The effects of dust outbursts on the anomalistic features observed by Rosetta Alice around 67P/Churyumov-Gerasimenko

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ABSTRACT

The Alice far-ultraviolet spectrograph on board the *Rosetta* spacecraft currently operating around the comet 67P/Churyumov-Gerasimenko experiences an anomalistic feature (AF) that has proven nearly constant at comet separations below 450 km.[1] This feature varies rapidly on a time scale of seconds and displays no relation to any measured parameters with the exception of comet separation. Simulations showed that nanograins and ions could create the feature through a range of possible masses, velocities, charges, and energies. This paper builds on research published in Noonan et al. 2016 that explored the behaviors and morphology of the AF. Observations taken on February 19th, 2016 during a dust outburst observed by several other instruments (Eberhard Grun, in prep) verified that the most common morphology of the AF is linked to dust and charged nanograins.

Keywords: Rosetta, comets, Alice, FUV, anomalistic, 67P/CG

1. INTRODUCTION

Starting August 7th of 2014, the same day as orbital insertion of the *Rosetta* spacecraft around comet 67P/Churyumov-Gerasimenko, the ultraviolet spectrograph (UVS) Alice[2] on Rosetta began to return exposures containing a concave feature near the 850Å portion of the detector. This anomalistic feature (AF) shared a shape with a scattered light feature that was noted before with the Lyman Alpha Mapping Project UVS on board the Lunar Reconnaissance Orbiter, in addition to Alice during the *Rosetta* Mars flyby, and initially it was determined to be normal scattered light. However, on August 29th, 2014 the feature began to quickly change shape and intensity, thus earning the nickname the "Chameleon". AF and Chameleon will be used

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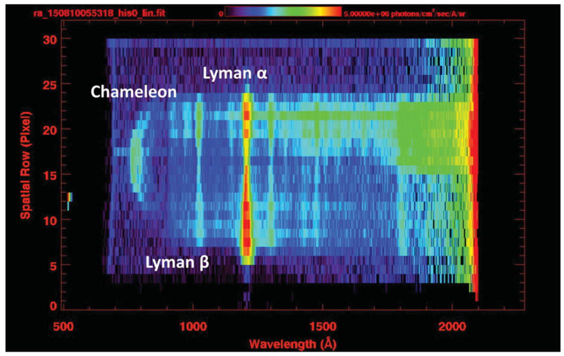

Figure 1. An average "Chameleon" AF for R-Alice, make note of the low counts relative to the cometary and Ly-α signal as well as the slight curvature of the AF. Figure reproduced from Reference 1

interchangeably throughout the paper to refer to this feature. By late December 2014, the frequency of the Chameleon in science images approached 100% at less than 450 km from the comet, with the AF occupying 80% of stellar calibrations, causing concern among the team that it might be harming the instrument and could create problems with science analysis if it persisted. In this report we discuss the morphology, strength, long term effects on operations, and verification of the simulations performed for ion and nanograin particles impacting the R-Alice detector.[1]

2. INSTRUMENT DESCRIPTION

The Alice instrument is a lightweight, low-power, imaging far-ultraviolet (FUV) spectrograph designed and built to gather spatially resolved spectra in the 700-2050 $\mathring{A}$ range with a spectral resolution of 8-12 $\mathring{A}$ for extended sources that fill the field of view. The instrument slit is 5.5° long and has a dog bone design that is 0.05° (100 microns) wide in the center 2.0°-long section and 0.10° (210 microns) wide in the sections on either end. The microchannel plate (MCP) detector is 35x20 mm with pixels 34x620 microns for the 1032 spectral columns and 32 spatial rows ; rows 6-24 are illuminated by the slit, and each row subtends 0.30°. The detector utilizes dual solar blind opaque photocathodes (CsI and KBr) and a two-dimensional double delay-line readout. An off-axis telescope directs into a 0.15-m normal incidence Rowland circle spectrograph with a concave holographic reflection grating, all of which are in an open system. More information on the Alice instrument is detailed by in Ref. 2.

