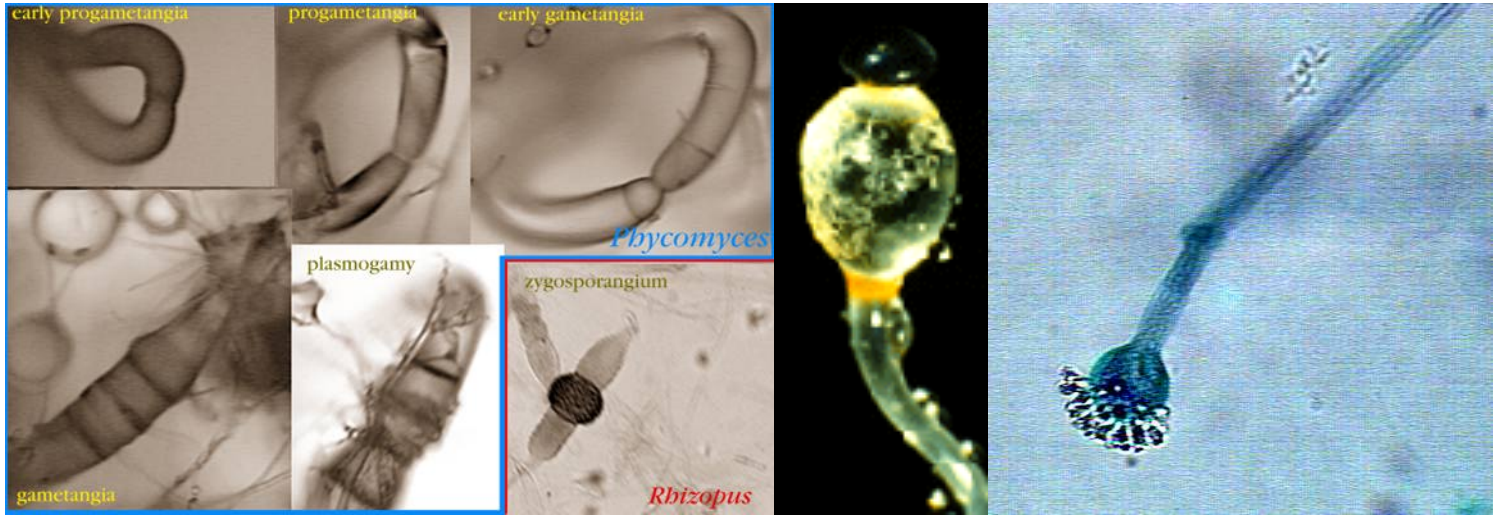
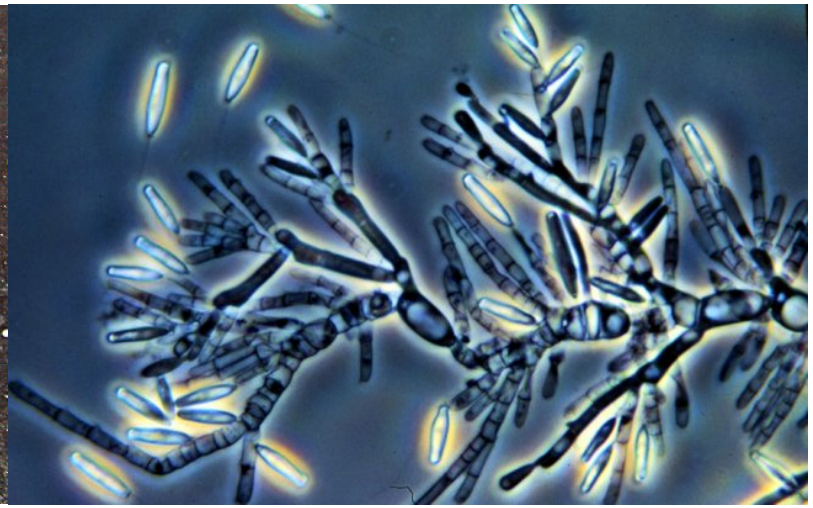

early progametangia
progametangia
early gametangia
Phycomyces
plasmogamy
zygosporangium
gametangia
Rhizopus

Zygomycota



Zygomycota

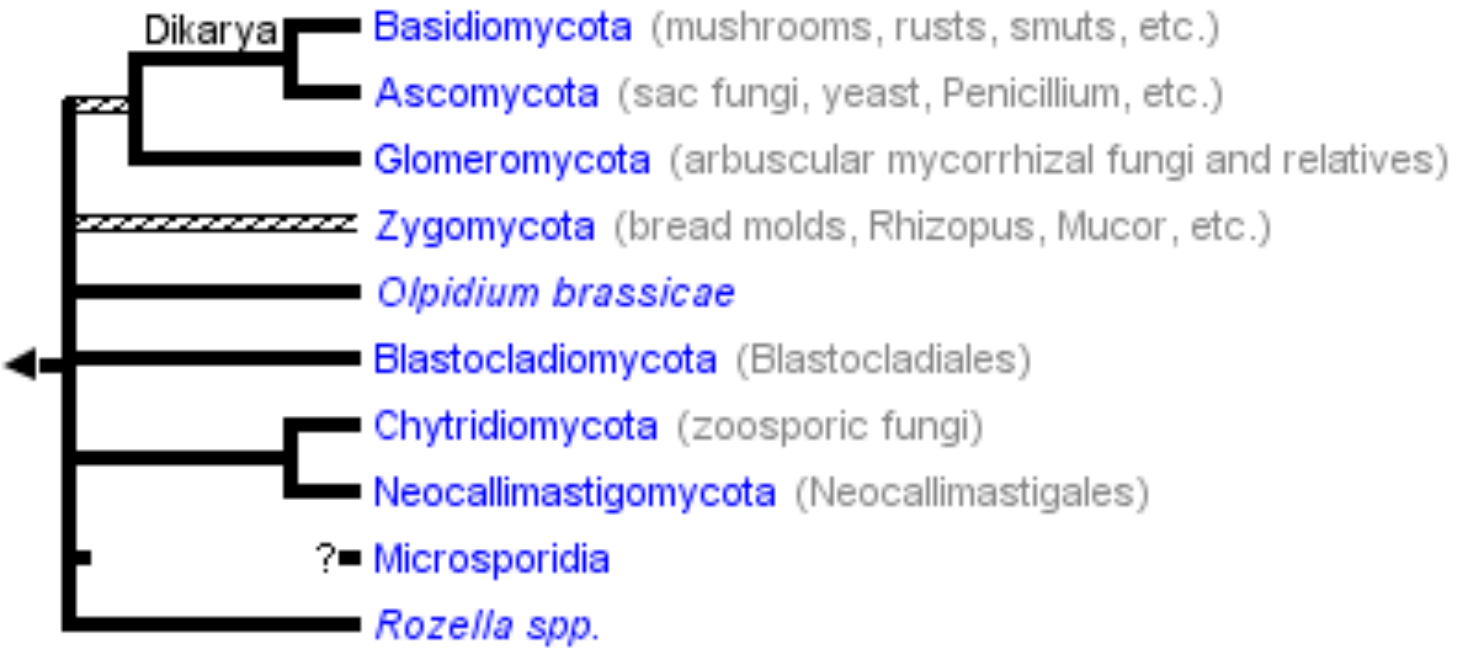
About 1%, ~ 1000 species of the named species of true fungi

Common species are saprobic, molds of fruit, grains
- Mucor, Rhizopus

Many are common on dung of various animals
- Pilobolus, Phycomyces, Coemansia

Others have highly specialized symbioses
- Endogone, ectomycorrhizal
- Zoopagales, parasites of rotifers, tardigrades
- Entomophthorales, parasites of insects
- Harpellales & Asellariales (“Trichomycetes”), specialized gut commensals of arthropods
- Some Mucorales are mycoparasites

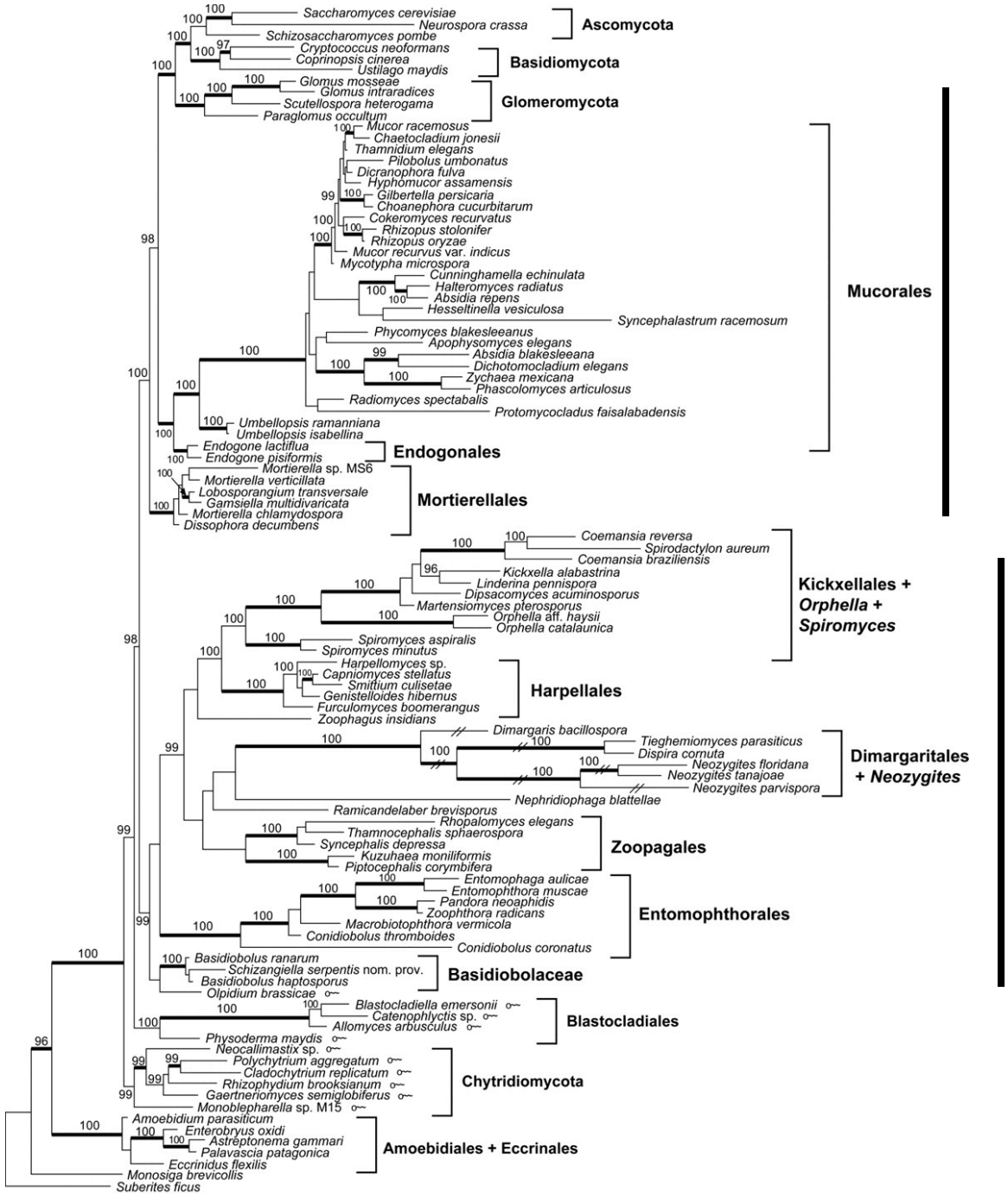
Relationship of the Zygomycota to the other phyla of Fungi is not completely clear and relationships of taxa within the Zygomycota are now being revised



Four subphyla currently recognized in the Zygomycota:

Mucormycotina
Entomophthoromycotina
Kickxellomycotina
Zoopagomycotina

(formerly orders Mucorales, Entomophthorales, Zoopagales)



Two main groups but do not correspond to the two classes Zygomycetes and Trichomycetes

Zygomycota

Formerly two Classes based on morphology and ecology:

- Zygomycetes
  - Wide diversity of forms
  - Various ecological modes
    - Saprobes, soil and dung
    - Parasites of small animals, insects
    - Parasites of other fungi
    - Opportunistic human/animal pathogens
    - Fruit/grain rots
    - Ectomycorrhizal (Endogonales)
- Trichomycetes (Harpellales, Asellariales)
  - Specialized parasites of arthropods

Zygomycota orders

Mucorales

Rhizopus

Pilobolus

Phycomyces

Mortierellales

Mortierella

Dimargaritales

Piptocephalis

Kickxellales

Coemansia, Spirodactylon

Endogonales

Endogone

Entomophthorales

Entomophthora

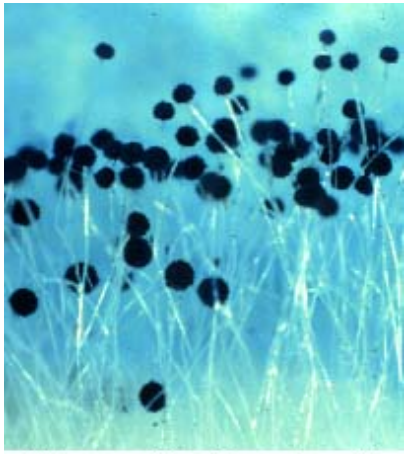
Zoopagales

Amoebophilus

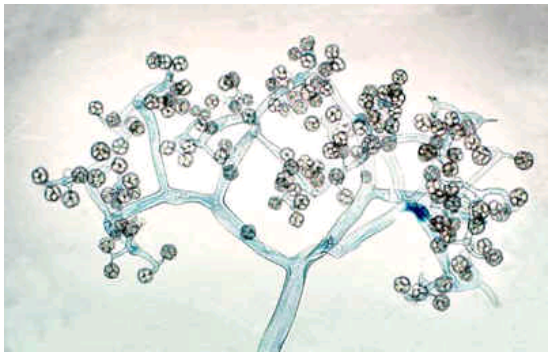
Euryncale

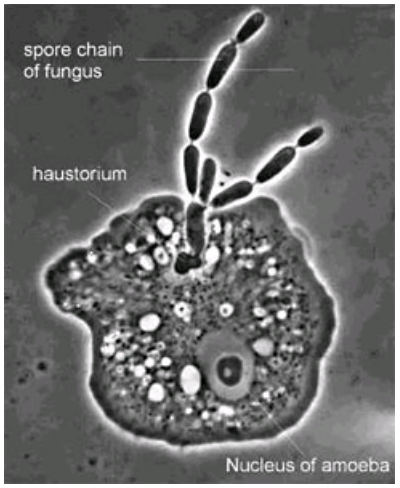
Harpellales

e. g. *Furcuolmyces boomerangus*



Rhizopus -black bread mold





General characteristics of Zygomycota

- "Primitive" early diverging fungal lineage
- <1% of all known species of fungi, ~1000 species
- primary colonizers of most substrates "sugar fungi"
- most species have thallus of coenocytic hyphae
- haploid nuclei in vegetative stage
- chitin cell walls
- no flagellated cell
- no centrioles; possess spindle pole bodies (SPBs)

Ecological diversity of Zygomycetes

Saprobes in soil and dung
- **Mucorales, Mortierellales, Kickxellales**

Parasites of invertebrates, insects, rotifers, amoebae
- **Entomophthorales, Zoopagales**

Mycoparasites
- **Mucorales, Dimargaritales, Zoopagales**

Ectomycorrhizal
- **Endogonales**

Human pathogens
- **Mucorales, Entomophthorales**

Obligate gut parasites of arthropods
- **“Trichomycetes” (Hapellales)**

Importance of Zygomycetes

Used in soy fermentations

- ***Rhizopus oligosporus*** **tempeh**
- ***Actinomucor elegans*** **tofu**

Human and animal pathogens

- **Basidiobolus and others, mucormycoses**

Storage rots of fruits

- ***Rhizopus stolonifer***

Plant pathogens

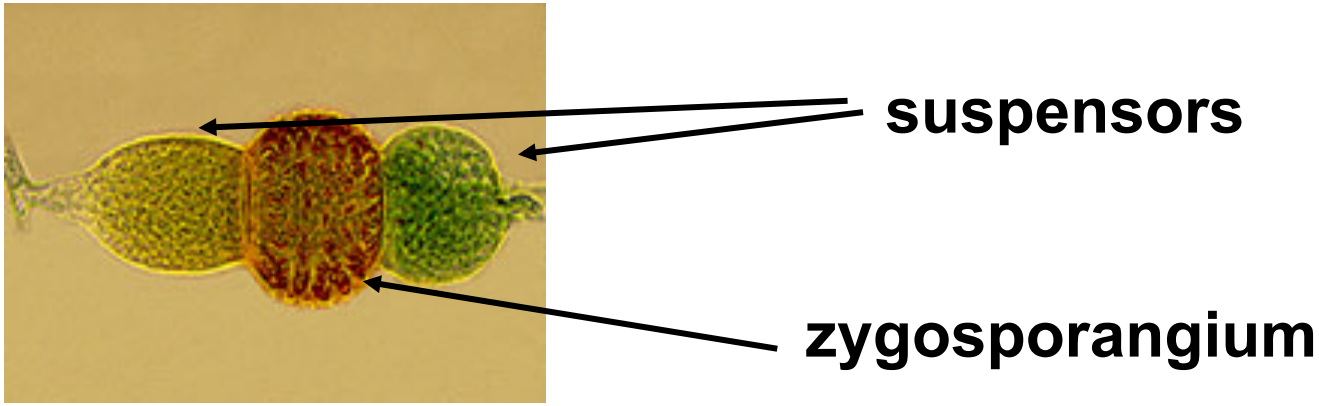
- ***Gilbertella, Rhizopus*** **(endosymbiotic** ***Burkholderia*****)**

