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## Real-time unsteady air flow prediction to reduces mechanic load variations and wind turbine maintenance costs

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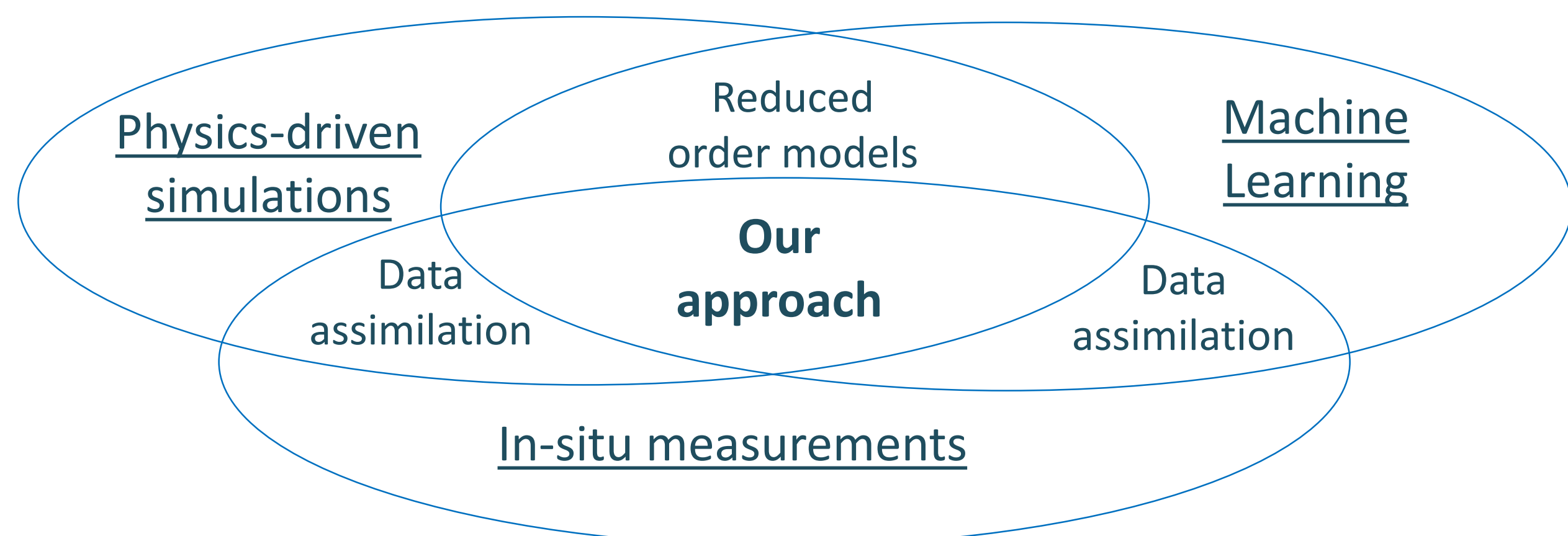


