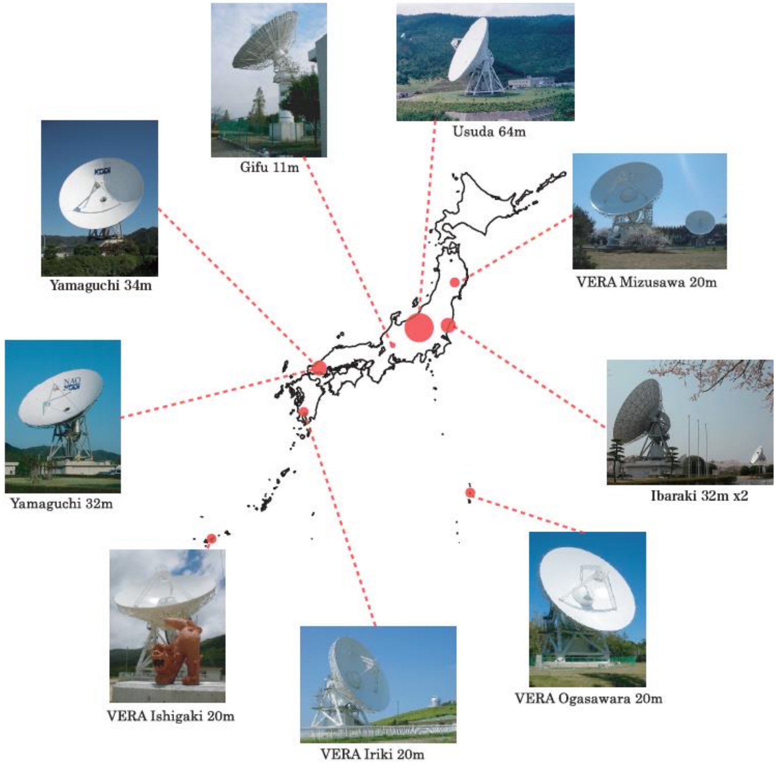
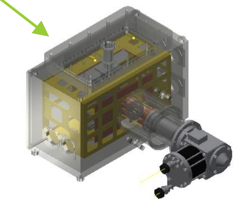
大学VLBI連携　Japanese VLBI Network

Exploring the Time-Varying Universe: From Nanoseconds to Gigaseconds

K. FUJISAWA (YAMAGUCHI UNIVERSITY)



- Collaboration Network of 6 Universities and NAOJ since 2005
  - NAOJ (VERA), Ibaraki, Tsukuba, Gifu, OMU, Yamaguchi, Kagoshima University
- Array
  - 9 telescopes (11m ~ 64m)
  - Baseline 50 - 2300 km
  - Frequency 6/8/22 GHz
  - Sensitivity 3 mJy (6/8 GHz, Ibaraki-Yamaguchi)
  - Ibaraki-Yamaguchi single baseline VLBI
  - Yamaguchi Interferometer (YI)
- Regular operation
  - 200 – 300 hr/yr, 30 observations/yr
    - EAVN observation: Ibaraki & Yamaguchi
    - Single-dish: >4000 hours / year
    - Receiver development
- Education: > 200 students have graduated
- Various contribution to astronomy



Receiver

Activities of the last 5 years of the JVN

VLBI Observation Time (hour)

	2019	2020	2021	2022	2023	AVG
C/X band	398	238	225	167	200	246
K band				131	62	97
Sum	398	238	225	298	262	284

- Including EAVN Observation (C and K band)
- K band observation is for EAVN at Takahagi
- Single-dish and Yamaguchi Interferometer observations are not included

Active VLBI Network

Activities of the last 5 years of the JVN

Number of JVN papers

	2019	2020	2021	2022	2023	sum
JVN observation paper	3	3	8	8	11	33
JVN related paper	9	11	10	18	20	68
sum	12	14	18	26	31	99

- Definition
    - JVN paper: JVN telescopes are used and JVN member leads the study
    - JVN related papers: JVN member is in the author
- JVN paper includes single-dish (non VLBI) observation results
    - Recent increase in the number of the JVN paper is due to the methanol maser monitoring program in Ibaraki

Active VLBI Network

Activities of the last 5 years of the JVN

Number of students involved in JVN

	Undergraduate					Master					PhD.				
	2019	2020	2021	2022	2023	2019	2020	2021	2022	2023	2019	2020	2021	2022	2023
Ibaraki	6	5	1	3	2	1	4	3	0	1	0	0	0	0	0
Gifu	4	4	4	2	1	1	2	2	1	3	0	0	0	0	0
OMU	0	2	3	3	1	0	0	0	3	4	1	0	0	1	1
Yamaguchi	10	8	8	5	10	4	4	5	3	5	0	0	0	0	0
Kagoshima	2	6	8	2	2	5	2	2	0	3	2	0	0	0	0
Total	102					58					5				

One of the goals of the JVN is to stimulate radio astronomy research in universities.

JVN contributes to the activities of astronomy

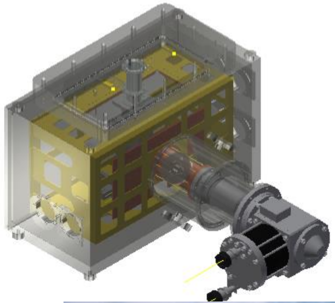
JVN University

Ibaraki University

- Operation of Hitachi 32m and Takahagi 32m
- Methanol maser study (single-dish and VLBI)

Yamaguchi University

- Operation of Yamaguchi 32m and 34m
- Ibaraki-Yamaguchi interferometer, collaboration with Ibaraki
- Star formation, AGN, Transient



Osaka Metropolitan University (OMU)

- Development of receivers of the JVN, education of students

Gifu University

- Operation of Gifu 11m
- Supernova, Evolved star and H_2O maser, collaboration with Kagoshima

Kagoshima University

- Operation of VERA Iriki 20m
- Evolved star, astrometry, collaboration with Gifu

1. Summary of the proposal

Science goals and objectives

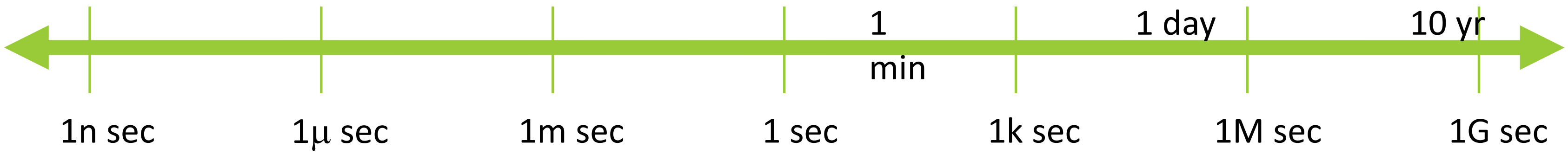
- "**Exploring the Time-Varying Universe: From Nanoseconds to Gigaseconds**"
- To observe time variation phenomena ranging from 1 nanosecond to 1 Gsecond (30 years), and to investigate the dynamics of objects using time variations and the high spatial resolution of VLBI as clues.

Threshold science

- Radiation mechanisms of pulsars and FRBs, jet formation mechanisms of X-ray binaries and active galactic nuclei, gas accretion mechanisms onto massive stars, acceleration mechanisms of cosmic rays, investigation of the internal and external physical states of evolved stars

Exploring the Time-Varying Universe: From Nanoseconds to Gigaseconds

Timescale



Nano-shot

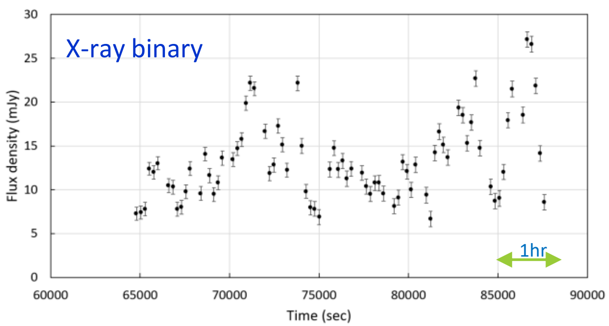
Giant-pulse / FRB

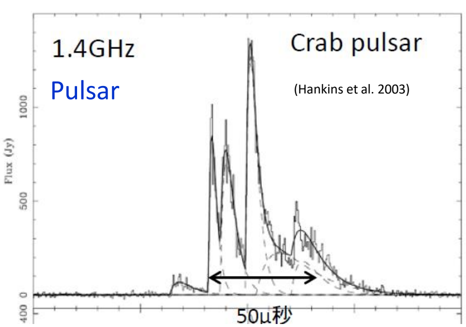
X-ray binary / flare star

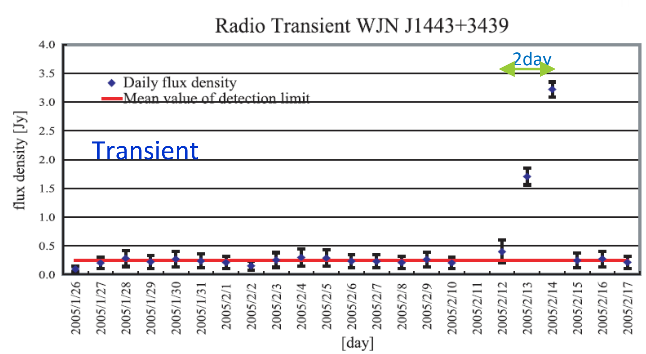
Very-high-energy gamma-ray AGN
Supernova / transient
High-mass protostar

