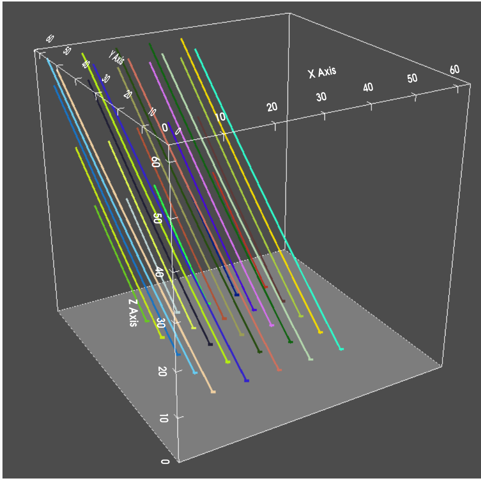
Reconstruction of Coronal Magnetic Fields using Physics-Informed Neural Networks

전민규

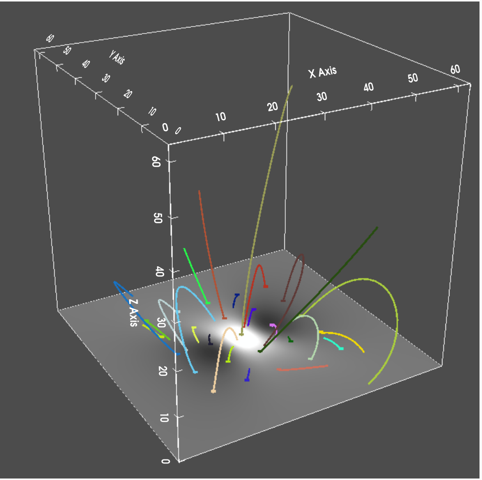
학사졸업논문

The 3D magnetic fields

PINN(0)

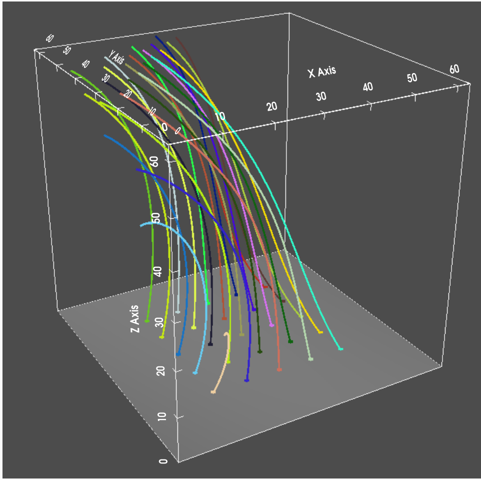


Low-Lou

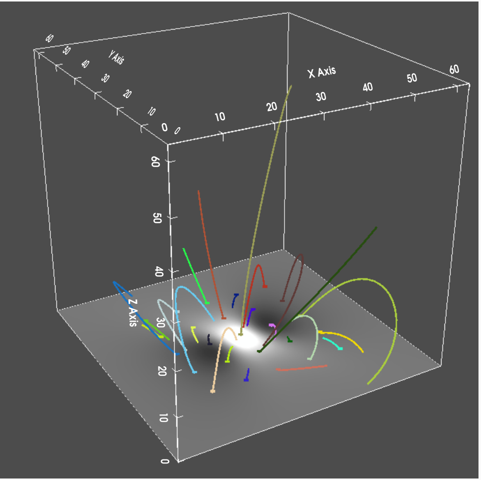


The 3D magnetic fields

PINN(100)

