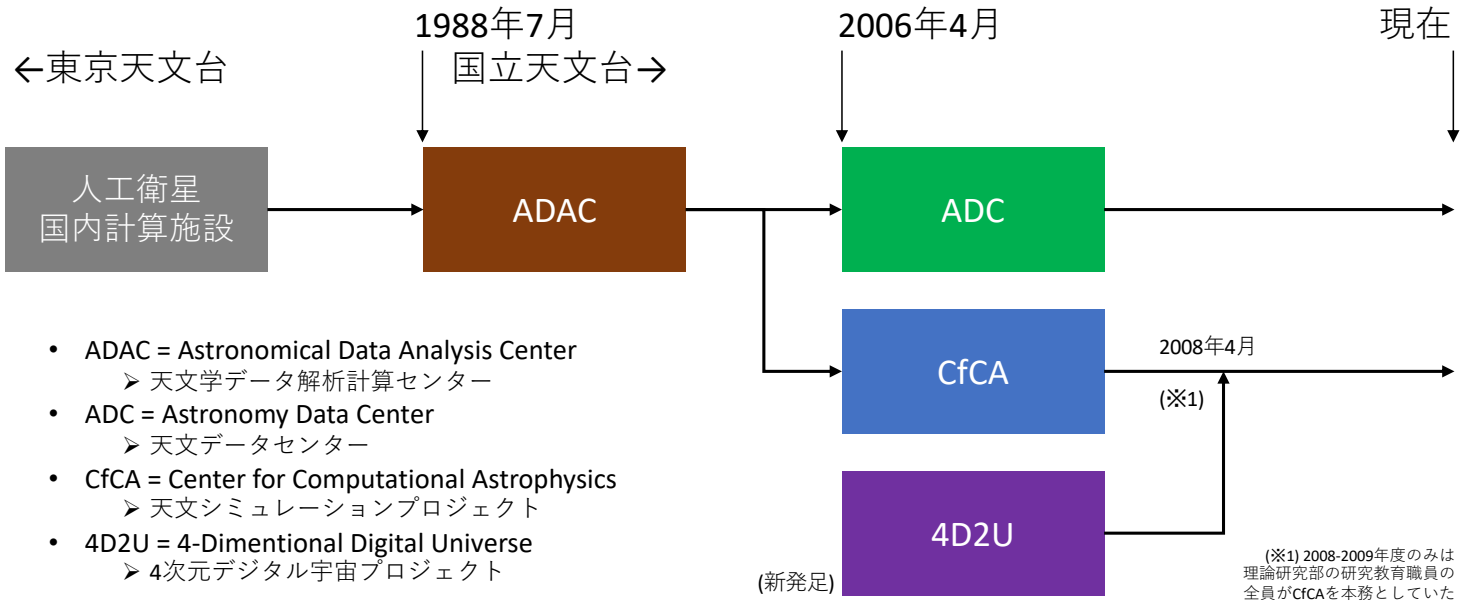
Center for Computational Astrophysics

Eiichiro Kokubo and CfCA Daemons

2022.12.8

Brief History



- ADAC = Astronomical Data Analysis Center
  - 天文学データ解析計算センター
- ADC = Astronomy Data Center
  - 天文データセンター
- CfCA = Center for Computational Astrophysics
  - 天文シミュレーションプロジェクト
- 4D2U = 4-Dimentional Digital Universe
  - 4次元デジタル宇宙プロジェクト

Scientific Goals and Missions (1)

Purpose

- 天文シミュレーションプロジェクト（CfCA）は宇宙を探求する計算天体物理学の日本における中核拠点としてこの研究分野の推進に取り組む。

Missions

本プロジェクトのミッションを以下に記す。

1. 多様な計算機資源を共同利用設備として日本の天文学コミュニティへ供用し、天文学・天体物理学の研究活動の進展を支援する。
2. 計算天体物理学の分野に於いて第一級の研究成果を挙げる。
3. 天文学のデータを用いた最先端コンテンツを開発し、天文学の最新の研究成果を社会へ向けて発信する。

Scientific Goals and Missions (2)

Primary Scientific Goals

本プロジェクトの主要科学達成目標を以下に記す。

1. 共同利用計算機設備の安定した運用を維持し、日本に於けるこの研究分野の中核的な役割を果たす。
2. 計算天体物理学に特化したハードウェアとソフトウェアの研究・開発を行い、天体物理学に関する第一級の学術的成果を得る。
3. 天文データを高度に可視化した 4 次元デジタル宇宙 (4D2U) の最先端コンテンツを開発する。

Members (Tenured)

Professors (2)

- E. Kokubo (Director), N. Tominaga

Associate Professors (2)

- T. Takiwaki, M. Machida

Lecturer (1)

- T. Ito (Deputy Director)

Assistant Professors (2)

- K. Iwasaki, T. Moriya

Engineer (1)

- K. Takahashi

(joint appointment from DoS and Mizusawa)

Members (Fixed-Term)

Research Expert (1)

- H. Nakayama

Specially Appointed Senior Specialists (3)

- H. Hohokabe, H. Fukushi, T. Kato

Specially Appointed Research Staffs (5)

- S. Ideguchi, Y. Matsumoto, T. Taki, Z. Keszthelyi, T. Nozawa

Research Supporters (3)

- K. Kano, C. Kimura, S. Hasegawa

Administrative Supporter (1)

- M. Masuyama

(4D2U) (KAKENHI)

CfCA HPC System

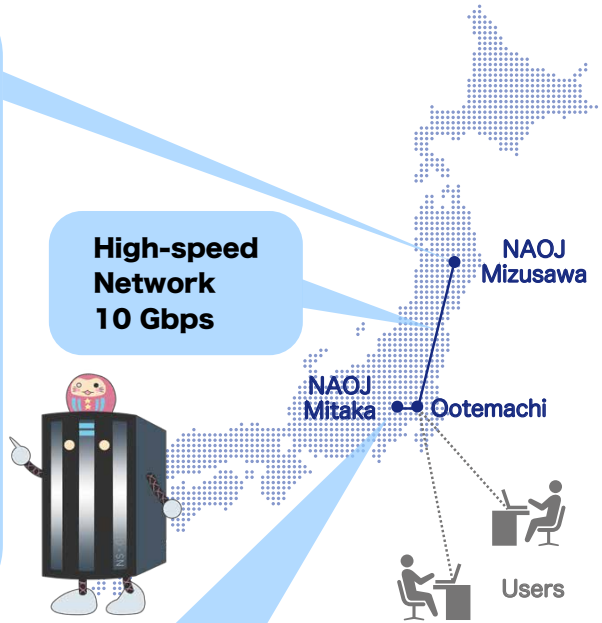
Supercomputer "ATERUI II" (Cray XC50)

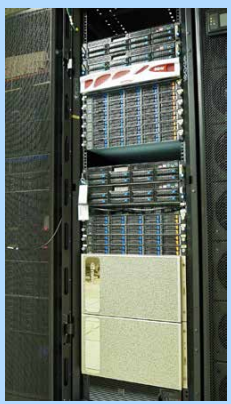
Theoretical Peak Performance: 3.087 Pflops
Main Memory: 385.9 TB
Nodes: 1,005

CPU: Intel Xeon Skylake 6148 2.4 GHz, 40 cores
Total Core Number: 40,200

File server (DDN EXA Scaler)

Disk Capacity: 6.5 PB



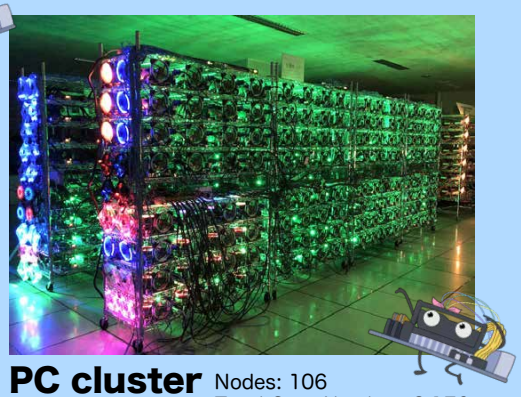


GPU server

Nodes: 6
Total GPU Number: 32 (NVIDIA A100)

Small Parallel Computers

Nodes: 10 (AMD EPYC 7402 : 6, AMD EPYC 74F3 : 4)
Total Core Number: 480



PC cluster

Nodes: 106
Total Core Number: 2,176
CPU: AMD Ryzen7 and 9 types of CPU

File server

Disk Capacity: ~ 8 PB

Analysis server

Nodes: 6
Core Number: 36 (※)
Main Memory: 1 TB (※)

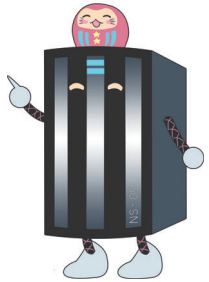
※ per 1 node

Not only supercomputer but also simulation infrastructure!

