Solar-sail acceleration model

Sail acceleration model - assumptions

Perfectly reflecting sail

- Pure specular reflection of the solar photons
  - The angle of reflection is equal to the angle of incidence
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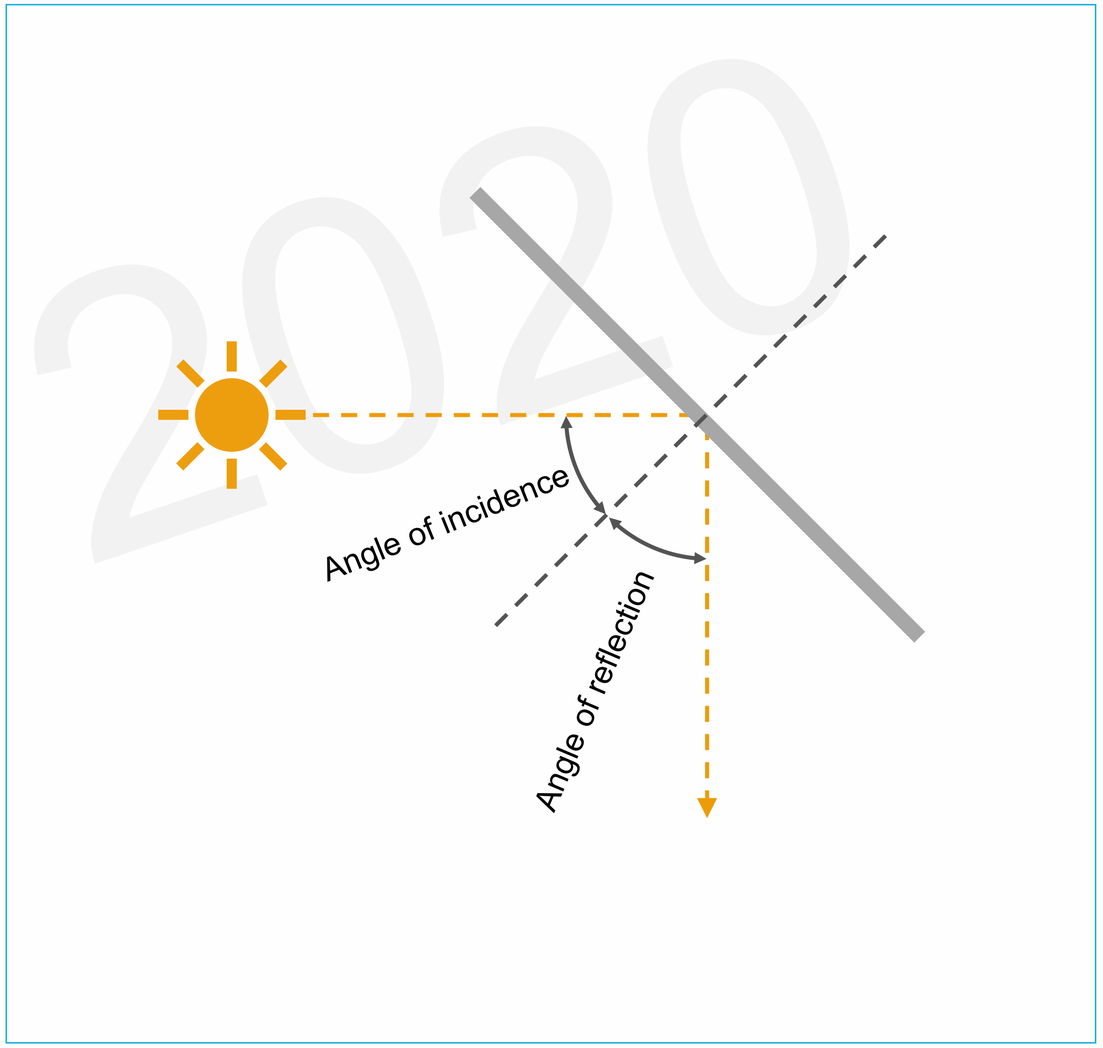
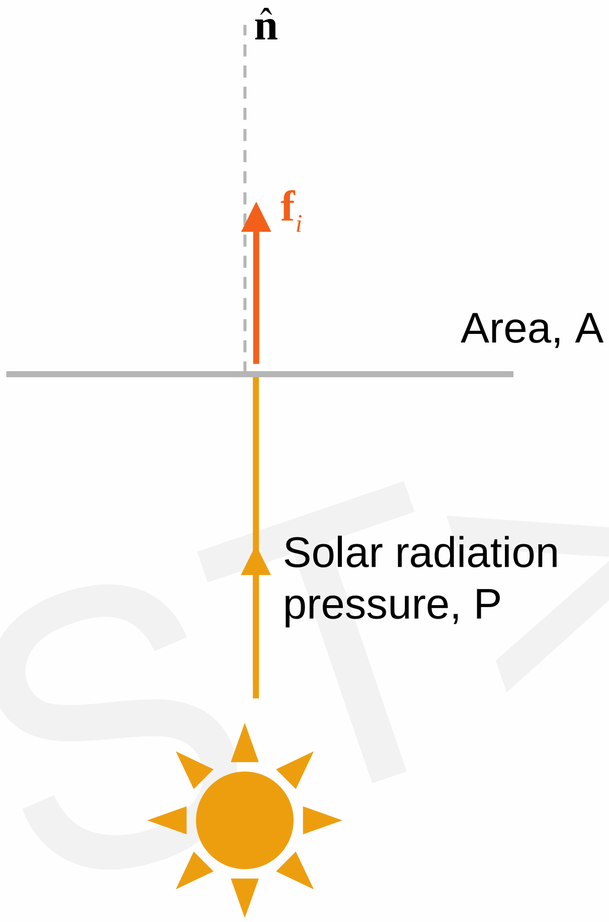
This is called an **ideal sail model**



Force on an ideal Sun-facing sail



- Incident force

$$\mathbf{f}_i = PA\hat{\mathbf{n}}$$

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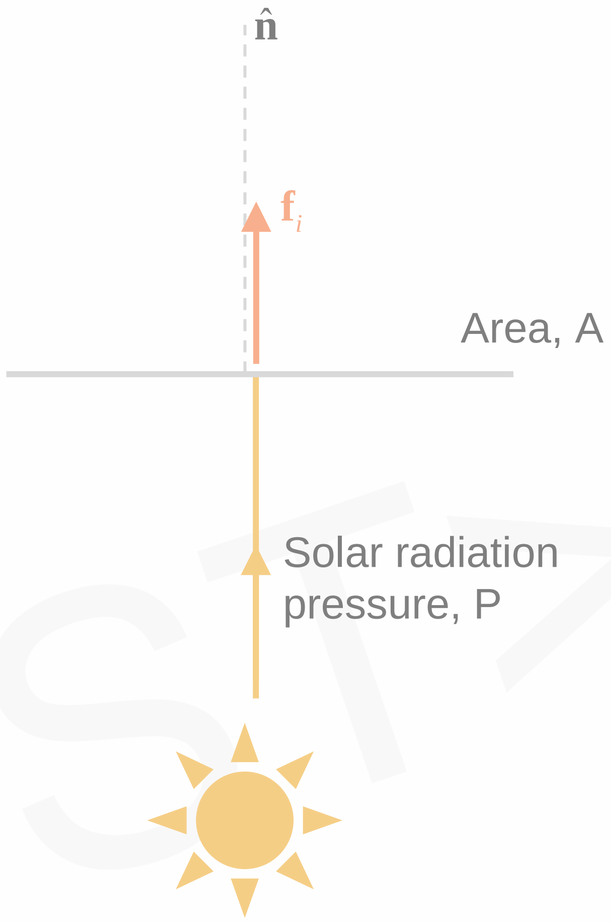

Quiz question

Is the solar radiation pressure at Earth's distance smaller, greater or equal to the pressure of a $1 bill in your hand?

