Detection of Dust Plume

Authors:

o Carl Hergenrother

History:

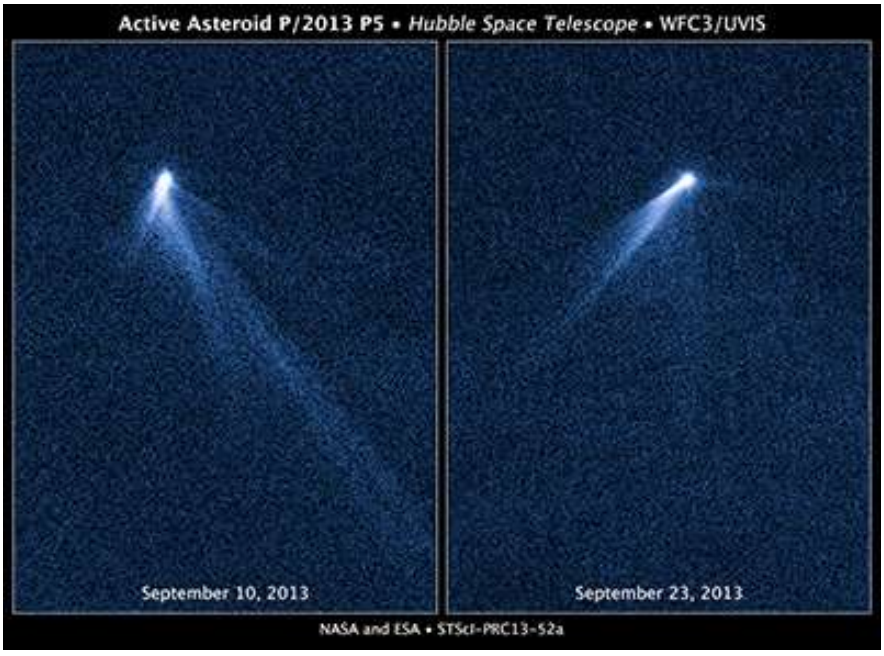
- Draft – 2013-Nov-14
- 2015-Mar-6 (Ed Beshore recovered glitch in display on wiki)
- 2015-May-1 (small formatting changes)
- 2016-Mar-23 (minor edits to phase function analysis and PSF modeling)

Description:

A search for dust in the vicinity of Bennu will be conducted during the Approach phase. Dust in the vicinity or escaping from the vicinity of Bennu may be due to a number of processes including:

1. impact by another natural body
2. erosional collisions between multiple natural satellites of Bennu
3. mass loss due to splitting events related to rapid rotation
4. mass loss Bennu due to electrostatic levitation
5. mass loss due to thermal decomposition
6. mass loss due to thermal fracture

For an example of a small asteroid experiencing recent episodes of rotation induced mass loss, see the following image of 'Comet' P/2013 P5 (PANSTARRS).

