Figure 1. The New Tree of Eukaryotes.
This summary is based on a consensus of recent phylogenomic studies. The colored groupings correspond to the current ‘supergroups’. Unresolved branching orders among lineages are shown as multifurcations. Broken lines reflect lesser uncertainties about the monophyly of certain groups. Star symbols denote taxa that were considered as supergroups in early versions of the supergroup model; thus, all original supergroups except Archaeplastida have either disappeared or been subsumed into new taxa. The circles show major lineages that had no molecular data when the supergroup model emerged, most often because they had not yet been discovered. Rappemonads (in parentheses) are placed on the basis of plastid rDNA data only. The putative new major lineages Microheliella and Anaeramoeba are not shown due to the limited evidence that they belong outside all existing groups shown here (Table 1).
[very simplified] scheme of plastid endosymbioses

(more in "Protistology")
oceanic phytoplankton – "basic scheme" of the **RECENT** global structure

Figure 3 - **Variations saisonnières des peuplements de phytoplancton** (en bleu : haptophytes; en vert : Prochlorococcus; en jaune : Synechococcus; en rouge : diatomées). Les diatomées abondent au printemps aux hautes latitudes, où les haptophytes dominent le reste de l’année. Prochlorococcus et Synechococcus dominent en permanence dans les régions tropicales.
Figure 1. Climatological map Distribution of annual marine NPP for (a) NASA Ocean Biogeochemical Model and (b) Vertically-integrated Production Model (VGPM) for the period from September 1998 to 2011 (Rousseaux – August 1999, Blue < 100 g C m⁻², Green > 110 g C m⁻² and < 400 g C m⁻², Red > 400 g C m⁻²) (Rutgers Institute of Marine and Gregg, 2014). Globally, diatoms accounted for about 50 per cent of NPP while coccolithophores, chlorophytes and cyanobacteria accounted for about 20 per cent, 20 per cent and 10 per cent, respectively. Diatom NPP was highest at high latitudes and in equatorial and eastern boundary upwelling systems. Coastal Sciences, http://marine.rutgers.edu/opp/. Coastal ecosystems (red – green) and the permanently stratified subtropical waters of the central gyres (blue) each account for ~30 per cent of the ocean’s NPP, whereas the former accounts for only ~8 per cent of the ocean’s surface area compared to ~60 per cent for the open ocean waters of the subtropics (Geider et al., 2001; Marañón et al., 2003; Muller-Karger et al., 2005).

Malone et al. 2016, Primary Production, Cycling of Nutrients, Surface Layer and Plankton
palaeozoic vs. recent marine phytoplankton

Götz & Feist-Burkhardt, 2012, Palaeogeogr, Palaeoclim, Palaeoecol
Le Hérissé et al., 2009, Palynol.
Fig. 2. Molecular timescale for Heterokonta using minimum and maximum inference of the age of the root at 900 Ma (grey) and 1200 Ma (black), respectively (Douzery et al. 2004), and with Rhizosolenia root constrained to 93 Ma based on biochemical isoprenoid evidence in this genus by Sinninghe-Damsté et al. (2004). A grey box indicating the time point of the P/T boundary at 250 Ma as estimated from the minimum and maximum age priors (program constraints as above) is placed over tree. a = origin of the pigmented Heterokonta, b = origin of the diatoms. All time estimates in the table inset are shown with the time as estimated with a 900 or 1200 Ma constraint on the crown group radiation and their standard error. Original data set found in Medlin et al. (1997). Heterotrophic taxa are coloured in grey.
Fig. 3. Molecular timescale for haptophytes using minimum and maximum inference of the age of the root at 900 Ma (grey) and 1200 Ma (black), respectively (Douzery et al. 2004). A grey box indicating the time point of the P/T boundary at 250 Ma as estimated from the minimum and maximum age priors (program constraints as above) is placed over tree. a = divergence of the two classes, b = radiation of the order Prymnesiales. All time estimates in the table inset are shown with the time as estimated with a 900 or 1200 Ma constraint on the crown group radiation and their standard error. Original data set found in Edvardsen and Medlin (2007). Heterotrophic taxa are coloured in grey.
classical geological boundary Proterozoikum vs. Mesozoikum

dramatic decline of diversity (oceans > continents)
extinction of multiple high-order lineages – including apparent algal/protist groups
dramatic fluctuation in sea level
fluctuations in global temperature
jumps in primary productivity (ratio of C12/C13)
changes in basic features of rivers (braided vs. meandering)
long-term change in vegetation patterns
acidification of oceans and strong increase in their oxygen limitation / anoxia
increase in atmospheric CO2, decline in oxygen concentration
recent estimates of time scale: between 251.941 ± 0.037 and 251.880 ± 0.031 My

