Limiting factors in single particle cryo electron tomography.

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Supplemental Material

Protein complex	Origin	Reference	Publication Year	N part	Under–focus [µm]	Reso–lution [nm]	Pixel size [nm]	Classes	Sym–metry	Ice thick–ness [nm]	mag [x1000]	Camera [pixels]	Accelerating voltage [keV]	Energy filter used?	Angular coverage [deg]	Total electron dose [e/A^2]	Largest linear size [nm]	Dualtilt used?	Data processing software
Bacterial flagellar motor	*Borrelia burgdoferii*,flgJBb deletion mutant	[1]	2012	321	4 to 6	3.5	0.22	1	1	300	31	4096	300	no	128	100	100	no	[2]
Basal body triplet		[3]	2012	1644	9 to 24#	33	6.5	1	1	300	34	2048	300	yes	120	80	39	no	[4,5]
Ebola Virus capsid		[6]	2012		6 to 8			1	1		25 to 50		300		120	60		no	ARGOS
Marburg Virus		[7]	2011	68		2.6	0.49	3	1	100	27.5	2048	300	yes	120	100	77	no	[8]
Bacterial flagellar motor	*Borrelia burgdoferii*	[9]	2012	138	10	4.6	0.82	2	c16	300		2048	300	yes	120	200	100	no	[9]
Influenza virus		[10]	2012		4	2.5	0.78		c3			2048	120	yes	132	70	35	no	[11] and [12]
Inner dynein arms and inter-doublet links in	mouse respiratory cilia	[13]	2012	45	4 to 4.5			1	1		27	2048	200	yes	120		96	no	[12] and [5]
Flagellum	*Trypanosoma brucei*	[14]	2011		6 to 10			1	C1, longitudinal repeat	300	11 to 16	4096	200	yes	120	60-74	96	no	[15]
Actin-myosin contacts in muscle, freeze substituted		[16]	2010	515		3.5	0.69	7	C1, longitudinal repeat	50		2048	300	no	144	420	39	yes	[2]
Bacterial flagellar motors	*A. longum*	[17]	2011	35	8 to 12	8.4	1.9	1	C16			2048	300	yes	120	200	100	part.	[12] and [18]
	B. burgdorferi		2011	43	8 to 12	5	1.3	1	C16	300		2048	300	yes	120	200	100	part.	
	T. primitia		2006	20	10 to 18	7.7	1.9	1	C16	300		2048	300	yes	120	200	100	part.	
	H. hepaticus		2011	60	8 to 12	5	1.3	1	C13			2048	300	yes	120	200	100	part.	
	C. jejuni		2011	15	8 to 12	6.4	1.9	1				2048	300	yes	120	200	100	part.	
	H. gracilis		2011	94	8 to 12	5.9	1.3	1				2048	300	yes	120	200	100	part.	
	V. cholerae		2011	16	8 to 12	8.3	1.9	1				2048	300	yes	120	200	100	part.	
	S. enterica		2011	83	8 to 12	4.8	1.3	1		600		2048	300	yes	120	200	100	part.	
	E. coli		2011	46	8 to 12	5.9	1.3	1		600		2048	300	yes	120	200	100	part.	
	C. crescentus		2011	30	8 to 12	5.9	1.3	1		400		2048	300	yes	120	200	100	part.	
	H. neptunium		2011	27	8 to 12	6.8	1.5	1				2048	300	yes	120	200	100	part.	
Radial spokes	*Chlamydomonas flagella*	[19]	2011		6 to 8	3.3	1	1	C1, longitudinal repeat	350		2048	300	yes	130	100	96	no	
Procapsid possible packaging intermediates	Bacteriophage ϕ6	[20]	2011	120	4	4.4	0.78	4	C5	50	22		120	yes	132	70	50	no	[12]

