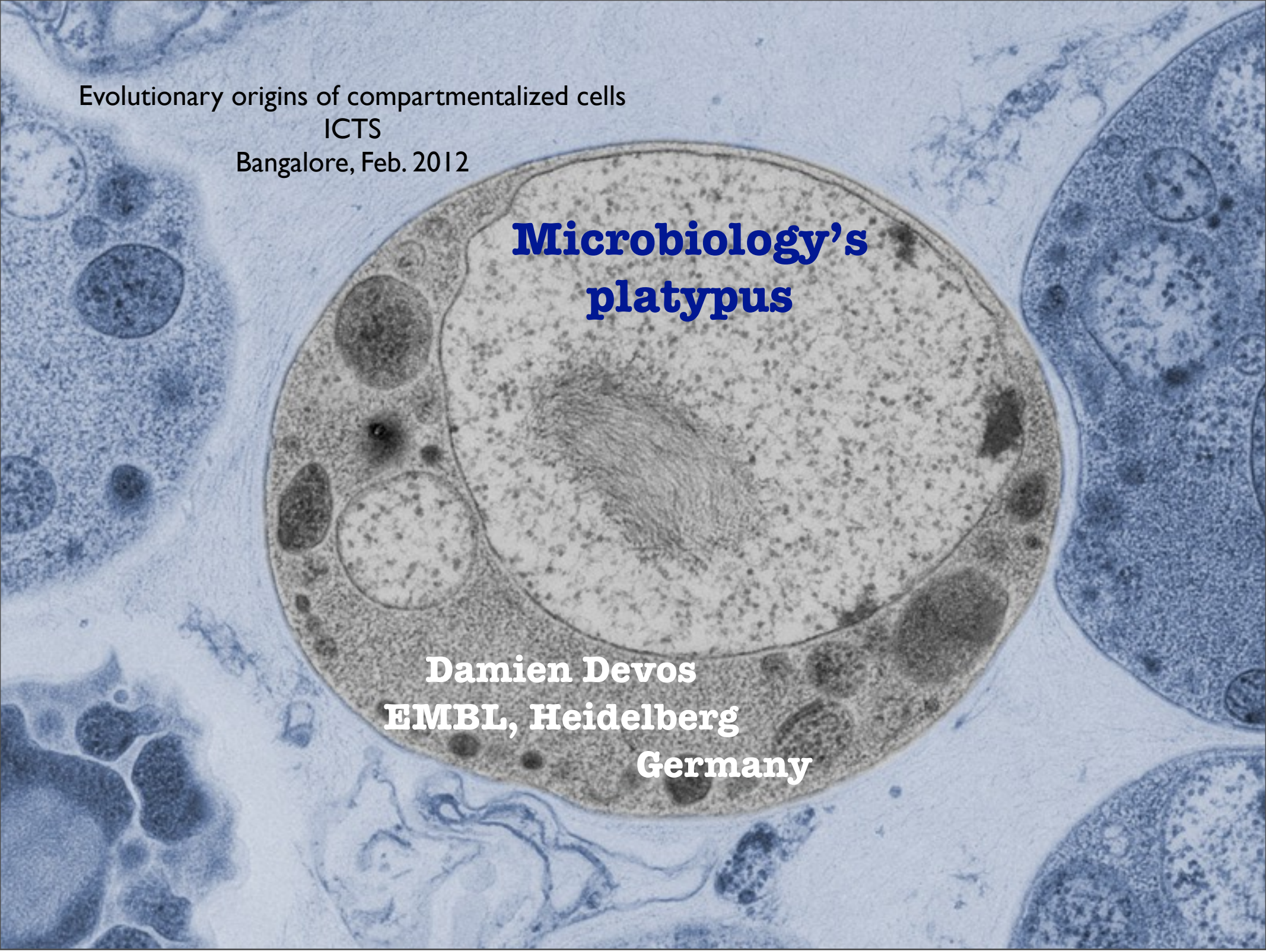
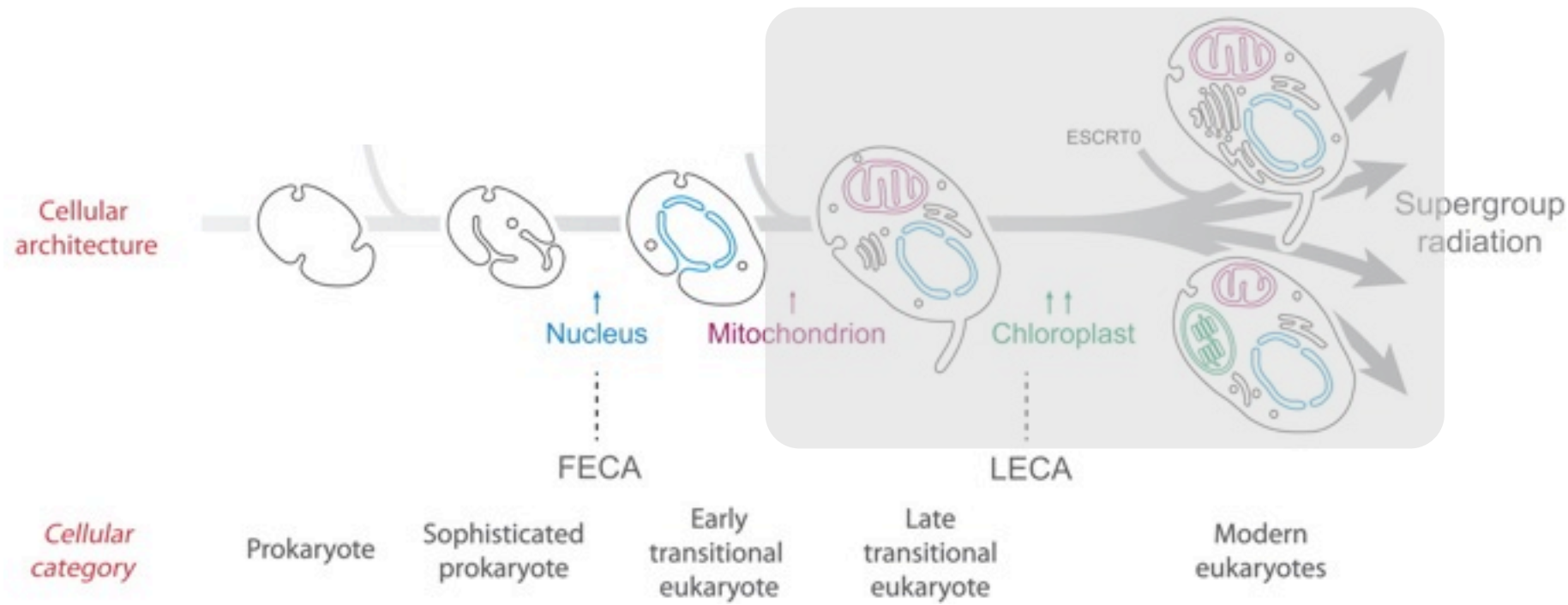


Evolutionary origins of compartmentalized cells
ICTS
Bangalore, Feb. 2012

Microbiology's platypus

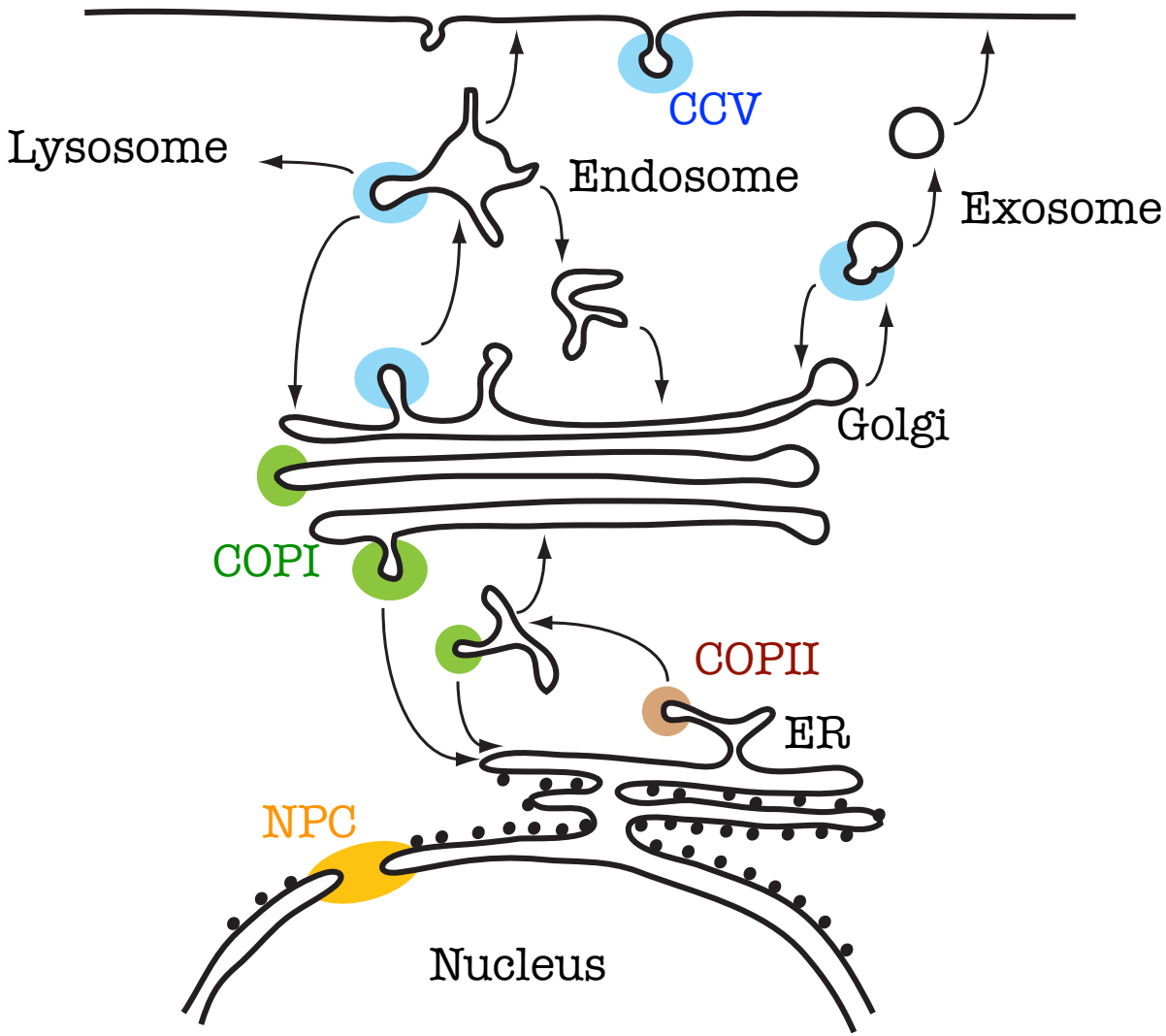
Damien Devos
EMBL, Heidelberg
Germany

Before the endosymbionts



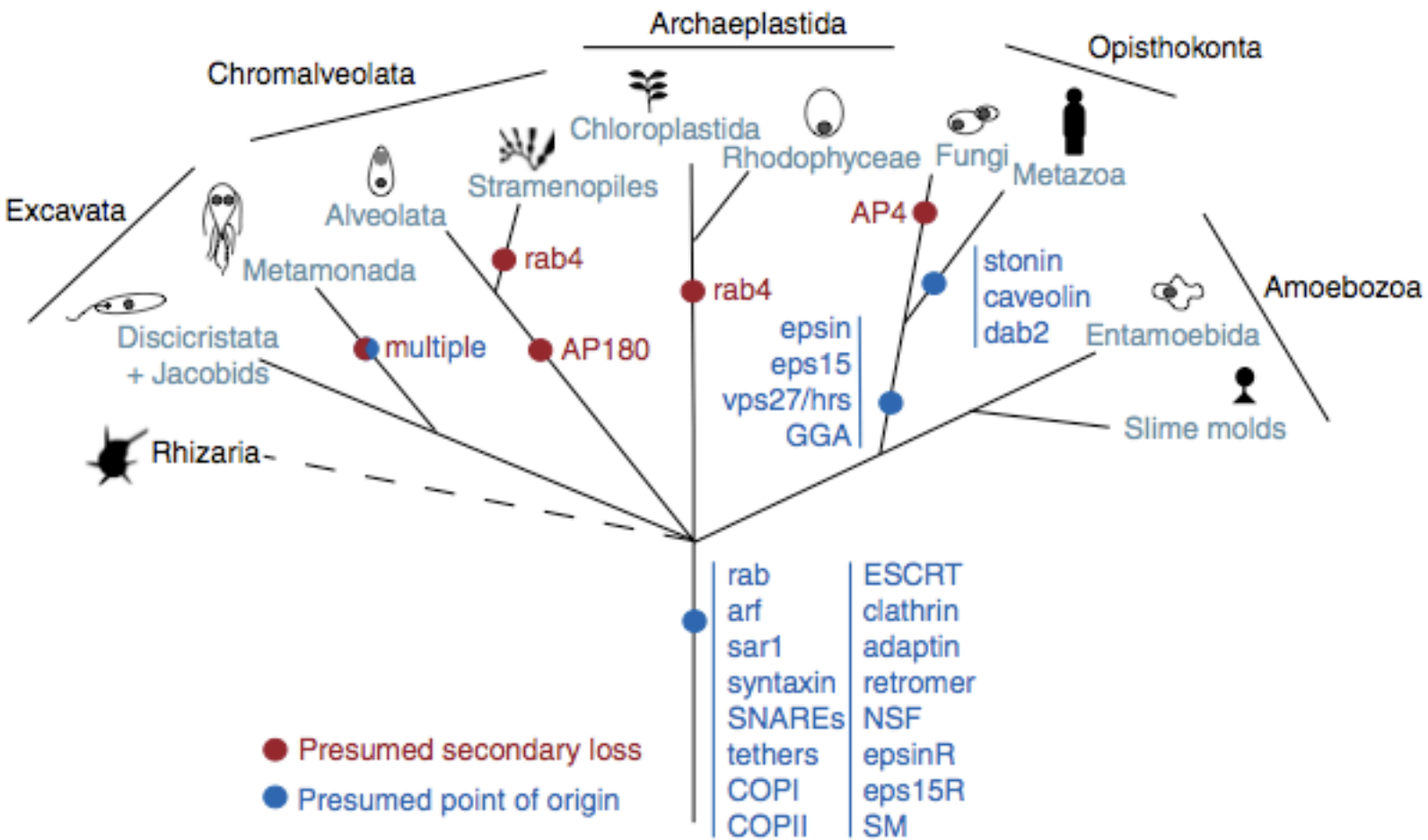
Field *et al.*, *JCB* 2011

Eukaryotic Membrane Systems



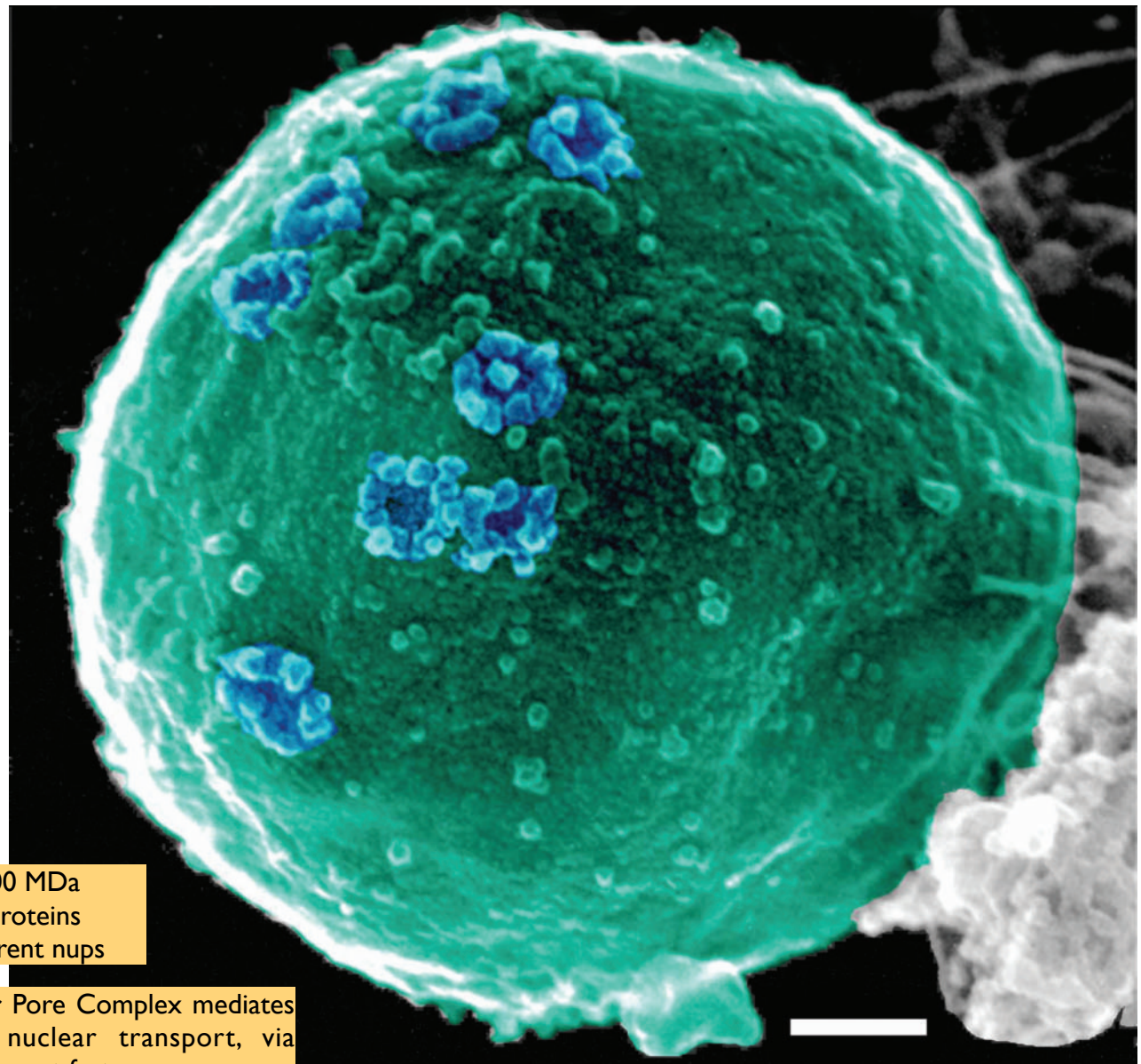
Devos DP

LECA already had a complex endomembrane system including nucleus and NPC



Dacks & Field, *JCS* 2007

The Nuclear Pore Complex



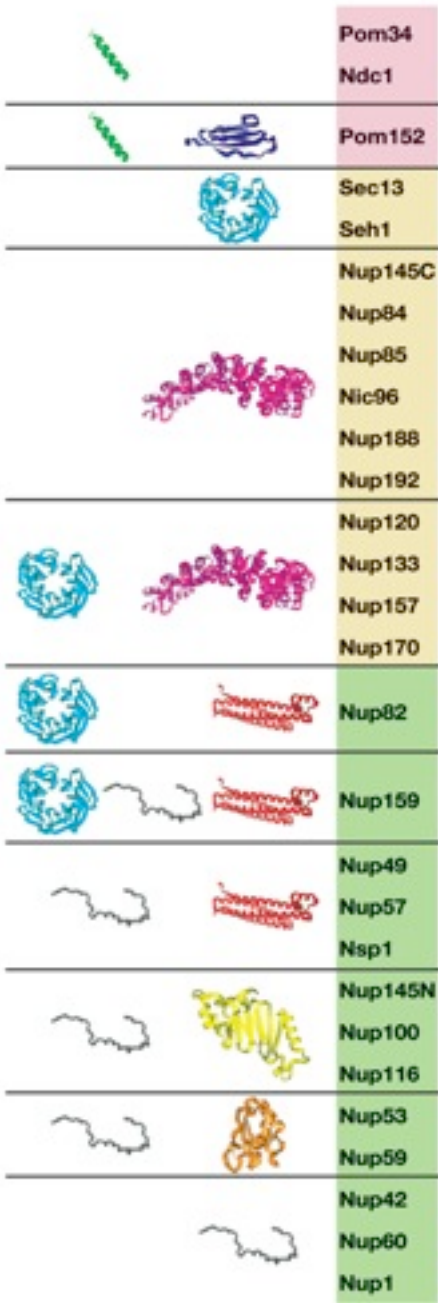
~50-100 MDa
~480 proteins
~30 different nups

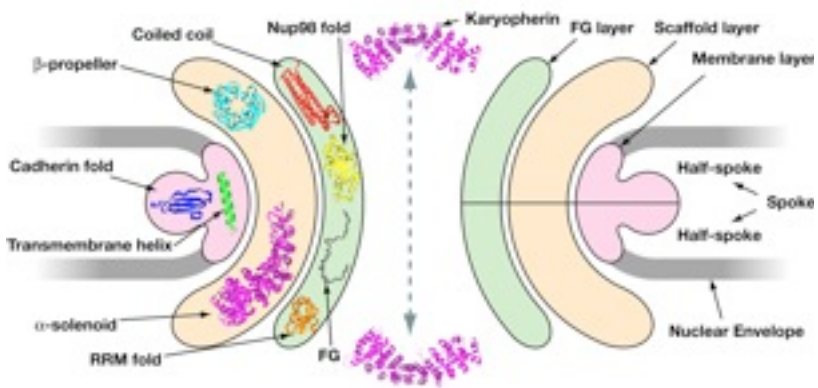
The Nuclear Pore Complex mediates all known nuclear transport, via cognate transport factors.