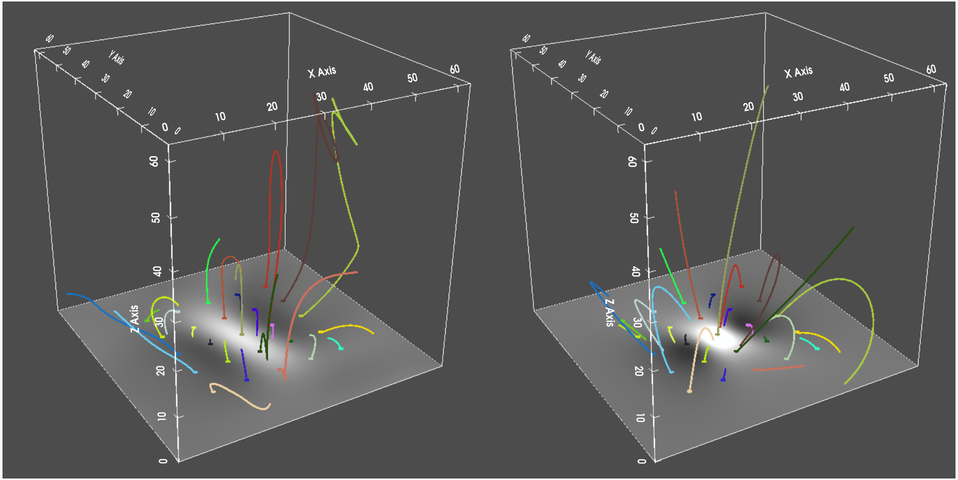


Low-Lou



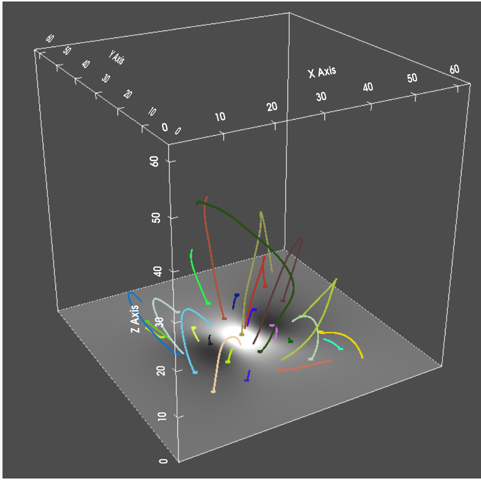
The 3D magnetic fields

PINN(1000) Low-Lou

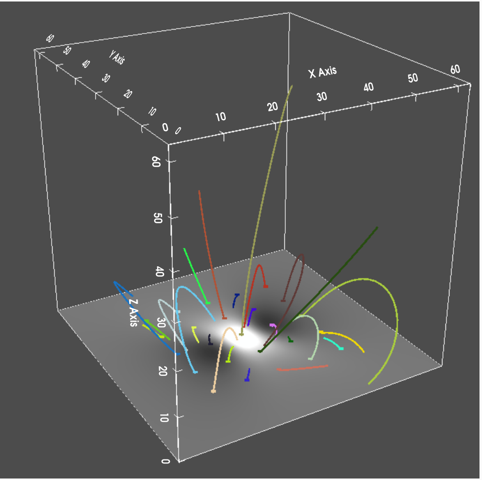


The 3D magnetic fields

PINN(10000)

