

A magnetic protein biocompass

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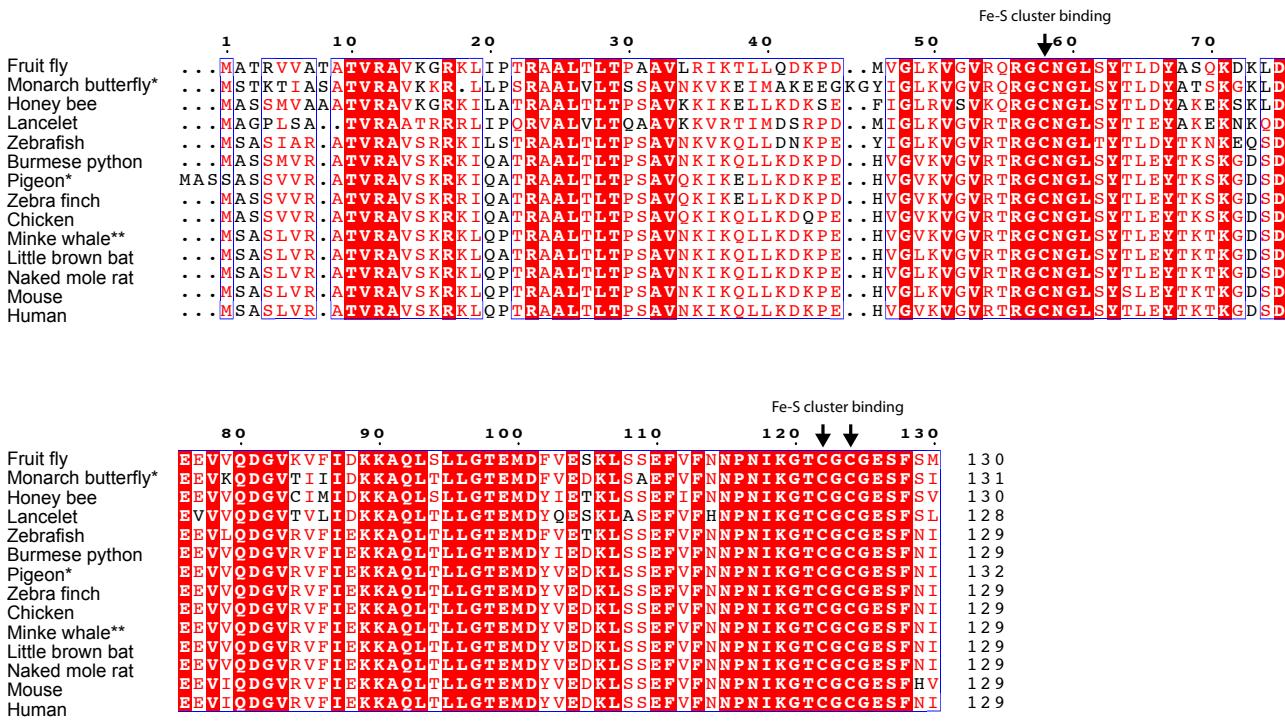
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Supplementary Figures and Legends



Supplementary Figure 1: Sequence alignment of MagR from representative species. Arrows show the conserved residues for Fe-S cluster binding. Species' common name, Latin name and MagR's Sequence ID in NCBI are listed as follows:

Fruit fly (*Drosophila melanogaster*), NP_573062.1;

Monarch butterfly (*Danaus plexippus*), EHJ65133.1*;

Honey bee (*Apis mellifera*), XP_624993.1;

Lancelet (*Branchiostoma floridae*), XP_002589524.1;

Zebrafish (*Danio rerio*), NP_001020349.1;

Burmese python (*Python bivittatus*), XP_007429307.1;

Pigeon (*Columba livia*), XP_005508102.1*;

Zebra finch (*Taeniopygia guttata*), XP_002194930.1;

Chicken (*Gallus gallus*), XP_003643055.1;

Minke whale (*Balaenoptera acutorostrata*), XP_007198694.1**;

Little brown bat (*Myotis lucifugus*), XP_006102189.1;

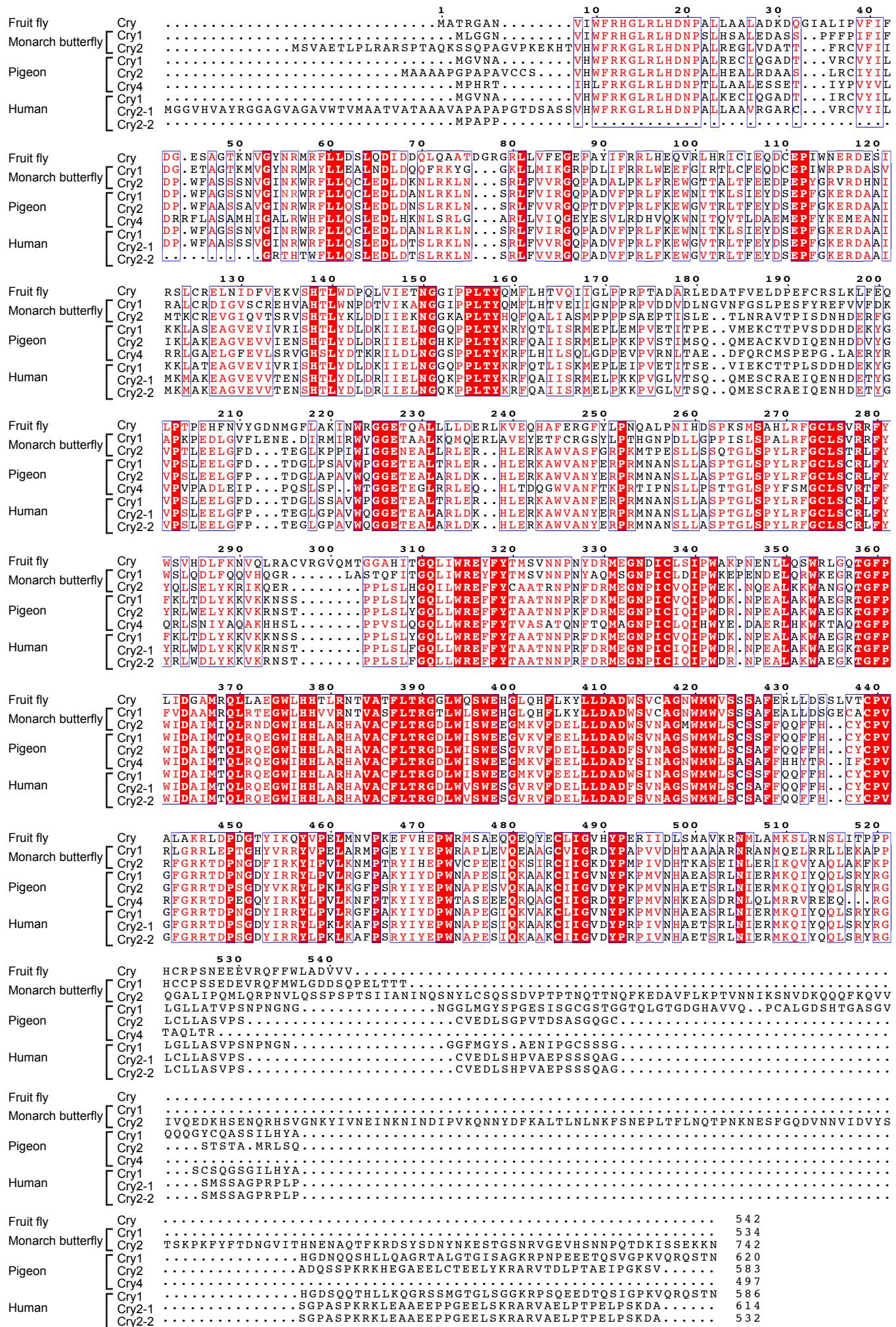
Naked mole rat (*Heterocephalus glaber*), XP_004879403.1;

Mouse (*Mus musculus*), NP_081197.1;

Human (*Homo sapiens*), NP_112202.2.

*: MagR sequences from monarch butterfly and pigeon are generated from this study and slightly different from NCBI sequence. The reference sequences from the NCBI genbank were found to be incorrect. Genomic DNA of monarch butterfly and pigeon were extracted in the lab and primers were designed based on genome assembly downloaded from NCBI to achieve missing regions.

**: MagR sequence of minke whale was re-annotated from genome assembly downloaded from NCBI by comparison with human and sheep MagR coding sequences.



Supplementary Figure 2: Sequence alignment of Cryptochromes (Crys) from four representative species. Most animals have several classes of Crys and are aligned in this figure. Species' common name, Latin name and Crys' Sequence ID in NCBI are listed as follows:

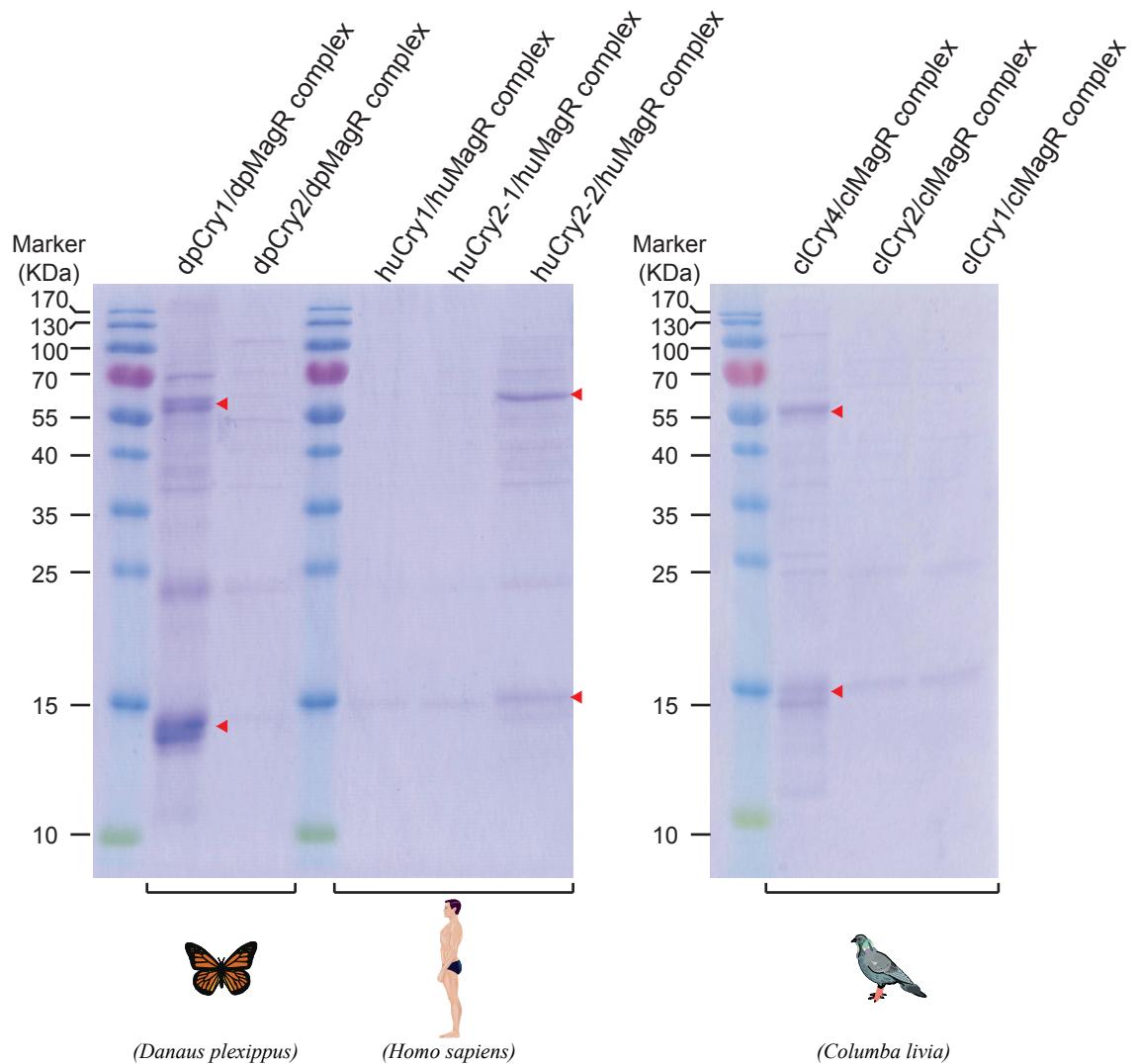
Fruit fly (*Drosophila melanogaster*), NP_732407.1 (Cry);

Monarch butterfly (*Danaus plexippus*), EHJ63675.1 (Cry1) and EHJ74426.1 (Cry2);

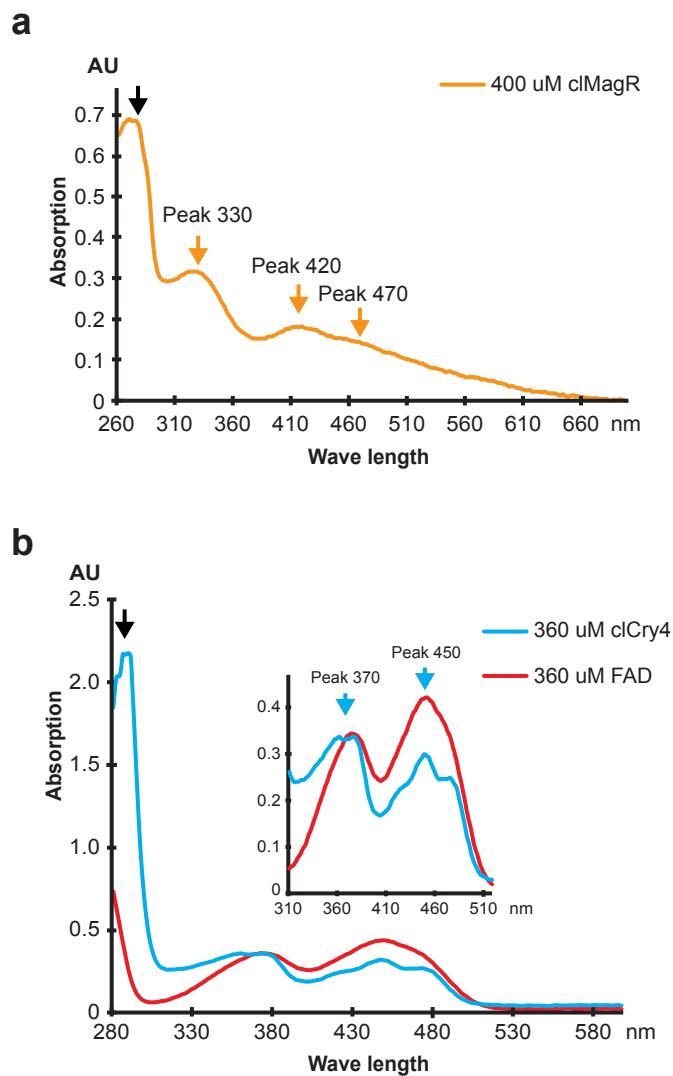
Pigeon (*Columba livia*), AHW46848.1 (Cry1);

Human (*Homo sapiens*), EAW97797.1 (Cry1), NP_066940.2 (Cry2-1) and NP_001120929.1 (Cry2-2).

Note: Pigeon Cry2 and Cry4 are annotated from pigeon reference genome downloaded from NCBI genbank and compared with chicken cryptochrome coding sequences. The first exon of cry2 was incomplete in genome assembly so we designed primers for PCR and re-sequenced to achieve full coding sequence and translated into protein sequence. The primers were designed using Primer3 based on chicken and pigeon reference genomes.



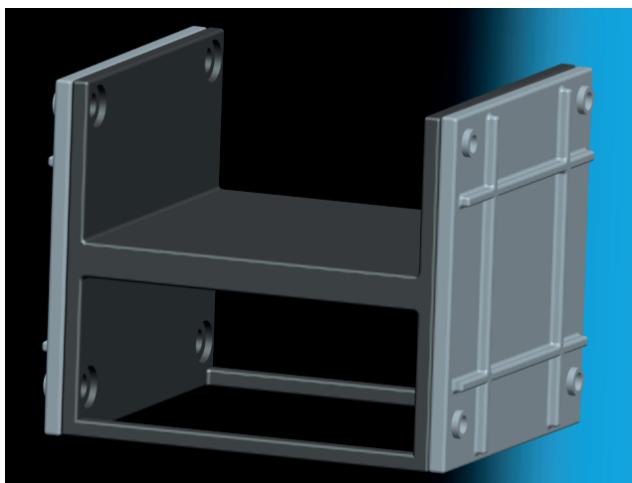
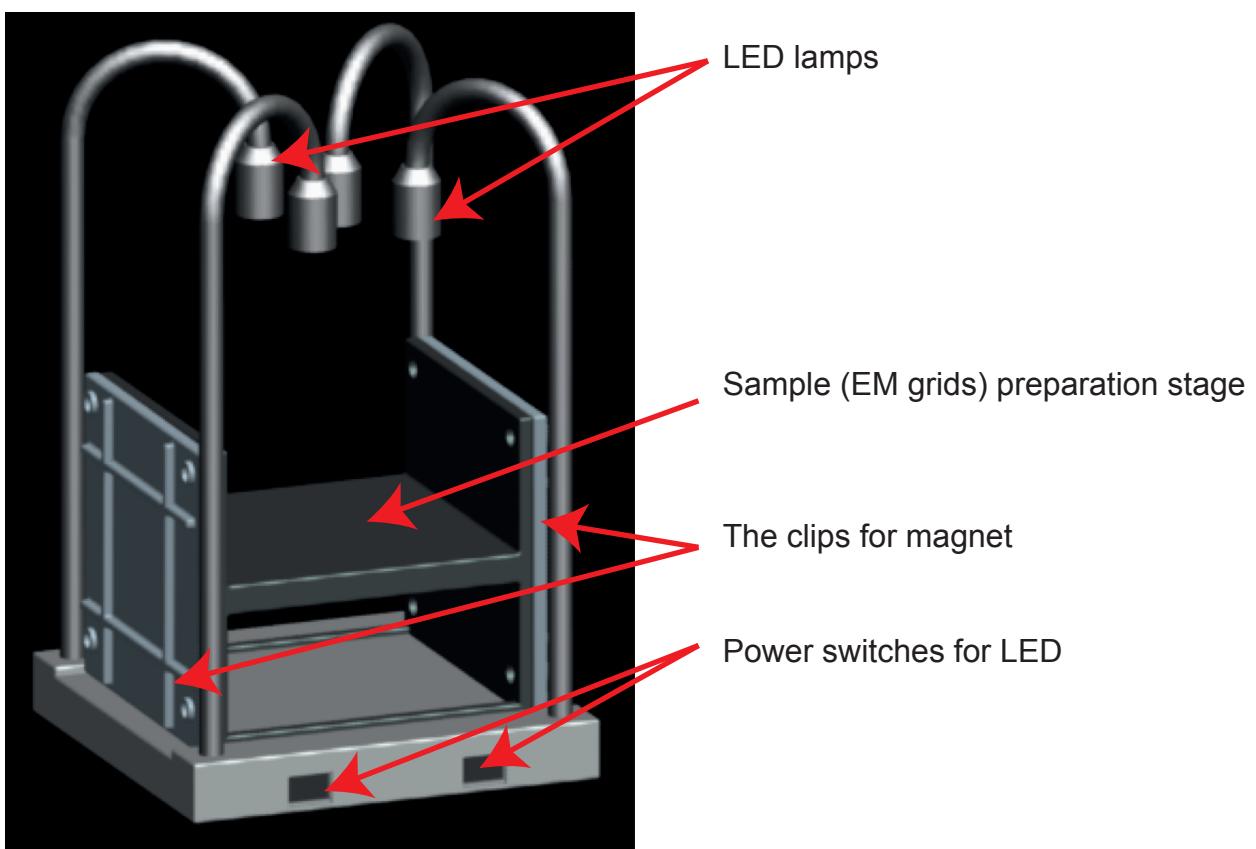
Supplementary Figure 3: The specificity of Cry and MagR interaction in different species.
 In those animals with several classes of cryptochromes (Crys), only one Cry forms complex with MagR and can be co-purified as complex. The sole Cry interact with MagR in fruit fly (*Drosophila melanogaster*, see Fig. 2c). dpCry1, but not dpCry2 forms complex with dpMagR in monarch butterfly (*Danaus plexippus*). clCry4, but not clCry1 and clCry2, forms complex with clMagR in pigeon (*Columba livia*). huCry2-2, but not huCry1 and huCry2-1, forms relatively weak complex with huMagR in human (*Homo sapiens*). Arrows show the co-purified Crys (upper) and MagRs (lower) from different species.