Scale bar: 100 nm

Kiseleva Nature Cell Biology 2004

Simplified organization of the NPC





Devos *et al.*, *PNAS* 2006; Alber *et al.*, *Nature* 2007

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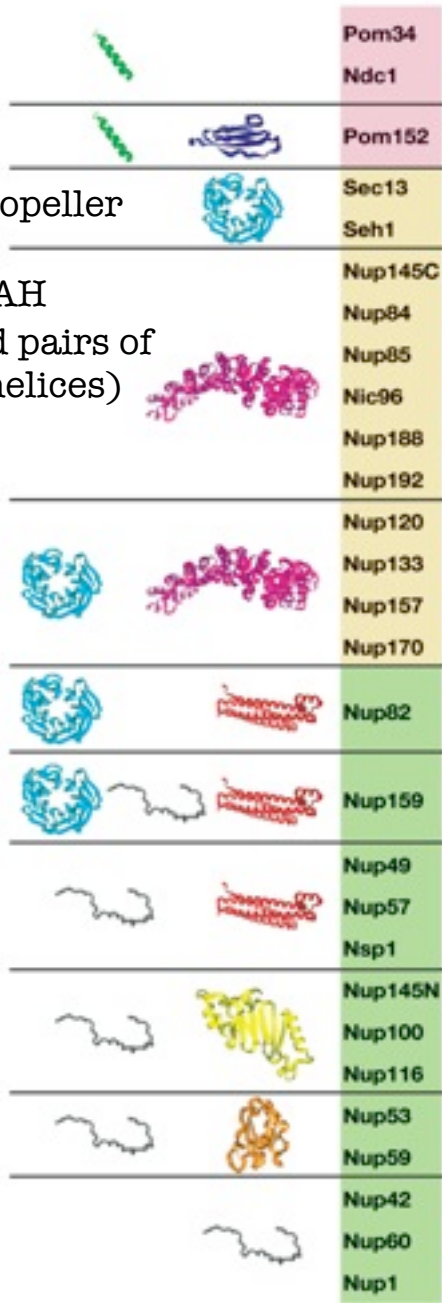
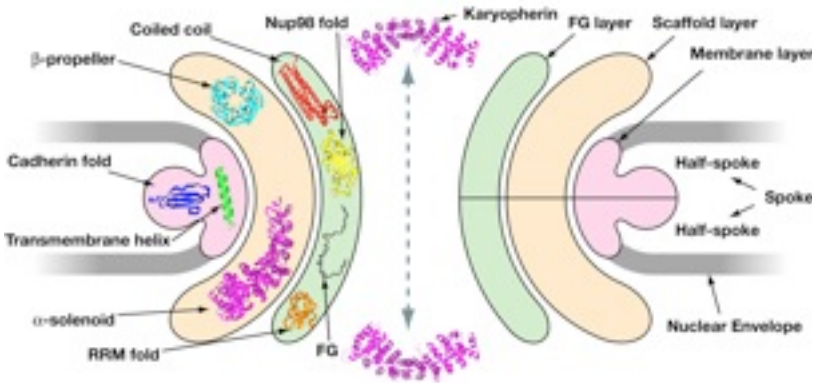


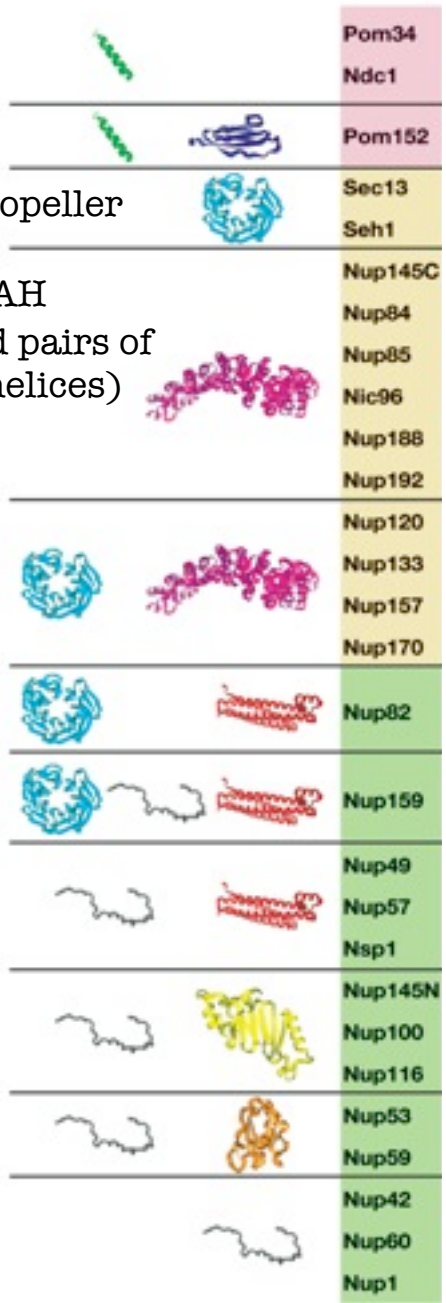
beta-propeller

SPAH
(Stacked pairs of alpha-helices)



Devos *et al.*, *PNAS* 2006; Alber *et al.*, *Nature* 2007

Simplified organization of the NPC



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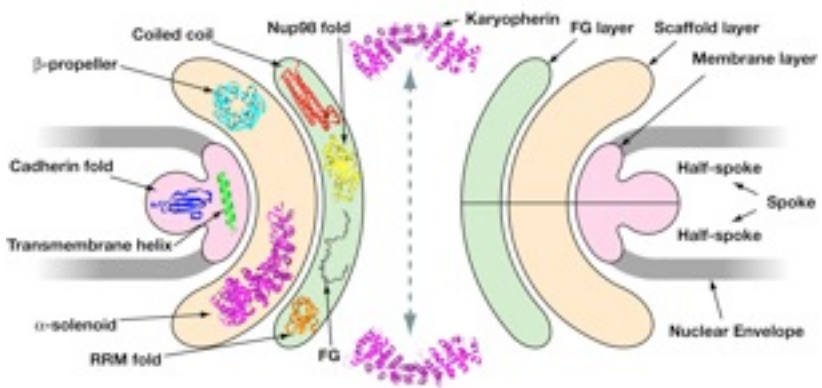

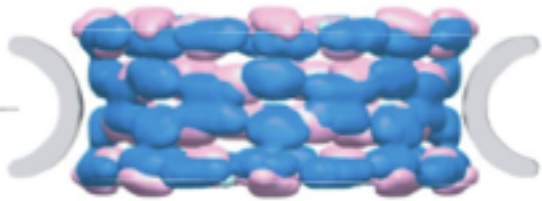

Devos *et al.*, *PNAS* 2006; Alber *et al.*, *Nature* 2007

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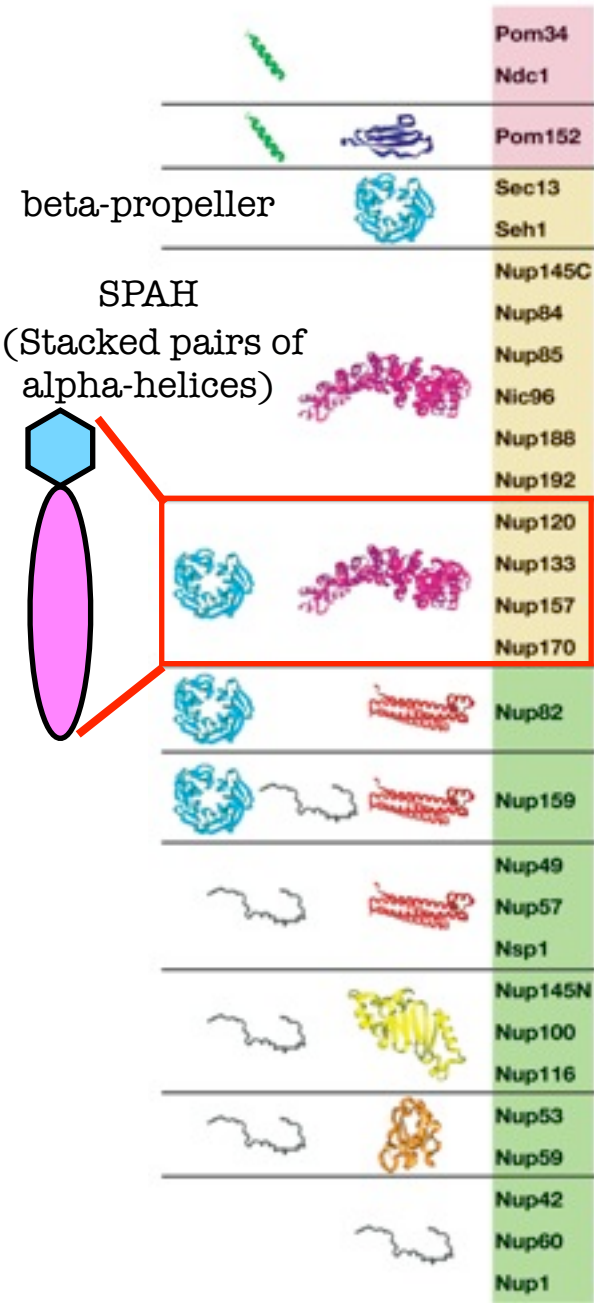

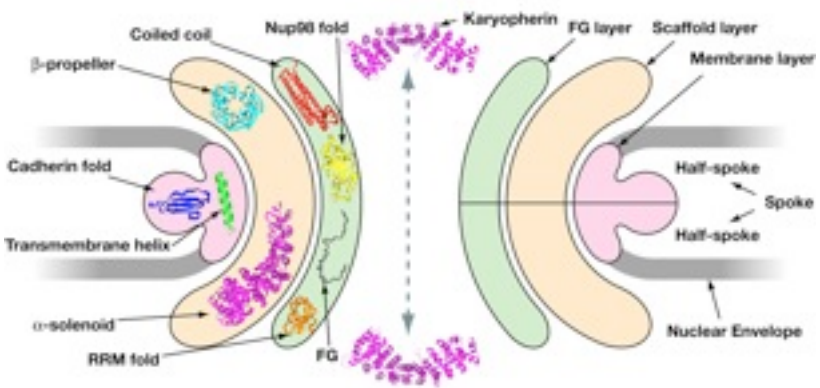

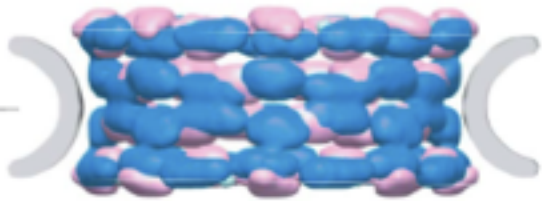

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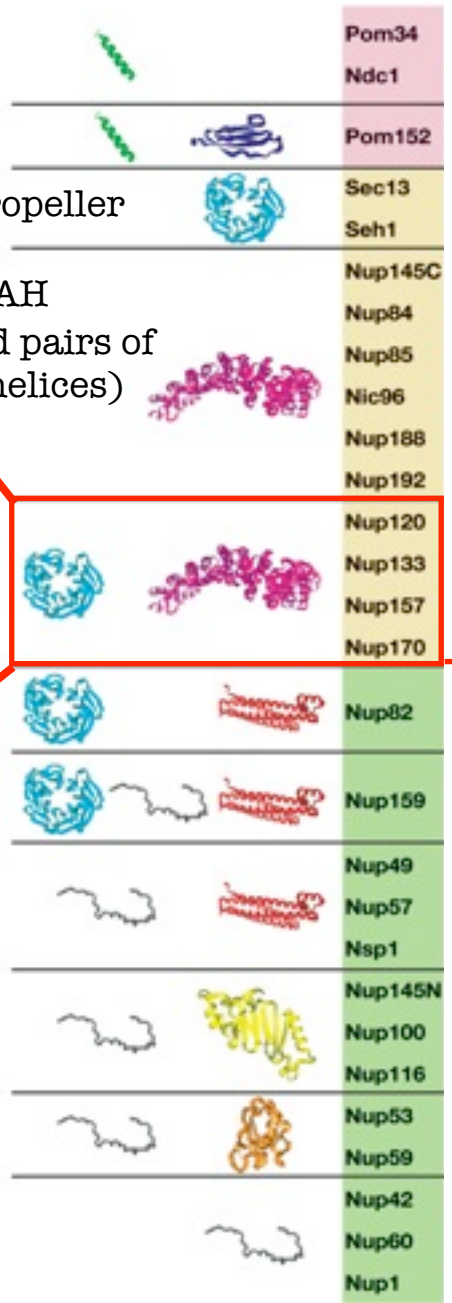

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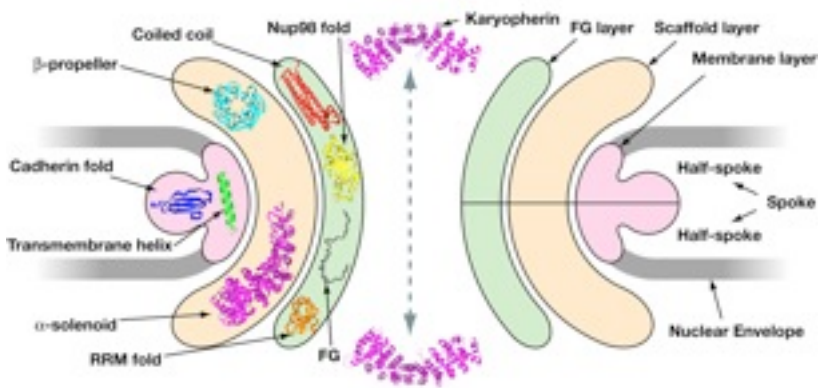
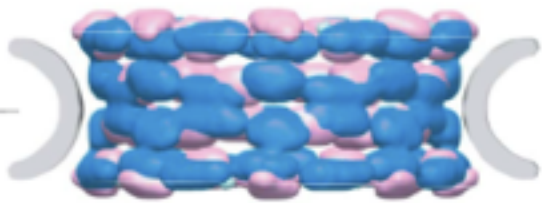
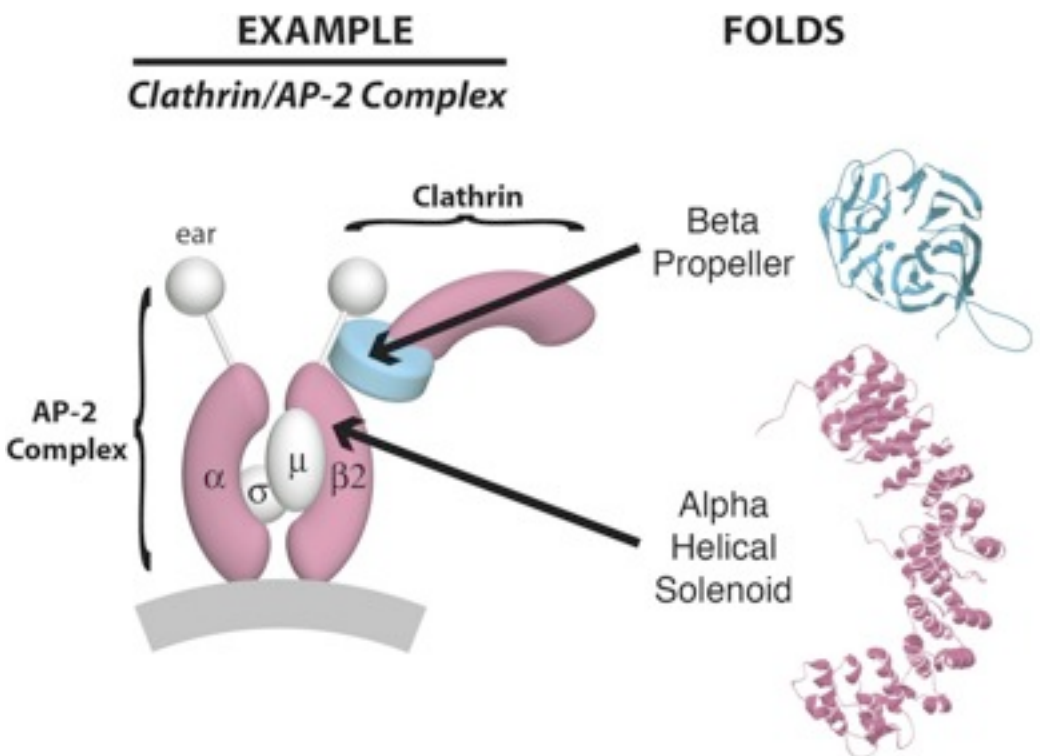




Particular architecture
restricted to eukaryotic proteins
involved in NPC
or coated vesicles

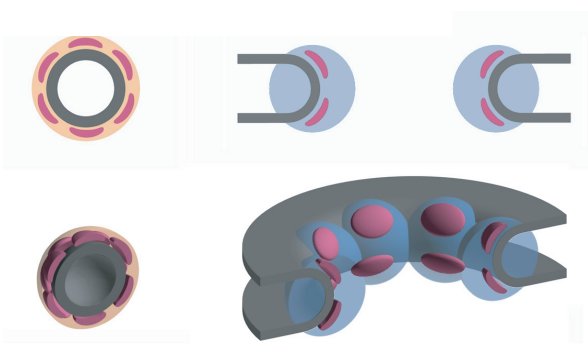
Devos *et al.*, *PNAS* 2006; Alber *et al.*, *Nature* 2007

NPC and Coated Vesicle share a unique architecture



CCVs	COPI	COPII	NPC
Clathrin-N	**α-subunit-N**	**Sec31-N**	**Nup120-N**
	β'-subunit-N	Sec13	**Nup133-N**
		Seh1	Sec13
			Seh1
Clathrin-C	**α-subunit-C**	**Sec31-C**	**Nup120-C**
α–subunit	**β'-subunit-C**		**Nup133-C**
β-subunit	β-subunit		Nup85
γ–subunit	γ -subunit		Nup84
δ–subunit	ε -subunit		Nup145C
ε-subunit			

Membrane coats architecture
(Nt-propeller + Ct-SPAH)



Devos *et al.*, *PLoS Biology* 2004

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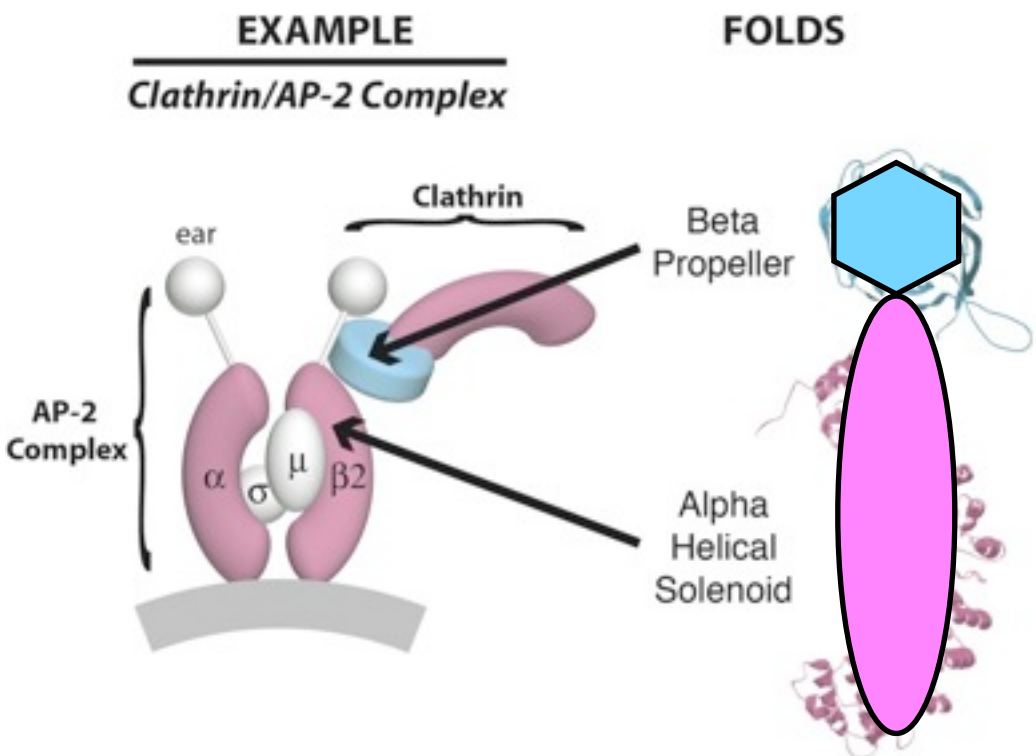

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	β'-subunit-N	Sec13	**Nup133-N**
		Seh1	Sec13
			Seh1
Clathrin-C	**α-subunit-C**	**Sec31-C**	**Nup120-C**
α–subunit	**β'-subunit-C**		**Nup133-C**
β-subunit	β-subunit		Nup85
γ–subunit	γ -subunit		Nup84
δ–subunit	ε -subunit		Nup145C
ε-subunit			