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DNA ejection machinery	*Bacillus anthracis, phage 8a*	[21]	2011	2518	4 to 6	3.6	0.39	4	5 and 6	100		4096	300	no	128	100	200	no	[2]
Envelope Glycoproteins	Trimeric Simian Immunodeficiency Virus	[22]	2011	900-4800	2.5	2.5	0.41	10	C3	100	34	2048	200	yes	125	90	41	no	[23]
Doublet microtubules in flagella	Chlamydomonas and sea urchin sperm, drc Mutants	[24]	2011	1980	6 to 8	3.3	1	1	C1, longitudinal repeat	200		2048	300	yes	130	100	96	no	[25]
	Chlamydomonas and sea urchin sperm, pWT		2011	720	6 to 8	3.4	1	1	C1, longitudinal repeat	200		2048	300	yes	130	100	96	no	
	Chlamydomonas and sea urchin sperm, pWT		2011	210	6 to 8	3.9	1	1	C1, longitudinal repeat	200		2048	300	yes	130	100	96	no	
	Chlamydomonas and sea urchin sperm, in Flagella		2011	470	6 to 8	3.6	1	1	C1, longitudinal repeat	200		2048	300	yes	130	100	96	no	
	Chlamydomonas and sea urchin sperm, isolated DMT		2011	118	6 to 8	3.8	1	1	C1, longitudinal repeat	200		2048	300	yes	130	100	96	no	
Flagella	sea urchin sperm	[26]	2006		3.5 to 5	3	0.53	1	1	100		2048	300	yes	130	65	96	no	[12] and [5]
Flagella	sea urchin sperm	[27]	2005	56	3 to 6	5.8	0.59	1	1	200		2048	300	yes	130	100	96	no	[28]
	Bacteriophage P1 infecting e.coli	[29]	2011	219	9		0.78	3	5 and 6	300		2048	300	no	128	100	278	no	[2]
	Dengue virus	[30]	2011	30	3 to 5	4	0.78	1	icosahedral	150		2048	120	yes	128	85	78	no	[15]
Torroidal surface complex	Bacteriophage ϕ12	[31]	2011	744	8	2.6	0.88	1	C6	100		2048	300	yes	130	80	22	no	[8]
Chemotactic arrays	*E. coli*	[32]	2011	1098	5 to 8	3.3	0.75	1	C6	600	18	2048	300	yes	140	70-280	113	no	[15]
Bacterial flagellar motor, FliL-mutant	*Borrelia burgdorferi*	[33]	2011	711	5	4	0.56	1	1	300		4096	300	no	128	100	143	no	[2]
Envelope Glycoproteins	Trimeric Simian Immunodeficiency Virus	[34]	2010	4000	2.5	2	0.41	10	C3	100	34	2048	200	yes	130	90	41	no	[23]
GAG protein layer	HIV-1	[35]	2010		2.6 to 2.9	2.65	0.4	1	C6	150		2048	300	yes	120	90	38	no	[8]
GAG protein layer	Native HIV-1 budding sites	[36]	2010		6 to 8	4	0.713-0.82	1	C6			2048	300	yes	120	80	38	no	[8]
Photosystem II	Spinach chloroplasts	[37]	2011	100	8	4	0.58	1	1	150		2048	300	yes	136	80	32		[25] , [15]
GAG protein layer	HIV-1	[38]	2011		4 (first zero 3.7nm)	4	0.78			150		2048	120	yes	132	70	125		[12]
	RNA releasing poliovirus	[39]	2011	540	6	4.5	0.42	1	icosahedral	60	34	2048	300	yes	140	140	54	no	[5]
Double hairpin	Moloney murine leukemia virus	[40]	2010	38	8		0.65	2	1		23	4096	200	yes	120	90	10	no	[4]
Flagellar motor	*Treponema palladum*	[41]	2010	830	4 to 6	4	0.28	1	1	300		4096	300	no	130	100	143	no	[2]
Surface Layer	*Caulobacter crescentus*	[42]	2010	3777	3.6 to 12		0.69	2	C6	500		2048	300	yes	124	140	76	no	[8] and [43]
GAG protein layer	HIV	[44]	2010	9698	4.5	2.8	0.4	1	C6	150		2048	300	yes	120	70	38	no	[8]

