

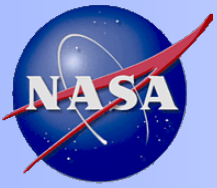


*X-ray Computed Tomography of
Tranquility Base Moon Rock*

Dr. Justin S. Jones / Code 541

Dr. Jim Garvin / Code 600

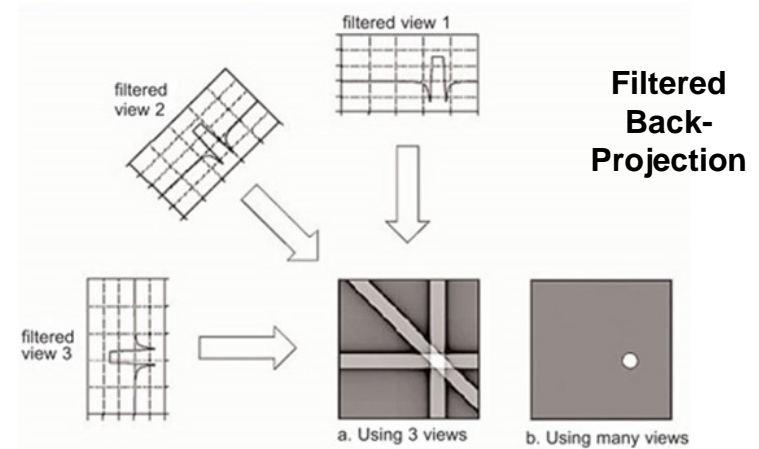
***Collaborators: Mike Viens/540,
Ryan Kent/541, and Bruno Munoz/541***



GSFC X-Ray CT System (Code 541 NDE Laboratory)

Technique Background:

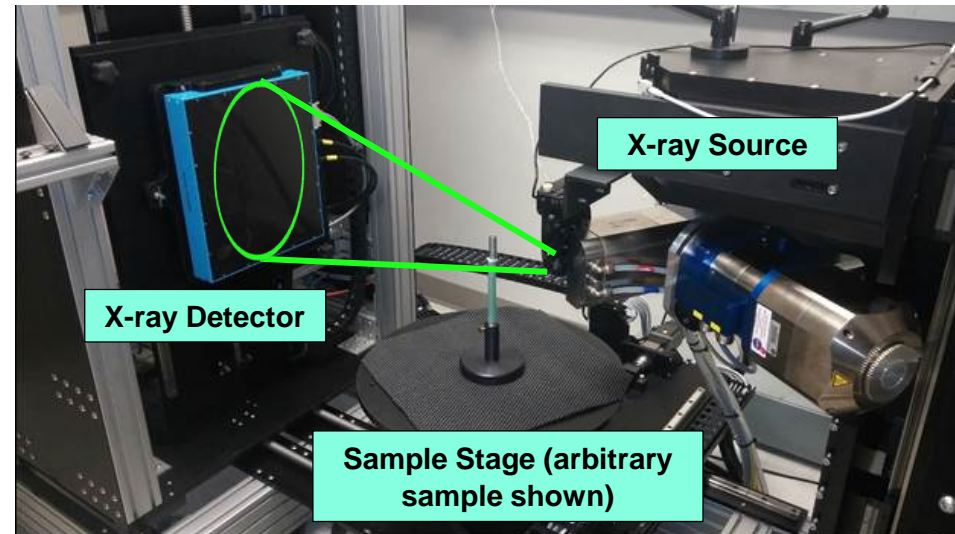
- X-ray Computed Tomography (CT) is very similar to Medical “CAT” scans
- An x-ray source creates a “cone beam” which enables geometric magnification
- A series of 2D radiographs are taken at precise angle steps as the part rotates
- Feldkamp **filtered back-projection** algorithm is applied to image “projections” to create 3D reconstructed “volume”



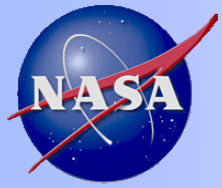
Reprinted with permission from Smith. *The Scientist and Engineer's Guide to Digital Signal Processing*. ©1997-1998. Available at: <http://www.DSPguide.com>. Accessed May 23, 2012.¹⁸

Main Components:

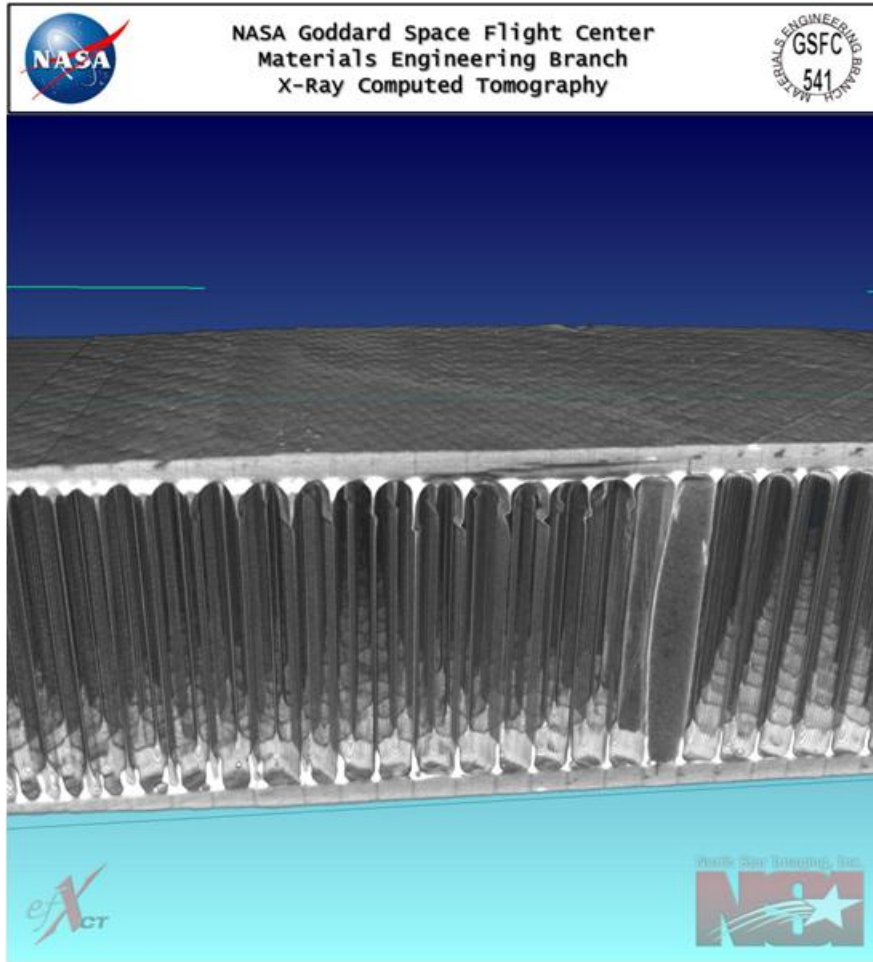
- 7-axis motion/manipulator system, up to 100lb capacity on rotation stage
- Detector: Dexela 7529 CMOS with CsI scintillator
 - 75 μm pitch, 3888 x 3072 pixel array
- X-ray Source: Yxlon FXE-225.99 Dual Head Microfocus: 225kV
- Installed in radiation shielded room
- North Star Imaging and VG Studio Max software
- Reconstruction PC with 4 Tesla GPU computing



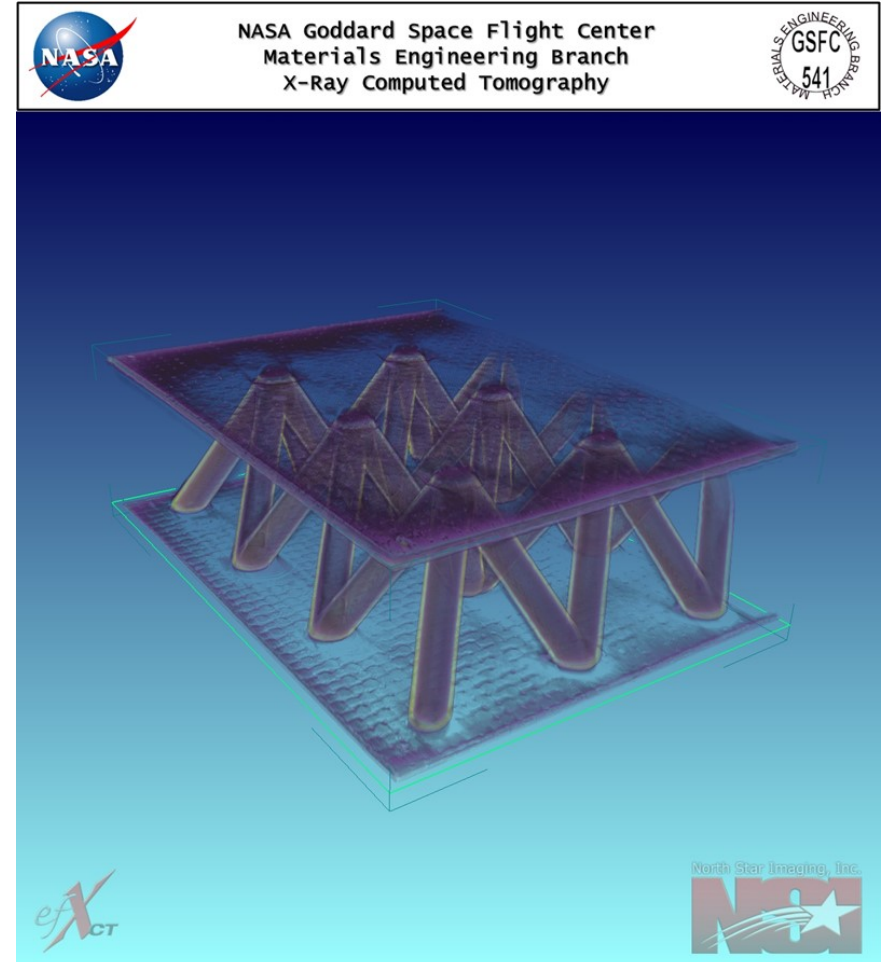
North Star Imaging, custom X5000CT



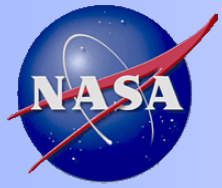
GSFC CT Examples - Composites



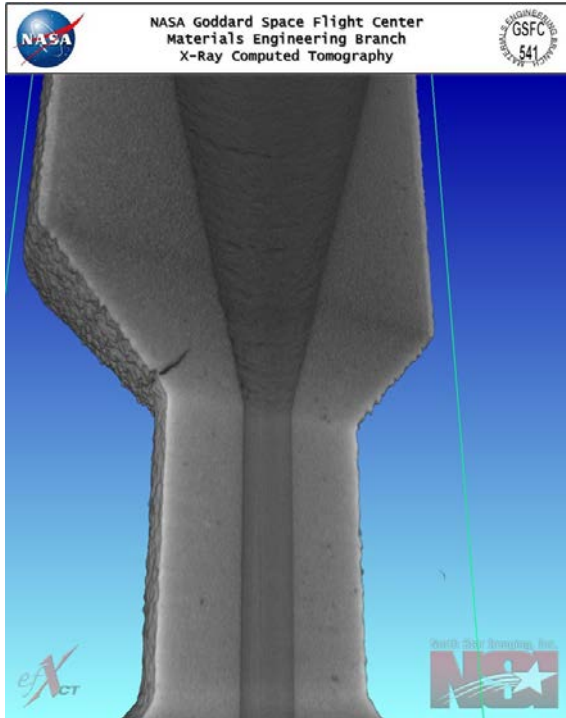
Impact Damage in Structural Composite



Experimental "Topological Core" Composite Structure

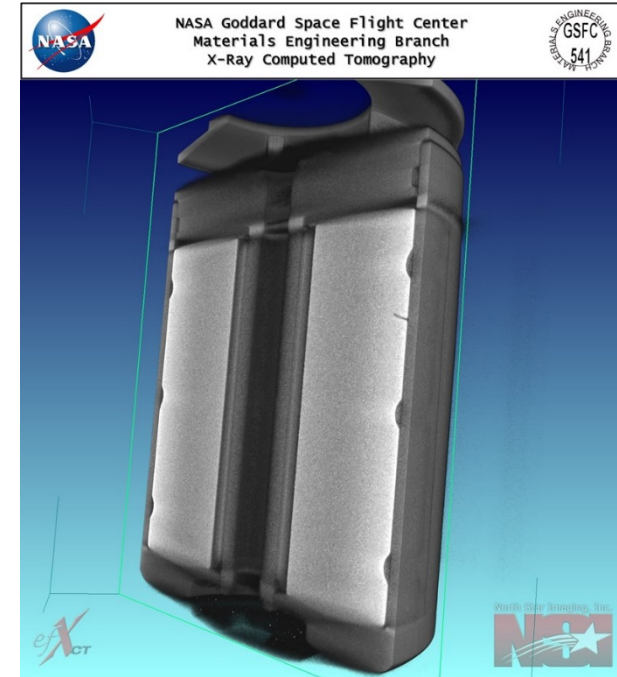
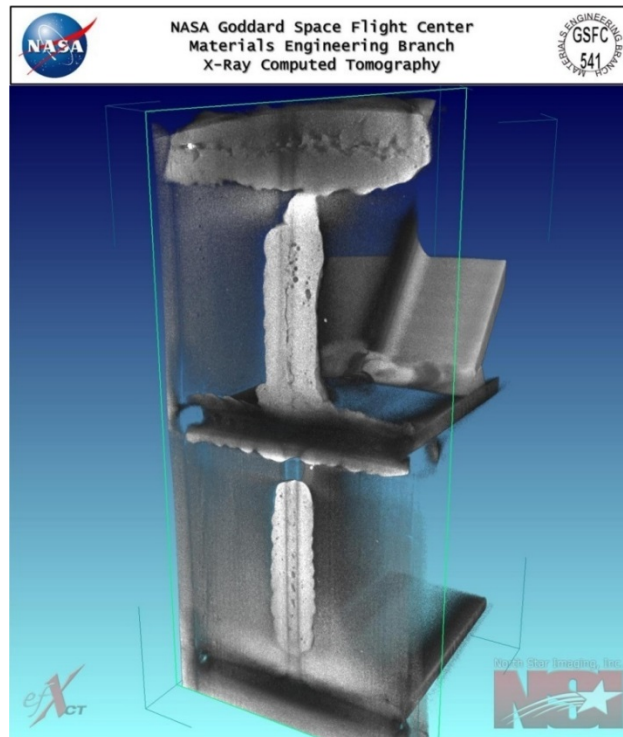


