Austrian Academy of Sciences
Space Research Institute
Department of Experimental Space Research

ROSETTA-MIDAS
Particle Catalogue Document

Version 1.0
17/12/2018

Introduction & Purpose

The Micro-Imaging Dust Analysis System (MIDAS) dust particle catalogue consists of a comprehensive list of all possible cometary dust identifications made by the MIDAS instrument. The purpose of this document is to give a description of the catalogue. For the specific format of parameters see the catalogue label file.

Catalogue Description

Table 1 lists the information available in the catalogue, which is thereafter discussed in more detail in the following text.

Column Position	Column Name	Description
1	Particle ID	Unique particle identification string consisting of the start time of the scan containing the particle, a particle number corresponding to the mask number in the mask file and BROWSE images, and the MIDAS dust collection target number. e.g. 2016-02-22T232219_P01_T06 , where 2016-02-22T232219 is the start time of the scan in year-month-day hours minutes seconds format, P01 is the particle/mask number, T06 shows that the particle was found on target 6.
2	Particle Scan File	The full PSA archive path and filename of the image containing the particle.
3	Particle Mask File	The full PSA archive path and filename of the file containing the particle mask (all particles in one image are masked in the same mask file, the Particle Bounding Box, column 29, can be used to extract a single particle).
4	Prescan File	If found, a Prescan (full PSA archive path and filename is given) is the closest previous scan of the same region on the target in which the current particle was identified, and the identified particle is not present (i.e. the particle arrived on the target between the Prescan File and the Particle Scan File).
5	Flag 1: Prescan Flag	Values: 0: No prescan 1: Corresponding features seen in both the prescan and particle scan can be used to visually identify that the same region has been scanned and that the particle feature is not present in the prescan. 2: The same region has been scanned by the prescan, as determined from the commanded scan coordinates, but there are no visible features available to confirm this, the identified particle feature is not present in the prescan. 3: The same region has been scanned as determined

		from the commanded scan coordinates, the identified particle is not seen in the prescan but may be hidden by bad/failed scanning regions in the prescan. 4: The target has not been exposed between the prescan and particle scan such that the particle identified must have been deposited on the target in some other fashion.
6	Flag 2: Particle Flag	Values: 1: Probably cometary in origin. 2: More doubt as to the particle origin. 3: Cannot differentiate between the particle and contamination. 4: More than one particle identification in the scan shows the same repeatable morphology, suggesting that contamination on the tip is being imaged rather than the particle on the target surface.
7	Flag 3: Imaging Quality	Values: 1: The entire particle has been imaged with no imaging issues. 2: The whole particle is not fully imaged (*e.g.* the particle is cut-off at the edge of the image boundaries such that part of the particle lies outside of the image, the full cantilever extension is reached such that part of the particle may not have been imaged), otherwise no imaging problems. 3. Imaging artefacts or issues in the scanning (overwrites values 1 and 2).
8	Flag 4: Multiple Fragments	Values: 0: Multiple fragments not flagged. 1: There are clear multiple fragments contained within the particle mask/identification which were too hard to separate and may be separate particles or part of the same main particle.
9	Flag 5: Trust Height	If the particle is not fully imaged, the scan is at too lower resolution, or has one of a variety of imaging problems, then the estimation of the particle height may not be reliable, this is flagged by the flag value of 2. Values: 1: ok 2: not trusted
10	Flag 6: Physical Alteration Scan	Values: 0: Not flagged. 1: There is a previous scan of the same target region made just prior to the current scan or in-between the current scan and the last scan in which a particle was seen in the same region (Linked Particle ID) which is either a contact mode scan (physically touching the particle) or a failed scan in which it appears that a large particle is being stuck by the cantilever/tip.

