Hematophagy (Bloodsucking) in animals

陈光霁 2023.07.26

Hematophagy (Bloodsucking)

Feeding on blood of another living organism

Bloodsucking Creatures:

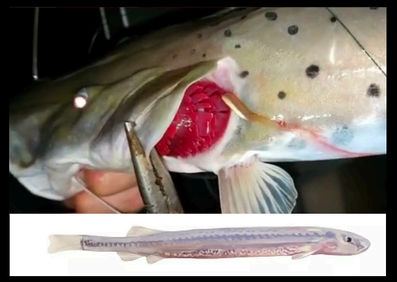
insects
(eg. mosquitoes)

arachnids
(eg. tick[蜱虫])

leeches

15,000 blood-feeding species representing at least 6 evolutionary events

nematode worms



fish
(eg. candiru[卷须寄生鲇])

Vampire Bats

- 30,000 bloodsuckers out of the roughly 1.5 or 1.6 million species of animals that have been described is a very, very small number.
- The first known hematophages (blood feeders) were the *protomosquitoes*, of which there is fossil evidence from 220 million years ago (Schutt 2008).

Two Ancient Mosquito Species

Adaptations for Hematophagy

Blood feeders need to

(i) find a host on which to feed

- ecto- or endoparasites [外寄生或内寄生]
- a combination of visual, olfactory, and temperature cues to find their hosts

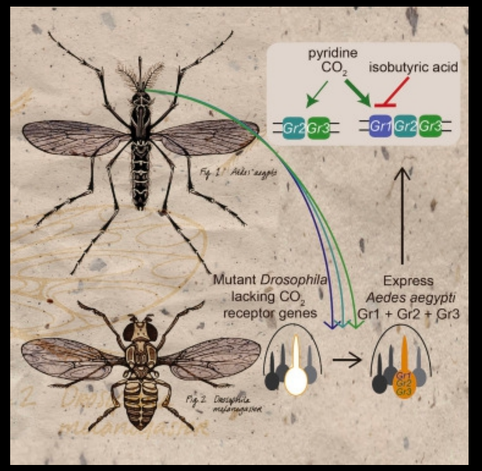
(ii) attach to the host in order to feed

(iii) access the blood of their host

- piercing/sucking or ripping/tearing

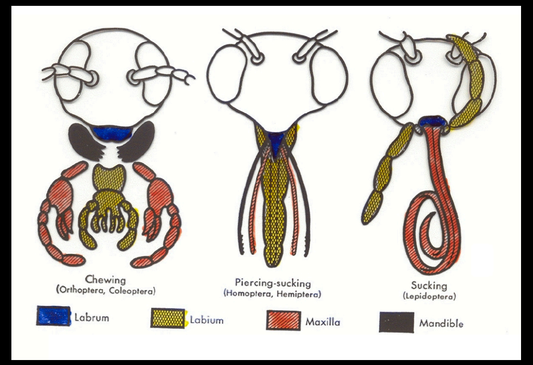
(iv) **digest** the blood meal

- comprised of protein and water
  - accumulation of nitrogenous waste products
- poisonous due to iron toxicity



Carbon Dioxide Receptor Subunits to Odor Detection

ecto- or endoparasites (eg. lice in the hair)

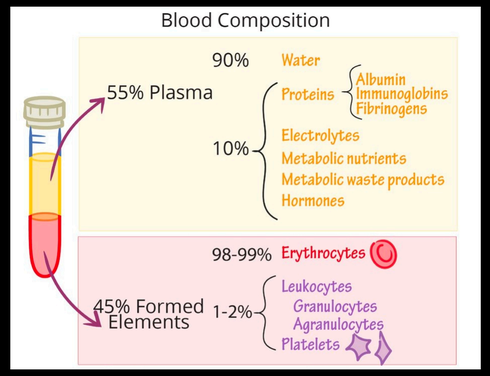


piercing/sucking

Why Do Bloodsucking Animals Feast on Blood?

- Ecological niche ?
  - Since those bigger animals no longer served as viable prey, these animals evolved to favor a mutation — bloodsucking — that still allowed them to feast without having to catch, subdue and kill their food.

- Nutritional benefits ?
  - Blood is a rich source of protein, iron, and other essential nutrients that are necessary for the survival and reproduction of these animals.



- Nutritional disadvantage ?
  - Obligate sanguivory requires adaptation to
    - very low levels of some nutrients (essential amino acids and the vitamin B complex)
    - Iron concentration
    - nitrogenous waste products (renal disease-like symptoms).

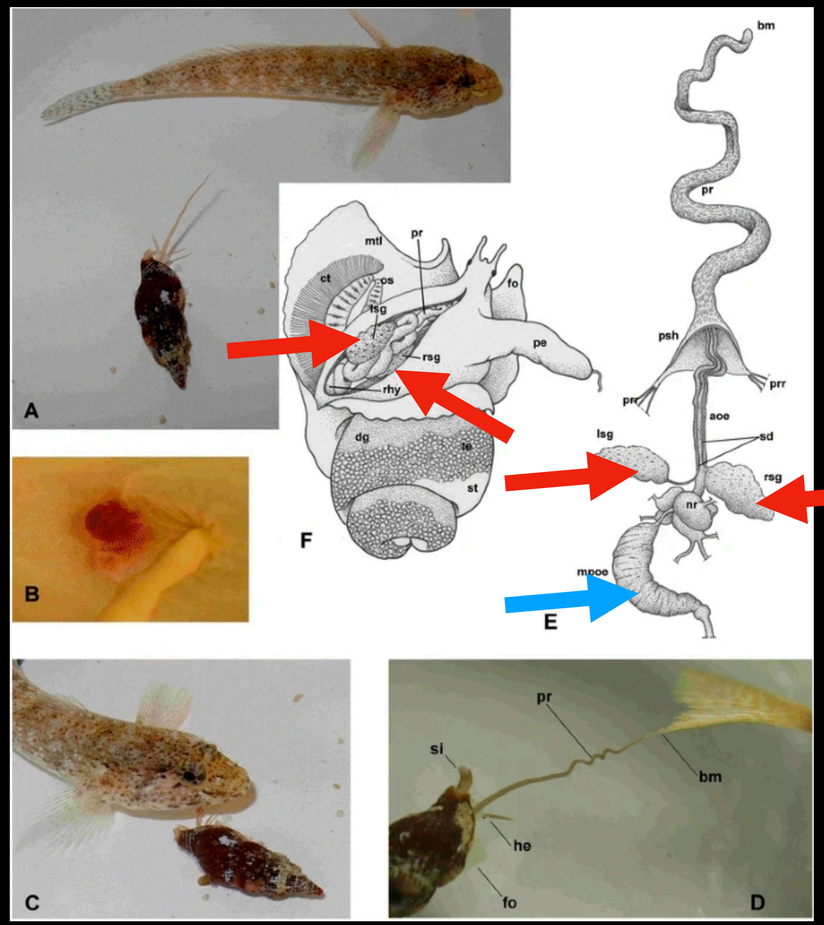
Vampire snail

Leeches

Vampire Bats

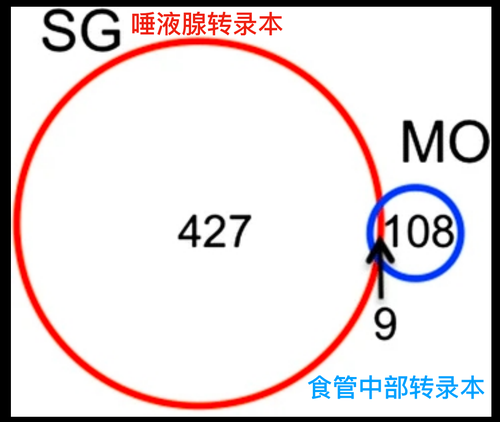
Vampire finch

Vampire snail *Colubraria reticulata* (Mollusca, Gastropoda)



Vampire snail
(*Colubraria reticulata*)

RNA-seq of mid-oesophagous[食管中部], salivary glands[唾液腺] and whole body.



Colubraria reticulata secretes chemicals that disrupts the process of blood clotting and wound healing.

1. Anesthetics [麻醉剂]
   - ShK, Turripeptide, ADA, and CAP-ShK.
2. Anticoagulants [抗凝血剂]
   - PS1, Meprin, and Kunitz.
3. ACE [血管紧张素转换酶]
   - increase blood pressure

Colubrariidae [布纹螺科]

The trait of feeding on blood is likely shared by the entire family.

Modica, M.V. et al. (2015) BMC Genomics

Vampire snail

Leeches

Vampire Bats

Vampire finch

Molecular mechanisms underlying hematophagia of leech genomes

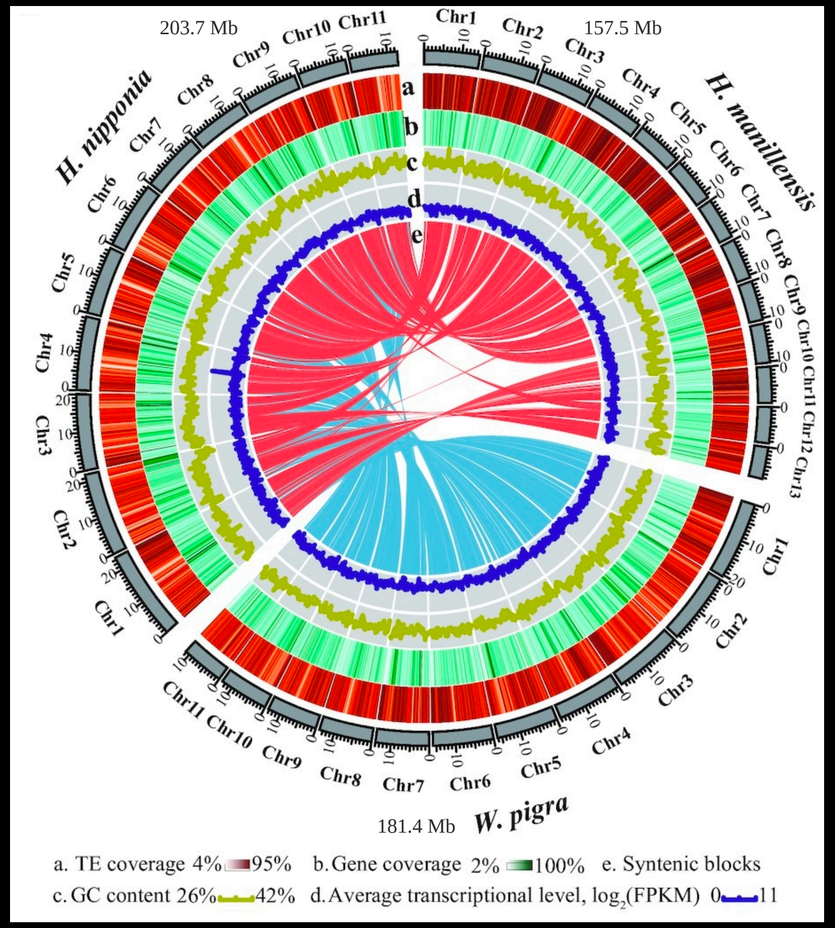
Bloodsucking

East Asian Leech
(*Hirudo nipponia*, 日本医蛭)

