Участие Сибирского Суперкомпьютерного Центра СО РАН в Президентской программе исследовательских проектов «Проведение исследований на базе существующей научной инфраструктуры мирового уровня»

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Institute of Computational Mathematics and Mathematical Geophysics SB RAS
Supported by RSCF project No. 19-71-20026

Head of the lab
Igor Chernykh

Astrophysics group (Igor Kulikov)	Plasma physics group (Vitaly Vshivkov)	Geophysics group (Boris Glinskiy)	Siberian Supercomputer Center

RSC

~100 TFLOPS

Intel Xeon
Platinum 8268

Intel Xeon
Gold 6248R

Intel Xeon
E5-2697Av4

Intel Xeon
Phi 7290

~100 TFLOPS

Процессоры Intel (2009-2012)
NVIDIA Tesla 2090M

Siberian Supercomputer Center 2020

NKS-1P system (RSC hot water cooling system):

- **27 nodes: 2 CPU Intel Xeon E5-2697v4 [128 GB DDR4, 256 GB DDR4] (864 cores) (1 node with 2x375GB Intel Optane [IMDT])**
- **16 nodes: 1 CPU Intel Xeon Phi 7290 KNL [16 GB MCDRAM+96 GB DDR4] (1152 cores)**
- **1 node: 2 CPU Intel Xeon Platinum 8268 [192 GB DDR4, 4TB SSD]**
- **Intel OmniPath 100Gbit**
- **Intel Lustre – 200 TB**

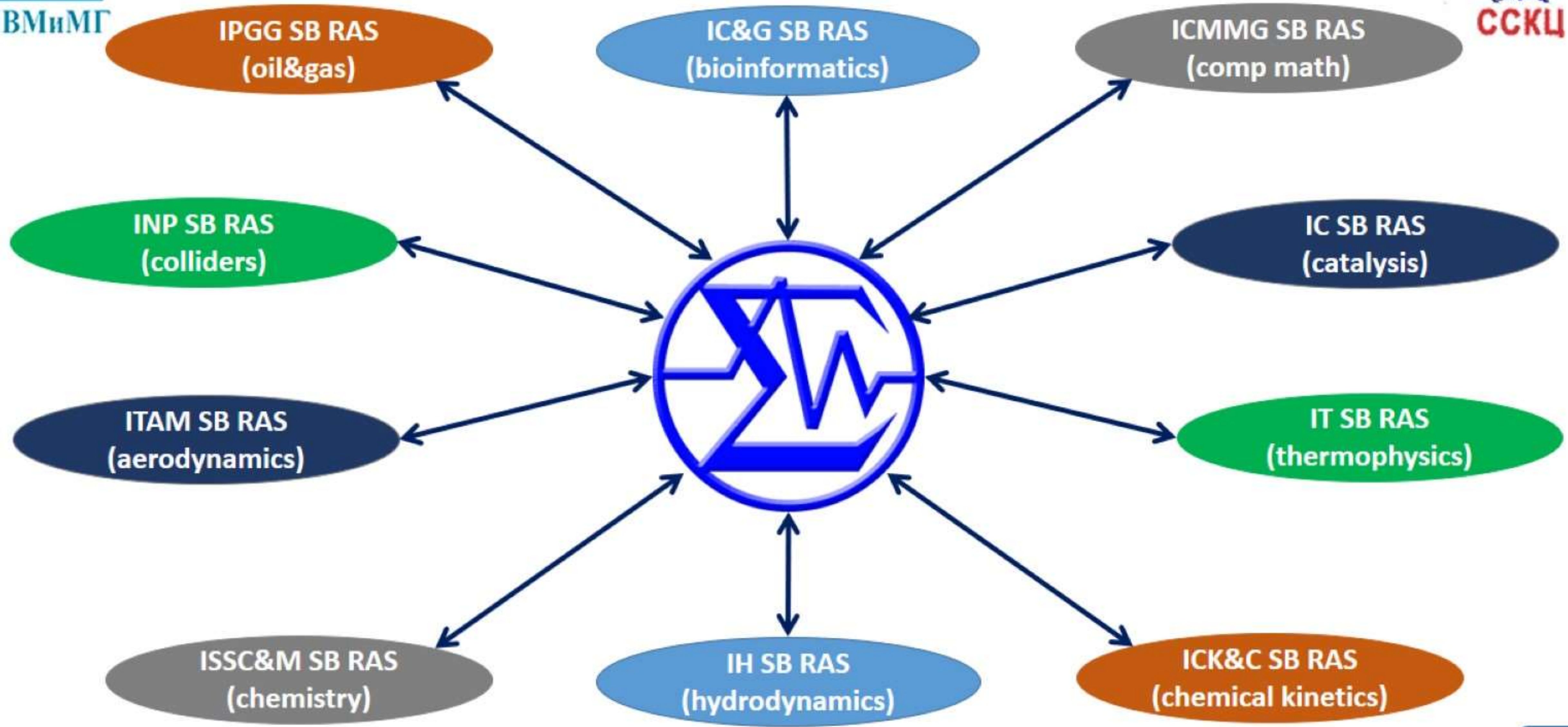
NKS-30T system (air cooling system) 2009-2011 years:

