

National Aeronautics and Space Administration



ARTEMIS II

LUNAR SCIENCE
DATA USER GUIDE

Artemis II Lunar Science Data User Guide

Version 1.0

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1. Overview

1.1. Purpose and Scope of Document

This Lunar Science Data User Guide (“User Guide”) describes the data products in the Artemis II science data archive in sufficient detail to enable users to read and understand the data. It also describes the Planetary Data System (PDS) archive bundles, which define the structure in which the data products, documentation, and supporting materials are stored. This User Guide is intended for the scientists who will analyze the data, including those associated with the project, members of the general planetary science community, and users from the broader public who would like a deeper understanding of the data.

Data products described in this User Guide are science observations curated by the Artemis II Lunar Science Team (LST), including images of the Earth, Moon and deep space collected by the Artemis II crew using handheld cameras, crew-recorded verbal observations of the Moon, Orion vehicle camera imagery collected during lunar flyby, temperature and humidity data of Orion sample storage lockers, and other opportunistic science observations of the Earth-Moon system. These products and archive were guided by the Artemis II Open Science and Data Management Plan (OSDMP) developed by the LST prior to the mission. There are many more image and data products collected during the Artemis II mission that were not curated by the LST but may be of interest to users seeking a broader and more contextual understanding of mission events. Although not included in this science archive, references and links to other science or non-science data from the mission are provided in Section 1.5.

Note: At the time of writing, the archive collection for the small number of crew captured images from the iPhone 17 Pro Max was still being prepared. There are references to these images throughout this User Guide; however, an update to the archive and this User Guide will be made upon later release.

1.2. Applicable Documents

The PDS maintains a set of key documents and webpages at <https://pds.nasa.gov> that describes the PDS4 Standards used to produce the Artemis II science data archive. These documents are revised approximately every six months with each new release of the PDS Information Model. Current and previous versions may be found at the links below.

1. Planetary Data System Standards Reference, <https://pds.nasa.gov/datastandards/documents/sr/current>
2. PDS4 Data Dictionary, <https://pds.nasa.gov/datastandards/documents/dd/current>
3. Planetary Data System (PDS) PDS4 Information Model Specification, <https://pds.nasa.gov/datastandards/documents/im/current>
4. Data Providers' Handbook: Archiving Guide to the PDS4 Data Standards, <https://pds.nasa.gov/datastandards/documents/dph/current>
5. PDS4 Concepts, <https://pds.nasa.gov/datastandards/documents/concepts/>

The documents included with this archive and NASA Technical Reports Server describe in more detail the Artemis II mission, science operations, and the instruments and sensors that are part of that mission:

1. Artemis II Lunar Science Data User Guide (this document)
2. Artemis II Open Science and Data Management Plan (OSDMP)
3. Artemis II Preliminary Lunar Science Report (“Preliminary Lunar Science Report”), <https://ntrs.nasa.gov/citations/20260009221>

4. Artemis II Lunar Science Operations Report (“Lunar Science Operations Report”), <https://ntrs.nasa.gov/citations/20260009223>

1.3. Getting Started

Section 1 provides an overview of this document and quick references for getting familiar with the archive. Section 2 provides an overview of the Artemis II mission, its science objectives, and major science observations conducted during the mission. Major activities are broken down by mission flight day and time range. Section 3 provides descriptions of the cameras and other instruments used to record these observations, including information on observing sequences and the configuration and settings used during the observations. Section 4 provides a description of the PDS4 archive structure and the types of products included in the archive. Section 5 describes the processes and software used to generate data products, including the important information required to understand and use the data.

1.3.1. Accessing and searching the archive

As described in Section 4, Artemis II science data bundles are archived in the Planetary Data System (PDS) at different Discipline Nodes according to their area of expertise. For this archive, the PDS Geosciences (GEO) Node is the Lead Node and hosts the mission bundle of documents [including the Data User Guide, OSDMP, static Lunar Targeting Package (LTP), and Outgoing Target Request (OTR) list] and Orion environment data (data logger temperature and humidity data), the Cartography and Imaging Sciences (CIS) Node hosts crew handheld camera and Orion camera image and audio bundles, and the Navigation and Ancillary Information Facility (NAIF) Node hosts the SPICE bundle of kernels with spacecraft and instrument navigation and ancillary information (e.g., trajectory, attitude, etc.). Each node provides public access to the data via its website and the main PDS website provides a search function across all of PDS. Table 1 lists the recommended citation and Uniform Resource Locators (URLs) for the main PDS search function and for the specific websites for each bundle at the various PDS nodes. Note that these URLs are not immutable and may change in the future.

The PDS provides specific web-based tools that allow for facet-based search on the metadata (e.g., time of observation, camera type, processing level, exposure, etc.). For Artemis II science image data, the PDS Cartography and Imaging Sciences Node provides search capabilities through its Image Atlas: <https://pds-imaging.jpl.nasa.gov/tools/atlas/search>

Users preferring to browse the web-based directory structure can do so by starting at the parent directory for each data bundle and then navigating down into collections and subdirectories. At the CIS Node, browsing can be completed using the Atlas Archive Explorer:

<https://pds-imaging.jpl.nasa.gov/tools/atlas/archive-explorer>

Other starting points for directory browsing are found at the websites listed in Table 1. For advanced users wanting programmatic access to the archive, PDS also provides an API that can be used to search PDS4 data included as part of the registry: <https://nasa-pds.github.io/pds-api/index.html>

Users can always contact the Planetary Data System for assistance finding a data product:

- General PDS inquiries: pds_operator@jpl.nasa.gov
- Geosciences Node: geosci@wunder.wustl.edu
- Cartography and Imaging Sciences Node: pds-img-jpl@jpl.nasa.gov or pds-img-usgs@usgs.gov

Table 1. Archive URLs and citations for the PDS-wide search and individual PDS Nodes.

PDS Archive Bundle	URL	PDS Node
PDS-Wide Data Search	https://pds.nasa.gov/datasearch/data-search/	
Links to All Bundles	https://pds-geosciences.wustl.edu/missions/artemis2/index.htm	GEO
Crew Camera (Nikon camera images, iPhone images)	https://pds-imaging.jpl.nasa.gov/tools/atlas/archive-explorer?mission=artemis2&bundle=artemis2_crew_camera Citation: Artemis II Lunar Science Team (2026). Artemis II Crew Camera Data Bundle, Planetary Data System (PDS) Cartography and Imaging Sciences (CIS) Node. https://doi.org/10.17189/x52v-tb80	CIS
Orion Camera (Orion vehicle camera images and video)	https://pds-imaging.jpl.nasa.gov/tools/atlas/archive-explorer?mission=artemis2&bundle=artemis2_orion_camera Citation: Artemis II Lunar Science Team (2026). Artemis II Orion Camera Data Bundle, Planetary Data System (PDS) Cartography and Imaging Sciences (CIS) Node. https://doi.org/10.17189/hzev-nq50	CIS
Mission Audio (PCD and voice loop audio and transcripts)	https://pds-imaging.jpl.nasa.gov/tools/atlas/archive-explorer?mission=artemis2&bundle=artemis2_mission_audio Citation: Artemis II Lunar Science Team (2026). Artemis II Mission Audio Data Bundle, Planetary Data System (PDS) Cartography and Imaging Sciences (CIS) Node. https://doi.org/10.17189/4a29-dz64	CIS
Mission (Data User Guide, OSDMP, LTP, OTR database, and temperature/ humidity data)	https://pds-geosciences.wustl.edu/artemis2/urn-nasa-pds-artemis2_mission/ Citation: Artemis II Lunar Science Team (2026). Artemis II Mission Data Bundle, Planetary Data System (PDS) Geosciences (GEO) Node. https://doi.org/10.17189/36fx-pd80	GEO
SPICE (Orion trajectory and other ancillary data)	https://naif.jpl.nasa.gov/pub/naif/pds/pds4/artemis2/artemis2_spice/ Citation: Bailey, A. M., and Semenov, B. V. (2026). Artemis II Mission SPICE Bundle. Planetary Data System (PDS) Navigation and Ancillary Information Facility (NAIF) Node. https://doi.org/10.17189/7ezn-0294	NAIF

1.4. Citing the Data

The data archive bundles and collections have digital object identifiers (DOIs) that can be used to provide citations for the archive datasets. For example, the crew camera data bundle can be cited as follows:

Artemis II Lunar Science Team (2026). Artemis II Crew Camera Data Bundle, Planetary Data System (PDS) Cartography and Imaging Sciences (CIS) Node. <https://doi.org/10.17189/x52v-tb80>

Table 1 provides recommendation citation format for the data bundles. Additional guidelines can be found at the PDS website: <https://pds.nasa.gov/datastandards/citing/>

PDS bundle, collection, and document product DOIs can also be found using the PDS DOI search tool (<https://pds.nasa.gov/tools/doi/#/search>) or by examining the information contained in individual PDS bundle and collection metadata labels.

For images collected by the Artemis II crew, reference and credit can be given by providing the NASA ID followed by “NASA/Artemis II Crew.” For example:

NASA ID art002e0012321, Credit: NASA/Artemis II Crew

1.5. Other Artemis II Mission Data

Additional mission data and some scientifically relevant data can also be found at other NASA repositories and are accessible through their websites. Known hosting sites at the time of preparation of this User Guide are provided in Table 2. Note that the data listed here may not have undergone the rigorous review and curation of data included in the PDS science archive. Additionally, mission data will eventually be submitted for preservation to the National Archives and Records Administration (NARA) (<https://www.archives.gov/>) per NASA Procedural Requirements (NPR) 1441.1, NASA Records Management Program Requirements. For records of historical significance from mission programs and projects, these records are permanent, with transfer to the National Archives 7 years after close of that program/project or its cutoff.

Further, radiation data from the Hybrid Electronic Radiation Assessor (HERA) dosimeter is planned to be archived in the PDS separately from the science data described herein. See the Artemis II OSDMP for more details on the HERA sensor anticipated data types.

Table 2. Location of additional Artemis II imagery and data.

Site Name	URL	Data Types
Gateway to Astronaut Photography of Earth (GAPE)	https://eol.jsc.nasa.gov	Astronaut-acquired Imagery of Earth and Moon (lossy jpegs with option to download raw images) with interactive webmap.
NASA Image and Video Library	https://images.nasa.gov/ Artemis II images can be found by searching imagery.nasa.gov with the Artemis II keyword .	Mission Imagery (activities and context).
Orion to Earth Voice Loop Audio	Internet Archive https://archive.org/download/Artemis-II-ACR-Collection Artemis II ACR Collection Posted by John Stoll, NASA Johnson Space Center	Audio files in WAV format as digitized, cataloged and archived by the Houston Audio Control Room (ACR), at the NASA Johnson Space Center.

2. Artemis II Mission Overview

NASA’s Artemis II mission was primarily a human spaceflight test mission to demonstrate that the integrated Space Launch System (SLS) rocket and Artemis II Orion spacecraft could safely support human life in the deep-space environment beyond low-Earth orbit. The mission had four crew members: Commander (CDR) Reid Wiseman, Pilot (PLT) Victor Glover, and Mission Specialist (MS1) Christina Koch from NASA and Mission Specialist (MS2) Jeremy Hansen from the Canadian Space Agency (CSA). The European Space Agency (ESA) provided the European Service Module that powered and propelled the

Orion capsule. For a more complete description of Artemis II, see <https://www.nasa.gov/artemis-ii-press-kit/>

The Artemis II Lunar Science Team supported the mission by enabling the study of the Moon and the Earth through crew training and science target planning for the collection of crew handheld images, audio recordings, annotations, and vehicle imagery. These operational roles and activities are described in the Lunar Science Operations Report.

2.1. Artemis II Mission Science Objectives

A full description of the Lunar Science Team science objectives for the Artemis II mission is provided in the Preliminary Lunar Science Report. A summary of these objectives is shown in Table 3. For a broader description of the Artemis II mission priorities, refer to the Artemis II Reference Guide (2025) (<https://www.nasa.gov/wp-content/uploads/2026/01/a2-reference-guide-012825.pdf?emrc=979554>).

Table 3. Artemis II Lunar Science Team science themes and objectives.

Science Theme	Science Objectives	Priority
Impact Flashes	• Characterize impact events observed by the crew.	1
Color Provinces and Albedo Variations	• Characterize color/albedo associated with different physical properties. • Characterize color/albedo associated with different geochemical/compositional properties	1
Photometric Observations	• Describe changes in spatial and temporal scales of color/albedo variations.	2
Impact History	• Characterize features of impact structures. • Characterize features of young crater systems. • Characterize ejecta interactions with surrounding features.	2
Lunar Environment and Deep Space	• Determine whether lofted lunar dust is identifiable from lunar orbit that would allow for the characterization of the lunar exosphere environment. • Characterize deep space.	2
Tectonic History	• Characterize region-scale fault complexes including relationships (e.g., cross-cutting) with surrounding features. • Characterize floor-fractured craters. • Characterize massifs.	2
Future Sites and Poles	• Characterize the regional context for past landing sites. • Characterize the regional context for potential future landing sites. • Characterize polar regions.	2
Limb and Terminatory Morphology	• Characterize the lunar limb, surface features along the limb, and the horizon. • Characterize surface features at the lunar terminator.	3
Volcanic History	• Characterize the variety of mare volcanism. • Characterize the variety of non-mare volcanism. • Determine if cryptomare are identifiable from orbital data.	3
Earth Observations	• Characterize Earth's atmosphere. • Characterize Earth's surface.	3

2.2. Mission Events and Science Activities and Instruments

A summary of the major mission events and science observing time periods for each flight day (FD) is provided in Table 4. The Artemis II mission began on Flight Day 1 (2026-04-01 22:35:12 UTC) with a successful launch of the Space Launch System (SLS) rocket and a proximity operations demonstration where the crew manually maneuvered Orion near the spent Interim Cryogenic Propulsion Stage (ICPS) rocket stage. On Flight Day 2, the spacecraft executed the critical Translunar Injection (TLI) burn, sending the crew toward the Moon. Flight Day 3 was marked by the cancellation of the first outbound trajectory correction (OTC) burn due to the precision of the TLI, allowing the crew to focus on medical drills and cabin setup. Flight Day 4 featured a manual piloting demonstration to test Orion's handling in deep space, while Flight Day 5 involved a comprehensive evaluation of the Orion Crew Survival System suits and the OTC-2 burn. The outbound phase culminated on Flight Day 6 with the lunar flyby, during which the crew conducted the mission's primary science observations and passed approximately 6,543 km above the lunar farside at closest approach (i.e., lunar pericyynthion) at 2026-04-06 23:00 UTC.

The return journey commenced on Flight Day 7 with the first return trajectory correction burn (RTC-1) and the initial public release of captured images from lunar flyby. On Flight Day 8, the crew conducted a radiation shielding demonstration and held a live news conference from deep space, followed by Flight Day 9, which was dedicated to the RTC-2 burn and final cabin stowage for reentry. The mission concluded on Flight Day 10 as Orion performed a final trajectory burn and a skip reentry maneuver to shed velocity. The spacecraft splashed down safely in the Pacific Ocean on at 2026-04-11 00:07 UTC.

A number of NASA and public websites can be searched to provide more complete summaries of mission events, including:

- NASA News Release: <https://www.nasa.gov/news-release/>
- NASA Artemis Blogs: <https://www.nasa.gov/blogs/artemis/>

As Table 4 summarizes, Artemis II science observation activities spanned the mission with Flight Days 1-5 involving short ~15-30 min opportunistic imaging events when Orion windows were purposefully pointed at the Earth or Moon, a window quality assessment, and final mission preparation for the lunar flyby observations. Primary lunar observations occurred during an approximately 6.75-hour period around lunar flyby on Flight Day 6. The observing sequence during lunar flyby was structured around the Lunar Targeting Plan (LTP), which is described in more detail (with UTC times) in the Lunar Science Operations Report and Preliminary Lunar Science Report, with a static pdf version of the LTP provided as a document to this archive. Flight Day 7 was dedicated to final observations and crew debrief activities. Post-splashdown activities included a dedicated lunar observation debrief with the crew. Serendipitous science observations were made throughout the 10-day mission, when the Earth, the Moon, or the Milky Way were visible to the crew from the Orion windows, whether observation-enabling spacecraft pointing was intentional for science or not. Table 4 lists these “unscheduled” crew science activities, with time ranges determined based on the beginning and end of clusters of crew camera image collection times.

Table 4. Major crew science observation periods during the Artemis II mission.

Flight Day	Time Start (UTC)	Time End (UTC)	Crew Science Activity	Scheduled Crew Member(s), Position	Instrument/Sensor Used
FD01	2026-04-01 22:35:12	2026-04-02 18:15:12	Mission Events: SLS Launch, proximity operations demonstration. Mission Start Time: 2026-04-01 at 22:35:12 UTC		
	2026-04-02 11:35:16 (Planned: 12:15:21)	2026-04-02 12:40:35 (Planned: 12:40:12)	Scheduled Earth Photos – Crew Preference Imaging (Earth, Other)	MS1 Koch, MS2 Hansen	Nikon D5-015 Long Lens iPhone 17 Pro Max
FD02	2026-04-02 18:15:12	2026-04-03 16:35:12	Mission Events: Translunar Injection (TLI) burn		
	2026-04-02 18:44:20	2026-04-02 19:13:20	Unscheduled Imaging (Earth, Cabin, Crew, Other)	Crew	Nikon D5-015 Long Lens Nikon D5-017 35 mm Lens
	2026-04-03 00:17:24	2026-04-03 00:42:25	Unscheduled Imaging (Earth, Deep Space, Other)	Crew	Nikon D5-015 Long Lens Nikon D5-017 Short Lens iPhone 17 Pro Max
FD03	2026-04-03 16:35:12	2026-04-04 16:35:12	Mission Events: Cabin setup, medical drills, first outbound trajectory correction (OTC-1) burn canceled		
	2026-04-03 23:28:06	2026-04-03 23:49:20	Unscheduled Imaging (Earth and Moon)	Crew	Nikon D5-015 Long Lens Nikon D5-017 Short Lens Nikon Z9-019 35 mm Lens
	2026-04-04 02:03:08	2026-04-04 04:08:46	Unscheduled Imaging (Moon)	Crew	Nikon D5-015 Long Lens
	2026-04-04 04:28:27 (Planned: 04:20:12)	2026-04-04 05:39:38 (Planned: 05:20:12)	Scheduled Window Quality DFTO	PLT Glover Window 2, 3 and Docking Window	Nikon D5-015 Long Lens
FD04	2026-04-04 16:35:12	2026-04-05 15:50:12	Mission Events: Orion manual piloting demo		
	2026-04-05 03:55:23 (Planned: 04:30:12)	2026-04-05 04:10:58 (Planned: 04:50:12)	Scheduled Opportunistic Imaging (Moon)	PLT Glover CDR Wiseman MS1 Koch	Nikon D5-015 Long Lens Nikon Z9-019 35 mm Lens
	2026-04-05 05:36:35	2026-04-05 05:47:50	Unscheduled Imaging and Audio	MS1 Koch	PCD 3 (tests of ambient audio noise) Nikon D5-017 Short Lens
	2026-04-05 06:34:45	2026-04-05 06:44:05	Unscheduled Imaging (Earth)	Crew	Nikon D5-015 Long Lens Nikon D5-017 Short Lens

