西北农林科技大学
Northwest A&F University

植物保护学院

普通昆虫学（一）General Entomology

—昆虫形态学 Insect Morphology


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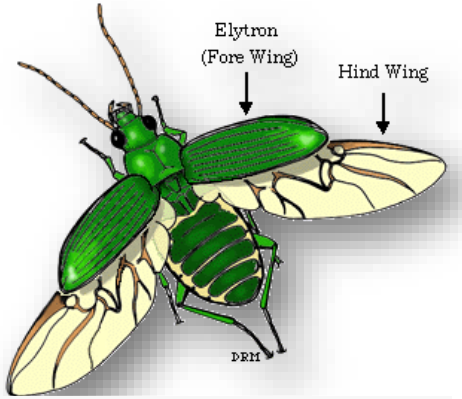
所在学院：植保学院

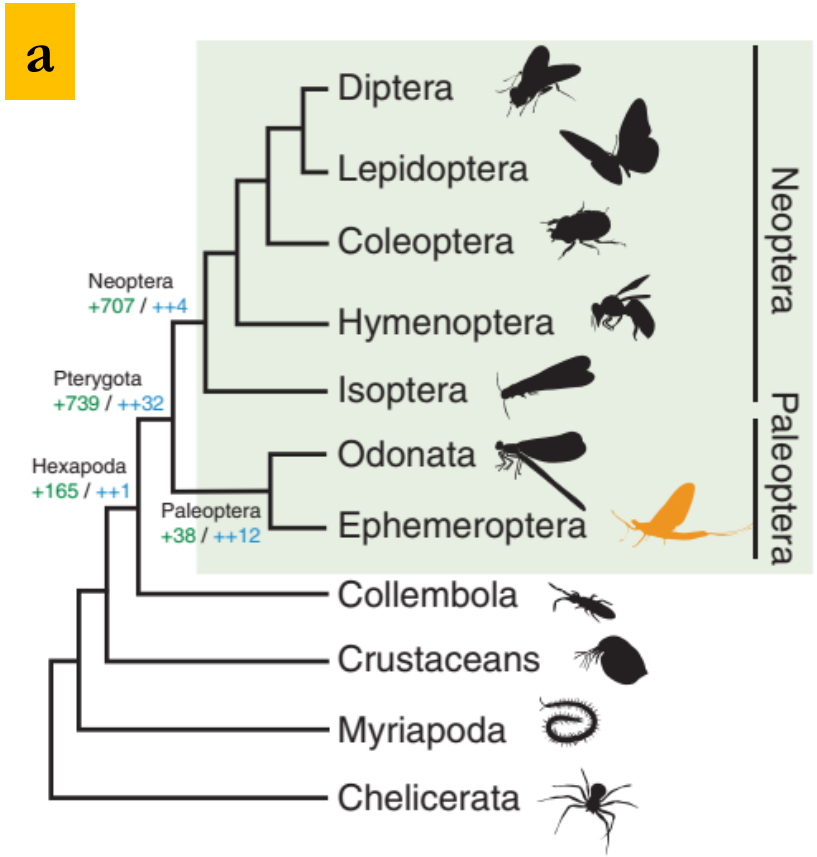
Lecture 5 Wings of Insects

第五讲　昆虫的翅

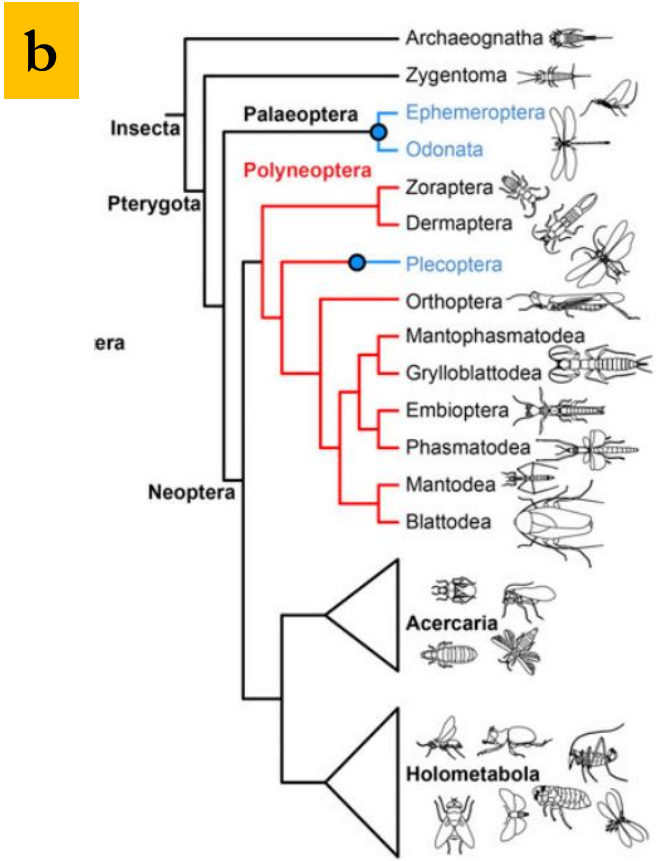


- Insects are the earliest group that evolved the flight ability in animals, which is the most important key innovation in the evolution.

- It opened up a whole new realm for feeding, escape, and dispersal.



Pterygota insects (green rectangle). Ephemeroptera (mayflies, in orange) are within Paleoptera. Number of gene gains (in green) and core gene gains (in blue)



Phylogenomic tree of a resolved Polyneoptera (red), reflecting a **terrestrial origin of insect flight.**

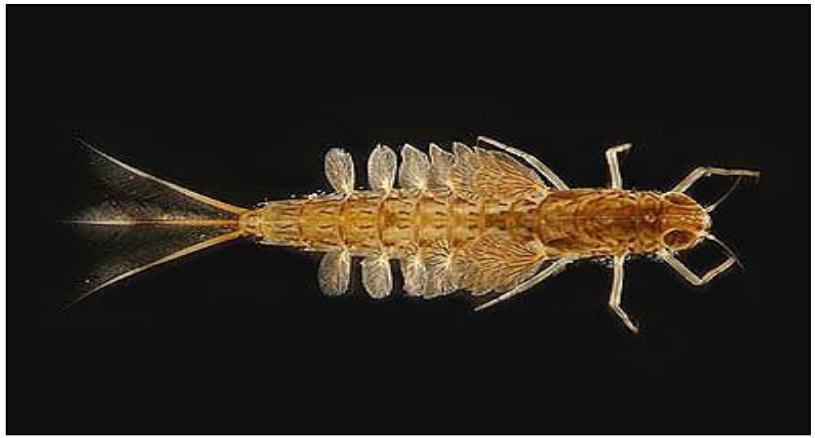
1. Development and General Structure 翅的发生与构造

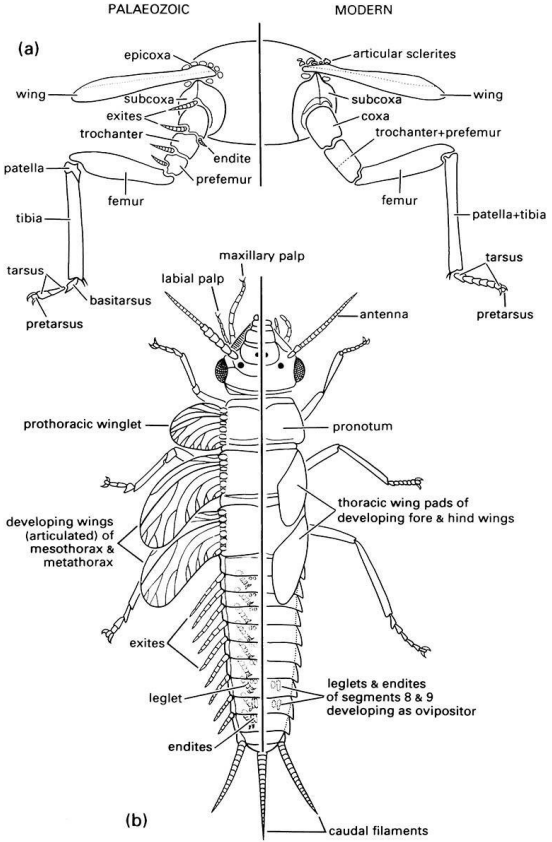
Hypotheses about the origin of the wings：

I. Pleuron hypothesis 侧板翅源说 (Kukalova-Peck, 1983)

II. Paranotal lobe hypothesis 侧背叶翅源说 (Packard, 1898)

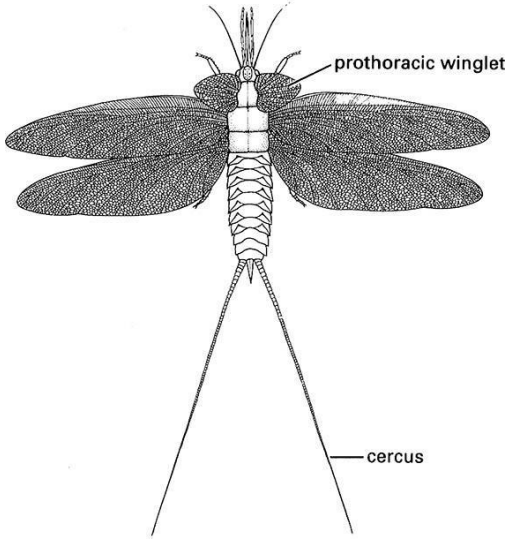
III. Tracheal gill hypothesis 气管腮翅源说 (Gegenbaur, 1870)

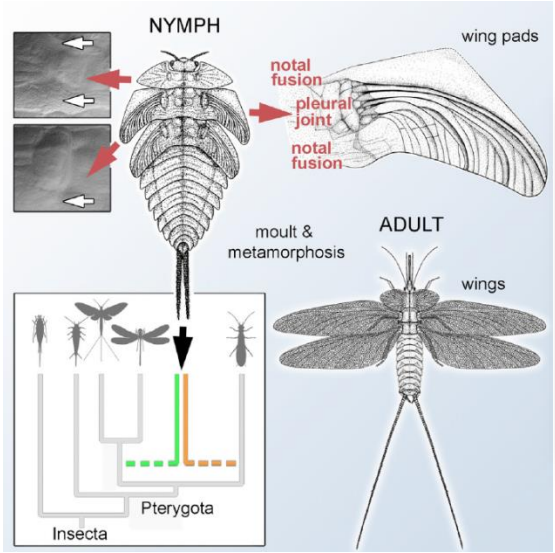




Paranotal theory 侧背叶翅源说

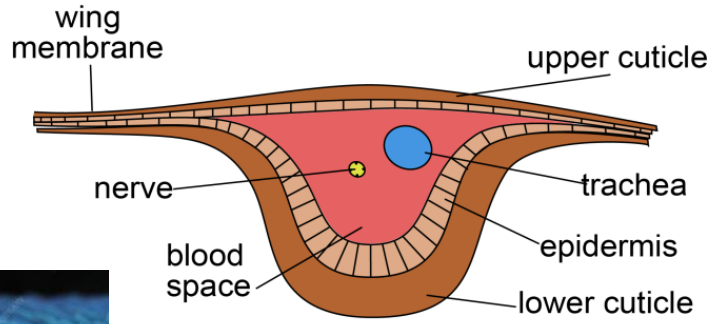
- The wing was developed from paranotal lobes（侧背叶）
  - paranota are lobes postulated to have been derived from thoracic terga.
    随进化发展，背、腹面表皮互相贴紧、融合，形成膜质翅面
  - 部分形成空腔（翅脉），以容纳神经和气管