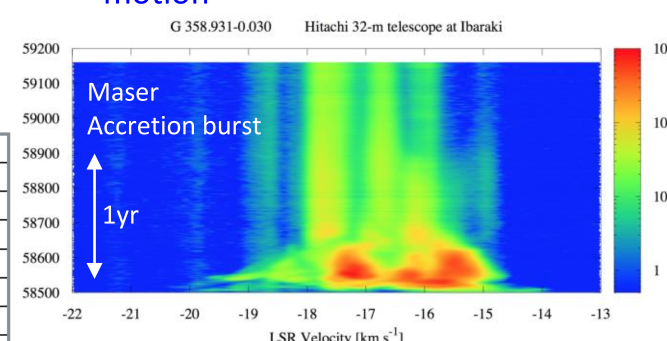
Methanol maser variability: accretion burst / long periodicity

OH/IR stars P-L relation
SNR distance
annual parallax / proper motion









Characteristics of JVN as a research organization

Time domain astronomy will continue to develop greatly in the future. For example, interesting phenomena are being discovered one after another, such as research into the short-term radiation mechanisms of pulsars and long-term flux variability of star-forming regions.

In this context, we use our own telescopes, innovate uniquely, and observe over long periods of time. Students are also deeply involved in this process. These are the features of JVN. We will introduce specific research topics later, but we believe that this research system itself is unique and valuable.

We plan to continue this unique activity for the next 10 years.

時間領域天文学は今後も大きく発展する。例えば長短時間のパルサーの放射機構の研究、長期間にわたる星形成領域の変動現象など、面白い現象が次々と見つかっている。

そのような背景において、我々は自分たちの望遠鏡を使い、独自の工夫をして、長時間をかけて観測する。まあそこに学生が深く関与する。これらがJVNの特長である。具体的な研究課題は後で紹介するが、むしろそのような研究体制自体が独特のものであり、価値がある、と我々は考えている。

この活動を維持することを今後１０年の目標としている。

2. Science goals

What can we learn from changes in an object's intensity, spectrum, structure, and other phenomena that change over time?

3. Scientific objectives

1. Gas accretion mechanisms onto massive stars
2. Radiation mechanisms of pulsars and FRBs
3. Acceleration mechanisms of cosmic rays
4. Investigation of the internal and external physical states of evolved stars
5. Development study of observing system

Ibaraki University

High-cadence monitoring observations of methanol masers

Objectives

1. study mechanisms of periodic flux variation,
2. study accretion burst by detecting rapid flux change (~ flare, burst, ...),
3. estimate magnetic field by Zeeman effect by dual polarization obs.

2013-2022

- 6.668 GHz

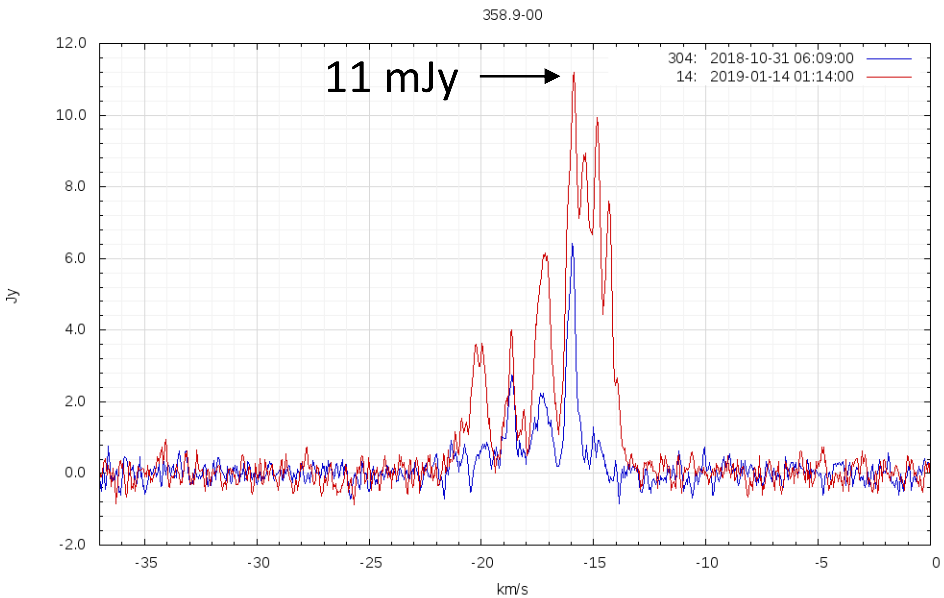
2023-

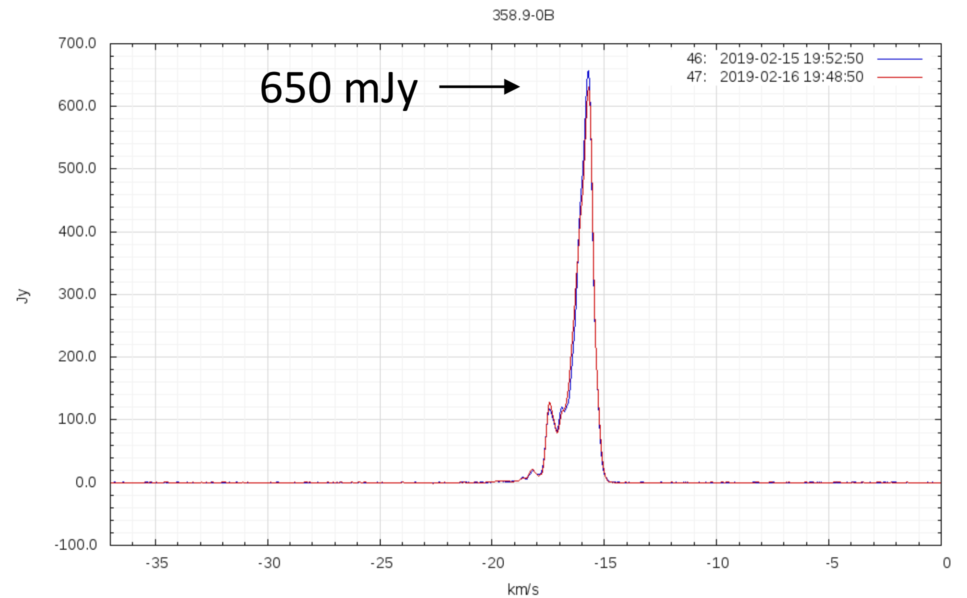
- 6.668 (LHCP only) & 12.178 (LHCP only) @ Hitachi
- 19.967 (LHCP only) & 23.121 GHz (RHCP only) @ Takahagi

