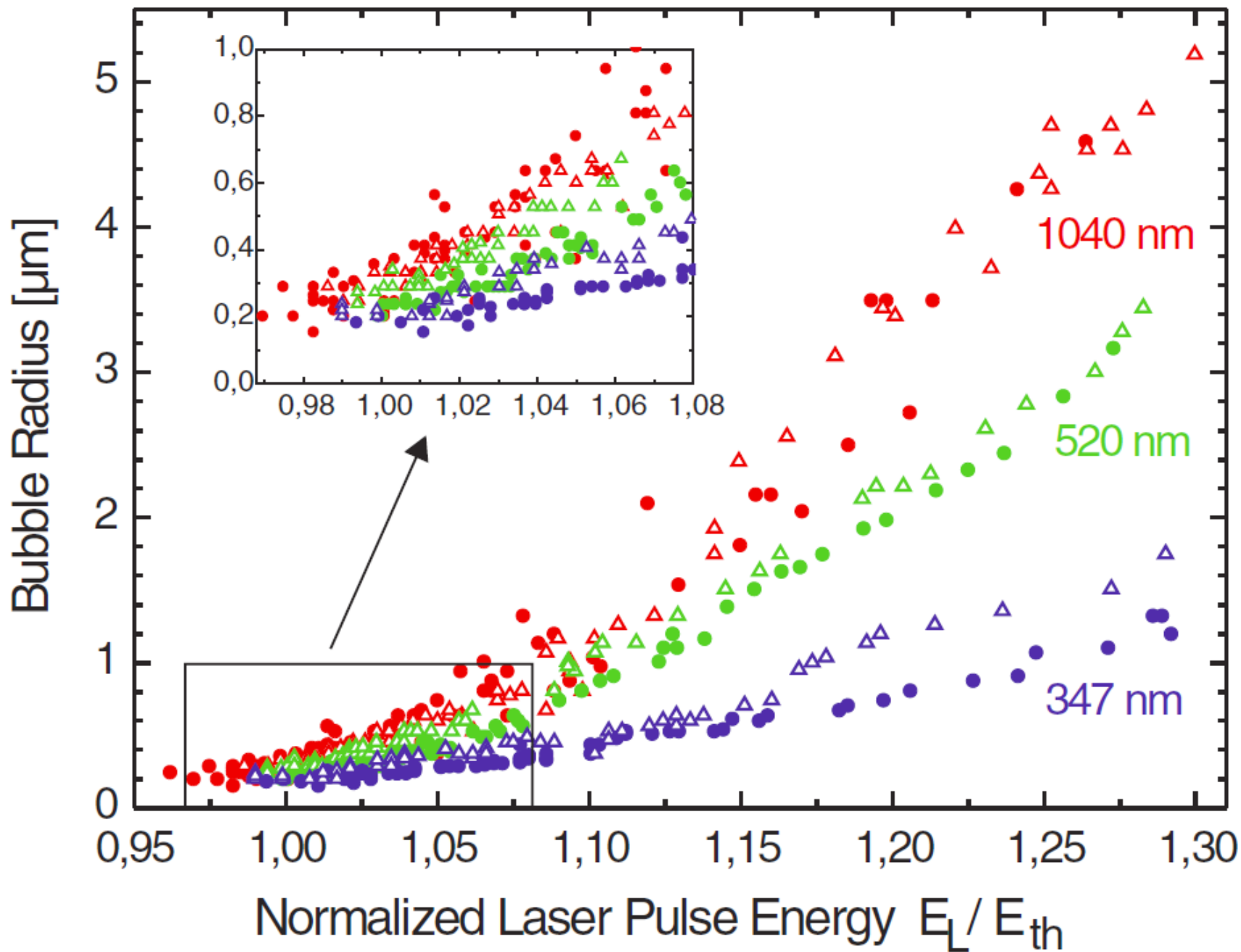