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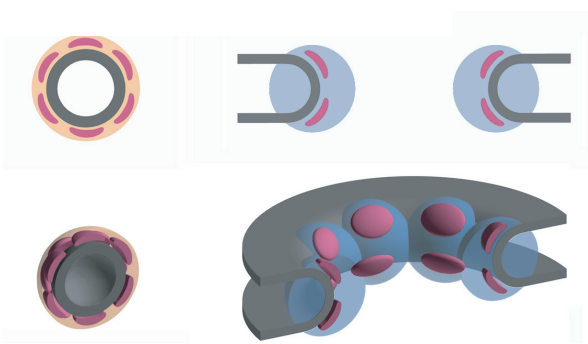
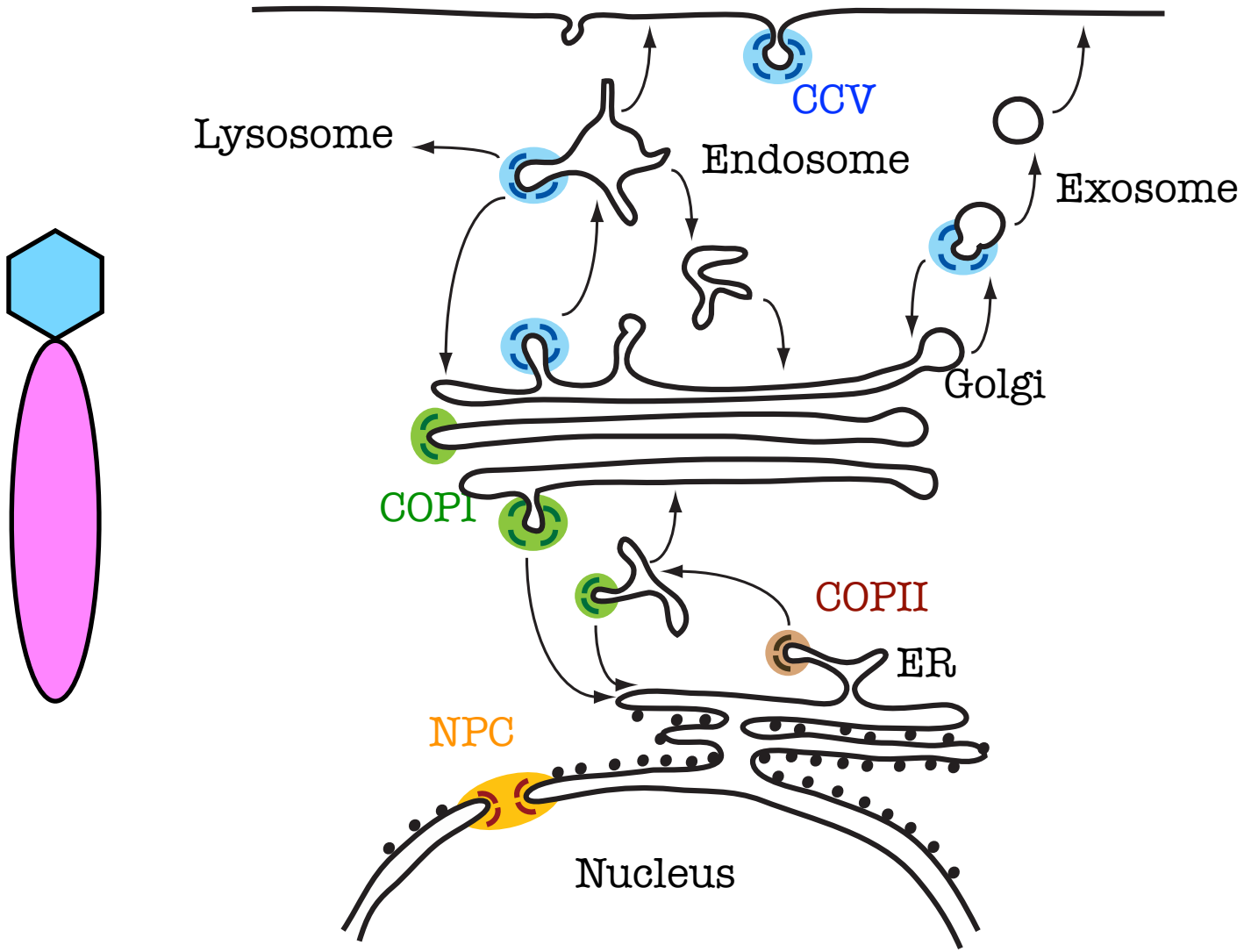


Devos *et al.*, *PLoS Biology* 2004

MC Proteins in Eukaryotic endomembrane complexes

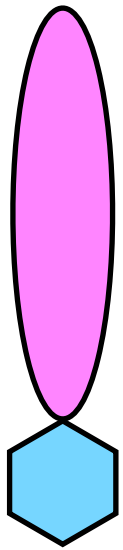


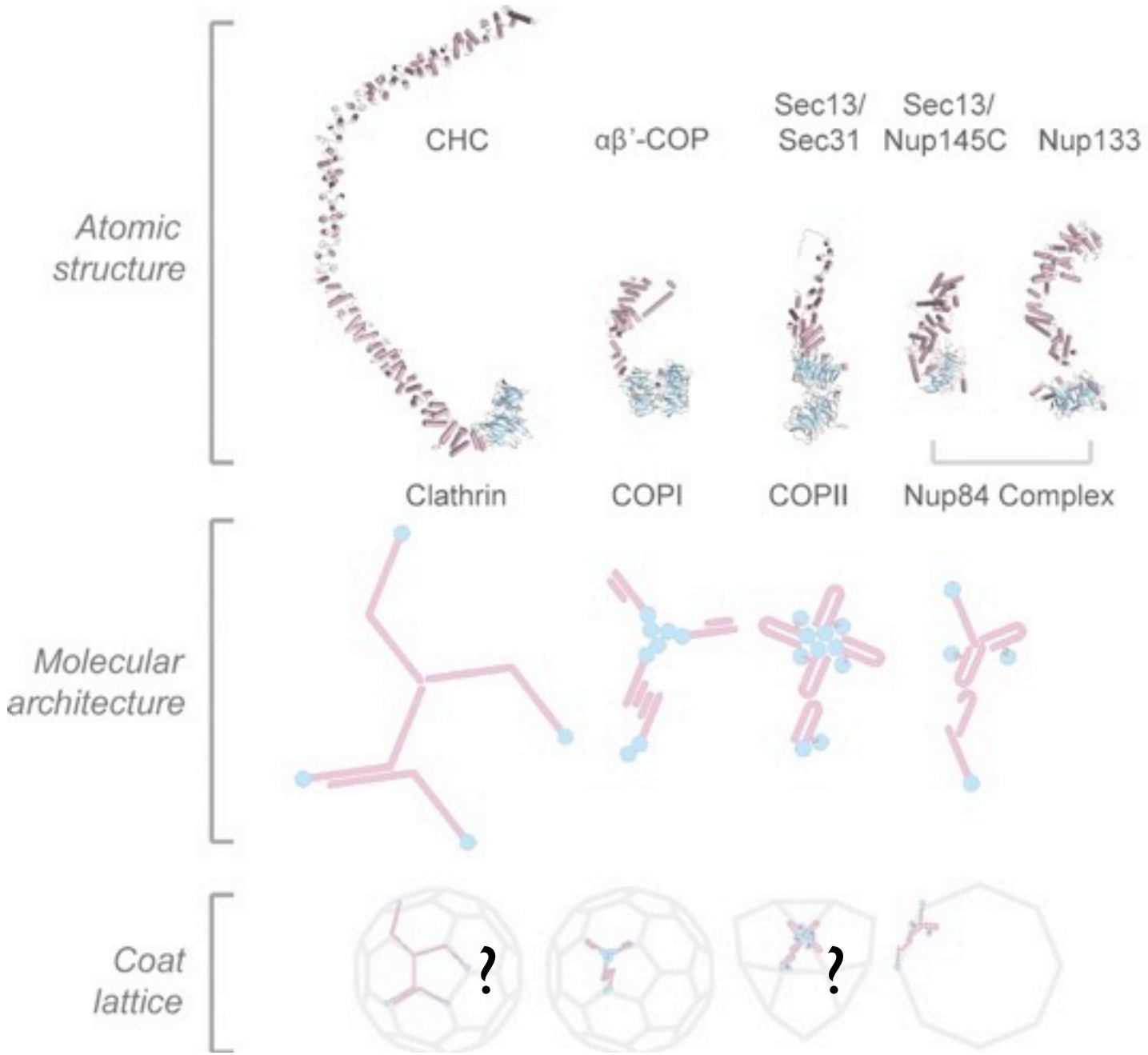
Devos *et al.*, *PLoS Biology* 2004

Similarities and differences between MC proteins

Devos *et al.*, *PLoS Biology* 2004

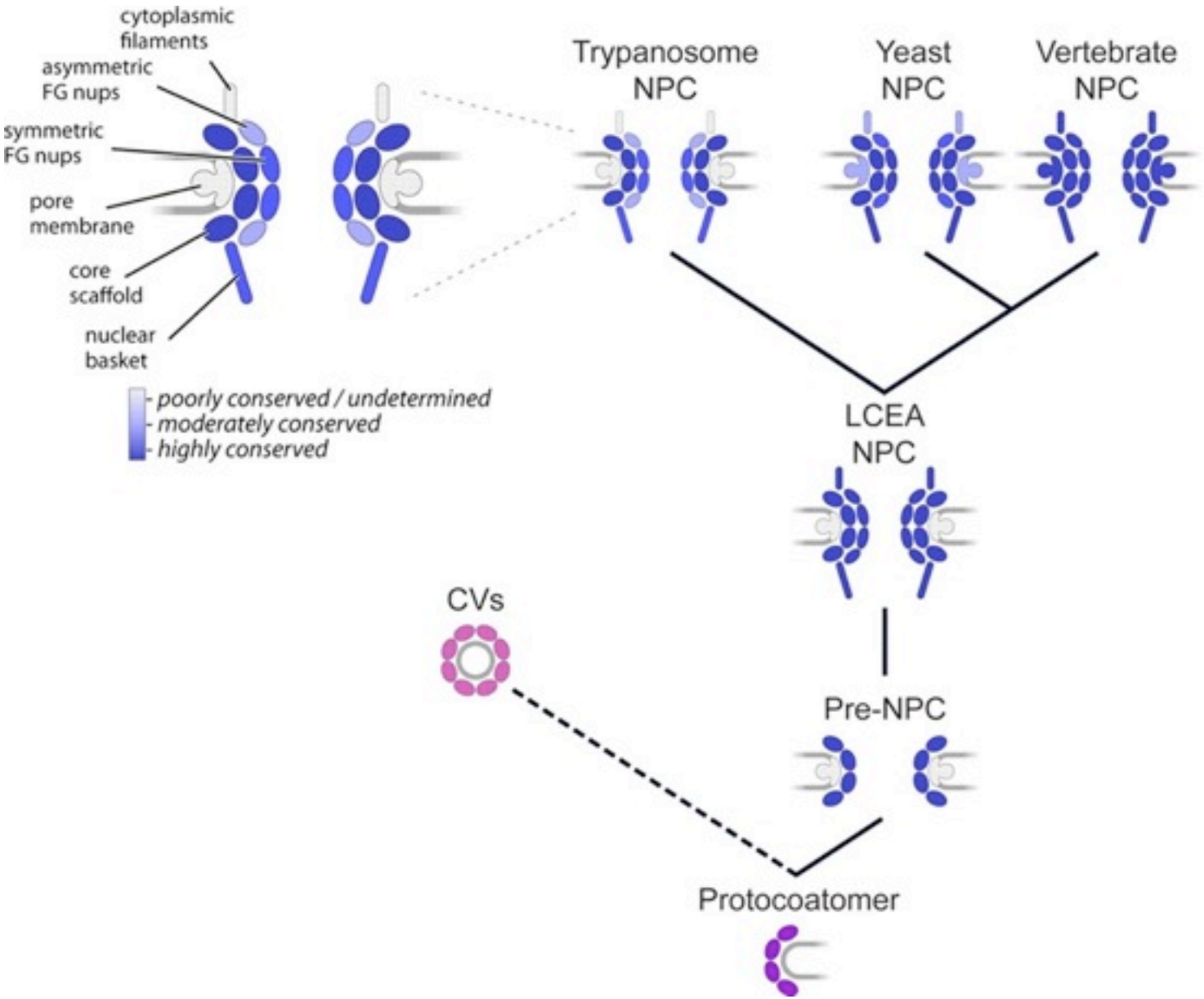
NPC lattice and assembly/disassembly





Field *et al.*, *JCB* 2011

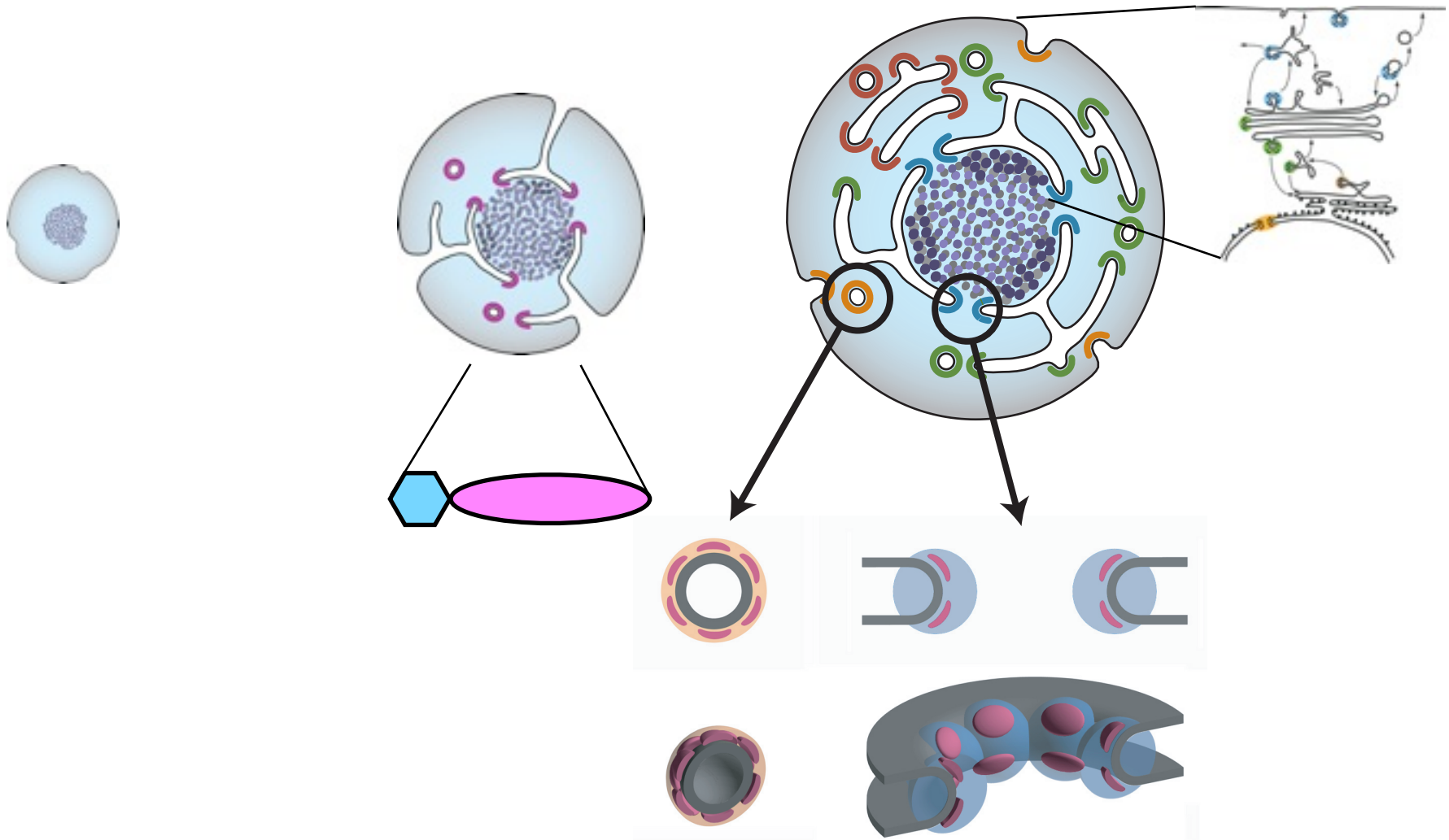
Architecture Conserved from the Last Common Eukaryotic Ancestor



DeGrasse *et al.*, *Mol. Cell. Proteom.* 2009

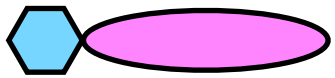
The Protocoatomer Hypothesis

Prokaryote Early Eukaryote Modern Eukaryote



Devos *et al.*, *PLoS Biology* 2004

Membrane Coat Proteins

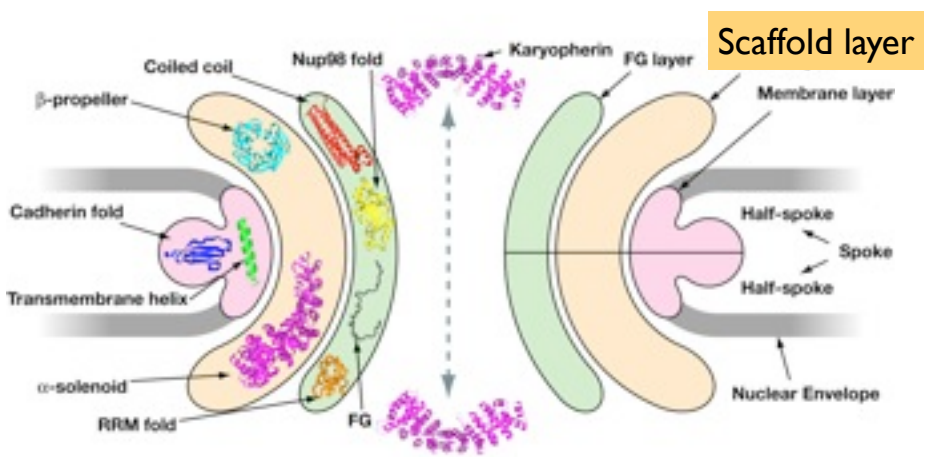


Essential to the integrity of each compartment

Scaffold

Earliest steps of eukaryotic evolution

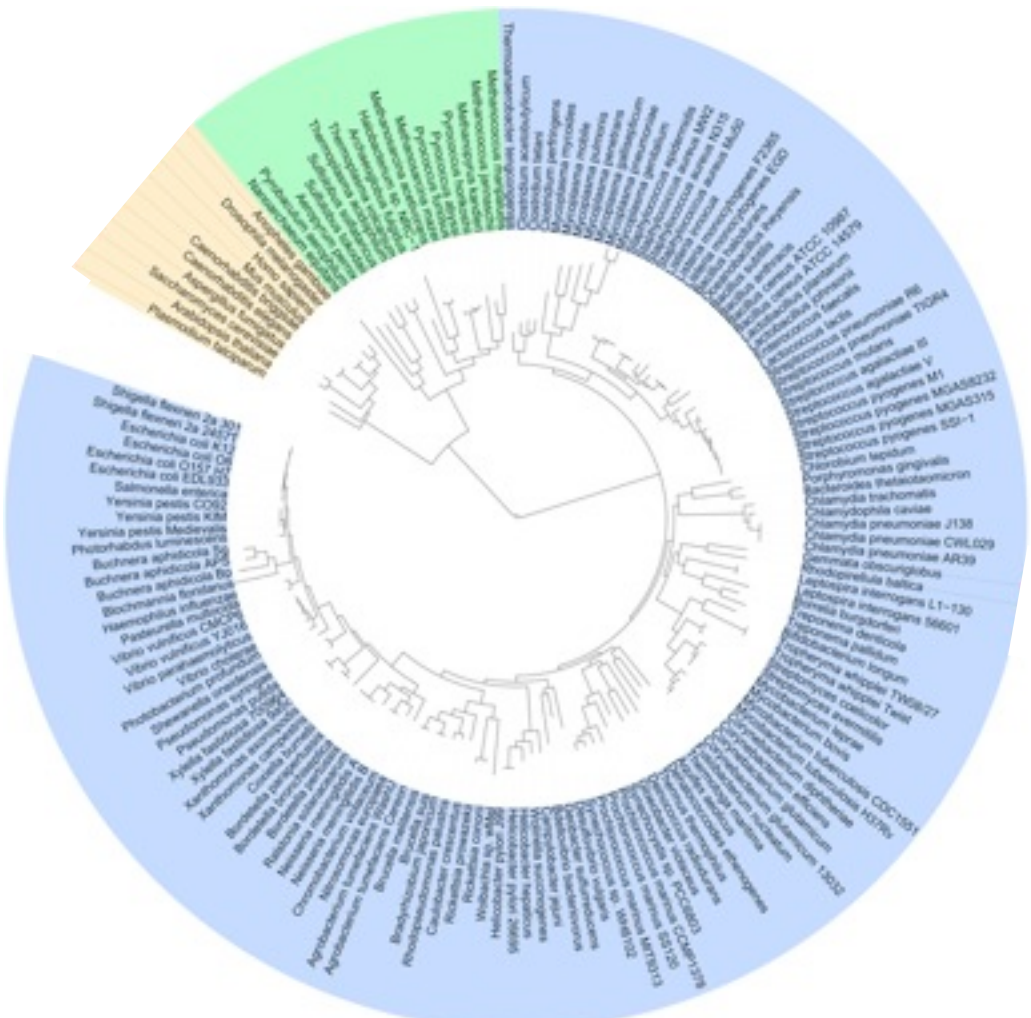
Ancestor of the eukaryotes



Devos *et al.*, *PLoS Biology* 2004

Searching for the origin of Euk MCs

Fold assignments
>200 complete genomes
~1x10exp9 sequence



Eukarya
Archea
Bacteria

Santarella *et al.*, *PLoS Biology* 2010

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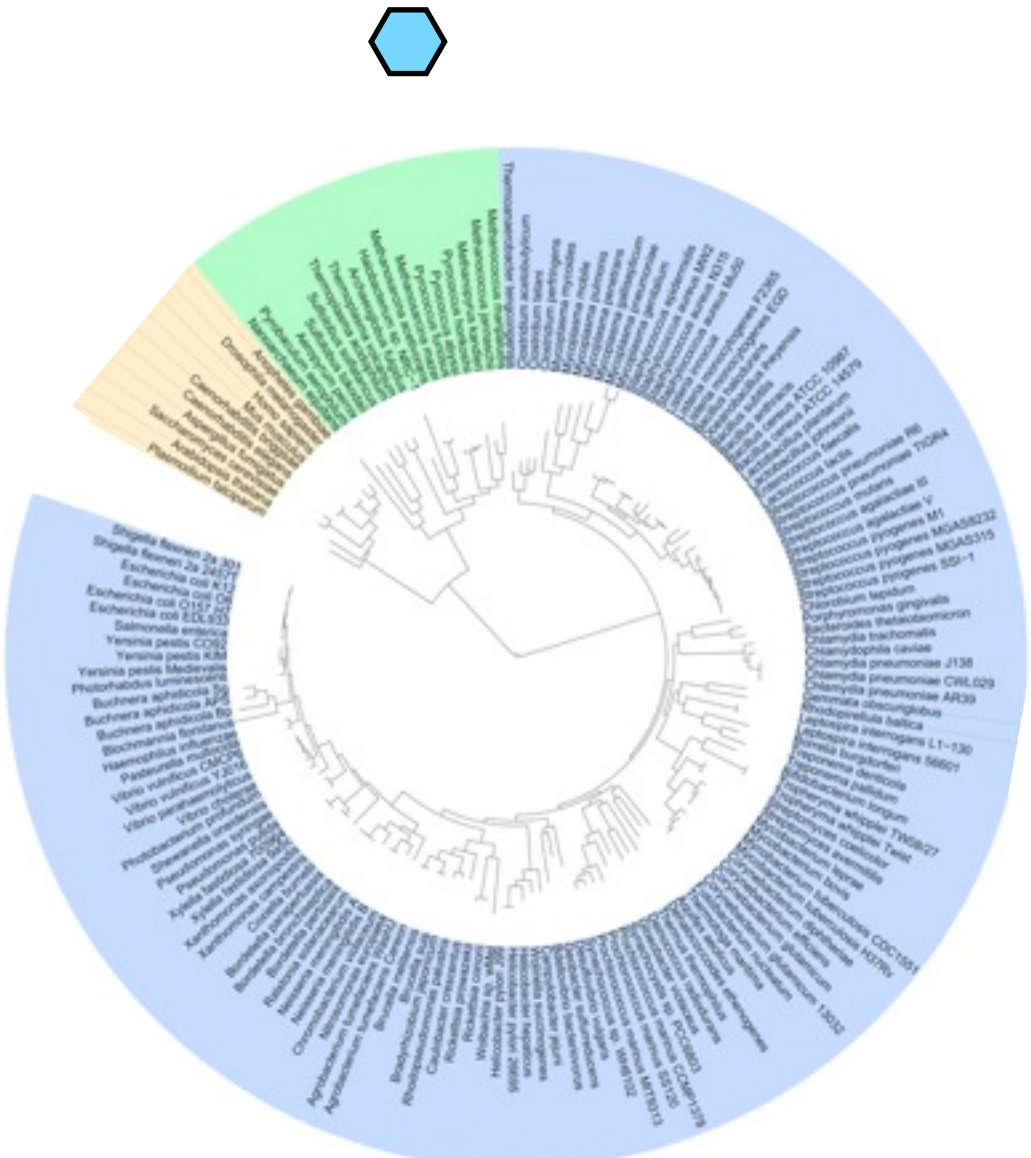