NS-05 ATERUI II (Cray XC50)

Peak Performance: 3 Pflops

TOP500 384 (2022.11)



CfCA HPC System (2022.12)

Cray XC50 (ATERUI II)

- Massively parallel scalar computer (40200 cores, 3.087 Pflops, 385.9 TB)

Small Parallel Computer (DIY)

- 480 cores (AMD EPYC)

GPGPU Cluster (DIY)

- NVIDIA Tesla A100 x 32

PC Cluster (DIY)

- Small-scale non-parallel calculation (AMD Ryzen, Intel Core i5 & i7)

File Server (DIY)

- Parallel RAID (8 PB)

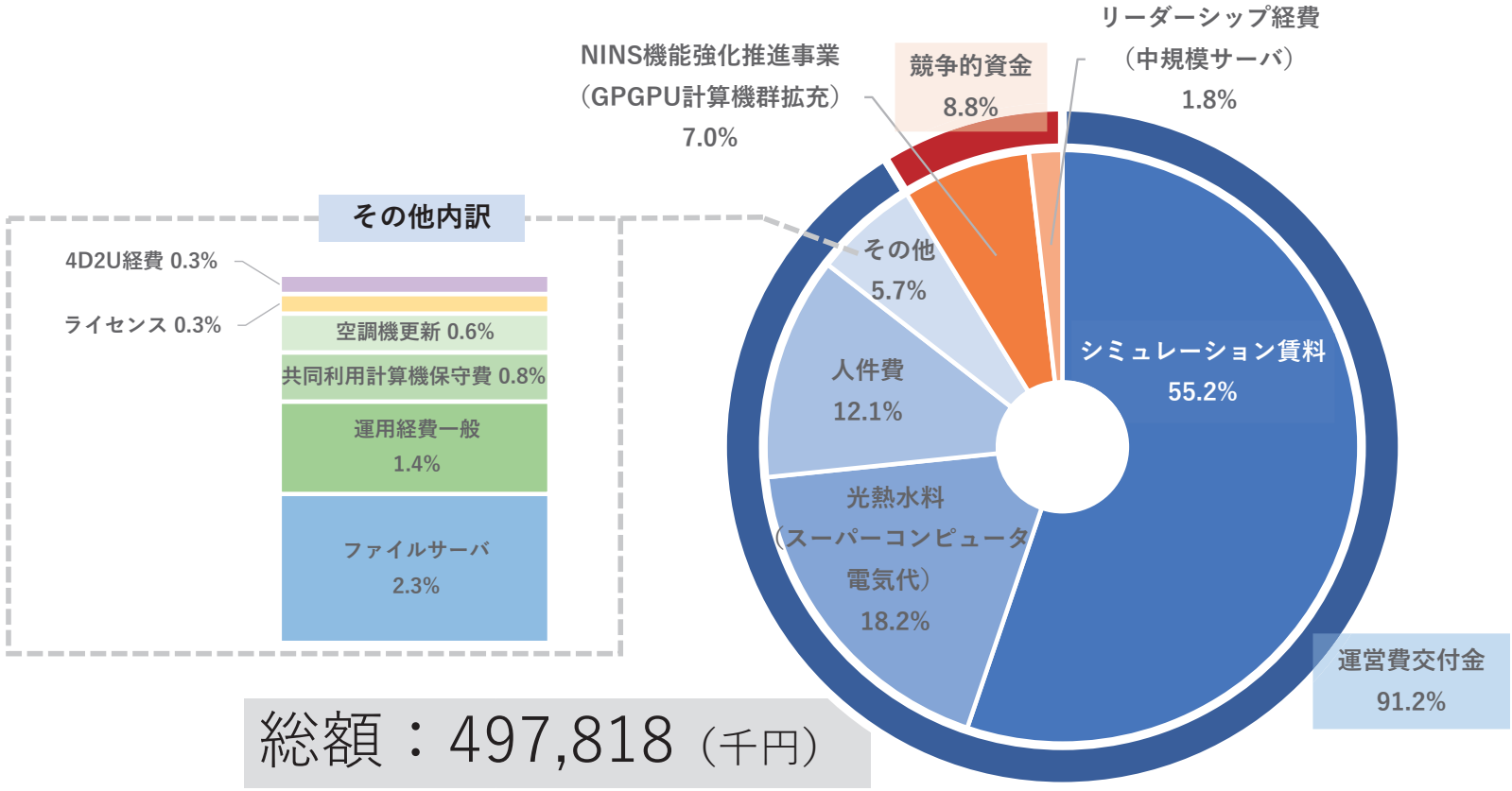
Data Analysis Server (DIY)

- (36 cores, 1 TB memory) x 6 nodes

All in stable operation!

Budget Profile

天文シミュレーションプロジェクト　2021年度予算内訳



総額：497,818（千円）

Number of Users and Publications

FY	# of users	# of publications	XC30/50 OR
2017	241	149	94%
2018	255	150	93%
2019	287	137	94%
2020	298	179	93%
2021	288	167	96%

9 Nature/Science papers in FY2017-21

3 press releases in FY2021

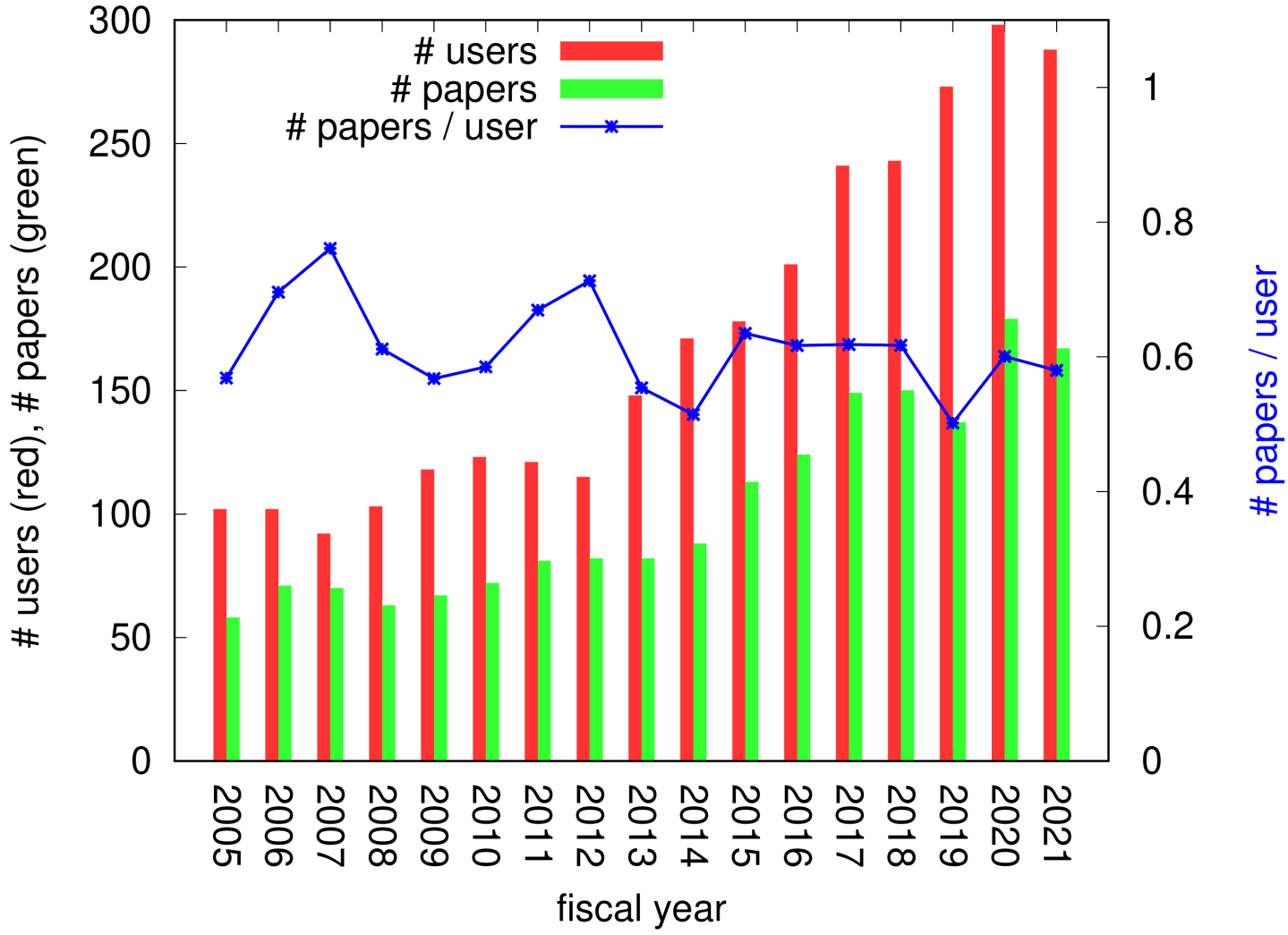
Average Citation Count: 32 (Web of Science 2022.8.23)

FY2021	total	XC50	GPU/GRAPE	PC cluster
users	288(40%)	237	18	61
papers	167	136	9	38

