

Radio astronomy developments in Republic of Korea

August 5, 2022

Division B, IAUGA, BEXCO, Busan

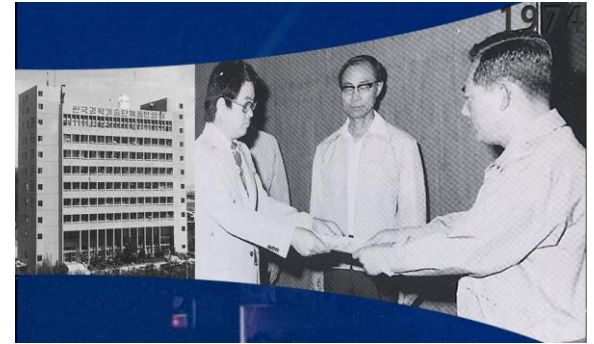
Se-Hyung Cho



Start of Radio Astronomy and Construction of TRAO 14 m Radio Telescope at KASI

Sept. 1974 : Korean National Astronomy Observatory (KNAO) was established by presidential decree under the Ministry of Science and Technology

July 1975 : Dr. Young-Key Min, who majored in radio astronomy, was appointed as **the first director of KNAO**
→ **The construction plan** of Korean radio telescope and **the radio astronomy lecture** at Seoul National University



Awarded the first director's appointment letter of KNAO (1975 Jul.)

May 1980 : **The budget for the construction plan** of radio telescope **was submitted**
→ **The site purchase budget** of the observatory was secured

◆ **Observation band and contract of radio telescope**
→ In consideration of the global development trend and investment efficiency, it was decided to observe **mm wave** rather than cm.
→ **ESSCO's 14m radio telescope system of USA** (same type as FCRAO telescope)

Dec. 1981 : The contract was signed with ESSCO

Installation, Supplement of system facilities, and Commissioning of 14 m Radio Telescope

Oct. 1985 : Start of antenna & Radome installation of 14 m telescope



Installation of 14m telescope (Oct. 1985)

Mar. 1986 : Restructuring from KNAO to ISSA, reorganization from cosmic radio wave obs. and research lab. to **Taeduk Radio Astronomy Observatory (TRAO)**

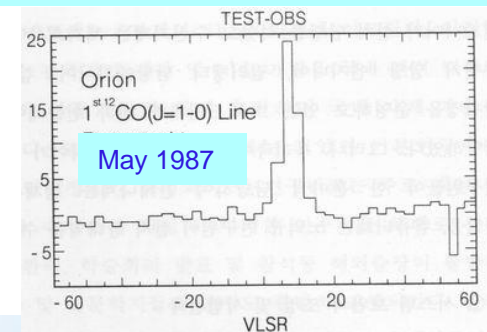
Feb. 1987 : Completion of **installation of** whole 14 m radio telescope system : RXs, spectrometers, S/W



TRAO hanging ceremony (Mar. 1986)

Mar. 1987 – May 1989 : The first light from Orion KL with 14m telescope (May 1987), complement of system equipment, commissioning (panel adjustment, performance measurement, test obs. etc)

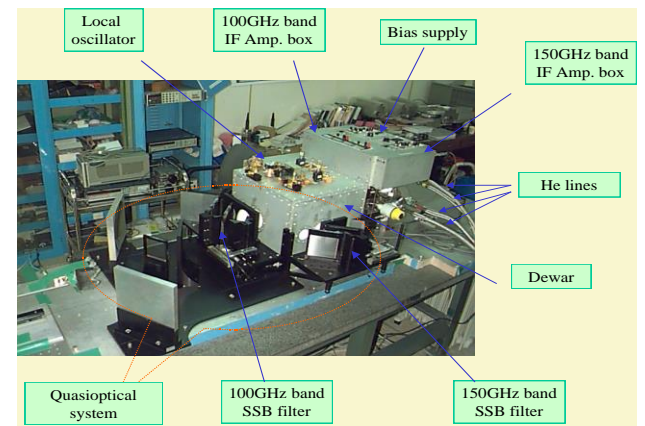
Nov. 1989 : Start of astronomical obs. and open use to Korean astronomy community



