Revolutionize our understanding of the Universe
with a next-generation radio astronomy-driven big data facility

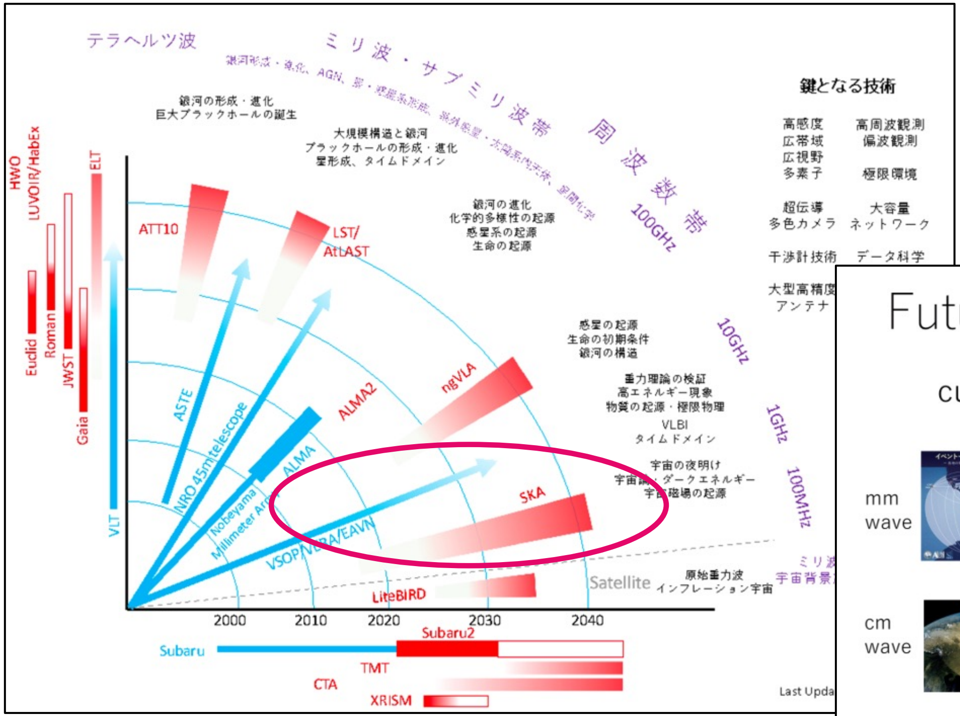
Square Kilometre Array Phase 1 (SKA1)

Takuya Akahori
Lead of SKA1 Promotion Group

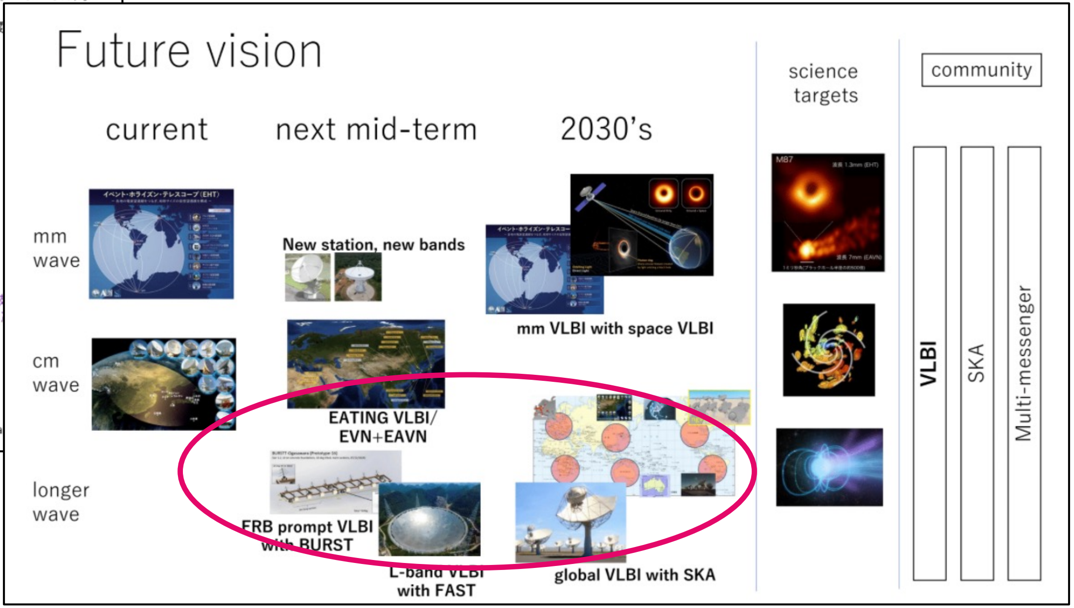
国立天文台SKA1サブプロジェクト
NAOJ SKA1 Promotion Group

SKAJ

Before Starting…



A slide from Tamura-san
(Figure made by JRAF)



A slide from Honma-san
(Vision of VLBI)

Contents

Part 1: Science Plan (~15min)

Part 2: Project Plan (~15 min)

SKA1 Science Plan

国立天文台SKA1サブプロジェクト
NAOJ SKA1 Japan Promotion Group

2. Science goals

When and how were the **first stars and galaxies** formed?

How were **supermassive black holes** created?
(Do nHz gravitational waves exist?)

When and where was **cosmic magnetism** emerged, evolved, and distributed?

3. Scientific objectives

- SKA community in Japan has discussed key sciences in 2021 symposium, then determined the following three key science objectives.

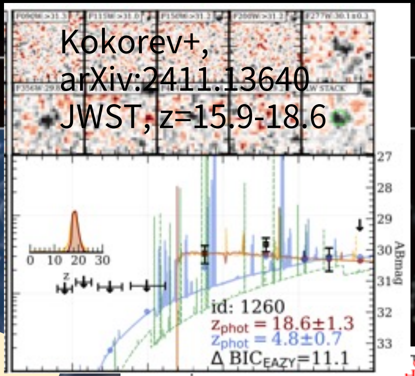
Deciphering the cosmic reionization with cosmology and astrophysics

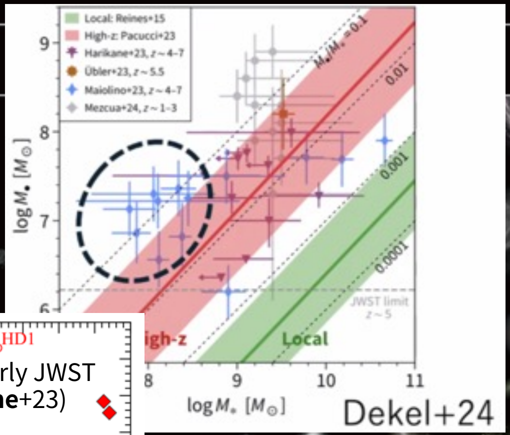
In-depth/Tomographic study of the magnetic field governing the cosmic hierarchy and activities

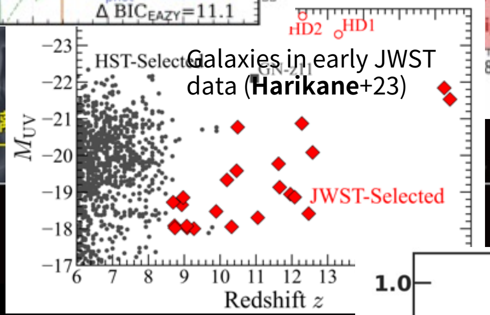
Pioneering long-wavelength gravitational-wave astronomy with pulsar observations.

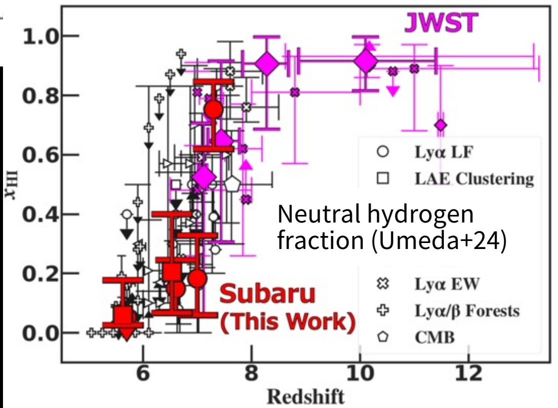
Epoch of Reionization

Dark Age
Cosmic Down (CD)
Epoch of Reionization (EoR)









HI relative brightness

Optical depth

$$\delta T_b(\nu) = \frac{T_S - T_\gamma}{1+z}(1 - e^{-\tau_{\nu_0}})$$

$$\approx 27 x_{HI}(1+\delta)\left(1 - \frac{T_\gamma}{T_s}\right)\left(\frac{H}{dv_{||}/dr_{||}}\right)\left(\frac{1+z}{10}\right)^{1/2}\left(\frac{0.15}{\Omega_m h^2}\right)^{1/2}\left(\frac{\Omega_b h^2}{0.023}\right)[\mathrm{mK}]$$

Hubble const.

Baryon density parameter

CMB temperature

Redshift

Neutral fraction

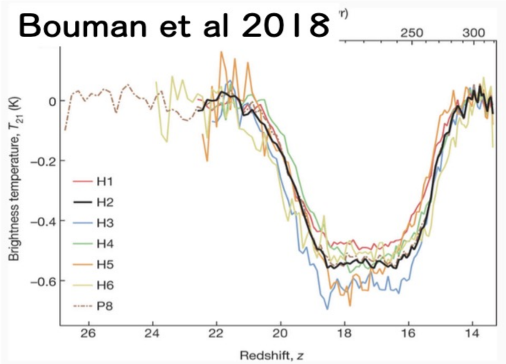
Spin temperature

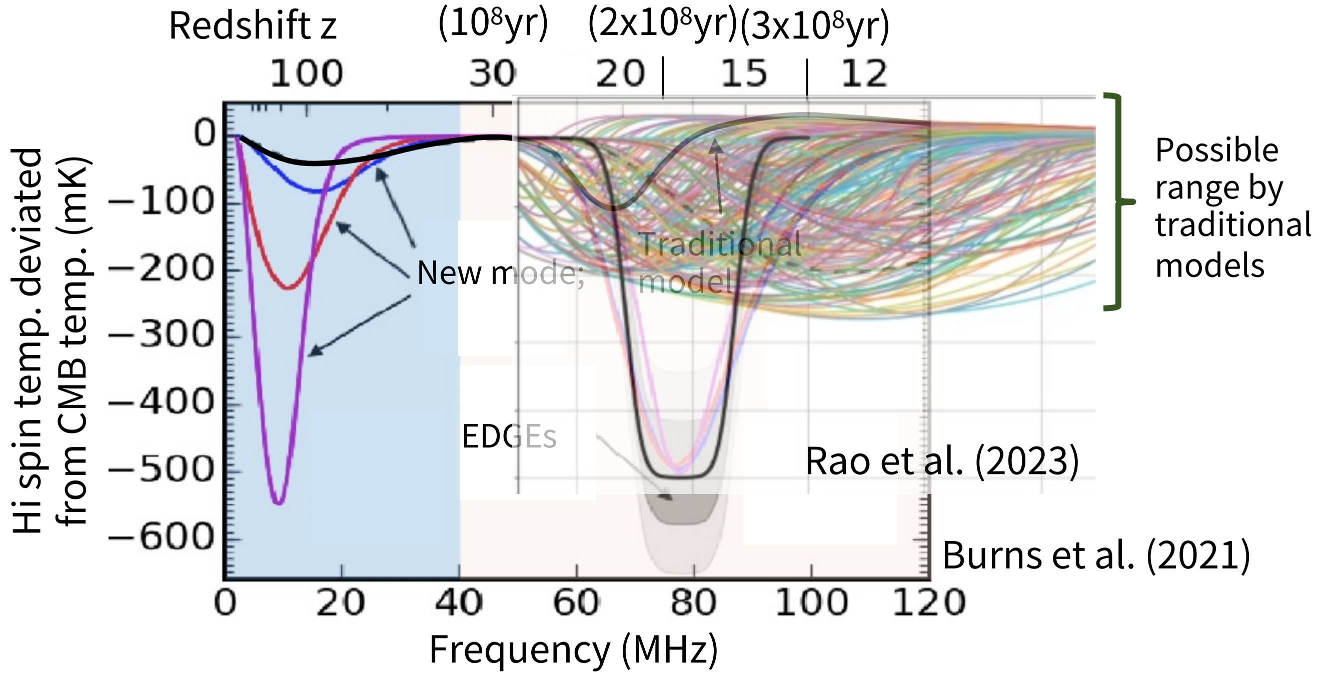
Gas over-density

LoS velocity gradient

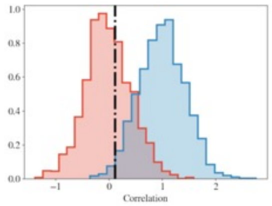
Dark matter density parameter

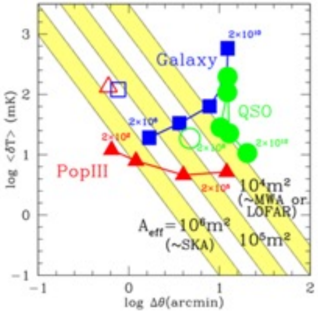
Epoch of Reionization





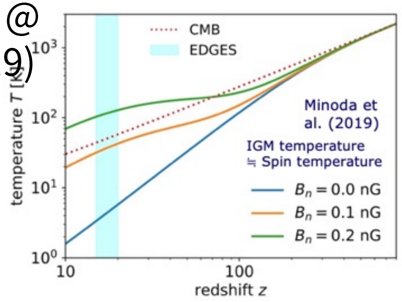
SARAS3 claims no detection





PopIII, Galaxies, QSOs formation (**Yajima**+13; **Tanaka**+18)

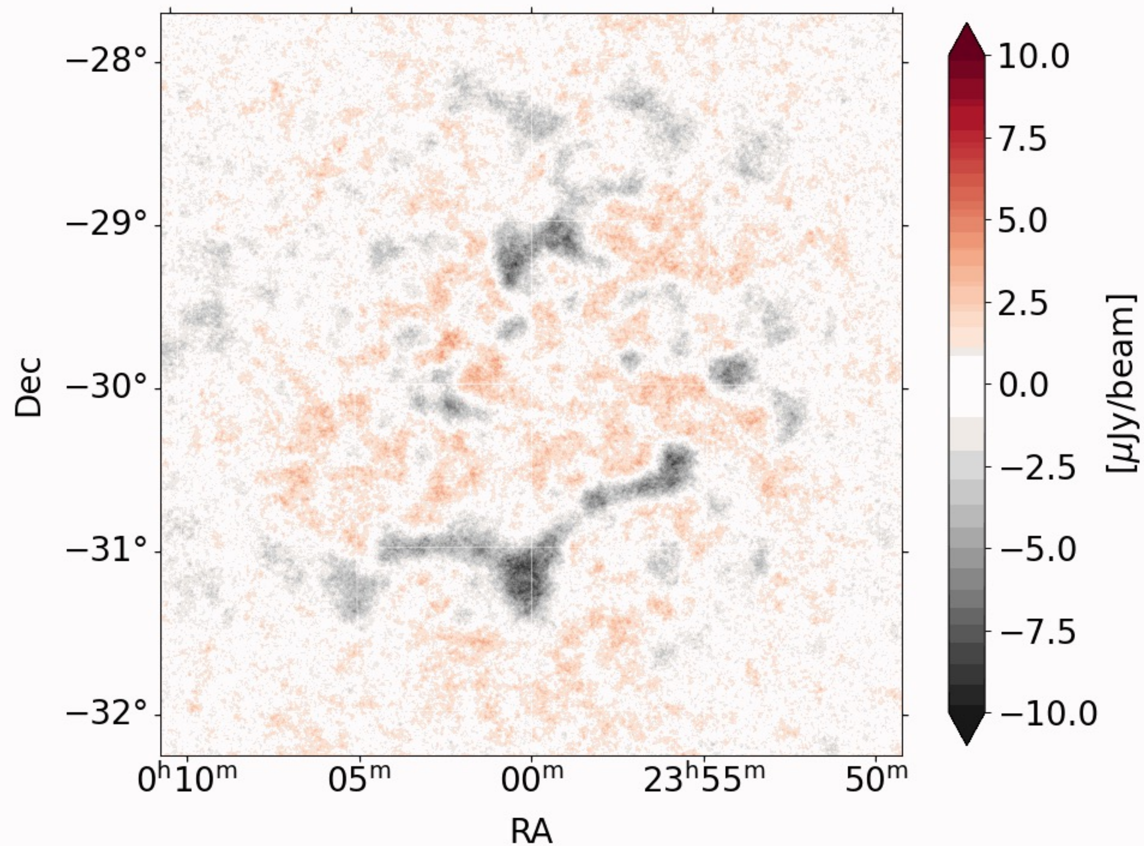
Magnetic fields @ EoR (**Minoda**+19)