- **576 CPU Intel Xeon E5450/E5540(2688 cores)**
- **80 CPU Intel Xeon X5670(480 cores)**
- **120 GPU NVIDIA Tesla M 2090(61440 threads)**
- **Infiniband QDR**
- **HP Ibrix – 90 TB**

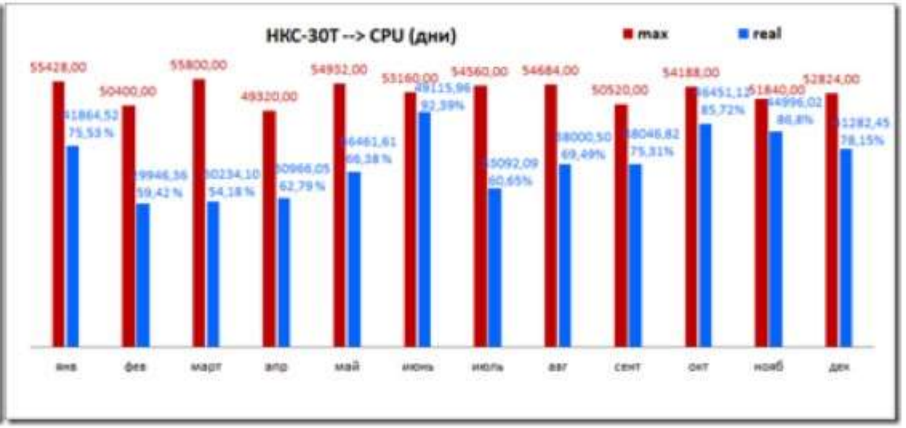
ИВМиМГ

ССКЦ

Main SSCC customers

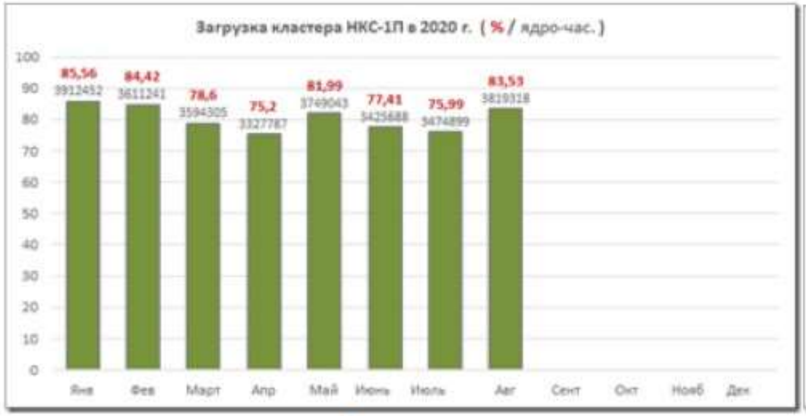


Siberian Supercomputer Center
2019 statistics



Customers: 252 (55 scientific organizations)
Research papers published: 129
R&D projects: 120

Siberian Supercomputer Center
2020 statistics



Ремонт системы охлаждения

Теоретический пик пакетных систем запуска задач

Customers: 252 (55 scientific organizations)

R&D projects: 140

Siberian Supercomputer Center
2020 statistics

ИВМиМГ

ССКЦ

РНФ 19-71-20026 «Численное моделирование открытых плазменных ловушек для решения задач управляемого термоядерного синтеза с использованием перспективных высокопроизводительных вычислительных систем», рук Черных И.Г.

РНФ 19-77-20130 «Фундаментальные основы импульсного электромагнитного зондирования с управляемым спектром: теоретическое обоснование инновационного геофизического метода геологоразведки с использованием высокопроизводительных вычислений на базе Сибирского суперкомпьютерного центра СО РАН», рук. Глинских В.Н.

РНФ 19-77-20004 «Проявление связности систем трещин в волновых полях – численные исследования процессов распространения сейсмических и акустических волн в флюидонасыщенных трещиновато-пористых средах», рук. Роменских Е.И.

