wwPDB EM Validation Summary Report (i)

Oct 8, 2026 – 08:14 PM JST

PDB ID	:	28FS / pdb_000028fs
EMDB ID	:	EMD-81712
Title	:	Cryo-EM structure of hydrogenase-2 in complex with L1 (left)
Authors	:	Zhang, N.; Huang, Y.; Zhang, L.
Deposited on	:	2026-06-24
Resolution	:	2.49 Å(reported)

This is a wwPDB EM Validation Summary Report for a publicly released PDB entry.

We welcome your comments at *validation@mail.wwpdb.org*
A user guide is available at
https://www.wwpdb.org/validation/2017/EMValidationReportHelp
with specific help available everywhere you see the (i) symbol.

The types of validation reports are described at
http://www.wwpdb.org/validation/2017/FAQs#types.

The following versions of software and data (see references (1)) were used in the production of this report:

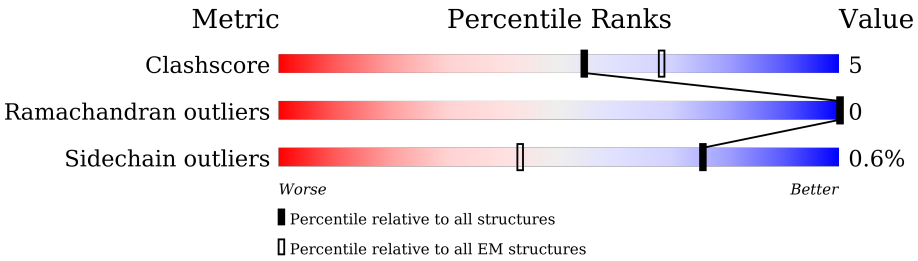
EMDB validation analysis	:	0.0.1.dev133
Mogul	:	1.8.5 (274361), CSD as541be (2020)
MolProbity	:	4-5-2 with Phenix2.2
Percentile statistics	:	20250101.v01 (using entries in the PDB archive January 1st 2025)
EM percentile statistics	:	202505.v01 (Using data in the EMDB archive up until May 2025)
MapQ	:	1.9.13
Ideal geometry (proteins)	:	Engh & Huber (2001)
Ideal geometry (DNA, RNA)	:	Parkinson et al. (1996)
Validation Pipeline (wwPDB-VP)	:	2.51

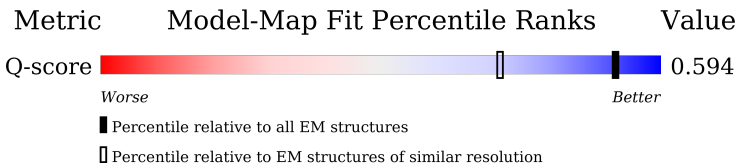
1 Overall quality at a glance (i)

The following experimental techniques were used to determine the structure:
ELECTRON MICROSCOPY

The reported resolution of this entry is 2.49 Å.

Percentile scores (ranging between 0-100) for global validation metrics of the entry are shown in the following graphic. The table shows the number of entries on which the scores are based.





Metric	Whole archive (#Entries)	EM structures (#Entries)	Similar EM resolution (#Entries, resolution range(Å))
Clashscore	229148	23984	-
Ramachandran outliers	224038	23583	-
Sidechain outliers	223484	23102	-
Q-score	-	25397	6237 (2.00 - 2.99)

The table below summarises the geometric issues observed across the polymeric chains and their fit to the map. The red, orange, yellow and green segments of the bar indicate the fraction of residues that contain outliers for >=3, 2, 1 and 0 types of geometric quality criteria respectively. A grey segment represents the fraction of residues that are not modelled. The numeric value for each fraction is indicated below the corresponding segment, with a dot representing fractions <=5% The upper red bar (where present) indicates the fraction of residues that have poor fit to the EM map (all-atom inclusion < 40%). The numeric value is given above the bar.

Mol	Chain	Length	Quality of chain
1	E	82	21% 79% 12% 9%
2	A	298	79% 11% 10%
2	C	298	77% 12% 10%
3	B	567	85% 12% •

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Mol	Chain	Length	Quality of chain
3	D	567	85% 12%

The following table lists non-polymeric compounds, carbohydrate monomers and non-standard residues in protein, DNA, RNA chains that are outliers for geometric or electron-density-fit criteria:

Mol	Type	Chain	Res	Chirality	Geometry	Clashes	Electron density
6	FCO	D	601	-	-	X	-

2 Entry composition (i)

There are 7 unique types of molecules in this entry. The entry contains 13322 atoms, of which 0 are hydrogens and 0 are deuteriums.

In the tables below, the AltConf column contains the number of residues with at least one atom in alternate conformation and the Trace column contains the number of residues modelled with at most 2 atoms.

- Molecule 1 is a protein called binder L1.

Mol	Chain	Residues	Atoms				AltConf	Trace
			Total	C	N	O		
1	E	75	520	320	95	105	0	0

- Molecule 2 is a protein called Hydrogenase-2 small chain.

Mol	Chain	Residues	Atoms					AltConf	Trace
			Total	C	N	O	S		
2	A	267	2059	1304	364	378	13	4	0
2	C	267	2059	1306	362	378	13	5	0

There are 12 discrepancies between the modelled and reference sequences:

Chain	Residue	Modelled	Actual	Comment	Reference
A	294	HIS	-	expression tag	UNP P69741
A	295	HIS	-	expression tag	UNP P69741
A	296	HIS	-	expression tag	UNP P69741
A	297	HIS	-	expression tag	UNP P69741
A	298	HIS	-	expression tag	UNP P69741
A	299	HIS	-	expression tag	UNP P69741
C	294	HIS	-	expression tag	UNP P69741
C	295	HIS	-	expression tag	UNP P69741
C	296	HIS	-	expression tag	UNP P69741
C	297	HIS	-	expression tag	UNP P69741
C	298	HIS	-	expression tag	UNP P69741
C	299	HIS	-	expression tag	UNP P69741

- Molecule 3 is a protein called Hydrogenase-2 large chain.

Mol	Chain	Residues	Atoms					AltConf	Trace
			Total	C	N	O	S		
3	B	551	4319	2748	741	812	18	6	0

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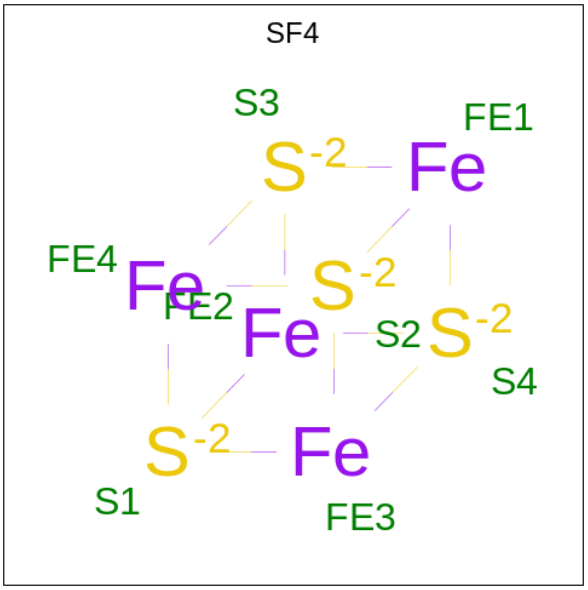
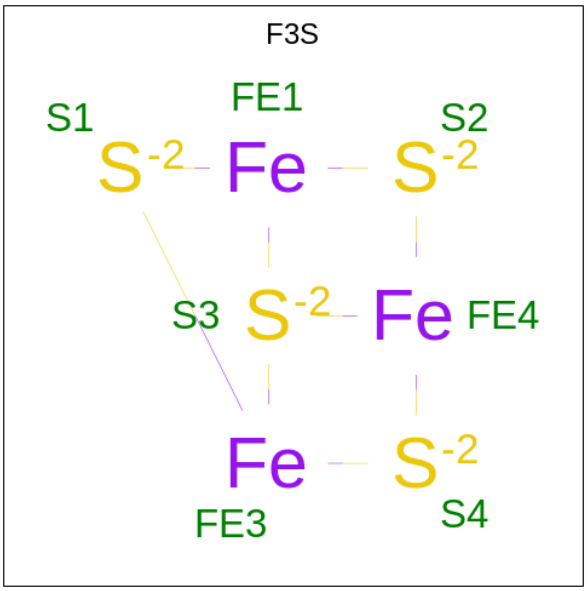
Mol	Chain	Residues	Atoms					AltConf	Trace
			Total	C	N	O	S		
3	D	551	4303	2738	740	807	18	3	0

- Molecule 4 is IRON/SULFUR CLUSTER (CCD ID: SF4) (formula: Fe_4S_4).