(): % of students

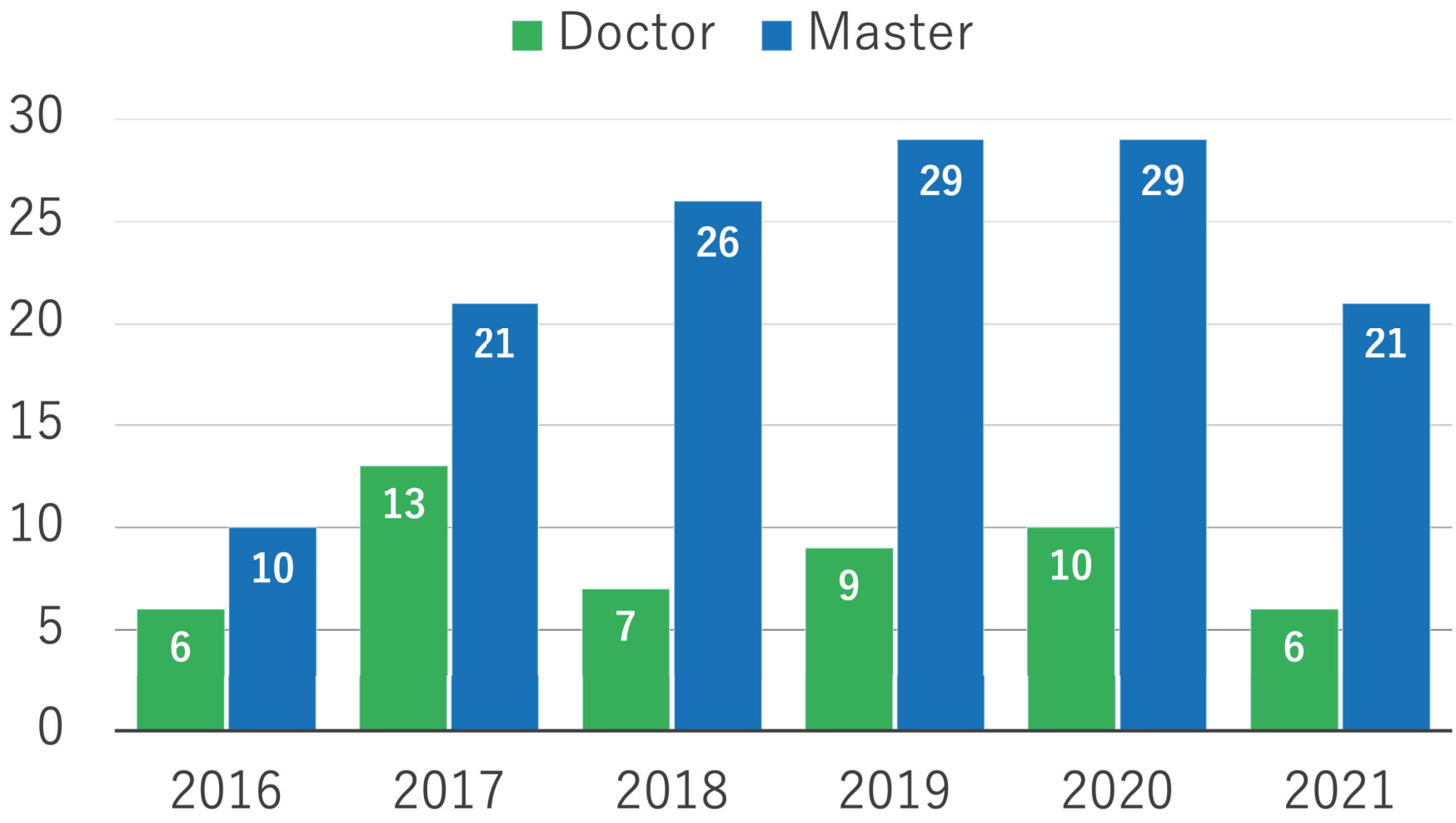
Internal Collaborations: ADC(Subaru HSC), TMT, ...

Number of Users and Publications



# of papers/user is constant

Thesis

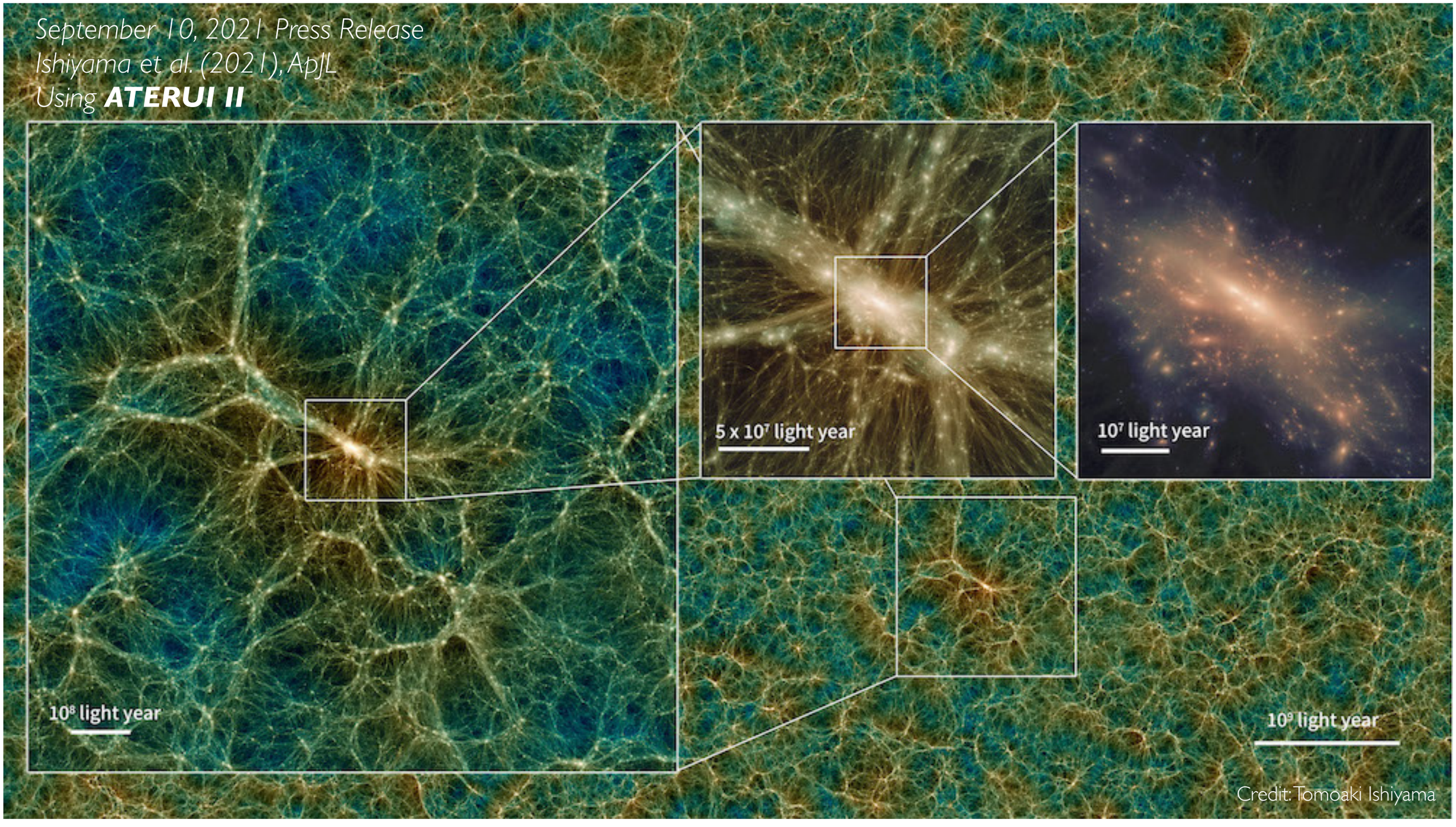


More than 20 theses per year at CfCA!

Recent Results

Center for Computational Astrophysics

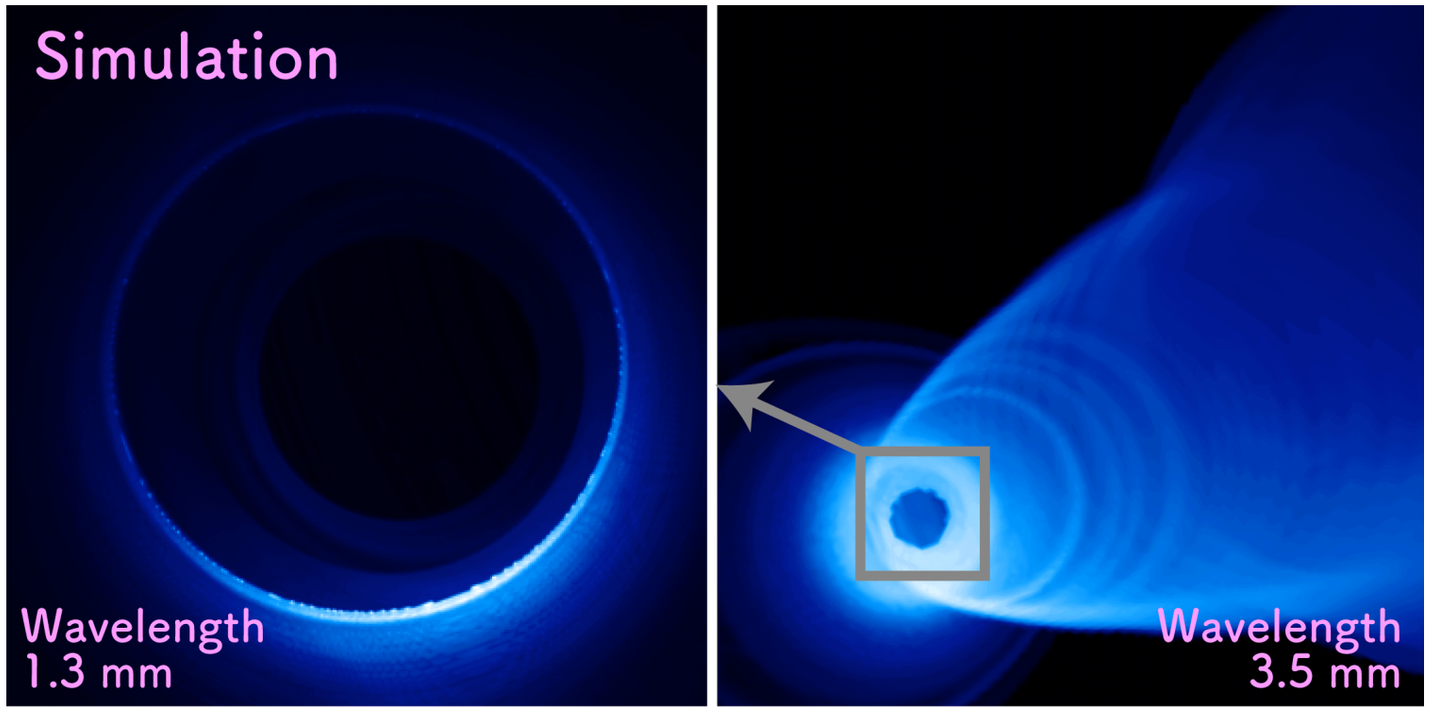
The World's Largest Simulated Large-Scale Structure "Uchuu"



- *N*-body simulation of 2.1 trillion dark matter particles using all cores of **ATERUI II**.
- It is used for comparison with cosmological observations by the Subaru Telescope and other telescopes.