Bioinsecticides, biocontrol

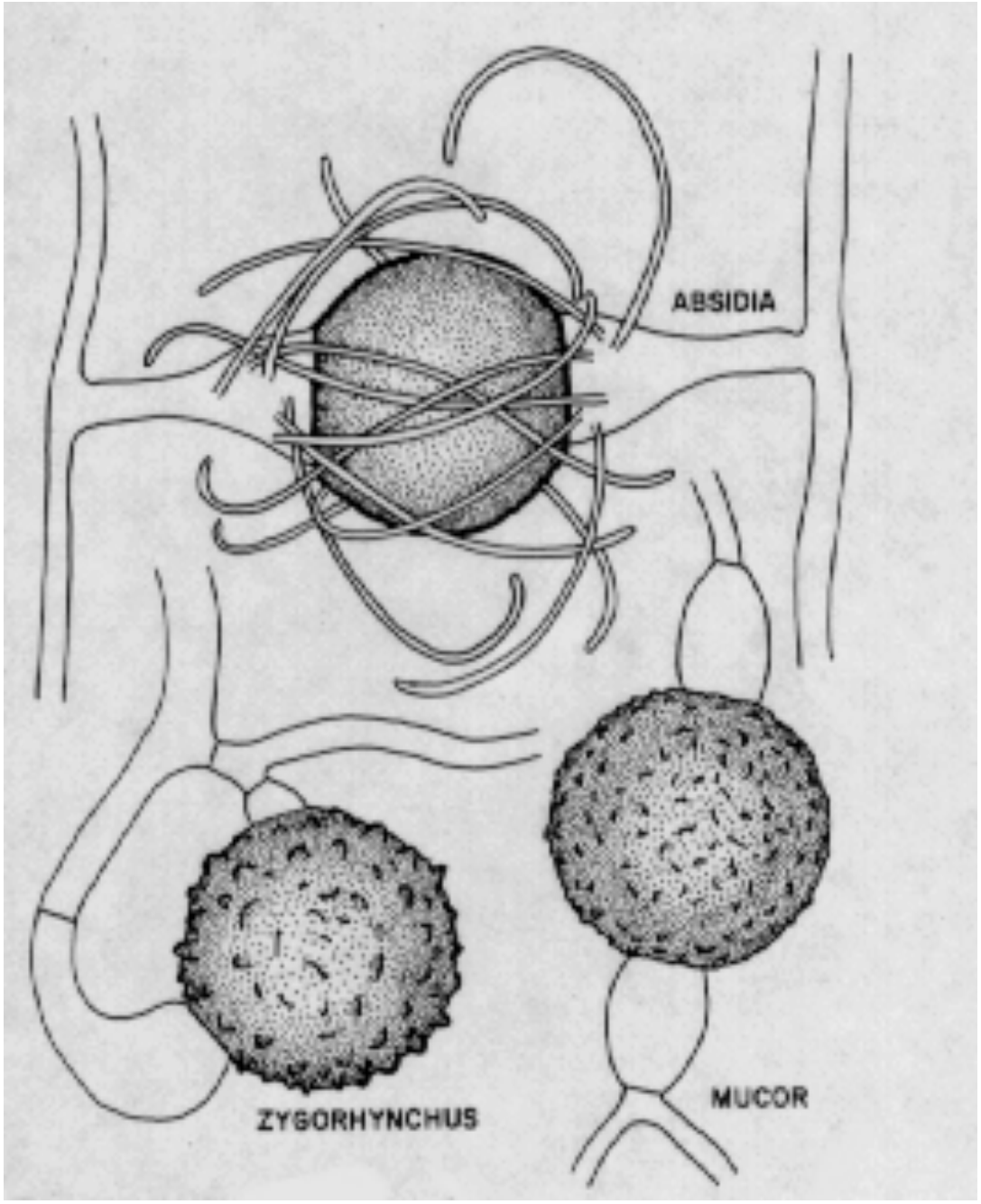
- ***Entomophaga maimaga***

Sexual reproduction by production of **zygospores** (=thick-walled resting spores) within **zygosporangia** that are formed by fusion of **gametangia,** hyphal branches

- **zygos (Gr.) - yoke, joining**
- **refers to the fusion of gametangia to form a unique structure called the zygosporangium**



www.botany.hawaii.edu/faculty/wong/Bot201/Zygomycota/Zygomycota.htm

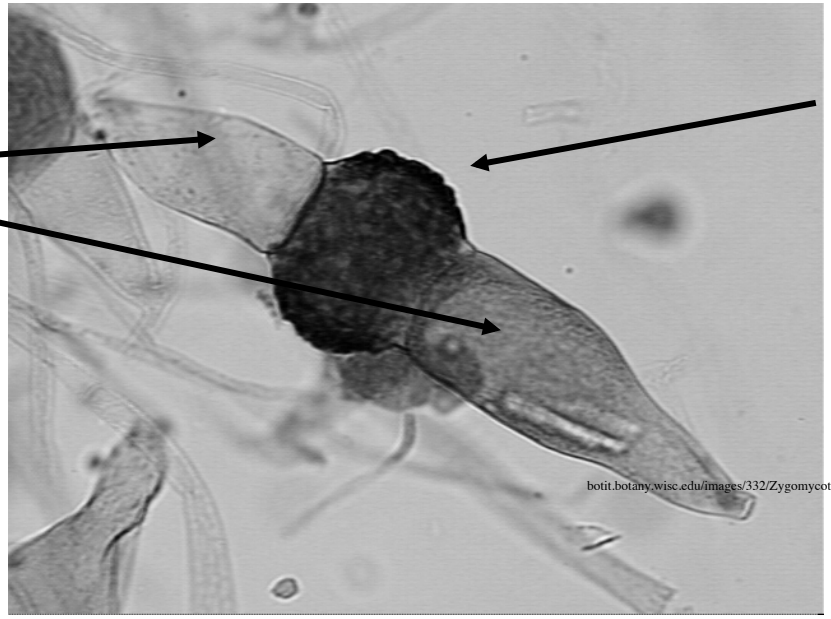


Zygosporangia

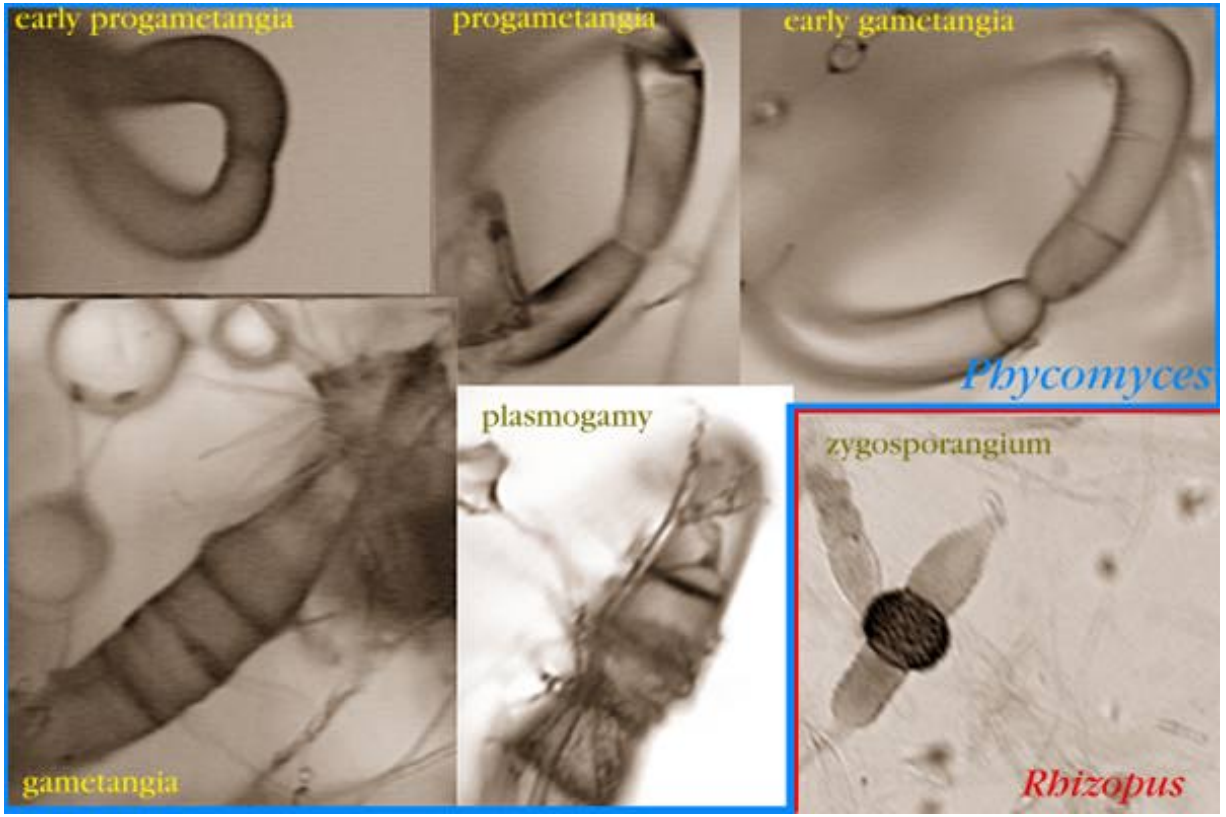
mating in Zygomycetes by isogamous hyphal fusion

Sexual reproduction

- gametangial copulation, somatogamy
- conjugation by two morphologically similiar gametangia
- gametangia are differentiated hyphal branches
- differentiation in Mucorales controlled by pheromones
- produce a zygosporangium
- homo- & heterothallic species (unifactorial)

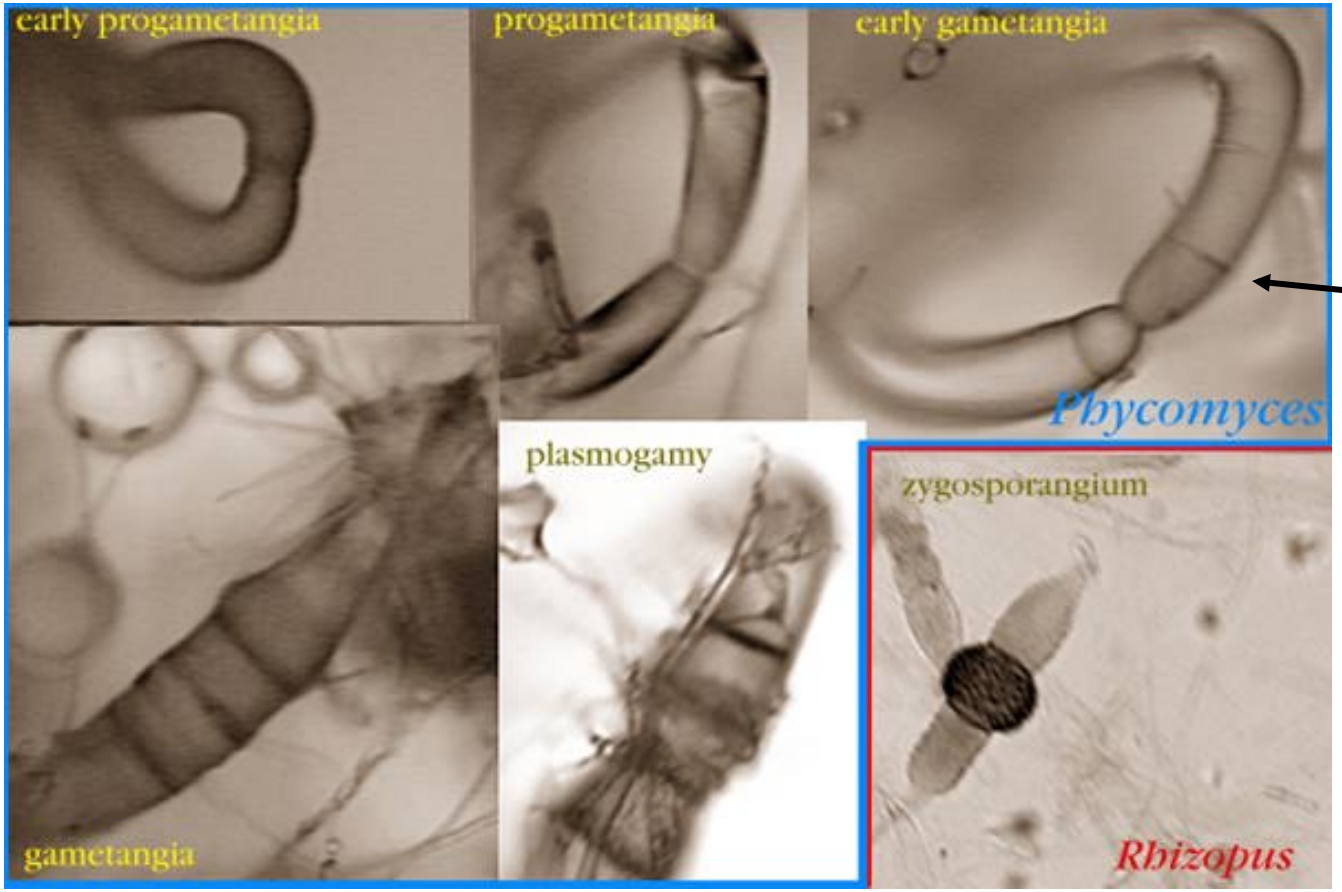


Sexual reproduction

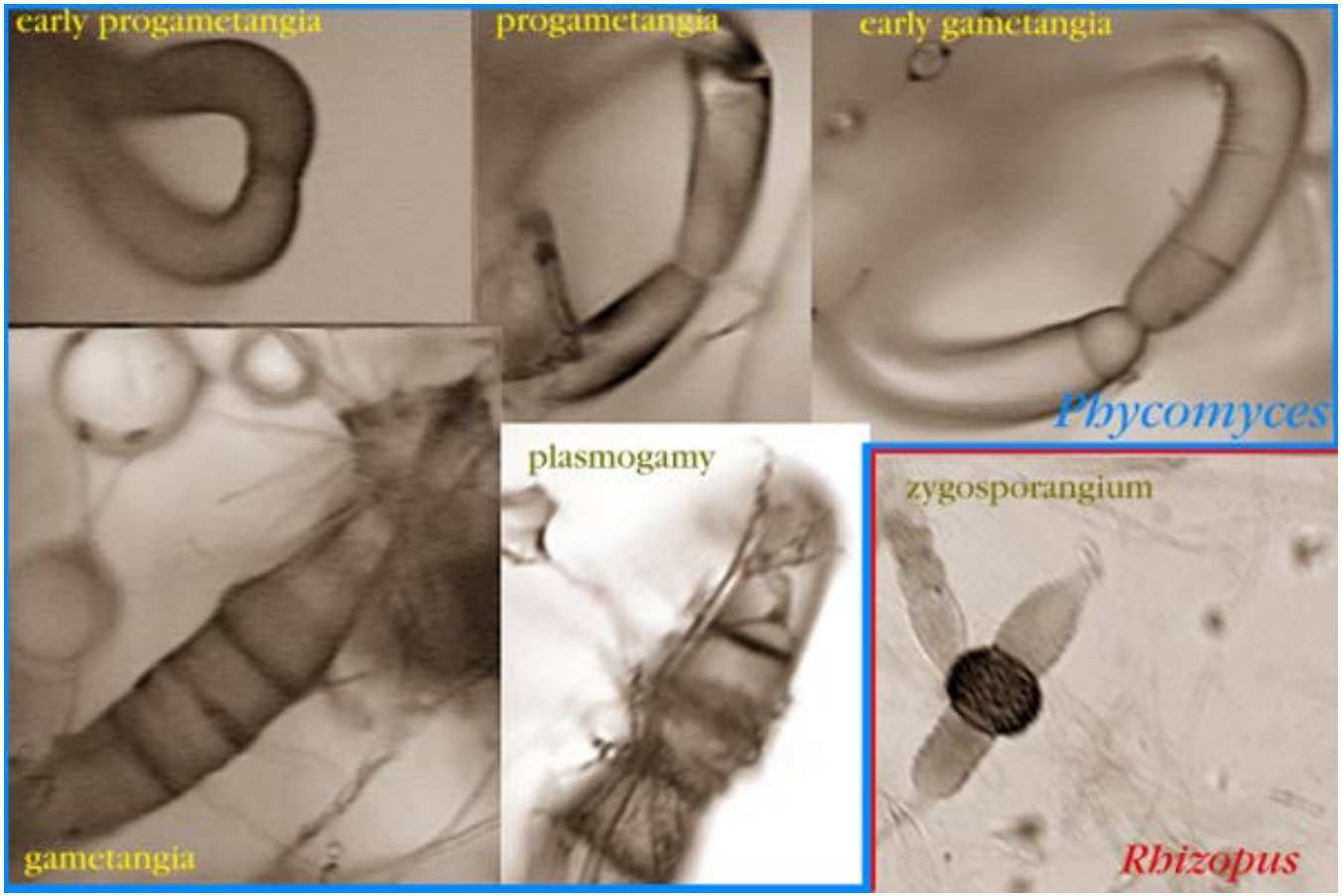


- formation of specialized hyphae: zygophores
- compatible zygophores are attracted to each other by pheromones of the opposite mating type, trisporic acids