РНФ 19-72-20114 «Разработка системы моделирования, обработки и хранения данных установки класса мегасайенс "Супер С-тау фабрика"», рук. Логашенко И.Б.

Siberian Supercomputer Center
2020 statistics

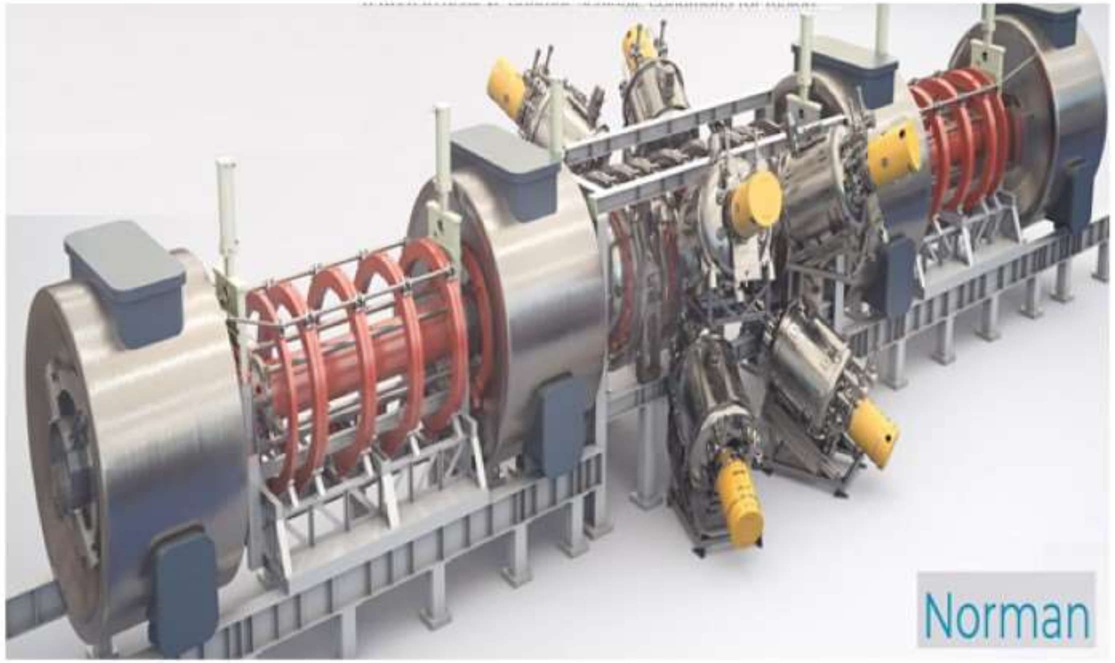
РНФ 19-71-20026 – 1200 тыс. р = 46153 узло/часа
РНФ 19-77-20130 – 1200 тыс. р = 46153 узло/часа
РНФ 19-77-20004 – 700 тыс. р = 26923 узло/часа
РНФ 19-72-20114 – 1200 тыс. р = 46153 узло/часа

Introduction

- One of application of plasma physics is construction of magnetic trap for confinement of the thermonuclear plasmas.
- Excess of thermonuclear power over input power was demonstrated experimentally in tokamaks ($Q \sim 1$). The International Thermonuclear Experimental Reactor (ITER) considering as prototype of commercial reactor is being built now.
- Parameters of the best stellarators are close to the parameters of the best tokamaks.
- Alternative conceptions of magnetic plasma confinement (such as open traps and field-reversed configurations, FRCs) are developed.

Introduction

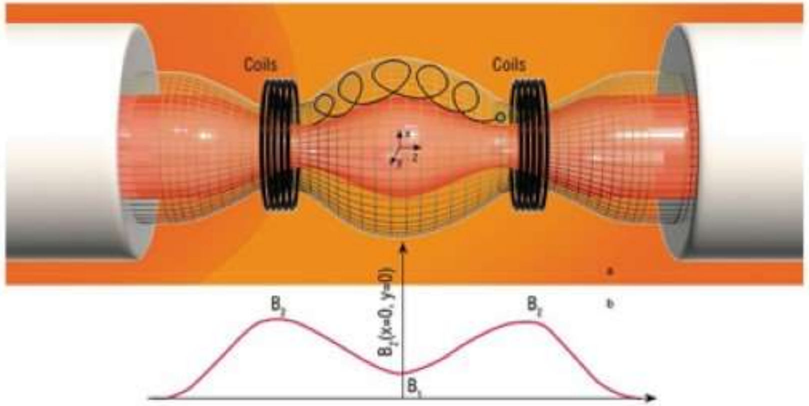
Open magnetic traps : GDT (BINP SBRAS) ,
Norman (TAE Technologies, USA)



