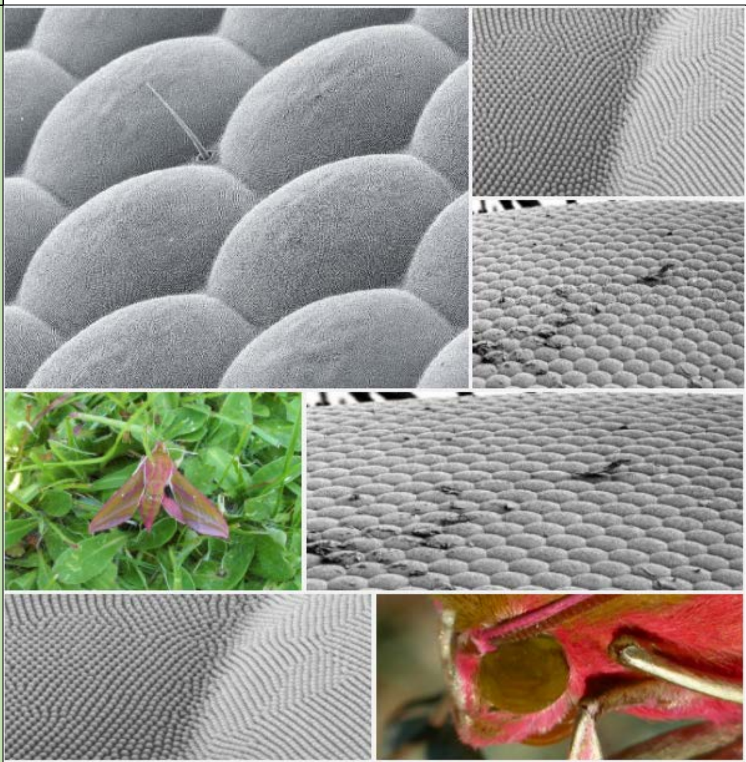
生物策略表

類別	生物策略 (Strategy)
生物策略 STRATEGY	抗反射的眼睛 (Eyes are anti-reflective)
生物系統 LIVING SYSTEM	象鷹蛾 *Deilephila elpenor* (Elephant hawk-moth)
功能類別 FUNCTIONS	#改變光線/顏色 #保護免受動物危害 #Modify light/color #Protect from animals
作用機制標題	夜行性蛾類的眼睛由於奈米級的凸起而抗反射 (Eyes of nocturnal moths are anti-reflective due to nanoscale protrusions.)
生物系統/作用機制示意圖	

作用機制摘要說明 (SUMMARY OF FUNCTIONING MECHANISMS)

蛾類的眼睛覆蓋著獨特的次波長 (sub-wavelength) 結構，這比起傳統的抗反射 (anti-reflective) 塗層，能夠使很廣波長範圍內的光反射極大地降至最低。蛾類角膜晶體 (corneal lenses) 的外表面覆蓋著規律樣式的錐狀隆凸 (conical protuberance)，一般的高度和間隔是 200-300 奈米(nm)。這些隆凸透過在空氣—晶體的界面間 (air-lens interface) 創造出一個折射系數梯度 (refractive index gradient) ，使得空氣和眼睛之間的光速變化更加逐漸地過渡，因而最小化光線的反射。這些獨特的構造幫助蛾類在月光之下閃躲 (evade) 掠食者的偵測，並最大化獲取光線，使能夠在黑暗中看見物體。由蛾類眼睛所啟發的抗反射塗層展現出對寬廣光波範圍的高性能及低製造成本，最近已經被使用在太陽能板的開發，以及很多其它具潛力的產品應用。

Moths have unique sub-wavelength structures coating their eyes which dramatically minimize light reflection over a much broader range of wavelengths than conventional anti-reflective coatings. The outer surfaces of moth corneal lenses are covered with a regular pattern of conical protuberances, generally 200-300 nm in height and spacing. These protuberances reduce light reflection by creating a refractive index gradient between the air-lens interface, more gradually transitioning the change in light speed between the air and eye and hence minimizing reflection. These unique structures help moths evade detection by predators in moonlight and maximize light capture for seeing in the dark. Moth-eye inspired antireflective coatings that demonstrate high-performance over large band widths at low fabrication cost have recently been developed for solar panels, with many other potential products applications.

文獻引用 (REFERENCES)
「蛾類的眼睛有兩種獨特的 (characteristic) 視覺構造，可能有增加感光度的功能：脈絡膜層鏡片 (tapetal mirror) 以及角膜乳突陣列 (corneal nipple array) (Miller, 1979)。脈絡膜層是由感桿束 (rhabdom) 近側部分的微氣管 (tracheole) 所構成，能反射未被吸收的光線回到感桿束之中，因此提供了第二次機會使光線被吸收。角膜乳突陣列，被稱為「蛾眼」構造，是一組高度大約在 200 nm 的隆凸，有著薄層抗反射塗層的作用。基本上在真正的蝴蝶中都保有這些構造，但鳳蝶科 (Papilionidae) 中所有物種都缺乏這兩種構造 (Bernhard et al., 1970; Stavenga et al., 2006)。」。(Takemura et al. 2007) “The eyes of moths have two characteristic optical structures that probably function to increase the light sensitivity: the tapetal mirror and the corneal nipple array (Miller, 1979). The tapetum is composed of tracheoles at the proximal portion of the rhabdom and reflects unabsorbed light back into the rhabdom, thus providing a second chance for light to be absorbed. The corneal nipple array, known as the ‘moth-eye’ structure, is a set of protuberances of height about 200•nm, acting as a thin-film antireflection coating. These structures are basically retained in the apposition eyes of true butterflies, but all species in the family Papilionidae lack both (Bernhard et al., 1970; Stavenga et al., 2006).” (Takemura et al. 2007)

參考文獻清單與連結 (REFERENCE LIST)
Takemura, S., D. G. Stavenga, and K. Arikawa. (2007). Absence of eye shine and tapetum in the heterogeneous eye of *Anthocharis* butterflies (Pieridae). *Journal of Experimental Biology* 210: 3075-3081. (https://jeb.biologists.org/content/210/17/3075)

延伸閱讀
AskNature Team. (1 October, 2016). Enhanced scintillation materials. *AskNature*. Retrieved from: https://asknature.org/idea/enhanced-scintillation-materials/ AskNature Team. (1 October, 2016). Moth eye antireflective coatings. *AskNature*. Retrieved from: https://asknature.org/idea/moth-eye-antireflective-coatings/

AskNature Team. (1 October, 2016). MothEye and MARAG films. *AskNature*. Retrieved from: https://asknature.org/idea/motheye-and-marag-films/
生物系統延伸資訊連結 (LEARN MORE ABOUT THE LIVING SYSTEM/S)
https://en.wikipedia.org/wiki/deilephila_elpenor https://www.onezoom.org/life/@deilephila_elpenor https://eol.org/pages/508359
撰寫/翻譯/編修者與日期
譚國鋈翻譯 (2020/09/30)；許秋容編修 (2021/04/16)
AskNature 原文連結
https://asknature.org/strategy/eyes-are-anti-reflective/