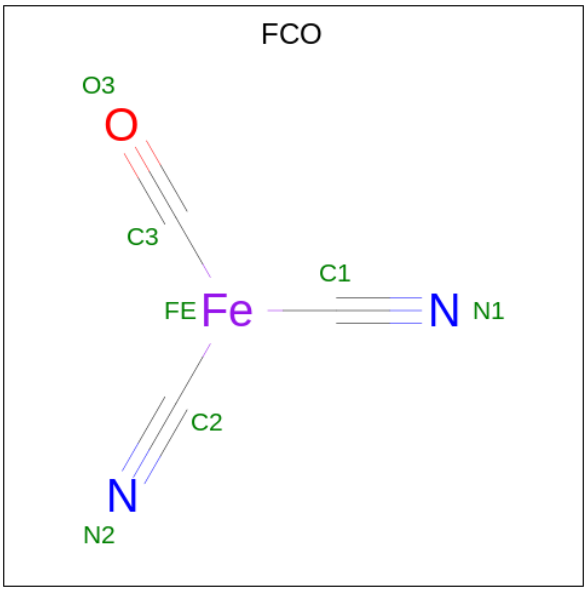
Mol	Chain	Residues	Atoms			AltConf
			Total	Fe	S	
4	A	1	8	4	4	0
4	A	1	8	4	4	0
4	C	1	8	4	4	0
4	C	1	8	4	4	0

- Molecule 5 is FE3-S4 CLUSTER (CCD ID: F3S) (formula: Fe_3S_4).



Mol	Chain	Residues	Atoms			AltConf
			Total	Fe	S	
5	A	1	7	3	4	0
5	C	1	7	3	4	0

- Molecule 6 is CARBONMONOXIDE-(DICYANO) IRON (CCD ID: FCO) (formula: C_3FeN_2O).



Mol	Chain	Residues	Atoms					AltConf
			Total	C	Fe	N	O	
6	B	1	7	3	1	2	1	0

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Mol	Chain	Residues	Atoms					AltConf
			Total	C	Fe	N	O	
6	D	1	7	3	1	2	1	0

- Molecule 7 is NICKEL (II) ION (CCD ID: NI) (formula: Ni).

Mol	Chain	Residues	Atoms		AltConf
			Total	Ni	
7	B	1	1	1	0
			Total	Ni	
7	D	1	1	1	0

3 Residue-property plots (i)

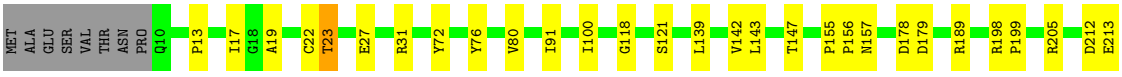
These plots are drawn for all protein, RNA, DNA and oligosaccharide chains in the entry. The first graphic for a chain summarises the proportions of the various outlier classes displayed in the second graphic. The second graphic shows the sequence view annotated by issues in geometry and atom inclusion in map density. Residues are color-coded according to the number of geometric quality criteria for which they contain at least one outlier: green = 0, yellow = 1, orange = 2 and red = 3 or more. A red diamond above a residue indicates a poor fit to the EM map for this residue (all-atom inclusion < 40%). Stretches of 2 or more consecutive residues without any outlier are shown as a green connector. Residues present in the sample, but not in the model, are shown in grey.

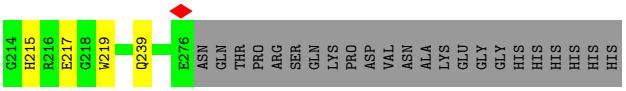
- Molecule 1: binder L1

Chain E:

- Molecule 2: Hydrogenase-2 small chain

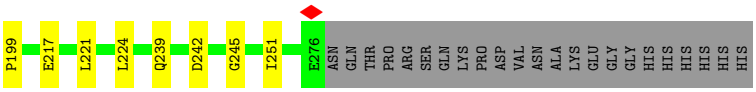
Chain A:





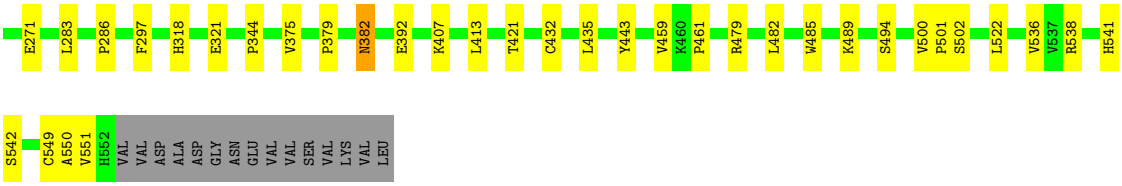
- Molecule 2: Hydrogenase-2 small chain

Chain C:



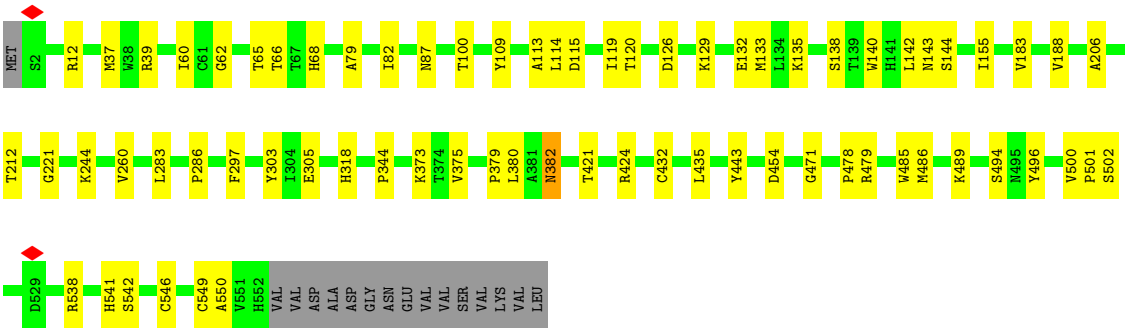
- Molecule 3: Hydrogenase-2 large chain

Chain B:



- Molecule 3: Hydrogenase-2 large chain

Chain D:



4 Experimental information (i)

Property	Value	Source
EM reconstruction method	SINGLE PARTICLE	Depositor
Imposed symmetry	POINT, Not provided	
Number of particles used	216621	Depositor
Resolution determination method	FSC 0.143 CUT-OFF	Depositor
CTF correction method	NONE	Depositor
Microscope	TFS TITAN THEMIS	Depositor
Voltage (kV)	300	Depositor
Electron dose ($e^-/Å^2$)	50	Depositor
Minimum defocus (nm)	800	Depositor
Maximum defocus (nm)	2000	Depositor
Magnification	Not provided	
Image detector	FEI FALCON IV (4k x 4k)	Depositor
Maximum map value	0.891	Depositor
Minimum map value	-0.280	Depositor
Average map value	0.002	Depositor
Map value standard deviation	0.029	Depositor
Recommended contour level	0.137	Depositor
Map size (Å)	186.0, 186.0, 186.0	wwPDB
Map dimensions	200, 200, 200	wwPDB
Map angles (°)	90.0, 90.0, 90.0	wwPDB
Pixel spacing (Å)	0.93, 0.93, 0.93	Depositor

5 Model quality (i)

5.1 Standard geometry (i)

Bond lengths and bond angles in the following residue types are not validated in this section: F3S, NI, FCO, SF4

The Z score for a bond length (or angle) is the number of standard deviations the observed value is removed from the expected value. A bond length (or angle) with $|Z| > 5$ is considered an outlier worth inspection. RMSZ is the root-mean-square of all Z scores of the bond lengths (or angles).

Mol	Chain	Bond lengths		Bond angles	
		RMSZ	$\#\|Z\|>5$	RMSZ	$\#\|Z\|>5$
1	E	0.10	0/524	0.28	0/714
2	A	0.10	0/2122	0.28	0/2888
2	C	0.10	0/2131	0.27	0/2900
3	B	0.09	0/4441	0.25	0/6054
3	D	0.09	0/4419	0.25	0/6024
All	All	0.10	0/13637	0.26	0/18580

There are no bond length outliers.

