

Heat Transfer: Radiation

Energy Balance

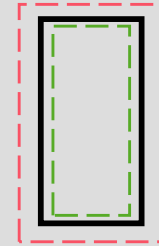
Prof. Dr.-Ing. Reinhold Kneer

Prof. Dr.-Ing. Dr. rer. pol. Wilko Rohlf

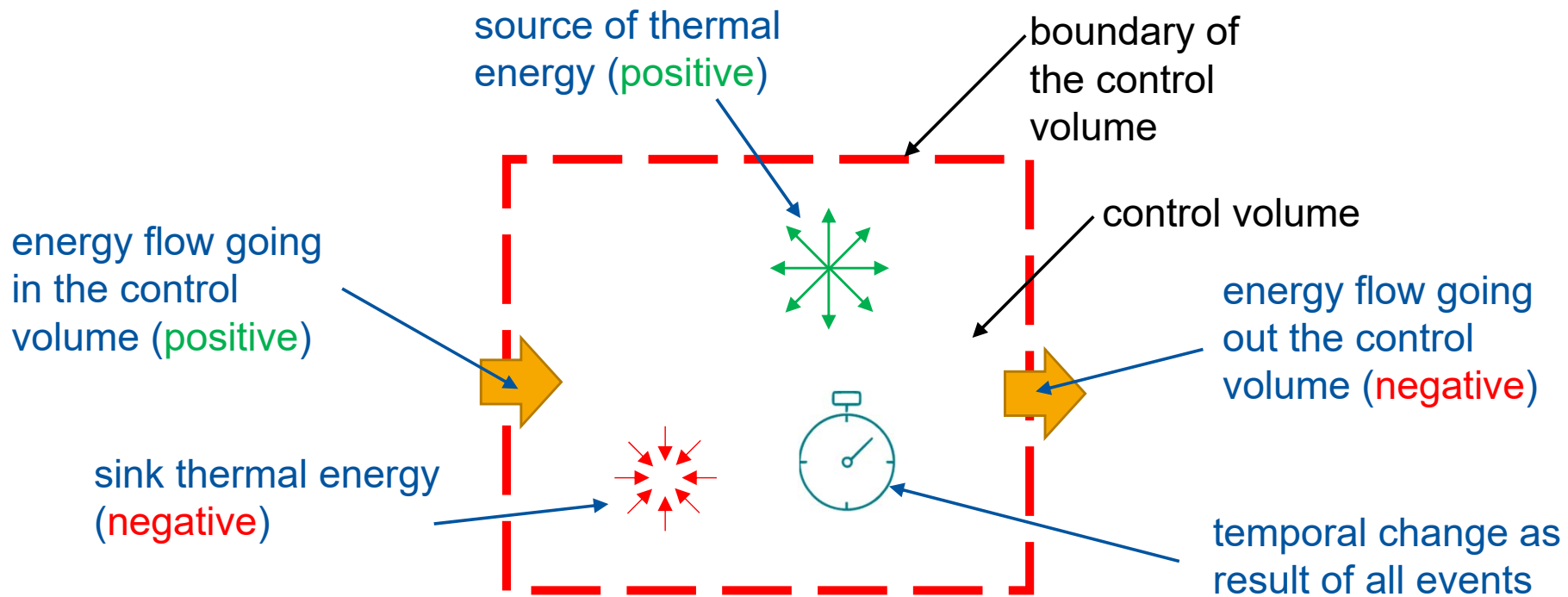
Learning goals

Energy balances:

- ▶ Understanding the concept of energy balances in radiative heat transfer
- ▶ Ability to set up energy balances around a body
- ▶ Understanding of internal and external energy balances



What is an energy balance?