- fuse in pairs at their tips; form fusion septum
- tips of zygophores swell to form progametangia



- **gametangial septum forms near tips of progametangia**
- **terminal cell is gametangium**
- **subterminal cell is suspensor cell**



- **fusion septum dissolves**
- **plasmogamy results in prozygosporangium**
- **followed by karyogamy, enlargement, development of thick multilayered wall: zygosporangium**

Zygospore germination

- zygospore doesn't equal zygosporangium
  produced within zygosporangium

- typically long resting period prior to germination

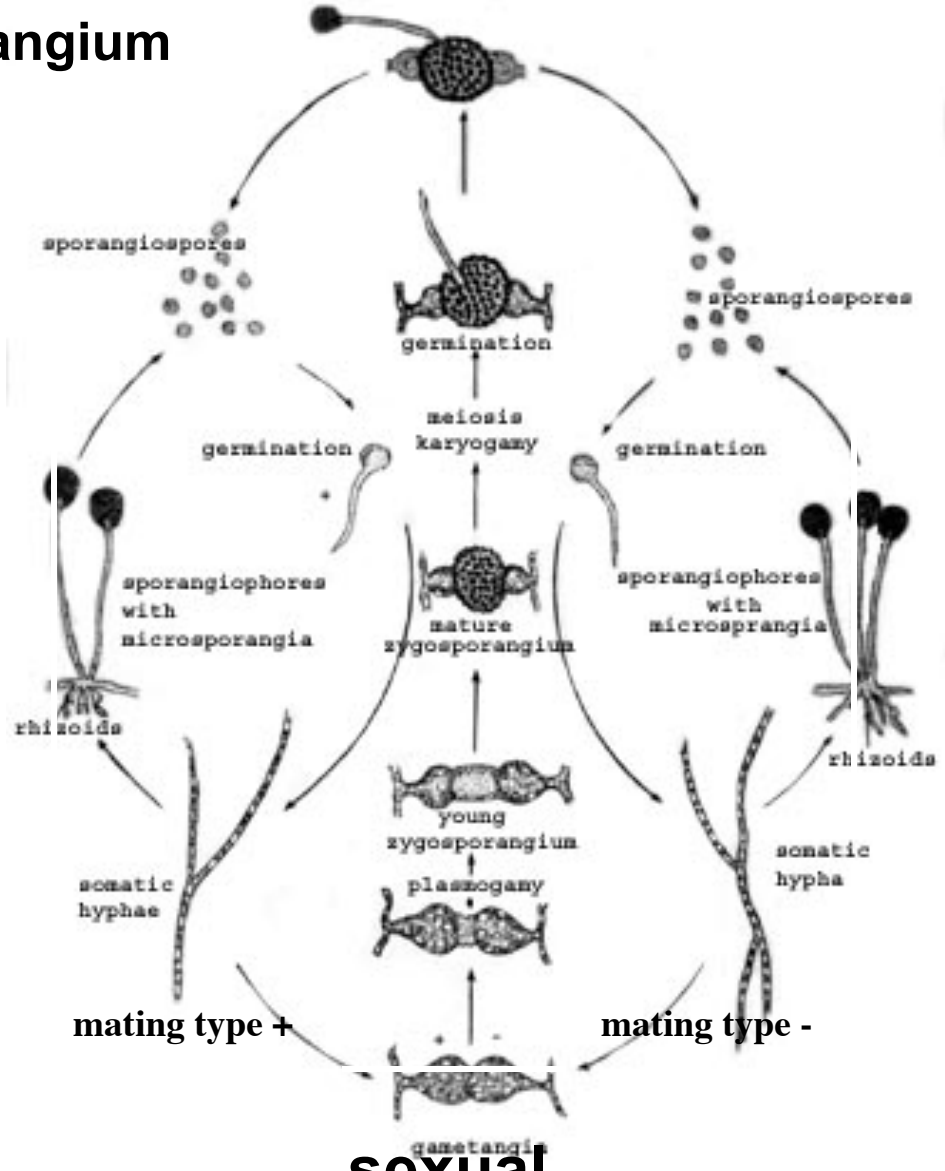
- zygosporangium cracks open
  zygospore germinates a sporangiophore that develops a germ sporangium

- meiosis occurs before or during zygospore germination
  followed by numerous rounds of mitosis

- germ sporangium produces sporangiospores that are dispersed, germinate, & produce a mycelium

Rhizopus life cycle

germ sporangium

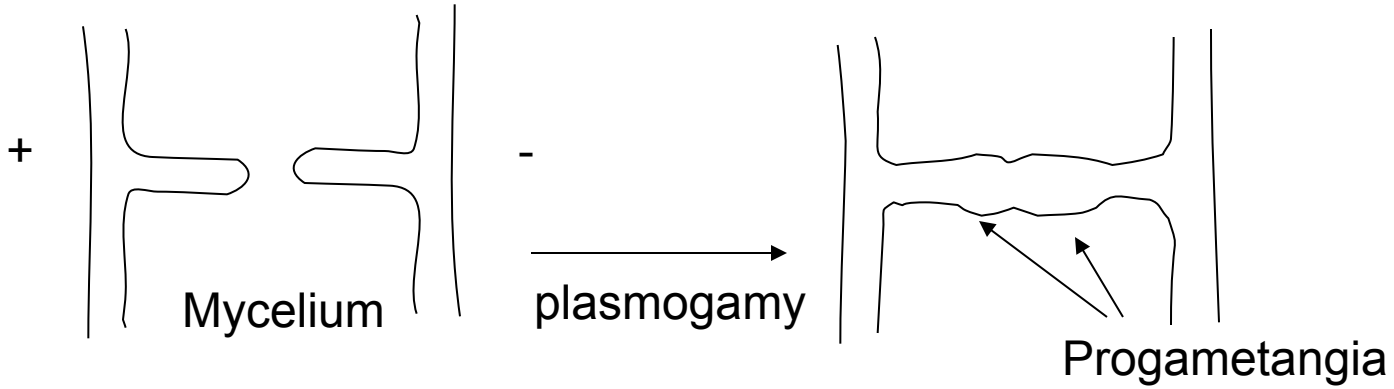


asexual reproduction

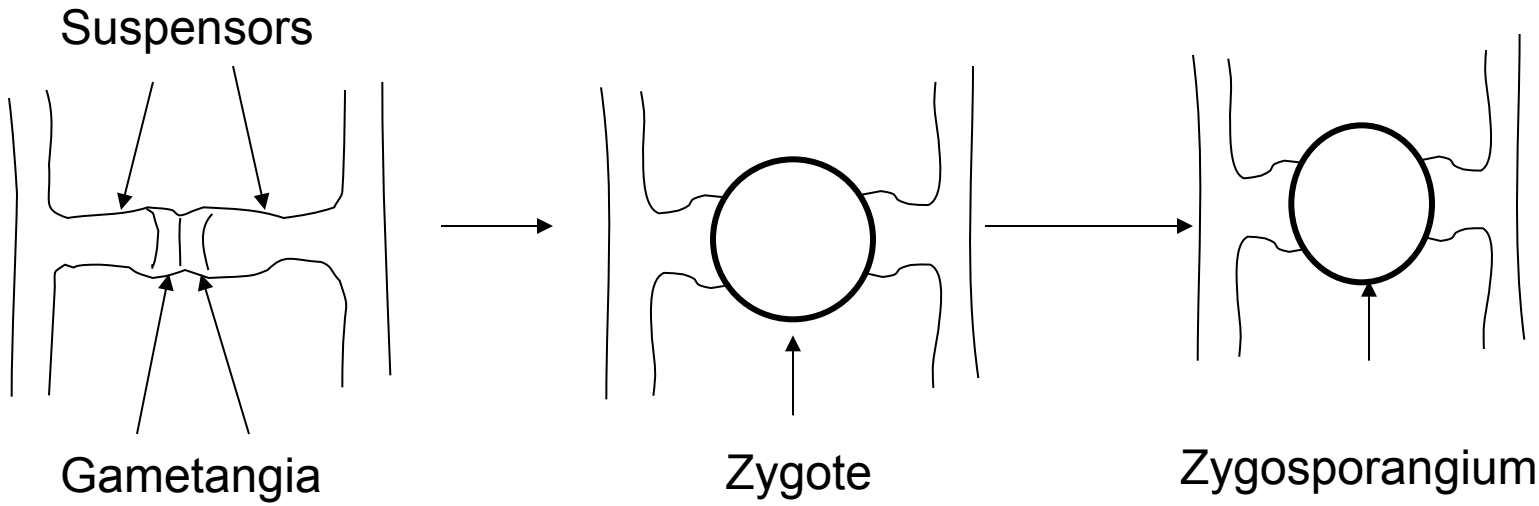
asexual reproduction

sexual reproduction

Zygomycete pheromones, trisporic acids



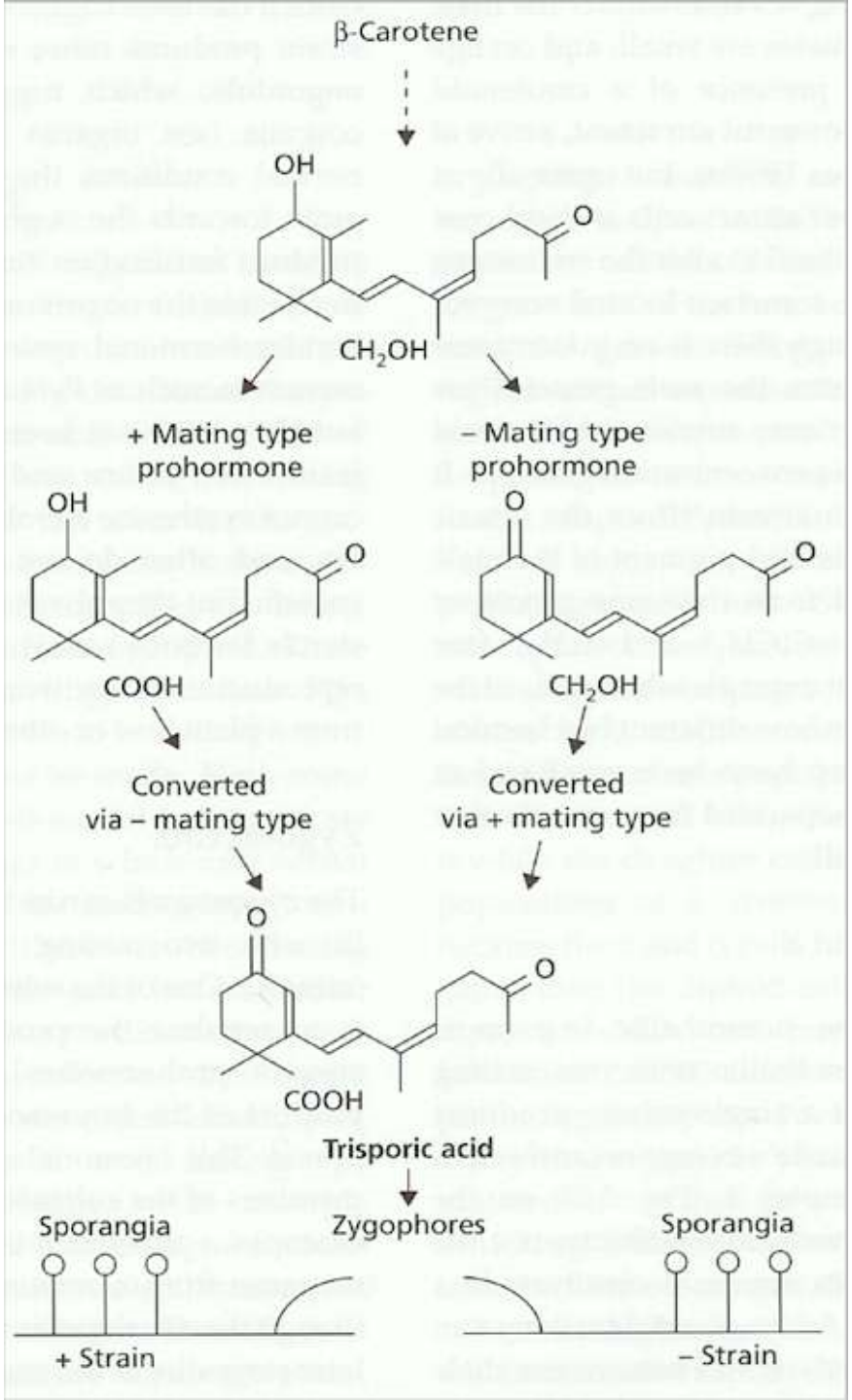
+ and – mating types produce phermones that are converted to trisporic acid by the opposite mating type



Sexual compatibility in *Rhizopus*

A.F. Blakeslee 1904
- **first example of sexual incompatibility in fungi**
- **somes species could only produce zygospores when paired with certain isolates**
- **designated +/-**

Burgeff 1924
- **First demonstration of pheromones in fungi**
- **hormonal substance responsible for incompatibility trisporic acid**
- **each strain produces precursor molecules that the compatible strain converts to trisporic acid (TSA)**
- **TSA triggers positive feedback & production of more precursor**
- **results in maturation of gametangia and gametangial fusion**
- **Induces zygophore formation**
  - **Represses sporangiophore formation**

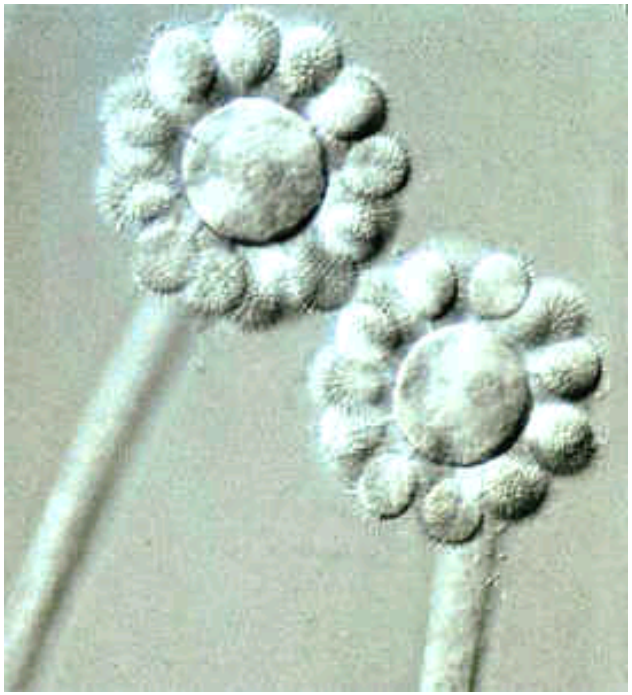


Zygomycete pheromones

B-carotene, trisporic acid

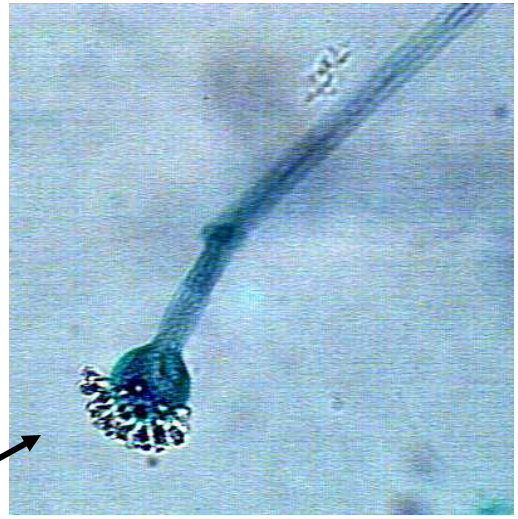
Asexual Reproduction

- **Sporangia**
  - Sporangiospores delimited from cytoplasm by cleavage vesicle fusion, similar to free cell formation
- **Sporangiola**
  - Reduced sporangia having one or a few sporangiospores. Single sporangiola resemble conidia.