There are no bond angle outliers.

There are no chirality outliers.

There are no planarity outliers.

5.2 Too-close contacts (i)

In the following table, the Non-H and H(model) columns list the number of non-hydrogen atoms and hydrogen atoms in the chain respectively. The H(added) column lists the number of hydrogen atoms added and optimized by MolProbity. The Clashes column lists the number of clashes within the asymmetric unit, whereas Symm-Clashes lists symmetry-related clashes.

Mol	Chain	Non-H	H(model)	H(added)	Clashes	Symm-Clashes
1	E	520	0	530	8	0
2	A	2059	0	1987	27	0
2	C	2059	0	1995	24	0
3	B	4319	0	4264	45	0
3	D	4303	0	4246	47	0
4	A	16	0	0	0	0
4	C	16	0	0	0	0
5	A	7	0	0	0	0

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Mol	Chain	Non-H	H(model)	H(added)	Clashes	Symm-Clashes
5	C	7	0	0	0	0
6	B	7	0	0	1	0
6	D	7	0	0	2	0
7	B	1	0	0	0	0
7	D	1	0	0	0	0
All	All	13322	0	13022	134	0

The all-atom clashscore is defined as the number of clashes found per 1000 atoms (including hydrogen atoms). The all-atom clashscore for this structure is 5.

The worst 5 of 134 close contacts within the same asymmetric unit are listed below, sorted by their clash magnitude.

Atom-1	Atom-2	Interatomic distance (Å)	Clash overlap (Å)
3:B:500:VAL:HG11	3:B:549:CYS:HB3	1.68	0.75
3:D:65:THR:HG23	3:D:66:THR:HG23	1.76	0.67
2:A:157:ASN:ND2	2:A:239:GLN:O	2.29	0.65
3:D:68:HIS:NE2	3:D:549:CYS:SG	2.58	0.64
3:B:144:SER:HB3	3:D:144:SER:HB3	1.81	0.63

There are no symmetry-related clashes.

5.3 Torsion angles (i)

5.3.1 Protein backbone (i)

In the following table, the Percentiles column shows the percent Ramachandran outliers of the chain as a percentile score with respect to all PDB entries followed by that with respect to all EM entries.

The Analysed column shows the number of residues for which the backbone conformation was analysed, and the total number of residues.

Mol	Chain	Analysed	Favoured	Allowed	Outliers	Percentiles	
1	E	73/82 (89%)	73 (100%)	0	0	100	100
2	A	269/298 (90%)	261 (97%)	8 (3%)	0	100	100
2	C	270/298 (91%)	262 (97%)	8 (3%)	0	100	100
3	B	555/567 (98%)	541 (98%)	14 (2%)	0	100	100
3	D	552/567 (97%)	539 (98%)	13 (2%)	0	100	100
All	All	1719/1812 (95%)	1676 (98%)	43 (2%)	0	100	100

There are no Ramachandran outliers to report.

5.3.2 Protein sidechains (i)

In the following table, the Percentiles column shows the percent sidechain outliers of the chain as a percentile score with respect to all PDB entries followed by that with respect to all EM entries.

The Analysed column shows the number of residues for which the sidechain conformation was analysed, and the total number of residues.

Mol	Chain	Analysed	Rotameric	Outliers	Percentiles	
1	E	45/52 (86%)	45 (100%)	0	100	100
2	A	216/239 (90%)	213 (99%)	3 (1%)	59	81
2	C	217/239 (91%)	214 (99%)	3 (1%)	59	81
3	B	471/479 (98%)	468 (99%)	3 (1%)	78	91
3	D	468/479 (98%)	466 (100%)	2 (0%)	84	93
All	All	1417/1488 (95%)	1406 (99%)	11 (1%)	76	88

5 of 11 residues with a non-rotameric sidechain are listed below:

Mol	Chain	Res	Type
2	C	66	HIS
2	C	251	ILE
3	D	382[B]	ASN
3	D	382[A]	ASN
3	B	382[A]	ASN

Sometimes sidechains can be flipped to improve hydrogen bonding and reduce clashes. 5 of 11 such sidechains are listed below:

Mol	Chain	Res	Type
3	D	411	ASN
3	D	495	ASN
3	D	520	GLN
3	D	497	GLN
3	B	520	GLN

5.3.3 RNA (i)

There are no RNA molecules in this entry.

5.4 Non-standard residues in protein, DNA, RNA chains (i)

There are no non-standard protein/DNA/RNA residues in this entry.

5.5 Carbohydrates (i)

There are no oligosaccharides in this entry.

5.6 Ligand geometry (i)

Of 10 ligands modelled in this entry, 2 are monoatomic - leaving 8 for Mogul analysis.

In the following table, the Counts columns list the number of bonds (or angles) for which Mogul statistics could be retrieved, the number of bonds (or angles) that are observed in the model and the number of bonds (or angles) that are defined in the Chemical Component Dictionary. The Link column lists molecule types, if any, to which the group is linked. The Z score for a bond length (or angle) is the number of standard deviations the observed value is removed from the expected value. A bond length (or angle) with $|Z| > 2$ is considered an outlier worth inspection. RMSZ is the root-mean-square of all Z scores of the bond lengths (or angles).

Mol	Type	Chain	Res	Link	Bond lengths			Bond angles		
					Counts	RMSZ	$\#\|Z\| > 2$	Counts	RMSZ	$\#\|Z\| > 2$
5	F3S	A	302	2	0,9,9	-	-	-		
4	SF4	A	303	2	0,12,12	-	-	-		
6	FCO	B	601	3	1,6,6	2.90	1 (100%)	-		
4	SF4	C	303	2	0,12,12	-	-	-		
6	FCO	D	601	3	1,6,6	2.88	1 (100%)	-		
5	F3S	C	302	2	0,9,9	-	-	-		
4	SF4	A	301	2	0,12,12	-	-	-		
4	SF4	C	301	2	0,12,12	-	-	-		

In the following table, the Chirals column lists the number of chiral outliers, the number of chiral centers analysed, the number of these observed in the model and the number defined in the Chemical Component Dictionary. Similar counts are reported in the Torsion and Rings columns. '-' means no outliers of that kind were identified.

Mol	Type	Chain	Res	Link	Chirals	Torsions	Rings
5	F3S	A	302	2	-	-	0/3/3/3
4	SF4	A	303	2	-	-	0/6/5/5
4	SF4	C	303	2	-	-	0/6/5/5
5	F3S	C	302	2	-	-	0/3/3/3
4	SF4	A	301	2	-	-	0/6/5/5
4	SF4	C	301	2	-	-	0/6/5/5

All (2) bond length outliers are listed below:

Mol	Chain	Res	Type	Atoms	Z	Observed(Å)	Ideal(Å)
6	B	601	FCO	O3-C3	-2.90	1.12	1.16
6	D	601	FCO	O3-C3	-2.88	1.12	1.16

There are no bond angle outliers.

There are no chirality outliers.

There are no torsion outliers.

There are no ring outliers.

2 monomers are involved in 3 short contacts:

Mol	Chain	Res	Type	Clashes	Symm-Clashes
6	B	601	FCO	1	0
6	D	601	FCO	2	0

5.7 Other polymers (i)

There are no such residues in this entry.

5.8 Polymer linkage issues (i)

There are no chain breaks in this entry.

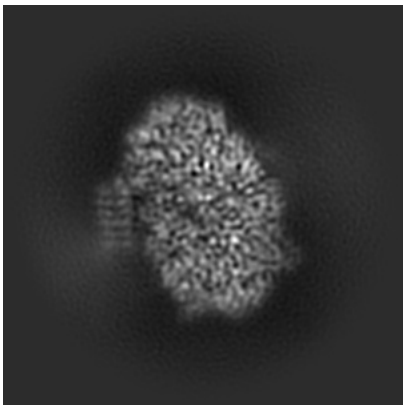
6 Map visualisation (i)

This section contains visualisations of the EMDB entry EMD-81712. These allow visual inspection of the internal detail of the map and identification of artifacts.