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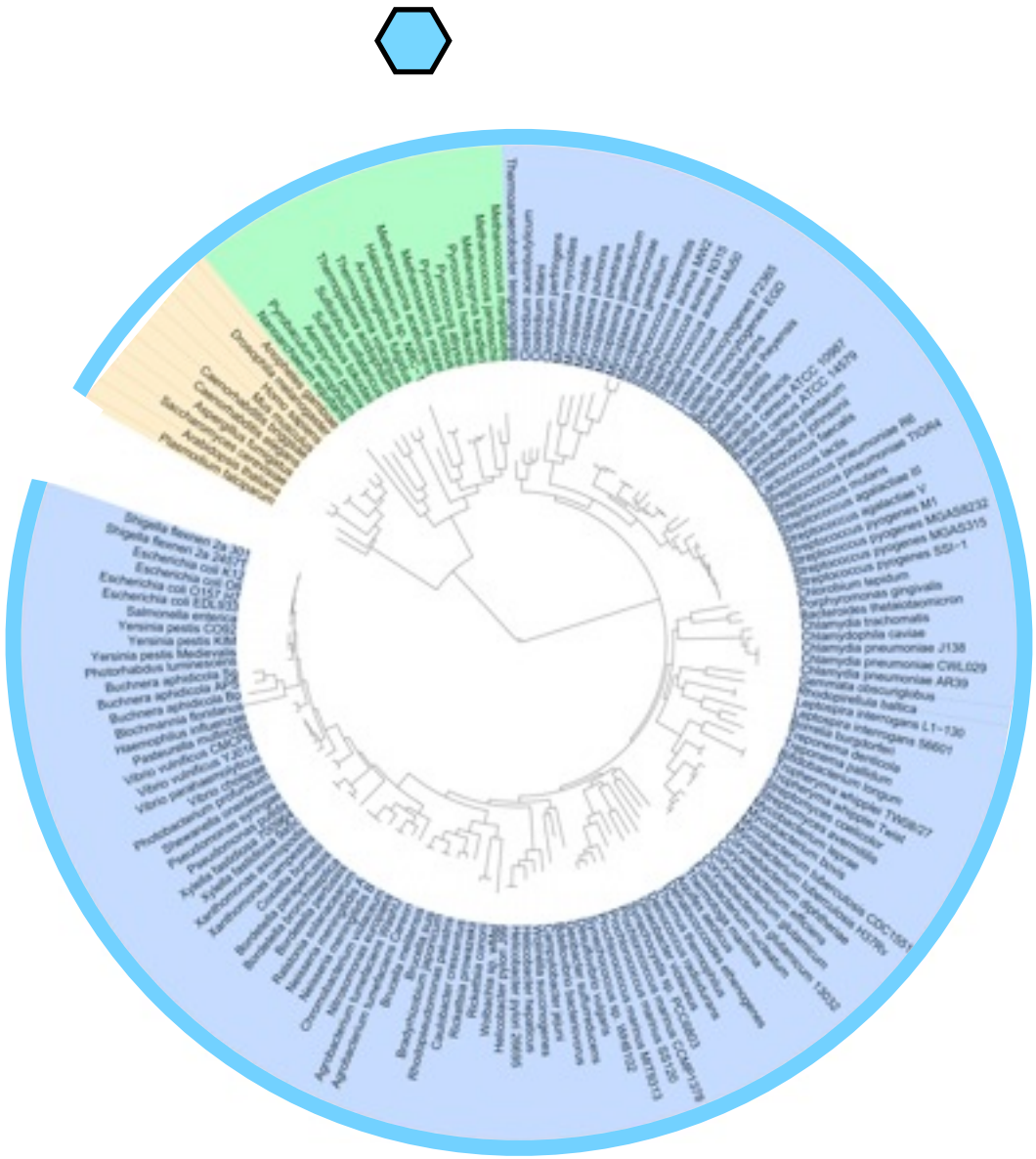

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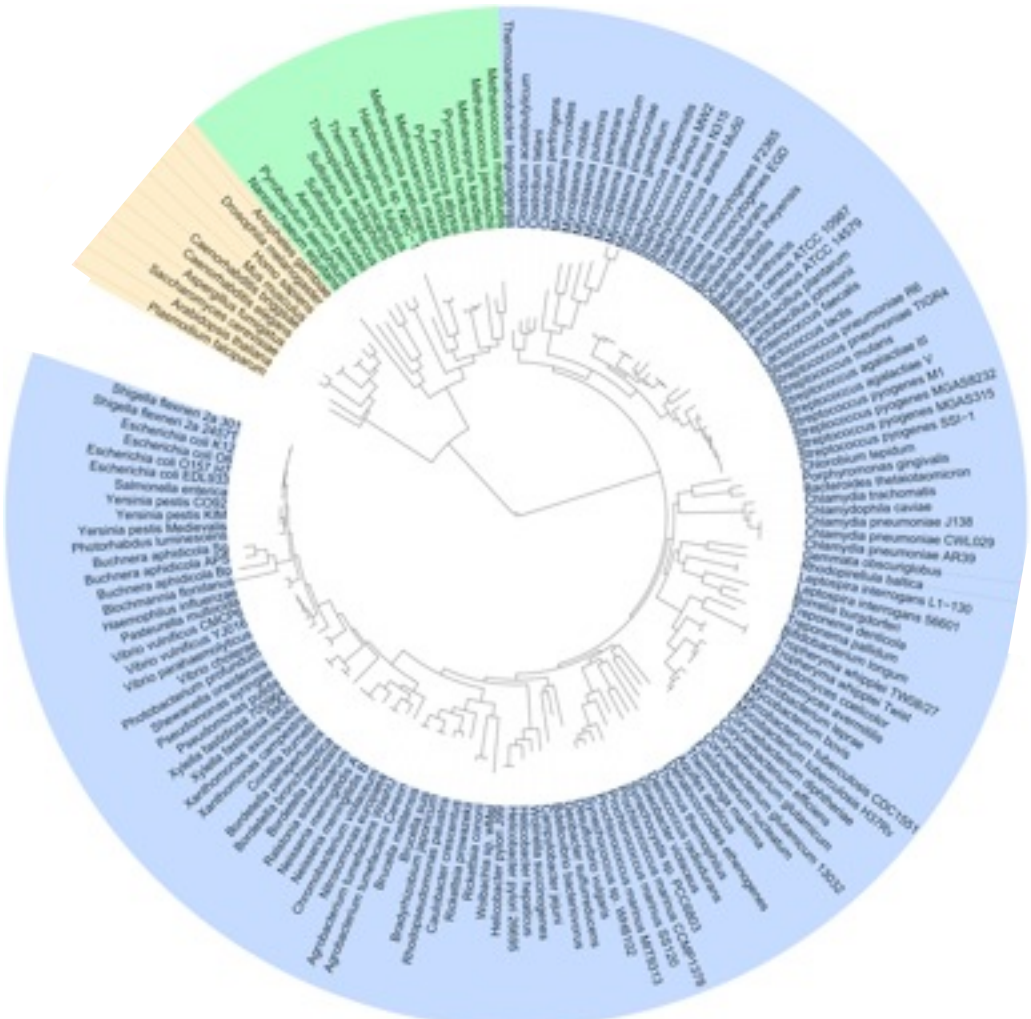

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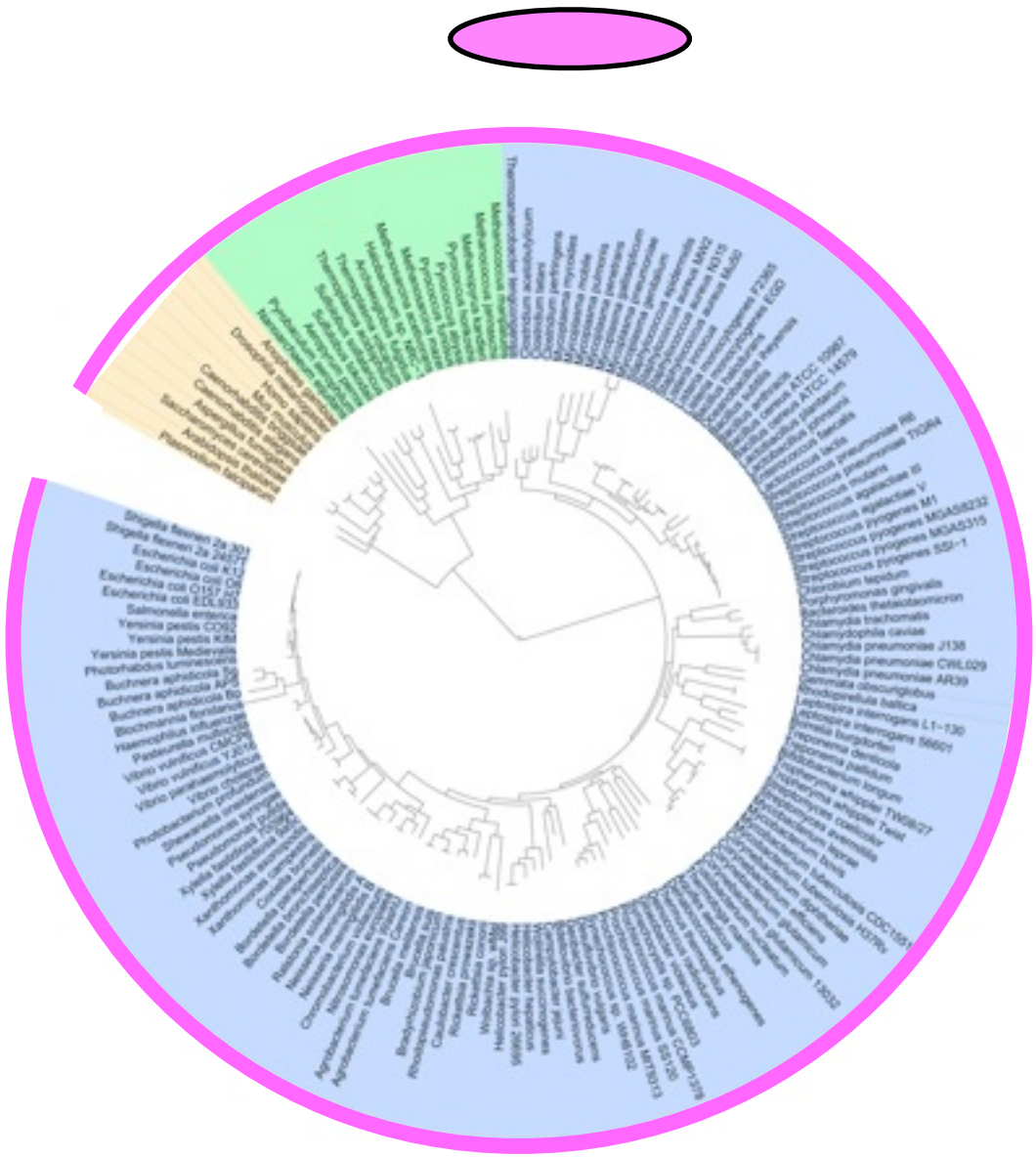

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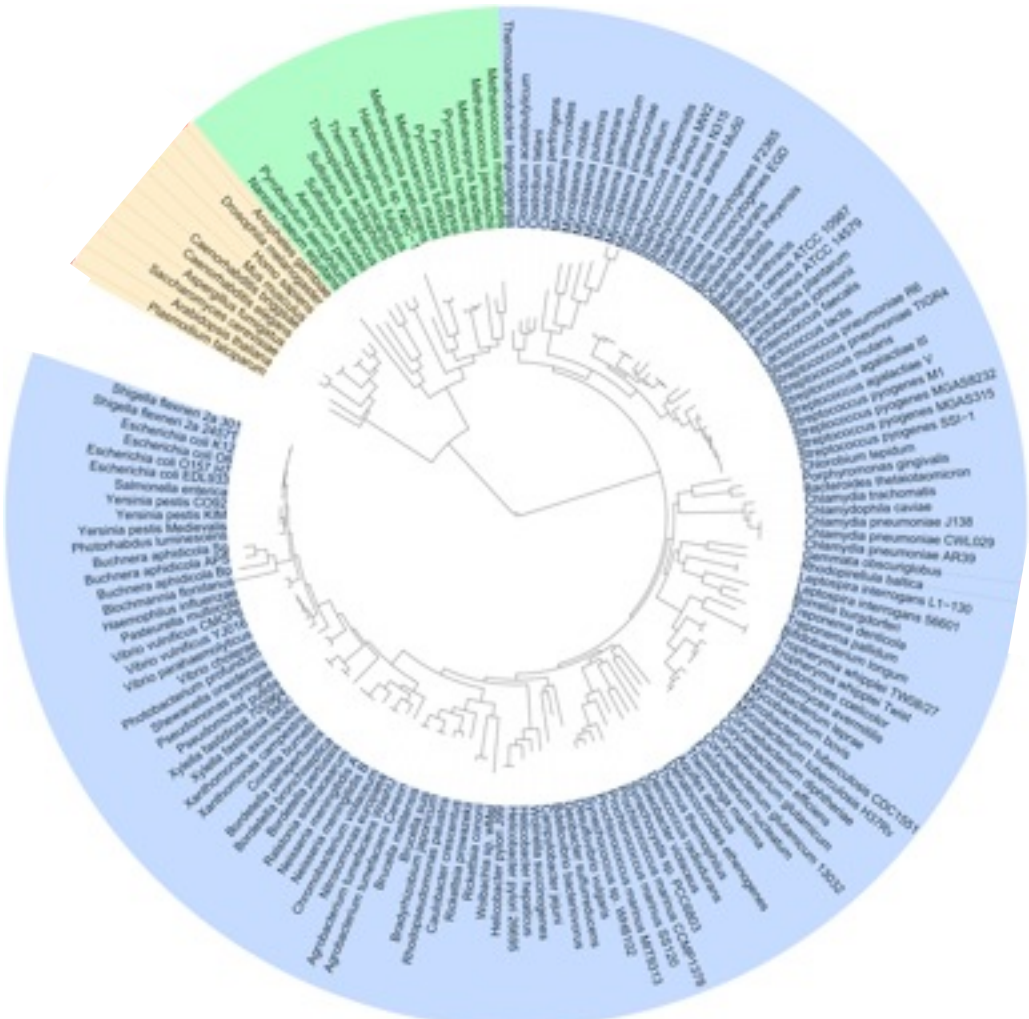

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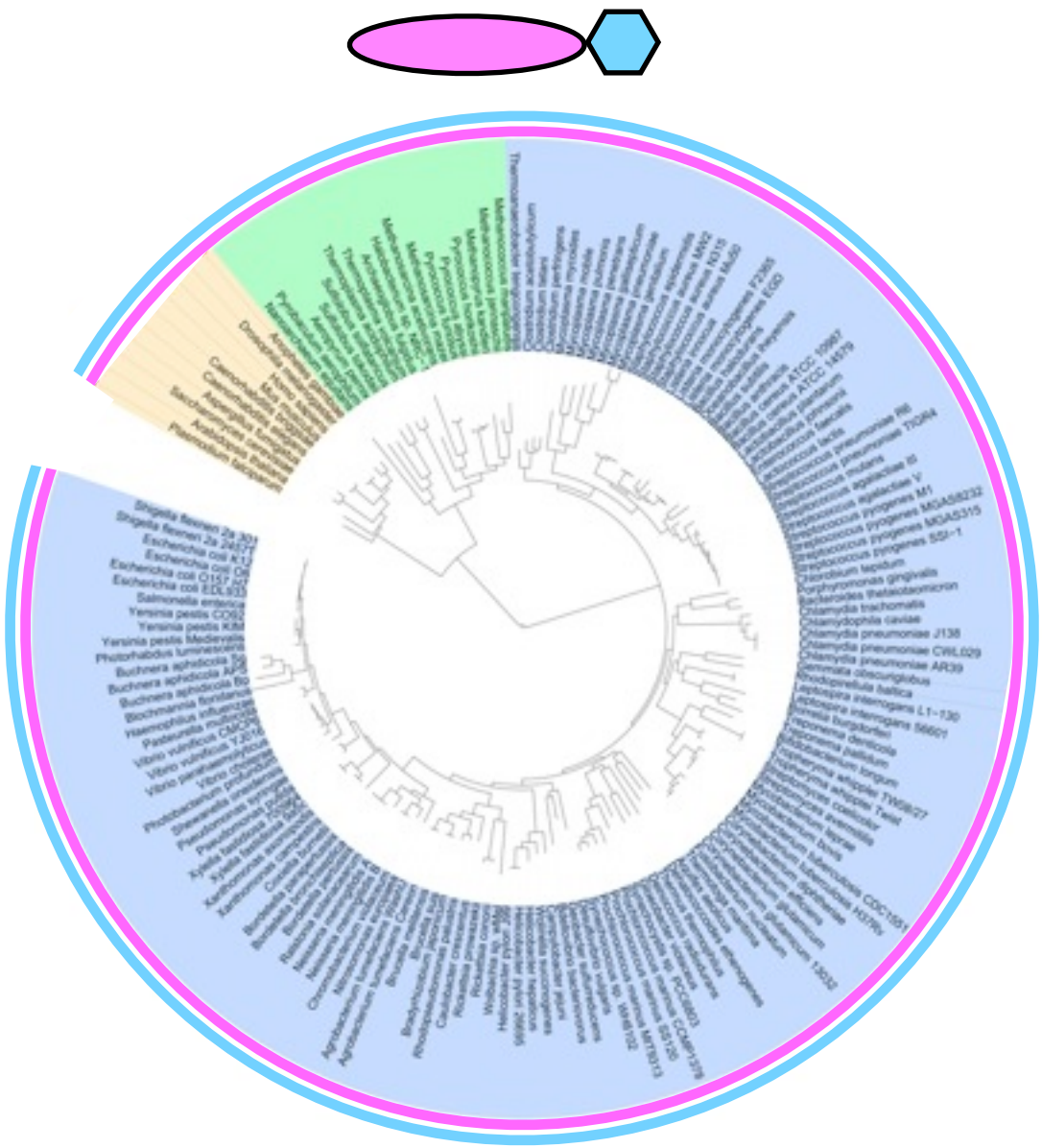