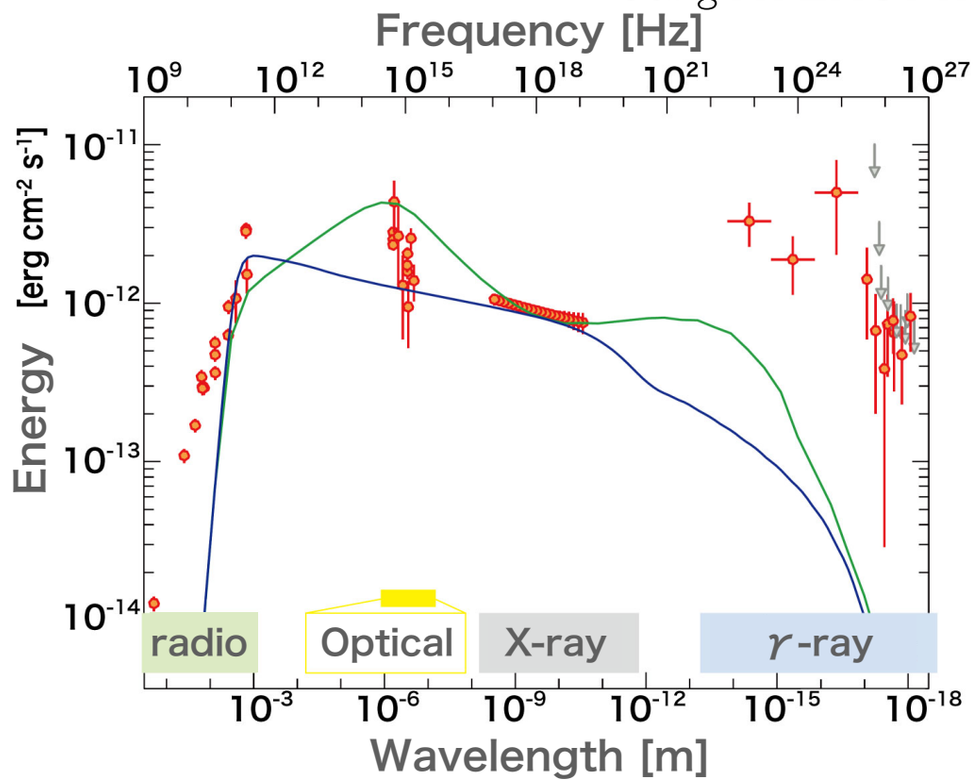
Radiative Transfer Simulation of M87*

April 10, 2019 Press Release
EHT Collaboration (2019), ApJL
Using ***ATERUI II*** *by* ***Tomohisa Kawashima (CfCA)***



Credit: Tomohisa Kawashima, Masanori Nakamura

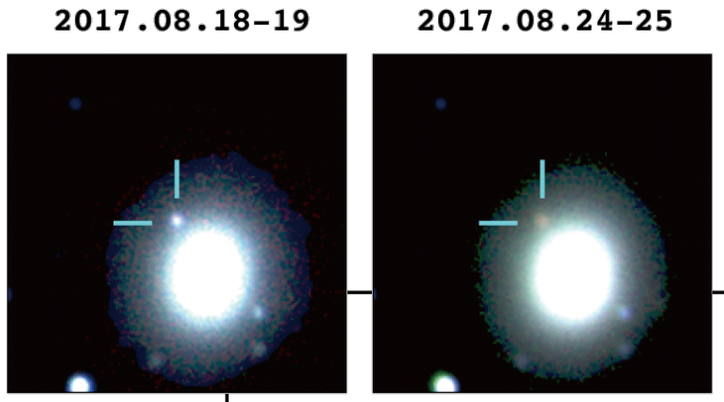
April 14, 2021 Press Release
EHT Multi-Wavelength Science Working Group (2021), ApJL
Using ***ATERUI II***



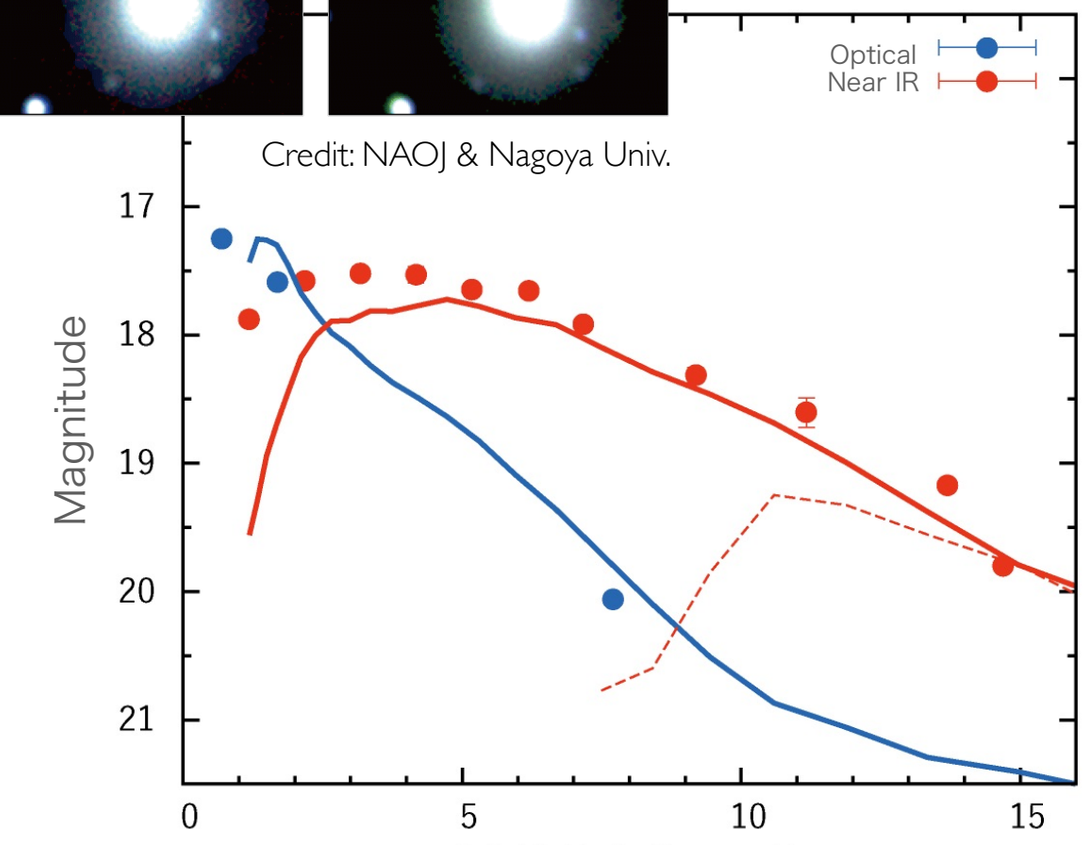
Credit: The EHT Multi-wavelength Science Working Group

- **ATERUI II** performed general relativistic ray-tracing radiative transfer simulations of the supermassive black hole at the center of M87.
- A Japanese member of the EHT theoretical and simulation working group developed an advanced and accurate general relativistic radiative transfer code used in one of the EHT simulations, and compared the simulated models computed by **ATERUI II** with the observational data.
- By comparing **ATERUI II** simulations and muliti-wavelength simultaneous observation data, the EHT team attempted to understand M87* surroundings.

