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Statistical approach for the evaluation of an effective conductivity in a complex solid

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Methodology

Statistical method of Monte Carlo to solve combined conductive-radiative heat transfer in the solid phase of a porous medium.

Model

- **Solid spheres** at the stationary state

$$\nabla^2 T(\mathbf{x}) = 0 \quad (\text{solide}) \quad (1)$$

- **Vacuum** at the stationary state

$$\omega \cdot \nabla I = 0 \quad (\text{void}) \quad (2)$$

- **Solid/Void boundary condition** : conduction/radiation

$$-\lambda \nabla T \cdot \mathbf{n} = \epsilon \sigma T^4 \quad (3)$$

$$-\epsilon \int_{\partial H(\mathbf{n})} \omega' \cdot \mathbf{n} I(\mathbf{y}, -\omega') d\omega'$$

Statistical formulation

- **Solid spheres** (with $\mathbf{v}_i = (-1)^i \mathbf{e}_{\lfloor \frac{i+1}{2} \rfloor}$)

$$T(\mathbf{x}) = \frac{1}{6} \sum_{i=1}^6 T(\mathbf{x} + \delta \mathbf{v}_i) \quad (4)$$

Discretization of space on an orthonormal basis $(\mathbf{x}, \mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3)$

- **Vacuum**

$$T_R = \mathbb{E}(A_{R,bot} T_{min} + A_{R,C} T(\mathbf{Y}_R)) \quad (5)$$

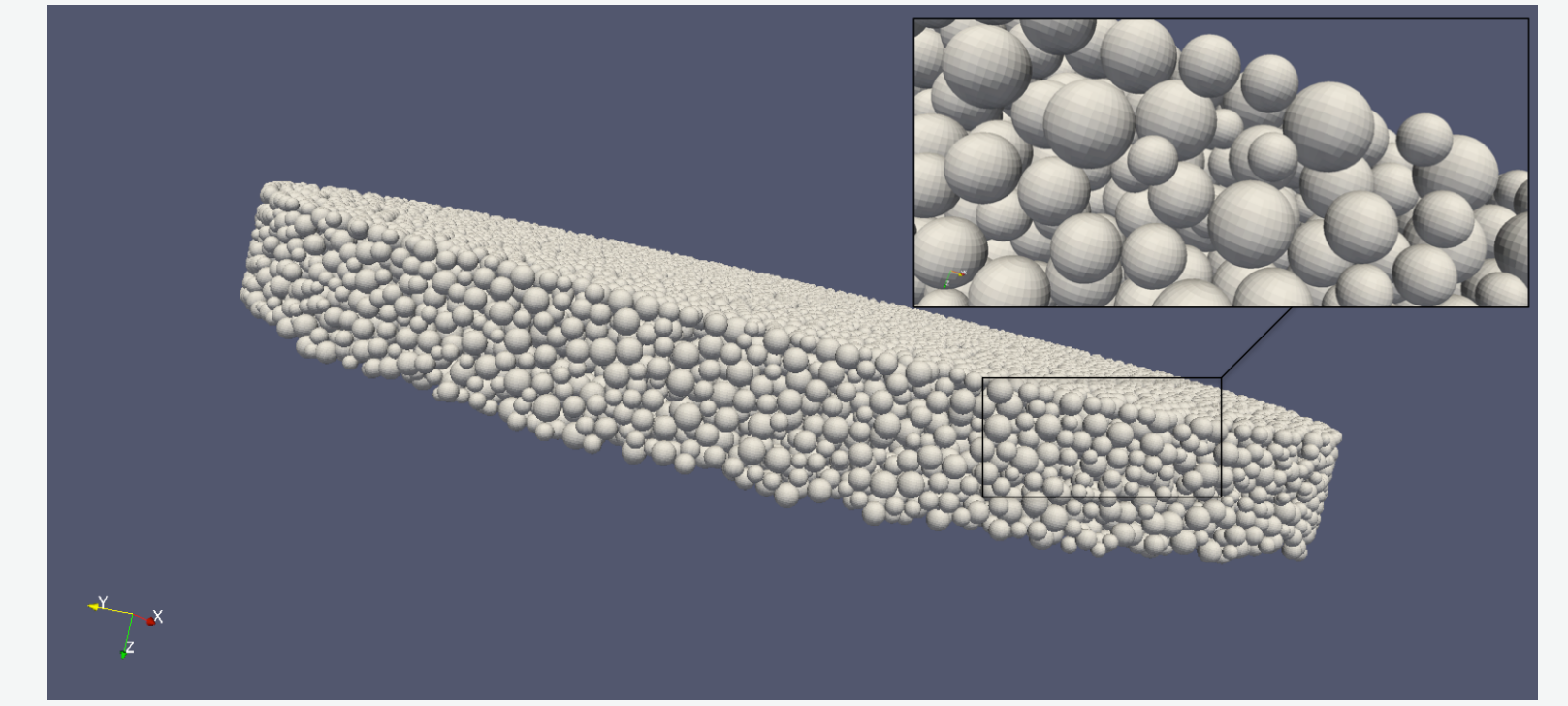
$$+ A_{R,top} \left(\frac{\varphi}{\pi h} + T_R(\mathbf{Y}_R, \Omega_R) \right)$$

