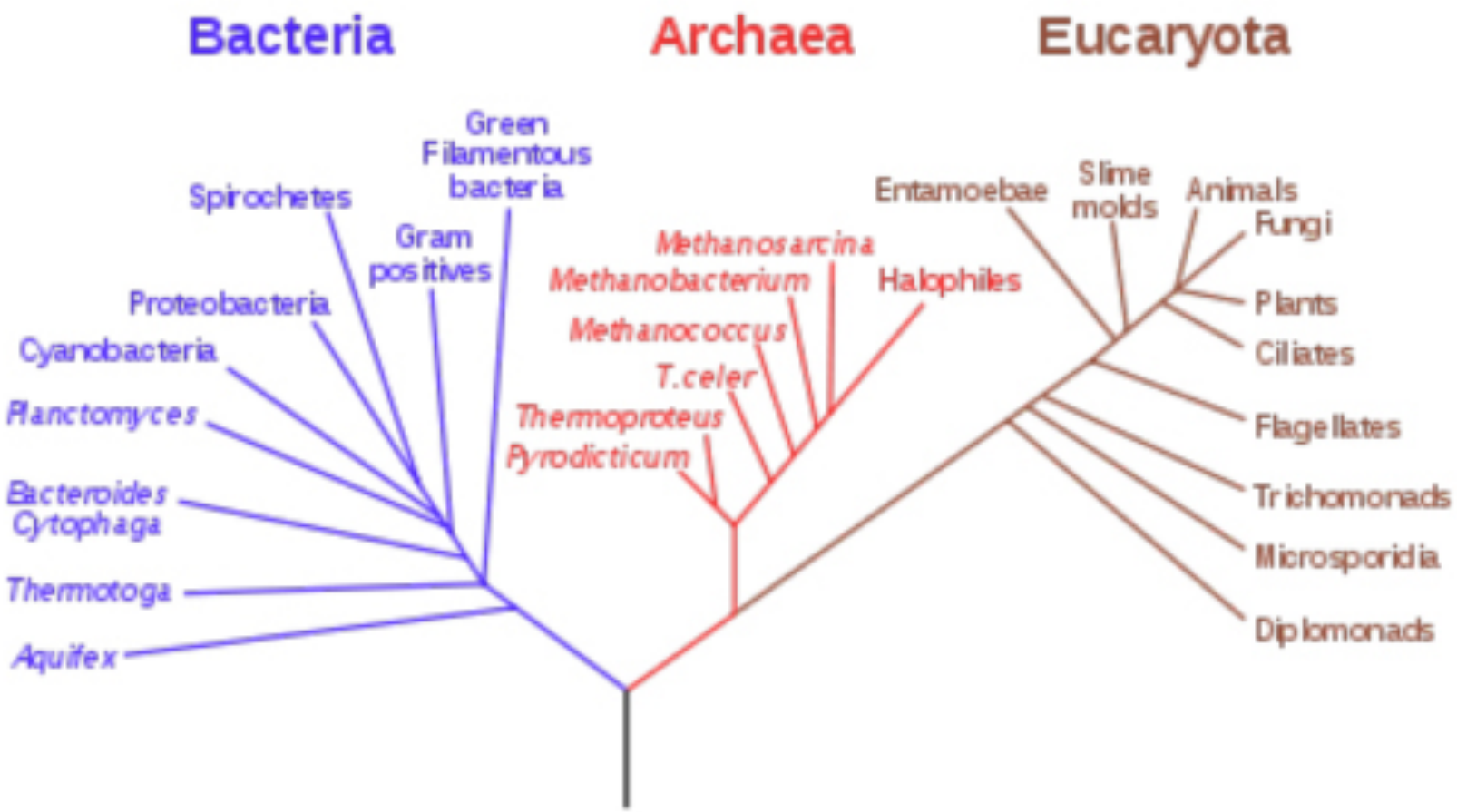
Introductory Mycology BI 432/532

Lecture 2: Overview of Fungi

Phylogenetic Tree of Life



Fungi are:

- **Microbes (mostly)**
- **Eukaryotic**, **heterotrophic** organisms that obtain nutrients by **absorption** and reproduce by **spores**.

  Extracellular enzymes act on complex substrates, low molecular weight breakdown products are absorbed through the fungal cell wall.

Fungi live in their food.

Nutrition

- **Heterotrophs (chemoheterotrophs)**
- **Aerobes, facultative anaerobes (except *Neocallimastix*)**
- Absorptive nutrition
- Secrete extracellular enzymes that act on complex substrates
- **Saprobes**: decay dead organic matter
- **Parasites**: biotroph, necrotroph

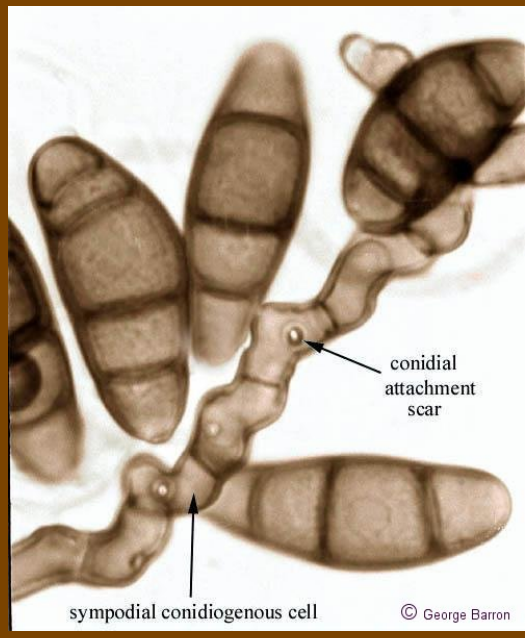


Reproduce by **spores**

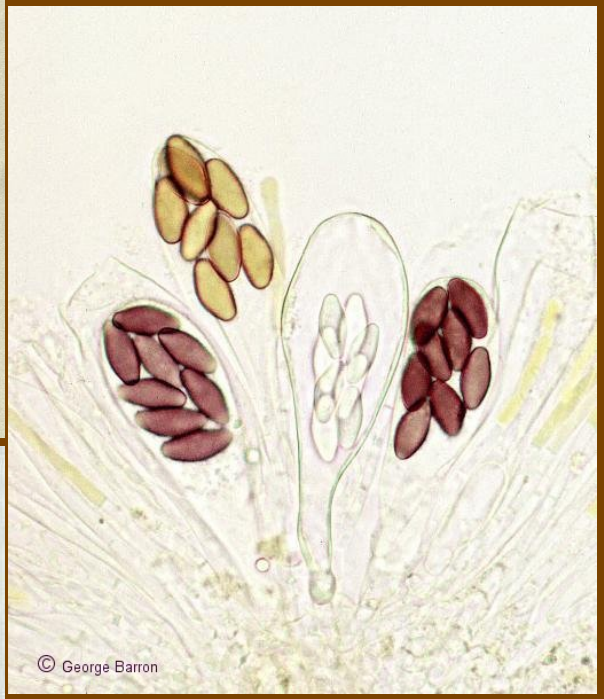
Reproduction, dissemination or survival structures

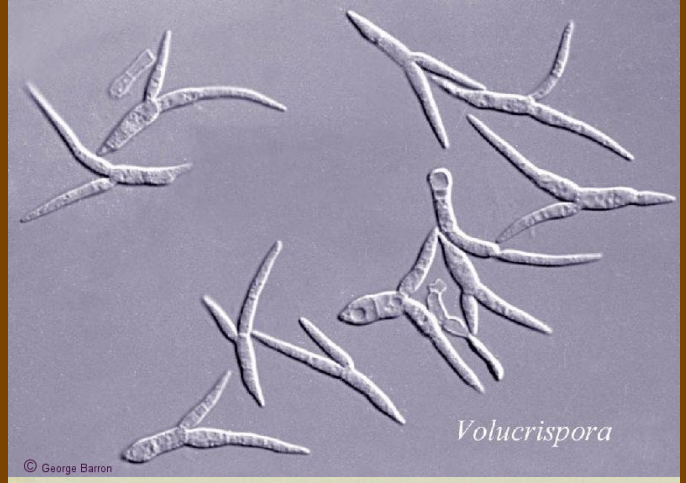
A differentiated structure that may be specialized for dissemination, a resistant structure produced in response to adverse conditions, and/or produced during or as a result of a sexual or asexual reproductive process.

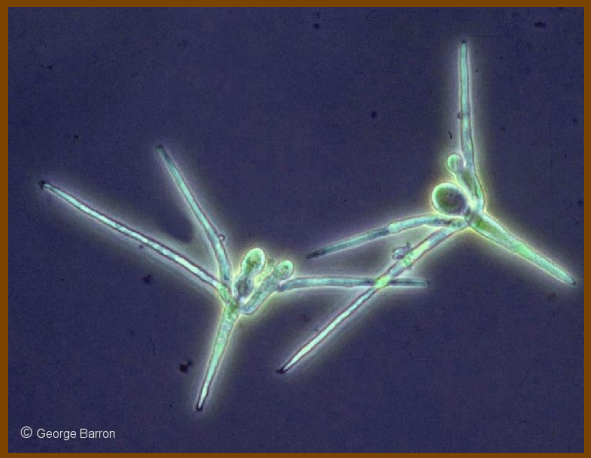
Spores may be one-celled or multicelled, colorless or pigmented (brown)

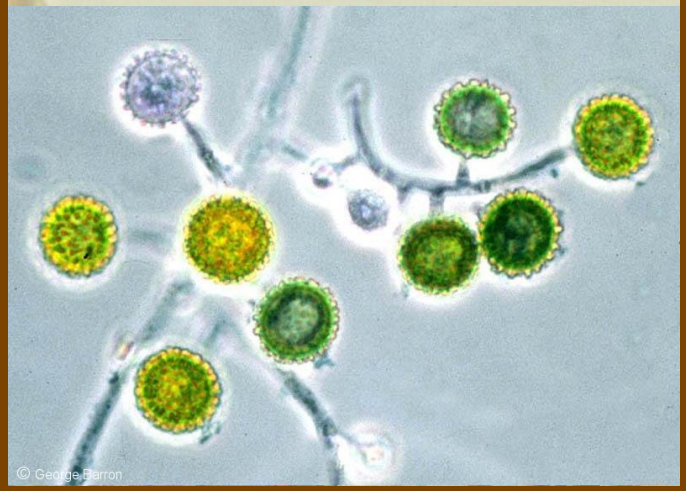


Fungal spores



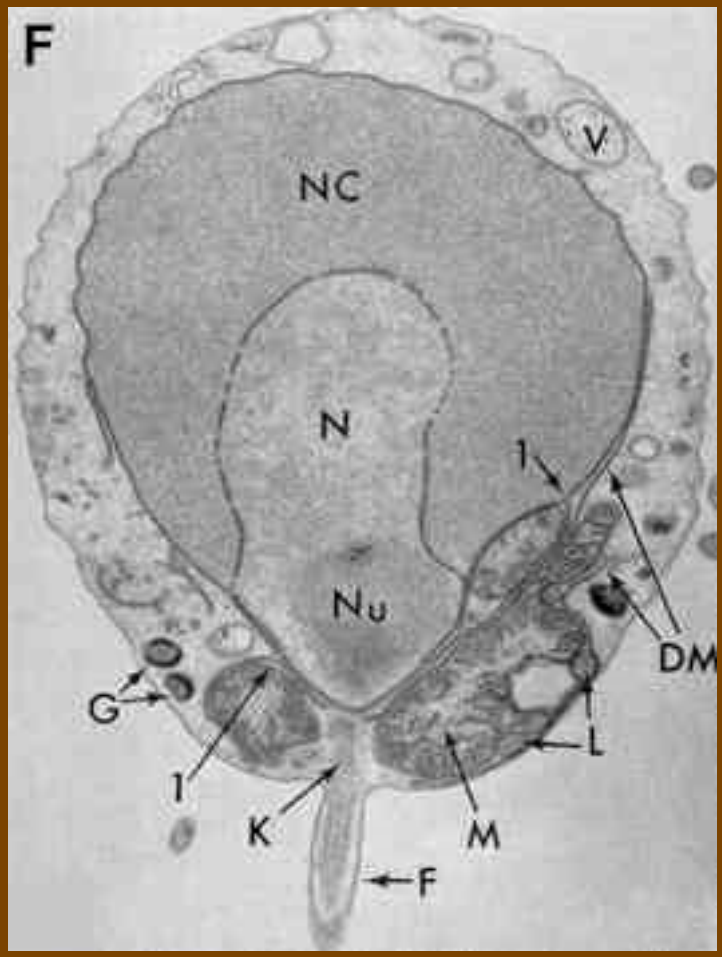






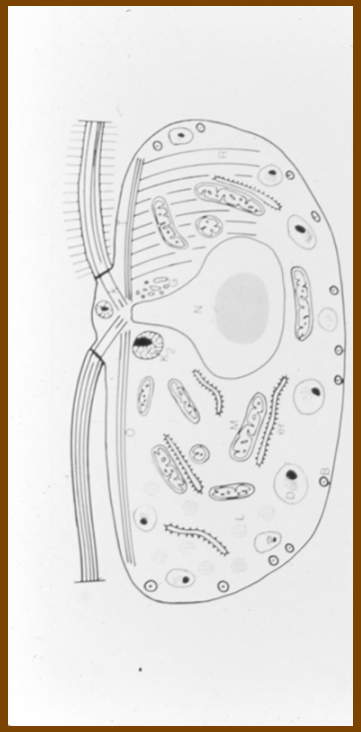
Spores of some true fungi (chytrids), and fungus-like taxa (Oomycetes) are motile zoospores