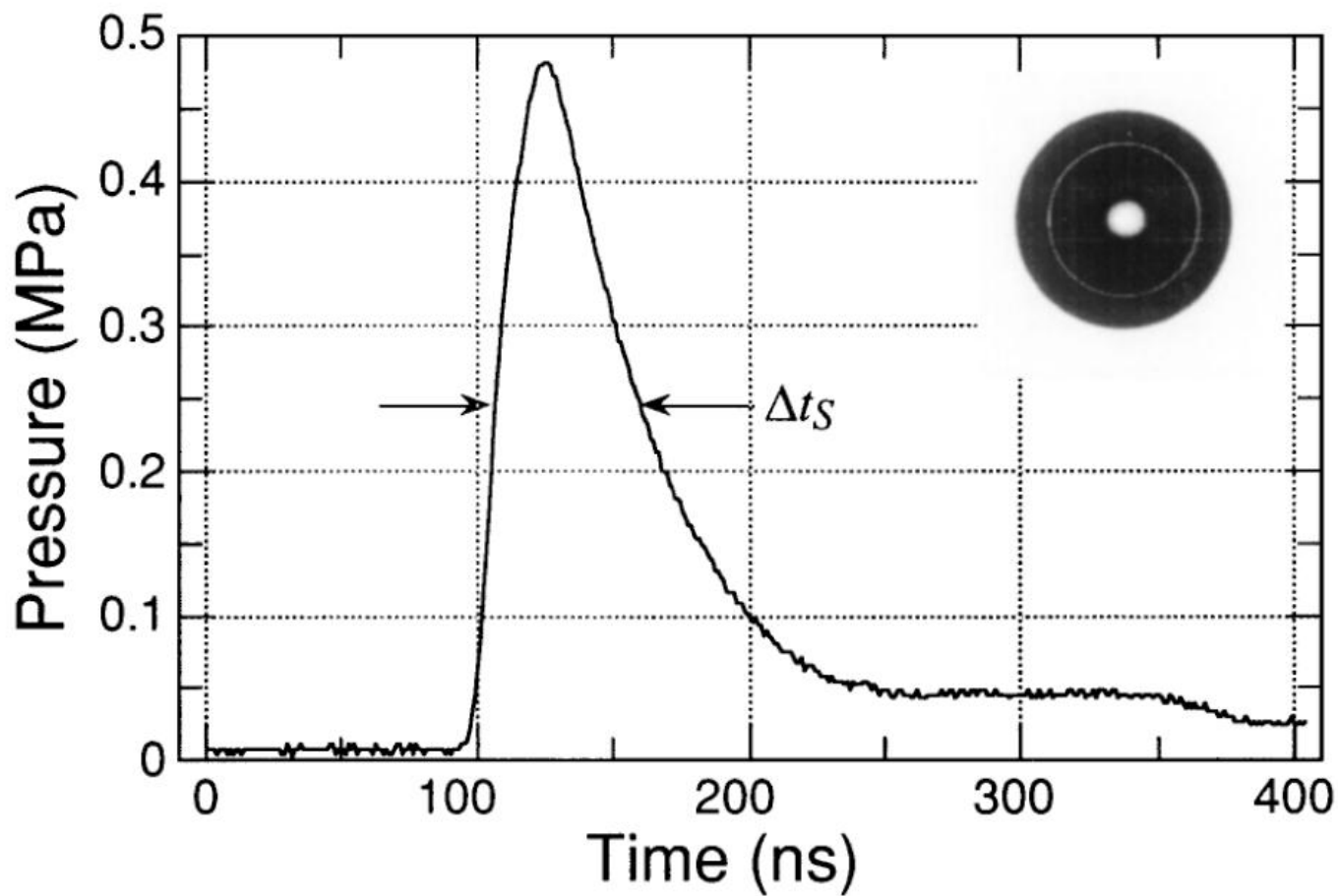


