Université de Liège

RAY TRACING ENHANCEMENT FOR SPACE THERMAL ANALYSIS: ISOCELL METHOD

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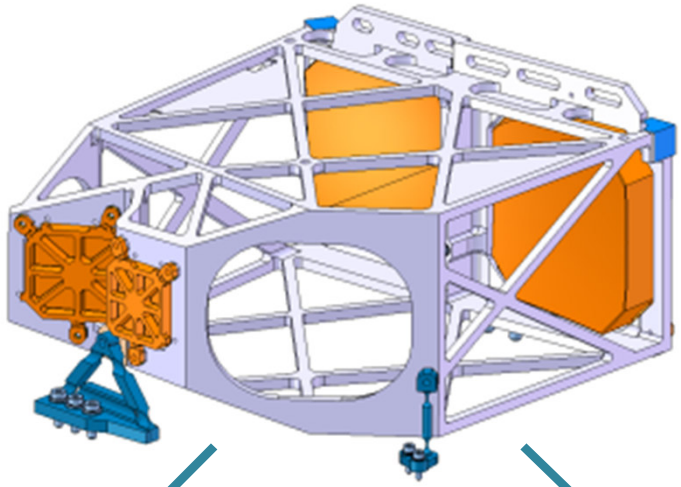
27th Space Thermal Analysis Workshop, ESTEC, Dec. 4th, 2013

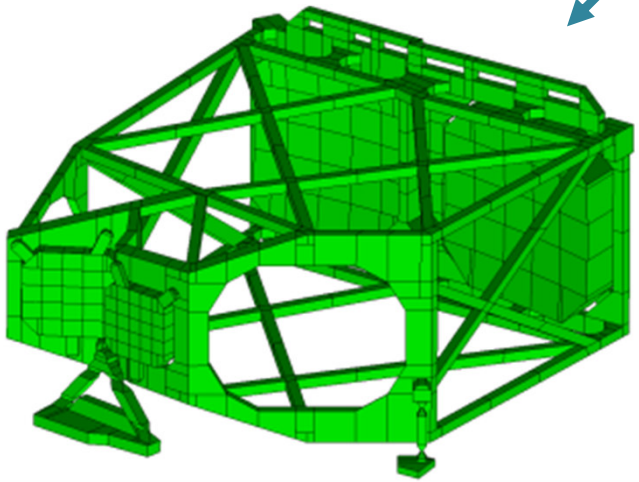
FINITE ELEMENT VS. LUMPED PARAMETER



MTG IRS BTA: strong thermal requirements

Detailed GMM and TMM necessary

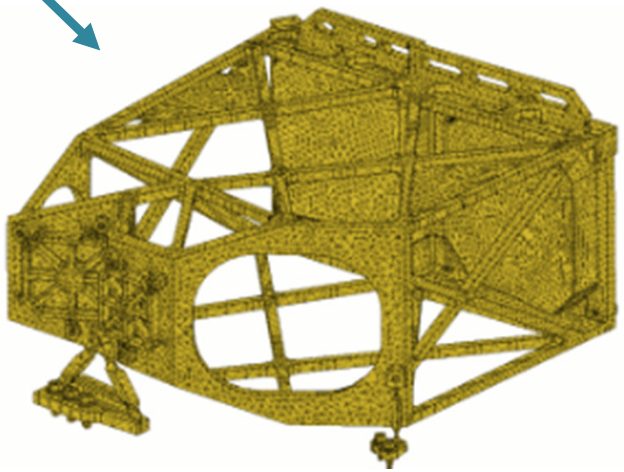
Lumped parameter method



Error-prone manual inputs: geometry & conductive links

Thermo-mechanical: map the T° on the FEM

Finite Element method



Automatic meshing & conductive links

Thermo-mechanical analyses straightforward

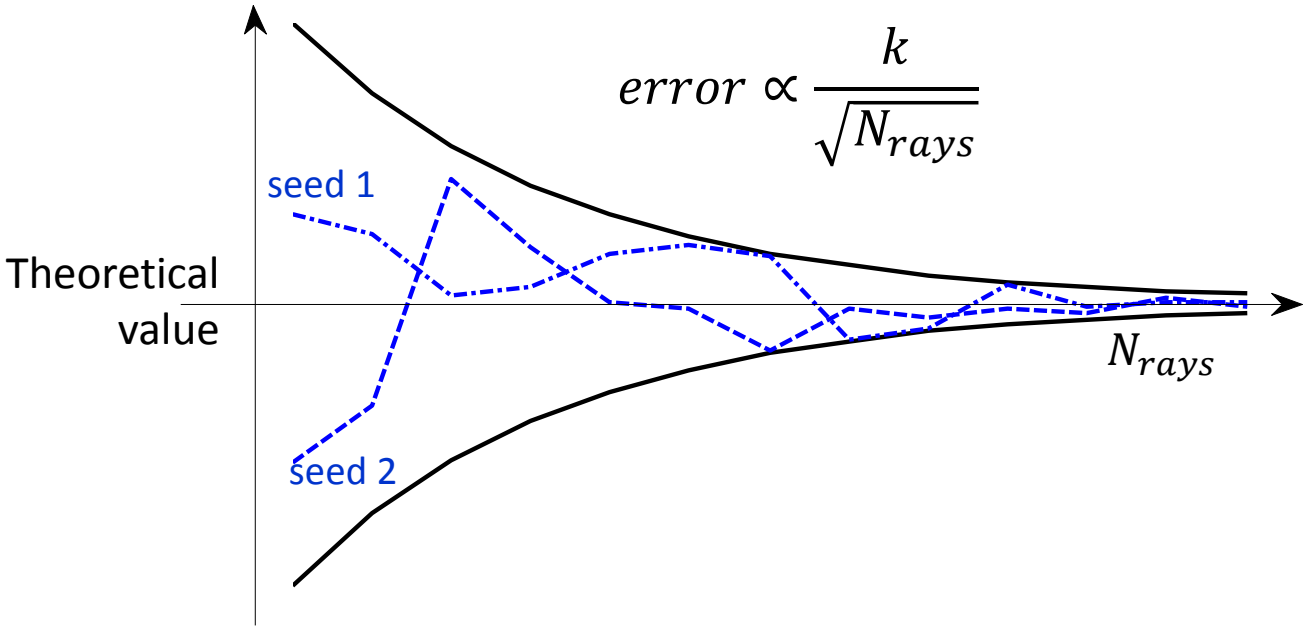
RADIATIVE THERMAL ANALYSIS IS EXPENSIVE

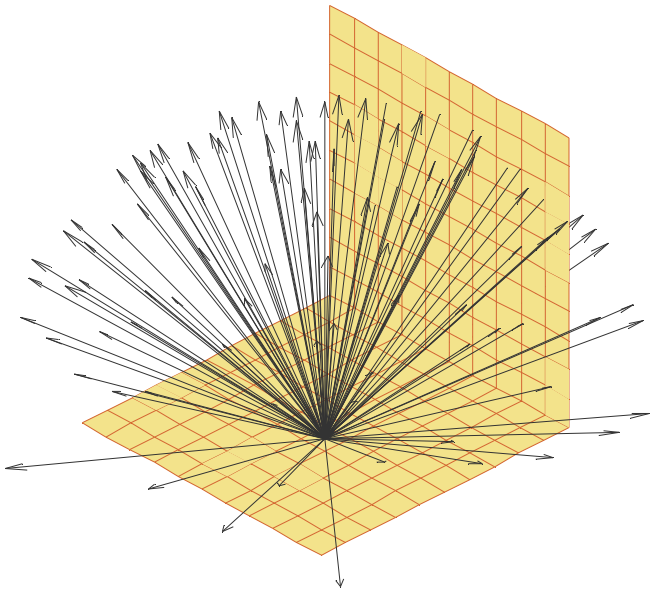
Radiative exchange factors: proportional to (# of elements)^2

× wavelength bands (infrared, visible, multispectral)

× orbit positions & geometrical configurations

Computed mostly through Monte-Carlo ray-tracing:





How to decrease computation time?