to be upgraded to

- 6.668, 12.178, 19.967, 23.121 at LHCP and RHCP simultaneously

Accretion burst of G358.93-00.03





2018-10-31
2019-01-14

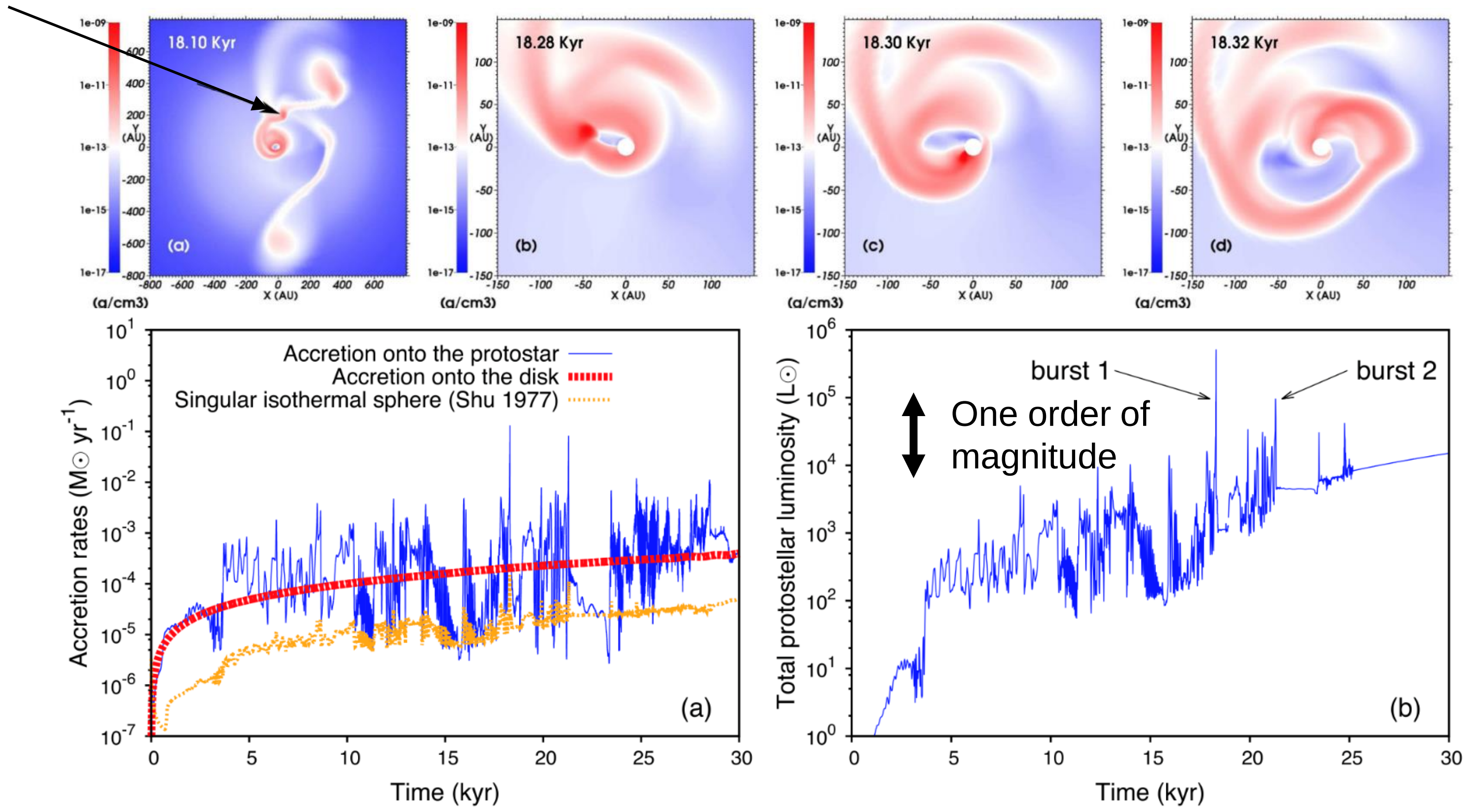
2019-02-15

Ibaraki group has been conducting a large-scale monitoring program of 6.7 GHz methanol maser with Hitach 32-m radio telescope (iMet http://vlbi.sci.ibaraki.ac.jp/iMet/).
In January to February 2019, they found that the flux density of 6.7 GHz methanol maser of G358.93-00.03 increased 60 times in 30 days, and the spectrum changed drastically. Ibaraki group reported the discovery on ATel No. 12446. It was revealed by the follow-up observations in the world that the burst was caused by accretion burst.

Accretion burst in high-mass protostars

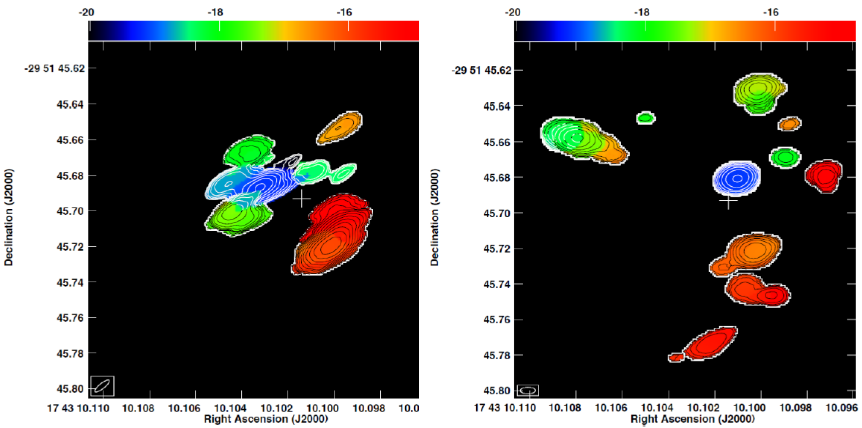
(e.g., Meyer+ 17, 18)

blobs accretes onto the central star → L becomes >10 times more luminous



In the formation of high-mass stars, disk gas accrete onto the central star NOT at a constant rate, but rather large amounts of gas accrete intermittently over short periods of time (upper panel). This is the accretion burst. The luminosity of the central star temporarily increases due to the accretion burst (lower panel). This heats the surrounding dust and gas, resulting in an enhancement of the maser.

Discovery of Heat Wave



https://www.nao.ac.jp/news/science/2023/20230228-dos.html

Follow-up VLBI observation of G358 accretion burst

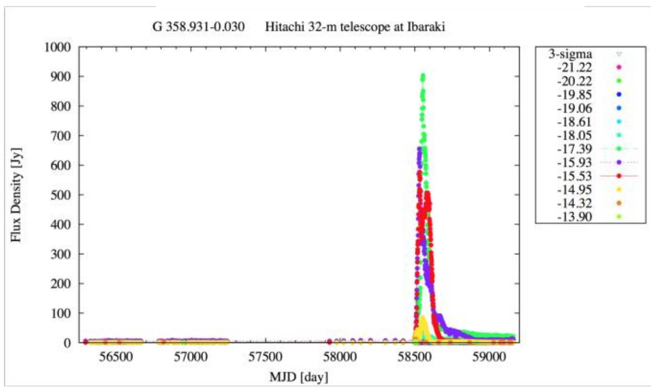
- Burns et al. 2020, Nature Astronomy, 4, 506-510
- Burns et al. 2023, Nature Astronomy, 7, 557-568

Heat Wave: A new method for studying star formation

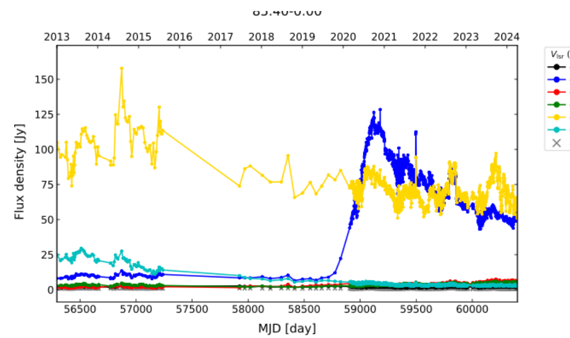
- The maser emission region spreads out over time. The strong radiation generated by the accretion burst propagates while heating the surrounding gas.
- By overlapping the maser distributions obtained from multiple observations, the gas distribution around the protostar was depicted. The gas had a spiral structure with four arms.

Rapid flux change detected by Hitachi 32-m in 2019-2024

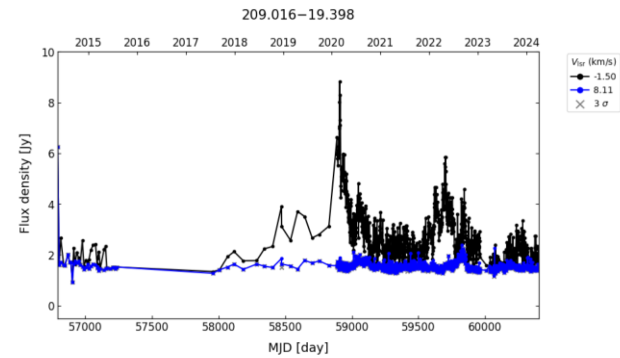
Detected on 2019/Jan./14



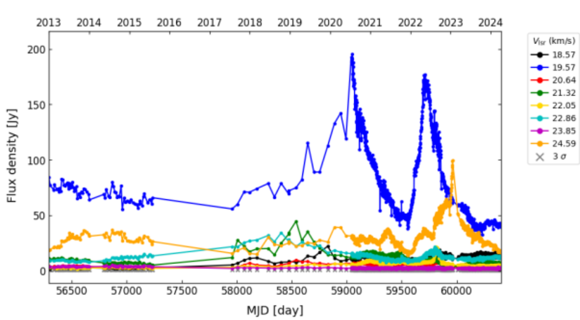
detected on 2020/Feb./10



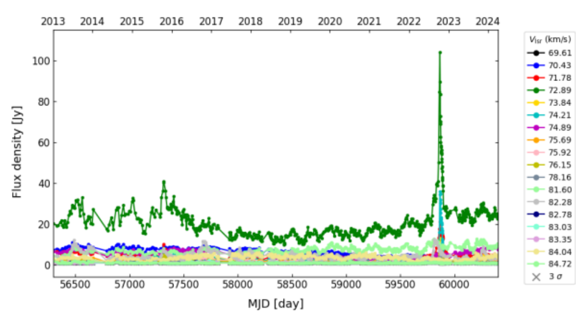
Detected on 2020/Feb./28



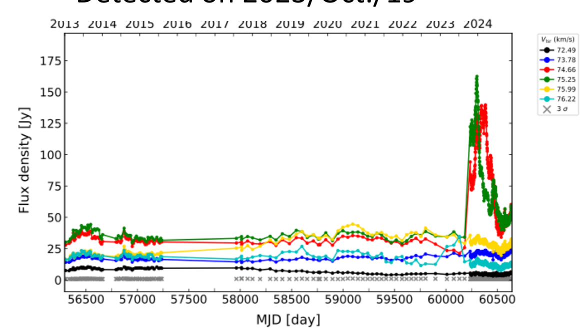
Detected on 2020/Jul./13



Detected on 2022/Oct./01



Detected on 2023/Oct./19



Time variations of four 6.7 GHz methanol maser sources which show rapid flux change in 2019-2024 detected by Hitachi 32-m.