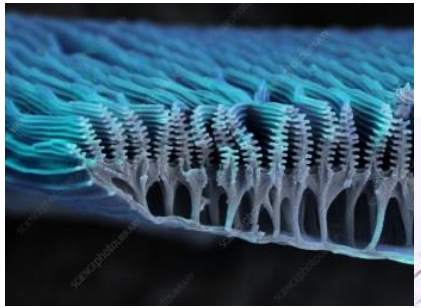


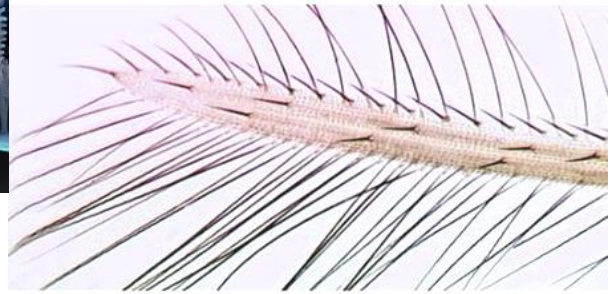


Structure of wings and its variation

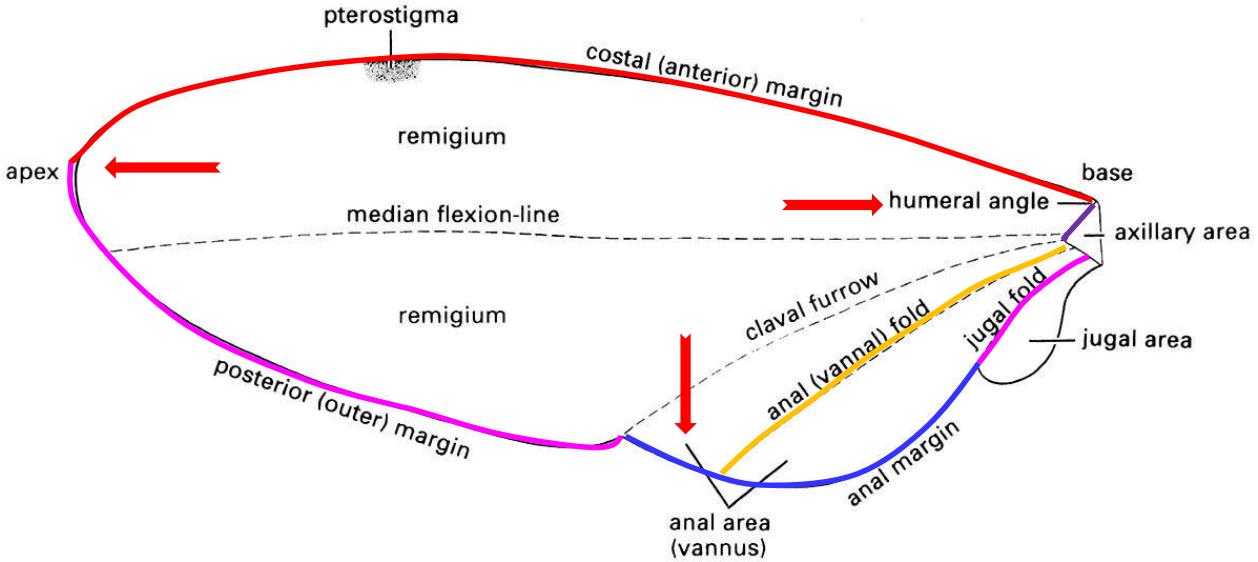
- **Structure 构造**
  - epicuticle 上表皮, cuticle 表皮, basement membrane 底膜, veins 空腔（翅脉）
  - **Slipcover of wings**
    - **Setae / hairs**
    - **microtrichia**
    - **scales, the flattened setae found on butterflies and moths**



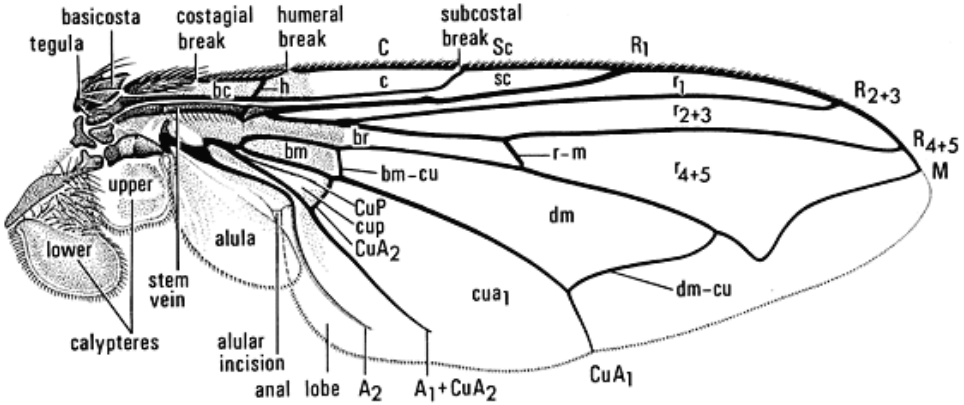


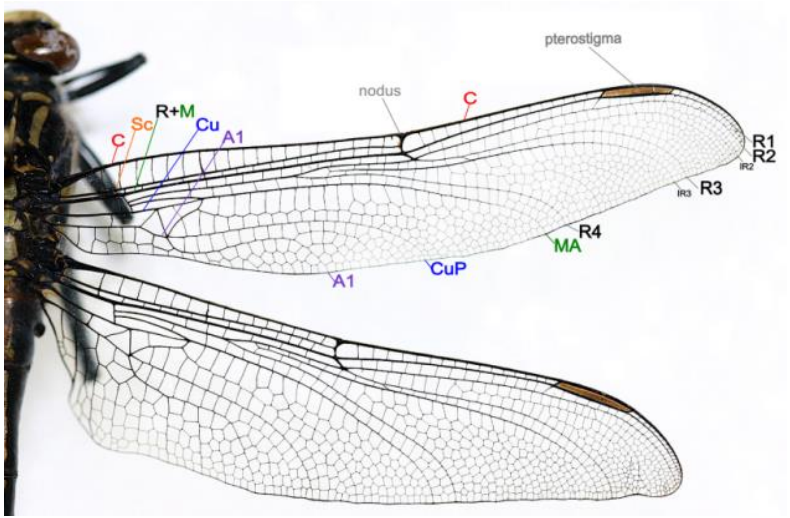


- **Usually triangle in shape, three margins and three angles and three folds, four regions**
  - **Costal margin 前缘— Outer margin 外缘— Inner margin 后（内）缘**
  - **Humeral angle 肩角— Apical angle 顶角— Anal angle 臀角**
  - **Basal fold 基褶， Vannal fold 臀褶， Jugal fold 轭褶**
  - **Axillary region 腋区， Remigium 臀前区， Vannal region (Vannus) 臀区， Jugal region 轭区**



- **Vein 翅脉: 翅的两层薄壁间纵横分布的条纹，由气管部位加厚形成。**
- **Some groups also with**
  - **Alula 翅瓣 Calypter 腋瓣**
  - **Pterostigma 翅痣 - an opaque or pigmented spot anteriorly near the apex of the wing**





2. Variations and modifications of wings

（1）Primitively and secondarily wingless

- In Apterygota, the wings are never present, primitively wingless, such as silverfish and springtails.
- In Pterygota, some insects lost their wings, but their ancestors ever possess wings, secondary wingless, such as bedbugs, lice, and fleas.

I. Apterogota 无翅亚纲： without wing 原生无翅

II. Pterogota有翅亚纲 – with or without wing

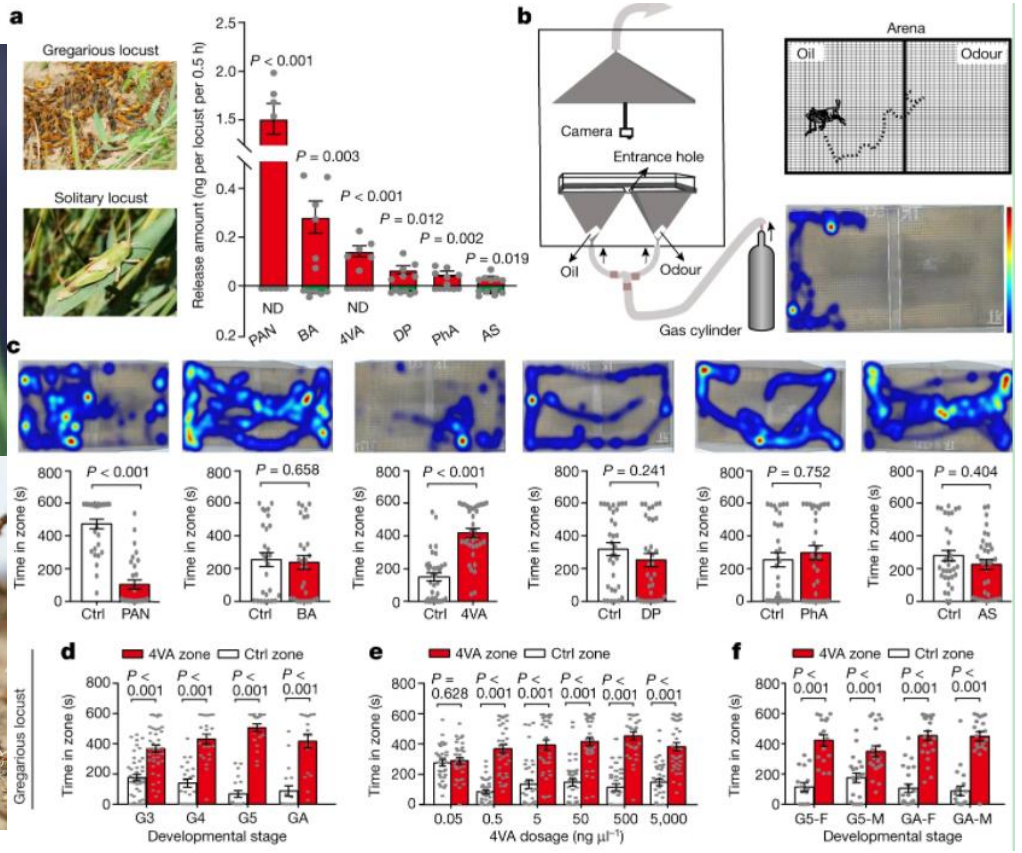
- The complete absence of wings is secondarily as in all lice and which is a secondary condition and associated with the habits
  - soil-dwelling
  - endoparasitism
    - Lice, Flea

(2) Size and shape

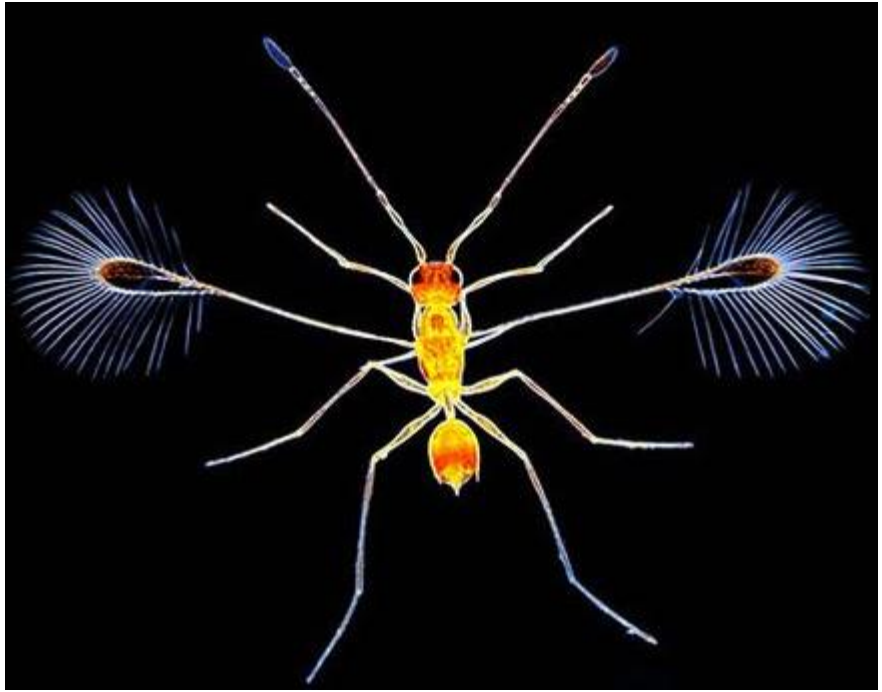
- **Macropterous 长翅型:**
- **Brachypterous 短翅型:**
- **Apterous 无翅型:**
  - **Parasites, such as fleas, lice, bedbugs, are often wingless;**
  - **Ecological adaptation: polymorphism, such as aphids, planthoppers.**