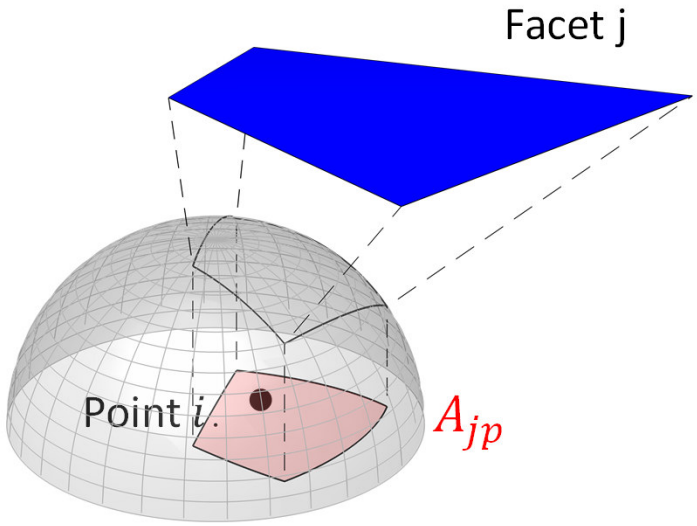
1. Decrease the number of rays: **isocell ray direction sampling**

2. Decrease the number of faces: **super-faces**

MONTE-CARLO RAY DIRECTION SAMPLING

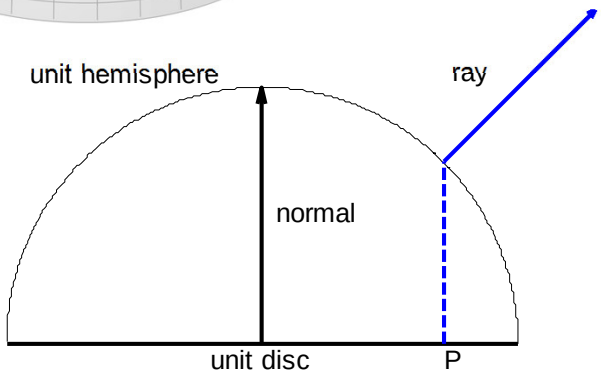
Based on Nusselt's analogy

$$F_{ij} = \frac{A_{jp}}{\pi}$$

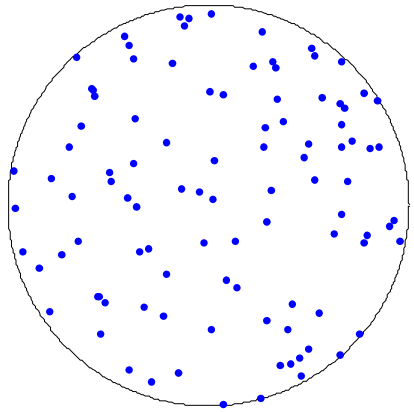


And Malley's method:

- 1 point on the unit disc defines the ray direction
- Sampling of the unit disc



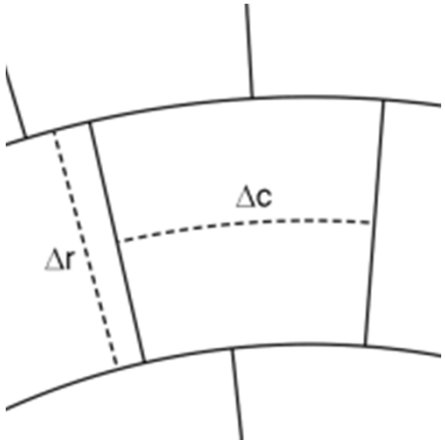
$$F_{ij} = \frac{\text{Number of rays emitted by facet i, hitting j}}{\text{total number of rays emitted by facet i}}$$



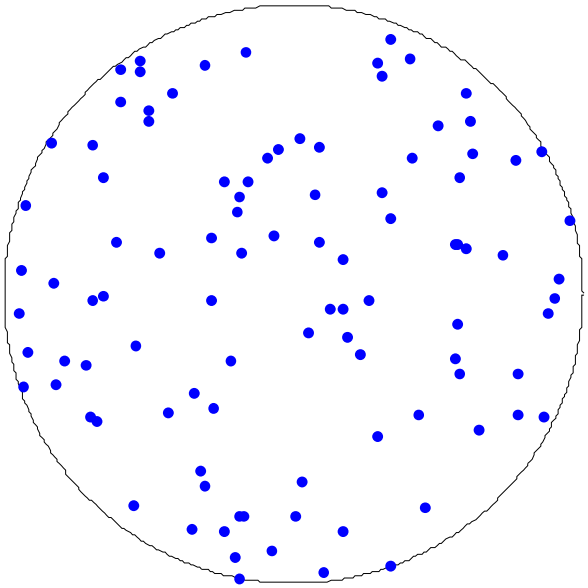
ISOCELL: MORE UNIFORM DIRECTION SAMPLING

More uniform ray direction sampling:

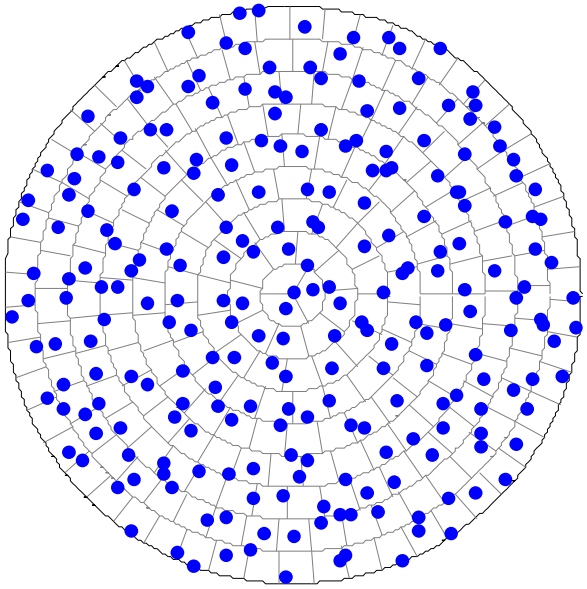
- Divide the unit disc into cells of equal area and aspect ratio $\frac{\Delta r}{\Delta c} \sim 1$
- Fire one ray per cell