VLBI follow-up of GRB221009A

Long GRB on 2022-10-09 (GCN#32632, #32636, #32648, #32677)

- Nearby (z~0.15), Large energy (~10^{55} erg), High-energy photn (17 TeV)
- 'Hystorical' GRB

VLBI follow-up with JVN (Ibaraki-Yamaguchi)

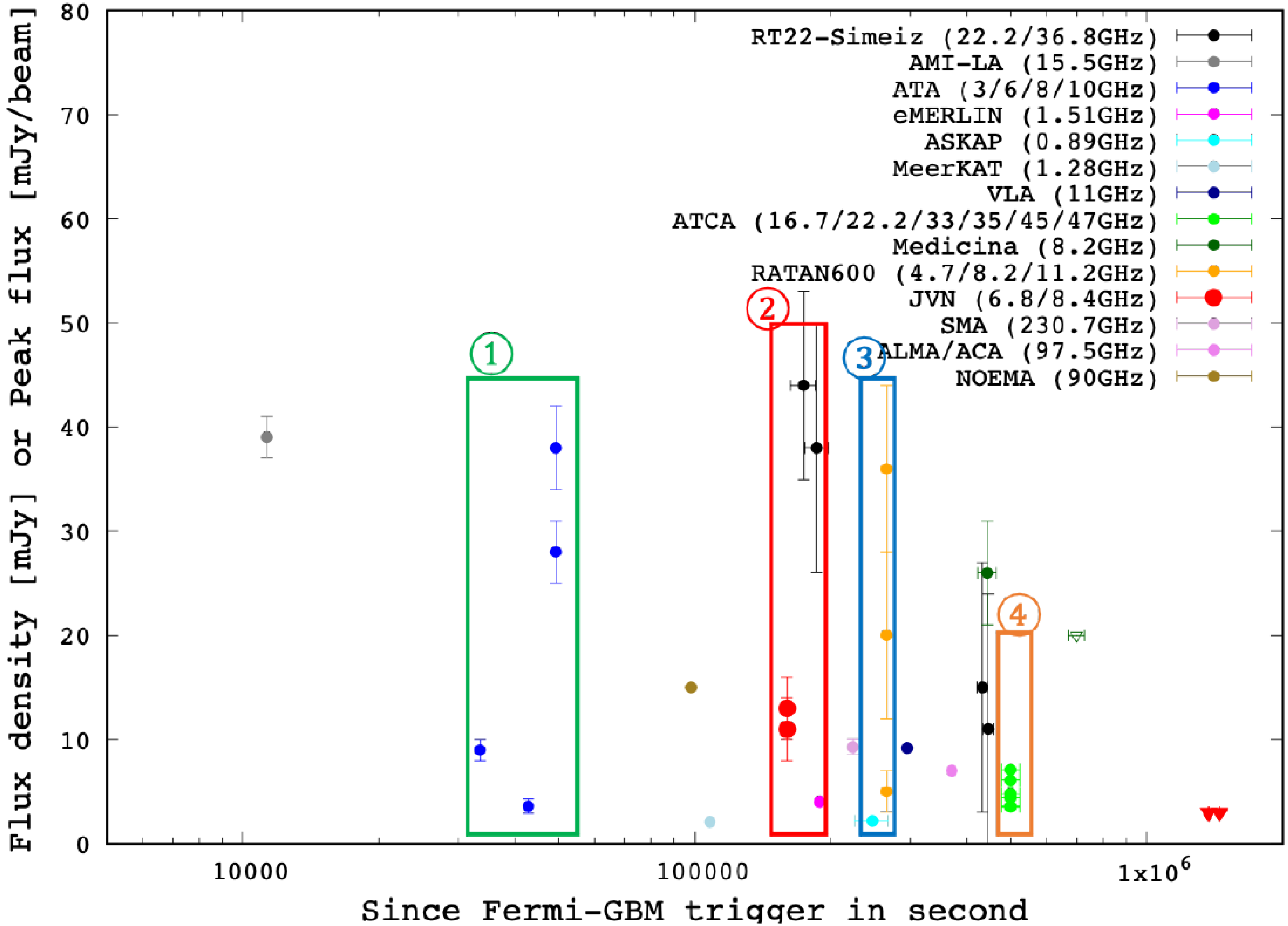
- 1.85 day after the GRB alart … flexible network
  - The earlest follow-up by VLBI
- 6.8 and 8.4 GHz simultaneously

Detection (Niinuma et al. 2022, GCN #32949)

	6.8 GHz	8.4 GHz
Flux density	13±3 mJy	11±3 mJy
Brightness temperature	> 5.3 x 10^6 K	> 3.0 x 10^6 K

On 15 and 16 day follow-up → non-detection < 3 mJy

Spectral evolution of GRB221009A



New JVN Science

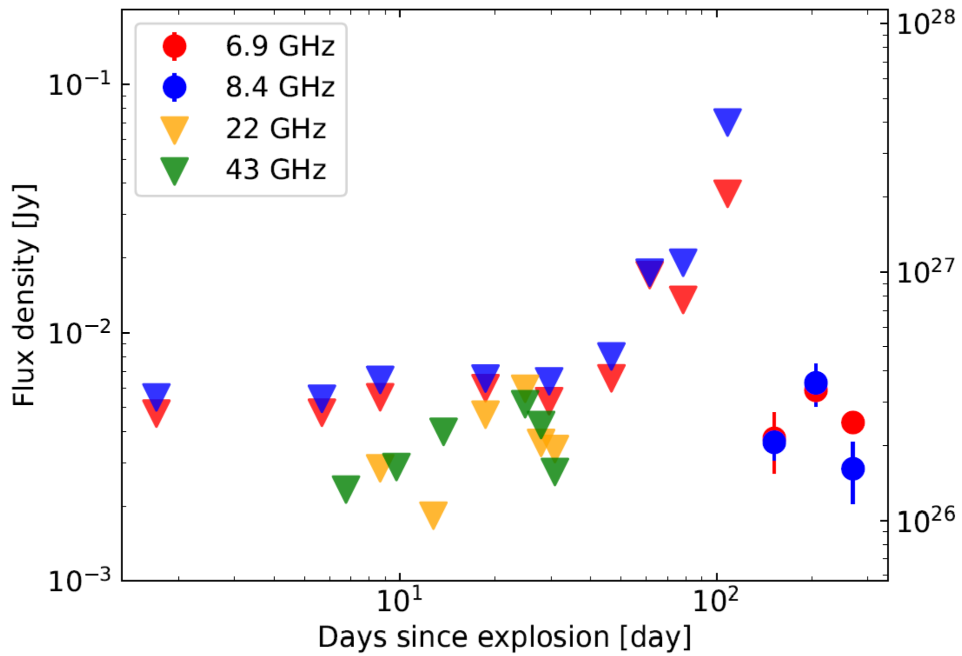
An example of Time Domain VLBI Astronomy: Iwata et al. (2024)

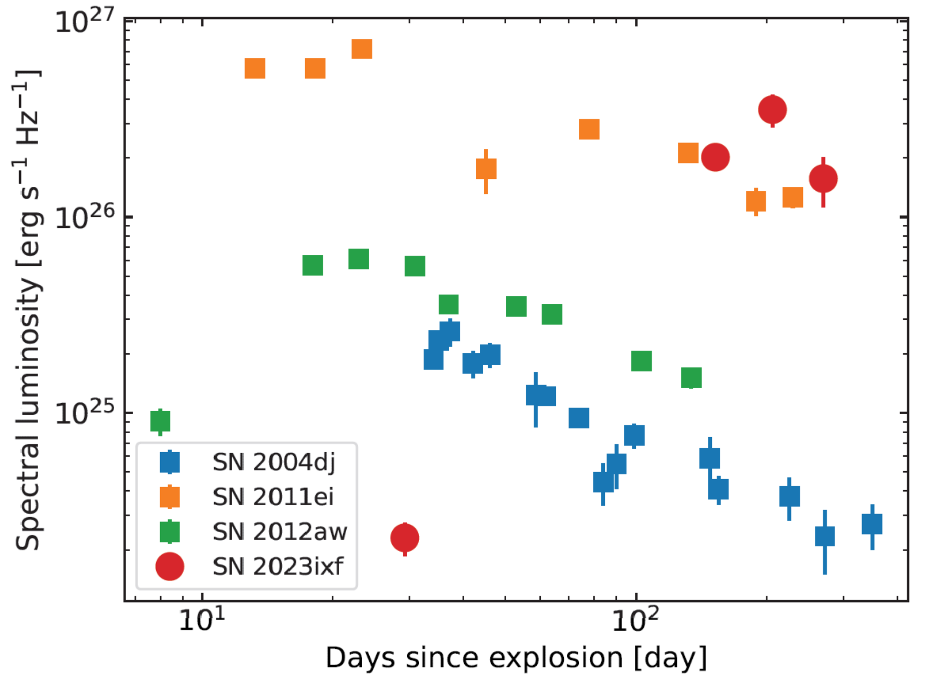
Radio emission from supernova

- The gas surrounding the star formed by the mass-loss just before the supernova explosion collides with the supernova blast wave, emitting radio waves
- By observing the radio, the mass-loss process just before the explosion could be investigated.