Epoch of Reionization

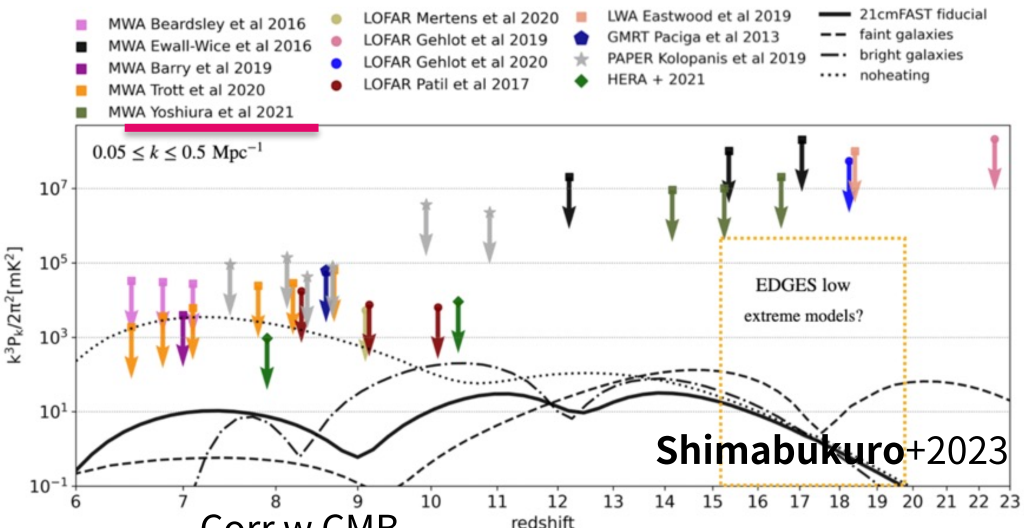
- **A simulated SKA1 LOW HI image**
  - Data taken from SKA Data Challenge 3a
  - EoR + noise + instrumental effects ov the 166-181 MHz range, natural weighting.
  - Movie in frequency (redshift) domain
  - Black for ionized regior
- **We will see real one soon!!**

EoR Imaging with SKA1



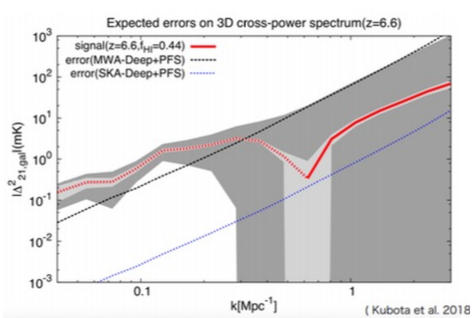
Epoch of Reionization

- ~2033: Imaging EoR, Power spectrum of CD
- 2034~: Imaging CD
- Threshold: Detection of HI at EoR (z~8-15), strongest constraint on HI at CD (z>15)
- Strength: Cross Correlation

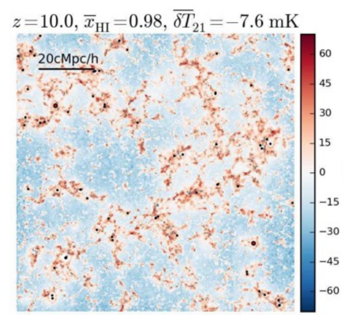


Shimabukuro+2023

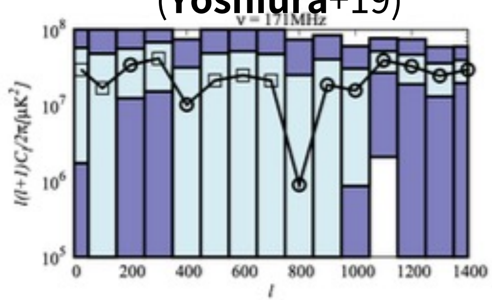
Corr w Lyα (**Kubota**+18)



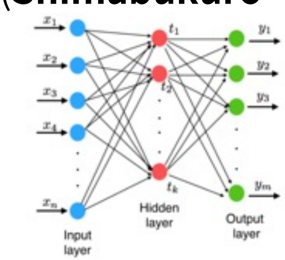
Corr w [OIII] (**Moriwaki**+19)



Corr w CMB (**Yoshiura**+19)

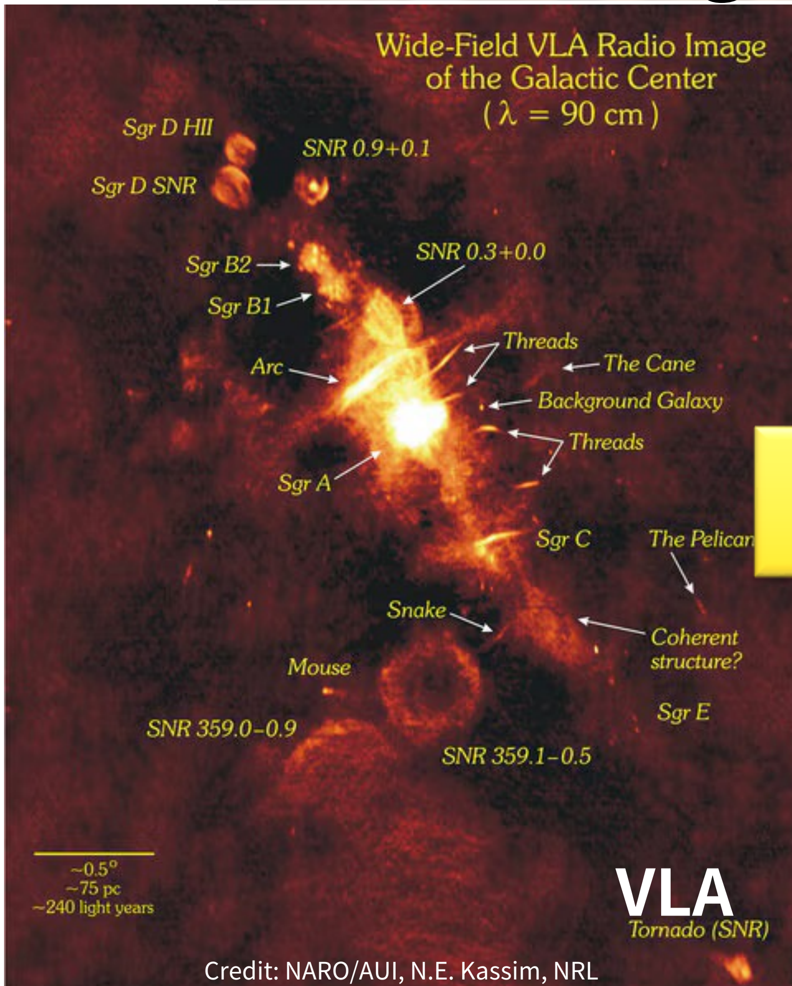


Neural network (**Shimabukuro**+17)