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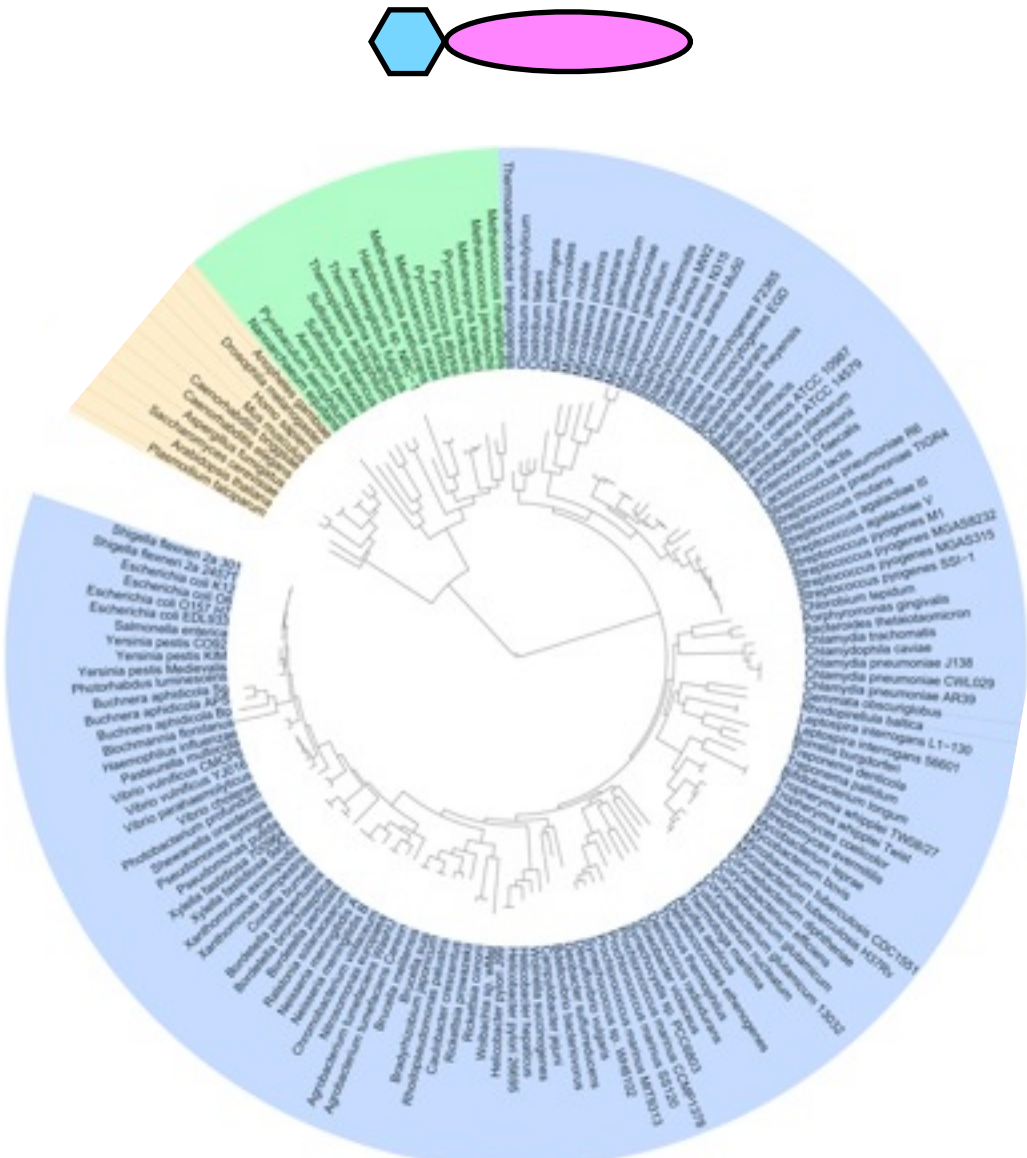

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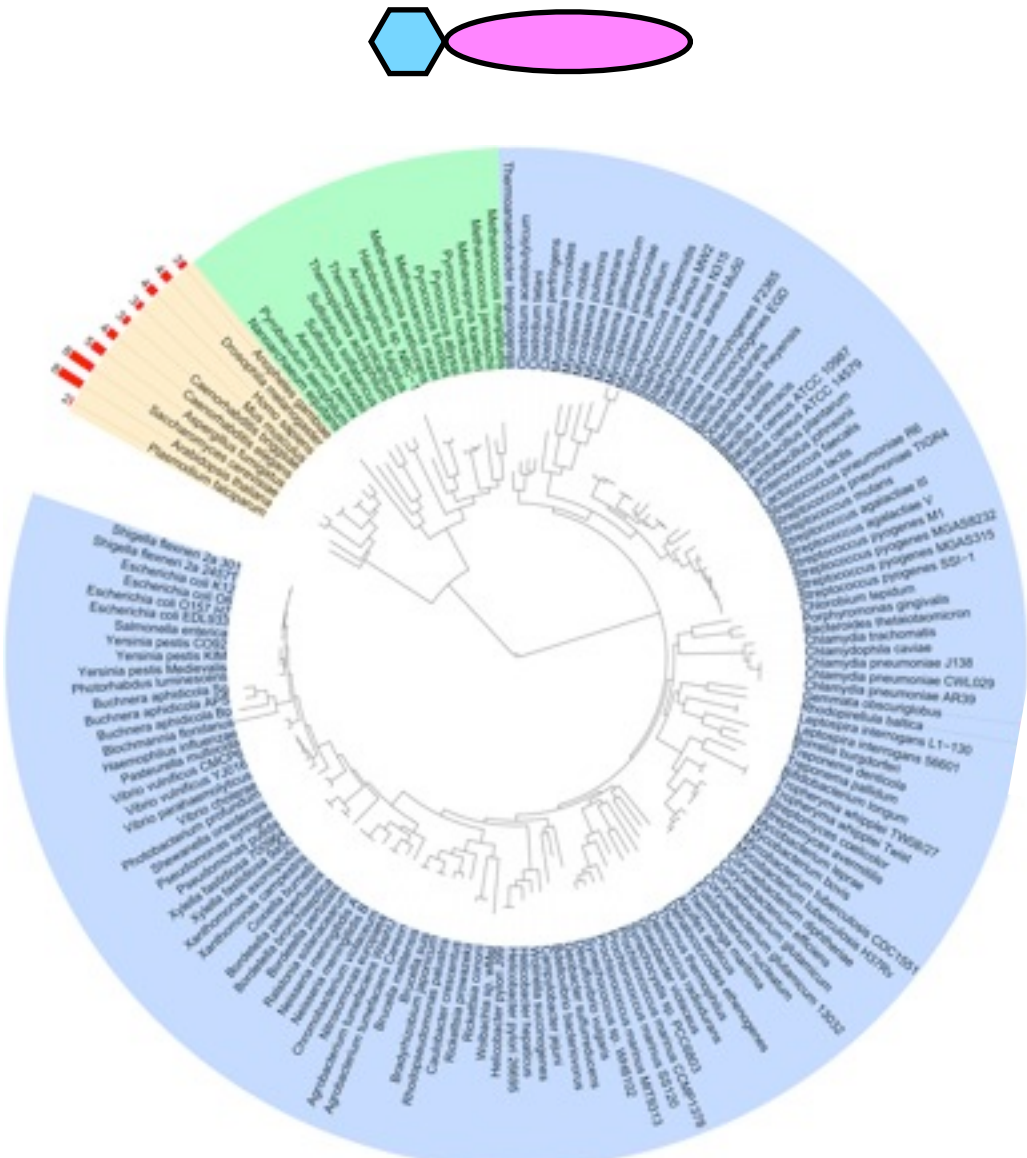

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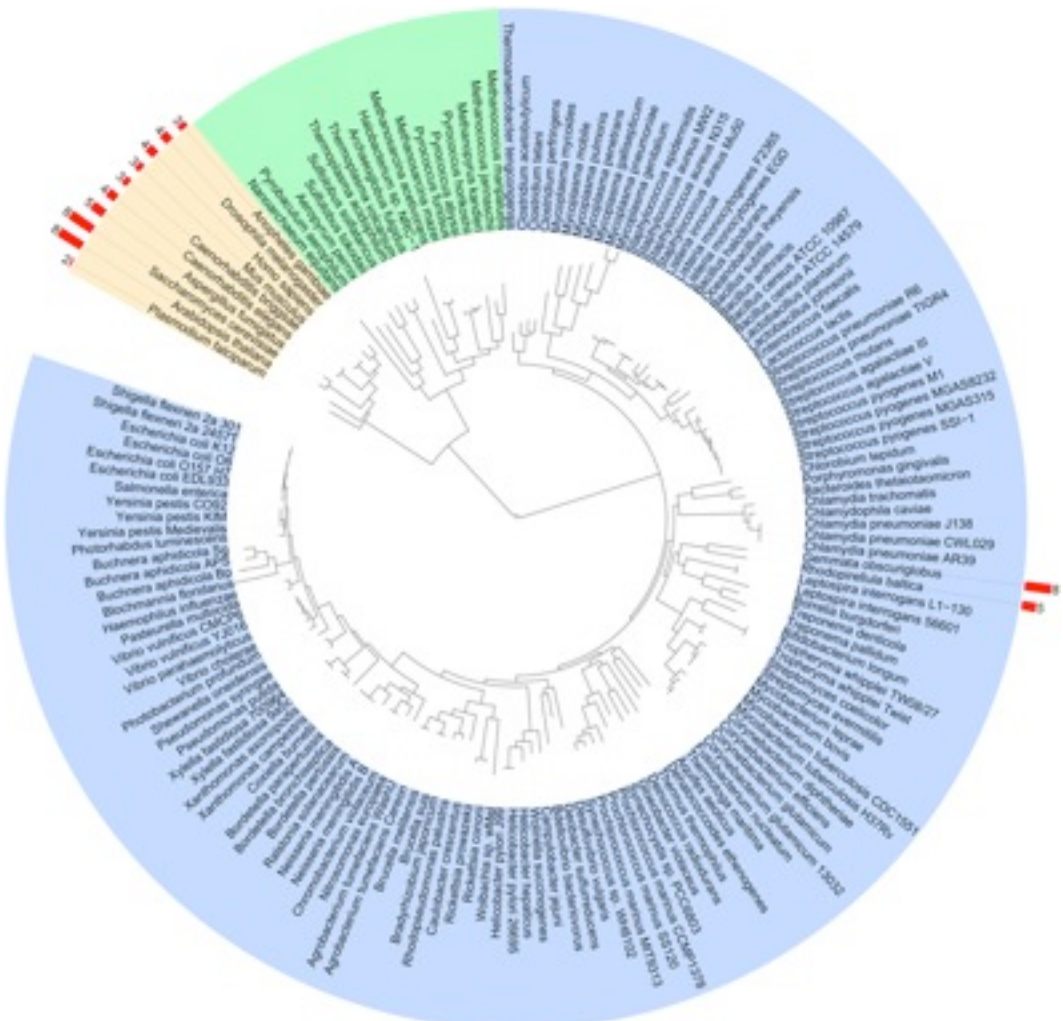


Eukarya
Archea
Bacteria

Santarella *et al.*, *PLoS Biology* 2010

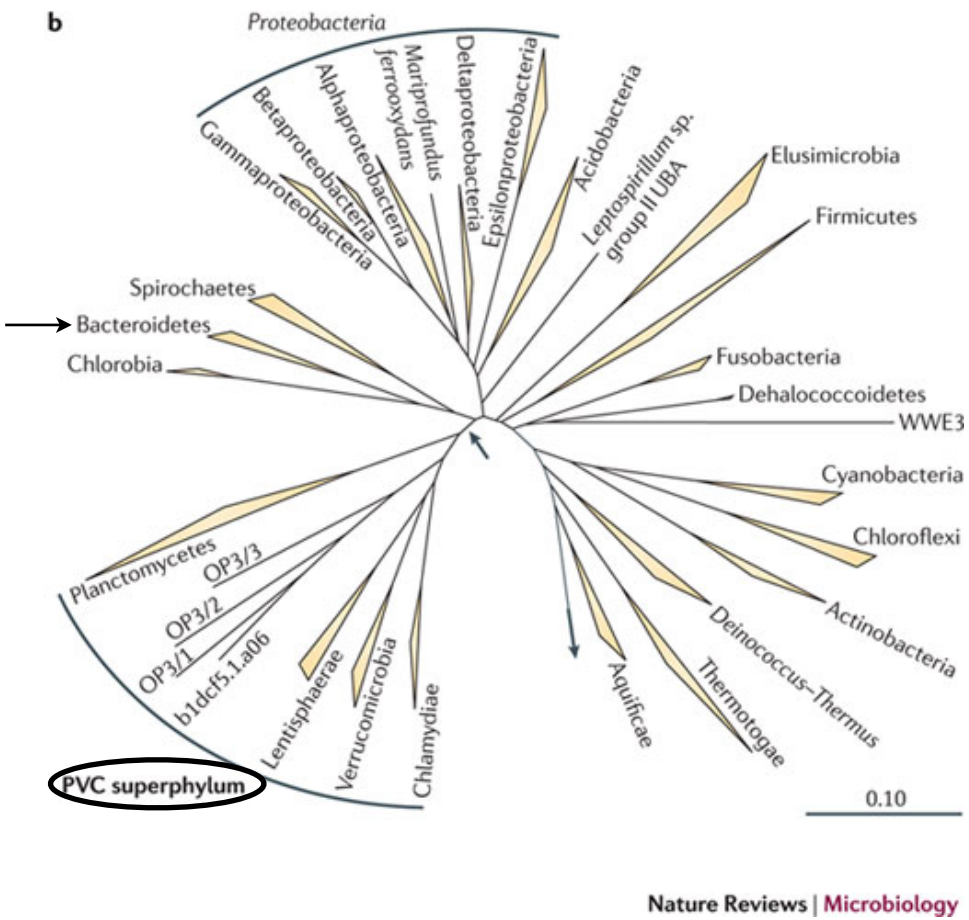
MC Proteins in bacteria

Species	Phylum	Number of MCs
Chlamydophila felis Fe/C-56	C	0
Candidatus Protochlamydia amoebophila UWE25	C	0
Chlamydia muridarum Nigg	C	0
Victivallis vadensis BAA-548	L	0
Lentisphaera araneosa HTCC2155	L	9
Candidatus Kuenenia stuttgartiensis	P	0
Blastopirellula marina DSM 3645	P	11
Planctomyces maris DSM 8797	P	11
Rhodopirellula baltica SH 1	P	5
Gemmata obscuriglobus UQM 2246	P	8
Akkermansia muciniphila BAA-835	V	0
Methylacidiphilum infernorum V4	V	0
Opitutaceae bacterium TAV2	V	0
Opitutus terrae PB90-1	V	0
Pedosphaera parvula Ellin514	V	9
Verrucomicrobium spinosum	V	16
Chthoniobacter flavus Ellin428	V	14

V: Verrucomicrobia, L: Lentisphaerae, P: Planctomycetes, C: Chlamydiae

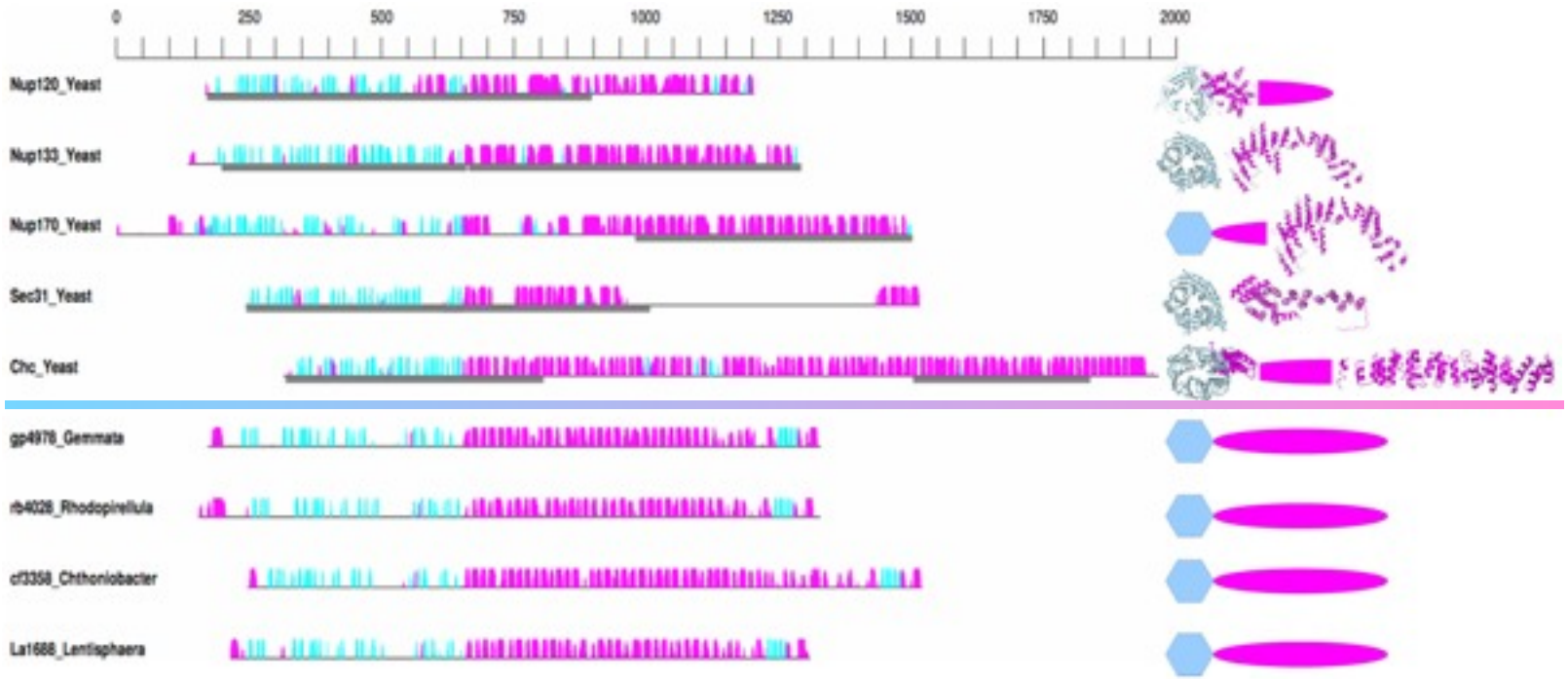
Santarella *et al.*, *PLoS Biology* 2010

The PVC bacterial super-phylum



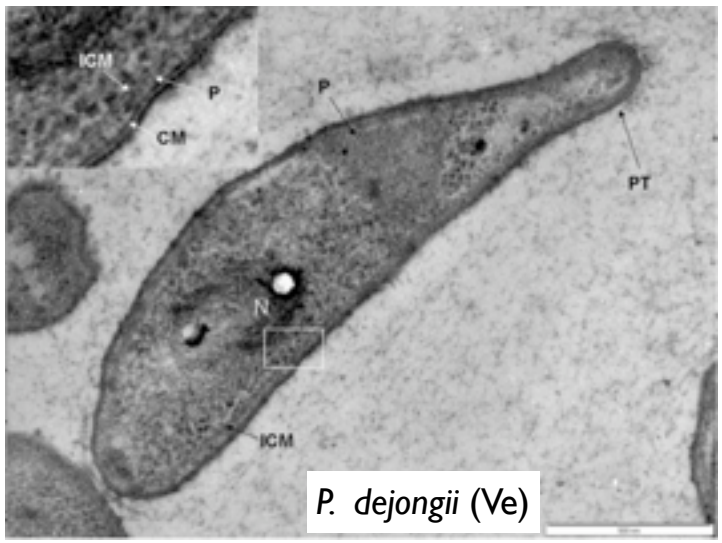
Fuerst & Sagulenko *Nat Rev Microbiol* 2011

Bacterial proteins have the MC architecture

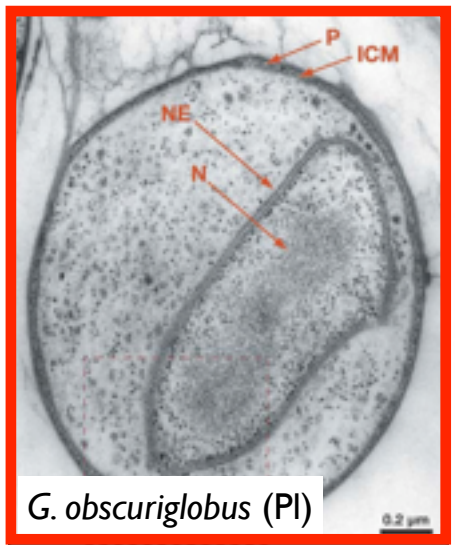


Santarella *et al.*, *PLoS Biology* 2010

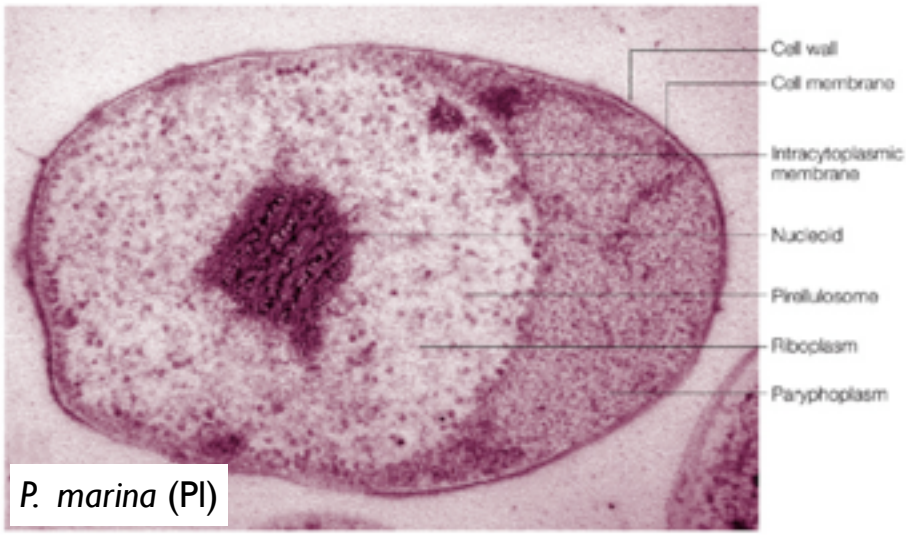
PVC: The Compartmentalized Bacteria



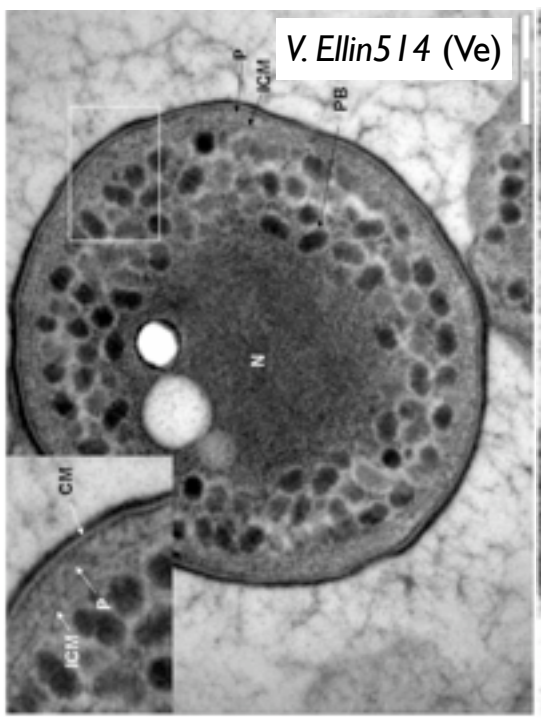
P. dejongii (Ve)