JVN Observation of SN 2023ixf

- 1.7 – 270 days after supernova explosion
- "In this case, the mass-loss rate of the progenitor is estimated to have increased from ~10^{-6} – $10^{-5} M_\odot\ yr^{-1}$ to ~$10^{-4} M_\odot\ yr^{-1}$ between 28 and 6 years before the explosion."





Kagoshima & Gifu University

Revealing detailed evolution in AGB phase

Transition from OH/IR to non-variable OH/IR stars

Objective: ・Revealing detailed picture of evolution in late-AGB phase（L, M, dM/dt, etc.）

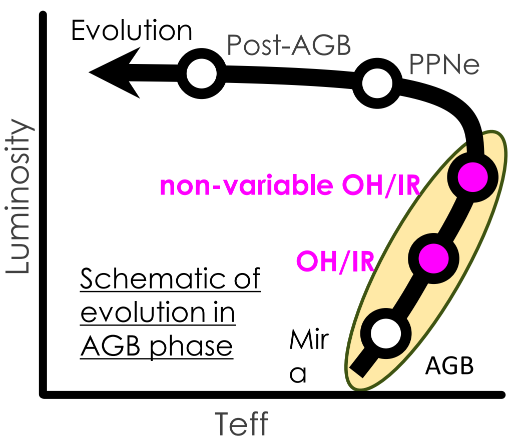
Target src: ・100 AGB stars on a transition phase from OH/IR to non-variable OH/IR stars

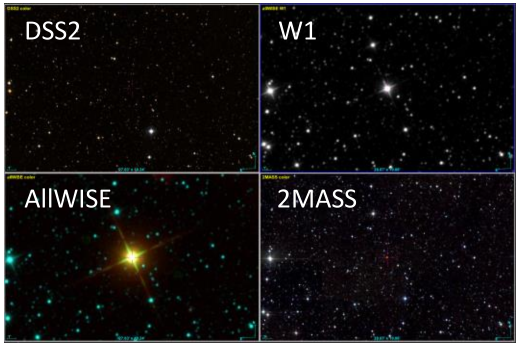
Methodology: ・Astrometric VLBI observations to derive parallactic distances

・H_2O and OH maser VLBI mapping to clarify circumstellar morphology and kinematics

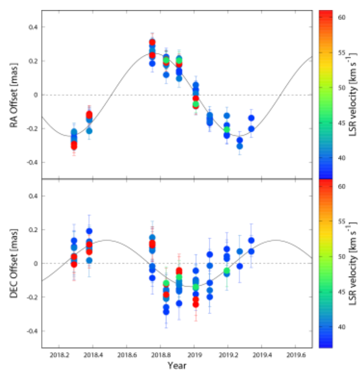
・SED modeling to derive bolometric luminosities using radiative transfer calculation

・Collaboration with TNRT-40m（OH maser observation）, TAO（Infrared observation）

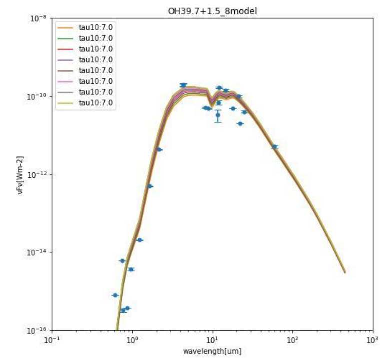




Multi color image of OH/IR star



VLBI Parallax

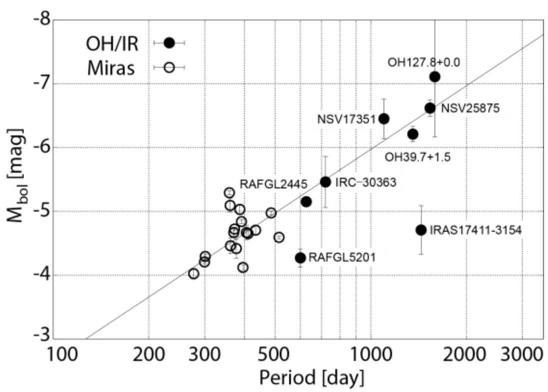


SED modeling → Luminosity

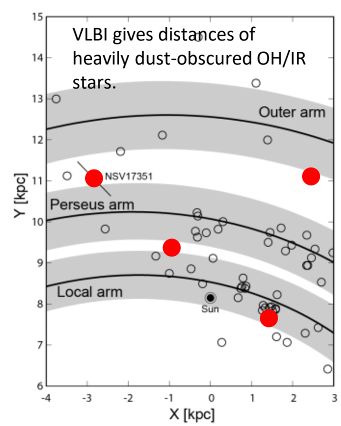
Kagoshima & Gifu University

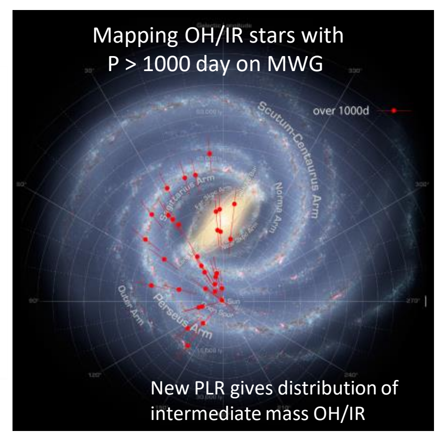
New period-M_{bol} relation and application of AGB star studies to Galactic dynamics

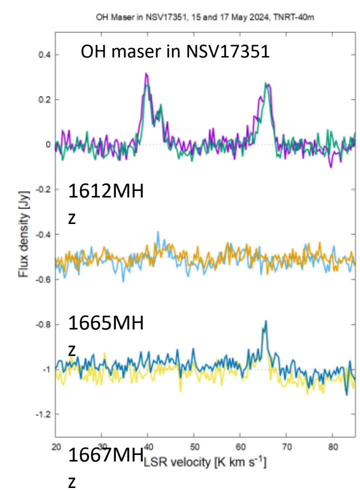
- Constructing new period-M_{bol} relation extended to P >1000 day through VLBI observations of OH/IR stars
- Distance estimation of heavily dust-obscured AGB stars using the period-M_{bol} relation
- Mapping intermediate-mass OH/IR stars in MWG for validating the model of spiral arm structure and evolution
- Taking full advantage of VLBI astrometry for dust-obscured AGB stars using OH/H_2O/SiO masers



New period-M_{bol} relation extended to P>1000days.







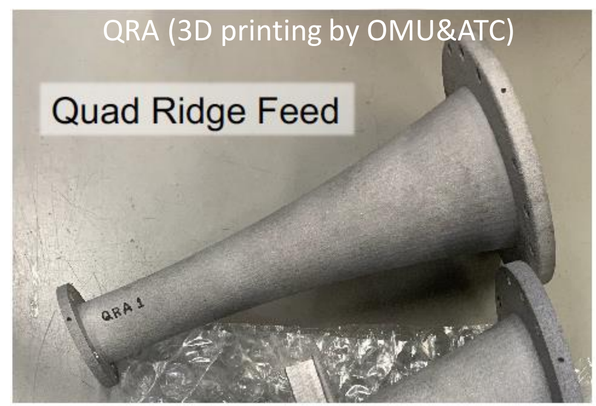
New Development

- Development 1: mm-wavelengths
  - HINOTORI: triple-band receiving system@NRO
- Development 2: cm-wavelengths & wide-band

cm-λ Wide-band receiver

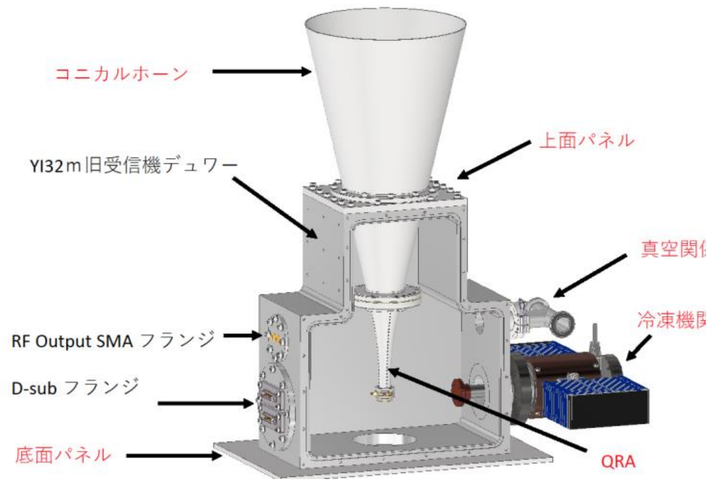
- Led by
  - Yamaguchi U. Osaka Metropolitan U.. Yamanashi U. and NAOJ
- Difficulties:
  - Radio Frequency Interference: RFI
  - Bandwidth ratio of 1:3 or more
- Key:
  - Quadruple-ridged horn antenna (QRA)
  - High Temperature Superconducting Filter (HTSF)


QRA (machining by KMCO)