# Real-time unsteady air flow prediction to reduce mechanical load variations and wind turbine maintenance costs

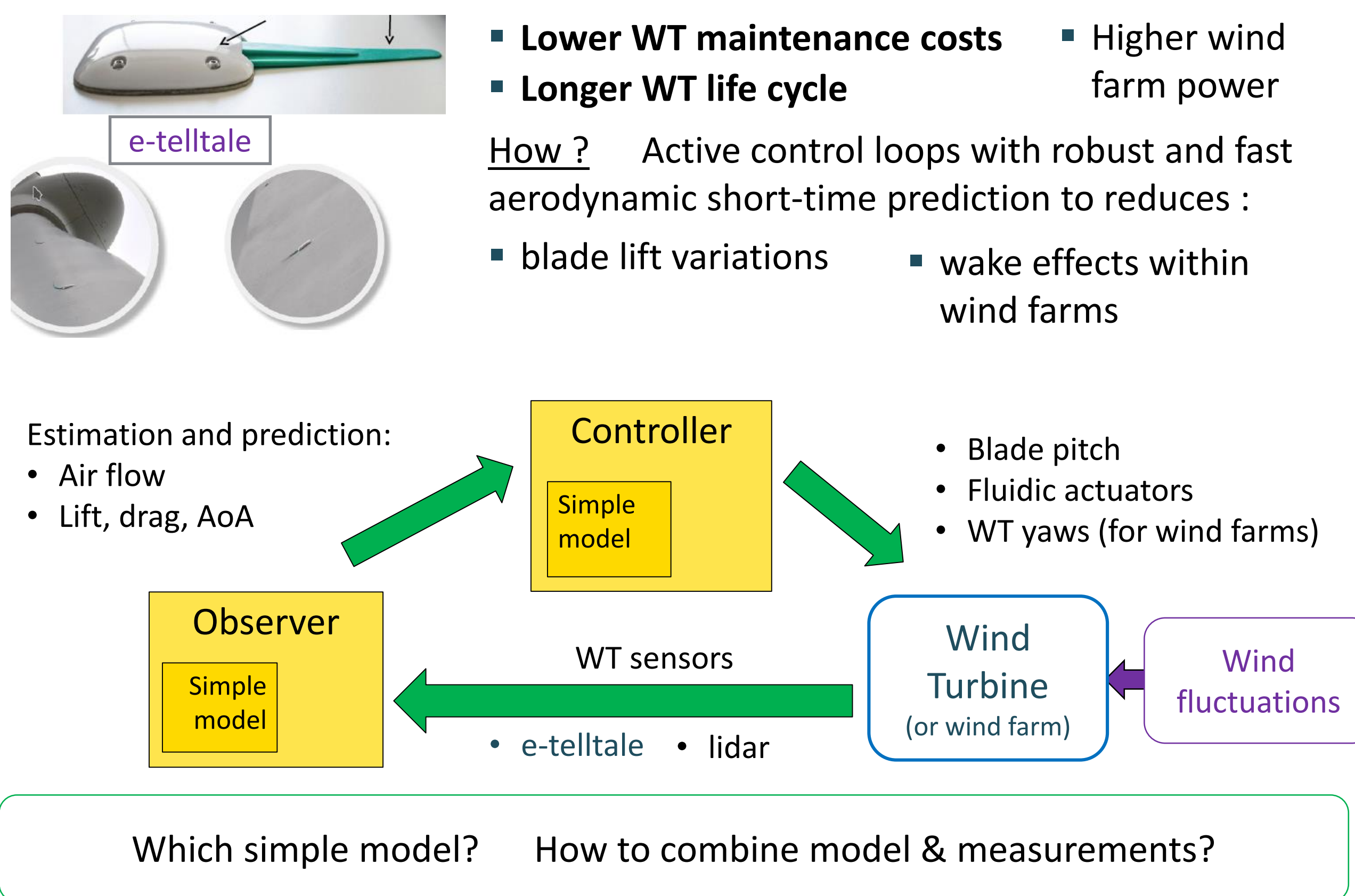
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## ABSTRACT

For actively controlling aerodynamic systems – like Wind Turbine (WT) blades -- it can be necessary to estimate in real-time and predict the air flow around those systems. We propose here a new method which combines machine learning, physical models and measurements for this purpose. Very good numerical results have been obtained on wake flows.



