Swimming behavior of zooplankton in turbulent flow

FloMat2015

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March 25, 2015

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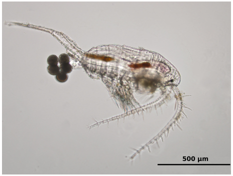
Introduction

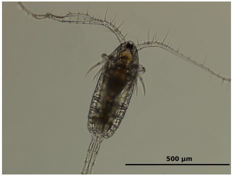
Calanoid copepods are ubiquitous in brackish and marine ecosystems

- A major component of the plankton community
- Considerable effort to understand their ecology
- Swimming behavior mediates:
  - How they exploit their environment
  - How they interact with other organisms



Copepods live in a constantly flowing environment

- Generally advected by large eddies but can respond actively to the ambient flow
- No experimental results on their small-scale response to turbulence
- Hypothesis: copepods can control the direction and magnitude of motion imposed by small-scale turbulent transport



Obtaining three-dimensional Lagrangian information

- We need a large number of long trajectories for robust statistical analysis
- No standard technique to recover the position information of moving animals

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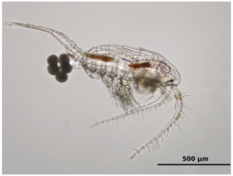

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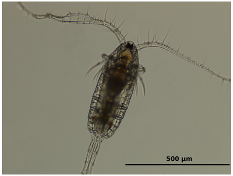

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Results
Swimming dynamics

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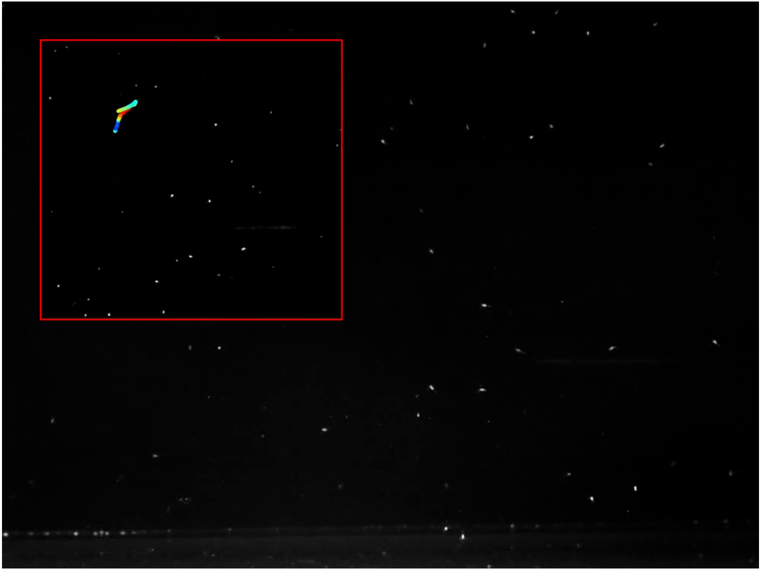
Swimming dynamics - Motion in turbulent flow



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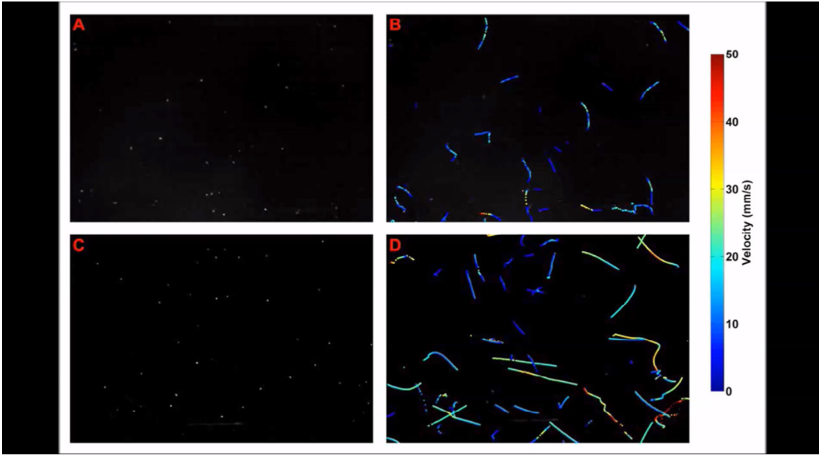