3. AF MORPHOLOGY

The earliest apparitions of the AF were a slight curve that opened toward the Ly-α emission line at 1215.67 $\mathring{A}$ and only extended between rows 13 and 20 on the detector (Fig. 1). Additionally the AF began to exhibit multiple curves appearing out of the original 850 $\mathring{A}$, extending to the blue end of the detector in a pattern similar to a ripple. During the dust outburst seen on February 19th, 2016 four of these curves were seen, and some combination of these curves is present in nearly all science images. The largest fraction of counts reported in images containing

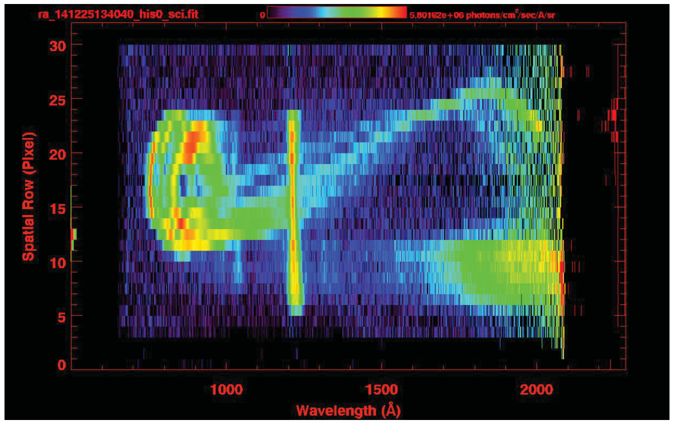

Figure 2. Similar morphology as in Fig. 1, but with increased non-focused counts in the middle rows on the detector near Ly-α as well as "tails" extending towards rows out of reach of normal optical path. Figure reproduced from Reference 1

the AF come from the 790-1000 $\AA$ range, corresponding to columns 790-900 on the detector, with a physical width of about 3.7 mm. By the end of 2014 several morphologies were seen that peaked concern, due to the increased size of tails coming from the normal AF region (Fig. 2). However, these tails do not appear often, and when they do they have much lower count rates than the primary Chameleon region containing the curves. More images and information on the AF can be found in 1.

The most useful way to characterize the AF is by determining its count rate, both alone and relative to the total count rate that the Alice instrument reports. Alice telemetry reports total count rate information for the entire detector at certain intervals during observations, but those count rate data do not contain spatial information about where each count was detected on the MCP. Determination of the count rate in a certain area requires processing an image (typical exposure times of 5-10 minutes), summing up all the counts for that area and dividing by the exposure time. This process produces an average count rate in the AF region for the observation that can then be compared to the total count rate for the observation. When the two values are close it can be implied that most of the counts reported in the higher-cadence total count rates came from the AF, and so those higher-cadence total count rates can then be used as a proxy to see how the AF behaves during an observation. For example, on the 23rd of October an image was taken on the shadowed side of 67P/C-G that contained a strong AF (Fig. 3), and the count rate information for that observation details the temporal variability the AF exhibits (Fig. 4). This particular AF has an average count rate of 320 +/- 180 counts/s, significantly different than the 220 +/- 20 count/s average of the AF free exposures.[1] This temporal variability of the AF will be revisited in the context of the February 19th, 2016 dust outburst later in the paper.

High activity associated with the AF initially appeared to occur on a monthly timescale, but this rate increased along with cometary activity, especially in December of 2014. At that time, intense AF's began occurring more frequently. Occasionally, like on December 28th, 2014, the count rate from the AF 790-1000 column area was strong enough to trigger a count rate safety for Alice. Currently this count rate safety limit is set at 15544 Hz, and had previously only been reached when very bright O and B stars passed through the Alice slit. During periods of intense

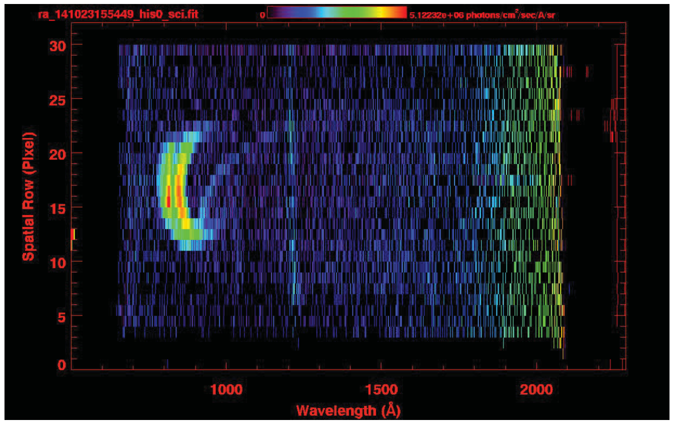

Figure 3. A Chameleon that appeared when performing a shadowed nucleus observation on October 23rd, 2014. Figure reproduced from Reference 1