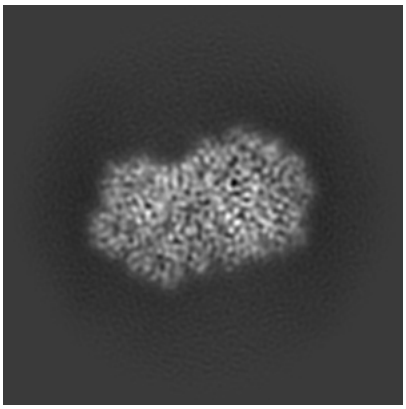
Images derived from a raw map, generated by summing the deposited half-maps, are presented below the corresponding image components of the primary map to allow further visual inspection and comparison with those of the primary map.

6.1 Orthogonal projections (i)

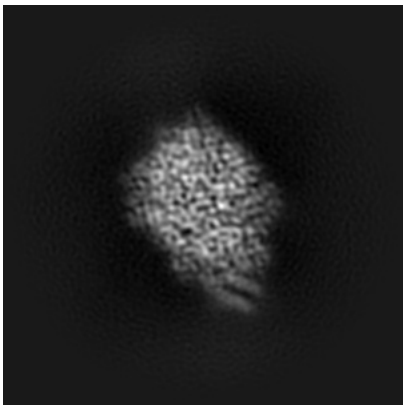
6.1.1 Primary map



X

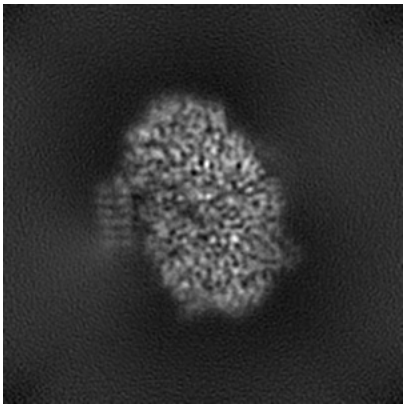


Y

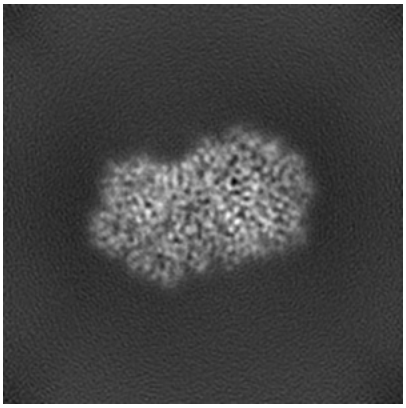


Z

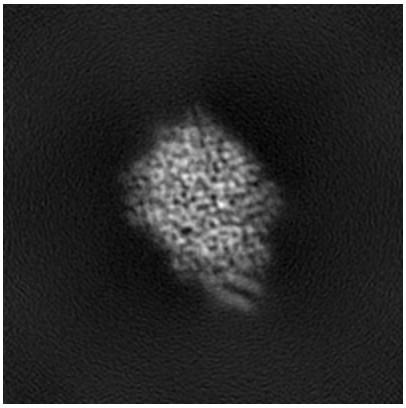
6.1.2 Raw map



X



Y

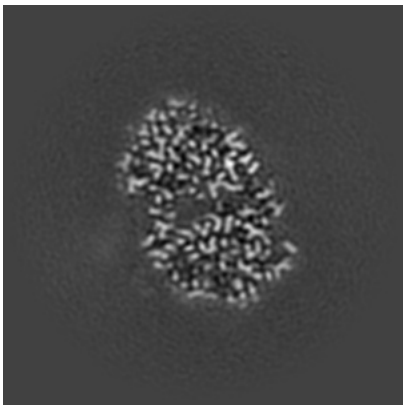


Z

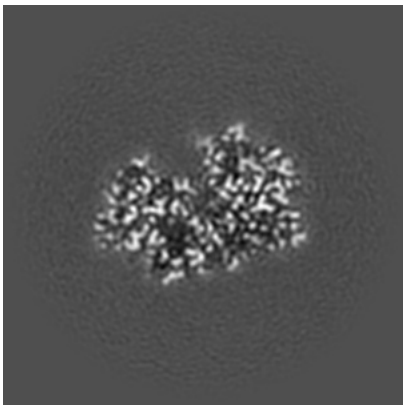
The images above show the map projected in three orthogonal directions.

6.2 Central slices (i)

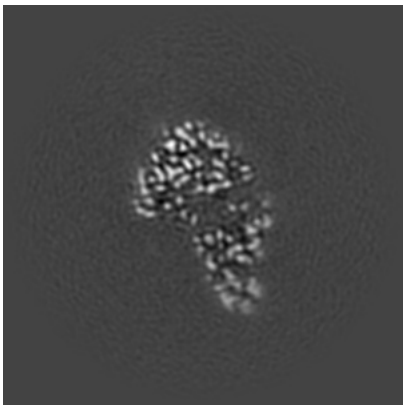
6.2.1 Primary map



X Index: 100

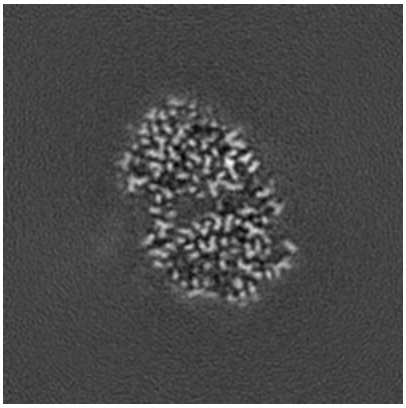


Y Index: 100

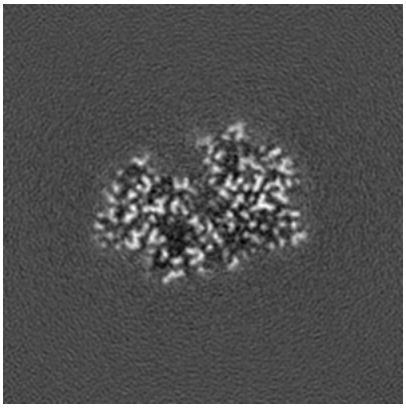


Z Index: 100

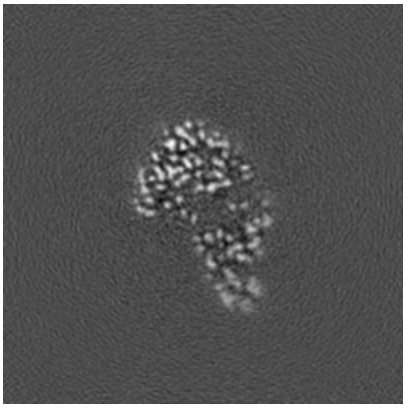
6.2.2 Raw map



X Index: 100



Y Index: 100

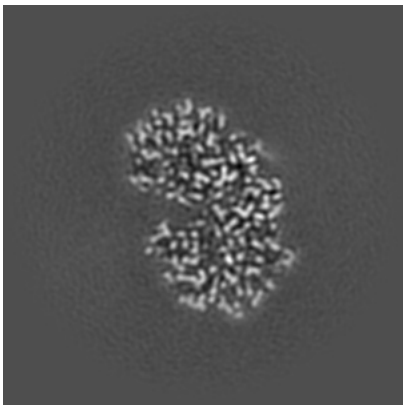


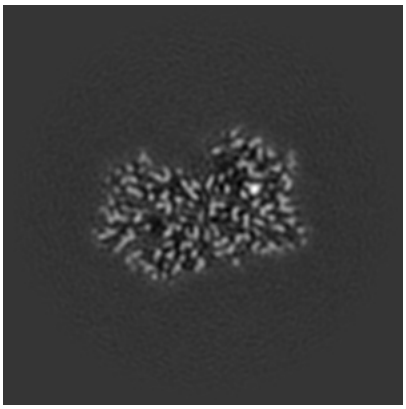
Z Index: 100

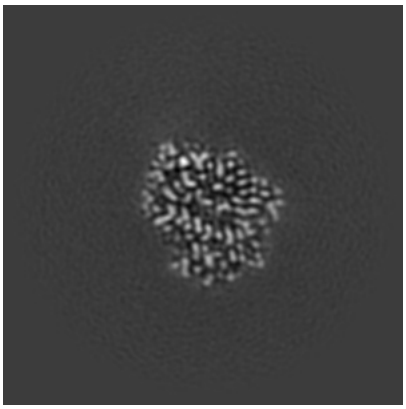
The images above show central slices of the map in three orthogonal directions.

