Supplementary figures

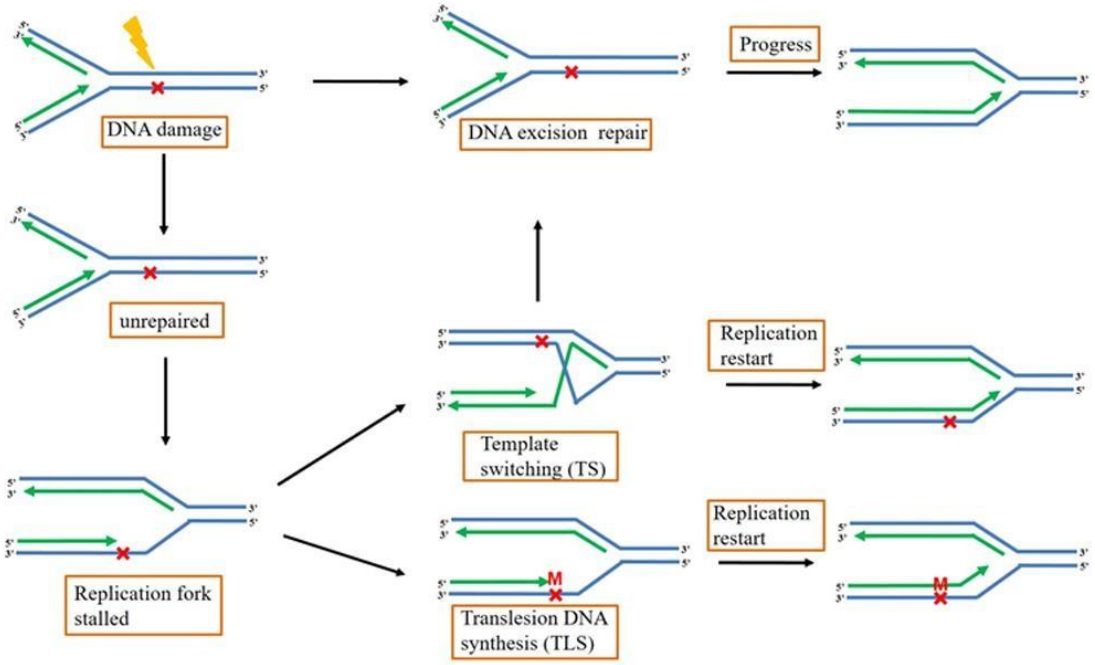

Figure S1. Schematic diagram illustrating two bacterial pathways for restarting replication forks. Most base-specific damage is repaired by DNA repair before replication. DNA lesions that is not repaired in time or near the replication fork will stall replication. Two pathways for stalled fork recovery, error-prone translesion DNA synthesis (TLS) and error-free template switching (TS), can bypass the lesions to restart DNA replication downstream. Newly synthesized DNA strand and their templates are shown in green and blue, and 3′-ends of growing DNA chains are shown by arrows. The sites of DNA damage (×) and mutation (M) were shown in red.

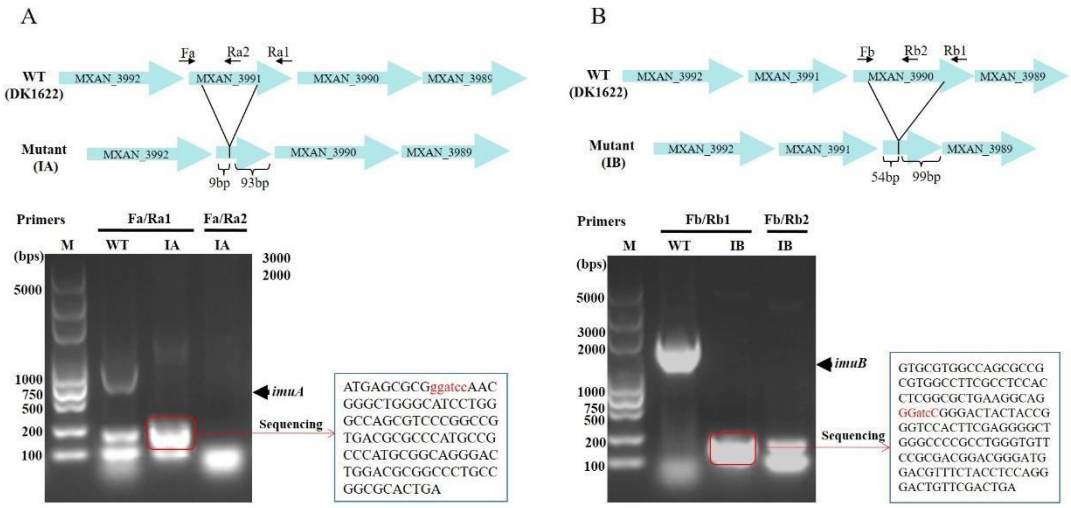

Figure S2. Marker-free gene knockout *of imuA* (A) and *imuB* (B) in *M. xanthus* DK1622. The schematic maps of the location for gene knockout are provided as the upper panel. In the process of gene knockout, the N- and C-terminal respectively retain some bases linked by a *Bam*H1 recognition sequence (ggatcc). The lower panel is the PCR validation of the mutants with primers indicated by black arrows in upper schematic maps. Further sequencing results of the PCR product from the mutants are shown aside and the N-and C-terminal residues are linked by *Bam*HI sites (red).