a) Smaller

b) Equal

c) Greater

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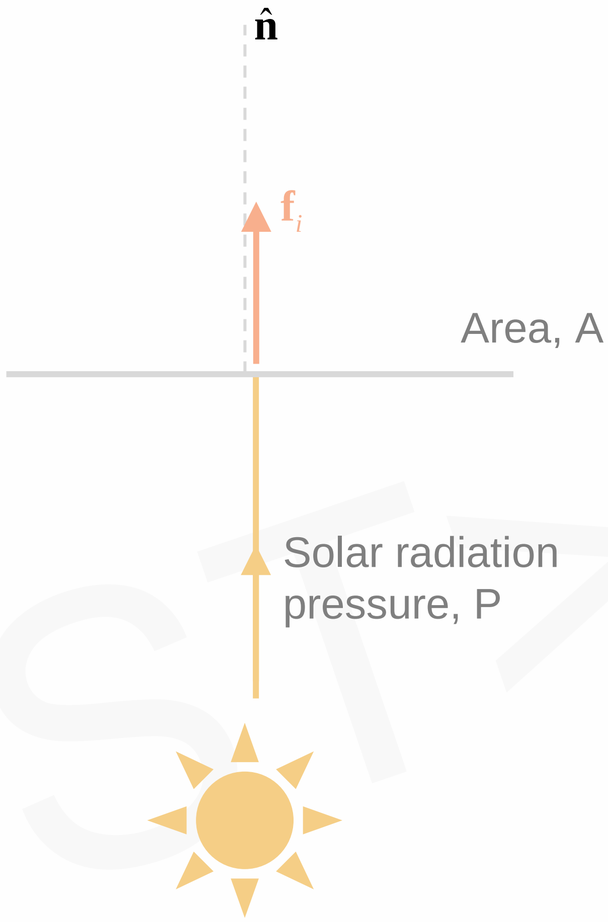

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Solar radiation pressure → ± 4.5 μN/m²

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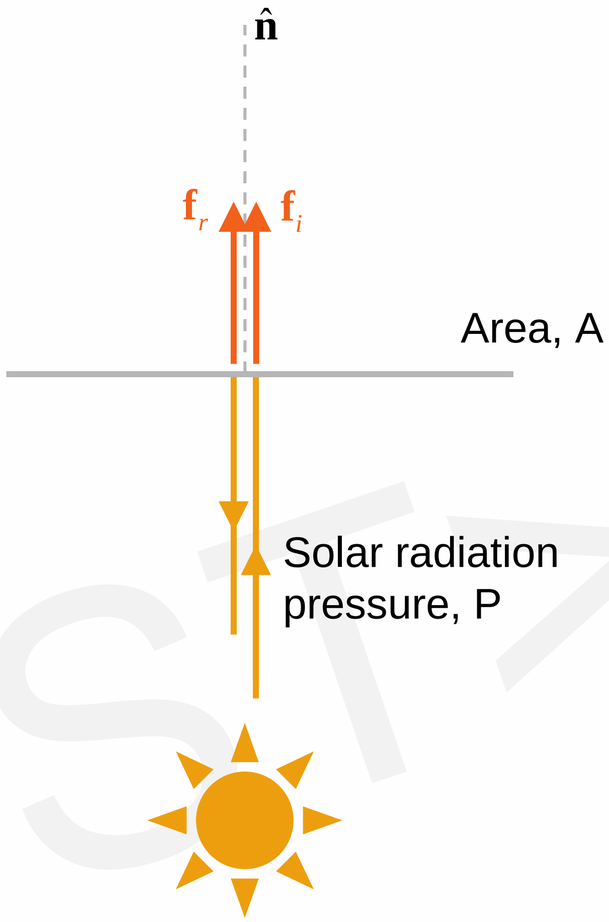