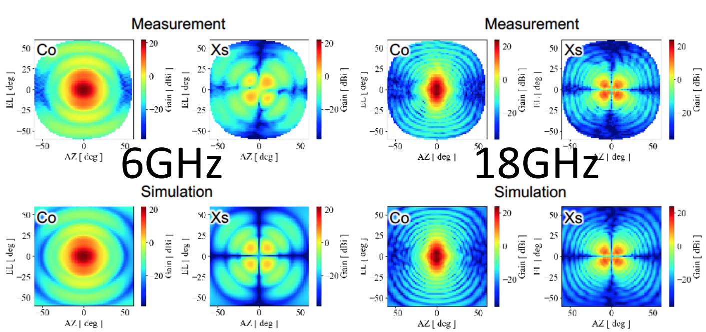


QRA (3D printing by OMU&ATC)

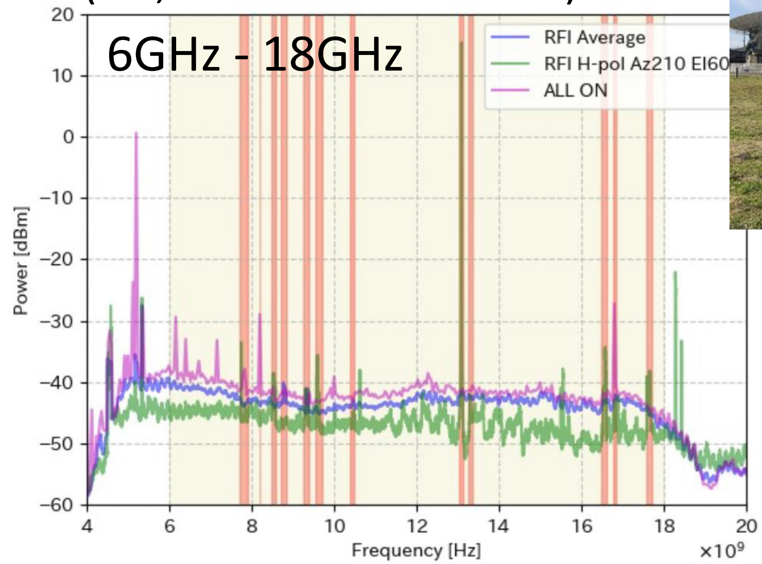
Development of broadband cm-wavelengths receiver



Result① Far-field beam patternでSimulationと比較

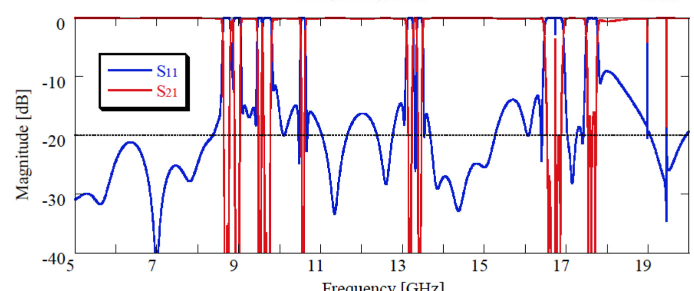


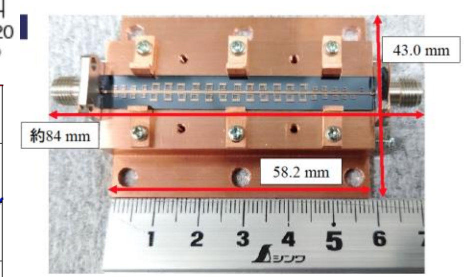
Percentage Bandwidth 100%
(i.e., bandwidth ratio 1:3)

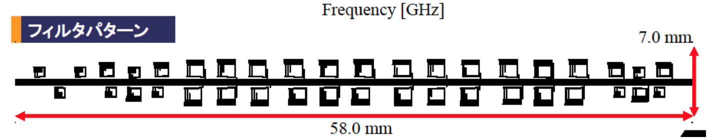


RFI survey @ VERA Mizusawa

Several RFI/EMI



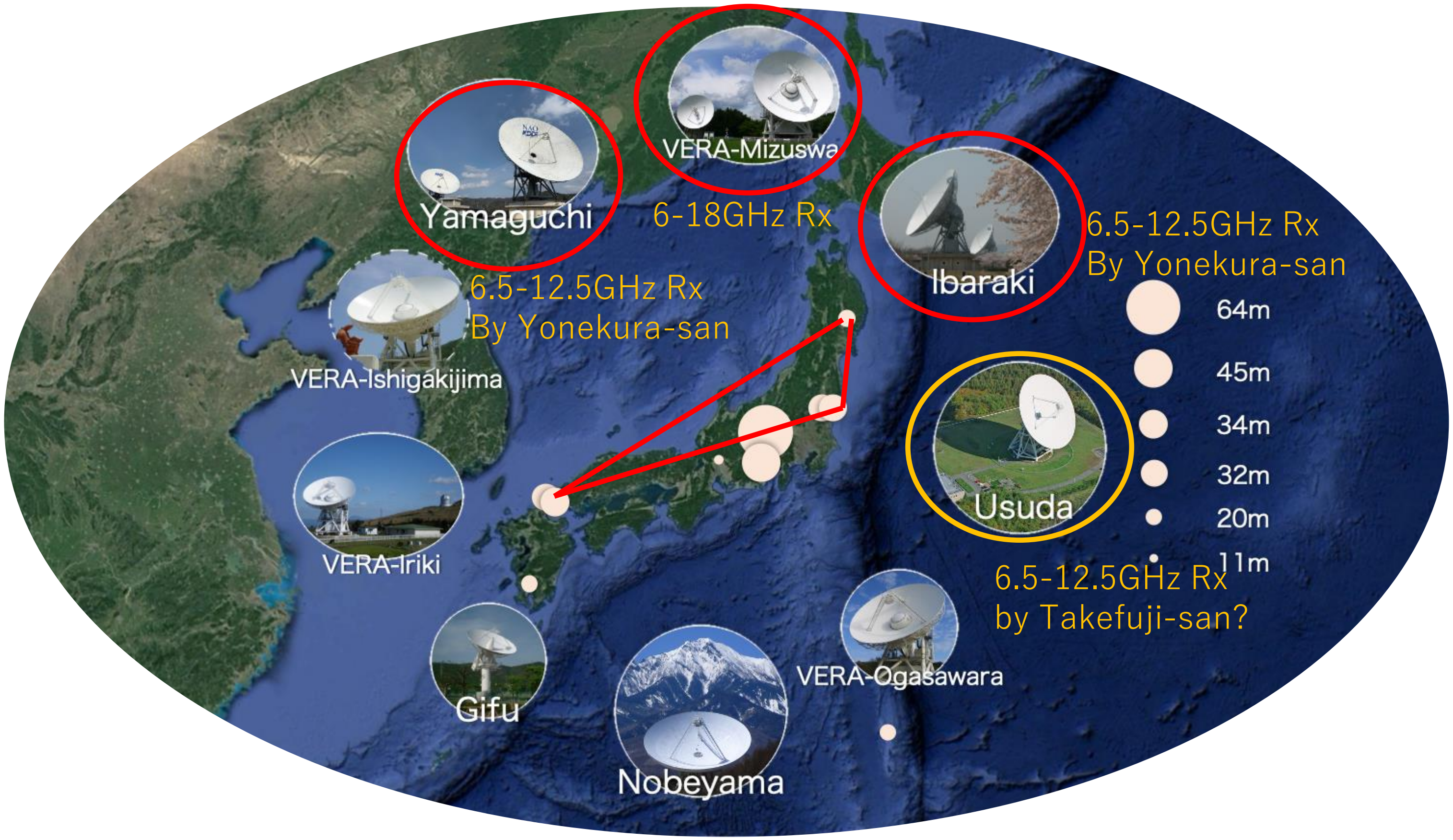




- Low insertion loss
- Steep cutoff

HTS multi-band rejection filter

Enhancement of cm-VLBI capability



Baseline Sensitivity of VERA Miz – YAM/IBA: 1.5mJy/σ -> 0.6 mJy/σ

- VERA Miz: η~55%, Tsys〜60K (target value), Bandwidth : 0.5 -> 2GHz、Integ time : 5min

※Discussed by JVN white paper (2016)

4. Science Investigations

5. Instruments and data to be returned

Gas accretion mechanisms onto massive stars
- Ibaraki's iMet monitoring program including 6.7 and 12.2 GHz lines

Radiation mechanisms of pulsars and FRBs
- Yamaguchi 32m/34m and JVN monitoring

Jet formation mechanisms of X-ray binaries and active galactic nuclei
- Yamaguchi 32m/34m and JVN monitoring

Acceleration mechanisms of cosmic rays
- Gifu 11m, Nobeyama 45m and VERA

Investigation of the internal and external physical states of evolved stars
- VERA and Gifu 11m monitoring

JVN's Contributions to Japanese Radio Astronomy

Fostering Radio Astronomy Group at Hokkaido University and University of Tsukuba

- Radio astronomy groups at Hokkaido University and University of Tsukuba were partially initiated by the JVN. These universities produced radio astronomers.

The success of young researchers at Gifu University

- JVN formed a radio astronomy group at Gifu University. It has become a research center that goes beyond VLBI.

Kagoshima and JVN

- JVN also contributed to Kagoshima University becoming a research center for astronomy to some extent.

