Reverse Engineering Design of Directional Microstructured Radiators

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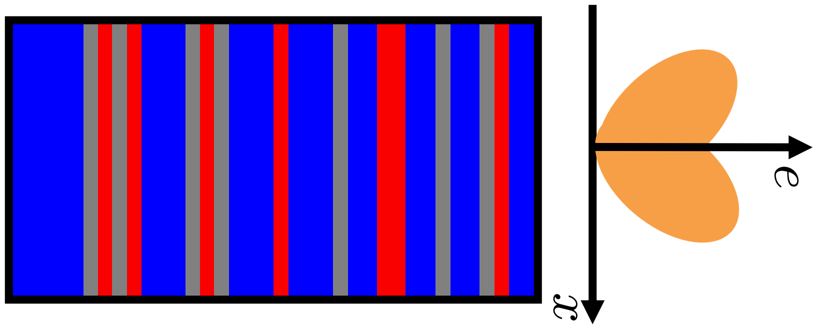


The Advanced Concepts Team

What is the ACT?

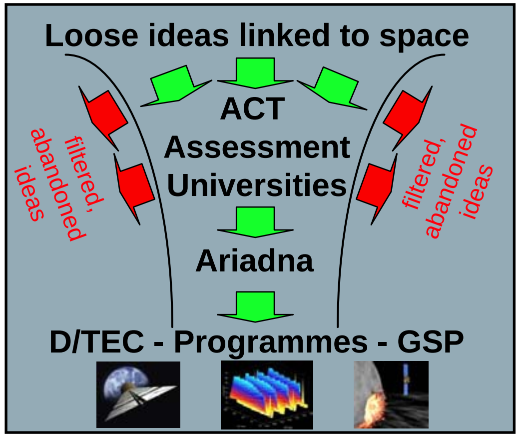
Multidisciplinary research group:

- Artificial Intelligence
- Biomimetics
- Energy Systems
- Fundamental Physics
- Informatics
- Mission Analysis
- Nanotechnologies
- Propulsion

Who constitute the ACT?

- 2 Staff
- 6 Research Fellows
- 5 Young Graduate Trainee

How the ACT works?



- Loose ideas linked to space
- First basic filtering of loose ideas linked to space
- Preliminary ACT assessments - second filter
- Academic assessment **ARIADNA**
- Eventual transfer to ESA R&D programmes

Layout

1. Introduction to directional microstructured radiators
2. Reverse engineering strategy
3. Case studies:
   - Quasi-isotropic radiator at room temperature
   - Directional radiator in the near infrared
4. Conclusions and Outlook

1. Introduction to directional microstructured radiators

2. Reverse engineering strategy

3. Case studies:

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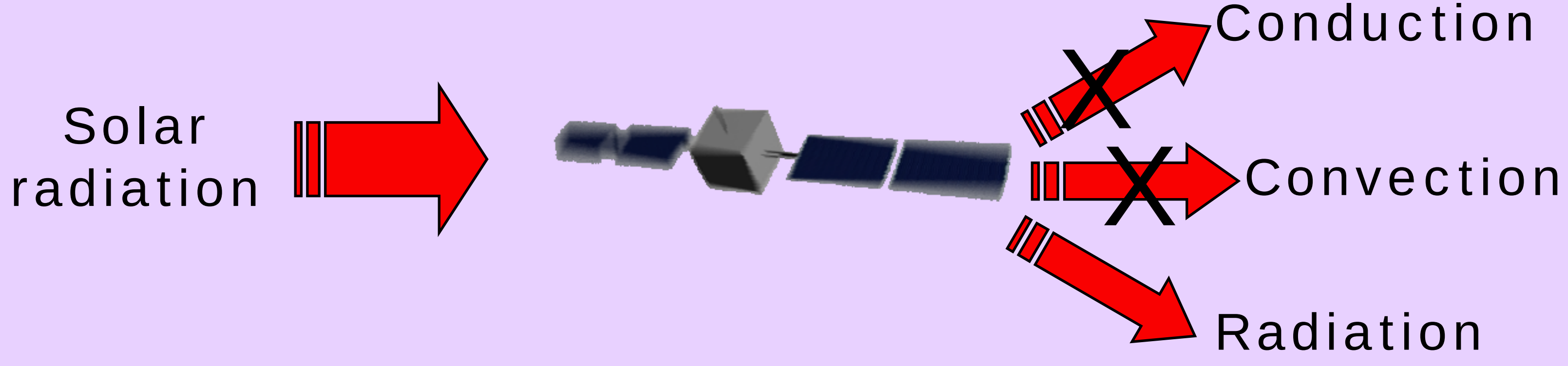
4. Conclusions and Outlook

