Statistical Investigation of Cryogenic Target Defects

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Summary

A statistical analysis of defects on LLE cryogenic targets has been carried out

- Optically obtained defect data from 2010 to 2014 has been analyzed
- Two types of defects are observed ("darks" and "dendrites")
- The analysis rules out some proposed explanations for the origins of the defects

The cause of the defects is still not understood.

TC12103

The statistical analysis has led to several results

- The likelihood of finding a dendrite is uniform with respect to latitude
- The likelihood of finding a dark is not uniform with respect to latitude
- There is no evidence that defect frequency depends on a target's orientation in the target fill rack
- The defect count is not dependent on the number of days elapsed from filling to imaging
- The average number of defects on targets has not changed over the past several years
- The largest dendrite on targets with dendrites has increased in size over time

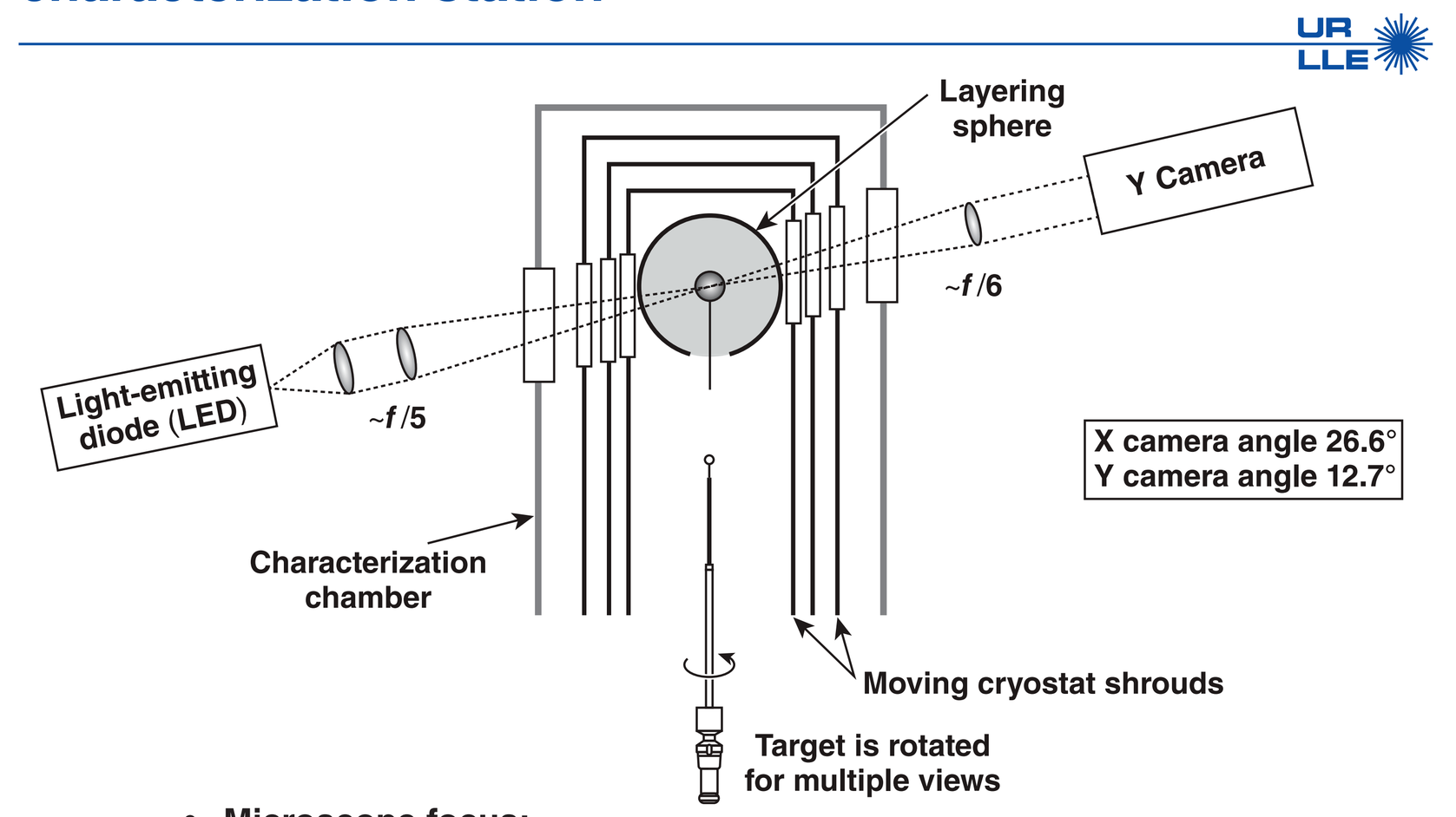
TC12104

Abstract

After hollow cryogenic targets are formed with a frozen layer of DT, images of them are routinely taken and analyzed for quality control. Often, imperfections with an appearance of either cracks ("dendrites") or dark spots ("darks") appear on the surface of the target. Many aspects of these defects, including origin, composition, and impact on target performance, are not well understood. Images and information pertaining to a large sample of targets were drawn from a database and different properties were analyzed using various statistical techniques. The tests performed resulted in information about the nature of the defects (e.g., location and size) that rule out some theories and support others. The source of the defects is still not understood.

TC12105

Defects in cryogenic targets are viewed in the target characterization station

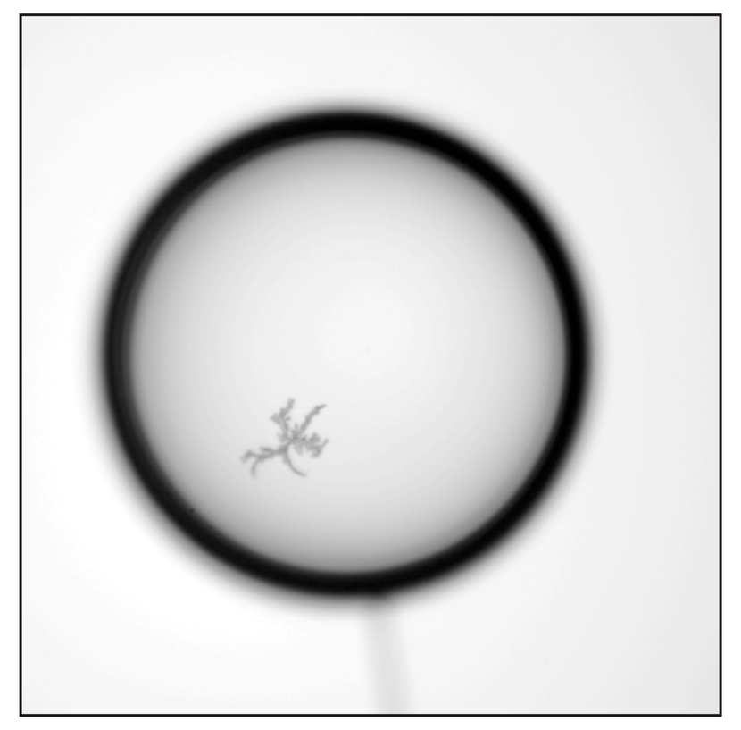


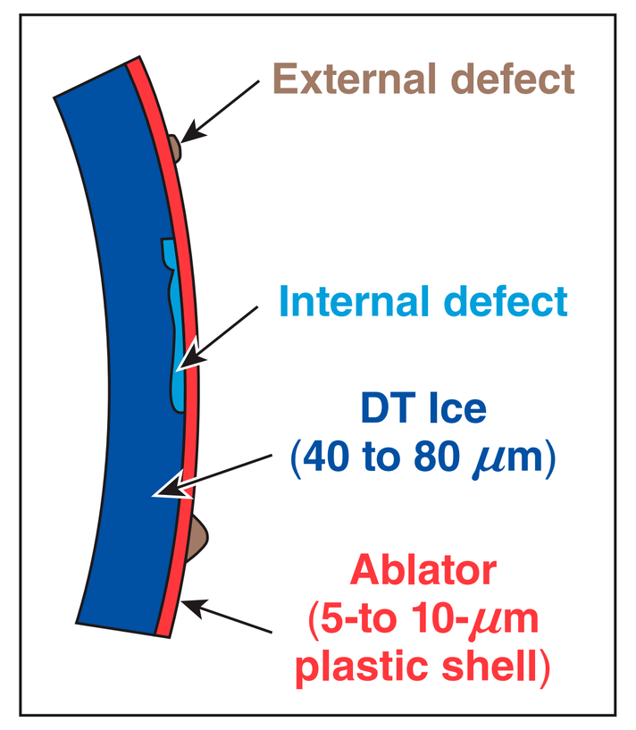
- Microscope focus:
  - At center of target for bright-ring ice layer characterization
  - At front surface of target for defect imaging