Chytrid zoospores have a single posteriorly directed flagellum

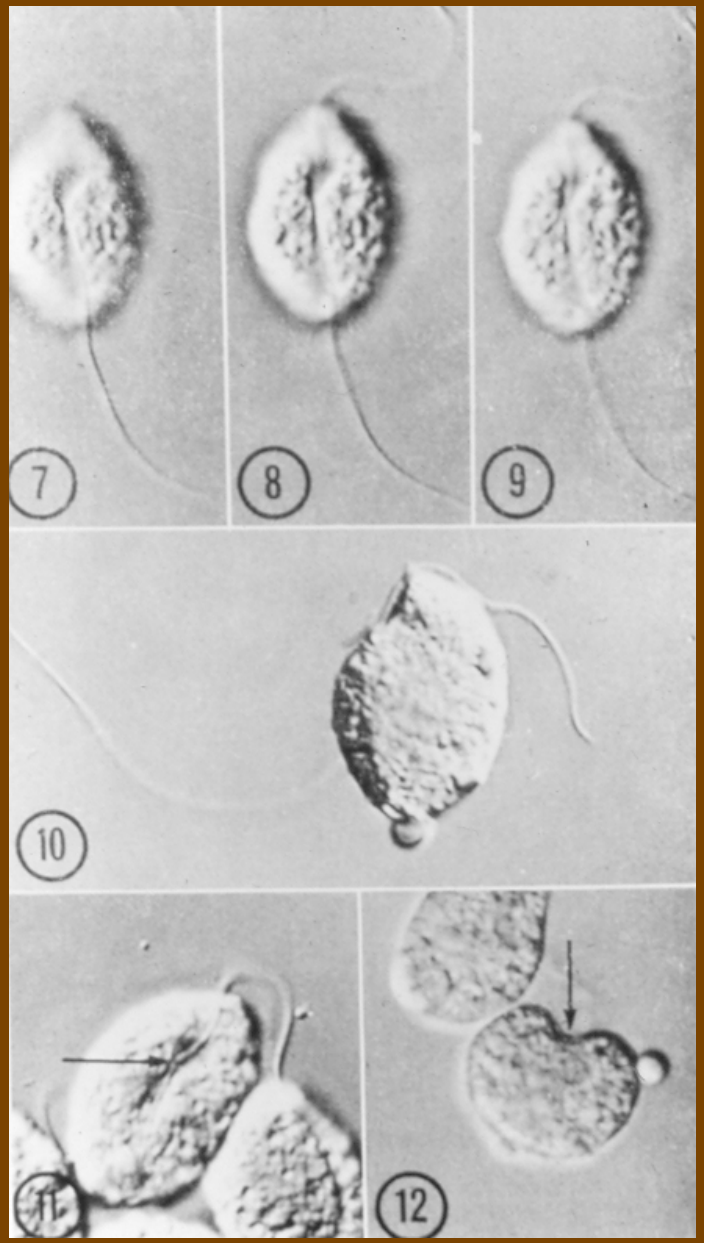


Oomycetes

fungus-like organisms more closely related to plants than to true fungi



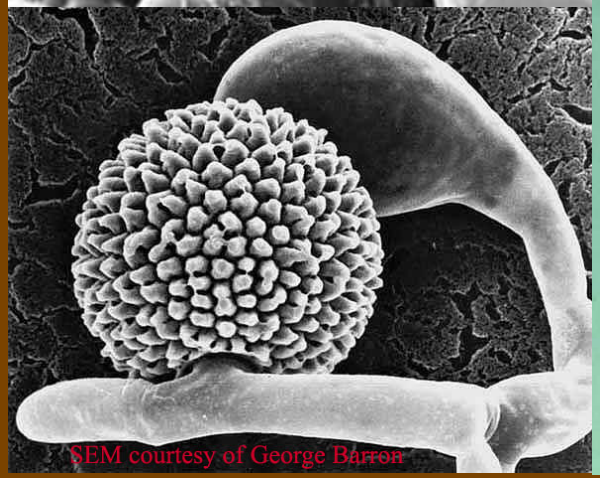
Oomycete zoospores have two flagella,
one anteriorly directed and one posteriorly directed



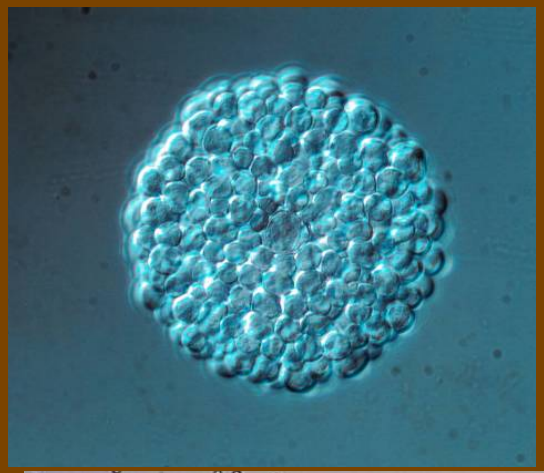
Spores of “higher fungi”—zygomycetes, ascomycetes, basidiomycetes—are non-motile

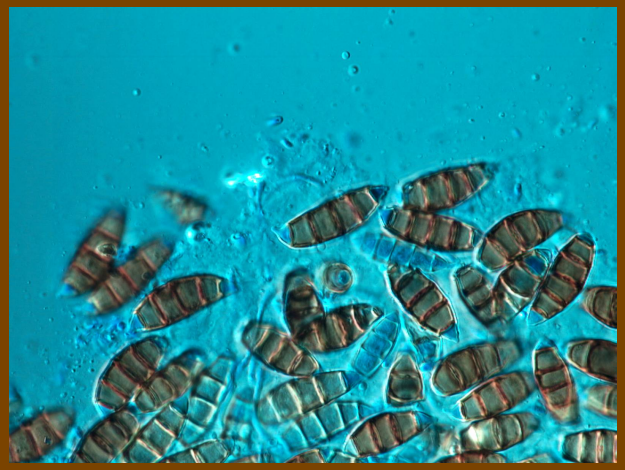
Spores of fungi may result from sexual (meiotic division) or asexual (mitotic division) processes

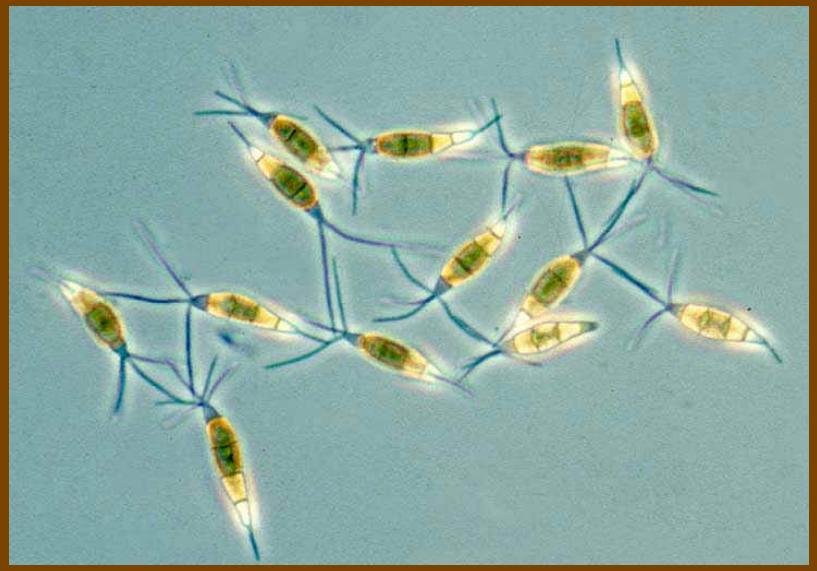
Major groups of fungi (phyla) mainly based on how sexual spores are formed



Asexual spore diversity

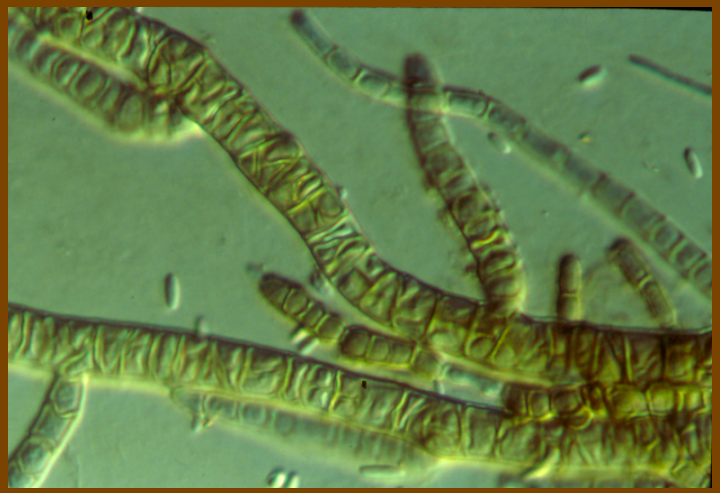






Cellular structures

- Simple organization, vegetative (thallus) and reproductive structures (sporocarps, sporangia)
- The somatic body of most fungi is a **thallus** composed of **hyphae** (sing. **hypha**) that elongate by **tip growth**
- unicellular (**yeast**), filamentous, or both (=dimorphic)
- **Hypha** (pl. hyphae) is the basic "cellular" unit in filamentous fungi; they may be septate or coenocytic (aseptate); collectively a **mycelium**