Solitary phase(left)v/s Gregaria phase(right)

4-Vinylanisole (4VA，4-乙烯基苯甲醚) is an aggregation pheromone in locusts



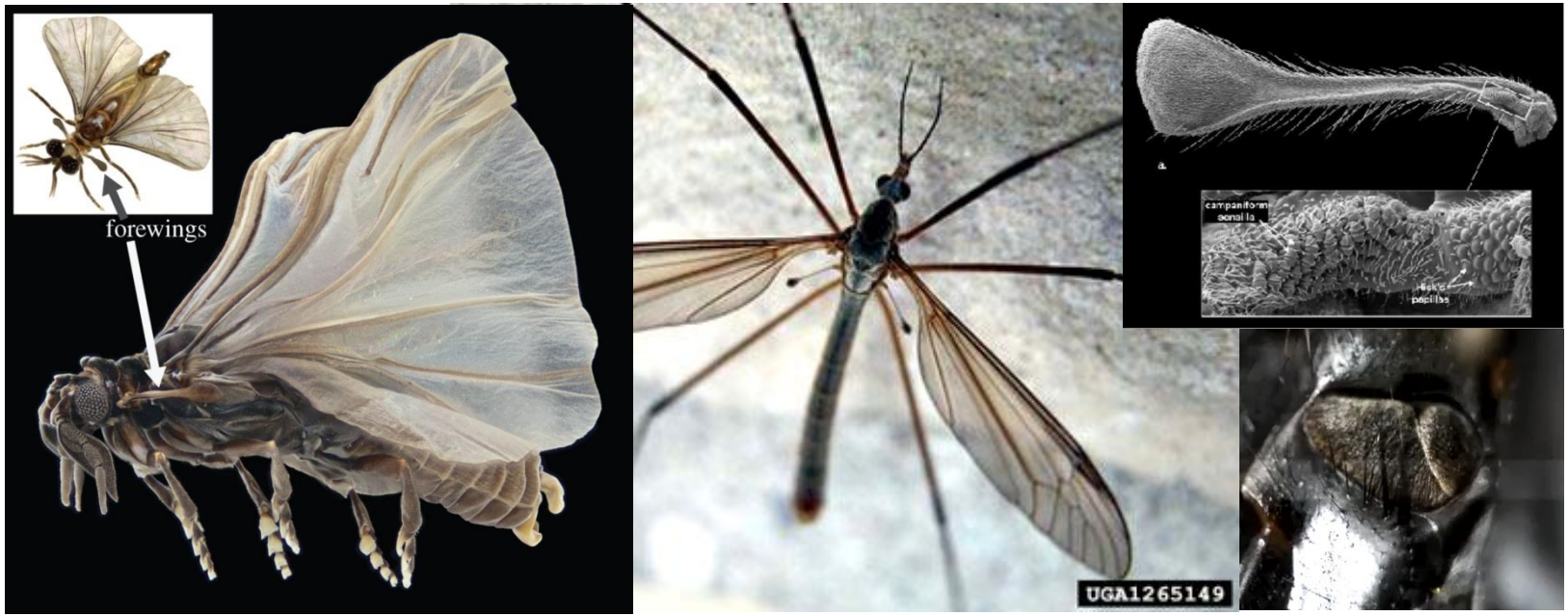
Guo *et al. 2020* Nature




100 μm

Texture 质地 – degree of sclerotization

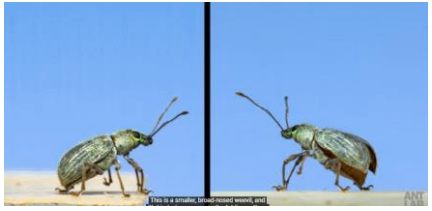
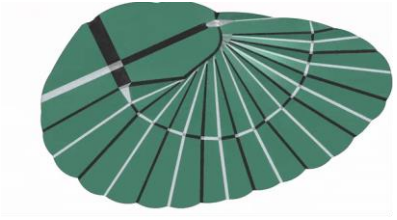
- Typically membranous and transparent
- However, from this basic pattern are derived many other conditions

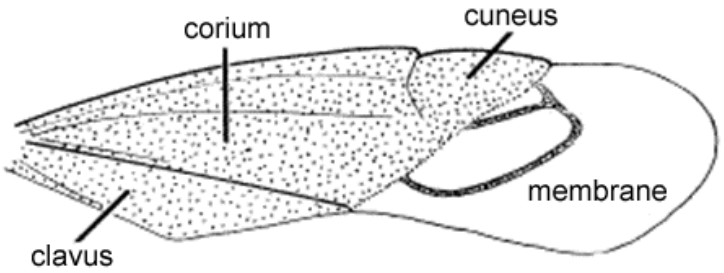


- **In Diptera, Strepsiptera the hind and fore wings are reduced and modified as stabilizers, haltere平衡棒, and do not function as wings.**



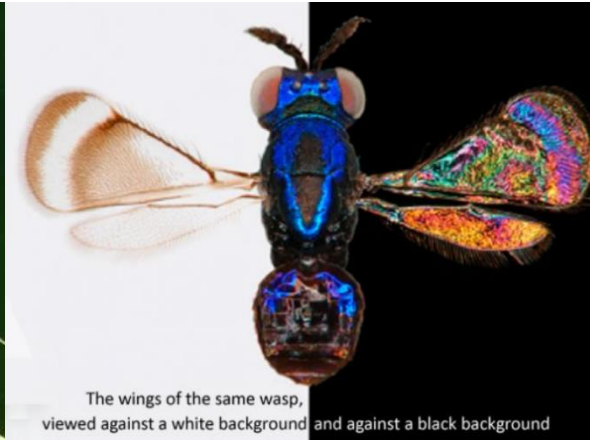

- **In beetles, the fore wings are hardened and serve as protective covering for membranous hind wings, called elytra鞘翅 (sl. elytron).**



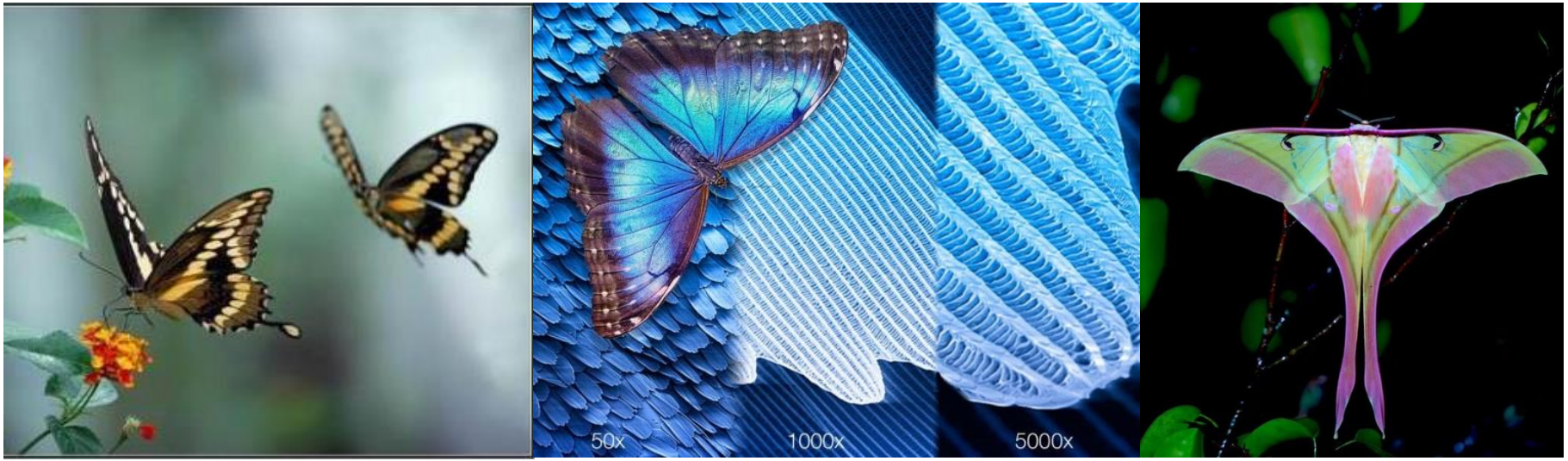
- **In bugs, the basal part of fore wings is thickened and the apical part is membranous, called hemelytra半鞘翅.**

- **In grasshopper, the fore wings are thickened and leathery, called tegmen 覆翅（pl. tegmina）.**
- **In some insects, wings are used to make sounds, e.g. in crickets, katydids, grasshoppers.**



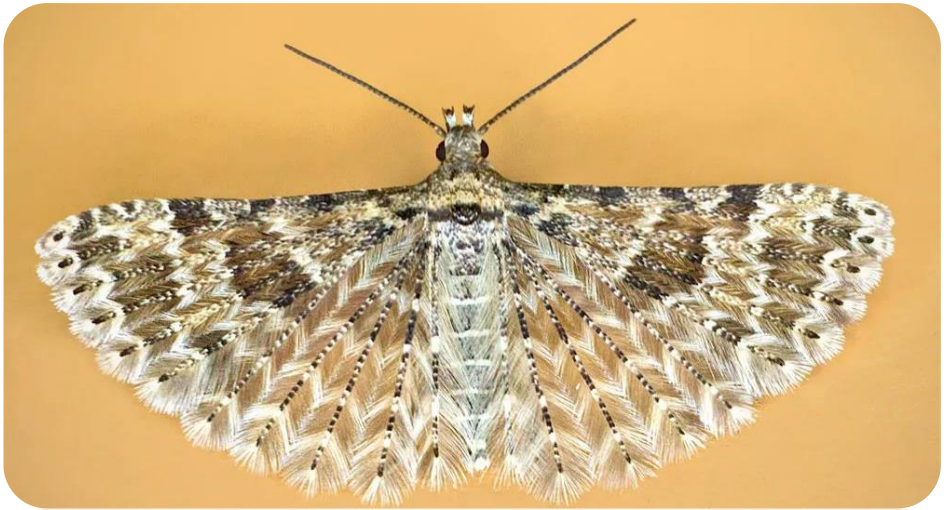
- **In wasps, dragonflies, and mayflies etc., wings are membranous and clear, called membranous wing膜翅**

- **In thrips, slender front and hind wings with long fringes of hair along the margin, called fringed wing 缨翅.**



- **In Lepidoptera (moths and butterflies), front and hind wings are covered with flattened setae or scales, called lepidotic wing鱗翅**

羽蛾科Pterophoridae



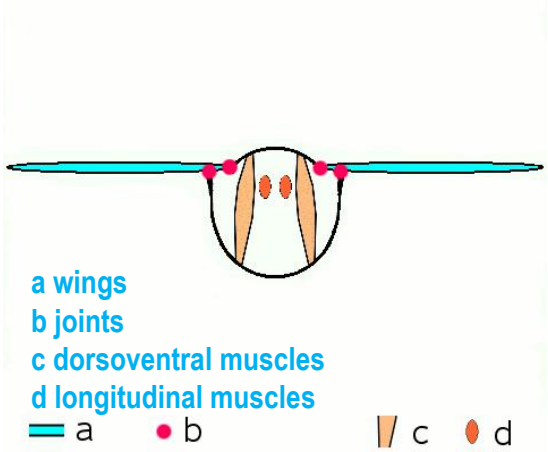
翼蛾总科Alucitoidea

- **In Trichoptera (caddisflies), the long, silky hairs that cover most of the body and wings (piliferous wing).**

3. Functions of wings

– Flight 飞行

- The two-winged condition is aerodynamically more efficient than the four-winged condition

