Machine-learned Closure Relation for the Core-collapse Supernova Neutrino Transport.

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Outline

Supernova

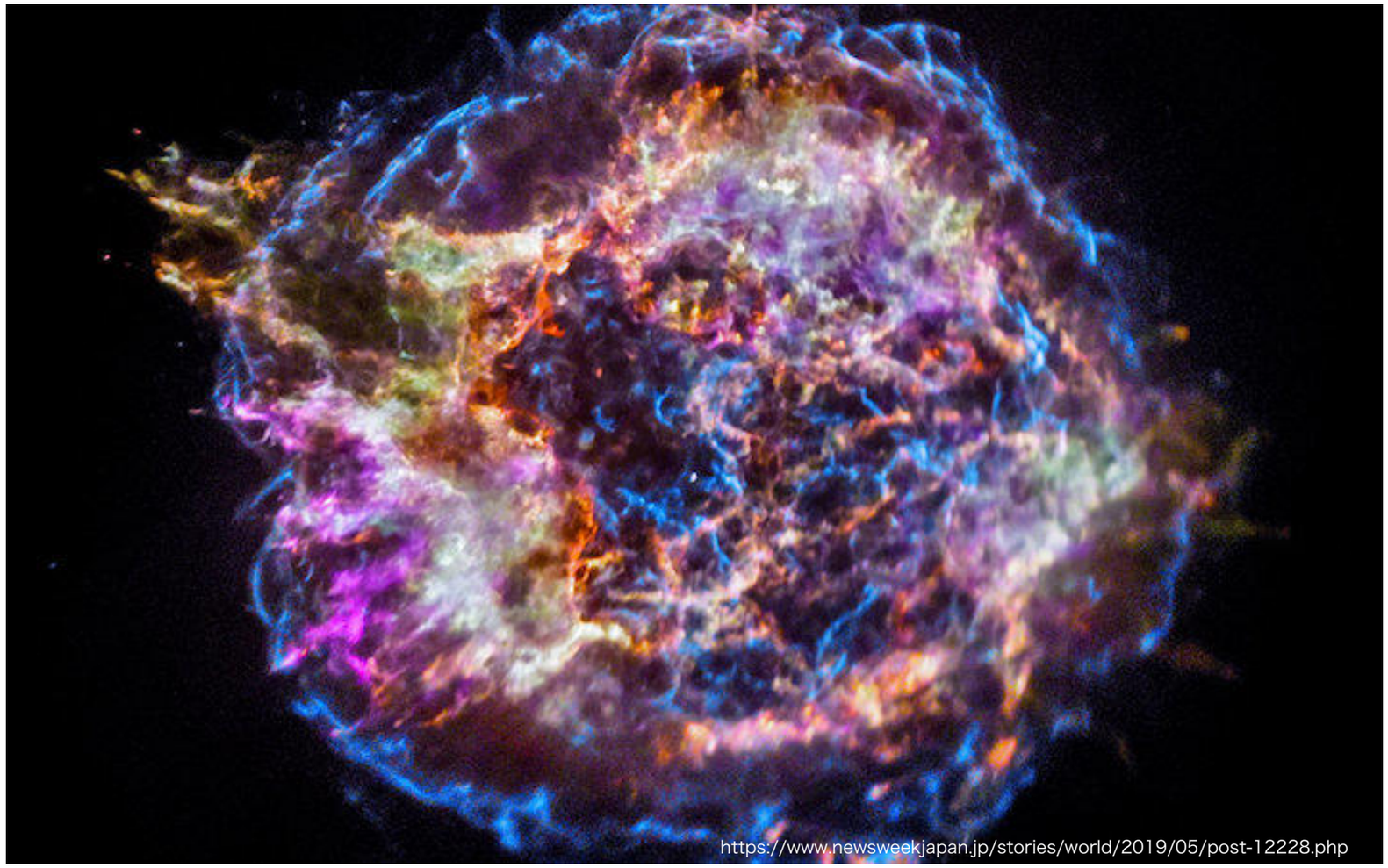

Fig.1 Supernova

An explosion phenomenon that occurs when a star, which is about eight times more than the Sun, completes nuclear fusion inside.

We have to think about neutrino transportation

Introduction

Boltzmann equation

7-dimensional equation of Phase space, momentum space and time

$$\frac{\partial f}{\partial t} + \boldsymbol{v}\frac{\partial f}{\partial \boldsymbol{r}} + \boldsymbol{F}\frac{\partial f}{\partial \boldsymbol{P}} = \left(\frac{df}{dt}\right)_{\mathrm{coll}}$$

Numerical calculation takes time.