FD05	2026-04-05 15:50:12	2026-04-06 14:50:12	Mission Events: Orion Crew Survival System Suit evaluation, outbound trajectory correction burn 2 (OTC-2)		
	2026-04-05 16:31:56	2026-04-05 16:41:21	Unscheduled Imaging (Moon)	Crew	Nikon D5-015 Long Lens
	2026-04-06 01:31:31	2026-04-06 01:42:29	Unscheduled Imaging (Moon)	Crew	Nikon D5-015 Long Lens
	2026-04-06 02:38:59	2026-04-06 02:42:55	Unscheduled Imaging (Moon)	Crew	Nikon D5-015 Long Lens iPhone 17 Pro Max
	2026-04-06 03:17:50 (Planned: 03:25:12)	2026-04-06 03:49:59 (Planned: 03:45:12)	Scheduled Opportunistic Imaging (Moon)	PLT Glover CDR Wiseman	Nikon D5-015 Long Lens to 35 mm Lens Change Nikon D5-017 Long Lens Nikon Z9-019 Long Lens
	2026-04-06 05:42:06	2026-04-06 05:52:35	Unscheduled imaging (Moon)	Crew	Nikon D5-015 35 mm Lens Nikon D5-017 Long Lens Nikon Z9-019 Short Lens
FD06	2026-04-06 14:50:12	2026-04-07 15:35:12	Mission Events: Lunar Flyby, Moon closest approach, Loss of Signal (LOS) between earthset and earthrise		
	2026-04-06 16:13:57	2026-04-06 16:38:18	Unscheduled Imaging (Moon)	Crew	Nikon D5-015 35 mm Lens Nikon D5-017 Long Lens Nikon Z9-019 Long Lens
	2026-04-06 17:03:15	2026-04-06 18:17:09	Unscheduled Imaging, Pre-Flyby Crew Conference and Camera Setup	Crew	Nikon D5-015 Long Lens Nikon D5-017 Short Lens Nikon Z9-019 35 mm Lens iPhone 17 Pro Max
	2026-04-06 18:19:10 (Planned: 18:45:12)	2026-04-07 01:48:10 (Planned: 01:40:12)	Lunar Flyby start LTP Target 1 to end LTP Target 30	All crew members. Primary config: Window 2 (Primary Camera) Window 3 (unaided eye) Docking Window, Window 1 (floating observations)	PCD2 and PCD3 (Primary Recordings) Nikon D5-015 Long Lens Nikon D5-017 Short Lens Nikon Z9-019 35 mm Lens iPhone 17 Pro Max
FD07	2026-04-07 15:35:12	2026-04-08 15:35:12	Mission Events: First return correction burn (RTC-1).		
	2026-04-07 19:41:35 (Planned: 19:30:12)	2026-04-07 19:48:59 (Planned: 19:50:12)	Scheduled Opportunistic Imaging (Moon)	MS1 Koch	Nikon D5-015 Long Lens
	2026-04-07 21:12:18	2026-04-07 21:37:21	Unscheduled Imaging (Star Fields, Deep Space)	Crew	Nikon Z9-019 35 mm Lens
FD08	2026-04-08 15:35:12	2026-04-09 15:35:12	Mission Events: Radiation shielding demonstration		

	2026-04-09 03:33:42	2026-04-09 03:58:30	Unscheduled Imaging (Earth)	Crew	Nikon D5-015 35-mm Lens Nikon Z9-019 Long Lens
	2026-04-09 04:07:02	2026-04-09 04:28:31	Unscheduled Imaging (Earth)	Crew	Nikon D5-015 35-mm Lens Nikon Z9-019 Long Lens
FD09	2026-04-09 15:35:12	2026-04-10 15:35:12	Mission Events: Second return correction burn (RTC-2) and final cabin stowage for reentry.		
	--	--	None	--	--
FD10	2026-04-10 15:35:12	2026-04-11 00:07:00	Mission Events: Final trajectory burn and a skip reentry maneuver. Splashdown.		
	--	--	None	--	--

3. Instrument and Sensor Overview and Observations

This section provides an overview of the cameras and other instruments used to conduct scientific observations and to collect the measurements and data contained in this archive. **Details on camera and instrument specifications are provided in the Artemis II OSDMP, Section 5. Science Instrumentation and references therein which is included as a document to this archive.**

3.1. Crew Observations: Nikon D5 and Z9 Cameras

Two handheld Nikon D5 digital single-lens reflex (DSLR) cameras (Serial Numbers, SN, 3500015 and 3500017) were used by the crew during the Artemis II mission. One camera (SN 3500015) was primarily paired with an 80-400 mm focal length “Long Lens” for about 98% of its science images and the other camera (SN 3500017) was primarily paired with the 12-24 mm “Short Lens” for about 57% of its science images (and 29% with the Long Lens) during opportunistic imaging and lunar flyby imaging activities (Table 4, Figure 1). The cameras could also be paired with a 35-mm lens for deep space imaging (occurred in < 15% of science images), but this lens was intended for use for interior images. Images were collected with the cameras pointing out various Orion windows depending on the observation activity and crew configuration (Section 3.1.1). As a mirrored camera, the viewfinder of the Nikon D5 was used by the crew as a monocular for conducting observations of the Moon and other targets of interest. The mirrored viewfinder allowed the crew’s eyes to stay adjusted to the lunar surface brightness while making descriptions at a higher magnification. Due to its proven reliability and ability to withstand the ionizing radiation and thermal stresses of low Earth orbit, NASA has integrated unmodified Nikon D5 units into its standard flight kit for the International Space Station (ISS) and astronaut training. For Artemis II, the history of the camera on the ISS as well as the extremely low light sensitivity made the Nikon D5 ideal for lunar observations.

One handheld Nikon Z9 camera (SN 39200019) was used for science observations throughout the mission. It was manifested to provide a complementary dataset to the Nikon D5 images and to test data collection procedures in preparation for future Artemis missions where the Z9 will be the primary camera as part of the technical core of the Handheld Universal Lunar Camera (HULC). During Artemis II, the Nikon Z9 was primarily paired with a 35-mm lens for 74% of its science images (other images were mostly with the Long Lens) and was the primary camera used during the eclipse observations conducted during the lunar flyby.

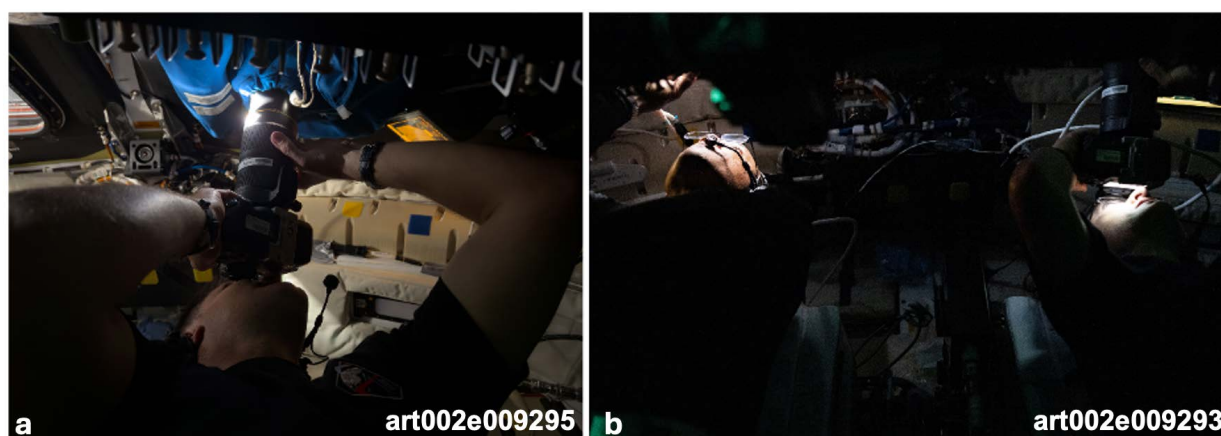


Figure 1. (a) MS2 Jeremy Hansen captures images with the Nikon D5 camera and Long Lens through the camera shroud covering Window 2 of the Orion spacecraft (NASA ID art002e009295). (b) PLT Victor Glover (without camera) and MS1 Christina Koch (with Nikon D5 camera, Long Lens) at Orion Windows 3 and 2, respectively, conducting observations during lunar flyby (NASA ID art002e009293).

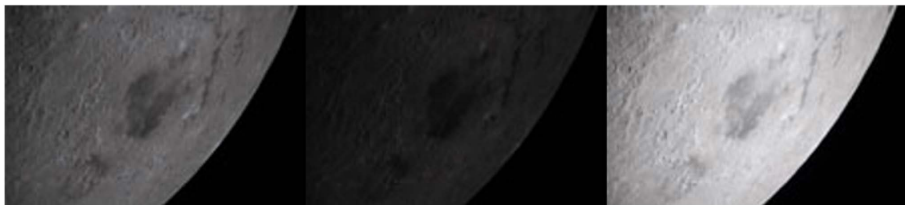
3.1.1. Nikon D5 and Z9 camera observing procedures and configuration

Each camera configuration was established as part of a standard operating procedure during use. The crew also had freedom to adjust settings on the fly to achieve their desired imagery. These procedures include lens selections and camera settings and are part of the recorded internal operations products. A summary of Nikon D5 and Z9 image collection procedures and configuration during the mission is provided in Table 5, with further descriptions provided in the Lunar Science Operations Report. Note that D5 camera observations were conducted with an optical (mirrored) viewfinder, not electronic, which allowed for more natural crew color acuity. The crew reported during the mission and post-mission debriefs that for visual lunar observations, the Nikon D5 camera was the best tool because it did not affect the way they saw the colors of the lunar surface.

For image capture, the cameras were configured based on activity. These settings included camera mode, exposure bracketing type, and ISO settings. For lunar and Earth observations, the crew members were trained to first take context images with a zoomed-out view before using the zoom capabilities. For large areas, crew members were trained to take mosaics with a 30-50% overlap. During the lunar flyby, imaging prompts for the crew member with the camera were included in the Lunar Targeting Plan.

Images were recorded by each camera in either Nikon Raw (for D5 cameras) or Nikon High Efficiency Star (HE*) (for Z9 camera) formats, serving as the source images for the science data archive (Section 5.2). The images were saved to storage cards, which were then transferred to the crew PCDs for downlink during the mission. Those images not downlinked during the mission were retrieved post-mission directly from the storage cards returned by the crew. The image metadata is included with the images in the archive and can provide insight into the specific camera settings for the observations.

Table 5. Nikon D5 and Z9 image collection and configuration.

Parameter Name	Configuration, Adjustments, and Collection Notes
Exposure	Images were collected as single frames or sets of 3 (more common) to 5 bracketed exposures. These changes in exposure were achieved by changing the shutter speed. Exposure sets may be identified either by visual inspection of image sequences or from the metadata. Here is an example of a 3-exposure bracket set determined from the camera model, serial number, shutter count, and exposure value: (left) art002e010230_nkd5015_src_v01.nef, Shutter Count = 4945, Exposure = 0 (center) art002e010231_nkd5015_src_v01.nef, Shutter Count = 4946, Exposure = -2 (right) art002e010232_nkd5015_src_v01.nef, Shutter Count = 4947, Exposure = +2  Note that a five-exposure bracket set (used with the Nikon D5-015 during sunset) would have exposure values of 0, -6, -3, +3, +6.
Clock	As part of the procedure, the camera clock (in UTC) was checked against the time on the PCD (in UTC) prior to each observing activity, with adjustments made if necessary.
ISO	ISO is a camera setting that controls the camera sensor's sensitivity to light. For lunar observations, the ISO was initially set to account for the illumination of the lunar surface at an ISO 400 with Long Lens or ISO 2000 for the interior with Short Lens but could be adjusted by the crew to account for the illumination of the scene.
Noise Reduction	Noise reduction filtering was turned off during science observations, including the lunar flyby. As a result, noise sources such as "hot pixels" are not filtered out of images. A dark frame (e.g., image with lens cap on) was not collected during the mission, but images of deep space and other image sequences could be used with advance software packages to filter hot pixels from image frames, if desired.
Lens	Nikon D5-015 was primarily paired with the 80-400 mm Long Lens, Nikon D5-017 was primarily paired with the 12-24 mm Short Lens, and Nikon Z9-019 was primarily paired with the 35 mm lens. However, all three lenses were used at different times on all three Nikon cameras.
Lens Placement on Windows	Crew members were trained and instructed to place camera lens flush against the window. The Window Quality DFTO (Section 3.1.2), also instructed crew members where to position the Nikon D5 camera lens with respect to the center of the window during lunar flyby for best image quality.
Crew Configuration and Observing Windows	Opportunistic imaging made use of a variety of Orion windows. During lunar flyby, the primary configuration was with crew members positioned on their backs at Window 2 with Nikon D5 (or Z9 during Eclipse) and at Window 3 for unaided-eye observations. When not at the primary windows during lunar flyby, the crew reported using the Docking Hatch Window to collect additional imagery. Windows 1 and 4 were also available for additional observations.
External Light	The crew used a shroud and other light-dampening material during the lunar flyby to block internal lights and the sunlight that reflected off materials inside the cabin. Crew

	reported significant sun glare off reflective material within the cabin, which affected observations during lunar flyby. For deep sky and galactic observations, crew reported excessive reflection from the solar arrays.
Image Sequence	During the lunar flyby, the image sequence was generally driven by the Lunar Targeting Plan, but the crew had flexibility to image other targets during the observation period. The crew captured multiple images over a single target area to enable advanced post-processing, such as the generation of High Dynamic Range (HDR) products. Crew members were trained to first take context images with a zoomed-out view before using the zoom capabilities. For large areas, crew members were trained to take mosaics with a 30-50% overlap. Image sequences also include multiple image captures at different camera settings as the crew made adjustments to achieve the desired image quality.

3.1.2. Window Quality DFTO and observing windows

The Artemis II Orion forward windows (Figure 2) are made of a three-layer stack of 0.5-inch-thick panes, with an outer thermal pane of fused silica, a middle thermal pane of cast acrylic and inner pressure pane of stretched acrylic. These layers, especially the cast acrylic can distort and alter images collected through them. Unfortunately, pre-mission characterization of images collected using the Nikon cameras and through the full three-stack panes of the forward windows on Orion could not be conducted. It was therefore critical to assess window quality in flight but before the lunar flyby science observations to determine if a change in observing configuration was necessary. To assist in the assessment, on Flight Day 3 Pilot Victor Glover performed a Window Quality Developmental Flight Test Objective (DFTO) to assess window quality for observations. Table 4 provides the UTC time range of observations made during the DFTO activities.

A report on the Window Quality DFTO analysis and results is provided in Appendix E. Based on the results, no changes to the planned configuration for flyby observations were made. The analysis revealed that Window 2 was the best window for imaging and that the crew had a GO for collecting images at 400 mm focal lengths. The spacecraft was pointed to position the Moon in Window 2 with the recommendation to conduct imaging observations from the left position (left side of the window when facing the window from inside the cabin). This was communicated via a Flight Note and verbalized over the Orion-to-Earth 1 voice loop as a reminder during the pre-flyby preparations on Flight Day 6.



Figure 2. Orion vehicle observing windows: forward Windows 1, 2, 3, and 4, Side Hatch, and Docking Hatch.

3.1.3. Nikon camera characterization and lens distortion model

The Nikon D5 and Z9 cameras were not calibrated to meet specific science requirements for the Artemis II mission. Prior to flight, the only characterization performed was a geometric lens distortion calibration of the Nikon D5 cameras fitted with first the 80-400 mm lens and then the 14-24 mm lens. Each was set to varying focal lengths based on the lens markings by Nikon. The geometric lens distortion calibration was only completed on the Nikon D5 cameras because of the late addition of the Nikon Z9 camera to the Orion

manifest. Details on this pre-flight activity and the resulting lens distortion correction model are provided as a document to this archive (artemis2_nikon_lens_distortion_correction.pdf). No color-calibration imaging was completed, either to characterize the camera sensors themselves or through the Orion windows.

3.2. Mission Audio: PCD and Voice Loops

3.2.1. PCD audio descriptions

Crew members used four Portable Computing Devices (PCDs) during the mission, with one (PCD 4) failing part-way through the mission. Their primary uses for science observations were 1) to record audio of crew observations while paired with a Peltor Headset, 2) to record handwritten crew notes of observations, 3) to serve as an imagery relay for mission downlink, and 4) to provide the Lunar Targeting Package to support lunar observations.

To start the mission, each crew member had an assigned PCD, which was a Microsoft Surface Pro 5 tablet (Table 6). Failure of PCD 4 prior to lunar flyby caused CDR Wiseman and MS1 Koch to share PCD 1 for the remainder of the mission. During the lunar flyby, PCD 2 and PCD 3 were the primary devices for recording audio observations (using the system audio recorder and Peltor headset) from crew members configured at Orion's Windows 2 and 3. Throughout the mission, each PCD was synced with the Orion clock time, which also served as the reference clock for the crew handheld cameras. The audio recordings were saved as M4A formatted files and downlinked during the mission for use in scientific analysis (Section 5.4).

Verbal observations were made by the crew with both the unaided eye and with the Nikon D5 camera (configuration described more in Section 3.1.1 and Table 5). The crew noted during the post-mission debrief that during audio recordings, the Peltor headset was often worn in a one-ear on, one-ear off configuration to allow the crew member to be able to converse with each other about synchronous observations. These conversations are apparent in the PCD audio recordings where multiple crew members can be heard in the foreground and background.

Table 6. PCD Number and crew use during the mission.

PCD Number	Primary Crew Member
PCD 1	CDR Wiseman's primary PCD; shared with MS1 Koch after PCD4 failure
PCD 2	PLT Glover's primary PCD; recorded audio of MS2 Hansen and PLT Glover during lunar flyby
PCD 3	MS2 Hansen's primary PCD; recorded audio of MS1 Koch and CDR Wiseman during lunar flyby
PCD 4	MS1 Koch primary's PCD; failed part-way through the mission

Any annotations by the crew members were made in a pre-set OneNote file on the PCD that crew had at the time of observations. OneNote files were set up on each PCD before the lunar flyby and included a set of pages with images at different zoom levels and perspectives for each target in the Lunar Targeting Plan. These pages served as base images on which the crew could annotate to record observations. The entire OneNote file (.one) was downlinked as the source file that was then converted to a PDF/A formatted file for the science archive.

3.2.2. Voice loop description

The primary voice loop between the crew members and NASA Johnson Space Center (JSC) mission control was Orion-to-Earth 1 (O/E-1), which was also publicly aired during NASA video streams during the mission. Orion-to-Earth 2 (O/E-2) was used sparingly during loss of signal on O/E-1. Both O/E-1 and O/E-2 voice loops provided scientific context during opportunistic imaging and the lunar flyby as Situational Reports (SitReps) where the crew members described lunar observations and cabin configuration.

3.3. Orion Cameras: SAW Cam 2, 3, 4, Cab Cam 2, OpNav, DCAM

3.3.1. Orion vehicle camera descriptions

The Lunar Science Team received and archived data from six Orion vehicle cameras. Their primary function during the mission was to support imaging for various spacecraft and engineering assessments, with science observations provided primarily during lunar flyby. Figure 3 shows the placement of each camera on Orion, with camera specifications provided in the Artemis II OSDMP.

