Mechanical role of the tube feet in sea star locomotion

Amandine Deridoux[1,2*], Patrick Flammang[2] Sylvain Gabriele[1]

[1] Laboratory for Complex Fluids and Interfaces, Mechanobiology & Biomaterials group, Research Institute for Biosciences, University of Mons, Mons, Belgium

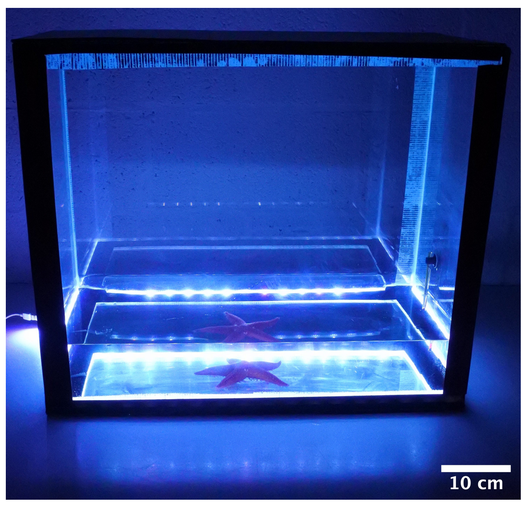
[2] Biology of Marine Organisms and Biomimetics Unit, Research Institute for Biosciences, University of Mons, Mons, Belgium

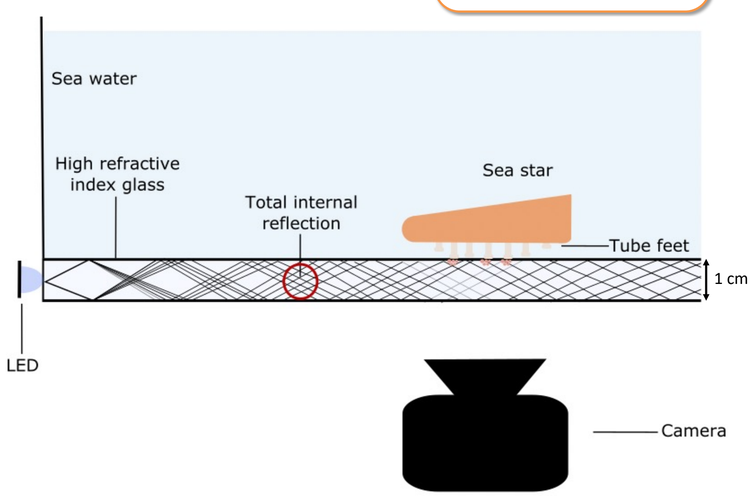
*Contact: Amandine.DERIDOUX@umons.ac.be

Sea stars use a multitude of small hydraulic organs (i.e., the tube feet or podia) to locomote but also attach strongly to the seafloor, and to pry open the mussels on which they feed. Tube feet are secretory organs in which two types of adhesive cells co-secrete a blend of adhesive proteins to form the adhesive layer joining the tube feet to the substrate. Despite a growing interest, the mechanisms of sea star locomotion remain unclear. For example, how these invertebrates can have such synchronized locomotion without a central brain and is there a relationship between their morphology and crawling speed are still open questions. Regardless of the paramount importance of tube feet in sea star locomotion, the relationships between the sea star mass or the number of tube feet in contact with a surface during movement and locomotion speed are still poorly understood.

