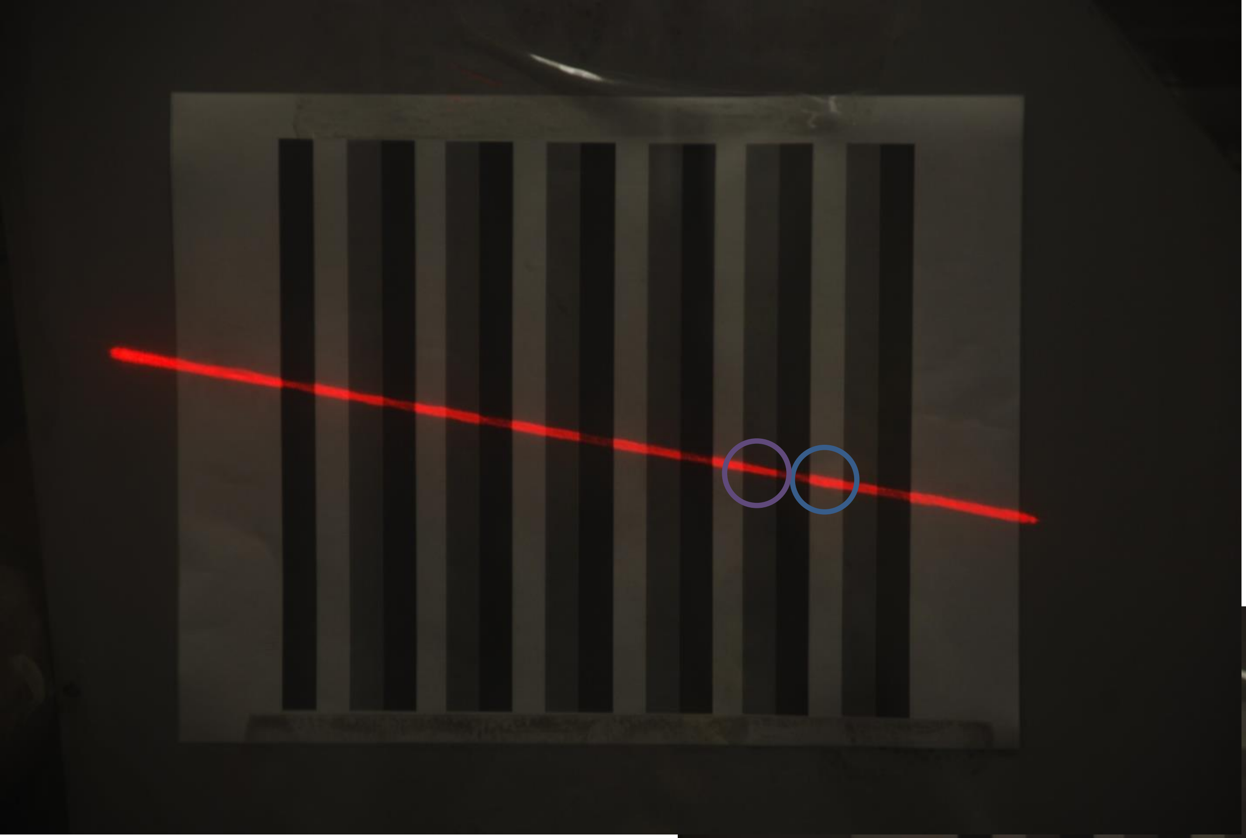
Optical Extinction Measurements of Dust Density in GMRO Regolith Test Bin

J. Lane, R. Mueller, J. Mantovani, M. Nugent, A. Nick,
J. Schuler, and I. Townsend

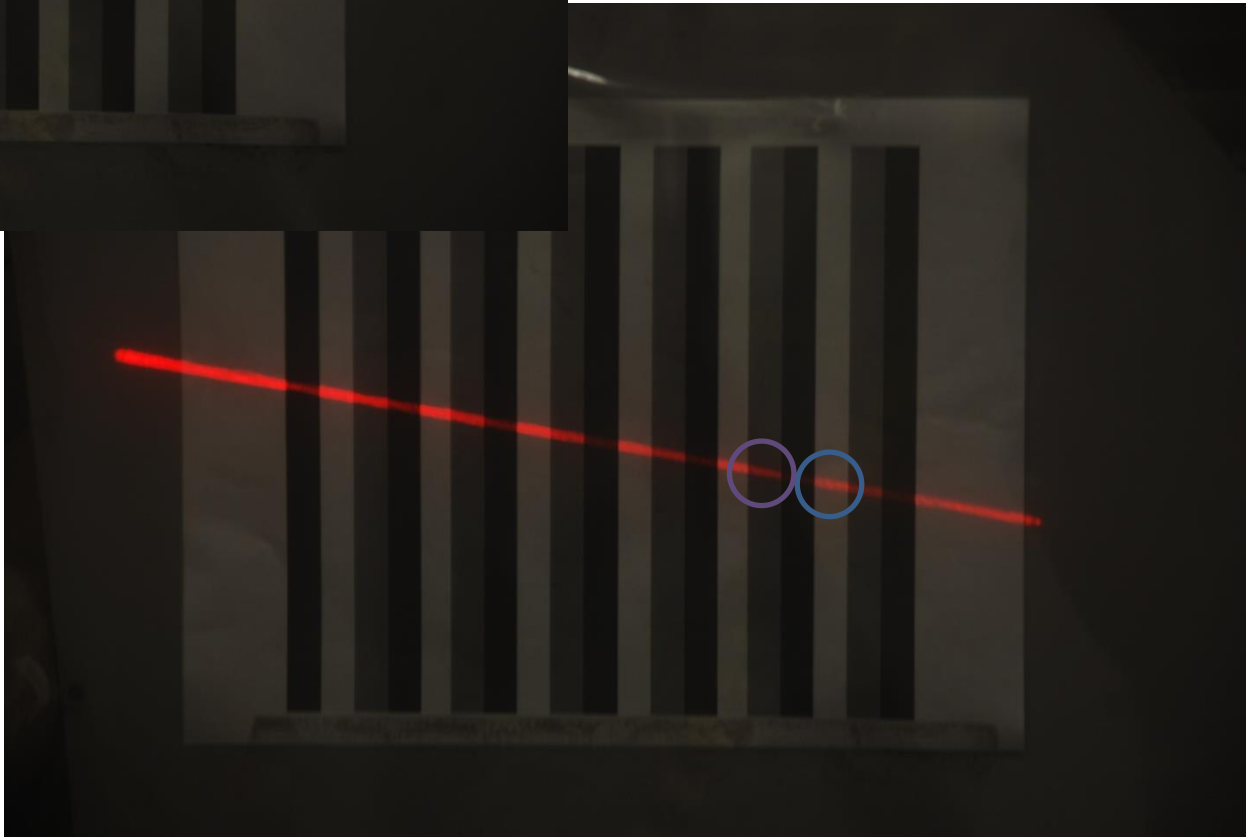
Granular Mechanics and Regolith Operations Lab
Kennedy Space Center, FL 32899

Earth and Space 2016, Orlando, Florida
April 11-15, 2016

Optical Density Using a Target



without dust



with dust

Average particle Size from Optical Density

$$\langle D \rangle = \frac{3\dot{m}L}{2v_p \rho_p \ln\left((l'_L - l_0)/(l_L - l_0)\right)}$$

$\langle D \rangle$ = average scattering cross-section diameter

L = distance laser travels through dust ≈ 0.5 in = 0.0127 m

$\dot{m}$ = mass transfer rate ≈ 0.0125 kg/s

l_L = luminosity of target with laser without dust

l'_L = luminosity of target with laser with dust

l_0 = luminosity of target without laser (background light only)

ρ_p = particle bulk density ≈ 3100 kg/m^3

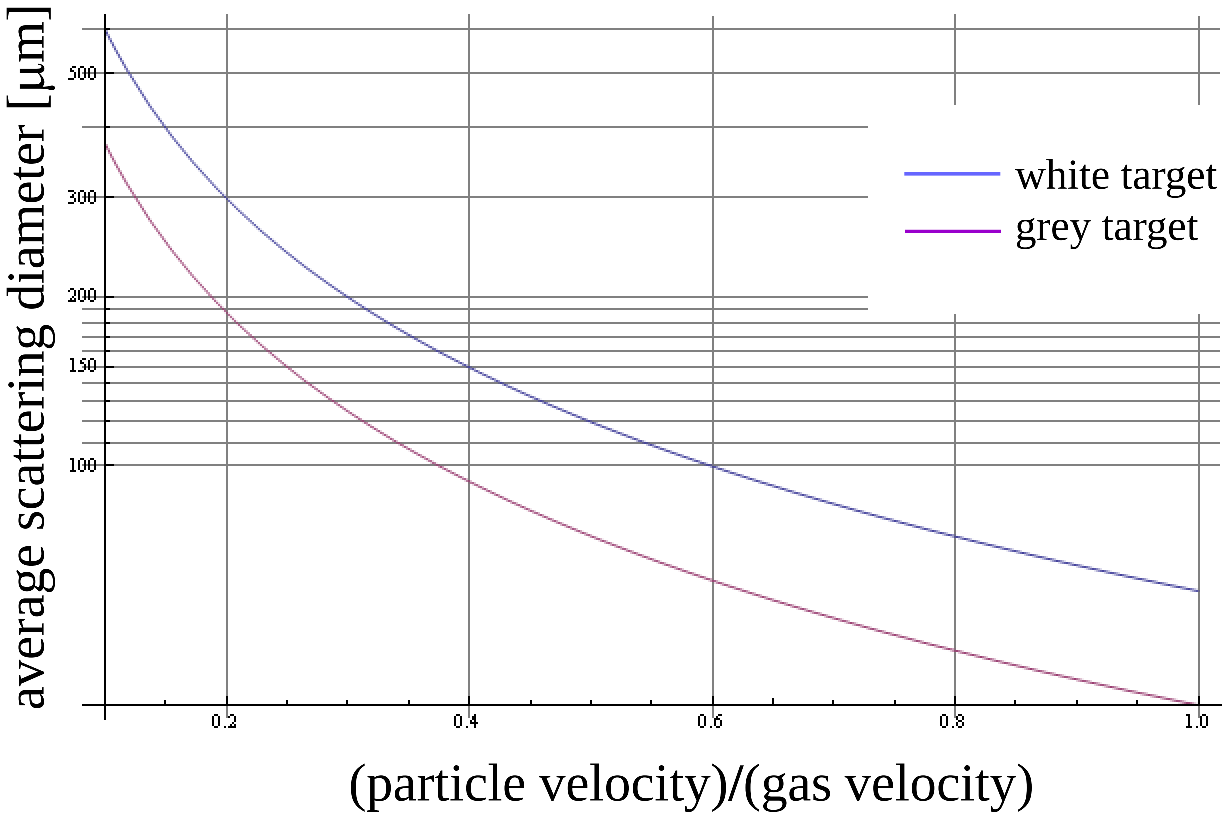
$v_p = e\, v_g$ = particle velocity m/s (v_g = gas velocity ≈ 17.7 m/s)

$l \equiv 0.299$ R + 0.587 G + 0.114 B , *luminosity* according to PhotoShop

Luminosity Measurements

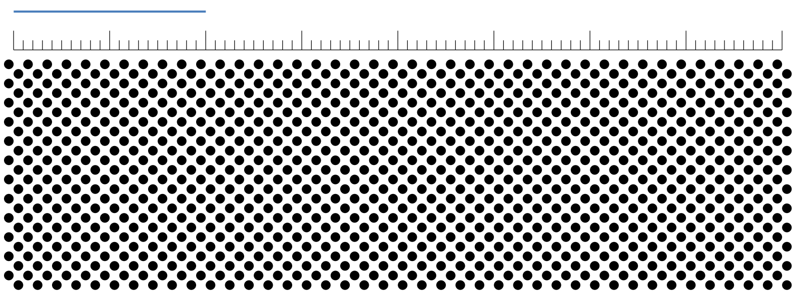
	l_L	l'_L	l_0
white target	97.1	80.5	58.9
gray target	70.9	46.2	29.6

Average particle Size from Optical Density



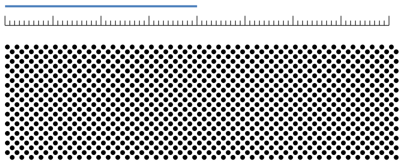
Optical Density 2D Calibration

Test Transparency



D = 0.050 [in]

$$n\sigma = \pi/8$$



D = 0.025 [in]

xCalc v2.nb

```
c = ((pLp - p0) / (pL - p0))
x[pLp_, p0_, pL_] = -Log[c]
x[42.23, 2, 59.76]
Exp[-x[41.9, 2, 59.02]]
x[22.5, 2, 42.61]
Exp[-x[22.5, 2, 42.61]]
x[11.7, 2, 19.4]
Exp[-x[11.7, 2, 19.4]]

-p0 + pLp
---------
-p0 + pL

     -p0 + pLp
-Log[---------]
     -p0 + pL

0.361684

0.699754

0.683589

0.504802

0.584344

0.557471

Quit[]

1 - Pi / 8 // N

0.607301

a = 10
L = 1
M = 10 000 000
x = L / M
Exp[-a L] // N
(1 - a x) ^M // N

10

1

10 000 000

    1
----------
10 000 000

0.0000453999

0.0000453997

Limit[(1 - a L / m) ^m, m → Infinity]

e^(-a L)
```

100%

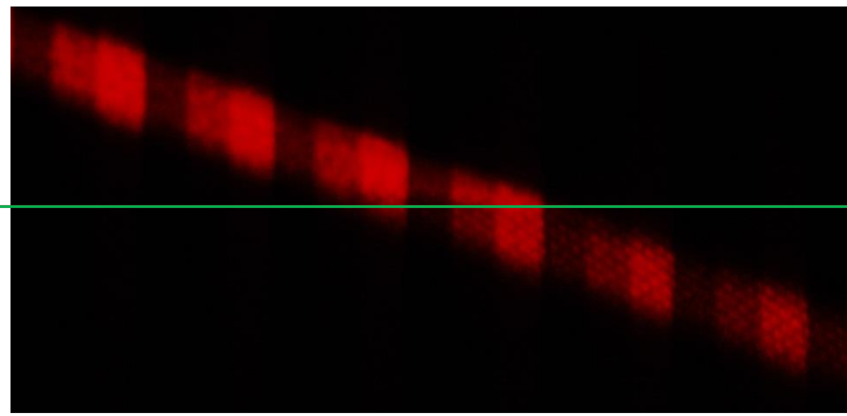
$$c = \frac{p_L' - p_0}{p_L - p_0}$$

White Target: $c = 0.700$
Grey Target: $c = 0.505$
Black Target: $c = 0.557$

$1 - n\sigma = 1 - \pi/8 = 0.6073$

2D Test Image

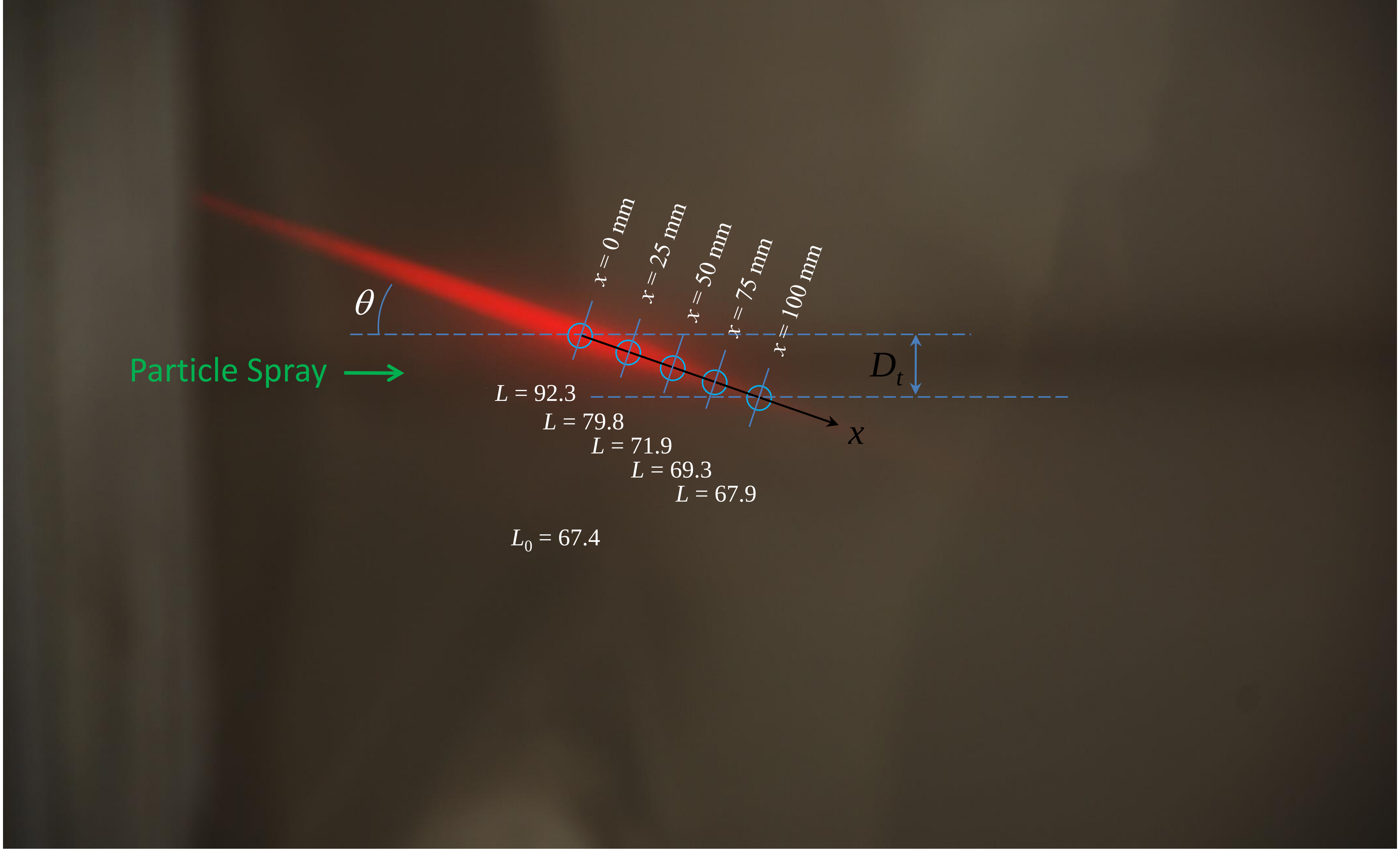
without “dust”

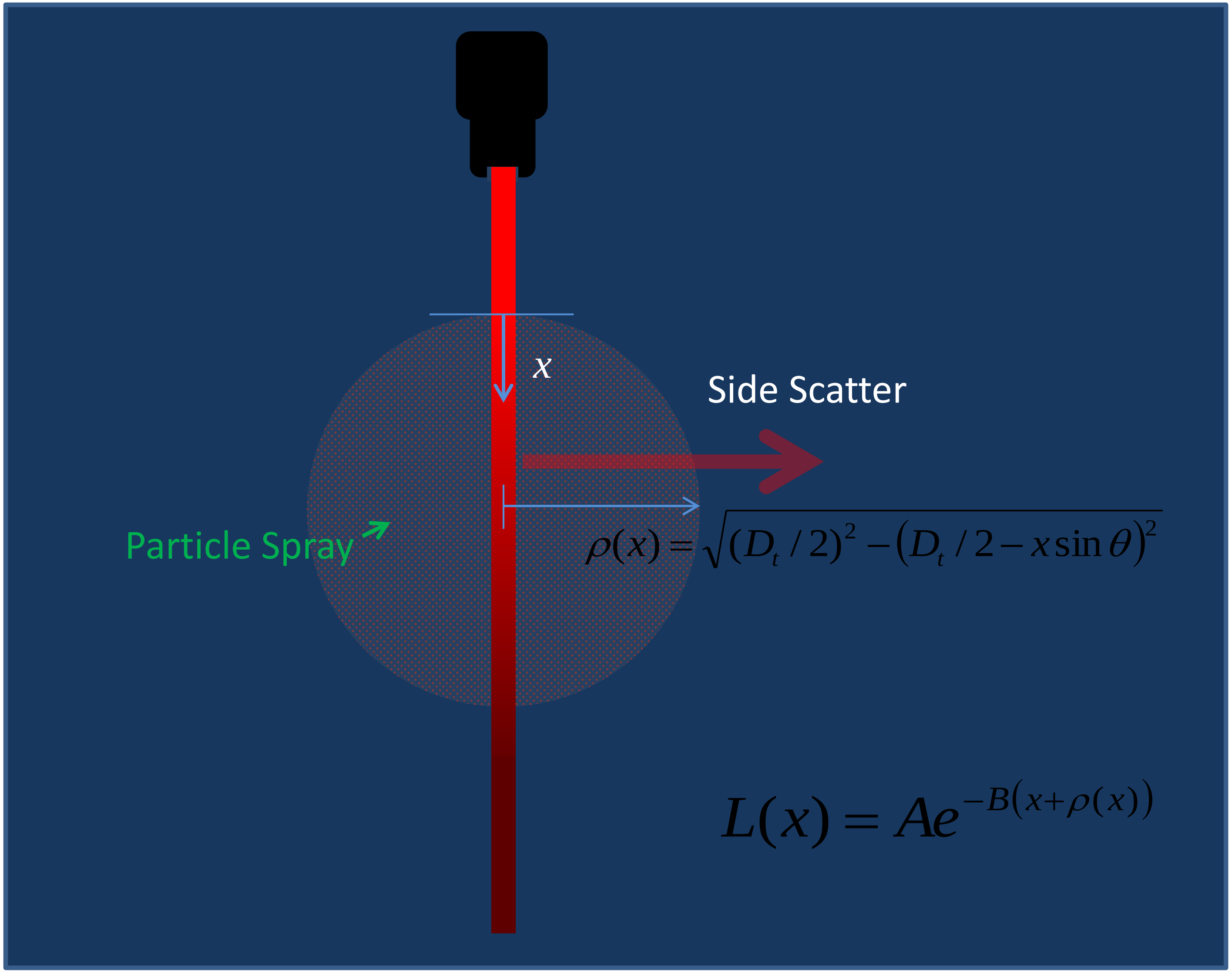


with “dust”

Optical Density Using Side-Scatter

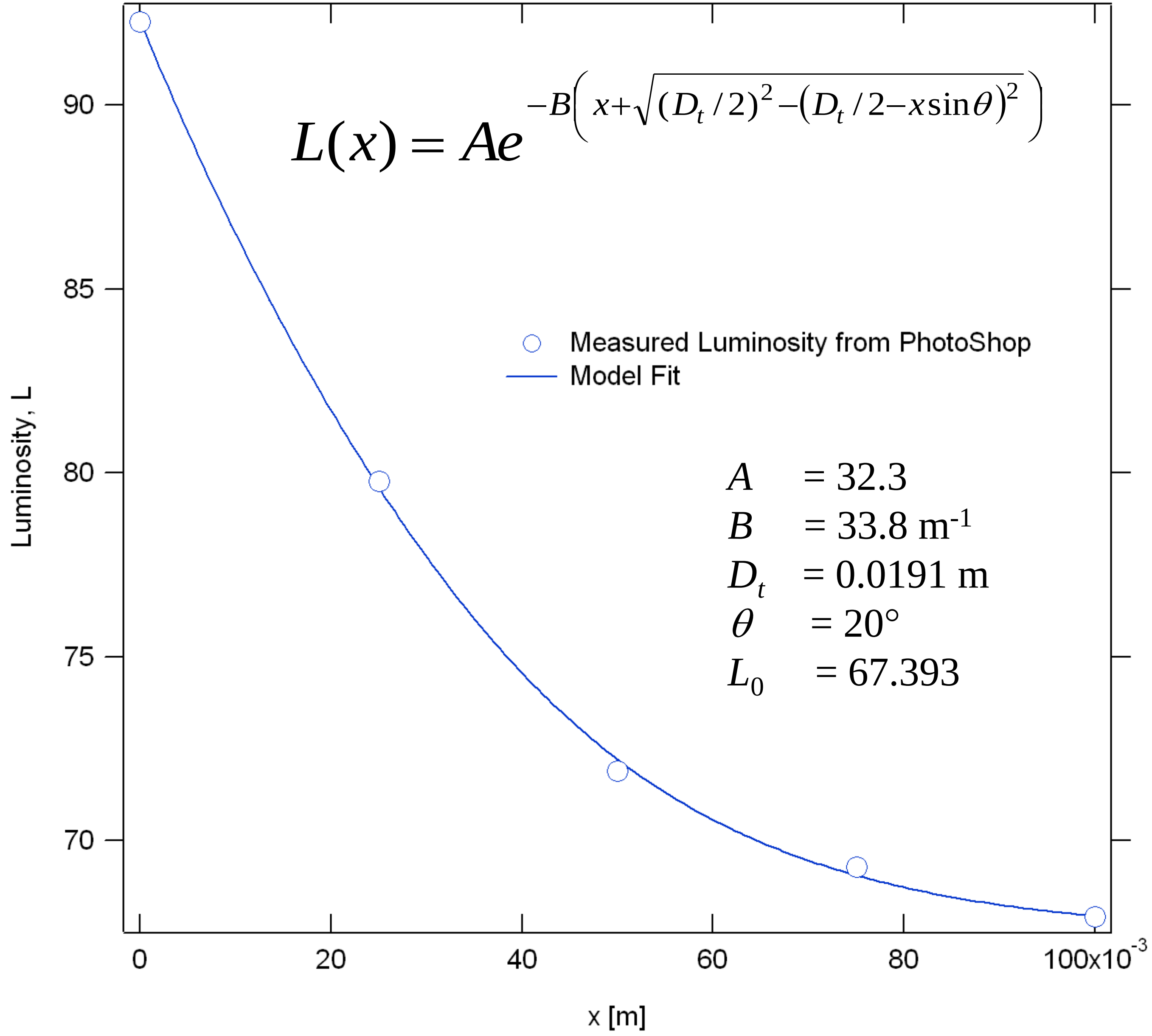
Luminosity Values as a Function of *x*





x
Side Scatter
Particle Spray
$\rho(x) = \sqrt{(D_t/2)^2 - (D_t/2 - x\sin\theta)^2}$
$L(x) = Ae^{-B(x+\rho(x))}$