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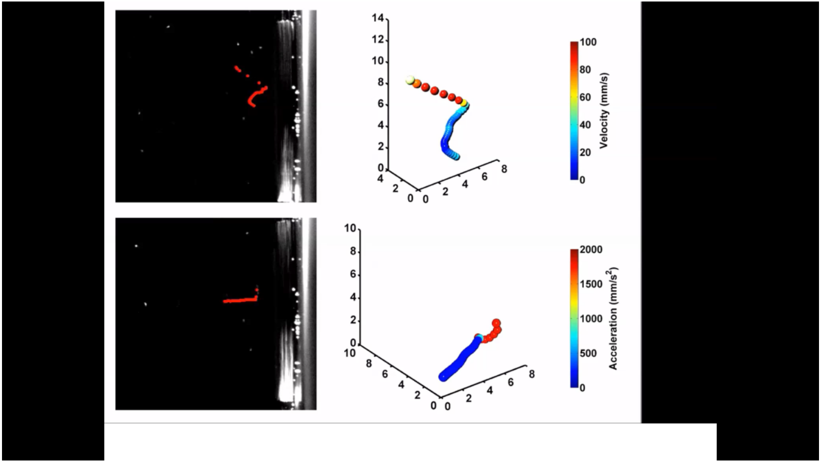

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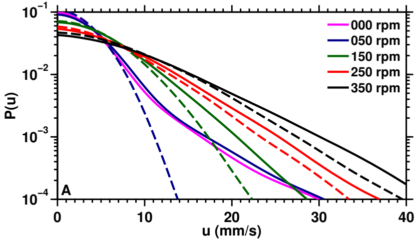
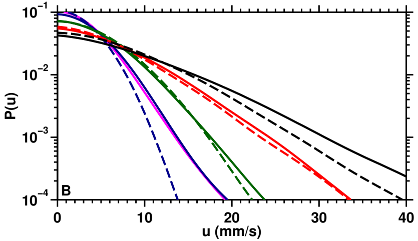
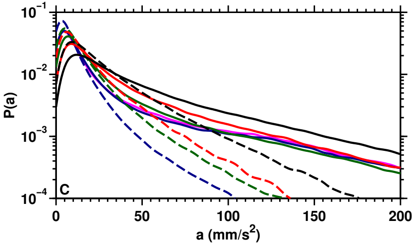


- Velocity magnitude of living copepods exceeds that of inert particles ...
- ... but varies between genders: males have a more active motility pattern
- Very low intensity of turbulence does not trigger significant response
- The behavioral response depends on turbulence intensity

Solid lines: living; **Dashed lines:** dead





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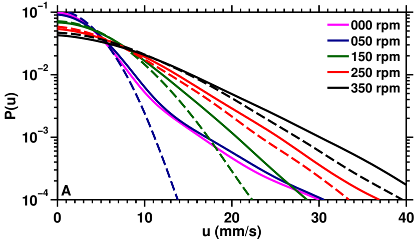

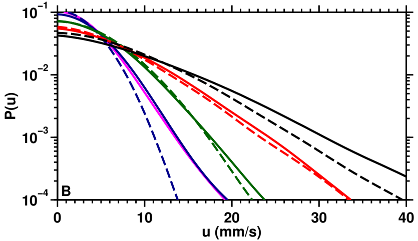

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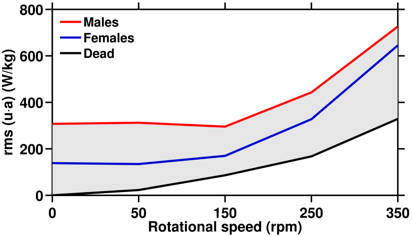

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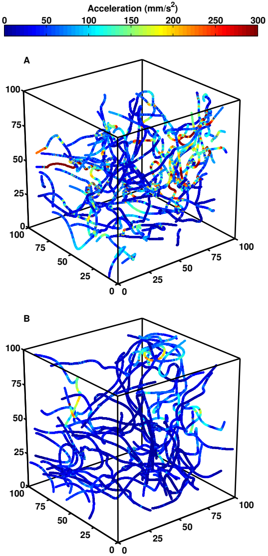

- Behavior contributes substantially to the dynamics of copepods in turbulent flows
- The contribution of behavior reduces as flow motion increases ...
- ... but regains significance after a moderate level
- Copepods adjust their behavior and swimming effort according to the flow
- Suggests adaptation to optimize trade-offs between gains and costs
    - Gains: retaining the ability to carry out behavioral processes and interactions
    - Costs: energy expenditure and hydrodynamic conspicuousness

A. Living males B. Inert

An adaptive behavioral mechanism

- To retain swimming efficiency in turbulent flows
- To improve survival and mating performance in a complex and dynamic environment