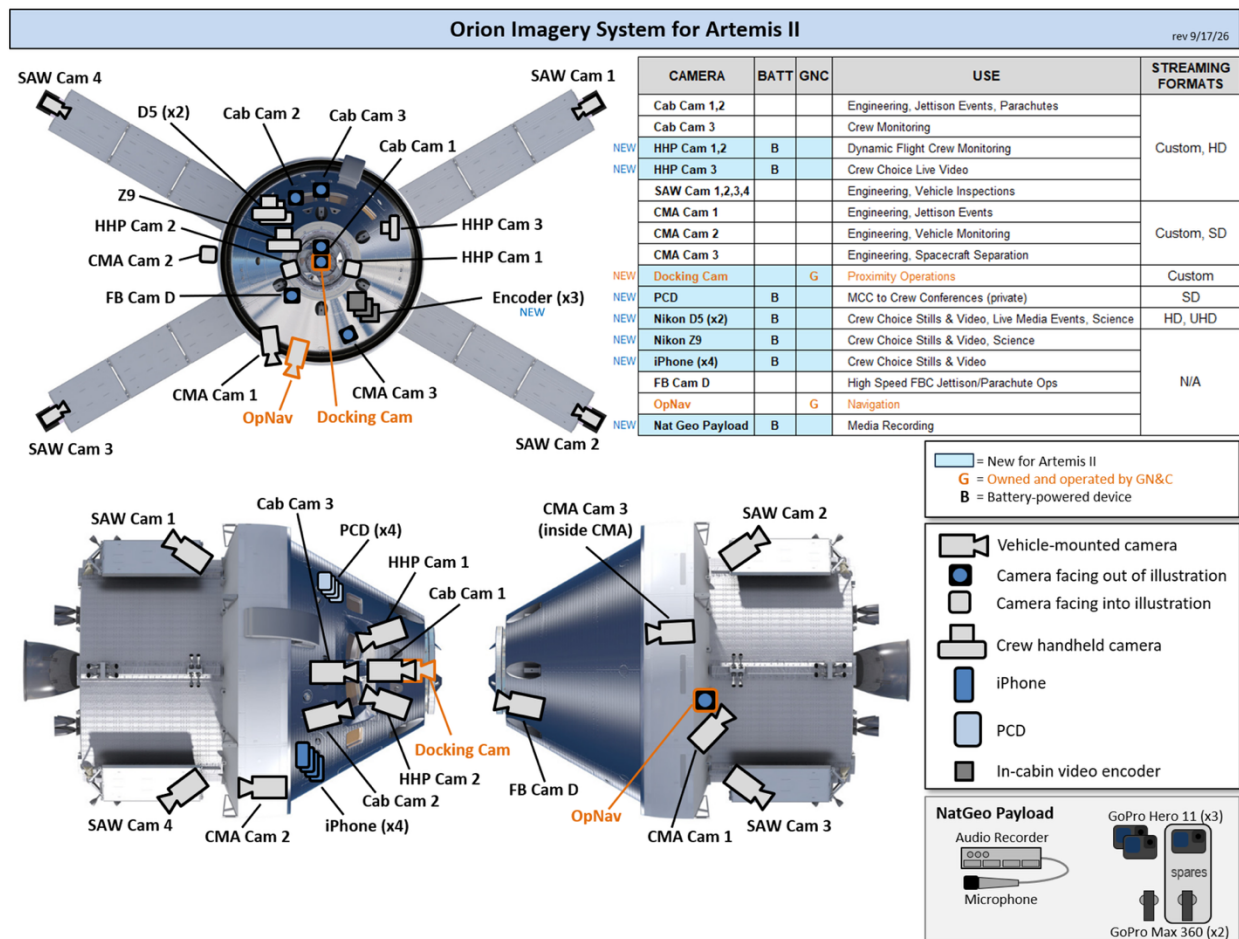


Figure 3. Orion Imagery System configuration for Artemis II. Includes vehicle-mounted cameras used for monitoring spacecraft performance, (both exterior and interior to the crew cabin), crew handheld devices, navigation sensors, biomedical cameras, and the National Geographic public outreach payload. Note that additional cameras are shown that are not part of the science archive.

Orion Solar Array Wing (SAW) Cam 2, 3, and 4 (also abbreviated as SAW2, SAW3, and SAW4 for the science data archive) are modified GoPro Hero 4 Black cameras and are mounted to the ends of the Orion solar arrays, with SAW Cam 3 used as the primary camera for collecting images and video during the lunar flyby due to the orientation of the Orion spacecraft. SAW Cam 1 did not collect relevant science data during the mission. Cab Cam 2 (also a GoPro Hero 4 Black and abbreviated in the archive as CAB2) is mounted to the inside of Window 3, providing views from within the Orion Vehicle. The Docking Camera (DCAM) is a Malin Space Science Systems custom design camera (with Complementary Metal-Oxide-Semiconductor, CMOS, sensors) and the Optical Navigation (OpNav or ONAV) camera is a Pixelink Prometheus PL-D725MU. Both are monochrome cameras and primarily supported Guidance Navigation & Control (GNC) activities during the mission.

3.3.2. Orion vehicle camera imaging during the lunar flyby

The Lunar Science Team and vehicle camera science lead worked closely with the NASA JSC Image Science and Analysis Group and the Imagery Ops Team to plan science observations with vehicle cameras during the lunar flyby. Vehicle camera science observations were designed to assist with achieving science objectives with coverage of the Moon during the flyby by providing views from an externally mounted camera (outside the influence of the cabin windows), furnishing context and complementary observations to crew images and descriptions of colors, brightness, and other aspects of lunar surface features (Figure 4; Table 7).

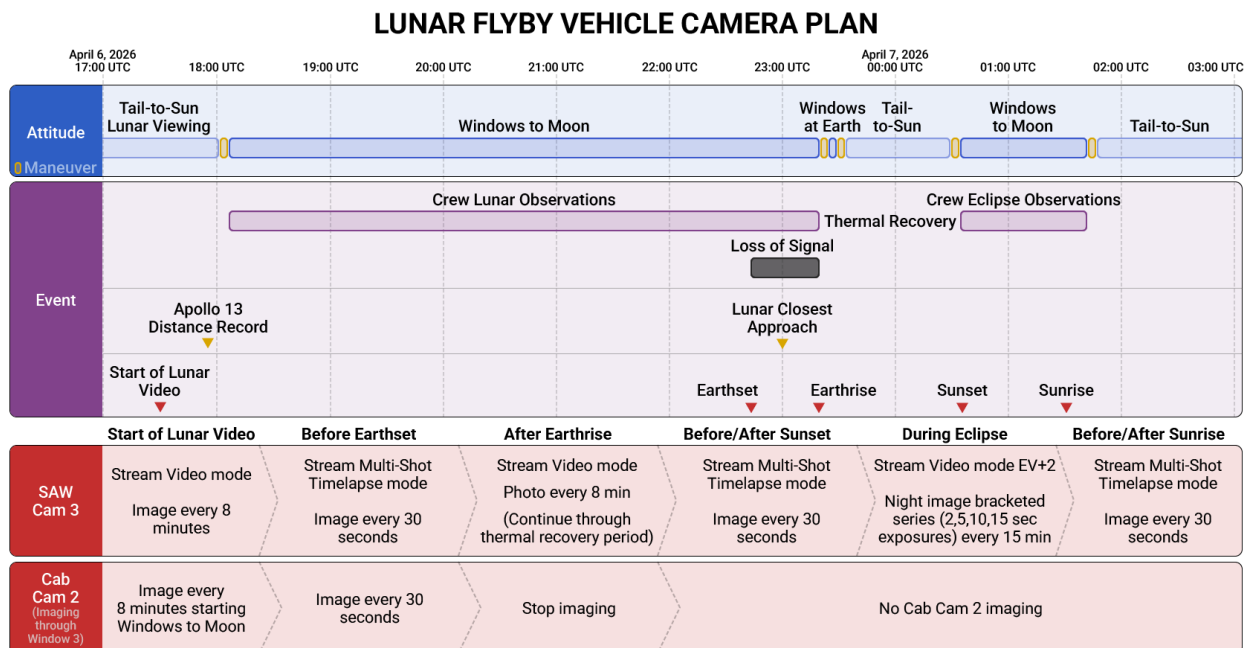


Figure 4. A visual representation of the vehicle camera (SAW Cam 3 and Cab Cam 2) science observations during the lunar flyby. Tail-to-Sun = attitude with -X axis to the Sun which allows solar charging; Maneuver is to change attitude.

The two vehicle cameras used for observations during the flyby were the SAW Cam 3 mounted on Orion's solar array wing 3, and Cab Cam 2 mounted inside Orion to capture the crew's perspective through Orion's forward Window 3 (Figure 3; Table 7). SAW Cam 3 streamed video in real time during the flyby and

acquired the camera's highest resolution still images (4000x3000 pixels, or 12 megapixels). Cab Cam 2 also was sequenced to acquire its highest resolution still images at 12 megapixels. Still images were obtained at a cadence of one every 8 minutes to correspond with the cadence of LTP targets. Surrounding the dynamic events of earthrise, earthset, sunrise, and sunset, still images were acquired by SAW Cam 3 and Cab Cam 2 in a multi-shot timelapse mode at a cadence of every 30 seconds including through the entirety of the Loss of Signal (LOS) after earthset. During the eclipse, SAW Cam 3 was transitioned to night imaging settings with the illuminator off and still images were captured in a night photo mode in a bracketed series of 2-, 5-, 10-, and 15-second exposures every 15 minutes (Figure 4; Table 7). Time ranges (in UTC yyyy-mm-dd hh:mm:ss format), modes, and cadence of still image acquisition by SAW Cam 3 and Cab Cam 2 during the lunar flyby are shown in Table 7.

Table 7. Summary of SAW Cam 3 and Cab Cam 2 science imaging during the lunar flyby.

Camera	Imaging Type	Start time UTC	End Time UTC	Cadence	Mode	Science Justification
SAW Cam 3	Still Imaging	2026-04-06 17:45:24	2026-04-06 22:30:25	One image every 8 minutes		Cadence selected to correspond with the cadence of crew LTP targets
SAW Cam 3	Still Imaging	2026-04-06 22:34:14	2026-04-06 23:26:44	One image every 30 seconds	Multi-shot timelapse mode	Capture images at a higher rate to capture views of the full earthset, the lunar surface during LOS, and earthrise
SAW Cam 3	Still Imaging	2026-04-06 23:27:26	2026-04-07 00:27:17	One image every 8 minutes		Cadence selected to correspond with the cadence of crew LTP targets
SAW Cam 3	Still Imaging	2026-04-07 00:28:09	2026-04-07 00:39:39	One image every 30 seconds	Multi-shot timelapse mode	Capture images at a higher rate to capture full sunset and beginning of the eclipse
SAW Cam 3	Still Imaging	2026-04-07 00:40:29	2026-04-07 01:11:49	Four Images every 15 minutes	Night photo bracketed series of 2-, 5-, 10-, and 15-second exposures	Capture images at multiple exposures for the low illumination conditions during the eclipse
SAW Cam 3	Still Imaging	2026-04-07 01:22:40	2026-04-07 01:36:09	One image every 30 seconds	Multi-shot timelapse mode	Capture images at a higher rate to capture views of the lunar surface during the end of eclipse and during the full sunrise
Cab Cam 2	Still Imaging	2026-04-06 17:58:48	2026-04-06 22:30:44	One image every 8 minutes		Capture the crew's perspective through Orion's forward window number 3. Cadence selected to correspond with the cadence of crew LTP targets
Cab Cam 2	Still Imaging	2026-04-06 22:34:33	2026-04-06 23:26:34	One image every 30 seconds	Multi-shot timelapse mode	Capture the crew's perspective through Orion's forward window number 3. Images acquired at a higher rate to capture views of the full earthset, the lunar surface during LOS, and earthrise

Cab Cam 2	Still Imaging	2026-04-06 23:27:46	2026-04-06 23:27:46 (imaging ended before vehicle attitude change for thermal recovery after the eclipse)	One image every 8 minutes		Capture the crew's perspective through Orion's forward window number 3. Cadence selected to correspond with the cadence of crew LTP targets
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3.3.3. Orion SAW Cam 3 video

The SAW Cam 3 streamed video in real time during the lunar flyby (see Table 4 for UTC time range and Table 8 for camera time sequence around this time) and other portions of the mission. During the lunar flyby, even though the camera was set to acquire 30 frames per second (frames/sec), the video data were not always streamed to the ground at the original frame rate. Due to low downlink bandwidth available during that portion of the mission, the onboard video encoder's frame rate was lowered to provide a more stable image in the live stream downlink. Therefore, the effective frame rate for streaming video recorded on the ground was lower than the original frame rate. The metadata for the streamed video reflects the ground-decoded video frame rate which is not always equal to the effective frame rate of the video. The downlink encoder IDs and the effective frame rate for the SAW Cam 3 video and other downlink information is available in Table 8 and is also included with the metadata in the archive.

Table 8. Live stream frame rates and sizes of SAW Cam 3 video prior to and during lunar flyby.

Encoder and Video File Name	File NASA ID	ID	Color	Frame Size	Frames Rate (fps)	Bitrate (kbps)
Encoder ID 8 at UTC 2026-04-06 15:53:52.845		8	Color	1280x720	30	1300
ART-DL-1_2026_096_1540_09000_2336030	art002m1010961540					
ART-DL-1_2026_096_1555_10000_2336058	art002m1010961555					
ART-DL-2_2026_096_1540_05000_2336032	art002m1020961540					
ART-DL-2_2026_096_1555_09000_2336056	art002m1020961555					
Encoder ID 3 at UTC 2026-04-06 16:47:24.844		3	Color	640x360	5	240
ART-DL-1_2026_096_1648_13000_2336059	art002m1010961648					
ART-DL-1_2026_096_1701_00000_2336078	art002m1010961701					
ART-DL-1_2026_096_1736_44000_2336079	art002m1010961736					
ART-DL-1_2026_096_1740_42000_2336131	art002m1010961740					
ART-DL-2_2026_096_1648_13000_2336057	art002m1020961648					
ART-DL-2_2026_096_1701_00000_2336080	art002m1020961701					
ART-DL-2_2026_096_1736_44000_2336081	art002m1020961736					
ART-DL-2_2026_096_1740_42000_2336133	art002m1020961740					
Encoder ID 8 at UTC 2026-04-06 17:40:09.848		8	Color	1280x720	30	1300
ART-DL-1_2026_096_1939_18000_2336132	art002m1010961939					
ART-DL-1_2026_096_1940_51000_2336200	art002m1010961940					

ART-DL-1_2026_096_2139_14000_2336312	art002m1010962139					
ART-DL-1_2026_096_2338_11000_2336419	art002m1010962338					
ART-DL-2_2026_096_1939_13000_2336134	art002m1020961939					
ART-DL-2_2026_096_1941_00000_2336198	art002m1020961941					
ART-DL-2_2026_096_2139_14000_2336323	art002m1020962139					
ART-DL-2_2026_096_2338_11000_2336431	art002m1020962338					
Encoder ID 7 at UTC 2026-04-06 23:40:46.828	No archive files	7	Color	1280x720	5	650
Encoder ID 3 at UTC 2026-04-06 23:47:37.846		3	Color	640x360	5	240
ART-DL-1_2026_097_0138_15000_2336461	art002m1010970138					
ART-DL-2_2026_097_0138_15000_2336459	art002m1020970138					
Encoder ID 0 at UTC 2026-04-07 01:53:28.840	No archive files	0	Color	640x360	1	50

Since the video was only streamed, it was not saved on the camera, and when the frame rate was lowered due to the decreased bandwidth, the additional frames were not recorded. Notably, one of the periods affected by the lower bandwidth was the solar eclipse period of the lunar flyby. The end of the lunar flyby livestream is considered to be 2026-04-07 01:45 UTC. This is the end time of the Eclipse Observation Attitude (when CM window 2 was pointed at the Moon). Note that the livestream continued past this time, but the vehicle was no longer intentionally pointed for the flyby.

During the eclipse, SAW Cam 3 was commanded to take a 2-minute-and-10-second video that was not in the original vehicle imaging plan. This video (NASA ID art002m1200970119) was collected to help keep the camera warm while the Moon was between Orion and the Sun. This video was not streamed in real-time but was temporarily stored on SAW Cam 3. The data was later transferred off the camera to the internal camera controllers and was retrieved post-splashdown. As the video was not streamed, it therefore retains the collected framerate of 30 frames/sec. This is the only recorded video from lunar flyby that was collected and retrieved post-flight.

3.3.4. Orion DCAM and OpNav imaging activities

The DCAM primarily supported the Proximity Operations (Prox Ops) demonstration about 3 hours into the mission. During Prox Ops the DCAM was used to visualize the detached upper stage of the SLS as the crew piloted Orion to simulate rendezvous with a future lunar lander. The OpNav camera takes images of celestial bodies, like the Earth and Moon, against starfield backgrounds. By measuring the size, position, and phase of these objects, the onboard camera computes the spacecraft's exact range, bearing, and trajectory (Inman et al 2024). Since the DCAM and OpNav cameras are fixed to the spacecraft, the attitude and trajectory determine the field of view of the camera. Following the successful Prox Ops demonstration, the DCAM as well as the OpNav cameras collected additional imaging of both the Earth and Moon when they were in their view or in support of other mission or Developmental Flight Test Objectives (DFTOs). Though these images were not planned by the science team, they are of secondary benefit and could be used for future scientific analyses.

3.4. Orion Environmental Monitoring

Two Onset HOBO MX1101 data loggers (unique IDs SN 1104 and SN 1105) were used to measure temperature, humidity, and dew point data in order to characterize the storage compartments (Lockers D/E)

within Orion throughout the Artemis II trajectory. Measurements were made at 60-second intervals from 2026-03-26 16:25:46 to 2026-04-21 20:50:46 UTC (for SN 1104) and from 2026-03-26 16:29:26 to 2026-04-21 20:38:26 UTC (for SN 1105). In doing so, this information provided baseline environmental data expected for samples to be returned in these same lockers for future Artemis missions. Two bags containing the data loggers were put in the lockers during nominal load back before the first launch window in February 2026. Data Logger SN 1104 was in Locker E Bag L_011 for the entire duration of the mission. Data Logger SN 1105 was in Locker D, Bag L_022 for launch and was moved to Locker F, Bag R_027 on Flight Day 09 sometime between 2026-04-09 18:00:00 and 21:00:00 UTC and stayed there for the rest of the mission. Other events and times relevant for the HOBO data logger recordings:

- Orion power down: 2026-04-11 00:30:00 UTC
- Orion secured in recovery ship well deck: 2026-04-11 08:14:00 UTC
- Bags handed over to cargo mission support San Diego: after 2026-04-14 19:00:00 UTC

Flight certification and functional tests and inspections of the data loggers were completed after flight configuration and prior to the mission, including verification of measurements of temperature and humidity with laboratory sensors. Although the data loggers were set to overwrite the start of recorded memory in the event that the data memory became full, the data loggers were recovered with ample time and memory to preserve the full length of recorded measurements.

4. PDS4 and Archive Organization

This section describes the organization of the Artemis II science data archive according to the PDS4 Information Model. See Appendix C for directory trees for each of the bundles contained in the archive.

4.1. Planetary Data System (PDS) Archive Overview

The NASA PDS consists of a set of Discipline Nodes, each one specializing in a subset of planetary science such as atmospheres, geosciences, and planetary rings. The PDS operates on the principle that planetary science data are best archived by experts in each field of study. Table 9 shows the PDS nodes that have the responsibility to archive and host Artemis II science data.

Table 9. Bundles archived at the PDS Nodes.

Bundle	PDS Node	
artemis2_crew_camera	CIS	Cartography and Imaging Sciences Node, U.S. Geological Survey, Flagstaff, Arizona, and Jet Propulsion Laboratory, Pasadena, California
artemis2_orion_camera		
artemis2_mission_audio		
artemis2_mission	GEO	Geosciences Node, Washington University, St. Louis, Missouri
artemis2_spice	NAIF	Navigation and Ancillary Information Facility, Jet Propulsion Laboratory, Pasadena, California

4.2. Archive Bundles, Collections, and Products

PDS develops standards for stable, accessible, well-documented science archives, and specifies how these standards are implemented. The current standard for PDS archives is PDS4. This standard organizes science data and documentation into bundles, collections, and products, summarized below. Readers unfamiliar with the PDS4 standard are referred to the PDS Concepts Document (listed in Section 1.2) for a detailed explanation.

The highest level of organization for a PDS4 archive is the bundle. A bundle is a set of one or more related collections which may be of different types. A collection is a set of one or more related basic products that are typically all of the same type. Bundles and collections are logical structures, not necessarily tied to any physical directory structure or organization.

The Artemis II science data archive is organized into five PDS4 bundles by instrument platform (crew and Orion camera bundles), mission (mission audio and mission document bundles), or navigation and ancillary information (SPICE bundle). The Artemis II science data bundles include collections of data products, documents, and other products organized by processing level and type, as shown in Table 10.

Within each collection, individual products are generally arranged into sub-directories by Flight Day (fd01, fd02, fd03, etc.). Placement into Flight Day subdirectories was determined based on the metadata UTC date and time recorded by each instrument or sensor at the time of collection. The relationship between Flight Day and UTC time is provided in Table 4. Each product also has its own unique name based on the file naming conventions in Appendix D. More details on product types are provided in Section 5, with bundle and collection directory structure provided in more detail in Appendix C.