Luminosity Values as a Function of *x*



Average Particle Size from Optical Density

$$\overline{D} = \frac{6\dot{M}}{\pi D_t^2 \xi v_g \rho_p B}$$

$\overline{D}$ = average scattering cross-section diameter of particles

B = from luminosity fit = 33.8 m^{-1}

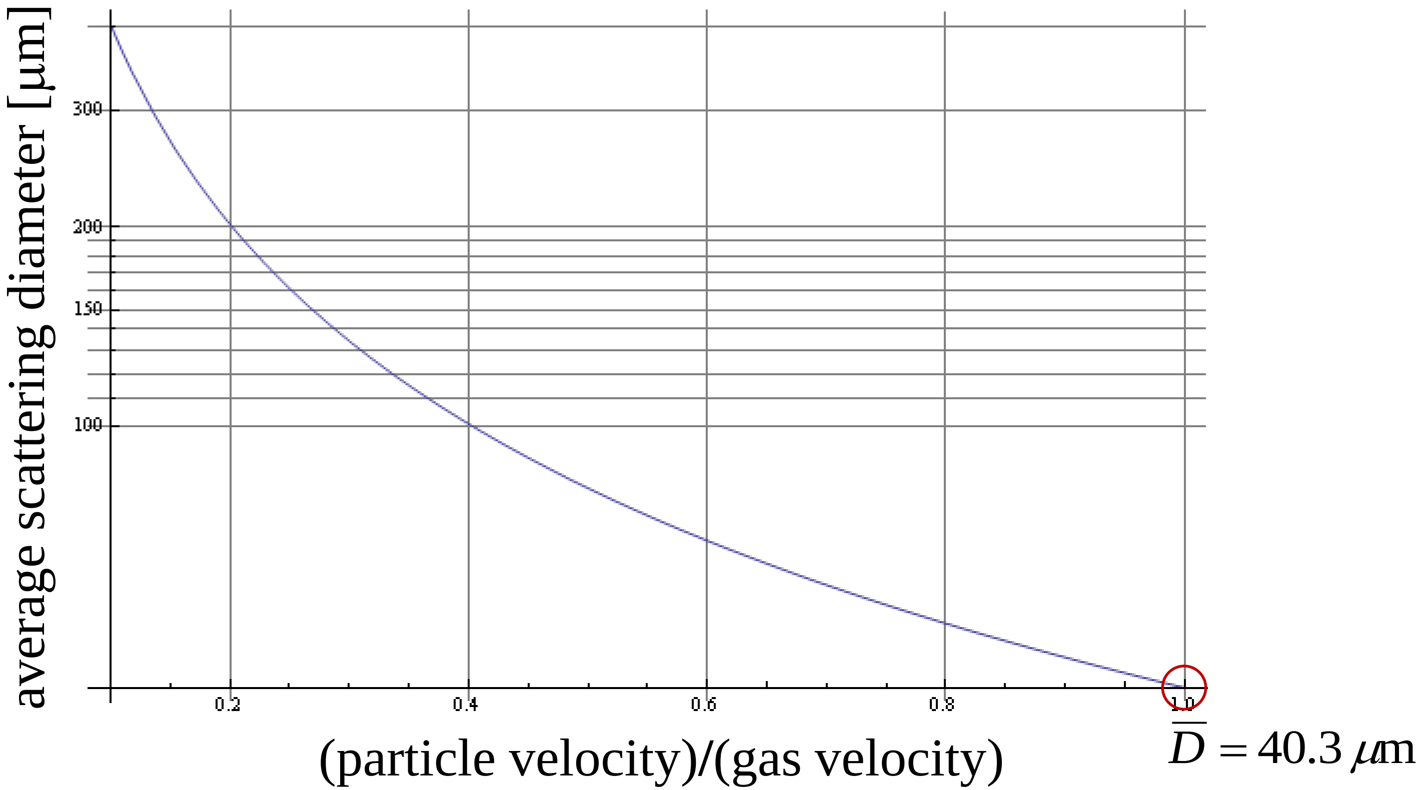
$\dot{M}$ = mass transfer rate ≈ 0.0250 kg/s

D_t = diameter of spray ≈ 0.75 in = 0.0191 m

ρ_p = particle bulk density ≈ 3100 kg/m^3

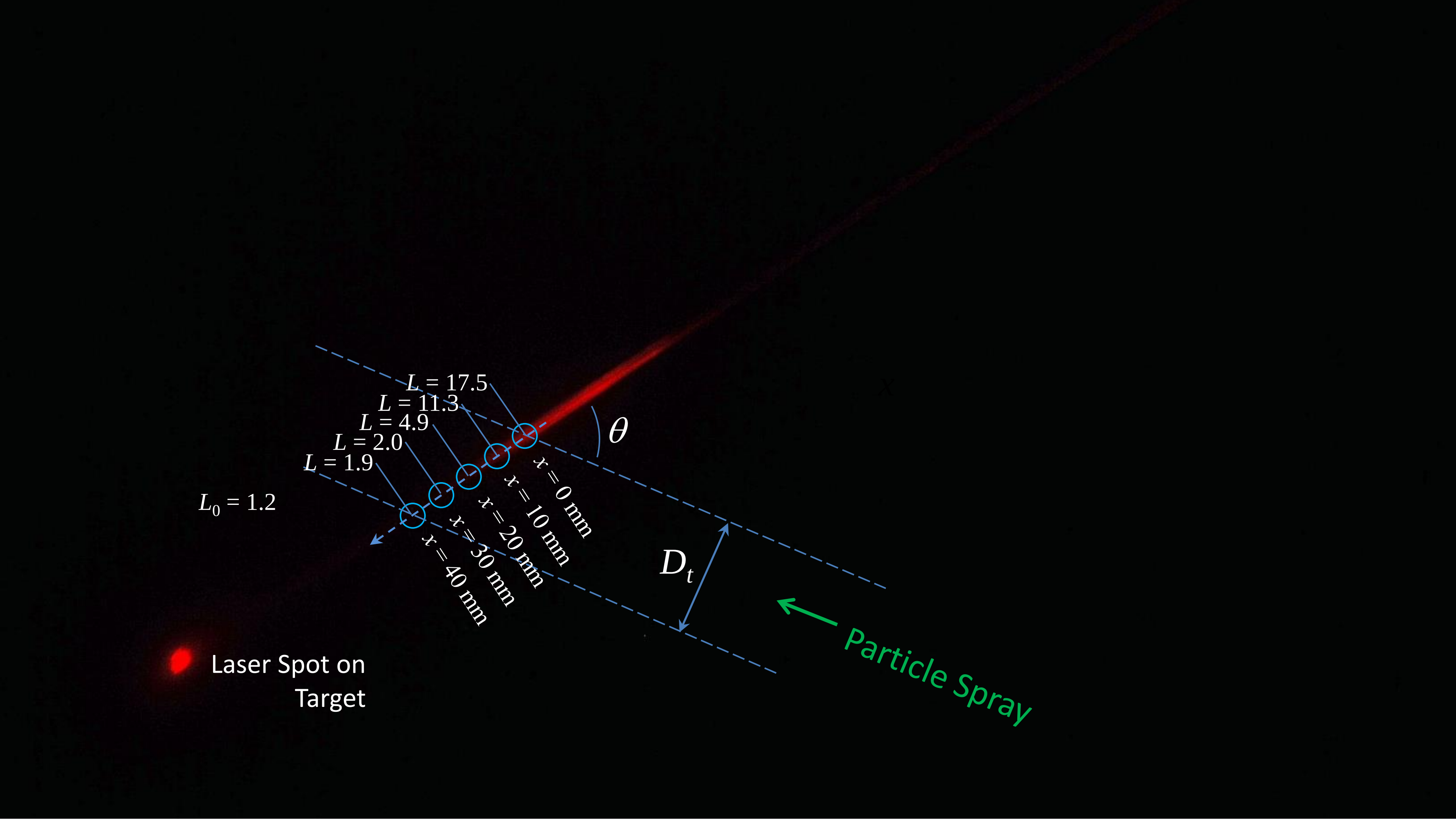
$v_p = \xi v_g$ = particle velocity m/s (v_g = gas velocity ≈ 31.1 m/s)

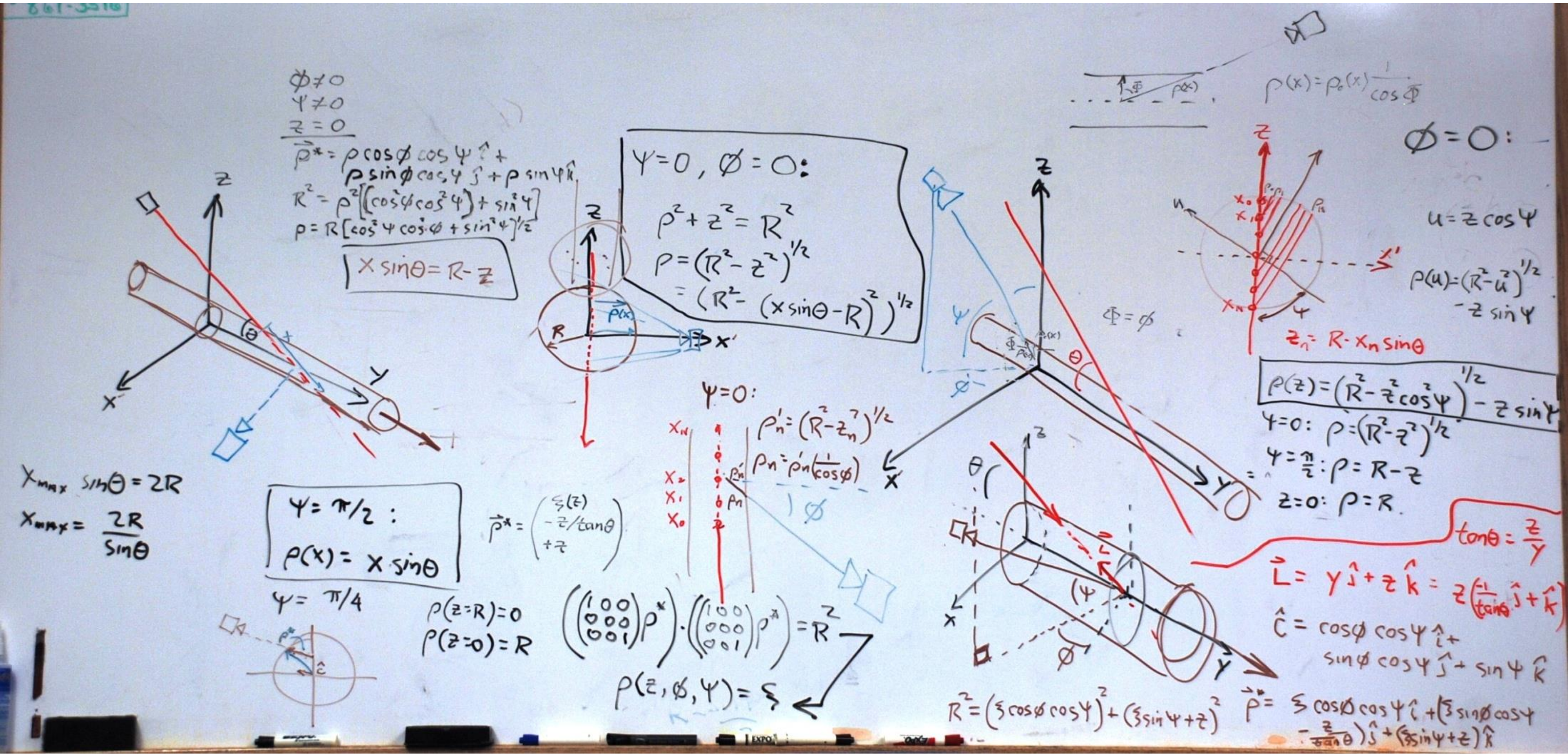
Average Particle Size from Optical Density



Optical Density Using Side-Scatter with Camera at Arbitrary Angle

Luminosity Values as a Function of *x*
12-16-11 experiment





Φ≠0
Ψ≠0
z=0
ρ* = ρ cos φ cos ψ î + ρ sin φ cos ψ ĵ + ρ sin ψ k̂
R² = ρ²[(cos²φ cos²ψ) + sin²ψ]
ρ = R[cos²ψ cos²φ + sin²ψ]^1/2
x sinθ = R - z
Xmax sinθ = 2R
Xmax = 2R / sinθ
Ψ = π/2 :
ρ(x) = x sinθ
Ψ = π/4
Ψ=0, φ=0:
ρ² + z² = R²
ρ = (R² - z²)^1/2
= (R² - (x sinθ - R)²)^1/2
Ψ=0:
ρ'n = (R² - zn²)^1/2
ρn = ρ'n (1/cos φ)
ρ(z=R) = 0
ρ(z=0) = R
ρ(z, φ, ψ) = ξ
ρ(x) = ρ0(x) 1/cos Φ
Φ = φ
φ = 0 :
u = z cos ψ
ρ(u) = (R² - u²)^1/2 - z sin ψ
zn = R - xn sinθ
ρ(z) = (R² - z² cos²ψ)^1/2 - z sin ψ
ψ=0: ρ = (R² - z²)^1/2
ψ = π/2 : ρ = R - z
z=0: ρ = R
tanθ = z/y
L = y ĵ + z k̂ = z(1/tanθ ĵ + k̂)
Ĉ = cos φ cos ψ î + sin φ cos ψ ĵ + sin ψ k̂
R² = (ξ cos φ cos ψ)² + (ξ sin ψ + z)²
ρ* = ξ cos φ cos ψ î + (ξ sin φ cos ψ - z/tanθ) ĵ + (ξ sin ψ + z) k̂

3DModel.nb

```
ρs[ξ_] = {ξ Cos[ϕ] Cos[ψ], ξ Sin[ϕ] Cos[ψ] - z / Tan[θ], ξ Sin[ψ] + z};
MatrixForm[ρs[ξ]]
xzP = {{1, 0, 0}, {0, 0, 0}, {0, 0, 1}};
MatrixForm[xzP]
Solve[R^2 == (xzP.ρs[ξ]).(xzP.ρs[ξ]), ξ]
{ρ1[z_, ϕ_, ψ_], ρ2[z_, ϕ_, ψ_]} = ξ /. %;

FullSimplify[ρ1[z, ϕ, ψ], {R > 0 == 0, Im[z] == 0, Im[ϕ] == 0, Im[ψ] == 0}]
FullSimplify[ρ2[z, ϕ, ψ], {R > 0 == 0, Im[z] == 0, Im[ϕ] == 0, Im[ψ] == 0}]

FullSimplify[ρ2[z, 0, 0], {R > 0, Im[z] == 0, Im[ϕ] == 0, Im[ψ] == 0}]
FullSimplify[ρ2[0, 0, ψ], {R > 0 == 0, Im[z] == 0, Im[ϕ] == 0, Im[ψ] == 0}]
FullSimplify[ρ2[z, 0, ψ], {R > 0 == 0, Im[z] == 0, Im[ϕ] == 0, Im[ψ] == 0}]
FullSimplify[ρ2[z, 0, Pi / 2], {R > 0 == 0, Im[z] == 0, Im[ϕ] == 0, Im[ψ] == 0}]
FullSimplify[ρ2[z, ϕ, 0], {R > 0 == 0, Im[z] == 0, Im[ϕ] == 0, Im[ψ] == 0}]
```

$$\begin{pmatrix} \xi \operatorname{Cos}[\phi] \operatorname{Cos}[\psi] \\ -z \operatorname{Cot}[\theta] + \xi \operatorname{Cos}[\psi] \operatorname{Sin}[\phi] \\ z + \xi \operatorname{Sin}[\psi] \end{pmatrix}$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\Big\{\Big\{\xi \to \Big(-16 z \operatorname{Sin}[\psi] - \sqrt{\left(-4 \left(8 R^2 - 8 z^2\right) (-6 - 2 \operatorname{Cos}[2\phi] - \operatorname{Cos}[2\phi - 2\psi] + 2 \operatorname{Cos}[2\psi] - \operatorname{Cos}[2\phi + 2\psi]) + 256 z^2 \operatorname{Sin}[\psi]^2\right)}\Big) \Big/ (2 (6 + 2 \operatorname{Cos}[2\phi] + \operatorname{Cos}[2\phi - 2\psi] - 2 \operatorname{Cos}[2\psi] + \operatorname{Cos}[2\phi + 2\psi]))\Big\},$$
$$\Big\{\xi \to \Big(-16 z \operatorname{Sin}[\psi] + \sqrt{\left(-4 \left(8 R^2 - 8 z^2\right) (-6 - 2 \operatorname{Cos}[2\phi] - \operatorname{Cos}[2\phi - 2\psi] + 2 \operatorname{Cos}[2\psi] - \operatorname{Cos}[2\phi + 2\psi]) + 256 z^2 \operatorname{Sin}[\psi]^2\right)}\Big) \Big/ (2 (6 + 2 \operatorname{Cos}[2\phi] + \operatorname{Cos}[2\phi - 2\psi] - 2 \operatorname{Cos}[2\psi] + \operatorname{Cos}[2\phi + 2\psi]))\Big\}\Big\}$$

$$-\frac{2 \left(2 z \operatorname{Sin}[\psi] + \sqrt{(R - z) (R + z) \left(3 + \operatorname{Cos}[2\phi] - 2 \operatorname{Cos}[2\psi] \operatorname{Sin}[\phi]^2\right) + 4 z^2 \operatorname{Sin}[\psi]^2}\right)}{3 + \operatorname{Cos}[2\phi] - 2 \operatorname{Cos}[2\psi] \operatorname{Sin}[\phi]^2}$$

$$\rho(x, \phi, \psi) = \frac{2 \left(-2 z \operatorname{Sin}[\psi] + \sqrt{(R - z) (R + z) \left(3 + \operatorname{Cos}[2\phi] - 2 \operatorname{Cos}[2\psi] \operatorname{Sin}[\phi]^2\right) + 4 z^2 \operatorname{Sin}[\psi]^2}\right)}{3 + \operatorname{Cos}[2\phi] - 2 \operatorname{Cos}[2\psi] \operatorname{Sin}[\phi]^2}$$

$$\sqrt{R^2 - z^2}$$

$$R$$

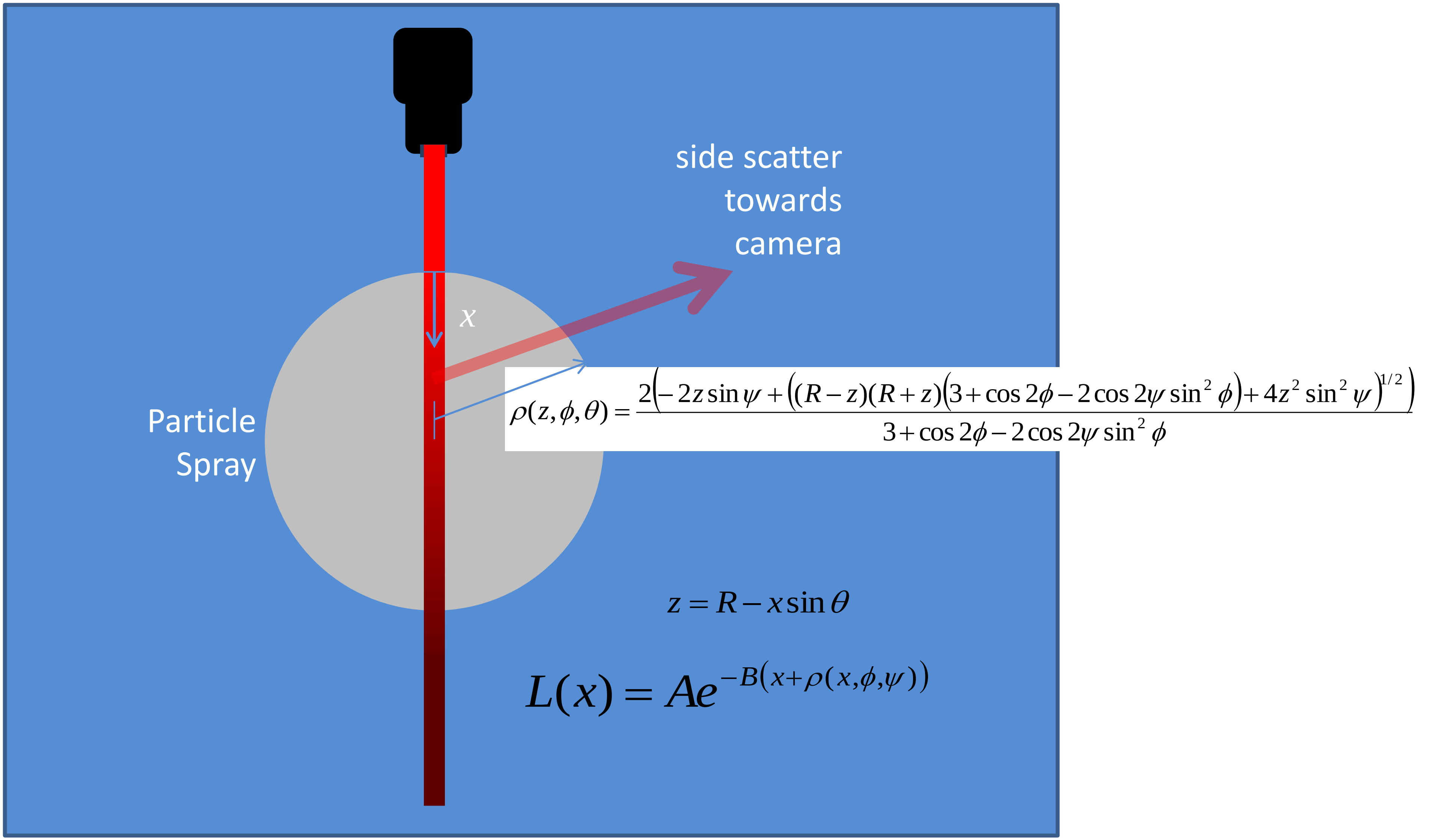
$$-z \operatorname{Sin}[\psi] + \sqrt{R^2 - z^2 + z^2 \operatorname{Sin}[\psi]^2}$$

$$R - z$$

$$\sqrt{R^2 - z^2} \operatorname{Abs}[\operatorname{Cos}[\phi]] \operatorname{Sec}[\phi]^2$$

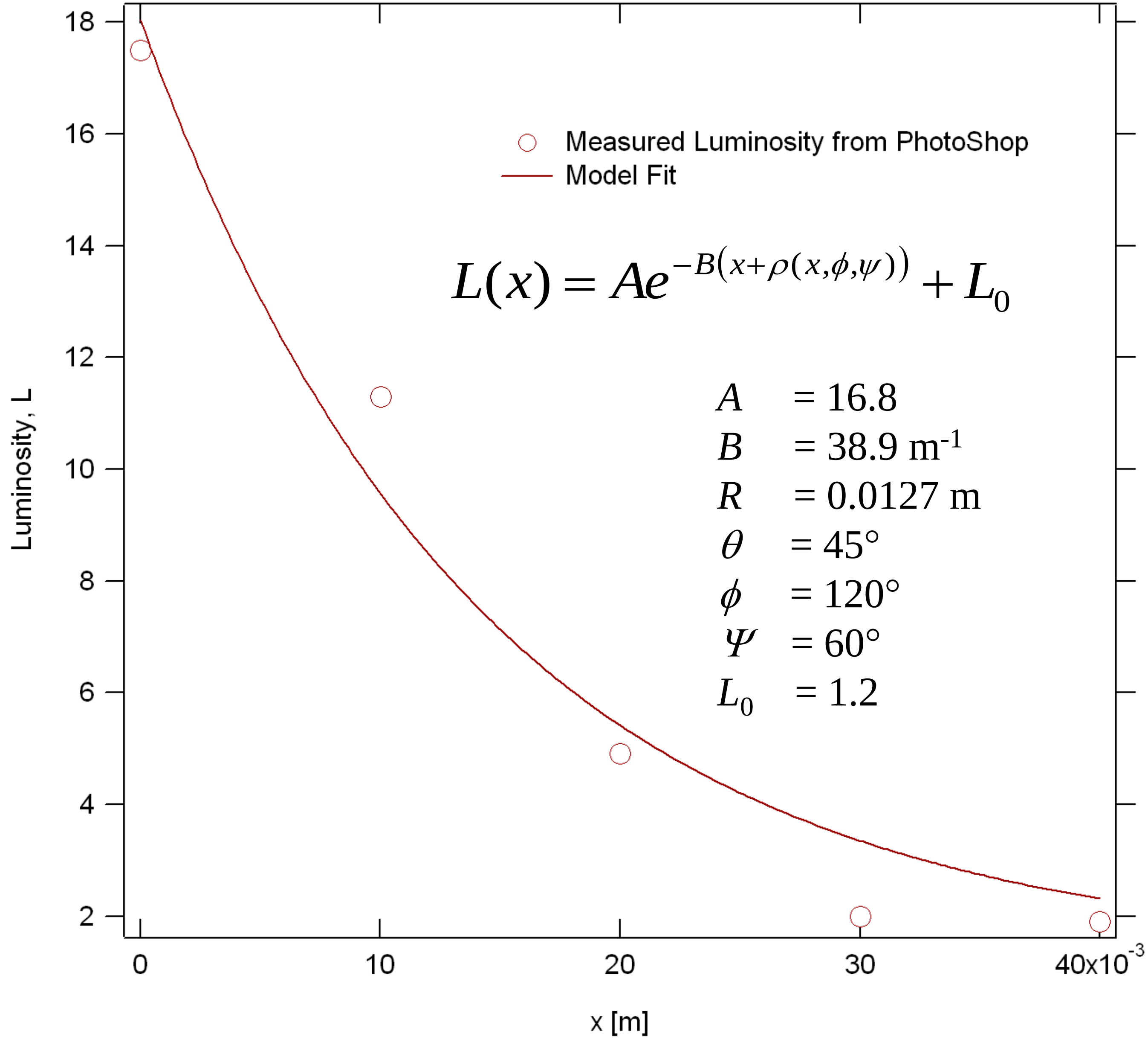
```
Quit[]
```

100%



side scatter towards camera
x
Particle Spray
$\rho(z,\phi,\theta) = \frac{2\left(-2z\sin\psi + \left((R-z)(R+z)\left(3+\cos 2\phi - 2\cos 2\psi \sin^2\phi\right) + 4z^2\sin^2\psi\right)^{1/2}\right)}{3+\cos 2\phi - 2\cos 2\psi \sin^2\phi}$
$z = R - x\sin\theta$
$L(x) = Ae^{-B\left(x+\rho(x,\phi,\psi)\right)}$

