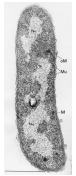
真核微生物：演化、多樣性與環境

Chuan Ku
顧銓
植物暨微生物學研究所
Institute of Plant and Microbial Biology

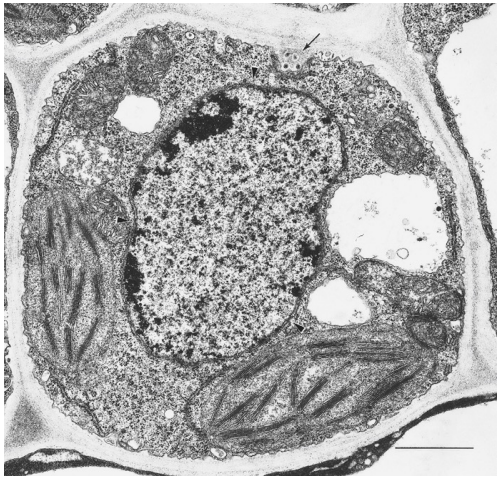
Academia Sinica, Taiwan
January 20, 2024

生命的兩種型式

原核生物（細菌與古菌）



真核生物



Strasburger's Plant Sciences 2014

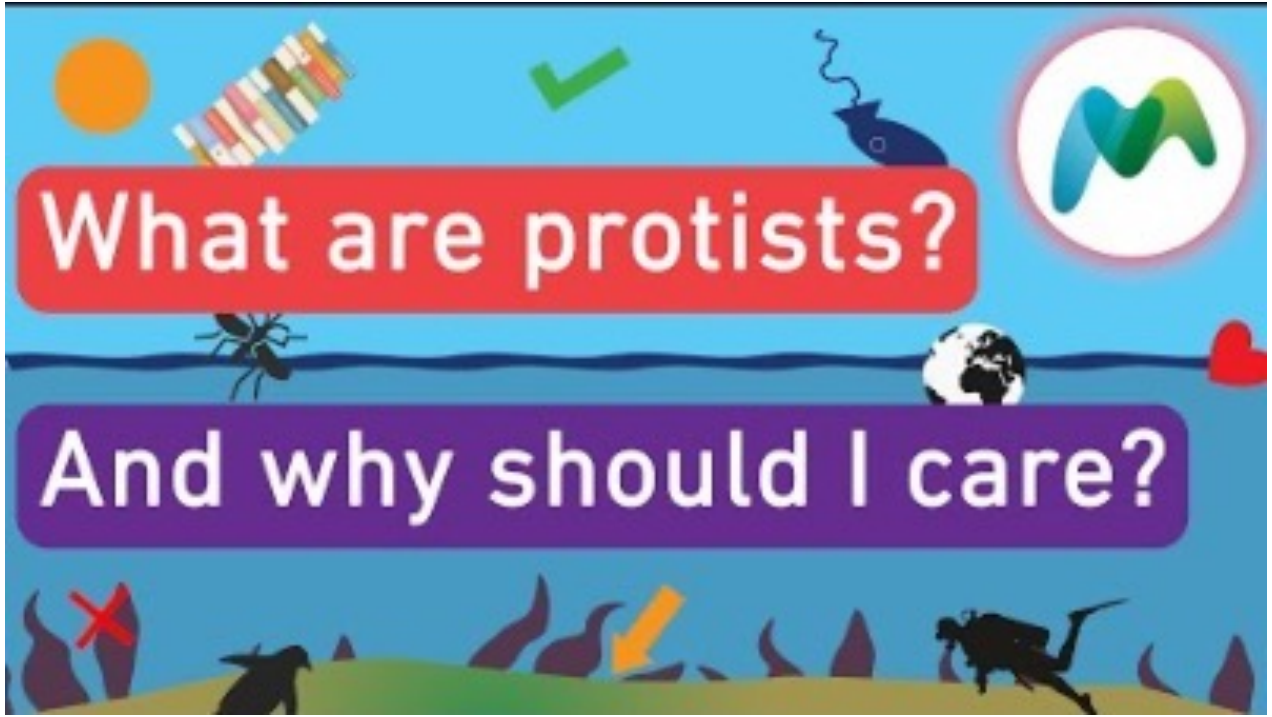
形形色色的真核生物：微生物佔了絕大多樣性

Katz et al. 2012 *Ann. Rev. Microbiol.*

名詞解釋

- 原生生物（protists）是不屬於動物、植物或真菌的真核生物
- 原生生物包含單細胞（unicellular）原生生物及多細胞（multicellular）原生生物
- 肉眼不可見的真核生物又稱微真核生物（microeukaryotes）或真核微生物

為什麼要認識原生生物?



https://youtu.be/0Cbpgoyo6UU?si=btGt0fejO7qfCXs5&t=85

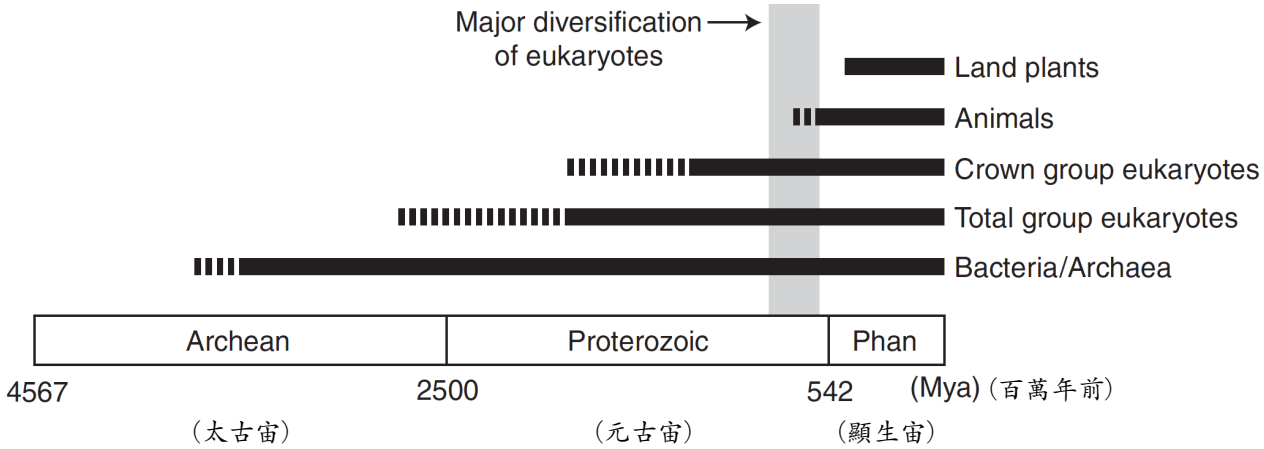
大綱

- 真核生物與其胞器的起源與演化
- 藻類：多樣性、功能與重要性
- 其他單細胞真核生物：寄生蟲與環境微生物
- 真核生物的巨大病毒

大綱

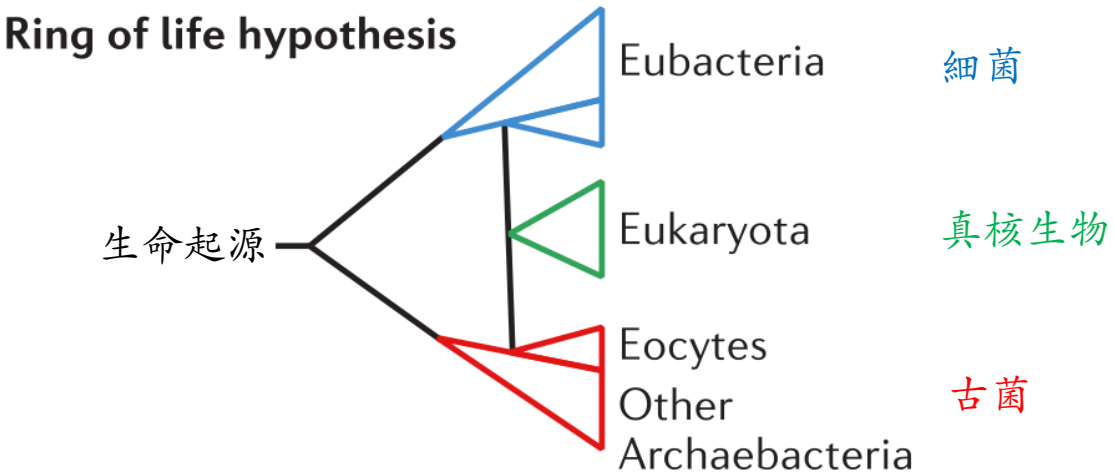
- 真核生物與其胞器的起源與演化
- 藻類：多樣性、功能與重要性
- 其他單細胞真核生物：寄生蟲與環境微生物
- 真核生物的巨大病毒

真核生物起源：化石紀錄



Knoll 2014 *CSH Persp. Biol.*

真核生物起源：基因體顯示融合自細菌與古菌

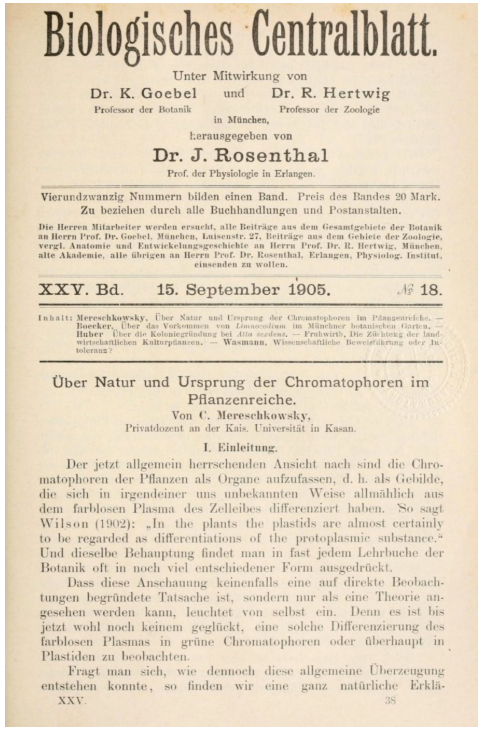


McInerney et al. 2014 *Nat. Rev. Microbiol.*

真核生物胞器起源：內共生理論

康士坦丁·梅勒施科夫斯基

Konstantin Mereschkowsky (1855–1921)



Biologisches Centralblatt.

Unter Mitwirkung von

Dr. K. Goebel und Dr. R. Hertwig

Professor der Botanik in München, Professor der Zoologie

herausgegeben von

Dr. J. Rosenthal

Prof. der Physiologie in Erlangen.

Vierundzwanzig Nummern bilden einen Band. Preis des Bandes 20 Mark. Zu beziehen durch alle Buchhandlungen und Postanstalten.

Die Herren Mitarbeiter werden ersucht, alle Beiträge aus dem Gesamtgebiete der Botanik an Herrn Prof. Dr. Goebel, München, Luisenstr. 27, Beiträge aus dem Gebiete der Zoologie, vergl. Anatomie und Entwickelungsgeschichte an Herrn Prof. Dr. R. Hertwig, München, alte Akademie, alle übrigen an Herrn Prof. Dr. Rosenthal, Erlangen, Physiolog. Institut, einsenden zu wollen.

XXV. Bd. 15. September 1905. № 18.

Inhalt: Mereschkowsky, Über Natur und Ursprung der Chromatophoren im Pflanzenreiche. — Boecker, Über das Vorkommen von *Dionaeodium* im Münchner botanischen Garten. — Huber, Über die Koloniegründung bei *Atta sexdens*. — Frühwirth, Die Züchtung der landwirtschaftlichen Kulturpflanzen. — Wasmann, Wissenschaftliche Beweisführung oder Intoleranz?

Über Natur und Ursprung der Chromatophoren im Pflanzenreiche.

Von C. Mereschkowsky,

Privatdozent an der Kais. Universität in Kasan.

I. Einleitung.

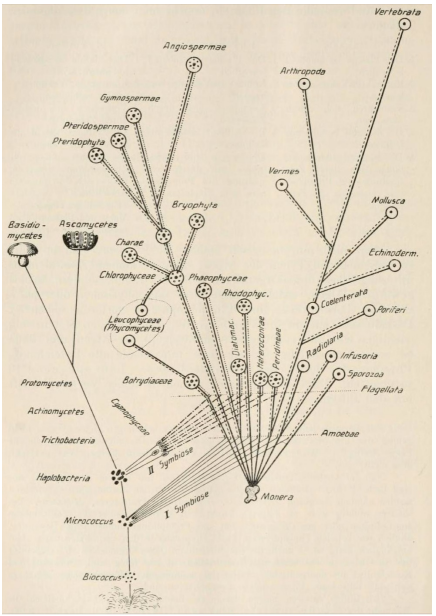
Der jetzt allgemein herrschenden Ansicht nach sind die Chromatophoren der Pflanzen als Organe aufzufassen, d. h. als Gebilde, die sich in irgendeiner uns unbekannten Weise allmählich aus dem farblosen Plasma des Zelleibes differenziert haben. So sagt Wilson (1902): „In the plants the plastids are almost certainly to be regarded as differentiations of the protoplasmic substance." Und dieselbe Behauptung findet man in fast jedem Lehrbuche der Botanik oft in noch viel entschiedener Form ausgedrückt.

