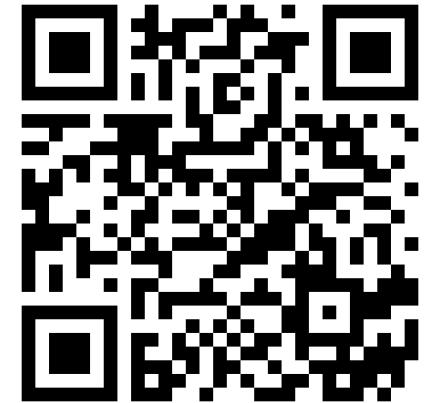


Sumário

- O que é a redução ao polo (RTP)
- Como calcular a RTP
- Desenvolvimentos teóricos
- Possível generalização
- Comentários finais

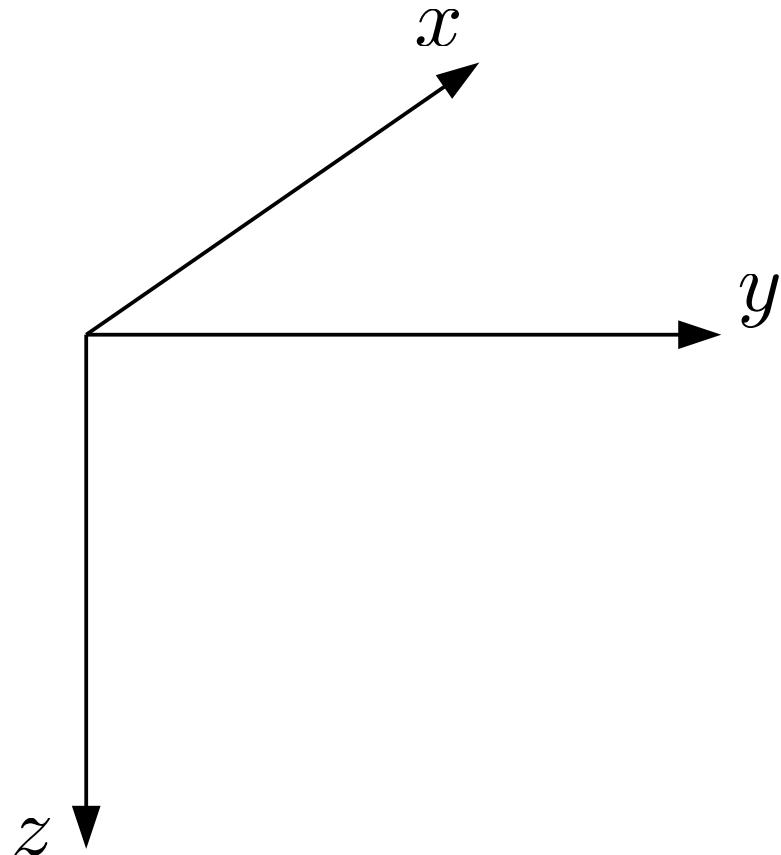


Sumário

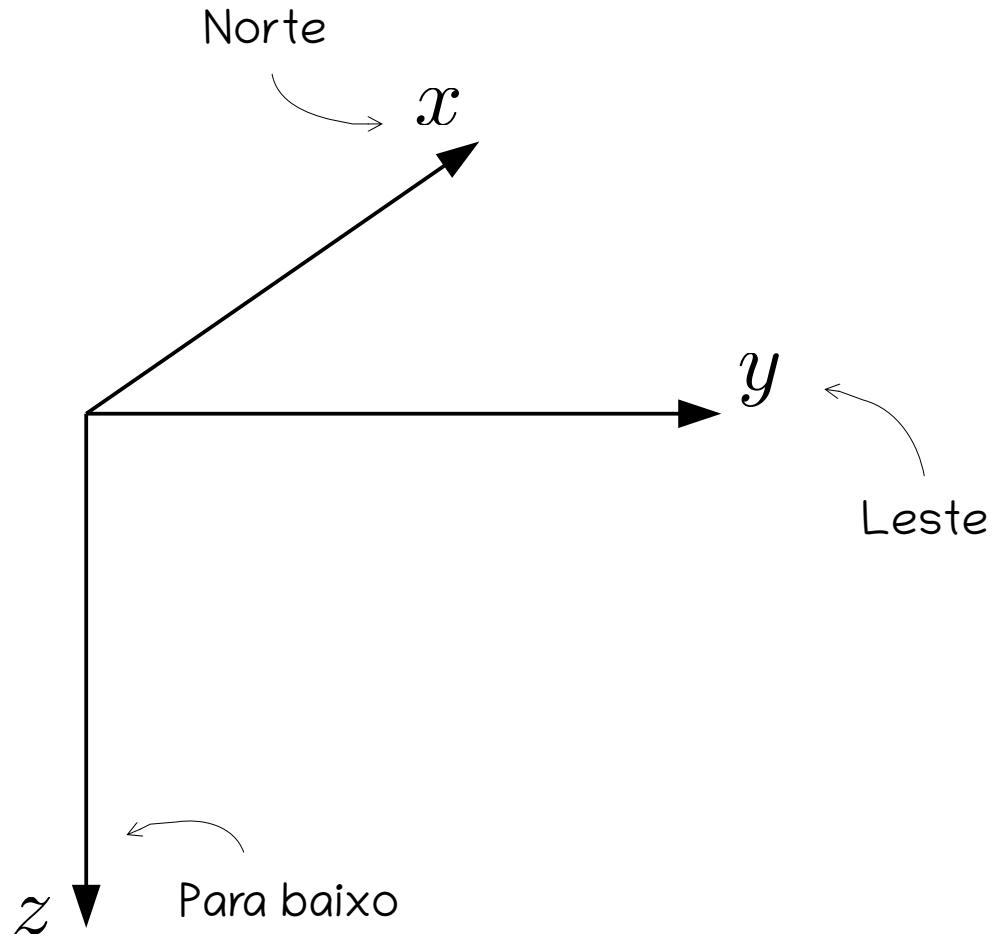
- **O que é a redução ao polo (RTP)**
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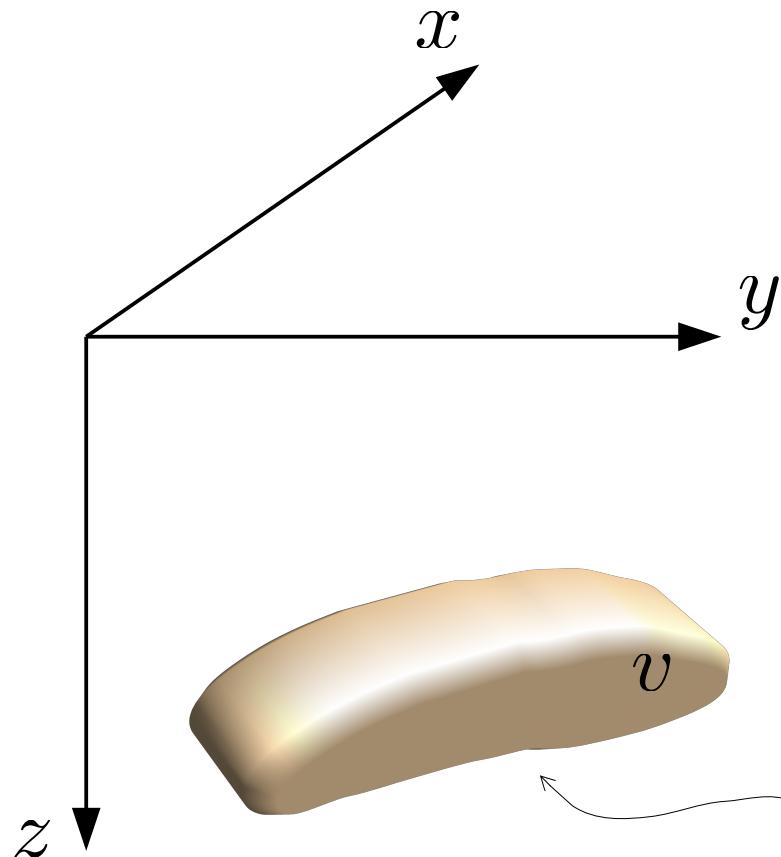


Sistema topocêntrico de coordenadas Cartesianas



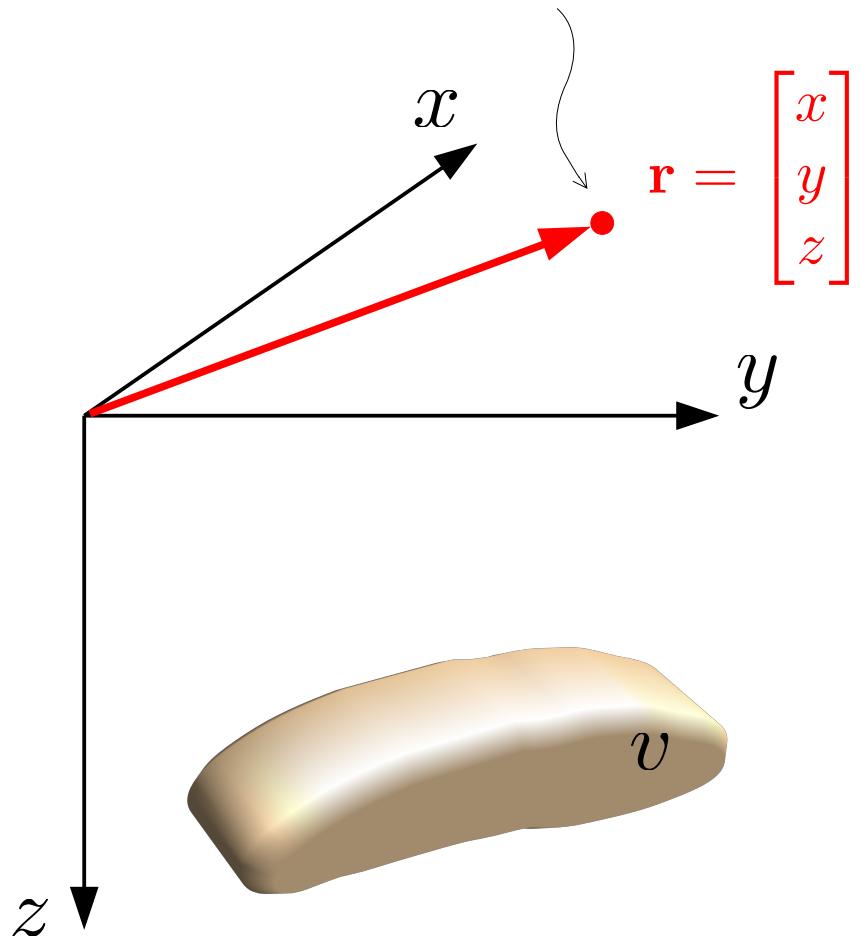
Sistema topocêntrico de coordenadas Cartesianas





fonte com
volume
 v

ponto de observação



ponto de observação

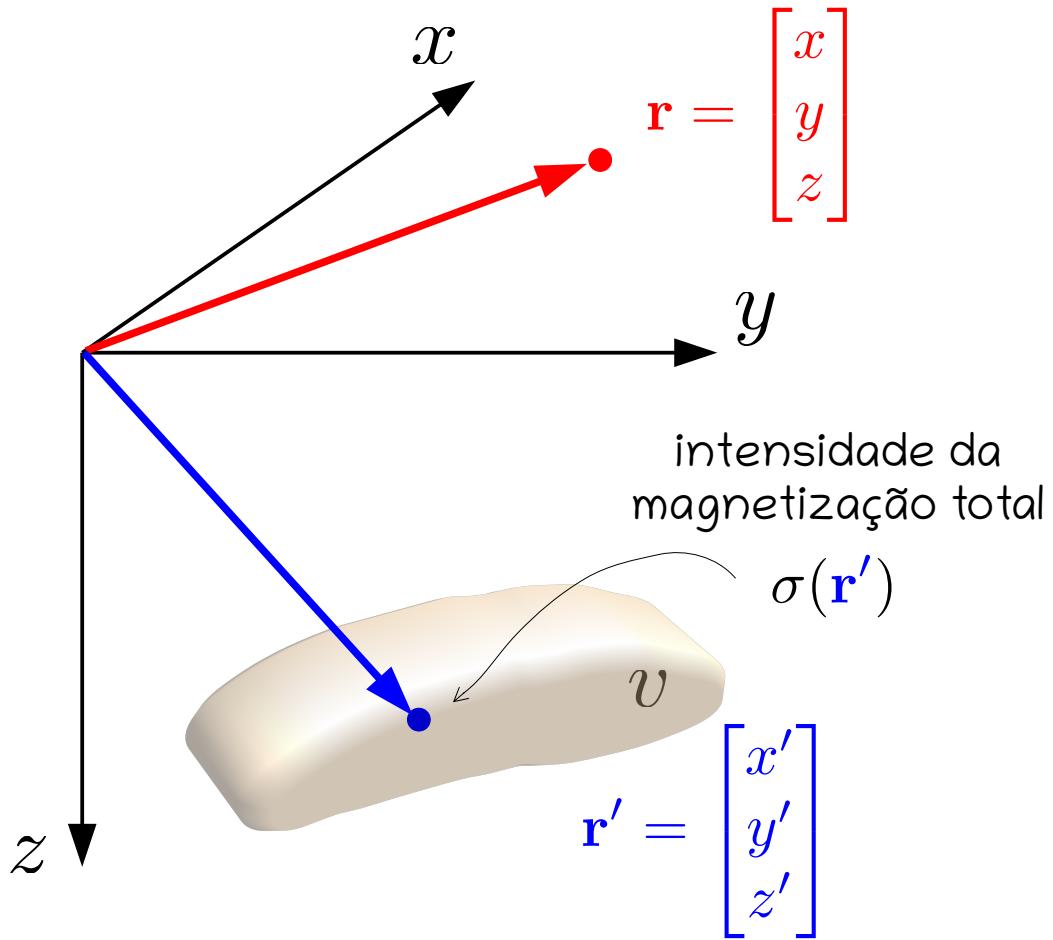
A 3D Cartesian coordinate system is shown with three axes: x (vertical), y (horizontal to the right), and z (depth). A red vector \mathbf{r} originates from the origin and points to a red dot representing the "ponto de observação".

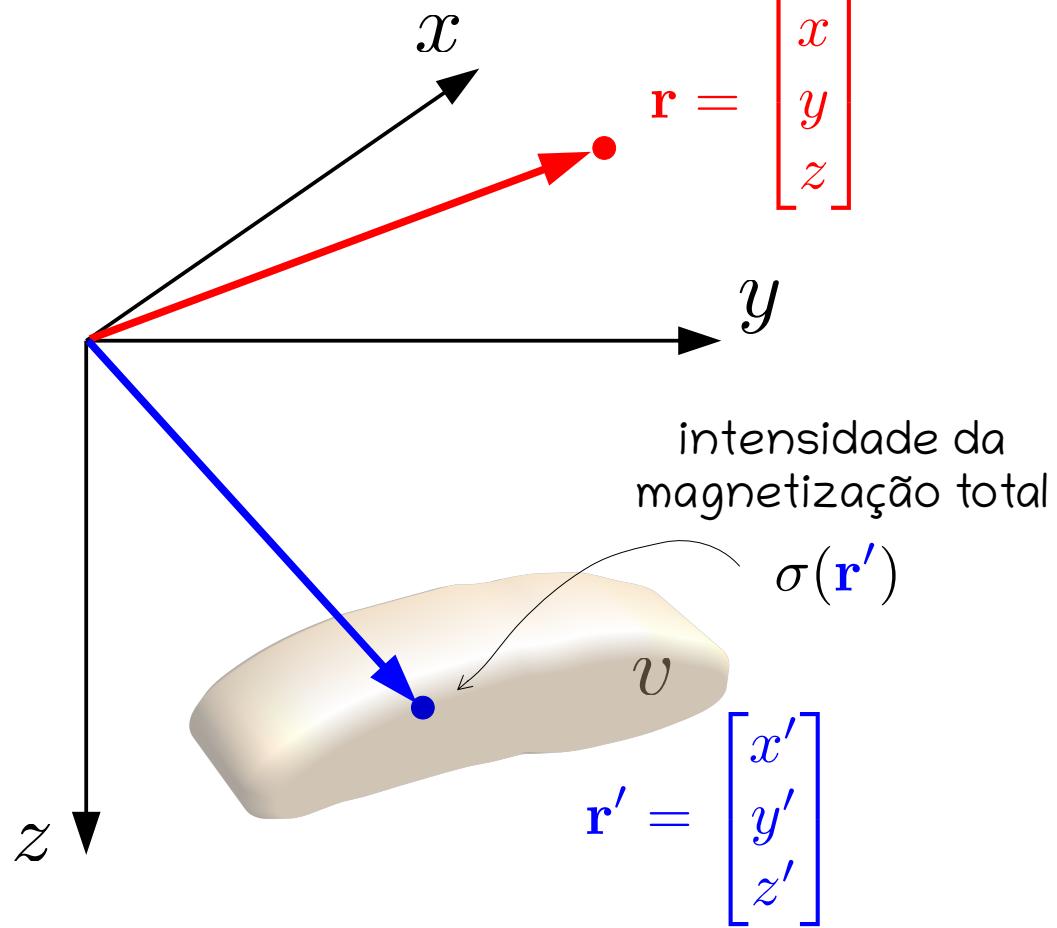
$$\mathbf{r} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

ponto dentro
da fonte

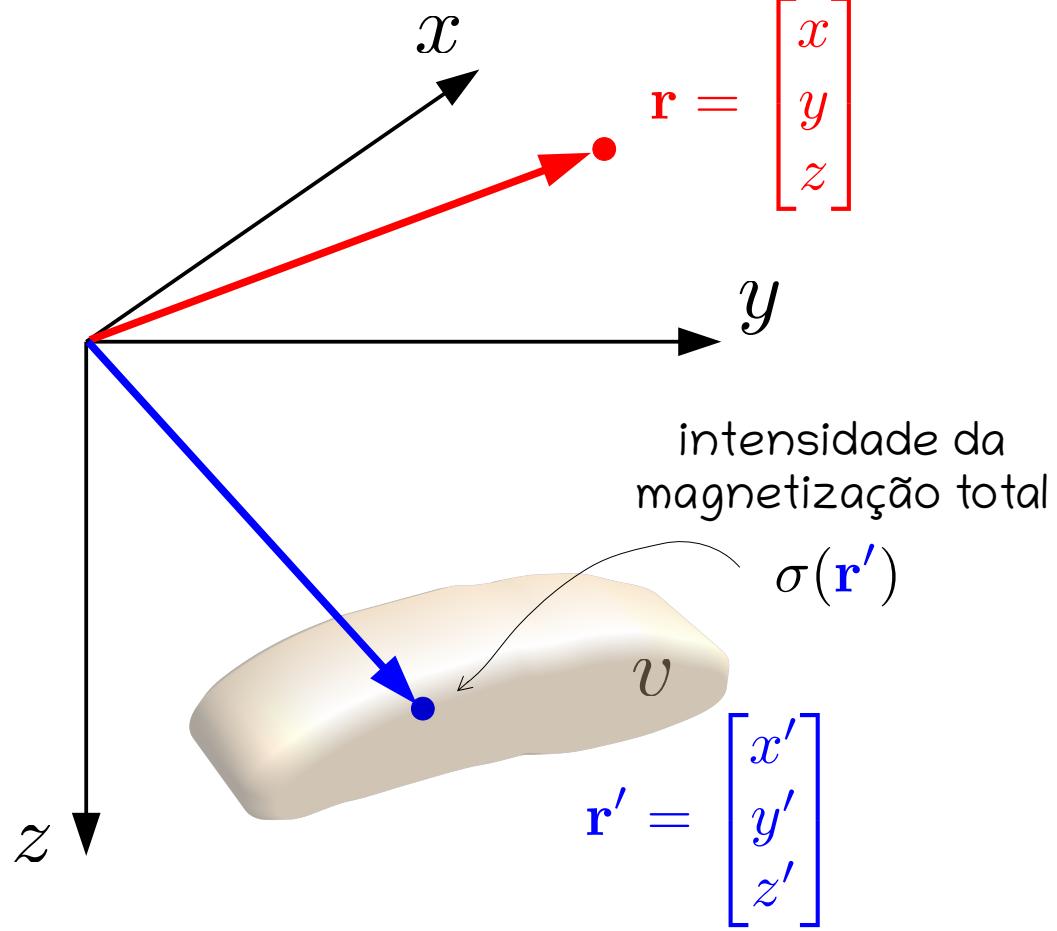
A 3D Cartesian coordinate system is shown with three axes: x (vertical), y (horizontal to the right), and z (depth). A blue vector \mathbf{r}' originates from the origin and points to a blue dot representing the "ponto dentro da fonte" (point inside the source) located within a light brown, irregularly shaped volume labeled v .

$$\mathbf{r}' = \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$$



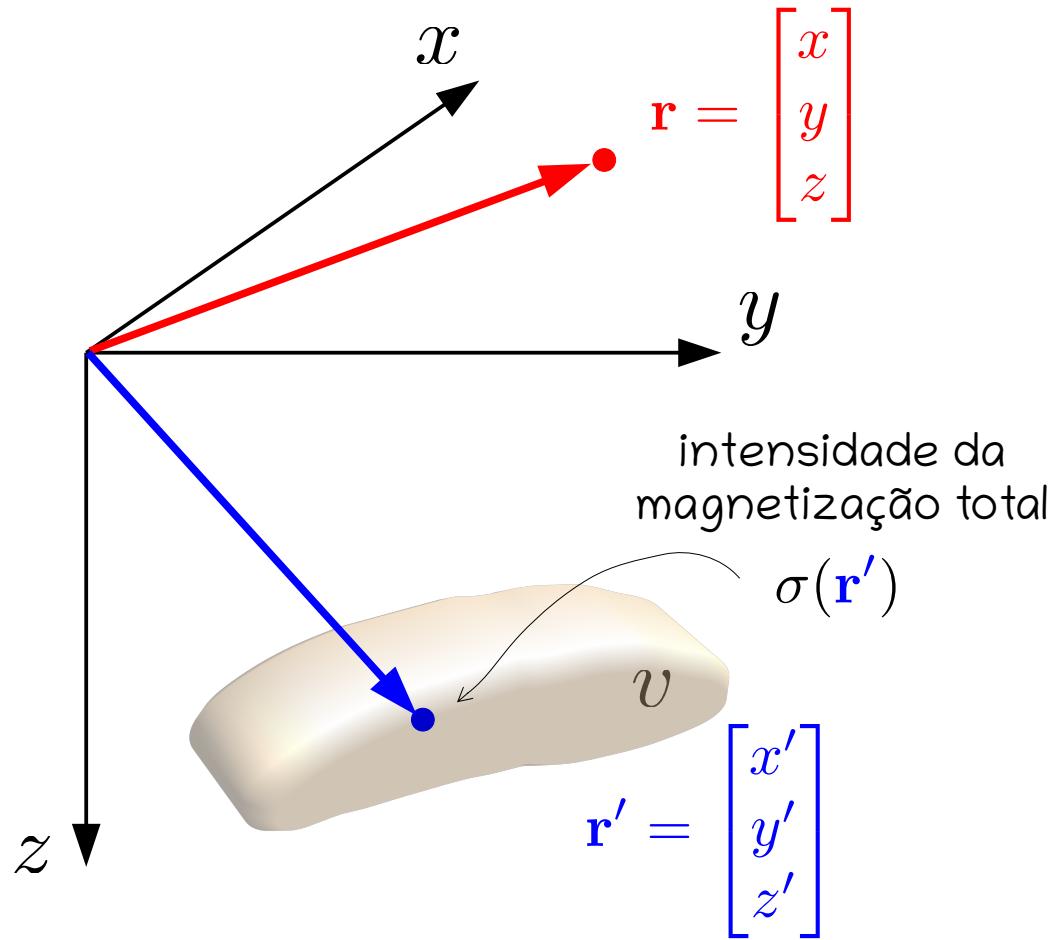


$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$



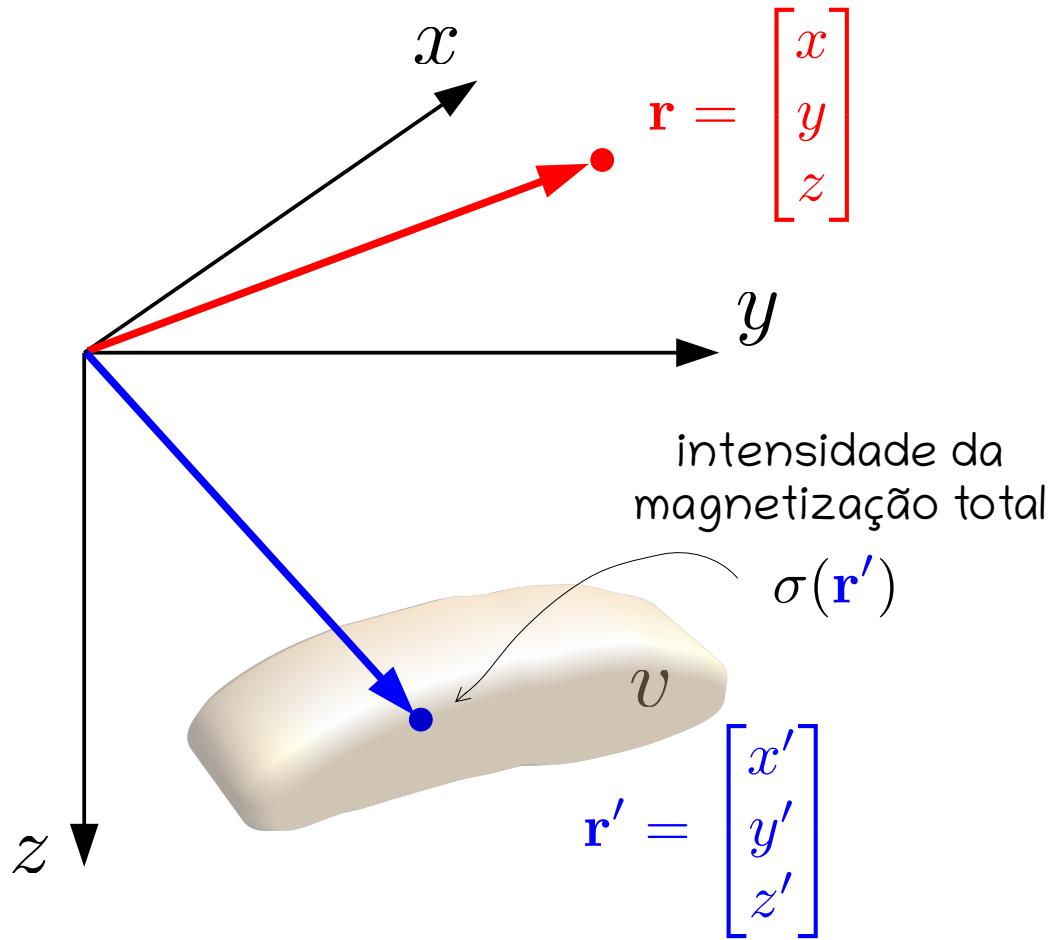
$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$dx' dy' dz'$



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

constante definida
em termos da
permeabilidade
magnética no vácuo

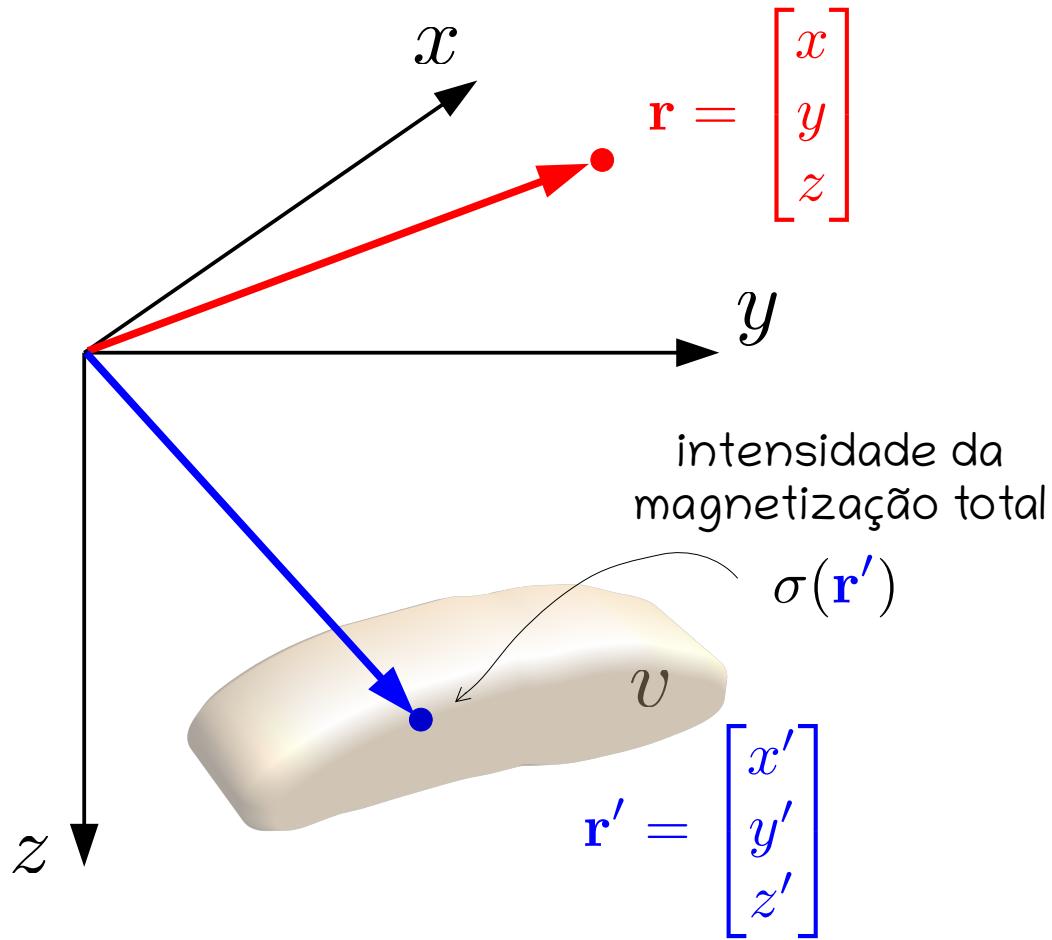


$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Esta função se aproxima de 0 junto com suas primeiras derivadas à medida em que $\|\mathbf{r} - \mathbf{r}'\|$ tende a infinito, para um \mathbf{r}' fixo, e é harmônica em pontos \mathbf{r} fora da fonte, ou seja:

$$\partial_{xx} U(\mathbf{r}) + \partial_{yy} U(\mathbf{r}) + \partial_{zz} U(\mathbf{r}) = 0$$

para $\mathbf{r} \notin v$



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

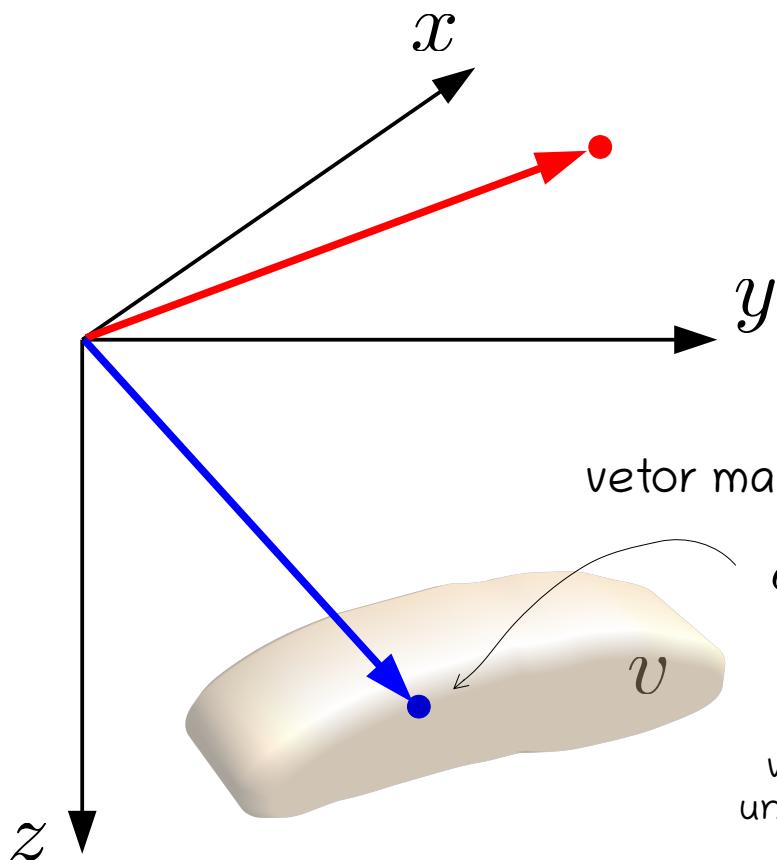
Esta função se aproxima de 0 junto com suas primeiras derivadas à medida em que $\|\mathbf{r} - \mathbf{r}'\|$ tende a infinito, para um \mathbf{r}' fixo, e é harmônica em pontos \mathbf{r} fora da fonte, ou seja:

$$\partial_{xx} U(\mathbf{r}) + \partial_{yy} U(\mathbf{r}) + \partial_{zz} U(\mathbf{r}) = 0$$

para $\mathbf{r} \notin v$

Note que a função $U(\mathbf{r})$ é análoga ao potencial gravitacional

$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$



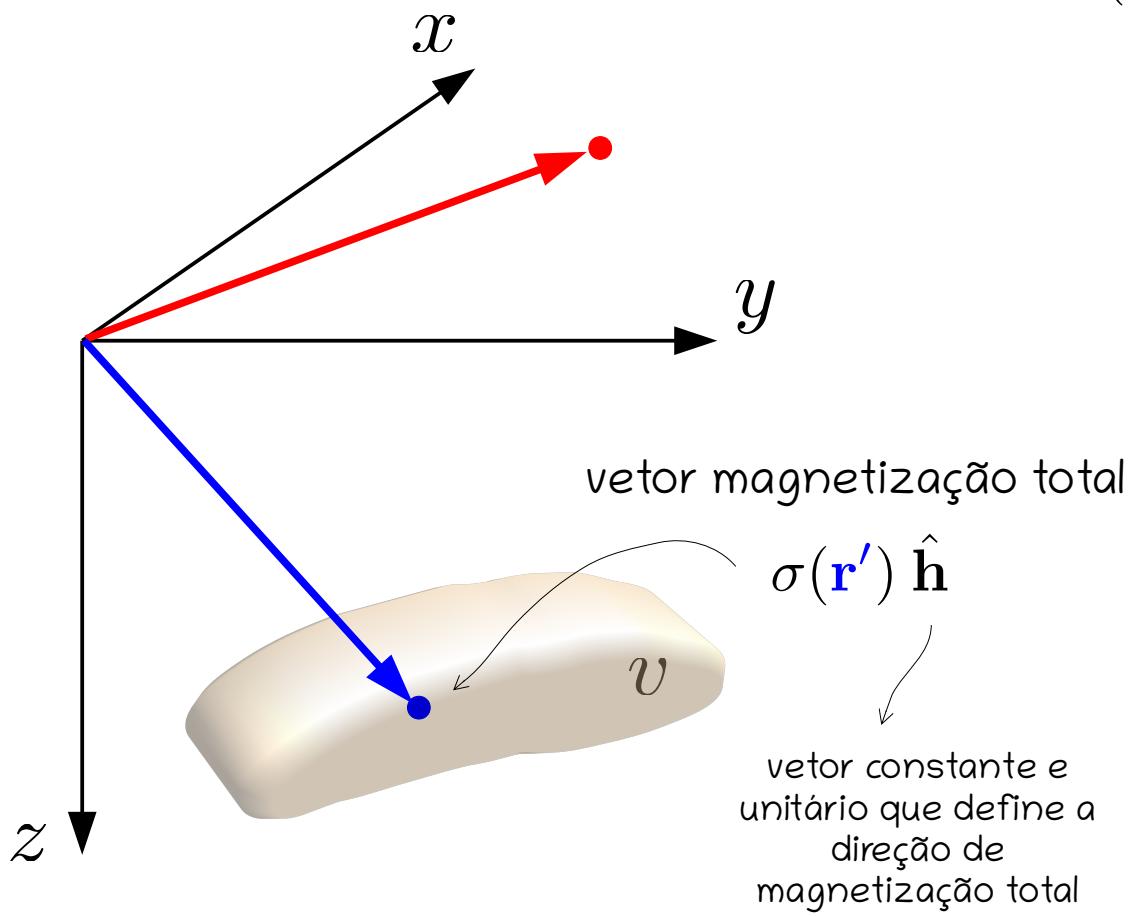
vetor magnetização total

$\sigma(\mathbf{r}') \hat{\mathbf{h}}$

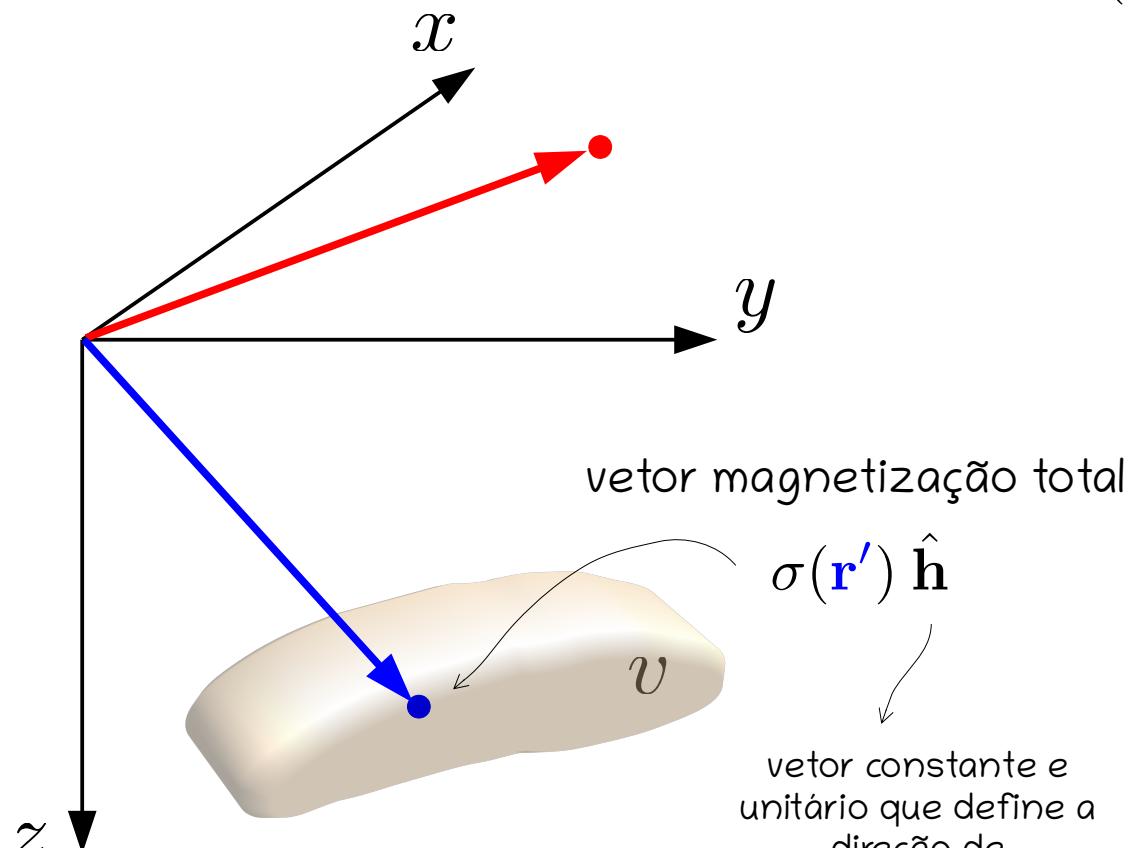
vetor constante e
unitário que define a
direção de
magnetização total

$$\hat{\mathbf{h}} = \begin{bmatrix} \hat{h}_x \\ \hat{h}_y \\ \hat{h}_z \end{bmatrix} = \begin{bmatrix} \cos I_h \cos D_h \\ \cos I_h \sin D_h \\ \sin I_h \end{bmatrix}$$

$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$



$-\partial_h U(\mathbf{r})$ potencial mag. escalar



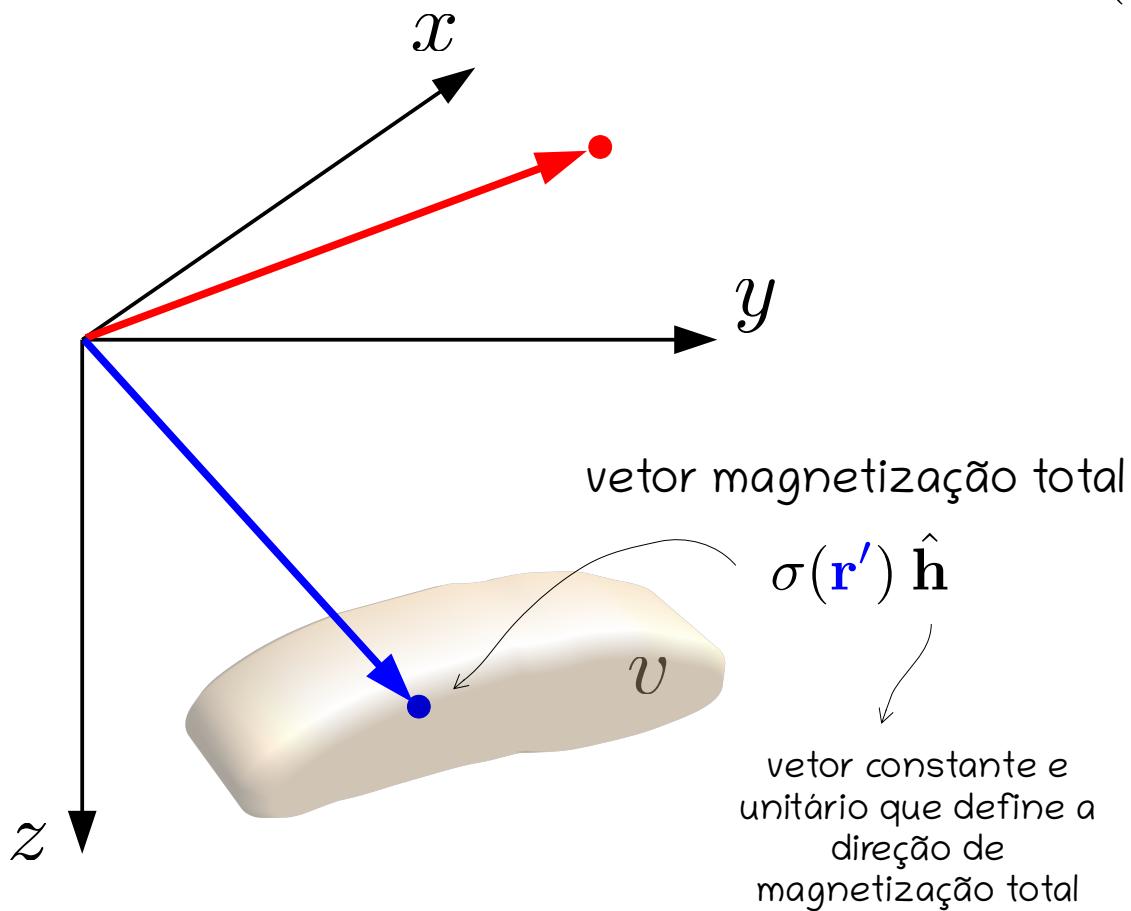
$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$$\partial_h U(\mathbf{r}) = \nabla U(\mathbf{r})^\top \hat{\mathbf{h}}$$

$\sigma(\mathbf{r}') \hat{\mathbf{h}}$

vetor constante e
unitário que define a
direção de
magnetização total



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

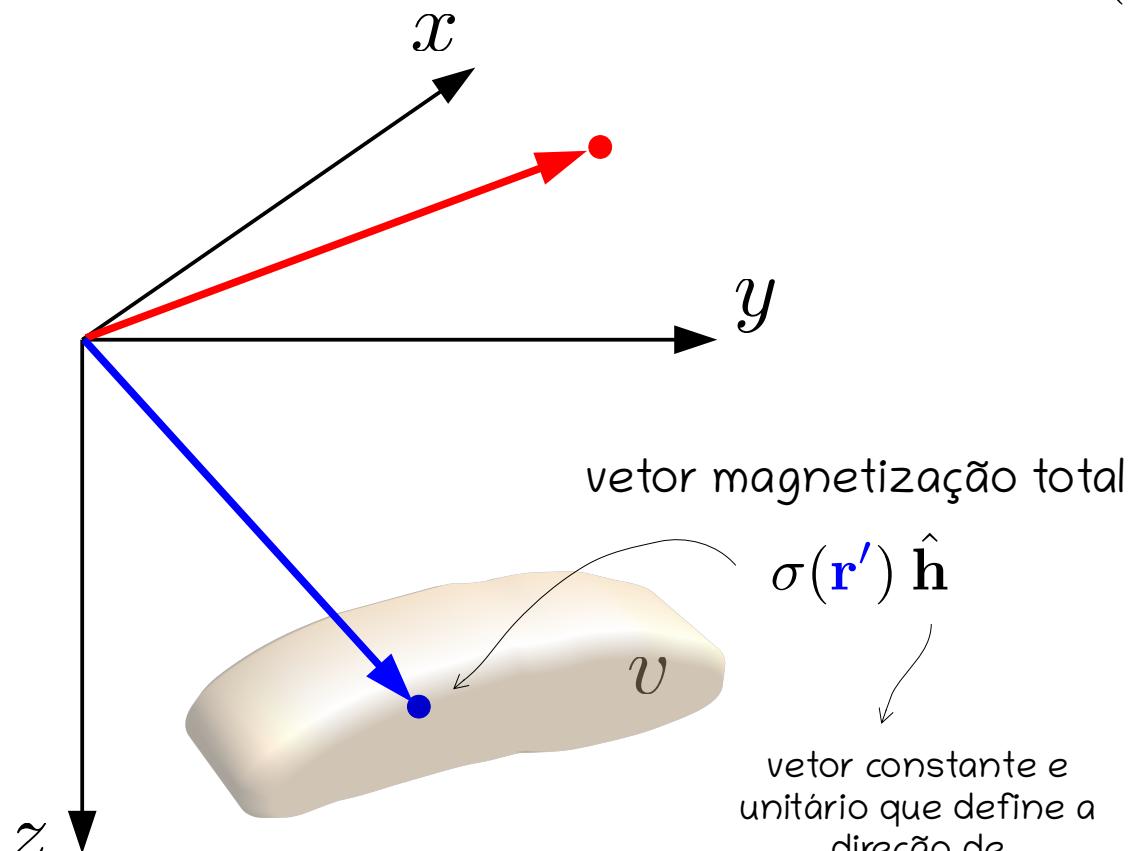
$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$$\partial_h U(\mathbf{r}) = \nabla U(\mathbf{r})^\top \hat{\mathbf{h}}$$

$$\partial_\alpha U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \partial_\alpha \left(\frac{1}{\|\mathbf{r} - \mathbf{r}'\|} \right) dv'$$

$\alpha = x, y, z$

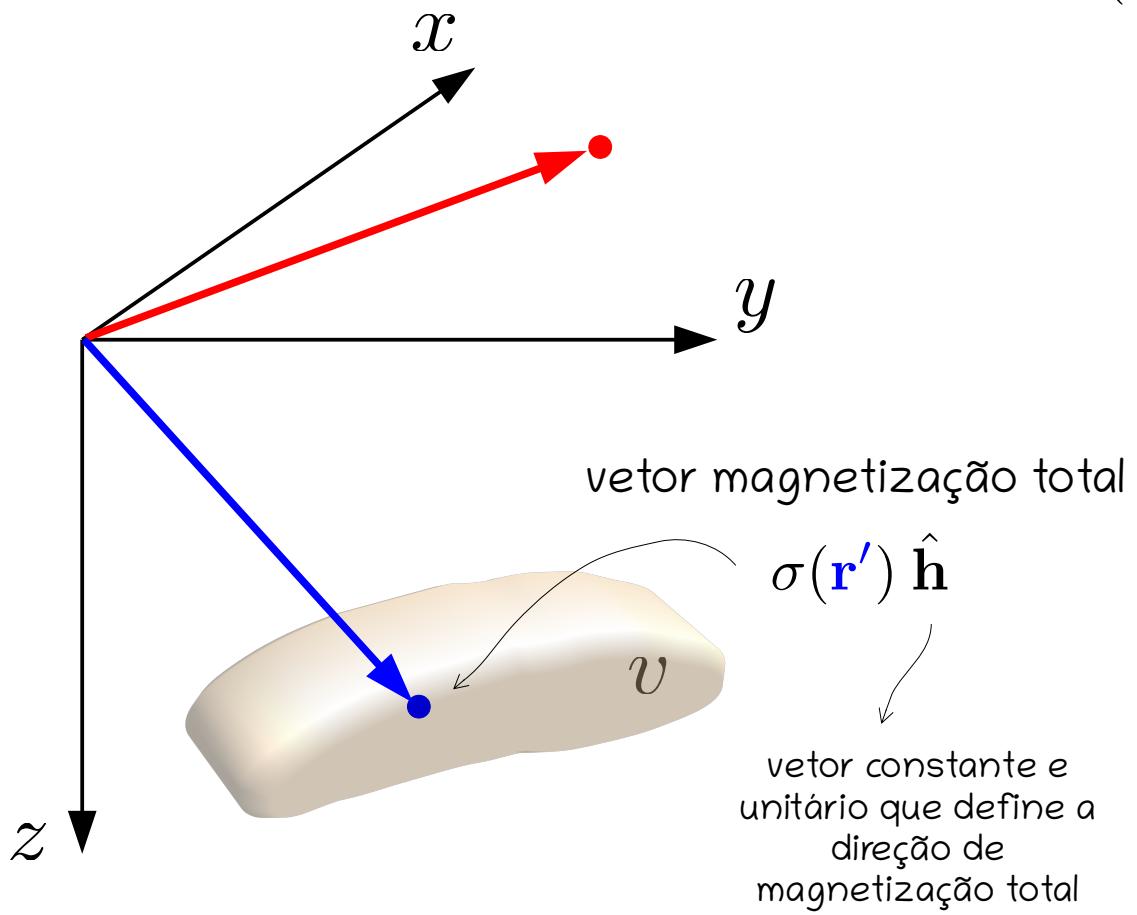
derivadas parciais de 1ª ordem



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

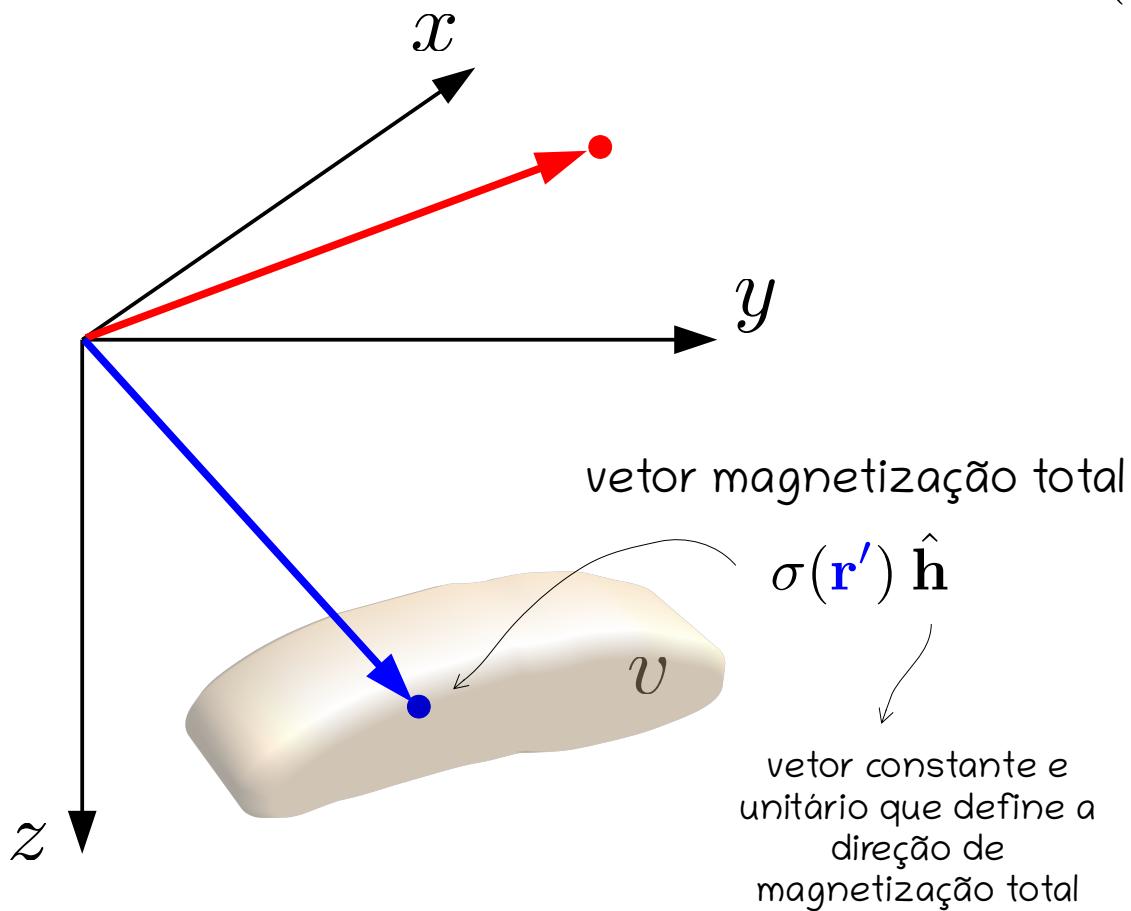


$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$$\partial_{\alpha h} U(\mathbf{r}) = \partial_{\alpha} \nabla U(\mathbf{r})^{\top} \hat{\mathbf{h}}$$



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

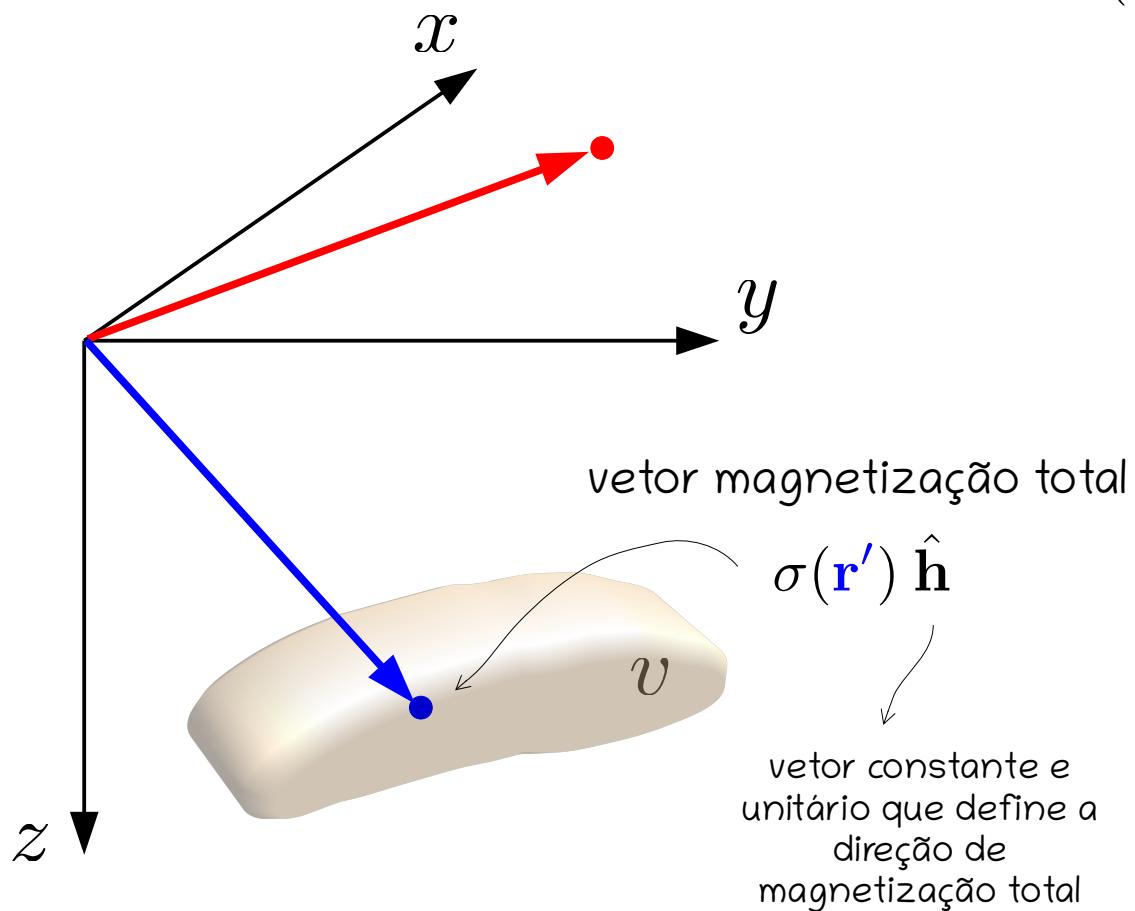
$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$$\partial_{\alpha h} U(\mathbf{r}) = \partial_{\alpha} \nabla U(\mathbf{r})^{\top} \hat{\mathbf{h}}$$

$$\partial_{\alpha} \nabla U(\mathbf{r}) = \begin{bmatrix} \partial_{\alpha x} U(\mathbf{r}) \\ \partial_{\alpha y} U(\mathbf{r}) \\ \partial_{\alpha z} U(\mathbf{r}) \end{bmatrix}$$

derivadas
 parciais de 2^a
 ordem

$$\alpha = x, y, z$$



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$$\partial_{\alpha h} U(\mathbf{r}) = \partial_{\alpha} \nabla U(\mathbf{r})^{\top} \hat{\mathbf{h}}$$

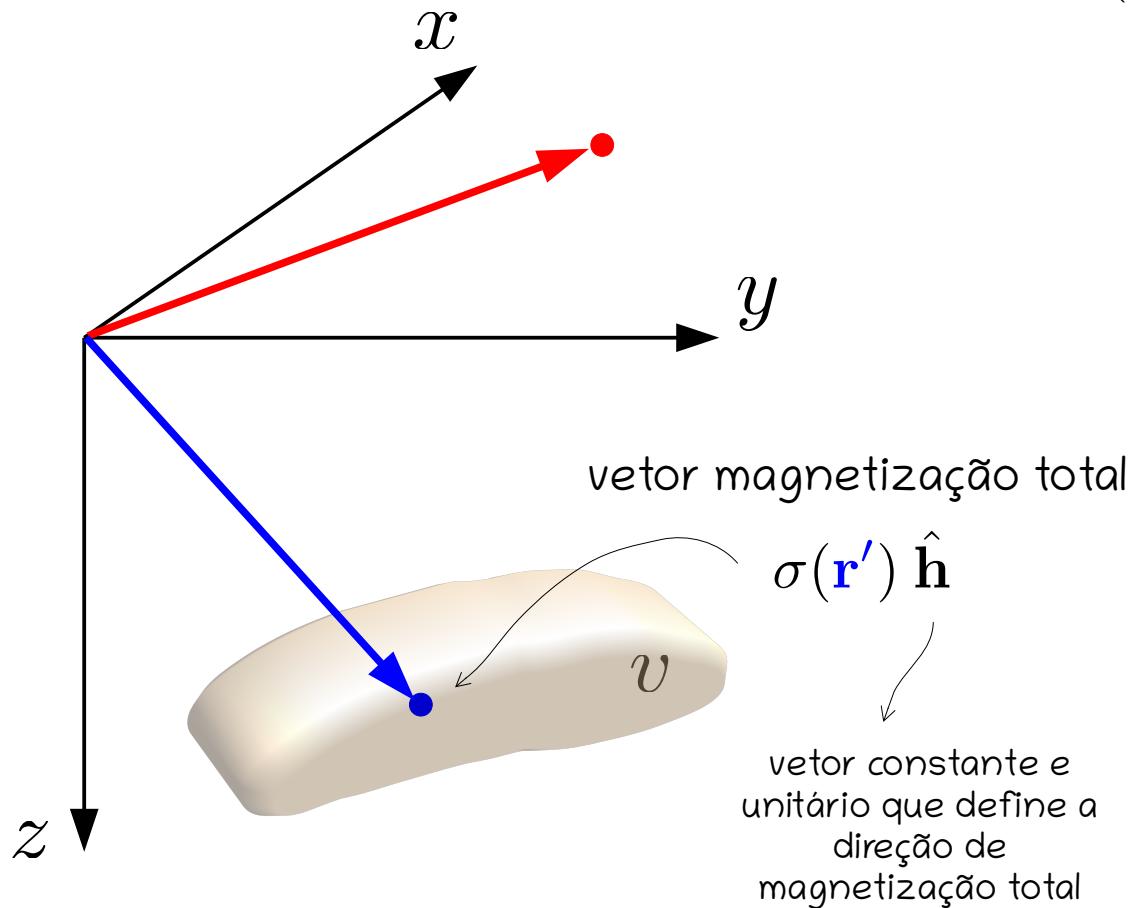
$$\partial_{\alpha} \nabla U(\mathbf{r}) = \begin{bmatrix} \partial_{\alpha x} U(\mathbf{r}) \\ \partial_{\alpha y} U(\mathbf{r}) \\ \partial_{\alpha z} U(\mathbf{r}) \end{bmatrix}$$

derivadas
parciais de 2ª
ordem

$$\alpha = x, y, z \quad \beta = x, y, z$$

$$\partial_{\alpha\beta} U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \partial_{\alpha\beta} \left(\frac{1}{\|\mathbf{r} - \mathbf{r}'\|} \right) dv'$$

Blakely (1996, p. 82)



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

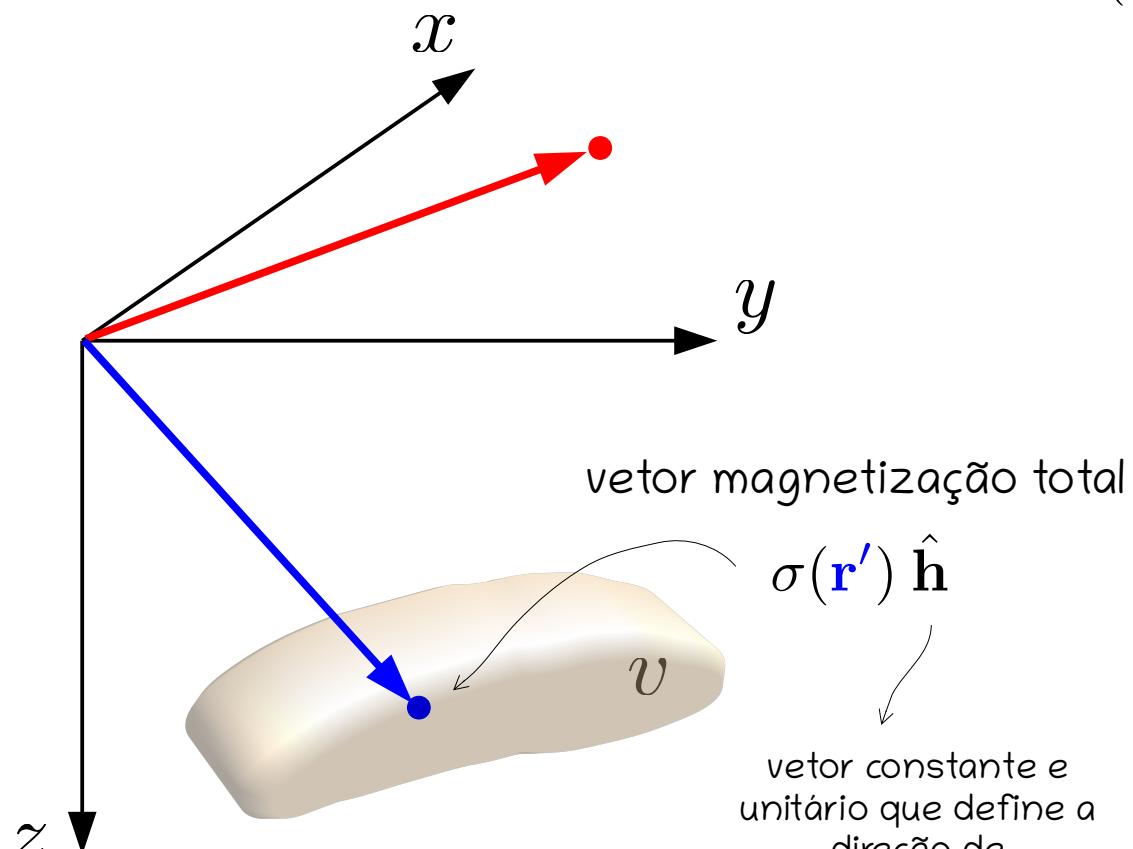
$$\partial_{\alpha h} U(\mathbf{r}) = \partial_{\alpha} \nabla U(\mathbf{r})^{\top} \hat{\mathbf{h}}$$

$$\partial_{\alpha} \nabla U(\mathbf{r}) = \begin{bmatrix} \partial_{\alpha x} U(\mathbf{r}) \\ \partial_{\alpha y} U(\mathbf{r}) \\ \partial_{\alpha z} U(\mathbf{r}) \end{bmatrix}$$

derivadas parciais de 2ª ordem

$$\alpha = x, y, z \quad \beta = x, y, z$$

$$\partial_{\alpha \beta} U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \partial_{\alpha \beta} \left(\frac{1}{\|\mathbf{r} - \mathbf{r}'\|} \right) dv'$$