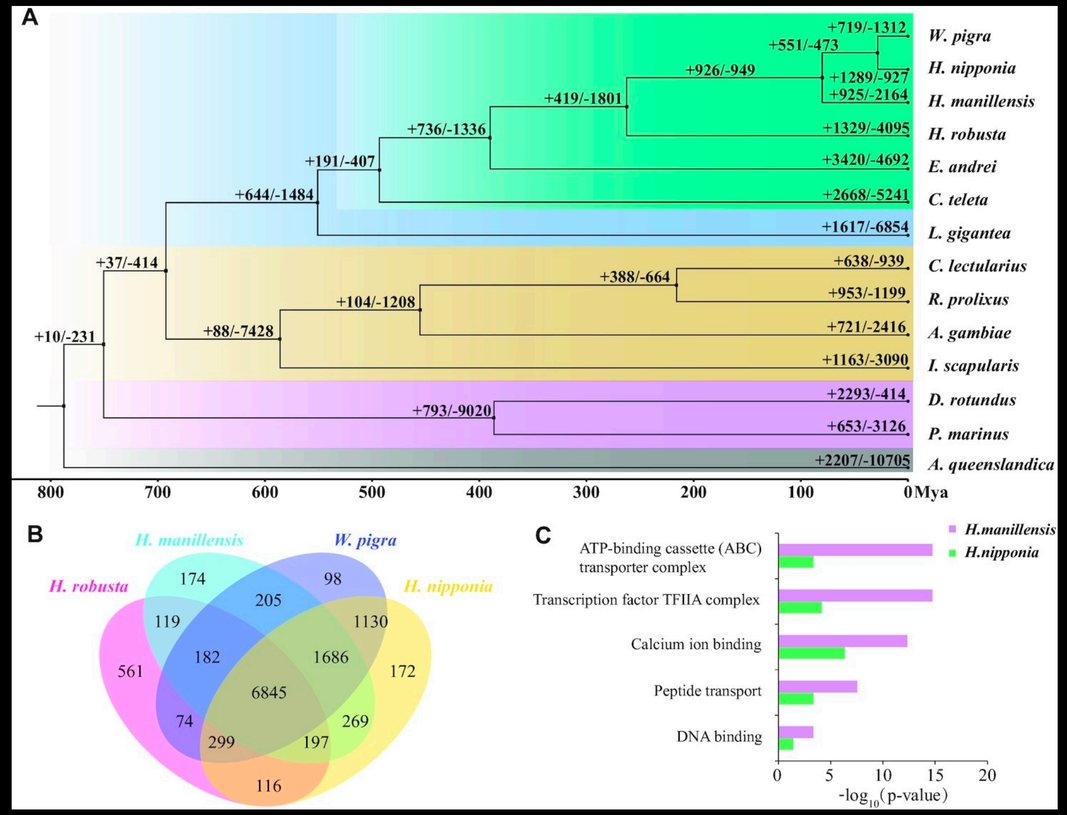
Hirudinaria manillensis
欧洲医蛭

Nonbloodsucking

Whitmania pigra
宽体金线蛭



Comparative genomic analysis of the 3 leech species.



GO of expanded gene families in both bloodsucking leech species

1. ATP-binding cassette transporter complex,
2. transcription factor IIA complex,
3. calcium ion binding functions

Zheng J. et al. (2023) GigaScience.

Molecular mechanisms underlying hematophagia of leech genomes

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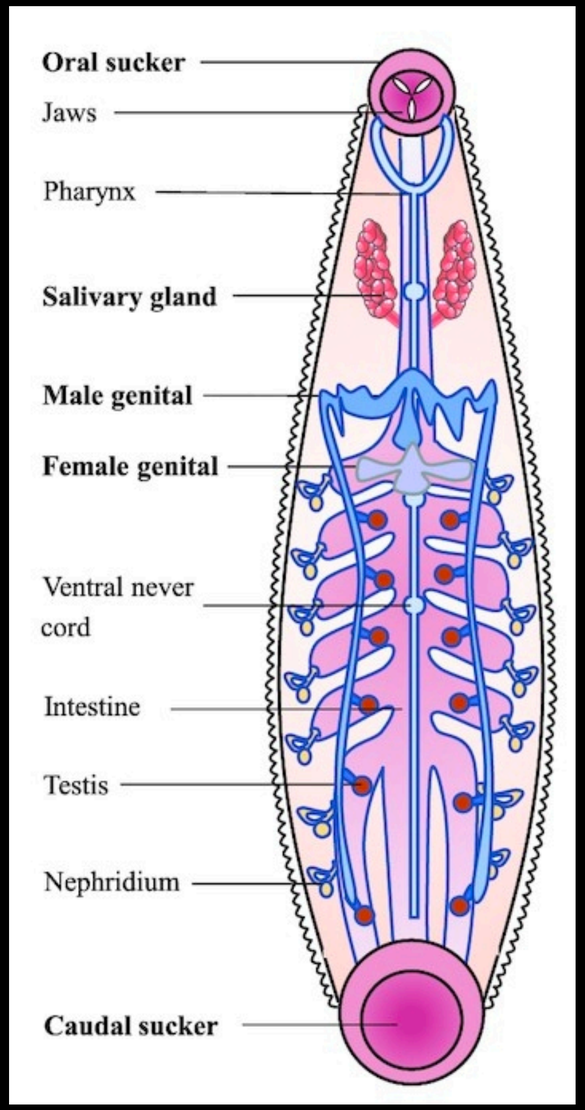
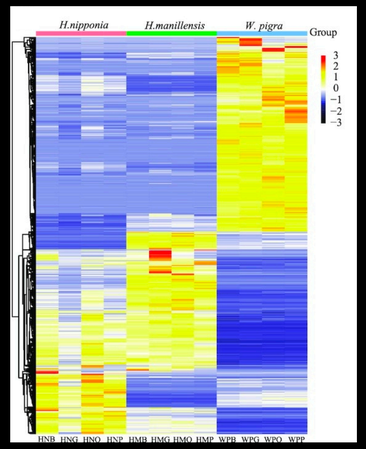




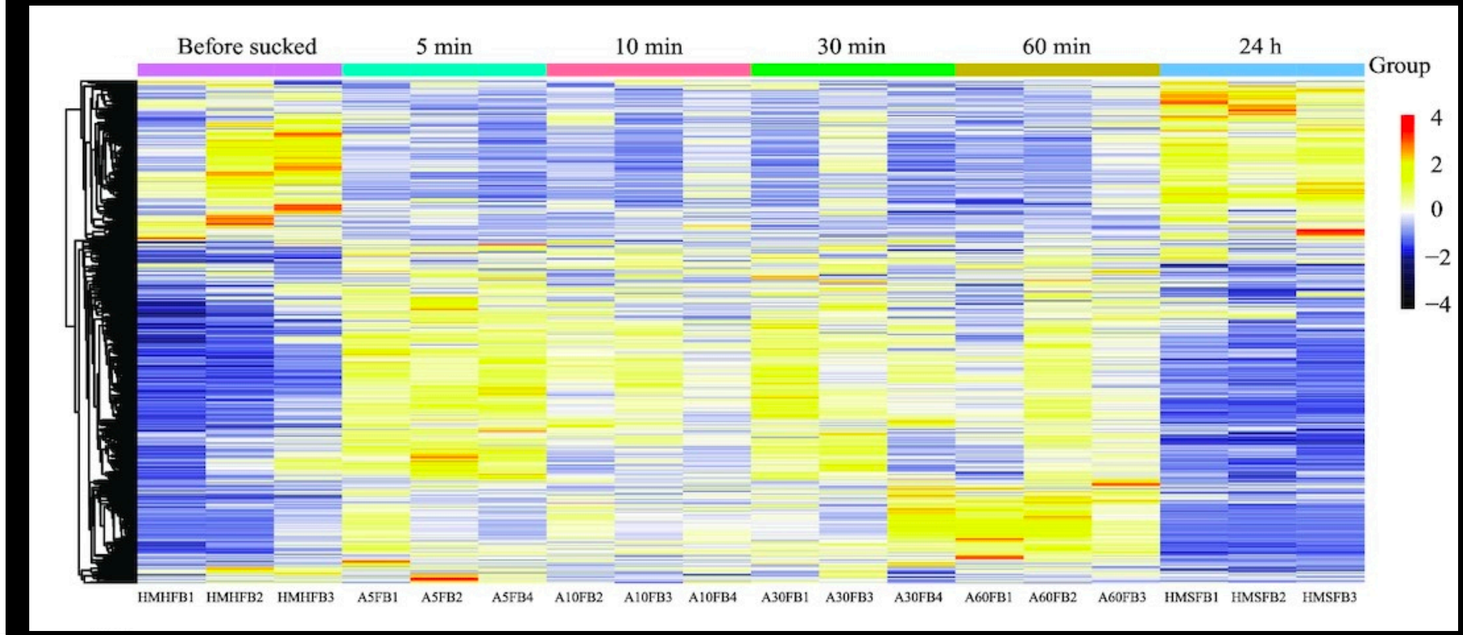
Tissue of different body parts:

- B: Body
- G: Genital gland
- O: Oral sucker
- P: Posterior sucker

- **2 bloodsucking leeches shared similar expression patterns**

Transcriptome dynamics during bloodsucking in *H. manillensis*

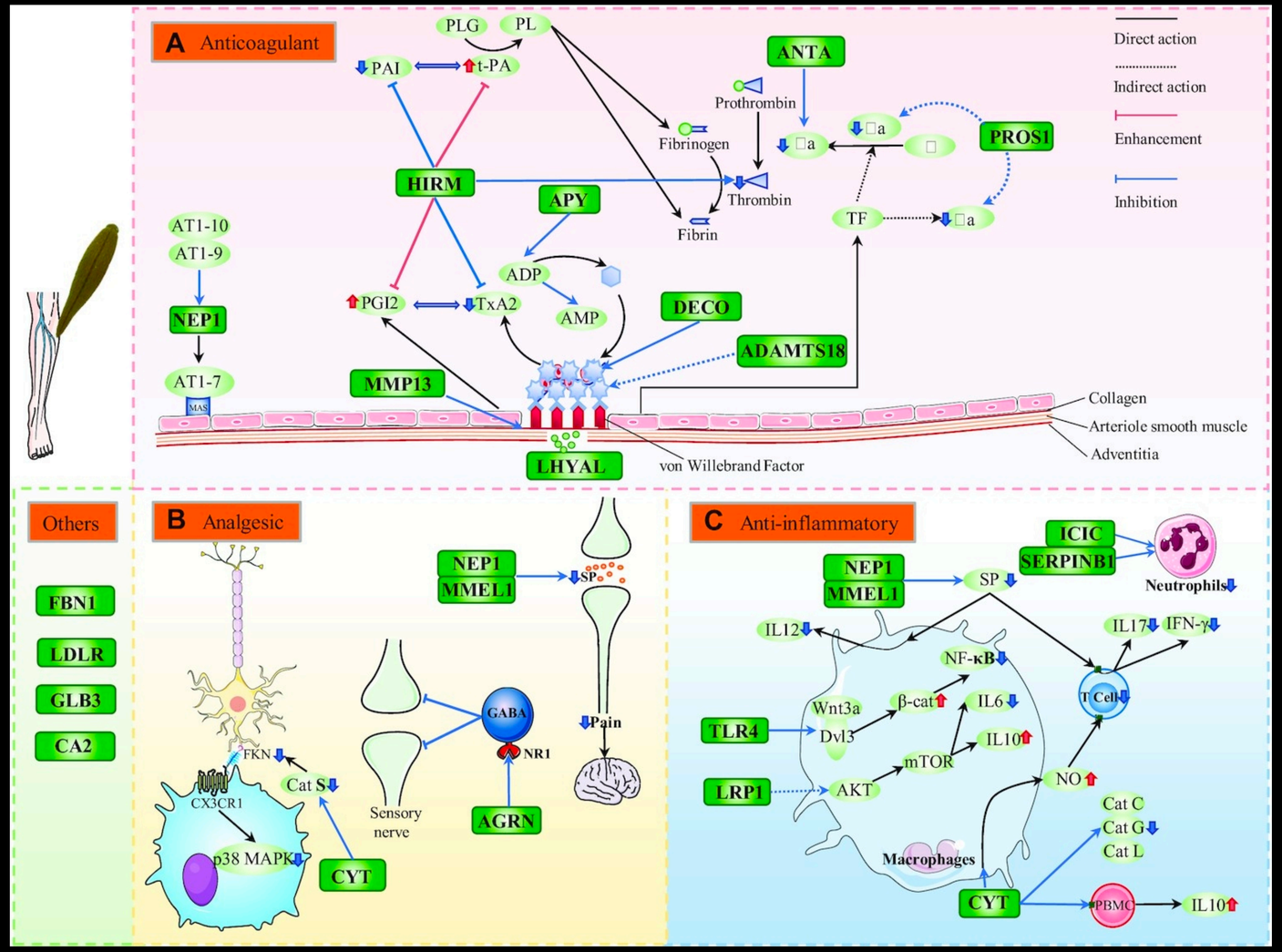
- **DEGs responded quickly after bloodsucking and continuously changed in the following 60 min, restored after 24 hours**



GO & KEEG: DEGs enriched to calcium-related regulation.

Zheng J. et al. (2023) GigaScience.

Molecular mechanisms underlying hematophagia of leech genomes

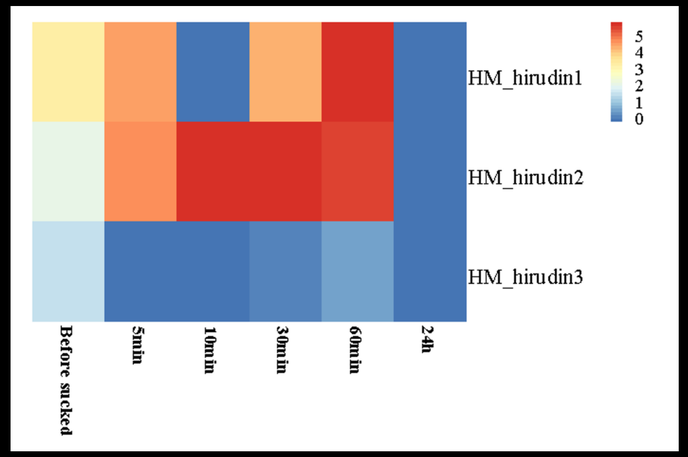


Leeches avoid detection by hosts during the bloodsucking:

A. inhibition of blood coagulation 抑制血液凝固
B. alleviation of pain 减轻疼痛
C. suppression of inflammation 抑制炎症

HIRM (hirudin 水蛭素) in *H. manillensis*

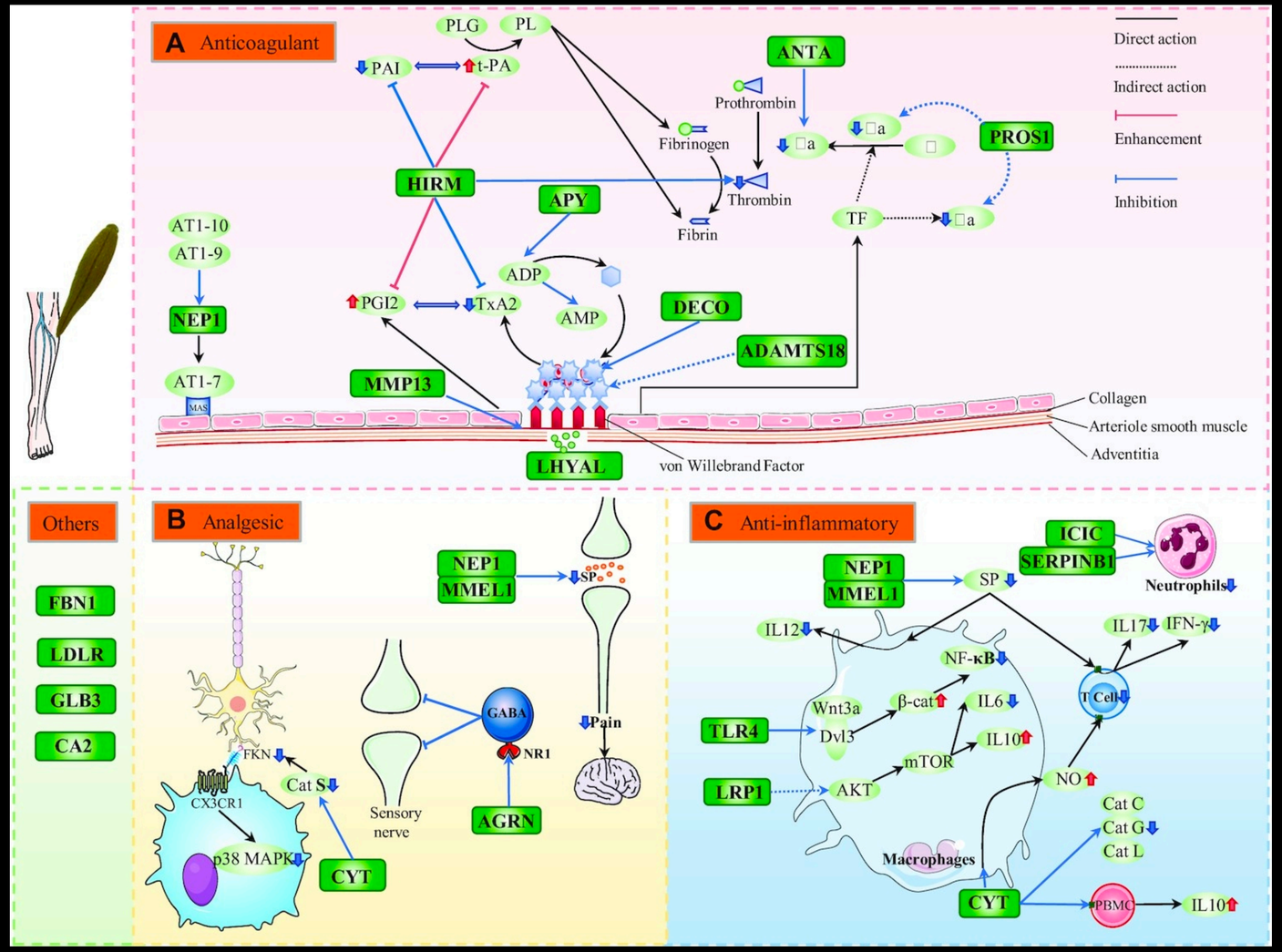
- increased with the time of physiological coagulation



水蛭素(hirudin)是一种天然抗凝剂，因为它具有特异性的抗凝血酶作用，有助于治疗血栓。

Zheng J. et al. (2023) GigaScience.

Molecular mechanisms underlying hematophagia of leech genomes



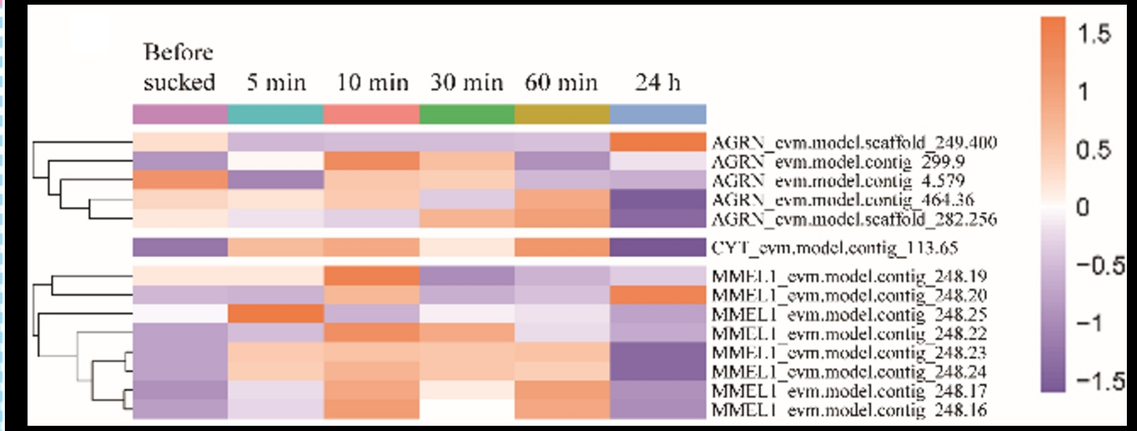
Leeches avoid detection by hosts during the bloodsucking:

A. inhibition of blood coagulation 抑制血液凝固

B. alleviation of pain 减轻疼痛

- *AGRN*、*CYT* 和 *MMEL1*

C. suppression of inflammation 抑制炎症



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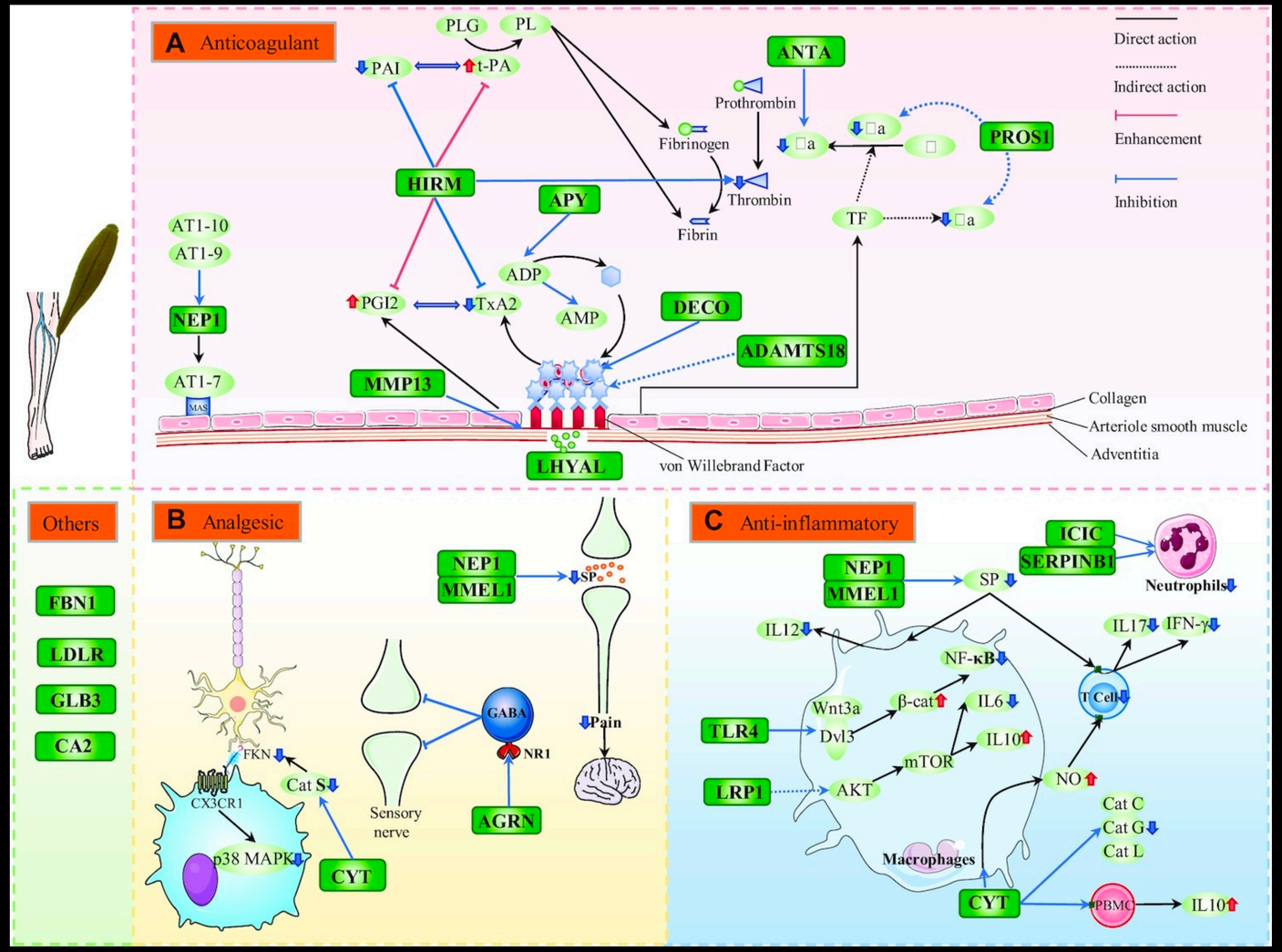
Molecular mechanisms underlying hematophagia of leech genomes



Leeches avoid detection by hosts during the bloodsucking:

A. inhibition of blood coagulation 抑制血液凝固

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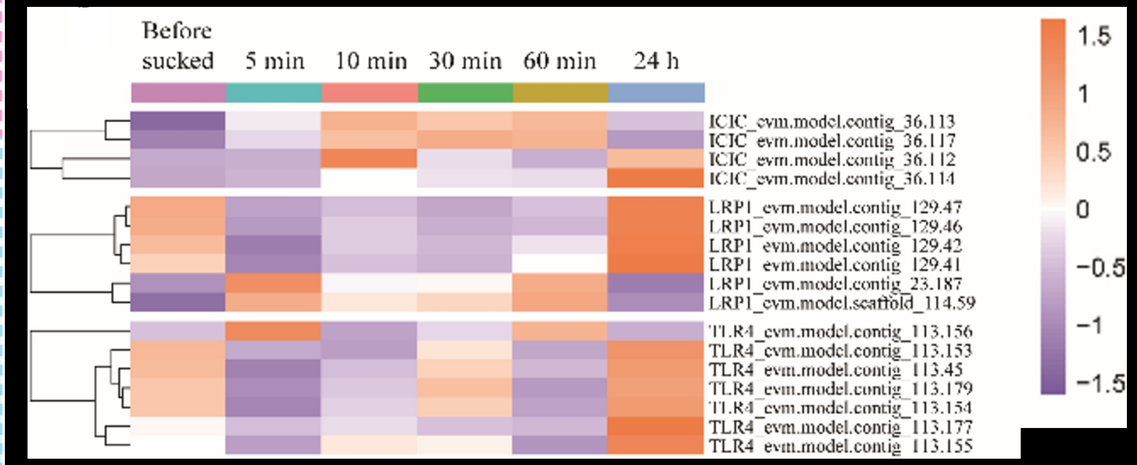
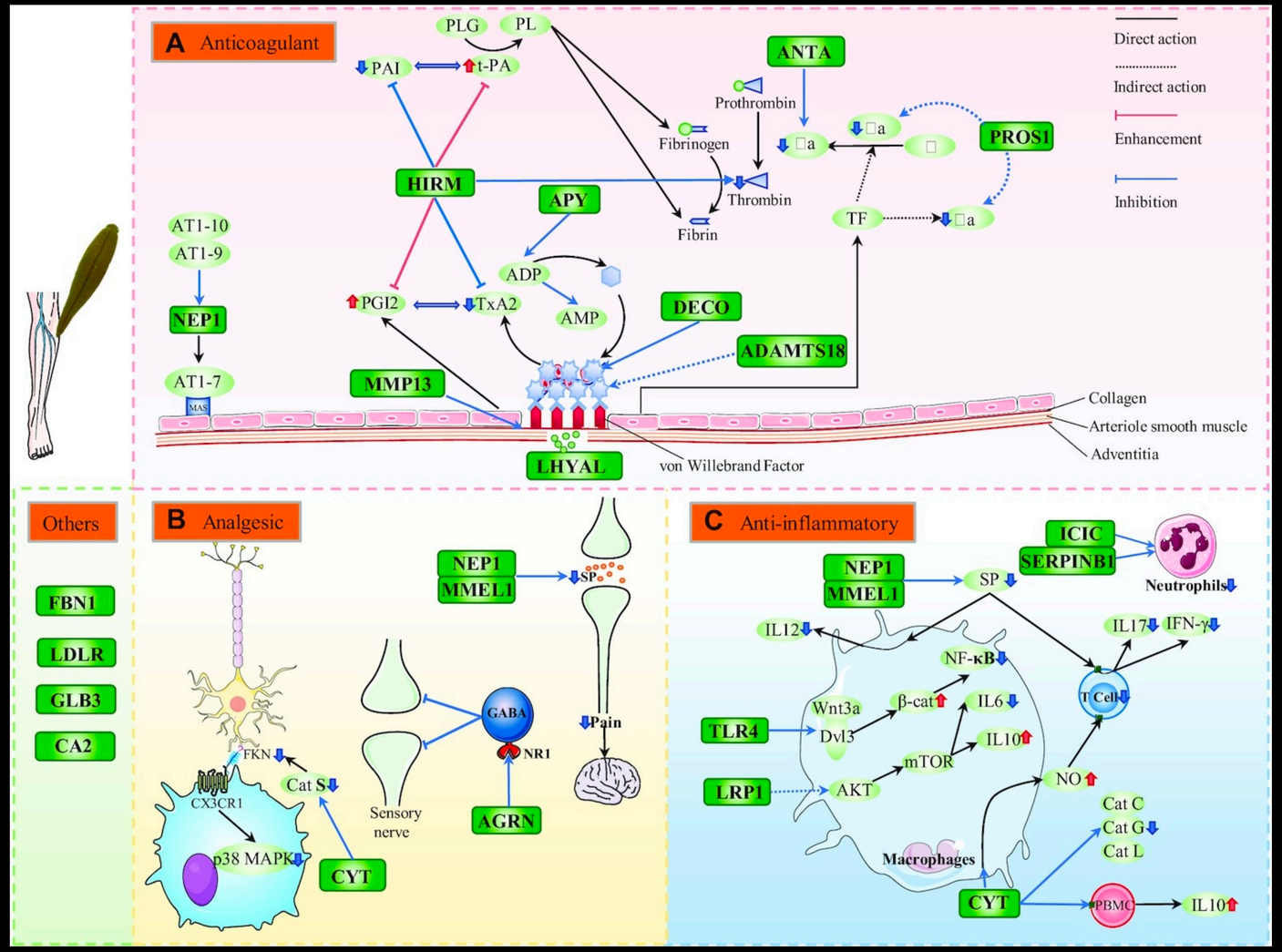
- *ICIC*、*LRP1* 和 *TLR4*



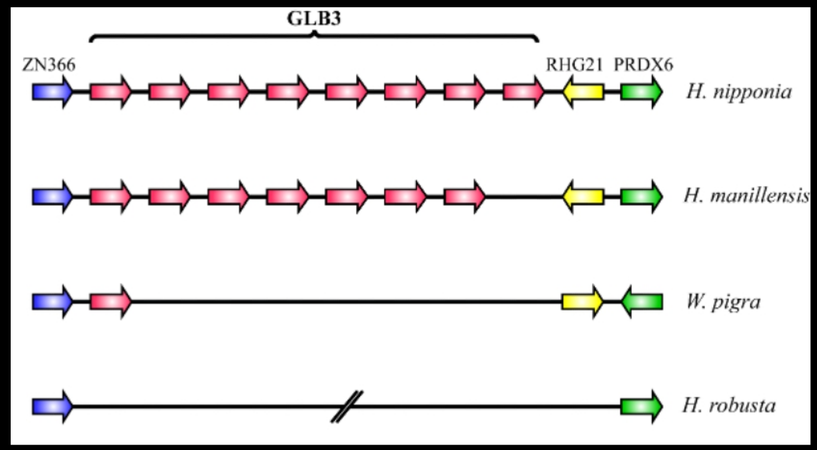
- Most *TLR4* and *LRP1* copies *decreased quickly at the beginning* of the bloodsucking process and *increased after bloodsucking*
- Indicating: leeches always maintain anti-inflammatory proteins for swift release into the prey body

Zheng J. et al. (2023) GigaScience.

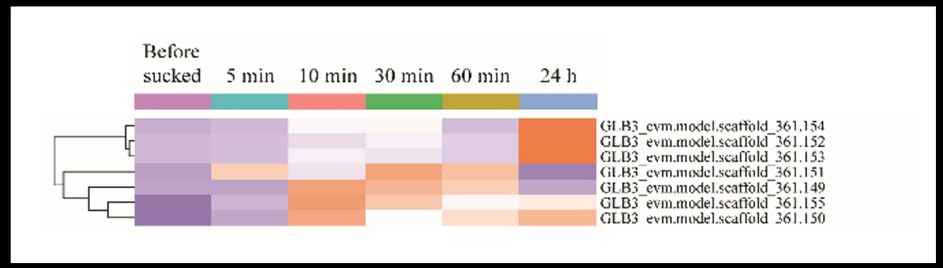
Molecular mechanisms underlying hematophagia of leech genomes



- **The blood meal**
  - A leech feeds five times its body weight in blood, up to ten times sometimes.