11	Linked Particle ID	Particles have been scanned in more than one image. The Linked Particle ID provides a link between these particles and is equal to the Particle ID of the previous identification of the same particle (blank string if not previously seen). If the ID contains the linked particle number 00 (i.e. 2014-11-19T213423_P00_T10) the particle could be linked to the given scan (as the same target region is covered) but not to a specific particle in that scan (*e.g.* the particle may be a remnant of a damaged particle in the linked scan).
12	Linked Particle Scan	The full archive path and filename for the linked particle scan.
13	Flag 7: Linked Particle Flag	Values: 0: No linked particle. 1: The linked particle is likely the same particle. 2: It is likely that the linked particle is the same particle but there are more visible differences which cause some doubt (the particles may be different particles or the same particles with larger visible differences between scans caused by a number of possibilities, *e.g.,* the scan resolution has significantly changed, a different tip has been used, the particle has been damaged or moved during scanning, there is an imaging/failed scanning in some regions.) 3: The current particle identified is likely the remnants of a particle previously scanned in the Linked Particle Scan but we are unable to link to a specific particle (the particle number is always 00 in the Linked Particle ID in this case).
14	Master ID	The Particle ID of the first time the particle is seen. All identifications of the same particle in different scans can be extracted by the same Master ID. However, not all particles could be linked to a specific particle in a previous scan but appear to be the remnants of a previously identified, and now damaged, particle (Linked Particle Flag value of 3). Since we cannot link to a previous specific particle, the Particle ID of the remnant now becomes a new Master ID for this any subsequent identifications of the same remnant. A link between all remnants and parent particles is represented by the Master Scan below.
15	Master Scan	While the Master ID links all identifications of the same particle which can be clearly identified as the same particle, the Master Scan provides a cross-link between the scans/image files in which all identifications of the same particle have been made, as well as all possible remnants of the same particles (see Linked Particle Flag value 3).

		It consists of the full PSA archive path and filename of the first scan (Particle Scan File) in which any particles possibly linked to the current identification were seen, and thus allows these scans to be extracted from the catalogue.
16	Area Pixels	Total area of the particle mask in pixels.
17	Area Microns	Total area of the particle mask in microns.
18	Zmin, Zmax, Zmean	[Minimum, Maximum, Mean] pixel height within the particle mask in microns.
19	Particle Height	Height estimation of the particle determined from the height of the highest pixel within the particle mask and the median height of the pixels surrounding the mask (i.e. the target surface), where the target has been levelled by a mean plane subtraction (excluding particle masks and bad regions in the fit) prior to height estimation.
20	Particle Height Standard Deviation of Surrounding Pixels	The standard deviation of the heights of the pixels surrounding the particle mask used for height estimation.
21	X and Y Step	X and Y pixel resolution in nm [X step, Y step].
22	X Y Origin	The X and Y location of the upper left corner of the image on the target relative to the target centre [X origin, Y origin].
23	X Y Length	The X and Y length of the image in microns [X length, Y length].
24	Tip Number	Cantilever and tip used in scanning.
25	Target	The dust collection target number.
26	Last Tip Image Start Time	Start time of the last tip image of the tip used in scanning.
27	Tip Image	Filename of the last image made of the tip on the tip calibration target.
28	Particle Bounding Box	The image coordinates [minimum row position, maximum row position, minimum column position, maximum column position] in pixels which can be used to extract the particle mask/data from the mask/image files for the particle identified.

Table 1. List of columns in the particle catalogue.

All MIDAS images have been visually examined for possible cometary dust. Each cometary dust identification is recorded in the particle catalogue. Each particle has been masked using the open source Gwyddion Atomic Force Microscope (AFM) software, a link to the particle mask file is provided in the catalogue along with several flags highlighting the quality and/or confidence of the identification and image/scan quality, as well as additional parameters describing the particle and image properties. Table 1 contains a description of all columns contained within the catalogue. Below we describe the procedure used in creation of the catalogue and expand on the description of its contents.