TRAO Receivers at Early Stage



- **85~116 GHz Schottky-barrier diode mixer RX** ($T_{\text{sys}} \sim 500$ K at 86 GHz) from Millitech, USA
- **85~116 GHz single-sideband SIS RX** ($T_{\text{sys}} \sim 420$ K at 86 GHz) : **First SIS RX developed by Dr. S.-H. Han in 1993**
- **124~174 GHz double-sideband Schottky-barrier diode mixer RX** (SSB T_{sys} : from 600 to 1000 K): from German RPG company in 1993
- **100/150 GHz dual-channel SIS receiver developed by Dr. S.-T. Han (1996-98)**
 - Both SiO $J=2-1$ and $J=3-2$ ($v=1, 2, 3$) masers were observed from 1998 simultaneously
 - SSB T_{sys} : ranged from 200 K to 400 K at 100 GHz, 400 K to 800 K at 150 GHz band
 - **Springboard for the development of the KVN 4-channel receiver**

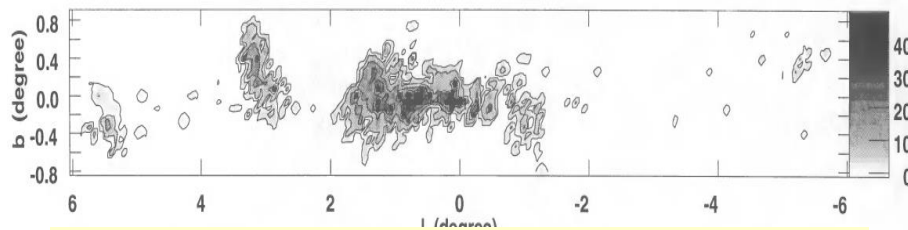


Sciences with TRAO 14 m Tel. : 100/150 GHz RXs and 100 GHz Multibeam Receivers



- Molecular clouds, star formation activity and evolution, evolved stars, Galactic center etc. ► Mapping and survey of thermal and maser lines

- Publications (1985-2021, including papers on system) : ~107
- PhD/MS thesis : ~9/18



HCN obs. toward Galactic Center Region : C. W. Lee, 1996

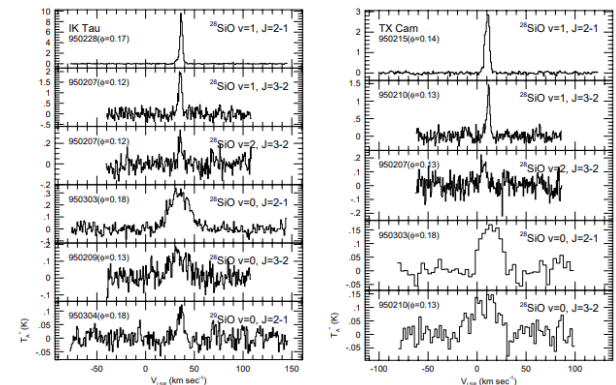
- Since 2009, large area obs. using the multibeam Rxs QUARRY and SEQUOIA (4x4 array), operating at 85 - 115 GHz range

- TRAO KSP (Key Science Program) (2016-2019)

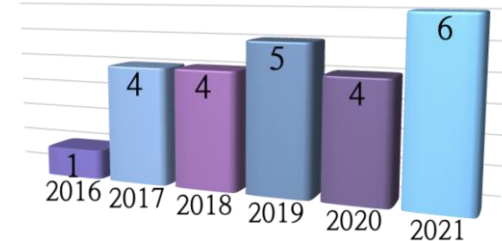
- C. W. Lee (FUNS: Filaments, the Universal Nursery of Stars)
- J. E. Lee (TIMES: mapping Turbulent properties In star-forming MolEcular clouds down to the Sonic scale)
- T. Liu (TOP: TRAO Observations of Planck cold clumps)

