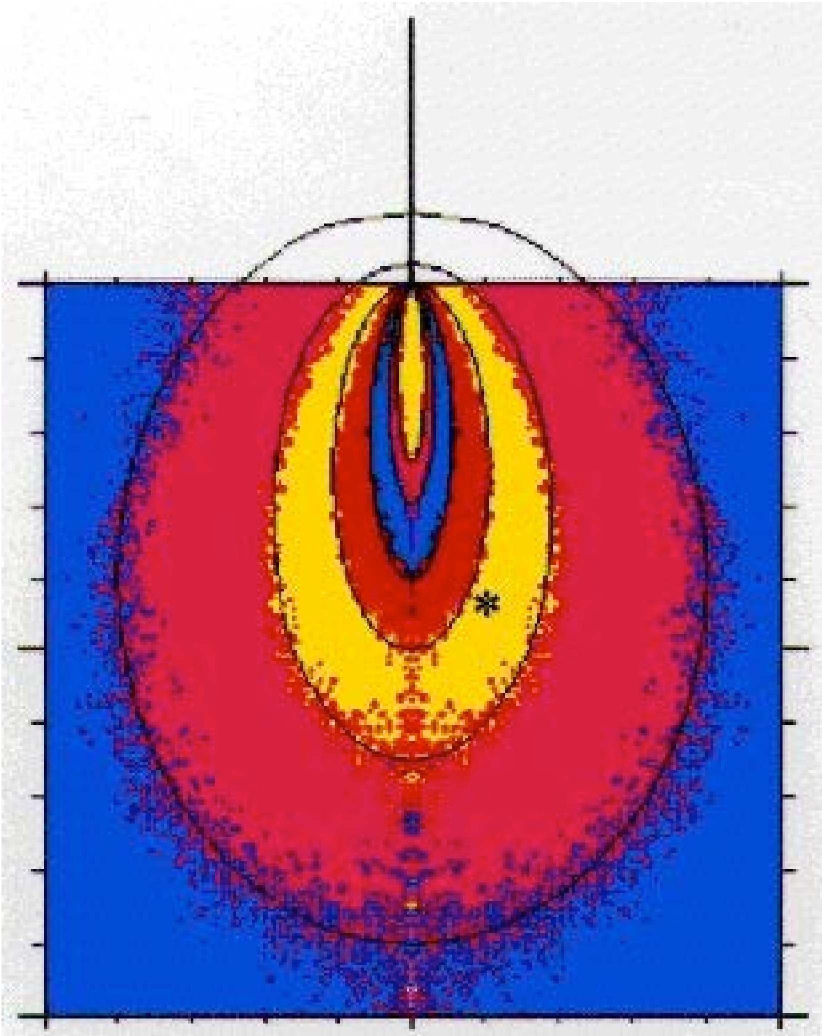


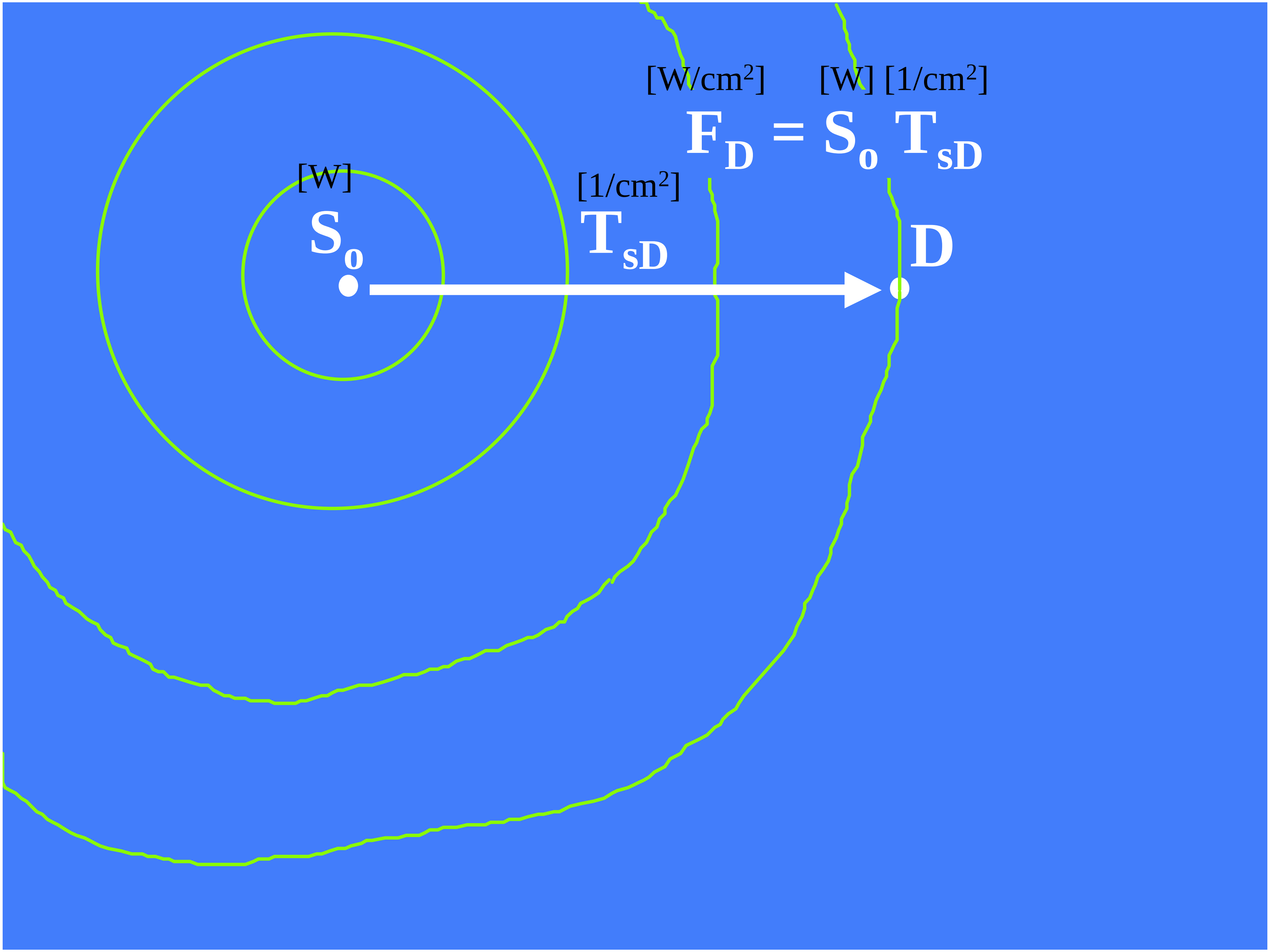
# Origins of optical contrast in tissues


**Steven L. Jacques**
*jacquess@ohsu.edu*
*http://omlc.ogi.edu*

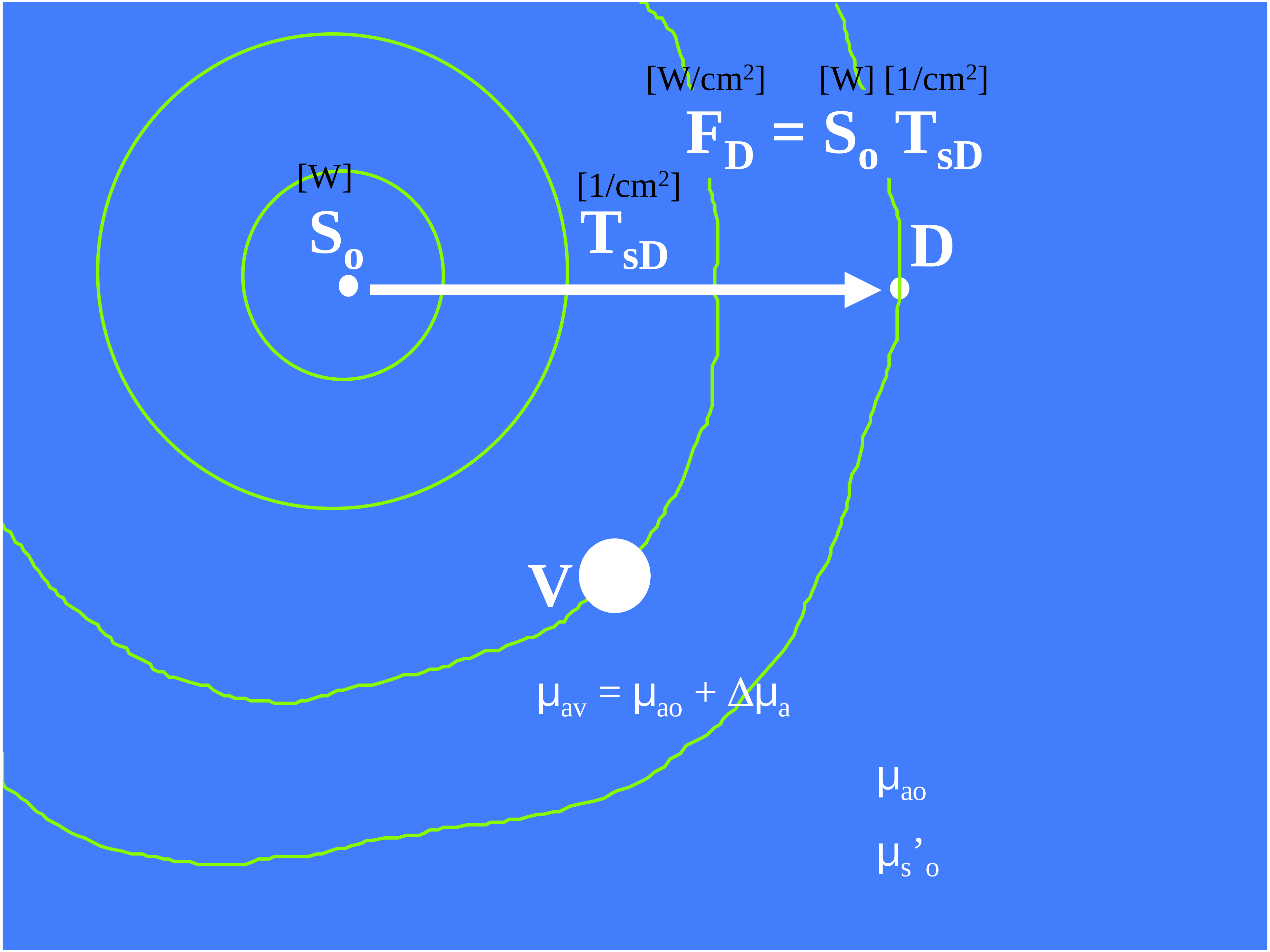
**Depts. of Biomedical Engineering and Dermatology**
Oregon Health & Science University, Portland OR, USA