Burges, 2014, Nature 111

Siberian traps
Haptista - Haptophyta

lineage including organisms with key effects on global ecosystem (carbon cycle, dimethylsulfide);
ca 300 recent species, only about 15 species in freshwater [incl. Corcontochrysina noctivaga]
some marine and brackish taxa produce toxins (e.g. Prymnesium – fish poisoning)

Diagrammatic cross-section of a coccolithophore cell and cell-wall coverings

Haptophyta – phylogeny and systematics

Pavlovophyceae
Coccolithophyceae

Edvardsen & Medlin, 2007
**Coccolithales**

coccoliths – calcium carbonate scales on cellular surface

holococcoliths – develop externally on cells

heterococcoliths – develop inside the cells, complex 3D shapes

calcification: $2 \text{HCO}_3^- + \text{Ca}^{2+} = \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$

haptophytes make up about 50% of total inorganic carbon pump in the oceans
Figure 2 - Typical coccolithophore life-cycle, and three examples
Evolutionary patterns of diversity in major marine phytoplankton groups
Figure 3 - Variations saisonnières des peuplements de phytoplancton (en bleu : haptophytes; en vert : Prochlorococcus; en jaune : Synechococcus; en rouge : diatomées). Les diatomées abondent au printemps aux hautes latitudes, où les haptophytes dominent le reste de l’année. Prochlorococcus et Synechococcus dominent en permanence dans les régions tropicales.
white tides

and - dimethylsulfide - source for the condensation nuclei of clouds
Emiliania huxleyi – one of the most frequent recently occurring eukaryots on Earth

E. hux. is evolutionarily very young – only since Pleistocene
Emiliania huxleyi (Isochrysidales, Noelaerhabdaceae)

Plate 1 - Noelaerhabdaceae: Emiliania

E. hux type A

E. hux type B
Gephyrocapsa oceanica
(Isochrysidales, Noelaerhabdaceae)
- 7.3 my to recent
Young et al., 2003, Journal of Nannoplankton Research
http://www.mikrotax.org/Nannotax3/

Coccolithus pelagicus
(Coccolithales, Coccolithaeae)
- 66 my to recent

Discosphaera tubifera
(Syracosphaerales, Rhabdosphaeraceae)
- 16 my to recent
Braarudosphaera bigelovii
(Braarudosphaeraceae)
- 100.5 my to recent

- an old lineage (since Mesozoic)
- coccoliths develop extracellularly (i.e. probably not homological with other groups)
- probably belongs to Prymnesiales, together with "naked" haptophytes
- haploid stage is known as Chryschromulina parkeae
- in cells - endosymbiotic coccoid, nitrogen-fixing cyanobacterium
- typical coastal planktonic organisms

http://www.mikrotax.org/Nannotax3/
Hagino et al., 2013, Plos One
Coccolithophores and global calcification

Betzler et al., 2017, IODP; Anderson, 2016, Oceanbites
calcifying organisms, such as Coccolithophores, provide long-term carbon sink mechanisms, compensating for instantaneous CO$_2$ excursions.
calcification:  
\[2 \text{HCO}_3^- + \text{Ca}^{2+} = \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}\]

only about 0.5% of \(\text{CaCO}_3\) produced at the surface reaches the ocean floor

DIC is about 15% higher in ocean depths and this is of key importance for atmospheric \(\text{CO}_2\) levels

saturation horizon – below which \(\text{CaCO}_3\) dissolves
**Phaeocystis** – flagellate with sticky chitinous filaments

Genus *Phaeocystis* - ca 10% of global DMS production, coastal white tides
Chrysochromulina

unicellular, planktonic marine [rarely freshwater] flagellates
haptonema usually prominent – attachment to the substrate or to the prey
mixotrophy - phagotrophy, osmotrophy

zdroj: nordicmicroalgae.org
Hymenomonas - a freshwater coccolithophore genus

nonmotile haploid cells (Apistonema stage) and flagellated diploid stage

occurs in oligotrophic phytoplankton
Pavlovophyceae - non-calcified flagellates, incl. some brackish and freshwater taxa

Exanthemachrysis
Pavlova
Rebecca
Diacronema

Rebecca salina

Bendif et al., 2011, Protist

Diacronema (Corcontochrysis) noctivaga
Cryptophyta

cryptophytes – flagellates with (red algal) nucleomorphs, phycobilins (without phycobilisomes) and trichocysts (heterotrophic nutrition)

plankton of freshwater and seas, about 200 species
Cryptomonas – most frequent freshwater genus

marine cryptophytes – e.g. *Rhodomonas* a *Chroomonas*
mostly (sub-)tropical shelf seas