- Since 2020, Large Program and General Program

- 5 -13 proposals are carried out annually ► ~4 papers/yr



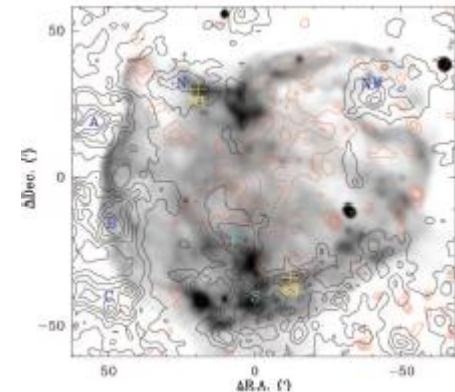
Obs. of SiO J=2-1 and J=3-2 emission in late-type stars : S.-H. Cho et al. 1998



Numbers of papers by year

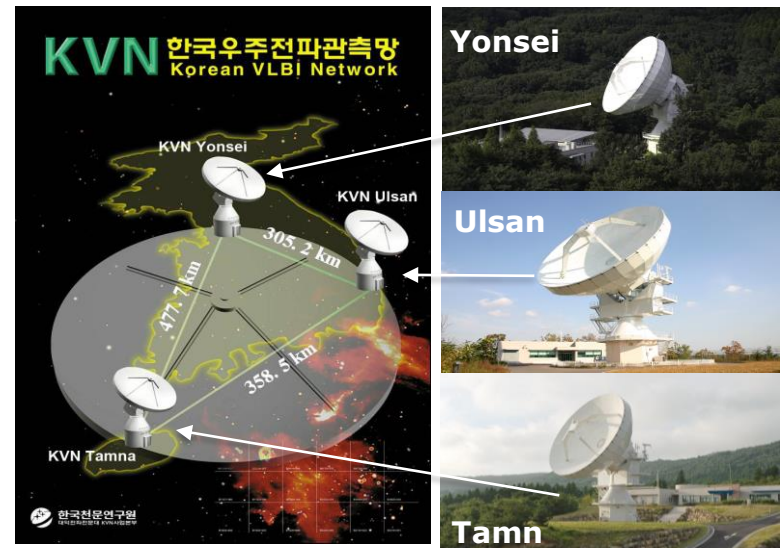
SRAO 6 m Radio Telescope at SNU Campus

- **Seoul Radio Astronomy Observatory (SRAO)** was opened in **April 2002** based on the 6 m radio telescope installed at Seoul National Univ. campus
- Antenna : 6.1 m in diameter (HPBW \sim 120" at 100 GHz),
- Receivers & Spectrometer :
85-115 GHz SIS Rx ($T_{\text{sys}}=500\sim 800$ K),
210-270 GHz SIS Rx (since 2013),
autocorrelation spectrometer
- **Rxs and SW were developed by graduate students**
- Sciences with the SRAO 6 m tel. :
Molecular clouds, SNRs etc.
- Interaction between the SNR HB 21 and molecular clouds, *D.Y. Byun, B.-C. Koo et al. 2006, ApJ, 637, 283*



Korean VLBI Network : Construction Period (2001-2008)

- Discussion of the next new project after the 14m radio telescope from the mid-1990s
→ **KVN project** was promoted to have a global competitiveness by observing wavelengths **up to millimeter wave**.
- **2000** : Secure budget for **KVN project (21 m x 3 tel.)**
- **2001** : Site selection
- **2004** : Contract of Antenna Purchase
- **2006** : Completion of KVN Ulsan observatory building
- **2007** : Installation of KVN Ulsan Telescope
- **2008** : Installation of KVN Tamna and Yonsei Telescopes



Telescope Installation and Completion Ceremony in 2008



Oct. 2008 KVN Yonsei



Mar. 2007 lifting of KVN Ulsan tel



Dec. 2008, KVN completion ceremony (KVN Ulsan)



