Reduced Models for Gas-Solids Flows: Coarse Discrete Element Method and Phase-Space Proper Orthogonal Decomposition

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Contributors

- **Coarse DEM**
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- **Phase-space based POD**
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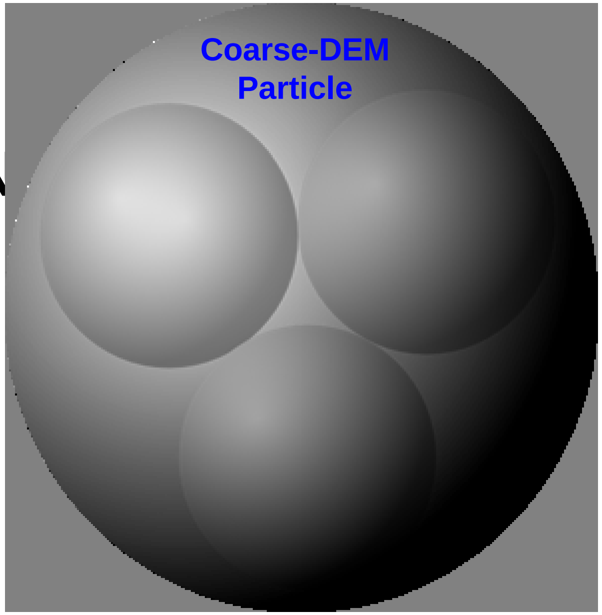
Motivation

- **Can we coarsen sampling in space and time to create more efficient algorithms?**
- **What are the levels of approximations we can make to solve the problems of interest?**
- **In the first problem on coarse DEM, we are sampling in the particle space**
- **In the second problem on PPOD, we are sampling in phase space (time) to construct more efficient POD basis**

Coarse DEM

- **Inspired by MP-PIC development and discrete extensions of Patankar & Joseph (IJMF, 2001)**
- **Each coarse DEM particle represents N number of original particles at close packing**
- **The coarse particles are subjected to collisions etc. just as in DEM and the drag computation is based on the original particle size and density**
- **Major assumption: Internal collisions within the parcel do not have any first-order effects and the parcels are homogeneous**

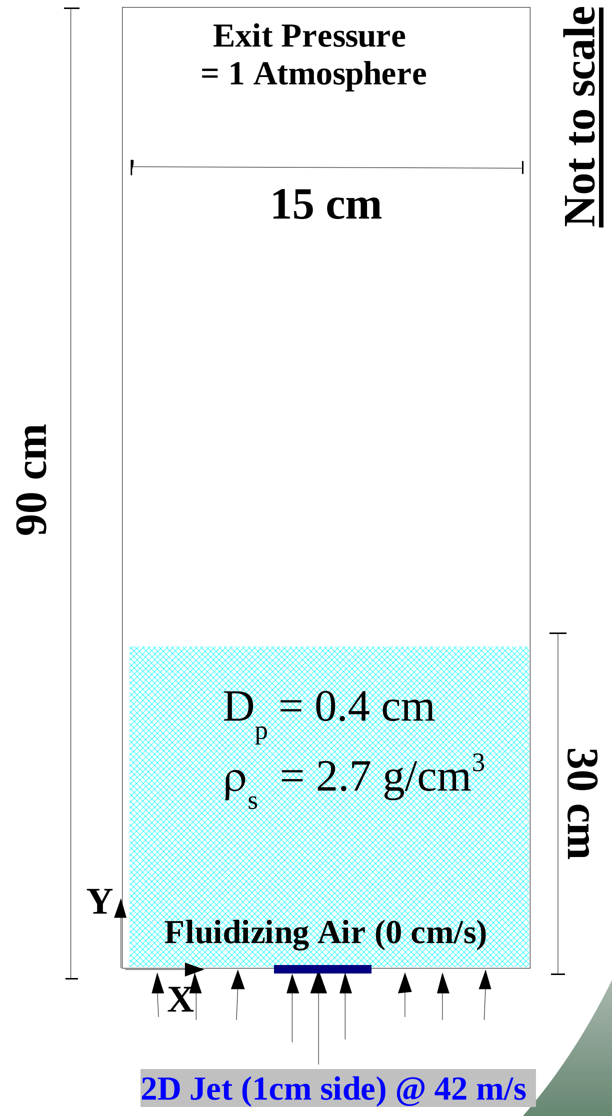


Coarse DEM - Pros and Cons

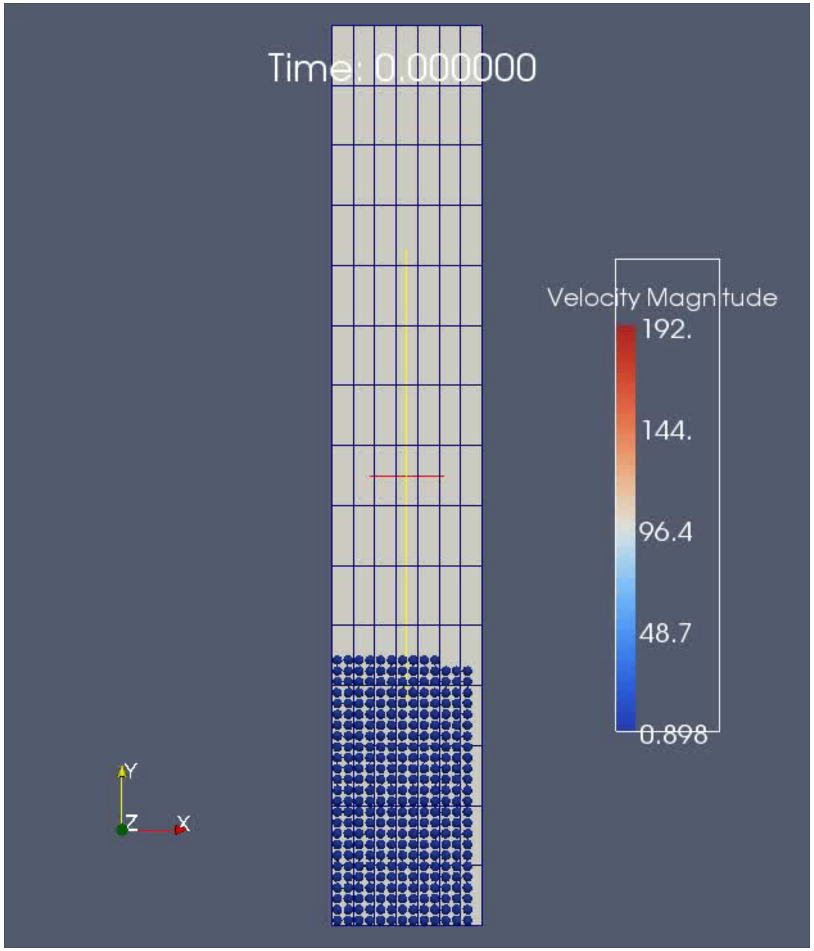
- **Pros**
  - **Drastically reduce the computational costs**
  - **Includes both normal and tangential forces**
    - **Address close-packing naturally**
  - **Accounts for particle rotation**
  - **Superior solids advection through the Lagrangian tracking of the particles**
  - **Use existing Eulerian-Lagrangian Framework**
  - **Multiple particle size?**
- **Cons**
  - **No mathematical framework to bound the error from the approximation**
  - **There is no way A priori to judge the sampling accuracy and efficiency**
- **Here we present some preliminary results – what-if numerical experiments**