GSFC CT Examples - Metallic Parts

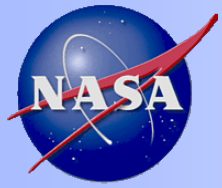


Europa: Additively
Manufactured "Venturi"
with stress relief crack

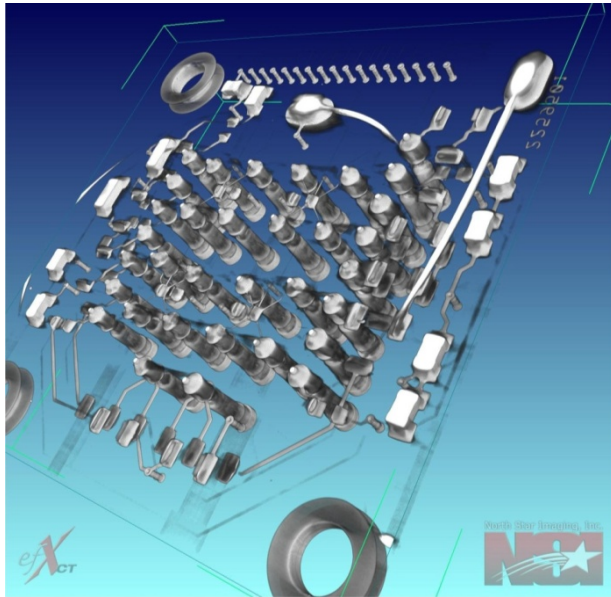
JWST: ISIM Structure 3D
Welded Joint



ISS: Cracked magnet in
EMU FPS Rotor
Assembly

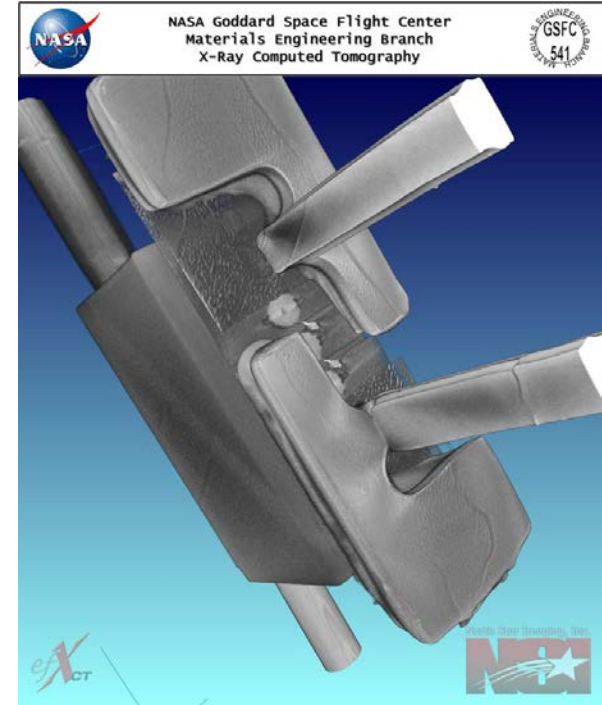
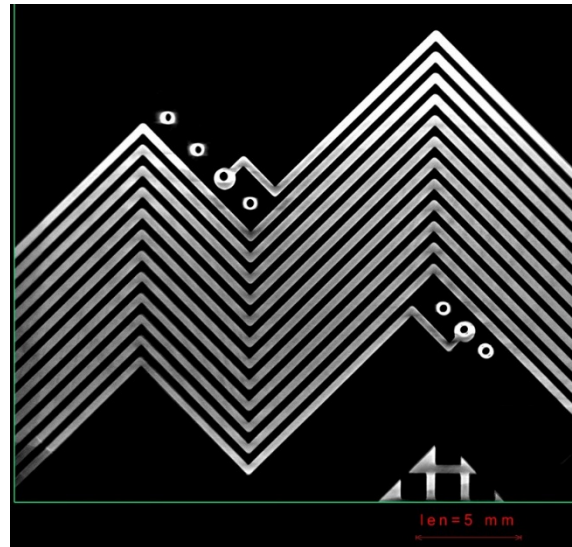


GSFC CT Examples - Circuit Boards/Components

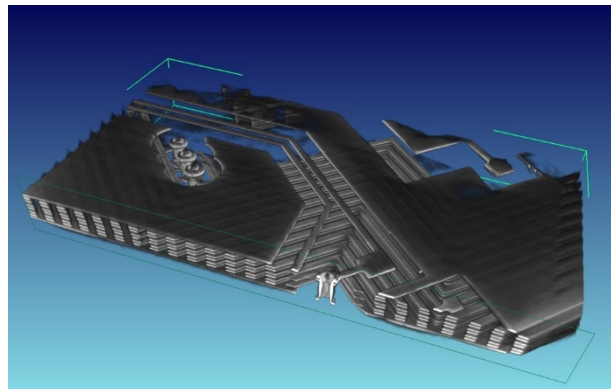


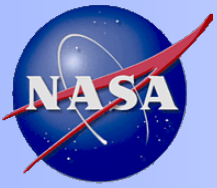
Full Circuit Board

Circuit Board Interior Wiring Plane



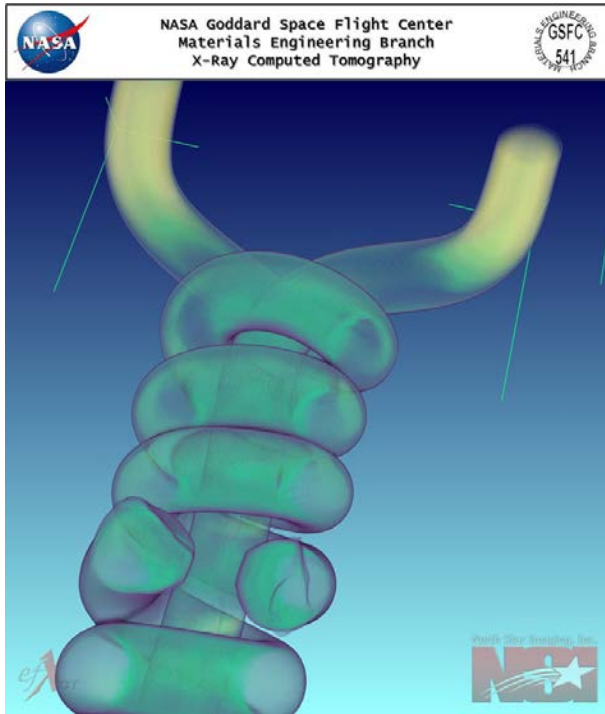
HV801 Diode Terminals



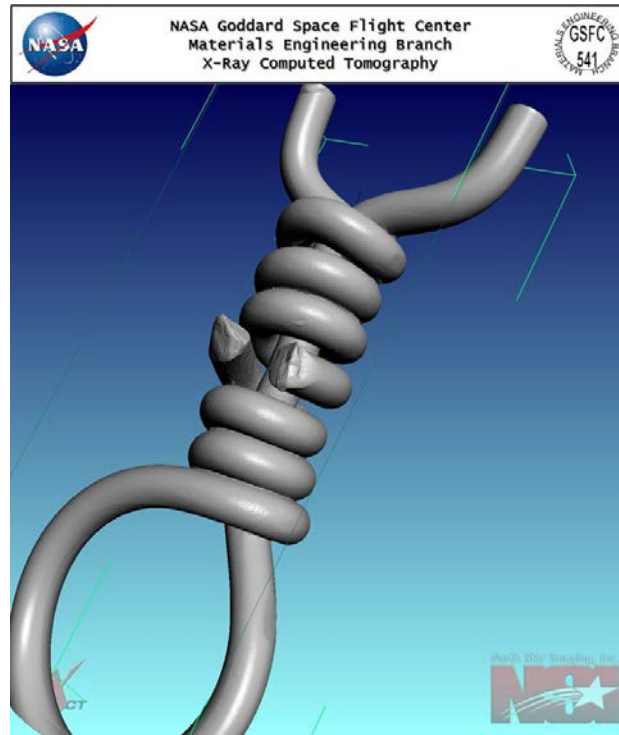


GSFC CT Examples - Reverse Engineering / 3D Reproduction

JWST: CT Scan of Transition Link Assembly (fuse wire, ~1cm)



3D Model "Surfacing" to export as STL file for CAD/FEA/3D printer



3D printed replica of actual TLA (lower) at 10x scale

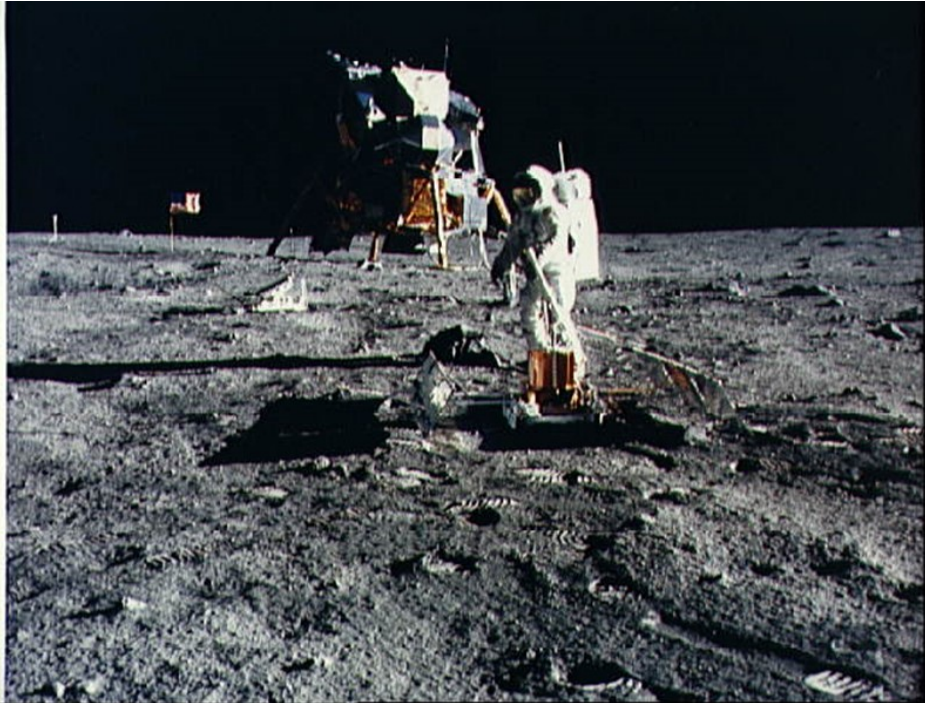




Apollo 11 Mission Background

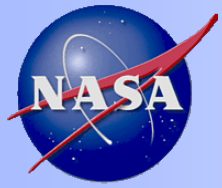
The following text was sourced, with minor edits, from the NASA site:

<http://nssdc.gsfc.nasa.gov/nmc/masterCatalog.do?sc=1969-059C>

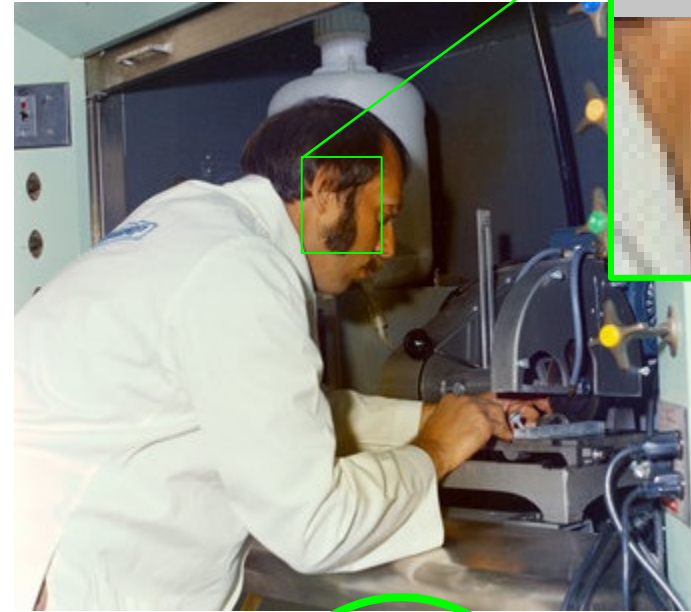


<http://nssdc.gsfc.nasa.gov/planetary/lunar/apollo11.html>

- *'The Lunar Module landed at 20:17:40 UT (4:17:40 p.m. EDT) on 20 July 1969 in the region known as Mare Tranquillitatis (the Sea of Tranquility) at 0.6741 degrees N latitude, 23.4730 degrees E longitude'*
- *'Armstrong reporting, "Houston, Tranquility Base here - the Eagle has landed".'*
- *'Neil Armstrong stepped onto the lunar surface at 02:56:15 UT on 21 July (10:56:15 p.m. July 20 EDT), stating "That's one small step for man, one giant leap for mankind".'*
- *'The astronauts deployed the EASEP and other instruments, took photographs, and collected 21.55 kg [47lbs] of lunar rock and soil.'*
- *'The astronauts traversed a total distance of about 250 meters, both ranging up to about 100 meters from the LM.'*

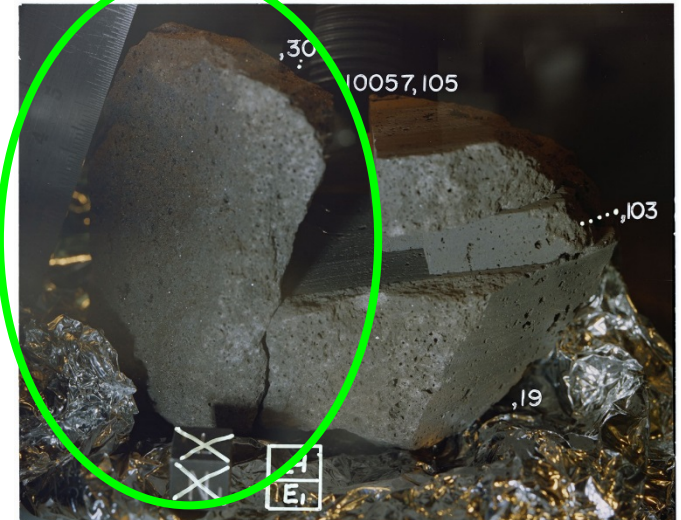


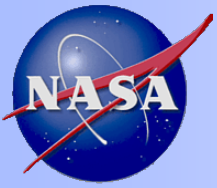
Lunar Sample 10057



no longer permitted
in NASA labs

- The Apollo 11 Moon Rocks discussed here are basalts, similar to those on Earth but high TiO_2 and low SiO_2 .
- This sample (10057) is described as high K, VHT (very high titanium), fine grained, and has about 10% vesicle content (pores)
- This sample is 3.63 billion years old
- In 1976, Sample 10057 was sectioned into multiple smaller samples





Lunar Sample 10057-[XX]