Directed Evolution Project Notes

Ablation via Ionization

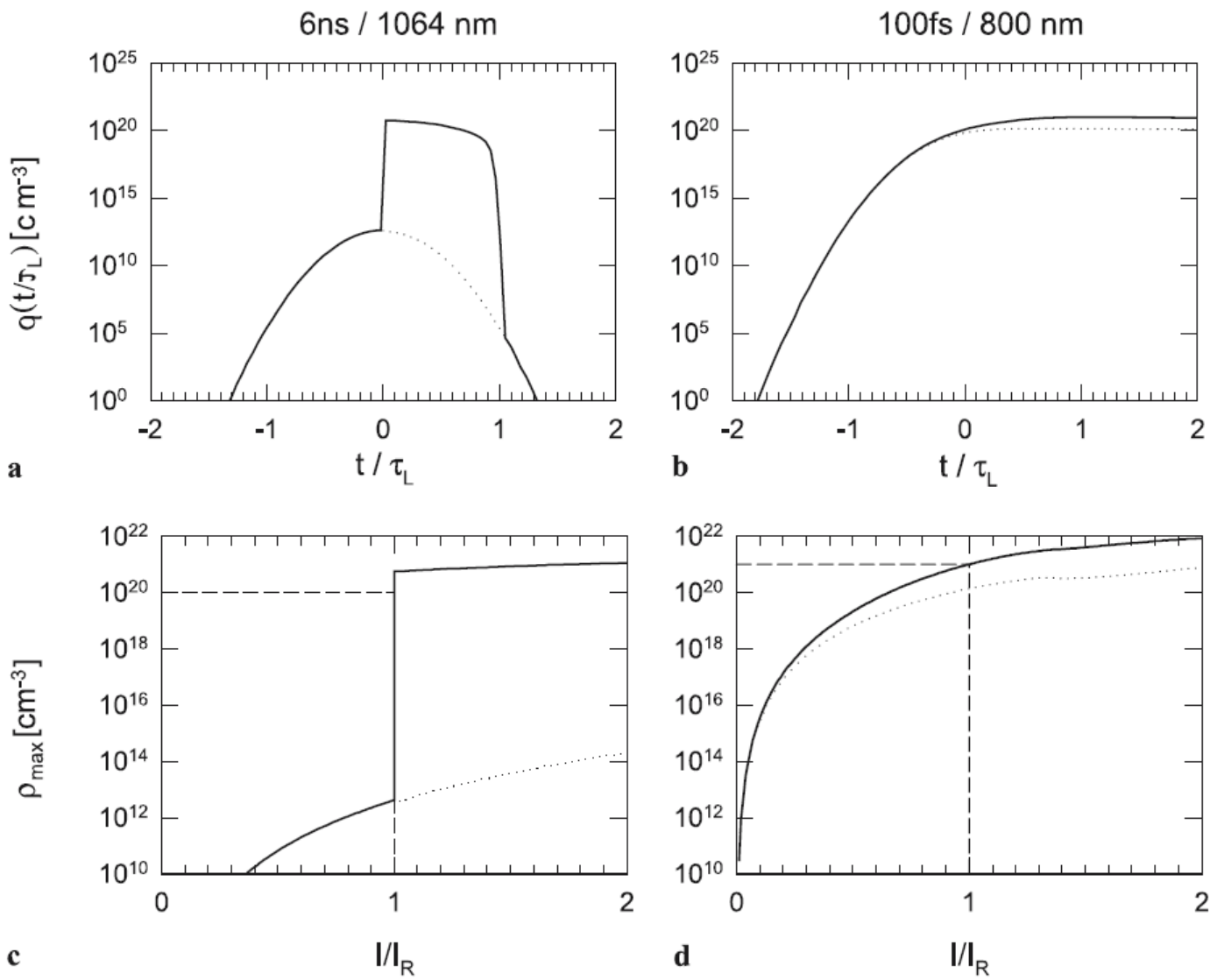
1. [Bubble Energy vs. Pulse vs. Wavelength](#)
2. [Femtosecond Pressure Time Dynamics](#)
3. [Electron Density at Different Timescales](#)
4. [Irradiance Threshold vs. Pulse Length](#)
5. [Bubble Radius vs. Pulse Energy](#)
6. [Irradiance Threshold vs. Wavelength vs . Pulse](#)
7. [Water breakdown across parameters](#)
8. [E. Coli shell properties](#)
9. [E. Coli volume, size, mutation statistics](#)