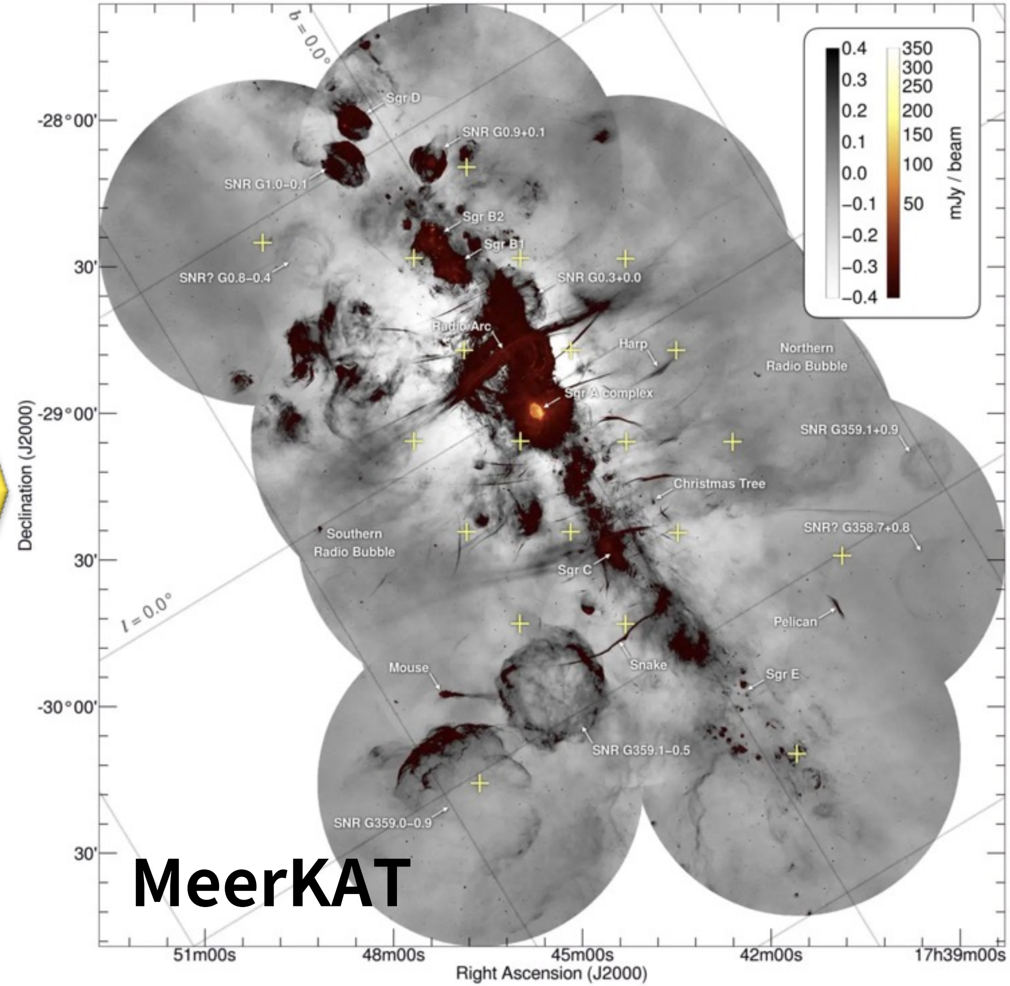


We can enjoy this science if we join SKA

Cosmic Magnetism



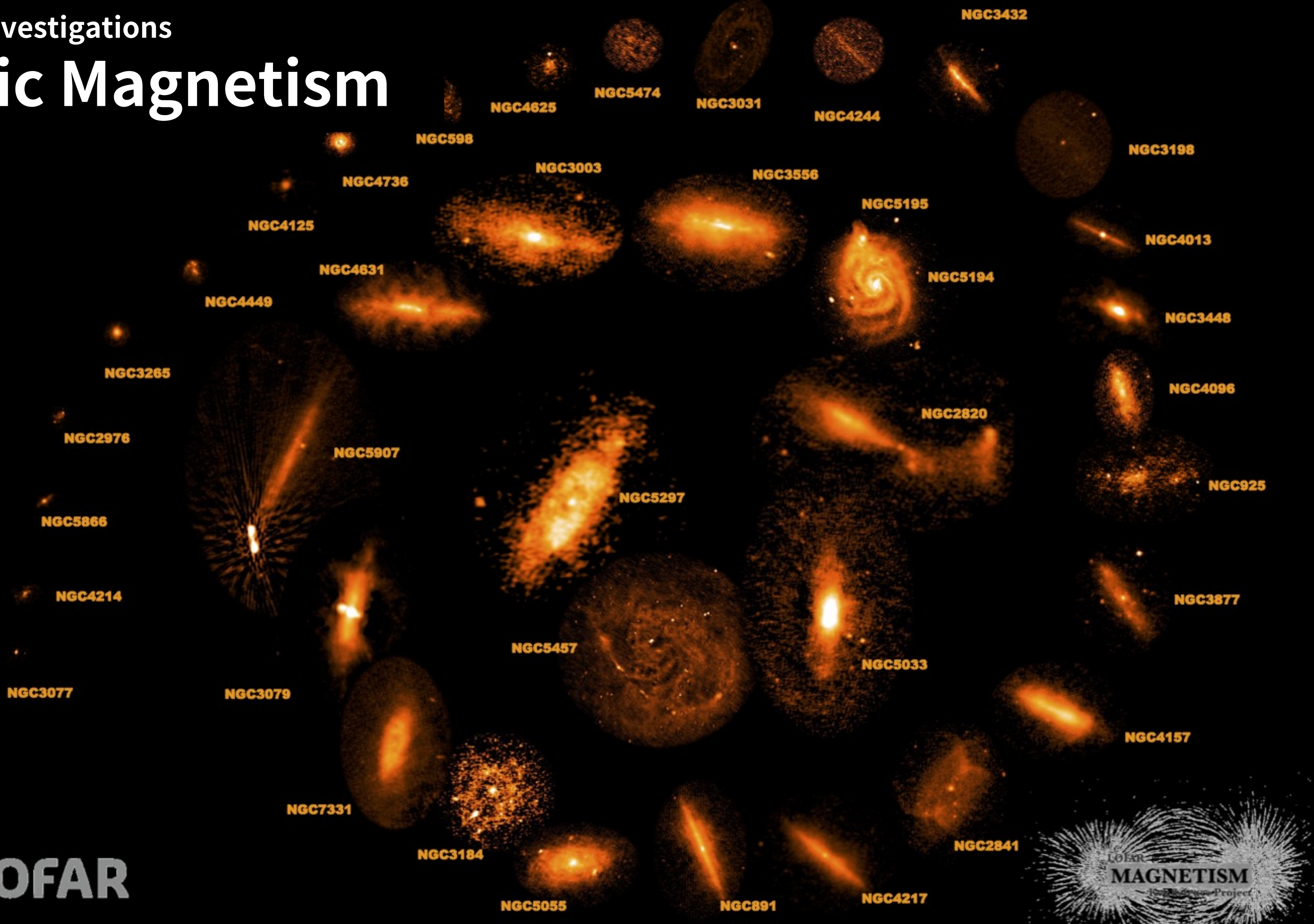
Credit: NARO/AUI, N.E. Kassim, NRL



Credit: I. Heywood et al., 2022, ApJ

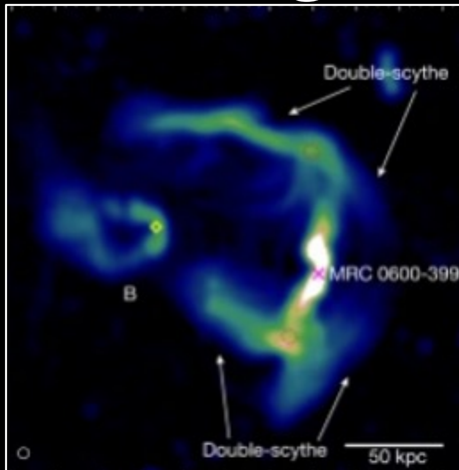
4. Science Investigations

Cosmic Magnetism

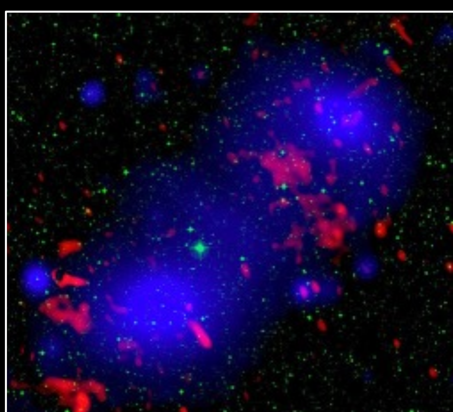


LOFAR

Cosmic Magnetism

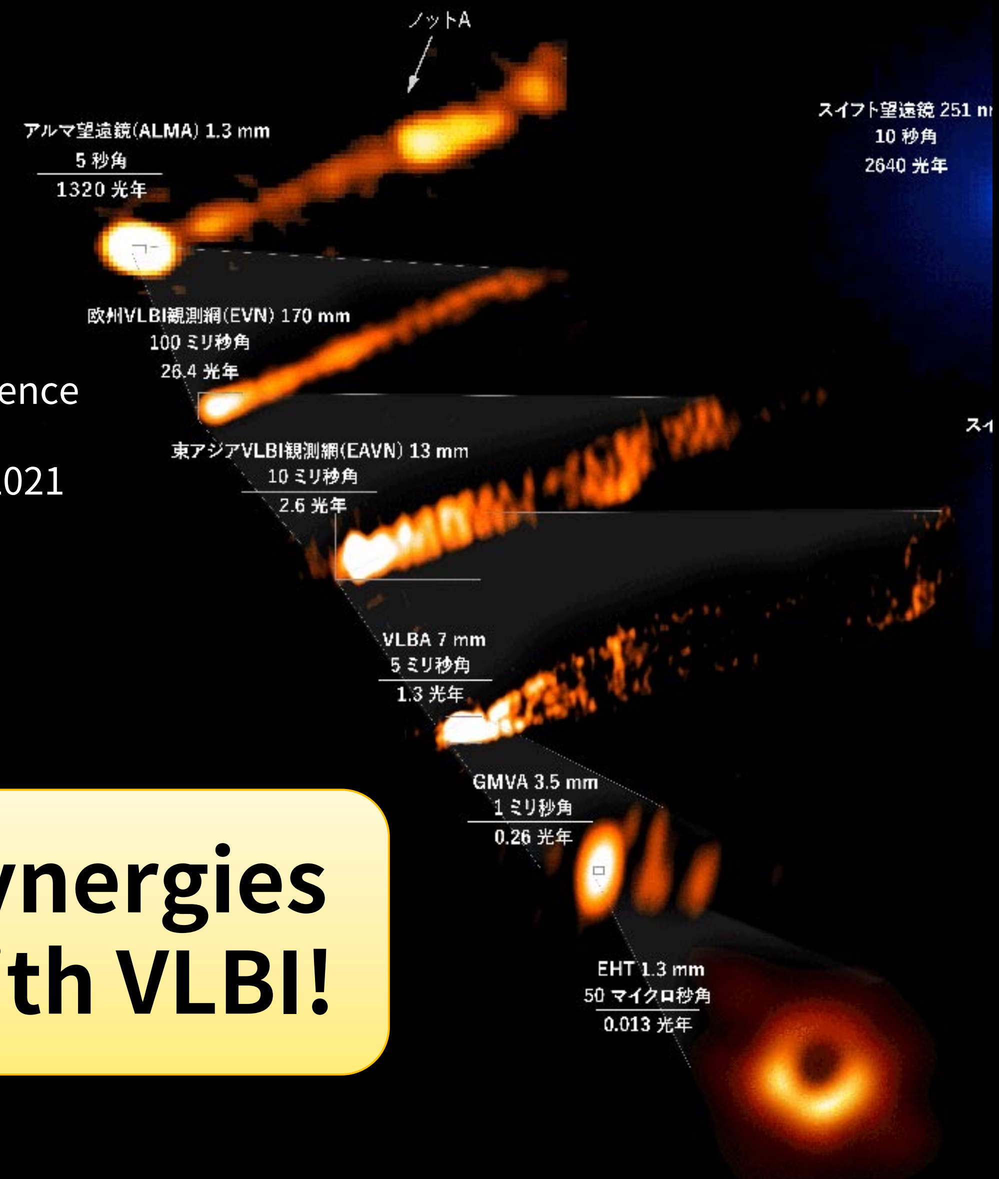


Chibueze, **Sakemi, Omura, Machida**+2021



Kurahara, Akahori+2023

The EHT MWL Science Working Group+2021

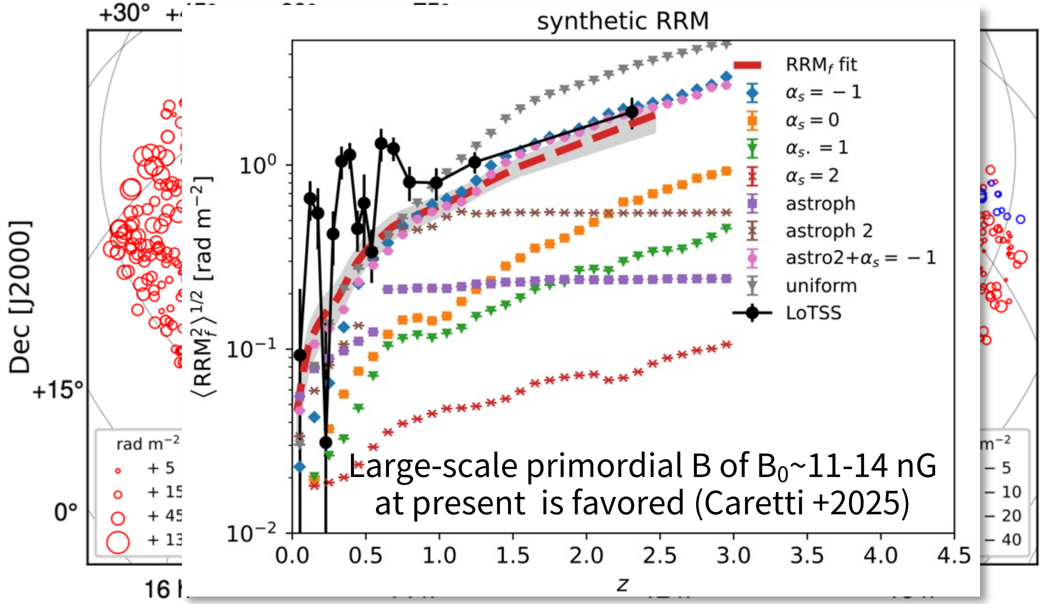


Synergies with VLBI!

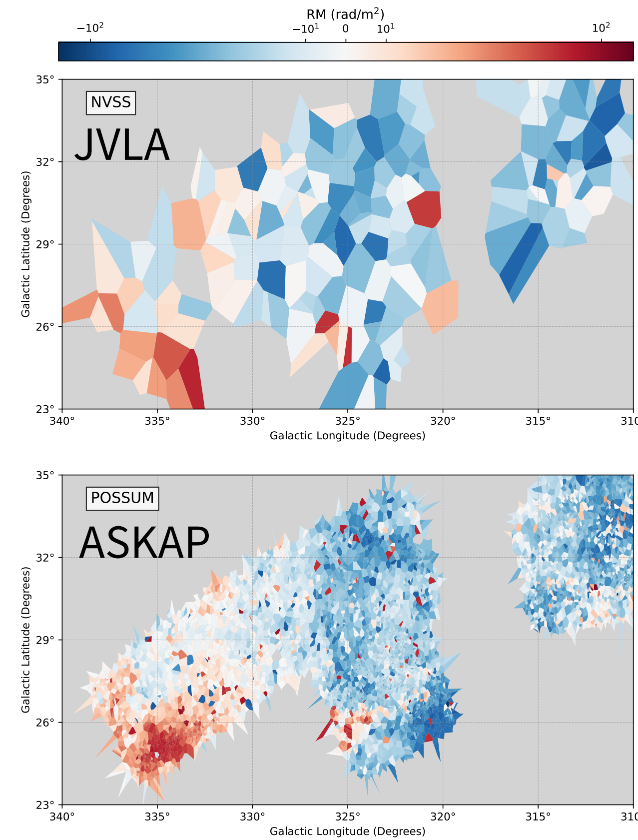
4. Science Investigations

Cosmic Magnetism

- ~2033: Wide, 300 RMs/deg^2, all-sky
- 2034~: Deep, 5000 RMs/deg^2 (>1/arcmin^2)
- Threshold: Denser (>30) (semi) all-sky RM grids
- Strength: Faraday Tomography



O'Sullivan,.., **Ideguchi**+2023

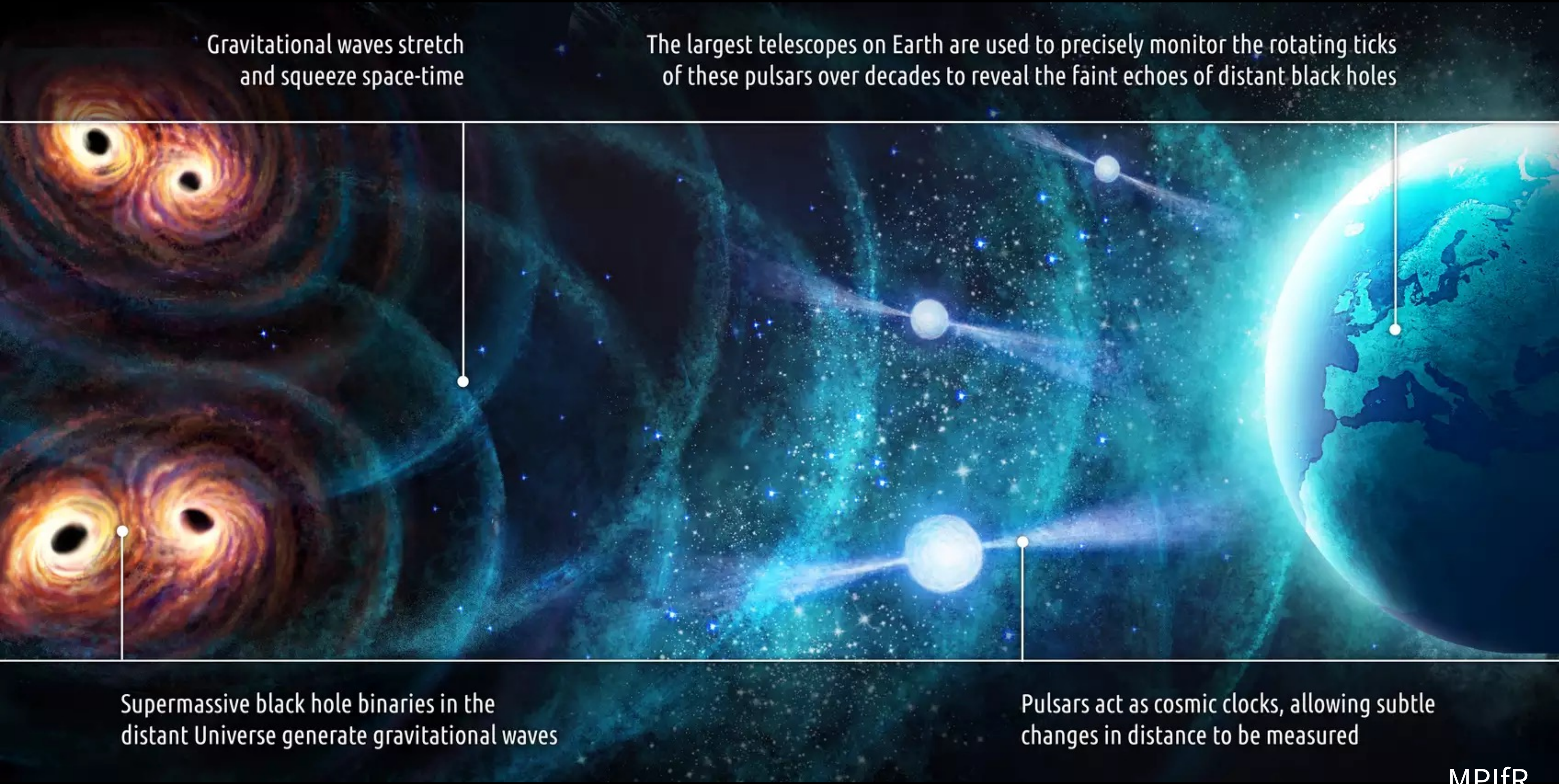


Gaensler,.., **Akahori**+submitted

We can enjoy this science if we join SKA

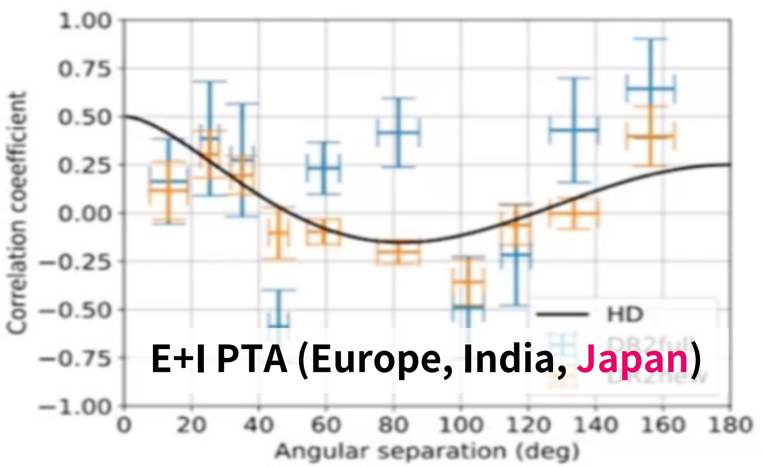
4. Science Investigations

Pulsars and GWs

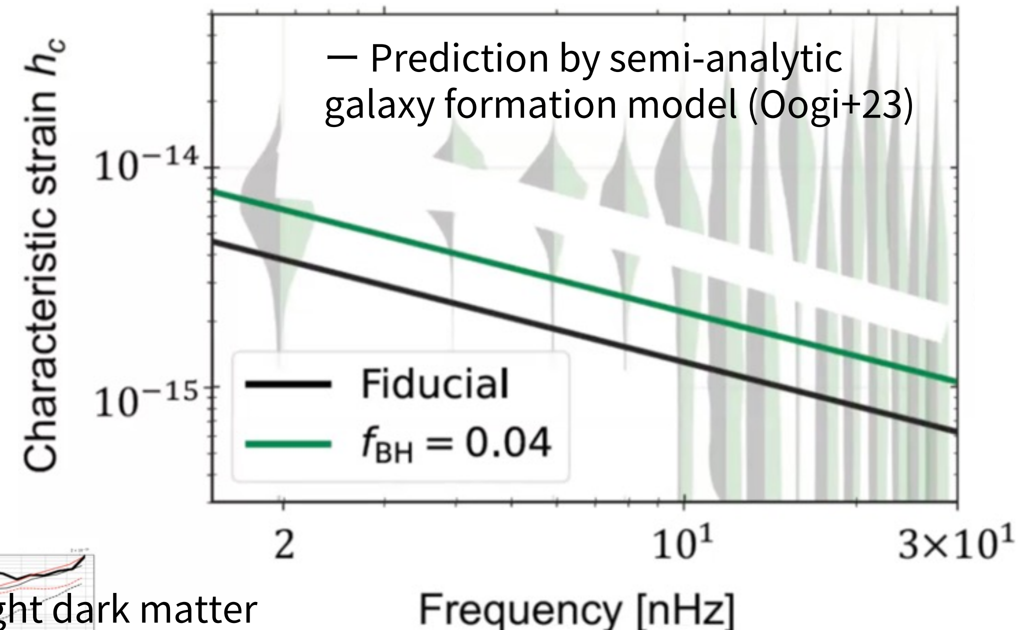


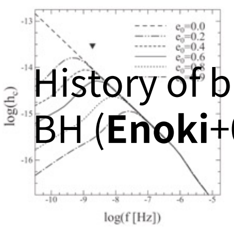
Pulsars and Gravitational Waves

"Hellings-Downs" Curve

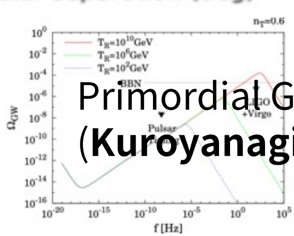


E+I PTA (Europe, India, Japan)

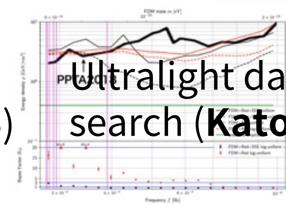




History of binary BH (**Enoki**+07)

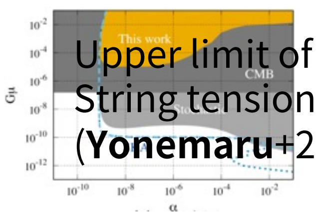


Primordial GW (**Kuroyanagi**+15)

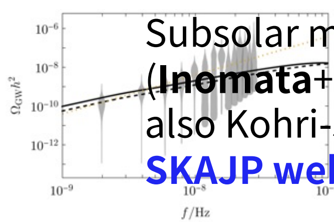


Ultralight dark matter search (**Kato**+20)

Changing the semi-analytic model parameters to fit the PTA observations does not fit the galaxy/AGN observations! See Enoki-san's **SKAJP webinar** (https://ska-jp.org).