Dass diese Anschauung keinenfalls eine auf direkte Beobachtungen begründete Tatsache ist, sondern nur als eine Theorie angesehen werden kann, leuchtet von selbst ein. Denn es ist bis jetzt wohl noch keinem geglückt, eine solche Differenzierung des farblosen Plasmas in grüne Chromatophoren oder überhaupt in Plastiden zu beobachten.

Fragt man sich, wie dennoch diese allgemeine Überzeugung entstehen konnte, so finden wir eine ganz natürliche Erklä-

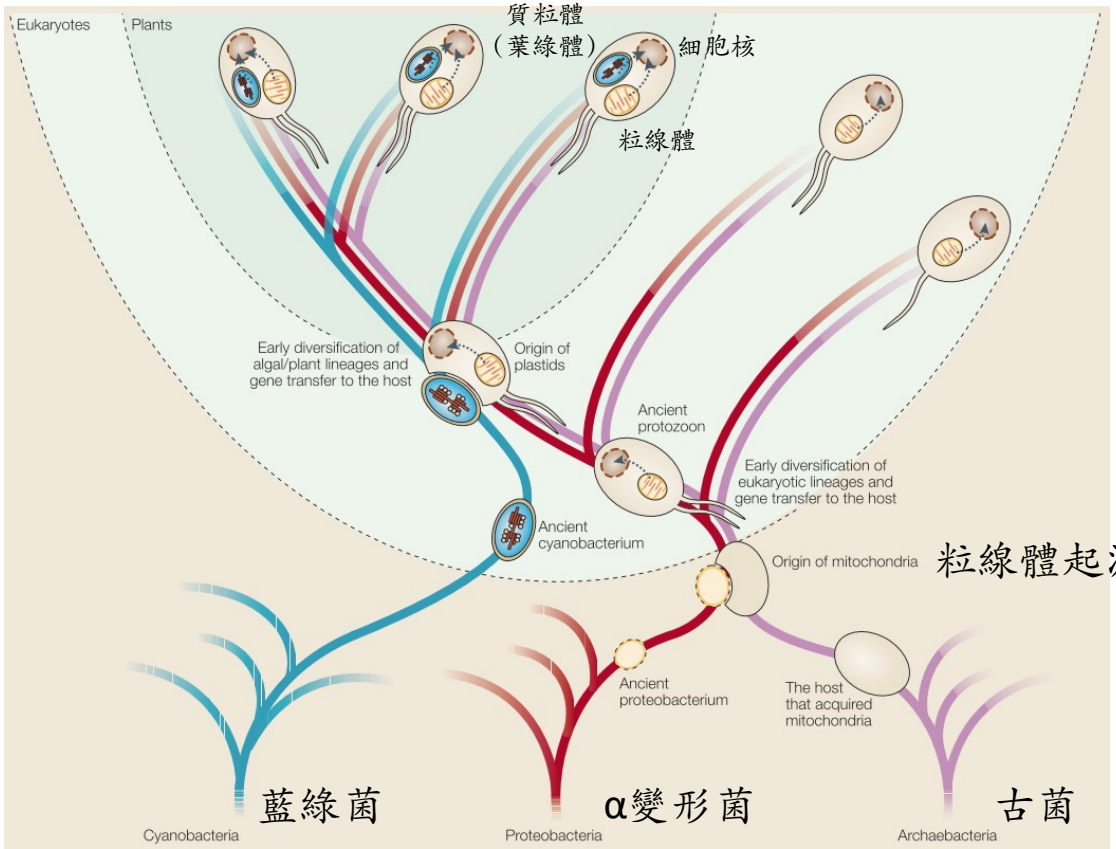
XXV. 38

Mereschkowsky 1905 *Biol. Centralbl.*



Mereschkowsky 1910 *Biol. Centralbl.*

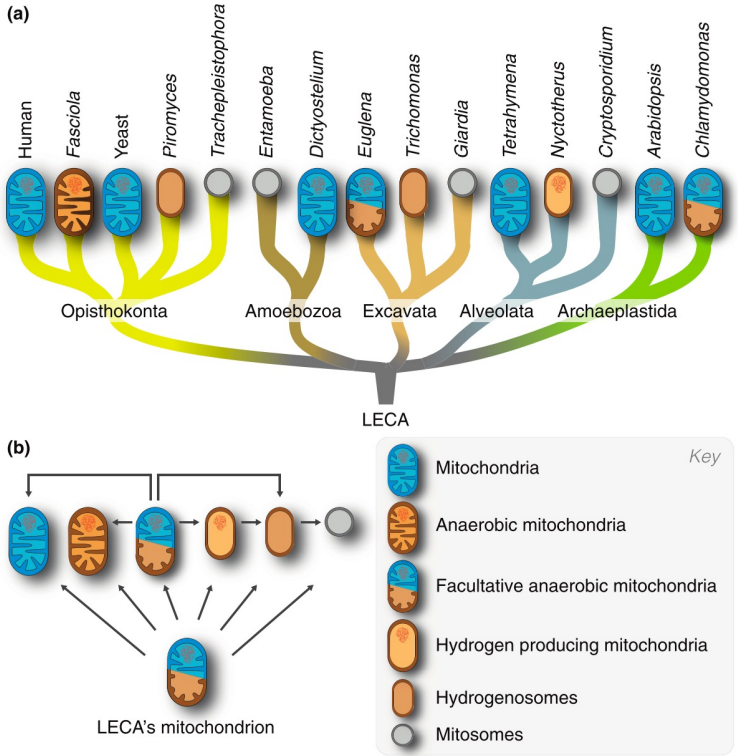
真核生物與胞器起源：內共生造就胞器與基因體融合



粒線體起源/真核生物起源

Timmis 2004 *Nat. Rev. Genet.*

源自α變形菌的粒線體演化成各種型式



粒線體

厭氧粒線體

兼性厭氧粒線體

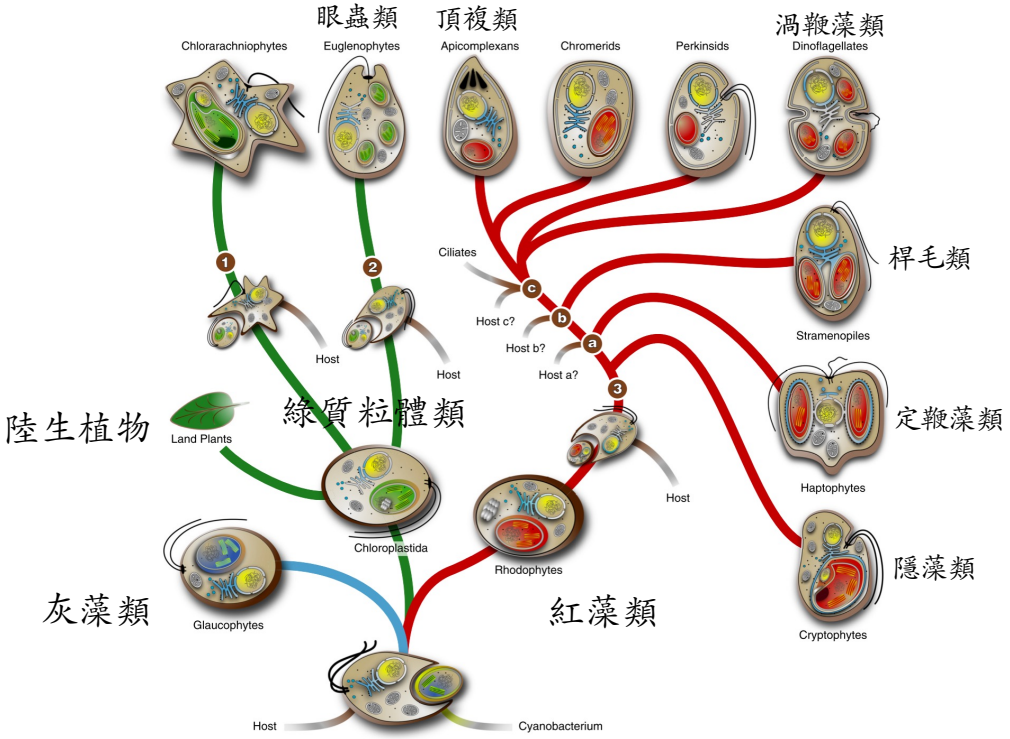
產氫粒線體

氫酶體

線狀體

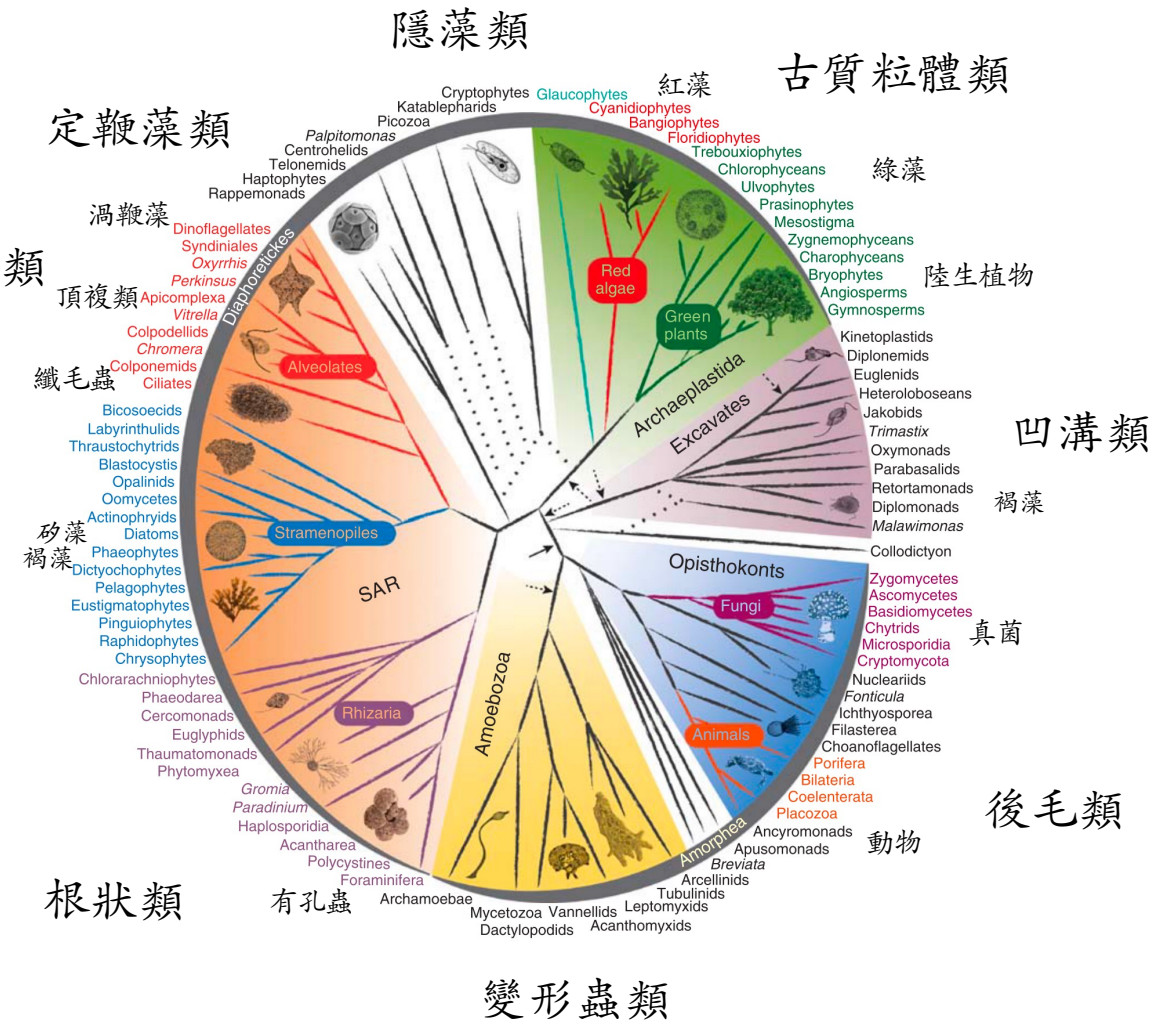
Zimorski et al. 2014 *Curr. Opin. Microbiol.*