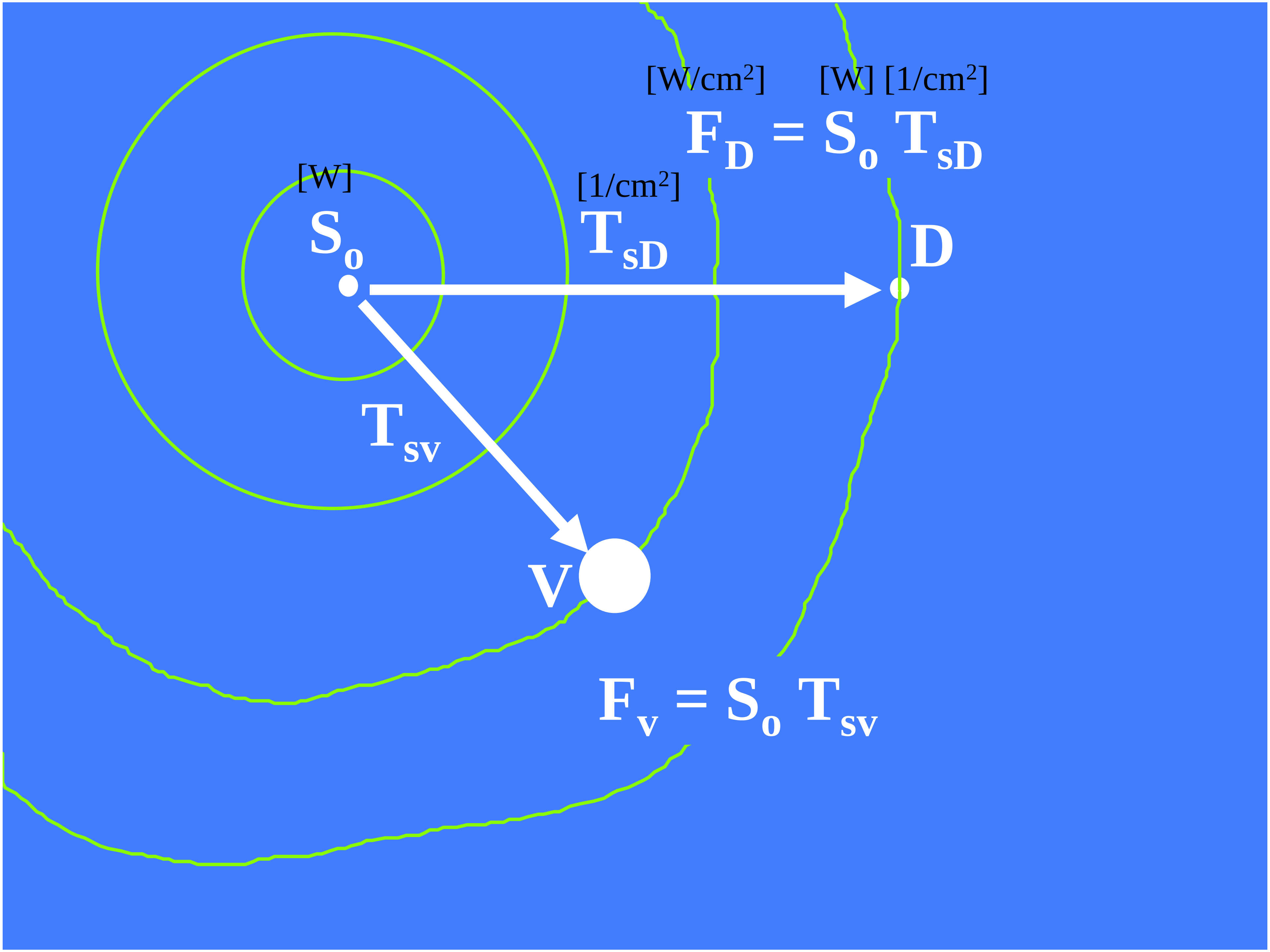

1. Optical properties
2. How to measure optical properties
3. Light transport
4. **Complex tissues**

# Perturbation theory

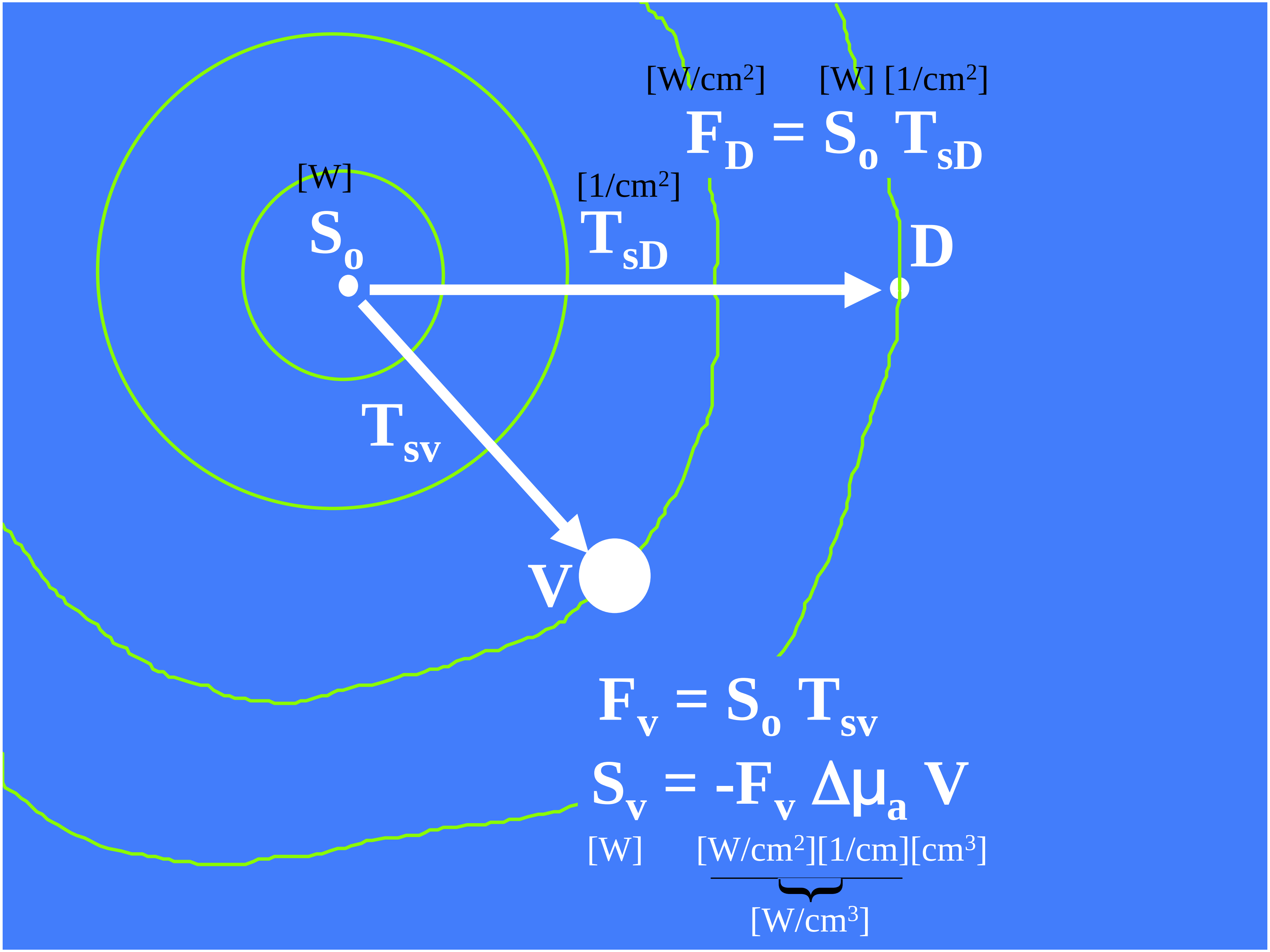


[W/cm2]
[W] [1/cm2]
FD = So TsD
[W]
So
[1/cm2]
TsD
D

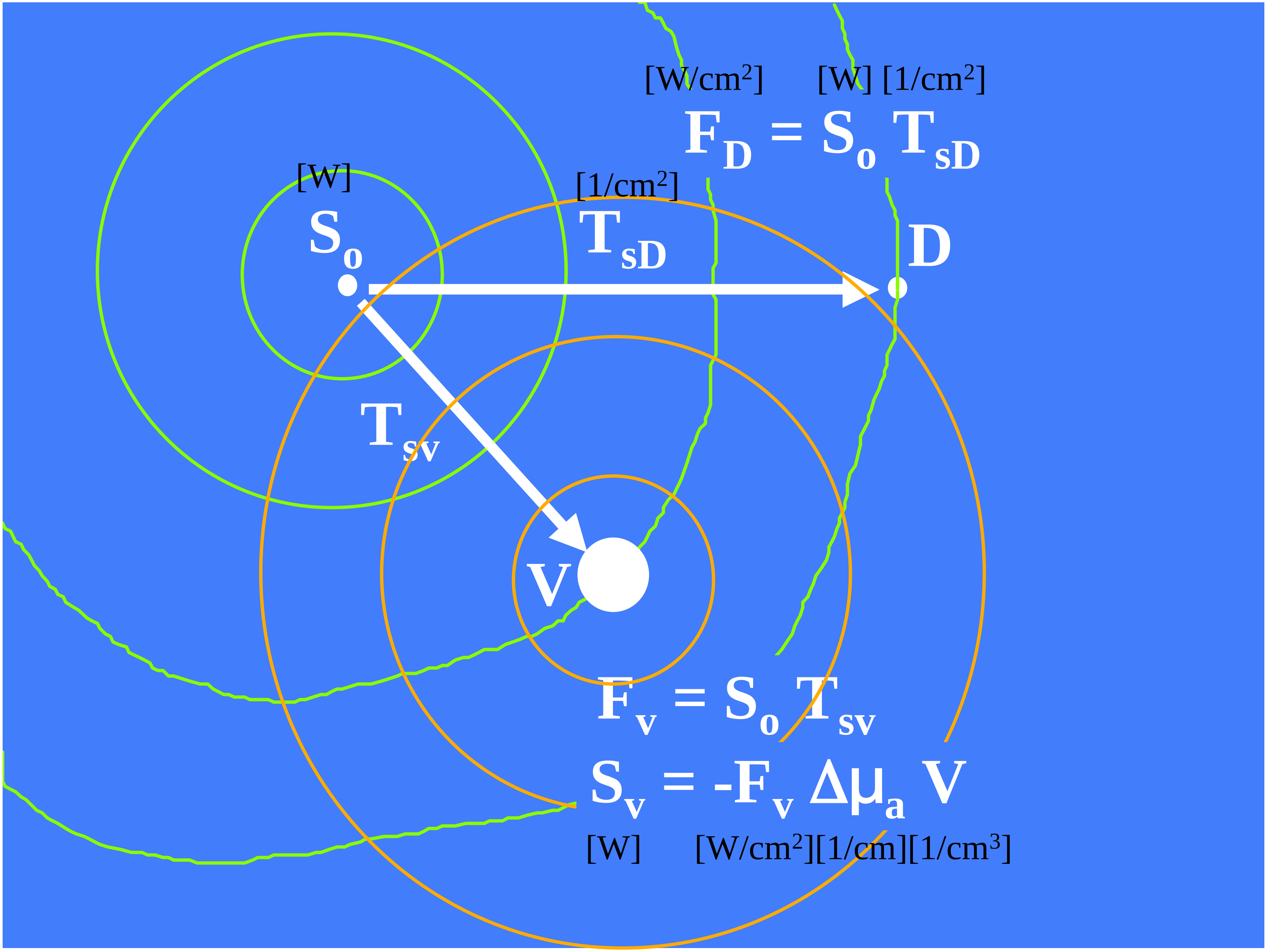

[W/cm2]
[W] [1/cm2]
F_D = S_o T_sD
[W]
S_o
[1/cm2]
T_sD
D
V
μ_av = μ_ao + Δμ_a
μ_ao
μ_s' o