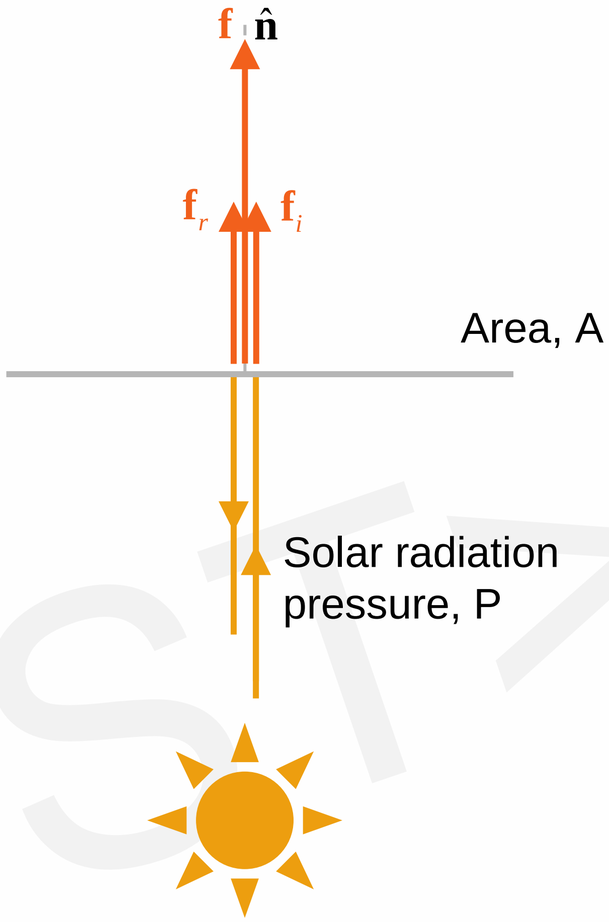
- Incident force

$$\mathbf{f}_i = PA\hat{\mathbf{n}}$$

- Reflected force

$$\mathbf{f}_r = PA\hat{\mathbf{n}}$$

Force on an ideal Sun-facing sail



- Incident force

$$\mathbf{f}_i = PA\hat{\mathbf{n}}$$

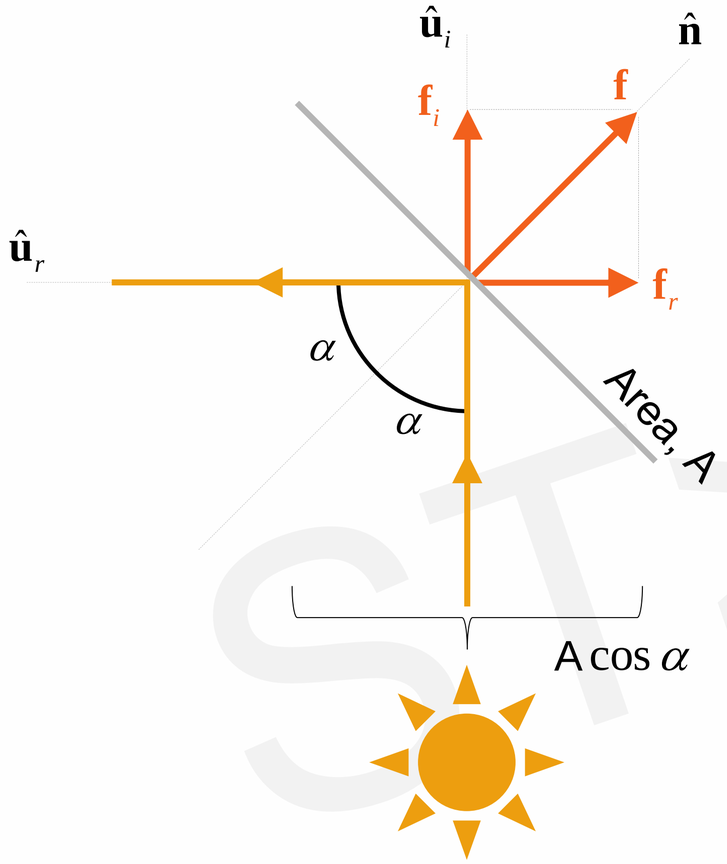
- Reflected force

$$\mathbf{f}_r = PA\hat{\mathbf{n}}$$

- Total force

$$\mathbf{f} = \mathbf{f}_i + \mathbf{f}_r = 2PA\hat{\mathbf{n}}$$

Force on an ideal pitched sail



- Incident force

$$\mathbf{f}_i = \qquad \hat{\mathbf{u}}_i$$

- Reflected force

$$\mathbf{f}_r = -PA\cos\alpha\hat{\mathbf{u}}_r$$

- Total force

$$\mathbf{f} = \mathbf{f}_i + \mathbf{f}_r$$

Trigonometry

$$\mathbf{f} = 2PA\left(\cos\alpha\right)^2\hat{\mathbf{n}}$$

Force on an ideal pitched sail

$$\mathbf{f} = 2PA\left(\cos\alpha\right)^2 \hat{\mathbf{n}}$$

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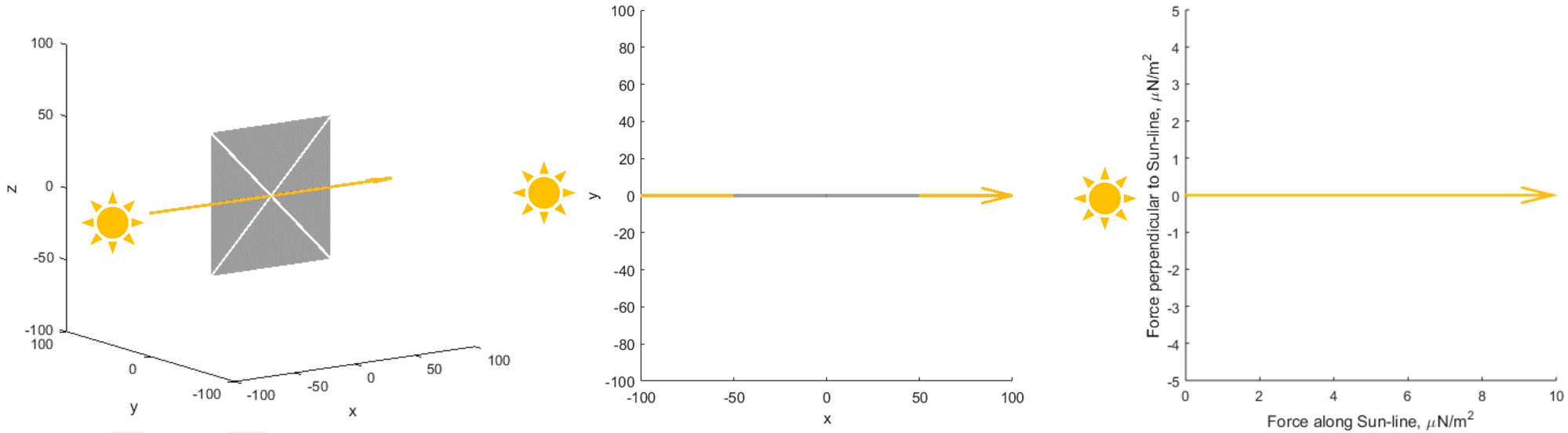
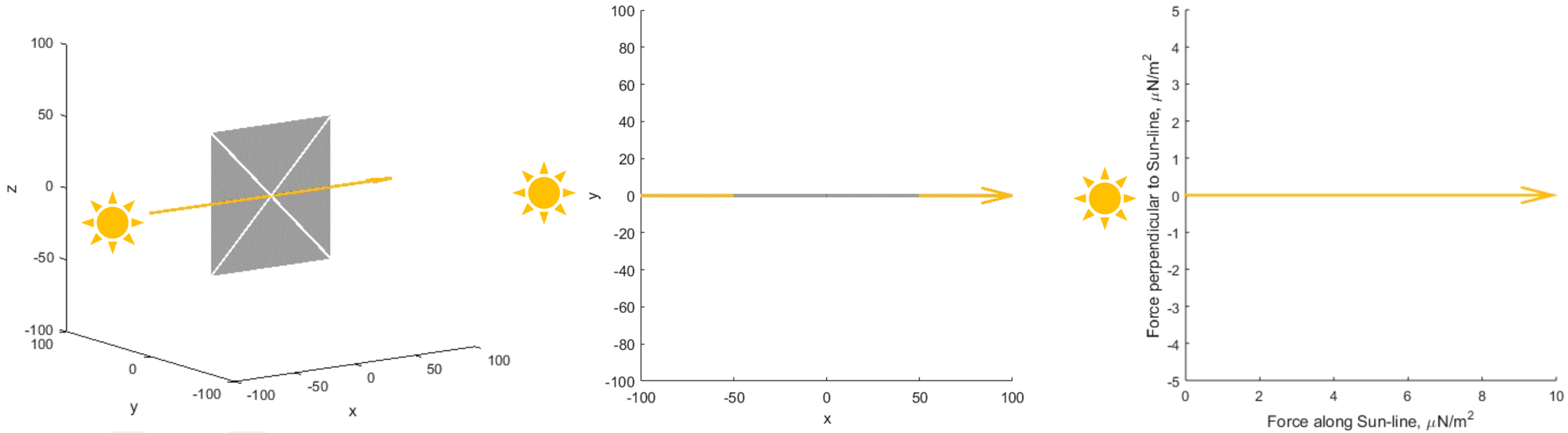


Force on an ideal pitched sail

- No force component in the direction of the Sun

$$\mathbf{f} = 2PA\left(\cos\alpha\right)^2 \hat{\mathbf{n}}$$



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- No force component in the direction of the Sun
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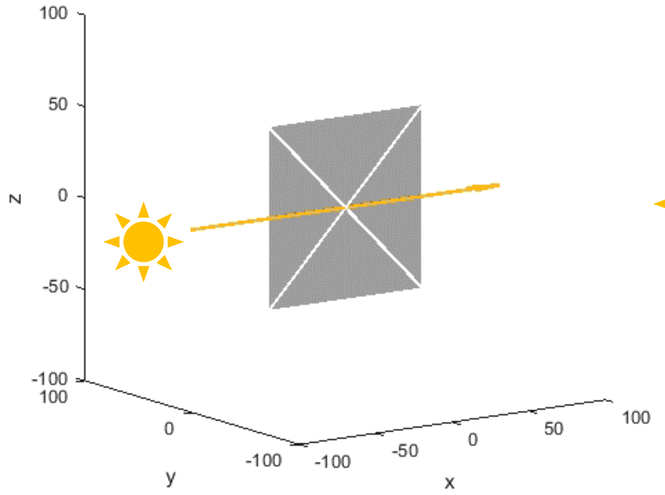

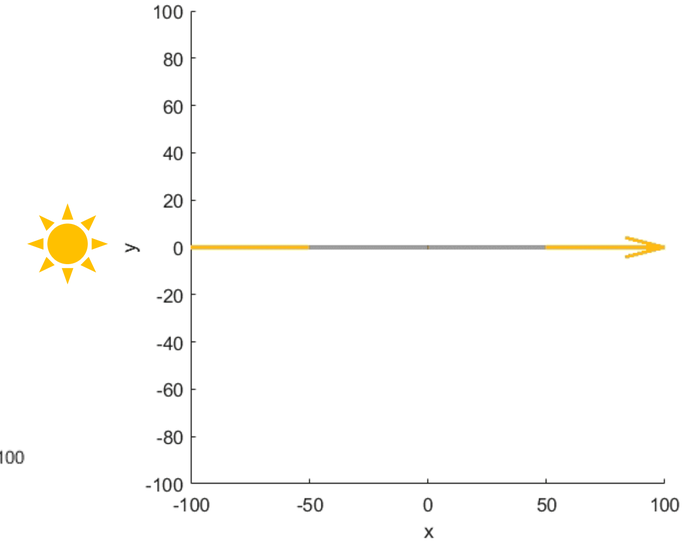

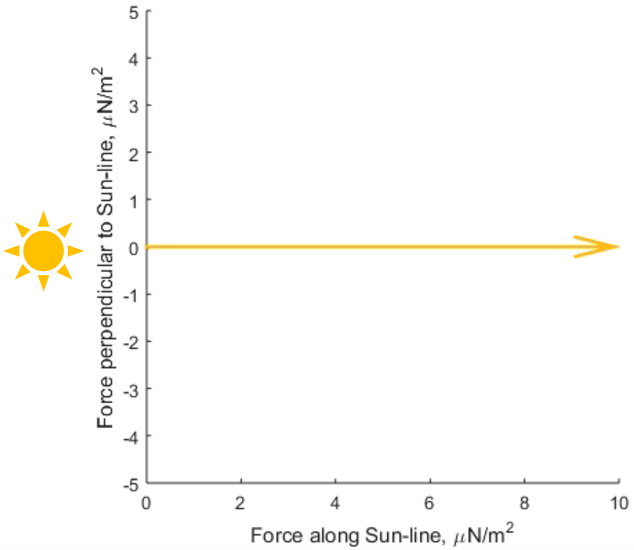

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- No force component in the direction of the Sun
- Force magnitude/direction is constrained to “force bubble”
- Need a very large sail area to create significant force

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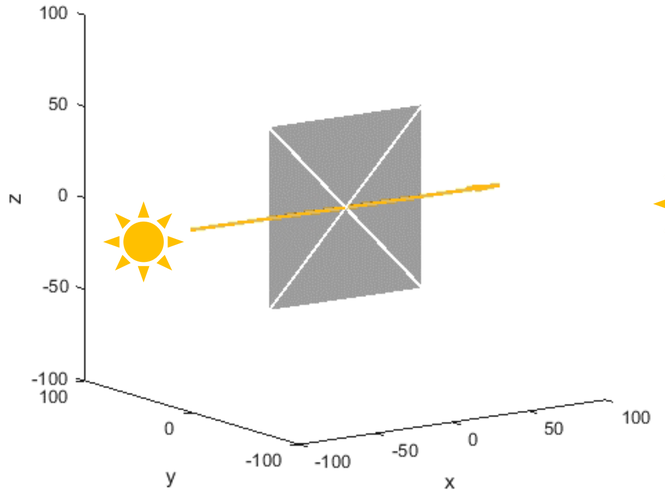