Luminosity Values as a Function of *x*



Average Particle Size from Optical Density

$$\overline{D} = \frac{6\dot{M}}{\pi\, D_t^2 \xi v_g \rho_p B}$$

$\overline{D}$ = average scattering cross-section diameter of particles

B = from luminosity fit = 38.9 m^{-1}

$\dot{M}$ = mass transfer rate ≈ 0.0370 kg/s

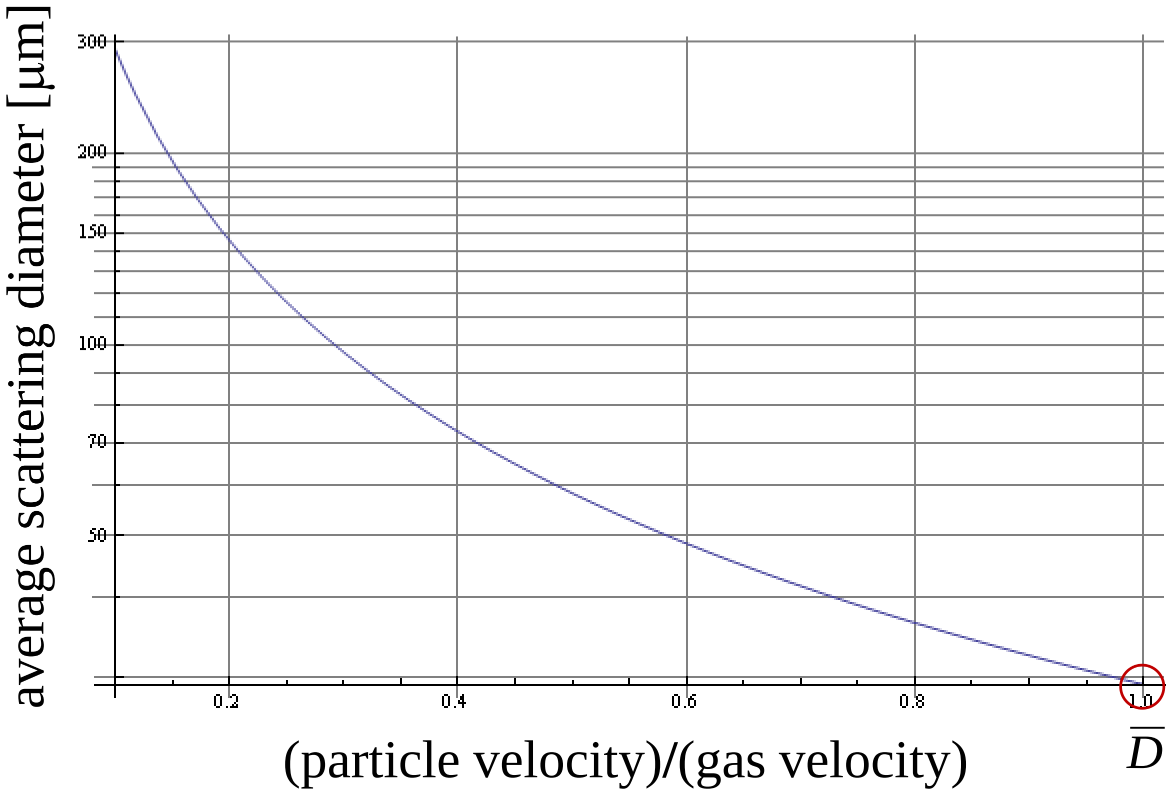
D_t = diameter of spray ≈ 1.0 in = 0.0254 m

ρ_p = particle bulk density ≈ 3100 kg/m^3

$v_p = \xi\, v_g$ = particle velocity m/s (v_g = gas velocity ≈ 31.1 m/s)*

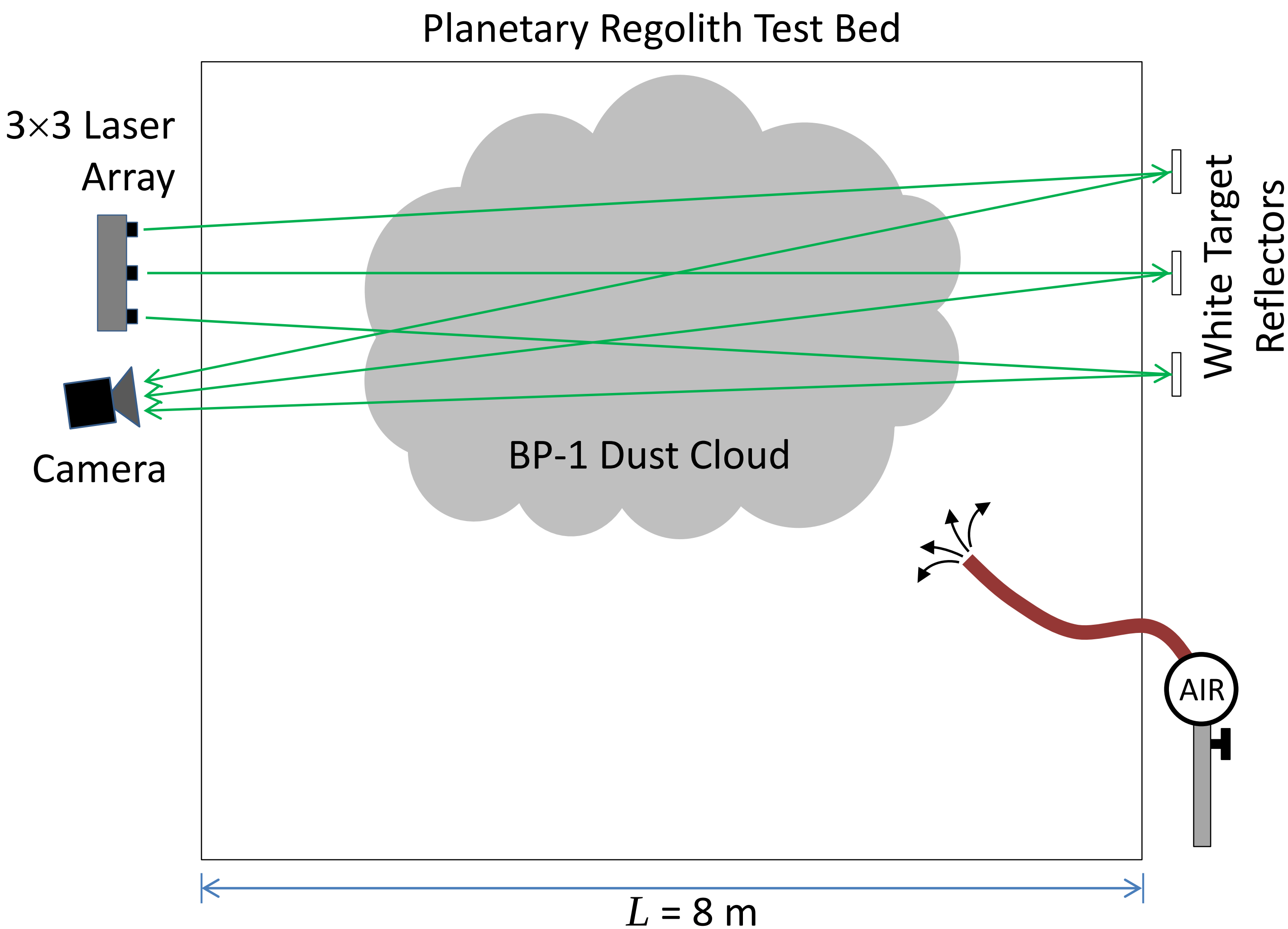
* gas flow = 4.7 CFM through a 3/8 inch pipe

Average Particle Size from Optical Density

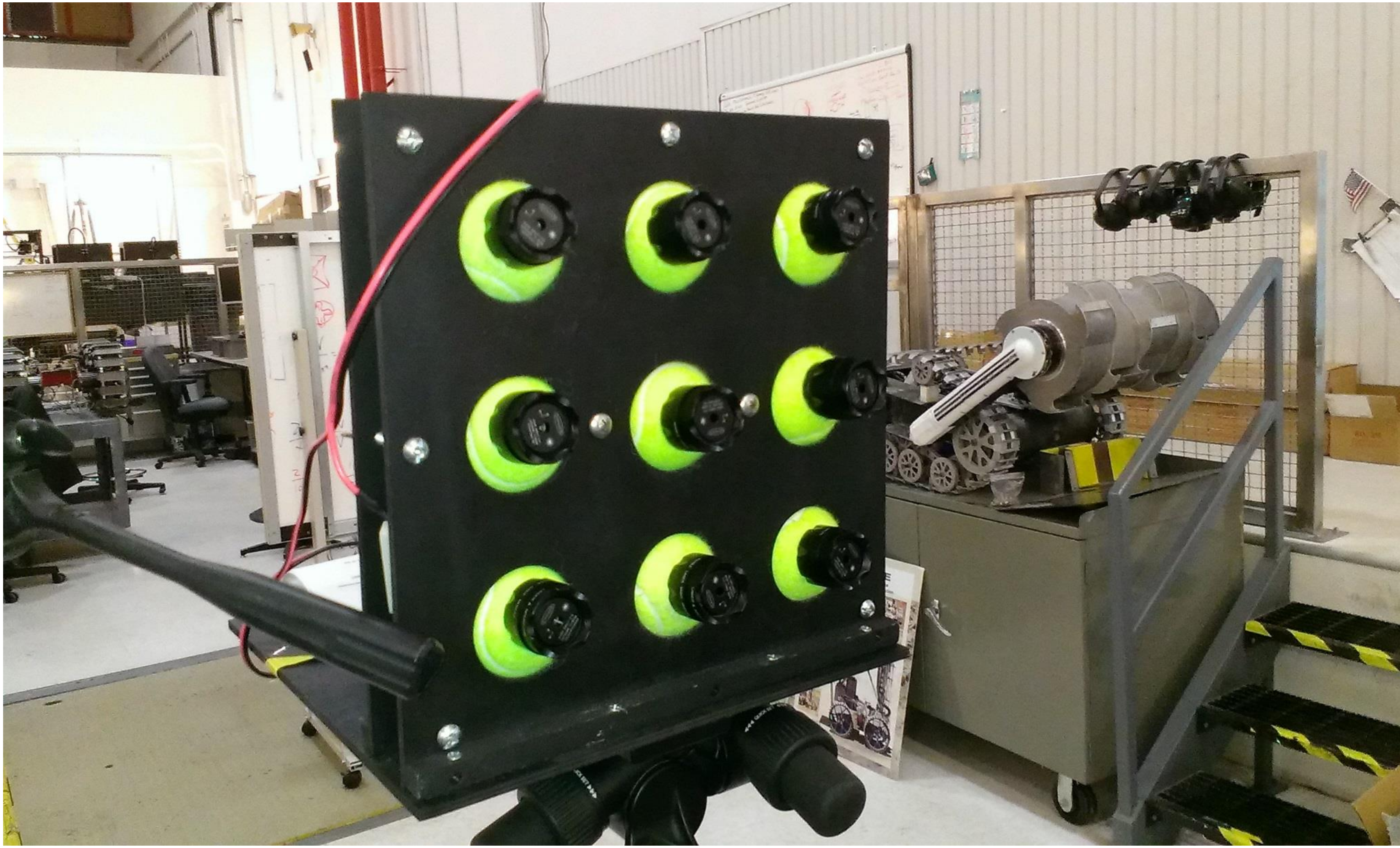


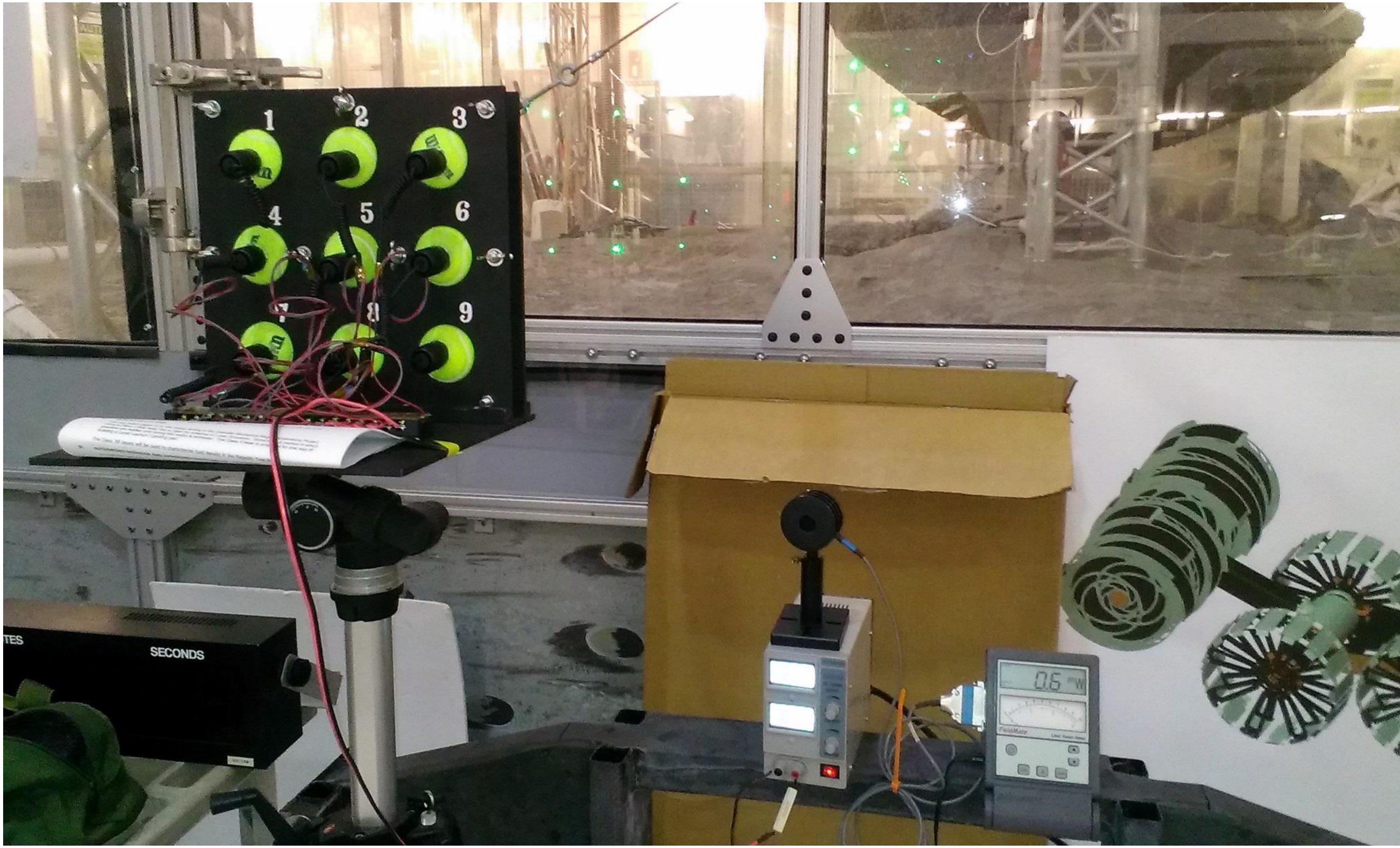
$\overline{D} = 29.1\,\mu m$

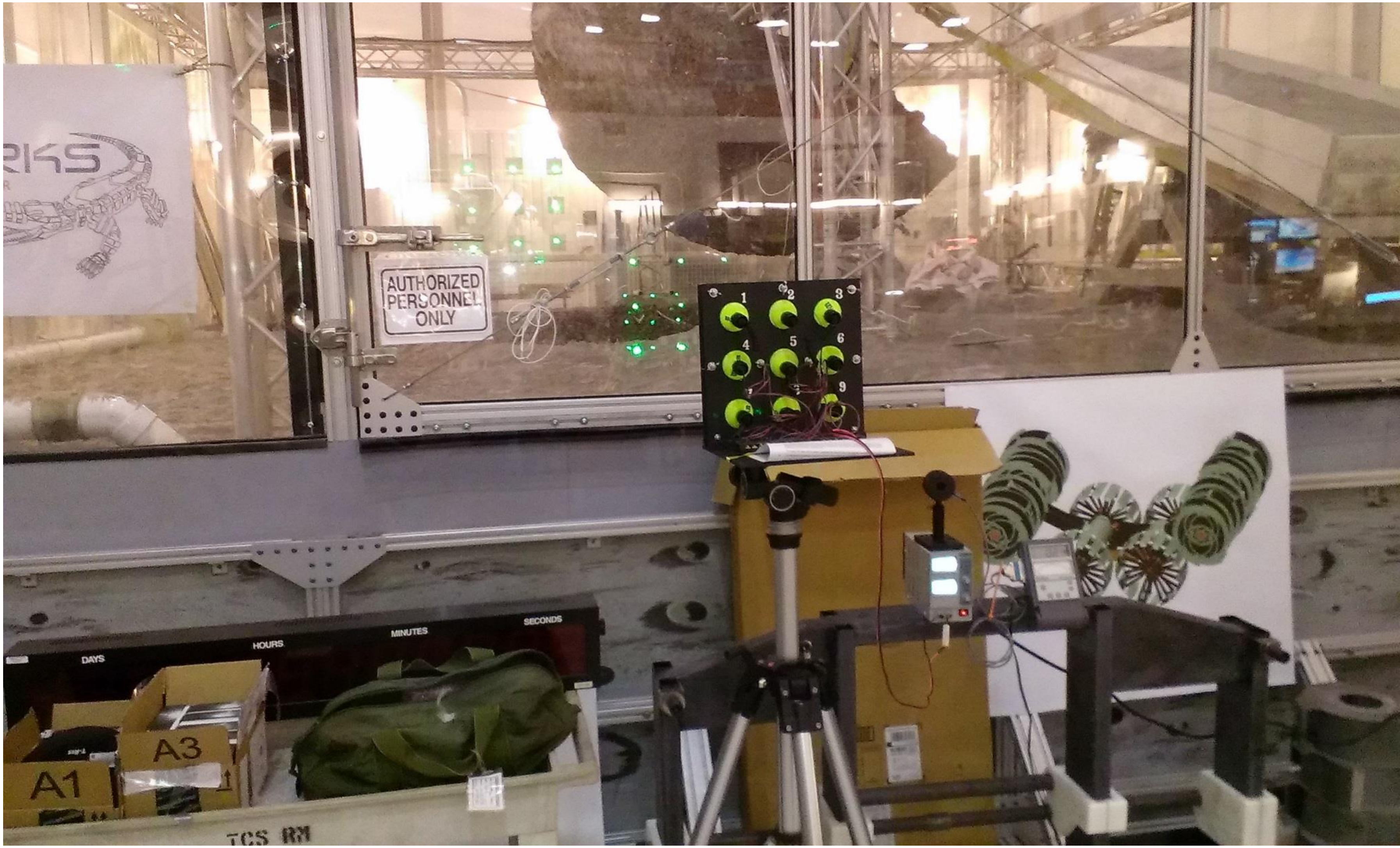
Regolith Test Bin (RTB)
Swampworks,
Kennedy Space Center, FL


Planetary Regolith Test Bed
3×3 Laser
Array
Camera
BP-1 Dust Cloud
White Target
Reflectors
AIR
L = 8 m


UCLA




1
2
3
4
5
6
7
8
9
SECONDS
0.6 mW



AUTHORIZED
PERSONNEL
ONLY
DAYS
HOURS
MINUTES
SECONDS
A1
A3
TCS RM


AUTHORIZED
PERSONNEL
ONLY

Intensity of Reflected Beam: $I(x) = I_0 e^{-\pi Q_e \alpha x/4}$

Extinction Coefficient: $\alpha = -\frac{4}{\pi Q_e x} \ln\left(\frac{I(x)}{I_0}\right)$

Q_e = Extinction Efficiency (≈ 2)

x = Total Optical Distance

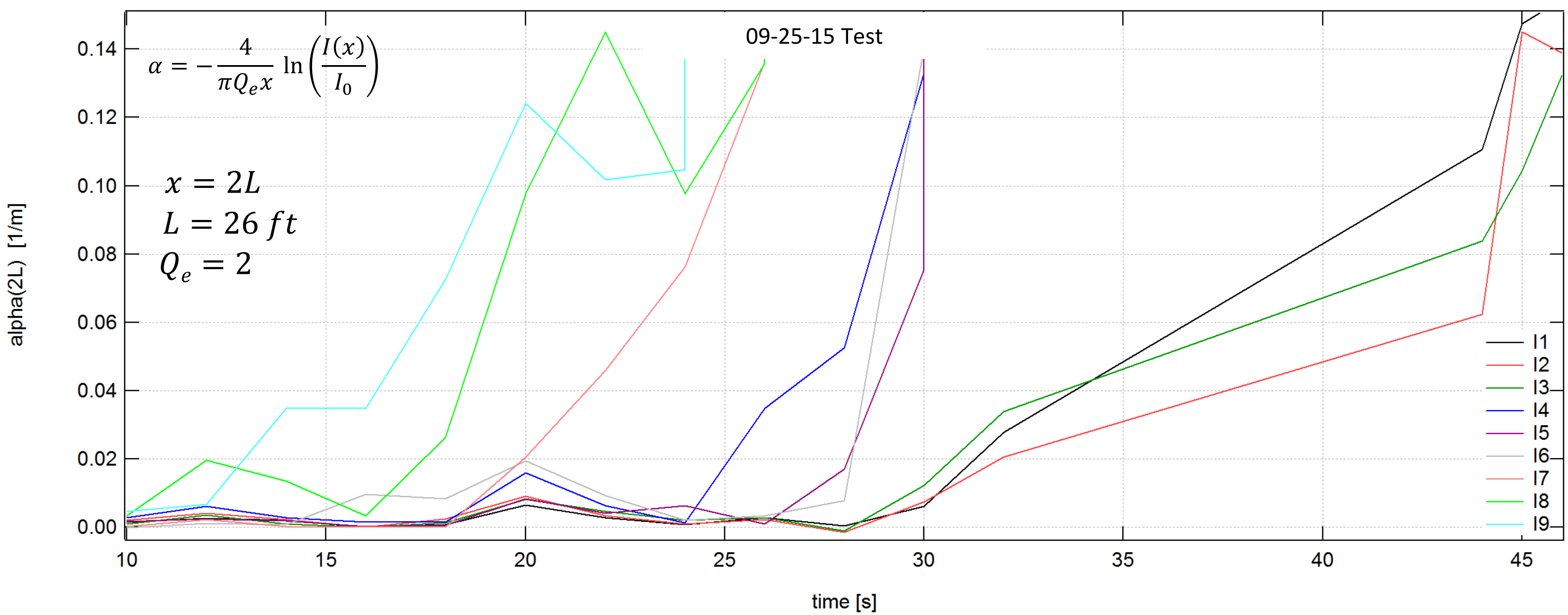
= $2L$ (where L is bin width ≈ 7.9 m)

$$\alpha = -\frac{4}{\pi Q_e x} \ln\left(\frac{I(x)}{I_0}\right) \ [\mathrm{m}^{-1}]$$