源自藍綠菌的質粒體透過多次內共生進入不同支系



Zimorski et al. 2014 *Curr. Opin. Microbiol.*

真核生物的主要演化支系

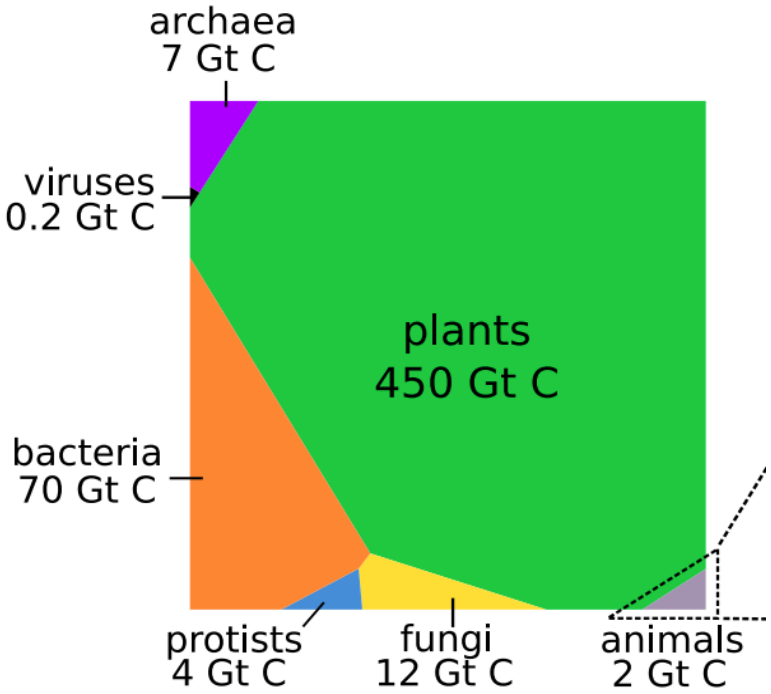


Burki 2014 *CSHPB*

大綱

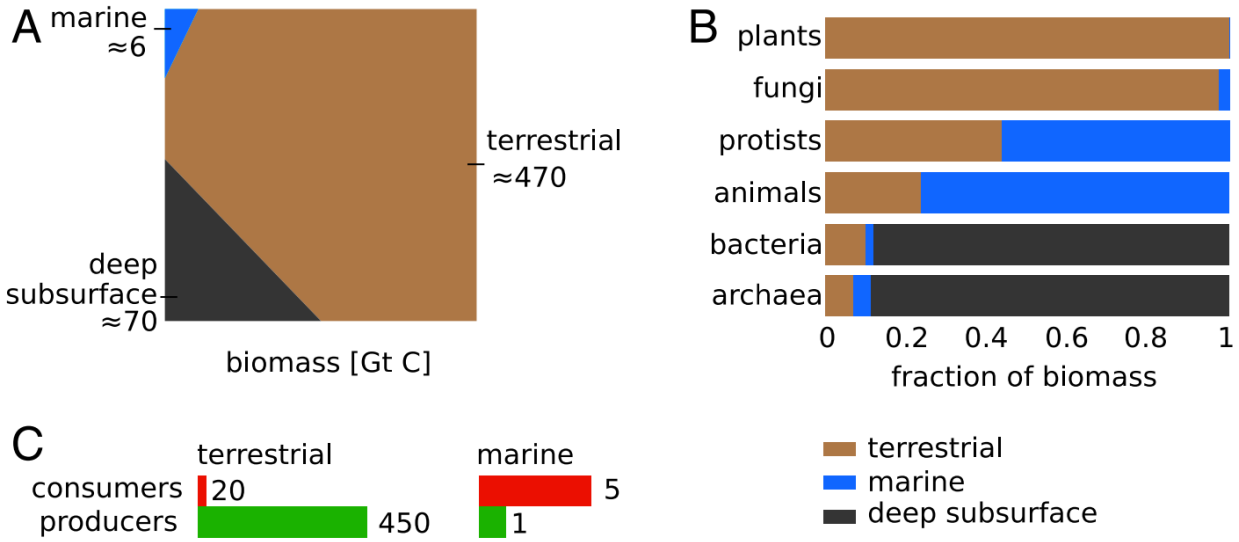
- 真核生物與其胞器的起源與演化
- 藻類：多樣性、功能與重要性
- 其他單細胞真核生物：寄生蟲與環境微生物
- 真核生物的巨大病毒

地球生物質量分佈：不同分類群比較



Bar-On et al. 2018 *Proc. Nat. Acad. Sci. USA*

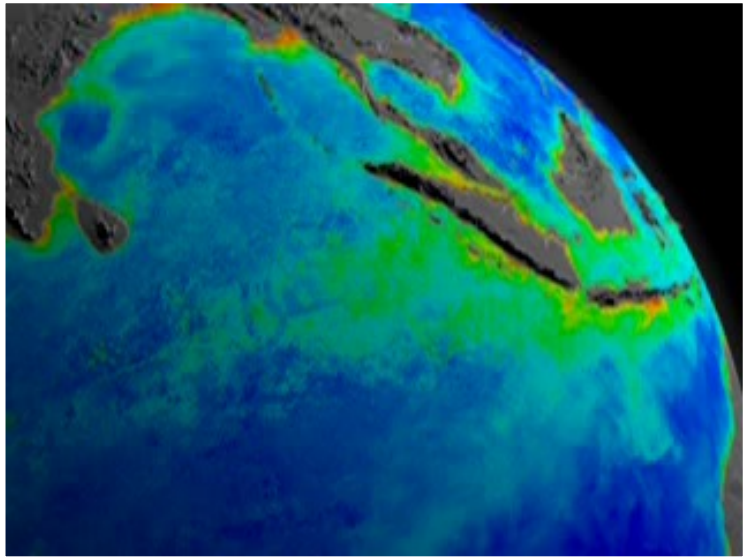
地球生物質量分佈：不同生態環境比較



Bar-On et al. 2018 *Proc. Nat. Acad. Sci. USA*

與陸生植物一樣重要的生產者：海洋微藻

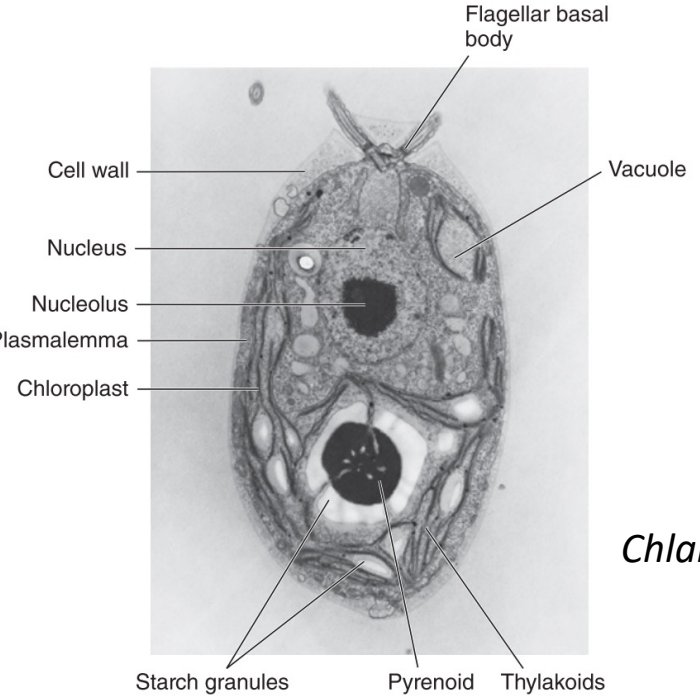
- 可行光合作用生物量中只佔 1%
- 貢獻 50% 的二氧化碳固定量
- 在各種元素的生地化循環中扮演重要角色



Source: NASA

澱粉核 (pyrenoid):
藻類提高光合作用的秘密武器

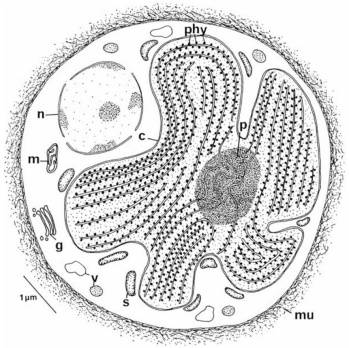
Pyrenoid: **proteinaceous** area of the **chloroplast** associated with the formation of storage product



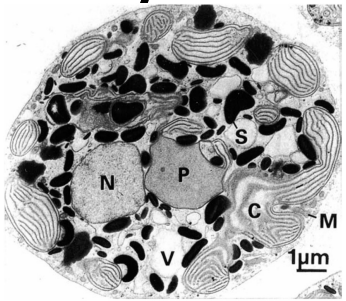
單胞藻
Chlamydomonas

Fig. 25.1, Prescott's Microbiology, 2017

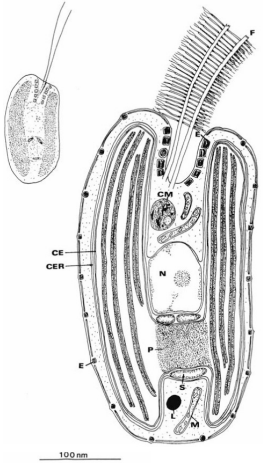
Pyrenoids in diverse algae



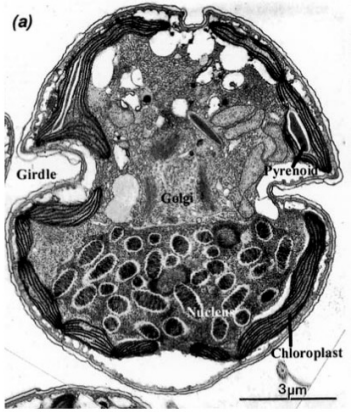
Porphyridium (Rhodophyta)



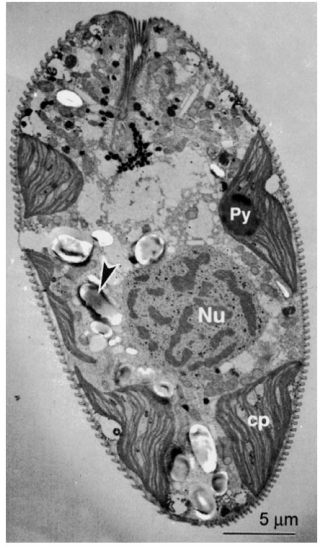
Rhodella (Rhodophyta)



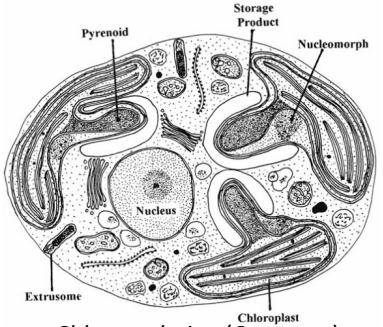
Cryptophyceae



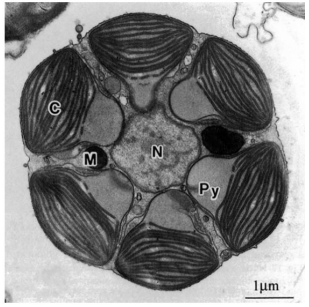
Karlodinium (Dinophyta)



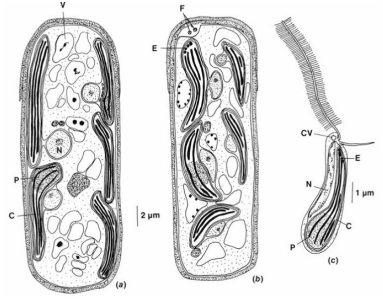
Euglena (Discoba)



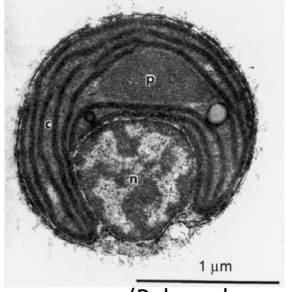
Chlorarachnion (Cercozoa)



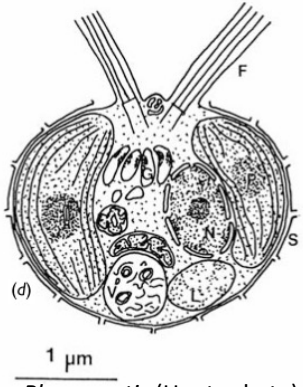
Pedinella (Dictyochophyceae)



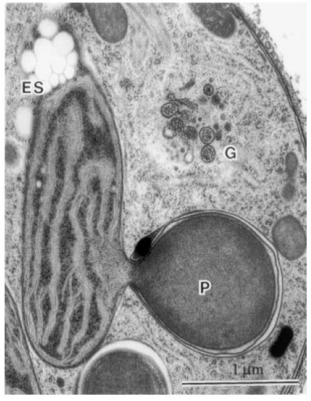
Pseudobumilleriopsis (Xanthophyceae)



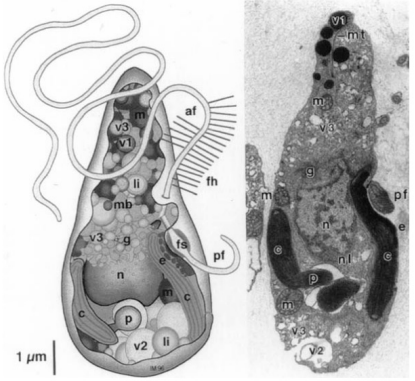
Aureococcus (Pelagophyceae)



Phaeocystis (Haptophyta)



Scytosiphon (Phaeophyceae)



Ectocarpus (Phaeophyceae)