1. Introduction to directional microstructured radiators

General Problem: Thermal control of Spacecraft

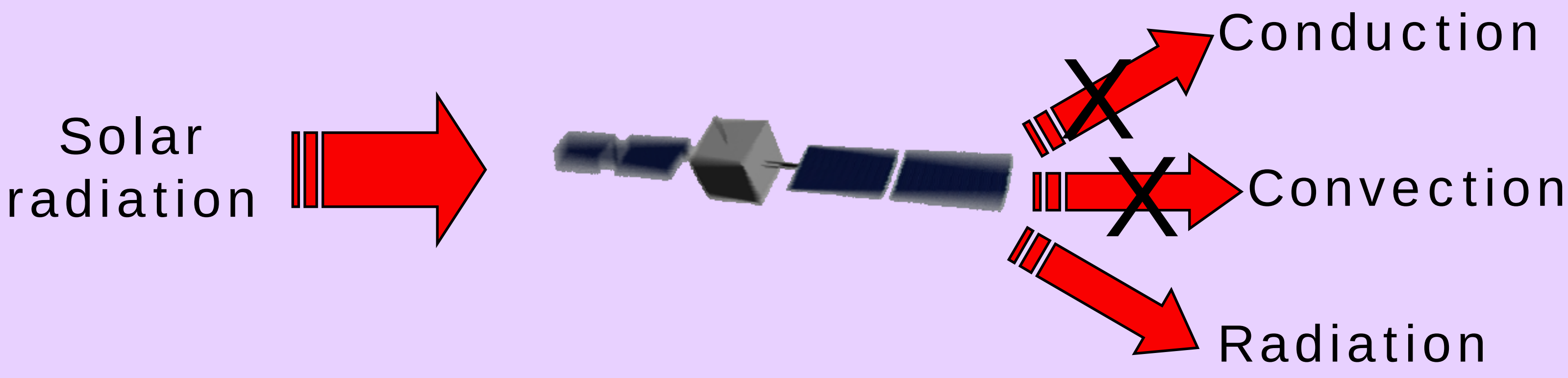


Proposal: Design surface finishes with spatially coherent thermal radiation

1. Polar materials + surface grating
2. Photonic band gap materials
3. Polar materials / metallic layer + photonic structures
4. Left-Handed material

1. Introduction to directional microstructured radiators

General Problem: Thermal control of Spacecraft



Proposal: Design surface finishes with spatially coherent thermal radiation

1. Polar materials + surface grating
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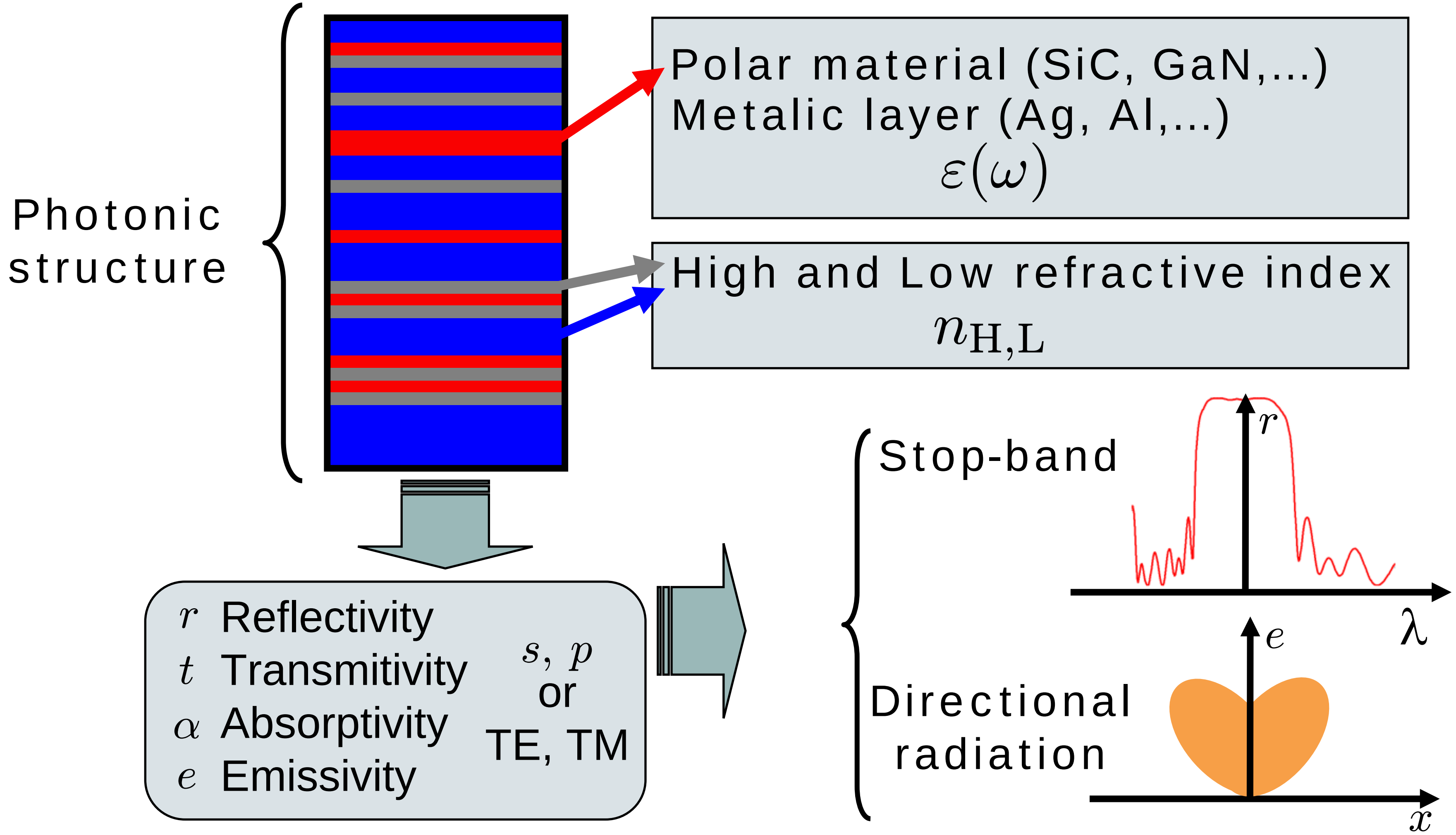
Schematic description of the concept:



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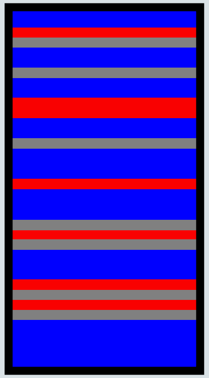
2. Reverse engineering strategy

Objective of the study: For a given radiation distribution find the suitable multilayer structure.