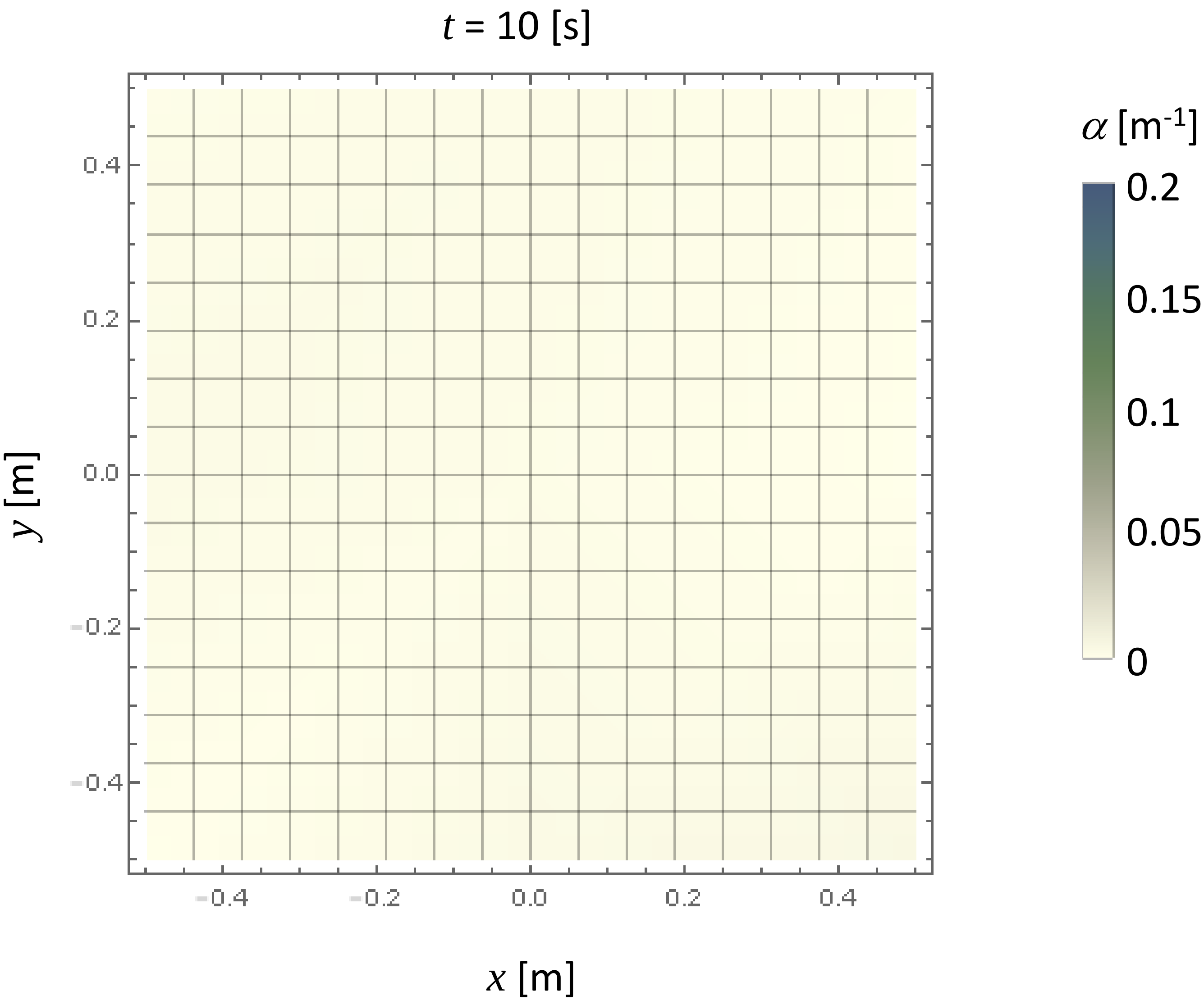
$$\alpha = \int_0^\infty D^2 N(D) dD$$

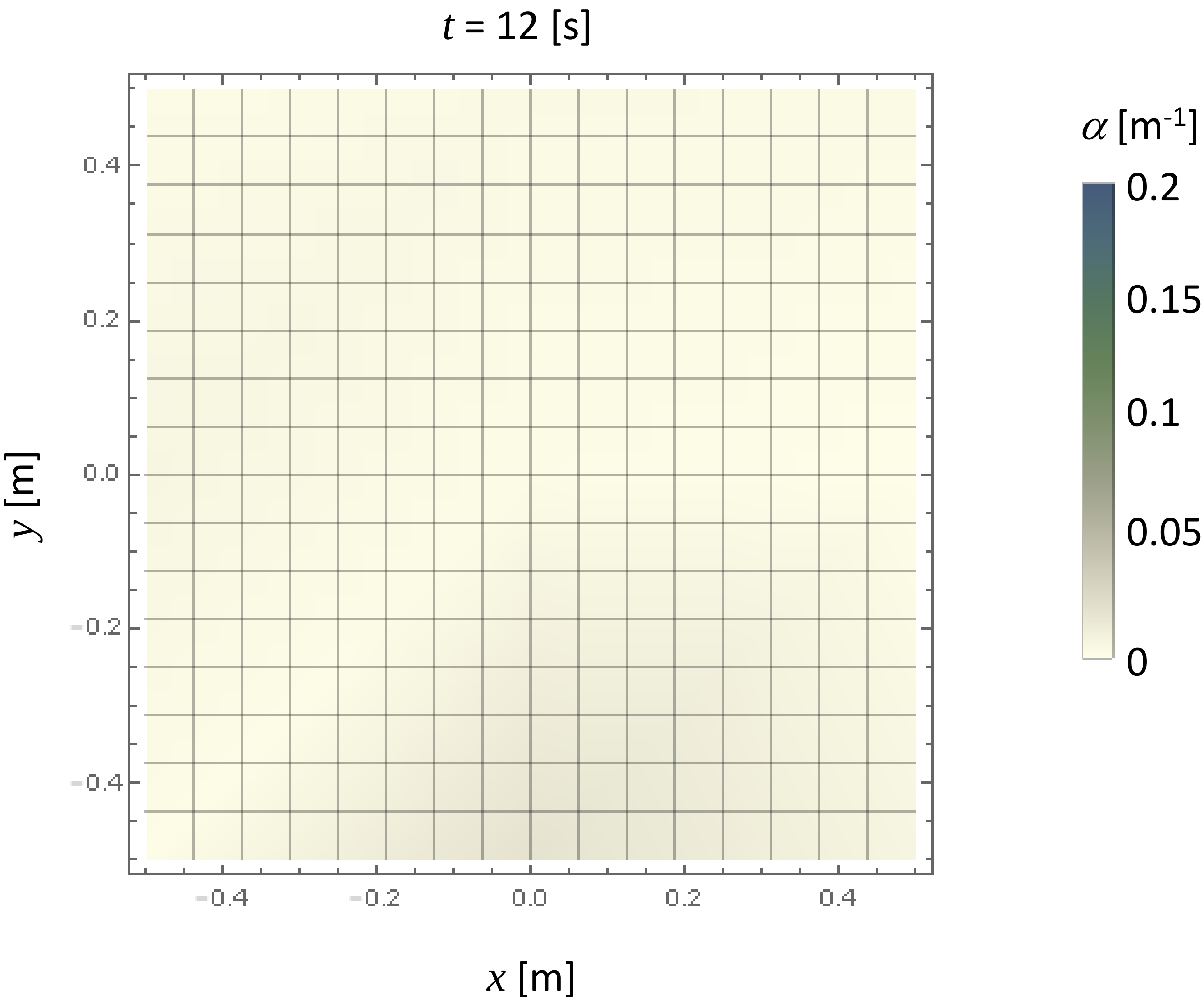
D = Particle Diameter [m]

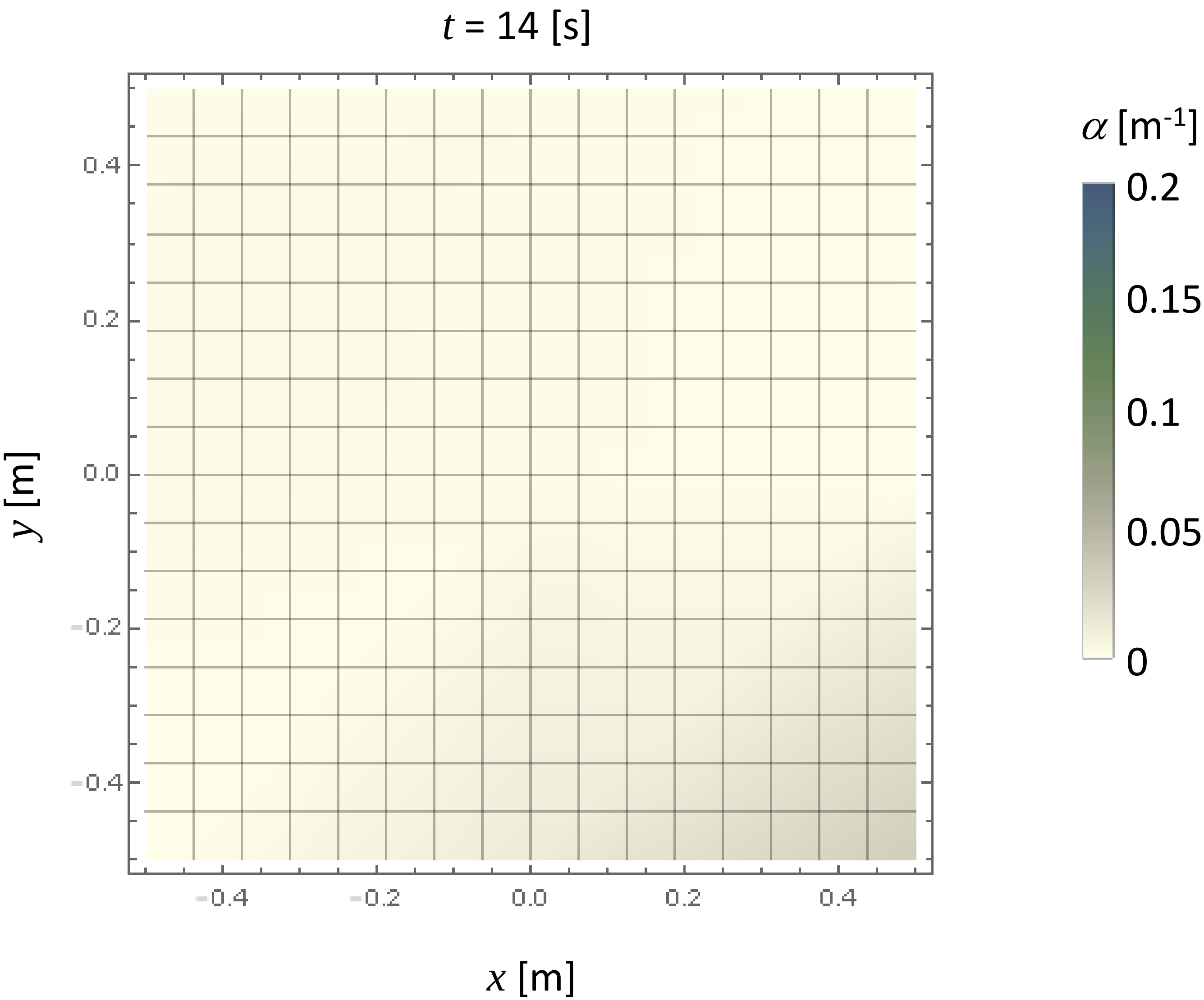
$N(D)$ = Particle Size Distribution [$\mathrm{m}^{-3}\ \mathrm{m}^{-1}$]



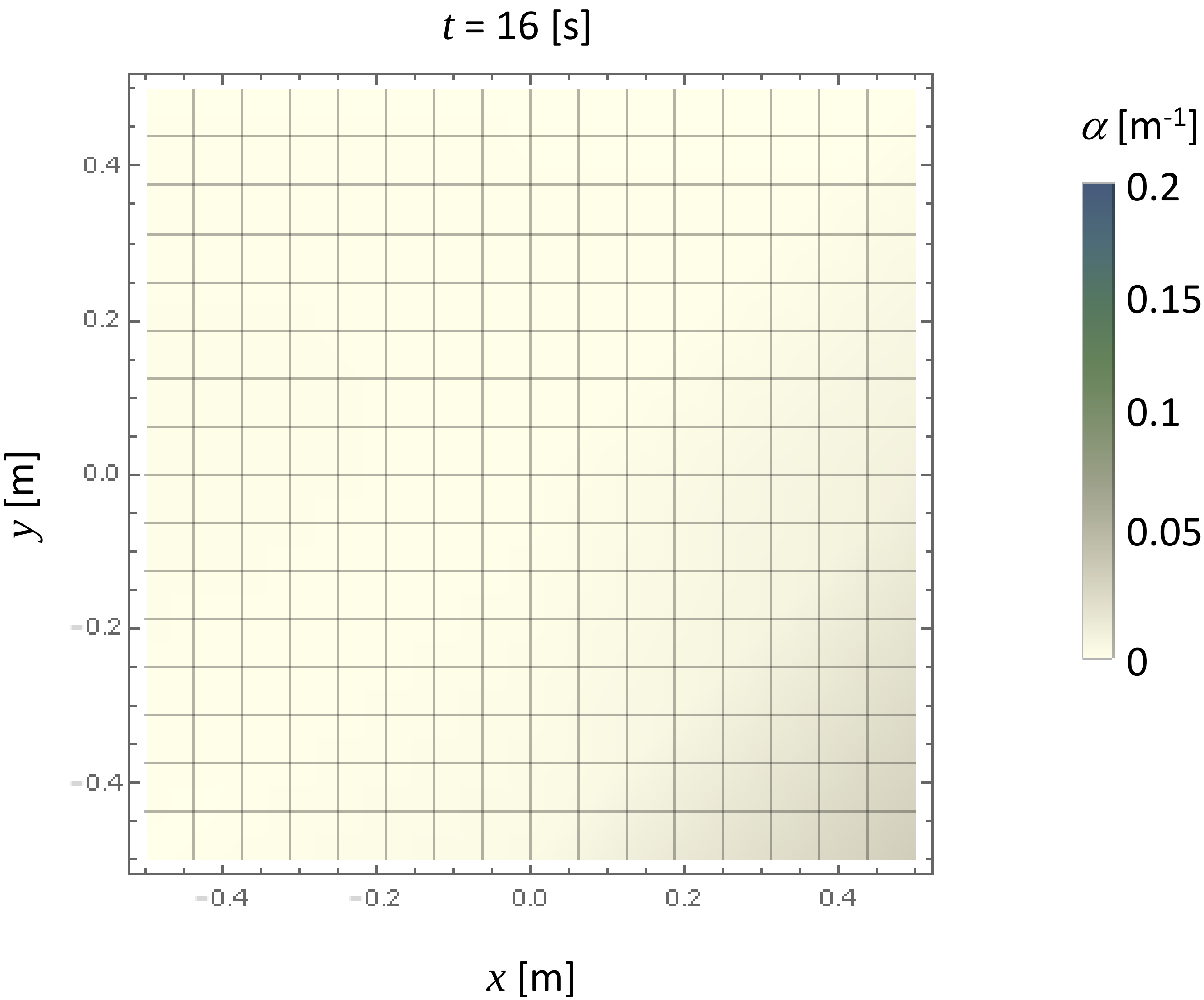
09-25-15 Test
$\alpha = -\frac{4}{\pi Q_e x} \ln\left(\frac{I(x)}{I_0}\right)$
$x = 2L$
$L = 26\ ft$
$Q_e = 2$
alpha(2L) [1/m]
time [s]
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
10
15
20
25
30
35
40
45
I1
I2
I3
I4
I5
I6
I7
I8
I9


t = 10 [s]
y [m]
x [m]
0.4
0.2
0.0
-0.2
-0.4
α [m-1]
0.2
0.15
0.1
0.05
0

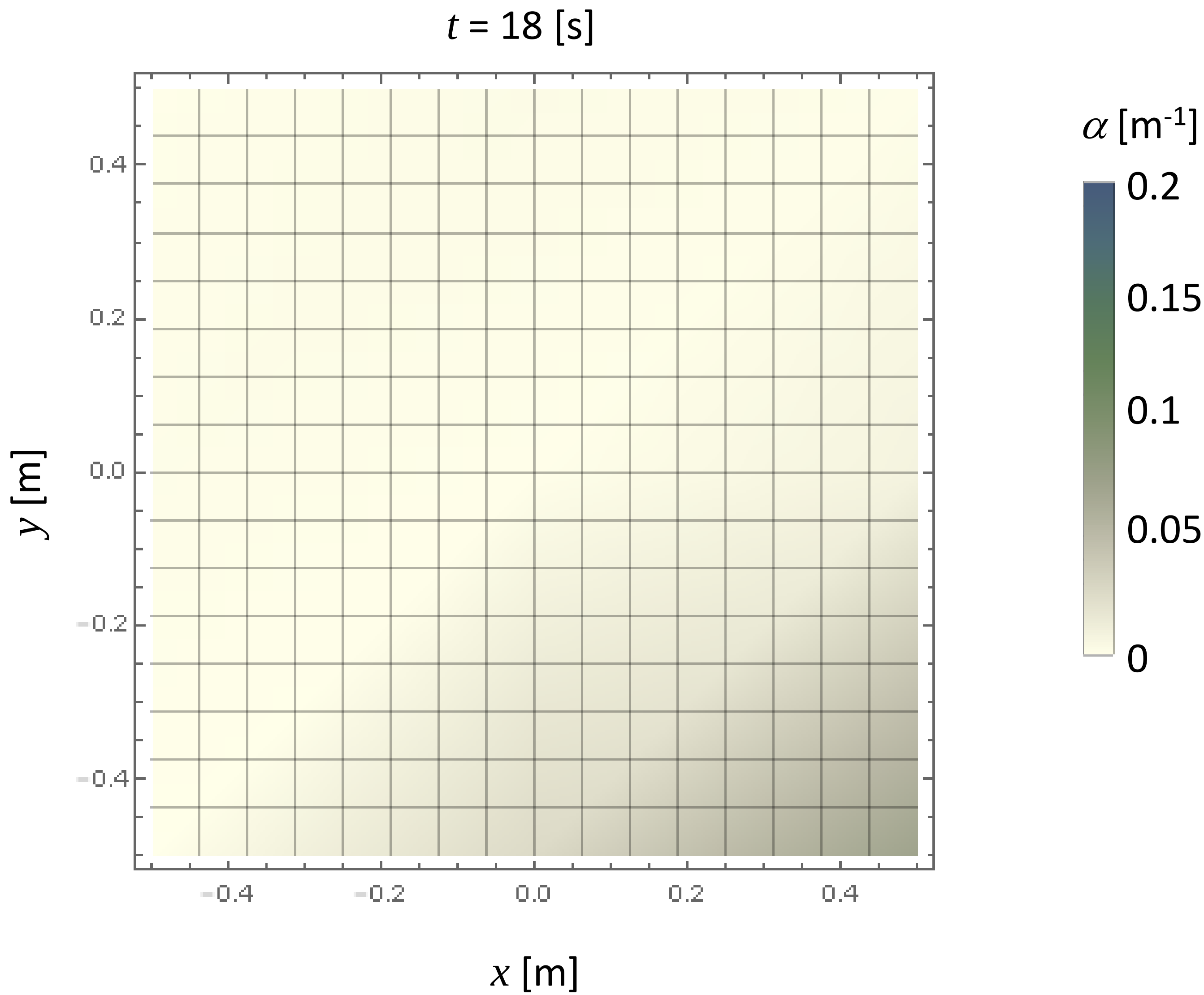

t = 12 [s]
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]
α [m-1]
0.2
0.15
0.1
0.05
0

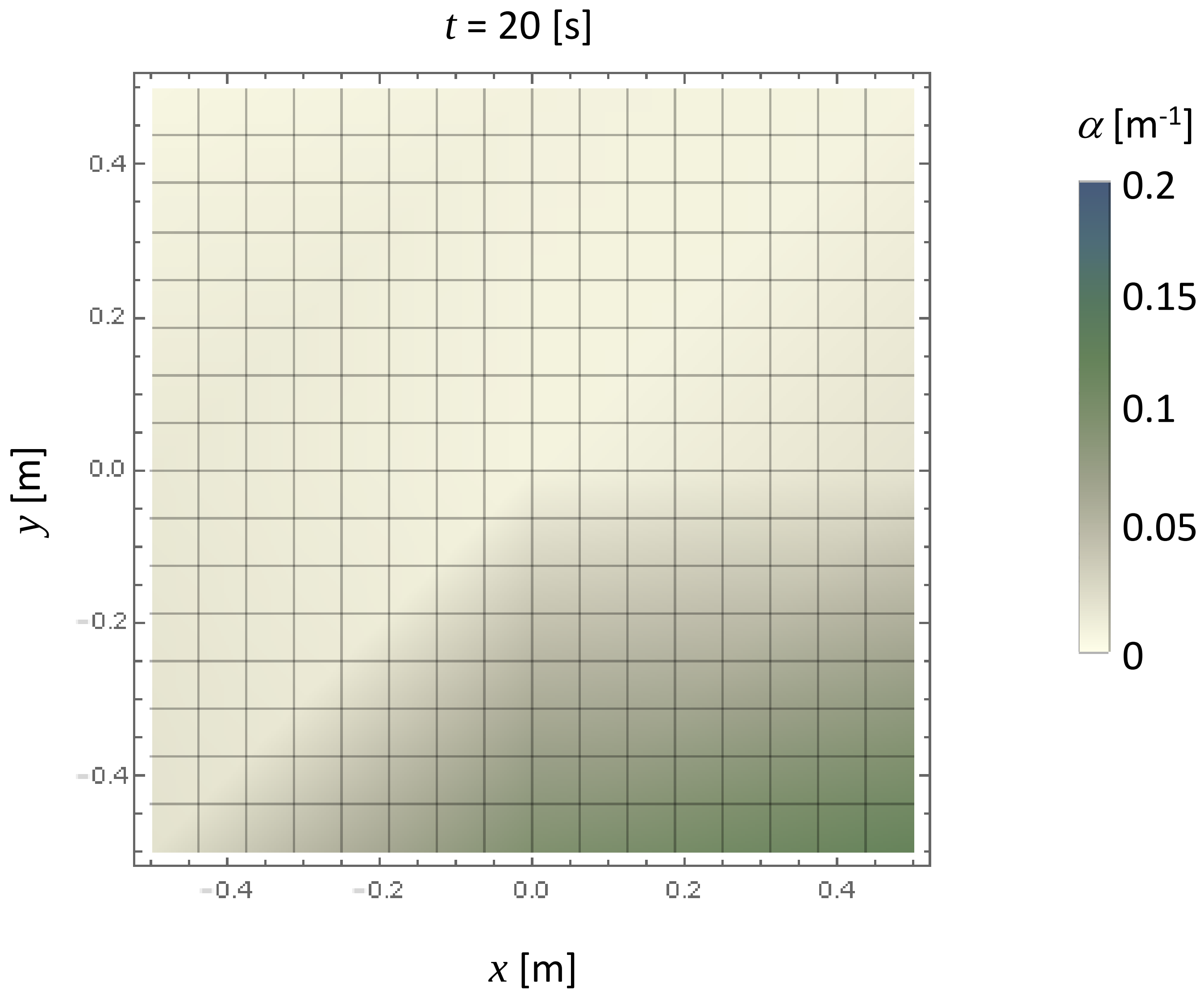


t = 14 [s]
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]
α [m^{-1}]
0.2
0.15
0.1
0.05
0