Protein complex	Origin	Reference	Publication Year	N part	Under–focus [µm]	Reso–lution [nm]	Pixel size [nm]	Classes	Sym–metry	Ice thick–ness [nm]	mag [x1000]	Camera [pixels]	Accelerating voltage [keV]	Energy filter used?	Angular coverage [deg]	Total electron dose [e/A^2]	Largest linear size [nm]	Dualtilt used?	Data processing software
	HIV		2010	5438	2.1	2.55	0.4	1	C6	150		2048	300	yes	120	70	38	no	
	M-PVM		2010	10858	2.2	2.65	0.4	1	C6	150		2048	300	yes	120	70	38	no	
	RSV		2010	6732	2	2.3	0.4	1	C6	150		2048	300	yes	120	70	38	no	
Thermosomes		[11]	2010	3455	2.5		0.43	3	1	50		2048	160	no	120		34	no	[11]
Phage head head	Epsilon15 Bacteriophage	[45]	2010	50	0*	2.5		1	icosahedral	150	30	2048	300	yes	140	80	100	no	[4]
	Epsilon15 Bacteriophage		2010	95	0*	3		1	1	150	30	2048	300	yes	140	80	100	no	
Multidrug efflux pump	*Pseudomonasaeruginosa*	*[46]*	2010	919	4	3		1	C3		27.5	2048	300	yes	138	60	21	no	[5]
Podovirus P-SSP7	*Prochlorococcus host cells*	*[47]*	2010	29				1	1			4096	300	no			50	no	
	Bacteriophage ϕ6	[48]	2010	315	4	3.7	0.78	1	1	50	38.5	2048	120	yes	140	75	50	no	[12]
	Bacteriophage BPP-1	[49]	2009	60			0.39					4096	300	no	140	100	68	no	
	Microtubule-kinesin complex	[50]	2010	99	6	3.2	0.76	1	helical 16	50	29	4096	200	no	140	100	130	no	[25]
Ribosomes	Human cells	[51]	2010	1911	6	3.9	0.82	2	1	200-400	17.5	2048	300	yes	130	85	30	no	[8]
ATP synthase	*Polytomella mitochondria*	*[52]*	2010	166	10	5.7	0.73	1	1			2048	300	yes		80	87	yes	[25]
Nuclear pore complex	*Xenopus*	*[53]*	2010	2488	4 to 6	6.4	0.65	1	1	200		2048	300	yes	124	-	150	no	[8]
Bacterial flagellar motor	*Treponema pallidum*	*[54]*	2009		15	10				300			400	yes	120	120		no	[5]
	Bovine papiloma virus	[55]	2009	519	9#	4		1	12	50			300	yes			50	no	[25]
Bacterial flagellar motor	*Borrelia burgdorferi*	[56]	2010	138	10	4.6	0.82	1	c16	300		2048	300	yes	120	200	100	no	[8]
	PRD1 bacteriophage	[57]	2009	311	3 to 5.6 (mean 4) #	2.2	0.47	1	icosahedral	100		2048	300	yes	126	70	100	no	[8] and [12]
Bacterial flagellar motor	*Borrelia burgdorferi*	[58]	2009	1280	4 to 6	3.5	0.22	1	1	300		4096	300	no	130	100	100	no	[2]
	Borrelia burgdorferi, transposon mutant		2009	1100	4 to 6	3.5	0.22	1	1	300		4096	300	no	130	100	100	no	
	detergent treated *Borrelia Burgdoferii*, WT		2009	454	4 to 6	3	0.22	1	1	300		4096	300	no	130	100	50	no	
Triad Junctions		[59]	2009	49	10	7.1	0.5	3	C4	250		1024	200	no	120	-	30	no	[5]
Flagella	*Chlamydomonas*, WT	*[60]*	2008	559	2 to 4	4.1	0.7	1	1		19.3	2048	200	yes	120	-	96	no	[5] and [61]
	Chlamydomonas, oda1-		2008	656	2 to 4	3.8	0.7	1	1		19.3	2048	200	yes	120	-	96	no	
Chemotactic arrays, TsrQEQE	*E. coli*	[62]	2008	3972	5 to 8	3.3		2	c3	500	44	2048	300	yes	140	60-80	20	no	[15]
Chemotactic arrays TsrQEQE+serine	*E. coli*		2008	23505	5 to 8	3.3		1	c3	500	44	2048	300	yes	140	60-80	20	no	
Chemotactic arrays	*Caulobacter crescentus*	[63]	2008	1200	4 to 6		7.5	1	c6	350	18	2048	300	yes	140	45-75	47	no	