Input: $e(\lambda, \theta) \; r(\lambda, \theta)$ → **Optimization process** → **Output:** $n(\lambda, z)$

Optimization solver: Genetic Algorithm

Multilayer codification



Array element ↓ Material layer

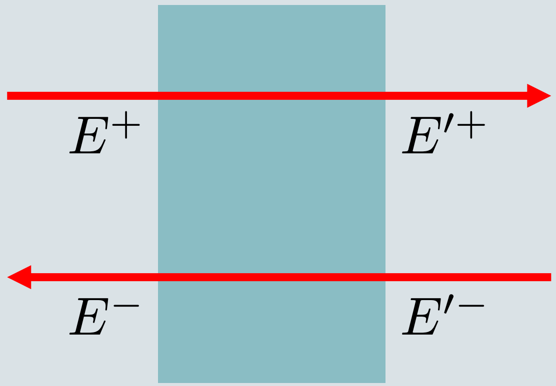
Initial random population
↓
Evolution with genetic operators
↓
Best solution

2. Reverse engineering strategy

Fitness function:

$$J = \int_{\lambda_{\min}}^{\lambda_{\max}} \int_{\theta_{\min}}^{\theta_{\max}} (e^s - e^{\text{Target}})^2 + (e^p - e^{\text{Target}})^2 + (r^s - r^{\text{Target}})^2 + (r^p - r^{\text{Target}})^2 \, d\lambda \, d\theta$$

Physical model: Transfer matrix formalism



$$\begin{pmatrix} E^+ \\ E^- \end{pmatrix} \xrightarrow{\text{Transfer matrix}} \begin{pmatrix} E'^+ \\ E'^- \end{pmatrix}$$

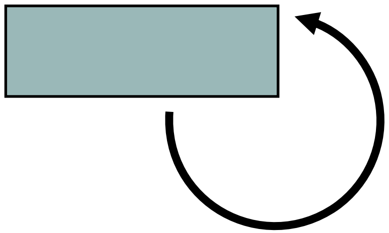
Reflection + Transmission

Energy conservation + Kirchhoff's law

Emission

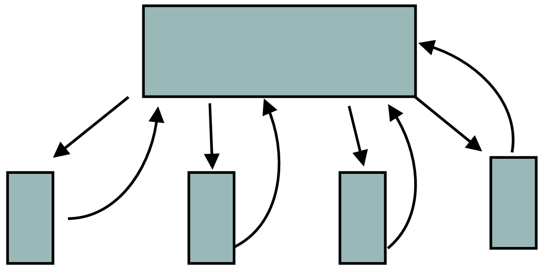
Implementation of the GA algorithm

Single CPU



Single CPU evolves all the population

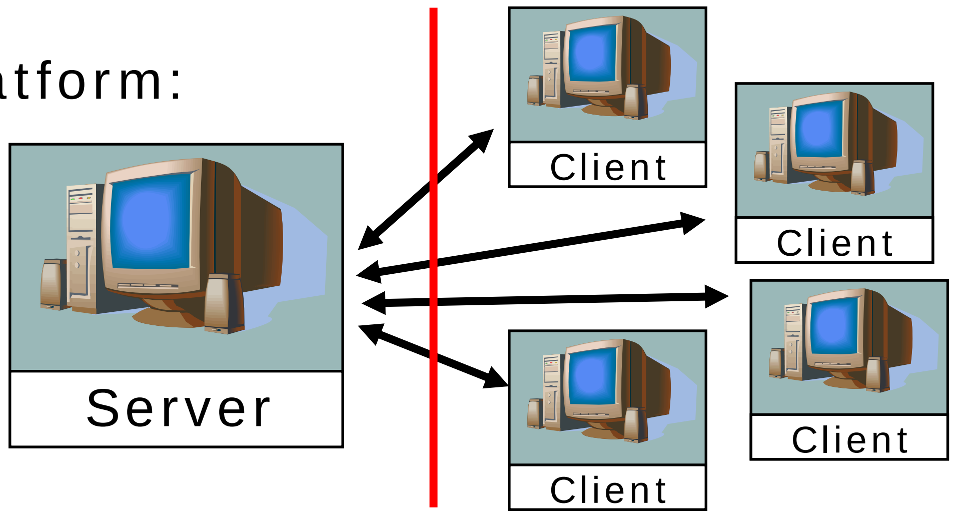
Distributed Computation (DC)



Each CPU evolves a part of the population

Physical DC platform:

Population Initialization
+
Sub-population distribution



Population evolution

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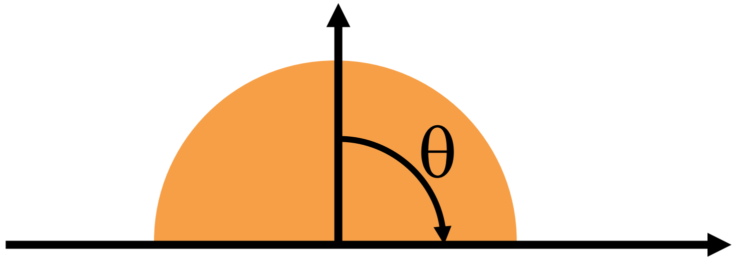
Quasi-isotropic radiator at room temperature