Lee, Phycology, 2008

澱粉核
碳集中機制

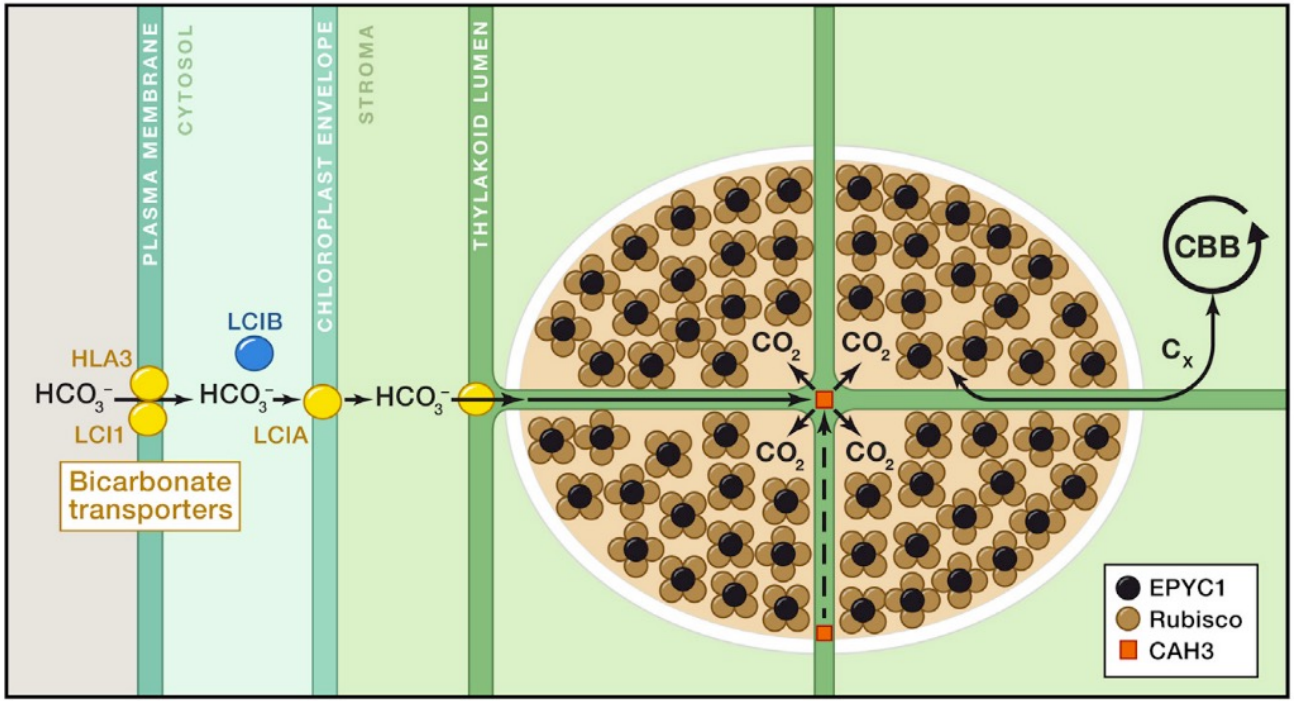


Figure 1. Simplified Model for CO_2-Concentrating Mechanisms in the Pyrenoid of *Chlamydomonas*

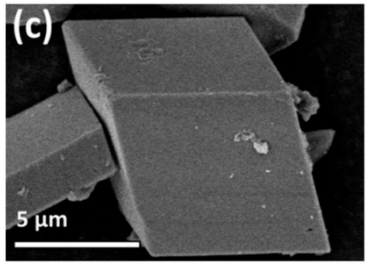
The liquid-like matrix of the pyrenoid is shown as a network of Rubisco aggregates held together by EPYC1 in which each EPYC1 protein (black sphere) binds four Rubiscos (brown sphere). Inorganic carbon is imported as HCO_3^- into the cell by the bicarbonate transporters LCI1 and HLA3, which form a complex on the plasma membrane. Alternatively, CO_2 may also enter the cell and be converted to HCO_3^- possibly by LCIB. Entry of HCO_3^- into the chloroplast is mediated by LCIA on the chloroplast envelope and into the thylakoid lumen by an unknown transporter. Finally HCO_3^- diffuses into the pyrenoid through the membrane tubules connected to the thylakoid network (dark green), where it is converted to CO_2 by CAH3 (orange square) and available for CO_2 fixation by Rubisco. The white layer around the pyrenoid represents the starch sheath. The cytosol and stroma are indicated. CBB, Calvin-Benson cycle; C_X, putative shuttle for Rubisco substrates and products.

Rochaix 2017 *Cell*

鈣板藻及其多樣的碳酸鈣外殼

$Ca^{2+} + HCO_3^- \rightarrow CaCO_3 + H^+$

方解石結晶



Ritchie et al. 2013 *CrystEngComm*

五種鈣板藻

Scyphosphaera apsteinii

Emiliania huxleyi

Calcidiscus leptoporus

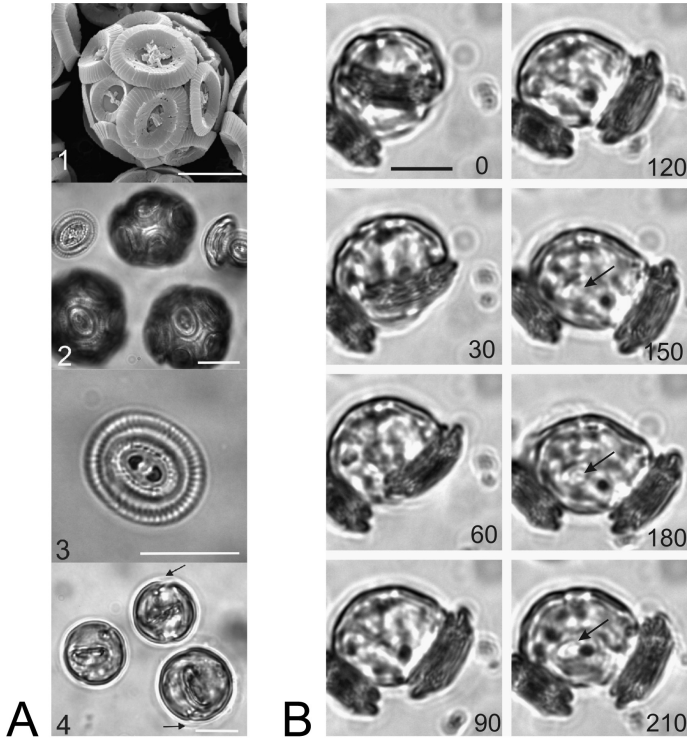
Gephyrocapsa oceanica

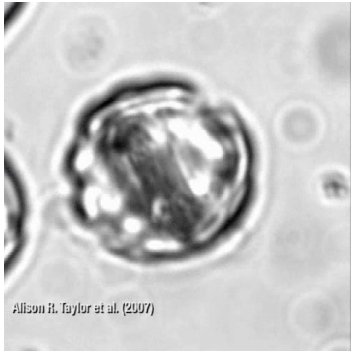
Coccolithus braarudii

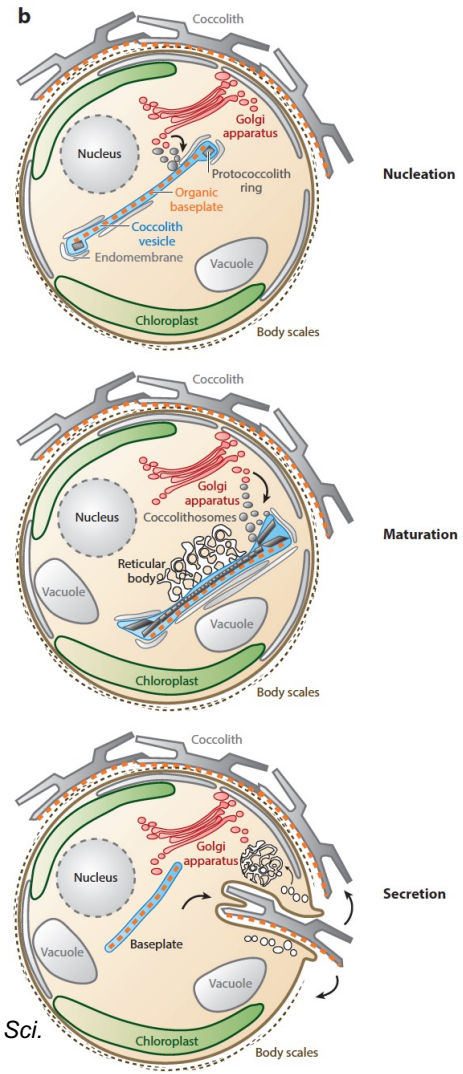
10 µm

Taylor et al. 2017 *Annual Rev. Mar. Sci.*

鈣板藻：鈣板生成







Modified from Taylor et al. 2007 *Eur. J. Phycol.*

Taylor et al. 2017 *Annual Rev. Mar. Sci.*

鈣板藻：前世今生

世界上最大的藻華

Emiliania huxleyi
（赫胥黎氏艾密利鈣板藻）

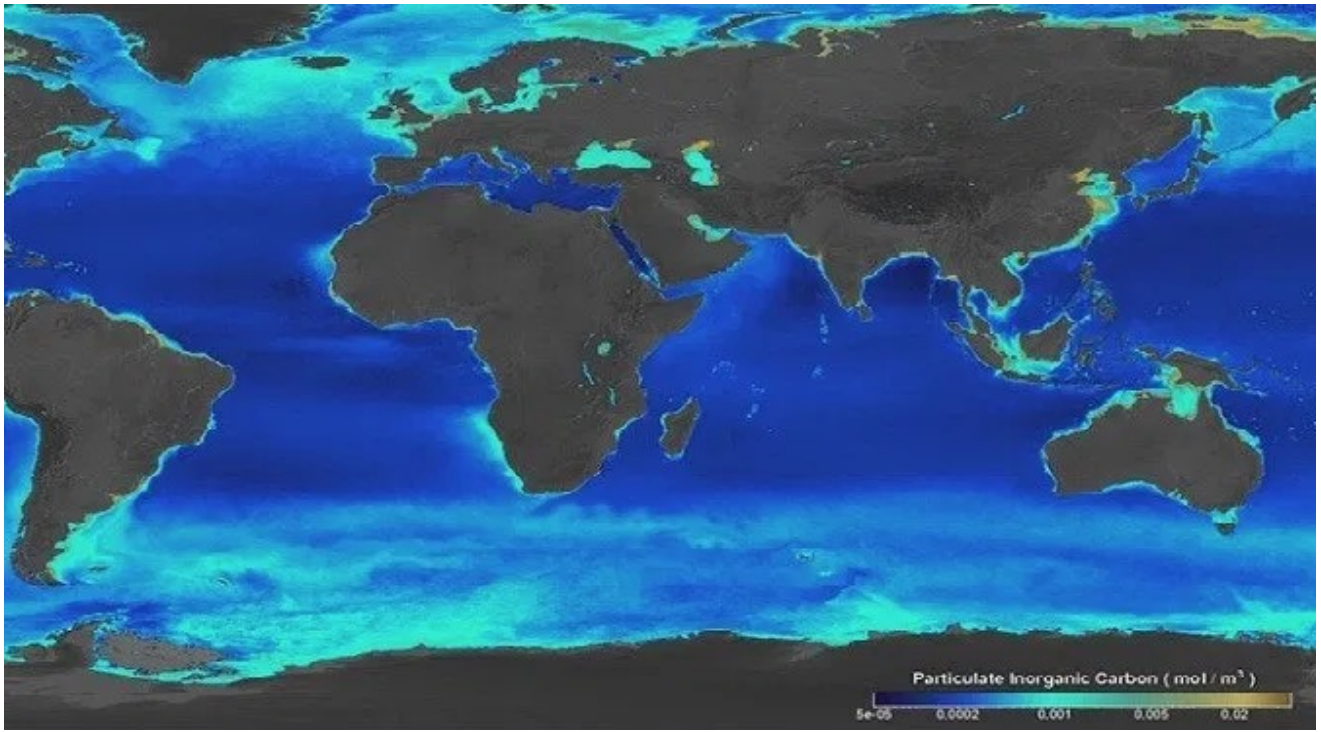
Source: Steve Groom (Landsat)

鈣板藻化石

英格蘭的多佛懸崖

Source: Wikimedia

鈣板藻：全球分佈



https://news.algaeworld.org/aqua-modis-algae-great-calcite-belt-800x600/

為什麼藻類這麼重要?

https://www.youtube.com/watch?v=bcyIbq3NhI0

我們吃的是什麼藻？

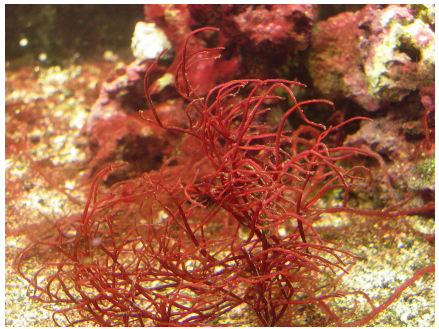
海草
海苔
海帶
海菜
海藻
海葡萄
石花菜
昆布
洋菜
紫菜
…

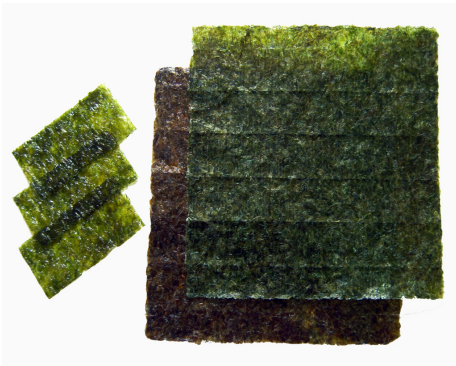
Table 1. Range of iodine content μg/g DW of examples of the 3 main classes of edible seaweeds

Classification and species	Common names	Iodine content, μg/g DW (range)	Grams of seaweed required to achieve daily RNI of 150 μg/day
Green algae (Chlorophyta)			
Undaria pinnatifida	Wakame	30–185	2.0–6.0
Ulva lactuca	Sea lettuce		
Ulva intestinalis			
Red algae (Rhodophyta)			
Palmaria	Dulse, dillisk	20–200	0.3–3.0
Porphyra	Nori		
Alaria	Irish wakame		
Chondrus crispus	Irish moss		
Brown algae (Phaeophyceae)			
Laminaria	Kombu	2,500–10,000	0.01–0.04
Ascophyllum			
Fucoids			