6.3 Largest variance slices (i)

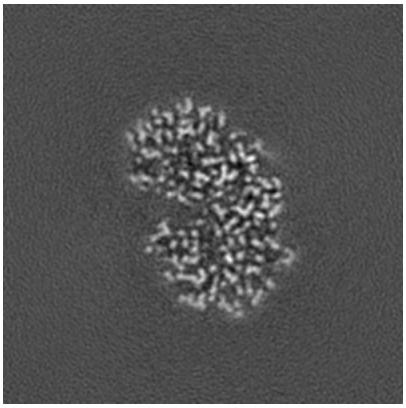
6.3.1 Primary map

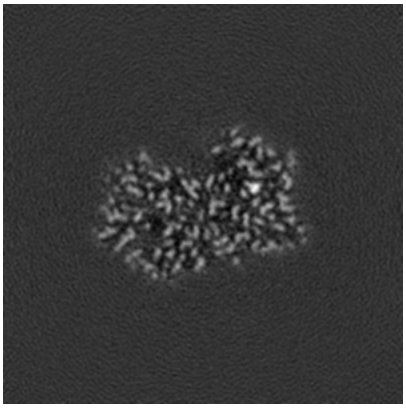

X Index: 94

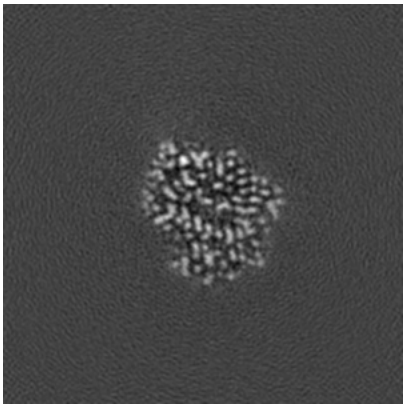

Y Index: 105


Z Index: 117

6.3.2 Raw map


X Index: 94

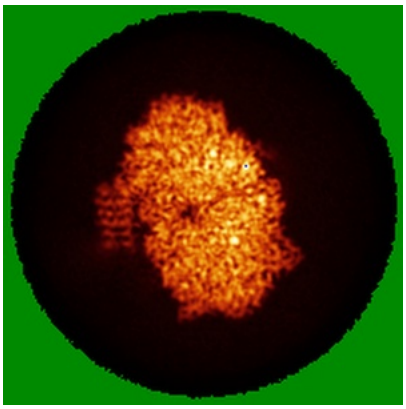

Y Index: 105

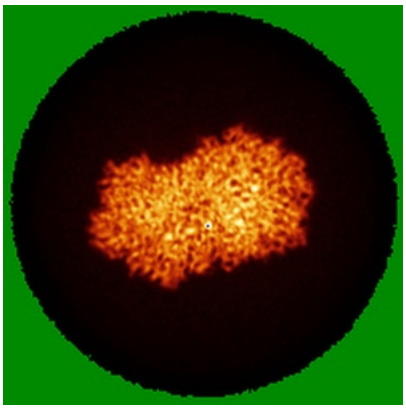

Z Index: 117

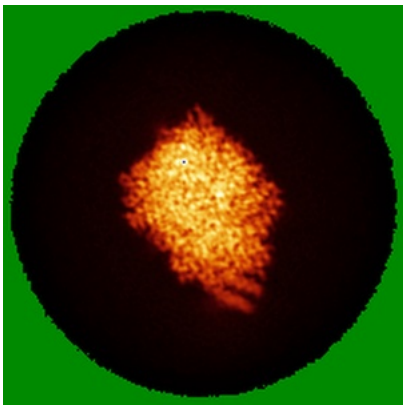
The images above show the largest variance slices of the map in three orthogonal directions.

6.4 Orthogonal standard-deviation projections (False-color) (i)

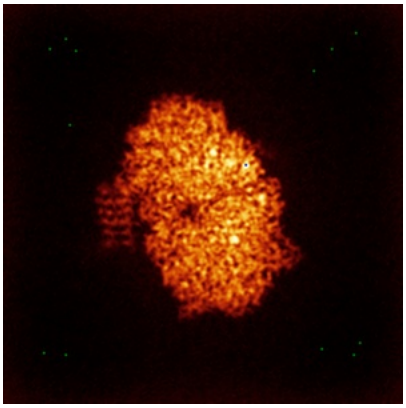
6.4.1 Primary map

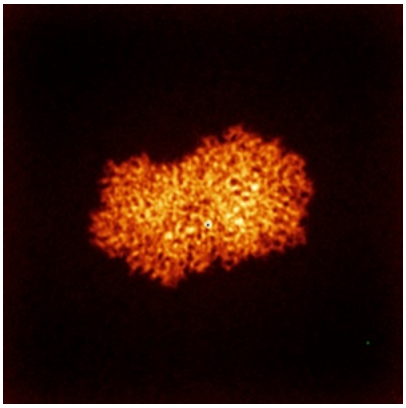

X

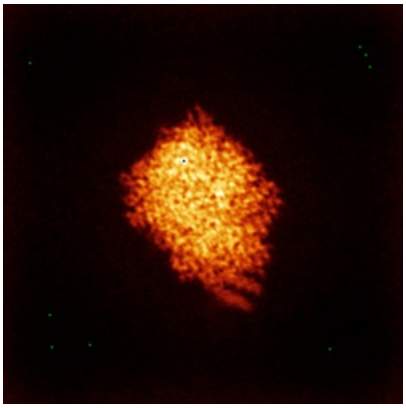

Y


Z

6.4.2 Raw map


X


Y


Z

The images above show the map standard deviation projections with false color in three orthogonal directions. Minimum values are shown in green, max in blue, and dark to light orange shades represent small to large values respectively.

6.5 Orthogonal surface views (i)

6.5.1 Primary map

X Y Z

The images above show the 3D surface view of the map at the recommended contour level 0.137. These images, in conjunction with the slice images, may facilitate assessment of whether an appropriate contour level has been provided.

6.5.2 Raw map

X Y Z

These images show the 3D surface of the raw map. The raw map's contour level was selected so that its surface encloses the same volume as the primary map does at its recommended contour level.

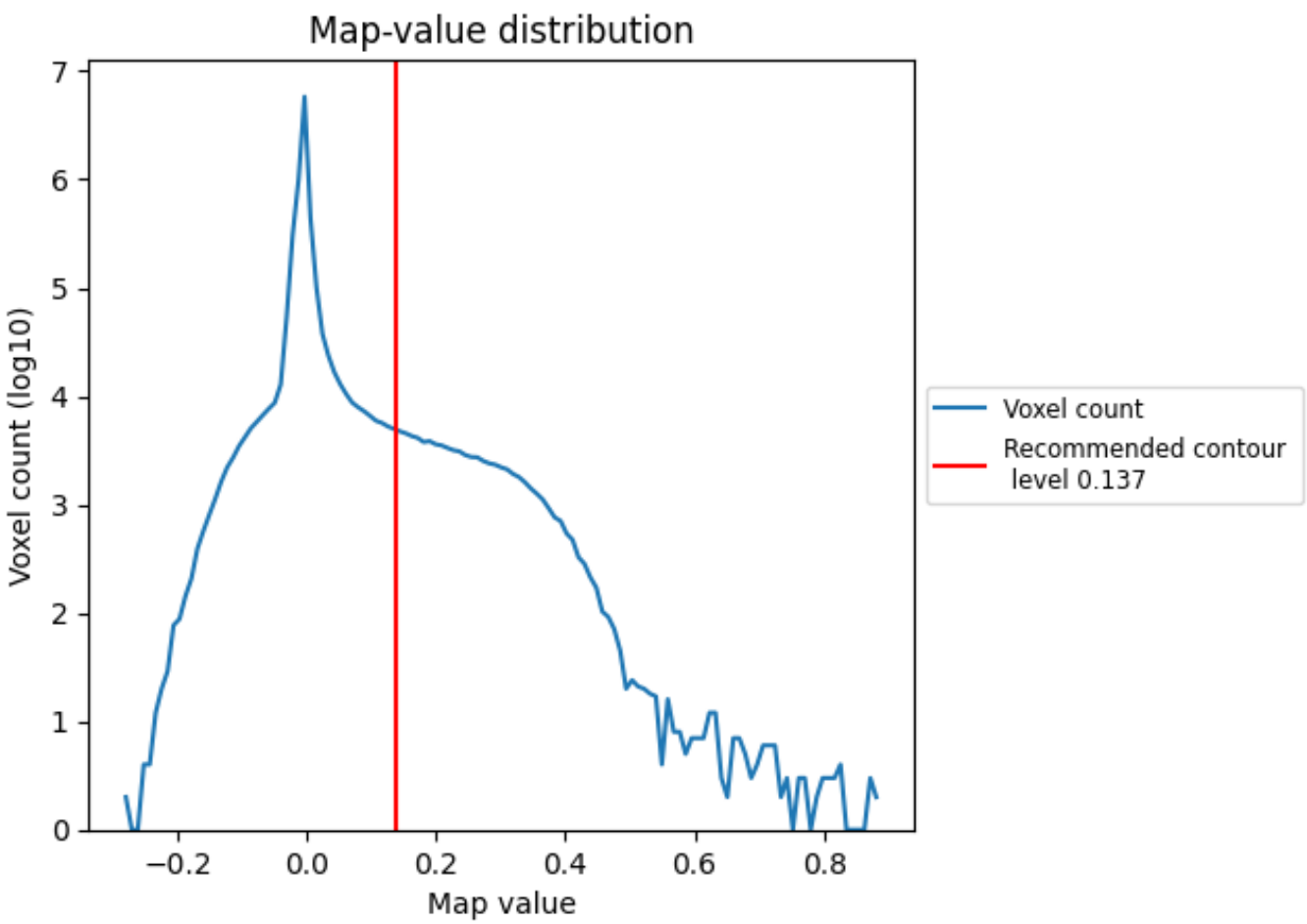
6.6 Mask visualisation (i)