Energy balance:

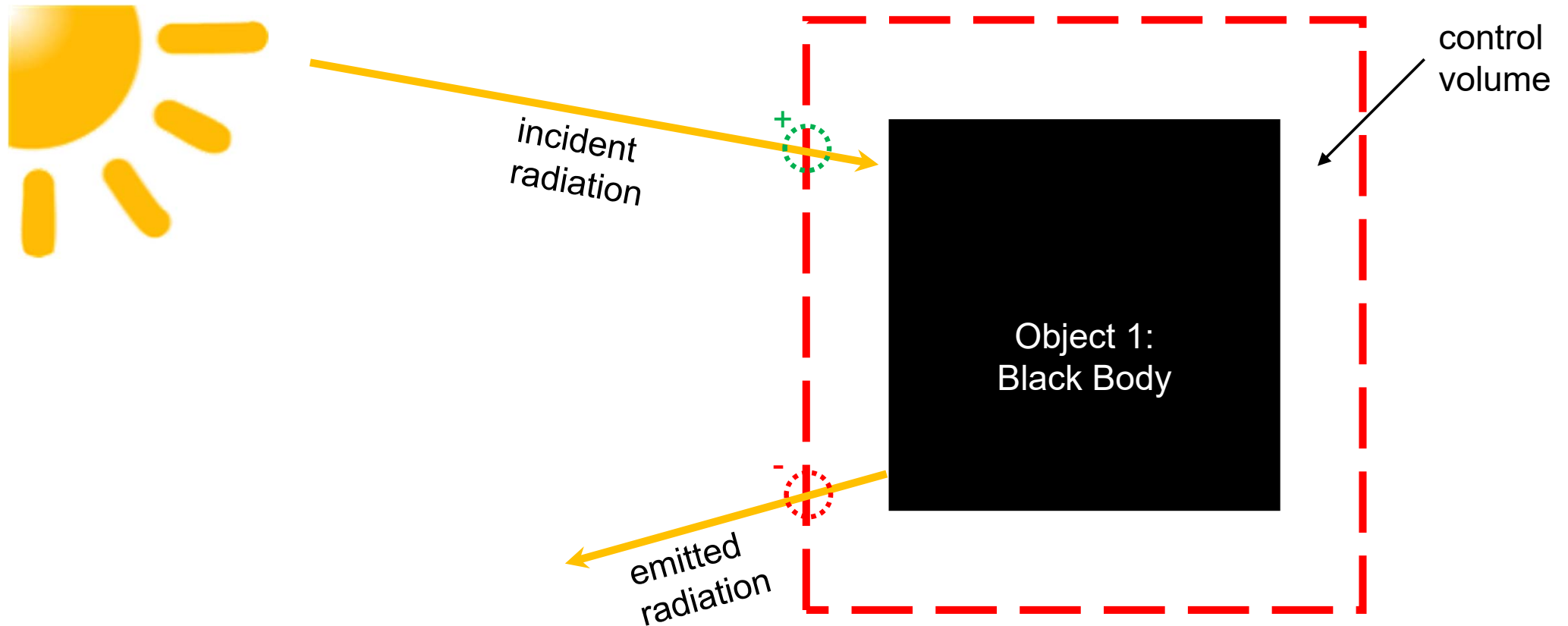
Temporal change =

Effect

+ Sum of all inflows
- Sum of all outflows
+ Sum of all sources
- Sum of all sinks