The first step in building the catalogue was to visually identify all possible cometary dust in MIDAS images. The most sure fire way to determine whether a feature in a scan is cometary in origin is to look for a previous scan of the same region on the dust collection target made prior to the last exposure of the target to space in which the particle is not present. While several such 'prescans' were commanded, due to the amount of time it takes to scan large areas of the MIDAS targets (see Table 1 Bentley *et al.,* 2016), and as MIDAS is not capable of exposing targets simultaneously as scanning them, a balance needed to be struck between time spent pre-scanning the targets and searching for dust particles on already exposed targets. Of the 1480 particle identifications in the particle catalogue, in only 111 cases (from 24 separate images) were we able to find prescans of the same region made prior to the last exposure. When scanning MIDAS targets the scan coordinates are pre-commanded before the start of the scan (see Bentley *et al.,* 2016). While this should allow us to know which regions on the target have been scanned, piezo controlled AFMs are always subject to the possibility of temperature drifts and non-linear behaviours such that there may be small offsets between the commanded scan coordinates and those actually achieved. Indeed, by comparing known features, some MIDAS scans were seen to show an offset of a few microns (which could not be quantified in any systematic way) from the commanded positions on the target. MIDAS targets have no regular pattern or feature etched on their surface that would allow visually identification that the same region has been scanned, but in some cases it is possible to cross-correlate common features to identify that indeed the same region on the target has been imaged. A Prescan Flag (Flag 1) value of 1 represents this case (11 particles from 3 images). A Prescan Flag value of 2 represents when the commanded positions suggest that the same region has been scanned but there are no visible features in the scans which allow us to confirm this (89 particle from 19 images). A Prescan Flag value of 3 represents when there is prescan of the same commanded position, the particle is not seen, but there are 'bad' or failed regions in the prescan which may prevent the particle from being seen (11 particles from 2 scans). A Prescan Flag value of 4 represents special cases when there was no exposure of the target between the prescan and the scan in which the particle is seen (35 particles from 9 images). These cases are likely particles which have previously attached themselves to the cantilever tip during scanning of a particle, and have subsequently fallen from the tip onto the target. The search criteria for a prescan is that it covers the same region of the target in which the particle is seen, occurs prior to the current scan, and that the particle identified is not present. MIDAS targets were exposed many times, therefore scans recorded as prescans for one particle entry may also contain other cometary dust particle identifications made in the catalogue, as the target may have been previously exposed and dust already collected and identified in different areas of the same image.

While a Prescan Flag value of 1 shows that the particle was not present prior to the previous exposure of the target, and is therefore likely to be cometary in origin, due to the low number of prescans available, we also flag how likely we believe that the dust identification is of cometary origin based on a different set of criteria, represented by the Particle Flag (Flag 2). A Particle Flag value of 1 represents when we are as sure as we can be that the particle is of cometary dust origin, that is, there is no reason to believe that it is not cometary in origin, *e.g.* it is too big to be contamination (see below for discussion on contamination), the 'splatter' pattern of many small particles is clear evidence of the fragmentation of larger particles on impact or during collection and is dissimilar to any contamination pattern seen, or we have seen the particle previously. A value of 1 is used even

when there is no prescan, and a total of 1132 of the 1480 particle identifications are flagged as such. A Particle Flag value of 2 represents there being more doubt as to the origins of the particle, *e.g.,* due to imaging issues, something unusual in the image or about the particle (32 cases from 19 scans). MIDAS targets scanned prior to their first exposure to space often showed small features which can be indistinguishable from the smallest cometary dust particles. The majority of these have heights of less than 200 nm but occasionally can be larger, as shown in Figure 1. For all targets in which particles have been identified images, all images made prior to the first exposure to space were searched for possible contamination and any particle identifications which are similar in size to the maximal sized contamination identified on the target are flagged by the Particle Flag value of 3 (219 particles from 57 images). Occasionally all particle like features in one scan very clearly show the same morphology. In these cases, we believe the tip used in scanning to be strongly contaminated with particles stuck to the tip, or that the tip is very blunt, and while there are particles present on the target the shape of the tip and attached particles, rather than the shape of the particles on the target, are being imaged. Such events are flagged with a Particle Flag value of 4 (97 cases in 16 scans).