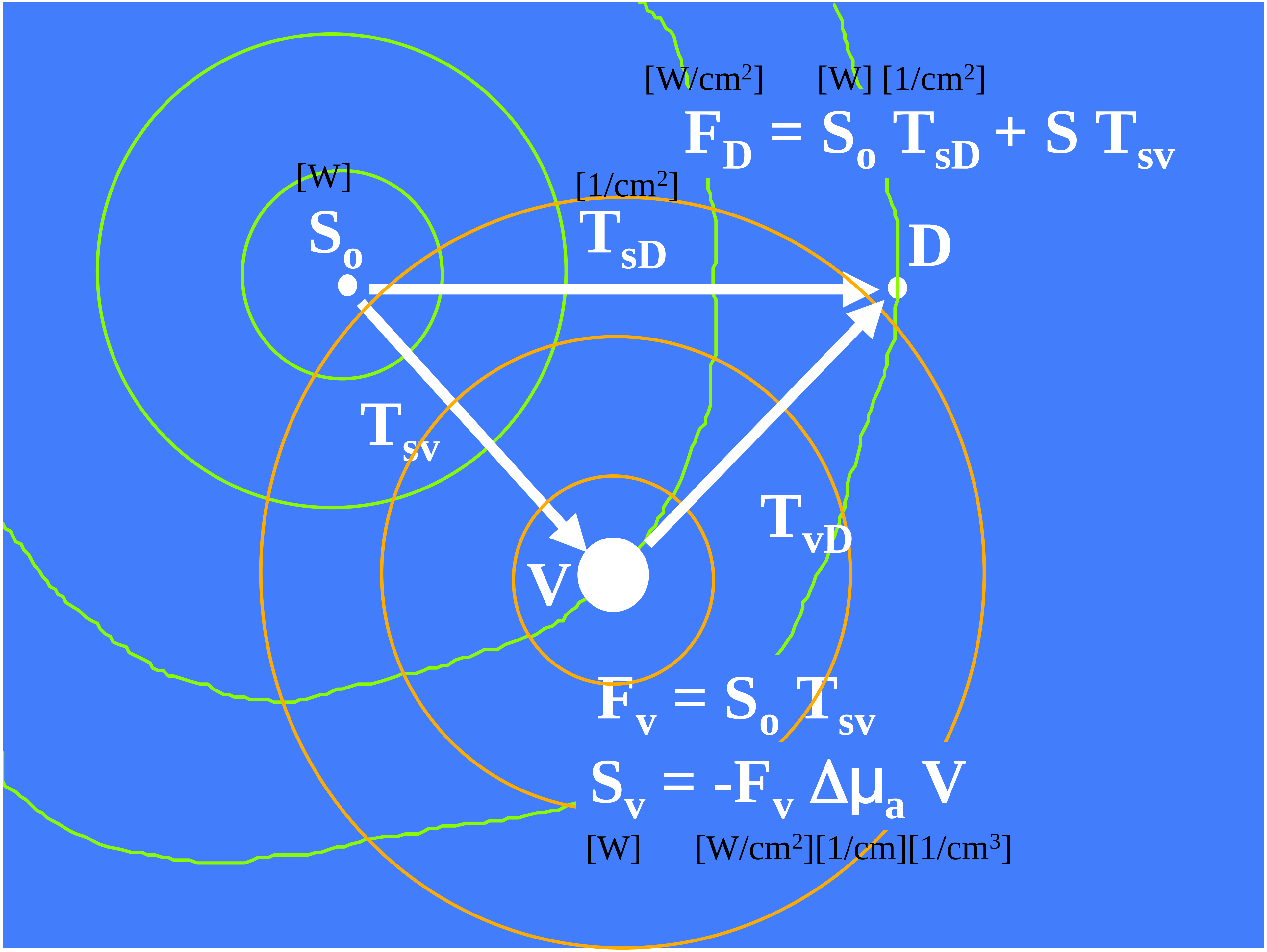
[W/cm2]
[W] [1/cm2]
$F_D = S_o T_{sD}$
[W]
$S_o$
[1/cm2]
$T_{sD}$
D
$T_{sv}$
V
$F_v = S_o T_{sv}$



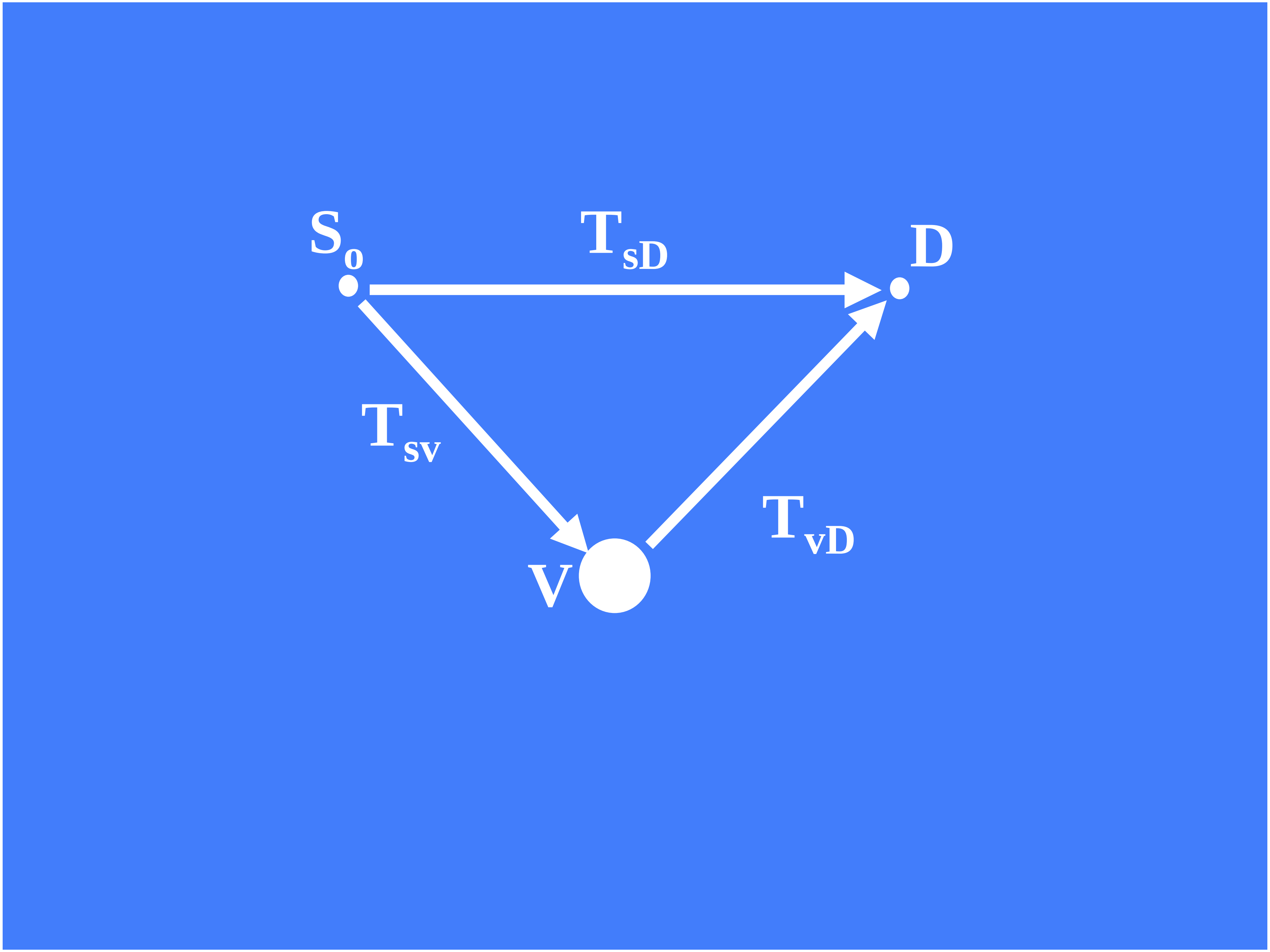
[W/cm2]
[W] [1/cm2]
FD = So TsD
[W]
So
[1/cm2]
TsD
D
Tsv
V
Fv = So Tsv
Sv = -Fv Δμa V
[W]
[W/cm2][1/cm][cm3]
[W/cm3]