Simulations of Electromagnetic Radiation from Neutron Star Mergers

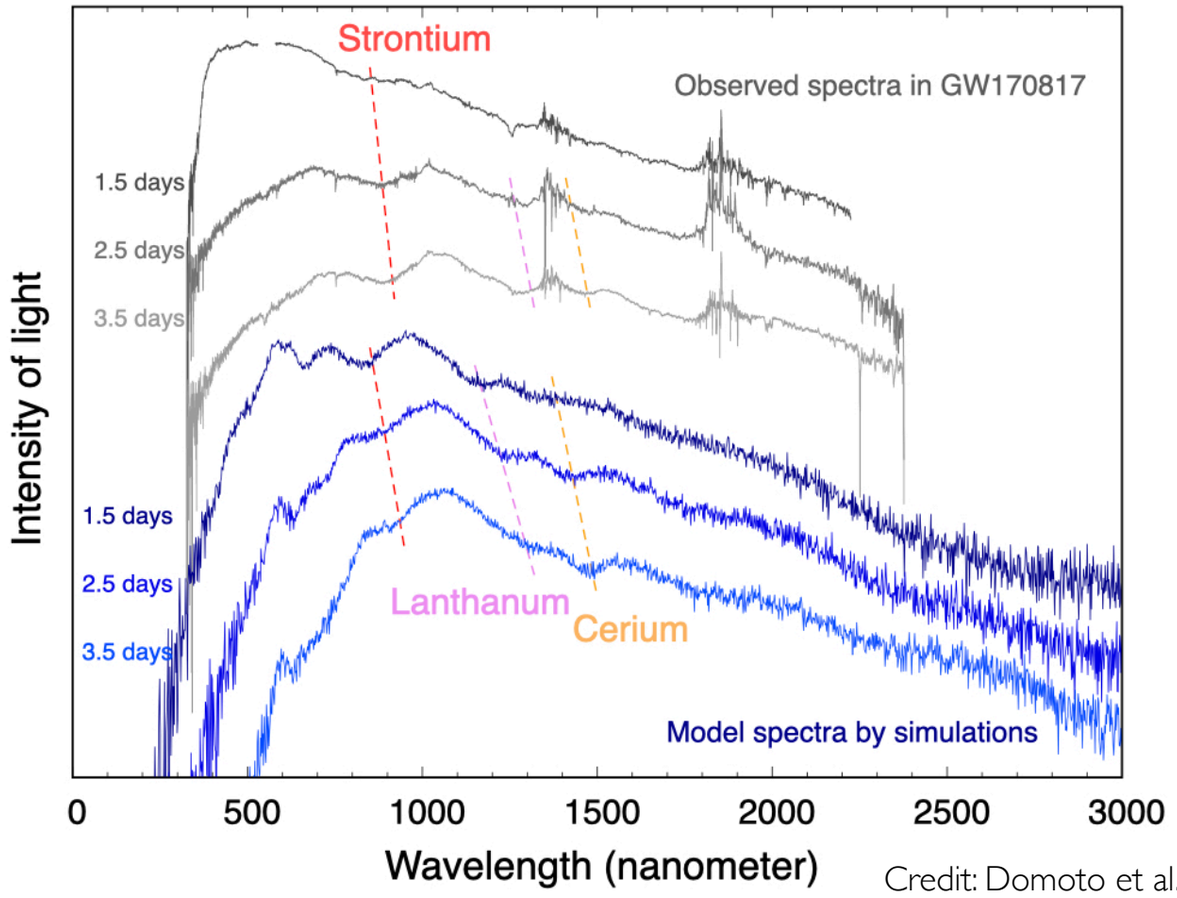


October 16, 2017 Press Release
Tanaka et al. (2017), PASJ
*Using **ATERUI** by **Masaomi Tanaka (CfCA)***



Credit: NAOJ

October 27, 2022 Press Release
Domoto et al. (2022), ApJ
*Using **ATERUI II***

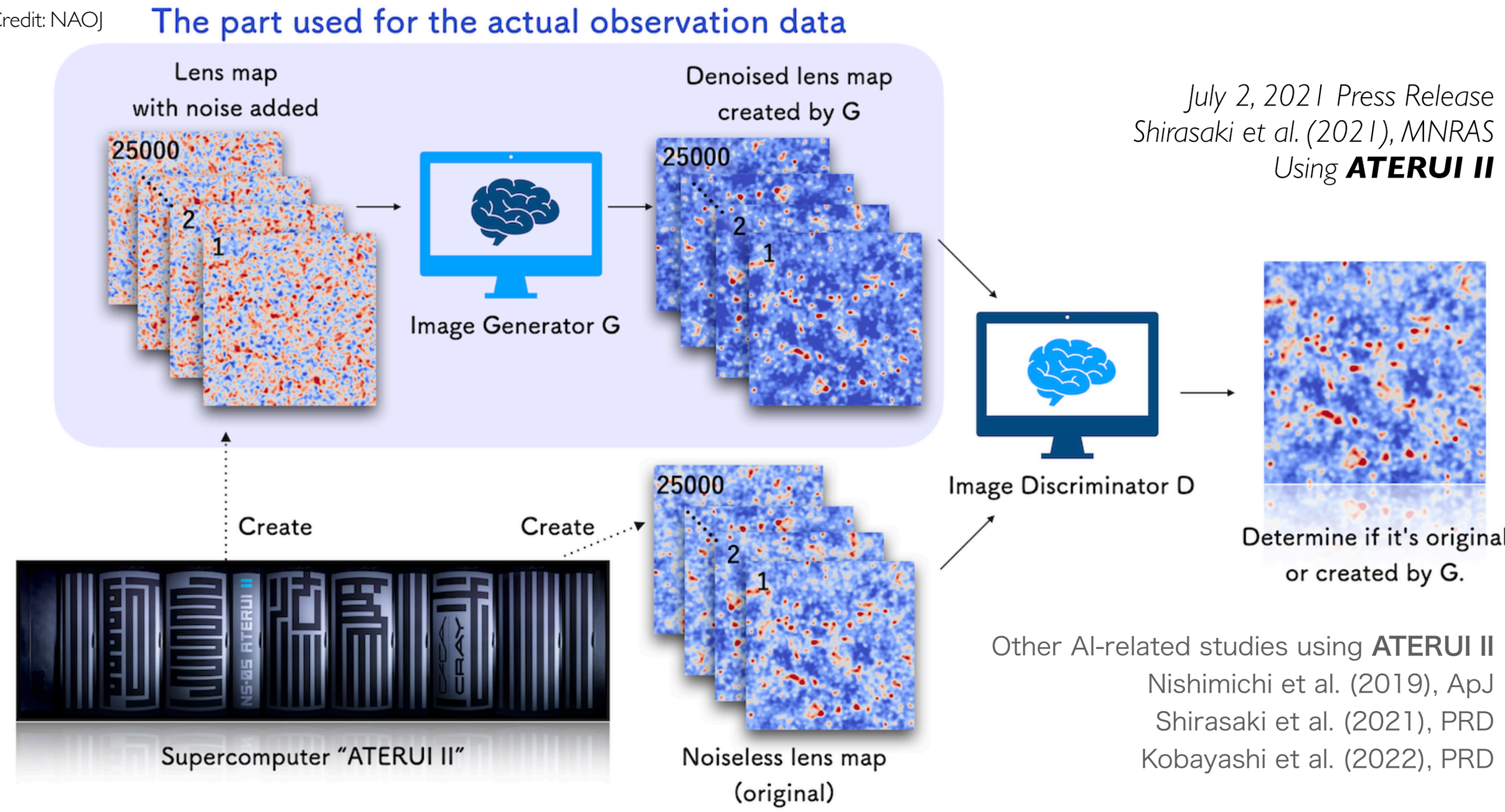


Credit: Domoto et al.

- The kilonova from neutron star merger GW170817, observed in 2017, exhibited the light curve predicted by **ATERUI.**
- Using the nuclear database, detailed spectra of kilonova were simulated by **ATERUI II** to identify for the first time the species of rare-earth elements synthesized in GW170817.
- **ATERUI II** has contributed from the prediction of kilonova's electromagnetic emissions to the identification of the elements synthesized by NS merger.

Generation of Training Data for Artificial Intelligence

Credit: NAOJ



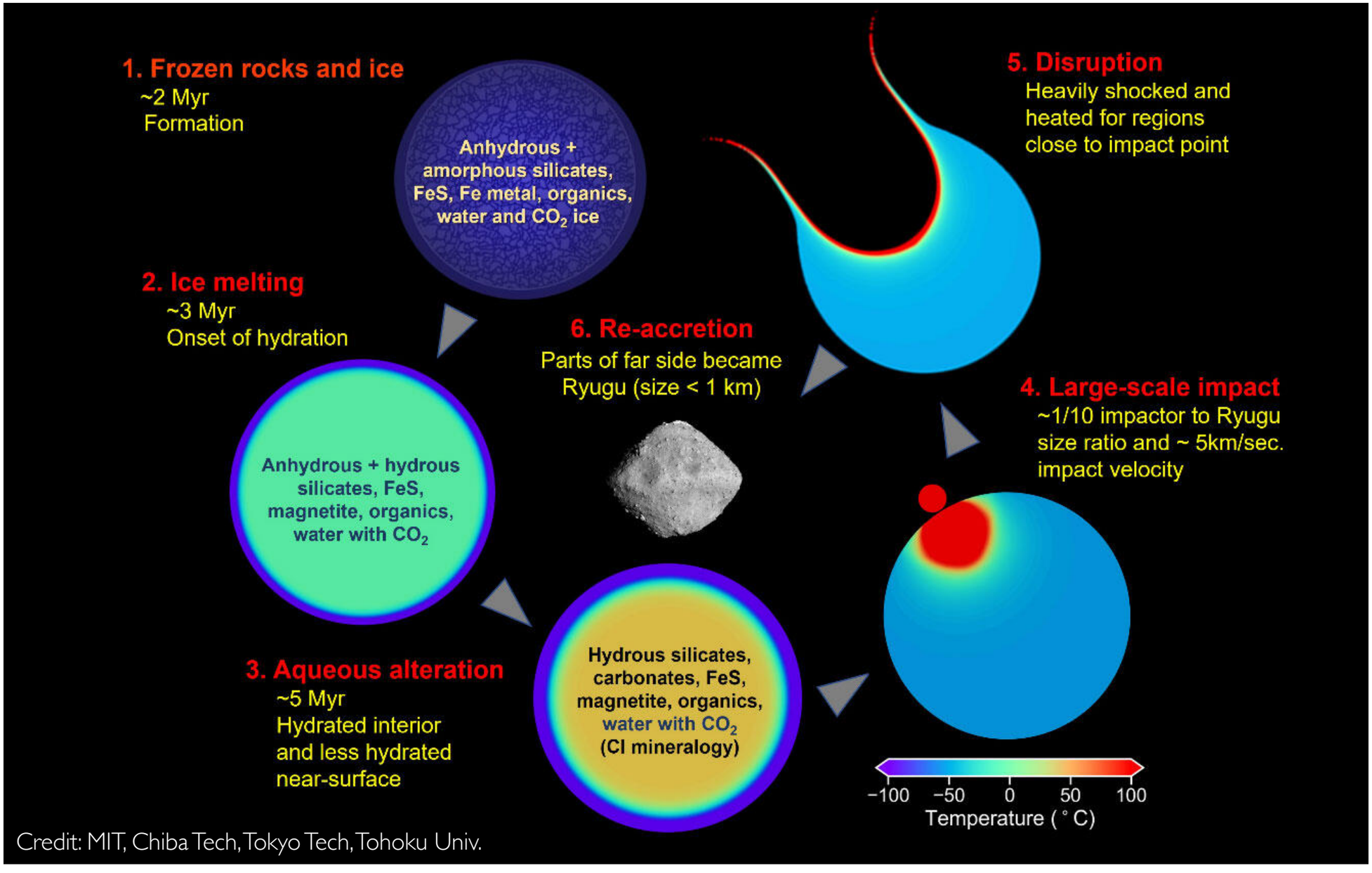
July 2, 2021 Press Release
Shirasaki et al. (2021), MNRAS
Using ***ATERUI II***

Other AI-related studies using **ATERUI II**
Nishimichi et al. (2019), ApJ
Shirasaki et al. (2021), PRD
Kobayashi et al. (2022), PRD

- A large amount of data is needed to train the AIs used in cosmology research (simulated observational data, universes with different cosmological parameters, etc …). Simulations by **ATERUI II** generate data for training these AIs.