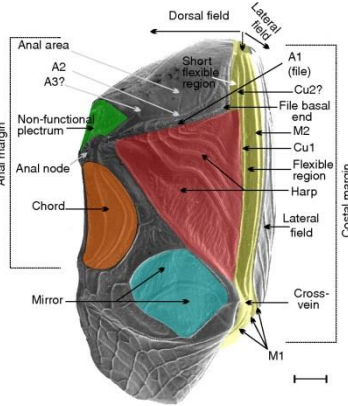


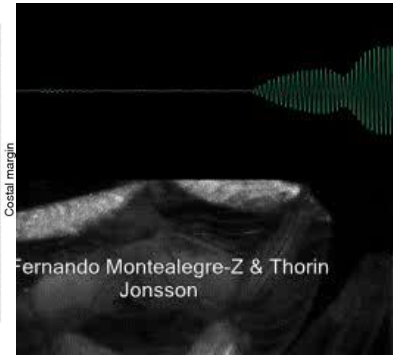
Protection 保护

Sound making 发声

Air conditioning 空调

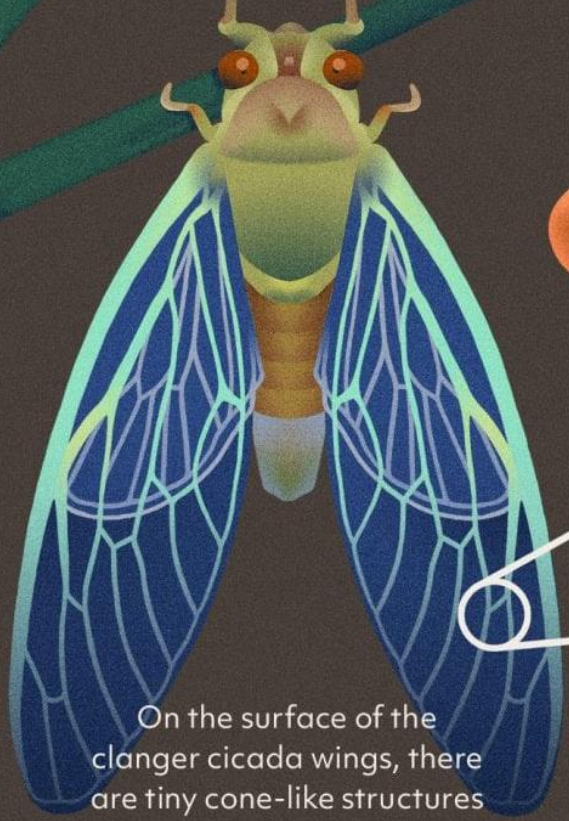
Luring 引诱



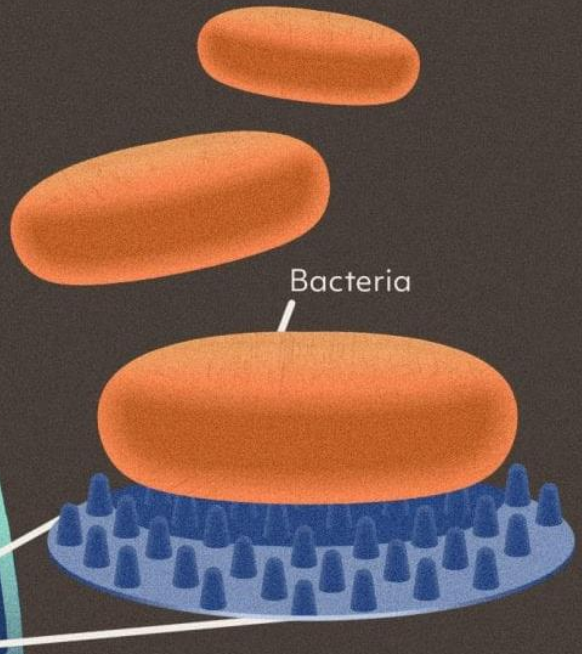


BIOLOGICAL STRATEGY

Nanopillars vs. Bacteria

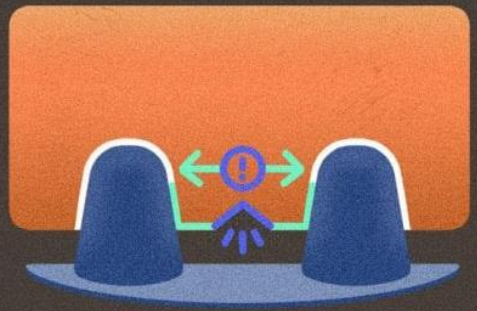


On the surface of the clanger cicada wings, there are tiny cone-like structures known as nanopillars.

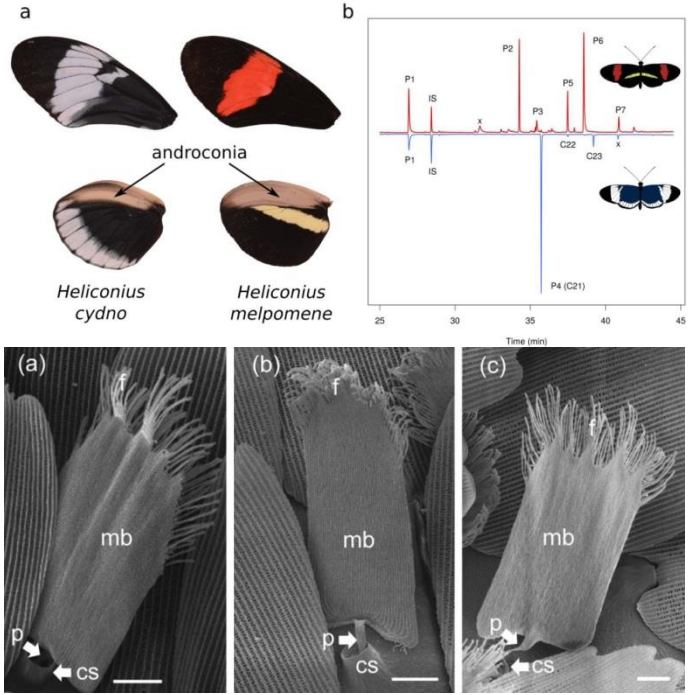


These structures are spaced out evenly and protrude upward from the wings' surface.

As more and more of the bacterial membrane wall adheres to the nanopillar ...



the portion between nanopillars is stretched, eventually reaching a breaking point which kills the bacteria.

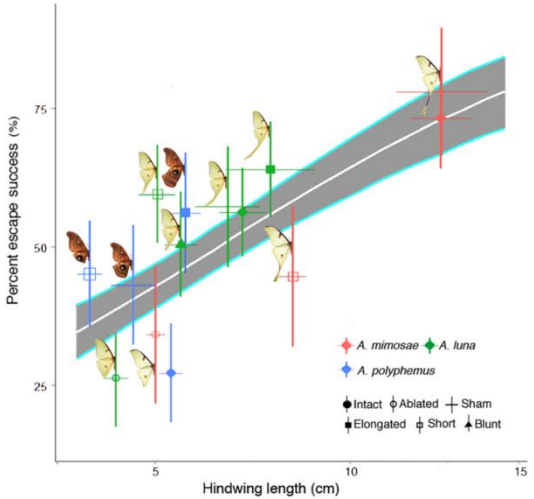


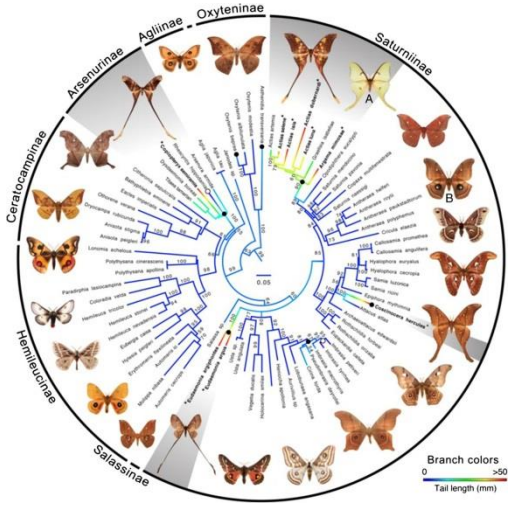
Male hindwing scent scales of *Heliconius*

f—fringes, p—pedicel, cs—cuticular socket, and mb—main body or blade

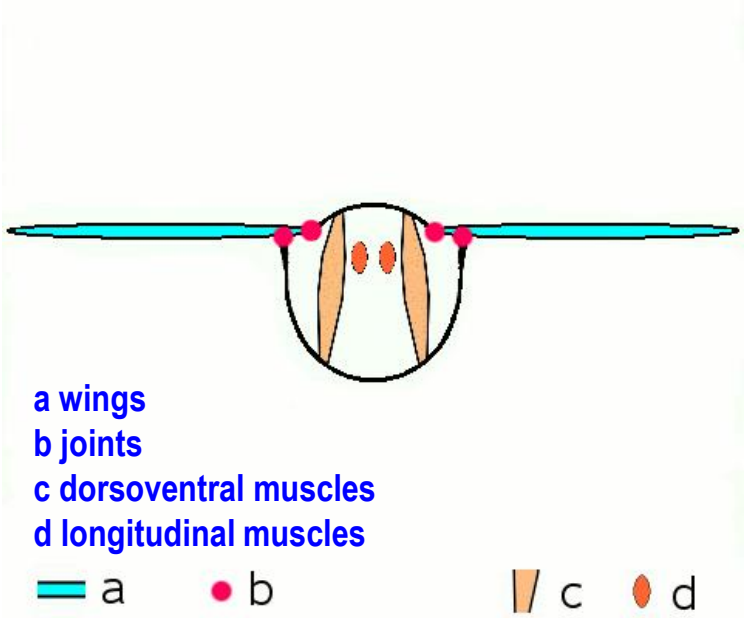
***Ochlodes sylvanus* sex brand highlighted**