Test Obs. and Regular Operating Period : 2009 ▶

- 2009 – 2010 : Test observations of single dish and, **22/43 GHz fringe detection from KVN 3 stations** , 22/43 GHz fringe detection between KVN and Japanese VERA stations, Start of KVN single dish research
- 2011 : Installation of 86/129 GHz RXs and test obs.
- 2012 : **Simultaneous fringe detection at 22/43/86/129 GHz bands**, Completion of East Asian VLBI Research Center, Started scientific research using KVN
- 2013 – 2022 Present :
 - **Regular operation of KVN VLBI for astronomical purpose**
 - **Perform of KVN KSP and KaVA/EAVN Large Program**
 - **Open use** to domestic, east Asia, and worldwide astronomical community twice a year
 - ▶ KVN website (<http://kvn.kasi.re.kr>)

22/43/86/129 GHz 4 Channel RX in 2012

■ Purpose for Simultaneous Multi-Frequency Observations

- 22/43/86/129 GHz (Dual Pol : LCP & RCP)

2300 mm

■ Conceptual Design in 2003

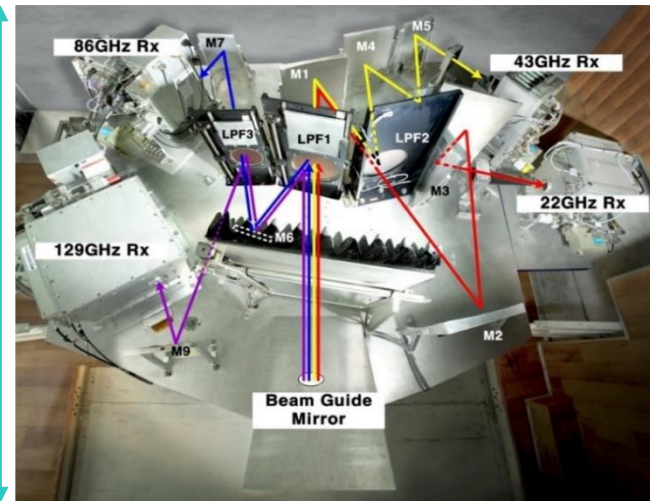
■ Quasi-Optic Circuits

- Design & Analysis
- Beam Measurement

■ Installation and Test

- 22/43 GHz in 2008-2009
- 86/129 GHz in 2011-2012

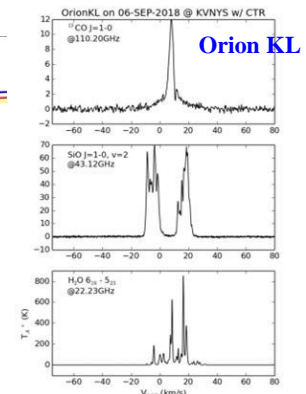
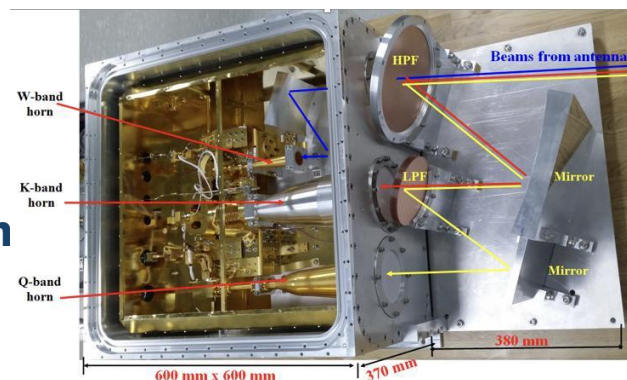
2600 mm



▶ Development of Compact Triple band Receiver (K/Q/W, Apr 2015~ Sept. 2018)

▶ E-KVN and INAF Italy, worldwide standard system in mm-VLBI

By S-T Han et al.