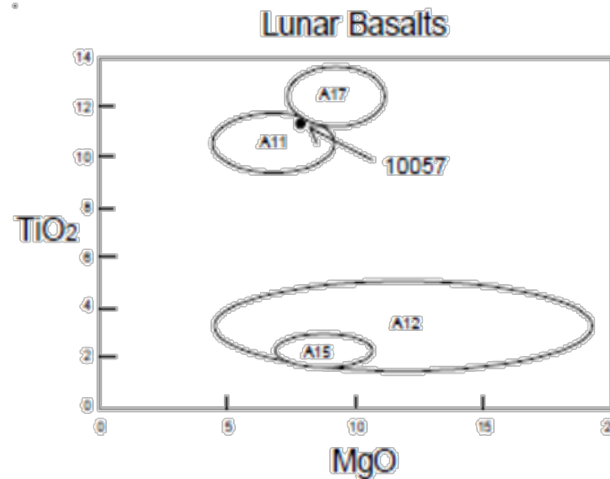
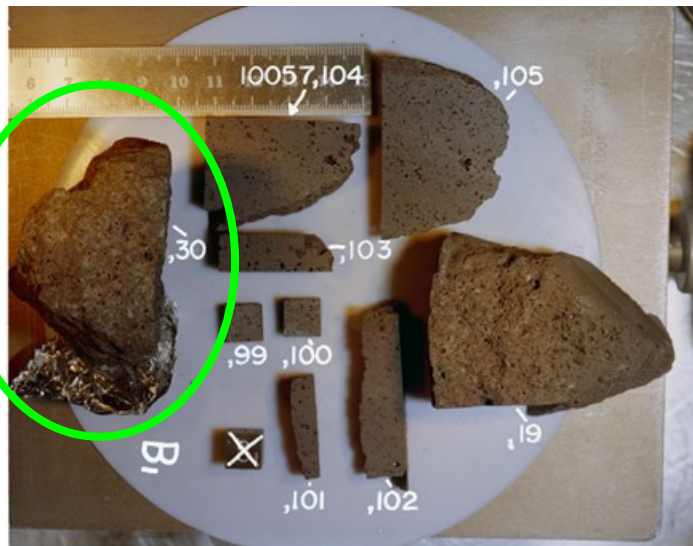
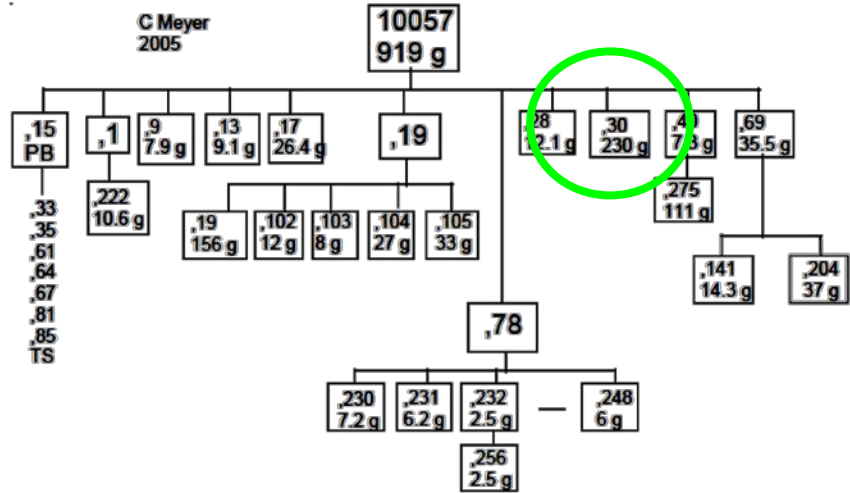
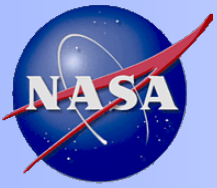


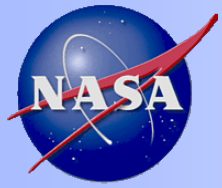
Figure 6: Space Window at US National Cathedral in Washington DC with piece of 10057 located in center of rose window.



Lunar Sample 10057-30



<http://www.lpi.usra.edu/lunar/samples/atlas/images/hires/10057/S99-10758.jpg>



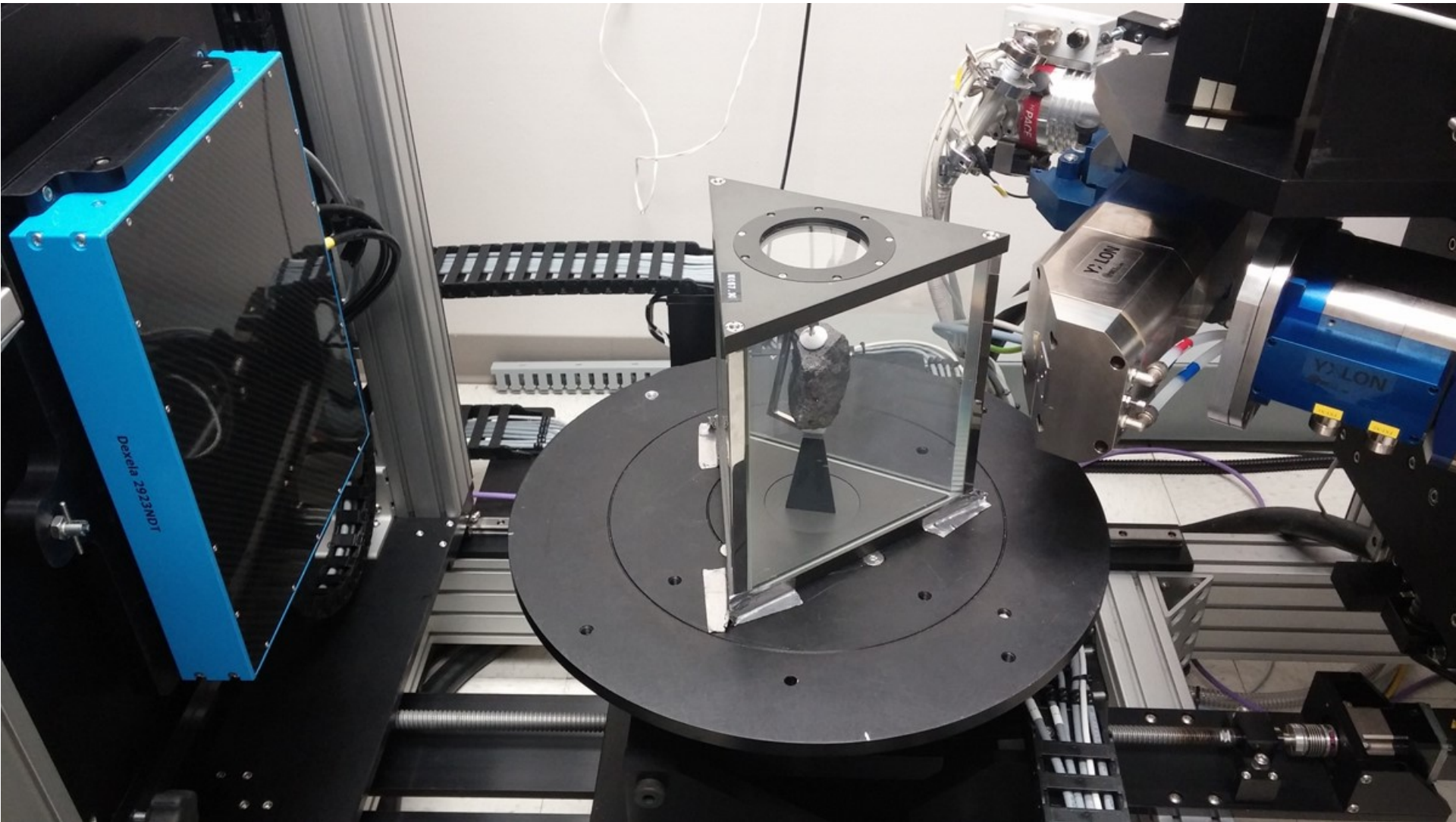
Lunar Sample 10057-30



<http://www.lpi.usra.edu/lunar/samples/atlas/images/hires/10057/S99-10757.jpg>

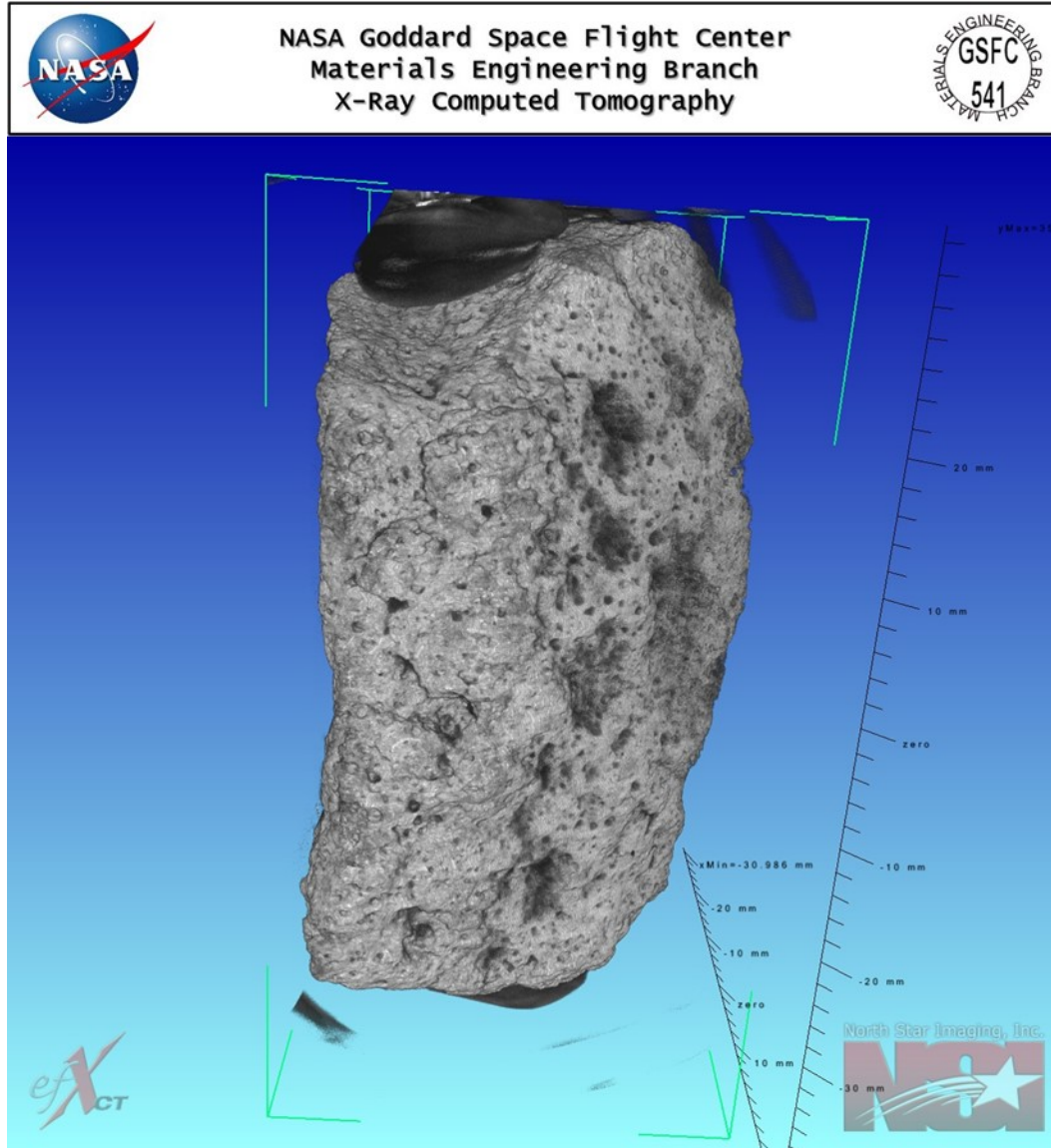


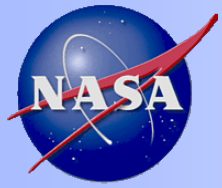
GSFC X-Ray CT Setup



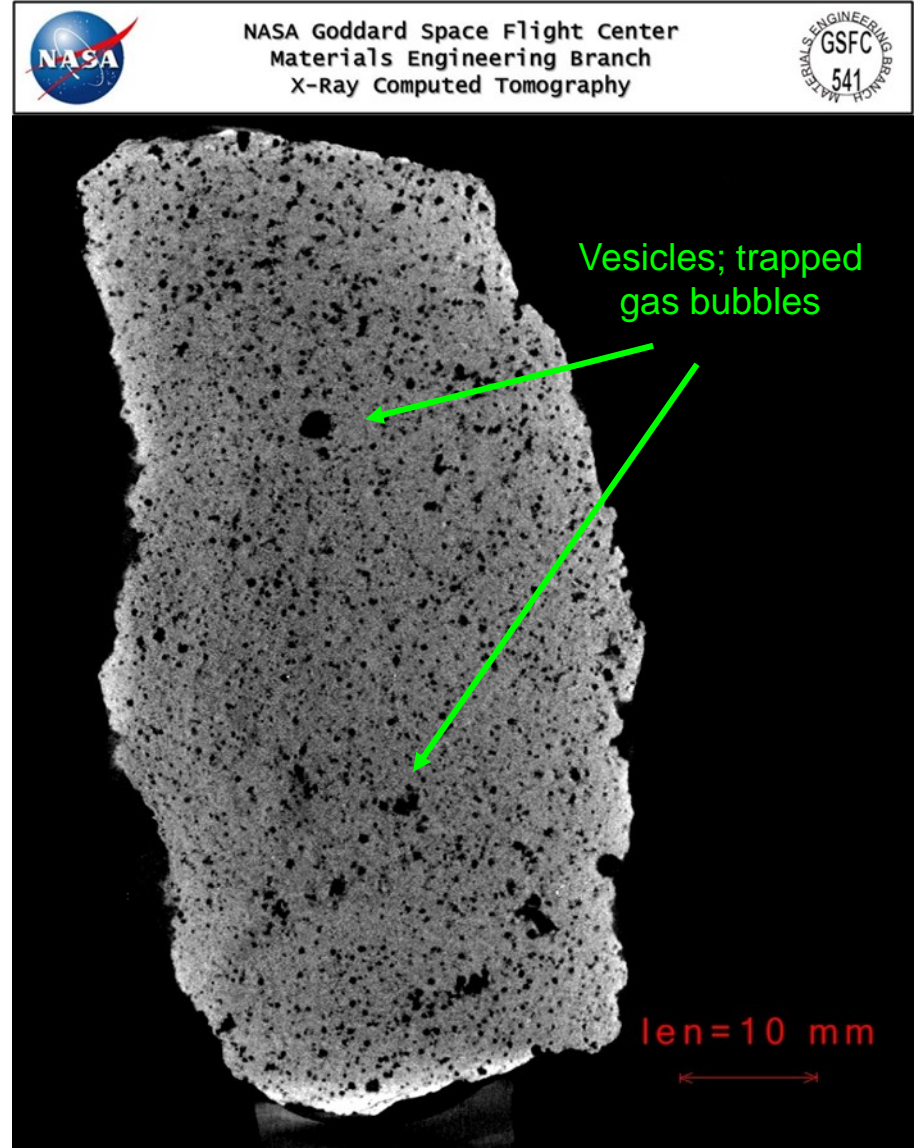
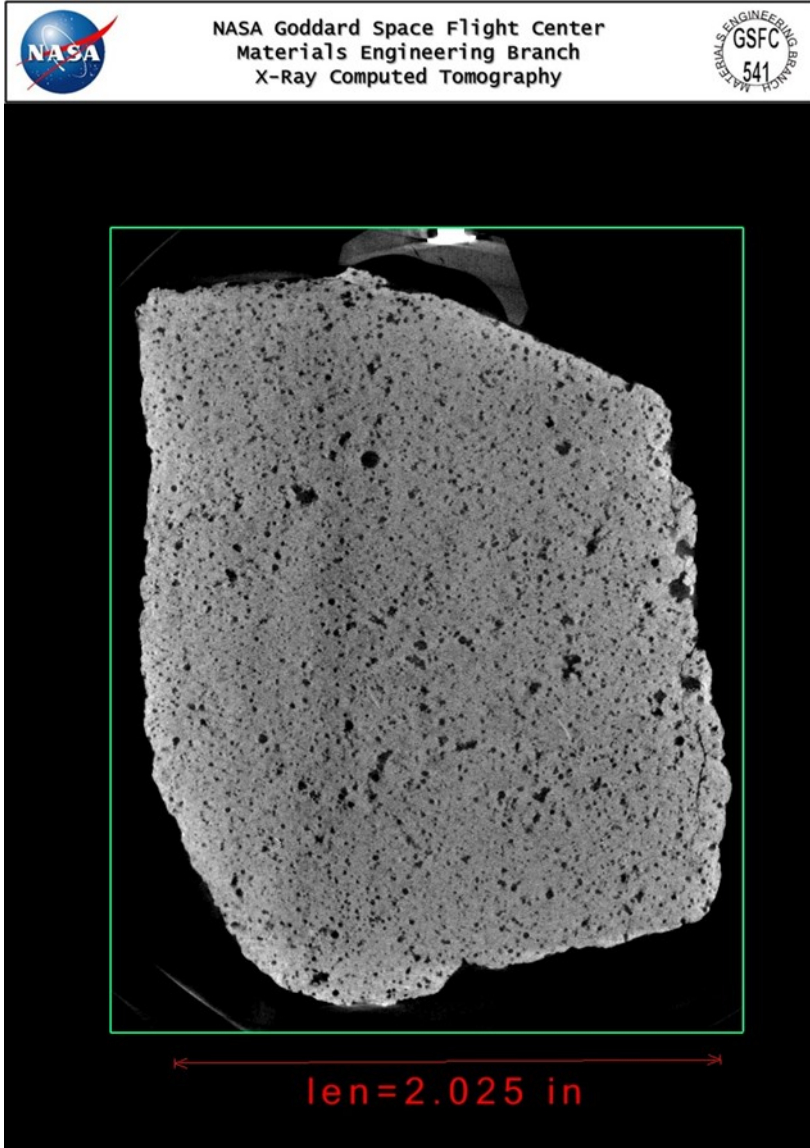