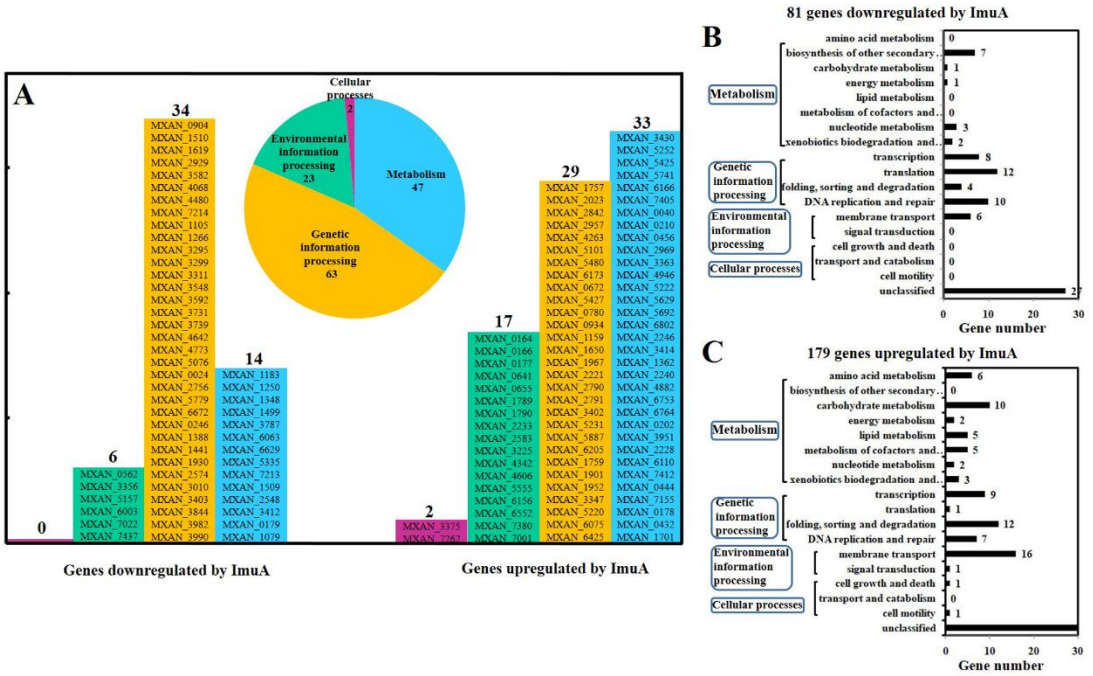

Figure S3. Comparative transcriptome analysis on the *imuA* deletion and overexpression mutants. The transcriptome of wild-type strain was used as the reference and each transcriptome of the three strains was obtained from the average of three repeated sequencing data. The genes differentially expressed in mutants were retrieved. Totally, 260 genes that were synchronously changed in the *imuA* deletion and overexpression mutants were counted. Of the 260 genes, 135 were classified of their functions by KEGG. (A) Classification of 135 function-annotated genes according to KEGG pathway. The genes downregulated and upregulated by ImuA are listed in the left and the right panes, respectively. Details of these genes are provided in **Tables S1** and **S2**. (B) GO analysis of the 81 genes downregulated by ImuA (upregulated in the deletion mutant and downregulated in the overexpression mutant). (C) GO analysis of 179 genes upregulated by ImuA (downregulated in the deletion mutant and upregulated in the overexpressed mutant).

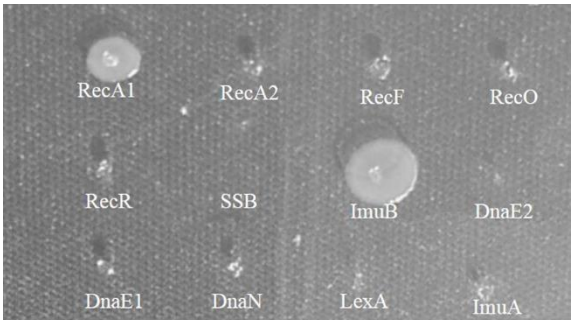

Figure S4. Using ImuA as a baiting protein to screen its interacting proteins by Y2H method. ImuA was cloned into pGBKT7 plasmid and used as a bait to screen its interacting proteins among the known replication and recombination proteins in pGADT7 in AH109.