TC12106

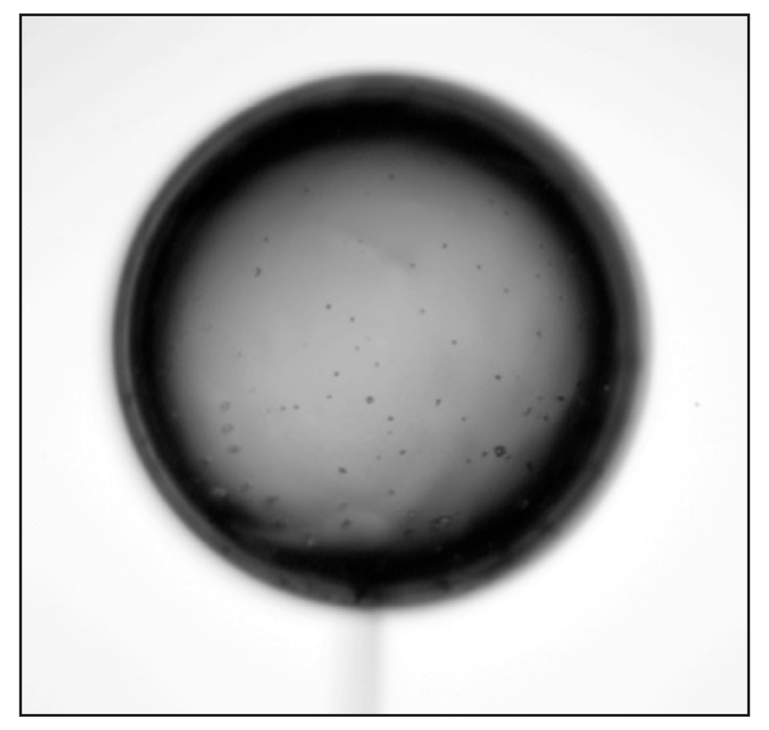
LLE cryogenic DT targets frequently exhibit non-ice defects that exist on the inside and outside of the shell

"Dendrite"





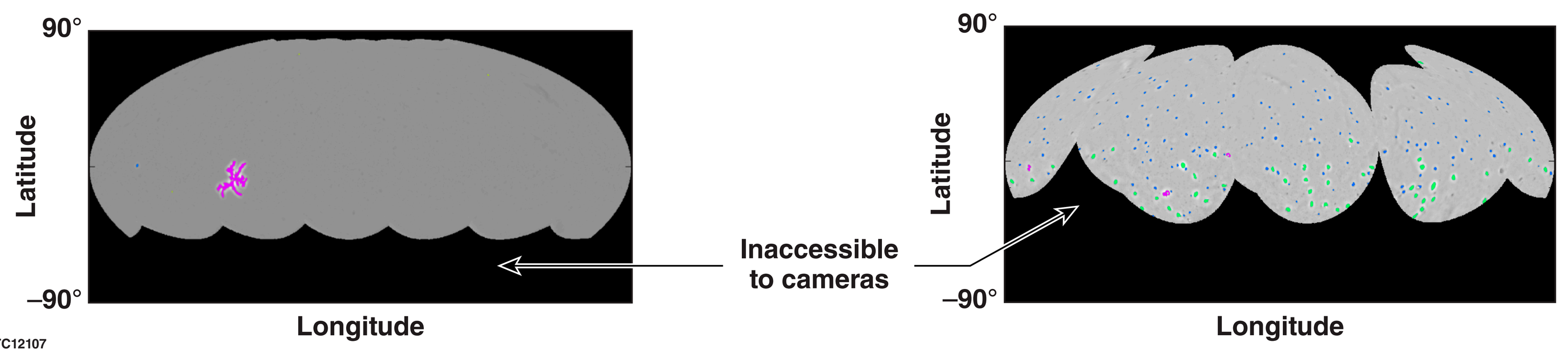
"Dark"



"Dendrite"
- Characteristics
  - large perimeter per surface area
  - appears crystalline
  - occurs inside of shell
- Suspected nature
  - frozen condensate or stress cracks in plastic shell

"Dark"
- Characteristics
  - small perimeter per surface area
  - observed inside and outside of shell
- Suspected nature
  - small particulate defects on outside of target

Mollweide projections



TC12107

Data from the cryogenic defect analysis (CDA) program was used for the statistical analysis

- Examples of defect characteristics
  - category
  - size
  - count
  - perimeter

	Number					Real Area (sq. um)				
Target ID	dendrites	iceFeat	lowCont	medBlack	smBlack	dendrites	iceFeat	lowCont	medBlack	smBlack
CRYO-2087-	6		10	3	2	4743.3		476.3	1353.5	217.4
CRYO-2085-	2		5		5	6945.9		299.9		453.7
CRYO-2084-	4		5		3	6453.9		147.9		154.1
CRYO-2088-	2	13		3	13	1739.2	12713.0		822.3	2409.0
CRYO-2087-	9	23		8	6	3966.2	19082.9		1903.2	687.0
CRYO-2085-	2	39		34	10	369.4	12922.7		7279.1	629.2
CRYO-2086-	6	15		3	12	6299.4	31602.9		1294.2	873.7
CRYO-2080-	1		5	1		3243.5		840.1	222.1	
CRYO-2082-	4		14	1	19	3907.3		524.2	517.1	1614.8
CRYO-2078-	1		3		1	6005.5		82.7		102.7
CRYO-2081-	2		13		2	3142.8		476.5		205.6
CRYO-2081-	1	3	2		5	2406.1	1027.5	78.2		294.2
CRYO-2081-	5		4	1	8	4207.9		136.2	290.7	404.2
CRYO-2081-	5		6		2	3823.6		661.1		219.9
CRYO-2071-	7	5	39	11	36	3612.4	1861.1	2901.4	1916.9	3314.6
CRYO-2072-	7	25	6	2	21	4528.2	6697.8	1075.5	636.0	1429.7
CRYO-2072-	7	2	17	7	21	2861.0	681.0	1145.5	2009.7	1843.2
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CRYO-2083-	1		12		3	2900.1		497.6		282.3
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CRYO-2082-	2		20	1	5	2335.9		857.3	178.4	530.8
CRYO-2074-	1	1	21		2	642.0	13468.0	879.9		217.8

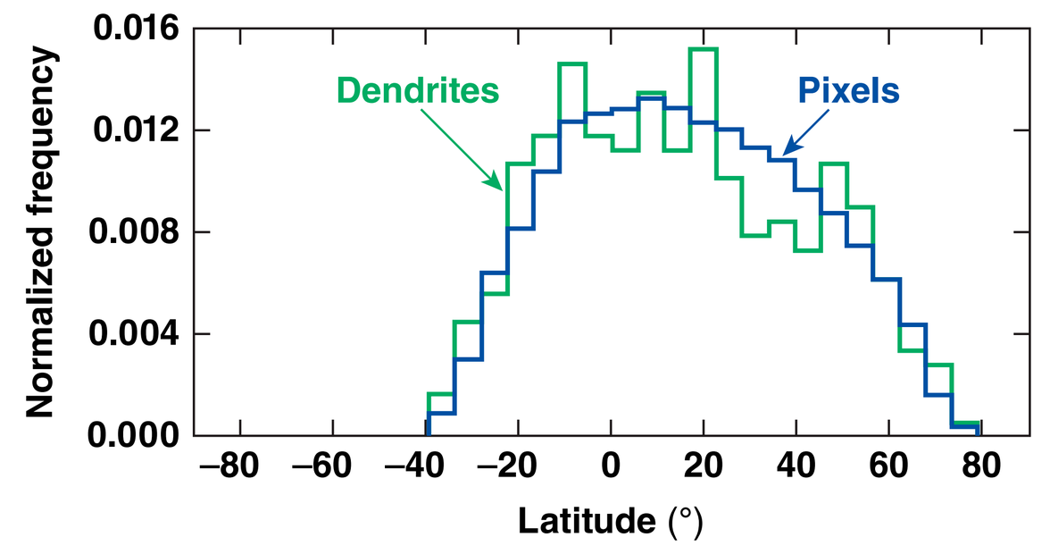
- The CDA program (written in Matlab) assembles a 2-D Mollweide projection of the field of view from the X and Y cameras by stitching together images
- The program then generates defect morphology characteristics that are used to assign the defect to a category
- No defect depth information is available

