Research closure relation of radiation transport by neural network

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What is a Supernova explosion ?

Explosion phenomenon that occurs at the end of the evolution of massive star.

Collapse due to self-gravity.

Explosion model by neutrino heating is influential.

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Accurate handling of neutrino radiation transport is essential.



Radiation transport equation.

Radiation transport equation

$$\frac{\partial f}{\partial t} + \boldsymbol{P}\cdot\frac{\partial f}{\partial \boldsymbol{r}} + \dot{\boldsymbol{P}}\frac{\partial f}{\partial \boldsymbol{P}} = \left(\frac{df}{dt}\right)_{\text{collision}}$$

Simulation calculation spends many time !?

↓

Approximate equation.

nth moment $M^{i_1 i_2 \dots i_n} = \int f l^{i_1} l^{i_2} \dots l^{i_n} d^2\Omega \quad \left(l = \frac{\boldsymbol{P}}{|\boldsymbol{P}|}\right)$

$$\frac{\partial E}{\partial t} + \nabla\cdot\boldsymbol{F} = Q$$

$$\frac{\partial \boldsymbol{F}}{\partial t} + \nabla\cdot\boldsymbol{K} = \boldsymbol{Q'}$$

$$E = \epsilon\int f d^2\Omega$$
$$F^{i_1} = \int f l^{i_1} d^2\Omega$$
$$K^{i_1 i_2} = \int f l^{i_1} l^{i_2} d^2\Omega$$
$$Q = \int S_{rad} d^2\Omega$$
$$Q'^{i_1} = \int S_{rad} l^{i_1} d^2\Omega$$

This is not Closure equation

Assume $\boldsymbol{K} = \boldsymbol{K}(E, \boldsymbol{F})$

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Closure relation is established.

Closure relation.

Eddington tensor

↓

$$\boldsymbol{K} = E\boldsymbol{T}(E, \boldsymbol{F})$$

↑

Energy density

$$T^{ij} = \frac{3\chi - 1}{2}\frac{F^i F^j}{F^2} + \frac{1-\chi}{2}\delta^{ij}$$

$$\chi = \frac{3 + 4\tilde{f}^2}{5 + 2\sqrt{4 - 3\tilde{f}^2}}$$

$$\tilde{f} = \frac{|\boldsymbol{F}|}{cE}$$

Expressing the optical depth of a supernova.

This relation equation is named M1 Closure.

However, this approximation is not good.

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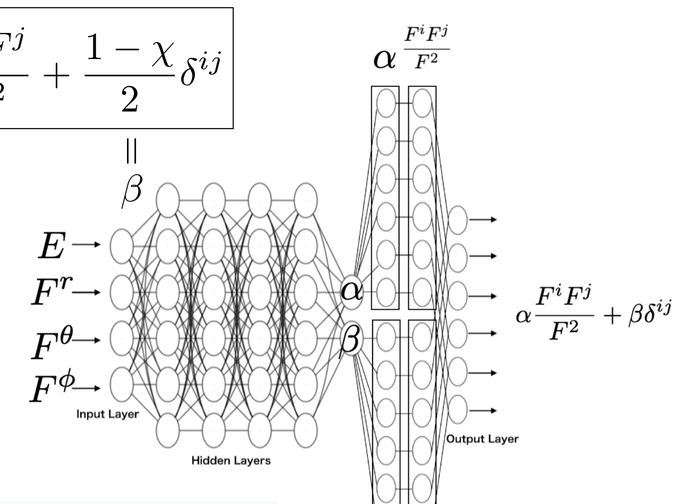
Will improve using deep learning.