Simulation of the Thermal History of Asteroids

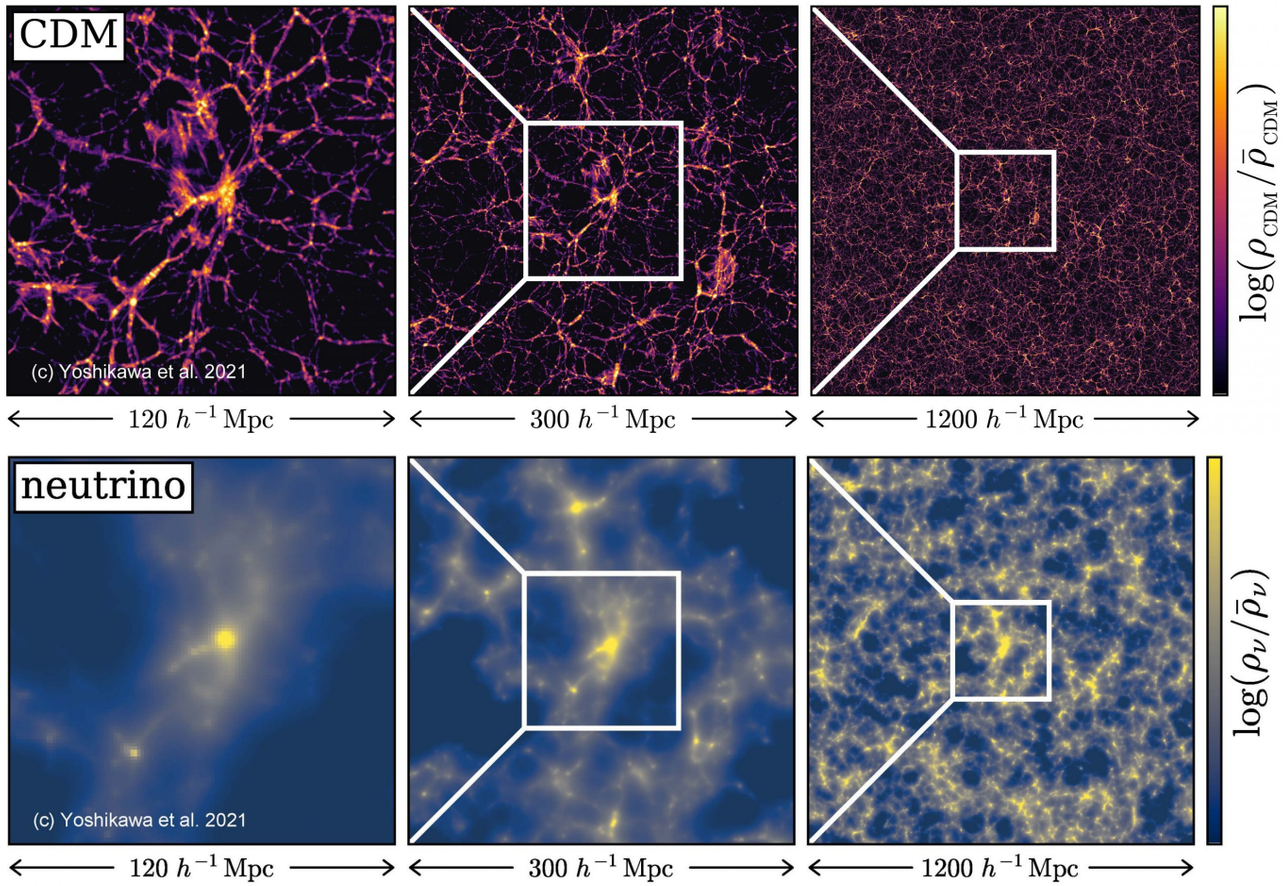
September 23, 2022 Press Release from JAXA
Nakamura et al. (2022), Science
Using ***PC cluster***



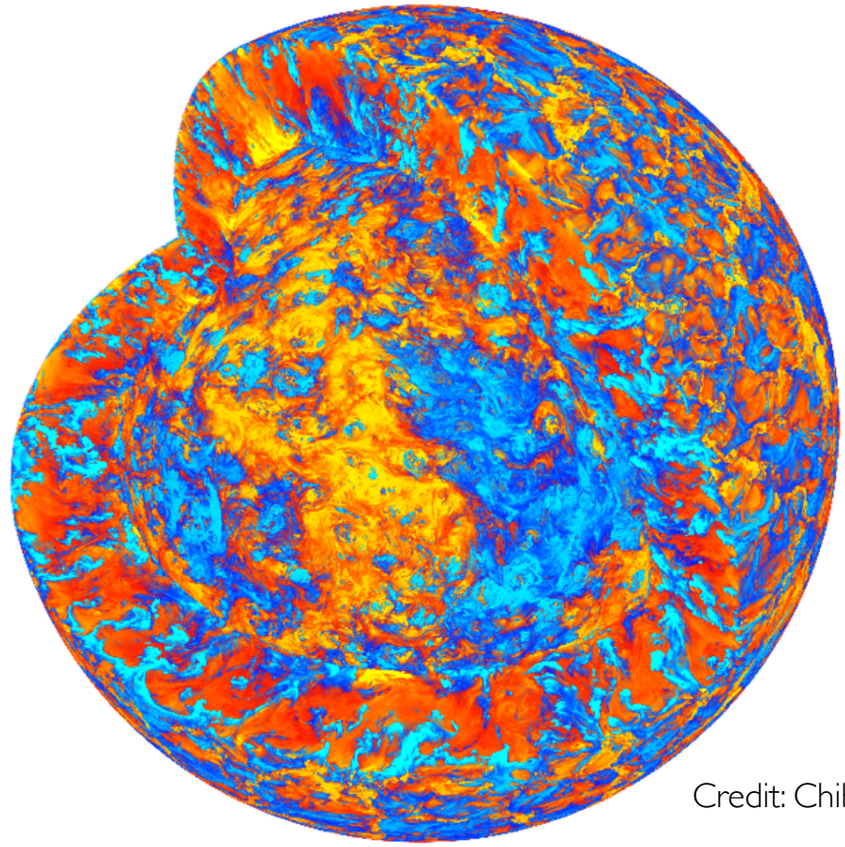
- **PC cluster** calculations of small-object impacts, as well as Hayabusa2 sample or meteorites analysis, can help to unravel the thermal history of asteroids.

Preparation for Large-Scale Simulation by Supercomputer Fugaku

October 28, 2021 Press Release from Univ. of Tsukuba
Yoshikawa et al. (2021)
Nominated as a finalist for the ACM Gordon-Bell Prize
*Using Fugaku and **ATERUI II***



September 14, 2021 Press Release from Chiba Univ.
Hotta et al. (2021), Nature Astronomy
*Using Fugaku and **ATERUI II***



Credit: Chiba University

- **ATERUI II** was used for simulations in preparation for a larger simulation to be performed at Fugaku.
- Left: The Vlasov simulation of cosmic relic neutrinos combined with N-body simulation of cold dark matter in the context of large-scale structure formation in the Universe performed on Fugaku. The code for this simulation was developed using **ATERUI II**.
- Right: The solar differential rotation was reproduced for the first time with the highest-resolution simulation by Fugaku. Simulations using **ATERUI II** were used to select appropriate parameters for the Fugaku calculation.