- 7 or 8 copies of *GLB3* [血红蛋白] were tandemly arranged in the 2 bloodsucking leeches



- 3 *GLB3* copies displayed significant expression level changes after the bloodsucking process

Zheng J. et al. (2023) GigaScience.

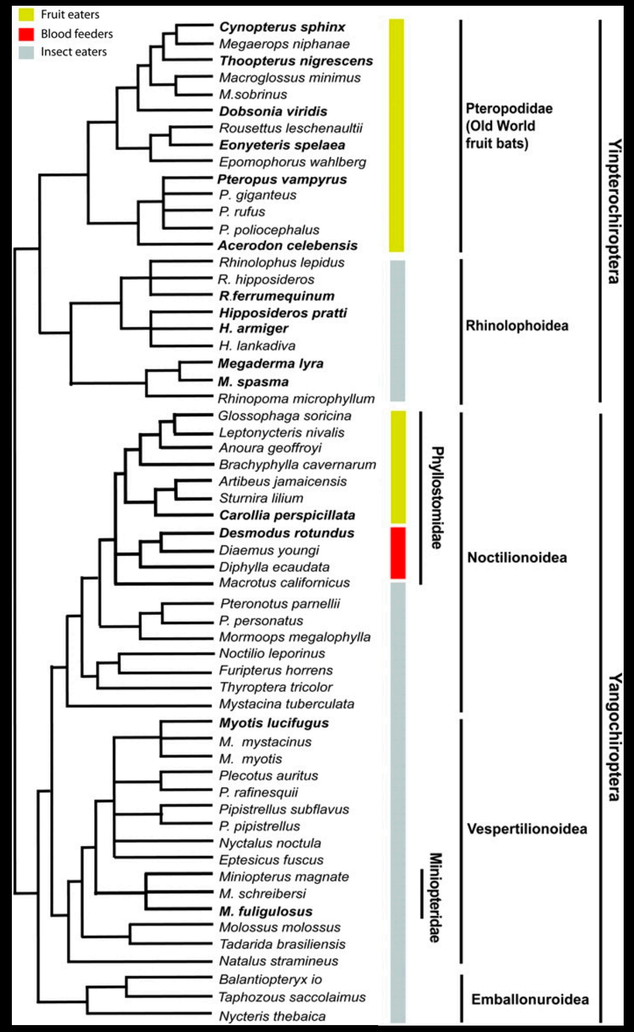
Vampire snail

Leeches

Vampire Bats

Vampire finch

Lost Genes Explain Vampire Bats' Diet of Blood



modified from Fig 2 of
Huabin Zhao. et. al. (2011) *Molecular Biology and Evolution*

Blood feeding习性只出现在三种蝙蝠：

common vampire bat
(*Desmodus rotundus,* 吸血蝠)

white-winged vampire bat
(Diaemus youngi, 白翼吸血蝠)

hairy-legged vampire bat
(*Diphylla ecaudata,* 毛腿吸血蝠)

Fruit feeding:

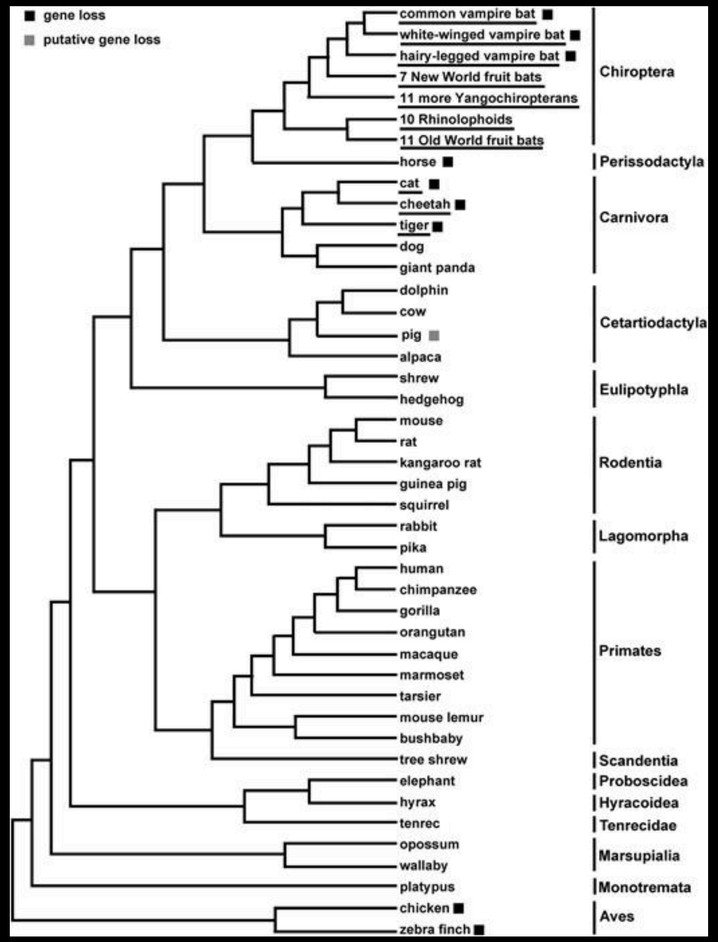
greater short-nosed fruit bat
(*Cynopterus sphinx,* 短吻果蝠)

Pallas's long-tongued bat
(*Glossophaga soricina,* 鼬形长舌蝠)

Insect feeding:

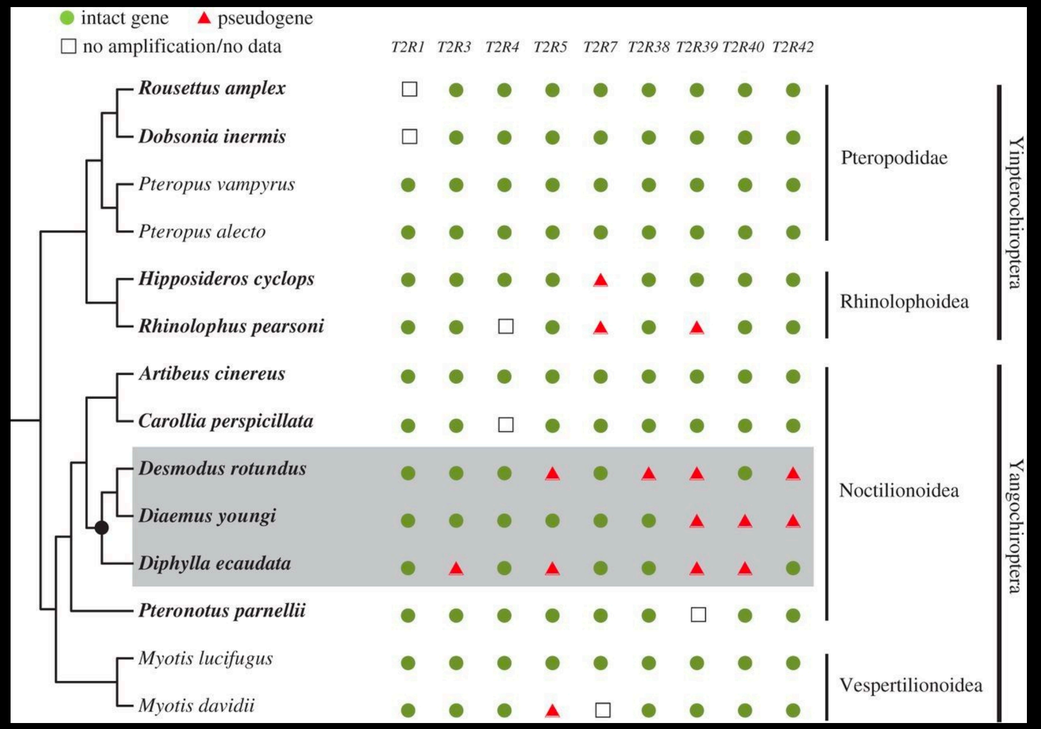
Chinese rufous horseshoe bat
(*Rhinolophus sinicus,* 中华菊头蝠)

Lost Genes Explain Vampire Bats' Diet of Blood



Tas1r2 [sweet taste] loss in 3 vampire bats

- **Vampire bats**
  - can't taste sweet or umami (savory) flavors
  - have the receptor genes necessary for tasting bitter flavors (but less)



Vampire bats have more bitter taste receptor (T2R) pseudogenes.

common vampire bat
(*Desmodus rotundus,* 吸血蝠)

white-winged vampire bat
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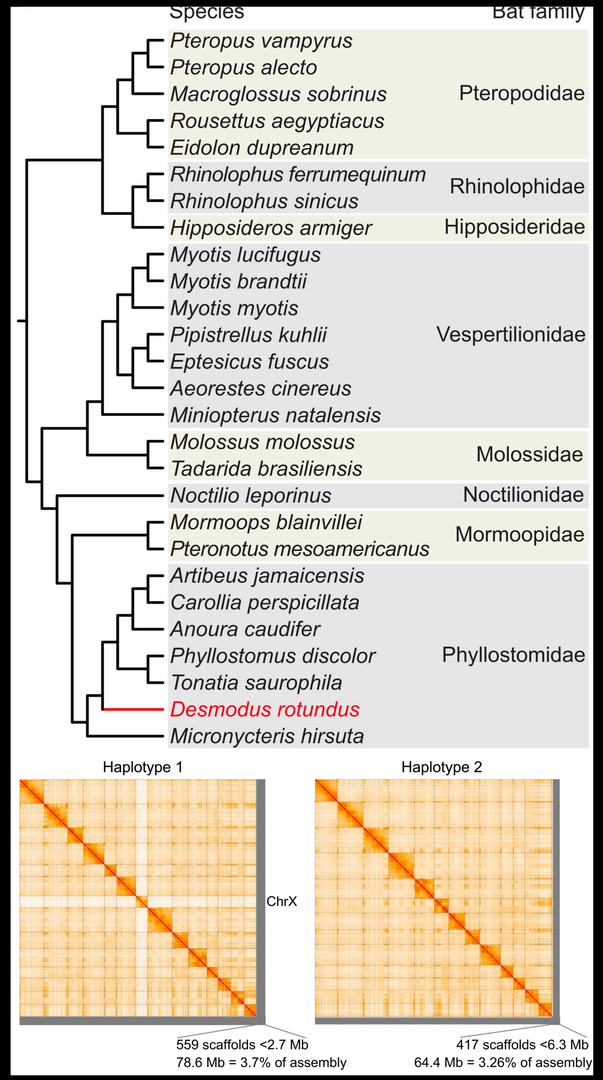
hairy-legged vampire bat
(*Diphylla ecaudata,* 毛腿吸血蝠)