Coarse DEM – Problem definition and setup

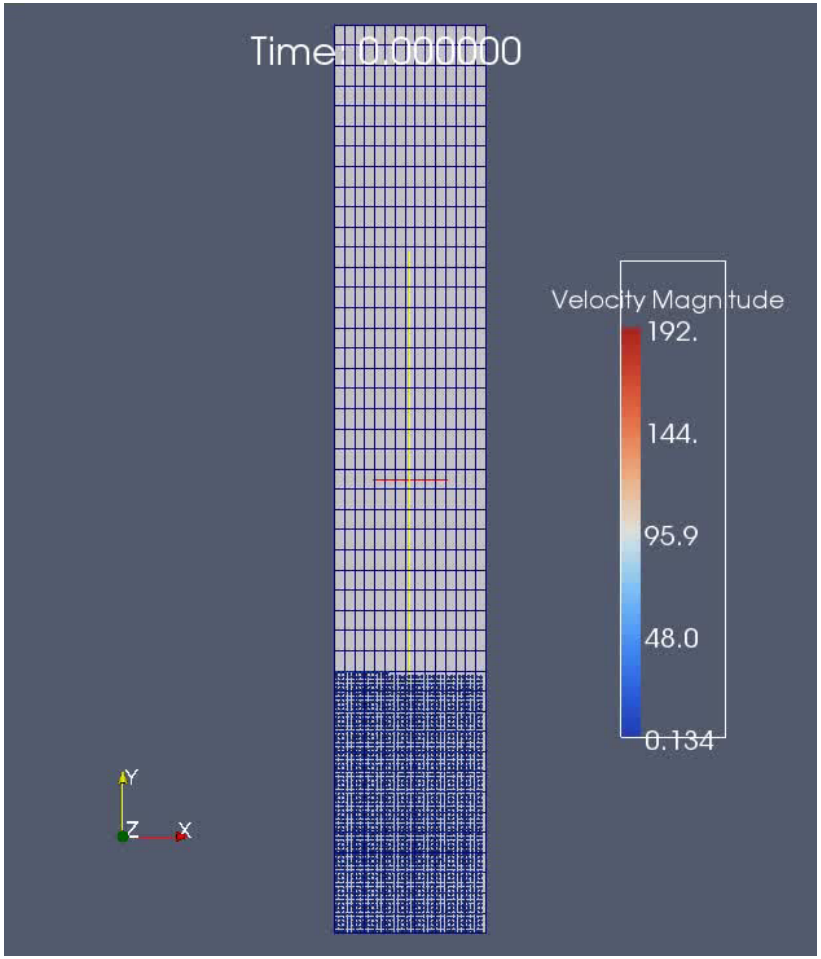
- **Fine DEM**
  - **Grid: 15x45= 675**
  - **2148 particles**
  - **8 hours for 20s simulation**
- **Coarse DEM**
  - **Grid: 7x15= 105**
  - **322 particles (ambiguity about 3D particles in a 2D simulation)**
  - **23 minutes for 20s simulation**