Completion Ceremony of East Asia VLBI Research Center (Sept. 2012)



Daejeon HW Correlator (K-J Joint Correlator)

- Correlation for 16 Stations of EAVN
- Commissioning from 2011 to 2012



DIFX SW Correlator

- Linux Cluster
- KVN only data
- Operation from 2012



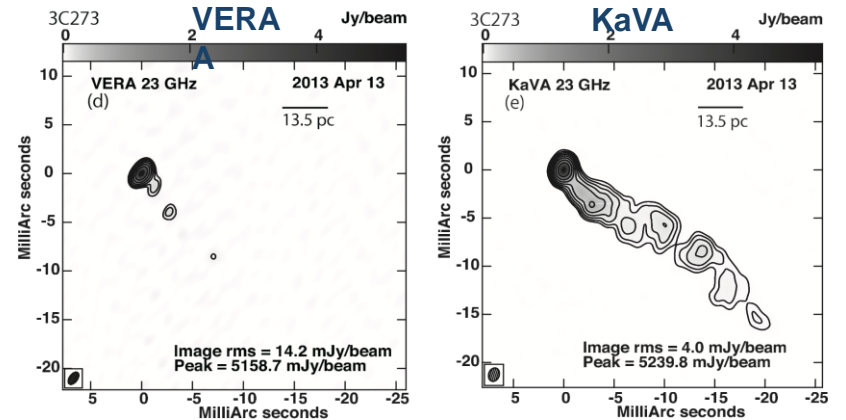
Completion Ceremony of **East Asia VLBI Research Center**
(Sept. 2012, at KASI headquarters in Daejeon)

Combined Network of KVN and VERA : KaVA in 2010

Based on KASI-NAOJ MOU
for VLBI Collaboration in Sept. 2002



- KaVA ang. resolution : ~ 1.2 mas
(at 22 GHz) ~ 0.6 mas (at 43 GHz)
- Frequency : 22 & 43 GHz
- Baseline : 300 - 2300 km
- Formed in 2010
- ~ 1000 hrs /yr from 2013



Ninuma et al.
2014 PASJ



East Asian VLBI Network

- **KVN + VERA + NRO 45m + Tianma 65m (SHAO) + Nanshan 26m (XAO)**
 - The highest resolution of 0.5 mas at 22 GHz
- **MOU for EAVN Collaboration in 2018**
- **Regular Operation from 2018**
- **22/43GHz (+ 6.7/8GHz)**



KVN KSP and KaVA/EAVN Large Program



■ KVN Key Science Program (1st generation 2015 – 2019)

- Origins of Gamma-ray Flares in Active Galactic Nuclei : iMOGABA and MOGABA (PI : Sang-Sung Lee, KASI)
- The Plasma-physics of Active Galactic Nuclei : PAGaN (PI : Sascha Trippe, SNU)
- Simultaneous Monitoring Obs. of KVN 4 Bands toward Evolved Stars (PI : Se-Hyung Cho, KASI)

■ KVN Key Science Program (2nd generation 2020B –)

- The World's Largest Plasma Physics Study of AGN with KVN (PI : Sascha Trippe, SNU)
- Simultaneous Monitoring of SiO and H₂O Masers toward Evolved Stars II (PI: Yungjoo Yun, KASI)

■ KaVA (EAVN) Large Program I. (2015-2017)

- Exploring the vicinity of super-massive black hole with KaVA : Intensive monitoring of M87 and Sgr A* (Co-PIs : Motoki Kino, NAOJ), B. W. Sohn, KASI)
- Expanded Study on Stellar Masers : ESTEMA (Co-PIs : Hiroshi Imai, Kagoshima Univ., Se-Hyung Cho, KASI)
- Understanding high-mass star formation through KaVA observations of water and methanol masers (Co-PIs : Hirota Tomoya, NAOJ, Kee-Tae Kim, KASI)

KVN Operation & Publications

- Over 3000 hrs/yr
(KVN only: 50%,
overseas joint network: 50%)