TC12108

Hypothesis: More defects occur on the upper half of the target because of falling debris from equipment

Result: No evidence of this for dendrites or darks

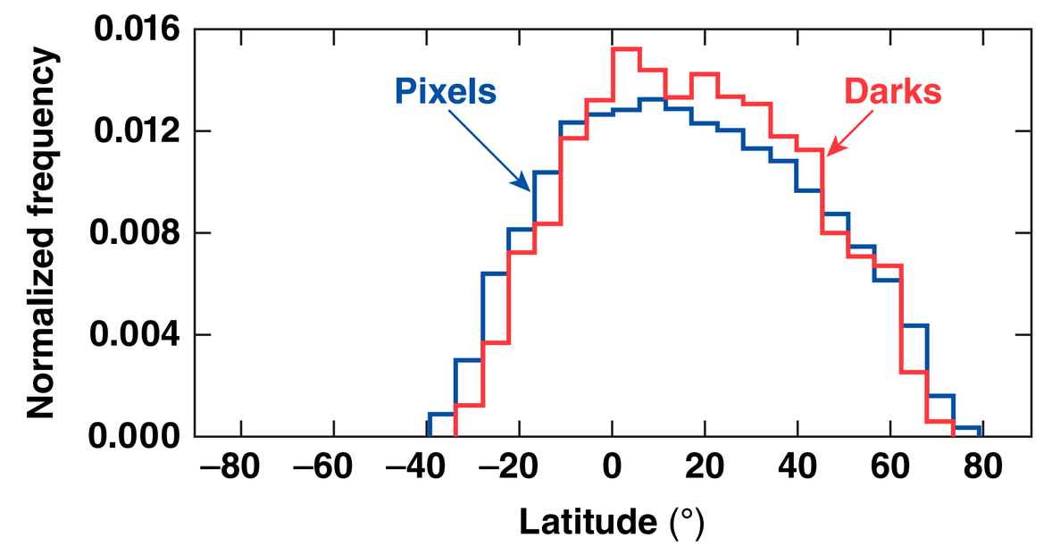
The likelihood of finding a dendrite is uniform with respect to latitude



- Kolmogorov–Smirnov test results
  - H_0: the latitudes of pixels and dendrites are drawn from the same distribution
  - H_a: the latitudes of pixels and dendrites are not drawn from the same distribution
  - p value = 0.32

TC12110

The distribution of darks with respect to latitude is different from the distribution of pixels



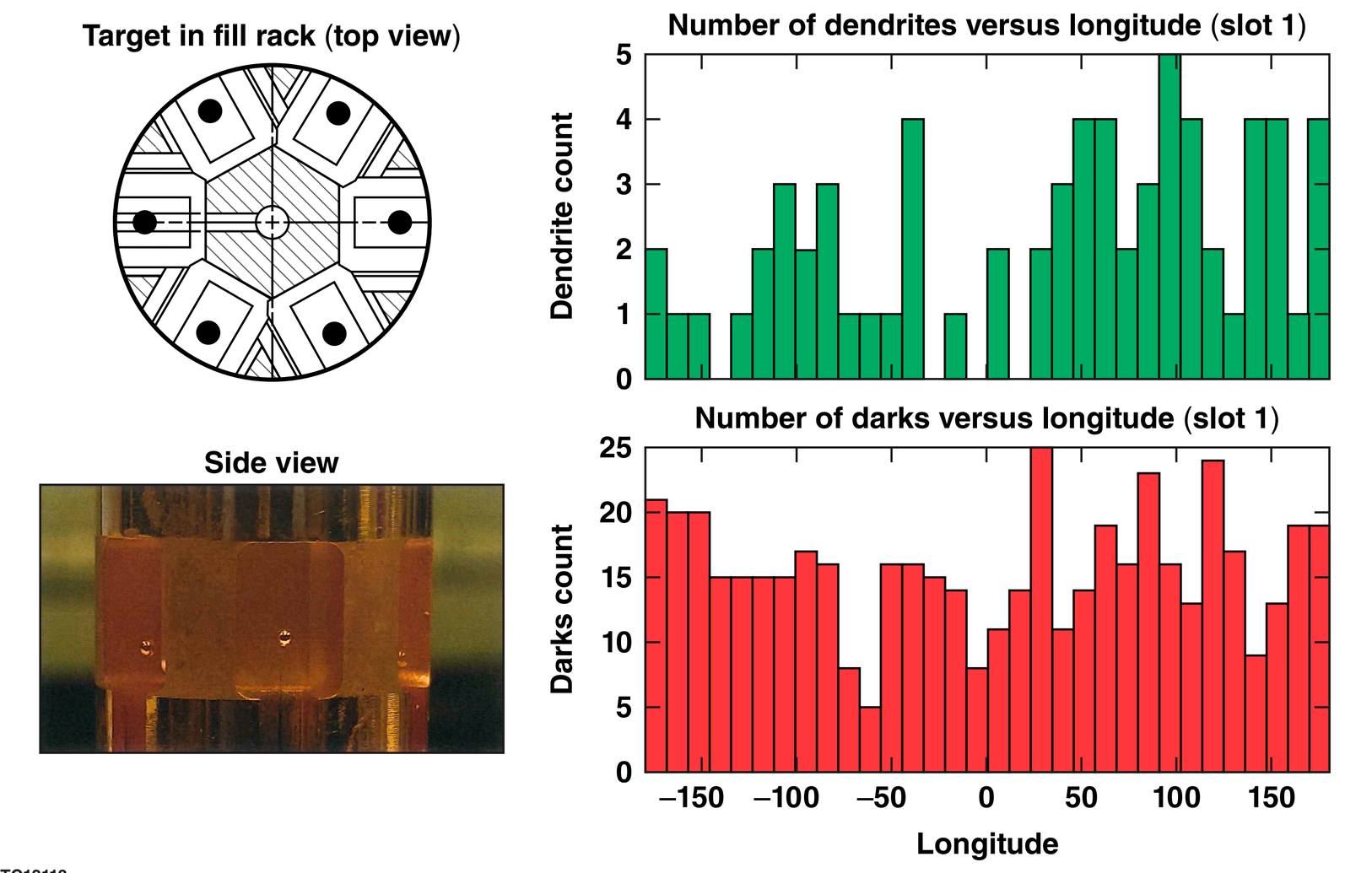
- The frequency of darks between latitudes 0° and 40° is higher with statistical significance but is not explained by the hypothesis
  - p value = 1.65×10^{-9}

TC12111

Hypothesis: More defects occur at longitudes where the target is not shadowed by the pole in the target fill rack