Coarse DEM: Results



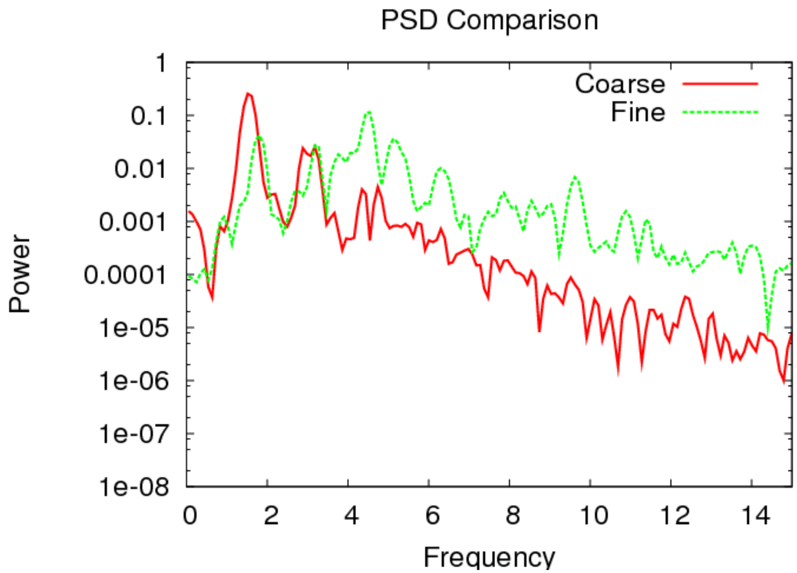
Coarse

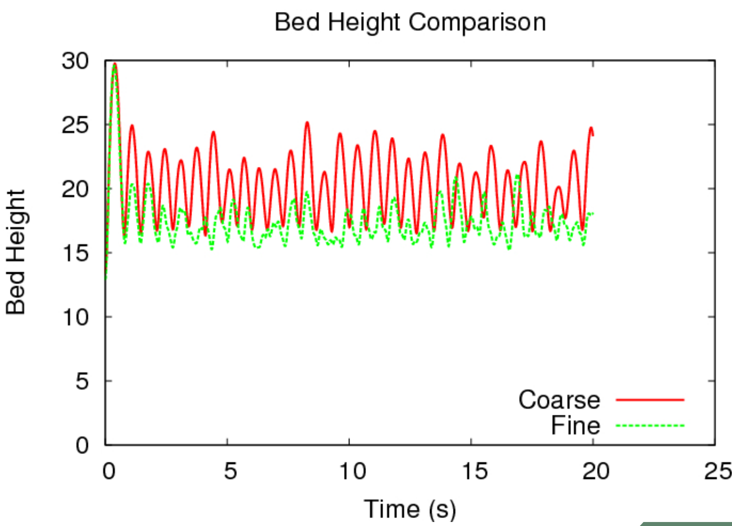


Coarse

Coarse DEM: Results

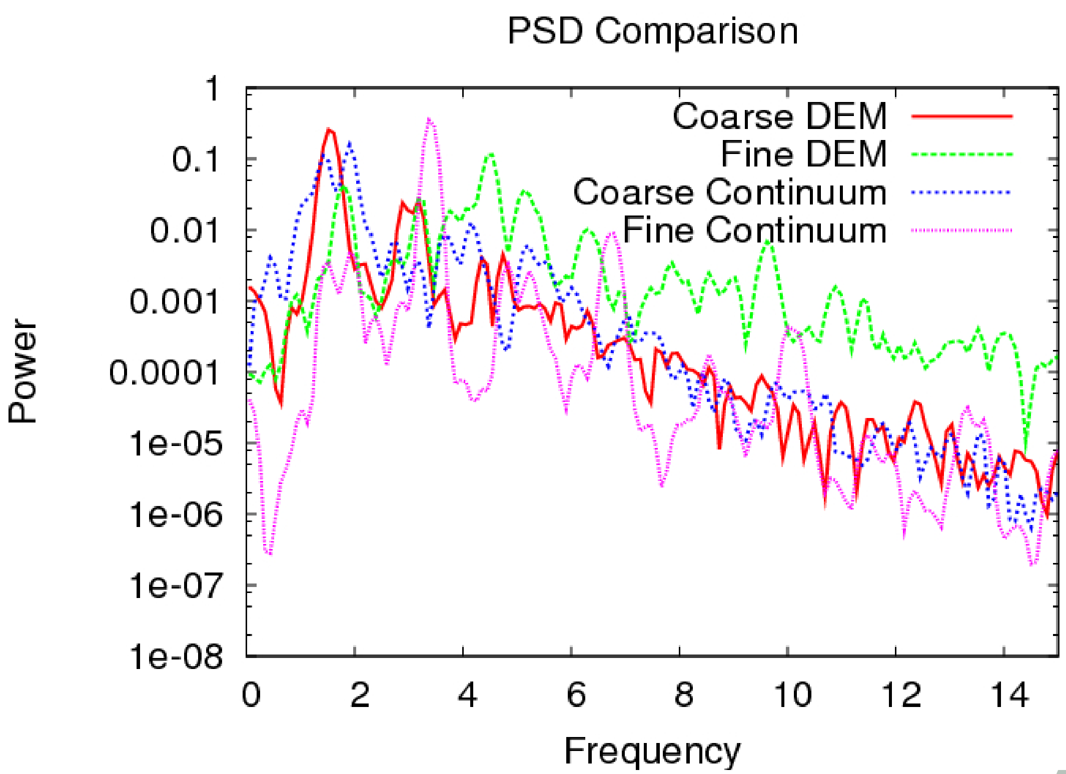
- **The first two modes seem to be reasonable**
- **The bed height has same qualitative behavior but quantitatively different**
  - **2D vs. 3D particle in a 2D domain?**
  - **What would be the effect on conversion and residence time?**





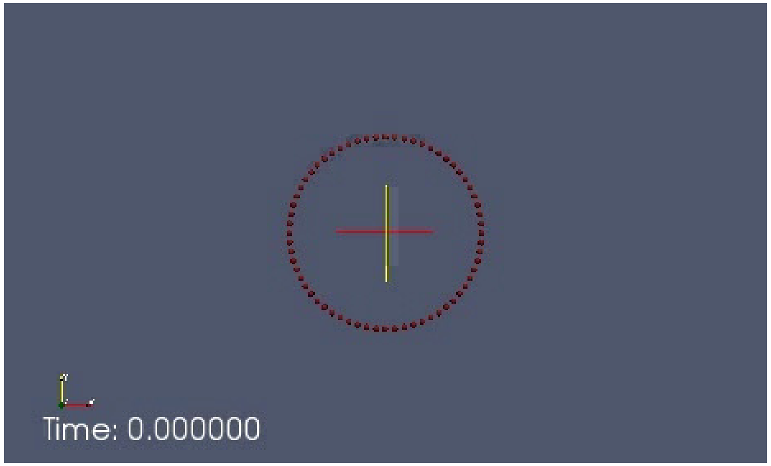
Coarse DEM: Results

- **The coarse continuum (7x23) seems to only resolve the first slowest mode**
- **The fine continuum (15x45) seems to have additional modes but does not have the same behavior as fine DEM at higher frequencies**
  - **Lack of particle-level fluctuations**
  - **Role of granular stress formulation**



Coarse DEM: Advantages of Lagrangian advection of particles

- **Convection of particles on a sphere and circle**
- **On an Eulerian grid, these sharp interfaces would have diffused**
- **The sharp interfaces are very important in driving the dynamics of multiphase flows**
- **This might be one reason why poor sampling in Eulerian approach gives bad results while the Lagrangian can still give decent results?**
  - **More work needs to be done to ascertain the same**
  - **Provide clues as to how one can make Eulerian calculations more efficient**



Coarse DEM: Conclusions

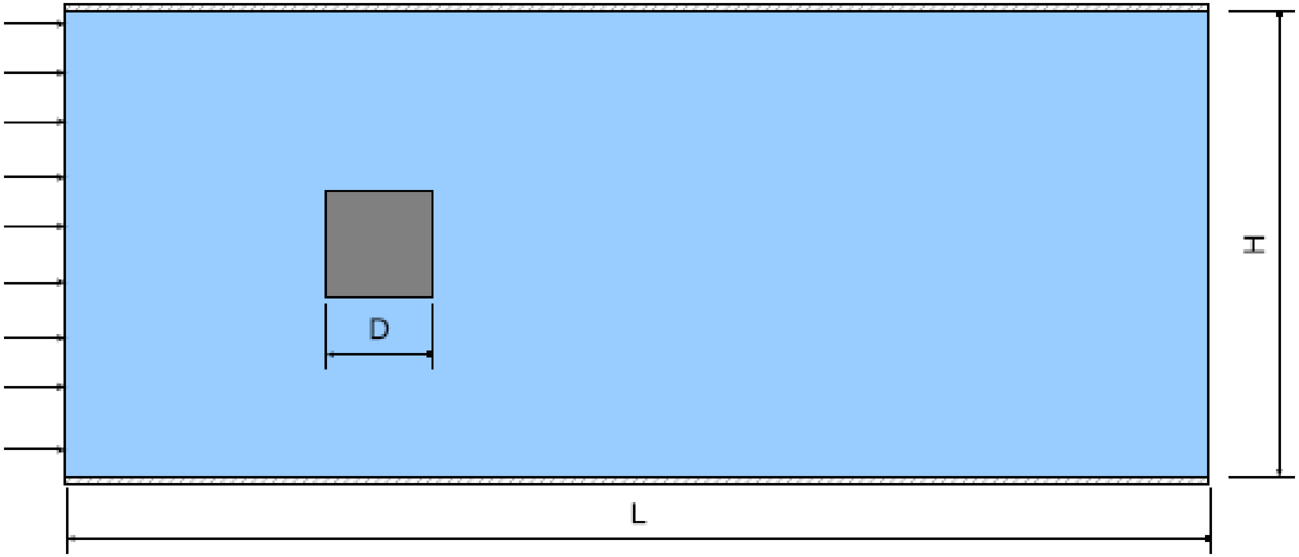
- The initial results are very promising and the tests will be extended to other fluidized bed systems
  - Validation
- Further work needs to be done with varying size of the parcels
  - Understand and quantify the errors from the parcel size
  - A 3D problem with 3D particles would be a more suitable problem to analyze
- The role of Lagrangian vs. Eulerian advection needs to be ascertained

Phase-space based POD (PPOD?)

