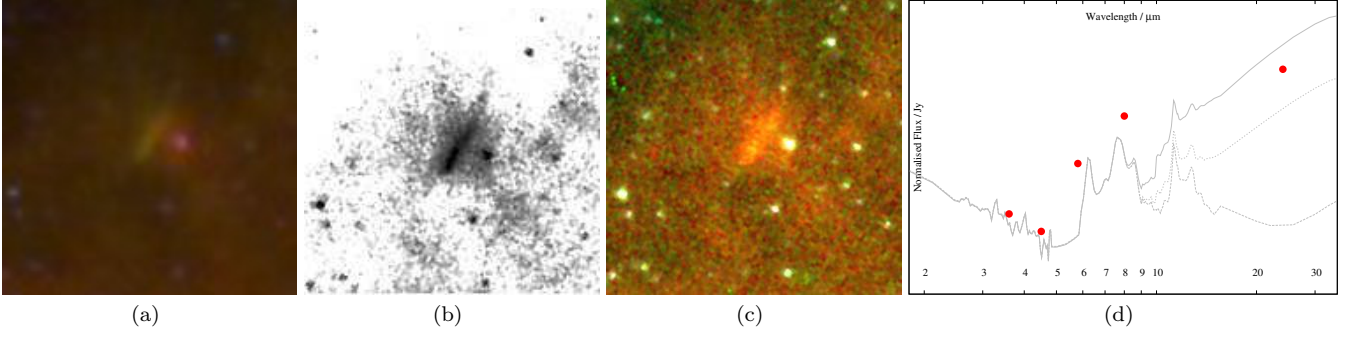

Figure 6. Data for galaxy candidate 7. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
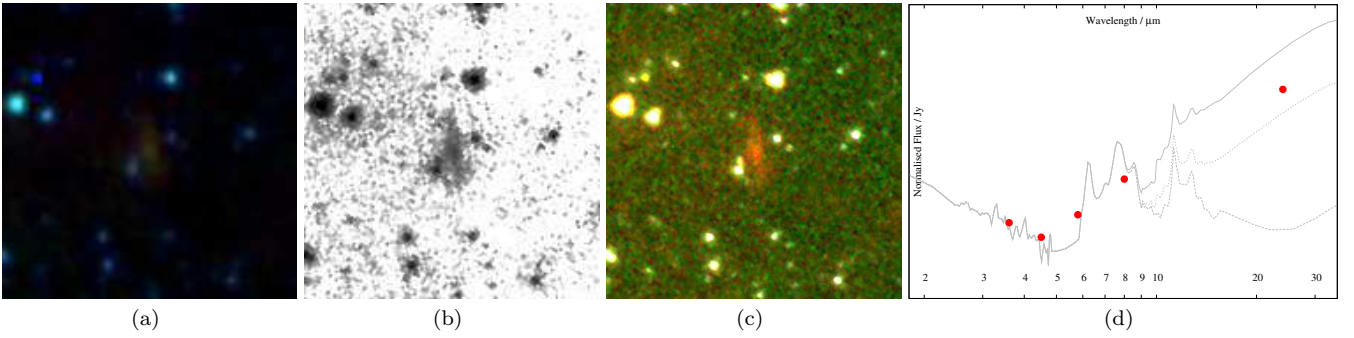
Figure 7. Data for galaxy candidate 8. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.

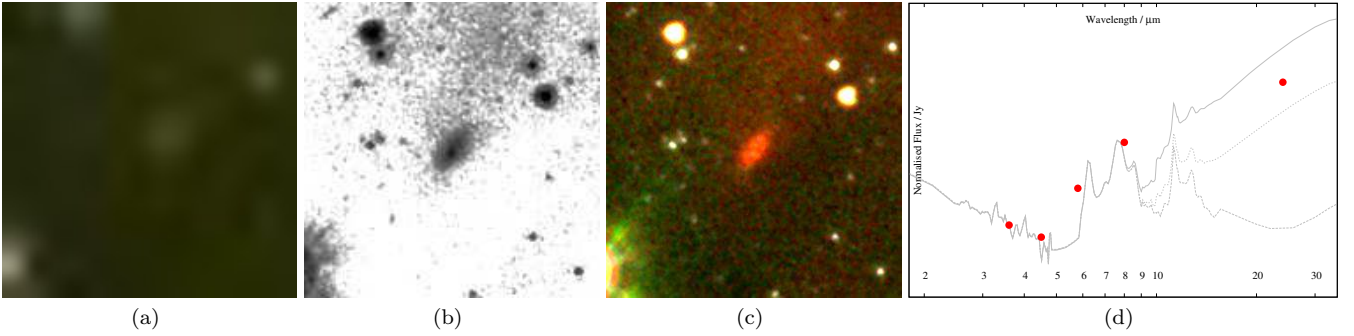
Figure 8. Data for galaxy candidate 9. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.