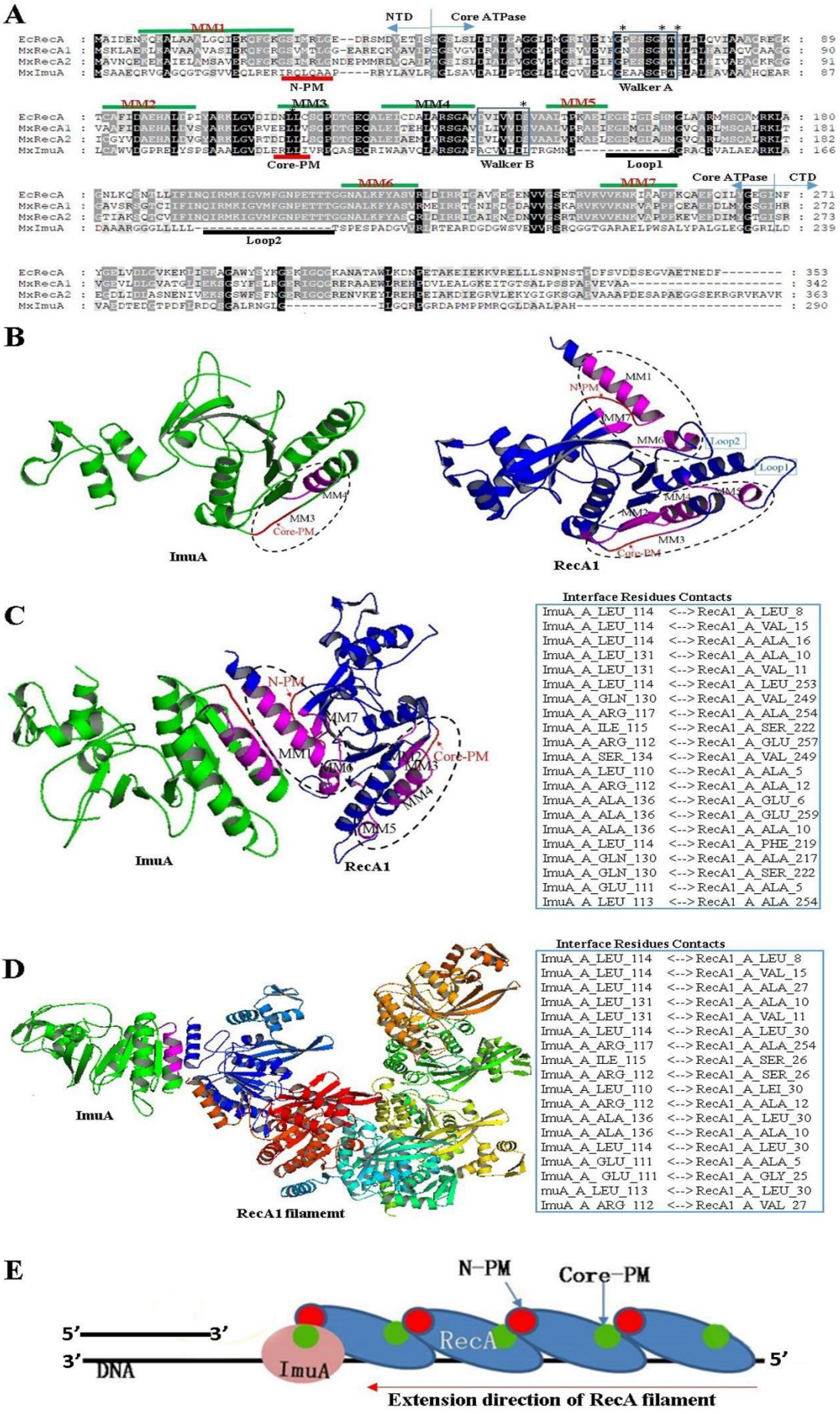
A
NTD
Core ATPase
MM1
N-PM
Walker A
MM2
MM3
MM4
MM5
Core-PM
Walker B
Loop1
MM6
MM7
Core ATPase
CTD
Loop2
EcRecA
MxRecA1
MxRecA2
MxImuA
B
ImuA
RecA1
MM1
N-PM
MM7
MM6
Loop2
Loop1
MM4
MM5
MM2
MM3
Core-PM
C
ImuA
RecA1
N-PM
MM7
MM1
MM6
MM5
MM4
MM5
Core-PM
Interface Residues Contacts
ImuA_A_LEU_114 <--> RecA1_A_LEU_8
ImuA_A_LEU_114 <--> RecA1_A_VAL_15
ImuA_A_LEU_114 <--> RecA1_A_ALA_16
ImuA_A_LEU_131 <--> RecA1_A_ALA_10
ImuA_A_LEU_131 <--> RecA1_A_VAL_11
ImuA_A_LEU_114 <--> RecA1_A_LEU_253
ImuA_A_GLN_130 <--> RecA1_A_VAL_249
ImuA_A_ARG_117 <--> RecA1_A_ALA_254
ImuA_A_ILE_115 <--> RecA1_A_SER_222
ImuA_A_ARG_112 <--> RecA1_A_GLU_257
ImuA_A_SER_134 <--> RecA1_A_VAL_249
ImuA_A_LEU_110 <--> RecA1_A_ALA_5
ImuA_A_ARG_112 <--> RecA1_A_ALA_12
ImuA_A_ALA_136 <--> RecA1_A_GLU_6
ImuA_A_ALA_136 <--> RecA1_A_GLU_259
ImuA_A_ALA_136 <--> RecA1_A_ALA_10
ImuA_A_LEU_114 <--> RecA1_A_PHE_219
ImuA_A_GLN_130 <--> RecA1_A_ALA_217
ImuA_A_GLN_130 <--> RecA1_A_SER_222
ImuA_A_GLU_111 <--> RecA1_A_ALA_5
ImuA_A_LEU_113 <--> RecA1_A_ALA_254
D
ImuA
RecA1 filamemt
Interface Residues Contacts
ImuA_A_LEU_114 <--> RecA1_A_LEU_8
ImuA_A_LEU_114 <--> RecA1_A_VAL_15
ImuA_A_LEU_114 <--> RecA1_A_ALA_27
ImuA_A_LEU_131 <--> RecA1_A_ALA_10
ImuA_A_LEU_131 <--> RecA1_A_VAL_11
ImuA_A_LEU_114 <--> RecA1_A_LEU_30
ImuA_A_ARG_117 <--> RecA1_A_ALA_254
ImuA_A_ILE_115 <--> RecA1_A_SER_26
ImuA_A_ARG_112 <--> RecA1_A_SER_26
ImuA_A_LEU_110 <--> RecA1_A_LEI_30
ImuA_A_ARG_112 <--> RecA1_A_ALA_12
ImuA_A_ALA_136 <--> RecA1_A_LEU_30
ImuA_A_ALA_136 <--> RecA1_A_ALA_10
ImuA_A_LEU_114 <--> RecA1_A_LEU_30
ImuA_A_GLU_111 <--> RecA1_A_ALA_5
ImuA_A_GLU_111 <--> RecA1_A_GLY_25
muA_A_LEU_113 <--> RecA1_A_LEU_30
ImuA_A_ARG_112 <--> RecA1_A_VAL_27
E
N-PM
Core-PM
5′
3′
3′
DNA
ImuA
RecA
5′
Extension direction of RecA filament