Moths with longer hindwings escape an increasing proportion of bat attacks

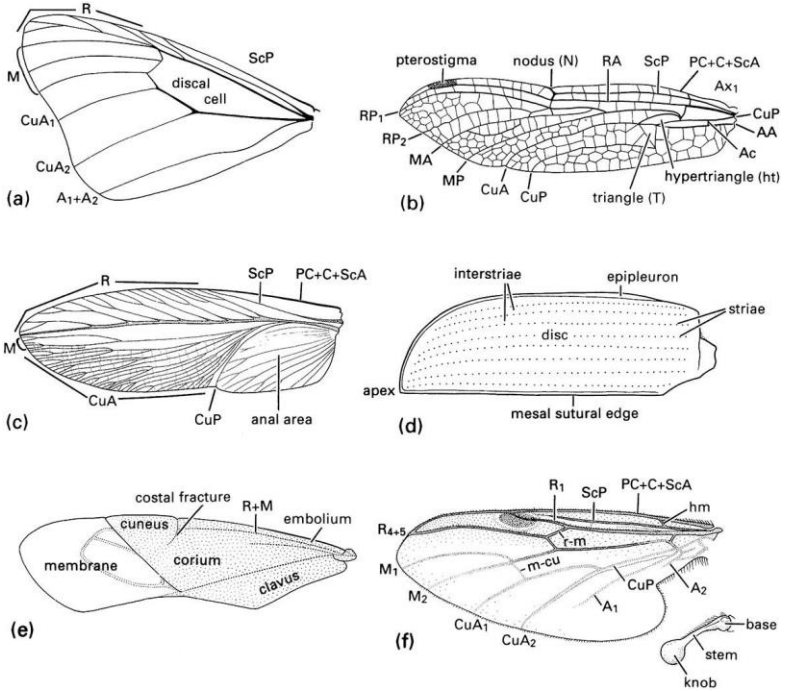




Summary


a wings
b joints
c dorsoventral muscles
d longitudinal muscles
a
b
c
d

The diversity of wing patterns across insect orders



Wing taxonomy: size, shape and structure
Adapted from Misof *et al.* 2014,

Assignment

- **To discuss the evolutionary and function of insect wings.**

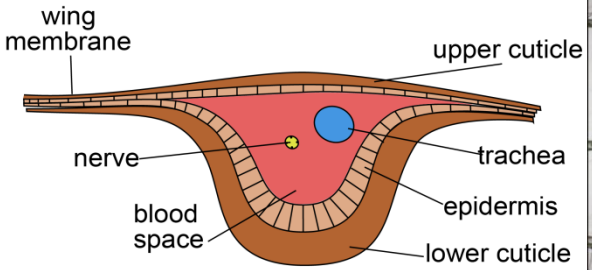
Further reading

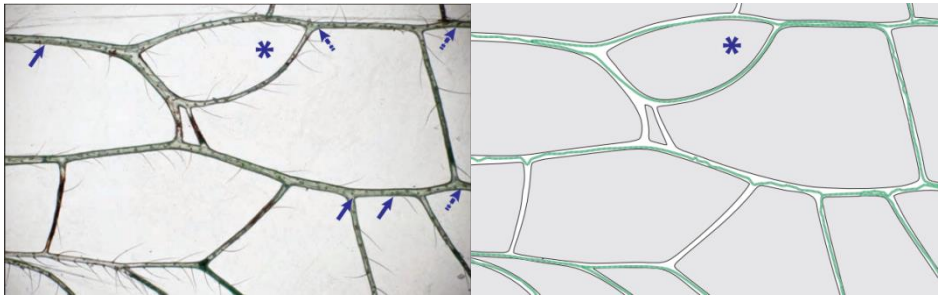
- Zhang CX, *et al.* (2019) Molecular mechanisms of wing polymorphism in insects. *Annual Review of Entomology*. 64: 297-314.
- Ross A, (2017) Insect Evolution: The origin of wings. *Current Biology*. 27(3): 113-115.
- Ohde T, *et al.* (2013) Insect morphological diversification through the modification of wing serial homologs. *Science,* 340:495-498.
- Misof B, *et al. (*2014) Phylogenomics resolves the timing and pattern of insect evolution. *Science*, 346: 763-767

Lecture 5 Veins and Venation of Insects

第五讲　昆虫的翅脉

1. Veins 翅脉

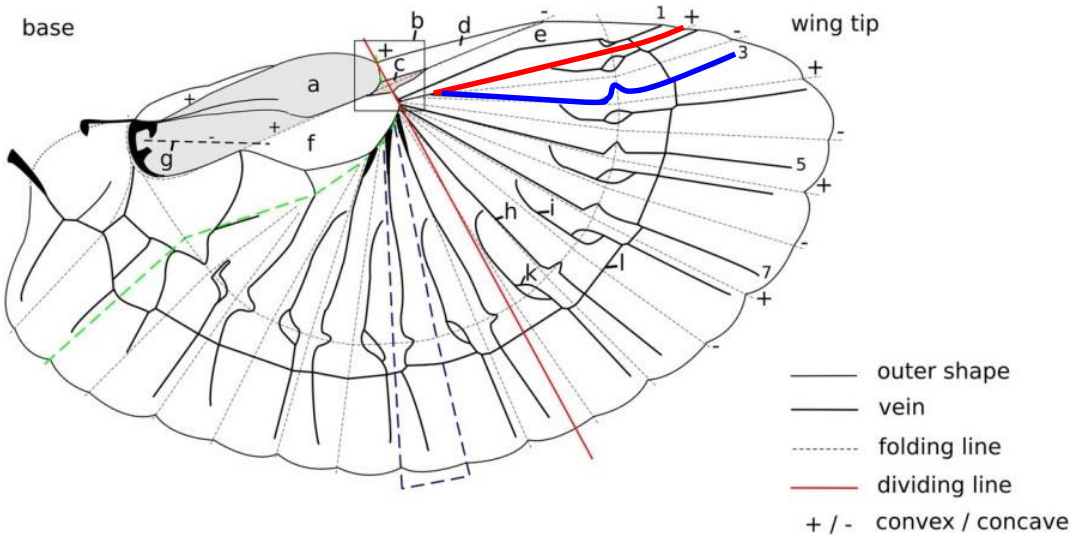




Solid arrows indicate points of tracheal division, dashed arrows indicate fusions of veins with multiple tracheae present; course of tracheae indicated by green lines

2. Type of veins 翅脉类型

- convex vein 凸脉 +
- concave vein 凹脉 -
- longitudinal vein 纵脉：
  capital letters
- cross vein 横脉：
  lowercase letters



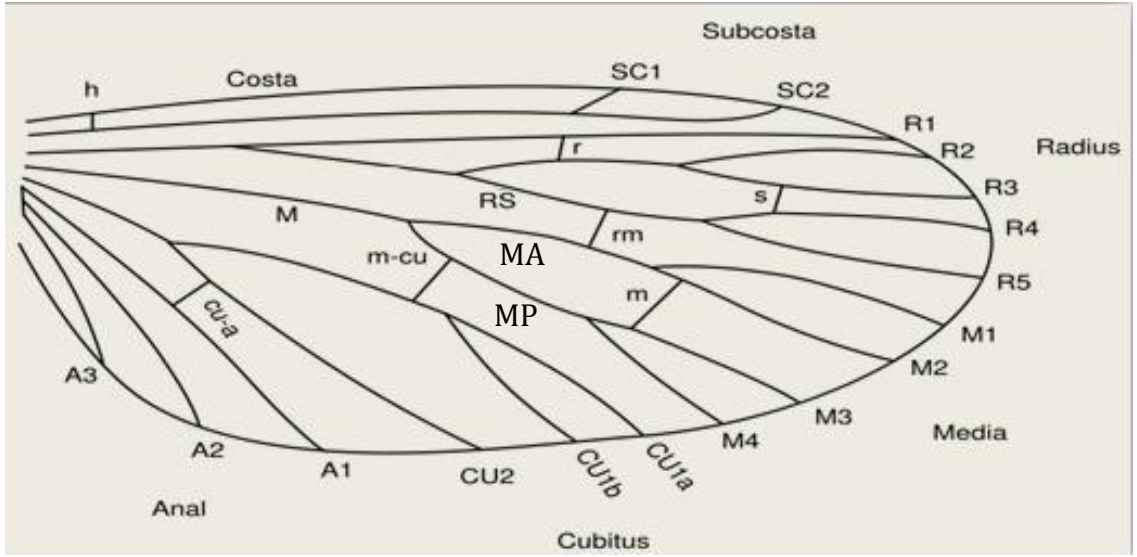
3. Venation 脉序

- consistent within groups (especially in families and orders)
- often differ between groups
- provide major features used in insect classification and identification.
- the basic pattern is the same
  - hypothetical primitive pattern of wing venation 假想原始脉序

Comstock-Needham System 康尼系统

J. H. Comstock

J. G. Needham



Costa (C) – the leading edge of the wing
Subcosta (Sc) – second longitudinal vein (behind the costa), typically unbranched
Radius (R) – third longitudinal vein, one to five branches reach the wing margin
Media (M) – fourth longitudinal vein, one to four branches reach the wing margin
Cubitus (Cu) – fifth longitudinal vein, one to three branches reach the wing margin
Anal veins (A1, A2, A3) – unbranched veins behind the cubitus

7条主纵脉

- Costa (C) 前缘脉 +
- Subcosta (Sc) 亚前缘脉 -
- Radius (R) 径脉 +
- Media (M) 中脉 -
- Cubitus (Cu) 肘脉 -
- Anal vein (A) 臀脉
- Jugal veins (1J, 2J) 轭脉

6条横脉

横脉名称	简写	连接的纵脉
humeral crossvein 肩横脉	h	C 和 Sc
radial crossvein 径横脉	r	R_1 和 R_2
sectorial crossvein 分横脉	s	R_3和R_4 或 R_{2+3}和R_{4+5}
radiomedial crossvein 径中横脉	r-m	R_{4+5} 和 M_{1+2}
medial crossvein 中横脉	m	M_2 和 M_3
mediocubital crossvein 中肘横脉	m-cu	M_{3+4} 和 Cu_1

h cross-veins – run between the costa and subcosta

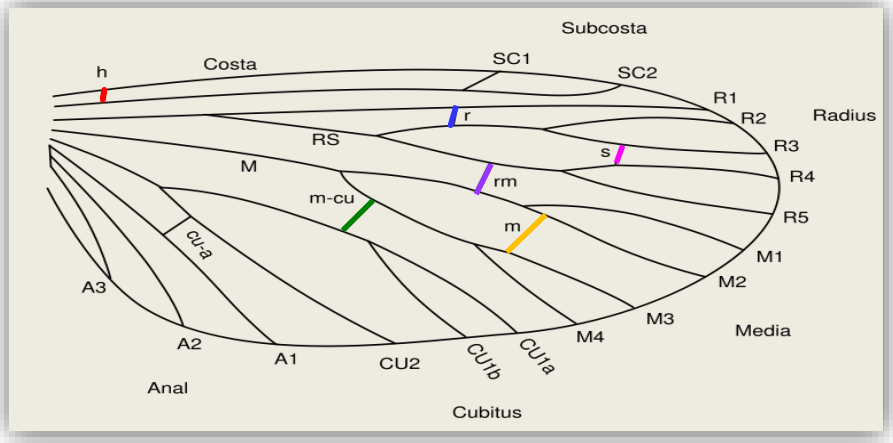
r cross-veins – run between the first and second branches of the radius

s cross-veins – run between adjacent branches of the radius

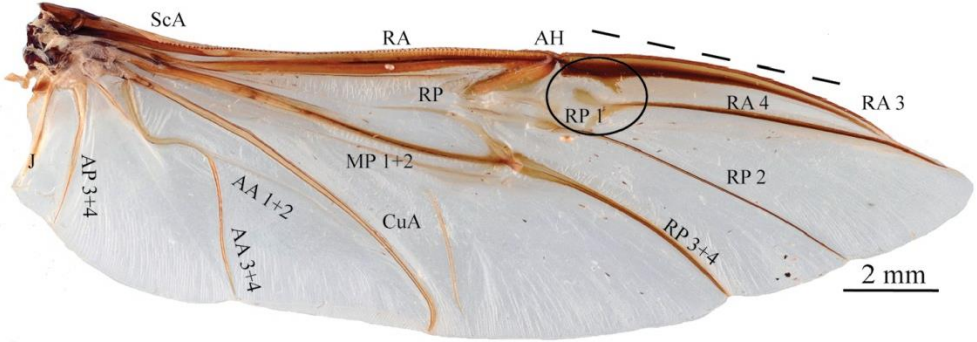
r-m cross-veins – run between the radius and media

m cross-veins – run between adjacent branches of the media

m-cu cross-veins – run between the media and cubitus

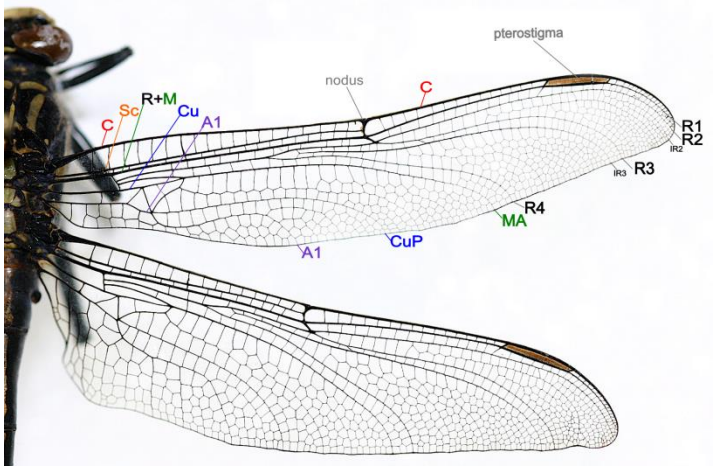


Coleoptera



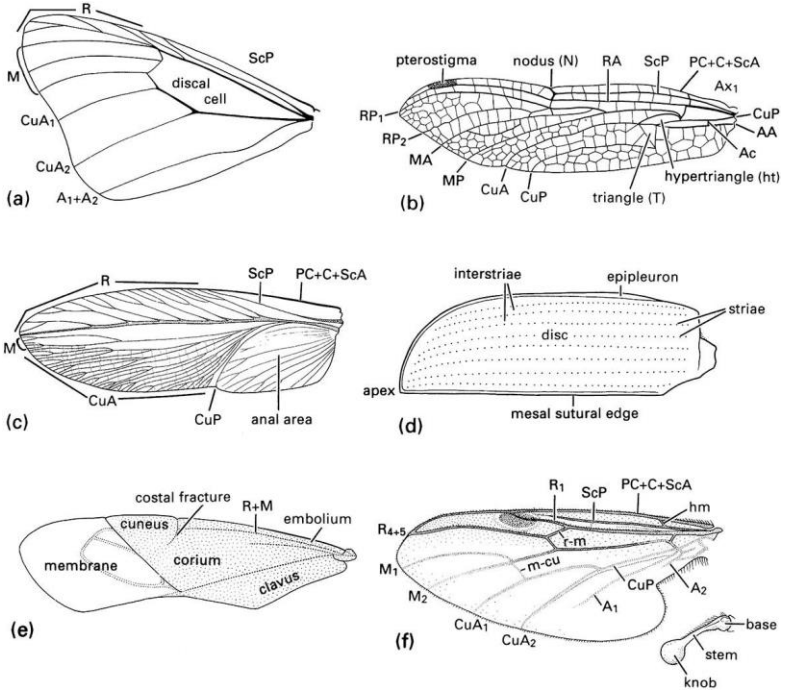
Costa (C), Subcosta posterior (ScP) – at the leading wing marginal, fused for most of the length.
Radius anterior (RA) – divided into two branches beyond the middle of the wing.
Radius posterior (RP) – basal connection is lost.
Media posterior (MP) – branches, long and strong vein.
Cubitus anterior (CuA)
Anal veins (AA, AP) – veins behind the cubitus, separated by anal fold.