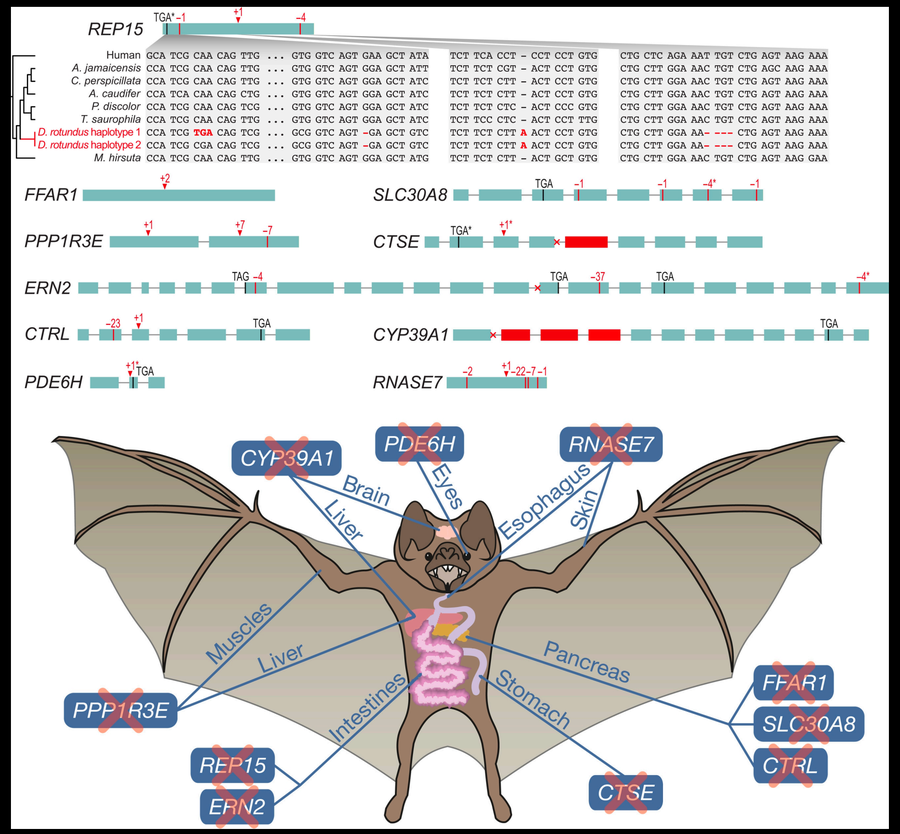
Hong Wei and Zhao Huabin. (2014) Proc. R. Soc. B.

Lost Genes Explain Vampire Bats' Diet of Blood



TOGA
TOOL TO INFER ORTHOLOGS FROM GENOME ALIGNMENTS

RESEARCH ARTICLE
ZOONOMIA
Science
Integrating gene annotation with orthology inference at scale



Gene-inactivating mutations, indicating that potential transcripts cannot be translated into a full-length protein.

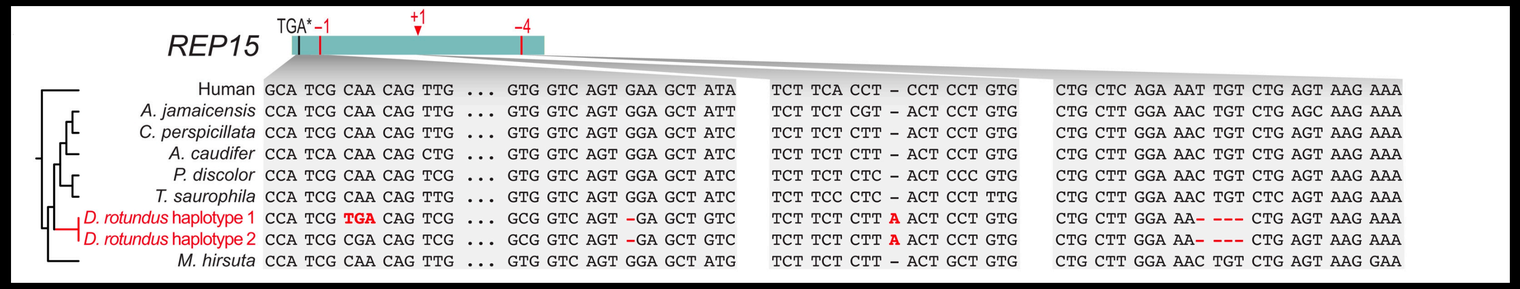
- **13 vampire bat–specific gene losses**:
  1. sweet taste receptor gene
     - *TAS1R2*
  2. bitter taste receptor genes
     - *TAS2R5*
     - *TAS2R42*
  3. 10 genes new reported
     - Loss of *CYP39A1* and advanced social behavior
     - Loss of *ERN2* and low dietary fat content
     - Losses of *FFAR1* and *SLC30A8* and reduced insulin secretion
     - Loss of *REP15* and enhanced iron excretion
     - ……

Moritz Blumer et al. (2022) Sci. Adv.

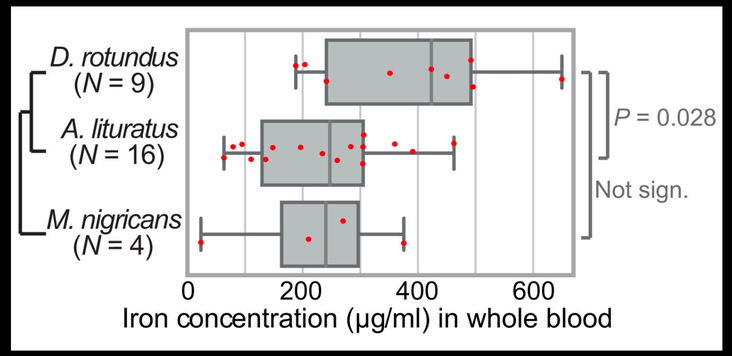
Lost Genes Explain Vampire Bats' Diet of Blood

The loss of *REP15*

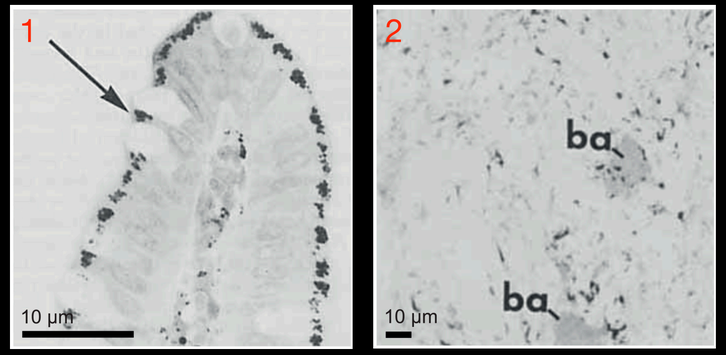
- involved in regulating cellular iron uptake



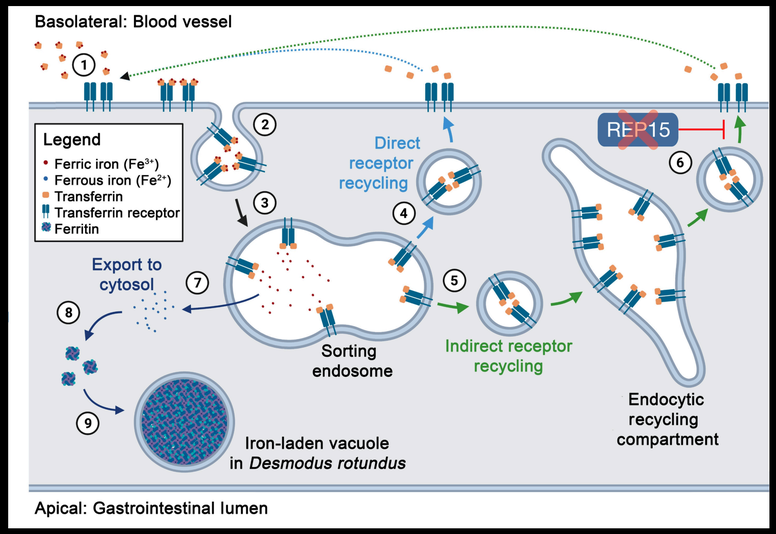
Gene-inactivating mutations of *REP15*: 1 base A insertion & 4 base lost



Vampire bats had higher blood iron levels



Mechanism to reduce systemic iron levels
D. Morton, W. A. Wimsatt. (1980) Anat. Rec.



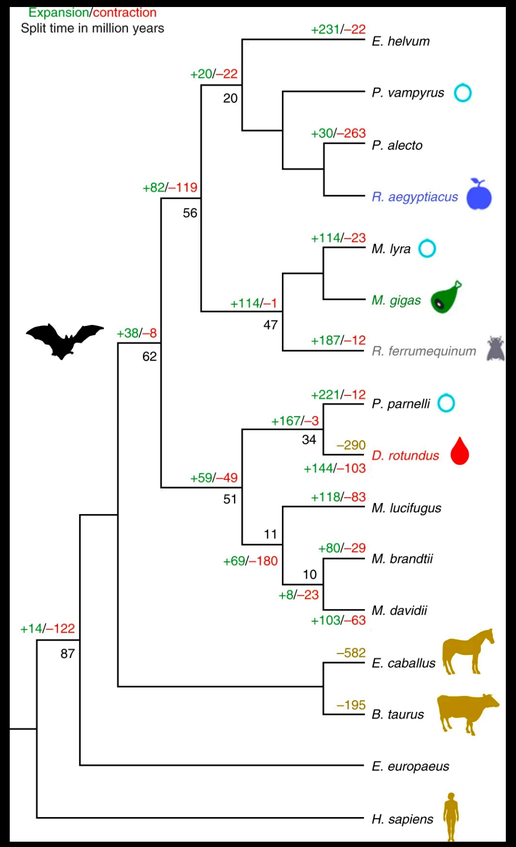
the loss of *REP15* in *D. rotundus* enhances iron accumulation in gastrointestinal tract cells.