G. obscuriglobus (Pl)

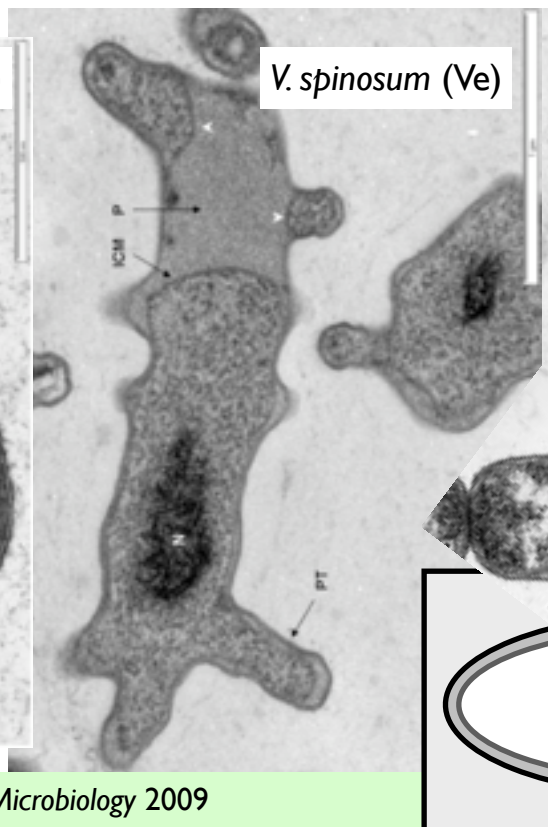


P. marina (Pl)

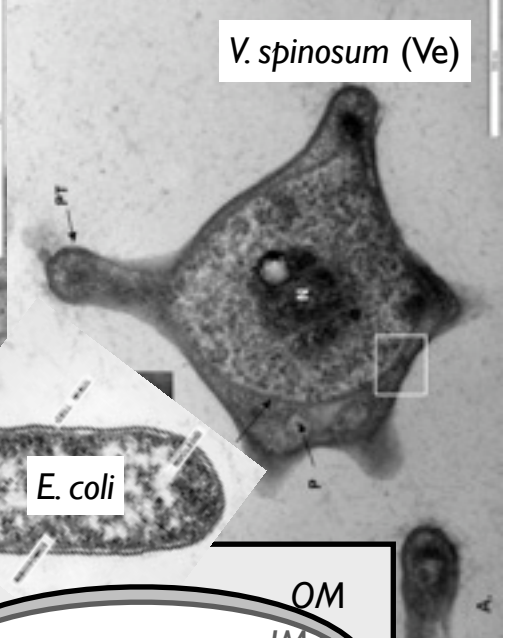


V. Ellin514 (Ve)

P. dejongii (Ve)



V. spinosum (Ve)



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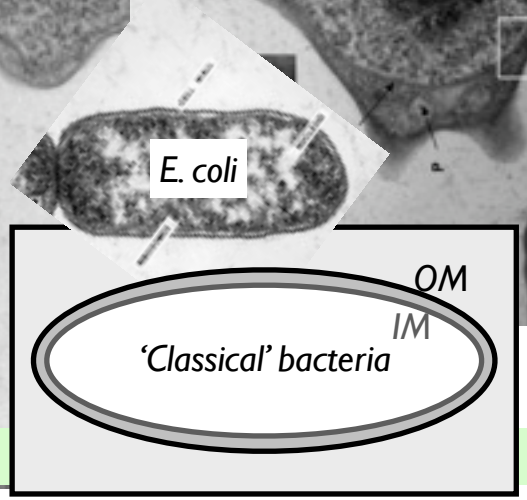
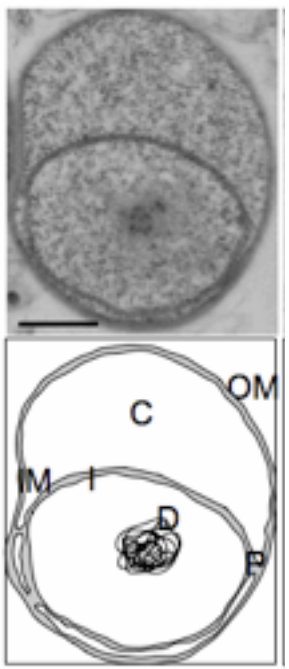


Lee et al., *BMC Microbiology* 2009

Gemmata obscuriglobus endomembrane variability



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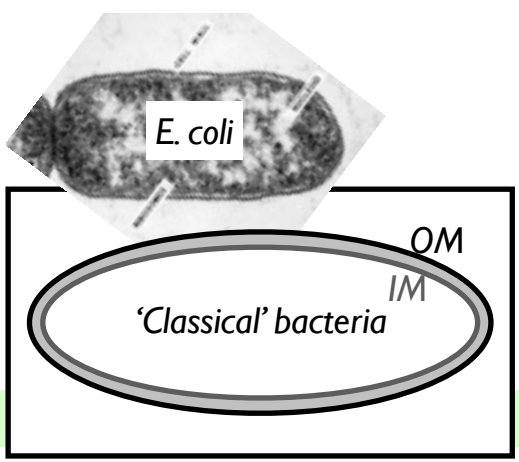

Santarella *et al.*, *PLoS Biology* 2010

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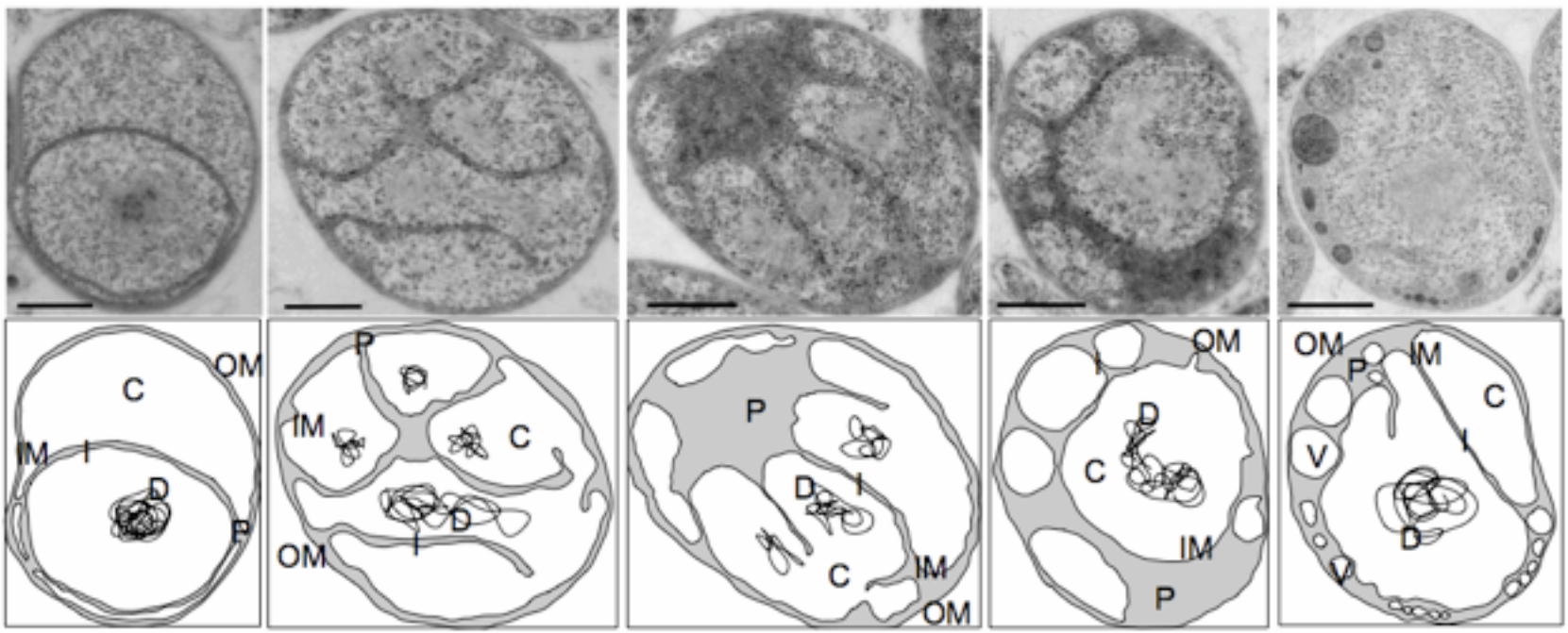

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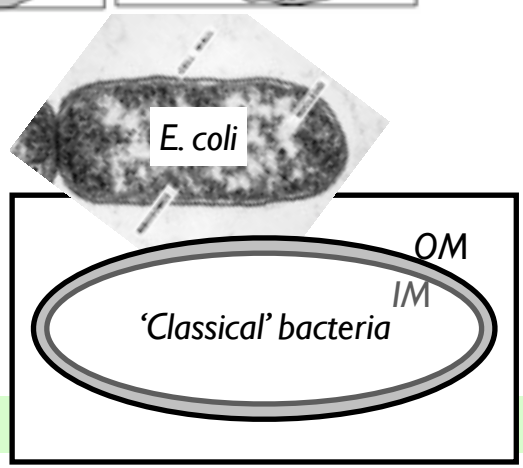
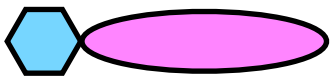
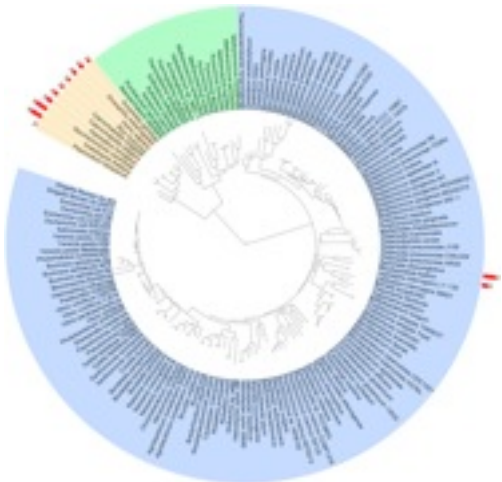


Santarella *et al.*, *PLoS Biology* 2010

Bacterial MC at the vesicle membranes





Santarella *et al.*, *PLoS Biology* 2010

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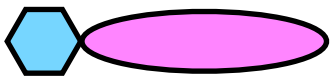

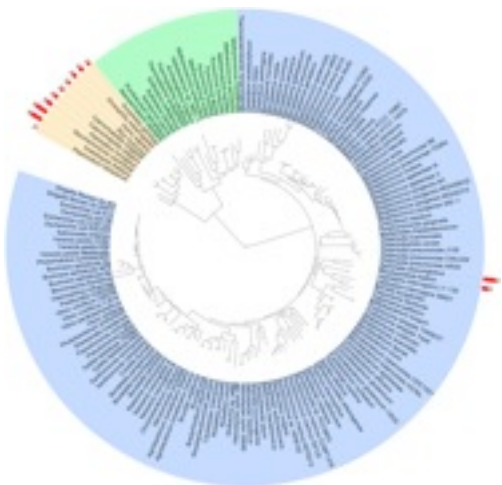

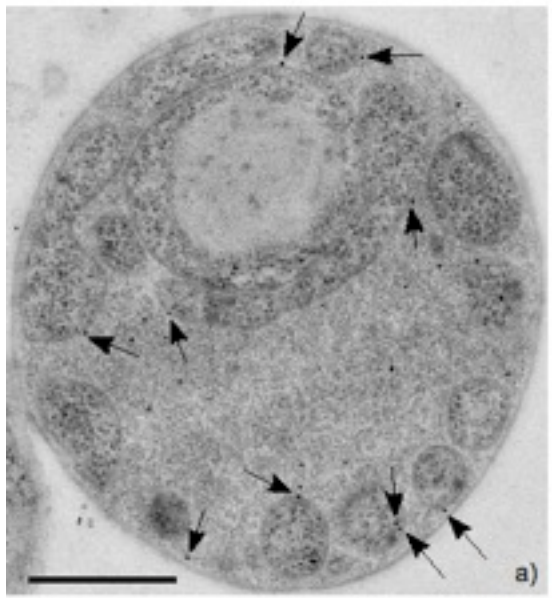

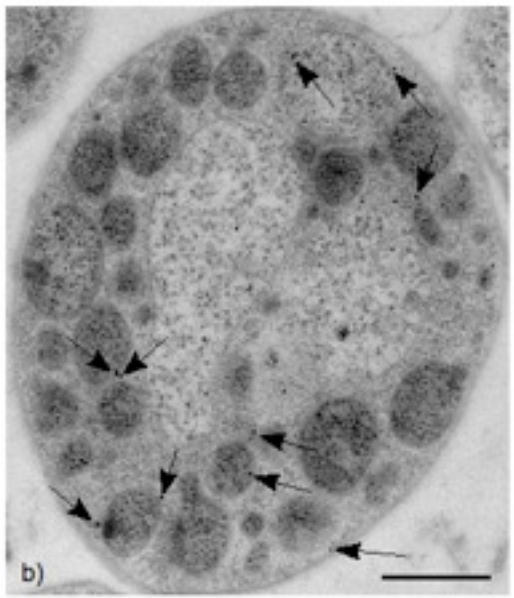

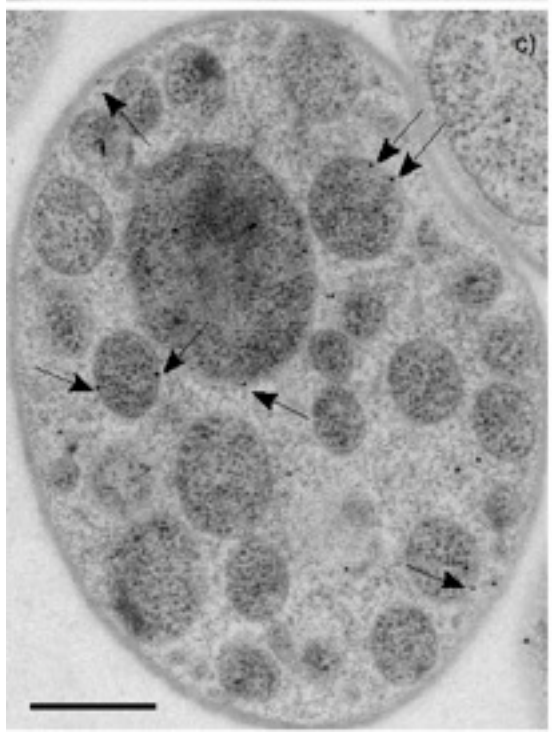

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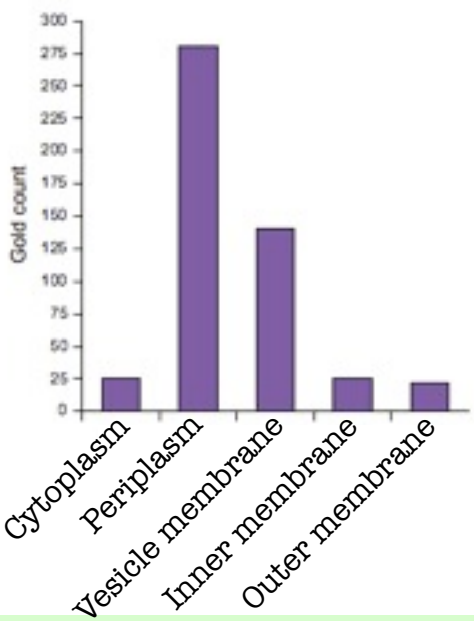

Santarella *et al.*, *PLoS Biology* 2010

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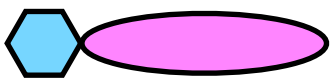
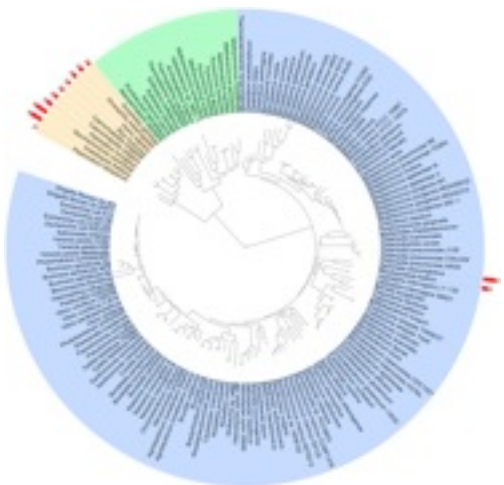
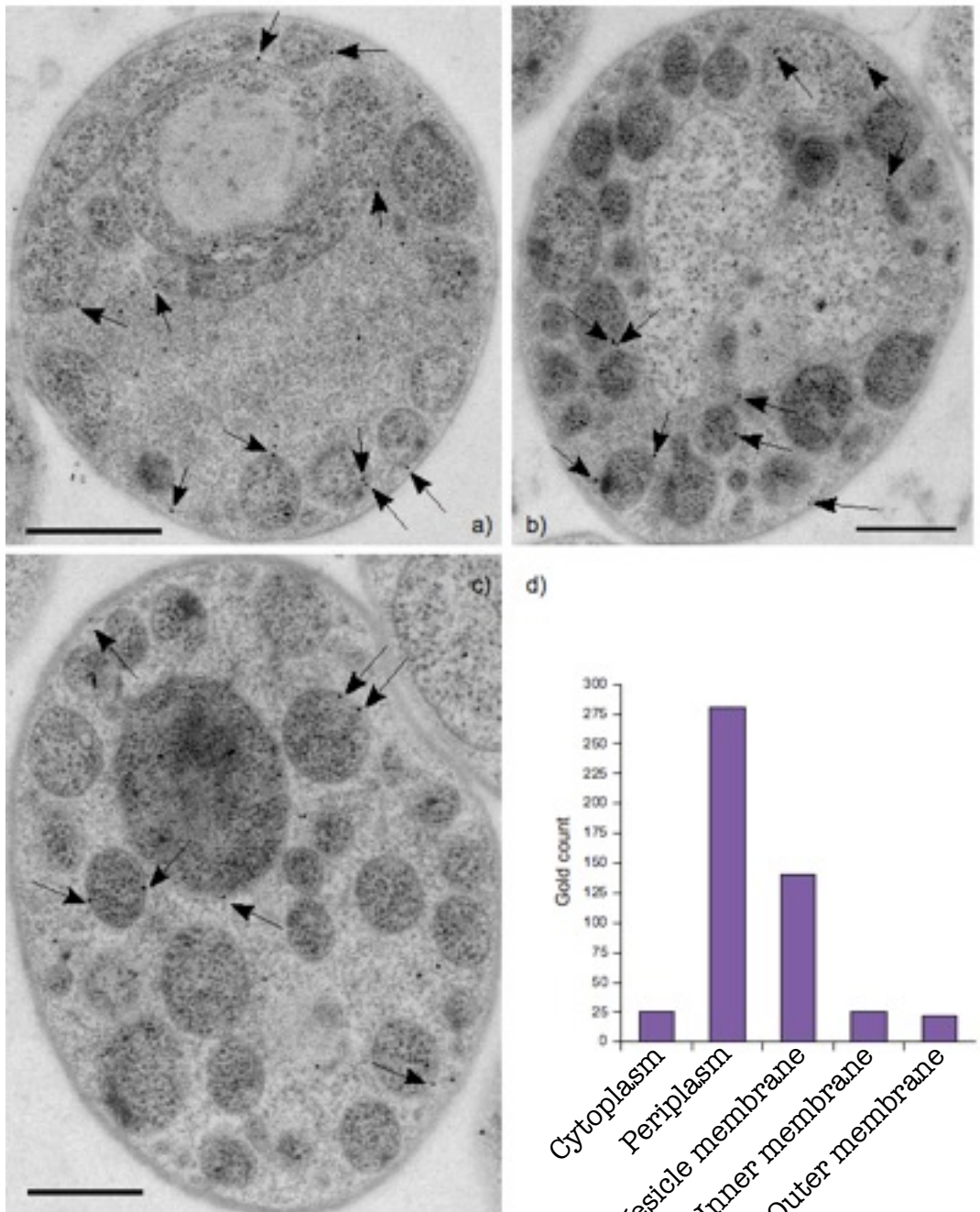


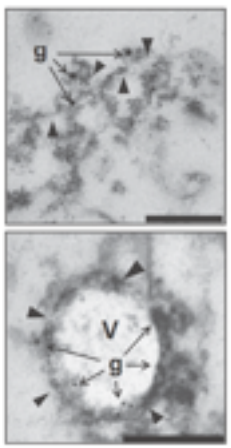


Bacterial endomembrane system unlike any other bacterial one sustain by eukaryotic-like membrane coats