Cause

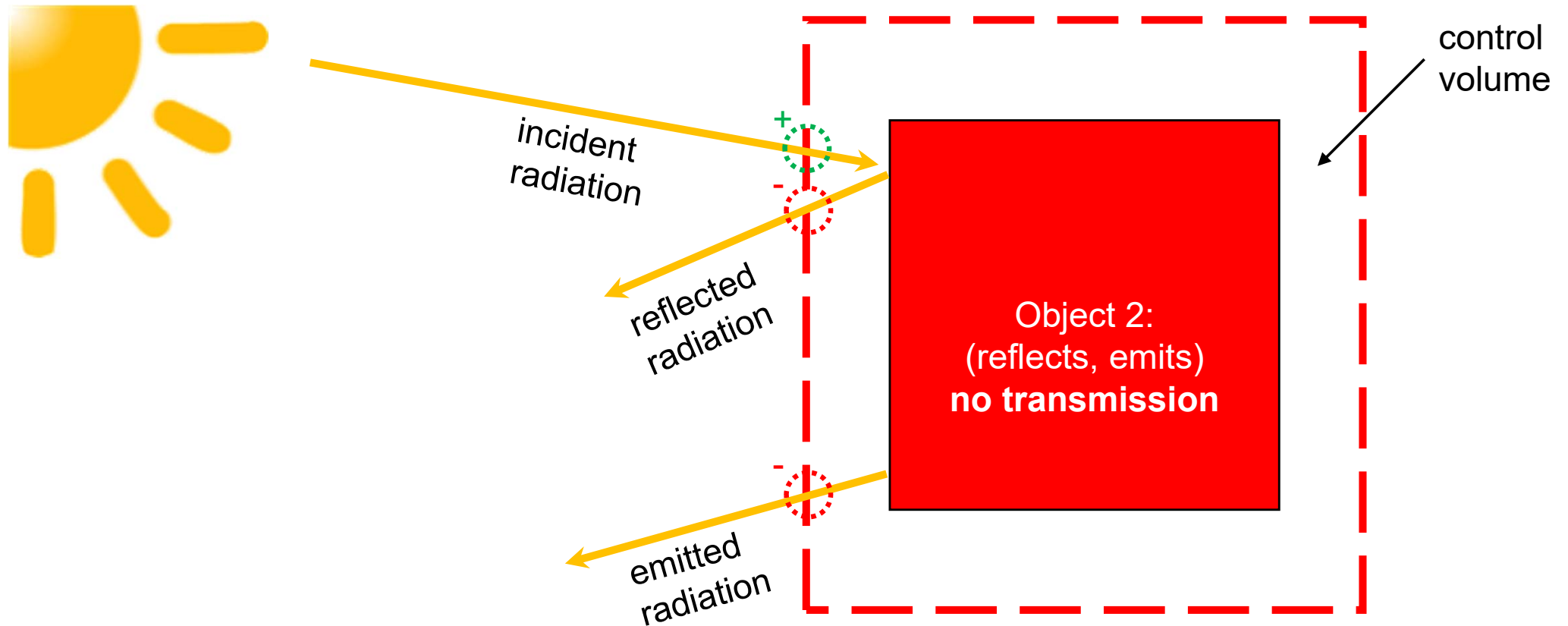
Energy balance



Outer energy balance:

$$\frac{\partial U}{\partial t} = \Sigma \dot{Q}_{in} - \Sigma \dot{Q}_{out}$$

Energy balance

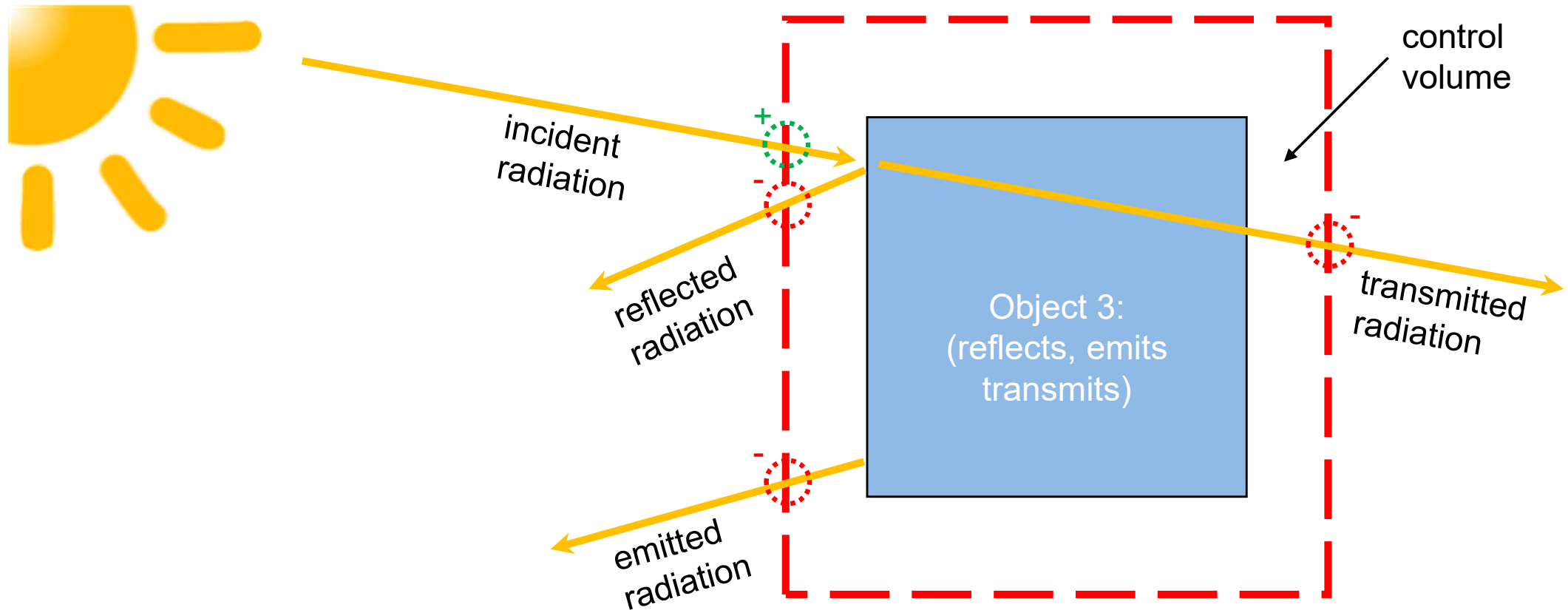


considers all energy flows
across the CV-borders

Outer energy balance:

$$\frac{\partial U}{\partial t} = \Sigma \dot{Q}_{in} - \Sigma \dot{Q}_{out}$$

Energy balance



Outer energy balance:

$$\frac{\partial U}{\partial t} = \Sigma \dot{Q}_{in} - \Sigma \dot{Q}_{out}$$

Outer energy balance



incident
radiation

reflected
radiation

emitted
radiation

control
volume

transmitted
radiation

Object 3:
(reflects, emits
transmits)

Outer energy balance:

$$\Sigma \dot{Q}_{\text{incoming}} = \Sigma (\dot{Q}_i \phi_{i,3})_{\text{arriving}}$$

Surface brightness of Body i
x
View factor from Body i to Body 3

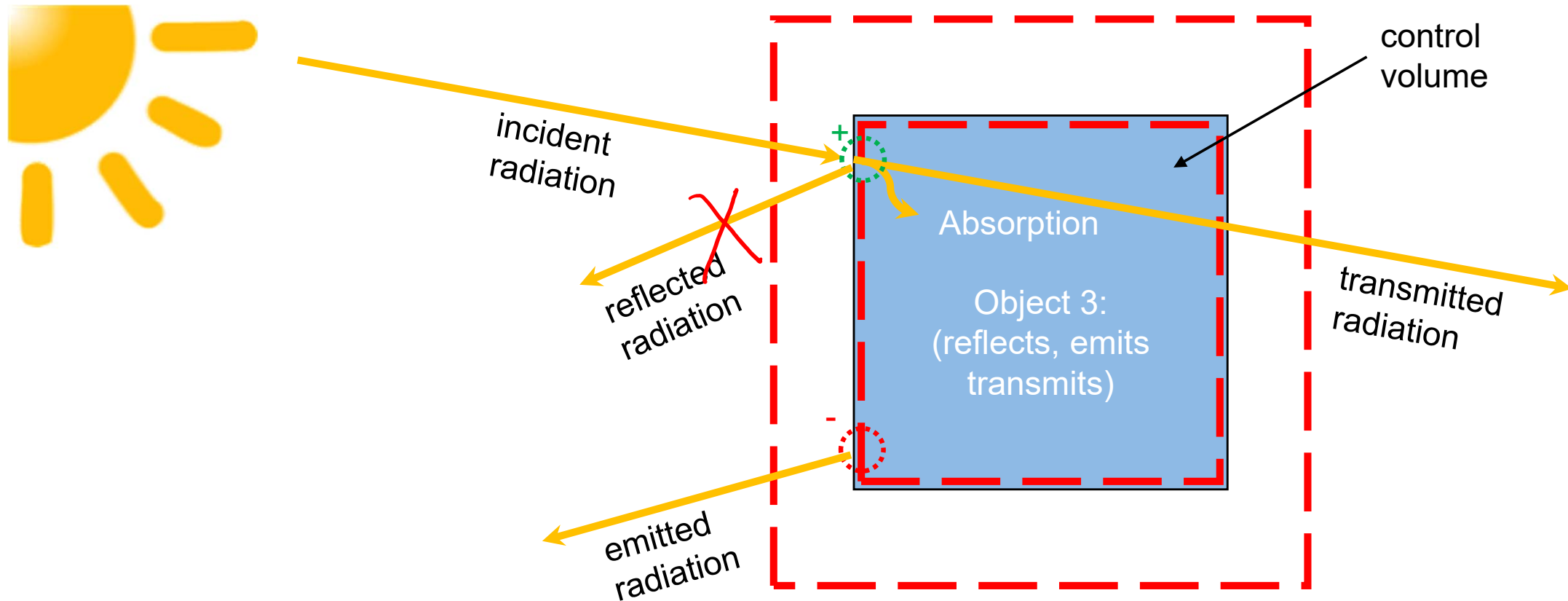
$$\Sigma \dot{Q}_{\text{outcoming}} = \dot{Q}_3$$