This section was not generated. No masks/segmentation were deposited.

7 Map analysis (i)

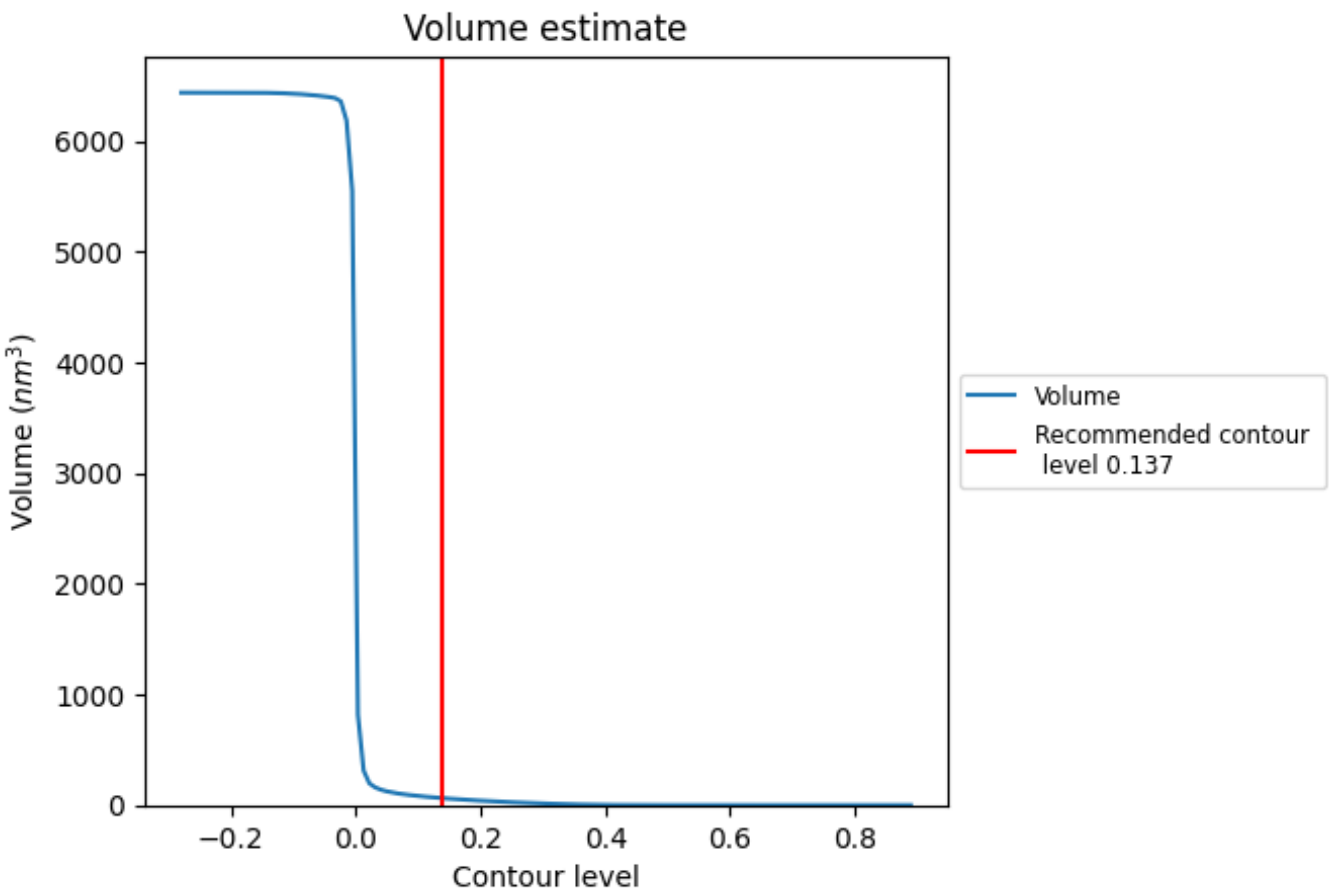
This section contains the results of statistical analysis of the map.

7.1 Map-value distribution (i)



The map-value distribution is plotted in 128 intervals along the x-axis. The y-axis is logarithmic. A spike in this graph at zero usually indicates that the volume has been masked.

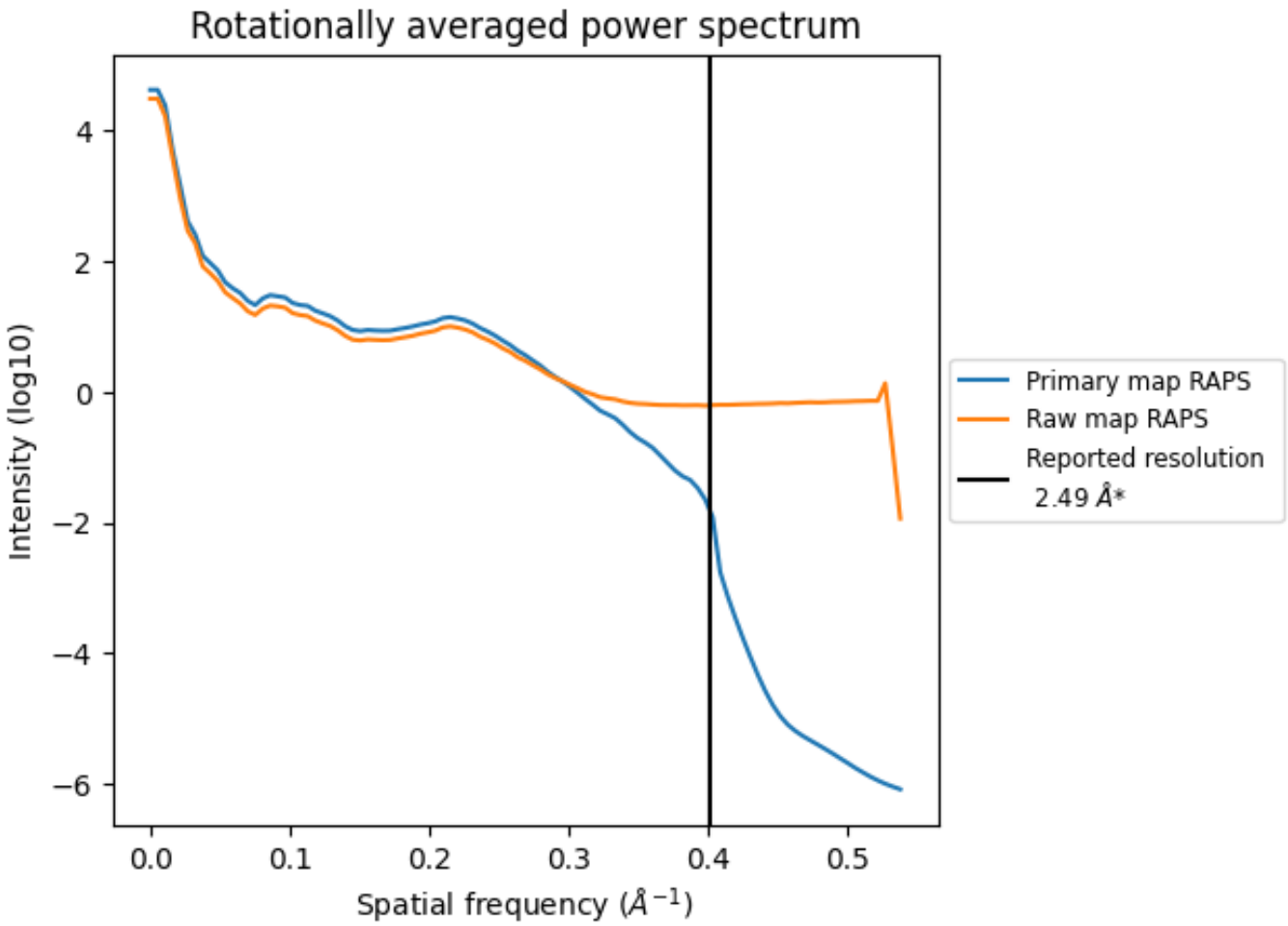
7.2 Volume estimate (i)



