OA1.5 - What happened to the phycobilisome? Losses, replacements and repurposing in the evolution of photosynthetic eukaryotes.

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The recent explosion in genomic information has revealed a multitude of ways in which photosynthetic eukaryotes have gained genes: primary, secondary and tertiary endosymbioses, horizontal gene transfer, gene and genome duplication, virus infection, etc., with the result that their genomes are a mosaic of genes from many sources. Gene losses are also common, but what are the processes that could have lead to the loss of a large multiprotein structure like the phycobilisome (PBS), the light-harvesting antenna of the ancestral cyanobacterium? It is a highly ordered complex made up of phycobiliprotein rods held together by protein linkers, and organized to give a very efficient energy cascade from phycoerythrin (PE) to phycocyanin (PC) to allophycocyanin (APC) to the reaction centres. In spite its optimal design, the PBS was completely lost from the green algal/plant lineage, one of the three lineages with primary chloroplasts. A necessary pre-condition for this loss must have been the evolution of an alternative light-harvesting antenna not present in the ancestral cyanobacterium, namely the three-helix Chl-binding LHC family. But this didn't lead to the loss of the PBS in the red algal lineage, which also has the LHC family but still maintains PBSs that are at least as complex as cyanobacterial PBSs (Zhang et al. Nature 551:57-63, 2017).
However, the red PBS was lost from all the algae that acquired red algal plastids via independent secondary endosymbioses. In most cases this was accompanied by massive expansion of the LHC superfamily. Going further, in the spirit of "reduce-reuse-recycle", the cryptophyte algae salvaged the plastid-encoded PE-β subunit and combined it with a nuclear-encoded protein of unknown origin to make a completely different tetrameric phycobiliprotein antenna, and relocated it to the thylakoid lumen. There are a number of questions about what processes could have led to these losses and replacements –were losses gradual or drastic – and what selective forces (if any) were involved. Possible contributing factors include a more complex assembly process for the PBS, the difficulty of relocating its nuclear-encoded components across the four plastid membranes resulting from secondary endosymbiosis, a higher nitrogen demand/chromophore in biliproteins versus LHCs, the photoprotective carotenoids and xanthophyll cycling in the LHC family, and even intermolecular competition between old and new subunits in the cryptophytes. And, as in all evolutionary enquiries, the roles of chance and contingency should not be neglected (Supported by a NSERC Discovery Grant).