asexual reproduction

some sporangiospores look like conidia, but have an outer sporangial wall--derived from larger multi-spored sporangia



sporangiospores

- sporangioles
  - reduced sporangia with or w/o columella
  - produce one to few spores
- sporangia and sporangioles can be formed on the same sporangiophore

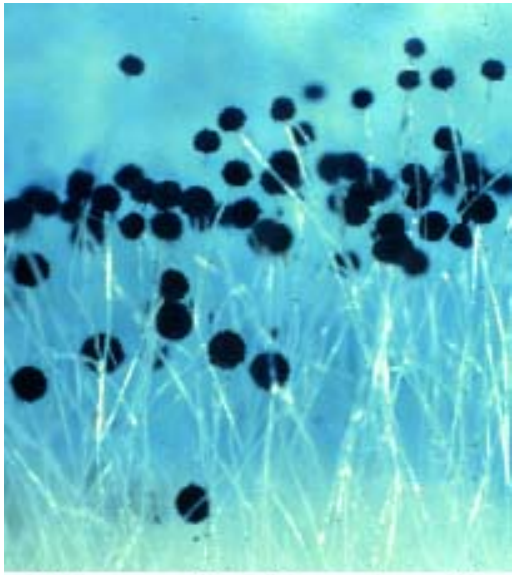
Phylum Zygomycota

Under revision, the 12 clades identified by molecular systematics do not correspond exactly to the 10 orders currently recognized

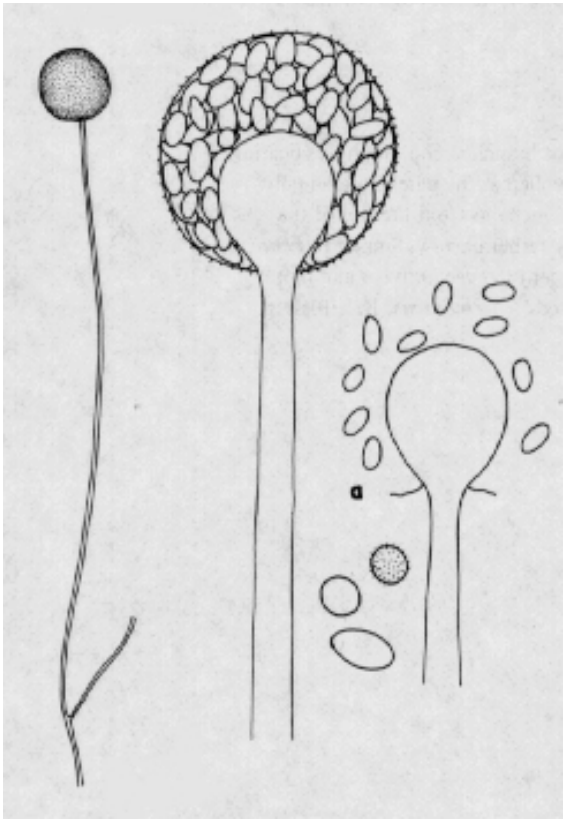
- 10 Orders, ~168 genera, ~1000 species
  - Mucorales
  - Mortierellales
  - Endogonales
  - Kickxellales
  - Dimargaritales
  - Basidiobolales (Basidiobolaceae)
  - Zoopagales
  - Entomophthorales
  - Harpellales
  - Asellariales

MUCORALES

largest order, 47 genera, 130 species
most common species
used in industry and food production
Rhizopus spp. used in industry
fumaric, lactic, citric, succinic & oxalic acids
food production
tempeh

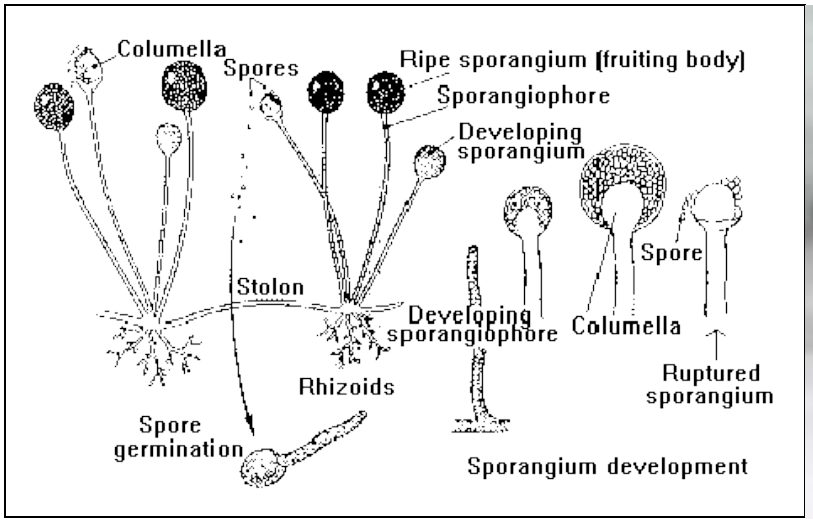


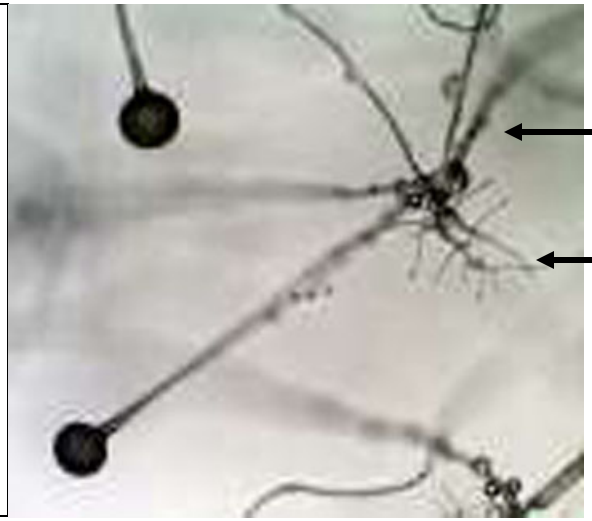
Rhizopus -black bread mold



Structures

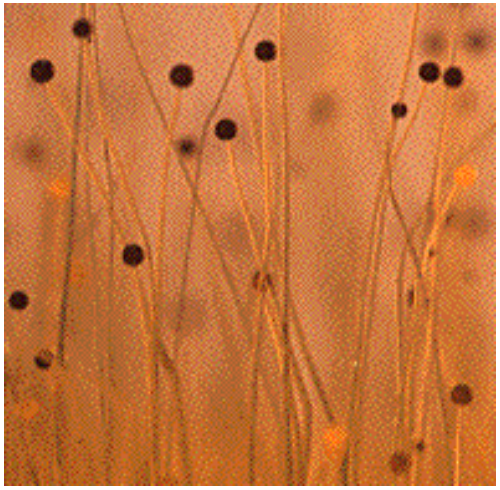
- coenocytic hyphae
- septa associated only with reproductive structures
- rhizoids: root-like hyphae that adhere reproductive structures to substrate
- stolon: connect two groups of rhizoids



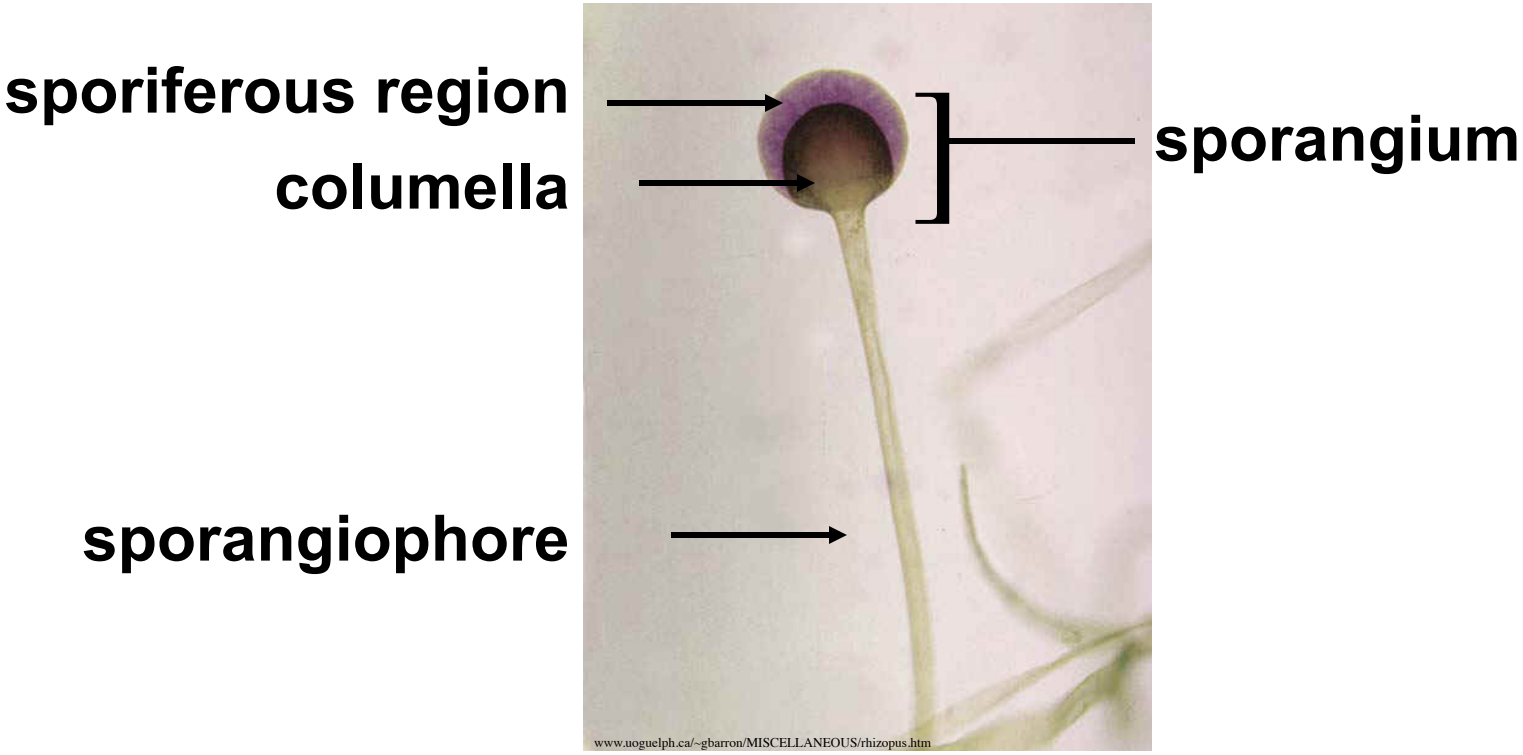


Sporangia of Phycomyces

Phototropic sporangia have been used as model systems for study of photorecptors

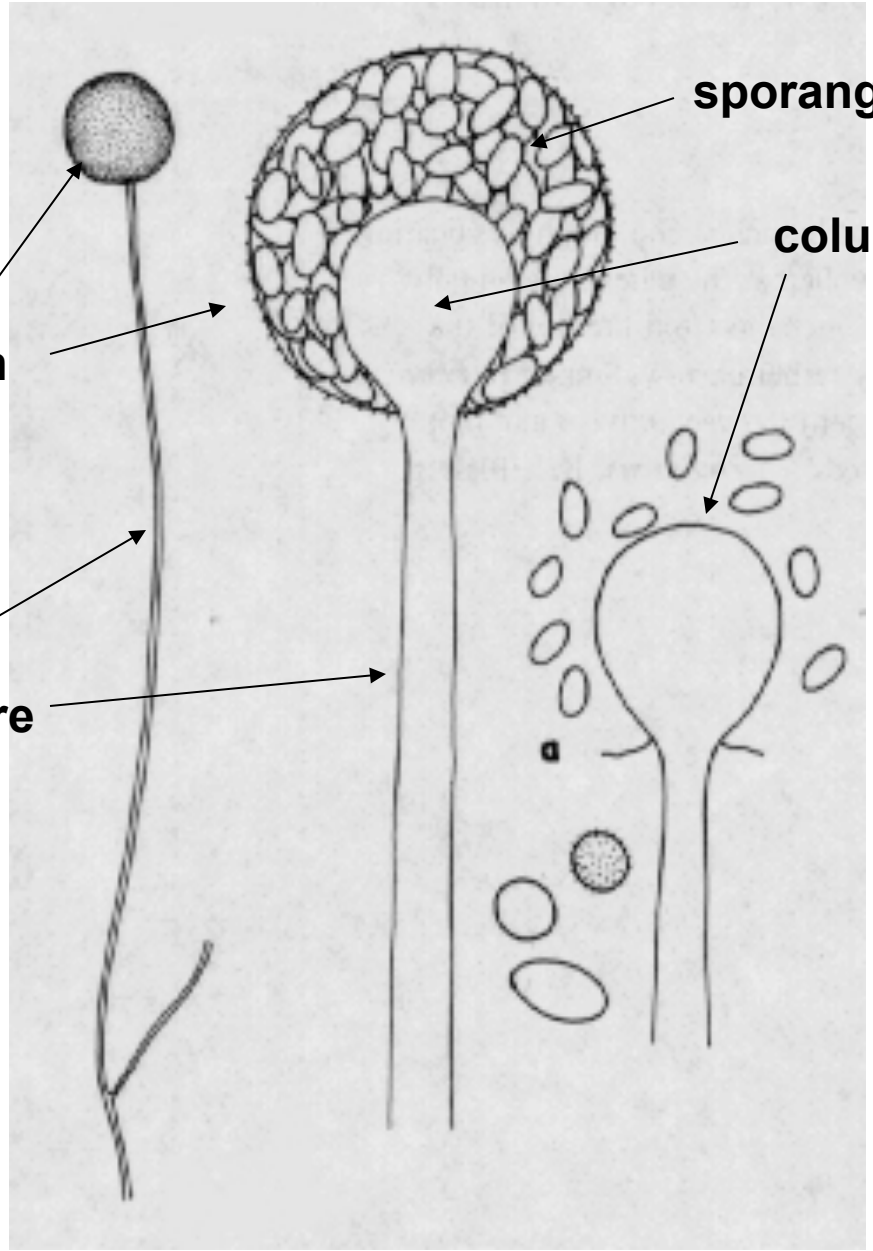


Asexual reproduction



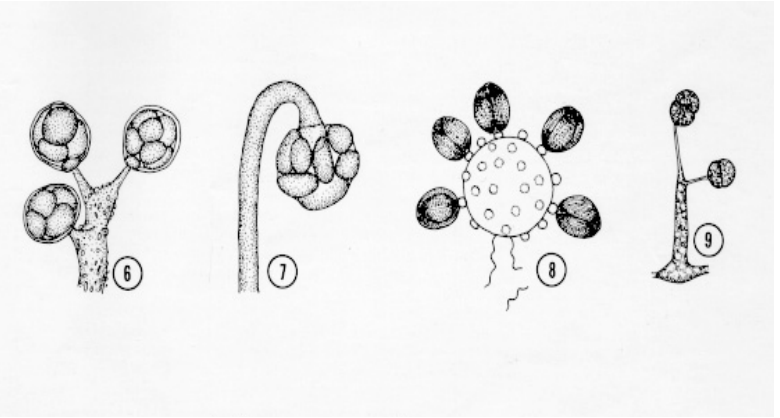
- sporangiophores simple to branched
- sporangium: +/- columella with outer sporiferous region
- sporangium produces thousands of sporangiospores