Surface brightness from Body 3

Outer energy balance:

$$\frac{\partial U}{\partial t} = \Sigma \dot{Q}_{\text{in}} - \Sigma \dot{Q}_{\text{out}}$$

Inner energy balance

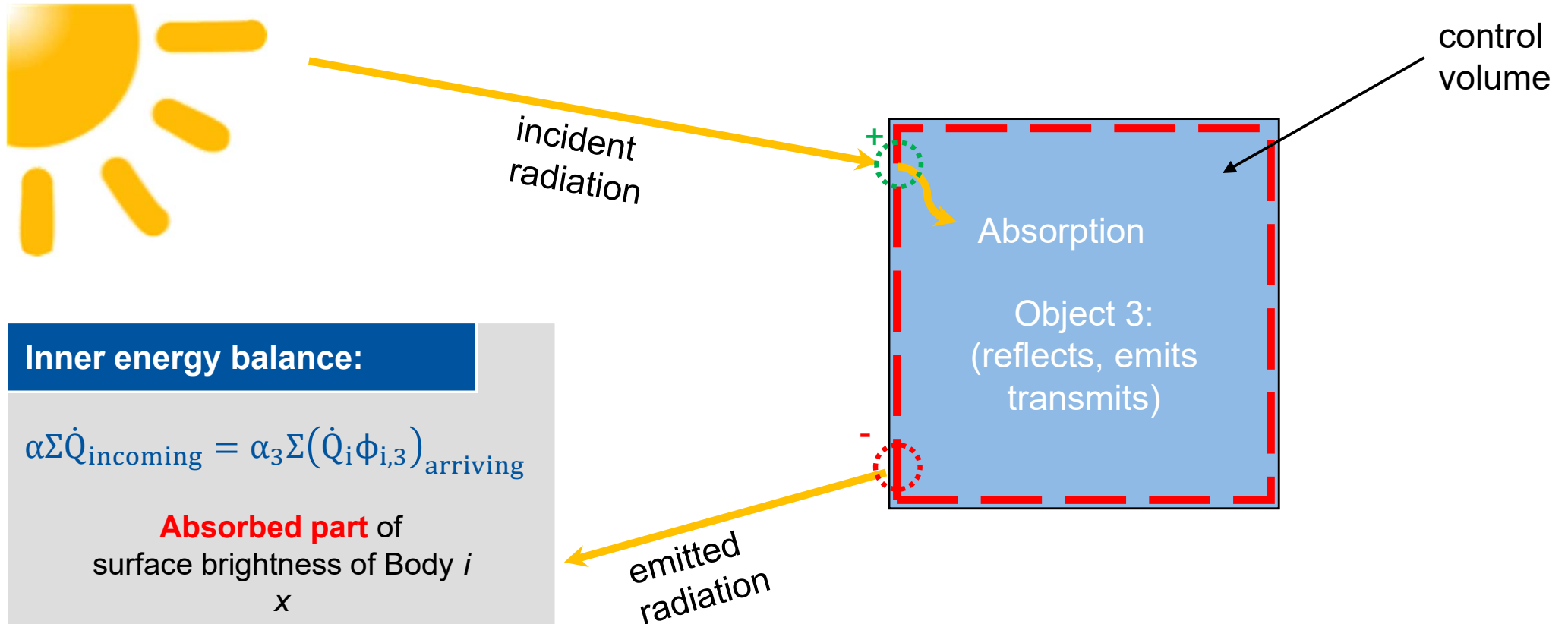


considers only
energy flows, which
change the inner energy

Inner energy balance:

$$\frac{\partial U}{\partial t} = \alpha \Sigma \dot{Q}_{\text{in}} - \Sigma \dot{Q}_{\text{emitted}}$$