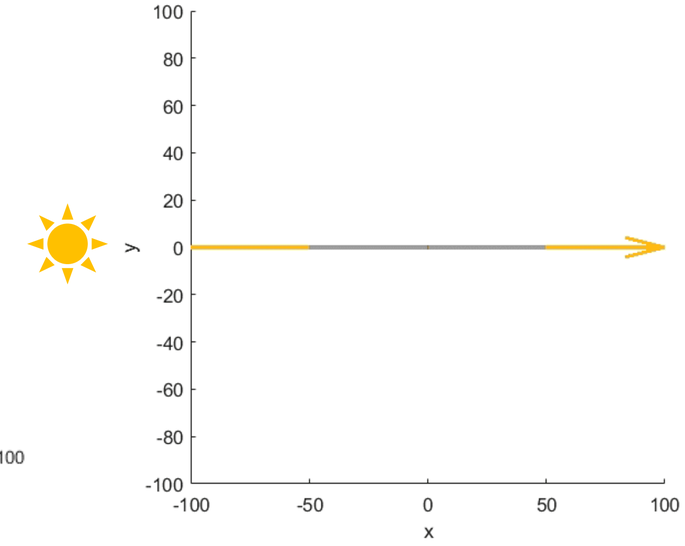

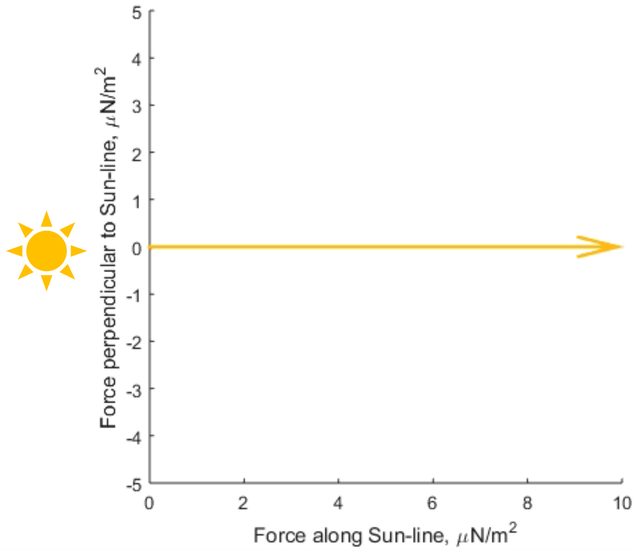

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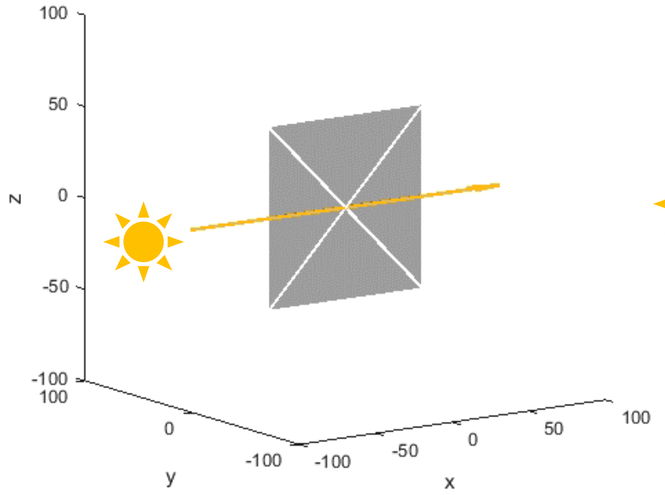

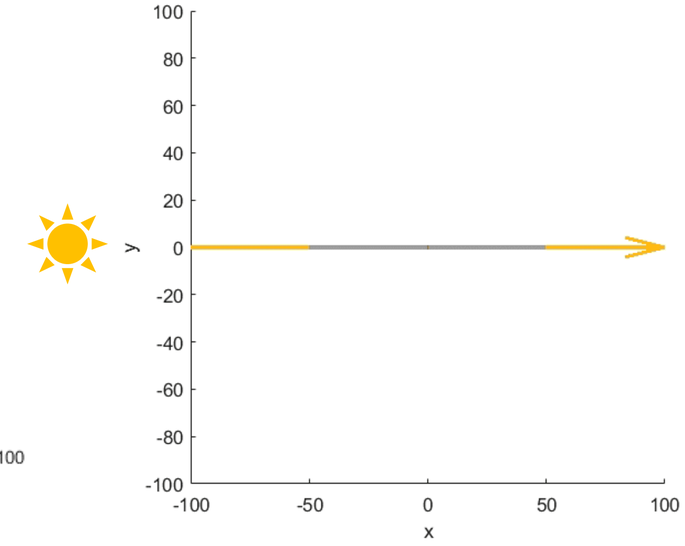

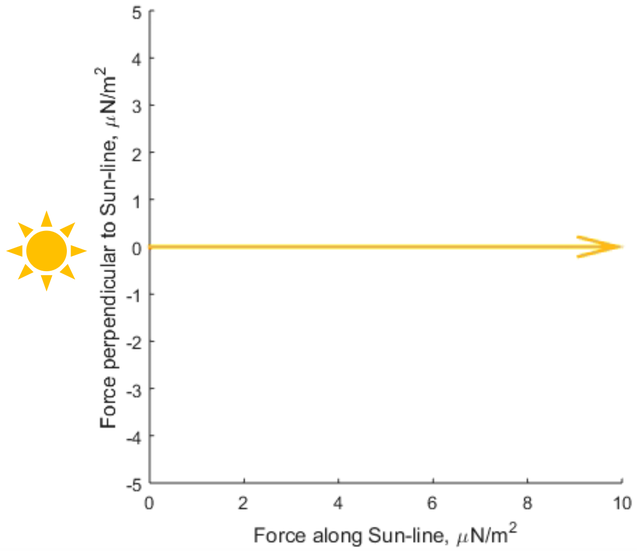

Solar-sail performance index

- Different sail sizes, masses of spacecraft
- Different sail configurations
- … how to compare the performance of different solar sails?

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- Divide by mass to obtain the solar-sail acceleration

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Area-to-mass ratio

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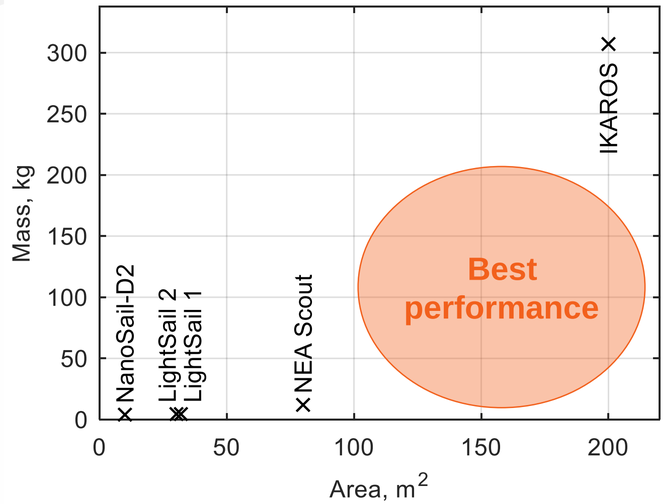

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- Manipulate to write the solar-sail acceleration as a function of the solar gravitational acceleration

$$\mathbf{a} = \beta\frac{\mu_\odot}{r^2}\left(\cos\alpha\right)^2 \hat{\mathbf{n}}$$

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Solar gravitational acceleration

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Solar- sail lightness number