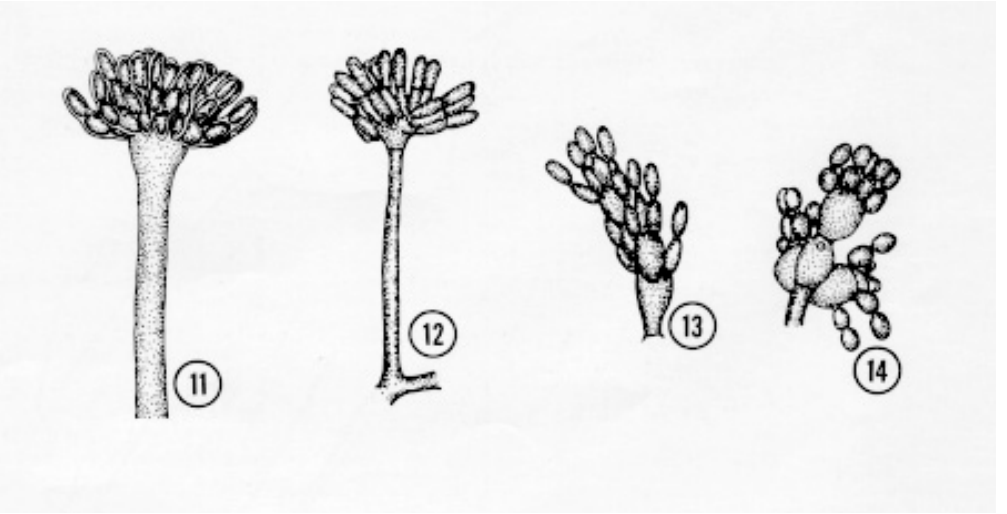
Mucor



Sporangiolum

- A reduced sporangium containing 1-50 sporangiospores
- Merosporangium is a sporangiolum with spores in linear series



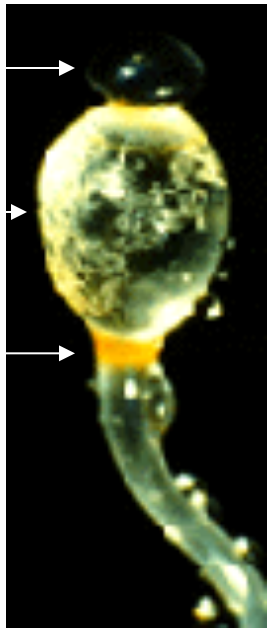


Ecology

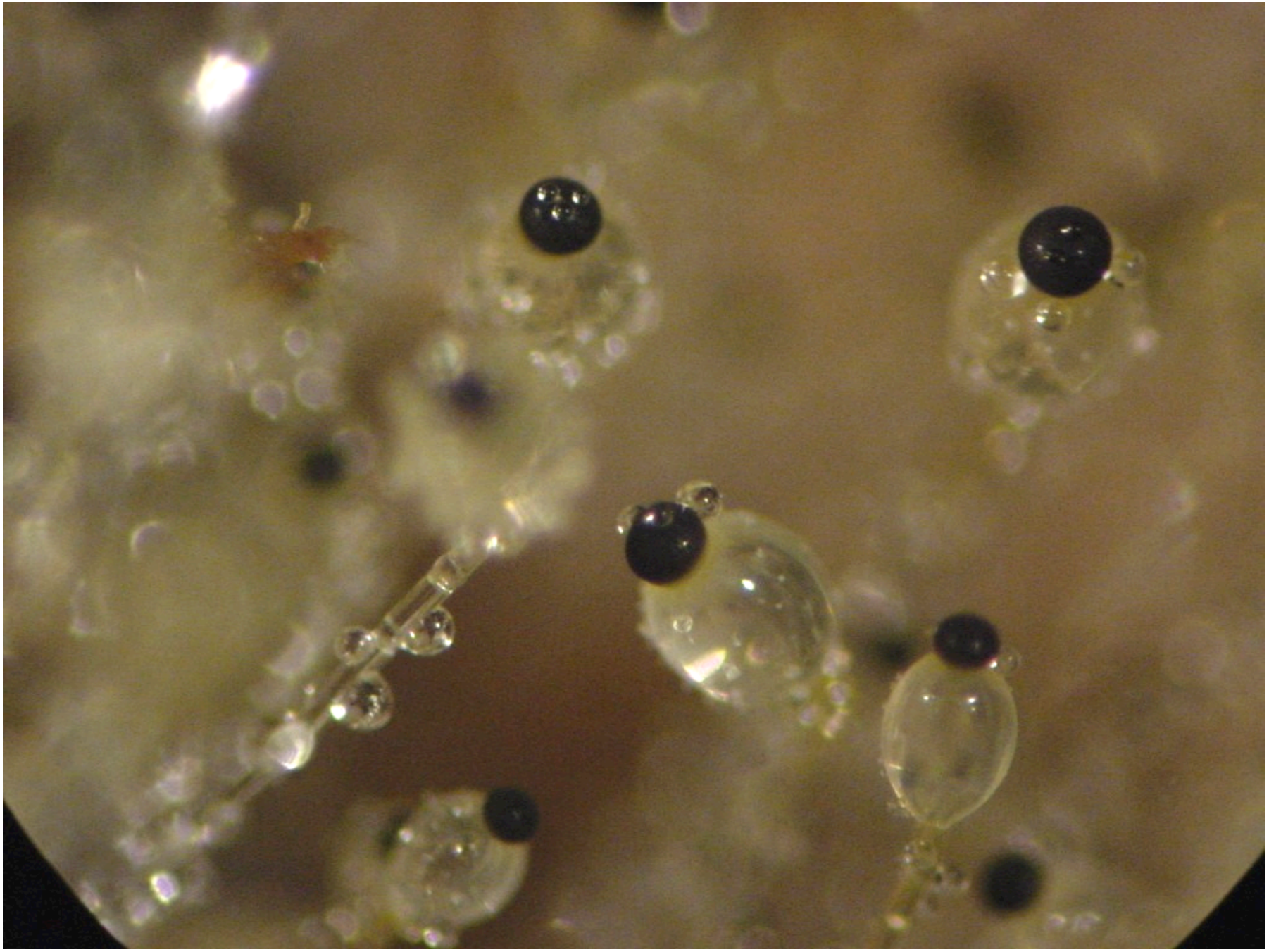
- Saprotrophs
  - Soil, dung, humus
- Plant pathogens
  - *Choanephora cucurbitarium*
    - on flowers & fruits of cucurbits
  - *Rhizopus stolonifer*
    - Post-harvest pathogen of strawberries, sweet potatoes
- Animal/human pathogens
  - Species of *Absidia, Mucor, Rhizopus, Saksanea* – zygomycoses, mucormycoses
- Mycoparasites on various other fungi

Pilobolaceae

***Pilobolus* (hat thrower)**

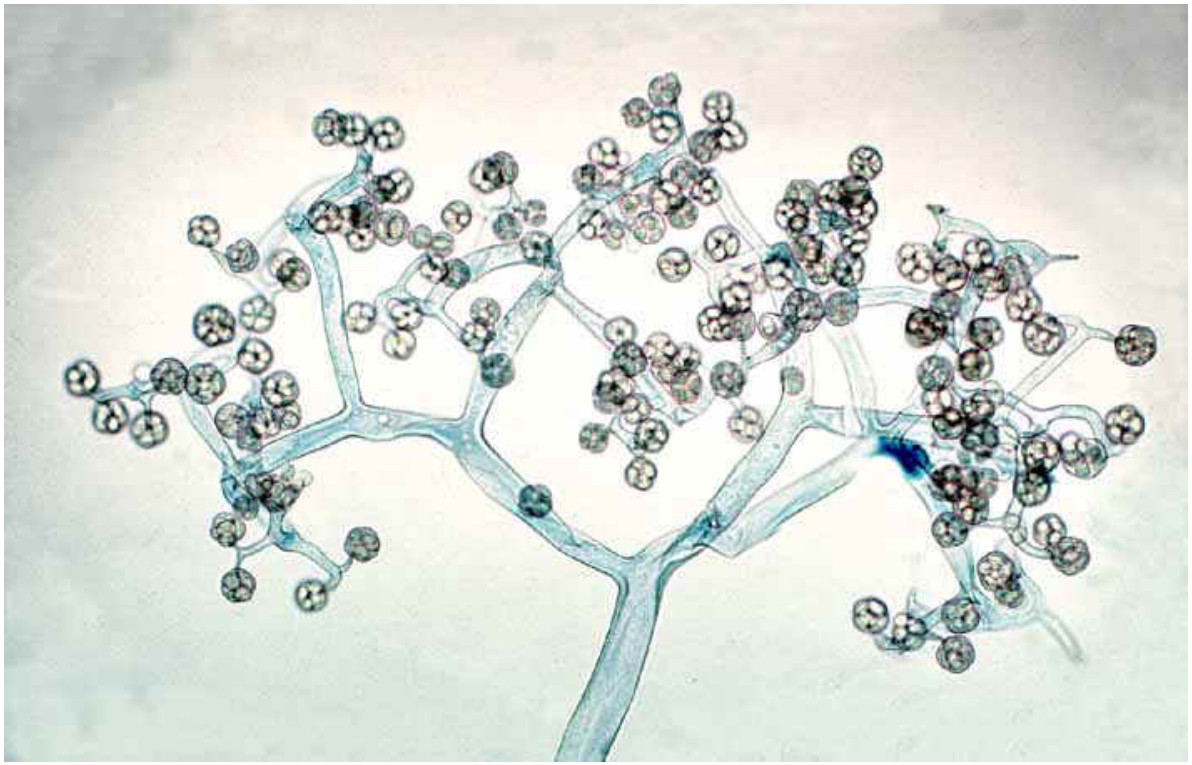


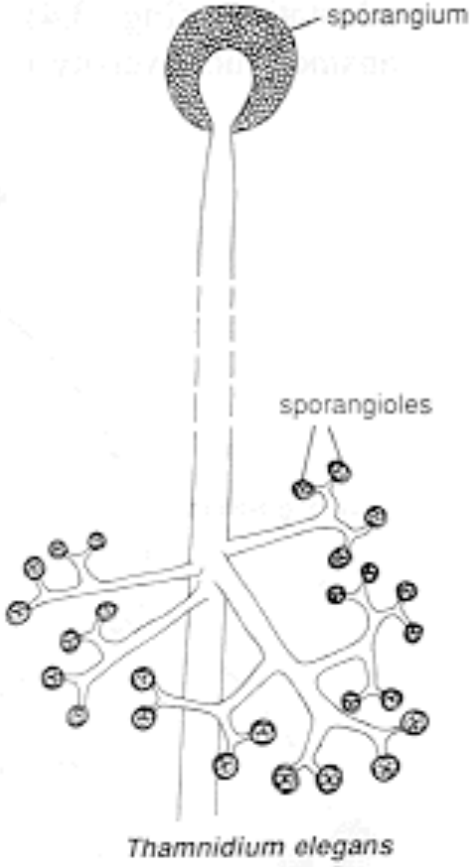
- **sporangiophore extending from substrate**
- **end of sporangiophore is a swollen subsporangial vesicle (ssv)**
- **sporangium sits on top of the ssv**
- **ssv is directed towards light by carotenoid ring**
- **ssv acts as lens concentrating light rays**
- **pressure builds up in the ssv, propelling the sporangium up to 2 meters**
- **sporangium sticks vegetation**
- **sporangia are ingested by animal, pass through GI tract & spores germinate in dung**



Thamnidium

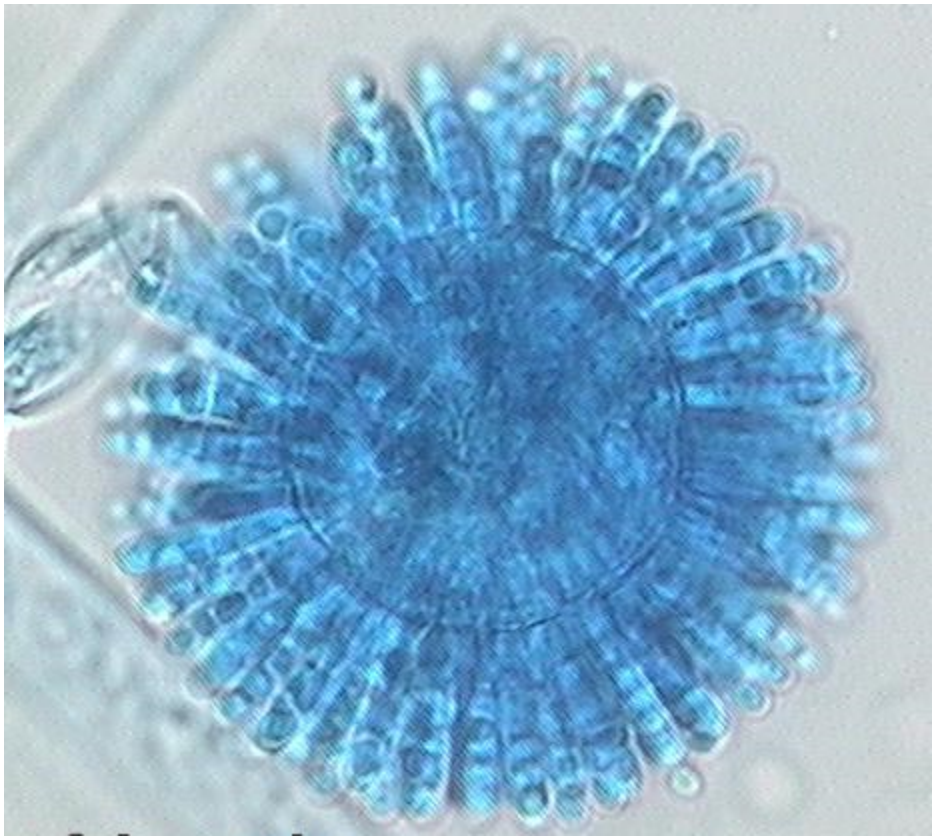
Sporangia and sporangiola on the same sporangiophore

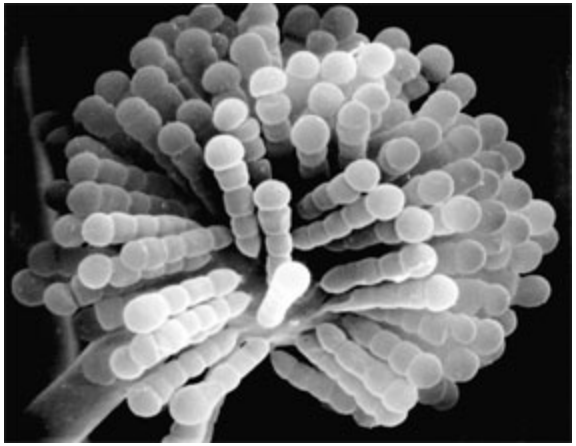




Syncephalastrum

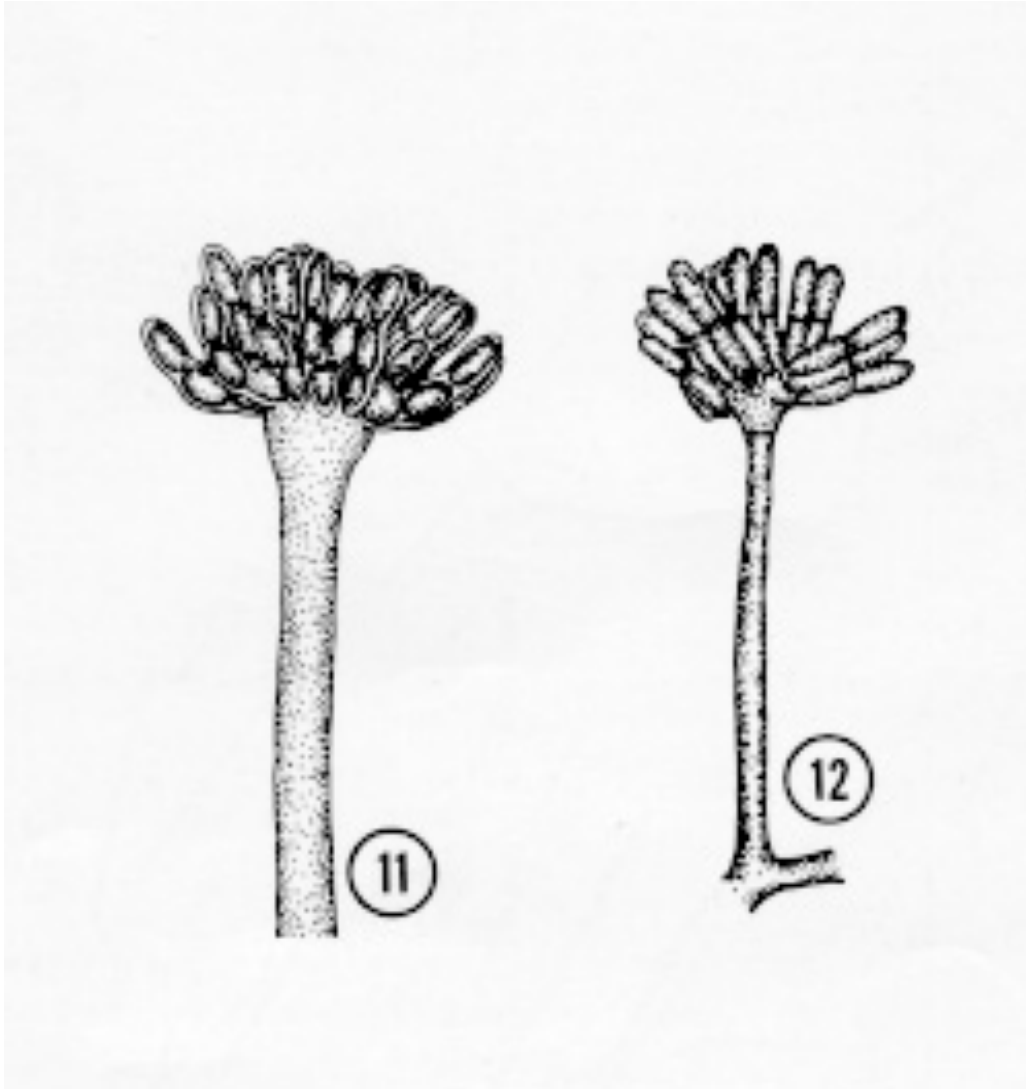
Merosporangia -
sporangiospores in linear series