Figure S5. Sequence and structure analysis of *M. xanthus* ImuA. (A) Sequence alignment of *M. xanthus* ImuA (MxImuA) with RecA1 (MxRecA1), RecA2 (MxRecA2) and *E. coli* RecA (EcRecA). The ATP binding Walker A and B motifs are marked in blue frame, the putative DNA binding sites (Loop 1 and Loop 2) are underlined in black. Seven monomer binding sites (MM1-7) and two filamentous polymerization sites (NPM and Core-PM) were marked with green and red lines, respectively. Conservative amino acids of Walker A, core-PM and Walker B motifs were marked with asterisks. (B) Three-dimensional structure model of *M. xanthus* ImuA and RecA1. Protein structure was predicted with I-TASSER (https://zhanglab.ccmb.med.umich.edu/ITASSER). The binding sites on RecA protein surface were concentrated in two regions, including N-PM and Core-PM respectively. ImuA only retains the binding region with Core-PM. (C) Protein-protein docking prediction of ImuA and RecA1. The interface residues were predicted with PRISM Webserver (http://cosbi.ku.edu.tr/prism/index.php). (D) Predicting the interactions between ImuA and RecA1 filament. RecA1 filament structures were built by homology modeling using *E. coli* RecA filament model (PDB ID:1N03) as template. (E) Predicted interaction diagram of *M. xanthus* ImuA with RecA1. N-PM and core-PM are the binding sites located at N-terminal and core ATPase domain of RecA to form polymers.

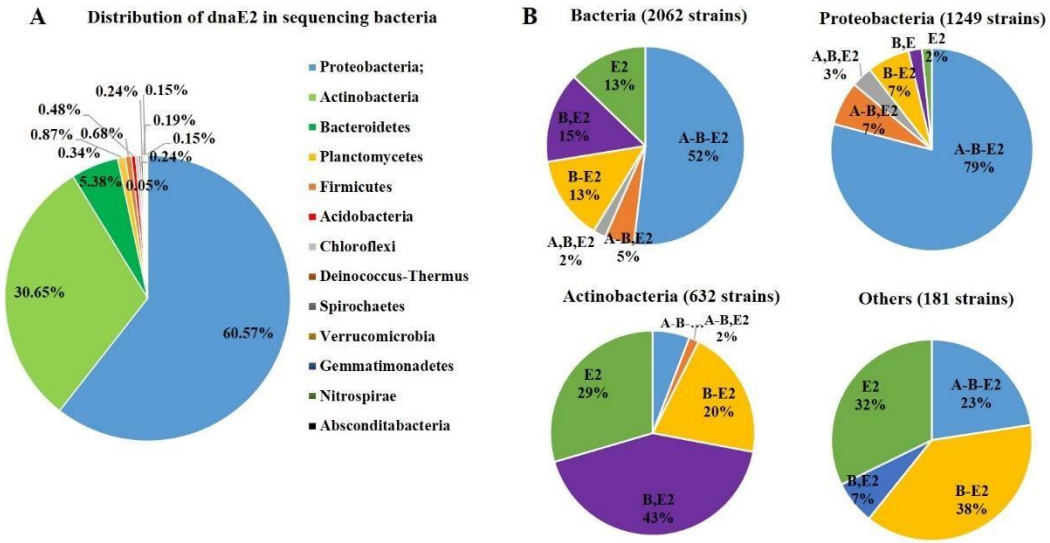

Figure S6. Distribution and location relationships of *imuA*, *imuB* and *dnaE2* genes in sequenced bacterial genome. (A) Distribution of *dnaE2*. The *dnaE2* is distributed in 13 bacterial phyla. (B) Location relationship of *imuA, imuB* and *dnaE2* in the 2062 genomes carrying *dnaE2*. A-B-E2: *imuA*, *imuB* and *dnaE2* genes coexist in the same genome and are adjacent to each other; A-B,E2: *imuA*, *imuB* and *dnaE2* genes coexist in the same genome and *imuA-imuB* are adjacent to each other, *dnaE2* is separated; A,B,E2: *imuA*, *imuB* and *dnaE2* genes coexist in the same genome and are separated to each other; B-E2: *imuB* and *dnaE2* genes coexist in the same genome and are adjacent to each other, *imuA* disappears; B,E2: *imuB* and *dnaE2* genes coexist in the same genome and are separated to each other, *imuA* disappears; E2: only a *dnaE2* gene, *imuA* and *imuB* disappear.

Supplementary tables

Table S1. 81 genes downregulated by ImuA

	Pathway	Gene ID	Protein	Function
Metabolism (14 genes)	Biosynthesis of other secondary metabolites	MXAN_1183	Spermidine synthase	Spermidine synthesis
	Biosynthesis of other secondary metabolites	MXAN_1250	Riboflavin-specific deaminase, C-terminal	Riboflavin synthesis
	Biosynthesis of other secondary metabolites	MXAN_1348	SAM-dependent methyltransferase	Methylation
	Biosynthesis of other secondary metabolites	MXAN_1499	Thiamin biosynthesis protein ThiF	Thiazole synthesis
	Biosynthesis of other secondary metabolites	MXAN_3787	SAM-dependent methyltransferase	Methylation synthesis
	Biosynthesis of other secondary metabolites	MXAN_6063	Indole-3-glycerol-phosphate synthase	Shikimate acid synthesis
	Biosynthesis of other secondary metabolites	MXAN_6629	Prenyltransferase, ubia family	Bacterioruberin synthesis
	Carbohydrate metabolism	MXAN_5335	Glycosyl transferase family 2	Polysaccharide synthesis
	Energy metabolism	MXAN_7213	Cytochrome-c peroxidase	Antioxidant response
	Nucleotide metabolism	MXAN_1509	diadenosine tetraphosphate (Ap4A) hydrolase	Ap4A hydrolysis. sporulation
	Nucleotide metabolism	MXAN_2548	Pseudouridine synthase	Pseudouridine synthesis
	Nucleotide metabolism	MXAN_3412	dTMP kinase	dTTP synthesis
	Xenobiotics biodegradation and metabolism	MXAN_0179	Metallo-beta-lactamase family protein	β-lactams drug-resistance
	Xenobiotics biodegradation and metabolism	MXAN_1079	N-acetyltransferase	myriocin drug-resistance
Environmental information processing (6 genes)	Membrane transport	MXAN_0562	Phosphate-selective porin O and P	Phosphate transporter
	Membrane transport	MXAN_3356	Oligopeptide transporter, OPT family	transporters of small oligopeptides
	Membrane transport	MXAN_5157	Branched-chain amino acid transport protein (azld)	Amino acid transporter
	Membrane transport s	MXAN_6003	ABC transporter, ABC-2 type	Export of drugs and carbohydrates
	Membrane transport	MXAN_7022	MATE family efflux transporter	Drug/sodium antiporters