## APPLICATIONS



## METHODOLOGY

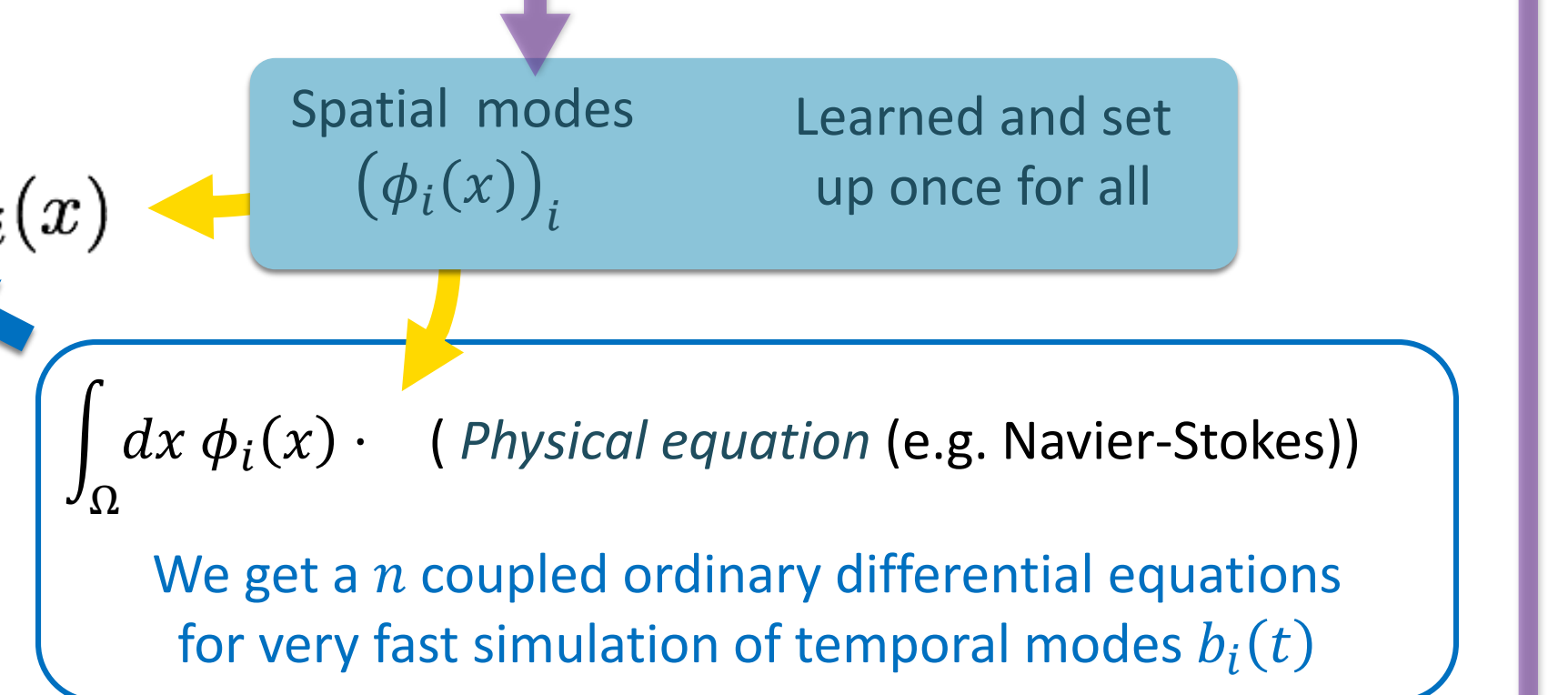
### 1. Ultra-fast CFD simulations with intrusive reduced order models (ROM)

- Principal Component Analysis (PCA) on a dataset to reduce the degrees of freedom (dof) :