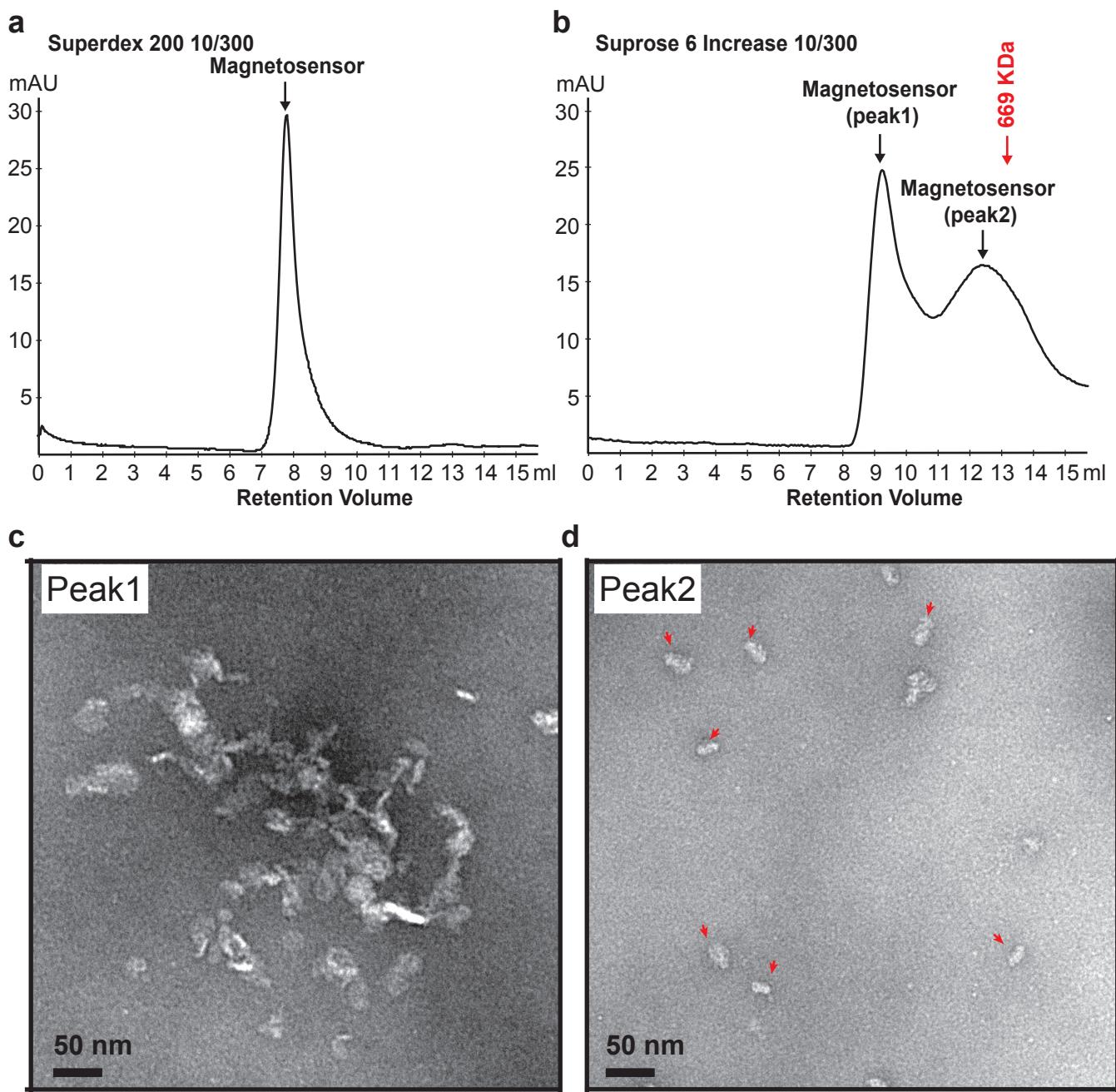
Supplementary Figure 4: Absorption spectrum of clMagR and clCry4. The protein concentration was 400 uM clMagR (orange curve, **a**) in 20 mM Tris, pH7.5, 150 mM NaCl and 360 uM clCry4 (cyan curve, **b**) in 20 mM Tris, pH8.0, 150mM NaCl. Same concentration of FAD (Sigma, F6625) was prepared in the same buffer as a reference control (red curve, **b**). The spectra were recorded with Nanodrop 2000 spectrophotometer at room temperature. The black arrows show the absorption peak of protein (280 nm), and orange and cyan arrows show absorption peaks for Fe-S cluster and FAD respectively.

a, clMagR exhibited an absorption spectrum with maxima at 330 nm and 420 nm (with a shoulder at 470 nm), which is indicative for the formation of a [2Fe2S] cluster.

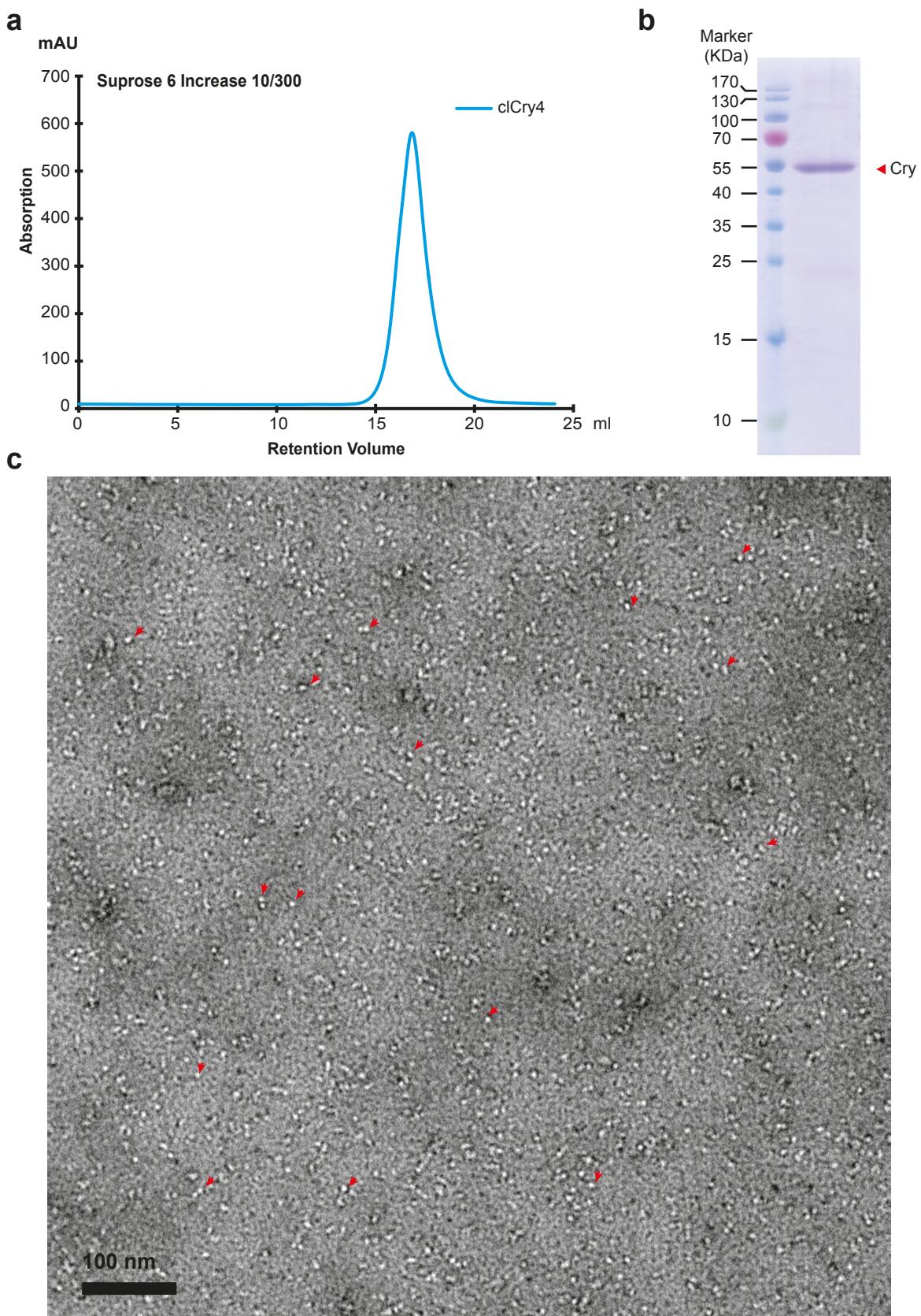
b, Absorption spectrum of clCry4 with maxima at 370 nm and 450 nm, reveals the presence of FAD group. As a control, 360 uM FAD showed similar absorption peaks as clCry4.

a**b**

Supplementary Figure 5: Customized work stage for EM sample preparation. A pair of magnets can be installed at both sides of the stage to generate a parallel magnetic field. Four LED lamps provided light. EM grids are normally prepared in the middle of the work stage. **a**, The base of the work stage. **b**, Image of the EM sample preparation stage.

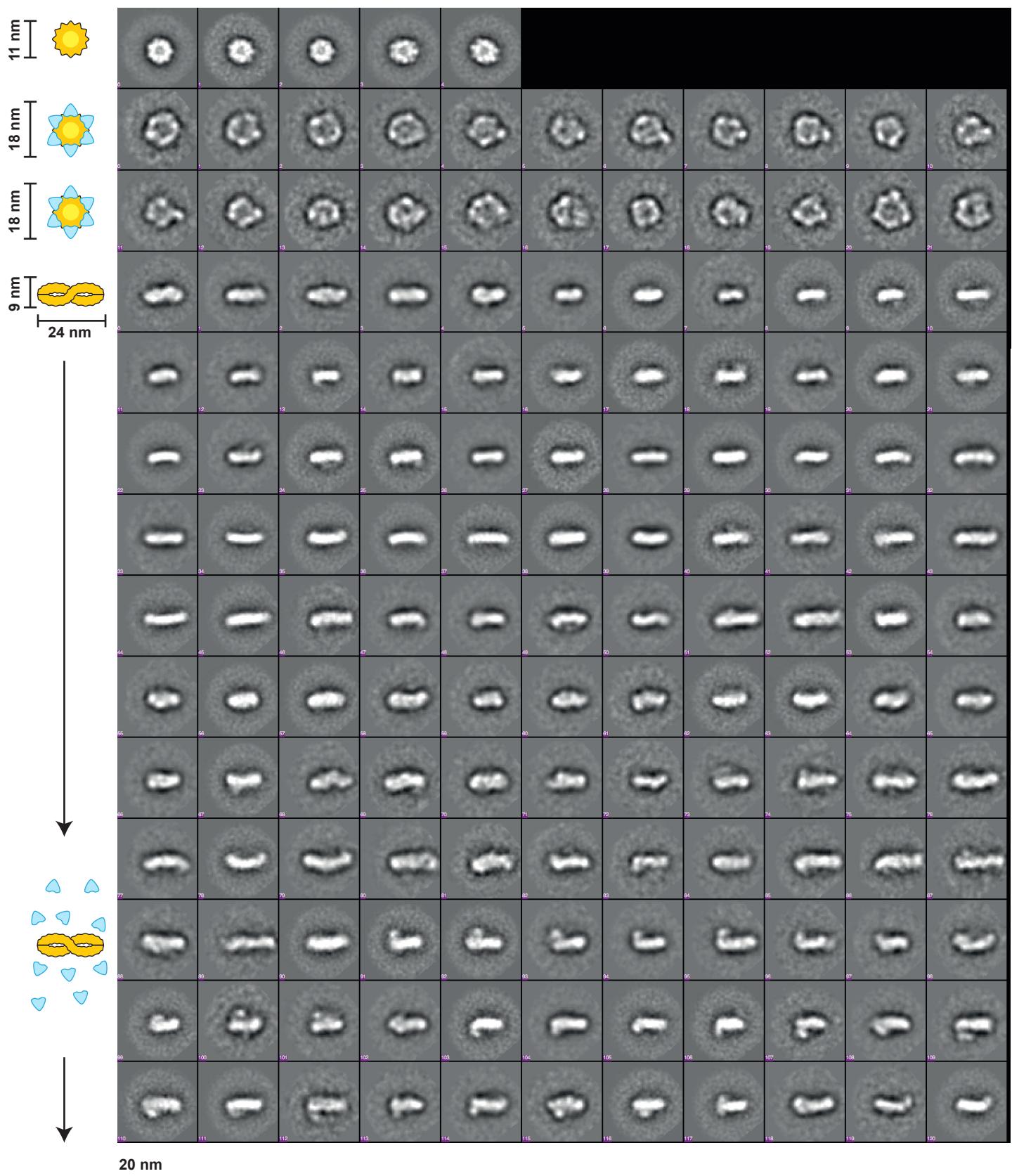


Supplementary Figure 6: Size Exclusion Chromatographic (SEC) separation and EM structural comparison of magnetosensor protein complex purified from different peaks. a, SEC on Superdex 200 column 10/300 GL (GE Healthcare); b, The same protein preparation was loaded on Superose 6 Increase column 10/300 GL (GE Healthcare), and peak1 and peak2 both containing clCry4 and clMagR protein complex; c, Negative staining EM image of protein fraction from peak1, showing aggregation of magnetosensor proteins; d, Negative staining EM image of protein fraction from peak2, showing isolated particles of magnetosensor protein complex. Red arrows show rod-like isolated magnetosensor protein complexes.

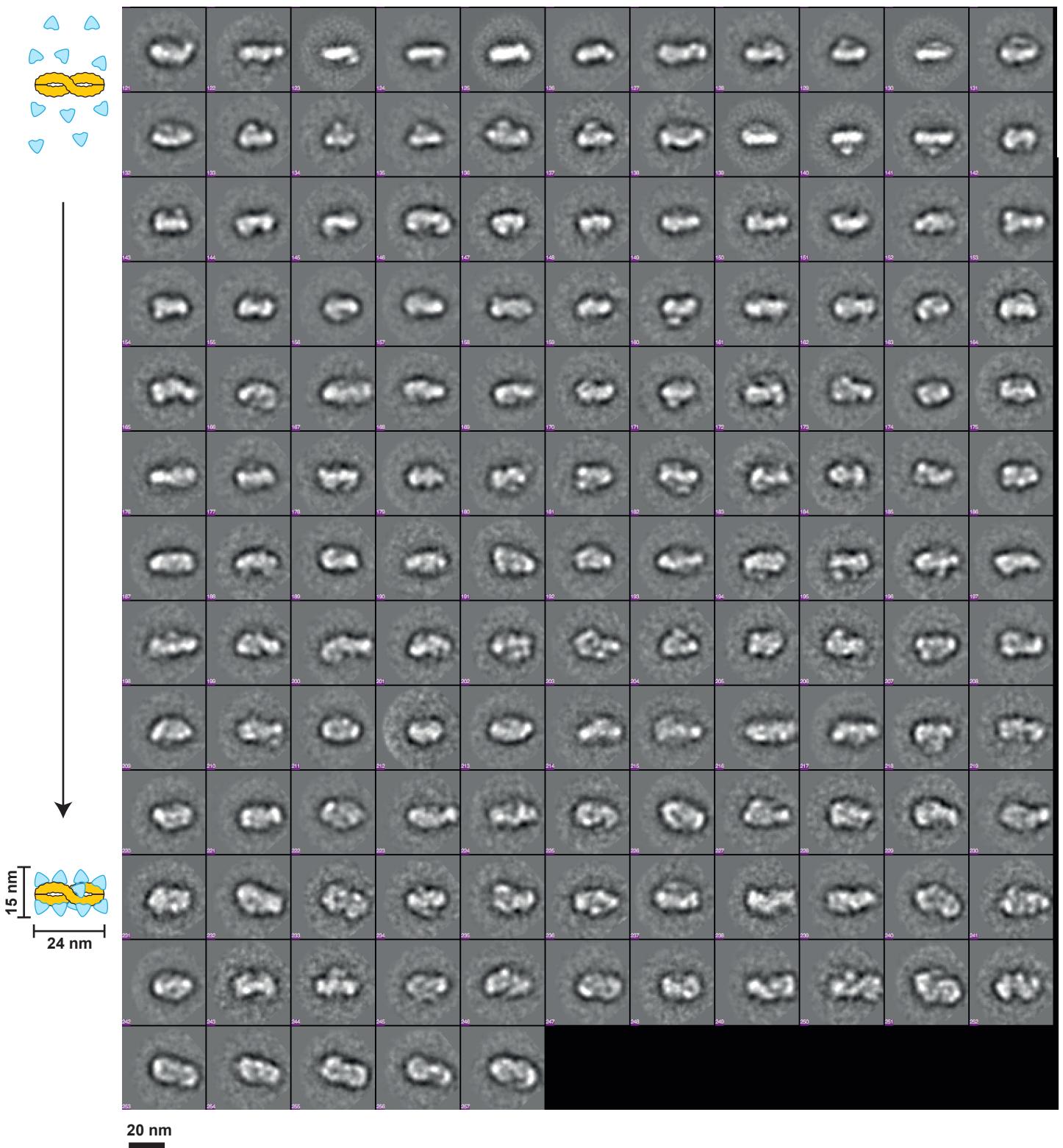


Supplementary Figure 7: Purification of clCry4 and negative staining EM image of clCry4 alone.

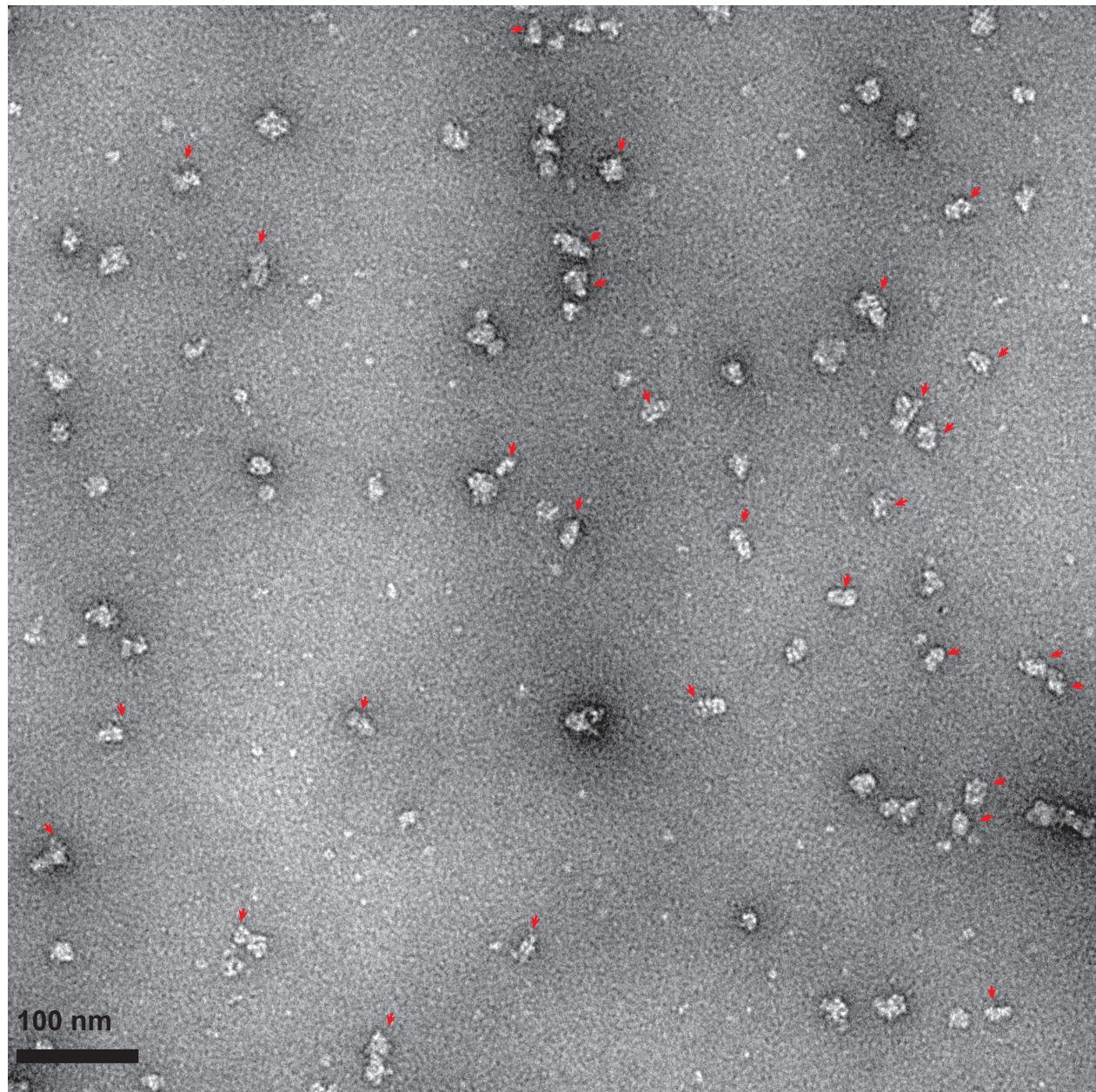
a, SEC on Superose 6 Increase column 10/300 GL (GE Healthcare) showing the homogeneity of clCry4 preparation (arrow); **b**, The SDS-PAGE of clCry4 from peak in a (arrow); **c**, Negative staining EM image of clCry4 protein from peak in a. One complete, representative, raw CCD image is shown for clCry4 alone, which is distinctive from EM image of clCry4/clMagR magnetosensor complex (see Supplementary Figs 6 and 8 and Fig. 2i-k). Scale bar represents 100 nm. (Note: The molecular weight of clCry4 is 55 KDa, compared with 840 KDa of calculated molecular weight of clCry4/clMagR magnetosensor).