Each data product consists of one digital object in one file, accompanied by a detached PDS4 label file in XML format (Section 4.3). Document files are also archived and assigned PDS labels. PDS labels provide identification and other metadata for the data and document files. Collections and bundles are also considered products in PDS4 and therefore have their own labels.

Every product, including collections and bundles, also has a unique logical identifier (LID). Each LID begins with the prefix “urn:nasa:pds”. The LIDs for bundle and collections in the archive are shown in Table 10. Product LIDs are composed of the collection LID plus a colon plus the product label file name, minus the XML extension and version number. An example LID for a Nikon D5 source product would be:

urn:nasa:pds:artemis2_crew_camera:data_source:art002eXXXXXX_nkd5015_src.nef

Table 10. Archive bundles and collections with their Logical Identifiers (LIDs).

Bundle	Collection Logical Identifiers	Contents
artemis2_crew_camera	urn:nasa:pds:artemis2_crew_camera:data_source	Source Nikon D5 and Z9 camera images
	urn:nasa:pds:artemis2_crew_camera:data_raw	Converted Raw Nikon D5 and Z9 images
	urn:nasa:pds:artemis2_crew_camera:data_processed	Processed Nikon D5 and Z9 images
	urn:nasa:pds:artemis2_crew_camera:browse	Browse Nikon D5 and Z9 images

artemis2_orion_camera	urn:nasa:pds:artemis2_orion_camera:browse_source	Browse and Source Orion camera images
	urn:nasa:pds:artemis2_orion_camera:data_raw_image	Converted raw Orion Camera image
	urn:nasa:pds:artemis2_orion_camera:data_video	Orion camera video
artemis2_mission_audio	urn:nasa:pds:artemis2_mission_audio:data_audio_pcd	Audio data (PCD)
	urn:nasa:pds:artemis2_mission_audio:data_audio_loops	Audio (Voice loops)
	urn:nasa:pds:artemis2_mission_audio:data_transcripts_pcd	Transcripts (PCD Audio)
	urn:nasa:pds:artemis2_mission_audio:data_transcripts_loops	Transcripts (Voice loop Audio)
	urn:nasa:pds:artemis2_mission_audio:annotations	Annotations (PCD)
artemis2_mission	urn:nasa:pds:artemis2_mission:document	Documents
	urn:nasa:pds:artemis2_mission:data_orion_environment	Orion Environment Data (temp/humidity) from HOBO data loggers.
artemis2_spice	urn:nasa:pds:artemis2_spice:spice_kernels	SPICE kernels and required auxiliary files arranged in the standard format
	urn:nasa:pds:artemis2_spice:document	SPICE documents
	urn:nasa:pds:artemis2_spice:miscellaneous	Miscellaneous SPICE information

4.3. XML Labels

The metadata for a PDS4 product is recorded in a PDS4 label using XML (eXtensible Markup Language). Typically, a label has the same file name as the data file it describes but with the extension “.xml”. A product may consist of more than one data object (i.e. a table or an image) in a file, and it may consist of more than one data file, but a product always has exactly one detached PDS4 label file. Some data products have other kinds of metadata embedded in the data files. XML is a widely used standard for storing metadata, and while it is easy for software to read, it can be more difficult for humans to read. XML labels are best viewed using an XML-aware editor that can help by color-coding the XML elements and allowing the reader to open and close sections of the label. Some commonly used XML-aware editors include Notepad++, Visual Studio Code, xmplify, and Oxygen. Oxygen is the editor used by many PDS personnel.

4.4. Data Dictionaries

The content of PDS4 XML labels is rigorously controlled by PDS to ensure quality and consistency. Every element in a PDS4 label is defined in a data dictionary, either in the core PDS dictionary or in one of several discipline-specific or mission-specific dictionaries. Table 11 lists the dictionaries used in the Artemis II science data archives. These dictionaries are actively maintained and frequently updated, but previous versions remain available. The versions listed in the table are those that were in place at the time of the first Artemis II science data release. All PDS dictionaries may be found at <https://pds.nasa.gov/datastandards/dictionaries/>.

Further information on the data dictionaries and the class and attributes used is provided in the Artemis 2 Product Label Keyword Definitions table included in the document collection to this archive (artemis2_label_definitions in both PDF and HTML format).

Table 11. Data Dictionaries used in the Artemis II science data archives.

Dictionary	File Name	PDS Node Steward
PDS Core Dictionary	PDS4_PDS_1Q00.*	PDS Engineering Node
Audio Video Discipline Dictionary	PDS4_AV_1Q00_1000.*	PDS Cartography and Imaging Sciences
Cartography Discipline Dictionary	PDS4_CART_1Q00_1970.*	PDS Cartography and Imaging Sciences
COTS Camera Discipline Dictionary	PDS4_COTS_CAMERA_1Q00_1000.*	PDS Cartography and Imaging Sciences
Context Type List: Instrument Discipline Dictionary	PDS4_CTLI_1Q00_2300.*	PDS Atmospheres Node
Display Discipline Dictionary	PDS4_DISP_1Q00_1510.*	PDS Cartography and Imaging Sciences
Geometry Discipline Dictionary	PDS4_GEOM_1Q00_19B0.*	PDS Geosciences Node
Imaging Discipline Dictionary	PDS4_IMG_1Q00_1940.*	PDS Cartography and Imaging Sciences
Surface Imaging Discipline Dictionary	PDS4_IMG_SURFACE_1Q00_1280.*	PDS Cartography and Imaging Sciences
Mission Information Discipline Dictionary	PDS4_MSN_1Q00_1330.*	PDS Cartography and Imaging Sciences
Surface Mission Discipline Dictionary	PDS4_MSN_SURFACE_1Q00_1310.*	PDS Cartography and Imaging Sciences
Processing Information Discipline Dictionary	PDS4_PROC_1Q00_1400.*	PDS Cartography and Imaging Sciences

5. Data Products

Artemis II data products consist of source, raw, processed, and browse, and document products. As described in Section 4.3, every data product has a detached PDS4 label file in XML format that describes the associated metadata and adheres to PDS4 standards (Section 1.2).

The product file naming convention is provided in Appendix D. Most products in the archive have an assigned NASA ID, which is retained in the PDS archive file name. Importantly, the sequential numbering applied to the NASA ID is based on the sequence in which the file was received and catalogued by the NASA JSC ground image processing facility, which does not necessarily match the time sequence in which the observation was recorded during the mission. For a time-ordered understanding of each file, the user should refer to the recorded time (in UTC) provided in each file's metadata labels under the xml tag `<start_date_time>`.

Table 12. PDS4 data processing level definitions.

PDS4 Processing Level	Description
Source (Not a standard PDS4 Processing Level)	Original data from the camera or instrument with no format conversion applied. In most cases, the original source product was preserved as either a “native” product or “browse” product according to PDS4 standards.
Raw	Original data from an experiment. If compression, reformatting, packetization, or other translation has been applied to facilitate data transmission or storage, those processes are reversed so that the archived data are in a PDS approved archive format. Important Note: For this archive, raw data is defined as the data received from the system and converted to a PDS-approved format, as necessary. For Nikon camera data, the source files are converted to raw TIFF files. For Orion camera data, this includes images that were processed by the camera when no original “as-collected” sensor data were acquired.
Partially Processed	Data that have been processed beyond the raw stage, but which have not yet reached calibrated status. Important Note: For this archive, partially processed data is defined as data that have been processed on the ground beyond what has been received. This applies to Nikon camera images, in particular. Orion camera images were not further processed on the ground and are therefore designated as “Raw” products.
Calibrated	Data converted to physical units, which makes values independent of the experiment. Important Note: For this archive, no calibrated data products are provided.
Derived	Results that have been distilled from one or more calibrated data products (for example, maps, gravity or magnetic fields, or ring particle size distributions). Supplementary data, such as calibration tables or tables of viewing geometry, used to interpret observational data should also be classified as ‘derived’ data if not easily matched to one of the other three categories. Important Note: For this archive, no derived data products are provided.

Table 12 defines the standard PDS processing levels for these data products and Tables 13, 14, 15, and 16 provide summaries of the data product types for each bundle and collection in the archive.

While not a standard PDS4 processing level, “Source” data is used here to refer to the original data from the camera or instrument with no format conversion applied. Data were provided to the LST in a range of formats, including compressed versions and proprietary formats that may become deprecated or unviewable over time or are otherwise not retrievable with open-source tools. These formats were generally not PDS4 compliant as a science observation product and therefore required conversion before archiving. In most cases, the original source product was preserved as either a “native” product or “browse” product according to PDS4 standards.

Table 13. Crew Camera product types.

PDS4 bundle:collection	Product and File Names	PDS4 Processing Level/Type	Product Description	PDS4 Data Type
artemis2_crew_camera:data_source	Crew Handheld Camera Source art002eXXXXXX_nkd5015_src_vXX.nef art002eXXXXXX_nkd5017_src_vXX.nef art002eXXXXXX_nkz9019_src_vXX.nef	N/A (Source)	Nikon D5 and Z9 native source images	Encoded Native
artemis2_crew_camera:data_raw	Crew Handheld Camera Raw art002eXXXXXX_nkd5015_raw_vXX.tif art002eXXXXXX_nkd5017_raw_vXX.tif art002eXXXXXX_nkz9019_raw_vXX.tif	Raw	Nikon D5 and Z9 raw converted images	Array 2D image
artemis2_crew_camera:data_processed	Crew Handheld Camera Processed art002eXXXXXX_nkd5015_prc_vXX.tif art002eXXXXXX_nkd5017_prc_vXX.tif art002eXXXXXX_nkz9019_prc_vXX.tif	Partially Processed	Nikon D5 and Z9 processed images	Array 3D image
artemis2_crew_camera:browse	Crew Handheld Camera Browse art002eXXXXXX_nkd5015_prc_vXX.png art002eXXXXXX_nkd5017_prc_vXX.png art002eXXXXXX_nkz9019_prc_vXX.png	N/A (Browse)	Nikon D5 and Z9 browse images (from processed images)	Encoded Image

Table 14. Orion Camera product types.

PDS4 bundle:collection	Product and File Names	PDS4 Processing Level/Type	Product Description	PDS4 Data Type
artemis2_orion_camera:browse_source	Orion Camera Browse art002eXXXXXX_saw2_src_vXX.jpg art002eXXXXXX_saw3_src_vXX.jpg art002eXXXXXX_saw4_src_vXX.jpg art002eXXXXXX_cab2_src_vXX.jpg art002eXXXXXX_onav_raw_vXX.png art002eXXXXXX_dcam_src_vXX.png	N/A (Browse)	Orion camera browse images (most from compressed source images)	Encoded Image
artemis2_orion_camera:data_raw_image	Orion Camera Raw art002eXXXXXX_saw2_raw_vXX.tif art002eXXXXXX_saw3_raw_vXX.tif art002eXXXXXX_saw4_raw_vXX.tif art002eXXXXXX_cab2_raw_vXX.tif art002eXXXXXX_onav_raw_vXX.tif art002eXXXXXX_dcam_raw_vXX.tif	Raw	Orion camera raw converted images	Array 2D/3D image
artemis2_orion_camera:data_video	Orion Camera Video art002mXXXXXXXXXX_saw3_vid_vXX.mp4	Raw	SAW3 camera videos as mp4s	Encoded Video

Note: The browse_source collection contains original source JPEG and PNG images, which in PDS4 are restricted to being used as browse products due to their compressed formats. For SAW Cam 2, 3, 4 and Cab Cam 2, the original source JPEG is used as the browse data product. Similarly, for DCAM, the original source PNG is used as the browse data product.

Table 15. Mission Audio product types.

PDS4 bundle:collection	Product and File Names	PDS4 Processing Level/Type	Product Description	PDS4 Data Type
artemis2_mission_audio: data_audio_pcd	PCD Audio Raw art002aXXXXXX_pcd2_raw_vXX.m4a art002aXXXXXX_pcd3_raw_vXX.m4a	Raw	PCD audio recordings (m4a)	Encoded Audio
artemis2_mission_audio: data_audio_loops	Voice Loop Audio Raw art002_2026-04-06_oe1_raw_v01.m4a art002_2026-04-07_oe1_raw_v01.m4a art002_2026-04-07_oe2_raw_v01.m4a	Raw	Voice Loop audio recordings (m4a)	Encoded Audio
artemis2_mission_audio: data_transcripts_pcd	PCD Audio Transcripts art002aXXXXXX_pcd2_trn-csv_v01.csv art002aXXXXXX_pcd2_trn-srt_v01.srt art002aXXXXXX_pcd3_trn-csv_v01.csv art002aXXXXXX_pcd3_trn-srt_v01.srt	Processed	Transcripts from PCD audio in both csv and srt formats	Table Delimited & Stream Text
artemis2_mission_audio: data_transcripts_loops	Voice Loop Audio Transcripts art002_2026-04-06_oe1_trn-csv_v01.csv art002_2026-04-06_oe1_trn-srt_v01.srt art002_2026-04-07_oe1_trn-csv_v01.csv art002_2026-04-07_oe1_trn-srt_v01.srt art002_2026-04-07_oe2_trn-csv_v01.csv art002_2026-04-07_oe2_trn-srt_v01.srt	Processed	Transcripts from voice loop audio in both csv and srt formats	Table Delimited & Stream Text
artemis2_mission_audio: annotations	PCD Annotations art002e009303-e009388_pcd1_ann_v01.pdf art002e009389-e009474_pcd2_ann_v01.pdf art002e009475-e009560_pcd3_ann_v01.pdf art002e016252_pcd_ann_v01.pdf art002e050885_ann_v01.pdf	Document	Crew annotations from PCDs	Document (PDF/A)

Table 16. Mission bundle product types.

PDS4 bundle:collection	Product and File Names	PDS4 Processing Level or Type	Product Description	PDS4 Data Type
artemis2_mission: document	Artemis II Science Mission Documents artemis2_data_user_guide.pdf artemis2_label_definitions.pdf artemis2_lunar_targeting_package.pdf artemis2_lunar_targeting_package_pdfa.pdf artemis2_lunar_targeting_package_extended.pdf artemis2_lunar_targeting_package_extended_pdfa.pdf artemis2_nikon_lens_distortion_correction.pdf artemis2_osdmp.pdf artemis2_outgoing_target_request.json	Document	Mission documents	Document (PDF/A, ASCII, HTML)
artemis2_mission: data_orion_environment	Orion Environment Raw art002_XXX-XXXXXX_XXX- XXXXXX_hobo1104_raw_vXX.csv art002_XXX-XXXXXX_XXX- XXXXXX_hobo1105_raw_vXX.csv	Raw	HOB0 temperature/humidity data in csv format	Table Delimited

5.1. General Archive Generation Pipeline

Source data and metadata were received by the Lunar Science Team and then processed via a PDS4 archive software pipeline developed in close collaboration with the PDS. The basic steps used to generate the data-archive products, collections, and bundles are summarized below:

1. Generate bundle directory structure (Bundle/Collections/Subfolders)
2. Generate products by processing source data and other higher-level data products according to the steps described in Sections 5.2 to 5.4.
3. Design PDS4 XML labels using sample data products from pre-mission and mission files:
 - a. The Lunar Science Team and the PDS reviewed the embedded metadata for each data type and determined which subset of the metadata provided scientifically useful and accurate information for inclusion in the label. The final subset of metadata was chosen to provide an information-rich label while minimizing information on instrument settings or attributes that was either redundant, poorly understood, or was not used during the mission. Label templates were designed that mapped the chosen subset of embedded metadata tags to existing PDS4 Data Dictionary classes and attributes or, in some cases, to newly development Data Dictionary classes or attributes.
4. For each data product, generate PDS4 XML labels:
 - a. Extract embedded metadata from source data (using ExifTool, or other metadata extraction tool; see Section 6) into a json file and append additional metadata structures as needed.
 - b. Use the PDS-provided software (Labelocity, see Section 6) and label template mapping to the PDS4 Data Dictionaries with json metadata file to generate XML PDS4 label files for each data product.
5. Assemble data products and labels into bundles and collections.
6. Generate collection product inventory and XML label file for each collection (one inventory file and one label file for each collection).
7. Generate label files for each bundle (one per bundle)
8. Validate each Bundle using PDS4 Validate tool.
 - a. Generate a validation report.
 - b. Iterate as necessary by resolving validation issues and re-running the Validate Tool until the issues resolve.

5.2. Crew Camera Data Products

Images from the Nikon D5 and Nikon Z9 cameras consist of the source image files, raw files that have been converted to PDS4-compliant array image format, processed images, and browse image products. No calibration has been applied to these products. A description of the Nikon D5 and Z9 cameras is provided in Section 3.1. File name identifiers for the different products are provided in Table 13 and in the file naming conventions in Appendix D.

5.2.1. Nikon sensor color array and image processing

The Sun emits energy over a broad spectrum of wavelengths (Figure 5a), with visible light representing a narrow band of reflected energy over the range of approximately 380-750 nm, near the peak of emission of solar energy. Humans perceive color as the light that is reflected, with the Earth's atmosphere absorbing a significant fraction of the total solar radiation energy (Figure 5a). Sensors for light – from human eyes to the handheld cameras designed to record that light – are tailored for the solar energy that makes it through Earth's atmosphere. Outside of Earth, the entire solar spectrum becomes available again and can be altered in a similar way by gases or particles encountered elsewhere.

The sensors of both the Nikon D5 and Z9 cameras were not specifically designed for space or lunar observations and only record a part of the total reflectance from incoming solar radiation over the 400-700 nm color spectrum of visible light. Although the specifications are unpublished by Nikon, the company's cameras have proprietary filters that allow light to pass through three narrow bandwidths of the visible spectrum at red (R), green (G) or blue (B) wavelengths, arranged in a Bayer mosaic color filter array (Figure 5b,c). In this arrangement, there are twice the number of green pixels on the sensor – half of the total – with the remaining half split evenly between red and blue. This pattern has alternating rows of BGBGBGBGB and GRGRGRGRG with the green pixels arranged diagonally from one another. The shorthand for this type of color filter array (CFA) is RGGB (Figure 5b).

The RGGB Bayer pattern is recorded and stored differently in the different products included in this archive:

1. Source Data Products (Section 5.2.2): The recorded Nikon Electronic Format (NEF) wraps and reversibly compresses the Bayer pattern in a proprietary format. Nikon has not published details on the specifications for this format, so the RGB filter parameters are not fully known.
2. Raw Data Products (Section 5.2.3): For scientific use and for long-term preservation, the raw values from each of the RGB sensors were extracted from the NEF files, leaving the Bayer pattern intact but as a single grayscale image. The open-source software Libraw was used for this processing. When zooming in on these images they will appear pixelated and show the RGGB Bayer pattern in grayscale (Figure 6). This reduced file-size approach results in each pixel recording only a single color channel (R, G, or B). There were no additional sensors on this mission to validate the color spectrum retrieved by the Nikon cameras or to perform calibration.
3. Processed Data Products (Section 5.2.4): The Bayer pattern can be “demosaiced” using a post-processing algorithm that interpolates the full RGB color over every pixel given the retrieved RGGB values. The Nikon NX Studio software was used for the generation of processed products, as its algorithm provides the best-tuned interpretation of the proprietary format for RGB interpolation. For processed images, different software interprets and processes the Bayer pattern and camera metadata with varying results. Each of these demosaicing algorithms has the potential to introduce artifacts as they were trained on images attained of Earth where the atmosphere has removed a significant fraction of insolation (Figure 5a, the light gray shading). Open-source tools that apply algorithms to infer the RGB of each pixel often create spurious artifacts, or “mealworm” looking images on close inspection. Images processed through NX Studio typically avoid these artifacts but may reduce fine details.