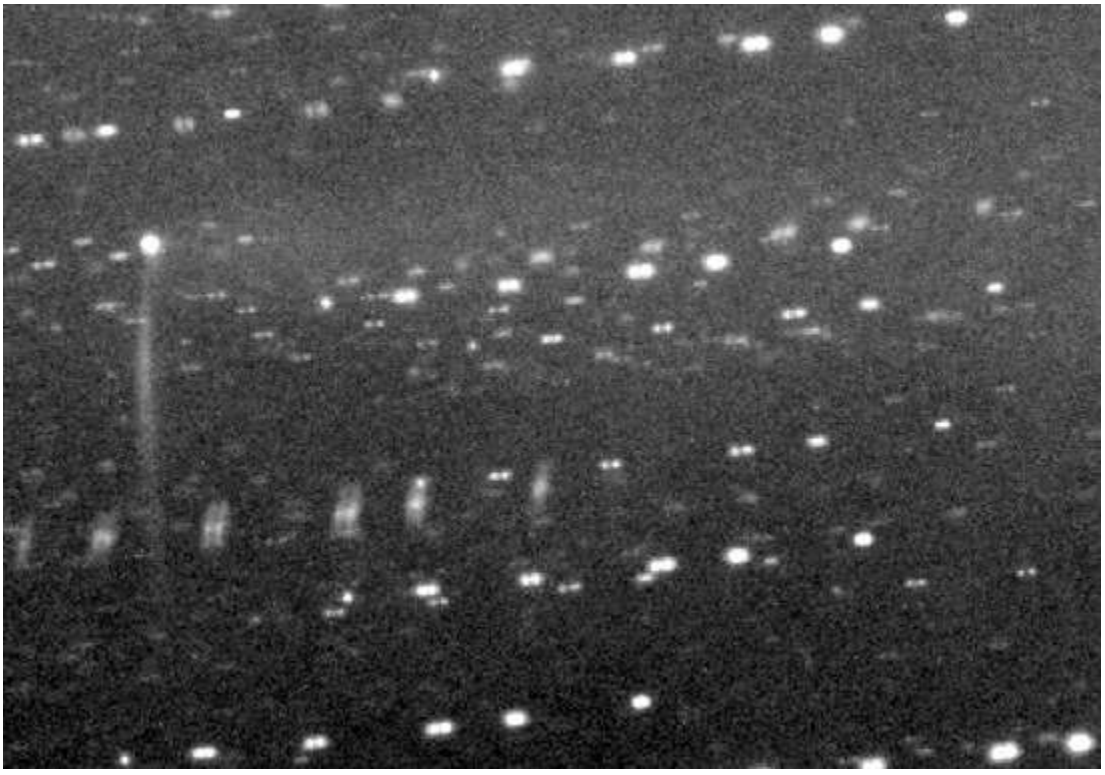


The search for dust will employ three different techniques; direct detection of dust, point spread function modeling and phase function analysis.