200 years of research on hyphae

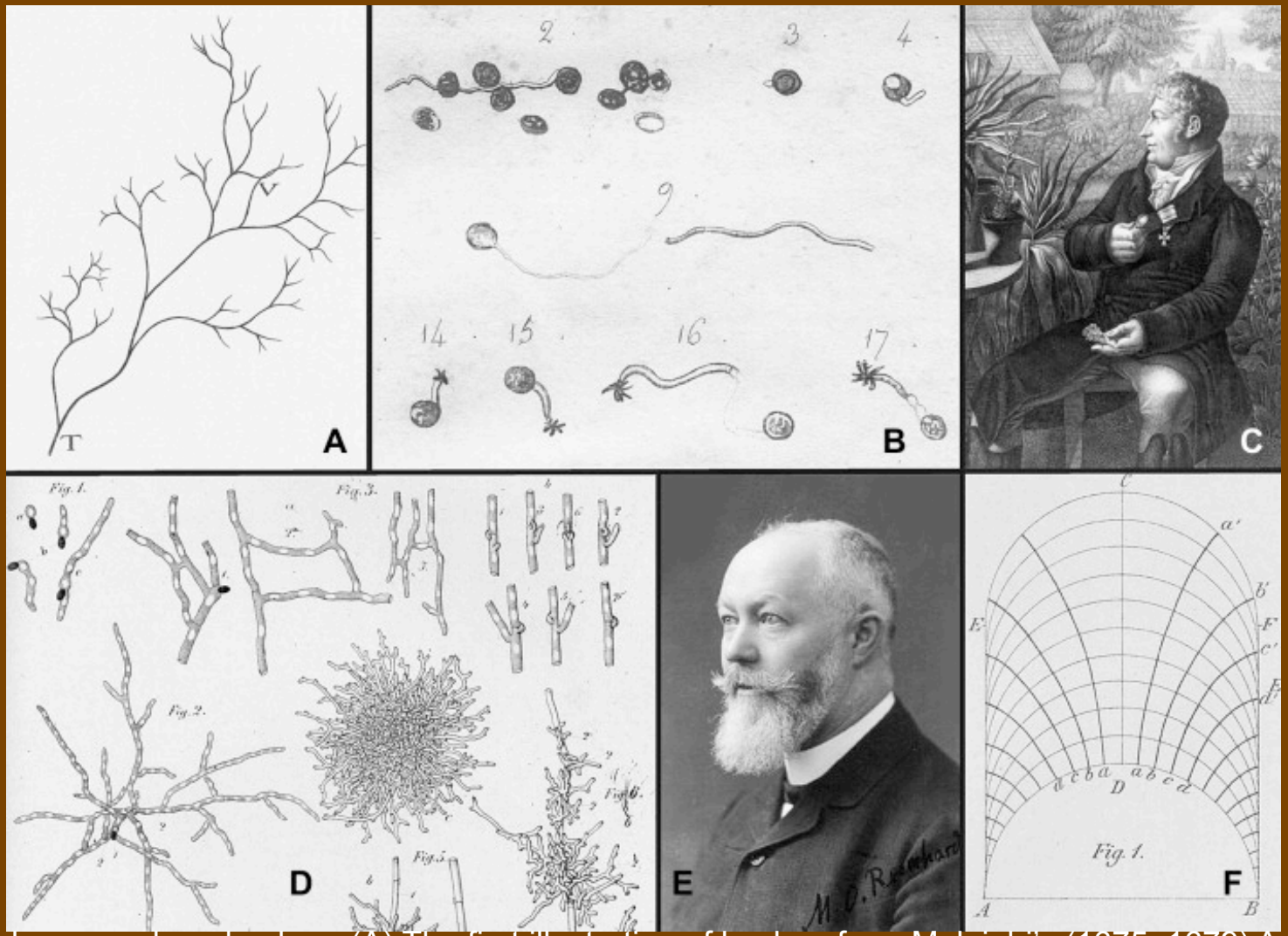
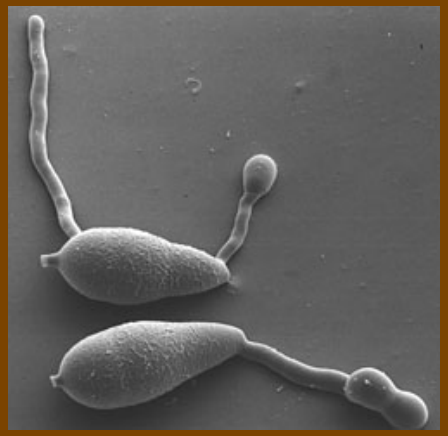


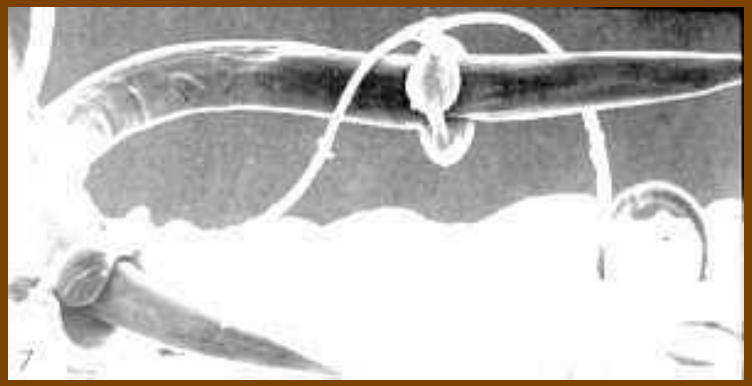
Fig 1. Early research on hyphae. (A) The first illustration of hyphae from Malpighi's (1675–1679) Anatome Plantarum. (B) Detail from classic illustration of spore germination in Tilletia caries by Prévost (1807). (C) Carl Ludwig Willdenow (1765–1812), the scientist who coined the term 'hypha' in 1810. (D) Illustration of spore germination and hyphal development by Oscar Brefeld (1872). (E) Max Otto Reinhardt (1854–1935). (F) Diagram of hyphal apex showing trajectories of points on the surface of the extending cell wall from Reinhardt (1892).

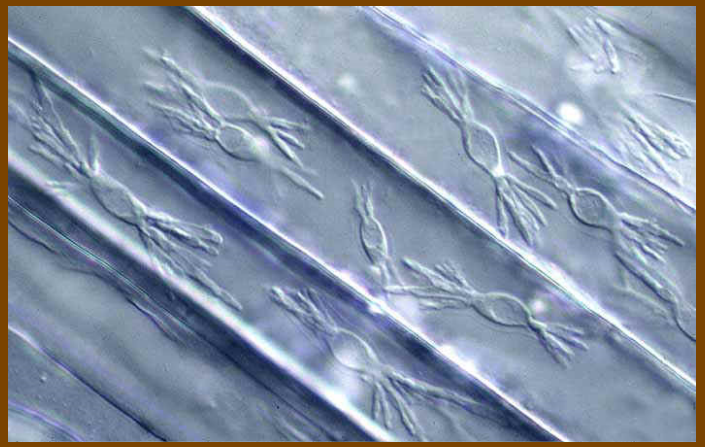
Hyphal modifications: variations on a simple structure

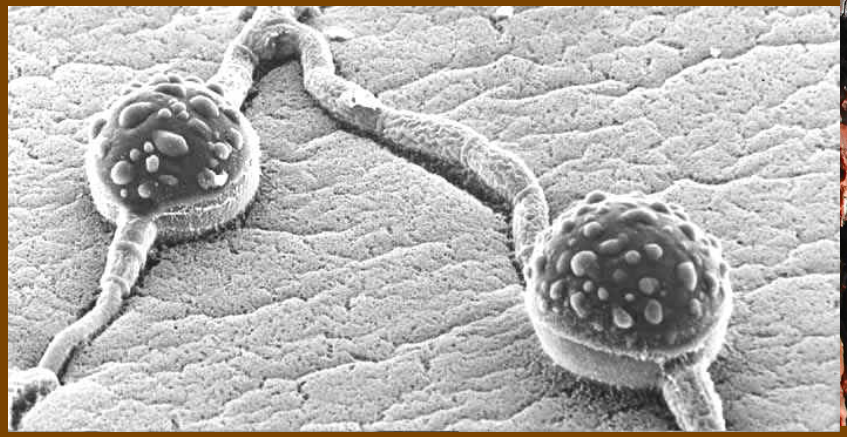
infection structures
    appressoria, haustoria, rhizomorphs
survival structures
    sclerotia, chlamydospores
dispersal structures
    conidia – asexual spores
trapping structures
    nematode traps, nets, adhesive knobs

Hyphal modifications









Reproduction

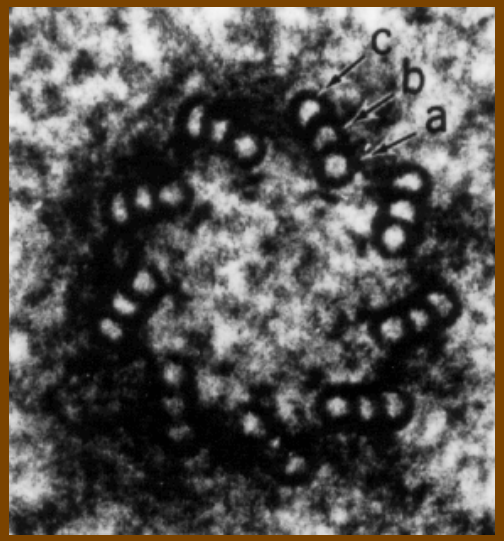
- Sexual reproduction: spores have meiotically derived nuclei
- Monoecious or dioecious: reproductive structures of one or both mating types may be present in the same individual
- **Homothallic** (self fertile/compatible)
- **Heterothallic** (obligately outcrossing)
- Genetic mating system MAT loci
  in ascomycetes, single locus,
  two allele
  Tetrapolar or bipolar systems in basidiomycetes--1 to hundreds of "sexes"
- Asexual reproduction
  – Spores with mitotically derived nuclei

Different fungi may have sexual, asexual, or both modes of reproduction in life cycle

sexual reproduction: nuclei derived from meiotic division, sometimes called meiospores (ascospores, basidiospores, zygospores)

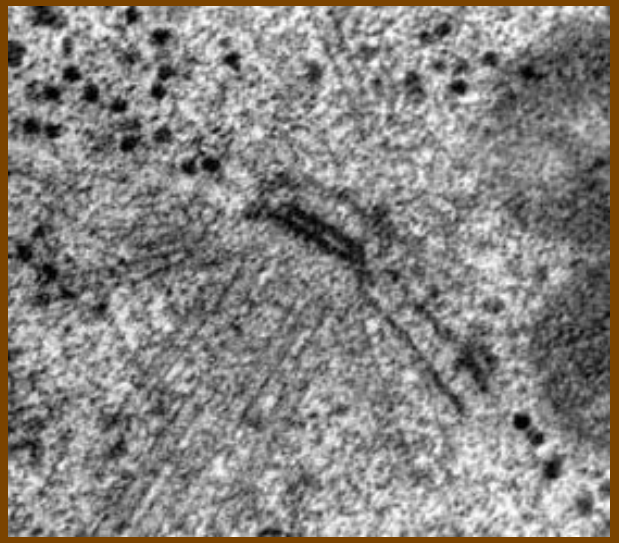
asexual reproduction: nuclei derived from mitotic division, sometimes called mitospores (conidia, sporangiospores)

- Mitosis
  - **intranuclear**: nuclear membrane doesn't break down until late in mitosis
  - **centric** in flagellated forms; typical centrioles of eukaryotes
  - **noncentric** in nonflagellated forms; possess **spindle pole bodies** (SPBs); differ from centrioles in lacking microtubular component



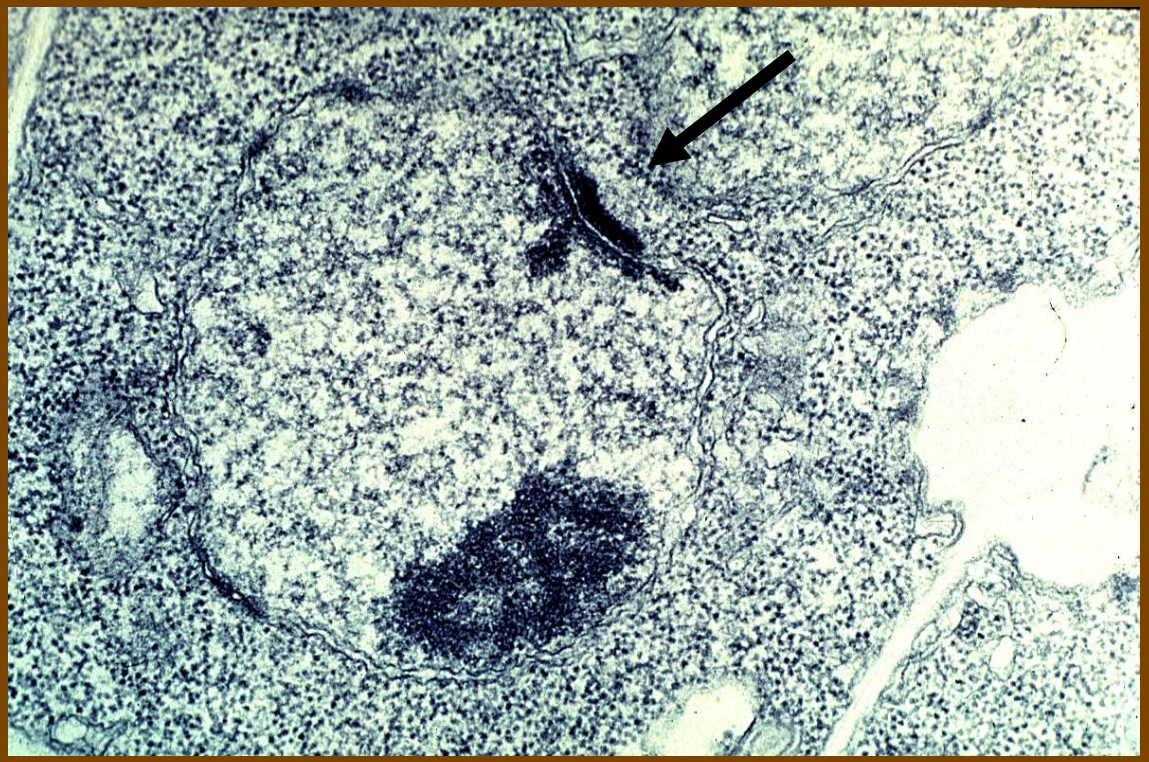
centriole

SPB



Spindle pole bodies (SPB)

Nucleus associated structure, function like centriole



Function as microtuble organizing centers in nuclear divisions
Duplicates during prophase, move to opposite sides of dividing nucleus
Spindle apparatus develops