Odonata

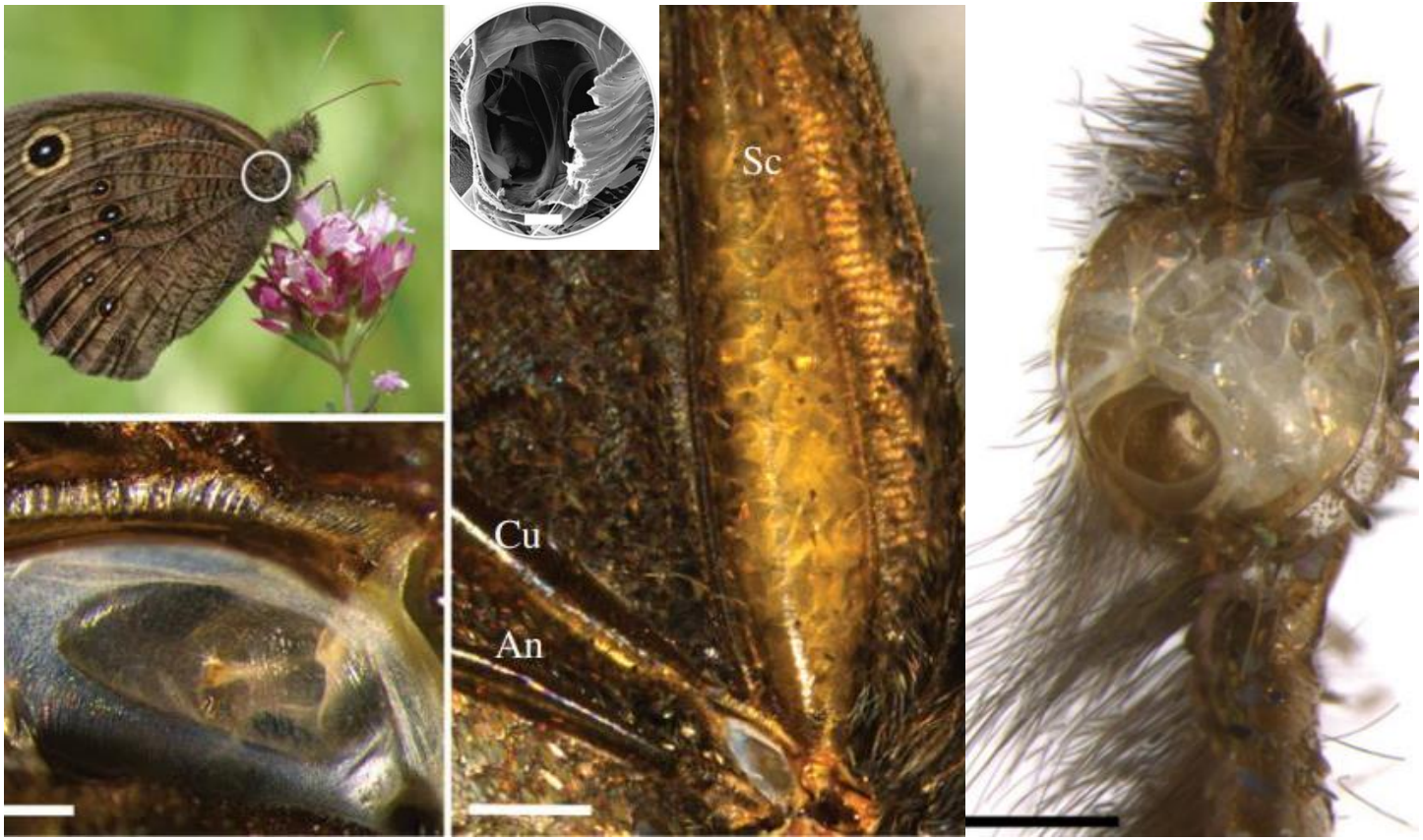


Costa (C) – at the leading edge ot the wing, strong and marginal, extends to the apex of the wing.
Subcosta (Sc) – second longitudinal vein, it is unbranched, joins C at nodus.
Radius and Media (R+M) – third and fourth longitudinal vein, the strongest vein on the wing, with branches, R1-R4, reach the wing margin, the media anterior (MA) are also reach the wing margin. IR2 and IR3 are intercalary veins behind R2 and R3 respectively.
Cubitus (Cu) – fifth longitudinal vein, cubitus posterior (CuP) is unbranched and reach the wing margin.
Anal veins (A1) – unbranched veins behind the cubitus.

The diversity of wing patterns across insect orders



Wing taxonomy: size, shape and structure
Adapted from Misof *et al.* 2014,

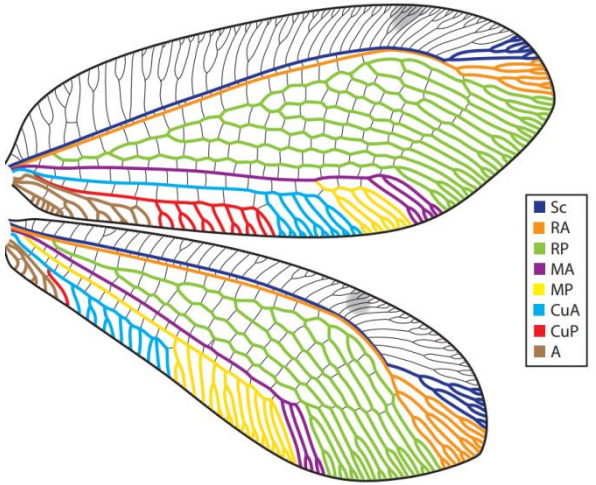


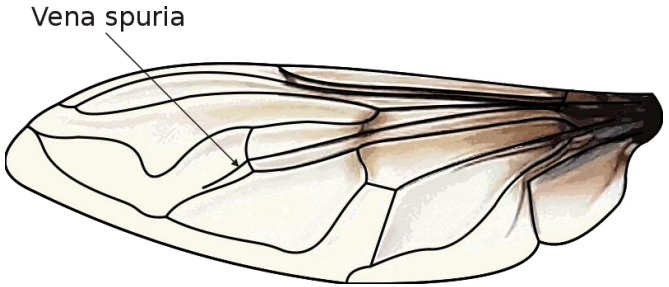
Inflated wing veins contribute to butterfly hearing

4. Modifications of venation patterns 翅脉的变化

1) Increasing 增多

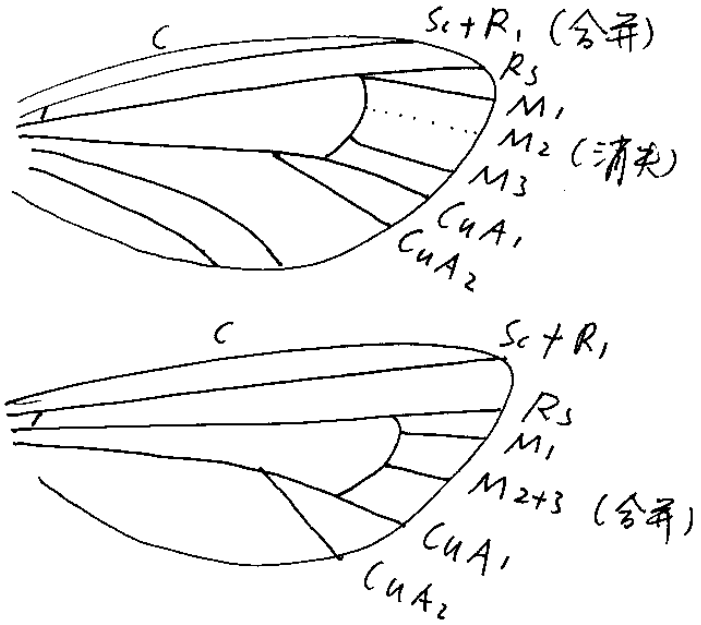
- accessory veins 副脉
  - occur by the branching of existing veins
  - 标记时在原有纵脉之后加上小写字母a, b, c等，如R_{1a}, R_{1b}
- intercalary veins 闰脉（加插脉）
  - development of additional veins between the original ones
  - 标记时在其前一纵脉简写前加一大写的“I”，如IM_1