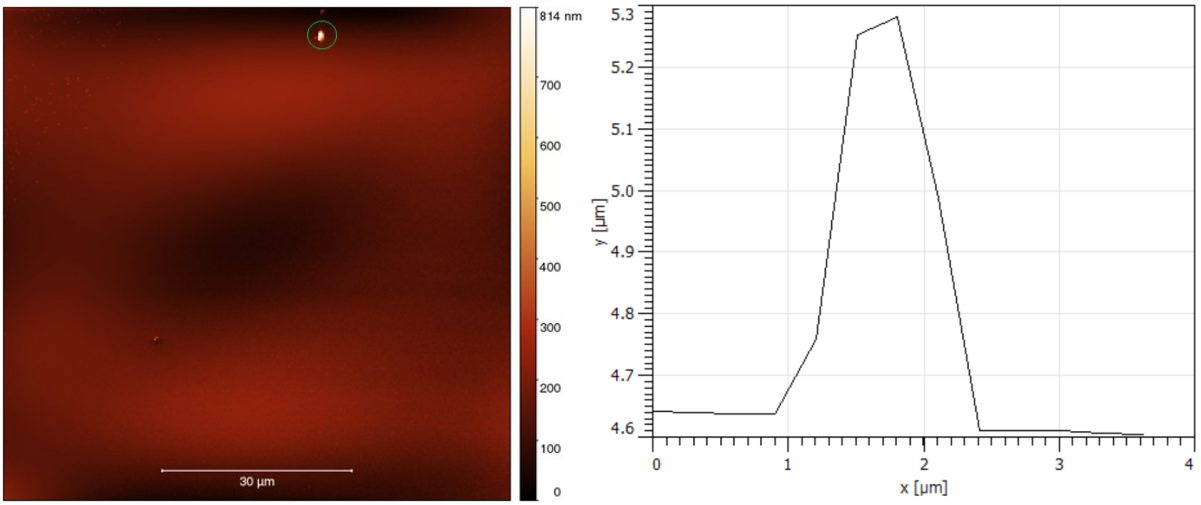

Figure 1. Left hand side: MIDAS scan of target 13 made on 2015-02-28 prior to the first exposure of the target to space showing a contamination feature (green circle). Right hand side: Height profile across the feature shown by the green circle.

There are 4 more flags providing information on the imaging quality and additional information of each particle. Table 2 below summarises the number of particles and images for each flag number.

	Number of Particles	Number of Images
Total Particles	1480	230
Flag 1: Prescan Flag		
0: No Prescan	1334	210
1: Visually identified the same region	11	3
2: Target address only cross-correlated	89	19
3: Artefact inhibits confirmation	11	2
4: No exposure between scans	35	9
Flag 2: Particle Flag		
1: Confidence level 1- Probably cometary in origin	1132	199
2: Confidence level 2- More doubt	32	19
3: Confidence level 3- Cannot differentiate from contamination	219	57
4: Tip contamination	97	16
Flag 3: Imaging Quality		
1: Entire particle imaged	866	168
2: Partial particle imaged	278	123
3: Imaging issue	336	102
Flag 4: Multiple Fragments		
0: Not flagged as having multiple fragments	1346	225
1: Clear multiple fragments	134	62
Flag 5: Trust Height		
1: yes	1034	194
2: no	446	120
Flag 6: Physical Alteration Scan		
0: no	1199	194
1: yes	281	37
Flag 7: Linked Particle Flag		
0: No linked particle	810	143
1: Confidence 1- the same particle	341	86
2: Confidence 2- less certain	52	31
3: Remnants	277	38
Number of unique Master ID	1088	
Number of unique Master Scan		140

Table 2. Number of particles and scans for different flag values. If one wished to extract all well imaged, unaltered, whole particles, which we have highest reasonable confidence are cometary in origin the following flag values would be used: Flag 1- not equal to 4, Flag 2=1, Flag 3=1, Flag 4=0, Flag 5=1, Flag 6=0 and Flag 7-not equal to 3, resulting in 438 separate particle identifications consisting of 357 unique particles (excluding rescans of the same particles using the Master ID) from 80 different target regions (same target regions extracted with Master Scan).

The Imaging Quality flag (Flag 3) describes how well the particle is imaged in the scan. If the entire particle has been imaged with no imaging issues Flag 3 has a value of 1 (866 cases from 168 scans). If there are no imaging issues but the entire particle has not been imaged (part of the particle fall

outside of the boundaries of the image, or the cantilever has reached maximum extension such that all of the particle cannot be reached, or parts of the particle are hidden by failed regions in the scan) a Flag 3 value of 2 is used (278 cases from 123 images). Various imaging issues can occur during scanning which may cause poor imaging of the particles, these visually identified cases (336 particles from 102 images) have a Flag 3 value of 3.

As with all AFM's, all MIDAS particles are a convolution of the tip and the particle, with the strength of the effect variable for every particle dependent on the condition of the tip and the morphology of the particle. MIDAS features a tip imaging target which allows the first 700 nm of the MIDAS tips to be imaged, however since the particles imaged by MIDAS where found to be much larger than this, a full tip deconvolution is not possible. In addition, tip images are sporadic due to time constants. While an experienced AFM expert may be able to quickly visually determine tip artefacts and issues within the images, due to the varied and complicated nature of such convolution we find no quantitative measure to describe it, and do not attempt to label such artefacts or issues beyond flagging clear imaging issues/failures (Flag 3 value 3) and repeatable patterns which are clearly tip artefacts (Flag 2 value 4), and leave such a further detailed analysis to the individual scientist. A table of all available tip images (MID_TIP_IMAGES.pdf) is provided in the archive.