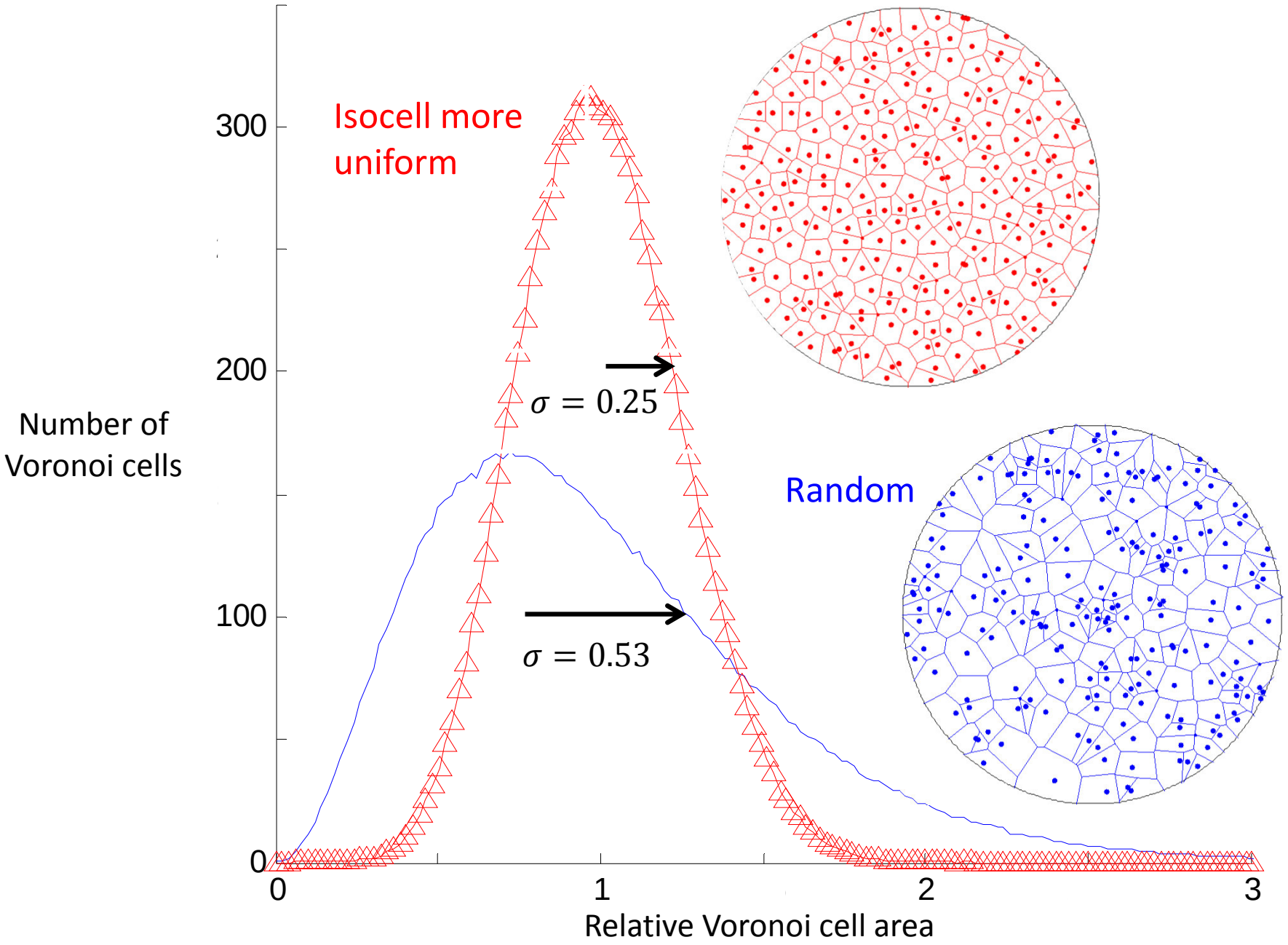
Random (classic) sampling



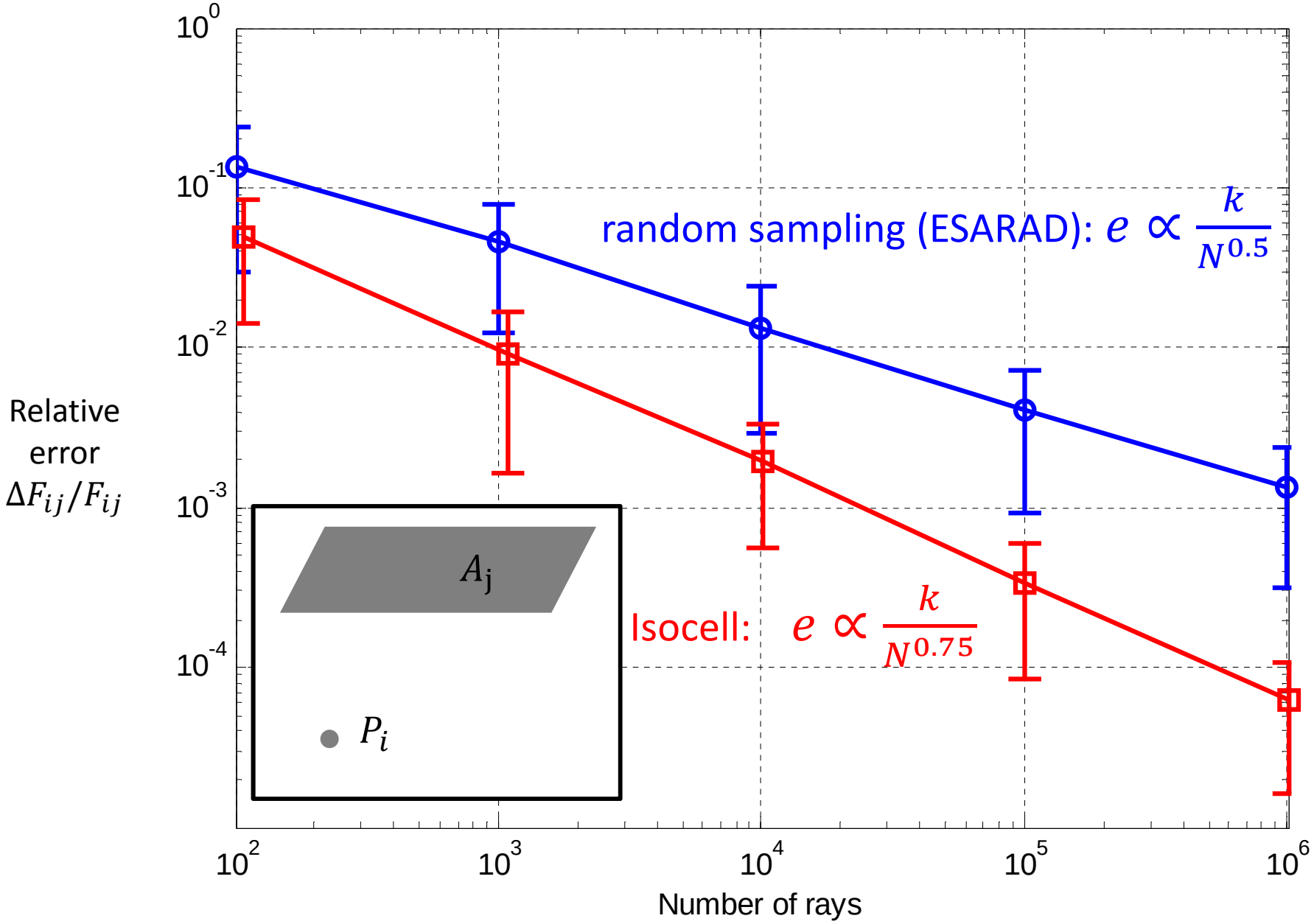
Isocell sampling



CONFIRMATION: UNIT DISC VORONOI CELL AREA



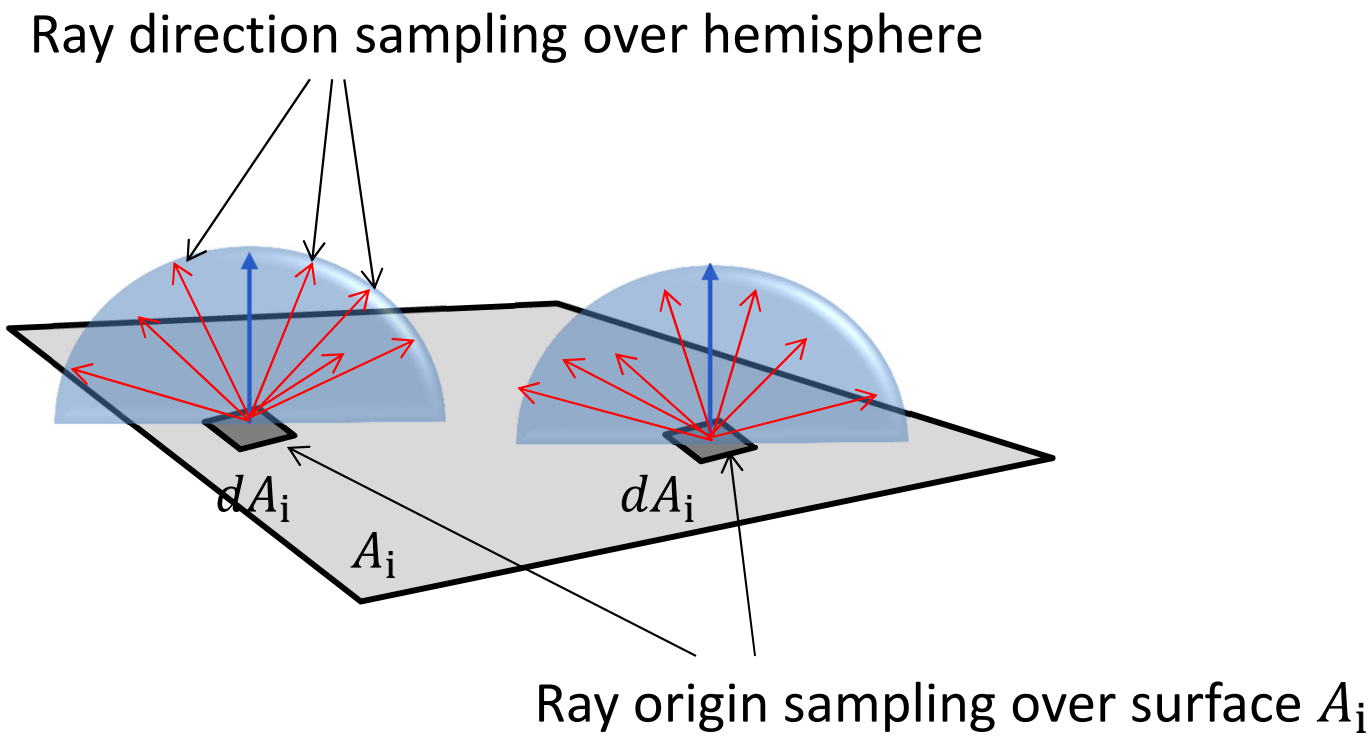
POINT-WISE VF: ISOCELL REQUIRES LESS RAYS



SURFACE & DIRECTION SAMPLING

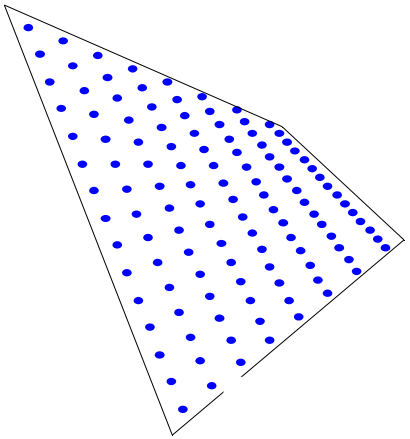
2 alternatives:

- Local direction sampling at each origin
- Global direction sampling & distribution among the origins