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gp120 trimers	HIV-1	[64]	2008		2	2.2	4.1	1	c3	150		2048	200	yes	140	80	15	no	[2]
ATP synthase dimers	rat liver	[65]	2008	235	10 to 15	5		1	1	160		2048	300	yes		100 - 200	40	no	[5]
	Simian Virus 40	[66]	2007	13	10	7	0.55	1	icosahed ral	100		2048	300	yes		55-75	50	no	[8] and [12]
Donut-shaped surface spike	cystovirus ϕ12	[67]	2008	1300	8#	4.6		1	1	150	43	4096	200	no	140	30-40	20	no	[5] and [2]
Cadherins in desmosomes		[68]	2007		4 to 9	3.4	0.6	1	1	50$		2048	300	yes	130	40	34	no	
Nuclear pore complex	*Dictyostelium discoideum*	*[69]*	2007	4184	12 to 15	5.8	0.82	1	1	500		2048	300	yes	126	NA	150	no	[8]
Outer dynein arms		[70]	2007	667	2 to 3	4.5		1	1	250		2048	200	yes	120	30	120	no	
ENV spike	SIV	[71]	2006	2986	4 to 6	2.8	0.55	1	c3	150		2048	300	yes	123	50 to 70	12	no	[8]
Portal	Herpes Simplex Virus	[72]	2006	150		5.5	0.78	1	c5	150	38	2048	120	yes	114	35 to 80	150	no	[12]
Nuclear pore complex	Isolated Xenopus nuclear envelope	[73]	2003	446	1.5	12		1	c8	200		1024	120	yes	120	20 to 28	150	no	[28]
	Hepes Simplex Virus	[74]	2003	11	8	5.6		1	icosahed ral	250			120	no	123	40	50	no	[12]
Envelope protein	Retrovirus	[8]	2005	1114	4 to 6	2.7	5.5	1	c3	100	55	2048	300	yes	132		20	no	[8]
Thermosome		[75]	1997	307		2	0.48	1	82 point group	50			120	no	101	20	20	no	[28]
GAG protein layer	Immature HIV	[76]	2009		2 to 5#	1.7	0.4	1	1	150		2048	300	yes	126	70	100	no	[8]
Matrix protein	Measles virus	[77]	2011	1400	3 to 6	4.4	0.38	1	1		39.4	2048	200	no	120		50	no	[78]
Radial spokes of cilia and flagella		[79]	2011	2400	3 to 5	3.9		1	1	220	19	2048	200	yes	120		96	no	[12] and [5]
Radial spokes in cilia and flagella		[80]	2012	1300	8	3.6	1	1	1	200	13.5	2048	300	yes		100	96	no	[25]
Bovine respirasome		[81]	2011	2466	2	2.2	0.38	1	1	50	78	2048	200	yes	130	40	30	no	[8] and [11]
Envelope Glycoproteins	Simian Immunodeficiency Virus	[22]	2011	4826	2.5	2.5	0.41	1	c3	100		2048	200	yes	125	70-140	41	no	[23]
Chromatin fibers		[82]	2011	1000	6.5 to 8	4.3	0.6	1	1	80$	22500	2048	300	yes	126	90	60	no	[83] and [84]
gp140	HIV-1	[85]	2011	4000	2.5	2	0.41	1	C3	100	34	2048	200	yes	130	90	41	no	[23]
Desmosomal plague		[86]	2011		4 to 9	3.2	0.6	1	1	50$		2048	300	yes	130	40	25	no	[8]
Envelope spikes	HIV-1	[87]	2011	1463	4 to 5	3.3	0.23	1	c3	170	39	4096	300	no	130	100	14	no	[2]
envelope spikes	AIDS virus	[88]	2006	6175	4 to 6	3.2	0.56	1	c3	150	43	2048	300	no	140	60	14	no	[2]
RNA Packaging Element	Retrovirus	[89]	2010	47		4	0.65	2	1	50	23	4096	200	yes	120		10	no	
	Sulfolobus turreted icosahedral virus	[90]	2010	123	10 to 14	6.5	1.26	2	icosahed ral	300	18	4096	300	yes	120	160	100	no	[91]
Hibernating ribosomes	Bacterial cell lyzates	[92]	2010	1232	3		0.28	1	1	100	54	4096	160	no	120	50	50	no	[8]

