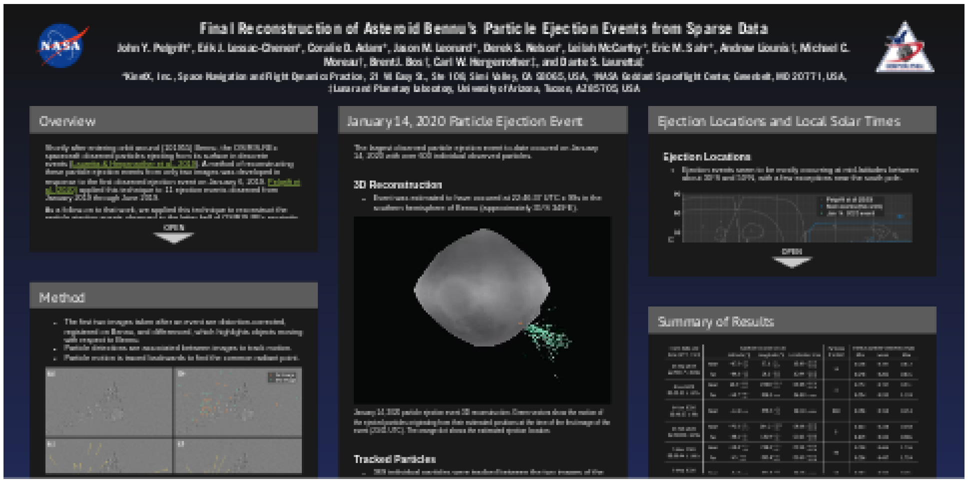
# Final Reconstruction of Asteroid Bennu's Particle Ejection Events from Sparse Data



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OSIRIS-REX
ASTEROID SAMPLE RETURN MISSION

**PRESENTED AT:**

# OVERVIEW

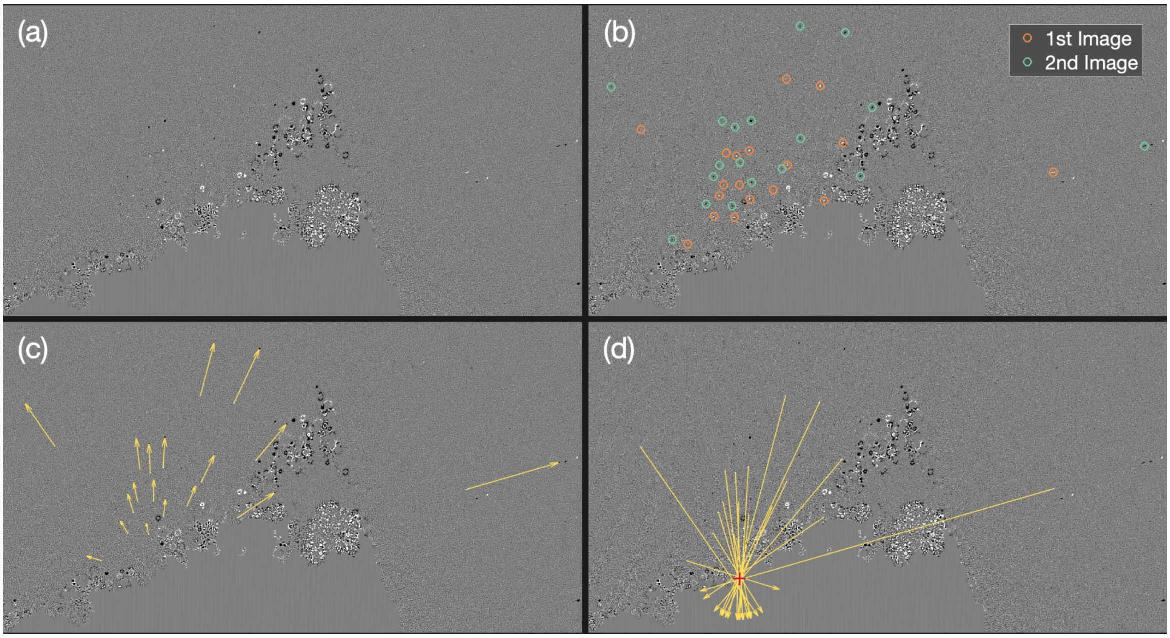
Shortly after entering orbit around (101955) Bennu, the OSIRIS-REx spacecraft observed particles ejecting from its surface in descrete events (Lauretta & Hergenrother et al., 2019 (https://doi.org/10.1126/science.aay3544)). A method of reconstructing these particle ejection events from only two images was developed in response to the first observed ejection event on January 6, 2019. Pelgrift et al. (2020) (https://doi.org/10.1029/2019EA000938) applied this technique to 11 ejection events observed from January 2019 through June 2019.