Result: No evidence of this for dendrites or darks

The longitudinal distribution of defects shows no evidence for the hypothesis

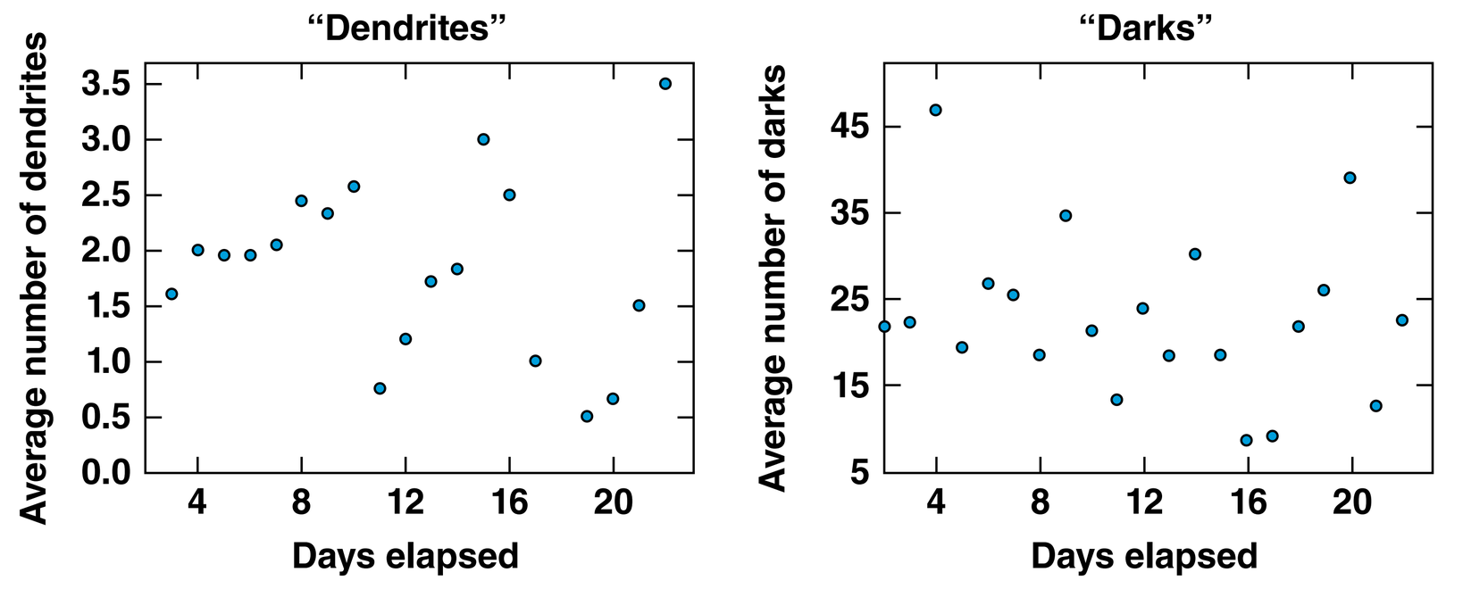


TC12113

Hypothesis: Defect formation depends on the time elapsed between target filling and shooting

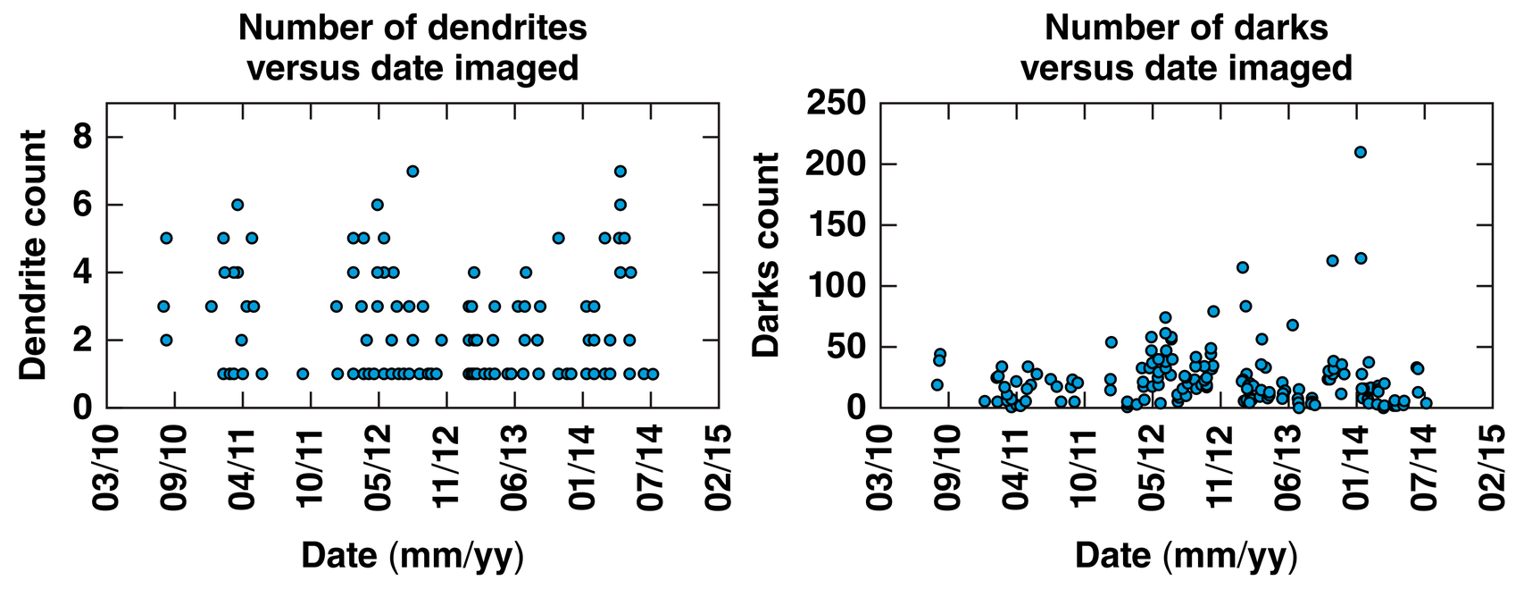
Result: No such dependence is seen

The average number of defects shows no correlation with the time spent in storage after filling



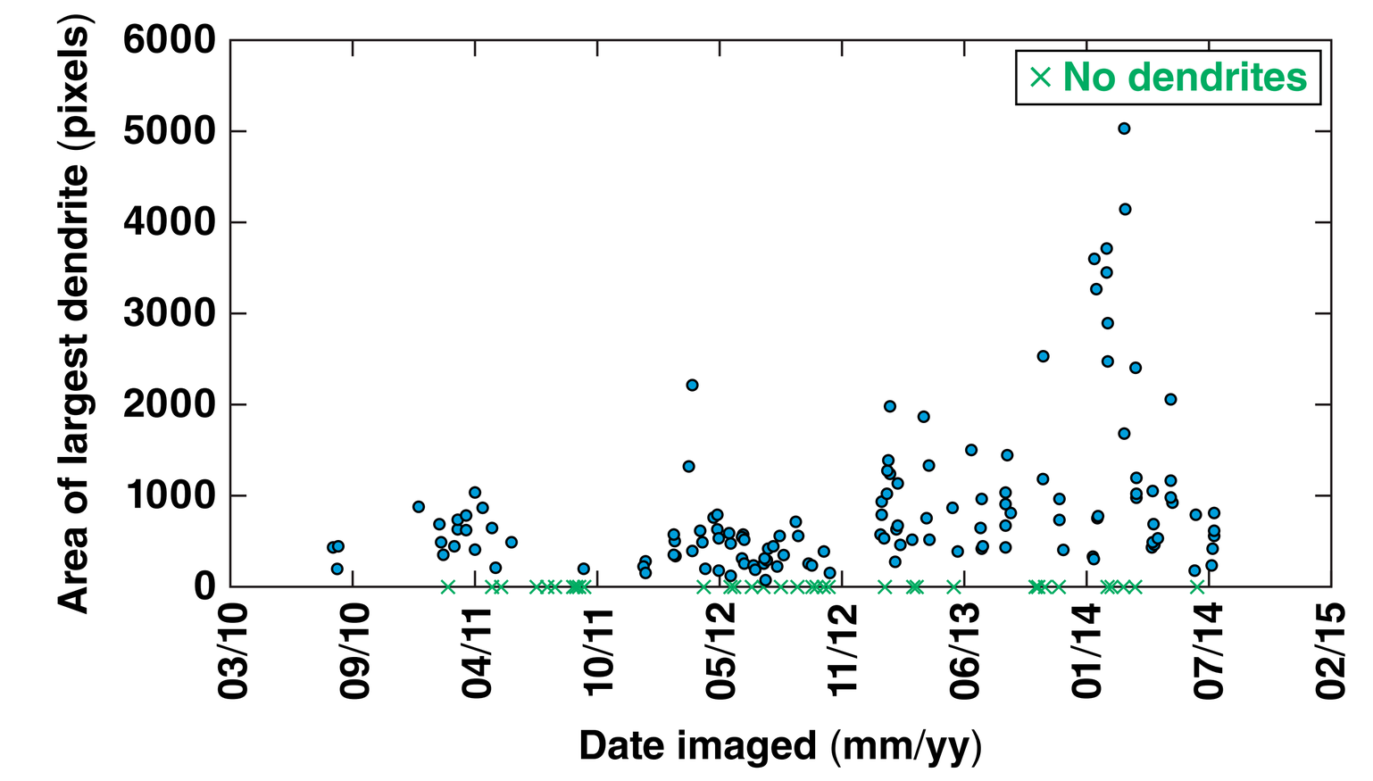
TC12115

There is no apparent change in the average number of defects per target over time