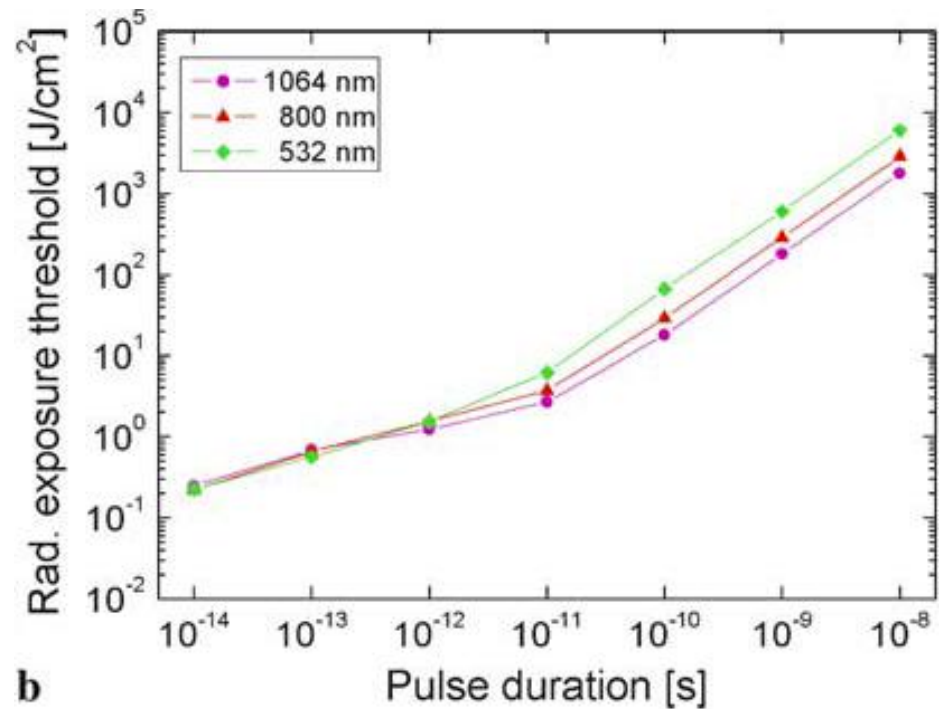
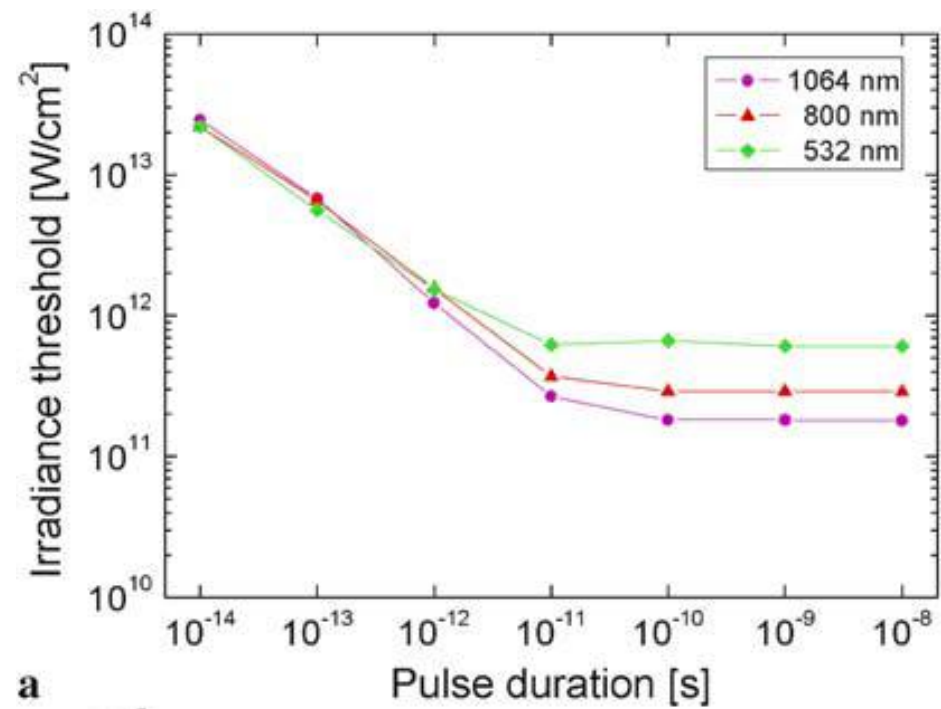