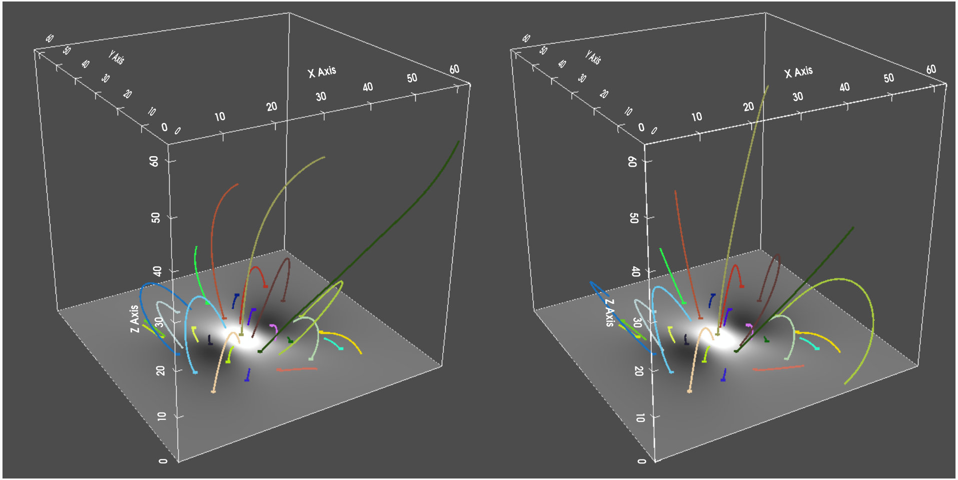


Low-Lou



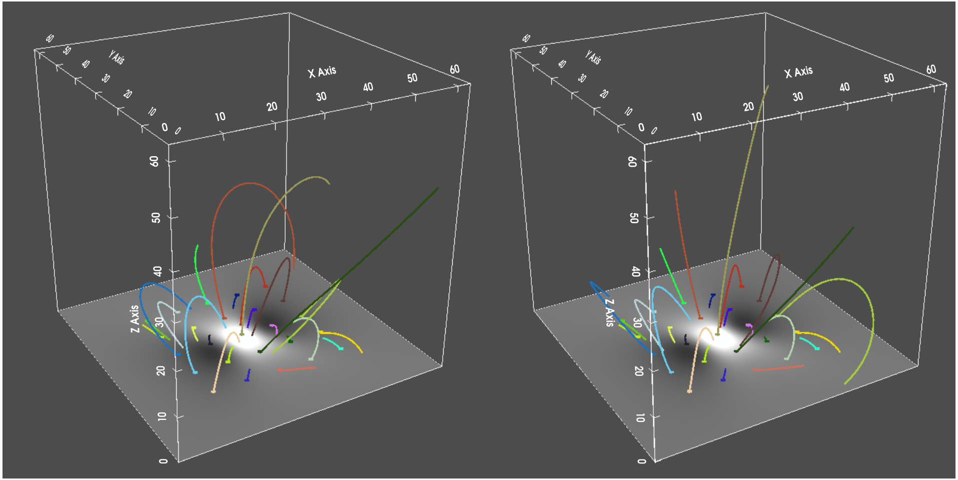
The 3D magnetic fields

PINN(25000) | Low-Lou



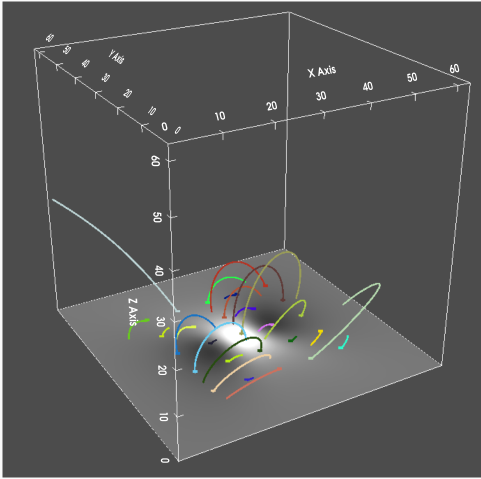
The 3D magnetic fields

PINN(50000) | Low-Lou

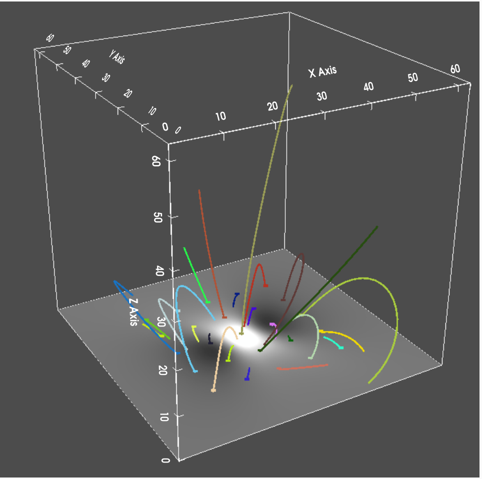


The 3D magnetic fields

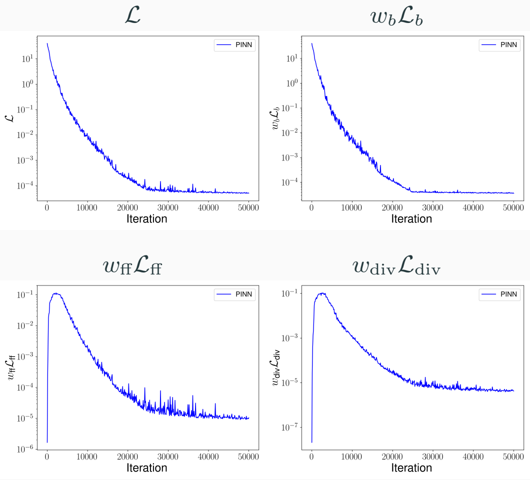
Potential



Low-Lou



Loss



$$\hat{\mathbf{B}} = \mathcal{N}(\boldsymbol{x};\boldsymbol{\theta})$$

$$\mathcal{L}_{\text{ff}}(\boldsymbol{\theta};\mathcal{T}_f) = \frac{1}{|\mathcal{T}_f|}\sum_{\boldsymbol{x}\in\mathcal{T}_f}\frac{|(\nabla\times\hat{\mathbf{B}})\times\hat{\mathbf{B}}|^2}{|\hat{\mathbf{B}}|^2}$$

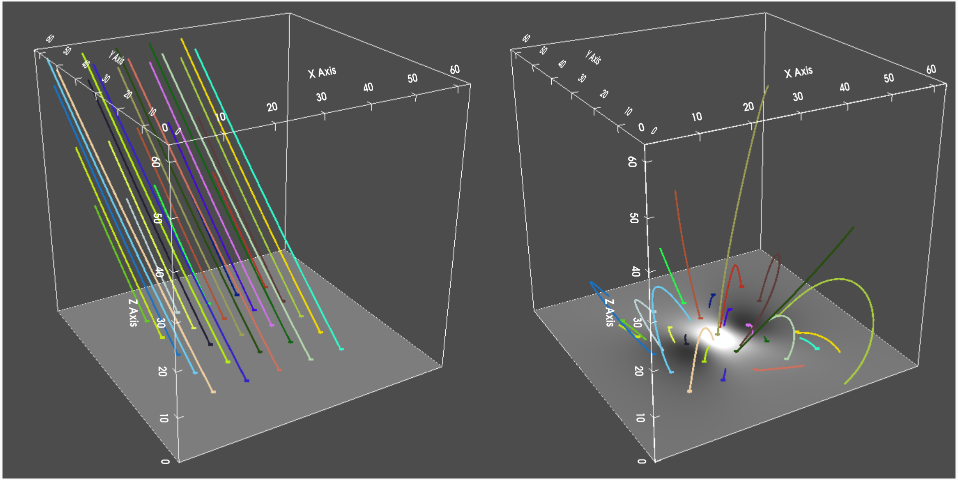
$$\mathcal{L}_{\text{div}}(\boldsymbol{\theta};\mathcal{T}_f) = \frac{1}{|\mathcal{T}_f|}\sum_{\boldsymbol{x}\in\mathcal{T}_f}|\nabla\cdot\hat{\mathbf{B}}|^2$$

