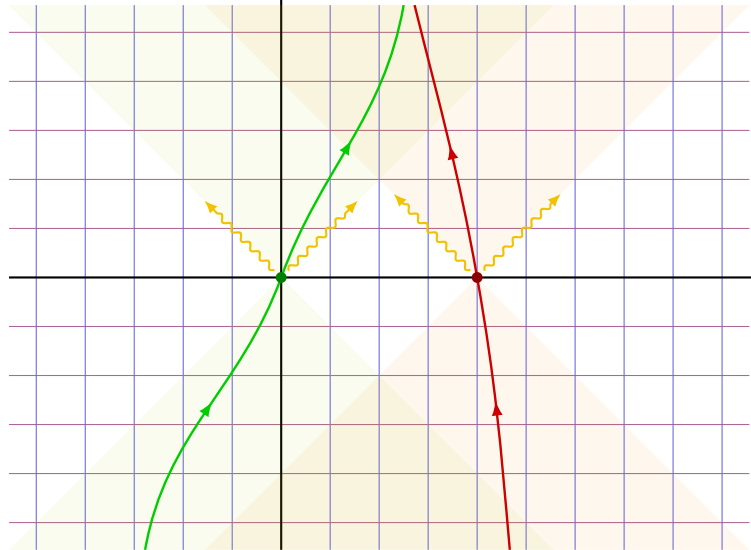
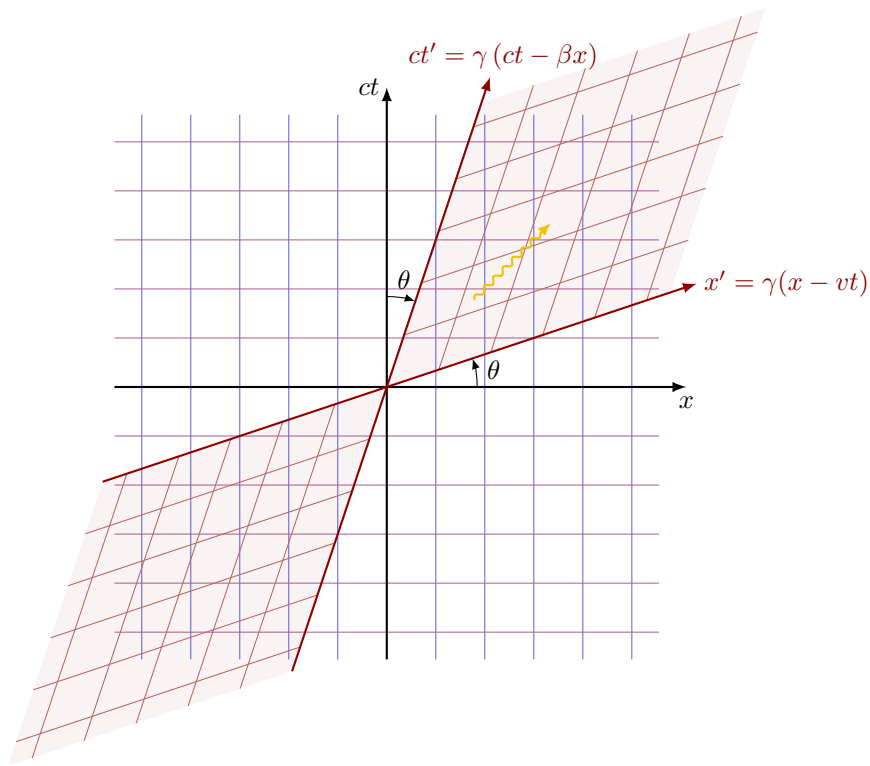


