

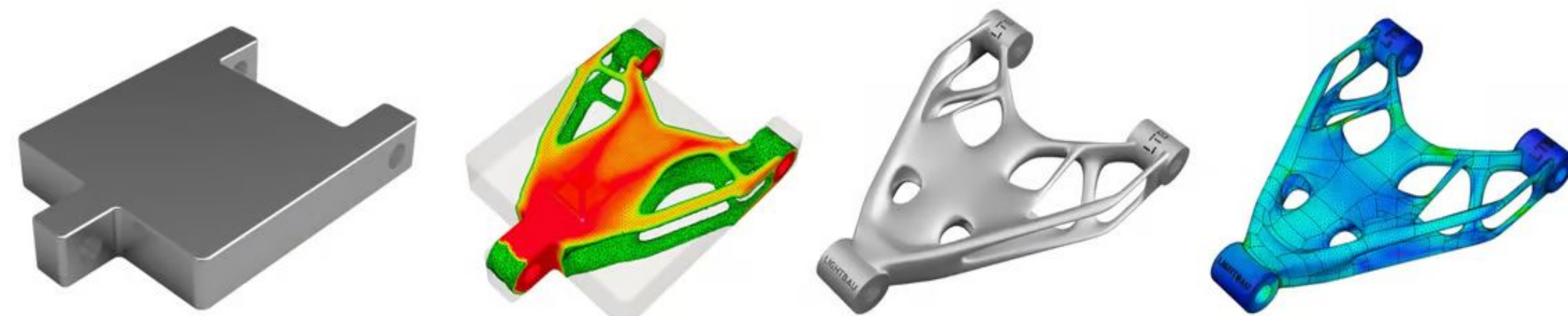
Minimizing Plasma-Facing Component Heat Flux Using Unsupervised Mesh Generation

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Motivation and Background

- Plasma-facing components (PFCs) require fine-tuned designs optimized for multiple parameters in order to survive high heat loads, heat flux - a significant design challenge
- **Topology optimization** algorithms can explore design spaces and discover novel designs beyond conventional methods, but existing tools are often strictly constrained
- A machine-learning model that **autonomously learns design parameters with minimal restrictions to generate PFC topologies that minimize peak heat flux** can be generalized for many applications



Example of topology optimization - structural optimization with finite element method

Defining the Objective Function

- What defines an "optimal" PFC design?
 - Peak heat flux must be minimized
 - Surface must be sufficiently smooth - machining constraint and avoiding features with high heat loads
 - Algorithm should modify individual elements while moving elements together with awareness of global geometry

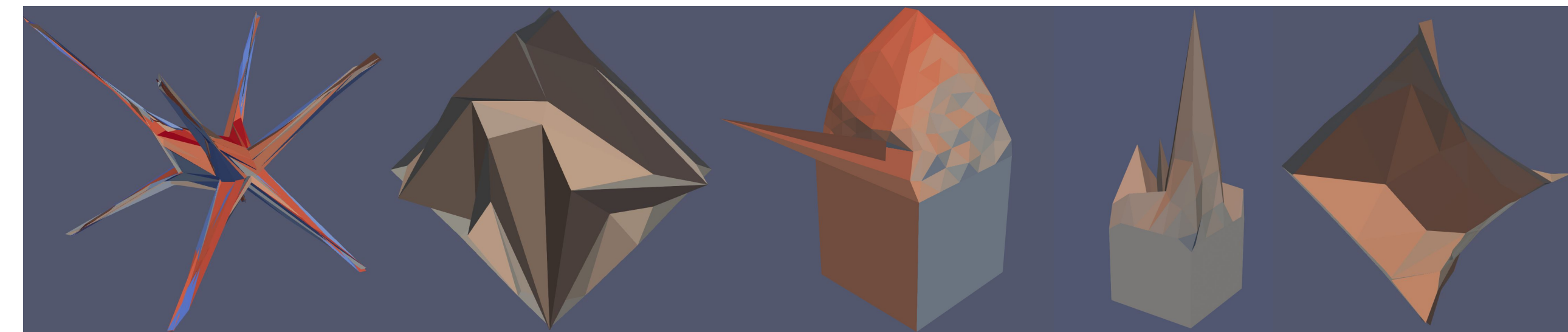
$$C_0 \cdot \text{MAX}(q) + C_1 \cdot \sum_i \frac{q_i}{(\sum q)_0} + C_2 \cdot \sum_{ij} \frac{\frac{1}{2} \alpha_{ij} E_{ij}}{(\sum_{ij} \frac{1}{2} \alpha_{ij} E_{ij})_0}$$