$$\mathcal{L}_b(\boldsymbol{\theta};\mathcal{T}_b) = \frac{1}{|\mathcal{T}_b|}\sum_{\boldsymbol{x}\in\mathcal{T}_b}|\hat{\mathbf{B}}-\mathbf{B}|^2$$

$$\mathcal{L}_f = w_{\text{ff}}\mathcal{L}_{\text{ff}} + w_{\text{div}}\mathcal{L}_{\text{div}} + w_b\mathcal{L}_b$$

The 3D magnetic fields

PINN(0) Low-Lou



Figures of merit (Schrijver et al. 2006)

$$C_{\text{vec}} = \frac{\sum_i \mathbf{B}_i \cdot \mathbf{b}_i}{(\sum_i |\mathbf{B}_i|^2 \sum_i |\mathbf{b}_i|^2)^{1/2}}$$

$$C_{\text{CS}} = \frac{1}{M} \sum_i \frac{\mathbf{B}_i \cdot \mathbf{b}_i}{|\mathbf{B}_i||\mathbf{b}_i|}$$

$$E'_n = 1 - \frac{\sum_i |\mathbf{B}_i - \mathbf{b}_i|}{\sum_i |\mathbf{b}_i|}$$

$$E'_m = 1 - \frac{1}{M} \frac{\sum_i |\mathbf{B}_i - \mathbf{b}_i|}{\sum_i |\mathbf{b}_i|}$$