Smyth 2021 *Eur. Thyroid J.*

我們吃的是什麼藻？





2012 Raven Biology of Plants; https://commons.wikimedia.org/w/index.php?curid=15142919; https://en.wikipedia.org/wiki/Nori#/media/File:Nori.jpg; https://health.udn.com/health/story/6037/5342162;

大綱

- 真核生物與其胞器的起源與演化
- 藻類：多樣性、功能與重要性
- 其他單細胞真核生物：寄生蟲與環境微生物
- 真核生物的巨大病毒

其他單細胞真核生物如何獲取營養

- 寄生
- 攝食
- 共生

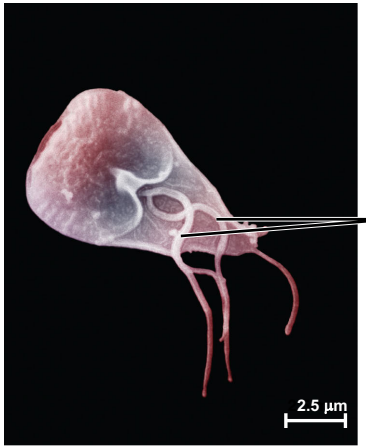
其他單細胞真核生物如何獲取營養

- 寄生
- 攝食
- 共生

寄生：凹溝類

小腸梨形蟲

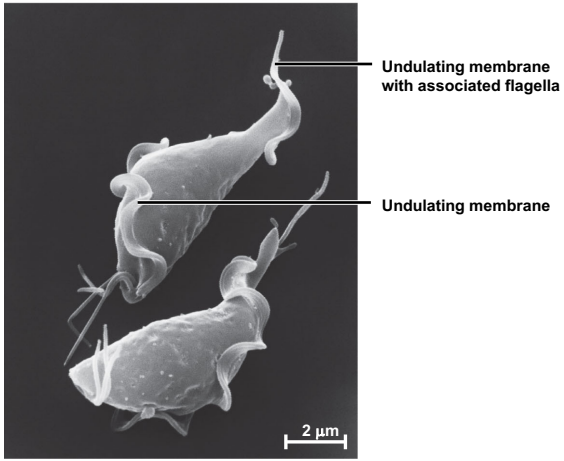
（線狀體）



(a) *Giardia intestinalis*

陰道滴蟲

（氫酶體）



(b) *Trichomonas vaginalis*

Fig. 25.4, Prescott's Microbiology, 2017

寄生：
凹溝類

梨形蟲出鞘

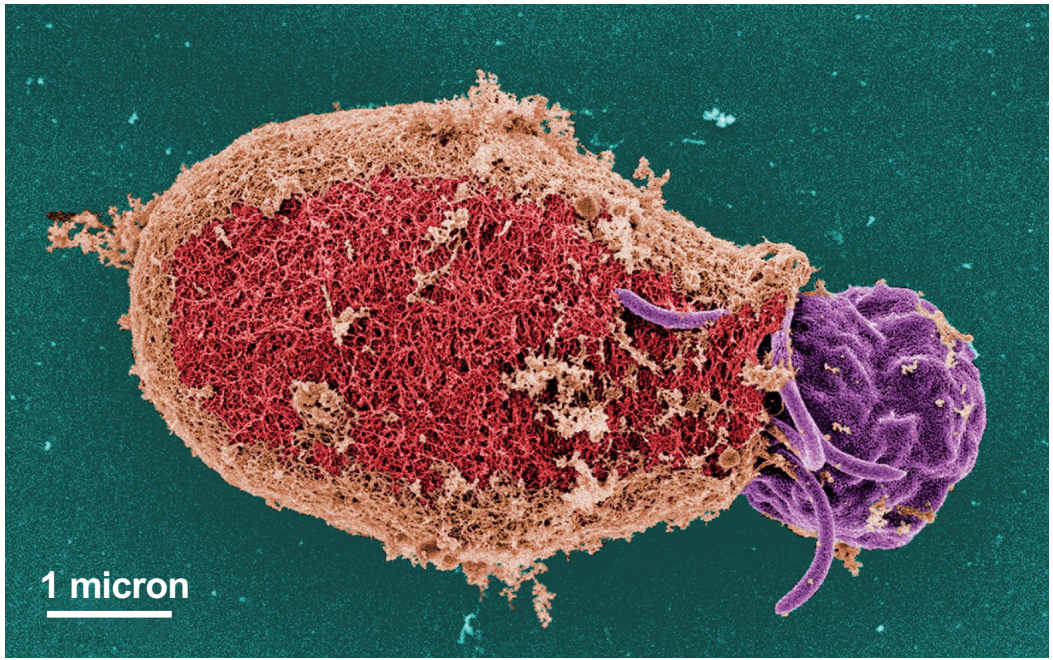
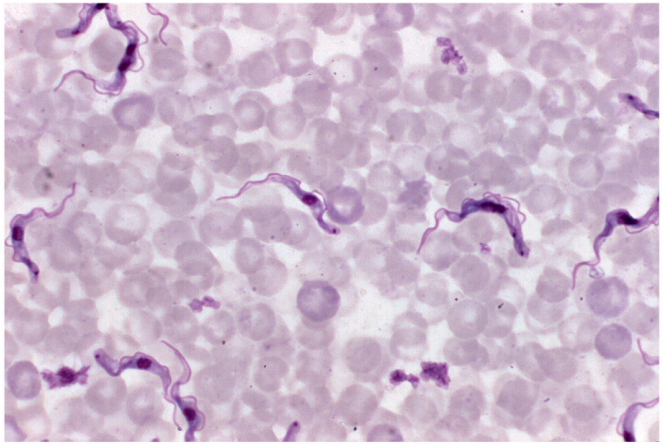


Fig. 25.2, Prescott's Microbiology, 2017

寄生：
凹溝類

布氏錐蟲（非洲昏睡病）



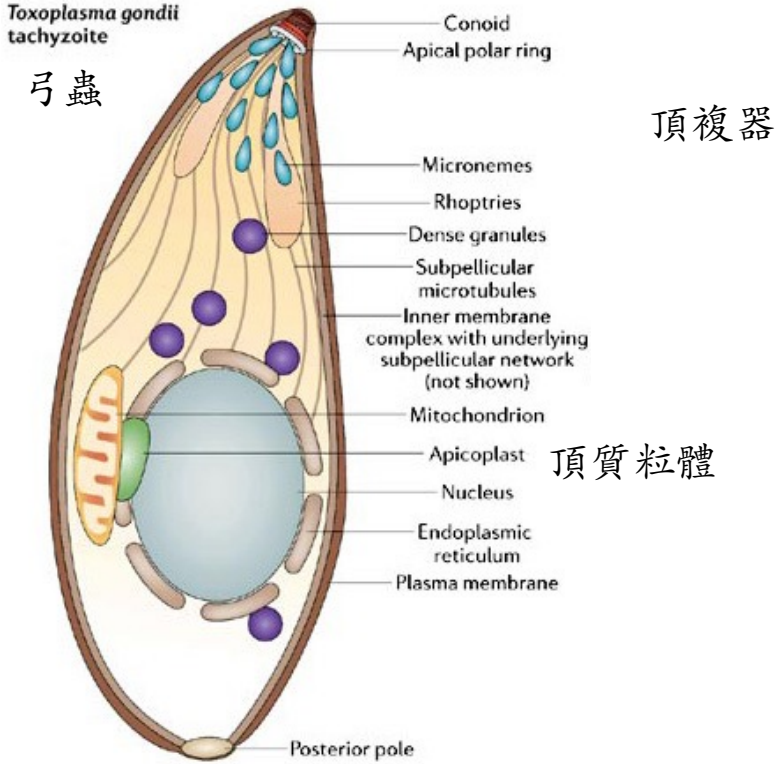
(a)

(b)

Fig. 25.6, Prescott's Microbiology, 2017

寄生:
頂複類

細胞結構



https://www.nature.com/scitable/topicpage/the-apicoplast-an-organelle-with-a-green-14231555/

寄生：頂複類

瘧原蟲：生活史

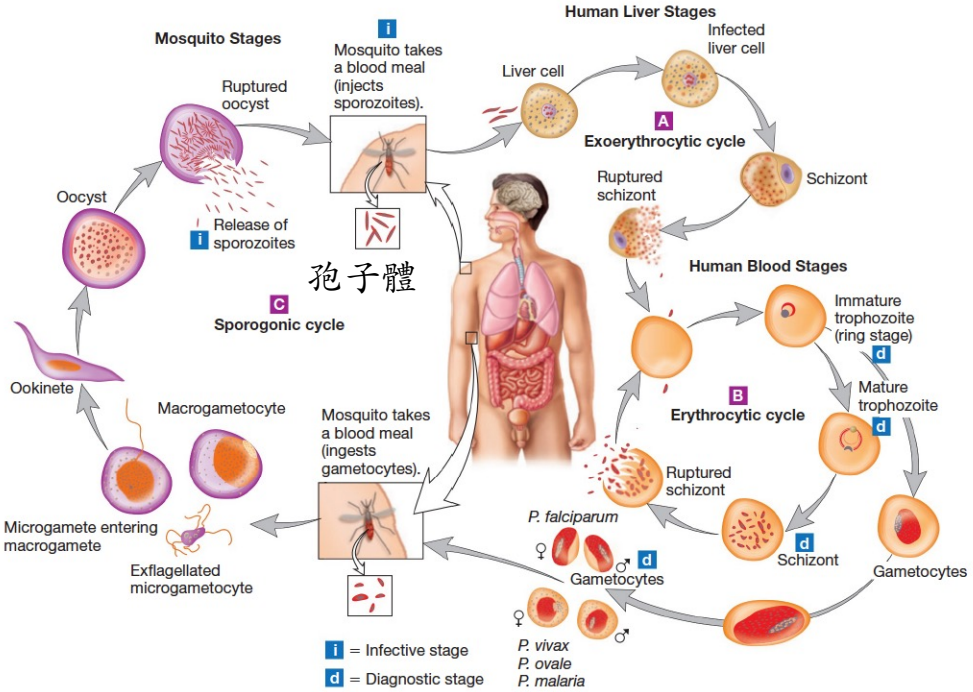


Figure 40.7 Malaria. Life cycle of *Plasmodium vivax*. Note the (A) exoerythrocytic cycle, (B) the erythrocytic cycle, and (C) the sporogonic cycle.

MICRO INQUIRY *How is a schizont formed? What is the cell type that is released from erythrocytes, and where does the protist go next?*

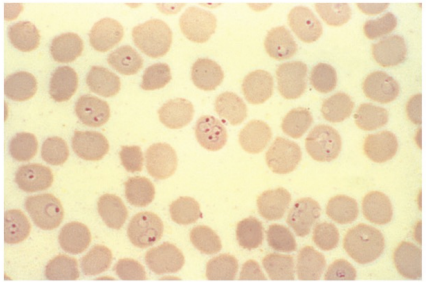


Figure 40.8 Malaria: Erythrocytic Cycle. Trophozoites of *P. falciparum* in circulating erythrocytes; light micrograph (×1,100). The young trophozoites resemble small rings within the erythrocyte cytoplasm.