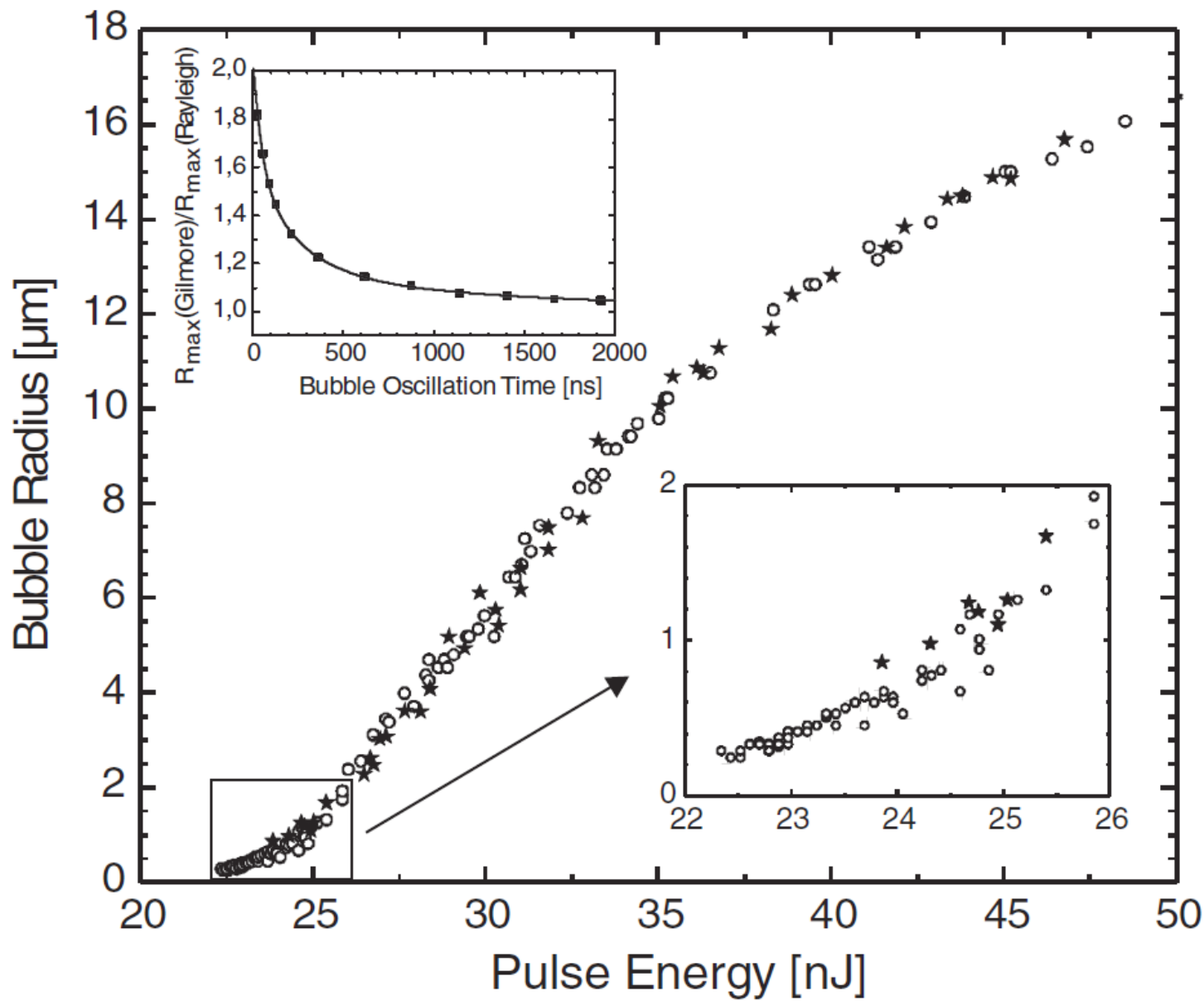
λ [nm]	β	E_p [μ J]	p_s [MPa]	Δt_S [ns]	E_S [μ J]	E_S/E_p [%]	T_{osc} [μ s]	R_{max} [μ m]	E_B [μ J]	E_B/E_p [%]
1064	1	18.0 ± 0.1	0.158 ± 0.028	42.0 ± 0.5	0.64	3.6	27.7	151.3	1.45	9.1
1064	2	36.4 ± 0.2	0.283 ± 0.008	47.5 ± 1.0	2.33	6.4	45.3	247.6	6.35	17.3
1064	5	90.9 ± 0.3	0.475 ± 0.009	53.0 ± 0.5	7.32	8.1	65.9	360.1	19.57	21.5
1064	10	182.2 ± 0.9	0.659 ± 0.005	59.0 ± 0.5	15.69	8.6	86.6	473.3	44.41	24.4
532	1	1.89 ± 0.10	0.038 ± 0.008	26.0 ± 0.5	0.023	1.2	8.3	45.4	0.039	2.1
532	2	3.78 ± 0.13	0.091 ± 0.005	31.0 ± 0.5	0.157	4.2	13.8	75.4	0.180	4.2
532	5	9.19 ± 0.30	0.202 ± 0.008	36.0 ± 0.5	0.90	9.8	26.9	147.0	1.33	14.3
532	10	19.15 ± 0.60	0.310 ± 0.001	43.0 ± 0.5	2.53	13.2	37.5	205.0	3.60	19.3