	Membrane transport	MXAN_7437	Cobalt-zinc-cadmium resistance protein CzcA	Heavy metal efflux pump
Genetic information processing (34 genes)	Transcription	MXAN_0904	B12 binding domain/transcriptional regulator, merr family	Transcription factor
	Transcription	MXAN_1510	DNA-directed RNA polymerase sigma-70 factor	RNA polymerase
	Transcription	MXAN_1619	Deor family transcriptional regulator	Transcription factor
	Transcription	MXAN_2929	DNA-directed RNA polymerase sigma-70 factor	RNA polymerase
	Transcription	MXAN_3582	Cold-shock protein cspd	Transcription factor
	Transcription	MXAN_4068	Trna 2-thiouridine synthesizing protein A,tusa	Transcription factor
	Transcription	MXAN_4480	Transcriptional regulator	Transcription factor
	Transcription	MXAN_7214	ECF subfamily RNA polymerase sigma factor 70	RNA polymerase
	Translation	MXAN_1105	RNA-binding protein (yhby domain)	Translation factor
	Translation	MXAN_1266	Trna-hydroxylase miae	Posttranscriptional modification
	Translation	MXAN_3295	30S ribosomal protein S12	Ribosomal protein
	Translation	MXAN_3299	30S ribosomal protein S10	Ribosomal protein
	Translation	MXAN_3311	50S ribosomal protein L5	Ribosomal protein
	Translation	MXAN_3548	Trna (guanosine(37)-N1) methyltransferase, trmd	Posttranscriptional modification
	Translation	MXAN_3592	50S ribosomal protein L35	Ribosomal protein
	Translation	MXAN_3731	Trna isopentenyltransferase miaa	Posttranscriptional modification
	Translation	MXAN_3739	16S rrna (cytosine967-C5) methyltransferase	Posttranscriptional modification
	Translation	MXAN_4642	Tlya family rrna (cytidine-2'-O)-methyltransferase	Posttranscriptional modification
	Translation	MXAN_4773	50S ribosomal protein L32	Ribosomal protein
	Translation	MXAN_5076	50S ribosomal protein L25	Ribosomal protein
	Folding, sorting and degradation	MXAN_0024	Ribonuclease R	RNA degradation
	Folding, sorting and degradation	MXAN_2756	Serine protease/ trypsin-2	Protein degradation
	Folding, sorting and degradation	MXAN_5779	Type 4 prepilin-like proteins leader peptide-processing enzyme	Posttranslational modification
	Folding, sorting and degradation	MXAN_6672	Molecular chaperone grpe	Protein folding
	DNA replication and repair	MXAN_0246	DNA replication and repair protein RecF	Homologous recombination

	DNA replication and repair	MXAN_1388	DNA recombination/repair protein RecA	Homologous recombination
	DNA replication and repair	MXAN_1441	DNA recombination/repair protein RecA	Homologous recombination
	DNA replication and repair	MXAN_1930	Recombination protein recR	Homologous recombination
	DNA replication and repair	MXAN_2574	Ribonuclease HII	Primer excision
	DNA replication and repair	MXAN_3010	Site-specific recombinase XerC	Chromosome dimer resolution
	DNA replication and repair	MXAN_3403	6-O-methylguanine DNA methyltransferase	Direct repair
	DNA replication and repair	MXAN_3844	Site-specific recombinase XerD	Chromosome dimer resolution
	DNA replication and repair	MXAN_3982	Error-prone DNA polymerase DnaE2	Error-prone DNA replication
	DNA replication and repair	MXAN_3990	Error-prone DNA polymerase ImuB	Error-prone DNA replication
Unclassified（27 genes）	Unclassified	MXAN_3767	Hypothetical protein	
	Unclassified	MXAN_3770	Hypothetical protein	
	Unclassified	MXAN_3818	TIGR02265 family protein	
	Unclassified	MXAN_3971	Hypothetical protein	
	Unclassified	MXAN_4631	Rossman fold protein, TIGR00730 family	
	Unclassified	MXAN_0847	Hypothetical protein	
	Unclassified	MXAN_1144	Hypothetical protein	
	Unclassified	MXAN_1346	Hypothetical protein	
	Unclassified	MXAN_1625	Hypothetical protein	
	Unclassified	MXAN_1626	Hypothetical protein	
	Unclassified	MXAN_1634	Hypothetical protein	
	Unclassified	MXAN_1648	Hypothetical protein	
	Unclassified	MXAN_1657	Hypothetical protein	
	Unclassified	MXAN_2146	Hypothetical protein	
	Unclassified	MXAN_2561	Hypothetical protein	
	Unclassified	MXAN_3166	Hypothetical protein	
	Unclassified	MXAN_3223	Hypothetical protein	
	Unclassified	MXAN_3237	Hypothetical protein	
	Unclassified	MXAN_4485	Hypothetical protein	
	Unclassified	MXAN_4744	Hypothetical protein	
	Unclassified	MXAN_5088	Hypothetical protein	
	Unclassified	MXAN_5091	Hypothetical protein	
	Unclassified	MXAN_5126	Hypothetical protein	
	Unclassified	MXAN_5228	Hypothetical protein	
	Unclassified	MXAN_5676	Hypothetical protein	
	Unclassified	MXAN_7191	Hypothetical protein	
	Unclassified	MXAN_7195	Hypothetical protein	