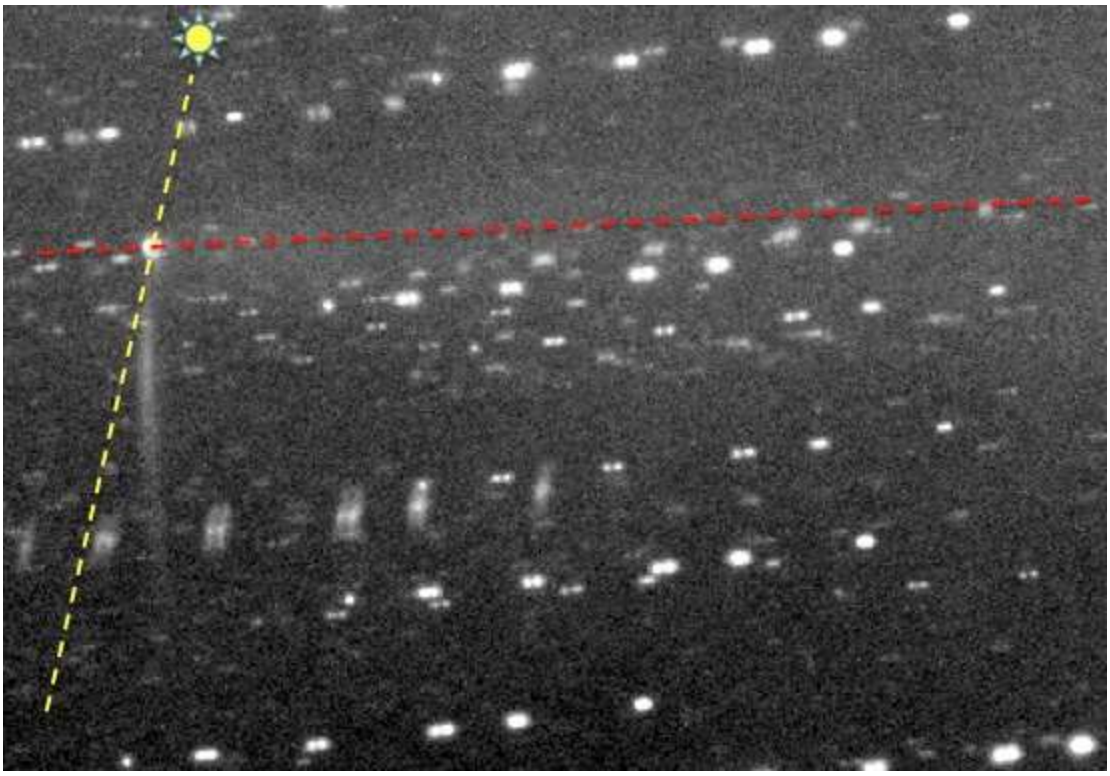
Direct detection of dust

A sequence of images centered on Bennu will be obtained using the OCAMS Polycam instrument. The image sequence will be median co-added on the motion of Bennu to produce a map of the dust near Bennu. Dust will exhibit itself as diffuse features either around Bennu, trailing Bennu in the anti-solar direction, or trailing Bennu along its orbit. Mapping the spatial extent and brightness of the dust will allow an estimate of the size distribution of the dust and the time of its release to be determined. These techniques have been commonly used to measure the same for active comets.

The following two images of low activity comet 49P/Arend-Rigaux show dust material trailing the comet in both the anti-solar and orbit vectors. The first image is non-annotated to show the spatial distribution of the dust in better detail.



The second image is annotated with the solar direction (yellow dashed line) extending away from the Sun (yellow Sun symbol) and the orbit plane (red dashed line) shown. The broad material along the orbit is large dust released months earlier while the material in the anti-solar direction is finder dust released only days to weeks prior to the time of the image.