1. 胃肠道上皮细胞的液泡中富集铁
2. 胃肠道细胞脱落到肠腔

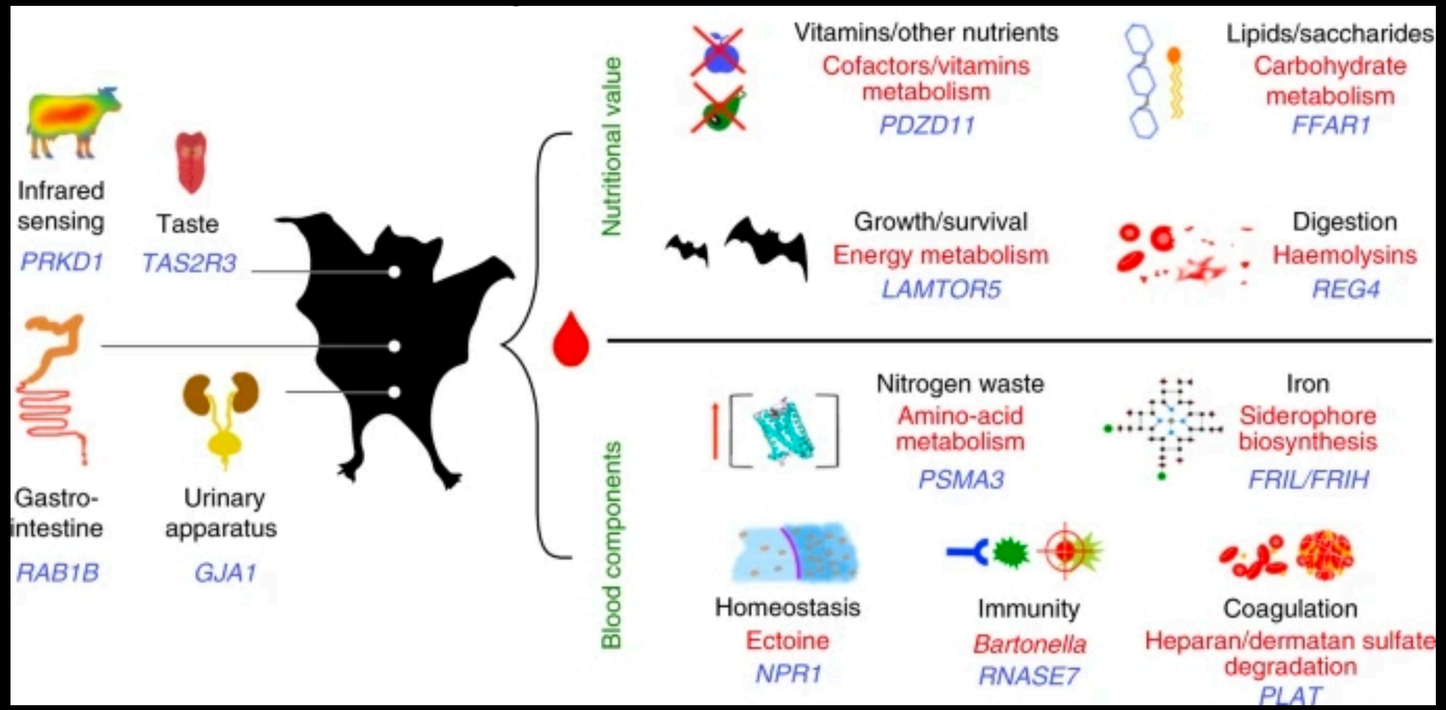
Moritz Blumer et al. (2022) Sci. Adv.

Adaptational contributions to sanguivory in vampire bat

Adaptations



Gene expansion & contraction

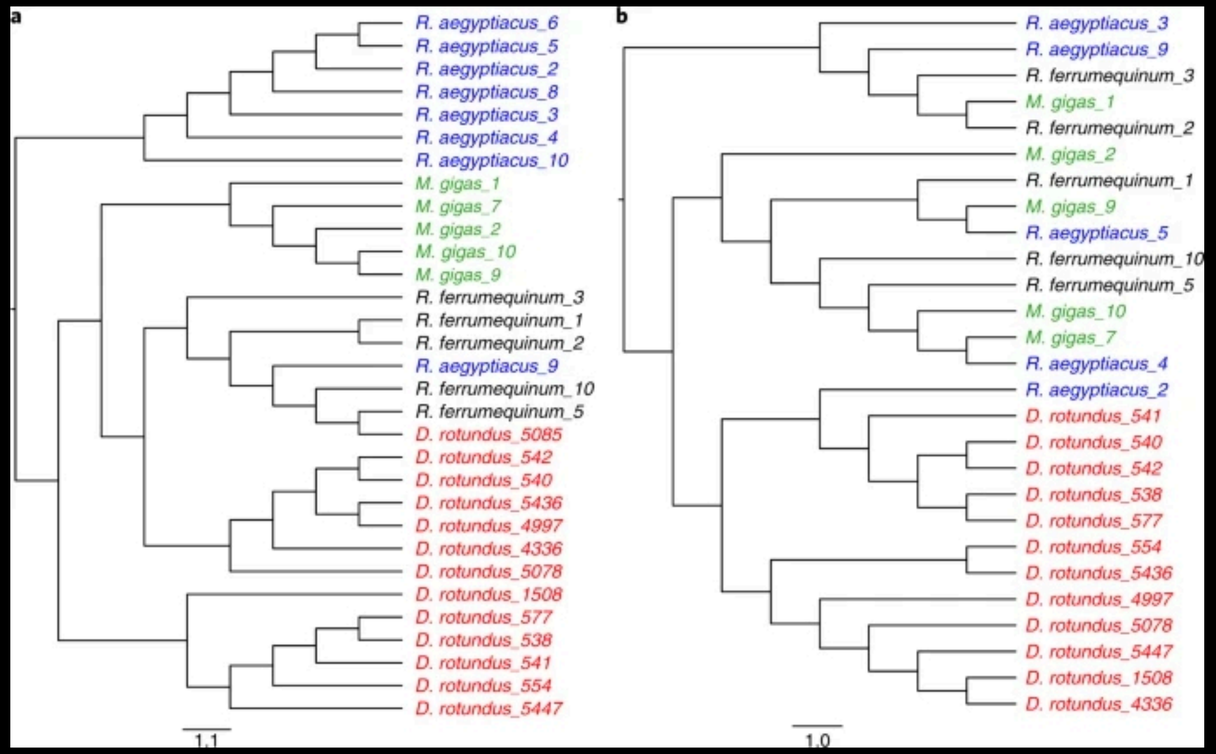


Adaptational contributions to sanguivory (blue labels for host *positive selection genes*).

Zepeda Mendoza et al. (2018) Nat. Ecol. Evol.

Adaptational contributions to sanguivory in vampire bat

Gut microbiome



D. rotundus (sanguivorous [吸血食性], red),

R. ferrumequinum (insectivorous [食虫食性], black),

M. gigas (carnivorous [食肉食性], green),

R. aegyptiacus (frugivorous [食果食性], blue).

a. Euclidean distance dendrogram of the *microbial presence/absence identifications* at the species taxonomical level.

b. Euclidean distance dendrogram from the UniProt-identified ***abundance functions*** from the normalized samples.

- This suggests that the functional profile is less influenced by phylogeny than the taxonomic profile, and that the common vampire bat gut microbiome harbours a set of functions ***specialized to its extreme diet***.

Zepeda Mendoza et al. (2018) Nat. Ecol. Evol.

- Anesthetics [麻醉剂]
- Anticoagulants [抗凝血剂]
- ACE [血管紧张素转换酶]

Vampire snail

Leeches

- inhibition of blood coagulation [抑制血液凝固]
- alleviation of pain [减轻疼痛]
- suppression of inflammation [抑制炎症]

Adaptations?

- Lost Genes
  - Enhanced iron excretion
  - low dietary fat content
  - Advanced social behavior
  - Reduced insulin secretion
- Gut microbiome

Vampire Bats

Vampire finch

Obligatory [专性吸血]

Facultative [兼性吸血] ✓

Bloodsucking in birds

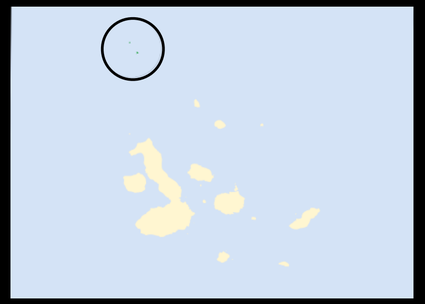
Vampire ground finch
(*Geospiza septentrionalis*)
吸血地雀

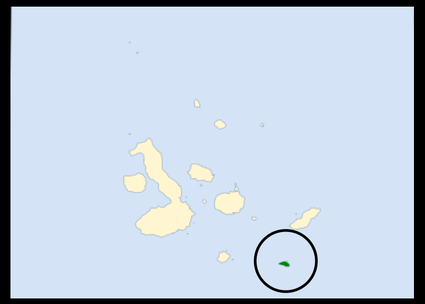
Hood mockingbird
(*Mimus macdonaldi*)
冠嘲鸫

Galápagos mockingbird
(*Mimus parvulus*)
加岛嘲鸫

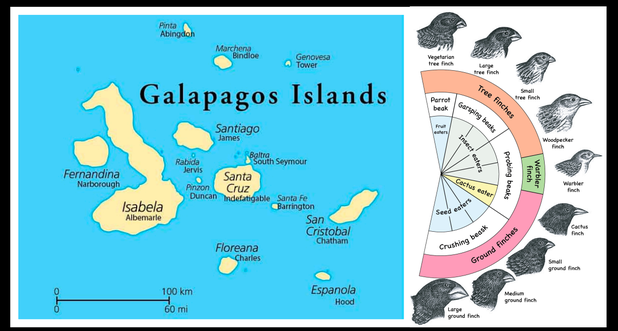
Red-billed oxpecker
(*Buphagus erythrorynchus*)
红嘴牛椋鸟

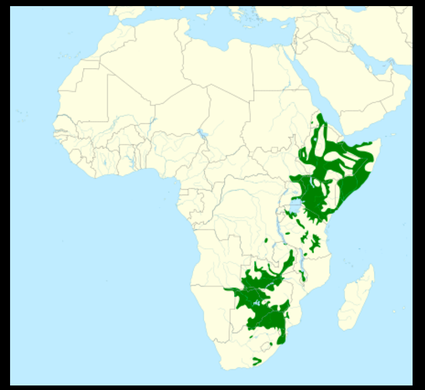
Yellow-billed oxpecker
(*Buphagus africanus*)
黄嘴牛椋鸟