Organelles

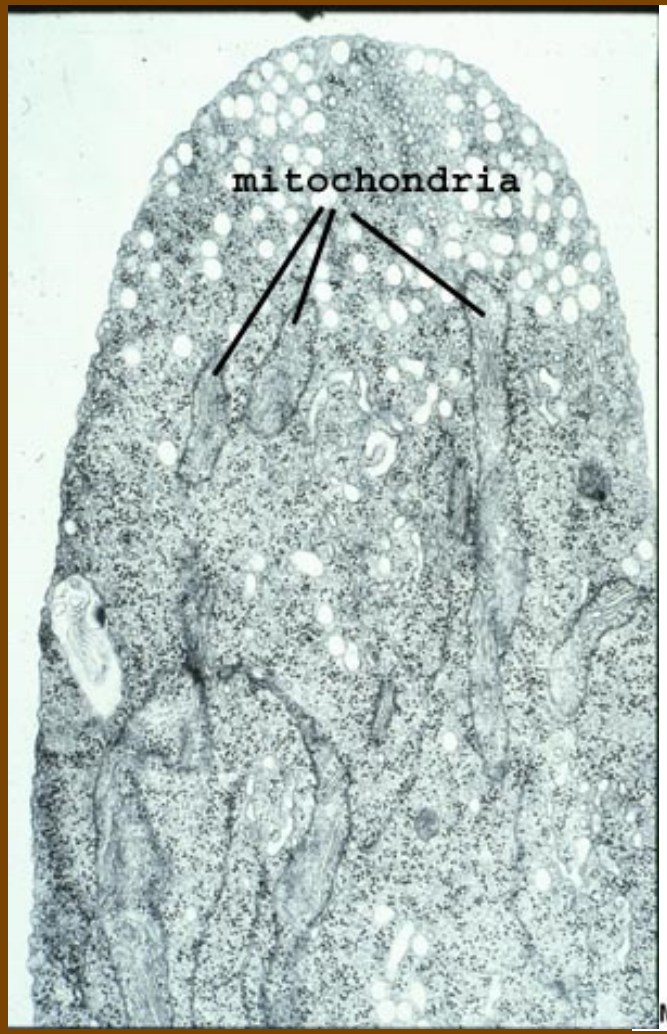
- typical eukaryote assemblage of organelles + fungal specific ones (e.g. chitosomes)
- mitochondria
- endoplasmic reticulum
- dictyosome cisternae

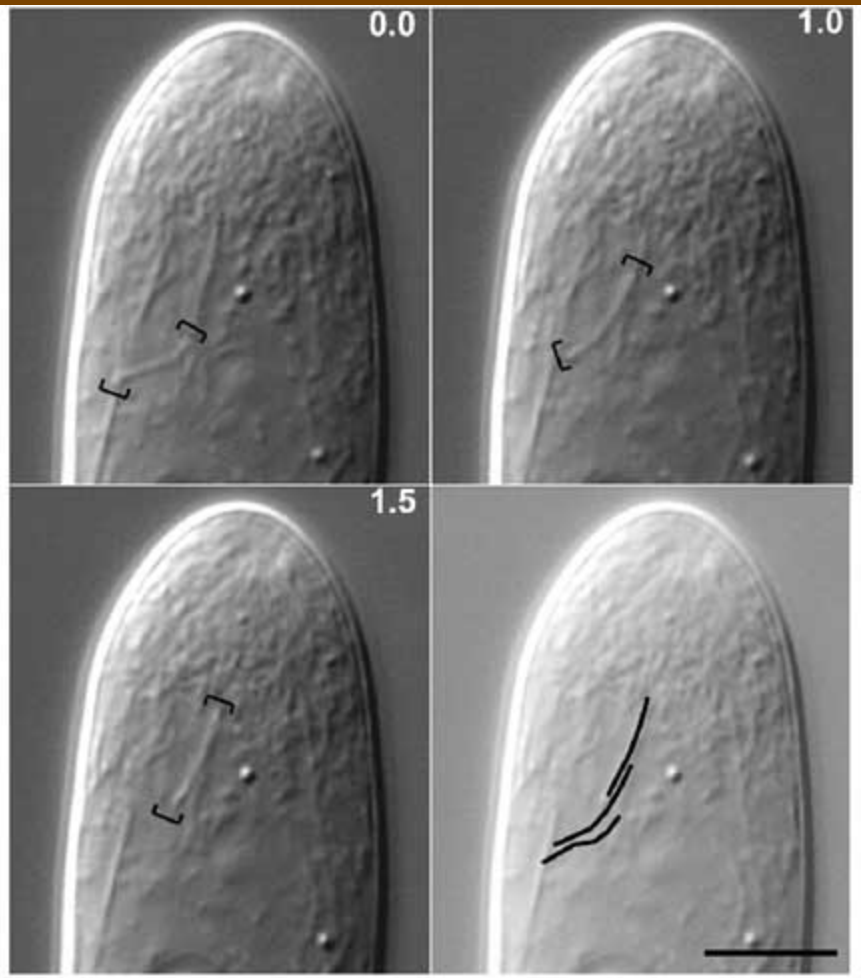
  (=golgi apparatus)
- vacuoles
- **microbodies**

  function in fatty acid degradation, SOD dissipation, N metabolism

Mitochondria

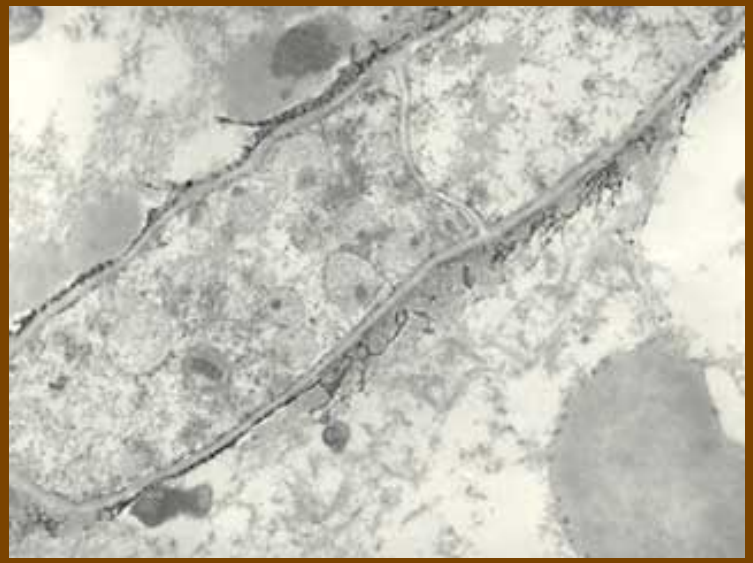
Most organelles aggregated behind hyphal tip; cytoplasm more distant behind tip becomes vacuolate, inactive.

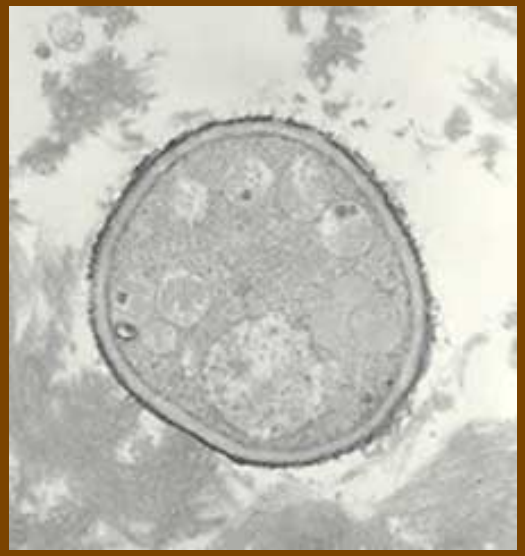


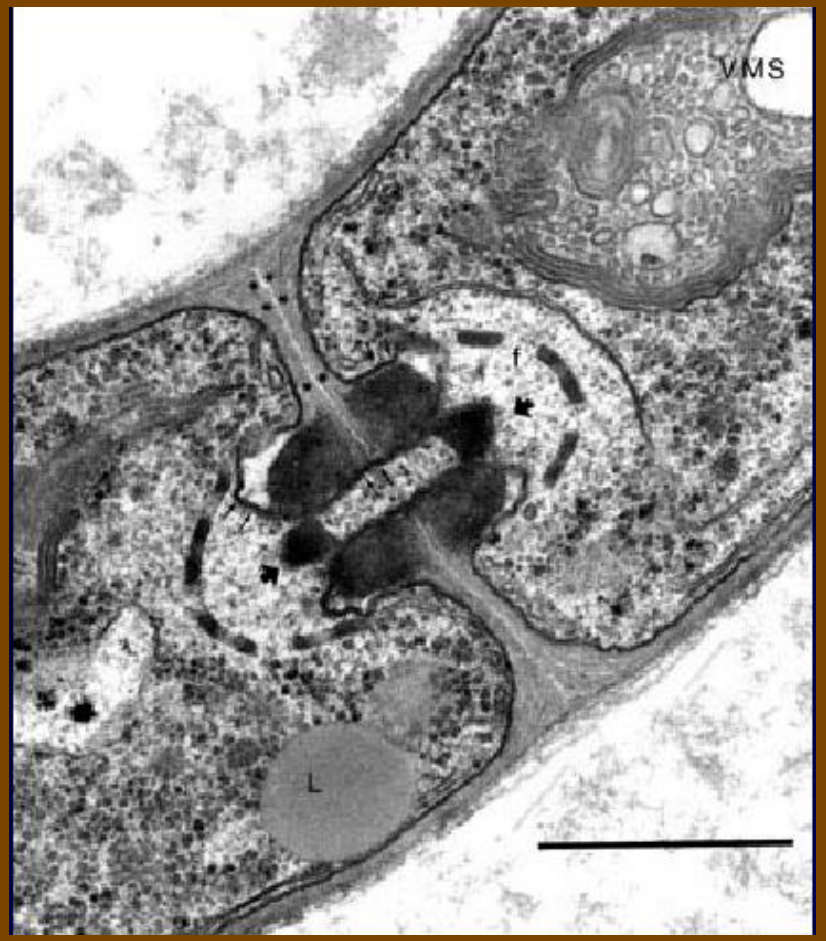


Mitochondrion movement in region IIA: McDaniel and Roberson, Fungal Genetics and Biology (in press)

