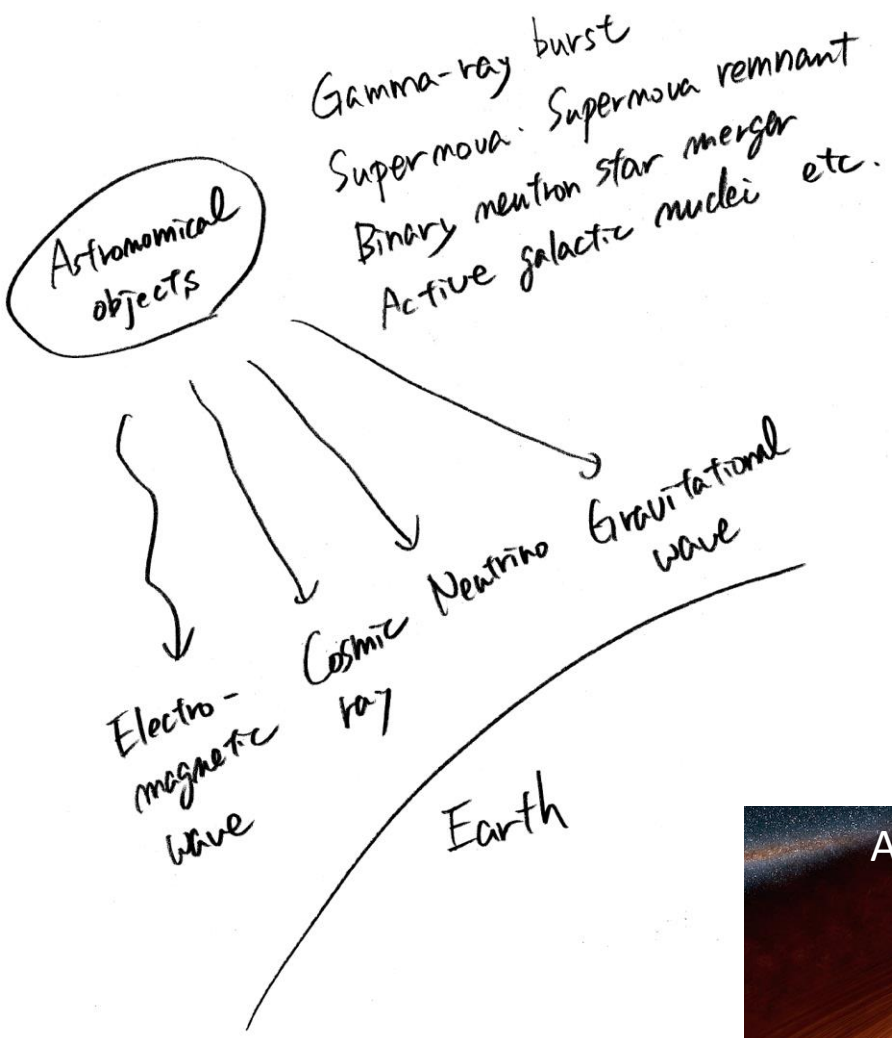
マルチメッセンジャー天文学連携拠点
Center for multi-messenger astronomy

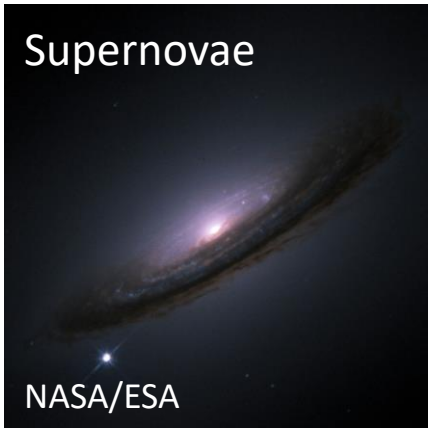
Nozomu Tominaga
(DoS, NAOJ)
On behalf of collaborators
(but the content is all my responsibility)