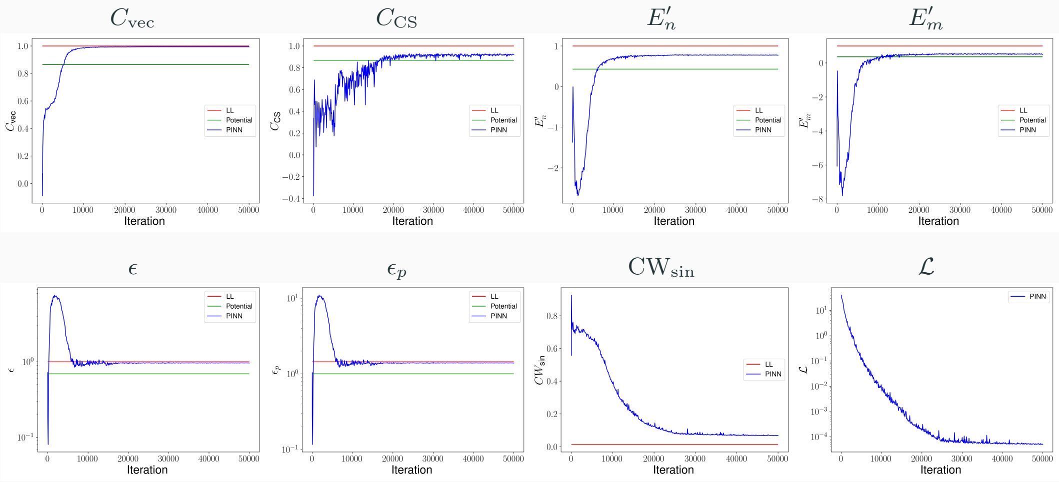
$$\epsilon = \frac{\sum_i |\mathbf{B}_i|^2}{\sum_i |\mathbf{b}_i|^2}$$

$$\epsilon_p = \frac{\sum_i |\mathbf{B}_i|^2}{\sum_i |\mathbf{B}_{\text{p},i}|^2}$$

$$\text{CW}_{\text{sin}} = \frac{\sum_i \frac{|\mathbf{J}_i \times \mathbf{B}_i|}{|\mathbf{B}_i|}}{\sum_i |\mathbf{J}_i|}$$

Here, i refers to each grid point, M is the total number of grid points, $\mathbf{B}$ is the numerical magnetic field, $\mathbf{b}$ is the reference magnetic field, $\mathbf{B}_{\text{p}}$ is the potential magnetic field whose lower boundary condition is the same as that of $\mathbf{B}$, and $\mathbf{J} = \nabla \times \mathbf{B}$ is the current density in an appropriate unit system.

Figures of merit + Loss



Figures of merit + Loss

Field	C_{vec}	C_{CS}	E'_n	E'_m	ϵ	ϵ_p	CW_{sin}	$\mathcal{L}$[a]
Low-Lou[b]	1.00000	1.00000	1.00000	1.00000	1.00000	1.44490	0.01308[c]	–
Potential	0.86465	0.86925	0.43003	0.36242	0.69209	1.00000	–[d]	–
PINN(0)	0.07115	0.33540	-1.37088	-6.07067	0.71824	1.03779	0.55813	40.23570
PINN(100)	0.25771	0.46100	-0.00643	-0.46701	0.08056	0.11640	0.76066	31.32017
PINN(1000)	0.54244	0.32404	-2.31914	-6.41640	5.59377	8.08246	0.71701	6.46577
PINN(10000)	0.98630	0.63065	0.68766	0.28275	0.96939	1.40068	0.38403	0.00848
PINN(25000)	0.99402	0.92134	0.78452	0.55897	0.96481	1.39406	0.07853	0.00006
PINN(50000)	0.99359	0.92271	0.77129	0.50928	0.96247	1.39068	0.06848	0.00005

[a] The total loss of PINN.

[b] The parameters of the Low-Lou model are $(n = 1, m = 1, l = 0.3, \Phi = \pi/2)$.

[c] This is not zero due to numerical grids.

[d] The metric CW_{sin} is undefined for the potential field.