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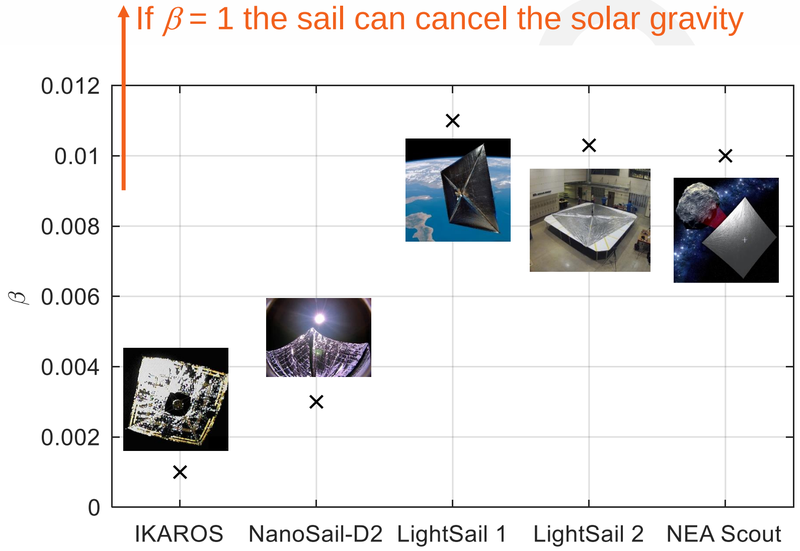

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To obtain a lightness number of 1, do you think the spacecraft should have an area-to-mass ratio larger, smaller or equal to tin foil?

a) Smaller

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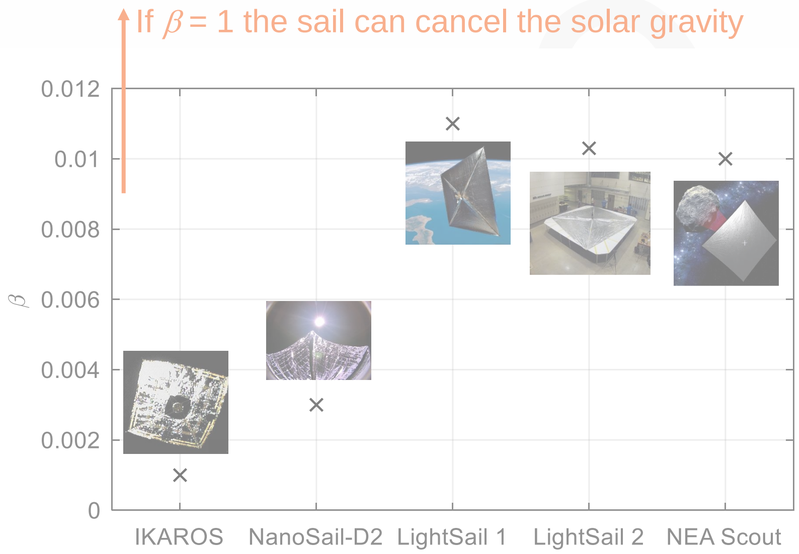

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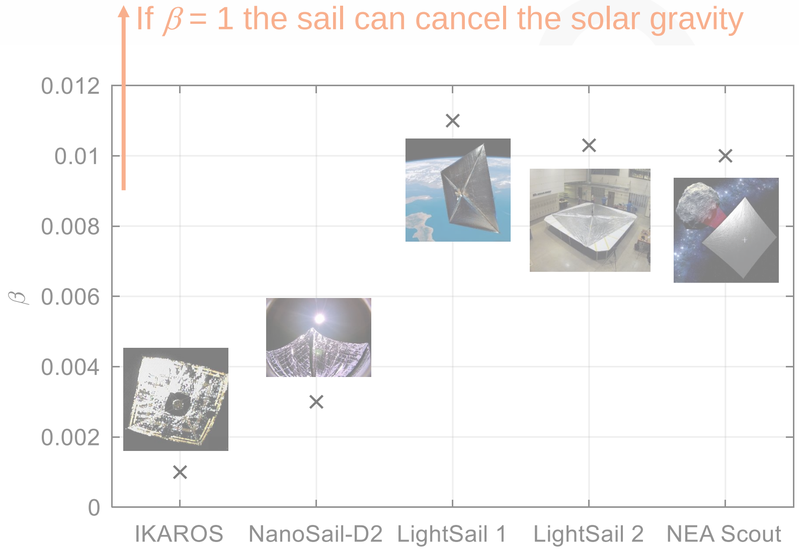
A solar-sail s/c with $\beta = 1 \rightarrow \pm 650$ m²/kg



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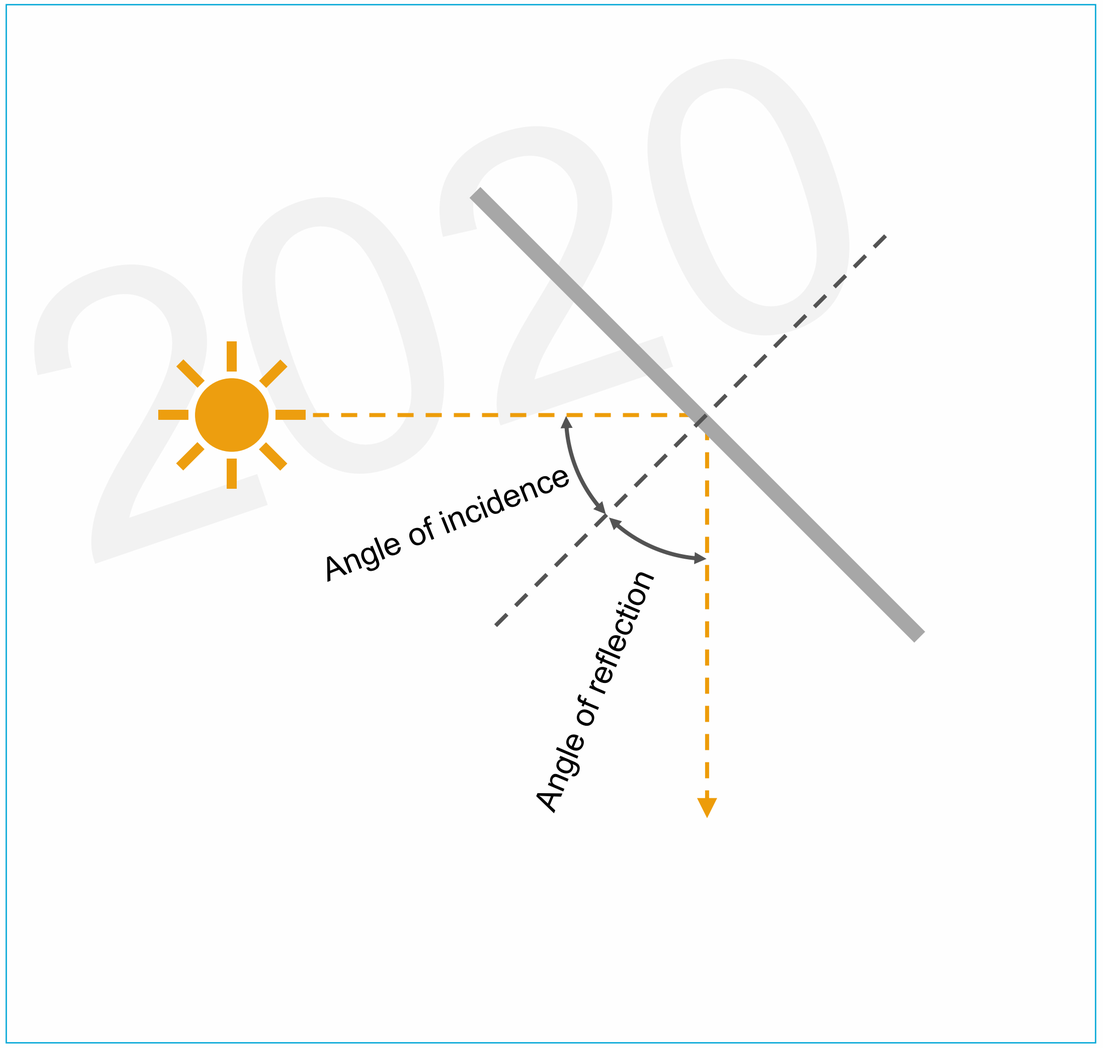