Lunar Sample 10057-30, CT Results





Lunar Sample 10057-30, CT Results

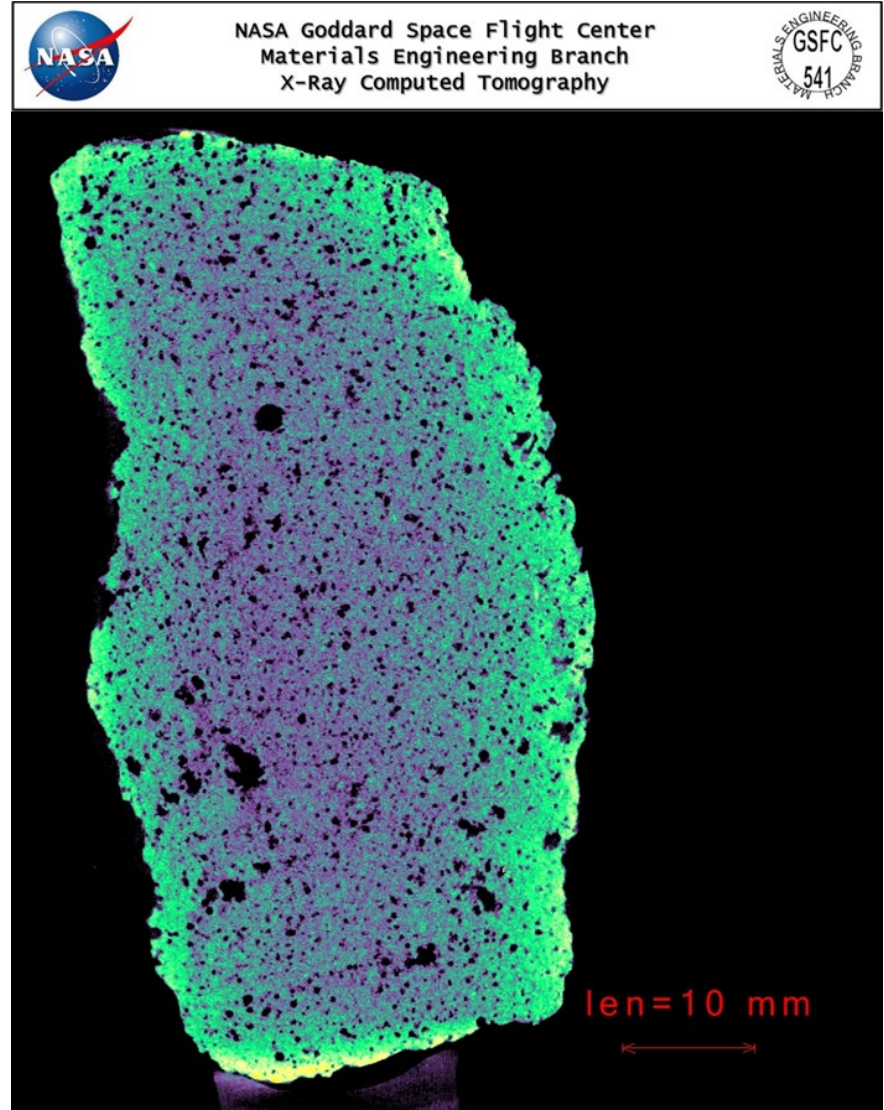


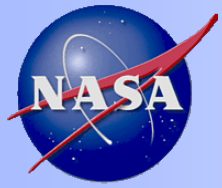


Lunar Sample 10057-30, CT Results



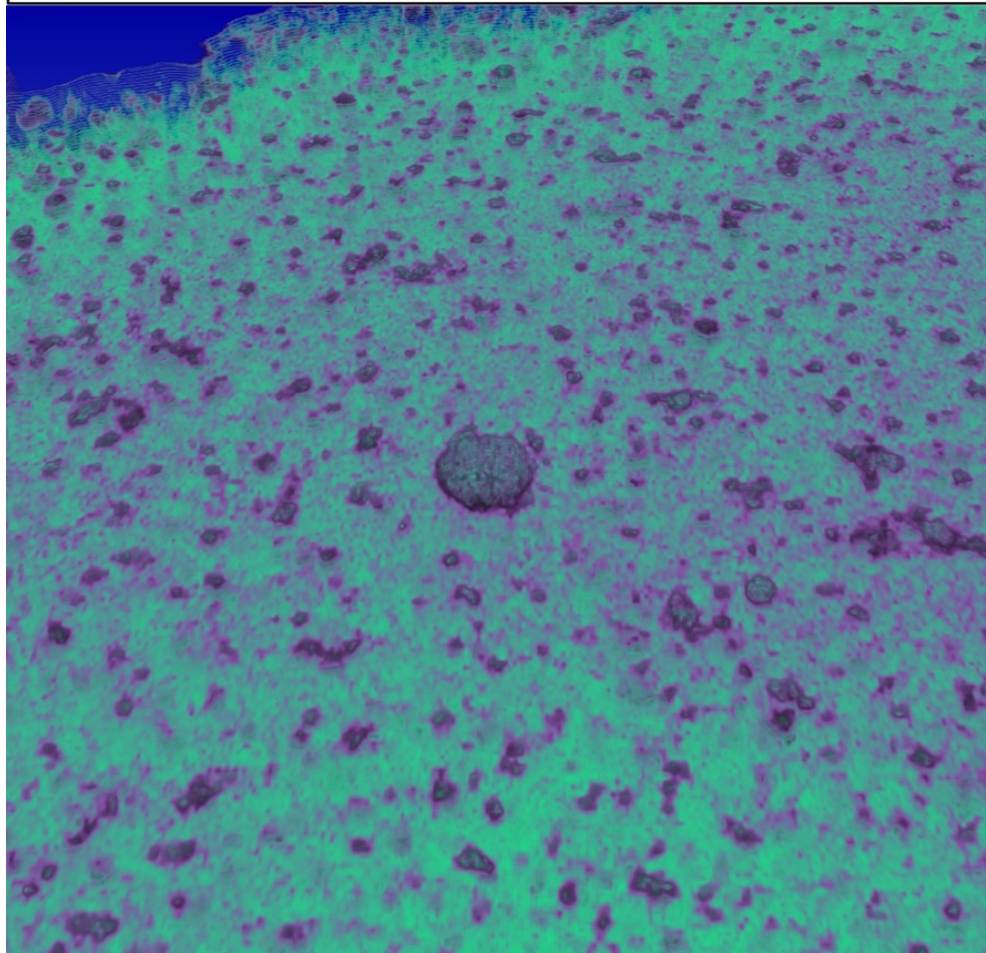
Could it really be made of "Green Cheese"?



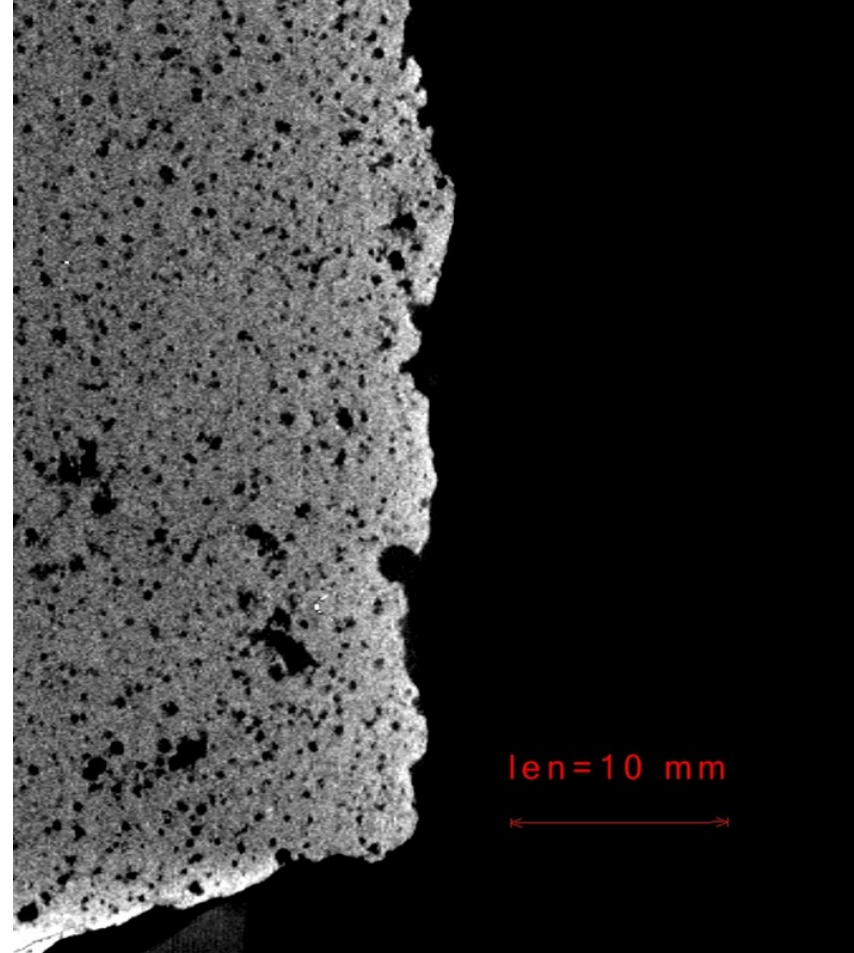


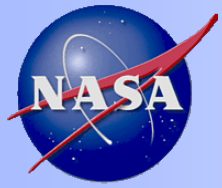
Lunar Sample 10057-30, CT Results

NASA Goddard Space Flight Center
Materials Engineering Branch
X-Ray Computed Tomography



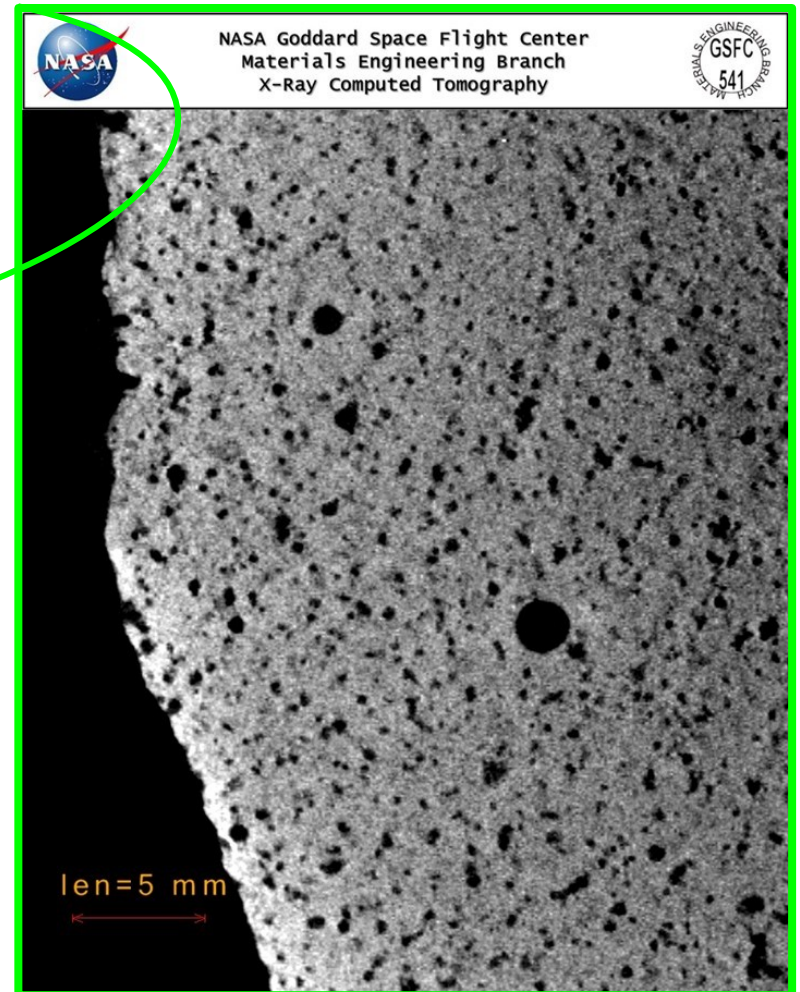
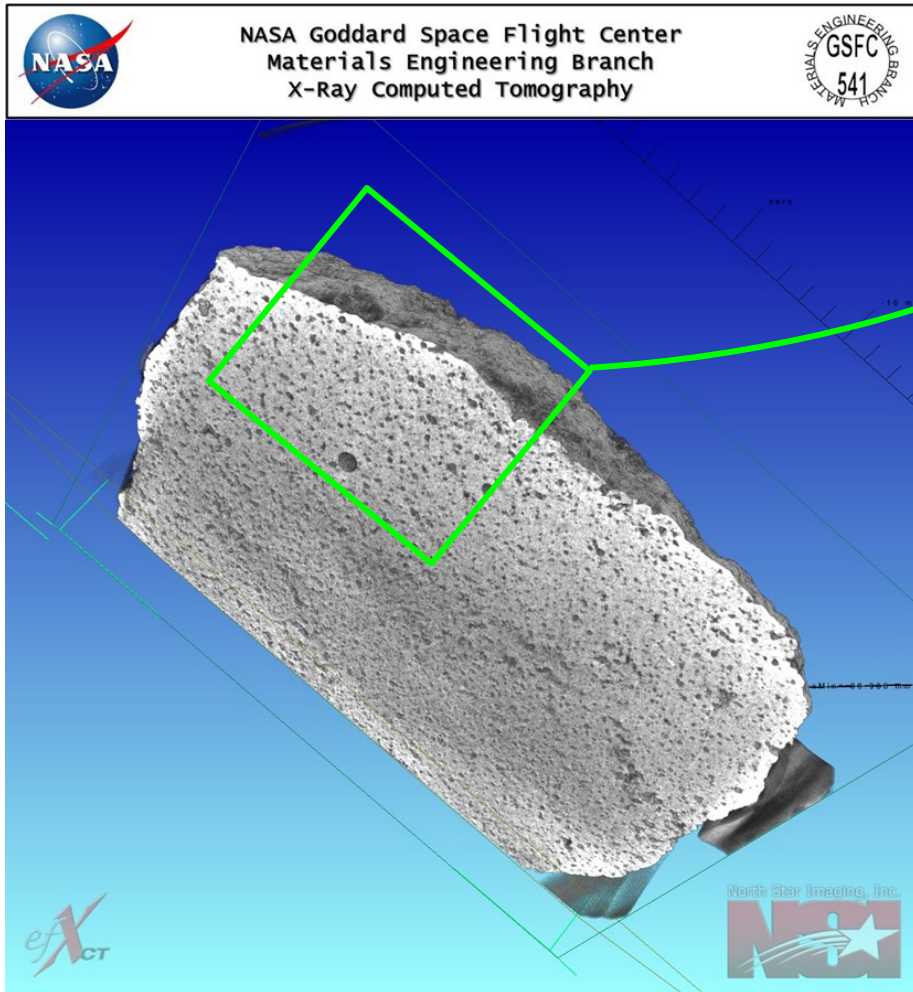
NASA Goddard Space Flight Center
Materials Engineering Branch
X-Ray Computed Tomography