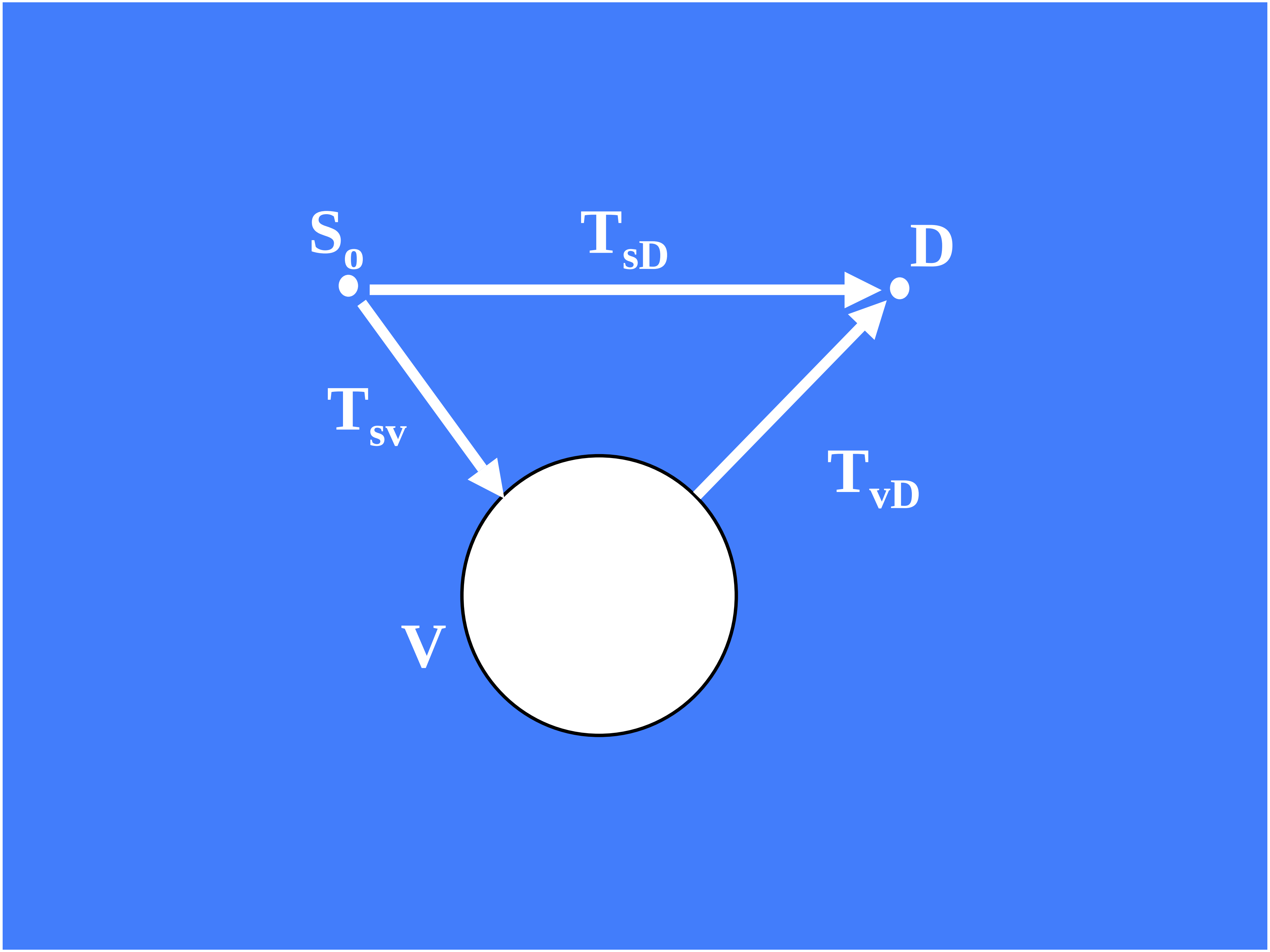
[W/cm2] [W] [1/cm2]
$F_D = S_o T_{sD}$
[W]
$S_o$
[1/cm2]
$T_{sD}$
D
$T_{sv}$
V
$F_v = S_o T_{sv}$
$S_v = -F_v \Delta\mu_a V$
[W] [W/cm2][1/cm][1/cm3]



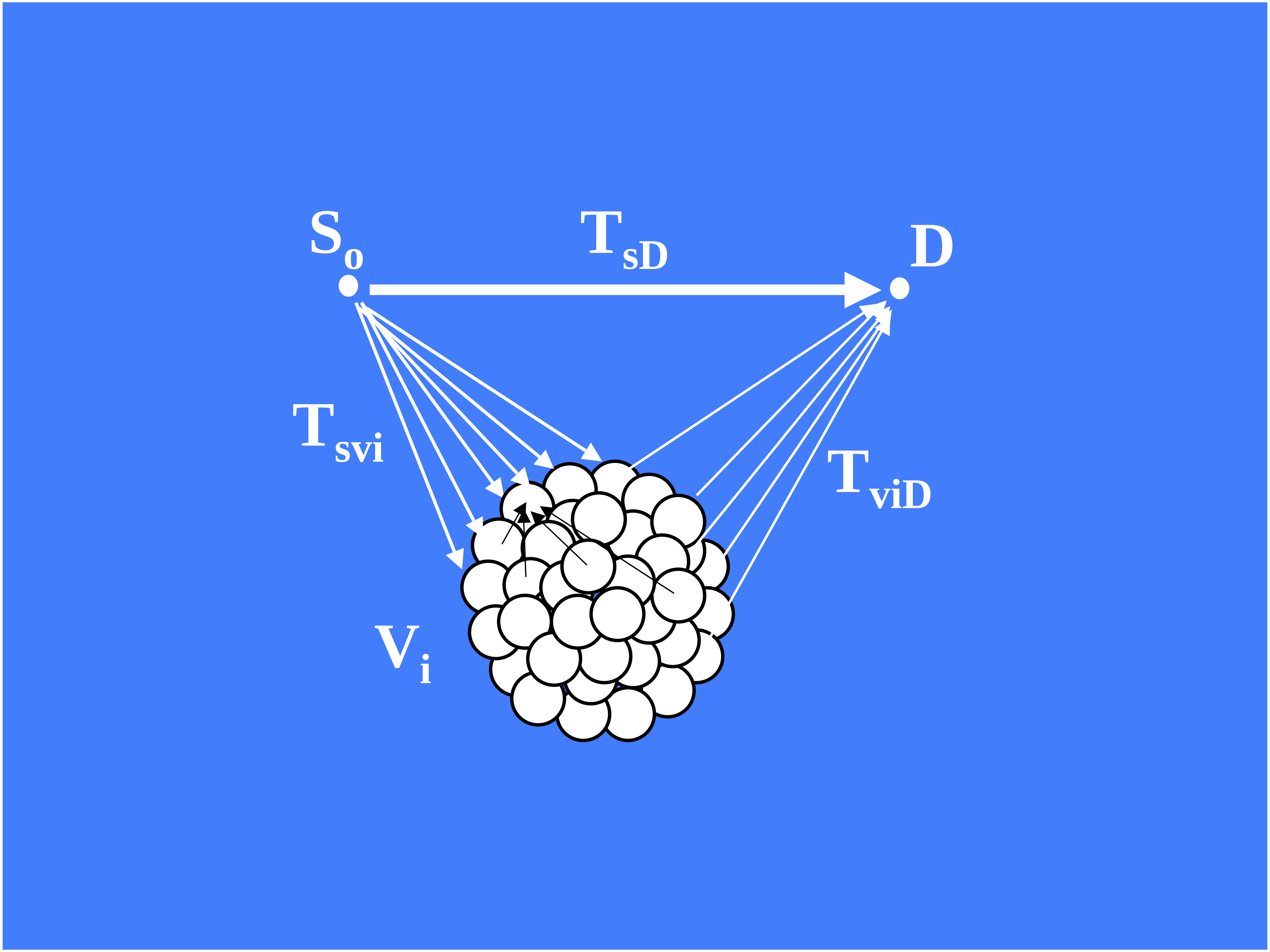
[W/cm2] [W] [1/cm2]
FD = So TsD + S Tsv
[W]
So
[1/cm2]
TsD
D
Tsv
TvD
V
Fv = So Tsv
Sv = -Fv Δμa V
[W] [W/cm2][1/cm][1/cm3]



So
TsD
D
Tsv
TvD
V



So
TsD
D
Tsv
TvD
V


$S_o$
$T_{sD}$
D
$T_{svi}$
$T_{viD}$
$V_i$

$$\begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ \dots \\ F_j \end{vmatrix} = \begin{vmatrix} T_{01} & T_{11} & \dots & T_{j1} \\ T_{02} & T_{12} & \dots & T_{j2} \\ T_{03} & T_{13} & \dots & T_{j3} \\ \dots & \dots & & \dots \\ T_{0j} & T_{1j} & \dots & T_{jj} \end{vmatrix} * \begin{vmatrix} S_0 \\ S_{v1} \\ S_{v2} \\ S_{v3} \\ \dots \\ S_{vj} \end{vmatrix}$$

$$S_{vi} = F_j \, \Delta\mu_{aj} \, V_j$$

$$\begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ \dots \\ F_j \end{vmatrix} = \begin{vmatrix} T_{01} & T_{11} & \dots & T_{j1} \\ T_{02} & T_{12} & \dots & T_{j2} \\ T_{03} & T_{13} & \dots & T_{j3} \\ \dots & \dots & & \dots \\ T_{0j} & T_{1j} & \dots & T_{jj} \end{vmatrix} * \begin{vmatrix} S_0 \\ S_{v1} \\ S_{v2} \\ S_{v3} \\ \dots \\ S_{vj} \end{vmatrix}$$

$$S_{vj} = F_i \, \Delta\mu_{ai} \, V_i$$

$$
\begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ \cdots \\ F_j \end{vmatrix}
=
\begin{vmatrix}
T_{01} & T_{11} & \cdots & T_{j1} \\
T_{02} & T_{12} & \cdots & T_{j2} \\
T_{03} & T_{13} & \cdots & T_{j3} \\
\cdots & \cdots & & \cdots \\
T_{0j} & T_{1j} & \cdots & T_{jj}
\end{vmatrix}
*
\begin{vmatrix} S_0 \\ S_{v1} \\ S_{v2} \\ S_{v3} \\ \cdots \\ S_{vj} \end{vmatrix}
$$

$$S_{vj} = F_i \, \Delta\mu_{ai} \, V_i$$

$$
\begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ \dots \\ F_j \end{vmatrix}
=
\begin{vmatrix}
T_{01} & T_{11} & \dots & T_{j1} \\
T_{02} & T_{12} & \dots & T_{j2} \\
T_{03} & T_{13} & \dots & T_{j3} \\
\dots & \dots & & \dots \\
T_{0j} & T_{1j} & \dots & T_{jj}
\end{vmatrix}
*
\begin{vmatrix} S_0 \\ S_{v1} \\ S_{v2} \\ S_{v3} \\ \dots \\ S_{vj} \end{vmatrix}
$$

$$S_{vj} = F_i \, \Delta\mu_{ai} \, V_i$$

$$
\begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ \cdots \\ F_j \end{vmatrix}
=
\begin{vmatrix}
T_{01} & T_{11} & \cdots & T_{j1} \\
T_{02} & T_{12} & \cdots & T_{j2} \\
T_{03} & T_{13} & \cdots & T_{j3} \\
\cdots & \cdots & & \cdots \\
T_{0j} & T_{1j} & \cdots & T_{jj}
\end{vmatrix}
*
\begin{vmatrix} S_0 \\ S_{v1} \\ S_{v2} \\ S_{v3} \\ \cdots \\ S_{vj} \end{vmatrix}
$$

$$S_{vj} = F_i \, \Delta\mu_{ai} \, V_i$$

$$\begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ \dots \\ F_j \end{vmatrix} = \begin{vmatrix} T_{01} & T_{11} & \dots & T_{j1} \\ T_{02} & T_{12} & \dots & T_{j2} \\ T_{03} & T_{13} & \dots & T_{j3} \\ \dots & \dots & & \dots \\ T_{0j} & T_{1j} & \dots & T_{jj} \end{vmatrix} * \begin{vmatrix} S_0 \\ S_{v1} \\ S_{v2} \\ S_{v3} \\ \dots \\ S_{vj} \end{vmatrix}$$