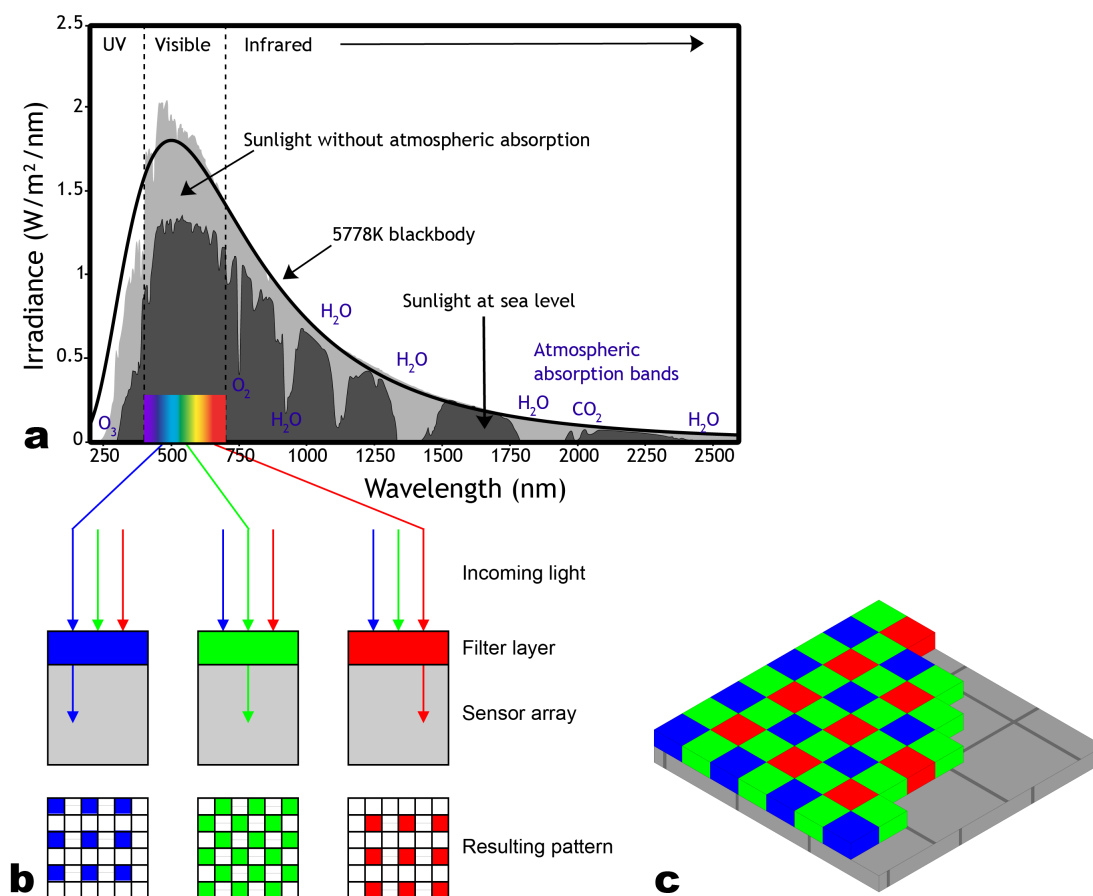


Figure 5. a) Illustration of the solar irradiance spectrum, with light gray indicating parts of the spectrum absorbed by Earth’s atmosphere and the visible spectrum highlighted with the rainbow. b) A camera sensor has filters for red, green, and blue color bands of the spectrum, allowing only (R)ED or (G)REEN or (B)LUE light to pass to the ‘pixels’ of the photo sensor array below. c) The resulting Bayer Mosaic Color Filter Array recorded by the camera. The Bayer Mosaic is arranged in a pattern of alternating rows of BGBGB and GRGRG such that there are twice as many green pixels as either red or blue pixels. Panel (a) altered from original by Robert A. Rohde (CC BY-SA 3.0, Wiki Commons^a). Panel (b) illustration altered from original by u/cburnett-Own work (CC BY-SA 3.0, Wiki Commons^b). Panel (c) illustration is from u/cburnett-Own work (CC BY-SA 3.0, Wiki Commons^c). ^ahttps://commons.wikimedia.org/wiki/File:Solar_spectrum_en.svg, ^bhttps://commons.wikimedia.org/wiki/File:Bayer_pattern_on_sensor_profile.svg, ^c<https://commons.wikimedia.org/w/index.php?curid=1496858>.

5.2.2. Crew camera: Source data products

The source data products are the original Nikon image files recorded by the cameras, with no processing applied. In PDS4, these are described as “product native” files that are in the original format of the camera as recorded during the observations. They preserve all original embedded metadata and pixel values. The handheld Nikon cameras recorded images in a proprietary Nikon Electronic Format (NEF, with extension .nef), a digital negative format that uses different compression algorithms between the D5 and Z9 models. The NEF format is commonly used as the starting point for processing and editing of Nikon digital photographs and is anticipated that many users accustomed to digital photo editing will start with these files over other formats. Many current digital image software can open NEF images but vary in the algorithms they use to interpret and display the image.

For the Nikon D5 cameras, images were recorded as 14-bit Nikon Raw (NEF) files with reversible, lossless compression plus associated metadata. For Nikon Z9 images, the files were recorded in the Nikon Raw High Efficiency star (HE*) format. These files appear with the same extension as the D5 cameras despite differences in the compression. The HE* format stems from a compression algorithm from TicoRAW (TinyCodecRAW), a proprietary format owned and licensed by intoPIX. It is not a true lossless compression, but is visually lossless for many applications, allowing for enhanced efficiency in space and battery usage. However, because it is proprietary, open source software options for the NEF-HE* format files are significantly more limited than the standard NEF files.

5.2.3. Crew camera: Raw data products

Although the NEF is the original source file recorded by the Nikon camera and may be consider ‘raw’ in most photographic applications, it is not an ideal ‘raw’ format for scientific use and preservation owing to its proprietary encoding that may be unreadable by open-source tools. Further, the PDS4 information model requires that image scientific observational data be formatted in a non-proprietary, simple 2D or 3D array to ensure long-term preservation.

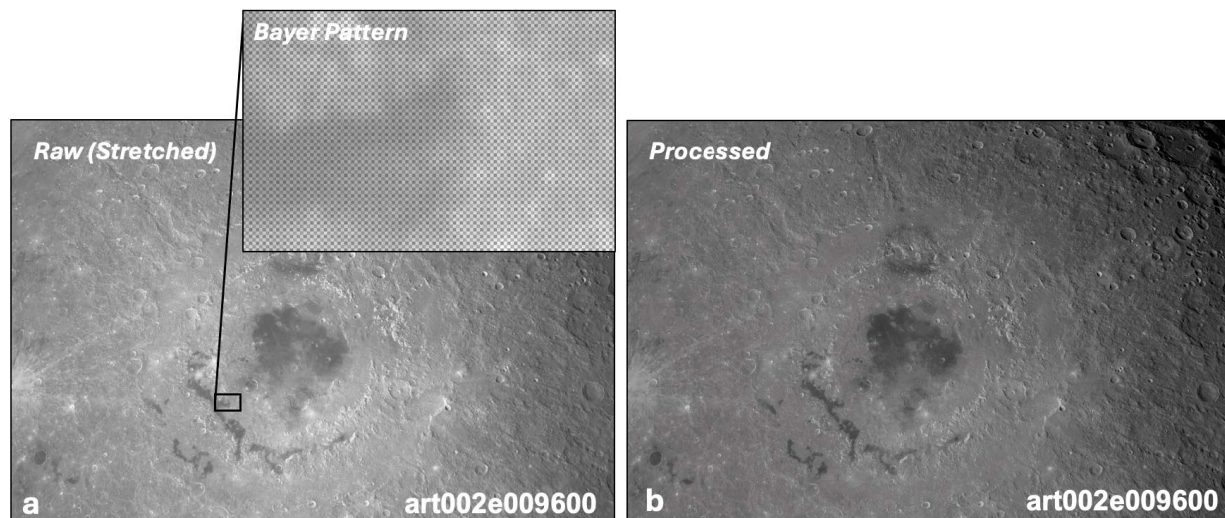


Figure 6. Example stretched raw (a) and processed (b) Nikon D5 images of Orientale Basin (art002e009600_nkd5015_raw_v01.tif and art002e009600_nkd5015_prc_v01.tif). The inset in (a) shows a zoom-in of the Bayer pattern of pixels from the raw product.

To address the need for scientific use and to be compliant with PDS4 standards, the Nikon D5 NEF source products were processed into ‘raw’ products using the open-source Libraw library (<https://libraw.org>) and the following command:

```
unprocessed_raw -T <FileName>.nef
```

This creates an uncompressed 16-bit Tagged Image File Format (TIFF, or .tif) file with the Bayer pattern intact from the original 14-bit NEF file. These images will appear dark when previewed or opened in a photo editor because of the extra two bits added. If desired, using the Libraw `-A` option can automatically provide autoscaling to compensate. The resulting images are also larger in size than a processed image since demosaicing requires interpolation at the edges, which are usually cropped in final processing. For instance, for the Nikon Z9, the original 8280 x 5520 pixels raw sensor image becomes 8256 x 5504 pixels when demosaiced into a processed image. Nikon D5 images have an original raw sensor image size of 5584 x

3728 pixels, while processed products are at a size of 5568 x 3712 (Figure 6). A pixel dimension comparison may be attained using Libraw by running the following command on the original NEF source file and comparing the Raw Inset and Image Size fields:

```
raw-identify -v -u -f -w <FileName>.nef
```

Libraw and nearly all modern open-source digital raw camera decoder software are based on work by David Coffin and his dcrw libraries developed from 1998 through 2018 (<https://github.com/ncruces/dcrw>). Libraw is maintained by a small working group, libraw.org, and maintains the basic functionality of dcrw. Libraw maintains an emulator for dcrw as well as several other functions to retrieve both the original Bayer pattern and demosaiced final image.

Unfortunately, as of the preparation of this archive, the Libraw library and other available open-source software did not support the direct processing of the Nikon Z9 NEF-HE* format to a product that preserves the Bayer pattern. As a solution, processing of Nikon Z9 NEF-HE* images were completed by first converting the NEF-HE* files to DNG (Digital NeGative) files, which is more widely supported by Libraw and other open-source software. Processing to DNG was completed using Adobe Digital NeGative convertor (Adobe DNG) (2026) version 18.3.0.2528, which allows for batch file processing using its GUI interface. After, the DNG files were produced, the 16-bit TIFF with the Bayer pattern intact was created using the same Libraw command:

```
unprocessed_raw -T <filename>.dng
```

As above, the output images will appear dark due to the addition of the extra two bits. If desired, a `-A` option can automatically provide autoscaling to compensate.

5.2.4. Crew camera: Processed data products

Processed products were generated to provide uncalibrated but interpreted image products that have undergone the most basic processing. They were generated by converting from the native source NEF or NEF-HE* format (.nef) to uncompressed 16-bit TIFF format (.tif) using the vendor-provided Nikon NX Studio software, NX Studio (2021) version 1.10.1 (see Section 6, Table 21) This software is available by Nikon for free with some limitations for use with its cameras and NEF digital negative images. NX Studio software algorithms are proprietary with a finely tuned methodology for demosaicing the RRGB Bayer pattern recorded by its sensors to a final, visually finished product.

In batch, images were exported as uncompressed 16-bit TIFF files with demosaicing using default Original Camera Settings (determined from the recorded camera metadata) and with sRGB and autoscaling applied to ensure that the images are viewable when expanded to 16-bit. Screenshots of the settings used are provided in Appendix F. NX Studio produces two images within the 16-bit TIFF output, the large, full resolution image as well as a browse image used by modern GUI based file browsers. As the processing algorithm employed by the software is likely based on images taken on Earth, it is possible that spurious artifacts could be introduced when applied to space-based and lunar observations. Colors output by the process cannot be completely verified or quantified without further information, calibration, and testing.

Other demosaicing software can be used to generate similar outputs to NX Studio but with varying results. For example, Adobe products (e.g., Photoshop) use Adobe Camera Raw software which can produce a near facsimile of the NX Studio postprocessing. The JPEG images available online at [Gateway to Astronaut](#)

[Photography of Earth](https://eol.jsc.nasa.gov) (<https://eol.jsc.nasa.gov>) and images.nasa.gov were generated using Adobe Camera Raw demosaicing or similar processing.

As a final step to make the TIFF output PDS4 compliant as a science observation product, the file was processed to remove strips with band interleaving using GDAL version 3.13.3 (2026) with the following command:

```
gdal_translate -of GTIFF -co COMPRESS=NONE -co INTERLEAVE=BAND -co  
PHOTOMETRIC=RGB -co BLOCKSIZE=${imgheight} <FileName>.tif <FileOut>.tif
```

Where `${imgheight}` is the number of rows in the image (either 3712 pixels for Nikon D5 images or 5504 pixels for Nikon Z9 images). Note that at the time of processing, the GDAL PDS4 driver fails to correctly process 16-bit TIFF images into an RGB array, defaulting instead (with no overrides possible) to single-band grayscale images if the input file is not 8-bit. The above command works by being explicit setting the TIFF output to be RGB with a structure that is PDS4-compliant.

5.2.5. Crew camera: Browse data products

Browse products were generated to provide a reduced-file size version of the processed data product for such uses such as quick browsing and other cases where scientific analysis is not required. Image Magick software (<https://imagemagick.org/>, which itself has a backend of Libraw / dcraw described above) was used to convert processed products (16-bit TIFF files) to 8-bit Portable Network Graphics (PNG) browse files (with no embedded files) using the following command:

```
magick -quiet <FileName>.tif[0] PNG8:<FileOut>.png
```

5.2.6. PDS4 labels and metadata

PDS4 labels were generated from a combination of the embedded metadata and additional metadata provided by the Lunar Science Team according to the following process (and outlined in Section 5.1) :

1. Extract embedded metadata from Nikon Raw or Nikon Raw HE* .nef file as json.
2. Add additional science team provided metadata fields to the json files (Table 17).
3. Using internal and PDS-provided label template scripts with the image and json pairs, generate XML label file.

The source NEF data products contain numerous embedded metadata fields (or “tags”) that describe information about the camera settings and parameters used to capture the image in standard formats. The open source ExifTool software (<https://exiftool.org/>; Harvey, 2026) was used to extract and output these metadata fields for processing of PDS4 labels. Other open-source tools are also available to view and manage Nikon camera metadata (see Section 6 and Table 21). ExifTool allows for reading and the extraction of various groups of metadata tags, including:

- Exchangeable image file format (Exif) (CIPA DC-008-Translation-2026 Exchangeable image file format for digital still cameras: Exif Version 3.1, https://www.cipa.jp/e/std/history_sec.html)
- XMP "Extensible Metadata Platform"
- Camera specific tags from Nikon and GoPro
- Alternate language tags, e.g., in XMP, PNG, QuickTime, and MXF information

Additional metadata were added, include NASA ID and information collected and generated by the science team. These were added to the json for inclusion in the PDS4 label, including those identified in Table 17.

Table 17. Additional metadata generated by the Lunar Science Team.

Metadata Field <i><xml Label tag name></i>	Description
NASA ID <i><msn:internal_id></i>	Assigned NASA ID. Note that voice loop audio files and HOB0 data logger files do not have NASA IDs.
Scheduled Activity <i><msn_surface:activity_id></i>	Planned science observation activity from mission scheduling tool and science team defined inputs. The scheduled activity field is populated by comparing the timeline in the LTP with the timestamp of each data item. In some cases, during mission operations, a human analyst noted a specific scheduled activity that differed from the LTP timeline activity. In these cases, the analyst designated activity overrides the LTP timeline activity. Users can search against the LTP target names or numbers to filter based on those identified activity names. Unlike crew data collection, vehicle camera data were not directed in correspondence to specific targets, so the scheduled activity for all vehicle data is labeled "Other".
Primary Target <i><msn_surface:target_id></i>	Main science target captured in crew image or being described in audio. Targets were determined by the Lunar Science Team during the mission through visual inspection and manual tagging using Lunar Targeting Plan target names for only a subset of images. Most audio files were assigned targets based on crew descriptions. These were not thoroughly verified post-mission and may contain errors.
Other Targets <i><msn_surface:Secondary_Targets></i> <i><msn_surface:target_id></i>	Other science targets captured in image or being described in audio. Targets were determined by the Lunar Science Team during the mission through visual inspection and manual tagging using Lunar Targeting Plan target names for only a subset of images. Most audio files were assigned targets based on crew descriptions. These were not thoroughly verified post-mission and may contain errors
Pixel coordinates and latitude/longitude for footprint vertices and control points <i><geom:vertical_coordinate_pixel</i> <i><geom:horizonatal_coordinate_pixel</i> <i><geom:pixel_latitude></i> <i><geom;pixel_longitude></i>	See section 5.2.7 for a detailed description. This was completed for a subset of Nikon images with the lunar surface in the image frame.

Metadata fields in the PDS4 label are described based on the definitions of the PDS4 data dictionaries. A table of the product label dictionary definitions is provided as a document to this archive (artemis2_label_definitions in PDF and HTML format).

Further, there were 41 total WAV audio files created using the Nikon D5 and Z9 cameras that that are not included with the archive. The voice transcriptions (where present) are instead included as target metadata to the associated images (under the tag *<msn_surface:target_id>*). Many of these have no audio content but served as tags to images of interest that crew members wanted to flag for PAO and science. Others (29 total) were used to describe the camera positioning and window location during the window quality DFTO activity on flight day 3. Table 18 lists the NASA IDs for those Nikon images with associated

WAV files with notes on their content. The only WAV file outside of the DFTO activity that had audio vice content was art002e019123, which recorded a voice memo from MS1 Koch, with the following transcription:

“Uh, centered in that photo is a very weird formation that I just happened to bring the lens across. It’s almost hard to tell what’s going on in the center of that crater that looks extremely new. It looks like there’s uplift. But it, I just can’t resolve what’s going on inside that little thing. So, there’s a picture of it.”

Table 18. Nikon image IDs with WAV file tags.

NASA ID	Camera	Flight Day	Scheduled Activity	Content
art002e023356	Nikon D5-015	2	Other	Tag only, no voice.
art002e000190	Nikon D5-015	2	Other	Tag only, no voice.
art002e000195	Nikon D5-017	2	Other	Tag only, no voice.
art002e004442, art002e004443, art002e004445, art002e004446, art002e004448, art002e004449, art002e004450, art002e004451, art002e004452, art002e004453, art002e004454, art002e004455, art002e004456, art002e004458, art002e004459, art002e004460, art002e004462, art002e004463, art002e004464, art002e004465, art002e004466, art002e004467, art002e004468, art002e004469, art002e004470, art002e004471, art002e004472, art002e004473, art002e004474	Nikon D5-015	3	DFTO	Short voice memos from PLT Glover on window location and position as part of Window quality DFTO. Added transcriptions to associated image metadata under primary target and label name: <msn_surface:target_id>
art002e024177	Nikon D5-015	5	Other	Tag only, no voice.
art002e014211	Nikon D5-017	6	Other	Tag only, no voice.
art002e012038	Nikon D5-015	6	Lunar Flyby: 02_Discussion #2: Near/Farside	Tag only, no voice.
art002e009978	Nikon D5-015	6	Lunar Flyby: 06_Reiner Gamma	Tag only, no voice.
art002e020081	Nikon D5-015	6	Lunar Flyby: 07_Whole Moon	Tag only, no voice.
art002e020120	Nikon D5-015	6	Lunar Flyby: 07_Whole Moon	Tag only, no voice.
art002e019123	Nikon D5-015	6	Lunar Flyby: f_Cabin and Window Teams Swap	20 s voice memo from MS1 Koch. Transcript provided in text above.
art002e015902	Nikon Z9-019	6	Lunar Flyby: 25_Discussion #6: Forward Look	Tag only, no voice.
art002e015908	Nikon Z9-019	6	Lunar Flyby: 25_Discussion #6: Forward Look	Tag only, no voice.