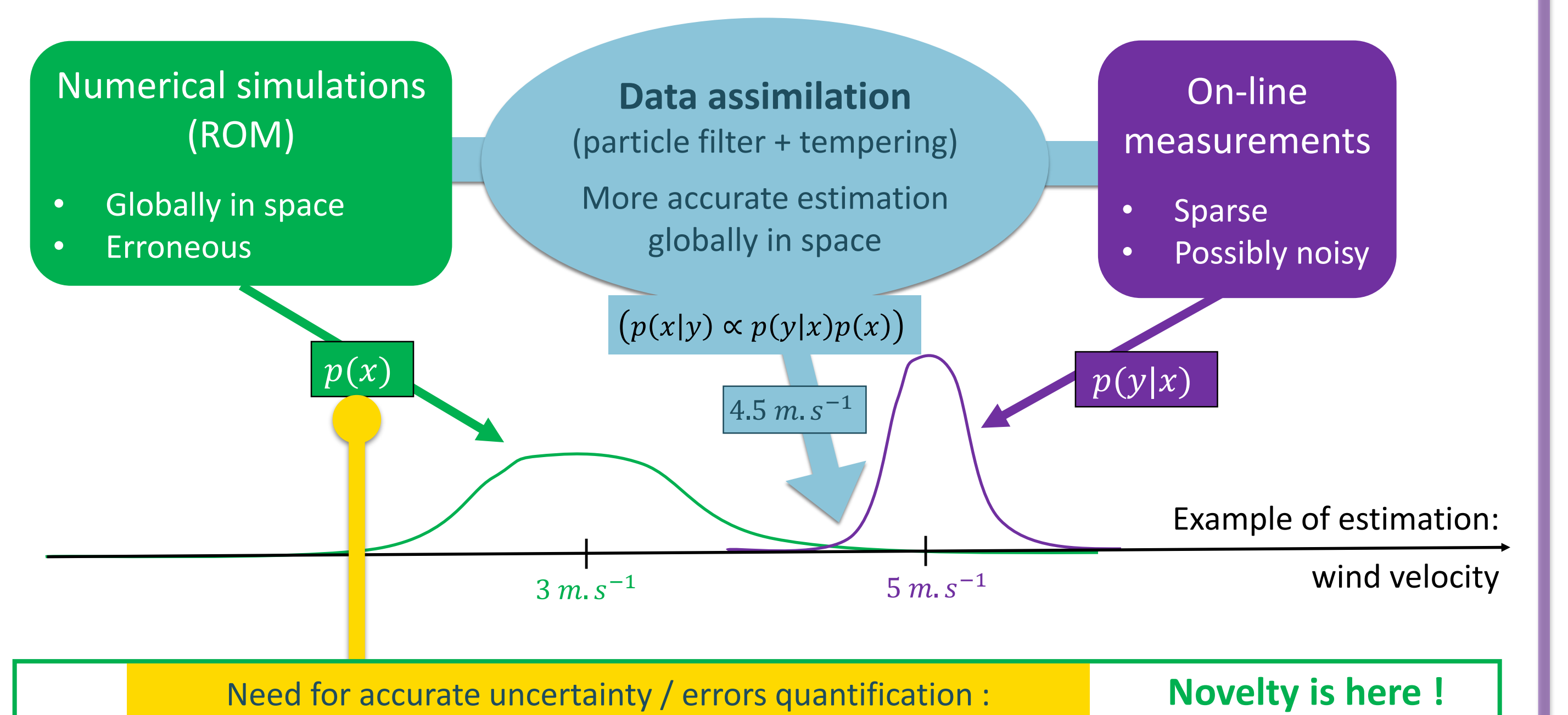


- Approximation (at small dof n):

$$v(x, t) \approx \sum_{i=0}^n b_i(t) \phi_i(x)$$



### 2. Measurement-simulation coupling (data assimilation)



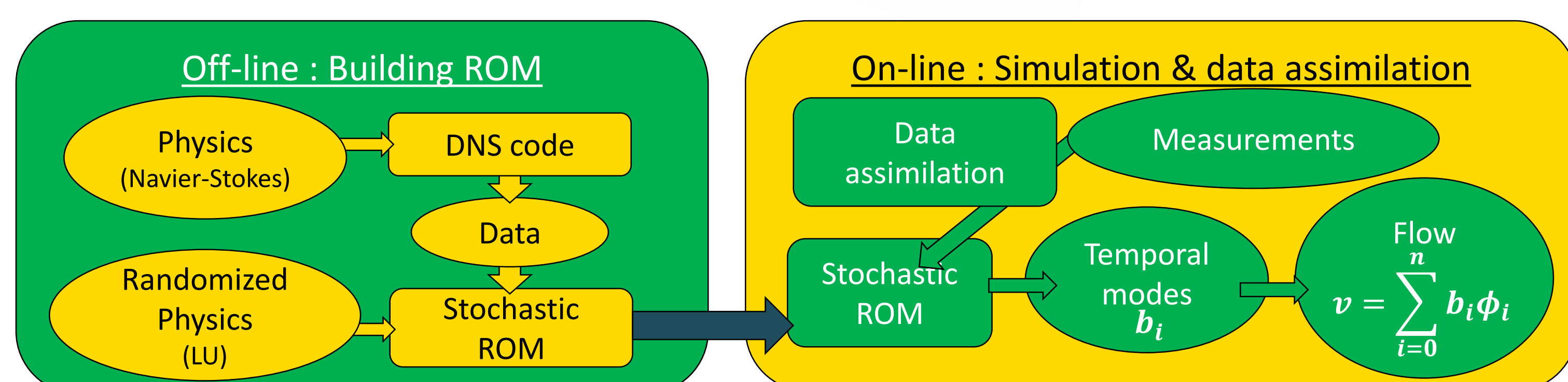
### 3. Randomized physics $p(x_{t+1}|x_t) \rightarrow$ Location uncertainty models (LUM)

Rigorous CFD stochastic closure, with physically-based multiplicative noise

## RESULTS FOR 8-DEGREE-OF-FREEDOM (DOF) SIMULATIONS COUPLED WITH A SINGLE MEASUREMENT POINT

	Reference : PCA-projection of the DNS (Optimal from 8-dof linear decomposition)	Our method : POD-Galerkin with Navier-Stokes under location uncertainty (LUM)	State-of-the-art : POD-Galerkin with Navier-Stokes + optimally tuned eddy viscosity & additive noise
Re 100, 2D 10 vortex shedding cycles after the learning period (DNS has $10^4$ dof)			
Re 300, 3D 14 vortex shedding cycles after the learning period (DNS has $10^7$ dof)			

## METHODOLOGY SUMMARY



## CONCLUSION

- Reduced order model (ROM) : for very fast and robust CFD  
Combine data & physics (built off-line)
- Data assimilation : to correct the fast simulation on-line by incomplete/noisy measurements
- Robust flow prediction far outside the learning period  
Optimal unsteady flow estimation/prediction in the whole spatial domain

## NEXT STEPS

- Real measurements
- Increasing complexity
- Control loop