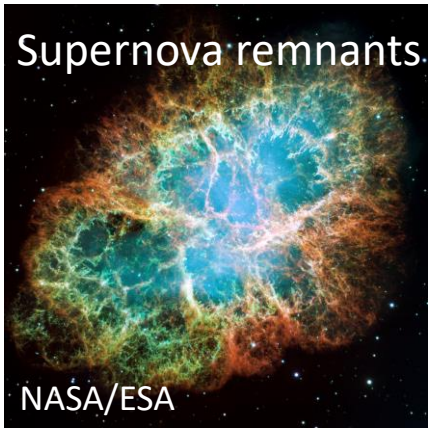
Collaborators

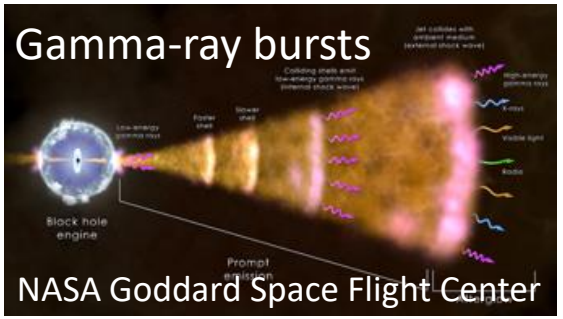
- NAOJ
  - N. Tominaga, T. Tomaru, Y. Aso, K. Kohri, T. Takiwaki, S. Iguchi, H. Izumiura, Y. Iwata, Y. Utsumi, R. Ohsawa, Y. Koyama, T. Takata, B. Hatsukade, H. Furusawa, S. Miyazaki, T. Moriya, M. Yoshida, TMT project
- Others
  - S. Yoshida (Chiba), M. Tanaka (Tohoku), D. Yonetoku (Kanazawa), K. Tsumura (Tokyo City), and more

Multi-messenger astronomy









1. Summary of proposal

- Science goals and objectives
  - Clarify the origin of matter and elements and the evolution of matter in the Universe
  - Verify the basic physics laws
- Science investigations, instrumentations and data
  - Develop multi-messenger astronomy
  - Clarify the nature of multi-messenger sources
  - Subaru2, ALMA2, KAGRA, OISTER, JVN, instruments managed by other institutes
  - Light curve, spectra, realtime report, multi-messenger information
- Threshold science
  - Immediate and continuous follow-up observations of multi-messenger sources using large-scale cutting-edge astronomical research facilities
  - Immediate data access and analysis and realtime reports
  - Clarification of the nature of multi-messenger sources
- Cost estimation
  - 200M JPY/year (NAOJ: 160M JPY/year)
- Project organization
  - Center of multi-messenger astronomy
  - Collaboration with other institutes for multi-messenger and multi-wavelength observations

2. Science goals

- Clarify the origin of matter and elements
- Clarify the evolution of matter in the Universe
- Verify the basic physics laws