As a follow-on to that work, we applied this technique to reconstruct the particle ejection events observed in the latter half of OSIRIS-REx proximity operations at Bennu, covering the time span from July 2019 through July 2020. We reconstructed 8 additional events, bringing the total number of Bennu particle ejection events reconstructed using this technique to 19.

The new dataset includes the largest event observed to-date on January 14 2020, with over 600 observed particles.

# METHOD

- The first two images taken after an event are distortion-corrected, registered on Bennu, and differenced, which highlights objects moving with respect to Bennu.
- Particle detections are associated between images to track motion.
- Particle motion is traced backwards to find the common radiant point.




Track identification and radiant point estimation for the May 3, 2020 event. (a) The NavCam images of the event are registered and differenced. Objects from the first image appear white, and objects from the second image appear black. (b) Particles detected in both images allow us to find a repeated pattern, (c) which is used to make associations that show the particles' apparent motion. (d) When the apparent motion is traced backwards, the lines intersect at a common radiant point (red cross) on Bennu.

- Ray tracing with the Bennu shape model is used to find the two possible surface locations that correspond to this radiant: one on the near side of Bennu and one on the far side.
- Relative angular speeds of each particle are used to infer 3D information, assuming all objects left the radiant at the same time.
- Objects measured with higher angular velocities with respect to their displacement from the radiant are assumed to be traveling towards the camera while while objects with lower angular velocities are assumed to be traveling away from the camera.
- This 3D information is combined with the estimated ejection surface location to find the particles positions at the epoch of each image and build a 3D model of the event.
- Particle velocities are then found using the change in position between the two images.
- Uncertainty in the ejection location is determined by re-performing the ray tracing after sampling the radiant point's pixel-space uncertainty and the event time uncertainty at their 3-sigma values.

# JANUARY 14, 2020 PARTICLE EJECTION EVENT

The largest observed particle ejection event to-date occured on January 14, 2020 with over 600 individual observed particles.

### 3D Reconstruction

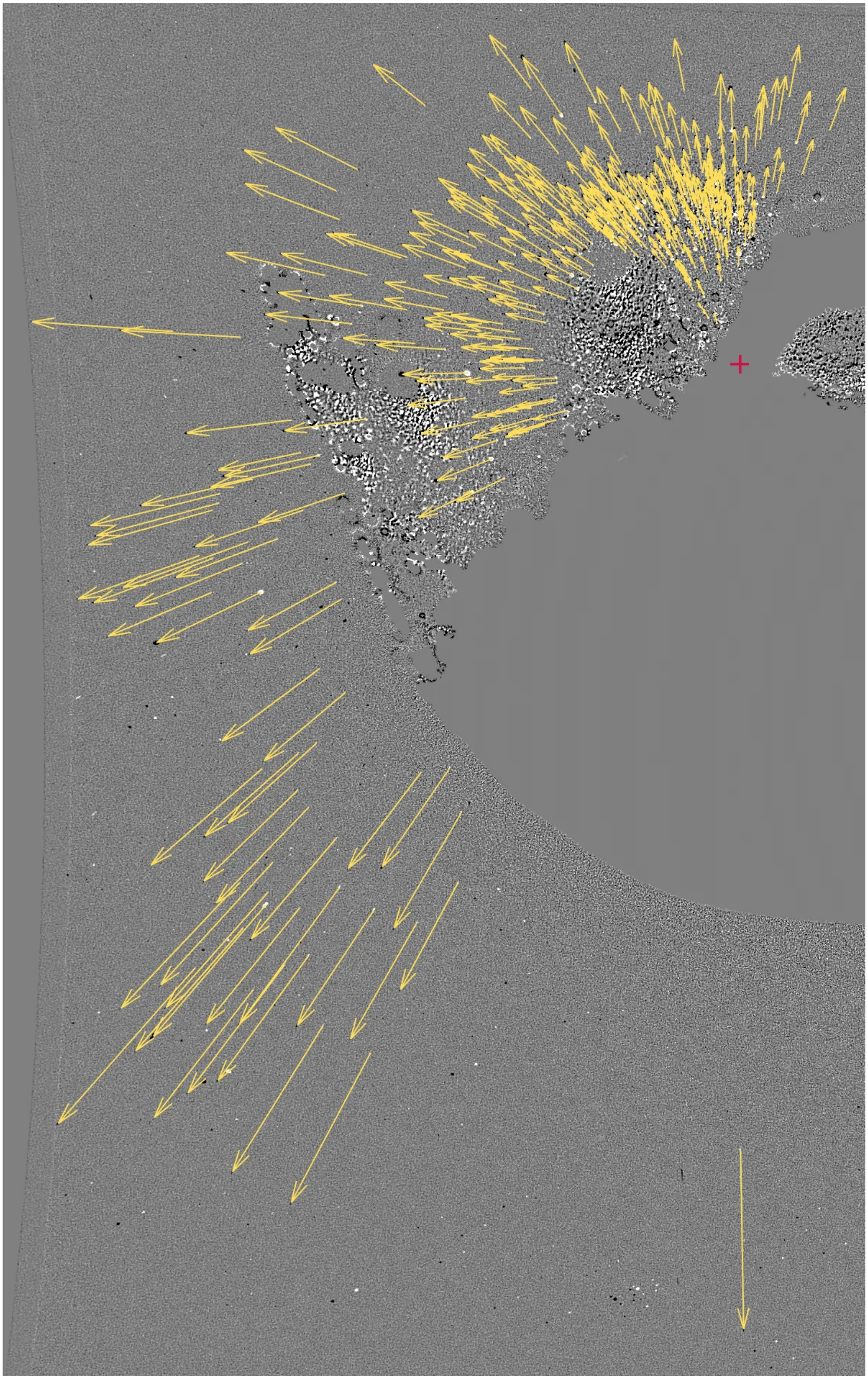
- Event was estimated to have occured at 22:46:37 UTC ± 99s in the southern hemisphere of Bennu (approximately 35°S 349°E).