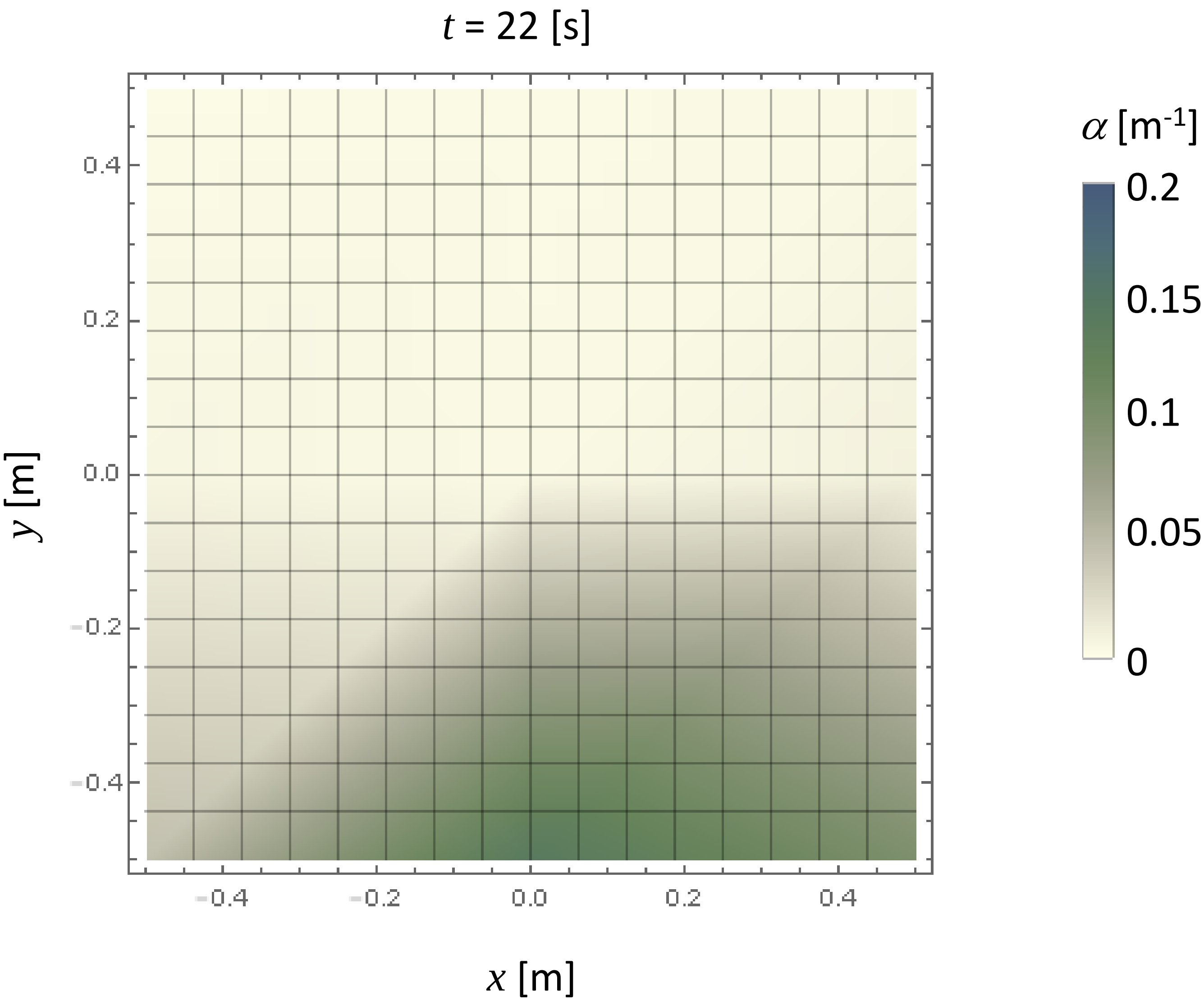


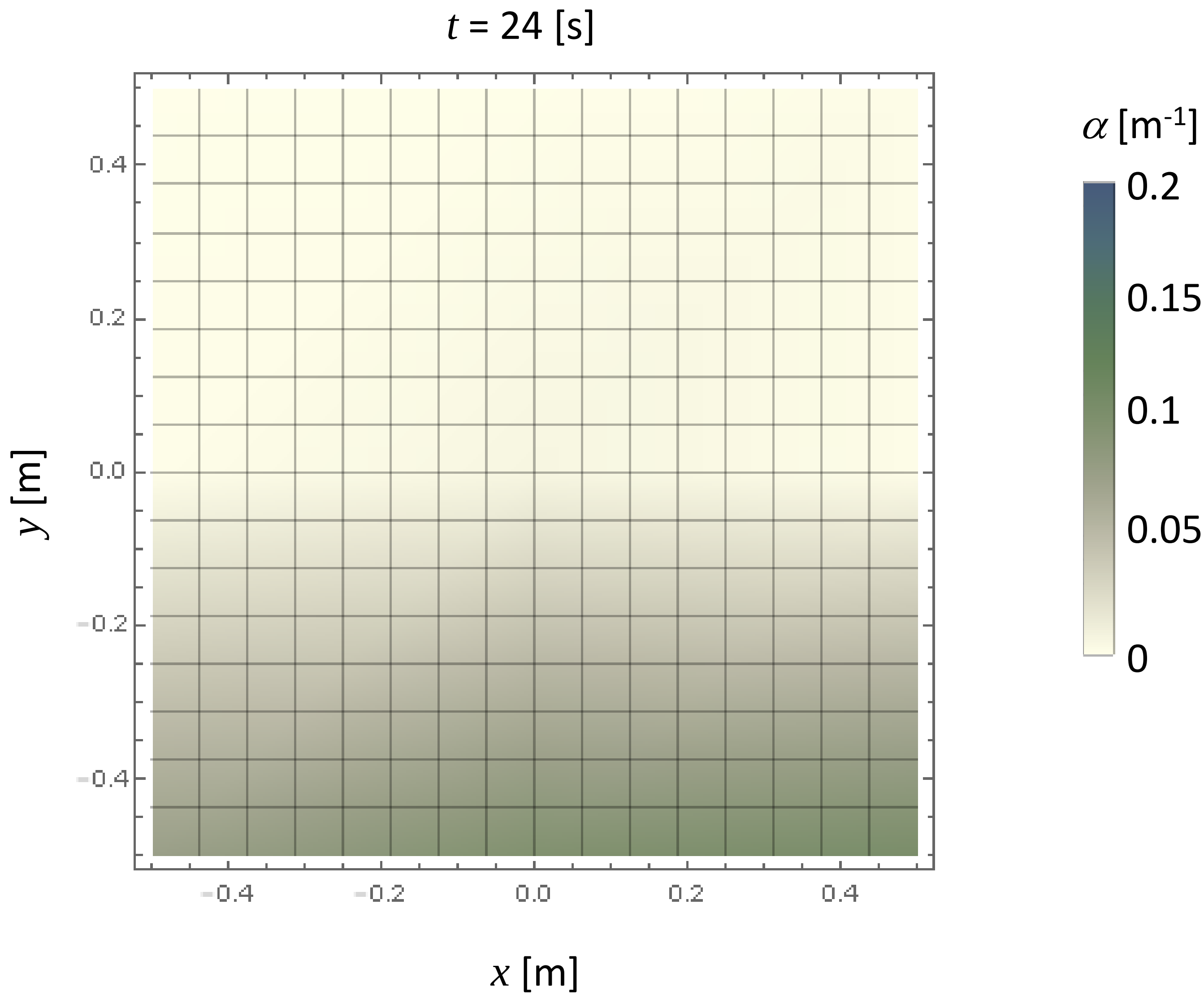
t = 16 [s]
α [m-1]
0.2
0.15
0.1
0.05
0
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]

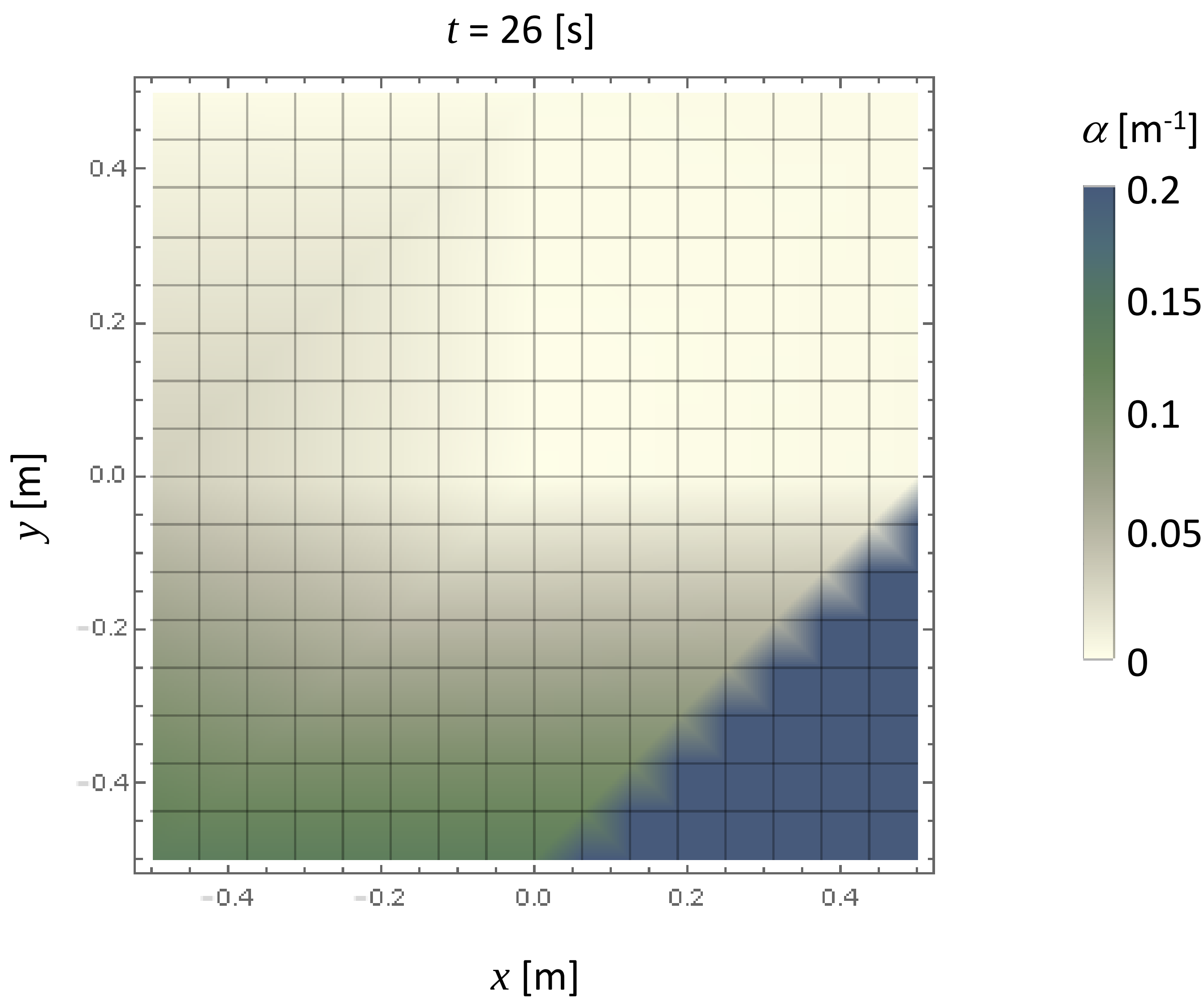

t = 18 [s]
α [m-1]
0.2
0.15
0.1
0.05
0
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]



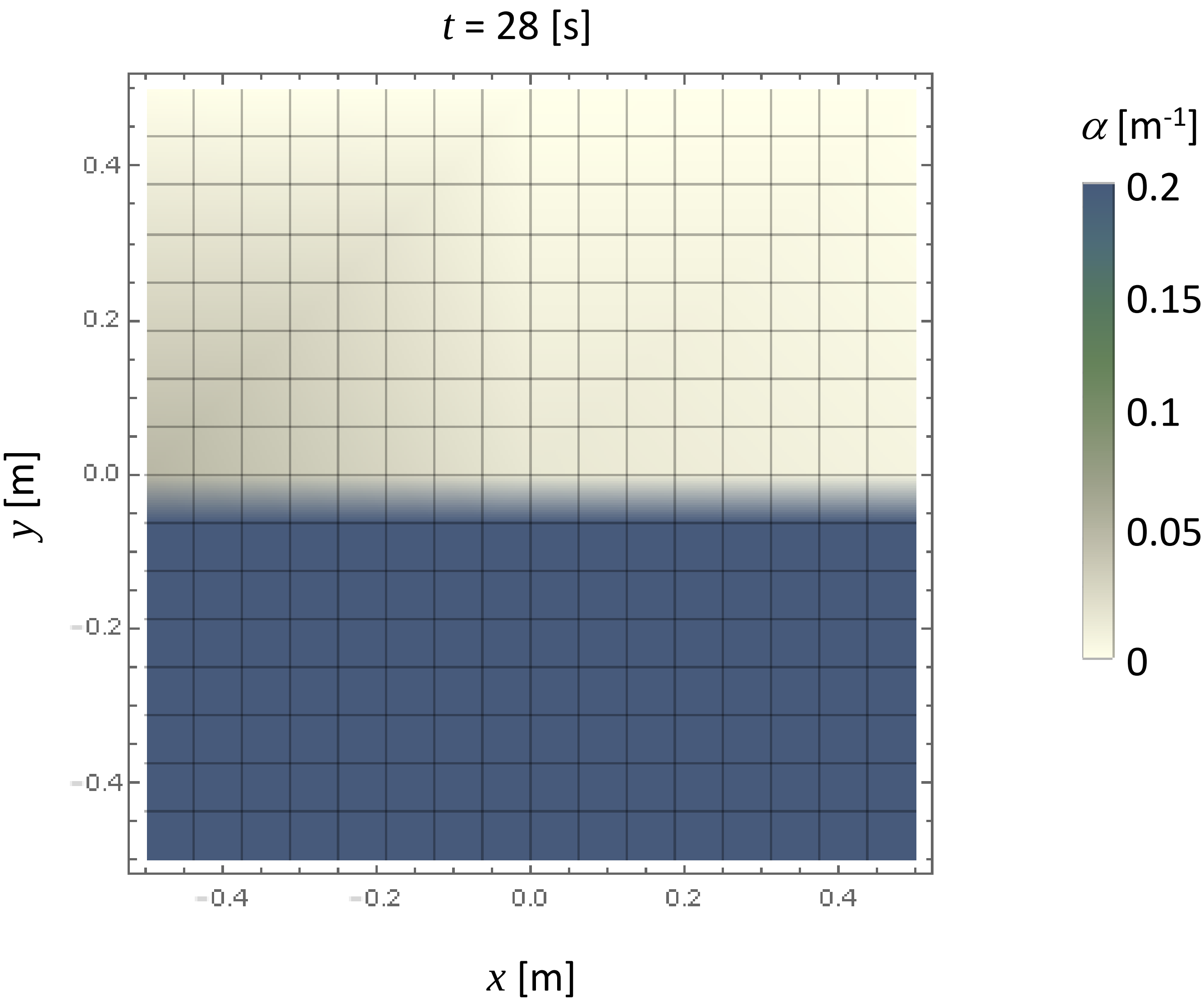
t = 20 [s]
α [m-1]
0.2
0.15
0.1
0.05
0
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]


t = 22 [s]
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]
α [m-1]
0.2
0.15
0.1
0.05
0

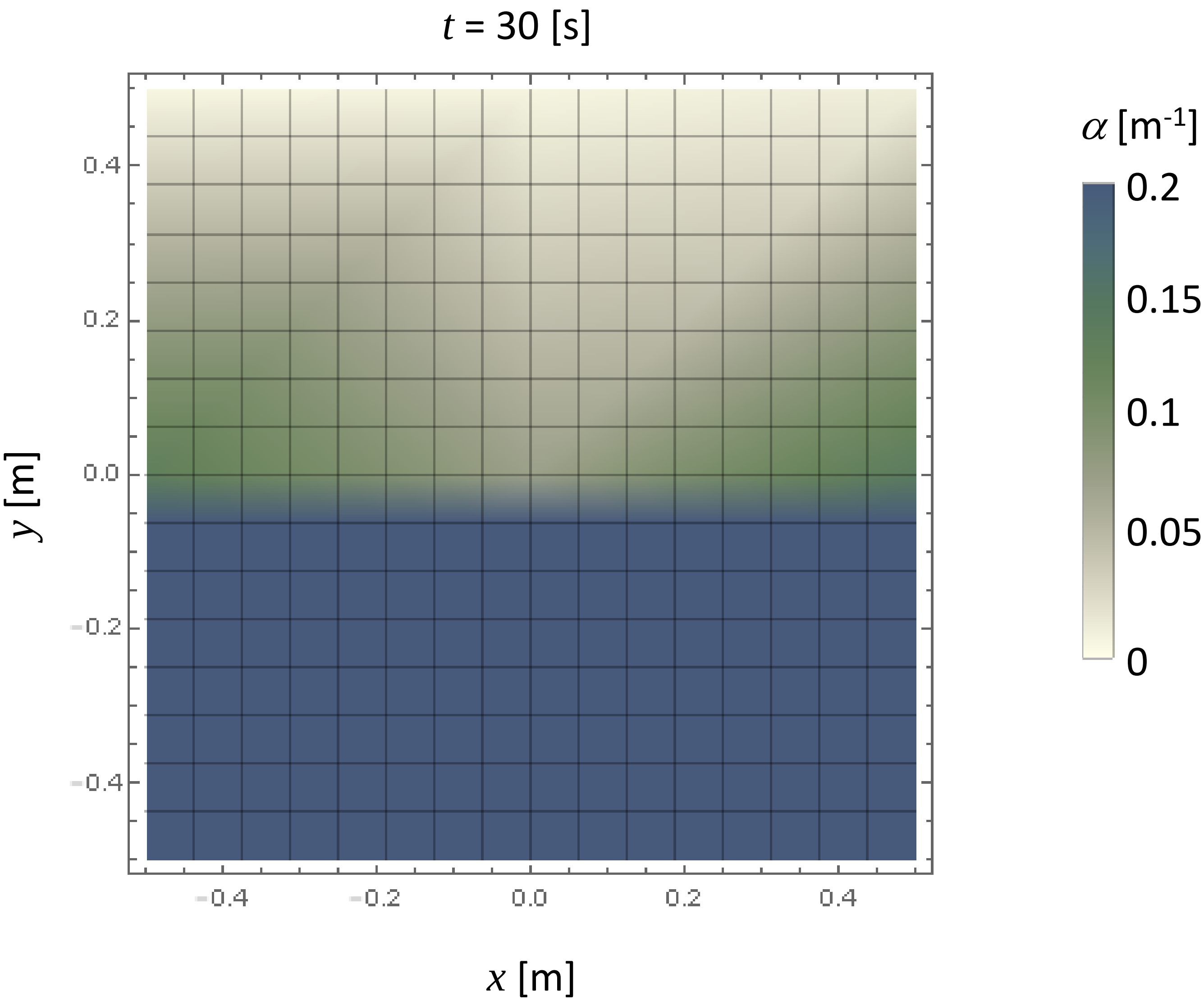

t = 24 [s]
y [m]
0.4
0.2
0.0
-0.2
-0.4
x [m]
-0.4
-0.2
0.0
0.2
0.4
α [m-1]
0.2
0.15
0.1
0.05
0



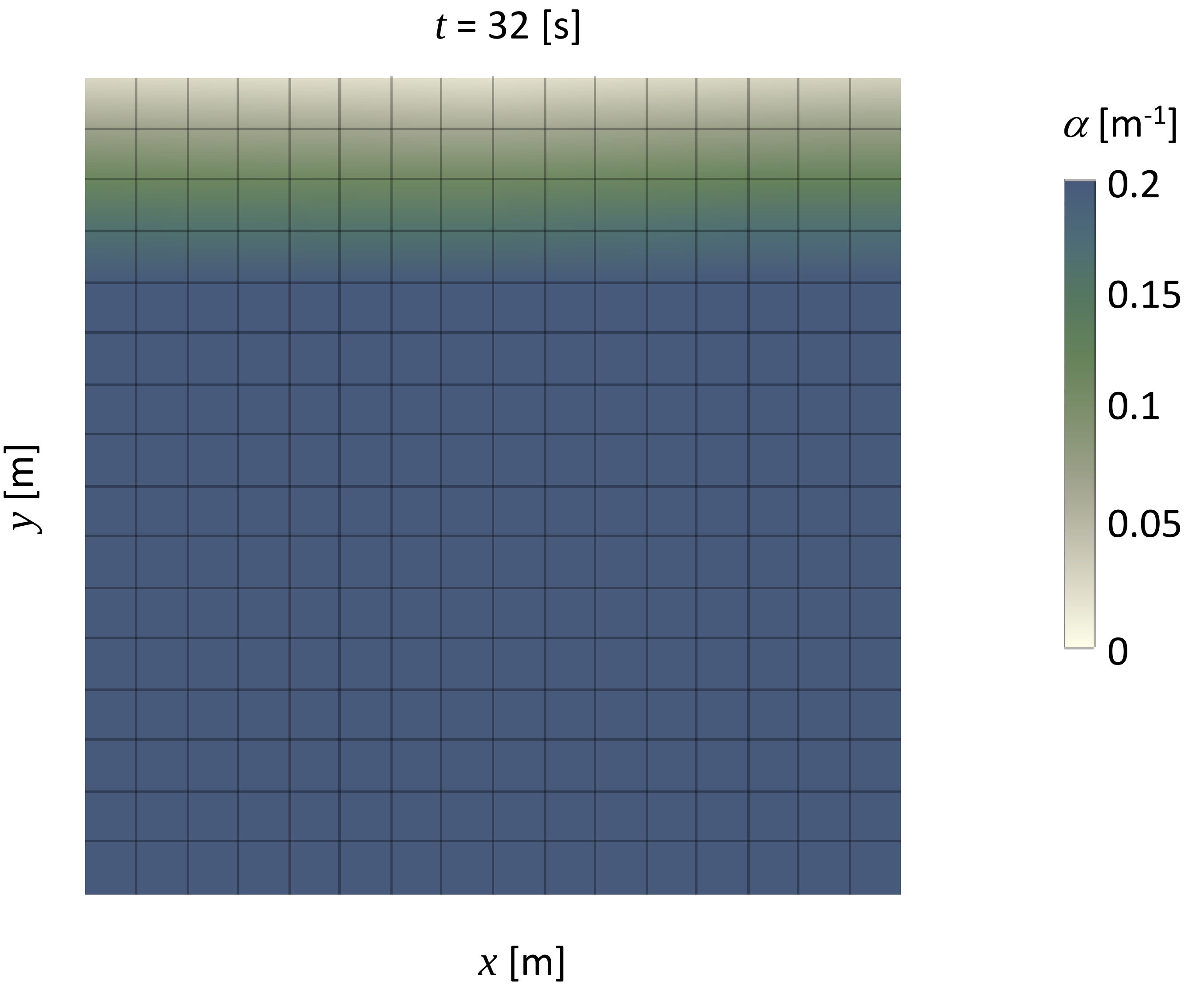
t = 26 [s]
y [m]
0.4
0.2
0.0
-0.2
-0.4
x [m]
-0.4
-0.2
0.0
0.2
0.4
α [m-1]
0.2
0.15
0.1
0.05
0



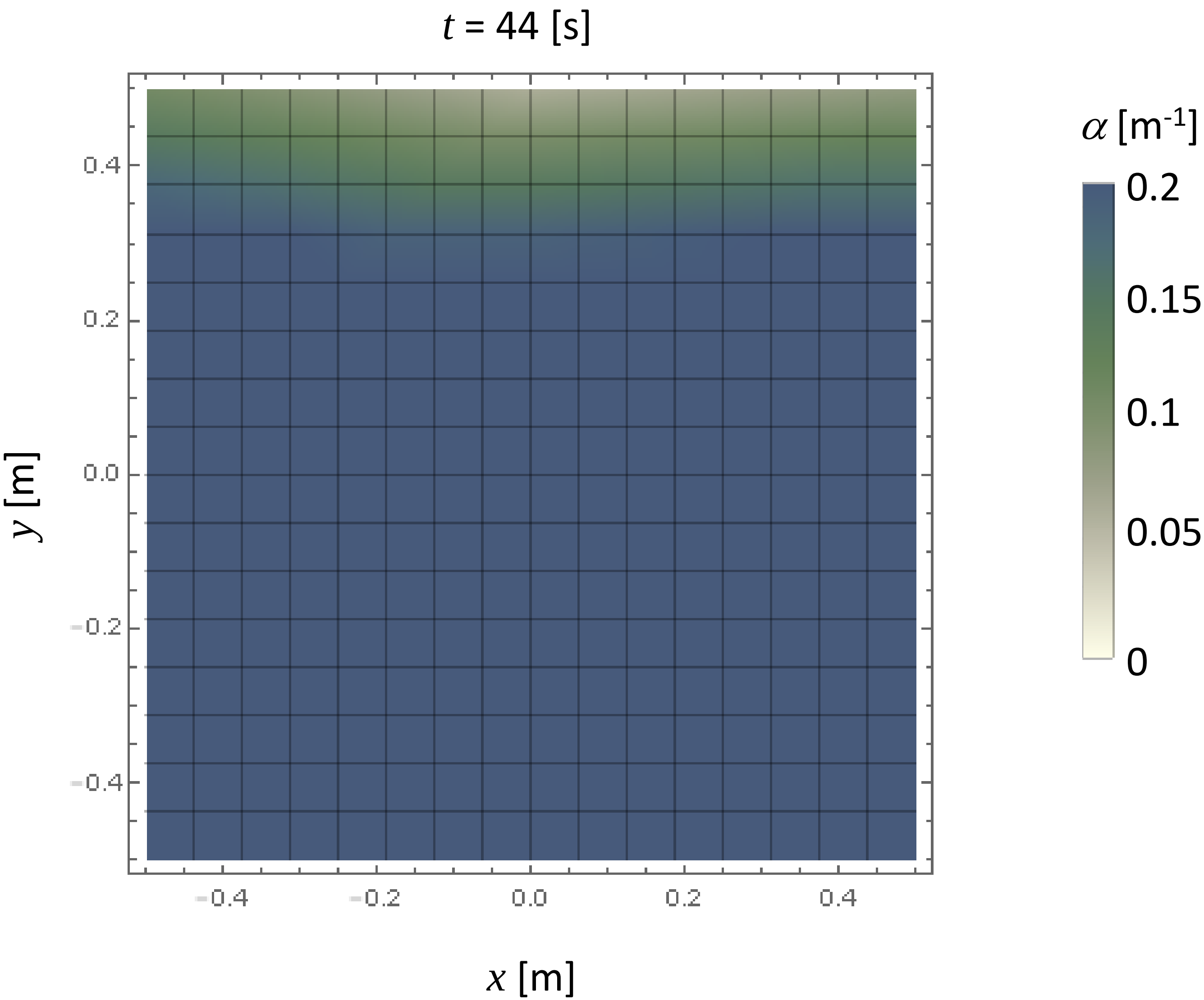
t = 28 [s]
α [m-1]
0.2
0.15
0.1
0.05
0
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]