The Multiple Fragments flag (Flag 4) is used when there are clear multiple fragments within the identified particle mask which may or may not be separate particle but were too difficult to separate as such or appear to belong to the same main particle.

The Trust Height flag (Flag 5) has a value of 2 when there are visually identified imaging issues which may cause any height estimation in the masked area to be incorrect (*e.g.* max/min cantilever extension reached, failed imaging covering part of the particle).

The Physical Alteration Scan flag (Flag 6) is used when there is a contact mode scan (in which mode the tip is gently pushed into the surface detected), or a failed scan in which it appears that a large particle may be being hit by the cantilever and a particle identification has not been made, in the same region of the target prior to the current scan, or between the current scan and the linked scan (*i.e.* between this scan and the last time the particle was scanned). That is, the particle may have been damaged during a previous failed or contact mode scan of the same region.

An individual particle can be imaged in more than one MIDAS scan. The Linked Particle ID represents the Particle ID of the last time the particle was seen, and the Linked Particle Scan the scan in which the particle was previously seen (its previous entry in the catalogue). The Linked Particle Flag (Flag 7) describes how sure we are that the linked particles are the same particle. A value of 1 is used when we are able to clearly distinguish that the two particles are the same (from the position on the target and either their morphology or from the distribution of other particles or features seen in the scans), while a value of 2 is used when there is more doubt. A value of three is used when the same region of the target in which the current particle identification is made has previously been scanned and there are particles present, but due to large visual differences in the morphology of the particles in the two scans we are unable to match between specific particles. It is likely in these cases that the particles in the first scan have been changed during scanning and we are now seeing the remnants of these original particles.

The Master ID represents the Particle ID of the first time the particle is seen in the catalogue. All identifications of the same particle in different scans can be extracted by the Master ID. However, not all particles could be linked to a specific particle in a previous scan but appear to be the remnants of a previously imaged particle/s that have been damaged in some way. Since we cannot link to a previous specific particle, the Particle ID of these new apparent remnants now become a new Master ID for this and any subsequent identifications of the same particle remnant. A link between all remnants and any possible parent particles is represented by the Master Scan, which represents the first scan in which any of the possibly linked particles have been seen. This is represented schematically in Figure 2.

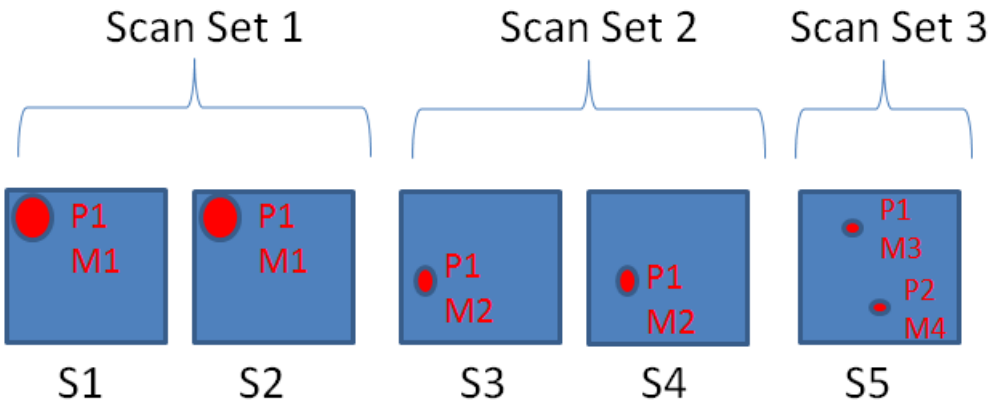

Figure 2. Schematic of how the particles seen in the same regions of a target are linked. All scan sets are of the same region of the target and taken sequentially in time. In the first scan set there is one particle, P1, represented by the red dot, in scans S1 and S2 (both P1 particles in S1 and S2 will have the particle/mask number 1 in their respective entries in the catalogue). Both S1 and S2 P1 particles have the same Master ID (the first time the particle is seen) M1 (M1 = S1-P1), and S2-P1 is also linked to S1-P1 through the Linked Particle ID. In the second scan set the same region of the target has been scanned as in scan set 1 (with no exposure of the target in between), but there is now one particle of very different morphology (particle S3-P1), which is also seen in the next scan (particle S4-P1). These two particles now share the same Master ID M2 (M2=S3-P1), and are also linked by the Linked Particle ID (linked particle ID for S4-P1 is S3-P1). S3-P1 is also linked to the scan S2 through the Linked Particle Scan (S2) and a Linked Particle Flag value of 3 (cannot link to a specific particle in the previous scan), while the particle number in the Linked Particle ID will be 00. In the third scan set the same target region has once again been scanned with no exposure of the target in-between, but now there are 2 separate smaller particles which both have their own new Master IDs, M3 and M4. Both of these particles are linked to the scan S4 through the Linked Particle Scan/ID with particle number value of 00 and with Linked Particle Flag Value of 3. All 6 particles have the same Master Scan of S1.