⇩

Use approximation method. But it is not good.

Up to about 20% error.

Method

Moment equation

Use moment method

To make it easier to understand.

$$\frac{\partial f}{\partial t} + \boldsymbol{P}\frac{\partial f}{\partial \boldsymbol{r}} = S_{rad}$$

Integrate momentum space

Each

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

0th, 1st

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

1st, 2nd

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

Method

M1 closure method

Assuming the relationship of $\boldsymbol{K} = \boldsymbol{K}(E, F)$

to close the hierarchy and solving it as an equation for E, F

It is called M1 closure method,
because it considers even the first-order equation.

$$\boldsymbol{K} = E\boldsymbol{T}$$

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

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

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

Eddington tensor

Method

Neural Network

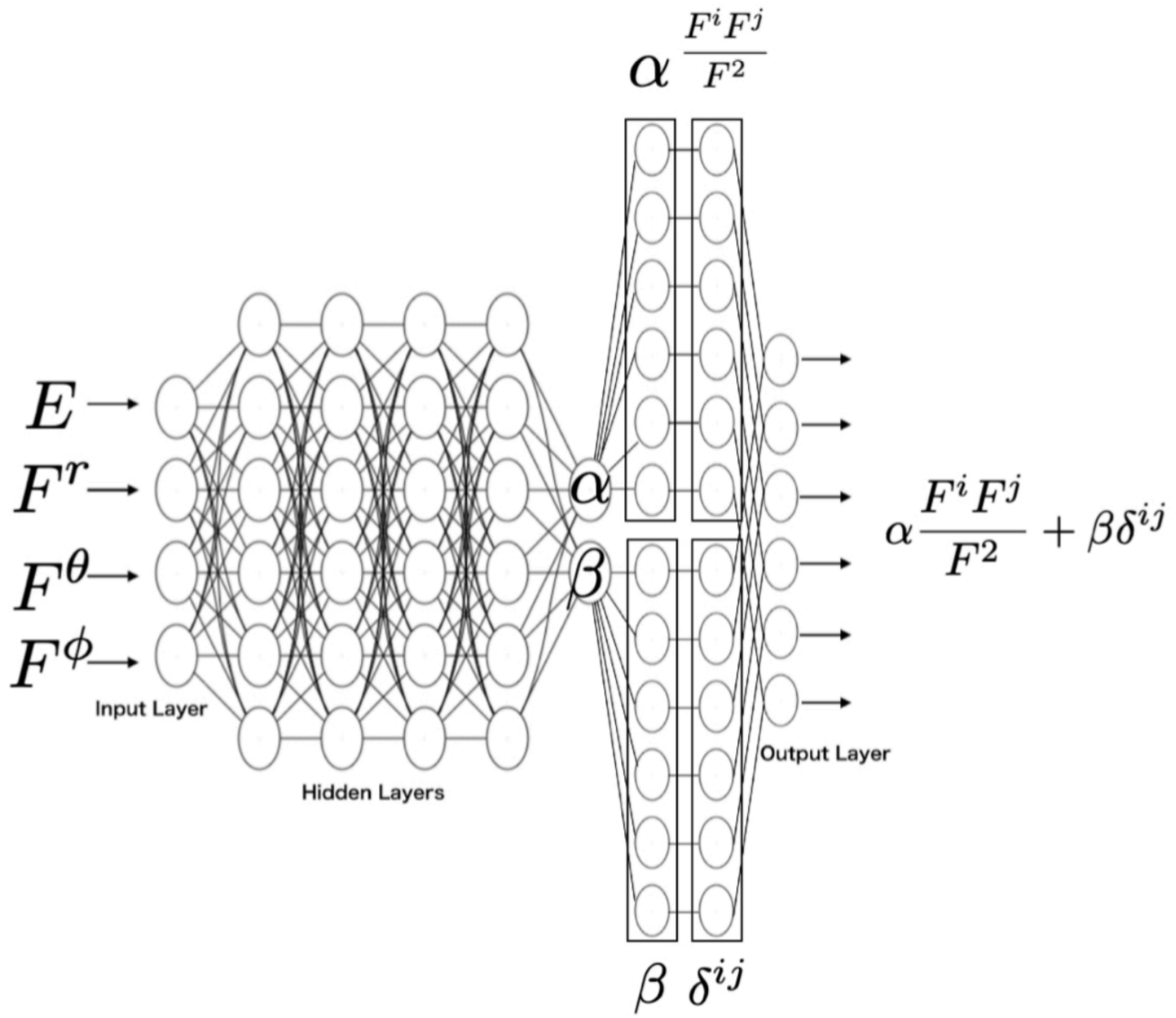

Fig.4 Tensor Basis Neural Network

6 layer 1024 node

Result

Deep Learning

TBNN

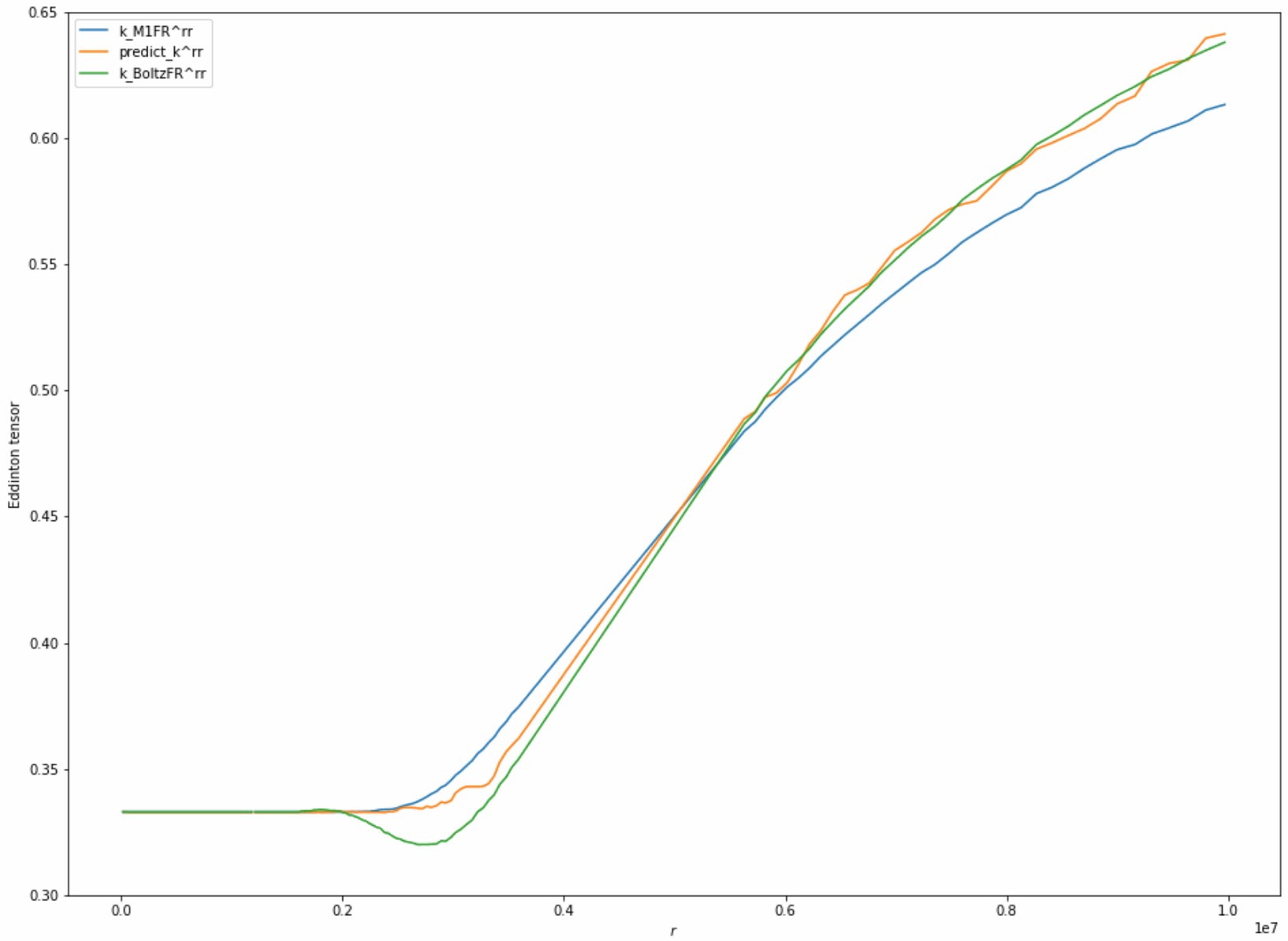

Fig.3 the diagonal component of Eddington tensor

Discussion

Thank you for listening.