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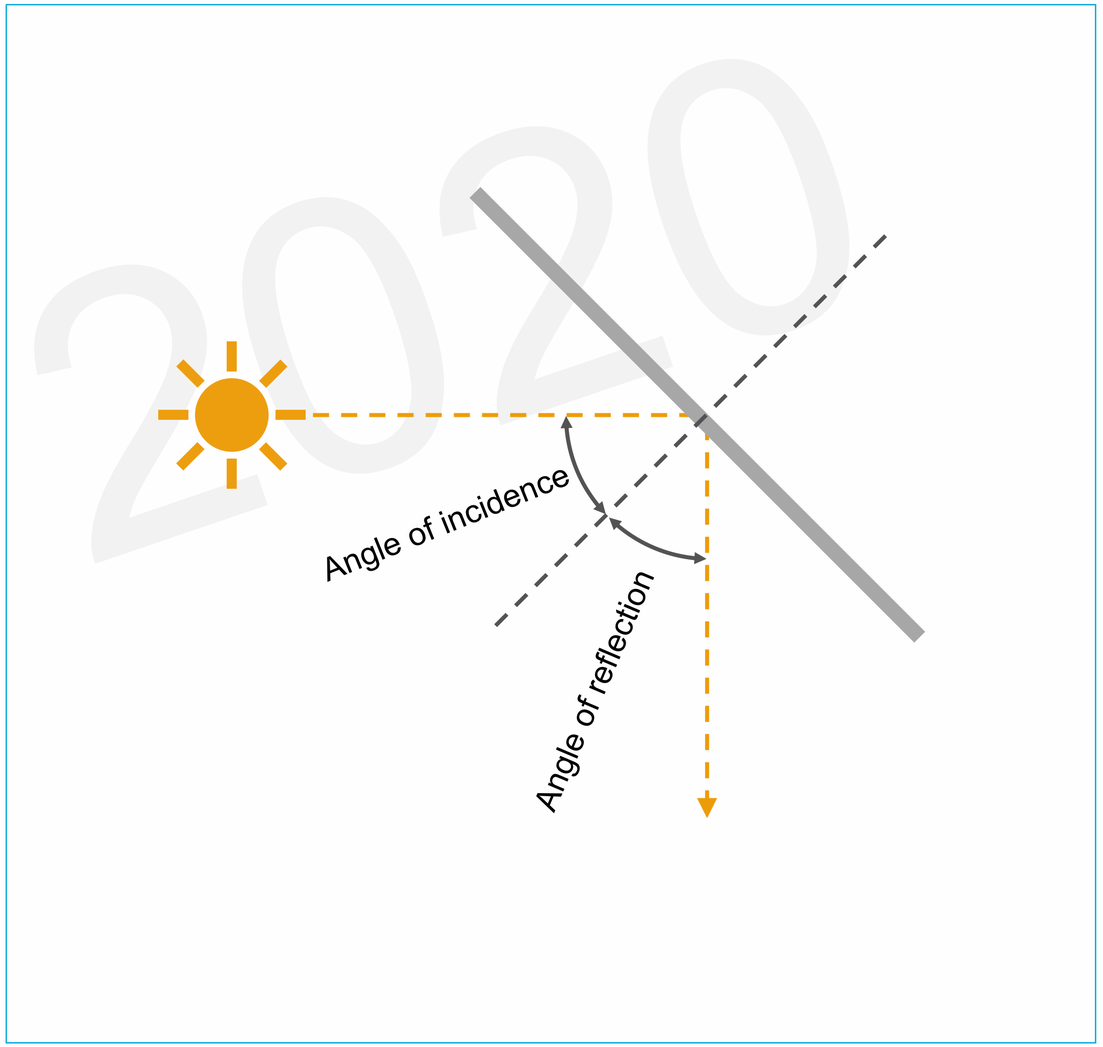

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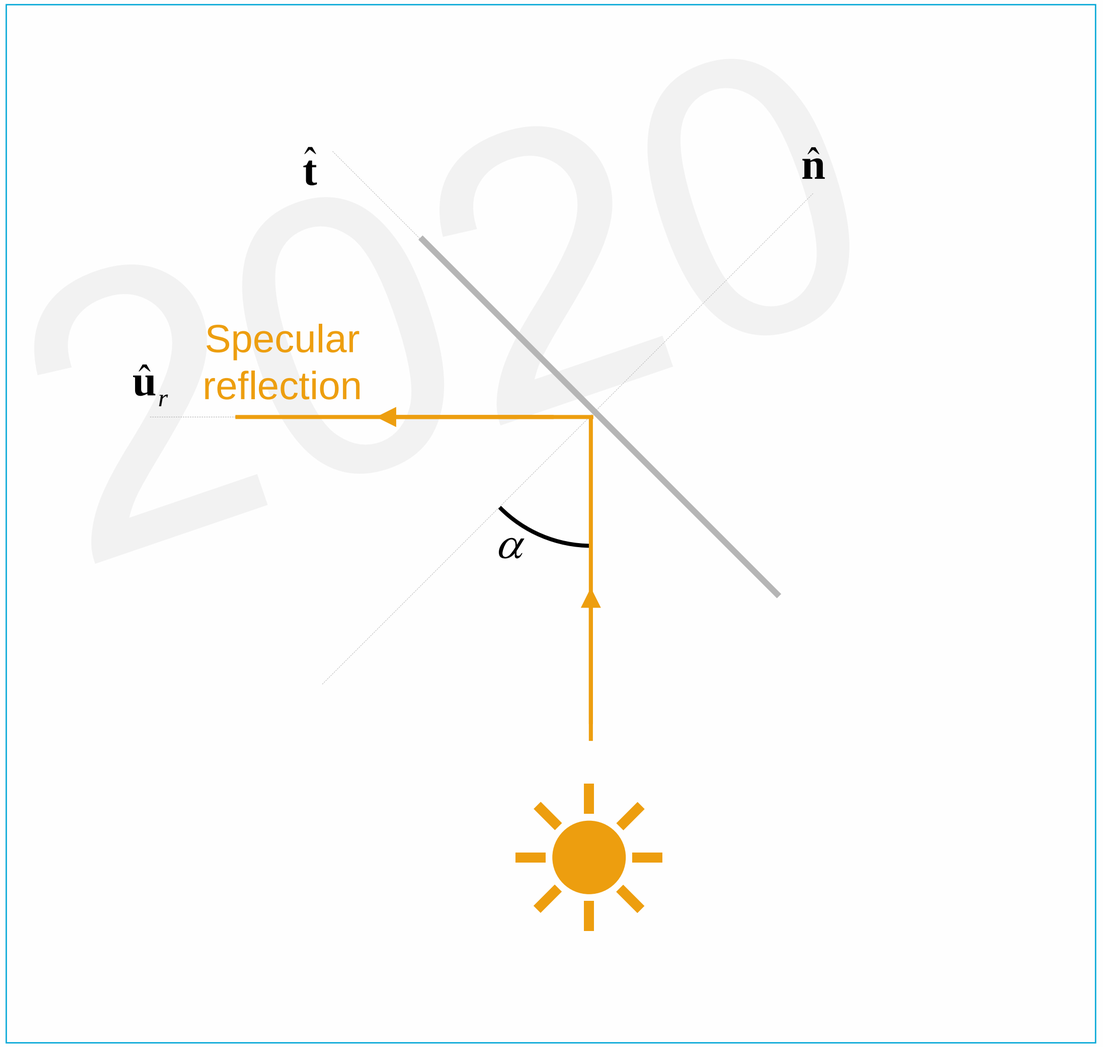