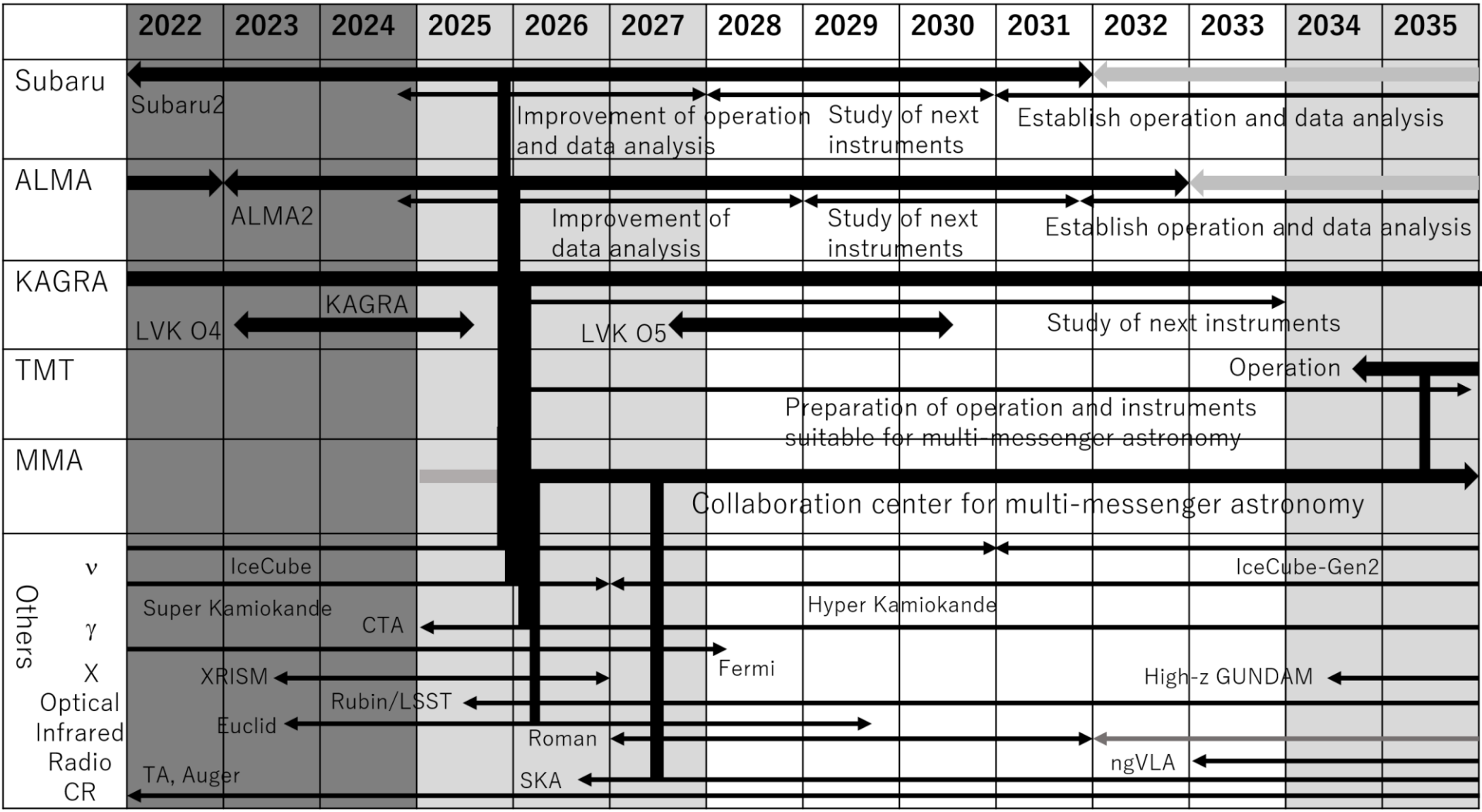
3. Scientific objectives

- Utilize any messengers from astronomical objects
- Develop multi-messenger astronomy

- Clarify the nature of multi-messenger sources and the origin of elements and cosmic rays
- Search new elemental particles

- Develop new astronomy using the multi-messenger sources

4 Science investigations - timeline



4.1 Science investigations until 2033

- Multi-messenger/multi-wavelength observation
  - Gravitational wave: LVK O5 run (2027-2030)
  - High-E neutrinos: IceCube-update (2022-), IceCube-Gen2 (2031-)
  - MeV neutrinos: Super Kamiokande-Gd (2024-), Hyper Kamiokande (2027-)
  - Gamma-ray: Cherenkov Telescope Array (2024-)
  - Cosmic rays: Telescope array, Auger
  - Other optical, infrared, radio: Rubin/LSST (2025-), Euclid (2023-), Roman (2027-), SKA (2026-)
- Immediate and continuous follow-up observations of multi-messenger sources using large-scale cutting-edge astronomical research facilities (Subaru2, ALMA2, KAGRA, OISTER, JVN)
  - Flexible, low-latency, and stable operation
  - Fast and stable network
  - Immediate data access and analysis, and realtime alerts
  - Time-domain archive
  - Coordinated observations over projects
- Clarify the nature of multi-messenger sources
- Identify requirements for next generation instruments
- Center for multi-messenger astronomy in NAOJ

4.2 Science investigations beyond 2034

- Multi-messenger/multi-wavelength observation
  - Gravitational wave: LVK O6? LIGO Voyager, Einstein telescope, Cosmic explorer
  - High-E neutrinos: IceCube-Gen2 (2031-)
  - MeV neutrinos: Hyper Kamiokande (2027-)
  - Gamma-ray, X-ray: CTA, High-z GUNDAM (2034-)
  - Cosmic rays: Telescope array, Auger
  - Other optical, infrared, radio: Rubin/LSST, Euclid, Roman, SKA, ngVLA (2033-), LST
- Lead the multi-messenger astronomy with electromagnetic observations, collaborating with other institutes and instruments
- Clarify the origin of matter and elements
- Verify the basic physics laws
- Develop next generation instruments