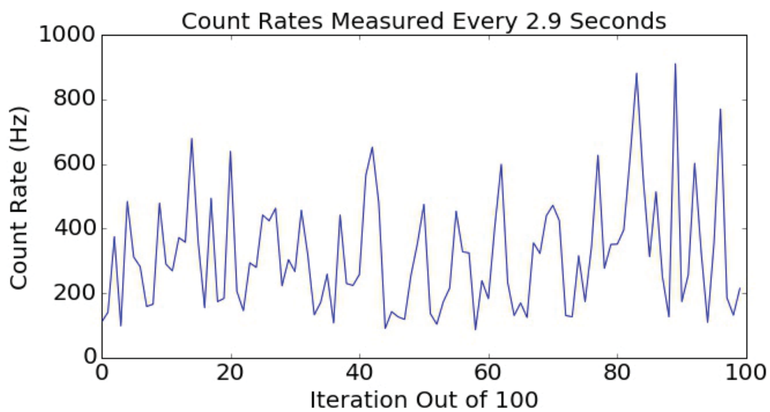

Figure 4. Alice count rate during the observation in Figure 3. Due to the geometry of staring at the shadowed side of 67P/C-G there is a minimal number of photons being detected. This allows for a determination of how the Chameleon behaves on a very short time scale. Figure reproduced from Reference 1

cometary activity and/or low distances to the nucleus of 67P the only way to truly prevent the Chameleon from manifesting is closing the Alice instrument door. The only observations to remain unchanged by the Chameleon are the Alice dark calibration observations, which are done with a closed door and thus a closed optical system.

4. POSSIBLE CAUSES

As previously stated, the AF was initially thought to be a scattered light effect related to the pointing of Alice relative to the sunlit nucleus of the comet. This hypothesis was supported by the observation that the Chameleon disappeared when the Alice aperture door was closed, i.e., during dark calibration exposures. Despite this support the hypothesis was rejected after investigating the count rate variability displayed by the AF, which is much higher than any change in photon flux. Since the AF has also been observed during stellar calibrations that were pointed several tens of degrees away from the comet and sun and during observations of the shadowed side of the nucleus a scattered light origin for the AF can be rejected further and

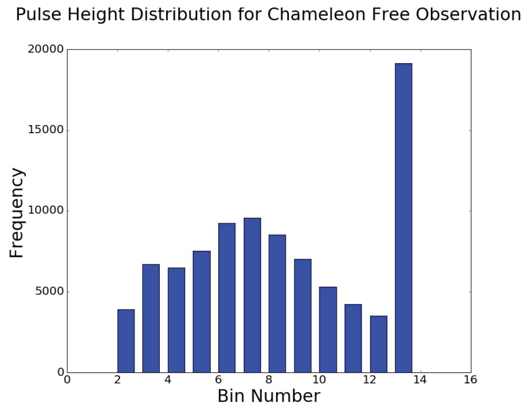

Figure 5. Average Pulse Height Distribution (PHD) for an Alice observation of the comet nucleus. Figure reproduced from Reference 1

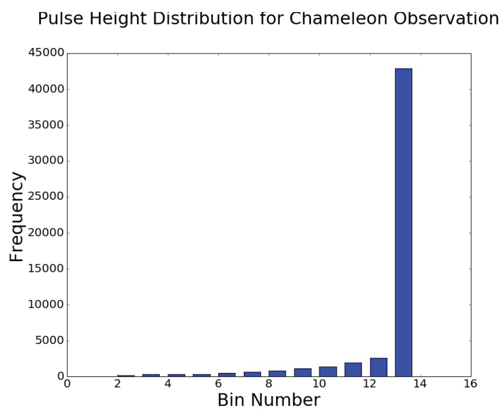

Figure 6. A Pulse Height Distribution plot for the Alice image with a AF shown in Fig. 3. A normal exposure would have a peak roughly 1/3rd the size in bin 14, and a rough Gaussian distribution centered on bin 6/7, as shown in Figure 5. This rules out FUV photons as the source of the AF. Figure reproduced from Reference 1

may suggest the possibility that the instrument is immersed in a nano/micrograin or charged particle environment, some of which may pass through the Alice slit.