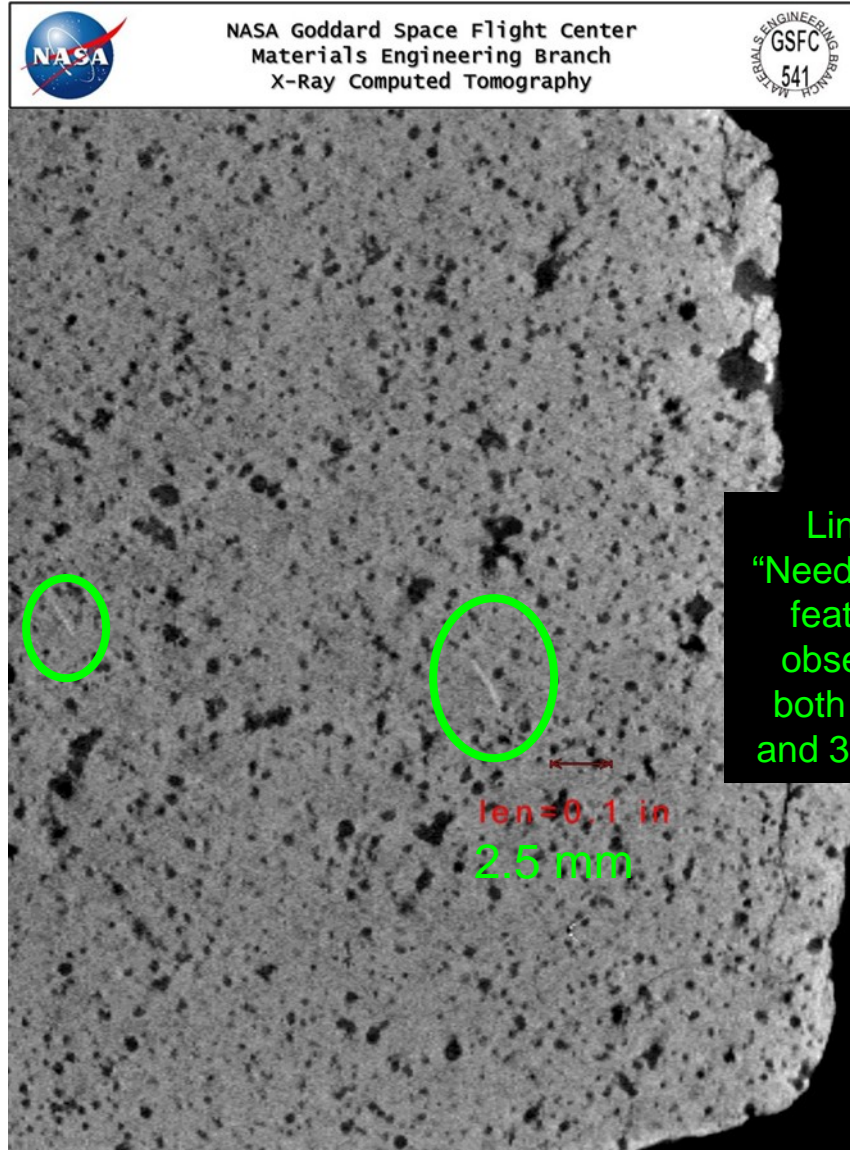
Lunar Sample 10057-30, CT Results

Video, go to: [160406 Garvin MOONROCK 10057-30 Slices.avi](#)

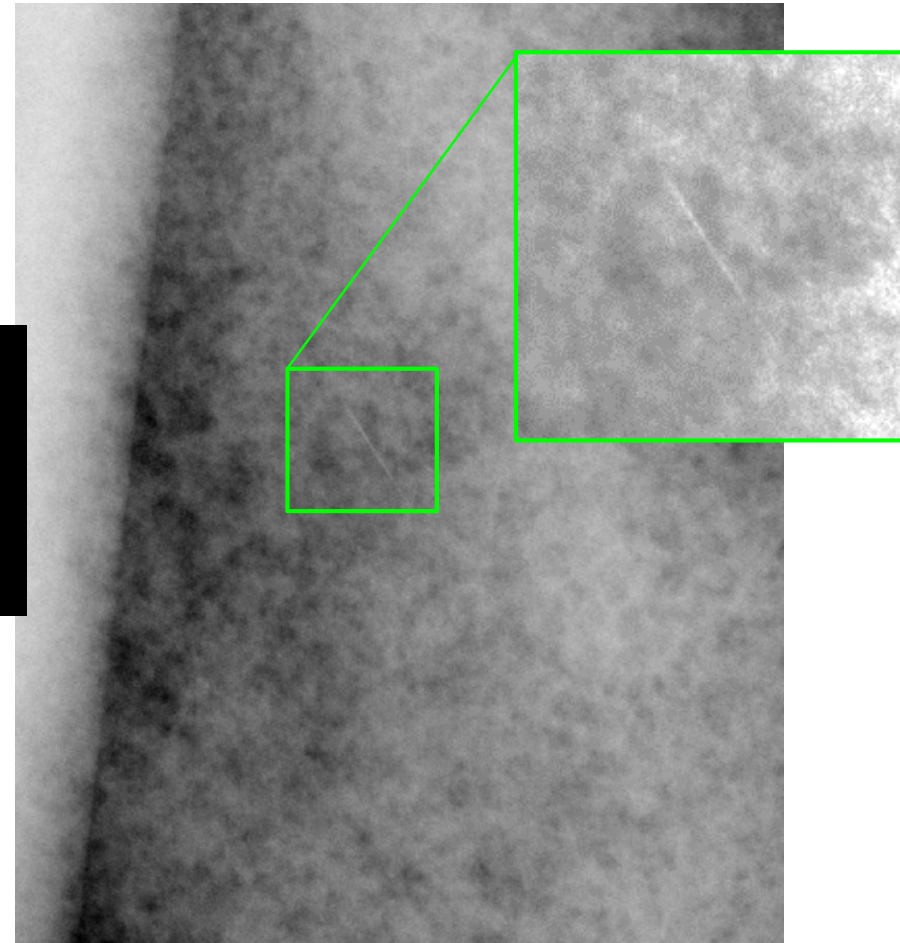


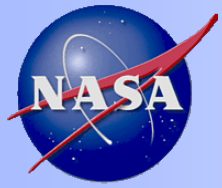


Lunar Sample 10057-30, CT Results

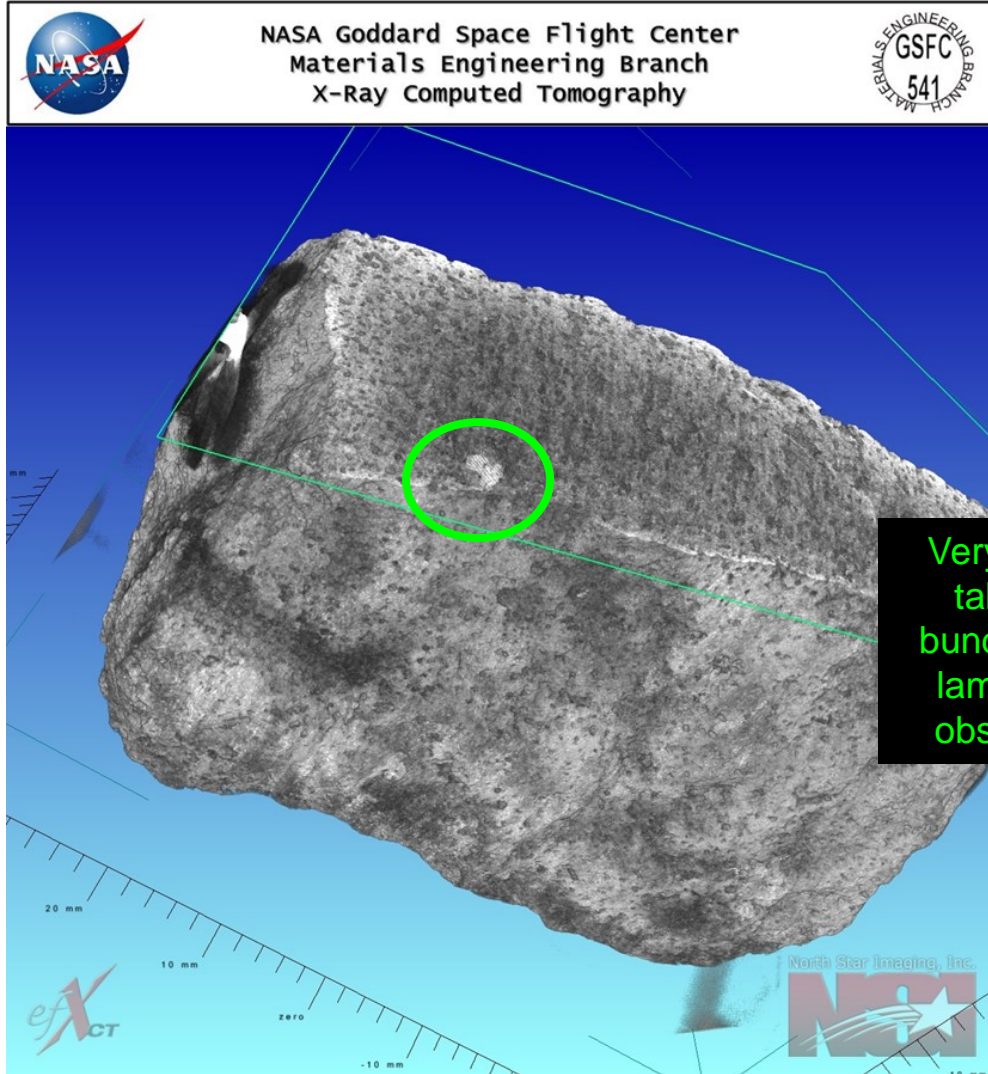


2D Radiograph Image (i.e. raw data)