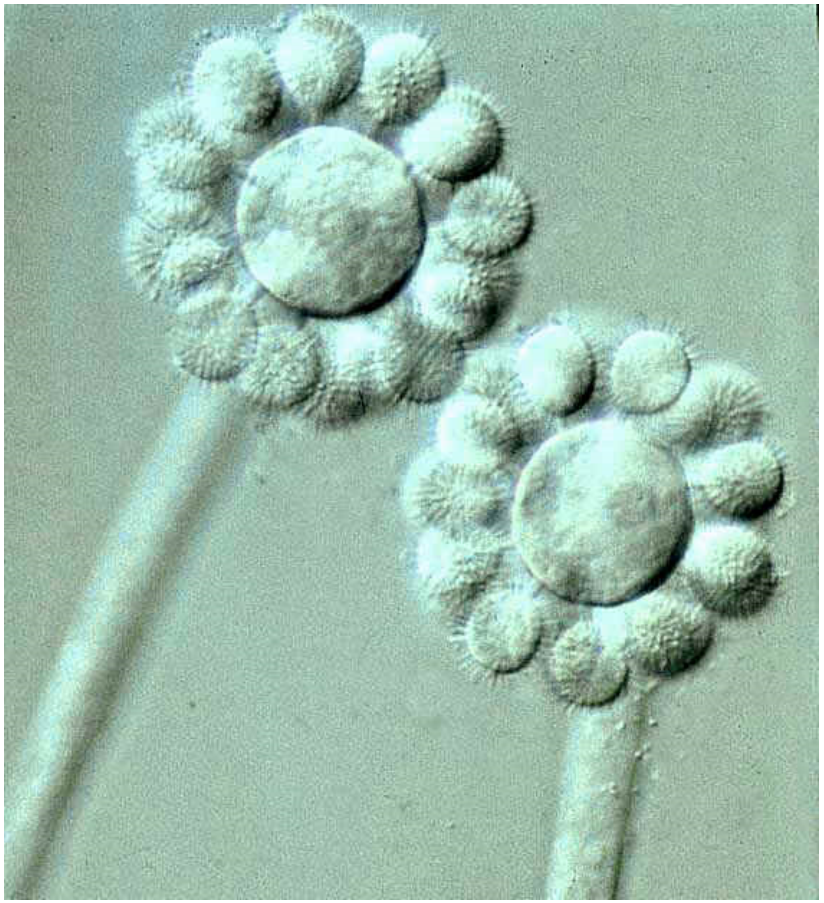
Syncephalis (11) and *Piptocephalis* (12)

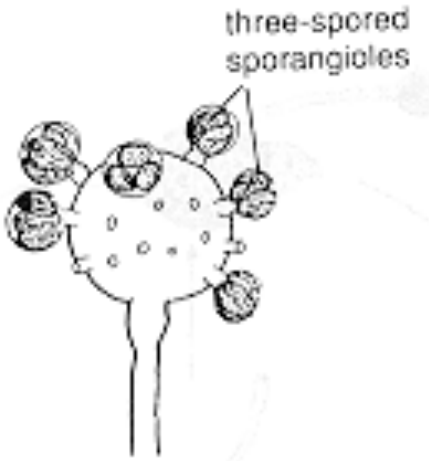
merosporangia



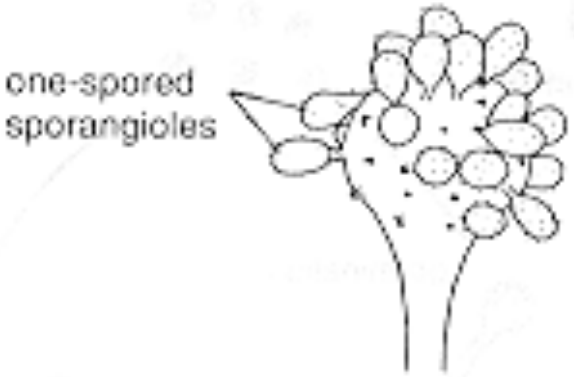
Choanephora and Cunninghamella

Sporangiola formed on separate sporangiophores





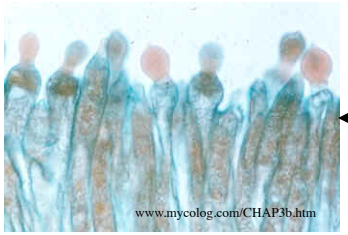
B: *Blakeslea trispora*



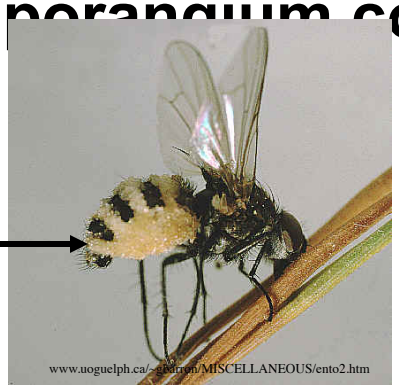
C: *Cunninghamella*

Entomophthorales

- parasites on insects
- *Entomophthora muscae* on common house fly
- conidia actively dispersed
- some have septate mycelium; break into hyphal bodies (hb)
- hb germinate to produce asexual spores
- two hb may act as gametangia, copulate, lateral outgrowth develop into zygosporangium contai a zygospore



conidia



hyphal body

Entomophthora maimaga

Being used as a biopesticide to control gypsy moth

Etienne Leopold Trouvelot

Settled in Medford Mass. in 1853. He was an amateur entomologist and wanted to start a silk industry in the USA. He introduced the European Gypsy Moth after a visit to France in the 1860s.

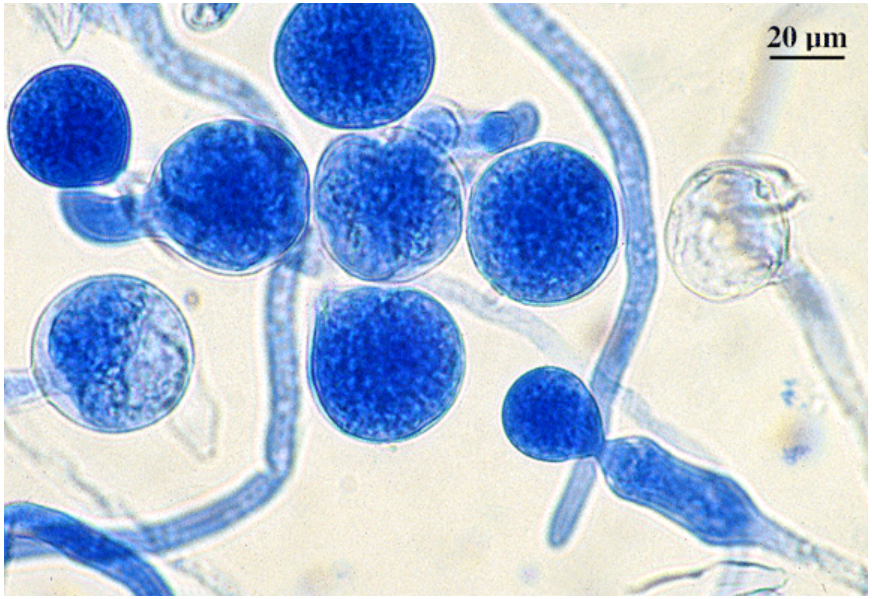
Larvae escaped from the population he was tending on trees in his back yard, after which he apparently lost interest in entomology and took up astronomy.

Trouvelot later worked at Harvard University and the Naval Observatory (now where the vice president lives)

Family Basidiobolaceae

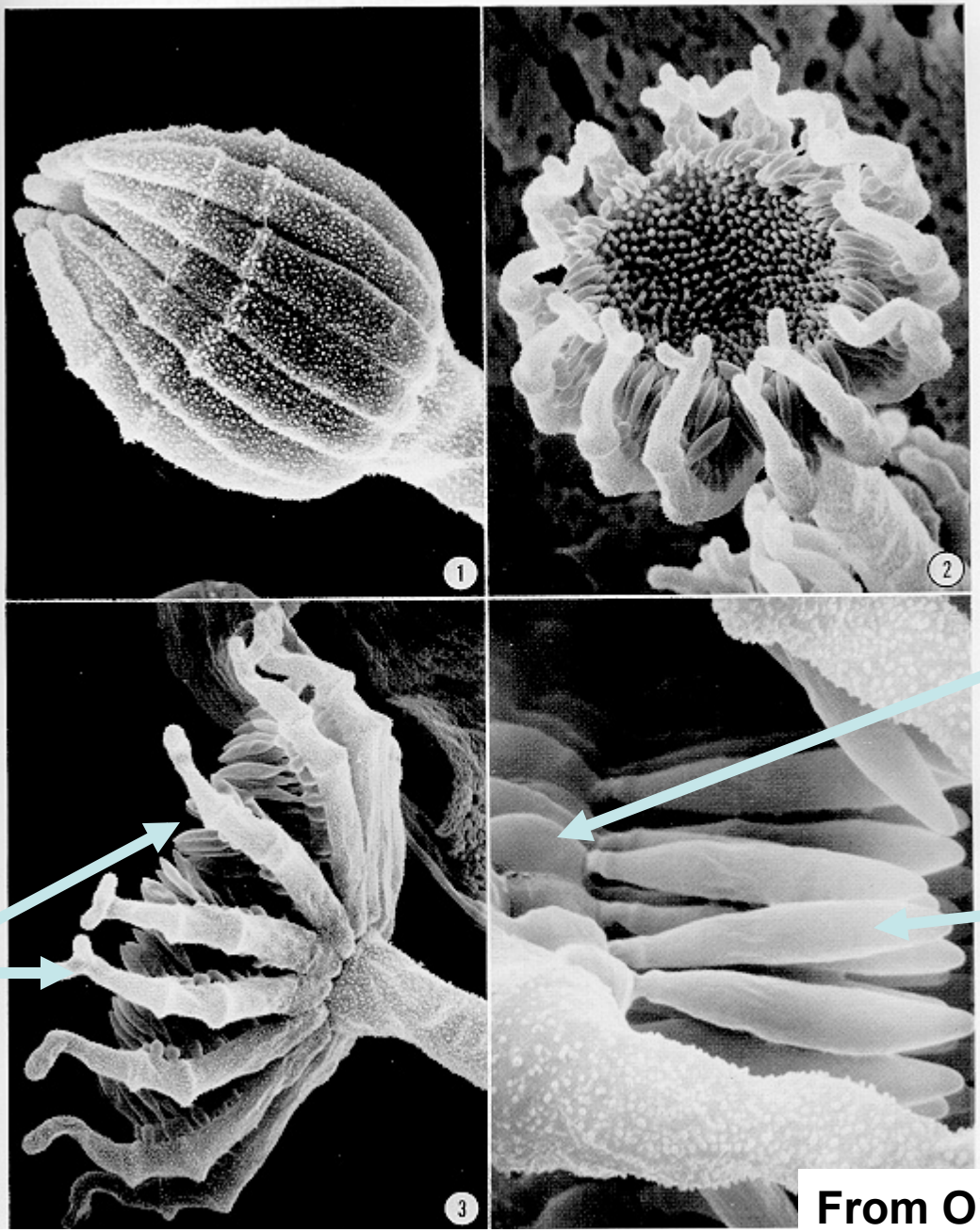
1 Genus, 4 species

Basidiobolus, saprobic, also cause of subcutaneous zygomycosis in humans



Order Kickxellales

- One family, 8 genera, 22 species
- Characterized by one-spored sporangiola formed on **pseudophialides** borne on **sporocladia**
- Extensively branched, septate mycelium
- Saprotrophs, common in soil and dung



pseudophialides

merosporangia

sporocladia

From O' Donnell 1979

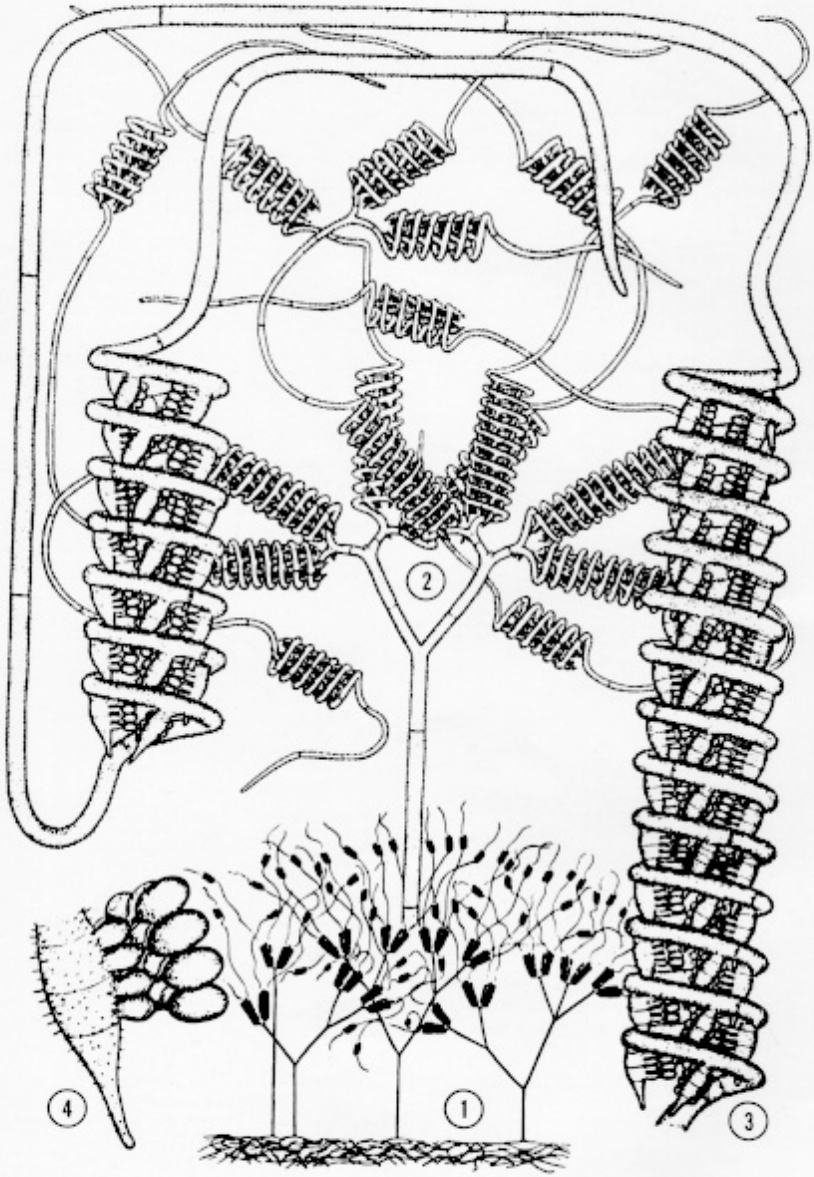
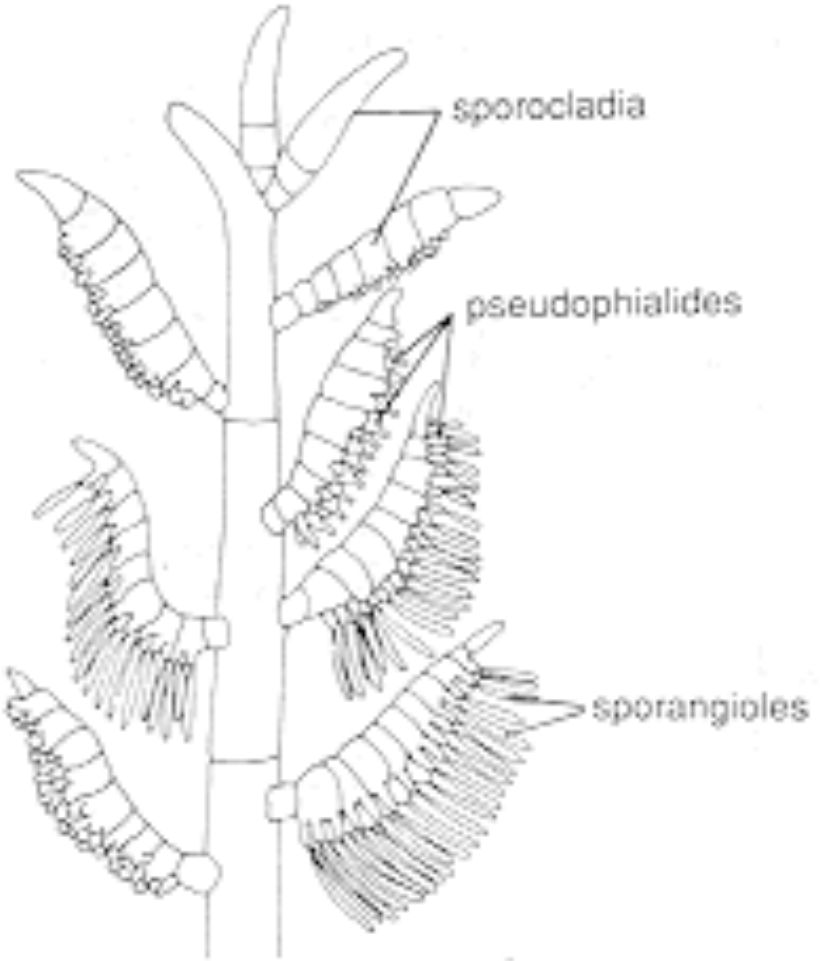