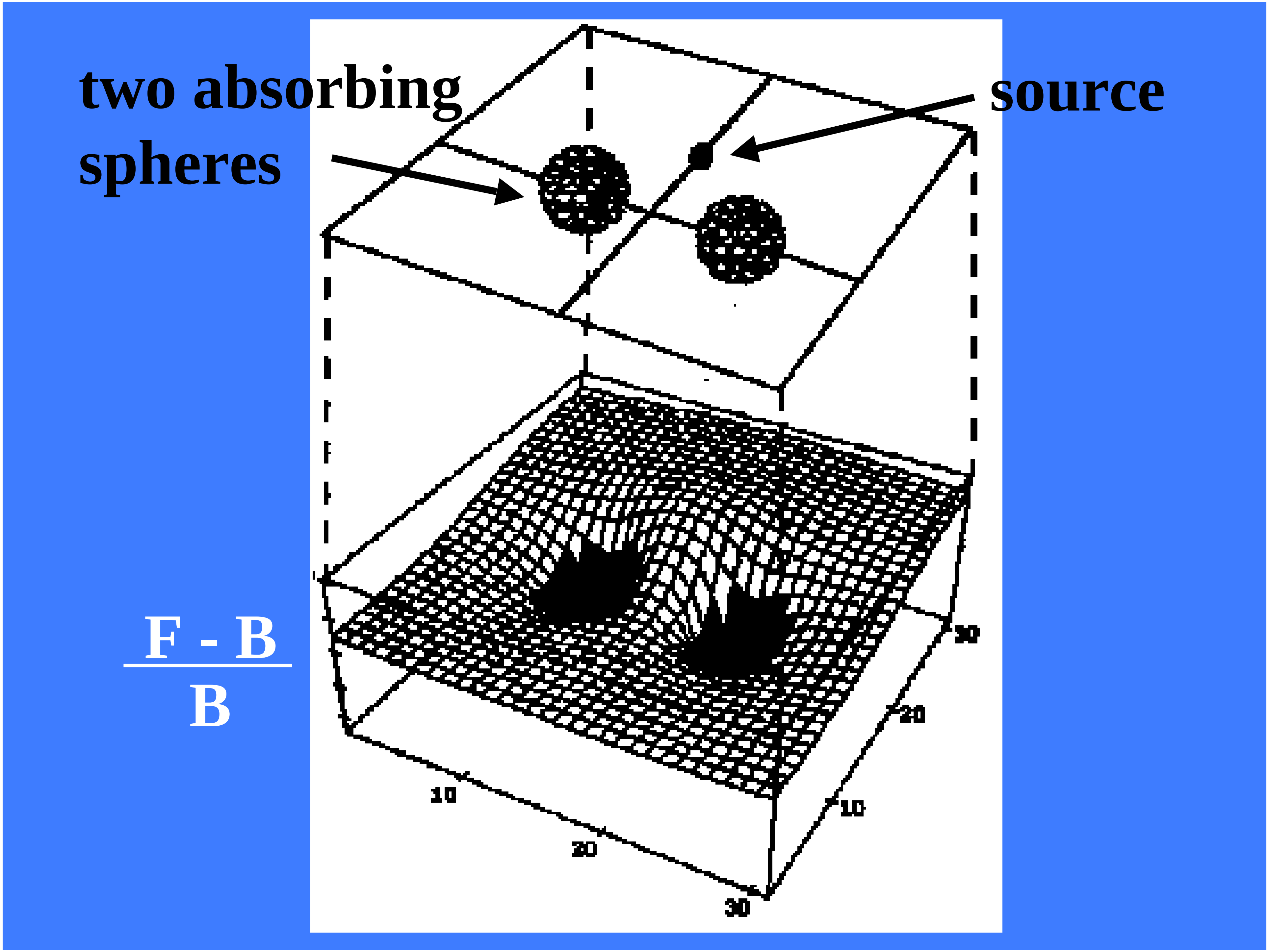
$$S_{vj} = -F_i \, \Delta\mu_{ai} \, V_i$$

$$
\begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ \cdots \\ F_j \end{vmatrix}
=
\begin{vmatrix}
T_{01} & T_{11} & \cdots & T_{j1} \\
T_{02} & T_{12} & \cdots & T_{j2} \\
T_{03} & T_{13} & \cdots & T_{j3} \\
\cdots & \cdots & & \cdots \\
T_{0j} & T_{1j} & \cdots & T_{jj}
\end{vmatrix}
*
\begin{vmatrix} S_0 \\ S_{v1} \\ S_{v2} \\ S_{v3} \\ \cdots \\ S_{vj} \end{vmatrix}
$$

$$S_{vj} = F_i \, \Delta\mu_{ai} \, V_i$$

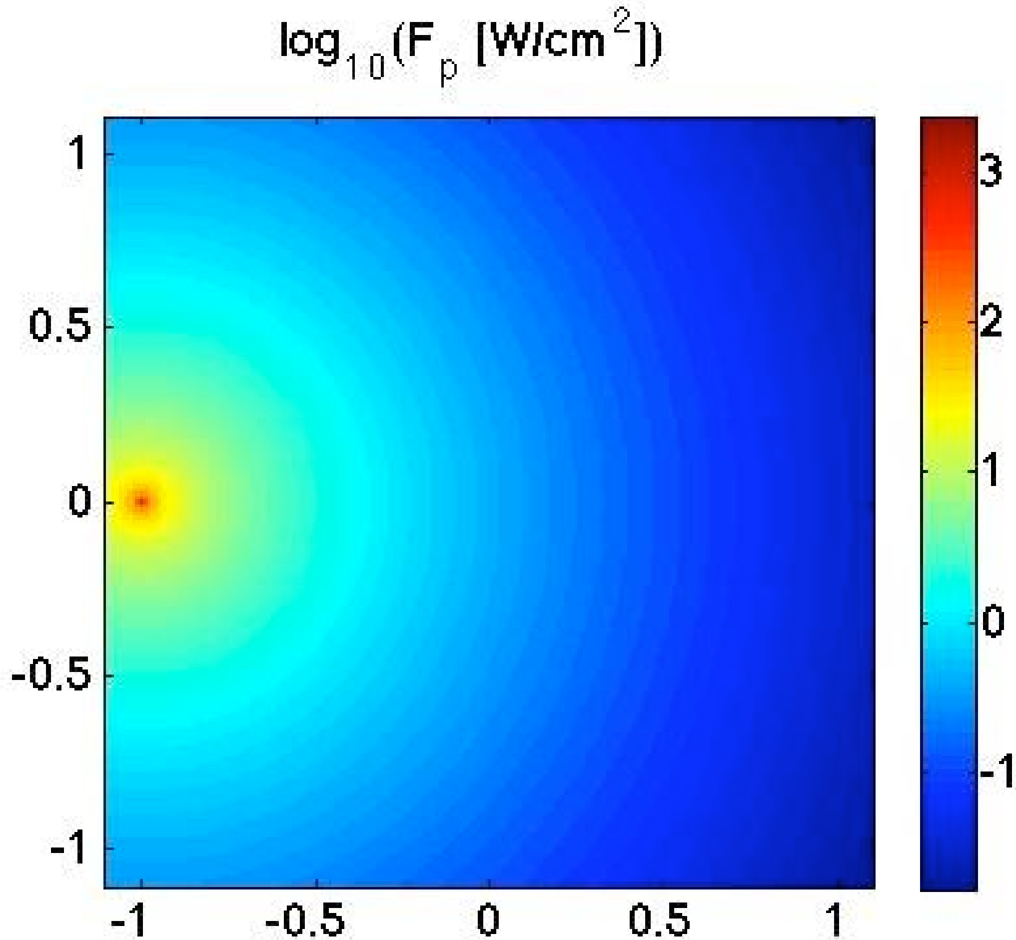
$$
\begin{vmatrix} F_1 \\ F_2 \\ F_3 \\ \cdots \\ F_j \end{vmatrix}
=
\begin{vmatrix}
T_{01} & T_{11} & \cdots & T_{j1} \\
T_{02} & T_{12} & \cdots & T_{j2} \\
T_{03} & T_{13} & \cdots & T_{j3} \\
\cdots & \cdots & & \cdots \\
T_{0j} & T_{1j} & \cdots & T_{jj}
\end{vmatrix}
*
\begin{vmatrix} S_0 \\ S_{v1} \\ S_{v2} \\ S_{v3} \\ \cdots \\ S_{vj} \end{vmatrix}
$$