4.3 Threshold Science

- Identification of electromagnetic counterparts of multi-messenger sources
- Clarification of the nature of multi-messenger sources

- Immediate and continuous follow-up observations of multi-messenger sources using large-scale cutting-edge astronomical research facilities
- Immediate data access and analysis, and realtime reports

5. Instruments and data to be returned

- Information of multi-messenger sources
  - NAOJ: Subaru, ALMA, KAGRA, optical, infrared, radio
    - Multicolor light curves (datetime, magnitude, filters)
    - Spectral evolution (datetime, spectra)
    - Immediate and continuous follow-up observations and realtime reports
  - Others: LVK, IceCube, SK & HK, CTA, TA/Auger, Satellites
    - Multi-messenger information (datetime, localization, properties, etc.)
    - Low-latency alerts

6. Originality and international competitiveness

- Multi-messenger astronomy
  - US: recommended in Astro2020, NOIRLab
  - Europe: Asterics

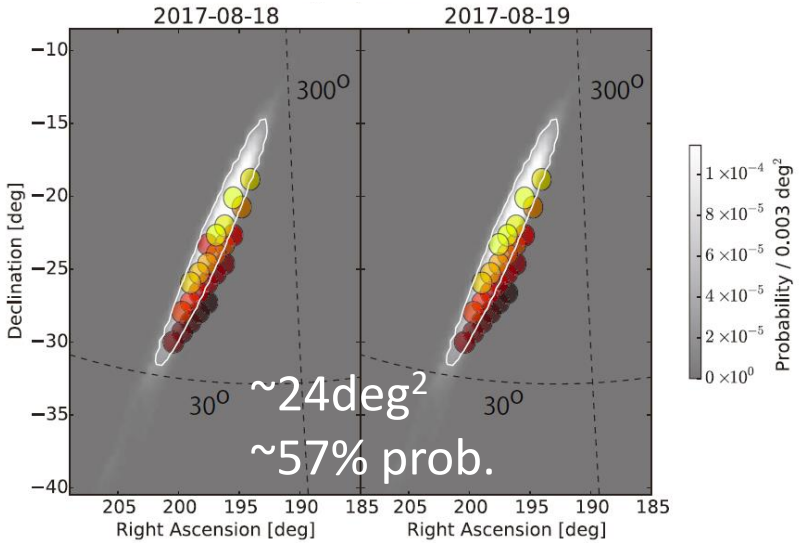
  Discussion and implementation are ongoing.

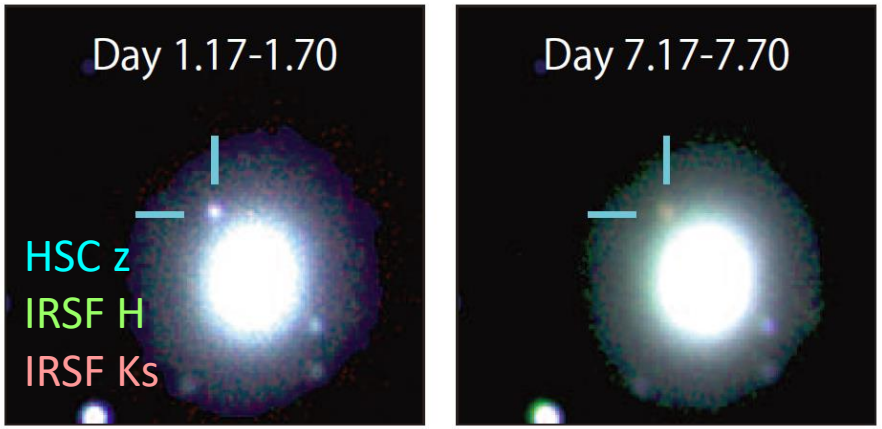
- Japan
  - All large-scale cutting-edge electromagnetic (optical, infrared, and radio) facilities are operated by NAOJ.
  - No arrangement among institutes is needed and easy to integrate data taken with multiple instruments.
  - NAOJ is the most suitable institute in the world.