TIRF based aquarium

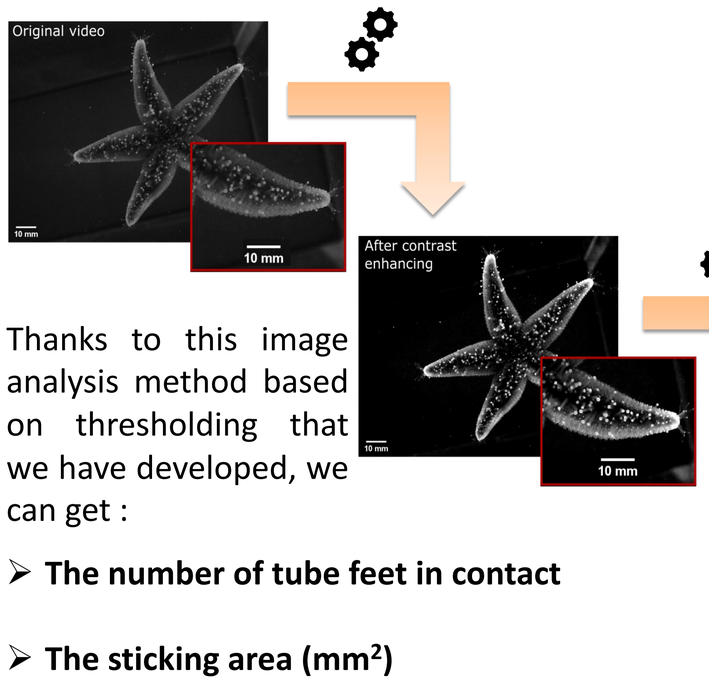
Sea water parameters :
T°= 15,5°C
pH = 8
Salinity = 34,8‰





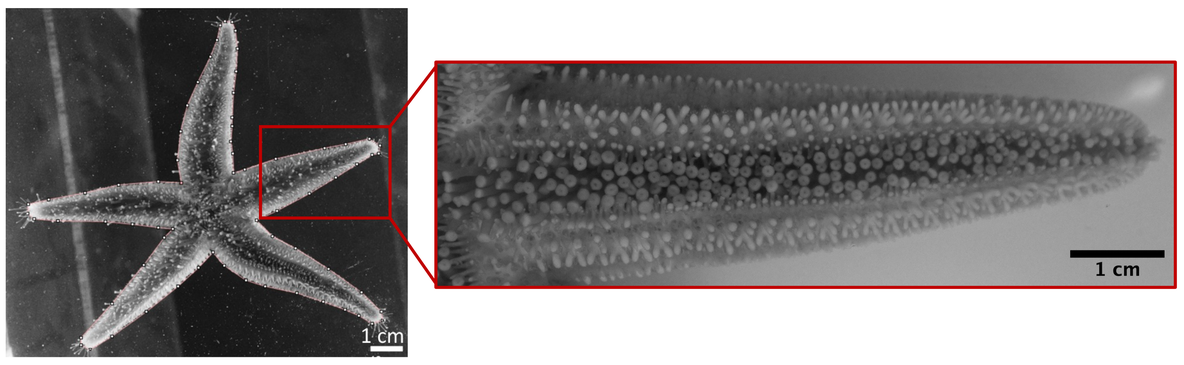
- Schematic of our experimental device that uses total internal reflection. The tube feet which come into contact with a surface provided with the TIRF will diffuse the light and this contact area will be illuminated.

Image analysis method



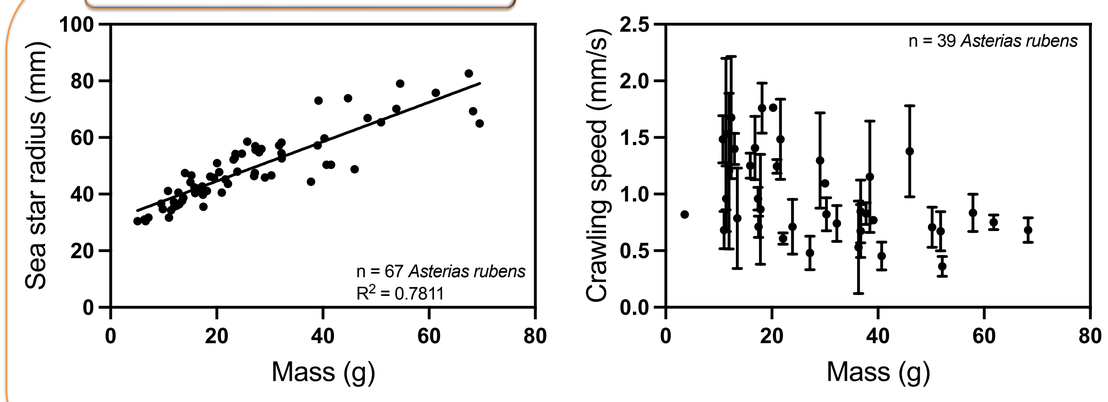
- Thanks to this image analysis method based on thresholding that we have developed, we can get :
  - ➢ **The number of tube feet in contact**
  - ➢ **The sticking area (mm²)**