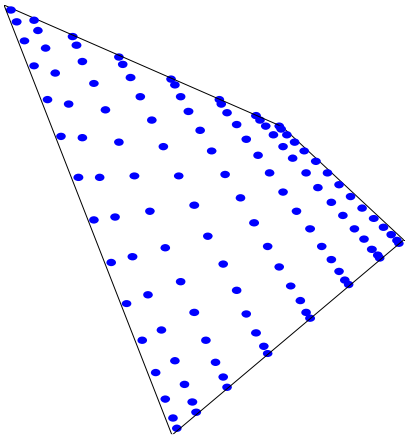


DIFFERENT SURFACE SAMPLING STRATEGIES

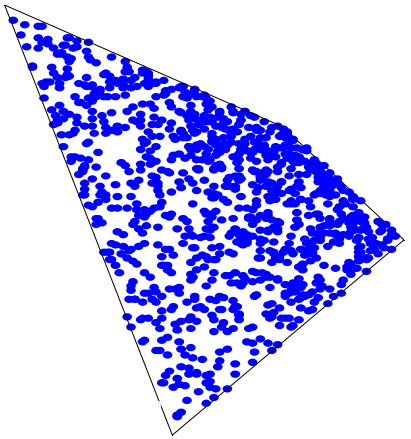
Uniform sampling



Gauss sampling

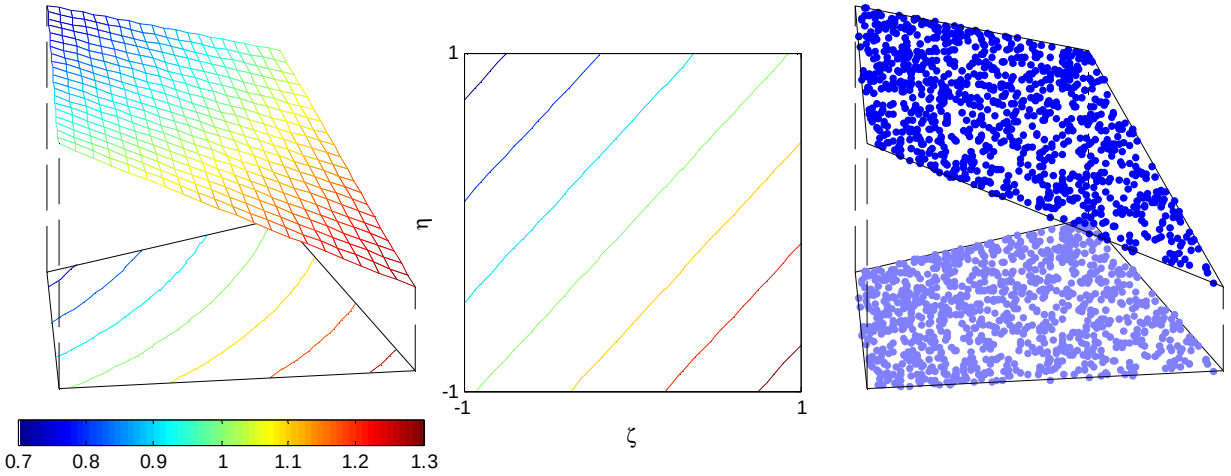


Random sampling



Problem: concentration due to non area-preserving mapping of the face

Solution: each origin is weighted by the Jacobian of the mapping (origins in denser regions less weighted and vice-versa)