$$ct' = ct$$

x

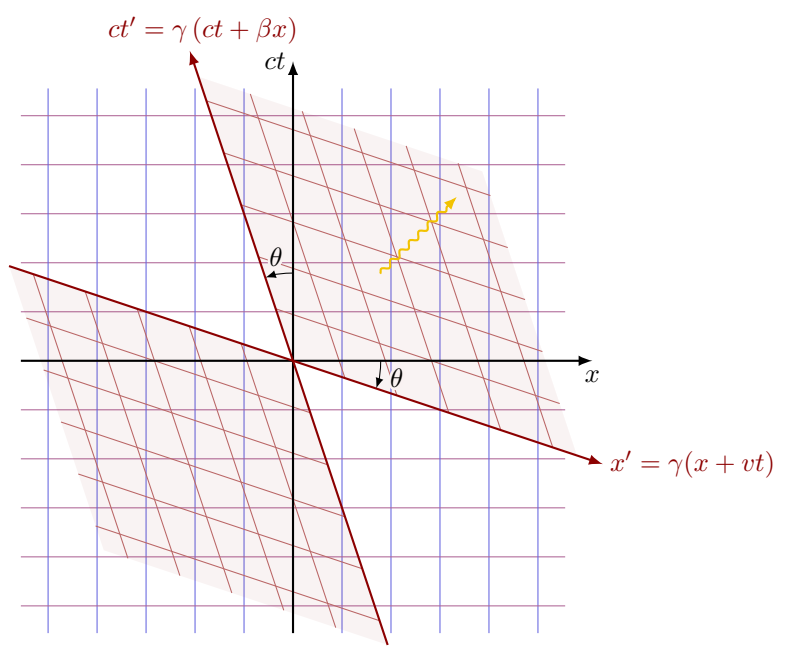


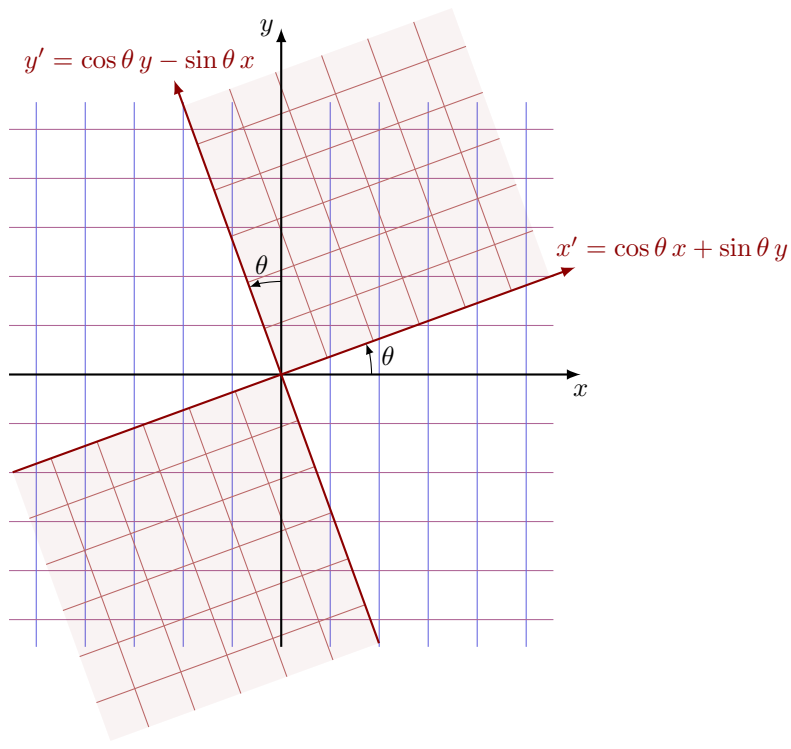


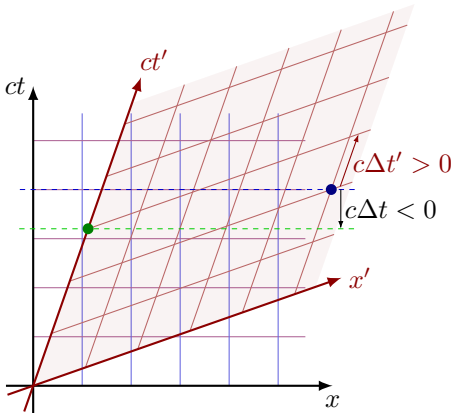
$$ct' = \gamma(ct + \beta x)$$

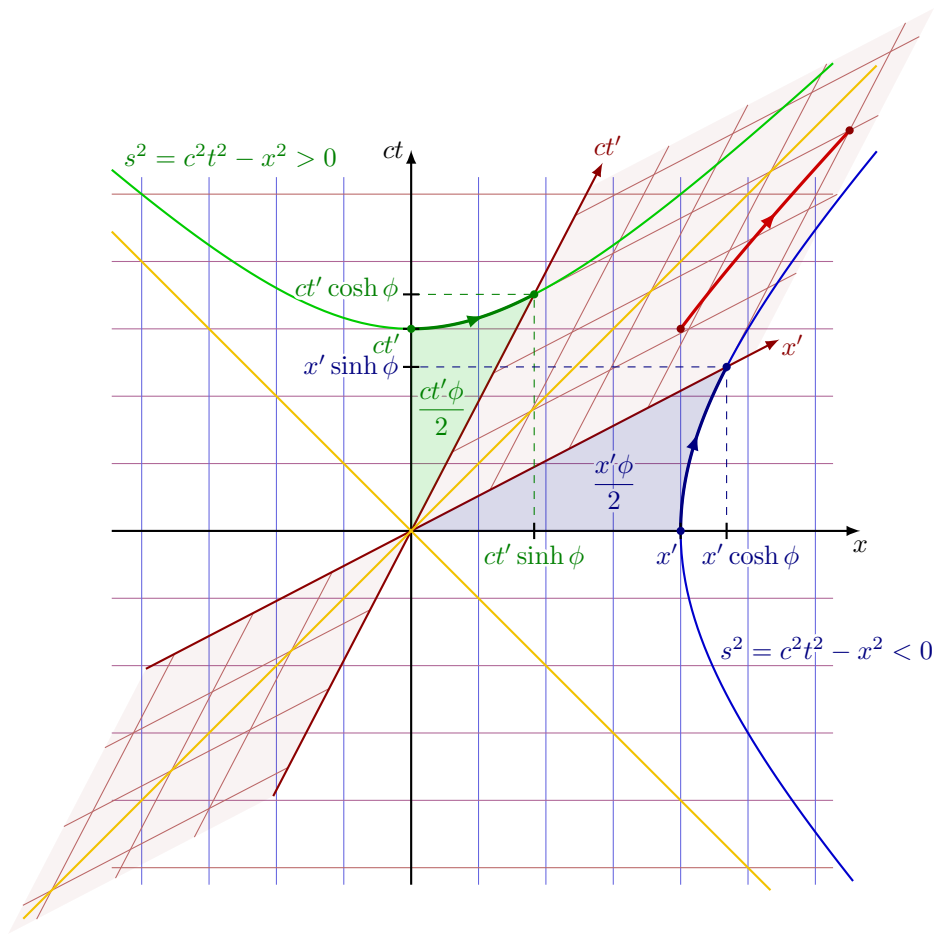
 ct θ θ x

$$x' = \gamma(x + vt)$$









Lorentz transformation in the x direction

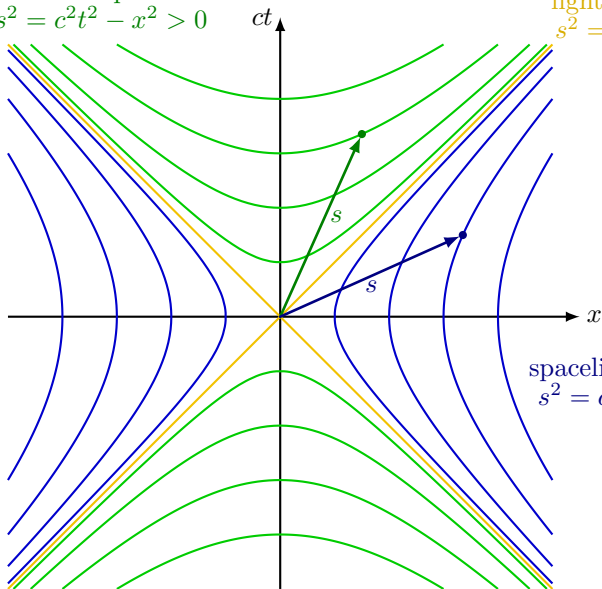
$$\begin{pmatrix} ct' \\ x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} \gamma & -\beta\gamma & 0 & 0 \\ -\beta\gamma & \gamma & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} ct \\ x \\ y \\ z \end{pmatrix}$$
$$= \begin{pmatrix} \cosh \phi & -\sinh \phi & 0 & 0 \\ -\sinh \phi & \cosh \phi & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} ct \\ x \\ y \\ z \end{pmatrix}$$