Upper limit of Cosmic String tension (**Yonemaru**+21)



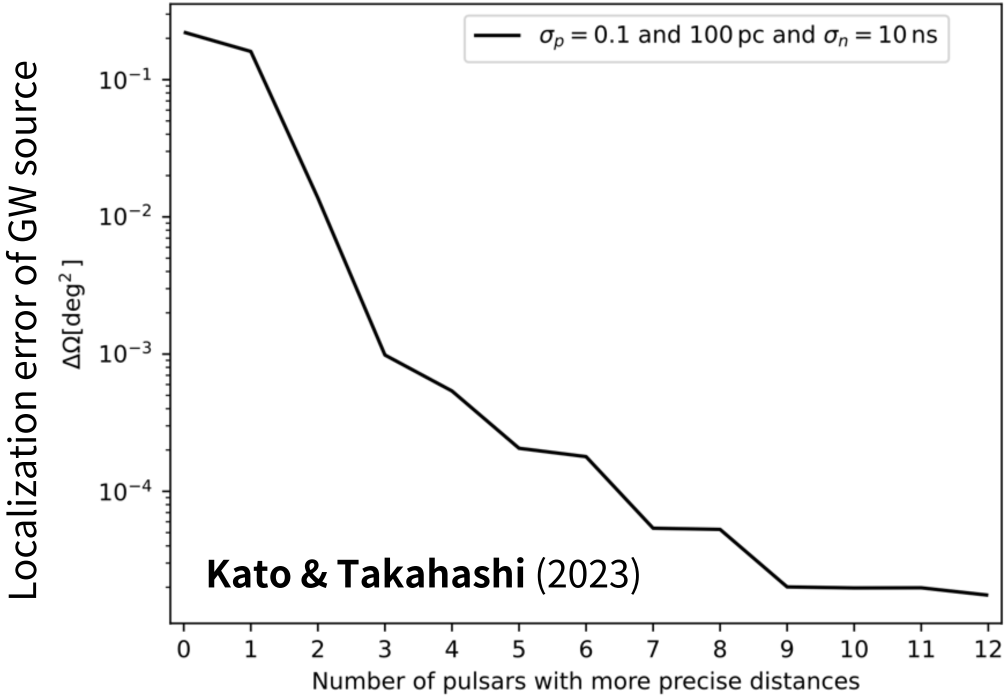
Subsolar mass PBH? (**Inomata**+23). See also Kohri-san's **SKAJP webinar**

Pulsars and Gravitational Waves

- ~2033: firm detection
- 2034~: GW astronomy
- Threshold: Better measurements of nHz GW
- Strength: VLBI

	# pulsars	# MSP
Parkes 2015	2300	113
SKA1	9000	1400
SKA2	30000	3000

Synergies with VLBI!



We can enjoy this science if we join SKA

Other Japanese Science Cases

2015: 8 chapters, 326 pages, cumulative 74 authors
(EoR, Cosmology, Galaxy Evolution, Pulsars, Magnetism, VLBI, ISM, Transients)

2020: 10 chapters, 463 pages, cumulative 135 authors
10 chapters (Star formation and Plants were added).

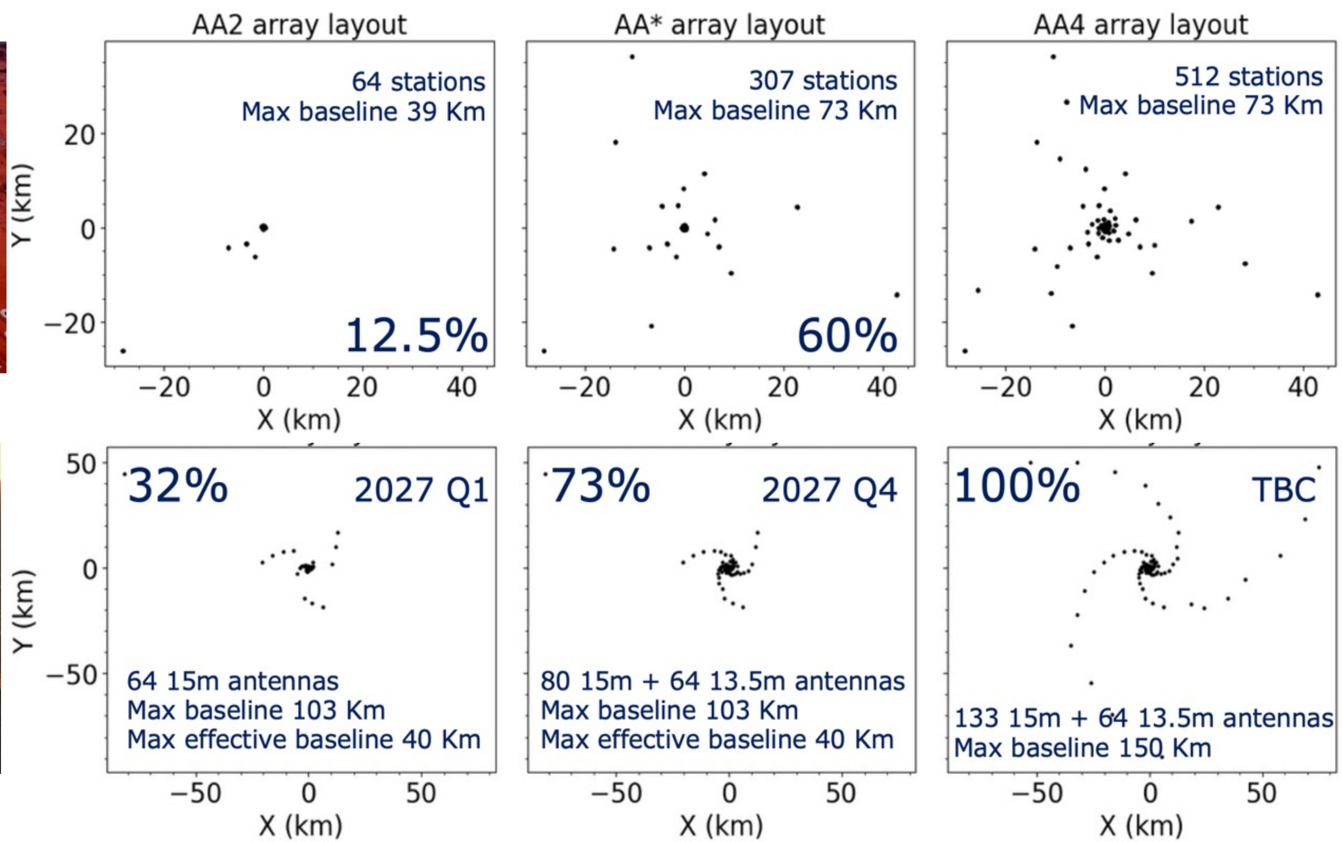
10 Science Working Groups in SKA-JP as of 2023

2023: PASJ Special Issue
Metre and Centimetre Radio Astronomy in the Next Decade
13 papers
https://academic.oup.com/pasj/pages/special-issue-metre-and-centimetre-radio-astronomy-in-the-next-decade

SKA LOW and MID

■ SKA consists of two telescopes, LOW and MID

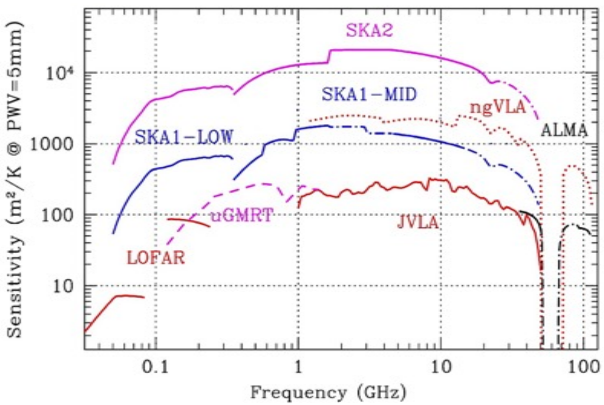
LOW: 50-350 MHz



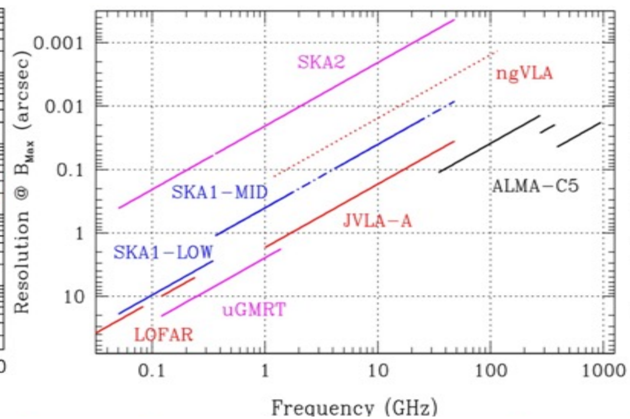
MID: 0.35-1.05 GHz (Band 1)
0.95-1.76 GHz (Band 2)
4.60-15.4 GHz (Band 5a,5b)

Ultimate Survey Performance

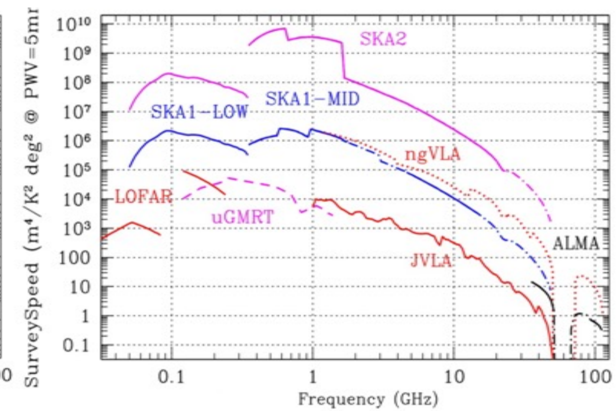
①Sensitivity



②Resolution



③Survey Merit



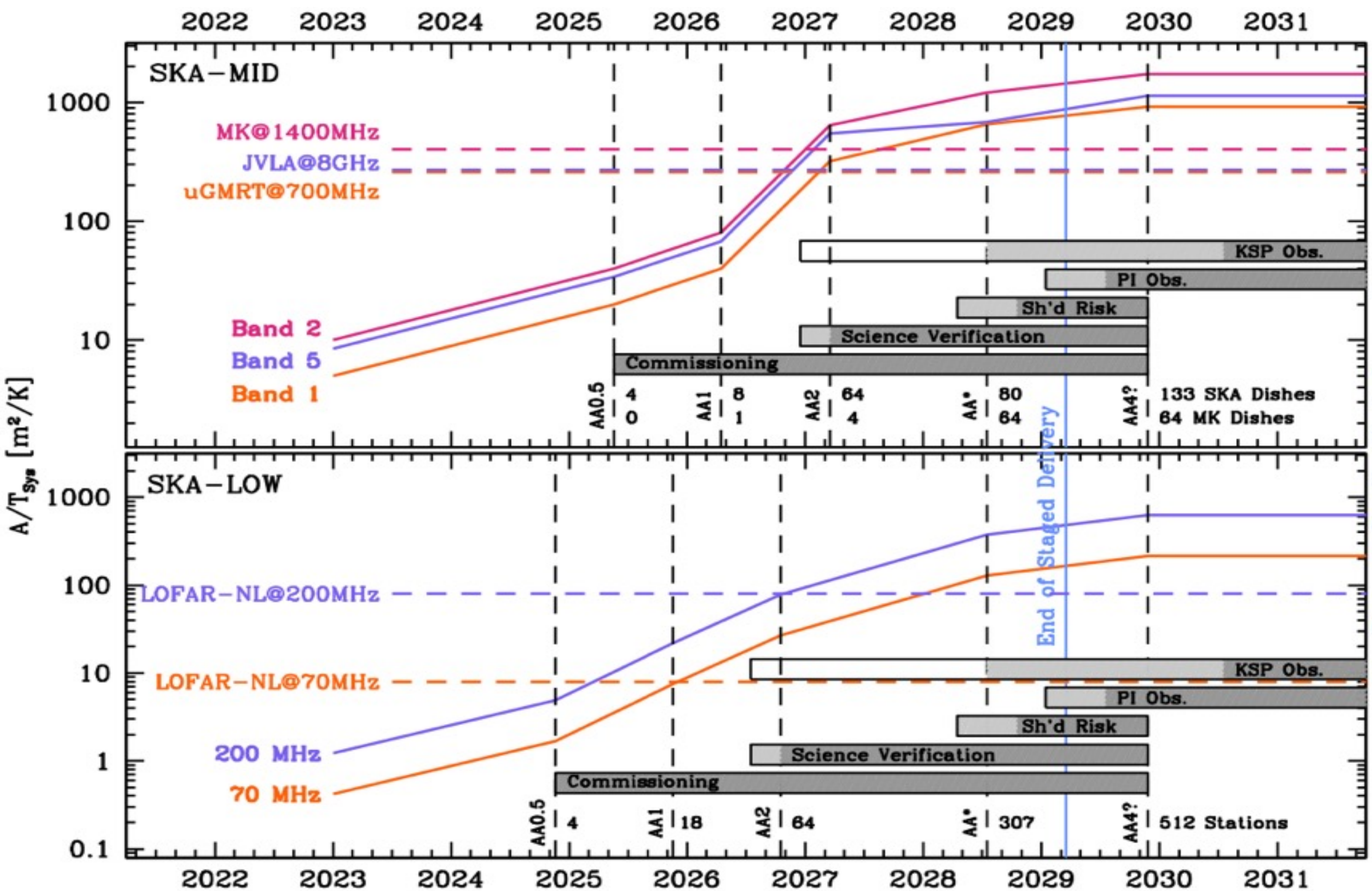
④Multi-mode

We can perform multiple observing modes simultaneously

Subarray	Band	Continuum Imag BW (MHz)	# Zoom Windows	# PSS Beams	PST BW (MHz)	# PST Beams	VLBI BW (MHz)	# VLBI Beams
1	2	810.0	3	1500	810.0	16	810.0	2

- **The sensitivity and resolution are 10 times better, the survey merit is 100 times better than the current largest facilities**
- **An effective annual operation time >> 1 year = 8760 hours**
  - There are two (LOW & MID) telescopes and there are multi-beam & multi-mode capabilities

Staged Delivery Plan



	LOW	MID
Start	2021.7	2021.7
AA0.5 Start	2024.7	2025.5
AA0.5 End	2024.12	2025.10
AA1 End	2025.11	2026.6
AA2 End	2026.10	2027.5
AA* End	2028.1	2028.3
Review	2028.4	2028.6
Staged Delivery End	2029.3	2029.3
AA4	TBD	TBD