Fungal cells have cell walls







Cell Wall Composition

- **chitin**

β1-4 n-acetyal glucosamine

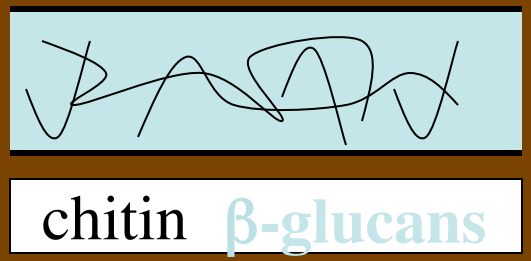
- **β-glucans**

polymers of glucose

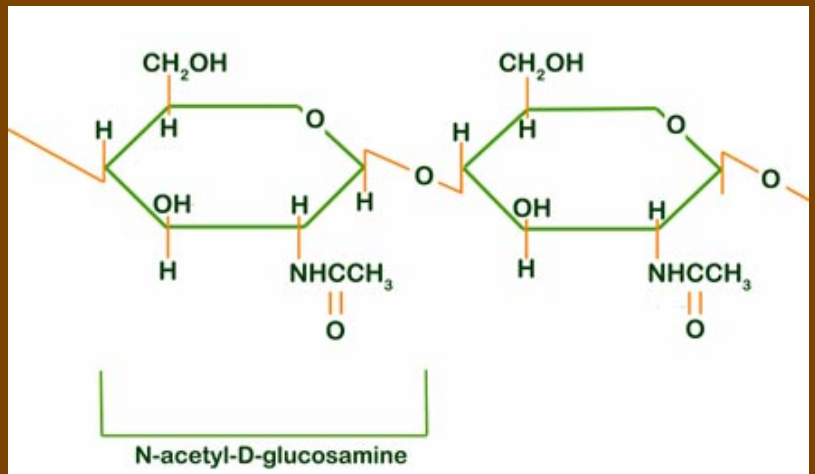
β1-3 gluc

- cellulose in few

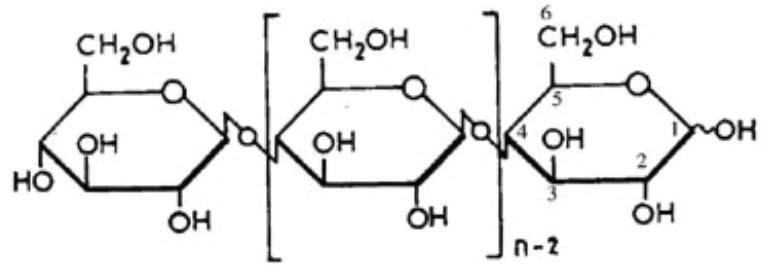
β1-4 glucose



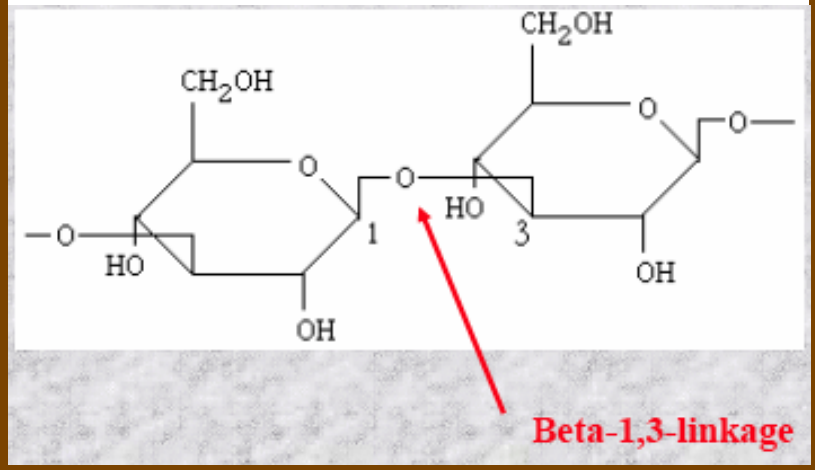
Chitin



Cellulose



β 1-3 glucan



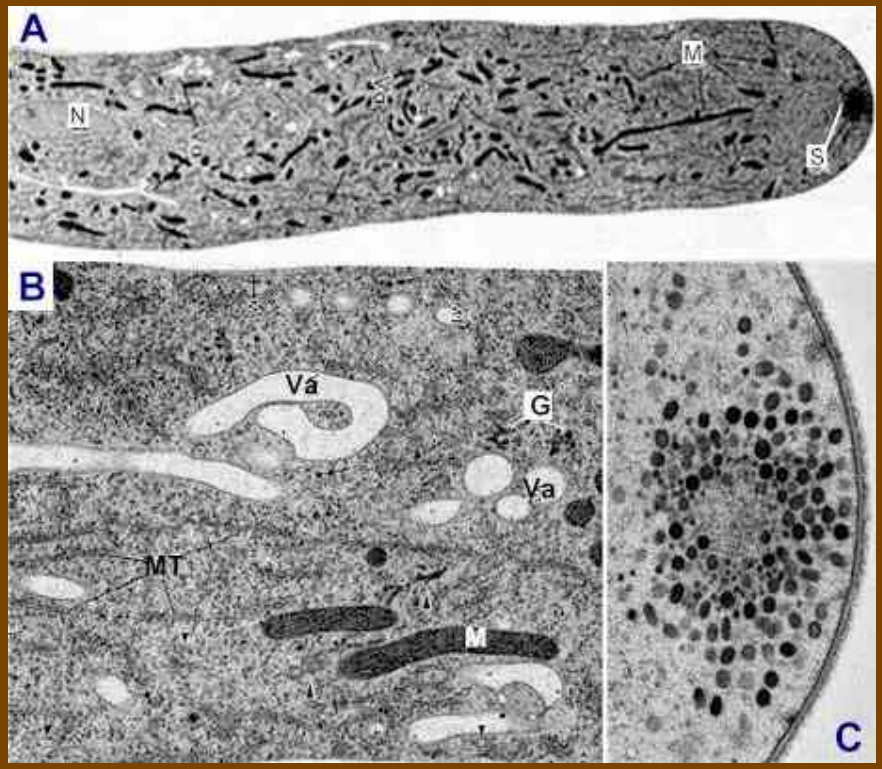
•fungal specific organelles involved in cell wall growth

Spitzenkörper

associated with growing hyphal tips in septate fungi

chitosome

microvesicles transporting chitin synthases to growing cell wall



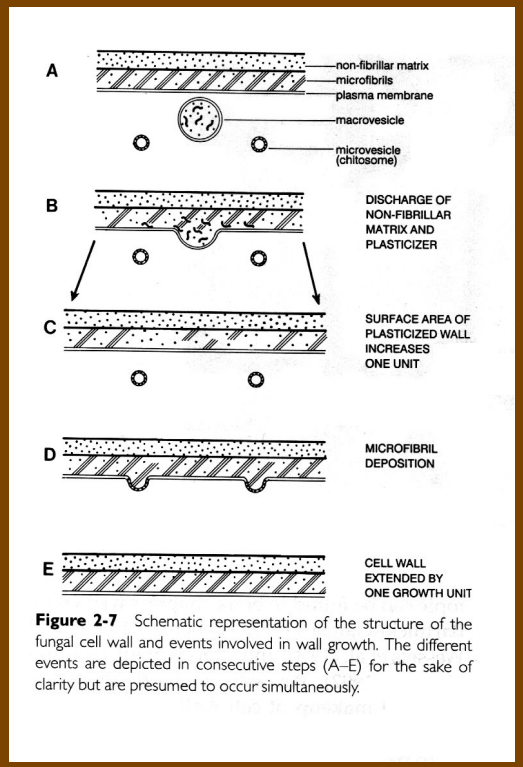
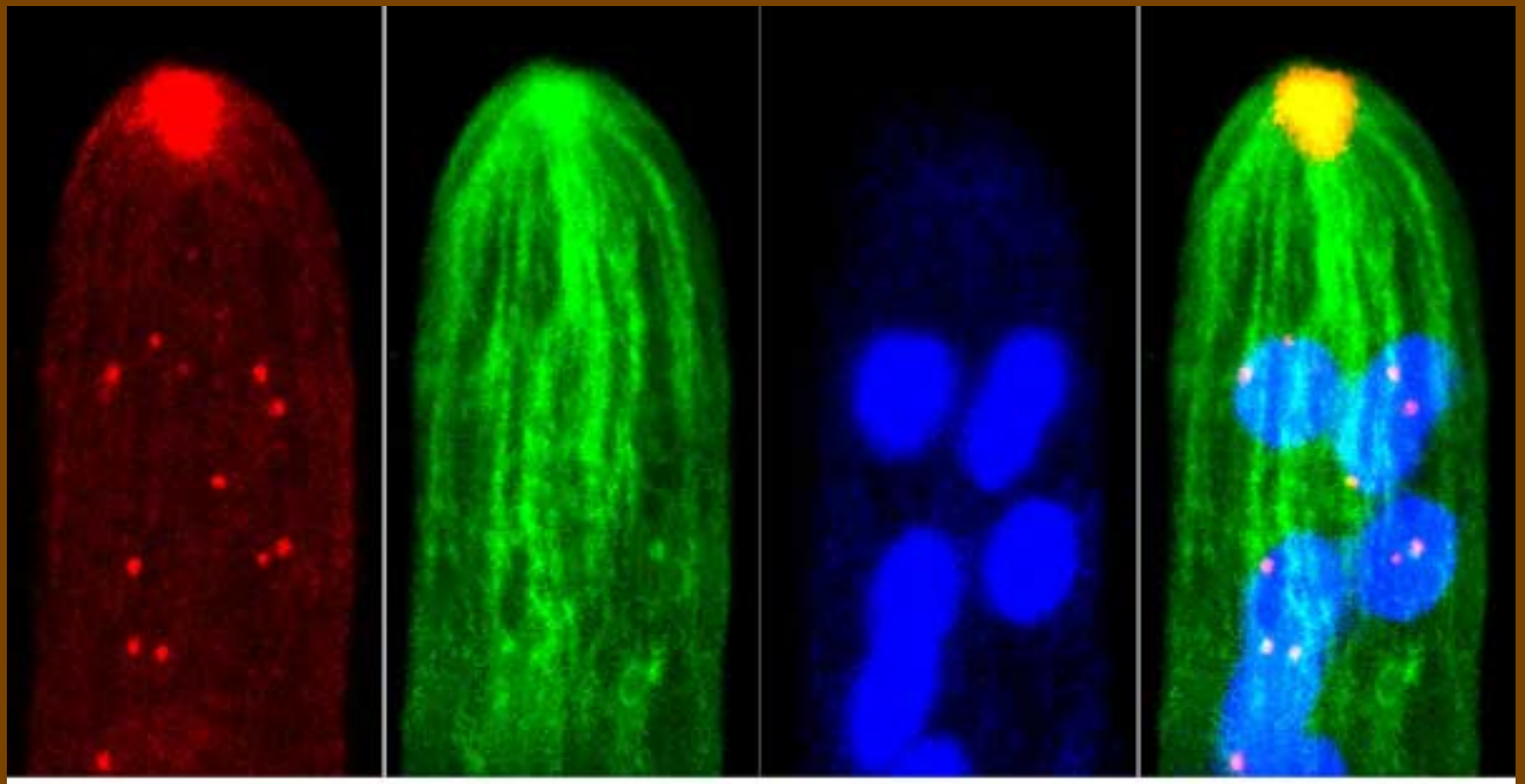


Figure 2-7 Schematic representation of the structure of the fungal cell wall and events involved in wall growth. The different events are depicted in consecutive steps (A–E) for the sake of clarity but are presumed to occur simultaneously.

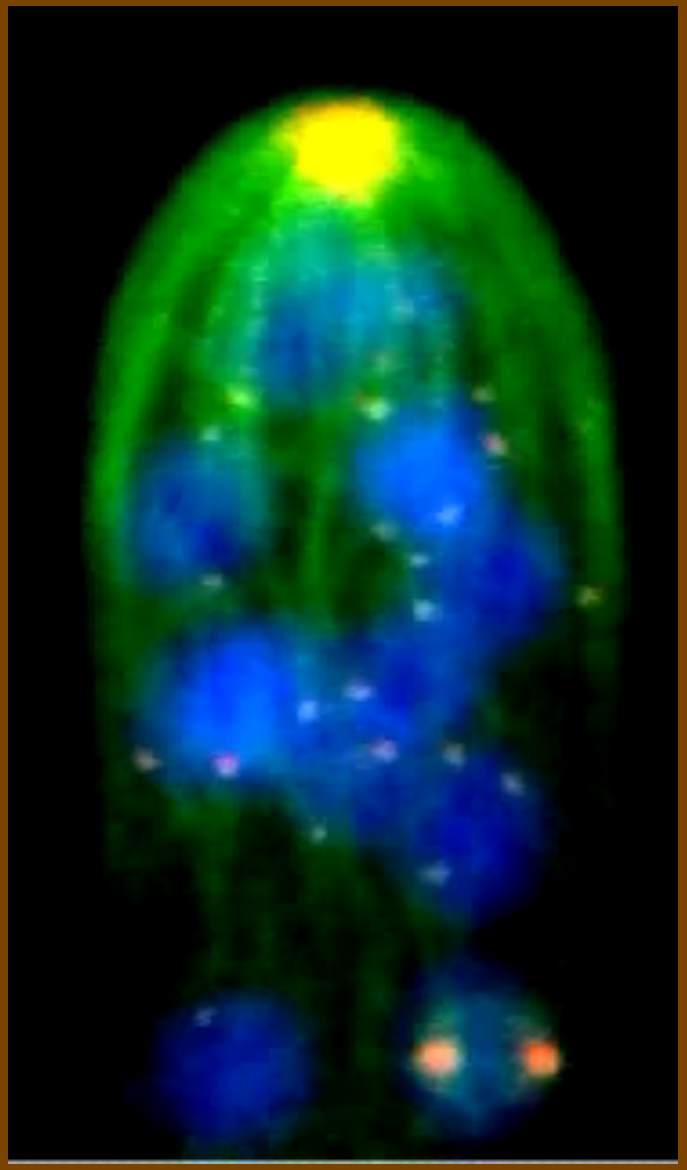
Cytoskeleton

Micotubule (tubulin) and actin filaments, an internal scaffold system
Hyphal growth is polar – extension at the hyphal tip
Vesicles move along cytoskeleton to deposit wall synthesis materials