Table S2. 179 genes upregulated by ImuA

	Pathway	Gene ID	Protein	Function
Metabolism (33 genes)	Amino acid metabolism	MXAN_3430	Acyl-coa thioesterase	Phenylalanine metabolism
	Amino acid metabolism	MXAN_5252	Glutathione S-transferase	Glutathione metabolism
	Amino acid metabolism	MXAN_5425	Poly-gamma-glutamate biosynthesis protein	Capsule synthesis
	Amino acid metabolism	MXAN_5741	D-alanine--D-alanine ligase	D-Alanine metabolism
	Amino acid metabolism	MXAN_6166	Serine dehydratase	Glycine, serine and threonine metabolism
	Amino acid metabolism	MXAN_7405	Proline dehydrogenase	Proline metabolism
	Carbohydrate metabolism	MXAN_0040	Glucose dehydrogenase	Pentose phosphate pathway
	Carbohydrate metabolism	MXAN_0210	Lytic transglycosylase	Peptidoglycan degradation
	Carbohydrate metabolism	MXAN_0456	Alcohol dehydrogenase	Glycolysis
	Carbohydrate metabolism	MXAN_2969	Acyl-coA dehydrogenase	Propanoate metabolism
	Carbohydrate metabolism	MXAN_3363	Lytic transglycosylase	Peptidoglycan degradation
	Carbohydrate metabolism	MXAN_4946	Transglycosylase	Glyoxylate cycle
	Carbohydrate metabolism	MXAN_5222	Succinate dehydrogenase	TCA cycle
	Carbohydrate metabolism	MXAN_5629	Alcohol dehydrogenase	Glycolysis
	Carbohydrate metabolism	MXAN_5692	Murein L,D-transpeptidase	Peptidoglycan synthesis
	Carbohydrate metabolism	MXAN_6802	NADP-dependent alcohol dehydrogenase	Glycolysis
	Energy metabolism	MXAN_2246	Fad oxidoreductase	Respiratory chain
	Energy metabolism	MXAN_3414	Cytochrome c	Respiratory chain
	Lipid metabolism	MXAN_1362	Cardiolipin synthase B	Glycerophospholipid metabolism
	Lipid metabolism	MXAN_2240	Zinc-binding dehydrogenase	Fatty acid elongation
	Lipid metabolism	MXAN_4882	Metallophosphoesterase	Phospholipid metabolism
	Lipid metabolism	MXAN_6753	Phospholipase D family	Glycerophospholipid metabolism
	Lipid metabolism	MXAN_6764	Carboxylesterase	Carboxylic esters degradation

	Metabolism of cofactors and vitamins	MXAN_0202	Amine oxidase, flavin-containing	Porphyrin synthesis
	Metabolism of cofactors and vitamins	MXAN_3951	MBL fold metallo hydrolase	Folate biosynthesis
	Metabolism of cofactors and vitamins	MXAN_2228	Pyrroloquinoline-quinone synthase	Pyrroloquinoline quinone synthesis
	Metabolism of cofactors and vitamins	MXAN_6110	4-diphosphocytidyl-2C-methyl-D-erythritol synthase	Folate synthesis
	Metabolism of cofactors and vitamins	MXAN_7412	Molybdenum cofactor guanylyltransferase	Folate synthesis
	Nucleotide metabolism	MXAN_0444	Pyridine nucleotide-disulfide oxidoreductase	Pyrimidine metabolism
	Nucleotide metabolism	MXAN_7155	Phosphoribosyltransferase	Ribo-nucleoside synthesis
	Xenobiotics biodegradation and metabolism	MXAN_0178	Rhodanese-like domain protein	Cyanide detoxification
	Xenobiotics biodegradation and metabolism	MXAN_0432	Metallo beta lactamase	Beta lactam resistance
	Xenobiotics biodegradation and metabolism	MXAN_1701	Dyp-type peroxidase family protein	Lignin oxidation
Environmental information processing （17 genes）	Membrane transport	MXAN_0164	Potassium-transporting atpase subunit A	Potassium ion transport
	Membrane transport	MXAN_0166	Potassium-transporting atpase subunit C	Potassium ion transport
	Membrane transport	MXAN_0177	Taue protein	Anions transport
	Membrane transport	MXAN_0641	Tspo/MBR family protein	Anions transport
	Membrane transport	MXAN_0655	Organic hydroperoxide resistance protein	Oxidative shock
	Membrane transport	MXAN_1789	ABC transporter, peptidase, C39 family	Bacteriocin transport
	Membrane transport	MXAN_1790	ABC transporter ATP-binding protein	Glutathione export
	Membrane transport	MXAN_2233	MFS transporter	Sugar transport
	Membrane transport	MXAN_2583	VTC domain-containing protein	Vacuolar transport
	Membrane transport	MXAN_3225	Sugar ABC transporter substrate-binding protein	Sugar transport
	Membrane transport	MXAN_4342	BON domain-containing protein	Osmotic shock

	Membrane transport	MXAN_4606	Carbohydrate-binding protein	Sugar transport
	Membrane transport	MXAN_5555	Iron ABC transporter	Iron transport
	Membrane transport	MXAN_6156	Cytochrome c-type biogenesis protein/thioredoxin	Transmembrane electron carrier
	Membrane transport	MXAN_6552	Peptide ABC transporter permease	Peptides/nickel transport
	Membrane transport	MXAN_7380	CBS domain-containing protein	Chloride channel
	Signal transduction	MXAN_7001	Response regulator	Two component system
Cellular processes	Cell motility	MXAN_3375	Gliding motility protein	Cell motility
	Cell growth and death	MXAN_7262	fruiting body developmental protein R	fruiting body development
Genetic information processing (30 genes)	Transcription	MXAN_1757	Lysr family transcriptional regulator	Transcription factor
	Transcription	MXAN_2023	Bola family transcriptional regulator	Transcription factor
	Transcription	MXAN_2842	Lysr family transcriptional regulator	Transcription factor
	Transcription	MXAN_2957	DNA-directed RNA polymerase sigma-70 factor	RNA polymerase
	Transcription	MXAN_4263	Tetr family transcriptional regulator	Transcription factor
	Transcription	MXAN_5101	RNA polymerase	RNA polymerase
	Transcription	MXAN_5480	Lysr family transcriptional regulator	Transcription factor
	Transcription	MXAN_6173	ECF subfamily RNA polymerase sigma factor	RNA polymerase
	Transcription	MXAN_0672	Cold-shock protein	Transcription factor
	Translation	MXAN_5427	Archease	RNA ligation
	Folding, sorting and degradation	MXAN_0780	Membrane-bound clpp-class protease	Protein degradation
	Folding, sorting and degradation	MXAN_0934	Peptidase S1	Protein degradation
	Folding, sorting and degradation	MXAN_1159	Protease	Protein degradation
	Folding, sorting and degradation	MXAN_1650	Peptidase S1	Protein degradation
	Folding, sorting and degradation	MXAN_1967	Peptidase S8	Protein degradation