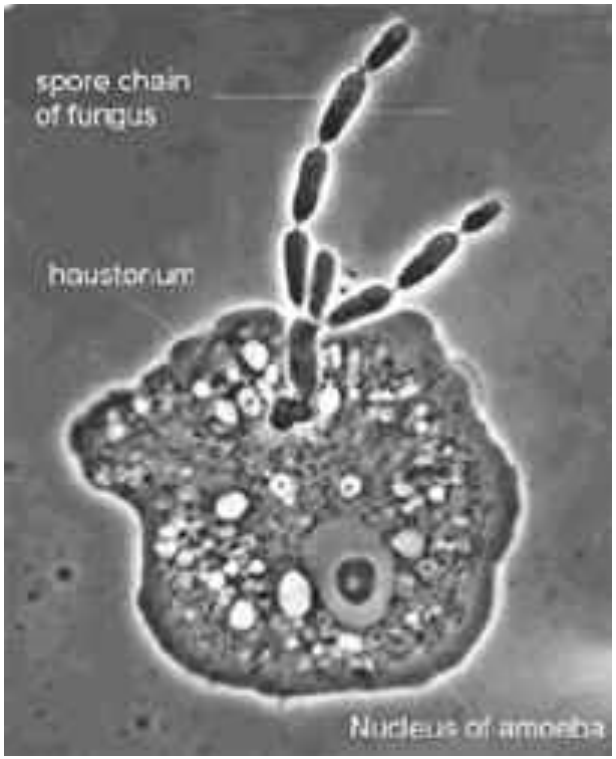
PLATE 73



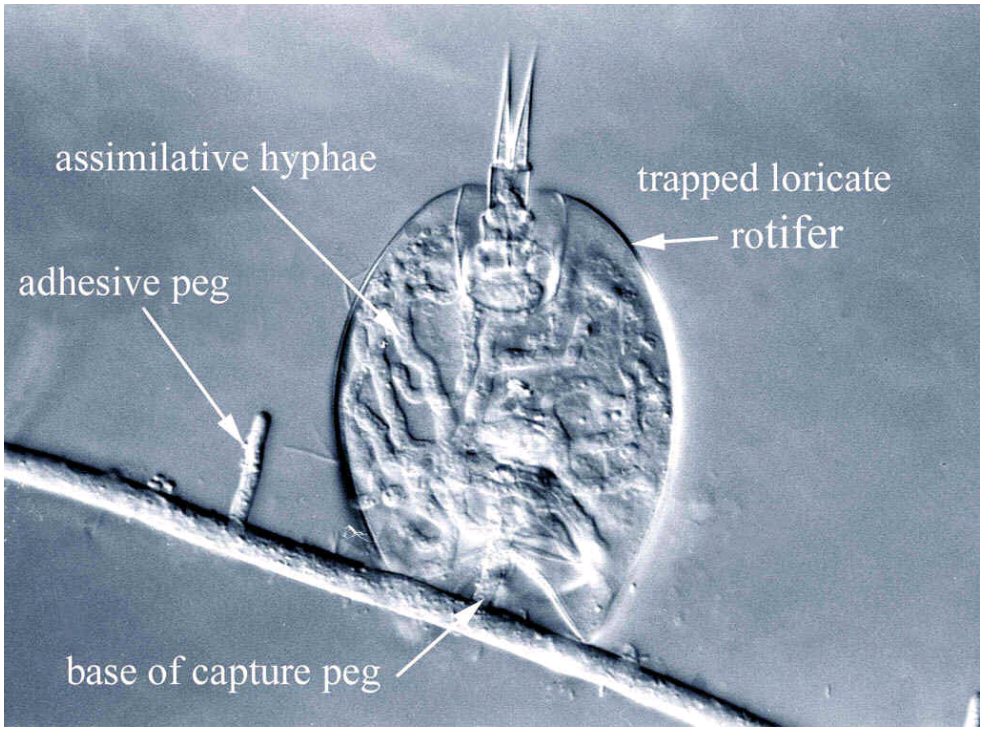
E: *Coemansia*

Order Zoopagales

Mycoparasites and parasites of small animals
Predaceous fungi

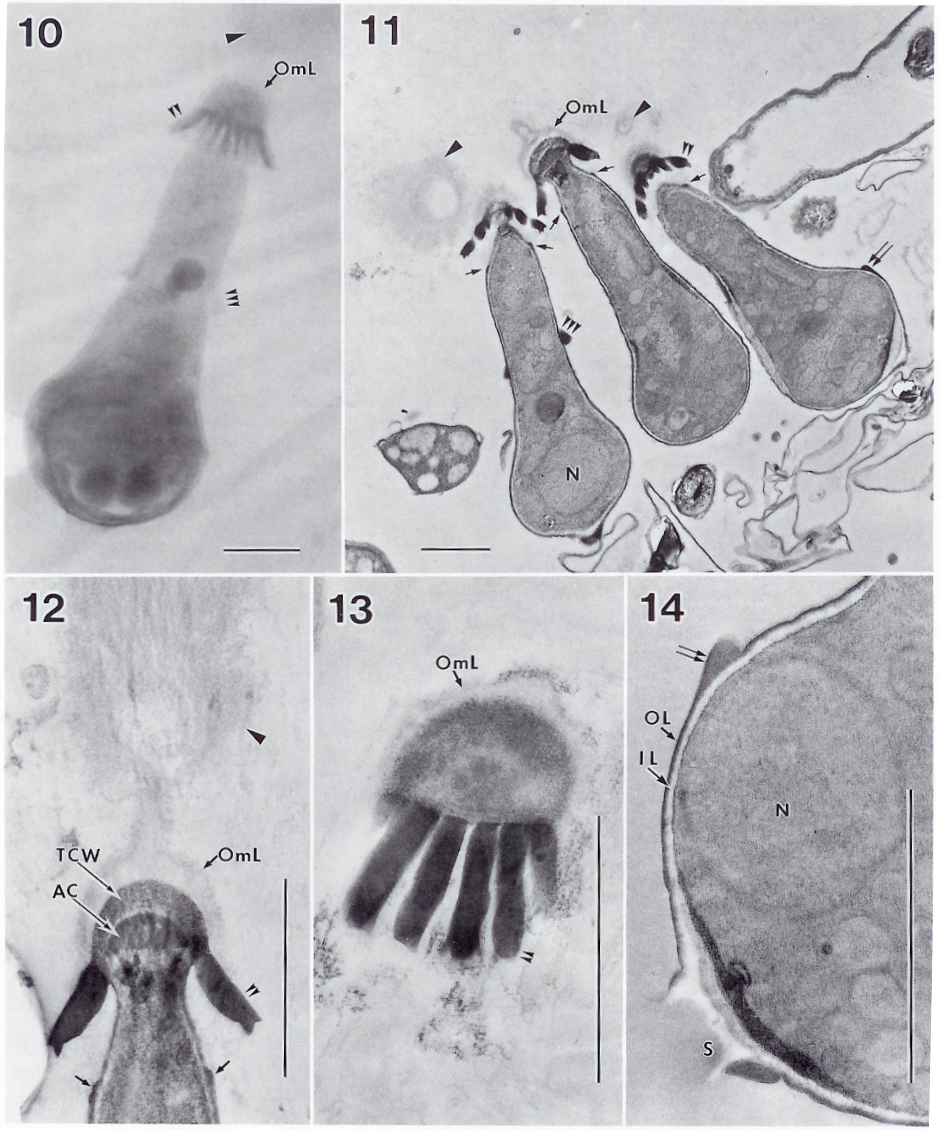


Amoebophilus simplex



Zoophagus insidians

Euryancale phallospora, an endoparasite of nematodes with “phallus shaped” conidia

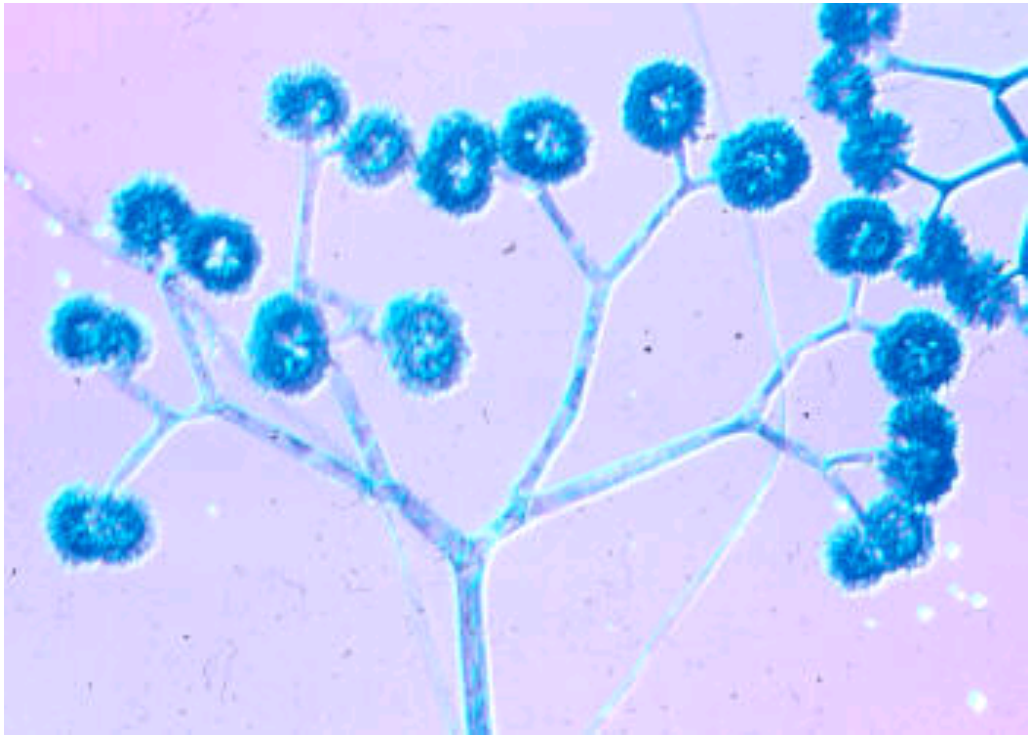


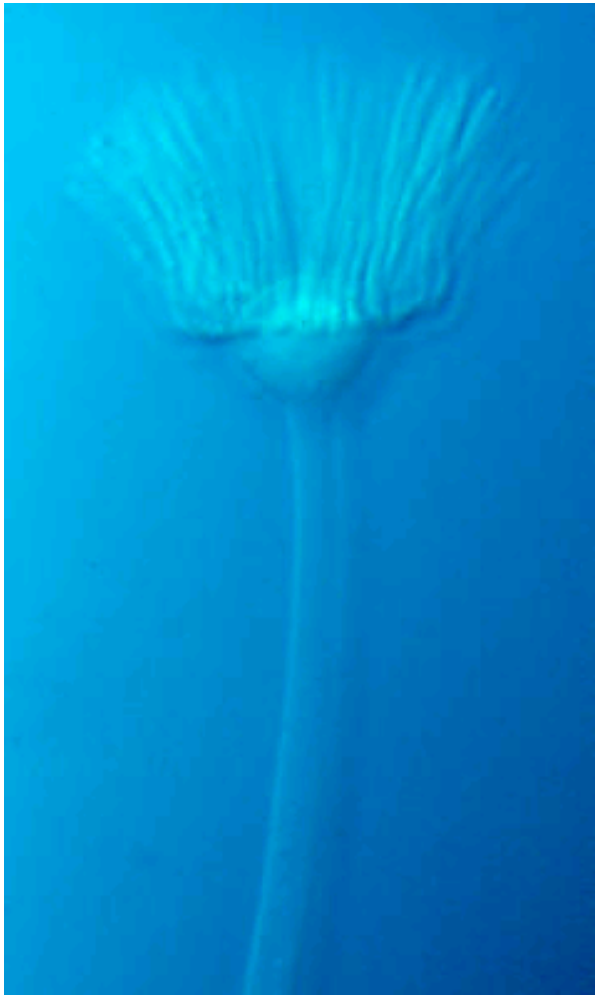
FIGS. 10–14. *Euryancale phallospora.* Electron micrographs. Bars = 1 μm. 10. High voltage electron micro graph of a thick (ca 5 μm) section showing a whole conidium. Arrowhead, a double and a triple arrowhead respectively, show the distal pouchy appendage, subapical bar-shaped appendage and lateral appendage. 11 Three liberated conidia in a thin section. Arrowheads show the pouchy appendage, while double arrowhea shows one of the subapical bar-shaped appendages. Arrows and a double arrow show the scar of separatio from the bar-shaped appendages, and from the lateral appendage, respectively. 12. Apical portion of a conidium Dome-shaped apex is composed of a hemispherical, apical core (AC) and a thick cell wall (TCW). The wall covered with a layer of weakly staining material, connected with the distal pouchy appendage (arrowhead) b a short, narrow stalk. Arrows show scars of separation from the subapical, bar-shaped appendages (doub arrowhead). 13. Apical portion of a conidium cut obliquely. Each of the bar-shaped appendages (double arrow head) measured 0.1 × 0.1 × 0.5 μm. 14. Basal portion of a conidium. A septum somewhat similar to that Trichomycetes is seen. Double arrow, scar of separation from the lateral appendage.