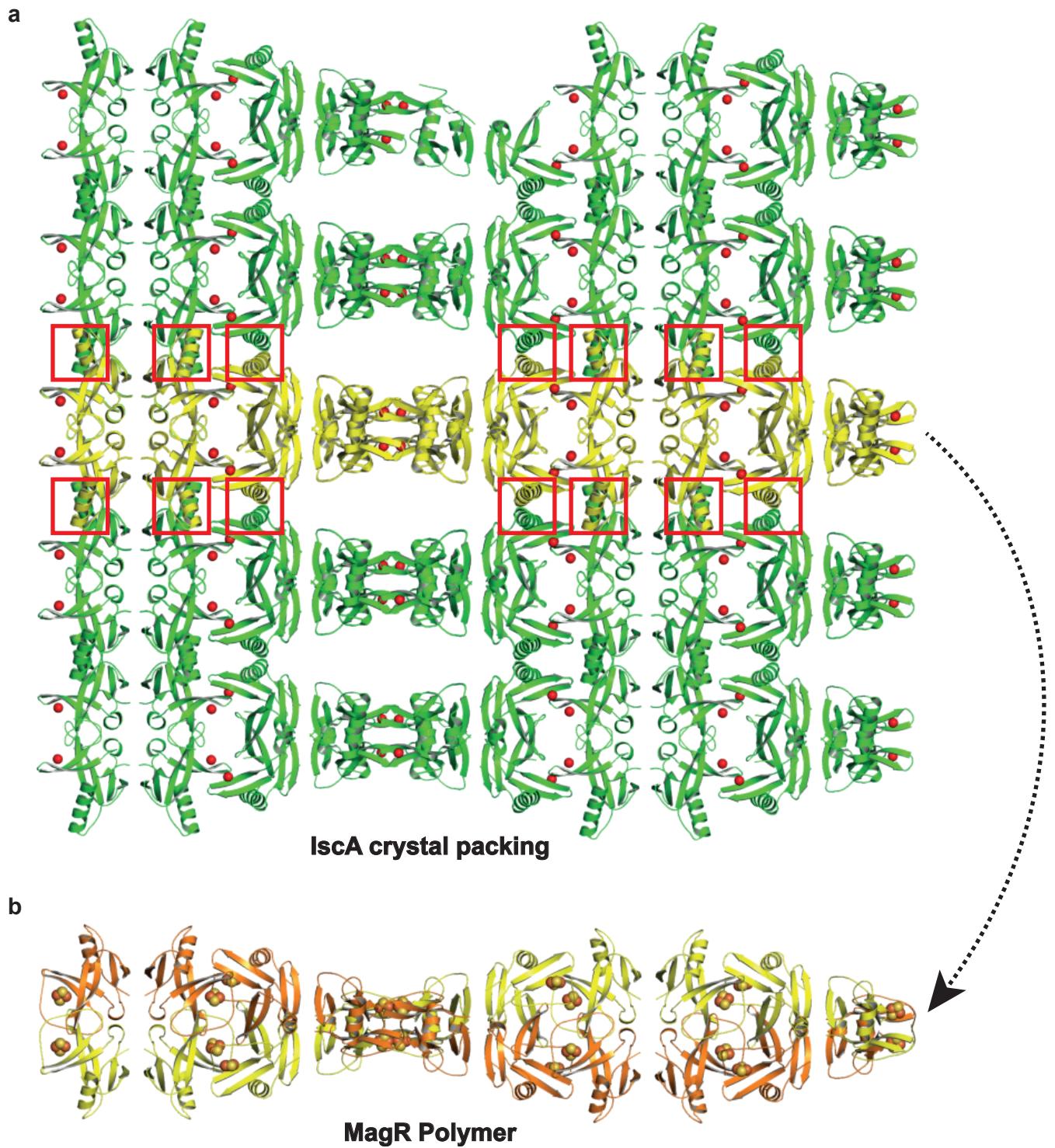
Supplementary Figure 8 (continued)



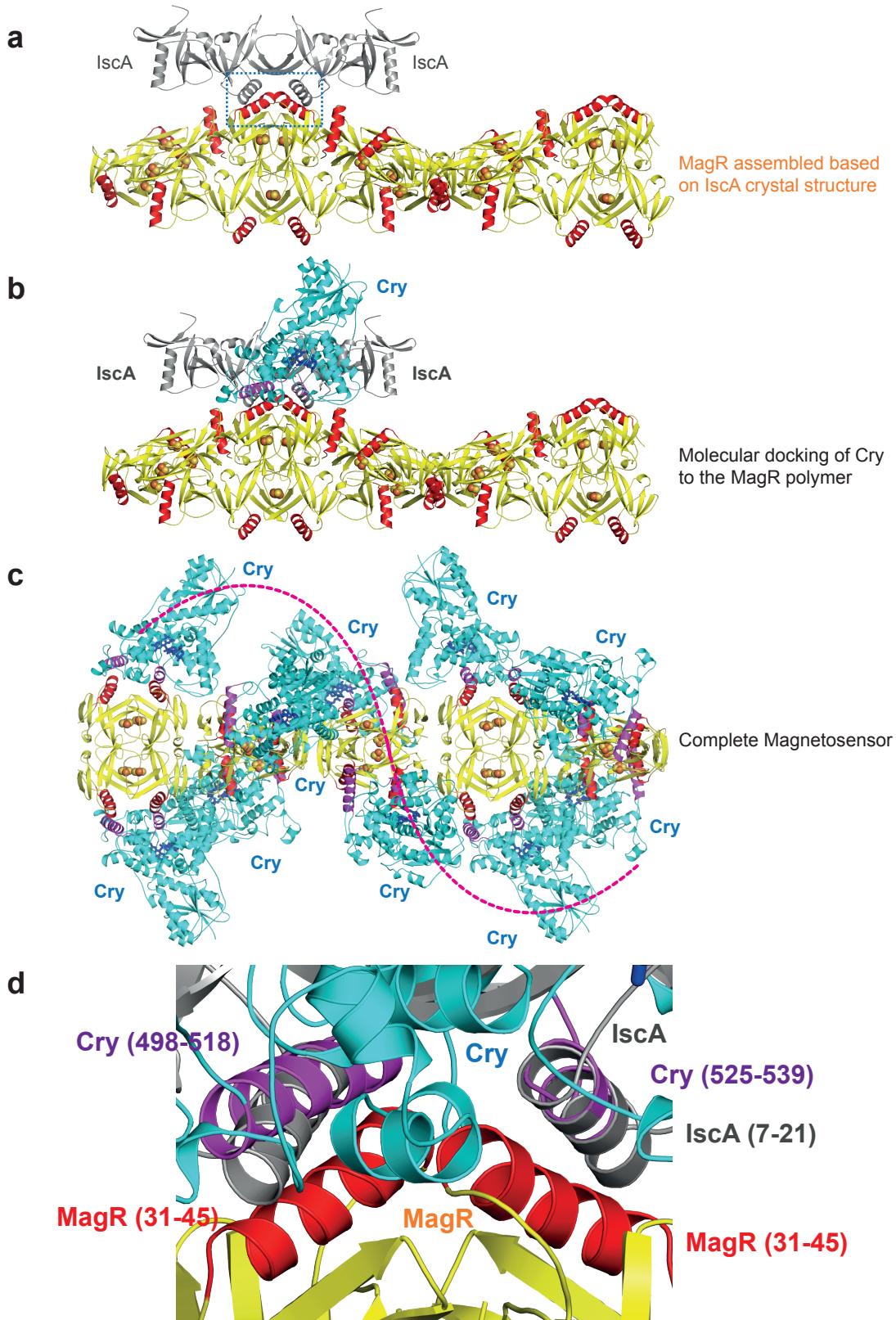
Supplementary Figure 8: EM class averages of clCry4/clMagR magnetosensor protein complex. All 285 class averages computed in this study, as summarized in Figure 2, are shown. The class averages are arranged in order by the shape of particles (from round disk shape to rod-like shape) and the size of particles (from smaller to larger), reading by row from left to right, and from top to bottom. The proposed structural architectures are illustrated as cartoons to the left. Scale bar represents 20 nm.



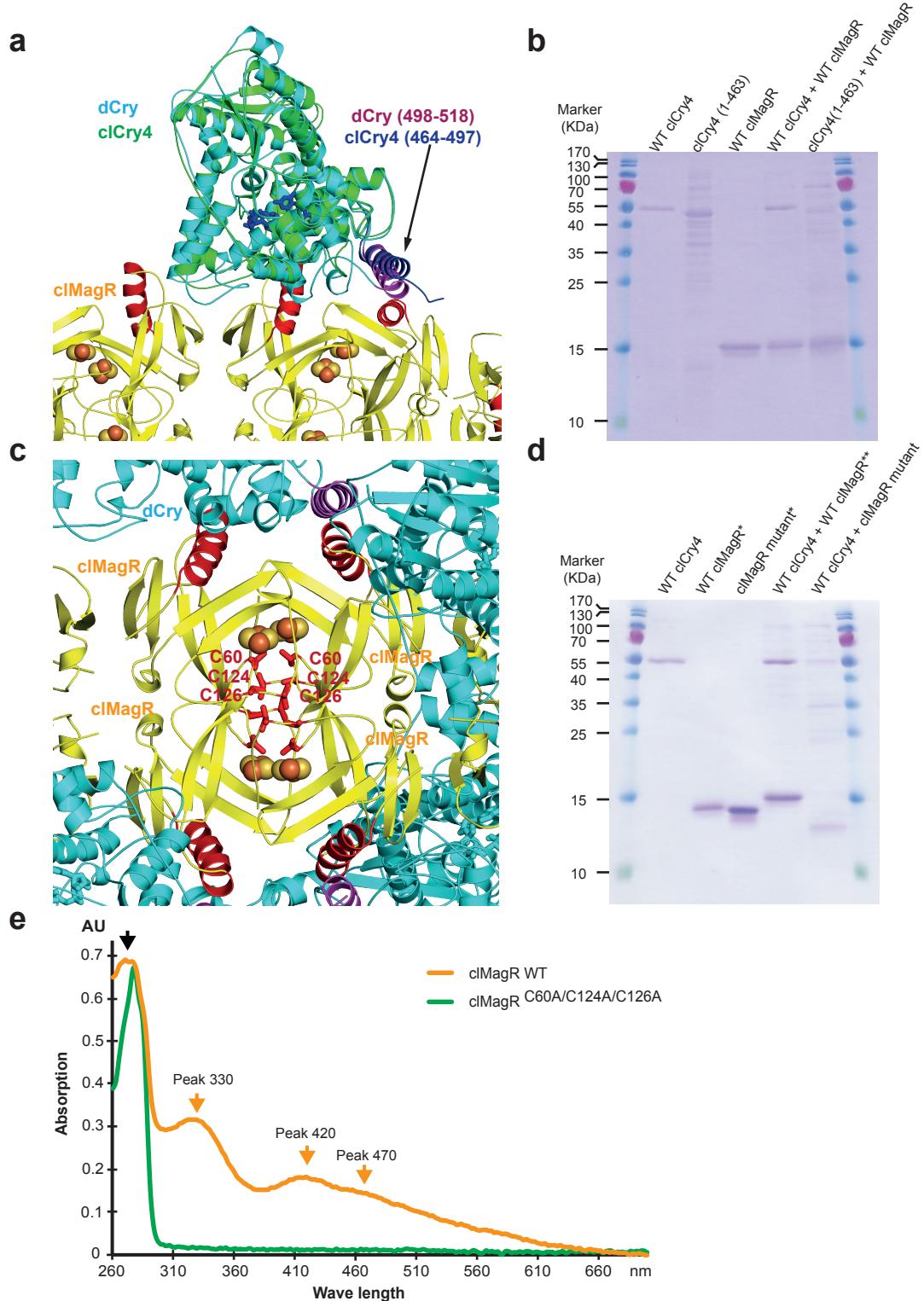
Supplementary Figure 9: Negative staining EM image of monarch butterfly dpCry1/dpMagR magnetosensor (50000X). One complete, representative, raw CCD image is shown for dpCry1/dpMagR magnetosensor protein complex preparation. EM grids were prepared under geomagnetic field, without external magnetic field. Scale bar represents 100 nm.



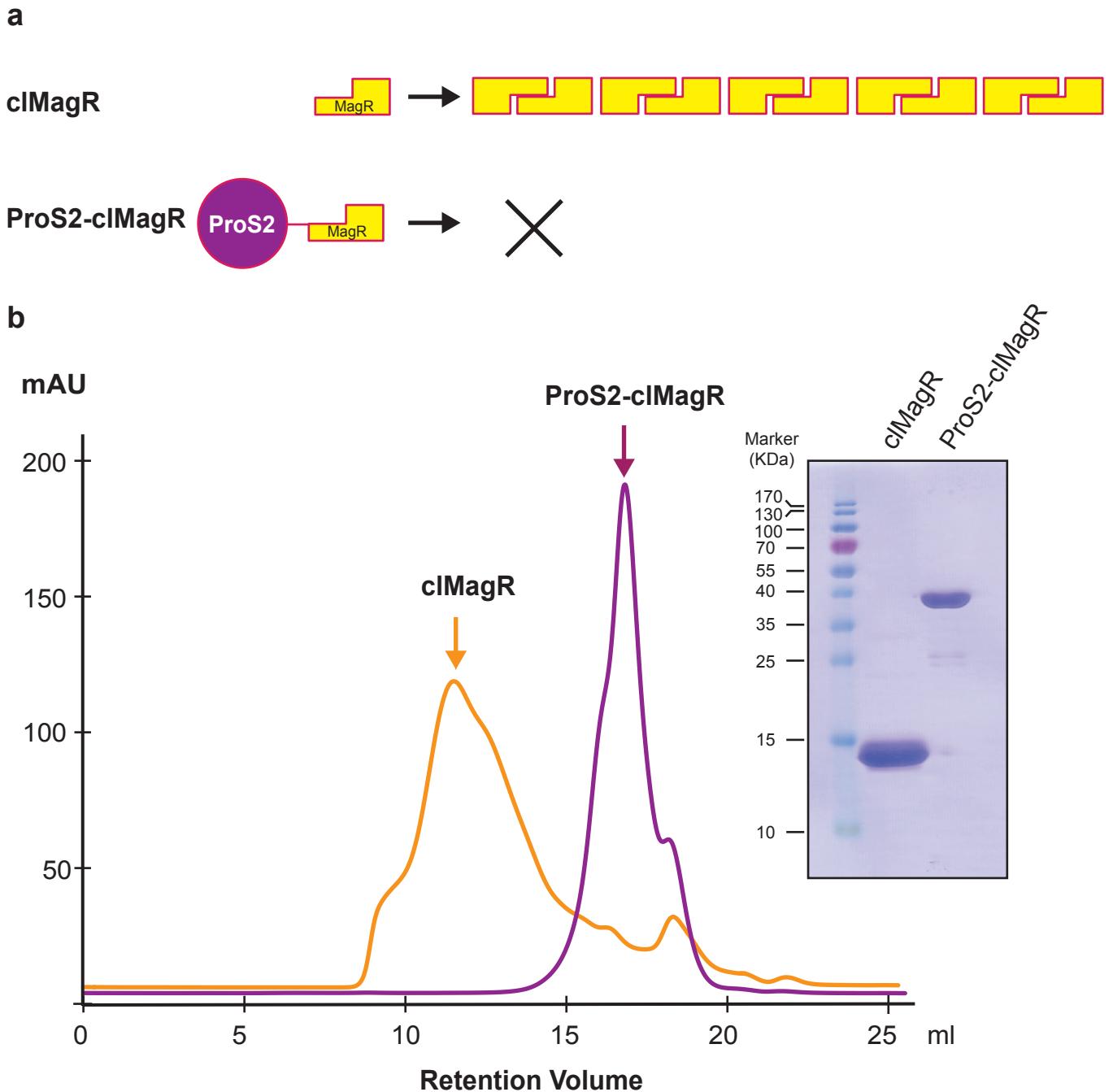
Supplementary Figure 10: Homology modeling of MagR polymer based on IscA crystal structure (PDB ID: 1R94). **a**, A section of the IscA crystal packing is shown. One representative linear assembly of IscA molecules is colored yellow; and the metals (Hg) in crystals are shown as red spheres. The major crystal packing interfaces mediated by ‘helix-helix’ interaction are shown in red boxes; **b**, The structural modeling of MagR assembly based on IscA structure and its crystal packing pattern.