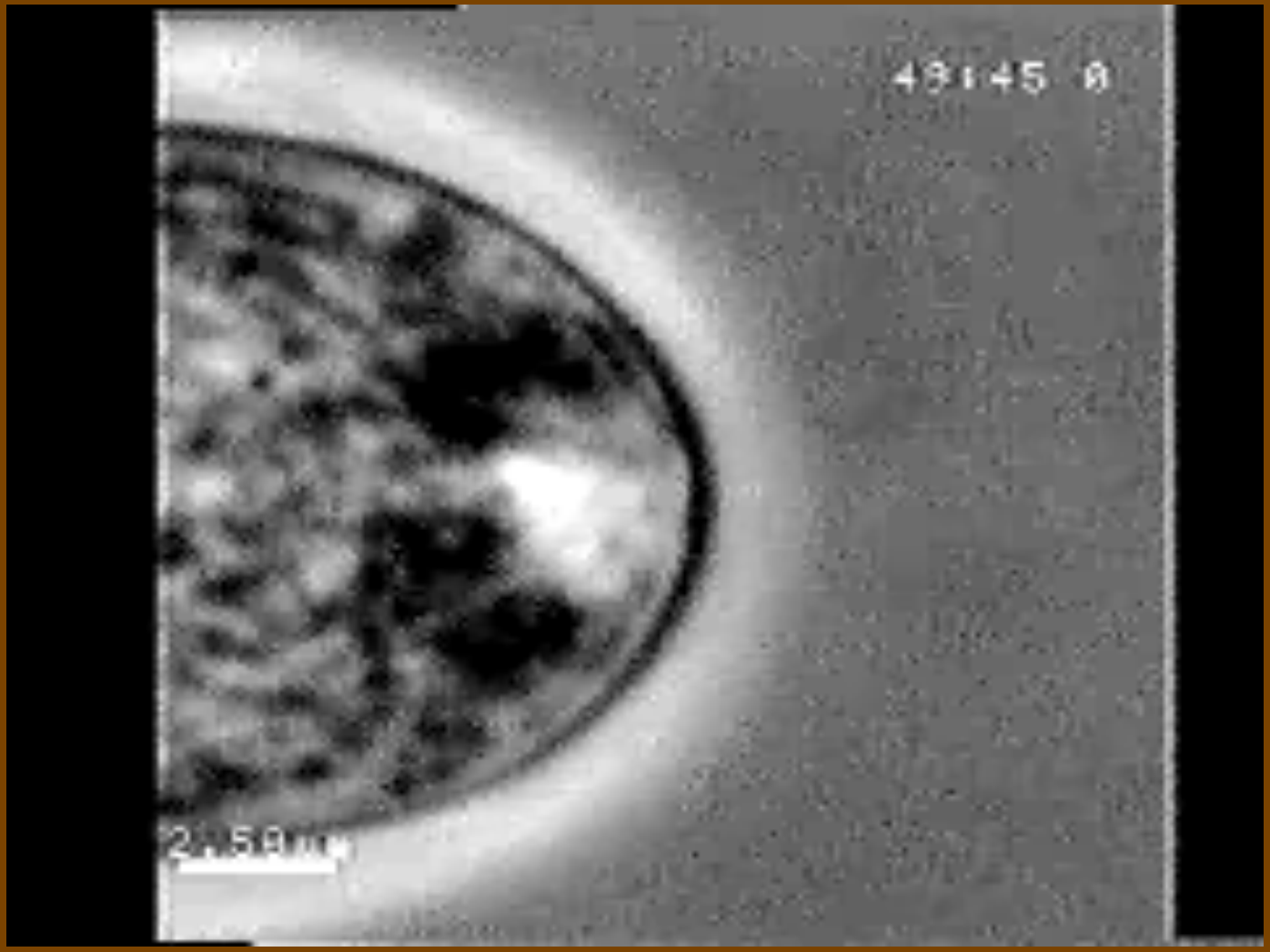


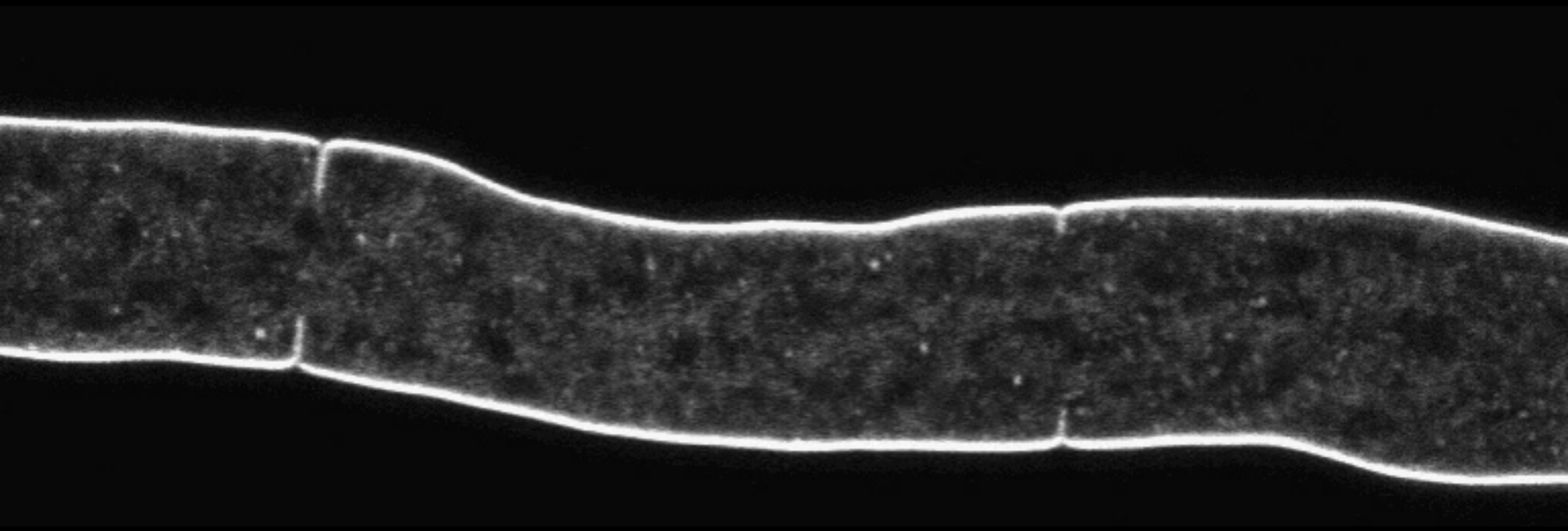
γ-tubulin, α-tubulin, nuclei: McDaniel and Roberson 1998 Protoplasma 203:118-123

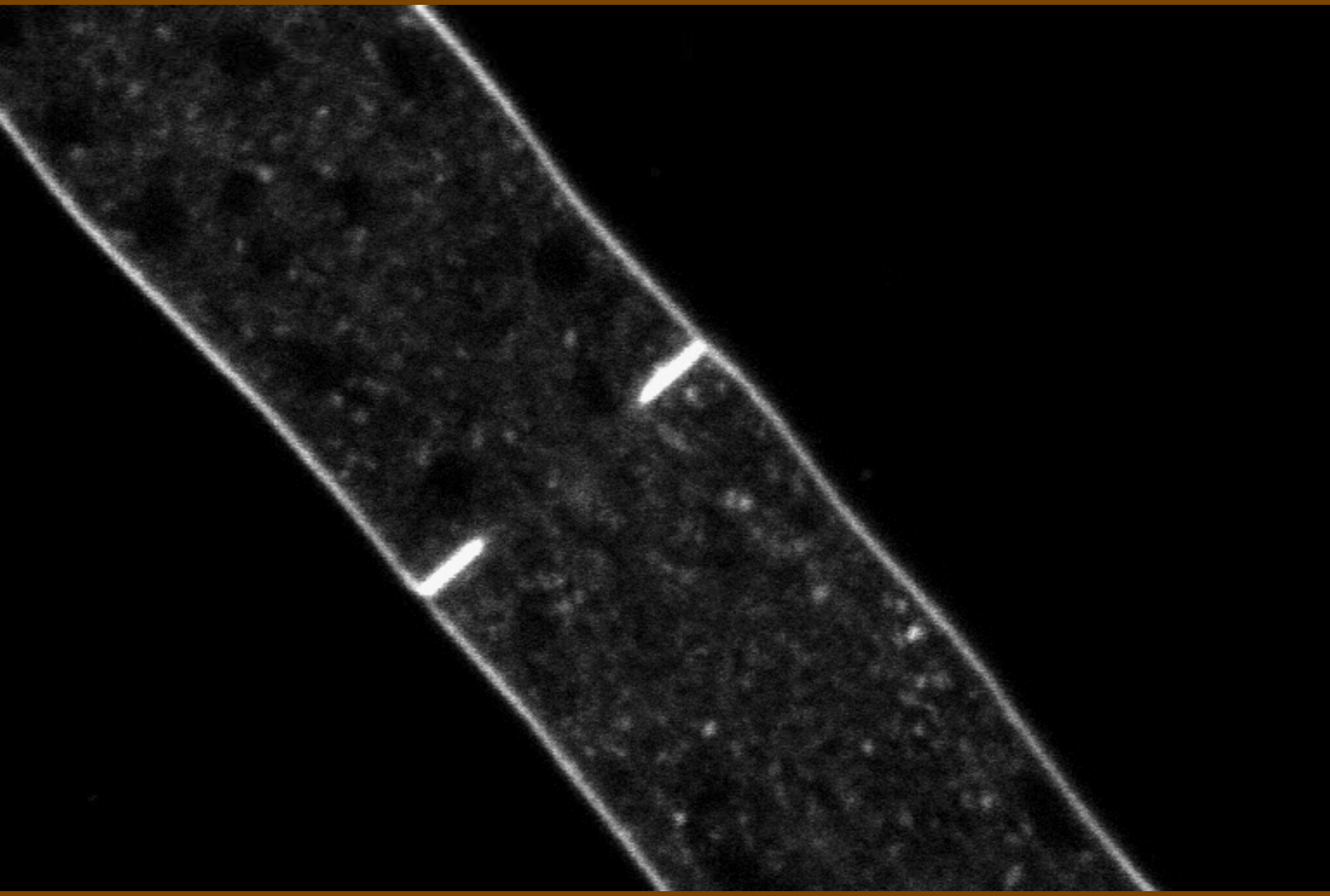
The Spitzenkörper
Vesicles, chitosomes actin filaments

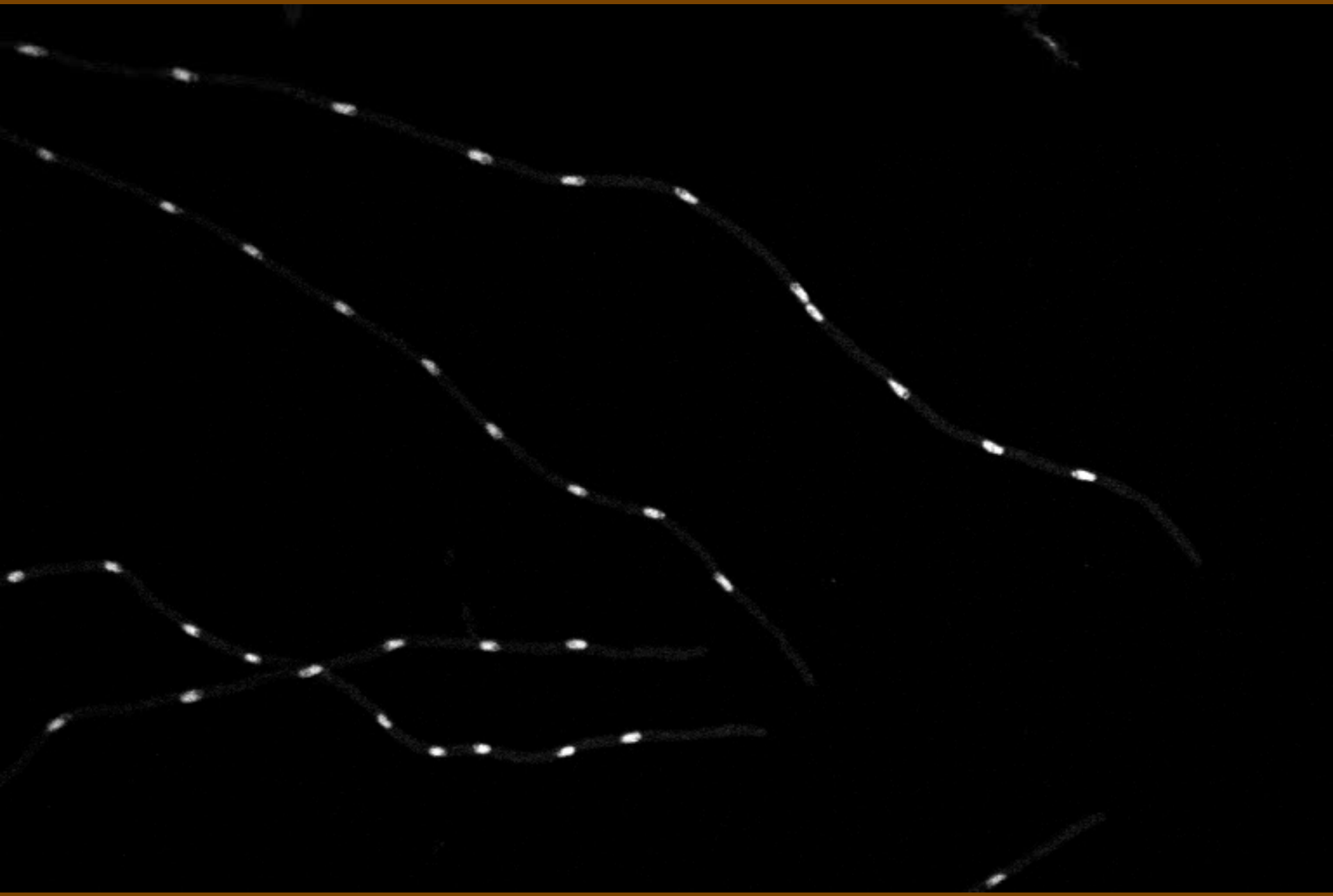


Cell wall synthesis materials are produced behind the hyphal tip and transported on the cytoskeletal scaffold to the Spitzenkörper