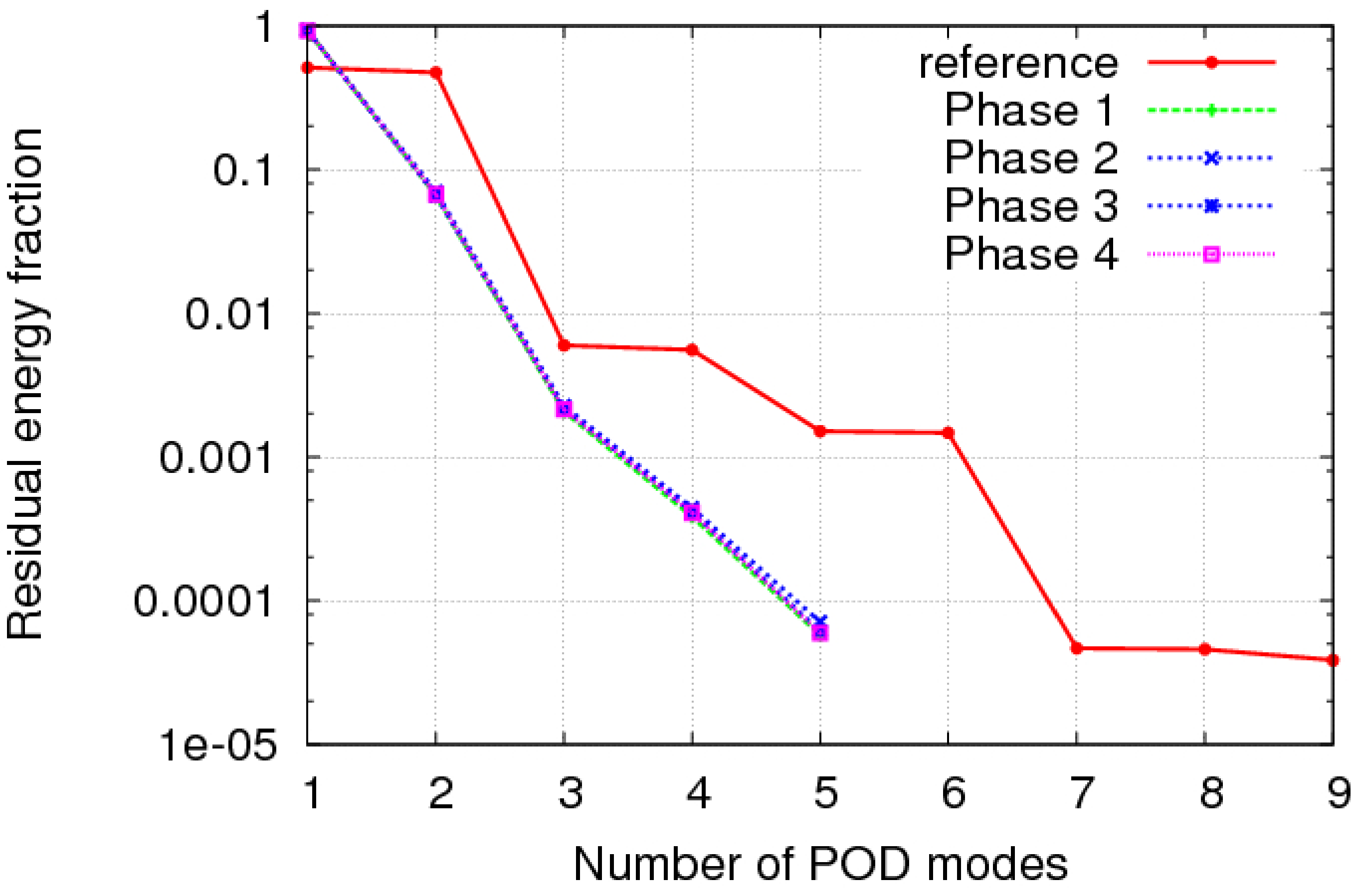
- **POD gives the most efficient basis to represent if the data lies close to linear subspaces**
- **Highly nonlinear data from multiphase flow calculations necessarily does not lie close to the linear subspaces**
  - **Large number of basis to represent the data**
  - **Slow convergence**
- **However, both experimental and numerical data has shown that multiphase systems lie on low dimensional manifolds**
  - **Maybe we can exploit this fact to construct localized POD basis in different phase space regions**
- **Here we present some preliminary results on two cases: flow over a square block and a flat bottomed spouted bed**

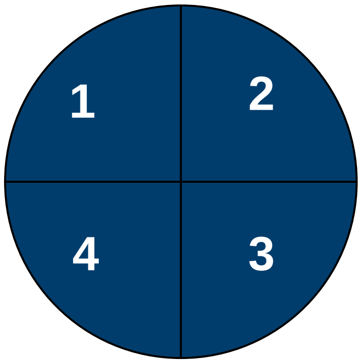
PPOD – Flow over a block: Setup

- **Re = ~75**
- **L/D = 20**
- **H/D = 9**
- **Vortex shedding frequency = 4.54s**



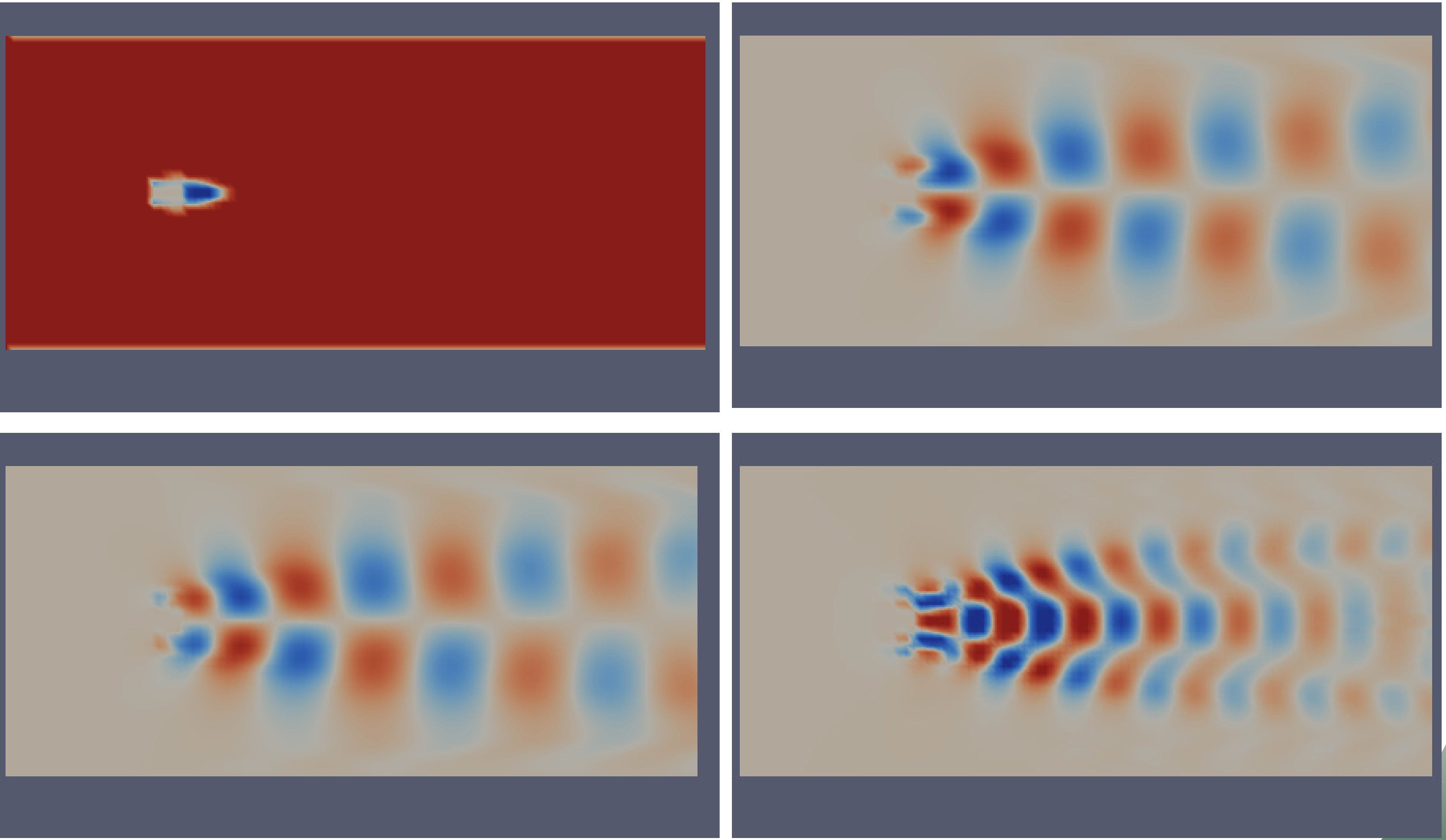
PPOD – Flow over a block: Energy Residual vs. POD modes