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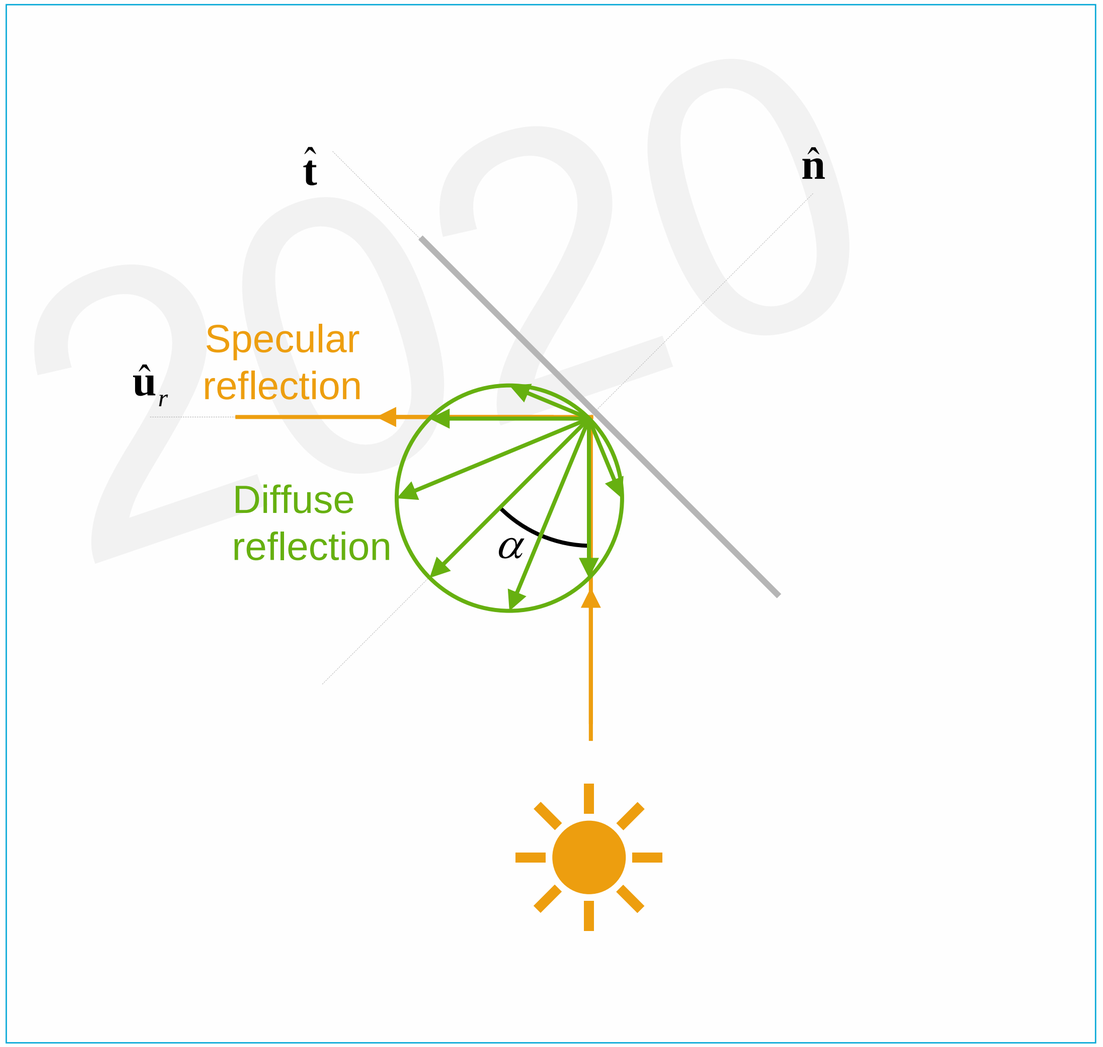

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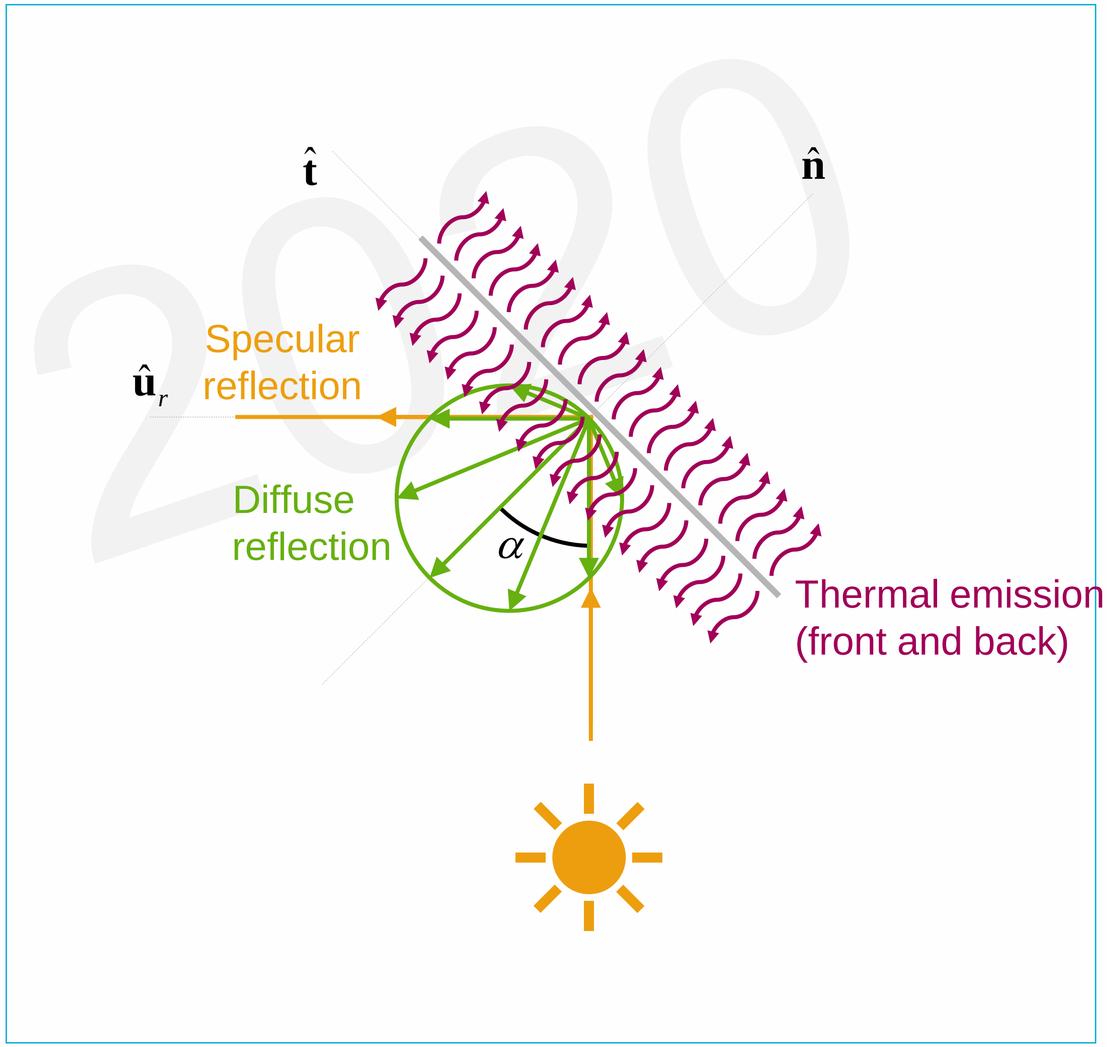

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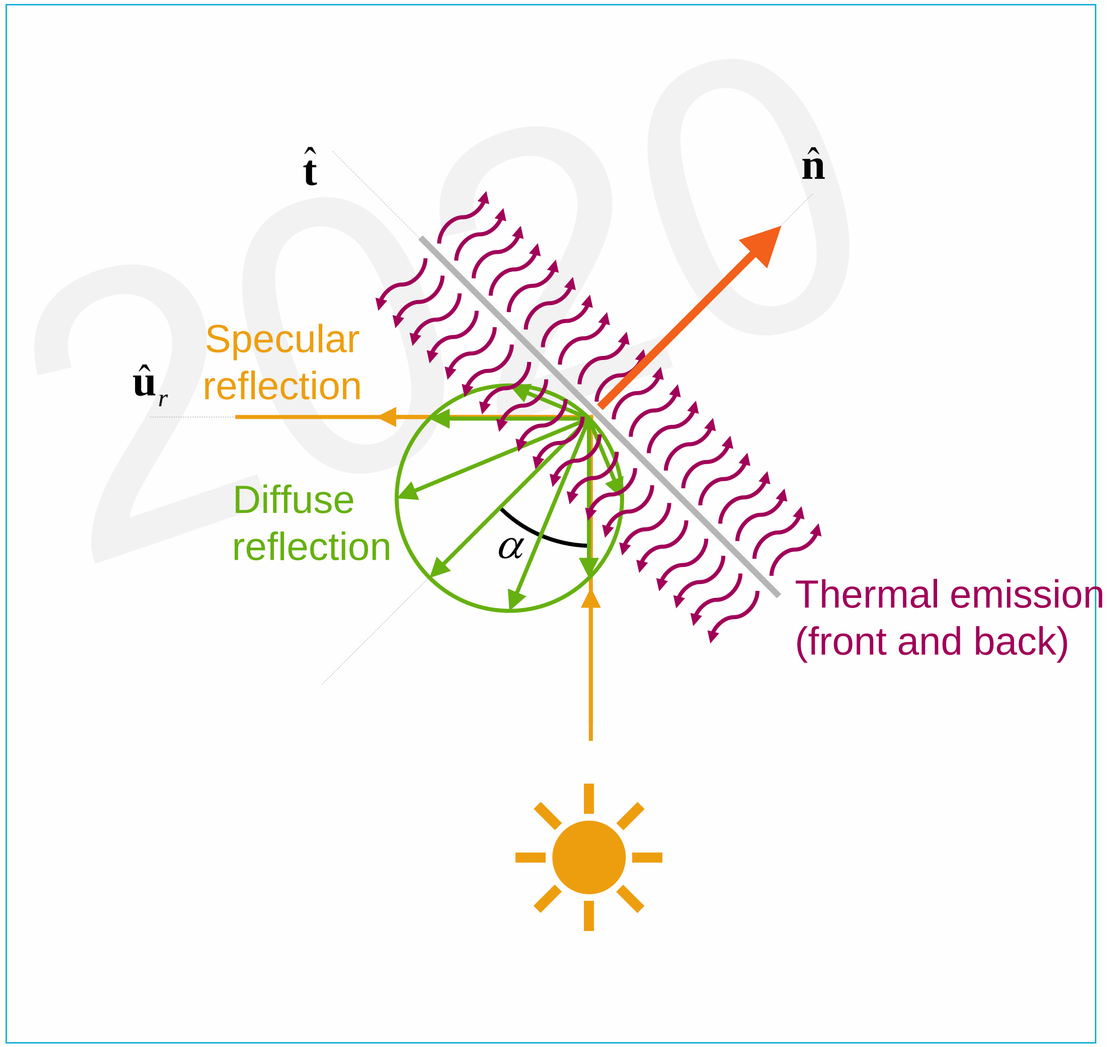