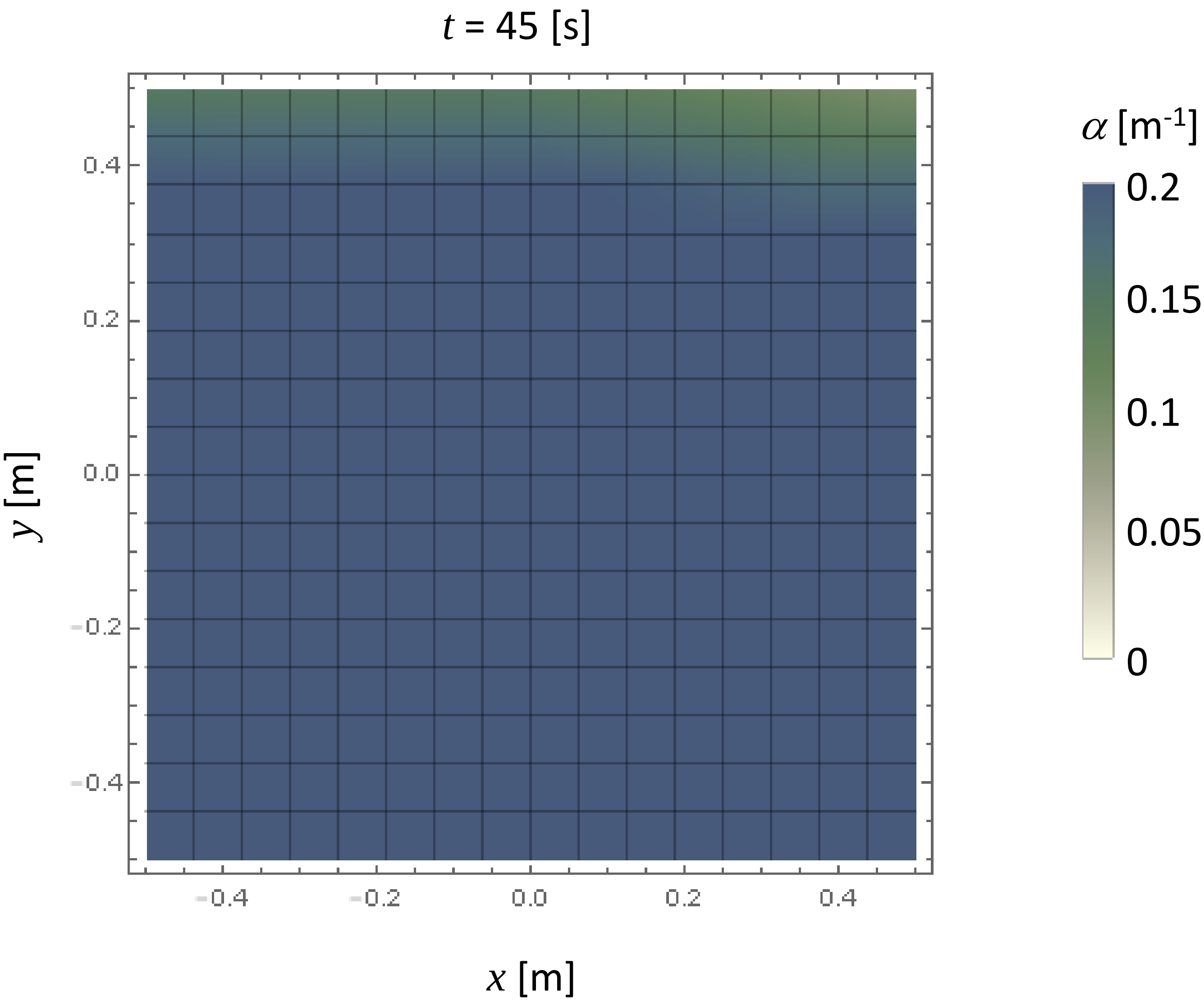
t = 30 [s]
α [m-1]
0.2
0.15
0.1
0.05
0
y [m]
0.4
0.2
0.0
-0.2
-0.4
x [m]
-0.4
-0.2
0.0
0.2
0.4



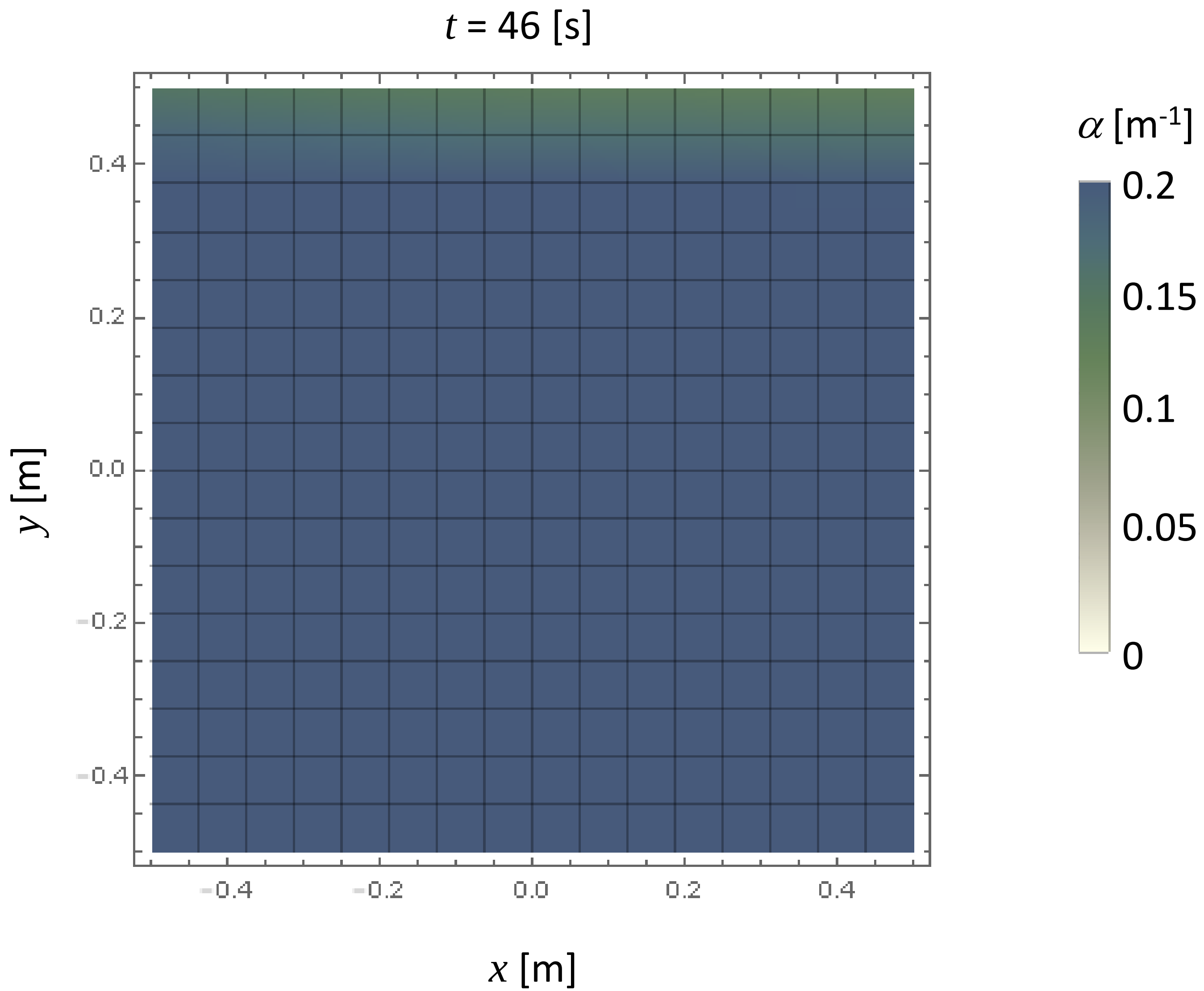
t = 32 [s]
α [m^{-1}]
0.2
0.15
0.1
0.05
0
y [m]
x [m]



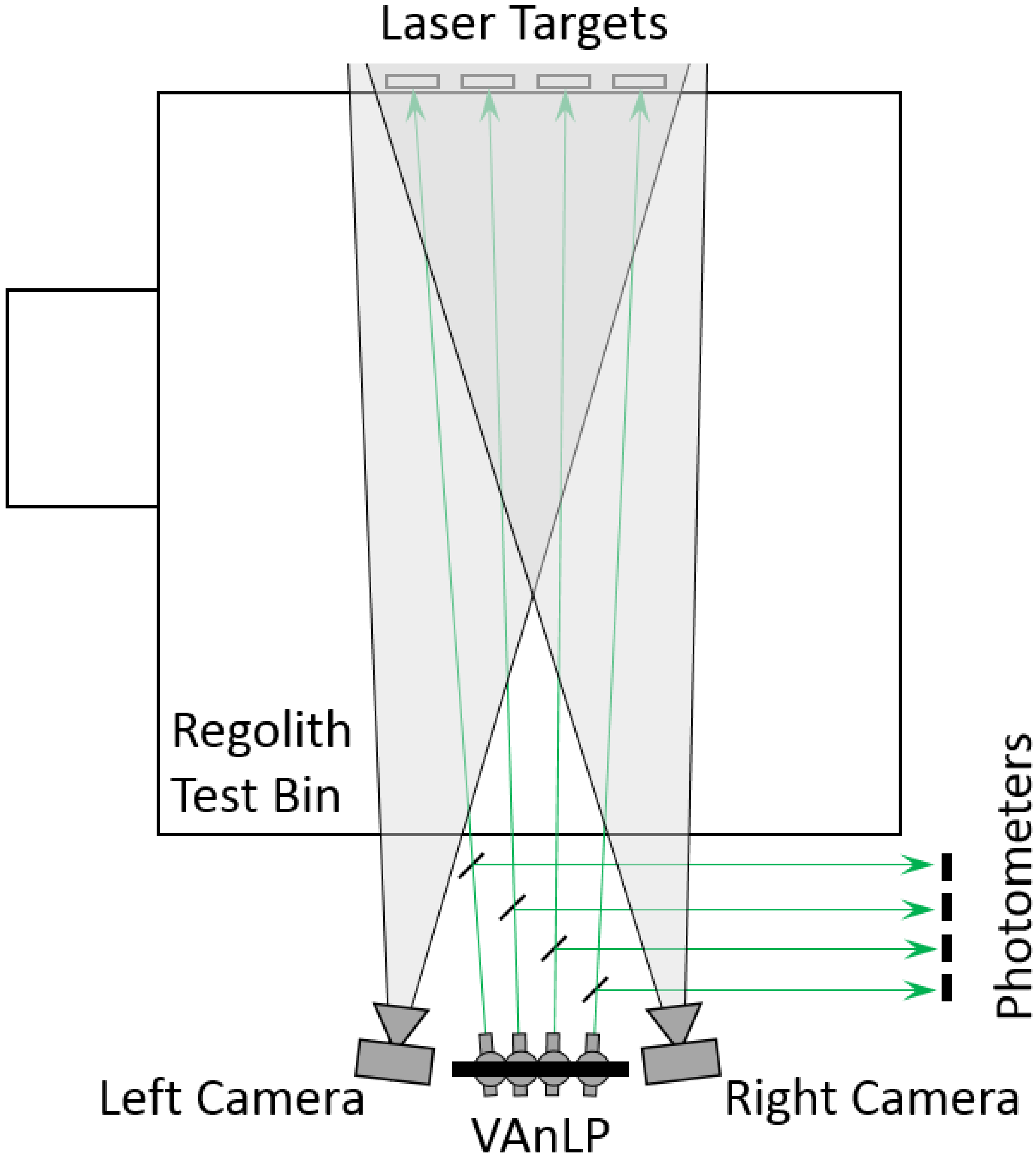
t = 44 [s]
y [m]
0.4
0.2
0.0
-0.2
-0.4
x [m]
-0.4
-0.2
0.0
0.2
0.4
α [m-1]
0.2
0.15
0.1
0.05
0



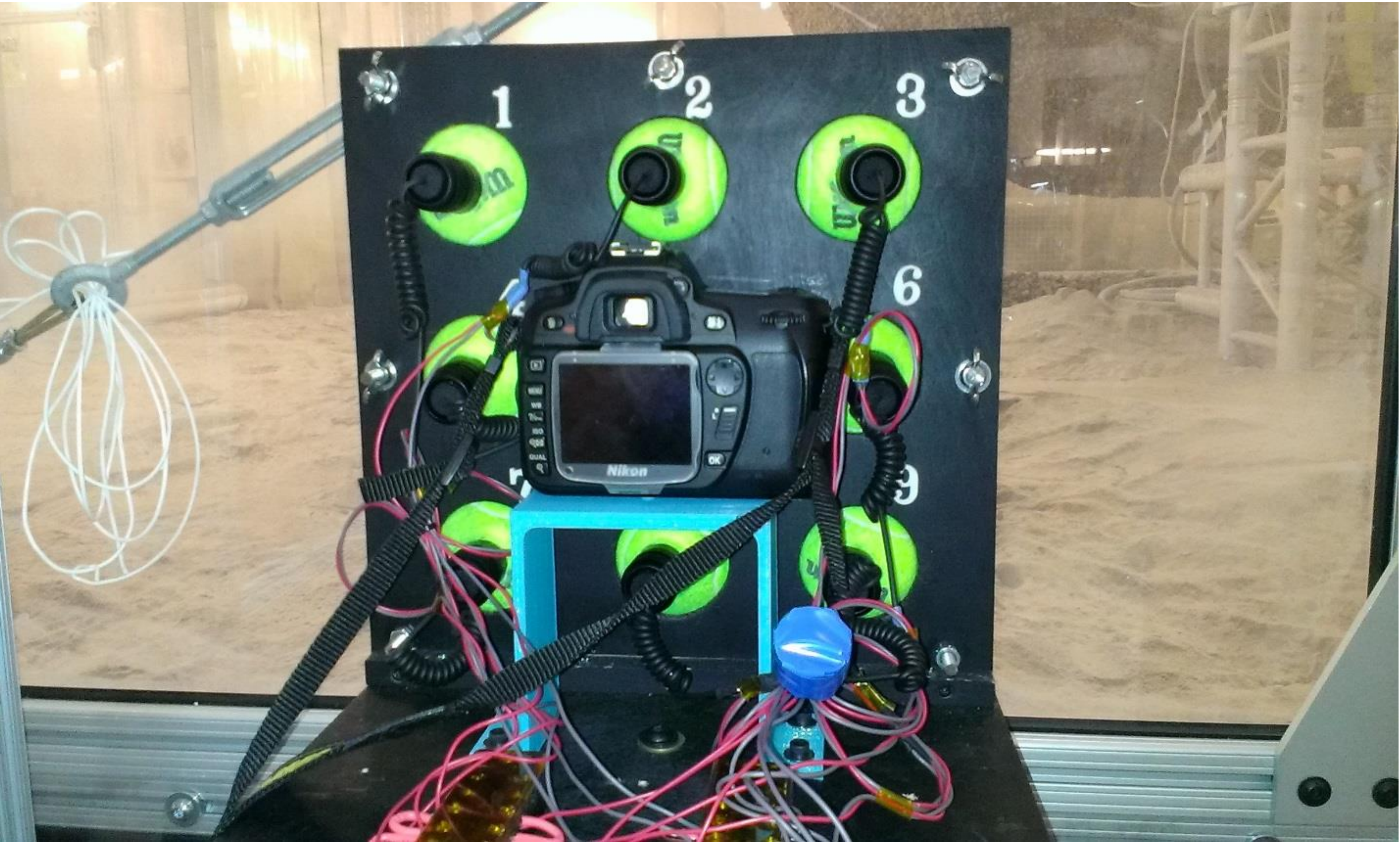
t = 45 [s]
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]
α [m-1]
0.2
0.15
0.1
0.05
0

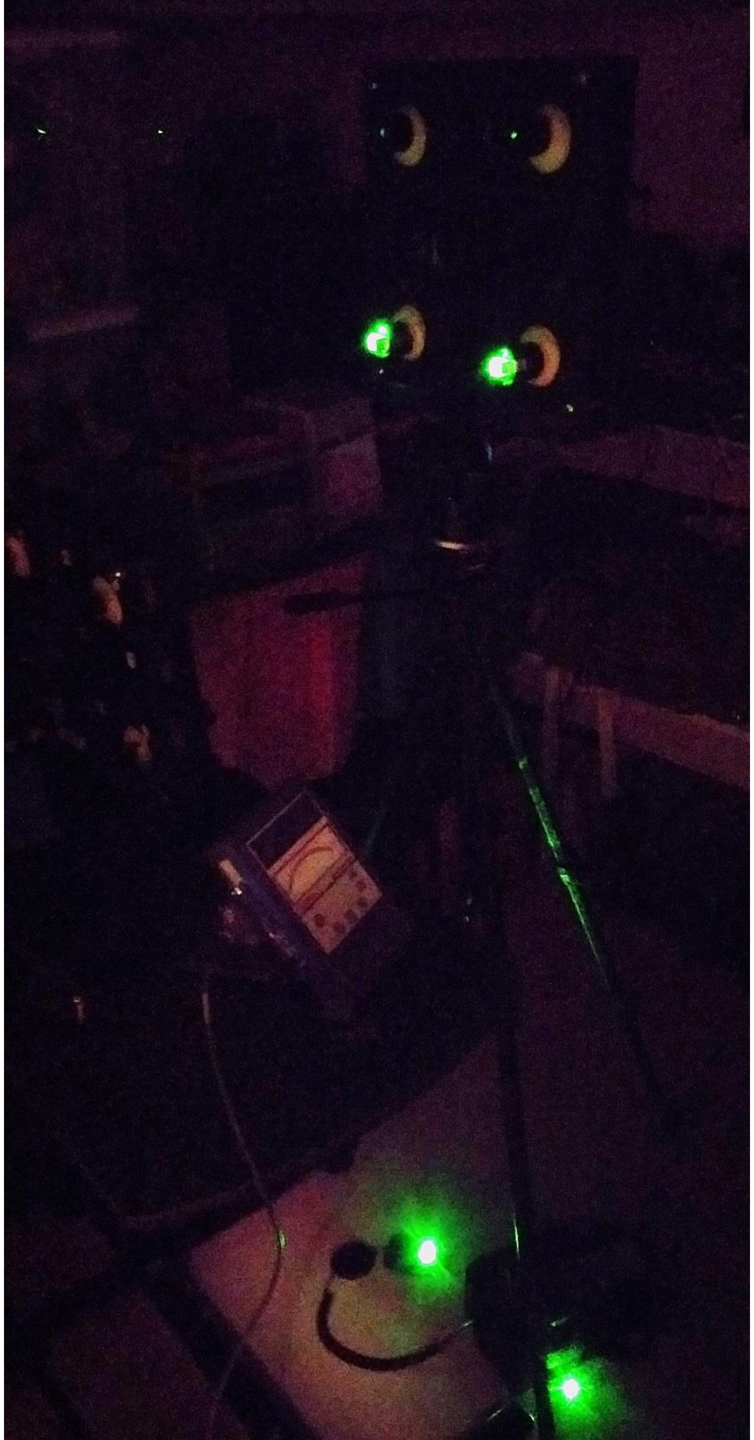


t = 46 [s]
0.4
0.2
0.0
-0.2
-0.4
y [m]
-0.4
-0.2
0.0
0.2
0.4
x [m]
α [m-1]
0.2
0.15
0.1
0.05
0


Laser Targets
Regolith
Test Bin
Photometers
Left Camera
VAnLP
Right Camera

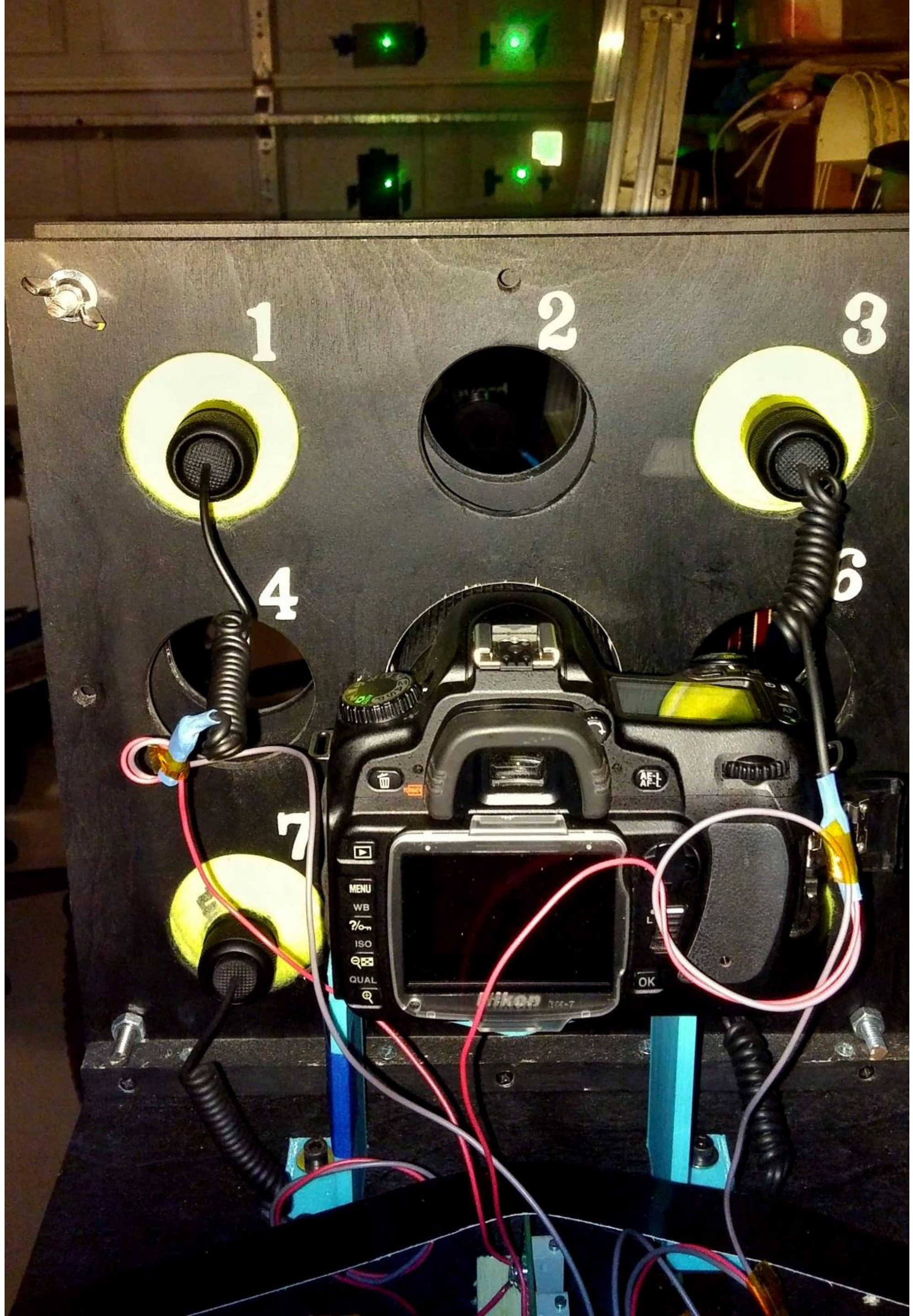
Variable angle eight laser pointer plus camera (VA8LP+C).