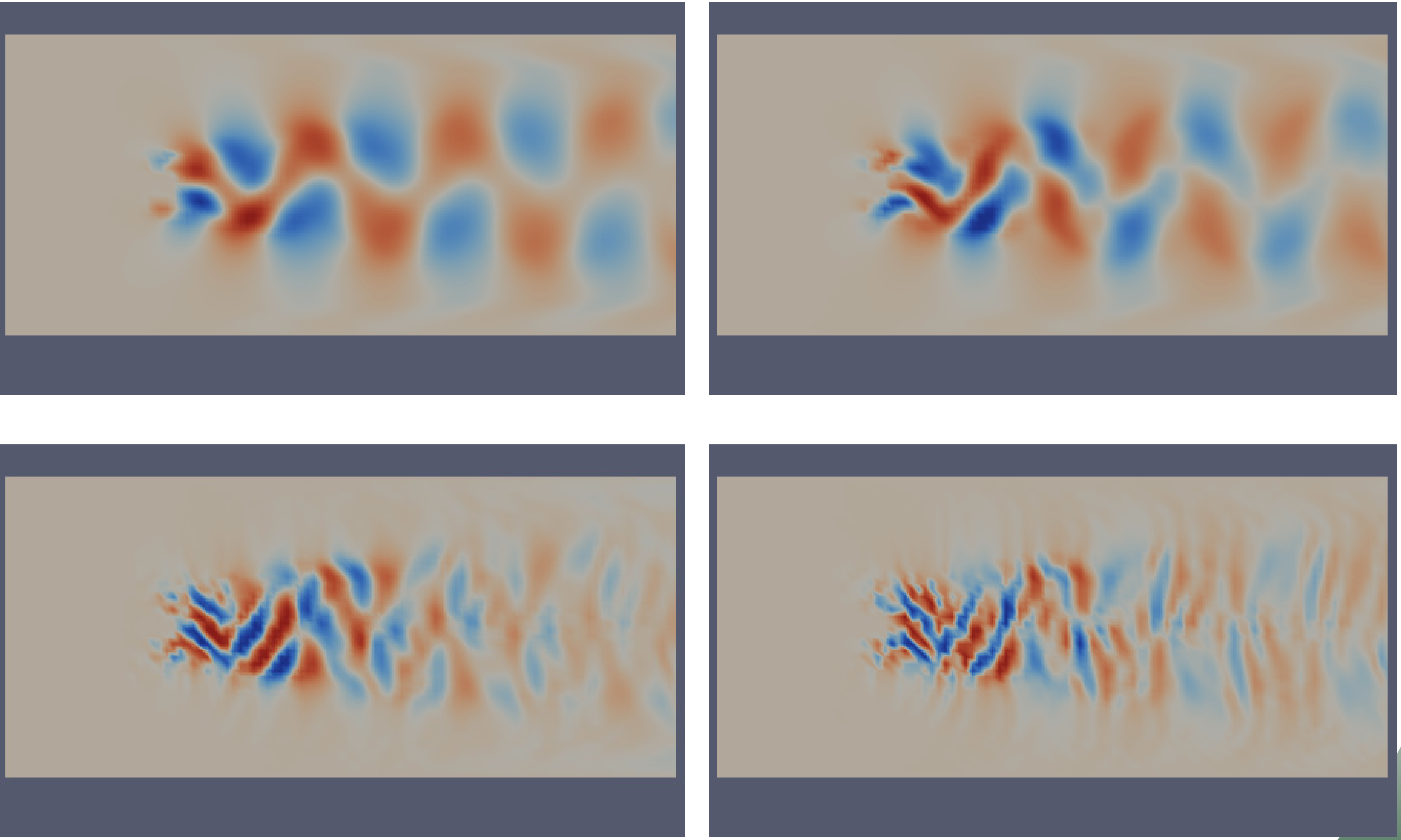


Exponential convergence with phase space subdivisions

PPOD – Flow over a block: POD basis for reference case

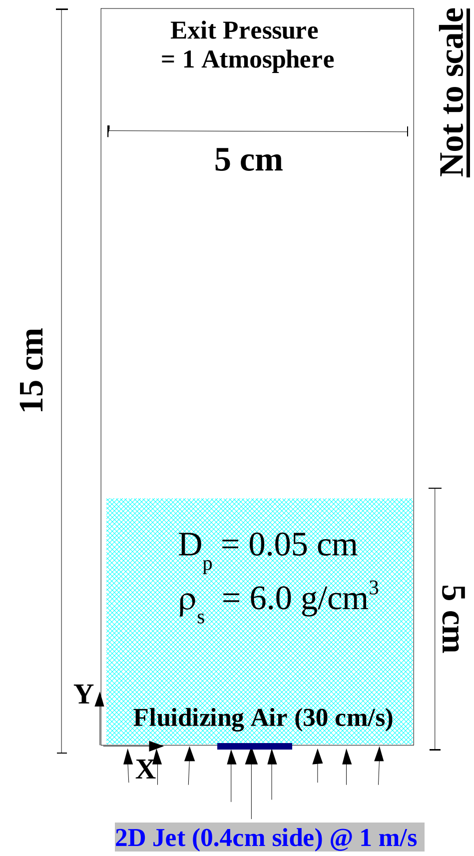


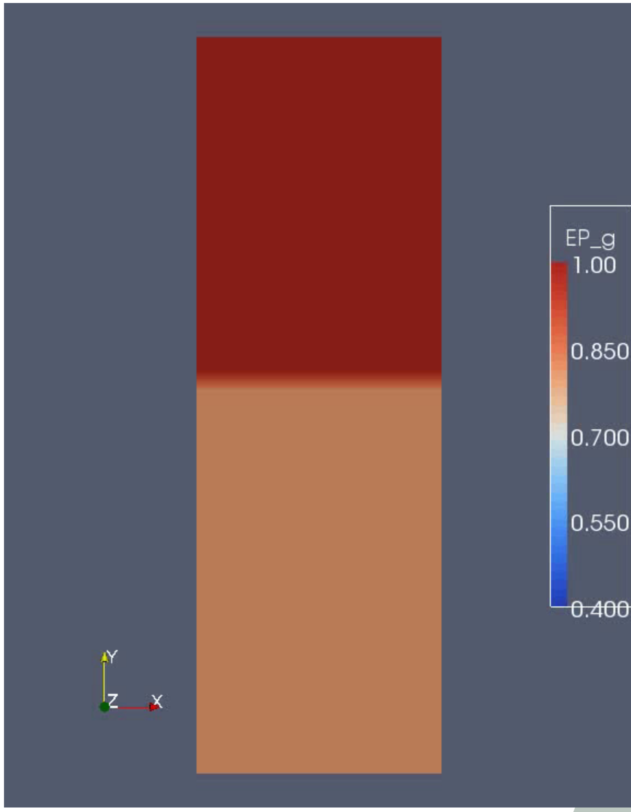
PPOD – Flow over a block: POD basis for phase 1