TC12116

The largest dendrite on a single target has increased in size over time



TC12117

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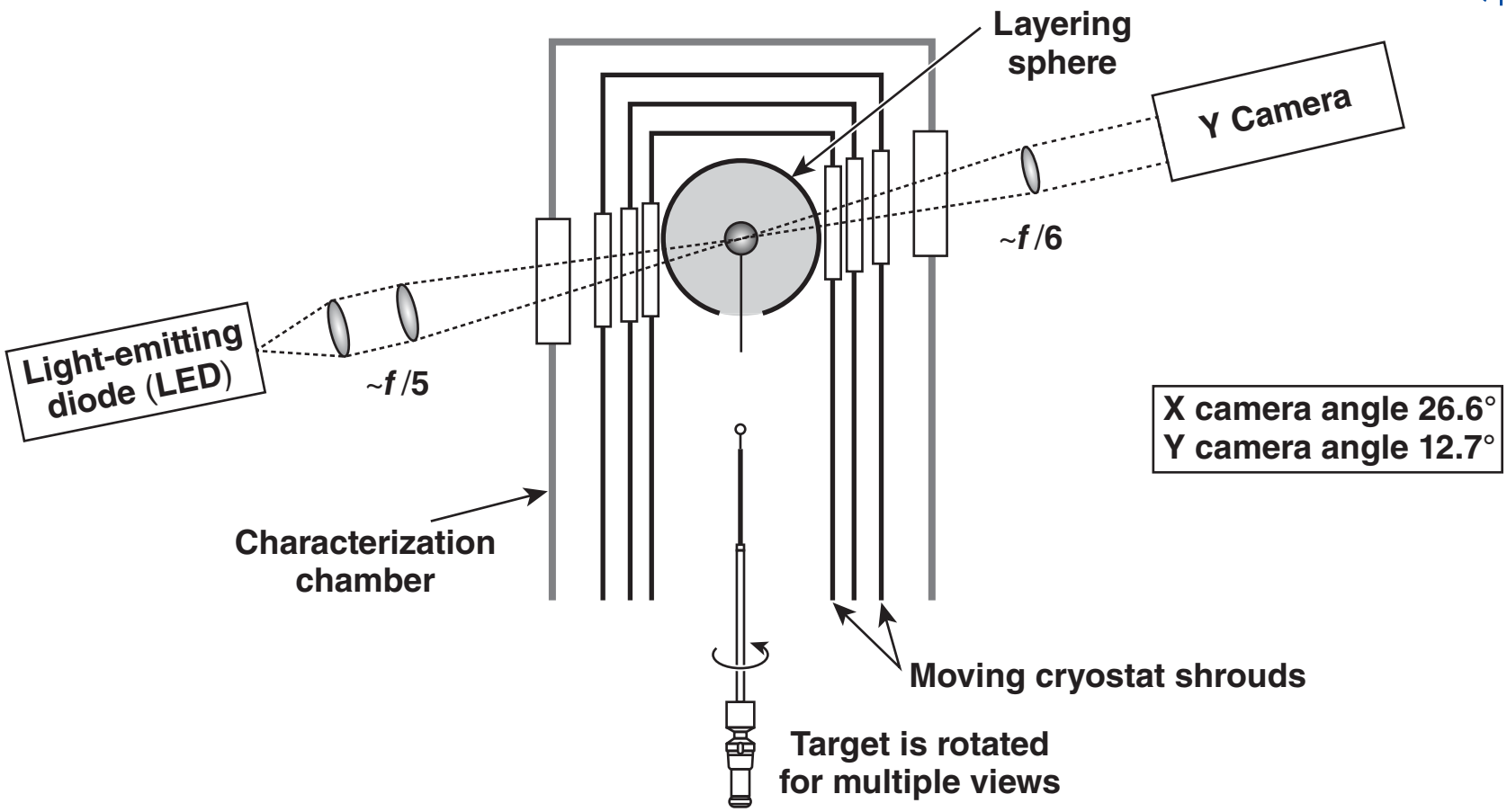

- Microscope focus:
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TC12106

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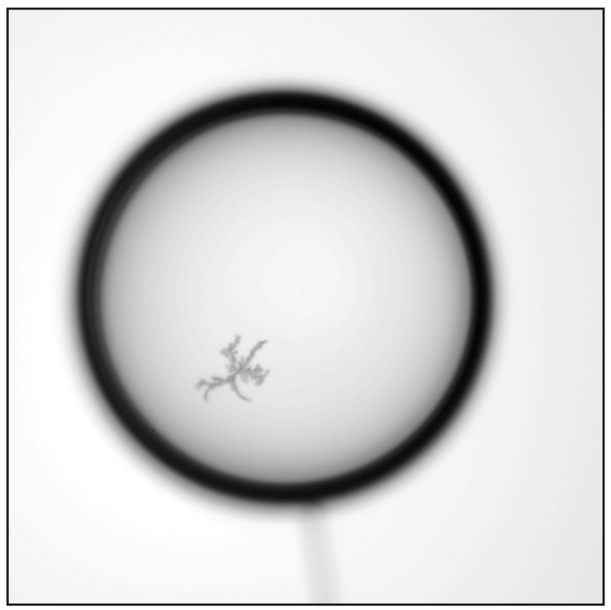

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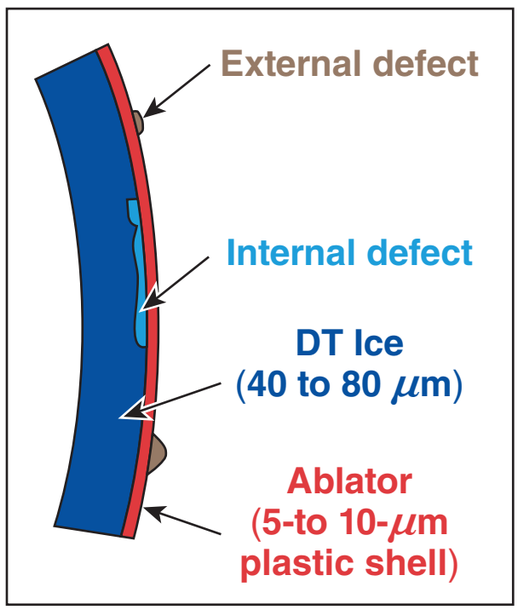

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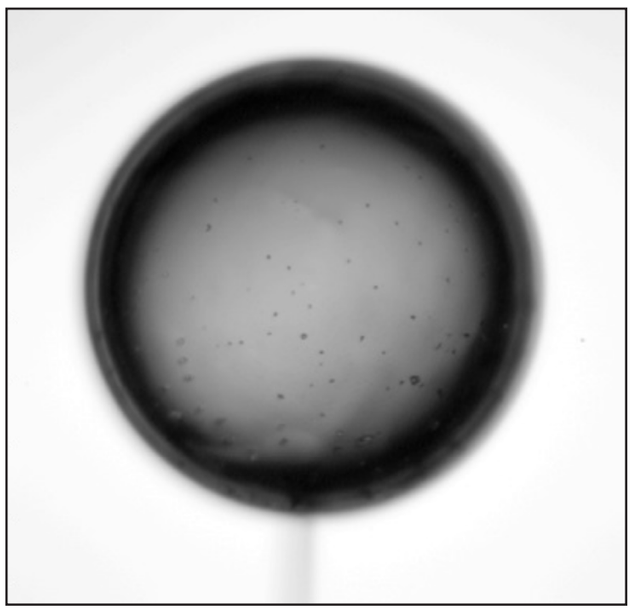