- ~40 proposals/yr

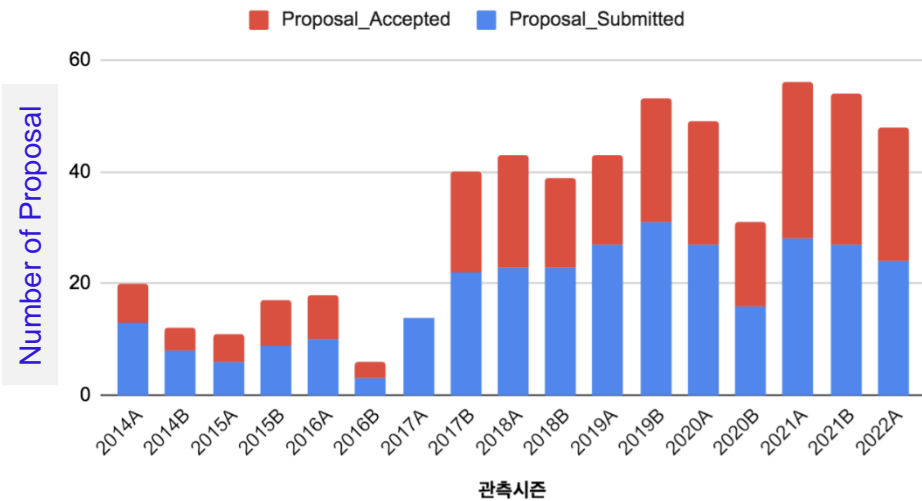
- ~20 papers/yr

- Remote Operation based on
10 GbE connection of
KREONET

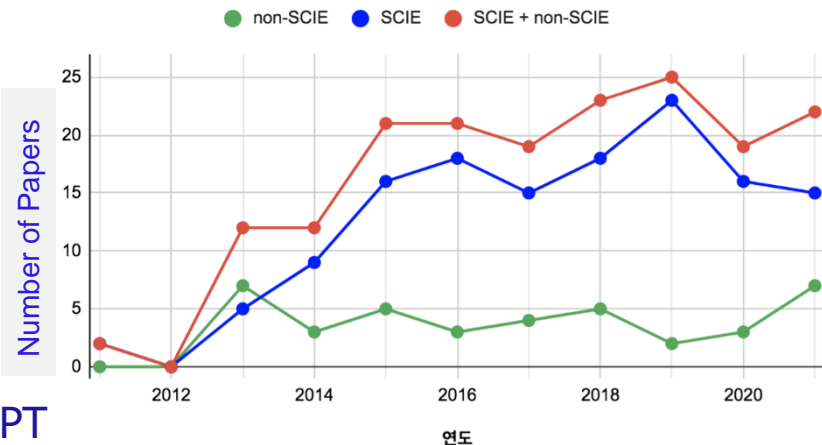
- Increasing Global
Collaborations : EVN, GMVA,
EHT

