

Acquiring the LONEOS Data
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ABSTRACT

This document describes how approximately 500,000 Flexible Image Transport System (FITS) images from the Lowell Observatory Near-Earth Object Survey (LONEOS) project were recovered for potential Planetary Data System (PDS) archiving.

1) INTRODUCTION

The Small Bodies Node (SBN) of NASA's Planetary Data System (PDS) program was given responsibility for archiving data from a number of NEO search programs including NEAT, Spacewatch, and Catalina Sky Survey, and is continuing to add additional survey projects such as ATLAS. Archiving of the LONEOS data was the final NEO search program to be archived at the SBN and this report summarizes SBN efforts, led by PI E. Tedesco and Co-I D. Davis, to carry out this task.

LONEOS was a 10-year program (1998 to 2008) at Lowell Observatory that searched for Near Earth Objects (NEOs). Starting on February 4 2000, this survey used a 0.61m Schmidt telescope located on Anderson Mesa about 19 km from the Lowell Observatory main campus on Mars Hill located near the center of Flagstaff, AZ. [See [loneos_project_description.pdf](#) for further details on data before February 4]. The initial phase of LONEOS (LONEOS-I) used a CCD camera developed at the University of Washington (Diercks, *et al.*, 1995, Micelli, *et al.*, 2008). In 2000, this camera was replaced with a camera developed for the project with twice the field of view as the previous one. This camera was used for the remainder of the Survey, LONEOS-II, which ran until 2008.

Following the NEO search program, Lowell scientists initiated a program to obtain lightcurves for a large number of NEOs. This program had two phases: the first, NEAPS, ran from May 2008 to December 2008, followed by LONEOS-Lightcurves which ran from January 2010 to June 2011. Together, these programs obtained lightcurves on 46 NEOs. Observational data from these projects was obtained from Lowell Observatory. but not included in the LONEOS archive.

This PDS/SBN archive includes only LONEOS-II data due to the lack of detailed information about how images were taken in LONEOS-I. In this second phase, the key parameters describing an image were specified by the Lowell Observatory Imaging System (LOIS) written into the header of each image. LOIS version 1.1 was introduced with images starting with January 4, 2000 and used through the end of 2000. Various versions of the information captured are identified by the version number: LOIS version 2.0.0.beta was used for 2003 and 3.2.0.beta for 2004. LOIS 4.2.0 and variants were used for images taken between February 2004 and March 2008, the end date of the LONEOS Survey.

This report describes the multiyear effort by the PDS to recover as much of the LONEOS data as possible for the SBN archive. Recovering the data was just the first step in creating an SBN-compliant data archive. Many of the files recovered, particularly those from backup tapes, turned out to be corrupted or otherwise unable to meet PDS archive standards. The LONEOS data archive produced by this project using the data collected as outlined here are described in [loneos_processing_details.pdf](#).

2) LONEOS DATA RECOVERED FROM LOWELL OBSERVATORY. The first step in archiving LONEOS data was to contact Lowell Observatory staff to obtain the data acquired by this program. This effort began in 2013, a full five years after the search program ended in 2008. It was immediately discovered that there had been no provision made for preserving LONEOS data when the project ended. Furthermore, the LONEOS PI (E. Bowell) and the project Software Engineer (B. Koehn) had both retired. The PI did suggest that we contact Mr. Brian Skiff who had been a principal observer with LONEOS and who might be able to locate data from this project. We contacted Skiff and Dr. Larry Wasserman, who was not part of LONEOS but who Skiff recommended because he was more familiar with how data was stored on various Lowell computers. What Wasserman found was that there was LONEOS data still available but it was divided between two computers and several hard disk arrays, many of which were in rather poor shape. Nonetheless, Wasserman began the laborious process of moving this data to a more reliable system so that it could be delivered to the PDS.

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In October 2014, Wasserman reported that they were able to write data from 2005, 2006, 2007, and 2008 from one machine (which was on its last legs) to a backup disk. A detailed email chronology of the efforts made by Dr. Wasserman is given in the Appendix.

Data recovered from the Lowell Hard Disk Drives (HDD) was sent to PDS/SBN in 2 deliveries: October 2014 and May 2016, though the 2016 delivery consisted of data recovered in 2015 but was not actually delivered to the SBN until 2016 (thus we count two deliveries from the 2016 delivery as described below). With this delivery in 2016, all data from the LONEOS project that was recoverable at Lowell had been delivered to the SBN. All told, 398,029 images from years 2000 through 2008 (except 2001 and 2002 and a small number in 2000) were delivered. Table 1 summarizes these deliveries.

This data is divided into three deliveries based upon the dates that the recovered data was written to hard drives and supplied to the SBN:

HDD-1. October 2014 delivery. Data from 2005 to 2008. Consisted of ~156,000 files (2.67 TB) from the period November 2005 to October 2007 with gaps from May 22 2007 to October 8 2007. March 2008 is the last data available.

HDD-2. Data recovered in 2015 but not delivered until May 2016. Data from 2000, 2003 and about 50% of the 2004 data.