$$S_{vj} = F_i \, \Delta\mu_{ai} \, V_i$$

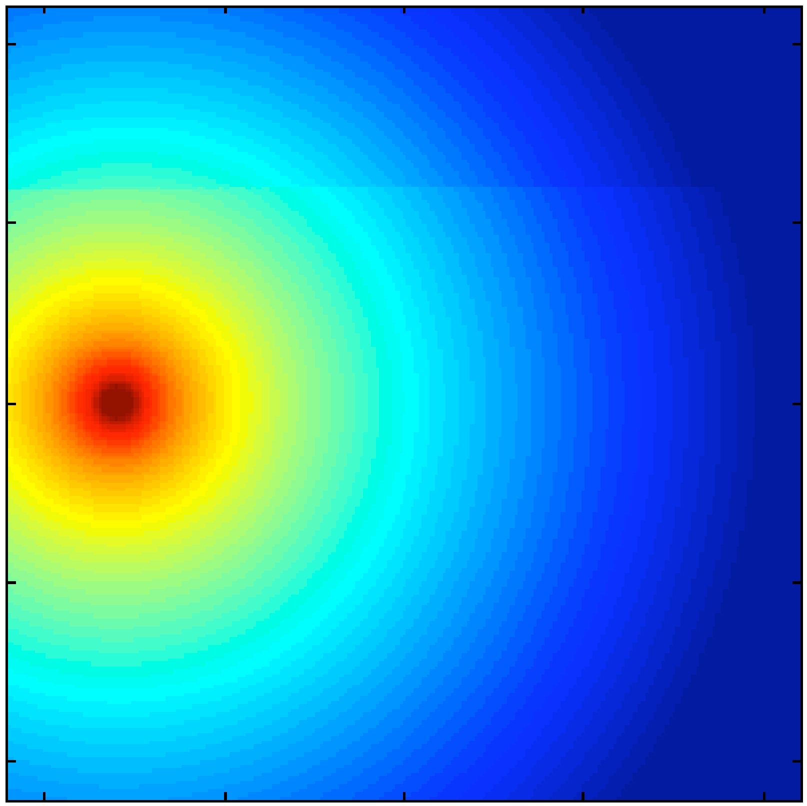

two absorbing spheres
source
F - B / B
10
20
30
10
20
30

example

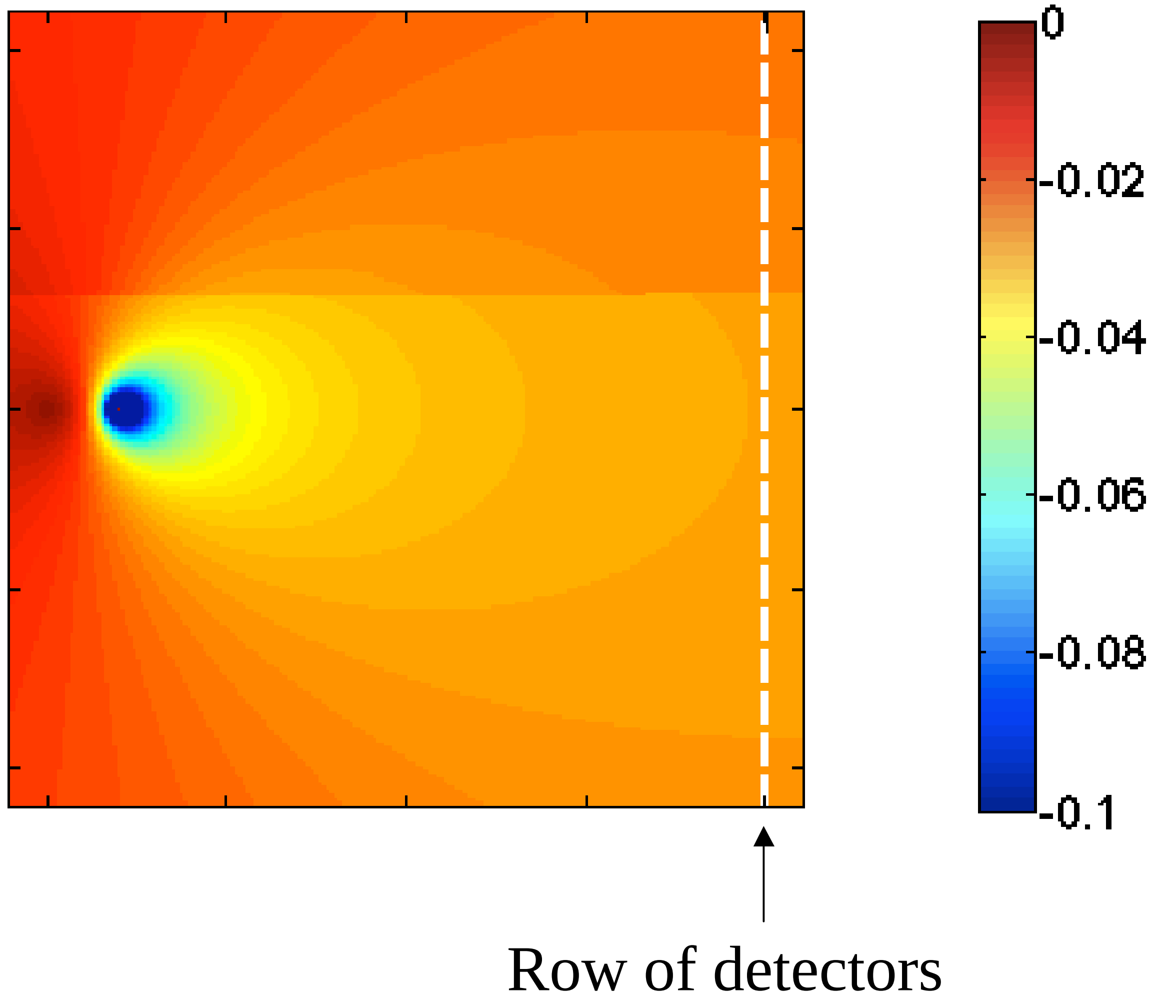
$$F_0 = F_{with.object}$$



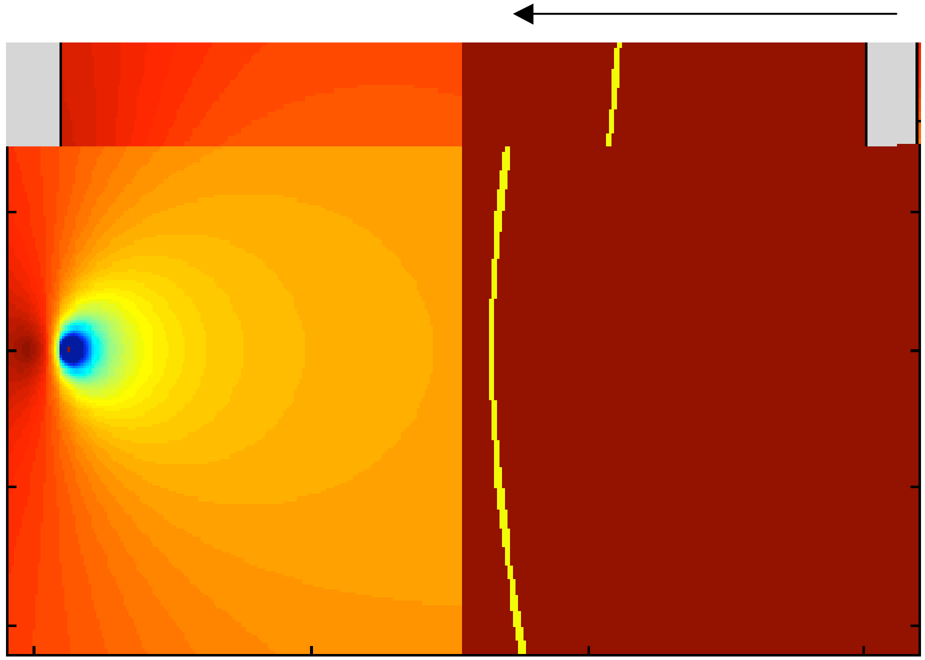
$$F_p = F_{with.object} - F_{no.object}$$



$$perturbation = \frac{F_{with.object} - F_{no.object}}{F_{no.object}} = \frac{F_p}{F_0}$$



increasing perturbation



response of detectors

total fluence rate

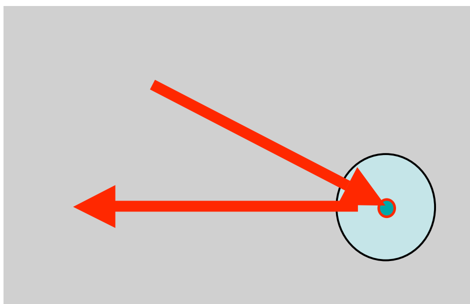
fluence rate without object

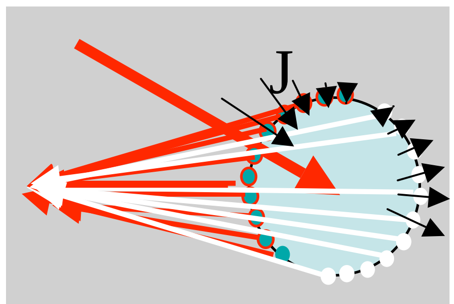
change in fluence rate because of object

$$F(r) = F_o(r) + F_{pert}(r)$$

where

$$F_{pert}(r) = \text{volume component} + \text{surface component}$$





# volume component =

fluence rate

P

transport

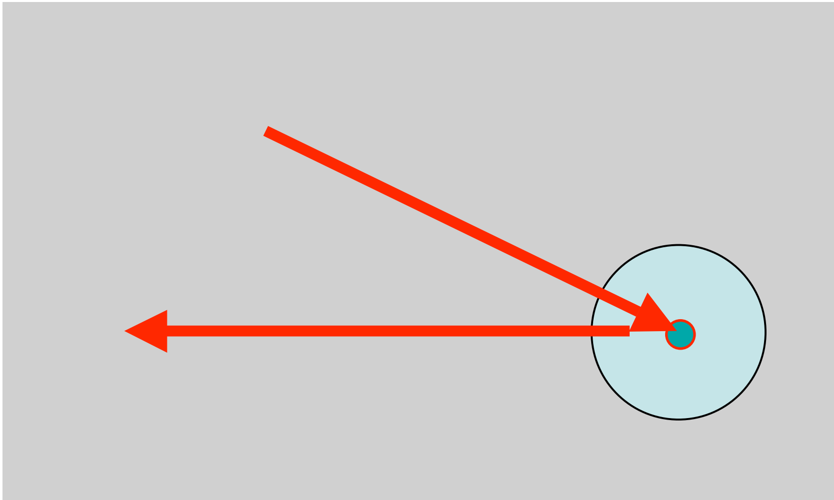
incremental volume

~ 0

$$-\int_{V_{object}} F(r') \left( \Delta\mu_a + \Delta\mu'_s \frac{\mu_{a0}}{\mu'_{s0}} + \frac{\Delta\mu_a \Delta\mu'_s}{\mu'_{s0}} \right) T(|r - r'|)\, dV'$$

incremental absorption

scattering-enhanced absorption



# surface component =

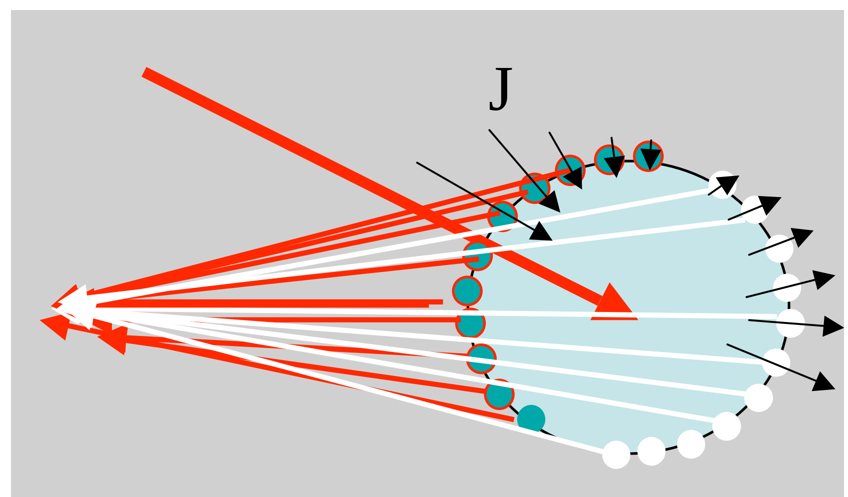
**incremental attenuation** | **P** | **transport** | **Incremental surface** | **flux**