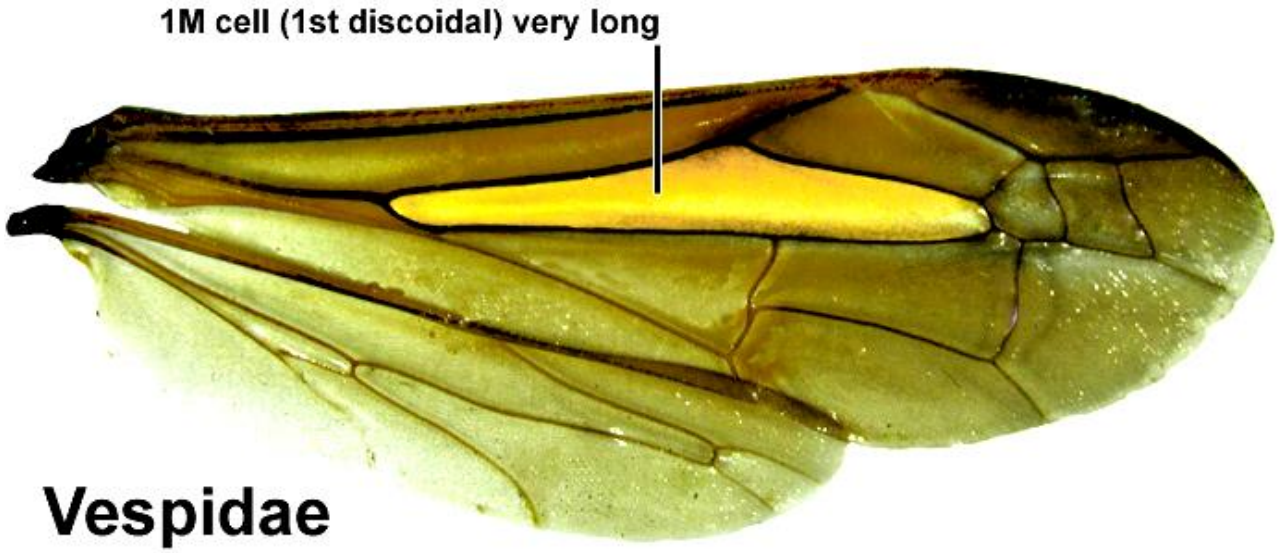
2) Reducing 减少

- fuse 合并： two veins fused together
  - 以“+”连接原来的纵脉名称表示
- lost 消失

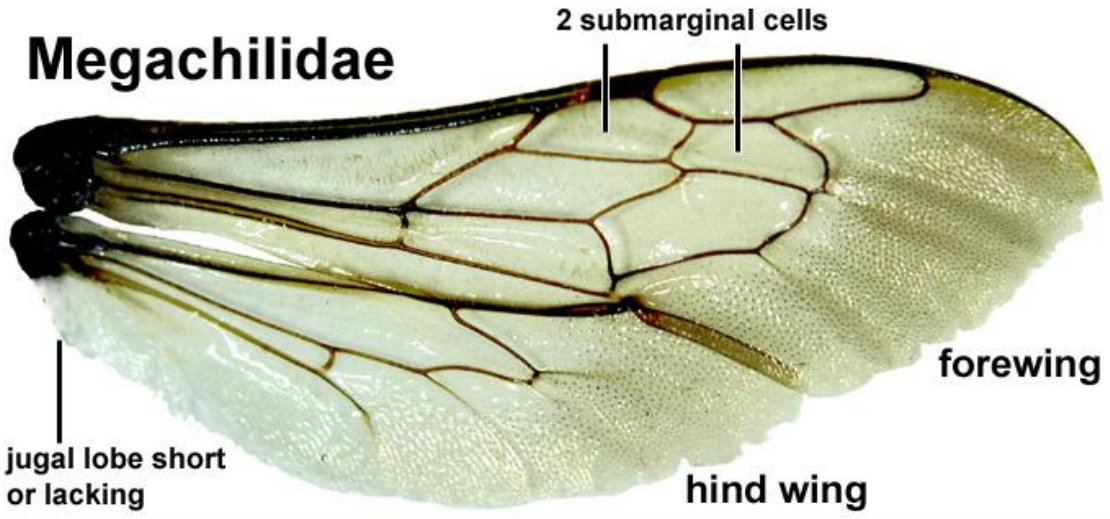


5. cells 翅室

- Closed/Enclosed cell 闭室
- Open cell 开室

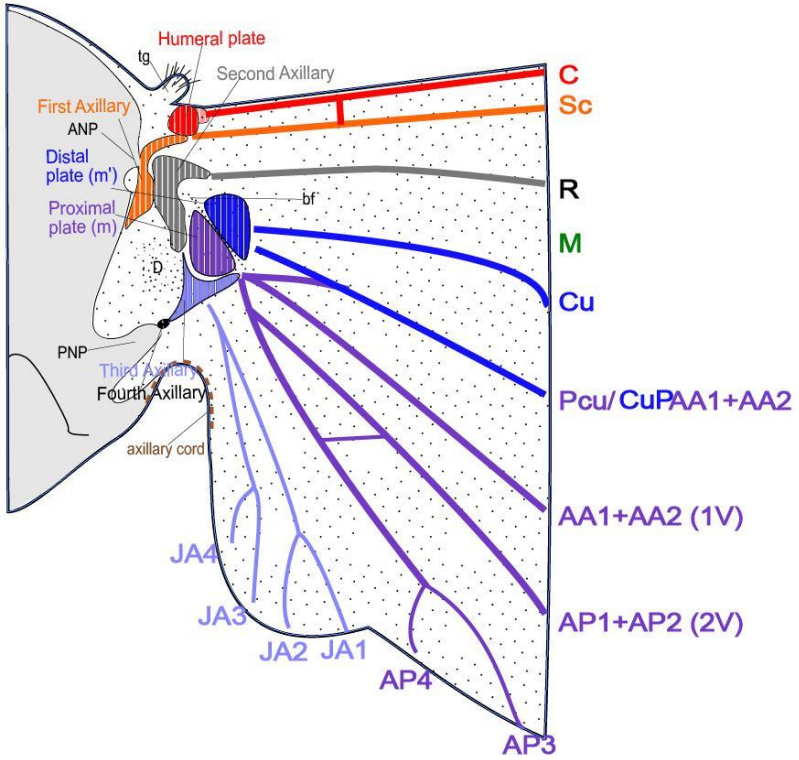


- **Cell nomenclature 翅室的命名**
  - **The cells are named after the longitudinal vein which forms their anterior edge 以其前缘的纵脉简写命名**
    - **Sc后的翅室即亚前缘室，记作cell Sc**
    - **如两个翅室之间的翅脉消失，如R_3消失，则R_2后的翅室应被记作cell R_{2+3}**



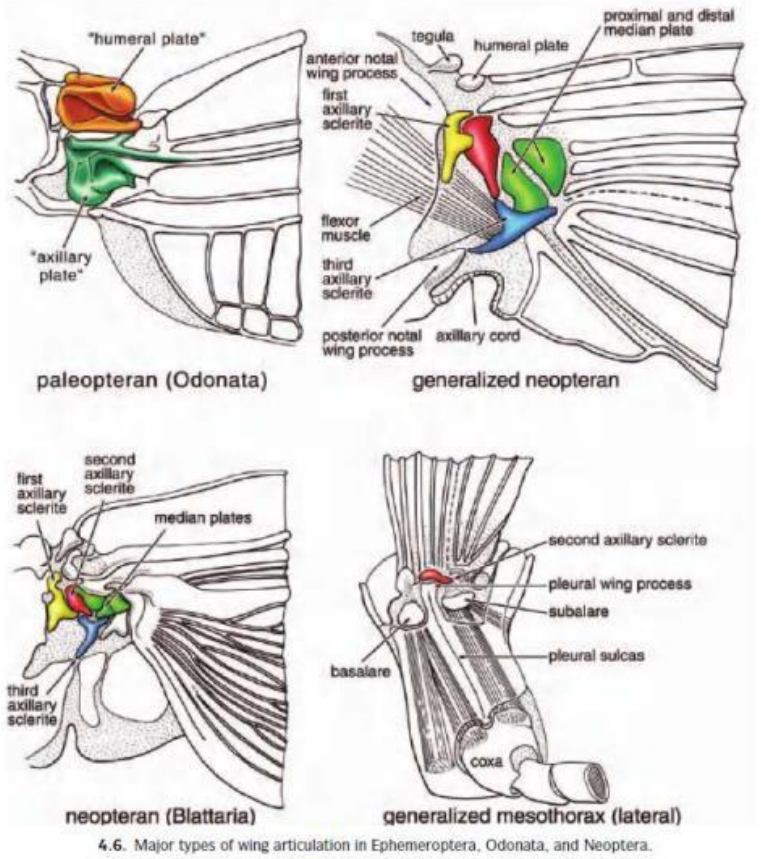
6. Articulation 翅的关节

- **Pteralia 翅基片**：翅基部膜质区中所有骨片的总称
  - **In all winged insects the axillary area contains the movable articular sclerites (pteralia) via which the wing articulates on the thorax**
  - **Humeral plate 肩片**
  - **Axillaries 腋片**：一般3~4片
  - **Median plates 中片**：被基褶分为内外两片
- **Tegula 肩板**
- **Axillary cord 腋索**

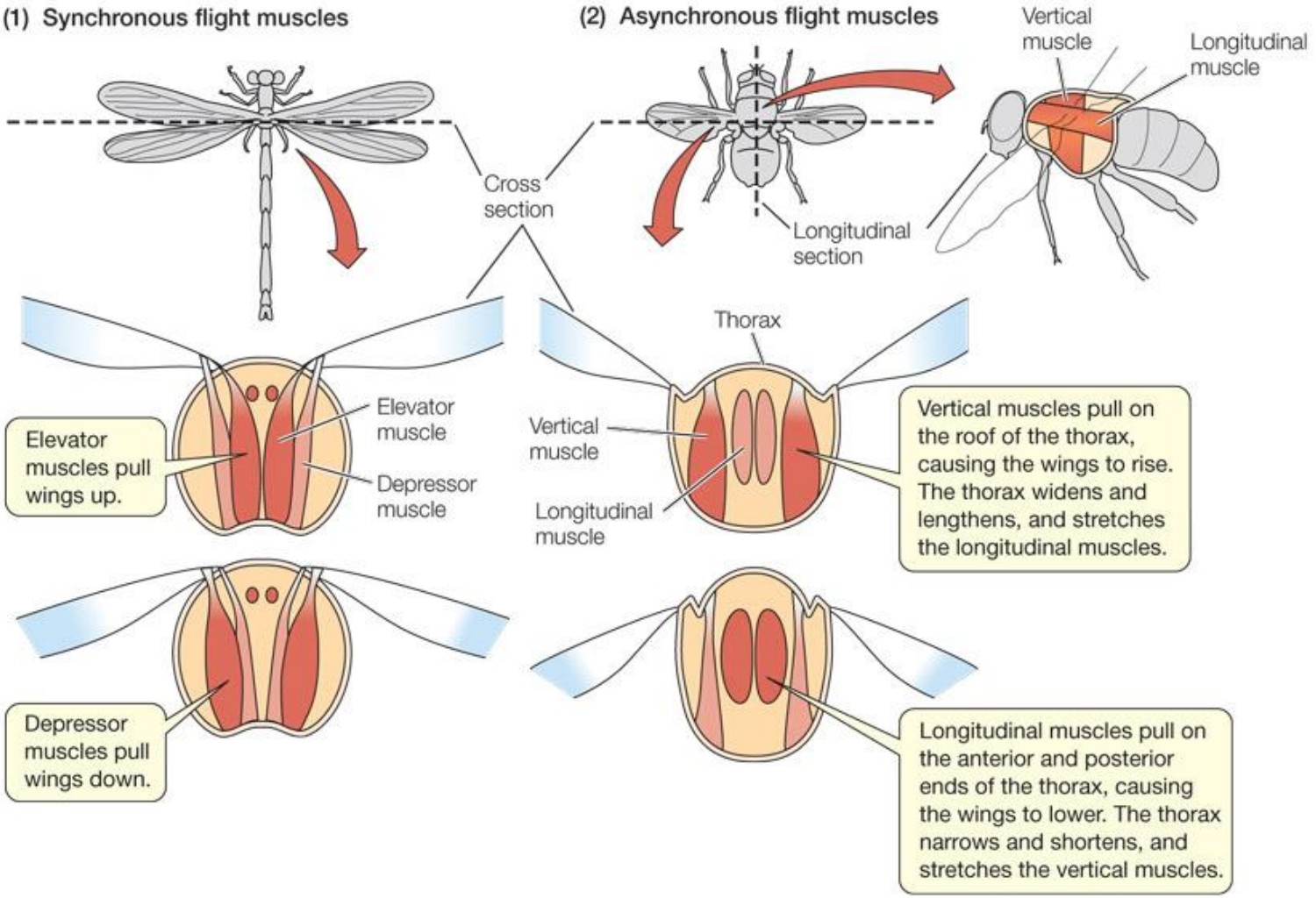


Folding mechanism

- **Paleopteran** are not able to fold the wings
- **Neoptera** are able to fold the wings back over their abdomen.
  - the **third axillary sclerite and pleural wing-folding** muscle.



4.6. Major types of wing articulation in Ephemeroptera, Odonata, and Neoptera.


(1) Synchronous flight muscles
(2) Asynchronous flight muscles
Vertical muscle
Longitudinal muscle
Cross section
Longitudinal section
Thorax
Elevator muscle
Depressor muscle
Elevator muscles pull wings up.
Vertical muscle
Longitudinal muscle
Vertical muscles pull on the roof of the thorax, causing the wings to rise. The thorax widens and lengthens, and stretches the longitudinal muscles.
Depressor muscles pull wings down.
Longitudinal muscles pull on the anterior and posterior ends of the thorax, causing the wings to lower. The thorax narrows and shortens, and stretches the vertical muscles.