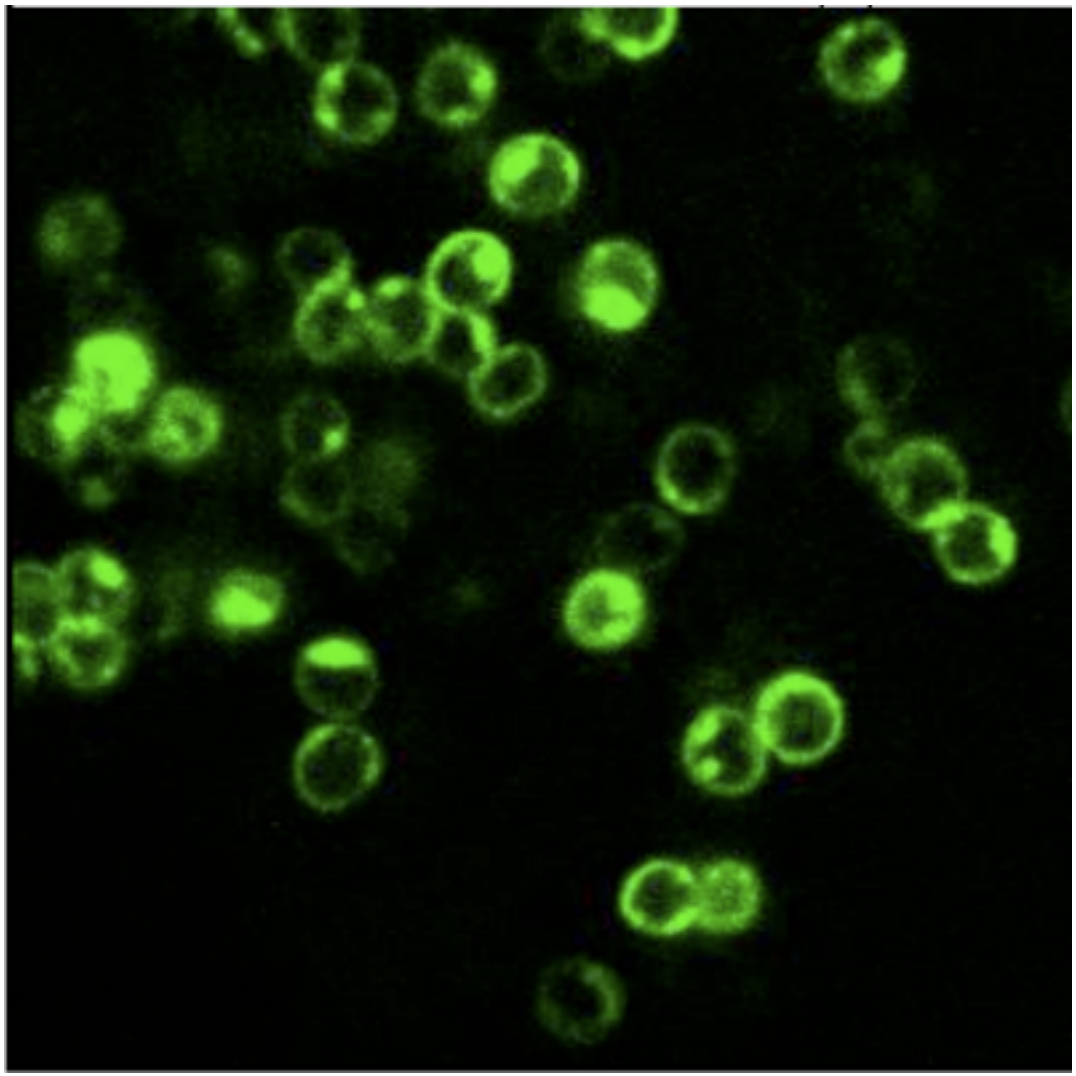


Santarella *et al.*, *PLoS Biology* 2010

Endocytosis in G. obscuriglobus

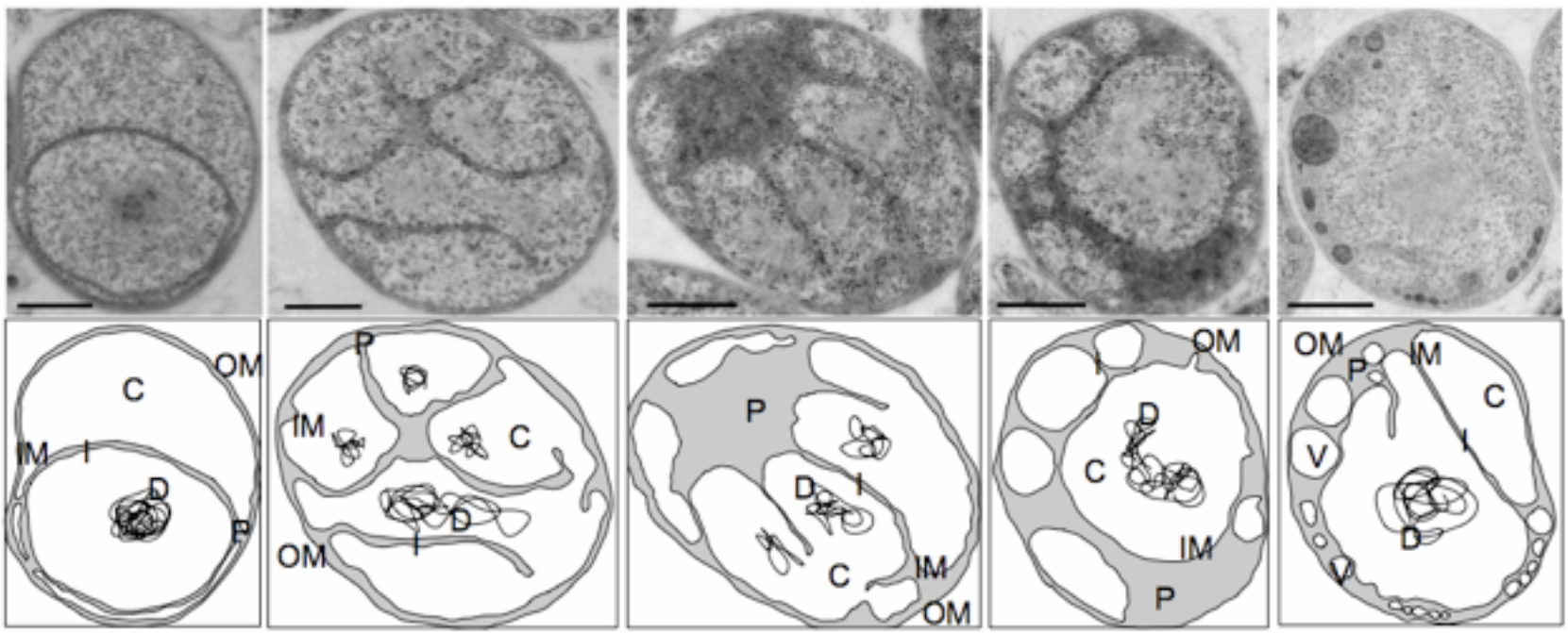


MCs associated
to vesicles



Lohnienne *et al.*, *PNAS* 2010

Gemmata obscuriglobus
The compartmentalized bacteria?



- C: Cytoplasm
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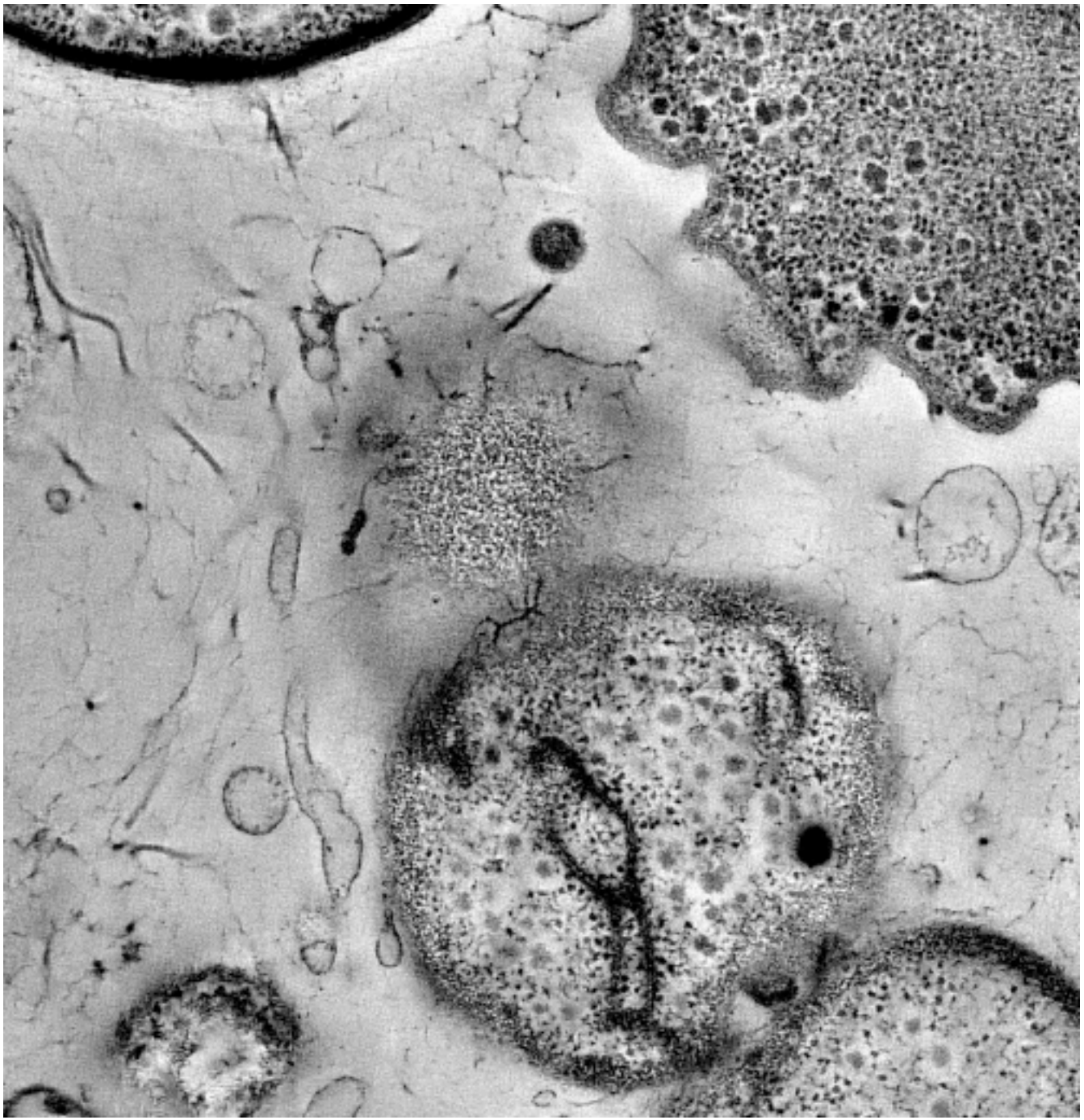
- I: Invagination (of the IM)
- D:DNA