timelike separation

$$s^2 = c^2t^2 - x^2 > 0$$

lightlike separation

$$s^2 = c^2t^2 - x^2 = 0$$



spacelike separation

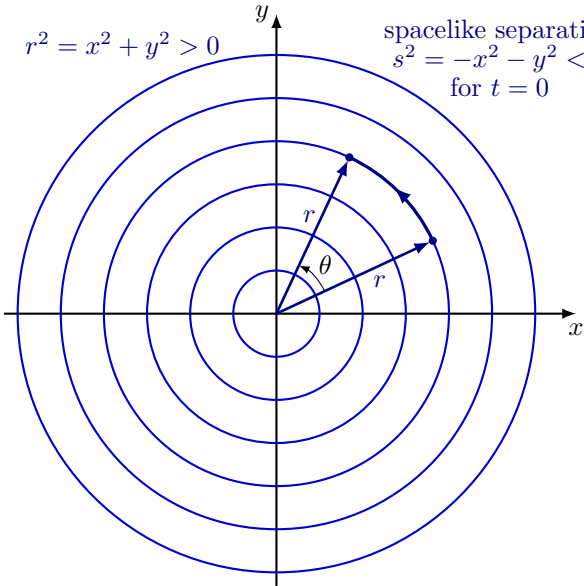
$$s^2 = c^2t^2 - x^2 < 0$$

Counterclockwise rotation in the xy plane

$$\begin{pmatrix} ct' \\ x' \\ y' \\ z' \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & \cos \phi & -\sin \phi & 0 \\ 0 & \sin \phi & \cos \phi & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \begin{pmatrix} ct \\ x \\ y \\ z \end{pmatrix}$$

$$r^2 = x^2 + y^2 > 0$$

spacelike separation
 $s^2 = -x^2 - y^2 < 0$
for $t = 0$



$$r^2 = x^2 + y^2 > 0$$

spacetime separation
 $s^2 = c^2 t^2 - x^2 - y^2$
from $(t, r) = (0, 0)$

$$s^2 < 0$$

$$s^2 = 0$$

$$s^2 > 0$$

x

y