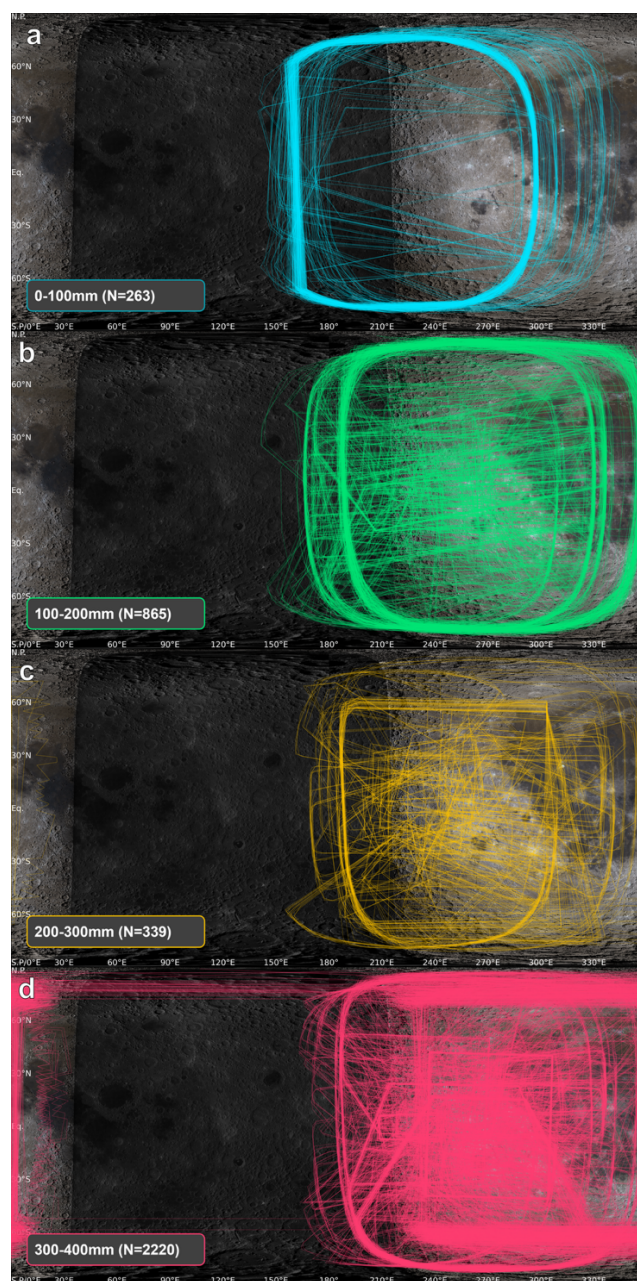


Figure 7. Spatial distribution of crew image footprints by focal length bins. This figure only includes images that were able to be georeferenced (3,101 of 10,339 or ~30% of all Nikon images) by the LST. This figure was made by plotting footprint vertices in matplotlib with lunar coordinates.

5.2.7. Geolocation of images and control points

The PDS4 metadata labels for processed products include control points and corner coordinates for 3,687 Nikon images of the Moon. A visualization of these image footprints binned by focal length is shown in Figure 7, where the footprint curvature is due to geolocation around the lunar limb and illuminated portions. The ground control points were produced following the strategy for geolocating astronaut photography of Earth developed in Find My Astronaut Photo (Stoken, 2023). Specifically, an illumination adjusted (for the time of the flyby) basemap was produced, tiled, and then embedded using the AstroLoc (Berton et al., 2025)

model into a vector database. Each crew image was then embedded with the same model, and the tiles with the lowest embedding distance were retrieved from the database.

Following EarthMatch (Berton et al., 2024) and using the LoMa-R (Nordström, 2026) image matching model as implemented in vismatch, the crew photo is matched to retrieved tiles (in the order of lowest to highest embedding distance). Once a tile has over N inlier matches, it is considered a positive pair and the matches become control points, connecting pixel coordinates in the crew image to points in the reference tile (which have known geocoordinates). Geocoordinates use the Moon IAU 2000 coordinate system for a spheroid with a semi-major axis radius of 1737.4 km and flattening of 0. Using the RANSAC algorithm, an affine transform is fit to the control points with rasterio (GDAL python wrapper). Then, corner coordinates are extracted from the resulting affine transform. For computational efficiency, tiepoints are computed on resized images (518x518 pixels for both crew image and retrieved tile) and then the tiepoints are rescaled to the full image resolution using (image_width/ 518, image_height/518) as the scaling factor. Each row/col value is scaled by the factor corresponding to its axis. Thus, there is inherent tiepoint precision loss due to matching on the downsampled image.

Given the limits of fitting the affine transform to a spheroid, for imagery with significant curvature the resulting transforms are only accurate in portions of the image. For images with only some corners intersecting the Moon, the non-intersecting corners are not defined. In some cases, typically when the full lunar disk is visible, there are valid control points but an invalid footprint (with image corner coordinates outside valid latitude/longitude ranges) due to the affine transform assumption and the image extent expanding off-Moon. When this occurs, footprint vertices as well as horizontal/vertical pixel field of view (derived from vertices) are omitted in the image metadata label, but control points are retained in the label for users who may want to use other transform methods.

Footprint coordinates are provided to assist users in spatial analysis of the data. Raw control points are provided for those users who would like to apply custom transforms for georectification, or other custom adjustments.

5.3. Orion Camera Data Products

The Orion camera products include raw and browse images from SAW Cam 2, 3, 4, and Cab Cam 2 (GoPro cameras) (Figure 8 and Figure 9) and the DCAM and OpNav cameras (both ElectroOptical CMOS cameras) (Figure 9). Raw video image products were archived from SAW Cam 3. A description of the Orion camera and SAW Cam 3 observation sequence is given in Section 3.3. Each of these products has associated metadata contained within detached PDS4 xml label files. No calibration was applied to these products. As with the Nikon cameras, these cameras all have filters and sensors that record discreet portions of the visible spectrum of light and therefore lack true color representation for lunar observations.

5.3.1. Orion camera: Raw data products

For SAW Cam 2, 3, 4 and Cab Cam 2, data were recorded and downlinked as lossy RGB Joint Photographic Experts Group (JPEG) files (.jpg); the raw RGB pixels with the Bayer pattern intact were not recorded. For PDS4 standards compliance, the JPEG files were converted to uncompressed 8-bit TIFF format (.tif) to serve as the raw image product. The conversion was made using the Geospatial Data Abstraction Library (GDAL, <https://gdal.org>) version 3.13.1 (2026) PDS4 driver with the following command:

```
gdal_translate -of PDS4 -co IMAGE_FORMAT=GEOTIFF -co INTERLEAVE=BSQ  
<FileName>.JPG <FileOut>.xml
```

This produces a band-interleaved PDS4-compliant TIFF file. It also creates a templated PDS4 XML label, which was used to verify the array XML structure for the final metadata labels. For the DCAM images, the

sensor captured the full visible spectrum (350-850 nm in monochrome) and recorded it in PNG format. As for the SAW and Cab Cam 2 cameras, this file is converted to TIFF format for PDS4 compliance. The conversion is made using GDAL version 3.13.3 (2026) PDS4 driver with the following command:

```
gdal_translate -of PDS4 -co IMAGE_FORMAT=GEOTIFF -co INTERLEAVE=BSQ  
<FileName>.PNG <FileOut>.xml
```

OpNav source images were already in uncompressed 8-bit TIFF format but required a change to remove striping for PDS4 compliance. The conversion is made using GDAL version 3.13.3 (2026-06-01) PDS4 driver with the following command:

```
gdal_translate -of PDS4 -co IMAGE_FORMAT=GEOTIFF -co INTERLEAVE=BSQ  
<FileName>.TIF <FileOut>.xml
```



Figure 8. Example Orion Solar Array Wing (SAW) camera images. A) SAW Cam 3, FD06, NASA ID art002e016278. B) SAW Cam 3, FD06, NASA ID art002e016319. C) SAW Cam 4, FD09, NASA ID art002e031471. D) SAW Cam 2, FD10, NASA ID art002e031040.



Figure 9. Example Orion camera images. A) OpNav, FD01, NASA ID art002e016319. B) DCAM, FD04, NASA ID art002e018504. C) OpNav, FD05, NASA ID art002e030321. D) Cab Cam A2, FD06, NASA ID art002e041332.

5.3.2. Orion camera: Browse data products

For the SAW Cam 2, 3, 4, and Cab Cam 2, the original source JPEG is used as the browse data product, reflected in the directory structure of `browse_source`. Similarly, for DCAM, the original source PNG is used as the browse data product.

For the OpNav camera, the original source TIFF is converted into a PDS compliant browse product in 8-bit PNG format. The conversion is made using Image Magick version 7.1.2 (2026) with the following command:

```
magick -quiet <FileName>.TIFF[0] PNG8: <FileOut>.png
```

5.3.3. Orion camera: Video Data Products

Video data products were collected from SAW Cam 3 in preset observing sequences around and during lunar flyby described in Section 3.3.3. These recordings have both video and audio channels and were streamed and ground recorded as Material eXchange Format (MXF) video. The audio channel for SAW Cam 3 was recorded on the ground simultaneously by the same mechanism as the loop audio, and thus the

audio channel that plays alongside the SAW Cam 3 video is the loop audio in many places, punctuated by long pauses. The audio was preserved in the archived video as it provides for a separate, absolute tie-point in time between the SAW Cam 3 video and the voice loop audio on Flight Day 6.

Because of bandwidth limitations, video was streamed at 5 frames per second (fps) for parts of the lunar flyby, which was less than the collected number of frames at 30 fps (<acquisition_frame_rate> in PDS4 label; see Section 3.3.3). Further, the video was ground recorded at 59.94 fps (<video_frame_rate> in PDS4 label) as MXF files due to NASA TV broadcasting standards; however the effective streamed frame rate of the SAW Cam 3 video remains at either 5 or 30 fps (<intermediate_frame_rate> in PDS4 label). There is a single video recorded at 30 fps locally on the SAW Cam 3 in MPEG-4 (MP4) format during the eclipse period, which was intended to keep the camera temperatures warm (see Section 3.3.3). The differences in the frame rates of the streamed and recorded video results in substantial reductions in the size of files during conversion to MP4 format for archiving.

The ground-recorded MXF video files use a codec that is not PDS4 compliant, and these files were therefore converted to MP4 (.mp4) with H.264 codec using the open-source software FFMPEG version N-121682-g7435a3180d (2025). Conversion from MXF to MP4 was achieved using the following command:

```
ffmpeg -i ${f} -map 0:v:0 -map 0:a -c:v libx264 -crf 10 -preset slow -profile:v high -pix_fmt yuv420p -c:a aac -b:a 256k -fps_mode cfr -map_chapters 0 -f mp4 ${new_rawfname}
```

FFMPEG is a command line only interface. HandBrake is another open source tool that uses the FFMPEG libraries but also has a graphical user interface. The equivalent conversion from MXF to MP4 using the HandBrakeCLI 1.11.2 (2026) command is:

```
HandBrakeCLI -i ${f} -o ${new_rawfname} -e x264 -q 10 --encoder-preset slow -encoder-profile high --crop 0:0:0:0 --keep-display-aspect --all-audio --aencoder aac --ab 256 --markers --format av_mp4 --cfr
```

Further, SAW Cam 3 video was recorded at the NASA JSC video handling facility on two separate Downlink Decoders (or channels). Both videos are essentially identical during lunar flyby but are preserved in the archive in separate sub-directories (channel1 and channel2).

5.3.4. Orion camera: Metadata notes

Corrections were made to the embedded times for original OpNav and DCAM images. For OpNav images, the embedded CreateDate time is related to the downlink time. The actual recorded time was contained in the original filename (housed inside of the Exiftool -XMP-iptcCore:AltTextAccessibility tag), which was extracted and re-constructed for inclusion of a corrected time in the PDS4 label metadata. For DCAM images, only a best estimate of the collection time based on received image directory batch times could be made. These corrected times were cross-checked with scheduled mission activities but may be offset by up to 5 minutes or more from the actual collection time.

5.4. Mission Audio Data Products

5.4.1. Mission audio: Audio products

The PCD audio recorder natively recorded as MPEG-4 Audio (M4A, or .m4a) files using the AAC (Advanced Audio Coding) codec, which are PDS4 compliant and were not further processed. Audio recordings were generated by the crew for each target in the Lunar Targeting Plan (LTP), although often a single file contains descriptions of multiple targets.

Voice Loop audio recordings were received as MP3 and converted to M4A for PDS4-compliance. They were split into lengths by UTC day around lunar flyby (2026-04-06 and 2026-04-07), with the UTC day indicated in the file name.

Crew members can be heard to have conversations between the two concurrent PCD audio recordings, and O/E-1 during observations, although background conversations are at varying levels of audibility. To facilitate understanding, it is often best to play these synchronously using system audio players (e.g., VLC Media Player or other applications).

Note that the embedded timestamps in the M4A PCD audio files are the end time of the audio recording. The start time can be obtained by subtracting the full length of the audio from this end recording time. These starts are included in the PDS4 label under the <start_date_time> tag.

5.4.2. Mission audio: Transcripts

Transcripts for PCD and voice loop audio recordings were generated using the open-source package [whisperX](https://github.com/m-bain/whisperx) (<https://github.com/m-bain/whisperx>), which is an Automatic Speech Recognition (ASR) model originally developed by OpenAI. Transcripts were generated using the large-v2 model with compute_type=float16 followed by an alignment model to generate per-word timestamps. Following transcription, additional UTC and Mission Elapsed Time (MET) information was added via custom Lunar Science Team developed scripts based on the audio creation time metadata stored in the audio file itself.

Following automatic generation, transcripts were manually checked by the Lunar Science Team and, as needed, corrected. Common corrections included misspellings of lunar feature or crew member names. Speaker diarization was also added manually during this process. Corrections generally followed the guidelines established by the [Smithsonian Digital Volunteers Transcription Center](https://transcription.si.edu/instructions/specialized/audio), (<https://transcription.si.edu/instructions/specialized/audio>) with minor modifications made to tailor to the Artemis II mission audio files.

One transcript file was produced for each PCD audio (.m4a) file. Voice Loop Transcripts were provided and edited for the UTC days of lunar flyby (2026-04-06 and 2026-04-07) only.

The csv transcriptions are comma delimited and organized in the structure shown in Table 19.

Table 19. Descriptions of transcript information.

Audio Time	UTC date time	Speaker	Transcription Text
Elapsed time from the start of the audio file. hh:mm:ss	UTC date and time in the following format: yyyy-mm-dd hh:mm:ss.fff	Crew member or Mission Control Wiseman, Glover, Koch, Hansen, CAPCOM, SCIENCE, or Crew (if voice could not be identified)	Text transcribed from the audio by the whisperx model and corrected by the Lunar Science Team. Note: Lines of text are broken up by speech pattern recognition, not by humans based on realistic speech decisions

5.5. Orion Environment Data

The HOBO data loggers produced tables of logged time (in central daylight time, CDT), temperature and relative humidity, and dew point information (Table 20). The logging interval was 60 seconds and was started six days before the mission on 2026-03-26 and continued until after the mission and upon recovery, with an end date of 2026-04-21. These were delivered to the science team in Excel xlsx format containing logged data and metadata. These were converted to csv files with detached PDS4 labels.

Table 20. HOBO data logger field descriptions.

#	Date-Time (CDT)	Temperature (deg C)	RH (%)	Dew Point (deg C)
Sequential sample number	CDT Date and Time mm/dd/yyyy hh:mm:ss 1-minute logging interval	Recorded temperature in degrees Celsius	Recorded percent relative humidity	Recorded Dew Point in degrees Celsius

5.6. Documents

Key documents included in the archive are listed above in Section 1.2. Additional documents are described below.

5.6.1. Lunar Targeting Package

The Lunar Targeting Package delivered to crew on Orion during the mission is an interactive browser-based tool that the crew displayed on their PCDs to guide their observations during lunar flyby. The original Lunar Targeting Package delivered for use on crew PCDs during the mission was a zipped folder containing jpegs, pngs, js files, css files, a htm file, OneNote files, and icons. To maintain a long-term and archivable product that ensures availability for decades, the PDS science archive contains only a non-interactive page by page screen capture document in PDF format ([artemis2_lunar_targeting_package.pdf](#), in the collection [artemis2_mission:document](#)) rather than the interactive tool itself.

The Lunar Targeting Package combines both the Lunar Targeting Plan (LTP) and the Lunar Geography Review (LGR). The LTP contains simulated views of the Moon from Orion to aid target localization, per-target objectives and notes, and observational reminders (“cues”) to assist in scientific description. In addition to target specific pages, the LTP contains an observation period overview map, a live timeline, and a user guide. The LGR is a reference tool with a labeled, graticulated lunar surface map (orthographic projection, with capability to cycle through hemispheres) at various phases, additional observation guidance, and a glossary. The archived PDF version of the Lunar Targeting Package has a Table of Contents with page separators briefly describing the parts of the document, including the LTP Overview, Timeline, Lunar Targets, and User Guide, and the LGR Views, Observation Guidance, Glossary, and Cue Card.

Both the Lunar Targeting Package and the Outgoing Target Request (next section) are described in more detail in the Artemis II Preliminary Lunar Science Report and Lunar Science Operations Report.

5.6.2. Outgoing Target Request (OTR)

The Outgoing Target Request (OTR) is a json file generated by the Artemis II Lunar Science Team in real-time during the mission and delivered to the Crew Lunar Observations (CLO) sub team for processing into the Lunar Targeting Plan. The file details in plaintext the specifics of the science team's request as well as information about a target's observation availability window, relationship to the Science Traceability Matrix (STM), and metadata required for LTP generation. A static view of the OTR is included as a json file to the document collection of this archive.

6. Tools

There are number of open-source and paid tools available to view, process, and analyze the data products contained within this archive. Table 21 provides a list of tools available through the PDS to specifically read and display PDS4 data products, including their metadata, to generate labels and to validate the archive. The table also lists tools used in the generation of the science archive products described in this User Guide, either provided commercially or through open-source access. This is a very incomplete list of all of the tools available, as the archived image, audio, and video formats can be read by many other current software tools. A quick web search can reveal additional software options.

Table 21. Software tools for working with archived data products.