[VIDEO] https://res.cloudinary.com/amuze-interactive/image/upload/f_auto,q_auto/v1638831423/agu-fm2021/45-33-c5-29-18-00-f6-fa-26-9e-c4-74-73-fe-4f-17/image/jan14_event_3d_ekusqj.mp4

January 14, 2020 particle ejection event 3D reconstruction. Green vectors show the motion of the ejected particles originating from their estimated positions at the time of the first image of the event (23:01 UTC). The orange dot shows the estimated ejection location.

### Tracked Particles

- 369 individual particles were tracked between the two images of the event and used in this analysis to estimate the ejection location.
  - Particles observed in front of Bennu allow us to rule out the far ejection location solution as a possibility.

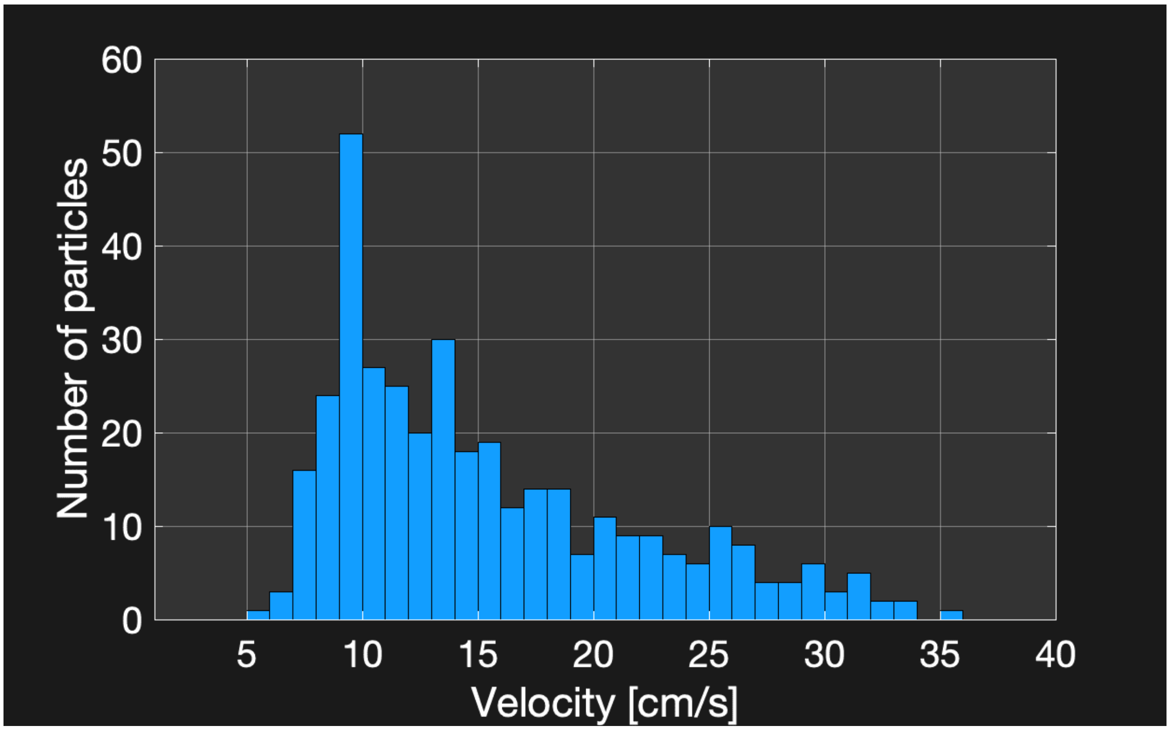