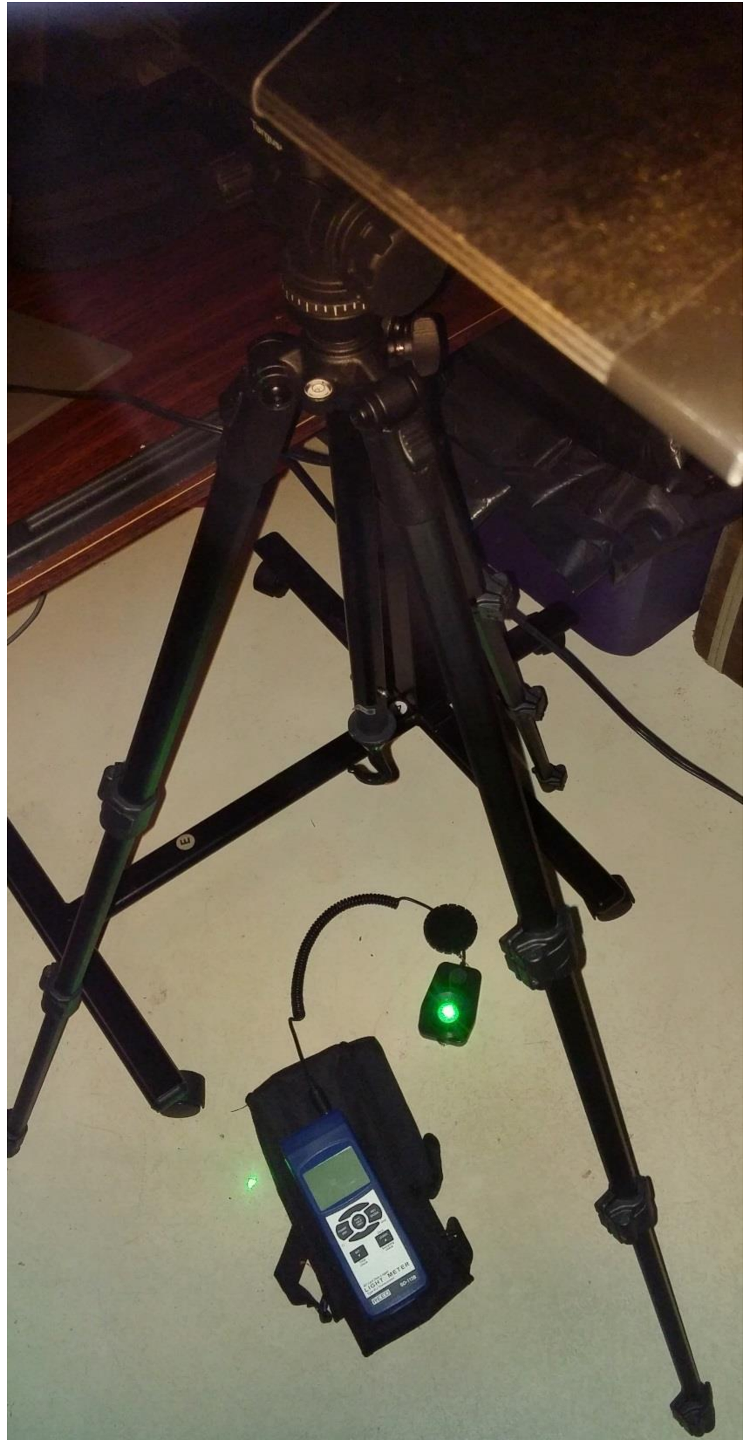


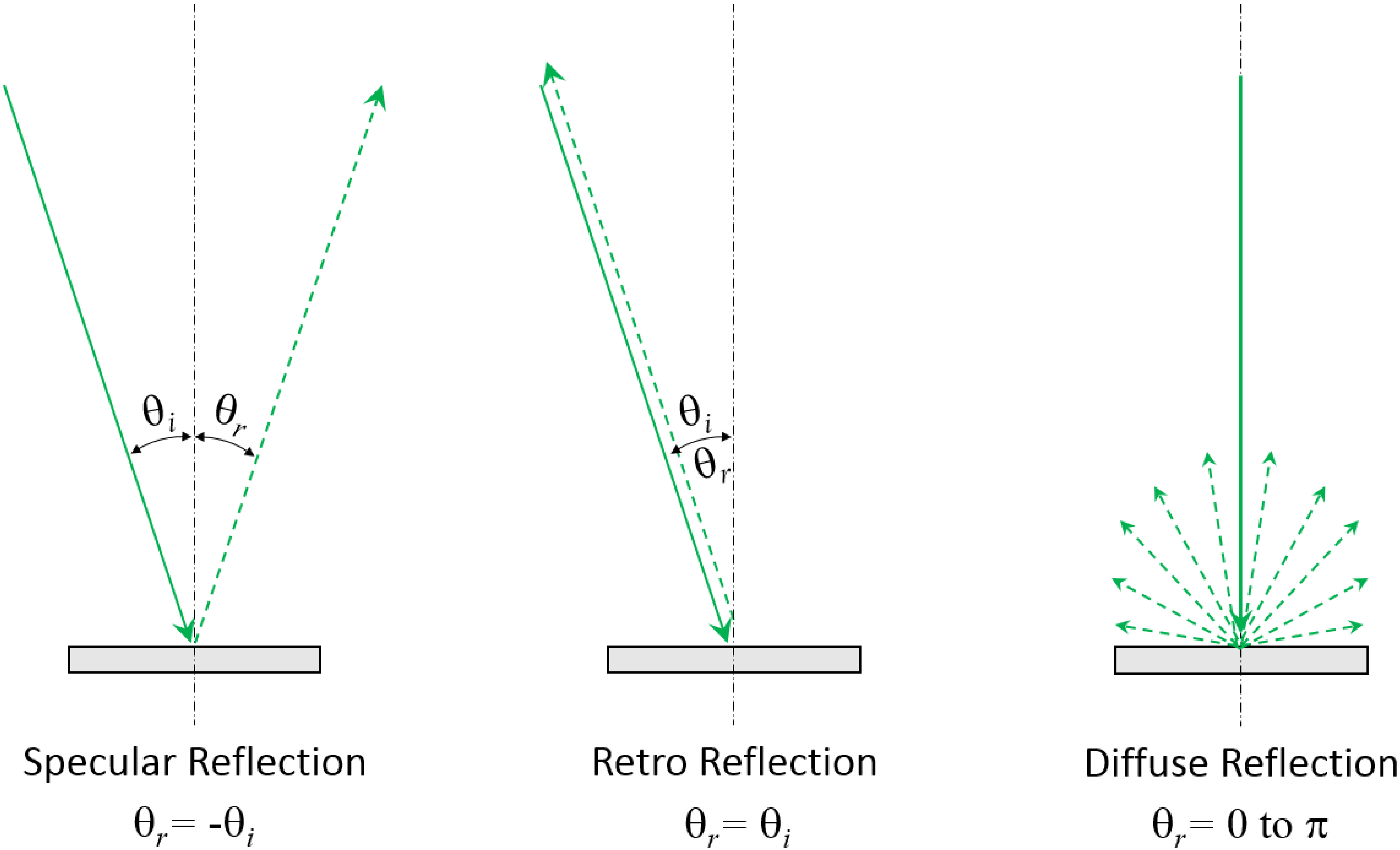


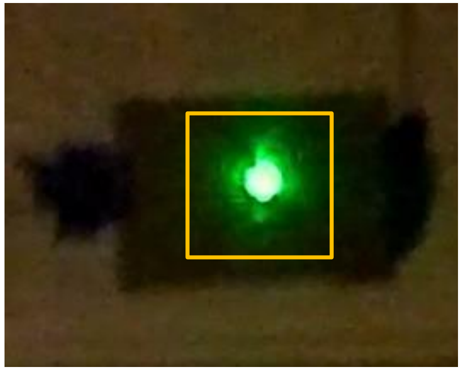

Nikon


Nikon
Targus

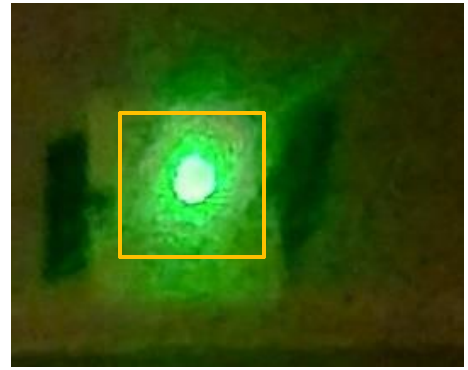

1
2
3
4
6
7
AF-L
MENU
WB
ISO
QUAL
OK


REED
LIGHT METER


θi
θr
Specular Reflection
θr = -θi
θi
θr
Retro Reflection
θr = θi
Diffuse Reflection
θr = 0 to π

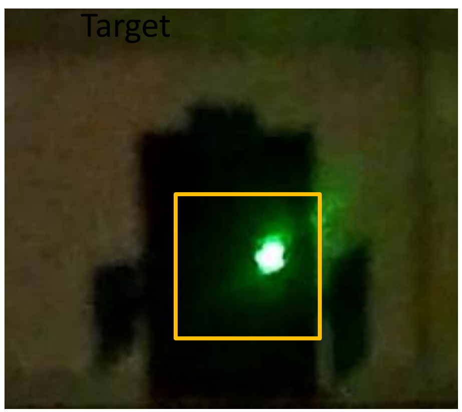


Diffuse (Gray) Target



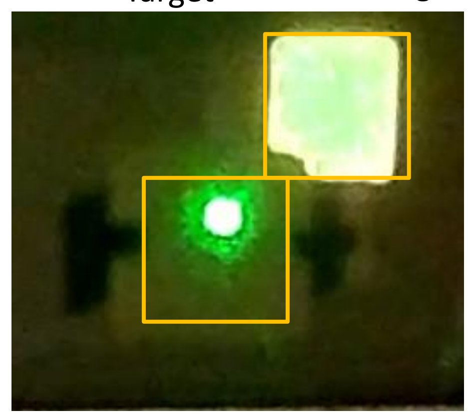
Diffuse (White) Target

Diffuse (Black) Target

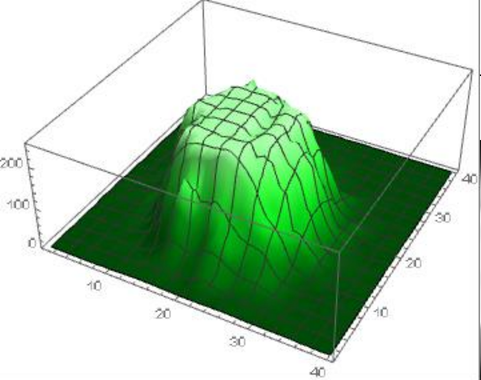


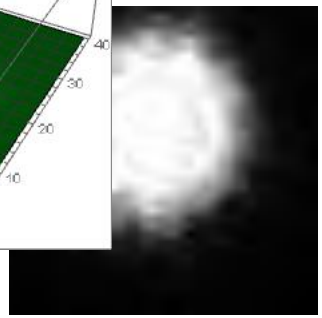
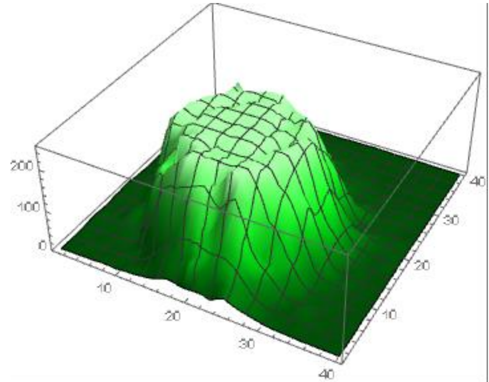
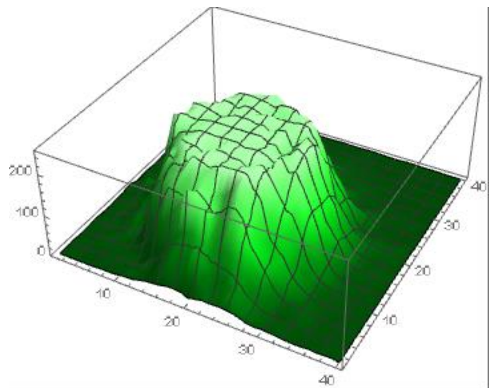
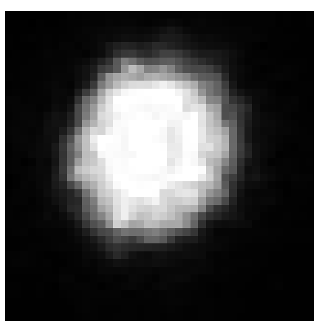
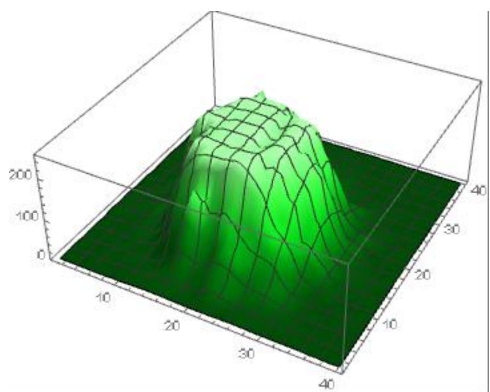
Diffuse (White) Target

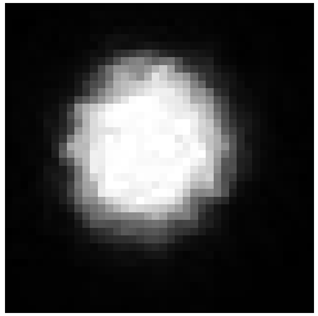
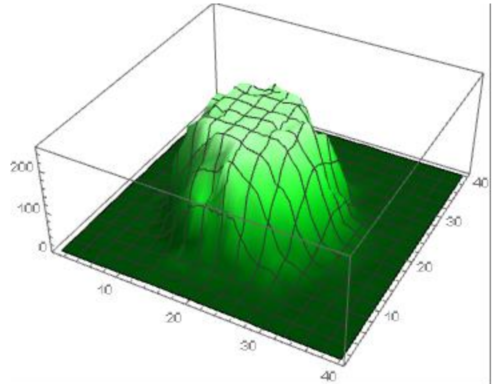
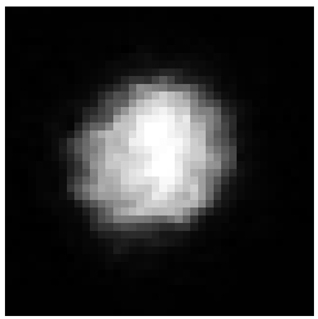
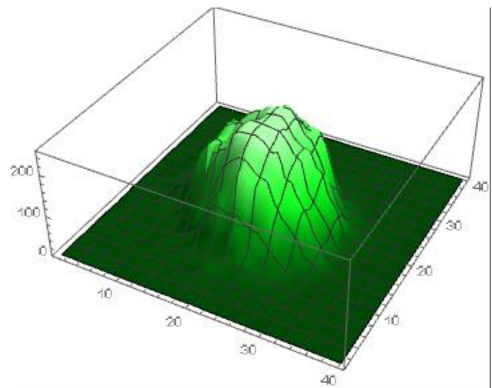
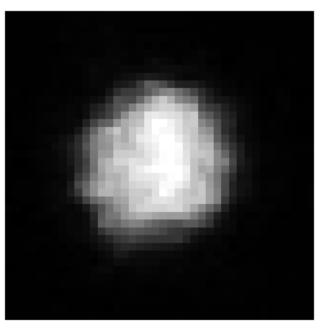
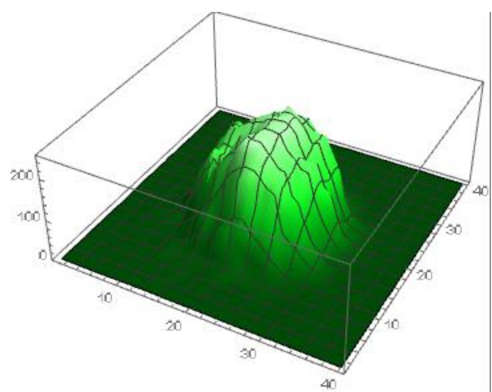
Retro Target

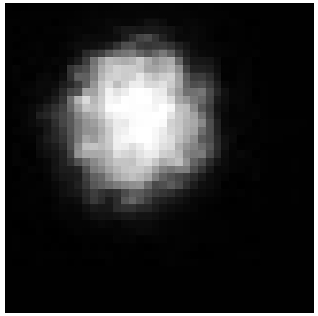
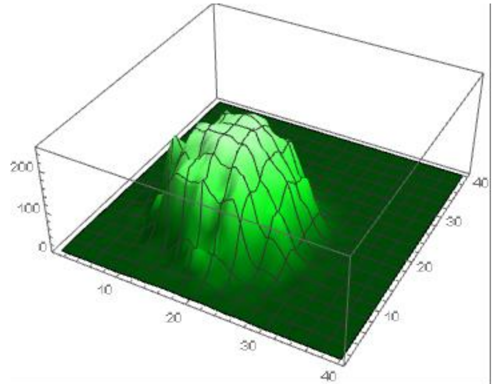
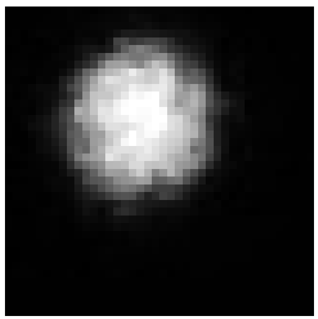
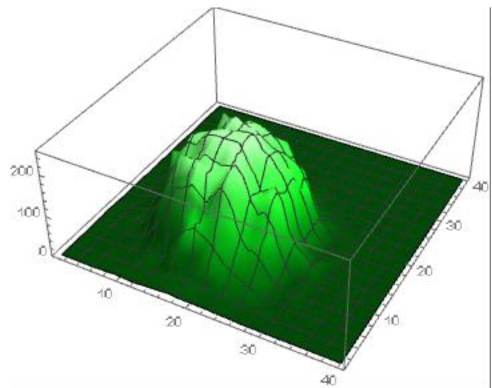
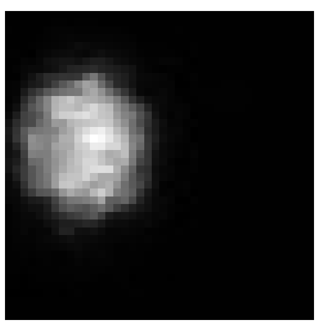
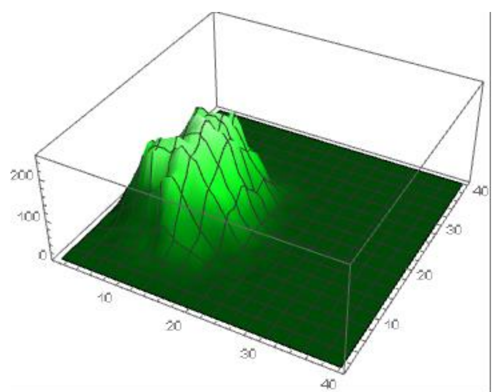


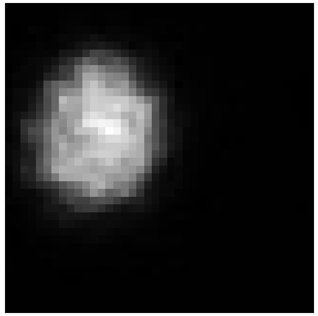
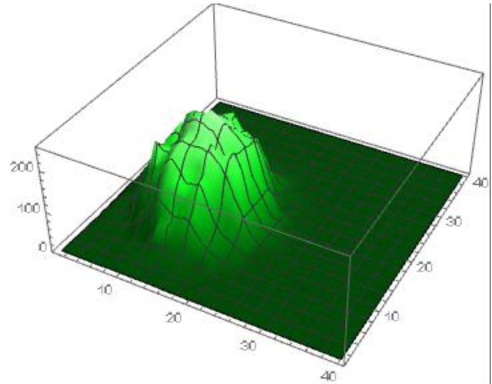
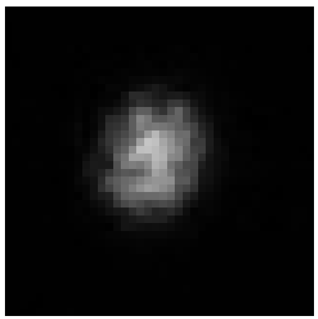
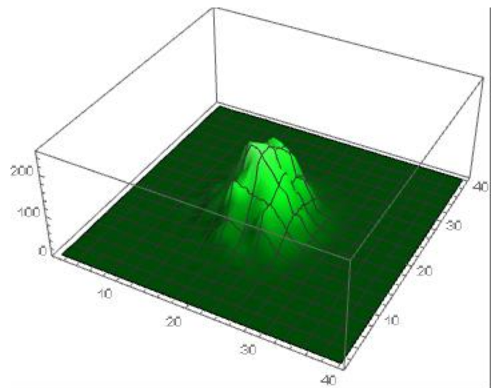
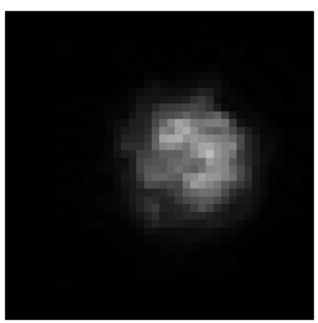
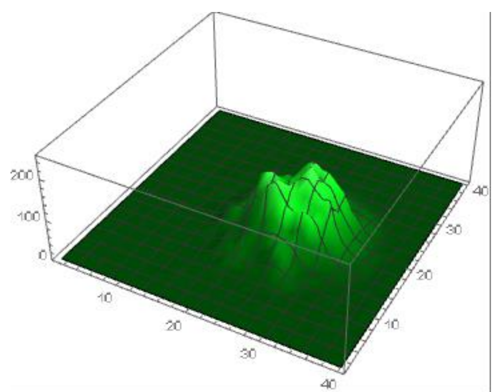
Camera image, DSC_0037.jpg corresponding to above Figures c and d: ISO = 100, shutter speed = 1/320 s, and aperture = *f*/11.

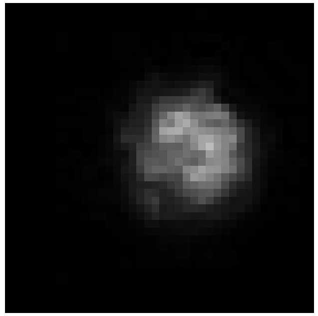
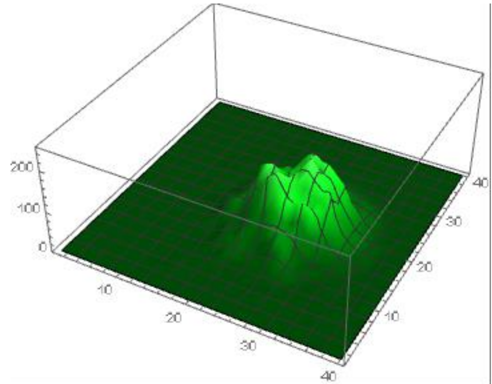
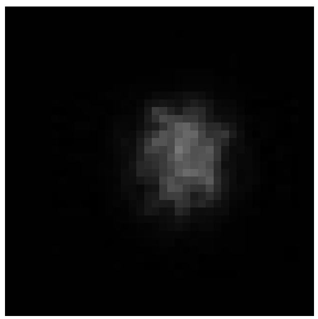
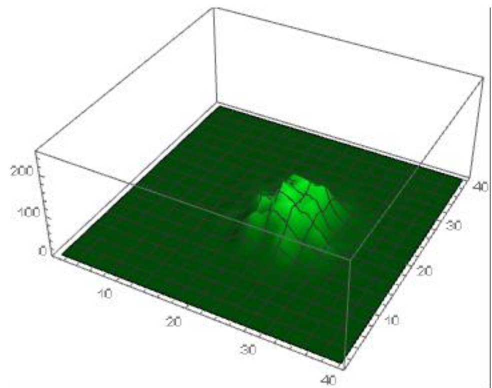
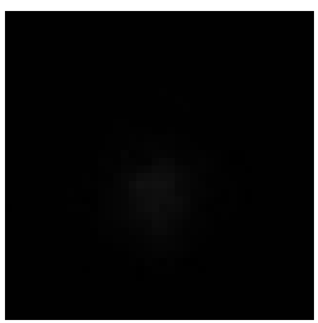
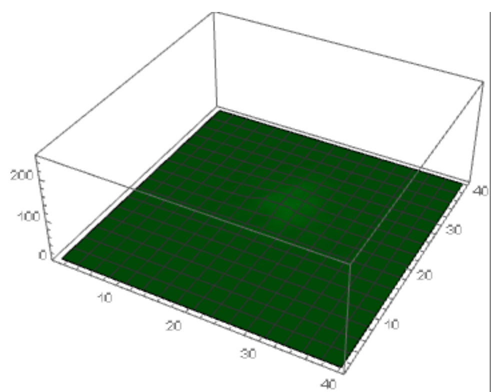


		DSC_0037.JPG No Filter Max I = 255. Avg I = 218.847 Avg D = 23.4529 Sat Cnt = 87
		DSC_0038.JPG No Filter Max I = 255. Avg I = 220.741 Avg D = 23.1524 Sat Cnt = 76
		DSC_0039.JPG YG Filter Max I = 255. Avg I = 217.703 Avg D = 20.7143 Sat Cnt = 63

		DSC_0040.JPG YG Filter Max I = 255. Avg I = 216.244 Avg D = 20.0267 Sat Cnt = 42
		DSC_0041.JPG 2×YG Filter Max I = 255. Avg I = 197.824 Avg D = 16.7746 Sat Cnt = 16
		DSC_0042.JPG 2×YG Filter Max I = 255. Avg I = 198.391 Avg D = 16.5453 Sat Cnt = 14

		DSC_0043.JPG SG1 Filter Max I = 255. Avg I = 200.598 Avg D = 16.5068 Sat Cnt = 12
		DSC_0044.JPG SG1 Filter Max I = 255. Avg I = 198.065 Avg D = 16.5837 Sat Cnt = 12
		DSC_0045.JPG SG2 Filter Max I = 255. Avg I = 180.729 Avg D = 13.3512 Sat Cnt = 1

		DSC_0046.JPG SG2 Filter Max I = 254. Avg I = 176.553 Avg D = 14.3175 Sat Cnt = 0
		DSC_0047.JPG SG2+YG Filter Max I = 197. Avg I = 136.62 Avg D = 9.50789 Sat Cnt = 0
		DSC_0048.JPG SG2+YG Filter Max I = 188. Avg I = 128.167 Avg D = 10.3418 Sat Cnt = 0

		DSC_0049.JPG SG2+2×YG Filter Max I = 130. Avg I = 86.6522 Avg D = 7.65304 Sat Cnt = 0
		DSC_0050.JPG SG2+2×YG Filter Max I = 119. Avg I = 82.1475 Avg D = 8.81292 Sat Cnt = 0
		DSC_0051.JPG SG1+SG2+2×YG Filter Max I = 16. Avg I = 11.8864 Avg D = 7.48482 Sat Cnt = 0