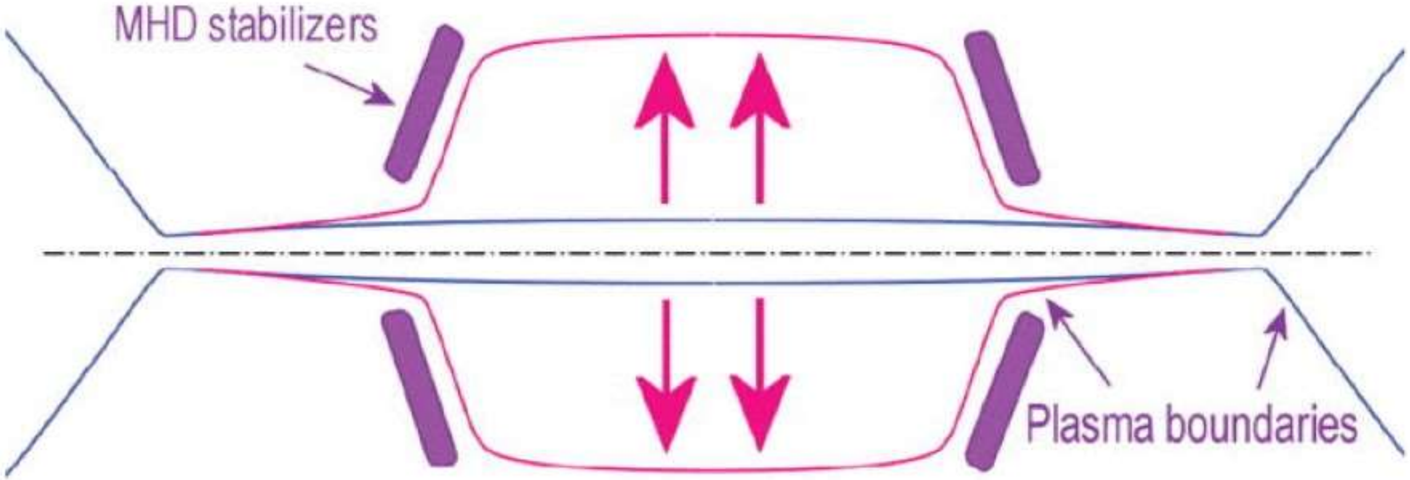
GDT facility
L=7m , D=1m, Te=1 keV, ß=0.6

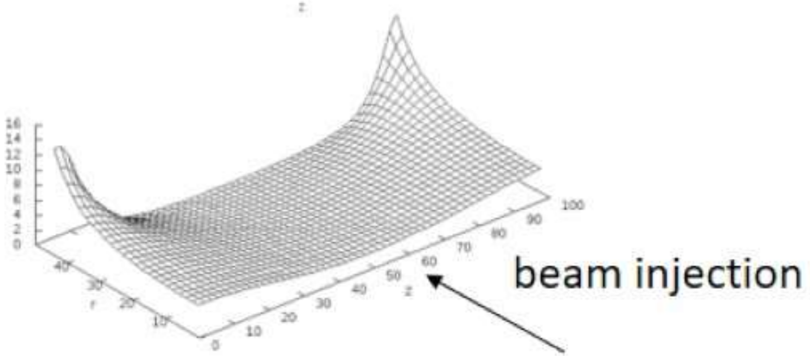
C-2W Ti=1keV, t*= 5ms
L=3m, D=40 cm
T= 20 million°C
$^{11}B + p \text{----} 3\,^{4}He$

Magnetic trap



A. Shosin 23 Apr 2018 , Budker's Universe , volume Special Issue, N1





A. D. Beklemishev **Diamagnetic "bubble" equilibria in linear traps** Phys. Plasmas23, 082506 (2016)

Equations

The kinetic Vlasov equation (ions)

$$\frac{\partial f_i}{\partial t} + \vec{v}\frac{\partial f_i}{\partial \vec{r}} + \frac{\vec{F}_i}{m_i}\frac{\partial f_i}{\partial \vec{v}} = 0$$

$$\vec{F}_i = e\left(\vec{E} + \frac{1}{c}[\vec{v},\vec{B}]\right) + R_i$$

$$n_i(\vec{r}) = \int f_i(t,\vec{r},\vec{v})d\vec{v}$$

$$\vec{V}_i(\vec{r}) = \frac{1}{n_i(\vec{r})}\int \vec{v} f_i(t,\vec{r},\vec{v})d\vec{v}$$