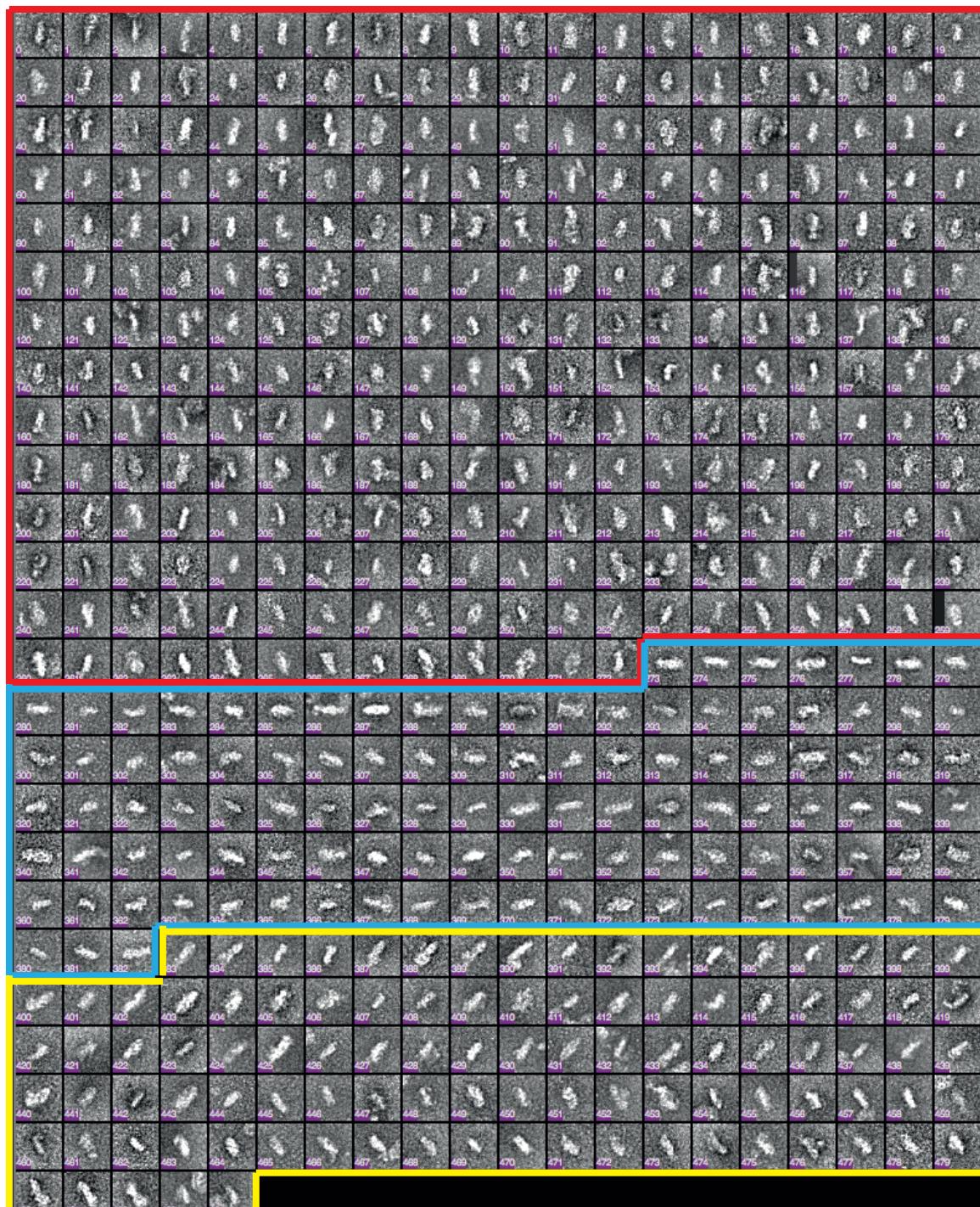
Supplementary Figure 11: Molecular docking of Cry to the MagR polymer, and the complete structural model of Cry/MagR magnetosensor protein complex. **a**, MagR assembled based on IscA crystal structure (yellow) and neighboring IscA molecules are shown (gray). One representative major crystal packing interface is shown in the box, and two conserved α -helices involved the ‘helix-helix’ interaction are red; **b**, full-length Cry crystal structure (PDB ID: 4GU5, cyan) was docked to the rod-like clMagR core structure, via alignment of the two conserved helices (purple) of Cry structure to the two conserved helices (red) of MagR; **c**, A complete magnetosensor protein complex structure model with 10 Crys helically binding to the rod-like MagR polymer consisting of 20 MagRs, via helix-helix interaction; **d**, The interface of proposed Cry/MagR interaction in the magnetosensor complex structural model. IscA structure (gray) was shown as a reference, two conserved helices (purple) in Cry (cyan) and two conserved helices (red) in MagR (yellow) are shown.



Supplementary Figure 12: Validation of magnetosensor structural model. **a**, The conserved C-terminal alpha-helix of Cry (498–518 in fly dCry and 464–497 in pigeon clCry4) forms major interface between Cry and MagR; **b**, Deletion of the conserved alpha-helix of clCry4 greatly reduced complex formation; **c**, Structural model shows three conserved cysteines (C60, C124 and C126) form the Fe-S cluster binding site; **d**, Replacing three conserved cysteine residues with alanine residues in clMagR abolished the Cry-MagR interaction; **e**, Absorption spectrum of purified wild type clMagR (orange) and clMagR cys mutant (green) confirmed the absence of Fe-S cluster in clMagR cys mutant. Cyan: dCry; Green: clCry; Yellow: clMagR. Conserved cysteine residues shown as red sticks, proposed Fe-S clusters as spheres, FAD in blue sticks. The conserved C-terminal helices forming major interfaces between Cry and MagR are highlighted in purple (dCry), blue (clCry4) and red (clMagR). Note: The expression vector of WT MagR (labeled **) used for complex purification was slightly different than the expression vectors for MagR or its mutants (labeled *). To achieve better yield for complex purification, a flexible linker (GGGGS)2 was inserted between the StrepII tag and MagR sequence, which added about 1 KDa to the molecular weight compared with the constructs to express MagR and MagR mutant alone.



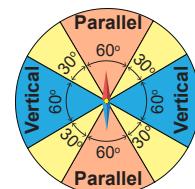
Supplementary Figure 13: MagR polymerization was interrupted by insertions in its N-terminal.
a, Schematic shows the polymerization of MagR (upper) and how polymerization is interrupted by adding a 24 KDa tag to the N-terminal of MagR in our ProS2-MagR construct (lower); **b**, Purification of clMagR and ProS2-clMagR. Left: size Exclusion Chromatographic (SEC) separation of clMagR and ProS2-MagR on Superose 6 Increase column 10/300 GL (GE Healthcare), showing the clMagR polymer (orange) and ProS2-clMagR dimer and monomers (purple). Right: SDS PAGE of the purified clMagR and ProS2-clMagR proteins.



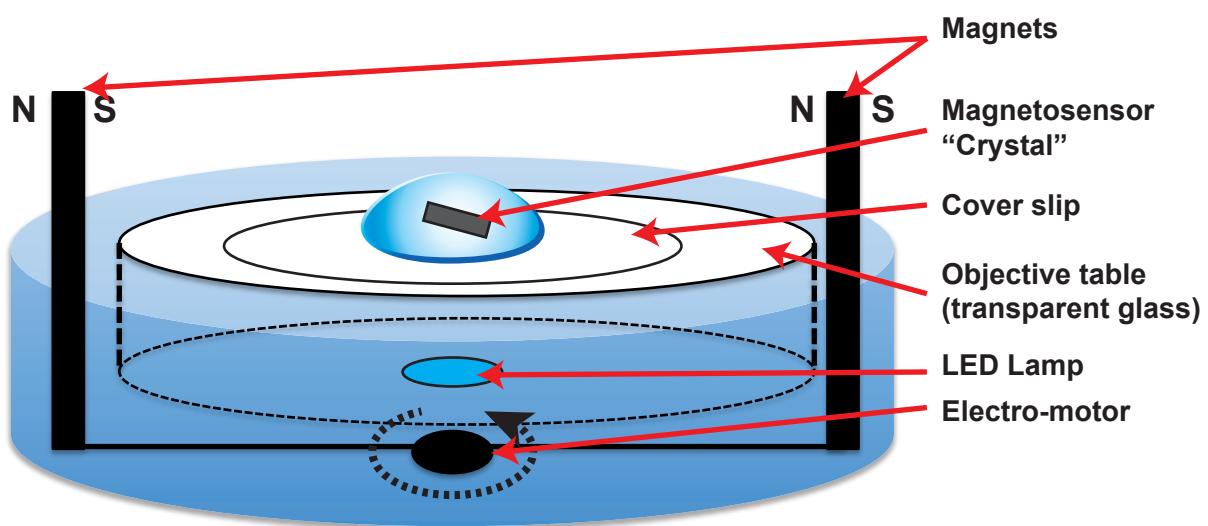
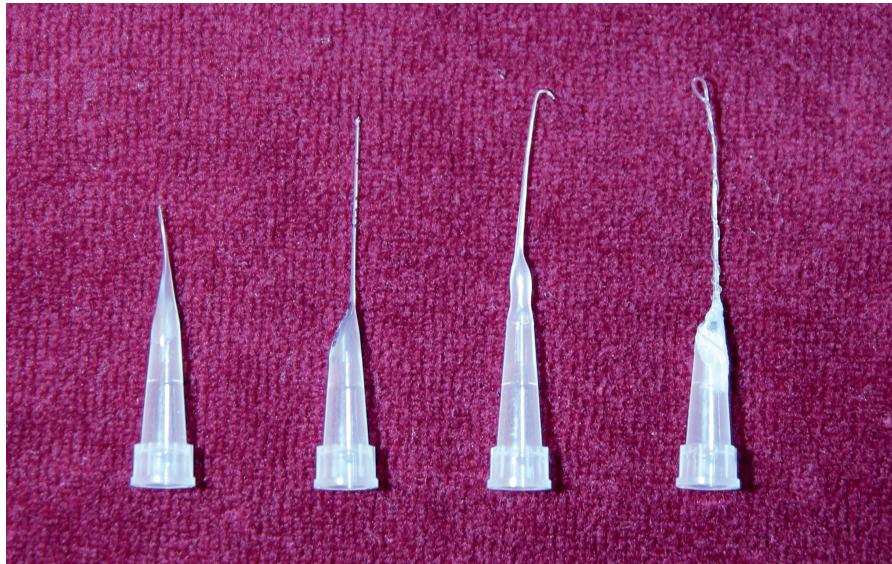
 Particles parallel to the magnetic field direction (Parallel)

 Particles Vertical to the magnetic field direction (Vertical)

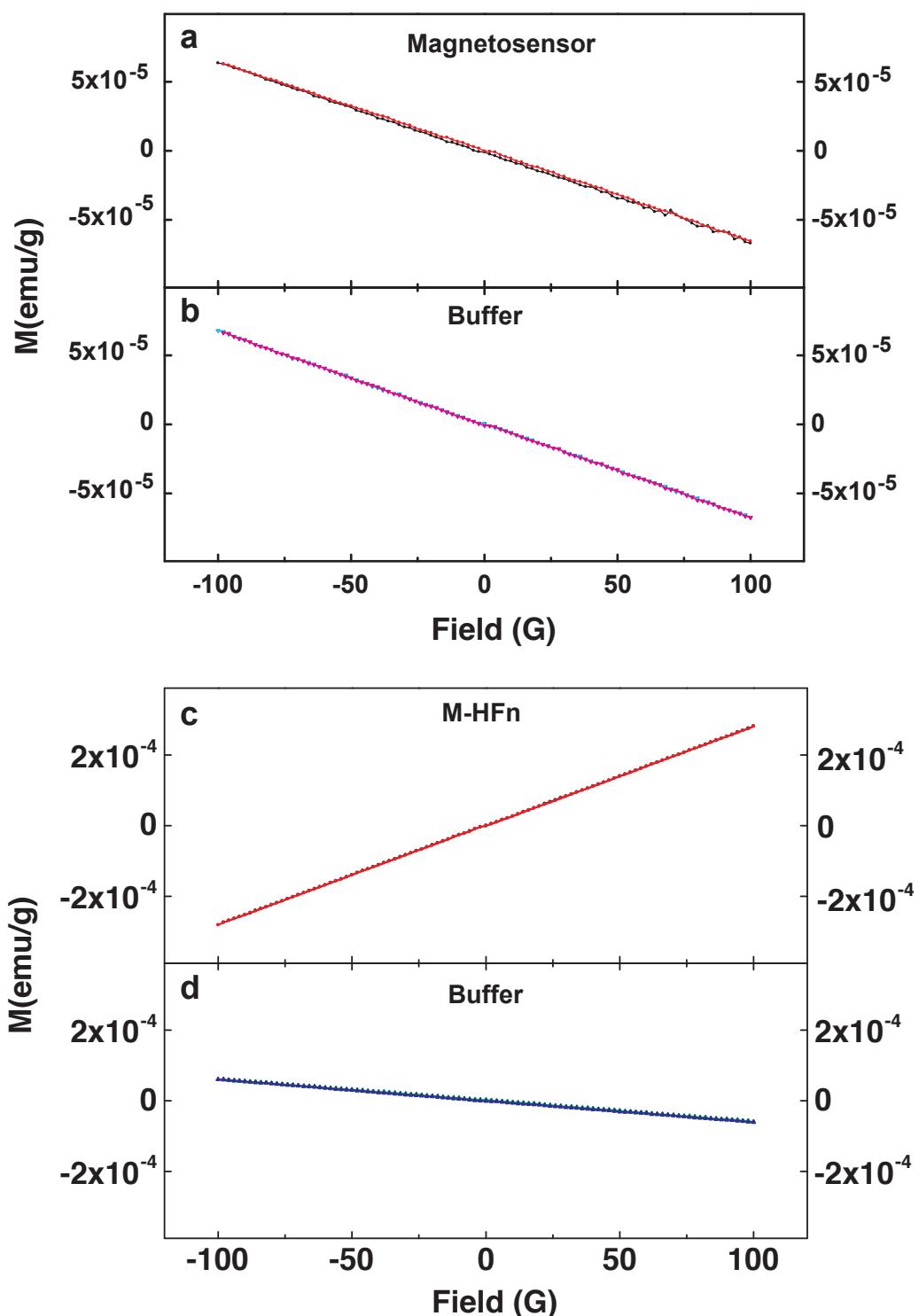
 Particles in between two above directions (Others)



Supplementary Figure 14: Magnetosensor protein complex possess intrinsic magnetic polarity and align with magnetic field. Shows one representative result of three independent experiments (see Fig. 5a,b). 485 raw particles from one single EM experiment were picked from CCD raw images using EMAN and grouped into three different orientations (boxed in red, cyan and yellow) based on their original orientation in raw images.

a**b**

Supplementary Figure 15: Customized microscopic objective table with rotating magnetic field (a) and crystal handling tools made from 10 μ l plastic pipette tips (b).



Supplementary Figure 16: Magnetic properties of clCry4/clMagR protein complex, synthesized magnetite-containing HFn (M-HFn) nanoparticles and buffers. **a**, The field dependence of magnetization of clCry4/clMagR protein solution with buffer. A hysteresis loop is obvious besides the diamagnetic background. **b**, The field dependence of magnetization of buffer of clCry4/clMagR complex. The obvious linear dependence indicates that no ferrimagnetic ordering exists in buffer. **c**, The field dependence of magnetization of M-HFn solution with buffer. The linear dependence is obvious, indicating the non-ferrimagnetic character of M-HFn. **d**, The field dependence of magnetization of buffer of M-HFn. The obvious linear dependence indicates that no ferrimagnetic ordering exists in M-HFn storage buffer. All data were collected at 298 K, the maximal external magnetic field $H = 100$ G. The results shown are representative of six independent experiments.

Supplementary Tables and Legends

Supplementary Table 1: 199 potential iron-containing (binding) protein candidates for the magnetoreceptor from the first round of screening in *Drosophila melanogaster*. Candidates picked out for the next (second) round of screening have a white background, others have a gray background.

Number	Flybase Gene ID	Gene ID	Official Symbol	GO Term	Head (including Brain, Eye) specific expression*	Used for the 2nd Screen
1	FBgn0000406	35008	Cyt-b5-r	mitochondrion lipid particle iron ion binding electron carrier activity fatty acid biosynthetic process oxidoreductase activity, acting on paired donors, with oxidation of a pair of donors resulting in the reduction of molecular oxygen to two molecules of water heme binding oxidation-reduction process	Yes	Yes
2	FBgn0000409	34996	Cyt-c-p	mitochondrion electron transporter, transferring electrons from CoQH2-cytochrome c reductase complex and cytochrome c oxidase complex activity iron ion binding mitochondrial matrix mitochondrial inner membrane electron carrier activity heme binding oxidative phosphorylation	Yes	Yes
3	FBgn0000449	45282	dib	chitin-based embryonic cuticle biosynthetic process iron ion binding dorsal closure ecdysone biosynthetic process mitochondrial inner membrane electron carrier activity central nervous system development mitochondrion head involution midgut development ecdysteroid 22-hydroxylase activity ecdysone metabolic process oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	No	No
4	FBgn0000473	35587	Cyp6a2	response to caffeine membrane iron ion binding electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bounded organelle oxidation-reduction process heme binding	Yes	Yes
5	FBgn0001208	38871	HN	phenylalanine 4-monooxygenase activity tryptophan 5-monooxygenase activity iron ion binding lipid particle L-phenylalanine catabolic process eye pigment biosynthetic process phagocytosis, engulfment oxidation-reduction process	Yes	Yes
6	FBgn0001977	49424	1(2)35Bg	2 iron, 2 sulfur cluster binding electron carrier activity metal ion binding apoptotic process iron-sulfur cluster assembly negative regulation of apoptotic process ovarian follicle cell development	Yes	Yes
7	FBgn0001992	49165	CYP303A1	sensory organ development iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bounded organelle	Yes	Yes

8	FBgn0003308	41605	ry	xanthine dehydrogenase activity xanthine oxidase activity iron ion binding peroxisome microtubule associated complex purine base metabolic process pyrimidine base metabolic process arginine metabolic process tryptophan metabolic process glycerophospholipid metabolic process determination of adult lifespan UDP-N-acetylglucosamine dehydrogenase activity electron carrier activity molybdopterin cofactor binding compound eye pigmentation flavin adenine dinucleotide binding 2 iron, 2 sulfur cluster binding oxidation-reduction process	Yes	Yes
9	FBgn0003312	44858	sad	iron ion binding dorsal closure ecdysone biosynthetic process electron carrier activity central nervous system development mitochondrion motor neuron axon guidance head involution membrane ecdysteroid 2-hydroxylase activity midgut development oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	No	No
10	FBgn0003388	39592	Shd	border follicle cell migration iron ion binding dorsal closure electron carrier activity growth of a germarium-derived egg chamber central nervous system development ecdysone 20-monoxygenase activity mitochondrion membrane head involution midgut development ecdysteroid biosynthetic process oxidation-reduction process heme binding	Yes	Yes
11	FBgn0003486	38631	spo	heme binding iron ion binding monooxygenase activity oxidoreductase activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen central nervous system development cuticle development dorsal closure ecdysone biosynthetic process embryonic development via the syncytial blastoderm embryonic digestive tract development head involution midgut development oogenesis	No	No
12	FBgn0004577	2768671	Pxd	peroxidase activity iron ion binding extracellular region phagocytosis, engulfment response to oxidative stress eggshell chorion assembly heme binding neurogenesis chorion oxidation-reduction process	Yes	Yes
13	FBgn0004959	32857	phm	border follicle cell migration ecdysteroid 25-hydroxylase activity iron ion binding oogenesis endoplasmic reticulum insecticide metabolic process ecdysone biosynthetic process electron carrier activity embryonic development via the syncytial blastoderm intracellular membrane-bound organelle membrane oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process	No	No

14	FBgn0005626	38746	PLE	tyrosine 3-monoxygenase activity iron ion binding cellular_component catecholamine metabolic process courtship behavior male courtship behavior adult locomotory behavior aromatic amino acid family metabolic process wing disc development thermosensory behavior regulation of dopamine metabolic process dopamine biosynthetic process dopamine metabolic process thermotaxis developmental pigmentation cuticle pigmentation regulation of adult chitin-containing cuticle pigmentation adult chitin-containing cuticle pigmentation oxidation-reduction process regulation of epithelial cell migration, open tracheal system	Yes	Yes
15	FBgn0005670	31188	Cyp4dl	lipid particle iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
16	FBgn0010019	30986	Cyp4gl	lipid metabolic process iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	No	No
17	FBgn0010100	44149	acolN	mitochondrion lipid particle tricarboxylic acid cycle 4 iron, 4 sulfur cluster binding aconitase hydratase activity	Yes	Yes
18	FBgn0010383	32858	CYP18A1	steroid biosynthetic process metamorphosis ecdysteroid catabolic process iron ion binding steroid hydroxylase activity prepupal development electron carrier activity pupation intracellular membrane-bound organelle membrane imaginal disc-derived leg morphogenesis chorion-containing eggshell formation oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	Yes	Yes
19	FBgn0011576	31192	Cyp4d2	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	Yes	Yes
20	FBgn0011672	42490	Mvl	copper ion homeostasis plasma membrane iron assimilation positive regulation of iron ion transmembrane transport transition metal ion homeostasis viral entry into host cell divalent metal ion transport multicellular organismal iron ion homeostasis sensory perception of sweet taste membrane manganese ion transmembrane transporter activity copper ion transmembrane transporter activity integral component of plasma membrane copper ion import iron ion transmembrane transporter activity transition metal ion transport symporter activity endosome	No	No