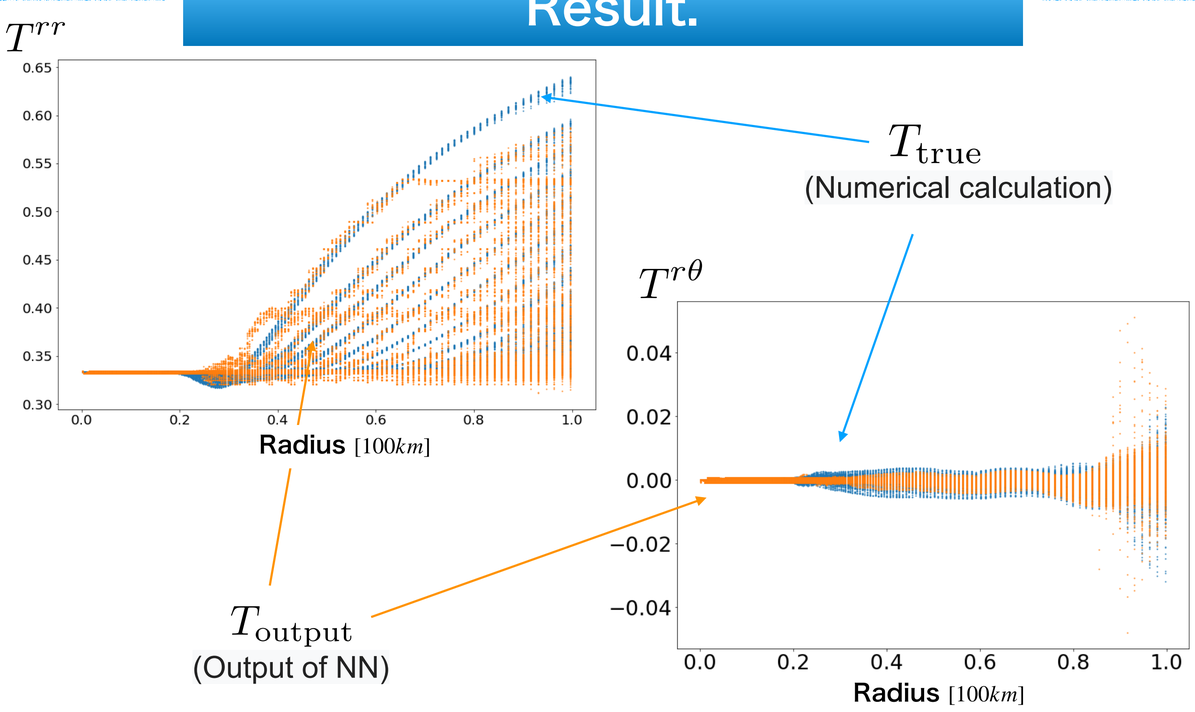
$$T^{ij}(E, \boldsymbol{F}) = \frac{3\chi - 1}{2}\frac{F^i F^j}{F^2} + \frac{1-\chi}{2}\delta^{ij}$$

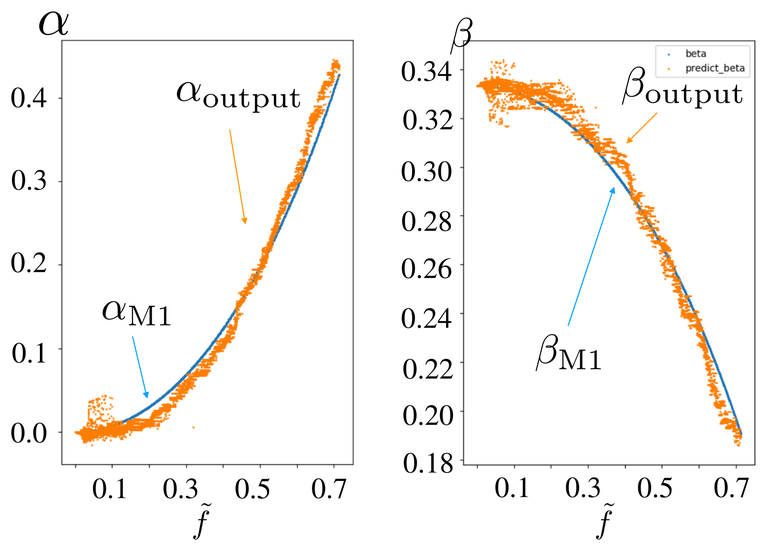
α β



This is deep neural network model.

Result.





The reason why an approximation is not good ?

Difference between NN and M1 was born.

Summary and Future work.

Reproducibility was obtained by NN.

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Evaluate whether rotation model can be reproduced.

Further assume the following equation.

$$\alpha\frac{F^i F^j}{F^2} + \beta\delta^{ij} + \kappa v^i v^j + \phi\sigma^{ij} + \psi\omega^{ij} + \theta(F^i v^j + F^j v^i) + \tau(F^i v^j - F^j v^i)$$

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