Morphological parameters



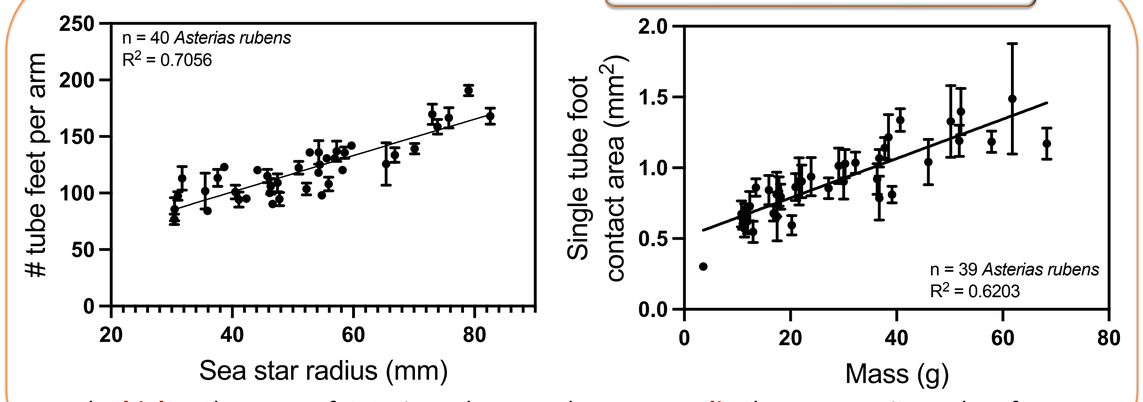
- *Asterias rubens* oral surface is covered with hundreds of tube feet (highlight).

Sea star mass



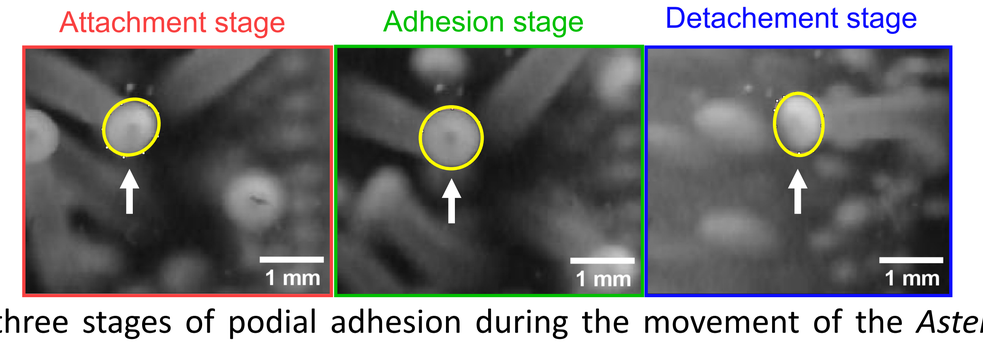
Asterias rubens mass **does not impact** the crawling speed