Maxwell's equations (magnetic field, electric field, ...)

$$\frac{1}{c}\frac{\partial \vec{E}}{\partial t} = rot\vec{B} - \frac{4\pi}{c}\vec{j}$$

$$\frac{1}{c}\frac{\partial \vec{B}}{\partial t} = -rot\vec{E}$$

$$div\vec{E} = 4\pi\rho$$

$$div\vec{B} = 0$$

$n_i = n_e$ Quasineutral plasma

$$R_i = -R_e$$

$$\vec{j} = e(n_i\vec{V}_i - n_e\vec{V}_e)$$
$$\rho = e(n_i - n_e)$$

MHD equations (electrons)

$$-e\vec{E} - \frac{e}{c}[\vec{V}_e,\vec{B}] - \frac{\nabla p_e}{n_e} + \vec{R}_e = m_e\frac{d\vec{V}}{dt}$$

$$\vec{R}_e = -m_e\frac{\vec{V}_e - \vec{V}_i}{\tau_{ei}}$$

Heat conduction equation (electron's temperature)

$$n_e\left(\frac{\partial T_e}{\partial t} + (\vec{V}_e\nabla)T_e\right) = (\gamma - 1)\left(Q_e - div\vec{q}_e - p_e div\vec{V}_e\right)$$

$$Q_e = \frac{j^2}{\sigma}$$

$$\vec{q}_e = -k\nabla Te$$

State equation

$$p_e = n_e T_e$$

Component notation

$$\frac{dV_{ir}}{dt} = E_r + V_{i\varphi}B_z - V_{iz}B_\varphi + \frac{V_{i\varphi}^2}{r} + \frac{\kappa}{n_e}\frac{\partial B_\varphi}{\partial z}$$
$$\frac{dV_{i\varphi}}{dt} = E_\varphi + V_{iz}B_r - V_{ir}B_z - \frac{V_{i\varphi}V_{ir}}{r} - \frac{\kappa}{n_e}\left(\frac{\partial B_r}{\partial z} - \frac{\partial B_z}{\partial r}\right)$$
$$\frac{dV_{iz}}{dt} = E_z + V_{ir}B_\varphi - V_{i\varphi}B_r - \frac{\kappa}{n_e}\frac{1}{r}\frac{\partial\left(rB_\varphi\right)}{\partial r}$$

$$\frac{dr_i}{dt} = V_{ir}$$
$$\frac{dr_z}{dt} = V_{iz}$$

$$-\frac{\partial B_\phi}{\partial z} = n_i V_{ir} - n_e V_{er}$$
$$\frac{\partial B_r}{\partial z} - \frac{\partial B_z}{\partial r} = n_i V_{i\phi} - n_e V_{e\phi}$$
$$\frac{1}{r}\frac{\partial\left(rB_\phi\right)}{\partial r} = n_i V_{iz} - n_e V_{ez}$$

$$E_r = V_{ez}B_\varphi - V_{e\varphi}B_z - \frac{1}{2n_e}\frac{\partial p_e}{\partial r} - \frac{\kappa}{n_e}\frac{\partial B_\varphi}{\partial z}$$
$$E_\varphi = V_{er}B_z - V_{ez}B_r + \frac{\kappa}{n_e}\left(\frac{\partial B_r}{\partial z} - \frac{\partial B_z}{\partial r}\right)$$
$$E_z = V_{e\varphi}B_r - V_{er}B_\varphi - \frac{1}{2n_e}\frac{\partial p_e}{\partial z} - \frac{\kappa}{n_e}\frac{1}{r}\frac{\partial\left(rB_\varphi\right)}{\partial r}$$

$$\frac{\partial B_r}{\partial t} = -\frac{\partial E_\varphi}{\partial z}$$
$$\frac{\partial B_\varphi}{\partial t} = -\frac{\partial E_r}{\partial z} + \frac{\partial E_z}{\partial r}$$
$$\frac{\partial B_z}{\partial t} = -\frac{1}{r}\frac{\partial\left(rE_\varphi\right)}{\partial r}$$

$$n_e\left(\frac{\partial T_e}{\partial t} + (\vec{V}_e\nabla)T_e\right) = 2\kappa n_e(\gamma - 1)\left[\left((V_{er} - V_{ir})^2 + \left(V_{e\varphi} - V_{i\varphi}\right)^2 + (V_{ez} - V_{iz})^2\right) + \frac{k}{n_e}\left(\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial T_e}{\partial r}\right) + \frac{\partial}{\partial z}\left(r\frac{\partial T_e}{\partial z}\right)\right) - T_e\left(\frac{1}{r}\frac{\partial(rV_{er})}{\partial r} + \frac{\partial V_{ez}}{\partial z}\right)\right]$$