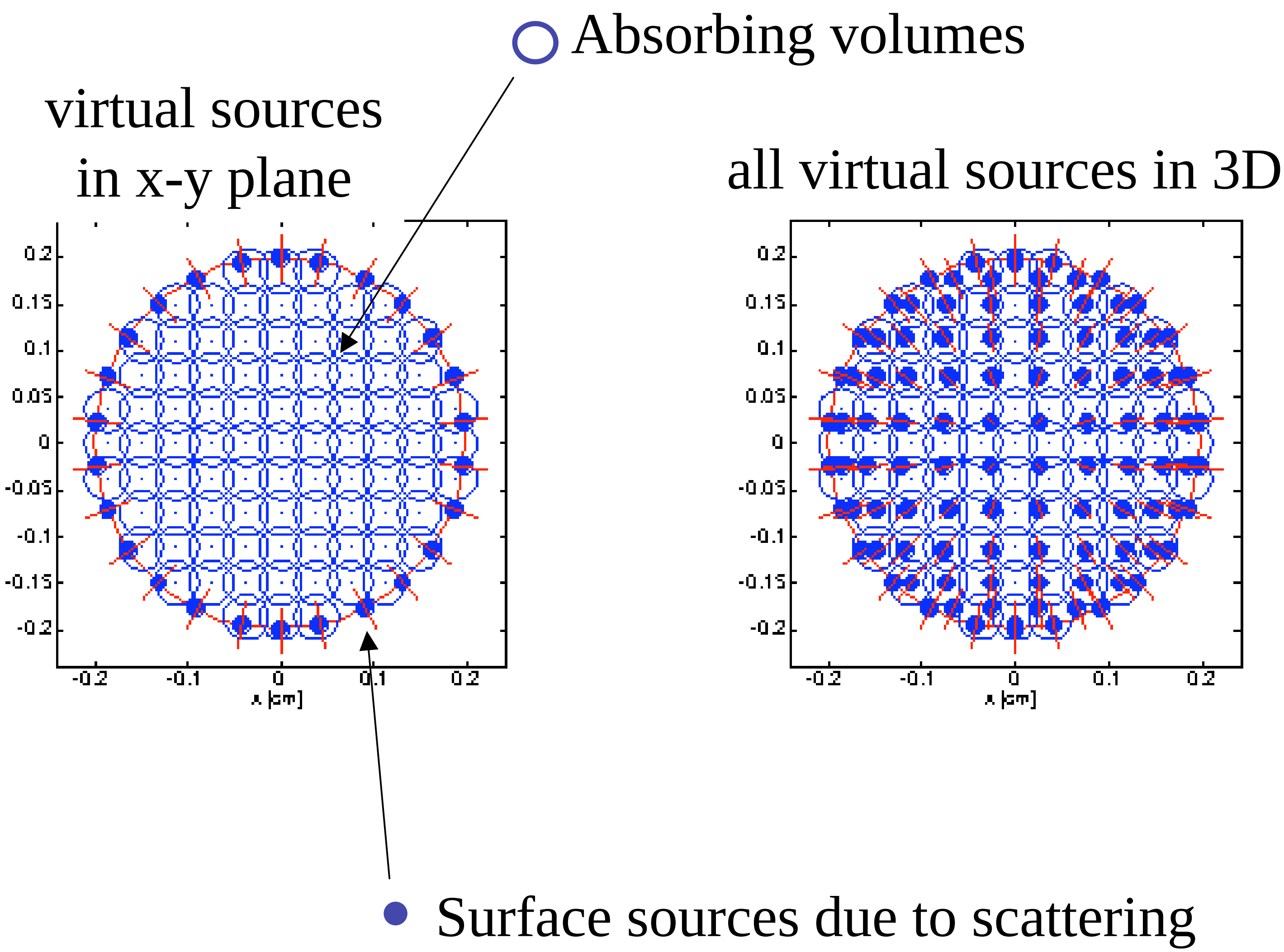
$$\frac{\Delta\mu_a + \Delta\mu'_s}{\mu'_{s0}} \int_{S_{object}} T(|r - r'|)\, J \bullet dS'$$