Tool Name	URL and Description
PDS4 Tools	
<i>PDS Tool Registry</i>	https://pds.nasa.gov/tools/tool-registry/ Registry of PDS tools available to read, display, and search PDS archive data.
<i>Python PDS4 Tools</i>	https://sbnwiki.astro.umd.edu/wiki/Python_PDS4_Tools Python read-in tools for PDS4 data.
<i>ReadPDS</i>	http://pdssbn.astro.umd.edu/tools/tools_readPDS.shtml IDL read-in tools for PDS4 data.
<i>PDS4 Viewer</i>	https://pdssbn.astro.umd.edu/tools/pds4_tools_info/pds4_viewer.html A general read-in and visualization GUI tool for PDS4 data, running on multiple platforms.
<i>Planetary Data Reader (PDR)</i>	https://pdr.readthedocs.io/en/latest/ This tool provides a single command line interface for reading most "primary observational data" products currently archived in the PDS (under PDS3 or PDS4).
<i>Labelocity</i>	https://github.com/NASA-AMMOS/labelocity A flexible, customizable, multimission automated system for PDS4 label production by NASA Jet Propulsion Laboratory (JPL). Used to generate the PDS4 labels for this archive.
<i>PDS Validate Tool</i>	https://nasa-pds.github.io/validate/ Open source software tool to verify that PDS4 product labels and data meet PDS standards.
Images	
<i>Libraw</i>	https://www.libraw.org/ Opensource software for reading and processing many commercial camera Raw formats.
<i>Image Magick</i>	https://imagemagick.org/ Common open source photo editing software, handling a range of image formats.
<i>Adobe Photoshop</i>	https://www.adobe.com/products/photoshop.html Common paid photo editing software. Uses Adobe Camera Raw for processing Nikon NEF image formats.
<i>Adobe Digital Negative Converter</i>	https://helpx.adobe.com/camera-raw/using/adobe-dng-converter.html Adobe software (current free download) for converting commercial camera raw image formats to Adobe Digital NeGative (DNG) format.
<i>NX Studio</i>	https://downloadcenter.nikonimglib.com/en/products/564/NX_Studio.html

	Nikon image processing software (current free download with sign up required).
<i>GDAL</i>	https://gdal.org/ Translator library for raster and vector geospatial data formats that is released under an X/MIT style Open Source license by the Open Source Geospatial Foundation. It supports PDS4 datasets and other image formats (e.g., TIFF, JPEG, PNG).
<i>Others</i>	There are many other open source and proprietary image analysis and processing tools that support the archive formats.
Audio and video	
<i>ffmpeg</i>	https://www.ffmpeg.org/ A cross-platform open-source software to record, convert and stream audio and video.
<i>Handbrake</i>	https://handbrake.fr/ An open-source tool for converting video from nearly any format to a selection of modern, widely supported codecs.
<i>System players</i>	Operating systems have many default software packages for playing audio and video, such as MacOS QuickTime and Windows Media Player.
<i>Others</i>	There are many paid (e.g., Adobe Premiere and Audition) and open source audio and video editing software that can be easily found through a web search.
Metadata Extraction	
<i>ExifTool</i>	https://exiftool.org/ Platform-independent Perl library plus a command-line application for reading, writing and editing meta information in a wide variety of files. Used for extracting embedded metadata tags for this archive.
<i>MediaInfo</i>	https://mediaarea.net/en/MediaInfo Open-source tool for a unified display of technical and tag metadata for video and audio files.
XML Editors	
<i>Notepad++</i>	https://notepad-plus-plus.org/ XML editor built for Microsoft Windows.
<i>Visual Studio Code</i>	https://github.com/microsoft/vscode Open source code editor by Microsoft, supporting most major programming languages.
<i>xmplify</i>	https://xmplifyapp.com/ XML editor built specifically for macOS.
<i>Oxygen</i>	https://www.oxygenxml.com/ Advanced commercial tool for XML editing, authoring and development.

7. Appendices

7.1. Appendix A: Acronyms

Acronym	Definition
AAC	Advanced Audio Coding
ACR	Audio Control Room
API	Application Interface
Cab	Cabin
CDR	Commander
CDT	Central Daylight Time
CFA	Color Filter Array
CIS	Cartography and Imaging Sciences
CLO	Crew Lunar Observations
CM	Crew Module
CMOS	Complementary Metal-Oxide-Semiconductor
CSA	Canadian Space Agency
DCAM	Docking Camera
DFTO	Developmental Flight Test Objective
DNG	Digital NeGative
DOI	Digital Object Identifiers
DSLR	Digital Single-Lens Reflex
ESA	European Space Agency
FD	Flight Day
GAPE	Gateway to Astronaut Photography of Earth
GEO	Geosciences Node
GDAL	Geospatial Data Abstraction Library
GISS	Goddard Institute for Space Studies
GMT	Greenwich Mean Time
GNC	Guidance Navigation & Control
GSFC	Goddard Space Flight Center
HDR	High Dynamic Range
HE*	High Efficiency Star
HERA	Hybrid Electronic Radiation Assessor
HTML	HyperText Markup Language
HULC	Handheld Universal Lunar Camera
ICPS	Interim Cryogenic Propulsion Stage
ISO	International Organization for Standardization (measure of camera sensor sensitivity to light)
ISS	International Space Station
JPEG	Joint Photographic Experts Group
JSC	Johnson Space Center

JSON	JavaScript Object Notation
LID	Logical Identifier
LOS	Loss of Signal
LST	Lunar Science Team
LTP	Lunar Targeting Plan
MET	Mission Elapsed Time
Mnvr	Maneuver
M4A	MPEG-4 Audio
MPEG	Moving Picture Experts Group
MP4	MPEG-4 Part 14
MS1	Mission Specialist 1
MS2	Mission Specialist 2
MXF	Material eXchange Format
NAIF	Navigation and Ancillary Information Facility
NASA	National Aeronautics and Space Administration
NEF	Nikon Electronic Format
O/E	Orion to Earth
OPTIMIS	Operations Planning Timeline Integration System
OpNav, ONAV	Optical Navigation
OSDMP	Open Science and Data Management Plan
OTC	Outbound Trajectory Correction
OTR	Outgoing Target Request
PCD	Portable Computing Device
PDS	Planetary Data System
PLT	Pilot
PNG	Portable Network Graphics
RGB	Red, Green, Blue
RTC	Return Trajectory Correction
SAW	Solar Array Wing
SLS	Space Launch System
SN	Serial Number
SPICE	Spacecraft, Planet, Instrument, C-matrix, Events
STM	Science Traceability Matrix
TIFF	Tagged Image File Format
TLI	Translunar Injection
URL	Uniform Resource Locator
UTC	Coordinated Universal Time
WAV	Waveform Audio File Format
XML	eXtensible Markup Language
XMP	Extensible Metadata Platform

7.2. Appendix B: References

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7.3. Appendix C. PDS Archive Directory Structure

```

artemis2_crew_camera
|-----data_source
|       |-----fd01
|       |           |-----art002eXXXXXX_nkd5015_src_vXX.nef
|       |           |-----art002eXXXXXX_nkd5015_src_vXX.xml
|       |           |-----art002eXXXXXX_nkd5017_src_vXX.nef
|       |           |-----art002eXXXXXX_nkd5017_src_vXX.xml
|       |           |-----art002eXXXXXX_nkz9019_src_vXX.nef
|       |           |-----art002eXXXXXX_nkz9019_src_vXX.xml
|       |-----fd02
|       |-----fd03
|       |-----fd04
|       |-----fd05
|       |-----fd06
|       |-----fd07
|       |-----fd08
|       |-----fd09
|       |-----fd10
|-----data_raw
|       |-----fdXX
|       |           |-----art002eXXXXXX_nkd5015_raw_vXX.tif
|       |           |-----art002eXXXXXX_nkd5015_raw_vXX.xml
|       |           |-----art002eXXXXXX_nkd5017_raw_vXX.tif
|       |           |-----art002eXXXXXX_nkd5017_raw_vXX.xml
|       |           |-----art002eXXXXXX_nkz9019_raw_vXX.tif
|       |           |-----art002eXXXXXX_nkz9019_raw_vXX.xml
|-----data_processed
|       |-----fdXX
|       |           |-----art002eXXXXXX_nkd5015_prc_vXX.tif
|       |           |-----art002eXXXXXX_nkd5015_prc_vXX.xml
|       |           |-----art002eXXXXXX_nkd5017_prc_vXX.tif
|       |           |-----art002eXXXXXX_nkd5017_prc_vXX.xml
|       |           |-----art002eXXXXXX_nkz9019_prc_vXX.tif
|       |           |-----art002eXXXXXX_nkz9019_prc_vXX.xml
|-----browse
|       |-----fdXX
|       |           |-----art002eXXXXXX_nkd5015_prc_vXX.png
|       |           |-----art002eXXXXXX_nkd5015_prc_vXX.xml
|       |           |-----art002eXXXXXX_nkd5017_prc_vXX.png
|       |           |-----art002eXXXXXX_nkd5017_prc_vXX.xml
|       |           |-----art002eXXXXXX_nkz9019_prc_vXX.png
|       |           |-----art002eXXXXXX_nkz9019_prc_vXX.xml

```

artemis2_orion_camera

```

|-----browse_source
|
|-----fd01
|         |-----art002eXXXXXXX_saw2_src_vXX.jpg
|         |-----art002eXXXXXXX_saw2_src_vXX.xml
|         |-----art002eXXXXXXX_saw3_src_vXX.jpg
|         |-----art002eXXXXXXX_saw3_src_vXX.xml
|         |-----art002eXXXXXXX_saw4_src_vXX.jpg
|         |-----art002eXXXXXXX_saw4_src_vXX.xml
|         |-----art002eXXXXXXX_cab2_src_vXX.jpg
|         |-----art002eXXXXXXX_cab2_src_vXX.xml
|         |-----art002eXXXXXXX_onav_raw_vXX.png
|         |-----art002eXXXXXXX_onav_raw_vXX.xml
|         |-----art002eXXXXXXX_dcam_src_vXX.png
|         |-----art002eXXXXXXX_dcam_src_vXX.xml
|
|-----fd02
|-----fd03
|-----fd04
|-----fd05
|-----fd06
|-----fd07
|-----fd08
|-----fd09
|-----fd10
|-----data_raw_image
|         |-----fdXX
|         |         |-----art002eXXXXXXX_saw2_raw_vXX.tif
|         |         |-----art002eXXXXXXX_saw2_raw_vXX.xml
|         |         |-----art002eXXXXXXX_saw3_raw_vXX.tif
|         |         |-----art002eXXXXXXX_saw3_raw_vXX.xml
|         |         |-----art002eXXXXXXX_saw4_raw_vXX.tif
|         |         |-----art002eXXXXXXX_saw4_raw_vXX.xml
|         |         |-----art002eXXXXXXX_cab2_raw_vXX.tif
|         |         |-----art002eXXXXXXX_cab2_raw_vXX.xml
|         |         |-----art002eXXXXXXX_onav_raw_vXX.tif
|         |         |-----art002eXXXXXXX_onav_raw_vXX.xml
|         |         |-----art002eXXXXXXX_dcam_raw_vXX.tif
|         |         |-----art002eXXXXXXX_dcam_raw_vXX.xml
|-----data_video
|         |-----fdXX
|         |         |-----channelXX
|         |         |         |-----art002mXXXXXXXXXXXX_saw3_raw_vXX.mp4
|         |         |         |-----art002mXXXXXXXXXXXX_saw3_raw_vXX.xml
|         |         |-----other
|         |         |         |-----art002mXXXXXXXXXXXX_saw3_raw_vXX.mp4
|         |         |         |-----art002mXXXXXXXXXXXX_saw3_raw_vXX.xml

```

artemis2_mission_audio

```

|-----data_audio_pcd
|       |-----fd01
|       |-----fd02
|       |-----fd03
|       |-----fd04
|       |-----fd05
|       |-----fd06
|       |       |-----art002aXXXXXXX_pcd2_raw_vXX.m4a
|       |       |-----art002aXXXXXXX_pcd2_raw_vXX.xml
|       |       |-----art002aXXXXXXX_pcd3_raw_vXX.m4a
|       |       |-----art002aXXXXXXX_pcd3_raw_vXX.xml
|       |-----fd07
|       |-----fd08
|       |-----fd09
|       |-----fd10
|-----data_audio_loops
|       |-----art002_2026-04-XX_oe1_raw_vXX.m4a
|       |-----art002_2026-04-XX_oe1_raw_vXX.xml
|       |-----art002_2026-04-XX_oe2_raw_vXX.m4a
|       |-----art002_2026-04-XX_oe2_raw_vXX.xml
|-----data_transcripts_pcd
|       |-----fdXX
|       |       |-----art002aXXXXXXX_pcd2_trn-csv_vXX.csv
|       |       |-----art002aXXXXXXX_pcd2_trn-csv_vXX.xml
|       |       |-----art002aXXXXXXX_pcd2_trn-srt_vXX.srt
|       |       |-----art002aXXXXXXX_pcd2_trn-srt_vXX.xml
|       |       |-----art002aXXXXXXX_pcd3_trn-csv_vXX.csv
|       |       |-----art002aXXXXXXX_pcd3_trn-csv_vXX.xml
|       |       |-----art002aXXXXXXX_pcd3_trn-srt_vXX.srt
|       |       |-----art002aXXXXXXX_pcd3_trn-srt_vXX.xml
|-----data_transcripts_loops
|       |-----art002_2026-04-0X_oe1_trn-csv_vXX.csv
|       |-----art002_2026-04-0X_oe1_trn-csv_vXX.xml
|       |-----art002_2026-04-0X_oe1_trn-srt_vXX.srt
|       |-----art002_2026-04-0X_oe1_trn-srt_vXX.xml
|       |-----art002_2026-04-07_oe2_trn-csv_vXX.csv
|       |-----art002_2026-04-07_oe2_trn-csv_vXX.xml
|       |-----art002_2026-04-07_oe2_trn-srt_vXX.srt
|       |-----art002_2026-04-07_oe2_trn-srt_vXX.xml
|-----annotations
|       |-----art002e009303-e009388_pcd1_ann_vXX.pdf
|       |-----art002e009303-e009388_pcd1_ann_vXX.xml
|       |-----art002e009389-e009474_pcd2_ann_vXX.pdf
|       |-----art002e009389-e009474_pcd2_ann_vXX.xml
|       |-----art002e009475-e009560_pcd3_ann_vXX.pdf
|       |-----art002e009475-e009560_pcd3_ann_vXX.xml

```

artemis2_mission**-----document**

- |-----artemis2_data_user_guide.pdf
- |-----artemis2_data_user_guide.xml
- |-----artemis2_label_definitions.pdf
- |-----artemis2_label_definitions.xml
- |-----artemis2_lunar_targeting_package.pdf
- |-----artemis2_lunar_targeting_package.xml
- |-----artemis2_lunar_targeting_package_pdfa.pdf
- |-----artemis2_lunar_targeting_package_extended.pdf
- |-----artemis2_lunar_targeting_package_extended.xml
- |-----artemis2_lunar_targeting_package_extended_pdfa.pdf
- |-----artemis2_nikon_lens_distortion_correction.pdf
- |-----artemis2_nikon_lens_distortion_correction.xml
- |-----artemis2_osdmp.pdf
- |-----artemis2_osdmp.xml
- |-----artemis2_outgoing_target_request.json
- |-----artemis2_outgoing_target_request.xml

-----data_orion_environment

- |-----art002_XXX-XXXXXXX_XXX-XXXXXXX_hobo1104_raw_vXX.csv
- |-----art002_XXX-XXXXXXX_XXX-XXXXXXX_hobo1104_raw_vXX.xml
- |-----art002_XXX-XXXXXXX_XXX-XXXXXXX_hobo1105_raw_vXX.csv
- |-----art002_XXX-XXXXXXX_XXX-XXXXXXX_hobo1105_raw_vXX.xml

7.4. Appendix D. File Naming Convention

Every PDS4 Archive Data Product produced by the mission that has an assigned NASA ID will have a file name that follows the convention specified below. The primary goals of this naming convention are:

- Ensure uniqueness for every single archive data product across all instruments, all venues, and for the life of the mission.
- Provide consistency in structure to ease parsing of the various fields
- Provide both machine and human readability of file names.

In section 6C.1.1 of the PDS Standards Reference, the PDS identifies the rules governing selection of file names. The following subset of those rules pertains to this convention:

- The file name must be unique within a directory.
- The file name must be no longer than 255 characters.
- The file name must be case-insensitive.
- The file name must be constructed from the character set
 - A-Z ASCII 0x41 through 0x5A,
 - a-z ASCII 0x61 through 0x7A,
 - 0-9 ASCII 0x30 through 0x39,
 - dash “-” ASCII 0x2D
 - underscore “_” ASCII 0x5F and
 - period “.” ASCII 0x2E
- The file name must not begin or end with a dash, underscore, or period
- The file name must include at least one period followed by an extension

The fields that make up the file name are depicted as follows (for data with NASA IDs):

<NASA ID>_<instrument ID>_<product type>_<version>.<extension>

Table 22. Description of file name fields.

Field	Description	Format
NASA ID	NASA ID assigned by NASA Johnson Space Center Imagery Online to data from NASA managed systems. This is a permanent identifier for Artemis II data products across NASA data-serving systems.	Still Images: art002ennnnnnn Audio: art002annnnnnn Video: art002mnnnnnnnnnn Where <i>nnnnnn</i> is the sequential six-digit number for stills and audio, and <i>nnnnnnnnnn</i> for video is video channel (first three digits) followed by UTC DOYhhmm (last seven digits), Example: 1013331009 *Note: The sequential numbering of the NASA ID for images and audio is the order in which the files are received and catalogued, not necessarily in time-order sequence.
Instrument ID	Instrument identifier	nk d5nnn = crew Nikon D5 with last three digits of camera serial number specified (<i>nnn</i>) nk z9nnn = crew Nikon Z9 with last three digits of camera serial number specified (<i>nnn</i>) saw n = Orion solar array wing (SAW) camera with camera number specified (<i>n</i>)

		cabn = cabin camera with camera number specified onav = OpNav camera dcam = Docking Camera iph17 = iPhone 17 Pro Max pcdn = portable computing device with number specified oe1 = O/E-1 Voice loop oe2 = O/E-2 Voice loop hobonnnn = HOBO data logger with <i>nnnn</i> specifying ID number
Product Type	Processing level or type of product	src = original source data raw = raw data; converted from original to PDS4 compliant product (if required) prc = processed trn-csv = transcript csv trn-srt = transcript srt ann = annotation Other as specified by instrument
Version	Version number	vmm mm = two digit major version number A change in data warrants a major version change, while a change in metadata would be a minor change
Extension	Product extension type	Based on source file and PDS4 compliant file type. Still images: .tif for image files (PDS4) with .jpg and .png for original source files (vehicle images) or .nef (source Nikon images), and .png for browse. Crew Audio: .m4a/.mp4 for audio files (PDS4) and original files (PCD and voice loops) Video: .mp4 for video files (PDS4) Crew Audio Transcripts: .csv and .srt for audio transcripts (PDS4) Crew Annotations: .pdf for crew annotation files Documentation: .pdf for mission reports and other documentation (PDS4)

Examples:

Nikon D5 camera (SN 3500015), NASA ID art002e024481, version 1, nef (source), tif (raw and processed) and png (browse from processed tif)

art002e024481_nkd5015_src_v01.nef

art002e024481_nkd5015_raw_v01.tif

art002e024481_nkd5015_prc_v01.tif

art002e024481_nkd5015_prc_v01.png

Nikon D5 camera (SN 3500017), NASA ID art002e026016, version 1, nef (source), tif (raw and processed), and png (browse from processed tif)

art002e026016_nkd5017_src_v01.nef

art002e026016_nkd5017_raw_v01.tif

art002e026016_nkd5017_prc_v01.tif

art002e026016_nkd5017_prc_v01.png

Nikon camera 3 (Z9 camera SN 3920019), NASA ID art002e027742, version 1, nef (source), tif (raw and processed), and png (browse from processed tif)

art002e027742_nkz9019_src_v01.nef
art002e027742_nkz9019_raw_v01.tif
art002e027742_nkz9019_prc_v01.tif
art002e027742_nkz9019_prc_v01.png

iPhone 17 Pro Max, NASA ID art002e041867, tif (raw), png (browse)

art002e041867_iph17_raw_v01.tif
art002e041867_iph17_raw_v01.png

PCD 2 audio file, NASA ID art002a000034, version 1, m4a (raw audio) and txt and srt (transcript) files

art002a000034_pcd2_raw_v01.m4a
art002a000034_pcd2_trn-csv_v01.csv
art002a000034_pcd2_trn-srt_v01.srt

PCD1,2,3 annotation files, using NASA ID taken from first jpeg in sequence and with an appended “-eXXXXXX” to indicate the NASA ID of the last page in the document

art002e009303-e009388_pcd1_ann_v01.pdf
art002e009389-e009474_pcd2_ann_v01.pdf
art002e009475-e009560_pcd3_ann_v01.pdf

Orion SAW camera 3 Still, (browse_source and raw), version 1, jpeg (browse_source) and tif (raw) files

art002e031160_saw3_src_v01.jpg
art002e031160_saw3_raw_v01.tif

Orion SAW camera 3 Video, version 1, mp4 files (raw)

art002m1010961940_saw3_raw_v01.mp4

Orion CAB camera 2, version 1, jpeg (browse_source), tif (raw) file

art002e041314_cab2_src_v01.jpg
art002e041314_cab2_raw_v01.tif

Orion OpNav camera, version 1, tif file (browse_source and raw)

art002e000156_onav_raw_v01.png
art002e000198_onav_raw_v01.tif

Orion Docking Camera, NASA ID art002e018386, version 1, png file (browse_source), and tif (raw) file

art002e018386_dcam_src_v01.png
art002e018386_dcam_raw_v01.tif

Convention for files *without* NASA IDs:

Voice Loop Format

art002_<UTC Date in YYYY-MM-DD>_<instrument ID>_<data type>_<version>.<extension>

Orion to Earth 1 and 2 Voice Loops and Transcripts

art002_2026-04-06_oe1_raw_v01.mp4
art002_2026-04-06_oe1_trn-csv_v01.csv
art002_2026-04-06_oe1_trn-srt_v01.srt

art002_2026-04-07_oe2_raw_v01.mp4
art002_2026-04-07_oe2_trn-csv_v01.csv
art002_2026-04-07_oe2_trn-srt_v01.srt

HOBO data loggers (SN 1104 and SN 1105)

art002_<UTC Start Date in DOY-hhmmss>_<UTC End Date in DOY-hhmmss>_<instrument ID>_<data type>_<version>.<extension>

art002_086-162546_111-205046_hobo1104_raw_v01.csv
art002_086-162926_111-203826_hobo1105_raw_v01.csv

7.5. Appendix E. Window Quality DFTO Report

The following is the report prepared by NASA JSC ISAG and the Artemis II Lunar Science Team after the FD03 Window Quality DFTO to record the initial image assessments and recommendations on window location and camera placement for the lunar flyby.