Algorithm

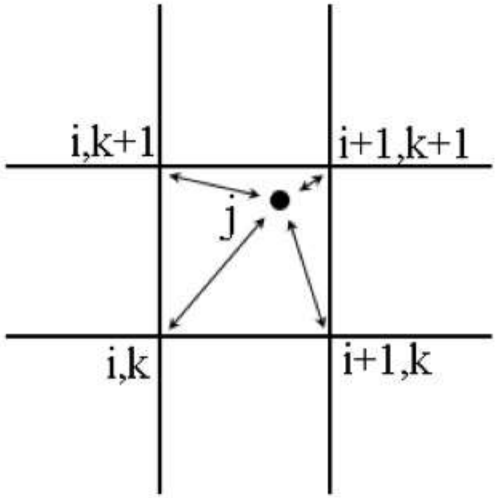
✓ Cylinder coordinate system due to the axial symmetry, r=0 is singularity

✓ Hybrid model, the ions are described kinetically, the electrons – with MHD

✓ Particles-in-cell method with PIC form-factor

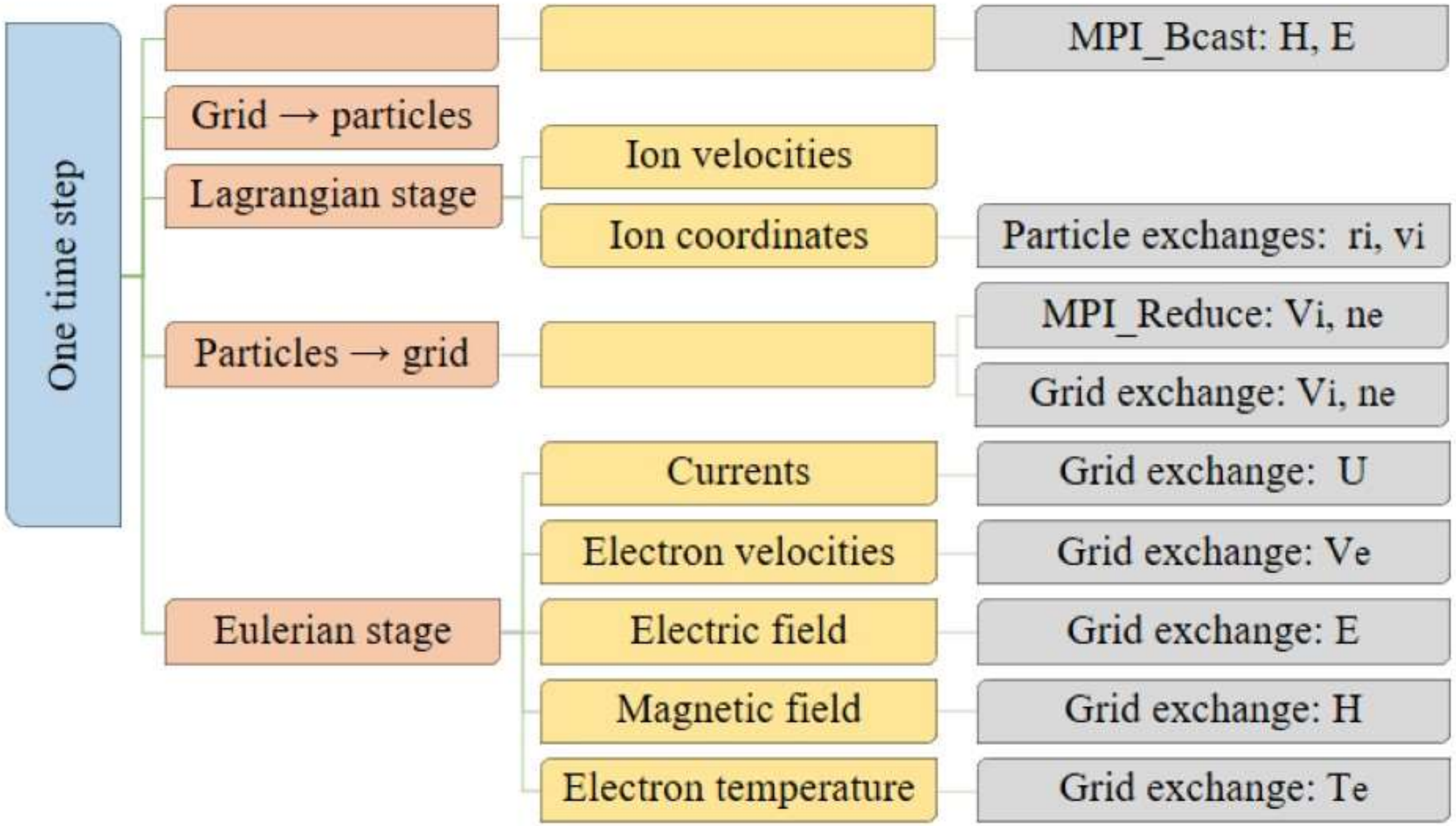
✓ Shifted for half of the steps grids