HDD-3. Data recovered in 2016 and delivered in May 2016. This delivery contained the remainder of the data from 2004 plus lightcurve data from 2010 and 2011.

Table 1. Summary of LONEOS Data Recovered from Computers at Lowell Observatory

Year	Number of Files	Delivery	LOIS Version
2000	2,238	HDD-2	1.1
2001	0		
2002	0		
2003	44,222	HDD-2	3.2.0 beta
2004	27,506	HDD-2	3.2.0 beta
2004a	54,493	HDD-3	3.2.0 beta
2005	17,722	HDD-1	4.2.0
2006	79,185	HDD-1	4.2.0
2007	59,461	HDD-1	4.2.0
2008	7,430	HDD-1	4.2.0
Total Delivered	292,257		

In summary, all of the data recovered from Lowell HDD was from 2003 to 2008 and the bulk of the pre-2003 LONEOS data was apparently lost.

We are indebted to Wasserman and Skiff for their dedicated labor to recover these data from two failing computers at Lowell Observatory. Without their substantial effort to recover this data, it would have been lost forever. It was close to doing exactly that as the RAID arrays and several computers were in

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danger of failing with no apparent efforts being made to preserve data.

3) ANOTHER SOURCE OF LONEOS DATA IS UNCOVERED!

In the course of searching for this “missing data,” a potential secondary source of LONEOS data was uncovered in 2017: LONEOS data had been shipped to Dr. James Bauer and Dr. Kenneth Lawrence at the Jet Propulsion Laboratory (JPL) via 171 DAT (135 Sony 8mm SDX1-35C and SDX2-50C Aitech Data Cartridges, hereafter referred to as “tapes”). The tapes had been sent to JPL by LONEOS Software Engineer Bruce Koehn to test whether JPL could read these tapes.

Unfortunately, JPL was not able to read these tapes and they were just sitting on the shelf in an office at JPL. When Co-I D. Davis heard about them, he contacted Bauer and Lawrence who were more than happy to send them to Tucson which they did in April 2017.



LONEOS tapes as they were delivered to Tucson in 2017.

With the tapes in hand, the next step was to read them and transfer the data to a modern medium for permanent storage. SBN personnel tried several possibilities in the Tucson area – the University of Arizona, Kitt Peak National Observatory, and others – without success. However, PI Tedesco did uncover a small company in Tempe, AZ, Data Recovery & Computer Repair (DR), which specializes in recovering data from old tapes. As a test of the ability of DR to recover data from our tapes, four tapes were sent to DR which did successfully recover much of the data. With results from this test in hand and lacking additional options, a contract was issued to DR to recover as much data as possible from the tapes.

DR completed this contract in 2019 and found the following:

1. Of the 171 tapes, 58 were empty.
2. Tapes 1-42 contained data were from the Pre-LONEOS Search Phase (LONEOS-I) and thus were not included in this SBN archive.
3. Tapes 43-171 contained files obtained between January 4 2000 and 2003. Table 2 summarizes the

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data recovered from these files.

We note that without these tapes, there would have been no data recovered for the years 2001 and 2002. For the year 2000, PI Tedesco found that “about half the nights from the year 2000 were lost (we never received them on either a tape or HDD) and at most half of the images written to the tapes we received were recovered. That is, we have about 25% of the images actually obtained in 2000. And it’s by no means certain that all those recovered are actually useable FITS images.”

Table 2. Files Recovered from LONEOS Tapes – 2000 to 2003

Year	Number of Files	Source (Directory)	LOIS Version
2000	43,508	0043-0082	1.1
2001	30,611	0083-00126	1.1
2002	4,491	0147-00158	1.3.2.2
2003	27,162	00158-00167	2.0 beta
Total Files Recovered	105,772		

The total archive of LONEOS data recovered amounts to 416,819 files. However, many of these files were unusable for generating archivable images for the PDS which is the goal of this project. None of the recovered LONEOS files came with accompanying documentation.

Diligent searches for published and unpublished documentation of any type (including Lowell Observatory internal publications and NASA progress, annual, and final reports) failed to discover anything describing the details of how the program was conducted or the contents and format of the various files. Both the PI and Software Engineer of LONEOS have retired and were not available to provide any details regarding the existing data. Thus, what we know about the project comes from questions answered by the still active (as of 2023) principal observer (Brian Skiff), non-project publications that mention it, and (as far-as-we-know), an unpublished manuscript at an *Astronomy or Sky & Telescope* level (Bowell, *et al.*, 2008), a couple of handwritten notes, and what we could glean from the image files themselves.

The sole publication with hard information on the LONEOS program is the Stokes, *et al.* (2008) paper in the Asteroids III book. However, it has little information on the camera.

4. REFERENCES

Bowell, E., Koehn, B., Skiff, B. (2008). The Lowell Observatory Near-Earth-Object Search (LONEOS): Ten years of asteroid and comet discovery (2008). LONEOS History, Lowell Observatory Library Collection (unpublished).