Scale bars: 500nm

Santarella *et al.*, *PLoS Biology* 2010

Gemmata 3D

Sections 250nm
Technai F30 300kv (FEI)
Dual axis tilt series
IMOD
1130 slices/5



Outer Membrane

Inner Membrane

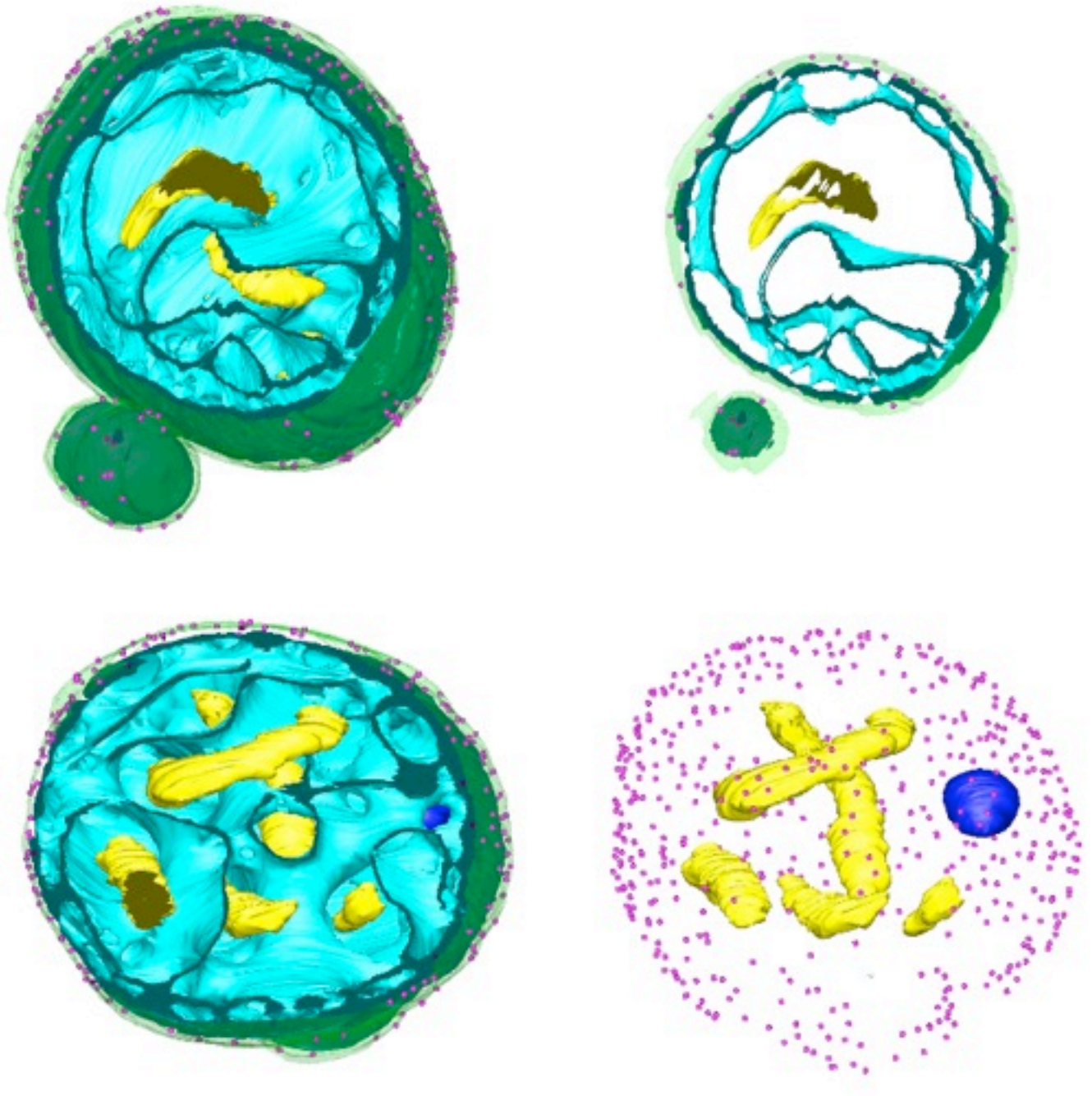
DNA

Granule

Pit

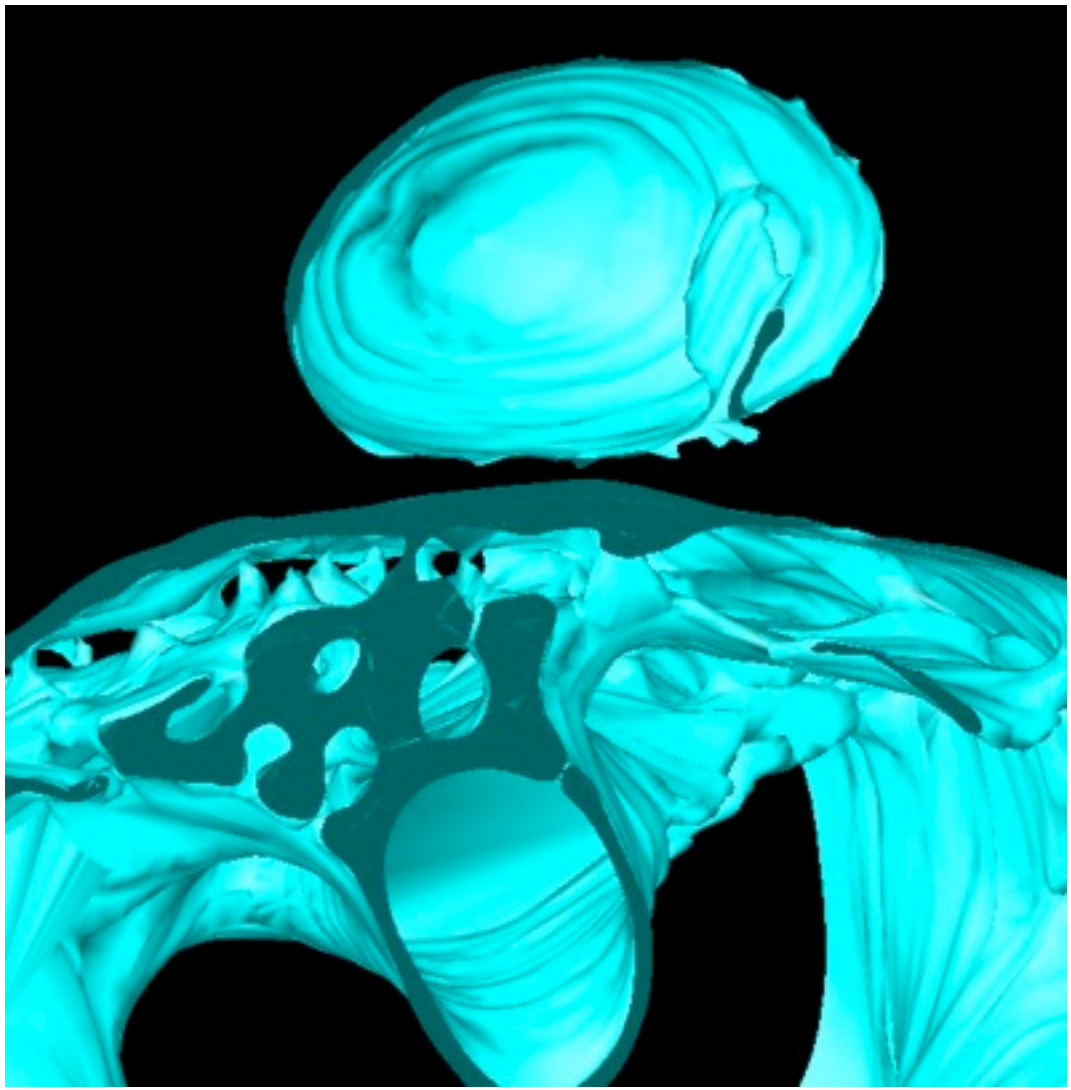
Prugnaller *et al., in preparation.*

No bacterial nucleus



Prugnaller *et al., in preparation.*

Bud and neck



Prugnaller *et al., in preparation.*

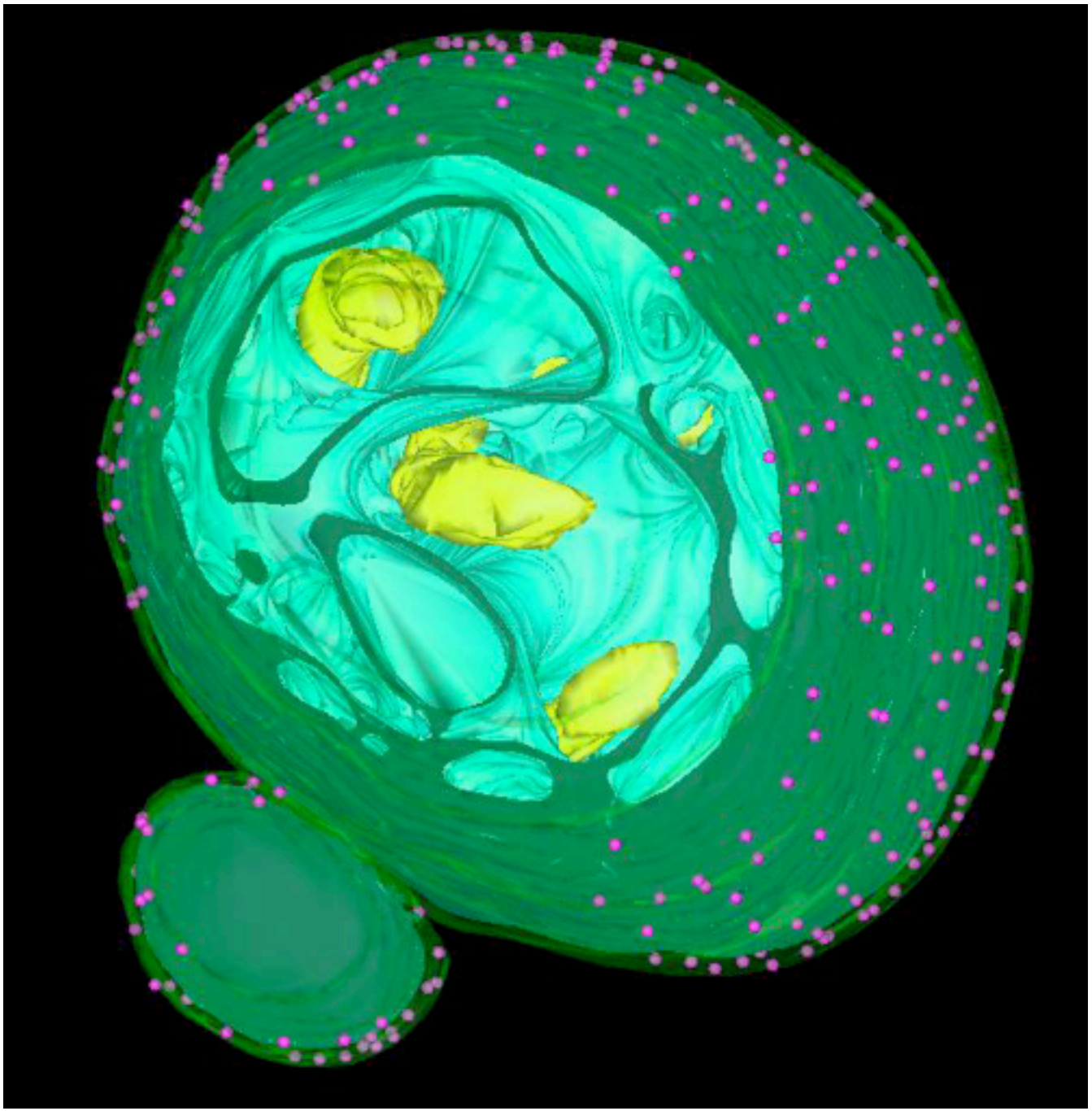
Bud neck

Scale bar: 100nm

Prugnaller *et al., in preparation.*

Gemmata 3D

Sections 250nm
Technai F30 300kv (FEI)
Dual axis tilt series
IMOD
1130 slices/5



Outer Membrane
Inner Membrane
DNA
Granule
Pit

Prugnaller *et al., in preparation.*

Gemmata 3D
conclusions

Extensive membrane organisation

No compartments

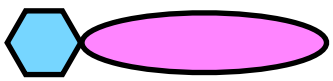
No nucleus

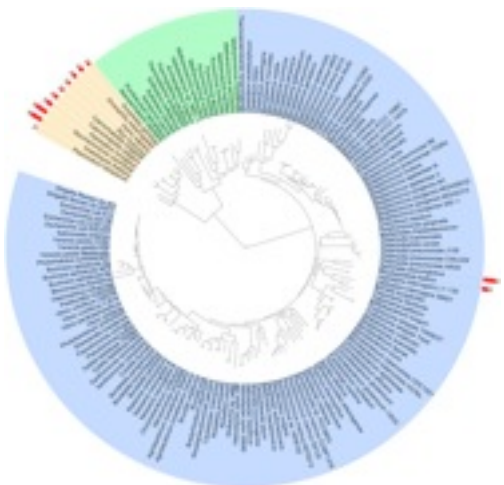
Several chromosomes

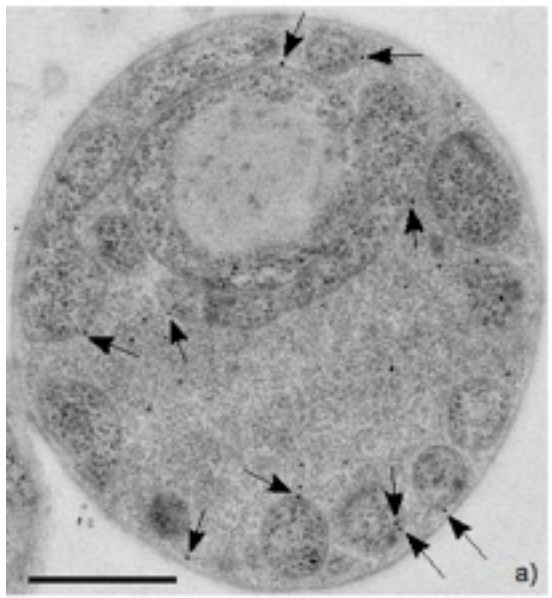
Bud membrane

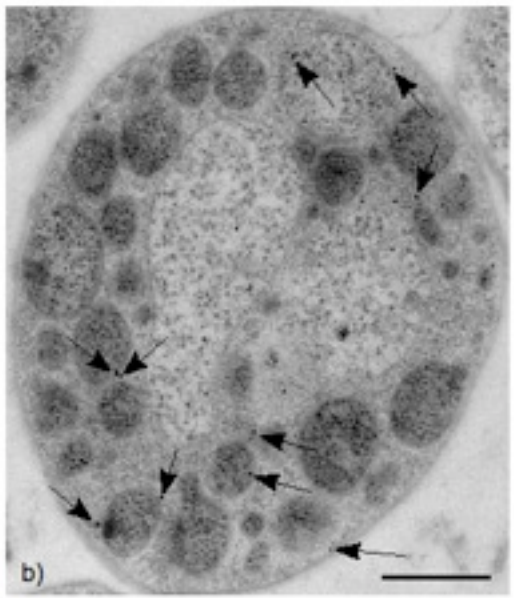
Prugnaller *et al., in preparation.*

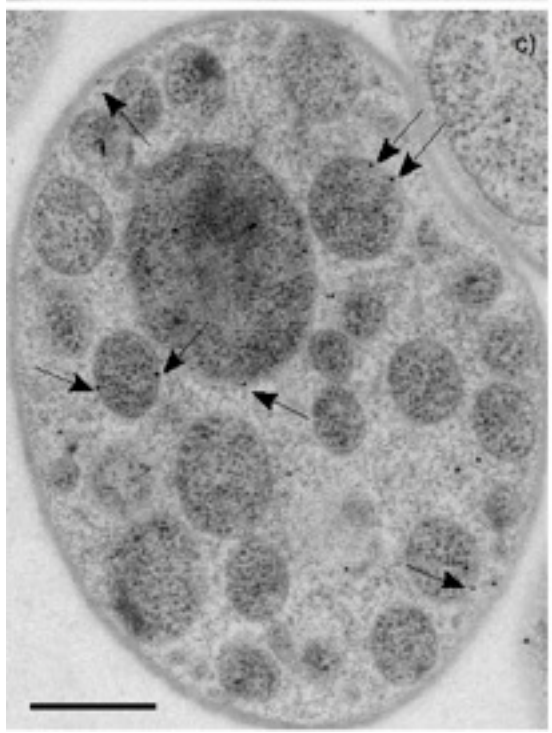
Complex bacterial endomembrane system











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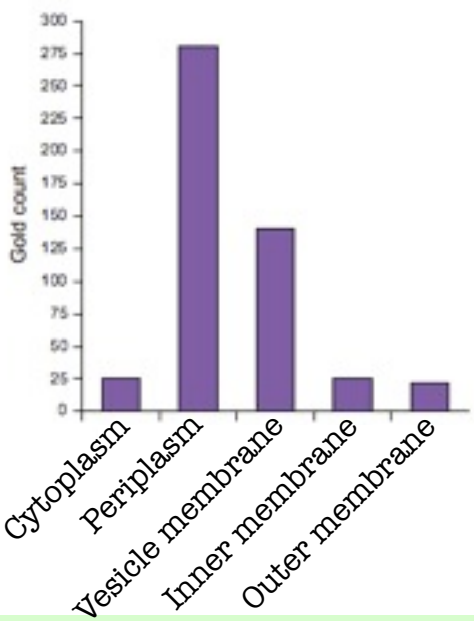
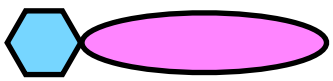
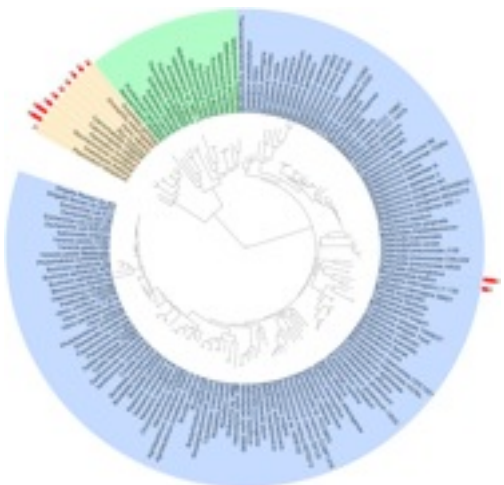


Santarella *et al.*, *PLoS Biology* 2010

Complex bacterial endomembrane system





Bacterial endomembrane system
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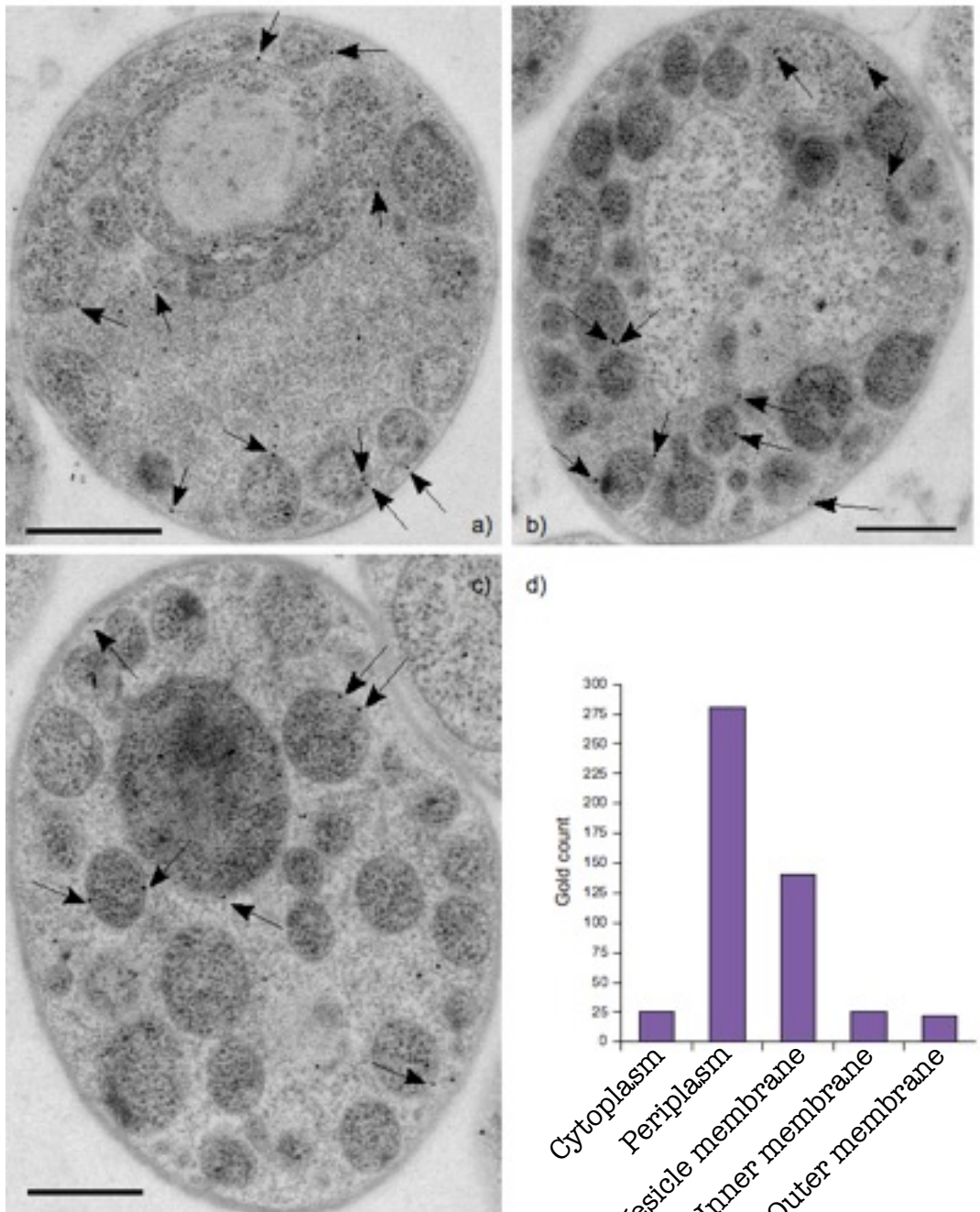

Santarella *et al.*, *PLoS Biology* 2010

Homologous?

Lack of sequence similarity

(doesn't imply lack of homology MreB/Actin & FtsZ/Tubulin)

HGT (too complex)

Convergence

Similarity of features (tertiary structure and function)

Devos & Reynaud, *Science* 2010; Reynad & Devos, *Proc R Soc B* 2011

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The bacterial PVC superphylum might have lain on the path of the origin of the eukaryotic endomembrane

Devos & Reynaud, *Science* 2010; Reynad & Devos, *Proc R Soc B* 2011

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The bacterial PVC superphylum might have lain on the path of the origin of the eukaryotic endomembrane

Might the bacterial PVC superphylum have lain on the path of the origin of other eukaryotic or archaeal characters?

Devos & Reynaud, *Science* 2010; Reynad & Devos, *Proc R Soc B* 2011

Euk/Arch characteristics in the PVC superphylum

PVC Superphylum		
Features	**Specific to**	**Found in**
Compartmentalized cell plan (*20*)	Eu	Pl, Ve
DNA surrounded by membrane (*21*)	Eu	Pl
Condensed DNA (*22*)	Eu	Pl
Division by budding (*24*)***	Eu	Pl
Membrane coats (*11*)	Eu	Pl
Sterol (*25*)	Eu	Pl, Ch
Peptidoglycan loss (*26*)	Eu, Ar*	Pl, Ch
Proteic cell wall (*27*)	Eu	Pl
Ester and ether lipids (*28*)	Ar	Pl
FtsZ loss (*7*)	Eu, Ar**	Pl, Ch
Tubulin (*8, 9*)	Eu	Ve
C1 transfer (*29, 30*)	Ar	Pl
Endocytosis (*15*)	Eu	Pl

Eukaryotes (Eu),
Planctomycetes (Pl),
Gemmata obscuriglobus(Ge),
Annamox (An),
Verrucomicrobia (Ve),
Chlamydiae (Ch),
Archaea (Ar),
Crenoarchaeota (Cr).

Devos & Reynaud, *Science* 2010; Reynad & Devos *Proc R Soc B* 2011

Euk/Arch characteristics in the PVC superphylum

- No other prokaryote display so many euk or arch features.

- There is no other prokaryote that combines all those similarities into a single group.

- In some cases, PVC one is the most similar to the eukaryotic equivalent or to the primitive feature (endomembranes/sterol).

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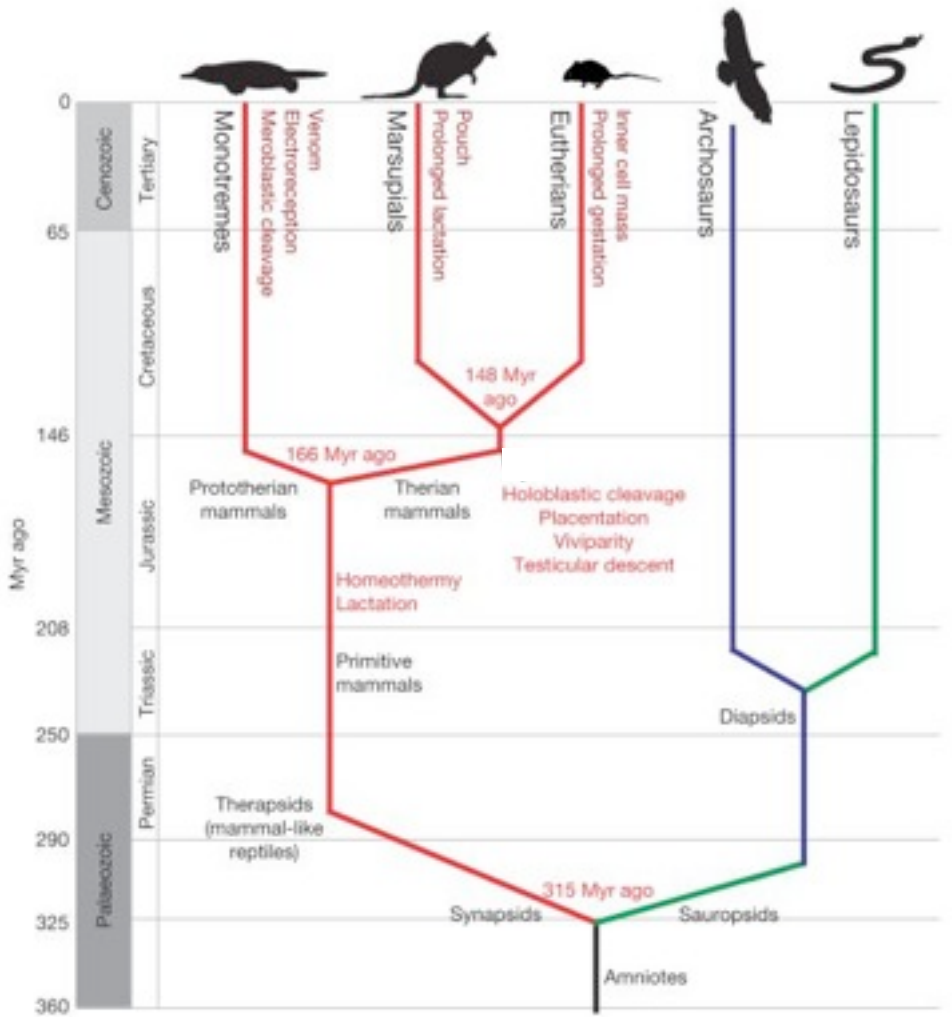
Devos & Reynaud, *Science* 2010; Reynad & Devos *Proc R Soc B* 2011

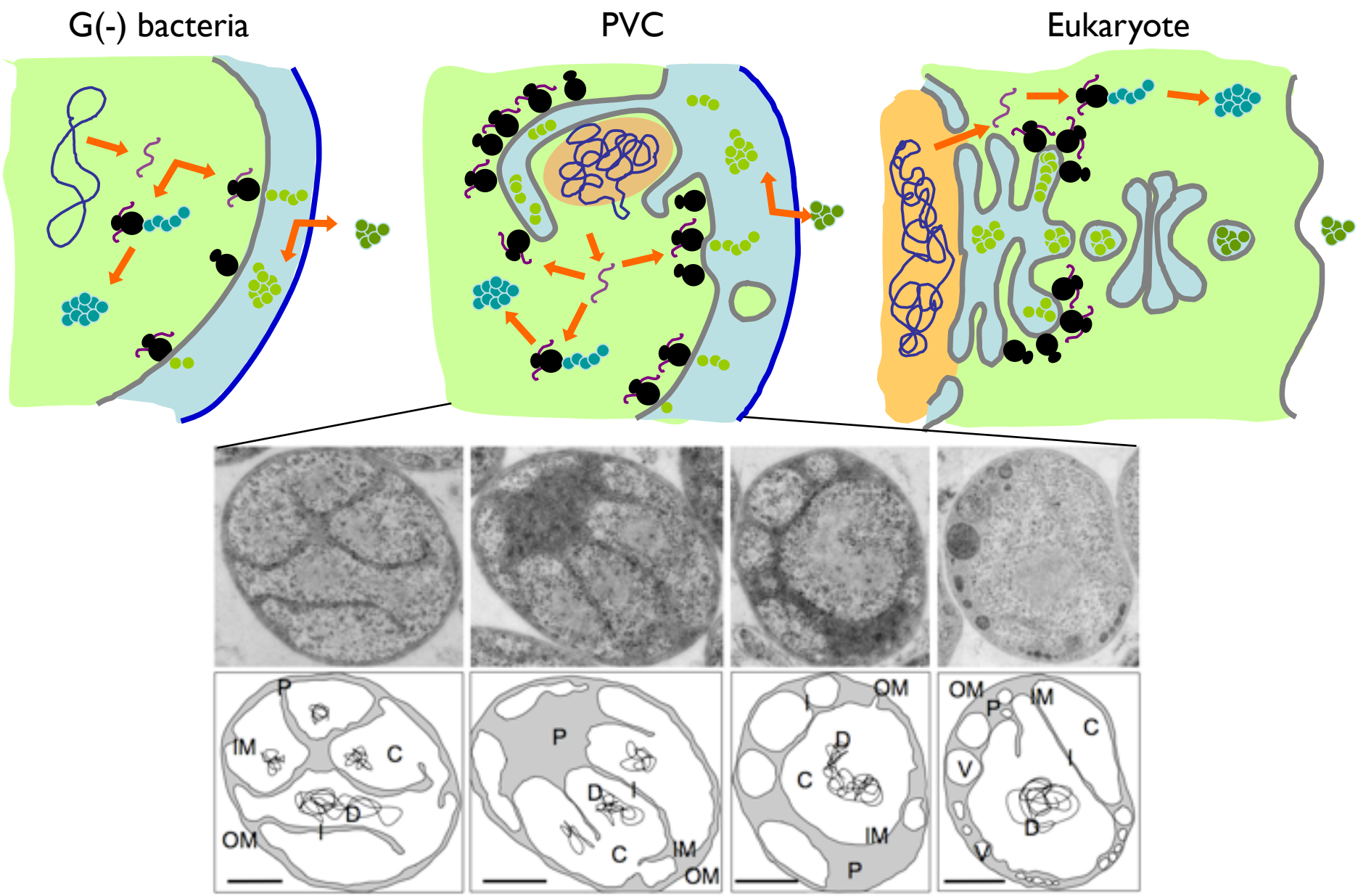
Microbiology's platypus



Similar to the platypus that exhibits a combination of characteristics that are a legacy of the common ancestor shared between birds, reptiles and mammals, the archaeal and eukaryotic features found in PVC members might reflect a common ancestor between bacteria and the LAECA

Warren *et al.*, *Nature* 2008

Internalization of the bacterial periplasm at the origin of the eukaryotic endoplasm



Devos & Reynaud, *Science* 2010; Reynad & Devos *Proc R Soc B* 2011

Thanks to

Andrej Sali
Frank Alber
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Queensland Uni, Australia
John Fuerst

UCD, Ireland
Emmanuel Reynaud

EMBL
Iain Mattaj
Sabine Pruggnaller
Rachel Santarella
and the Mattaj group

Mike Rout
Brian Chait
Josef Franke
Svetlana Dokudovskaya
Rosemary Williams

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and the Sali Group

Queensland Uni, Australia
John Fuerst

Center for Organismal Studies (COS) Heidelberg Univ.

Now hiring!

UCD, Ireland
Emmanuel Reynaud

Mike Rout
Brian Chait
Josef Franke
Svetlana Dokudovskaya
Rosemary Williams

EMBL
Iain Mattaj
Sabine Pruggnaller
Rachel Santarella
and the Mattaj group