Acceleration of the spherically symmetric Bolzmann equation for supernova explosion simulations on GPU, Pezy-SC, and SX-Aurora

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Multi-dimensional Modeling and Multi-Messenger observation
from Core-Collapse Supernovae (4M-COCOS)
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Core-collapse supernovae

- Supernova explosion simulation
  - Matter: hydrodynamics
  - Neutrino transport is important: described by Boltzmann equation
  - Equation of state for high temperature and density
  - Gravitational effect governed by general relativity
- Large scale simulation is essential to understand explosion mechanics
  - Fluid instability may play a key role (dimensionality is important)
  - Boltzmann eq.: evolution eq. of 6D distribution function

$$\frac{dx^\mu}{d\tau}\frac{\partial f_\nu}{\partial x^\mu} + \frac{dp^\mu}{d\tau}\frac{\partial f_\nu}{\partial p^\mu} = \left(\frac{\delta f_\nu}{\delta \tau}\right)_{\mathrm{coll}} \qquad f_\nu(x,p) : \text{neutrino distribution function}$$

  - Quantitative (spatial) 3D simulation is only possible at Exa-scale
  - Systematic study is needed for 1D, 2D, 3D simulations
- Numerical simulations
  - Massively parallel supercomputers (K, Fugaku, …)
  - How about accelerators ?

Spherically symmetric system

- Spherically symmetric system
  - Systematic survey of massive stars is necessary
  - Basis for 2D/3D simulations and observations
  - 1st principle calculation (Full GR+Hydro.+Boltzmann)
  - Testbed for developing GPU code
- Numerical setup
  - GR Lagrangian hydrodynamics + S_N + Implicit scheme
  - Boltzmann equation for neutrinos $$\frac{\partial f_\nu}{\partial t} + \mu \frac{\partial f_\nu}{\partial r} + \frac{(1-\mu^2)}{r}\frac{\partial f_\nu}{\partial \mu} = \left(\frac{\delta f_\nu}{\delta t}\right)_{\mathrm{coll}}$$
  - Linear equation is solved at every step of time evolution

    → Primary bottleneck
    - BiCGStab algorithms for a block tridiagonal matrix
  - Secondary bottlenecks:
    - Collision term in Boltzmann equation
    - Inversion of diagonal block matrices
- These bottlenecks are target of offloading to GPU/Pezy-SC

Machines

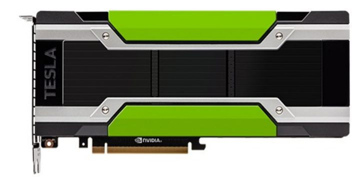
Performance is measured on the following machines

- NVIDIA P100 GPU (Pascal)

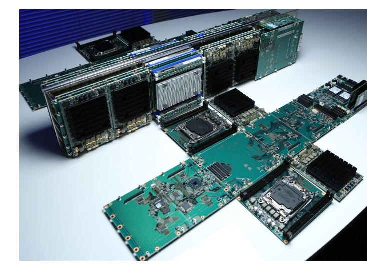
  H.M. & K.S. Lecture Note in Comp. Sci. 10962 (2018) 440

  H.M. & K.S. IEEE Xplore, Proceedings of CANDAR2018, 56

  - 4.7 TFlops/device for double precision
  - High memory and host-device bandwidths



- Pezy-SC: Suiren-Blue @KEK
  - Many-core accelerator
  - 1.5 TFlops/device
  - 1024 MIMD cores with hierarchical structure
  - Liquid cooling for low power consumption



- NEC SX-Aurora TSUBASA
  - Vector architecture: Latest product of SX-series
  - 2.46 TFlops/Vector Engine
  - High memory bandwidth: 1228 GB/s (B/F=0.5)
  - Vector Engine works as a usual MPI node