Support from Fukui University of Technology

- When the radio astronomy group and radio telescope were established at Fukui University of Technology, the JVN group (Professor Yonekura) was the first to go out to provide support.

Contributions to student education and researcher training at Osaka Prefecture University

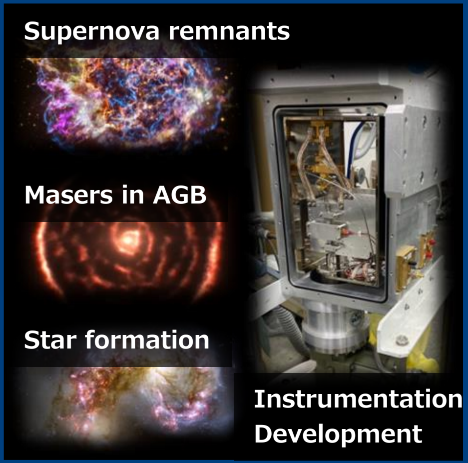
- Professor Ogawa of Osaka Prefecture University played an extremely large role in the development and research of radio astronomy.

Gifu University "Space Science Laboratory"

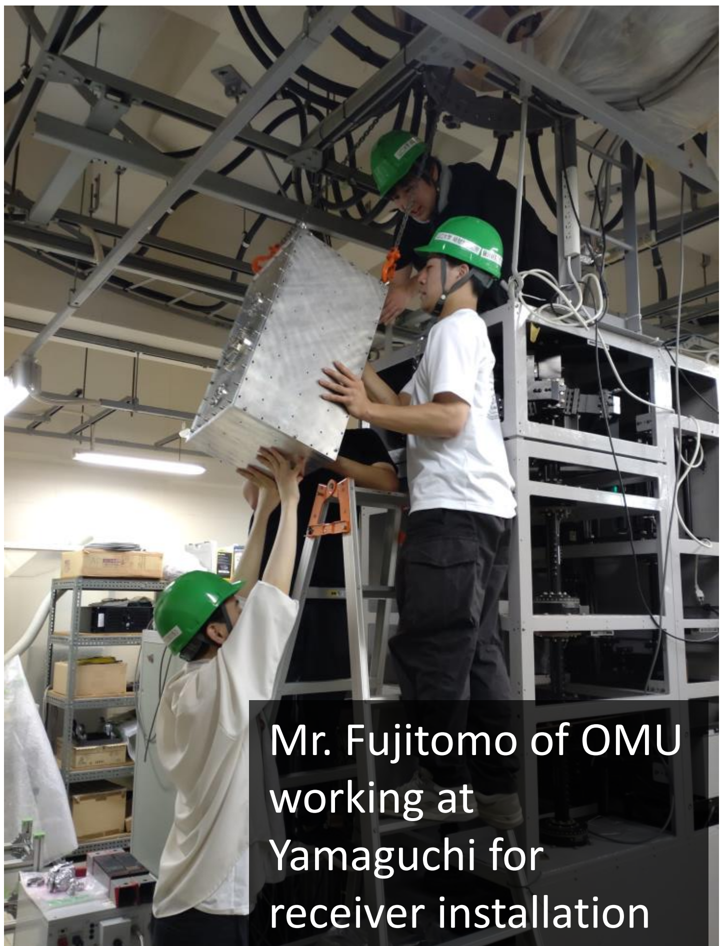
宇宙科学研究室

岐阜大学 工学部 電気電子・情報工学科 応用物理コース

ウェブページ

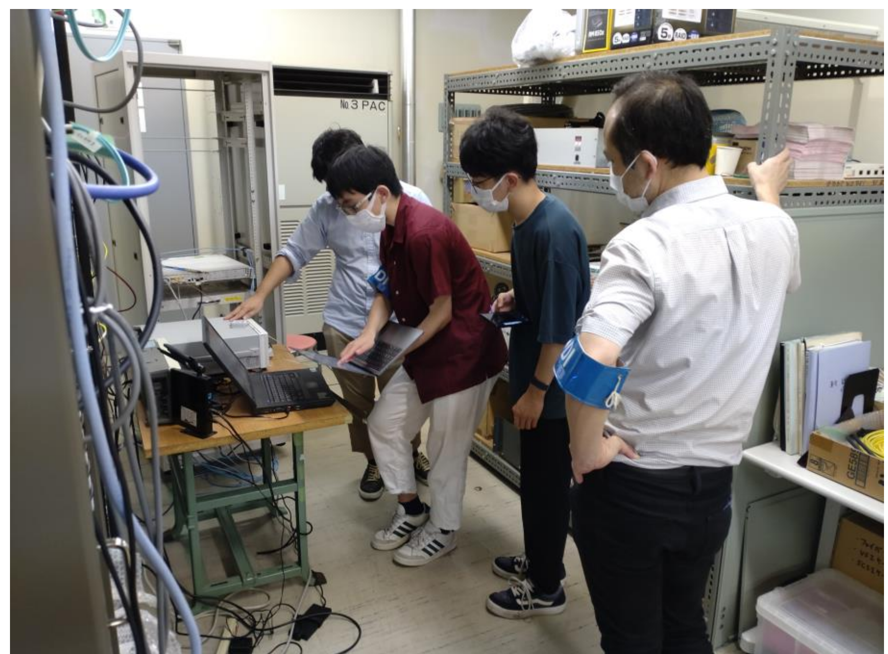


Inter-university cooperation and student education



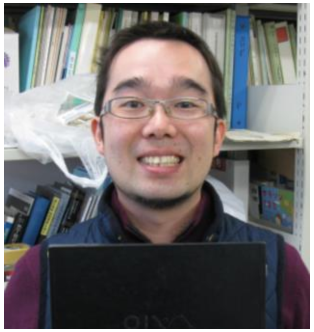
Mr. Fujitomo of OMU working at Yamaguchi for receiver installation

Professor Nakanishi from Kagoshima University visited Yamaguchi with his students for test observations.



Fostering researchers through JVN research

Motogi: PhD from Hokkaido University, Associate Professor at Yamaguchi University, one of the young leaders in radio astronomy in Japan



Nagayama: PhD from Kagoshima University, achieved 10μas positional accuracy with VERA

Sugiyama: PhD from Yamaguchi University, currently working at the National Astronomical Risearch Institute of Thailand as a leader in the construction of Thailand's first 40m radio telescope TNRT

Murase: PhD from Kagoshima University, currently an assistant professor at Gifu University, one of the young leaders in radio astronomy in Japan

JVN and Large Telescopes

Complementally with (open-use) large telescopes

- Large survey / long-term monitoring with JVN
- Detail Study with Large Telescopes

High-mass protostar G353 (Motogi)

- Water maser monitoring with JVN telescope
- Pole-on outflow by VERA
- Disk around the central star by ALMA

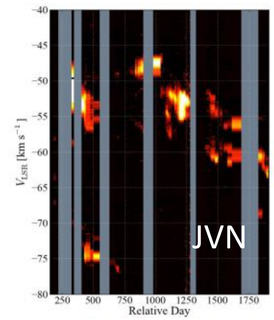
Methanol maser variability (Yonekura)

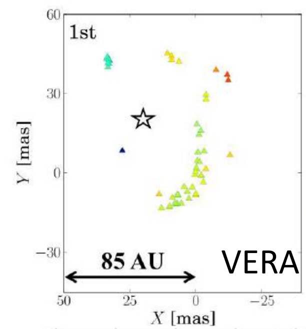
- Long-term monitoring with JVN telescope
- Discovery of Accretion burst
- Imaging by VLBI

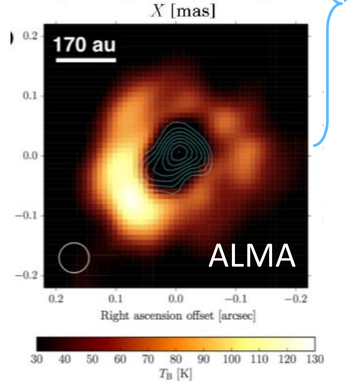
Agile follow-up (Niinuma, Iwata)