	Folding, sorting and degradation	MXAN_2221	Protease	Protein degradation
	Folding, sorting and degradation	MXAN_2790	Protease	Protein degradation
	Folding, sorting and degradation	MXAN_2791	Protease	Protein degradation
	Folding, sorting and degradation	MXAN_3402	Peptidase S11	Protein degradation
	Folding, sorting and degradation	MXAN_5231	CPBP family intramembrane metalloprotease domain-containing protein	Protein degradation
	Folding, sorting and degradation	MXAN_5887	Serine protease	Protein degradation
	Folding, sorting and degradation	MXAN_6205	Collagenase	Protein degradation
	DNA replication and repair	MXAN_1759	DNA alkylation repair protein	Excision repair
	DNA replication and repair	MXAN_1901	DDE transposase	DNA transposition
	DNA replication and repair	MXAN_1952	RadC	DNA repair
	DNA replication and repair	MXAN_3347	HNH endonuclease	Excision repair
	DNA replication and repair	MXAN_5220	DNA-3-methyladenine glycosylase II	Base excision repair
	DNA replication and repair	MXAN_6075	DNA helicase Lhr	DNA repair
	DNA replication and repair	MXAN_6425	Endonuclease III Base excision DNA repair protein	Base excision repair
Unclassified (98 genes)	Unclassified	MXAN_0022	Hypothetical protein	Unknown function
	Unclassified	MXAN_0069	Hypothetical protein	Unknown function
	Unclassified	MXAN_0187	Hypothetical protein	Unknown function
	Unclassified	MXAN_0192	Hypothetical protein	Unknown function
	Unclassified	MXAN_0324	Deda family protein	Unknown function
	Unclassified	MXAN_0394	Hypothetical protein	Unknown function
	Unclassified	MXAN_0431	Hypothetical protein	Unknown function
	Unclassified	MXAN_0443	Hypothetical protein	Unknown function
	Unclassified	MXAN_0466	Hypothetical protein	Unknown function
	Unclassified	MXAN_0488	Hypothetical protein	Unknown function
	Unclassified	MXAN_0536	Hypothetical protein	Unknown function
	Unclassified	MXAN_0545	Hypothetical protein	Unknown function
	Unclassified	MXAN_0551	Hypothetical protein	Unknown function
	Unclassified	MXAN_0594	Hypothetical protein	Unknown function
	Unclassified	MXAN_0702	Hypothetical protein	Unknown function
	Unclassified	MXAN_0905	Hypothetical protein	Unknown function
	Unclassified	MXAN_0929	Hypothetical protein	Unknown function
	Unclassified	MXAN_1045	Hypothetical protein	Unknown function

	Unclassified	MXAN_1046	Hypothetical protein	Unknown function
	Unclassified	MXAN_1126	Hypothetical protein	Unknown function
	Unclassified	MXAN_1161	Hypothetical protein	Unknown function
	Unclassified	MXAN_1413	Hypothetical protein	Unknown function
	Unclassified	MXAN_1702	Hypothetical protein	Unknown function
	Unclassified	MXAN_1783	Hypothetical protein	Unknown function
	Unclassified	MXAN_1829	Hypothetical protein	Unknown function
	Unclassified	MXAN_1850	Hypothetical protein	Unknown function
	Unclassified	MXAN_2191	Hypothetical protein	Unknown function
	Unclassified	MXAN_2222	Hypothetical protein	Unknown function
	Unclassified	MXAN_2376	Hypothetical protein	Unknown function
	Unclassified	MXAN_2753	Hypothetical protein	Unknown function
	Unclassified	MXAN_2855	Hypothetical protein	Unknown function
	Unclassified	MXAN_2856	Hypothetical protein	Unknown function
	Unclassified	MXAN_2877	Hypothetical protein	Unknown function
	Unclassified	MXAN_3134	Hypothetical protein	Unknown function
	Unclassified	MXAN_3141	Hypothetical protein	Unknown function
	Unclassified	MXAN_3161	Hypothetical protein	Unknown function
	Unclassified	MXAN_3164	Hypothetical protein	Unknown function
	Unclassified	MXAN_3179	Hypothetical protein	Unknown function
	Unclassified	MXAN_3231	Hypothetical protein	Unknown function
	Unclassified	MXAN_3260	Hypothetical protein	Unknown function
	Unclassified	MXAN_3481	Hypothetical protein	Unknown function
	Unclassified	MXAN_3637	Hypothetical protein	Unknown function
	Unclassified	MXAN_3649	Hypothetical protein	Unknown function
	Unclassified	MXAN_3695	Hypothetical protein	Unknown function
	Unclassified	MXAN_3804	Hypothetical protein	Unknown function
	Unclassified	MXAN_3871	Hypothetical protein	Unknown function
	Unclassified	MXAN_3893	Membrane protein	Unknown function
	Unclassified	MXAN_3964	Hypothetical protein	Unknown function
	Unclassified	MXAN_3968	Hypothetical protein	Unknown function
	Unclassified	MXAN_3979	Hypothetical protein	Unknown function
	Unclassified	MXAN_4291	Hypothetical protein	Unknown function
	Unclassified	MXAN_4312	Hypothetical protein	Unknown function
	Unclassified	MXAN_4379	Hypothetical protein	Unknown function
	Unclassified	MXAN_4493	Hypothetical protein	Unknown function
	Unclassified	MXAN_4496	Hypothetical protein	Unknown function
	Unclassified	MXAN_4524	Hypothetical protein	Unknown function
	Unclassified	MXAN_4572	Hypothetical protein	Unknown function
	Unclassified	MXAN_4721	Hypothetical protein	Unknown function
	Unclassified	MXAN_5000	Hypothetical protein	Unknown function
	Unclassified	MXAN_5190	Hypothetical protein	Unknown function
	Unclassified	MXAN_5272	Hypothetical protein	Unknown function
	Unclassified	MXAN_5276	Hypothetical protein	Unknown function
	Unclassified	MXAN_5297	Hypothetical protein	Unknown function
	Unclassified	MXAN_5304	Hypothetical protein	Unknown function
	Unclassified	MXAN_5307	Hypothetical protein	Unknown function
	Unclassified	MXAN_5311	Hypothetical protein	Unknown function
	Unclassified	MXAN_5498	Hypothetical protein	Unknown function
	Unclassified	MXAN_5542	Hypothetical protein	Unknown function
	Unclassified	MXAN_5845	Hypothetical protein	Unknown function