- **Linearized solid/void boundary condition**

$$T(\mathbf{y}) = p_S T(\mathbf{y} - \delta_b) + p_R T_R(\mathbf{y}) \quad (6)$$

Test Case

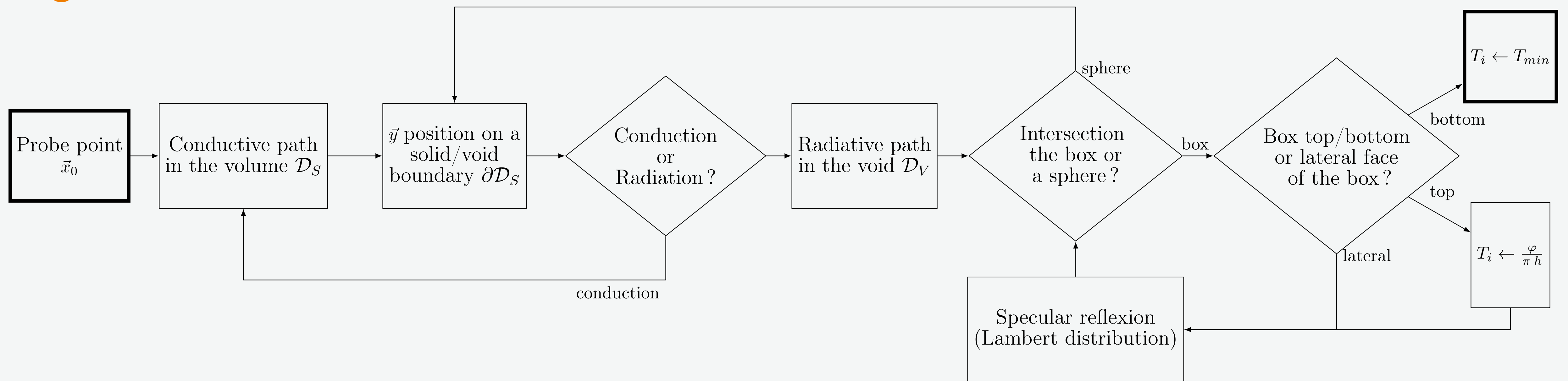
- **3D slab-shape** Assembly of solid spheres interpenetrating slightly in the void



Assumptions :