Radiation distribution



T=300 K

Acording to Wien´s law:

$$\lambda_{\max} \approx 10\ \mu\mathrm{m}$$

Combination of materials

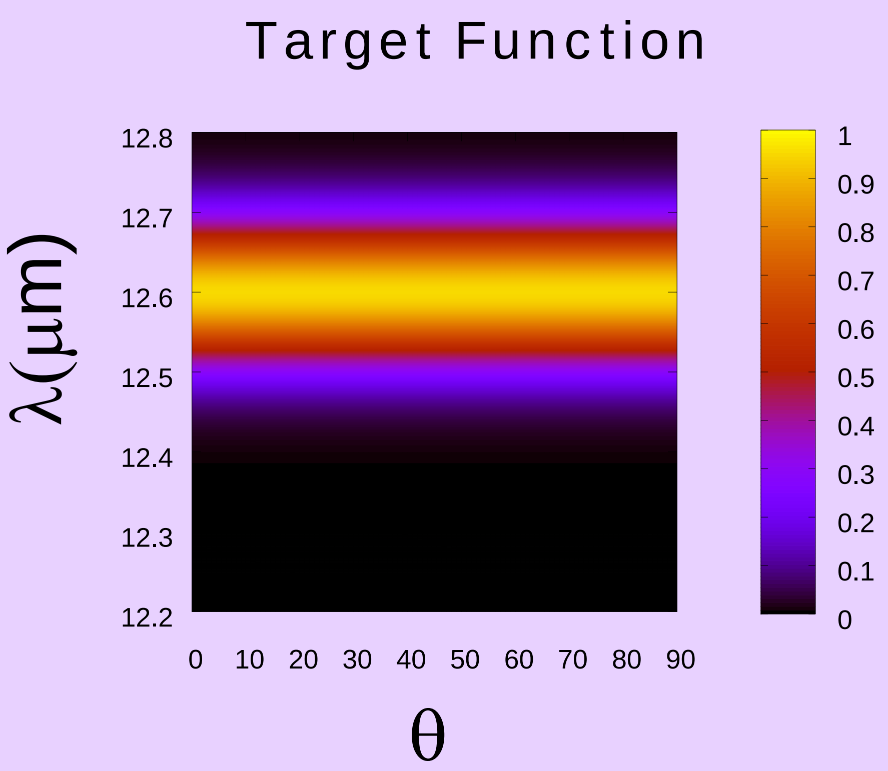
- Polar Material: 3C-SiC (emission at 12.6 μm)
- Low index material: CdTe n_L=1.6
- High index material: Ge n_H=4.0

Parameters of the structure

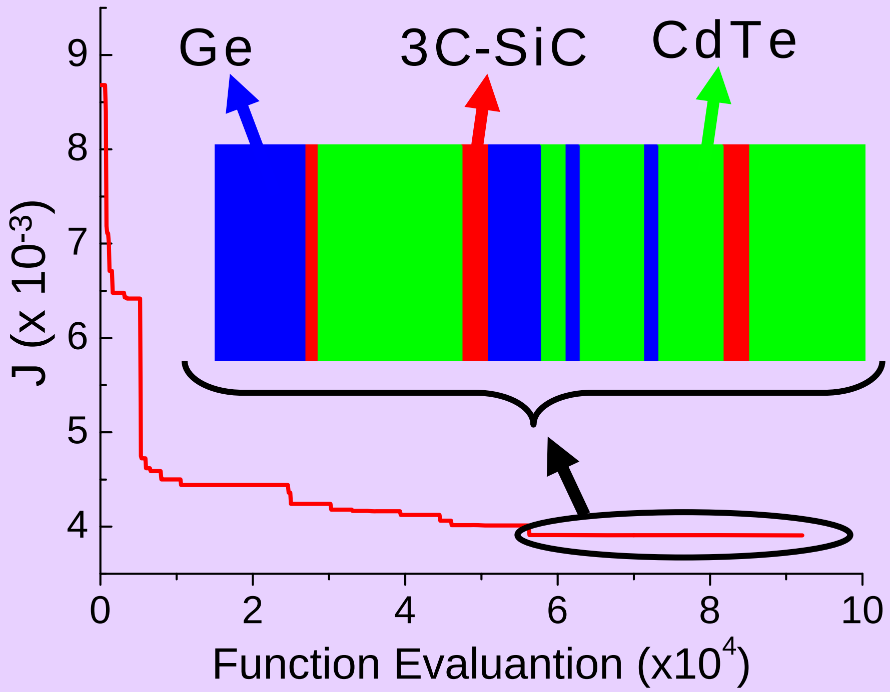
- 50 layers => 3^{50} (~7×10^{25}) possible combinations
- 100 nm thickness