7. Current status

- Gravitational waves

Only 1 object

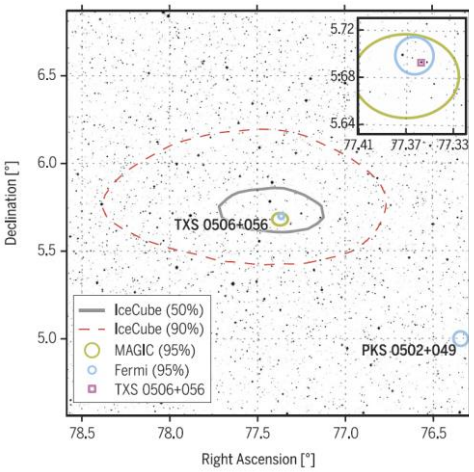


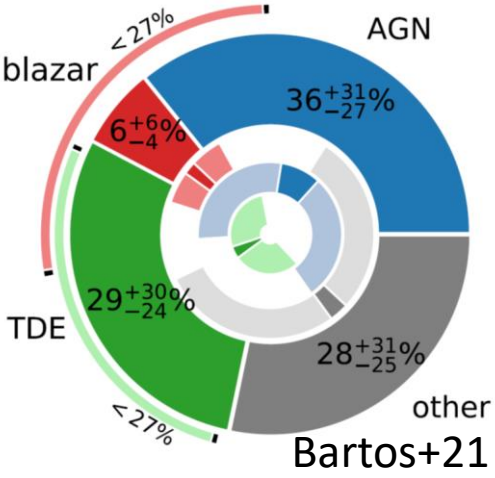


NT+18; Utsumi, Takana, NT+18

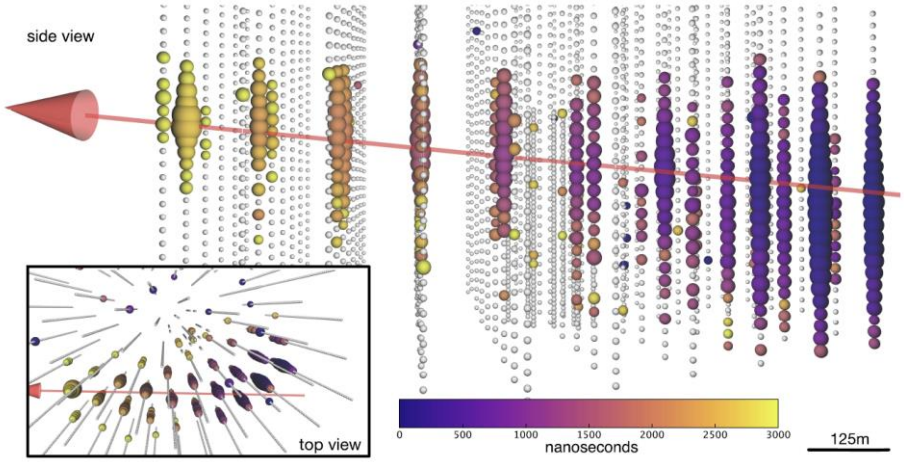
- High-E neutrinos

Origin is unclear





Bartos+21



IceCube+18

7. Current status

- Operations and systems of large-scale cutting-edge astronomical research facilities are not designed for multi-messenger astronomy.
- Well-organized, well-coordinated, and stable operations and systems are needed.

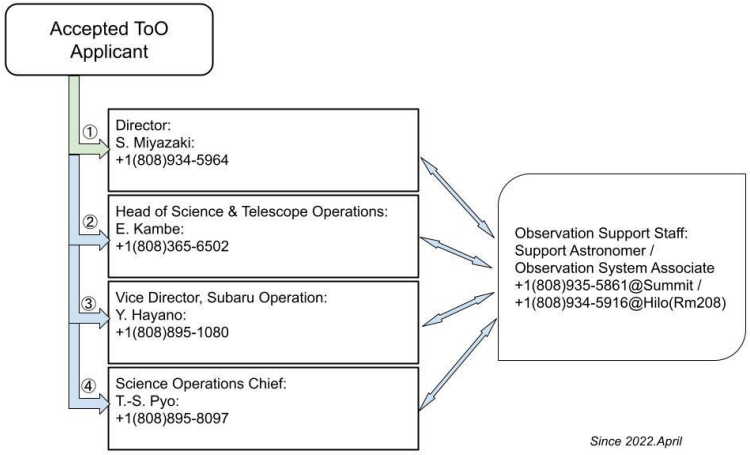
- Some important functions are under improvement and development.
- Data analysis pipeline for Subaru/HSC and Subaru/PFS, after transferring raw or processed data, a part of science platform and database for time-domain astronomy using Subaru, and a new instrument for Subaru (NINJA) are under development with Grants-in-Aid for Scientific Research (Kakenhi).