One theory considered and simulated in Reference 1 is that extremely small particles of dust (micrometer to nanometers in size) in the environment around 67P/C-G are the cause of the Chameleon. These particles may have found their way into the aperture of Alice and, through Brownian motion, passed through the open slit that divides the telescope of Alice from the detector. The slit would act as a regulator, with only the particles that possess certain velocity vectors capable of passing through. The electric field generated by the Quantum Efficiency (QE) grid on top of the detector could cause these moving charged dust particles to curve towards the detector once they pass through the slit, with each of the curves on the detector representing a particular mass/charge ratio. This would be due to the fact that the velocity vectors of particles passing through the small slit would be roughly similar.

The Alice instrument engineering housekeeping files also provide information that can help

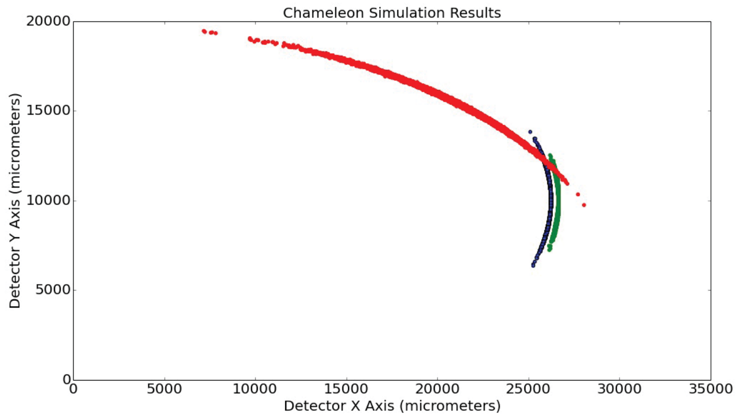

Figure 7. Model of the Chameleon made using a simple simulation of charged masses and a large E field. Each color represents a different input velocity from set of 10,000 particles breaking apart upon entrance to the slit. Notice the Chameleon is mirrored relative to prior images, this is due to a point of view looking towards the detector from the grating. Above images are viewing the detector from behind. Figure reproduced from Reference 1

to quantify the AF. Most useful are the pulse height distribution (PHD) data, which indicates the energy of the detected particles. An ideal PHD plot would look something like Figure 5 where the majority of counts are in a Gaussian in the lower bins, and a peak in bin 13, which is the overflow bin for particles that are above certain energy. When the AF is active, a much different PHD is produced (Fig. 6); the overflow bin becomes much higher than any of the counts in the lower Gaussian bins, an indication that the particles being observed during the intense AF events have larger energies than FUV photons. More information about the behavior of the AF relative to cometary position can be found in Reference 1.

5. FEBRUARY 19TH, 2016 DUST OUTBURST AND AF BEHAVIOR

On February 19th 2016 several *Rosetta* instruments sensitive to dust and ions detected a large increase in activity indicative of a dust only outburst like the ones seen in the summer of 2015 by R-Alice.[3] This outburst was not captured in the R-Alice slit, however, though both the ROSINA and GIADA instruments detected large increases in their mass spectrometer and dust detector, respectively. Despite non-ideal timing of exposures for R-Alice during the peak of the activity between UTC 10:00 and 13:00 hours a second smaller peak was detected by ROSINA around 16:00, and near the same time R-Alice managed to take an exposure dominated by the Chameleon, shown in Figure 8. Following the results of the charged nanograin model the change in position and strength of each curve on the detector is an indication that a large number of dust particles of several different charge/mass ratios were present in the instrument, possibly due to the same dust outburst detected by ROSINA and GIADA.

Engineering count rate data for the UTC 16:27 exposure, seen in Fig. 9, shows the same erratic tendencies that the AF displayed in Fig. 6, but on a much larger scale. Just over halfway into the observation the count rate almost triggered a brightness safety at 15,000 Hz after nearly bottoming out at 0 Hz just 15 iterations prior. The pulse height distribution seen in Fig. 10 also