Inner energy balance



Inner energy balance:

$$\alpha \Sigma \dot{Q}_{\text{incoming}} = \alpha_3 \Sigma (\dot{Q}_i \phi_{i,3})_{\text{arriving}}$$

Absorbed part of
surface brightness of Body i
 \times
View factor from Body i to Body 3

$$\Sigma \dot{Q}_{\text{outgoing}} = \dot{Q}_{3,\epsilon}$$

Emission from Body 3

Inner energy balance:

$$\frac{\partial U}{\partial t} = \alpha \Sigma \dot{Q}_{\text{in}} - \Sigma \dot{Q}_{\text{emitted}}$$

Comparison: Inner and Outer Energy Balance

Inner energy balance:

$$\frac{\partial U}{\partial t} = \alpha \Sigma \dot{Q}_{\text{in}} - \Sigma \dot{Q}_{\text{emitted}}$$

Outer energy balance:

$$\frac{\partial U}{\partial t} = \Sigma \dot{Q}_{\text{in}} - \Sigma \dot{Q}_{\text{out}}$$

Inner energy balance - Explanation:

$$\alpha \Sigma \dot{Q}_{\text{incoming}} = \alpha_3 \Sigma (\dot{Q}_i \phi_{i,3})_{\text{arriving}}$$

Absorbed part of
surface brightness of Body i
 \times
View factor from Body i to Body 3

$$\Sigma \dot{Q}_{\text{outgoing}} = \dot{Q}_{3,\epsilon}$$

Emission from Body 3

Outer energy balance - Explanation:

$$\Sigma \dot{Q}_{\text{incoming}} = \Sigma (\dot{Q}_i \phi_{i,3})_{\text{arriving}}$$

Surface brightness of Body i
 \times
View factor from Body i to Body 3

$$\Sigma \dot{Q}_{\text{outcoming}} = \dot{Q}_3$$

Surface brightness from Body 3

Comparison: Inner and Outer Energy Balance

Inner energy balance:

$$\frac{\partial U}{\partial t} = \alpha \Sigma \dot{Q}_{\text{in}} - \Sigma \dot{Q}_{\text{emitted}}$$

Outer energy balance:

$$\frac{\partial U}{\partial t} = \Sigma \dot{Q}_{\text{in}} - \Sigma \dot{Q}_{\text{out}}$$

Inner energy balance - Explanation:

$$\alpha \Sigma \dot{Q}_{\text{incoming}} = \alpha_3 \Sigma (\dot{Q}_i \phi_{i,3})_{\text{arriving}}$$

Absorbed part of
surface brightness of Body i
 \times

View factor from Body i to Body 3

Only the absorbed part of the surface brightness is taken into account in the inner balance. Reflection and Transmission play no role.

In the surface brightness of the outer balance Reflection and Transmission are again taken into account.

$$\Sigma \dot{Q}_{\text{outgoing}} = \dot{Q}_{3,\epsilon}$$

Emission from Body 3

Outer energy balance - Explanation:

$$(\dot{Q}_i \phi_{i,3})_{\text{arriving}}$$

Surface brightness of Body i
 \times

View factor from Body i to Body 3

$$\dot{Q}_3$$

Surface brightness from Body 3

Conclusion: The result from Inner and Outer Energy Balance is identical

Advantage inner balance:
Less terms

Advantage outer balance:
Direct calculation with surface brightness

Comprehension Questions

Which events lead to a temporal change of the thermal energy in the control volume?

**Which terms are considered additionally in the outer energy balance?
How can inner and outer energy balance be transformed into each other?**

For which applications is an inner or external energy balance more useful?