7. Current status

Subaru

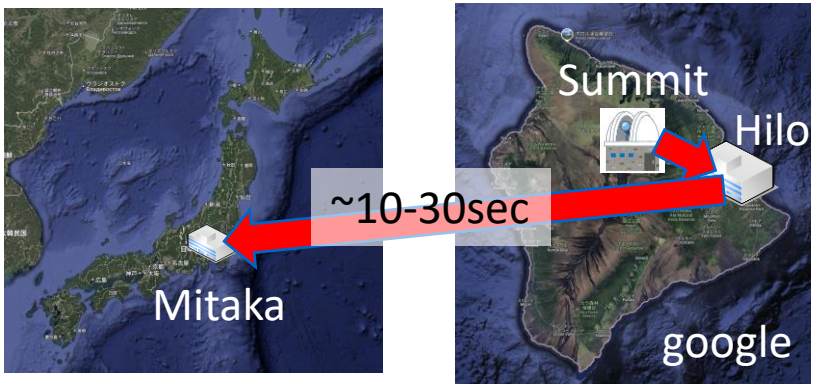
Examples to be improved

- Target of opportunity observation



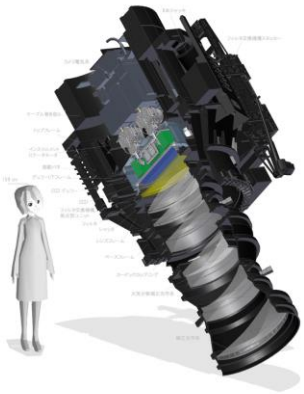
For non-rapid ToO programs, you need to submit your request by 9:00 am Hawaii time one day before your observing night.
A rapid ToO (for HSC queue at first) is under implementation led by Pyo-san.

- High-speed network



High-speed (100Gbps) communal-use network between Hawaii and Mitaka was established in 2023. But it is not always available.

- Short overhead (HSC)