January 14, 2020 particle ejection event tracked particles shown over the registered and differenced images of the event. Vectors show the motion between the images of each particle and the red cross marks the estimated radiant point.

- Some faster-moving particles were observed at the edges of the first image that had left the camera field-of-view (FOV) by the second image and thus could not be included in this analysis.

### Ejection Velocities

- Estimated ejection velocities range from 5 to 35 cm/s.
  - Observational limits mean that there could also be particles with velocities outside this range.
  - Any faster-moving particles would have left the camera FOV by the time the first image was taken (~15 minutes after the event).



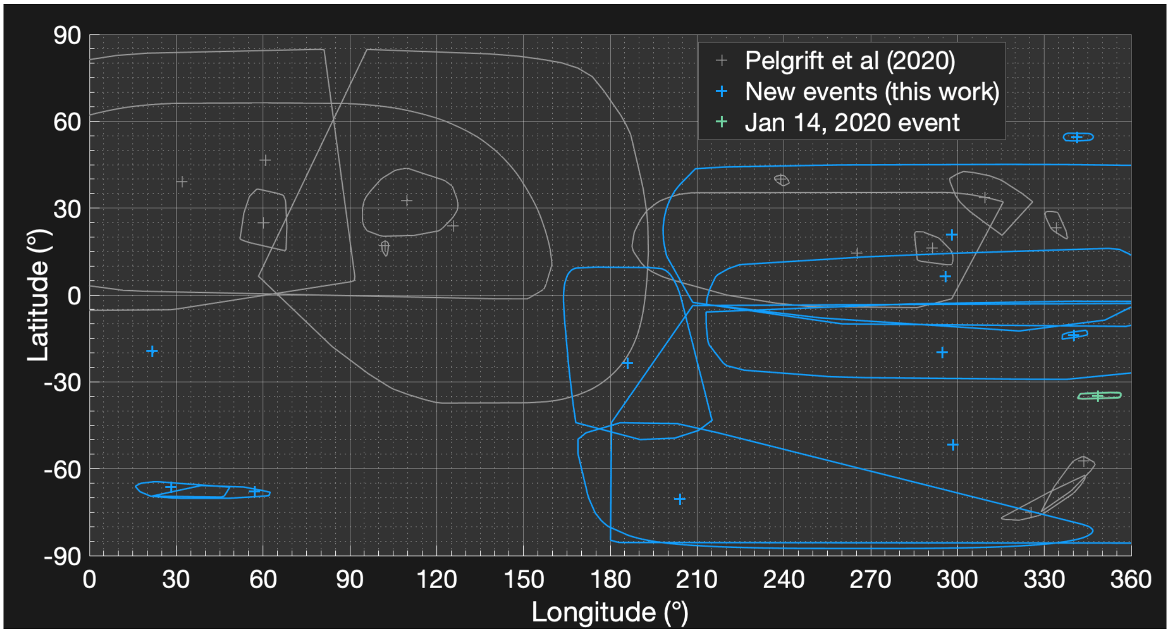

January 14, 2020 ejection event estimated particle velocities.