Galápagos Islands



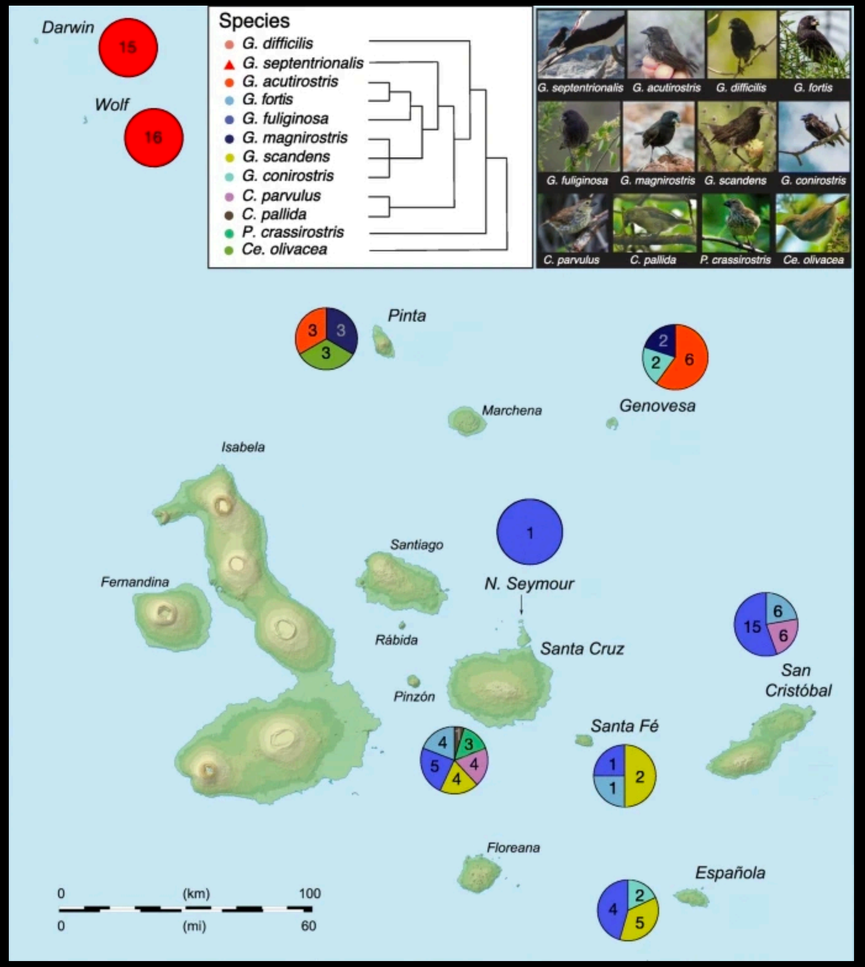


East Africa

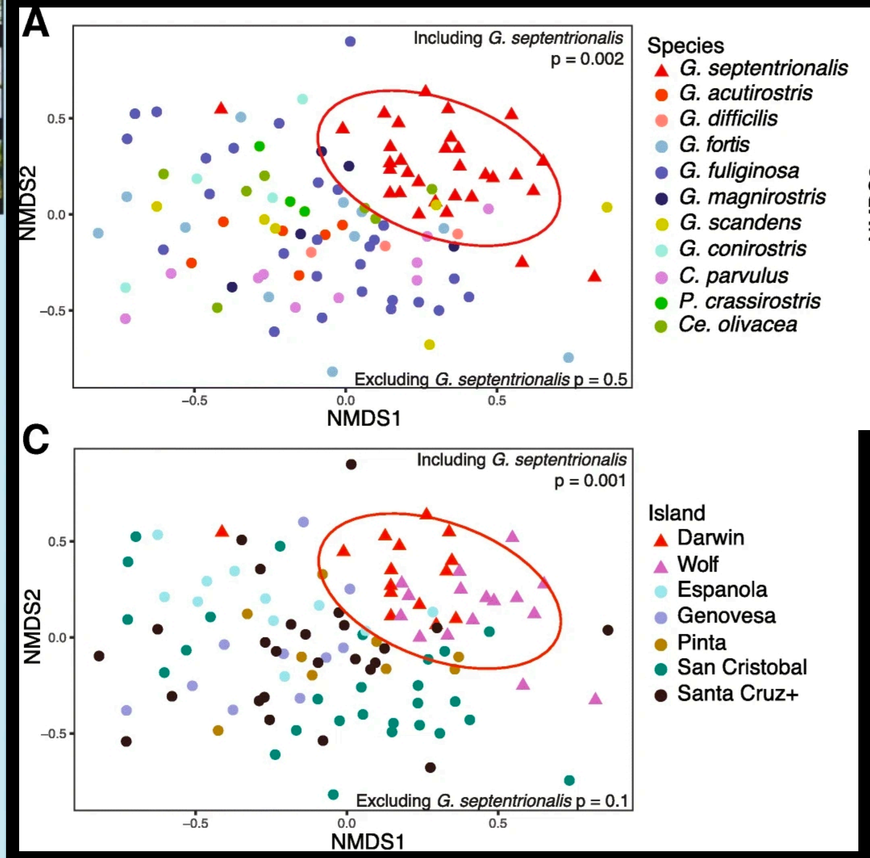
Sub-Saharan Africa

The gut microbiome of the Galápagos vampire finch

Gut microbiome



Overview of finch gut microbiome samples collected from the Galápagos Islands.



The gut microbiome of vampire finch (*Geospiza septentrionalis*) clustered in **A** species, **B** diet, **C** island levels.

Michel, A.J. et al. (2018) Microbiome

Bloodsucking in birds

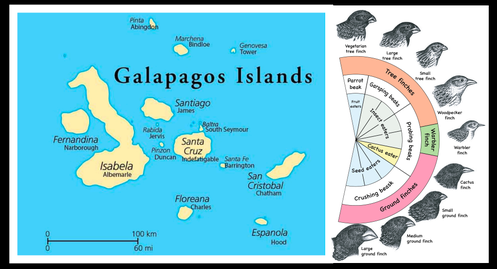
Vampire ground finch
(*Geospiza septentrionalis*)
吸血地雀

Hood mockingbird
(*Mimus macdonaldi*)
冠嘲鸫

Galápagos mockingbird
(*Mimus parvulus*)
加岛嘲鸫

Red-billed oxpecker
(*Buphagus erythrorynchus*)
红嘴牛椋鸟

Yellow-billed oxpeckers
(*Buphagus africanus*)
黄嘴牛椋鸟



Galápagos Islands

East Africa

Sub-Saharan Africa

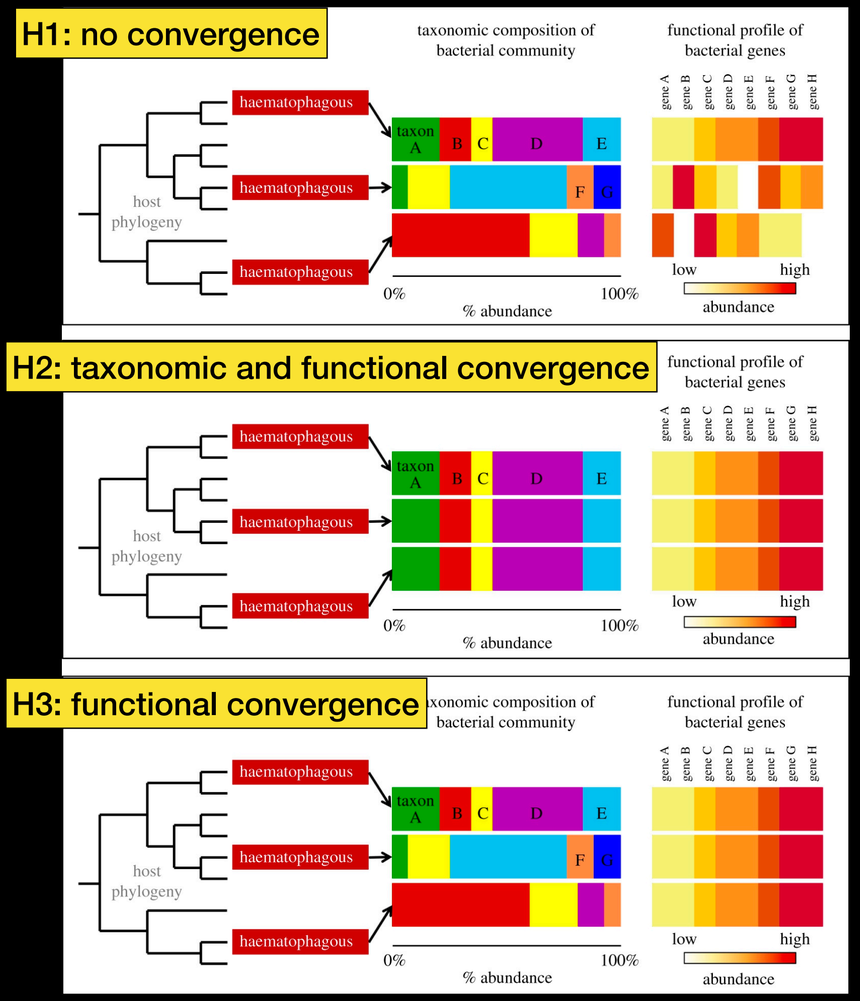
Large-billed crow
(*Corvus macrorhynchos*, 大嘴乌鸦)
suck deer blood [reports from the zoo]

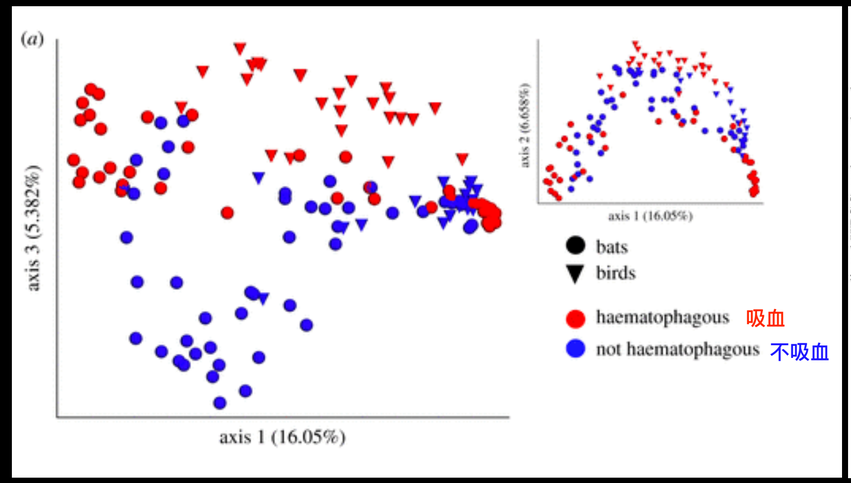
Tristan thrush
(*Turdus eremita*, 特里斯坦鸫)
suck penguin blood [BBC documentary]

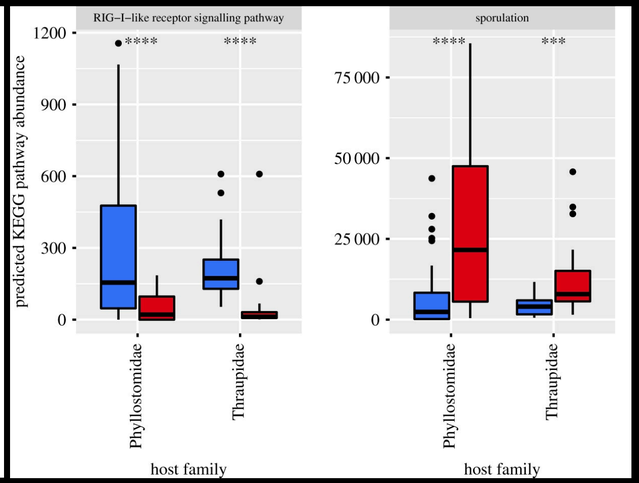
食虫假说?

Is there convergence of gut microbes in blood-feeding vertebrates?

Convergence in gut microbiome?







Microbiome between haematophagous bats and birds:

- no associated at the amplicon sequence variants level
- weak associated at the overall community level
  - axis 3 in figure [variance 5.382%]
- more strongly converge in key taxa and predicted functions
  - Gene-I-like (RIG-I-like) receptor signalling pathway [基因样受体信号通路]
  - Sporulation [孢子形成]

Song, S.J. et al. (2019) Philosophical Transactions of the Royal Society B

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Thanks for your listening!

Q & A

A display of preserved blood-sucking specimens