Figure 9. Data for galaxy candidate 10. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
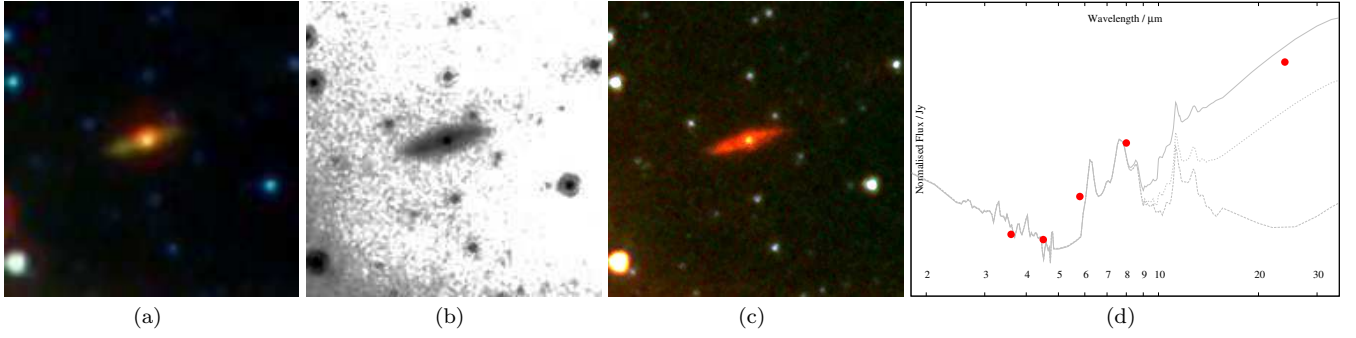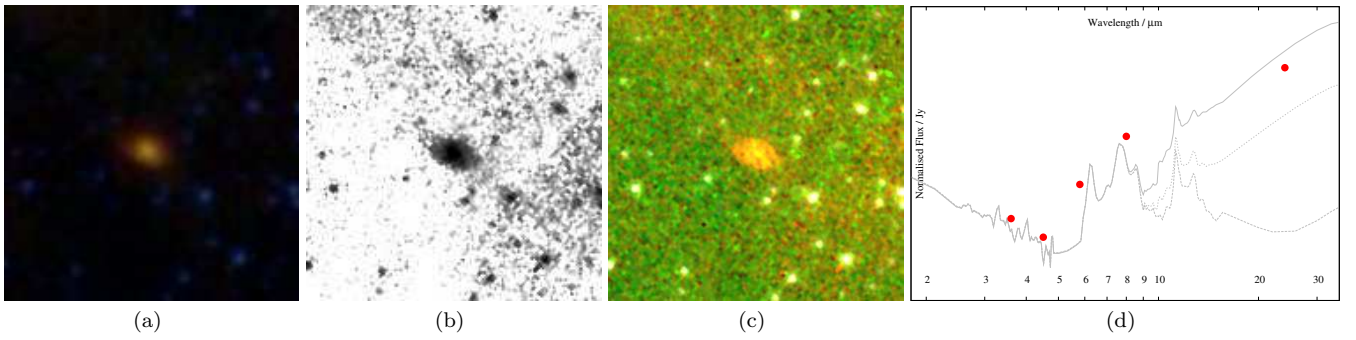
Figure 10. Data for galaxy candidate 11. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.

Figure 11. Data for galaxy candidate 12. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
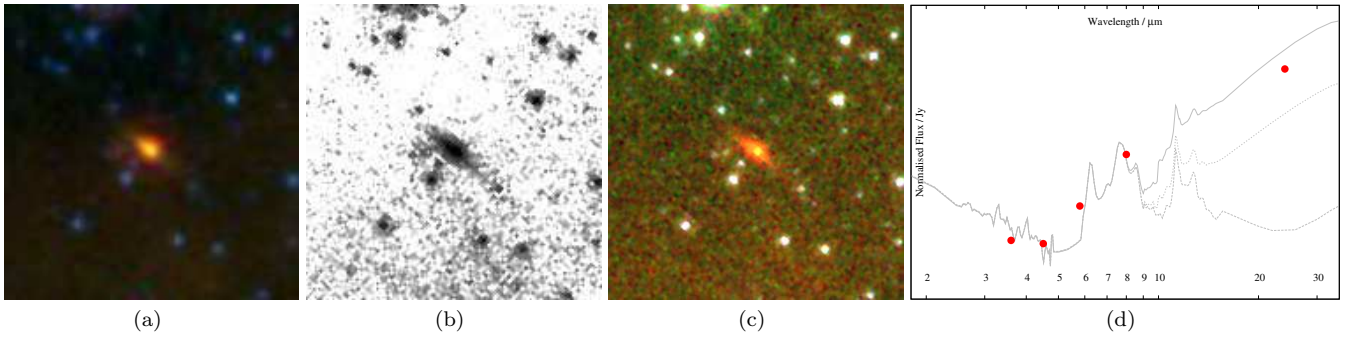