5. Instruments and data to be returned

AIV Rollout Plans

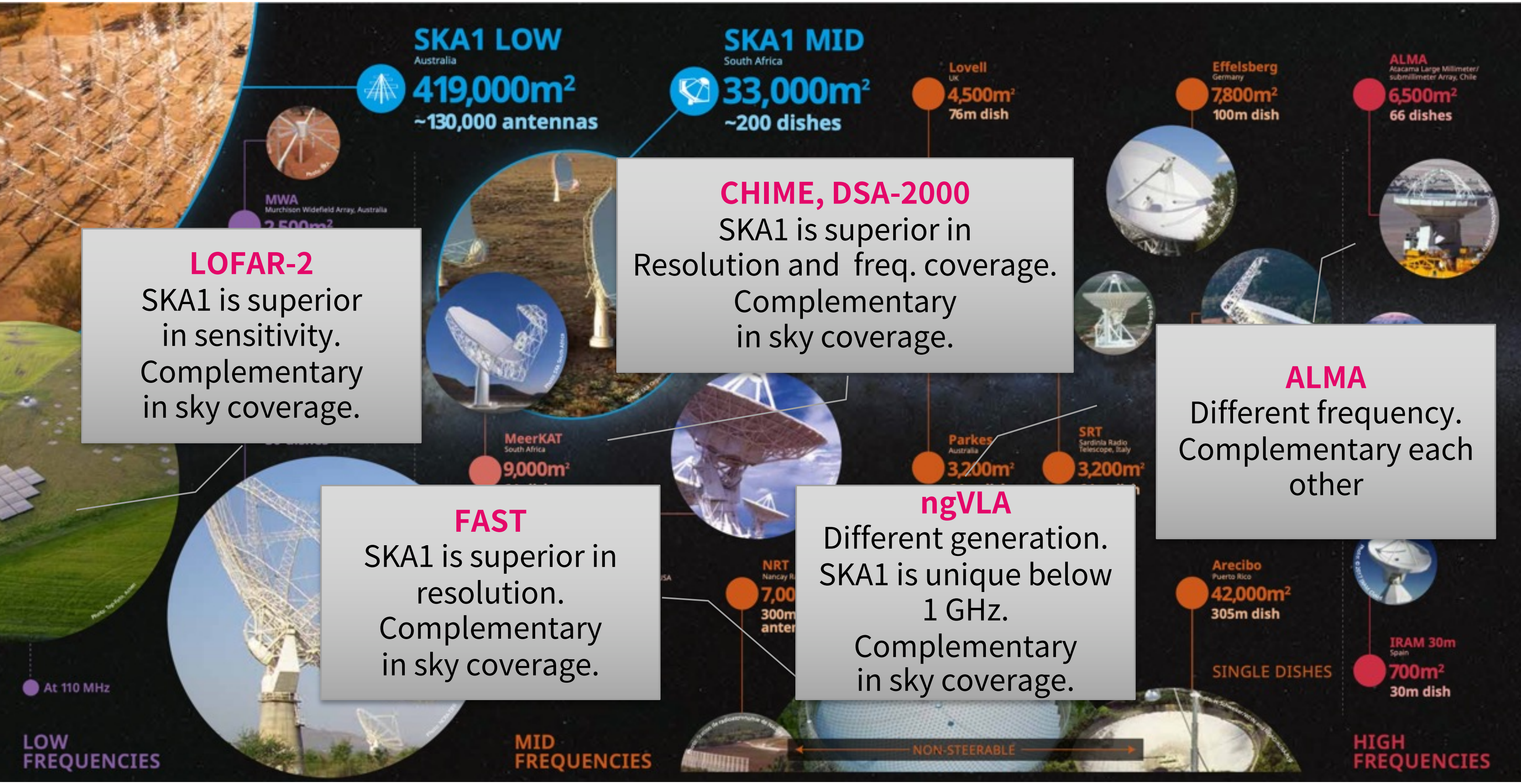
	LOW Stations	Imaging	Pulsar Timing, Dynamic Spectrum	Pulsar Search	Transient Buffer, VLBI	**MID** Bands	Imaging	Pulsar Timing, Dynamic Spectrum	Pulsar Search	Transient Buffer, VLBI
AA0.5	**6**	✓ 75 MHz Con./Lines				**4** B2 (B5)	✓ 800 MHz Con./Lines 16k			
AA1	**18**	✓ 75 MHz Con./Lines 8 station beams, 512 sub-stations		✓ 30 beams		**8** B1 B2 B5(#2-4)	✓ 800 MHz Con./Lines 16k	✓ 1 beam 400 MHz BW		
AA2	**64**	✓ 150 MHz Con./Lines 16 zoom, 1.8 kHz 8 station beams, 720 sub-stations	✓ 4 beams	✓ 30 beams	**LOW VLBI**	**64** B1 B2 B5(#32)	✓ 800 MHz Con./Lines 16k	✓ 6 beam 800 MHz BW De-dispersion	✓ 16 beams Full BW No pipelined No real time	
AA*	**307**	✓ 300 MHz Con./Lines 32 zoom, 230 Hz 8 station beams, 1440 sub-stations	✓ 8 beams	✓ 250 beams De-dispersion	✓ Commensal Full	**144** B1 B2 B5(#80)	✓ 5200 MHz Con./Lines 64k, zoom Pipelined	✓ 16 beam Full BW De-dispersion	✓ 1125 beams Full BW No pipelined No real time	**MID VLBI**
AA4	**512**	✓ 300 MHz Con./Lines 64 zoom, 14 Hz 8 station beams, 2880 sub-stations	✓ 16 beams	✓ 500 beams De-dispersion	✓ Commensal Full	**197** B1 B2 B5(#133)	✓ Full Con./Lines 64k, zoom Pipelined	✓ 16 beam Full BW De-dispersion	✓ 1500 beams Full BW Pipelined Real time	✓ 4 beams

5-Years Key Science Projects

	周波数 Hz	分解能 kHz	感度 image rms	Dynamic range dB	時間分解 msec	空間分解 arcsec	視野 deg^2	天域 deg^2	積分時間 hr	掃天時間 hr	備考
EoR imaging	50-200 M	1000	1.4 mK	50/50	400	300	20	100	2000	5000	Deep
EoR power spectrum	50-200 M	1000	4.6 mK	50/40	400	300	20	1000	200	5000	Drift
	50-200 M	1000	14 mK	50/35	400	300	20	10000	200	5000	Wide
Pulsar Searching	150-350 M	75	20 μJy	30/25	0.05	145	11 min^2	30000	40 m	12750	Tied-Array Beams
	650-950 M	75	13 μJy	30/25	0.05	65	1.2	2400	10 m	800	Tied-Array Beams
	1.25-1.55 M	75	7 μJy	30/25	0.05	43	0.39	2400	10 m	2400	Tied-Array Beams
Pulsar Timing	150-350 M	75	10 μJy	30/40	0.0001	8	65 sec^2	0.9 min^2	40 m	4300	Tied-Array Beams
	950-1769 M	75	3 μJy	30/40	0.0001	7	50 sec^2	0.7 min^2	15 m	1600	Tied-Array Beams
HI High-z	790-950 M	50	16 μJy	50/35	150	2-10	1.1	5.4	1000	5000	Line
HI Low-z	1300-1400 M	20	14 μJy	50/30	150	2-10	0.38	3.8	200	2000	Line
HI MW	1415-1425 M	4	75 μJy	50/30	150	2-10	0.38	1080	4.4	12600	Line
Cosmology High-z IM	350-1050 M	300	3.3 mJy	40/40	150	1.7 deg	1.4	30000	2.2	10000	Drift, Line, Wide
Cosmology ISW, Dipole	1-1.7 G	1000	7 μJy	45/30	150	2	0.38	31000	0.12	10000	Wide
Continuum +Mag. Band 2	1-1.7 G	1000	1.3 μJy	60/30	150	0.5	0.38	1000	3.8	10000	Wide
	1-1.7 G	1000	250 nJy	60/30	150	0.5	0.38	7.8	95	2000	Medium
	1-1.7 G	1000	65 nJy	60/30	150	0.5	0.38	0.38	2000	2000	Deep
Continuum +Mag. Band 5	7-11 G	4000	400 nJy	45/30	150	0.05	30 min^2	0.5	16.4	1000	Wide
	7-11 G	4000	50 nJy	45/30	150	0.05	30 min^2	30 min^2	1000	1000	Deep
Cradle of Life	8-12 G	4000	80 nJy	40/25	150	0.04	18 min^2	0.05	600	6000	Multiple Clouds

6. Originality and international competitiveness

Other Telescopes



LOFAR-2
SKA1 is superior in sensitivity. Complementary in sky coverage.

CHIME, DSA-2000
SKA1 is superior in Resolution and freq. coverage. Complementary in sky coverage.

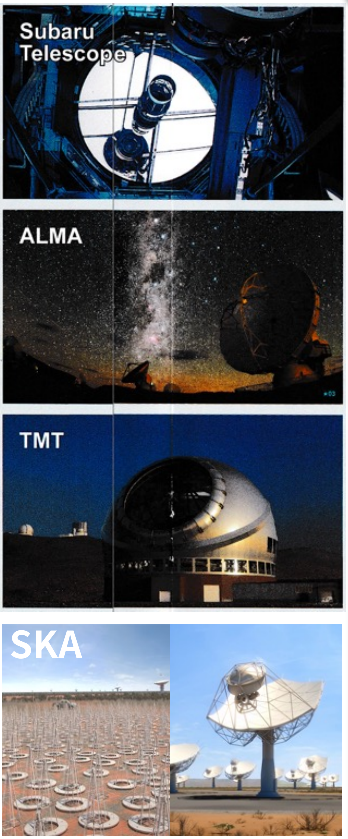
ALMA
Different frequency. Complementary each other

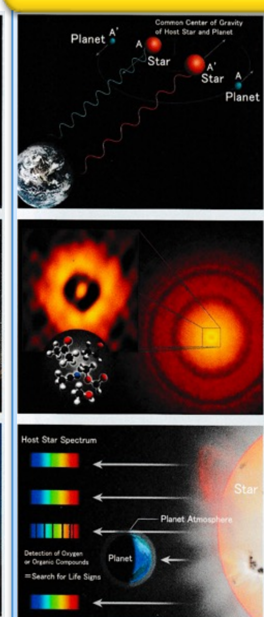
FAST
SKA1 is superior in resolution. Complementary in sky coverage.

ngVLA
Different generation. SKA1 is unique below 1 GHz. Complementary in sky coverage.

Synergies with NAOJ Key Sciences

Worried that we will fall behind in these sciences if we do not participate in SKA.
SKA is very important for Subaru3, ALMA3, TMT, and future projects too.





Finding Habitable ExoPlanets

The Subaru Telescope searches for exoplanets with masses similar to Earth through high precision spectroscopy to detect the wobble in the host star induced by the orbital motion of the planet.

The host star moves in reaction to the planet's orbital motion. Planets can be detected indirectly via spectroscopic observations of the Doppler effect produced in the light from the host star.

Finding Building Blocks for Life

ALMA devotes its energies to observations of formation sites of planets as the cradles of life, and searches for organic molecules which provide the building blocks for life.

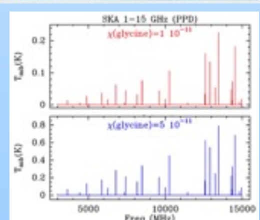
The protoplanetary disk around the young star TW Hydrae photographed by ALMA. The radius of a gap near the central star (inset zoom-in) is comparable to Earth's orbit. ALMA detects the radio waves from various molecules in this kind of planet formation site. *01

Finding Life Signs

TMT will target exoplanets discovered by the Subaru Telescope for detailed investigations of the planets' atmospheres through very high accuracy spectroscopic observations to try to find signs of life. This combined with ALMA's findings about the materials for life found in protoplanetary disks will bring us closer to understanding the origin of life in the Universe.

If oxygen or an organic compound is found through spectroscopic observations of the atmospheres of exoplanets, the odds are high that life exists there.

Finding exoplanets, Amino acid, and SETI



Search for Very Distant Objects

By searching for very distant objects in survey observations by the Subaru Telescope's ultra-wide-field-of-view Hyper Suprime-Cam, we can find targets for detailed follow-up observations using ALMA or TMT.

Countless galaxies in the distant Universe photographed by Hyper Suprime-Cam on the Subaru Telescope. The Prime Focus Spectrograph currently under development will accurately determine their distances.

Determining Chemical Composition

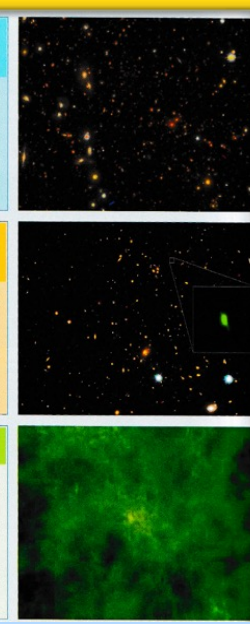
ALMA conducts high sensitivity follow-up observations of very distant object candidates discovered by the Subaru Telescope, catching radio waves emitted by the atoms contained in those objects to determine their chemical composition. This provides clues about the evolution of the earliest galaxies in the Universe.

ALMA false color image (green zoom-in inset) showing the oxygen in the galaxy MACS 1149-JD1 located 13.28 billion light-years from Earth. *02

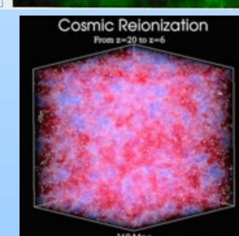
Finding the First Stars

TMT will conduct high sensitivity follow-up observations of very distant object candidates observed by the Subaru Telescope, detecting the characteristic light emitted by helium atoms to elucidate when the first generation of stars formed and what their characteristics were.

A scene from a computer simulation depicting the birth of the first stars in the Universe. Verifying the results of theoretical studies of the first stars through observations is another important theme. *04



Finding the soil of the First Stars



Elucidate the 3D distribution of dark matter over wide areas through observations of **gravitational lensing** based on ultra-wide-field images

Use its high resolution to measure the **rotation curve of individual galaxies** and determine the dark matter distribution within a galaxy

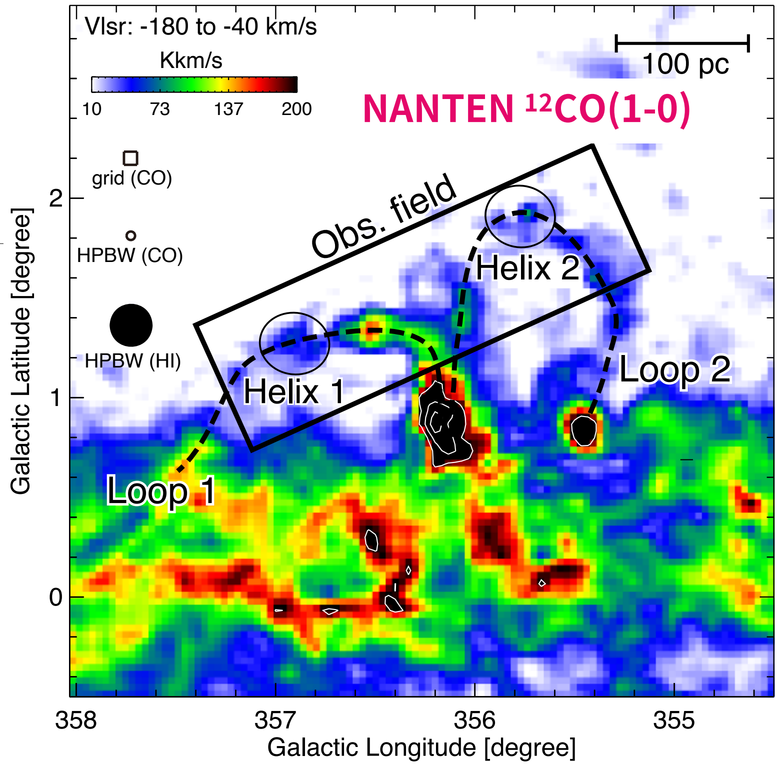
Will provide a clues to the nature of dark energy by directly measuring **the change in the expansion rate** of the Universe

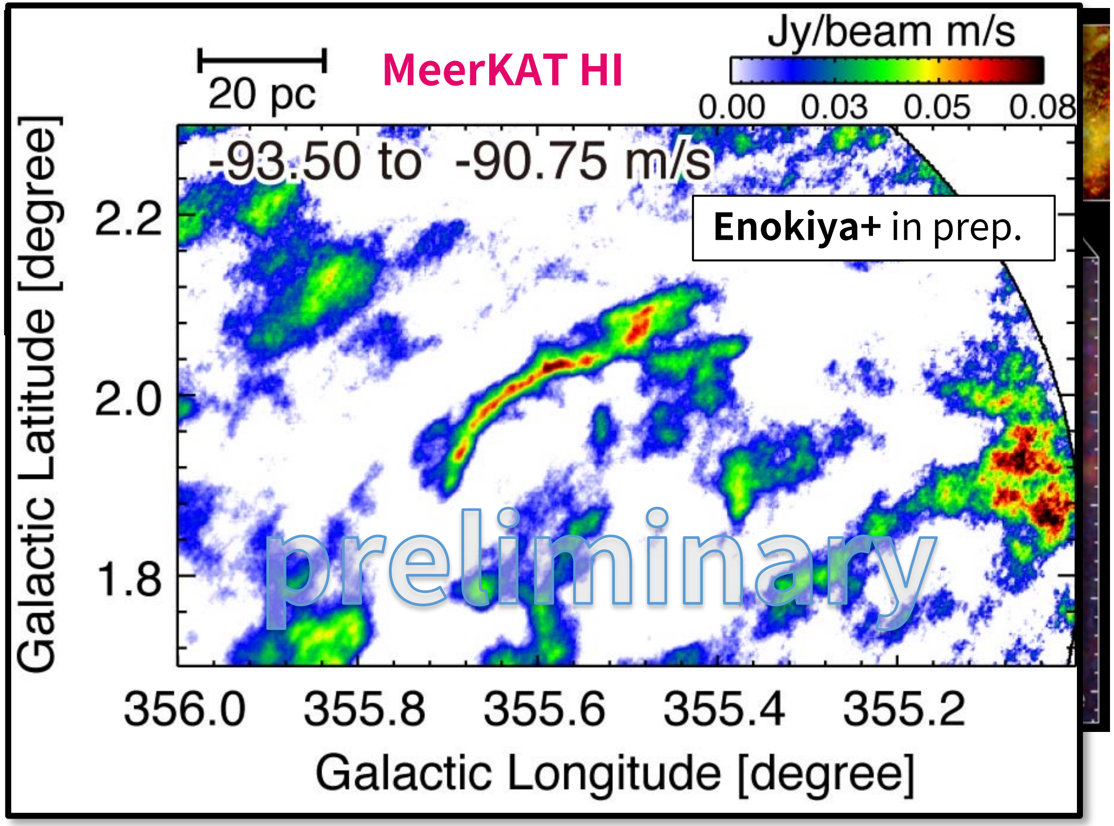
Exploring the **non-Gaussianity** in density fluctuation. **Ultralight dark matter** search by PTA. Polarimetry for cosmic birefringence caused by **ALP DM**.