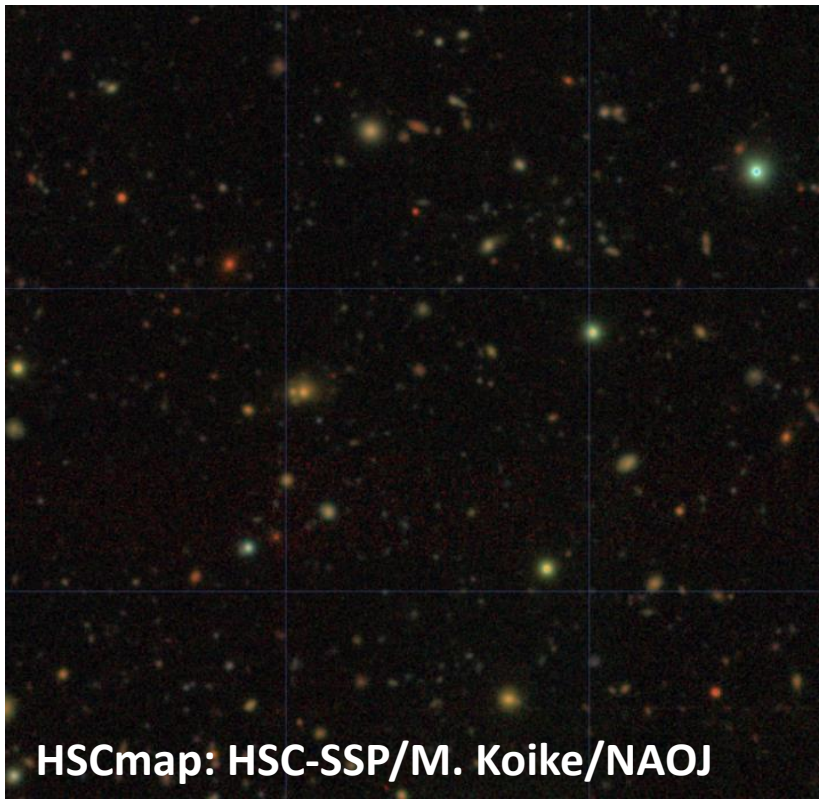


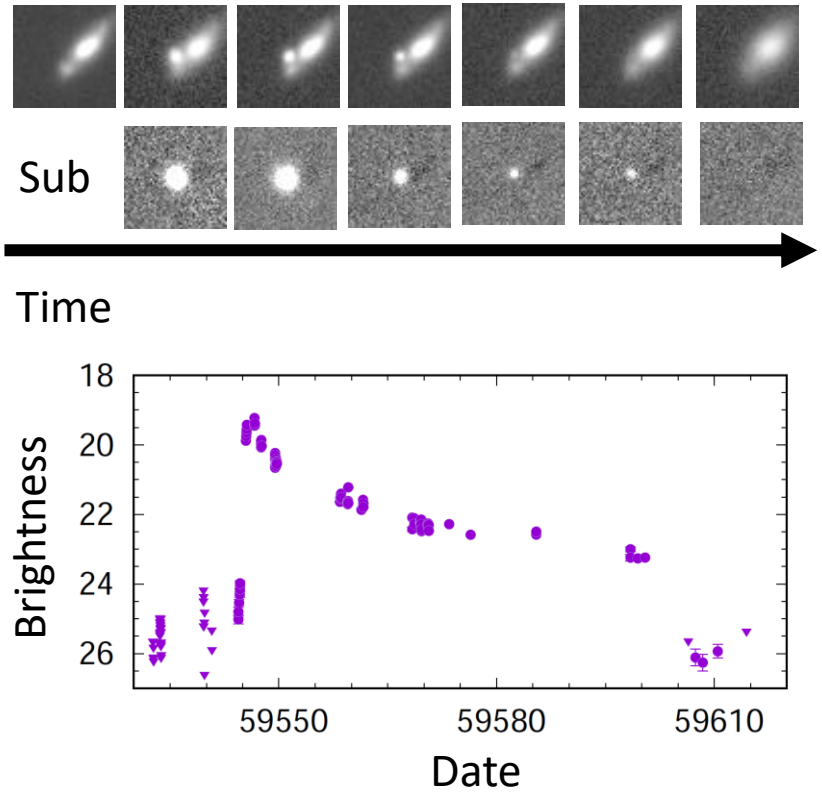
Exposure | Overhead

Overhead time of HSC is ~30-40sec, comparable with an exposure time for a wide tiling survey.
A short overhead enhance efficiency in MMA.

7. Current status

- Time-domain archive is not available.
  - Subaru, ALMA, etc
- If available, non-experts, theoretical researchers, can start researches using the data.





8. Cost assessments, budget line and status

- Data analysis and archive system: 300M JPY/6years
  - High-speed storage and high-speed database: >20PB
    - Subaru/HSC, PFS, ULTIMATE, ALMA, OISTER, JVN, VLBI
    - Rubin/LSST, Euclid, Roman, SKA, ngVLA
    - Multi-messenger information
  - CPU: > 2000 cores
    - Realtime data analysis
    - Science platform
  - Computer room, electricity, stable network, etc

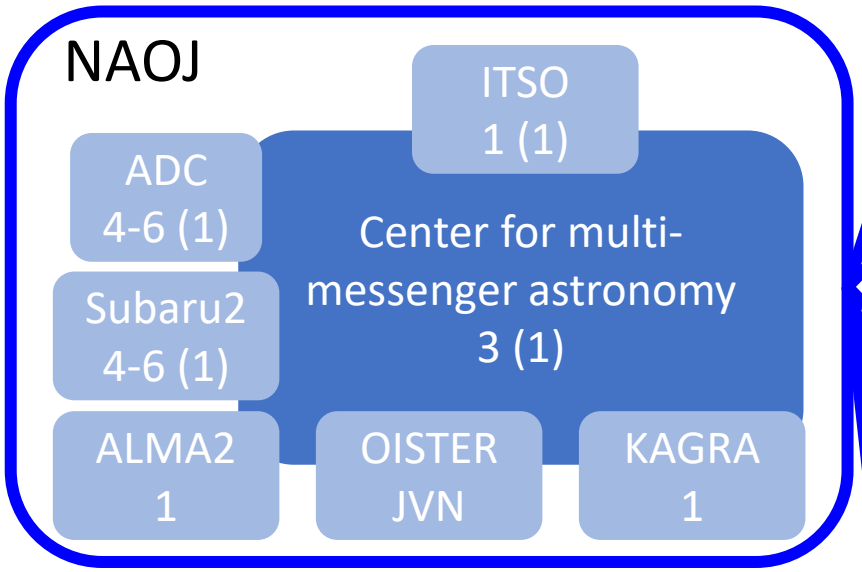
8. Cost assessments, budget line and status