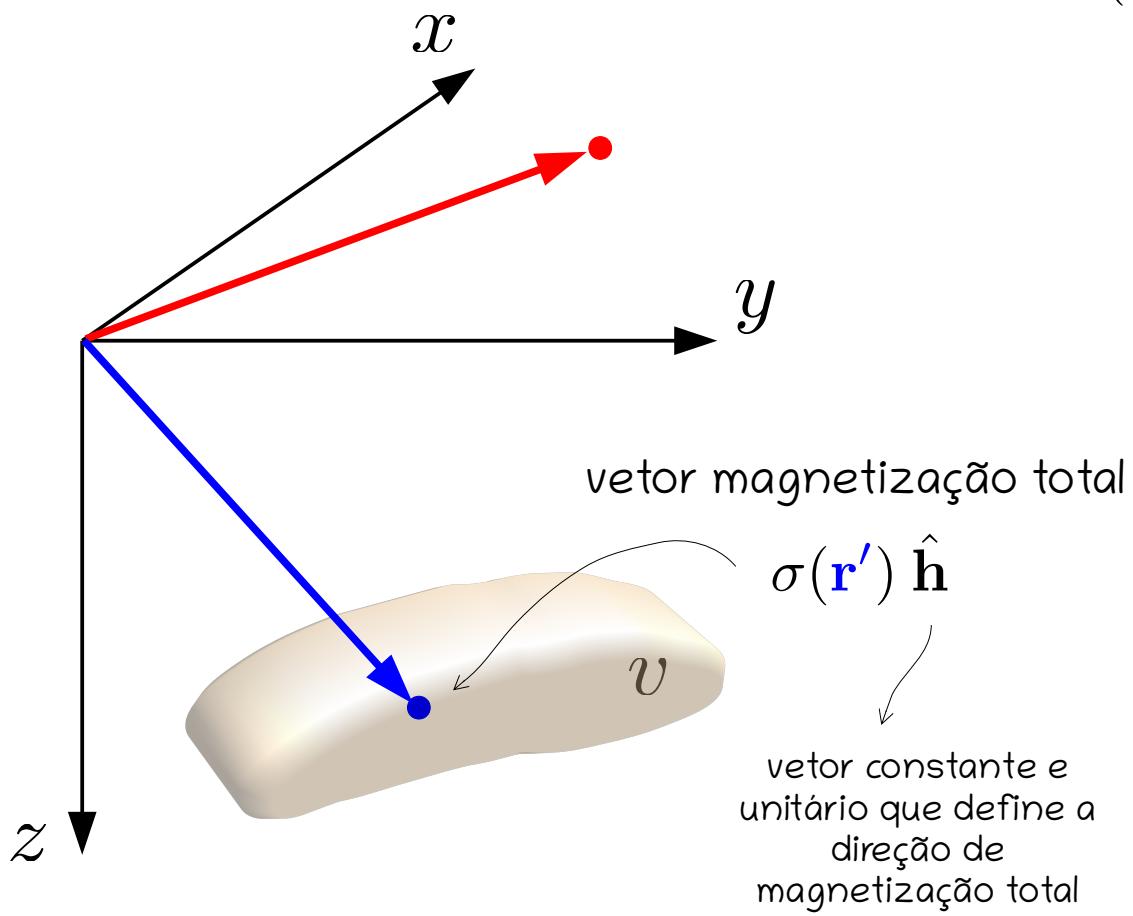
$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

vetor constante e
unitário que define a
direção de
magnetização total



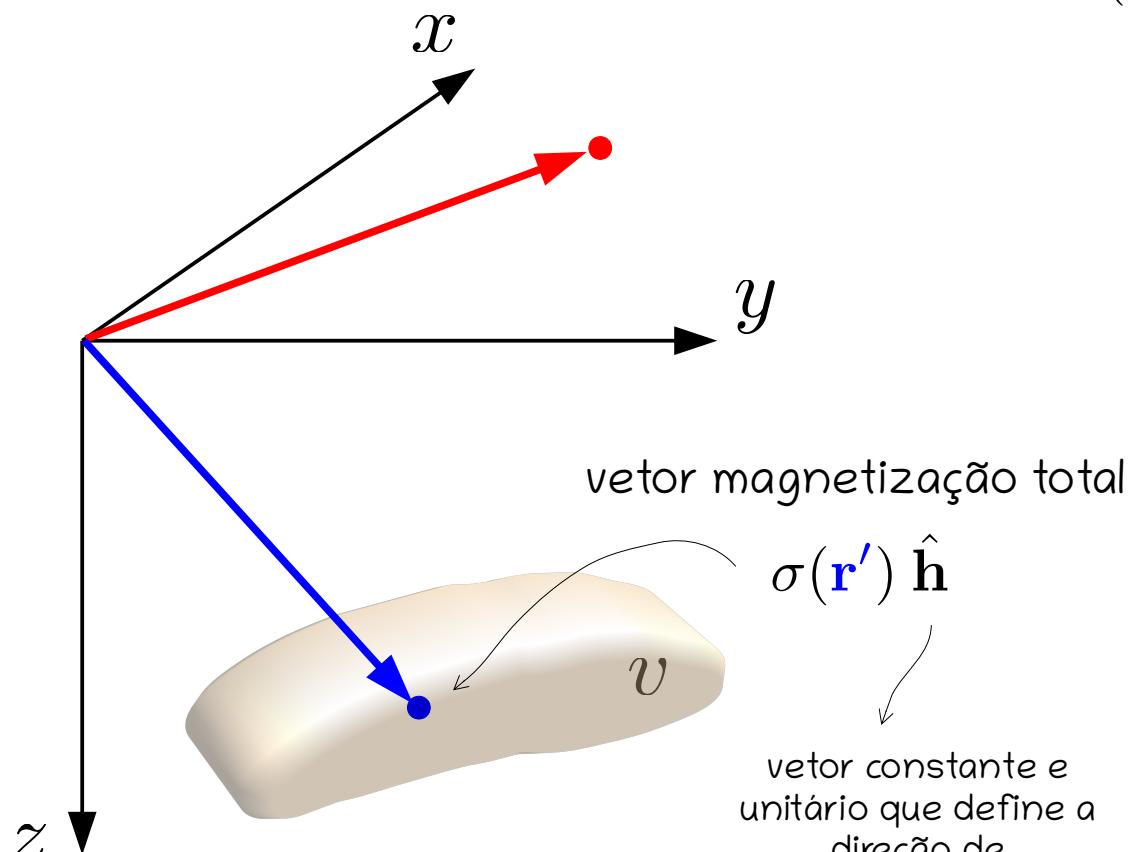
$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

$$\hookrightarrow \partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

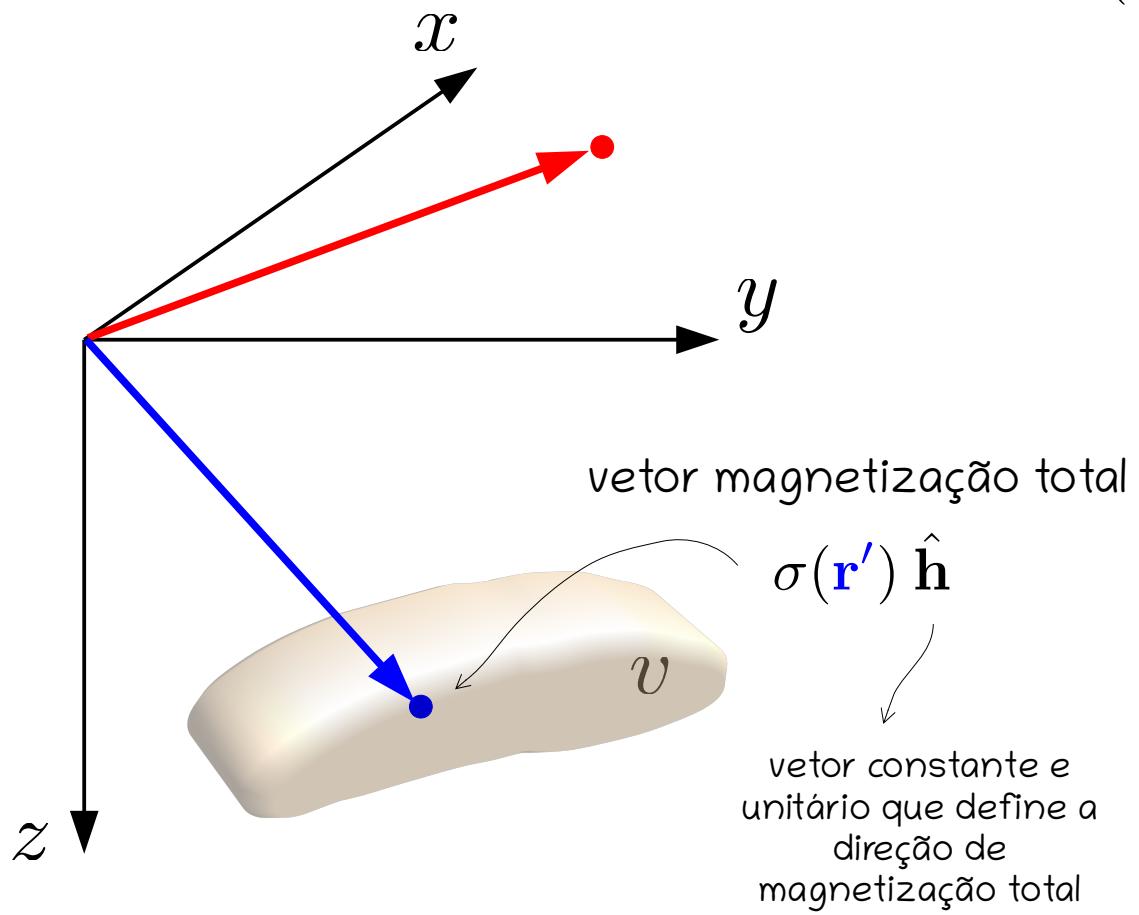
$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

$$\hookrightarrow \partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$

vetor unitário constante que define a direção do campo principal

$$\hat{\mathbf{t}} = \begin{bmatrix} \hat{t}_x \\ \hat{t}_y \\ \hat{t}_z \end{bmatrix} = \begin{bmatrix} \cos I_t \cos D_t \\ \cos I_t \sin D_t \\ \sin I_t \end{bmatrix}$$



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

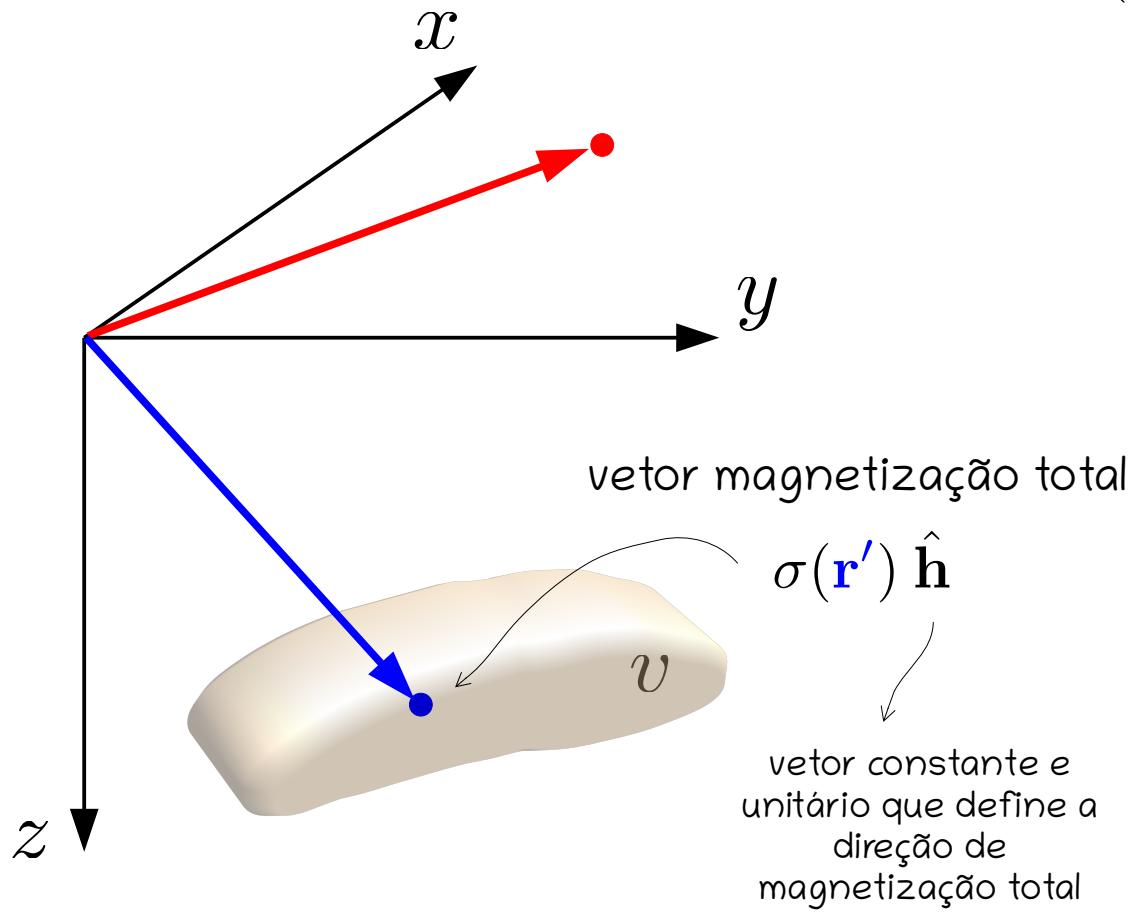
$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

$$\hookrightarrow \partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$

$$\hat{\mathbf{t}} = \begin{bmatrix} \hat{t}_x \\ \hat{t}_y \\ \hat{t}_z \end{bmatrix} = \begin{bmatrix} \partial_x U(\mathbf{r}) & \partial_y U(\mathbf{r}) & \partial_z U(\mathbf{r}) \\ \partial_y U(\mathbf{r}) & \partial_y U(\mathbf{r}) & \partial_z U(\mathbf{r}) \\ \partial_z U(\mathbf{r}) & \partial_z U(\mathbf{r}) & \partial_z U(\mathbf{r}) \end{bmatrix}$$

$$\mathbf{H}_U(\mathbf{r}) = \begin{bmatrix} \partial_{xx} U(\mathbf{r}) & \partial_{xy} U(\mathbf{r}) & \partial_{xz} U(\mathbf{r}) \\ \partial_{xy} U(\mathbf{r}) & \partial_{yy} U(\mathbf{r}) & \partial_{yz} U(\mathbf{r}) \\ \partial_{xz} U(\mathbf{r}) & \partial_{yz} U(\mathbf{r}) & \partial_{zz} U(\mathbf{r}) \end{bmatrix}$$

Blakely (1996, p. 179, 196)



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

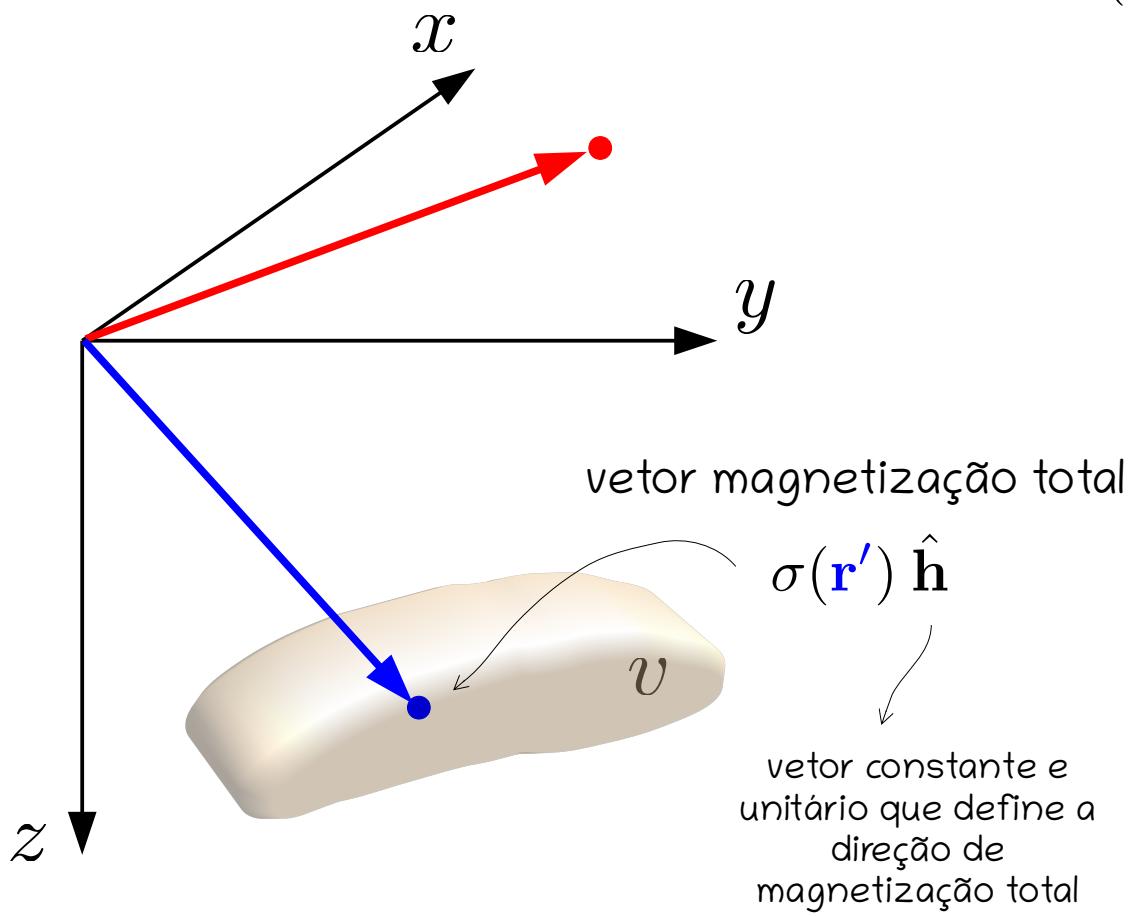
$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

$$\hookrightarrow \partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$

$$\mathbf{H}_U(\mathbf{r}) = \begin{bmatrix} \partial_{xx} U(\mathbf{r}) & \partial_{xy} U(\mathbf{r}) & \partial_{xz} U(\mathbf{r}) \\ \partial_{xy} U(\mathbf{r}) & \partial_{yy} U(\mathbf{r}) & \partial_{yz} U(\mathbf{r}) \\ \partial_{xz} U(\mathbf{r}) & \partial_{yz} U(\mathbf{r}) & \partial_{zz} U(\mathbf{r}) \end{bmatrix}$$



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

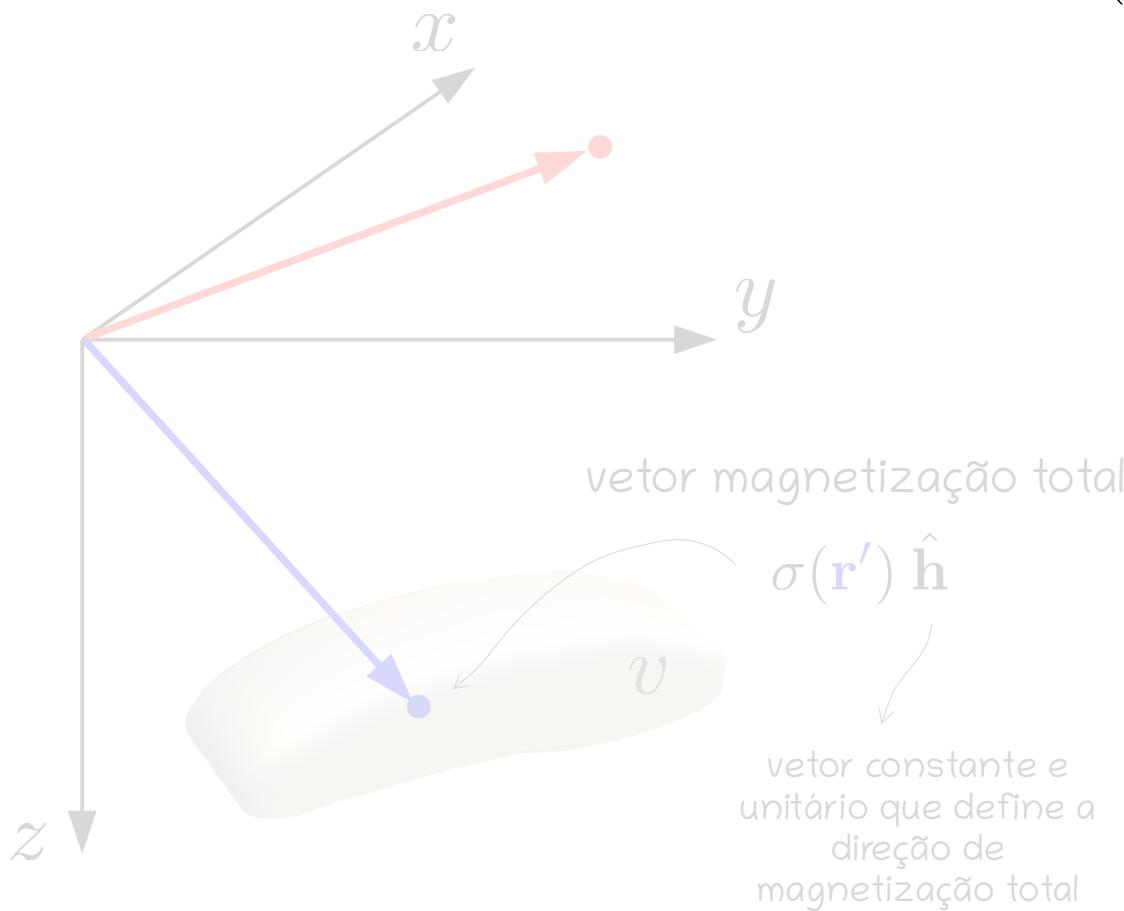
$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

$\partial_{zz} U(\mathbf{r})$ anomalia RTP

$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

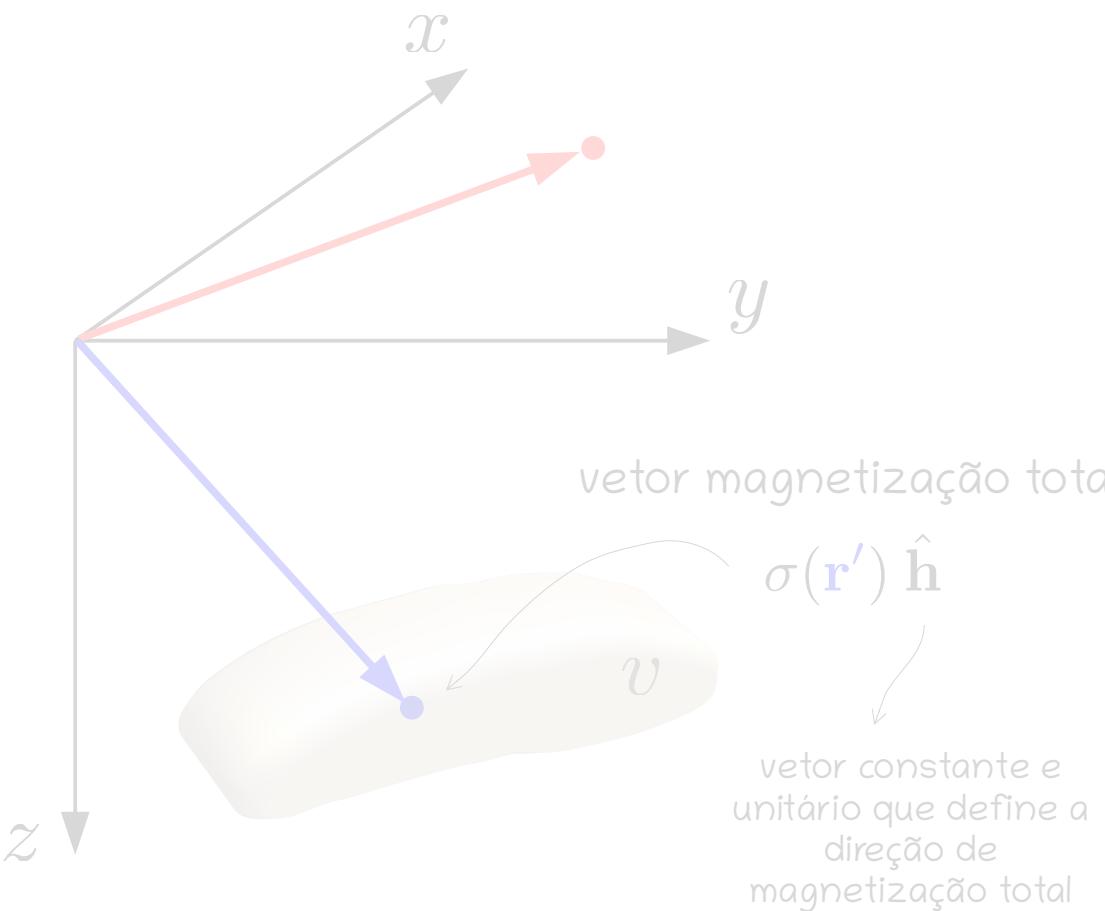


$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

$\partial_{zz} U(\mathbf{r})$ anomalia RTP



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

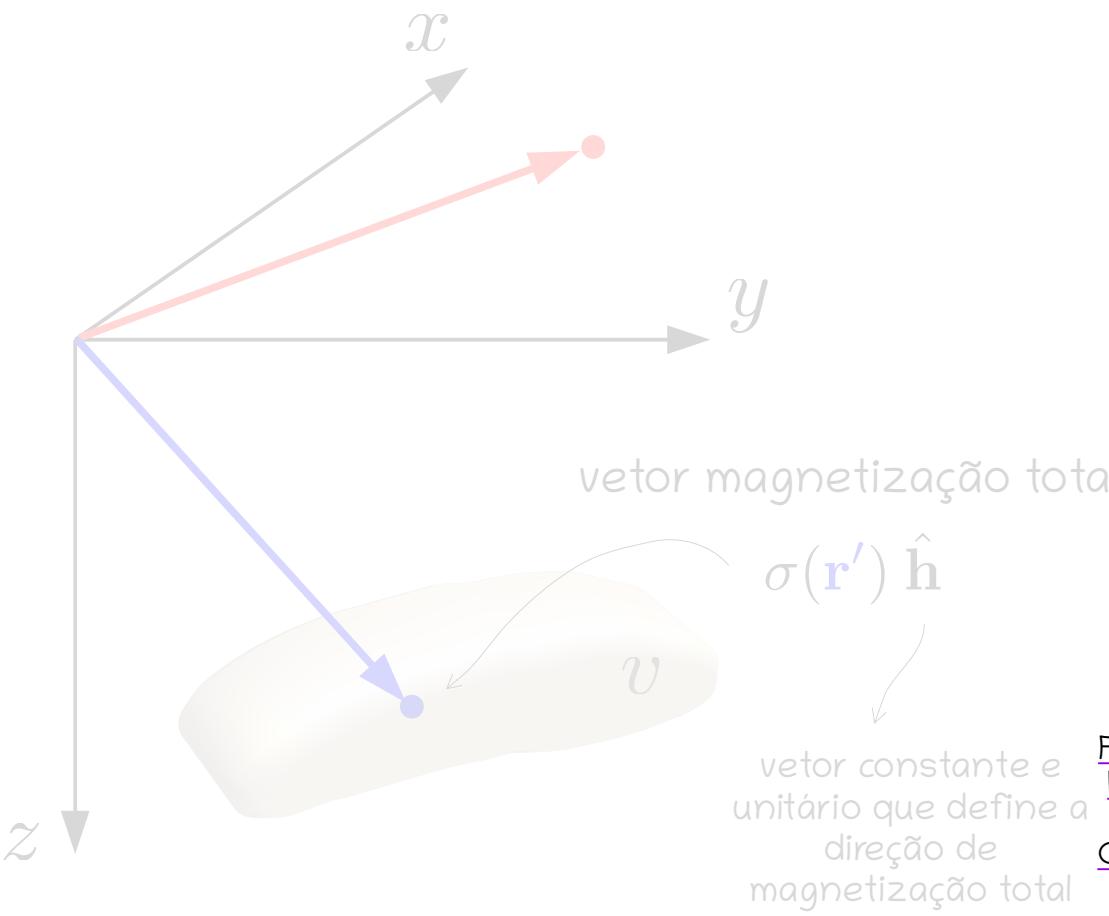
$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

$\partial_{zz} U(\mathbf{r})$ anomalia RTP

Baranov (1957) foi o primeiro a propor esta transformação



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$-\partial_h U(\mathbf{r})$ potencial mag. escalar

$\partial_{\alpha h} U(\mathbf{r})$ componente α da indução mag.

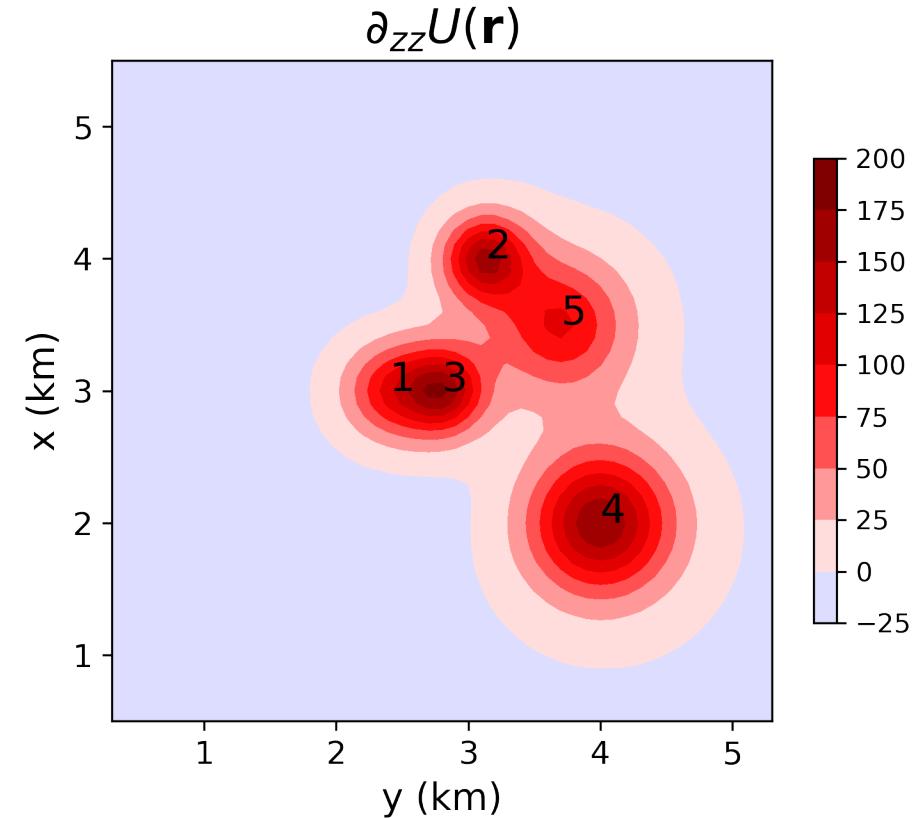
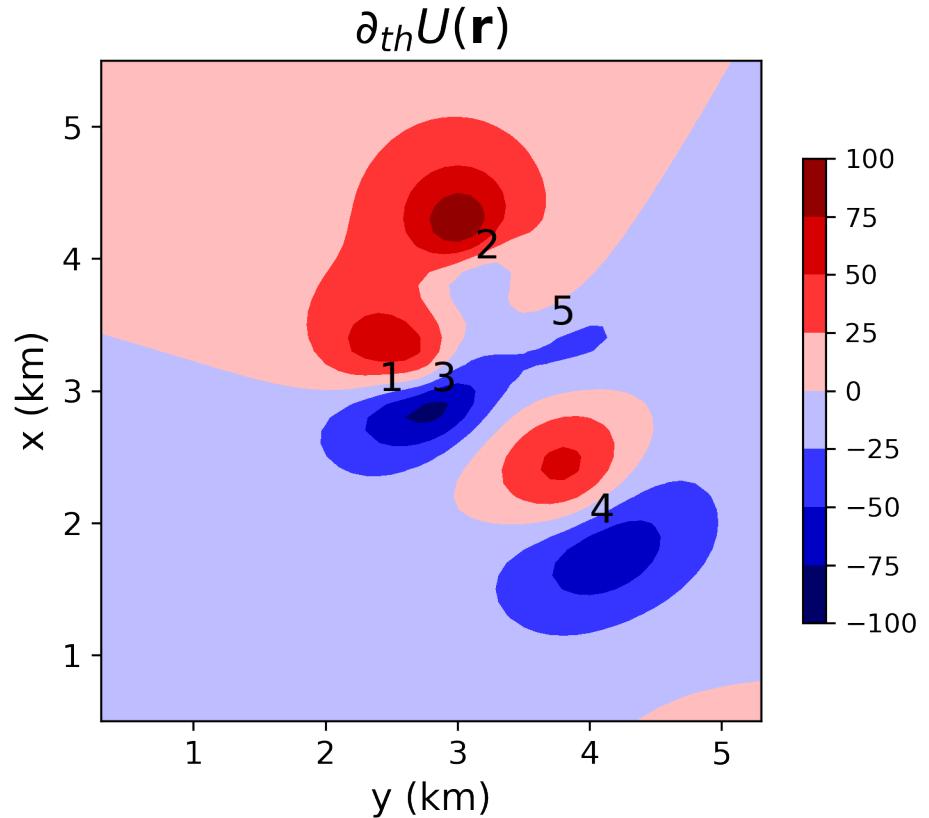
$\partial_{th} U(\mathbf{r})$ an. de campo total (aproximada)

$\partial_{zz} U(\mathbf{r})$ anomalia RTP

Desde então, muitos trabalhos foram publicados sobre este tema [Ervin \(1976\)](#), [Baranov e Naudy \(1964\)](#), [Silva \(1986\)](#), [Hansen e Pawłowski \(1989\)](#), [Mendonça e Silva \(1993\)](#), [Fedi et al. \(1994\)](#), [Arkani-Hamed \(1998\)](#), [Lu \(1998\)](#), [Swain \(2000\)](#), [Lu et al. \(2003\)](#), [Bilim e Ates \(2004\)](#), [Dannemiller e Li \(2006\)](#), [Arkani-Hamed \(2007\)](#), [Guo e Meng \(2013\)](#), [Oliveira Jr. et al. \(2013\)](#), [Zhang et al. \(2014\)](#), [Zhang et al. \(2018\)](#), [Reis et al. \(2020\)](#), [Ribeiro \(2020\)](#), [Ribeiro-Filho et al. \(2020\)](#)

$$I_t = -25^\circ \quad I_h = -30^\circ$$

$$D_t = -30^\circ \quad D_h = -19^\circ$$



Sumário

- **O que é a redução ao polo (RTP)**
- Como calcular a RTP
- Desenvolvimentos teóricos
- Possível generalização
- Comentários finais



Sumário

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Há duas abordagens para o cálculo da RTP

Há duas abordagens para o cálculo da RTP

Domínio do espaço

Domínio de Fourier

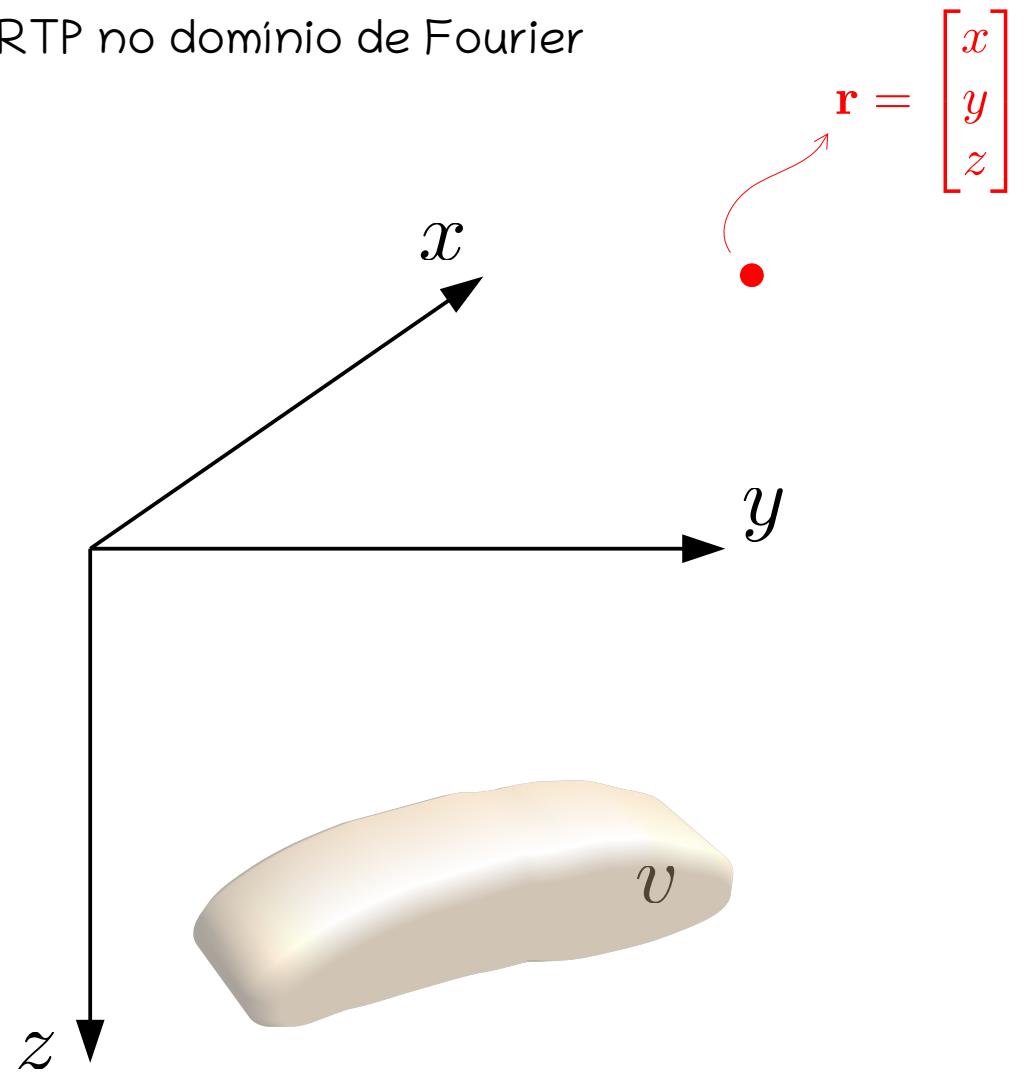
Há duas abordagens para o cálculo da RTP

Domínio do espaço

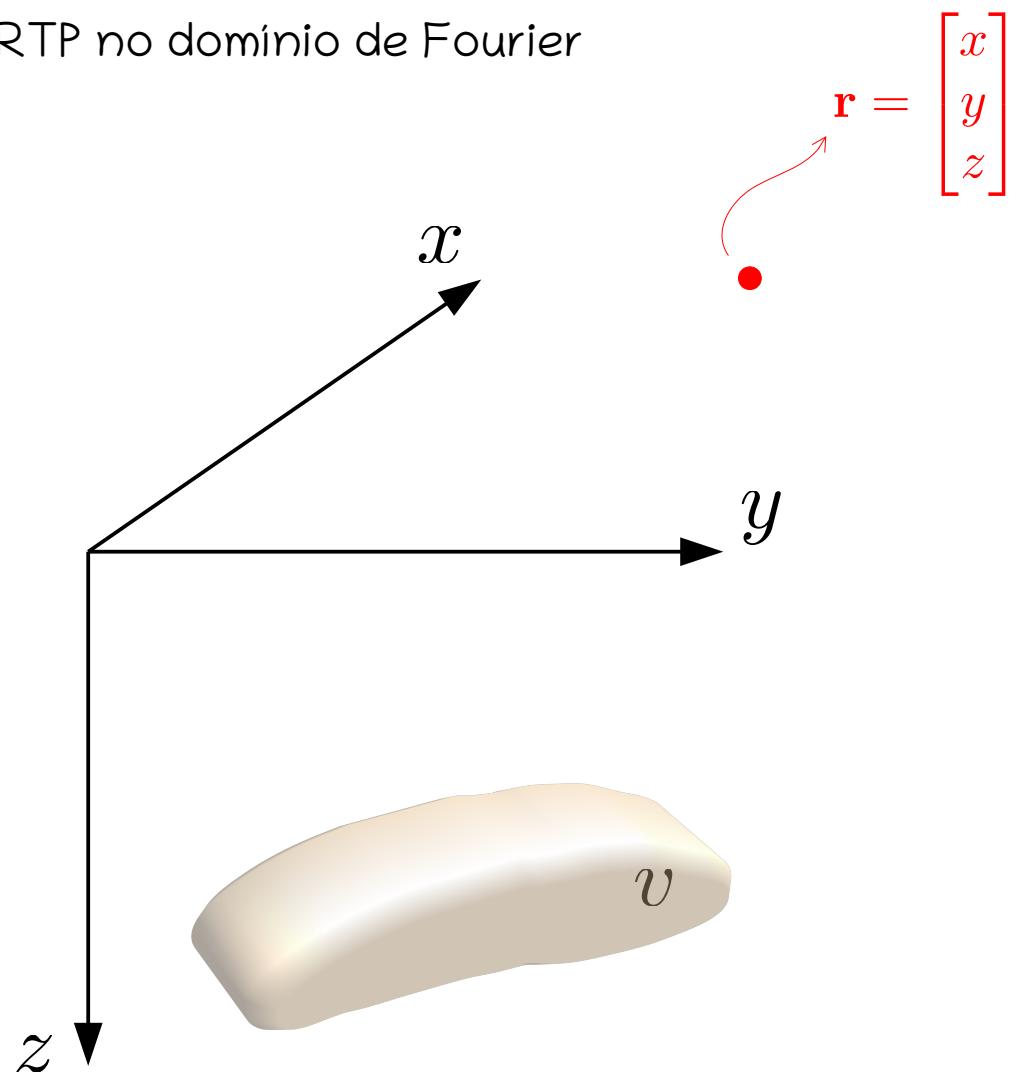
Domínio de Fourier

RTP no domínio de Fourier

RTP no domínio de Fourier



RTP no domínio de Fourier

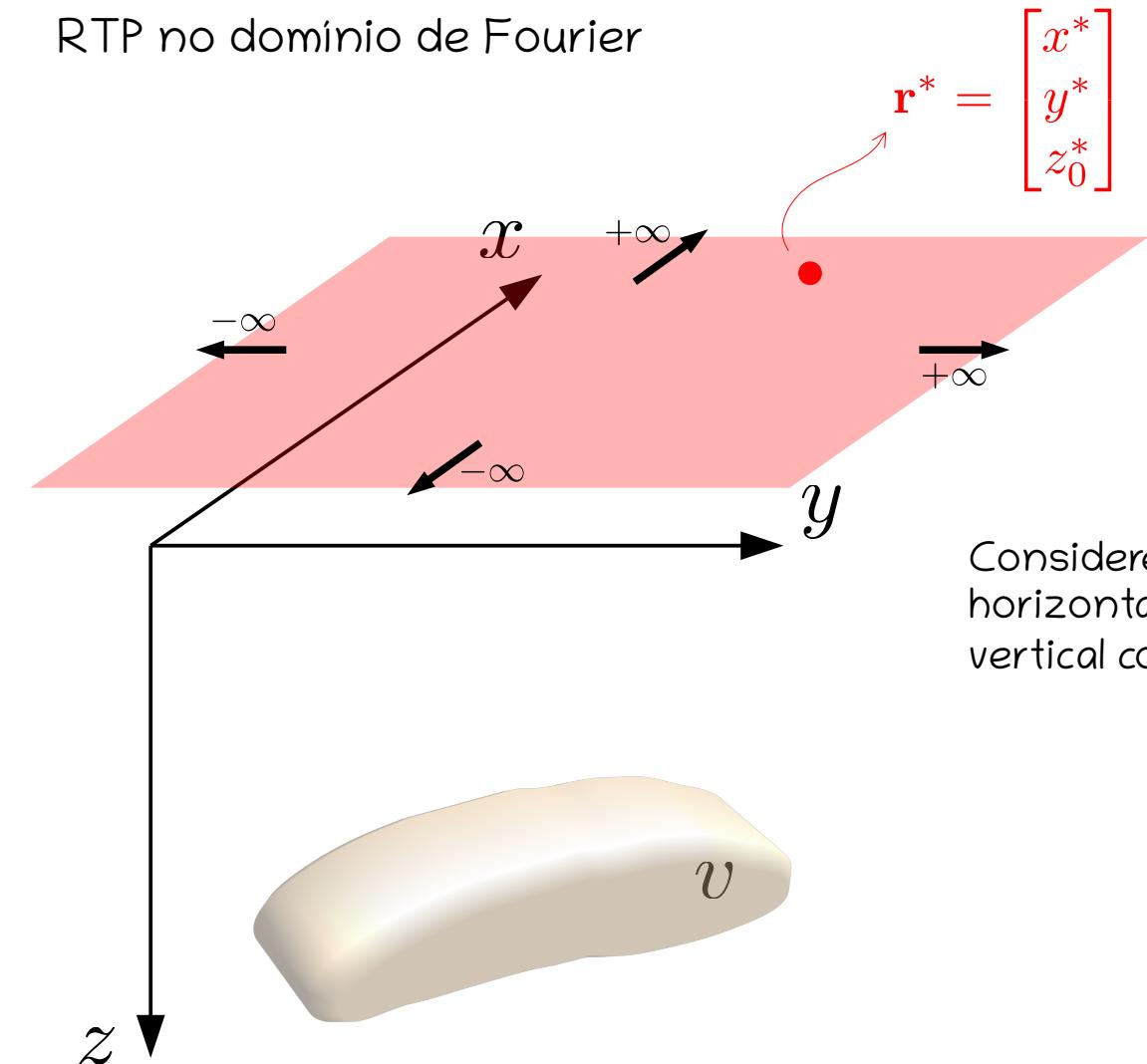


$$\mathbf{r} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

$$\partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$

an. de campo total

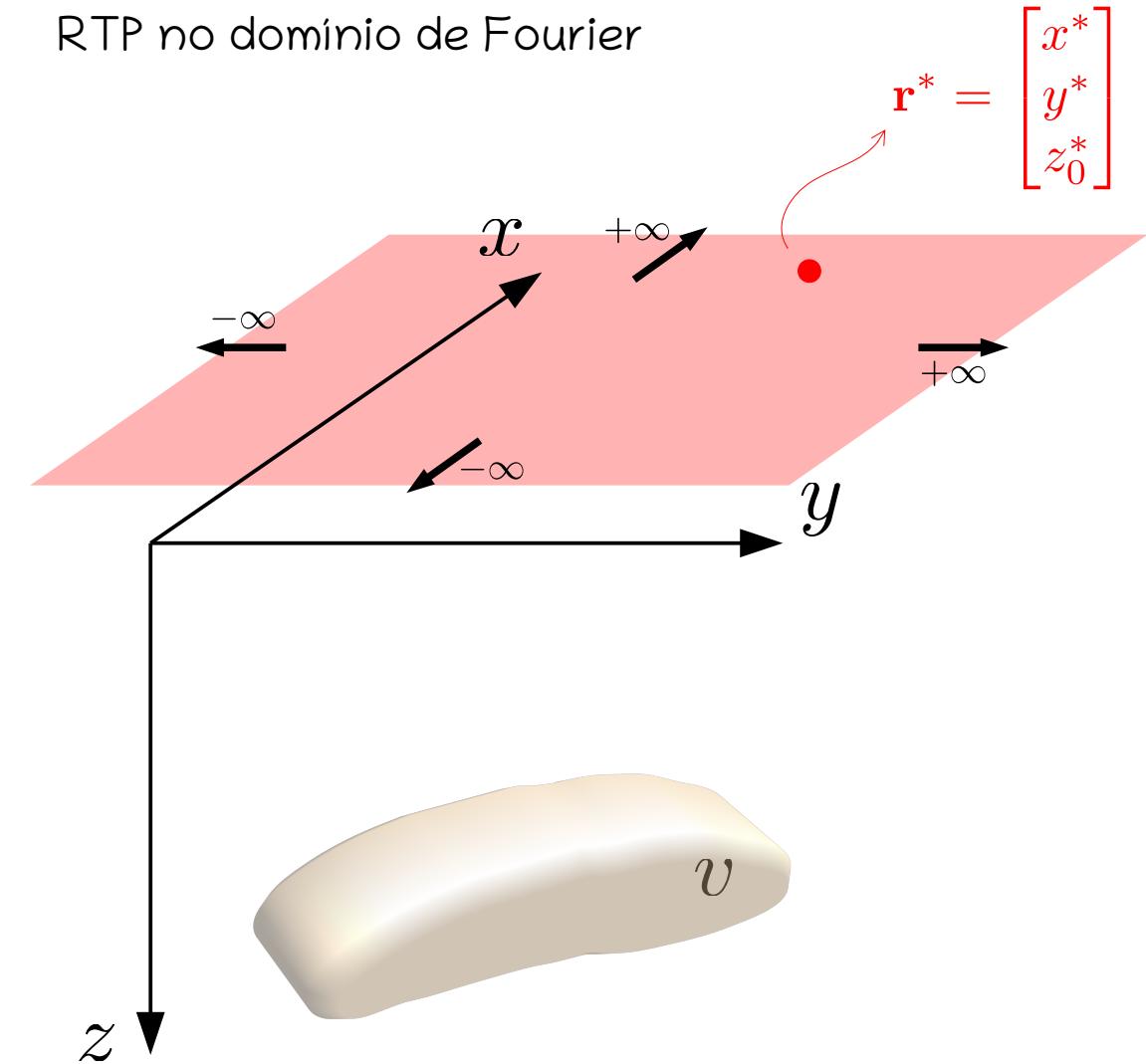
RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

RTP no domínio de Fourier



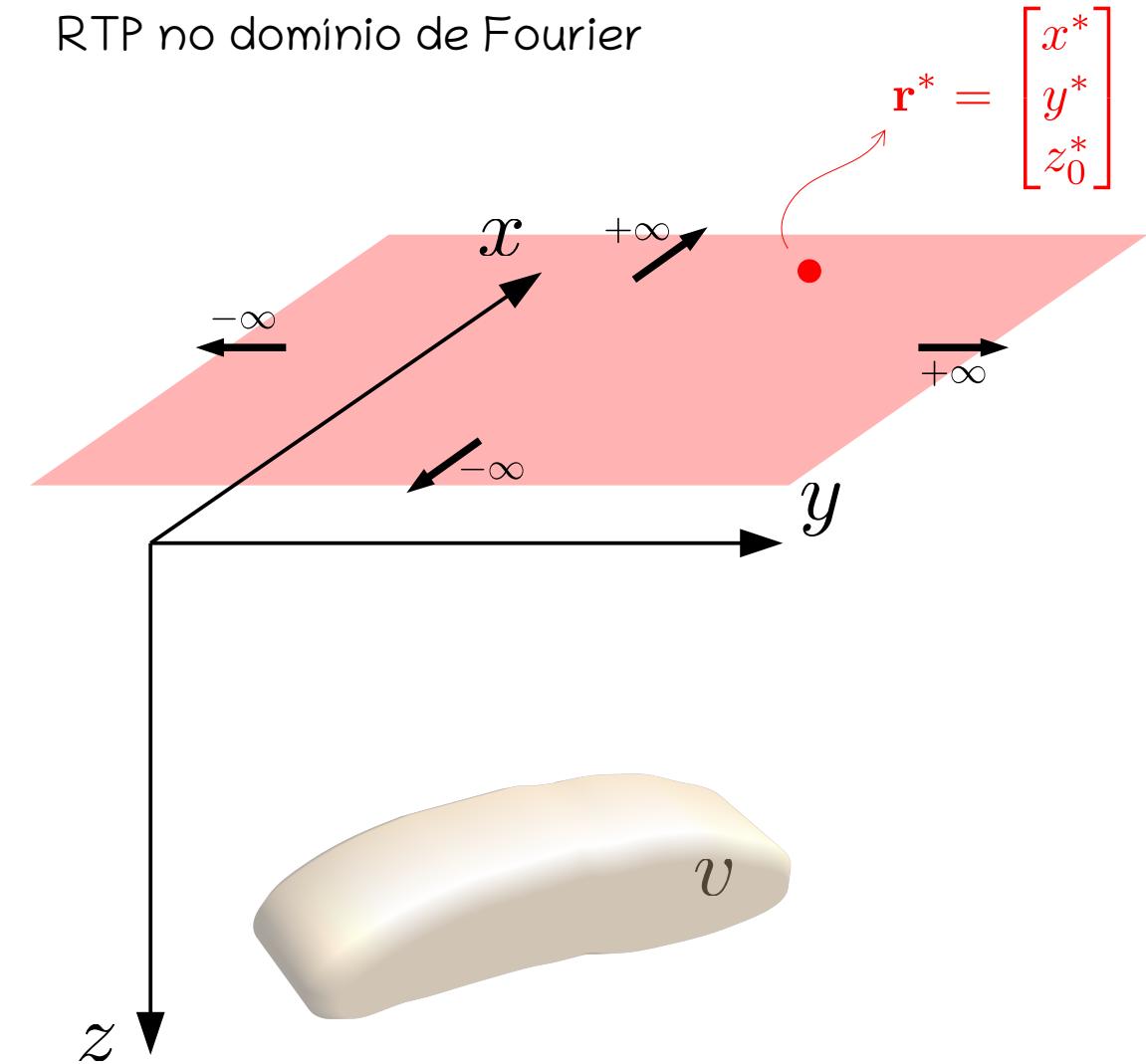
$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\curvearrowleft \mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

Transformada de Fourier 2D
sobre o plano horizontal $z = z_0^*$

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

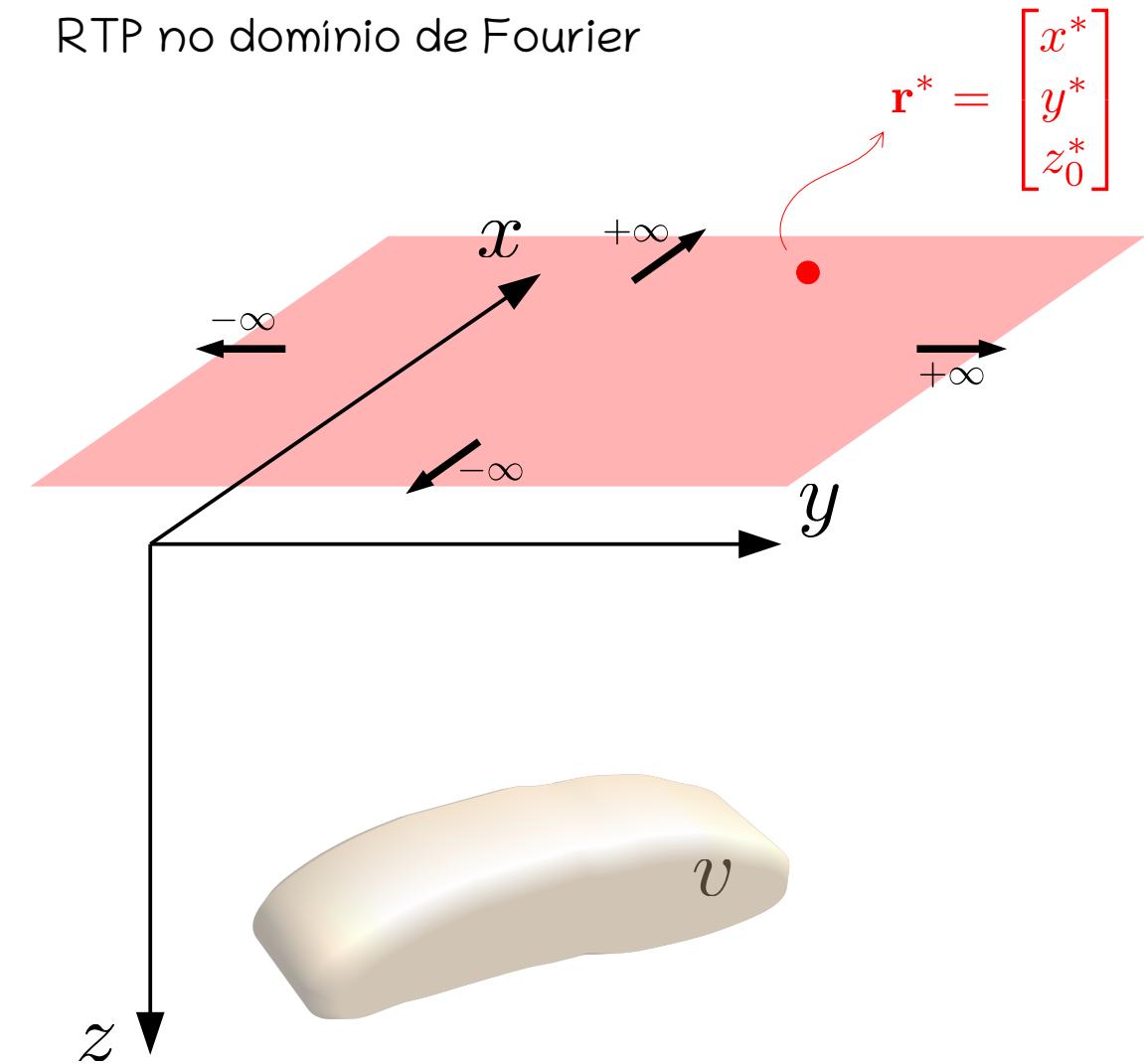
$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

$$\Theta_t = \hat{t}_z + i \frac{\hat{t}_x k_x + \hat{t}_y k_y}{|k|}$$

$$\Theta_h = \hat{h}_z + i \frac{\hat{h}_x k_x + \hat{h}_y k_y}{|k|}$$

funções complexas
definidas em termos
das direções do
campo principal e da
magnetização total

RTP no domínio de Fourier



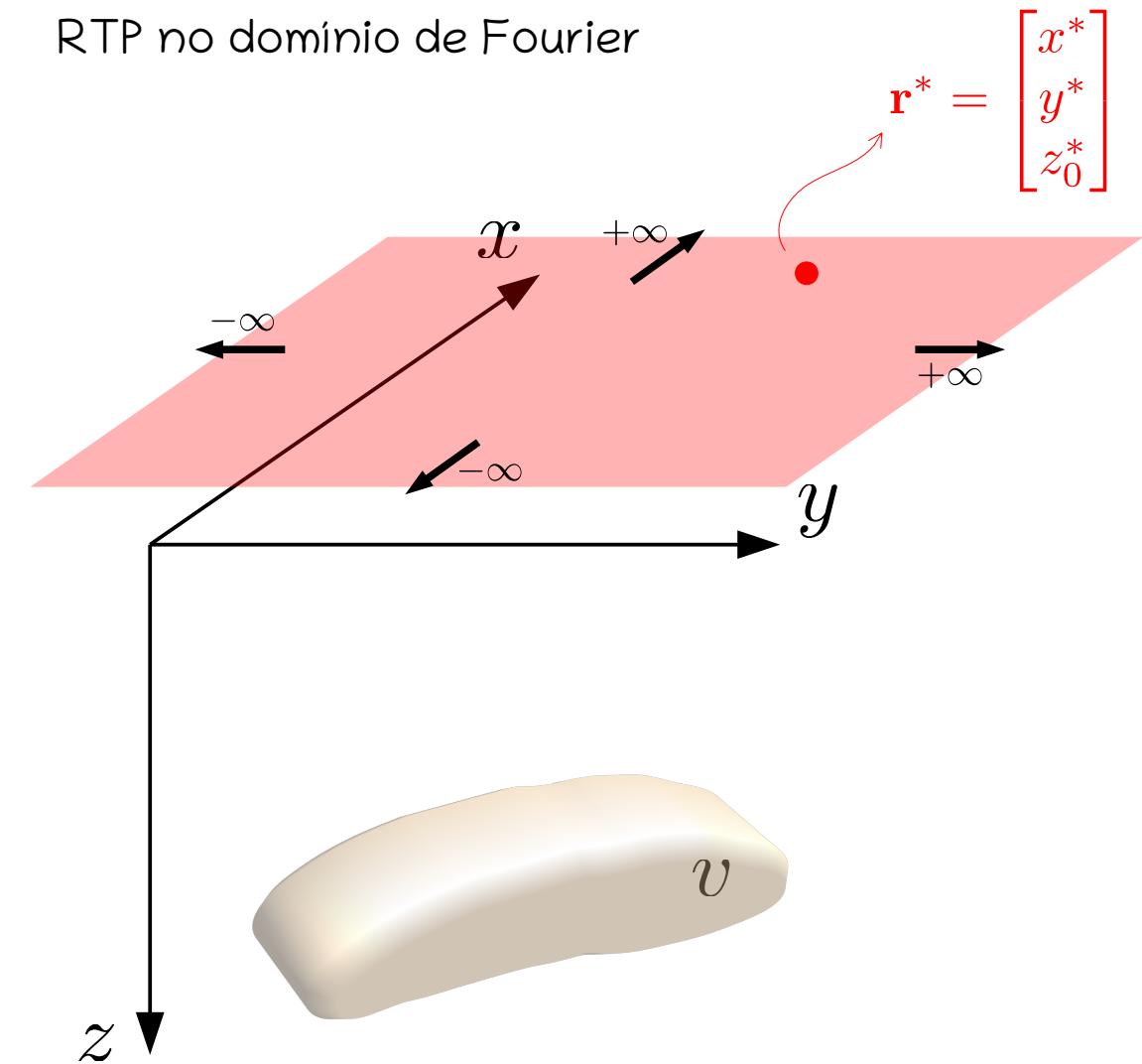
$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

Transformada de Fourier 2D da anomalia RTP

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

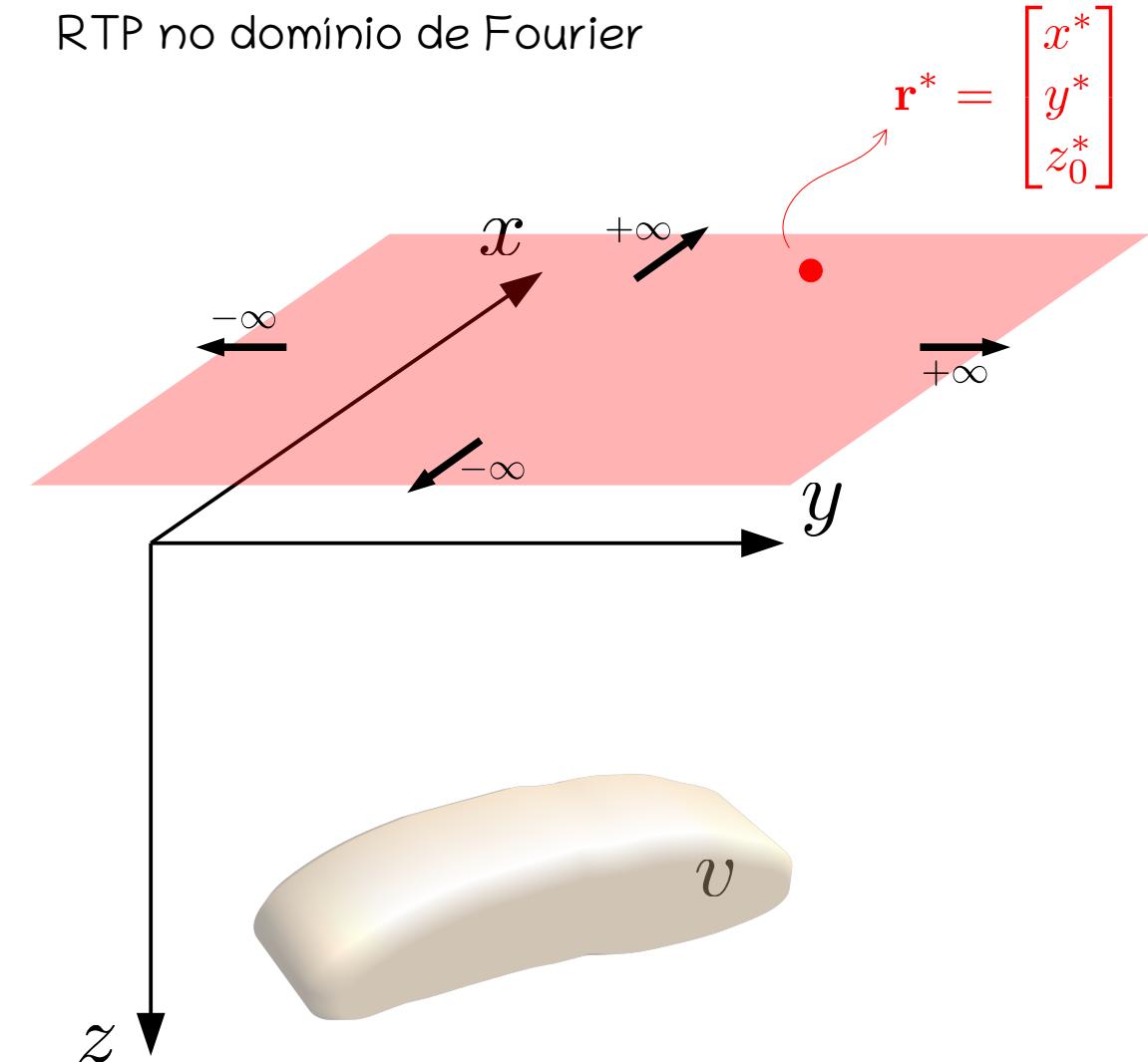
an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

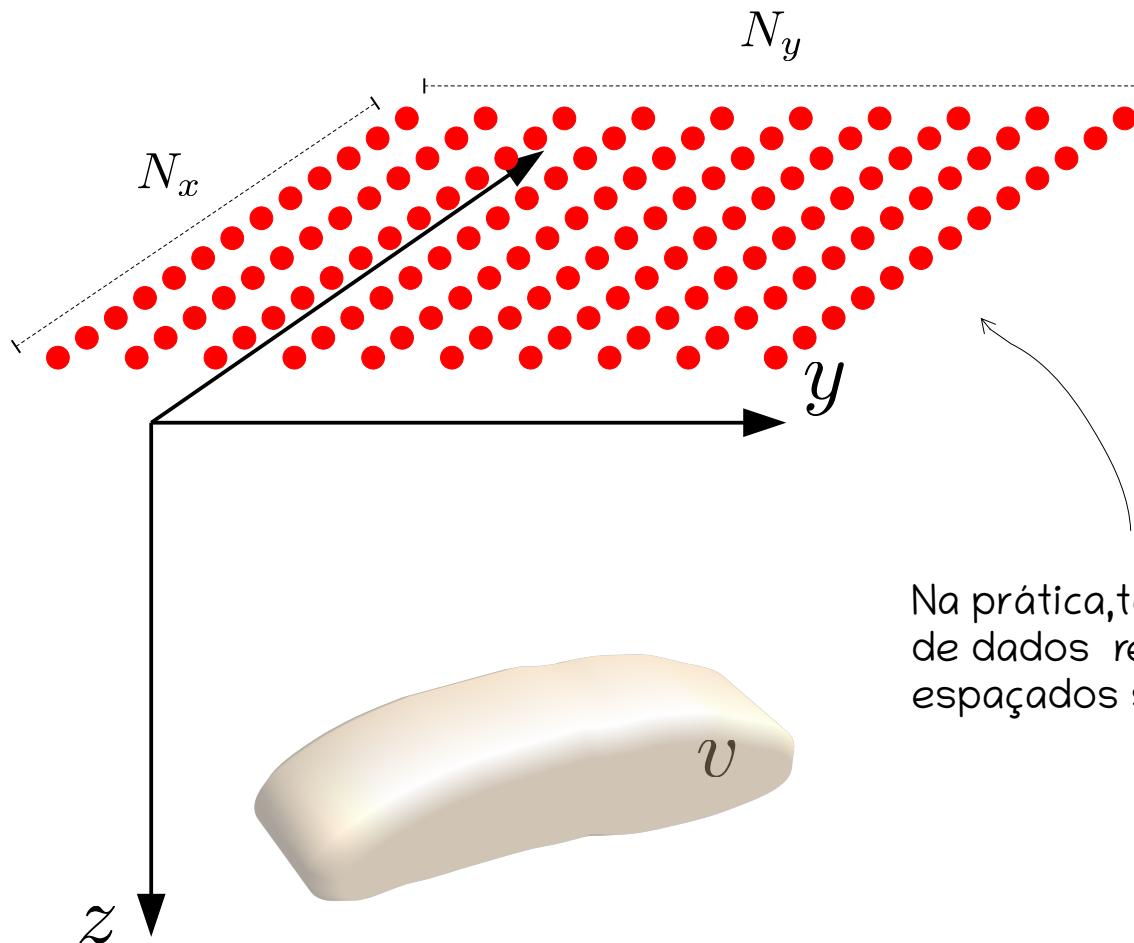
$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

Detalhes sobre a dedução destas equações podem ser encontrados em Gunn (1975) ou Blakely (1996, p. 331), por exemplo.