**Background attenuation**

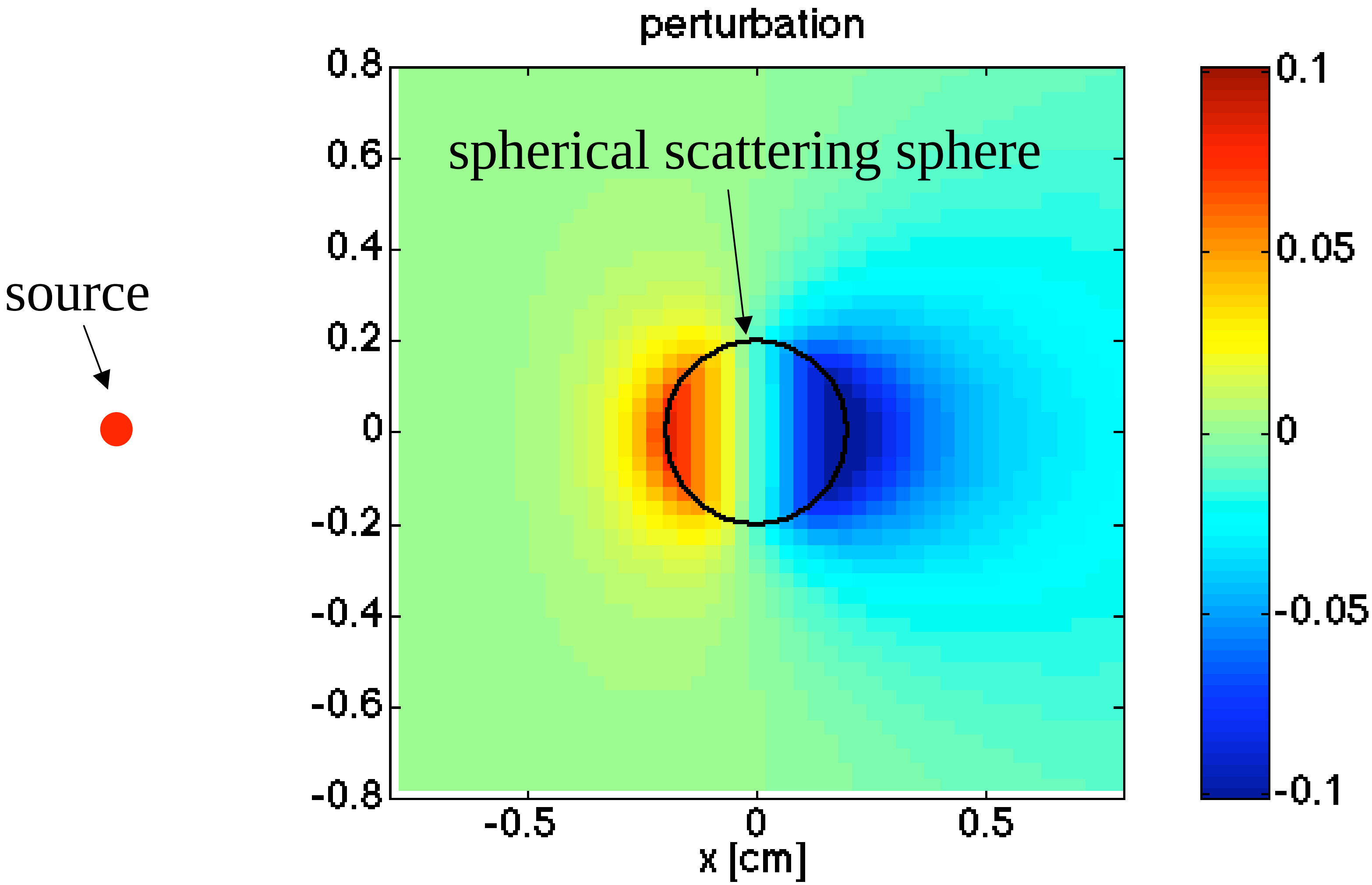
where

$J = -D\nabla F$ , flux entering surface of object



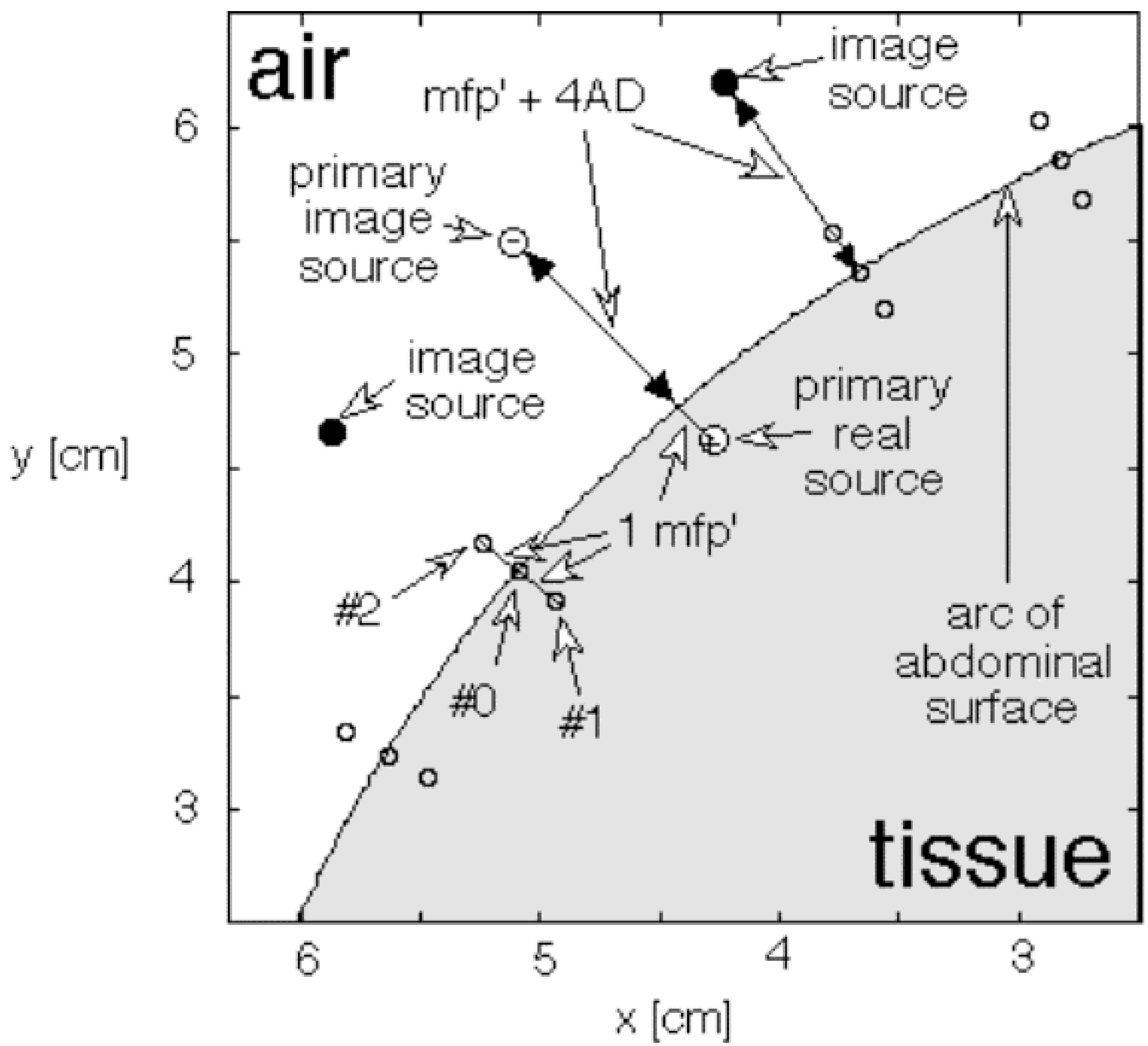

Absorbing volumes
virtual sources
in x-y plane
all virtual sources in 3D
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.2
-0.1
0
0.1
0.2
x [cm]
Surface sources due to scattering

# Perturbation by object



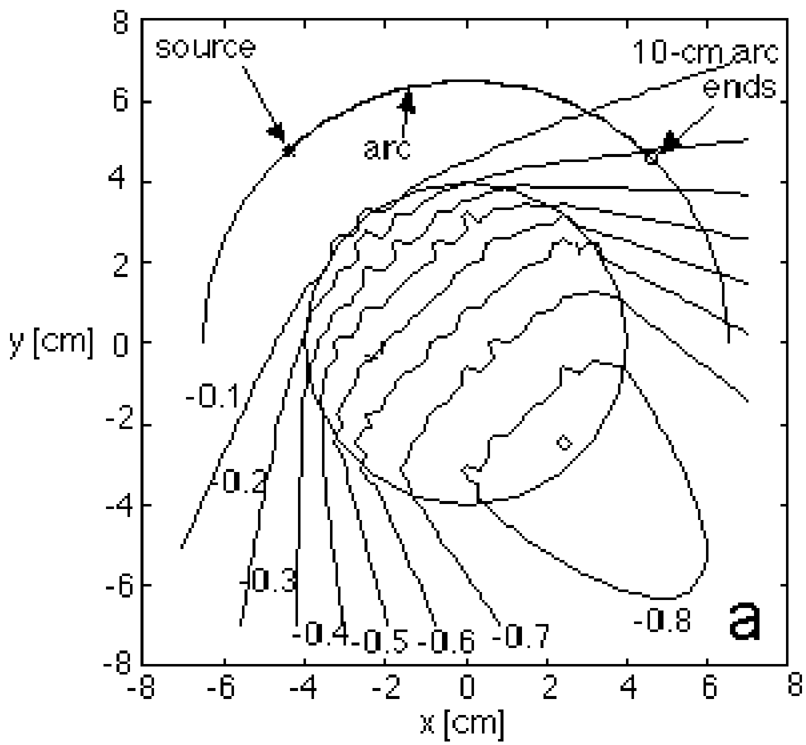

$\mu_{a\ object} = \mu_{a0} = 0.1\ cm^{-1}$

$\mu'_{s\ object} = 20\ cm^{-1},\ \ \mu'_{s0} = 10\ cm^{-1}$

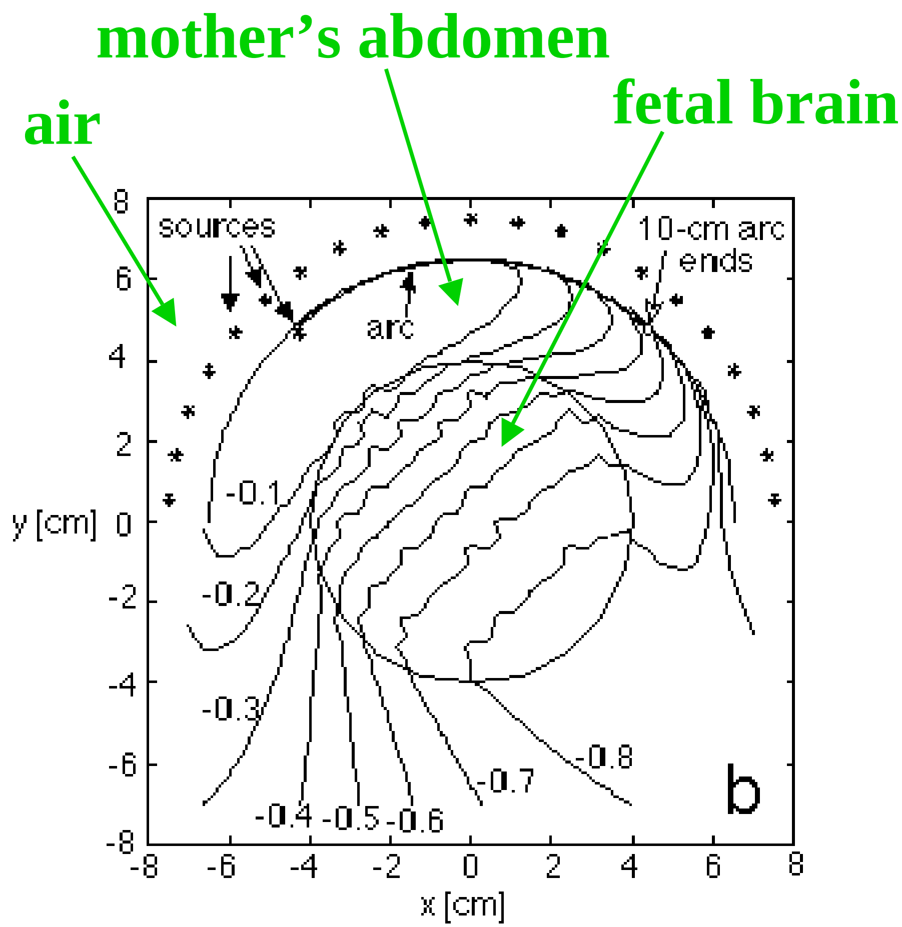

air
tissue
image source
mfp' + 4AD
primary image source
image source
primary real source
1 mfp'
#2
#0
#1
arc of abdominal surface
y [cm]
x [cm]
6
5
4
3

# Perturbation by object

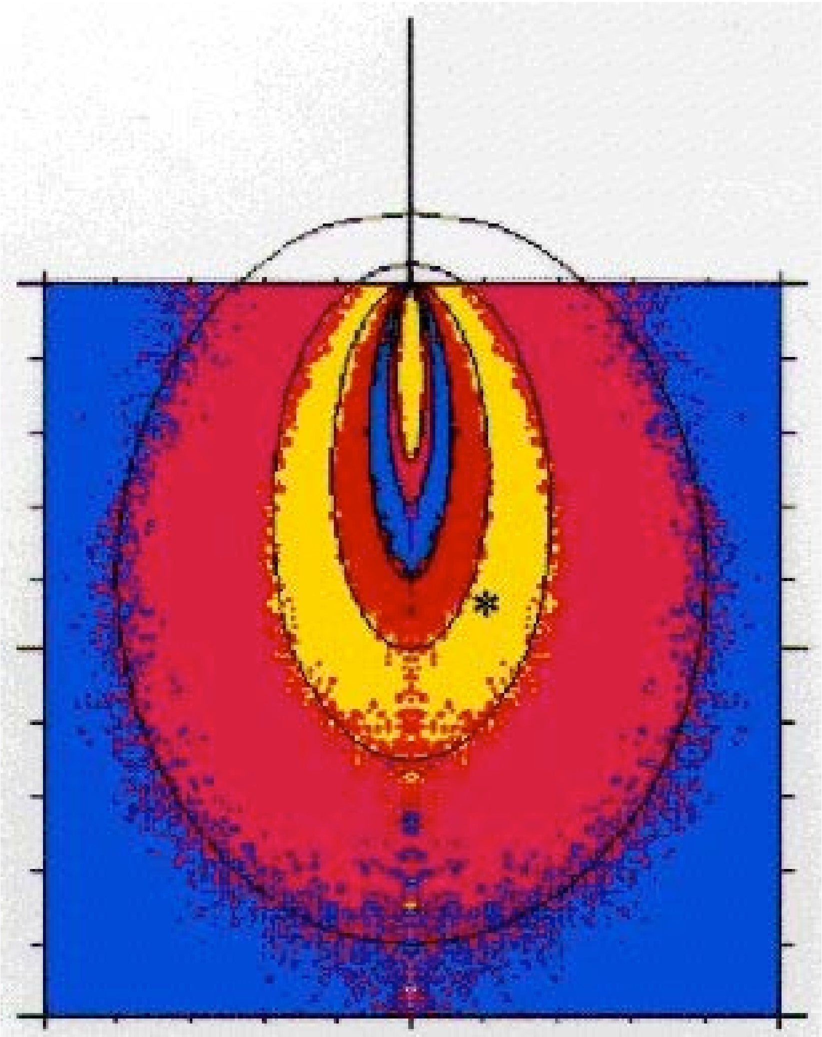
$$P = \frac{T_{\text{with fetus}} - T_{\text{without fetus}}}{T_{\text{without fetus}}}$$




no air/tissue boundary




with air/tissue boundary



# Origins of optical contrast in tissues

**Steven L. Jacques**
*jacquess@ohsu.edu*
*http://omlc.ogi.edu*

**Depts. of Biomedical Engineering and Dermatology**
Oregon Health & Science University, Portland OR, USA

1. Optical properties
2. How to measure optical properties
3. Light transport
4. Complex tissues