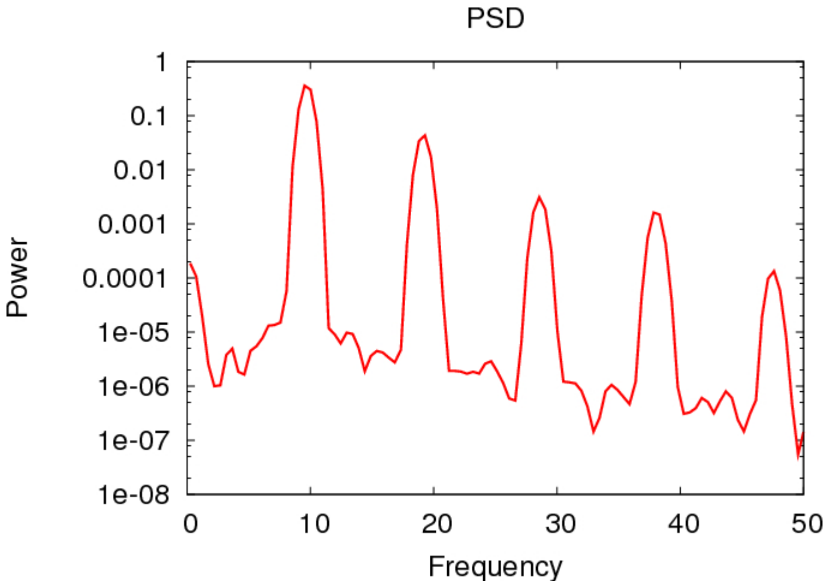
PPOD – Spouted bed

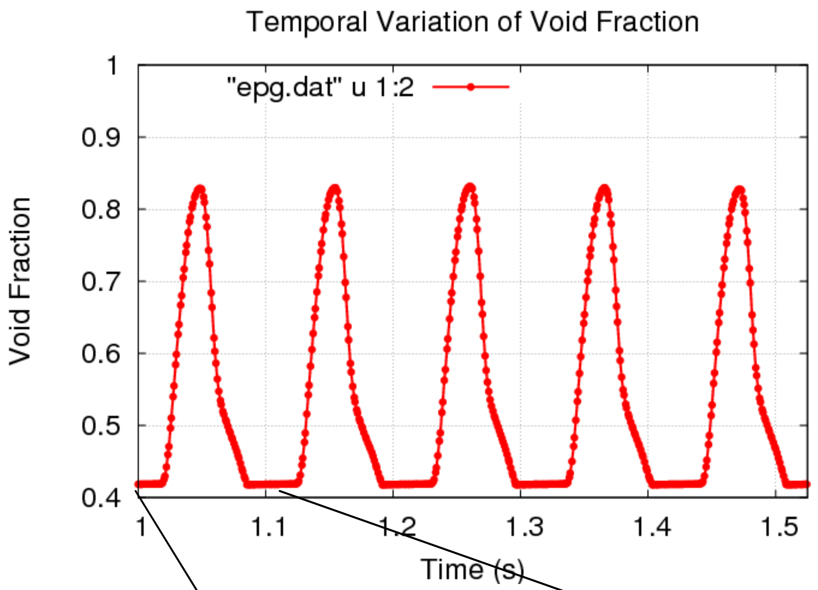
- **Grid 50x75**
- **Exhibits periodic behavior**
- **Can we construct local POD basis based on phase angle just as in the flow over the block?**



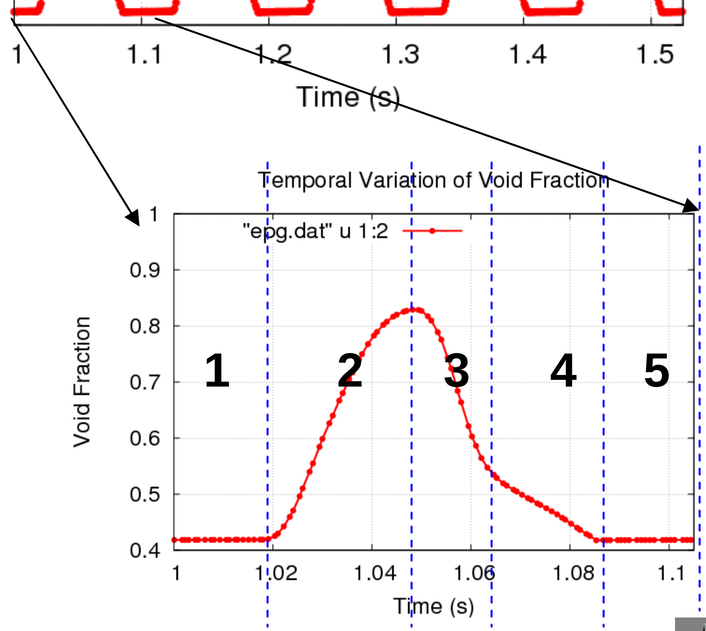


PPOD – Spouted bed: Can we exploit the periodicity?