- Characteristics
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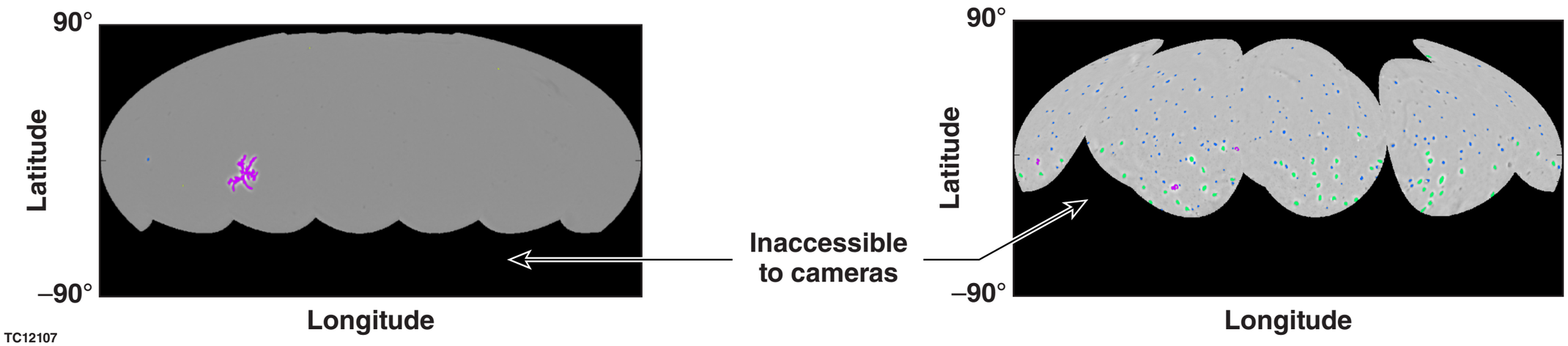
  - observed inside and outside of shell
- Suspected nature
  - small particulate defects on outside of target

Mollweide projections



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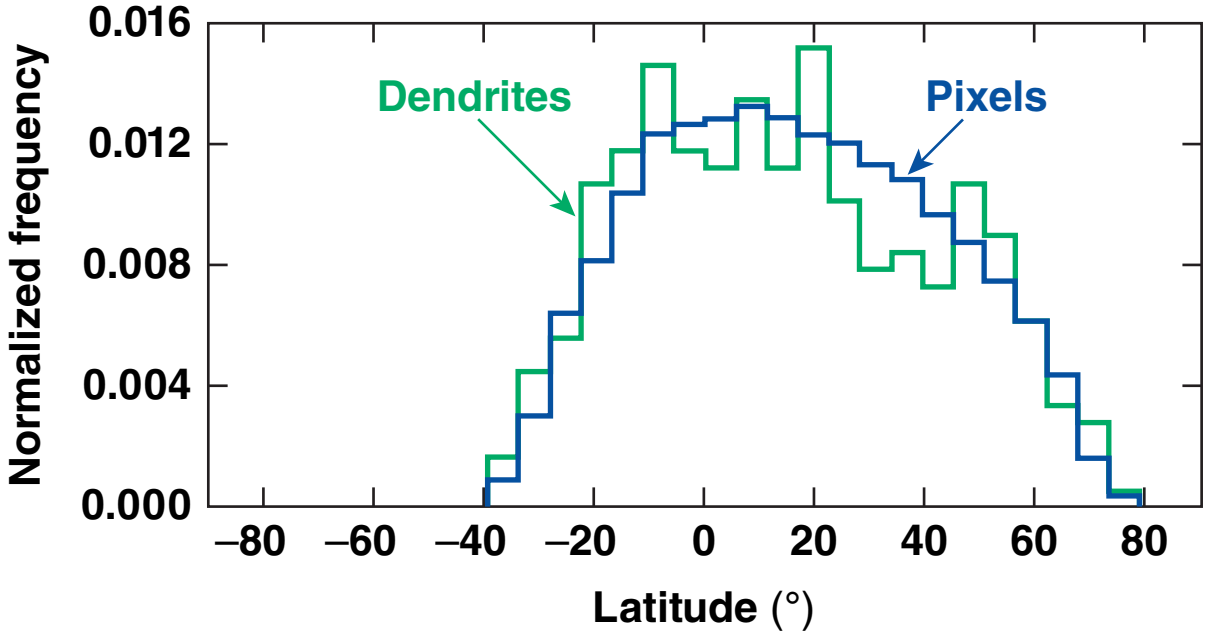
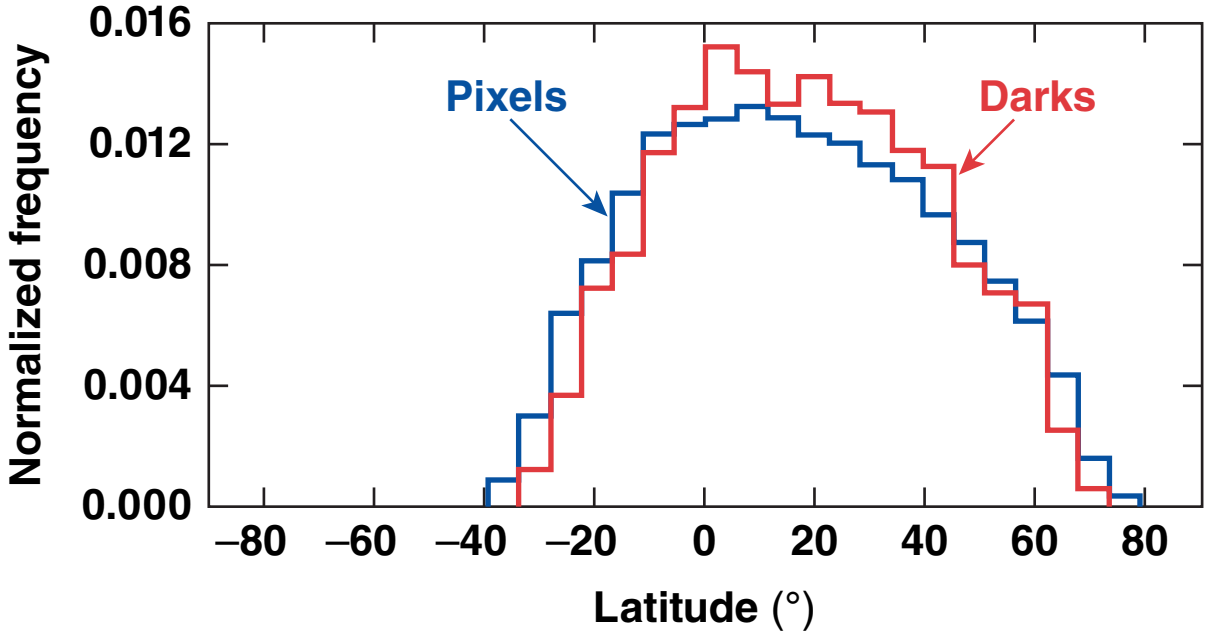


- Kolmogorov–Smirnov test results
  - H_0: the latitudes of pixels and dendrites are drawn from the same distribution
  - H_a: the latitudes of pixels and dendrites are not drawn from the same distribution
  - p value = 0.32

TC12110

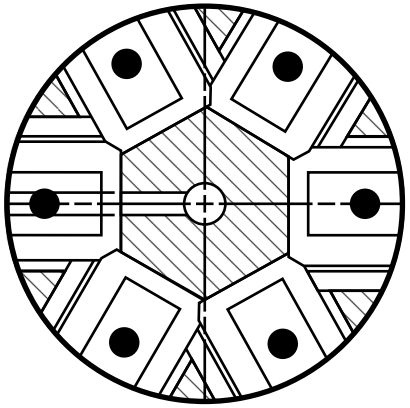
The distribution of darks with respect to latitude is different from the distribution of pixels