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

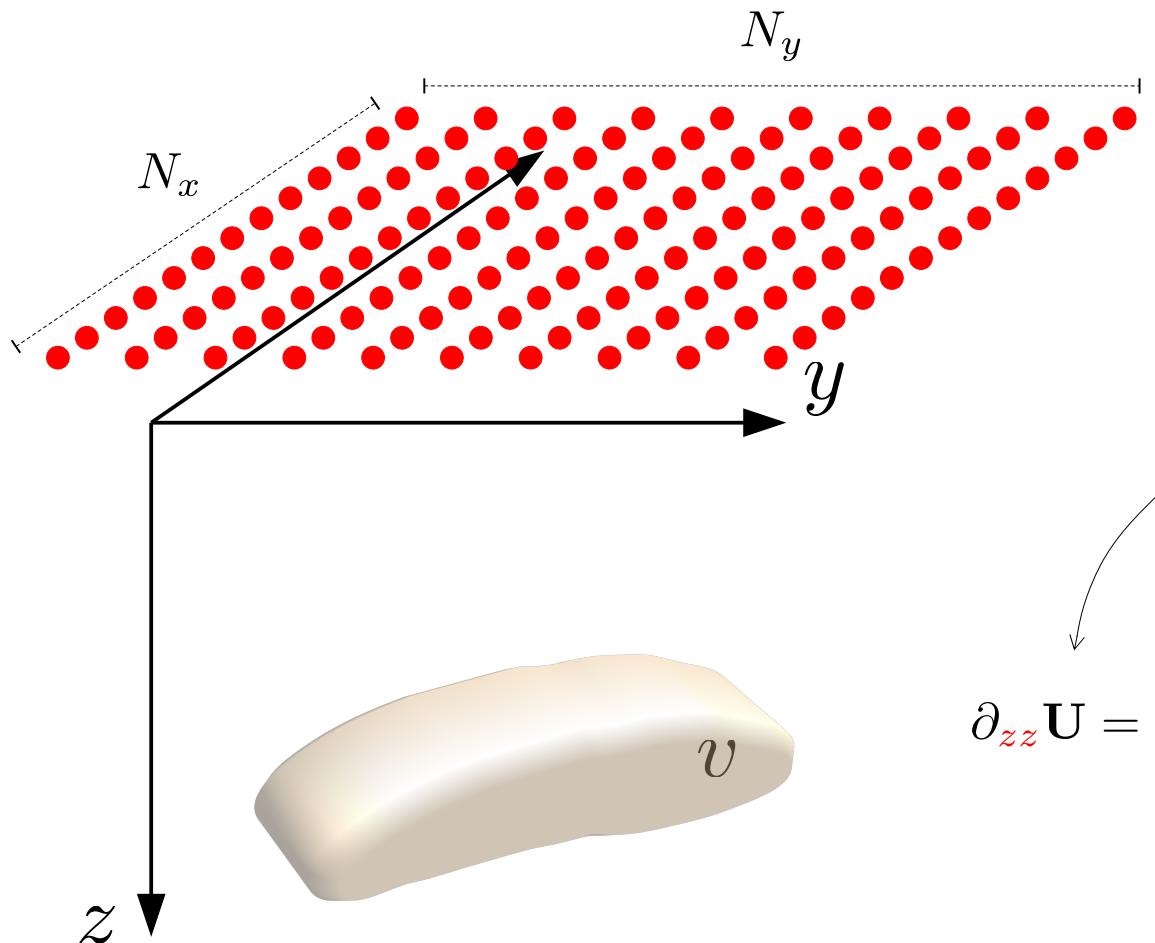
$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

Na prática, temos um grid
de dados regularmente
espaçados sobre o plano

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

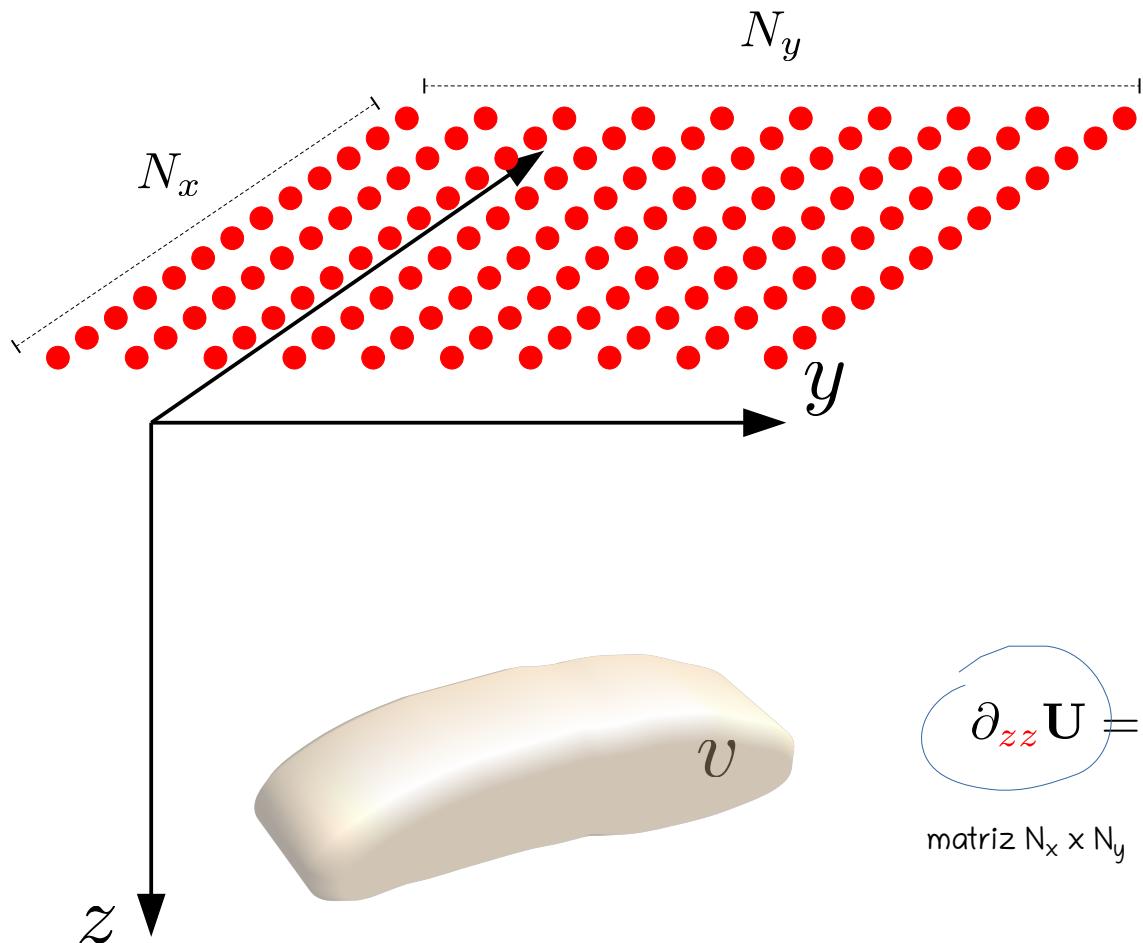
$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

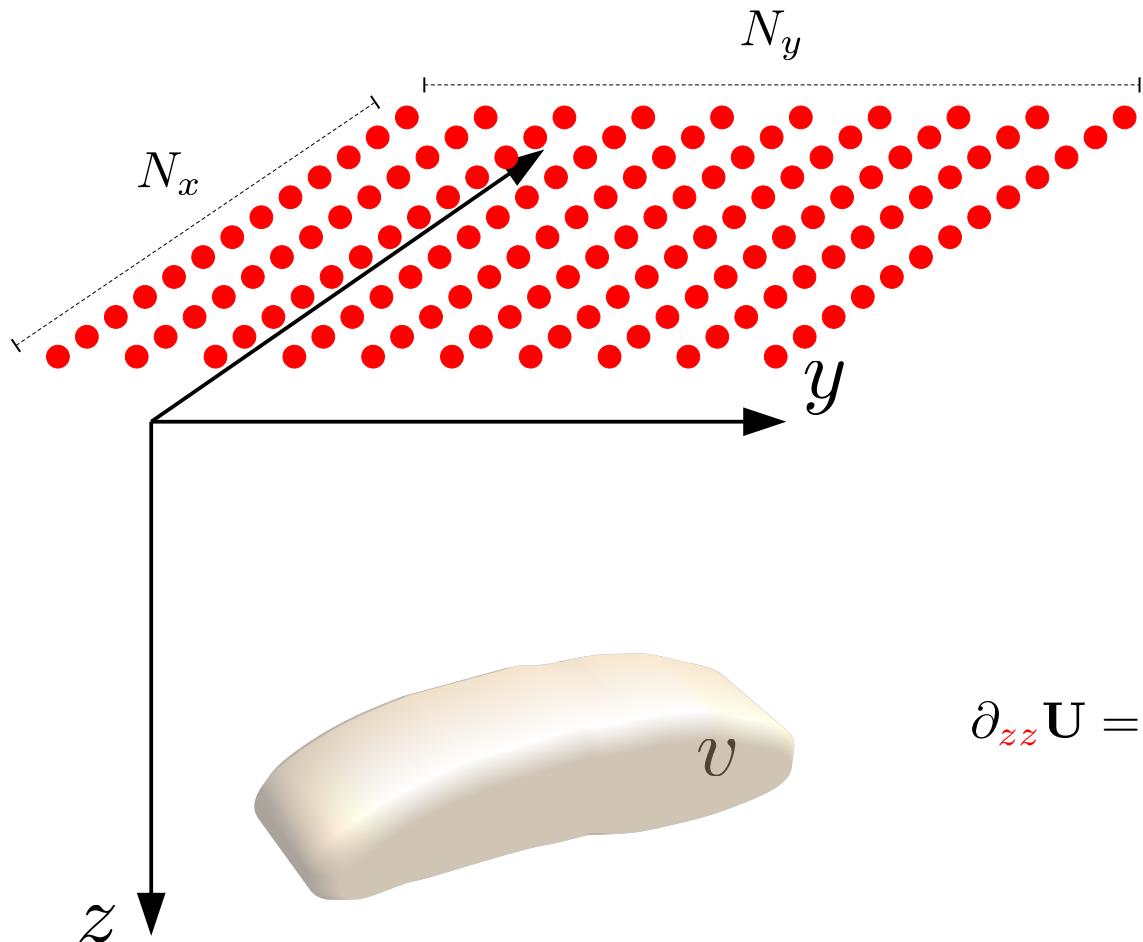
$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

matriz $N_x \times N_y$

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

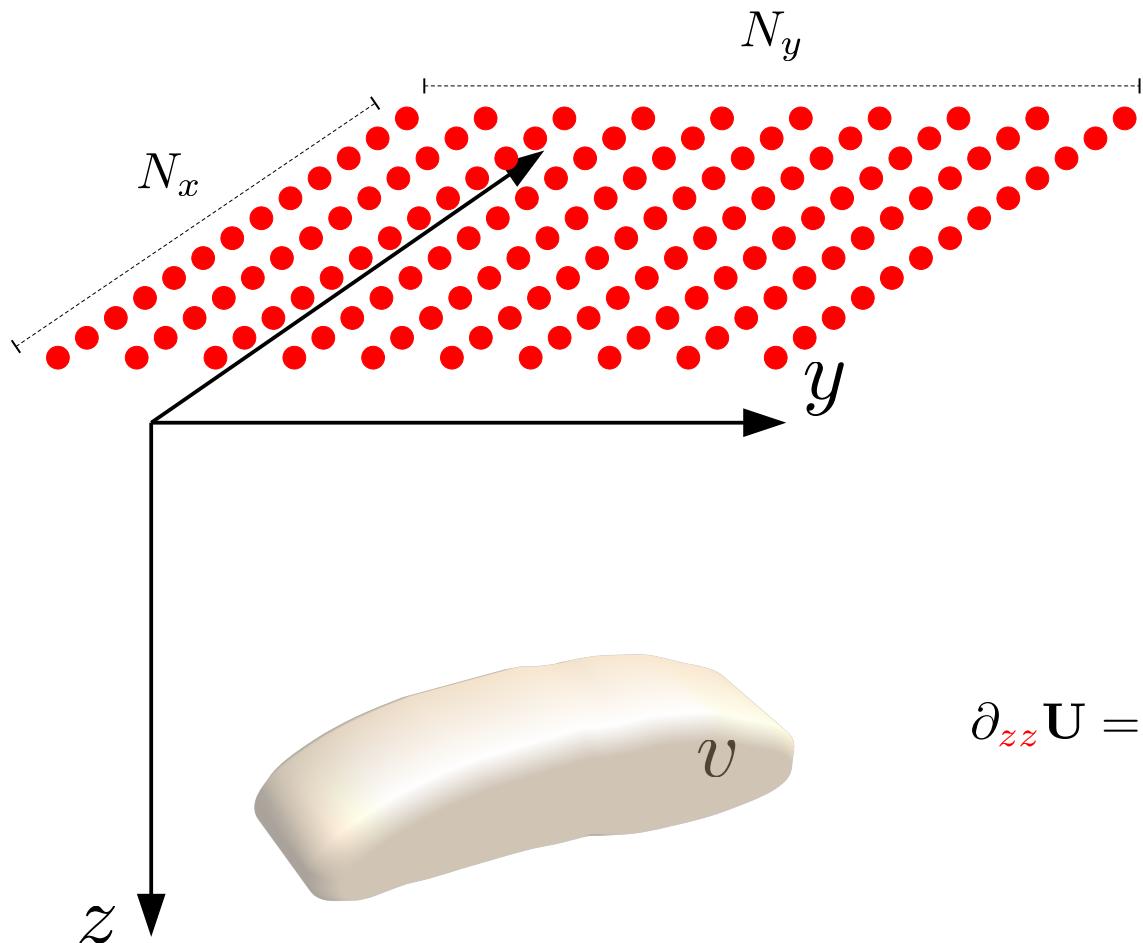
$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

matriz $N_x \times N_y$

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

Transformada de Fourier 2D

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

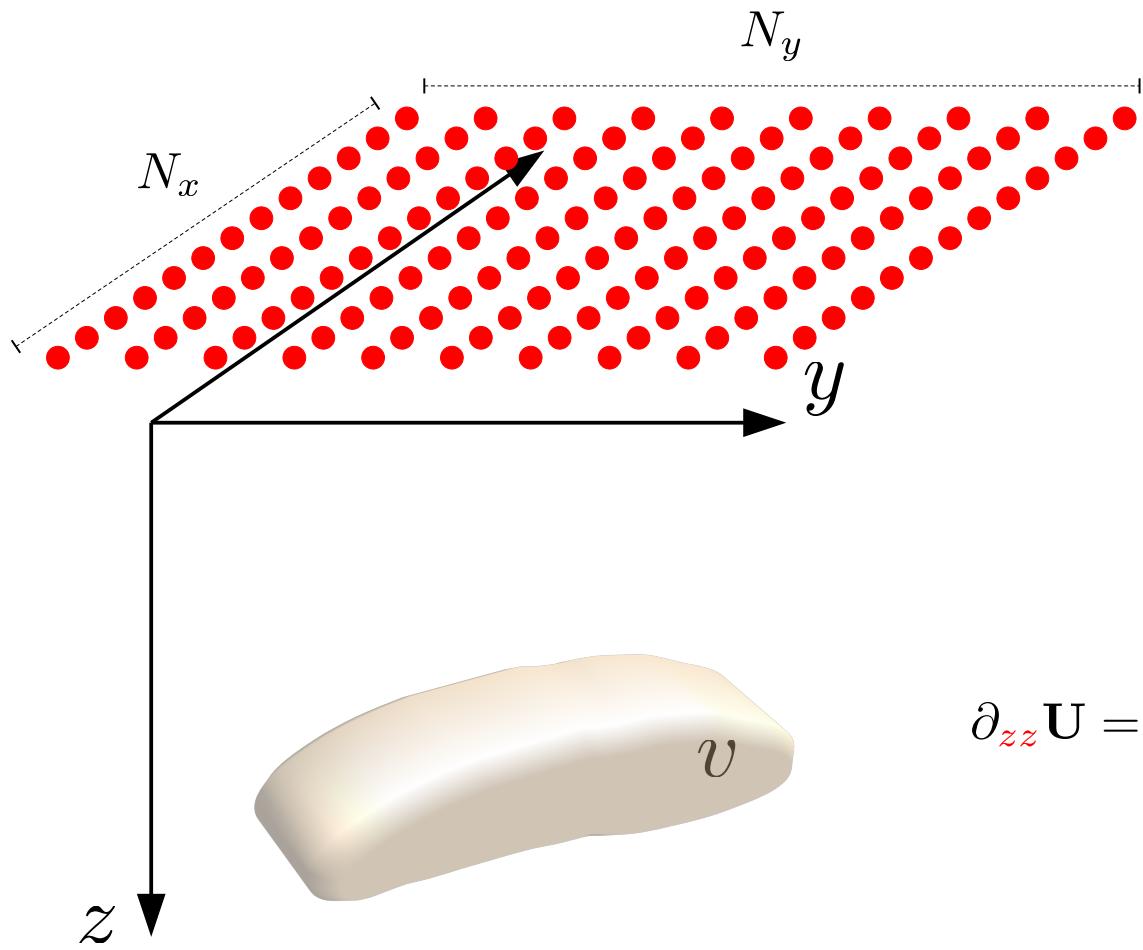
$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

matriz $N_x \times N_x$

matriz $N_y \times N_y$

Jain (1989, p. 146)

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

Transformada de Fourier 2D

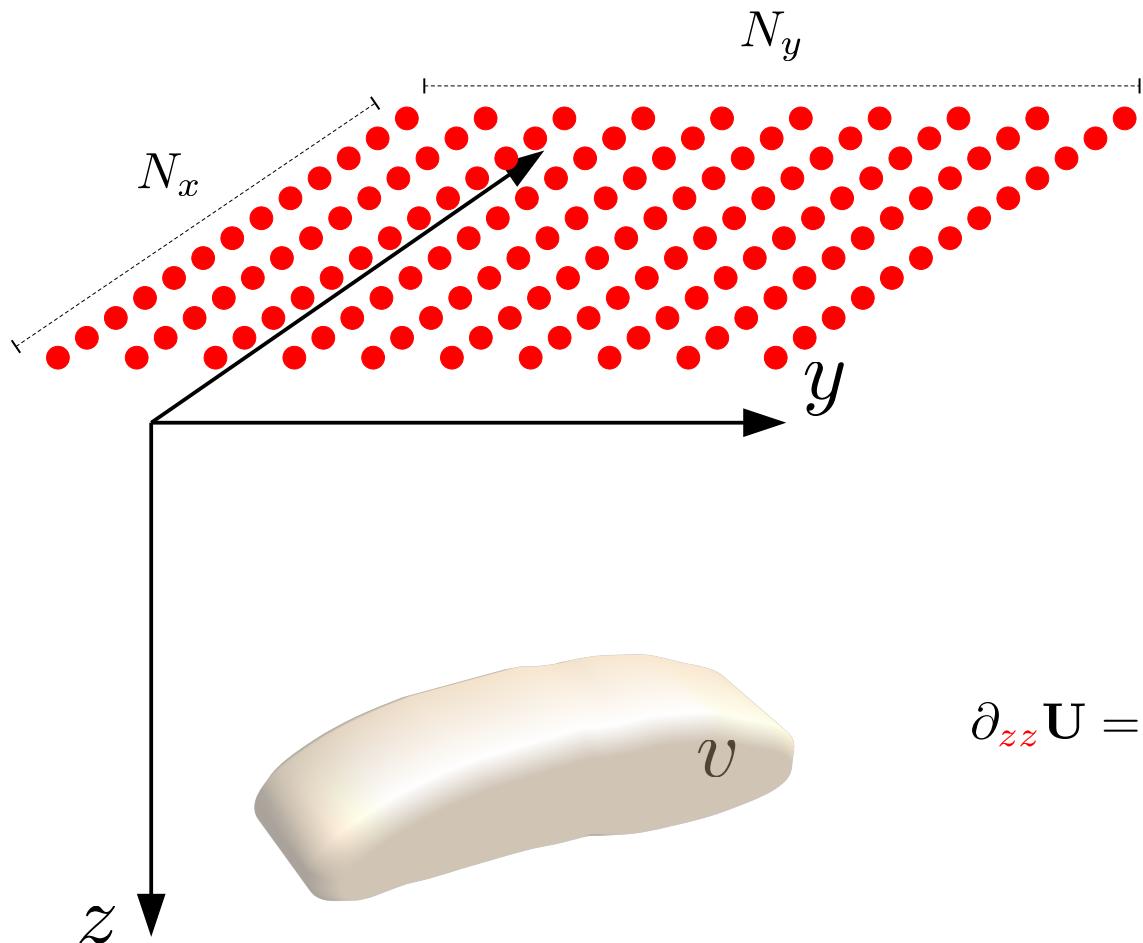
$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

FFT

$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

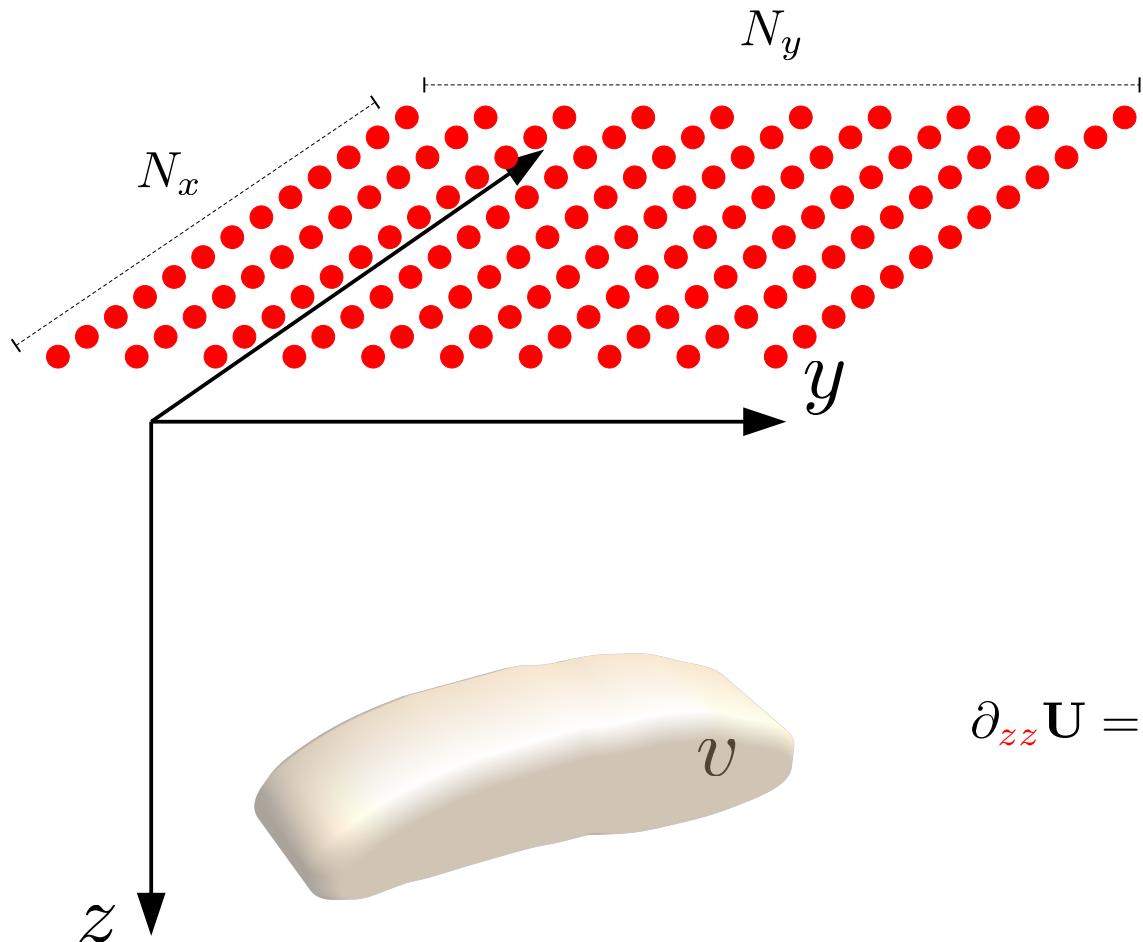
Filtro RTP

$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

$$(\Theta_t \circ \Theta_h)$$

produto elemento a elemento entre matrizes
 $N_x \times N_y$

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

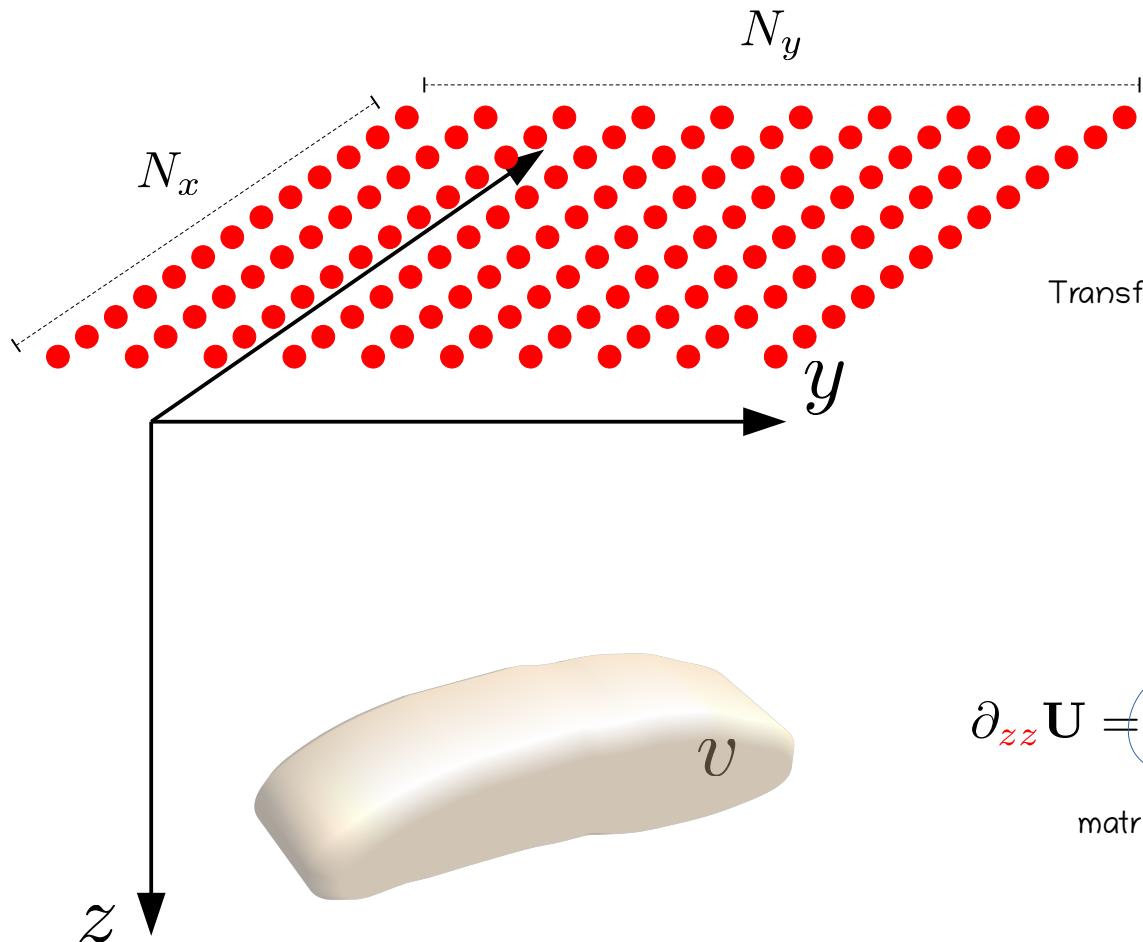
$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

divisão elemento a elemento entre matrizes
 $N_x \times N_y$

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

Transformada inversa de Fourier 2D

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

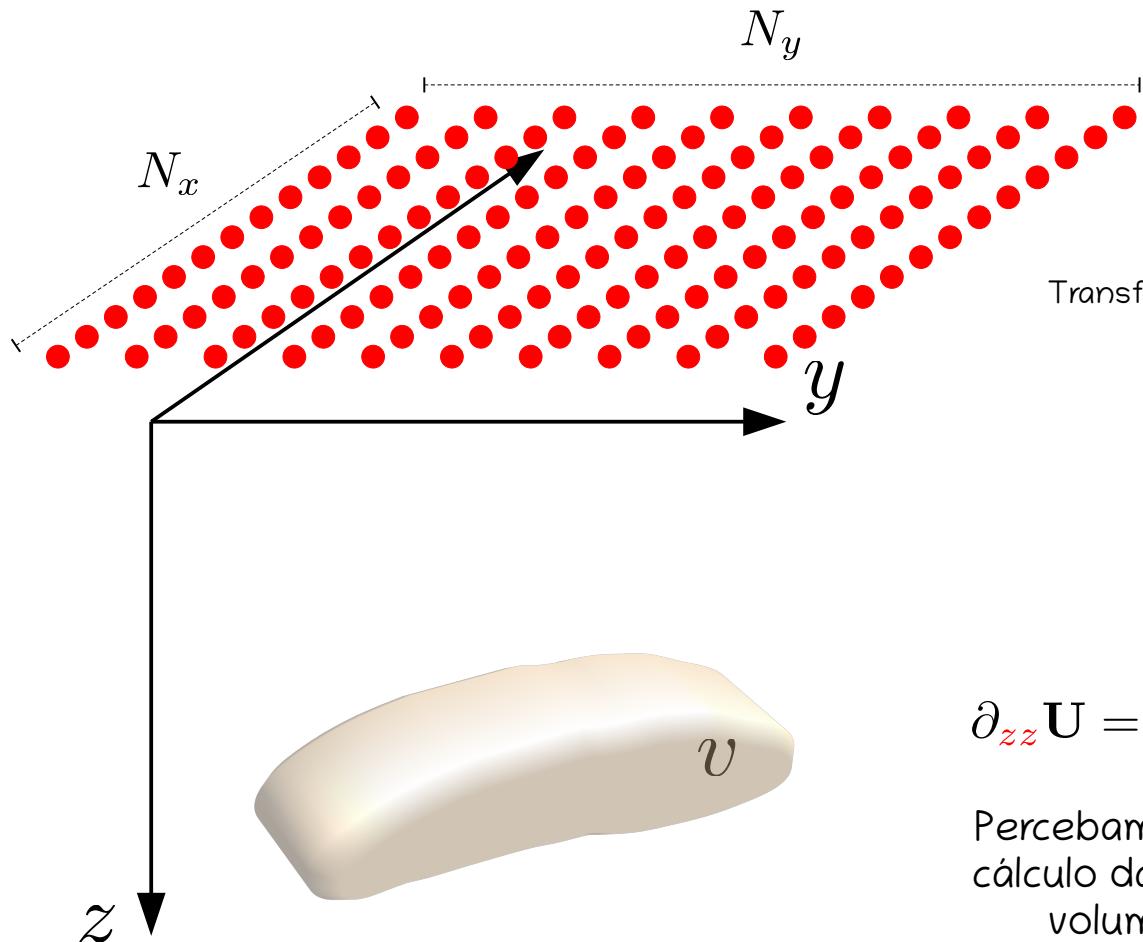
$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

matriz $N_x \times N_x$

matriz $N_y \times N_y$

Jain (1989, p. 147)

RTP no domínio de Fourier



$$\partial_{th} U(\mathbf{r}^*) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}^*) \hat{\mathbf{h}}$$

an. de campo total

$$\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\} = \Theta_t \Theta_h \mathcal{F}\{\partial_{zz} U(\mathbf{r}^*)\}$$

Transformada inversa de Fourier 2D

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

anomalia RTP

$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$

Percebiam que esta expressão é deduzida a partir do cálculo da Transformada de Fourier 2D da integral de volume que define a anomalia de campo total

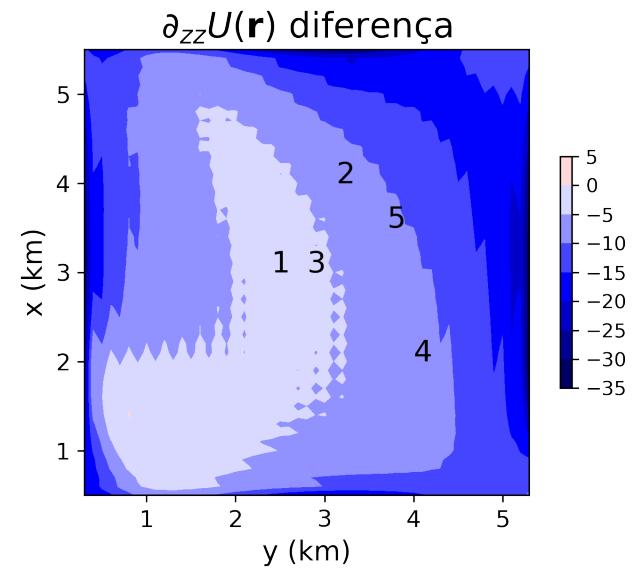
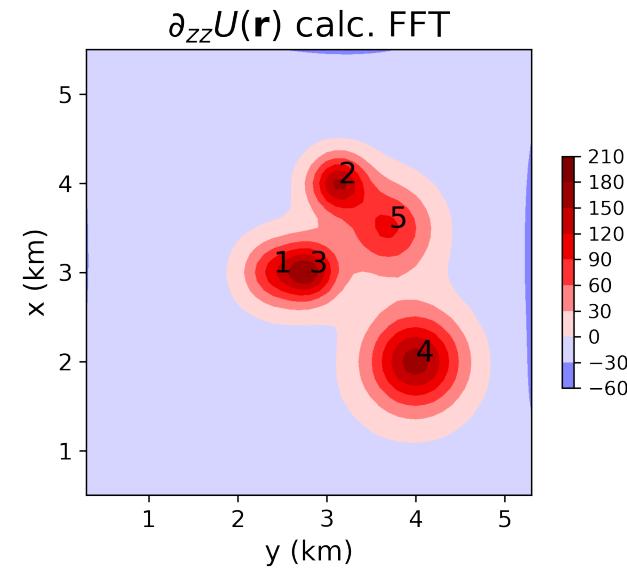
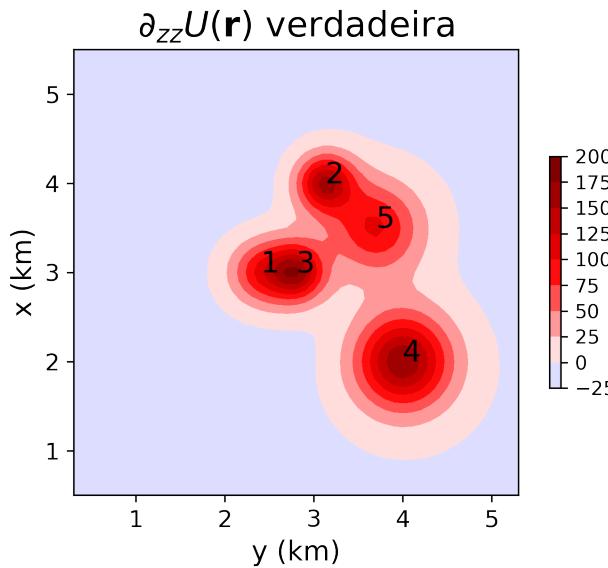
$$I_t = -25^\circ$$

$$I_h = -30^\circ$$

$$D_t = -30^\circ$$

$$D_h = -19^\circ$$

$$\partial_{\textcolor{red}{zz}} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\Theta_t \circ \Theta_h) \right\} \mathcal{F}_y^{-1}$$



Há duas abordagens para o cálculo da RTP

Domínio do espaço

Domínio de Fourier

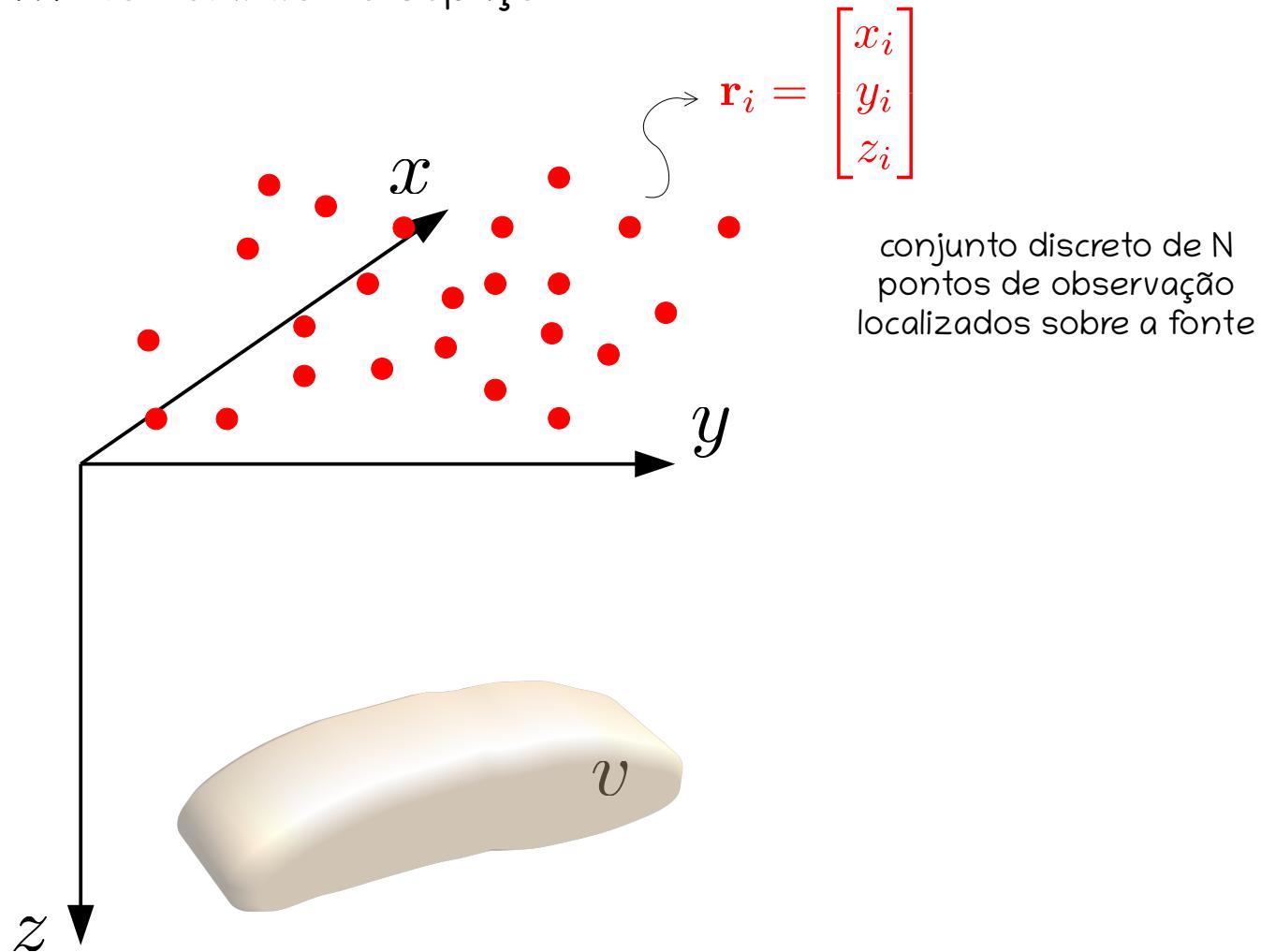
Há duas abordagens para o cálculo da RTP

Domínio do espaço

Domínio de Fourier

RTP no domínio do espaço

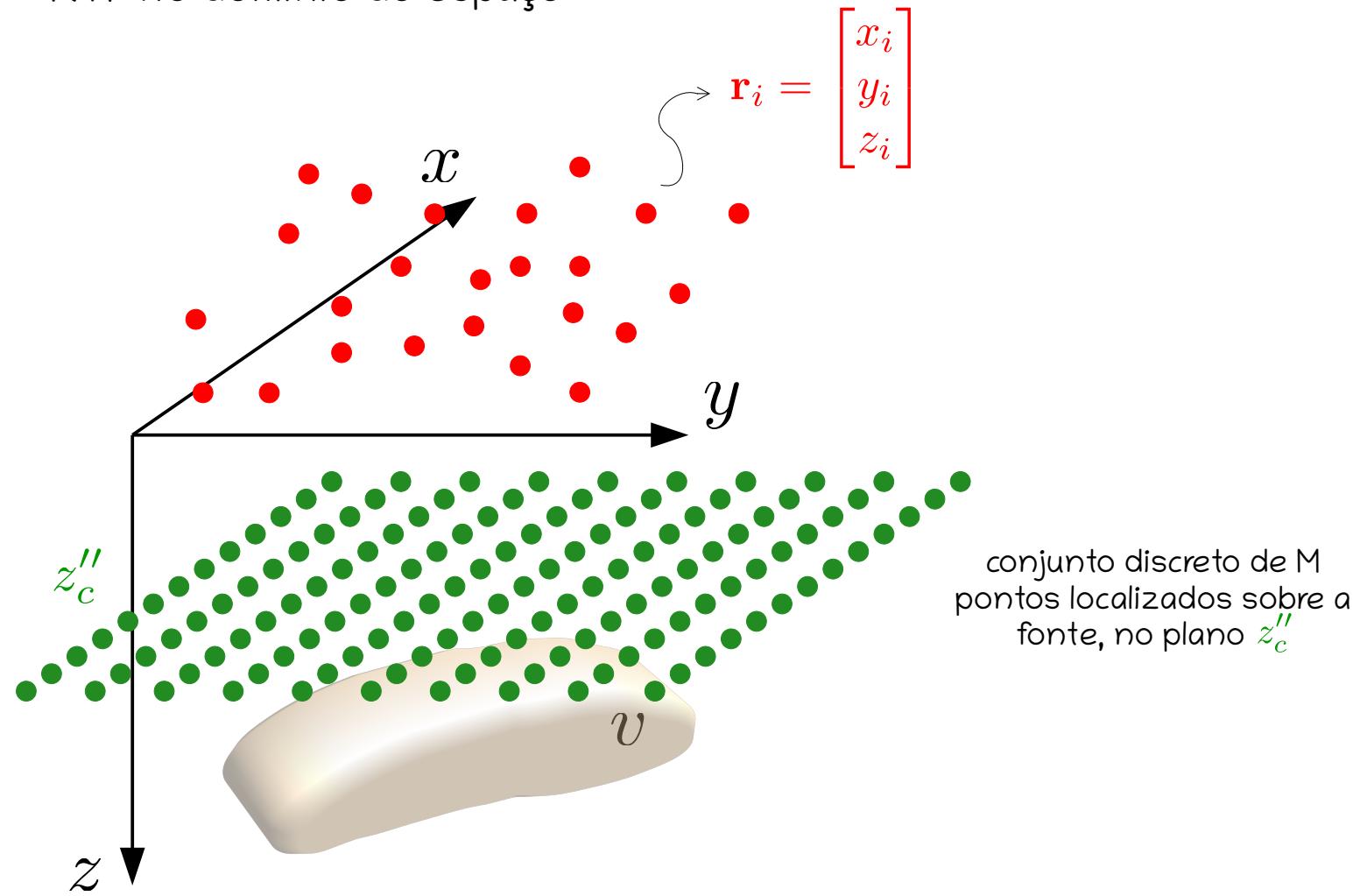
RTP no domínio do espaço



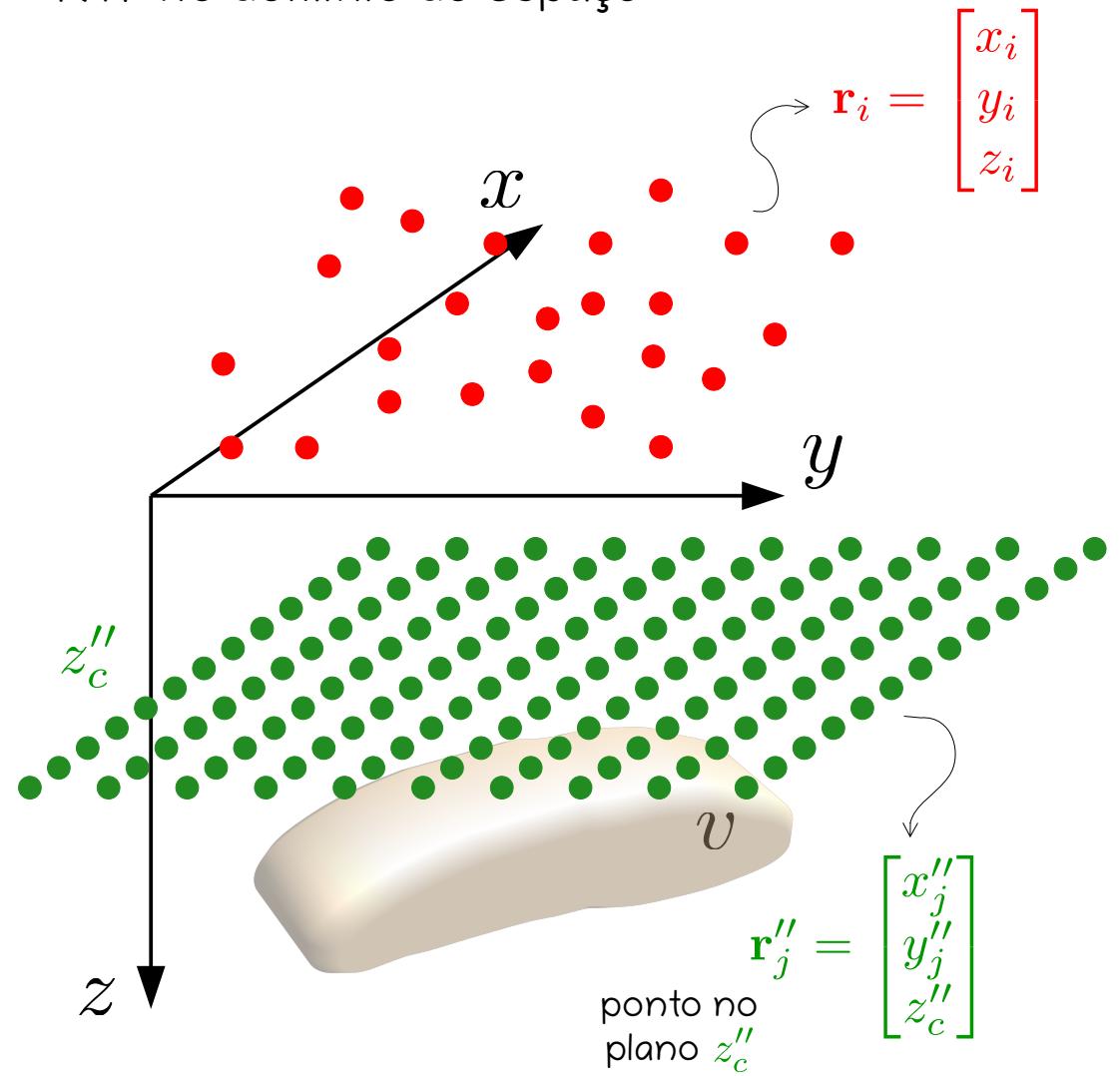
$$\mathbf{r}_i = \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}$$

conjunto discreto de N
pontos de observação
localizados sobre a fonte

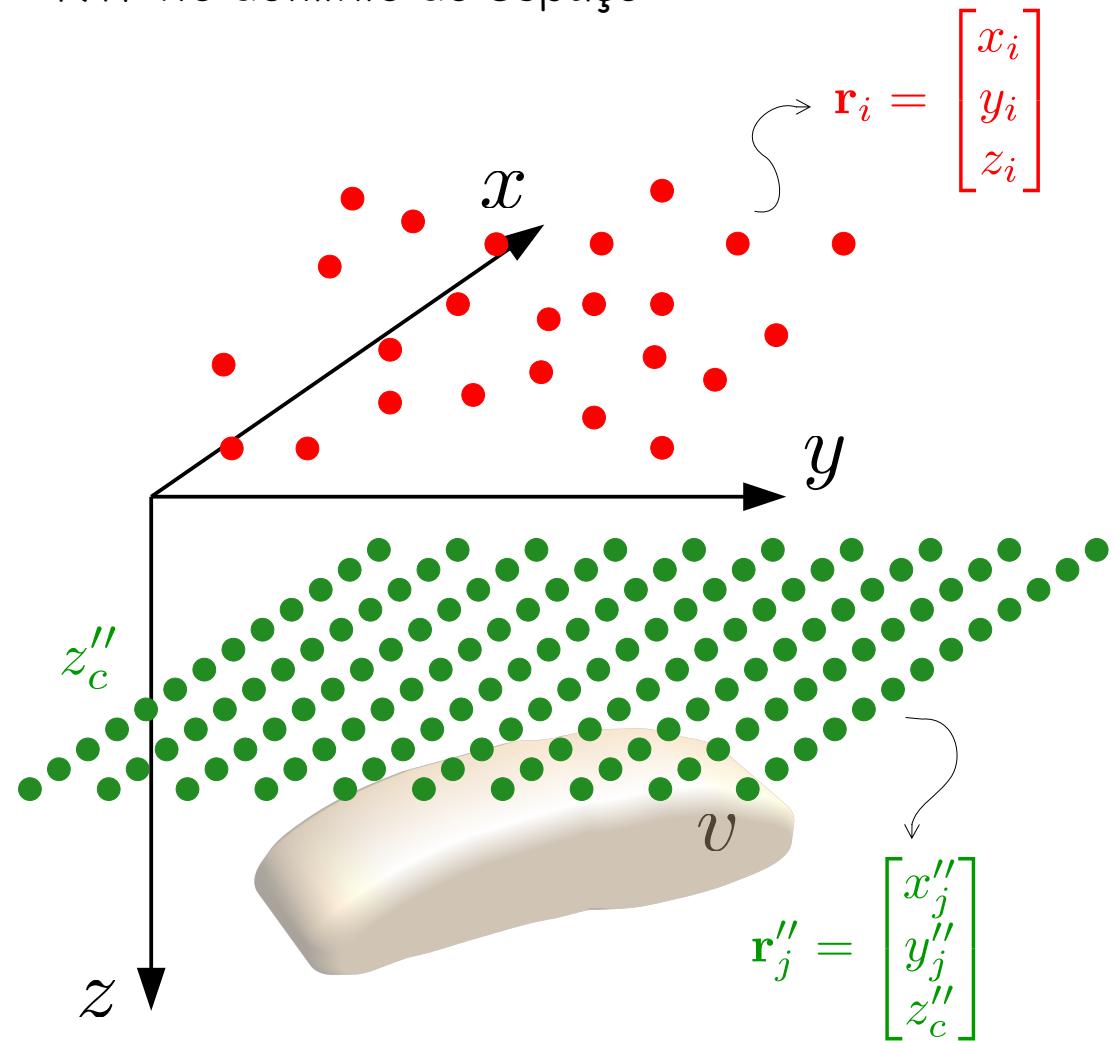
RTP no domínio do espaço



RTP no domínio do espaço

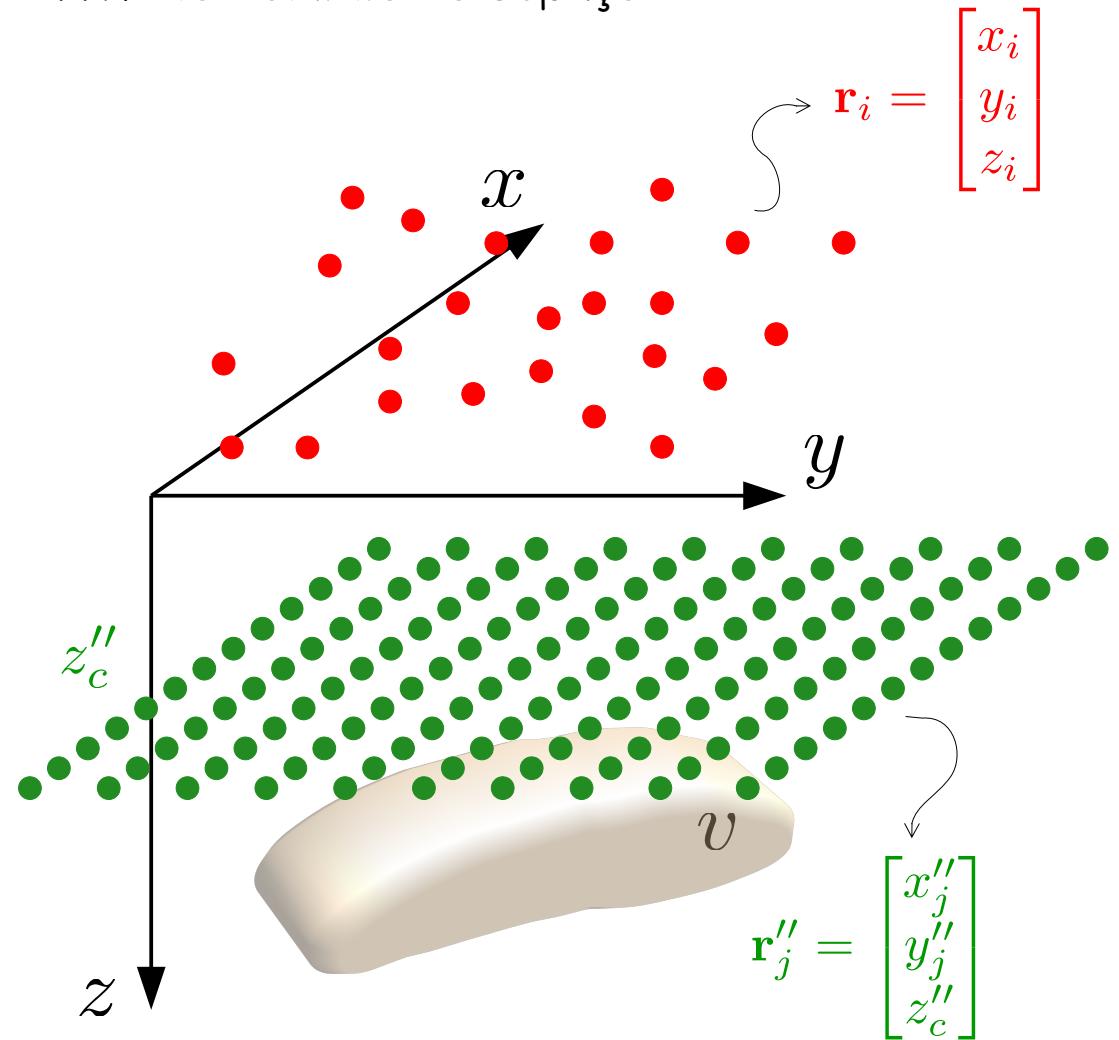


RTP no domínio do espaço



$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}''_j)$$

RTP no domínio do espaço

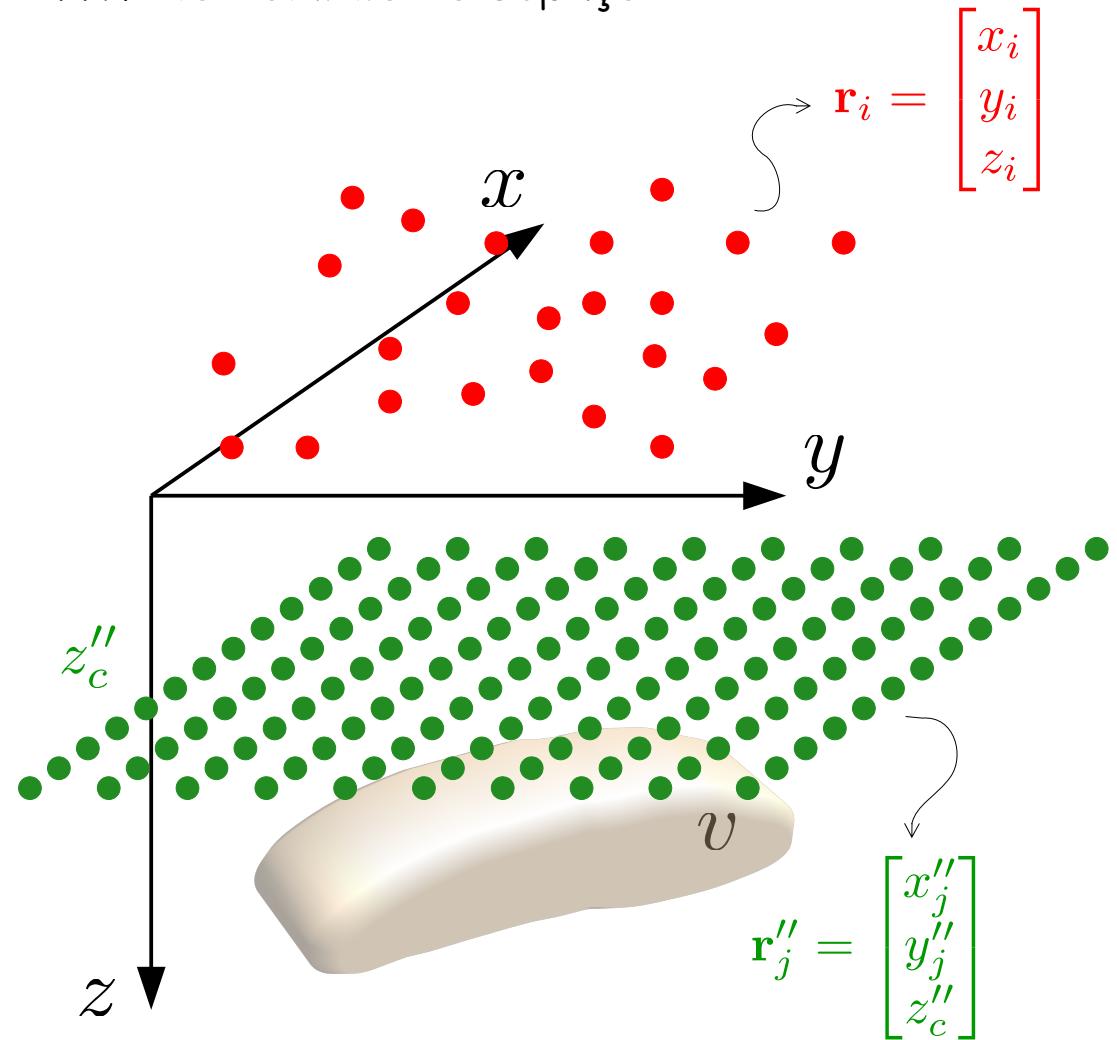


$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

$$\Psi(\mathbf{r}_i, \mathbf{r}_j'') = \frac{1}{2\pi} \frac{1}{\|\mathbf{r}_i - \mathbf{r}_j''\|}$$

$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'') = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}_j'') \hat{\mathbf{h}}$$

RTP no domínio do espaço



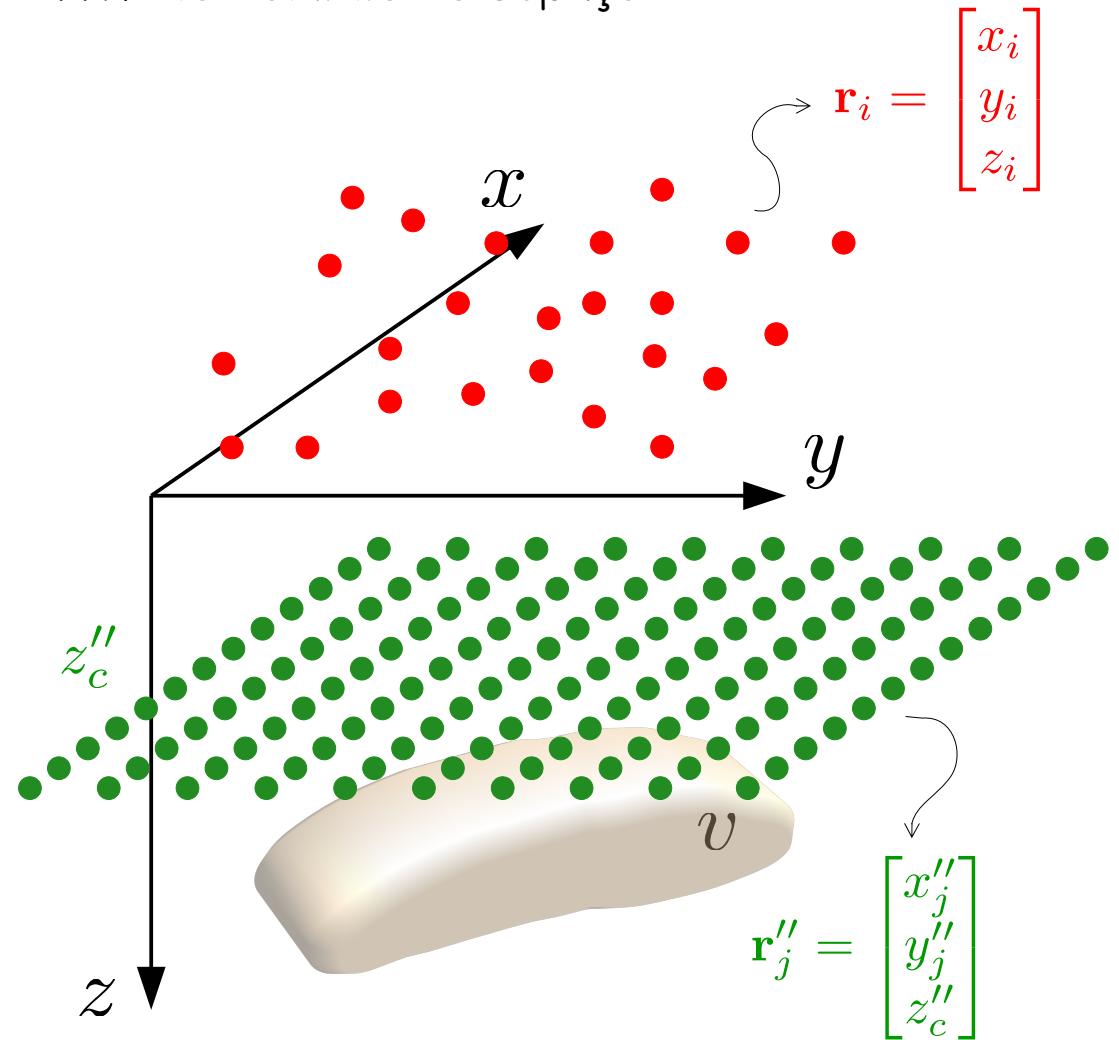
$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