營養體

Fig. 40, Prescott's Microbiology, 2017

其他單細胞真核生物如何獲取營養

- 寄生
- 攝食
- 共生

攝食結構

- 溝口
- 偽足
- 刺胞

攝食：纖毛蟲

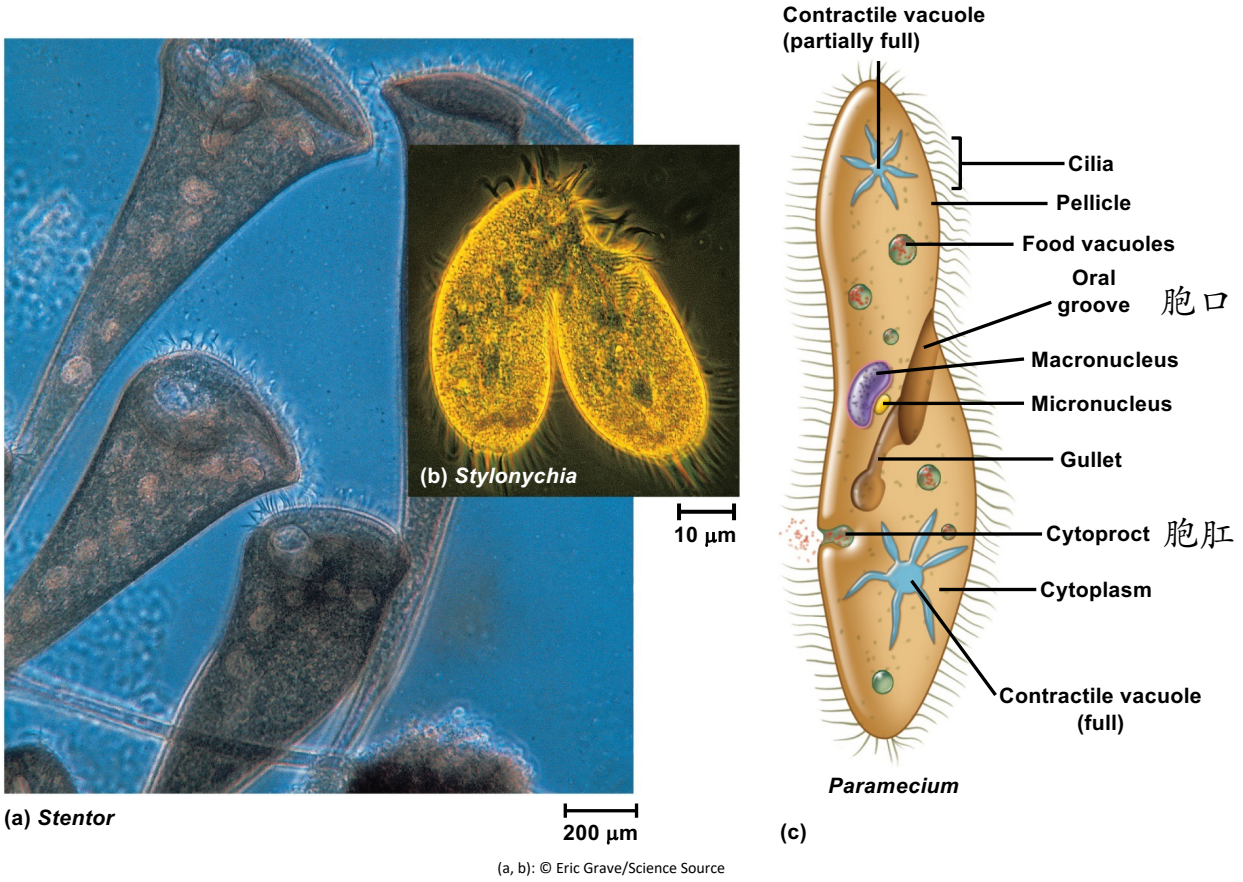


Fig. 25.14, Prescott's Microbiology, 2017

纖毛蟲生活史:
大核、小核與接合

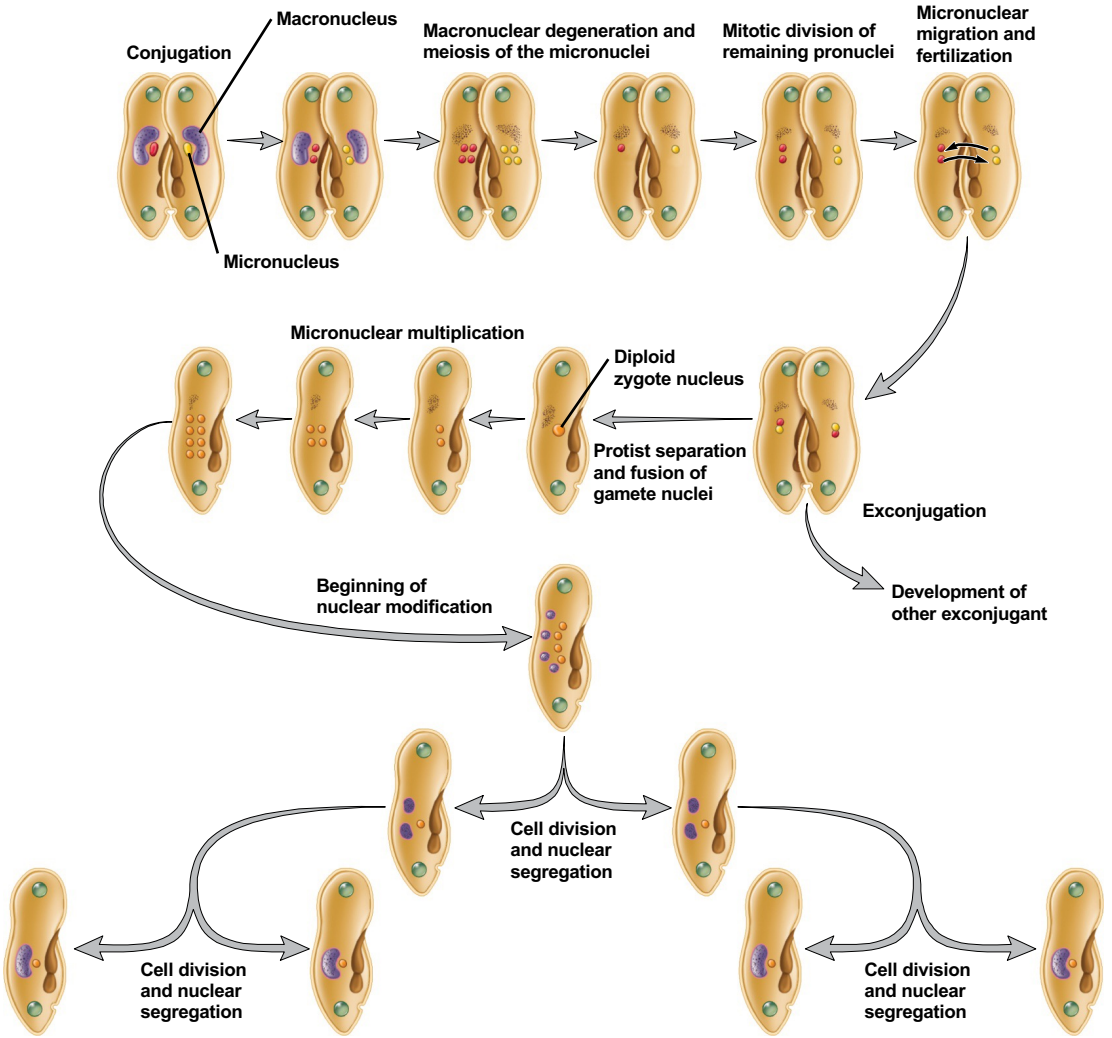


Fig. 25.15, Prescott's Microbiology, 2017

偽足

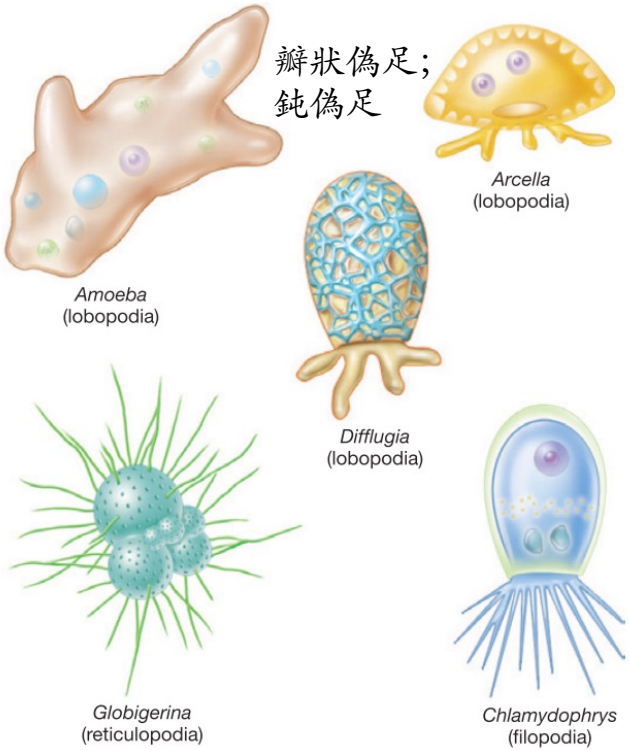
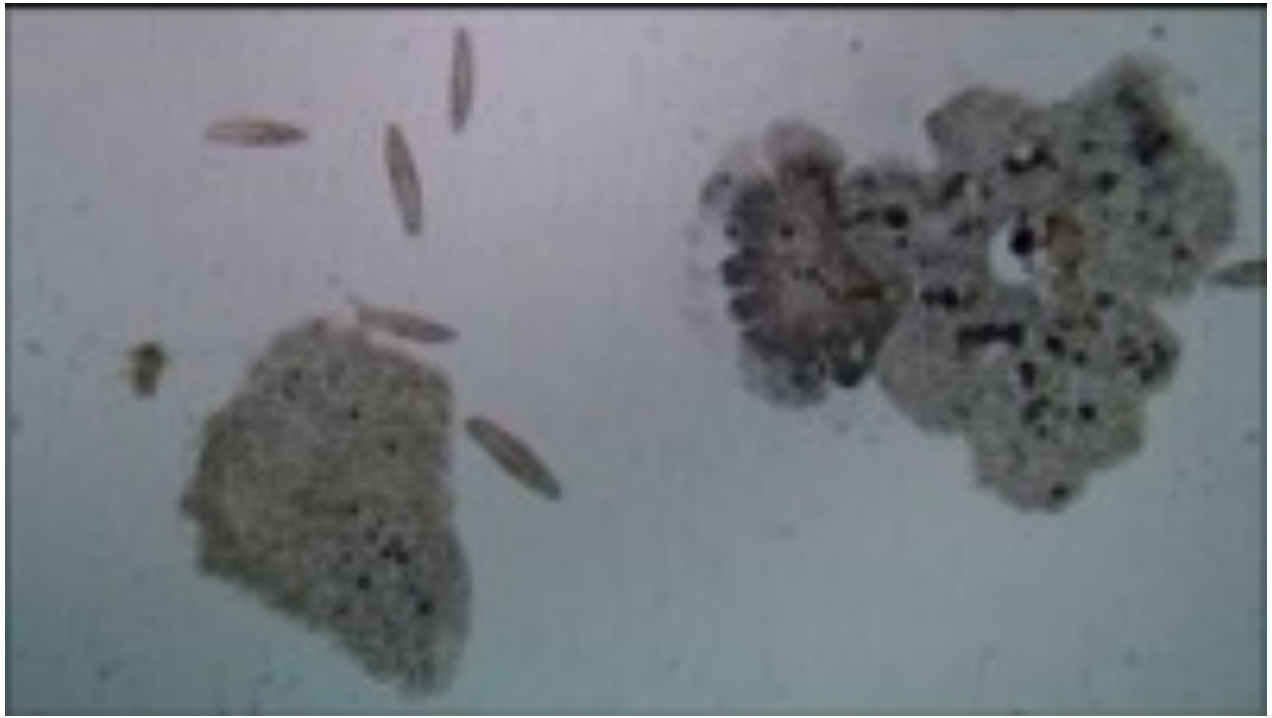