MINIMIZE PEAK HEAT FLUX — WITH LOCAL & GLOBAL CHANGES

SMOOTHING TERM

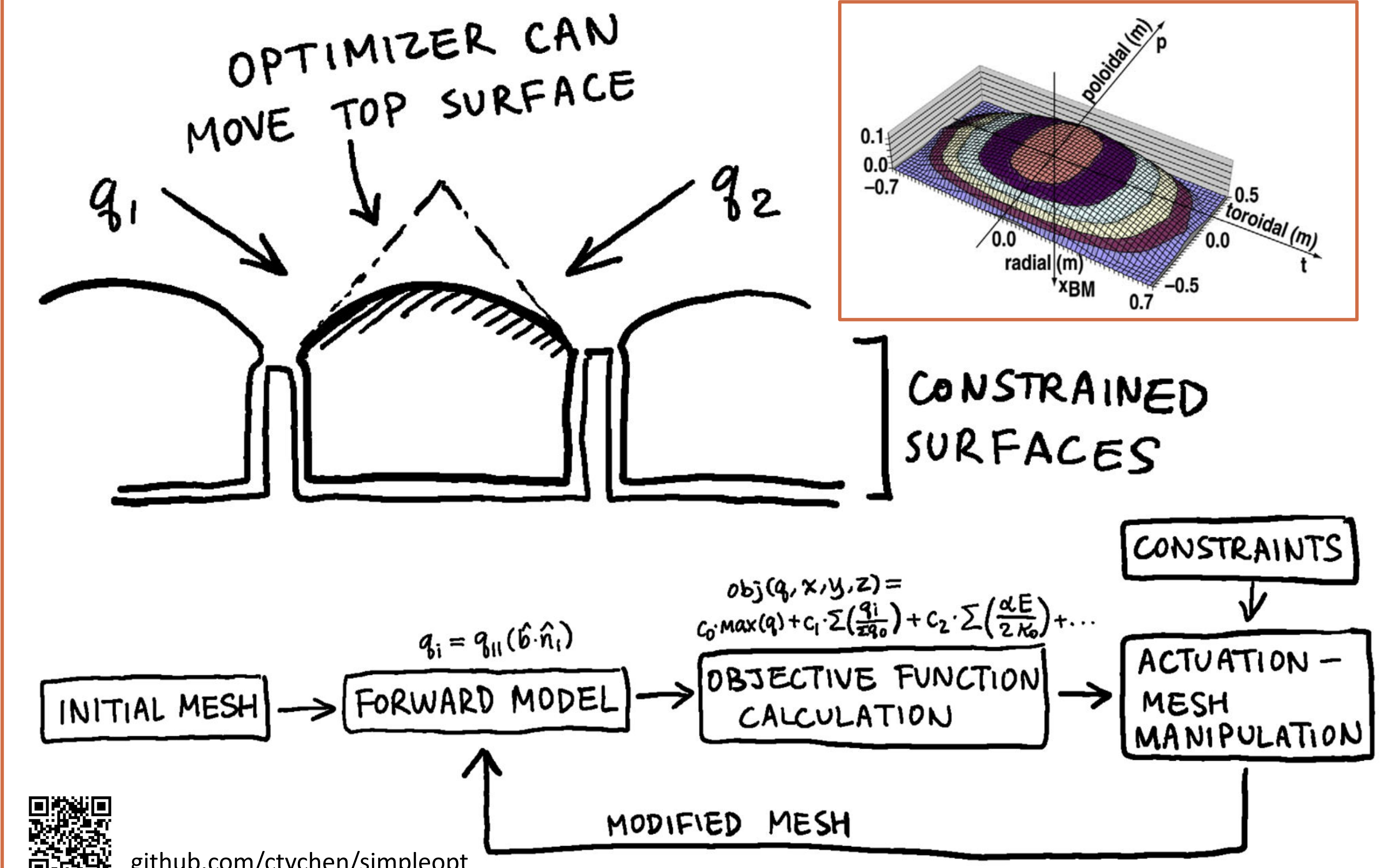
APPROX. INTEGRAL OF MEAN CURVATURE

- Choosing objective function takes tuning - many solutions possible



Can we generate topology for a bi-directional plasma surface?