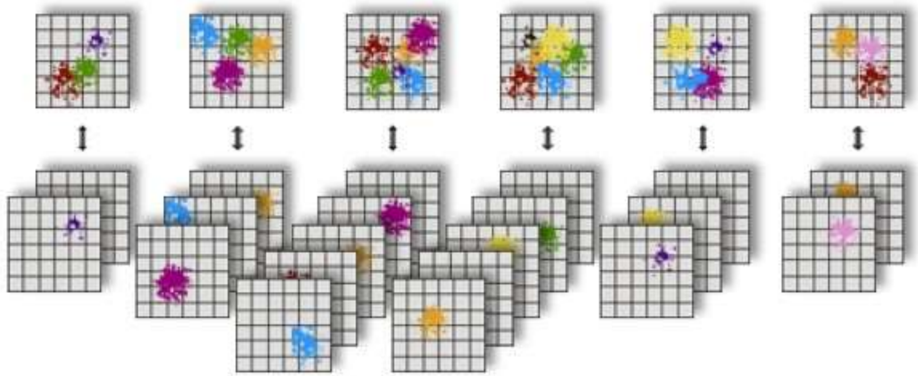
✓Mixed Euler-Lagrangian decomposition for the parallelization



particles >> cells

Parallel Method



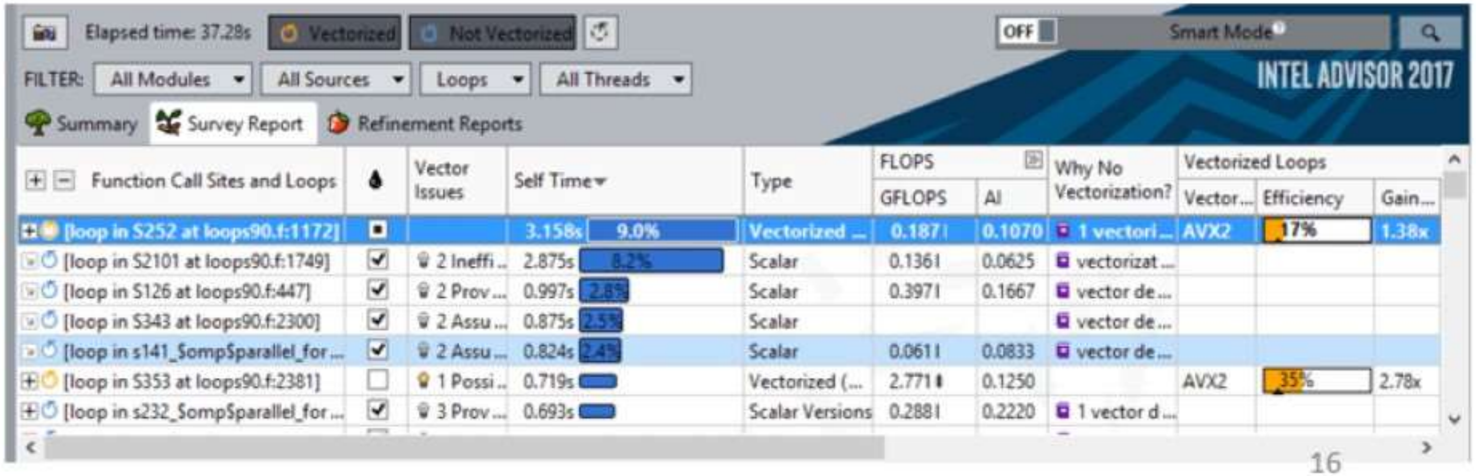


Numerical Experiments

Intel Xeon
Platinum 8268
(2x24cores, 2.9GHz)
AVX512
mpiifort -axCORE-AVX512

Intel Xeon
E5-2697Av4
(2x16cores, 2.6 GHz)