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	Intact starved E.coli		2010	601	9#	3	0.71	1	1	400	42	2048	300	yes	120		50	no	
Bacterial membrane Eflix pump		[46]	2010	919	4	3	0.82	1	1	100	27.5	2048	300	yes	138	60	30	no	[5]
PSII in chloroplast membranes		[93]	2010	300	6 to 10		0.71	1	2	150$		2048	300	yes	130	150	10	no	[25]
ATP synthase in chloroplast membranes			2010	50	6 to 10		0.71	1	1	150$		2048	300	yes	130	150	12	no	
	Bordetella bacteriophage	[49]	2010	60			0.4	1	icosahedral	100		4096	300	no	140	100	70	no	[2]
Dynein regulatory complex in cila and flagella		[94]	2009	720	6 to 8	3.3		1	1		13.5	2048	300	yes	130	100	96	no	[25]
Inner dynein arms and inter-doublet links in	*Chlamydomonas* flagella	[95]	2009	405	2 to 4							2048	200	yes	120		96	no	[12] and [5]
ATP synthase dimers		[52]	2009	550	10	5.7	0.7	1	c2	500	41.4	2048	300	yes		80	30	yes	[25]
Envelope Spikes	HIV-1	[96]	2008	2070			0.56	8	c3	100	43	2048	300	no	130	100	12	no	[2]
	Rift Valley Fever Virus	[97]	2008	46		6		1	icosahedral	150	15	4096	200		136		100	no	[15] and [4]
Integrin $\alpha_{IIb}\beta_3$ in Membrane Environment		[98]	2008	1715	6		0.56					2048	300	no	124		11	no	[2]
	Kaposi's sarcoma-associated herpesvirus	[99]	2008	297	8		0.89	1	1			4096	300		140		100	no	[100]
Receptor–membrane complex	Poliovirus	[101]	2007	1200	4	3	0.99	1	c5	150		2048	300	yes	132	100	50	no	[5] and [25]
26S proteasome		[102]	2006	153	2.5	3.5	0.39	1	c2	80	36		160	no	120	20	50	no	[61]
Capsid	Herpesvirus	[103]	2007	38		5.7		1	icosahedral	200	27.8		200	no	140	50	200	no	[4]
Glycoprotein spikes	Influenza	[104]	2006		4 to 6		0.78			150		2048	120	yes	136	55	20	no	
Axonemes	Chlamydomonas	[25]	2006	280	6 to 8	4	0.95	1	1	200		2048	300	yes	130	100	96	no	[25]
Bacterial flagellar motor	*Treponema primitia*	[105]	2006	20	10 to 18	7	0.98	1	c16	250		2048	300	yes	126	110	100	no	[12] and [18]
Myosin V (neg stain)		[106]	2006	4029	5 to 12#	2.4	0.56	1	C6	50	43	2048	300	no	140	30	40	yes	[5]
Virus core	Hepatitis B	[107]	2006	80	5.7#	2.4	5	1	icosahedral			2048	300	no	102			no	[12]
Pyruvate and 2-Oxoglutarate Dehydrogenase Complexes	*E. coli*	[108]	2005	305	10	5.5	0.82	1	octahedral	50	27.5	2048	300	yes	126	120	15	yes	[12] and [18]
Thermosome		[109]	1998	307	2	2.8	0.48	1	82 point group	50	39		120	no	101	20	20	no	[28]
Nuclear pore complex	*Dictyostelium discoideum*	[110]	2004	267	15	8.3	0.82		c8	500		2048	300	yes	126		150	no	[8]

Table S1. Protein complexes studied by cryo electron tomography and sub-tomogram averaging with acquisition parameters.

Remarks for Table S1:

- Each publication may contain several structures acquired at different imaging conditions, in such cases several rows are possible for one publication
- Publication year may mismatch with the values in the table due to advance publication date.
- In cases resolution was not explicitly specified but the Fourier Shell Correlation (FSC) curve was provided, we estimated the resolution from the intersection of the FSC curve with the 0.5 – line.
- For underfocus values, # indicates that CTF correction was applied, * indicates the use of a phase plate.
- Number of classes and symmetry was assumed to be 1 resp. p1, unless another value is specified.
- Accelerating voltage was assumed to be highest achievable for the specified microscope unless another value specified.
- Ice thickness is specified in some manuscripts, for others we estimated as minimal possible ice thickness the dimension needed for accommodating the samples.

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