By K.-T. Kim's PPT

KVN/KaVA/EAVN Proposals



Number of Papers by Year



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KVN SPECIAL ISSUE

KVN Special Issue

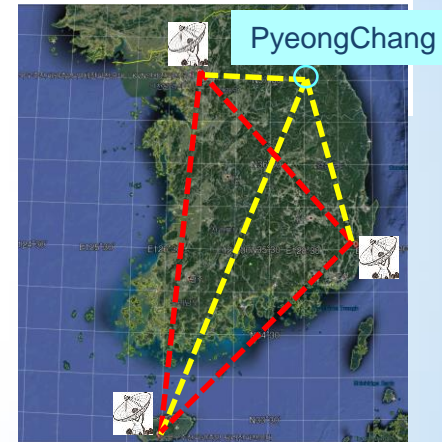
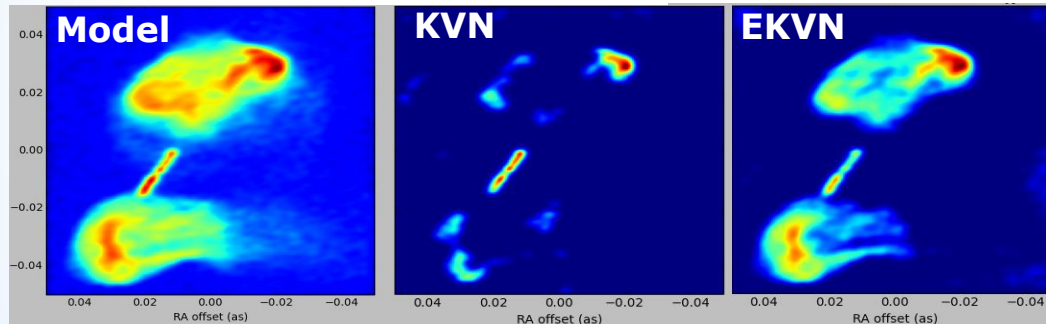
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Extended-KVN from 2020

■ E-KVN : Construction of 4th New Telescope from 2020

■ 4th Telescope (D~21 m) at PyeongChang Campus of SNU, Gangwon Province

- High surface accuracy ($\sim 80 \mu\text{m}$) for 230 GHz observation
- Two times more baselines from 3 to 6 combinations
- Amplitude self-calibration, Wideband M/F Image synthesis



KVN PyeongChang Site, SNU PyeongChang Campus (June 2, 2022)

Korea joined the East Asia ALMA consortium

- **Aug. 2014, NINS** (National Institutes of Natural Sciences) of Japan and **KASI signed an agreement** on the operations and development of ALMA

- ▶ Korea officially joined the East Asia ALMA consortium

- ◇ **ALMA user community in Korea** : Participated in obs. research **from Cycle 2**

■ ALMA development participation (2017-)

- GPU spectrometer development for TP array
 - ▶ Installation (Feb.), science verification (June) in 2022
- ALMA band 7+8 Rx development for ASTE : single-pixel, 275-500 GHz
 - ▶ **Delivery to NAOJ in Oct. 2022**



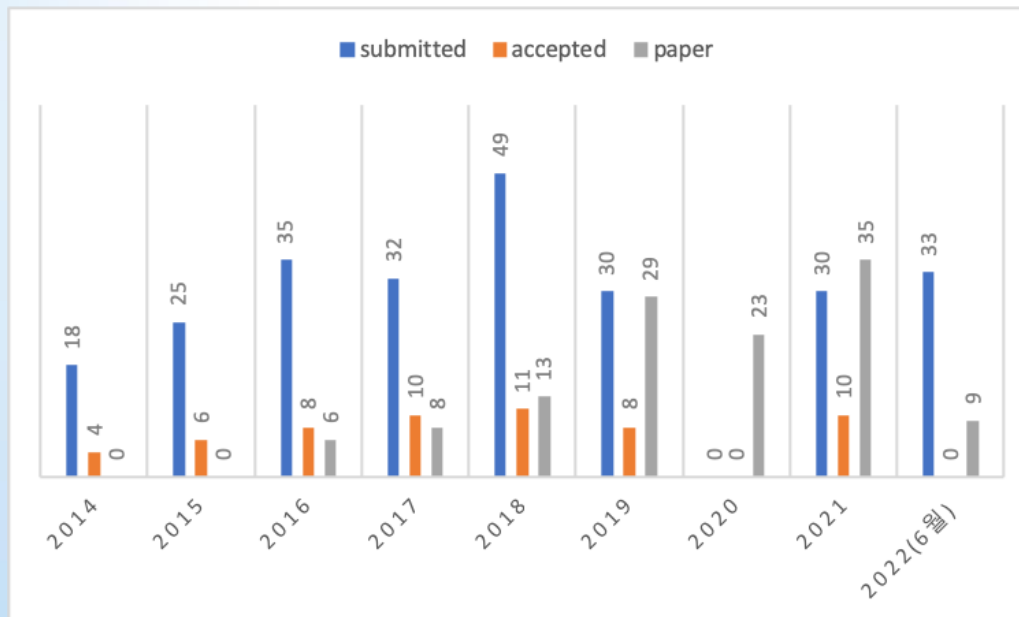
Cold cartridge assembly (ASTE 275-500 GHz Rx)