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$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'') = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}_j'') \hat{\mathbf{h}}$$

vetor unitário constante que define a direção do campo principal

RTP no domínio do espaço



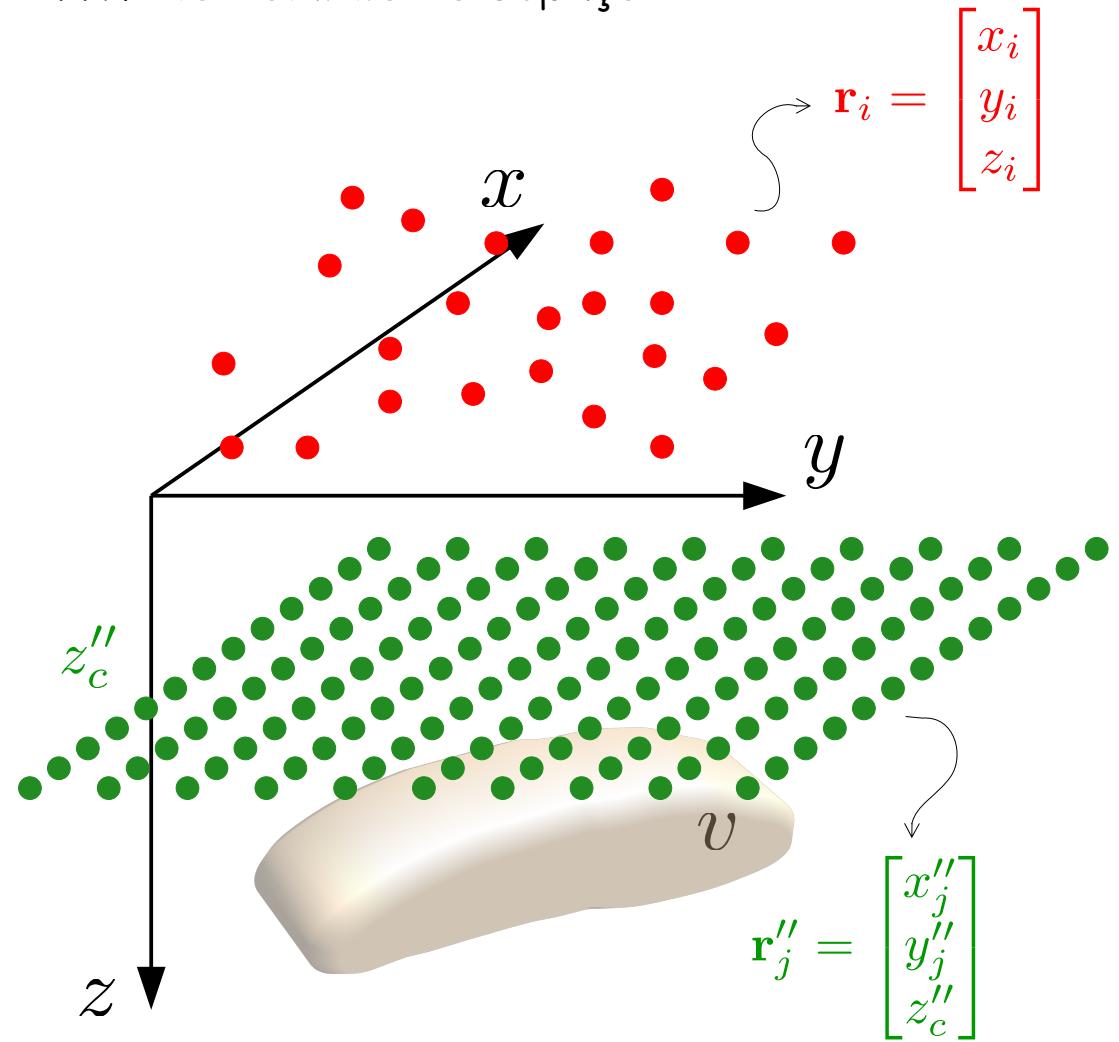
$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

$$\Psi(\mathbf{r}_i, \mathbf{r}_j'') = \frac{1}{2\pi} \frac{1}{\|\mathbf{r}_i - \mathbf{r}_j''\|}$$

$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'') = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}_j'') \hat{\mathbf{h}}$$

vetor unitário constante que define a direção da magnetização total

RTP no domínio do espaço



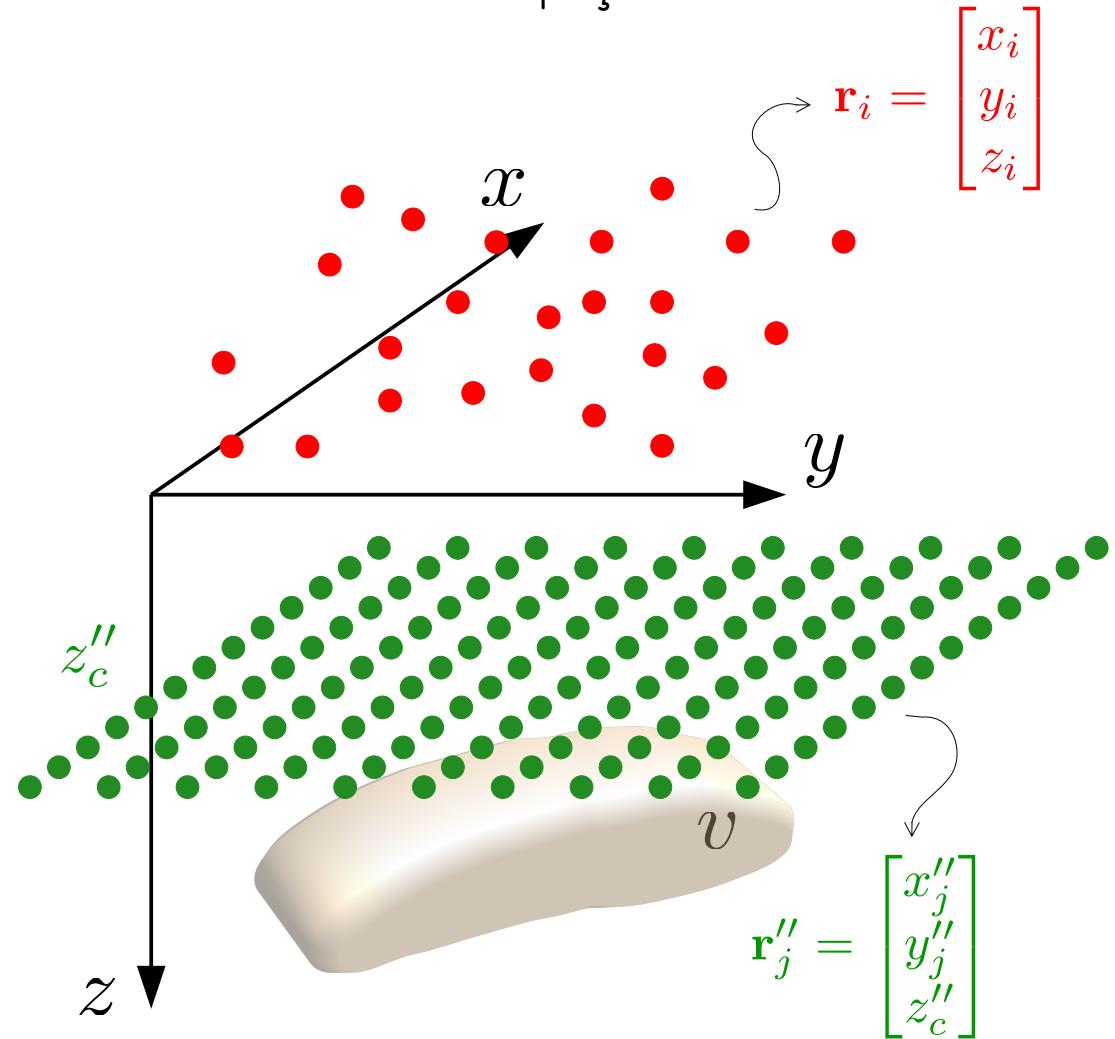
$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

$$\Psi(\mathbf{r}_i, \mathbf{r}_j'') = \frac{1}{2\pi} \frac{1}{\|\mathbf{r}_i - \mathbf{r}_j''\|}$$

$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'') = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}_j'') \hat{\mathbf{h}}$$

$$\mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') = \begin{bmatrix} \partial_{xx} \Psi(\mathbf{r}, \mathbf{r}'') & \partial_{xy} \Psi(\mathbf{r}, \mathbf{r}'') & \partial_{xz} \Psi(\mathbf{r}, \mathbf{r}'') \\ \partial_{xy} \Psi(\mathbf{r}, \mathbf{r}'') & \partial_{yy} \Psi(\mathbf{r}, \mathbf{r}'') & \partial_{yz} \Psi(\mathbf{r}, \mathbf{r}'') \\ \partial_{xz} \Psi(\mathbf{r}, \mathbf{r}'') & \partial_{yz} \Psi(\mathbf{r}, \mathbf{r}'') & \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') \end{bmatrix}$$

RTP no domínio do espaço



$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

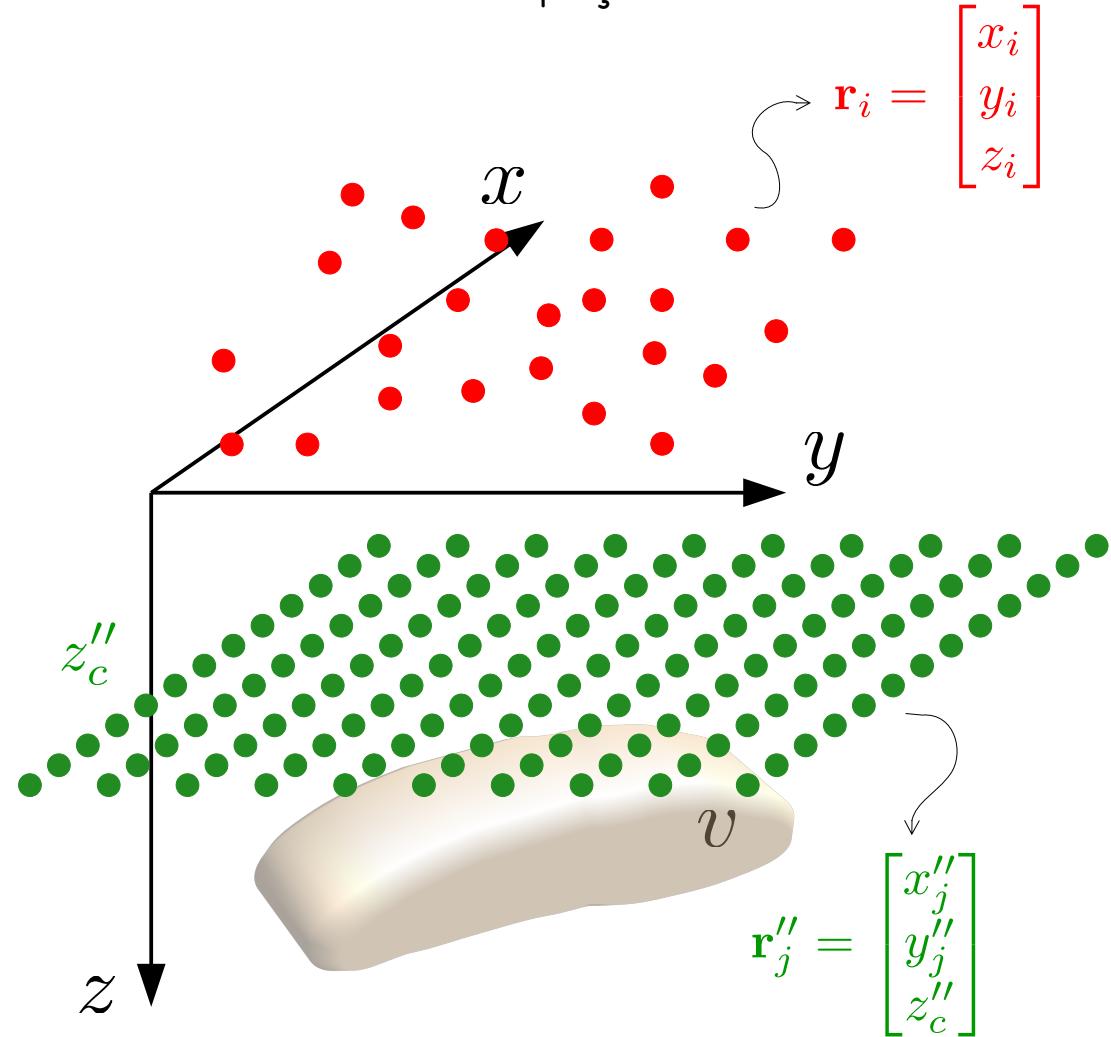
$$\Psi(\mathbf{r}_i, \mathbf{r}_j'') = \frac{1}{2\pi} \frac{1}{\|\mathbf{r}_i - \mathbf{r}_j''\|}$$

$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'') = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}_j'') \hat{\mathbf{h}}$$

$$p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

representa a an. de campo total
aprox. produzida no ponto de
observação \mathbf{r}_i por um dipolo
localizado em \mathbf{r}_j''

RTP no domínio do espaço



$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}''_j)$$

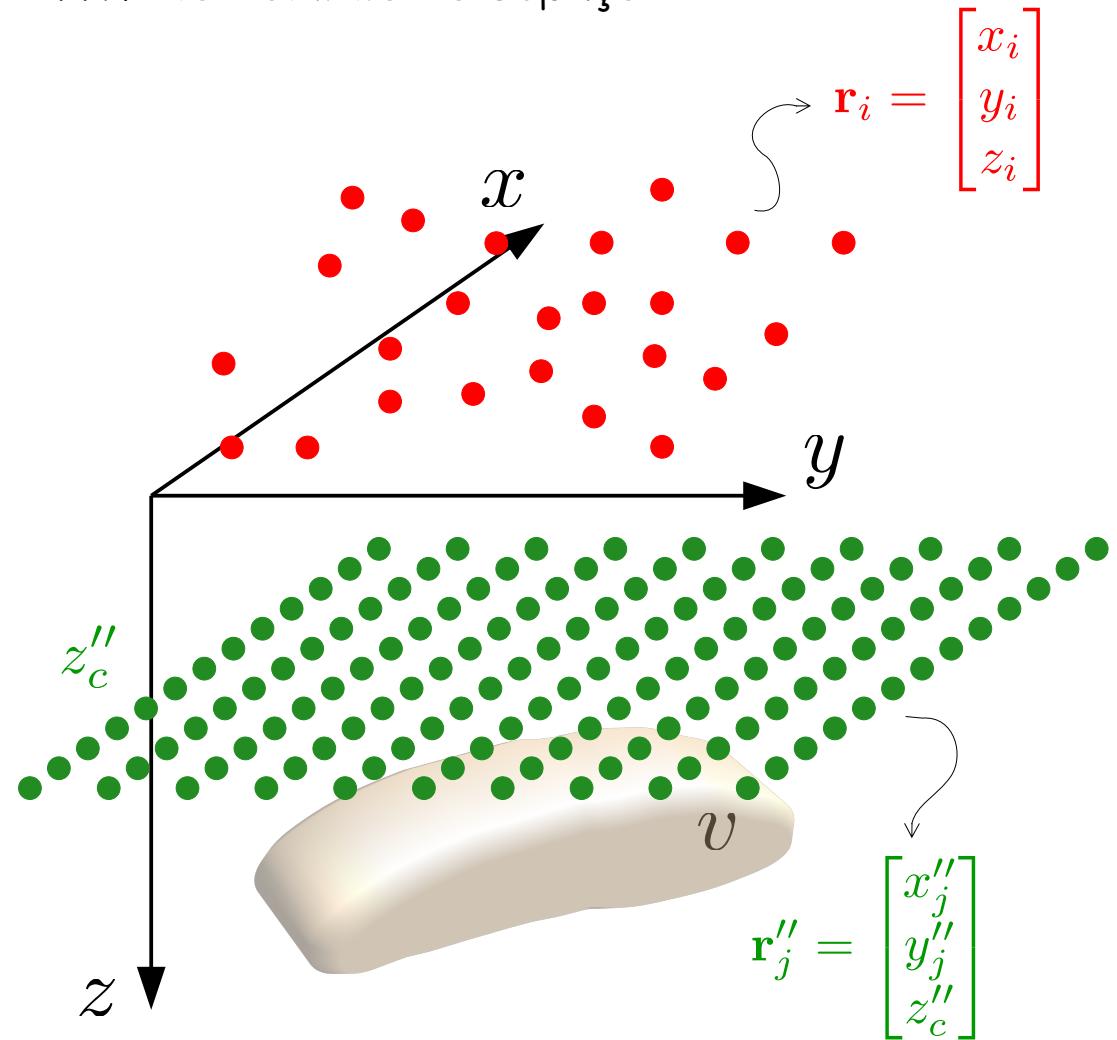
$$\Psi(\mathbf{r}_i, \mathbf{r}''_j) = \frac{1}{2\pi} \frac{1}{\|\mathbf{r}_i - \mathbf{r}''_j\|}$$

$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}''_j) = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}''_j) \hat{\mathbf{h}}$$

$$\mathbf{d} \approx \mathbf{A} \mathbf{p}$$

Resolver este sistema
para o vetor \mathbf{p}

RTP no domínio do espaço



$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

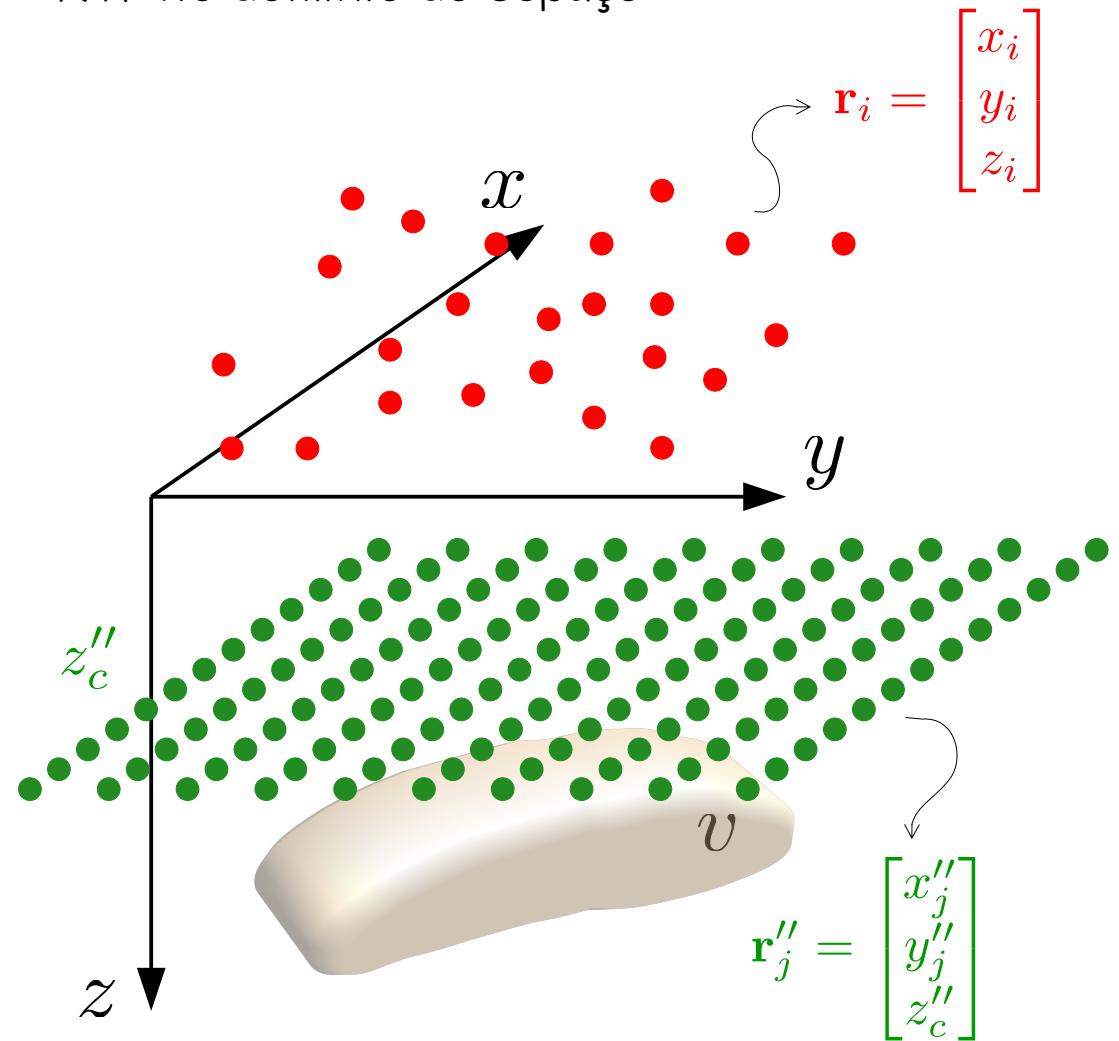
$$\Psi(\mathbf{r}_i, \mathbf{r}_j'') = \frac{1}{2\pi} \frac{1}{\|\mathbf{r}_i - \mathbf{r}_j''\|}$$

$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'') = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}_j'') \hat{\mathbf{h}}$$

$$\mathbf{d} \approx \mathbf{A} \mathbf{p}$$

$$\mathbf{p} = \begin{bmatrix} p_1 \\ \vdots \\ p_M \end{bmatrix}$$

RTP no domínio do espaço



$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

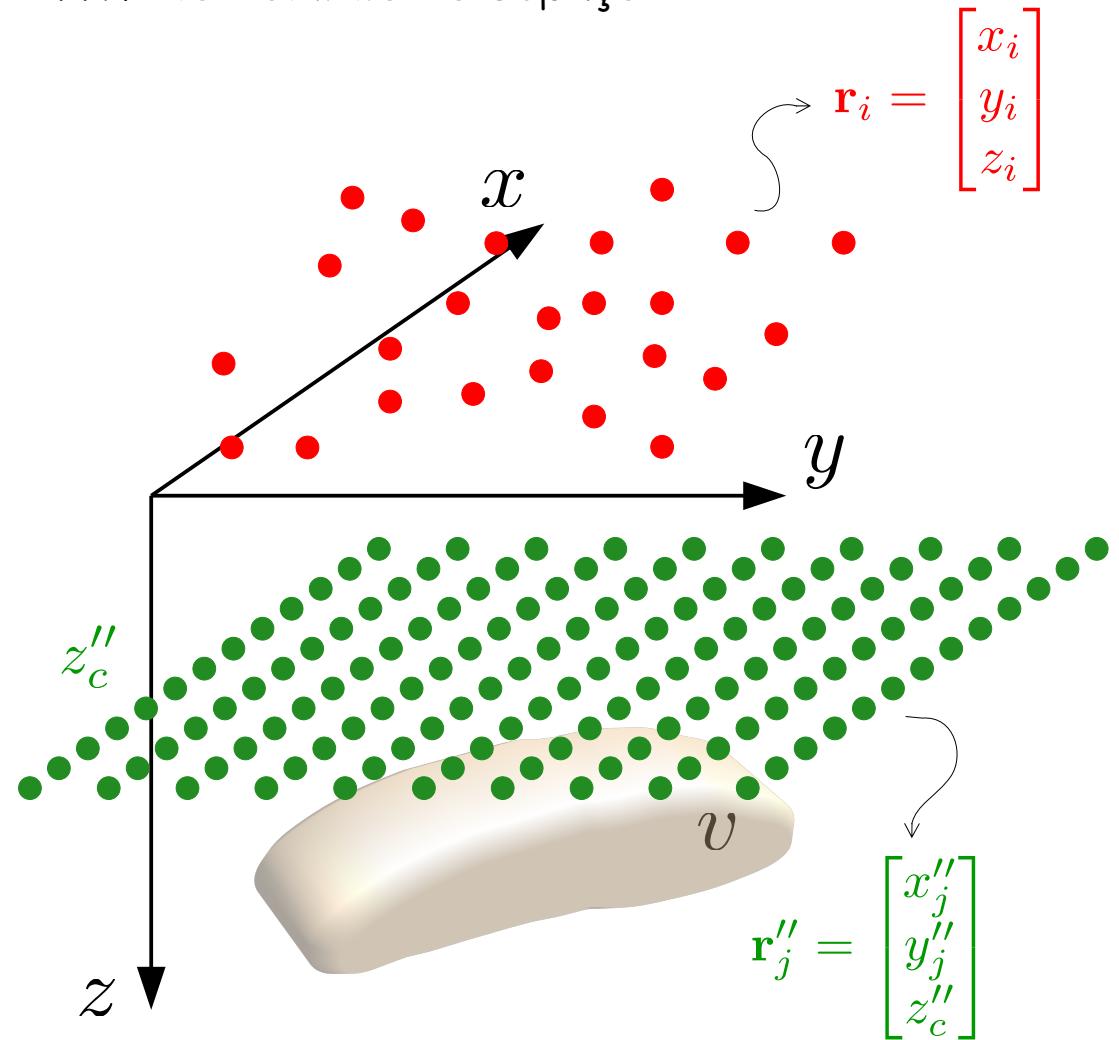
$$\Psi(\mathbf{r}_i, \mathbf{r}_j'') = \frac{1}{2\pi} \frac{1}{\|\mathbf{r}_i - \mathbf{r}_j''\|}$$

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$$\mathbf{d} \approx \mathbf{A} \mathbf{p}$$

$$\mathbf{p} = \begin{bmatrix} p_1 \\ \vdots \\ p_M \end{bmatrix}$$

RTP no domínio do espaço



$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M p_j \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

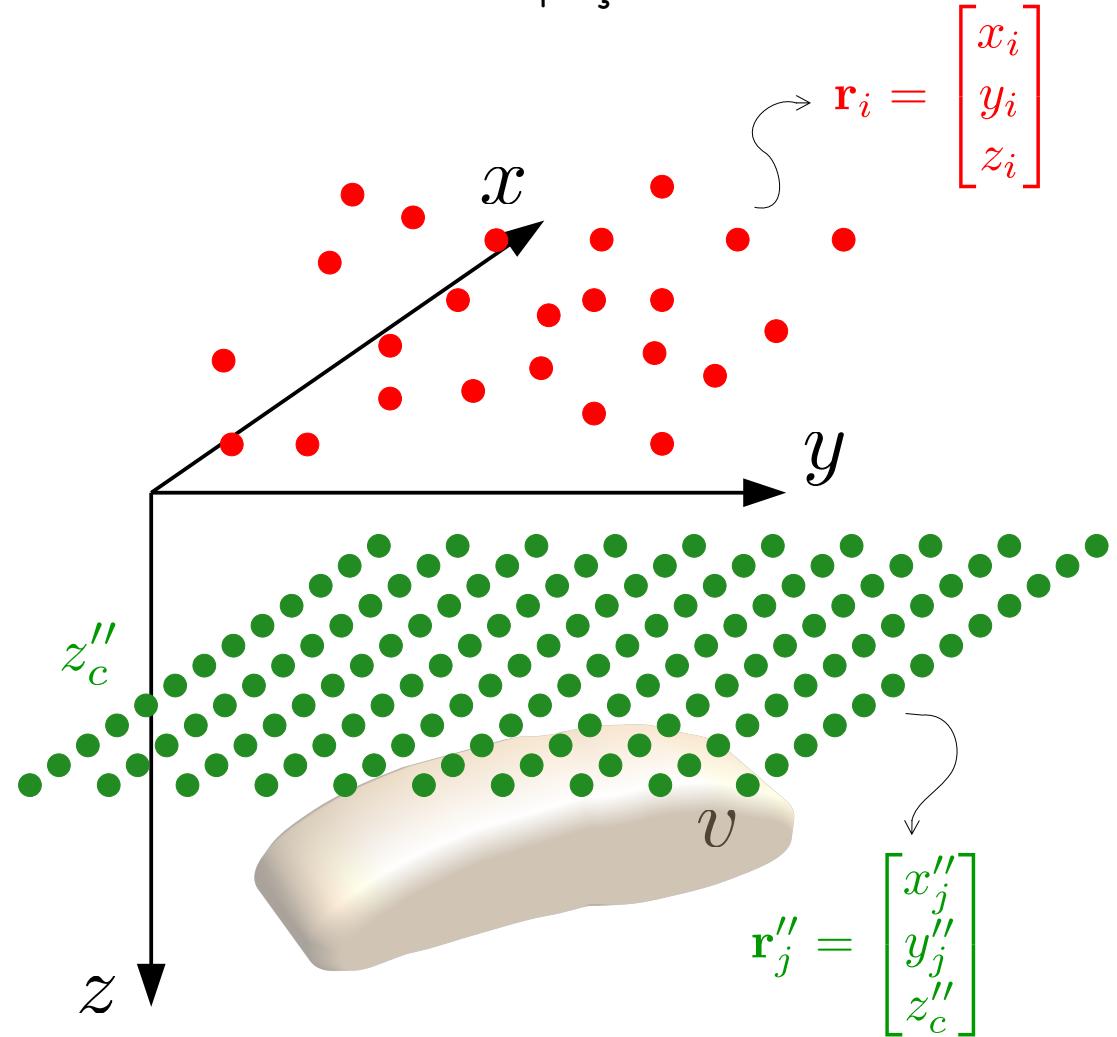
$$\Psi(\mathbf{r}_i, \mathbf{r}_j'') = \frac{1}{2\pi} \frac{1}{\|\mathbf{r}_i - \mathbf{r}_j''\|}$$

$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'') = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}_j'') \hat{\mathbf{h}}$$

$$\mathbf{d} \approx \mathbf{A} \mathbf{p}$$

$$\mathbf{d} = \begin{bmatrix} \partial_{th} U(\mathbf{r}_1) \\ \vdots \\ \partial_{th} U(\mathbf{r}_N) \end{bmatrix}$$

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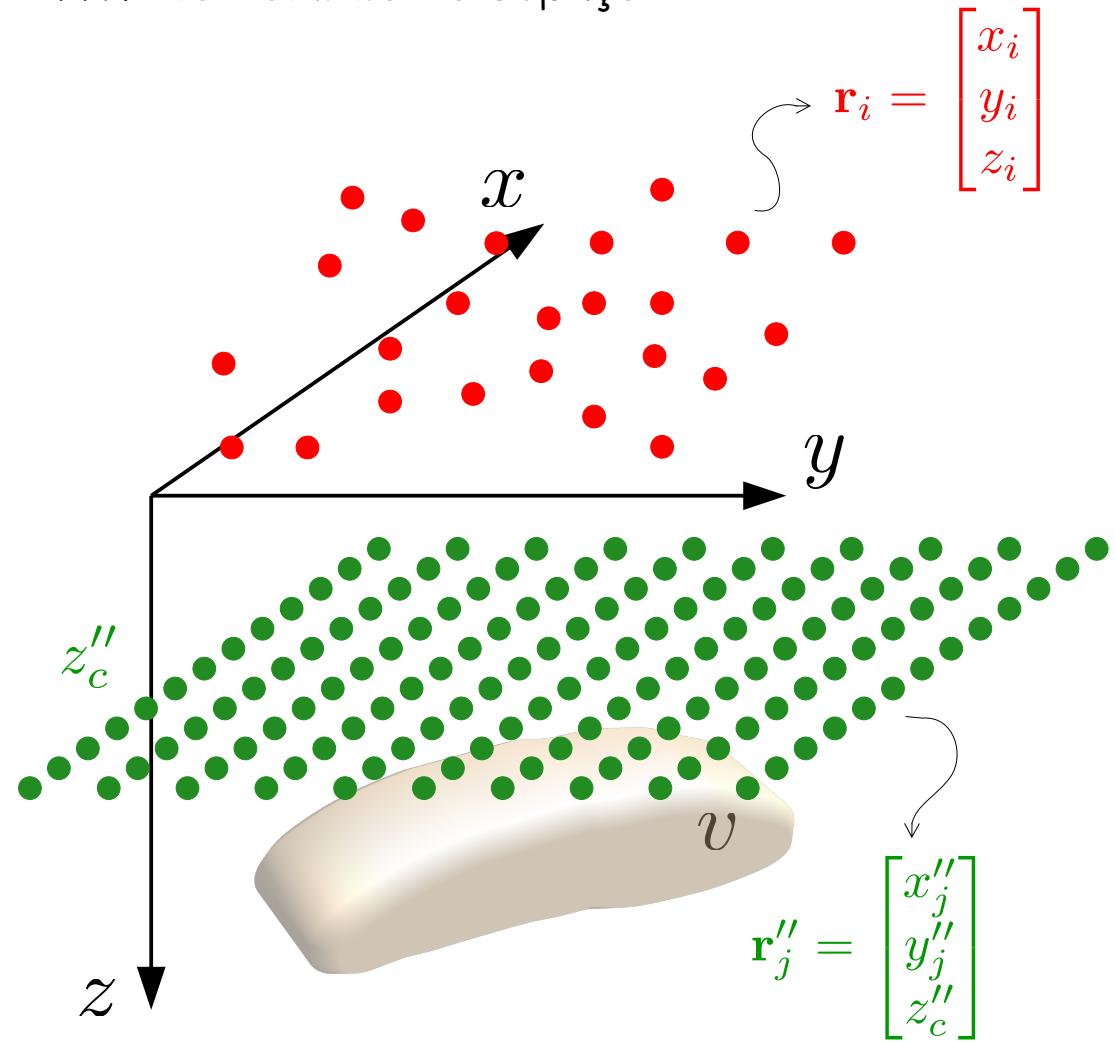
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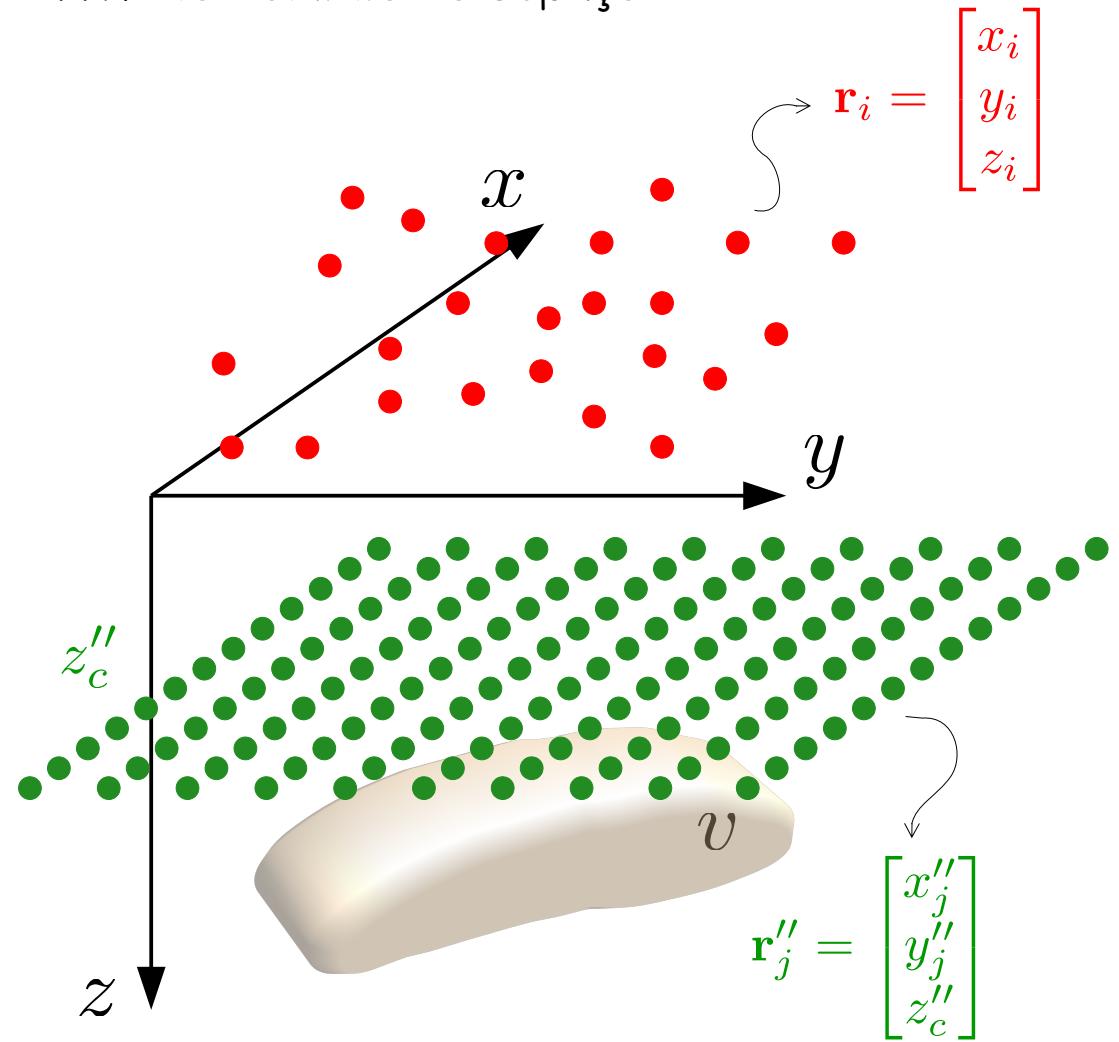
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$$\mathbf{A} = \begin{bmatrix} \partial_{th} \Psi(\mathbf{r}_1, \mathbf{r}_1'') & \cdots & \partial_{th} \Psi(\mathbf{r}_1, \mathbf{r}_M'') \\ \vdots & & \vdots \\ \partial_{th} \Psi(\mathbf{r}_N, \mathbf{r}_1'') & \cdots & \partial_{th} \Psi(\mathbf{r}_N, \mathbf{r}_M'') \end{bmatrix}$$

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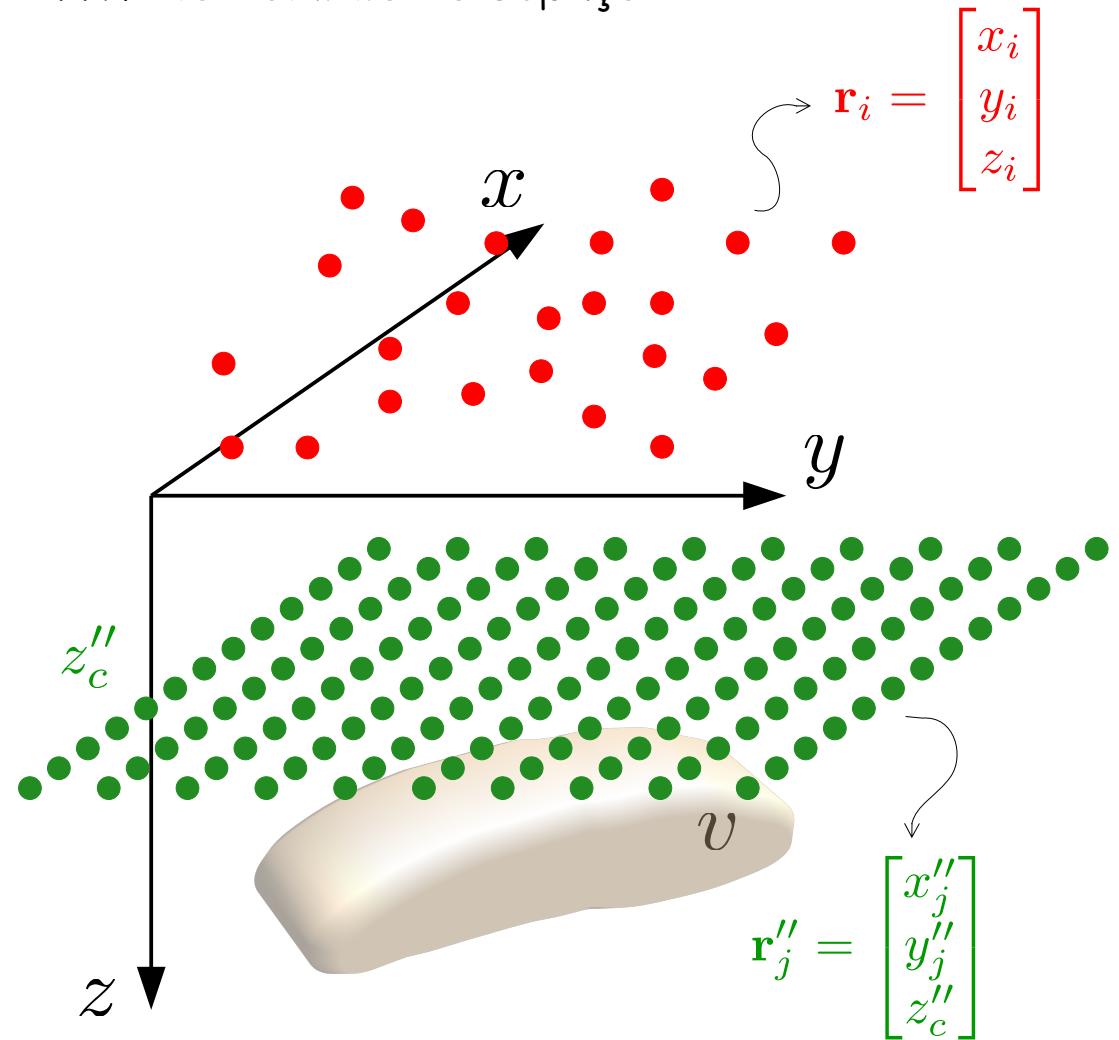
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RTP no domínio do espaço



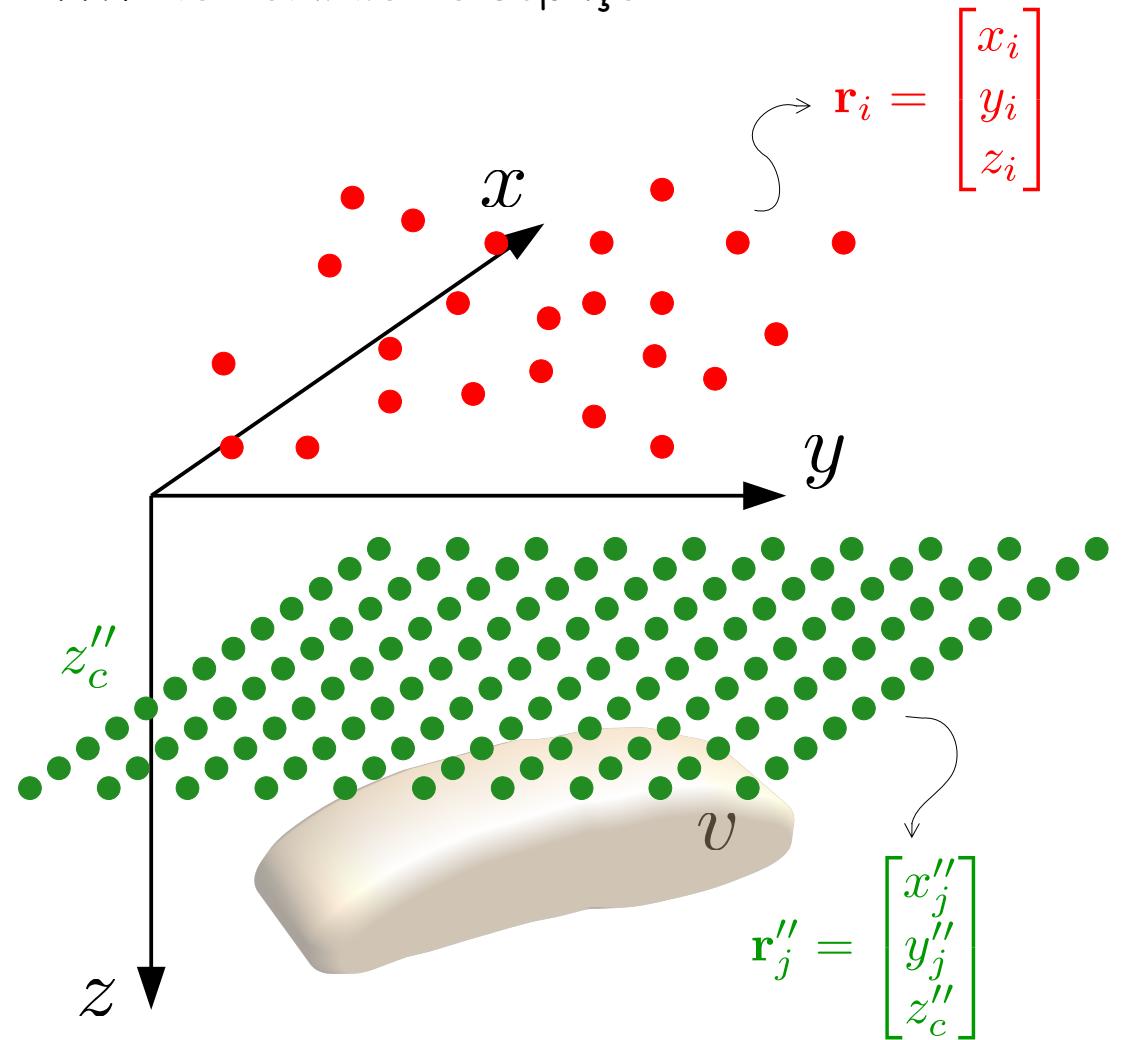
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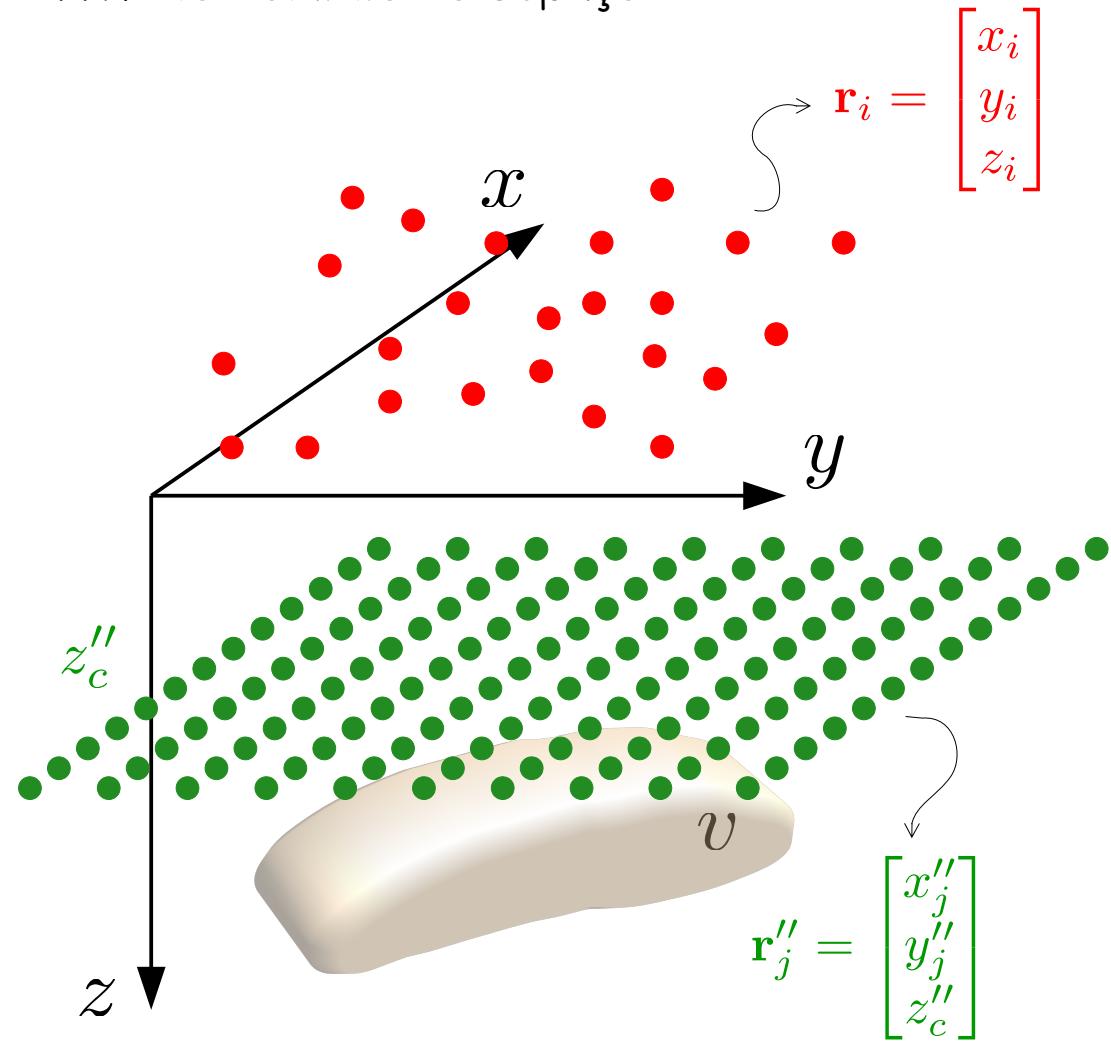
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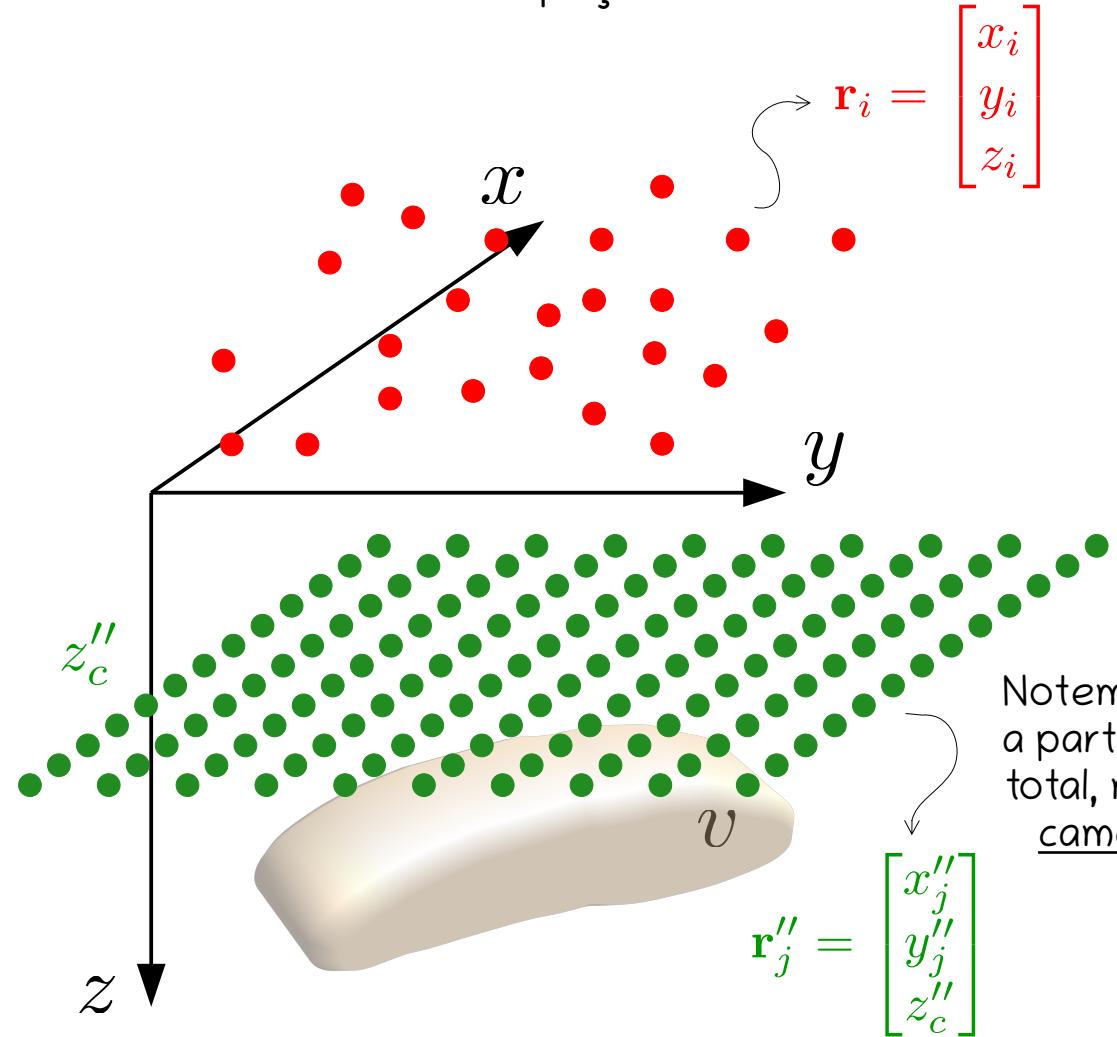
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anomalia RTP
estimada nos pontos
de observação

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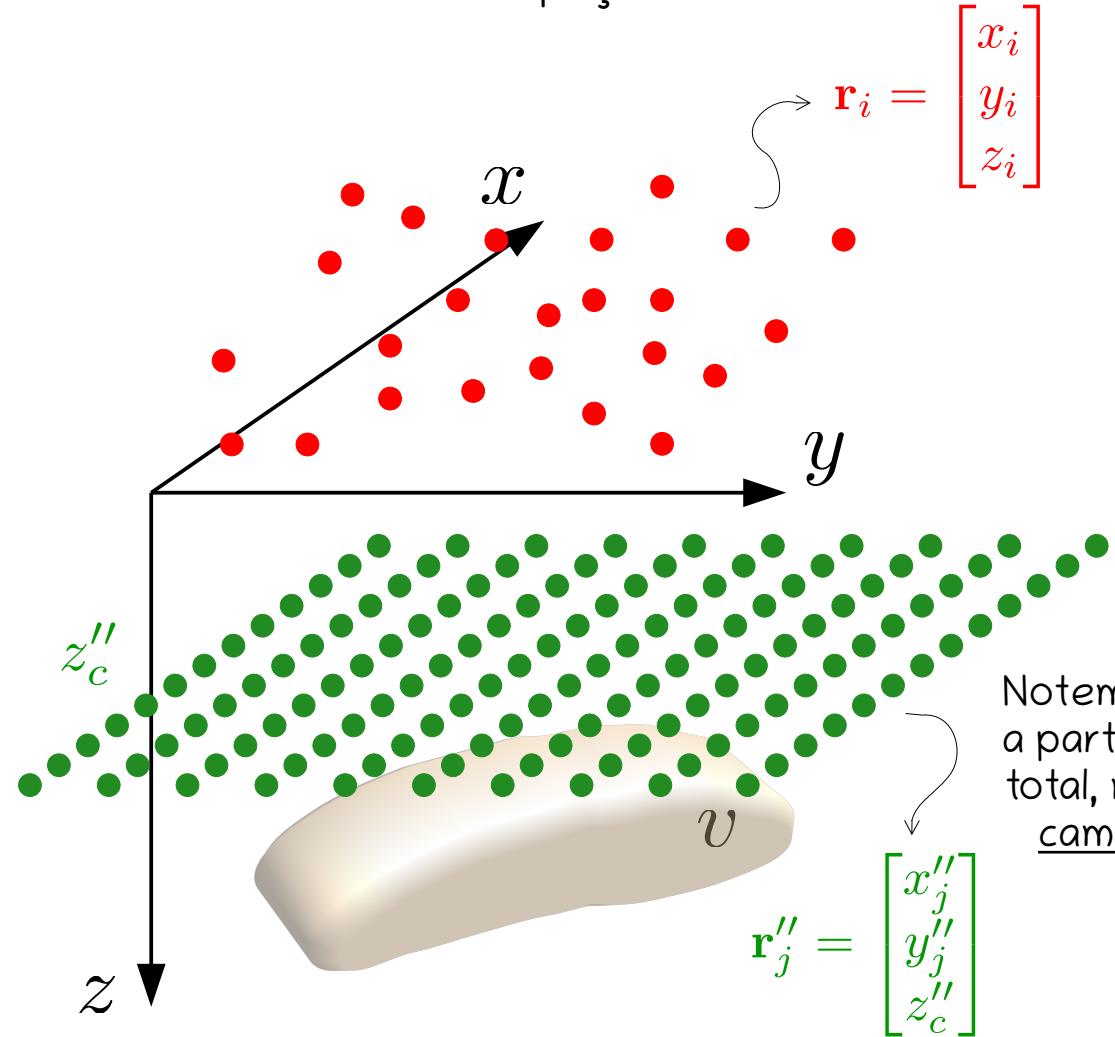
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RTP no domínio do espaço



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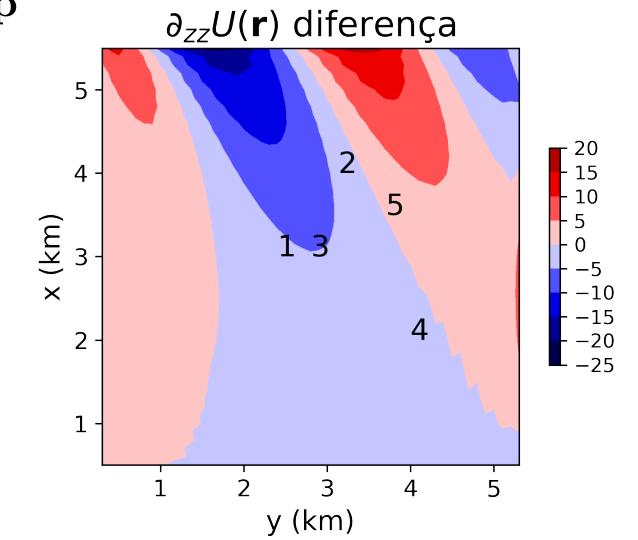
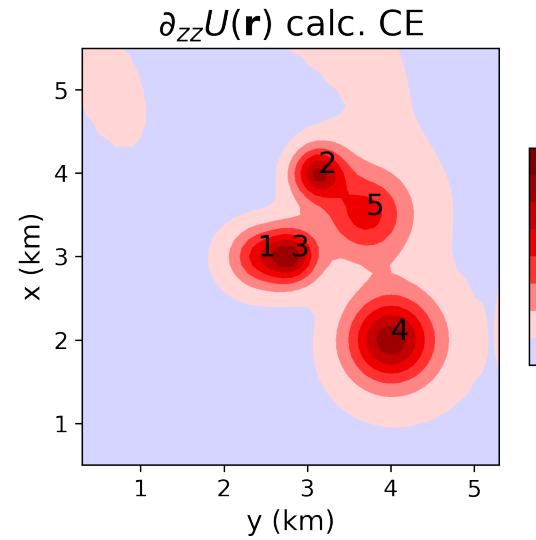
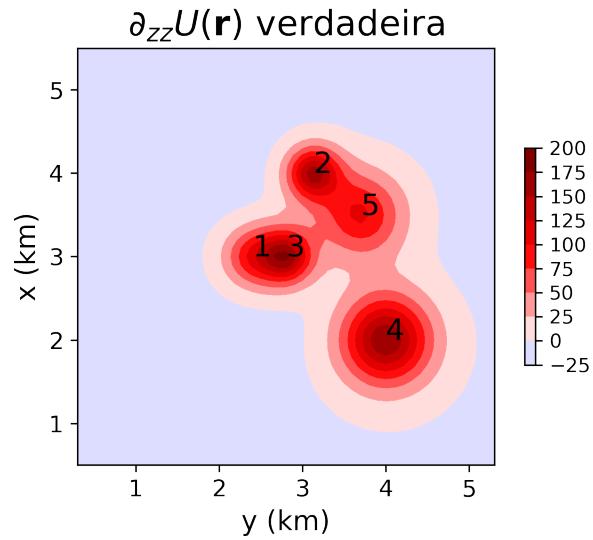
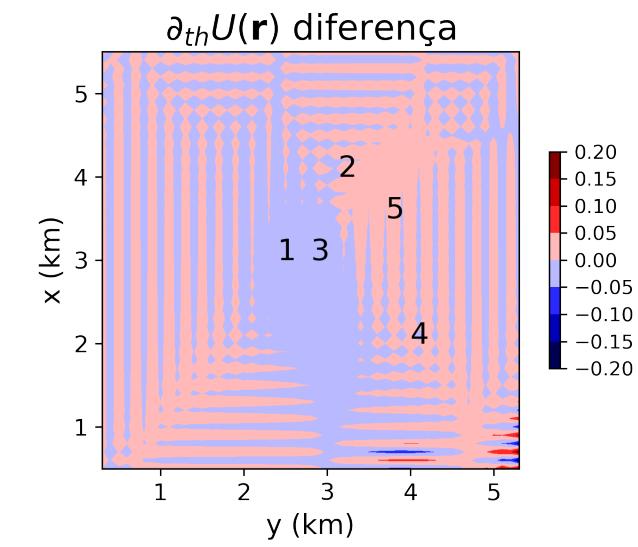
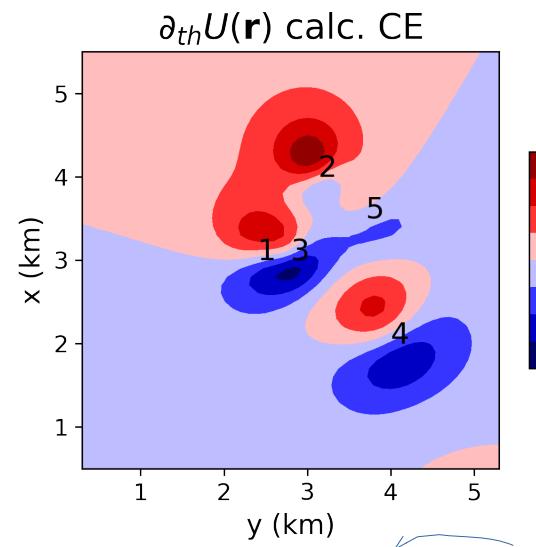
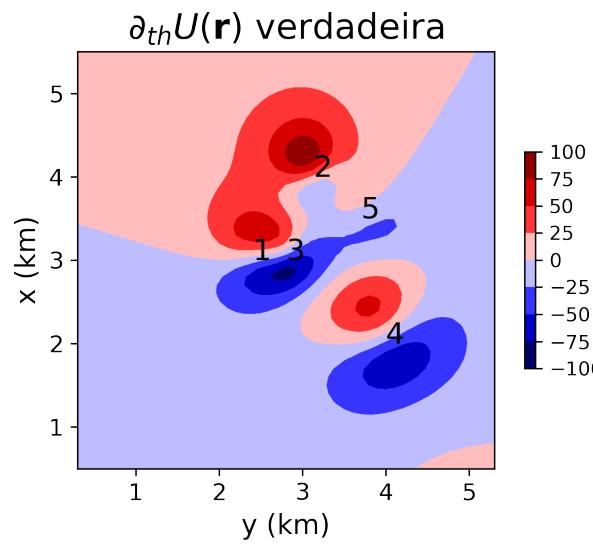
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Esta formulação foi proposta originalmente por Silva (1986)

$$I_t = -25^\circ \quad D_t = -30^\circ \quad I_h = -30^\circ \quad D_h = -19^\circ$$

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Há duas abordagens para o cálculo da RTP