Multiphoton vs. Cascade





Bubble radii R_{\max} at $\lambda=1040$ nm, $NA=0.8$



Laser Parameter & Breakdown Threshold

Pulse duration	Wavelength nm	Focusing angle °C	Measured spot diameter / μm	I_{th} $\times 10^{11} \text{ W cm}^{-2}$	F_{th} J cm^{-2}
76 ns	750	19	20	0.23	1750
6 ns	1064	32	5.5	0.66	398
6 ns	1064	22	7.6	0.47	284
6 ns	1064	8	11.5	0.79	472
6 ns	1064	5.4	14.6	1.1	648
30 ps	1064	28	4.6	4.6	13.8
30 ps	1064	22	4.7	4.5	13.6
30 ps	1064	14	5.8	3.0	9.0
30 ps	1064	8.5	9.6	4.5	13.6
30 ps	1064	4	19.5	3.7	11.1
60 ps	532	13	5.6	2.8	16.8
3 ps	580	16	5.0	8.5	2.6
300 fs	580	16	5.0	47.6	1.4
100 fs	580	16	4.4	111.0	1.1

Water Breakdown Experimental/Theoretical

Pulse duration	Wave-length (nm)	NA or focusing angle	Gaussian (G) or Top hat (T)	Measured spot diameter (μm)	Diffraction-limited spot (μm)	Breakdown criterion	E_{th} (μJ)	F_{th} (J/cm^2)	I_{th} ($\times 10^{11} \text{ W}/\text{cm}^2$)	I_{rate} ($\times 10^{11} \text{ W}/\text{cm}^2$)	Source	Factors influencing the measured threshold value
10 ns	1064	14°	G	4.0	4.0	L	400	3200	3.2		[178]	Spherical aberrations, ps spikes because of longitudinal mode beating
7 ns	1064		G	75	75	L		245	0.35		[99, 100]	Longitudinal mode beating, self-focusing
6 ns	1064	32°	G	5.4	5.4	L	89.9	396	0.66	1.79	[15]	Longitudinal mode beating
6 ns	532	22°	G	5.3	5.3	L	38.5	174	0.29	6.06	[15]	Longitudinal mode beating
6 ns	1064	NA 0.9	T	1.44	1.44	L	18.3	1122	1.87		[3]	Longitudinal mode beating, absorption in microscope objective
6 ns	532	NA 0.9	T	0.72	0.72	L	1.89	462	0.77		[3]	not considered
220 ps	1064		G	37	37	L		64.9	2.95	1.81 (100 ps)	[99, 100]	Self-focusing
200 ps	800	NA 0.65	T	1.50	1.50	B	4.0	90.4	4.52	2.90 (100 ps)	[179, 180]	Spherical aberrations
60 ps	532	16.7°	T	7.2	7.2	L	10.0	24.4	4.07	6.63 (100 ps)	[136]	Moderate spher. aberrations
40 ps	1064	14°	G	4.0	4.0	B	1.6	64.0	16		[178]	Spherical aberrations
30 ps	1064		G	37	37	L		19.2	6.41		[99, 100]	Self-focusing