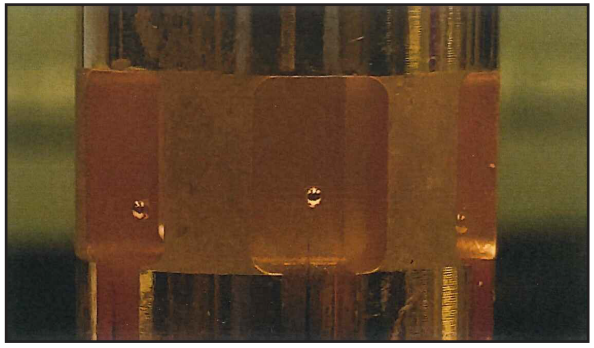
- The frequency of darks between latitudes 0° and 40° is higher with statistical significance but is not explained by the hypothesis
  - *p* value = 1.65×10^{-9}

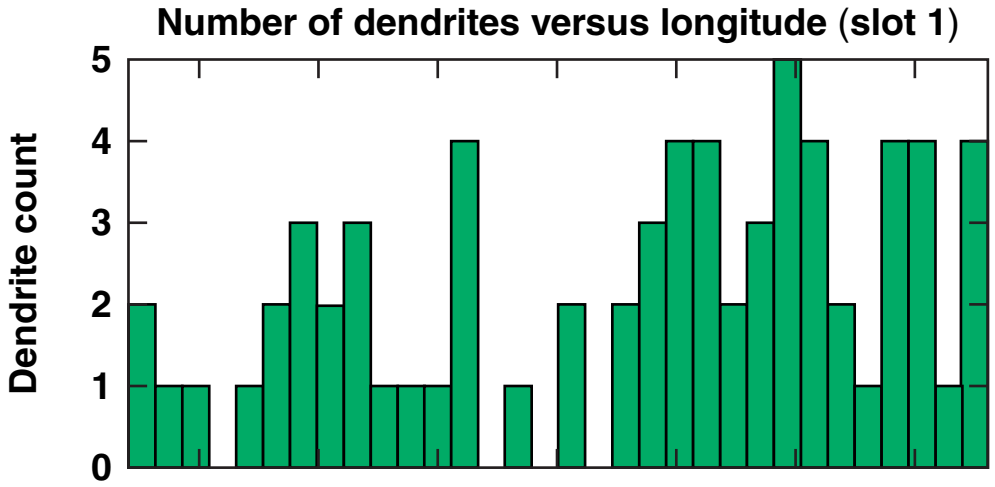
The longitudinal distribution of defects shows no evidence for the hypothesis

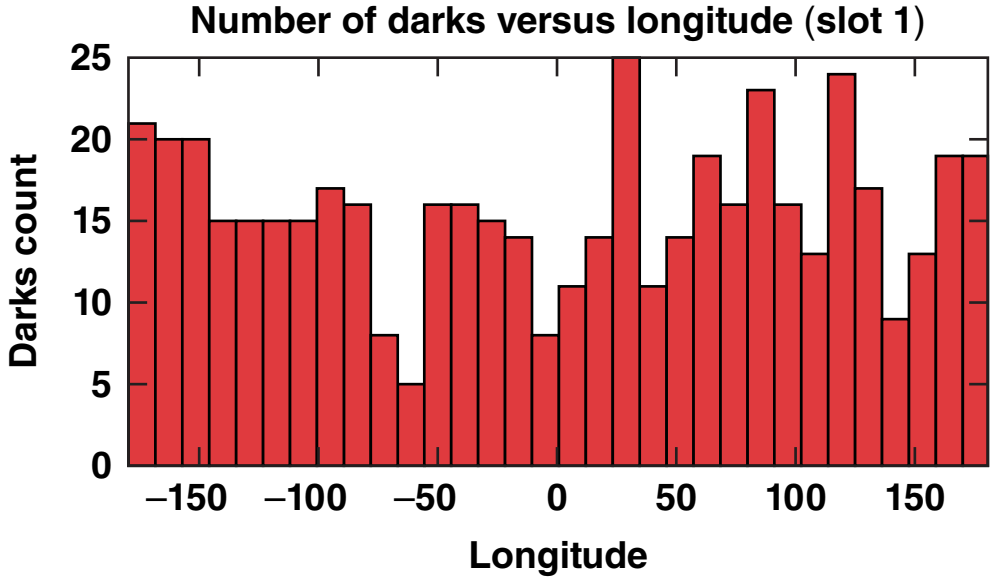
Target in fill rack (top view)