Tube feet morphometry



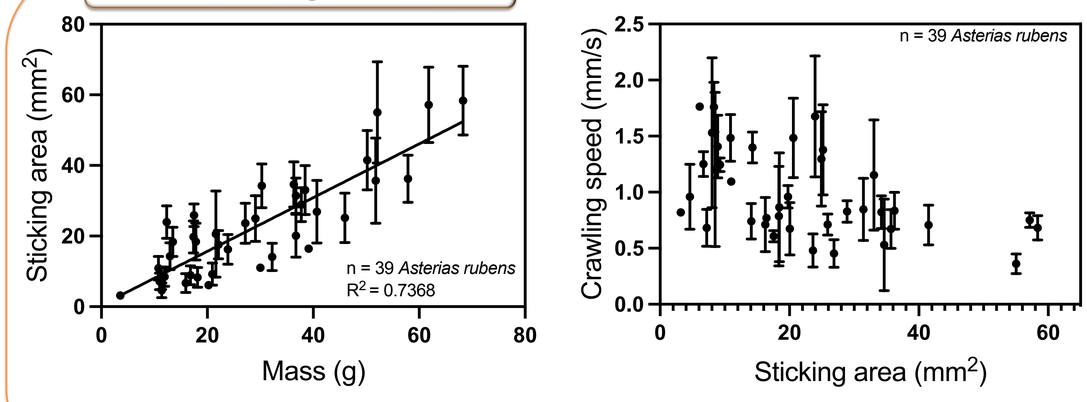
The **higher** the mass of *Asterias rubens* : - the **more podia** there are on its oral surface
- the **larger** their contact area

Adhesion dynamics parameters



- The three stages of podial adhesion during the movement of the *Asterias rubens* have been demonstrated thanks to videos at high magnification. The tube feet residence time is equivalent of the adhesion stage duration.

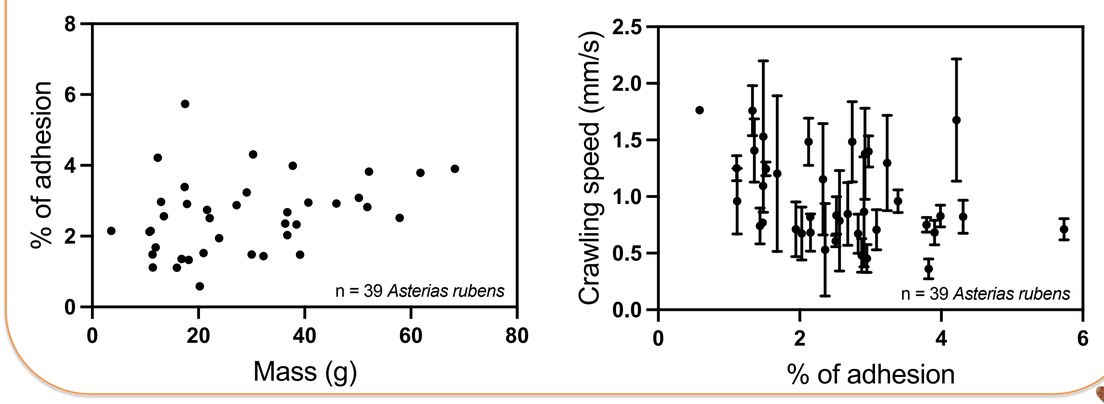
Sticking area



The **higher** the mass of *Asterias rubens*, the **greater** its sticking area

Percentage of adhesion

$$\text{Percentage of adhesion} = \frac{\text{sticking area}(mm^2)}{\text{ambulacral groove area}(mm^2)} * 100$$



Conclusion and perspectives

Altogether, these results highlight that the larger the sea star gets, the more tube feet they possess on their oral surface, and the more tube feet they use when they move. In the end, the percentage of adhesion used during the movement seems constant for all sea stars. Therefore, we hypothesize that is why the crawling speed remains constant.

The overarching goal of this project is to figure out the parameters that truly impact sea star locomotion to obtain **clear locomotion laws**. In the long term, we aim to develop a **biomechanical model of sea star locomotion** based on the measurement of the adhesion energy exerted by a sea star according to **the number of tube feet**.

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