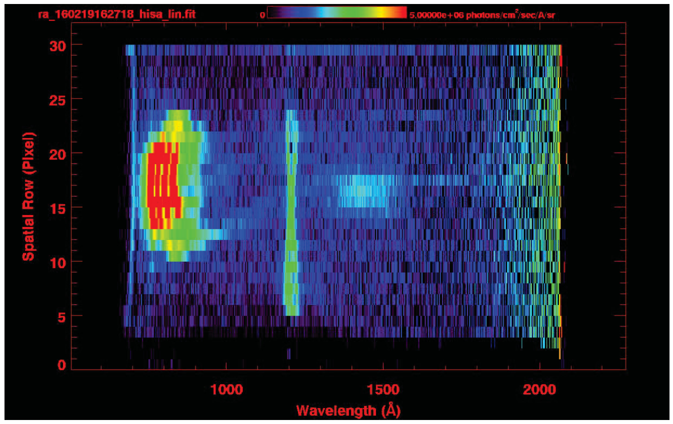

Figure 8. R-Alice exposure taken at UTC 16:27 on February 19th. Note the four distinct curves apparent in the AF, similar to the morphology that resulted from the Python dust break-up simulation shown in Figure 7. The high counts present in the AF indicate a large flux of dust particles with several different mass/charge ratios, velocities, or both.

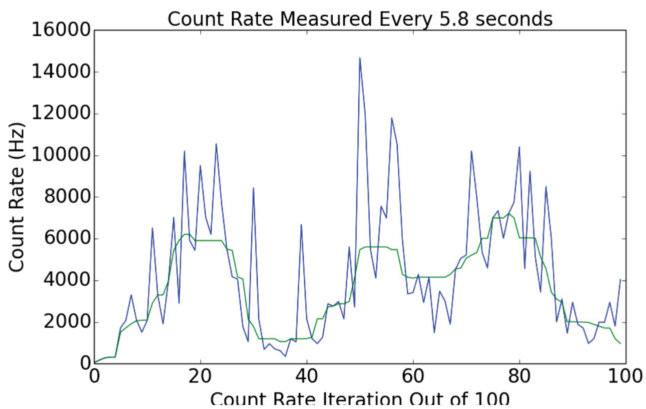

Figure 9. Count rate for the exposure in Fig. 8. The blue line represents specific values from the R-Alice engineering data and the green line is a smoothed version using a boxcar 3 wide.

presents an interesting issue; the number of counts in the lower energy bins, typical of photons, have reached digital saturation at 65535 counts, as has the column that is seen to contain the majority of AF counts in Fig. 6. Since the relation between the impacting particle and pulse height distribution is not yet understood it is uncertain what the implication of this distribution is. However, the dust outburst provided a large supply of nanograins into the instrument's open environment, confirming the theory that the slightly curved feature in Reference 1 is indeed the result of nanograin particles.

6. CONCLUSION

Over twelve years after launch the Alice instrument continues to perform remarkably in the unique environment surrounding comet 67P/Churyumov-Gerasimenko. Over 15,000 exposures have been taken, providing crucial information about the atomic and molecular processes and composition of the coma and nucleus. Simulations of ions and of dust in the Alice instrument performed in Reference 1 were compared to exposures taken during the dust outburst that

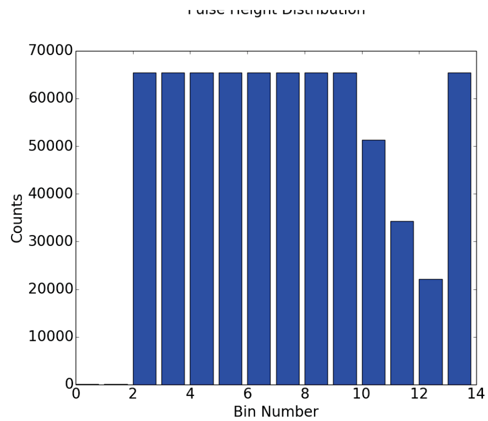

Figure 10. Pulse Height Distribution for the AF seen during the dust outburst on February 19th, 2016. Notice that Bins 3-9 and 14 have reached digital saturation.

occurred on February 19th, 2016. This comparison showed that simulations performed using nanograins entering the slit would created similar shapes as seen on February 19th, evidence that the most common appearance of the AF is caused by dust. For future UVS missions to unique and extreme environments in terms of dust, ions, and electrons, more research into this AF will determine if there are possible instrument enhancements that could mitigate the intensity or even appearance of the AF, an ion repeller grid for example. Future research to determine the exact mass/charge ratio of the particles and impact velocities would allow insight into the origin and composition of the particles and ways to minimize the science impact for these future mission.

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