Quasi-isotropic radiator at room temperature

input

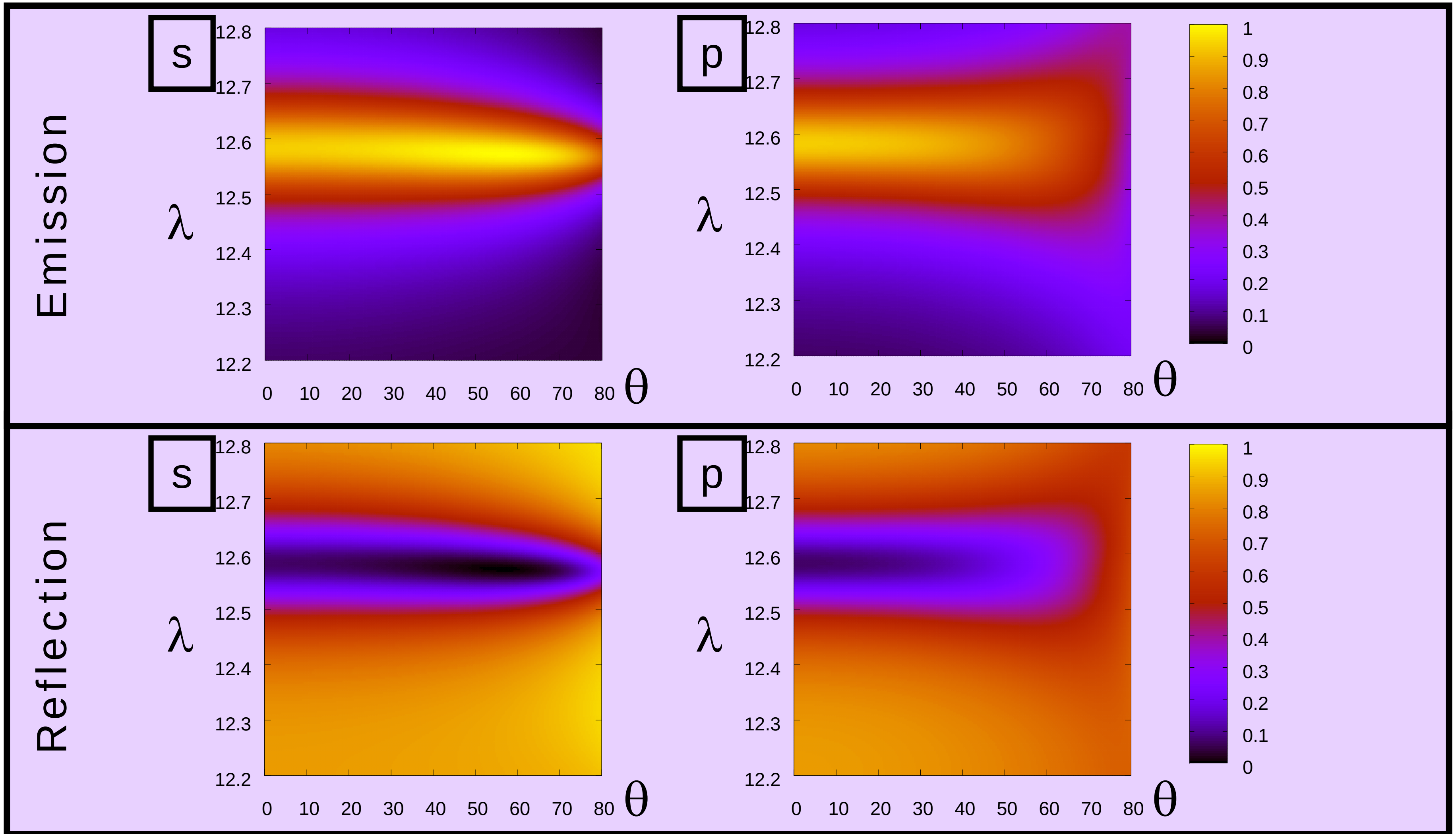


output

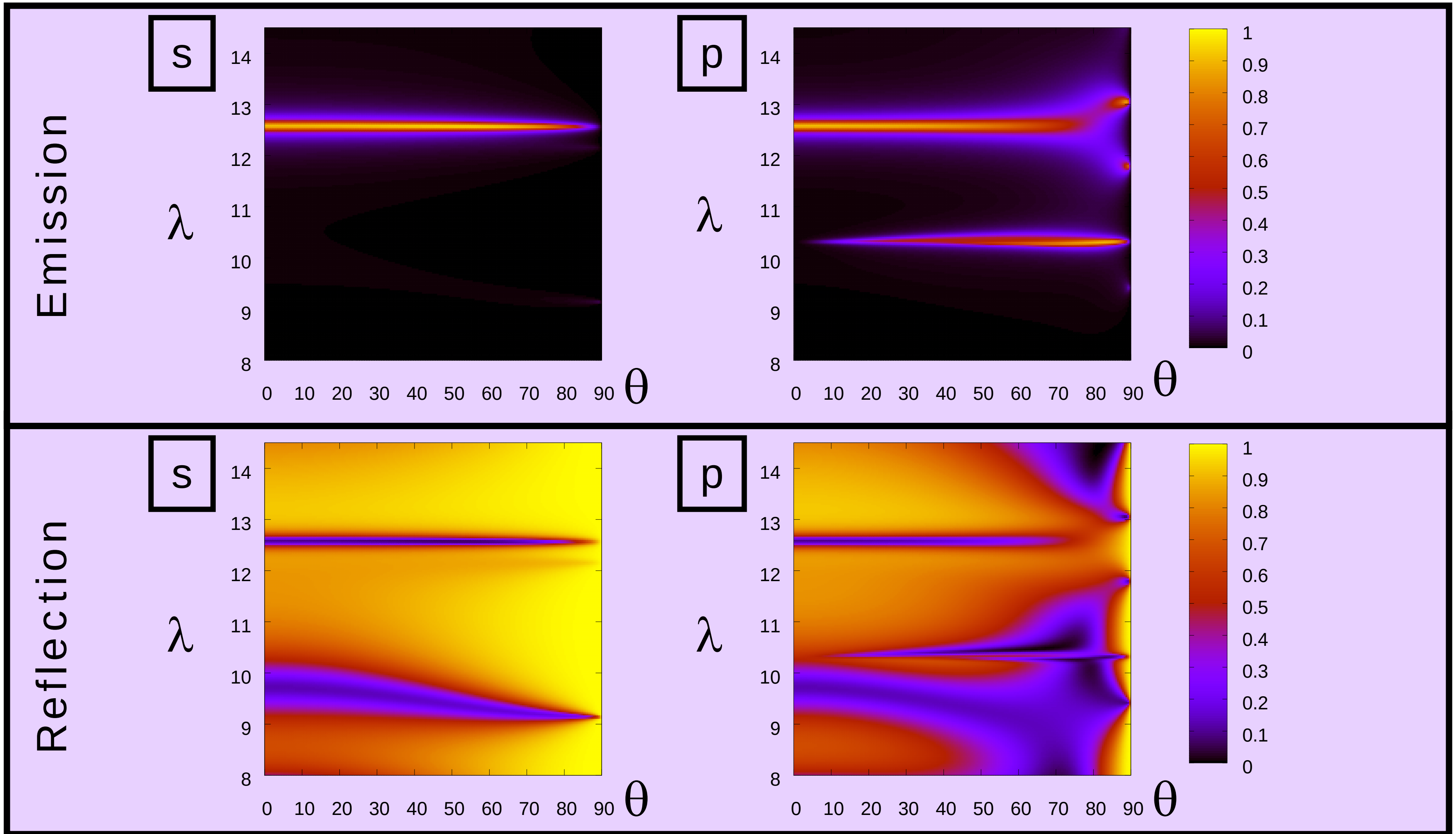


N. Generations ≡ 100 Function Eval.

Quasi-isotropic radiator at room temperature