30 ps	1064	22°	G	4.7	4.7	L	2.38	13.6	4.53	2.67 (10 ps)	[15]	Self-focusing
30 ps	532	22°	G	3.4	3.4	L	1.01	11.3	3.75	6.19 (10 ps)	[15]	Self-focusing
3 ps	580	16.7°	TG	10.8	10.8	B	1.1	1.25	4.15		[136]	Moderate spher. aberrations
3 ps	580	16°	G	5.0	5.0	B	0.51	2.6	8.5	15.3 (1 ps, 532 nm)	[80, 81]	Moderate spher. aberrations
300 fs	580	16.7°	TG	10.8	10.8	B	1.0	1.1	36.0		[136]	Moderate spher. aberrations, self-focusing
300 fs	580	16°	G	5.0	5.0	B	0.29	1.4	47.6		[15]	Self-focusing
150 fs	620		G	5.0	5.0	B		0.87	58.0		[181]	Self-focusing
150 fs	620		G	5.0	5.0	B		1.3	86.7		[181]	Self-focusing
125 fs	580	16.7°	TG	10.8	10.8	B	0.35	0.4	30.6		[136]	Moderate spher. aberrations, self-focusing
100 fs	580	16°	G	4.4	4.4	B	0.17	1.1	111.0	55.9 (532 nm)	[80, 81]	Self-focusing
100 fs	800	NA 0.65	T	1.50	1.50	B	≈ 0.1	5.64	564	65.4	[182]	Spherical aberrations
44 fs	810	$\approx 16^\circ$	G	≈ 10	≈ 10	B	0.19	0.22	50		[183]	Strong self-focusing

TABLE I. Elastic shell properties of specific bacteria yeast cells: E is the Young's modulus

Cell	E (MPa)	Poisson's ratio	Radius (μm)	Thickness (nm)	T (N/m)	Turgor pressure (MPa)
<i>E. coli</i> ^b	25	0.16	0.50	6	7.5×10^{-3}	0.3
<i>C.eugametos</i> ^b			8	60	38	9.5
<i>B. emersonii</i> ^b			10	450	32	6.5
Yeast ^c	0.6	0.5	1.5–8			
Yeast ^c	$K_A=12.9$ (N/m)	0.5		90		

Various E. Coli Size Statistics

Cell length	2 μm or 2×10^{-6} m
Cell diameter	0.8 μm or 0.8×10^{-6} m
Cell total volume	1×10^{-15} L or 1×10^{-18} m ³
Cell aqueous volume	7×10^{-16} L
Cell surface area	6×10^{-12} m ²
Periplasm volume	6.5×10^{-17} L
Cytoplasm volume	6.7×10^{-16} L
Envelope volume	1.6×10^{-16} L
Inner Membrane thickness	8×10^{-9} m
Outer Membrane thickness	8×10^{-9} - 15×10^{-9} m
Periplasm thickness	1×10^{-8} m
Average diameter of ave. protein	5 nm
Diameter of chromosome	490 μm
Diameter of condensed chromosome	17 μm

Mutation Rate / Base	5×10^{-10}
Mutation Rate / Genome	0.0025