21	FBgn0011676	34495	Nos	FMN binding NADP binding NADPH-hemoprotein reductase activity calmodulin binding flavin adenine dinucleotide binding heme binding iron ion binding nitric-oxide synthase activity imaginal disc development negative regulation of DNA replication negative regulation of cell proliferation nervous system development nitric oxide biosynthetic process nitric oxide mediated signal transduction positive regulation of guanylate cyclase activity regulation of heart rate regulation of organ growth synapse assembly	Yes	Yes
22	FBgn0011769	39070	fdxH	mitochondrion biological_process 2 iron, 2 sulfur cluster binding electron carrier activity	Yes	Yes
23	FBgn0013674	192469	COX1	cytochrome-c oxidase activity heme binding iron ion binding aerobic respiration oxidative phosphorylation sleep	No	No
24	FBgn0013771	36663	Cyp6a9	iron ion binding membrane insecticide metabolic process electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bounded organelle	Yes	Yes
25	FBgn0013772	36666	Cyp6a8	response to caffeine membrane iron ion binding insecticide metabolic process alkane 1-monoxygenase activity electron carrier activity lauric acid metabolic process intracellular membrane-bounded organelle oxidation-reduction process heme binding	Yes	Yes
26	FBgn0013773	49847	Cyp6a22	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bounded organelle	No	No
27	FBgn0014028	35590	SdhB	mitochondrial respiratory chain complex II microtubule associated complex tricarboxylic acid cycle mitochondrial electron transport, succinate to ubiquinone succinate dehydrogenase (ubiquinone) activity electron carrier activity 2 iron, 2 sulfur cluster binding	Yes	Yes
28	FBgn0014469	35822	Cyp4e2	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bounded organelle	Yes	Yes
29	FBgn0015032	43663	Cyp4c3	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bounded organelle heme binding oxidation-reduction process	Yes	Yes
30	FBgn0015033	38841	Cyp4d8	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bounded organelle heme binding	Yes	Yes

31	FBgn0015034	44632	Cyp4e1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	Yes	Yes
32	FBgn0015035	34291	Cyp4e3	lipid particle iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	Yes	Yes
33	FBgn0015036	31193	Cyp4ael	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	No	No
34	FBgn0015037	45524	Cyp4p1	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	Yes	Yes
35	FBgn0015038	35634	Cyp9b1	monooxygenase activity iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
36	FBgn0015039	35635	Cyp9b2	monooxygenase activity iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	Yes	Yes
37	FBgn0015040	37941	Cyp9c1	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	Yes	Yes
38	FBgn0015221	44965	Fer2LCH	intracellular ferritin complex cellular iron ion homeostasis chaeta development hemolymph coagulation locomotor rhythm Golgi apparatus iron ion transport extracellular region ferrous iron binding ferric iron binding less	Yes	Yes
39	FBgn0015222	46415	Fer1HCH	cellular iron ion homeostasis intracellular ferritin complex Golgi apparatus cell proliferation microtubule associated complex fusome iron ion transport extracellular region post-embryonic development ferrous iron binding ferric iron binding	Yes	Yes
40	FBgn0015623	33883	Cpr	NADPH-hemoprotein reductase activity NADPH-hemoprotein reductase activity iron ion binding endoplasmic reticulum lipid particle FMN binding oxidation-reduction process	No	No

41	FBgn0015714	45556	Cyp6a17	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen thermosensor behavior intracellular membrane-bound organelle oxidation-reduction process heme binding	Yes	Yes
42	FBgn0017566	31762	ND75	NADH dehydrogenase activity mitochondrion cellular respiration ATP synthesis coupled electron transport mitochondrial respiratory chain complex I iron-sulfur cluster binding electron carrier activity NADH dehydrogenase (ubiquinone) activity	Yes	Yes
43	FBgn0017567	44207	ND23	NADH dehydrogenase activity mitochondrion 4 iron, 4 sulfur cluster binding mitochondrial respiratory chain complex I mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity	Yes	Yes
44	FBgn0017592	5657524	Irp	mRNA binding iron ion binding regulation of translational initiation by iron	No	No
45	FBgn0021906	44390	Rfesp	mitochondrion ubiquinol-cytochrome-c reductase activity 2 iron, 2 sulfur cluster binding microtubule associated complex mitochondrial electron transport, ubiquinol to cytochrome c mitochondrial respiratory chain complex III	Yes	Yes
46	FBgn0022355	32821	Tsf1	iron ion transmembrane transporter activity extracellular region iron ion transport cellular iron ion homeostasis defense response ferric iron binding	Yes	Yes
47	FBgn0023541	45706	Cyp4d14	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	No	No
48	FBgn0024957	41269	Irp-1B	4 iron, 4 sulfur cluster binding iron ion binding regulation of translational initiation by iron aconitase hydratase activity metabolic process iron-responsive element binding mRNA binding	Yes	Yes
49	FBgn0024958	42689	Irp-1A	4 iron, 4 sulfur cluster binding iron ion binding regulation of translational initiation by iron aconitase hydratase activity iron-responsive element binding ventral furrow formation mRNA binding	Yes	Yes
50	FBgn0025454	36316	Cyp6g1	response to organophosphorus iron ion binding membrane insecticide catabolic process response to DDT electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen response to mercury ion heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
51	FBgn0025628	31174	CG4199	cytoplasm oxidoreductase activity cell redox homeostasis flavin adenine dinucleotide binding 2 iron, 2 sulfur cluster binding oxidation-reduction process	No	No
52	FBgn0026190	43624	PH4alphaMP	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	Yes	Yes

53	FBgn0026666	32513	1(1)G0136	iron-sulfur cluster assembly iron-sulfur cluster binding structural molecule activity	Yes	Yes
54	FBgn0027657	41930	Glob1	oxygen binding iron ion binding oxygen transporter activity heme binding oxygen transport	Yes	Yes
55	FBgn0028940	34817	Cyp28a5	monooxygenase activity membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
56	FBgn0029158	40259	Las	mitochondrion lipoate biosynthetic process lipoate synthase activity 4 iron, 4 sulfur cluster binding	Yes	Yes
57	FBgn0029172	44006	FAD2	cytokinesis stearoyl-CoA 9-desaturase activity iron ion binding endoplasmic reticulum fatty acid biosynthetic process phagocytosis, engulfment courtship behavior membrane pheromone metabolic process oxidation-reduction process	No	No
58	FBgn0030092	31845	FH	ferroxidase activity mitochondrion cellular iron ion homeostasis axon transport of mitochondrion iron chaperone activity response to hydrogen peroxide regulation of mitochondrial membrane potential oxidation-reduction process	Yes	Yes
59	FBgn0030304	32093	Cyp4g15	steroid biosynthetic process membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	Yes	Yes
60	FBgn0030339	32138	Cyp28c1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
61	FBgn0030367	32170	Cyp311a1	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
62	FBgn0030369	32172	Cyp318a1	monooxygenase activity membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	Yes	Yes
63	FBgn0030449	32260	Fer3HCH	cellular iron ion homeostasis intracellular ferritin complex cellular response to iron ion starvation iron ion transport ferrous iron binding ferric iron binding positive regulation of JAK-STAT cascade	No	No
64	FBgn0030485	32300	CG1998	iron ion binding fatty acid biosynthetic process C-4 methylsterol oxidase activity oxidation-reduction process	Yes	Yes

65	FBgn0030509	32325	CG11162	iron ion binding fatty acid biosynthetic process C-4 methylsterol oxidase activity oxidation-reduction process	No	No
66	FBgn0030615	32444	Cyp4s3	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
67	FBgn0030718	32565	CG9172	NADH dehydrogenase activity mitochondrial respiratory chain complex I assembly quinone binding 4 iron, 4 sulfur cluster binding mitochondrial respiratory chain complex I mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity response to reactive oxygen species determination of adult lifespan	Yes	Yes
68	FBgn0030949	32859	Cyp308a1	iron ion binding membrane insecticide metabolic process electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	Yes	Yes
69	FBgn0030975	32887	CG7349	tricarboxylic acid cycle mitochondrial respiratory chain complex II 2 iron, 2 sulfur cluster binding succinate dehydrogenase activity electron carrier activity	No	No
70	FBgn0031126	33056	Cyp6v1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	No	No
71	FBgn0031182	33127	Cyp6t1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
72	FBgn0031432	33438	Cyp309a1	membrane iron ion binding electron carrier activity lateral inhibition oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
73	FBgn0031604	33649	ELP3	nucleus cytoplasm regulation of transcription from RNA polymerase II promoter locomotory behavior transcription elongation factor complex N-acetyltransferase activity phosphorylase kinase regulator activity sleep photoreceptor cell maintenance synaptic growth at neuromuscular junction iron-sulfur cluster binding	No	No
74	FBgn0031688	33748	Cyp28d2	monooxygenase activity membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	Yes	Yes

75	FBgn0031689	33749	Cyp28d1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
76	FBgn0031693	33754	Cyp4ac1	membrane insecticide catabolic process iron ion binding electron carrier activity hormone metabolic process oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
77	FBgn0031694	33755	Cyp4ac2	iron ion binding membrane insecticide catabolic process electron carrier activity hormone metabolic process oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	Yes	Yes
78	FBgn0031695	33756	Cyp4ac3	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
79	FBgn0031771	33852	CG9140	NADH dehydrogenase activity mitochondrial respiratory chain complex I 4 iron, 4 sulfur cluster binding NAD binding FMN binding mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity	Yes	Yes
80	FBgn0031925	34036	Cyp4d21	monooxygenase activity mating cytoplasm membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
81	FBgn0032116	34258	CG3759	ferroxidase activity cell surface copper ion binding iron ion transmembrane transporter activity basal part of cell iron ion homeostasis intrinsic component of external side of plasma membrane oxidation-reduction process	Yes	Yes
82	FBgn0032393	34613	CG12264	mitochondrion cytoplasm iron-sulfur cluster assembly alanine biosynthetic process cysteine metabolic process microtubule associated complex pyridoxal phosphate binding cysteine desulfurase activity cystathione gamma-lyase activity	Yes	Yes
83	FBgn0032597	35000	CG17904	4 iron, 4 sulfur cluster binding iron-sulfur cluster assembly nucleotide binding	No	No
84	FBgn0032603	35009	CG17928	iron ion binding lateral inhibition fatty acid biosynthetic process oxidoreductase activity, acting on paired donors, with oxidation of a pair of donors resulting in the reduction of molecular oxygen to two molecules of water heme binding oxidation-reduction process	Yes	Yes

85	FBgn0032693	35115	Cyp310a1	membrane iron ion binding negative regulation of Wnt signaling pathway electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding intracellular membrane-bound organelle oxidation-reduction process	No	No
86	FBgn0032754	35183	CG10700	2 iron, 2 sulfur cluster binding flavin adenine dinucleotide binding cell redox homeostasis ferredoxin-NAD(P) reductase activity oxidation-reduction process	No	No
87	FBgn0032907	35365	CG9272	DNA repair 4 iron, 4 sulfur cluster binding base-excision repair oxidized pyrimidine nucleobase lesion DNA N-glycosylase activity DNA binding cellular response to DNA damage stimulus	No	No
88	FBgn0033065	35543	Cyp6w1	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	Yes	Yes
89	FBgn0033100	35585	CG3420	2 iron, 2 sulfur cluster binding intracellular membrane-bound organelle	No	No
90	FBgn0033121	35608	Cyp6u1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
91	FBgn0033292	35821	Cyp4ad1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	No	No
92	FBgn0033304	35837	Cyp6a13	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen defense response to bacterium heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
93	FBgn0033395	35946	Cyp4p2	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
94	FBgn0033397	35948	Cyp4p3	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	Yes	Yes
95	FBgn0033524	36105	CYP49A1	mitochondrion iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	No	No

96	FBgn0033696	36317	Cyp6g2	monooxygenase activity iron ion binding membrane electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
97	FBgn0033697	36318	Cyp6t3	iron ion binding membrane regulation of developmental growth ecdysone biosynthetic process electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
98	FBgn0033753	36378	Cyp301a1	mitochondrion tergite morphogenesis iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process	Yes	Yes
99	FBgn0033775	36412	Cyp9h1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	Yes	Yes
100	FBgn0033972	36655	CIA01	molecular_function cellular_component iron-sulfur cluster assembly neurogenesis	Yes	Yes
101	FBgn0033978	36661	Cyp6a23	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding intracellular membrane-bound organelle oxidation-reduction process	No	No
102	FBgn0033979	36662	Cyp6a19	monooxygenase activity membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	No	No
103	FBgn0033980	36664	Cyp6a20	defense response to Gram-negative bacterium iron ion binding membrane aggressive behavior electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
104	FBgn0033981	36665	Cyp6a21	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
105	FBgn0033982	36667	Cyp317a1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes

106	FBgn0034007	36695	CG8102	NADH dehydrogenase activity 4 iron, 4 sulfur cluster binding mitochondrial respiratory chain complex I mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity extracellular space multicellular organism reproduction	No	No
107	FBgn0034053	36752	Cyp4aal	monooxygenase activity membrane insecticide catabolic process iron ion binding electron carrier activity hormone metabolic process oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	No	No
108	FBgn0034094	36800	Tsf3	cellular iron ion homeostasis response to bacterium iron ion transmembrane transporter activity iron ion transport extracellular region ferric iron binding	Yes	Yes
109	FBgn0034214	36954	CG6550	4 iron, 4 sulfur cluster binding RNA modification cellular component transferase activity	No	No
110	FBgn0034251	36998	CG11423	mitochondrial respiratory chain complex I 4 iron, 4 sulfur cluster binding NAD binding FMN binding NADH dehydrogenase (ubiquinone) activity oxidation-reduction process	No	No
111	FBgn0034364	37139	CG5493	iron ion binding L-cysteine metabolic process cysteine dioxygenase activity oxidation-reduction process	Yes	Yes
112	FBgn0034387	37163	Cyp12b2	mitochondrion iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	Yes	Yes
113	FBgn0034756	37594	Cyp6d2	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen response to camptothecin oxidation-reduction process heme binding intracellular membrane-bound organelle	Yes	Yes
114	FBgn0035187	38121	Trh	phenylalanine 4-monooxygenase activity tryptophan 5-monooxygenase activity tryptophan 5-monooxygenase activity iron ion binding tryptophan metabolic process serotonin biosynthetic process regulation of circadian sleep/wake cycle, sleep oxidation-reduction process	Yes	Yes
115	FBgn0035244	38193	ABCB7	transporter activity ATP binding mitochondrial inner membrane heme transporter activity heme transport integral to membrane iron-sulfur cluster assembly ATPase activity, coupled to transmembrane movement of substances ATP-binding cassette (ABC) transporter complex transmembrane transport	Yes	Yes
116	FBgn0035344	38311	Cyp4d20	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	Yes	Yes
117	FBgn0035529	38530	CG1319	2 iron, 2 sulfur cluster binding mitochondrial matrix electron carrier activity	No	No

118	FBgn0035600	38612	CG4769	lipid particle electron transporter, transferring electrons within CoQH2-cytochrome c reductase complex activity iron ion binding mitochondrial electron transport, ubiquinol to cytochrome c mitochondrial respiratory chain complex III oxidative phosphorylation heme binding	Yes	Yes
119	FBgn0035790	38840	Cyp316a1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
120	FBgn0035890	38956	CG13667	biological_process iron ion binding NADPH-hemoprotein reductase activity FMN binding oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen, NAD(P)H as one donor, and incorporation of one atom of oxygen oxidoreductase activity oxidation-reduction process cytosol	No	No
121	FBgn0036122	39238	Mocs1	4 iron, 4 sulfur cluster binding Mo-molybdopterin cofactor biosynthetic process molybdopterin synthase complex catalytic activity metal ion binding	Yes	Yes
122	FBgn0036147	39265	CG6199	perinuclear region of cytoplasm L-ascorbic acid binding iron ion binding endoplasmic reticulum procollagen-lysine 5-dioxygenase activity growth of a germarium-derived egg chamber extracellular space oxidation-reduction process	Yes	Yes
123	FBgn0036262	39391	CG6910	inositol catabolic process inositol oxygenase activity cytoplasm iron ion binding oxidation-reduction process	Yes	Yes
124	FBgn0036299	39435	Tsf2	iron ion transmembrane transporter activity extracellular region iron ion transport cellular iron ion homeostasis ferric iron binding septate junction assembly	No	No
125	FBgn0036663	39878	CG9674	glutamate synthase (NADH) activity iron ion binding iron-sulfur cluster binding glutamate biosynthetic process FMN binding glutamate synthase (NADPH) activity flavin adenine dinucleotide binding oxidation-reduction process	Yes	Yes
126	FBgn0036778	40005	Cyp312a1	monooxygenase activity iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding intracellular membrane-bound organelle oxidation-reduction process	No	No
127	FBgn0036793	40023	CG4174	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No
128	FBgn0036795	40025	CG18233	L-ascorbic acid binding iron ion binding endoplasmic reticulum oxidoreductase activity procollagen-proline 4-dioxygenase activity cellular_component oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process multicellular organism reproduction	No	No

129	FBgn0036796	40026	CG18231	L-ascorbic acid binding iron ion binding endoplasmic reticulum procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No
130	FBgn0036806	40037	Cyp12c1	mitochondrion iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	Yes	Yes
131	FBgn0036910	40161	CYP305A1	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
132	FBgn0037011	40282	CG4858	4 iron, 4 sulfur cluster binding iron-sulfur cluster assembly nucleotide binding ATP binding	Yes	Yes
133	FBgn0037385	40726	glob3	oxygen binding iron ion binding oxygen transport heme binding	No	No
134	FBgn0037601	41019	Cyp313b1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	No	No
135	FBgn0037637	41059	CG9836	iron-sulfur cluster binding iron-sulfur cluster assembly iron ion binding	Yes	Yes
136	FBgn0037816	41271	CG6345	4 iron, 4 sulfur cluster binding RNA modification regulation of cyclin-dependent protein serine/threonine kinase activity transferase activity	Yes	Yes
137	FBgn0037817	41272	Cyp12e1	mitochondrion iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	Yes	Yes
138	FBgn0037862	41326	CG4706	mitochondrion tricarboxylic acid cycle 4 iron, 4 sulfur cluster binding aconitase hydratase activity extracellular space multicellular organism reproduction	No	No
139	FBgn0038005	41486	Cyp313a5	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
140	FBgn0038006	41487	Cyp313a2	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	Yes	Yes
141	FBgn0038007	41488	Cyp313a3	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	No	No

142	FBgn0038037	41520	Cyp9f2	membrane iron ion binding electron carrier activity wing disc development oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding intracellular membrane-bound organelle oxidation-reduction process	Yes	Yes
143	FBgn0038076	41563	Cyp313a4	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
144	FBgn0038095	41586	Cyp304a1	membrane iron ion binding insecticide metabolic process electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	No	No
145	FBgn0038194	41706	Cyp6d5	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
146	FBgn0038236	41759	Cyp313a1	membrane iron ion binding insecticide metabolic process electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	Yes	Yes
147	FBgn0038347	41894	CG18522	iron ion binding 2 iron, 2 sulfur cluster binding flavin adenine dinucleotide binding oxidoreductase activity, acting on CH-OH group of donors electron carrier activity oxidation-reduction process	Yes	Yes
148	FBgn0038348	41895	CG18519	iron ion binding 2 iron, 2 sulfur cluster binding flavin adenine dinucleotide binding oxidoreductase activity, acting on CH-OH group of donors electron carrier activity oxidation-reduction process	Yes	Yes
149	FBgn0038349	41896	CG6045	iron ion binding 2 iron, 2 sulfur cluster binding xanthine dehydrogenase activity flavin adenine dinucleotide binding electron carrier activity oxidoreductase activity, acting on CH-OH group of donors oxidation-reduction process	Yes	Yes
150	FBgn0038350	41897	CG18516	iron ion binding 2 iron, 2 sulfur cluster binding flavin adenine dinucleotide binding electron carrier activity oxidoreductase activity, acting on CH-OH group of donors oxidation-reduction process	Yes	Yes
151	FBgn0038680	42293	Cyp12a5	mitochondrion iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process	Yes	Yes
152	FBgn0038681	42294	Cyp12a4	mitochondrion iron ion binding electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	Yes	Yes