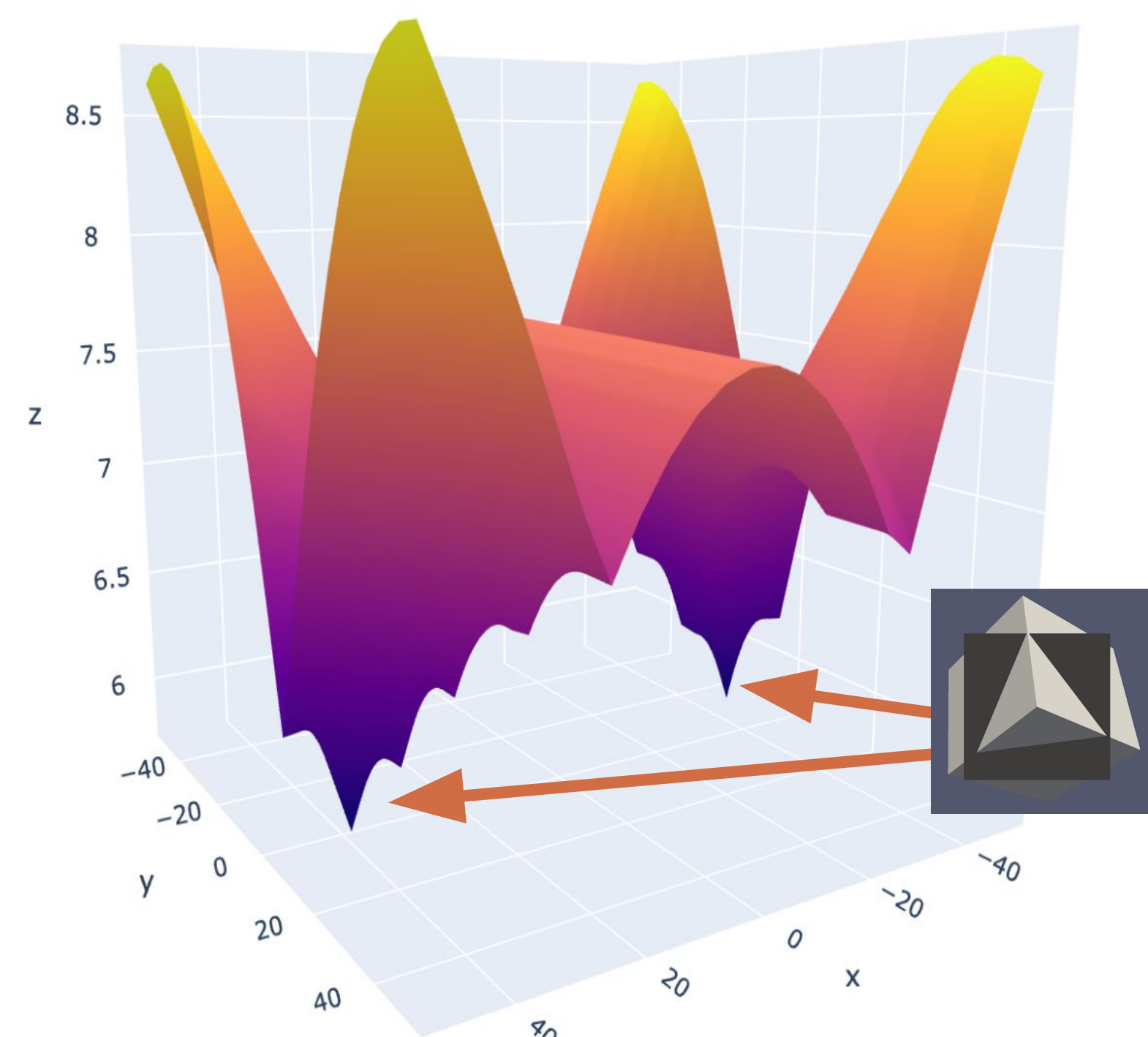
Example: ITER first wall, Stangeby 2009



First Results, Step By Step

1. Exploring space of solutions

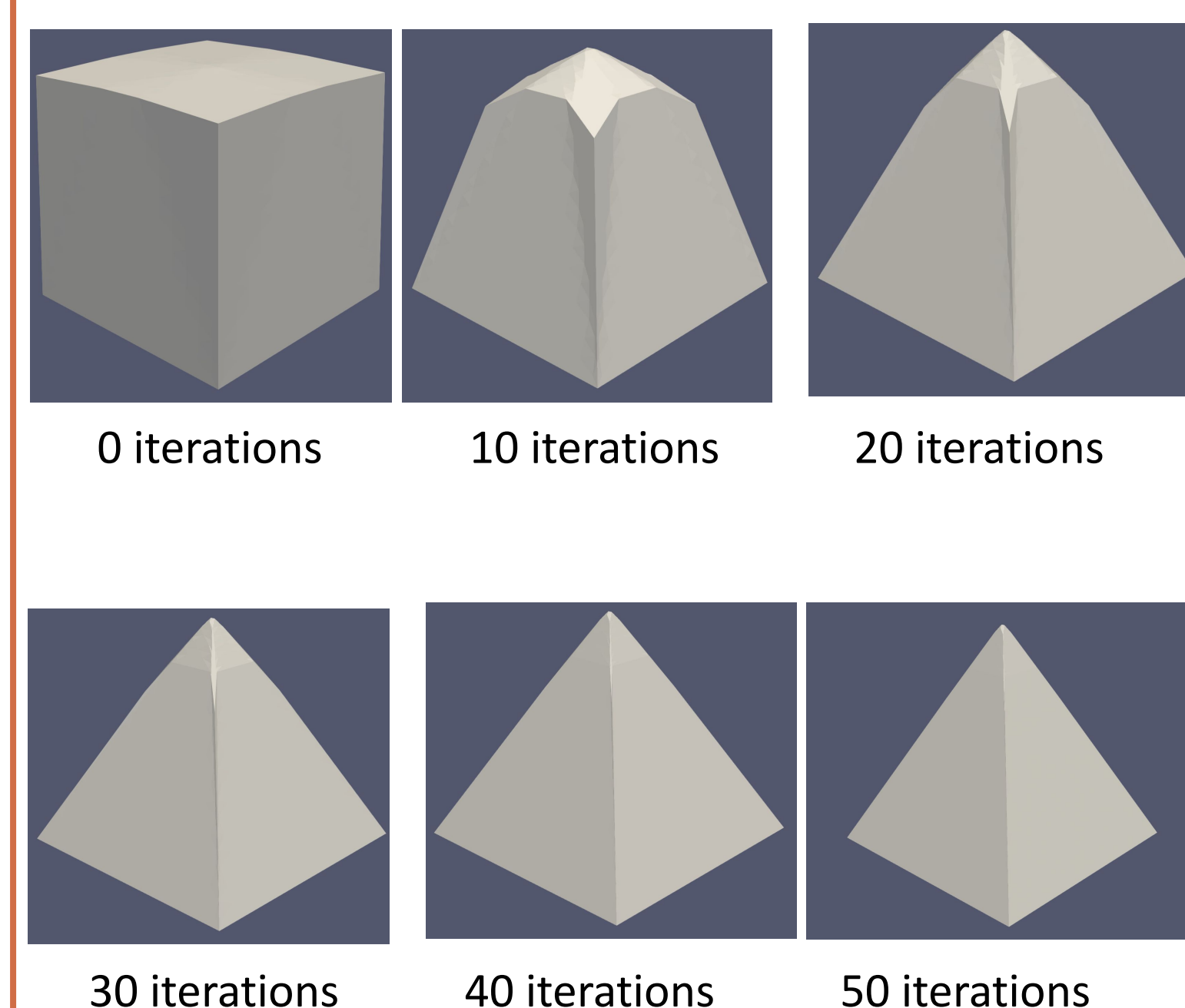
- Understanding sensitivity of objective function and optimization with simple problem with deterministic solutions
- Toy problem: rotate cube to minimize heat flux
- Solutions found at family of local minima