7.5.1. Background of activity and description

The 3-pane windows can influence the distortion and color from interior camera images. Information is known on each pane individually, but not how they act as a set. The objective of the Window Optical Quality DFTO is to configure the Nikon D5 camera to take pictures out of the forward windows and the docking hatch window to determine optical quality and the best window to use during the lunar flyby. No changes to the planned configuration for flyby observations were made post- Window Quality DFTO. The analysis reveals Window 2 as the best window for imaging, and we are Go for collecting images at 400 mm focal lengths. The spacecraft was pointed to put the Moon in Window 2 and imaging should be completed from the left position.

The docking hatch window is optically superior to the forward windows, but completing operations using the docking hatch window would limit observations to one crew member. Therefore, we would still prefer to use the forward windows for observations but hope we can get images through the docking hatch window on lunar approach.

We recommend providing reminders to the crew to keep the lens flush with the window as much as possible to prevent imaging through multiple windowpanes at an angle. If an image must be acquired at an angle, the recommendation is to limit the maximum focal length to 200 mm or to acquire the image at multiple focal lengths.

7.5.2. Supporting information

For the analysis of the Optical Quality DFTO, the target was the Earth. The distinctly visible clouds were used to look for textures and hard contrast shifts. These cloud structures enabled the comparison of the images collected in different windows, at different positions, and with different focal lengths. Assessments were made through overlapping and side-by-side comparisons of images.

7.5.3. Selection of focal length

Images were collected with the Nikon D5 camera fitted with an 80-400 mm zoom lens set to focal lengths values of 80, 135, 200, and 400 mm. We focused on the comparison between the 200 mm and 400 mm focal lengths due to the greater sensitivity of the longer focal lengths to the optical characteristics of the windows.

Most images collected at 200 mm are clearer than those collected at 400 mm despite the increase in magnification. This is counter to expectations in the absence of distortion, where 400 mm images would resolve more detail than shorter focal lengths. For Window 3 at all positions (Left, Center, and Right), the 200 mm images were substantially clearer and resolved more detail than the 400 mm images (Figure 11). However, the 400 mm images were clearer and resolved more detail than the 200 mm images in the Window 2 Left position (Figure 10). For the Docking Hatch Window, the 400 mm image provides the most detail over the 200 mm image (Figure 12).

7.5.4. Selection of window

While images through the Docking Hatch Window at all focal lengths show little to no degradation, this window will not allow multiple crew members to simultaneously view the Moon during the lunar flyby. Therefore, the decision was made to select between Window 2 and Window 3. Following the analysis of images and .wav files collected in FD03 by pilot Victor Glover, the lunar science team has chosen Window 2 for imaging during the lunar flyby. Within Window 2, images to left of center were the clearest. Thus,

the science team chose to have the entire lunar disk centered in Window 2 and image from the Left position. At a focal length of 400 mm, the image taken through the Left side of Window 2 shows the most detail and is only slightly less detailed than the same focal length picture taken through the docking hatch window.

Window 3 images were the lowest quality. Images taken through all areas of Window 3 are significantly poorer in detail compared to images shot through the docking hatch and appear smeared as if the shutter was open too long, a consequence of poor wavefront properties of acrylic materials. The analysis team determined the images shot through this window were taken at an angle off-normal to the panes instead of straight through it due to the constraints of combining this imaging activity with another timed activity. This was confirmed by the Spacecraft Pointing group that the Earth was placed at an angle of 16 degrees from the center of Window 3. Regardless of the circumstances that occurred during Window 3 imaging, the science team lacked clear evidence that supports using it for imaging during the lunar flyby.

7.5.5. Supporting images

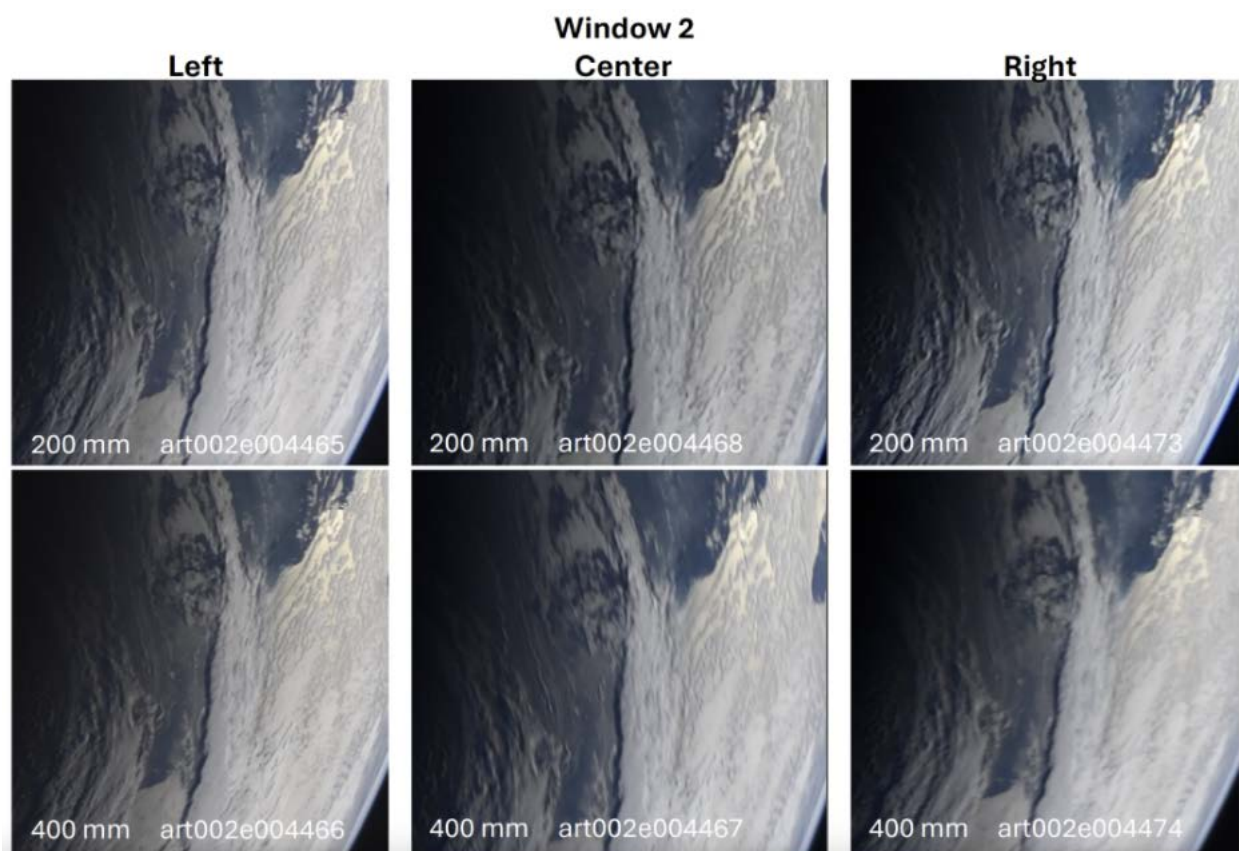


Figure 10. Side-by-side cropped views of images acquired at 200 and 400 mm focal lengths in the Left, Center, and Right positions of Window 2.

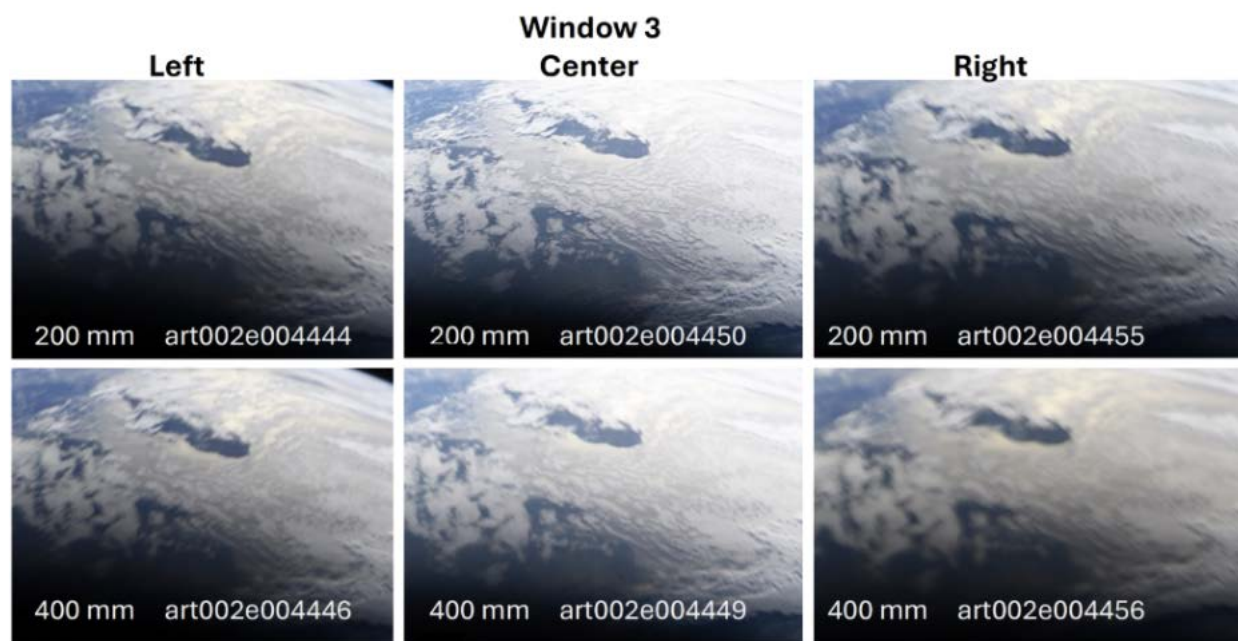


Figure 11. Side-by-side cropped views of images acquired at 200 and 400 mm focal lengths in the Left, Center, and Right positions of Window 3.

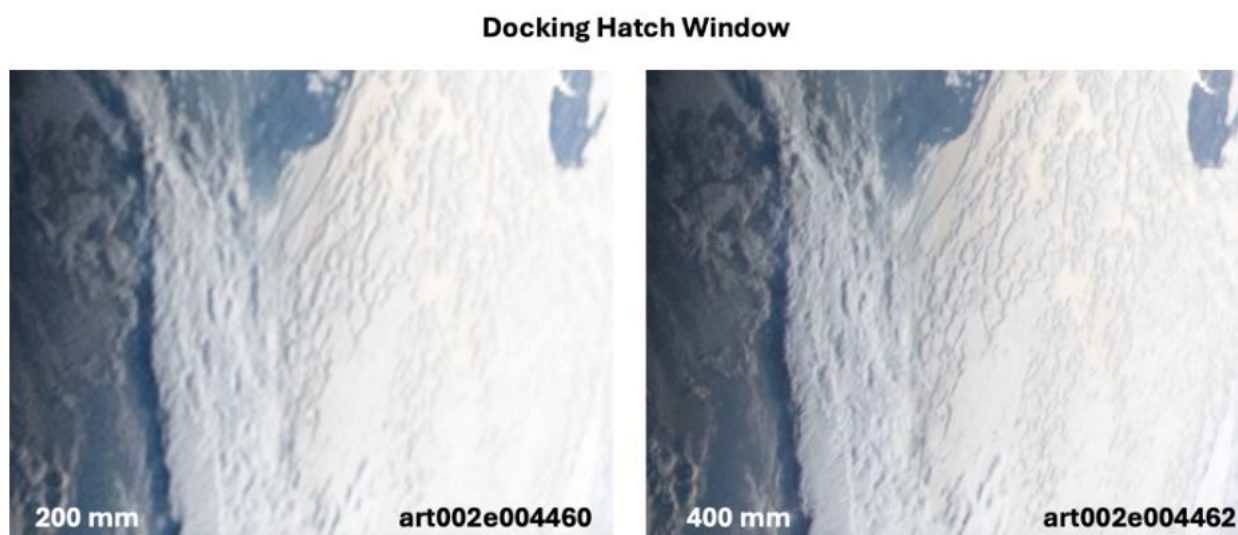


Figure 12. Side-by-side cropped views of images acquired at 200 and 400 mm focal lengths in the Docking Hatch Window. Images have the best quality of all windows, and the 400 mm image shows more detail, as expected.

7.6. Appendix F. NX Studio Options used for Nikon Processed Products

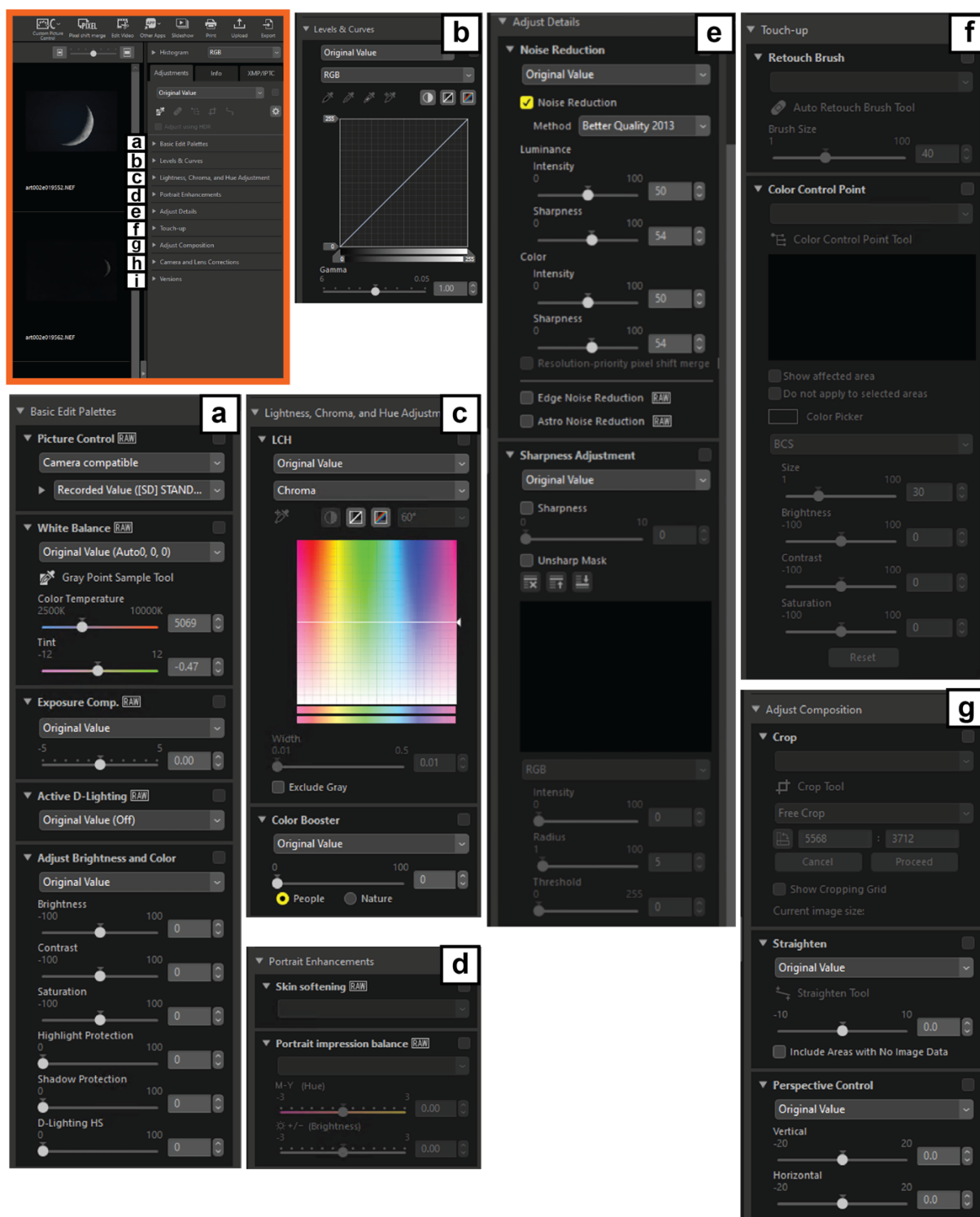


Figure 13. NX Studio parameters used to generate the processed Nikon D5 and Z9 camera images. Upper left panel shows the menu of options, and panels a to i expand the menus to show the parameter settings. The settings follow the default original values recorded by the camera. Panels h and i are continued on the next page.

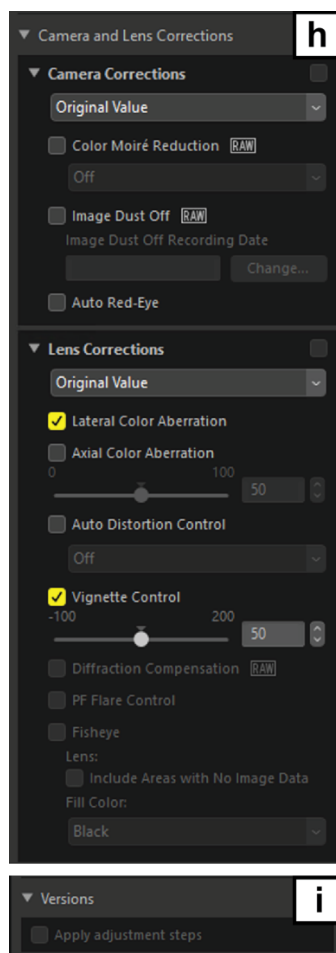


Figure 13 (continued)

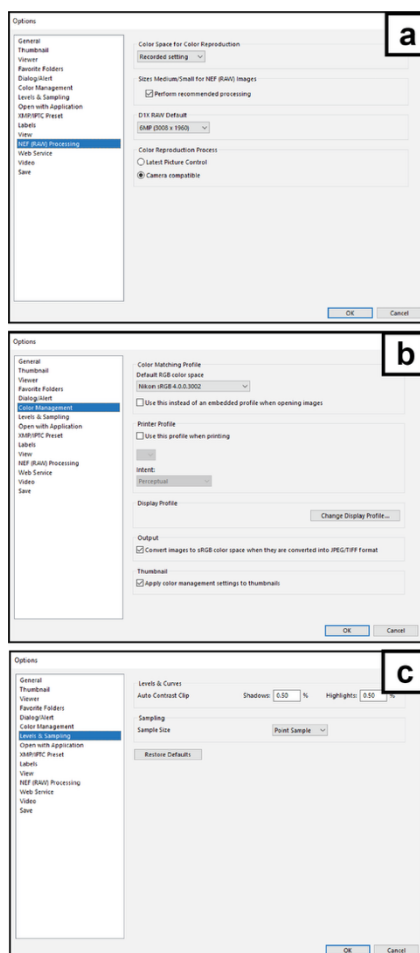


Figure 14. Additional menu options in NX Studio for processing the Nikon D5 and Z9 images.