- Velocities range from well below to well above Bennu's approximate escape velocity of 20 cm/s indicating a variety of trajectory types:
  - > ~20 cm/s = escape trajectories
  - ~15–20 cm/s = possibility of being captured into orbit
  - < ~15 cm/s = suborbital trajectory that re-impacts asteroid

# EJECTION LOCATIONS AND LOCAL SOLAR TIMES

### Ejection Locations

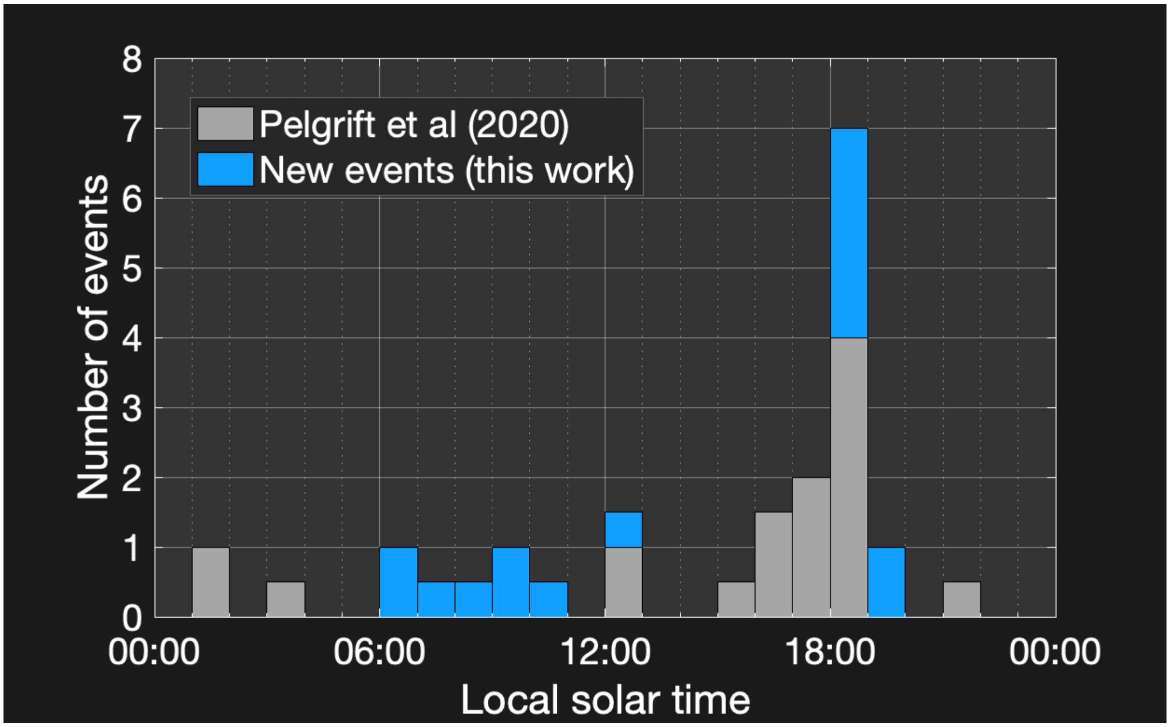
- Ejection events seem to be mostly occurring at mid-latitudes between about 30°S and 50°N, with a few exceptions near the south pole.




Estimated ejection locations for 19 particle ejection events observed by OSIRIS-REx with contours indicating 3-sigma uncertainty bounds (both near and far solutions shown if one could not be ruled out). Events analyzed in the previous work shown in gray. New events introduced in this work shown in blue, with the January 14, 2020 event highlighted in green.

### Local Solar Times

- The new dataset includes more events occuring in morning local solar times (LSTs) than previously observed, but overall most events are still occuring at afternoon LSTs, especially around 18:00.




Estimated local solar times for 19 particle ejection events observed by OSIRIS-REx. Events analyzed in the previous work shown in gray. New events introduced in this work shown in blue. If neither the near nor far solution for an event could be ruled out, each solution was counted as half an event.