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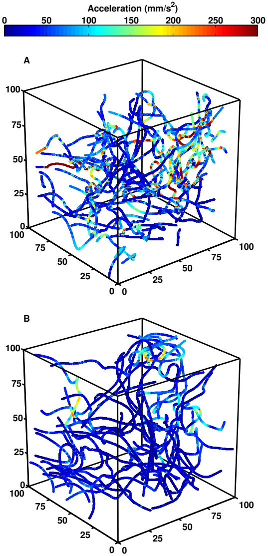
Swimming dynamics



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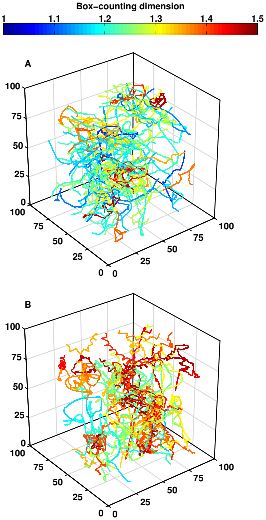
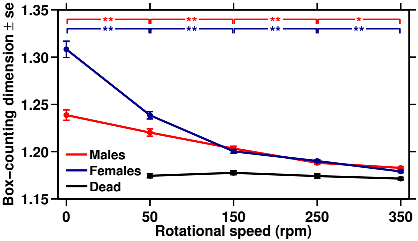
Trajectory dimorphism



- In species that produce pheromones for mating:
  - Males and females have distinct motility patterns
  - A strategy to increase encounter rate
  - Previous measurements conducted in still water
- Turbulence cancels gender-specific differences in swimming complexity
- At a substantial intensity of turbulence, trajectory geometry resembles that of inert particles

A. Males B. Females



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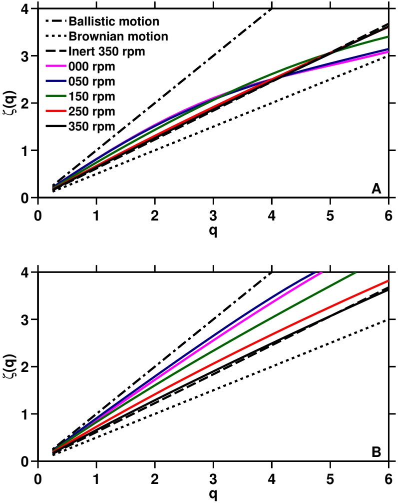
Motion strategy



A. Males B. Females

- Motion strategy determines:
  - The probability of interaction with other organisms
  - How individuals explore and exploit their dilute environment
- An optimized trade-off between:
  - Beneficial encounters with resources and mates
  - Dangerous meetings with predators
- In calm water and weak to moderate turbulence: multifractal random walk
- At substantial turbulence intensities: monofractal superdifusive motion

Turbulence cancels innate movement strategies

- Effects on geometry complexity
- Altered dispersive properties of motion

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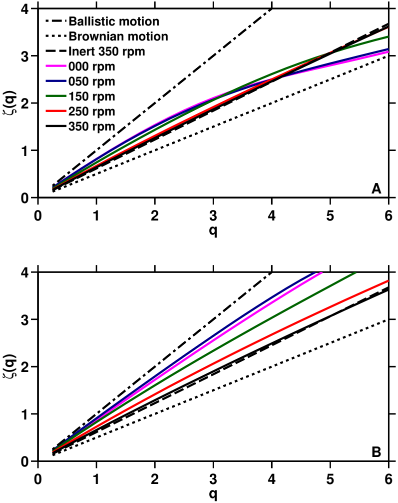
Motion strategy



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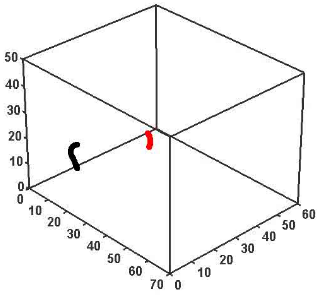
Conclusion

- Motion strategies are inefficient in turbulent environments …
- … but swift movements may matter more
  - To race up pheromone trails
  - To flee from predators
  - To catch a nearby prey
- Interaction outcome and success depend on:
  - Copepod perception distance
  - Relative velocity between two organisms
- Copepods provide additional effort when turbulence is significant



A compensatory response to the increase in flow velocity

- A behavioral adaptation to retain swimming efficiency in energetic environments
- Other physical processes or behavioral traits may increase encounter rates
  - Flow-driven preferential concentrations
  - Behavior-mediated aggregation and retention mechanisms in estuaries
- **Variability of turbulence: possible windows for motion strategies**

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