From NAOJ Pamphlet 2023

Synergy with Nobeyama and NANTEN

HI → Seed of Star Formation





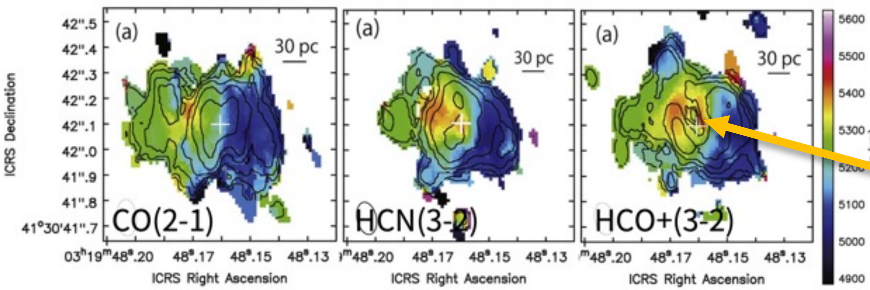
Synergy with ALMA/ngVLA

HI → Galaxy Ecosystem

Intergalactic space (Intracluster medium)

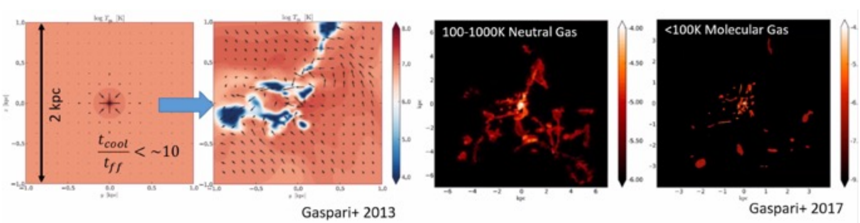
Cooling flow?? — AGN heating??

HI — HI

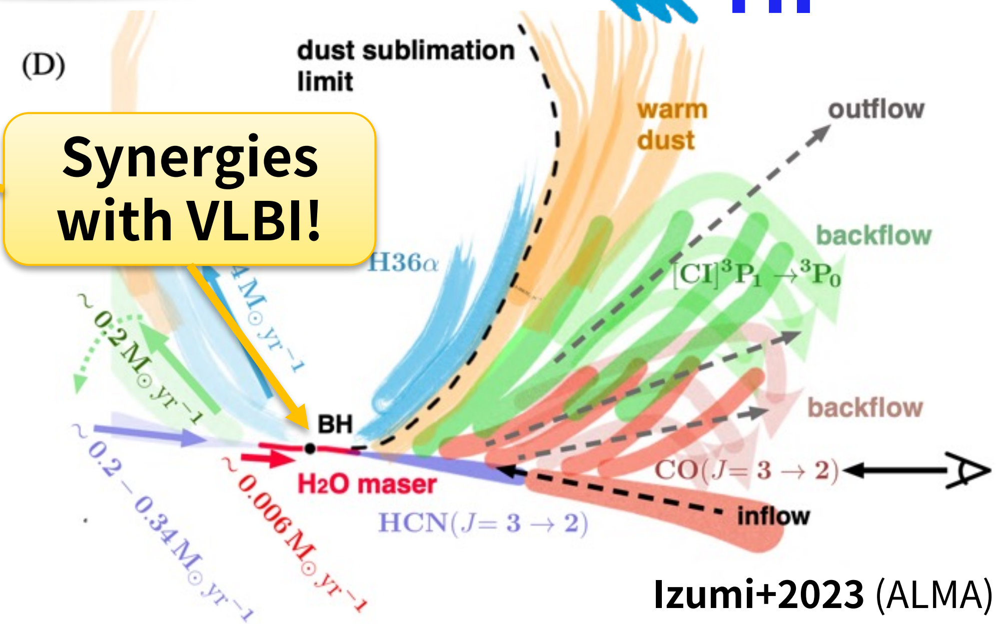


From **Nagai+2019** (ALMA)

Chaotic Cold Accretion?



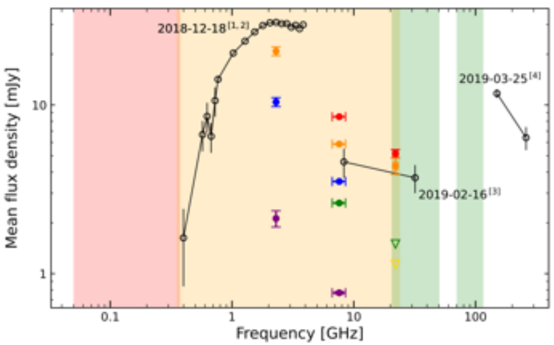
Synergies with VLBI!

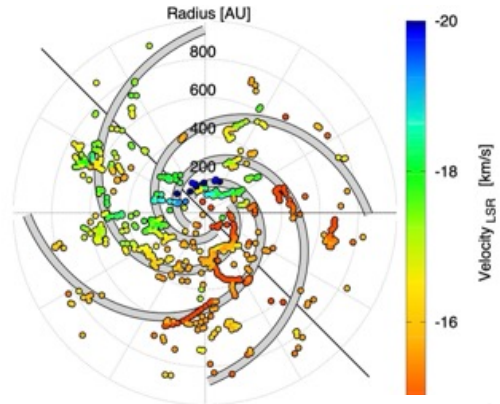


Izumi+2023 (ALMA)

Synergy with Subaru/TMT

Transients → Multi-messenger

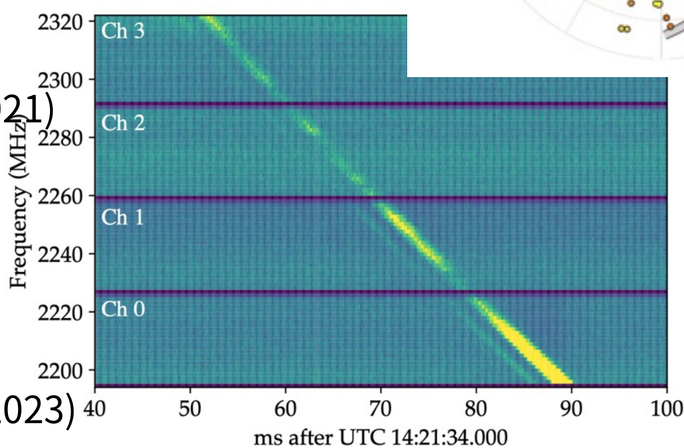




Methanol maser accretion burst
Burns, Hirota+(2023)

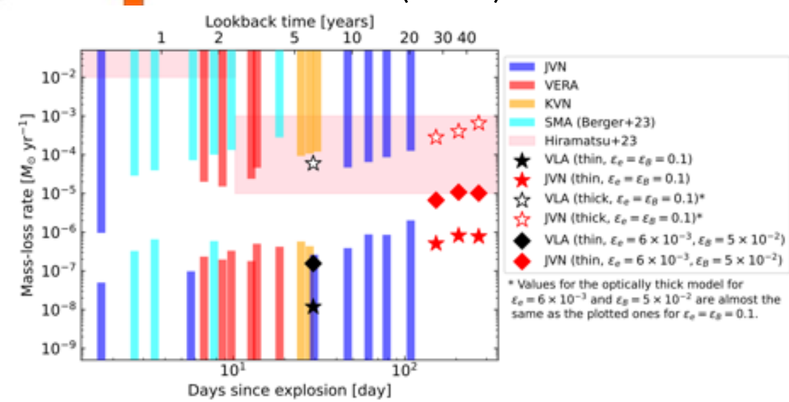
Synergies with VLBI!

Magnetar radio outburst
Eie, Honma+(2021)



Fast radio burst
Ikebe, Honma+(2023)

Radio follow-up of Supernova
Iwata+(2024)



SKA1 Project Plan

国立天文台SKA1サブプロジェクト
NAOJ SKA1 Japan Promotion Group

SKAJ

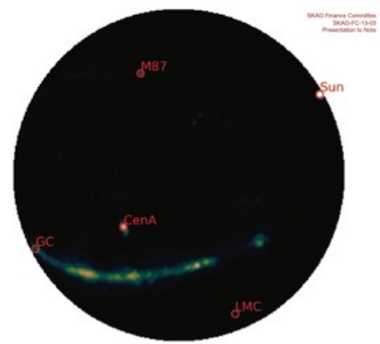
SKA1 Construction (as of Nov 2024)

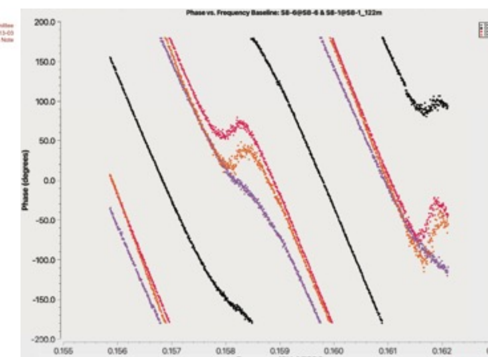
MID – South Africa




First antenna assembly almost completed.
Second antenna in progress.
Third one arrived at the site.

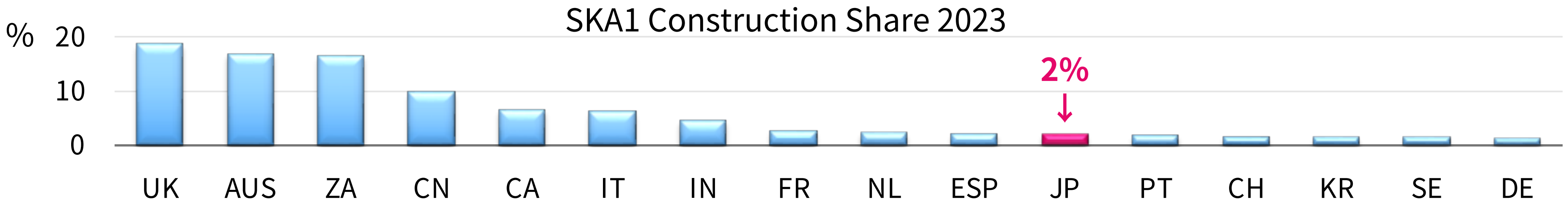
LOW – Australia



All 4 AA0.5 stations were handed over to AIV team
All-sky map using single station
First fringe detection using two stations

Japanese Share and Scope



Construction 1117M€ (880+ contingency 237)
>70% Fair Work Return

Operation 905M€ (Op., Enabler, Develop)
Cash (2021-2030, 10 years)

SKA1 baseline design 2022M€

1659.2M€ (82% of BD) was expected as of 2021.6
AA* was defined based on this budget

158 M€

~300 M€

Latest estimate of the budget to achieve AA*
→need more 158M€

The council has been discussing it for a year.

- COVID19: stagnation of logistics
- Ukraine invasion: supply chain, fuel
- Inflation: silicon
- Exclusion of Japan (50.7M€)
- Cost reduction by SKAO (-50.7M€)

Maybe approved in 2025.3 Council

Latest estimate of the budget to achieve AA4 from AA*
→need more ~300M€

The task force was made in the Council

Japan is a key!

Is 2% Small or Large?

1. Decreasing Japan's share of world-largest projects

- ATLAS instrument share ~6 %, LHC share ~3%
- Japan's GDP share ~4.0 % (2024.2)

2. 2% is comparable to major European countries

- We will obtain the outcomes like France, Netherlands, Spain, Germany

3. In line with past examples and current capability

- Focusing on 3 key science will boost the outcome effectively

Common-use category	# of proposals from Japan	# of approvals	# of papers
Key Science Projects (large & long-term proposals)	15-30	3	6
PI Proposals (small & short-term proposals)	33-66	6	6
Total (per year)	48-96	9	12*†

* This number per cost is comparable to those of Subaru and ALMA.

† This number is comparable to the current SKAJP's output using SKA precursors/pathfinders.

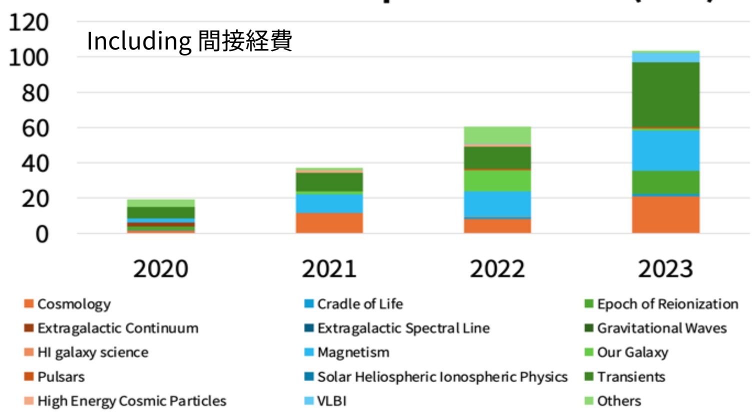
Budget Profile

＊Permanent staff cost is **excluded**.