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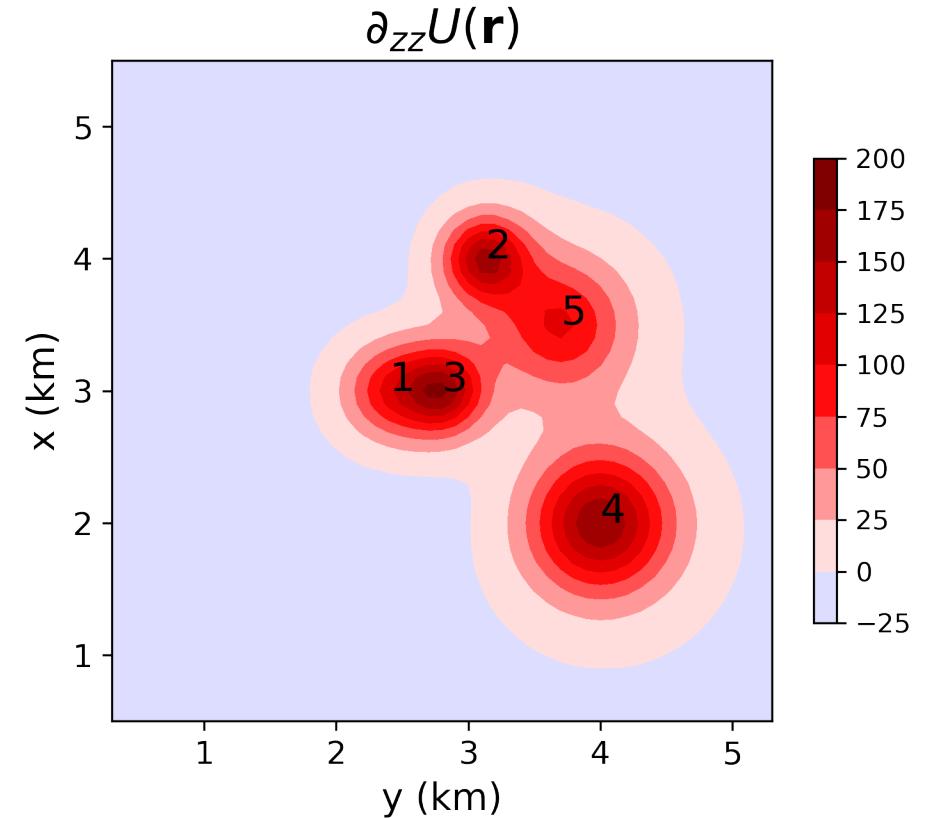
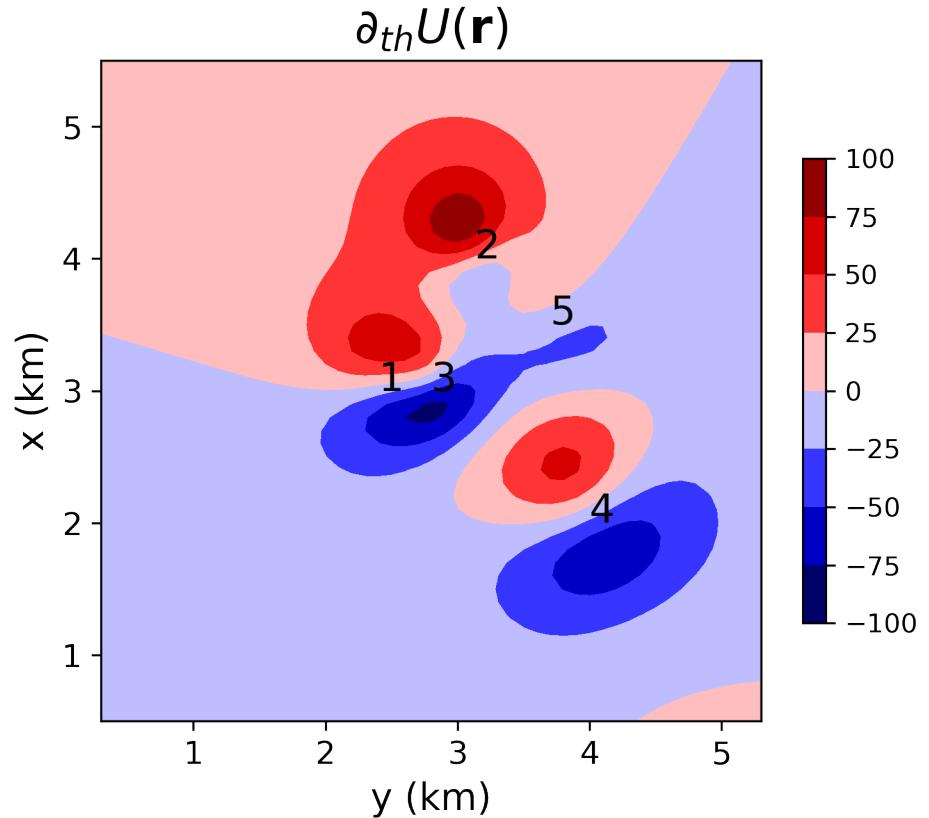
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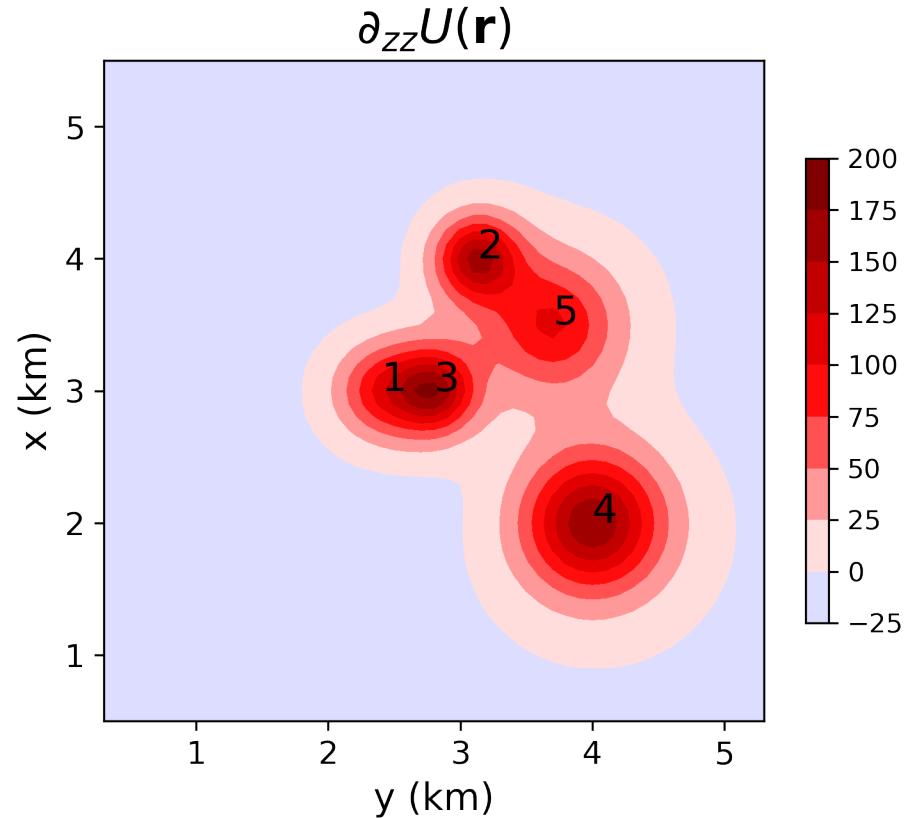
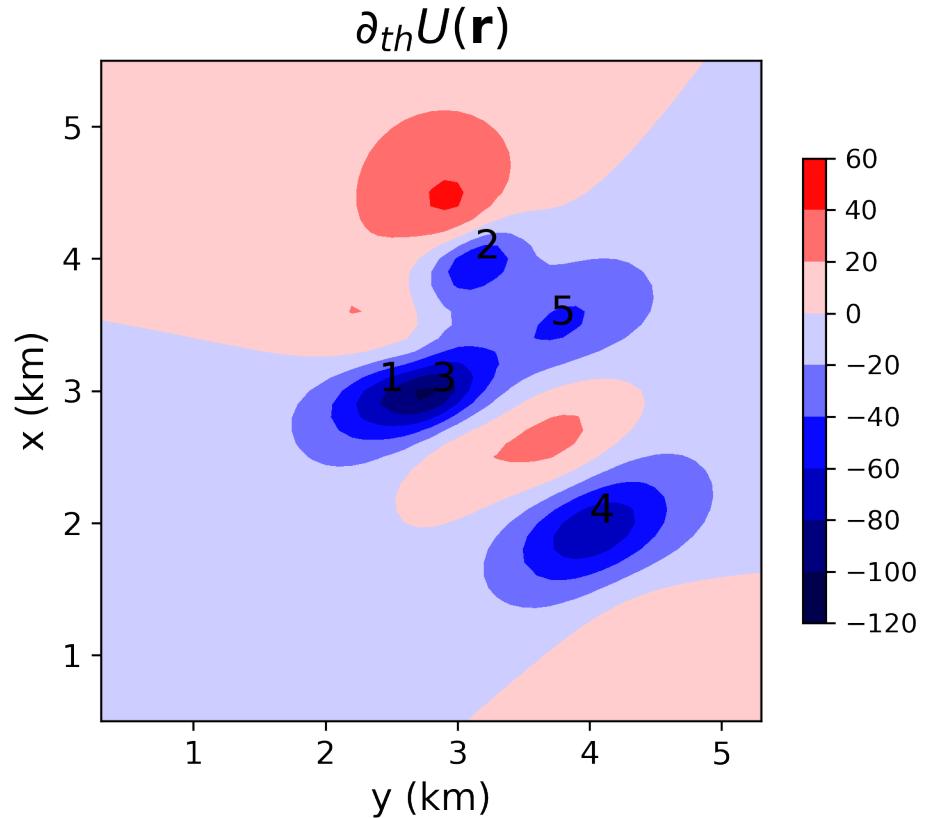


$$I_t = -5^\circ$$

$$I_h = -6^\circ$$

$$D_t = -30^\circ$$

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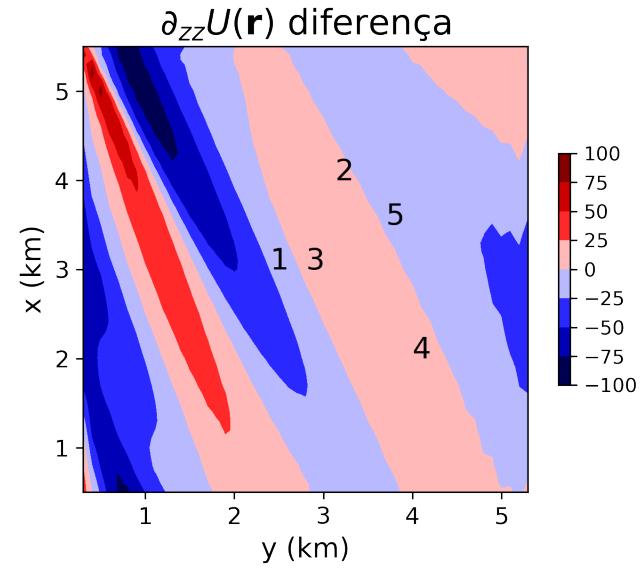
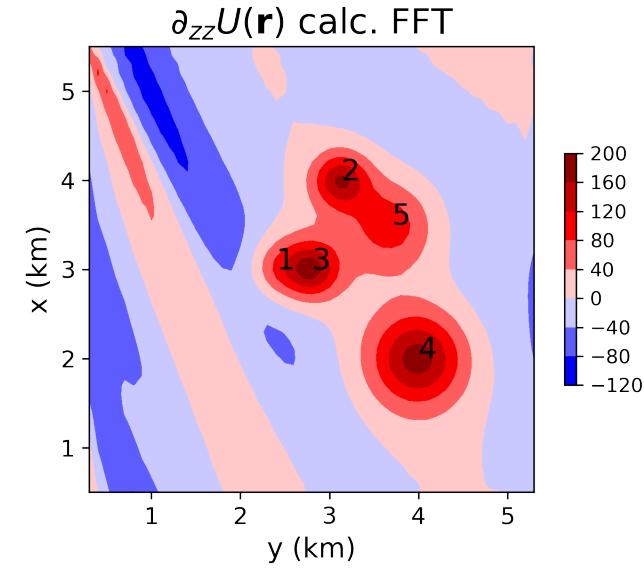
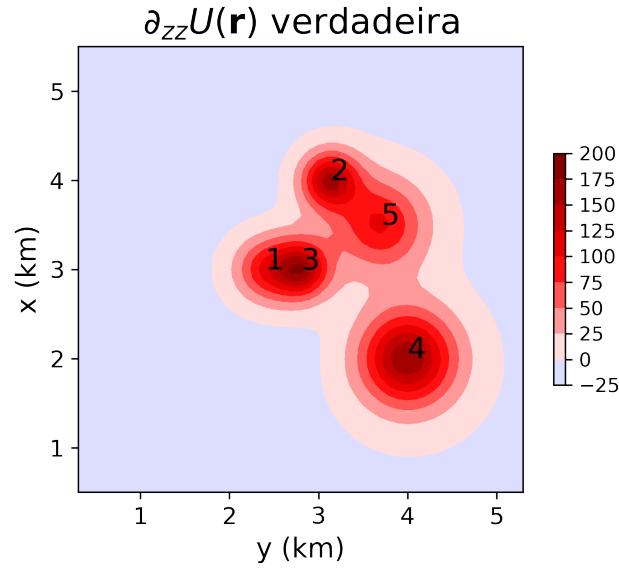


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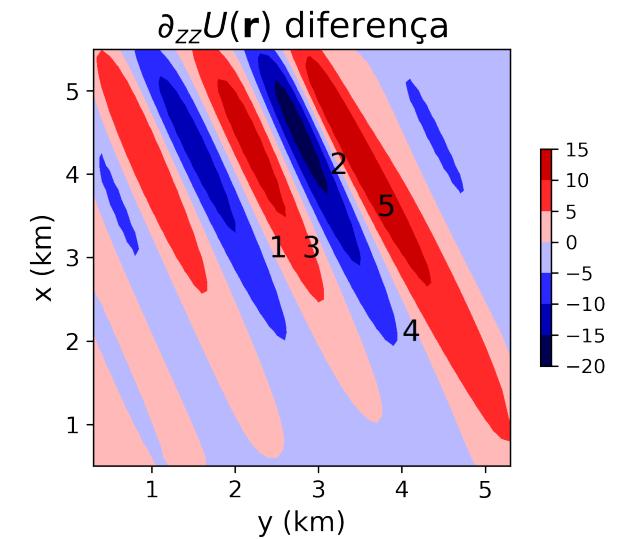
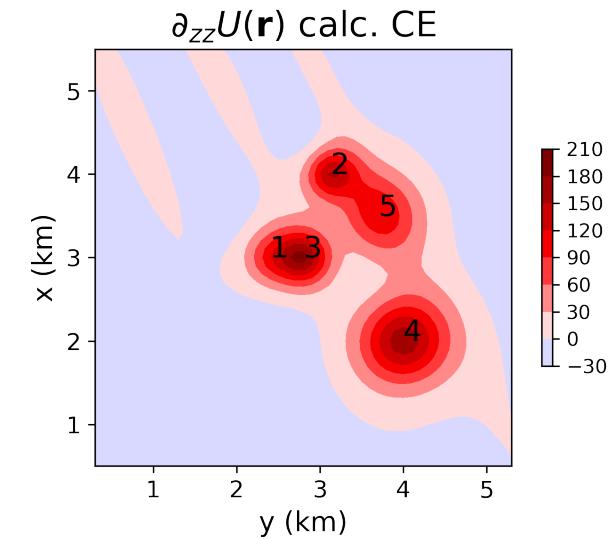
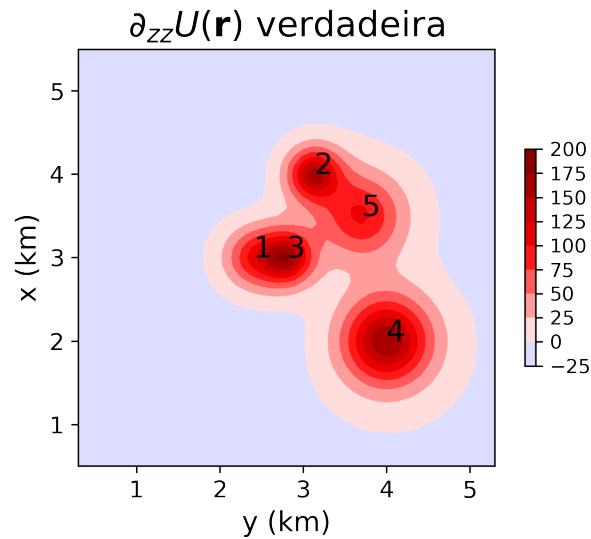
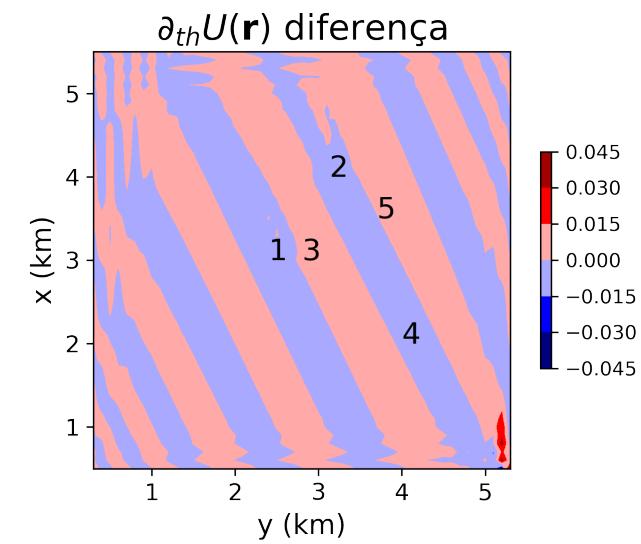
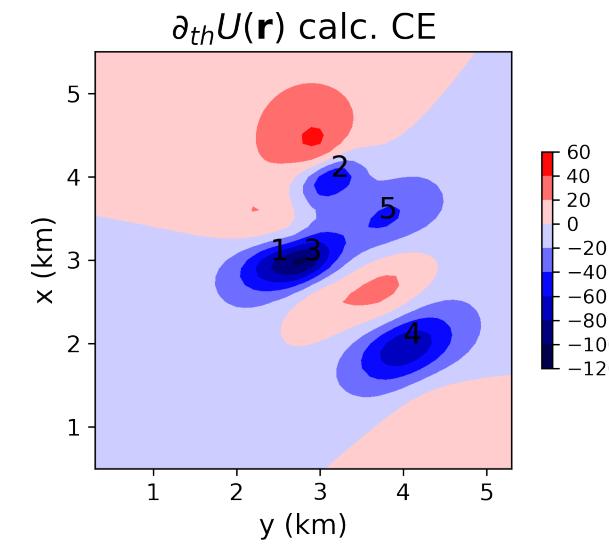
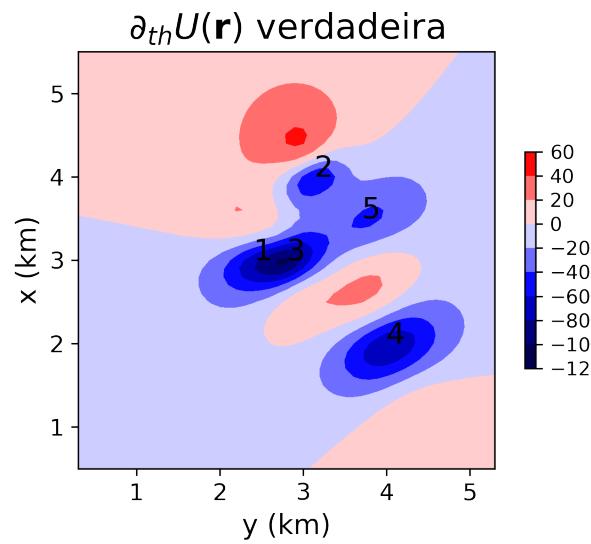
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Sumário

- O que é a redução ao polo (RTP)
- **Como calcular a RTP**
- Desenvolvimentos teóricos
- Possível generalização
- Comentários finais



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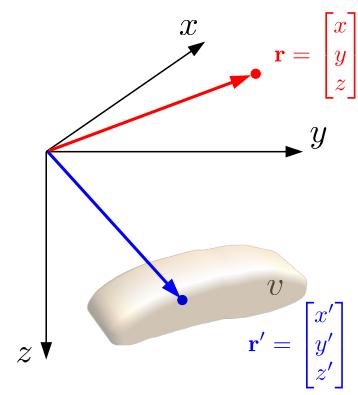
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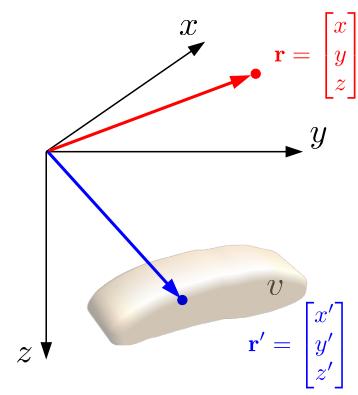


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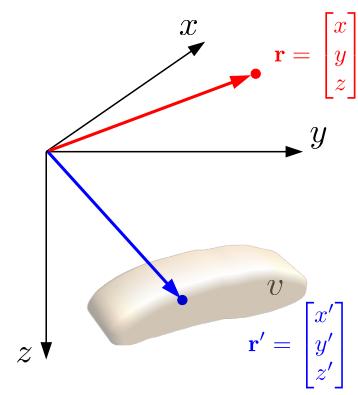
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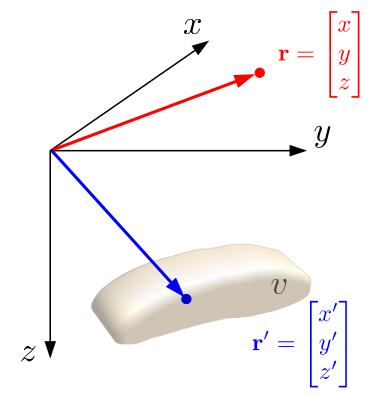


$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

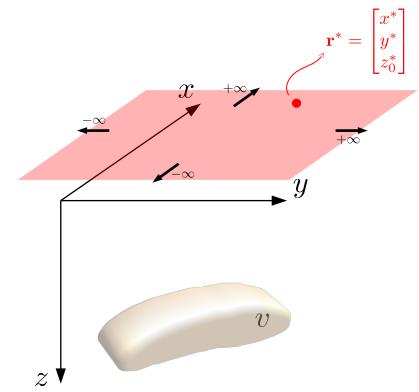


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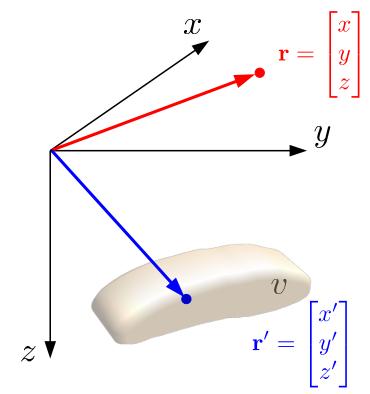
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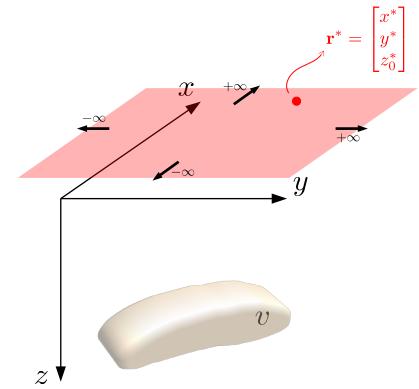
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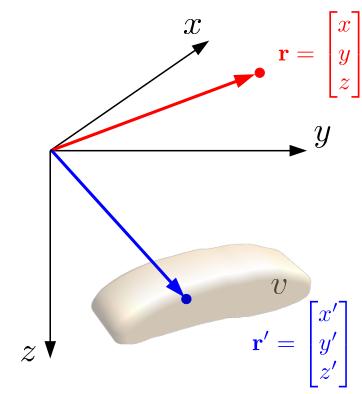


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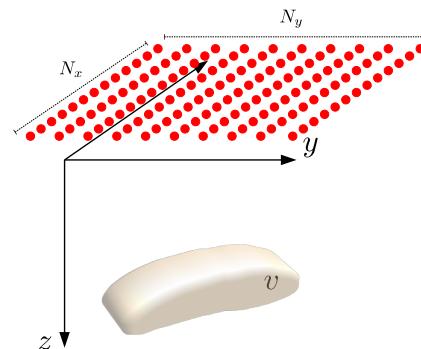
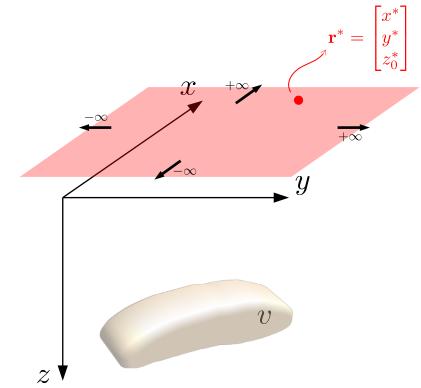


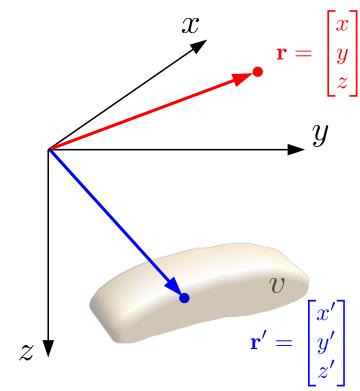
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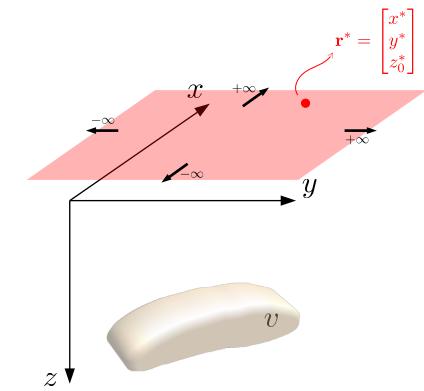
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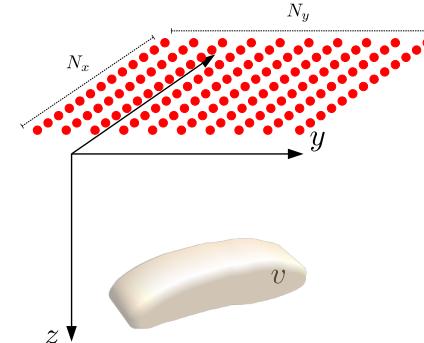
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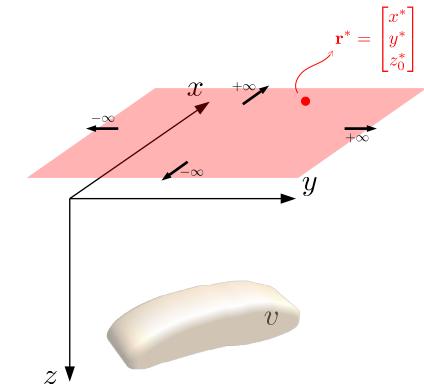
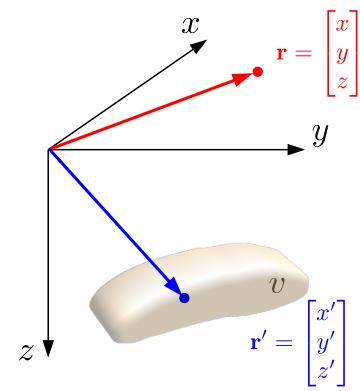
$$\partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$



$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\boldsymbol{\Theta}_t \circ \boldsymbol{\Theta}_h) \right\} \mathcal{F}_y^{-1}$$





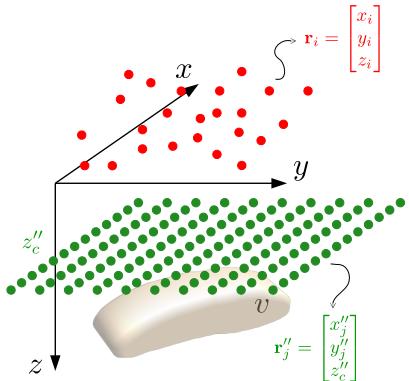
$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} d\mathbf{v}'$$

$$\partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$

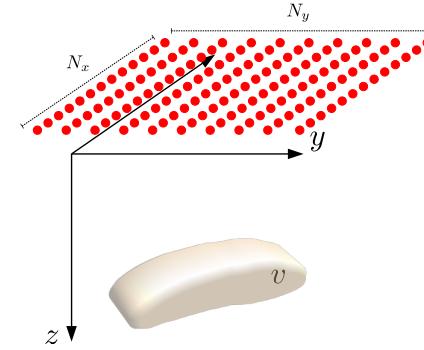
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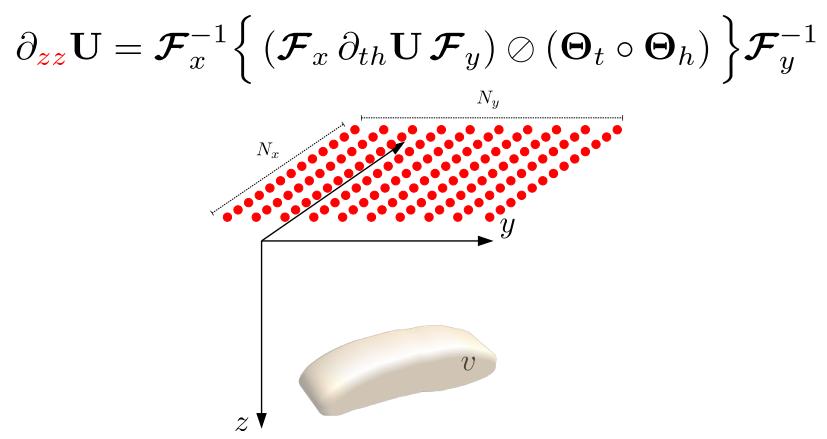
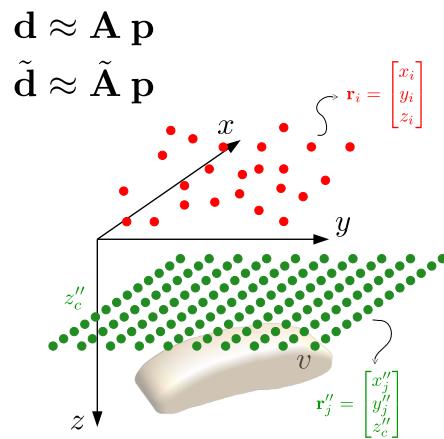
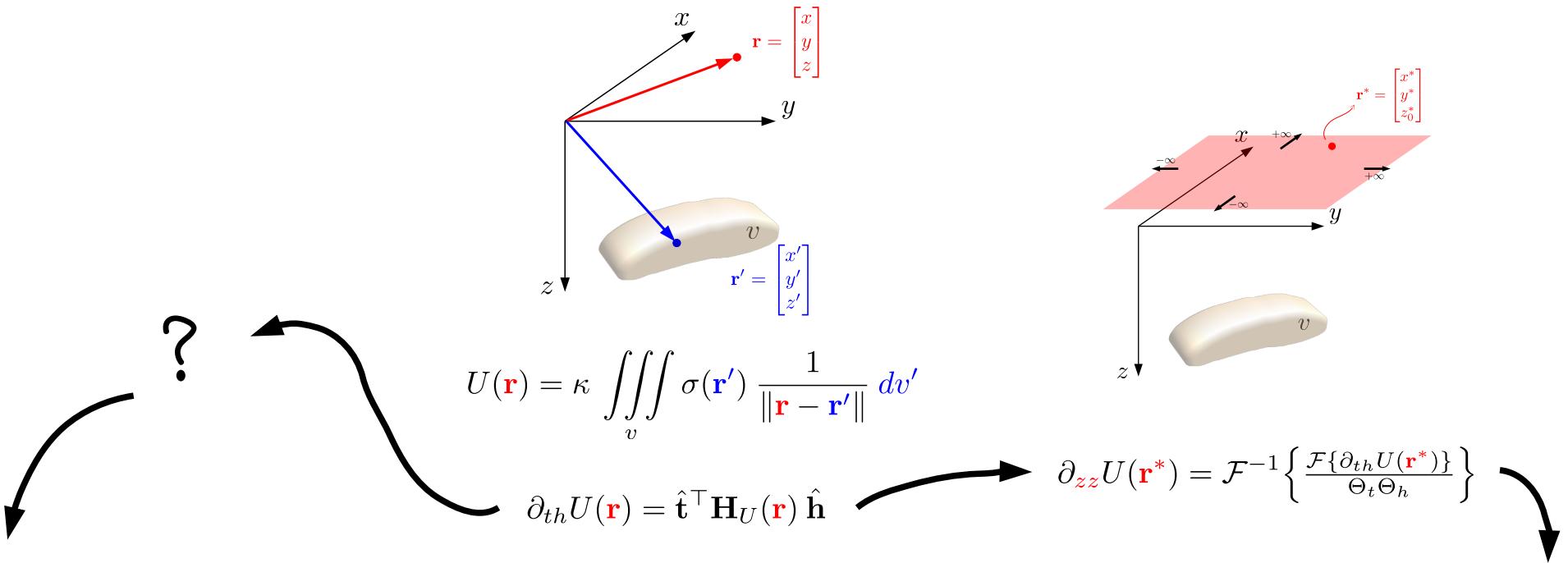
$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

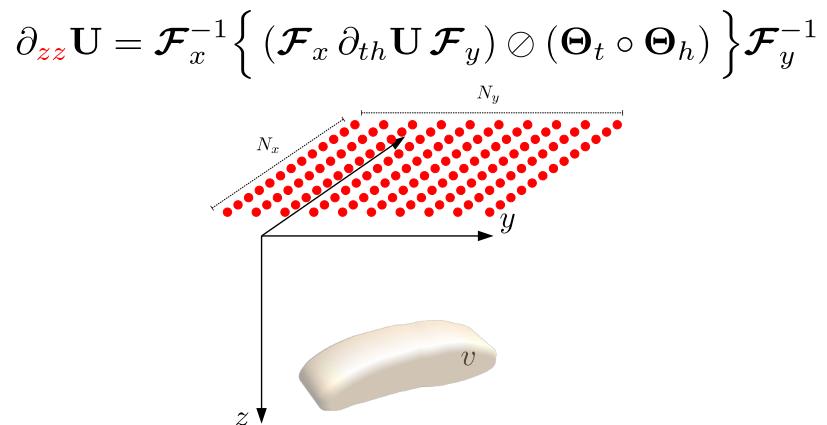
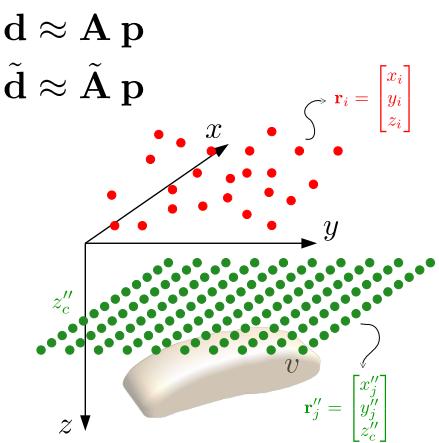
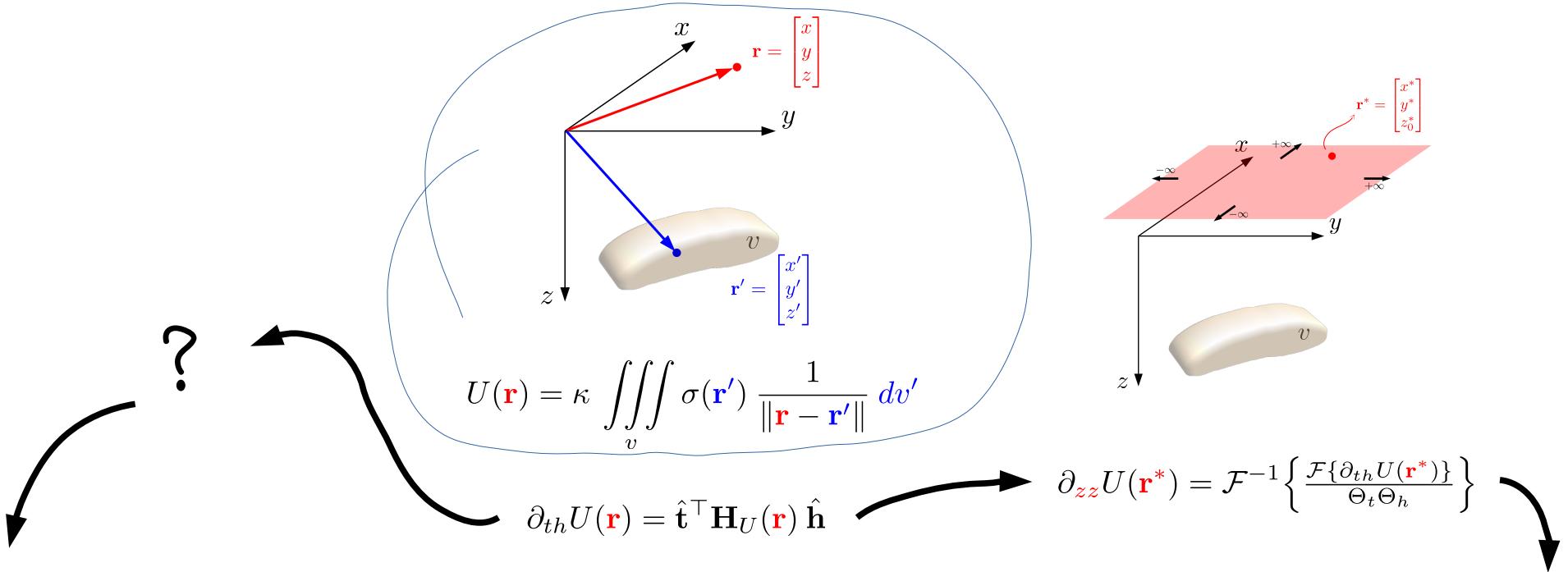
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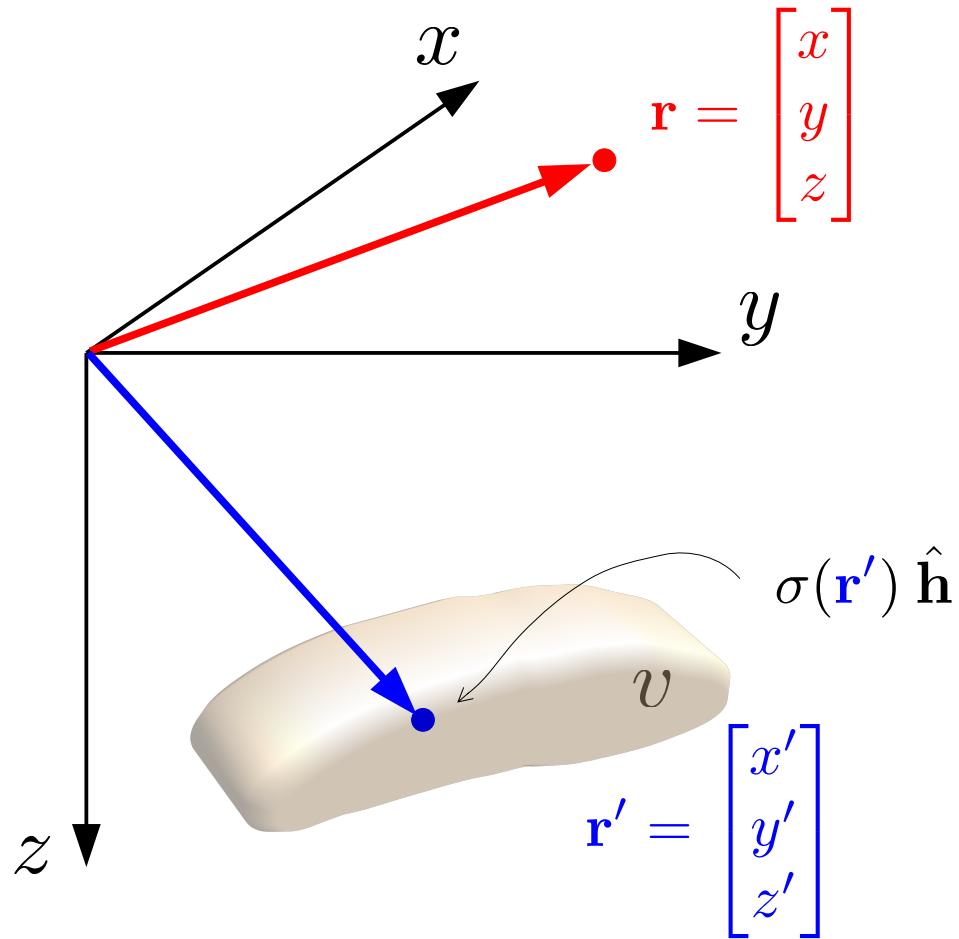
$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\boldsymbol{\Theta}_t \circ \boldsymbol{\Theta}_h) \right\} \mathcal{F}_y^{-1}$$



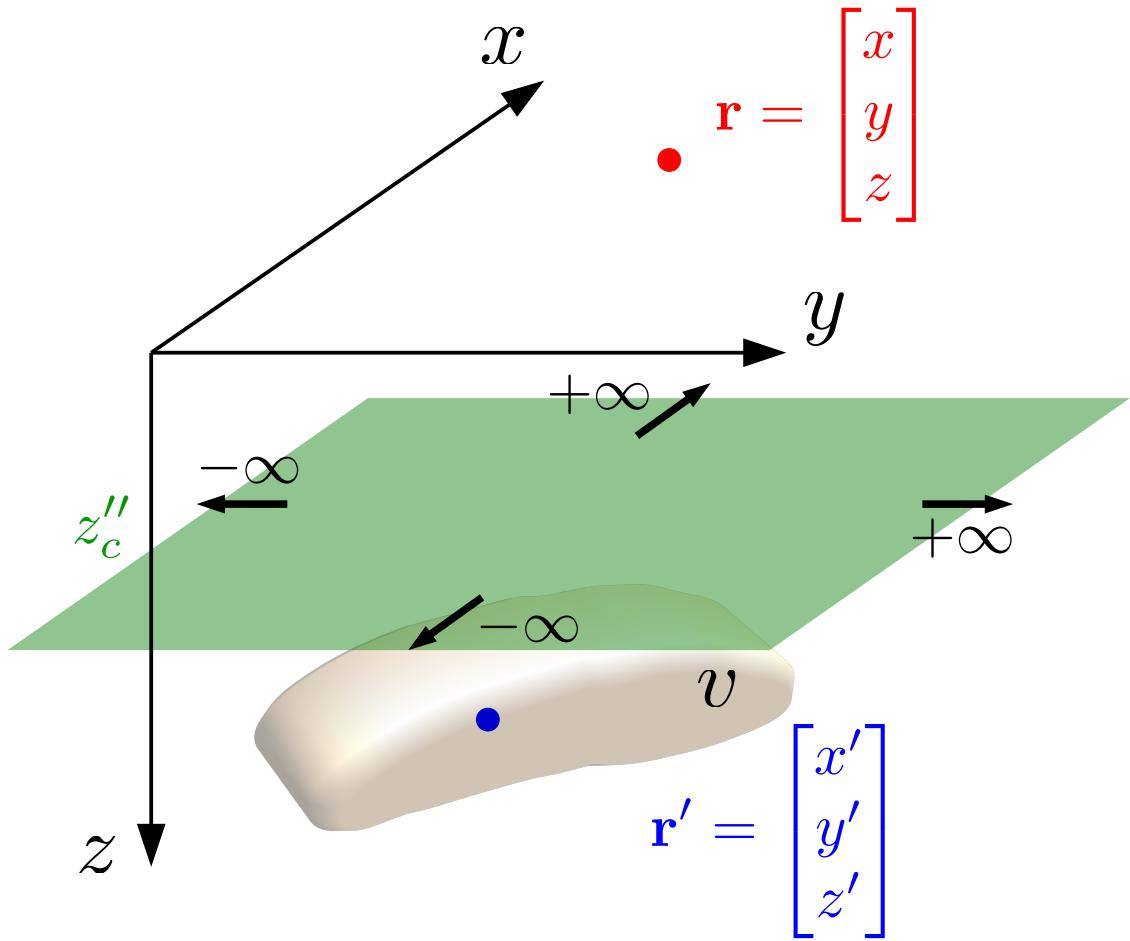




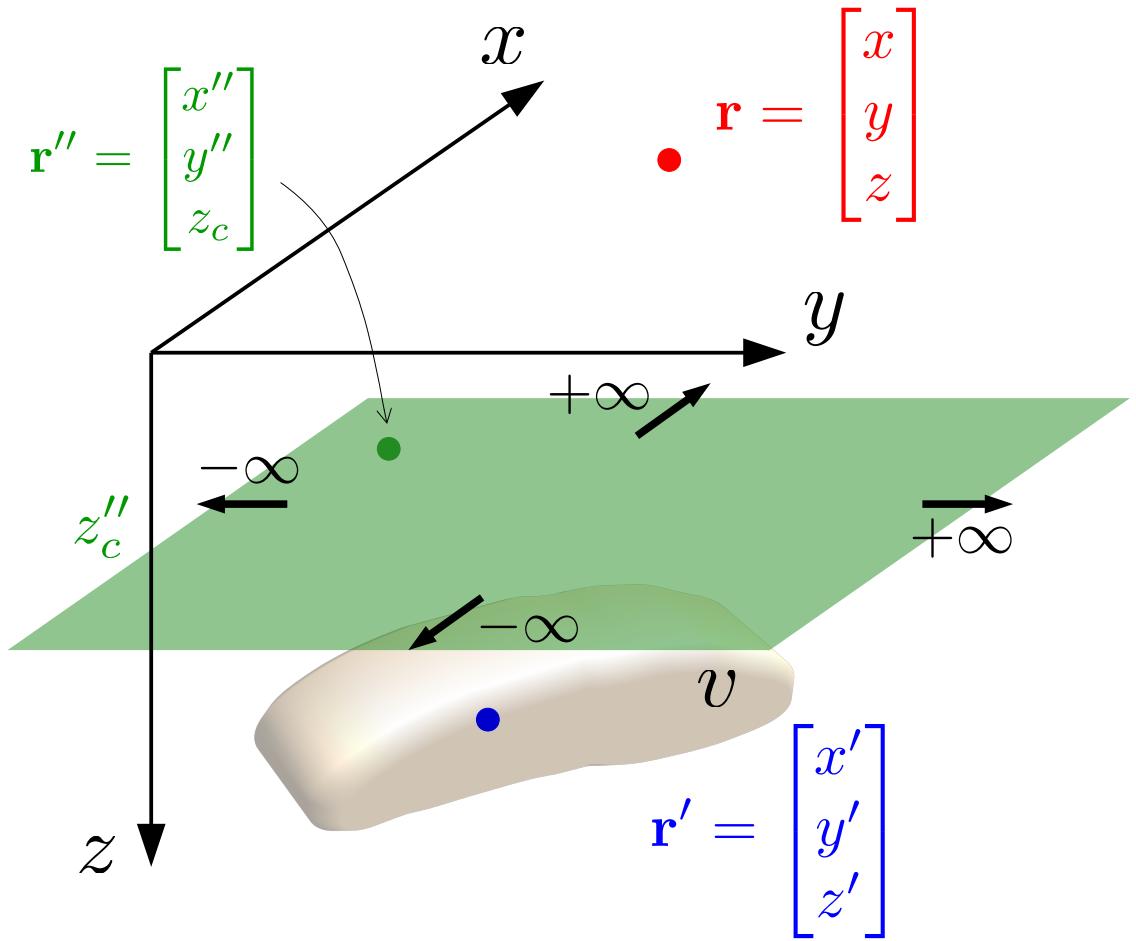
$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$



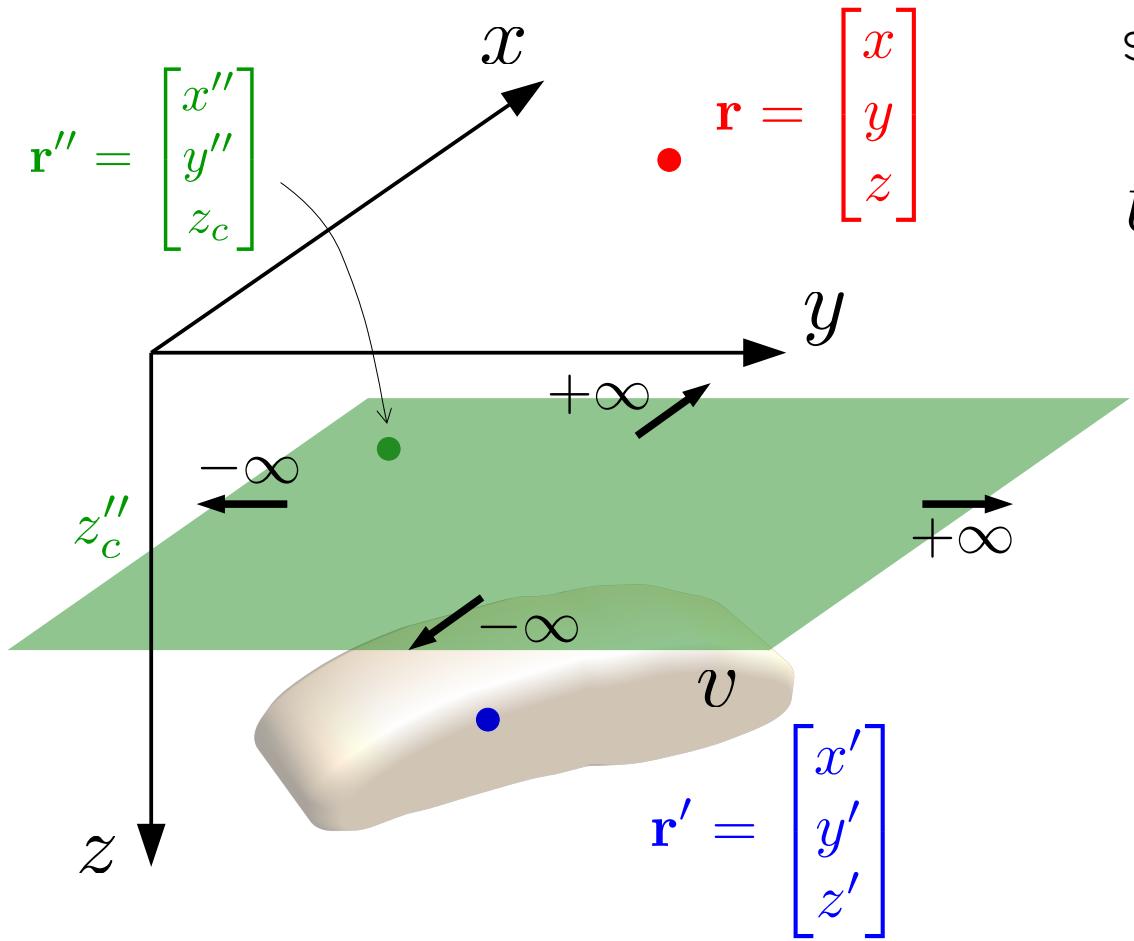
$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

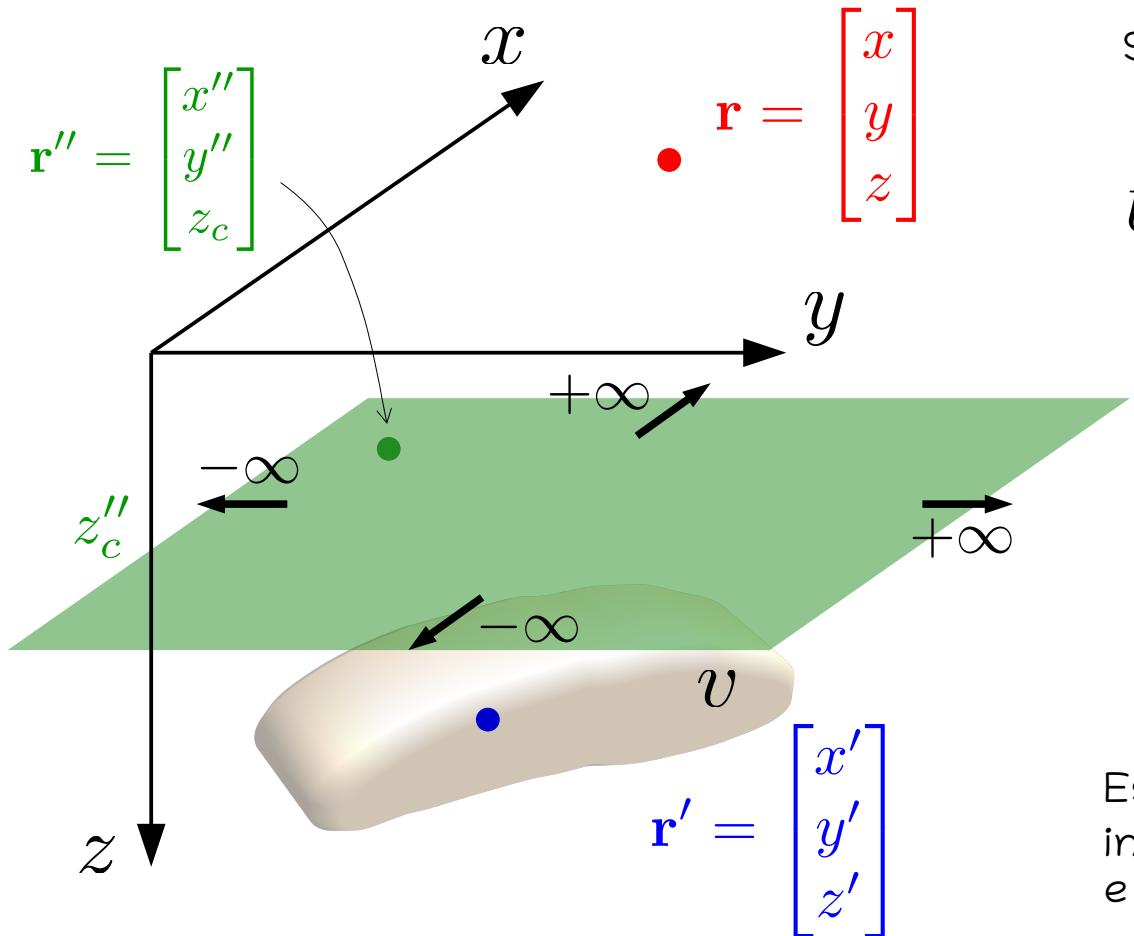


$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$





$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

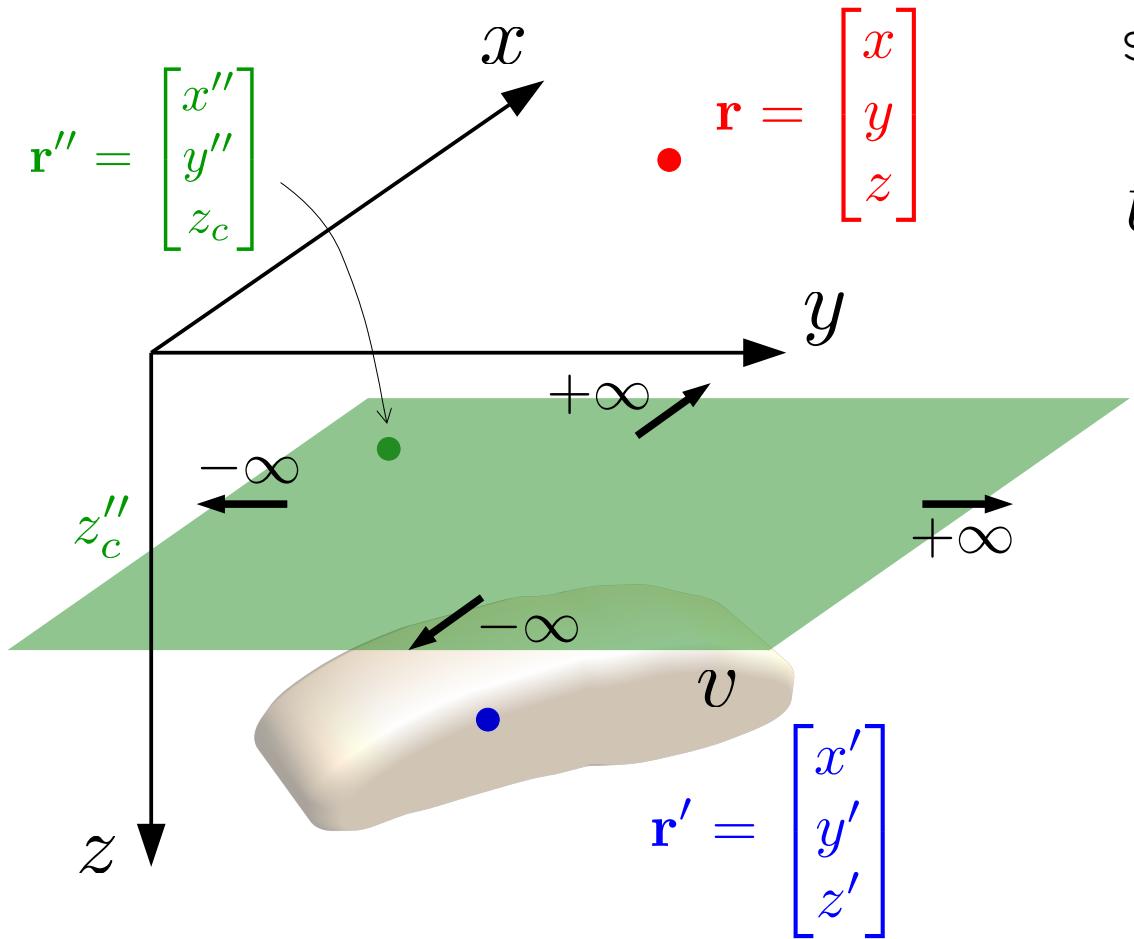
Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

que representa a solução do problema de Neumann ou do **segundo problema de valor de contorno da teoria do potencial** sobre o plano ([Kellogg, 1967, p. 246](#))

$$\partial_z U(\mathbf{r}'') = \kappa \iiint_v \sigma(\mathbf{r}') \partial_z \frac{1}{\|\mathbf{r}'' - \mathbf{r}'\|} dv'$$

Esta função é definida em termos da intensidade de magnetização total $\sigma(\mathbf{r}')$ e é positiva em todos os pontos \mathbf{r}''



$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

que representa a solução do problema de Neumann ou do **segundo problema de valor de contorno da teoria do potencial** sobre o plano ([Kellogg, 1967, p. 246](#))

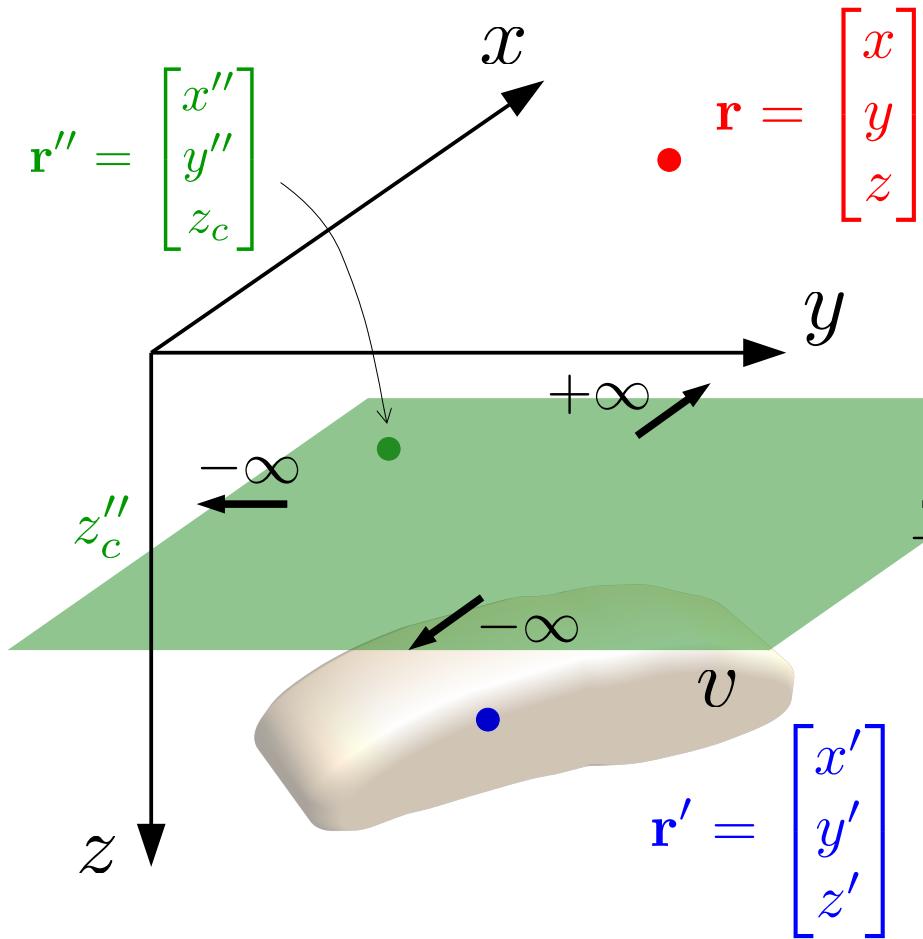
$$\partial_z U(\mathbf{r}'') = \kappa \iiint_v \sigma(\mathbf{r}') \partial_z \frac{1}{\|\mathbf{r}'' - \mathbf{r}'\|} dv'$$

$$\Psi(\mathbf{r}, \mathbf{r}'') = \frac{1}{2\pi} \frac{1}{\|\mathbf{r} - \mathbf{r}''\|}$$

$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

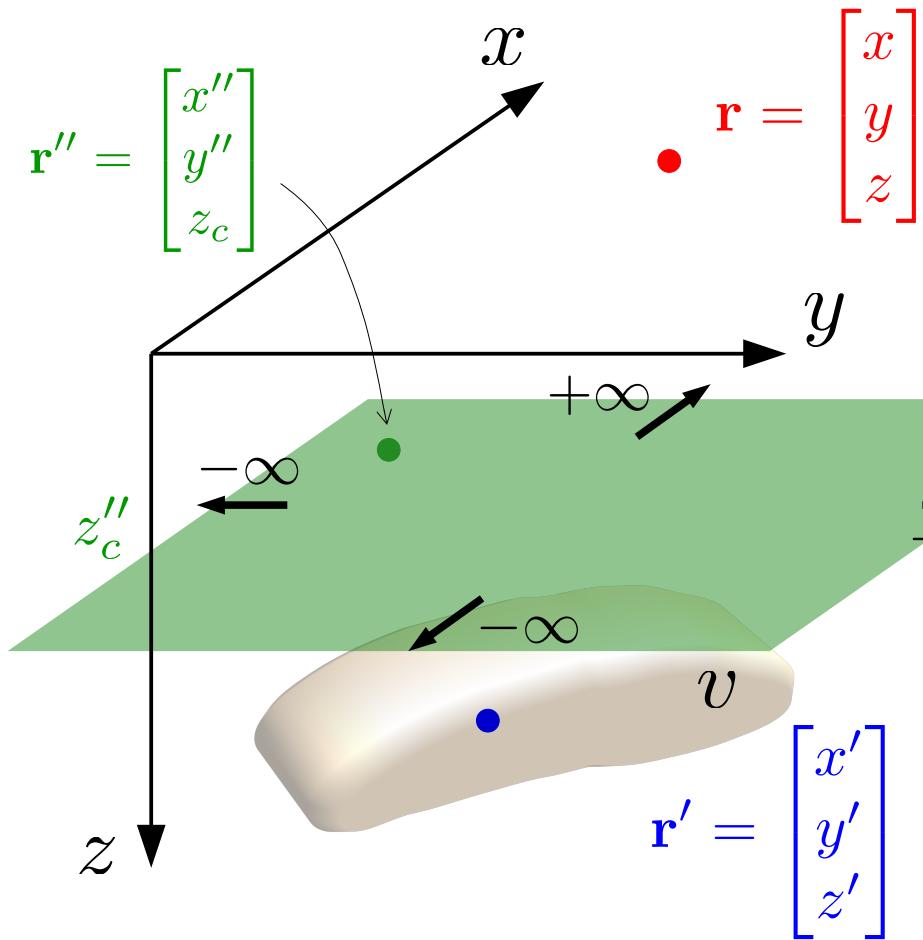


$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS'' \quad \text{an. de campo total}$$

$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



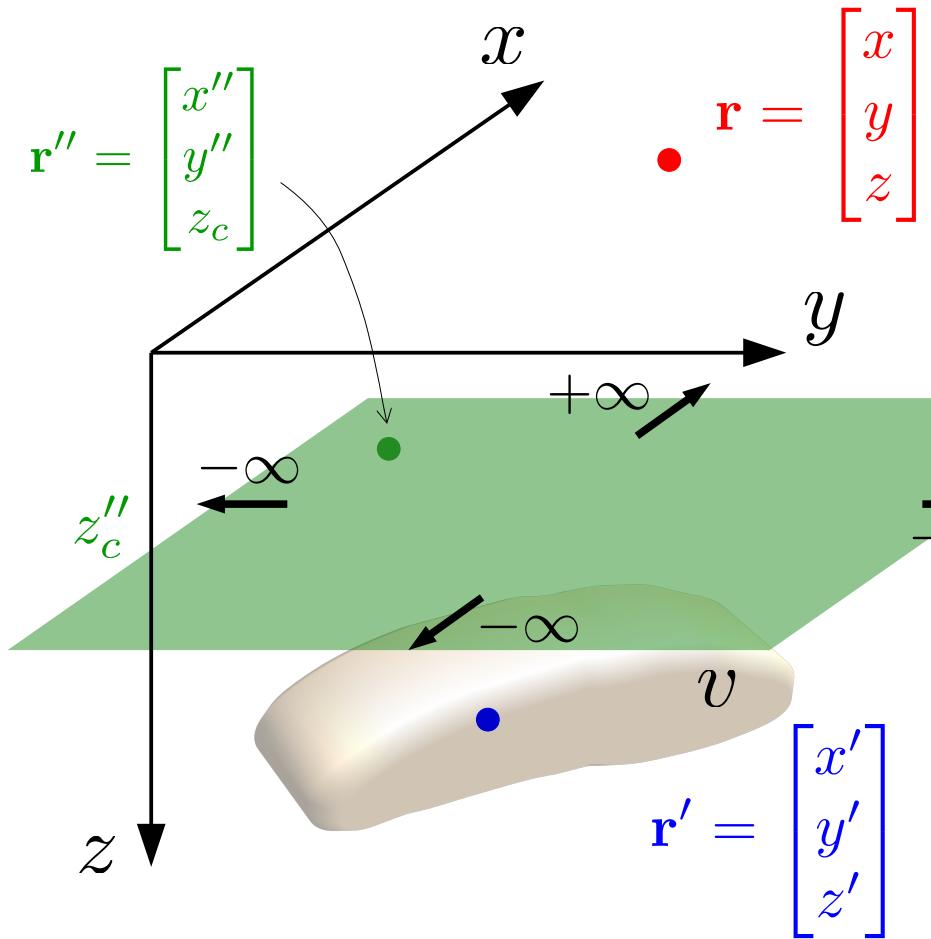
$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \text{an. de campo total} \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

$$\partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'') = \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}_i, \mathbf{r}_j'') \hat{\mathbf{h}}$$

$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



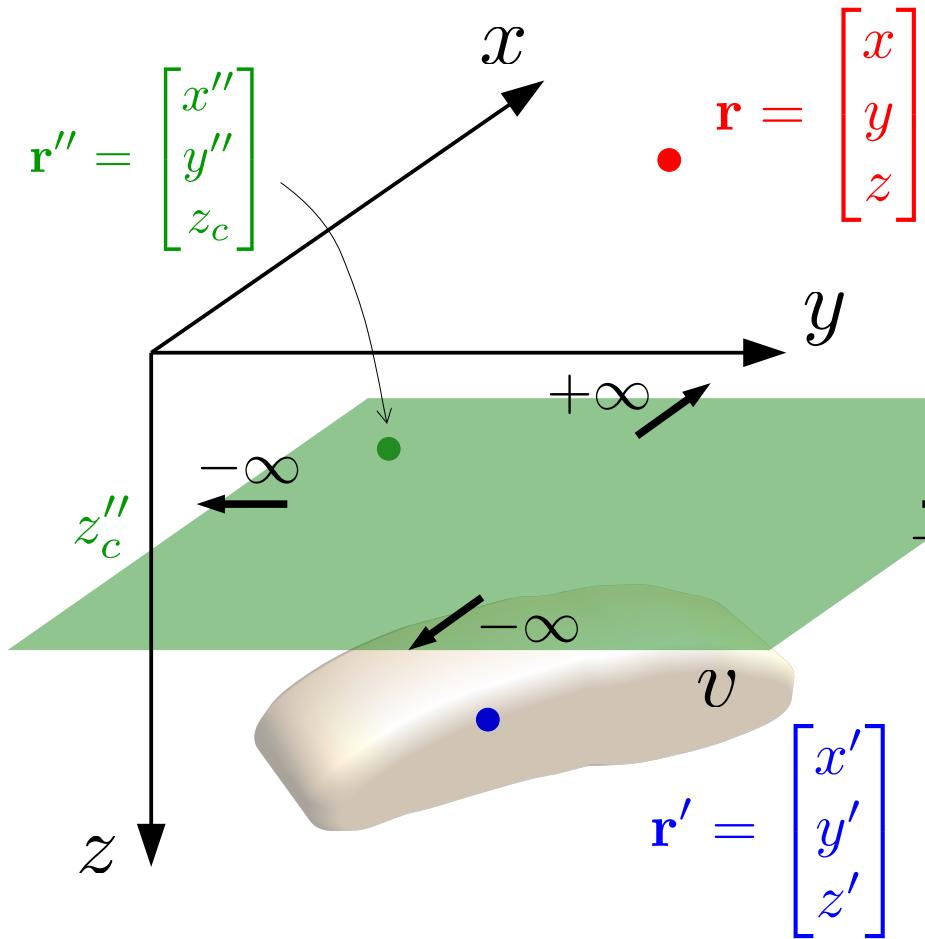
$$\partial_{th} U(\mathbf{r}) = \iint \text{an. de campo total} \quad \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