Side view

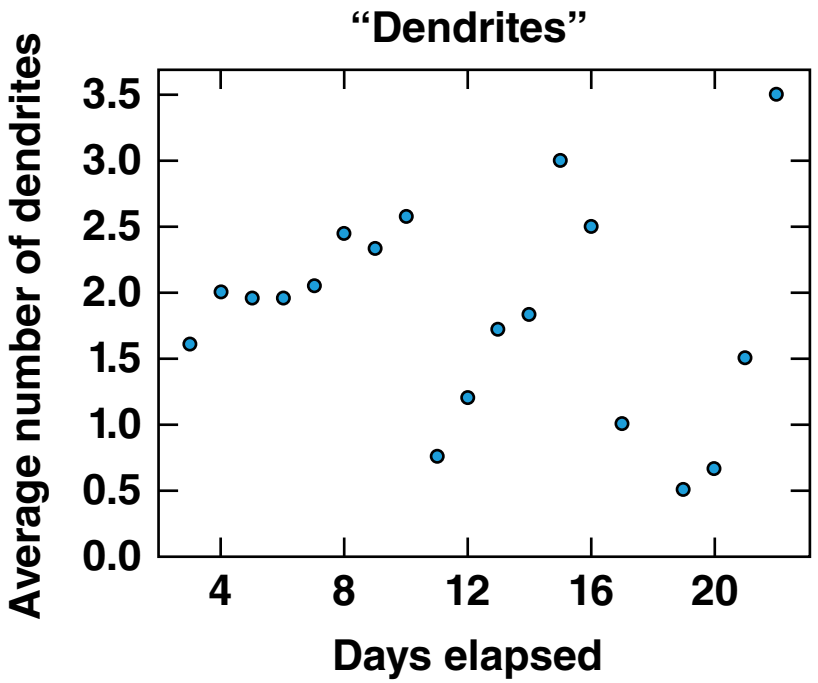


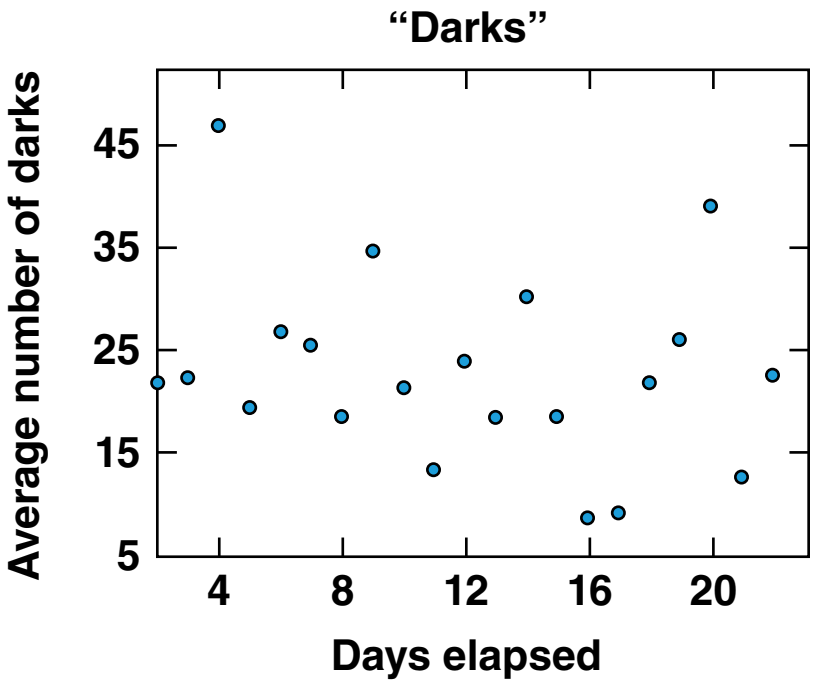




TC12113

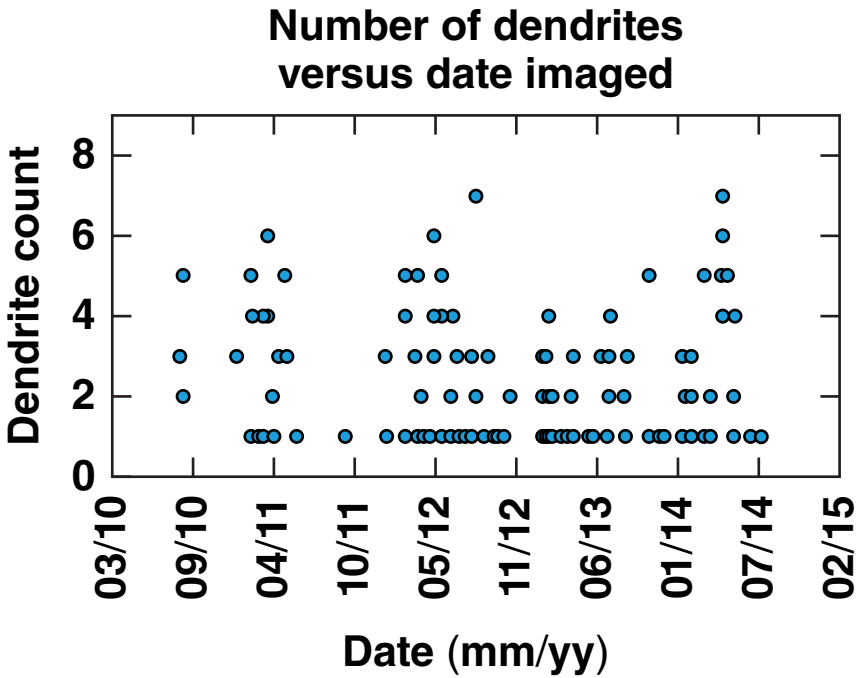
The average number of defects shows no correlation with the time spent in storage after filling

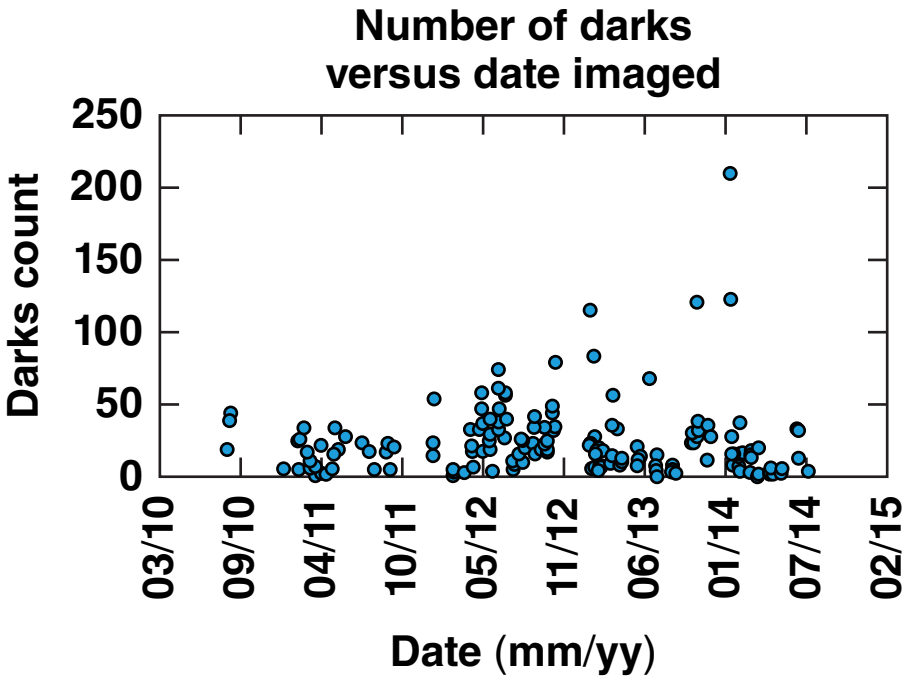




TC12115

There is no apparent change in the average number of defects per target over time





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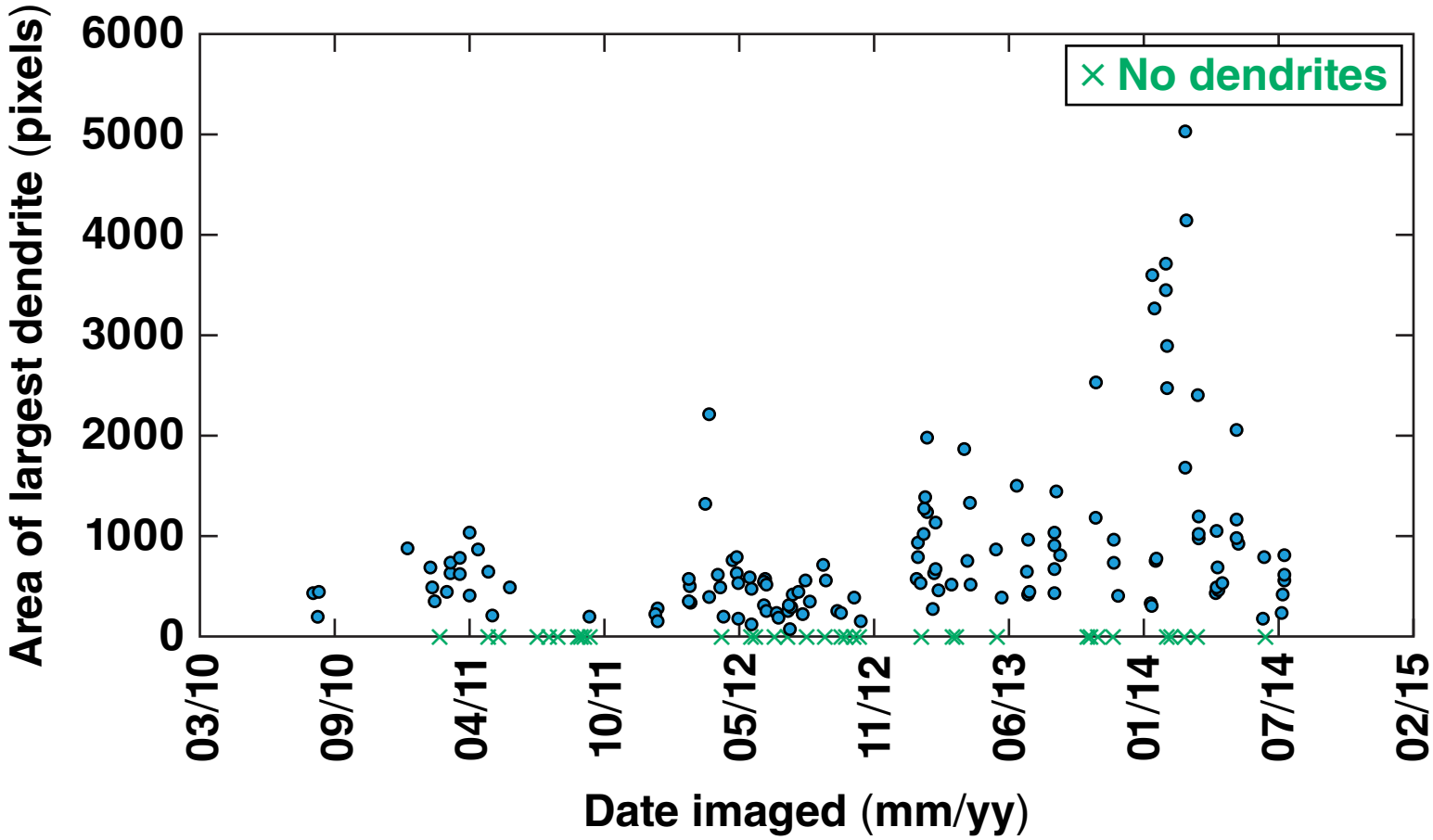

TC12117