Conidia of *Euryancale* are adapted to lodge in the buccal cavity of the nematode, have adhesive frill for attachment once it is ingested

Piptocephalis and Syncephalis

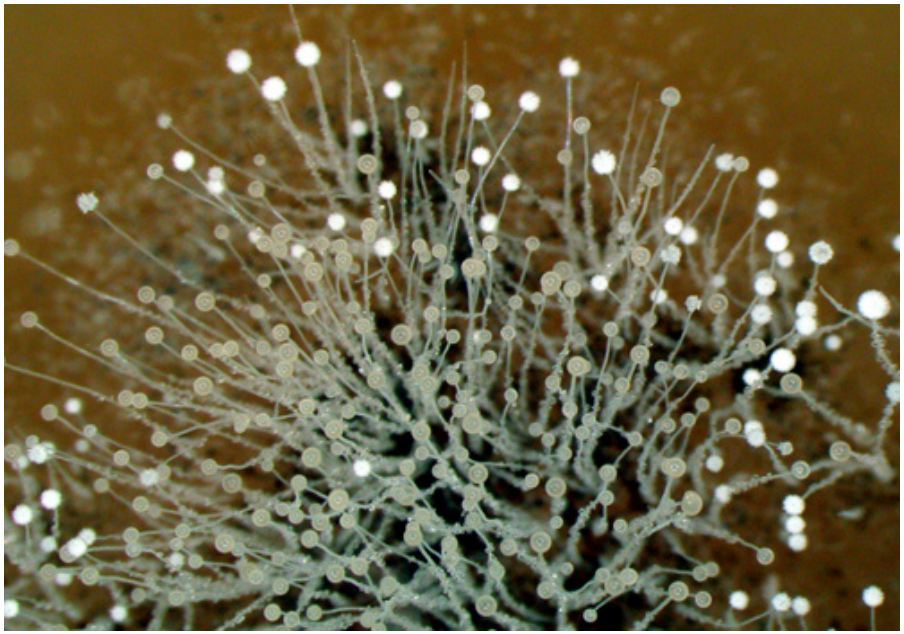
Biotrophic, haustorial mycoparasites, mainly of Mucoraceae





Order Dimargaritales

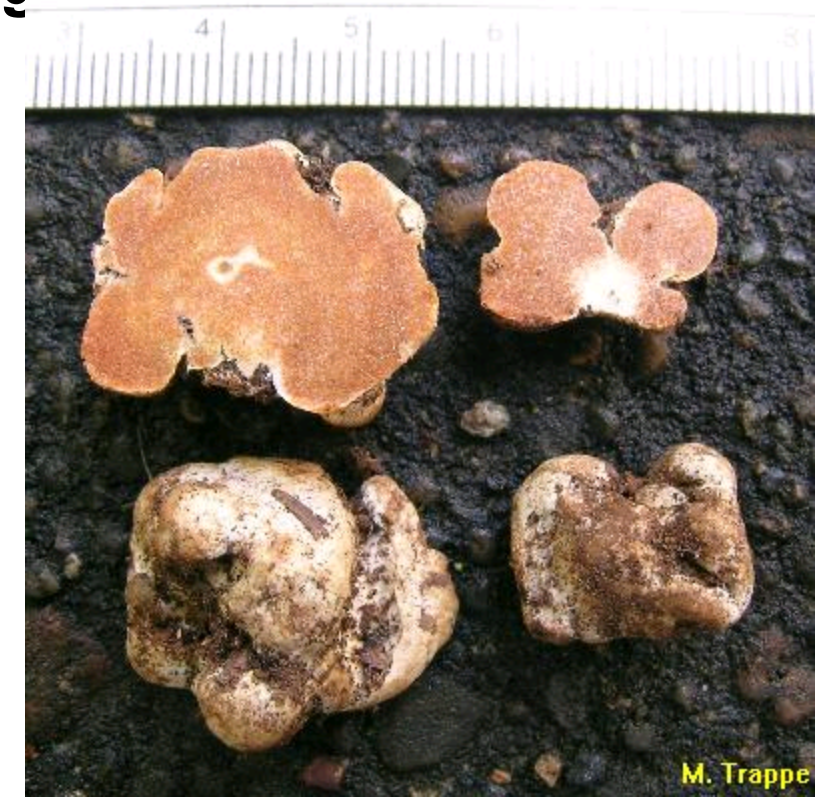
- One family, 4 genera, 14 species
- Characterized by 2-spored merosporangia formed on terminal inflated ampullae
- Produce branched, septate hyphae with unusual, dumbbell-shaped septal plugs
- Obligate mycoparasites of mucoraceous fungi
  - Biotrophic, haustorial



Order Endogonales

Endogonaceae

Endogone **a zygomycetous truffle, 'pea truffle'**
ectomycorrhizal
sporocarps contain zygospores



Order Zoopagales

- Five families, 21 genera, 163 species
- Coenocytic or septate hyphae
- Conidia or multispored merosporangia
- All members are obligate parasites of other fungi or microscopic animals (amoebae, rotifers, nematodes)
  - Ectoparasitic, endoparasitic or predaceous
  - Haustoria formed in host in ectoparasitic and predaceous species

“Class Trichomycetes”

Molecular studies show not really a separate class
under revision
2 Orders, 55 Genera, 220 species

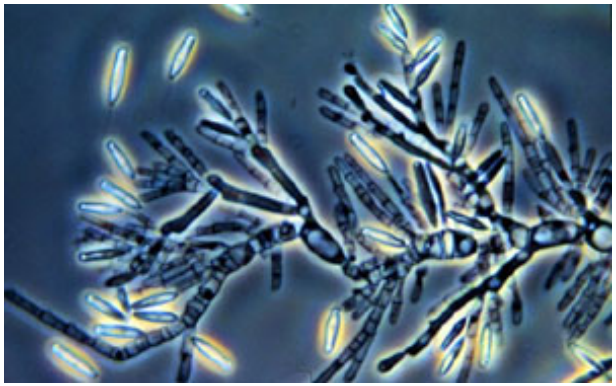
- **obligately associated with living arthropods**
  often aquatic arthropods
  insects, millipedes, crustaceans
- **attach to the hindgut via a holdfast**
- **grow within the hindgut of their hosts**
  Aquatic insect larvae feed on detritus, algae, etc.
- **mostly commensals, some beneficial or antagonists**
- **many species produce septate hyphae**

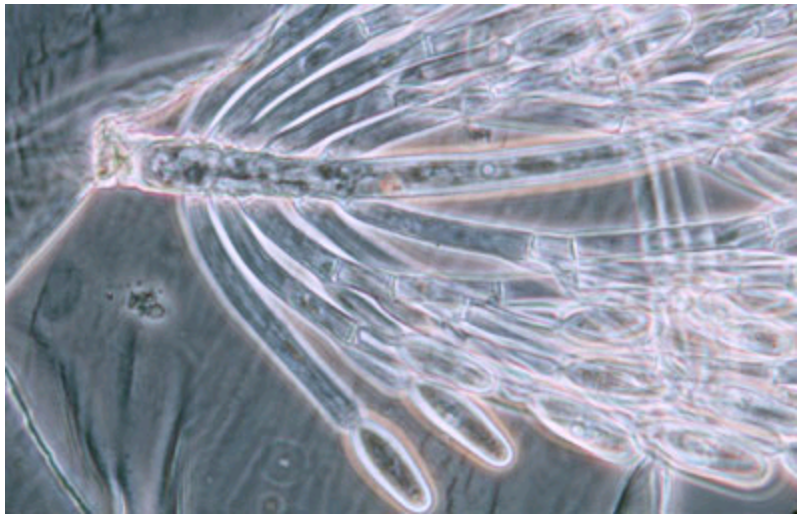
Zygomycota

Trichomycetes

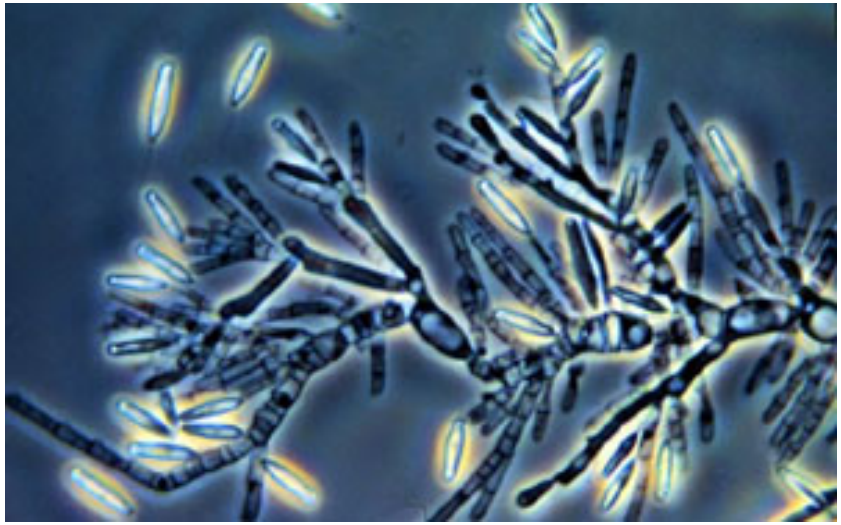
Harpellales

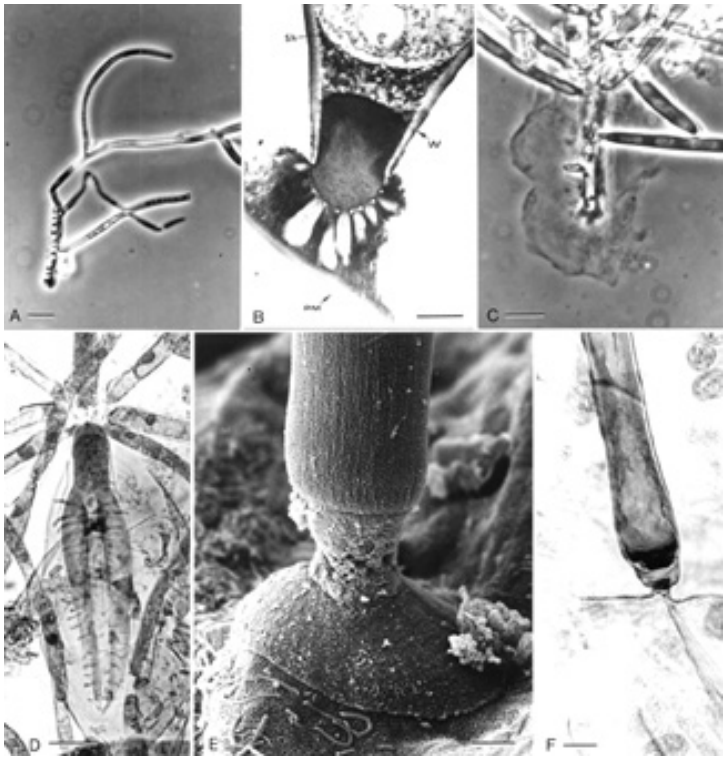
Smittium

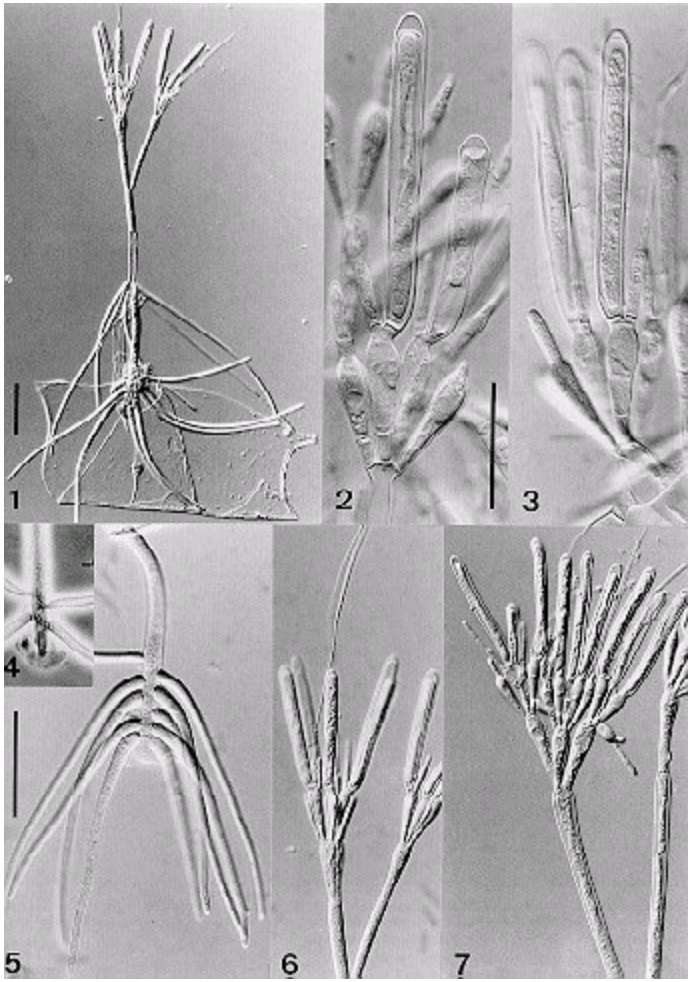




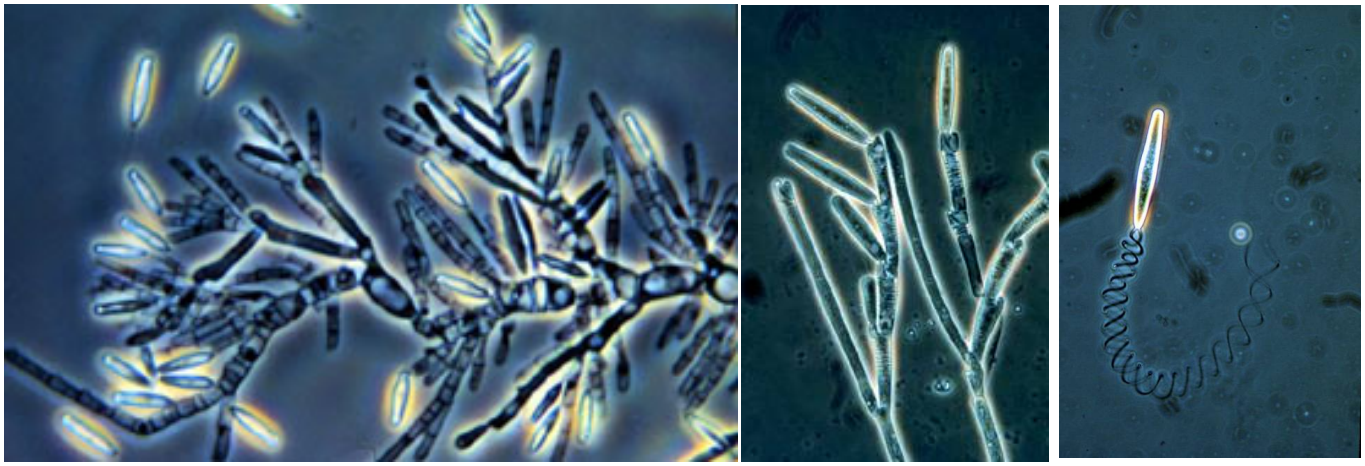
Attach to hindgut of various aquatic arthropods



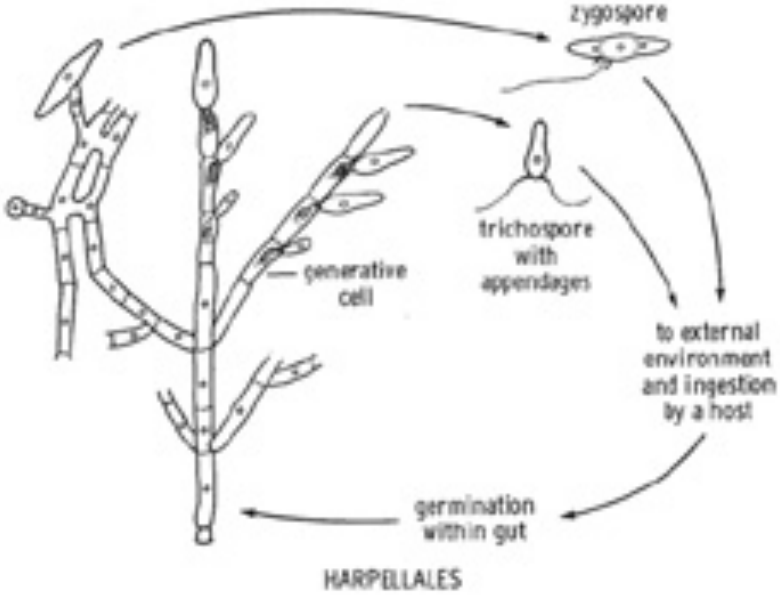

A
B
C
D
E
F

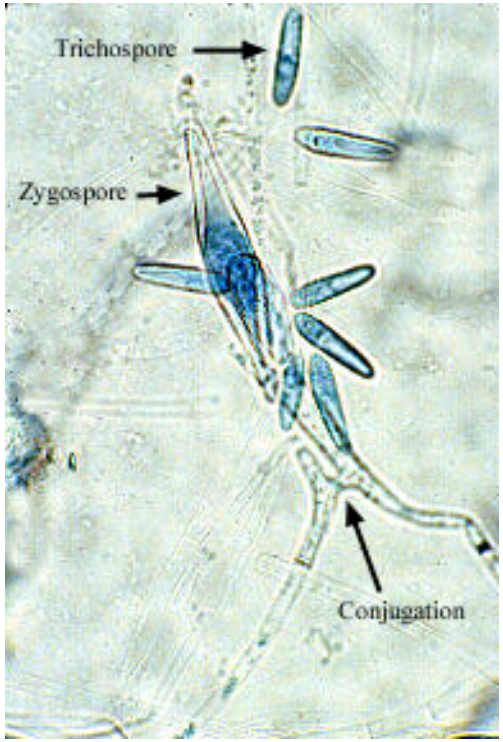

1
2
3
4
5
6
7

Asexual spores - trichospores



Sexual spores - zygospores





Harpellales attach to hindgut of various arthropods, mainly aquatic insect larvae, also, millipedes, terrestrial beetles, fiddler crabs