153	FBgn0038795	42421	CG4335	trimethyllysine dioxygenase activity gamma-butyrobetaine dioxygenase activity L-ascorbic acid binding iron ion binding carnitine biosynthetic process oxidation-reduction process	Yes	Yes
154	FBgn0039006	42682	Cyp6d4	chaeta development membrane iron ion binding electron carrier activity wing disc development oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	Yes	Yes
155	FBgn0039205	42926	CG13623	iron-sulfur cluster binding iron-sulfur cluster assembly structural molecule activity lateral inhibition	Yes	Yes
156	FBgn0039387	43134	CG5959	ferroxidase activity copper ion homeostasis copper ion binding iron ion transmembrane transporter activity L-ascorbate oxidase activity oxidation-reduction process	Yes	Yes
157	FBgn0039519	43304	Cyp6a18	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	No	No
158	FBgn0039561	43353	mfrn	mitochondrion mitochondrial iron ion transport transmembrane transporter activity mitochondrial inner membrane iron ion transmembrane transporter activity spermid differentiation mitochondrial envelope transmembrane transport	Yes	Yes
159	FBgn0039651	43457	CG14508	electron transporter, transferring electrons within CoQH2-cytochrome c reductase complex activity iron ion binding mitochondrial electron transport, ubiquinol to cytochrome c mitochondrial respiratory chain complex III oxidative phosphorylation heme binding	No	No
160	FBgn0039669	43477	cg2014	NADH dehydrogenase activity quinone binding 4 iron, 4 sulfur cluster binding mitochondrial respiratory chain complex I mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity	No	No
161	FBgn0039776	43620	PH4alphaE8B	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	Yes	Yes
162	FBgn0039779	43623	PH4alphaSG2	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen salivary gland morphogenesis oxidation-reduction process	No	No
163	FBgn0039780	43625	PH4alphaNE1	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	Yes	Yes

164	FBgn0039782	43627	CG15539	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No
165	FBgn0039783	43628	PH4alphaNE2	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen extracellular space oxidation-reduction process multicellular organism reproduction	No	No
166	FBgn0039784	43629	CG9698	procollagen-proline 4-dioxygenase activity iron ion binding endoplasmic reticulum procollagen-proline 4-dioxygenase complex oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen peptidyl-proline hydroxylation to 4-hydroxy-L-proline L-ascorbic acid binding oxidation-reduction process	Yes	Yes
167	FBgn0040528	50001	CG15864	L-ascorbic acid binding iron ion binding endoplasmic reticulum procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No
168	FBgn0041337	33439	Cyp309a2	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bounded organelle	Yes	Yes
169	FBgn0042182	3771984	CG18749	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity extracellular region oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen multicellular organism reproduction oxidation-reduction process	Yes	Yes
170	FBgn0042189	59227	CG17376	iron-sulfur cluster binding	No	No
171	FBgn0050489	246648	Cyp12d1-p	mitochondrion iron ion binding response to DDT electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	Yes	Yes
172	FBgn0050502	35670	CG30502	sphingolipid metabolic process iron ion binding endoplasmic reticulum fatty acid biosynthetic process fatty acid in-chain hydroxylase activity heme binding oxidation-reduction process	No	No
173	FBgn0051013	326111	CG31013	L-ascorbic acid binding iron ion binding endoplasmic reticulum procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No

174	FBgn0051014	326112	PH4alphaSG1	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen salivary gland morphogenesis oxidation-reduction process	No	No
175	FBgn0051015	43640	PH4alphaPV	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No
176	FBgn0051016	326113	CG31016	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process multicellular organism reproduction	No	No
177	FBgn0051017	326114	PH4alphaNE3	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No
178	FBgn0051065	318575	CG31065	iron-sulfur cluster binding sodium channel activity integral component of membrane sodium ion transport	No	No
179	FBgn0051278	41282	CG31278	iron ion binding peptide deformylase activity	Yes	Yes
180	FBgn0051373	318700	CG31373	iron ion binding peptide deformylase activity	No	No
181	FBgn0051524	318781	CG31524	L-ascorbic acid binding iron ion binding endoplasmic reticulum procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No
182	FBgn0052068	326189	CG32068	L-methionine salvage from methylthioadenosine acireductone dioxygenase [iron(II)-requiring] activity oxidation-reduction process	Yes	Yes
183	FBgn0052199	40028	CG32199	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	No	No
184	FBgn0052201	317911	CG32201	procollagen-proline 4-dioxygenase activity iron ion binding procollagen-proline 4-dioxygenase complex oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen peptidyl-proline hydroxylation to 4-hydroxy-L-proline L-ascorbic acid binding oxidation-reduction process	No	No
185	FBgn0052500	2768879	CG32500	ATP-dependent helicase activity cytoplasm iron-sulfur cluster binding iron ion binding iron-sulfur cluster assembly nucleic acid binding ATP binding	Yes	Yes
186	FBgn0052857	318252	CG32857	ATP-dependent helicase activity cytoplasm iron-sulfur cluster assembly iron-sulfur cluster binding iron ion binding nucleic acid binding ATP binding	Yes	Yes

187	FBgn0053196	318824	dp	endonuclease activity serine-type endopeptidase inhibitor activity calcium ion binding proteinaceous extracellular matrix open tracheal system development apposition of dorsal and ventral imaginal disc-derived wing surfaces chitin-based embryonic cuticle biosynthetic process chitin-based cuticle attachment to epithelium lateral inhibition 4 iron, 4 sulfur cluster binding	Yes	Yes
188	FBgn0053502	2768875	CG33502	ATP-dependent helicase activity molecular_function biological_process cytoplasm iron ion binding iron-sulfur cluster binding iron-sulfur cluster assembly cellular_component nucleic acid binding ATP binding	Yes	Yes
189	FBgn0053503	2768720	Cyp12d1-d	mitochondrion iron ion binding response to DDT electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	Yes	Yes
190	FBgn0062442	43459	cgl458	molecular_function biological_process 2 iron, 2 sulfur cluster binding cellular_component intracellular membrane-bounded organelle	Yes	Yes
191	FBgn0085374	5740402	CG34345	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline lateral inhibition procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	Yes	Yes
192	FBgn0086357	33905	Sec61alpha	rough endoplasmic reticulum cell death Sec61 translocon complex cuticle development SRP-dependent cotranslational protein targeting to membrane, translocation positive regulation of iron ion transmembrane transport dorsal closure positive regulation of viral entry into host cell head involution neuron projection morphogenesis protein transporter activity fusome negative regulation of autophagy cellular response to virus positive regulation of cell death	No	No
193	FBgn0086450	31858	su(r)	dihydroorotate oxidase activity dihydrouracil dehydrogenase (NAD ⁺) activity cytoplasm 'de novo' pyrimidine base biosynthetic process UMP biosynthetic process electron carrier activity dihydropyrimidine dehydrogenase (NADP ⁺) activity dihydropyrimidine dehydrogenase (NADP ⁺) activity iron-sulfur cluster binding oxidation-reduction process	Yes	Yes
194	FBgn0086689	40633	Hph	peptidyl-proline 4-dioxygenase activity response to hypoxia peptidyl-proline dioxygenase activity L-ascorbic acid binding iron ion binding positive regulation of cell growth cellular response to hypoxia peptidyl-proline hydroxylation cellular response to DNA damage stimulus protein localization protein export from nucleus peptidyl-proline hydroxylation to 4-hydroxy-L-proline trachea morphogenesis nucleoplasm terminal branching, open tracheal system oxidation-reduction process	No	No

195	FBgn0086706	39027	pix	ATP binding cytoplasm mitochondrion eukaryotic translation initiation factor 3 complex translation translational initiation ribonuclease inhibitor activity electron carrier activity cell growth mRNA metabolic process ATPase activity growth ribosomal small subunit binding negative regulation of neuron apoptosis iron-sulfur cluster binding	Yes	Yes
196	FBgn0086907	34995	Cyt-c-d	mitochondrion electron transporter, transferring electrons from CoQH2-cytochrome c reductase complex and cytochrome c oxidase complex activity iron ion binding activation of cysteine-type endopeptidase activity involved in apoptotic process mitochondrial matrix mitochondrial inner membrane sperm individualization electron carrier activity regulation of compound eye retinal cell programmed cell death oxidative phosphorylation heme binding	No	No
197	FBgn0086917	5740359	spok	iron ion binding ecdysone biosynthetic process molting cycle, chitin-based cuticle oxidoreductase activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen cellular_component oxidation-reduction process heme binding	Yes	Yes
198	FBgn0250846	40807	gloB2	iron ion binding oxygen binding heme binding oxygen transport	No	No
199	FBgn0259697	5740633	nvd	metamorphosis multicellular organism growth instar larval development 2 iron, 2 sulfur cluster binding ecdysteroid biosynthetic process oxidoreductase activity oxidation-reduction process	Yes	Yes

Supplementary Table 2: 132 protein candidates for the magnetoreceptor with head specific expression from the second round of screening. We compared the mean expression level in head (headMean) or brain (brainMean) or eyes (eyeMean) with the total expression mean value (flyMean) for all 199 iron-containing (binding) proteins, and 132 proteins with at least one value (headMean, or brainMean, or eyeMean) higher than (colored in yellow background) total mean expression (flyMean) were picked out in this round and are shown in the table. Candidates picked out for the next (third) round of screening have a white background, others have a gray background.

Number	Flybase_Gene_ID	FlyAtlas_hits	oligo	flyMe an	brain Mean	headMe an	eyeMean	tagMe an	sgMe an	cropMea n	midgut Mean	tubule Mean	hindgut Mean	heart Mean	fatbody Mean	ovary Mean	testis Mean	accMe an	v_spt Mean	m_spt Mean	carMea n	l_CNS Mean	l_sg Mean	l_midgut Mean	l_tubule Mean	l_hindgutM ean	l_fat Mean	l_tra Mean	l_car Mean	1S2Me an	Predicted Transmembrane Protein	Used for the 3rd Screen	
1	FBgn0000406	1	1632623_at	856.8	146	2635.3	1981.175	123.3	20.3	64.2	41.8	242.7	441.3	4124.9	5125.6	4.1	7.1	3.2	5086.7	4644.7	4043.2	1.125	31.6	406.2	654.3	172.1	1007.1	49.825	24	1.25	Yes	No	
2	FBgn0000409	1	1641049_at	2732.3	2817.3	2437	2525.675	3788.1	2981	2579.6	2640.3	3496.1	4139.4	3383.3	3065	1650.7	293.6	714.1	2354.1	2442	5673.4	1625.78	1616	2516.9	470.8	2691.8	199.1	1323.9	2123	2565.7	No	Yes	
3	FBgn0000473	1	1626401_at	38.1	47.7	146.6	24.275	20.5	5.8	70.7	45.7	499.7	204.9	14.15	3.9	2.2	2.5	3.4	3	90.7	2.875	2.6	10.9	33.5	5.6	9.1	0.875	1.1	1.375	No	Yes		
4	FBgn0001208	1	1638325_at	407.3	37.8	2438.2	1792.35	41.2	11.6	33.4	2.9	32.5	105.6	1324.2	2985.7	3.6	163.4	2.6	2908.6	2022.7	2151.2	1.175	62.1	4.5	7.6	39	5662	72.925	518.25	2.1	No	Yes	
5	FBgn0001977	2	1634344_at	17.7	29.8	21.5	20.675	32.7	13.1	24.4	26.7	52	22.9	27.2	27.5	9.5	11.8	20.4	22.4	21.5	34.9	32.65	17.3	20.5	69.4	24.4	36.7	30.675	42.8	45.85	No	Yes	
6	FBgn0001992	1	1628551_at	1.5	3.9	2.6	0.525	0.8	8.1	1.8	1	1.5	2.6	1.1	1.8	1.2	1.1	6.9	0.7	1.6	3.7	2.05	1.9	2	3.6	1.3	3.3	2.075	0.975	1.925	Yes	No	
7	FBgn0003308	1	1638882_at	41.1	80.7	142.3	100.2	62.7	146.1	98.7	97.6	770.2	49.1	128.25	232.3	2.6	18.3	7.4	328.1	221.4	131.3	38.35	46.4	21.9	287	28.8	167.1	99.425	89.3	61.725	No	Yes	
8	FBgn0003388	2	1635002_at	6	5.9	8.5	5.35	5.4	14.1	2.5	9.5	5.5	7.8	1.475	7.6	3.2	3	9.1	4.4	4	7.6	3.025	2.8	39.8	76.4	20	100	1.25	35.75	6.2	No	Yes	
9	FBgn0004577	2	1623410_at	1.5	0.4	0.5	3.35	2.6	19.7	2.2	0.7	1.4	2	3.825	3.1	0.5	0.9	1.9	2.1	1.7	2.8	1.55	2.7	0.7	2.7	205.9	1.7	115.75	2105.4	1.9	Yes	No	
10	FBgn0005626	1	1624452_at	4.7	123.3	38.7	3.775	48.5	1	1.6	3.7	2.2	4	1.675	3.7	2.1	0.2	5.2	3.1	3.3	24.6	2.5	2.2	2.5	2	0.8	1.45	10.75	2.4	No	Yes		
11	FBgn0005670	1	1629875_at	72.3	2.1	112.9	95.45	1.4	2	1.4	865.3	1.9	4.9	153.68	302.2	0.7	1.4	1.3	284.2	329.9	99.5	0.4	120.7	1114.1	13.5	121.5	4712.6	38.175	25.45	0.75	Yes	No	
12	FBgn0010100	1	1634989_at	2232.9	2071.4	2481.1	1398.575	2350.6	3341	2124	2606.9	3759.1	2998.4	1976.3	2447.7	145.8	849.6	1725	1635.3	5567.3	1086.93	1662	1535.8	3163.2	2635.4	740.5	1257.3	3030.5	901.33	No	Yes		
13	FBgn0010383	2	1641022_at	53	21.9	74.1	51.175	19.6	16	14.4	14.9	15.4	26	97.425	250.6	43.5	5	8.8	301.1	168.7	143.7	11.875	15.6	12.3	8.7	12.2	14.2	167.7	245.58	9.125	Yes	No	
14	FBgn0011576	1	1636793_at	78.3	31.1	217.7	195.675	34.6	71.7	185.8	99.2	231.05	243	213.05	6.2	28.5	65.7	66.7	22.9	19.7	196.7	289.2	10.35	20	542.1	405.2	105	512.5	16.375	22.4	17.7	Yes	No
15	FBgn0011676	1	1625574_at	8.6	377.1	57.7	9.025	184.6	9.3	2.7	3.4	6.8	3.575	6	4	30	4.9	3	2.9	2	50.55	3.5	1.7	3	1.6	3.1	1.525	3	11.55	No	Yes		
16	FBgn0011769	1	1627945_at	96.2	180.2	100.2	83.775	196	95.2	119.8	113.6	151.1	156.2	75.025	108.7	112.4	99.6	74.6	84.5	100.8	131.05	136.1	78.9	86.5	154.2	52.2	112.8	99.2	149.8	No	Yes		
17	FBgn0013771	1	1628345_at	58.9	35.9	87.4	20.35	35.4	103	218.8	200.3	304.3	227.3	42.825	114.3	49.8	14.4	28.9	188.3	172.6	53.9	14.825	14	115.9	52.8	200.5	11.9	57.15	12	40.8	Yes	No	
18	FBgn0013772	1	1640755_at	110	9.7	260.3	136.575	6.3	7.6	2613.5	59.3	3140.8	858	199.25	339.9	4.7	6.2	5.6	183	63.1	312.7	2.225	7.1	27.8	667.3	57.9	39.3	5.95	6.3	48.125	Yes	No	
19	FBgn0014028	1	1640632_at	1148.3	1075.9	1236.6	1129.075	1265.1	1369	942.9	926.5	979	1856.4	1187	829.6	395.6	80.4	462.5	728	3170	500.55	594.5	1440.3	765.4	1507.6	272.3	273	707.53	1253.9	816.48	No	Yes	
20	FBgn0014469	1	1627844_at	602.7	57.9	133.4	471.65	55.1	252.7	2473	771.1	1426.9	1367.7	1826.9	2101.6	500.6	30.9	842.3	2373.9	1645.1	1344.5	10.475	245	775.9	252.5	457.8	3261.3	94.55	311.65	268.1	Yes	No	
21	FBgn0015032	1	1636716_at	11.3	3.4	31.9	69.25	7.1	5.8	107.3	4.4	3.9	82.9	2.675	10.5	0.9	14.4	1.6	4.8	7.1	10.2	1.625	7.5	5.5	6.2	83.3	7.3	62.875	96.925	1.3	No	Yes	
22	FBgn0015033	1	1626198_at	42.4	4.9	119.5	59.575	4.7	13	10.2	247.8	168.8	43.8	98.825	29.3	6.4	39.5	155.6	37.5	26.2	89.3	4.4	9.9	656.1	34	13.5	48.7	6.775	10.675	3.175	No	Yes	
23	FBgn0015034	1	1639539_at	78.4	2.8	138.5	150.775	2.9	3.6	63.9	19.7	326.2	115.6	411.4	426.2	2.2	2.9	1098.6	30.6	14.7	377.2	6.5	1.7	3.9	24.6	10.6	7.4	17.675	91.275	0.55	Yes	No	
24	FBgn0015035	1	1623068_at	80.9	3.3	377.1	406.55	4.3	10	129	22.9	825.4	40	192.55	720.3	2.6	2.1	182.2	142.7	41.2	458.5	2.275	9.8	20.4	47.7	14.5	131.2	20.975	272.98	1.725	No	Yes	
25	FBgn0015037	1	1638053_at	416.1	23.3	2122.3	95.1	251.2	25.8	55.3	128.4	1671.7	3362.7	1384.9	609.88	1374	4.3	106.8	255.1	804.9	165.6	140.5	2.025	21	1315.4	1746.9	850.9	1198.8	36.375	203.03	27.875	No	Yes
26	FBgn0015038	1	1639495_at	37.1	7.9	164.7	73.625	6.5	10.2	273.5	130.1	11.9	134.4	72.675	167.1	1.3	2.1	5.8	80.9	96.9	99.4	3.4	17.4	58	65.1	91.1	9.05	7.95	1.75	No	Yes		
27	FBgn0015039	1	1635008_at	361.2	35.6	954.3	284.3	33.3	275.3	4104.9	1430.5	479.5	1347.1	249.3	455.5	37.5	51.1	53.4	54.5	351.6	973.7	7.55	106.2	1670.7	2148.8	510.1	1031.1	25.05	59.375	5.95	No	Yes	
28	FBgn0015040	1	1641428_at	71.7	52	138.4	63.725	26.7	245	260.9	188.7	413.3	377.7	286.5	111.8	14.7	13.8	916.5	230.9	205.2	123	142.775	396.1	542.3	464.7	795.1	10.51	983.13	357	607.7	Yes	No	
29	FBgn0015221	1	1636186_s_at	2342.2	2438.2	3010.3	4363.175	3016.5	3319	2310.3	5072.4	4347.9	2889.9	6964.9	4851.5	1411.5	2117.4	2434.1	4927.5	4609.6	4625.3	1957.05	1535	5224.9	9404.8	2234.7	3266	2197.5	1682	67.175	No	Yes	
30	FBgn0015222	1	1630334_s_at	2599.9	2715.4	3110.5	5038.48	3491.7	2921	2707.3	5718.6	6279.5	3147.2	6880.2	4995.5	1679.5	3126.2	2240.5	5512	5546.5	5393.6	2253.08	1354	5580.8	4310.9	2792.7	4238.1	3091.3	2416.6	3674.2	No	Yes	
31	FBgn0015714	1	1628052_at	59	123.1	154.4	275.375	79.7	18.6	29.5	143.9	59.4	408.7	31.5	41.5	16.1	6	4.9	68.6	56.3	63.9	50.2	8.55	6.5	20.6	60.4	132.1	37.9	47.7	3.425	435	No	Yes
32	FBgn0017566	1	1638593_s_at	525.3	752	673.7	794.2	955.7	936	475.4	350	941.5	838.9	698.98	786.1	199.7	224.7	339.4	531.8	462.5	1805.1	296.95	466.9	527.3	269.4	844.2	177.1	215.05	579.48	288.25	No	Yes	
33	FBgn0017567	1	1627220_at	1642.3	1819	1683.5	2040.125	2418.1	1789	1276.2	1467.7	1604.6	2235.9	1944.7	1484	835.9	664.3	1064.6	1291.2	1276.1	1306.5	3867.125	1123	1148.5	712.7	1489.2	653.8	819.6	1273.6	686.3	No	Yes	
34	FBgn0021906	2	1631856_s_at	1002.8	956.8	1134.1	1184.326	1407.1	1962	1045.8	123.3	364.2	169.8	127.7	1157.9	474.																	