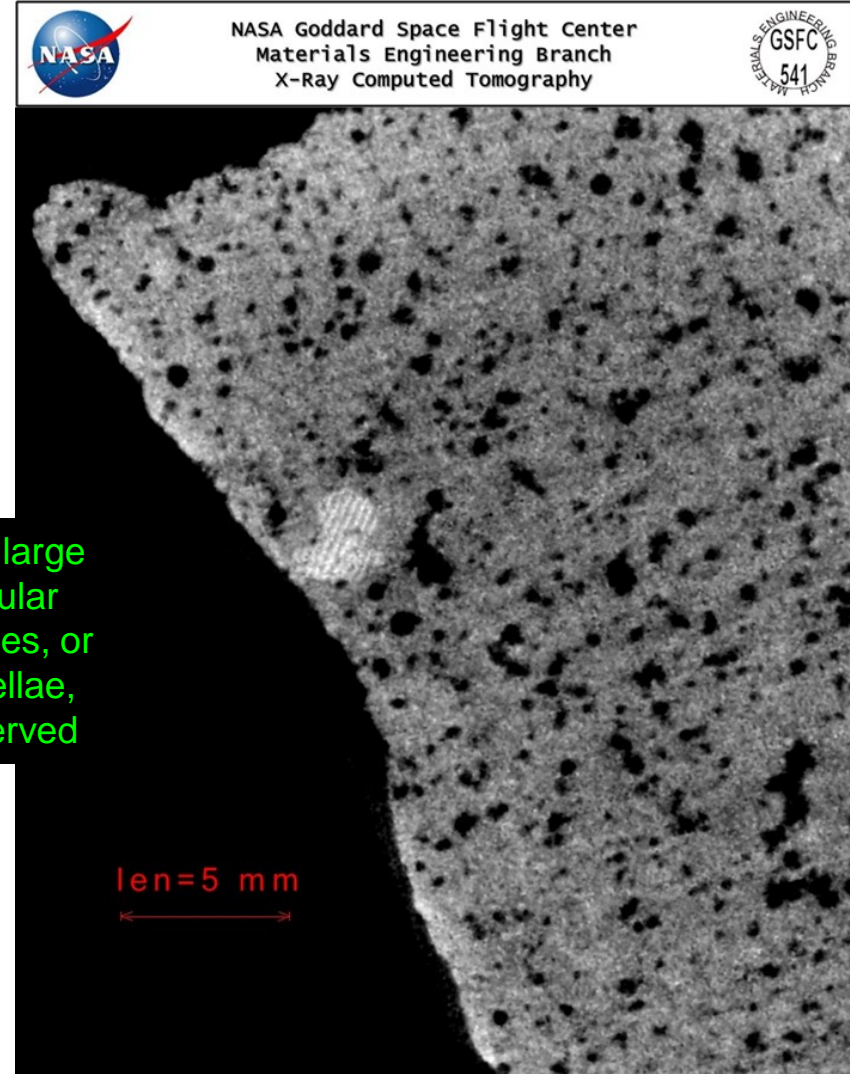


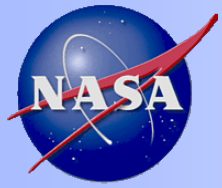


Lunar Sample 10057-30, CT Results



Very large
tabular
bundles, or
lamellae,
observed

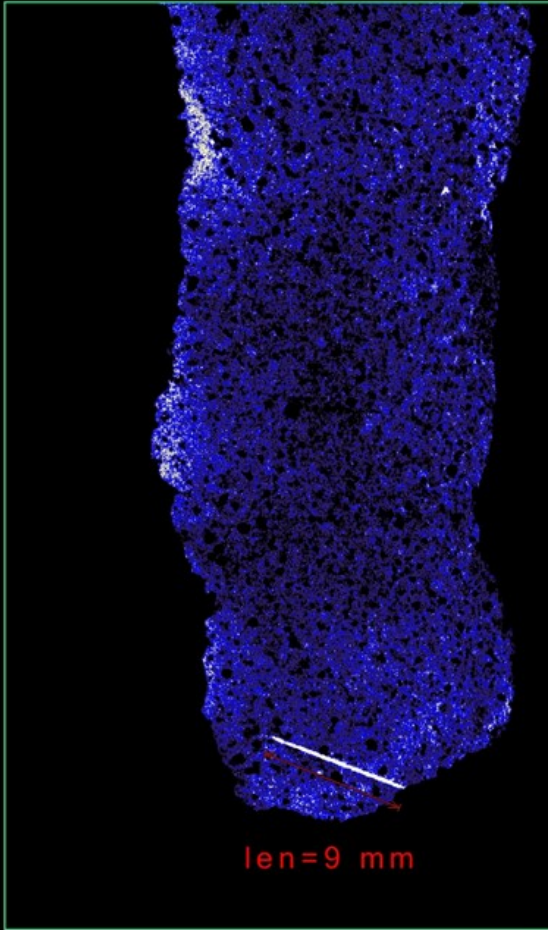




Lunar Sample 10057-30, CT Results



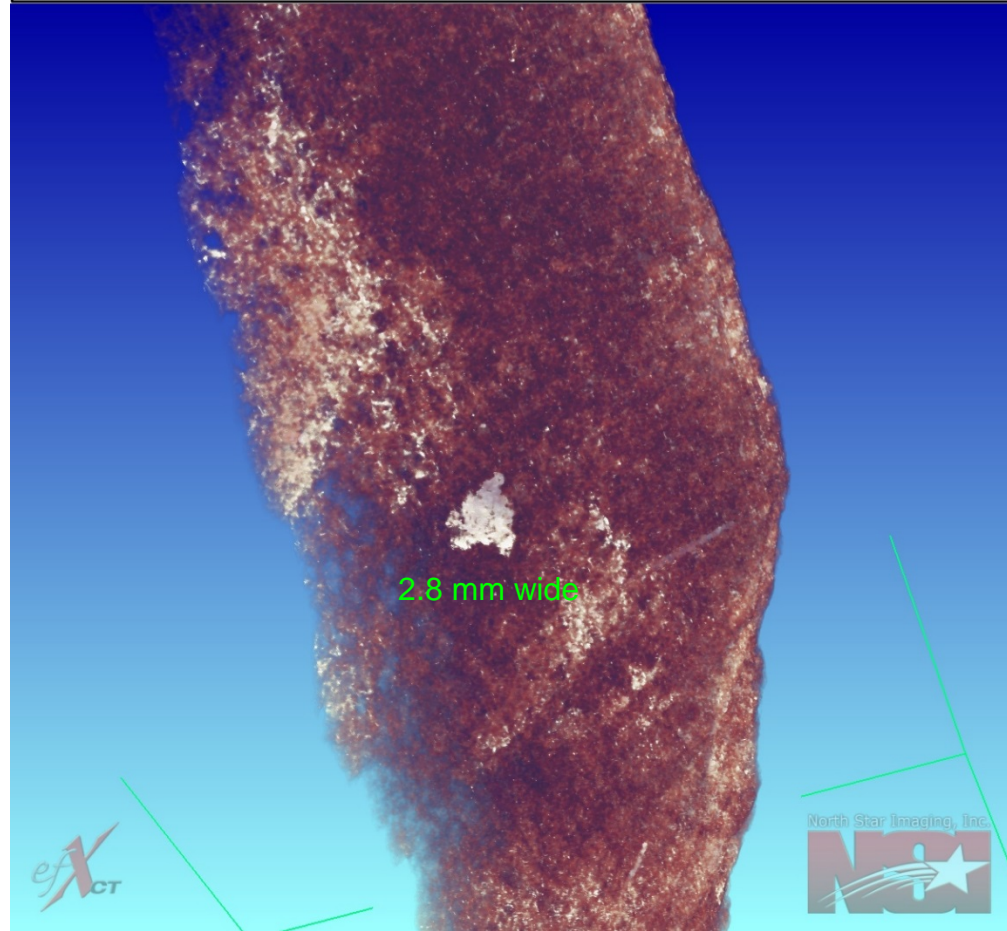
NASA Goddard Space Flight Center
Materials Engineering Branch
X-Ray Computed Tomography



len=9 mm



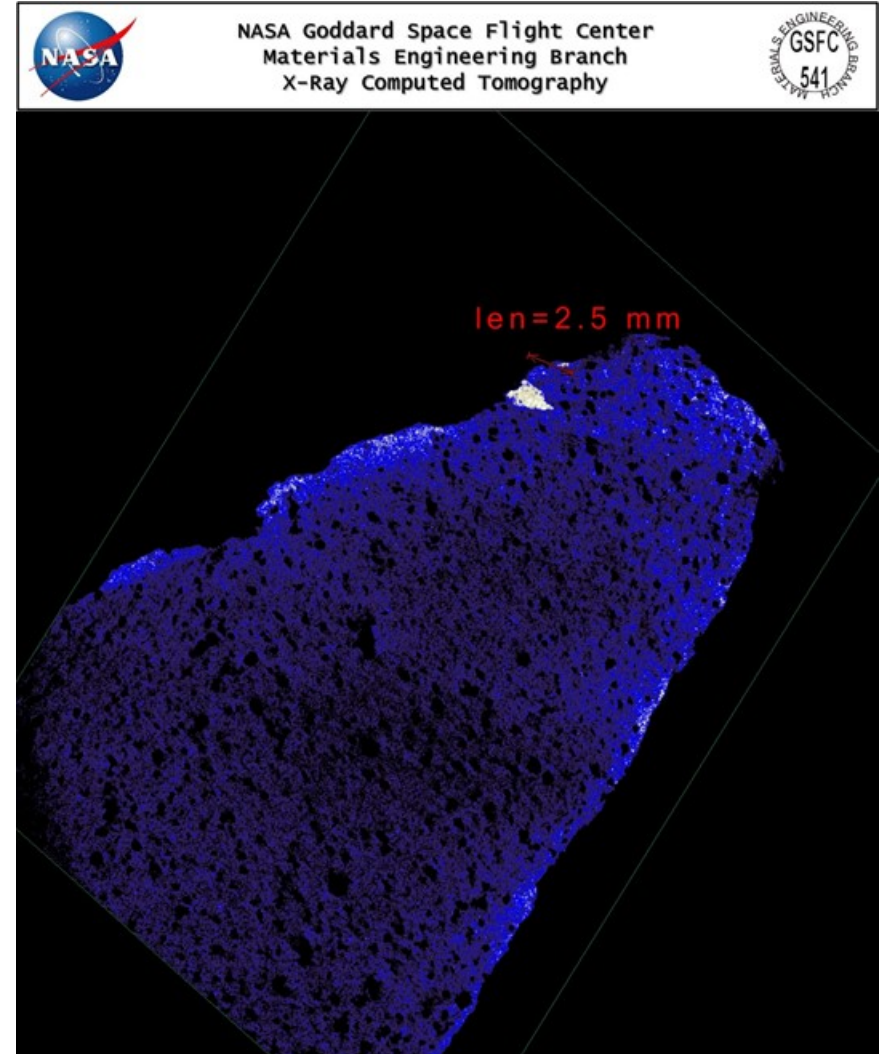
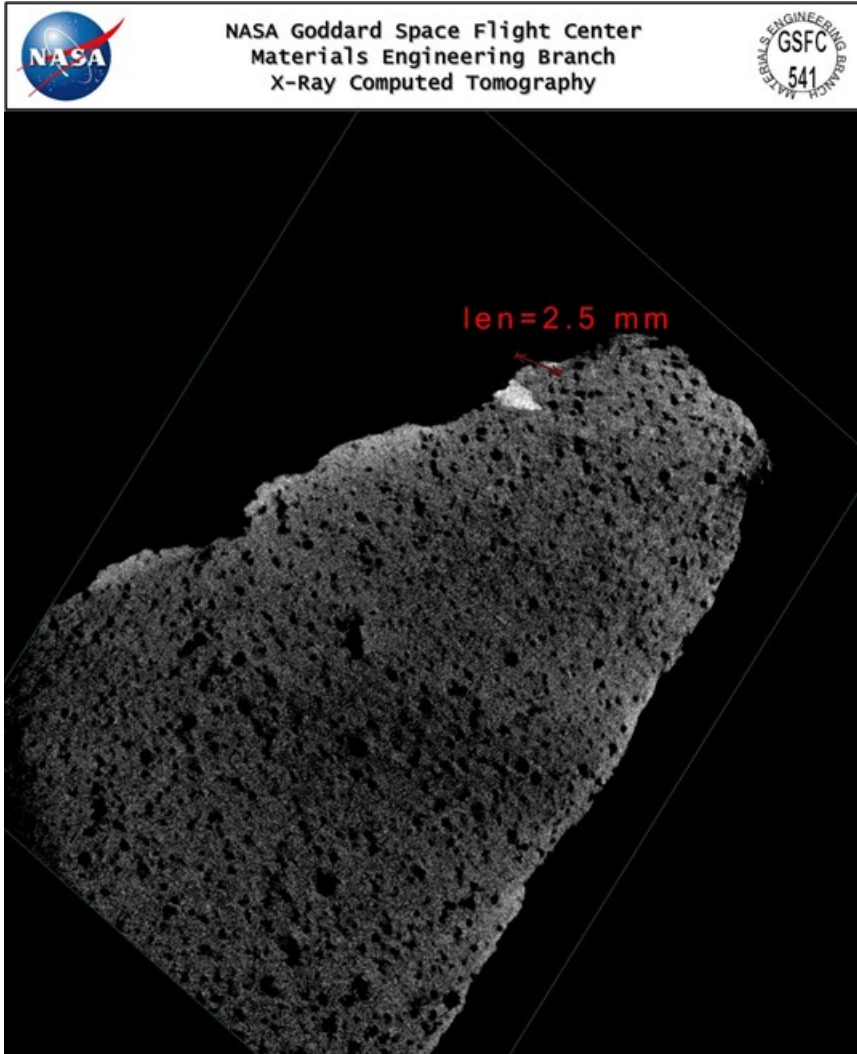
NASA Goddard Space Flight Center
Materials Engineering Branch
X-Ray Computed Tomography

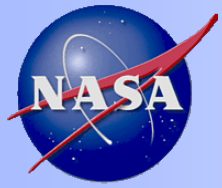


2.8 mm wide



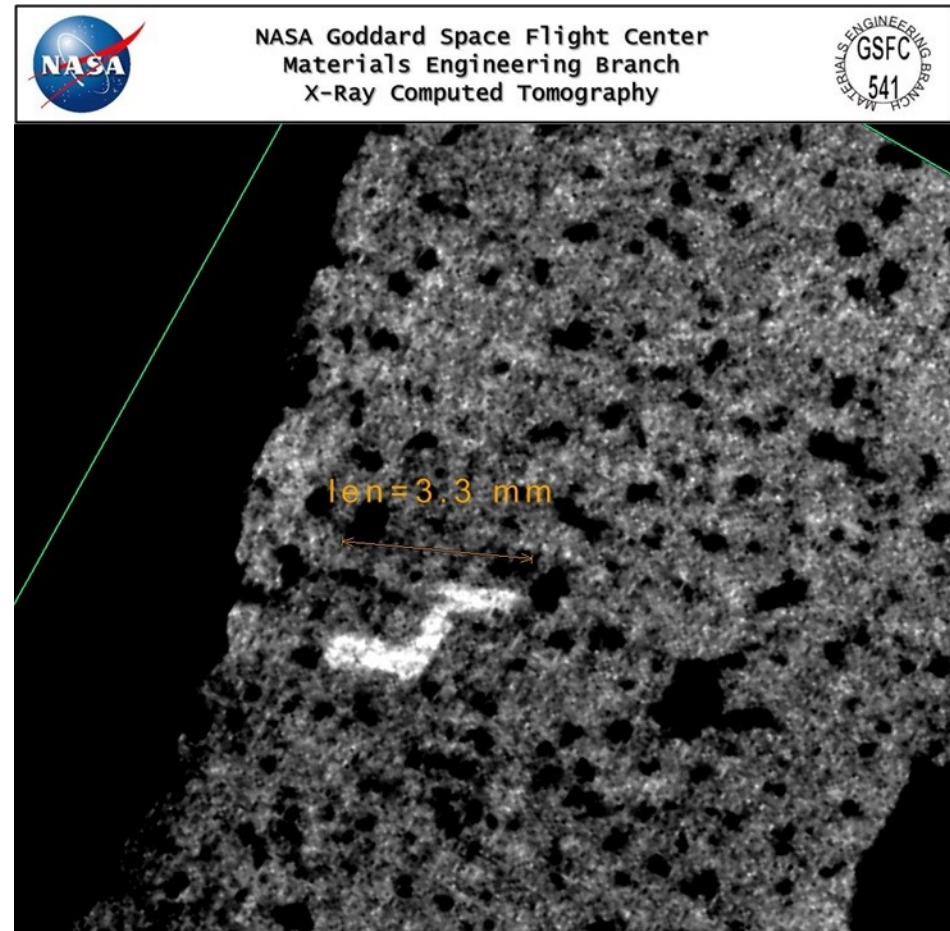
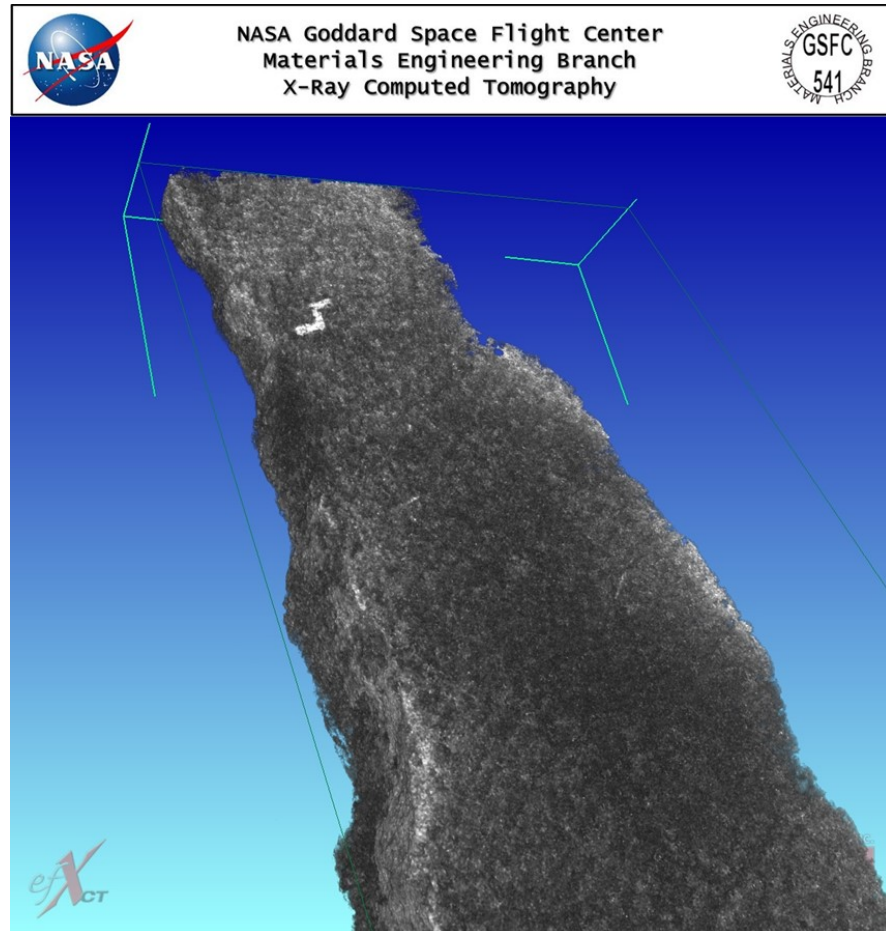
Lunar Sample 10057-30, CT Results