School and Meeting

FY2022

Name	Date	# of participants
iSALE school	6.17-7.15	10
XC50 beginner course	8.22	12
XC50 intermediate course	8.23	10
Users' meeting	1.26-27	-
N-body school	2.6-9	-
MHD school	2.20-23	-
GPU Workshop	6.29, 1.17	19 (6.29)

Increasing users and fostering next generations

Supercomputer Replacement (1)

時期

- 2024-5 年度 (5-6 年に 1 度)

性能

- CPU: x86-64?
- メモリ・ストレージ: アップグレード

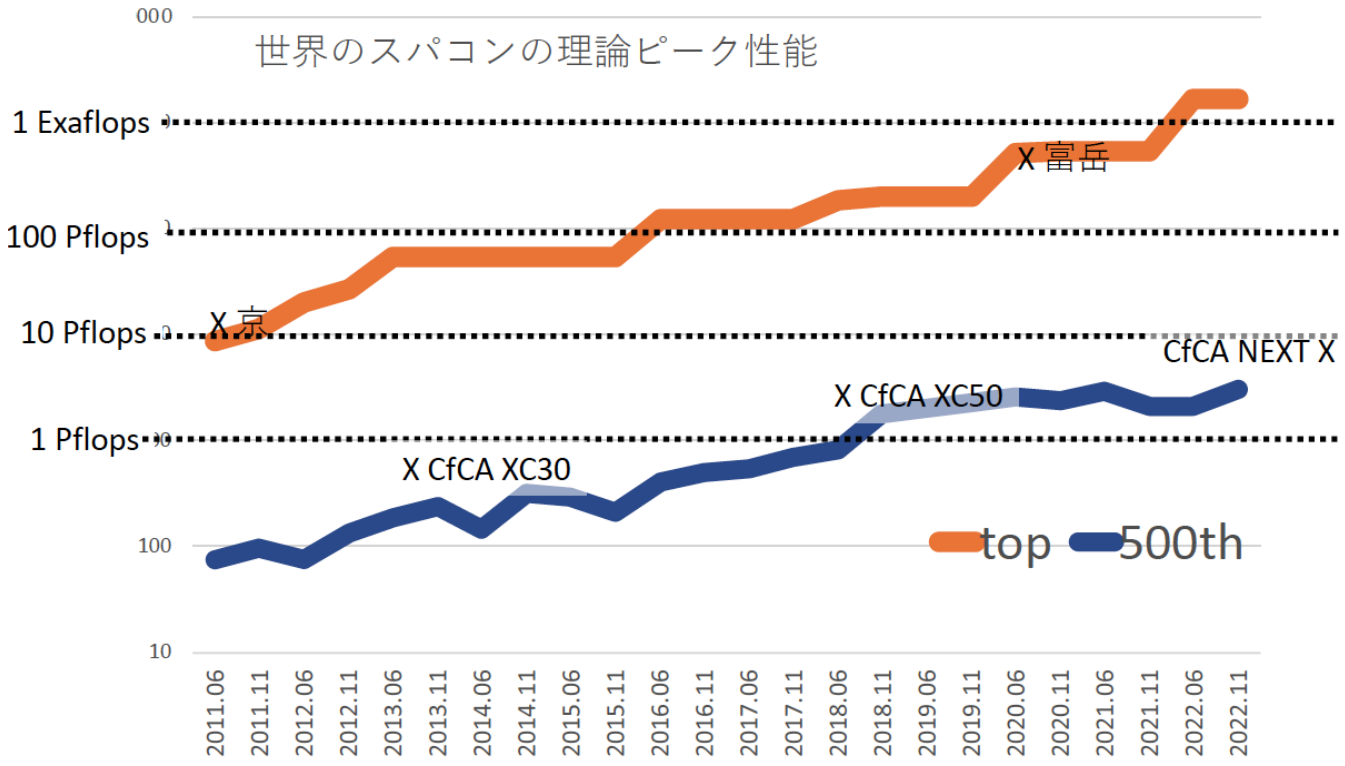
課題

- 電気代高騰
- 半導体価格高騰
- 円安

	2008 XT4	2013 XC30	2018 XC50	2024-2025 目標値
演算性能 [PFlops]	0.027	0.502	3.087	6-10
メモリ[TB]	6	94	385	1000-1500
ストレージ[PB]	0.060	0.820	6.5	10-15

Supercomputer Replacement (2)

TO500



スーパーコンピュータ性能

- 旗艦: ～ 1 位
- 国立天文台: ～ 100 位

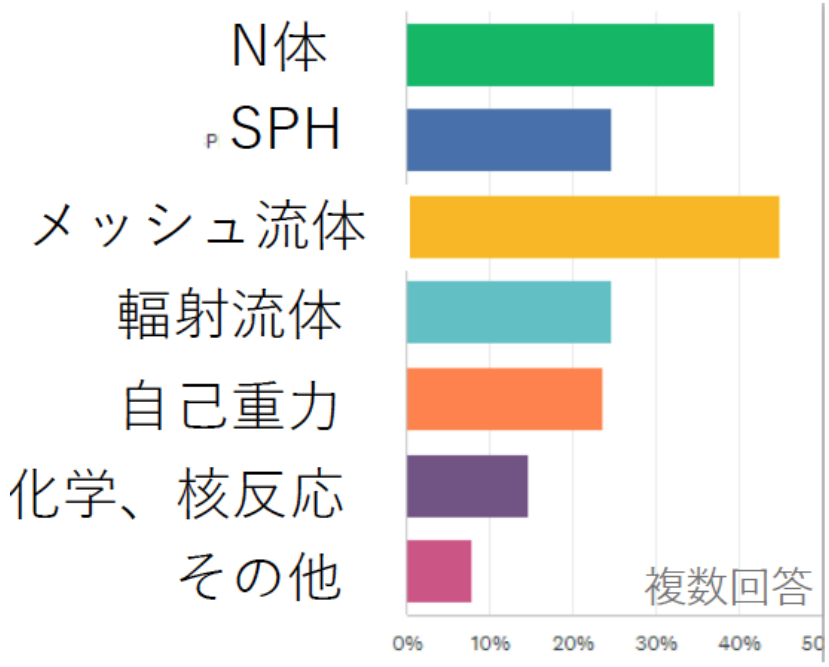
Simulation with TNG Supercomputer

Recent Trends

- almost all objects
- variety of methods

Strategy

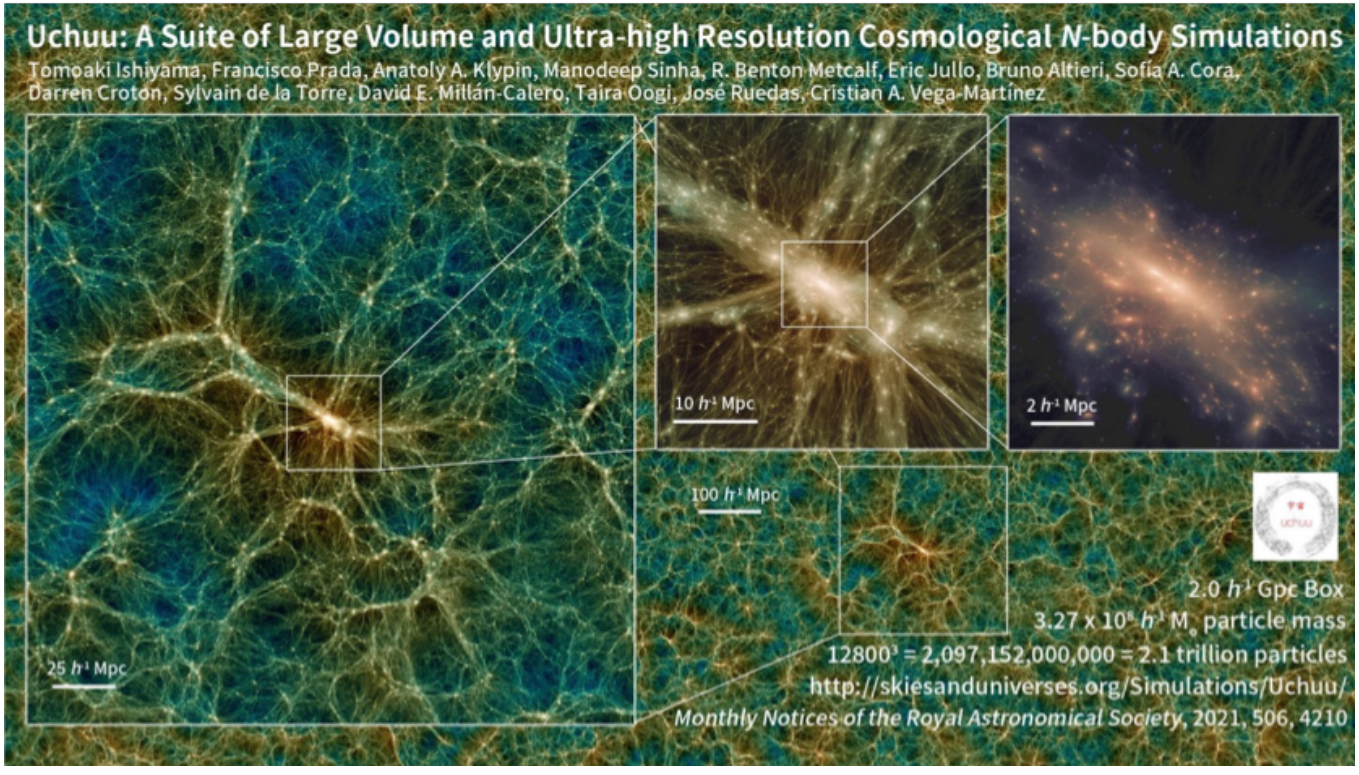
- high-resolution/large-scale simulations
- with more realistic physics



Science Targets with TNG Supercomputer (1)

Large-Scale Structure

- Gpc scale simulations
- comparison with wider/deeper observations (HSC, PFS, Euclid, JWST)
- formation of AGNs