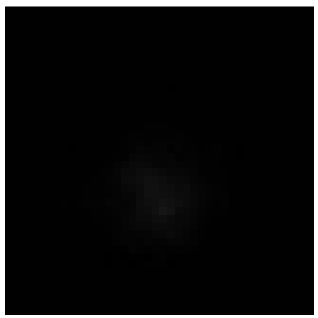
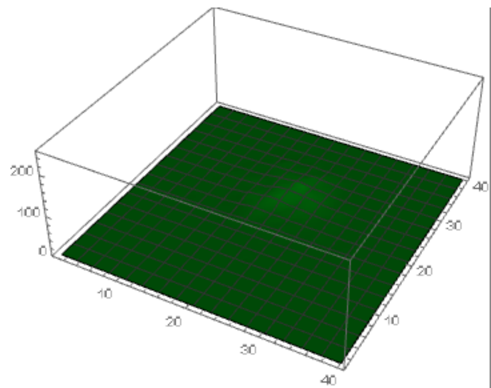
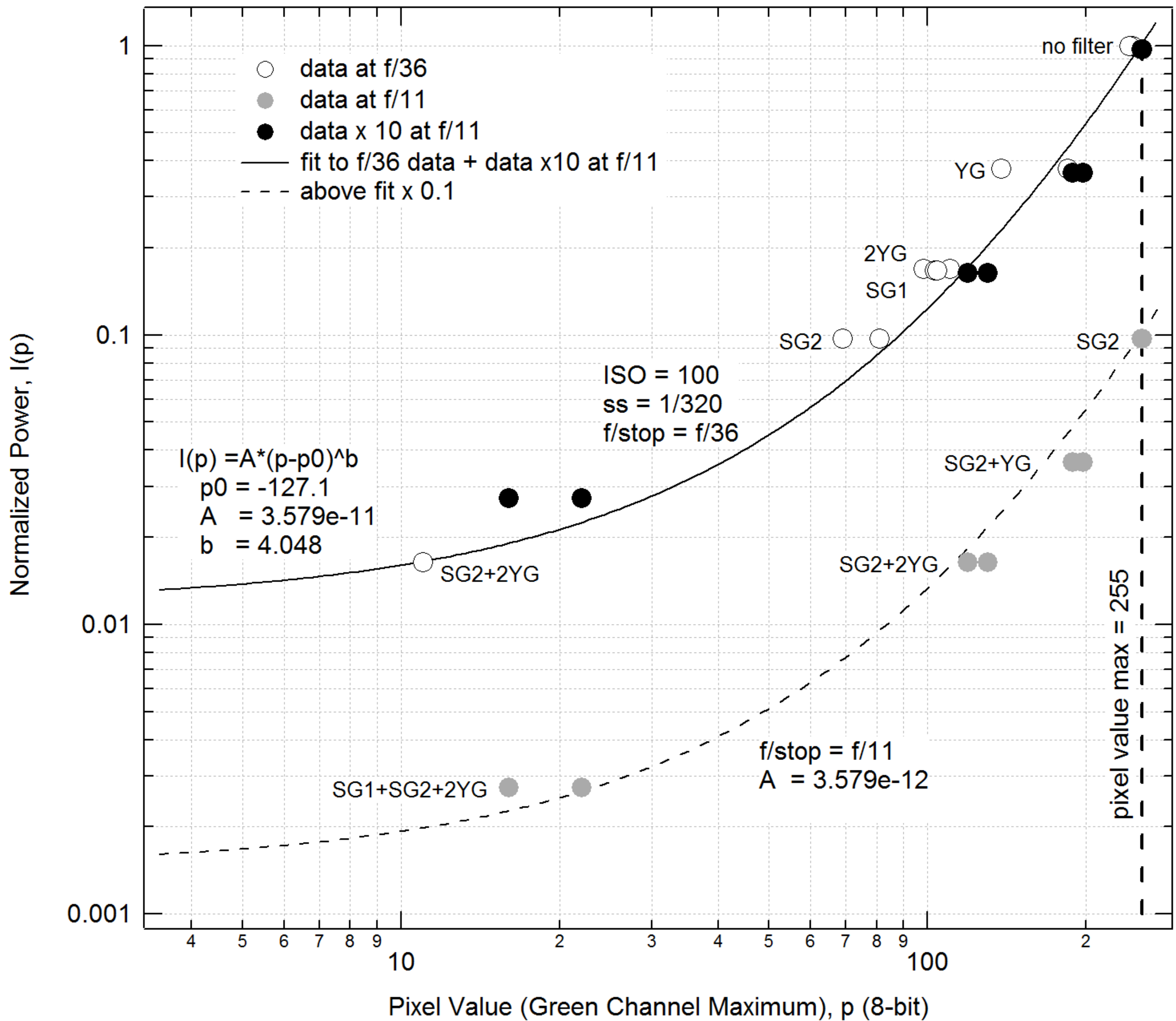
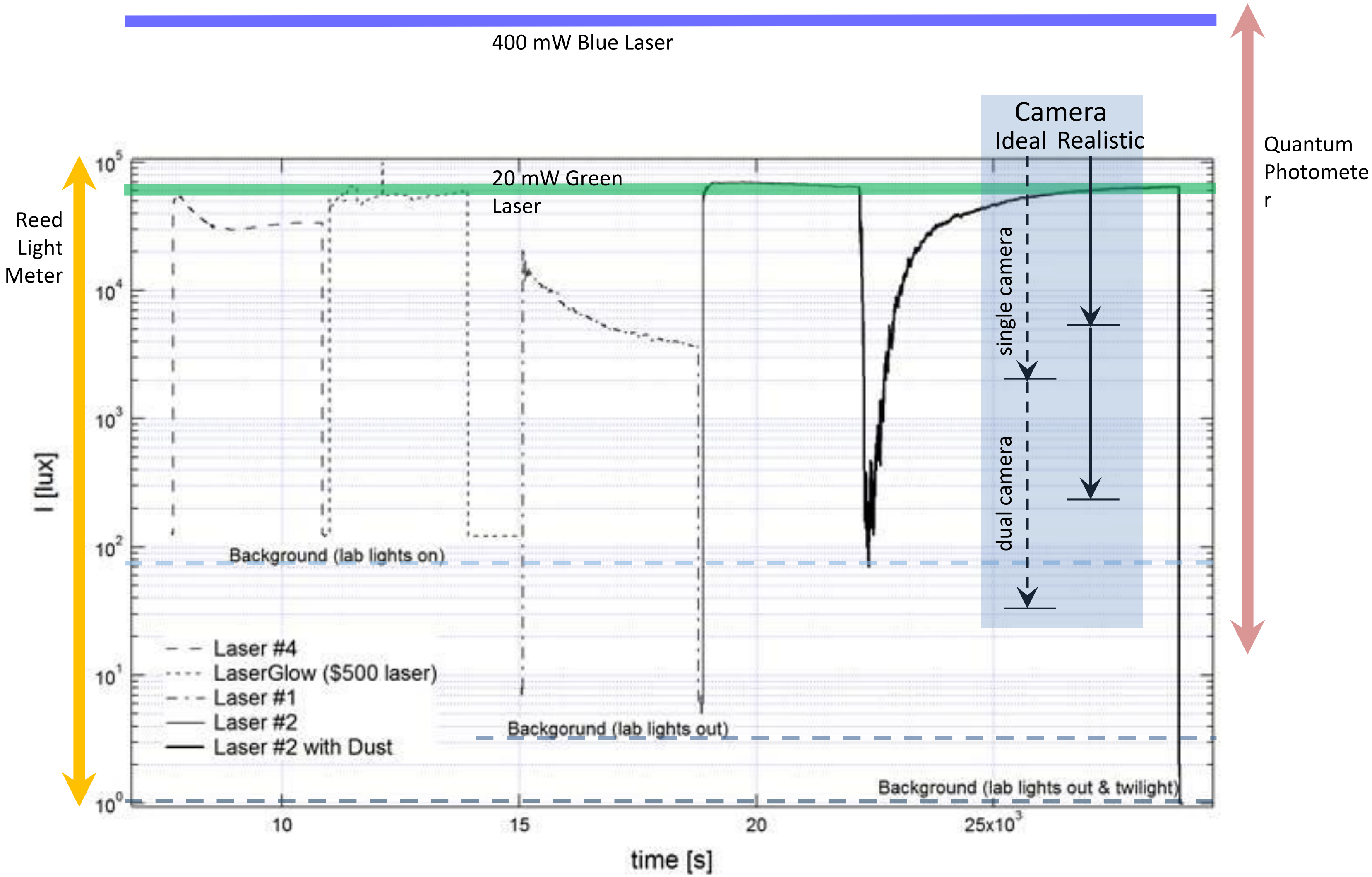
		DSC_0052.JPG SG1+SG2+2×YG Filter Max I = 22. Avg I = 14.8148 Avg D = 5.86323 Sat Cnt = 0

Image processing results for *f*/11 test.

Image File	Max Intensity	Saturated Pixel Count	Saturated Pixel Count Fraction		Spot Diameter [pixels]	Image Width [pixels]	Image Height [pixels]	spot x coord	spot y coord
DSC_0037.JPG	255.	87	0.201389	218.847	23.4529	3872	2592	2465	2058
DSC_0038.JPG	255.	76	0.180523	220.741	23.1524	3872	2592	2465	2059
DSC_0039.JPG	255.	63	0.186944	217.703	20.7143	3872	2592	2456	2056
DSC_0040.JPG	255.	42	0.133333	216.244	20.0267	3872	2592	2457	2058
DSC_0041.JPG	255.	16	0.0723982	197.824	16.7746	3872	2592	2470	2072
DSC_0042.JPG	255.	14	0.0651163	198.391	16.5453	3872	2592	2470	2074
DSC_0043.JPG	255.	12	0.0560748	200.598	16.5068	3872	2592	2451	2050
DSC_0044.JPG	255.	12	0.0555556	198.065	16.5837	3872	2592	2452	2049
DSC_0045.JPG	255.	1	0.00714286	180.729	13.3512	3872	2592	2443	2047
DSC_0046.JPG	254.	0	0.	176.553	14.3175	3872	2592	2445	2049
DSC_0047.JPG	197.	0	0.	136.62	9.50789	3872	2592	2491	2063
DSC_0048.JPG	188.	0	0.	128.167	10.3418	3872	2592	2493	2072
DSC_0049.JPG	130.	0	0.	86.6522	7.65304	3872	2592	2494	2074
DSC_0050.JPG	119.	0	0.	82.1475	8.81292	3872	2592	2494	2081
DSC_0051.JPG	16.	0	0.	11.8864	7.48482	3872	2592	2484	2098
DSC_0052.JPG	22.	0	0.	14.8148	5.86323	3872	2592	2485	2098

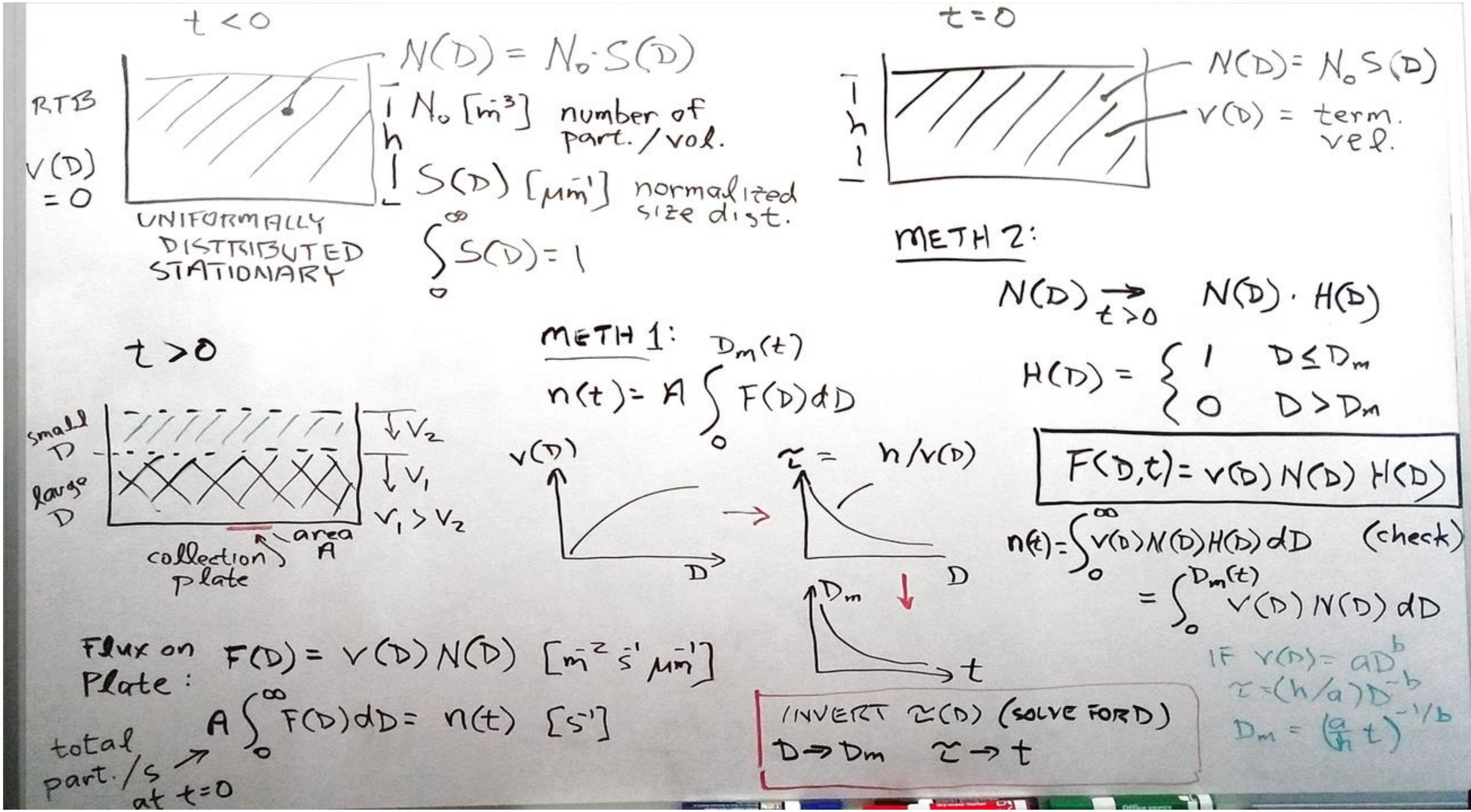


data at f/36
data at f/11
data x 10 at f/11
fit to f/36 data + data x10 at f/11
above fit x 0.1
no filter
YG
2YG
SG1
SG2
SG2
ISO = 100
ss = 1/320
f/stop = f/36
I(p) =A*(p-p0)^b
p0 = -127.1
A = 3.579e-11
b = 4.048
SG2+YG
SG2+2YG
SG2+2YG
SG1+SG2+2YG
f/stop = f/11
A = 3.579e-12
pixel value max = 255
Normalized Power, I(p)
Pixel Value (Green Channel Maximum), p (8-bit)
1
0.1
0.01
0.001
4
5
6
7
8
9
10
2
3
4
5
6
7
8
9
100
2

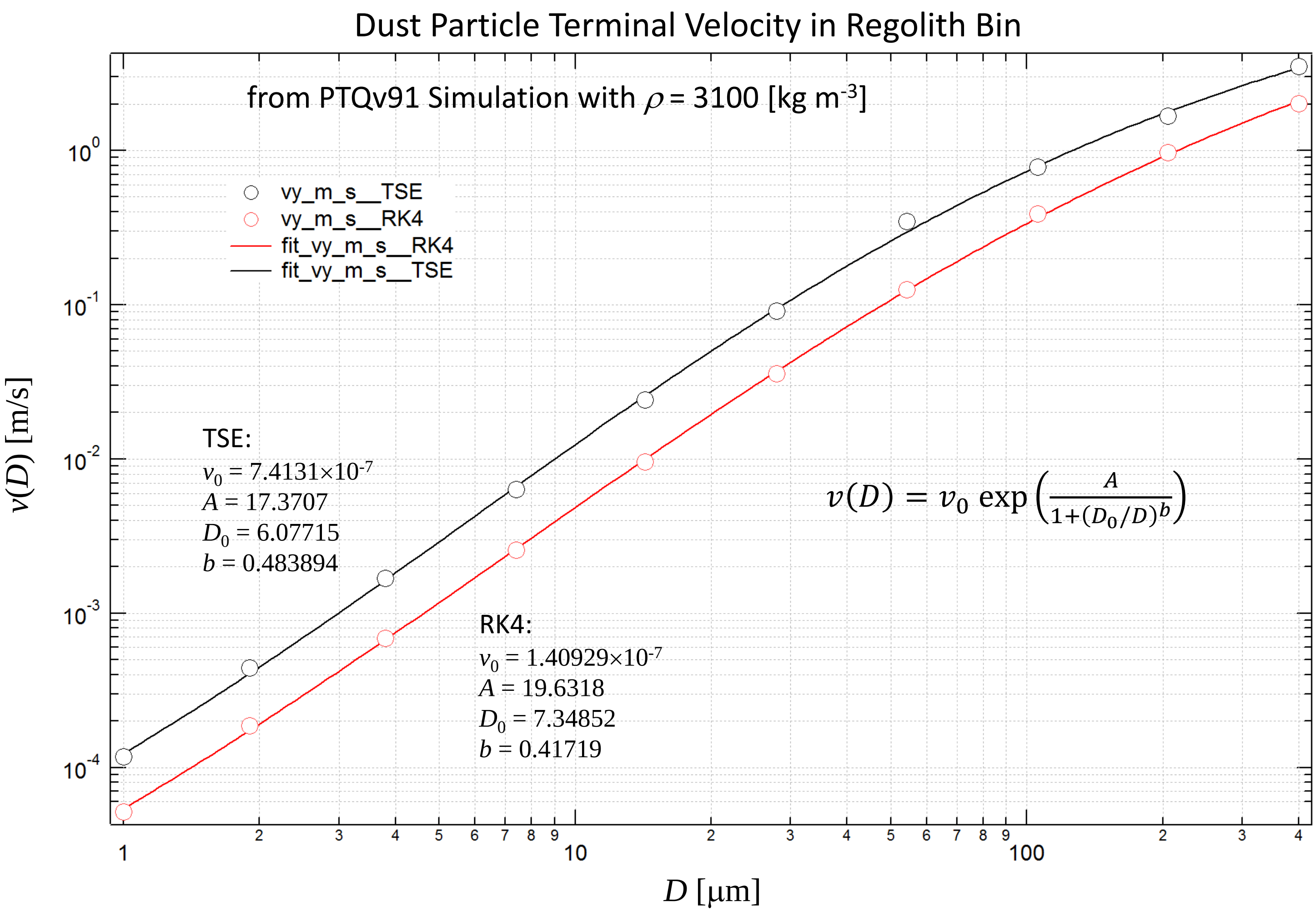


400 mW Blue Laser
Camera
Ideal Realistic
Quantum Photometer
20 mW Green Laser
Reed Light Meter
single camera
dual camera
Background (lab lights on)
Backgorund (lab lights out)
Background (lab lights out & twilight)
Laser #4
LaserGlow ($500 laser)
Laser #1
Laser #2
Laser #2 with Dust
I [lux]
time [s]
10
15
20
25x10^3

Simulation of Particle Settling In Regolith Test Bin



These results are generated by using the particle trajectory simulation code (PTQv91), with some minor modifications. The plot shows predicted terminal velocity of simulant particles versus diameter. Note that 1 um particles take 10000 s (~ 3 h) to settle 1 m according to this simulation. That would mean that 1 um particles thrown up to the ceiling (4 m) could take 12 h to totally settle. On the other end of the spectrum, The 100 um particles fall one meter in 2 s (8 s from top of the bin).



Dust Particle Terminal Velocity in Regolith Bin
from PTQv91 Simulation with ρ = 3100 [kg m-3]
vy_m_s__TSE
vy_m_s__RK4
fit_vy_m_s__RK4
fit_vy_m_s__TSE
TSE:
v0 = 7.4131×10-7
A = 17.3707
D0 = 6.07715
b = 0.483894
RK4:
v0 = 1.40929×10-7
A = 19.6318
D0 = 7.34852
b = 0.41719
v(D) = v0 exp(A/(1+(D0/D)^b))
v(D) [m/s]
D [µm]
10^0
10^-1
10^-2
10^-3
10^-4
1
10
100

LASER Side Scatter Model And Measurements

The following model is a 4-parameter model composed of three sample points along the laser beam, as viewed by an oblique angle from the camera. The contour graphs show the solution of the 4 parameters - the first is the initial intensity value [W/m^2], and the last three are optical extinction coefficients in [1/m]. These values agree well with the laser spot measurements.

$$\text{emin} = 0.0154047 \qquad P = \begin{pmatrix} 974\,000. \\ 0.01006 \\ 0.02032 \\ 0.0822 \end{pmatrix}$$

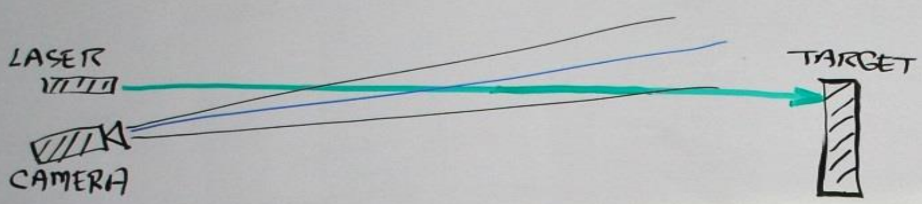
Advantages of this technique as compared to the spot measurement are:

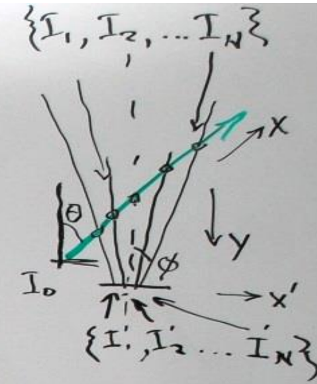
1) Provides discrete data along the beam path.
2) Does not require an initial calibration measurement of the no dust case.

Disadvantages:

1) More calculations and processing is required.
2) The results are very dependent on optical alignment (camera relative to laser).

$\mathrm{Exp}[-2\mathrm{Pi}\, i\, m k/L]$ $\quad P' = (1-x)P_0 + P x$





$$S(\alpha) = \frac{F_0}{Y^2}\left(1 - e^{-\alpha(x) b/\cos\theta}\right)$$

$$\Theta \to 0 \Rightarrow Y \to X$$

FOR N=3:

$$I(x) = I_0\, e^{-\int \alpha(x)\,dx}$$

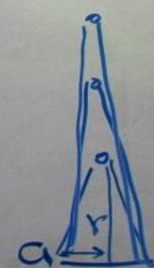
$$I'(x') = I(x)\, e^{-\int \alpha(y)\,dy} \quad S(\alpha)$$

$$I = \begin{pmatrix} I_1 \\ I_2 \\ I_3 \end{pmatrix} = I_0 \begin{pmatrix} e^{-\alpha_1 \Delta x_1} \\ e^{-\alpha_1 \Delta x_1 - \alpha_2 \Delta x_2} \\ e^{-\alpha_1 \Delta x_1 - \alpha_2 \Delta x_2 - \alpha_3 \Delta x_3} \end{pmatrix}$$

$$I' = \begin{pmatrix} I_1\, e^{-\alpha_1 \Delta x_1}\left(1 - e^{-\alpha_1 b/\cos\theta}\right) F_0/x_1^2 \\ I_2\, e^{-\alpha_1 \Delta x_1 - \alpha_2 \Delta x_2}\left(1 - e^{-\alpha_2 b/\cos\theta}\right) F_0/x_2^2 \\ I_3\, e^{-\alpha_1 \Delta x_1 - \alpha_2 \Delta x_2 - \alpha_3 \Delta x_3}\left(1 - e^{-\alpha_3 b/\cos\theta}\right) F_0/x_3^2 \end{pmatrix}$$

$$= I_0 F_0 \begin{pmatrix} \left(e^{-2\alpha_1 \Delta x_1}\right)\left(1 - e^{-\alpha_1 b/\cos\theta}\right) x_1^{-2} \\ \left(e^{-2\alpha_1 \Delta x_1 - 2\alpha_2 \Delta x_2}\right)\left(1 - e^{-\alpha_2 b/\cos\theta}\right) x_2^{-2} \\ \left(e^{-2\alpha_1 \Delta x_1 - 2\alpha_2 \Delta x_2 - 2\alpha_3 \Delta x_3}\right)\left(1 - e^{-\alpha_3 b/\cos\theta}\right) x_3^{-2} \end{pmatrix}$$

$$I'(x') = I_0 F_0\, e^{-2\int \alpha(x)\,dx}\left(1 - e^{-\alpha(x) b/\cos\theta}\right) x^{-2}, \quad x \gg a$$



$$F \propto F_0/r^2$$

$$F_0 \simeq 4\pi a^2\ ?$$

$$\frac{M_x d}{2f} = -\tan\phi_0$$

LASER LINE:

$$y(x') = \frac{1}{\sin\theta}(x' - x_0)$$

CAMERA RAY:

$$y_k(x') = \frac{1}{\sin\phi_k} x'$$

$$\phi_0 = -\frac{1}{2}\phi$$

$$\phi_{N/2} = 0$$

$$\phi_N = \frac{1}{2}\phi$$

$$\phi_k = \frac{\phi_0}{N}\left(k - \frac{N}{2}\right)$$

$$y(x') = y_k(x')$$

$$\frac{1}{\sin\theta}(x' - x_0) = \frac{x'}{\sin\phi_k}$$

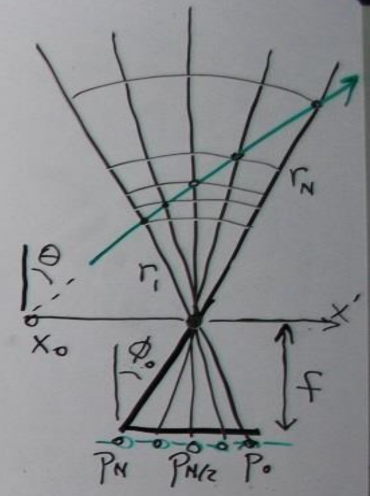
$$\left(\frac{\sin\phi_k}{\sin\theta} - 1\right) x' = \frac{\sin\phi_k}{\sin\theta} x_0$$

$$x'_k = \left(\frac{\sin\phi_k}{\sin\phi_k - \sin\theta}\right) x_0 \equiv \lambda_k x_0$$

$$y_k = \left(\frac{1}{\sin\phi_k - \sin\theta}\right) x_0 = \psi_k x_0$$

$$\Delta x_k = \left[(x'_k - x'_{k-1})^2 + (y_k - y_{k-1})^2\right]^{1/2}$$
$$= \left[(\lambda_k - \lambda_{k-1})^2 + (\psi_k - \psi_{k-1})^2\right]^{1/2} x_0$$

$$x_k = \left[(x'_k - x_0)^2 + y_k^2\right]^{1/2}$$
$$= \left[(\lambda_k - 1)^2 + \psi_k^2\right]^{1/2} x_0$$



$M_x \times M_y$

Image array

Questions