# SUMMARY OF RESULTS

| Event date and time (UTC, ±1σ) | | Ejection location (±3σ) Latitude (°) | Longitude (°) | Local solar time | Particles tracked | Inertial particle velocities (m/s) Min | Mean | Max |
|---|---|---|---|---|---|---|---|---|
| 13 Sep 2019 22:40:17 ± 101s | Near | $-67.9^{+2.0}_{-2.4}$ | $57.1^{+5.4}_{-35.7}$ | $12{:}39^{+00:39}_{-02:02}$ | 14 | 0.046 | 0.197 | 0.812 |
| | Far | $-66.3^{+1.8}_{-3.5}$ | $28.2^{+20.2}_{-12.3}$ | $10{:}44^{+01:13}_{-00:32}$ | | 0.048 | 0.203 | 0.835 |
| 8 Jan 2020 06:22:13 ± 1373s | Near | $20.9^{+24.2}_{-31.7}$ | $298.0^{+119.3}_{-99.7}$ | $06{:}08^{+01:36}_{-01:34}$ | 11 | 0.052 | 0.197 | 0.931 |
| | Far | $-51.7^{+48.9}_{-34.1}$ | 298.5 ±180 | 06:10 ± 12:00 | | 0.054 | 0.235 | 1.139 |
| 14 Jan 2020 22:46:37 ± 99s | Near | −34.8 ±1.1 | $348.6^{+7.9}_{-7.1}$ | 18:03 ± 00:04 | 369 | 0.056 | 0.150 | 0.353 |
| 13 Feb 2020 02:40:08 ± 221s | Near | $-70.5^{+26.4}_{-17.0}$ | $204.2^{+142.6}_{-35.3}$ | $08{:}28^{+08:33}_{-01:35}$ | 5 | 0.103 | 0.248 | 0.450 |
| | Far | $-23.5^{+33.1}_{-26.4}$ | $185.9^{+29.3}_{-22.1}$ | $07{:}15^{+01:06}_{-00:39}$ | | 0.139 | 0.323 | 0.585 |
| 5 Mar 2020 08:36:44 ± 1001s | Near | $-19.8^{+17.6}_{-9.4}$ | $294.8^{+71.6}_{-81.7}$ | $09{:}14^{+01:56}_{-01:54}$ | 49 | 0.090 | 0.464 | 1.736 |
| | Far | $6.5^{+9.6}_{-18.9}$ | $295.8^{+70.7}_{-82.5}$ | $09{:}19^{+01:52}_{-01:58}$ | | 0.096 | 0.497 | 1.759 |
| 3 May 2020 01:53:58 ± 51s | Near | −54.5 ±1.3 | $341.4^{+5.5}_{-4.8}$ | 18:05 ± 00:08 | 18 | 0.081 | 0.195 | 0.491 |
| 24 May 2020 21:21:31 ± 3s | Near | −19.3 ±0.3 | 21.8 ±0.3 | 18:40 ± 00:01 | 6 | 0.139 | 0.349 | 0.558 |
| 31 Jul 2020 00:16:37 ± 64s | Near | $-13.8^{+1.6}_{-1.4}$ | $340.3^{+4.7}_{-4.1}$ | $19{:}03^{+00:03}_{-00:04}$ | 8 | 0.113 | 0.218 | 0.375 |

Reconstruction results for Bennu particle ejection events observed from July 2019 through July 2020. Only near or far solution shown when one could be ruled out.