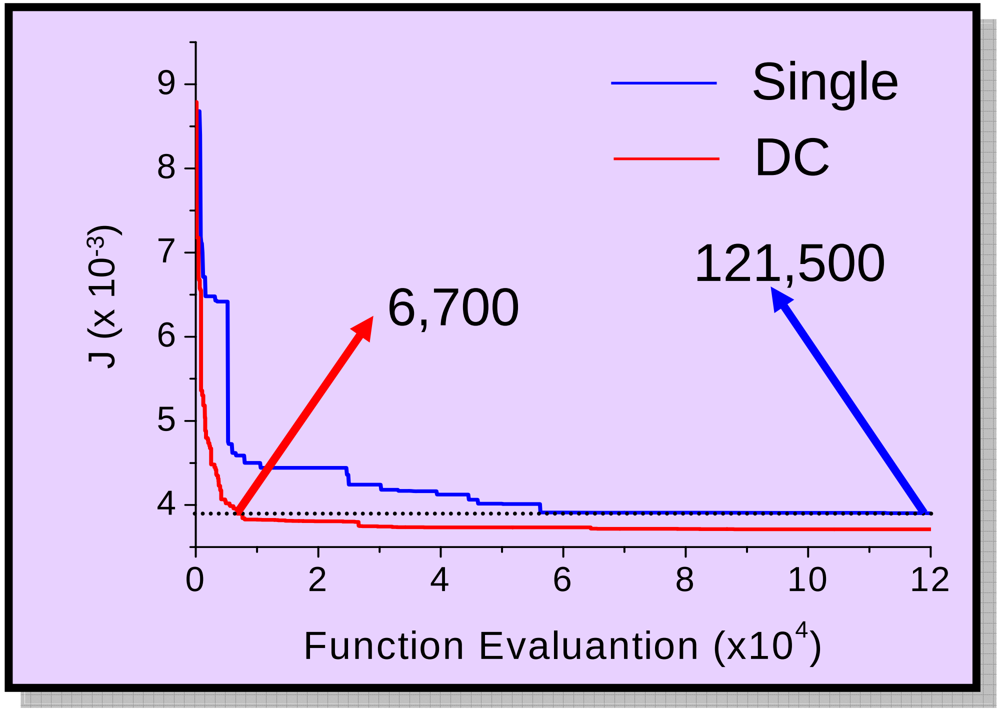


Quasi-isotropic radiator at room temperature



Quasi-isotropic radiator at room temperature

Implementation into the DC



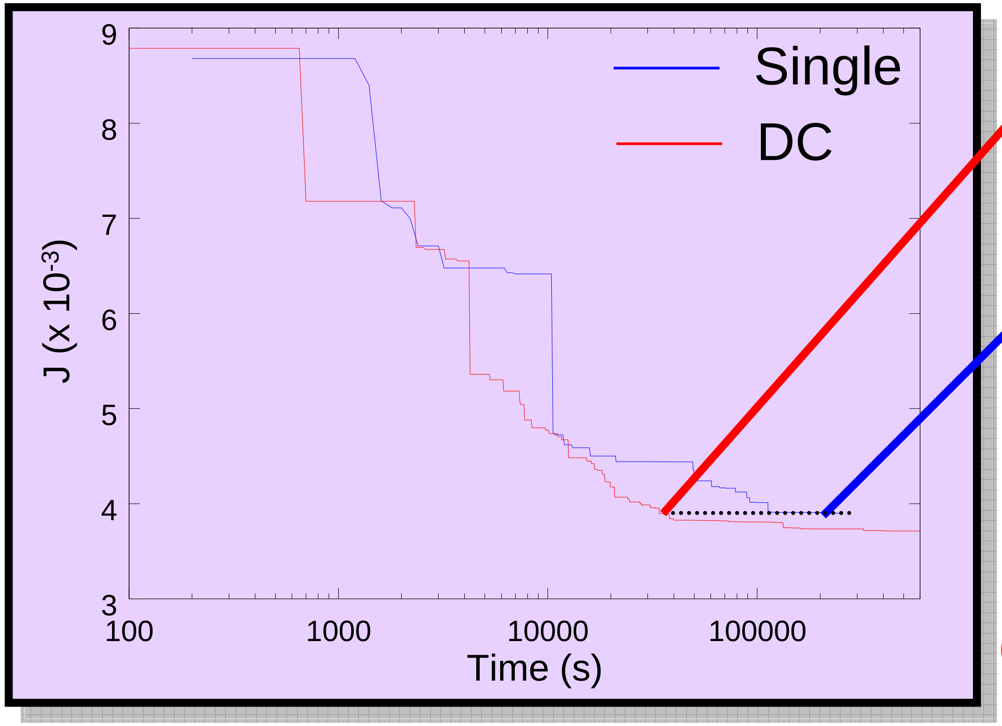
Run Details:

1. Single CPU
   - ESAGRID (Pentium Xeon 2.40 GHz)
   - Average function evaluation time: ~ 2 s
2. DC
   - 12 Dell Desktops
   - Average function evaluation time: ~ 5 s

Outperformance ~ factor 18

Quasi-isotropic radiator at room temperature

Time reduction



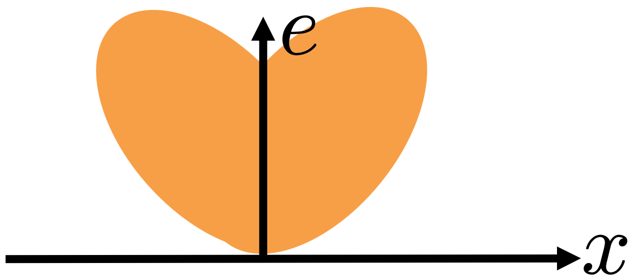
T=33,500 (9 h)

T=235,000 (2 d 17 h)

Outperformance ~ factor 7

Directional radiator in the near infrared

Radiation distribution



Working spectral range

[1.8 μm – 2.8 μm]

Combination of materials

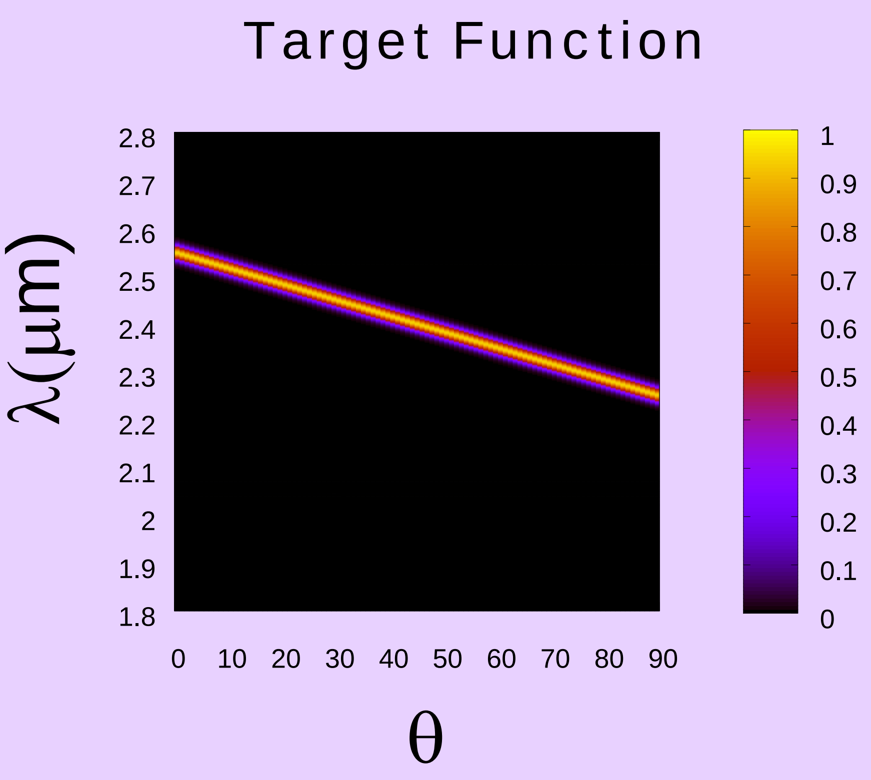
- Metal Layer: Ag (broad emission)
- Low index material: SiO_2 n_L=1.45
- High index material: Si n_H=3.3

Parameters of the structure

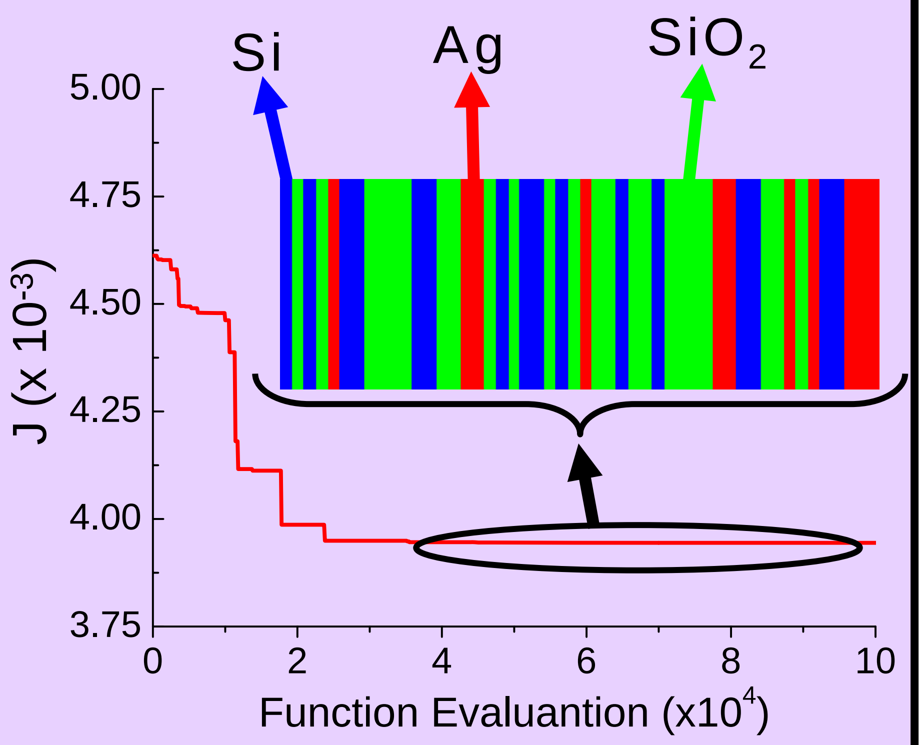
- 50 layers => 3^{50} (~$7 \cdot 10^{25}$) possible combinations
- 50 nm thickness