■ **ALMA participation (2021-2029)** : total budget \$22M (250억) for 9 yrs

- GPU correlator development for ALMA Compact+Main arrays
- Single-pixel Rx development for ALMA band 8
- EA-ARC Korean node operation

■ **Number of Proposals and Papers by ALMA User Community in Korea**



■ ALMA proposal : ~30/yr (~27% accepted)

■ Paper : ~25/yr (2018-2021)

By K.-T. Kim's PPT

Korea joined the EAO JCMT operation



- The JCMT is the first telescope operated by the **EAO** (East Asian Observatory), which was established by the **EACOA** (East Asian Core observatories Association)
- Member institutions : NAOC China, ASIAA Taiwan, NAOJ Japan, and KASI Korea
- **JCMT operation was transferred to the EAO in Mar. 2015.**



The JCMT Image Credit:
William Montgomerie

- **Sharing of operating expenses**
(USD 0.5-0.65 million/yr from 2015) **and support of JCMT Board/TAC**
- Participation in the **JCMT Large Programs**
- **Publications : ~20 papers/yr (2019-2021)**

Radio Astronomy Division

Korea Astronomy and Space Science Institute

■ Organization of Division

- Taeduk Radio Astronomy Observatory (TRAO)
- Korean VLBI Network (KVN) Group
- Atacama Large Millimeter Array (ALMA) Group
- Radio Astronomy Technology Development Group
- Radio Astronomy Research Group

■ **Manpower : 88 staffs** (regular ; astronomer, engineer & technician etc. ~**47**, non-regular ; post-doc, graduate student, administrative support etc. ~**41**)

■ **Annual budget (2021) : ~6.1 million USD**
including EKVN budget



University with Radio Astronomy Faculty

| Universities | Faculties | Research Fields |
|-------------------------------------|--|---|
| UST-KASI (Univ. of Sci. & Tech.) | Sang-Sung Lee (Chief Major Professor) and other ~7 faculties | AGN, Star Formation, Evolved Stars, Radio Tel. System etc. |
| Seoul Nat. Univ. | Bon-Chul Koo (1992-2022.2), Yong-Sun Park (1999.9-), Sascha Trippe (2011.3-) Woojin Kwon (2020.3-) | Interstellar Matter, SNRs, Star Formation, Radio Tel. System, AGN |
| Kyung Hee Univ. | Jeong-Eun Lee (2017. 3-) | Astrochemistry, Star Formation |
| Yonsei Univ. | Aeree Chung (2010-) | Extragalactic Astronomy |
| Sejong Univ. | Sungeun Kim (2004-) Se-Heon Oh (2019-) Jeffrey A. Hodson (2020-) | Extragalactic Astronomy, AGN |
| Kyungpook Nat. Univ. | Jae-Young Kim (2021-) | Black Hole, High Energy Astronomy |
| Korea Nat. Univ. of Education | Jungjoo Sohn (2018-) | Star Formation |

Future Prospect



- There will be **two important directions** for the development of radio astronomy in Korea.
 - One direction is to have international capabilities and competitiveness in the (sub)millimeter wavelength range through **KVN/EKVN** itself and joint network operation with KVN-based **KaVA/EAVN, GMVA, and EHT**.
 - The other is to secure global competitiveness through international participation in the world's most advanced large-scale observation facilities such as **ALMA, SKA** and **ngVLA**.
- **Synergy of KVN with ALMA/K-GMT** and joint studies with theorist will lead to higher impact research.
- Cultivating **more interferometry experts** in science and technology are required.