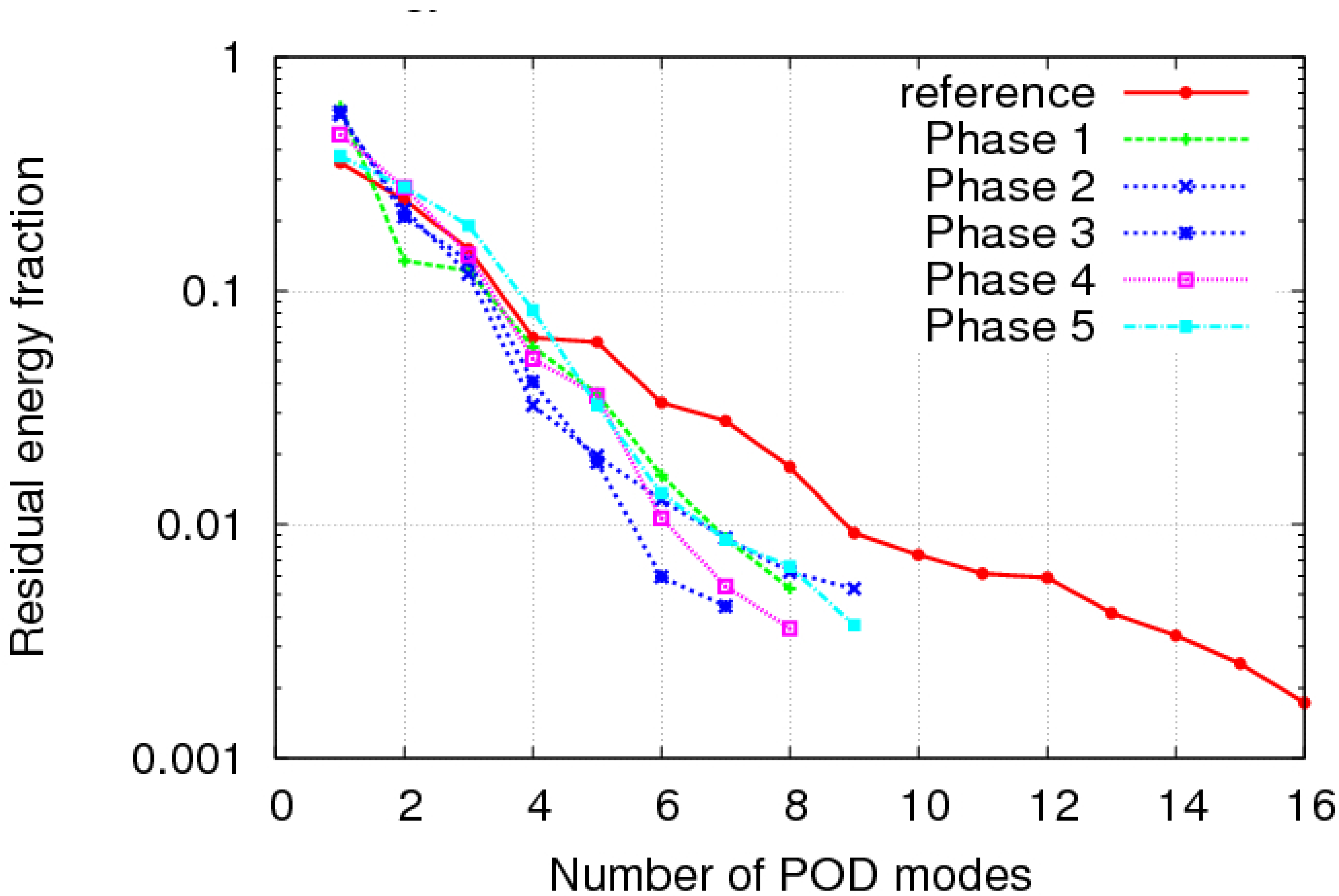




- **High frequency pulse**
- **Can we exploit this phenomena?**

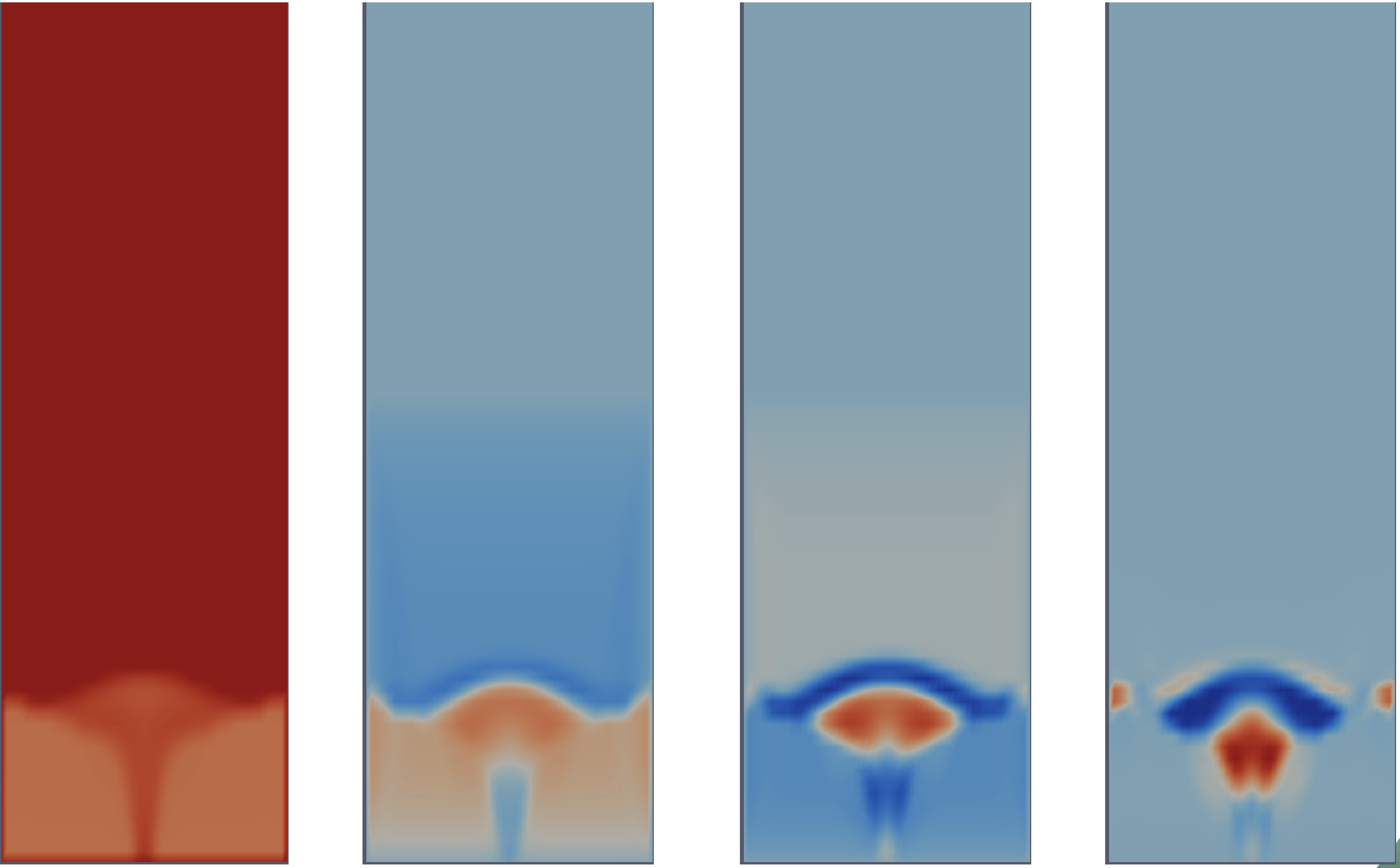


PPOD – Spouted bed: Energy residual vs. POD modes

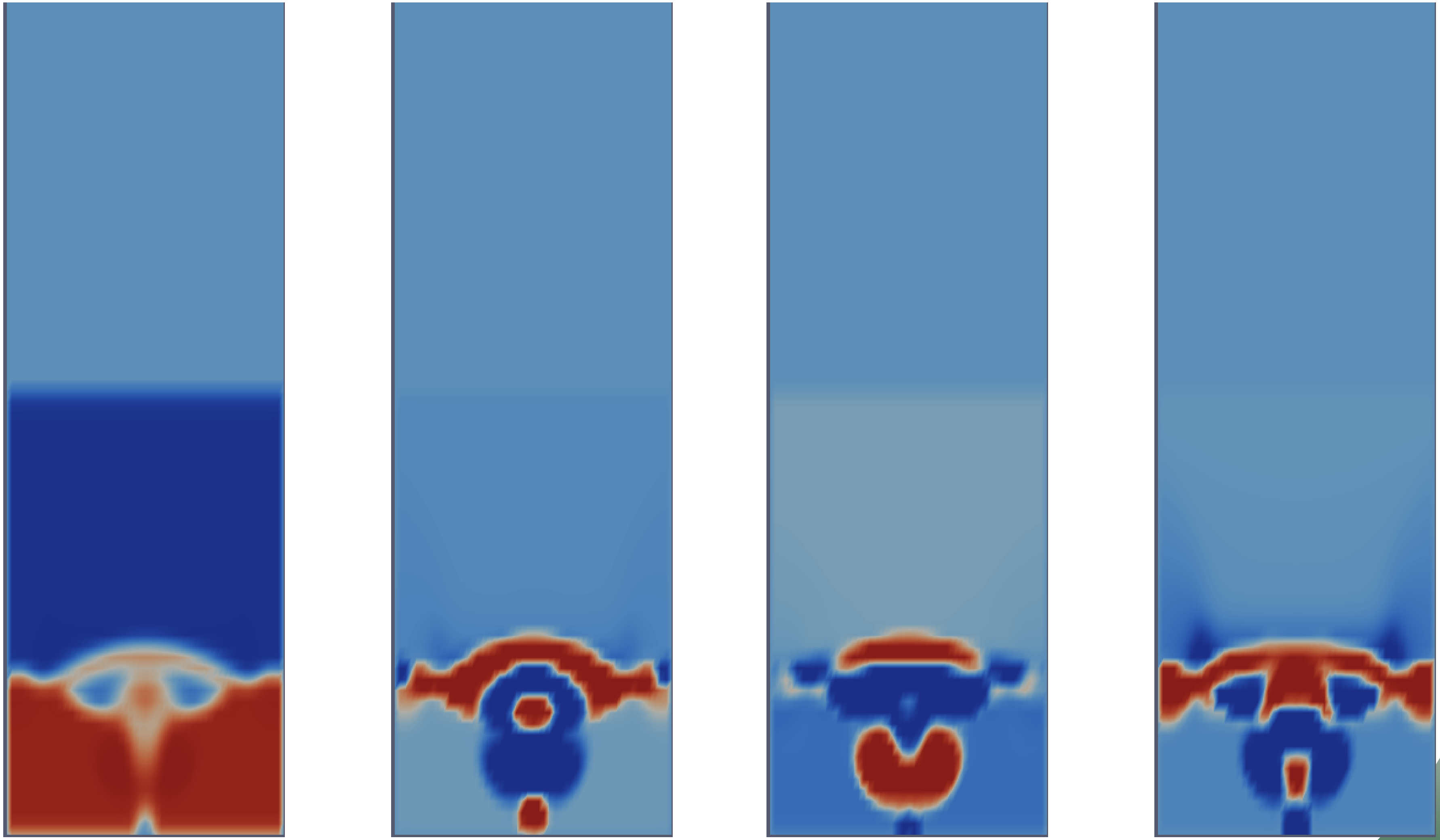


Rapid convergence with phase space subdivisions

PPOD – Spouted bed: POD basis snapshots for reference case



PPOD – Spouted bed: POD basis snapshots from phase 1

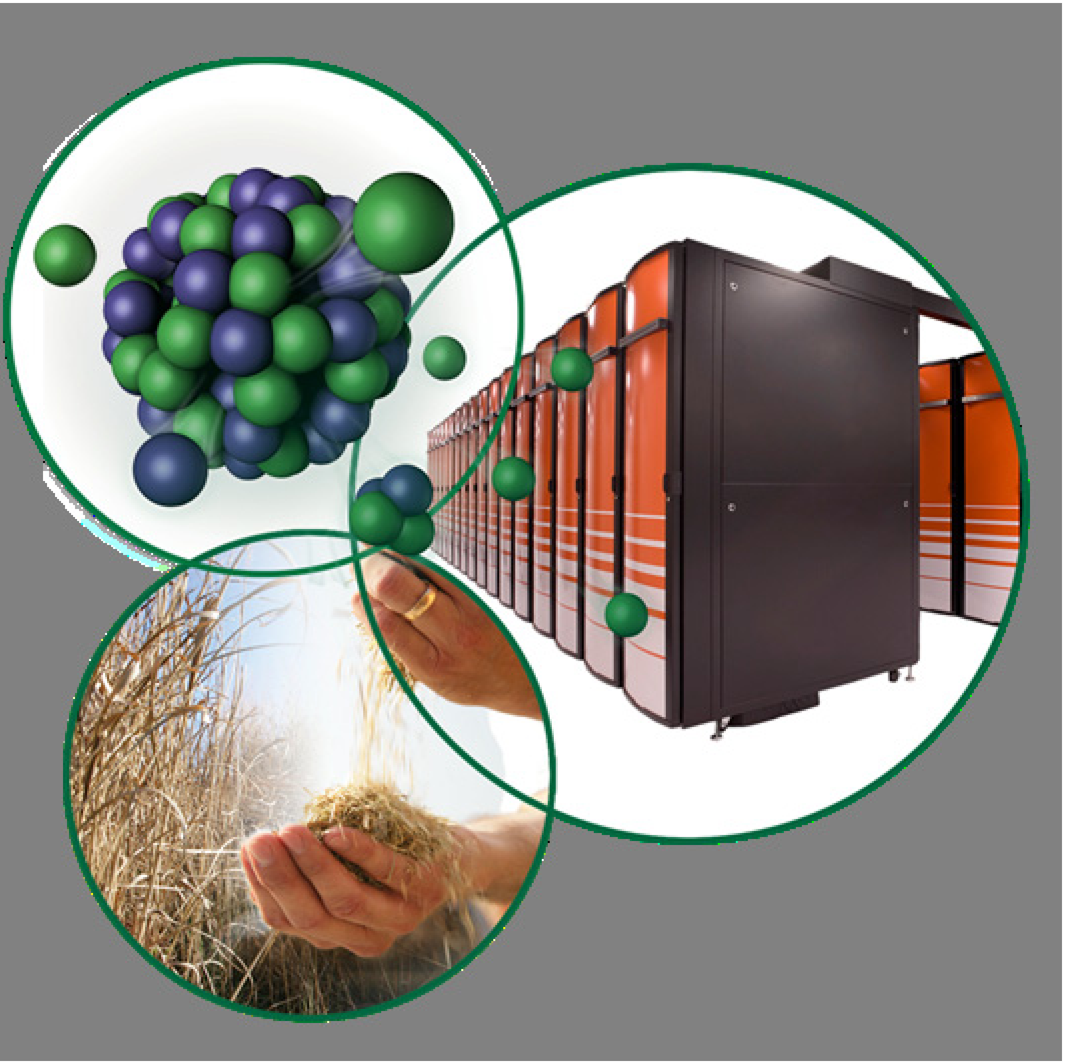


PPOD – Conclusions

- Linear subspaces identified based on physics can be exploited to construct efficient POD basis
- For the simple problems illustrated here, the number of modes reduces by ½ to get to given tolerance
  - More important is consistent exponential convergence
- Need to be further explored and generalized

Conclusions and future work

- **There might be still opportunities in ways we can sample our systems to improve computational efficiency**
- **This is work in progress and both these avenues will be explored during rest of the FY**
  - **More systematic study on the coarse DEM**
    - **Identify the differences between forms of coarsening procedures – maybe perform a detailed budget analysis**
  - **Explore the efficiency of PPOD for different parameter space**



Thank You!!