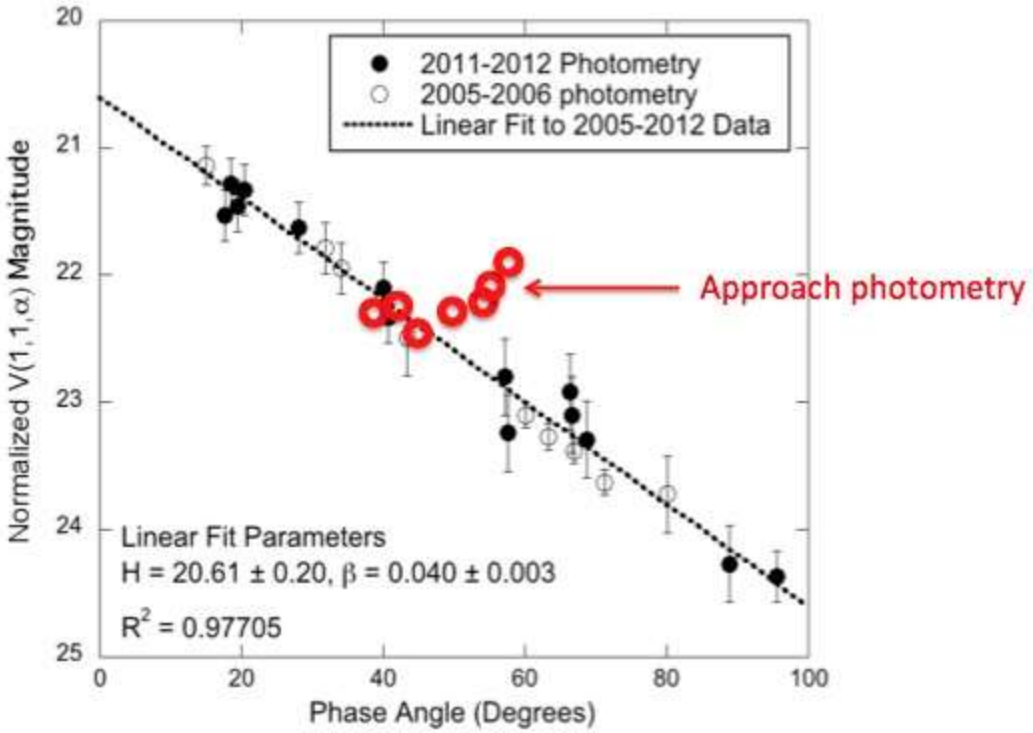


Point Spread Function (PSF) modeling

Point Spread Function (PSF) modeling involves median co-adding the sequence of OCAMS images on the position of the stars. The PSF of a number of co-added G-class main sequence (Sun-like) stars will be compared to the PSF of images median co-added on the position of Bennu. A broadening of Bennu's PSF relative to the Sun-like background stars is indicative of a dust atmosphere or coma in the vicinity of Bennu.

Phase Function Analysis

The phase function of Bennu between phase angles of ~15 and 100 degrees was acquired from ground-based telescopic observations (contained in the DRA). During the Approach phase, a new phase function will be constructed from OCAMS MapCam and PolyCam data. A direct comparison between the ground-based DRA function and the Approach phase analysis will be made. The existence of unresolved dust within the 'seeing disk' of Bennu will be detected as a brightening of the Approach phase function relative to the DRA function at the same phase angle. The amount of brightening will be used to determine the concentration of the dust within the PSF of Bennu.



Parameters:

infile - the OCAMS image files (including standard OCAMS header/metadata) to search for dust, SPICE kernels (SPK S/C, Bennu SPK, Frame Kernel, Instrument Kernel, SCLK)

outfile – co-added images of dust (or lack of dust) in the region around Bennu, difference in PSFs of co-added Bennu and co-added background stars, estimate of dust concentration and mass loss, estimate of dust particle sizes and time of ejection from the surface of Bennu

Algorithm equations:

Direct Detection of Dust

OCAMS images will be 'stack and shifted' to the position of Bennu with the following algorithm.

$$dx\_n = xt - xc\_n$$
$$dy\_n = yt - yc\_n$$

where (xt, yt) is the target (x, y) each image is to shifted to, (xc_n, yc_n) is the (x, y) of Bennu on image 'n', and (dx_n, dy_x) is the number of pixels image 'n' will be shifted to co-align on Bennu. The same algorithm will be used for 'stack and shifting' on the background stars except (xc_n, yc_n) is the (x, y) of the stars rather than Bennu. The IRAF task 'xshift' will be used to automatically conduct these shifts.

Point Spread Function (PSF) modeling
The algorithm for PSF modeling is described in Jewitt (2009).

Multi-aperture photometry will be conducted on the co-added Bennu and background star images. The following equation will be used

$$m_d = -2.5 \log_{10} \left(10^{-0.4m_2} - 10^{-0.4m_1}\right)$$

where m1 is the apparent magnitude of a background star within an annulus of aperture on the wings of the PSF, m1 is the apparent magnitude of Bennu within an annulus of aperture on the wings of the PSF and m_d is the difference in the apparent magnitude of a background star and Bennu within an annulus of aperture on the wings of the PSF. The exact size and location of the annulus relative to the PSF will be determined from OCAMS Cruise phase calibration data.

Phase Function Analysis

The algorithm of dust detection via phase function analysis is simply the difference in the expected brightness of Bennu at that phase angle and measured brightness.

delta_m(1,1,a) = H(1,1,a) - m(1,1,a)

where m(1,1,a) is the apparent magnitude of Bennu at a phase angle of 'a' and normalized to 1 AU from the Sun and Earth, H(1,1,a) is the phase function magnitude of Bennu at a phase angle of 'a' and normalized to 1 AU from the Sun and Earth and delta_m(1,1,a) is the difference in the two. This resulting dust plume detection phase function analysis data product is the same as the Asteroid Phase Functions data product.

Proposed software:

IRAF, Excel

Additional references:

o Jewitt, D. and Li, J. 2010. 'Activity in Geminid parent (3200) Phaethon', Astronomical Journal 140,1519.

o Jewitt, D. 2009. 'The active Centaurs', Astronomical Journal 137, 4296-4312.