- AGN's Gamma-ray, Neutrino event
- GRB
- Supernova

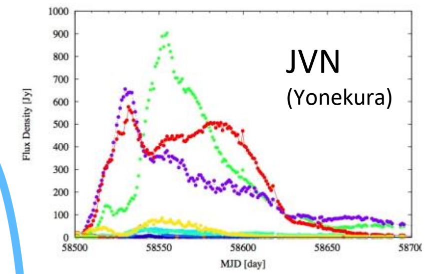
G353





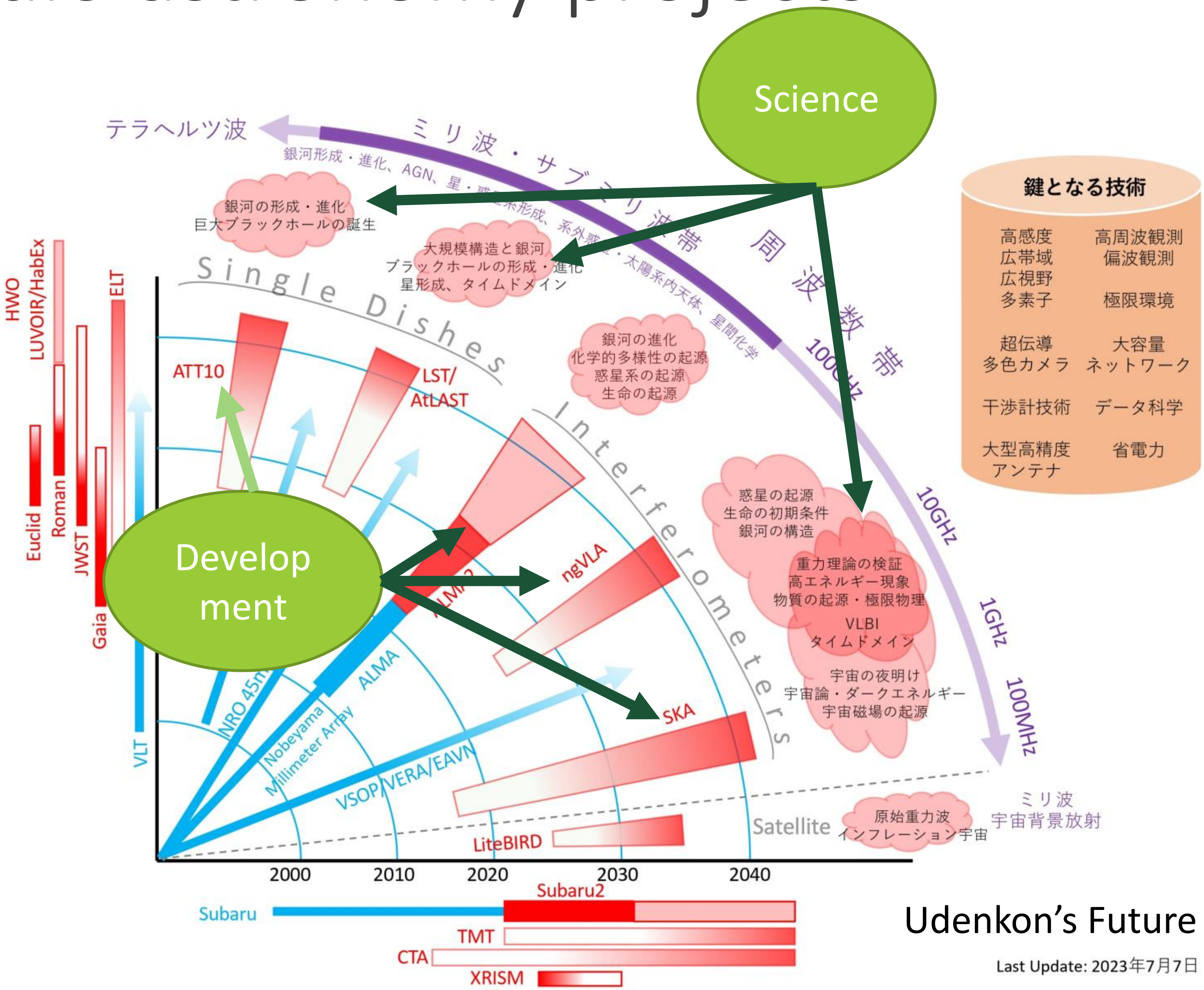


Accretion Burst



(Burns)

JVN’s contribution to the future radio astronomy projects



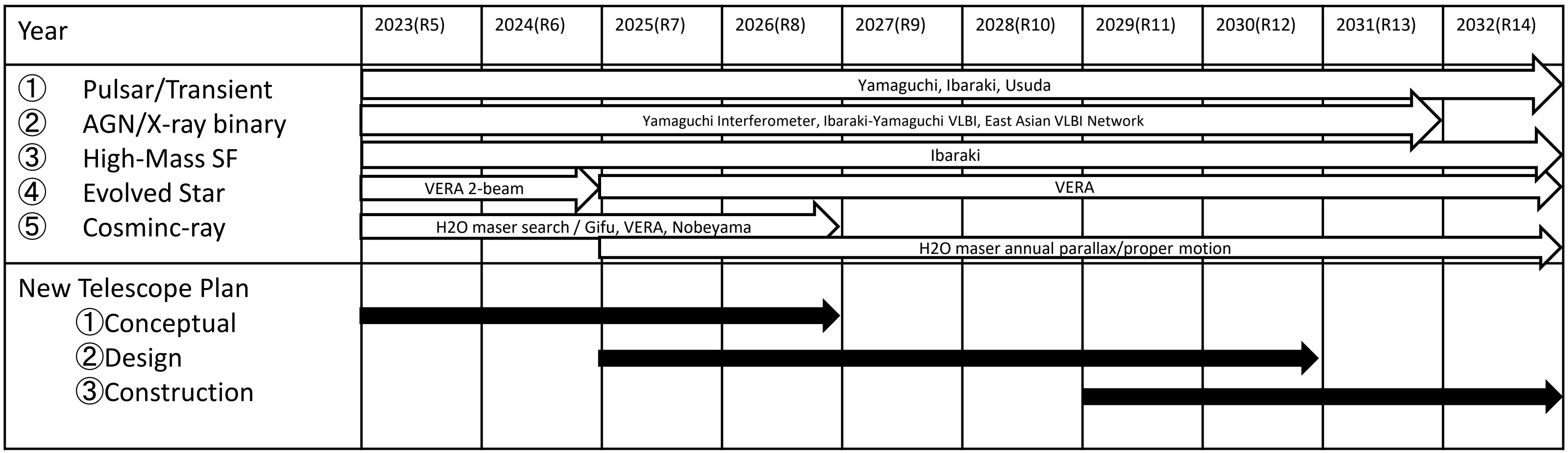
Udenkon’s Future Image

Last Update: 2023年7月7日

Telescope Aging and New Telescope Plan

- JVN's core telescopes are in Yamaguchi and Ibaraki. They were built 40 years ago, and there is a high risk of breakdown in the long term.
- Relatively inexpensive, high-performance telescopes are now available worldwide through the development of large interferometers such as the SKA. We believe that it will become necessary for us to build such telescopes ourselves.
- The main objectives of the new telescope are as follows:
  - Participate in international VLBI observations
  - Develop scientific research currently being conducted by JVN
  - Technology development and experimental observations
  - Educate students by having them participate in these activities

Timeline


Year
2023(R5)
2024(R6)
2025(R7)
2026(R8)
2027(R9)
2028(R10)
2029(R11)
2030(R12)
2031(R13)
2032(R14)
① Pulsar/Transient
② AGN/X-ray binary
③ High-Mass SF
④ Evolved Star
⑤ Cosminc-ray
Yamaguchi, Ibaraki, Usuda
Yamaguchi Interferometer, Ibaraki-Yamaguchi VLBI, East Asian VLBI Network
Ibaraki
VERA 2-beam
VERA
H2O maser search / Gifu, VERA, Nobeyama
H2O maser annual parallax/proper motion
New Telescope Plan
①Conceptual
②Design
③Construction

6. Originality and international competitiveness

This research plan will organize radio telescopes operated by universities and the Mizusawa VLBI Observatory into a VLBI observation network to conduct VLBI and radio astronomy observations. As mentioned above, there are large VLBI networks in the world, but all of them are national observatory organizations or associations of such organizations. In contrast, JVN has the advantages of (1) being a VLBI observation network operated primarily by universities, which gives it a high degree of freedom, and (2) being able to conduct observations over long periods of time on specific themes.

JVN's organization allows for great flexibility in observations, and allows for the rapid response and long-term monitoring required for time-domain astronomy. This is an important characteristic for conducting collaborative observations with telescopes of other wavelengths (for example, visible light, X-rays, and neutrinos). It is of great significance to be able to provide radio observation data to other fields.

7. Current Status

Regular operation

8. Cost assessments, budget line and status

TBD

9. Project Organization

University and Mizusawa

10. Why NAOJ ?

1. The Ibaraki and Yamaguchi stations are radio telescope owned by NAOJ.
2. NAOJ's Mizusawa VLBI Observatory is the development center for VLBI observational technology in Japan.
3. JVN conducts imaging observations using VERA.

For these reasons, it is essential that JVN research be conducted together with the NAOJ Mizusawa VLBI Observatory.

JVN also contributes to the development of observation systems at VERA Mizusawa and Nobeyama Radio Observatory, and there is fruitful interaction.

Characteristics of JVN as a research organization

Time domain astronomy will continue to develop greatly in the future. For example, interesting phenomena are being discovered one after another, such as research into the short-term radiation mechanisms of pulsars and long-term flux variability of star-forming regions.

In this context, we use our own telescopes, innovate uniquely, and observe over long periods of time. Students are also deeply involved in this process. These are the features of JVN. We believe that this research system itself is unique and valuable.

We plan to continue this unique activity for the next 10 years.

時間領域天文学は今後も大きく発展する。例えば長短時間のパルサーの放射機構の研究、長期間にわたる星形成領域の変動現象など、面白い現象が次々と見つかっている。

そのような背景において、我々は自分たちの望遠鏡を使い、独自の工夫をして、長時間をかけて観測する。まあそこに学生が深く関与する。これがJVNの特長である。そのような研究体制自体が独特のものであり、価値がある、と我々は考えている。

この活動を維持することを今後１０年の目標としている。