Este termo representa a anomalia de campo total (aproximada) produzida no ponto \mathbf{r} por um dipolo localizado em \mathbf{r}''

$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

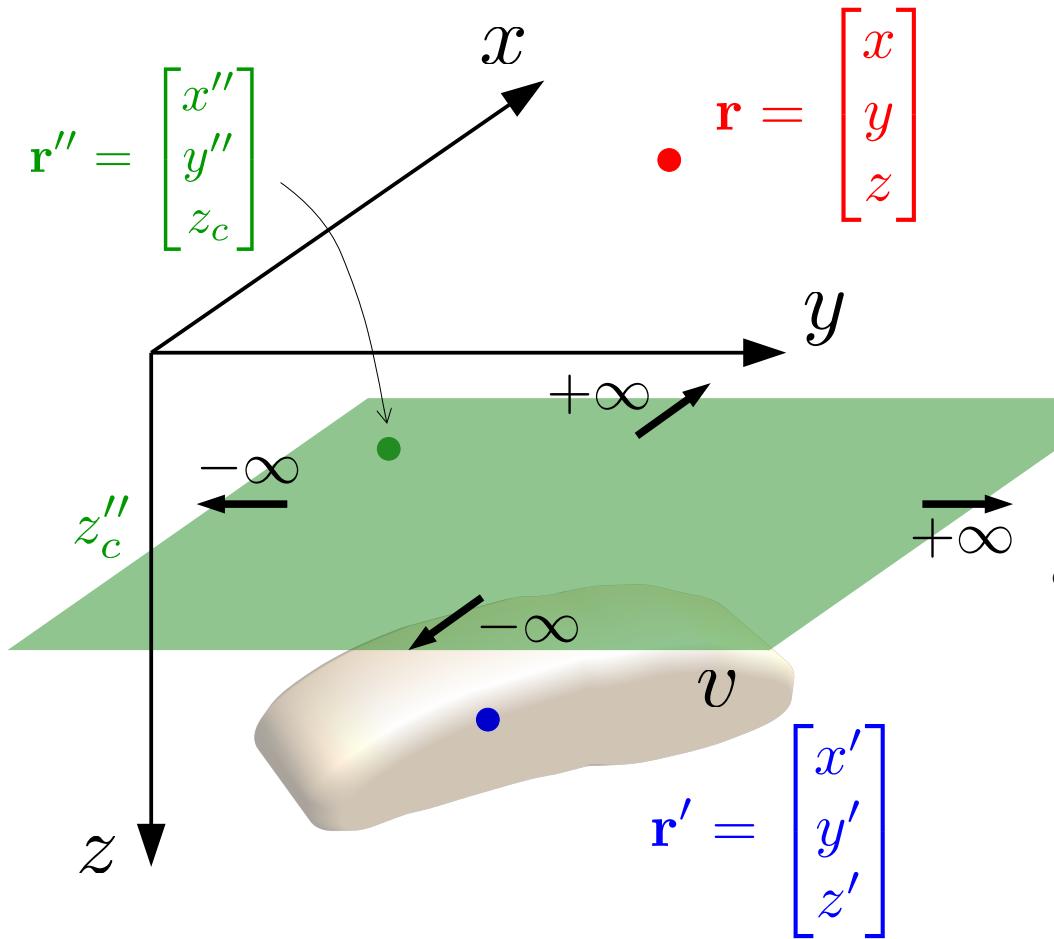
an. de campo total

Esta equação prova a existência de uma camada de dipolos que é plana, infinita, contínua, está localizada sobre a fonte e reproduz exatamente a an. de campo total em qualquer ponto \mathbf{r} acima do plano da camada

$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



$$\partial_{th} U(\mathbf{r}) = \iint_{\text{an. de campo total}} \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

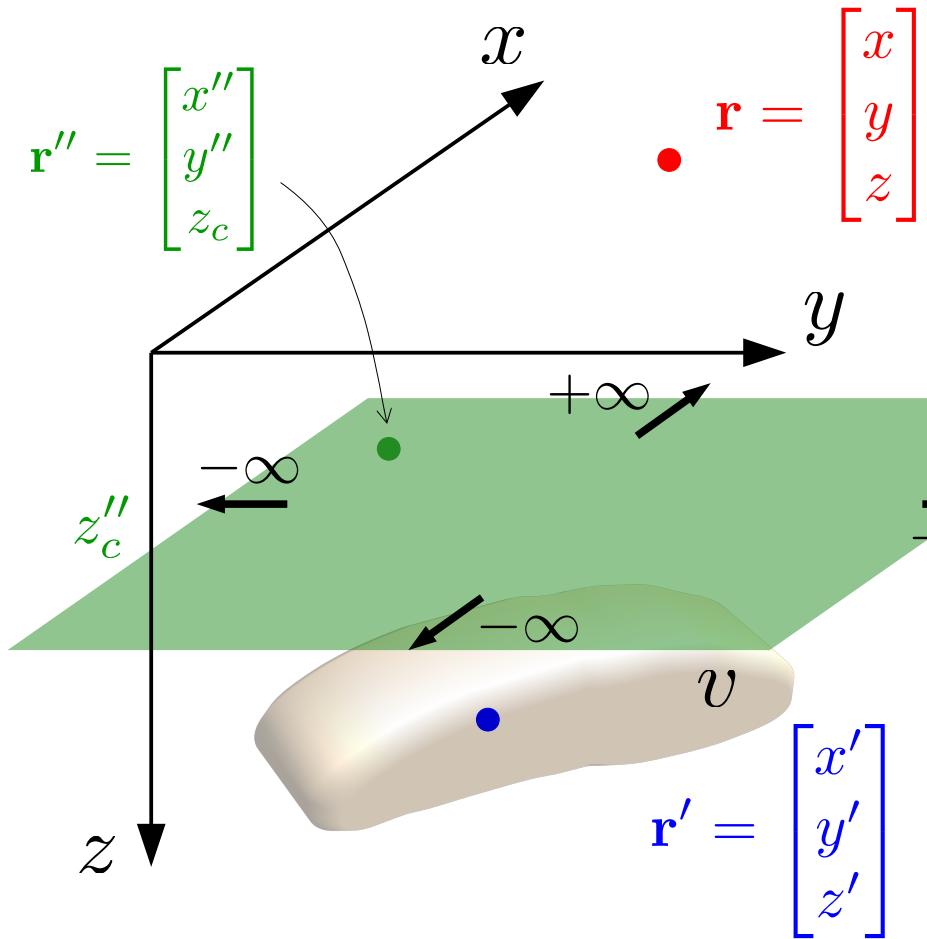
camada

Esta equação prova a existência de uma camada de dipolos que é plana, infinita, contínua, está localizada sobre a fonte e reproduz exatamente a an. de campo total em qualquer ponto \mathbf{r} acima do plano da camada

$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

an. de campo total

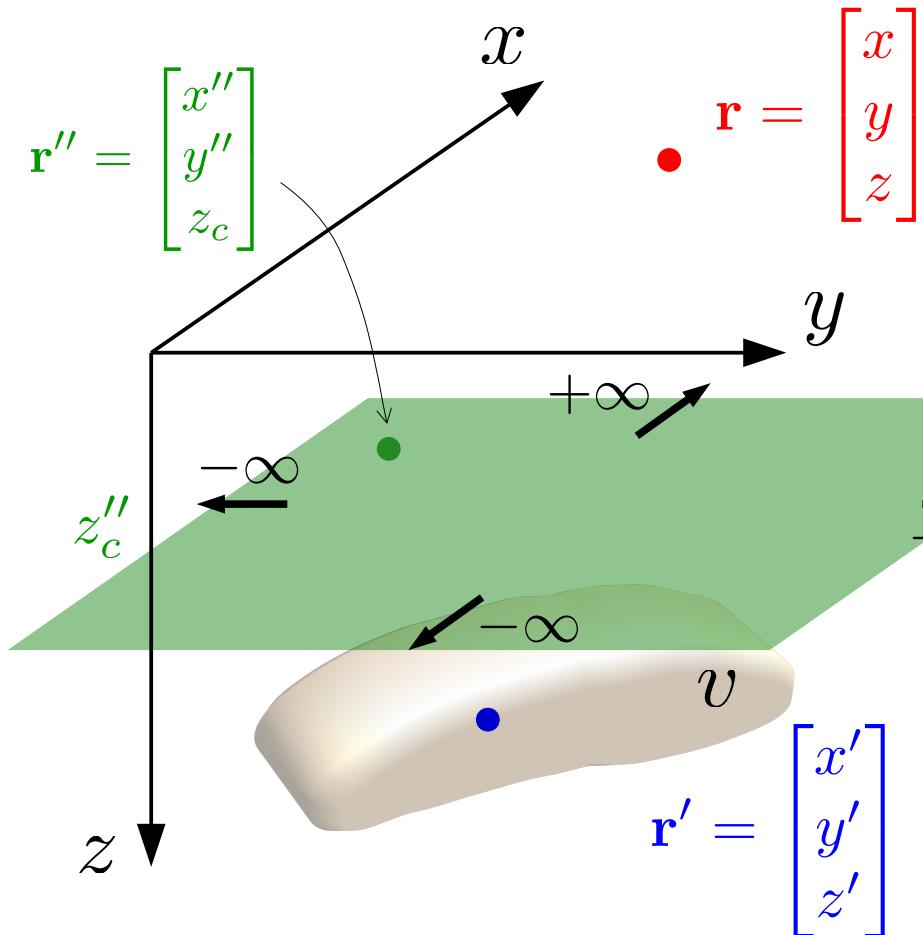
$$\partial_{zz} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

anomalia RTP

$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

an. de campo total

$$\partial_{zz} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

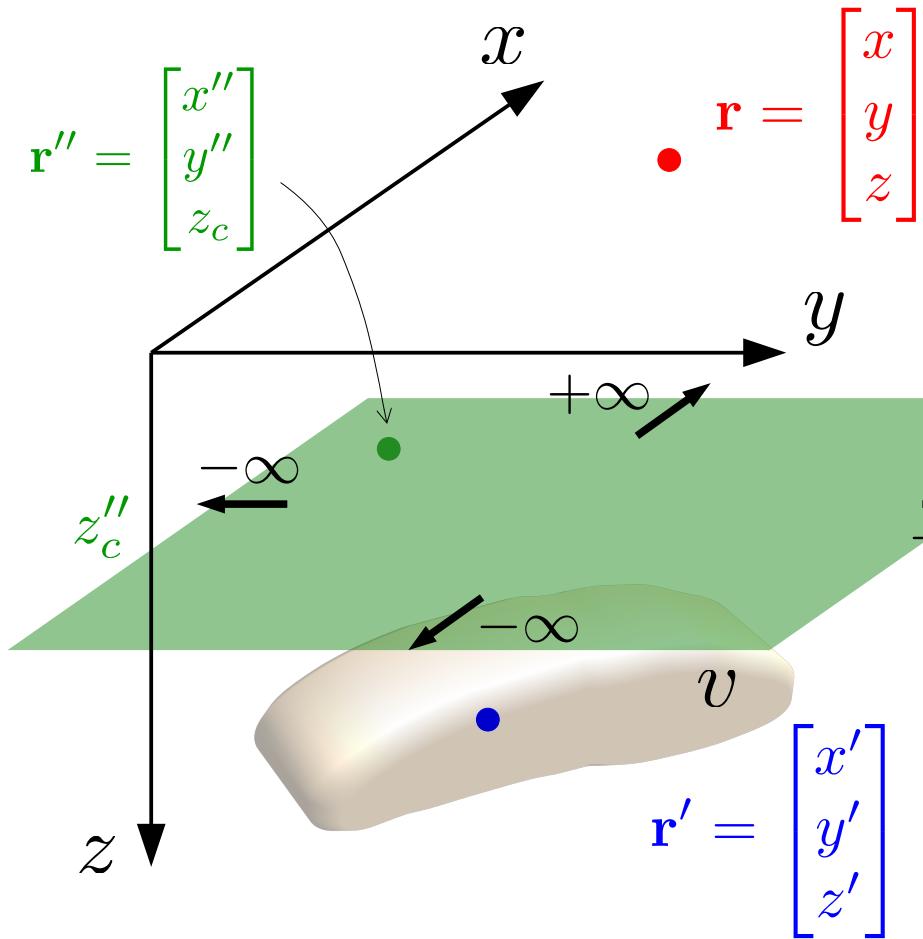
anomalia RTP

Esta equação mostra que a mesma camada também reproduz exatamente a anomalia RTP

$$U(\mathbf{r}) = \kappa \int_v \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

an. de campo total

$$\partial_{zz} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

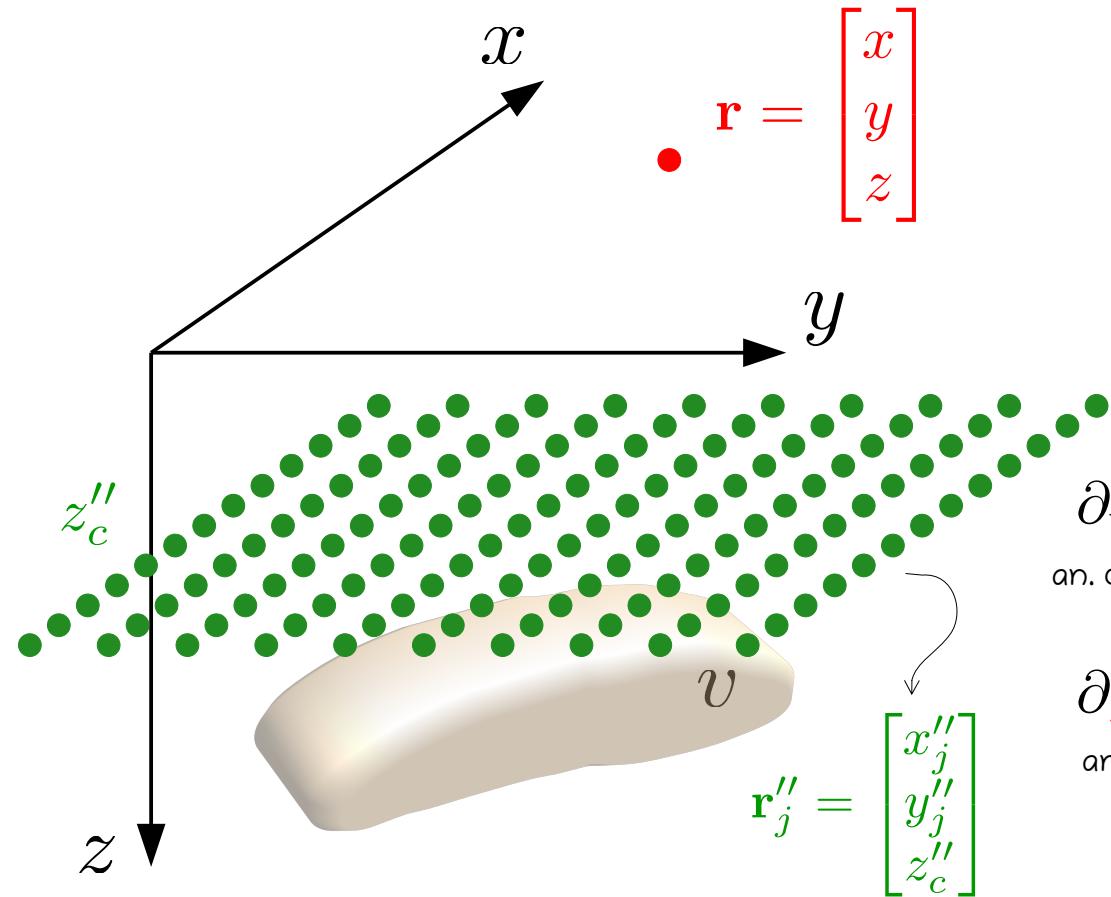
anomalia RTP

Seguindo uma abordagem ligeiramente diferente da que apresentada aqui, [Reis et al. \(2020\)](#) foram os primeiros a mostrar estas equações

$$U(\mathbf{r}) = \kappa \int_v^{} \iiint \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

Sabemos que (e.g., [Roy, 1962](#); [Reis et al., 2020](#)):

$$U(\mathbf{r}) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \partial_z U(\mathbf{r}'') \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

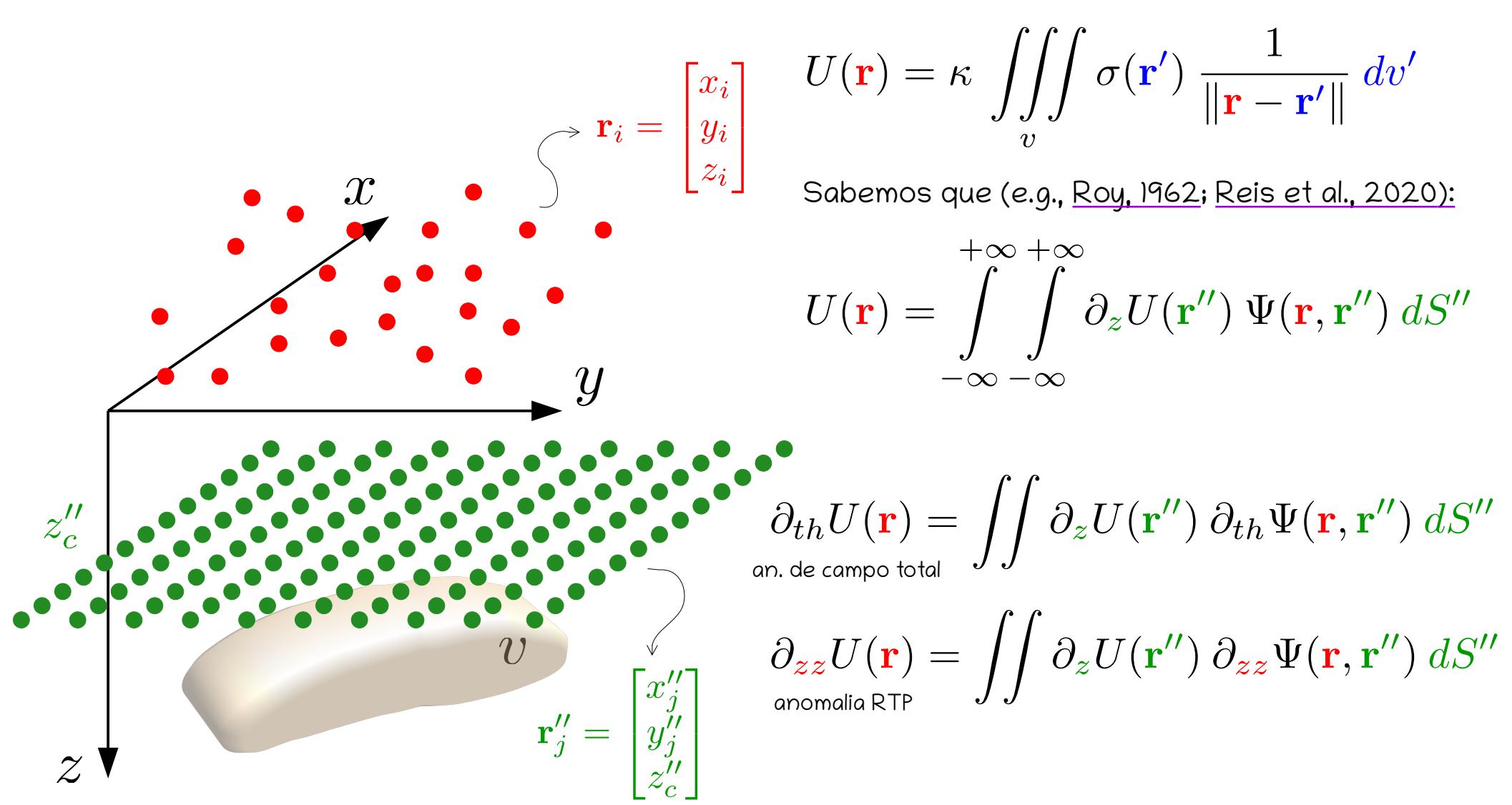


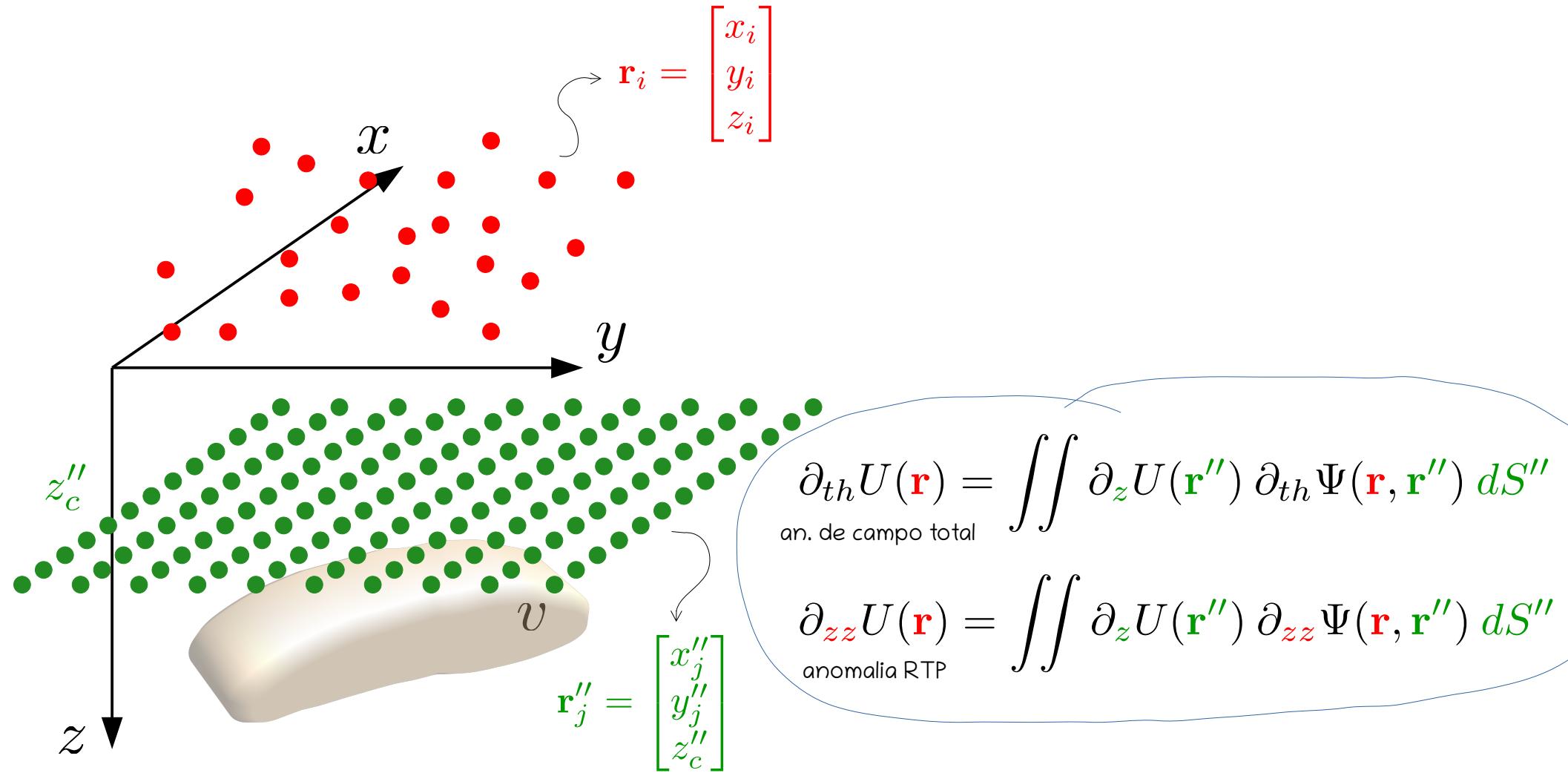
$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

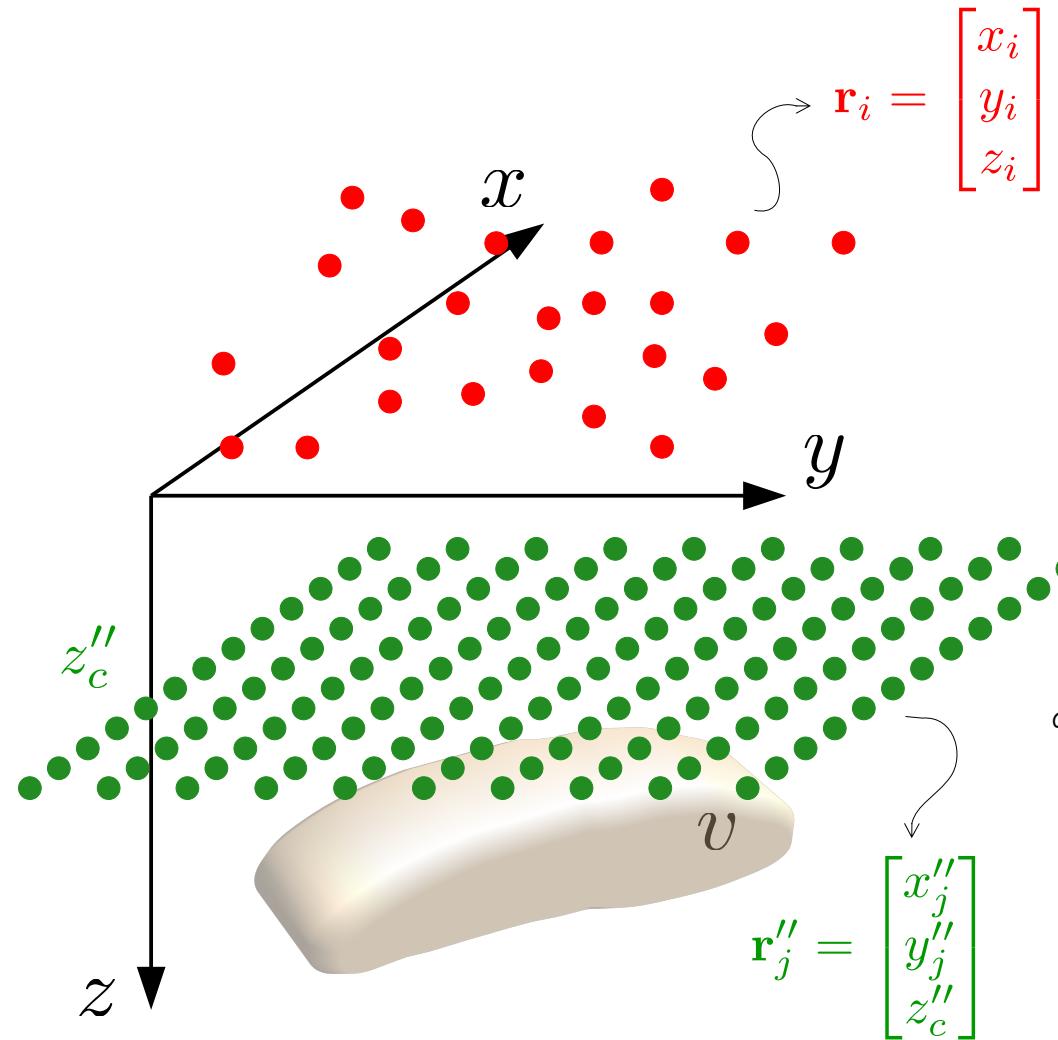
an. de campo total

$$\partial_{zz} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

anomalia RTP



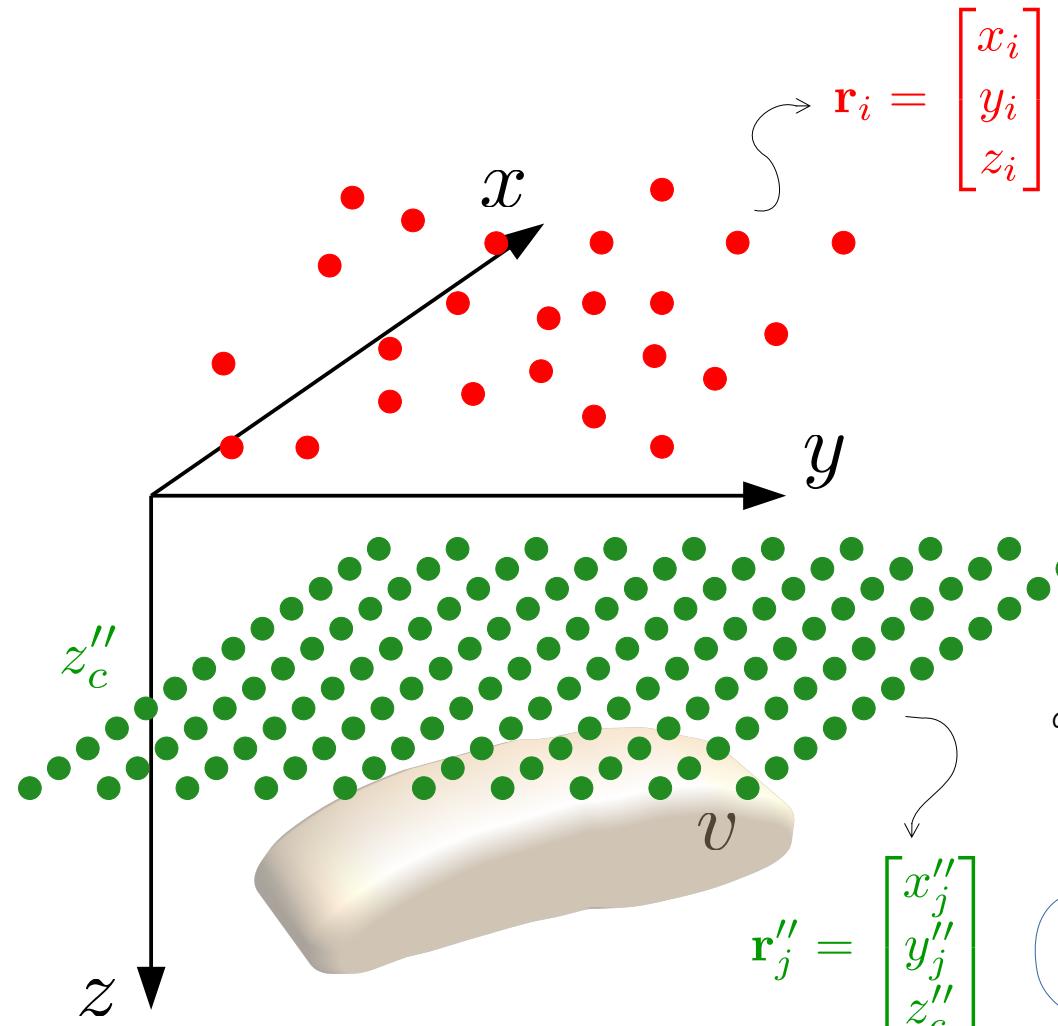




$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M \partial_z U(\mathbf{r}_j'') \Delta S_j'' \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$
 an. de campo total

$\partial_{zz} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$
 anomalia RTP



$$\partial_{th} U(\mathbf{r}_i) \approx \sum_{j=1}^M \partial_z U(\mathbf{r}_j'') \Delta S_j'' \partial_{th} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$$

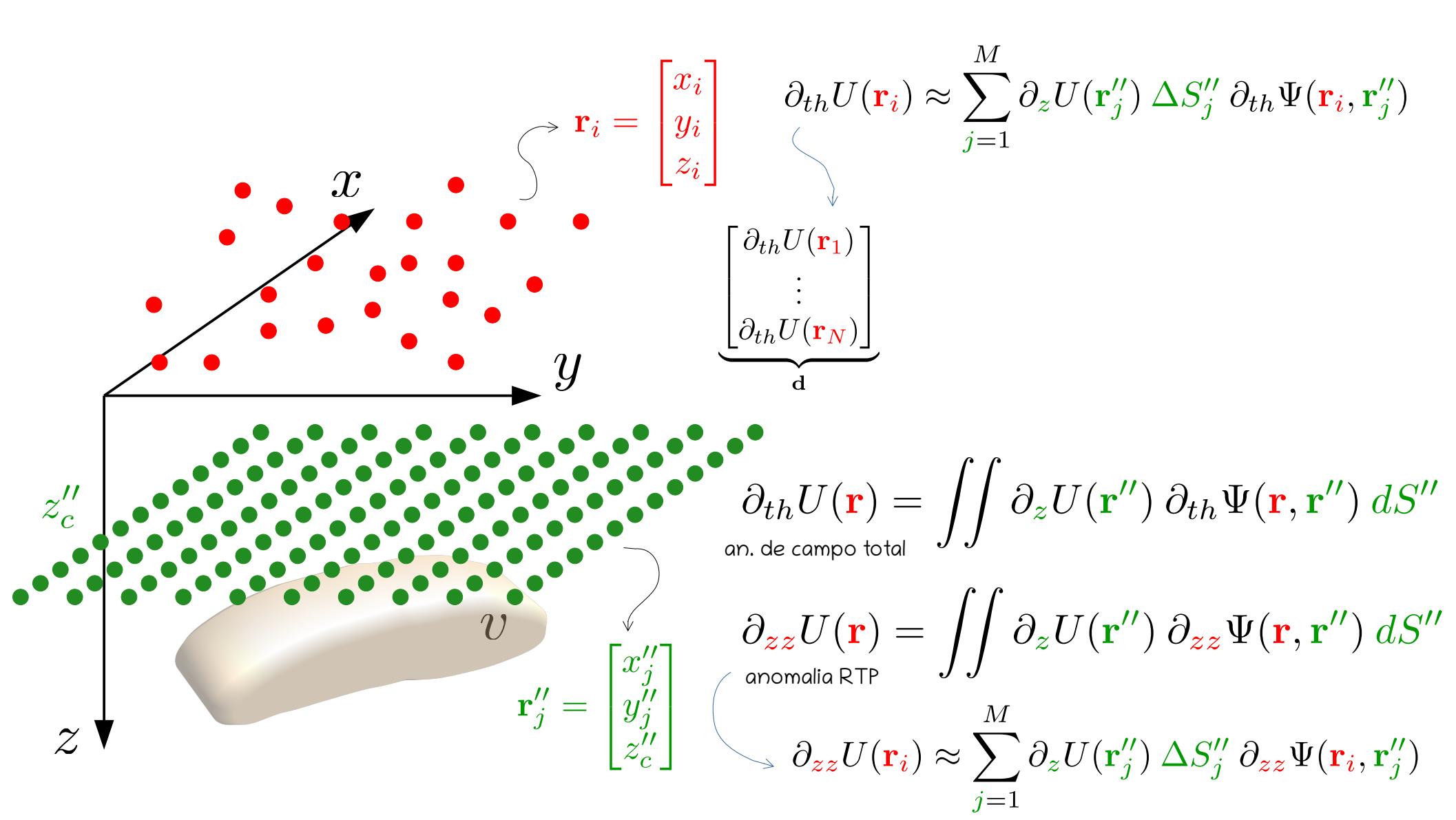
$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$

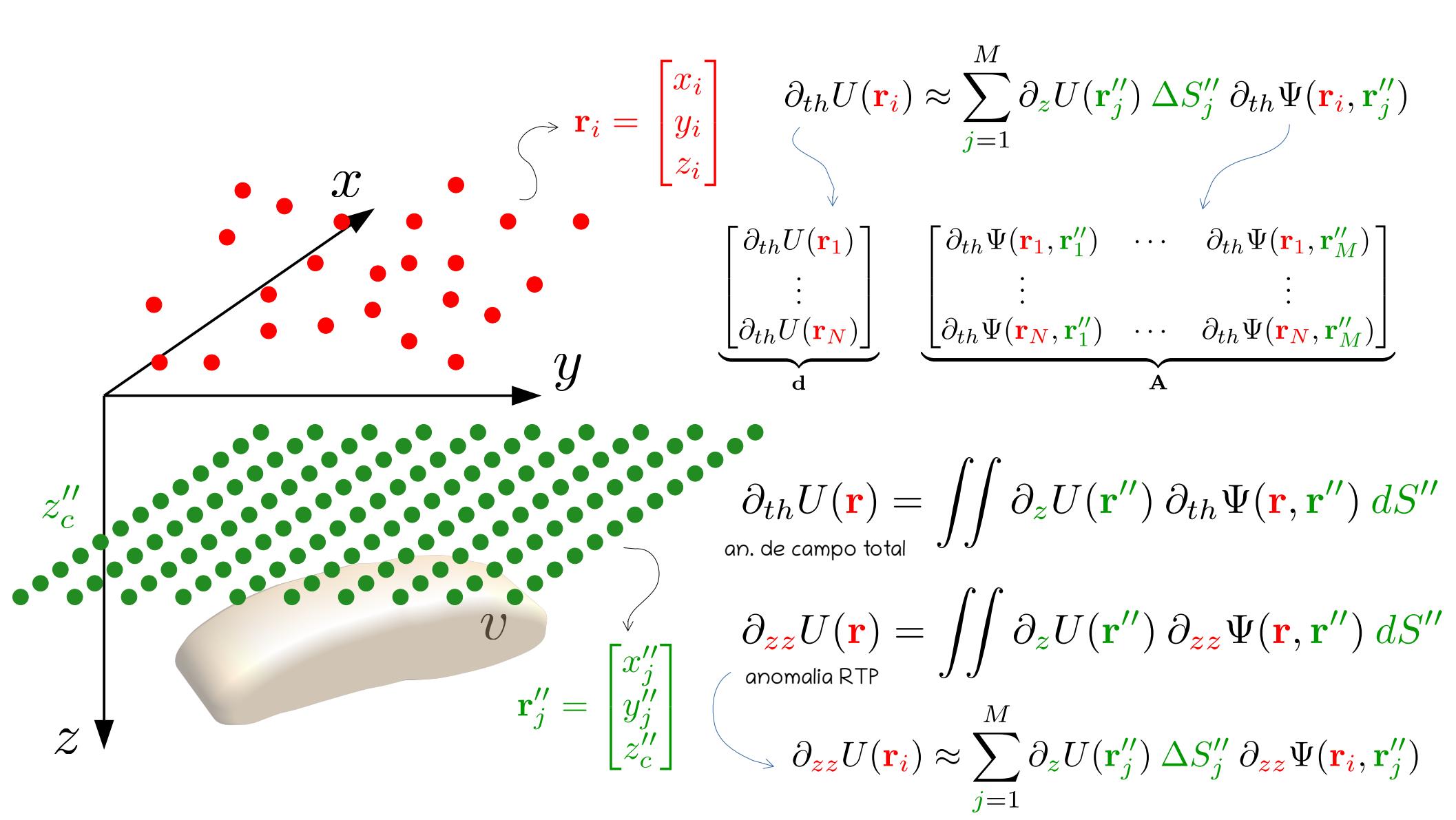
an. de campo total

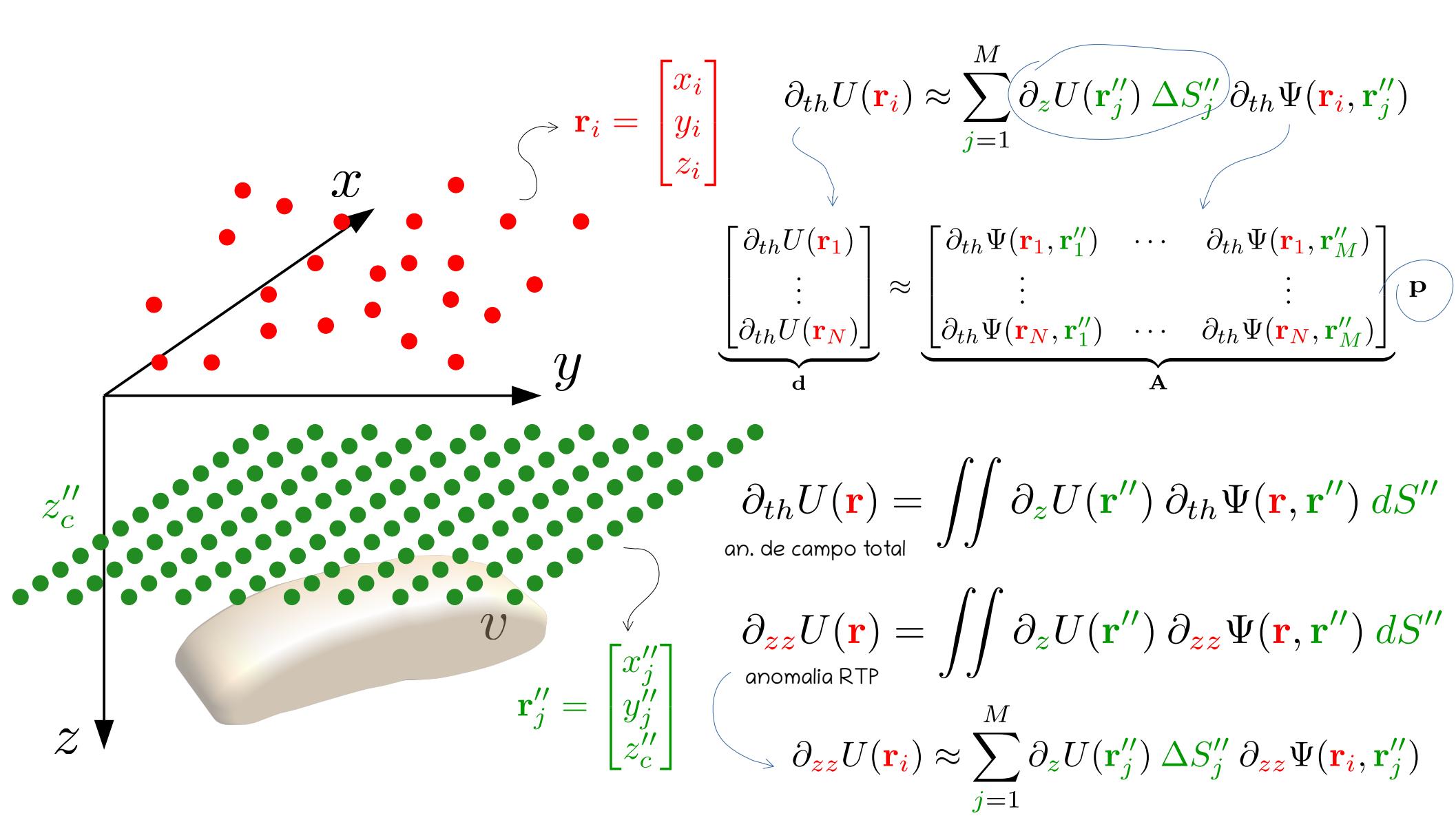
$\partial_{zz} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$

anomalia RTP

$\partial_{zz} U(\mathbf{r}_i) \approx \sum_{j=1}^M \partial_z U(\mathbf{r}_j'') \Delta S_j'' \partial_{zz} \Psi(\mathbf{r}_i, \mathbf{r}_j'')$

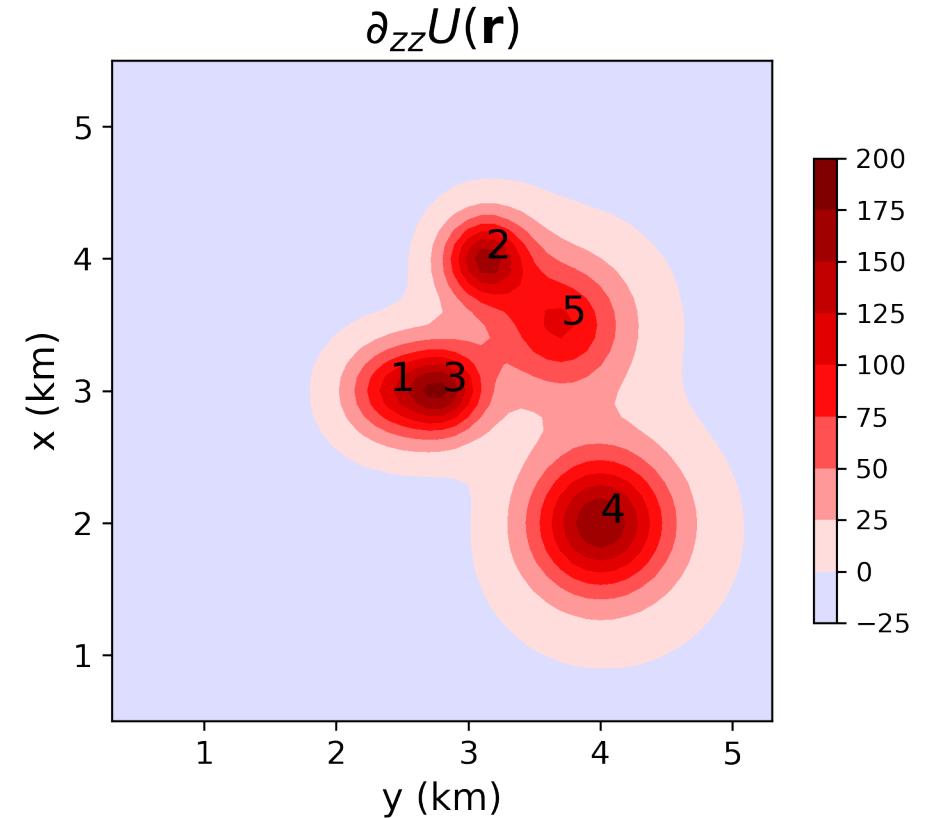
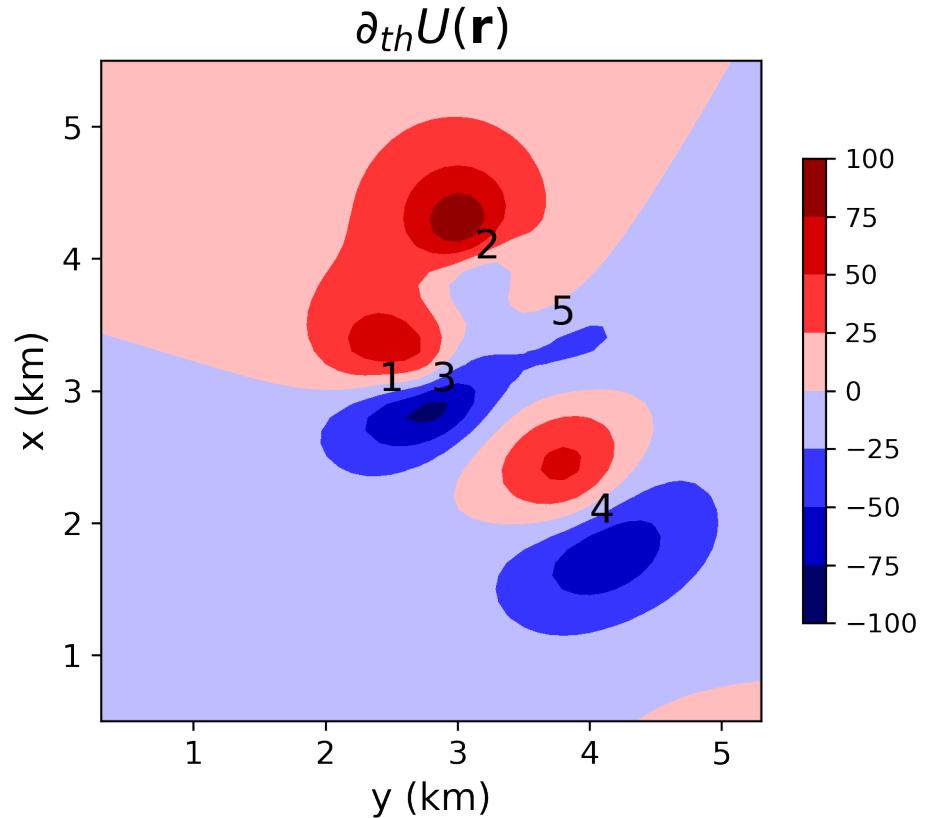






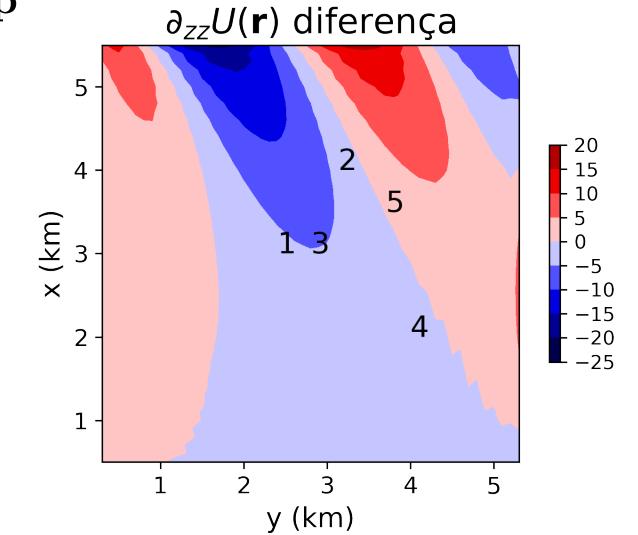
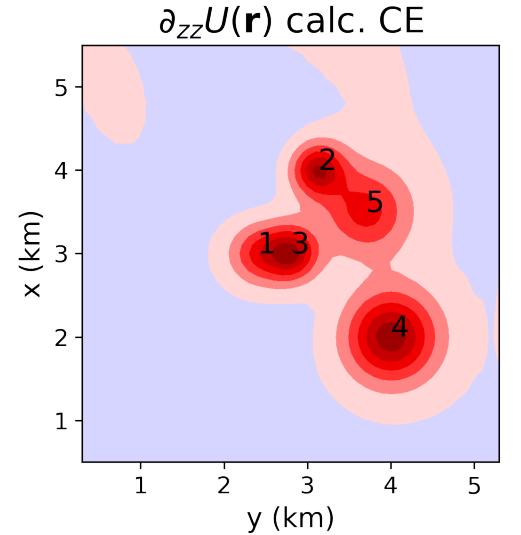
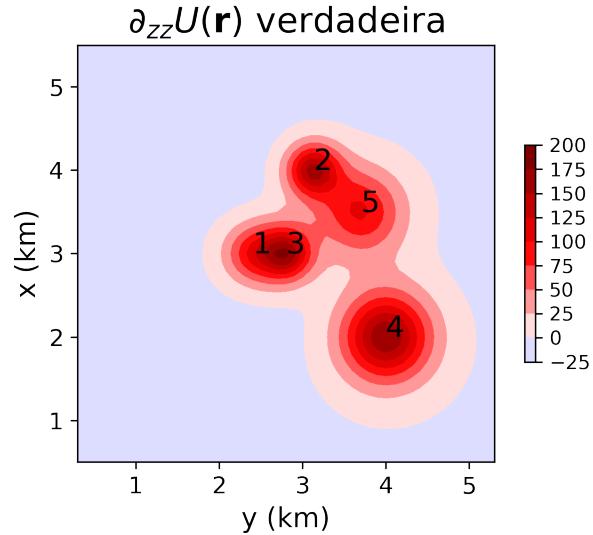
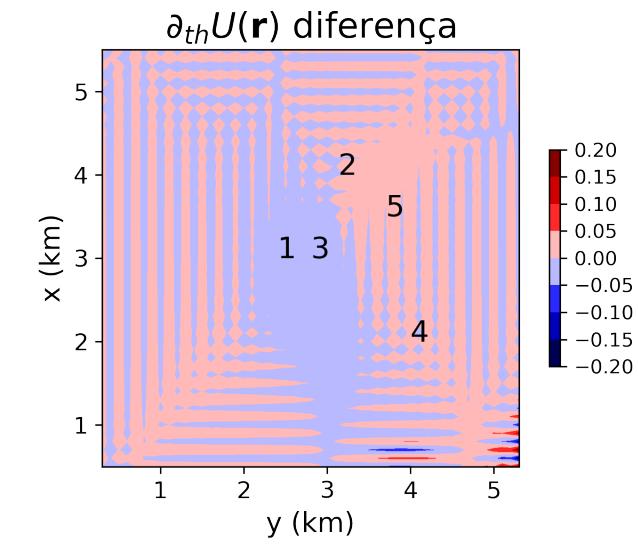
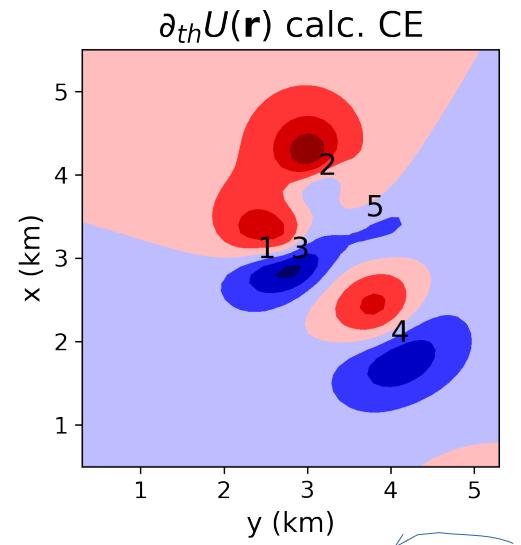
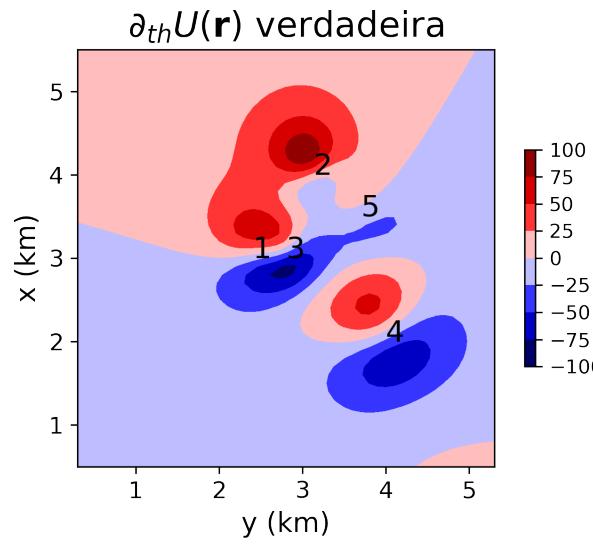
$$I_t = -25^\circ \quad I_h = -30^\circ$$

$$D_t = -30^\circ \quad D_h = -19^\circ$$

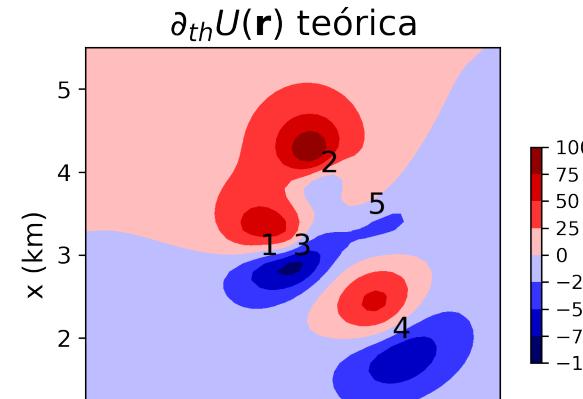
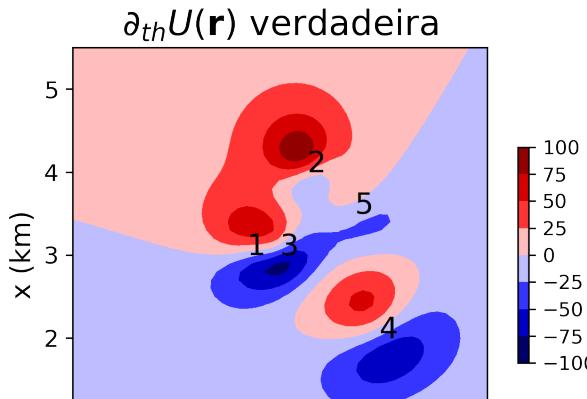


$$I_t = -25^\circ \quad D_t = -30^\circ \quad I_h = -30^\circ \quad D_h = -19^\circ$$

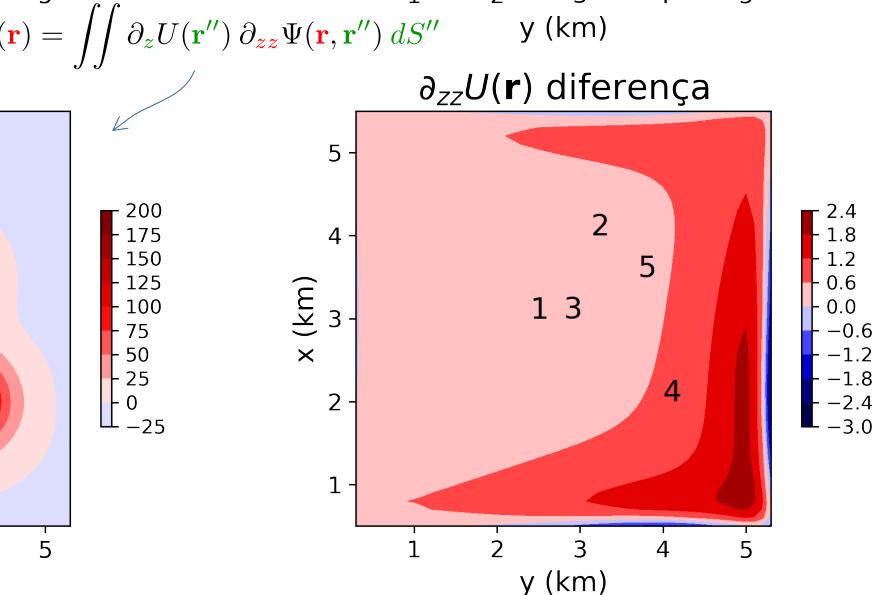
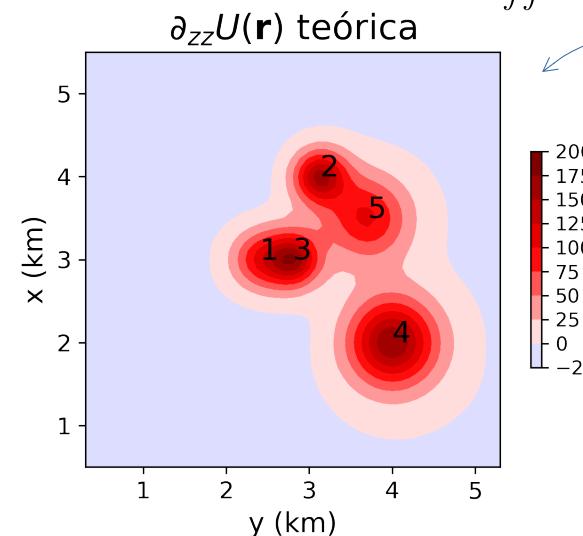
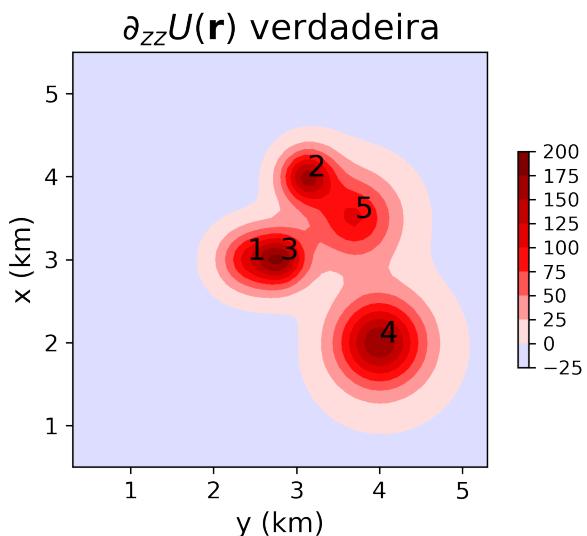
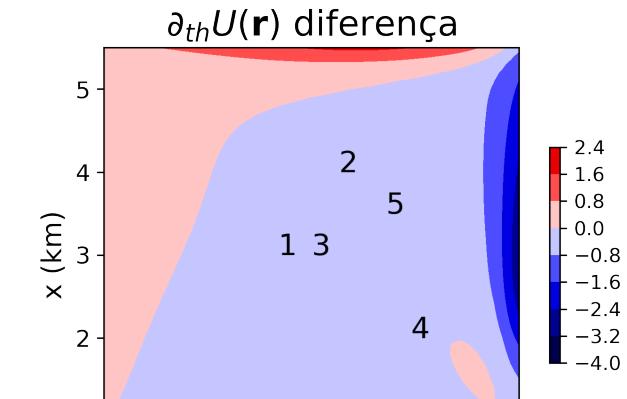
$$\mathbf{d} \approx \mathbf{A} \mathbf{p}$$



$$I_t = -25^\circ \quad D_t = -30^\circ \quad I_h = -30^\circ \quad D_h = -19^\circ$$



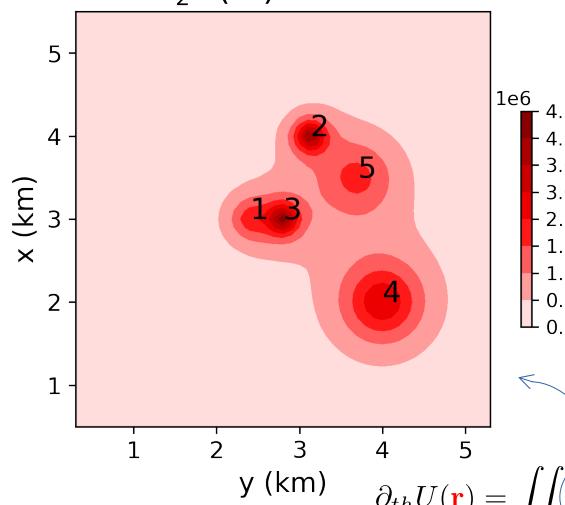
$$\partial_{th}U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