Intel Xeon
Phi 7290
(1x72cores, 1.5GHz)
AVX512
mpiifort -axCORE-AVX512



Numerical Experiments

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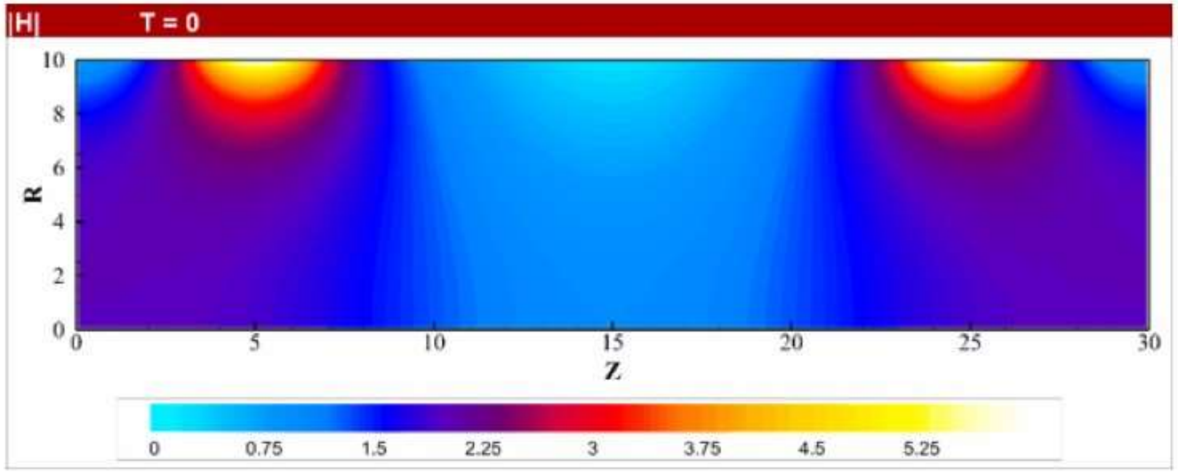
(2x16cores, 2.6 GHz)

Intel Xeon
Phi 7290
(1x72cores, 1.5GHz)

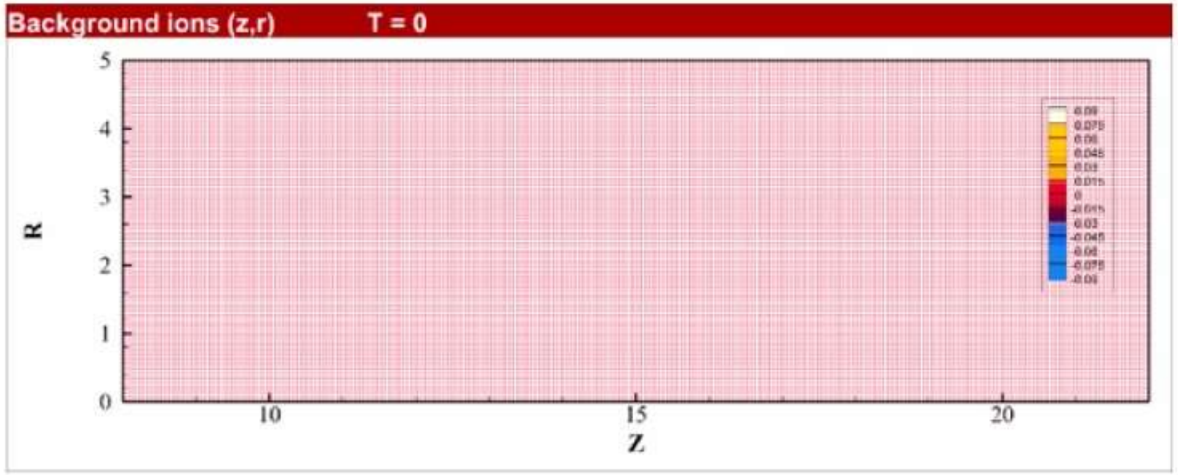
	MPI off, s	MPI on (15, 15), s	MPI on (15,32), s
Intel Xeon Phi 7290 (KNL) avx512	10300	4650	1070
Intel Xeon E5-2697A v4 (Broadwell)	2089	1019	582
Intel Xeon Platinum 8268 (CascadeLake)	1654	868	379
Intel Xeon Platinum 8268 (CascadeLake) avx512	1472	773	378

Results

Time steps – 4.8e6
Background ions – 1.2e5
Beam ions – 1.3e6
Grid: 100x300



Absolute value of magnetic field
Grid: 100x300



Conclusion

- The numerical code is applicable for simulation with parameters close to real experimental conditions.
- Formation of quasi-stationary structure of magnetic field with region of negligible field is demonstrated.
- This code have high potential for auto-vectorization

Thank you for your attention