Figure 12. Data for galaxy candidate 13. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
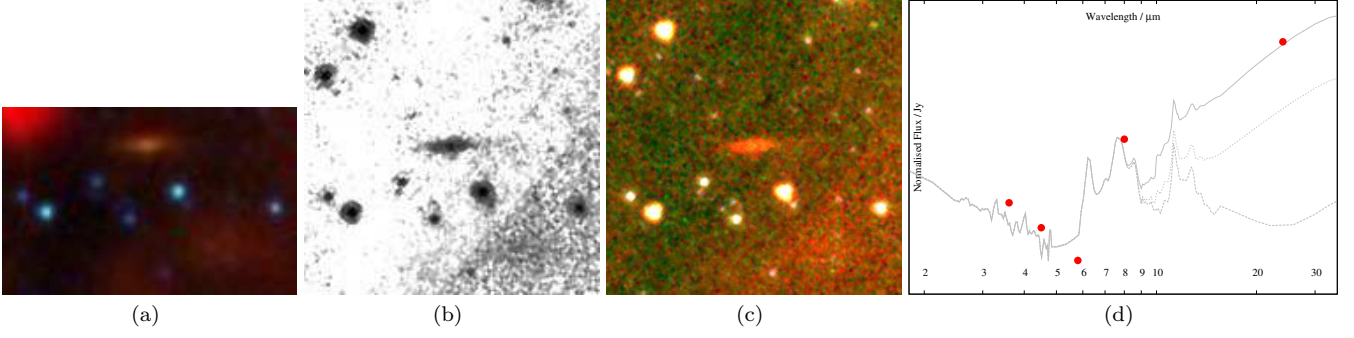
Figure 13. Data for galaxy candidate 14. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
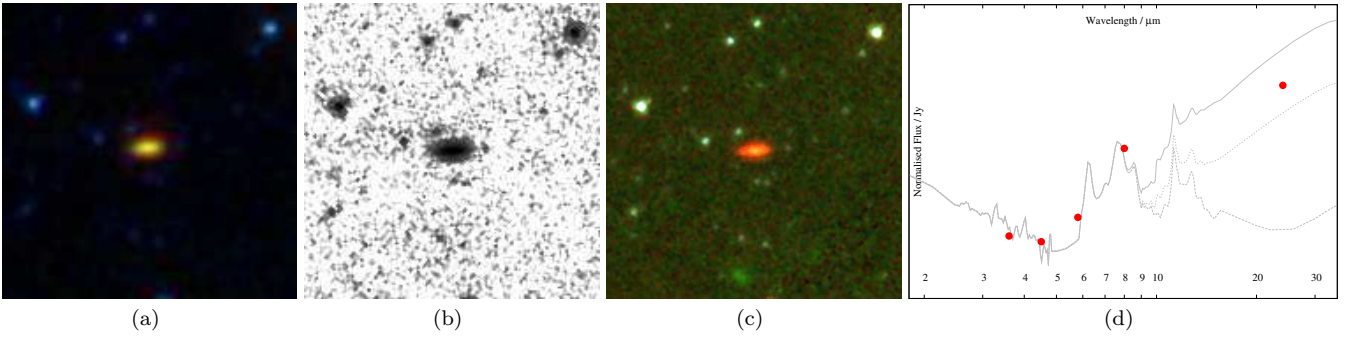

Figure 14. Data for galaxy candidate 15. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.

Figure 15. Data for galaxy candidate 16. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.
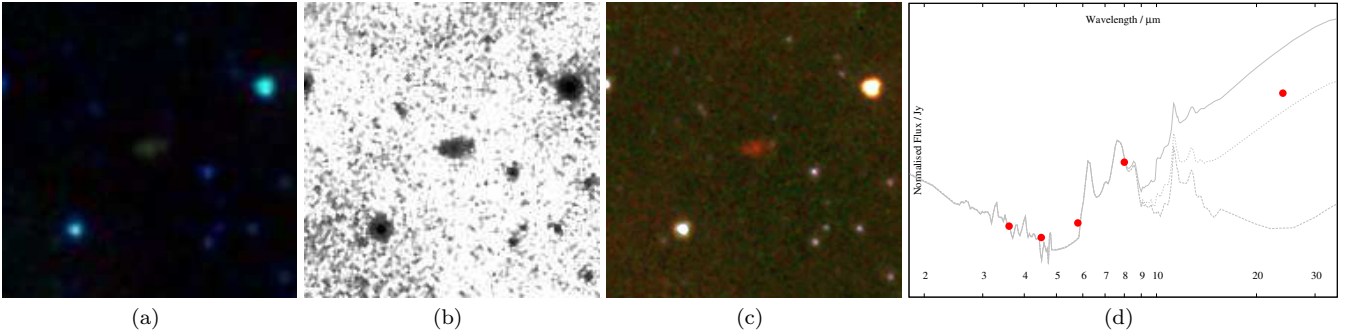
Figure 16. Data for galaxy candidate 18. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.

Figure 17. Data for galaxy candidate 19. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.

Figure 18. Data for galaxy candidate 20. Subfigures show (a) MWP image cutout; (b) IRAC 8μm data; (c) Three-colour composite with RGB channels using Spitzer IRAC bands 8μm, 4.5μm and 3.6μm respectively; and (d) measured SED for this object.