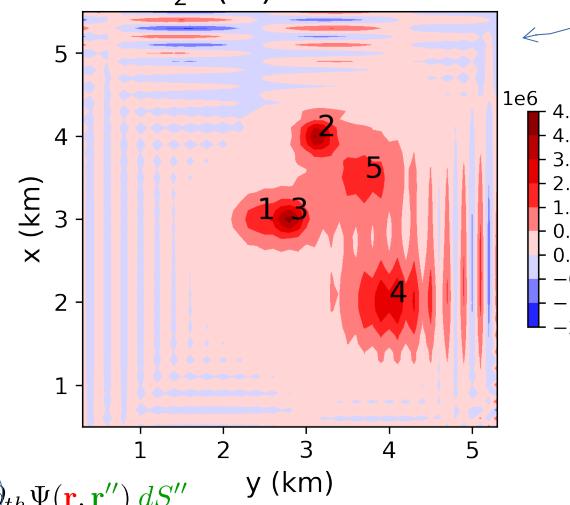
$$I_t = -25^\circ \quad D_t = -30^\circ \quad I_h = -30^\circ \quad D_h = -19^\circ$$

$$\mathbf{d} \approx \mathbf{A}\mathbf{p}$$

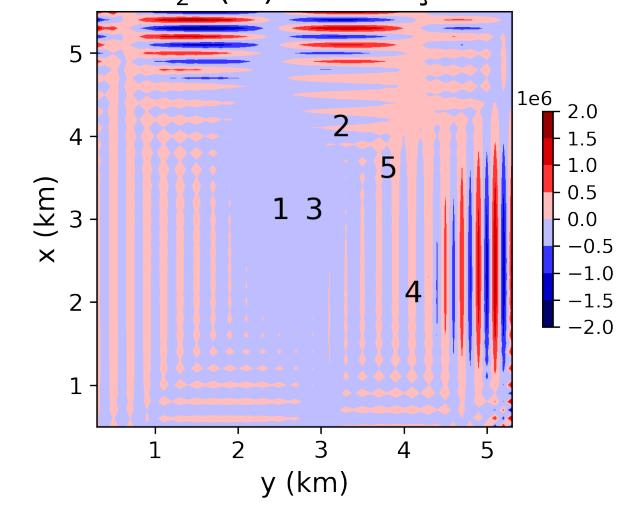
$\partial_z U(\mathbf{r}'')$ teórica



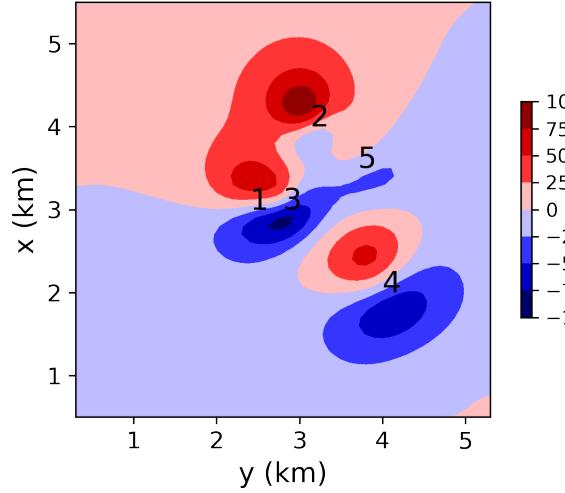
$\partial_z U(\mathbf{r}'')$ calc. CE



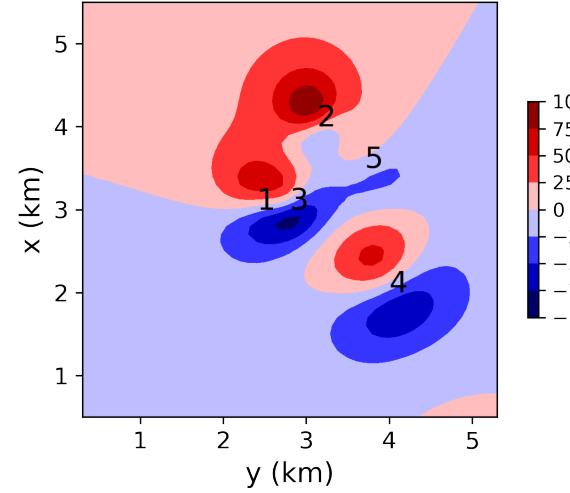
$\partial_z U(\mathbf{r}'')$ diferença



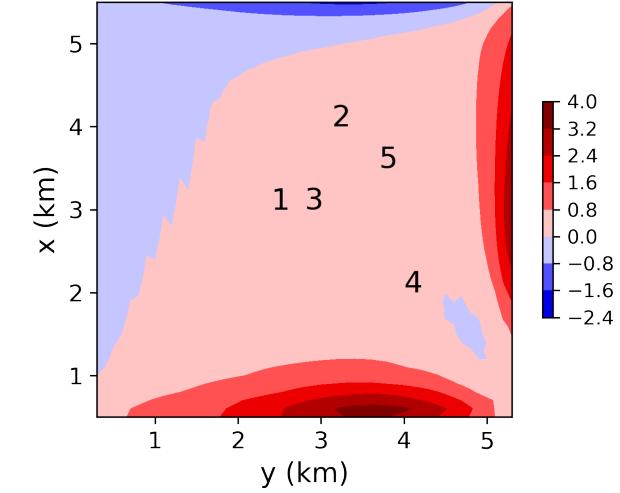
$\partial_{th}U(\mathbf{r})$ teórica



$\partial_{th}U(\mathbf{r})$ calc. CE



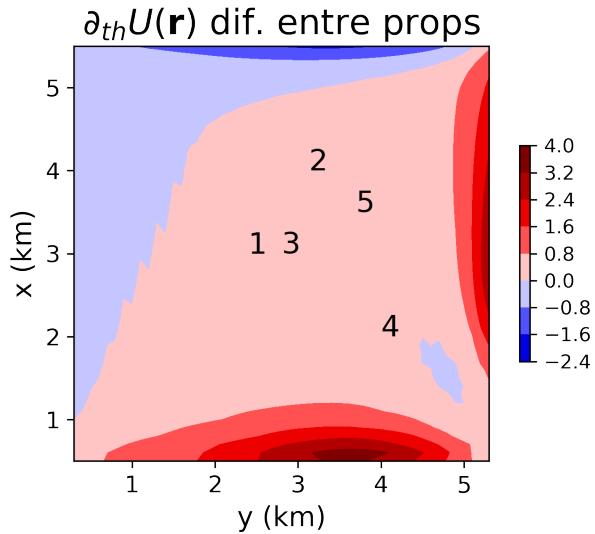
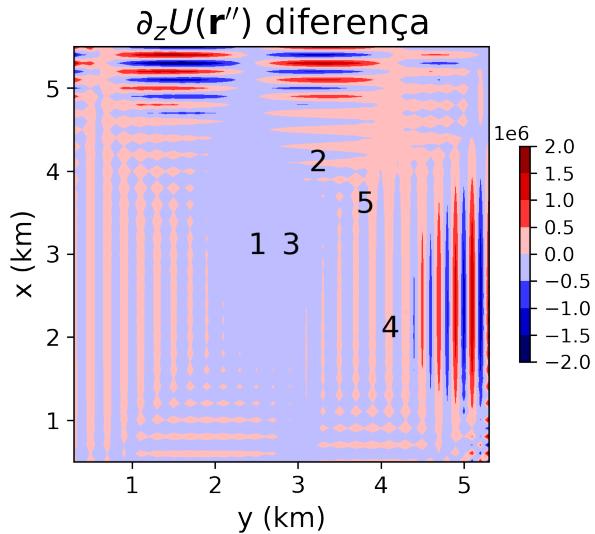
$\partial_{th}U(\mathbf{r})$ dif. entre props



$$\partial_{th}U(\mathbf{r}) = \iint (\partial_z U(\mathbf{r}'')) \partial_{th}\Psi(\mathbf{r}, \mathbf{r}'') dS''$$

$$I_t = -25^\circ \quad D_t = -30^\circ \quad I_h = -30^\circ \quad D_h = -19^\circ$$

A camada de dipolos obtida a partir da diferença entre a CE e a teórica parece produzir um campo nulo, isto é, parece ser um aniquilador

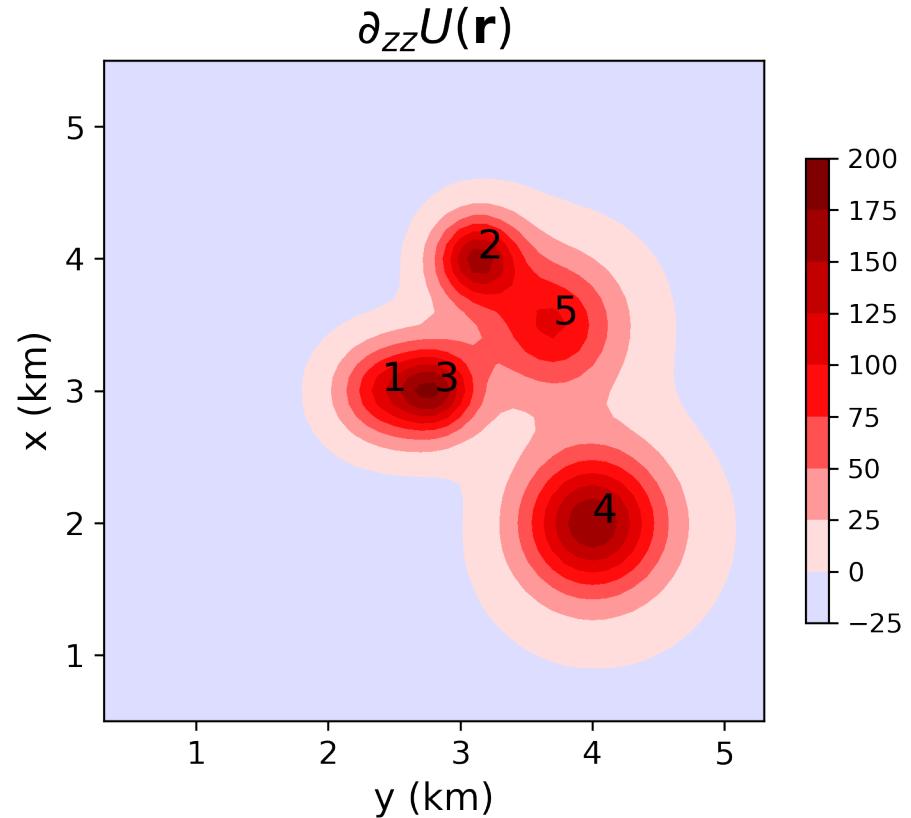
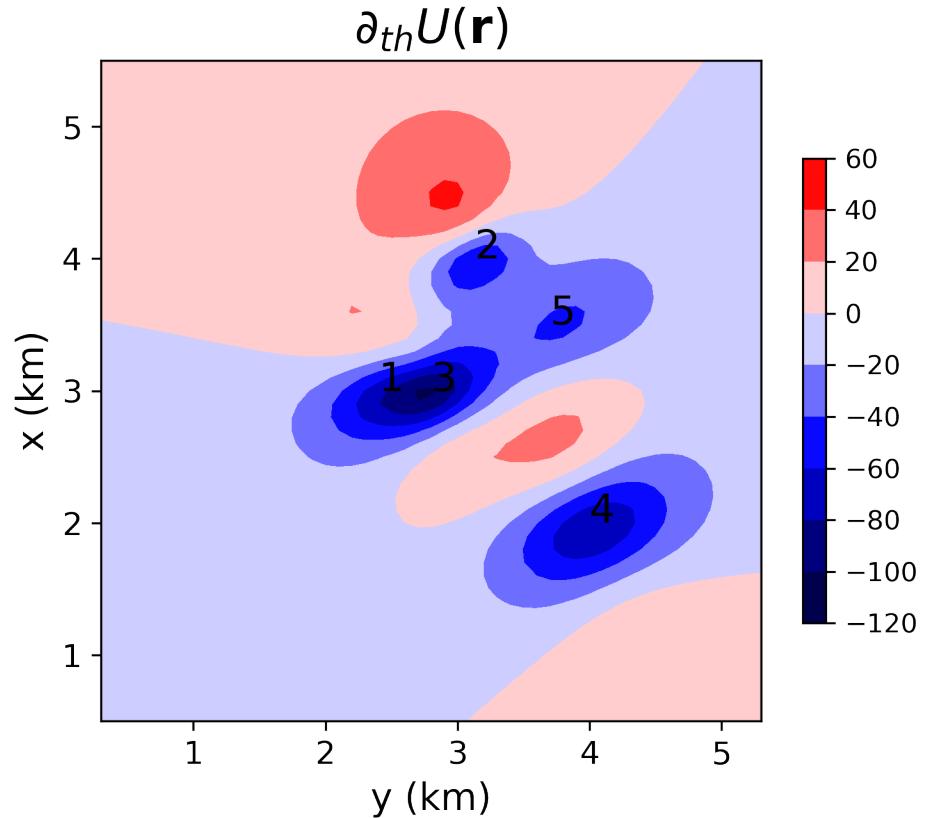


$$I_t = -5^\circ$$

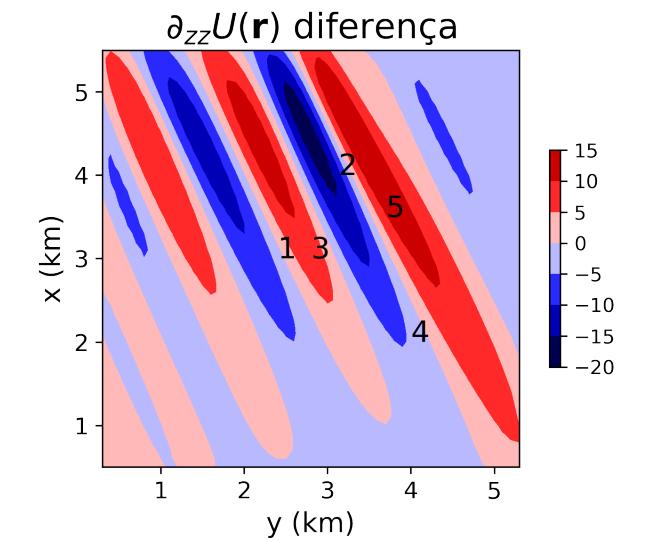
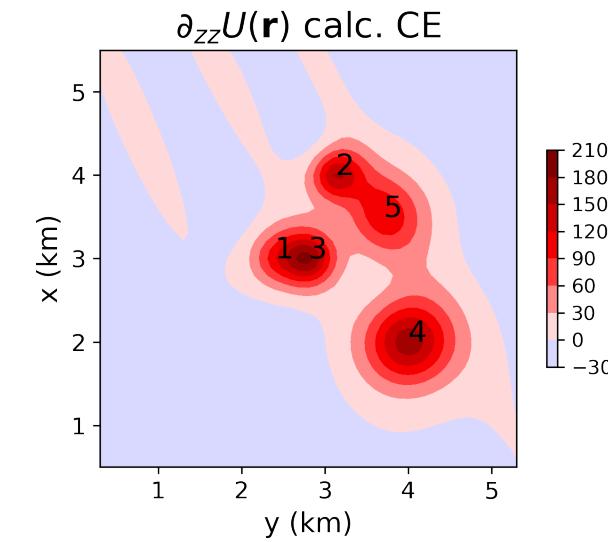
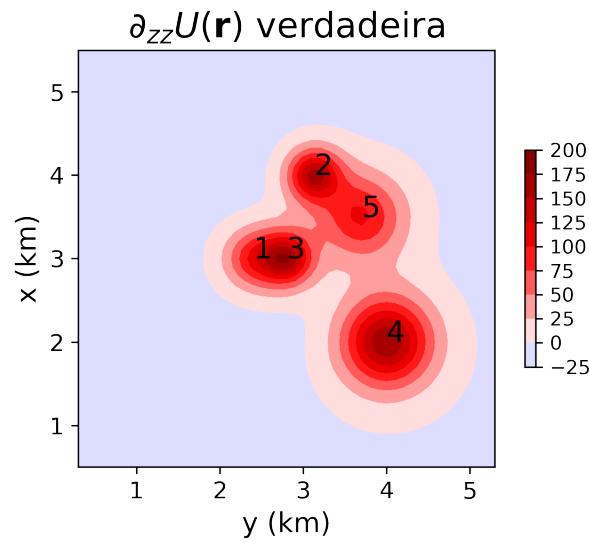
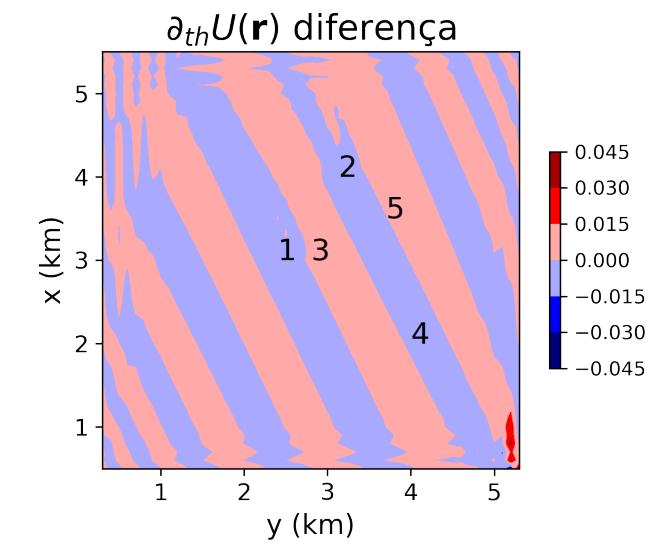
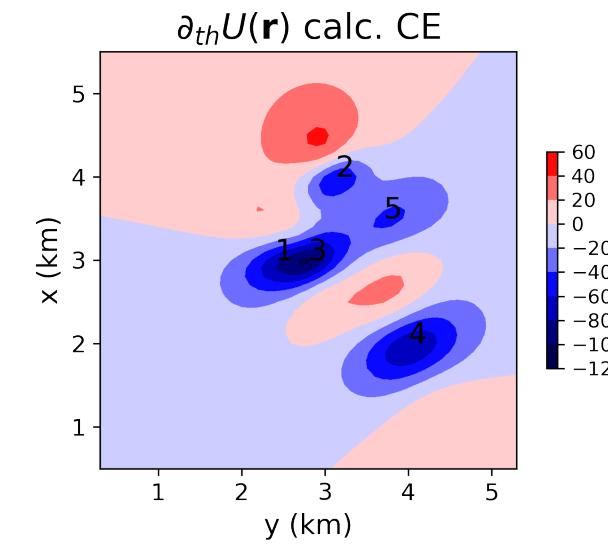
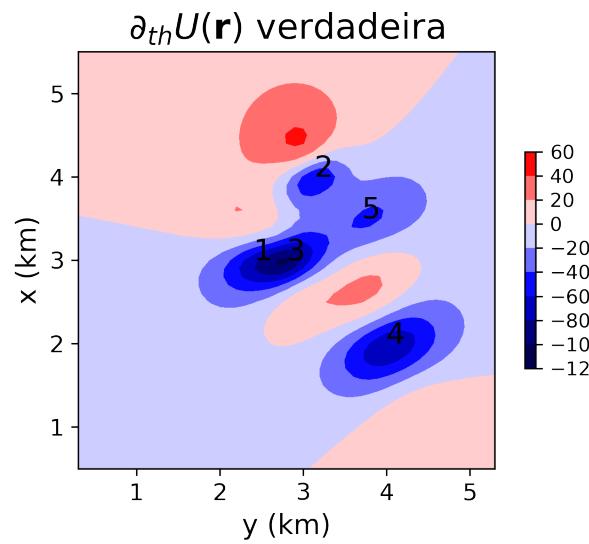
$$I_h = -6^\circ$$

$$D_t = -30^\circ$$

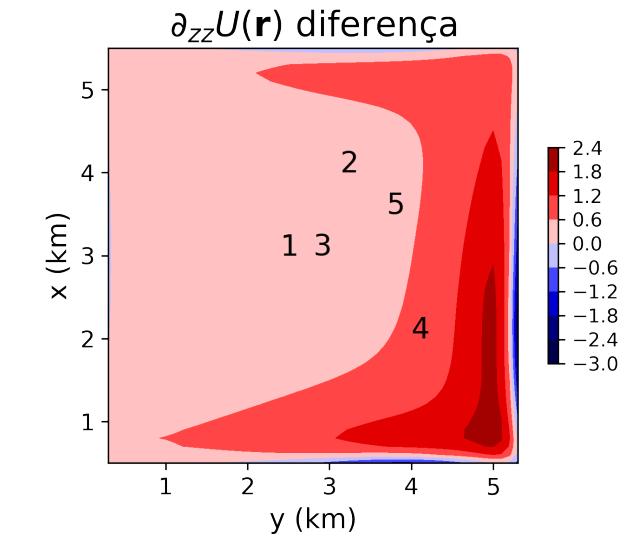
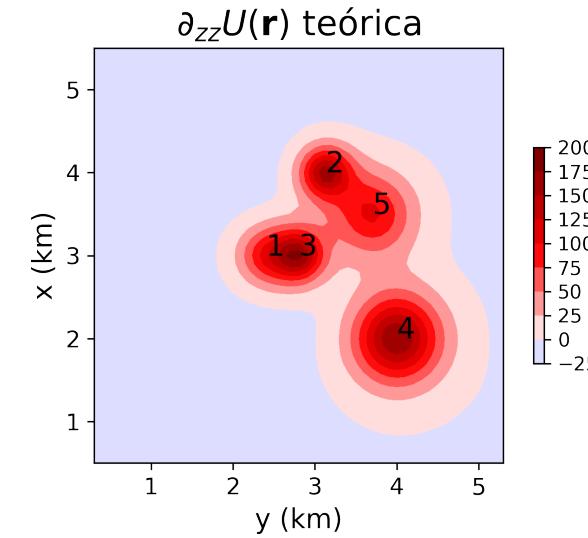
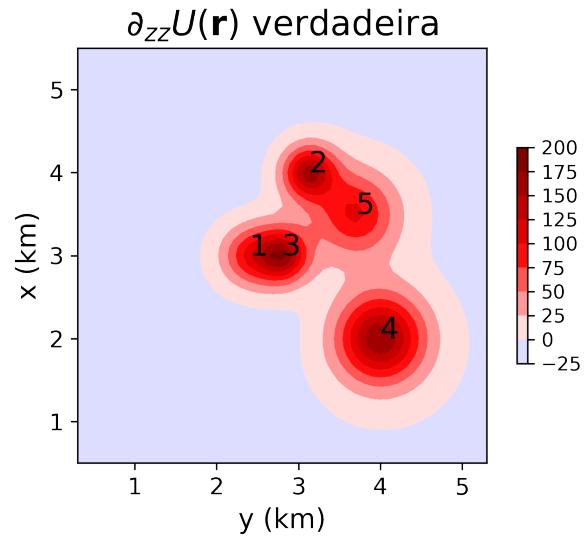
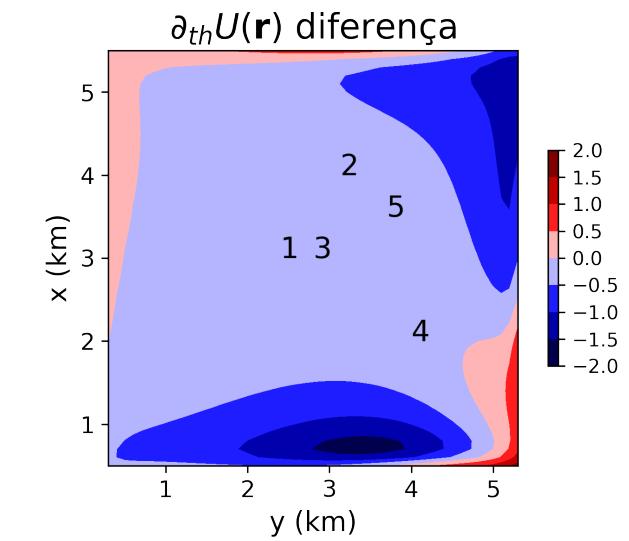
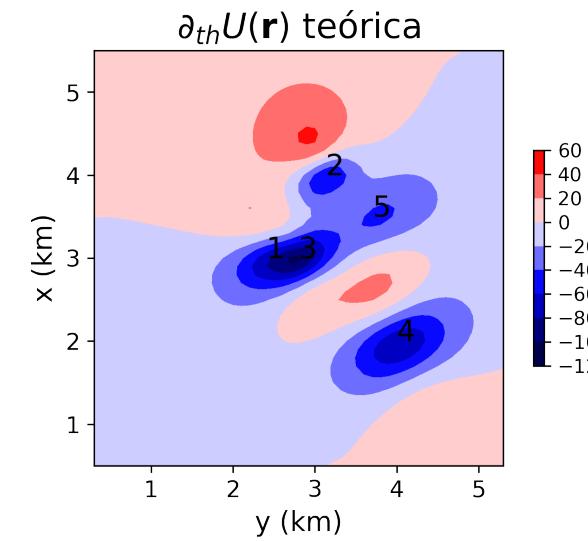
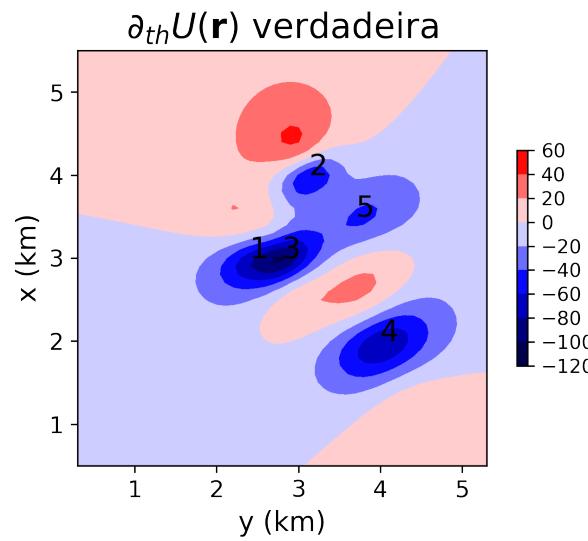
$$D_h = -19^\circ$$



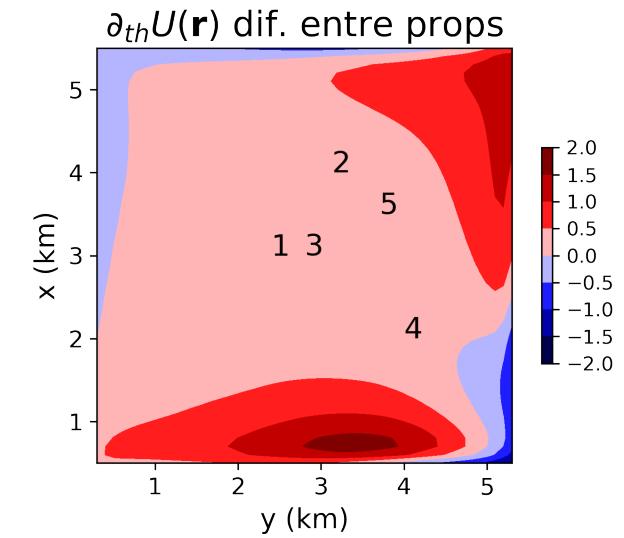
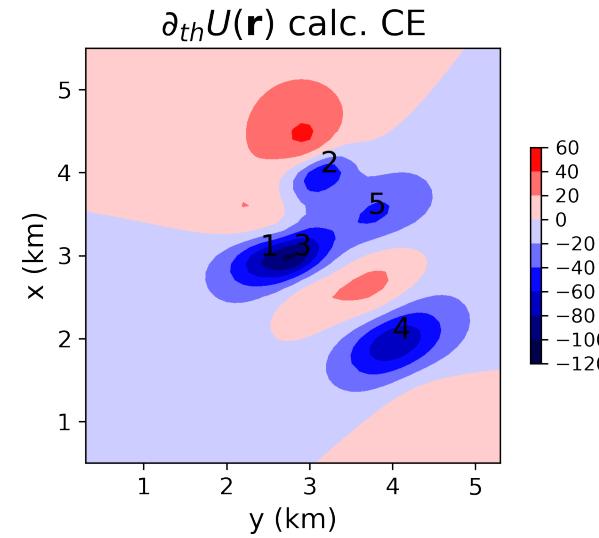
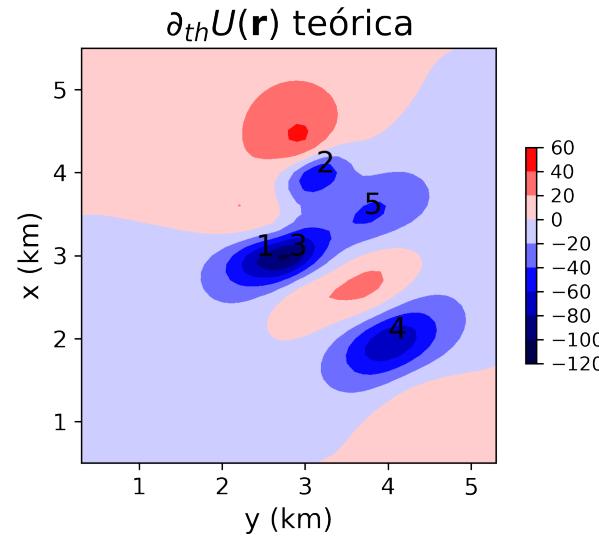
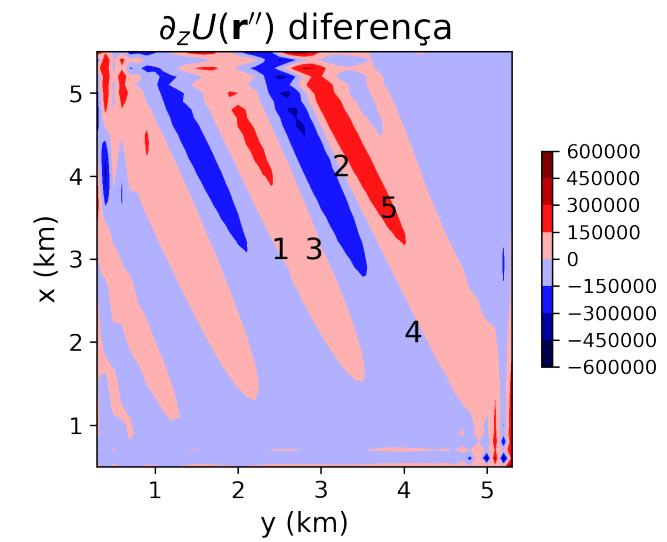
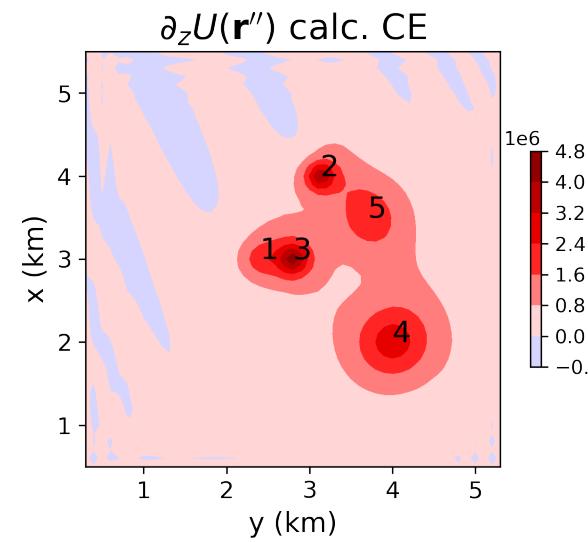
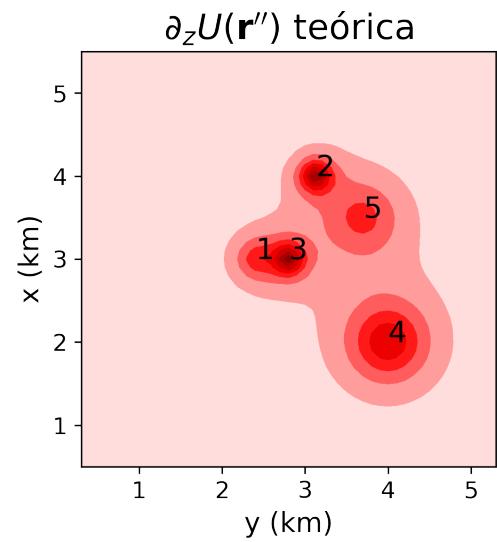
$$I_t = -5^\circ \quad D_t = -30^\circ \quad I_h = -6^\circ \quad D_h = -19^\circ$$

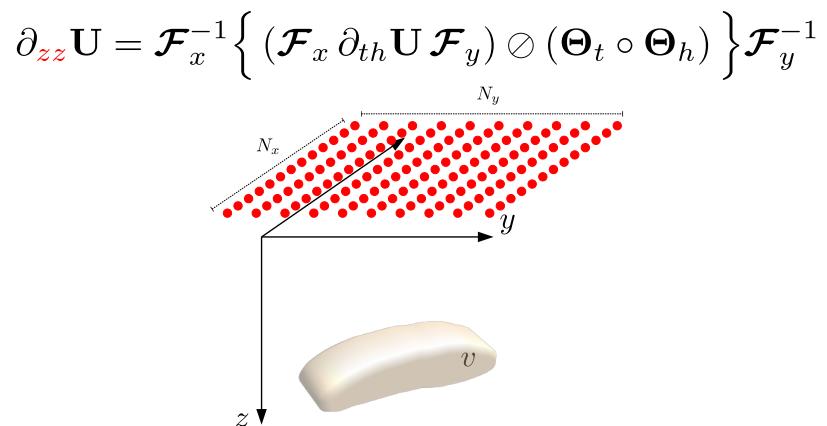
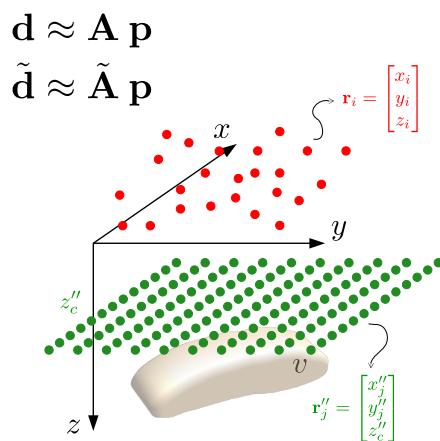
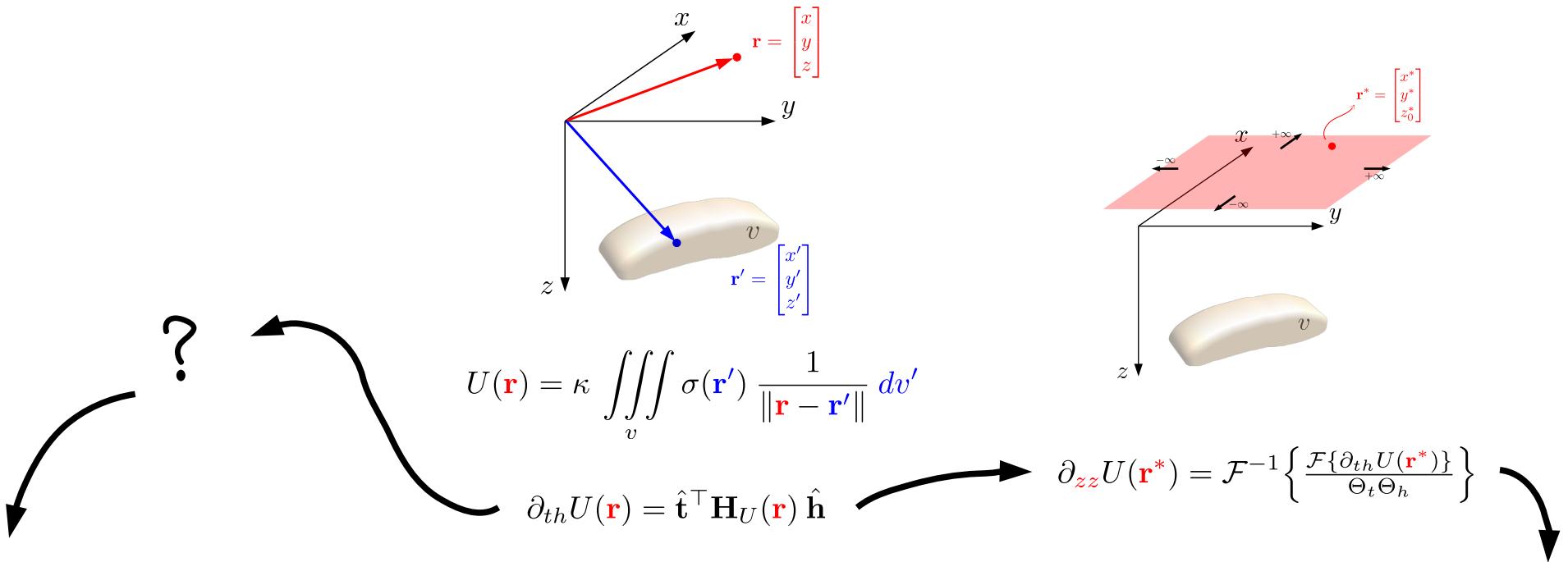


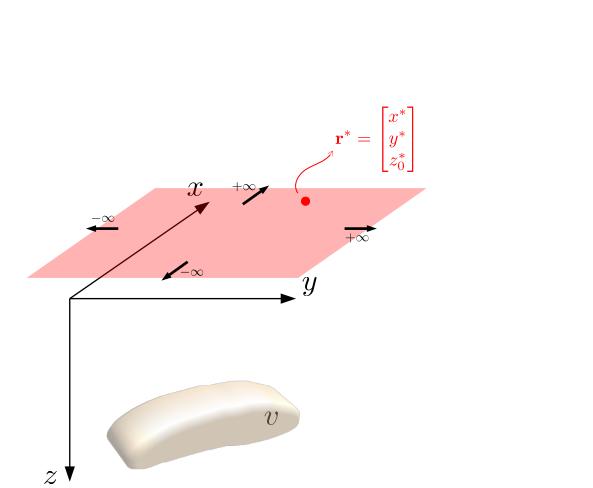
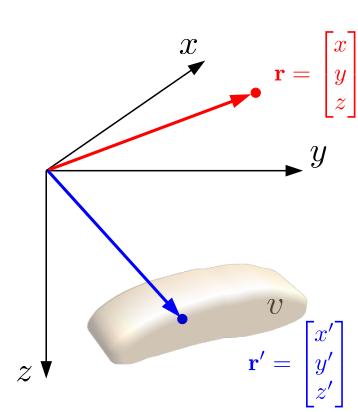
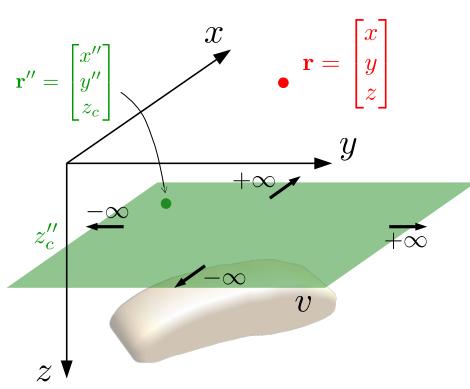
$$I_t = -5^\circ \quad D_t = -30^\circ \quad I_h = -6^\circ \quad D_h = -19^\circ$$



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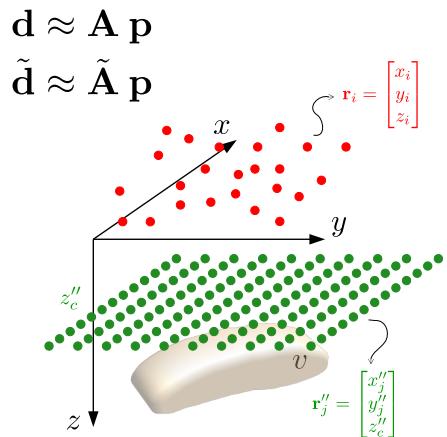
$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

$$\partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$

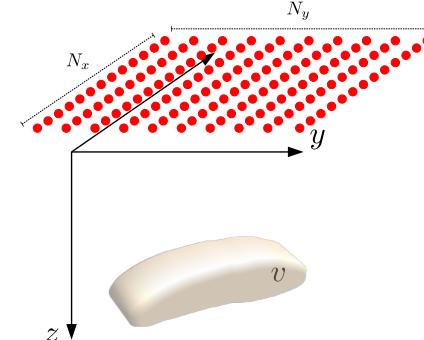
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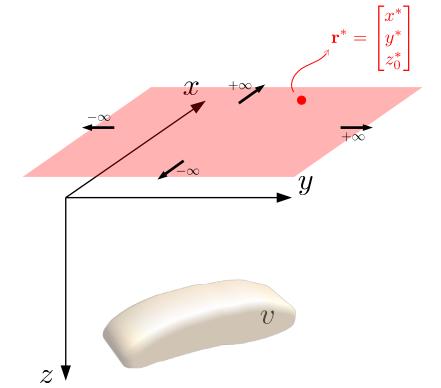
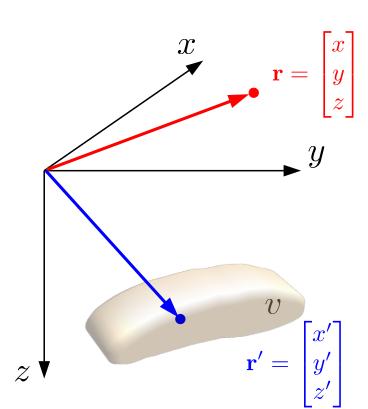
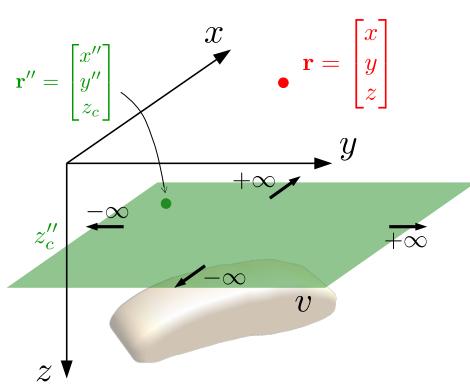
$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

↙



$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\boldsymbol{\Theta}_t \circ \boldsymbol{\Theta}_h) \right\} \mathcal{F}_y^{-1}$$





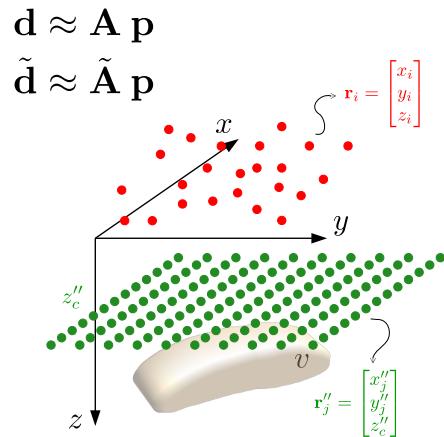
$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

$$\partial_{zz} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

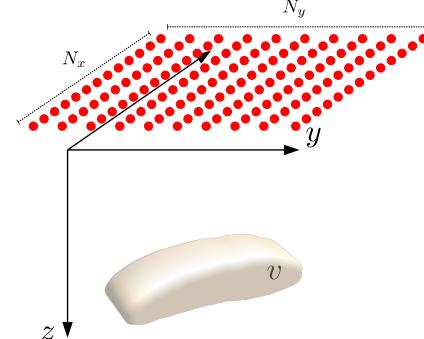
$$U(\mathbf{r}) = \kappa \iiint_v \sigma(\mathbf{r}') \frac{1}{\|\mathbf{r} - \mathbf{r}'\|} dv'$$

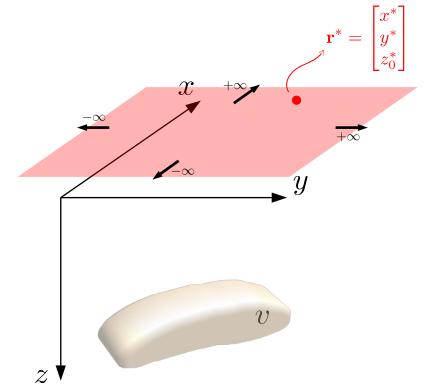
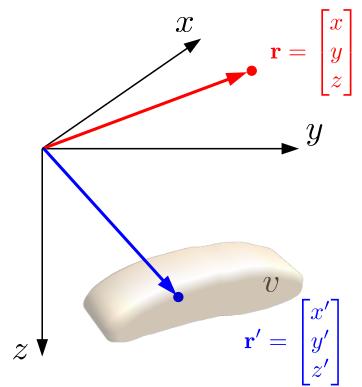
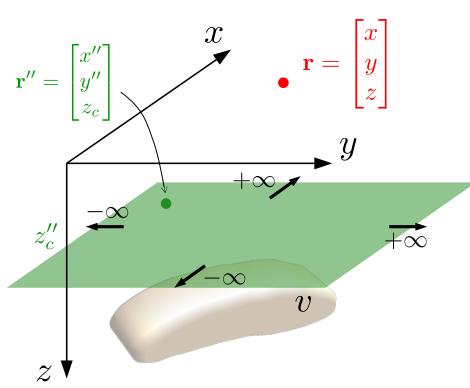
$$\partial_{th} U(\mathbf{r}) = \hat{\mathbf{t}}^\top \mathbf{H}_U(\mathbf{r}) \hat{\mathbf{h}}$$

$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$



$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\boldsymbol{\Theta}_t \circ \boldsymbol{\Theta}_h) \right\} \mathcal{F}_y^{-1}$$





$$\partial_{th} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{th} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

$$\partial_{zz} U(\mathbf{r}) = \iint \partial_z U(\mathbf{r}'') \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$

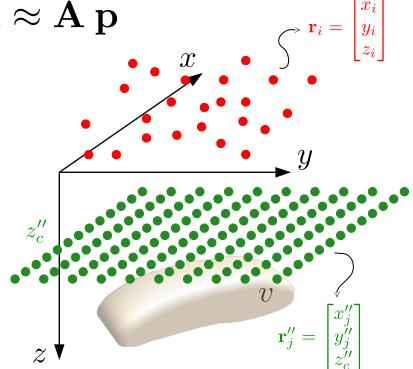
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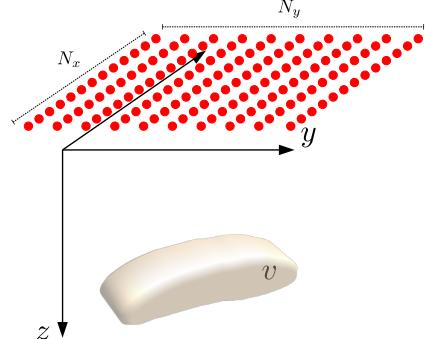
$$\partial_{zz} U(\mathbf{r}^*) = \mathcal{F}^{-1} \left\{ \frac{\mathcal{F}\{\partial_{th} U(\mathbf{r}^*)\}}{\Theta_t \Theta_h} \right\}$$

$$\mathbf{d} \approx \mathbf{A} \mathbf{p}$$

$$\tilde{\mathbf{d}} \approx \tilde{\mathbf{A}} \mathbf{p}$$



$$\partial_{zz} \mathbf{U} = \mathcal{F}_x^{-1} \left\{ (\mathcal{F}_x \partial_{th} \mathbf{U} \mathcal{F}_y) \oslash (\boldsymbol{\Theta}_t \circ \boldsymbol{\Theta}_h) \right\} \mathcal{F}_y^{-1}$$



Sumário

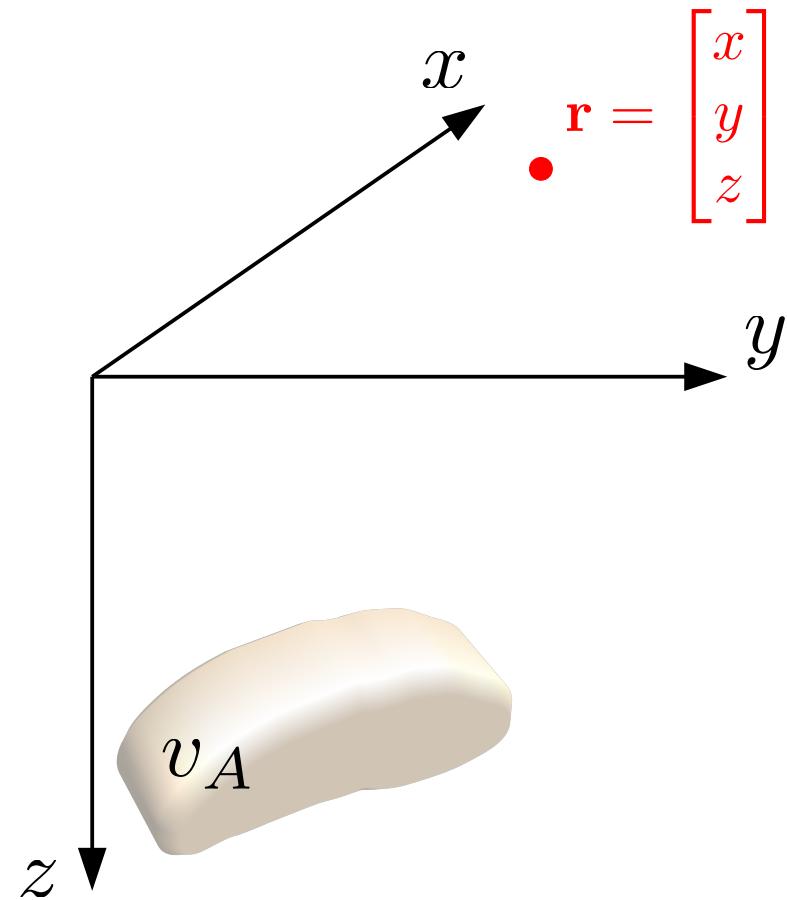
- O que é a redução ao polo (RTP)
- Como calcular a RTP
- **Desenvolvimentos teóricos**
- Possível generalização
- Comentários finais

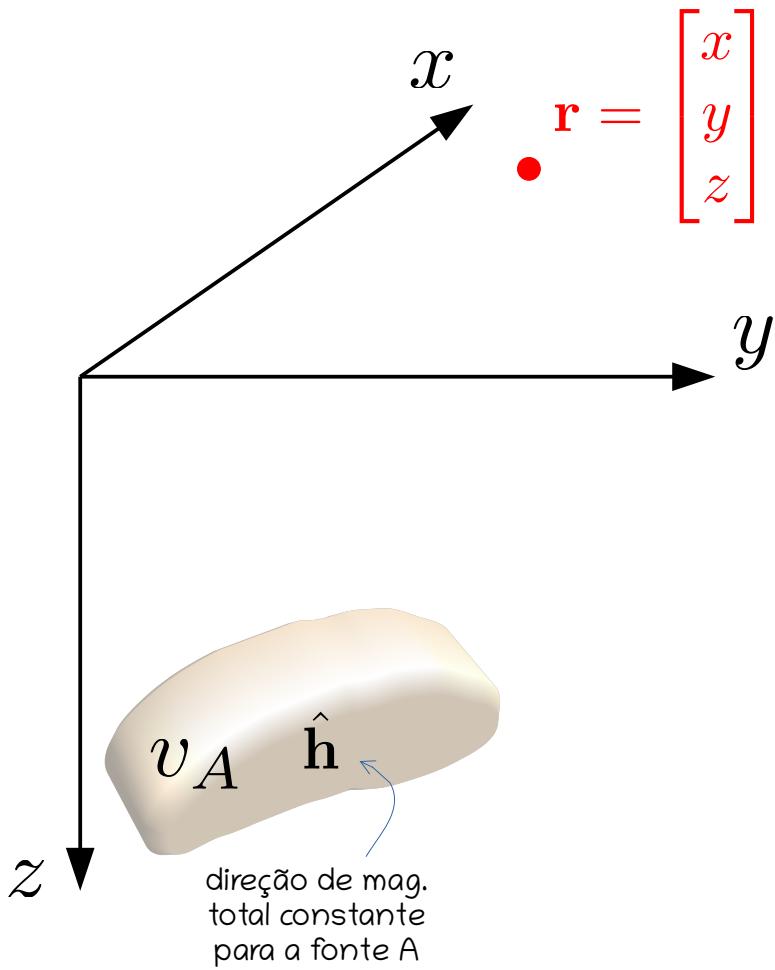


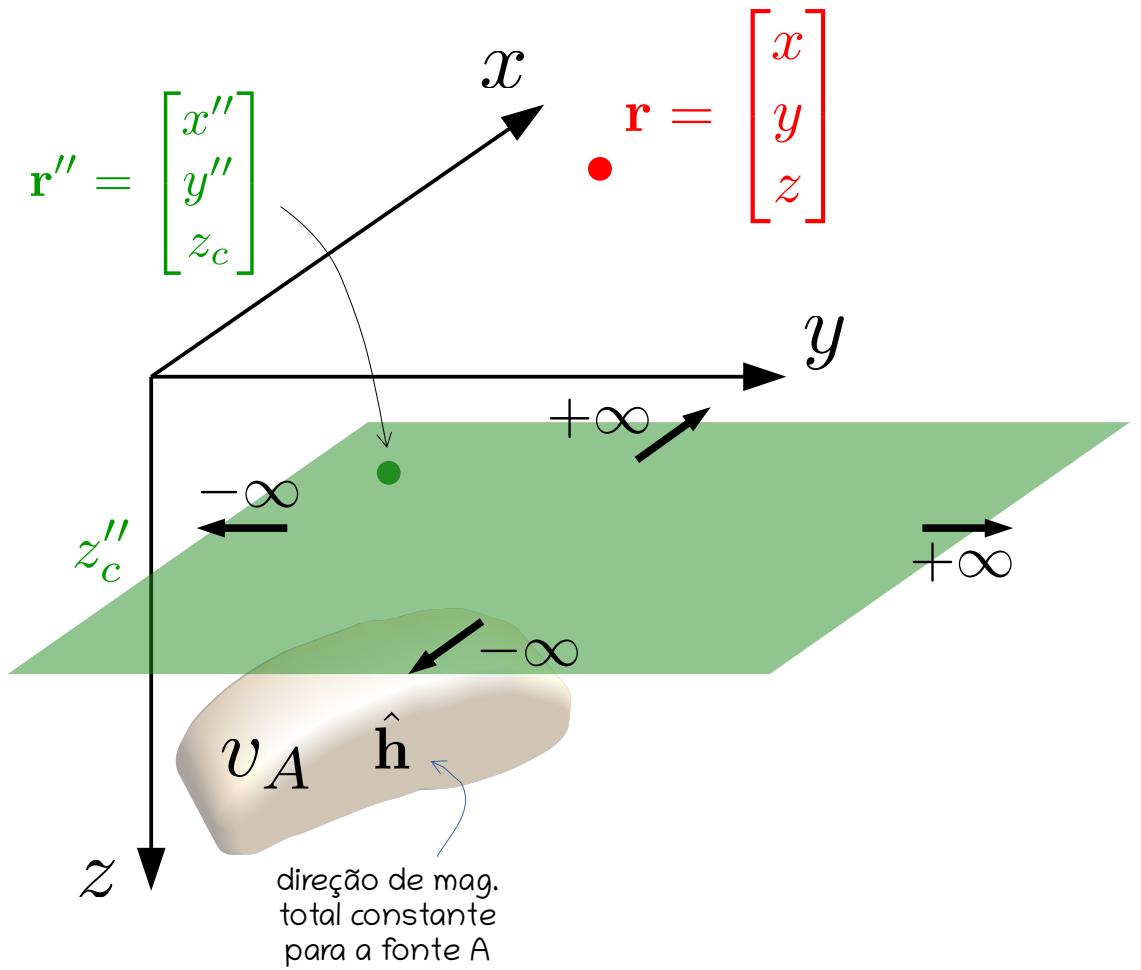
Sumário

- O que é a redução ao polo (RTP)
- Como calcular a RTP
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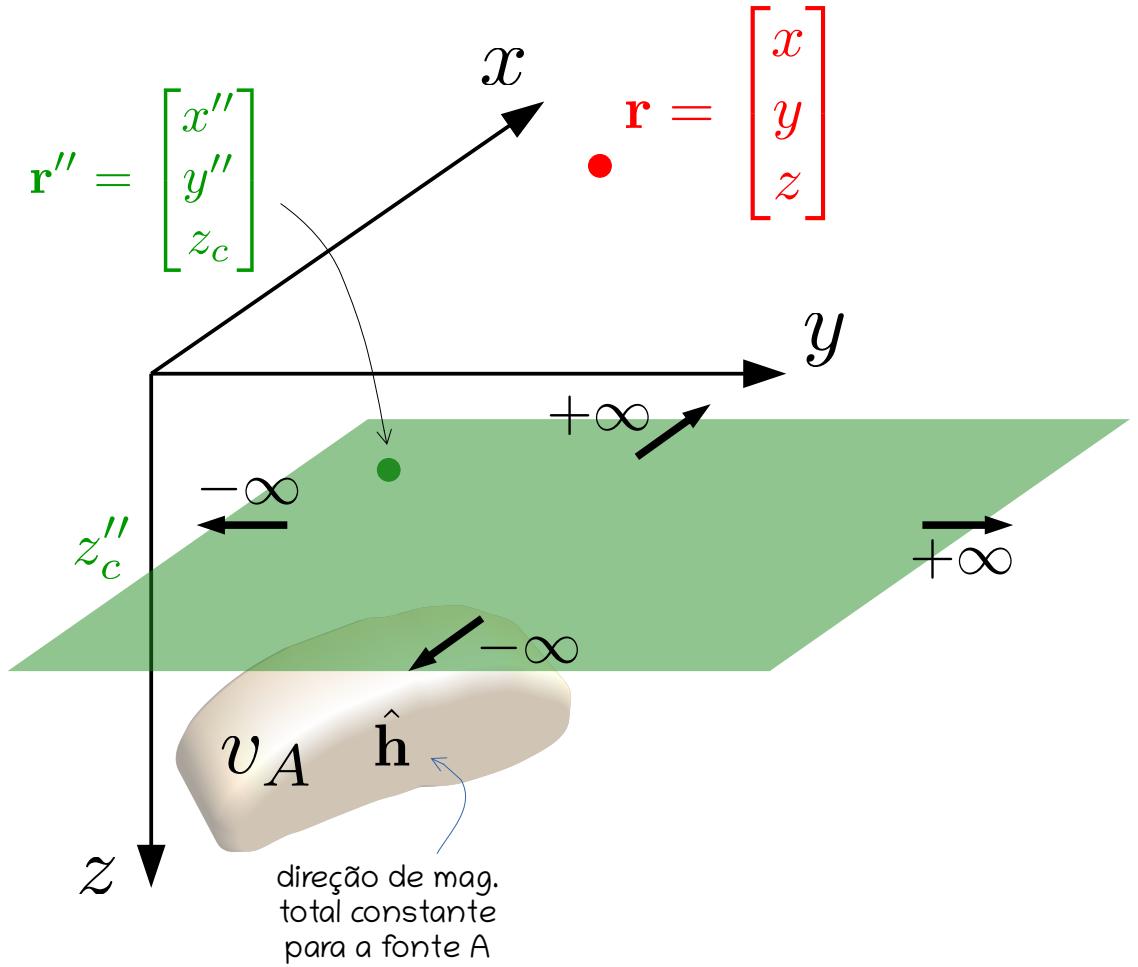




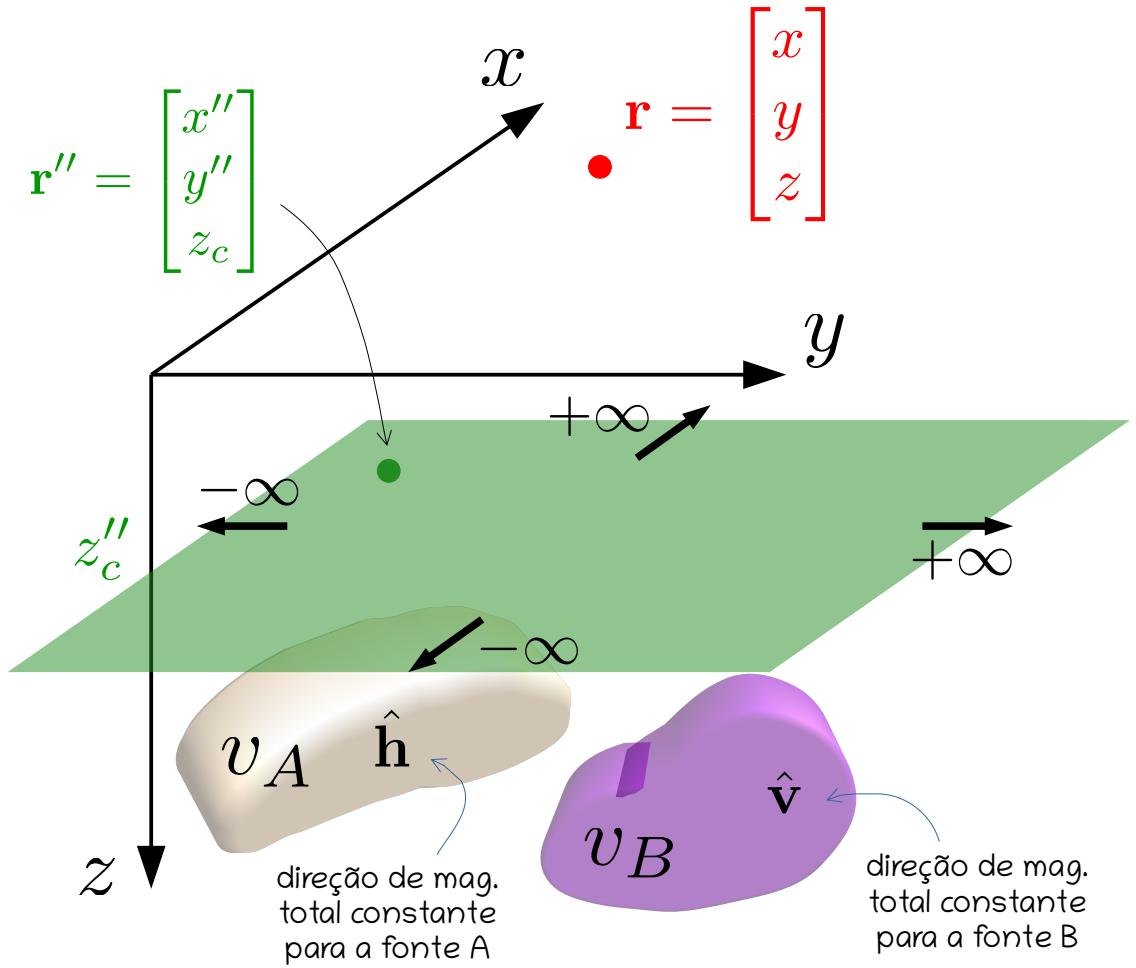




$$\partial_{th} U_A(\mathbf{r}) = \iint \partial_{\textcolor{violet}{z}} U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} \, dS''$$

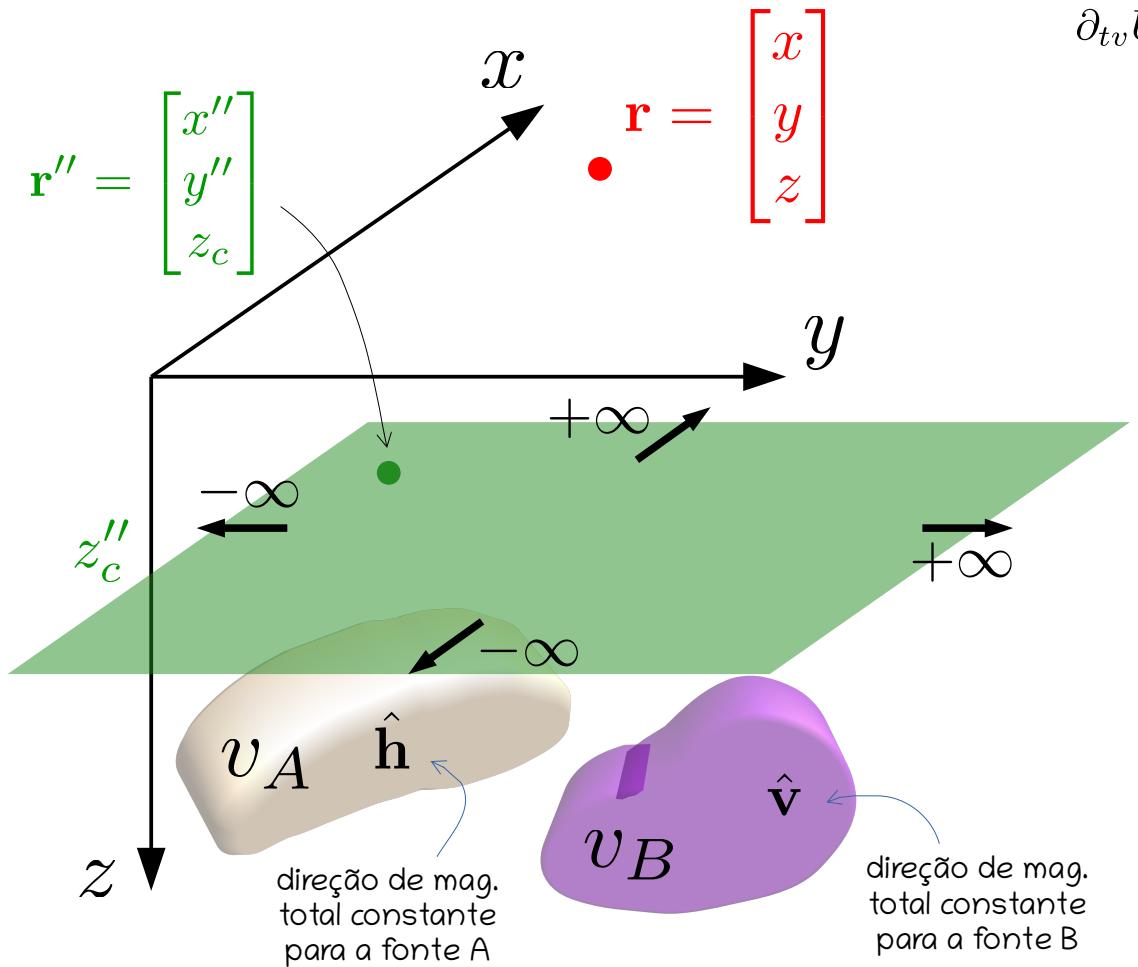


$$\partial_{th} U_A(\mathbf{r}) = \iint \partial_{\textcolor{violet}{z}} U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} \, dS''$$



$$\partial_{th} U_A(\mathbf{r}) = \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS''$$

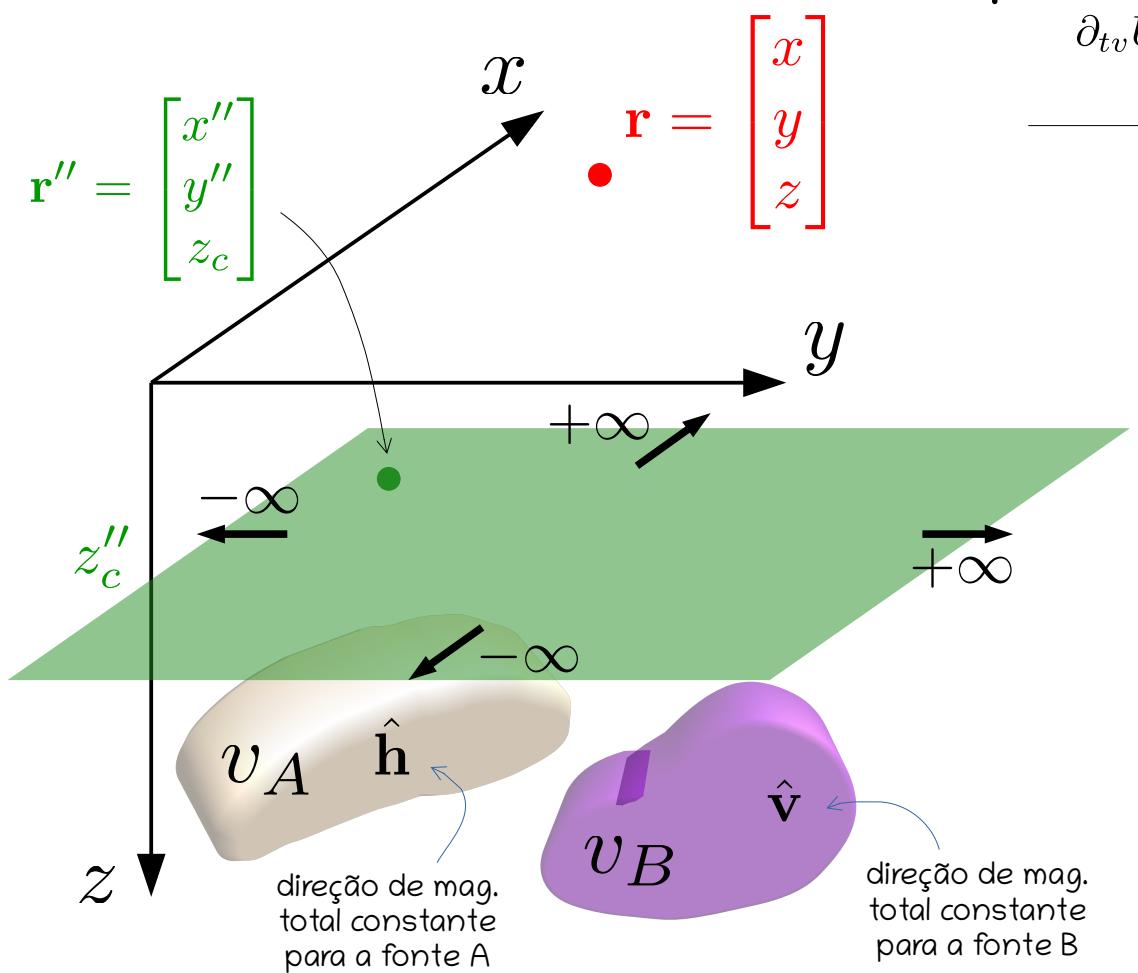
$$\partial_{tv} U_B(\mathbf{r}) = \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS''$$