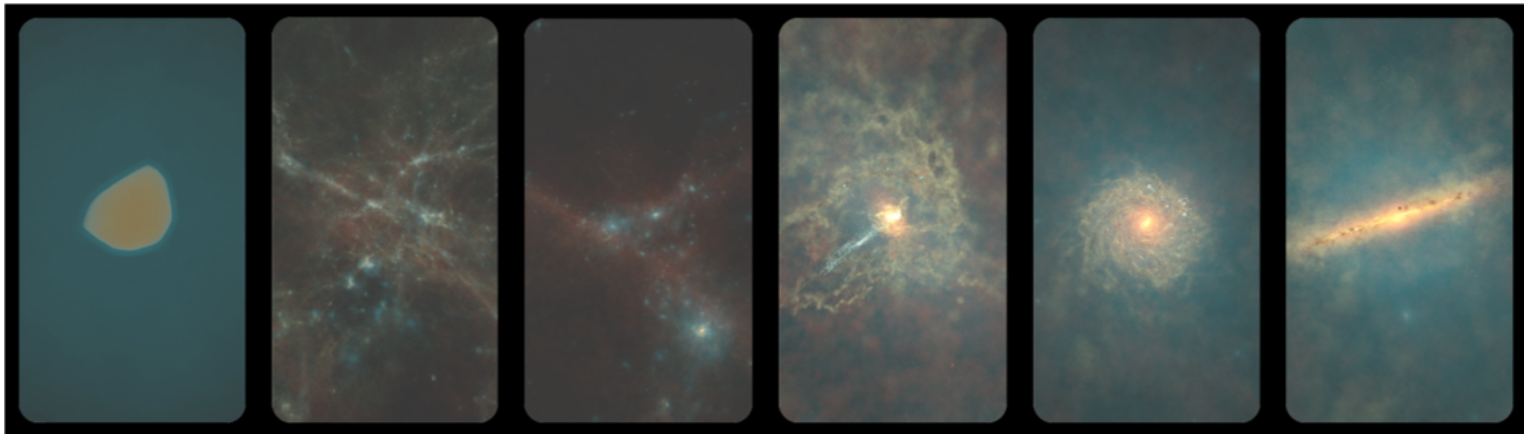


(T. Ishiyama)

Science Targets with TNG Supercomputer (2)

Galaxy/Star Cluster Formation and Evolution

- (star by star simulations)
- formation of (small) milky-way galaxy
- origin of Hubble sequence
- formation of BH binaries (LIGO-VIRGO-KAGRA)

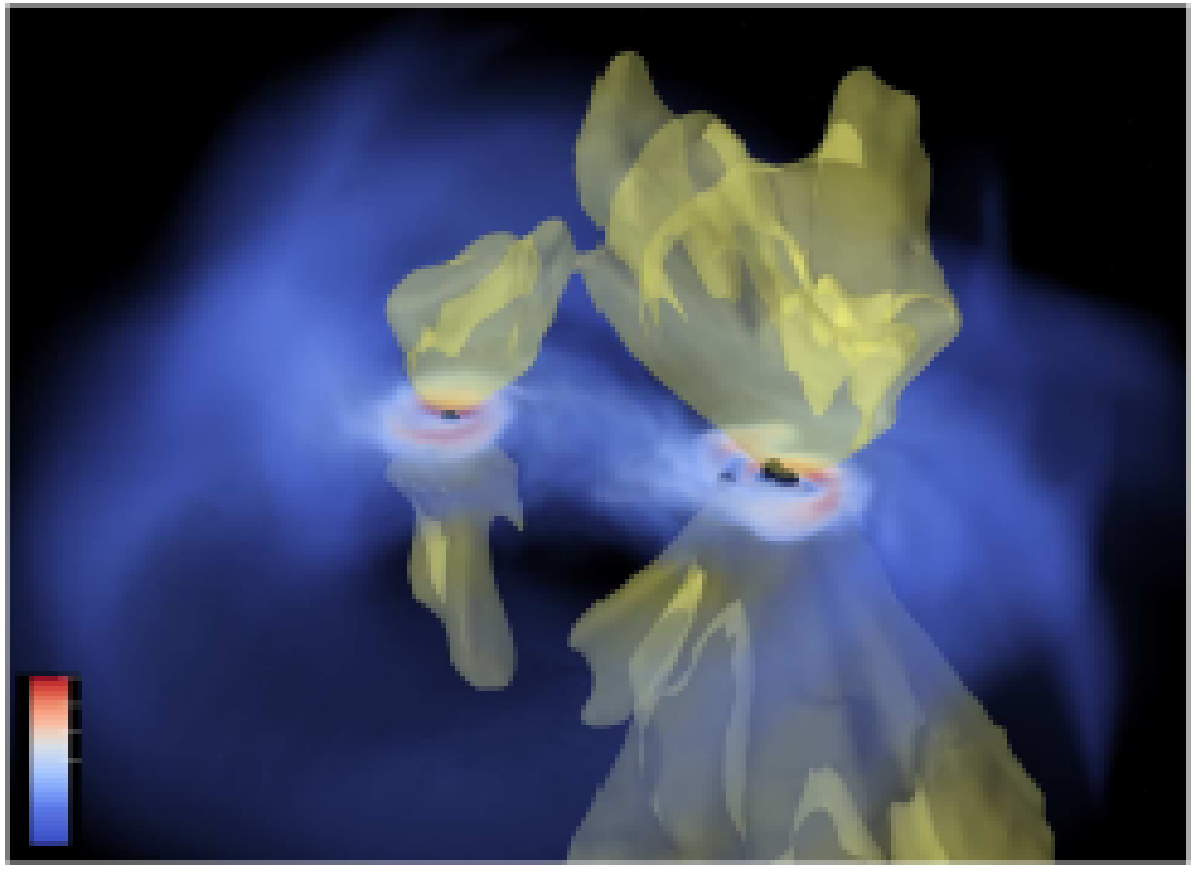


(T. Saito)

Science Targets with TNG Supercomputer (3)

Formation of First Stars

- more realistic physics (radiative transfer, stellar wind, ...)

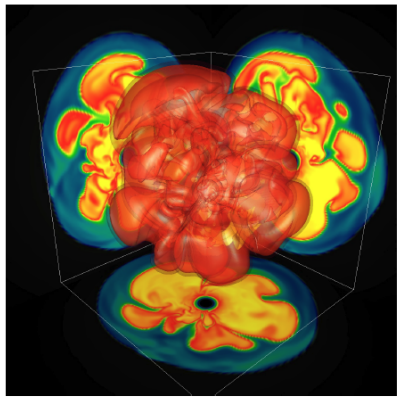


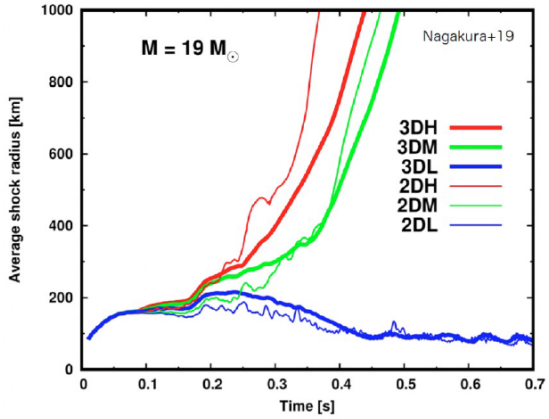
(K. Sugimura)

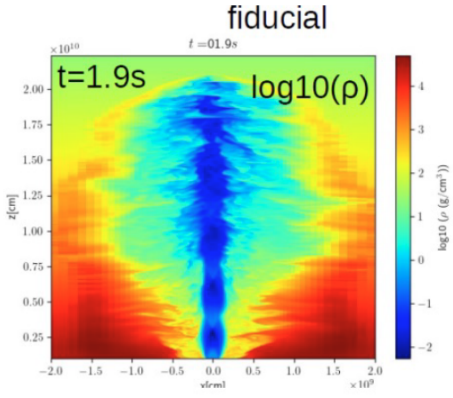
Science Targets with TNG Supercomputer (4)

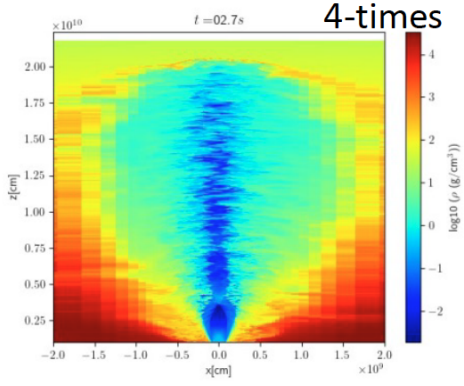
Super Novae/Gamma-Ray Bursts

- realistic explosion energy/jet structure
- magneto-hydrodynamics simulations









(T. Takiwaki, H. Nagakura, A. Mizuta)

技術的側面の将来展望

スーパーコンピュータリプレイス

- 2024-5 年度: 大規模並列計算機?
- 202X 年度: 加速器搭載計算機?

ハードウェア

- 加速器 (GPGPU、統合 GPU、... - 多様なプログラミングモデル) 対応

ソフトウェア

- 公開コード・ライブラリ開発・実行支援
- 機械学習環境整備
- リモートデスクトップ高速化

将来計画・課題

運用方針

- カテゴリ制 (ポイント制ではない)
- 無料
- strategic/intensive プログラム?
  - 富岳連携プログラム
  - コード開発プログラム
  - ...

人材育成

- 院生支援
- 若手プログラム?

人員体制

- 技術職員 (ハードウェア開発、ソフトウェア開発、...) 増員

台内協働

- 天文データセンター
- ...

国立天文台で実施する意義

シミュレーション

- 研究の基盤技術

役割

- 国立天文台: 望遠鏡に近い数値実験装置
- コミュニティ: 中心的シミュレーションインフラストラクチャの安定供給
  参考: 2021 年 12 月理論懇決議「国立天文台の天文専用スパコンは現在・将来の天文学の全体に (理論だけでなく観測・実験に対しても) 非常に重要と考えております。」
- 社会: 可視化した研究成果の発信

参考: Missions

1. 多様な計算機資源を共同利用設備として日本の天文学コミュニティへ供用し、天文学・天体物理学の研究活動の進展を支援する。
2. 計算天体物理学の分野に於いて第一級の研究成果を挙げる。
3. 天文学のデータを用いた最先端コンテンツを開発し、天文学の最新の研究成果を社会へ向けて発信する。