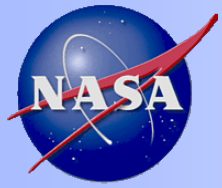




Lunar Sample 10057-30, CT Results

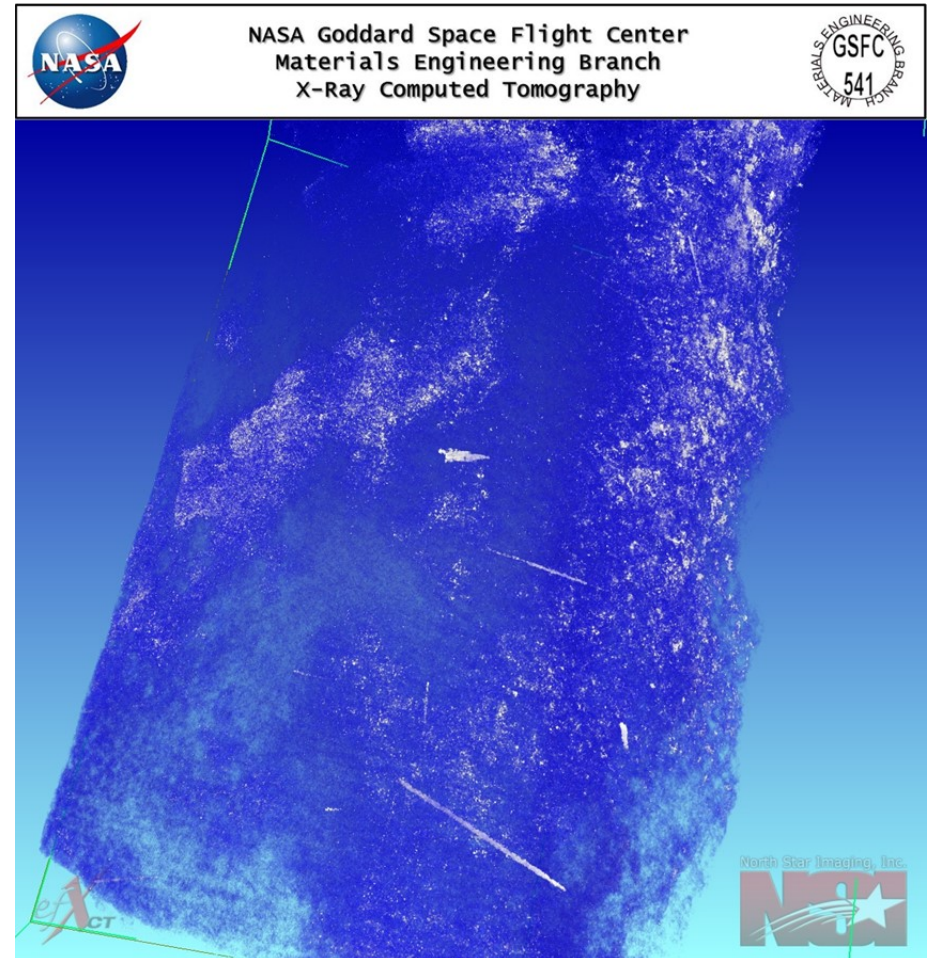
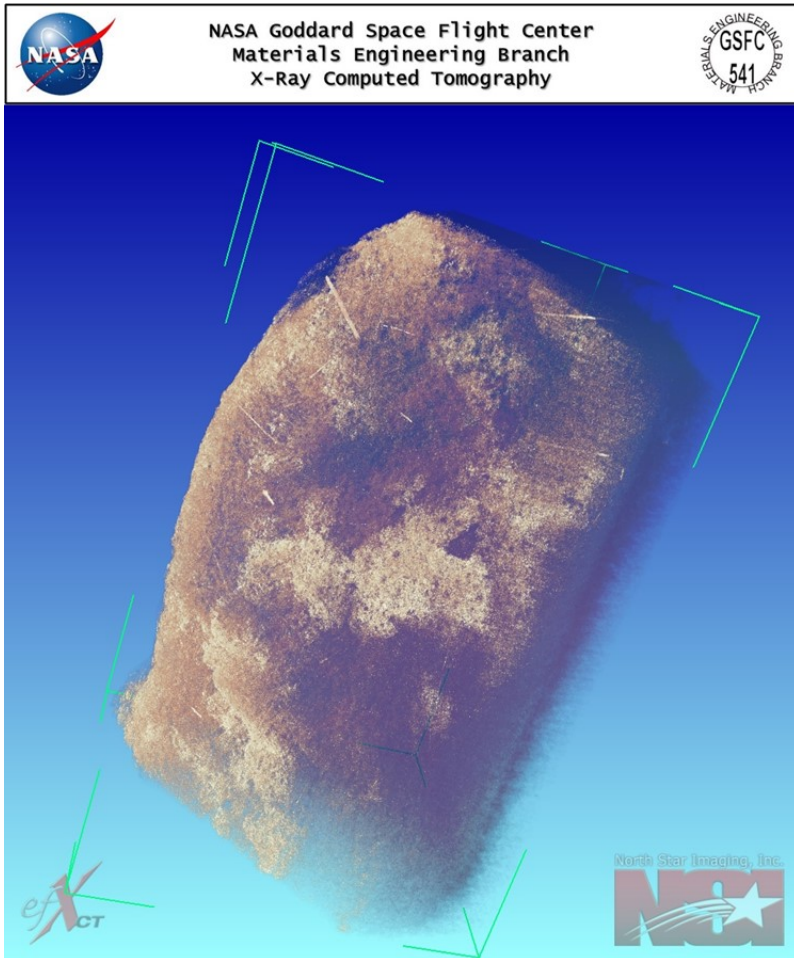
Video, go to: [160413_Garvin_MOONROCK_10057-30_ZoomInPlate_S-Ilmenite.avi](#)

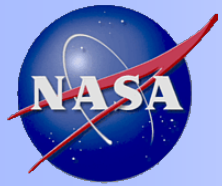




Lunar Sample 10057-30, CT Results

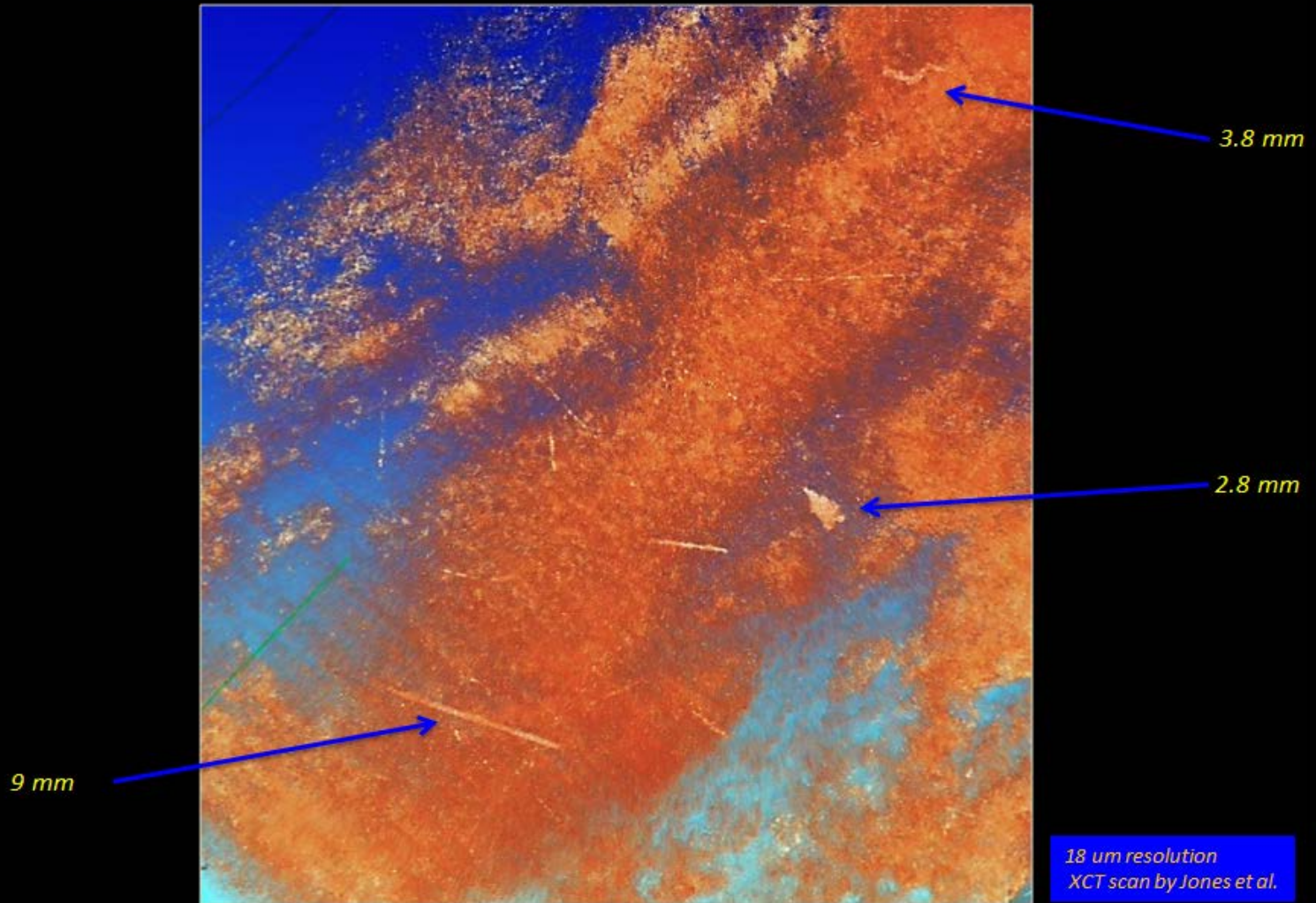
Video, go to: [160413_Garvin_MOONROCK_10057-30_ZoomInPlate_Ilmenite.avi](#)

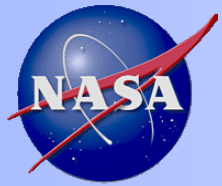




Lunar Sample 10057-30, CT Results

Ilmenite needles and tabular bundles in lunar basalt sample 10057,30





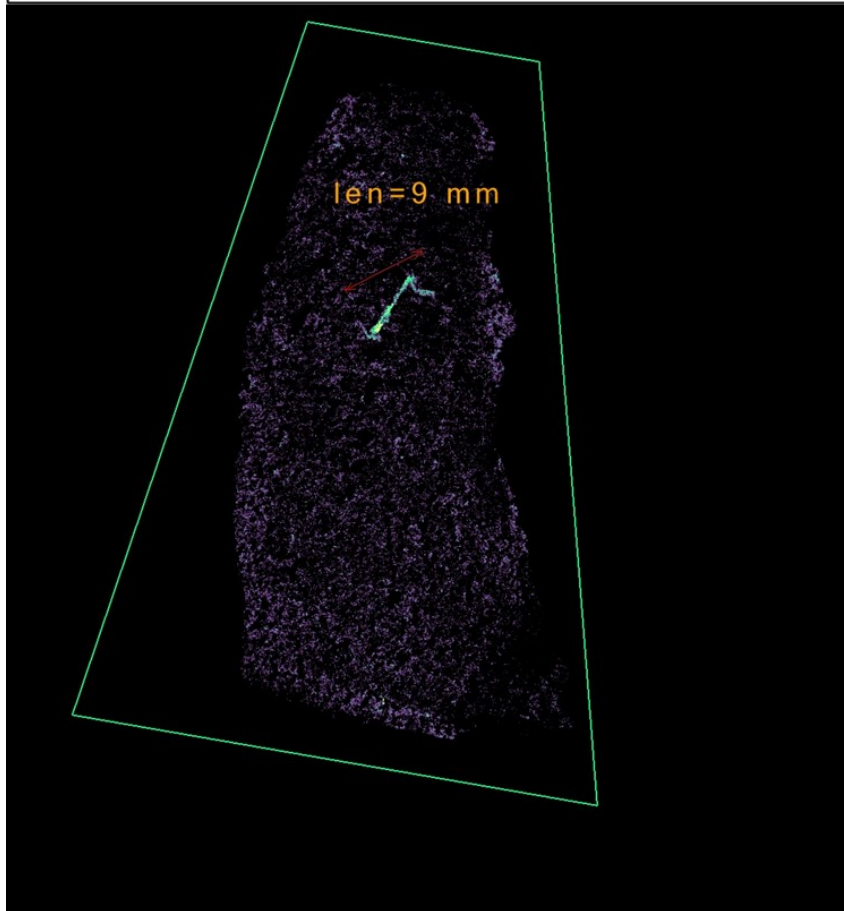
Lunar Sample 10057-30, CT Results

Longer, "archival" scan revealed more detail

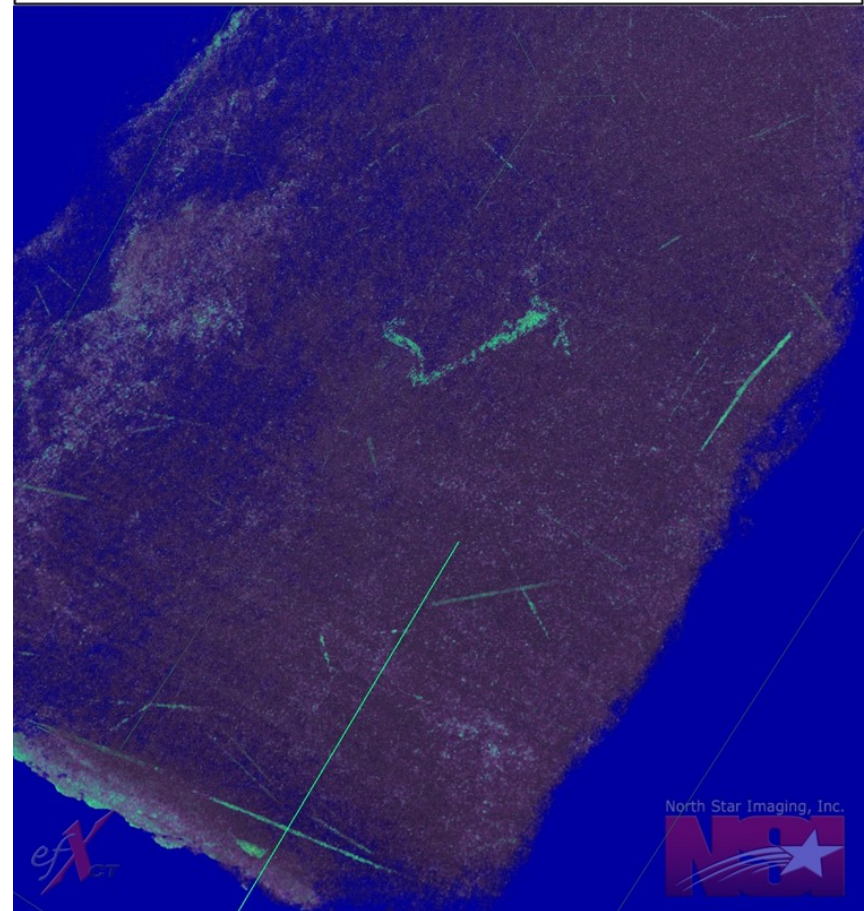
Video, go to: [160506 Garvin MOONROCK 10057-30 LongScan Ilmenite.avi](#)