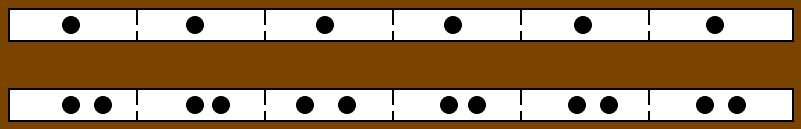




Fungi vary in number of nuclei and sometimes types of nuclei in cells

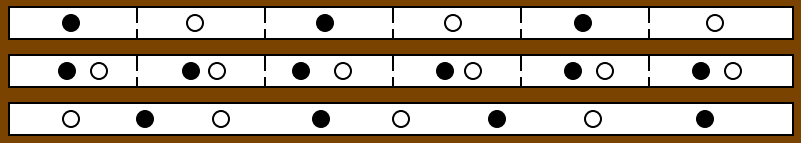
- Uni, bi- or multinucleate, depending on phylum/order
- Haploid, diploid (uncommon)
- **Monokaryon, homokaryon**

  All nuclei are identical, there may be mutliple nuclei per hyphal compartment (cell)



- **Dikaryon, heterokaryon**

  Unique to fungi, 2 different, compatible haploid nuclear types pair and divide synchronously; delay between fusion of gametes and fusion of nuclei



Different dikaryon types

Phylogeny

- Phylogeny, phylogenetics: the study of evolutionary relationships
- Whittaker (1969) proposed 5 kingdoms:
  - Prokaryotes, Eukaryotes (Animals, Plants, Fungi, Protists)
- At least 7 kingdoms are now recognized:
  - Eubacteria
  - Archaebacteria
  - Animalia
  - Plantae
  - Eumycota (Fungi)
  - Stramenipila (Chromista)
  - Protoctista (Protozoa, Protista)

Phylogenetics: inferring evolutionary relationships, lineages

Prior to PCR & gene sequencing, phylogenetic relationships were inferred from:

- Morphology: structure, subcellular structure
- Biochemistry: synthetic pathways, composition of cell components
- Shared life history traits
- Ecological characteristics
- Reproductive structures and mechanisms

all subject to errors, evolutionary convergence

Traditional phylogenetics (morphology/ecology)

Recognition of Fungi as a separate kingdom Whittaker (1969) predated gene sequencing, molecular phylogenetics.

Fungi were recognized as a distinct evolutionary lineage based on:

- filamentous structure
- reproduction by spores
- absorptive, heterotrophic nutrition

Major groups, phyla, within the fungi were also well established prior to DNA sequencing, based on details of structures, reproduction, cell wall composition, biochemical pathways, cellular organelles, ecology.

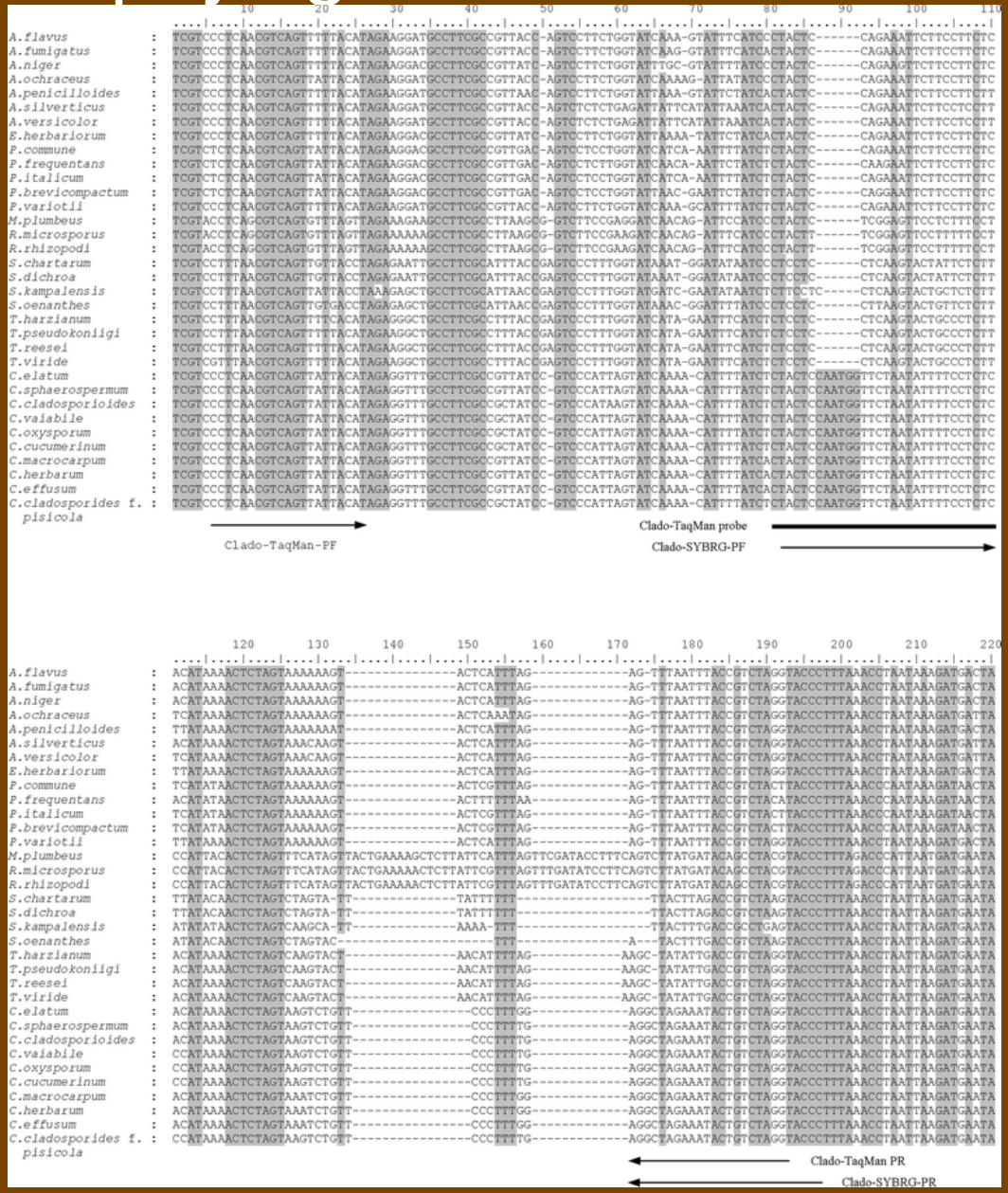
TRUE Fungi comprise a separate lineage, but not all organisms formerly classified as Fungi are part of the same lineage

Fungal phyla:

- Ascomycota
- Basidiomycota
- Zygomycota
- Chytridiomycota
- Oomycota—later shown to belong to the plant lineage

Molecular phylogenetics

Since 1990s, development of polymerase chain reaction (PCR), rapid DNA sequencing and computing capacity, phylogenetic inferences have increasingly been based on comparisons of gene sequences.



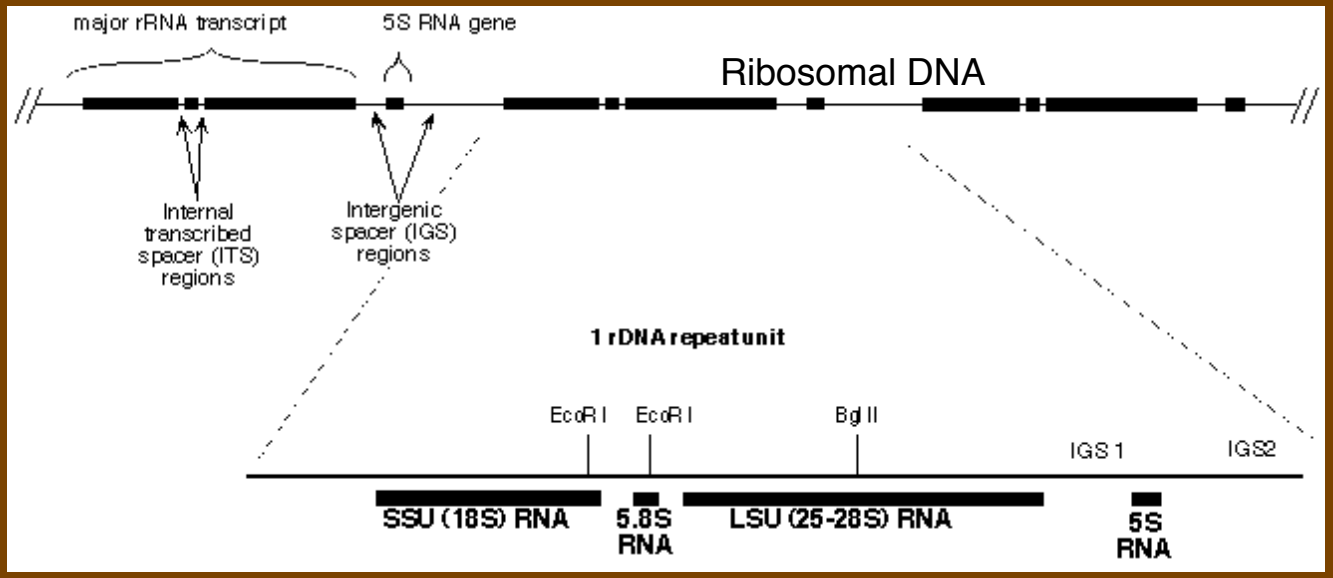
Molecular phylogenetics

Advantages of direct gene sequence comparisons:

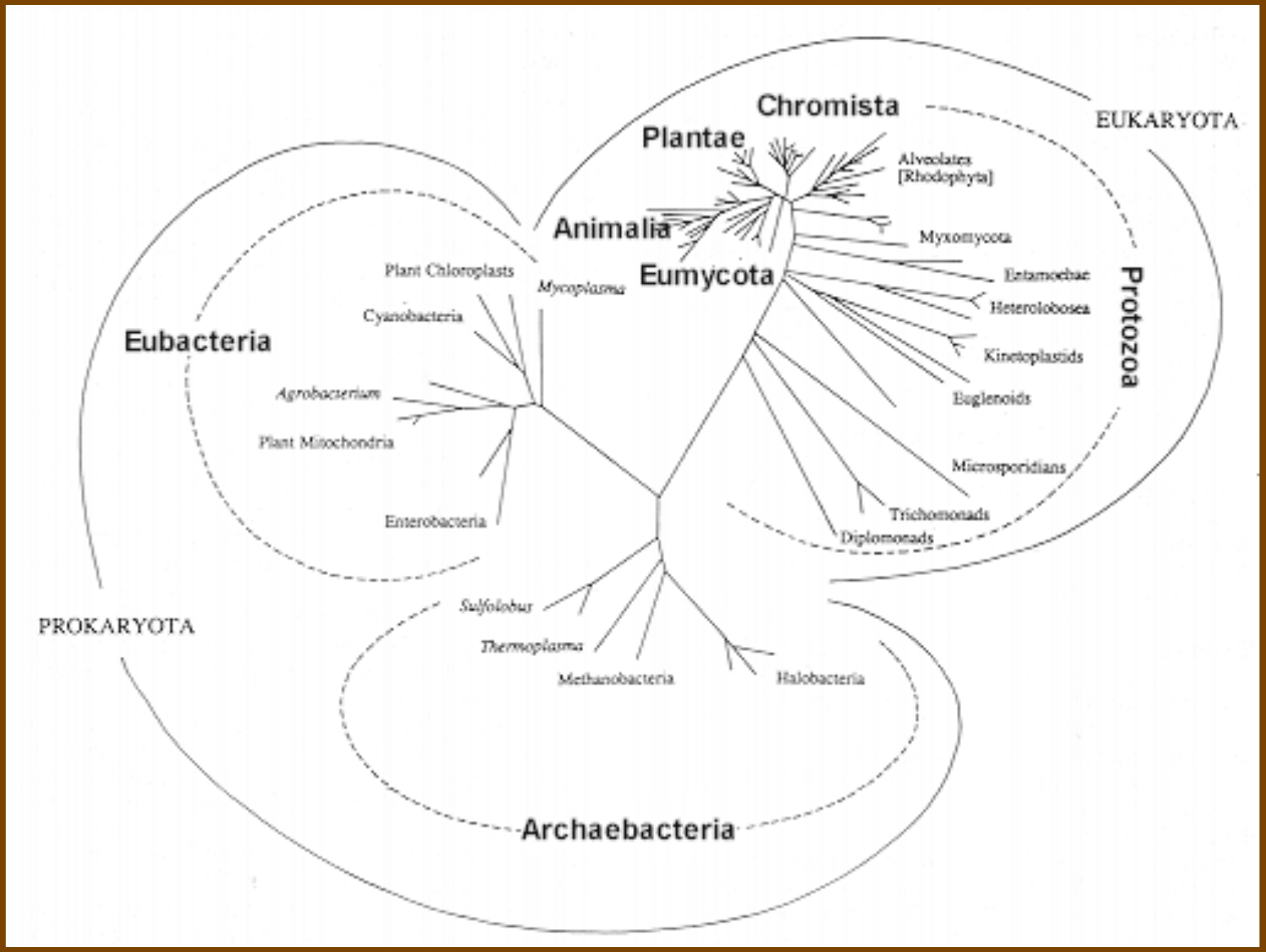
- each base position in gene sequence an independent character
- possible to have hundreds of characters to compare in a gene sequence, together with invariant base positions that allow sequence alignment
- can compare shared genes/sites across multiple taxa
- it is quantitative; relative probabilities can be estimated, statistical tests applied
- neutral mutations can be used
- allow quantitative tests of monophyly (a single evolutionary lineage having a common ancestor, a natural evolutionary group) vs polyphyly (an unnatural group, arising from different evolutionary ancestry)

Molecular phylogenetic analysis

- Has used mainly ribosomal genes (ITS, LSU, SSU, IGS)
- Can be used across all eukaryote taxa
- Nuclear genes
- Multiple copies in the genome, arranged as a series of repeating units
- Variable and conserved regions, amenable to testing closely or distantly related taxa
- Various other genes also used, multigene analyses
  - translation elongation factor (tef 1)
  - beta tubulin
  - histone



Fungi are one of the “crown eukaryote” groups that diverged about 1 billion years ago



Molecular phylogenetics

Has helped to settle some long standing questions, and provide new insights concerning evolutionary relationships in the fungi:

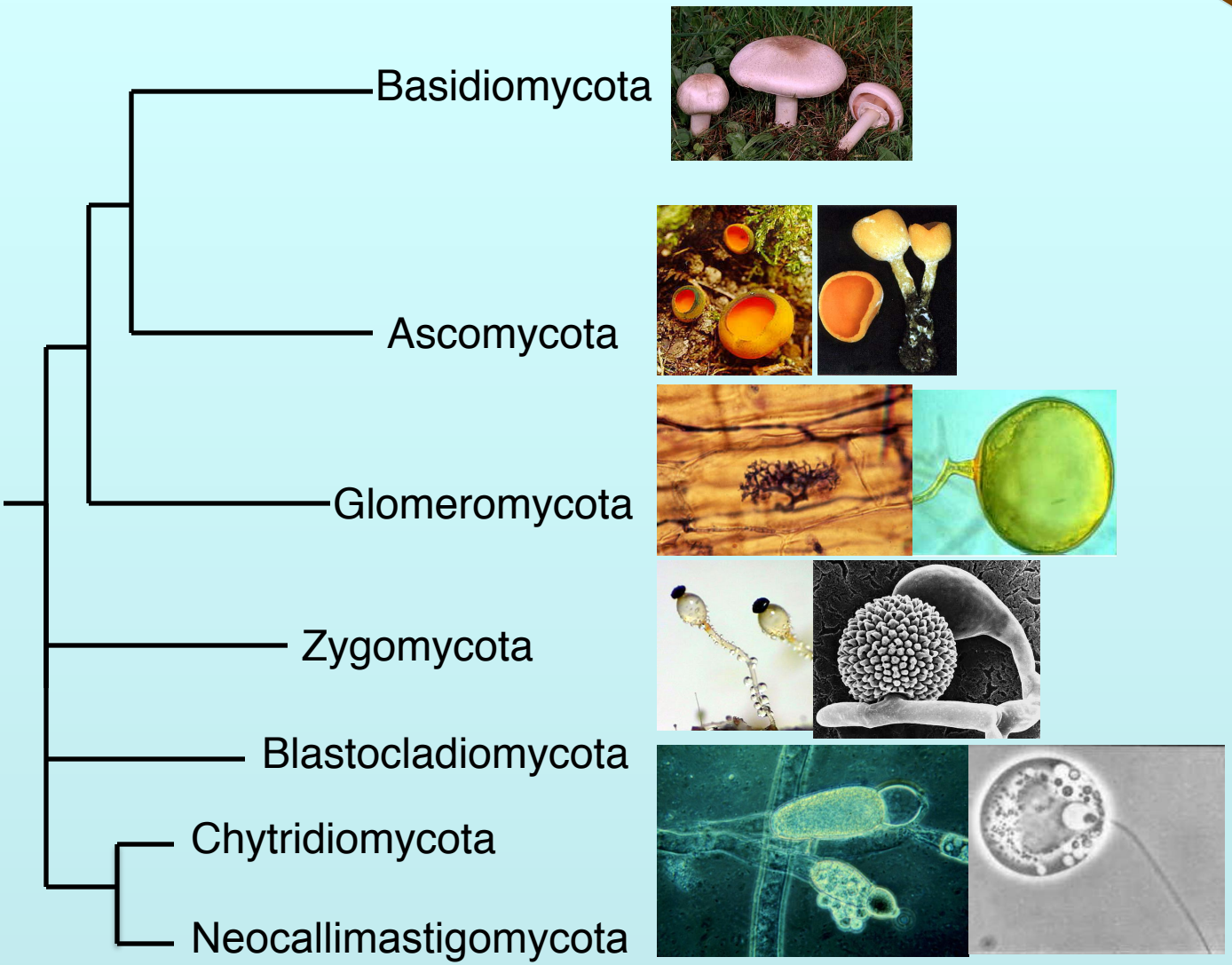
- Fungi as traditionally constituted (at least by some mycologists) is polyphyletic.

- The phylum Oomycota has a different ancestry than the true fungi, Eumycota.

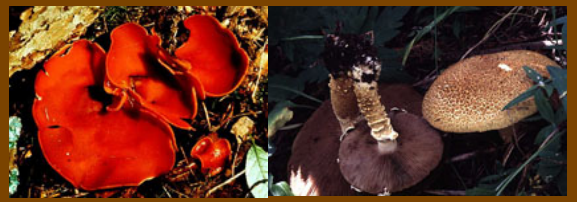
- True fungi, Eumycota, are more closely related to animals than to plants. The Oomycota however are a part of the kingdom Chromista (or Stramenopila), together with the Hyphochytridiomycota and Labyrinthulomycota.

- Floridean hypothesis disproved. Hypothesis on evolutionary origin of fungi was that they shared a common ancestry with the red algae (Rhodophyta), based on similarities of reproduction, alternation of diploid sporophyte and haploid gametophyte generations, filamentous growth, parasitism in both groups.

Phyla of Fungi



Phylogenetic Classification of Fungi

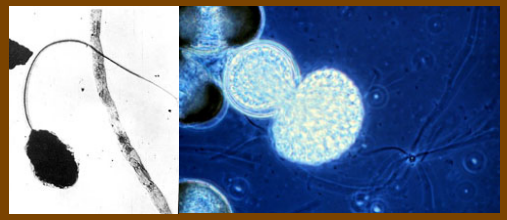


- Dikarya- Ascomycota+Basidiomycota
  septate hyphae, complex sporocarps

- Glomeromycota (4 orders, 10 genera)
  aseptate hypha, lack of meiosis (?)

- Zygomycota (14 orders, ~175 genera)
  mostly aseptate hyphae, zygosporangium
  - Dimargaritales
  - Entomophthorales
  - Mucorales
  - Zoopagales
  - Endogonales
  - Trichomycetes
  - Harpellales
  - Kickxellales

- Chytridiomycota (4 orders, ~110 genera)
  aseptate hyphae, zoospore
  Chytridiales
  Monoblepharidales
  Spizellomycetales



Recently Recognized Phyla

- Blastocladiomycota (2001; 1 order, 14 genera)
  Blastocladiales

- Neocallimastigomycota (2007; 1 order, 5 genera)
  Neocallimastigales

Both formerly orders in Chytridiomycota

Fungi Eumycota, Kingdom, monophyletic

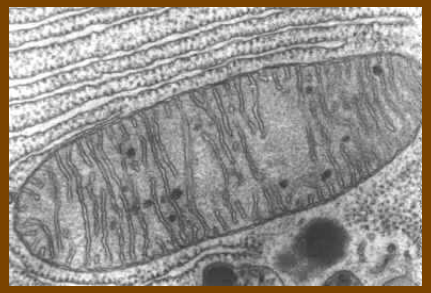
fungi Eumycota plus fungus-like organisms, polyphyletic

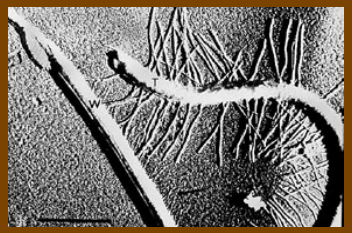
Chromista (Stramenopila)
- Phyla: Oomycota
  - Hyphochytriomycota
  - Labyrinthulomycota

Protists (Protoctists)
- Phyla: Plasmodiophoromycota
  - Dictyosteliomycota
  - Acrasiomycota
  - Myxomycota

"-mycota" because these groups were traditionally studied by mycologists, not because they are related to Fungi

Some characters that separate the the Kingdom Fungi from "Chromistan fungi"

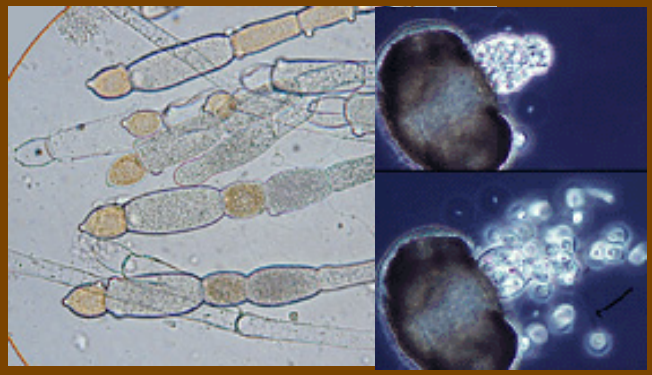




	Kingdom Fungi	Chromistan fungi
mitochondria:	cristae flattened	cristae tubular
motile cells:	no motile cells or posterior flagellum	motile cells with anterior or lateral heterokont flagella
cell wall carbohydrate:	β-glucans, chitin, chitosan	-glucans, cellulose
lysine biosynthesis:	alpha-aminoadepic acid (AAA)	diaminopimelic (DAP)
storage compound:	glycogen, α 1,4 glucan	mycolaminarins, β 1,3 glucan
sterols	ergosterol	fucosterol
ploidy	haploid in somatic cells	diploid in somatic cells
Phyla: (covered in class)	Chytridiomycota Zygomycota Glomeromycota Basidiomycota Ascomycota	Oomycota Hyphochytridiomycota Dictyosteliomycota Myxomycota

General characteristics of the Phyla of the Kingdom Fungi

Chytridiomycota & Blastocladiomycota: (900 spp.)
- unicellular to mycelial (coenocytic)
- zoospores with single posterior whiplash flagellum
- aquatic & terrestrial



Zygomycota: (1100 spp.)
- generally coenocytic mycelium
- production of zygosporangia & zygospores

Glomeromycota: (170)
- formerly part of Zygomycota (Glomales)
- coenocytic mycelium
- no known sexual reproduction
- arbuscular mycorrhizae (Glomerales)