Diercks, A.H., Angione, J., Stubbs, C.W., Cook, K.H., Bowell, E., Koehn, B., Nye, R., Dodgen, D. (1995). Cameras and Systems for Electronic Photography and Scientific Imaging. Proceedings of IS&T/SPIE’s Symposium on Electronic Imaging: Science and Technology. San Jose, CA (USA). Volume 2416. [DOI.org/10.1117/12.204839](https://doi.org/10.1117/12.204839)

Micelli, A., Rest Armin, A., Stubbs, C., Hawley, S., Cook, K., Magnier, E., Krisciunas, K., Bowell, E., Koehn, B. (2008). Evidence for distinct components of the galactic stellar halo from 838 RR Lyrae stars discovered in the LONEOS-I Survey. *Astrophysical Journal* 678, 865-887. DOI: https://ui.adsabs.harvard.edu/link_gateway/2008ApJ...678.865M/doi:10.1086/533484

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*****Appendix*****

Email Chronology from L. Wasserman 2014-2016. Permission to use these emails was granted by Dr. Wasserman.

Larry Wasserman
<lhw@lowell.edu>

Thu, Mar 21,
9:23 AM

Thanks -- I certainly have no objections to sharing my e-mail.

Larry

16 Oct 2014 From Larry W.

OK -- good news and bad news. We have written the data which is archived on one of the two computers to a backup disk. That's the LONEOS data for 2005,2006,2007,2008. This machine appears to be on it's last legs, but we got the data off. This machine is currently also used to do initial processing of asteroid light curve data so we are making plans to move that function to another computer and retire this machine. But that's not as easy as it sounds because some of the software used to do the reductions was written in ADA and will have to be rewritten in something else. Now, there is more LONEOS data on a second machine which is currently turned off because we are unable to get it to boot. Once the first machine is no longer needed, we can swap the disks from this machine into the first and backup that data. And no, we can't just put the disks into some other computer -- each machine has 24 400 Gb disks arranged as two sets of raid disks with 6/6 of these disks making up a 2.4 Tb raid pair. The data are striped across the 6 disks so we can't even try to read the disks one at a time.

PSI sent 2 HDDs to Wasserman to copy data onto. The first data delivery of LONEOS data on one of these HDDs consisted of 163,798 images from 2005, 2006, 2007 and 2008 which were copied from Computer #1 and was delivered to the SBN in October, 2014.

Work continued at Lowell to recover additional data. SBN contacted Larry in 2015 to ascertain the progress in data recovery:

7/30/15. From Larry W. We now have the second computer that had LONEOS data on it running again, and I'm in the process of writing data to the 2nd disk you sent us. However, it looks like we still have enough data to fill that disk and run over. Would you like to send us a 3rd disk? The first HDD, returned to PSI in Oct. 2014 was backed up at PSI, wiped clean and sent to Larry.

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On 14 August 2015, Wasserman reported:

Well, we've run into a problem, but we may have a solution... We have two computers each with two large (~Tb?) raid clusters. The disks we sent you earlier contained the two clusters from computer #1.

AWe have now backed up cluster #1 on computer #2. I know that it contains 2000, 2003 and half of 2004. This disk is ready to be sent to you. However, cluster #2 on computer #2 has died. I know it contains the other half of 2004 and _I think_ 2005/2006.

However, this second HDD was not delivered to SBN/PSI in 2015.

In 2016, LW reported:

Lawrence Wasserman <lhw@lowell.edu>

Fri, Apr 29, 2016, 3:11 PM

to me

"https://mail.google.com/mail/u/0/images/cleardot.gif"*MERGEFORMATINET

So I now have all the remaining readable LONEOS data backed up onto two of your external disks. Where do I send them to?

Larry

Don Davis <drd@psi.edu>

Sat, Apr 30, 2016, 8:41 AM

Excellent, Larry. Please send the drives to:

Planetary Science Institute
Attention: Jesse Stone
1700 E. Ft. Lowell Rd, Ste 106
Tucson, AZ 86719-2395
Ph: 520/622-6300

I take it from your message that some of the data is not readable - about how much of the original data is no recoverable? Is this some of the early data?

Thank you again for you help in getting this data to the PDS; I know that this effort was not part of your "job description" but we do appreciate you work in helping us to acquire it.

Now to get it archived!

Don

Larry Wasserman <lhw@lowell.edu>

Sat, Apr 30, 2016, 12:45 PM

I'm not sure how much was not readable. There were two 500 Gb disks that didn't respond (both from 2004 -- some or all of that data may have been on the big systems anyway). And we had problems with one of the big raid systems. Since it was unreadable it's difficult to know what was there. I may not have a chance to send the disks this week -- company coming, but I'll send it the following at the latest.

Larry

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From: Lawrence Wasserman lhwl@lowell.edu

Date: Wed, May 11, 2016 at 3:19 PM

Subject: Disks

To: "Donald R. Davis" <[K"mailto:drd@psi.edu"\"_blank"drd@psi.edu](mailto:drd@psi.edu)>

The two disks were shipped off today...

*******END OF APPENDIX*******