- Human resources: 14-18 persons: 150M JPY/year
  - Center for MMA
    - Management and strategy: 1 person (faculty)
    - System implementation (optical/infrared, radio): 2 persons
    - Concurrent appointments of faculties in NAOJ projects
  - ADC
    - Maintenance: 1 person (faculty)
    - System installation and implementation (pipeline, science platform, high-speed storage and database, etc.): 3-5 persons
  - Subaru
    - Operation design: 1 person (faculty)
    - System and operation improvement (HSC, PFS, ULTIMATE, etc.): 3-5 persons
  - IT Security Office
    - Network maintenance: 1 person (faculty)
  - ALMA
    - Construction of time-domain archive system: 1 person
  - GW
    - Construction of data analysis system: 1 person
  - OISTER, JVN, and VLBI

8. Cost assessments, budget line and status

- Budget line
  - Management Expense Grant
    - Budget requests
    - NINS reorganization
  - Existing Large Scientific Research
    - Subaru2 (incl. MMA -2031), ALMA2 (-2032), TMT (20xx-)
  - Grants-in-Aid for Scientific Research
    - Scientific Research (S) (PI: M. Yoshida) -FY2025 (NINJA)
    - Transformative Research Areas (A) (PI: S. Yoshida) -FY2027 (1 postdoc)
    - Scientific Research (S) (PI: N. Tominaga) -FY2028 (2 postdocs, >3PB, >500cores)
    - New proposals after FY2027/2028
      - Scientific Research (A,S), Specially Promoted Research, Transformative Research Areas (A), WPI?

9. Project organization



Number of new faculty staffs is in ().

Gravitational wave
Advanced LIGO, advanced Virgo, KAGRA

High-energy neutrinos
IceCube (Chiba University, 10)

MeV neutrinos
Super Kamiokande, Hyper Kamiokande

Cosmic rays
Telescope array, Auger

Gamma-ray
Cherenkov telescope array, Fermi

X-ray
XRISM, High-z GUNDAM (Kanazawa Univ., etc.)

Researchers
Tohoku University, etc.

Only a part of potential collaboration and institutes are listed.
Any institutes interested in MMA are welcome to join.

<u>Education of young researchers</u>

The researchers will become researchers who will lead the next generation of big-data astronomy.

10. Why NAOJ? - activity

- Effective use of large-scale cutting-edge astronomical research facilities: Subaru2 (HSC/PFS/ULTIMATE), ALMA2, KAGRA, ADC, CfCA, ATC, TMT
  - Flexible operation
  - Immediate data access and analysis
  - Fast and stable network
  - Efficient archive system, in particular on time series
  - Preparation and coordination over projects
- Sufficient infrastructure (network, room, power, and A/C)
- Increase faculty members and system engineers working on the multi-messenger astronomy in each project
- Center for multi-messenger astronomy
  - Collaboration among NAOJ projects
  - Coordination with other institutes and instruments
    - Rubin/LSST, SKA, ngVLA, Euclid, Roman, IceCube-Gen2, HK, CTA, XRISM, High-z GUNDAM, LAPYUTA, GREX-PLUS, TA
  - Investigation and development of next-generation large-scale facilities if necessary

10. Why NAOJ? - reason

- All large-scale cutting-edge electromagnetic (optical, infrared, and radio) facilities are operated by NAOJ.
- No other institutes in Japan can integrate these observations and lead the collaboration with other multi-messenger or multi-wavelength institutes and instruments.
- Multi-messenger astronomy requires the improvement of infrastructure and operation. These sometime donot fit with Kakenhi.
- NAOJ is the most suitable institute for the multi-messenger astronomy in the world.

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