GAUSS SAMPLING: GAUSS WEIGHTS

Constant # of rays per origin

$$F_{i\to j} = \sum_{k=1}^{N_{rays}} W_k F^k_{di\to j}$$

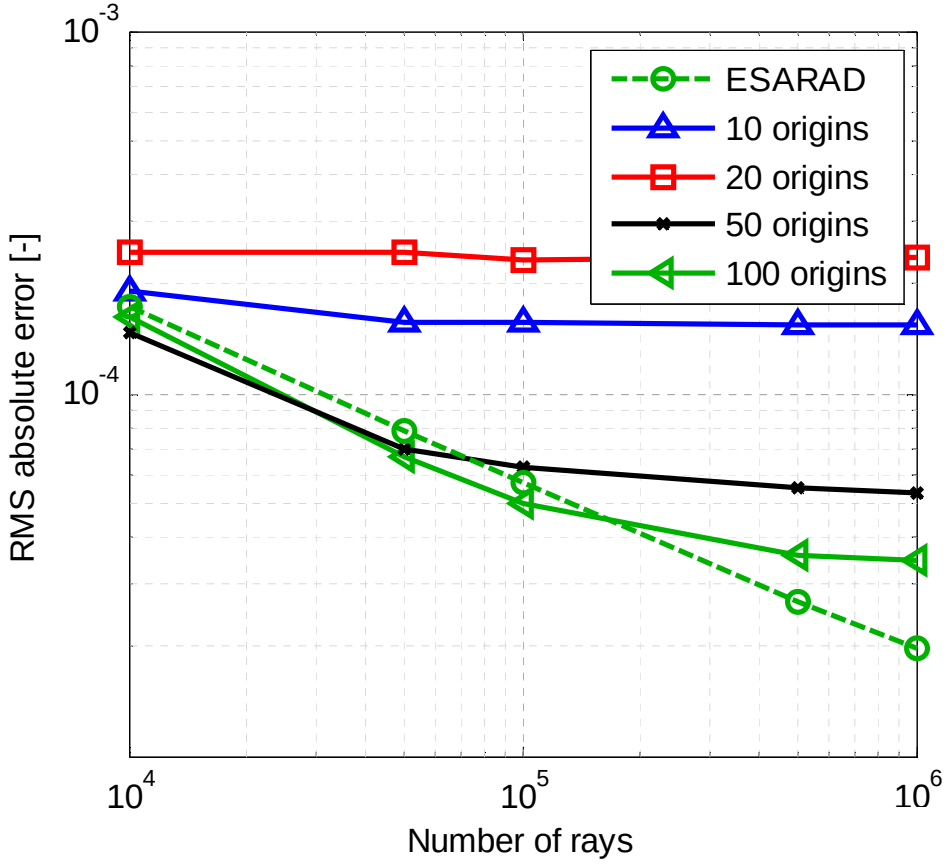
Point-wise view factor

Uniform & random sampling: $W_k = 1 \ \ \forall k$

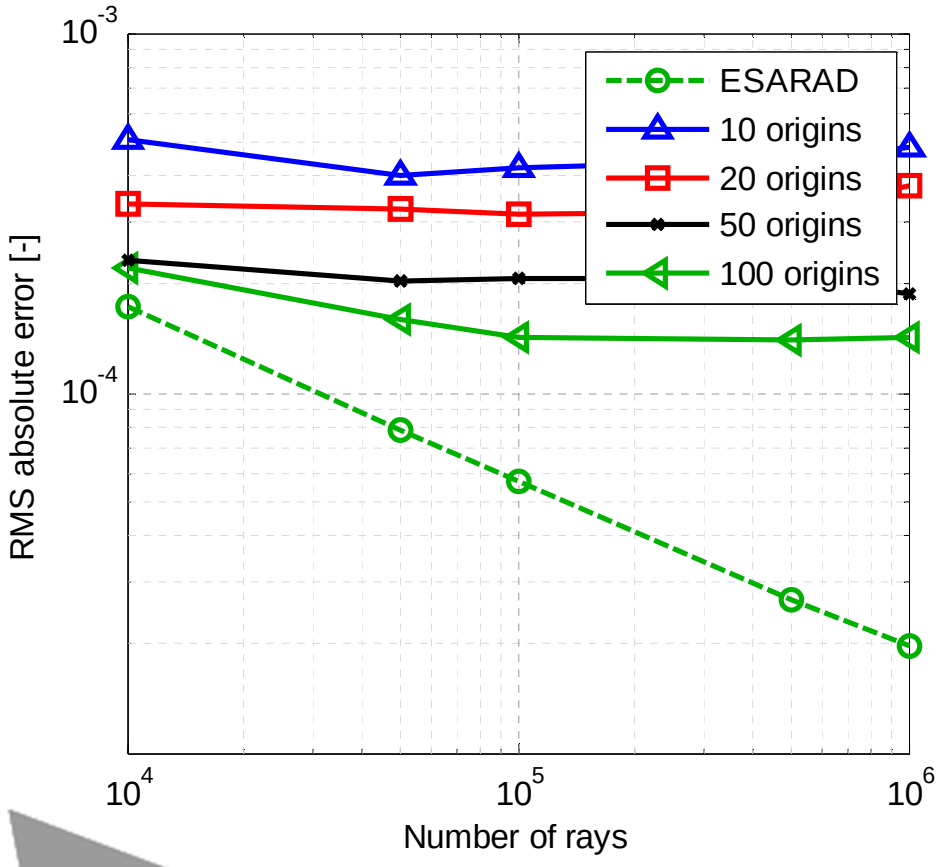
Gauss sampling: $W_k =$ Gauss-Legendre quadrature weights