2. Mesh manipulation with objective function

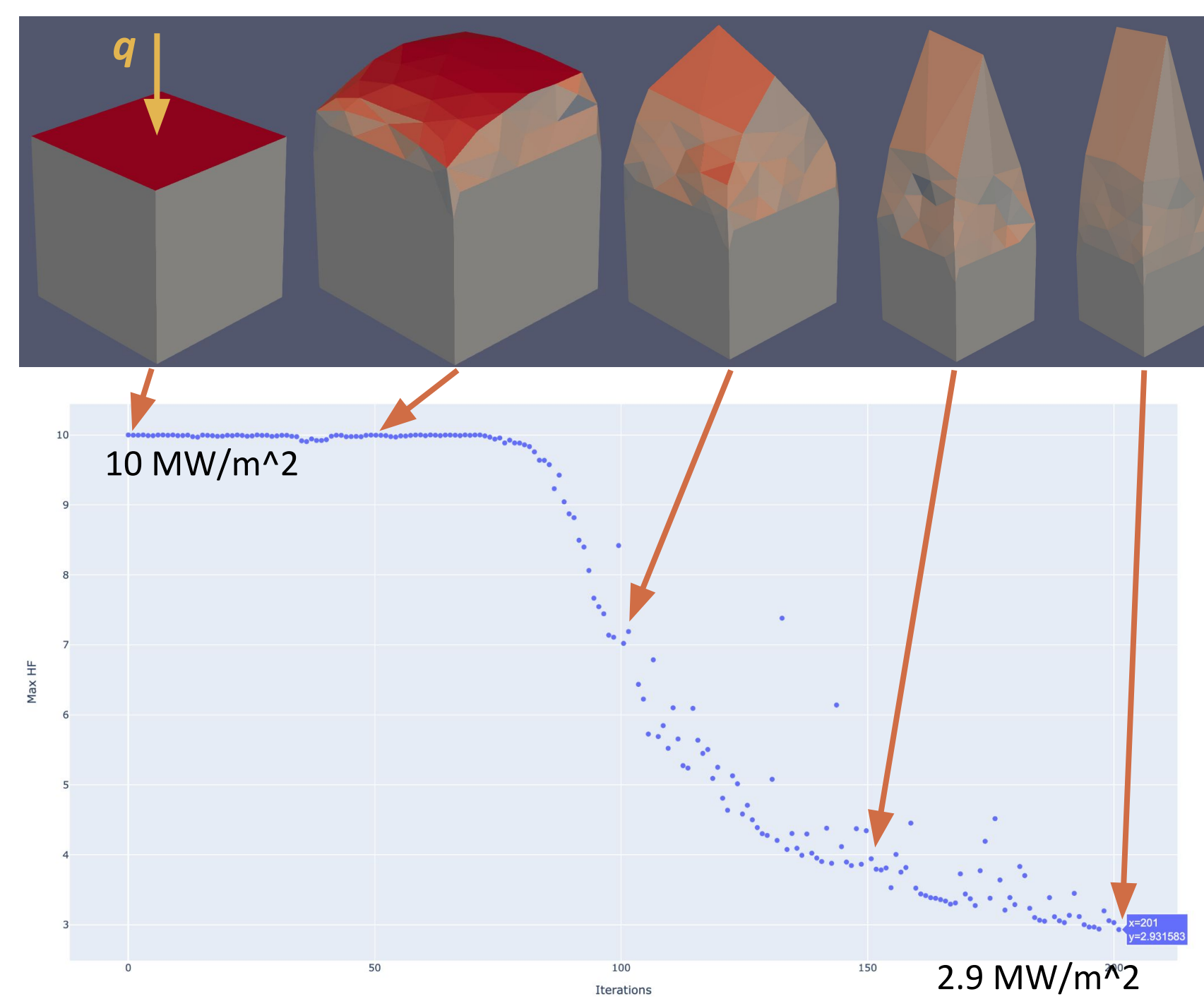
- Toy problem: using gradient descent, transform cube → pyramid
- Objective function:

$$|V_{\text{MESH}} - V_{\text{MESH} \wedge \text{TARGET}}|$$



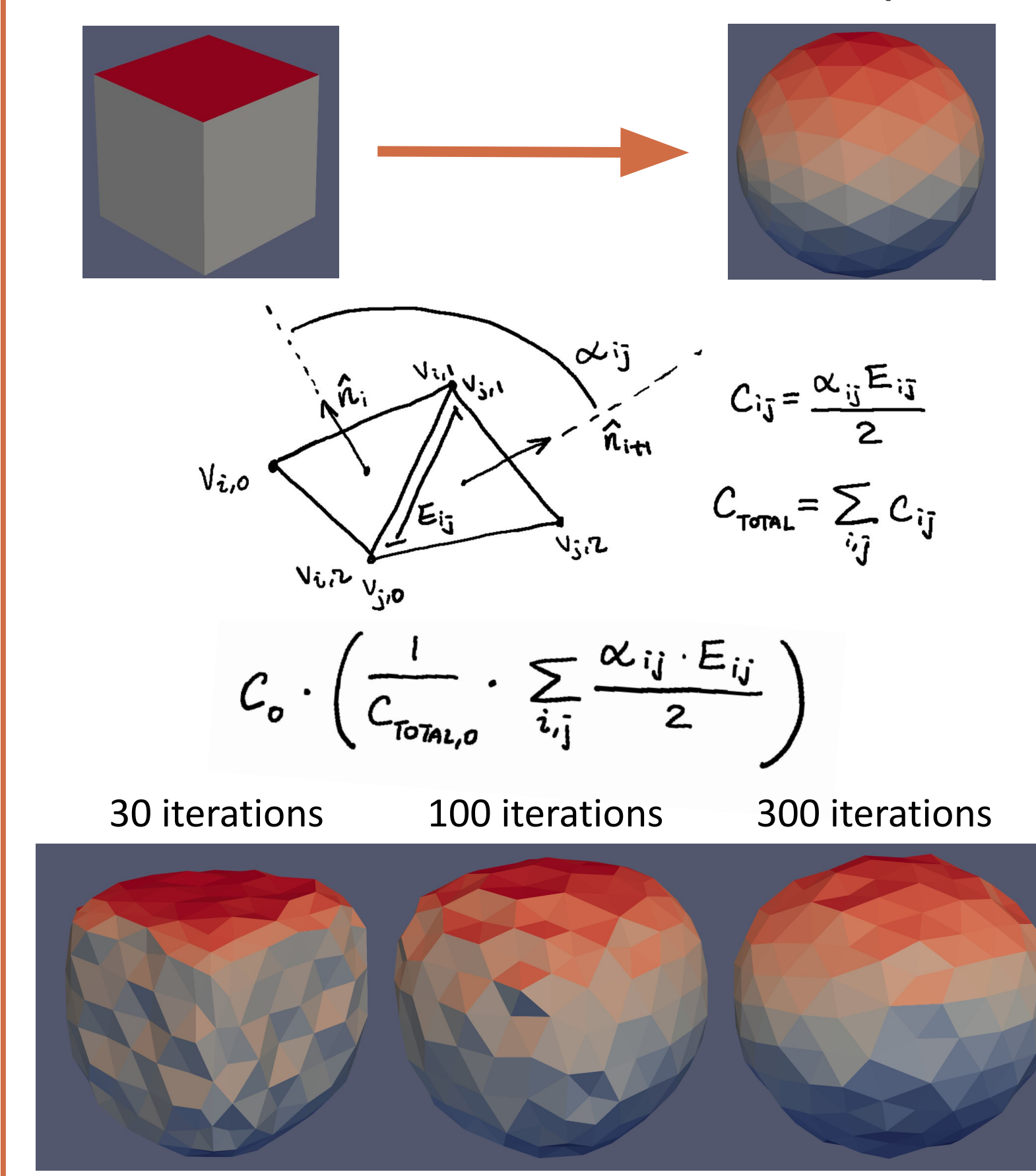
3. Generate meshes that minimize 1D heat flux, given constraints

- Objective function:
- $$C_0 \cdot \text{MAX}(q) + C_1 \cdot \sum_i \frac{q_i}{(\sum q)_0} + C_2 \cdot \sum_{ij} \frac{|\hat{n}_i - \hat{n}_{i+1}|}{(\sum |\hat{n}_i - \hat{n}_{i+1}|)_0}$$
- PEAK HEAT FLUX SUMMED HEAT FLUX ON FACES SUM OF DIFFERENCES BETWEEN FACE NORMALS
- Peak heat flux after 200 iterations:



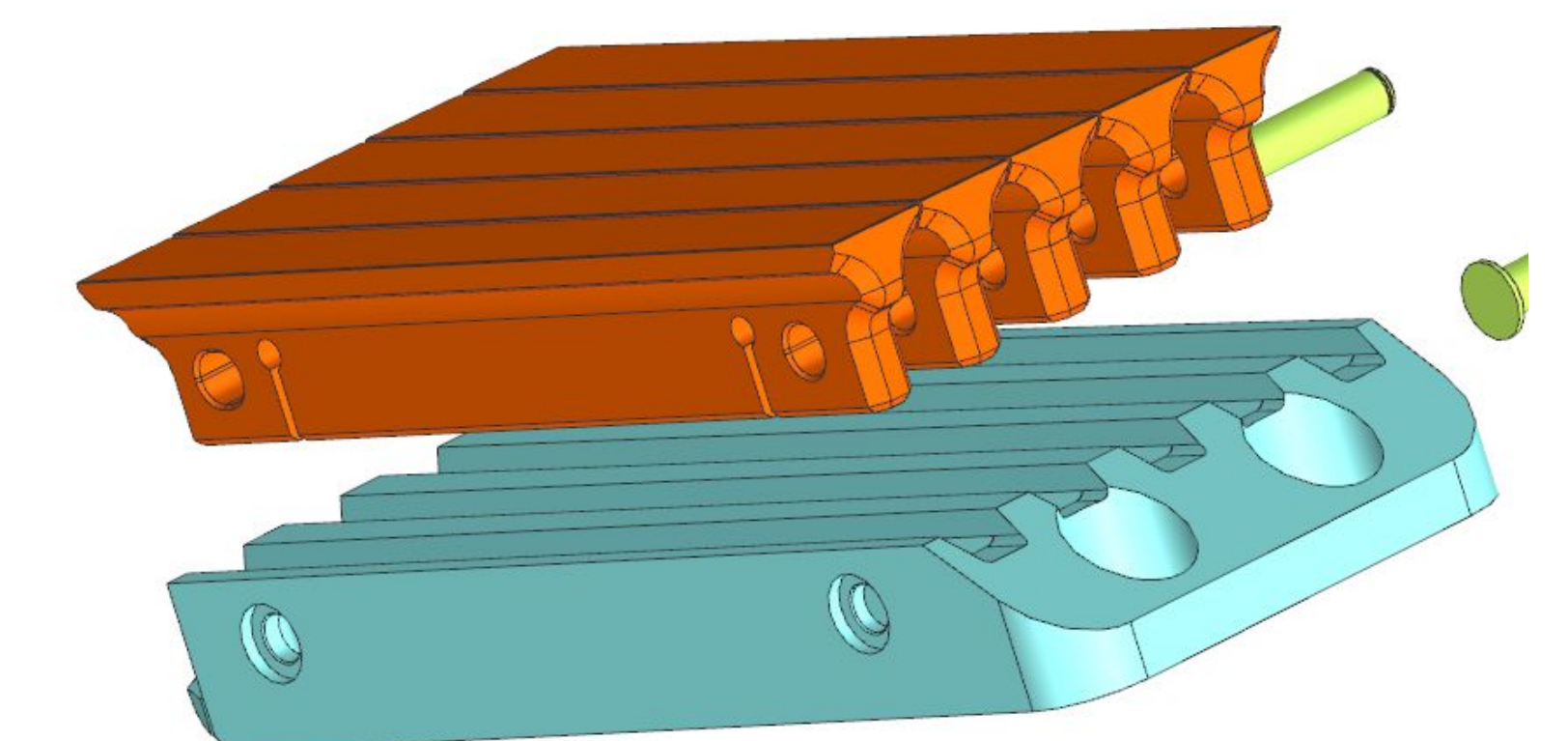
4. Find metrics to control smoothness

- Toy problem: using an objective function that represents a generalizable definition of curvature, transform cube → sphere



Future Work

- Improve smoothing and tune algorithm with heat flux, curvature terms
- Implement volume, bounding box constraints to generate surfaces of PFCs in carrier:



Above: PFCs mounted in carrier, constraining movement of surfaces and volume

- Generate limiter designs and compare to human designs eg. Stangeby 2009.
- Add more complex heat flux modeling, eg. Heat flux Engineering Analysis Toolkit (Looby 2022)
- Generalize for different constraints
 - Possible targets to attempt (eventually): Divertor R-Z contour, antenna design, ...