The volume at the recommended contour level is 64 nm^3; this corresponds to an approximate mass of 58 kDa.

The volume estimate graph shows how the enclosed volume varies with the contour level. The recommended contour level is shown as a vertical line and the intersection between the line and the curve gives the volume of the enclosed surface at the given level.

7.3 Rotationally averaged power spectrum (i)

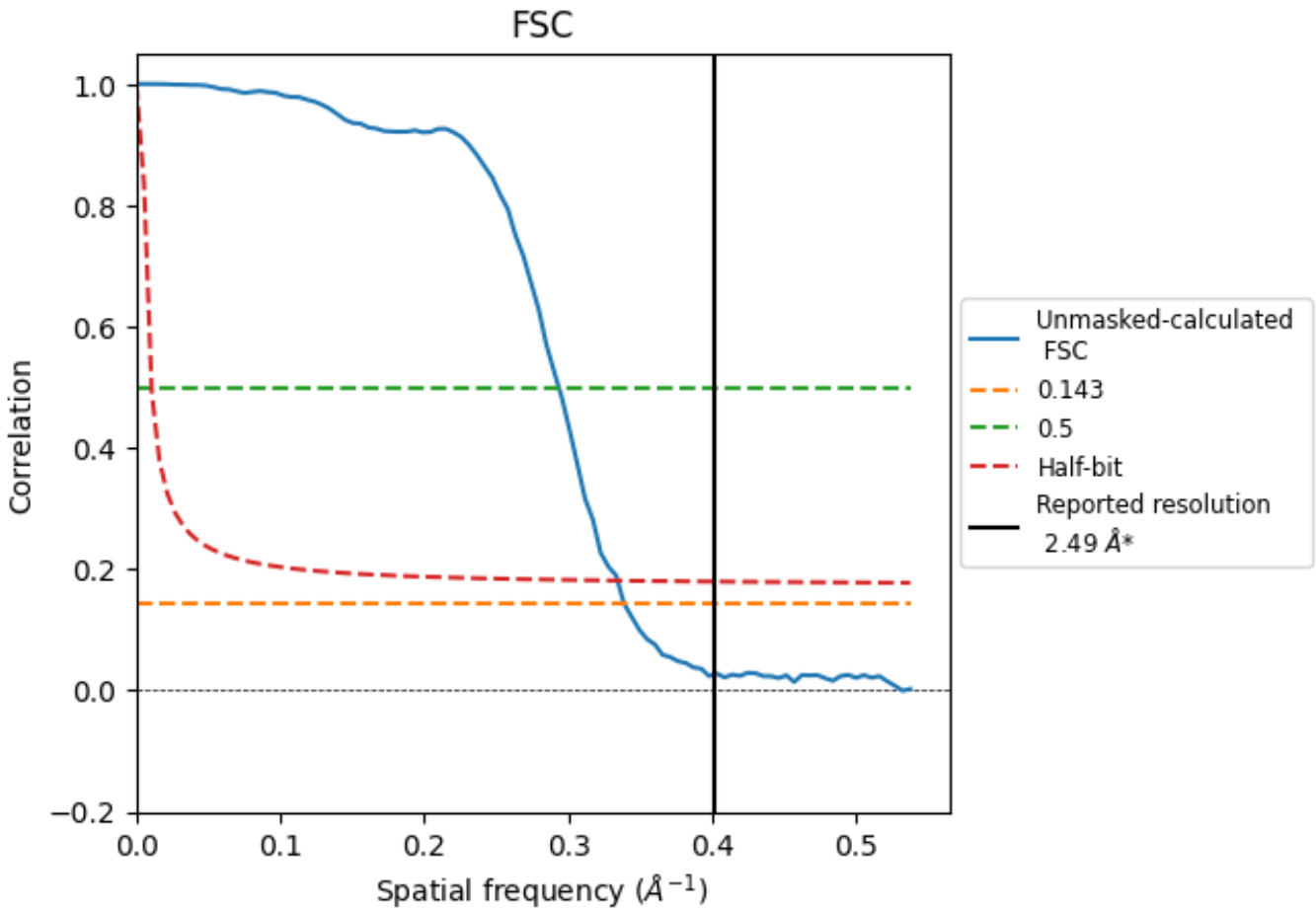


*Reported resolution corresponds to spatial frequency of 0.402 Å^{-1}

8 Fourier-Shell correlation (i)

Fourier-Shell Correlation (FSC) is the most commonly used method to estimate the resolution of single-particle and subtomogram-averaged maps. The shape of the curve depends on the imposed symmetry, mask and whether or not the two 3D reconstructions used were processed from a common reference. The reported resolution is shown as a black line. A curve is displayed for the half-bit criterion in addition to lines showing the 0.143 gold standard cut-off and 0.5 cut-off.

8.1 FSC (i)



*Reported resolution corresponds to spatial frequency of 0.402 Å^{-1}

8.2 Resolution estimates (i)

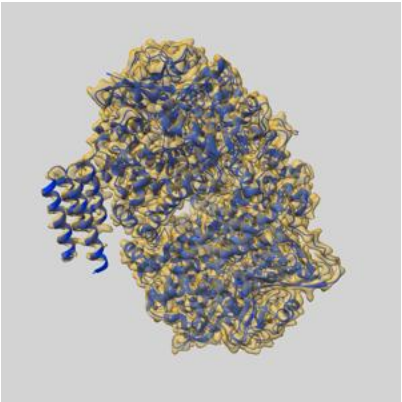
Resolution estimate (Å)	Estimation criterion (FSC cut-off)		
	0.143	0.5	Half-bit
Reported by author	2.49	-	-
Author-provided FSC curve	-	-	-
Unmasked-calculated*	2.95	3.41	2.99

*Resolution estimate based on FSC curve calculated by comparison of deposited half-maps. The value from deposited half-maps intersecting FSC 0.143 CUT-OFF 2.95 differs from the reported value 2.49 by more than 10 %

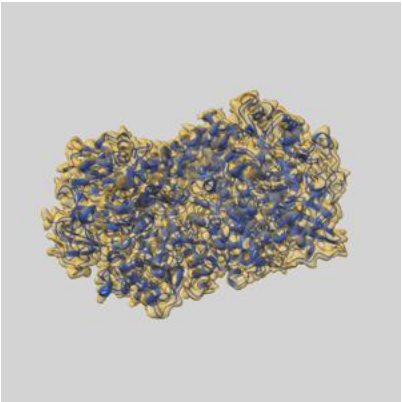
9 Map-model fit (i)

This section contains information regarding the fit between EMDB map EMD-81712 and PDB model 28FS. Per-residue inclusion information can be found in section 3 on page 8.