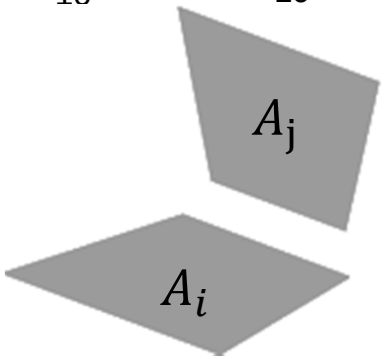
SURFACE SAMPLING IS CRITICAL

Uniform origin sampling &
Local Isocell direction sampling



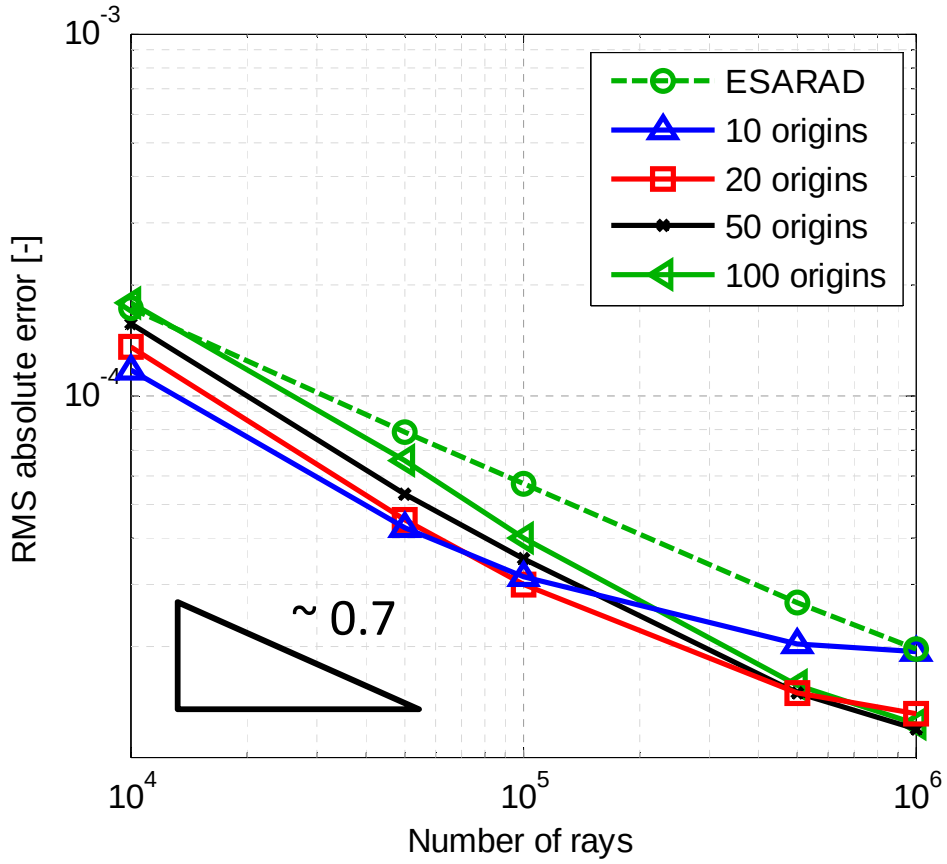
Random origin sampling &
Local Isocell direction sampling



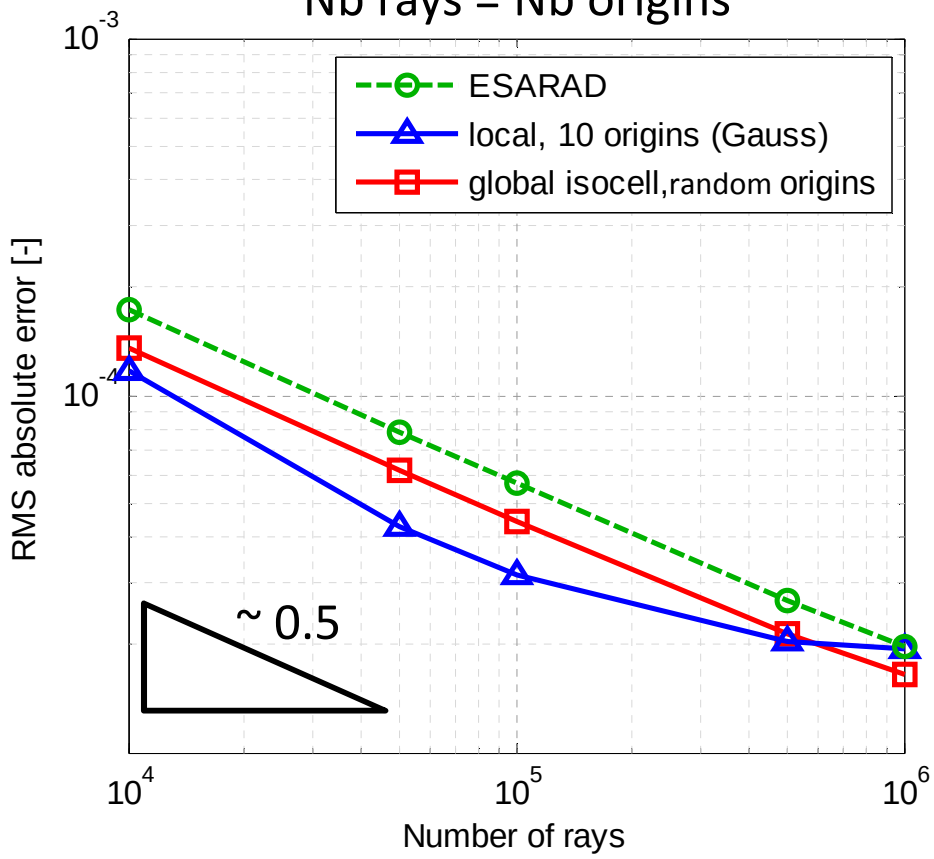


GAUSS SAMPLING GIVES BETTER RESULTS

Gauss origin sampling &
Local Isocell direction sampling



Random origin sampling &
Global Isocell direction sampling
Nb rays = Nb origins



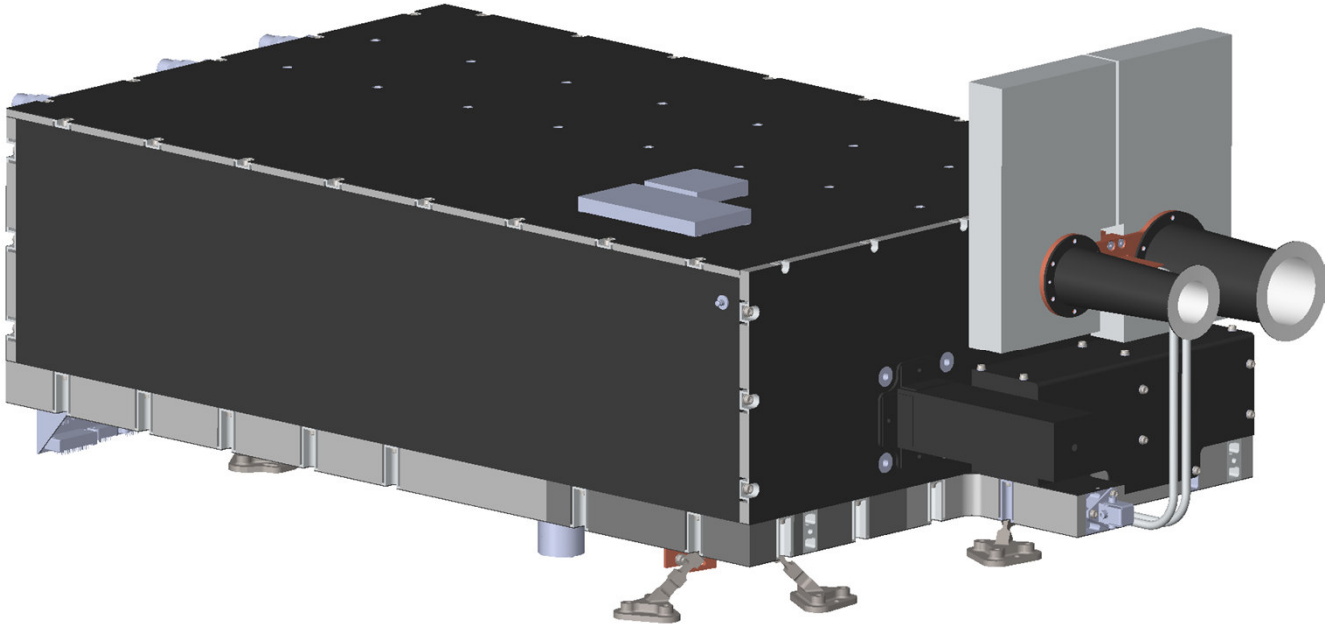
Global direction sampling:

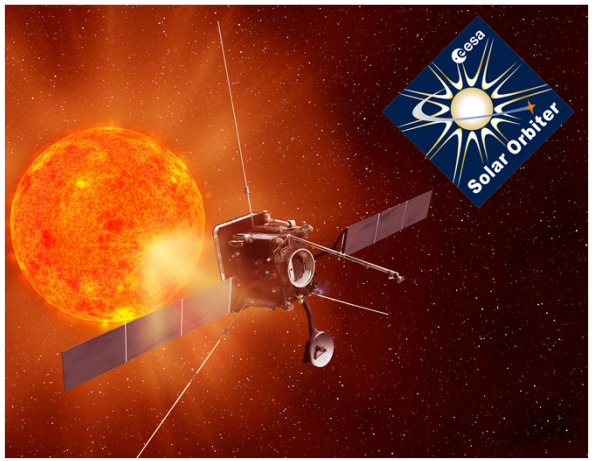
- Still ~2x better than ESARAD
- Does not need to specify a number of origins

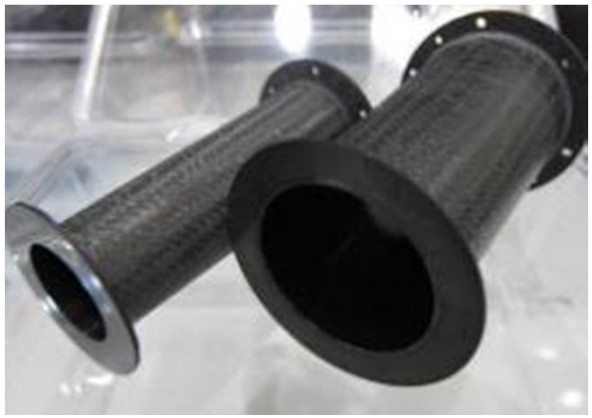
EUI ENTRANCE BAFFLE ON SOLAR ORBITER

0.28 AU perihelion: 17.5kW/m²

Coated CFRP entrance baffle and filter to reject unwanted light

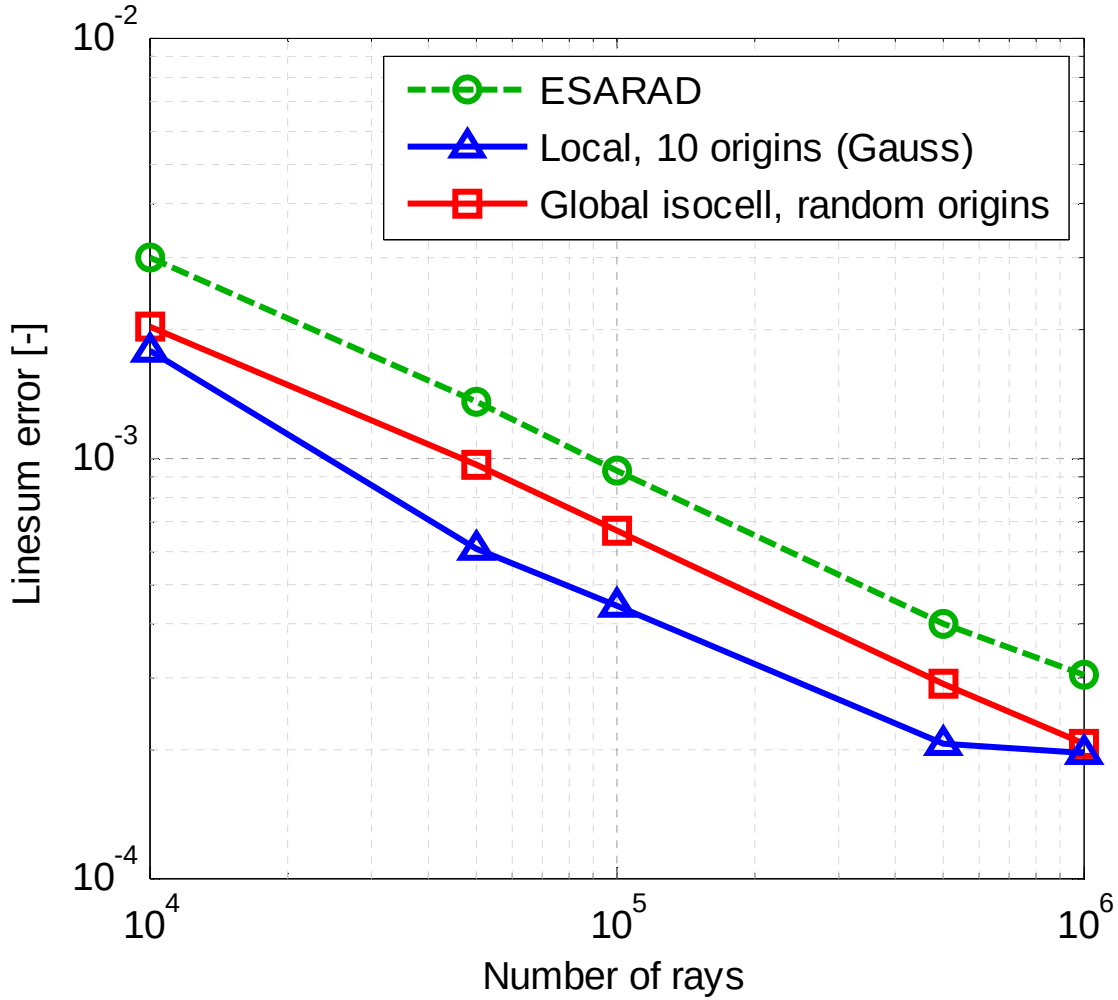


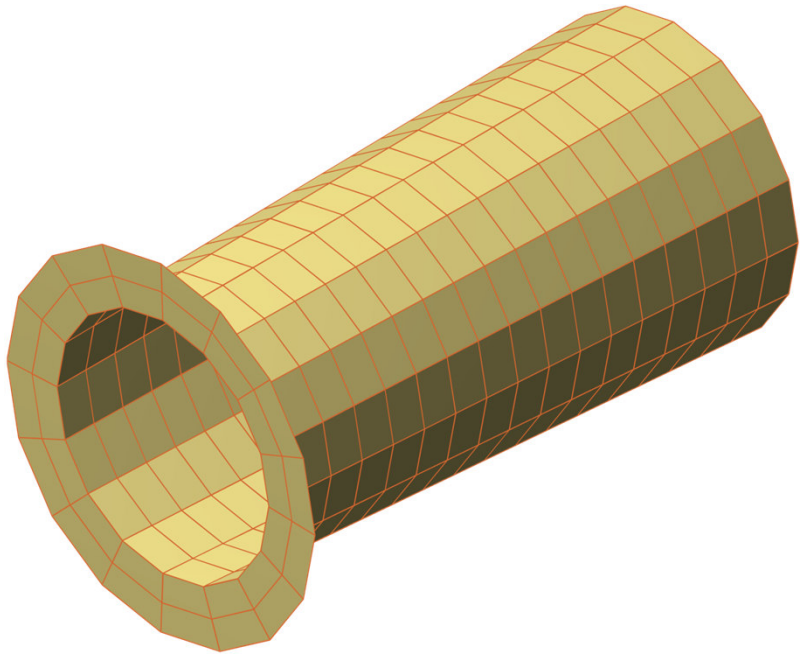




RADIATIVE EXCHANGE FACTORS GLOBAL ERROR

$$LSE_{RMS} = \sqrt{\frac{1}{N}\sum_i LSE_i^2} = \sqrt{\frac{1}{N}\sum_i \left(1 - \sum_j F_{ij}\right)^2}$$