Additional information in the catalogue includes, the area of the particle mask in pixels and microns, the mean, maximum and minimum height of pixels in the mask in microns, an estimation of the height of the particle from the difference of the median of the heights of all pixels surrounding the

particle mask (every pixel immediately adjacent to the edge of the mask, representing the height of the target surface) and the tallest pixel in the mask. In addition, the X and Y resolution (step size) of the scan, the X and Y coordinate of the first pixel in the scan (top left hand pixel in all images) in target coordinates, the X and Y length of the image, the tip number and target number used in scanning, the filename and start time of the last image of the tip made on the tip imaging target, as well as a bounding box containing the pixel coordinates which can be used to extract individual particles/masks from the image/mask files.

BROWSE Images

There are three BROWSE images for each scan/image containing particles in the particle catalogue. These can be found in the BROWSE directory of the particle catalogue dataset. The filenames correspond to the Particle Scan File in the particle catalogue, as shown in Figure 3 below:

PRV_filename_ZS – BROWSE image of the MIDAS scan.

PRV_filename_MK BROWSE image of the particle masks.

PRV_filename_SP BROWSE image of the scan location on the MIDAS target.

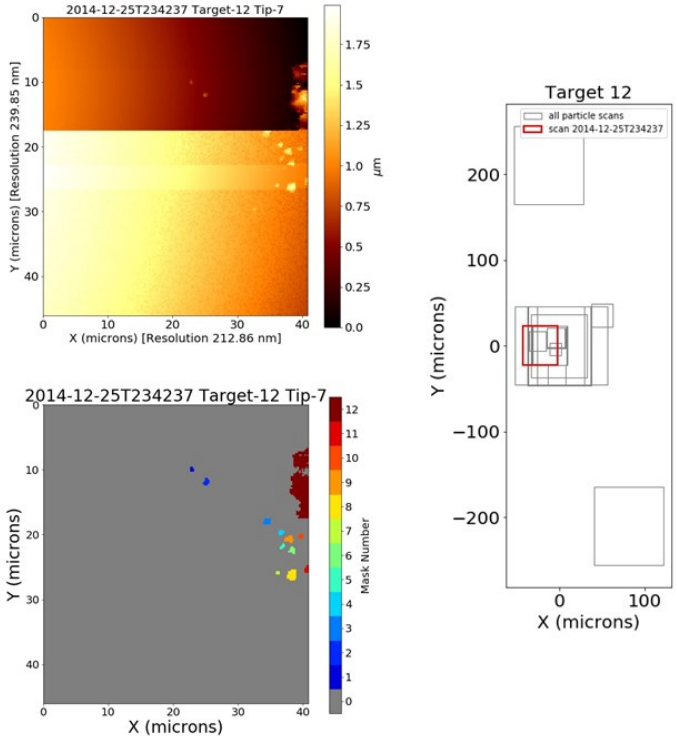

Figure 3. Example of particle catalogue BROWSE images. Particle entries in the catalogue for the image shown are from the Particle Scan File 'RO-C-MIDAS-3-ESC1-SAMPLES-V3.0/IMG_1435401_1501400_022_ZS'. The BROWSE images are found in the BROWSE directory of the particle catalogue datasets. The top left image shows the BROWSE image of the MIDAS scan (browse image filename 'PRV_1435401_1501400_022_ZS'). The bottom left figure shows the BROWSE image of the particle masks, where the mask number shown corresponds to the particle number in the Particle ID's of the catalogue (browse image filename 'PRV_1435401_1501400_022_MK'). The figure on the right shows the BROWSE image of the scan location on the MIDAS target (red) and all other scans made on the target in which particles were found (grey) (browse image filename 'PRV_1435401_1501400_022_SP').

References:

Bentley, M.S., *et al.,* MIDAS: Lessons learned from the first spaceborne atomic force microscope, Acta Astronautica, 2016, DOI: 10.1016/j.actaastro.2016.01.012.