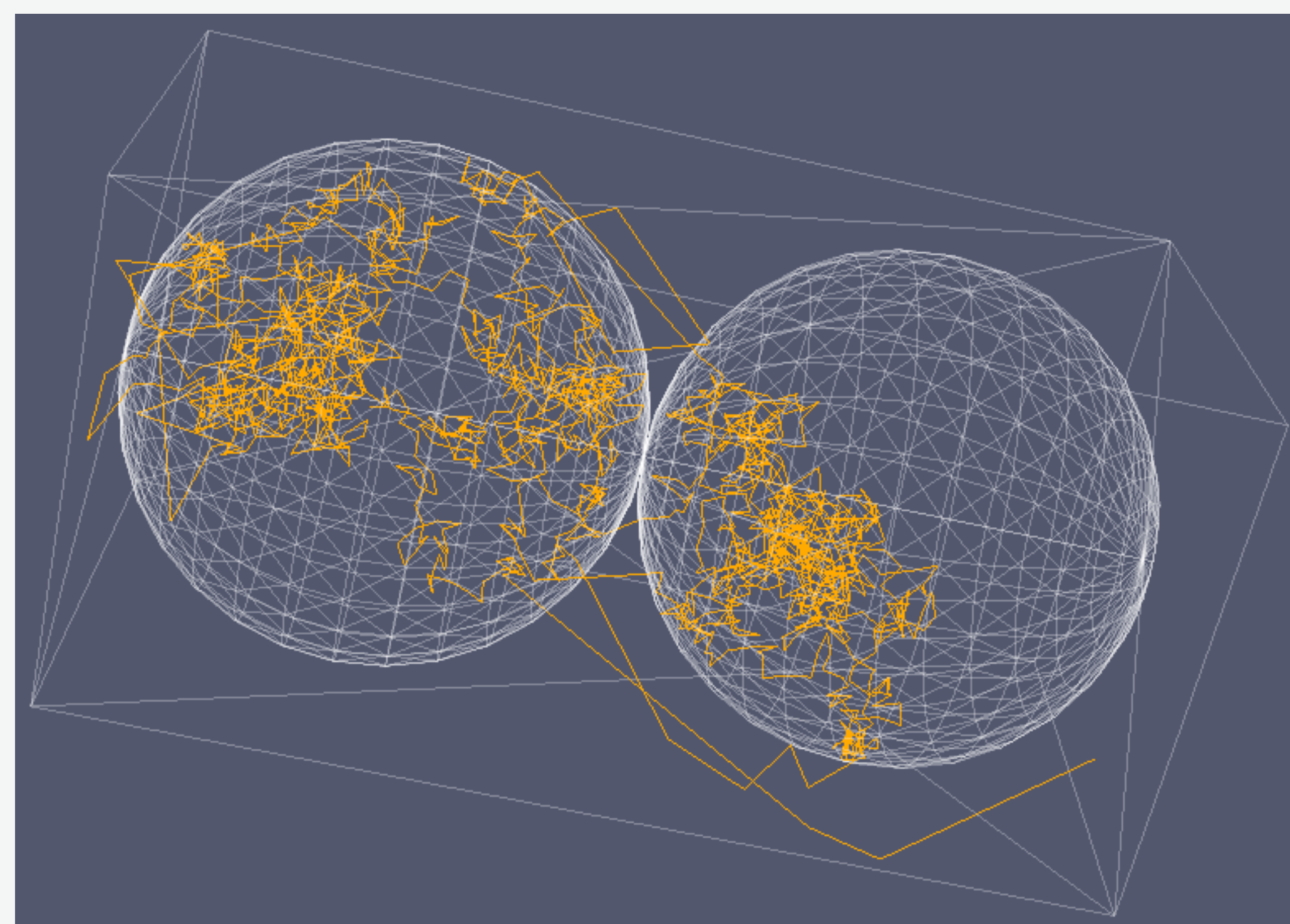
- Grey opaque spheres ϵ
- Radiative heat flux φ
- Radiative temperature T_{min}