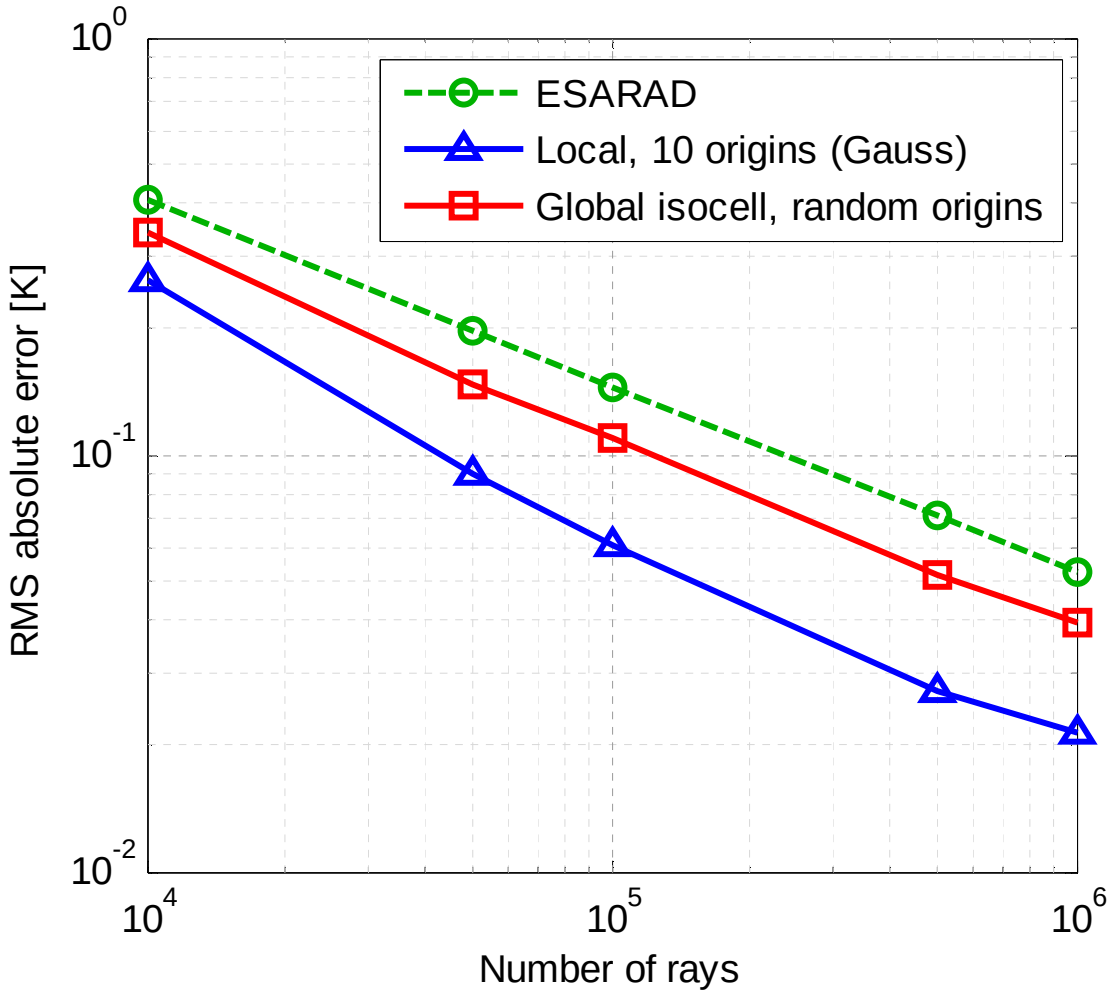


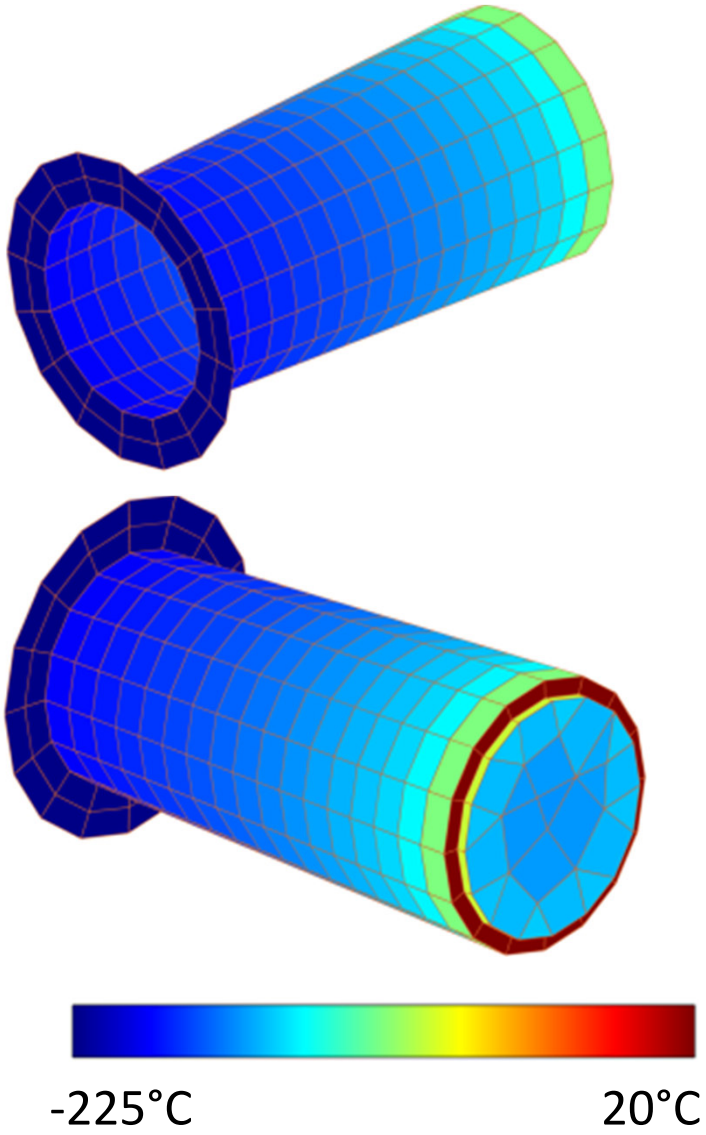


Convergence on Temperatures

Benchmark: pure radiative equilibrium

3K environment, 293K boundary





CONCLUSIONS

Isocell direction sampling offers significant improvement

Surface sampling is critical

50% reduction of number of rays with global direction sampling

Same performances on simple case and real-life space structure

First step to bridge the gap between structural and thermal analysis

Thank you for your attention…

Any question?

REFERENCES

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