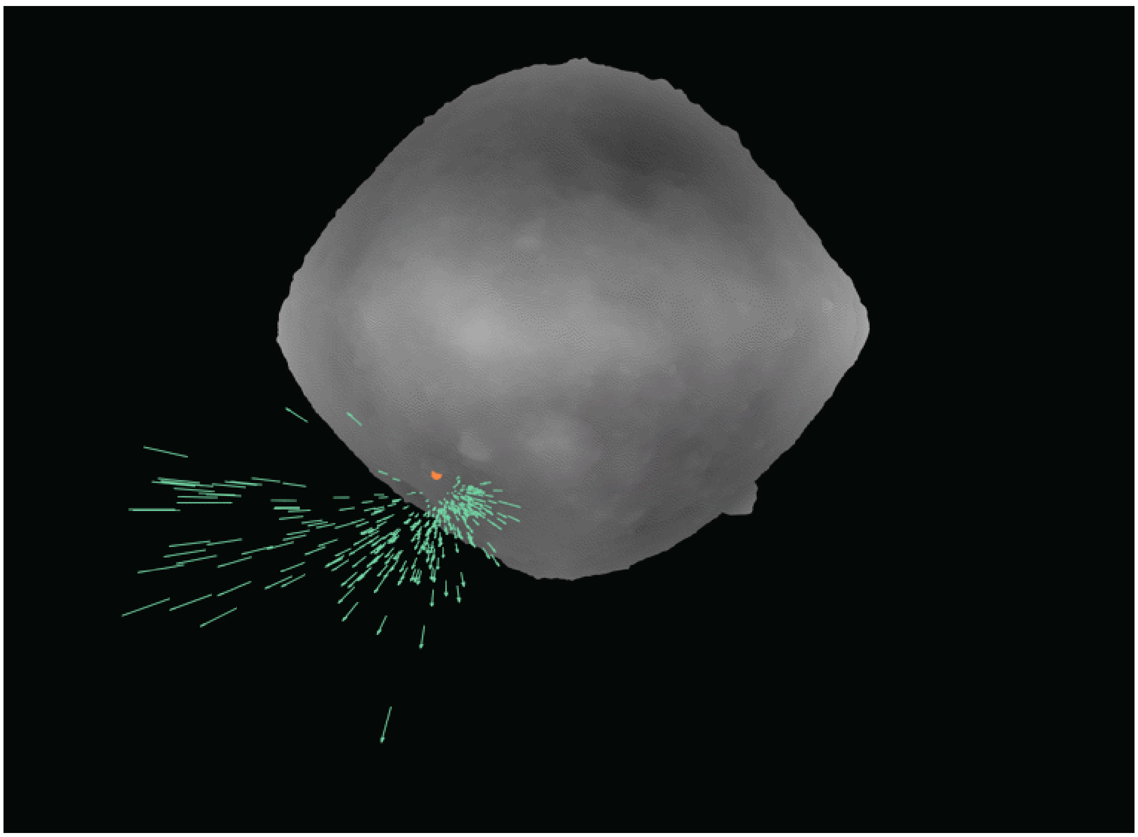
- 8 Bennu particle ejection events from July 2019 through July 2020 were reconstructed using the technique presented in Pelgrift et al. (2020) bringing the total number of events reconstructed with this technique to 19.
- In the full dataset of 19 events, we observed the same trend noted in the original work where the majority of events were estimated to have occurred at mid-latitudes and afternoon local solar times (LST).
    - Most events are occuring around 18:00 LST.
- The new dataset includes the largest observed event to-date on January 14, 2021 with over 350 tracked particles.
- These results are vital to understanding and characterizing this newly observed phenomenon at small bodies.

# DISCLOSURES

This material is based upon work supported by the National Aeronautics and Space Administration under Contracts NG13FC02C and NNM10AA11C issued through the New Frontiers Program.

# ABSTRACT

On January 6, 2019, OSIRIS-REx first observed particles ejecting from the surface of near-Earth asteroid (101955) Bennu. This ejection event was unexpected and was only captured by chance in a pair of optical navigation images taken by the OSIRIS-REx NavCam 1 imager. With this limited dataset of only two observations per ejected particle, traditional orbit determination to reconstruct the particles' trajectories was not possible. Therefore, a new technique was developed for reconstruction of the ejection event based on some simplifying assumptions that the particles all ejected from the same location at the same time and that their velocities remained constant after ejection (a reasonable approximation for fast-moving particles given Bennu's weak gravity). This technique was then applied to reconstruct those particle events observed by the OSIRIS-REx spacecraft at Bennu from January 2019 through June 2019 by Pelgrift et al. (2020). We present a follow-on to that work that applies the same technique to reconstruct the particle ejection events observed in the latter half of OSIRIS-REx proximity operations at Bennu, covering the time span from July 2019 through July 2020. We reconstructed 8 additional events, bringing the total number of Bennu particle ejection events reconstructed using this technique to 19. The new dataset includes the largest event observed to-date, with over 350 individual tracked particles. The new events have particle ejection velocities similar to the previous events, ranging from 5 cm/s to 1.8 m/s. In the full dataset of 19 events, we observed the same trend noted in the original work where the majority of events were estimated to have occurred at mid-latitudes and afternoon local solar times (LST).



(https://agu.confex.com/data/abstract/agu/fm21/6/8/Paper_990086_abstract_923138_0.gif)

Reference:

Pelgrift, J. Y., Lessac-Chenen, E. J., Adam, C. D., Leonard, J. M., Nelson, D. S., McCarthy, L., et al. (2020). Reconstruction of Bennu particle events from sparse data. Earth and Space Science. 7, e2019EA000938. https://doi.org/10.1029/2019EA000938

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Pelgrift, J. Y., Lessac-Chenen, E. J., Adam, C. D., Leonard, J. M., Nelson, D. S., McCarthy, L., et al. (2020). Reconstruction of Bennu particle events from sparse data. *Earth and Space Science*. 7, e2019EA000938. https://doi.org/10.1029/2019EA000938 (https://doi.org/10.1029/2019EA000938)