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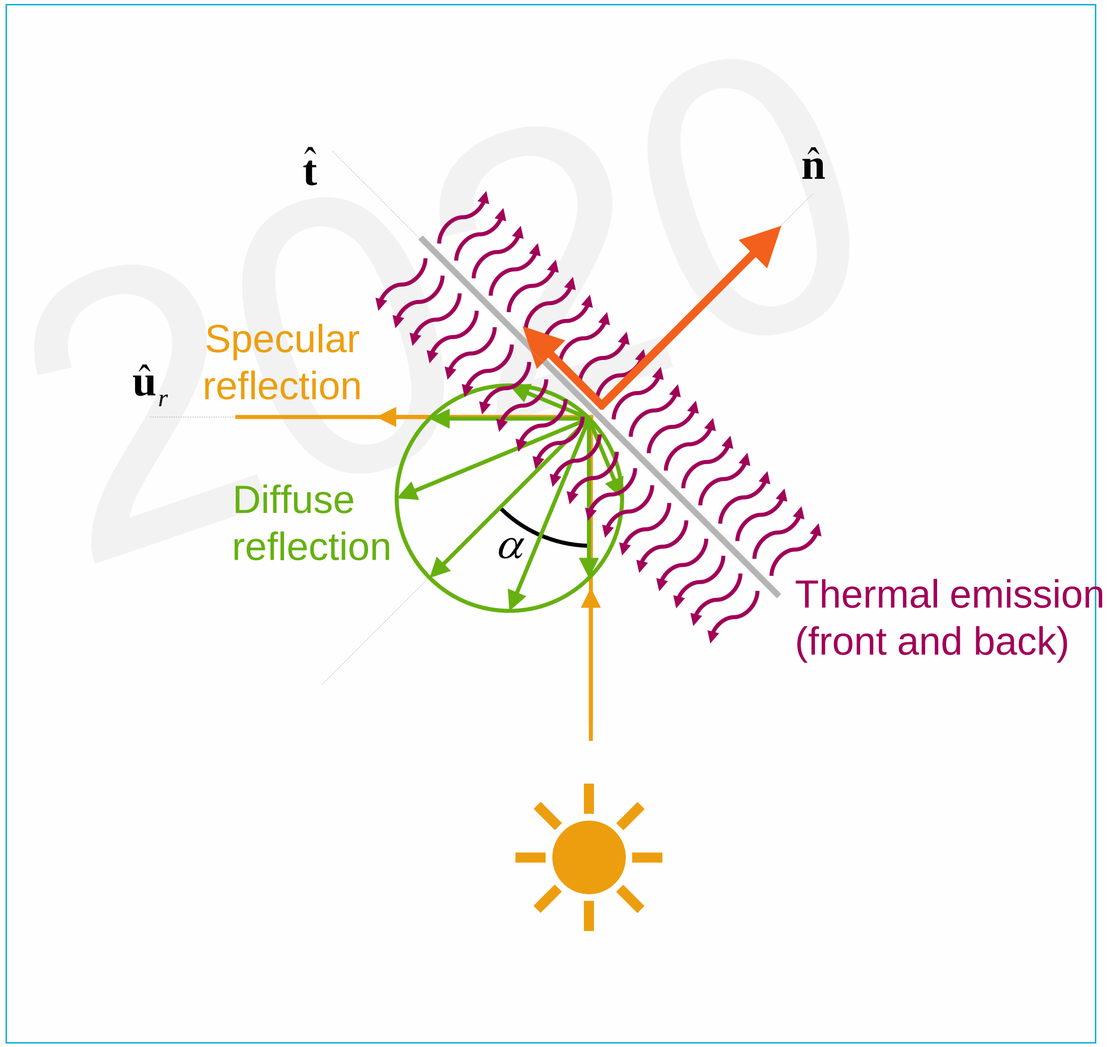

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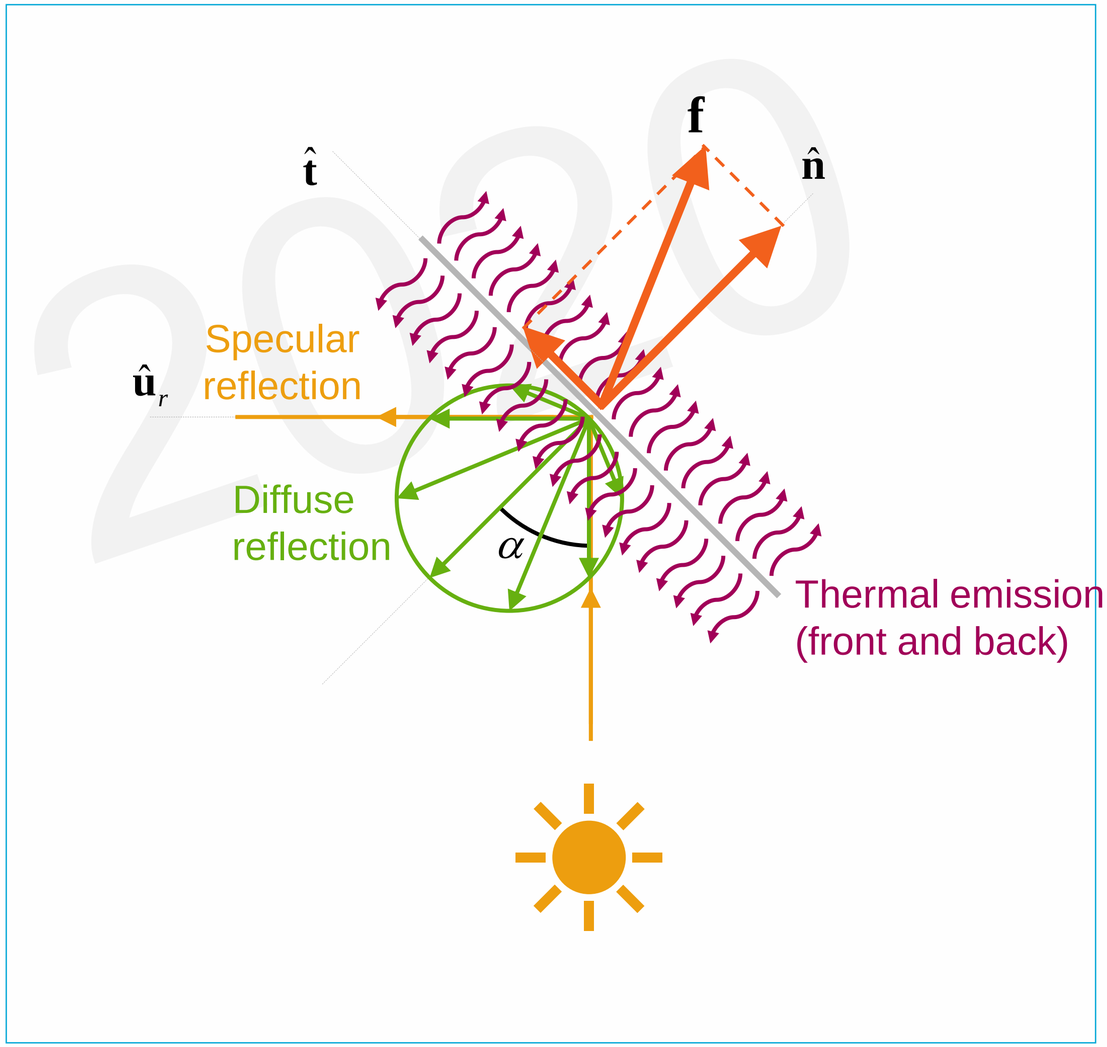

End of video