Quasi-isotropic radiator at room temperature

input



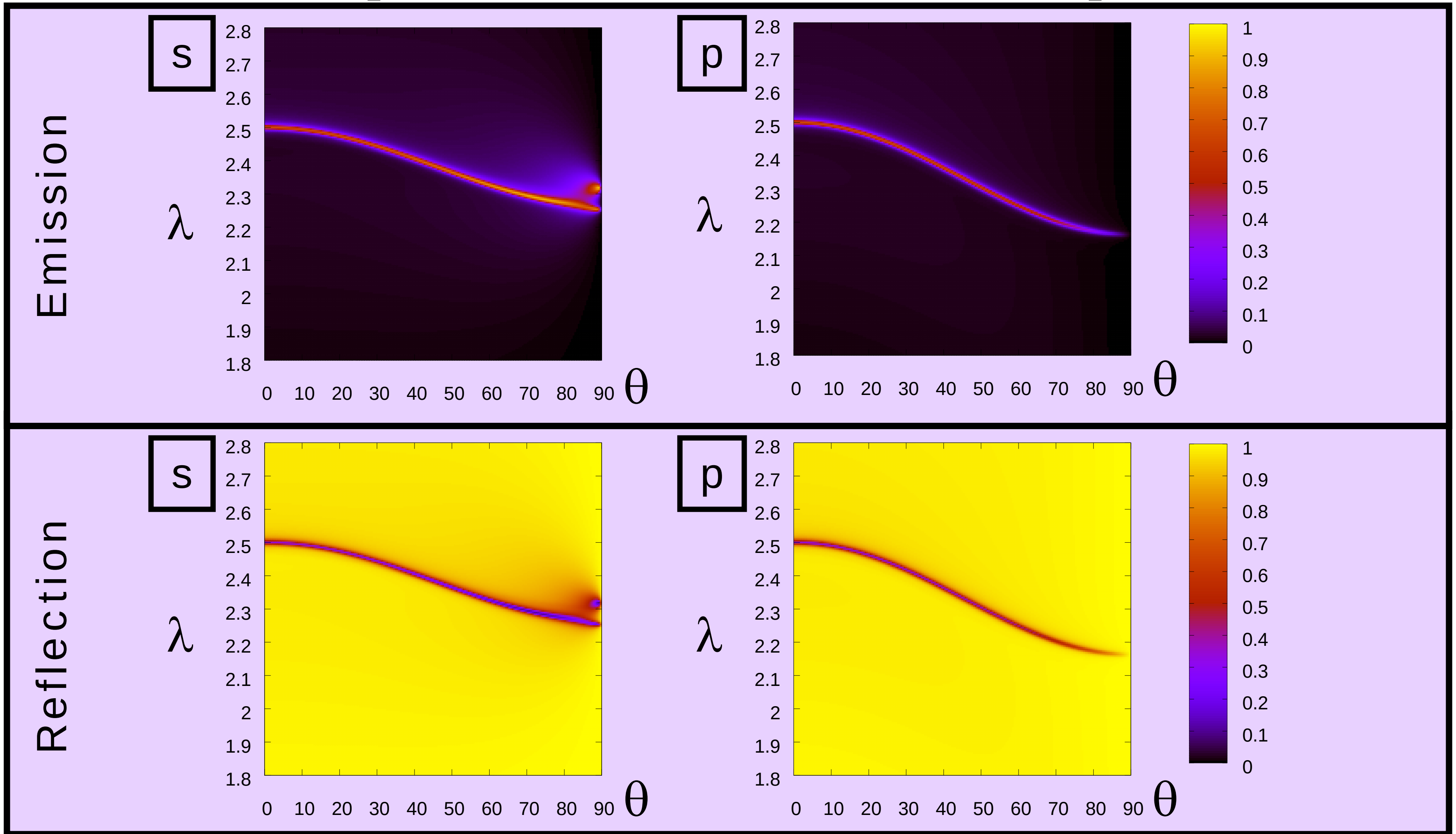
output



N. Generations ≡ 100 Function Eval.

3. Case studies

Quasi-isotropic radiator at room temperature



4. Conclusions and Outlook

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Conclusions

- Development of a Reversal Engineering Tool for designing directional microstructured radiators
- Proof their suitability for different types of radiators
- Implementation of a distributed version of the GA solver
- Distributed strategy shows an outperformance of factor 7

Outlook

- Asses the feasibility of the optimized structure (explore materials for the active layer)
- Study the “control” over the reflectivity and emissivity features
- Implement other GO solvers into the tool (DIGMO)
- Combine this proposal with surface gratings to improve the directivity

End

Thank you for your attention !

More Information:

- About the **ACT**: https://www.esa.int/act
- About **ARIADNA**: http://www.esa.int/gsp/ACT/ariadna/index.htm
- About **Microstructured Radiators**: Ariadna Final Report
  http://www.esa.int/gsp/ACT/doc/ARI/ARI%20Study%20Report/ACT-RPT-NAN-ARI-069501-Micro_Radiators-Nantes.pdf
- About **DIGMO**: http://www.esa.int/gsp/ACT/inf/op/act-dc_digmo.htm