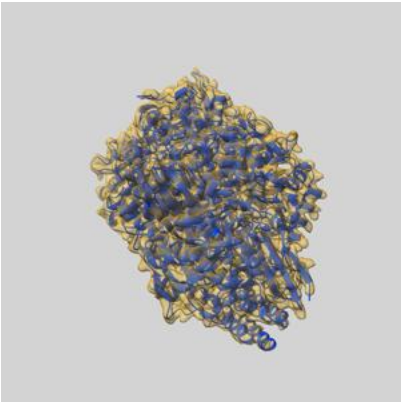
9.1 Map-model overlay (i)



X



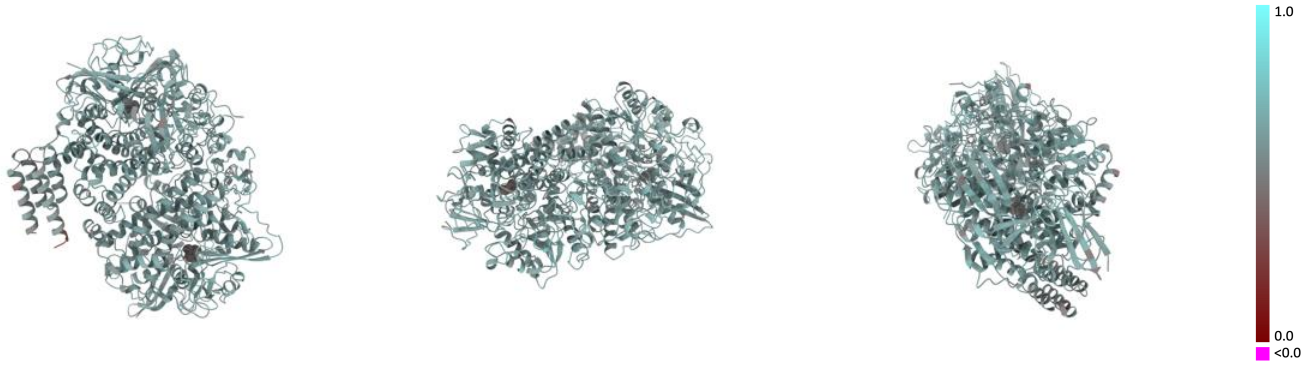
Y



Z

The images above show the 3D surface view of the map at the recommended contour level 0.137 at 50% transparency in yellow overlaid with a ribbon representation of the model coloured in blue. These images allow for the visual assessment of the quality of fit between the atomic model and the map.

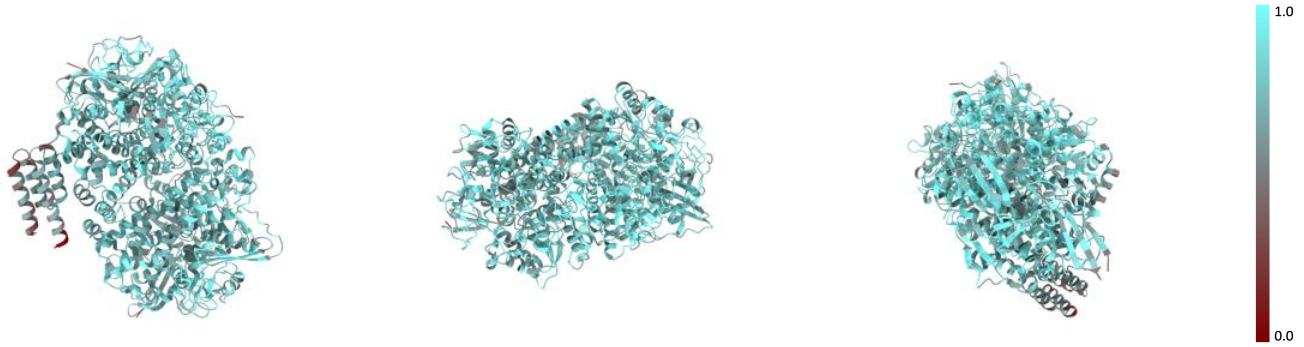
9.2 Q-score mapped to coordinate model (i)



X Y Z

The images above show the model with each residue coloured according its Q-score. This shows their resolvability in the map with higher Q-score values reflecting better resolvability. Please note: Q-score is calculating the resolvability of atoms, and thus high values are only expected at resolutions at which atoms can be resolved. Low Q-score values may therefore be expected for many entries.

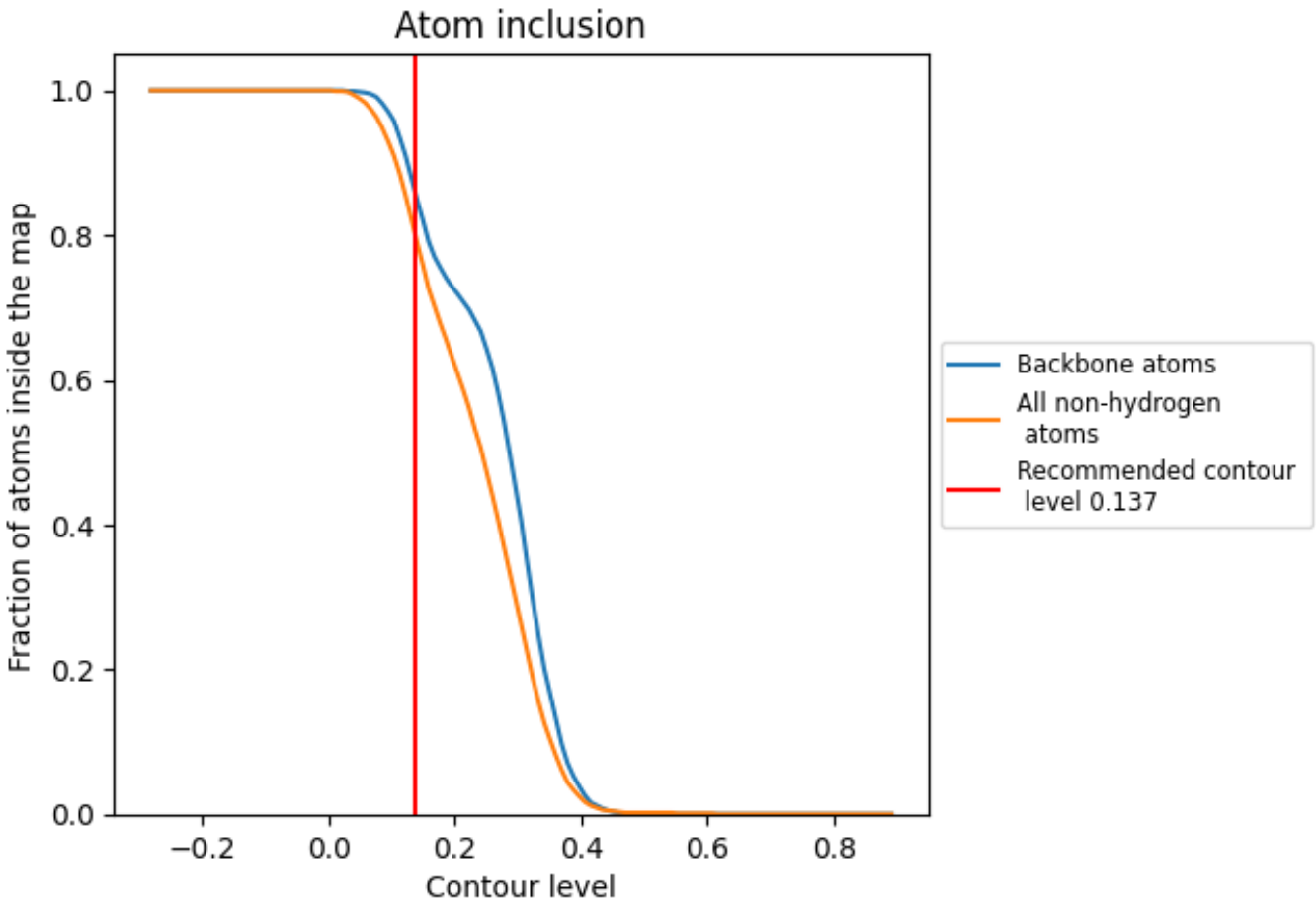
9.3 Atom inclusion mapped to coordinate model (i)



X Y Z

The images above show the model with each residue coloured according to its atom inclusion. This shows to what extent they are inside the map at the recommended contour level (0.137).

9.4 Atom inclusion (i)



At the recommended contour level, 86% of all backbone atoms, 80% of all non-hydrogen atoms, are inside the map.

9.5 Map-model fit summary (i)

The table lists the average atom inclusion at the recommended contour level (0.137) and Q-score for the entire model and for each chain.

Chain	Atom inclusion	Q-score
All	0.8030	0.5940
A	0.8370	0.5990
B	0.8160	0.5980
C	0.8130	0.5990
D	0.8050	0.5950
E	0.5140	0.5160