64	FBgn0032603	1	1641108_at	82.8	47.2	422.2	287.55	62.7	137.9	11.1	108.8	134.1	39.7	285.95	303.9	7.8	10.8	21.8	276	202.2	576	6.1	8.7	73	58.9	22.6	108.5	17.7	49.625	9.5	No	Yes			
65	FBgn003065	1	1634143_at	242.8	274.6	1436.8	505.225	384.2	17	76.4	16	31.7	171.8	2029.3	2831.2	2.4	13.2	5.9	2686.3	2347.9	2088.4	6.775	16.8	209.5	10.2	11.9	18.9	54.875	26.25	8.15	No	Yes			
66	FBgn003121	1	1633008_at	123.2	141.5	108.5	91.525	176.8	55.8	118.6	116.6	150.1	136.4	110.9	117.8	259.8	88.2	46.7	124.7	146.9	129.4	108.85	49	195.1	230.9	115.4	112.4	87.225	101.98	118.63	Yes	No			
67	FBgn0033304	1	1635110_at	93.9	192.8	248.6	145.8	323.2	275.7	147.6	303.4	406.1	227.3	396.58	218	34.1	28.4	365.5	239.1	246.7	229	29.8	110.7	850.7	1018.5	552.1	213.2	290.98	140.35	13.225	No	Yes			
68	FBgn0033395	1	1640566_at	9.9	2.5	10.8	1.1	2.2	8.3	4.3	63.7	13.3	26.3	2.175	7.7	1.9	1.5	17.5	5.5	7	4.2	4.075	3	2.1	10.9	4	5.9	3.25	6.225	6.675	Yes	No			
69	FBgn0033397	1	1634731_at	68.2	0.5	41.4	100.225	1.8	8.1	49.9	4.4	1264.5	35.4	35.8	110.9	5.3	106	5569.5	114.1	164.5	60.6	1.75	2.4	25.4	496.9	68.2	27.6	14.925	60.75	10.5	Yes	No			
70	FBgn0033696	1	1633060_at	10.3	98.6	85	1.175	14.1	5.4	5.9	10.9	2.9	3.9	1.4	4.8	0.9	3.8	3.8	3	2.7	7.2	12.725	3.6	4.9	2	4	12.6	3.85	6.225	9.9	Yes	No			
71	FBgn0033697	1	1627974_at	9.3	3.5	77.5	15.8	1.9	6.2	5.2	1.9	1.8	9.4	5.775	20.1	3.6	0.5	4	11.9	10.5	17.2	2.95	4.5	1.3	4.7	2.7	21.1	3.95	4.4	1.375	No	Yes			
72	FBgn0033753	1	1634139_at	10.7	12.7	11.5	8.4	10	14.5	8	8.2	6.8	471.1	5.175	4.9	1.4	1.8	1.9	5.4	3.7	11.7	9.325	8.6	11.6	2.5	230.9	4.1	226	23.575	2.375	No	Yes			
73	FBgn0033757	1	1624159_at	20.6	66.7	80.4	34.5	109.7	15.9	11.2	166.6	11.9	84.1	33.05	60.9	2.9	3.1	6.3	74.5	32.9	66.3	40.625	11.1	67.2	29.4	284.5	308.4	5.35	21.775	7.5	No	Yes			
74	FBgn0033972	1	1639968_at	228.4	221.9	248.2	268.15	230.3	81.8	573.1	237	756.5	387.2	466.95	354.1	291	142.2	658.8	398	460.8	331.5	278.625	522	220.2	631.5	367.9	321.8	476.5	317.88	259.05	No	Yes			
75	FBgn0033980	1	1632021_at	158.3	166.4	593.2	616.575	356.0	161.9	524.8	348.5	433.5	596.2	536.73	221.7	19	24.6	62.5	174.2	175.4	823.8	21.925	7.1	28.8	23.7	62.7	6.4	13.675	16.96	245.05	Yes	No			
76	FBgn0033981	1	1624939_at	50.5	2.5	113.7	48.975	5.2	15.6	18	951.4	251	232.4	17.975	54.4	1.4	5.6	7.8	37.5	19.2	126.6	2.4	2.7	499.5	148.3	98	233	6.575	58.225	3.825	No	Yes			
77	FBgn0033982	1	1626905_at	13.3	5.3	13.4	6.2	2.3	4.9	34.3	35.5	30.8	78.6	4.025	5.1	3.6	3	4.3	1.2	5	13.9	0.7	1.2	64.9	43.8	36.8	2.5	14.075	1.975	10.575	Yes	No			
78	FBgn0034094	1	1633017_at	23	4.1	95.8	109.15	7.4	13.7	208.7	7.6	12.6	128.2	396.4	99.6	4	22.3	1.9	58.4	117.3	95.3	5.525	27.9	15.2	16.9	166.6	114.7	2.7	100.48	86.5	No	Yes			
79	FBgn0034364	1	1627912_at	57.6	13.2	537.6	168.975	14.5	12.4	8	5.6	121.43	77.5	1.8	12.5	1.3	137.1	39.6	132.3	1.425	52	4.5	7.9	10.9	1884.8	5.775	9.725	0.9	No	Yes					
80	FBgn0034387	1	1630170_at	50.7	173.5	191.3	117.575	257.7	129.3	160.3	73.4	76.4	105.9	99.225	214.4	3.3	13	41.9	130.1	202.8	229.9	36	17.8	53.6	103.1	83.2	11.7	16.4	74.675	20.8	No	Yes			
81	FBgn0034756	1	1635593_at	24.6	7.6	35.8	15.85	6.3	179.4	12.5	67.4	87.9	58.8	92.325	85	18.8	14.2	58.9	127	117.3	50.9	9.1	254.3	22.4	458.8	68.6	1185	123.33	27.825	22.025	No	Yes			
82	FBgn0035187	1	1624616_at	10.4	109.1	38.2	6.375	100.4	5.1	2.6	4.3	4.9	2.8	6.925	12.4	1	2.1	7.4	9.7	11.4	8.6	81.325	9.3	7.8	4	0.7	11	3.975	6.35	1.35	No	Yes			
83	FBgn0035244	1	1638547_s_at	80.7	133.6	88	104.625	184	284.6	118.1	159.2	337.2	101.7	200.9	255.2	123	79.5	80.8	240.1	222.3	106.1	106.925	133	180.9	106.9	168	44	74.15	196.83	187.75	Yes	No			
84	FBgn0035344	1	1625338_at	57.2	6.6	263.6	193.125	4.8	4.8	10.9	8.7	7.4	10.4	409.95	509.8	0.8	1.5	4.2	354.5	346.7	285.7	1.15	3.9	3.4	10.5	2.3	3.2	83.875	33.725	3.3	No	Yes			
85	FBgn0035600	1	1625412_at	219.6	9	231.5	6	264.0	289.2	975	292.8	3644	2681.8	1755.2	3576.7	3615.6	3429.3	2889.3	1117.1	122.5	1160	3495.4	3372	4884.3	1303.88	1328	1788.4	1032.3	2554	558.9	132.1	2898.9	945.98	No	Yes
86	FBgn0035690	1	1634540_at	1.9	2.4	2.5	1.825	3.5	10.5	6.6	4.6	6	3.8	3.9	4.7	1.2	7.5	5.2	2.8	2.7	7.4	2.65	3.2	8.1	4.3	3.9	6.6	0.6	2.675	3.025	No	Yes			
87	FBgn0036122	1	1631994_a_at	38.1	59.2	88.1	35.9	85.5	29.6	64.8	146.9	88.9	23.5	26.95	33.8	60	15.3	49.5	8	31.1	48.7	38.75	25	38	25.7	46.3	46.7	85.75	54.875	81.025	No	Yes			
88	FBgn0036147	1	1625588_s_at	148.5	200.9	94.1	83.875	189.7	50.3	45.2	23.8	40.4	107.6	266.98	398.4	207.9	21.8	28.9	4	461	330.4	180.2	247.95	42.2	17.1	82	92.5	503.2	88.7	346.08	545.55	No	Yes		
89	FBgn0036262	1	1639424_at	403.2	191.2	881.5	190.05	388.7	33.5	100.5	9.6	59.6	189.1	2221.4	2741	7.2	17.8	12.7	4562	4042.9	1334.3	8.625	18.2	8.5	4.9	20	671.9	15.675	55.35	0.425	No	Yes			
90	FBgn0036663	1	1629048_s_at	207.5	1295.6	878	1957.325	1700.4	692.2	512.2	150.2	48.2	498.2	416.18	133.4	54	70.5	904.8	130.2	100.8	239.7	66.135	97.4	273.2	225	143.7	232.5	349.53	248.35	No	Yes				
91	FBgn0036806	1	1624953_at	71.7	24.7	179.4	56.4	27.4	430.3	36.1	67.84	293.7	357.5	1.8	5.3	100.7	308.4	336.8	224.4	4.6	60.5	409.2	358.3	156.3	87.1	11.6	25.175	41.4	No	Yes					
92	FBgn0036910	1	1628584_at	81.7	122.8	31.4	110.225	111.7	20.8	2.4	51.6	15.7	17.2	46.6	28.8	17.2	49.6	26.8	18.4	59.3	579.9	307.8	38.2	8.7	43	5.8	47.8	27	75.05	0.9	17.175	No	Yes		
93	FBgn0037011	1	1625315_at	217	12.9	296.4	459.9	19.6	493.6	310.6	510.4	310.3	389.5	19.4	55.5	392.1	447.1	498.8	322.6	217.975	355.4	222.8	504	235	556.1	384.45	254.8	378.95	No	Yes					
94	FBgn0037637	1	1624966_at	868.4	1705.4	1393.9	1239.7	2832.5	1104	746.3	1062.1	1722.1	1052.2	1138.2	874	280.1	401.6	645.9	1120.6	1098.4	2504.8	495.3	370.7	691.6	635.7	721.3	389.8	452.63	539.68	562.9	No	Yes			
95	FBgn0037816	1	1628790_at	3.7	2.7	3.8	1.325	1.7	7.4	4.2	3.1	2	2.5	5.375	5.2	4.2	3.2	11.4	3.5	5.2	8.5	8	9.6	5.6	3	3.5	5	8.3	6.55	4.2	No	Yes			
96	FBgn0037817	2	1637309_a_at	46.2	144.4	147.1	87.5	249.4	122.2	177.7	152.5	151.4	94.3	262.6	288.9	6.8	14	32.8	273.5	222.3	178.8	278.8	430.6	365.6	370.2	187.4	542.8	569.78	391.98	181.73	No	Yes			
97	FBgn0038005	1	1623795_at	4.9	5.7	4.1	6.35	9.1	7.9	6.9	6.1	7.2	4.9	2.475	8.4	1.4	5.4	8.1	4.1	6.1	17.3	9.325	4	8	2.7	1.3	8.6	37.45	11.4	6.525	No	Yes			
98	FBgn0038006	1	1623727_at	2.8	2.9	5.4	3.25	2.9	12.3	3.8	6.3	2.2	2.9	5.775	4.8	2.6	1.1	5	1.2	1.1	7.6	1.15	3.7	5.4	2.6	1.4	1.9	3.65	2.175	2.95	No	Yes			
99	FBgn0038037	1	1639944_at	426	918.4	1219.9	1475.6																												

Supplementary Table 3: 98 non-membrane protein candidates for the magnetoreceptor from the third round of screening. We analyzed all 98 candidates using literature searches and bioinformatics studies, and carefully selected 14 (white backgrounds) for the next (fourth) round of screening.

Number	Flybase Gene ID	Gene ID	Official Symbol	GO Term	Notes	Used for the 4th Screen?
1	FBgn0000409	34996	Cyt-c-p	mitochondrion electron transporter, transferring electrons from CoQH2-cytochrome c reductase complex and cytochrome c oxidase complex activity iron ion binding mitochondrial matrix mitochondrial inner membrane electron carrier activity heme binding oxidative phosphorylation	Well studied Cytochrome, The possibility of involvement in magnetoreception is low	No
2	FBgn0000473	35587	Cyp6a2	response to caffeine membrane iron ion binding electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bounded organelle oxidation-reduction process heme binding	Well studied Cytochrome, The possibility of involvement in magnetoreception is low	No
3	FBgn0001208	38871	HN	phenylalanine 4-monoxygenase activity tryptophan 5-monoxygenase activity iron ion binding lipid particle L-phenylalanine catabolic process eye pigment biosynthetic process phagocytosis, engulfment oxidation-reduction process	Iron ion binding protein. Phenylalanine and tyrosine catabolism. Unlikely to get involved in magnetoreception pathway.	No
4	FBgn0001977	49424	1(2)35Bg	2 iron, 2 sulfur cluster binding electron carrier activity metal ion binding apoptotic process iron-sulfur cluster assembly negative regulation of apoptotic process ovarian follicle cell development	Expression in head is relatively low	No
5	FBgn0003308	41605	ry	xanthine dehydrogenase activity xanthine oxidase activity iron ion binding peroxisome microtubule associated complex purine base metabolic process pyrimidine base metabolic process arginine metabolic process tryptophan metabolic process glycerophospholipid metabolic process determination of adult lifespan UDP-N-acetylglucosamine dehydrogenase activity electron carrier activity molybdopterin cofactor binding compound eye pigmentation flavin adenine dinucleotide binding 2 iron, 2 sulfur cluster binding oxidation-reduction process	1335 amino acids. Key enzyme in purine degradation. Catalyzes the oxidation of hypoxanthine to xanthine. Unlikely to get involved in magnetoreception pathway.	No
6	FBgn0003388	39592	Shd	border follicle cell migration iron ion binding dorsal closure electron carrier activity growth of a gerarium-derived egg chamber central nervous system development ecdysone 20-monoxygenase activity mitochondrion membrane head involution midgut development ecdysteroid biosynthetic process oxidation-reduction process heme binding	Expression in head is relatively low	No

7	FBgn0005626	38746	PLE	tyrosine 3-monooxygenase activity iron ion binding cellular_component catecholamine metabolic process courtship behavior male courtship behavior adult locomotory behavior aromatic amino acid family metabolic process wing disc development thermosensory behavior regulation of dopamine metabolic process dopamine biosynthetic process dopamine metabolic process thermotaxis developmental pigmentation cuticle pigmentation regulation of adult chitin-containing cuticle pigmentation adult chitin-containing cuticle pigmentation oxidation-reduction process regulation of epithelial cell migration, open tracheal system	not Fe-S Cluster	
8	FBgn0010100	44149	acoN	mitochondrion lipid particle tricarboxylic acid cycle 4 iron, 4 sulfur cluster binding aconitate hydratase activity	Iron sensor and aconitate hydratase	
9	FBgn0011676	34495	Nos	FMN binding NADP binding NADPH-hemoprotein reductase activity calmodulin binding flavin adenine dinucleotide binding heme binding iron ion binding nitric-oxide synthase activity imaginal disc development negative regulation of DNA replication negative regulation of cell proliferation nervous system development nitric oxide biosynthetic process nitric oxide mediated signal transduction positive regulation of guanylate cyclase activity regulation of heart rate regulation of organ growth synapse assembly	Well studied. The possibility of involvement in magnetoreception is low	No
10	FBgn0011769	39070	fdxH	mitochondrion biological_process 2 iron, 2 sulfur cluster binding electron carrier activity	Fe-S cluster binding protein. Electron transport from NADPH to Ferredoxin.	Yes
11	FBgn0014028	35590	SdhB	mitochondrial respiratory chain complex II microtubule associated complex tricarboxylic acid cycle mitochondrial electron transport, succinate to ubiquinone succinate dehydrogenase (ubiquinone) activity electron carrier activity 2 iron, 2 sulfur cluster binding	Well studied in respiratory chain complex II. The possibility of involvement in magnetoreception is low	No
12	FBgn0015032	43663	Cyp4c3	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
13	FBgn0015033	38841	Cyp4d8	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No

14	FBgn0015035	34291	Cyp4e3	lipid particle iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
15	FBgn0015037	45524	Cyp4p1	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
16	FBgn0015038	35634	Cyp9b1	monooxygenase activity iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
17	FBgn0015039	35635	Cyp9b2	monooxygenase activity iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	The cytochrome P450 gene superfamily.	No
18	FBgn0015221	44965	Fer2LCH	intracellular ferritin complex cellular iron ion homeostasis chaeta development hemolymph coagulation locomotor rhythm Golgi apparatus iron ion transport extracellular region ferrous iron binding ferric iron binding less	In Drosophila, Ferritin 1 heavy chain homolog (Fer1HCH) and Ferritin 2 light chain homolog (Fer2LCH) encode the ferritin subunits that compose the major, secreted form of ferritin (C HARLESWORTH et al. 1997; G BORGIEVA et al. 1999, 2002)	No
19	FBgn0015222	46415	Fer1HCH	cellular iron ion homeostasis intracellular ferritin complex Golgi apparatus cell proliferation microtubule associated complex fusome iron ion transport extracellular region post-embryonic development ferrous iron binding ferric iron binding		No
20	FBgn0015714	45556	Cyp6a17	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen thermosensory behavior intracellular membrane-bound organelle oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
21	FBgn0017566	31762	ND75	NADH dehydrogenase activity mitochondrion cellular respiration ATP synthesis coupled electron transport mitochondrial respiratory chain complex I iron-sulfur cluster binding electron carrier activity NADH dehydrogenase (ubiquinone) activity	NADH to ubiquinone, Electron transportation?	Yes
22	FBgn0017567	44207	ND23	NADH dehydrogenase activity mitochondrion 4 iron, 4 sulfur cluster binding mitochondrial respiratory chain complex I mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity	NADH to ubiquinone, Electron transportation?	Yes

23	FBgn0024957	41269	Irp-1B	4 iron, 4 sulfur cluster binding iron ion binding regulation of translational initiation by iron aconitate hydratase activity metabolic process iron-responsive element binding mRNA binding	Iron regulatory protein. mRNA binding make it unlikely to get involved in magnetoreception pathway.	No
24	FBgn0024958	42689	Irp-1A	4 iron, 4 sulfur cluster binding iron ion binding regulation of translational initiation by iron aconitate hydratase activity iron-responsive element binding ventral furrow formation mRNA binding	Iron regulatory protein. mRNA binding make it unlikely to get involved in magnetoreception pathway. It has similar expression level in most organs.	No
25	FBgn0026190	43624	PH4alphaMP	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	Component of prolyl 4-hydroxylase. Expression in head is relatively low. Unlikely to be involved in magnetoreception pathway.	No
26	FBgn0026666	32513	1(1)G0136	iron-sulfur cluster assembly iron-sulfur cluster binding structural molecule activity	Fe-S cluster binding and structural molecule.	Yes
27	FBgn0027657	41930	Glob1	oxygen binding iron ion binding oxygen transporter activity heme binding oxygen transport	Iron (heme axial ligand). Belongs to the globin family.	No
28	FBgn0029158	40259	Las	mitochondrion lipoate biosynthetic process lipoate synthase activity 4 iron, 4 sulfur cluster binding		Yes
29	FBgn0030092	31845	FH	ferroxidase activity mitochondrion cellular iron ion homeostasis axon transport of mitochondrion iron chaperone activity response to hydrogen peroxide regulation of mitochondrial membrane potential oxidation-reduction process		Yes
30	FBgn0030367	32170	Cyp311a1	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is relatively low.	No
31	FBgn0030615	32444	Cyp4s3	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is relatively low.	No
32	FBgn0030718	32565	CG9172	NADH dehydrogenase activity mitochondrial respiratory chain complex I assembly quinone binding 4 iron, 4 sulfur cluster binding mitochondrial respiratory chain complex I mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity response to reactive oxygen species determination of adult lifespan	Fe-S cluster and quinone binding. Electron transportation?	Yes