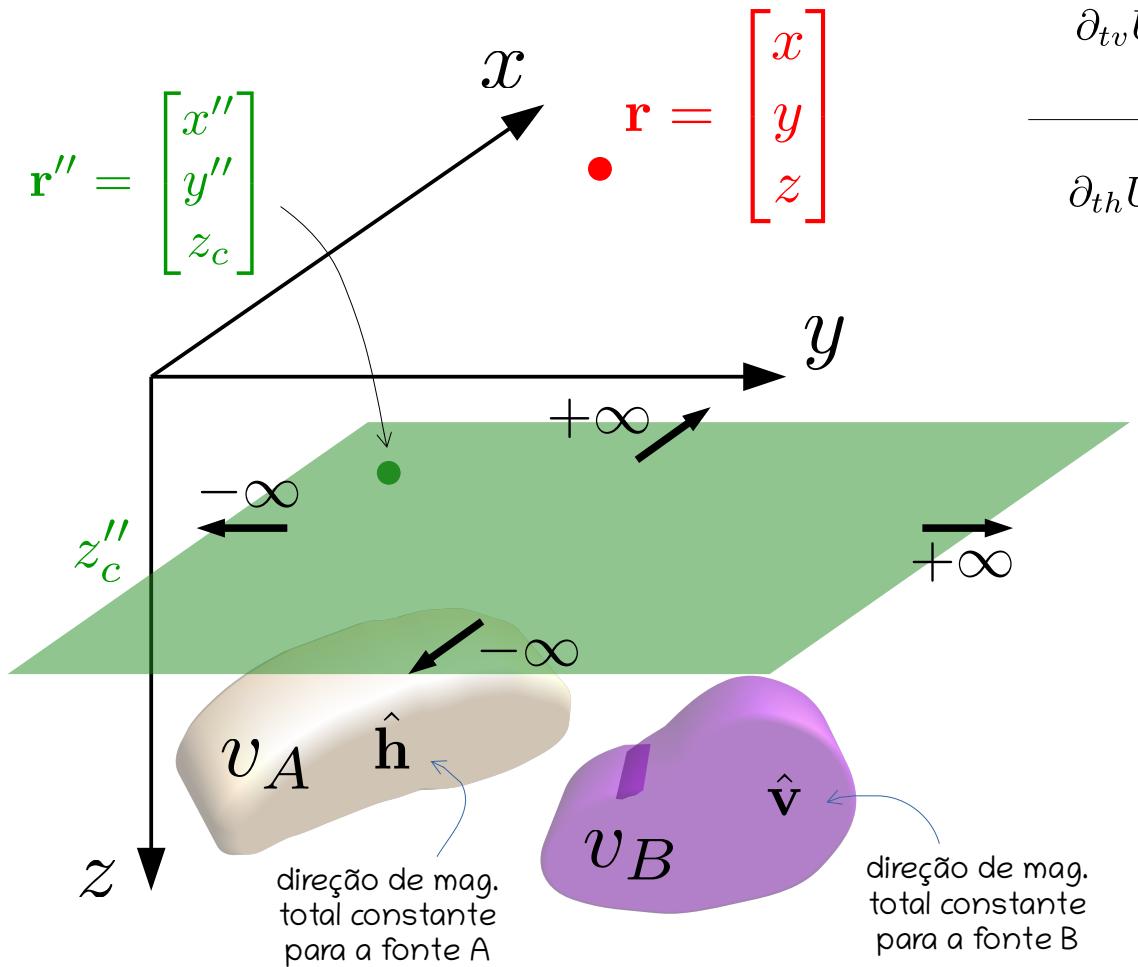


$$\partial_{th} U_A(\mathbf{r}) = \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS''$$

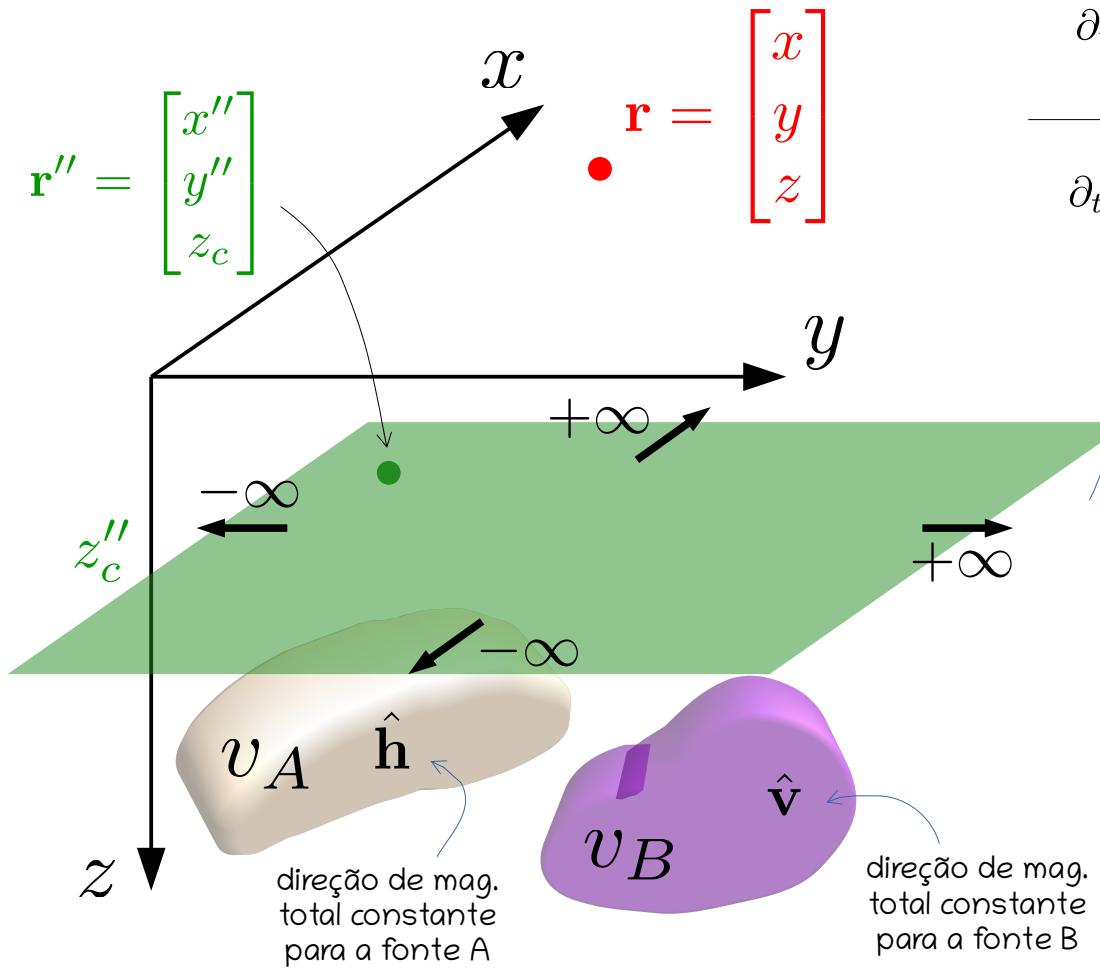
+

$$\partial_{tv} U_B(\mathbf{r}) = \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS''$$

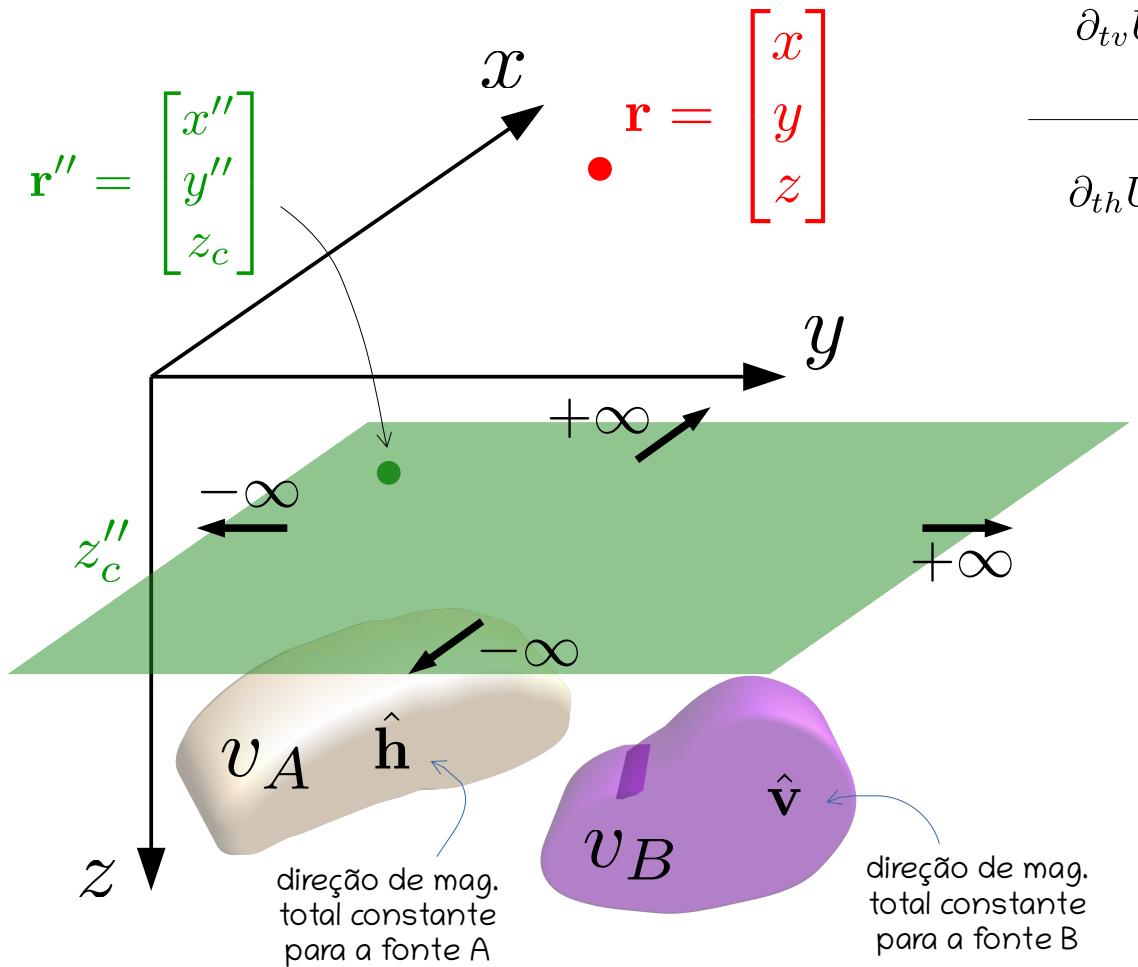




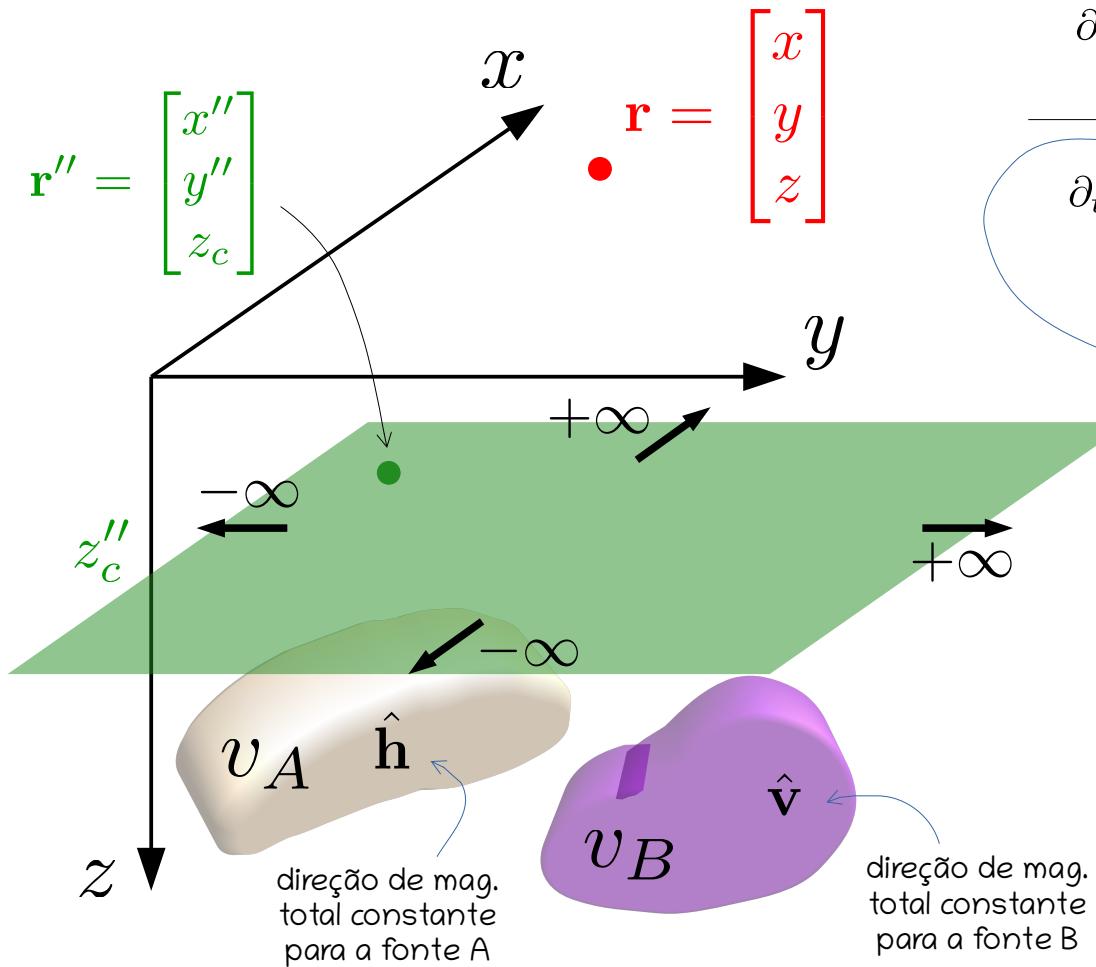
$$\begin{aligned}
 \partial_{th} U_A(\mathbf{r}) &= \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS'' \\
 + \quad \partial_{tv} U_B(\mathbf{r}) &= \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS'' \\
 \hline
 \partial_{th} U_A(\mathbf{r}) + \partial_{tv} U_B(\mathbf{r}) &= \\
 &= \iint \|\mathbf{w}(\mathbf{r}'')\| \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{w}}(\mathbf{r}'') dS''
 \end{aligned}$$



$$\begin{aligned}
 \partial_{th} U_A(\mathbf{r}) &= \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS'' \\
 + \quad \partial_{tv} U_B(\mathbf{r}) &= \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS'' \\
 \hline
 \partial_{th} U_A(\mathbf{r}) + \partial_{tv} U_B(\mathbf{r}) &= \\
 &= \iint \|\mathbf{w}(\mathbf{r}'')\| \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{w}}(\mathbf{r}'') dS'' \\
 \hat{\mathbf{w}}(\mathbf{r}'') &= \frac{\mathbf{w}(\mathbf{r}'')}{\|\mathbf{w}(\mathbf{r}'')\|}
 \end{aligned}$$

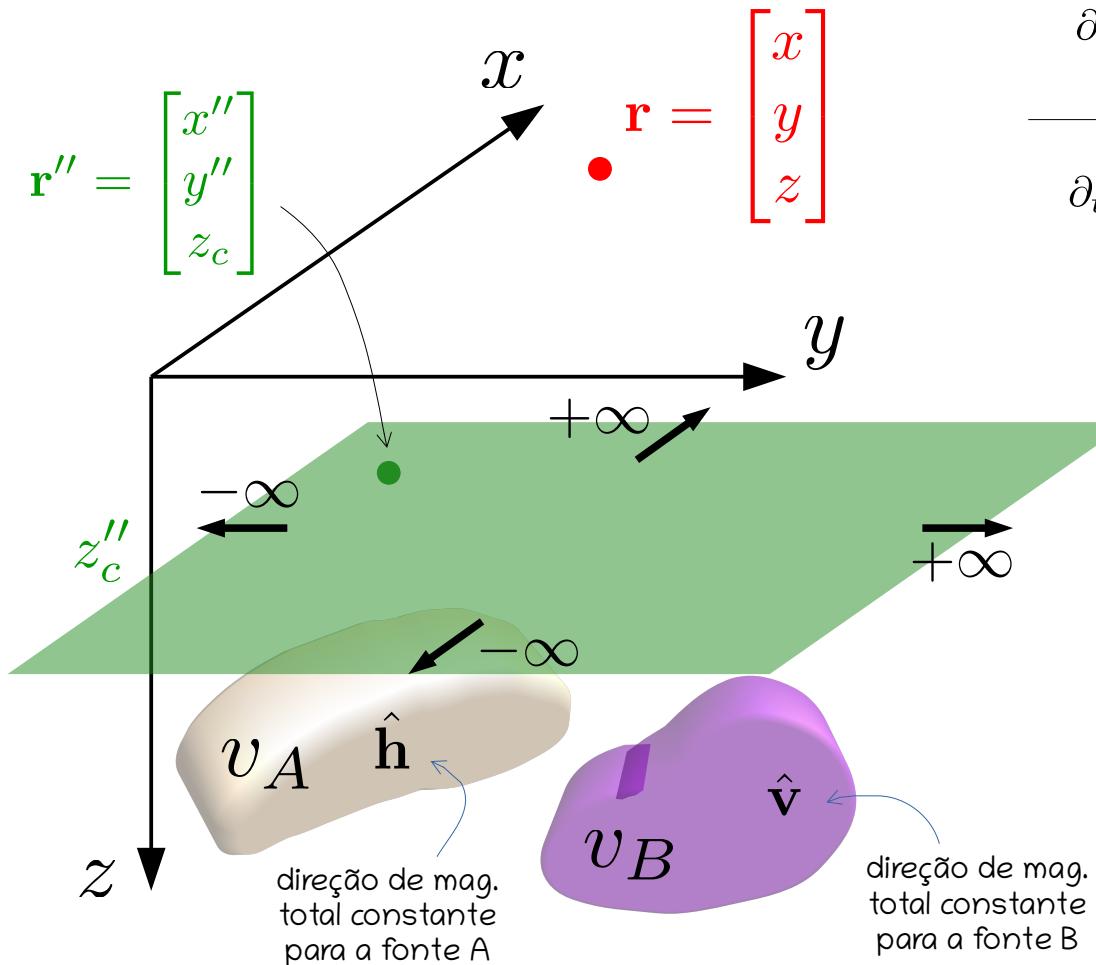


$$\begin{aligned}
 \partial_{th} U_A(\mathbf{r}) &= \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} \, dS'' \\
 + \quad \partial_{tv} U_B(\mathbf{r}) &= \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} \, dS'' \\
 \hline
 \partial_{th} U_A(\mathbf{r}) + \partial_{tv} U_B(\mathbf{r}) &= \\
 &= \iint \|\mathbf{w}(\mathbf{r}'')\| \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{w}}(\mathbf{r}'') \, dS'' \\
 \hat{\mathbf{w}}(\mathbf{r}'') &= \frac{\mathbf{w}(\mathbf{r}'')}{\|\mathbf{w}(\mathbf{r}'')\|} \quad \mathbf{w}(\mathbf{r}'') = \partial_z U_A(\mathbf{r}'') \hat{\mathbf{h}} + \partial_z U_B(\mathbf{r}'') \hat{\mathbf{v}}
 \end{aligned}$$



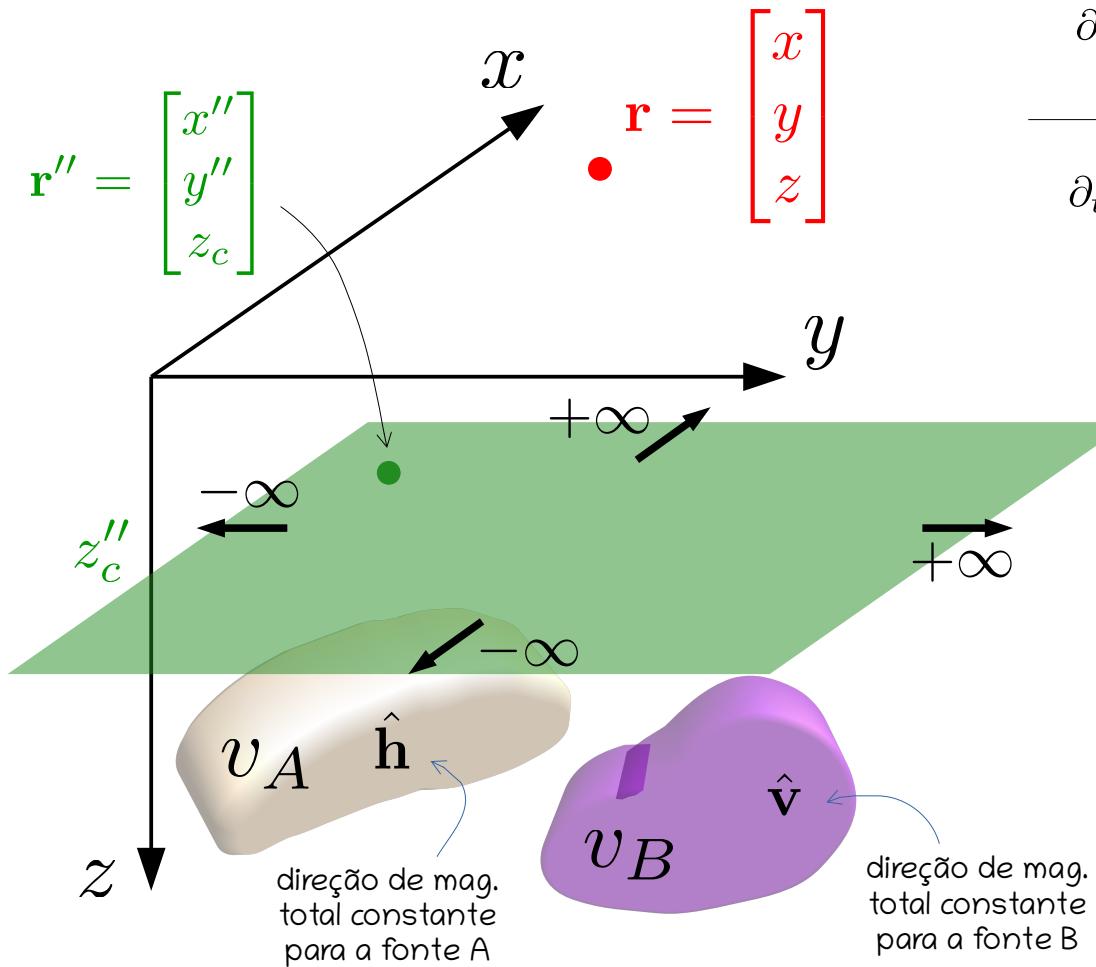
$$\begin{aligned}
 \partial_{th} U_A(\mathbf{r}) &= \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS'' \\
 + \quad \partial_{tv} U_B(\mathbf{r}) &= \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS'' \\
 \hline
 \partial_{th} U_A(\mathbf{r}) + \partial_{tv} U_B(\mathbf{r}) &= \\
 &= \iint \|\mathbf{w}(\mathbf{r}'')\| \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{w}}(\mathbf{r}'') dS'' \\
 \hat{\mathbf{w}}(\mathbf{r}'') &= \frac{\mathbf{w}(\mathbf{r}'')}{\|\mathbf{w}(\mathbf{r}'')\|} \quad \mathbf{w}(\mathbf{r}'') = \partial_z U_A(\mathbf{r}'') \hat{\mathbf{h}} + \partial_z U_B(\mathbf{r}'') \hat{\mathbf{v}}
 \end{aligned}$$

Como podemos ver, existe uma camada de dipolos que reproduz exatamente a anomalia de campo total resultante



$$\begin{aligned}
 \partial_{th} U_A(\mathbf{r}) &= \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS'' \\
 + \quad \partial_{tv} U_B(\mathbf{r}) &= \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS'' \\
 \hline
 \partial_{th} U_A(\mathbf{r}) + \partial_{tv} U_B(\mathbf{r}) &= \\
 &= \iint \|\mathbf{w}(\mathbf{r}'')\| \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{w}}(\mathbf{r}'') dS'' \\
 \hat{\mathbf{w}}(\mathbf{r}'') &= \frac{\mathbf{w}(\mathbf{r}'')}{\|\mathbf{w}(\mathbf{r}'')\|} \quad \mathbf{w}(\mathbf{r}'') = \partial_z U_A(\mathbf{r}'') \hat{\mathbf{h}} + \partial_z U_B(\mathbf{r}'') \hat{\mathbf{v}}
 \end{aligned}$$

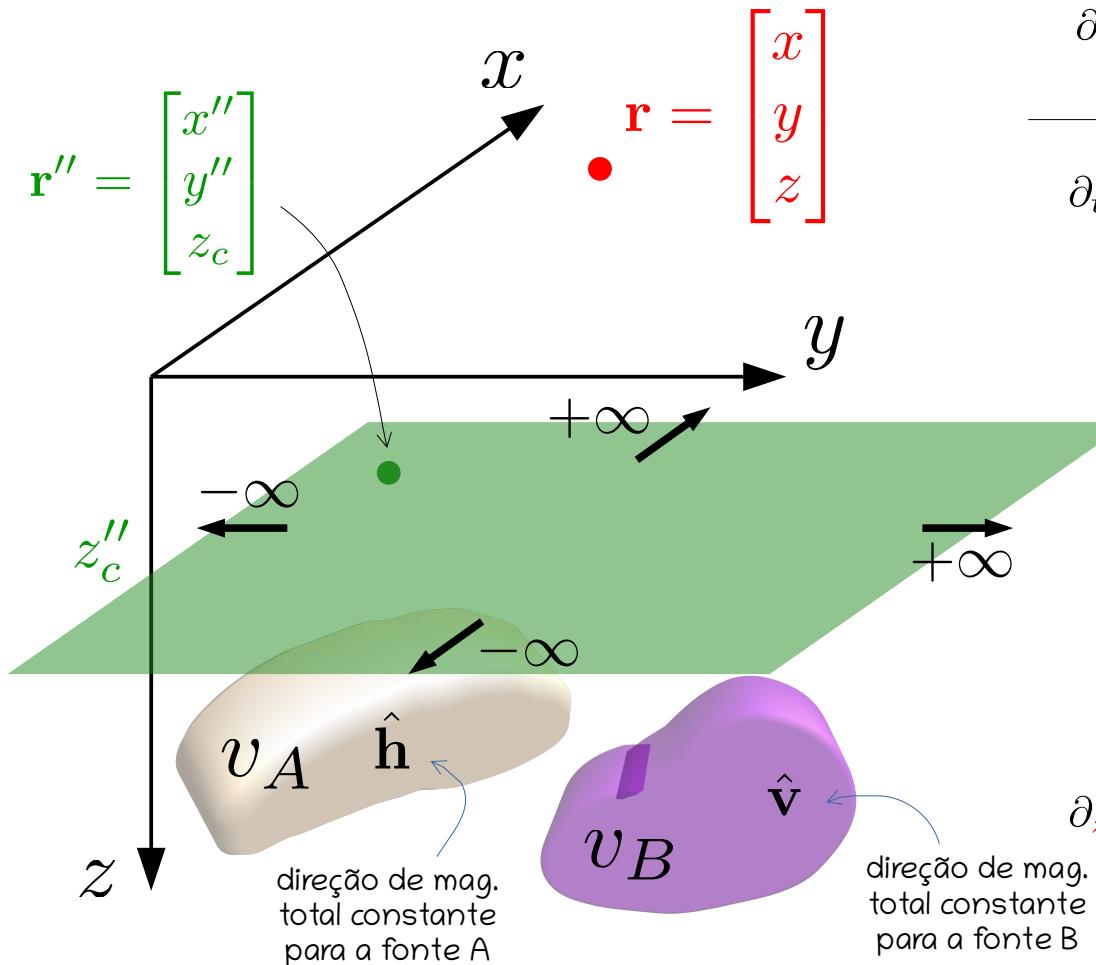
Essa camada, contudo, possui uma direção de magnetização $\hat{\mathbf{w}}(\mathbf{r}'')$ que varia com a posição



$$\begin{aligned}
 \partial_{th} U_A(\mathbf{r}) &= \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS'' \\
 + \quad \partial_{tv} U_B(\mathbf{r}) &= \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS'' \\
 \hline
 \partial_{th} U_A(\mathbf{r}) + \partial_{tv} U_B(\mathbf{r}) &= \\
 &= \iint \|\mathbf{w}(\mathbf{r}'')\| \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{w}}(\mathbf{r}'') dS'' \\
 \hat{\mathbf{w}}(\mathbf{r}'') &= \frac{\mathbf{w}(\mathbf{r}'')}{\|\mathbf{w}(\mathbf{r}'')\|} \quad \mathbf{w}(\mathbf{r}'') = \partial_z U_A(\mathbf{r}'') \hat{\mathbf{h}} + \partial_z U_B(\mathbf{r}'') \hat{\mathbf{v}}
 \end{aligned}$$

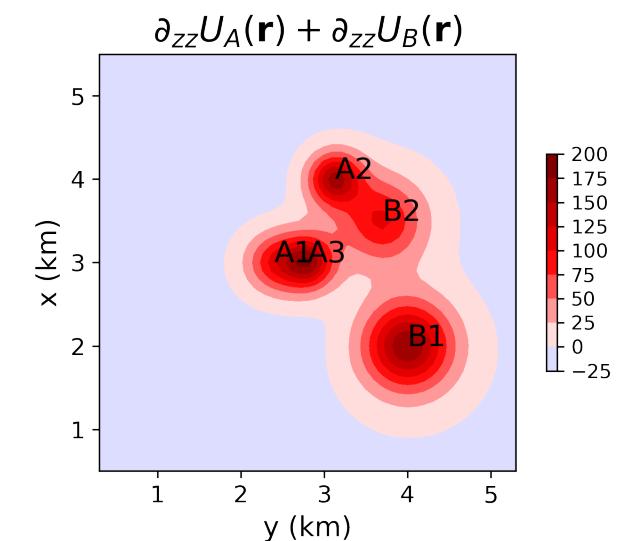
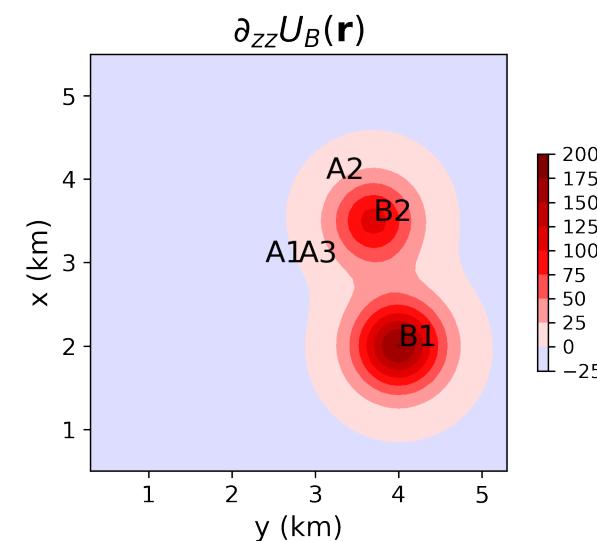
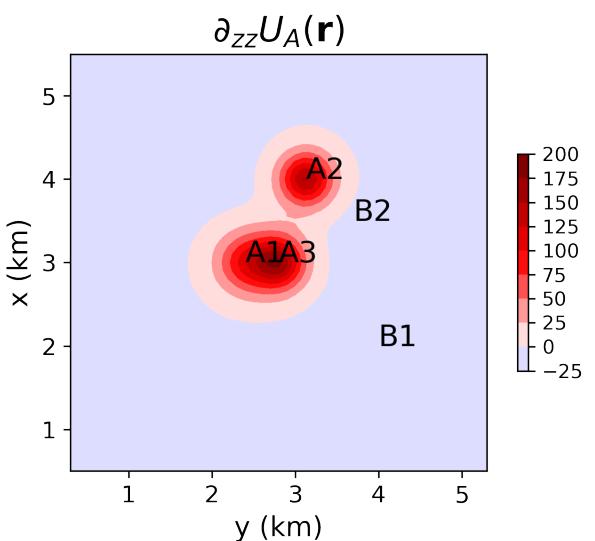
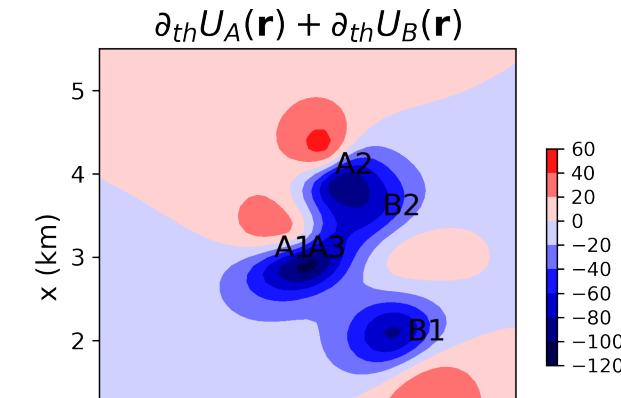
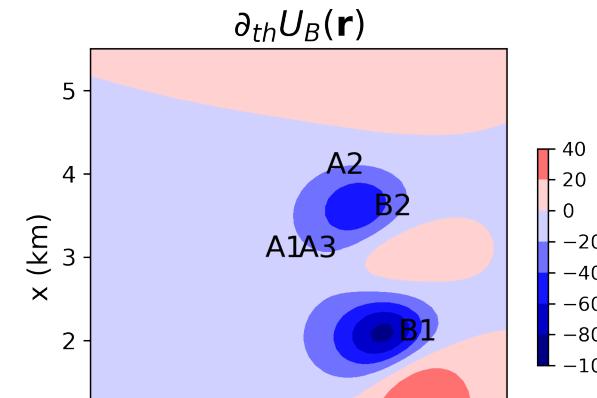
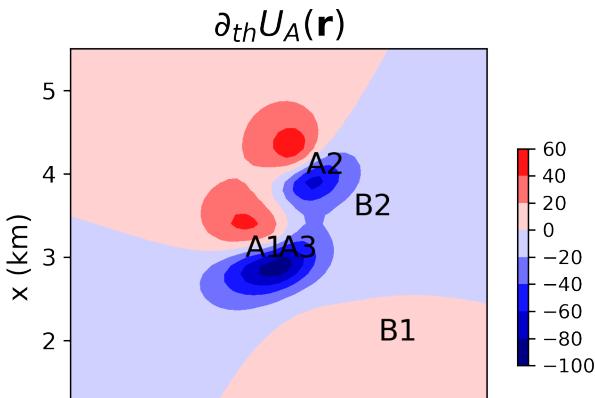
anomalia RTP produzida pela camada heterogênea

$$\mathcal{R}(\mathbf{r}) = \iint \|\mathbf{w}(\mathbf{r}'')\| \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''$$



$$\begin{aligned}
 \partial_{th} U_A(\mathbf{r}) &= \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS'' \\
 + \quad \partial_{tv} U_B(\mathbf{r}) &= \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS'' \\
 \hline
 \partial_{th} U_A(\mathbf{r}) + \partial_{tv} U_B(\mathbf{r}) &= \\
 &= \iint \|\mathbf{w}(\mathbf{r}'')\| \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{w}}(\mathbf{r}'') dS'' \\
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 \text{anomalia RTP produzida pela camada heterogênea} \\
 \mathcal{R}(\mathbf{r}) &= \iint \|\mathbf{w}(\mathbf{r}'')\| \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS'' \\
 \text{soma das anomalias RTP produzidas por cada fonte} \\
 \partial_{zz} U_A(\mathbf{r}) + \partial_{zz} U_B(\mathbf{r}) &= \\
 &= \iint [\partial_z U_A(\mathbf{r}'') + \partial_z U_B(\mathbf{r}'')] \partial_{zz} \Psi(\mathbf{r}, \mathbf{r}'') dS''
 \end{aligned}$$

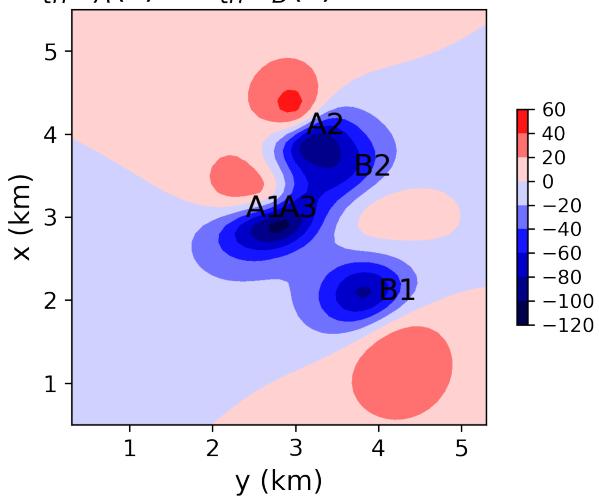
$$I_t = -5^\circ \quad D_t = -30^\circ \quad I_A = -26^\circ \quad D_A = -19^\circ \quad I_B = 45^\circ \quad D_B = 10^\circ$$



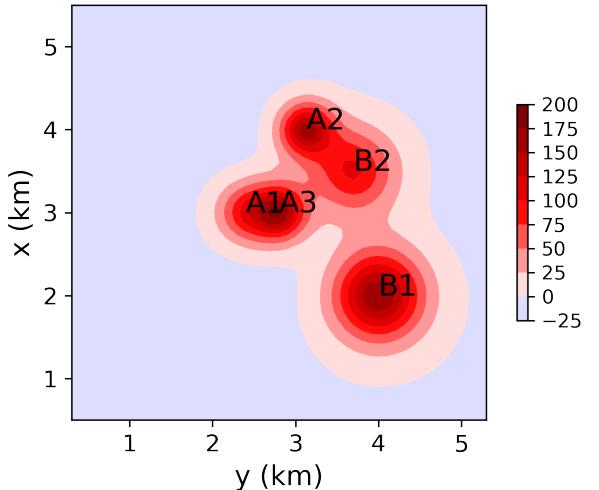
$$I_t = -5^\circ \quad D_t = -30^\circ \quad I_A = -26^\circ \quad D_A = -19^\circ$$

$$I_B = 45^\circ \quad D_B = 10^\circ$$

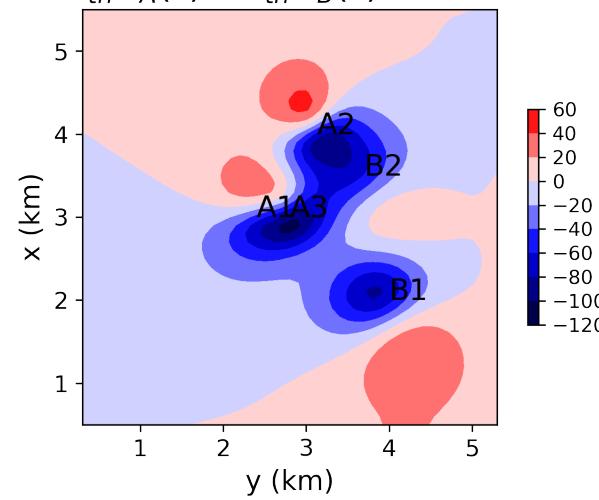
$\partial_{th}U_A(\mathbf{r}) + \partial_{th}U_B(\mathbf{r})$ verdadeira



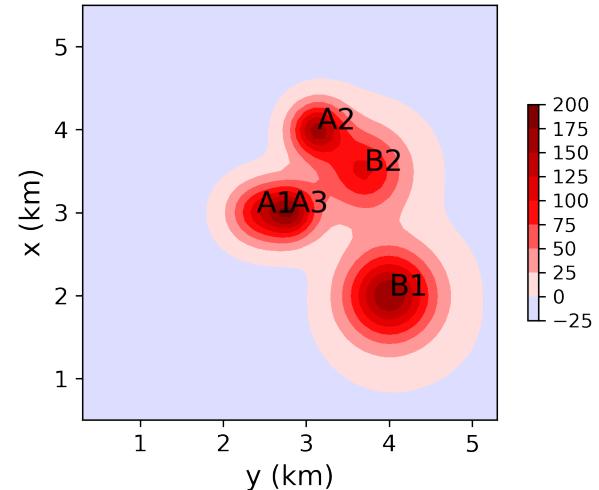
$\partial_{zz}U_A(\mathbf{r}) + \partial_{zz}U_B(\mathbf{r})$ verdadeira



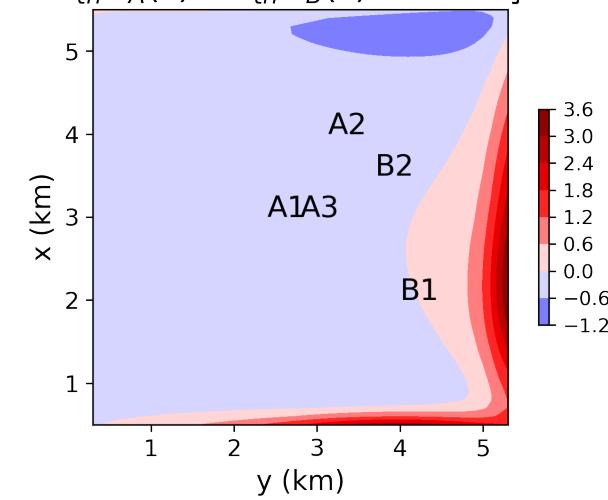
$\partial_{th}U_A(\mathbf{r}) + \partial_{th}U_B(\mathbf{r})$ teórica



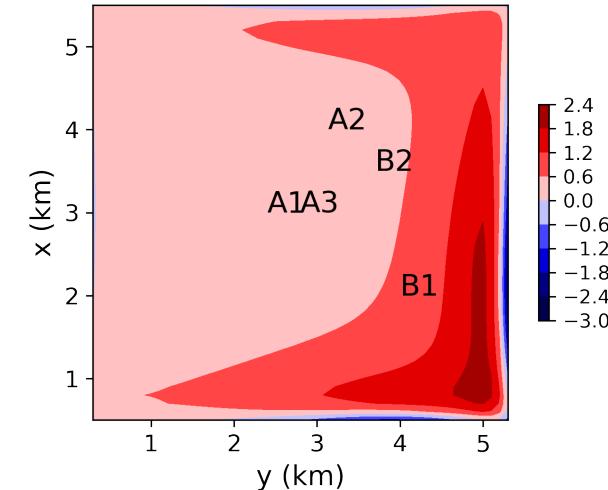
$\partial_{zz}U_A(\mathbf{r}) + \partial_{zz}U_B(\mathbf{r})$ teórica



$\partial_{th}U_A(\mathbf{r}) + \partial_{th}U_B(\mathbf{r})$ diferença



$\partial_{zz}U_A(\mathbf{r}) + \partial_{zz}U_B(\mathbf{r})$ diferença

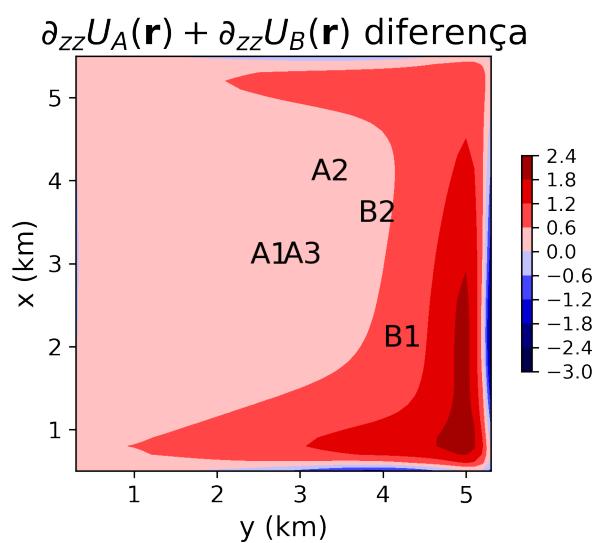
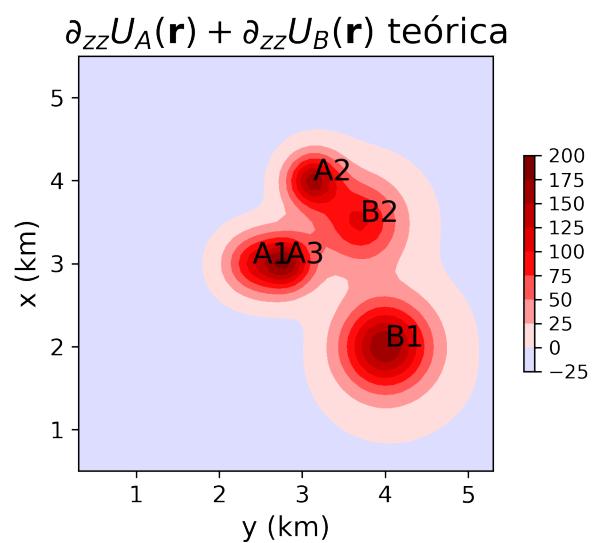
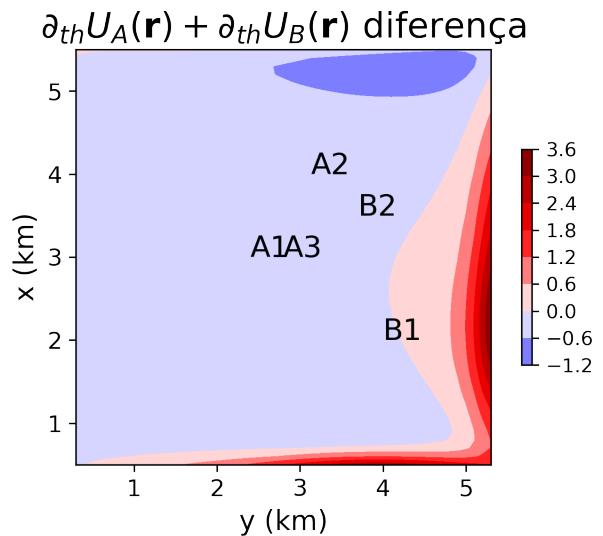
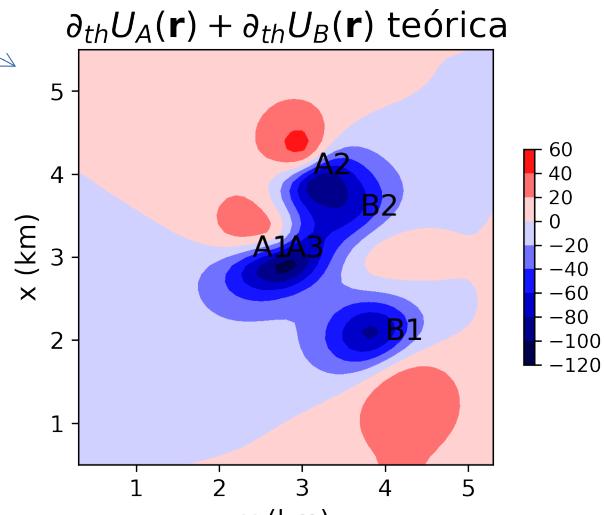


$$I_t = -5^\circ \quad D_t = -30^\circ \quad I_A = -26^\circ \quad D_A = -19^\circ$$

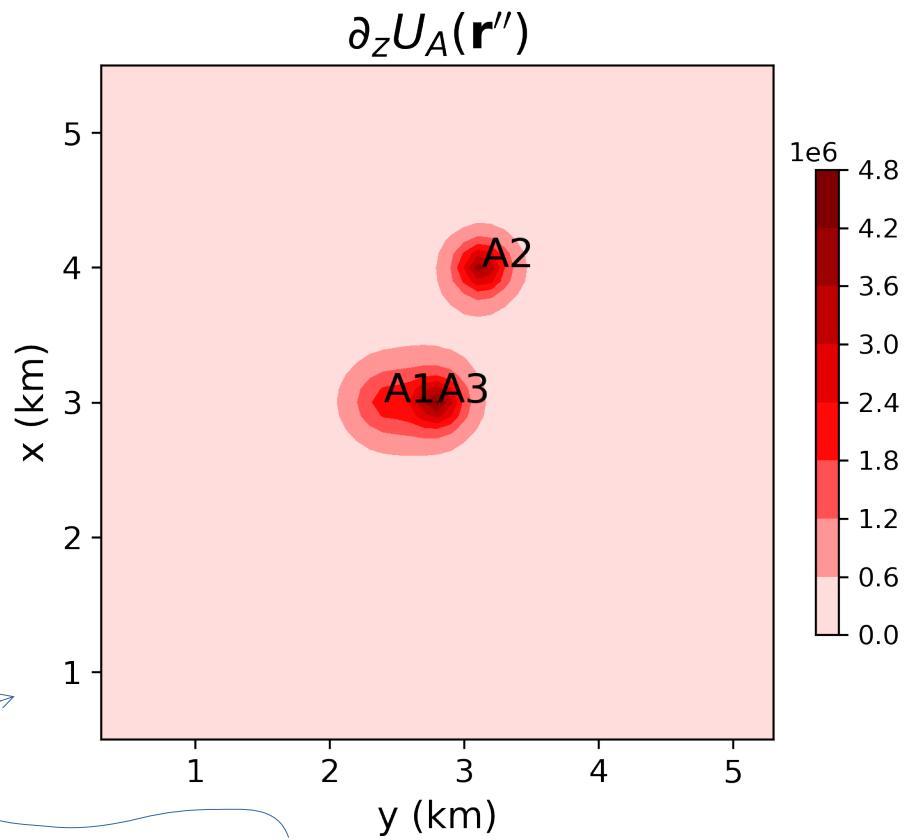
$$I_B = 45^\circ \quad D_B = 10^\circ$$

$\partial_{th}U_A(\mathbf{r}) = \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} dS''$

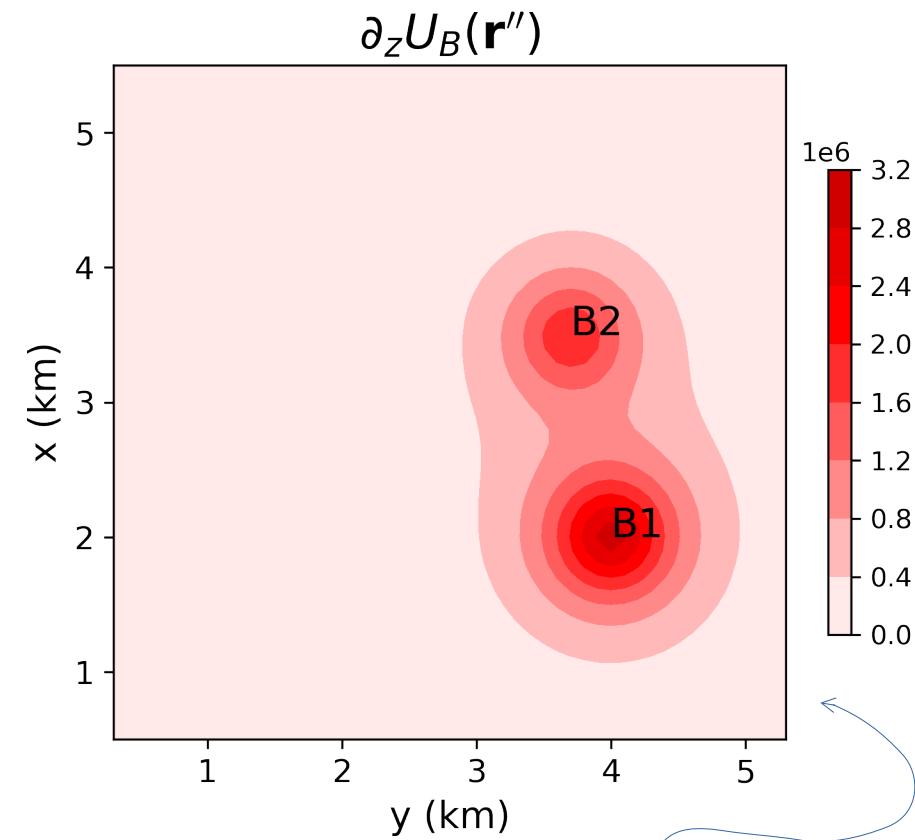
$\partial_{tv}U_B(\mathbf{r}) = \iint \partial_z U_B(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{v}} dS''$



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$$\partial_{th} U_A(\mathbf{r}) = \iint \partial_z U_A(\mathbf{r}'') \hat{\mathbf{t}}^\top \mathbf{H}_\Psi(\mathbf{r}, \mathbf{r}'') \hat{\mathbf{h}} \, dS''$$



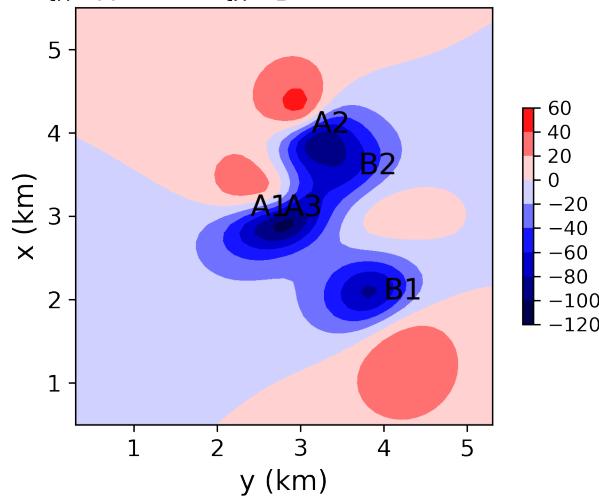
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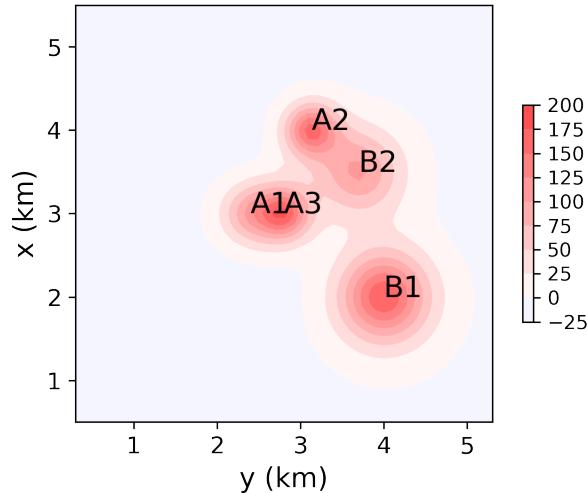
$$I_A = -26^\circ \quad D_A = -19^\circ$$

$$I_B = 45^\circ \quad D_B = 10^\circ$$

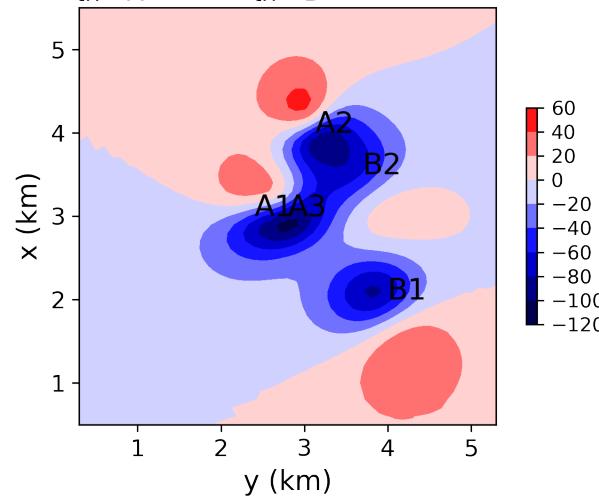
$\partial_{th}U_A(\mathbf{r}) + \partial_{th}U_B(\mathbf{r})$ verdadeira



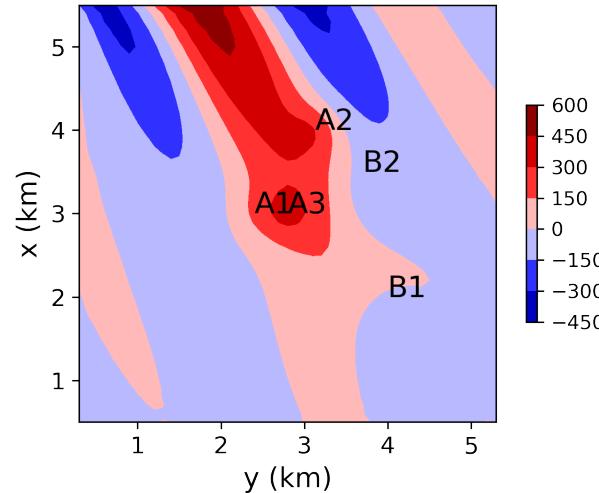
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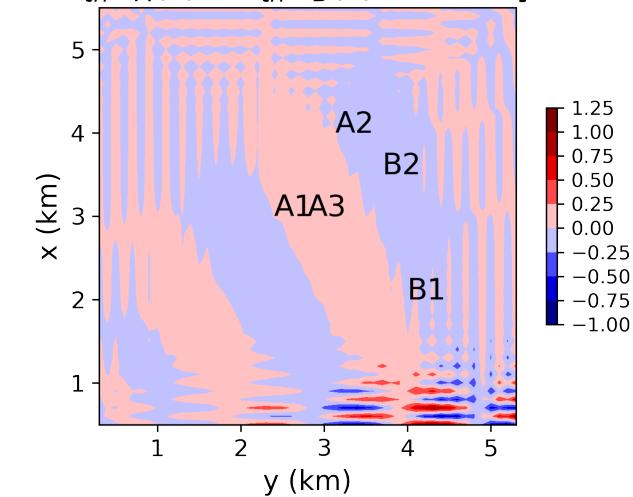
$\partial_{th}U_A(\mathbf{r}) + \partial_{th}U_B(\mathbf{r})$ calc. CE



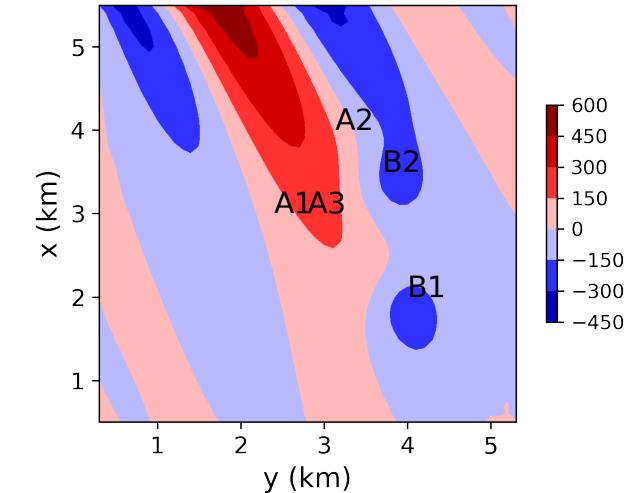
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$\partial_{th}U_A(\mathbf{r}) + \partial_{th}U_B(\mathbf{r})$ diferença



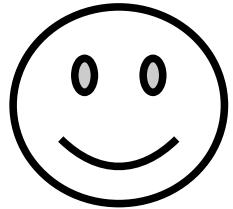
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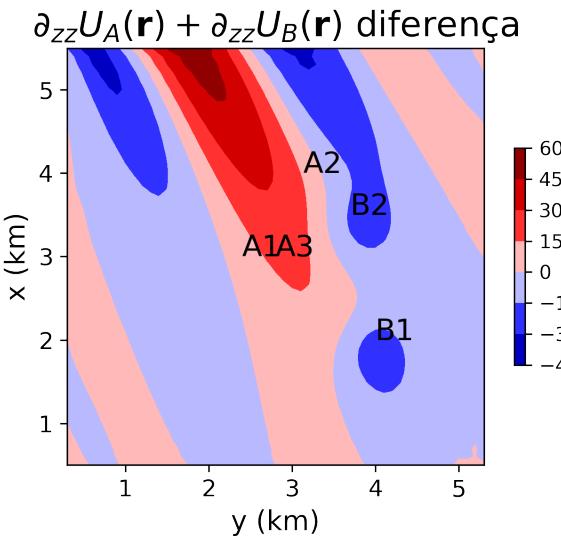
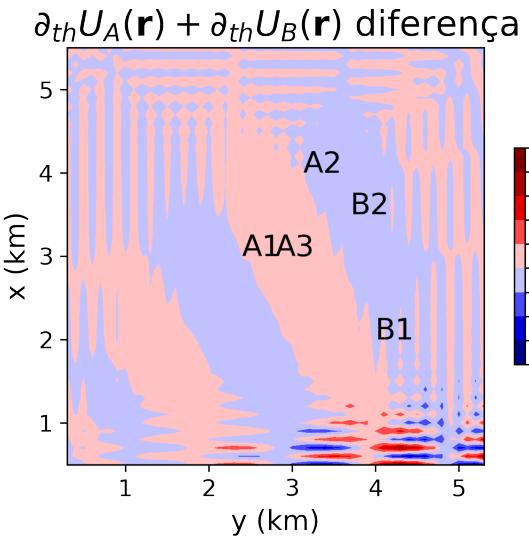
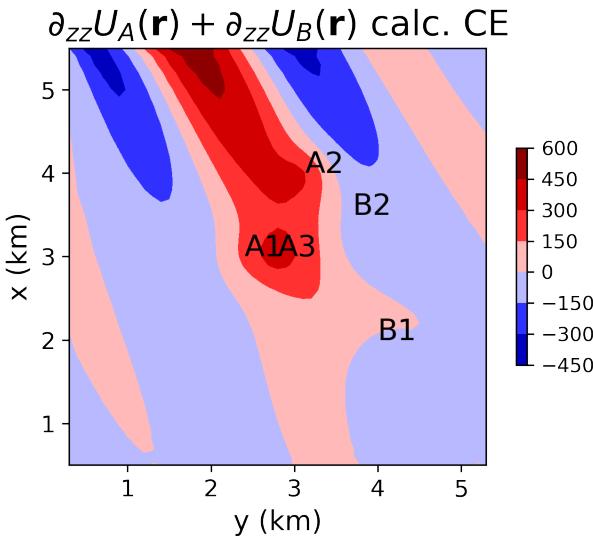
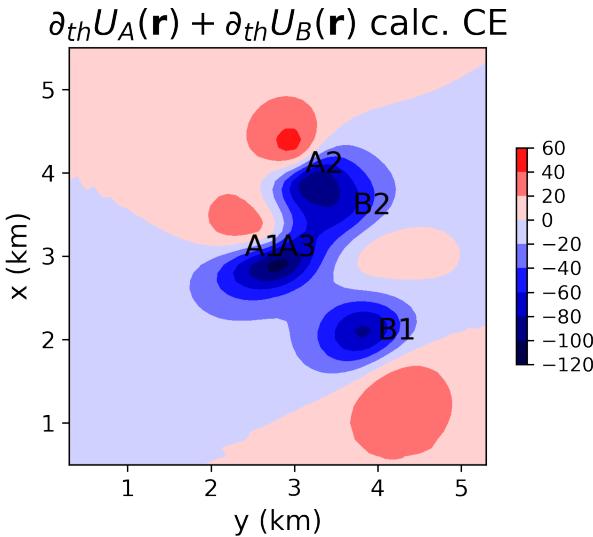
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A camada de dipolos estimada numericamente ajusta a anomalia de campo total, mas não recupera a anomalia RTP



Sumário

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- Como calcular a RTP
- Desenvolvimentos teóricos
- **Possível generalização**
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- A RTP é uma importante técnica de processamento/interpretação de dados magnéticos.
- Uma de suas principais limitações é que esta requer que as fontes tenham direção de magnetização constante.
- A presente pesquisa busca investigar aspectos teóricos da RTP.
- A partir dos resultados obtidos até o momento, foi possível explicar, pela primeira vez, as principais bases teóricas para o cálculo da RTP no domínio do espaço para fontes com direção de mag. constante.
- Também foi possível provar, de forma inédita, a existência de uma camada de dipolos que ajusta a anomalia de campo total e reproduz a anomalia RTP para o caso em que as fontes possuem direção de magnetização heterogênea.
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- É possível deduzir a existência de uma camada de dipolos que cruza as fontes e, ainda assim, ajusta a anomalia de campo total e reproduz a anomalia RTP? Na prática, sabemos que essa camada existe.
- Há parâmetros das fontes 3D verdadeiras que podem ser extraídos a partir da camada teórica de dipolos? Os resultados sugerem que a camada possui o mesmo centro de “massa” e momentos horizontais das fontes verdadeiras.
- Qual é a explicação teórica, no domínio do espaço, para o surgimento das “estrias” associadas a inclinações baixas? Há uma explicação no domínio de Fourier.
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Muito obrigado pela
atenção!



Oliveira Jr, Vanderlei C. (2022): Possível aplicação da redução ao polo para fontes com direção de magnetização heterogênea. **figshare**. Presentation.
<https://doi.org/10.6084/m9.figshare.19956953.v1>