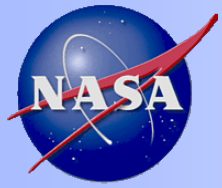


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Materials Engineering Branch
X-Ray Computed Tomography

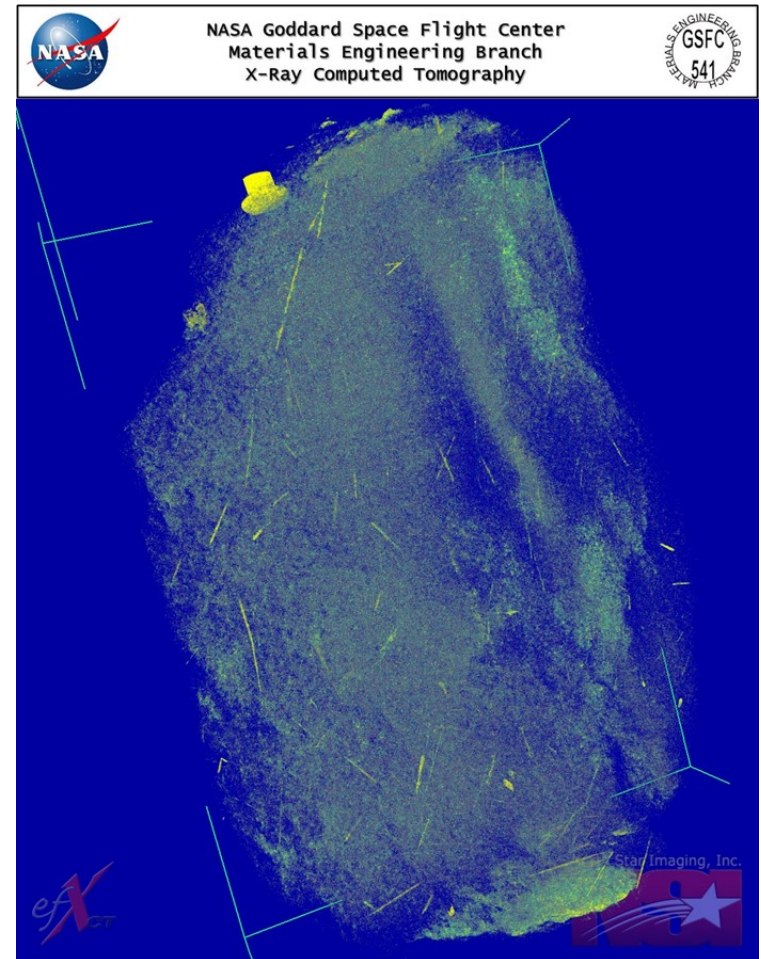
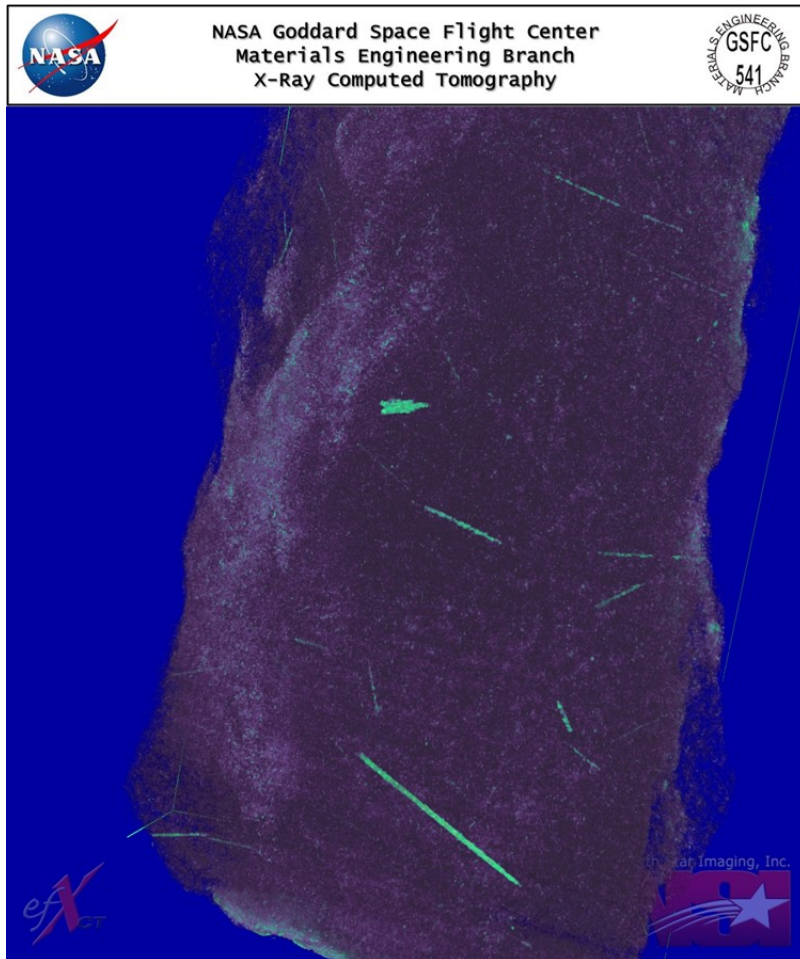




Lunar Sample 10057-30, CT Results

Longer, "archival" scan revealed more detail

Video, go to: [160506_Garvin_MOONROCK_10057-30_LongScan_Ortho.avi](#)





Lunar Sample 10057-30, Possible Mineral Content: Ilmenite

Ilmenite



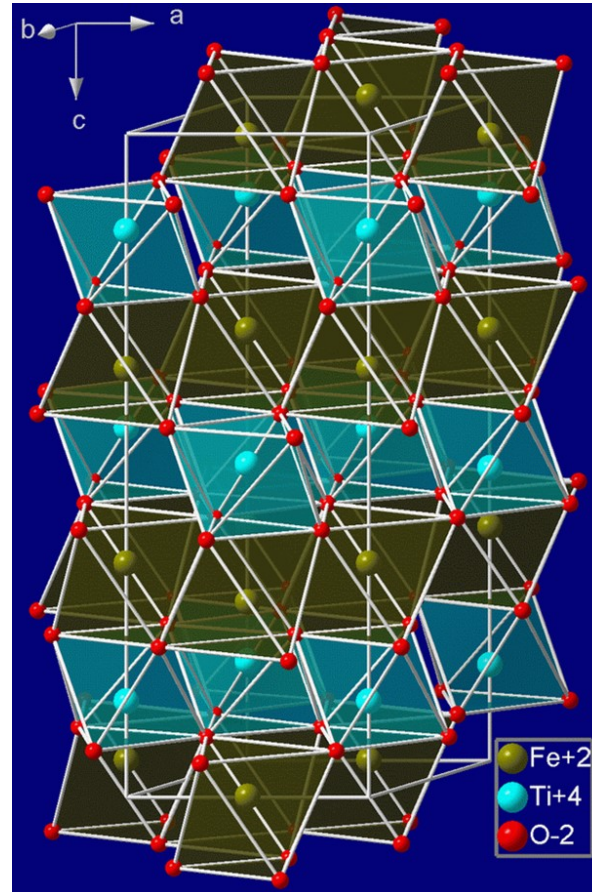
Ilmenite from Miass, Ilmen Mts, Chelyabinsk Oblast', Southern Urals, Urals Region, Russia. 4.5 x 4.3 x 1.5 cm

General

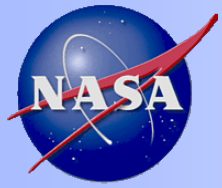
Category	Oxide mineral
Formula (repeating unit)	iron titanium oxide, FeTiO_3
Strunz classification	4.CB.05
Dana classification	04.03.05.01
Crystal system	Trigonal - rhombohedral
Unit cell	$a = 5.08854(7) \text{ \AA}$, $c = 14.0924(3) \text{ \AA}$; Z=6

Identification

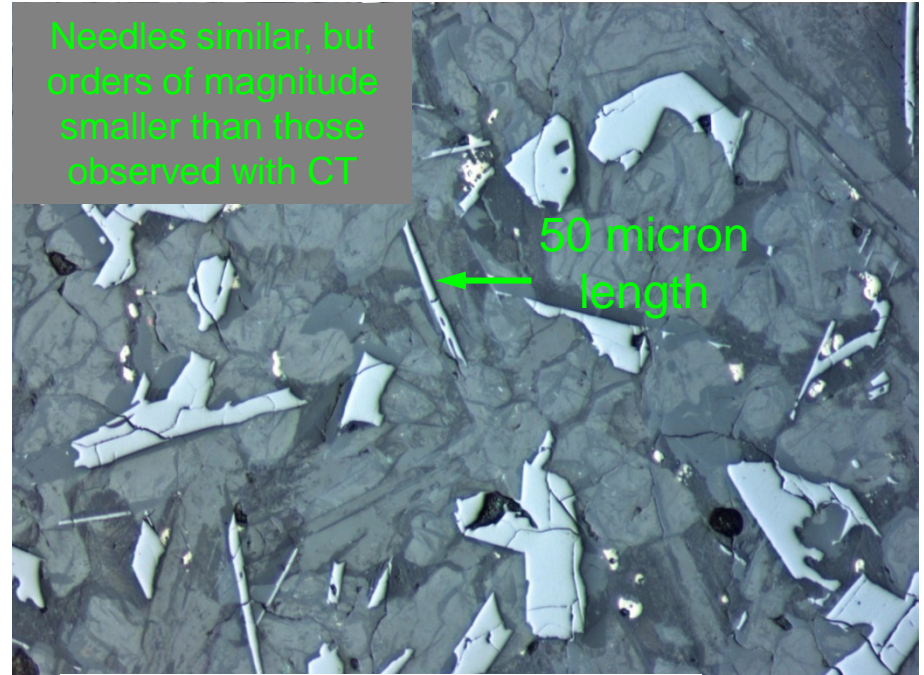
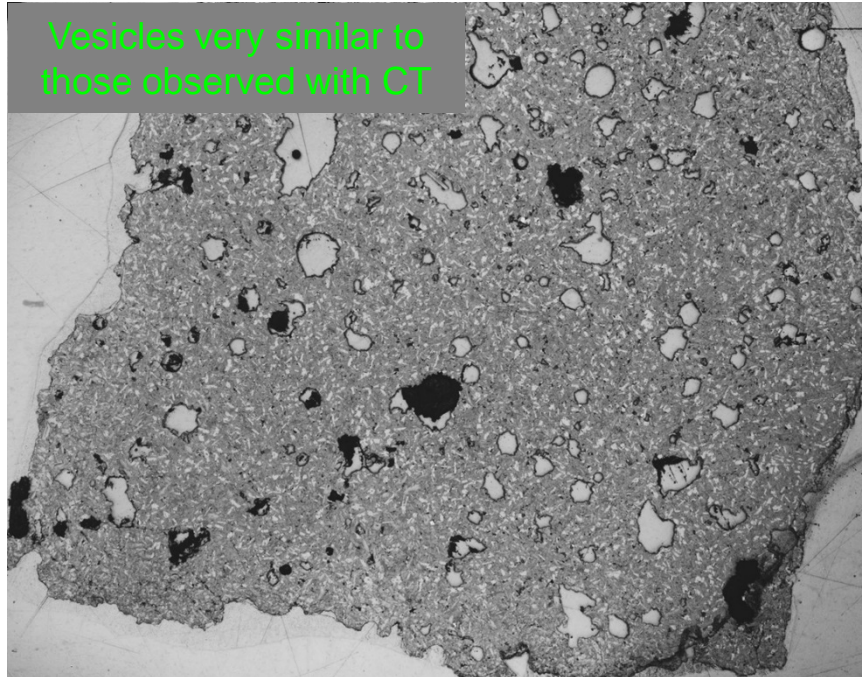
Color	Iron-black; gray with a brownish tint in reflected light
Crystal habit	Granular to massive and lamellar exsolutions in hematite or magnetite



<https://en.wikipedia.org/wiki/Ilmenite>

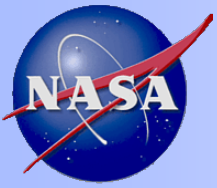


Lunar Sample 10057, Prior Petrology



Mission	Apollo 11
Sample	10057
Split	0
Photo Number	S69-59408
Film Type	Black & White
Description	Black and white Thin Section photograph of Apollo 11 Sample(s) 10057.
Source	NASA/JSC

Mission	Apollo 11
Sample	10057
Split	35
Photo Number	JSC04223
Lithology	basalt
Image Type	reflected light microscope image
Thin Section Type	standard thin section
Field of View	0.70 mm
Magnification	10x
Source	JSC



Conclusions

- We are reporting the first micro-CT scan results from the Apollo Lunar Sample #10057.30
- This non-destructive evaluation of one of the most primitive types of rocks in the solar system has discovered a 3D distribution of needle-like and tabular crystals; likely Fe-Ti oxides (possibly ilmenite).
 - These crystals are much larger than previously observed, which carries geological implications for how 3.63 billion year old erupted lunar lavas may have formed and even “flowed”.
 - An “archival scan” using higher frame averaging and more projections revealed an even higher number of very large grained ilmenite.
- Ongoing efforts to quantify size, distribution, and map orientations of these features, which will help us better understand the Moon’s evolution.
- Ongoing efforts to acquire new, smaller Lunar Samples in order to achieve higher resolution scans (down to ~5 μm). This could resolve the interconnectivity of the oxides in the matrix of silicate minerals.
- Possible next steps:
 - IRAD Feasibility study for on-board x-ray CT for future spacecraft (ISS or Mars rovers)
 - xCT study for other interesting samples: Martian meteorites, Shocked vs Unshocked Sandstone from Meteor Impact Site at Coconino, Deep Crustal (upper mantle) rock from Iceland volcano, Asteroid return samples
 - Working with Mars Science team to research 3D topo imagers to replace MaHLI for Mars2020 mission.



Thanks for your time!