33	FBgn0030949	32859	Cyp308a1	iron ion binding membrane insecticide metabolic process electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is relatively low.	No
34	FBgn0031694	33755	Cyp4ac2	iron ion binding membrane insecticide catabolic process electron carrier activity hormone metabolic process oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is relatively low.	No
35	FBgn0031771	33852	CG9140	NADH dehydrogenase activity mitochondrial respiratory chain complex I 4 iron, 4 sulfur cluster binding NAD binding FMN binding mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity	High expression level in head. NAD, FMN and Fe-S cluster binding and possible electron transportation?	Yes
36	FBgn0031925	34036	Cyp4d21	monooxygenase activity mating cytoplasm membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
37	FBgn0032116	34258	CG3759	ferroxidase activity cell surface copper ion binding iron ion transmembrane transporter activity basal part of cell iron ion homeostasis intrinsic component of external side of plasma membrane oxidation-reduction process	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is relatively low.	No
38	FBgn0032393	34613	CG12264	mitochondrion cytoplasm iron-sulfur cluster assembly alanine biosynthetic process cysteine metabolic process microtubule associated complex pyridoxal phosphate binding cysteine desulfurase activity cystathione gamma-lyase activity	iron-sulfur cluster assembly and microtubule associated complex?	Yes
39	FBgn0032603	35009	CG17928	iron ion binding lateral inhibition fatty acid biosynthetic process oxidoreductase activity, acting on paired donors, with oxidation of a pair of donors resulting in the reduction of molecular oxygen to two molecules of water heme binding oxidation-reduction process	Cytochrome b5-like heme/steroid binding domain; Fatty acid desaturase. Unlikely to involve in magnetoreception	No
40	FBgn0033065	35543	Cyp6wl	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
41	FBgn0033304	35837	Cyp6a13	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen defense response to bacterium heme binding oxidation-reduction process intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No

42	FBgn0033697	36318	Cyp6t3	iron ion binding membrane regulation of developmental growth ecdysone biosynthetic process electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Expression in head is relatively low.	No
43	FBgn0033753	36378	Cyp301a1	mitochondrion tergite morphogenesis iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process	The cytochrome P450 gene superfamily. Expression in head is relatively low.	No
44	FBgn0033775	36412	Cyp9h1	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle heme binding oxidation-reduction process	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
45	FBgn0033972	36655	CIA01	molecular_function cellular_component iron-sulfur cluster assembly neurogenesis	WD40 repeat. May form a circularised beta-propeller structure. Not favorable to assemble as rod-like structure.	No
46	FBgn0033981	36665	Cyp6a21	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
47	FBgn0034364	37139	CG5493	iron ion binding L-cysteine metabolic process cysteine dioxygenase activity oxidation-reduction process	Degradation of cysteine and homocysteine. Unlikely to involved in magnetoreception pathway.	No
48	FBgn0034387	37163	Cyp12b2	mitochondrion iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
49	FBgn0034756	37594	Cyp6d2	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen response to camptothecin oxidation-reduction process heme binding intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is relatively low.	No
50	FBgn0035187	38121	Trh	phenylalanine 4-monoxygenase activity tryptophan 5-monoxygenase activity tryptophan 5-monoxygenase activity iron ion binding tryptophan metabolic process serotonin biosynthetic process regulation of circadian sleep/wake cycle, sleep oxidation-reduction process	Tryptophan hydroxylase. Unlikely to involved in magnetoreception pathway.	No
51	FBgn0035344	38311	Cyp4d20	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No

52	FBgn0035600	38612	CG4769	lipid particle electron transporter, transferring electrons within CoQH2-cytochrome c reductase complex activity iron ion binding mitochondrial electron transport, ubiquinol to cytochrome c mitochondrial respiratory chain complex III oxidative phosphorylation heme binding	Respiratory electron transport? Heme binding and Iron ion binding.	No
53	FBgn0035790	38840	Cyp316al	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is relatively low.	No
54	FBgn0036122	39238	Mocs1	4 iron, 4 sulfur cluster binding Mo-molybdopterin cofactor biosynthetic process molybdopterin synthase complex catalytic activity metal ion binding	Isoform Mocs1a and isoform Mocs1b probably form a complex that catalyzes the conversion of 5'-GTP to cyclic pyranopterin monophosphate. Expression in head is relatively low.	No
55	FBgn0036147	39265	CG6199	perinuclear region of cytoplasm L-ascorbic acid binding iron ion binding endoplasmic reticulum procollagen-lysine 5-dioxygenase activity growth of a germarium-derived egg chamber extracellular space oxidation-reduction process	ER and extracellular space	No
56	FBgn0036262	39391	CG6910	inositol catabolic process inositol oxygenase activity cytoplasm iron ion binding oxidation-reduction process		Yes
57	FBgn0036663	39878	CG9674	glutamate synthase (NADH) activity iron ion binding glutamate biosynthetic process FMN binding glutamate synthase (NADPH) activity flavin adenine dinucleotide binding oxidation-reduction process	2114 amino acids!!! Iron ion binding.	No
58	FBgn0036806	40037	Cyp12c1	mitochondrion iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
59	FBgn0036910	40161	CYP305A1	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
60	FBgn0037011	40282	CG4858	4 iron, 4 sulfur cluster binding iron-sulfur cluster assembly nucleotide binding ATP binding	NUBP1-NUBP2 heterotetramer. Unlikely to get involved in magnetosensor formation with cryptochrome.	No
61	FBgn0037637	41059	CG9836	iron-sulfur cluster binding iron-sulfur cluster assembly iron ion binding	Iron-sulfur cluster binding. Mitochondrial iron-sulfur cluster biogenesis.	Yes

62	FBgn0037816	41271	CG6345	4 iron, 4 sulfur cluster binding RNA modification regulation of cyclin-dependent protein serine/threonine kinase activity transferase activity	CDK5RAP1-like protein. Expression in head is extremely low.	No
63	FBgn0037817	41272	Cyp12e1	mitochondrion iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
64	FBgn0038005	41486	Cyp313a5	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is extremely low.	No
65	FBgn0038006	41487	Cyp313a2	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen intracellular membrane-bound organelle oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is extremely low.	No
66	FBgn0038037	41520	Cyp9f2	membrane iron ion binding electron carrier activity wing disc development oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding intracellular membrane-bound organelle oxidation-reduction process	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
67	FBgn0038076	41563	Cyp313a4	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding. Expression in head is extremely low.	No
68	FBgn0038194	41706	Cyp6d5	membrane iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
69	FBgn0038236	41759	Cyp313a1	membrane iron ion binding insecticide metabolic process electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process intracellular membrane-bound organelle heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No

70	FBgn0038347	41894	CG18522	iron ion binding 2 iron, 2 sulfur cluster binding flavin adenine dinucleotide binding oxidoreductase activity, acting on CH-OH group of donors electron carrier activity oxidation-reduction process	1273 amino acids. Oxidoreductase activity, acting on CH-OH group of donors. Unlikely to involve in magnetoreception.	No
71	FBgn0038348	41895	CG18519	iron ion binding 2 iron, 2 sulfur cluster binding flavin adenine dinucleotide binding oxidoreductase activity, acting on CH-OH group of donors electron carrier activity oxidation-reduction process	1222 amino acids. Expression in head is extremely low. Oxidoreductase activity, acting on CH-OH group of donors. Unlikely to involve in magnetoreception.	No
72	FBgn0038349	41896	CG6045	iron ion binding 2 iron, 2 sulfur cluster binding xanthine dehydrogenase activity flavin adenine dinucleotide binding electron carrier activity oxidoreductase activity, acting on CH-OH group of donors oxidation-reduction process	Xanthine dehydrogenase activity. Unlikely to involve in magnetoreception.	No
73	FBgn0038350	41897	CG18516	iron ion binding 2 iron, 2 sulfur cluster binding flavin adenine dinucleotide binding electron carrier activity oxidoreductase activity, acting on CH-OH group of donors oxidation-reduction process	Expression in head is relatively low.	No
74	FBgn0038680	42293	Cyp12a5	mitochondrion iron ion binding electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
75	FBgn0038681	42294	Cyp12a4	mitochondrion iron ion binding electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Has a role in resistance to insecticide lufenuron, but no other insecticides. Iron (heme axial ligand) binding.	No
76	FBgn0038795	42421	CG4335	trimethyllysine dioxygenase activity gamma-butyrobetaine dioxygenase activity L-ascorbic acid binding iron ion binding carnitine biosynthetic process oxidation-reduction process	Not Fe-S cluster binding protein.	No
77	FBgn0039006	42682	Cyp6d4	chaeta development membrane iron ion binding electron carrier activity wing disc development oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bounded organelle	The cytochrome P450 gene superfamily. Expression in head is relatively low.	No
78	FBgn0039205	42926	CG13623	iron-sulfur cluster binding iron-sulfur cluster assembly structural molecule activity lateral inhibition	iron-sulfur cluster binding	Yes
79	FBgn0039387	43134	CG5959	ferroxidase activity copper ion homeostasis copper ion binding iron ion transmembrane transporter activity L-ascorbate oxidase activity oxidation-reduction process	Expression in head is extremely low. Not Fe-S cluster binding protein. Copper ion binding protein.	No
80	FBgn0039776	43620	PH4alphaEFB	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	Procollagen-proline 4-dioxygenase complex. Not Fe-S cluster binding protein.	No

81	FBgn0039780	43625	PH4alphaNE1	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	Procollagen-proline 4-dioxygenase complex. Expression in head is extremely low. Not Fe-S cluster binding protein.	No
82	FBgn0039784	43629	CG9698	procollagen-proline 4-dioxygenase activity iron ion binding endoplasmic reticulum procollagen-proline 4-dioxygenase complex oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen peptidyl-proline hydroxylation to 4-hydroxy-L-proline L-ascorbic acid binding oxidation-reduction process	Expression in head is extremely low. Not Fe-S cluster binding protein.	No
83	FBgn0041337	33439	Cyp309a2	iron ion binding membrane electron carrier activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen heme binding oxidation-reduction process intracellular membrane-bound organelle	The cytochrome P450 gene superfamily. May be involved in the metabolism of insect hormones and in the breakdown of synthetic insecticides. Iron (heme axial ligand) binding.	No
84	FBgn0042182	3771984	CG18749	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline procollagen-proline 4-dioxygenase activity extracellular region oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen multicellular organism reproduction oxidation-reduction process	Iron ion binding. Expression in head is relatively low.	No
85	FBgn0050489	246648	Cyp12d1-p	mitochondrion iron ion binding response to DDT electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Iron (heme axial ligand) binding.	No
86	FBgn0051278	41282	CG31278	iron ion binding peptide deformylase activity	Expression in head is relatively low, and NOT a Fe-S cluster binding protein.	No
87	FBgn0052068	326189	CG32068	L-methionine salvage from methylthioadenosine acireductone dioxygenase [iron(II)-requiring] activity oxidation-reduction process	1, 2-dihydroxy-3-keto-5-methylthiopentene dioxygenase. Binds 1 iron ion per monomer. Can also use other divalent metal cations. Not Fe-S cluster.	No
88	FBgn0052500	2768879	CG32500	ATP-dependent helicase activity cytoplasm iron-sulfur cluster binding iron ion binding iron-sulfur cluster assembly nucleic acid binding ATP binding	NFU1 iron-sulfur cluster scaffold homolog, mitochondrial. It has similar expression level in all organs.	No
89	FBgn0052857	318252	CG32857	ATP-dependent helicase activity cytoplasm iron-sulfur cluster assembly iron-sulfur cluster binding iron ion binding nucleic acid binding ATP binding	NFU1 iron-sulfur cluster scaffold homolog, mitochondrial. It has similar expression level in all organs.	No

90	FBgn0053196	318824	dp	endonuclease activity serine-type endopeptidase inhibitor activity calcium ion binding proteinaceous extracellular matrix open tracheal system development apposition of dorsal and ventral imaginal disc-derived wing surfaces chitin-based embryonic cuticle biosynthetic process chitin-based cuticle attachment to epithelium lateral inhibition 4 iron, 4 sulfur cluster binding	Extracellular matrix. Unlikely to get involved in magnetosensor formation with Cryptochrome.	No
91	FBgn0053502	2768875	CG33502	ATP-dependent helicase activity molecular_function biological_process cytoplasm iron ion binding iron-sulfur cluster binding iron-sulfur cluster assembly cellular_component nucleic acid binding ATP binding	Belongs to the NifU family. It has similar expression level in all organs.	No
92	FBgn0053503	2768720	Cyp12d1-d	mitochondrion iron ion binding response to DDT electron carrier activity response to insecticide oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen oxidation-reduction process heme binding	The cytochrome P450 gene superfamily. Only expressed in adults.	No
93	FBgn0062442	43459	cg1458	molecular_function biological_process 2 iron, 2 sulfur cluster binding cellular_component intracellular membrane-bounded organelle	CDGSH iron-sulfur domain-containing protein 2 homolog	Yes
94	FBgn0085374	5740402	CG34345	procollagen-proline 4-dioxygenase complex L-ascorbic acid binding iron ion binding endoplasmic reticulum peptidyl-proline hydroxylation to 4-hydroxy-L-proline lateral inhibition procollagen-proline 4-dioxygenase activity oxidoreductase activity, acting on single donors with incorporation of molecular oxygen, incorporation of two atoms of oxygen oxidation-reduction process	Expression in head is relatively low	No
95	FBgn0086450	31858	su(r)	dihydroorotate oxidase activity dihydouracil dehydrogenase (NAD ⁺) activity cytoplasm 'de novo' pyrimidine base biosynthetic process UMP biosynthetic process electron carrier activity dihydropyrimidine dehydrogenase (NADP ⁺) activity dihydropyrimidine dehydrogenase (NADP ⁺) activity iron-sulfur cluster binding oxidation-reduction process	Dihydropyrimidine dehydrogenase. It has similar expression level in all organs.	No

96	FBgn0086706	39027	pix	ATP binding cytoplasm mitochondrion eukaryotic translation initiation factor 3 complex translation translational initiation ribonuclease inhibitor activity electron carrier activity cell growth mRNA metabolic process ATPase activity growth ribosomal small subunit binding negative regulation of neuron apoptosis iron-sulfur cluster binding	Pixie, isoform A	Yes
97	FBgn0086917	5740359	spok	iron ion binding ecdysone biosynthetic process molting cycle, chitin-based cuticle oxidoreductase activity oxidoreductase activity, acting on paired donors, with incorporation or reduction of molecular oxygen cellular_component oxidation-reduction process heme binding	Expression in head is relatively low	No
98	FBgn0259697	5740633	nvd	metamorphosis multicellular organism growth instar larval development 2 iron, 2 sulfur cluster binding ecdysteroid biosynthetic process oxidoreductase activity oxidation-reduction process	Expression in head is relatively low	No

Supplementary Table 4: The 14 candidates we used for the first round of experimental validation (designated as the fourth round of screening. Candidates confirmed with strong expression in head picked out for the next (fifth) round of screening (see Fig. 2b,c) have a white background in the table.

Number	Gene ID	Official Symbol	GO Term	FlyAtlas hits	<i>In vivo</i> Expression confirmed (Transcriptional Level)	Used for Experimental Validation
1	FBgn0017566	31762	ND75	NADH dehydrogenase activity mitochondrion cellular respiration ATP synthesis coupled electron transport mitochondrial respiratory chain complex I iron-sulfur cluster binding electron carrier activity NADH dehydrogenase (ubiquinone) activity	Yes	Yes
2	FBgn0026666	32513	1(1)G0136	iron-sulfur cluster assembly iron-sulfur cluster binding structural molecule activity	Yes	Yes
3	FBgn0029158	40259	Las	mitochondrion lipoate biosynthetic process lipoate synthase activity 4 iron, 4 sulfur cluster binding	Yes	Yes
4	FBgn0030092	31845	FH	ferroxidase activity mitochondrion cellular iron ion homeostasis axon transport of mitochondrion iron chaperone activity response to hydrogen peroxide regulation of mitochondrial membrane potential oxidation-reduction process	Yes	Yes
5	FBgn0030718	32565	CG9172	NADH dehydrogenase activity mitochondrial respiratory chain complex I assembly quinone binding 4 iron, 4 sulfur cluster binding mitochondrial respiratory chain complex I mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity response to reactive oxygen species determination of adult lifespan	Yes	Yes
6	FBgn0031771	33852	CG9140	NADH dehydrogenase activity mitochondrial respiratory chain complex I 4 iron, 4 sulfur cluster binding NAD binding FMN binding mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity	Yes	Yes
7	FBgn0032393	34613	CG12264	mitochondrion cytoplasm iron-sulfur cluster assembly alanine biosynthetic process cysteine metabolic process microtubule associated complex pyridoxal phosphate binding cysteine desulfurase activity cystathione gamma-lyase activity	Yes	Yes

8	FBgn0036262	39391	CG6910	inositol catabolic process inositol oxygenase activity cytoplasm iron ion binding oxidation-reduction process	Yes	Yes
9	FBgn0037637	41059	CG9836	iron-sulfur cluster binding iron-sulfur cluster assembly iron ion binding	Yes	Yes
10	FBgn0039205	42926	CG13623	iron-sulfur cluster binding iron-sulfur cluster assembly structural molecule activity lateral inhibition	No	No
11	FBgn0011769	39070	fdxH	mitochondrion biological_process 2 iron, 2 sulfur cluster binding electron carrier activity	No	No
12	FBgn0017567	44207	ND23	NADH dehydrogenase activity mitochondrion 4 iron, 4 sulfur cluster binding mitochondrial respiratory chain complex I mitochondrial electron transport, NADH to ubiquinone NADH dehydrogenase (ubiquinone) activity	No	No
13	FBgn0062442	43459	cgl458	molecular_function biological_process 2 iron, 2 sulfur cluster binding cellular_component intracellular membrane-bounded organelle	No	No
14	FBgn0086706	39027	pix	ATP binding cytoplasm mitochondrion eukaryotic translation initiation factor 3 complex translation translational initiation ribonuclease inhibitor activity electron carrier activity cell growth mRNA metabolic process ATPase activity growth ribosomal small subunit binding negative regulation of neuron apoptosis iron-sulfur cluster binding	No	No

Supplemental Table 5. Species and Cry/MagR combinations we tested in this study

Species (Common Name and Latin Name)	Protein Combinations		Complex Formation**
	MagR	Cry	
Fruit fly (<i>Drosophila melanogaster</i>)	dMagR	dCry	+
Monarch butterfly (<i>Danaus plexippus</i>)	dpMagR	dpCry1	+
		dpCry2	
Domestic pigeon (<i>Columba livia</i>)	clMagR	clCry1	
		clCry2	
		clCry4	+
Naked mole rat (<i>Heterocephalus glaber</i>)	hgMagR	hgCry1	***
		hgCry2	+
Minke whale (<i>Balaenoptera acutorostrata</i>)	baMagR	baCry1	
		baCry2	+
Human (<i>Homo sapiens</i>)	hMagR	hCry1	
		hCry2-1*	
		hCry2-2*	+

* : Two isoforms of human Cryptochrome.

** : Co-expression and co-purification was used to check the complex formation (as described in supplemental methods)

***: Further confirmation is required, since weak bands of hgCry1 and hgMagR appeared in some experiments, though much weaker than the hgCry2/hgMagR combination.

Supplementary Video Legends

Supplementary Movie 1: A movie showing one magnetosensor protein crystal in hanging drop rotating in a synchronizing frequency as the external magnetic field Crystal rotates (the crystal appears as brown-to-black rod-like shape).

Supplementary Movie 2: A movie showing several translucent yellowish crystals with different shapes and sizes in one single hanging drop rotating in a synchronizing frequency as the external magnetic field Crystal rotates.