Algorithm

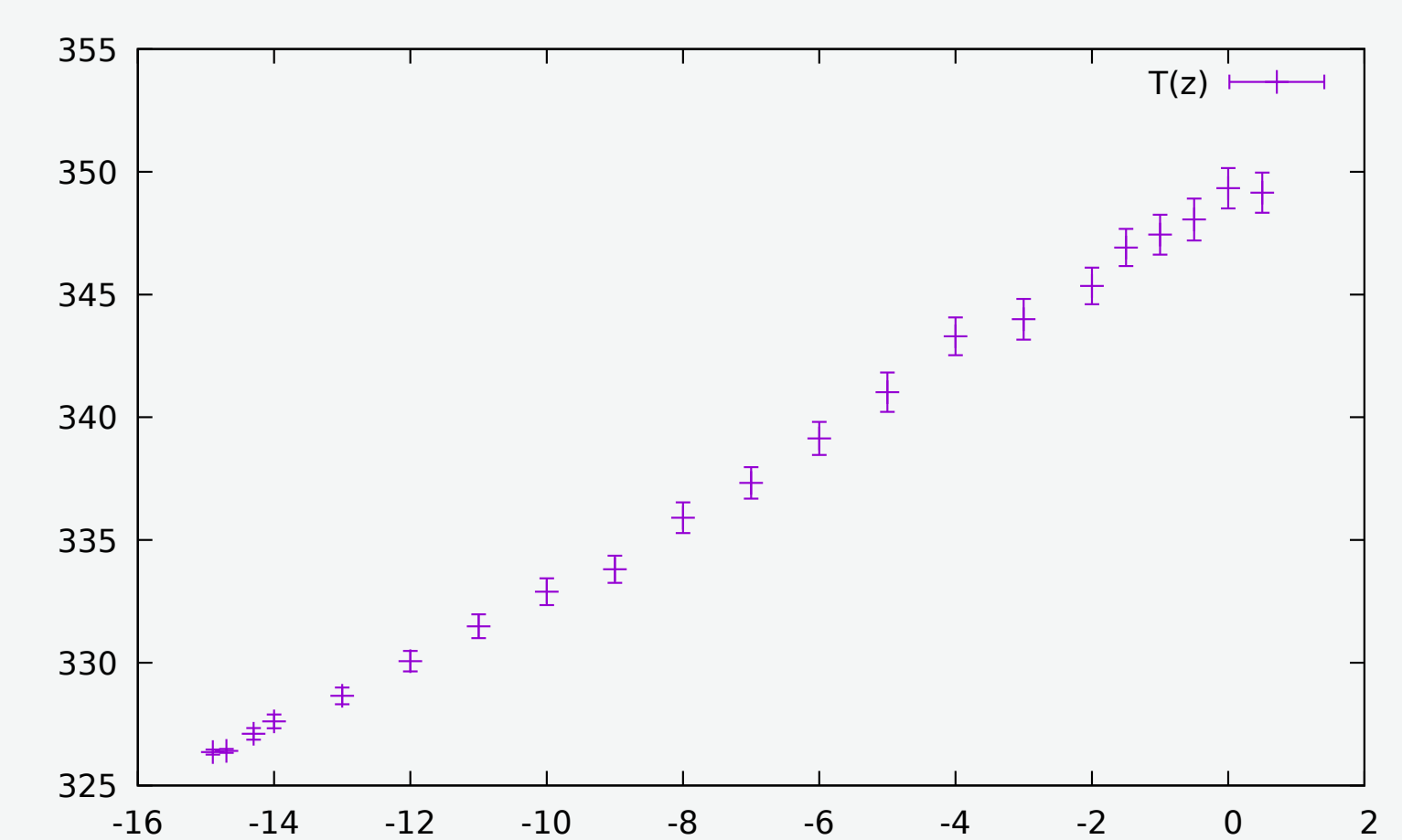


Conducto-radiative paths

- **Representation of the paths** from the probe point \mathbf{x}_0



Approach to obtain λ_{eff}



- **Temperature profile** $T_m(z)$ of the bed of spheres :

$$T_m(z) = \frac{1}{n} \sum_{i=0}^n T_i(\mathbf{x}) \quad (7)$$

- **Continuity of flux** at the solid/void boundary :

$$\lambda_{eff} = \frac{\varphi}{dT_m/dz} \quad (8)$$

NB: λ_{eff} computation is not complete yet, the aim is hence to present the method.

Conclusion

- A single Monte Carlo algorithm to solve combined conductive-radiative problem in a complex solid.
- Realizations of the algorithm can be interpreted as a succession of conductive-radiative paths.
- **Perspectives :**
 - Validation of the algorithm
 - Computation of the temperature as a function of the effective conductivity (Symbolic Monte Carlo)