7. wing-coupling mechanism 翅的连锁机制

1) 双动类

- Groups with fore and hind wings both developed have no wing-coupling apparatus
  - dragonflies 蜻蜓
  - mayflies 蜉蝣
  - termites 白蚁
  - lacewings 草蛉

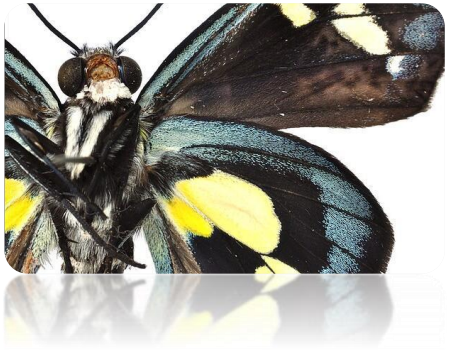
2) 单动类

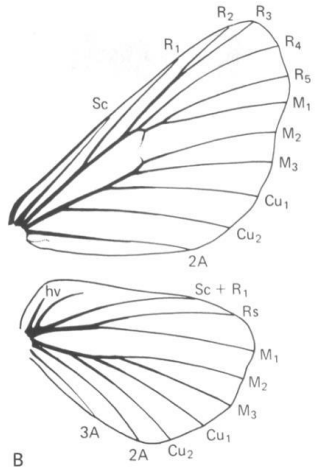
- 直翅目、革翅目、鞘翅目、双翅目
  - With fore or hind wings modified have no wing-coupling apparatus
- 鳞翅目、同翅目、半翅目、膜翅目等
  - Wing-coupling mechanism have evolved that link together the fore and hind wings
  - 前翅发达，是主要的飞行器官；后翅不发达，飞行时须以连锁器官钩连在前翅上

连锁的主要类型

A. amplexi form 翅抱型

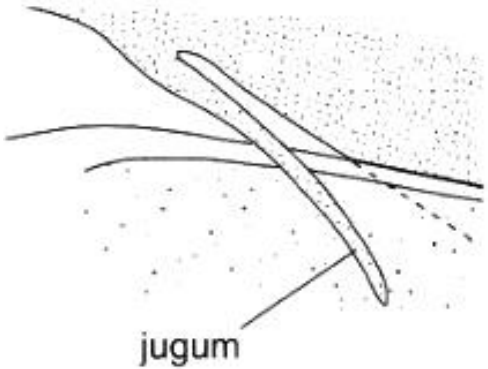
- Butterflies and some huge moths（枯叶蛾、蚕蛾）
- An enlarged humeral area of the hindwing is broadly overlapped by the forewing.
- The power stroke of the forewing pushes down the hindwing in unison.

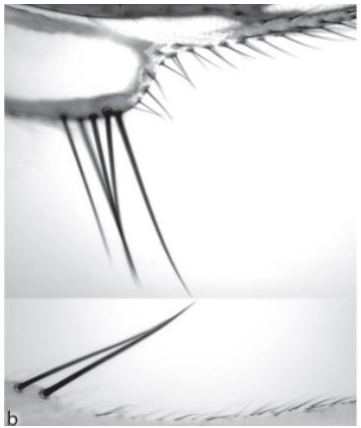




B. jugate form 翅轭型

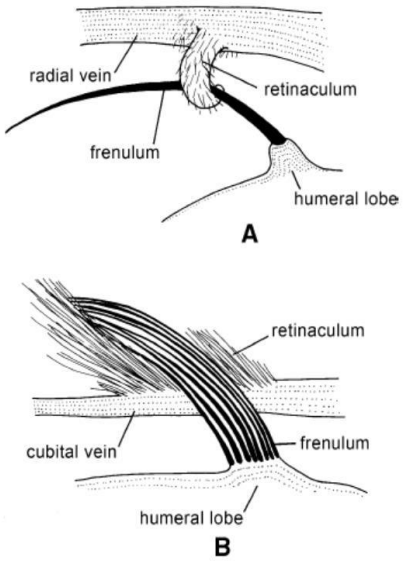
- some primitive moths have enlarged lobe-like area near the basal posterior margin at the base of the forewing, called jugum, that folds under the hindwing in flight
- mecopteran insects

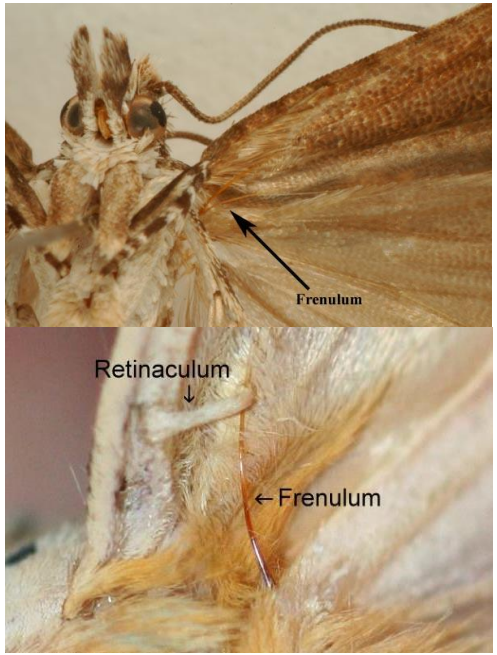




C. frenate form 翅缰型

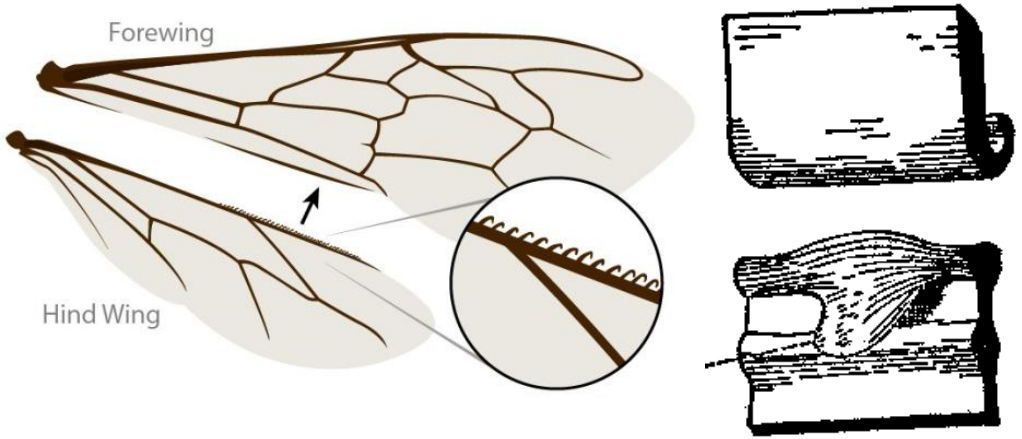
- **Most moths**
- a hook like or hard brush structure (retinaculum 翅缰钩) in radial vein or cubital vein of fore wing
- the hind wing has spine like or long hard spinous structure called frenulum 翅缰（雄蛾一根，雌蛾数根）which is locked into retinaculum



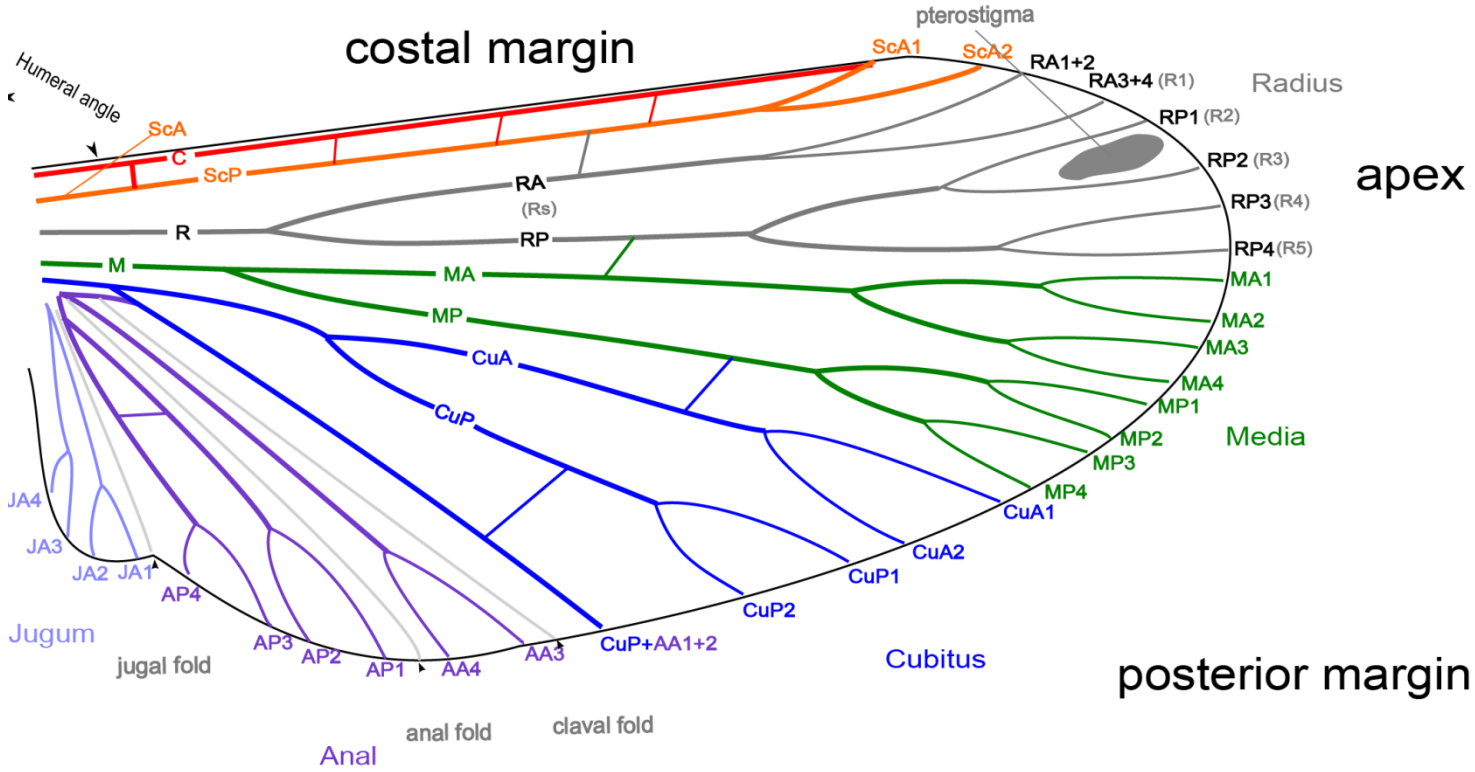


D. fold form 翅褶型

- the wing-coupling apparatus consisting of a long, downturned fold on the forewing and a short, upturned lobe on the hind wing
  - fold-hook form 褶钩型
    - Wasps, Aphids
  - fold-fold form 褶褶型
    - Cicadas



Summary


costal margin
pterostigma
Humeral angle
ScA
C
ScP
ScA1
ScA2
RA1+2
RA3+4 (R1)
Radius
RP1 (R2)
RP2 (R3)
RP3 (R4)
RP4 (R5)
apex
RA
(Rs)
R
RP
M
MA
MP
CuA
CuP
MA1
MA2
MA3
MA4
MP1
MP2
MP3
MP4
CuA1
CuA2
CuP1
CuP2
Media
JA4
JA3
JA2
JA1
AP4
AP3
AP2
AP1
AA4
AA3
CuP+AA1+2
Jugum
jugal fold
Cubitus
posterior margin
anal fold
claval fold
Anal

Assignment

- **To illustrate the hypothetical primitive pattern of wing venation.**

Further reading

- Ross A, (2017) Insect evolution: the origin of wings. *Current Biology*. 27(3): 113-115.
- Shimmi O, *et al.* (2014) Insights into the molecular mechanisms underlying diversified wing venation among insects. *Proc. R. Soc. B.* 281: 20140264. http://dx.doi.org/10.1098/rspb.2014.0264.
- Misof B, *et al. (*2014) Phylogenomics resolves the timing and pattern of insect evolution. *Science*, 346: 763-767.