Fig. 25.7, Prescott's Microbiology, 2017

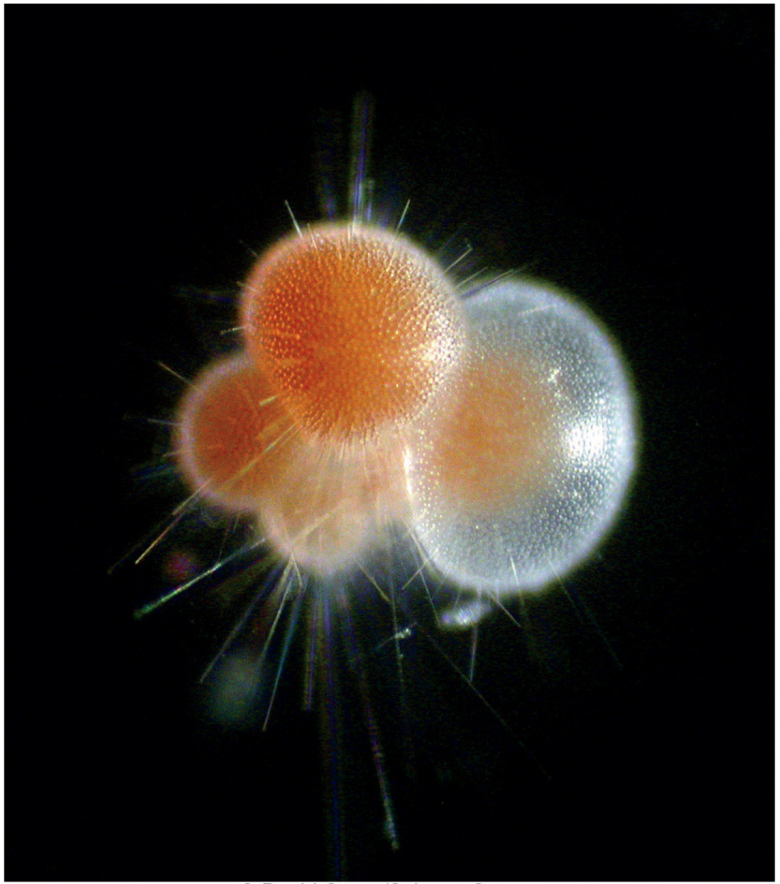
變形蟲運動

Chaos carolinense
Tubulinea
Amoebozoa
Amorphea



https://www.youtube.com/watch?v=OvysPtfWgVo&ab_channel=Sci-Inspi

有孔蟲：鈣質外殼

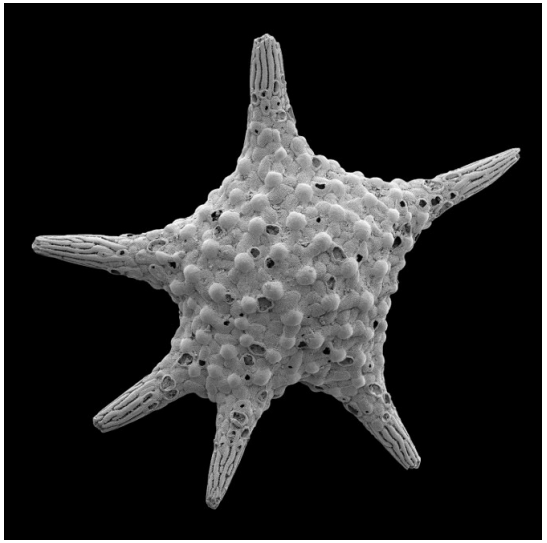


© David Caron/Science Source

Fig. 25.11, Prescott's Microbiology, 2017

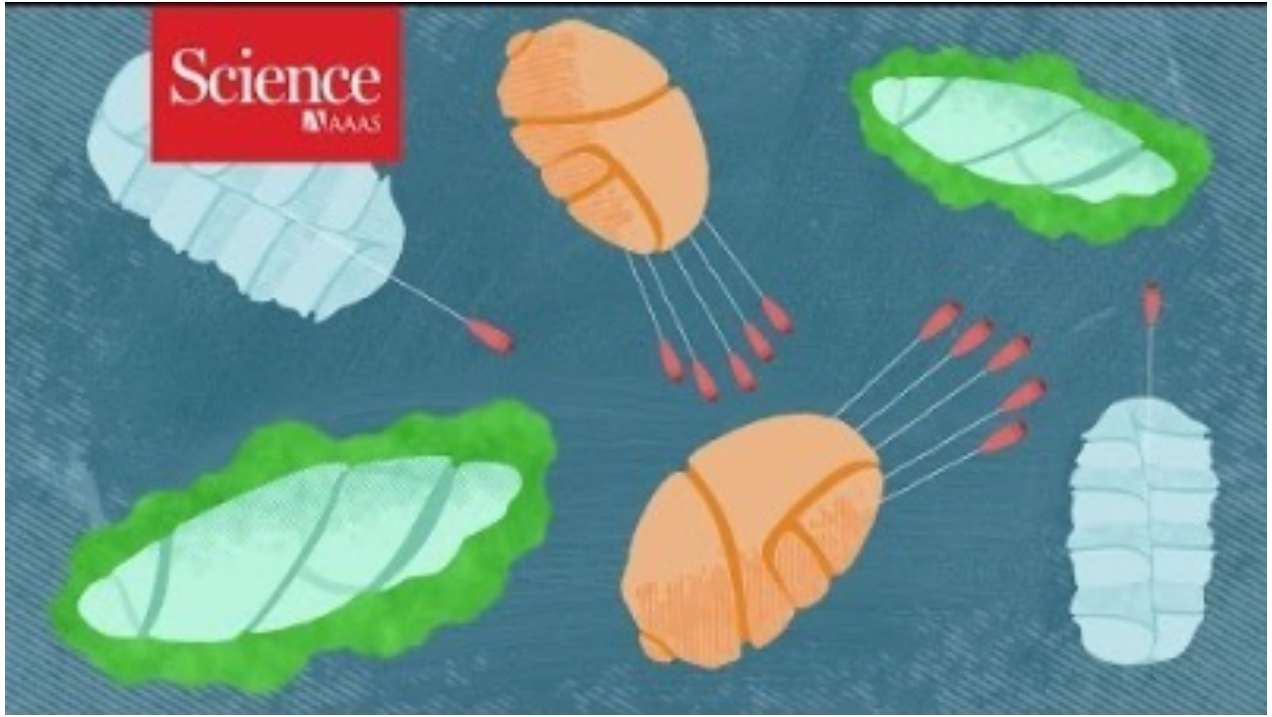
星砂是一類有孔蟲外殼

Baculogypsina sphaerulata



Polykrikos
Gymnodiniaceae
Gymnodiniales
Dinoflagellata
Alveolata
SAR

渦鞭蟲的刺胞

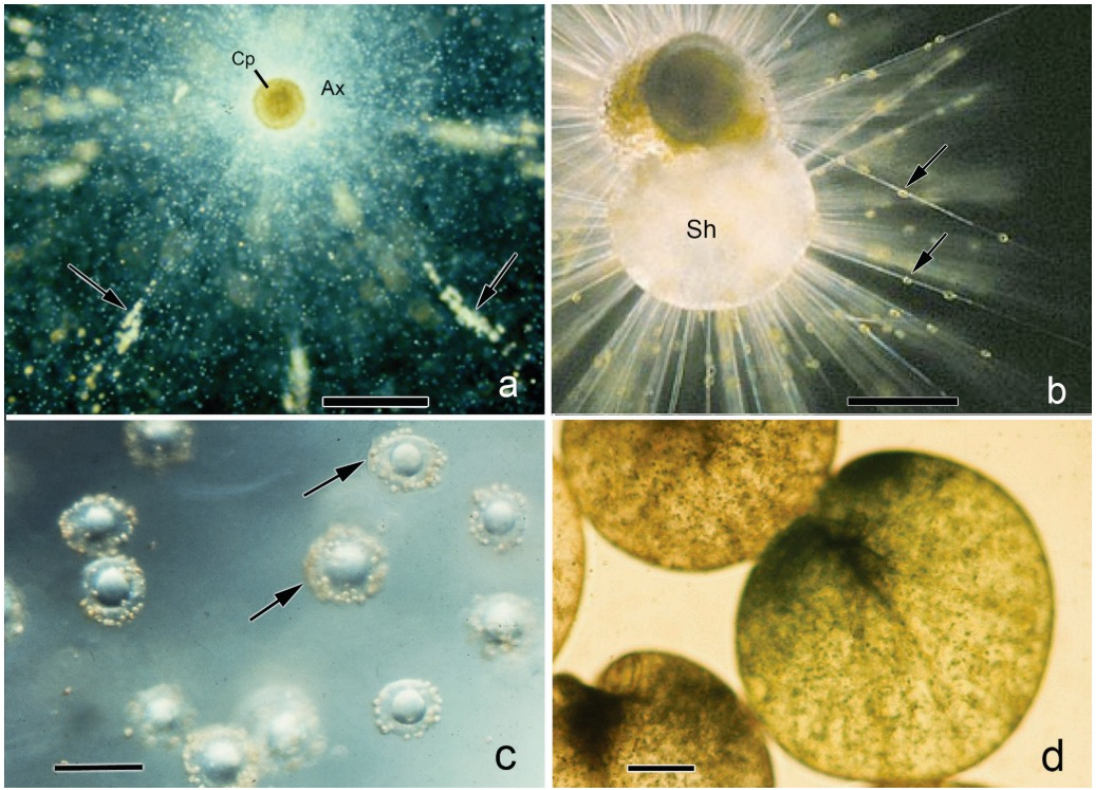


https://www.youtube.com/watch?v=9KtSQphEeKc&ab_channel=ScienceMagazine

其他單細胞真核生物如何獲取營養

- 寄生
- 攝食
- 共生

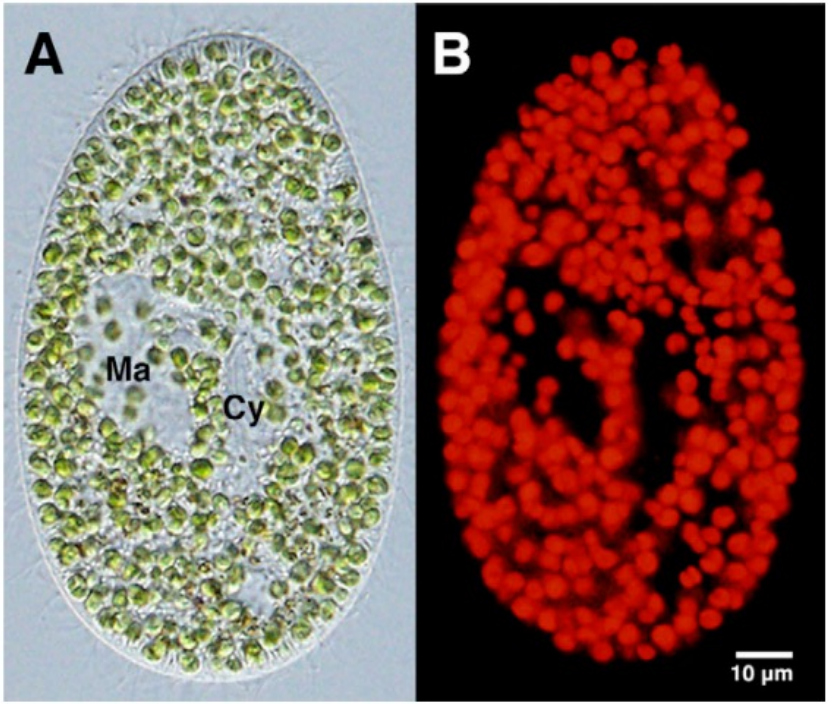
藻類共生在海洋中十分常見



夜光蟲
（渦鞭藻）

Anderson 2014 *Acta Protozoologica*

草履蟲與小球藻（綠藻）



Kodama and Fujishima 2015 *Biol. Open*

大綱

- 真核生物與其胞器的起源與演化
- 藻類：多樣性、功能與重要性
- 其他單細胞真核生物：寄生蟲與環境微生物
- 真核生物的巨大病毒

典型的病毒：濾過性病毒

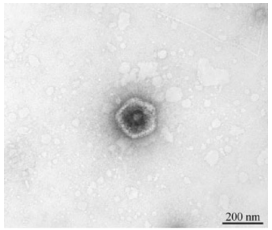
“they could not be seen, could not be cultivated in the absence of cells and, most important of all, were not retained by bacteria-proof filters.”
(Introduction to Modern Virology, 6th ed.)

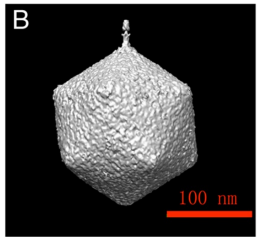
virus	size (nm)	genome size (base pairs)
porcine circovirus (PCV)	17	1,760
cowpea mosaic virus (CPMV)	28	9,400
cowpea chlorotic mottle virus (CCMV)	28	7,900
φX174 (*E. coli* bacteriophage)	32	5,400
tobacco mosaic virus (TMV)	40×300	6,400
polio virus	30	7,500
φ29 (*Bacillus* phage)	45x54	19,000
lambda phage	58	49,000
T7 bacteriophage	58	40,000
adenovirus (linear DNA)	88-110	36,000
influenza A	80-120	14,000
HIV-1	120-150	9,700
herpes simplex virus 1	125	153,000
Epstein-Barr virus (EBV)	140	170,000

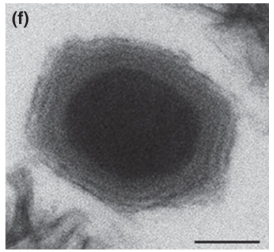
http://book.bionumbers.org/how-big-are-viruses/

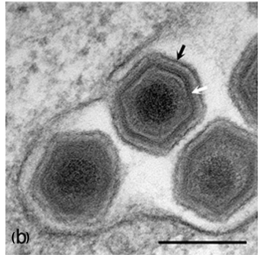
真核生物巨病毒：形态

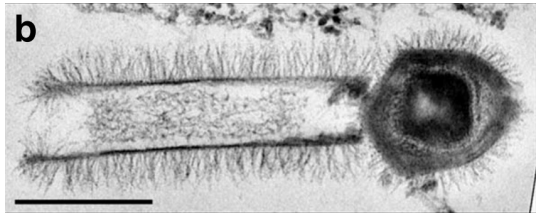
Asfarviridae
Iridoviridae
Phycodnaviridae
Marseilleviridae
Mimiviridae

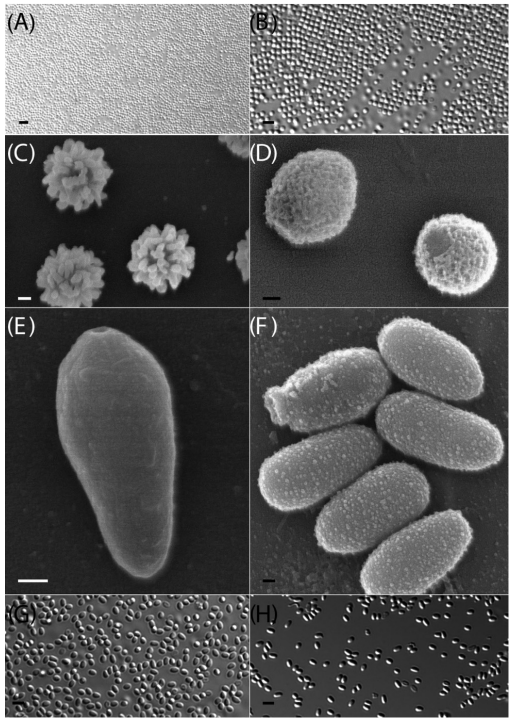


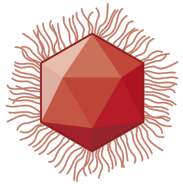




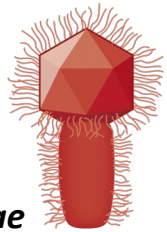




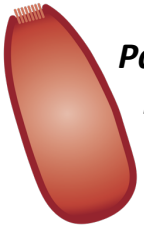




Mimiviridae



Mimiviridae



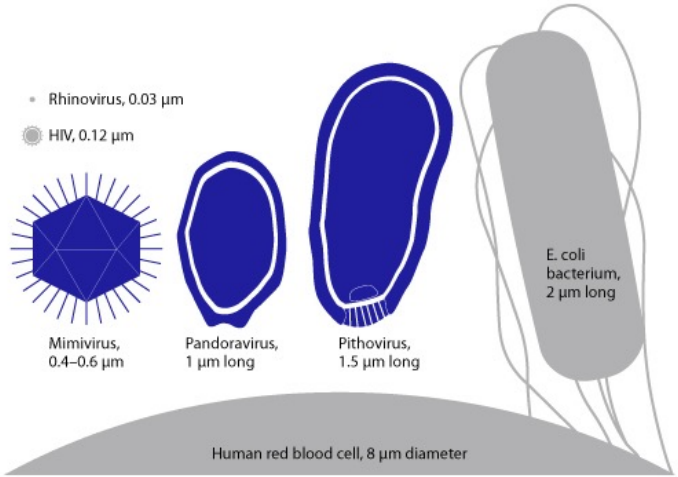
Pandoraviridae
Pithoviridae

Rowe et al. 2008 *J. Phycol.*; Zhang et al. 2011 *PNAS*; Schatz et al. 2014 *New Phytol.*; Alonso et al. 2018 *J. Gen. Virol.*; Abrahão et al. 2018 *Nat. Comm.*; Abergel et al. 2015 *FEMS Microbiol. Rev.*