	Unclassified	MXAN_5997	Hypothetical protein	Unknown function
	Unclassified	MXAN_6098	Hypothetical protein	Unknown function
	Unclassified	MXAN_6165	Hypothetical protein	Unknown function
	Unclassified	MXAN_6219	Hypothetical protein	Unknown function
	Unclassified	MXAN_6230	Hypothetical protein	Unknown function
	Unclassified	MXAN_6272	Hypothetical protein	Unknown function
	Unclassified	MXAN_6381	Hypothetical protein	Unknown function
	Unclassified	MXAN_6389	Hypothetical protein	Unknown function
	Unclassified	MXAN_6440	Hypothetical protein	Unknown function
	Unclassified	MXAN_6500	Hypothetical protein	Unknown function
	Unclassified	MXAN_6581	Hypothetical protein	Unknown function
	Unclassified	MXAN_6585	Hypothetical protein	Unknown function
	Unclassified	MXAN_6752	Hypothetical protein	Unknown function
	Unclassified	MXAN_6817	Hypothetical protein	Unknown function
	Unclassified	MXAN_6837	Hypothetical protein	Unknown function
	Unclassified	MXAN_6880	Hypothetical protein	Unknown function
	Unclassified	MXAN_6888	Hypothetical protein	Unknown function
	Unclassified	MXAN_6928	Hypothetical protein	Unknown function
	Unclassified	MXAN_7030	Hypothetical protein	Unknown function
	Unclassified	MXAN_7032	Hypothetical protein	Unknown function
	Unclassified	MXAN_7098	Hypothetical protein	Unknown function
	Unclassified	MXAN_7100	Hypothetical protein	Unknown function
	Unclassified	MXAN_7231	Hypothetical protein	Unknown function
	Unclassified	MXAN_7284	Hypothetical protein	Unknown function
	Unclassified	MXAN_7379	Hypothetical protein	Unknown function
	Unclassified	MXAN_7384	Hypothetical protein	Unknown function
	Unclassified	MXAN_7386	Hypothetical protein	Unknown function
	Unclassified	MXAN_7425	Hypothetical protein	Unknown function
	Unclassified	MXAN_7466	Hypothetical protein	Unknown function

Table S3. Distribution of *dnaE2* in bacteria and its coexistence with *imuA, imuB, recA, recO, recR, dnaN, umuC* and *umuD* genes

Distribution of *dnaE2* in bacteria			**Bacteria with *dnaE2* (2062 strains)**														
Phylum	**Total**	***dnaE2***	**Arrangement of *imuA*, *imuB* and *dnaE2* genes**						***recA***	***recO***	***recR***	***dna N***	***umuC***	***umuD***	***umuCD***	***imuA***	***imuB***
			A-B-E2	**A-B,E2**	**A,B,E2**	**B-E2**	**B,E2**	**E2**									
Absconditabacteria	2	1	1	0	0	0	0	0	1	1	1	1	0	0	0	1	1
Acidobacteria	15	10	7	0	0	2	0	1	10	10	10	10	0	0	0	7	9
Actinobacteria	862	632	37	10	0	130	269	186	627	629	628	629	35	34	31	48	448
Bacteroidetes	391	111	25	0	0	57	0	30	110	110	110	111	39	32	30	25	66
Chloroflexi	32	7	0	0	0	1	3	4	7	7	7	7	0	0	0	0	4
Deinococcus - Thermus	33	5	0	0	0	1	4		4	5	5	5	0	1	0	0	5
Firmicutes	885	14	0	0	0	1	3	9	13	13	13	13	1	0	0	0	4
Gemmatimonadetes	3	3	1	0	0	0	1	1	3	3	3	3	0	0	0	1	2
Nitrospirae	10	3	0	0	0	2	0	1	3	3	3	3	30	0	0	0	2
Planctomycetes	46	18	6	0	0	2	0	10	18	16	16	18	1	0	0	16	17
Proteobacteria	2897	1249	1002	89	43	86	27	20	1243	1241	1241	1243	194	219	172	1135	1229
Spirochaetes	89	5	0	0	0	2	0	3	5	5	5	5	0	0	0		2
Verrucomicrobia	16	4	1	0	0	2	1	0	4	4	4	4	0	0	0	1	4
Others	826	0															
Total	6107	2062	1080	99	43	286	308	265	2048	2047	2046	2052	300	286	233	1234	1793