← Construction → ← Operation →

	2024	2025	2026	2027	2028	2029	2030	sub total	2031	2032	2033	2034
Array	AA.5	AA1	AA2	AA*	AA4	AA4	AA4		SODP	SODP	SODP	SODP
# LOW	6	18	64	307	512	512	512					
# MID	4	8	64	144	197	197	197					
Unkokin (M¥)	20.9	35.3	34.7	34.1	13.8	13.8	13.8	145	14	13.4	13.4	13.4
Compet. (M¥)	~3	73	220	219	124	121	121	880	TBD	TBD	TBD	TBD
Gaisan (M¥)	-	-	-	-	3090	2844	2843	8777	681	680	635	620

Annual earned competitive Funds (M￥)



Unkokin: Essentials + AIV (2025-2027)
Competitive budget: AIV/CSV, VLBI, SRC
Gaisan Yokyu: RM2026, but not just for frontier budgets, but for any budgets (keywords: Big Data, Global South)

Note for Budget Plan

✓ SKAO Policy of Contribution

- Construction (1117 M€): more than 70% is goods/in-kind
- Operation (905 M€): 100% Cash

Construction + Operation = **Allowed range of Cash 44.8-61.4%**
(this plan 61.1%)
(Because of late participation)

✓ Foreign exchange risk

- We made a conservative plan (actual share ~2.13% – 2.82%)

Const. share 8.7 B¥	Original AA4 cost 2022 M€	Projected AA4 cost 2400 M€
170 ¥/€	2.52%	2.13%
150 ¥/€	2.82%	2.38%

SKAO and SKAJ

† Applied SKA for the MEXT Roadmap 2020/2023
‡ Some discussions are happening with ISEE and 南半球宇宙観測研究センター of DoS

Inter-governmental Organization SKAO

SKAO Council
Decision making

13 countries
+4 candidates

Committee
- Finance
- Science and Eng.
- Time Allocation

UK GHQ

AU LOW

ZA MID

Inter-University Cooperation SKAJ (under discussion)

NAOJ
Mng, Negotiation, Magnetism, AIV, Compressor, VLBI

secondment →

Nagoya † ‡
Mng, Funding, SRC
EoR, Gal. Evol., Cosmology, IPS

Kumamoto
Pulsars, Digitizer

Osaka Met.
Receiver

Gifu
Star formation

Yamaguchi
Transients, AIV

Kagoshima
MW/VLBI, AIV

THERS
東海大学機構

Other Universities and Institutes in future

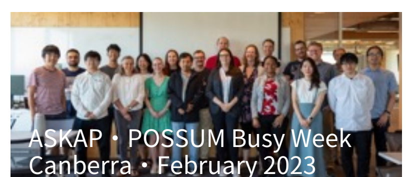
MEXT

SKAJP Executive Committee

Fostering Young Researcher

Science book, webinar series, SWG/EWG activity

→



WG Leader, Oversea stay, Funding PI

→

Becomes core member of executives

The SKA1 Promotion Group in NAOJ

グループリーダー： 赤堀卓也 60%
Group Leader : Takuya Akahori

シニアアドバイザ：小林秀行
Senior Advisor: Hideyuki Kobayashi

水沢VLBI観測所長：本間希樹 5%
MVO Director: Mareki Honma

事務：勝川まりえ 100%
Admin: Marie Katsukawa

広報：中西裕之 10%
Outreach: Hiroyuki Nakanishi

科学部門長：町田真美 10%
Head of Science: Mami Machida (DoS)

- 科学検討：廣田朋也 10% — Use cases: Tomoya Hirota
- 国際連携：高橋慶太郎 10% — Oversea: Keitaro Takahashi
- VLBI運用協定：寺家孝明 10% — VLBI Op./Alliance: Takaaki Jike
- VLBI運用協定：今井裕 10% — VLBI Op./Alliance Hiroshi Imai
- 講習会：藏原昂平 5% — VLBI Test: Kohei Kurahara
- 講習会：酒見はる香 5% — Tutorial: Haruka Sakemi

SRC部門長：市來淨與 10%
Head of SRC Kiyotomo Ichiki

- 部門長補佐：赤堀卓也 20% — Support: Takuya Akahori
- クラウド：山下一芳 60% — Cloud: Kazuyoshi Yamashita (ADC)
- クラウド：吉浦伸太郎 40% — Cloud: Shintaro Yoshiura
- クラウド：加藤亮 40% — Workflow: Ryo Kato
- クラウド：出口真輔 10% — Cloud: Shinsuke Ideguchi (CfCA)
- ワークフロー：岩田悠平 10% — workflow: Yuhei Iwata
- ワークフロー：酒見はる香 5% — Workflow: Haruka Sakemi
- 部門長補佐：大前陸人 10% — Support: Rikuto Omae

技術部門長：新沼浩太郎 10%
Head of Engineering: Kotaro Niinuma

- MID性能検証：砂田和良 80% — MID AIV: Kazuyoshi Sunada
- LOW性能検証：河野裕介 25% — LOW AIV: Yusuke Kono
- LOW開発：河野裕介 25% — LOW R&D: Yusuke Kono
- LOW開発：吉浦伸太郎 10% — LOW R&D: Shintaro Yoshiura
- VLBI記録系：小山友明 10% — VLBI Dev.: Tomoaki Oyama
- VLBI：藏原昂平 5% — VLBI Test: Kohei Kurahara
- 受信機：山崎康正 — Receiver: Yasumasa Yamazaki (ALMA)
- 将来技術発掘：河野裕介 20% — Engineering Items: Yusuke Kono

MVO staff 14, 3.9FTE + admin
NAOJ others 3, 0.2FTE+α
Universities 7, 0.7FTE

The Community's Voice

◆16 Years Activity of Japan SKA Consortium

国際活動

2011
東アジア
SKA科学
会議

2013 東アジア
SKA科学会議

2012-2014
「頭脳循環」
鹿大主導で
SKA関係国に
長期滞在

2016~
MWAに正式参加

2015年-2017年
「大学支援経費」鹿大からSKAに長期滞在

2014 マスタープラン
重点大型計画

2018 ASKAP・
MWAの国際会
議を国内招致

2017 マスタープラン
提案見送り

2019 東アジア
SKA科学会議

2020 マスタープラン
重点大型候補

2021 東アジア
SKA科学会議

2023~国際SRCに正式参加

2023 東アジア
SKA科学会議

2023 未来の学術振興
構想掲載

2023 PASJ特集号の出版

2023 日本天文学会
セッション

2024 SKA-JP
シンポジウム

国内活動

2008
日本SKA協会(SKA-JP)発足

2010/2011
マスタープラン
重点大型計画

2010/2012
ロードマップ掲載

2013 宇宙電波
懇談会シンポジ
ウムSKA特集

2015 日本版SKA
科学白書の出版

2015 日本天文学会セッション

2015 SKA-JP
ワークショップ

2016 SKA-JP
シンポジウム

2017 水沢SKA科学報告書の出版

2017 日本物理学会セッション

2020 日本版白書の更新

2019 SKA-JP
シンポジウム

2021 SKA-JP
科学戦略会議

2022-ウェビ
ナー開始

280 registered
as of 2024.7

We applied for the MEXT Roadmap(2023), with recommendations from Radio Astronomy Forum (#390) and Astronomical Society of Japan (#2300). But our application was not adopted.

It is natural for NAOJ, as an inter-university research institute corporation, to provide telescopes, which 280 people has desired for many years.

Activities conducted at NAOJ and significance

- **Negotiation**
  - with SKAO, MEXT, and stakeholders
  - Administration with overseas institutions
- **Science Promotion**
  - Collect and organize the telescope scientific information and share it to the community
- **Operation Support**
  - Know-how of providing a common-use telescope to the community
  - Help planning about JPSRC
- **Engineering Lead**
  - AIV and VLBI skills in NAOJ
  - Know-how of co-work with industries

Establishing a project office is the most natural way

【ATC/ADC】Will appreciate technical advice.
Hope to fund raising together. So far no resource required.

Some choices from items 11-17

国立天文台SKA1サブプロジェクト
NAOJ SKA1 Japan Promotion Group

SKAJ

SKAJ

11. Collaboration and spillover effects outside astronomy

Beyond Astronomy

4 質の高い教育をみんなに

Nobel Prize winner?

Excite the Citizon
Discovery of first stars and gravitational waves

Intellectual Value
Origins of galaxies, stars, and life

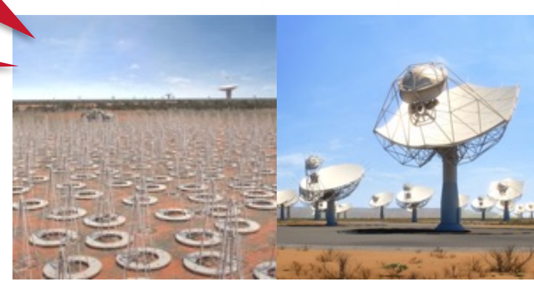
17 パートナーシップで目標を達成しよう

Affinity between STEM education and astronomy; the universe is a lifelong fountain of curiosity for both children and adults

International Cooperation
Cooperation of more than 16 countries around the world overlooking the globe
International goodwill through the power of youth

Friendship at international conferences, sharing worldviews and ethics through a bird's eye view of the universe

SKAO



16 平和と公正をすべての人に

DEI Initiative
Africa Development
Social Infrastructure
Future of Indigenous people

TICAD: African Development. Global South.
IAU "Astronomy as a tool of development"

Wi-Fi from radio Astronomy!

9 産業と技術革新の基盤をつくろう

Telecommunication
Frequencies that are familiar to people and have a wide range of applications

Information Tech.
Cloud, AI, Big Data

Technology to centralize and process the same amount of information as total domestic download traffic in one location

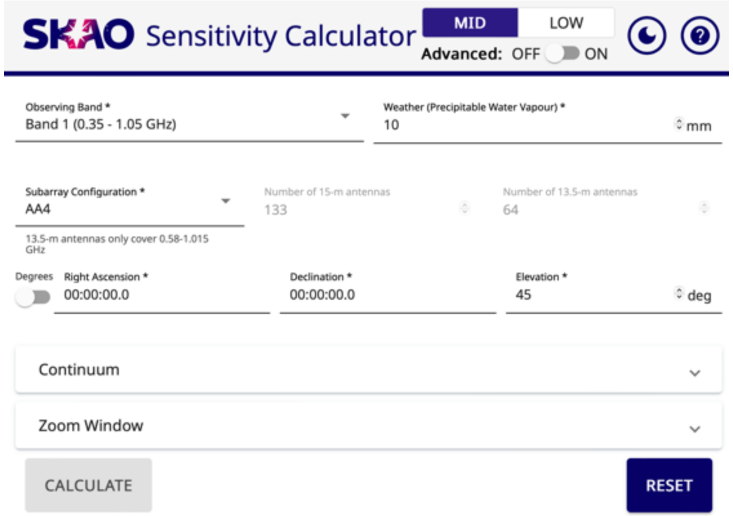
7 エネルギーをみんなにそしてクリーンに

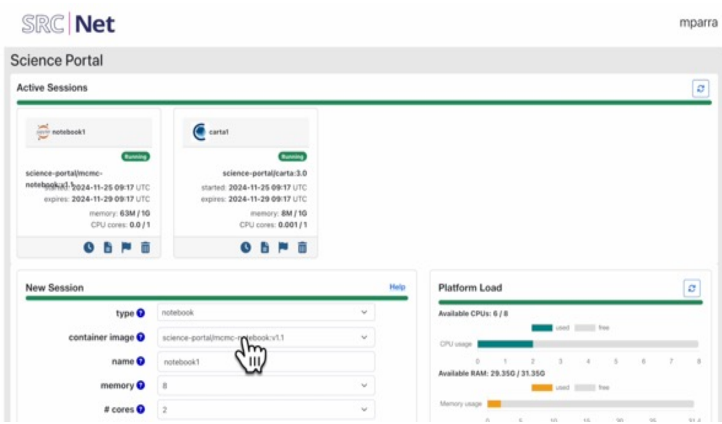
Green Tech.
Energy-saving technologies that enable telescopes to spread across continents and High durability technology

Optimal solution to deliver 3MW of electricity to 1,500 households in the Ogasawara Islands in an environmentally friendly manner

Common-Use System

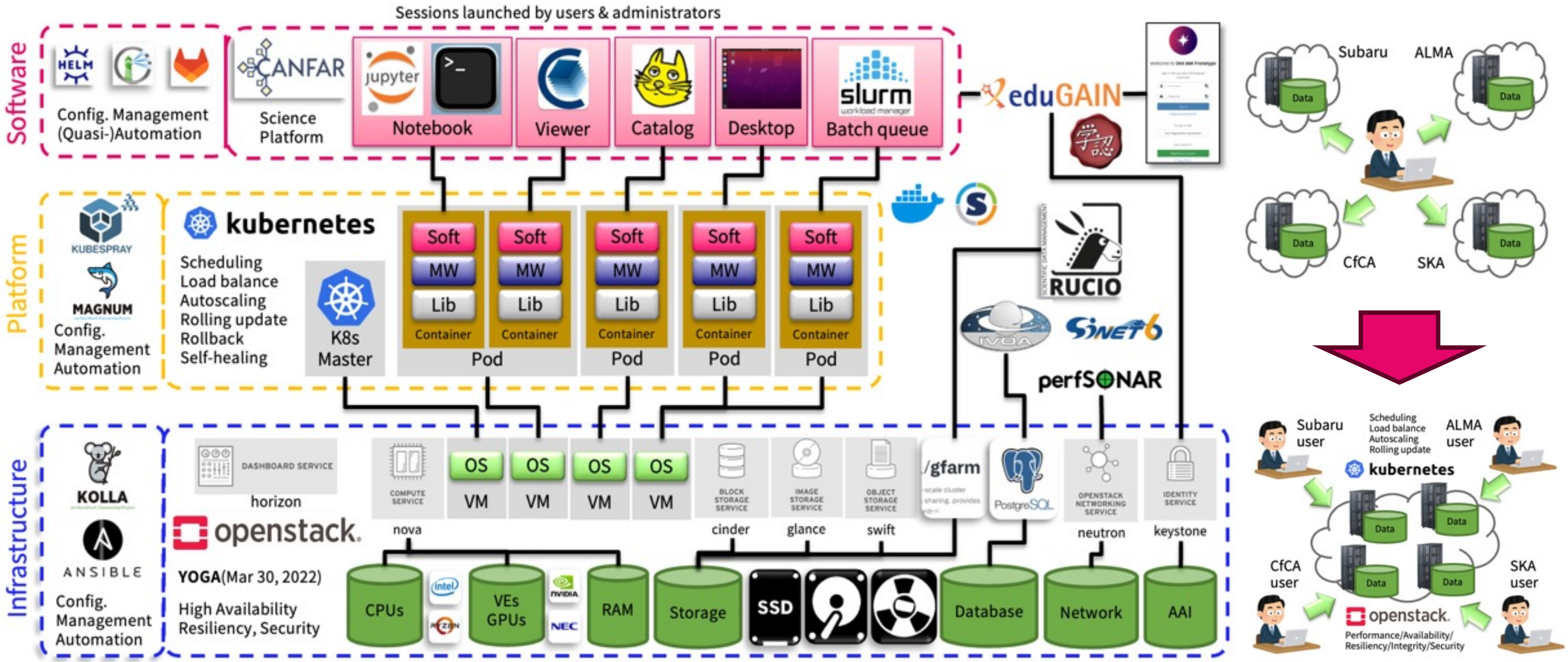
Plan an observation	☐ Sensitivity Calculator ☐ Sub-Array Mode
Write a proposal	☐ User Portal
Pier-review	☐ Policy discussion in the Council and by the community
Time allocation committee	
Allocation and Schedule	☐ Scheduler
Service Observation	☐ Telescope Manager
Processing and quality check	☐ SDP pipeline
Deliver the data through SRC	☐ SKA Regional Centre





12. Operations

SRCNet: Exa-scale science platform on Cloud



- Maybe possible to **consolidate NAOJ's computing and storage**.
- **SKA project can commit to improve NAOJ's digital infrastructure**.

Engineering Contribution Plan

AA*(2025-2027)
- ✓ AIV (4-5 FTE/year)

AA4 (2028-2030)
- ✓ Band5 Receiver
- ✓ Helium Compressor
- ✓ Band4/5 Digitizer
- ✓ AIV/CSV (4-7 FTE/year)

SODP (2031-)
- ✓ Band6
- ✓ VLBI Recorder

It's time. Show the flag!

- NAOJ has been providing 1.5 FTE since 2021 under the MoU. Univ. members will give further 1.0 FTE in total from FY2025.
- **Develop young researchers who know the telescope system** → it is benefit for science too

We do not make copies. We develop the systems that improve the performance.