真核生物巨病毒：顆粒大小

100–2500 nm

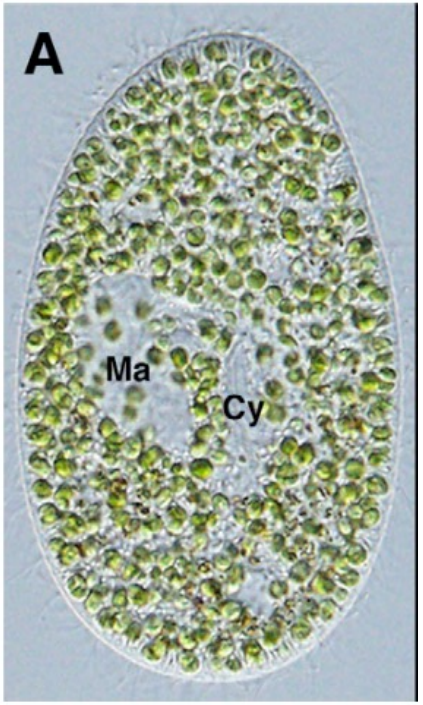
Mimivirus
(***Mimiviridae***)
(*mimic*king bacteria)



https://images.app.goo.gl/7MjgfYx9sjG7TiLWA

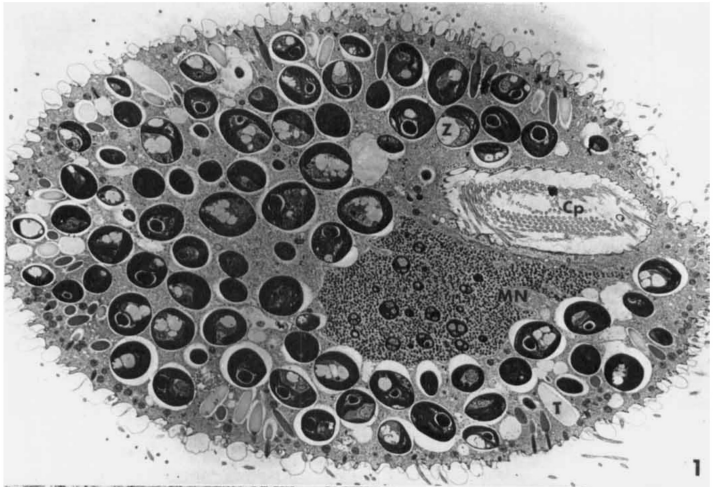
https://www.quantamagazine.org/were-giant-viruses-the-first-life-on-earth-20140710/

綠藻巨大病毒

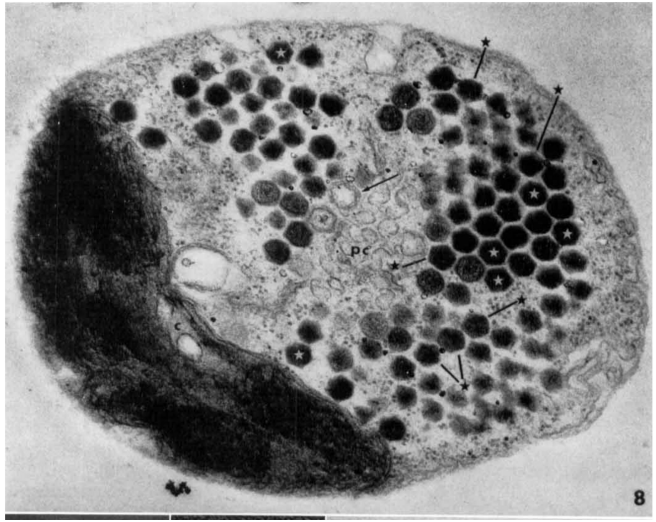


Kodama and Fujishima 2015 *Biol. Open*

有內共生綠藻的草履蟲



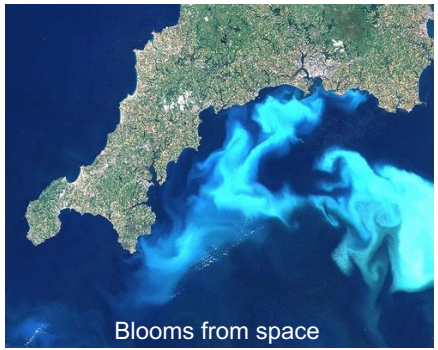
被病毒感染的綠藻

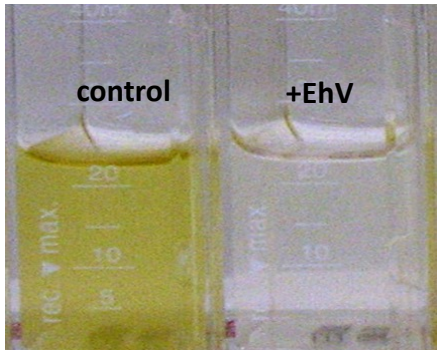


Kawakami and Kawakami 1978 *J. Protozool.*

鈣板藻病毒

基因體：400 kb





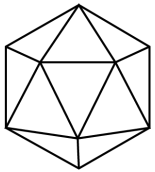
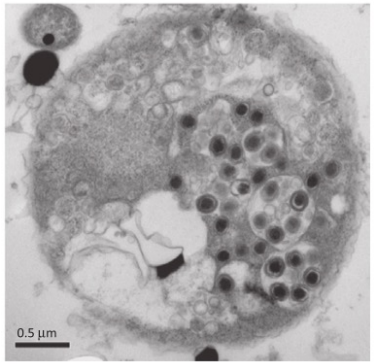
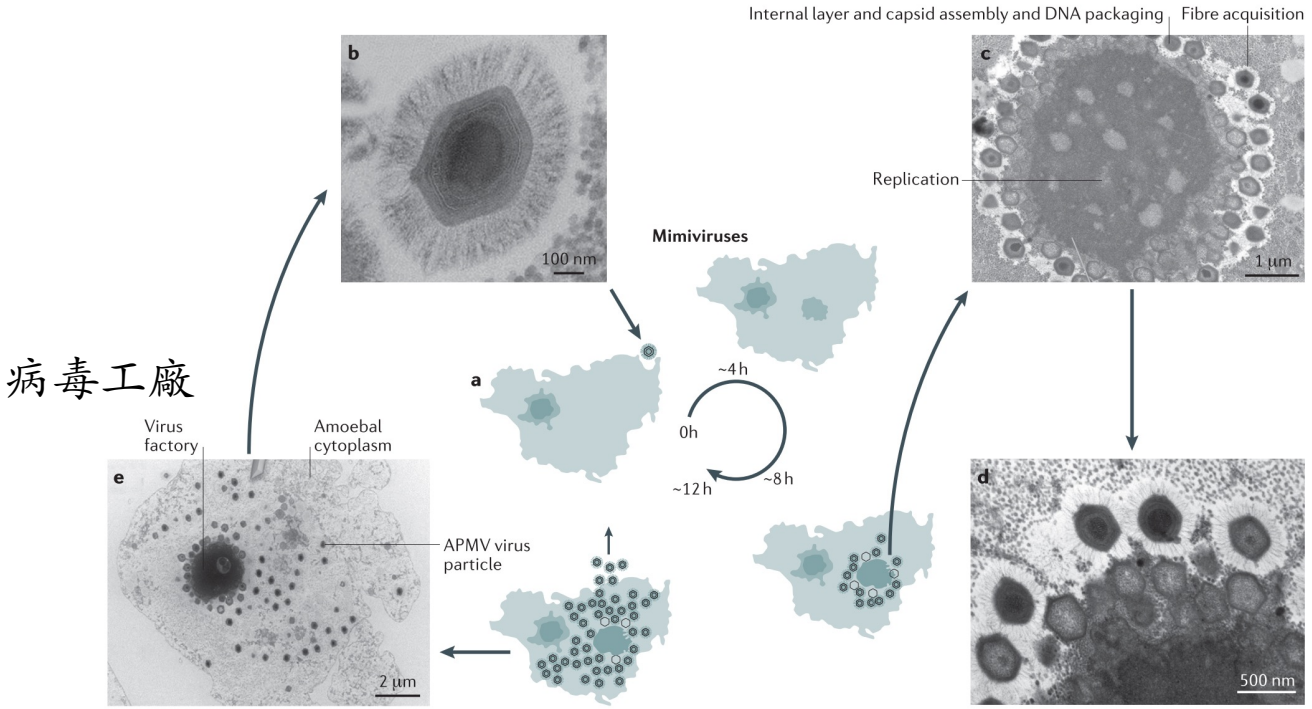


Image by Daniella Schatz



Rosenwasser et al. 2016
Trends Microbiol.

變形蟲的巨大病毒：擬菌病毒

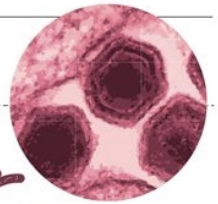


病毒工廠

Colson et al. 2017 *Nat. Rev. Microbiol.*

非洲豬瘟

AFRICAN SWINE FEVER



The African swine fever virus is associated with ticks that infest the common warthog in sub-Saharan Africa. The disease is usually deadly for pigs because no treatment is available and despite efforts over the years, there is still no vaccine for the complex virus. Though humans are not susceptible, an outbreak in a pig population could have serious socio-economic consequences.

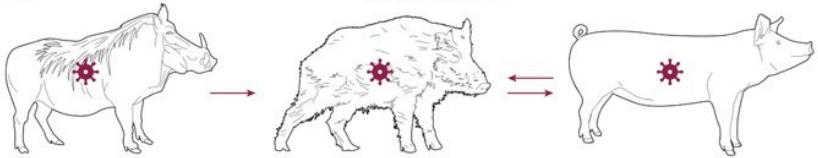
Methods of transmission in pigs:

The ASF virus can be spread through contact with infected animals, their excretions or carcasses.

Bites by infectious ticks

Contact with objects contaminated by the virus such as clothing, vehicles and other equipment.

Ingestion of meat or meat products from infected animals — kitchen waste, swill feed.



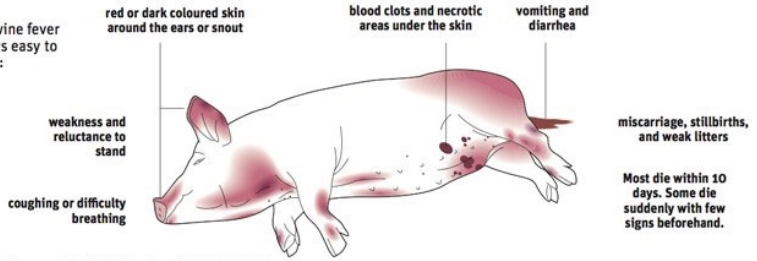
Warthogs are naturally resistant to the virus and usually do not develop clinical disease. They get infected as piglets and develop life-long immunity.

Wild boars, in which the virus is endemic, are usually exposed through contact with warthogs.

Domestic pigs are exposed through contact with infected pigs from other farms and wild boars. Spread is facilitated by human activities, such as movement of animals due to trade or sale of infected meat or animals.

Symptoms:

Clinical signs of African swine fever are variable and not always easy to recognize, but can include:



Sources: European Union Reference Laboratory; The Pirbright Institute | REUTER GRAPHIC

世界疫情

發布日期：112-01-13

https://asf.baphiq.gov.tw/ws.php?id=17888


警告
攜帶肉品入境
最高將重罰
100萬元
行政院農業委員會
動植物防疫檢疫局
Beagle
Brigade

非洲豬瘟病毒存活時間

The virus is infectious for:

•11 days in feces

•Months in bone marrow

•15 weeks in chilled meat

•>15 weeks in frozen meat

•3-6 months in cured hams that have not reached high-temperature cooking.

(Canadian Pork Council)

其他動物的巨大病毒

- 天花病毒、牛痘病毒、猴痘病毒
- 吳郭魚病毒、蛙類病毒
- 秋行軍蟲病毒

總結

- 真核生物源由細菌與古菌融合而成
- 內共生細菌演化成各式各樣的粒線體或質粒體相關胞器
- 囊、鞘、殼等是真核微生物常見的構造，提供保護或其他功能
- 藻類固定全球一半的碳，其中鈣板藻有碳酸鈣外殼且是重要生產者
- 非自營真核微生物可透過寄生、攝食、共生獲取營養
- 巨大病毒感染各類真核生物，對環境與糧食意義重大