- These developments and know-how of system engineering will also **benefit** Japanese telescopes such as **EAVN, JVN, Nobeyama** as well as future projects such as **ngVLA**

	Improvement	Mass production	Test facility
Band 5	better/wider bandwidth	#60 by industry	Yamaguchi or OMU
Compressor	smaller size, higher power	#60 by industry	TBD
Digitizer	direct sampling	#60 by industry	Kumamoto

AIV: key to make the gigantic system real

■ Key Technologies

- **AIV-JP in verification team**. Plan & do the test procedure to evaluate that the system satisfies the system requirements → Need skills of RF/IF/Digital + **new skill sets, e.g., SAFe, TANGO**
- **CSV**. Evaluate that the telescope satisfies the science requirements → Obtaining experiences useful for science too

■ Heritages, dev. status and plan

- SKAO has high expectations for JP's skills of AIV (Nobeyama, ALMA, and VERA)
- **AIV MoU** bet. NAOJ and SKAO since 2021. **LOW - Y. Kono, S. Yoshiura:** Test procedures of AA0.5, verification tests. **MID - K. Sunada:** RFI monitoring system, dish pointing, etc
- Mitaka: Test and evaluation of phase center of the log-periodic antenna, and test signal generator (e.g., Yoshiura, OML)

■ Acquisition surveillance

LOW AIV team

Visit to MID AIV team

Experiments at Mitaka HQ with young researchers

Band 5/6 Receivers

Key Technology

- Single pixel feed: very wideband antenna
- Polarizer: good cross-pol. specification

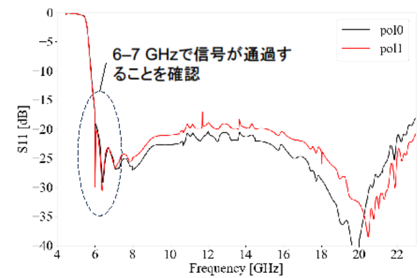
Heritages, dev. status and plan

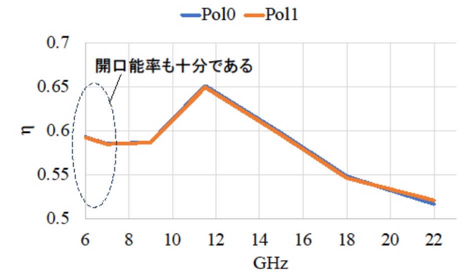
- **Toward 100% fractional bandwidth (Kimura/JAXA, Hasegawa/NICT, Yamazaki/NAOJ, Dakie/OMU)**
- Niinuma Kiban-A (6-18 GHz), Sekiya NINS R&D → 6-18 GHz ultra-wide receiver and 13 band rejection filter by HTSF
- Ujihara Kiban-A, Hada Kiban-A → Relevant activities.
- Ichikawa Kiban-A, Kawaguchi NAOJ-R&D → Radiometer (improve knowledge of VLBI data reduction)
- Continue researches about the possibility to expand the frequency up to 26 GHz

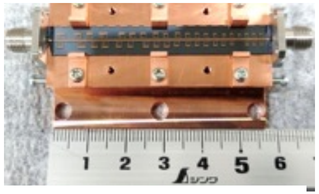
Acquisition surveillance

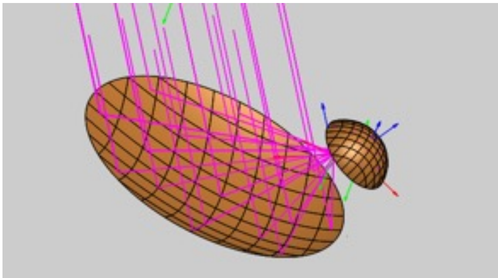
- LNA: buy from Low Noise Factory or **collaboration with Swiss team**

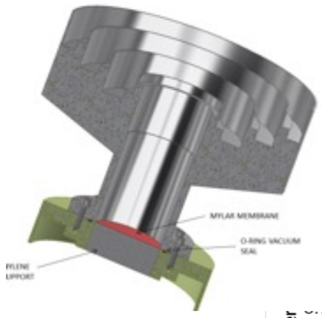
反射損失　比帯域100%　開口能率

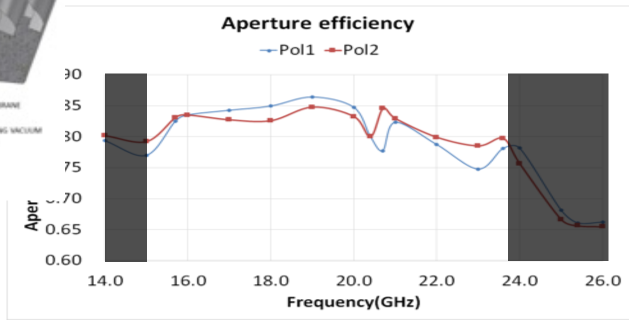




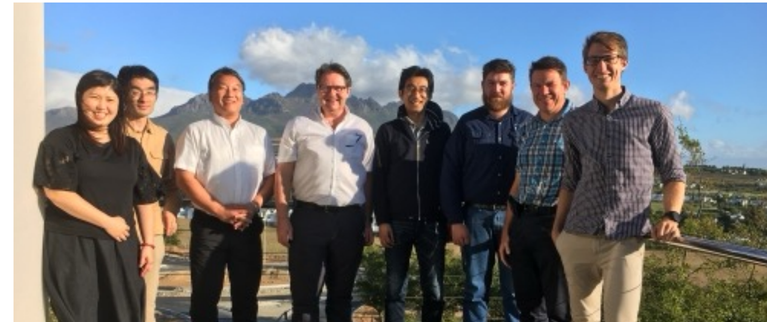








Helium Compressor



Key Technology

- Limited space and electricity
- Matching with cold-heads procured by other countries
- Outdoor use

Heritages, development status and plan

- **Sumitomo Heavy Industry (SHI)**
- **We visited South Africa with SHI team in 2020 and learn about the demand and requirements of SKAO**
- Sumitomo FA40 cooling test was made.

Acquisition surveillance

- Instead of making a new test facility, can we utilize the existing facilities at universities, the Industry, or NAOJ?

https://www.shi.co.jp/

Digitizer

Key Technology
- Band4/5 (2.8-15.4GHz) digitization; down convert vs. direct sample
- Electromagnetic interference (EMI)
- Thermal design, Outdoor use

Heritages, development status and plan
- OCTAD, KJCC, …
- Nakanishi NAOJ-R&D, Kiban-C→ Digital signal processing circuit (ROACH)
- Elecs Industry Co. Ltd.
  - ➢ We are keeping discussions about developing our "improved" digitizer for Band 4/5 including direct sampling
  - ➢ Good response from the industry

Acquisition surveillance: make or buy
- FPGA Direct RF-Series in sales

Direct RF sampler
（エレックス工業）

https://www.elecs.co.jp/en/

New Direct-to-Digital COTS Boards Are Powered by 64 Gsps Agilex™ 9 SoC FPGA Direct RF-Series

Posted on May 6, 2024 by Barnaby Wickham

Annapolis Micro Systems, a leading COTS board and systems supplier, is now offering two powerful direct-to-digital COTS products based on Altera's Agilex™ 9 SoC FPGA Direct RF-Series.

The WILDSTAR™ SAF1 Small Form Factor Module (WSSAF1) integrates the Agilex™ 9 AGRW014 FPGA in a palm-size unit, for edge applications close to the sensor and in other tight envelope man-portable environments. It delivers high-performance processing and four channels each of 64 Gsps A/D and D/A converting at 10-bit resolution.

The WILDSTAR™ 3AE1 3U OpenVPX FPGA Processor (WB3AE1) integrates the Agilex™ 9 AGRW027 FPGA in a standard 3U VPX SOSA™-aligned Plug-In Card (PIC) form factor. The AGRW027 FPGA delivers similar performance as the AGRW014 FPGA but with double the channels: 8x transmit and 8x receive.

"By supporting much higher conversion and processing rates, these boards make it possible for customers to acquire and process adversary emissions from a wider portion of the electromagnetic spectrum, with a lower SWaP RF front end," said Noah Donaldson, Chief Technical Officer, Annapolis Micro Systems. "Now larger swaths of the RF spectrum can be efficiently digitized, processed, and recorded at the edge."

"Altera's Agilex™ 9 SoC FPGAs have

VLBI Recorder

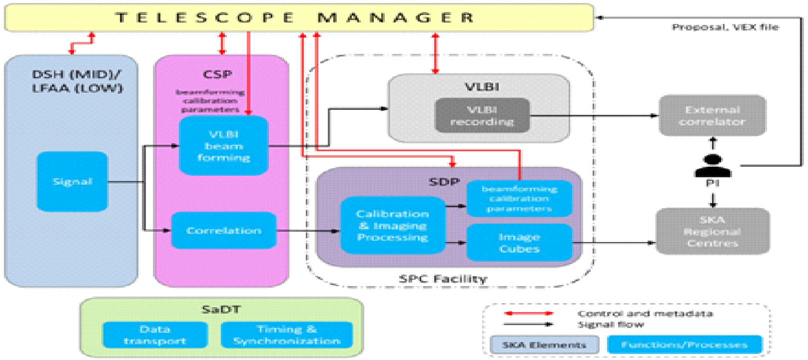
Key Technology

- SKA-VLBI is recognized as a major SODP candidate. Goal: astrometric accuracy of **1 micro-arcsec**. Requirements: minimize systematic errors → develop the **multi-beam** VLBI system and its calibration method
- Development and implementation of high-speed VLBI recording for more than 4 beams → data recording (800Gbps) is more than 100 times

Heritages, development status and plan

- SKAJP VLBI WG is discussing development plans (from 2027). SKAJ already started a test of 200 Gbps recording
- Imai JSPS Zuno-Junkan, bilateral → improvement of low-frequency astrometry (multi-view)
- Kobayashi NINS-OML, Yoshiura NINS-OML → Relevant activities.
- **200 Gbps recording tests underway (by Oyama-san NAOJ)**
- Toward SKA-LOW VLBI, **Iidata/Tohoku U.** contributes to **collaborations with GMRT and MWA** to test international baselines at low frequencies

Acquisition surveillance



SKA1-MID						
#sub-array	#VLBI beam	Bandwidth (per pol, MHz)	Digiti-zation	Sampling	Data rate (Gbps)	Buffer size (1h, TB)
1	4	256	2	Nyquist	8	3.5
1	4	512	2	Nyquist	16	7
2	4	512	2	Nyquist	32	14
1	4	2500	2	Nyquist	78.12	34
1	16	512	2	Nyquist	64	28
1	52	200	2	Nyquist	81.25	35.7
10	52	200	2	Nyquist	812.5	357

SKA1-LOW						
#sub-array	#VLBI beam	Bandwidth (per pol, MHz)	Digiti-zation	Sampling	Data rate (Gbps)	Buffer size (1h, TB)
1	4	256	2	Nyquist	8	3.5
1	16	256	2	Nyquist	32	14
1	16	256	8	Nyquist	128	56.3

Other Japanese Technologies

2016: First report
Overview of SKA system and developments

2021: Second report
Japanese strategy of SKA engineering contribution

- AIC/CSV
- Faraday Tomography
- EoR pipeline
- UHF receivers
- Band 6/7
- VLBI
- On-the-fly Interferometer

→ **7 Engineering Working Groups in SKA-JP as of 2024**

1. Summary of the proposal

SKA1 is only-one world-largest, general-purpose radio telescope covering the long-wavelength (<1GHz) in the coming decades with revolutionary survey performance

Sciences goals and Objectives

★Deciphering the cosmic reionization with cosmology and astrophysics

★ In-depth/Tomographic study of the magnetic field governing the cosmic hierarchy and activities

★Pioneering long-wavelength gravitational-wave astronomy with pulsar observations

Threshold science

★Detection of HI at EoR (z~8-15), strongest constraint on HI at CD (z>15)

★Denser (semi) all-sky RM grids

★Better measurements of nHz GW

Science investigations, instrumentation and data

SKA1 under construction. Early operation in 2026. Obs. readiness review in 2029.

★ x10 better sensitivity & resolution

★ x100 better survey capability

★ Multi-mode backend system

~9 approved proposals & 12 papers /year

SKA2 (x10 SKA1) in 2030's or later.

GHQ, UK
IGO, Treaty
SKAO Council
13 members

LOW, AU
Max 73.4 km
#512 (131k)
50-350 MHz

MID, ZA
Max 159.6 km
#197 (13.5m~15m)
0.35-15GHz

Cost estimation

Time proportional to construction.
Share = 2% = 10B¥ (Con. 2025-2030),
0.7B¥/yr (SODP. 2031-2034)
Like the shares of FR, NL, ESP, DE.

Project Organization

Cooperation with Universities and NAOJ

Beyond Astronomy

BIG DATA

1 EB/yr data archive in the distributed SKA Regional Centre Network (SRCNet).

SDGs

AU & ZA development, STEM, Info. tech., Green tech., Int'l partnership.

年次計画

← 建設前期フェイズ → (科研費・運交金): 2025 (R7), 2026 (R8), 2027 (R9)

← 建設後期フェイズ → (概算要求・科研費・運交金): 2028 (R10), 2029 (R11), 2030 (R12)

← 運用およびSODPフェイズ → (概算要求・科研費・運交金): 2031 (R13), 2032 (R14), 2033 (R15), 2034 (R16)

(科学) 科学奨励事業	*国立天文台*	「宇宙再電離」「宇宙磁場」「パルサー重力波」を重点的課題に据えて、研究調査や研究会開催の支援を通じて研究力を強化する。	国際会議の日本誘致、国際会議出張の旅費補助、他計画とのシナジー検討
(科学) 科学育成事業	*国立天文台*	国際研究拠点に特任助教を、国内研究機関に特任研究員を配置し、次世代のサイエンスリーダーの育成を図る。	次世代のサイエンスリーダーを持続的に育成するために、若手のキャリアアップに応える2種類のポストを用意
(SRC) SRC開発事業	*国立天文台＋名大*	SRCNetの国際共同開発に参加し、国産技術も取り入れつつSRCNetの継続的な改善を図る。	SRCNet v0.1, 0.2, 0.3, 1.0b, 1.0実装 最先端のIT技術や国産技術の調査・研究・導入
(SRC) ユーザー支援事業	*国立天文台＋名大*	JPSRCを安定的に運用する。ユーザーにデータとデータ解析のリソースを提供する。観測提案からデータ解析までをシームレスにサポート。	JPSRCの試験運用 JPSRCの運用 ヘルプデスク
(技術) AIV/CSV事業	*国立天文台＋国内大学*	国内研究者が長年の経験で培ってきた望遠鏡の性能出し・科学検証力を日本の核心的技術に位置づけ、SKAの実現に向けて国際貢献を果たす。	AA0.5, AA1, AA2, AA*, AA4のAIV活動 AA0.5, AA1, AA2, AA*, AA4のCSV活動
(技術) SDPソフト事業	*国立天文台＋国内大学*	科学検証とも密接に関わる科学データ処理のソフトウェアの改善・改修作業を、AIV/CSV担当者と連携して実施する。	データチャレンジへの参加 ソフト開発検証。CSV連携
(技術) Band５事業	*国立天文台＋山大＋大阪公大*	Band5cないしその発展形を国内大学がリードして開発し、国内企業で量産、国内大学に設備を整備しながら試験し出荷する。	設計試験、量産の準備 製造・検査
(技術) 冷凍機事業	*国立天文台＋鹿大*	コンプレッサを国立天文台と国内企業とで共同開発し、国内企業で量産、国内大学に設備を整備しながら試験し出荷する。	設計試験、量産の準備 製造・検査
(技術) デジタイザ事業	*国立天文台＋熊大*	ダイレクトサンプラを国立天文台と国内企業とで共同開発し、国内企業で量産、国内大学に設備を整備しながら試験し出荷する。	設計試験、量産の準備 製造・検査
(技術) Band６事業	*国立天文台＋山大＋大阪公大*	日本が得意とする高周波域の受信機を国際共同開発し、国内企業で量産、国内大学に設備を整備しながら試験し出荷する。	概念検討 設計試験、量産の準備 製造・検査
(技術) VLBI事業	*国立天文台＋大学VLBI連携*	VLBIデータの次世代高速記録系を開発し提供する。LOW-VLBIのAIV/CSVを基軸にアジア太平洋地域でのVLBI網構築にも協力。	設計試験 国内搭載・試験 製造・検査